Future forecasting

In recent years, numerous tools have become available to assist the aviation meteorologist in preparing and communicating forecasts. **John Snow**, Regents professor of Meteorology, examines the strengths and weaknesses of these tools, and introduces the latest technology on the horizon.

Supporting today's global aviation operations presents the aviation meteorologist with many challenges. Terminal forecasts require consideration of rapidly evolving weather at a specified locality while route forecasts require a continental to global perspective.

Identifying routes that minimise fuel usage by taking advantage of or avoiding strong winds at altitude (while ensuring passenger comfort by avoiding potentially turbulent regions) has recently received emphasis. The various forecast components covering departure, in flight and arrival must be melded into a seamless package of information, which can be clearly communicated to decision makers: air crew, airport operators, airline dispatch staff, and increasingly, passengers. When the weather changes while a flight is en route, updated forecast information must be provided quickly to all concerned.

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Fortunately, current weather forecasting tools include a wide range of sophisticated sensing systems, numerical weather prediction systems, and decision support systems.

Advances in weather radar

Radar technology was adapted to meteorological purposes more than 60 years ago. Initially, it was used to detect the presence of clouds and precipitation in an area. Meteorologists quickly learned to identify certain patterns within thunderstorms, squall lines, and other atmospheric phenomena. Locations of melting snow inside the cloud were identified by an increase in the strength of the returned signal, the so-called 'bright band'. The intensity of rainfall was also estimated from the strength of that signal. In addition, the presence of hail was inferred when the intensity of the returned signal was extreme.

The latest technology to be deployed is 'dual polarisation'. A dual-polarised radar system emits and receives electromagnetic waves that are both horizontally and vertically oriented, producing two output signals. By comparing the returns from precipitation for the differently oriented waves, much better estimates of precipitation type and intensity can be made. Less appreciated is the fact that having the two output signals allows for more sophisticated signal processing, improving every product coming from the radar. In addition, dual-polarisation products are currently being studied as a way to improve computerised weather forecasts.

Phased array technology is attractive because it offers very rapid scanning of the atmosphere, scanning the surrounding volume in a few tens of seconds rather than in the five or six minutes required with traditional rotating antennas. Such systems can also be multifunctional, performing aircraft tracking while at the same time monitoring the weather. Operational phased array weather surveillance radars will likely appear between 2015 and 2020.

John Snow

John Snow is a professor of meteorology and dean of the College of Atmospheric and Geographic Sciences. He came to Oklahoma University in 1994 from Purdue University, where he had been a faculty member in the Department of Earth and Atmospheric Sciences since 1977.

Collaborative adaptive radar systems

Many aviation weather hazards occur in the lowest two or three kilometers of the atmosphere. Under normal conditions, a radar views the atmosphere in much the same way as a searchlight (although bending of the beam does take place, under most conditions such bending is a minor consideration). Due to the curvature of the Earth, the further the beam gets from the radar, the higher it is above the local surface. Consequently, the lowest layer of the atmosphere is observed only in the area immediately proximate to the radar. Due to cost, large weather surveillance radars can only be deployed in widely spaced networks, leaving much of the lower atmosphere unobserved.

While large long-range radars will almost certainly have a place in meteorology for many years to come, the University of Massachusetts – Amherst and the University of Oklahoma, together with other university and industry partners, and with support from the National Science Foundation, have been exploring an alternative approach. This novel approach involves deploying a dense network of many small, short range (and ideally, relatively inexpensive) radars. Such arrays produce large amounts of data, observing the same region from several different directions simultaneously. Because of their numbers, such networks require a collaborative, adaptive control system to ensure that the phenomena of most interest are observed in detail while the rest of the region is monitored occasionally to prevent surprises. Such 'smart' networks are also resilient in the sense that if one or two systems are down for maintenance, the other systems still cover the area.

Microwave Radiometers

The gases and particles in the atmosphere all radiate very low power electromagnetic energy. Microwave radiometers detect a portion of this energy and interpret it to provide a unique picture of the three-dimensional local weather. Such systems can deliver continuous temperature, humidity, and liquid profiles for state-of-the-art nowcasting and short-term forecasting. For example, a radiometer can detect water vapor and cloud liquid water in the early stages of storm formation. Experience has shown that using microwave sensors can provide good one-hour rainfall estimates. The Meteorological Office at Dubai International airport (DXB) has determined that the radiometer installed at the airport has facilitated a 50% improvement of fog forecasts, resulting in significant cost and safety benefits.

Lightning

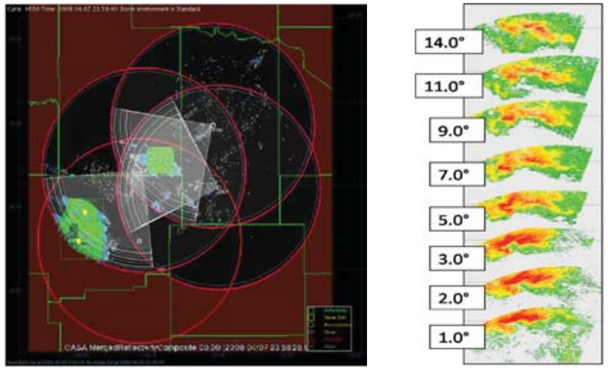
Lighting is a significant hazard to individuals who work in open spaces such as airport tarmacs. Cargo service, maintenance, and fueling personnel are at risk during lightning storms. Both direct-to-the-airplane and nearby lightning flashes can also damage aircraft electronic systems on the ground, during the critical take off and landing phases, and in flight. Those in charge of personnel safety and lightning protection need information to support better decisions concerning what action to take before, during, and at the end of storms.

Fortunately, as the economic impact of standing down outdoor personnel during lightning storms and the vulnerability of aircraft electronic systems to lightning have increased, so have the capabilities of tools to warn of these threats. Systems that accurately and efficiently locate cloud-to-ground (CG) lightning flashes have been developed and deployed in the US and other countries over the last two decades. In the US there are three competing systems with nationwide coverage that are relatively efficient (typically 90%) and accurate (typically within about 0.5km) in locating CG flashes. More recently, new systems known as lighting mapping arrays (LMA) have been developed to produce three-dimensional images of in-cloud (IC) portions of lightning flashes, from initiation.

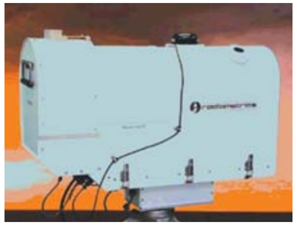
Currently, the instrument of choice for lightning-hazard warning decision support in regard to fist and last strikes are ground-based electric-field meters, best deployed in networks. Electric-field meters measure the electric field at their location, and the electric field is the result of charge overhead. Networks of electric field meters provide decision makers with an indication that charge is accumulating overhead at the beginning of storms and that it is dissipating at the end of storms. A new low-power, low maintenance electric-field meter is now commercially available at a price and with sufficient built in software support that it is now possible for small networks of field meters to be deployed and maintained economically. A small network of such sensors deployed around an airport and used in conjunction with a lightning location network provides a complete solution to warning for the lightning hazard.

Numerical Prediction on the Mesoscale

Aviation meteorologists are most interested in forecasts of phenomena that occur on what is termed the mesoscale: thunderstorms, squall lines, regions of clear air turbulence, waves over mountains, visibility impairment due to fog, snow, etc. Aviation-related phenomena such as icing or turbulence intensity are not directly computed by the numerical weather prediction systems. Instead, specific algorithms are developed, often as part of expert systems, to forecast these phenomena. Such systems combine forecast



A network of four small radars deployed in central Oklahoma by the Center for Collaborative Adaptive Sensing of the Atmosphere (CASA).



MP-3000A Hyper-Spectral Temperature, Humidity and Liquid Water Profiler by Radiometrics Corporation.

The Campbell Scientific, CS110 Electric Field Meter measures the vertical component of the atmospheric electric field for lightning warning applications.

model output (often from multiple models) with a variety of observations (including pilot reports), and incorporate the individual models' past performance.

Each run of a numerical model requires a starting point with initial conditions specified from observations everywhere within the computational domain and at its boundaries. Specialised computer programs, termed data assimilation systems, prepare the starting conditions using all available observations and previous forecast runs. The outputs of such assimilation systems have value in their own right since they provide a 'best estimate' of the current state of the atmosphere. The data assimilation system can also be continuously updated with near real-time inputs from sensing systems such as Doppler radar, RWPs and MPs to provide a four-dimensional picture of the evolving atmosphere.

Given that each numerical prediction system has peculiarities related to how it renders the atmosphere and the surface conditions, it is often advantageous to make several runs of each model with slightly different initial conditions. Such 'ensembles' of models allow forecasters to evaluate the how well the system is handling a particular meteorological situation. Often the ensemble will be run at a coarse resolution, allowing for guidance output to be prepared much more quickly. At the same time, a single very fine resolution run could be made to capture important detail. The composite result of the coarse ensemble runs then provides a measure of confidence to be placed in the high resolution run. Such numerical prediction systems have been demonstrated in quasi-operational settings by the Center for Analysis and Prediction of Storms at the University of Oklahoma, working in partnership with the NOAA Storm Prediction Center.

Weather Decision Support Systems

The experienced, well-trained human is still the most effective weather forecaster. The aviation meteorologist is still required to pick the best possible forecast models for the situation at hand and must therefore be skilled at three-dimensional pattern recognition, in understanding how each model has performed in similar situations in the past, and have knowledge of the biases inherent in each model. Data from every available platform must be considered to ensure that unusual situations are not lost in the assimilation process. The use of ensembles of runs of the same model (with slight variations in the initial conditions) and from several different models (with slightly different structure and representations of physical processes) may help in identifying the most likely evolution of the atmosphere, but how this evolution translates into specific temperature, wind, visibility, and rainfall forecasts is ultimately a human decision.

The flow of these data is continuous with new information arriving continuously. To manage this information, sophisticated decision support systems are required. These computer-based information management systems merge the arriving meteorological information with geographic information about the local area, airport details, and arriving and departing air traffic flows. ■