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MULTIMODEL FINE-RESOLUTION ENSEMBLES FOR SHORT-RANGE FORECASTS IN MOUNTAINOUS TERRAIN

Roland Stull*, Henryk Modzelewski, Xingxiu Deng, Yongmei Zhou, Li Huang,
Trina Cannon, George Hicks II, Duane Storey, Miranda Holmes, and James Charbonneau
University of British Columbia, Vancouver, BC, Canada

1. INTRODUCTION

An operational, 4-model, NWP ensemble has been run daily for a year as part of a project to improve short-term, mesoscale, forecast skill over the complex (steep mountain, coastal) terrain of western N. America. The four models used in this study include NMS (from U. Wisconsin), MM5 (from NCAR and Penn State), MC2 (from RPN Canada), and WRF (from NCAR and NCEP).

- NMS = Nonhydrostatic Modeling System
- MM5 = Mesoscale Model version 5
- MC2 = Mesoscale Compressible Community model
- WRF = Weather Research and Forecast model

All the models are run for the same set of nested domains of 108, 36, 12, and 4 km horizontal grid spacing. In addition, the MC2 and MM5 are run at 2 km grid spacing, with this finest grid covering the Georgia Basin (Seattle, Victoria, Vancouver, and vicinity). All initializations are from the 00 UTC Eta analysis, from NCEP.

Real-time forecasts and verification statistics may be viewed at http://weather.eos.ubc.ca/wxfcst/

2. LOCALIZATION BY KALMAN FILTERING

Because of the steep topography, all the models have large biases, due to the averaging of terrain elevation across individual grid cells, when verified against point surface observations. To correct for this, we have been testing Kalman-predictor post processing to remove the "localization" effects of terrain in our point meteogram forecasts.

From our daily verification results against roughly 500 surface weather stations during the whole year, we find that:

(1) Inclusion of the Kalman-corrected coarse-resolution grids with all the other medium and finer grids helps improve the ensemble average point meteograms.

(2) A simple average of the Kalman-filtered forecasts for all 18 ensemble members (from 4 models, each at 5 or 4 horizontal resolutions) performs equally as well as an average of the raw model outputs when weighted inversely by their error variances.

* *Corresponding author address*: Roland Stull, Dept. of Earth & Ocean Sci., Univ. of British Columbia, 6339 Stores Rd., Vancouver, BC V6T 1Z4, Canada. 604-822-5901; email: rstull (at) eos.ubc.ca

In the steep mountainous terrain of British Columbia, Canada, the amount of Kalman correction is dominated by the station-elevation effect, and therefore shows little correlation horizontally with the amount of correction at neighboring stations. This means that the Kalman correction from the individual points cannot be spread to neighboring grid points. Namely, it is problematic to try to generate a Kalman-corrected weather map in mountainous terrain. Instead, we are limited to producing Kalman-corrected point-forecast meteograms for the 500 individual weather station sites.

The procedures described in the previous paragraphs have been applied to the following surface weather elements: temperature, humidity, wind speed and direction, pressure, and precipitation. We find that the equally weighted, Kalman filtered forecast makes improved forecasts for all these variables except precipitation and wind direction, in the very mountainous terrain of British Columbia.

The Kalman filter-corrected precipitation forecasts usually verify worse than the raw model output. Experiments with neural network correction (which is a nonlinear approach, as opposed to the linear approach of the Kalman filter), performed no better than the Kalman filter; namely, it too made the precipitation forecasts worse in mountainous terrain.

3. EFFECT OF THE "PACIFIC DATA VOID" ON THE ENSEMBLE VS. RESOLUTION ISSUE

Given the very steep topography, we find that ensemble forecasts need both many members AND fine resolution (for at least some of the members). We also find, as was found by Mass and others, that finer resolutions often give worse verification scores in regions with steep topography.

The reason is as follows. Although fine resolution allows the fixed topography to generate realistic mesoscale flow features (convergence bands and meso-gamma circulations), these features can be erroneously shifted if the mean, synoptic-scale flow hitting the mountains is from slightly the wrong direction.

For example, a predominantly west wind in the real atmosphere might result in a convergence band in the valley to the east of the mountain, dropping heavy rain on a town there. However, if the modeled synoptic scale flow is from the west north west, then the model produces a realistic-looking convergence band that is slightly too far south of town, and forecasts none of the rain hitting town. The mesoscale forecast is a bust.

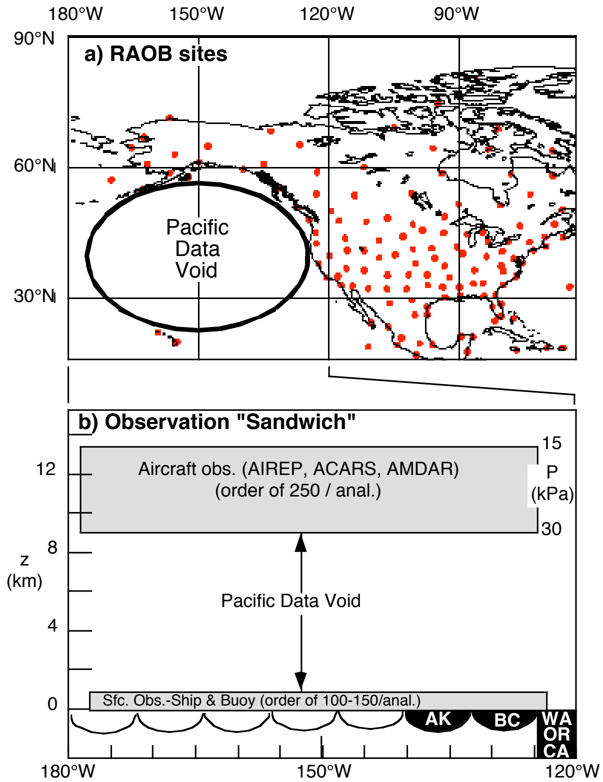


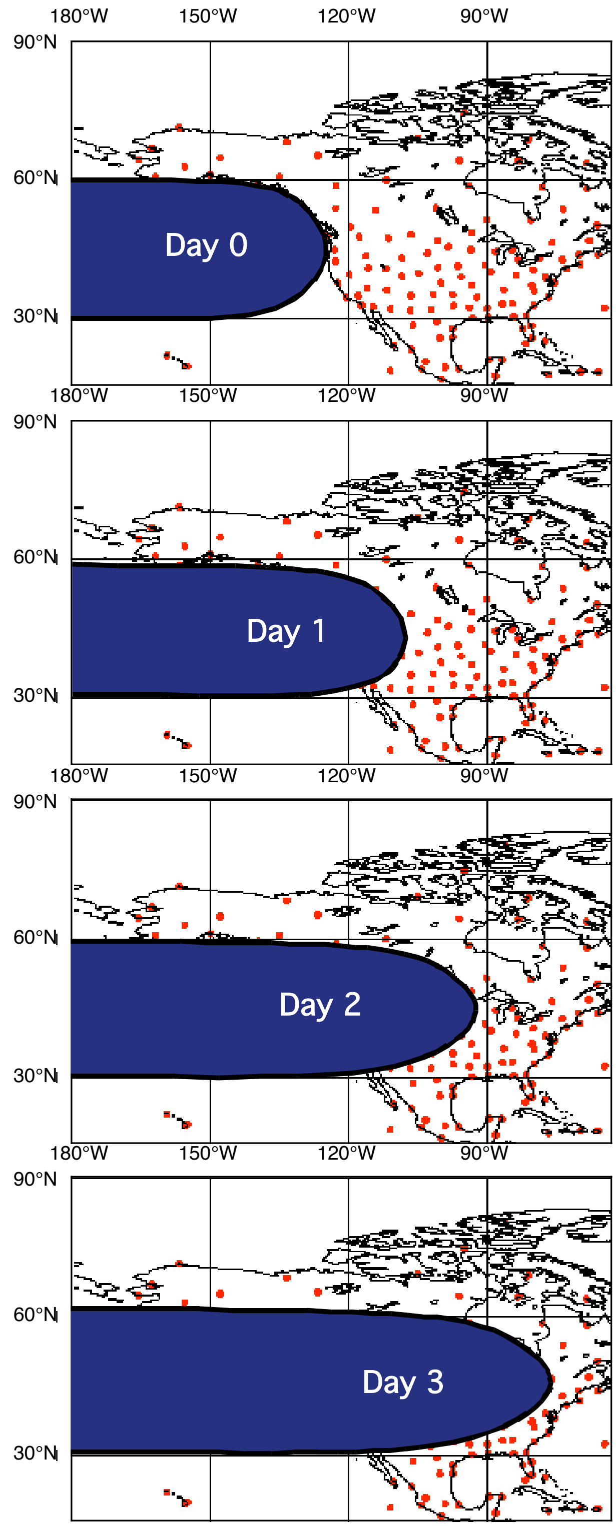
Figure 1. The Pacific Data Void.

This paradox has been traced to the lack of adequate in-situ wind and thermodynamic data in the lower and mid-troposphere over the Pacific Ocean, known locally as the “Pacific Data Void” (Fig. 1). Namely, slight errors in mean wind directly and timing of landfall of cyclones and fronts can cause geographic placement and timing errors as large as the mesoscale-gamma features being predicted. Further improvements in short range, 1-3 day, forecasts for British Columbia and Washington are unlikely until the data void is filled.

Because of the increased verification errors of high-resolution forecasts in mountainous terrain, we have the peculiar result that often coarser-mesh forecasts give better verification scores even though they completely lack any realistic mesocale features.

This leads to a counter-intuitive finding that our multi-model, multi-resolution ensemble average actually benefits by including the coarse resolution ensemble members along with the fine-resolution members. We suspect that is finding is specific only for steep mountainous regions immediately downwind of data-void regions, and would not be applicable in flat regions in the interior of data-rich continents.

4. SHADOW OF THE PACIFIC DATA VOID



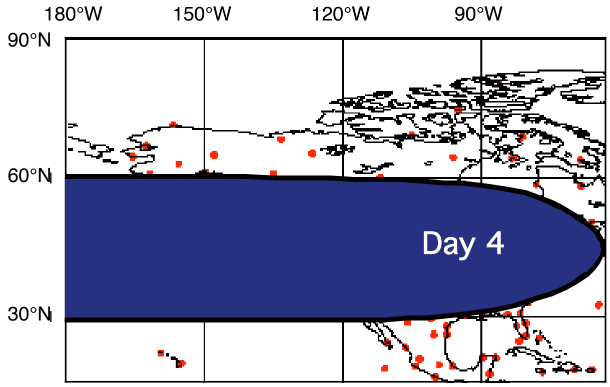


Figure 2. As forecast range progresses, the detrimental influence of the Pacific Data Void extends further east.

Due to the predominant west wind at mid-latitudes, the detrimental influence of the Pacific Data Void spreads downwind to the east as the forecast range progresses (Fig. 2).

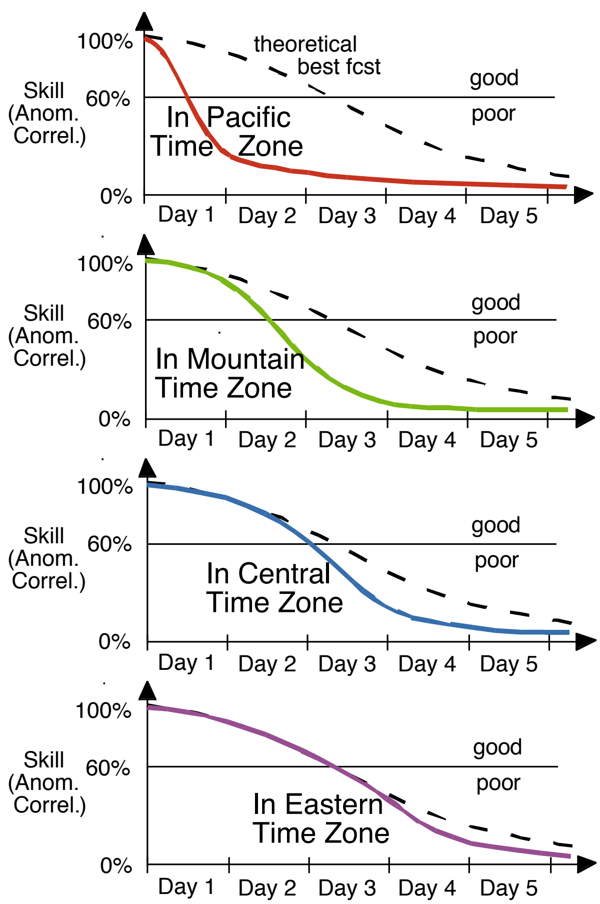


Figure 3. Idealization of NWP forecast skill (solid lines) in different parts of N. America, as roughly identified by their time-zone locations. Dashed line represents a theoretical best possible forecast skill.

The impact of this data void on the forecast skill downwind (estimated as an anomaly correlation), is greatest near the west coast, because the theoretical best forecast skill is high for a 1 to 2 day forecast, while the actual skill due to the data void is quite small. The curves in Fig. 3 apply only to the region of N. America dominated by mid-latitude westerlies. As the region of poor skill propagates east as forecast days progress, it is compared to theoretical best forecasts that are also significantly lower by that time. Thus, the impact of the data void there is only a slight decrease of an already poor skill.

In an integrated sense, the overall economic impact of the data void in any region is likely to be proportional to the area between the solid curve and the dashed curve in Fig. 3. This impact is extremely large in western N. America, and gradually diminishes further east.

It has been interesting to see that N. American national governments and their meteorological leaderships have been focusing mostly on increasing forecast skill for days 3 and 4 in the forecast. Since these national government headquarters are in the Eastern time zone for both the USA and Canada, one look at Fig. 3 shows why their focus is in that timeframe. However, for states and provinces in the Pacific Time Zone (in within the belt of mid-latitude westerlies), the area between these curves is so large, and happens so much early in the forecast, that it often seems to residents of the Pacific Northwest that they have been disenfranchised by the rest of their country.

The THORpex program aims to eliminate the Pacific Data Void by adding a balanced mixture of in-situ and new satellite observations. A separate paper (Spagnol et al, 2004) at this conference presents our development of a Rocketsonde Buoy System, as one of the in-situ systems being developed for THORpex.

5. FORECAST OUTPUT VISUALIZATION

The human-machine interface challenge is being addressed with several new types of graphic displays for output products. We have found that Vis5D, while extremely useful in research mode, is too complicated and time-consuming for operational meteorologists, who must meet short deadlines. We are experimenting with a display called Ensuite, which combines the ease of viewing a computer animation, with that of a multi-panel chart. More importantly, this display experiment allows easy display of ensemble members. We have also been exploring other graphics products that are more useful for fine resolution in steep terrain than are the traditional synoptic-scale maps.

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