Watching the weather

Better weather forecasting for more safety and comfort

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Weather forecasts: We watch the television for them and search for them in newspapers. We listen to them on the radio and check them on the Internet – and even on game consoles. The upcoming weather is an important factor in the planning of picnics or ski trips, in determining what clothes to wear or in ensuring our small talk conversations don't run out of topics. Farmers rely on weather forecasting to plan their work schedule. Maritime fishermen and sailors use weather maps to avoid the choppy seas and strong winds that can put the crew's life in danger. The aviation industry is dependent on weather forecasting to determine when to issue de-icing procedures, to route the air traffic in order to improve fuel consumption efficiency of airplanes and avoid hazards related to environmental conditions. Power distribution companies rely on weather forecasts to anticipate the electrical demand for heating or air conditioning. Accurately predicting the course of a hurricane can help save lives. For a multitude of reasons, humans have a need to know what the weather will be in the upcoming hours and days.

Photo courtesy of NPOESS IPO

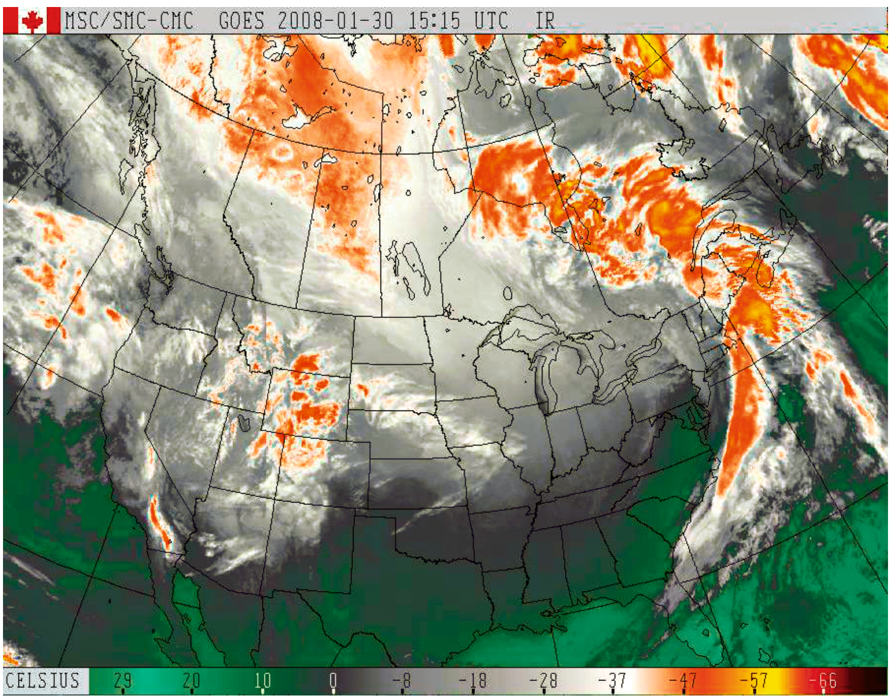
Weather and leisure

To issue local weather forecasts to end users, weather agencies need information on the current weather patterns over large areas of the globe. Real-time measurements of temperature, pressure, humidity, wind speed and direction, visibility and cloud cover are therefore necessary. Several parameters require not only data concerning conditions on the Earth's surface, but also measurements of conditions at various altitudes.

Meteorological data are obtained at fixed locations by trained observers or automated weather stations on the ground or on sea buoys. Some weather stations – about 800 in the world – also use weather balloons carrying radiosondes to collect meteorological data from ground level up to 30 km into the atmosphere. Typically, each of these stations launches two balloons per day. Meteorological data are also obtained from commercial airplanes and from some ships.

Data obtained from weather satellites are also extensively used. Images taken from space are very useful in the observation of cloud patterns over the Earth and in determining the motion of air masses on a global scale. Instruments carried on satellites are also used to estimate surface temperature, humidity, cloud height, concentration of certain chemicals, etc. There are two types of satellites used for weather forecasting. Some instruments are placed on geosynchronous satellites, ie, satellites orbiting at about 36,000 km of altitude, at the same rate the Earth rotates (the satellite remains fixed in the same place relative to the Earth). This allows instruments to constantly monitor a large area of the planet. Other instruments, placed on satellites at lower altitude (orbiting the Earth much more quickly), are used to collect data with a finer spatial resolution but not continuously; typically these instruments collect data of almost all locations on the planet twice per day. Generally, the meteorological information gathered from the current weather satellites is less accurate and coarser than the information obtained from weather stations, but satellites provide information for nearly the entire globe.

Most countries freely share the meteorological information they gather. All these data are then assimilated by weather agencies and entered into standard grids to determine the actual weather patterns at a given time over the globe. Critical parameters need to be interpolated to compensate for the scarce density of measurements in some regions of the Earth. The best estimate of the current weather pattern at a specific time is called a weather analysis. A weather analysis should not be confused with a forecast: By the time the analysis is completed, the weather has already changed.



Weather analyses are used by meteorologists to feed numerical weather prediction models. These are mathematical models running on powerful computers. The models extrapolate the current weather pattern into the future in order to make predictions of meteorological conditions a few hours or days into the future.

Current and future instruments made by ABB will help to better understand the atmosphere of our planet and the complex chemical and dynamic processes taking place over our heads.

Predicting the weather is not simple. The atmosphere is a complex thermodynamical system and conditions can change rapidly. The accuracy of the prediction is limited by the accuracy of the weather analyses used as input and these are limited by the quality and the amount of collected meteorological data. Within three days, the typical average accuracy of a weather forecast is between 60 and 80 percent. For predictions further into the future, the accuracy is reduced. The weather models also predict the average conditions over large areas (typically more than 1,500 km^2). Of course, in reality, the weather is not uniform over the prediction area and this is another source of error. Sometimes, the output of numerical weather prediction models are "touched up" and adjusted manually by experienced meteorologists in order to adapt the predictions to account for the latest local measurements or for localized features that are not considered by the models. This is one of the reasons why predictions issued by different sources for the same region may differ.

ABB now offers a product to add to the array of instruments used to gather meteorological data. This instrument, named AERI (Atmospheric Emitted Radiance Interferometer), is an infrared spectrometer (FT-IR). AERI instruments are ground-based and used to observe the atmosphere above them. They do this by measuring the infrared radiation coming from the atmosphere. These measurements are used to estimate vertical profiles of temperature and humidity in the lower atmosphere (up to about 5 km). The AERI instruments are fully automated; they transfer their data by wireless radio to a collecting station every ten minutes. This instrument has been developed in collaboration with the University of Wisconsin in the United States over the last decade and is now making its commercial debut. Several units have also been deployed for research purposes. Although the AERI instrument cannot measure at the altitudes achieved by the balloon-borne radiosondes, the instrument provides data continuously during both day and night and can be deployed at automated weather stations that do not have balloon-launching capability [1].

1 The CrIS (Cross-Track Infrared Sounder) interferometers will equip the new weather satellites of the United States.

Satellites

ABB is also involved in the design and manufacturing of instruments to equip the next generation of meteorological satellites. In 2005, ABB delivered the first unit of a series of interferometers. These interferometers constitute the core of the new atmospheric sounder that will equip the new weather satellites of the United States. The sounder, named CrIS (Cross-Track Infrared Sounder)[1], will perform measurements that will be used to derive vertical profiles of temperature, pressure, humidity and some chemicals in the troposphere over almost the entire globe **1**. ABB also provides the on-board equipment that will be used to calibrate the instrument during its day-to-day operation in space, and has developed the mathematical equations that will be used to calibrate the data of CrIS. Compared with current technologies, CrIS will provide more information while also attaining higher levels of accuracy. Overall, this instrument will improve the quality of data obtained from space used in numerical weather prediction models for weather forecasting [2]. More accurate weather forecasts can be expected when these new satellites are deployed in a few years' time. ABB is also currently conducting research with European and American partners to see how ABB technologies can be deployed on the next generation of geosynchronous meteorological satellites.

> Besides issuing weather forecasts, several meteorological agencies also conduct research to improve weather forecasting or to study peculiar meteorological phenomena.

Once these new instruments are operational, the quality and the quantity of information on the current weather will be improved. The resulting weather analyses will be more representative of the current weather: The forecasts made with the numerical weather prediction models will thus be more accurate.

Besides issuing weather forecasts, several meteorological agencies also conduct research to improve weather forecasting or to study peculiar meteorological phenomena. Several agencies also collect data on air quality, pollution and other parameters that are not necessarily used for weather forecasting. This can be on a regular basis or in response to an abnormal event such as a fire in a chemical plant.

For example, the Environmental Protection Agency of the United States operates an airplane containing a spectrometer made by ABB. This instrument is used to measure the concentration of various chemicals in the atmosphere. This airplane is part of a program named ASPECT (Airborne Spectral Photometric Environmental Collection Technology). It is an always-on-call emergency response system capable of mapping the distribution of hazardous chemicals in the air. This instrument has been deployed more than 60 times since 2001 to estimate the concentration and distribution of potentially hazardous chemicals after events such as the destruction of the Columbia Space Shuttle in 2003, wildfires in California, the fire of a methylacrylate production facility in southern Texas in 2005, and the aftermath of hurricanes Katrina and Rita in 2005 [3]. The data collected is used to make environmental impact studies, to issue evacuation recommendations, etc.

The Met Office of the United Kingdom also operates an ABB instrument. The device named ARIES was made in 1996 and has recently been upgraded. It is an instrument deployed under the wing of a BAE 146-301 airplane to make in-situ measurements of chemical constituents for atmospheric research purpose. Since 1996, this instrument has participated in more than 20 field measurement campaigns to improve knowledge of the atmosphere [4].

Footnote

1) The Cross-track Infrared Sounder (CrIS) will replace the High-resolution Infrared Radiation Sounder on the next generation of National Polar-orbiting Operational Environmental Satellite System (NPOESS) in the United States of America. The CrIS will provide improved measurements of temperature and moisture profiles in the atmosphere from an altitude of about 850 km. Visit http://www.ipo.noaa.gov/ for more details.

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2 The Canadian Space Agency's SciSat satellite is equipped with the ABB ACE-FTS (Atmospheric Chemistry Experiment – Fourier Transform Spectrometer) instrument

A satellite of the Canadian Space Agency, SciSat, is also equipped with an ABB instrument 2. Every day, it acquires about 2,700 high-resolution spectra of the upper atmosphere in the infrared portion of the electromagnetic spectrum. This instrument, named ACE, is primarily used to measure the concentration of stratospheric ozone. This gas blocks most of the harmful ultraviolet radiations from the sun. The satellite was launched in 2003 and the instrument has operated flawlessly since. The data acquired by ACE has also helped to understand the chemical processes that lead to the generation and destruction of ozone in the upper atmosphere[2)] [5].

Next year, the space agency of Japan will launch a new satellite named GOSAT with an instrument that contains an interferometer made by ABB. This instrument will be used to monitor the sources of carbon dioxide near the surface of the Earth [6]. Carbon dioxide is one of the important greenhouse gases in the atmosphere that affect the climate of the planet.

The atmosphere is a complex thermo-dynamical system and conditions can change rapidly.

Current and future instruments made by ABB will help to better understand the atmosphere of our planet and the complex chemical and dynamic processes taking place over our heads. They will also provide better quality data to improve the accuracy of weather forecasting, hereby improving your chances of rain-free picnics.

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Factbox Fourier Transform Spectroscopy

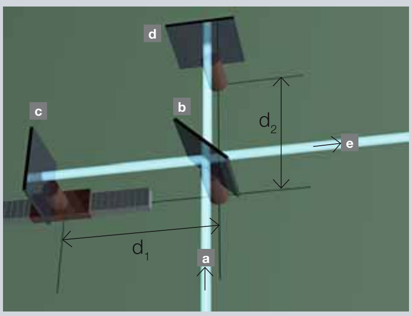
Fourier Transform Spectrometers (FTS) modulate an incoming infrared beam in a wavelength selective way by means of optical interference. The intensity of the incoming light a is split in two parts by the half-mirror beamsplitter (optical component b). The reflected part travels two times the distance d_1 separating the moving mirror c from the beamsplitter. Similarly, the transmitted part travels twice the distance d_2 separating the fixed mirror d from the beamsplitter. The transmitted and reflected beams are superimposed in the output beam e where they interfere with each other in either a constructive or destructive way depending on the wavelength of the incoming light and the distances d_1 and d_2. By moving mirror c, the intensity at the output of the interferometer varies as a cosine function as the interference goes though a sequence of completely constructive to complete destructive interference patterns. In fact, the intensity of the modulated output, also called the interferogram, for a monochromatic light at wavelength λ (or frequency $\nu \equiv c/\lambda$) entering the interferometer is given by

$$I(x;\nu) = I_0 \cos(2\pi\nu x)$$

where $x \equiv 2(d_1 - d_2)$ is the optical path difference between the two arms of the interferometer and I_0 is the intensity of the incoming monochromatic light. For a polychromatic input, the total interferogram is simply the sum of the monochromatic interferograms, ie,

$$I(x) = \int I_0(\nu)\cos(2\pi\nu x)\,d\nu$$

where $I_0(\nu)$ is the spectrum of the polychromatic incoming light. The interferogram is thus simply the Fourier Transform of the spectrum of the incoming light. Therefore the spectrum of the radiance entering the instrument can be reconstituted by evaluating the inverse Fourier Transform of the interferogram.



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[5] CSA, SCISAT – From dawn to twilight, http://www.space.gc.ca/asc/eng/satellites/scisat/, January 2008.
[6] JAXA, Greenhouse Gases Observing Satellite (GOSAT), http://www.jaxa.jp/projects/sat/gosat/index_e.html, January 2008.

Footnote
[2)] The Canadian SCISAT satellite is helping a team of Canadian and international scientists improve their understanding of the depletion of the ozone layer, with a special emphasis on the changes occurring over Canada and in the Arctic. The ACE-FTS instrument on board SCISAT simultaneously measures the temperature, trace gases, thin clouds, and aerosols found in the upper atmosphere from an altitude of 650 km.