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Animated Forecast Satellite Images - The Concept

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INTRODUCTION

The development of animated sequences of GOES-West imagery has allowed meteorologists to monitor cloud motions in a real-time frame. Using the observed motions and tendencies of cloud systems, the meteorologist can forecast these motions for a few hours into the future with a good deal of accuracy. To assist with short-range forecasting, it would be highly desirable to generate images that extend into the future and add them to the sequence.

THE PROBLEM

In order to generate an animation sequence that extends into the future, an image at each timestep of the sequence must be created. As with most problems in meteorology, the first and often the most difficult task is the definition of the field to be forecast. In the case of a satellite image, this task is formidable, requiring the objective definition of each cloud element over a very large geographic area. The motions and development of synoptic and mesoscale cloud systems are governed by different atmospheric processes, while at the same time systems of different scales interact.

Since the meteorologist may be concerned with only one particular system on any given day, it is possible to define only this system and deal with it exclusively in a forecast animated sequence. The images created (Figure 1) do not really resemble the satellite image (Figure 2) but greatly reduce the analytic processing required.

THE MECHANICS

The concept of forecast satellite image is not new. There are operational models today such as that of the Naval Environmental Prediction Research Facility in Monterey, California. All work done to date has demonstrated that what is obvious to the eye is only arduously represented mathematically

In defining a cloud system it is necessary to specify:

I = intensity of emitted radiation in the infrared (IR) or visual (VIS) bands.
C = centroid (centre of the system in the horizontal).
V = velocity of centroid.
B = boundary line of system.

v_i = velocity of each segment of B.
ΔI = change in I with time.

While ΔI, V, and v are all determined from history (i.e. a backward time average) one thing is certain, they are only approximations of the dynamic features of any cloud system. If these elements are used to produce a forecast image, the resultant image is merely an extrapolation of the system. There is no consideration of the second order terms,

$$dv/dt = v^{\cdot}, \quad dV/dt = V^{\cdot}, \quad dI/dt = I^{\cdot}$$

i.e. the changes in time of these characteristics which reflect the rate of development and acceleration of the system. Experience has shown these to be the more important considerations in most significant weather producing systems.

The use of extrapolative techniques for forecast images has been found by Muench and Hawkins (1979) to provide no improvement in weather element forecasts over a simple persistence forecast for the first few hours, and no improvement over the "age old" straight line extrapolation of synoptic scale systems.

The true complexity of this problem with all its inherent obstacles is expanded upon in Thomas (1984).

FORECAST TECHNIQUES

A. PIXEL INTENSITY TREND TECHNIQUE (PITT)

The simplest and most readily feasible approach is the Pixel Intensity Trend Technique (PITT). This method treats the digital data strictly as a matrix of numerical values. ΔI for each pixel would be determined for 1 or 2 hours merely as the change in intensity of the pixel. The new matrix of pixels can then be computed with ΔI and the matrix (i.e. satellite image) can then be displayed. This technique would be useful for only a 1 to 2 hour forecast.

B. CLOUD AREA EXTRAPOLATION TECHNIQUE (CAET)

In this technique, the cloud areas are defined objectively by a contour analysis of the intensity of each pixel. The numerical techniques required to define boundaries, centroids, etc., are available and practical if sufficient computing power is available. Extrapolation techniques as currently available can then be applied. The complexity of the defined system is determined by the number of cloud categories. This is essentially the RAINSAT technique as developed at McGill University. These techniques are more a display than a forecast tool and produce much the same result as rotating the grid under the image.

C. INTERACTIVE THREE LEVEL MODEL TECHNIQUE (ITLMT)

To produce a better forecast image, even by extrapolation techniques, it is necessary to start with a more realistic analysis. Only the meteorologist through an interactive system can define the physically distinct and pertinent features of the cloud field. The only reasonable tool for real-time analysis will be a digital tablet. Using this the meteorologist can trace and label the significant cloud boundaries. For example, mid-cloud systems, deformation boundaries, stratus areas, convective areas, etc. These cloud areas will be divided into boundary layer, mid-level, and cirrus level categories. The first and second order terms of motion and development will be calculated for each area in each category. From this point, with boundaries, centroids and tendencies defined, a forecast image can be generated. Defining the three regimes will result in some improvement over present forecast models.

D. NUMERICAL-MODEL OUTPUT CORRELATION TECHNIQUE (NOCT)

In order to generate dynamically realistic forecast satellite images for 12 hours or even longer, the analysis and definitions of the previous section will be only the starting point. It will be essential to correlate cloud systems to the dynamic processes which are responsible for them.

The boundary layer clouds are the easiest to handle and techniques are basically extrapolation. The development and/or motion of deep convective clouds however is not as straightforward. The triggering mechanism is often a dynamic process at mid levels.

The forecasting of middle cloud is perhaps the most important and without a doubt the most difficult. Work at the PWC and by others such as Rosendal (1976) indicates a high correlation between cloud systems and features of the 500 mb vorticity field. This is a field which is forecast by all numerical models. The main stumbling block here is that the objectively analysed fields are often in error over the Pacific where the correlation is needed. In order to have a good correlation at analysis time it will be necessary to adjust the analysis at 500 mb using the satellite data.

Cirrus cloud forecasts are more straight forward with distinct boundaries generally determined by the wind field. There is a very high correlation of cirrus clouds with deformation boundaries and horizontal wind shear.

With all three cloud regimes defined and all significant features correlated with dynamic processes at analysis time, the three fields can be generated and superimposed at forecast time to produce the image. With the first and last images complete, trajectories of cloud elements can be computed. The trajectories can then be used to generate images for the intermediate timesteps which can be used to generate the desired forecast animated sequence.

CONCLUSION

The generation of forecast satellite images is currently being accomplished. However, to improve the forecasts beyond that available from extrapolation will require a quantum leap in the sophistication of techniques. While the task is formidable, it appears that this improvement can be achieved with a real-time interactive satellite system which will rely heavily on the input of an operational meteorologist.

Forecast quality will undoubtly be, except in the very short range, determined by the skill of numerical forecast models.

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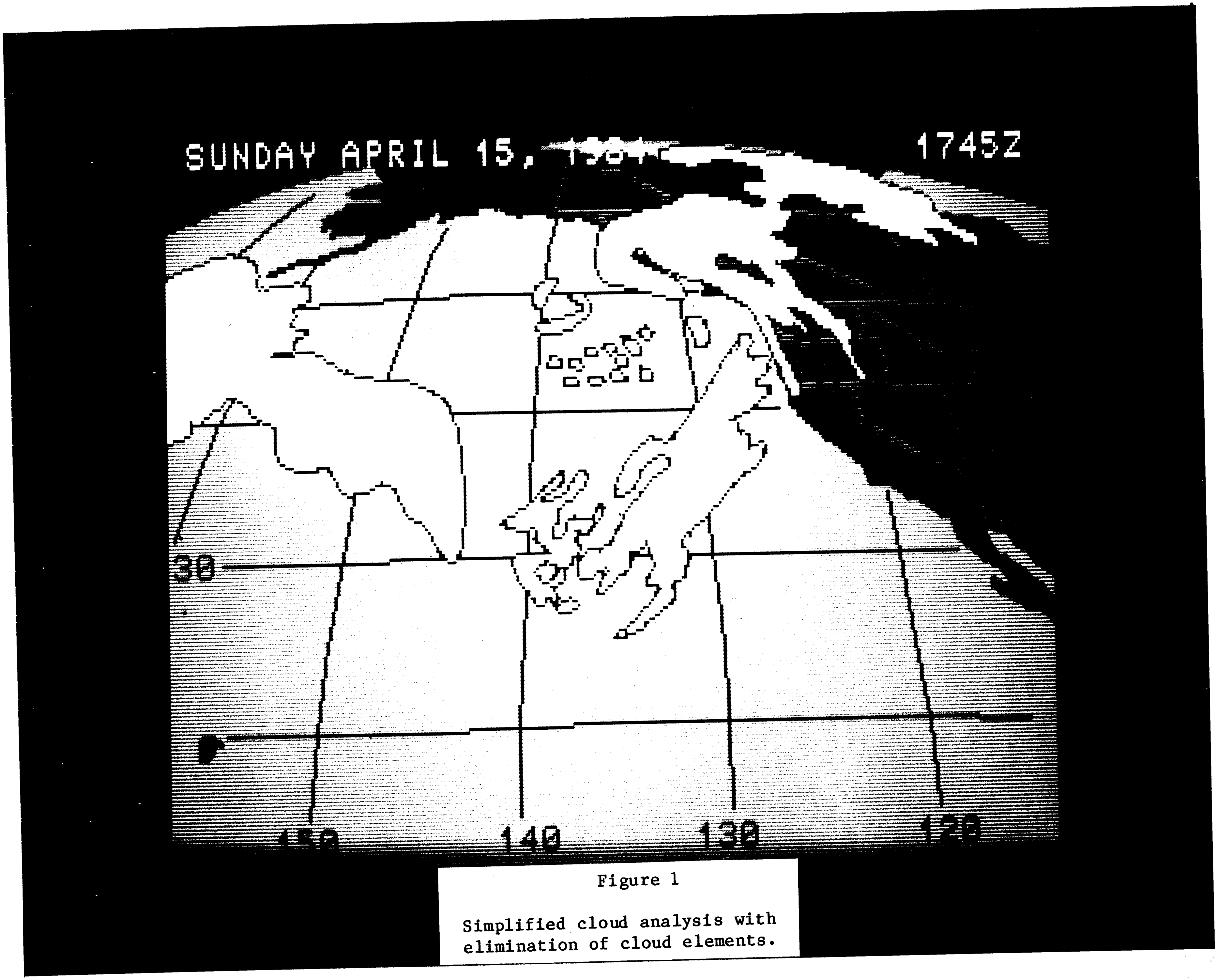

Figure 1

Simplified cloud analysis with elimination of cloud elements.

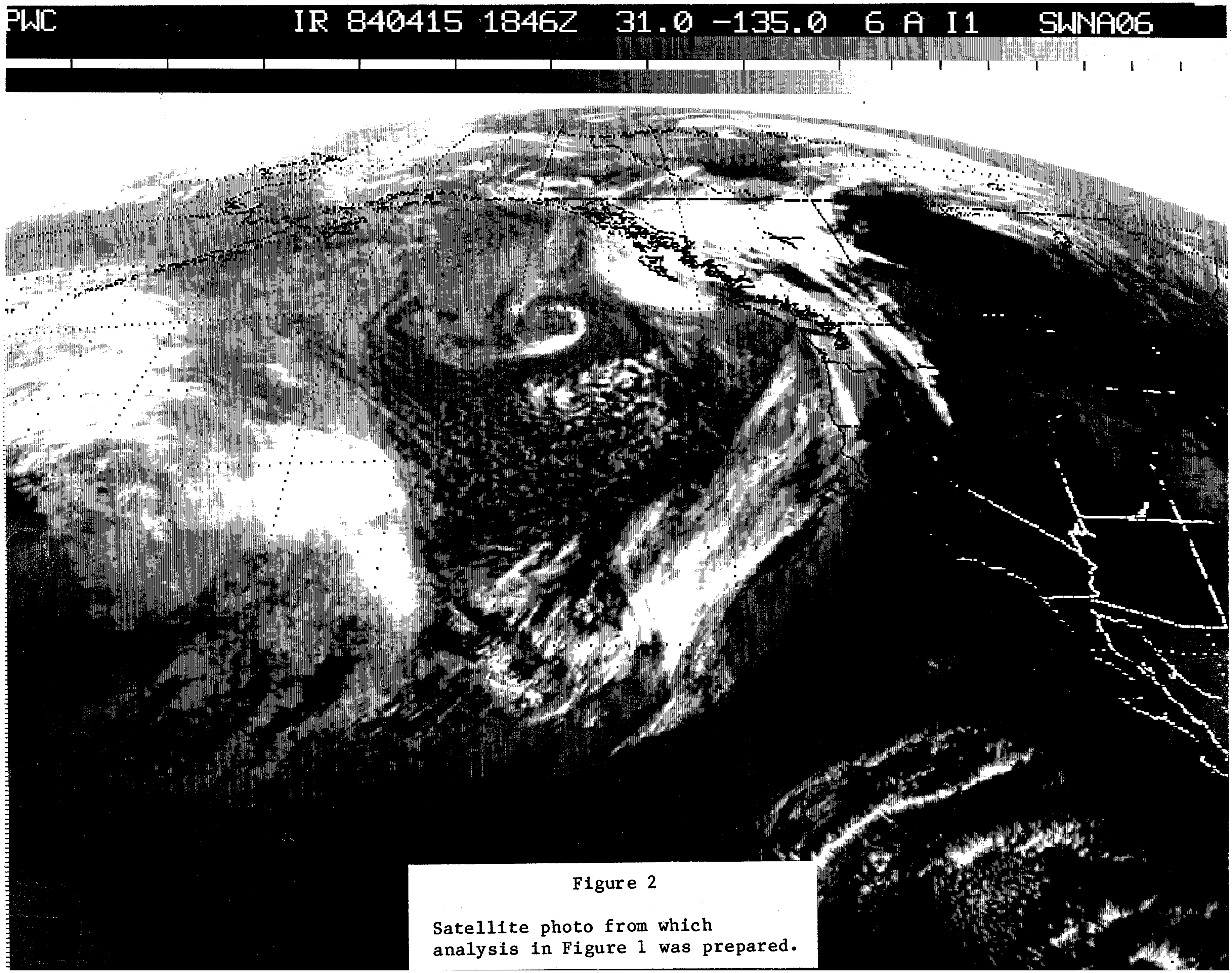

Figure 2

Satellite photo from which analysis in Figure 1 was prepared.