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Application of High-Altitude Long Endurance (HALE) Platforms in Emergency Preparedness and Disaster Management and Mitigation

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Executive Summary

The objective of this study has been to assess the potential application of High-Altitude Long Endurance (HALE)-based remote sensing technologies to disaster management and mitigation. This study has investigated the utility of HALE-based remote sensing to support the key emergency management activities of risk, vulnerability and preparedness assessment; situational awareness of disasters and other emergency situations; disaster management and mitigation efforts and post-disaster evaluations & "lessons learned" processes.

HALE systems use advanced aircraft or balloon technologies to provide mobile, usually uninhabited, platforms operating at altitudes in excess of 50,000 feet (15,000 m). A previous “companion” study concluded that the potential for currently-developing and future generations of HALE systems to carry out remote sensing or surveillance utilizing a wide range of sensor types, is very considerable.

The present study concludes that HALE Technology has the potential to provide valuable support to a number of key services, including remote sensing/ surveillance, search and rescue and communications, which are required for the effective management of a substantial range of Canadian natural disasters and human-made emergencies. The potential benefits of utilizing HALE technology in the management of emergency situations are expected to include the saving of human distress, suffering and life, as well as financial benefits.

As *remote sensing or surveillance* platforms, HALEs could perform high-resolution, high-continuity observation/ surveillance of emergency situations not possible with single satellites or small constellations and too costly to provide using airborne systems alone. HALE systems are capable of rapid deployment, can be used under hazardous conditions (uninhabited), can support other services of value to emergency management, and offer a greater degree of control of the asset by the emergency management organization than is typically possible with satellite systems.

For *search and rescue*, HALE platforms carrying search-and-rescue transponders, high-resolution imaging sensors and communications capabilities could provide a significant benefit to the task of precisely locating and rescuing distressed parties.

For *emergency communications*, HALE Platforms could support a number of communications functions, required for emergency management activities. The low altitude of HALE, compared to that of satellites, offers considerable potential for superior communications system performance, including enhanced RF link and frequency re-use.

For *navigation/ radiolocation*, HALE platforms carrying suitable equipment could contribute to more precise and reliable positioning, navigation and radiolocation systems, benefiting emergency management and other applications.

Additional applications of HALE platforms include the ability to provide superior remote sensing performance compared to satellite systems for a wide range of civil applications involving time-varying or emerging phenomena (e.g. environmental science, atmospheric science, communications, ocean monitoring, law enforcement, customs, immigration, urban planning and monitoring, road traffic monitoring, pollution control and others) and for a wide range of military applications including imagery intelligence, signal intelligence, electronic warfare and military search and rescue.

Of the available HALE technologies, aerodynamic HALE based on high-altitude and uninhabited aircraft technologies holds significant advantages over Aerostatic systems based on advanced balloon or airship technology for the bulk of emergency management applications.

The most valuable sensor types for HALE-based remote sensing/ surveillance in support to the management of a range of the most important Canadian natural disasters and human-made emergencies are Imaging Radar (SAR), Passive Optical/ IR High-Resolution Imagers, Imaging Multispectral Radiometers (Microwave) and specific sensor types providing specialized measurements addressing the needs of emergency management for individual human-made emergency types.

This study further concludes that the overall benefits to Canada - financial and social and human - of operating a HALE system for a range of applications, including emergency management, would merit the financial investment required.

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1.0 Introduction

Emergency management and remote sensing technologies have evolved almost exclusively of one another over the recent decades and yet these two fields have tremendous complementary potential. Figure 1.1-1 shows an example of the kind of high-resolution remote sensing imagery (part of the Washington D.C. area at 1-metre spatial resolution) which could play an important role in emergency management activities, including the management of natural disasters and human-made emergencies. The emergency management community requires rapid and effective response during emergency situations, as well as useful baseline and warning information prior to disasters and other emergencies. It is recognized that significant challenges exist in the implementation of current space-based remote sensing technologies in an operational context for emergency management and emergency preparedness. The development and use of next-generation remote sensing platforms, such as HALE, that could more appropriately address the needs of the emergency management community, requires considerable attention and assessment.

State-of-the art in HALE platform technology is exemplified by the US Air Force's Global Hawk Unmanned Endurance Air Vehicle, shown in Figure 1.1-2. The Global Hawk, currently in system trials, is designed to for fully-autonomously operation, with a maximum flight endurance of 40 hours. Global Hawk could fly up to 3,000 nautical miles (5,556 km) at up to 67, 000 ft (20, 422 m), loiter over a target area for 24 hours while using sensors or other equipment, and then return to base, all without human guidance. The air vehicle has a payload capacity of 2, 000 pounds (910 kg) mass. Current Global Hawk vehicles carry high-resolution synthetic aperture radar (SAR) and electro-optical/ infrared surveillance sensors.

As was determined in a previous "companion" study, funded by the Canadian Space Agency (CSA) and carried out by Milebrook Technology Inc. (CSA: "Analysis of Sensor and Platform Technologies for Application of High-Altitude Long-Endurance (HALE) Platforms in Remote Sensing"; 31st March 1999), the potential for currently-developing and future generations of HALE systems to carry out remote sensing, surveillance and other functions is very considerable. In the case of emergency management, HALE systems could perform high-resolution, high-continuity observation/ surveillance of emergency situations not possible with single satellites or small constellations and too costly to provide using airborne systems alone. HALE systems are capable of rapid deployment, can be used under hazardous conditions (unmanned), can support other services of value to emergency management and, unlike present-day remote sensing satellites, offer full control of the asset by the Emergency Management Organization (EMO).

Figure 1.1-1 Example of High-Resolution Remote Sensing Imagery
Part of the Washington D.C. Area at 1 Metre Spatial Resolution,
from the IKONOS-1 Spacecraft, 1999 *[Source: Space Imaging Inc].*

Figure 1.1-2 Global Hawk High-Altitude, Long-Endurance Unmanned Air Vehicle;
SAR & Electro-Optical/ IR Surveillance from 65, 000 ft (20 km) Alt.
[Source: Northrop Grumman Corporation].

2.0 HALE-Based Remote Sensing to Support Emergency Management

2.1 Introduction

In Chapter 2 the overall requirements for emergency management activities are identified by analyzing the mandate of Emergency Preparedness Canada and emergency management activities in general. The principal emergencies – natural disasters and human-made emergencies, in the Canadian context, are identified. For each type of natural disaster and human-made emergency the present and potential overall role of remote sensing, or surveillance, in the emergency management process is analyzed. From this, the unique or net-cost benefits (relative to other available platform technologies) accruing from the utilization of HALE technology to support remote sensing, surveillance and other emergency management-related applications, such as emergency communications, are identified and analyzed.

2.2 Emergency Management Requirements

2.2.1 Introduction

Emergency Preparedness Canada Disaster Database defines a Disaster as:

"A disaster is an interruption in time and space of normal processes causing death, injury or homelessness, economic or property loss, and/or significant environmental damage. The interruption is beyond the coping capacity of the community and/or is beyond the assumed risk factors of human activity. Assumed risk is inherent in most human activity such as transportation and handling of dangerous goods. The interruption precludes war."

2.2.2 The Emergency Management Cycle

Figure 2.2.2-1 illustrates the Emergency Management "Cycle", which "begins" with risk assessments, planning, arrangements, training and exercises, and "ends" with resolution of the disaster/emergency and reduced vulnerability and better preparedness for future disasters/emergencies of the same or similar kind.

The Mitigation Phase

Taking sustained actions to reduce or eliminate long-term risk to people and property from hazards and their effects.

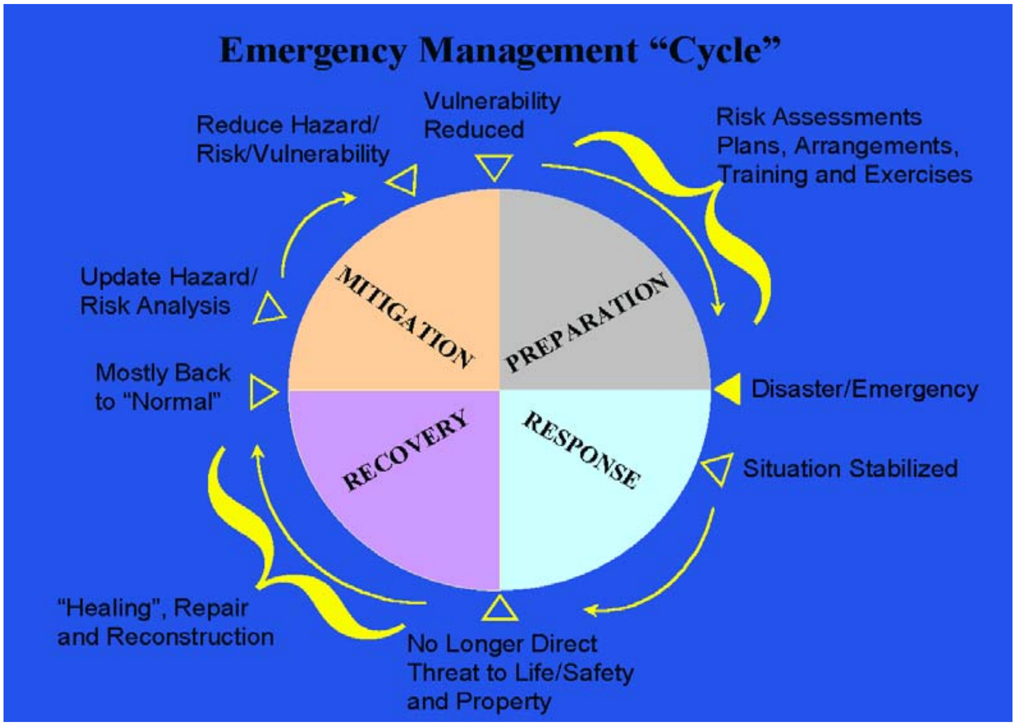
The Preparation (Preparedness) Phase

Building the emergency management profession to effectively prepare for, mitigate against, respond to, and recover from any hazard by planning, training, and exercising.

The Response Phase

Conducting emergency operations to save lives and property by positioning emergency equipment and supplies, evacuating potential victims, providing food, water, shelter, and medical care to those in need, and restoring critical public services.

Figure 2.2.2-1 The Emergency Management "Cycle"
[*Source: Emergency Preparedness Canada]*



The Recovery Phase

Rebuilding communities so individuals, businesses, and governments can function on their own, return to normal life, and protect against future hazards.

2.2.3 Principal Canadian Emergencies

Emergencies are usually grouped into the categories of Natural Disasters and Human-Made, or Technological Emergencies. The following are those emergencies of greatest historical and current relevance to Canada and to the mandate of EPC:

Natural Disasters:

- Floods
- Earthquakes
- Severe Storms

- Fire
- Landslides and Avalanches
- Drought
- Tsunami and Storm Surges
- Public Health

Human-Made Emergencies:

- Technological: Environmental, Industrial, Agricultural, Infrastructure and
- Essential Systems, etc.
- Transport: Road, Rail, Sea, Air
- Political or Social: Terrorism, Riot, Unrest, Civil Disobedience, etc.

Of Canadian historical disasters approximately 70% have been Natural Disasters, with 30% being Human-Made, or Technological Disasters. The "worst" Canadian historical disasters which have modern significance have been:

- Floods
- Droughts
- Severe storms.(freezing rain, tornadoes)
- Transportation accidents (road, rail, air, sea)
- Hazardous chemical disasters

2.2.4 The Mandate of the Emergency Preparedness Canada

Emergency Preparedness Canada (EPC) is a federal government organization within the Department of National Defence that plays a key role, on behalf of the Minister Responsible for Emergency Preparedness, in the development and maintenance of an appropriate level of civil emergency preparedness across Canada.

EPC's mission is: *"To safeguard lives and reduce damage to property by fostering better preparedness for emergencies in Canada".*

The functions of EPC are:

- Develop policies and programs.
- Support provincial preparedness.
- Analyze and evaluate risks & conduct research.
- Provide education and training.
- Enhance public awareness and understanding.
- Ensure continuity of constitutional government.
- Establish arrangements for provincial consultation.
- Support and coordinate the development and testing of institutional plans.
- Monitor and report potential, imminent or actual emergencies.

- Coordinate and support the implementation of civil emergency plans by government institutions.
- Provide authorized financial assistance to provinces.

The table of Figure 2.2.4-1 cross-references the principal functions of EPC with the phases of the Emergency Management Cycle.

Figure 2.2.4-1 Emergency Preparedness Canada (EPC) Functions within the Emergency Management Cycle.
[Source: Emergency Preparedness Canada]

EPC Functions	**The Emergency Management Cycle**			
	MITIGATION PHASE	**PREPARATION PHASE**	**RESPONSE PHASE**	**RECOVERY PHASE**
Develop Policies and Programs	**X**	**X**	–	**X**
Support Provincial Preparedness	**X**	**X**	–	**X**
Analyze and Evaluate Risks & Conduct Research	**X**	–	–	**X**
Provide Education and Training	**X**	**X**	–	**X**
Enhance Public Awareness and Understanding	**X**	**X**	–	**X**
Ensure Continuity of Constitutional Government	**X**	**X**	**X**	**X**
Establish Arrangements for Provincial Consultation	**X**	–	–	**X**

EPC Functions	The Emergency Management Cycle			
	MITIGATION PHASE	**PREPARATION PHASE**	**RESPONSE PHASE**	**RECOVERY PHASE**
Support and Coordinate the Development and Testing of Institutional Plans	**X**	–	–	**X**
Monitor and Report Potential, Imminent or Actual Emergencies	–	**X**	**X**	–
Coordinate and Support the Implementation of Civil Emergency Plans by Government Institutions	–	**X**	**X**	–
Provide Authorized Financial Assistance to Provinces	–	–	**X**	**X**

2.3 The Role of Remote Sensing in the Emergency Management Cycle

2.3.1 Introduction

Emergency management and remote sensing technologies have evolved almost exclusively of one another over the recent decades and yet these two fields have tremendous complementary potential. The emergency management community requires rapid and effective response during emergency situations, as well as useful baseline and warning information prior to disasters and other emergencies.

The following sections provide key definitions for remote sensing/ surveillance performance, typical remote sensing performance requirements for a range of types of ground target, summaries of the most important remote sensing and surveillance sensors and an analysis of the relative utility of the available remote sensing/ surveillance platform types relevant to roles in emergency management.

2.3.2 Remote Sensing and Surveillance Definitions

Civil remote sensing and military surveillance have developed in parallel and have used much common technology, but with different objectives.

Historically, surveillance has focused on *Foreground Phenomena* of military interest; tanks, aircraft, ships, troop movement, etc.; while civil remote sensing has been largely dedicated to observing "Background Phenomena" (slowly time-varying or invariant) of interest to civil authorities; terrain, oceans, vegetation, urban development, etc.

This relatively clear differentiation is blurring as new technological capabilities allow the military to use more and more Background Information (cartography, virtual/ electronic battlefield, robotic/ remote operations, etc.) and civil operators begin to use more and more Foreground Information (time-varying phenomena, ship tracking, law enforcement, drug interdiction, emergency management, etc.).

With reference to the system geometry illustrated in Figure 2.3.2-1, the basic performance specifications for remote sensing and surveillance are:

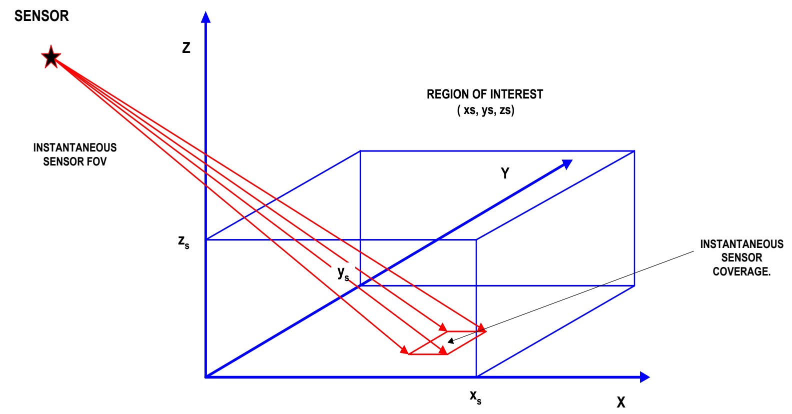
Coverage

Region of Interest:	The spatial volume (3D) or area (2D) which we want to observe/ survey.
Temporal Resolution:	How often we want to observe/ survey. (Determines the ability to adequately observe time-varying phenomena.)

Image Quality

Spatial Resolution:	Ability to resolve objects, features (Determines the ability to detect, classify, identify, characterize, track, etc.).
Radiometric Res.:	System sensitivity (in the presence of noise).
Spectral Resolution:	Ability to resolve spectrally-related information.

Figure 2.3.2-1 Remote Sensing/ Surveillance System Geometry.



2.3.3 Remote Sensing/Surveillance Performance Requirements

The table of Figure 2.3.3-1 illustrates the spatial resolution requirements (m) for a range of target types.

2.3.4 Sensor Types

The table of Figure 2.3.4-1 shows the Committee on Earth Observation Satellites (CEOS) remote sensing instrument (sensor) categories and their principal functions.

The table of Figure 2.3.4-2 summarizes the principal military surveillance sensor types and their principal functions.

Figure 2.3.3-1 Spatial Resolution Requirements (m) for a Range of Target Types

Object	**Detection**	**Recognition**	**Identification**	**Description**
Bridges	6	4.5	1.5	0.90
Radar	3	0.9	0.3	0.15
Radiocommunications	3	1.5	0.3	0.15
Material Depots	1.5	0.6	0.3	0.25
Troop Units or Bivouacs	6	2.1	1.2	0.30
Air Base Equipment	6	4.5	3	0.30
Artillery and Rockets	0.9	0.6	0.15	0.05
Aircraft	4.5	1.5	0.9	0.15
Headquarters	3.0	1.5	0.9	0.15
G-to-G Missile & A-A Sites.	3	1.5	0.6	0.30
Medium-Sized Surface Vessels	7.5	4.5	0.6	0.30
Vehicles	1.5	0.6	0.3	0.05
Land Mine Fields.	9	6	0.9	0.025
Ports	30	15	6	3
Coasts & Landing Beaches	30	4.5	3	1.5
Marshalling Yards/ Railway Shops	30	15	6	1.5
Roads	9	6	1.8	0.6
Urban Areas	60	30	3	3
Military Airfields	-	90	4.5	1.5
Submarines (Surfaced)	30	6	1.5	0.9

Figure 2.3.4-1 CEOS Remote Sensing Instrument (Sensor) Categories
[Source: Committee on Earth Observation Satellites]

Remote Sensing Instruments (CEOS)	Principal Functions
Atmospheric Chemistry Instruments	Chemical composition of the atmosphere
Atmospheric Sounders (IR & Microwave)	Atmosphere temperature & humidity profiles
Cloud Profile and Rain Radars	Cloud characteristics, water/ ice in precipitating clouds
Earth Radiation Budget Radiometers	Components of earth radiation budget
High-Resolution Imagers	Detailed images of the earth's surface
Imaging Multi-Spectral Radiometers (Visible, IR)	Spectral imaging of earth's atmosphere/ surface (Vis, IR)
Imaging Multi-Spectral Radiometers (Microwave)	Spectral imaging of earth's atmosphere/ surface (μ-wave)
Imaging Radars	High-resolution images of the earth's surface
Lidars	Laser reflection from earth's surface or atmosphere
Multi-Directional Radiometers	Diffused/emitted atmosphere/ surface radiation (multiple θ_I)
Ocean Colour Radiometers/ Imaging Spectrometers	Visible/ Near-IR radiance from marine waters
Polarimetric Radiometers	Polarimetric measurement of atmosphere/ surface radiation
Radar Altimeters	Surface topography profile
Wind Scatterometers	Ocean surface wind velocity

Figure 2.3.4-2 Principal Military Surveillance Sensor Types

Surveillance Sensor	Principal Functions
Radar: (Real-Aperture (RAR), Synthetic Aperture (SAR), Moving Target Indicator (MTI))	All-weather surveillance, High-resolution imaging (SAR), Detection of moving targets (MTI)
Electro-Optical	High-resolution imaging
Infra-Red	Thermal detection, Thermal imaging
LADAR	Targeting, Ranging
Meteorological Sensors (e.g.; Radiometers)	Meteorology

2.3.5 Remote Sensing/ Surveillance Platforms for Emergency Management

2.3.5.1 Introduction

Key remote sensing requirements for emergency management applications are rapid response to unforeseen events (Response Time), high frequency of observation (Temporal Resolution) and good Spatial Resolution. The cost of providing remote sensing/ surveillance services and the ability to guarantee the availability of the service are also very important considerations.

Emergency situations have traditionally been monitored using combinations of in-situ sensors, airborne sensors and space-based sensors. Each of these classes of sensor systems has its own limitations in the ability to adequately monitor rapidly-developing or emerging situations which may be manifested over large geographical regions. The following subsections address each of these classes of sensor system and summarize the potential benefits of the newest of these technologies, the High-Altitude Long Endurance (HALE) Platform.

2.3.5.2 In-Situ Sensors

In-situ sensors, such as rain gauges, water level gauges, anemometers and seismometers, usually located on land or in the ocean, can provide valuable data on the behaviour of pre-defined physical phenomena which may contribute to a natural disaster. Other types of in-situ sensor, such as pollution monitors, radiation monitors, traffic monitoring systems, etc. can provide data relating to potential or ongoing human-made emergencies.

In-situ sensors can be effective in monitoring reasonably well-defined phenomena over pre-defined geographical regions, such as the general occurrence of an earthquake or a flood. However, because of their discrete "point-sample" nature, in-situ sensors are limited in their capability to monitor unexpected events whose locations are unpredictable and may cover a large geographical area. Point sensors of this kind are also rather limited in their capability to help ongoing Response Phase activities such as locating and rescuing distressed personnel and detailed damage assessments of infrastructure, buildings, utilities, etc.

For these reasons, in-situ sensor capabilities should be regarded as only one element in the overall emergency management remote sensing capability.

2.3.5.3 Airborne Sensors

Before the advent of relatively capable remote sensing satellites such as ERS-1 and Radarsat, airborne sensor platforms, carrying radar, optical and other sensors, were a key capability in addressing many natural disaster and human-made emergency situations. Airborne platforms, such as the Canadian CONVAIR-580 SAR-carrying aircraft, operated by Environment Canada, are still able to provide valuable services in monitoring of specific emergency situations, environmental monitoring, testing and validation of new sensor developments, etc. Airborne platforms remain an important capability, particularly in applications for which local, rather than wide-area or global, coverage is required. However "traditional" airborne platforms are limited in their range and endurance, their operating cost and in the fatigue and risk imposed on crew. Satellite remote sensing systems, while still not able to provide the local observation continuity and resolution available from the best airborne systems, have largely taken over much of the routine remote sensing business, due to their global capabilities and the promise of competitive operating costs.

2.3.5.4 Space-Based Sensors

Satellite remote sensing systems have made major inroads into the remote sensing business over the last decade or so, particularly with the success of the European ERS series, the French SPOT series, the US NOAAA series and the Canadian Radarsat system. Remote sensing satellites can utilize a range of earth orbits ranging in altitude from several hundreds of kilometers to the geostationary location (40,000 km). In general, lower-altitude orbits allow better observation performance. And low-earth orbits (LEO), around 500 km to 1000 km altitude are most commonly used for surveillance and earth observation involving surface imaging. Higher orbits can successfully be used for specialized observations and meteorology, while lower (than 500 km) orbits suffer form limited lifetime due to atmospheric drag.

Despite the continuing development of new satellite systems, some carrying cloud-penetrating instruments which help to provide guaranteed observation, only very large (and very costly) constellations of satellites, all carrying high-resolution sensors, could meet the full need for guaranteed high-resolution, high observation continuity observation of localized regions, such as is required for response to a major natural disaster. Figure 2.3.5.4-1 summarizes the response time of a symmetrical surveillance satellite constellation as a function of the number of satellites. Virtually any value of response time can be achieved with a sufficiently large – and costly - constellation.

Two examples of conceptual satellite constellation systems are the European Space Agency's Coastal Zone Earthwatch (CZEW) Mission, currently in its study phase. The CZEW concept is for a synthetic aperture radar (SAR) instrument for risk management. The proposed solution consists of 6 SAR satellites carried on identical small satellites. Orbital analysis shows that, even with 6 satellites in 510 km orbits, the revisit time (temporal response) for most of inhabited Canada –between latitudes 42^0 and $55^{0\ -}$ is up to 12 hours (See Figure 2.3.5.4-2). One concept for the Discoverer II program, jointly run by the Defense Advanced Research Projects Agency (DARPA), US Air Force (USAF) and the National Reconnaissance Office (NRO), is for a 24-satellite constellation providing surveillance access to any point on the earth within 15 minutes, as illustrated in Figure 2.3.5.4-3).

All of these satellite constellation systems are as yet at the early concept stage and their ultimate cost, should they be implemented, would run into many millions, if not billions, of dollars. Notwithstanding this enormous expense, these large systems may not be able to provide the full system response and imaging performance required for emergency management activities.

For single-satellite systems, the ability to respond to, and return to, emerging situations is limited. Much work has gone into optimizing the emergency response performance of the RADARSAT –I system. However, the achievable response to changing events on the ground is limited by a number of factors, including the orbital trajectory of the satellite itself. Figure 2.3.5.4-4 shows the RADARSAT Emergency Response Process, commencing with an imaging request from an Emergency Management Organization (EMO), and ending with delivery of the final image back to the EMO. Figure 2.3.5.4-5 shows a Time Budget for this end-to-end process for events in Canadian territory. This analysis shows that, for randomly-located target events, the overall system response time is between approximately 2.0 and 7.0 days. This is generally considered inadequate to address many rapidly-evolving emergency situations. A Major factor in this overall response time is, of course, the position of the single satellite with respect to events on the ground. Figure 2.3.5.4-6 shows the coverage available from RADARSAT-I using the 500 km wide access swath; a). North America, one-day coverage; b). North America, three-day coverage; c). Amazonia, an example of equatorial coverage for three days. This confirms that to guarantee a revisit to a random location within Canadian territory requires at least 3 days.

Figure 2.3.5.4-1 The Response Time of a Symmetrical Constellation of Remote Sensing Satellites.

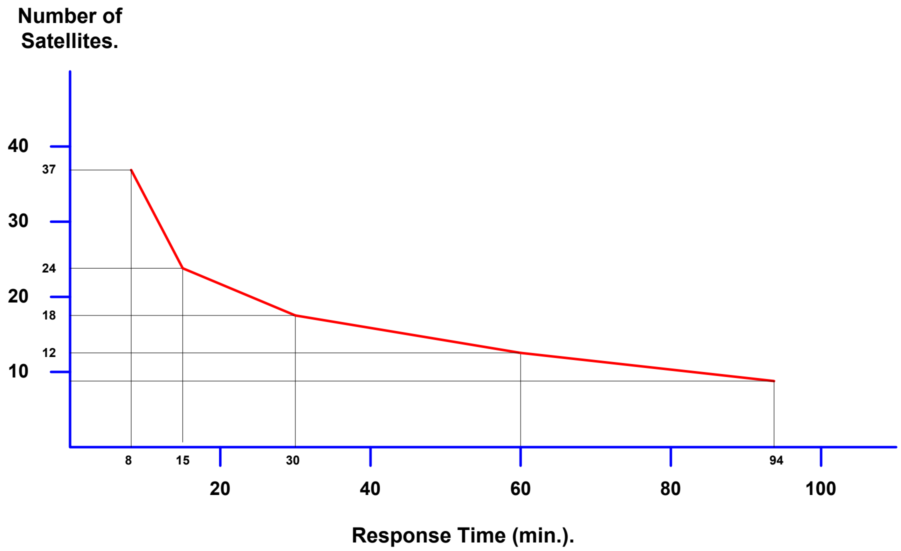


Figure 2.3.5.4-2 ESA Coastal Zone Earthwatch Mission: Mean Revisit Time with a $20^0 – 53.7^0$ Accessibility.
[Source: European Space Agency]

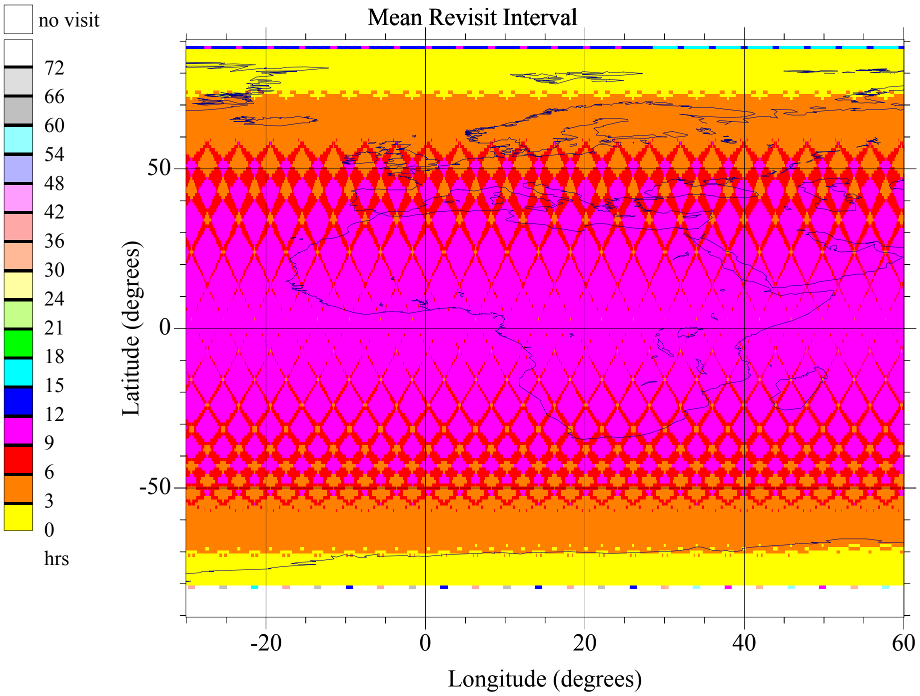


Figure 2.3.5.4-3 Discoverer II: A Constellation of 24 Satellites, at an Altitude of 440 km, could see Most Places in the World within 15 Minutes.
[Source: Defense Advanced Research Projects Agency]

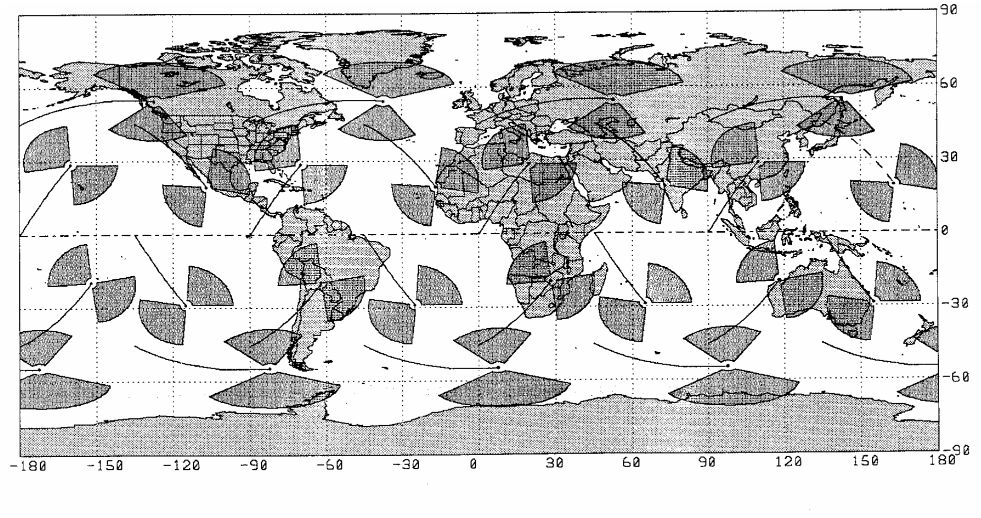


Figure 2.3.5.4-4 The RADARSAT-I Emergency Response Process.
[Source: Canadian Space Agency]

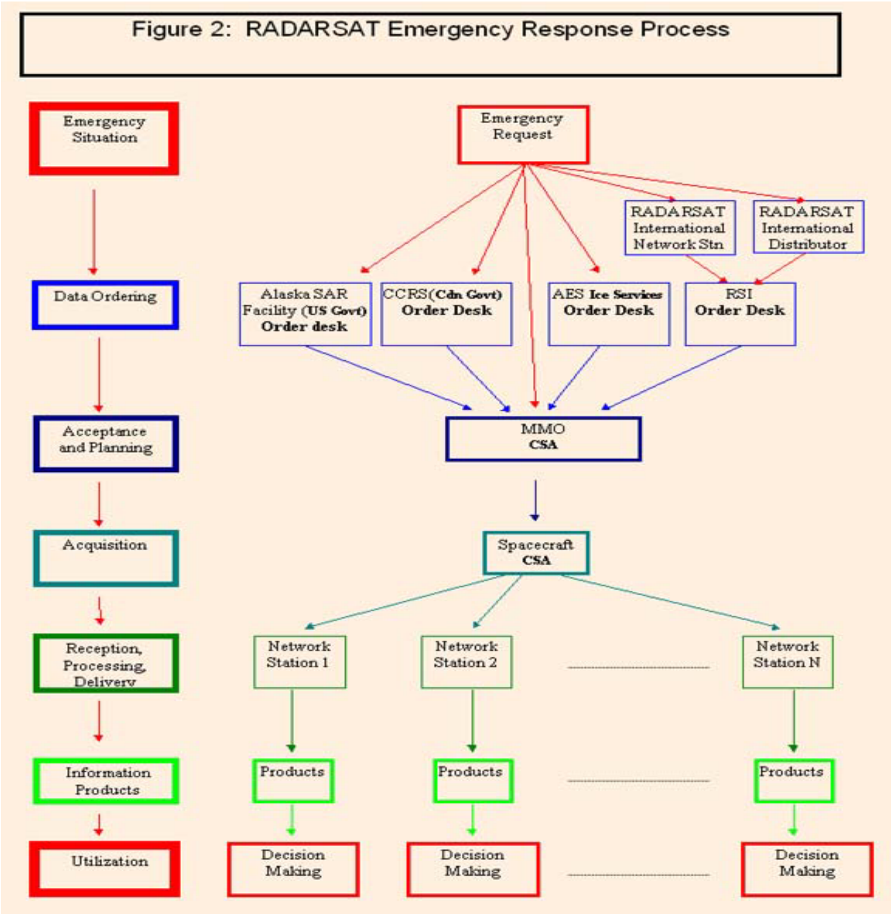
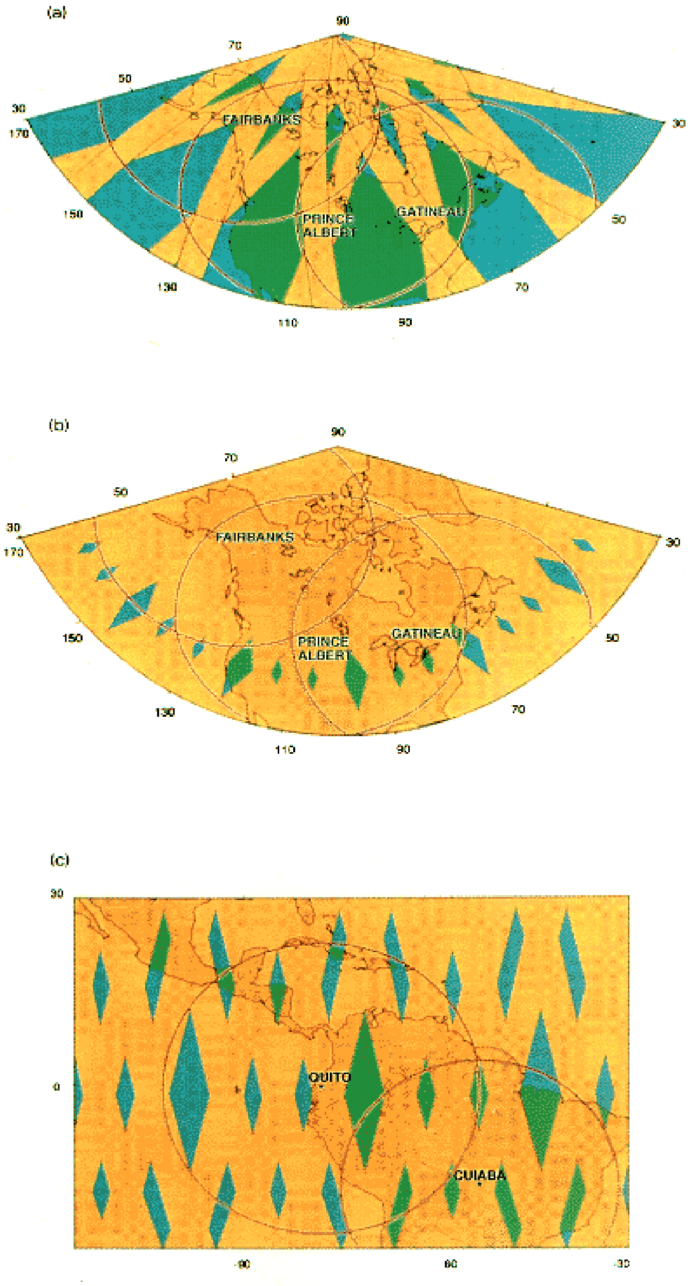


Figure 2.3.5.4-5 Time Budget for the End-to-End RADARSAT Emergency Response Process

Radarsat Response Budget; Unpredicted Emergency; First Image Take (Canada + 200 km Economic Zone)		
Time Element	**Key Activities**	**Typical Value (Radarsat-I)**
Emergency Situation	EMO confirms Emergency Situation	- At T = 0
Data Ordering	EMO defines requirements for imaging (In parameters required by the Satellite Operator; Emergency Request Form) and submits to the Satellite Operator (Canadian Government Order Desk).	- 3 hours
Acceptance and Planning	CSA Mission Management Office (MMO) assesses the request using The ***Guidelines for Emergency Data Acquisition.*** Observation for an accepted Emergency is carried out.	- 48 hours (Urgent Programming) - < 48 hours (CSA Emergency Acquisition Programming)
Acquisition	–	- 0 to 4.0 days (Coverage Access using Max. Swath Width; North of 48 deg. N. Most of Canada accessible within 3.0 days.)
Reception, Processing, Delivery	Image data is downlinked to receiving station (Prince Albert SK., Gatineau, QC), and conveyed to the Canadian Data Processing Facility (Gatineau, QC).	- 4.0 hours minimum (Near Real-Time Processing)
Information Products	Generate "Value-Added" Info Products	- Depends upon products required
Delivery to Users (s)	–	–
TOTAL (Not including time for image interpretation by EMOs)	–	- From ~ 2.0 days to ~ 7.0 days Additional time may be required for: Spatial Resolution < 25m Specified Incidence Angle. Additional time is required for: Image Processing other than "Near Real-Time Processing" Derivation of Specialized Information Products.

Figure 2.3.5.4-6 Coverage Available (Yellow) from RADARSAT-I Using the 500 km Wide Access Swath; a) North America, One-Day Coverage; b) North America, Three-Day Coverage; c) Amazonia, an Example of Equatorial Coverage for Three Days *[Source: Canadian Space Agency]*



Satellite in higher orbits than the low-earth orbit (LEO) systems discussed above can achieve better revisit time, but at the expense of significant degradation in the achievable image quality. Orbits at altitudes higher than LEO are not usually practicable for high-resolution imaging.

As well as the overall system performance limitations of space-based systems, large satellite remote sensing systems, whether they be privately or government operated, are being tasked using protocols, often including international dimensions, which limit the control which an individual Emergency Management Organization (EMO) can exercise towards addressing a developing situation for which the EMO holds the responsibility for providing assistance. In short, EMO's can find themselves "at the mercy" of satellite system operators in trying to muster adequate remote sensing services to meet urgent needs.

2.3.5.5 Unmanned Aerial Vehicles (UAV’s)

There has been a great deal of work, particularly in the US military, to develop unmanned aerial vehicles (UAV’s) for surveillance, reconnaissance and other applications. The companion report: “Analysis of Sensor and Platform Technologies for Application of High-Altitude Long-Endurance (HALE) Platforms in Remote Sensing"; 31st March 1999, provides an overview of current developments in UAV technology and an analysis of the potential for UAV’s to carry out remote sensing. Conventional UAV systems are well suited to tactical military missions, such as battlefield surveillance, but are limited in altitude performance, range, endurance and payload capacity. In addition, these conventional UAV’s are designed to operate at altitudes within the civil airspace should they be used in emergency management roles, a situation for which no regulatory framework currently exists.

These shortcomings of conventional UAV’s are being overcome with the development of a new breed of “super-UAVs’ - High-Altitude Long-Endurance (HALE) platforms, which fly above civilian airspace, have very great range and endurance and substantial payload capacity.

High-Altitude Long Endurance (HALE) technology, first developed for the military, promises to fill a niche area in remote sensing by providing high-resolution coverage with high observation continuity (temporal resolution) over limited regions not possible with single-satellites or small constellations, and too costly to provide using conventional airborne systems alone. Unmanned HALE systems are capable of being rapidly deployed to address emerging and developing situations in diverse geographical locations and can be used under hazardous conditions, such as extreme meteorological conditions, environmental disasters, nuclear accidents, etc. The remainder of this report is devoted to exploring and quantifying the potential benefits which HALE technology can bring to emergency management activities.

2.4 HALE-Based Remote Sensing in the Management of Natural Disasters

2.4.1 Introduction

The ability of remote sensing to support the management of natural disasters is now well accepted by major emergency management organizations. Present-day satellite systems are unable to fully meet the need for rapid response and continuity of observation required during the most urgent phases of the emergency management cycle. Airborne remote sensing systems can provide some more localized remote sensing capability, but generally with high operating costs and exposure of crew to risk. In-situ sensors, usually located on land or in the ocean, are limited in the amount of relevant information they can make available to EMO's, particularly during the Response and Recovery Phases.

The following sections examine the potential of remote sensing to support the management of each of the natural disasters most relevant to Canada, for example:

- Floods
- Earthquakes
- Severe Storms
- Fire
- Landslides and Avalanches
- Drought
- Tsunami and Storm Surges
- Public Health

[This analysis utilises information from the Interim Report of the Committee on Earth Observation Satellites (CEOS) Flood Hazard Team].

For each natural disaster type the unique or net-cost benefits (relative to other available remote sensing platform technologies) accruing from the utilization of HALE technology to support remote sensing are identified and analyzed.

2.4.2 Floods

2.4.2.1 Hazard Description

A flood can be defined as "any relatively high water flow that overtops the natural or artificial banks in any portion of a river or stream - when a bank is overtopped, the water spreads over the flood plain and generally becomes a hazard to society ". When extreme meteorological events occur in areas characterized by a high degree of urbanization, the flooding can be extensive, resulting in a great amount of damage and loss of lives.

Flooding takes many forms:

- River Floods: from winter and spring rains coupled with snow and ice melt, and torrential rains from decaying tropical storms, and monsoons;

- Coastal Floods: generated by winds from intense offshore storms and tsunamis; urban floods: as discussed above from urbanization (increases runoff 2 to 6 times over what would occur on natural terrain);

- Ice Jams: generated by natural or man/animal made obstructions;

- Flash Floods: Can occur within minutes or hours of excessive rainfall, a dam (natural or man-made) or levee failure, or a sudden release of water held by an Ice Jam. Flash floods are the number one weather-related killer in the USA.

Figure 2.4.2.1-1 shows an example of a severe river flood – the Fort Garry region of Southern Manitoba during the 1997 Red River Flood

It must be understood that not all "hydro-geological events" that cause destruction can be classified as floods:

In *Plain Areas*, damage tends to be caused by flooding, mainly controlled by water flow Here floods are caused by heavy precipitation in upstream areas.. The duration of effective rainfall necessary to produce floods in rivers (located in the Plain Area) is usually from hours to days. Flash floods can occur also and have a time period of six hours or less.

In *Mountainous Areas*, damage tends to be caused by landslides, hyper-concentrated flows, etc, that take place almost in the same time when the critical meteorological events occur.

In the frame of a general analysis it should be necessary to consider both flood and slope stability phenomena as different aspects of the same dynamic system: the drainage basin. The events deriving from slope dynamics (gravitational phenomena) and fluvial dynamics (floods) are commonly triggered by the same factor - heavy rainfall. Especially in mountainous areas, it is often impossible to analyze flooding risk without considering all the other phenomena associated with slope dynamics: erosion, slides, sediment transport, etc.

Figure 2.4.2.1-1 An Example of a Severe River Flood – the Fort Garry Region of Southern Manitoba during the 1997 Red River Flood
[Source: Environment Canada]

2.4.2.2 State-of-the Art Application of Remote Sensing

The Committee on Earth Observation Satellites (CEOS) Disaster Management Support Project continues to analyze the application of space-based remote sensing in disaster management. Through the CEOS Flood Hazard Team, which includes participation from the Canada Centre for Remote Sensing (CCRS), as well as from a number of other countries, the Disaster Management Support Project also looks at new satellite-based remote sensing capabilities which will be required for flood management. The remaining paragraphs in this section are summarized from the Interim Report of the CEOS Flood Hazard Team…

With respect to the cycle of disaster management, two main fields of interest have been generally defined for the use of remote sensing data, which can be integrated with GIS and with other information sources, in the flood domain:

a) Detailed Mapping Approach; that is required for the production of hazard assessment maps and for input to various types of hydrological and land use models. These mapping approaches are used at the regional and local scales; the user requirements are related to detailed mapping for updating (and sometime creating) risk maps. These maps contribute to the hazard and vulnerability aspects of flooding.

b) Large Scale (Broad Brush) Approach; that looks at the general flood situation within a river catchment or coastal belt with the aim of identifying areas at greatest risk and in the need of immediate assistance; in this case, remote sensing may contribute to the initialization of numerical weather prediction models and weather forecasts and for mapping inundated areas, mainly at the regional level.

As with many hazard-related applications, the presence of clouds has prevented guaranteed near real-time high resolution satellite observations of floods and flood coverage from such systems as LANDSAT, SPOT and IRS. The implementation of SAR sensors on RADARSAT, JERS-1, and ERS, and the more frequent (though less spatial resolution) NOAA AVHRR is improving the temporal performance of the flood monitoring and mapping function.

Currently, multi-channel and multi-sensor data sources from such satellites as GOES and POES have been used for meteorological evaluation, interpretation, validation, and integration (into Numerical Weather Prediction Models) to assess hydrological and hydro geological risks. These data are used to estimate precipitation intensity, amount, and coverage, measure moisture and winds, and to determine ground effects such as the surface (soil) wetness. Quantitative Precipitation Estimates (QPE) and Forecasts (QPF) use satellite data as one source of information to facilitate flood and flash flood forecasts in order to provide early warnings of flood hazard to communities.

Mitigation Phase

For regional methodologies, the essential input data are geomorphology, hydrological analysis, historical investigation of past events, and climatological. Remote sensing may help mapping geomorphic elements, providing meteorological data for hydrological modeling and contributing to mapping historical events. In the prevention area, these historical data sets can give managers a "heads up" on what is normally expected (e.g., precipitation); hydrological models can use this climatological data to give decision makers the typical response time for a particular precipitation event. Potential users are land planners (federal or national), hydro meteorologists, environmental and agricultural authorities.

Investigations on the local scale include: topography, hydraulic data, river bed roughness, sediment grain size, hydraulic calculations, land cover, and surface roughness. Remote sensing may contribute partially for mapping topography and in defining surface roughness and land cover. Potential users are land planners (local municipality), hydro meteorologists, and those in water management. Hazard data obtained on the local scale can be combined with vulnerability data on population, land use, type of buildings, type of contents, infrastructures, and activities, to assess the risk. In this case, remote sensing may contribute to updating cartography for land use. Cartographic updates is a critical aspect of remote sensing since there are often delays in some public administration for maintaining updated official cartography as well as illegal constructions in some areas that are not reported on official maps.

Preparation Phase (immediately before the flood)

This management category is probably the most promising field of application for remote sensing data. In this case, the differentiation between local and regional scale is less evident. Input data are meteorology, ice and snow conditions (coverage and depth), soil moisture, tidal conditions in coastal areas, water level, hydrological forecasts, DTM (Digital Terrain Mapping) topography, land cover, surface roughness, river bed roughness, soil type, and permeability. Satellite-derived parameters are also used in assimilation techniques to help initialize numerical weather prediction models where outputs are Quantitative Precipitation Forecasts (QPF). In all these above mentioned input data there is a contribution from remote sensing, with the only exception of river bed roughness. In addition to meteorological applications (NOWCASTING and prediction), the benefit from the use of remote sensing techniques is not essential in instrumentally monitored areas. However, remote sensing is essential in those areas not instrumentally monitored. Potential users are civil protection (federal and state), hydro meteorologists, local authorities, water management, and news media.

Response (during the flood)

This is the most delicate management category due to rescue operations and the safeguard of people and property. The following is information used and analyzed in real time (this includes data from the previous category - Preparedness): extent (aereal) mapping and monitoring in time (satellite, airborne, and direct survey), damage to buildings (remote sensing and direct inspections), damage to infrastructures (remote sensing and direct inspection), meteorological NOWCASTS (important real-time input from remote sensing data as to intensity/estimates, movement, and expected duration of rainfall), and evaluation of secondary disasters like waste pollution, etc., to be detected and assessed during the crisis (?) (remote sensing and others). Remote sensing data can also be of use in targeting rescue efforts. In this category, an important role is played by communication, for which satellite may provide an essential contribution. Potential users are the same as in the Preparedness category (civil protection, hydro meteorologists, local authorities, water management, media) plus insurance companies.

Recovery (after the flood)

This category includes reconstruction and rehabilitation. Information required for this category are accurate evaluations of damage extent. Remote sensing may contribute in the identification of the environmental impact of floods, while there is only a partial contribution in the identification of damage to infrastructures. Potential users are local authorities, insurance companies, public works, and water authorities.

2.4.2.3 Gaps and Potential Improvements in Remote Sensing Capability

Particularly during the Preparation, Response and Recovery Phases of the Emergency Management Cycle, many users of remote sensing data will need the information as part of a crisis management activity and will therefore require "near-real-time turnaround". Turnaround time is less demanding for those involved in hydrologic modeling, calibration/validation studies, damage assessment and the planning of flood mitigation.

Gaps exist and remote sensing data is not being used to its potential to help alleviate the problem of flood management. The Interim Report from the CEOS Flood Hazard Team has identified a number of desired technology-related improvements in the overall application of satellite remote sensing techniques to flood management:

- increase time and frequency of coverage;
- improve coverage access and delivery;
- increase the resolution of DTM for local application – this includes very local (1 m) information (town, small watershed, etc) that is very precise;
- develop/launch an operational satellite specifically dedicated to hydrological problems (Hydro SAT);
- have the ability to access information from all available data sources;
- formulate procedures that effects awareness, access, and products and services;
- launch meteorological satellites with higher resolution sensors in both time and space;
- place microwave sensors onboard geostationary satellites.

2.4.2.4 The Potential Role of HALE-Based Remote Sensing

Despite the continuing development of new satellite systems, some carrying cloud-penetrating instruments which help to provide guaranteed observation, only very large (and very costly) constellations of satellites, all carrying high-resolution sensors, could meet the full need to provide guaranteed high-resolution, high observation continuity observation of localized regions. This high-performance localized surveillance would be of great value during those phases of the flood disaster management cycle when events are changing relatively rapidly, i.e. the Preparation, Response and Recovery Phases. The development of such large satellite constellation systems is unlikely within the foreseeable future.

As well as the overall system performance limitations of space-based systems, large satellite remote sensing systems, whether they be privately or government operated, are being tasked using protocols, often including international dimensions, which limit the control which an individual Emergency Management Organization (EMO) can exercise towards addressing a developing situation for which the EMO holds the responsibility for providing assistance.

Following are some proposed applications areas in which HALE-based remote sensing could support the efforts of flood management by proving high-resolution, high observation continuity data with temporal response and exercisable control of the system not available with present or planned satellite-based systems.

Mitigation Phase

- Localized updates (high-risk areas) to hazard, risk, vulnerability and preparedness analyses and plans, procedures and programs, using high-resolution, high observation continuity capability.
- Verification of vulnerability reduction and preparedness measures.
- Calibration/ validation of satellite-based and other measurements.
- Localized updates to cartographic, geomorphological, hydrological, climatological studies (high-risk areas).
- High-resolution mapping analyses of relevant historical events.
- Localized investigations (high-risk areas) into topography, hydraulic data, river bed roughness, sediment grain size, hydraulic calculations, land cover, surface roughness.
- Local data can be combined with other sources, GIS, population, land use, building types, infrastructure, utilities, corridors, escape/rescue routes, etc.
- Training and exercises for Preparation Phase and Response Phase operations.

Potential users include emergency management organizations, land planners, water management authorities, hydro-meteorologists, hydro power companies, conservation authorities, planning authorities, environmental authorities, agricultural authorities, transportation routing.

Preparation Phase (Immediately before the flood)

- Localized updates (high-risk areas) to hazard, risk, vulnerability and preparedness analyses and plans, procedures and programs, using high-resolution, high observation continuity capability.
- Localized observations using high-resolution, high observation continuity capability: meteorology, ice and snow conditions (coverage and depth), soil moisture, tidal conditions in coastal areas, water level, hydrological forecasts, DTM (Digital Terrain Mapping) topography, land cover, surface roughness, river bed roughness, soil type and permeability.
- Calibration/ validation of satellite-based and other measurements.
- Training and exercises for Response Phase operations.

Potential users include emergency management organizations, water management authorities, hydro-meteorologists, local authorities, and news media.

Response Phase (During the flood)

- Extent mapping, water levels.
- Assessment of relief efforts required.
- Location of distressed personnel.
- Identification and monitoring of escape/ rescue routes/ corridors/ marshalling points/ landing sites.
- Targeting and direction of relief and rescue efforts.
- Assessment of effectiveness of relief efforts.
- Assessments of damage to buildings, property, infrastructure, utilities, transport corridors.
- Meteorological NOWCASTS, intensity/estimates, movement and expected duration of rainfall.
- Detection and evaluation of secondary disasters, such as landslides, pollution, technological hazards.

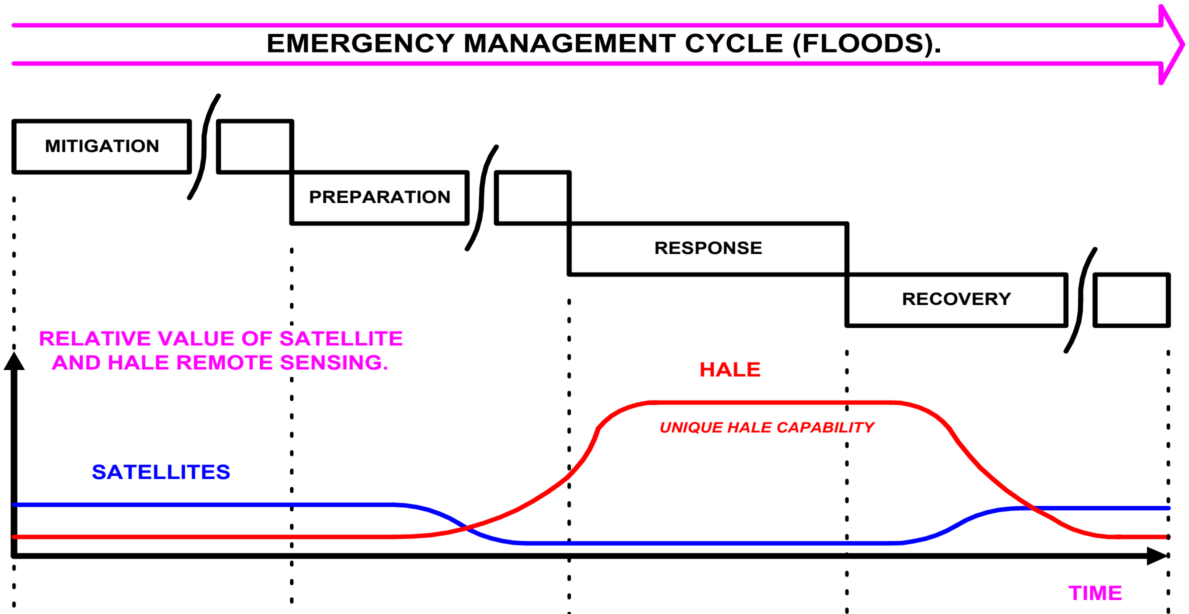
Potential users include emergency management organizations, water management authorities, hydro-meteorologists, local authorities, and insurance companies.

Recovery Phase (after the flood)

- Evaluation of potential for recurring threats.
- Damage assessments (property, infrastructure, environment), and damage report verification.
- Ground conditions (moisture, etc).
- Environmental impacts.
- Verification of recovery, reconstruction, rehabilitation, repair measures.
- Validation of predictive models.
- Inputs to updated hazard, risk, vulnerability and preparedness analyses, policies, plans, procedures, programs, arrangements,
- Inputs to historical database and "lessons learned" process.

Potential users include emergency management organizations, local authorities, water management authorities, hydro-meteorologists, insurance companies. Figure 2.4.2.4-1 illustrates the projected relative value of satellite-based remote sensing and HALE-based remote sensing in the Emergency Management Cycle for a Flood Disaster.

Figure 2.4.2.4-1 Satellite and HALE Remote Sensing in the Flood Management Cycle



SATELLITES:	SATELLITES:	SATELLITES:	SATELLITES:
- Analyses: geomorphology, hydrology, climatology, meteorology, preciptation. - Topography, hydraulic data, river bed, sediment, terrain, cover, cartography. - Response time, vulnerability, preparedness analysis and plans. - Historical investigations.	- Analyses: meteorological, precipitation, ice & snow, soil moisture, tidal conditions (coastal), water level, hydrological. - Topography, hydraulic data, river bed, sediment, terrain, land cover, soil type & permeability.	Low Temporal Resolution, Medium Spatial Resolution: - Extent, water level, damage (human assets, environment), precipitation (now & forecast), ice & snow, terrain movement, tidal conditions (coastal). hydrological. - Targeting of rescue efforts.	Low Temporal Resolution, Medium Spatial Resolution: - Damage to human assets. - Damage to environment. - Evaluation of potential for recurring threats.
HALE:	HALE:	HALE:	HALE:
- Localised tech. analyses (high-risk areas):topography, hydraulic data, river bed, sediment, terrain, land cover, cartography, etc. - Localised vulnerability and preparedness analyses & plans, and verification. - Calibration/ validation of other measurements. - Historical investigations. - Training & exercises for Response/ Recovery.	- Localised updates (high-risk areas) to analyses: meteorology, precipitation, ice & snow, soil moisture, tidal conditions (coastal), water level, hydrology, etc. - Localised updates: topogrpahy, hydraulic data, river bed, sediment, terrain,land cover, soil type & permeability, etc. - Localised vulnerability and preparedness analyses and plans. - Calibration/ validation of other measurements. - Preparatory Activities. - Relocation of High-Value Portable Assets.	High Temporal Resolution, High Spatial Resolution, Local Coverage: - Extent, water level, precipitation (now & forecast), ice & snow, terrain movement, tidal conditions (coastal). hydrological. - Assessment of required relief efforts, targeting and direction of relief efforts, and assessment of effectiveness. - Location of distressed personnel. - Identification of escape/ rescue routes/ corridors/ marshalling points/ landing sites. - Damage assessment (buildings, property, infrastructure,utilities, transport corridors). - Detection and evaluation of secondary threats, such as landslides, pollution, technological hazards.	High Temporal Resolution, High Spatial Resolution, Local Coverage: - Evaluation of potential for recurring threats. - Damage assessments (human assets, environment) and damage report verification. - Ground conditions (moisture,etc). - Verification of recovery, reconstruction, rehabilitation, repair measures). - Validation of predictive models. - Inputs to updated hazard, risk, vulnerability and preparedness analyses, policies, plans, procedures, programs, arrangements. - Input to historical database and "lessons learned" process.

2.4.3 Earthquakes

2.4.3.1 Hazard Description

Earthquakes can cause enormous damage in a very short time so it is necessary to quickly provide emergency help. Figure 2.4.3.1-1 shows examples, from recent California earthquakes, of how earthquakes can seriously damage residential property and transport infrastructure. In the days following an earthquake, more detailed information on structural damage is needed. As the days become weeks, additional information becomes less and less important. The rate at which the value of new information decays depends, in large part, on the geographic extent and communication infrastructure of the affected area and the concentration of population. In sparsely populated mountainous areas, information on villages affected by large earthquakes may be valuable days and even weeks after the event as rescue teams try to locate people in need of assistance. Thus, the information required is a function of both time and geographic distribution. Information on general damage (e.g., houses collapsed) is needed within hours or up to three days for localized events and within days to one or two weeks for more far-reaching events. This information need not always be cartographically accurate. As time progresses, more detailed, cartographically registered, data are needed (e.g., structural damage to buildings, infrastructure, roads, etc.). Registered data are also needed to spot and map the fires which frequently accompany earthquakes.

The urgency for information following a severe earthquake is so immediate that some major relief organizations depend upon damage assessment models. These models will contain data on the culture (buildings/ construction, etc.), infrastructure (roads, power/water plants, etc.) and other important aspects of the built environment (e.g. hazardous chemical stockpiles). In addition, the models will contain data relative to seismic acceleration (depth to bedrock, soil type etc.). With specific data on location, depth, magnitude and first arrival of a seismic event, these models can provide very valuable timely approximations to the extent of damage.

2.4.3.2 State-of-the-Art Application of Remote Sensing

The application of remote sensing technology in the Emergency Management Cycle for earthquake disasters has generally been limited to earthquake mechanism-type studies based on geology, change detection etc. The current minimum spatial resolution of most satellite remote sensing systems (ca. 10 metres) precludes the ability to reliably identify even major damage (e.g., building collapse). For Example, panchromatic SPOT imagery could not be used to detect major damage in villages following the Spitak (Armenia) earthquake. Such systems have been used to map damage resulting from earthquake-related fires (e.g., during the Kobe (Japan) earthquake), however, the minimum temporal frequency of observation (ca. 3 days) for a single satellite limits utility even for this application.

Useful satellite remote sensing for timely earthquake damage assessment will have to await the anticipated inauguration of high-resolution satellite imagery, and a significant increase in the number of satellites available. Aircraft imagery of damage at Kobe, acquired at 1-meter resolution and degraded step-wise to 10 meters indicates that 2-meter or better resolution is generally needed to reliably detect major damage. However, the temporal resolution afforded by individual satellites especially considering cloud cover) will still fall short of that needed unless multiple satellites are used.

Figure 2.4.3.1-1 Examples, From Recent California Earthquakes, of How Earthquakes Can Seriously Damage Residential Property and Transport Infrastructure. *[Source: United States Geological Survey]*

Mitigation Phase

It is possible, but very costly, to build an environment which will withstand any earthquake. This high cost dictates the need for accurate assessment of earthquake risk and vulnerability in terms of the probability of occurrence and magnitude, and the accelerations likely to be experienced. This is a difficult assessment in regions where earthquakes occur frequently but extremely difficult where they are rare. Where there is enough seismic data, the frequency of large-magnitude events can be gauged by extrapolation from the frequency of smaller events. This, however, is a first approximation; to get a better assessment, geophysicists try to locate, map, and understand local faults and their frequency and mechanism of rupture. This understanding is placed in the context of the regional tectonic setting of crustal motion (neo-tectonics). In areas of low seismicity (where earthquakes nevertheless can pose a serious threat), assessments of frequency (and magnitude) are based on geological evidence (slickensides, sand blows, etc.) and tectonic evidence is given greater weight. Following are areas of contribution of space-based remote sensing to earthquake mitigation (ranging from operational to research):

a) Lineament mapping: These (often obscure) lineations are observed in synoptic space images as, e.g., alignments of vegetation, topography, etc. They may be the surface manifestation of active faults and evidence of seismicity. (Virtually) constant (solar) illumination angle can seriously bias results and the relationship between lineaments and seismicity is not very strong. Nevertheless, in areas susceptible to occasional earthquakes and/or where other data are sparse, lineament mapping is a useful operational tool. Visible and infra-red imagery with moderate (>10 meter) resolution is generally used. Synthetic Aperture Radar (SAR) may also be used but the self-illumination of these systems can create false impressions of lineation.

b) Tectonic setting: The regional tectonic setting of an area forms the basis for assessing its seismicity. In some cases (e.g., Japan, Southern California) the setting is well-known, but in others (e.g., Central and Eastern US) the origin of seismicity is less clear. Several space-based techniques continue to contribute significantly to our understanding of regional tectonics including satellite geodesy (satellite laser ranging, very long baseline interferometry and use of the Global Positioning System). Radar (and, in the future, laser) altimetry are use, especially over the ocean, to map the geoid and gravity field. Even satellite data on the crustal magnetic field are used to study and interpret regional tectonics. Contributions from these geophysical satellites will increase as their capabilities (sensitivity, resolution) improve.

c) Neo-tectonics: Recent tectonic activity is closely linked with contemporary seismicity and is studied in several ways using satellite observations. For example, sand blows can provide critical evidence of recent tectonism especially in areas where other data are lacking. Visible/infra-red imagery is also used, for example, in studying displacements in streams and hillslopes which are also indicators of tectonic activity. For these studies, a spatial resolution of five meters is the best needed.

d) Fault-motion and strain: SLR (Side-Looking Radar) and VLBI (Very Long Baseline Interferometry) have, for two decades, been used to monitor the crustal movement (strain) in the vicinity of active faults. These techniques have been superseded by GPS; rapid development of inexpensive receivers has made it possible to install them in dense networks to monitor large areas, e.g., the whole Los Angeles Basin. Using this dense array, it will be possible to improve maps of known faults, detect possible unknown faults, and locate places on these faults which are locked and therefore susceptible to sudden rupture and earthquakes. Combining GPS with repetitive surveying using Interferometric SAR, it may be possible to produce series of strain maps of complete seismic areas, identifying those which are more prone to earthquakes. Subtle changes in the land surface (even changes in foliage or soil) can result in decorrelation on the InSAR returns particularly at short microwave wavelengths so, inasmuch as spatial resolution is not important for this application, L-band SAR (at 10-meter resolution or better) is preferred for interferometry.

e) Earthquake mechanisms: Recent elegant studies have shown that InSAR (Interferometric SAR) can be used to map very small (centimeter-level) crustal movements which occurred during and after earthquakes. These data relate to the mechanisms of rupture and can contribute to our understanding of earthquake mechanisms - an important factor in assessing risk and vulnerability. Again, the same considerations regarding wavelength and resolution prevail as in the case above. For studying co-seismic displacements (those taking place during and after the earthquake), acquisitions within several days after the event and continuing at this frequency for several weeks will be needed.

Preparation Phase

An earthquake prediction can be extremely dangerous. It can ignite fear and anxiety resulting in disorder and chaos and a level of damage and injury approaching that of the earthquake itself. It is for this reason that the State of California has lain down strict protocols for the evaluation and issuance of earthquake warnings. In addition to being validated and issued by an official authority, an effective prediction should be specific and accurate in three regards: time, place, and magnitude. The accuracies required vary with respect to the purpose of the prediction: public alerts should be accurate to within (about) 10 miles of the epicenter, a few days of occurrence and within 1 unit of magnitude. For other purposes (e.g., advanced warning to officials and public works) they may be less accurate but in this case care must be given to avoid public release or disclosure.

There are no generally accepted operational methods for predicting earthquakes. Although some successes have been claimed, they are questionable and, in any case, not sufficiently reliable. Techniques being investigated range from the reaction of animals to inert gas content of well waters. Variations in the electrical field have also been claimed to be precursors to earthquakes. Some of these “signals” have been observed from space and reported in the Russian and Japanese literature. However, the validity of this technique is hotly disputed. Thermal anomalies, particularly over the ocean, are also claimed as earthquake precursors but here again the reliability (and physics) of the process is being questioned.

While research on these space-based (and other) techniques continues, it seems that we are still far from a method which will provide predictions of sufficient accuracy to meet operational requirements.

2.4.3.3 Gaps and Potential Improvements in Remote Sensing Capability

The availability of 1or 2 metre spatial resolution satellite imagery will make a profound contribution to earthquake damage assessment and disaster response. However, this will only really be true if the improved resolution is accompanied by adequate temporal resolution and all-weather, day/ night imaging capability. There currently seems less hope that space techniques - or anything else - can help in effective earthquake prediction.

2.4.3.4 The Potential Role of HALE-Based Remote Sensing

Due to the low predictability and very short duration of actual earthquakes, combined with the need to provide very rapid response, and the system performance limitations described in the previous section, satellite-based remote sensing systems are currently of very limited value during the Response and Recovery Phases. Only very large (and very costly) constellations of satellites, all carrying high-resolution sensors with all-weather, day/ night capability, could meet the full needs of the Response and Recovery Phases.

As well as the overall system performance limitations of space-based systems, large satellite remote sensing systems, whether they be privately or government operated, are being tasked using protocols, often including international dimensions, which limit the control which an individual Emergency Management Organization (EMO) can exercise towards addressing a developing situation for which the EMO holds the responsibility for providing assistance.

Following are some proposed applications areas in which HALE-based remote sensing could support the efforts of earthquake disaster management by proving high-resolution, high observation continuity data with temporal response and exercisable control of the system not available with present or planned satellite-based systems.

Mitigation Phase

Localized updates (high-risk areas) to hazard, risk, vulnerability and preparedness analyses and plans, procedures and programs, using high-resolution, high observation continuity capability.

- Verification of vulnerability reduction and preparedness measures.
- Calibration/ validation of satellite-based and other measurements.
- Localized updates to geological, change detection, etc., studies (high-risk areas).
- High-resolution mapping analyses of relevant historical events.
- Local data can be combined with other sources, GIS, population, land use, building types, infrastructure, utilities, corridors, escape/ rescue routes, etc.
- Training and exercises for Response Phase operations.

Potential users include emergency management organizations (EMO's), land planners, utility companies, urban planning authorities, transportation routing.

Preparation Phase (Immediately before the earthquake).

The gross inaccuracy of present earthquake prediction methods and the restrictions on issuing earthquake warnings limit the scope of a Preparation Phase, as might be defined for other kinds of disaster where some warning signs of disaster activity may be observed. The role of remote sensing, be it space-based or airborne, is therefore compromised by the inability to adequately define the temporal and geographical framework for a meaningful Preparation Phase.

Response Phase (During and immediately following the earthquake).

- Assessments of damage to terrain, buildings, property, infrastructure, utilities, transport links.
- Assessment of relief efforts required.
- Location of distressed personnel.
- Identification and monitoring of escape/ rescue routes/ corridors/ marshalling points/ landing sites.
- Targeting and direction of relief and rescue efforts.
- Assessment of effectiveness of relief efforts.
- Detection and evaluation of secondary disasters, such as fires, pollution, technological hazards.

Potential users include emergency management organizations (EMO's), local authorities, insurance companies, and news media.

Recovery Phase (after the earthquake).

- Evaluation of potential for recurring threats.
- Damage assessments (buildings, property, infrastructure, utilities, transport links), and damage report verification.
- Assessment of environmental impacts.
- Verification of effectiveness of recovery, reconstruction, rehabilitation, repair measures.
- Data input to predictive models.
- Inputs to updated hazard, risk, vulnerability and preparedness analyses, policies, plans, procedures, programs, arrangements.
- Inputs to historical database and "lessons learned" process.

Potential users include EMO's, local authorities, water management authorities, utility companies, insurance companies.

2.4.4 Severe Storms

2.4.4.1 Hazard Description – Extratropical Storms

Large-scale, mid-latitude, storms are the main cause of blizzards, freezing rain and heavy snowfall in winter and can also cause intense rainfall, hailstorms, or spawn tornado families. The 1990s have seen an increase in the cost of natural disasters resulting from these storms.

During 1989-90, a series of intense winter storms struck northern Europe causing over 200 deaths and billions of dollars in damage. In July 1996, a low pressure system dumped 200 mm of rain in the Saguenay River region of Quebec in Canada and the resulting flash floods killed at least 10 people; 16,000 people had to be evacuated and losses were over US$ 500 million. The 1998 flooding of the Yangtze River in China was the most costly disaster of the year, claiming 4,150 lives, affecting 223 million people and causing $30 billion in damage. Figure 2.4.4.1-1 shows a typical scene of devastation in the streets of Ottawa during the Great Ice Storm of 1998, which severely affected Quebec and Eastern Ontario.

Significant achievements during the decade include improved forecast accuracy, resulting from improvements in numerical models, supported by enhanced observational systems and increased emphasis on user requirements and effective messaging. Using computer models, many extratropical storms can now be predicted well ahead of time and the timely issue of early warnings helps to mitigate their impacts.

For the future, it is critical that investments continue in surface and space-based observational networks, telecommunications and computer systems and numerical weather prediction along with related research and development. Since more people are living in vulnerable areas and, in many instances, they are taking inadequate precautions against extratropical storms, it is equally vital that emphasis continue to be placed on enhancing public awareness and understanding of hazards, early warnings and mitigation and preparedness actions. There is also a need, as for other types of natural disaster, to improve the ability to address the effects of storms in the Response and Recovery Phases of the Emergency Management Cycle.

Severe Local Storms and Tornadoes

Severe convective weather such as tornadoes, hail, damaging wind gusts and flash floods presents a serious threat to life and property in many parts of the world. Destructive tornadoes have been observed in all continents except Antarctica and their occurrence is, probably, vastly under-reported. In the Pacific and the Caribbean, landfalling tropical cyclones often spawn tornadoes. Figure 2.4.4.1-2 shows an example of the destruction caused by Hurricane Andrew, which struck the southern Florida peninsula and south central Louisiana in August 1992, causing $25 billion in damage in the US alone, making Andrew the most expensive natural disaster in US history. During the past 20 years, devastating tornado occurrences have resulted in hundreds of fatalities in places as far apart as Moscow and Bangladesh. Severe hailstorms, flash floods and dangerous wind gusts are also very widely experienced and damage from these non-tornadic events can also be catastrophic. In the last 15 years, hailstorms have caused damage in excess of US$ 500 million from Munich, Germany to Denver, USA and Sydney, Australia. A flash flood recently killed over 80 people at Biescas in the Spanish Pyrenees. Around the world, press reports are common of damage to buildings, aircraft, trees and crops caused by strong convective gusts.

Figure 2.4.4.1-1 A Typical Scene of Devastation in the Streets of Ottawa During the Great Ice Storm of 1998, which Severely Affected Quebec and Eastern Ontario. ***[Source: Ottawa Sun].***

Figure 2.4.4.1-2 Hurricane Andrew Caused $25 Billion in Damage in the Southern Florida Peninsula and South Central Louisiana in August 1992. *[Source: National Hurricane Center]*.

2.4.4.2 State-of-the-Art Application of Remote Sensing

Remote sensing of different kinds makes major contributions to management efforts in the pre-disaster phases of many severe storm situations through the provision of meteorological data and more localized information on storm behaviour. Significant progress has been made in understanding and modelling severe convective storms. Though increasing numbers of tornadoes have been reported in the US and property damage has increased in recent years, the annual death toll has dropped significantly. The decrease in fatalities is due to improvements in scientific understanding of severe storm formation, in observing technology and in the preparation and communication of warnings along with aggressive and successful public awareness and preparedness programs. Notable accomplishments include more widespread application of weather radars, particularly Doppler, leading to significantly increased lead times for tornado warnings and improved detection of heavy precipitation, enhanced observational coverage through automatic weather stations, improved tools such as workstations, advances in numerical models and improved public awareness of severe weather, particularly tornadoes. This has already led to a doubling of warning times, jumping from about nine minutes in 1990 to over 17 minutes in 1999.

The success of the above integrated approach combining improved storm detection, forecasting and warnings delivery with enhanced public awareness and education and well-exercised preparedness and response measures, makes it clear that this strategy should be transferred to all regions at risk. Particular issues for the future also include the need to: improve climatological estimates of the threats presented by severe weather; address probable under-reporting of severe weather occurrences; transfer research results and advanced forecast techniques; and to lessen the vulnerability of buildings and structures to severe weather phenomena.

2.4.4.3 Gaps and Potential Improvements in Remote Sensing Capability

Meteorological observations and local storm and weather observations can continue through the Response and Recovery Phases, providing valuable data on ongoing and forecast environmental conditions. There is in addition, as for many other natural disasters, a need to provide much better remote sensing capabilities to assist relief and recovery efforts beyond knowing the weather conditions. As for other disaster types, current satellite systems are unable to meet this need. Airborne systems, while often providing some useful local capability, are expensive to operate for Response and Recovery periods which may run into many days, and may involve physical risk to crew in severe weather situations.

2.4.4.4 The Potential Role of HALE-Based Remote Sensing

Following are some proposed applications areas in which HALE-based remote sensing could support the efforts of severe storm disaster management by proving high-resolution, high observation continuity data with temporal response and exercisable control of the system not available with present or planned satellite-based systems.

Mitigation Phase

- Localized updates (high-risk areas) to hazard, risk, vulnerability and preparedness analyses and plans, procedures and programs, using high-resolution, high observation continuity capability.
- Verification of vulnerability reduction and preparedness measures.
    - Calibration/ validation of satellite-based and other measurements.
    - High-resolution mapping analyses of relevant historical events.
- Local data can be combined with other sources, GIS, population, land use, building types, infrastructure, utilities, corridors, escape/ rescue routes, etc.
- Training and exercises for Response Phase operations.

Preparation Phase (Immediately before the storm arrives).

- Localized updates to hazard, risk, vulnerability and preparedness analyses and plans, procedures and programs, using high-resolution, high observation continuity capability.
- Localized observations using high-resolution, high observation continuity capability: meteorology, ice and snow conditions (coverage and depth), tidal conditions in coastal areas, water level, hydrological forecasts, DTM (Digital Terrain Mapping) topography, land cover, surface roughness.
- Calibration/ validation of satellite-based and other measurements.
- Training and exercises for Response Phase operations.

Potential users include emergency management organizations, water management authorities, hydro-meteorologists, local authorities, news media.

Response Phase (During and immediately following the storm).

- Localized observations using high-resolution, high observation continuity capability: meteorology, ice and snow conditions (coverage and depth), tidal conditions in coastal areas, water level, hydrological forecasts).
- Assessment of relief efforts required.
- Location of distressed personnel.
- Identification and monitoring of escape/ rescue routes/ corridors/ marshalling points/landing sites.
- Targeting and direction of relief and rescue efforts.
- Assessment of effectiveness of relief efforts.
- Assessments of damage to buildings, property, infrastructure, utilities, transport corridors.
- Detection and evaluation of secondary disasters, such as landslides, pollution, technological hazards.

Potential users include emergency management organizations, water management authorities, hydro-meteorologists, local authorities, insurance companies.

Recovery Phase (After the storm).

- Evaluation of potential for recurring threats.
- Damage assessments (property, infrastructure, environment), and damage report verification.
- Ground conditions (moisture, etc).
- Environmental impacts.
- Verification of recovery, reconstruction, rehabilitation, repair measures.
- Validation of predictive models.
- Inputs to updated hazard, risk, vulnerability and preparedness analyses, policies, plans, procedures, programs, arrangements.
- Inputs to historical database and "lessons learned" process.

Potential users include emergency management organizations, local authorities, water management authorities, meteorologists, hydro-meteorologists, insurance companies.

2.4.5 Fires

2.4.5.1 Hazard Description

Natural forest, brush and grassland ecosystems evolved with fire as an agent of ecological change. Human development has altered many natural landscapes and has placed people and human assets in direct contact with wildfire. Fires can spread quickly and can threaten settlements, human life and wildlife. Wildfires can also damage timber supplies and cause other economic upsets. Fires can also damage conservation areas and cause perturbations of atmospheric chemistry. Figure 2.4.5.1-1 shows a typical Canadian wildfire.

Most fires are caused by human activities or by natural phenomena such as volcanoes and lightning. Human related fires can be divided into intentional or accidental causes. Some intentional fires are arson fires that are set to create havoc and to cause damage; however, most intentional fires are related to forest or shrub removal for transformation of the land for agricultural purposes or for pasture regeneration. These fires are not seen just as a technical problem but also as a complex socio-economic issue.

To manage wildfires, the information needed varies not only by the user of the information but also by the phase of the fire. For suppression planning and for prioritization of areas for surveillance, it is important to assess the fire potential (*risk and hazard mapping*) in the most fire-prone areas. In the crisis phase, it is necessary to know the exact position of the fire (*detection*), how it is developing and spreading (*behaviour*), how it has progressed over time (*monitoring*) and how it is likely to develop into the future (*behaviour prediction*). After suppression it may be necessary to examine the type and extent of damage and to plan for recovery actions (*assessment, mapping, and recovery*).

2.4.5.2 State-of-the-Art Applications of Remote Sensing

Remote sensing can be used to detect and monitor forest fires and the re-growth following a fire. As a surveillance tool, routine sensing facilitates observing remote and inaccessible areas, alerting monitoring agencies to the presence and extent of a fire. Data from the NOAA (National Oceanic and Atmospheric Administration) AVHRR (Advanced Very-High Resolution Radiometer) thermal capability and GOES (Geostationary Operational Environmental Satellite) meteorological satellite can be used to delineate active fires and remaining "hot-spots" when optical sensors are hindered by smoke, haze, and /or darkness. Comparing burned areas to active fire areas provides information as to the rate and direction of movement of the fire. Remote sensing data can also facilitate route planning for both access to, and escape from, a fire, and supports logistics planning for fire fighting and identifying areas not successfully recovering following a burn.

Years following a fire, updates on the health and regenerative status of an area can be obtained by a single image, and multi-temporal scenes can illustrate the progression of vegetation from pioneer species back to a full forest cover.

The Committee on Earth Observation Satellites (CEOS) Disaster Management Support Project continues to analyze the application of space-based remote sensing in disaster management. Through the CEOS Fire Hazard Team, which includes participation from the Canada Centre for Remote Sensing (CCRS), as well as from a number of other countries, the Disaster Management Support Project also looks at new satellite-based remote sensing capabilities which will be required for fire management. The remaining paragraphs in this section are summarized from the Interim Report of the CEOS Fire Hazard Team:

Figure 2.4.5.1-1 A Typical Canadian Wildfire.
[Source: Canadian Interagency Forest Fire Centre].

In the following, fire management is divided into three different phases: Preparation, Response, and Recovery. The information requirements are normally different in different phases of the fire. The biggest differences relate to the temporal and spatial resolution and accuracy of the information.

Preparation Phase

The most important task in the Preparation Phase of fire management is fire risk assessment. Risk assessment can be used in the context of prevention, as the result of the risk assessment can help to select major risk areas for surveillance or impose restrictions on use of these areas. Two types of approaches are used to determine fire risk:

(a) The *structural*_approach, in which static factors (i.e. variables that do not change in a short lapse of time) are used to derive fire risk, and;

(b) The *dynamic* approach or real time fire risk, in which meteorological and vegetation derived variables are used to compute fire risk.

The *structural*_approach takes into account variables such as land use/land cover, fire history, demography, proximity to roads, and tourist pressure. High-resolution satellite imagery is used in this case to derive and update land cover maps. The rest of the variables are not derived from remote sensing.

The *dynamic* fire risk is usually derived in two ways, which in some cases are integrated. The first method uses remote sensing to derive vegetation stress variables, which are subsequently related to wildfire occurrence. The main data source for this method is NOAA/AVHRR data, the only available data at the time and spatial resolution needed for this purpose. Other alternatives data sources are ATSR/ ERS (European Remote Sensing Satellite/ Along-Track Scanning Radiometer), the VEGETATION instrument to be launched onboard the SPOT 4 satellite as well as the GLI (Global Imager) that will be launched onboard ADEOS-II. Water stress mapping is one of the most operational uses of remote sensing in wildfire management. Fire authorities of Spain and Southern France utilize these fire risk indices systematically during the fire season, which in these countries corresponds to summer months.

The second approach involves wildfire risk assessment derived from weather variables. These indices are mostly based on the estimation of vegetation moisture content from meteorological variables, but also include variables such as temperature, relative humidity, and wind patterns. Some of these variables can be derived from meteorological satellite data.

Response Phase

Satellite-borne sensors are available that can detect fires in the visible, thermal and mid-infrared bands. Active fires can be detected by either sensing their thermal or mid-infrared signature during the day or night, or by detecting the light from the fires at night. The sensors must also have frequent overflights and the data from the overflights must be available in near real-time.

The spectral, spatial and temporal resolutions of current satellite platforms do not comply with the needs for real-time detection of wildfires. However, detection of large wildfires in remote areas (such as Alaska and the tropical forest belts), has been successful using earth observation.

There are at least two global fire products, one produced by ESA (European Space Agency) and another one produced by the Space Applications Institute of the EC (European Community) Joint Research Centre. These products were produced at one point in time to determine global fire activity and were not intended to accurately determine the number and location of all wildfires. Neither of these products is being provided operationally. The level or reliability of both, given the lack of wildfire statistics, has not yet been assessed.

The FUEGO programme aims at developing the first near-real-time forest fire detection system for the Mediterranean area. The FUEGO system will consist of a constellation of dedicated small satellites. This programme is co-funded by the European Commission. This system is still in the development phase.

The existing satellite sensors with fire detection capabilities that are under utilized include NOAA-GOES, NOAA-AVHRR, and DMSP-OLS (Defense Meteorological Satellite Program – Operational Linescan System). Examination of fire products from these systems during August 1997 in Brazil indicated that the fire products from these systems are complementary. During September and October, 1997 DMSP fire products generated in near real-time were made available over the World Wide Web and were widely accessed. Some believe that the technology for generating and distributing daily fire products at regional to global scales from these three systems is feasible. This would provide an extremely valuable service for both fire management and prevention of disasters.

Since September 1997, an operational forest fire detection system for fire suppression has been implemented in Indonesia using NOAA-AVHRR and GMS (Japanese Geostationary Meteorological Satellite) for detecting fires and wind direction: the location of fires derived from night time NOAA-AVHRR are mapped on the high resolution satellite images overlaid with important GIS (Geographic Information System) information and reported to local fire fighters every morning.

Recovery Phase

The most important post-crisis activity in fire management is the assessment of the burnt area. Although remote sensing has already proven its usefulness in this activity very few authorities utilize space-borne data operationally in assessment of the fire damage. In space-borne remote sensing, the wildfire damage, the extension of burnt areas, is determined by the single-date or multi-temporal analysis of the images.

At national and international scales, NOAA/AVHRR data are mostly used for burnt area mapping. The VEGETATION instrument onboard SPOT 4 is a new alternative source of data. Other data types of similar spatial/spectral resolution are less diffused because of the difficulty in data acquisition and/or the lack of adequate data. At regional scales, within national boundaries, high-resolution data from the Landsat Thematic Mapper, and SPOT/ HRVIR (High

Resolution Visible & Infrared), are used to determine the extent of wildfire damage. The use of space-borne radar data (mainly from ERS/ SAR) has been also used experimentally but not operationally. This is probably because of the intrinsic complexity in computer processing of SAR images. Other suitable optical sensors - IRS-1C (Indian Remote Sensing Satellite-1C) and RESURS (Russian Satellite Series for Resource Monitoring), and microwave sensors – JERS (Japanese Earth Resources Satellite) and RADARSAT have not been used much so far.

The new medium spatial resolution data from the Indian and Russian remote sensing satellites in conjunction with the high spectral resolution (and also medium spatial resolution) of the EOS (Earth Observing System) MODIS (Moderate Resolution Imaging Spectrometer) instrument, the European MERIS (Medium Resolution Imaging Spectrometer) instrument aboard ENVISAT, and the (ADEOS-II (Japanese Advanced Earth Observing Satellite) instruments may provide very useful imagery for cartography of burnt areas at regional to international scales.

Some experimental projects have been carried out in order to derive the level of damage, the degree to which vegetation has been burnt, from high-resolution optical imagery with promising results. Landsat TM (Thematic Mapper) RESURS MSU-E (Multispectral Scanner – Electronic Scanning), and IRS-1C LISS-3 (Linear Imaging Self-Scanning Sensor) data have been used for this purpose. The forthcoming high spectral and spatial optical imagery may provide a unique data source for these types of analyses.

2.4.5.3 Gaps and Potential Improvements in Remote Sensing Capability

Gaps still exist and remote sensing data is not being used to its potential to help alleviate the problem of fire management. The spectral, spatial and temporal resolutions of current satellite platforms do not comply with the needs for real-time detection of wildfires, and they are not effective in supporting Response Phase activities. The Interim Report from the CEOS Fire Hazard Team makes a number of recommendations for improving the effectiveness of satellite remote sensing in fire management:

Preparation Phase

- Develop technologies and methods to generate global, accurate, updateable fire fuels maps.
- Develop meso-scale weather models for daily and 1-2 day prediction of dead fuel moisture, to replace ground weather stations

Response Phase

There is a need to develop a local operational satellite fire detection and monitoring system with an ultimate detection time of 5 minutes, repeat time of 15 minutes, spatial resolution of 250 meters, a confidence rate of 95%, with real time data transmission to local ground stations.

- Develop and implement a global operational system to distribution and access fire data to the user on a timely basis, with the existing satellites.

Recovery Phase

- Develop affordable and rapid access to all high resolution data streams, to develop applications that support the user community.
- Institute a more comprehensive global coverage of fires to assess the scale of the burning of biomass.
- Ensure the continuity of current civilian satellite systems for local and global coverage of fires.
- Examine co-operation possibility to use declassified information produced from classified military satellites for local and global coverage of fires.
- In the event that no single satellite satisfies the requirements for fires, it is recommended that international agreements be established to improve the access and affordability of data to the user community.

2.4.5.4 The Potential Role of HALE-Based Remote Sensing

Current satellite remote sensing systems are unable to fully address the problem of fire management. Shortfalls exist in both the system performance area (spectral, spatial and temporal resolutions) and in the ability to fully coordinate and focus the potential of the various satellite systems capable of contributing to fire management. In addition, the ability of EMO's to exercise priority, or control, over potentially highly useful satellite systems is limited and always subject to the uncertainties imposed by other tasking priorities.

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Following are some proposed applications areas in which HALE-based remote sensing could support the efforts of fire management by proving high-resolution, high observation continuity data with temporal response and exercisable effective control of the system not available with present or planned satellite-based systems.

Mitigation Phase

- Localized updates (high-risk areas) to hazard, risk, vulnerability and preparedness analyses and plans, procedures and programs, using high-resolution, high observation continuity capability.
- Verification of vulnerability reduction and preparedness measures.
- Calibration/ validation of satellite-based and other measurements.
- High-resolution mapping analyses of relevant historical events.
- Local data can be combined with other sources, GIS, population, land use, vegetation, forest cover, terrain, infrastructure, utilities, corridors, escape/rescue routes, etc.
- Training and exercises for Preparation Phase and Response Phase operations.

Potential users include EMO's, land planners, forestry authorities, conservation authorities, local authorities, fire authorities, utility companies, planning authorities, and transportation authorities.

Preparation Phase (Immediately before the fire).

Note: Fire outbreaks are generally difficult to predict with accuracy, though areas of particular susceptibility can sometimes be identified.

- Localized updates (high-risk areas) to hazard, risk, vulnerability and preparedness analyses and plans, procedures and programs, using high-resolution, high observation continuity capability.
- Calibration/ validation of satellite-based and other measurements.
- Identification of escape/ rescue routes/ corridors/ marshalling points/ landing sites.
- Identification and direction of preparatory activities, and development of Response Phase plans.

Potential users include EMO's, fire authorities, forestry authorities, conservation authorities, local authorities, utility companies, transportation authorities.

Response Phase (During and immediately following the fire).

- Fire detection, extent, behaviour, growth patterns.
- Assessments of damage to forests, brush, undergrowth, grasslands, buildings, property, infrastructure, utilities, transport links.
- Assessment of relief efforts required.
- Location of distressed personnel.
- Identification and monitoring of escape/ rescue routes/ corridors/ marshalling points/ landing sites.
- Targeting and direction of relief and rescue efforts, and assessment of effectiveness.
- Detection and evaluation of secondary disasters, such as pollution, technological hazards.

Potential users include EMO's, local authorities, firefighters, insurance companies, news media.

Recovery Phase (after the fire).

- Evaluation of potential for recurring threats.
- Assessment of burnt area and damage assessments (timber stocks, brush, undergrowth, grassland, vegetation, buildings, property, infrastructure, utilities, transport links, conservation areas), and damage report verification.
- Assessment of environmental impacts.
- Verification of recovery, reconstruction, rehabilitation, repair measures.
- Data input to predictive models.
- Inputs to updated hazard, risk, vulnerability and preparedness analyses, policies, plans, procedures, programs, arrangements.
- Inputs to historical database and "lessons learned" process.

Potential users include EMO's, local authorities, forest management authorities, conservation authorities, and insurance companies.

2.4.6 Landslides and Avalanches

2.4.6.1 Hazard Description

Landslides

Landslides occur in all regions of the world when masses of rock, earth, mine waste or debris move down slopes and result from rainstorms, earthquakes, volcanic eruptions and various human activities. They usually strike without warning destroying landscapes, buildings and homes, breaking electrical, water, gas, and sewage lines and disrupting roads and railways. Landslides and disastrous mudflows during the 1997 and 1998 hurricane seasons in Central America and the Caribbean caused untold damage and the tragic loss of thousands of lives in vulnerable communities. Landslides in the United States alone are estimated to cause an annual loss of about $1.5 billion and at least 25 fatalities and many areas of the globe are even more vulnerable. Figure 2.4.6.1-1 shows an example of a serious landslide in La Conchita, California in the spring of 1995.

Mitigation of the impacts of landslides requires hazard and vulnerability assessments and the implementation of risk management policies and strategies including public awareness campaigns, planning and development regulations, and construction codes and standards. Landslide, mudflow and debris-flow problems are often caused by mismanagement including unwise land-use practices on ground of questionable stability, particularly in mountain, canyon, and coastal regions. Significant progress has been made in that geotechnical experts can identify areas vulnerable to land slippage and provide early warnings of landslide hazards and advice on preparedness measures, such as evacuations. Land-use zoning, in partnership with professional inspections and proper design, can alleviate many of the problems associated with landslide hazards. Additional disaster mitigation measures include planting ground cover on slopes, installing flexible pipe fittings to avoid gas or water leaks and building channels and deflection walls to redirect the flow, and insurance.

For the future, achievement of a reduction in the tragic consequences of severe landslides and mudflows around the world requires continued emphasis on risk assessment and risk management, utilizing increasing scientific understanding of the factors which lead to landslides to develop and implement policies which will reduce exposure and vulnerability to these hazards.

Avalanches

Avalanches are a major hazard in many mountainous countries. They result in substantial loss of life, such as the 75 fatalities recorded in the European Alps during January-February 1999. Avalanche damage can also be very substantial, reaching 1 billion Swiss francs in Switzerland during the past winter, for example. Around the world, vulnerability to avalanches will continue to increase as winter recreational activities and facilities expand in mountainous regions. Figure 2.4.6.1-2 shows an example of the most dangerous type of avalanche – the slab avalanche.

Effective long term preventive measures to reduce avalanche vulnerability include hazard mapping, land use planning, development of protective forests and installation of protective structures. Short-term measures include avalanche forecasting, the issue of avalanche warnings, artificial releases of snow masses, road and rail closures and evacuations. Some governments already invest heavily on such avalanche protection measures because of their demonstrated cost effectiveness. Over the past 50 years, for example, about 1.5 billion Swiss francs has been invested in protective structures in Switzerland, in addition to the resources devoted to forecasting, hazard zoning and protective forests.

Figure 2.4.6.1-1 A Serious Landslide in La Conchita, California, Spring 1995.
[Source: United States Geological Survey].

Figure 2.4.6.1-2 The Most Dangerous Type of Avalanche – the Slab Avalanche.
[Source: NOVA/WGBH/PBS].

For the future, implementation of avalanche risk assessment and risk management is fundamental to the achievement of reductions in vulnerability. While this approach is in already place in some countries, it needs to be extended to other vulnerable regions. In order to improve its application, needs also exist for continued research into snow pack physical processes, improved avalanche forecast and hazard mapping techniques, better technical and construction measures and enhanced risk management methods.

2.4.6.2 State-of-the-Art Applications of Remote Sensing

Because of difficulty in predicting landslides and avalanches and the rapidity of their occurrence, the contribution of remote sensing to disaster management has focused on various observation techniques designed to support hazard and vulnerability assessments and mitigation efforts, including increased scientific understanding of the factors which lead landslides or avalanches to develop. Once a landslide or avalanche has occurred, there is little that the current performance capabilities of a satellite-based remote sensing system can do to help response activities or the rescue of victims.

2.4.6.3 Gaps and Potential Improvements in Remote Sensing Capability

The real needs of remote sensing capabilities which would help disaster management of landslides or avalanches focus – as for many natural disasters – on being able to maintain high-resolution observations on a near-continuous basis, to adequately monitor events which are happening much more rapidly than current satellites can observe. Improved spatial resolution – 1 metre or less – would also be very beneficial to the more general hazard and vulnerability assessment and mitigation efforts. As is the case for many natural disasters, improved local and area weather forecasting and nowcasting will always be useful in predicting and responding to landslides and avalanches.

2.4.6.4 The Potential Role of HALE-Based Remote Sensing

HALE systems promise to be able to meet some of the observation capability shortfalls described in the previous section and to allow EMOs a greater degree of operational control over the remote sensing asset than is generally available from satellite systems.

Following are some proposed applications areas in which HALE-based remote sensing could support the efforts of disaster management in the case of landslides or avalanches.

Mitigation Phase

- Localized updates (high-risk areas) to hazard, risk, vulnerability and preparedness analyses and plans, procedures and programs, and improving scientific understanding of the factors which lead to landslides or avalanches.
- Verification of vulnerability reduction and preparedness measures.
- Calibration/ validation of satellite-based and other measurements.
- Localized updates to cartographic, geomorphological, hydrological, topographical, climatological.
- Terrain, snow cover, land cover, surface roughness studies (high-risk areas).
- High-resolution mapping analyses of relevant historical events.
- Local data can be combined with other sources, GIS, population, land use, building types, planning regulations, infrastructure, utilities, corridors, escape/rescue routes, etc.
- Training and exercises for Preparation Phase and Response Phase operations.

Potential users include emergency management organizations, land planners, local authorities, water management authorities, environmental authorities, agricultural authorities, transportation routing, and recreational businesses.

Preparation Phase (Immediately before a landslide or avalanche).

Because of difficulty in predicting landslides and avalanches and the rapidity of their occurrence, there may be no meaningful Preparation Phase. Once it is evident that such an event is going to happen, or is happening, human response(s) will usually effectively constitute part of a Response Phase activity.

Response Phase (During and immediately after the landslide or avalanche).

- Assessment of relief efforts required.
- Location of distressed personnel.
- Identification and monitoring of escape/ rescue routes/ corridors/ marshalling points/ landing sites.
- Targeting and direction of relief and rescue efforts.
- Assessment of effectiveness of relief efforts.
- Assessments of damage to buildings, property, infrastructure, utilities, transport corridors.
- Local meteorological nowcasts and forecasts.

- Detection and evaluation of secondary hazards, such as further landslides or avalanches, pollution, technological hazards.

Potential users include emergency management organizations, local authorities, and insurance companies.

Recovery Phase (after the landslide or avalanche).

- Evaluation of potential for recurring threats.
- Damage assessments (property, infrastructure, environment), and damage report verification.
- Ground conditions (moisture, snow, ice, etc.).
- Environmental impacts.
- Verification of recovery, reconstruction, rehabilitation, repair measures.
- Validation of predictive models.
- Inputs to updated hazard, risk, vulnerability and preparedness analyses, policies, plans, procedures, programs, arrangements.
- Inputs to historical database and "lessons learned" process.

Potential users include emergency management organizations, local authorities, land planners, hydrologists, hydro-meteorologists, water management authorities, environmental authorities, agricultural authorities, transportation routing, recreational businesses, and insurance companies.

2.4.7 Tsunamis and Storm Surges

2.4.7.1 Hazard Description

Tsunamis

Earthquakes, volcanic eruptions or shifts in the sea bottom generate very large, fast-moving wave known as "tsunamis". These huge waves travel at speeds in excess of 700 km/h on the open sea but are of such long wavelength as to be barely noticeable. When they reach coastlines and, particularly, bays or inlets, however, they interact with the sea floor, reduce speed and build up to tremendous heights, presenting a major threat to people, animals and structures along the shoreline. Tsunamis have resulted in catastrophic natural disasters and the coastlines around the Pacific Ocean are particularly vulnerable. Figure 2.4.7.1-1 shows photographs of the effects of the 1960 Chilean Tsunami: a). Coastal area of Chiloe, Chile, where 200 hundred deaths were caused by the tsunami; b). Waiakea area of Hilo, Hawaii.

Mitigation and preparedness efforts for tsunamis focus on the provision of timely early warnings combined with ongoing public awareness and education programs. The need to enhance mitigation and preparedness, led UNESCO's IOC to establish, in 1968, an International Coordination Group for the Tsunami Warning System in the Pacific. The Pacific Tsunami Warning Centre (PTWC) in Honolulu is the headquarters of the International Tsunami Warning System and works with regional and national centres in monitoring seismological and tidal stations around the Pacific Ocean to evaluate earthquakes for their potential to generate tsunamis. IOC also maintains an International Tsunami Information Center (ITIC) which is responsible for monitoring warning programs, recommending improvements, assisting Member States to establish national warning systems, fostering research and improving preparedness throughout the Pacific Ocean.

The Decade has seen numerous improvements in tsunami mitigation. Numerical modelling techniques have been improved and are now applied to run-up mapping for hazard assessment and to forecasting. Historical data bases have been electronically archived and made readily accessible. New techniques have been developed for assessing the tsunamigenic potential of large earthquakes and improved observational instrumentation has been developed and deployed. Rapid telecommunications systems have been installed and educational materials prepared and disseminated.

For the future, progress needs to continue in all of the above areas. New local and regional warning systems should be established in the Pacific and other ocean basins that are without warning coverage. In particular, a more coordinated approach to the provision of warnings would be of benefit in the Mediterranean, the Caribbean and the Atlantic Ocean. Low cost automated techniques need to be developed for warning against local tsunamis and installed in regions at risk. Coastal regions at risk from landslide/submarine slump induced tsunamis need to be identified and strategies devised to help protect their communities. In addition, tsunami education needs to be institutionalized to maintain adequate awareness over the long time periods between destructive events.

Storm Surges

The combination of strong onshore winds, low atmospheric pressure and high astronomical tides can result in exceptionally high water levels known as storm surges. Around the world, storm surges present a major natural hazard in many vulnerable coastal and island regions. Large storm surges, with amplitudes up to several meters, are generated by tropical cyclones and regularly cause great destruction in the Pacific, Atlantic and Indian Oceans, the Bay of Bengal and the Gulf of Mexico. In 1970, a tropical cyclone induced storm surge sweeping over the coastal wetlands resulted in catastrophic damage and the deaths of 300,000 people in Bangladesh while a similar tragedy in 1991 killed over 100,000. Storm surges caused by extra-tropical storms sometimes also result in deaths and in catastrophic damage, as experienced by low-lying countries around the North Sea on a number of occasions during the past several decades. In the future, sea level rise associated with global warming and land subsidence along vulnerable coastlines may increase the amplitude of storm surges and increase vulnerability to them. Concern also exists that a rise in sea surface temperatures may increase the percentage of tropical cyclones which reach coastlines, leading to an increase in the frequency of damaging surges.

Figure 2.4.7.1-1 Effects of the 1960 Chilean Tsunami: a) Coastal area of Chiloe, Chile; b) Waiakea area of Hilo, Hawaii.
[Source: National Geophysical Data Center].

Mitigation and preparedness for storm surges involves a combination of measures including risk assessments, vulnerability reducing initiatives, provision of early warnings of impending surge events and evacuation planning to remove people from exposed, low-lying, areas. Efforts to reduce vulnerability encompass structural measures, such as sea walls, barrages and dykes and risk zoning, land use and development planning. The provision of timely early warnings of storm surges combined with solid evacuation plans is, however, critical to disaster reduction in the face of these most dangerous events.

During the Decade, great progress has been made in implementing early warning systems and in timely dissemination of warnings to the public as well as in public awareness and education. This is reflected in the dramatic decline in deaths due to storm surges from thousands each year to a few hundred annually.

For the future, a major challenge for the early warning community is to reduce the number of "false alarms" which cause unnecessary evacuations in the most vulnerable regions. Furthermore, the predicted location and magnitude of surges must be pinpointed with much greater accuracy. Achievement of these improvements will require substantial investment in research directed towards improving the prediction methods. In addition, public awareness and education efforts must continue to be supported as essential components of preparedness and mitigation.

2.4.7.2 State-of-the-Art Applications of Remote Sensing

Remote sensing can play an important role in the mitigation and preparedness activities described above for tsunamis and storm surges and, particularly, can play a role in the provision of early warning through meteorological, water level and other observations. Because of the rapidity with which these phenomena strike land and hence directly threaten human populations, current satellite remote sensing systems can do little more than record what has happened once landfall occurs.

2.4.7.3 Gaps and Potential Improvements in Remote Sensing Capability

Current satellite remote sensing systems do not possess the temporal or image quality performance to effectively support the Response Phase, and cannot provide all of the remote sensing needs of the Recovery Phase. To fully meet the challenge of responding to the impact on human society of tsunamis or storm surges, the ability to maintain high-resolution (1 metre or less) observations on a near-continuous basis over affected regions will be required. As for many natural disasters, improved local and area weather forecasting and nowcasting will always be useful in responding to the local effects of tsunamis or storm surges.

2.4.7.4 The Potential Role of HALE-Based Remote Sensing

Following are some proposed applications areas in which HALE-based remote sensing could support the efforts of tsunami or storm surge disaster management by proving high-resolution, high observation continuity data with temporal response and exercisable control of the system not available with present or planned satellite-based systems.

Mitigation Phase

- Localized updates (high-risk areas) to hazard, risk, vulnerability and preparedness analyses and plans, procedures and programs, and improved scientific understanding of tsunami and storm mechanisms.
- Verification of vulnerability reduction and preparedness measures.
- Calibration/ validation of satellite-based and other measurements.
- High-resolution mapping analyses of relevant historical events.

- Local data can be combined with other sources, GIS, population, land use, building types, infrastructure, utilities, corridors, escape/ rescue routes, etc.
- Training and exercises for Response Phase operations.

Preparation Phase (Immediately before the wave arrives).

- Localized observations of tidal conditions in coastal areas, water level, topography.
- Calibration/ validation of satellite-based and other measurements.
- Identification escape/ rescue routes/ corridors/ marshalling points/ landing sites.

Potential users include emergency management organizations, local authorities.

Response Phase (During and immediately following wave impact).

- Localized observations of tidal conditions in coastal areas, water level, topography.
- Assessment of relief efforts required.
- Location of distressed personnel.
- Identification and monitoring of escape/ rescue routes/ corridors/ marshalling points/ landing sites.
- Targeting and direction of relief and rescue efforts.
- Assessment of effectiveness of relief efforts.
- Assessments of damage to buildings, property, infrastructure, utilities, transport corridors.
- Detection and evaluation of secondary disasters, such as landslides, pollution, technological hazards.

Potential users include emergency management organizations, water management authorities, hydro-meteorologists, local authorities, insurance companies, and news organization.

Recovery Phase

- Evaluation of potential for recurring threats.
- Damage assessments (property, infrastructure, environment), and damage report verification.
- Ground conditions (moisture, etc).
- Environmental impacts.
- Verification of recovery, reconstruction, rehabilitation, repair measures.
- Validation of predictive models.
- Inputs to updated hazard, risk, vulnerability and preparedness analyses, policies, plans, procedures, programs, arrangements.
- Inputs to historical database and "lessons learned" process.

Potential users include emergency management organizations, local authorities, hydro-meteorologists, insurance companies, and news organizations.

2.4.8 Droughts

2.4.8.1 Hazard Description

Drought often affects very large areas for periods of months or even years. Drought can have serious impacts on regional food production and on economic performance, and may cause serious long-term health problems for affected populations. During 1967-1991, droughts affected 50 percent of the 2.8 billion people who suffered from all natural disasters and killed 35 percent of the 3.5 million people who lost their lives. In addition, relief measures following drought often involve high cost. In the current decade, which has been proclaimed the Decade for Natural Disaster Reduction, large-scale intensive droughts have been observed on all continents, leading to huge economic losses, destruction of ecological resources, food shortages and starvation of millions of people. Figure 2.4.8.1-1 shows a view of a widespread drought situation in Mexico during 1999.

Overall management of drought situations involves adequate prediction, monitoring/early warning, impacts assessment and response. Information required by emergency management organizations includes; early warning of drought onset; estimation of area**,** intensity and duration; a plan for immediate relief and long term management for drought mitigation; and validation by ground truth.

2.4.8.2 State-of-the-Art Applications of Remote Sensing

A number of satellite remote sensing systems are being applied in drought management support:

- GOES, METEOSAT, INSAT, GMS are used for prediction.
- NOAA/AVHRR, IRS/WiFS, SPOT4/Vegetation are used for monitoring and early warning.
- DMSP/SSMI and IRS-P4 MSMR data should be investigated together with the existing approaches as drought information.
- TRMM, RESOURCESAT, MODIS and MERIS need to be evaluated for monitoring.
- LANDSAT, IRS, SPOT is used for GIS based drought management system

Users of remote sensing data in drought management can include:

- Top policy makers at the national level and within international organizations, emergency management organizations and researchers
- Middle policy makers at the state and province level, emergency management organizations, state/ provincial authorities, researchers and insurers
- Local policy makers, local authorities, producers, farmers, suppliers, traders, builders and water managers.

Figure 2.4.8.1-1 A View of a Widespread Drought Situation in Mexico During 1999. *[Source: British Broadcasting Corporation].*

Mitigation Phase

Drought prediction can benefit from:

- Climate variability predictions using coupled ocean/atmosphere models.
- Survey of snow packs.
- Persistent anomalous circulation patterns in the ocean and atmosphere.
- Initial soil moisture.
- Assimilation of remotely sensed data into numerical prediction models.
- Knowledge of stored water available for domestic, stock, and irrigation uses.

Nearly-global seasonal climate anomaly predictions are possible due to the successful combination of new observational networks (for example, the TOGA TAO array in the equatorial Pacific and satellite altimeters) and improved initial and boundary conditions of ocean, atmosphere and land coupled models. Near-real time evaluation of in-situ and remote sensing data - allows for the first time physically-based drought warnings several months in advance, to which a growing number of countries already relate their policies in agriculture, fisheries and distribution of goods. Therefore any improvement in operational meteorological, oceanographic and hydrological observations, as well as in coupled ocean/atmosphere/land models, improves the quality of drought warnings. There are a number of satellite-based programs that are giving increasing detail about expected climatic change.

A number of organizations make seasonal predictions of temperature and precipitation anomalies. These include the National Centers for Environmental Prediction in the US, the European Centre for Medium Range Weather Forecasts (ECMWF) and the National Centre for Medium Range Weather Forecast of India (NCMRWF). The quality of these predictions is also a function of the quality and amount of satellite data assimilated into the starting fields (e.g., SST from AVHRR and profiles from TOVS on NOAA satellites ERS-2 scatterometer winds, SSM/I on DMSP satellites, all geostationary weather satellites: GOES-East, GOES-West, Meteosat, GMS of Japan, INSAT of India etc.). The new assimilation techniques have produced a stronger impact of space system data on the quality of weather and seasonal climate predictions.

The potential contribution of existing satellites is under-exploited, since neither is the synergy gained by the combination of data from individual satellite sensors fully used, nor is all satellite data distributed internationally.

Key user requirements for better drought prediction include being able to make predictions on a smaller scale, being able to improve the efficiency of all parts of the data dissemination and utilization chain, and improving information flow so that users get predictive data immediately.

Preparation Phase

Drought monitoring mechanisms exist in most countries using ground-based information on drought related parameters such as rainfall, weather, crop condition and water availability. Data from satellite remote sensing is highly complementary to those collected by in-situ systems. Satellites are often necessary for the provision of synoptic, wide-area coverage and frequent information required to put in-situ information into a larger spatial monitoring of drought conditions.

Rainfall, surface wetness and temperature monitoring

Currently, multi-channel and multi-sensor data sources from geostationary platforms such as GOES, METEOSAT, INSAT and GMS etc. and polar orbiting satellites such as NOAA, DMSP SSMI and the recently launched IRS-P4 MSMR have been used or are planned to be used for meteorological parameter evaluation, interpretation, validation and integration. The parameters estimated are precipitation intensity, amount, and coverage, atmospheric moisture and winds, and sometimes surface (soil) wetness. New algorithms are being developed that integrate the less direct but higher resolution (space and time) GOES precipitation estimates with the more physically based but lower resolution (both space and time) polar-orbiting satellite microwave estimates. A further improvement in the spatial distribution of rainfall is being achieved by integrating radar, rain gauges and remote sensing techniques.

Vegetation monitoring

Vegetation condition monitoring is currently possible with resolution ranging from NOAA AVHRR data at 1.1 km resolution in a daily revisit, IRS OCM at 360 m resolution in a two-day revisit, to IRS WiFS at 188 m resolution in a 5 day revisit. The normalized difference vegetation index (NDVI) and temperature condition index (TCI) derived from satellite data is accepted world-wide for regional monitoring.

Ongoing Programs

- Africa Real-Time Environmental Monitoring using Imaging Satellites (ARTEMIS) is operational at FAO, using METEOSAT rainfall estimates and AVHRR NDVI values for Africa.
- The USDA/NOAA Joint Agricultural Weather Facility (JAWF) uses Global OLR anomaly maps, rainfall maps, vegetation and temperature condition maps from GOES, METEOSAT, GMS and NOAA satellites.
- The Joint Research Centre (JRC) of the European Commission (EC) issues a periodical bulletin on agricultural conditions under MARS-STAT (Application of Remote sensing to Agricultural statistics) project which uses vegetation index, thermal based evapotranspiration and microwave based indicators.
- The Agricultural Division of Statistics, Canada issues weekly crop condition reports based on NOAA AVHRR NDVI along with agrometeorological statistics.
- National Remote Sensing Agency, Department of Space issues a biweekly drought bulletin and monthly reports at smaller administrative units for India under National Agricultural Drought Assessment and Monitoring System (NADAMS), which uses NOAA AVHRR and IRS WiFS based NDVI and ground based weather reports.
- Similar programs are followed in many countries world-wide, including some for specific drought prone areas in developing countries.

Response Phase

The assessment of drought impacts should be carried out following the subsequent ranking:

- Land use type
- Persistence of stressed conditions on an intra-seasonal and inter-seasonal time scale
- Demographics and infrastructure around the impacted area
- Intensity and areal extent
- Agricultural yield
- Impact associated with disease, pests, and potable water availability and quality, etc.
- Building subsidence

The drought impact is generally assessed by using satellite data as input for crop model yield estimates. High-resolution satellite sensors from LANDSAT, SPOT, IRS, etc. are being used for the assessment of impacts in a few areas, but in most cases this is not a country-wide activity.

- Water management
- Crop management
- Decisions for mitigation and alternative strategies

High resolution satellite sensors from LANDSAT, SPOT, IRS, etc. are being used. For example, in India, drought management action plan maps are being generated at watershed level for implementation in case of droughts. However, GIS based decision support systems need to be developed.

2.4.8.3 Gaps and Potential Improvements in Remote Sensing Capability

Improved remote sensing capability is required for:

- Early drought detection;
- Monitoring drought dynamics, delineating drought area and time;
- Assessment of drought impacts and possible consequences;
- Responding to the effects of drought;
- Supporting recovery from the effects of drought.

2.4.8.4 Potential Role of HALE-Based Remote Sensing

There is a great deal of satellite-based remote sensing capability which can be utilized throughout the drought management cycle. These systems can be reasonably effective in providing a “big picture” of general conditions – climatic, weather, soil moisture, crop condition, water source levels, etc. – over large areas. However, there remains an unfulfilled need to be able to more closely examine events and conditions at the local and regional level; particularly important for remote areas where reliable reporting of conditions may not always be possible.

Following are some proposed applications areas in which HALE-based remote sensing could support the efforts of drought management by proving high-resolution, high observation continuity data with temporal response and exercisable control of the system not available with present or planned satellite-based systems.

Mitigation Phase

- Localized updates (high-risk areas) to hazard, risk, vulnerability and preparedness analyses and plans, procedures and programs
- Verification of vulnerability reduction and preparedness measures
- Calibration/validation of satellite-based and other measurements
- High-resolution mapping analyses of relevant historical events
- Localized investigations (high-risk areas) into topography, hydraulic data, soil moisture, snow/ ice cover, climatic conditions, meteorology, crop growth and health, water source levels, soil type, and permeability
- Local data can be combined with other sources, GIS, population, land use, water sources, agriculture, etc.
- Training and exercises for Preparation Phase and Response Phase operations

Potential users include policy makers, international organizations, emergency management organizations, local authorities, water managers, researchers, producers, farmers, suppliers, traders, builders, and insurers.

Preparation Phase (In advance of the effects of the drought)

- Localized updates (high-risk areas) to hazard, risk, vulnerability and preparedness analyses and plans, procedures and programs
- Localized investigations (high-risk areas) into topography, hydraulic data, soil moisture, snow/ ice cover, climatic conditions, meteorology, crop growth and health, water source levels, soil type and permeability
- Calibration/ validation of satellite-based and other measurements
- Preparatory activities

Potential users include policy makers, international organizations, emergency management organizations, local authorities, water managers, researchers, producers, farmers, suppliers, traders, builders, and insurers.

Response Phase (During the drought)

- Hydraulic data, soil moisture, snow/ ice cover, climatic conditions, meteorology (nowcast and forecast), crop growth and health, water source levels
- Assessment of relief efforts required
- Location of distressed personnel
- Identification of sites for relief centres/ relief routes/ marshalling points/ landing sites
- Targeting and direction of relief and rescue efforts
- Assessment of effectiveness of relief efforts
- Detection and evaluation of secondary disasters, such as fires, subsidence, pollution, technological hazards, evidence of epidemic, or conflict

Potential users include policy makers, international organizations, emergency management organizations, local authorities, water managers, researchers, producers, farmers, suppliers, traders, builders, and insurers.

Recovery Phase (After the causes of drought have diminished)

- Evaluation of potential for recurring threats
- Hydraulic data, soil moisture, snow/ ice cover, climatic conditions, meteorology (nowcast and forecast), crop growth and health, water source levels
- Environmental impacts
- Verification of recovery, rehabilitation measures
- Validation of predictive models
- Inputs to updated hazard, risk, vulnerability and preparedness analyses, policies, plans, procedures, programs, arrangements
- Inputs to historical database and "lessons learned" process

Potential users include policy makers, international organizations, emergency management organizations, local authorities, water managers, researchers, producers, farmers, suppliers, traders, builders, and insurers.

2.4.9 Public Health Disasters

2.4.9.1 Hazard Description

The health consequences of large-scale natural disasters can be of enormous proportions. Characteristically, disasters create situations where there are many casualties, the majority of whom are in serious or critical condition and require immediate assistance. These casualties occur in a relatively short period of time and existing health facilities and personnel are often not able to deal with the nature and scope of the health emergency this presents. In addition, the medical and public health impacts are often exacerbated by difficulties of access to affected areas, damage to medical facilities, hospitals, clinics and supply stores as well as disruption of the supply chain. Long distances, low population density and the absence of stable communications can further increase the isolation of an area hit by a disaster and create a major challenge to providing timely medical help for large numbers of people.

In addition to the search and rescue operations mobilized immediately after a disaster, public health measures must be assessed and restored as quickly as possible. The basic public health functions after a disaster are the provision of temporary shelter, an adequate and clean water supply, food, and health and injury assessment and treatment for the inhabitants of the affected area. These efforts are frequently hampered by the absence of electricity, disruption of telecommunications, damage and pollution of water supplies, destruction of roads and bridges, the collapse of the transportation systems, destruction of housing and shelter, and lack of medical instruments and drugs. The destruction of air fields, road and rail links means that independent supplies of food need to be made available directly in disaster zones. The high probability of destruction of public health facilities means that mobile hospitals are needed close to the site of a disaster to offer treatment of shock and injuries, and that medical evacuation to other facilities has to be organized.

As well as the immediate health needs of stricken populaces, the prevention and control of disease is often a major consideration, especially when the time required to restore the normal infrastructure, sanitation, facilities, etc. runs into many days or weeks. Disease control takes on a different dimension after disasters, where there may be a breakdown of public health measures, lack of sanitation and clean water. Besides these considerations, other factors such as endemic diseases in an area, or their seasonality can contribute to the spread of disease. Frequently a disaster onset, and the subsequent assessment of vulnerability to potential outbreaks of disease serve as the stimulus for early warning to the public and throughout the health community.

The 1990 Baguio City earthquake in the Philippines provides an example. In the wake of the earthquake, the Philippines Department of Health issued a warning of the potential spread of typhoid fever, diarrhea, amoebiasis, cholera and other gastro-intestinal sickness in the temporary refugee camps that had developed in Baguio. The unsanitary disposal of wastes in the refugee encampments, the litter of spoiled foods and rubbish, and the lack of potable water, all aggravated by the intermittent inclement weather condition, were conducive to the epidemic incidence of deadly diseases. By employing public warning systems, health authorities appealed to the public to cooperate with measures designed to check the incidence of epidemic diseases and urged the fleeing residents to observe recommended preventive measures.

2.4.9.2 State-of-the-Art Applications of Remote Sensing

Many communities and countries are putting in place disaster preparedness plans. These local and national preparedness plans and rapid mobilization of assistance in health emergencies can be supported and enhanced by remote sensing technologies. The areas in which remote sensing technologies can provide support go beyond just disaster response, to disease prevention and control following a disaster.

Remote sensing technologies can help to assess and communicate the areas of damage and the extent of damage with respect to all of the above conditions. An accurate description of the disaster, including the location, the estimated number of people, the number and types of facilities affected, the environmental conditions and the likelihood of further events in an area are important to enable a coherent response and to plan for the institution of public health measures. This type of assessment can help distribute the resources throughout an area and help to inform health and medical facilities and personnel of the likelihood of epidemics and other adverse public health consequences of a disaster.

Baseline surveillance data on endemic disease distribution in an area can be used to assess the nature of disease threats to displaced people and enable public health action, such as immunization, to be taken to protect groups at risk. These types of data are crucial to obtain, in order to evaluate the evolution of eventual outbreaks or epidemics and to adapt disease control strategies.

2.4.9.3 Gaps and Potential Improvements in Remote Sensing Capability

There is a great deal of satellite-based remote sensing capability which can be utilized throughout the disaster management cycle to investigate and monitor health-related issues. These systems can be reasonably effective in providing a “big picture” of general conditions – climatic, weather, damage, pollution, distressed persons, etc. – over large areas. However, there remains an unfulfilled need to be able to more closely examine events and conditions at the local and regional level, including the plight of small groups of distressed persons; particularly important for remote areas where reliable reporting of conditions may not always be possible.

2.4.9.4 Potential Role of HALE-Based Remote Sensing

HALE systems are capable of providing high-resolution remote sensing with better observation continuity over localized regions than satellite or airborne systems. Much of this high spatial and temporal resolution data will contain important information for public health authorities, and many of the potential observation functions identified in the previous disaster sections for HALE-based remote sensing also have potential benefit for the maintenance of public health and disease prevention and control.

2.4.10 General Conclusions: Natural Disasters

The preceding disaster sections have shown that HALE-based remote sensing has the potential to play an important role in the management of many kinds of natural disaster. This promise is rooted in HALE's ability to provide remote sensing system performance not possible with present-day satellite systems and too costly and hazardous to crew to provide with conventional airborne remote sensing platforms.

The potential of HALE-based remote sensing in disaster management is, in many cases, greatest in the Response and Recovery Phases, when events are moving rapidly, and today's satellite systems are simply unable to provide the continuity of observation required to adequately observe them.

Much of the data gathered by a HALE remote sensing system over a disaster scene can have wider applications than supporting the immediate response to the event. These additional applications may include the restoration and maintenance of public health and the maintenance of public order.

While the potential for HALE-based remote sensing is different in each disaster case, HALE application areas within each phase of the disaster management cycle can be summarized as shown in the table of Figure 2.4.10-1.

Figure 2.4.10-1 HALE Application Areas in the Disaster Management Cycle.

HALE REMOTE SENSING APPLICATIONS	DISASTER MANAGEMENT PHASE			
	MITIGATION	PREPARATION	RESPONSE	RECOVERY
Inputs to hazard, vulnerability, preparedness analyses, plans, procedures	✓	✓		✓
Verification of vulnerability reduction and preparedness measures	✓	✓		
Inputs to long-term phenomenological studies	✓	✓		✓
Observations of immediate and ongoing events (natural & human)		✓	✓	✓
Inputs to meteorology		✓	✓	✓
Mapping of historic events	✓			
Calibration / validation of satellite and other observations	✓	✓		✓
Training and exercises for Preparation Phase activities	✓			
Training and exercises for Response Phase activities	✓	✓		
Assessment of relief efforts required			✓	
Location of distressed personnel			✓	
Identification & monitoring of access/ escape routes, marshalling points			✓	
Targeting & direction of relief efforts, and assessment of effectiveness			✓	
Damage assessments (property, infrastructure, corridors,etc.) & report verification			✓	✓
Detection and evaluation of secondary hazards/ recurring threats			✓	✓
Verification of recovery, reconstruction, rehabilitation, repair measures				✓
Assessment of environmental impacts				✓
Inputs to validation of predictive models				✓
Inputs to historical database/ lessons learned				✓

2.5 HALE-Based Remote Sensing in the Management of Human-Made Emergencies

2.5.1 Introduction

Human-made emergencies are emergency situations brought about by human activity or by the consequences of human activity. For this analysis human-made emergencies are categorized as follows:

- Technological: Environmental, Industrial, Agricultural, Infrastructure and Essential Systems, Nuclear Accidents, etc.
- Transport: Road, Rail, Sea, Air
- Political or Social: Terrorism, Riot, Unrest, Civil Disobedience, International, Economic, etc.

2.5.2 Technological Emergencies

2.5.2.1 Hazard Description

As human dependence on technology continues to increase, hazards associated with these technologies are tending to increase both in number and in the potential severity of their effects upon people and their environment. Risks to human society range from contamination of a local environment from careless dumping of toxic waste to the widespread international effects of a nuclear accident.

Severe accidents have happened which afflicted thousands of people. These have found expression in the public demand to provide technical and organizational tools for the prevention, mitigation and relief of disasters. Special international attention has focused attention on incidents of Bhopal, Mexico City, Basel, Seveso, the "Exxon Valdez" and Chernobyl. Expert groups, institutions, organizations, authorities and institutes work on the problems of prevention and relief on local, regional, national and even global basis.

There is a certain probability that the expanding genetic technology (gentechnology) will pose more problems of this kind in future. Substances in which self-reproduction is possible will need special global considerations. Another form of related threat is evident today in the transfer of biologically-active substances or species to places where they can destroy the natural established equilibrium. Special precautions will be necessary to avoid contamination with unpredictable effects to the environment.

Taking into consideration other possible effects of accidental releases of hazardous materials, including their progressive accumulation in plants, animals, fish or entire eco-systems, they can now more easily be distributed to very different regions of the world. Hence, the emergence of increasing risks of technological hazards has to be seen on a global dimension. A global threat of technological hazards can also be seen in the fact that facilities which may not comply with the safety standards enforced in industrialized countries can readily be transferred to poor, or non-industrialized, countries.

Major accidents can have long-lasting consequences, with many of them that extend beyond frontiers of an individual country. The ecological and economic cost of an accident is borne not only by the establishment affected but also by the states concerned. It must become an objective to keep the risk level as low as possible, taking into consideration the probable character of increasingly complex, and potentially more severe, technological incidents. It therefore becomes necessary to take measures that can ensure a high level of protection.

Examples of the type of actions which can constitute technological hazards:

- Release of chemicals into the atmosphere by explosion, fire
- Release of chemicals into water (groundwater, rivers etc.) by tank rupture, pipeline rupture, chemicals dissolved in water (fire)
- Chemical spills (including Oil) in marine environments
- Radioactive sources in metallurgical processes
- Release of radionuclides into the environment (satellite crash, nuclear accident)
- Contamination by waste management activities
- Soil contamination
- Groundwater contamination
- Releases and contaminations as a consequence of military actions (e.g. depleted uranium), or destruction of facilities
- Releases as consequence of the industrial use of biological material (e.g. viruses, bacteria, fungi, genetic material)
- Unforeseen weaknesses in highly-distributed or interconnected systems (e.g. Y2K, viruses).

2.5.2.2 State-of-the-Art Applications of Remote Sensing

2.5.2.2.1 Introduction

The utilization of remote sensing in the management of technological emergencies is in its infancy. Though remote sensing products could, for many types of technological emergency, be useful in the Mitigation, Preparation, Response and Recovery phases, the opportunity to take advantage of remote sensing technology has been severely limited by the spatial resolution, temporal resolution and response time available from present satellite systems. The monitoring of maritime oil spills is one example of a technological emergency for which satellite remote sensing has provided useful results. The use of remote sensing in the management of maritime oil spills is outlined in the following section.

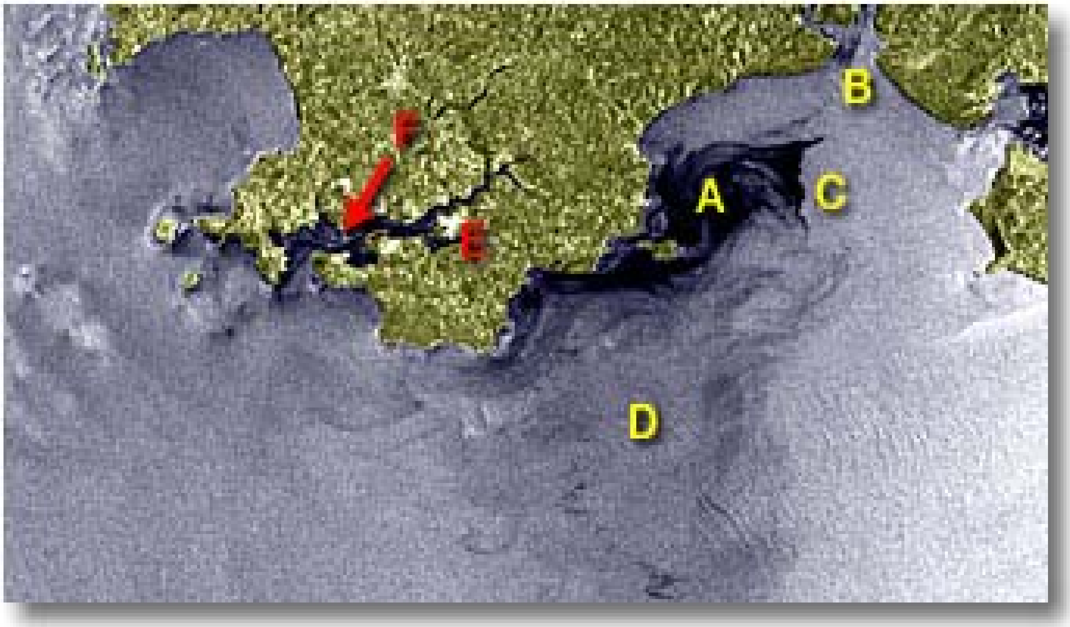
2.5.2.2.2 Maritime Oil Spills

Oil spills can destroy marine life as well as damage habitat for land animals and humans. The majority of marine oil spills result from ships emptying their bilge tanks before or after entering port. Large area oil spills result from tanker ruptures or collisions with reefs, rocky shoals, or other ships. These spills are usually spectacular in the extent of their environmental damage and generate wide spread media coverage.

Figure 2.5.2.2.2-1 shows a Radarsat image of an oil spill from the "Sea Empress", a 147,000 tonne supertanker, which ran aground on rocks off South Wales on the evening of February 15th,

1996. Seven days later, Radarsat captured this image, clearly delineating the remaining oil slick. Size, location and dispersement of the oil spill can be determined using this type of imagery. Depending on the reporting source, between 65,000 and 70,000 tonnes of light grade crude oil was spilt. The main body of the oil spill can be seen on the right hand side of the image. The spill appears on the image in black tones (A). Oil, which floats on the top of water, suppresses the ocean's capillary waves, creating a surface smoother than the surrounding water. This smoother surface appears dark in the radar image. The spill is spreading to the east, along the coast of Wales. The discharge from the Tywi River (B) is keeping the immediate shore clear. Between the river discharge and the currents in Carmarthen Bay (C) the slick extends south into the Bay. The potential impact of the oil lessens as the spill starts to emulsify (break-down) and clean-up efforts begin to take effect. As less concentrated oil remains on the water's surface, the capillary waves are not as effectively dampened and the area appears lighter in the Radar image (D).

Figure 2.5.2.2.2-1 Oil Spill off South Wales in 1996 (Radarsat).
[Source: Canada Centre for Remote Sensing].



To prevent illegal dumping at sea, legislation has been set up to allow coastal states to inspect all shipping within territorial waters and also to ensure national legislation preventing any dumping applies equally to national and foreign owned shipping. Enforcement relies on inspections carried out by marine engineers to ensure compliance with structural safety and cargo monitoring system legislation together with regular surveillance of national waters by airborne and ship patrols to deter offenders from illegal discharge of residue materials.

Remote sensing can be used to both detect and monitor spills. Routine surveillance of shipping routes and coastal areas is necessary to enforce maritime pollution laws and identify offenders. Remote sensing can also detect oil spills from ruptured pipelines, which may otherwise go unchecked for a period of time because of uncertainty of the exact location of the spill, and limited knowledge of the extent of the spill.

For ocean spills, remote sensing data can provide information on the rate and direction of oil movement through multi-temporal imaging, and input to drift prediction modelling and may facilitate in targeting clean-up and control efforts. Remote sensing devices used include the use of infrared video and photography from airborne platforms, thermal infrared imaging, airborne laser fluorosensors, airborne and space-borne optical sensors, as well as airborne and spaceborne synthetic aperture radar (SAR). SAR sensors have an advantage over optical sensors in that they can provide data under poor weather conditions and during darkness.

The key operational data requirements are fast turnaround time and frequent imaging of the site to monitor the dynamics of the spill. For spill identification, high resolution sensors are generally required, although wide area coverage is very important for initial monitoring and detection. Airborne sensors have the advantage of frequent site specific coverage on demand, however, they can be costly. Spills often occur in inclement weather, which can hinder airborne surveillance.

Laser fluorosensors are the best sensors for oil spill detection, and have the capability of identifying oil on shores, ice and snow, and determining what type of oil has been spilled. However, they require relatively cloud free conditions to detect the oilspill. SAR sensors can image oilspills through the localized suppression of Bragg scale waves. Oilspills are visible on a radar image as circular or curvilinear features with a darker tone than the surrounding ocean. The detection of an oilspill is strongly dependent upon the wind speed. At wind speeds greater than 10 m/s, the slick will be broken up and dispersed, making it difficult to detect. Another factor that can play a role in the successful detection of an oilspill is the difficulty in distinguishing between a natural surfactant and an oilspill. Multi-temporal data and ancillary information can help to discriminate between these two phenomena.

2.5.2.3 Gaps and Potential Improvements in Remote Sensing Capability

Like maritime oil spills, many technological emergencies involve rapidly changing, or emerging, phenomena which occur in diverse geographical locations. Present-day satellite remote sensing capabilities cannot provide the response and temporal resolution needed to adequately address many of these situations. Airborne platforms can be very costly to operate for extended periods and may involve risk to crew in hazardous situations.

2.5.2.4 The Potential Role of HALE-Based Remote Sensing

The potential role of HALE-based remote sensing in the management of technological emergencies bears similarities to that for natural disasters. As for natural disasters, some Mitigation Phase and Preparation Phase applications of remote sensing are of a less urgent nature, and may be served by satellite systems. As technological emergencies often provide little or no advance warning, the ability to respond rapidly (the Response Phase) and to stay over the scene until people are safe and the threat has been contained must be a key objective for any remote sensing activity. HALE platforms have the potential to provide this technical capability.

HALE systems also have the potential to provide emergency management organizations with a greater degree of control over the remote sensing asset than is normally possible using commercially-based satellite systems.

The most advantageous types of sensor for many types of technological emergency are likely to be high-resolution surface imaging sensors, i.e.; SAR, Electro-Optical, Infrared. This is because they can usually provide the greatest amount of information about immediate events where people and property are at risk, and where immediate relief efforts must be focused. As the technology develops, specialized measurements of ground surface, water surface, atmospheric and other phenomena, specific to the nature of the technological emergency, will also become important.

While the full potential for HALE-based remote sensing is different for each type of technological emergency, HALE application areas within each phase of the emergency management cycle can be summarized as shown in the table of Figure 2.5.2.4-1. It should be noted that, for many technological emergencies, the Preparation Phase may be of very short, or zero, duration. However, there exists the possibility of one or more technological emergency resulting directly from the effects of a preceding emergency, such as a natural disaster or other human-made emergency. In such cases, greater advance warning may be available, and the Preparation Phase may be longer.

Figure 2.5.2.4-1 HALE Applications in the Technological Emergency Management Cycle

HALE REMOTE SENSING APPLICATIONS	TECHNOLOGICAL EMERGENCY MANAGEMENT PHASE			
	MITIGATION	PREPARATION	RESPONSE	RECOVERY
Inputs to hazard, vulnerability, preparedness analyses, plans, procedures	✓	✓		✓
Verification of hazard & vulnerability reduction and preparedness measures	✓	✓		✓
Monitoring & verification of regulatory compliance	✓	✓		✓
Observations of immediate and ongoing events and phenomena		✓	✓	✓
Inputs to meteorology		✓	✓	✓
Mapping of historic events	✓			
Calibration / validation of satellite and other observations	✓	✓	✓	✓
Training and exercises for Preparation Phase activities	✓			
Training and exercises for Response Phase activities	✓	✓		
Assessment of relief efforts required			✓	
Location of distressed personnel			✓	
Identification & monitoring of access/ escape routes, marshalling points			✓	
Targeting & direction of relief efforts, and assessment of effectiveness			✓	
Damage assessments (property, infrastructure, corridors, etc.) & report verification			✓	✓
Detection and evaluation of secondary hazards/ recurring threats			✓	✓
Verification of recovery, reconstruction, rehabilitation, repair measures				✓
Assessment of environmental impacts				✓
Inputs to historical database/ lessons learned				✓

2.5.3 Transport Emergencies

2.5.3.1 Hazard Description

Transport in various forms continues to grow in volume as economies develop, communications technologies bring more information about distant locations, and as people's expectations about journeying beyond their own locality continue to expand. Further stimuli to the amount of transport of people and goods are the developing transport technologies, which make it possible for more and more people and goods to travel longer distances and more often.

With the great bounty of this increasing ability to move people and goods around come failures in road, rail, air and ocean transport systems which often have serious consequences in terms of human death and injury, loss of valuable goods and damage to the local environment. The total of lives lost and serious injuries resulting from transport incidents in North America runs into many thousands annually. However, much of this loss results from many relatively small incidents, particularly road traffic "accidents", each of which involves only a few people, and which are distributed through the community. As the community at large is able to absorb the effects of these many distributed episodes, much of this human and material loss does not figure in emergency management analyses at higher government levels, and government-level EMOs tend to focus on "extraordinary" events such as plane crashes, railway accidents and distressed large ocean vessels.

Despite the growth in transport technologies, most transport emergencies still result from human error, whether it be error in operating transport systems or failure to provide adequate safety in the design and construction of the systems themselves. Only occasionally are external factors, such as extreme weather, directly responsible for major transport emergencies.

2.5.3.2 State-of-the-Art Applications of Remote Sensing

The utilization of remote sensing in the management of transport emergencies is in its infancy. The opportunity to take advantage of remote sensing technology has been severely limited by the spatial resolution, temporal resolution and response time available from present satellite systems. Some success has been achieved in monitoring the movements of larger ocean vessels from space, but the small scale and distributed nature of land and air transport systems makes routine remote sensing, or surveillance, from space very difficult. Airborne remote sensing systems can be effective in land traffic and ocean traffic monitoring, but they are costly to operate for extended periods and do not generally provide cost-effective solutions to routine surveillance. Remote sensing in the field of transport emergencies has largely been confined to after-the-fact contributions to accident investigations of plane crashes and distressed large ocean vessels.

2.5.3.3 Gaps and Potential Improvements in Remote Sensing Capability

The potential for remote sensing to contribute to enhanced transport safety (emergency prevention) and to the management of occurring transport emergencies is very considerable.

However, it has been demonstrated through a number of well-publicized incidents, including air crashes, that state-of-the art remote sensing capabilities, such as Radarsat, are largely ineffectual in addressing transport incidents, or emergencies. Current systems are severely limited in spatial resolution, temporal resolution and in their response time to unexpected localized events, such as aircraft crashes.

2.5.3.4 The Potential Role of HALE-Based Remote Sensing

For remote sensing to play a fully meaningful role in transport safety and in transport emergency management, coverage will have to be much more localized, more continuous and with better spatial resolution, than is available from current satellite systems. Better understanding of localized weather and other conditions, and the ability to monitor traffic behaviour very closely are key potential applications for HALE-Based systems, which could initially take over the role of police traffic-surveillance helicopters, as a starting point for developing more advanced services. Remote sensing and surveillance capability could be combined with communications capabilities to closely co-ordinate police and emergency services and even for direct communication with drivers, as the technology evolves.

HALE systems could be deployed to the scene of major road incidents, rail incidents, and air crashes to support damage and casualty assessment and to support the direction of relief efforts.

The most important sensors types for transport safety and transport emergency management are likely to be high-resolution surface imaging sensors (SAR, Electro-Optical, Infrared) as these can provide the greatest amount of information about events on the ground or sea surface. As the technology develops, other sensors, such as those providing local meteorological information, may also be important.

2.5.4 Political or Social Emergencies

2.5.4.1 Hazard Description

Even in a democracy, governments must retain some capability to deal with internal threats to civil order or to national security. Most often in Canada police forces have been able to satisfactorily contain threats from terrorism, riot, unrest and civil disobedience, with military forces being reserved for dealing with only the most serious threats to society. In case of serious internal threats to the peace or to national security, measures akin to low-level military conflict may be deployed, and remote sensing, or surveillance, may constitute a valuable tool in identifying, monitoring and neutralizing illegal activity and restoring order.

2.5.4.2 State-of-the-Art Applications of Remote Sensing

Capabilities for high-resolution aerial or space-based surveillance with rapid response and high continuity of observation could play an important role in dealing with terrorism and other threats to the peace or to national security. Though current satellite remote sensing systems have been proven to be useful in some areas of law enforcement, such as identifying illegal crops and ship detection, their real utility in supporting activities such as anti-terrorism and civil unrest is severely limited by the available system performance. The spatial resolution, temporal resolution and response time of present-day satellite systems are simply inadequate to deal with such time-sensitive and small-scale phenomena.

2.5.4.3 Gaps and Potential Improvements in Remote Sensing Capability

As in quickly developing military conflict situations, anti-terrorism and similar internal security measures require surveillance capabilities whose performance can be measured in centimetres and seconds or minutes, rather than metres and hours or days. Present-day satellite systems are unable to provide this performance and airborne surveillance systems tend to be expensive to operate over extended periods, difficult to re-locate over large geographical regions, are more difficult to operate covertly and may involve risk and fatigue to human operators.

2.5.4.4 Potential Role of HALE-Based Remote Sensing

HALE Platforms could play a key role in the response to serious internal security threats by providing high-performance remote sensing, or surveillance, capabilities more effectively than alternative space-based or airborne systems.

The most important sensors types for the management of political or social emergencies are likely to be high-resolution surface imaging sensors (SAR, Electro-Optical, Infrared) as these can provide the greatest amount of information about events on the ground or sea surface. As the technology develops, other sensors, providing threat-specific observation data, and perhaps, local meteorological measurements, may also be important.

2.5.5 General Conclusions: Human-Made Emergencies

The preceding sections have shown that there is a wide range of human made emergency situations which could be managed more effectively if remote sensing, or surveillance, capabilities with adequate performance were available. These potential applications of high-performance remote sensing have not flourished due to shortfalls in the technology available, and emergency management organizations have had to focus on other means for gathering intelligence.

The potential of HALE-based remote sensing in the management of human-made emergencies will in many cases, be greatest in the Response Phase, as events may will usually be moving most rapidly, and the shortcomings of other intelligence sources will be most acute.

The most important overall sensors types for the management of human-made emergencies are likely to be high-resolution surface imaging sensors (SAR, Electro-Optical, Infrared) as these can provide the greatest amount of information about events on the ground or sea surface. As the technology of observing time-varying or emerging phenomena develops further, other sensors providing hazard-specific observation data and, perhaps, local meteorological measurements, may also be important.

3.0 Sensors and System Concepts

3.1 Introduction

In Chapter 3 a “Strawman” concept for a HALE remote sensing system in support to emergency management, and how this system may interface with the Emergency Preparedness Canada (EPC) operational information infrastructure are developed. Applications scenarios, and outline command and control, information processing and information dissemination requirements, are identified. Sensors (SAR, optical, other) which could be applied to the identified emergency management activities are analyzed and described. Performance achievable and the overall sensor characteristics for sensors available within the coming 0 - 3 years are quantified. Projections of the capabilities promised by, and key technologies required for, future HALE sensor concepts, are also given.

3.2 HALE Technologies

Fundamental HALE technologies currently under development are:

- Aerodynamic (airfoil-based), such as
    - Predator (Medium Altitude Endurance-MAE)
    - Global Hawk (High Altitude Endurance-HAE)
    - Pathfinder (Experimental HALE)

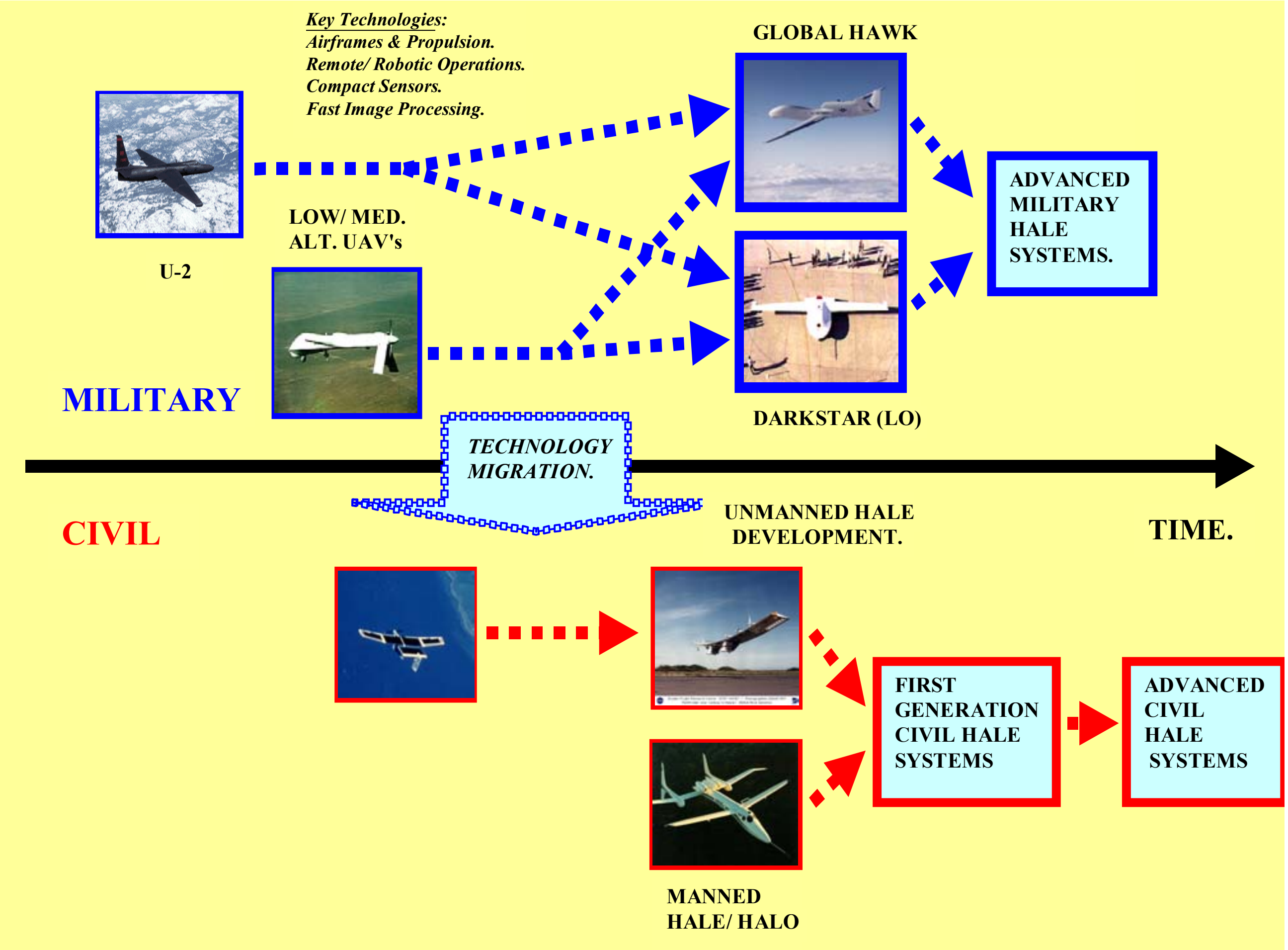
- Aerostatic (lighter-than-air); such as
    - NASA Ultra-Long Duration Balloon-ULDB
    - SkyStation

Aerostatic systems, based on advanced balloon or airship technology, are more difficult to control, provide more limited mobility, and platform translation (required for synthetic aperture radar-SAR) is more limited. *Aerodynamic* HALE, based on high-altitude and unmanned aircraft technologies, holds significant advantages for the bulk of emergency management applications.

Figure 3.2-1 illustrates the evolution of aerodynamic HALE technology, from military roots in U-2 high-altitude aircraft and "conventional" low-altitude UAVs; and from civil roots in high-endurance aircraft and manned HALE-type systems.

The military Global Hawk system, presently in its testing phase, is the most advanced aerodynamic HALE system in existence. Although some "migration" of this and other military technologies into the civil domain can be expected, this may be slow and HALE technology under development by civil agencies for civil applications, such as NASA’s ERAST (Environmental Research Aircraft and Sensor Technology Program), can be expected to be a key source of HALE technology for civil and commercial applications.

Figure 3.2-1 The Evolution of Aerodynamic HALE Technology from Military and Civil Roots.



3.3 Strawman System Concept

3.3.1 General

The strawman system concept is based on the Global Hawk unmanned High-Altitude Endurance (HAE) surveillance system [Northrop Grumman Corporation], which has been described in detail in the final report from the companion study; “Analysis of Sensor and Platform Technologies for Application of High-Altitude Long Endurance (HALE) Platforms in Remote Sensing.”

The Global Hawk air vehicle is designed for fully autonomous operations, with a maximum flight endurance of 40 hours. Global Hawk could fly up to 3,000 nautical miles (5,556 km) at up to 67,000 ft (20,422 m), loiter over a target area for 24 hours while using sensors or other equipment, and then return to base, all without human guidance. The air vehicle has a payload capacity of 2,000 pounds (910 kg) mass (more if less endurance is needed) within 135 ft^3

($3.83 m^3$) volume, and 20 kW of electrical power (400 Hz and DC). Future planned improvements promise to double this capacity. Figure 3.3.1-1 summarizes the technical specifications for the Global Hawk system (Air Vehicle, Sensors, Communications). Figure 3.3.1-2 shows dimensioned views of the Global Hawk air vehicle.

3.3.2 Payload

The development version of Global Hawk carries a sensor package of SAR/MTI (Moving Target Indicator), Infrared and visible wavelength imaging sensors.

During a 24-hour mission over a target area, the X-Band (9.35 GHz) SAR can image 40,000 square nautical miles (137,196 square km) with a spatial resolution of 1.0 m in search mode, or 1,900 2 km x 2 km spots at 0.3 m resolution. The SAR, built by Hughes, has a Ground Moving Target Indicator (GMTI) mode with a minimum detectable velocity of 4 knots (7.4km/hr). The SAR and either the Electro-Optical or Infrared sensor can be operated simultaneously.

The maximum imaging range for the SAR is 200 km. Global Hawk SAR data is processed onboard the aircraft and is transmitted as uncompressed (8 bits per pixel (bpp)) or compressed (2 bpp) images. Data is compressed using the Joint Photographic Experts Group (JPEG) compression algorithms. Images are transmitted in National Imagery Transmission Format Standard (NITFS) 2.0 format with support data extensions. SAR wide area search images are segmented. GMTI data is transmitted as a text product providing location and range velocity.

The Electro-Optical (EO)/ Infrared (IR) sensors operate in Wide Area Search (WAS), Spot Collection, and Point Target (continuous stare) modes, providing National Imagery Interpretability Rating Scale (NIIRS) rating capability of at least 6 for the EO and 5 for the IR, measured at 45 degrees depression from the horizontal, while in the WAS mode. The Hughes-built IR sensor operates in the 3-5 micron spectrum. Global Hawk EO/IR pixel data is processed aboard the air vehicle and transmitted as 1k x 1k image frames (EO) or 640 x 480 image frames (IR) in NITFS 2.0 format. All data links will be encrypted for security reasons.

Figure 3.3.1-1 Technical Specifications for the Global Hawk System
[Source: Northrop Grumman Corporation].

AIR VEHICLE

Wingspan	35.42m
Length	13.41m
Height	4.63m
Gross Takeoff Weight	11,612kg
Payload	907kg
Ferry Range	25,928km
Maximum Endurance	42 hrs
On-Station Endurance at 3,000 Nm	24 hrs
Loiter Velocity	635 km/hr TAS
Maximum Altitude	19,812m

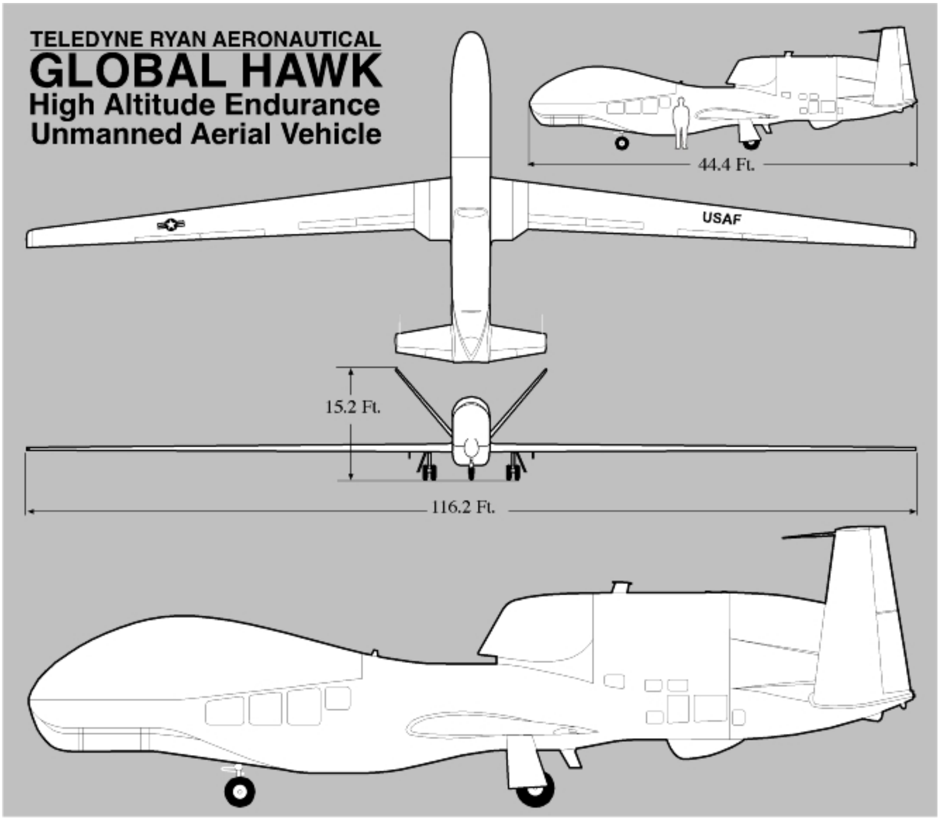
SENSORS

Synthetic Aperture Radar (SAR)	1.0 / 0.3 m resolution (WAS / Spot)
Moving Target Indicator Mode	7.4 km/hr Minimum Detectable Velocity
Electro-Optical	NIIRS 5.5 / 6.5 (WAS / Spot)
Infrared	NIIRS 5.0 / 6.0 (WAS / Spot)
Location Accuracy	<20 m CEP
Wide Area Search	137,196 km^2/ Day
Target Coverage	1,900 Spot Targets / Day

COMMUNICATIONS

SATCOM Datalink (SAR)	1.5, 8.67, 20, 30, 40, 47.9 Mbps
LOS Datalink	137 Mbps

Figure 3.3.1-2 Dimensioned Views of the Global Hawk Air Vehicle
[Source: Northrop Grumman Corporation]



3.3.3 Strawman Operations Concept

Figure 3.3.3-1 illustrates the strawman operations concept for HALE operations over a disaster area. The HALE platform can carry out surveillance and provide additional services, which may include two-way and broadcast communications, and search and rescue. HALE surveillance data is downlinked by Line-of-Sight (LOS) link or Satcom link. After suitable processing, which may involve the use of additional data sources, imagery is passed to the Disaster Relief Coordination Centre. The current Global Hawk system can relay data to suitably-equipped ground stations on either satellite link or LOS link at up to 50 Mbps.

Figure 3.3.3-2 illustrates the maximum payload ground coverage radius as a function of minimum elevation angle to the ground, for Geostationary (GEO) satellites, Low Earth Orbit (LEO) satellites and HALE at 20 km altitude. Figure 3.3.3-3 illustrates the instantaneous ground coverage access over the Ottawa Region from a HALE located at 20 km altitude. Instantaneous ground coverage access is 100 km radius with a minimum elevation angle of 10 degrees, and 35 km with a minimum elevation angle of 30 degrees.

The Global Hawk air vehicle [Northrop Grumman Corporation] is capable of fully autonomous operations once programmed by the ground station, including fully autonomous taxi, take-off, flight, and recovery. Aircraft system, sensor and navigational status are provided continuously to the ground operators through health and status downlink for mission monitoring, and the navigation and sensor plans can be dynamically updated in flight through any of the redundant data links. The Global Hawk has multiple contingency modes to provide safe, predictable operation in the event of lost data links, mission critical equipment, or flight critical equipment. Navigation is via inertial navigation with integrated GPS updates. Taxi, takeoff and landing accuracy requires the use of a Differential GPS (DGPS) system and a radar altimeter. The Global Hawk is designed to be self-deploying and can launch/ recover anywhere there is a compatible Special Category One (SCAT-1) DGPS landing system, and is capable of operating from a 5,000 ft (1,500m)runway (maximum weight, hot day conditions) in a 20 knot crosswind.

3.3.4 Command and Control

The Global Hawk Common Ground Segment (CGS) consists of a Launch and Recovery Element (LRE), a Mission Control Element (MCE), and communications, and support equipment. The CGS is capable of controlling up to 3 Global Hawk air vehicles simultaneously, to provide near real-time (NRT) transmission of sensor imagery. This system is transportable to any theatre of operations by moving the whole Ground Segment using no more than 4 C-130 equivalent loads.

Command and Control for the Global Hawk is through Ultra-High Frequency (UHF) Military Satellite or line-of-sight (LOS) duplex data links at 1.2 kilobits per second, or through the Ku-Band Satellite Communications (Satcom) or LOS Common Data Link (CDL) at 20.0 kbps.

Selected sensor data can also be transmitted via LOS data link and/or Satcom relay directly to properly equipped theatre exploitation sites and/or tactical field users, at selectable rates from 1.5 Mbps to 50 Mbps depending upon the capacity of the available link and capability of the ground receive terminal.

Figure 3.3.3-1 Strawman Operations Concept for HALE over a Disaster Area

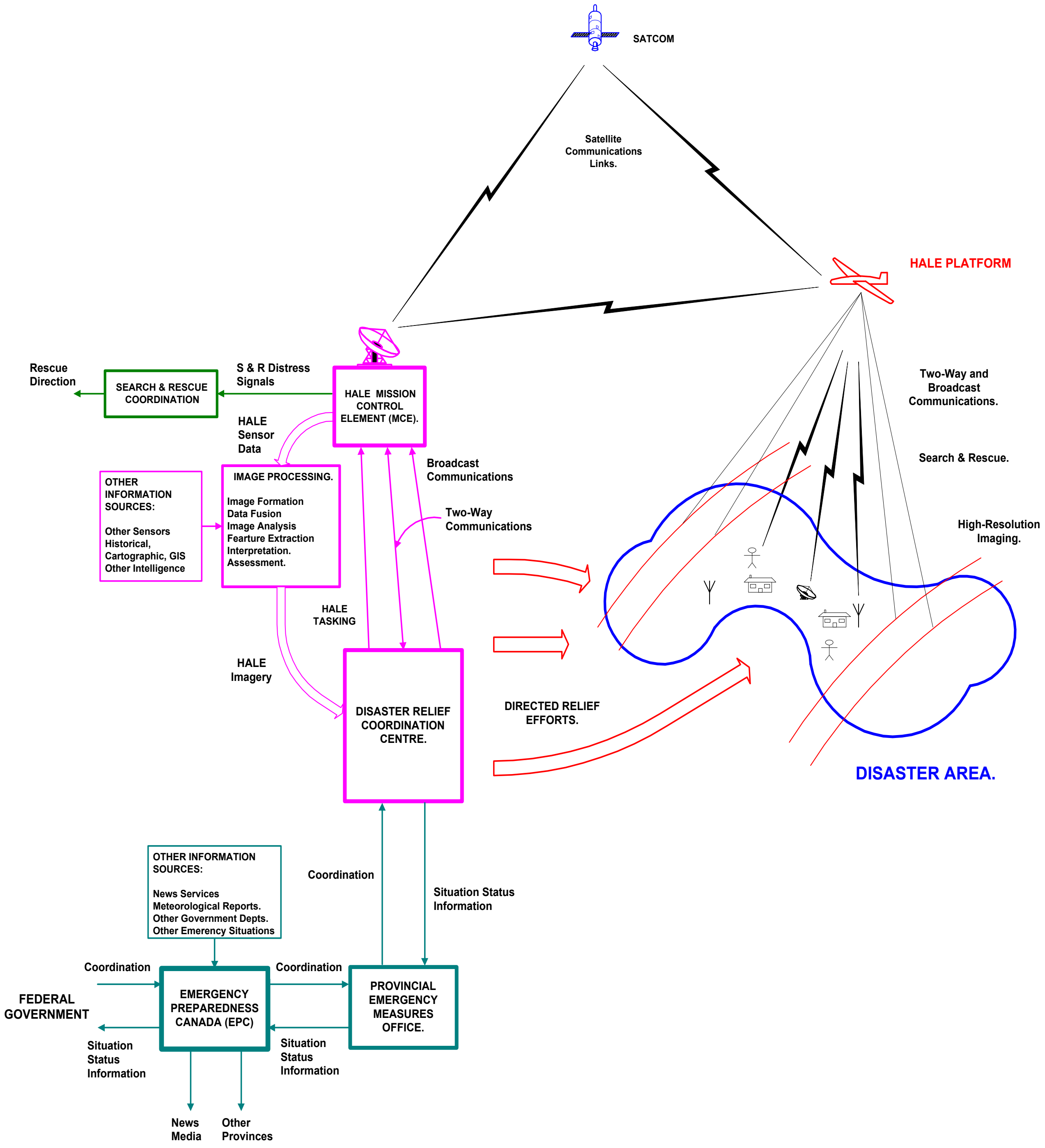
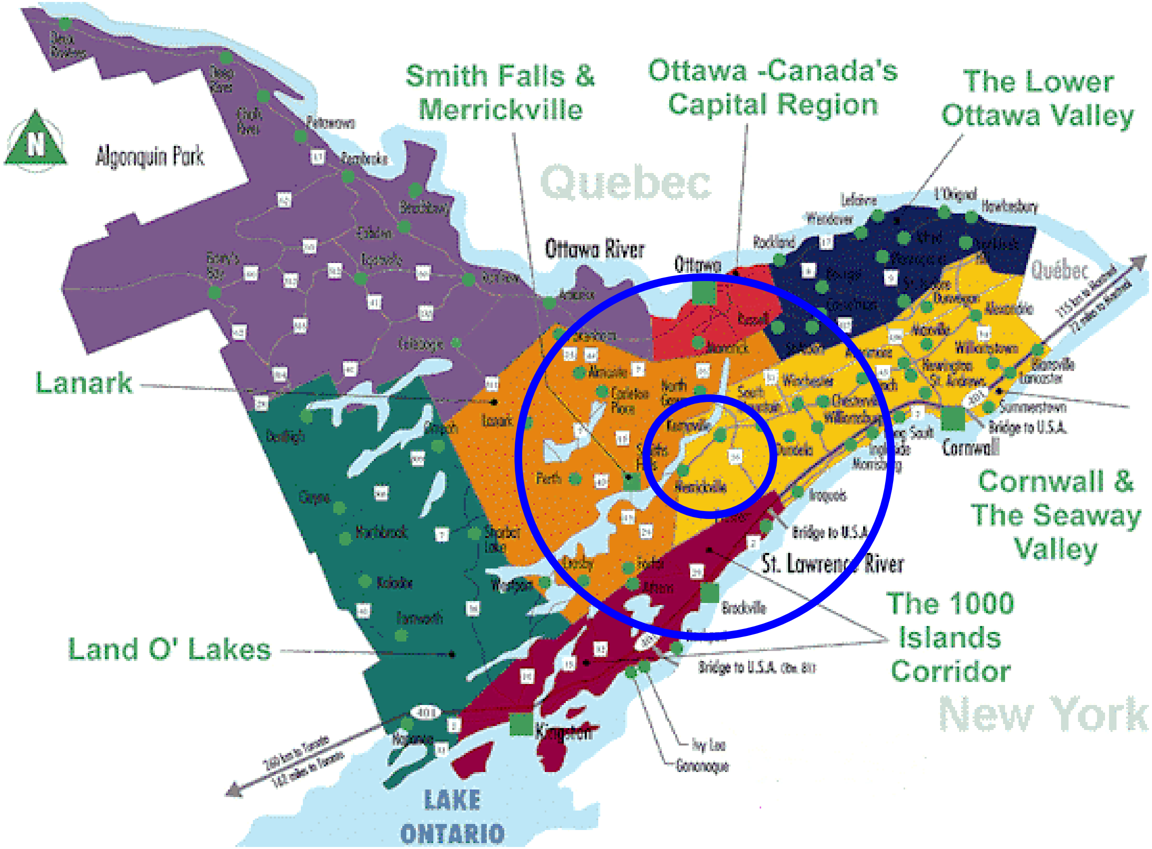


Figure 3.3.3-2 The Maximum Payload Ground Coverage Radius as a Function of Minimum Elevation Angle to the Ground, for Geostationary GEO) Satellites, Low Earth Orbit (LEO) Satellites and HALE at 20 km altitude.

Maximum Payload Coverage Radius (km)			
Elevation Angle (Degrees)	**Geostationary (GEO) Satellite at 36,000 km Altitude**	**Low Earth Orbit (LEO) Satellite at 780 km Altitude**	**HALE at 20 km Altitude**
0	9055	3005	504
10	7957	2007	108
20	6887	1463	54.1
30	5845	1057	34.4
40	4829	774	23.7
50	3835	563	16.7
60	2859	394	11.5
70	1898	251	7.3
80	946	122	3.5
90	0	0	0

Figure 3.3.3-3 The Instantaneous Ground Coverage Access over the Ottawa Region from a HALE Located at 20 km altitude. Instantaneous Ground Coverage Access is 100 km radius with a minimum elevation angle of 10 degrees, and 35 km radius with a minimum elevation angle of 30 degrees.



3.3.5 Operating Base

From an Operating Base in Central Canada (Winnipeg) the Global Hawk could reach any point in Canada or within the Canadian 200 km Economic Zone (see Figure 3.3.5-1), a maximum distance of 3,500 km, within approximately 6 hrs. Figure 3.3.5-2 shows an operational timeline for a 3-HALE system which can provide continuous operation over a designated region anywhere within Canada or its 200 km Economic Zone. Two HALE platforms provide the primary operational system, with a third as an operational backup in case of failure. Each primary HALE performs a 24-hour on-station surveillance program, with 6 hours each for the outward and return journeys and a 12-hour routine maintenance and turnaround period. These flight times relate to worst-case deployments at most-distant locations within Canadian territory.

Figure 3.3.5-1 HALE Operation to Anywhere in Canada + 200 km Economic Zone

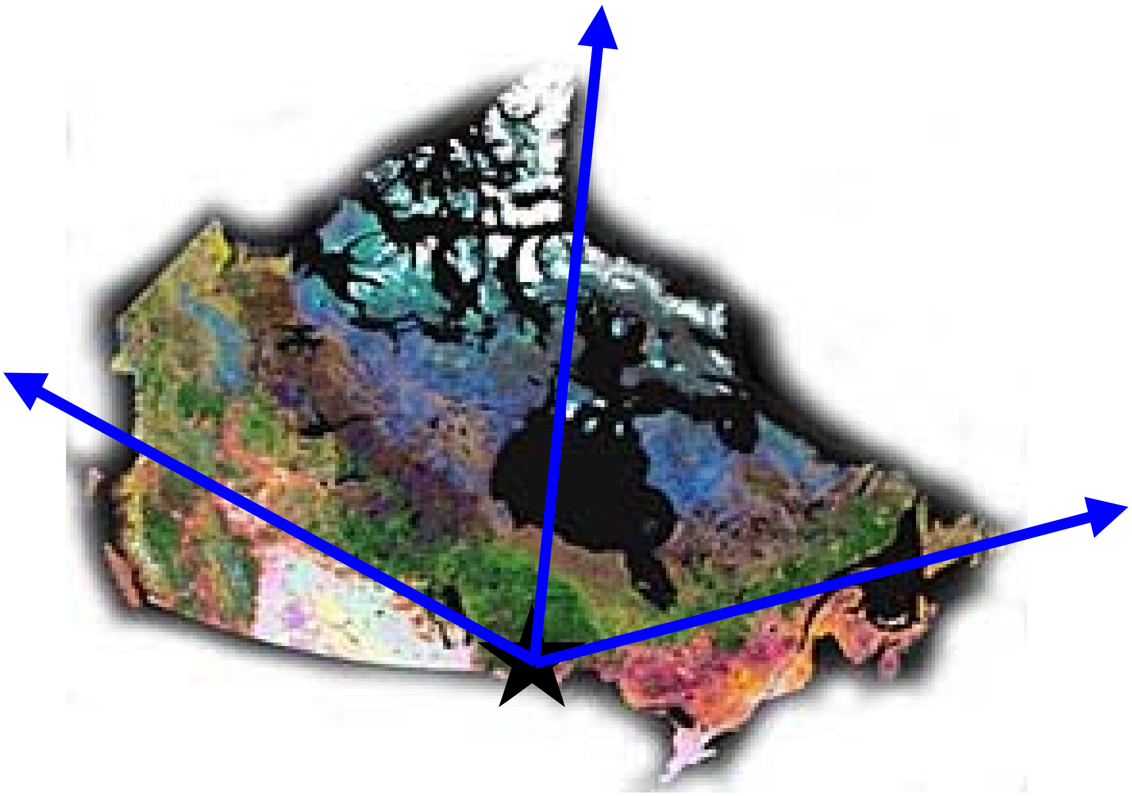
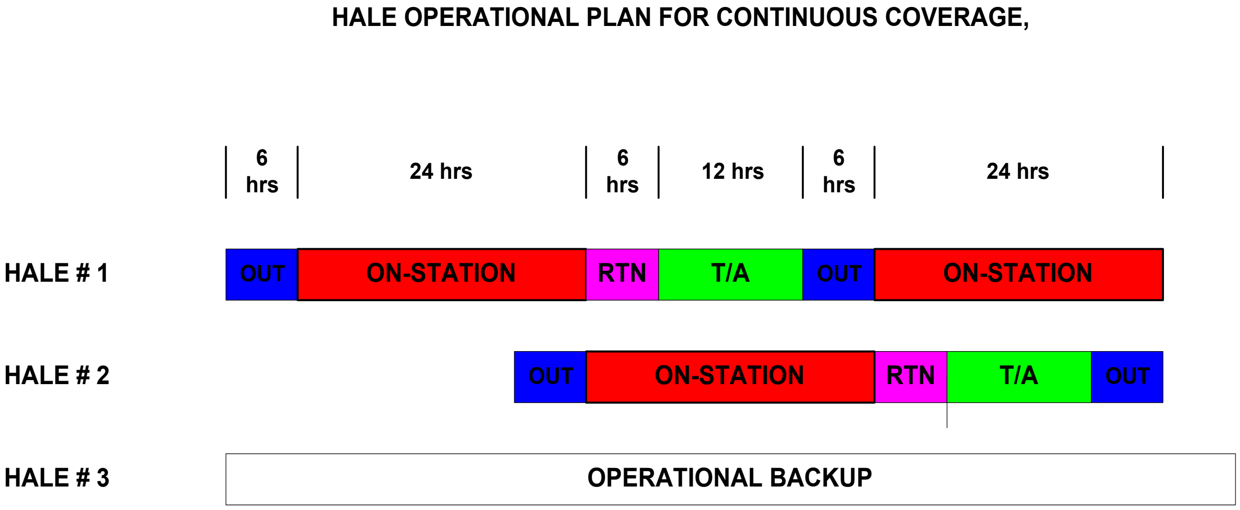


Figure 3.3.5-2 Operational Timeline for a 3-HALE System Providing Continuous Operation Over a Designated Region in Canada + Economic Zone



3.4 Example Mission

3.4.1 General

The surveillance capability of a HALE platform like Global Hawk can be illustrated by an example mission scenario. Figure 3.4.1-1 shows a NOAA image of the 1997 Red River Flood in Manitoba near to its height. The two 60 km x 60 km (= 3,600 km^2) rectangles together illustrate the approximate area affected by the flood. The surveillance capacity of the Global Hawk will allow X-Band SAR imaging of 137,196 square km per 24-hour on-station segment, with a spatial resolution of 1.0 m (Wide Area Search Mode). Use of the SAR allows imaging in the presence of clouds, which often accompany flooded areas, and at night. In the case of the Red River flood, a HALE like Global Hawk could image the entire 7,200 km^2 area in 1 to 2 hours, with a loiter velocity of approximately 343 knots (635 km/hr). Alternatively, the worst-affected areas, or where events are moving more rapidly, could be imaged more frequently. For example a single 3,600 km^2 ground square could be covered approximately every hour using a SAR ground swath of 7 to 10 km. This notional scenario is illustrated in Figure 3.4.1-2. For SAR operation the HALE platform needs to standoff some distance from the centre of the imaging swath to provide the sidelooking geometry for SAR operation.

3.4.2 HALE System Deployment

As was described in previous sections of this report, the value of HALE-based remote sensing with respect to other remote sensing capabilities, such as satellites, will in many emergency cases be greatest for those parts of the emergency management cycle in which events are changing most rapidly and the most urgent action is called for. Also, HALE systems may be operated as assets shared by more than one government department or agency, such as law enforcement, immigration, etc.; so that the utilization of HALE systems many be subject to rules of inter-departmental priority according to the seriousness of ongoing and potential situations, and it may not be possible to deploy HALE systems to support all parts of the emergency management cycle. In addition, there may be more than one ongoing emergency, further emphasizing the potential need to define prioritization philosophies. The table of Figure 3.4.2-1 summarizes potential relative priorities for the use of HALE-based and other remote sensing assets during the phases of a serious flooding situation.

Figure 3.4.1-1 Scenario for HALE Coverage of the 1997 Red River Flooding

[Source: Figure Based on National Oceanic and Atmospheric Administration Image]

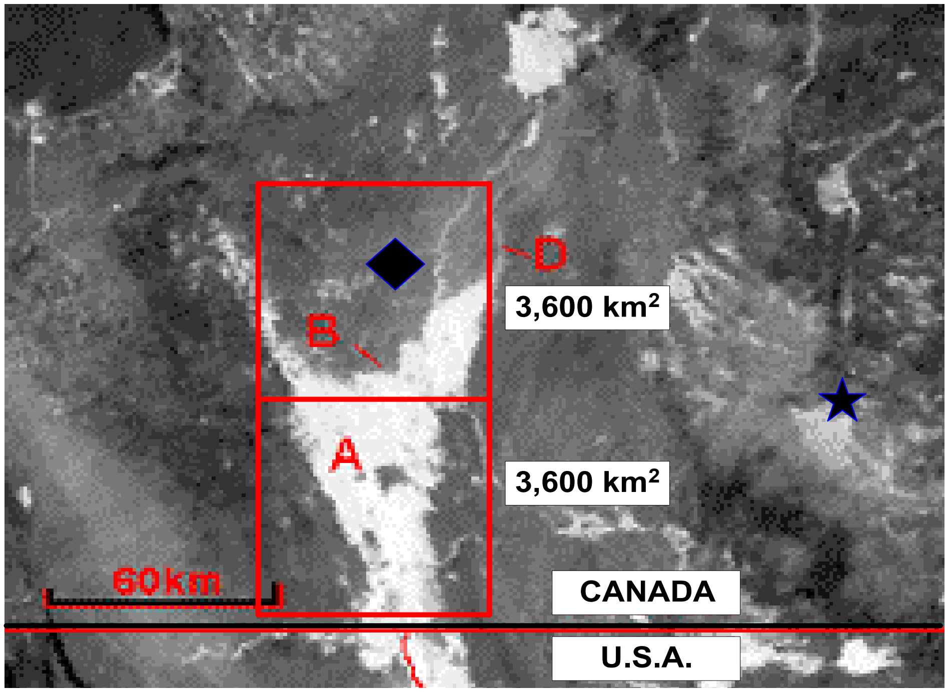


Figure 3.4.1-2 A Notional HALE Ground Coverage Pattern for a 60 km x 60 km Ground Area Using a SAR with 10 km Ground Swath

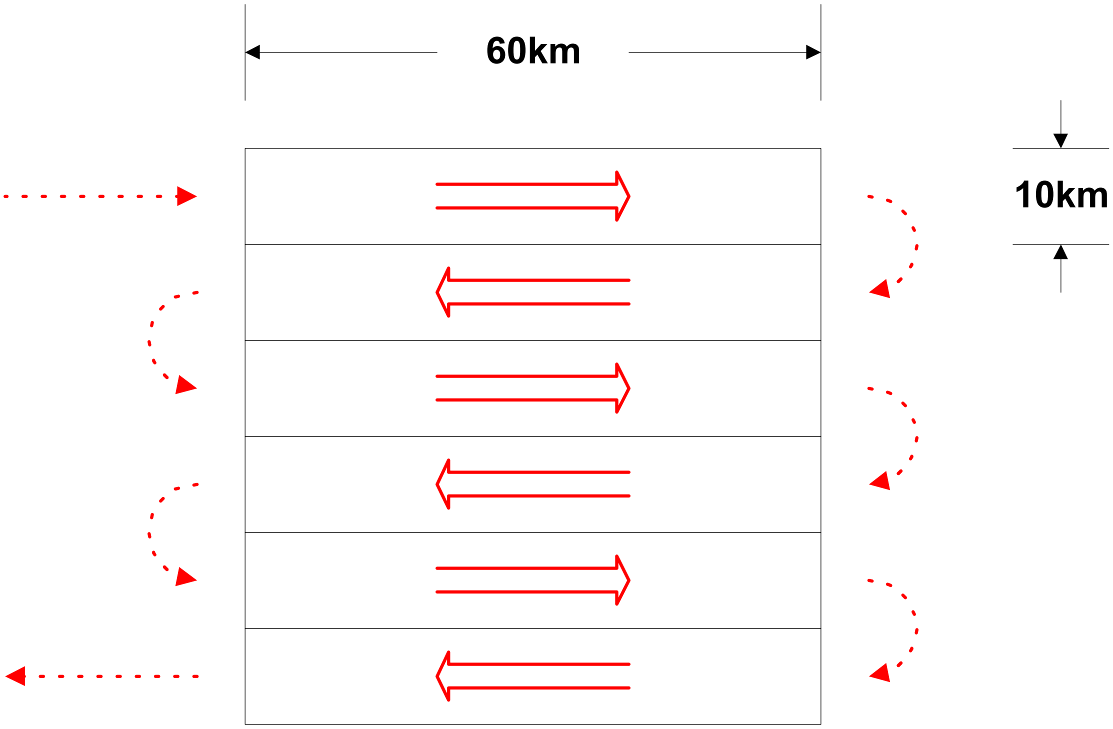


Figure 3.4.2-1 Relative Priorities for the Use of HALE-Based and Other Remote Sensing Assets During the Phases of a Serious Flooding Situation

Emergency Management Phase	Typical Phase Duration (Floods)	Flooding Status	Remote Sensing Needs	HALE Deployment Priority
MITIGATION	Months	Flooding Not Imminent	Routine data can be gathered from satellites, in-situ sensors, and other sources.	**LOW PRIORITY:** HALE system may be deployed for localized technical, hazard, vulnerability, preparedness and historical analyses, training, and calibration/ validation of other measurements.
PREPARATION **(Early Stages)**	Days/ Weeks	Flooding Imminent	Urgent data gathered from satellites, in-situ sensors and other sources.	**MEDIUM PRIORITY:** HALE system may be deployed for localized technical and preparedness analyses, and calibration/ validation of other measurements.
(Late Stages)	Days/ Hours	Flooding Quite Imminent	Emergency data gathered from satellites, airborne sensors, in-situ sensors, etc.	**MEDIUM/HIGH PRIORITY:** HALE system may be deployed for localized technical and preparedness analyses, and calibration/ validation of other measurements.
RESPONSE	Days	Flooding Ongoing	Emergency data gathered from satellites, airborne sensors, in-situ sensors and other sources.	**HIGH PRIORITY:** HALE system is deployed on a continuing basis as the principal surveillance capability for flood status/ conditions, relief/ rescue efforts, damage assessment, warning of secondary or recurring threats, and calibration/ validation of other measurements. HALE can also support search and rescue and emergency communications.
RECOVERY **(Early Stages)**	Weeks	Flooding Subsiding	Urgent data gathered from satellites, airborne sensors, in-situ sensors and other sources.	**HIGH PRIORITY:** HALE system is deployed for localized technical analyses, warning of secondary or recurring threats, assessment of effectiveness of recovery efforts, and calibration/ validation of other measurements.
(Late Stages)	Weeks/ Months	Flooding Subsided	Routine data can be gathered from satellites, in-situ sensors and other sources.	**MEDIUM/LOW PRIORITY:** HALE system may be deployed for localized support to recovery and cleanup, warning of secondary or recurring threats, assessment of effectiveness of recovery efforts, validation of predictive models, updates to hazard, vulnerability and preparedness analyses, "lessons learned" and historical databases, and calibration/ validation of other measurements.

3.5 Candidate Sensors for Emergency Management Applications

3.5.1 General

This section identifies those types of remote sensing and surveillance sensor which can be expected to be of the greatest value in the management of natural disasters and human-made emergencies.

A number of different types of sensor have been proven in Unmanned Aerial Vehicle (UAV) development programs, including the Global Hawk and Darkstar military HALE development programs. These sensor types are:

- Electro-Optical (NIIRS 6.5)
- Infrared (NIIRS 5.5)
- Synthetic Aperture Radar-SAR (1.0m resolution for wide area, 0.3m for spot)
- Ground Moving Target Indicator-GMTI (1.85 km/hr Minimum Detectable Velocity)
- LIDAR (Early Development in US Military)

There are a great many other types of sensor which could be supported from HALE platforms.

3.5.2 Sensors Available within 0-3 Years

3.5.2.1 Sensor Types

The table of Figure 3.5.2.1-1 shows the categorization of remote sensing instruments (sensors) used by CEOS (Committee on Earth Observation Satellites).

The following sections provide descriptions of each category of instrument and their applications, [taken from the Committee on Earth Observation Satellites (CEOS) 1997 Yearbook] and an analysis of their potential utility in emergency management.

Figure 3.5.2.1-1 CEOS Remote Sensing Instrument (Sensor) Categories
[Source: Committee on Earth Observation Satellites]

Remote Sensing Instruments (CEOS)	Principal Functions
Atmospheric Chemistry Instruments	Chemical composition of the atmosphere
Atmospheric Sounders (IR & Microwave)	Atmosphere temperature & humidity profiles
Cloud Profile and Rain Radars	Cloud characteristics, water/ ice in precipitating clouds
Earth Radiation Budget Radiometers	Components of earth radiation budget
High-Resolution Imagers	Detailed images of the earth's surface
Imaging Multi-Spectral Radiometers (Visible, IR)	Spectral imaging of earth's atmosphere/ surface (Vis, IR)
Imaging Multi-Spectral Radiometers (Microwave)	Spectral imaging of earth's atmosphere/ surface (μ-wave)
Imaging Radars	High-resolution images of the earth's surface
Lidars	Laser reflection from earth's surface or atmosphere
Multi-Directional Radiometers	Diffused/emitted atmosphere/ surface radiation (multiple θ_I)
Ocean Colour Radiometers/ Imaging Spectrometers	Visible/ Near-IR radiance from marine waters
Polarimetric Radiometers	Polarimetric measurement of atmosphere/ surface radiation
Radar Altimeters	Surface topography profile
Wind Scatterometers	Ocean surface wind velocity

Atmospheric Chemistry Instruments

Description

Atmospheric trace gases may be observed by detecting absorption or emission from their characteristic spectral lines. Atmospheric chemistry spectrometers and radiometers rely on this to provide information about the chemical composition of the atmosphere from passive measurements of the radiation present over a range of wavelengths, between the UV and microwave. Relatively broad-band radiometers may be used to detect the strong bands observed from ozone. For many other trace gases, however, high spectral resolution spectrometers are required since only very weak lines are available, and these are generally embedded in the continuum of lines from more abundant gases such as water vapour and carbon dioxide. The instruments are conventionally used in either nadir or limb-viewing mode:

- Nadir instruments look directly down at the Earth and measure the radiation emitted or scattered in a small solid angle centred about a given spot on the Earth – they typically provide high horizontal spatial resolution, but are limited in vertical resolution;

- Limb viewing instruments, by contrast, scan positions beyond the horizon so as to observe horizontal paths through the Earth's atmosphere at different altitudes. This geometry allows for very high vertical resolution, in the order of a few km, and is particularly useful for studying the middle atmosphere, although horizontal resolution is limited to around 300 km. Limb viewing allows measurement in either emission or absorption mode. Occultation (absorption) techniques rely either on the sun or other stars as the radiation source.

Applications

Measurements from atmospheric chemistry instruments are providing a global picture of the atmosphere and how it is varying on a daily, seasonal and geographic basis. These measurements have applications in a wide range of fields from monitoring emissions from volcanic eruptions through to climatology and operational meteorology. Historically, atmospheric chemistry spectrometers and radiometers were first used to monitor stratospheric ozone levels. Increasingly, instruments are now becoming available which offer information on other trace gases, including greenhouse gases which affect climate change, chemically active gases which affect the environment, and other gases and radicals impacting on the ozone cycle which therefore affect both climate and the environment.

In the future, the vertical resolution of these instruments is likely to increase to up to 1km. In addition, an extension of the measurements towards the lower atmosphere will allow for improved pollution monitoring capabilities and modelling of atmospheric processes. Better radiometric accuracy will also be achieved through improvements to light diffusion apparatus within some instruments.

Utility in Emergency Management

The measurement of atmospheric constituents may be applied to understanding the effects of:

- Volcanic ash and other volcanic emissions in the atmosphere;
- Wildfire emissions in the atmosphere;
- Other natural chemical processes in the atmosphere;
- Human-made pollution of the atmosphere (environmental and other human-made emergencies).

Atmospheric Sounders (Infrared and Microwave)

Description

Infrared (IR) and microwave atmospheric sounders provide information on the distribution of radiation emitted by the atmosphere from which vertical profiles of temperature and humidity through the atmosphere may be obtained. In general, sounders operate in nadir viewing mode and perform passive measurements of the radiation only in a finite number of channels aligned with the spectral features associated with the species under observation. Sounders are able to discriminate between radiation coming from different levels in the atmosphere by observing the spectral broadening of an emission line. This broadening, which is primarily caused by intermolecular collisions with other species, decreases with atmospheric pressure. The radiation received at the instrument with a wavelength close to the centre of the emission line will hence originate in the upper atmosphere, whilst radiation incident away from the centre of the emission line will come from the lower levels in the atmosphere.

Oxygen or carbon dioxide is usually used as a tracer for the temperature profiles since it is essentially uniformly distributed throughout the atmosphere, and hence temperature sounders often have a number of channels centred around the oxygen and carbon dioxide emission lines. For humidity profiling, either IR or microwave bands in the water spectrum are used. Although microwave sounders have the ability to sound through cloud and hence offer nearly all-weather capability, their spatial resolution (both vertical and horizontal) is essentially lower than that of the IR instruments. IR sounders are routinely used to provide temperature profiles from a few km altitude to the top of the atmosphere with a temperature accuracy of 2-3K, a vertical resolution of around 10 km and horizontal resolution between 10 and 100 km.

Future sounders such as the interferometer-based IASI are likely to benefit from improvements both in the accuracy and temperature measurements and also in the vertical spatial resolution. They will also have better spatial resolution and upper atmospheric sounding capabilities than current instruments. Developments in on-board instrument calibration will also eliminate the need for some internal calibration checks, freeing sensors to gather more data. Future microwave sounders will be capable of providing significantly improved global soundings and information on precipitation and ice.

Applications

Atmospheric sounders may be used to infer a wide range of key atmospheric parameters. The temperature and humidity profiles obtained from these instruments are used for operational meteorology and to build up a comprehensive weekly, monthly and seasonal database of values. Scientists are able to increase their understanding of the global climate which enables them not only to improve their skills for extended weather and climate forecasting, but also helps them to understand and differentiate important man-made changes from natural variations. These instruments may also provide data on the total column, or perceptible water content of the atmosphere, and on atmospheric discontinuities and instabilities.

Utility in Emergency Management

The measurement of temperature and humidity through the atmosphere is important to meteorology, climatology and to understanding man-made changes in climate. Effective and timely meteorology can be important in the management of a number of classes of emergency, including natural disasters and human-made emergencies. Detailed understanding of the effects of human activity on climate is very important to the prevention of human damage to global climate and to the global environment.

Cloud Profile and Rain Radars

Description

These instruments, which are still at a relatively early stage of development, are predominantly based on active microwave radar systems. Cloud profile radars use very short wavelength (mm) radar to detect scattering from non-precipitating cloud droplets or ice particles thereby yielding information on cloud characteristics such as moisture content and base height. Rain radars use centimetre radiation to detect backscatter from water drops and ice particles in precipitating clouds, and to measure the vertical profile of such particles.

One of the key challenges with rain radars is suppressing the return from surface clutter, which is inevitable much stronger than the rain echo. Radars are now being developed, however, which can map the 3-D distribution of precipitating water and ice in a relatively narrow swath (around 200 km) along the track of a low-altitude satellite and thereby infer more precise estimates of instantaneous rainfall.

Application

Measurements from cloud radar can provide information on cloud type and amount, and more importantly on cloud profile information which is required both for improving numerical weather prediction and for climate studies.

Measurement of liquid water and precipitation rate from space-borne rain radars will also provide a unique source of information, sine the ground-based rain radars used at present have limited coverage over the oceans. The availability of an extensive global dataset will be a valuable tool for climatologists and will have significant implications for meteorological forecasting Information on tropical rainfall is of particular importance, since more than two thirds of global rainfall is in the Tropics, and is a primary driver of global atmospheric circulation.

Utility in Emergency Management

The characterization of clouds and measurement of water and ice precipitation are important to meteorology, climatology and to understanding human impacts on climate. Effective and timely meteorology can be important in the management of a number of classes of emergency, including natural disasters and human-made emergencies.

Measurement of potential and ongoing precipitation can be particularly valuable to flood management, but also to other weather-related emergencies. Detailed understanding of the effects of human activity on climate is very important to the prevention of human damage to the global climate and to the global environment.

Earth Radiation Budget Radiometers

Description

These instruments provide measurements of the various components of the radiation budget. The instruments offer a high radiometric accuracy to allow accurate absolute measurements. Most radiometers have a narrow field of view and are used to measure the radiance in a particular direction. Using this, together with information on the angular properties of the radiation, the radiation flux may be obtained. In general, different instruments are used to measure the different components of the radiation budget:

- Broad-band radiometers are used to cover the full range of incoming solar radiation (0.2 - 4.0 microns) and long-wave emitted earth radiation (3 - 50 microns) – this range may be covered either by two single channels, or by a series of narrower band channels;

- Short wave radiometers are used to measure the reflected short-wave radiation from the Earth.

Advanced instruments have a directional capability and channels which allow study of the anisotropy and polarization characteristics of the radiation fluxes. Other instruments measure the true total radiation flux at the satellite. Although such instruments do not require information on the shape of the radiation field, their spatial resolution is much poorer than that offered by directional radiometers.

When combined with information that is required to account for the effects of atmosphere, direct measurements made by these instruments at the top of the atmosphere also allow for investigation of radiation fluxes at the earth's surface.

In the future, broad-band earth radiation budget radiometer data will be available from geostationary orbit offering significantly improved spatial resolution and radiometric accuracy, and more frequent data acquisition compared to current sources. These data will enable the development of more accurate models for converting sun radiance to top-of-atmosphere flux.

Application

The earth's radiation budget is an important forcing function behind change. Earth radiation budget radiometers offer a unique contribution to understanding of the budget, together with its relationship to global warming such as that resulting from the greenhouse effect. In addition, information from these instruments is of interest in studies of clouds (to investigate cloud radiation forcing, for example) and albedo.

Utility in Emergency Management

Measurement of the Earth's radiation budget is most valuable for longer-term climatological studies. As such, the information gathered, and the deductions which can be made from it, are part of a valuable understanding of the global climate, the global environment and of the effects of human activity on these. As such, earth radiation budget measurements probably have lower direct relevance to emergency management activities, which tend to take place on somewhat shorter timescales, than some other classes of remote sensing observation.

High-Resolution Imagers

Description

High resolution imagers provide detailed images of the earth's surface. In general, these are passive, nadir-viewing, instruments with a horizontal spatial resolution in the range 10 to 100 m, and with swath width of the order of 100 km. In the near future, very high resolution (VHR) imagery with spatial resolution in the range of 1 m to 5 m will be available from a number of commercial sources. High resolution imagers operate within the visible to infrared (IR) range and typically record images simultaneously at a number of wavelengths within this range. This increases the information content that may be derived from the imagery. In order to reduce atmospheric absorption and to increase image quality, the operating wavelengths of these instruments are selected to coincide with atmospheric windows. The instruments in this category do, however, suffer from an inability to penetrate thick cloud, rain or fog, and many are restricted to fair weather, daytime-only operation.

There is a wide range of examples of this category of instrument - many countries have and/ or are planning imaging programmes. Future imagers may have a greater number of sampling channels and are likely to have improved resolution, both spectral and spatial. More instruments will also become available that are capable of producing stereo images from data collected on a single orbit, i.e. along track, as opposed to across-track, whereby stereo images are acquired from different passes. More instruments will become available with the capability to acquire and distribute data to users in nearer to real-time.

Application

The data from high resolution imagers has perhaps the widest range of applications of any instrument category. Multi-purpose sea and land imagery, for example, is already used to provide information on:

- Mapping, cartography and the nature and extent of land cover;
- Urbanization and human activity;
- Vegetation type, structure and biomass;
- Agriculture;
- Geological mapping;
- Water bodies, including floods;
- Coastal erosion.

In addition, measurements from these imagers can contribute to investigations of cloud properties and extent, albedo and aerosol distribution over the ocean. Much of this information helps ecologists assess the impact of natural climate variations and human-induced activities on natural and managed ecosystems.

Utility in Emergency Management

High resolution imagers operating within the visible to infrared (IR) frequency range have considerable potential for observing a great range of surface phenomena associated with emergency management. The ability to provide high-resolution images from sensors with modest size, mass and power consumption make this class of instrument valuable for many remote sensing applications and many sensors of this type have been developed. Drawbacks with visible/ IR sensors are the difficulties imposed by thick cloud, rain or fog, and by night time conditions, thus making them difficult to depend upon as the only instrument type in an emergency management situation.

Imaging Multi-Spectral Radiometers (Visible, IR)

Description

Visible/ infrared (IR) imaging multi-spectral radiometers are used to image the Earth's atmosphere and surface, providing accurate spectral information at lower spatial resolution than the imagers discussed in the previous section. Sensing usually occurs in multiple narrow, precisely calibrated spectral channels. The spatial resolution obtained typically varies from 100 m up to several km and the swath width is generally in the range of several hundred to a few thousand km. These instruments cannot penetrate cloud or rain and hence are predominantly limited to clear weather observations. The information obtained from these instruments is often complemented by that from atmospheric sounders, since in deriving parameters such as surface temperatures, atmospheric effects such as absorption must be taken into account. Recent developments include improvements in spatial resolution, in some cases equivalent to those of high resolution imagers, and in spectral resolution and radiometric accuracy. Planned hyperspectral instruments will be able to simultaneously acquire imagery in many tens of wavebands which should significantly improve the quality of land cover and land use information derived from satellite imagery.

Application

Measurements from multi-spectral radiometers operating in IR and visible bands may be used to infer a wide range of parameters, including information on sea and land temperatures, snow and sea ice cover, and earth surface albedo. These instruments may also make measurements of cloud cover and cloud-top temperatures, and measurements of the motion vectors of clouds made by radiometers on geostationary satellites may be used to derive tropospheric wind estimates.

Visible/ IR radiometers are an important source of data on processes in the biosphere, providing information on global-scale vegetation and its variations on sub-seasonal scales which allow monitoring of natural, anthropogenic, and climate-induced effects on land ecosystems. Classification and seasonal monitoring of vegetation types on a global basis allows modelling of primary production (the growth of vegetation that is the base of the food chain) and terrestrial carbon balances. Such information is of great value in supporting the identification of drought areas and provides early warning of food shortages.

Multi-spectral radiometers are also important sources of ocean colour data, although more specialist instrument types are emerging for precise ocean colour measurements.

Utility in Emergency Management

Visible/ IR Imaging Multi-Spectral Radiometers can provide a number of classes of observation important to emergency management activities, including operational meteorology. The ability to perform snow and ice mapping may also be a useful contribution to some emergency management activities. Their vegetation-monitoring ability can provide data on vegetation food content, important for identifying drought areas and providing early warning of food shortages. The ability to observe vegetation can also be applied to estimations of fuel type, condition and distribution for wildfire prevention and monitoring.

Imaging Multi-Spectral Radiometers (Microwave)

Description

Imaging multi-spectral radiometers operate in a number of channels at microwave wavelengths, with the associated advantage of cloud penetration and hence all-weather capability. Depending upon the exact frequency channels used, other advantages over visible/ infrared (IR) radiometers include the ability to probe the dielectric properties of a surface or to penetrate certain surfaces - especially useful with vegetation and soil. As with other imaging radiometers, these instruments offer accurate spectral information, but only poor spatial resolution. At 90 GHz, the spatial resolution is typically 5 km, and for the lower frequencies it is of the order of tens of kilometres.

The spatial resolution of the images produced by these microwave radiometers is generally poorer than that of their visible or infra-red counterparts. As a consequence they are used for global rather than regional or local analysis.

Application

Measurements from imaging microwave radiometers may be used to infer a range of parameters. Snow and ice mapping (often in conjunction with other instruments) has become one of the primary uses of these instruments, due in part to their capability for cloud penetration. Current applications of passive microwave radiometer data include operational forecasting and climate analysis, and the prediction of sea ice concentrations, extent and ice type. Passive microwave radiometers are also used to provide cloud liquid water content information.

These instruments can also supply information on soil moisture content, which is a key surface parameter in agriculture, hydrology and climatology, and provides a measure of vegetation health.

Imaging microwave radiometers are also capable of contributing information on ocean salinity, which is important to our understanding of ocean circulation.

Utility in Emergency Management

Imaging microwave radiometers can contribute to operational meteorology, important to many emergency management activities. Because of their ability to monitor cloud liquid water content and soil moisture they can also provide specific support to flood management activities and drought management activities. The ability to perform snow and ice mapping may also be a useful contribution to some emergency management activities.

Imaging Radars

Description

Imaging radars generate microwave images of a surface. Such radars generally have a high spatial resolution (between 5 m and 100 m) and a swath width of around 100 km. Both synthetic aperture radars (SARs) and some real-aperture imaging radar systems fall into this category. The images produced have a similar resolution to those from high resolution optical imagers, but radars have the ability to "see" through clouds, providing data on an all-weather, day/ night basis. SARs also have the ability to penetrate vegetation and to sample surface roughness and surface dielectric properties. They may also be used to obtain polarization information and, although the operating wavelength is in general fixed for a given radar, radars operating at a variety of wavelengths are available.

Interferometric SARs record the phase shift between two images recorded at slightly different times, thereby providing accurate information on the motion of surface and targets and allowing large scale 3-D topographical images to be produced. Similar stereo images may be produced using conventional SAR images taken on adjacent orbits.

The beam shape and direction of future SARs will enable imagery to be acquired from many points on the earth more frequently. Multipolarized SARs will enable land cover to be classified more accurately and will provide quantitative data on biophysical parameters such as soil moisture and biomass.

Applications

Although a variety of backscatter measurements may be taken by imaging radars, interpretation of these measurements is a complex and developing science. However, significant advances are taking place in many areas are and the number of operational applications continues to grow.

Backscatter from the ocean can be used to deduce surface waves, to detect and analyze surface features such as fronts, eddies, and oil slicks and to detect and track ships. Operational wave and sea ice forecasting is also an important and growing near real-time application of SAR data.

Land images may be used to infer information on vegetation type and cover, and are therefore of use in forestry and agriculture. The ability of SARs to penetrate cloud cover makes them a particularly valuable in rainforest studies, and also in resource monitoring applications. The information obtained from such images depends upon the characteristics (e.g. wavelength) of the probing radiation. Under certain conditions, for example, some penetration of vegetation may be feasible. Such imagery is often used in order to complement visible/ IR multi-spectral imagery by, in effect, providing an additional microwave channel. One of the most important current applications of imaging radars is in all-weather measurements of snow and ice sheets, from which information on topography, texture and motion my be inferred.

Utility in Emergency Management

Because of their all-weather, day/ night imaging capability, and their capability for providing high-resolution imagery of a wide range of surface and near-surface phenomena, imaging radars, including SAR, can be expected to play a major role in remote sensing in support to emergency management. The capabilities of imaging radar systems are applicable to a wide range of natural disasters and human-made emergencies.

Lidars

Description

Lidars, or Light Detection and Ranging instruments, measure the radiation that is returned either from particles in the atmosphere or from the earth's surface when illuminated by a laser source. Compared with radar, the shorter wavelengths used in lidar allow greater detail to be observed, but cannot penetrate optically thick layers such as clouds. There are a number of different types of lidar instrument:

- *The Backscatter Lidar*, in which the laser beam is backscattered, reflected or re-radiated by the target gives information on the scattering and extinction coefficients of the various atmospheric layers being probed;
- *The Differential Absorption Lidar,* which analyses the returns from a tuneable laser at different wavelengths to determine densities of specific atmospheric constituents as well as water vapour and temperature profiles;
- *Doppler Lidar*, which measures the Doppler shift of the light backscattered from aerosol particles transported by the wind, thereby allowing the determination of wind velocity;
- *The Ranging and Altimeter Lidar*, which provides accurate measurements of the distance from a reference height to precise locations on the earth's surface.

Experimental lidar instruments have been flown on the Space Shuttle and several lidars are planned for satellite missions in the near future.

Applications

The different types of lidar may be used to measure a diverse range of parameters. Ranging and altimeter lidars may be used to provide surface topography information, for example on ice sheet height and land altitude. Multifrequency ranging lidars with probe wavelengths in the visible and near IR can be used to measure aerosol height and distributions and cloud height.

Differential Absorption and Backscatter Lidar may be used to measure cloud properties over an extended swath width, and Doppler Lidars may be used to measure 3-D winds. This capability for measuring clear air winds (i.e. in the absence of clouds or winds above clouds) is of particular importance since it will provide a unique source of information for meteorological forecasting, with the potential for significant improvements in accuracy.

Utility in Emergency Management

Ranging and altimeter lidars can be used to provide surface topography information. However, as lidars cannot penetrate optically thick layers such as clouds, their ability to support operational emergency management activities cannot be depended upon in the same way as for microwave radar. Lidars offer a valuable measurement capability for meteorology, which itself is an important information source in emergency management of both natural disasters and human-made emergencies.

Multi-Directional Radiometers

Description

Multi-Directional Radiometers are able to make observations of the diffused or emitted radiation from a particular element of the Earth's surface or clouds from more than one incidence angle. In this way, information on anisotropies in the radiation may be identified. The emphasis in these instruments is on spectral rather than spatial information with the result that the detection channels, which typically span the visible to the IR, are precisely calibrated and the spatial resolution is usually of the order of 1 km.

There are as yet few instruments in this category, although a number are planned for future missions.

Future instruments will have better spatial and spectral resolution and will acquire imagery from many more angles than current instruments. The additional information contained in these data will make it possible to set limits on particle size and composition as well as aerosol amount, measure over the ocean The new data will also be used to derive aerosol properties.

Multi-angle imaging of globally distributed cloudy regions at high resolution will enable direct validation of theoretical models and provide cloud-top height information previously not available.

Applications

In the IR, the multiple viewing angle capability of these radiometers is used to achieve accurate corrections for the effects of (variable) atmospheric absorption and therefore to infer precise temperature values, for example, of sea and land surfaces. In addition to accurate measurements of surface temperature, multi-directional radiometers are also capable of measuring cloud cover and cloud top temperature together with atmospheric water vapour and liquid water content.

In the visible and near IR spectrum, these instruments allow for improved measurements of the scattering properties of particles such as aerosols, and for the angular characteristics of the various contributions to the Earth radiation budget, including surface albedo to be measured. They also enable accurate measurements of parameters such as Normalized Difference Vegetation Indices (NDVI) which are used to assess vegetation state and crop yield at regional and global scales.

Utility in Emergency Management

The meteorology and climatology-related measurements available from Multi-Directional Radiometers can provide information of value to the emergency management process. The ability to provide improved measurement of aerosols and other particles may also be useful to some emergency management applications. Their vegetation-monitoring ability can provide data on vegetation food content, important for identifying drought areas and providing early warning of food shortages. The ability to observe vegetation can also be applied to estimations of fuel type, condition and distribution for wildfire prevention and monitoring.

Ocean Colour Radiometers/ Imaging Spectrometers

Description

Ocean Colour Radiometers and Imaging Spectrometers measure the radiance leaving marine waters in the visible and near IR spectrum in the range 0.4 to 0.8 microns, where the colour is characterized by the constituents of the water, typically phytoplankton, suspended particulate material and dissolved compounds. Differences in the intensity of light received in the different bands gives information on the concentration of a variety of substances present in the ocean.

These instruments have very narrow detection channels, around 10 nanometres wide, to measure fine spectral details. The spatial resolution of these instruments is typically 0.3 km to 1 km. Ocean Colour Radiometers are currently being developed which will have improved spatial, spectral and radiometric resolution compared to existing and previous instruments. Significant calibration and validation activities and algorithm development also continues - particularly with respect to measuring ocean productivity.

Applications

The colour of the oceans as seen from space is an indirect measurement of ocean biomass and its associated productivity, via phytoplankton pigment concentration (chlorophyll). These parameters are of considerable oceanographic and climatological significance as ocean productivity "drives" the air-to-sea exchange of biogenic greenhouse gases (e.g. CO_2). Ocean colour imagery can also be used to guide fishing fleets to biologically-rich areas. Other data that may be inferred from ocean colour measurements includes information about suspended matter (useful in coastal studies), biological productivity, marine pollution and coastal-zone water dynamics (eddies, currents, etc).

Utility in Emergency Management

Ocean Colour Radiometers and Imaging Spectrometers can provide information on:

- Ocean biomass – important to oceanographic and climatological studies, and to detection of human-made damage to the ocean environment;
- Marine pollution (environmental emergencies);
- Coastal-zone water dynamics and environmental damage resulting from human activity.

Polarimetric Radiometers

Description

Polarimetric Radiometers form a special category of imaging radiometer. They are used for applications in which radiative information is embedded in the polarization state of the transmitted, reflected or scattered wave. This type of instrument can measure the polarization state of the received radiation in a given waveband. Polarimetric radiometers usually operate in the visible and IR bands, and as with other radiometers, the bands used are generally precisely calibrated so that accurate spectral information is obtained. In addition, some polarimetric radiometers have a multi-directional capability so that directional information can also be determined.

Applications

The polarization information received by these radiometers may be used to infer a variety of parameters, including the size and scattering properties of liquid water, cloud particles and aerosols. In addition, these instruments offer the potential for providing information on the optical thickness and phase of clouds.

Polarimetric Radiometers also provide information on the polarization state of the radiation backscattered from the Earth's surface which supplements measurements obtained from other land and sea imaging instruments. Such measurements are of interest in a range of applications from investigations of albedo and reflectance to agriculture and the classification of vegetation.

Utility in Emergency Management

Polarimetric Radiometers are a special category of Imaging Radiometer. They are capable of providing information relating to meteorology, climatology, agriculture and classification of vegetation, all of which hold potential in emergency management-related applications.

Radar Altimeters

Description

Radar Altimeters are non-imaging radar sensors which use the ranging capability of radar to measure the surface topography profile parallel to the platform (satellite, aircraft, etc.) track. They provide precise measurements of the platform’s height above the ocean and, if appropriately designed, over land/ ice surfaces, by measuring the time interval between the transmission and reception of very short electromagnetic pulses.

To date, most spaceborne Radar Altimeters have been wide-beam (pulse-limited) systems operating from low earth orbits (LEO). Such altimeters are useful for relatively smooth surfaces such as oceans, but are ineffective over high relief continental terrain as a result of the large radar footprint. Successful exploitation of this height data is dependent upon precise determination of the satellite's orbit. A number of precision radar altimetry "packages" are available which contain:

- A high precision radar altimeter (with basic measurement accuracy in the range 2 cm to 4 cm);

- A means of correction for errors induced in the height measurements by variations in the amount of water vapour along the path (for example, by means of a microwave atmospheric sounder or radiometer);

- A high precision orbit determination system (typically based on GPS, the DORIS beacon/ satellite receiver system and/or a LIDAR tracking system).

Applications

A variety of parameters may be inferred using the information from Radar Altimeter measurements. These parameters include: time-varying sea surface height (ocean topography), the lateral extent of sea ice and the altitude of large icebergs above sea level; and the topography of land and ice sheets and even that of the sea floor. Satellite altimetry also provides information which is of use in measuring the precise geoid, and in mapping the sea surface wind speed and significant wave heights.

The new generation of current and future instruments have a larger swath width than past instruments enabling data to be acquired more frequently. Future instruments will also be configured to provide data in near real-time for incorporation into ocean circulation and wave forecast models used to generate marine information products.

Utility in Emergency Management

Radar Altimeters can provide information on the precise height of the earth's surface in its various forms (sea, land, ice, etc.). Although altimeter-derived information has generally been used in longer-term scientific studies of large-scale phenomena, there exists the possibility that altimeter data can contribute to some aspects of emergency management, such as Tsunami detection and observation, earthquake studies, sea ice observation, and landslides and avalanches. In addition, radar altimeter data can make contributions to meteorological and oceanographical studies into sea surface wind velocity, significant wave height and ocean currents.

Wind Scatterometers

Description

Wind Scatterometers use accurate measurements of the radar backscatter from the ocean surface from illumination by a microwave signal, to derive information on ocean surface wind velocity. At a given angle to the flight path of the satellite, the amount of backscatter depends on two factors - the size of the surface ripples on the ocean, and their orientation with respect to the propagation direction of the pulse of microwave radiation transmitted by the scatterometer. The first is dependent on wind stress and hence wind speed at the surface, while the second is related to wind direction. Hence measurements by such scatterometers (which usually combine observations from at least 3 antennas with different look directions) may be used to derive both wind speed and direction.

These instruments aim to achieve high accuracy measurements of wind vectors (speed and direction) and spatial resolution is of secondary importance (they generally produce wind maps with a resolution of the order of 50 km). Because these scatterometers operate at microwave wavelengths, the measurements are available irrespective of weather conditions.

Coverage from instruments currently in orbit is limited, however, since they have a single-sided field of view. Data from the limited period of operations of the dual-sided swath instrument NSCAT on ADEOS 9 which failed in June 1997) is of greater interest. Coverage will be greatly improved in the future with the flight of more dual-sided swath instruments.

Applications

Information from Wind Scatterometers provides a unique source of data on sea surface wind speed and direction which has important applications in operational weather forecasting and the investigation of climate models. There are numerous other applications of this data including the optimization of ship routes, measurement of sea ice extent and concentration, and emerging land surface applications, such as the monitoring of rain forests, snow conditions, tundra and deserts.

Utility in Emergency Management

Wind Scatterometers have been designed essentially for one specific measurement – sea surface wind velocity. This information has a number of potential applications in operational meteorology, climatology, and the prediction and observation of natural disasters associated with strong wind fields. The timely updating of ocean condition models is another valuable application area. In addition, some ocean-related applications associated with human activity, such as ship-routing, are being developed. There are also some emerging land applications, such as observation of the rain forests, where the impacts of human activity on the environment may be of significant interest to scientists and environmentalists.

3.5.2.2 Sensor Type Selection for Emergency Management Applications

The following tables identify current-generation sensor types applicable to remote sensing in support to emergency management:

Figure 3.5.2.2-1:	Natural Disasters.
Figure 3.5.2.2-2:	Human-Made Emergencies.

3.5.2.3 Sensor Value Analysis

The purpose of the **Sensor Value Analysis** is to provide an evaluation of which categories of current-generation sensor hold the greatest overall potential for performing HALE-based remote sensing/ surveillance in support to the management of a range of the most important Canadian emergency types.

Sensor Value Analysis: Natural Disasters

For each sensor category (see Section 3.5.2.1.) an overall *Relative Figure of Merit (RFOM)* is derived:

Sensor Category *Relative Figure of Merit (RFOM)* = Measure of the relative value of the sensor category for performing HALE-based remote sensing/ surveillance in support to the management of a range of the most important Canadian disaster types. The derivation of RFOM does not include the performance of routine meteorology.

$$\text{Sensor Category RFOM} = \sum_{\substack{\text{(all Canadian}\\ \text{Disaster types)}}} \left\{ \begin{array}{l} \text{Relative Frequency of Occurrence of the Disaster} \\ \times\ \text{Relative Potential Impact on the Community} \\ \times\ \text{Relative Value of the Sensor Category} \end{array} \right\}$$

The table of Figure 3.5.2.3-1 shows assigned values of the *Relative Frequency of Occurrence* and the *Relative Potential Impact on the Community* for each type of Canadian Natural Disaster.

The table of Figure 3.5.2.3-2 shows the derived values of *Relative Figure of Merit (RFOM)* for each HALE-Based Sensor Category.

From this analysis, the most valuable sensors for HALE-based remote sensing/ surveillance in support to the management of a range of the most important Canadian Disaster types are:

1) Imaging Radar (SAR)
2) Passive Optical/ IR High-Resolution Imagers
3) Imaging Multispectral Radiometers (Microwave)

Figure 3.5.2.2-1 Remote Sensing Sensor Types: Natural Disasters

Disaster Type	**Measurement/Observation Categories**		
	Surface Imaging	**Other/Specific**	**Meteorology/ Climatology**
Floods	• SAR • Passive Optical/IR Hi-Resolution Imagers • Imaging Microwave Radiometer (Soil Moisture) • LIDAR (Surface Topography) • Radar Altimeter (Water Surface Height) • Wind Scatterometer (Ocean/ Lake Condition)	• Atmospheric Sounders (Precipitation) • Cloud/ Rain Radar (Precipitation) • Imaging Microwave Radiometer (Cloud Water)	• Atmospheric Sounders • Cloud/ Rain Radar • Visible/ IR Imaging Radiometers • Imaging Microwave Radiometer • LIDAR • Multi-Directional Radiometers • Ocean Colour Radiometers/ Imaging Spectrometers • Polarimetric Radiometers • Radar Altimeter • Wind Scatterometer
Earthquakes	• SAR • Passive Optical/ IR Hi-Resolution Imagers • LIDAR (Surface Topography) • Radar Altimeter (Surface Height)	–	
Severe Storms	• SAR • Passive Optical/ IR Hi-Resolution Imagers • Visible/ IR Imaging Radiometers (Snow/ Ice Mapping) • Imaging Microwave Radiometers (Snow and Ice Mapping) • Wind Scatterometer (Ocean/ Lake Surface Wind Models)	• Cloud/ Rain Radar (Precipitation) • Ocean Colour Radiometers/ Imaging Spectrometers (Oceanography)	
Fires	• SAR • Passive Optical/ IR Hi-Resolution Imagers • Multispectral (Optical + NIR) • Visible/ IR Imaging Radiometers (Vegetation Monitoring) • Multi-Directional Radiometer (Vegetation State) • Polarimetric Radiometers (Vegetation Classification)	• Atmospheric Chemistry Instruments (Atmospheric Emissions) • Cloud/ Rain Radar (Precipitation)	

Figure 3.5.2.2-1 (Continued) Remote Sensing Sensor Types: Natural Disasters

Disaster Type	**Measurement/Observation Categories**		
	Surface Imaging	**Other/Specific**	**Meteorology/ Climatology**
Landslides & Avalanches	• SAR • Passive Optical/IR Hi-Resolution Imagers • Visible/ IR Imaging Radiometers (Snow/ Ice Mapping) • Imaging Microwave Radiometer (Snow and Ice Mapping) • LIDAR (Surface Topography) • Radar Altimeter (Surf Height)	• Cloud/ Rain Radar (Precipitation)	• Atmospheric Sounders • Cloud/ Rain Radar • Visible/ IR Imaging Radiometers • Imaging Microwave Radiometer • LIDAR • Multi-Directional Radiometers • Ocean Colour Radiometers/ Imaging Spectrometers • Polarimetric Radiometers • Radar Altimeter • Wind Scatterometer
Tsunami & Storm Surges	• SAR • Passive Optical/ IR Hi-Res Imagers • LIDAR (Surface Topography) • Radar Altimeter (Water Surf Ht) • Wind Scatterometer (Ocean/ Lake Condition)	• Ocean Colour Radiometers/ Imaging Spectrometers (Oceanography)	
Droughts	• SAR • Passive Optical/ IR Hi-Resolution Imagers • Visible/ IR Imaging Radiometers (Vegetation Monitoring) • Imaging Microwave Radiometer (Soil Moisture) • Multi-Directional Radiometer (Vegetation State, Crop Yield) • Polarimetric Radiometers (Vegetation Classification)	• Cloud/ Rain Radar (Precipitation) • Imaging Microwave Radiometer (Cloud Water)	
Public Health Disasters	• SAR • Passive Optical/ IR Hi-Resolution Imagers • Visible/ IR Imaging Radiometers (Vegetation Monitoring) • Multi-Directional Radiometer (Vegetation State, Crop Yield) • Polarimetric Radiometers (Vegetation Classification)	–	

Figure 3.5.2.2-2 Remote Sensing Sensor Types: Human-Made Emergencies

Emergency Type	Measurement/Observation Categories		
	Surface Imaging	Other/Specific	Meteorology/ Climatology
Technological	• SAR • Passive Optical/ IR Hi-Resolution Imagers • Laser Fluorosensor (Oil Spills) • Wind Scatterometer (Ocean/ Lake Condition and Observation of Large-Scale Phenomena/ Widespread Human Damage) • Visible/ IR Imaging Radiometers (Snow/ Ice Mapping and Vegetation Monitoring) • Imaging Microwave Radiometer (Snow and Ice Mapping, Soil Moisture) • Multi-Directional Radiometer (Vegetation State and Crop Yield) • Polarimetric Radiometers (Vegetation Classification)	• Atmospheric Chemistry Instruments (Atmospheric Pollutants) • Atmospheric Sounders (Human effects on Climate) • Cloud/ Rain Radar (Precipitation) • Ocean Colour Radiometers/ Imaging Spectrometers (Oceanography, Marine Pollution)	• Atmospheric Sounders • Cloud/ Rain Radar • Visible/ IR Imaging Radiometers • Imaging Microwave Radiometer • LIDAR • Multi-Directional Radiometer • Ocean Colour Radiometers/ Imaging Spectrometers • Polarimetric Radiometers • Radar Altimeter • Wind Scatterometer
Transport	• SAR • Passive Optical/ IR Hi-Res Imagers • Visible/ IR Imaging Radiometers (Snow/ Ice Mapping) • Imaging Microwave Radiometer (Snow and Ice Mapping) • Wind Scatterometer (Ocean/ Lake Condition)	• Ocean Colour Radiometers/ Imaging Spectrometers (Oceanography)	
Political or Social	• SAR • Passive Optical/ IR Hi-Res Imagers	–	

Figure 3.5.2.3-1 Relative Frequency of Occurrence and the Relative Potential Impact on the Community for each Type of Canadian Natural Disaster
[Source: Emergency Preparedness Canada]

Canadian Natural Disaster	Relative Frequency of Occurrence	Relative Potential Impact on the Community
Floods	1.0	1.0
Earthquakes	0.152	1.0
Severe Storms	0.958	0.6
Fires	0.303	0.4
Landslides & Avalanches	0.296	0.4
Tsunami and Storm Surges	0.021	0.3
Droughts	0.379	0.2
Public Health Disasters	0.021	0.2

Figure 3.5.2.3-2 Derived Values of Relative Figure of Merit (RFOM) for each HALE-Based Sensor Category for the Management of Canadian Natural Disasters.

Sensor Category	Sensor Category Overall Relative Figure of Merit (RFOM) (Normalized)	Sensor Category Overall Relative Figure of Merit (RFOM) (Normalized, Rounded)
Imaging Radar (SAR)	1.0	1.0
Passive Optical/ IR High Resolution Imagers	0.53	0.5
Imaging Multi-Spectral Radiometer (Microwave)	0.265	0.3
Cloud/ Rain Radar	0.239	0.2
Wind Scatterometer	0.166	0.2
Multi-Directional Radiometer	0.164	0.2
Radar Altimeter	0.161	0.2
Polarimetric Radiometer	0.156	0.2
Atmospheric Sounders (IR/ Microwave)	0.132	0.1
Ocean Colour Radiometer/ Imaging Spectrometer	0.100	0.1
Imaging Multispectral Radiometer (Visible/ IR)	0.089	0.1
LIDAR	0.028	0.0
Atmospheric Chemistry Instruments	0.008	0.0
Earth Radiation Budget Radiometer	0.00	0.0

Sensor Value Analysis: Human-Made Emergencies

The utilization of remote sensing in the management of human-made emergencies is in its infancy. The opportunity to take advantage of remote sensing technology in this field has been severely limited by the spatial resolution, temporal resolution and response time available from present satellite systems, and by the cost and other practical limitations of airborne systems.

This analysis indicates that the most valuable sensor types for HALE-based remote sensing/ surveillance in support to the management of a range of the most important Canadian Human-Made Emergencies are:

- Imaging Radar (SAR);
- Passive Optical/ IR High-Resolution Imagers;
- Specific sensor types providing specialized measurements addressing the needs of emergency management for individual human-made emergency types, such as Laser Fluorosensor for Oil Spill management.

Sensor Value Analysis: Emergency Management (Natural Disasters & Human-Made Emergencies)

The Sensor Value Analysis indicates that the most valuable sensor types for HALE-based remote sensing/ surveillance in support to the management of a range of the most important Canadian Natural Disasters and Human-Made Emergencies are:

- Imaging Radar (SAR);
- Passive Optical/ IR High-Resolution Imagers;
- Specific sensor types providing specialized measurements addressing the needs of emergency management for individual human-made emergency types, such as Laser Fluorosensor for Oil Spill management.

3.5.3 Key Characteristics of the Most Important Sensor Types

3.5.3.1 Introduction

The following sections examine the principal characteristics of the most important sensor types resulting from the Sensor Value Analysis:

- Synthetic Aperture Radar (SAR);
- Passive Optical/ Infrared (IR) High-Resolution Imagers.

3.5.3.2 Synthetic Aperture Radar (SAR)

Synthetic Aperture Radar uses the motion of the sensor platform with respect to the target in coherent processing of returned echoes to synthesize a very long radar antenna, hence achieving high along-track spatial resolution (see Figure 3.5.3.2-1). Pulse compression techniques can give associated high cross-track spatial resolution in the resulting image. The standard mode of SAR operation in imaging strips of the earth's surface, as the satellite or aircraft platform moves over it, is known as "Stripmap" Mode.

Figure 3.5.3.2-2 shows examples of imagery (30m resolution) from the ERS-2 SAR.

SAR "Spotlight" Mode, commonly used in military surveillance applications, uses radar beamsteering to achieve enhanced spatial resolution over limited ground areas.
Figure 3.5.3.2-3. illustrates the system geometries of SAR "Stripmap" and "Spotlight" modes.

The SAR system – best suited for observing static phenomena – may be combined with a Moving Target Indicator (MTI) capability.

SAR System Design

Figure 3.5.3.2-4 illustrates the key components of a SAR system. As SAR is essentially a coherent system, there must be compensation for motion of the platform to maintain the overall coherence of the system. The key performance parameters for an imaging SAR system are:

Coverage:	Swath Width, Incidence Angle, Duty Cycle, Repeat (Revisit) Cycle
Image Quality:	Radar Frequency/ Polarization, Spatial Resolution, Radiometric resolution/ Sensitivity, Dynamic Range, Radiometric Accuracy, Localization Accuracy

The SAR Sensor

Figure 3.5.3.2-5 shows a generic SAR Sensor. The SAR sensor is essentially a pulse-compression radar (high range, or across-track, resolution) in which coherence is preserved over many pulses, so allowing full SAR processing to achieve high resolution also in the along-track direction. In the overall design of a SAR system the achievable coverage is usually governed by the system geometry, the ability to revisit and, often, the system data handling capabilities.

Figure 3.5.3.2-1 SAR System Geometry

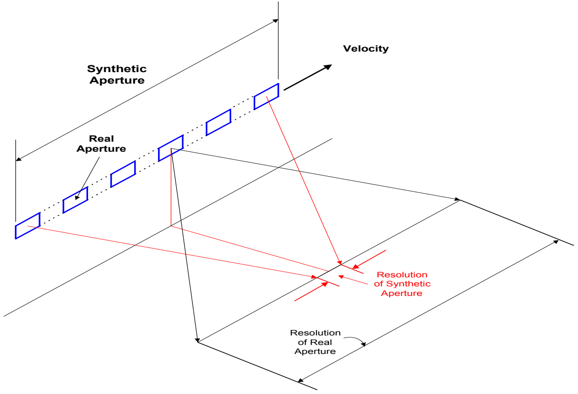


Figure 3.5.3.2-2 An Example of Imagery (30mResolution) from the ERS-2 SAR, Capetown, South Africa, 31st August 2001
[Source and Copyright: European Space Agency]

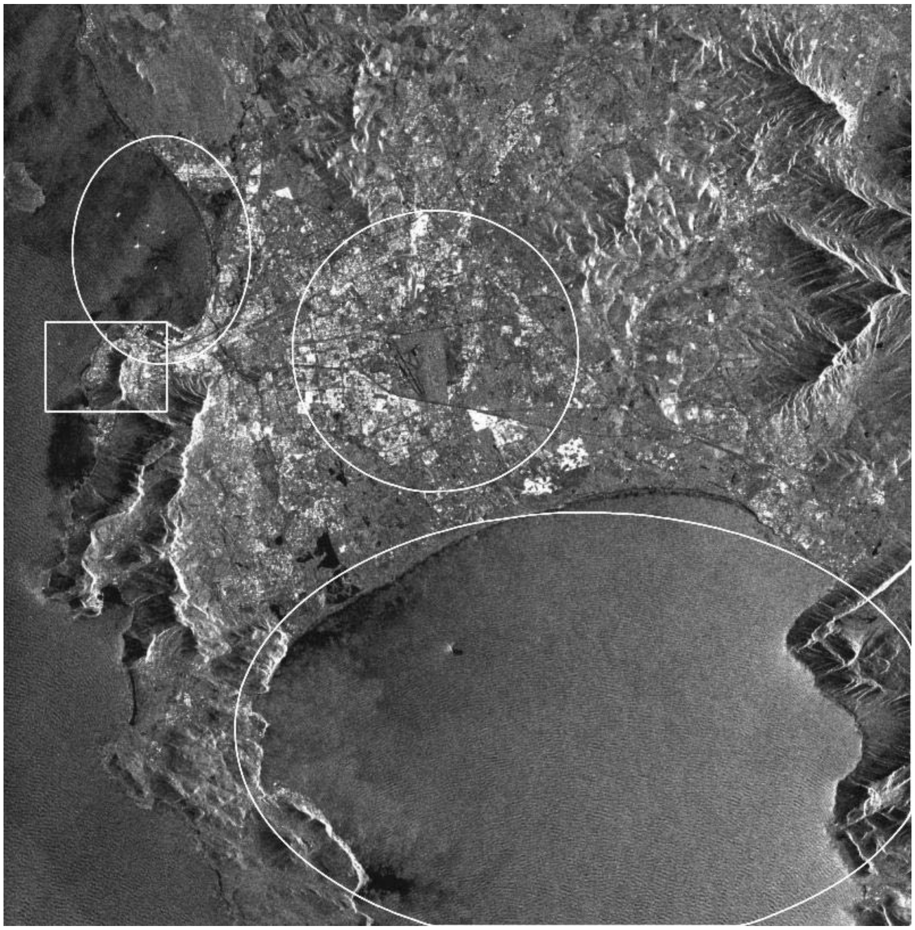


Figure 3.5.3.2-3 The System Geometries of SAR "Stripmap" and "Spotlight" Modes

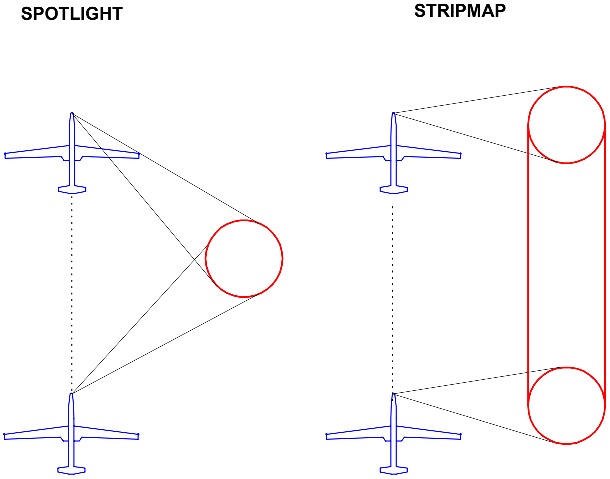


Figure 3.5.3.2-4 The Key Components of a SAR System

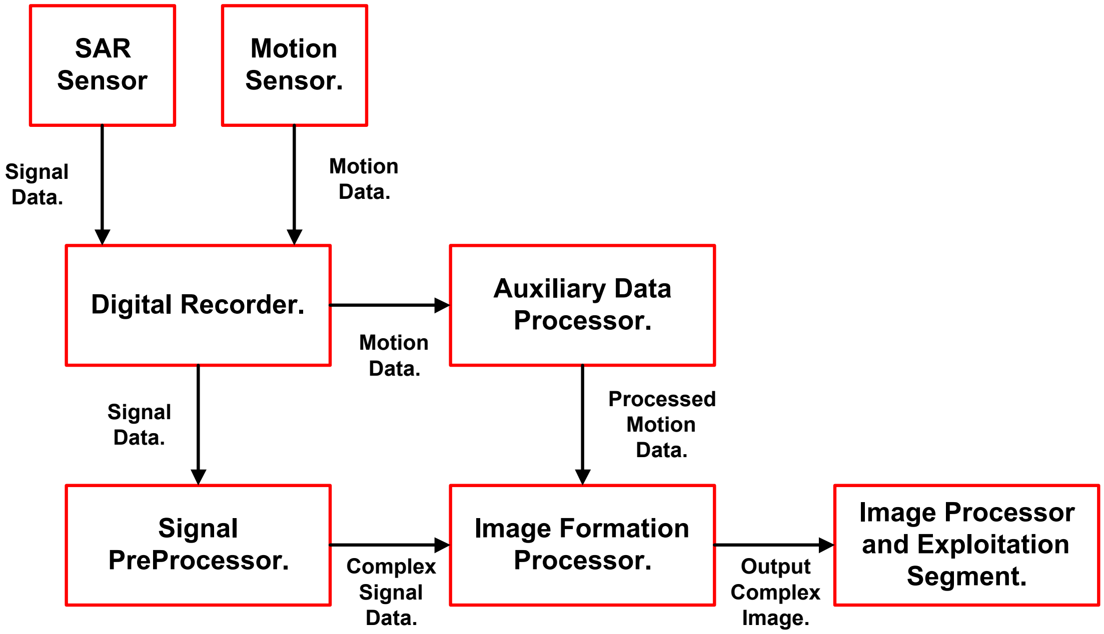
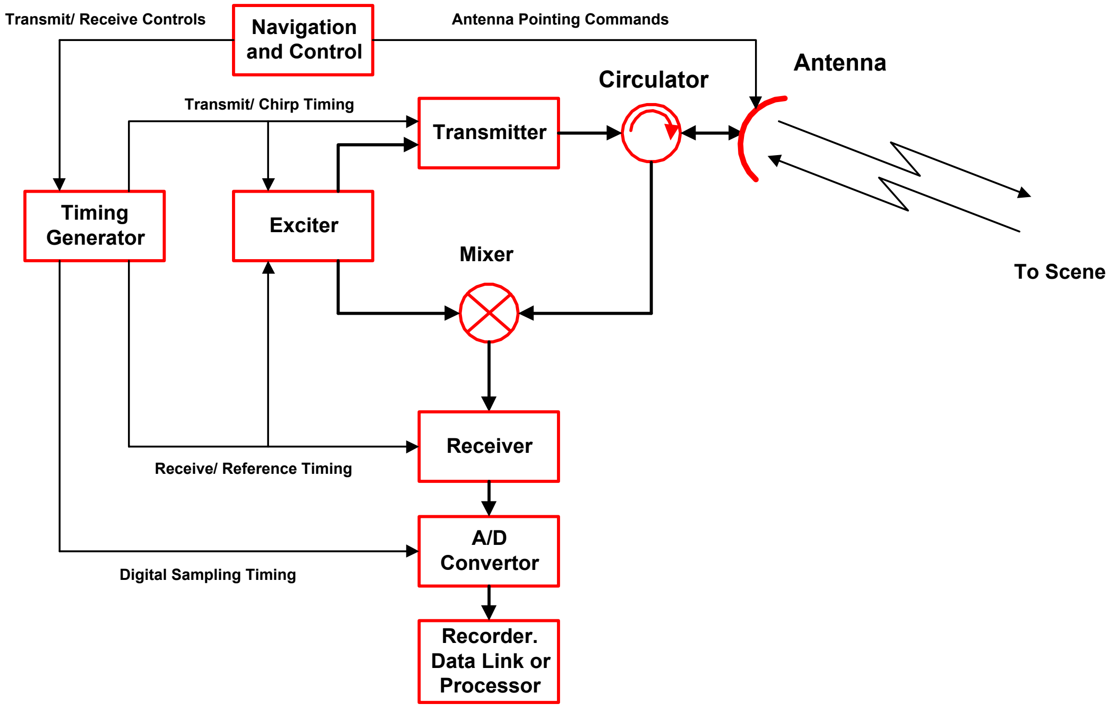


Figure 3.5.3.2-5 A Generic SAR Sensor



Radar frequencies range from 25 MHz(UHF) to 70 GHz (mm). A great deal of research worldwide has gone into identifying the most advantageous radar frequencies and polarization or polarization combinations for specific radar observation applications. The table of Figure 3.5.3.2-6 summarizes the results of work by NASA into radar frequency and polarization choices for a range of remote sensing applications. Generally, frequencies from the L-Band (1.0 to 2.0 GHz) to the X-Band (8MHz to 12.5MHz) have been selected for the majority of airborne and spaceborne SARs for remote sensing.

X-Band frequencies generally find favour for military applications, being good for surface feature imaging, technology availability and high spatial resolution (Bandwidth required ~ 500 to 1000 MHz for 0.3m resolution).

Because of the very much shorter signal path to the target, HALE-Based SAR requires much less transmitter power than spaceborne SAR for equivalent radiometric performance at equivalent incidence angles.

SAR Image Processing

A key component in the SAR system is the Image Processor which, amongst other functions, generates high along-track resolution by performing summation of sequences of radar returns to synthesize a long antenna.

SAR image formation requires considerable processing (usually on ground) to produce an image from *SAR Data* and *Sensor Motion Data* (coherent system). Image Formation Processor (IFP) operations include:

- Auxiliary data processing;
- Compensation for non-ideal waveform generator and propagation effects;
- Azimuth filtering (to limit azimuth scene size) and presuming;
- Range deskew;
- Motion compensation operations;
- Range filtering (to limit range scene size);
- Signal interpolation and decimation (data formatting);
- Aperture weighting for image sidelobe control;
- Two-dimensional Fourier transform (compression);
- Autofocus;
- Amplitude correction and radiometric calibration;
- Geometric distortion correction (interpolation).

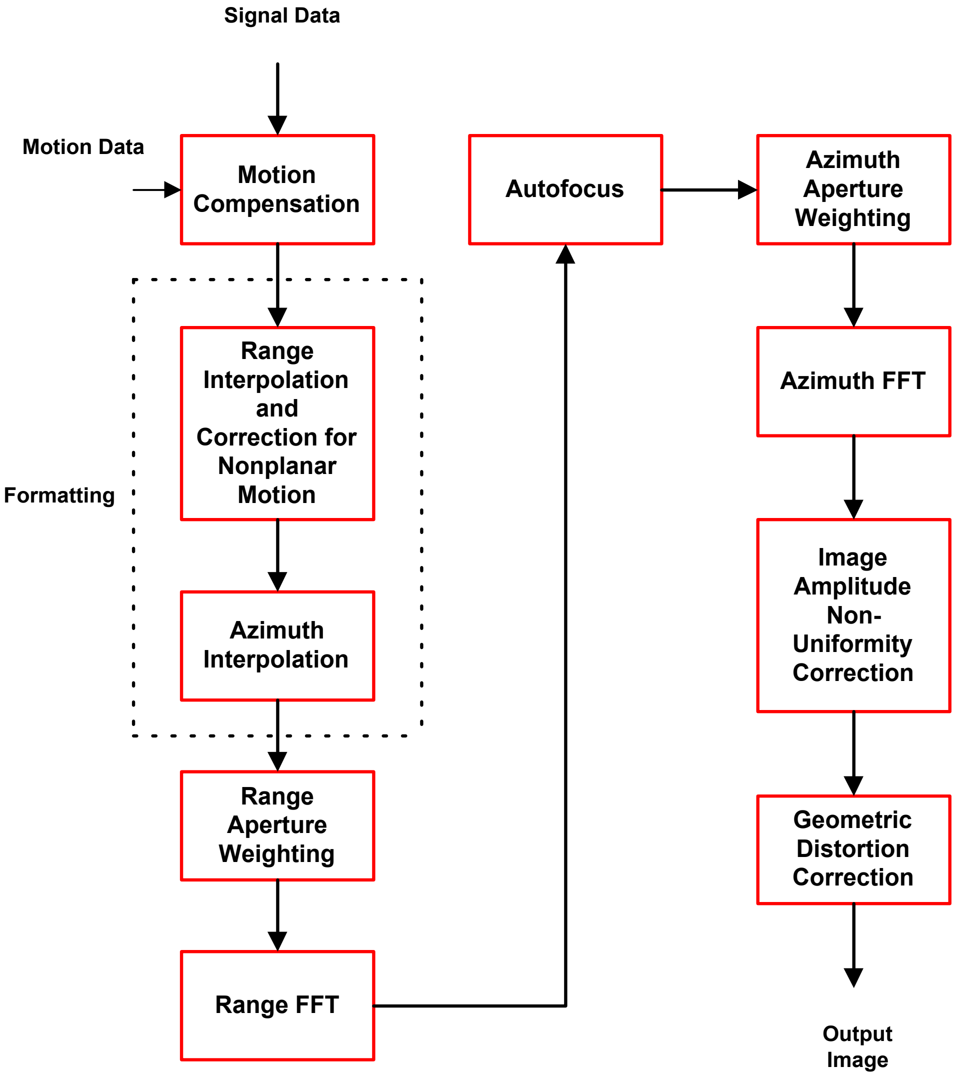
Figure 3.5.3.2-7 shows an example of SAR Image Formation.

Rapid SAR image processing will be a requirement for HALE-based remote sensing in support to emergency management. Benchmark performance required is < / = 1.0 hour from image take to delivery of the final image to its end user.

Figure 3.5.3.2-6 SAR Frequency and Polarization Choices for a Range of Remote Sensing Applications. *[Source: NASA Jet Propulsion Laboratory]*

Geophysical Parameters	**Algorithms and Mission Parameters**	**Maturity (Readiness for Operational Use)**
Surface deformation:	Repeat-pass interferometry within 1 month; L band; orbit control.	• Validated (line-of-sight) • Demonstrated (vector)
Pre- seismic	Multiple repeats (noise identification & reduction)	• Research
Co-seismic	Pre- and post- coverage	• Validated
Post-seismic	Targeted coverage	• Validated
Inter- seismic	Extended regional areal coverage (100s km) at low-res'n (25 m); long time series (yr), regular repeats (mo).	• Demonstrated (creep zones) • Research (other areas)
Pre-eruptive	Multiple repeats (noise identification and reduction)	• Research
Co-eruptive	Targeted coverage	• Validated
Inter-eruptive	Long time series. Regular repeats.	• Demonstrated
Landslides	Local coverage, high resolution.	• Demonstrated
Subsidence	Regional & local coverage	• Demonstrated
Other geometrical surface changes (e.g., lava flow):	Long time series; Regular repeats; L band	• Demonstrated
Glacier & ice sheet velocity: *Ice sheets*	L Band repeat-pass interferometry within 8 days, or C band within 2 days, at latitude > 658	• Demonstrated (L-band) • Validated (C-band)
Glaciers	Repeat-pass interferometry (1-2 days?) or pattern matching	• Demonstrated
Glacier volume & topography:	L Band repeat-pass interferometry within 8 days, or C band within 2 days	• Demonstrated
Forest biomass:		
Boreal	L band HV	• Demonstrated
Temperate	L band HV or P band HV	• Demonstrated
Tropical	P band HV	• Demonstrated
Vegetation Classification:		
Forest	L band dual pol.	• Research
Crops	L band quad pol.	• Research
Aerodynamic Roughness:	L band HV	• Demonstrated
Vegetation Moisture:	L dual pol., or C dual pol. (+ species type ancillary)	• Research
Soil moisture:		
Bare	L band quad-pol.	• Demonstrated
Grass and shrubs	L band quad-pol.	• Research
Forest	P band quad-pol.	• Research (early)
Snow volume and extent:		
Snow-covered area	C band HH + DEM, or C band quad-pol.	• Demonstrated
Wetness	C band quad-pol.	• Research
Water equivalence	Density from L – Quad pol. + depth from C or X-band	• Research
Inundation and extent (floods):		
Forests	L band HH	• Demonstrated
Non-woody wetlands	C band HH or VV	• Demonstrated
Post flood inventory	C and L band HH and HV	• Demonstrated
Oceans:		
Ice motion	C band HH and 3-day repeat	• Operational
Ice type	L band quad-pol.	• Demonstrated
Mesoscale circulation	L band quad-pol.	• Research

Figure 3.5.3.2-7 Example SAR Image Formation



The Global Hawk SAR System

The Global Hawk High Altitude Endurance (HAE) Air Vehicle SAR System [Northrop Grumman Corporation] has the following characteristics:

- SAR + Moving Target Indicator (MTI);
- X-Band (9.35 GHz);
- 600 MHz bandwidth (0.3m Resolution);
- 0.3m Resolution (Spot); 1.0m Resolution (Wide-Area Search - WAS);
- 0.4 knot (0.75 km/hr) Minimum Detectable Velocity (MDV) in MTI Mode;
- Location Accuracy: < 20 m CEP;

- Dual-Sided Operation;
- Coverage: 40,000 square nm./ day (WAS), 1,900 2 km x 2 km Spots/ day;
- Mechanically-Scanned Gimballed Radar Antenna;
- Commercial Air-Cooled Transmitter.

3.5.3.3 Passive Optical/ IR High-Resolution Imagers

Passive photonic sensors are capable of imaging over a range of wavelengths.

- Visible Light:	0.4 to 0.7 μm
- Infrared:	0.7 to 14 μm

Electro-Optical (EO) Systems (0.4 to 2 μm) collect mostly *reflected light.*

Infrared Systems (3 to 5 μm – Midwave Infrared (MWIR) and 8 to 14 μm – Longwave Infrared (LWIR)), also called *Forward-Looking Infrared* (FLIR) or *Imaging Infrared* (I^2R), respond primarily to *emitted light* from the scene.

Differences exist between performance parameters for *EO* and I^2R systems.

Selection of the Spectral band is driven by:

- The type of mission scenario;
- Target characteristics;
- Operating location;
- Look angle;
- Atmospheric climate (transmission window).

Figure 3.5.3.3-1 illustrates the generic architecture of EO and I^2R systems.

Figure 3.5.3.3-2 summarizes the primary optical bands for EO and I^2R systems.

Figure 3.5.3.3-3 shows a 1-metre resolution optical image from the IKONOS-1 satellite.

System Performance Parameters

Classical imaging performance parameters (Spatial Resolution, Sensitivity, etc.) are not adequate to fully define the performance of imaging systems for intelligence purposes. The *National Imagery Interpretability Rating Scale (NIIRS)* is a perceptually-based measure of interpretability, and is used by imagery analysts to perform a quantitative judgment on the interpretability of a particular image.

The NIIRS Rating – on a scale from 1 to 9 – defines the exploitation tasks that can be performed on an image, and accounts for all the factors affecting interpretability including spatial resolution and sensitivity.

The NIIRS Scale can be used to compare products of different imaging systems, and provides inherent target sizing within the definitions. For a NIIRS Rating, all lower-value NIIRS tasks can also be performed. Figure 3.5.3.3-4 shows a sample NIIRS description for visible imagery.

Figure 3.5.3.3-1 Generic Architecture of EO and I^2R Systems

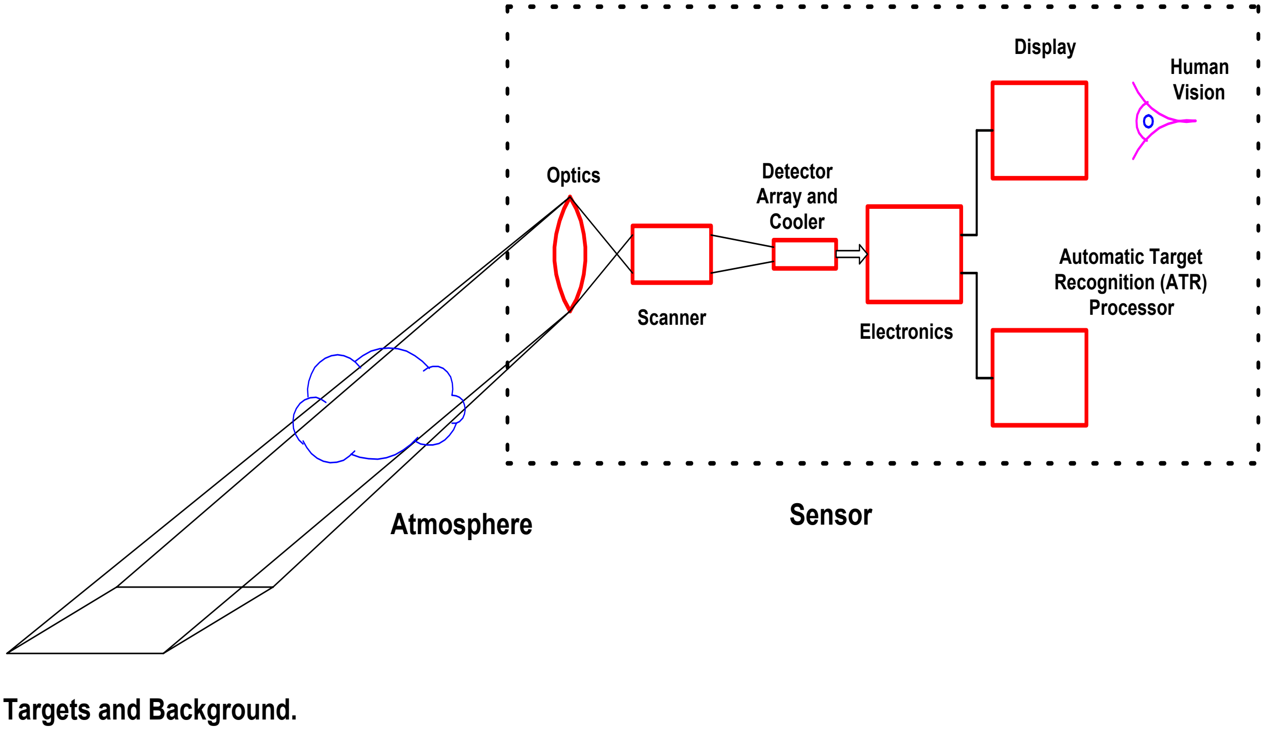


Figure 3.5.3.3-2 Primary Optical Bands for EO and I^2R Systems

System	Optical Band	Wavelength	Primary Light Source
	Ultraviolet	0.1 µm to 0.4 µm	Reflected
EO Systems	Visible	0.4 µm to 0.7 µm	
	Near Infrared (NIR)	0.7 µm to 1.1 µm	
	Shortwave Infrared (SWIR)	1.1 µm to 3.0 µm	
I^2R Systems	Midwave Infrared (MWIR)	3.0 µm to 5.0 µm	Emitted
	Longwave Infrared (LWIR)	8 µm to 14 µm	
	Far Infrared	14 µm to 100 µm	

Figure 3.5.3.3-3 1-Metre Resolution Optical Image from the IKONOS-1 Satellite (Washington DC, 30th September 1999)

[Source: Space Imaging Corporation]

Figure 3.5.3.3-4 A Sample NIIRS Description for Visible Imagery
[Source: Imagery Resolution Assessment and Reporting Standards (IRARS) Committee]

Rating level 0 • Imagery of no interpretive value	**Rating level 5** • Identify individual rail cars by type (gondola, flat, box) • Identify air surveillance radar on particular ships
Rating level 1 • Detect a medium-sized port facility • Distinguish between taxiways and runways at a large airfield	**Rating level 6** • Distinguish between models of small/ medium helicopters • Identify the spare tire on a medium-sized truck • Identify automobiles as sedans or station wagons
Rating level 2 • Detect large hangars at airfields • Detect large static radars • Detect military training areas • Detect large buildings	**Rating level 7** • Identify fitments and fairings on fighter-sized aircraft • Identify ports, ladders, vents on electronics vans • Detect the mount for antitank guided missiles
Rating level 3 • Identify wing configurations of large aircraft (straight, swept, delta) • Detect a helipad by configurations and markings • Identify a large ship in port by type (cruiser, auxiliary, merchant) • Detect trains or strings of rolling stock on standard railroad tracks)	**Rating level 8** • Identify the rivet lines on bomber aircraft • Identify a hand-held SAM • Detect winch cables on deck mounted cranes • Identify windshield wipers on a vehicle
Rating level 4 • Identify all large fighters by type (F-15, Foxbat, Fencer, F-14) • Detect presence of large individual radar antennas • Identify tracked vehicles by general type (artillery, river crossing eq, etc.) • Detect an open missile silo door • Determine the shape of the bow on a medium-sized submarine	**Rating level 9** • Identify vehicle registration numbers on trucks • Detect individual spikes in railroad ties • Identify braid in 1 to 3 inch diameter rope • Differentiate cross-slot from single-slot heads on aircraft skin panel fasteners

The GIQE (General Image Quality Equation) Model was developed to provide NIIRS predictions for a given system design and operating parameters. The GIQE is currently being used to model Unmanned Aerial Vehicle (UAV) sensor performance as well as upcoming commercial satellite systems. Performance goals for the Predator and Global Hawk UAVs have been specified in terms of the NIIRS. It is expected that the NIIRS rating system will become widely used for military imagery applications.

The GIQE Model predicts NIIRS as a function of image scale, sharpness or resolution, and signal-to-noise. The model was developed on a large database of images and imagery analyst (IA) responses and predicts a NIIRS rating with a standard error of 0.3. The GIQE allows system designers and operators to perform tradeoffs for the optimization of image quality. The GIQE was originally released in 1994 and has been updated since then.

The Global Hawk EO/ IR Sensors

The Global Hawk Electro-Optical (EO)/ Infrared (IR) sensors have the following characteristics:

- Electro-Optical: NIIRS 6.5;
- Infrared: NIIRS 5.5;
- Sensor Performance Modelled with GIQE;
- Targeting Accuracy: 20 m CEP.

3.5.4 Future Sensor Concepts

The development of new, more capable remote sensing sensors, for both civil and military applications, is continuing in many research groups and in private industry worldwide. Coincident with the interest in developing new sensor types is a drive to make future sensors smaller, lighter, more efficient and more capable.

In the civil domain, development work continues to improve the capabilities and payload resource requirements of many of the sensor types identified in section 3.5.2., and to create new sensor concepts based on established sensor principles and upon new ideas for detection, observation and measurement capability.

In the military domain, there is considerable interest in developing new applications for UAV and High Altitude Endurance (HAE) Platforms beyond those already proved, or being proven, on various unmanned platforms. New sensor concepts which are under consideration by the US Air Force (USAF) for inclusion in future Global Hawk payload complements include [Northrop Grumman Corporation]:

ABL: Airborne Laser

The ABL performs intercept on missiles early in their trajectory. Global Hawk may assist the ABL in its mission by carrying an accurate weather sensor over the target area.

AEW: Airborne Early Warning.

With suitable changes to the current Global Hawk radar to allow it to detect airborne targets, it is thought that the Global Hawk can do some of the AEW (AWACS) mission.

AFFR: Airborne Firefinder Radar

The Firefinder Radar is capable of locating and targeting enemy artillery and possibly theatre ballistic missiles by developing trajectory information from active radar returns.

AITP: Advanced Interferometric Synthetic Aperture Radar (SAR)

Digital Terrain Elevation (DTE) production in near real-time

Bistatic Radar

A bistatic radar receiver may be mounted on one UAV and the transmitter on another, or on a satellite. It may also be possible to use a receiver on the UAV to exploit returns form transmitters of opportunity.

BPI: Boost Phase Intercept

Detection of theatre ballistic missiles (TBM) in their boost phase, during which the TBM is a relatively large and vulnerable target; it does not manoeuvre and its plume/ exhaust presents a very high infrared signature.

FOPEN: Foliage Penetration Radar

Wideband FOPEN radar is capable of spotting targets under natural vegetation and under camouflage. FOPEN may be operated with other imaging sensors.

Imaging Spectrometer

An Imaging Spectrometer sensor returns images which include spatial and spectral information. Applications include agriculture, environmental monitoring, forestry, vegetation, geology, inland and ocean water and defence. Defence applications include land mine detection and camouflage distinction.

MARS: Multi-Sensor Agile Reconnaissance System

MARS will be a common sensor fusion baseline for different aircraft including HAE UAV platforms.

SIGINT: The collection of Signal Intelligence.

4.0 Benefits Analysis

4.1 Introduction

This Chapter provides an analysis of the overall benefits of using HALE-based remote sensing in emergency management applications, as described in Chapter 2, when compared to other available remote sensing technologies.

It is evident from this study and from the previous CSA-funded into the application of HALE systems in remote sensing, that HALE systems could perform high-resolution, high-continuity observation/ surveillance of emergency situations which is not possible with single satellites or small constellations and too costly to provide using airborne systems alone. HALE systems are capable of rapid deployment, can be used under hazardous conditions (unmanned), can support other services of value to emergency management, and offer a greater degree of control of the asset by the EMO than is available from commercial satellite systems. The performance benefits of HALE platforms applied to emergency management roles, compared to alternative satellite, airborne and in-situ sensor systems, are described in detail in Chapter 2.

It is not possible to quantify the full potential value of HALE technology in emergency management roles in monetary terms alone. This is because no other remote sensing technologies currently offer equivalent capabilities, and because human suffering and lives – not just money- will likely be saved. A full evaluation of the benefits of HALE technology in emergency management must include human and social, as well as cost, factors. The following subsections look at:

- *Social and human benefits*; which include savings of human distress, suffering and life.

4.2 Social and Human Benefits

Every year many Canadians are involved in emergency situations which lead to distress, suffering or death. There is little doubt that the total toll in suffering and loss of life could be reduced by the introduction of appropriate technologies which can improve the effectiveness of mitigation, preparation, response and recovery activities. The potential of HALE technology to reduce or alleviate these human and social tolls is difficult to quantify with great accuracy at this early stage in the development of the technology. However, it seems clear that the kind of enhancements which HALE can bring to remote sensing and other services supporting emergency management can make a real contribution to reducing the impact of emergency situations on individuals and upon society as a whole.

5.0 Additional Remote Sensing Applications

5.1 Introduction

This Chapter identifies additional, i.e. other than emergency management, application areas where HALE systems promise to provide unique advantages, or net cost advantages, over existing satellite-based or airborne remote sensing systems. This analysis is divided into:

- Civil Remote Sensing
- Military Applications

5.2 Civil Remote Sensing

5.2.1 General

HALE technology promises to fill a niche area in civil remote sensing by providing coverage and observation continuity over limited regions not possible with single-satellites or small constellations and too costly to provide using airborne systems alone. Unmanned HALE systems are capable of being rapidly deployed to address emerging and developing situations in diverse geographical locations and can be used under hazardous conditions, such as extreme meteorological conditions, environmental disasters, nuclear accidents, etc. In addition to applications identifiable today, it seems likely that new applications for HALE systems, both in remote sensing and in other fields, will be developed once platforms are in service and their utility has been fully demonstrated.

Figure 5.2.1-1 illustrates the "Gap" between current and wanted remote sensing system performance for many applications involving time-varying phenomena.

Figure 5.2.1-2 shows a concept for an integrated remote sensing infrastructure comprising low-earth orbit (LEO) satellites, medium-earth orbit (MEO) and geosynchronous (GEO) satellites, HALE platforms and airborne systems. This integrated remote sensing infrastructure is able to respond to a wide range of remote sensing applications, including those requiring rapid response and high continuity of observation.

5.2.2 Applications

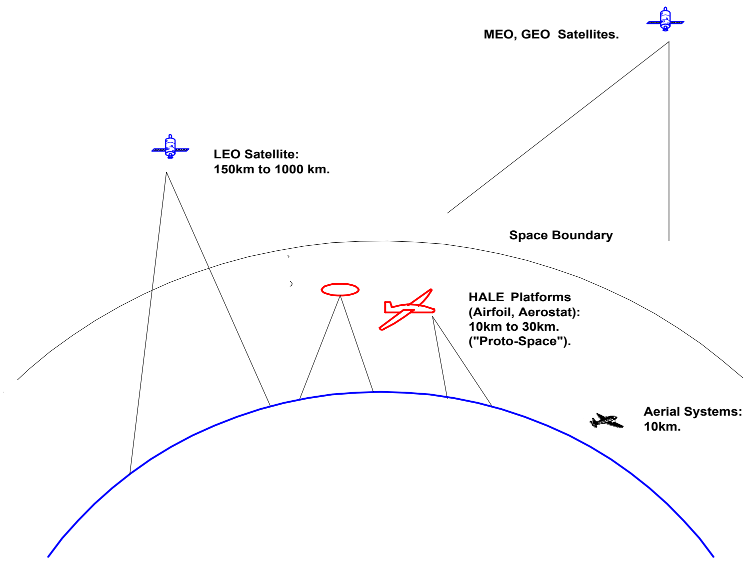
One of the principal benefits of HALE technology applied to remote sensing is the improved ability to observe time-varying or emerging phenomena in a way that the limited revisit of satellites does not allow.

To help reveal the full potential of HALE in this regard, currently identifiable remote sensing application areas can be categorized as *Invariant or Slowly-Varying Phenomena* or *Rapidly Time-Varying or Emerging Phenomena.*

Figure 5.2.1-1 The "Gap" Between Current and Wanted Remote Sensing System Performance for Many Applications Involving Time-Varying Phenomena.

WHAT CAN WE DO NOW ?			WHAT DO WE WANT TO BE ABLE TO DO ?	
<u>Image Performance.</u>			<u>Image Performance.</u>	
Resolution:	10m		Resolution:	< / = 1m
Swath Width:	50km		Swath Width:	To Allow Continuous Observation Everywhere (of Interest)
Observation Continuity:	Image Every 2/3 Days.		Observation Continuity:	
Radar Frequency:	Single		Radar Frequency:	Multiple
Radar Polarisation:	Single		Radar Polarisation:	Multiple
<u>System Response.</u>		HOW DO WE GET THERE AND HOW LONG WILL IT TAKE ? *(PROBLEM FOR INVESTORS AND DATA PRODUCT/ SERVICE ENTREPRENEURS.)*	<u>System Response.</u>	
Response Time (User Request to Final Data Delivery):	Variabale. 2/ 3 weeks to a few days(best). Dpends on Target Location, Order Precedence, System Constraints.		Response Time (User Request to Final Data Delivery):	1 Hour or less.
System Availability:	Not Guaranteed.		System Availability:	> / = 0.99

Figure 5.2.1-2 A Concept for an Integrated Remote Sensing Infrastructure Comprising LEO Satellites, MEO Satellites, HALE Platforms and Airborne Systems.



Invariant or Slowly-Varying Phenomena

These are phenomena which vary only slowly with time or are essentially invariant. Examples are geological studies, long-term agricultural studies, cartography and land use planning. No standard definition for the time-constant involved here exists; but broadly-speaking slowly-varying behaviour can be taken to mean that the frequency of observation can be less than once per day (24 hours). Because of their relatively invariant nature, they can often be adequately addressed with satellite-based remote sensing systems having appropriate resolution, polarization, etc.

Partly because of the way in which satellite remote sensing has developed (we have come to live with both the limitations and benefits of single-satellite systems), many of the currently-established application-areas of satellite remote sensing fall into this category.

Rapidly Time-Varying or Emerging Phenomena

These are phenomena which vary relatively rapidly with time and for which adequate characterization requires that the observation frequency be from less than 24 hours down to virtually continuous observation. The geospatial distribution (location, extent) of some of these phenomena (such as road traffic and harbour traffic), will be predictable, while some phenomena will occur or emerge quite unpredictably (such as natural disasters, human-made emergencies and law enforcement issues). Because of these demanding temporal and geospatial characteristics, these phenomena often cannot be adequately observed using single-satellite systems or small constellations of satellites. It is projected here that many of them may, however, be addressed effectively using HALE Platforms, which can be deployed to remote unpredicted locations and can provide high continuity of observation over limited regions.

Note that; some observable phenomena, or classes of phenomena, may not easily fall into one of the two above categories. For example, some aspects of agricultural remote sensing require frequent observation (Category 2) while some other aspects can be satisfied with much less frequent observation (Category 1).

It is evident, however, that there are many phenomena which do not fall into Category 1 and cannot be adequately observed with single-satellite systems or small constellations of satellites. The list of such phenomena can be expected to grow as observation techniques are further developed and new applications are identified and exploited. The following is a current list of such phenomena. This list does not include the natural disasters and human-made emergencies described in detail in Chapter 2.

Rapidly Time-Varying or Emerging Phenomena

Human-Made

- Ship Surveillance (Fisheries, Immigration, Smuggling, Distressed Vessels, Traffic Routing)
- Pollution and Waste Disposal/ Spills (Ocean, Land, Inland Water Quality, Air)
- Traffic Monitoring (Land Traffic, Air Traffic)
- Search & Rescue (Land, Sea, Urban)
- Urban Phenomena
- Law Enforcement (Terrorism, Organized Crime, Border Patrol, Remote Locations)
- Customs (Smuggling, Patrol of Borders, Approaches, Remote Locations)
- Immigration (Patrol of Borders, Approaches, Remote Locations)
- Short-Term Agricultural and Forestry Phenomena
- Security Services
- Natural Resource Inspection
- Inspection of Utilities (e.g. Pipelines, Structures, Power Lines)
- Movie Production (Filming, Site Survey)
- Airport and Terrain Surveillance (Anti-Terrorism, Flight Safety)
- Structure Damage/ Condition/ Integrity (Buildings, Bridges, Roads, Structures, Utilities)
- Oilfields (Survey, Production Sites)
- Environmental Safety, Environmental Damage Assessment, Environmental Management
- Features and Change Detection; Cueing of other Assets

Naturally Occurring

- Iceberg and Ocean Ice Monitoring (Maritime Traffic Safety)
- Surface Water Movements, Runoff
- Ice Movements (Sea, River); Meltwater
- Ocean Wind Patterns (Scatterometry)
- Vegetation Growth Patterns
- Ocean Current Measurement
- Animal Habitats/ Behaviour Patterns
- Atmospheric Studies

5.3 Military Applications

5.3.1 General

High Altitude Endurance Unmanned Aerial Vehicles promise a dramatic expansion in the current principal role of UAVs – the ability to collect Imagery Intelligence. In the relatively near term, a single HALE platform could collect around 40,000 square nautical miles of single polarization Synthetic Aperture Radar (SAR) imagery at 1 metre resolution per day. With the simultaneous deployment of mass-produced identical HALE units, carrying the same or different sensor type (s) the data collection rate over regions of interest could increase several fold beyond this. Imagery data can be applied to a wide range of applications from strategic surveillance to battlefield intelligence.

5.3.2 Applications

Potential future military applications for HALE systems include:

- Image Intelligence (IMINT)
- Theatre Ballistic Missile (TBM) Defence
- Early Warning
- Firefinding
- Bistatic Radar (With Other UAVs or Satellites)
- Interferometric SAR for Precise, Near Real-Time Terrain Mapping
- Special Application Imaging, such as Image Intensifier, Active Laser Rangefinders, Foliage Penetration, Subsurface Imaging, Thermal Imaging, Multi-Spectral Imaging, Landmine Detection, Acoustic Sensing
- Ground Moving Target Indicator (GMTI) Radar
- Air Moving Target Indicator (AMTI) Radar
- Multi-Sensor Reconnaissance
- Signal Intelligence (SIGINT)
- Electronic Warfare (ESM, ECM, ECCM)
- Communications (Battlefield, Theatre, Regional, Satcom-Linked)
- Military Search and Rescue
- Meteorology
- Lethal Operations
- Nuclear, Chemical, Biological (NBC) Weapons Detection
- Calibration/ Validation of Other Sensor Systems
- Information Support (e.g. Local Meteorology) to Other Sensor Systems

6.0 Additional HALE Services for Emergency Management

6.1 Introduction

HALE Platforms hold the potential to support a range of communications and other services currently served by satellite or terrestrial systems. The low altitude of HALE, relative to that of satellites, offers considerable potential for superior communications system performance, including enhanced RF link and frequency re-use. In addition to these technical benefits, relatively localized operation of HALE platforms to support emergency management could provide a greater degree of control over the communications asset to the emergency management organization.

The following sections give an analysis of additional services, other than remote sensing or surveillance, which may be supportable from HALE systems and which could potentially support emergency management activities. The following types of additional service are identified:

- Search and Rescue
- Communications (Two-Way and Broadcast)
- Navigation/ Radiolocation

6.2 Search and Rescue

6.2.1 Introduction

Members of Canada's search-and-rescue (SAR) network [National SAR Program, Department of National Defence] all have a common goal–to save lives. The members of this network include federal government departments that administer the SAR program, the Canadian Forces, the Canadian Coast Guard, and other agencies that conduct SAR operations, as well as volunteers from various aeronautical, maritime, and ground SAR organizations.

The national SAR program in Canada has three components: aeronautical, maritime, and ground.

- The *Canadian Forces* is responsible for coordinating and operating all resources available to search for and help *aircraft* in distress.

- The Canadian Forces provides aeronautical resources to support the *Canadian Coast Guard* in its mandate to search for and help *marine vessels* in distress.

- The *Department of Canadian Heritage* through Parks Canada provides *ground* SAR services in national parks, national historic sites, historic canals, and maritime conservation areas.

- Federal, provincial, and territorial governments are responsible for search and rescue of *ground, inland waterways*, and *rivers*.

On behalf of the provinces and territories, the *police forces* of the jurisdiction provide *ground* SAR services within their areas. While the police coverage includes regional and municipal forces, the provincial police forces are generally most often in charge.

In addition to professional members of the various organizations conducting SAR operations, volunteers make up a large part of the Canadian SAR team. Volunteers are involved in all aspects of SAR: in the air, on water, and on land. The Civil Air Search and Rescue Association (CASARA) is a national organization of volunteers that provides aircraft, trained pilots, navigators, and spotters for SAR operations. Although CASARA is administered independently of the Canadian Forces, it receives monetary, training, and evaluation support from the Canada's military. In addition, CASARA provides spotters to fly in Canadian Forces aircraft during major SAR operations to help search for lost people.

The Canadian Coast Guard Auxiliary, a volunteer organization established by the Canadian Coast Guard in 1978, is a valuable element of Canada's maritime SAR program. Made up of dedicated volunteers who help the Coast Guard with maritime SAR operations and prevention, the Auxiliary enhances Canada's SAR capability.

The composition of ground SAR teams varies among the provinces and territories. Generally, while police forces or specially trained volunteers are responsible for organizing and conducting ground SAR operations, trained volunteers are the backbone of most SAR efforts.

6.2.2 COSPAS-SARSAT

A key element in Canada's Search and Rescue operation is the ability to receive and locate distress signals sent out by distressed parties, who may be aircraft, ships or boats, or individuals. The COSPAS-SARSAT system (see Figure 6.2.2- 1) [COSPAS-SARSAT International Satellite System for Search and Rescue] detects the signals from emergency radio beacons (ERBs). There are three kinds of emergency radio beacons, classified by who uses them. Aircraft use Emergency Locator Transmitters (ELTs); ships use Emergency Position Indicating Radio Beacons (EPIRBs); and Personal Locator Beacons (PLBs) are used by people taking part in land activities such as hiking, camping or canoeing in the wilderness. After receipt and localization of a distress signal, the SAR organization mounts an operation, which may include aircraft, helicopters, ships, ground search teams, to complete the process of precise location, and rescue.

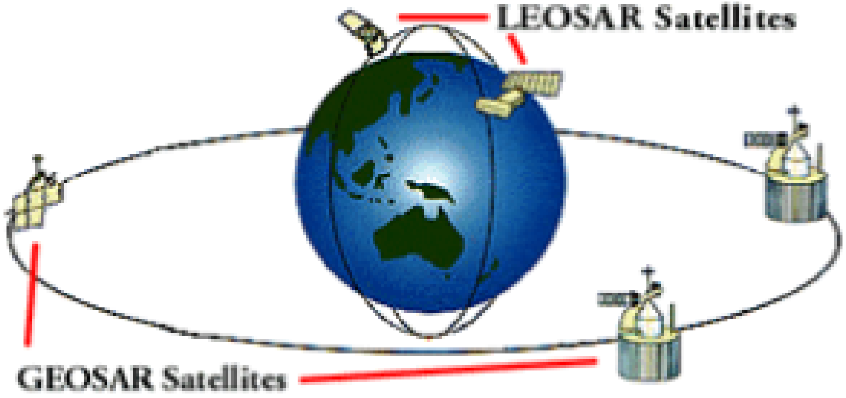
The first generation of emergency radio beacons, mostly ELTs, transmit on 121.5 MHz. Their signals can be received by the COSPAS-SARSAT satellites and by aircraft. The beacons can be located by a suitable homer and by COSPAS-SARSAT satellites. The second generation of radio beacons, developed to be more readily detected by satellites, transmit on 406 MHz. Codes transmitted by these beacons can include identification of the beacon, vehicle and its country of registration. The origin of the signal can be located within a radius of two kilometres worldwide. All these features make it much easier for Search and Rescue forces to respond to distress signals and to react quickly. Although COSPAS-SARSAT satellites were primarily designed to function on the much-improved 406 MHz frequency, they still have to provide for the thousands of 121.5 MHz beacons already in use. For this reason, the satellites have been designed to receive 121.5 MHz as well.

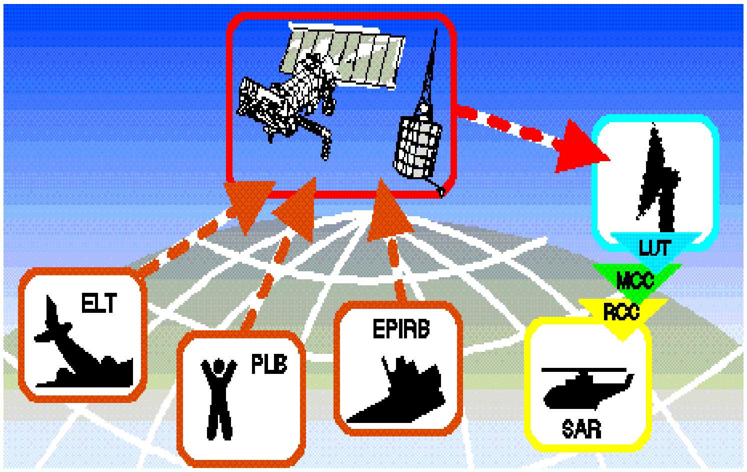
The satellite relays these distress signals to a ground station known as a Local User Terminal (LUT) where the origin of the distress call is calculated to a known accuracy. The ground station then relays this information to a Mission Control Centre (MCC) which alerts the SAR resource.

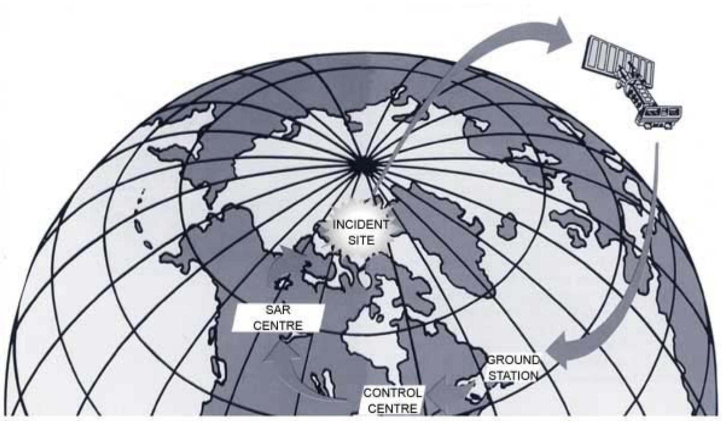
The original Canadian LUT is located in the Defence Research Establishment at Shirley's Bay, near Ottawa. Since the spring of 1988, new LUTs have been in use at Edmonton, Alberta, Goose Bay, Labrador, and Churchill, Manitoba. These additional LUTs have increased the effectiveness of COSPAS-SARSAT. The Canadian Mission Control Centre (CMCC) is located at Trenton, Ontario.

Figures 6.2.2-1 **COSPAS-SARSAT System**

[Source: COSPAS-SARSAT International Satellite System for Search and Rescue].







6.2.3 HALE Platforms in Search and Rescue

Use of HALE platforms could provide a number of benefits in Search and Rescue. HALES carrying SAR transponders (similar to those on the COSPAS-SARSAT satellites), high-resolution imaging sensors and communications capabilities could provide a combined improvement of the existing SAR radiolocation technique and an actual surface (land or sea) search using the surveillance sensors and any radio communications which can be established with the distressed party. Figure 6.2.3-1 shows a strawman concept for a HALE platform performing search and rescue functions. In many emergency situations, including natural disasters, distressed parties (personnel, groups of personnel, vehicles, etc.) will not be carrying Emergency Radio Beacons (ERBs), and the HALE's high-resolution imaging search capability, perhaps combined with other intelligence such as obtained via communications links, will become the principal location and identification tool.

6.3 Communications

6.3.1 Introduction

HALE Platforms could support a number of emergency communications functions, either as replacements for, or augmentations of, satellite-based or terrestrial services. The low altitude of HALE, relative to that of satellites, offers considerable potential for superior communications system performance, including enhanced RF link and frequency re-use.

6.3.2 HALE- Based Emergency Communications

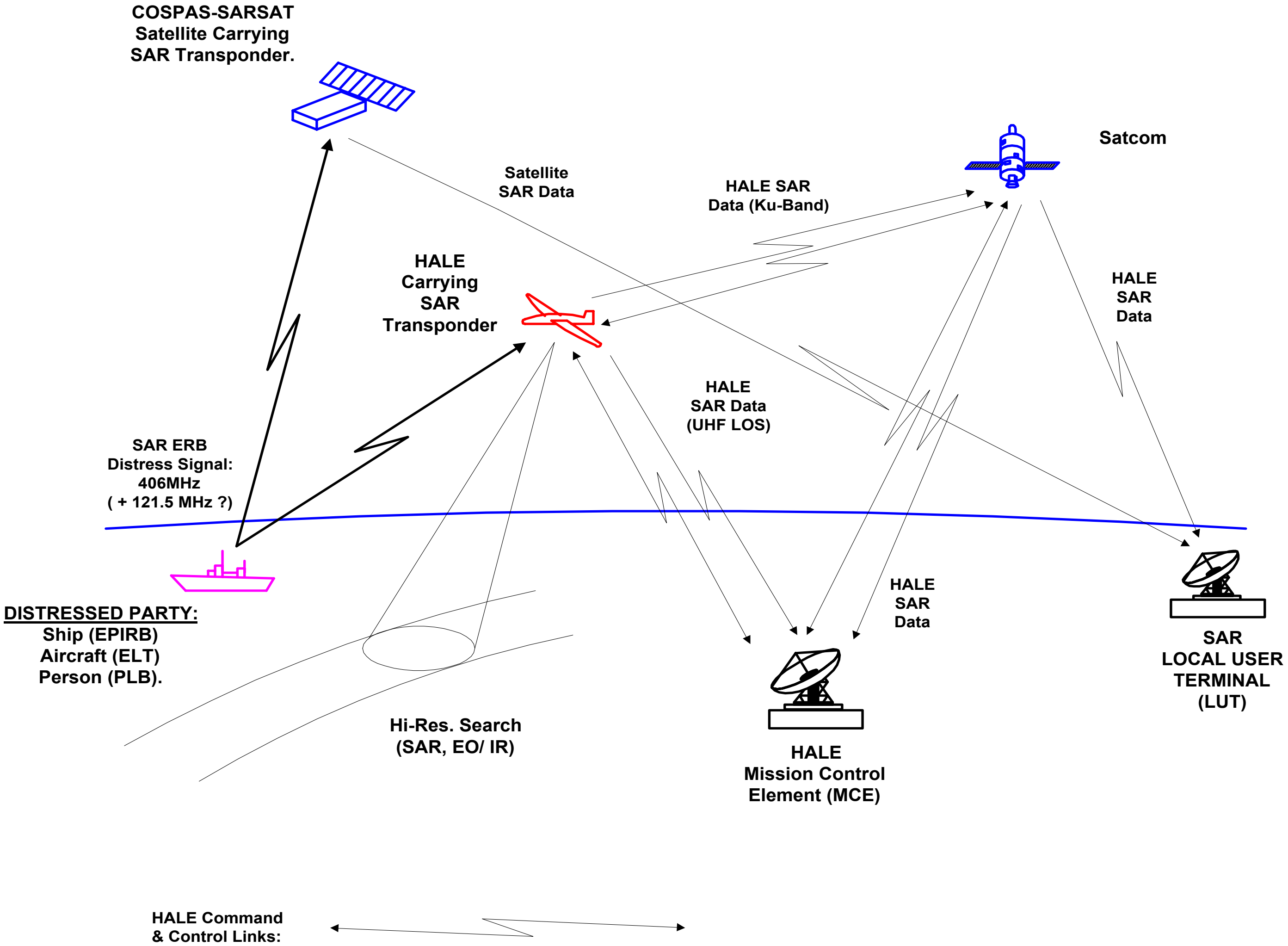
The tables of Figure 6.3.2-1 summarize a number of emergency communications functions which may be supportable from HALE platforms. These are divided into a). *existing emergency communications* functions already employed by emergency management organizations, and b). *advanced emergency communications* services, for which HALE platforms may provide an important part of the overall communications infrastructure, and for which new user equipment will, in principal, be required.

Figure 6.3.2-3 shows a HALE Platform providing emergency communications links.

6.3.3 Navigation/ Radiolocation

HALE platforms could contribute to more precise and reliable positioning, navigation and radiolocation. One proposal for achieving this is for HALE platforms to carry a navigation transponder similar to those carried on the INMARSAT-III geostationary spacecraft. These C-Band (uplink) / L-Band (downlink) transponders broadcast GPS-like signals on GPS's L1 frequency and serve to augment the accuracy, integrity, coverage and availability of the GPS system to civilian users. In this mode, the HALE transponder behaves as a "Pseudolite", behaving like a satellite-based navigation transponder, and contributing to enhancement of the performance of the GPS system for users within the HALE transponder's field of regard (FOR).

Figure 6.2.3-1 Strawman Concept for a HALE Platform Performing Search and Rescue Functions



ERB:	Emergency Radio Beacon.
EPIRB:	Emergency Position Indicating Radio Beacon.
ELT:	Emergency Locator Transmitter
PLB:	Personal Locator Beacon.

Figure 6.3.2-1(a) Potential Role of HALE in Existing Emergency Communications

Emergency Communications Function	Current Operations	Issues/ Limitations	Conceptual HALE Technology Benefits
Local communications between emergency service team members & between emergency service field leaders and base stations, local authorities.	• A number of slots in the VHF (30 MHz to 300 MHz) and UHF (300 MHz to 3 GHz) Bands for local communications. • Slots in the H.F. (3 MHz to 30 MHz Band, including CB radio, are available for emergency services (communications with base stations, local authorities, regional authorities). • A number of slots in the VHF and UHF Bands are available for Military Communications.	• Heavy demand for channels. • Systems must be capable of penetrating structures in urban areas. • Large, high buildings and hilly terrain can cause blockage of signals.	• HALE platforms may be capable of providing communications links in support to deployable surface communications systems, such as FEMA's Mobile Emergency Response Support (MERS) Multi-Radio Vehicle (MRV), shown in Figure 6.3.2-2.
	• Cellular Telephones operating in the 830 MHz range (handsets) and 870 MHz (towers).	• The mobility of cellular technology makes cellular telephones very attractive for emergency responders. However, cellular radio channels may become congested during disasters or serious emergencies. Cellular priority access capabilities are in development (in U.S.). • Cellular radio infrastructure (towers, etc) may be disrupted or disabled by the emergency. • The need to penetrate structures in urban areas places some limitations on utility of cellphones.	• Aerial platforms may be capable of supporting enhanced cellular telephone service by providing a "backup" cellular node repeater (a "tower") for damaged or saturated cellular systems. • Platforms with high inclination angle may mitigate propagation shadowing effects of buildings, terrain, etc. Further analysis is required to determine propagation performance, achievable platform altitude, impacts on user equipment, etc.
	• Paging: Nationwide pager, alphanumeric, e.g. Skypage.	• One-way communications only. Response requires some other communications capability.	• Aerial platforms may be capable of supporting paging services.

Figure 6.3.2-1(a) Potential Role of HALE in Existing Emergency Communications **(Continued)**

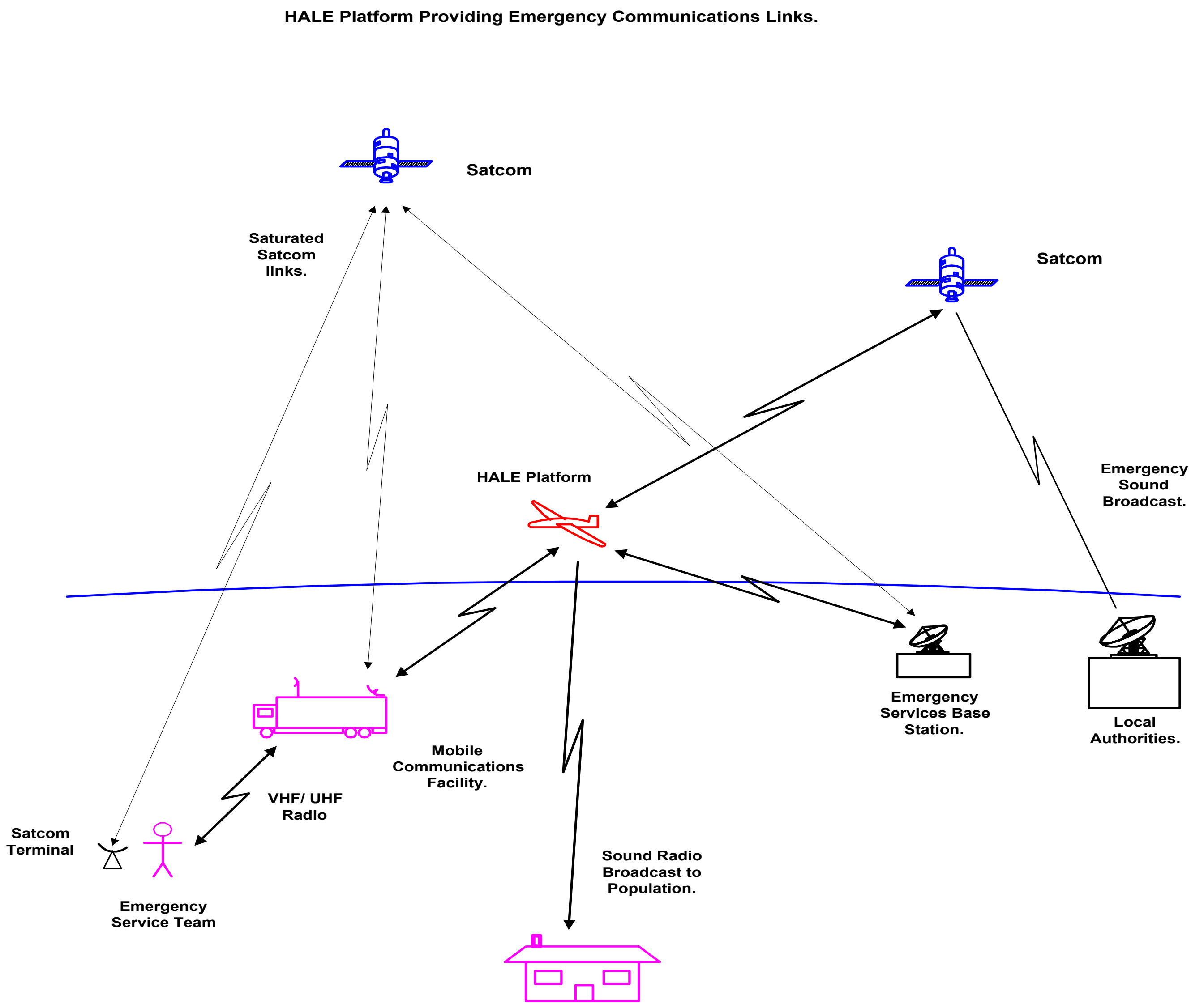
Emergency Communications Function	Current Operations	Issues/ Limitations	Conceptual HALE Technology Benefits
Local communications between emergency service team members & between emergency service field leaders and base stations, local authorities.	• Land-based telephone networks	• Emergency may occur in poorly-served area. • Telephone services may be disrupted or disabled by the emergency.	• HALE-based communications may provide alternatives to land-based telephone networks, through communications links to deployable surface communications systems, such as MERS, MATTS.
	• Satellite Telephones: INMARSAT, AMSC, IRIDIUM, etc., systems provide single channel voice, data.(L, Ku-Bands).	• May provide insufficient channel capacity for emergency services in a major disaster or emergency.	• HALE-based transponders may be capable of providing backups service to failed or saturated communications satellites.
Video Broadcast To record and disseminate video information from the disaster location.	• Land links or Satcom links	• Availability of land links in remote locations. • Integrity of landlinks in disaster/ emergency situations. • Availability of bandwidth on satcom services.	• HALE platforms could provide wideband repeater capability for video.
Broadcast of Emergency Information to affected population	• Commercial radio and TV services: o FM Radio = 88 to 108 MHz o TV = VHF, UHF	• It has been difficult to coordinate emergency information with the commercial needs of Radio and TV operators. Transmission systems may be disrupted or disabled by the emergency.	• HALE-based transponders could be used to relay a sound radio broadcast • HALE-based transponder could be used to broadcast video to DBS subscribers.

Figure 6.3.2-1 (b) Potential Role of HALE in Advanced Emergency Communications

Emergency Communications Function	Current Status/ Issues/ Limitations	HALE Technology Benefits
Airborne Communications Node (multiple services, broadband, internet, etc. Multiple nodes, frequency re-use, etc). Replace or augment satellite, terrestrial services.	• Example: US National Airborne Operations Center (NAOC). A manned airborne command, control, and communications centre to direct U.S. forces, execute emergency war orders and coordinate actions by civil authorities.	• HALE-based communications nodes could support a wide range of communications functions with regional communications performance superior to satellites, with low vulnerability to the effects of natural disasters and emergencies, and with no risk to crew. • HALE Communications Nodes could be used to act as backups to failed or saturated communications satellites (services to densely-populated or critical areas) for voice, data, internet, etc. services.
High latitude (northern) communications services; voice, data, Internet, etc.	• High latitude and physical remoteness of high northern regions • Leads to relatively poor terrestrial and satellite communications services.	• HALE systems could support a range of communications services in northern regions not well served by satellite or terrestrial services.
Virtual Emergency Management: To provide emergency management information regardless of physical location.	• Example: VEMIS. • Integration of fixed and mobile wireless and wired systems • Wired intra/ internet systems. • Terrestrial wireless systems • Satellite telecommunications.	—
Stratospheric Communications Networks; Inter-HALE links, (analogous to intersatellite links) to extend/ improve coverage and services.	• Current communications systems use ground-based or satellite-based infrastructure. Each of these has limitations in communications performance, cost, and vulnerability to the effects of natural disasters and emergencies.	• A multiplicity of communications services could be provided by Stratospheric Communications Networks, with communications performance superior to satellites, and cheaper to implement. Other benefits include high potential for frequency re-use, low vulnerability to the effects of natural disasters and emergencies, with no risk to crew.

Figure 6.3.2-2 FEMA's Multi-Radio Vehicle (MRV)
[Source: Federal Emergency Management Agency]

Figure 6.3.2-3 HALE Platform Providing Emergency Communications Links



7.0 Conclusions

High Altitude Long Endurance (HALE) Technology has the potential to support a number of key services which are required for the effective management of Canadian natural disasters and human-made emergencies. These services include remote sensing/ surveillance, search and rescue and communications. The benefits of injecting HALE technology into the management of emergency situations are expected to include saving of human distress, suffering and life.

As *remote sensing or surveillance* platforms, HALEs could perform high-resolution, high-continuity observation/ surveillance of emergency situations which is not possible with single satellites or small constellations and too costly to provide using airborne systems alone. HALE systems are capable of rapid deployment, can be used under hazardous conditions (unmanned), can support other services of value to emergency management, and offer a greater degree of control of the asset by the emergency management organization than is available from commercial satellite systems.

For *search and rescue*, HALE platforms carrying SAR transponders, high-resolution imaging sensors and communications capabilities could provide a significant benefit to the task of precisely locating and rescuing distressed parties.

For *emergency communications,* HALE Platforms could support a number of communications functions, required for emergency management activities. The low altitude of HALE, relative to that of satellites, offers considerable potential for superior communications system performance over localized areas, including enhanced RF link and frequency re-use.

For *navigation/ radiolocation*, HALE platforms carrying suitable equipment could contribute to more precise and reliable positioning, navigation and radiolocation systems, benefiting emergency management and other applications.

Additional applications of HALE platforms include the capability for providing superior remote sensing performance to satellite systems for a wide range of civil applications involving time-varying or emerging phenomena, and for a wide range of military applications including imagery intelligence, signal intelligence, electronic warfare and military search and rescue.

Of the *available HALE technologies*, aerodynamic HALE – based on high-altitude and unmanned aircraft technologies – holds significant advantages over Aerostatic systems – based on advanced balloon or airship technology – for the bulk of emergency management applications.

The most valuable *sensor types* for HALE-based remote sensing/ surveillance in support to the management of a range of the most important Canadian natural disasters and human-made emergencies are Imaging Radar (SAR), Passive Optical/ IR High-Resolution Imagers, Imaging Multispectral Radiometers (Microwave) *and* specific sensor types providing specialized measurements addressing individual emergency types.

Appendix A – Acronyms

A-A	Anti-Aircraft.
ABL	Airborne Laser.
ADEOS	Japanese Earth Observing Satellite.
A/D	Analogue-to-Digital.
AES	Atmospheric Environment Service.
AEW	Airborne Early Warning.
AFFR	Airborne Firefinder Radar.
AITP	Advanced Interferometric Synthetic Aperture Radar (SAR).
AMSC	American Mobile Satellite Corporation.
AMTI	Air Moving Target Indicator.
ARTEMIS	Africa Real-Time Environmental Monitoring using Imaging Satellites.
ATSR	Along-Track Scanning Radiometer.
AVHRR	Advanced Very High Resolution Radiometer.
AWACS	Airborne Warning and Control System.
BPI	Boost Phase Intercept,
CASARA	Civil Air Search and Rescue Association.
CB	Citizens Band.
CCRS	Canada Centre for Remote Sensing.
CDL	Common Data Link.
CEOS	Committee on Earth Observation Satellites.
CEP	Circular Error Probable.
CF	Canadian Forces.
CGS	Common Ground Segment.
CMCC	Canadian Mission Control Centre.
COSPAS	Soviet Union Search and Rescue Satellite.
CSA	Canadian Space Agency.
CZEW	Coastal Zone Earthwatch.
DARPA	Defense Advanced Research Projects Agency.
DEM	Digital Elevation Model.
DGPS	Differential Global Positioning System (GPS).
DMSP-OLS	Defense Meteorological Satellite Program-Operational Linescan System).
DND	Department of National Defence.
DTE	Digital Terrain Elevation.
DTM	Digital Terrain Mapping.
EC	European Community.
ECCM	Electronic Counter-Counter Measures.
ECM	Electronic Countermeasures.
ECMWF	European Centre for Medium Range Weather Forecasts.
ELT	Emergency Locator Transmitter.
EMO	Emergency Management Organization.
ENVISAT	European Space Agency Environmental Satellite.
EO	Electro-Optical.
EOS	Earth Observing System.

EPC	Emergency Preparedness Canada.
EPIRB	Emergency Position Indicating Radio Beacon.
ERAST	Environmental Research Aircraft and Sensor Technology.
ERB	Emergency Radio Beacon.
ERS	European Remote Sensing Satellite.
ESA	European Space Agency.
ESM	Electronic Support Measures.
FAO	Food and Agriculture Organization (of the UN).
FEMA	Federal Emergency Management Agency.
FFT	Fast Fourier Transform
FLIR	Forward-Looking Infrared.
FM	Frequency Modulation.
FOPEN	Foliage Penetration Radar.
FOR	Field of Regard.
FOV	Field of View.
GEO	Geostationary Orbit.
G-to-G	Ground to Ground.
GIS	Geographic Information System.
GIQE	General Image Quality Equation.
GLI	Global Imager.
GMS	Japanese Geostationary Meteorological Satellite.
GMTI	Ground Moving Target Indicator.
GOES	Geostationary Operational Environmental Satellite.
GPS	Global Positioning System.
HAE	High Altitude Endurance
HALE	High Altitude Long Endurance.
HALO	High Altitude Long Operation.
HF	High Frequency.
HRVIR	High Resolution Visible & Infrared.
IASI	Improved Atmospheric Sounder Interferometer.
IFP	Image Formation Processor.
IMINT	Imagery Intelligence.
INMARSAT	International Mobile Satellite Organization.
InSAR	Interferometric Synthetic Aperture Radar.
INSAT	Indian National Satellite.
IOC	Intergovernmental Oceanographic Commission (of UNESCO).
IR	Infrared
I^2R	Imaging Infrared.
IRS	Indian Remote Sensing Satellite.
IRS OCM	Indian Remote Sensing Satellite Ocean Colour Monitor.
ITIC	International Tsunami Information Centre
JAWF	Joint Agricultural Weather Facility.
JERS	Japanese Earth Resources Satellite.
JPEG	Joint Photographic Experts Group (JPEG).
JRC	Joint Research Centre.
LADAR	Laser Detection and Ranging.

LEO	Low Earth Orbit.
LIDAR	Light Detection and Ranging.
LISS	Linear Imaging Self-Scanning Sensor.
LO	Low Observable.
LOS	Line-of-Sight.
LRE	Launch and Recovery Element.
LUT	Local User Terminal.
LWIR	Longwave Infrared.
MAE	Medium Altitude Endurance.
MARS	Multi-Sensor Agile Reconnaissance System.
MARS-STAT	Application of Remote Sensing to Agricultural Statistics).
MATTS	Mobile Air Transportable Telecommunications System.
MERIS	Medium Resolution Imaging Spectrometer.
MERS	Mobile Emergency Response Support.
METEOSAT	European Meteorological Satellite.
MCC	Mission Control Centre.
MCE	Mission Control Element.
MDV	Minimum Detectable Velocity.
MMO	Mission Management Office.
MODIS	Moderate Resolution Imaging Spectrometer.
MSMR	Multi-Frequency Scanning Microwave Radiometer.
MSU-E	Multispectral Scanner-Electronic Scanning.
MTI	Moving Target Indicator.
MWIR	Midwave Infrared.
NADAMS	National Agricultural Drought Assessment and Monitoring System
NAOC	National Airborne Operations Centre.
NBC	Nuclear, Biological, Chemical.
NCMRWF	National Centre for Medium Range Weather Forecasts of India.
NDVI	Normalized Difference Vegetation Index.
NIIRS	National Imagery Interpretability Rating Scale.
NIR	Near Infrared.
NITFS	National Imagery Transmission Format Standard.
NM	Nautical Miles.
NOAA	National Oceanographic and Atmospheric Administration.
NRT	Near Real-Time.
NRO	National Reconnaissance Office.
NSCAT	NASA Scatterometer.
OGD	Other Government Department.
OLR	Ongoing Longwave Radiation.
PFA	Polar Format Algorithm.
PLB	Personal Locator Beacon.
POES	Polar Orbiting Operational Environmental Satellite.
PTWC	Pacific Tsunami Warning Centre
QPE	Quantitative Precipitation Estimate.
QPF	Quantitative Precipitation Forecast.
RAR	Real-Aperture Radar.

RESORCESAT	India/ US Remote Sensing Satellite (IRS-P6).
RESURS	Russian Satellite Series for Resource Monitoring.
RF	Radio-Frequency.
RFOM	Relative Figure of Merit.
RSI	Radarsat International.
SAM	Surface-to-Air Missile.
SAR	Synthetic Aperture Radar or Search and Rescue.
SARSAT	Search and Rescue Satellite.
SATCOM	Satellite Communications.
SCAT-1	Special Category 1.
SIGINT	Signal Intelligence.
SLR	Side-Looking Radar.
SPOT	Systeme Probatoire Observation de la Terre.
SSMI	Special Sensor Microwave Imager.
SST	Sea Surface Temperature.
SWIR	Shortwave Infrared.
TAS	True Air Speed.
TBM	Theatre Ballistic Missile.
TCI	Temperature Condition Index.
TM	Thematic Mapper.
TOGA TAO	Tropical Oceans and Global Atmosphere Experiment.
TOVS	TIROS Operational Vehicle Sounder.
TRMM	Tropical Rainfall Measuring Mission.
UAV	Unmanned Aerial Vehicle.
UHF	Ultra-High Frequency
ULDB	Ultra-Long Duration Balloon.
UNESCO	United Nations Educational, Scientific and Cultural Organization.
USAF	United States Air Force.
USDA	United States Department of Agriculture.
UV	Ultraviolet.
VEMIS	Virtual Emergency Management Information System.
VHF	Very High Frequency.
VHR	Very High Resolution.
VLBI	Very Long Baseline Interferometry.
WAS	Wide Area Search.
WiFS	Wide Field Sensor.
Y2K	Year 2000.
2D	Two Dimensional.
3D	Three Dimensional.

Appendix B – Bibliography

The bibliography provided below relates specifically to the subject of this final report, i.e; HALE Platforms in Emergency Management. A complementary bibliography on the subject of HALE Technology in Remote Sensing is provided in the companion report: *"Analysis of Sensor and Platform Technologies for Application of High-Altitude Long-Endurance (HALE) Platforms in Remote Sensing",* 31st March 1999.

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