5B.3 UNSTRUCTURED GRID ANTARCTIC WEATHER FORECAST SYSTEM

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1. INTRODUCTION

Weather forecasting in Antarctica is essential for US Antarctic Program (USAP) operations. However, forecasting in this region is extremely difficult both because the observational and modeling tools available are inadequate and because our understanding of the science behind the meteorology of Antarctica is incomplete. The weather of Antarctica is dominated by three factors: (1) the polar high and the baroclinic waves that circumnavigate the pole; (2) the terrain forcing that arises from the interaction of the complex topography and dynamically changing surface features with the larger scale flow; and (3) the katabatic processes that cool the near surface atmosphere at the higher surface elevations which leads to flow acceleration downslope. In order to forecast in this environment, it is essential that the models used resolve all of the important temporal and spatial scales of motion and include all of the important physical processes.

Improving the state of weather forecasting for USAP operations requires both improving the models and transitioning this capability to operations. Improving operational forecasting involves a *system of systems*, each of which must be considered in order to improve forecast skill: (1) data acquisition; (2) data ingest, quality control, and assimilation; (3) physical modeling; (4) visualization; and (5) results dissemination. For USAP operations, the basic lack of *in-situ* (only 32 surface observation and 8 rawinsonde stations exist) and remotely sensed (only partial satellite coverage exists and only during selected time periods of the day) data and data bandwidth are over-riding constraints that must be considered. Several groups are proposing new observation systems (ATOVS, COSMIC) that will add much needed data to the system, but this new data must be ingested, quality controlled, and assimilated into the forecasting systems.

At a recent NSF sponsored Antarctica Weather Forecasting Workshop (Bromwich, private communication) several themes emerged. The themes included:

- A need for more observational (*in-situ* and remotely sensed) data;
- A need for higher spatial resolution weather forecast models;
- A need to improve the physical parameterizations in forecast models;
- A need for field data to develop the improved parameterizations of surface properties and for model evaluation;
- Increased interaction between the research and operational communities; and
- Improved model guidance for the operational forecasters.

Most of the existing operational weather forecasting systems lack the ability to adapt to the underlying terrain as is required to simulate the highly scale interactive environment that exists in Antarctica. The Operational Multiscale Environment model with Grid Adaptivity (OMEGA) is a high resolution, high fidelity, operational weather forecasting system (Bacon *et al.*, 2000) based on an adaptive unstructured grid. OMEGA is a non-hydrostatic multiscale forecast model that has been used to forecast extreme or severe meteorological events from global scale to local scale as well as point and large area dispersion phenomena. SAIC has been exploring the utility of OMEGA for forecasting in Antarctica.

2. ANTARCTIC METEOROLOGY

Perhaps one of the most important mesoscale circulations generated from the interaction of the Antarctic surface with the atmosphere is the terrain forced (Schwerdtfeger, 1975) and katabatic (Parish, 1981) winds. Due to the diurnal heating and cooling of mountain slopes, thermal circulations often develop along these slopes. During the day, solar radiation warms the mountain slopes or valley walls, which in turn warm the air in contact with them. Due to convective mixing, air gets heated up to several hundred meters above the sloping surface. This heated air, being less dense than the air at the same elevation above valley floor, rises as an upslope wind. During the night, mountain slopes cool more quickly by outgoing radiation than the valley floor. The air in contact with the slopes and up to a depth of several tens of meters cools through conduction and turbulent mixing. This cooler dense air flows down the slope. These

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winds are sensitive to the local and regional topographic slope and diurnally varying temperature. They are observed in many mountainous regions of the world, particularly in Alaska, Greenland, Antarctica, Alps, Himalayas, and Rockies. Wind speeds of more than 90 m/s in Antarctica and 50 m/s in the mountain regions of Europe have been observed in some of these flows.

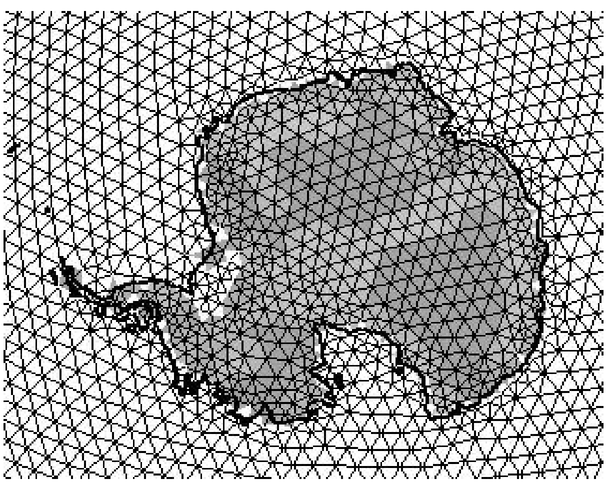
Intrinsic in the formation of katabatic flow is the exchange of heat and moisture between the surface and the lower layers of the atmosphere. This exchange is governed by the surface properties, which for the Antarctic involves a dynamic snow/ice condition. Fresh fallen snow has a low density, high ventilation factor, significant forward scattering component and hence different albedo and heat transfer coefficients than snow that has been compressed and glazed or completely melted to form an ice sheet. Blue ice has entirely different properties. Atmospheric radiation transport is an important factor in the melting of the snow surface and hence in the aging of the snow. Once the energy and moisture is in the lowest layer of the atmosphere, the boundary layer circulations and microphysics become important processes in determining the vertical energy and moisture distribution.

The discussion above shows how the atmospheric energy is distributed over a variety of flow modes, including thermally and internally generated global and local circulations and their eddies in an inherently multi-scale environment. The weather in Antarctica is significantly affected by this wide range of flow scales through variations in the mean transport wind, differential advection of moisture due to vertical and horizontal wind shear, and vertical mixing. When these complex flow modes and winds associated with them are generated, they can lead to ceiling and/or visibility restrictions on air operations. Therefore, these space-time flow scales and their interaction with each other and the moisture should be represented accurately in any study of Antarctic weather.

Accurate meteorological simulation requires accurate initial and boundary conditions. This includes surface variables such as elevation, land/water fraction, land use, vegetation, and soil texture. While many of these datasets are of high quality and high resolution (elevation at 1 km resolution) over most of the Earth, the quality of the standard datasets for the continent of Antarctica is limited. Figure 1 shows a comparison of a grid generated using the existing OMEGA elevation data, which has 30 arc-second resolution over most of the globe but which is essentially the USGS ETOPO5 (5 arc-minute or roughly 10 km) dataset over the continent of Antarctica, and the digital elevation model (DEM) produced by the Radarsat Antarctic Mapping Project (RAMP; Liu et al., 1999). Clearly the incorporation of the RAMP data and additional surface information would be a valuable addition to any system forecasting in Antarctica.

3. OMEGA

OMEGA is a complete, operational, atmospheric simulation system. It includes the



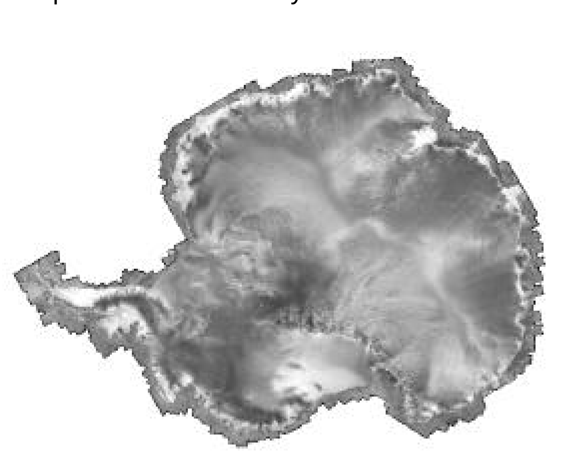


Figure 1. The triangular OMEGA grid, by its very nature, does not possess singularities at the poles - or anywhere else. The grid generator automatically identifies coastal regions and regions of complex terrain and refines them (left). The system, however, is limited by its input resolution, which could be significantly improved for Antarctica by the incorporation of the RAMP DEM (right). (*Note: DEM mosaic courtesy of Dr. Ken Jezek of The Ohio State University.*)

OMEGA model, static world-wide surface datasets required to define the necessary surface properties (elevation, land/water fraction, albedo, vegetation, *etc.*), data preprocessors to assimilate meteorological data, automated routines to download data from various operational data centers, as well as post-processors to analyze and visualize the simulation results. The kernel of the system is the OMEGA model – a three-dimensional, time-dependent, non-hydrostatic model of the atmosphere. It is built upon an unstructured triangular grid, which can adapt to a variety of static user-defined fields as well as dynamically during the simulation to the evolving weather (*cf.*, Figure 2). The unstructured triangular grid makes it possible to represent the underlying terrain with great accuracy. The dynamic adaptation increases the spatial resolution only where it is needed, (such as in the region of weather systems or steep terrain), automatically during runtime, thus optimizing the use of the computational resources.

The flexible OMEGA grid structure has proven to be extremely useful in modeling many complicated meteorological situations including those forced by topographic and/or coastal circulations, and even hurricanes. The latter provides an excellent example of the application of *dynamically adapting* unstructured grids to meteorological forecasting. OMEGA can automatically adapt its grid to the solution to provide better resolution where needed (*e.g.*, an aerosol or gas plume, or a surface temperature or pressure feature, such as the low central pressure of a hurricane). With dynamic adaptation, a model can concentrate its resolution on the regions of importance (steep gradients in the field variables), thus optimizing computational efficiency while maintaining the resolution needed to properly model the important physical processes.

The ability to provide high resolution in coastal regions and regions of complex terrain is obviously important for Antarctic weather simulation. Another area is the ability to simulate the multiscale interactions between the polar high circulation and baroclinic waves with the terrain and, once the high resolution terrain is incorporated, the ability to simulate the detailed surface and boundary layer processes that lead to katabatic winds.

4. ANTARCTIC WEATHER FORECASTING

As a demonstration, we built a grid for the Antarctic Peninsula (Figure 3a); the peninsula ranges in width from a few tens of kilometers at its most Northern extent to a few hundreds of kilometers near the continental landmass. We then performed a 24 hr forecast using the Navy Operational Atmospheric Prediction System (NOGAPS) analysis and forecast fields for the initial and lateral boundary conditions. The results indicate a significant amount of blocking of the synoptic flow as evidenced in the 24 hour OMEGA forecasted streamlines (Figure 3b). The NOGAPS

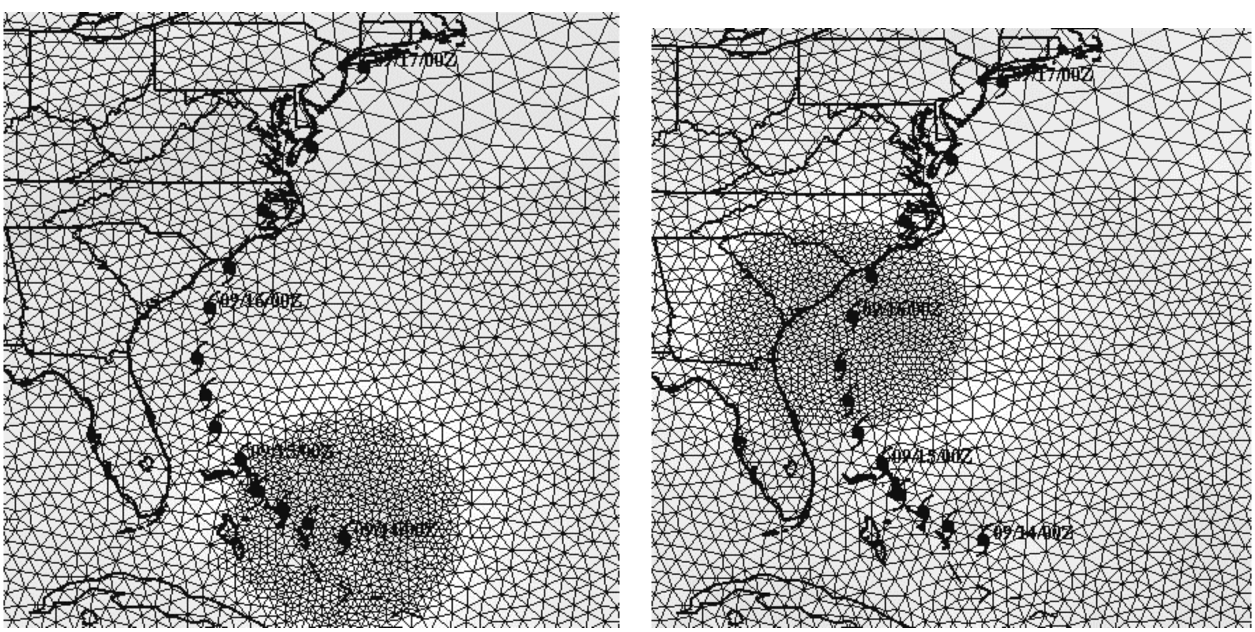


Figure 2. Dynamic adaptation improves efficiency by automatically putting high resolution only where required. Seen are the Hurricane Floyd grid initially (left) and at 48 hours (right); the black symbols are the observed track.

analysis fields (Figure 3c) could not see this effect due to the lack of detailed terrain in the model. This illustrates the importance of proper terrain representation in numerical weather simulations for Antarctica. The complexity of the terrain also provides a strong demonstration of the benefit of using an unstructured grid over traditional nested grid approaches.

The benefit of unstructured grid extends also to other surface properties. The air-surface physics that leads to the formation of katabatic winds in Antarctica are sensitive to the details of elevation changes as well as the surface condition (*e.g.*, blue ice, ice, packed snow, fresh snow). The incorporation of high resolution surface properties is considerably easier using an ustructured grid than a traditional mesh because these features often do not follow the grid alignment.

5. REFERENCES

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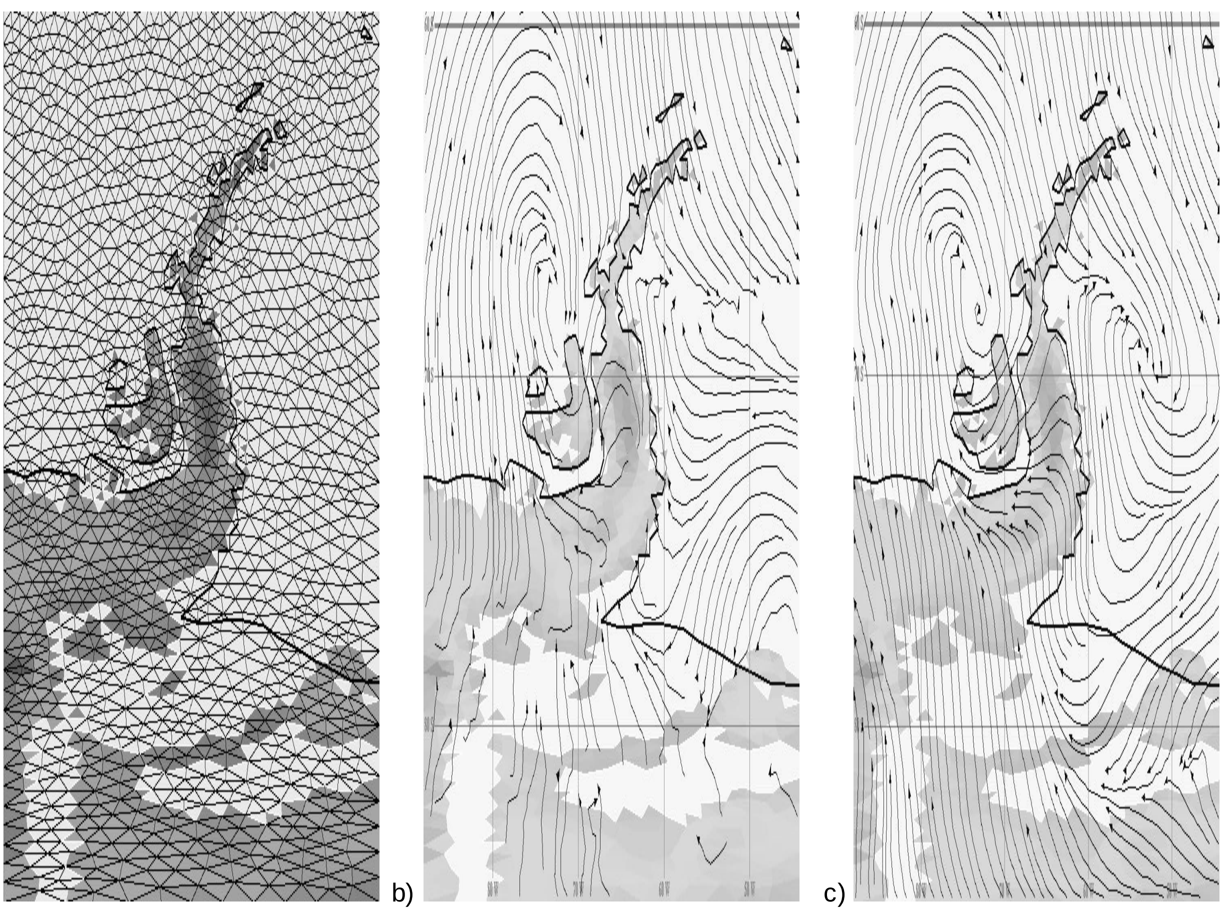

a) b) c)

Figure 3. (a) A regional OMEGA grid of the Antarctic Peninsula with grid resolution ranging from 30 to 75 km. The streamlines of the 24 hour OMEGA simulation (b) clearly show the effect of terrain blocking that is missing in the NOGAPS analysis (c) valid at the same time (0000UTC May 21, 2000).