by David H. Bromwich, Julien P. Nicolas & Jordan G. Powers

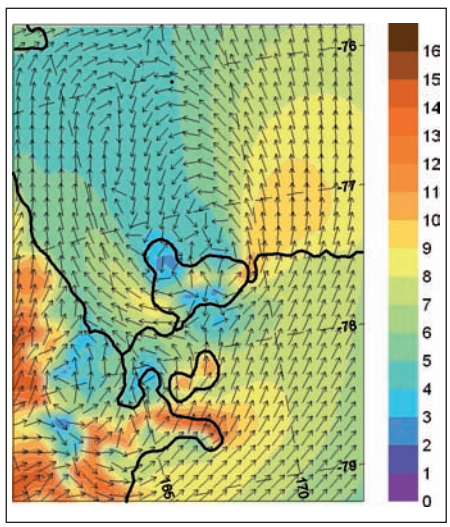
AMPS FORECASTS

The Antarctic Mesoscale Prediction System

Weather forecasting across Antarctica is improving using grids, models, and NWP, and through closer collaboration

"There is little doubt it has been a highly successful endeavor"

Pegasus Field white ice runway near McMurdo Station. A C-17 cargo jet is taking off over five LC-130 aircrafts. Courtesy of Air National Guard



Example of a climatological application of the AMPS forecast archive. Mean 10m wind vectors and wind speed (color scale) in m/s-1

Accurate weather forecasts are critical to logistical and scientific activities in Antarctica. While extreme weather can be life-threatening for scientific parties in field camps, more benign conditions (e.g. low visibility) can severely impede air operations. Furthermore, the high latitudes of the southern hemisphere remain a challenging place for real-time numerical models. This is due to the sparse observational network, the challenge of accurately representing the physics of the polar atmosphere, and the ice sheet's steep coastal terrain (where most Antarctic stations are located) that is poorly resolved by global models.

The challenges are particularly acute around McMurdo Station, the largest research base in Antarctica and the logistical hub of the United States Antarctic Program (USAP). The station is located on the southern tip of Ross Island, at the base of a 3,794m active volcano, Mt Erebus, and is bounded on the west by 3,000m high peaks of the Transantarctic Mountains. The station vicinity also coincides with the confluence of contrasting air masses: air descending from the east Antarctic plateau meets with the southerly Ross Ice Shelf air stream and the maritime air masses from the Ross Sea. The contrasts are exacerbated in the summer, at the peak of the field season, by the presence of open water in the McMurdo Sound, which enhances the formation of cloud and fog. Such conditions contribute to the frequent cyclogenesis observed in the western Ross Sea. The intensity of air traffic to and from McMurdo during the field season (95 round-trip flights from/to Christchurch, New Zealand, and 400 intracontinental missions from October 2009 to March 2010) leaves no doubt as to the importance of reliable weather forecasts.

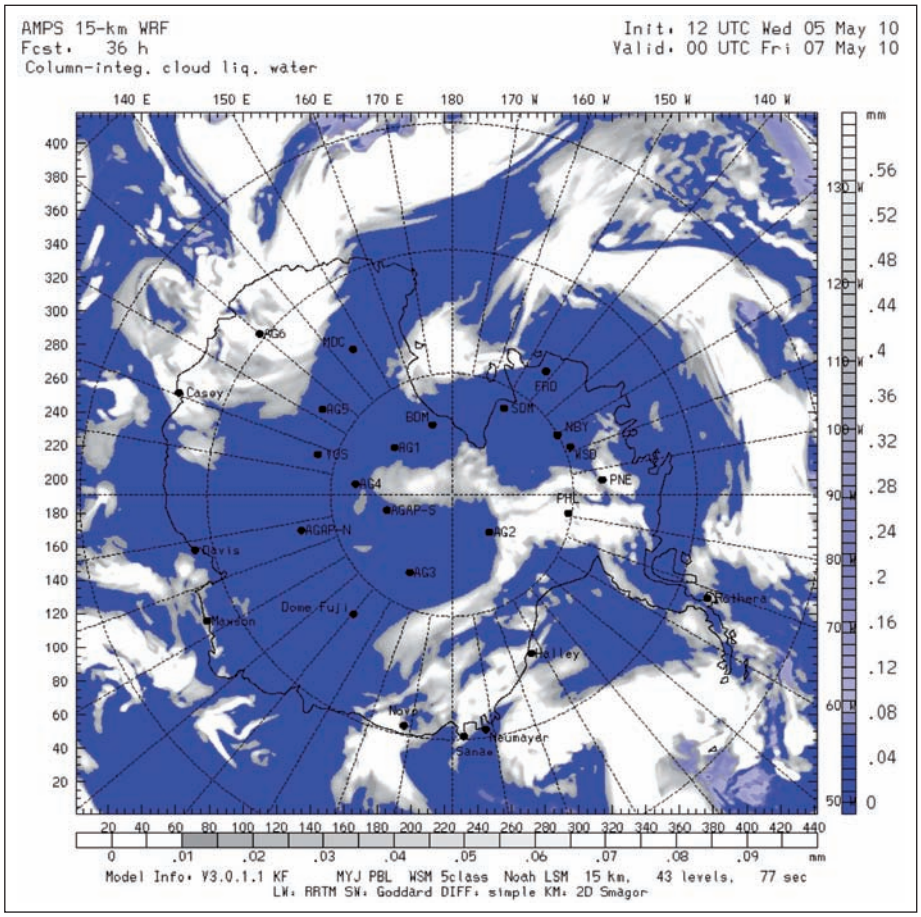
Objectives and participants

An early-season emergency evacuation from Amundsen-Scott South Pole Station in October 1999 served to highlight some weaknesses in the numerical weather prediction (NWP) capability over Antarctica.

As a follow-up to this event, the Antarctic Weather Forecasting Workshop held in May 2000 at the Byrd Polar Research Center (BPRC) at the Ohio State University formulated the need for a dedicated NWP effort for the Antarctic to support USAP operations. As a result, the Antarctic Mesoscale Prediction System (AMPS) project was proposed. The first numerical weather forecasts for Antarctica from AMPS were produced shortly after, in September 2000.

The AMPS project

Funded by the National Science Foundation's Office of Polar Programs, which also funds and manages the USAP, the AMPS project is a collaborative endeavor between the Microscale and Mesoscale Meteorology (MMM) Division of the National Center for Atmospheric Research (NCAR), the Polar Meteorology Group (PMG) of the BPRC, and the University of Colorado (CU). The project pursues three missions: first, to develop an experimental, real-time, high-resolution NWP capability for the Antarctic; second, to optimize the forecasting model for the polar environment



'Pseudo-satellite' product showing column-integrated water vapor in mm over AMPS 15km domain on May 7, 2010, 00:00 UTC. This product is available in real time on AMPS website

and to evaluate the model performance; and finally, to foster interactions among forecasters, researchers, and students.

Relying on the computational resources funded by NSF and on NCAR's expertise in real-time modeling, MMM is responsible for running the AMPS forecast model, for providing a web interface for forecast access, and for archiving the forecast output. The role of the PMG is to adapt the model for the Antarctic and to evaluate model performance, building upon its expertise in high-latitude climate modeling. The AMPS effort is primarily directed toward the forecasters of the Space and Naval Warfare (SPAWAR) Systems Centers who provide weather forecasts for USAP operations. The weather forecasting mission has been entrusted to this agency since 2000 when it took over Antarctic forecasting from the US Navy. The US Air Force and the New York Air National Guard play pivotal roles in their flying of C-17 and C-130 aircraft between Christchurch and McMurdo, as well as across the Antarctic continent.

Model configuration

The model configuration has changed greatly since the early days of the project. Currently, the AMPS model features six domains, including an overall coarse grid with higher-resolution nested grids over key areas.

The 45km horizontal resolution grid covers Antarctica and the Southern Ocean and includes New Zealand, the starting point of intercontinental flights to McMurdo, as well as the southern tips of the South America and Africa. The higher-resolution nests, which are two-way interactive with their parent domains, consist of a 15km domain over the entire Antarctic continent; 5km domains over the western Ross Sea, South Pole, and the Antarctic Peninsula; and a 1.67km domain over the critical Ross Island area. The grid resolutions, initially 90/30/10/3.3km respectively, were enhanced to 60/20/6.6/2.2km in September 2005, and to the current resolutions of 45/15/5/1.67km in October 2008. During the Antarctic field season, additional one-way nests over field camps are also implemented. For example, a 2.5km nest over the LARISSA field campaign region abutting the Antarctic Peninsula in January and February 2010.

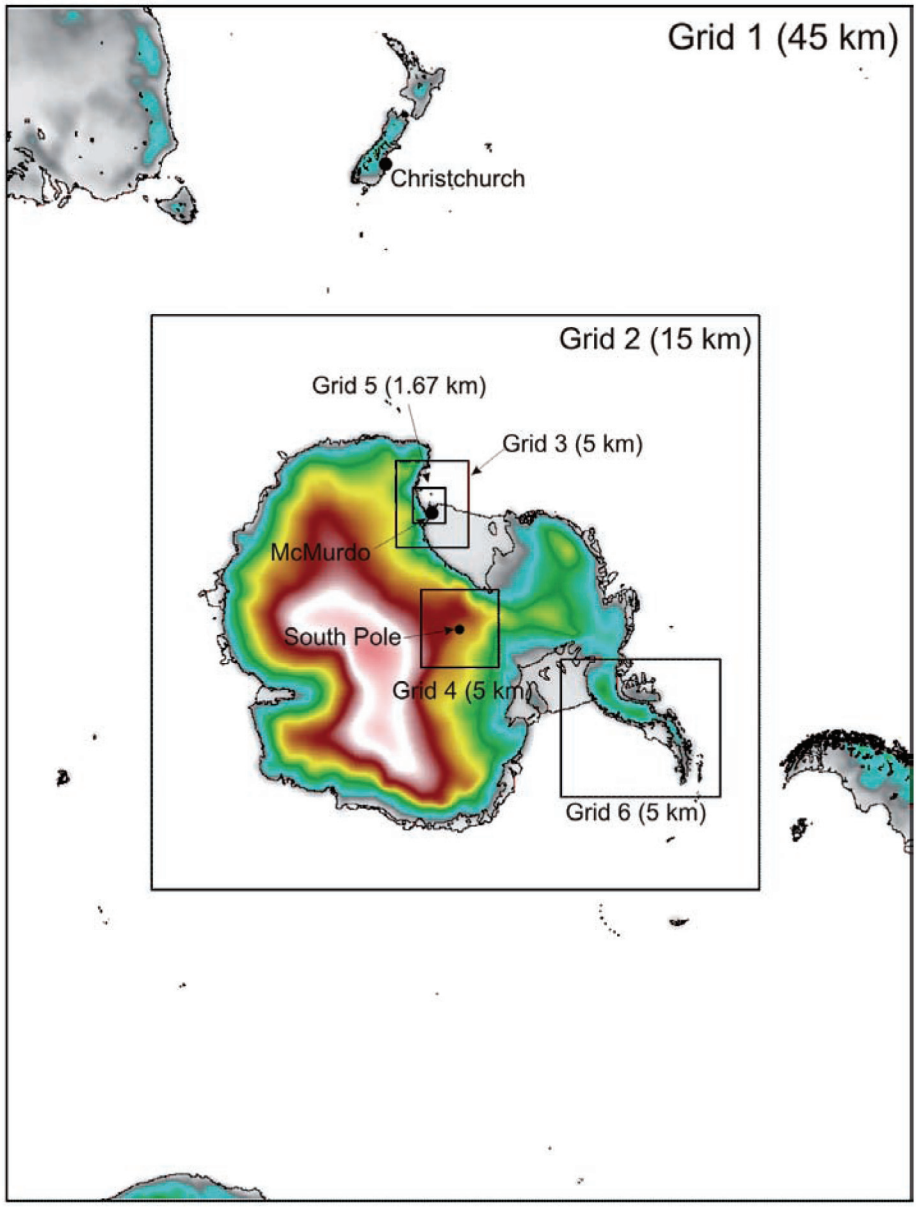
To generate AMPS forecasts, the Polar MM5, a version of the fifth generation Pennsylvania State University NCAR Mesoscale Model (MM5) optimized for high latitudes by the PMG, was employed until June 2008. Polar MM5 was superseded by a polar-modified version of WRF, a version of the state-of-the-art Weather Research and Forecasting (WRF) that includes PMG's polar modifications. The forecasts are generated twice-daily at NCAR, with forecast times out to 120h (five days) for the 45km and 15km domains, and 36h for the other domains.

The model initial and boundary conditions are derived from the National Centers for Environmental Prediction (NCEP) global forecasting system (GFS) output. The initial conditions are enhanced through regional data assimilation. A three-dimensional variational (3D-Var) assimilation system is used to ingest a host of observation types. These include surface reports from Antarctic manned and automatic weather stations and upper-air observations from radio soundings. Various types of satellite-derived data are assimilated and are highly beneficial due to the sparsity of conventional observations in high southern latitudes. These remotely-sensed observations include MODIS winds, COSMIC radio-occultation data, and more recently AMSU-A radiances.

Data products and users

AMPS forecasts are disseminated to the forecasting community primarily via a web interface (http://www.mmm.ucar.edu/rt/wrf/amps/), where a number of meteorological products can be readily viewed. These products are tailored to the needs of the SPAWAR forecasters operating at McMurdo forecast office (MacWeather) and at the SPAWAR Remote Operations Facility in Charleston, South Carolina, which handles forecasting for South Pole and field camps.

In addition to the website, a subset of the model output fields is distributed publicly worldwide via the Antarctic Internet Data Distribution (IDD) network, a system dedicated to Antarctic meteorological data sharing and based on Unidata's Local Data Manager (LDM) software. AMPS forecasts are also used by other national Antarctic programs, such as in Italy, Australia, the UK, Germany, and South Africa. An annual



The six AMPS domains with their horizontal grid spacings

Antarctic Meteorological Observation, Modeling and Forecasting workshop is organized each year to bring together the different participants in the AMPS and related projects, and the workshop has allowed AMPS to report on the hits and misses of the forecasting system and further to adapt the forecast products to needs.

Performance and benefits

The model performance has been monitored in multiple ways: by the MMM Division, on-site by forecasters at McMurdo, and by the PMG in comprehensive model performance reviews. This has allowed for a steady increase in the forecast quality.

Overall, the implementation of AMPS has proved a major breakthrough for logistical operations in the Antarctic. Midway through the five-hour Christchurch-McMurdo transit (the 'point of no return'), aircraft pilots may be instructed to turn back due to deteriorating weather at the destination. The implementation of AMPS has contributed to a 50% drop in the number of turnarounds or whiteout landings. While these improvements imply invaluable gains for personnel safety, they have also contributed to greatly reducing operational costs for the USAP. Additionally, AMPS has been instrumental in a number of high-profile rescue operations in Antarctica, such as the late-season evacuation of Dr Shemenski from the South Pole in April 2001, and the rescue of the German supply vessel Magdalena Oldendorff, which had become trapped in sea ice in June and July 2002.

Science

The collection of AMPS forecasts represents a 10-year-long archive featuring unprecedented high resolution and optimized polar physics. As such, it constitutes a valuable dataset for atmospheric studies. It is all the more interesting as existing global reanalyzes show major limitations in high latitudes, especially over the Antarctic. Currently, each AMPS forecast generates around 30Gb of data, representing a voluminous 22Tb per year, which are archived on NCAR's Mass Storage System.

In order to facilitate access to this dataset for the scientific community, a subset of this archive, featuring commonly used meteorological variables, is made freely available by the BPRC on its website (http://polarmet.osu.edu/PolarMet/ampsdb.html). Although the relatively short period and the changing model configuration are not optimal for long-term studies and trend analysis, the AMPS archive has already been applied to investigate specific weather events (such as a May 2004 windstorm at McMurdo) or for climatological studies (such as the climate of the McMurdo area, the Antarctic katabatic wind flow, the Ross Ice Shelf air stream, the precipitation regime in Dronning Maud Land, and the ocean influence in west Antarctica).

Perspectives

As the project approaches its 10th anniversary, there is little doubt it has been a highly successful endeavor that has been beneficial for, and has benefited from, operational needs and scientific interests. Among the pathways for future developments are the implementation of more advanced forecasting techniques and data sources (such as 4D-Var or ensemble data assimilation approaches and new satellite-derived observation types) and ensemble forecasting, to complement the current deterministic approach. ▮

David H. Bromwich & Julien P. Nicolas are from the Polar Meteorology Group, Byrd Polar Research Center, and Atmospheric Sciences Program, Dept. of Geography, The Ohio State University. Jordan G. Powers is from the Mesoscale and Microscale Meteoroglogy Division at NCAR. *The authors are very thankful to Dan Steinhoff, Andrew Monaghan and Kevin Maning for their contributions to the text and figures.*