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THE NEW FORMULA FOR COLD

It won't have any effect on the actual outdoor air temperature this winter, or how quickly our bodies lose heat in frigid blustery weather, but the new and improved wind-chill index launched this fall will give Canadians a more accurate idea of how cold it really feels outside.

The wind-chill formula, which was developed over the past two years by a team of scientists and medical experts from Canada and the United States, is based on new research using human test subjects and advanced computer technology, combined with recent advances in the understanding of how the body loses heat when exposed to cold.

The resulting wind-chill index is expressed in "temperature-like" units so as not to be confused with the actual temperature. Although many Canadians are already familiar with wind-chill information being expressed in these terms, the new numbers are different from what they have grown accustomed to. Scientists have found that wind chill was slightly over-estimated in the past, so that fewer warnings of extreme conditions will be issued under the new system.

The reason for the difference is that the old wind-chill index, which was created 60 years ago, was estimated by measuring heat loss from cylinders of water in the Antarctic. Unlike people, however, plastic cylinders do not have any internal heat source, nor do they respond physiologically to cold like humans do when the blood vessels at the surface of our skin constrict to conserve core body heat. Wind speeds used in the previous formula were also measured in towers located more than 10 metres above the ground, rather than at an average human height of 1.5 metres, where friction reduces the wind speed to about two thirds.

Environment Canada led the development of the new formula by hosting the world's first Internet workshop on wind chill in the spring of 2000. One of the first challenges facing scientists was to decide the best way to determine wind chill—a difficult task, because it expresses how

Volunteers equipped with heat-flow sensors and thermocouples participated in four 90-minute tests at different temperatures and wind speeds inside a refrigerated wind tunnel.

our exposed skin *feels* as a result of the combined effect of temperature and wind, rather than measuring an objective value. To determine the temperature at which still air would cause the equivalent rate of heat loss from your skin, scientists focused on the most exposed and frostbite-susceptible area of the human body: the face.

Environment Canada and the Department of National Defence (DND) worked closely together to develop an accurate facial-cooling model, beginning with tests on a mannequin head with a skin made of special thermo-conducting material. After measuring temperature changes and heat loss from the mannequin in different wind conditions, they devised a new mathematical model for estimating wind chill. To ensure the accuracy of the model, which factored in body and skin temperatures and skin resistance, the tests were then conducted on human subjects.

Human trials were carried out on six men and six women aged 22 to 42 at DND's Defence and Civil Institute of Environmental Medicine in Toronto this spring. Each subject participated in four 90-minute tests at different temperatures and wind speeds inside a refrigerated wind tunnel. Dressed in weather-appropriate clothing, but with their faces exposed, they walked on a treadmill at a rate of 4.8 km/h into an artificially generated wind of 10, 20 and 30 km/h at three air temperatures: 10ºC, 0ºC and -10ºC. In each test, the wind speed was initially set up at the low end and stepped up to the other two values at 30-minute intervals. In

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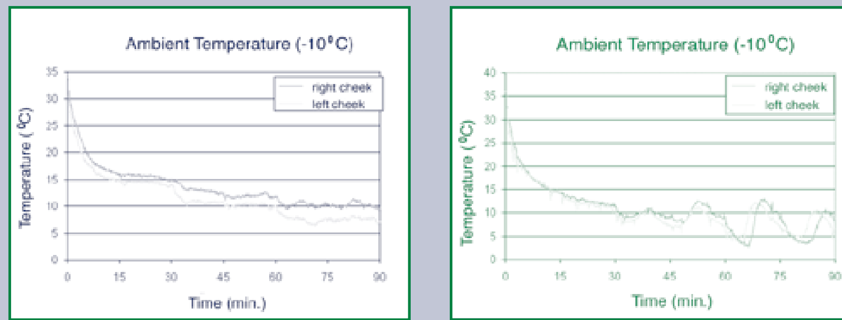
addition, a "wet" test was carried out at 10°C whereby each subject's face was sprayed with water at 15-second intervals, to determine the impact of water on facial cooling.



Graphs illustrating the differences in facial cooling between a volunteer whose heat loss during the trials was similar to that predicted by the model (left), and one who exhibited a strong cold-induced vaso dilation response (right).

Heat flow sensors and thermocouples attached to the subjects' faces measured heat loss and changes in skin temperature at the chin, nose, cheeks and forehead. Since the cheeks were among the coldest of these areas, they were used to calculate worst-case skin conditions. At the same time, participants were asked at regular intervals for their perceptions of the temperature, and how cold they felt. Thermometers showed that participants' core temperatures remained consistent despite changes in the external temperature and wind speed. However, significant differences were noted in facial skin temperature and heat loss—not only under different environmental conditions, but also among subjects.

The wet tests confirmed that wind makes you feel colder by evaporating any moisture on your skin—a process that draws more heat away from your body than when it is dry. Data collected showed the wind chill to be 5-10 degrees colder in wet conditions than in dry ones carried out at the same temperature. As a result of these findings, Environment Canada is considering the development of a marine wind-chill chart that will show different values for wet and dry conditions to help protect mariners exposed to heavy spray from frostbite.

Physiological differences among individuals are responsible for some people feeling the cold faster than others, even when exposed to the same combination of wind and temperature. One such difference is surface area—the less surface area you have in relation to your mass, the less heat you will lose. That means that people who are tall and thin tend to feel the cold sooner than those who are short and stocky. Over thousands of years, the facial features of people living in the Arctic have also developed specially to retain heat.

Another reason is that people with greater skin insulation (generally those who are heavier and better "padded") lose core body heat more slowly, and therefore have colder skin temperatures than people who have less insulation. As a result, these better-insulated people are more susceptible to frostbite—but less susceptible to hypothermia. People with less body insulation lose core body heat more rapidly, so their skin is warmer and, therefore, better protected from frostbite.

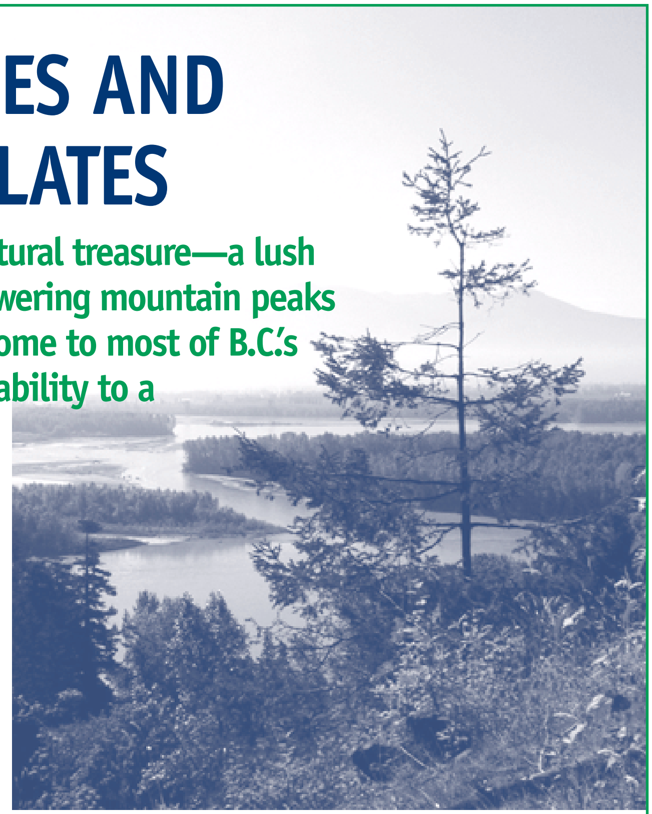
Another interesting difference demonstrated at the trials is that certain people who are well-adapted to cold exhibit a physiological response known as cold-induced vaso dilation—a mechanism that acts like a thermostat on a furnace. When the surface temperature of their skin falls to a certain level, the blood vessels that were constricted to conserve core body heat suddenly open up and send a flood of warm blood to the area to keep it from freezing. The sensors then kick in and close the blood vessels again until the temperature dips down to the critical level again, when the whole process is repeated. Seven of the 12 subjects in the trials exhibited this response.

In order to devise a wind-chill formula that protects people who are most susceptible to frostbite, researchers based their model on the five per cent of the population who experience the greatest facial cooling. The model was run more than 800 times with different combinations of wind speed and air temperature, to ensure consistency and accuracy. So as not to confuse it with actual temperature—which does not change regardless of how hard the wind blows—wind chill is now expressed in temperature-like units, without the use of the degree symbol. These temperature-like units liken how cold it feels under certain wind and temperature conditions to the temperature on a calm day.

In the future, scientists will study other factors that have an effect on the perception of cold, and incorporate them into the model to make it even more accurate. Warm sunlight on a winter day, for example, has a major impact on how cold exposed skin feels, but this impact is influenced by many factors—including latitude, longitude, elevation, cloud cover, time of day and date. Humidity will also be studied more closely, because a dry cold is generally perceived as warmer than a humid cold. As a first stage in this process, the new index gives Canadians a more realistic basis for protecting themselves against the potentially hazardous cooling effects of wind and temperature. S&E

STUDY EXAMINES SOURCES AND FORMATION OF PARTICULATES

British Columbia's Lower Fraser River Valley is a natural treasure—a lush lowland of fertile farms and forests bordered by towering mountain peaks and the shimmering waters of the Pacific Ocean. Home to most of B.C.'s population, the valley's unique geography and suitability to a wide range of human activities are also causing it some unique air-pollution problems.



Photos on pages 3 and 4: Wayne Belzer, Environment Canada.

Particulate matter, ground-level ozone, ammonia, nitrogen, sulphur oxides, volatile organic compounds and other pollutants from transportation, industry, agricultural operations and natural sources make their way into the air over the valley and are often trapped by topographical and meteorological conditions. Some of these chemicals interact and are transformed in the ambient air into urban smog, which can cause respiratory problems in humans. Smog can also combine with ammonia in agricultural areas to form white haze, a problem that reduces visibility and may also have health effects.

In an effort to better understand the sources, formation and distribution of particulate matter and ground-level ozone—two key components of smog—Environment Canada launched the Pacific 2001 Air Quality Study through the Georgia Basin Ecosystem Initiative. A key commitment under the initiative is to achieve air quality that supports healthy communities and ecosystems. The field study, which took place this summer, is the largest and most comprehensive of its kind ever to take place in Canada. Over 130 government, university and private-sector scientists from Canada, the United States, the United Kingdom, Italy and Denmark conducted some 160 experiments during August, the time of year when particulate matter concentrations in the region are at their highest.

A scientist with Environment Canada's Environmental Technology Centre lowers air-sampling equipment from the overpass above the Cassiar Tunnel in Vancouver.

The Fraser River Valley was an ideal location for the study because it is small and relatively self-contained, so most lower-level pollution is from local sources that are easily traced. To identify those sources and determine their relative contribution to the problem, scientists took ground measurements at five different locations representing the on-road transportation sector, a mixed urban-suburban setting, an urban-rural transition area, a remote natural setting and an agricultural area. In addition to traditional air-sampling equipment, they used state-of-the-art aerosol mass spectrometers, which are able to break particles into their chemical components. This molecular profile helps researchers trace the specific sources and processes involved in the formation of the particulate.

Measurements of higher-altitude pollutants were taken from tethered balloons and small aircraft equipped with a variety of sophisticated instruments, including a Lidar—a remote-sensing technology that locates particles in the atmosphere by bouncing laser beams off them, the same way that radars use radio signals.

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A Convair 580 mapped the spatial distribution of pollutants in the lower atmosphere and their movement under various meteorological conditions, while a Cessna 188 collected airborne samples for comparison with those taken on the ground. A scanning Lidar was also in operation at one of the ground sites.

Preliminary results have already revealed some interesting facts about the sources and behaviour of particulates in the study area. For example, weather patterns, heat and humidity were found to have a major impact on pollutant distribution in the Valley and its tributaries. Airborne Lidar detected a significant build-up of particles over the city of Vancouver two to three days after the arrival of a high-pressure weather system. During the day, air pollutants in the lower levels of the atmosphere—which were found to originate primarily from local sources—mix together in the heat of the sun to form smog. At night the surface of the earth cools down, separating the surface sources from pollution aloft. Winds push the pollutants up against the hillsides and pump them into the tributary valleys. If the winds are particularly strong, they will blow some of the pollution away to other areas; if not, it will descend back down toward the Valley floor again the next morning—making it possible for pollutants to linger in the region for days at a time.

Air-quality measurements taken at Eagle Ridge (a mountainous area where urban and natural emissions mix), Golden Ears Park (a remote site), and Boundary Bay shed some light on the contribution of natural or biogenic sources to air pollution. Data from the forested areas confirmed that trees are a source of volatile organic compounds, which combine in the atmosphere to form ground-level ozone and particulate matter. The fresh smell associated with a pine forest is actually the odour of terpenes—natural hydrocarbons that are emitted by coniferous trees and converted into particulate matter. Deciduous trees, such as maples and other hardwoods, release smaller hydrocarbons involved in ozone formation.

Measurements of natural emissions from seawater in the Strait of Georgia confirmed that large quantities of sulphur are produced by algae in the ocean; however the data were not sufficient to estimate overall contributions from this source. Sulphates and nitrates from the marine environment and other sources can combine with gaseous ammonia to form white haze. Since the Fraser Valley is a major farming area, ammonia emissions from agricultural activities (primarily manure spraying and fertilizing) contribute to particle formation. Scientists expect the data collected to enable them to quantify ammonia from this and other major sources, including the transportation sector.

Other experiments on emissions from the transportation sector yielded equally interesting findings. A large plume with a chemical signature matching it clearly to emissions from the shipping industry was tracked moving from the port area to the city of Vancouver. Shipping emissions have never been properly accounted for before, and are now seen as an important source of local pollution. A large quantity of data was also collected on emissions from light-duty traffic, which has long been considered a major source of pollution in the region. Filters removed from air samplers at Vancouver's Cassiar Tunnel contained a significantly higher concentration of black carbon than researchers expected to find, as carbon was not previously thought to be a major component of such emissions.

A large number of samples were collected, and remain to be analyzed in laboratories. Scientists who were involved in the Pacific 2001 study will gather at a data workshop in Vancouver to report on findings made to date. Two years after the completion of the field study, the data will be made public.

A tethered weather balloon at the Slocan site in Burnaby. The balloon was released to a height of about one kilometre, and then winched back down to provide a vertical profile of ozone and meteorological parameters, including wind speed and direction, humidity and temperature.

Information gained from Pacific 2001 will help to improve computer air-quality models used to assess the impact of various emission-control scenarios and initiatives, and will form the basis for developing sound public policy on air quality in the region—including a transboundary airshed plan for the Georgia Basin/Puget Sound area. It will also contribute directly to the implementation of Canada-wide standards for particulate matter and ozone and to the review of the Canada-United States Ozone Annex in 2004. A better understanding of the processes that lead to the formation and distribution of particulates and ozone will also help the international community take more effective action to meet the requirements of existing and future air-quality agreements. S&E

CLIMATE CHANGE AND CANADA'S WATER RESOURCES: PREDICTING THE FUTURE

The Mackenzie Basin covers 20 per cent of Canada, stretching from Jasper, Alberta, to the coast of the Beaufort Sea. For the past seven years, Environment Canada and university scientists have been toiling together in this vast landscape to learn more about the water and energy cycle in Canada's North—information that is vital to predicting the impacts of climate change on our water resources.

Canada has some of the largest freshwater reserves in the world. These reserves fluctuate widely due to natural variations in climate, and concerns are growing that changes in climate caused by human activities could have dramatic and unpredictable effects. For example, as the largest single North American source of freshwater for the Arctic Ocean, the Mackenzie River—ranked tenth largest in the world by drainage area—plays an important part in regulating the thermohaline (temperature and salinity) circulation of the world's oceans. A large-scale fluctuation in discharge from the Mackenzie would have consequences far beyond Canada's borders.

The need to know more about the interrelationships between climate and water resources, especially in large, high-latitude river basins such as the Mackenzie, prompted Environment Canada and colleagues in the scientific community to launch a new research program in Canada's North. Approximately 50 Canadian climatologists, meteorologists, hydrologists, remote-sensing experts and modellers from the Department's Meteorological Service of Canada and National Water Research Institute, and several Canadian universities embarked on the Mackenzie GEWEX Study (MAGS).

MAGS is a major component the World Climate Research Program's Global Energy and Water Cycle Experiment (GEWEX), which is investigating water and climate interrelationships at important sites around the world—including the Mississippi and Amazon rivers, the Baltic Sea, and Asia's monsoon and Siberian regions. Canadian scientists are playing a leading role in developing new knowledge about the processes that control the circulation, storage and distribution of water and energy in cold regions: processes that ultimately affect the global climate system.

Research on such a large scale poses many formidable challenges to scientists, particularly the difficulties of size, remoteness, and biophysical diversity in an area such as this. The Mackenzie Basin is made up of six main sub-basins, three great lakes—Great Slave Lake, Great Bear Lake and Lake Athabasca—and three major deltas, including the Peace Athabasca and Mackenzie. It encompasses Arctic tundra to the north, farm and ranchland to the south, lakes and wetland on the Interior Plains, mountainous regions in the west, and rocky Canadian Shield in the east. In most of the northern part of the basin the permafrost is continuous, and can be as thick as 500 metres.

The dramatic climate of the Mackenzie Basin presents its own challenges. Average monthly temperatures range from about 15°C in summer to about -30°C in winter. The range is much larger on a daily scale, however, with values from as high as 30°C to as low as -50°C. Large daily, seasonal and yearly variations in the basin's cloud systems (and their structure) have a profound effect on surface processes, including the amount of heat gained and lost. Cyclonic storms are a frequent occurrence for a large part of the year and, in the summer, the Basin experiences a large amount of convective activity and associated lightning. These and other atmospheric processes were not well understood before MAGS was launched.

Researchers knew from the outset that they would have to contend with incomplete data, as there is a limited observational network in the Mackenzie Basin. They tackled this problem by making maximum use of the information they did have—for example, using historical precipitation

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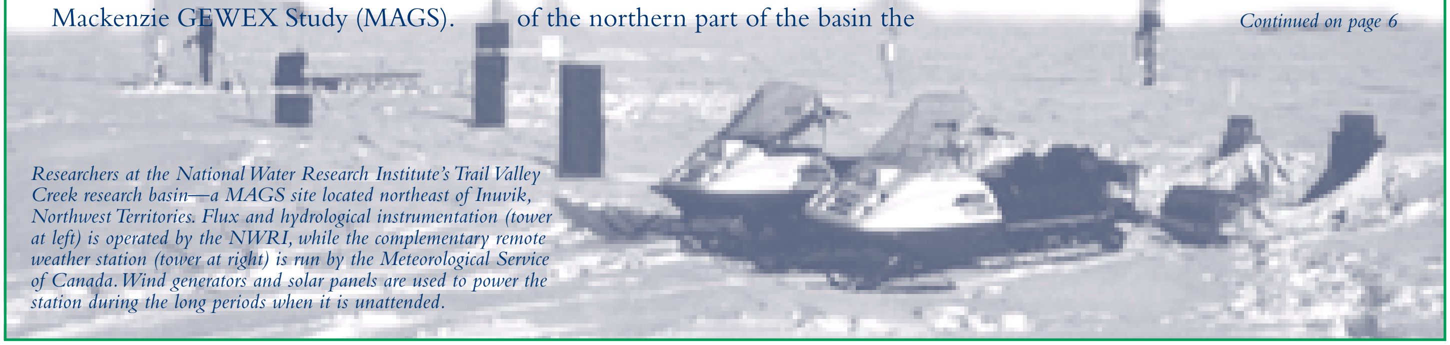

Researchers at the National Water Research Institute's Trail Valley Creek research basin—a MAGS site located northeast of Inuvik, Northwest Territories. Flux and hydrological instrumentation (tower at left) is operated by the NWRI, while the complementary remote weather station (tower at right) is run by the Meteorological Service of Canada. Wind generators and solar panels are used to power the station during the long periods when it is unattended.

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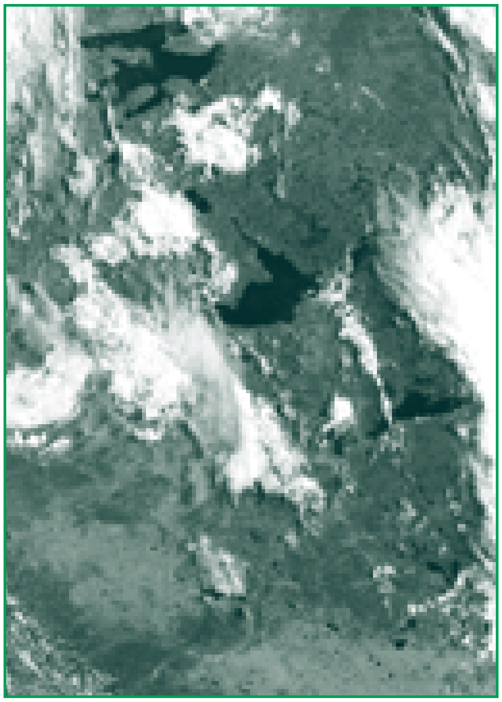
and discharge records to estimate the distribution of precipitation and runoff over the Basin. They also developed research strategies using remote-sensing tools to gather data, which could then be applied in many ways, such as to calculate break-up and freeze-up dates for the Mackenzie great lakes and to estimate the surface-atmosphere exchange of heat and moisture in key regions.

Over the course of the study, Environment Canada established several new automatic meteorological observing stations at sites where data were sparse. Each site also represented a different biophysical region: near Fort Simpson, wetland with discontinuous permafrost; Fort Liard, mountains; the Great Divide between the Yukon and Northwest Territories, alpine tundra; Yellowknife between the Great Slave and Great Bear lakes, shield lakes; Fort Good Hope, northern forested wetlands; and Inuvik, boreal forest-tundra transition and continuous permafrost.

To gather critical hydrological data, departmental researchers enhanced their instrumentation in four long-term research basins located in key areas. Data collected at these sites were augmented by data from a Canadian weather forecast model. Modelling experts made progress in modifying the Canadian Regional Climate Model for use over the Mackenzie Basin, and in linking the Canadian Land Surface Scheme with a hydrological model. Integrating these models is an important goal of the study, and is essential for testing our predictive ability under current conditions and for considering how climate and water resources will change in the future.

With the help of these tools and techniques, researchers focussed their studies on large-scale atmospheric processes, moisture recycling and energy fluxes, and discovered much new information about how moisture is distributed and redistributed in the area. During fall and spring, most moisture and precipitation is transported to the Basin along a "conveyor belt" that moves from the Pacific Ocean across the mountains. The mountains play a major role in converting this moisture into snow, which then provides snowmelt and runoff. In summer, evaporation from vegetation and open bodies of water is a major source of atmospheric



Satellite image of the Mackenzie River Basin, showing Great Bear Lake (top) and Great Slave Lake (bottom).

moisture and, along with convective clouds, is an important factor in its redistribution. Studies of the cyclonic weather systems showed they are responsible for a significant amount of precipitation in the Mackenzie Basin.

From research on snow, ice and permafrost, scientists gained greater insights into how blowing snow is redistributed, how effective forests are at intercepting snowfall, and how much snow is sublimated back to the atmosphere. They determined that water from melting snow infiltrates easily into frozen organic soils but not into ice-rich mineral soils, and that slopes with permafrost are efficient at moving water into streams, but those without sometimes yield no runoff at all. MAGS scientists are modifying hydrological models to account for these important variations.

Researchers investigating Great Slave Lake found a pronounced difference in cumulative annual evaporation between two years. The first, lower amount was consistent with estimates for high-altitude lakes, but the second, higher one was similar to amounts estimated for the Laurentian Great Lakes to the south. The higher amount could be explained by an exceptionally long ice-free period that resulted from thinner ice-cover in the second year, which, in turn, resulted from above-average air temperatures during an El Niño warming episode. The researchers believe that if an El Niño warming has this effect, warming caused by climate change from human activities will also cause great lakes in the North to behave more like their southern counterparts.

As the first phase of the study draws to a close, the MAGS team has made unparalleled progress toward understanding the links between water and climate in high latitudes. Five million dollars in new funding from the Natural Sciences and Engineering Research Council of Canada has already been secured for a second phase that will continue to bring the government and university science communities together over the next five years to produce better models and other tools for improved prediction of future changes to Canada's freshwater resources. S&E

S&E Bulletin

This bi-monthly newsletter provides information on Environment Canada's leading-edge science and technology.

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