Variability in shelf transports in the Gulf of Alaska. Part II: Downscaling atmospheric forcing using a mesoscale NWP model

Richard C. Steed, University of Washington, Department of Atmospheric Sciences
Nicholas A. Bond, University of Washington, JISAO

Abstract

The Gulf of Alaska (GOA) is subject to weather that s strongly impacted by its prominent coastal terrain. These effects must be included in the specification of atmospheric forcing of the ocean over the shelf of the GOA. It is possible to account for these effects given only large-scale representations of the atmosphere such as available from the NCEP/NCAR Reanalysis Project (NNRP) dataset through a method known as downscaling. The downscaling used here is dynamical, based on high-resolution NWP model simulations using the MM5. These simulations are run on a 15 km horizontal grid over the GOA using NNRP data, which is on a 1.5 degree horizontal grid, as input. Mesoscale meteorological phenomena that are known to be common in the coastal GOA, e.g., barrier jets and gap flows, appear to be much better represented in the MM5 simulations than in the original NNRP analyses. Those differences can be significant; a set of MM5 simulations from January, February, and March, 2001 showed average along-shore wind speeds in the northern GOA that averaged about 50% greater than their counterparts from the NNRP. Present work uses the MM5 driven by the NNRP to document how climate variability on large temporal and spatial scales is expressed in the coastal zone of the GOA.

1. Experimental Design

The overall goal of our research is to identify relationships between variations in environmental conditions and productivity of the north Pacific ecosystem. This project is focused on combining various modeling results in order to simulate these environmental conditions. To identify the relationships sought, historical ecosystem data is correlated with oceanic information. Ocean circulations in the Gulf of Alaska (GOA) region are strongly forced by meteorological conditions (Stabeno et al. 1995). Consequently, at the top level of this environmental simulation is atmospheric forcing. This paper describes the atmospheric modeling portion of the experiment, which is used to drive ocean modeling efforts, and ultimately, ecosystem modeling.

To drive these historical environmental simulations, data from the NCEP/NCAR Reanalysis Project (Kalnay et al., 1996) is used. This dataset is available from 1948 to present at 6 hour intervals. The NNRP gridded data was created by NCEP's GDAS data assimilation system using available historic observations and the MRF model to provide a continuous set of 3-dimensional "analyses" of the atmosphere throughout the time period. The gridded NNRP data is available on pressure levels, with horizontal grid spacing of 2.5 degrees.

During initial testing of the oceanic circulation simulations using the ROMS model, the NNRP dataset was used directly. Upon examination, the NNRP fields did not contain mesoscale structures such as the coastal jet, an important feature in the GOA region (Overland and Bond, 1993). For this reason, a method for physically downscaling the NNRP data is pursued to better resolve meteorological features which impact the ocean circulation.

In this experiment, version 3 of the 5th generation Penn State/ NCAR mesoscale model (MM5) (Dudhia, 1993) is used. To capture circulations on the scale of the Alaskan coastal jet, ~100 km, the MM5 is run in a nested configuration with an inner domain covering the Gulf of Alaska at 15 km horizontal grid spacing. Initial and lateral boundary conditions for these MM5 simulations are derived from the NNRP grids. The MM5 is configured with simple ice microphysics. the Kain-Fritsch convective parameterization, the MRF planetary boundary layer parameterization, a five-layer soil model, and cloud radiative forcing. To transition smoothly from the relatively coarse resolution of the NNRP grids to the 15 km domain of the MM5 simulations, the MM5 was configured with two outer domains covering progressively larger areas. The outer-most domain, at 135 km horizontal resolution, covers the North Pacific, Western North America, and Eastern Asia almost from equator to pole.

The MM5 simulations are run piecewise with overlapping 48 hour simulations to produce high-resolution atmospheric fields at 1 hour intervals throughout the years chosen for this study. Newtonian relaxation (nudging) is applied to the outermost domain in order to constrain the MM5's synoptic scale simulation to closely follow the guidance as given by the NNRP dataset.

Finally, the necessary parameters required by the oceanic circulation model are derived or extracted from the MM5 fields, and used to drive the ocean model simulations.

2. Results

Because the focus of the atmospheric modeling portion of this experiment is the adequately resolved simulation of meteorological features as compared to the already available NNRP dataset, comparisons are made here between MM5 results and NNRP analyses. Because the goal is to provide accurate atmospheric forcing as input to an ocean model, the fields used as forcing are examined most closely. Of these atmospheric fields, surface winds have the highest order impact on ocean circulation, and are presented here.

An example of the features of interest are provided by a winter case from February 2001 (Fig. 1). The coastal jet is evident as an area of enhanced southeasterly wind just off the coast of SE Alaska in the MM5 results. At the same time, the absence of this jet feature is apparent in the NNRP plot.

In contrast to wintertime conditions, which are dominated by frequent landfalling cyclones, more typical 2001 summer conditions are depicted in Figure 2. Although MM5 and NNRP are more similar here than in Figure 1., there still exists some enhancement of the alongshore component of wind, due to better resolution of the land-sea pressure gradient in the MM5.

Another difference frequently observed between MM5 and NNRP is the strength of the circulation about low pressure systems as they transit the area. As a result of higher resolution, the MM5 results show much tighter pressure gradients than do NNRP, especially on the land side of such systems, where the strongest winds are seen. Figure 3. shows an event from December 2001 illustrating this feature. Although the track of the low and it's magnitude are similar, much stronger wind is seen on the landward side of the low.

To quantify differences in winds between MM5 and NNRP, time series of surface wind are shown for specific points from both sources. Figure 4. is a plot of wind over time from MM5 and NNRP at two points: near-shore about 25 km south of Cordova, AK, and offshore about 250 km south of that. These stick-vector time-series show that MM5 produces much stronger winds along the coast than does NNRP, with a much greater preference for an along-shore direction. In the case of the offshore location, the differences are more subtle, with the general direction of the flow more similar.

The difference in wind, winter and summer, in both MM5 and NNRP, is quite distinct. The vector average wind from MM5 during the winter season is ESE 15 kts near-shore and S 7 kts offshore. Wind data extracted from NNRP over the same time period averaged SE 10 kts near-shore and SSE 9 kts offshore. During the summer months, MM5 winds average SE 4 kts near-shore and SSE 1 kt offshore, while in NNRP, both near- and offshore locations average SSE at 2 kts.

To see how differences between MM5 and NNRP are quite systematic, especially in directional preference, polar plots of U and V component wind are seen in Figures 5 and 6. These plots show clearly that MM5 produces stronger wind speeds with a more pronounced along-shore directional preference.

3. Conclusions

Obvious differences exist in the details of results from MM5 and NNRP. Downscaling the historical analyses of NNRP using the MM5 model produces meteorological structures which are qualitatively more in agreement with observations than using the NNRP data alone. The specific feature of the coastal jet, an area of enhanced wind along the coast resulting from terrain induced ridging during onshore flow situations, is resolved in the MM5 results, while much weaker or even absent in the NNRP fields. The effects of this feature are strongly felt in ocean circulation model results, indicating that the process of downscaling atmospheric forcing is an important step in simulating the overall environmental system in the Gulf of Alaska.

4. Ongoing Work

As this project continues through FY 2005, the methods described here will be extended to cover the period from 1997 through present, during which time extensive supplementary observational assets have been deployed in support of these efforts. To better understand how the GOA environmental system responds during changes in the climate regime, simulations will be performed over selected years before and after the 1976-77 "climate regime shift". It is planned to utilize all of these results to identify empirical relationships between synoptic-scale flow and mesoscale coastal meteorological structures.

5. References

Dudhia, J., 1993: A Nonhydrostatic Version of the Penn State-NCAR Mesoscale Model: Validation Tests and Simulation of an Atlantic Cyclone and Cold Front. *Mon. Wea. Rev.*, 121, 1493-1513

Kalnay, E., M.Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y. Zhu, A. Leetmaa, B. Reynolds, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K.C. Mo, C. Ropelewski, J. Wang, R. Jenne, and D. Joseph, 1996: The NCEP/NCAR 40-Year Reanalysis Project. *Bull. Amer. Meteor. Soc., 77, 437-472*

Overland, J.E., and N.A. Bond, 1993: The influence of Coastal Orography: The Yakutat Storm. *Mon. Wea. Rev.*, 121, 1388-1397

Stabeno, P. J., R. K. Reed, and J. D. Schumacher, 1995: The Alaska coastal current: Continuity of transport and forcing. *J. Geophys. Res.*, 100, 2477-2485.

Corresponding Author's Address:

Richard C. Steed
Department of Atmospheric Sciences
Box 351640
University of Washington
Seattle, WA 98195-1640
(206) 685-2183
email: steed@atmos.washington.edu

Figures:

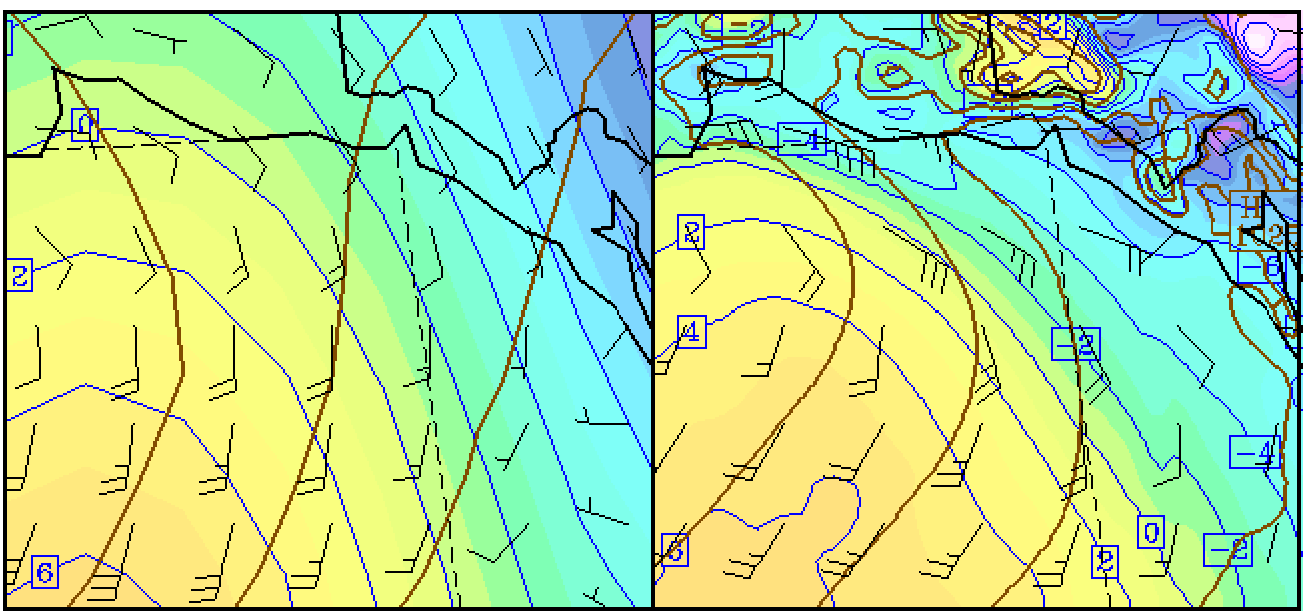

Figure 1. Surface winds in the northern Gulf of Alaska, 00 UTC 12 February 2001. Left shows NNRP and right MM5.

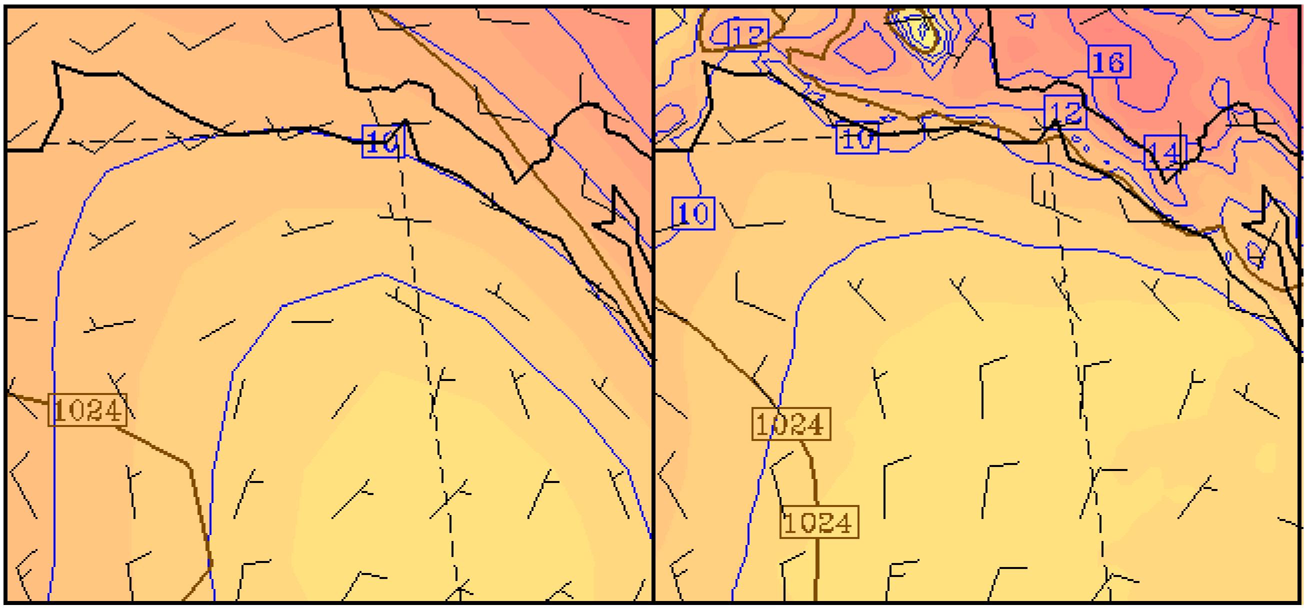

Figure 2. Surface winds in the northern Gulf of Alaska, 00 UTC 12 August 2001. Left shows NNRP and right MM5.

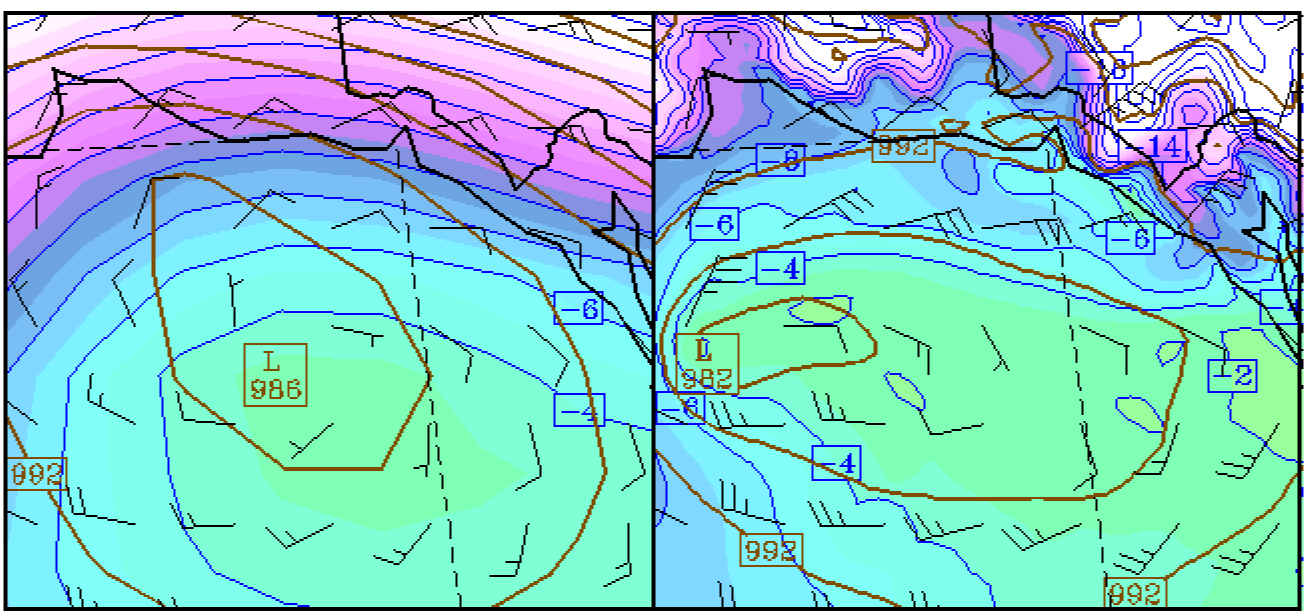

Figure 3. Surface winds in the northern Gulf of Alaska, 00 UTC 18 December 2001. Left shows NNRP and right MM5.

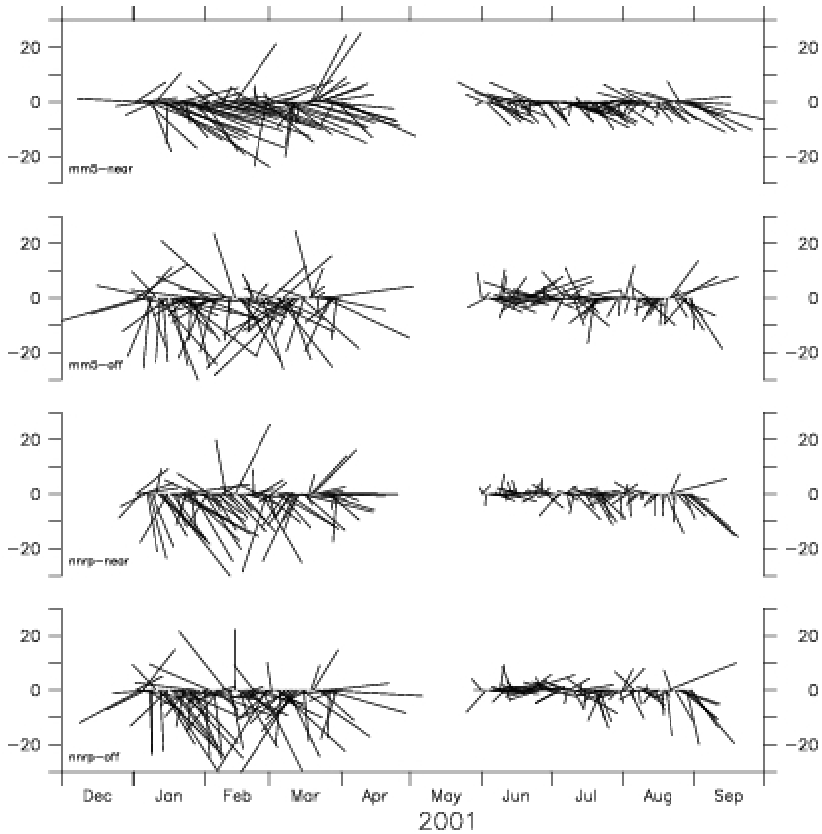

Figure 4. Time series of winds at two points in the Gulf of Alaska during two seasons in 2001. "near" indicates a point about 25 km S of Cordova, AK, and "off" indicates a point about 250 km south. The "sticks" point toward direction wind blows from. Length of "sticks" indicates speed in knots (see scale on ordinate). Top two series are MM5 and bottom are NNRP.

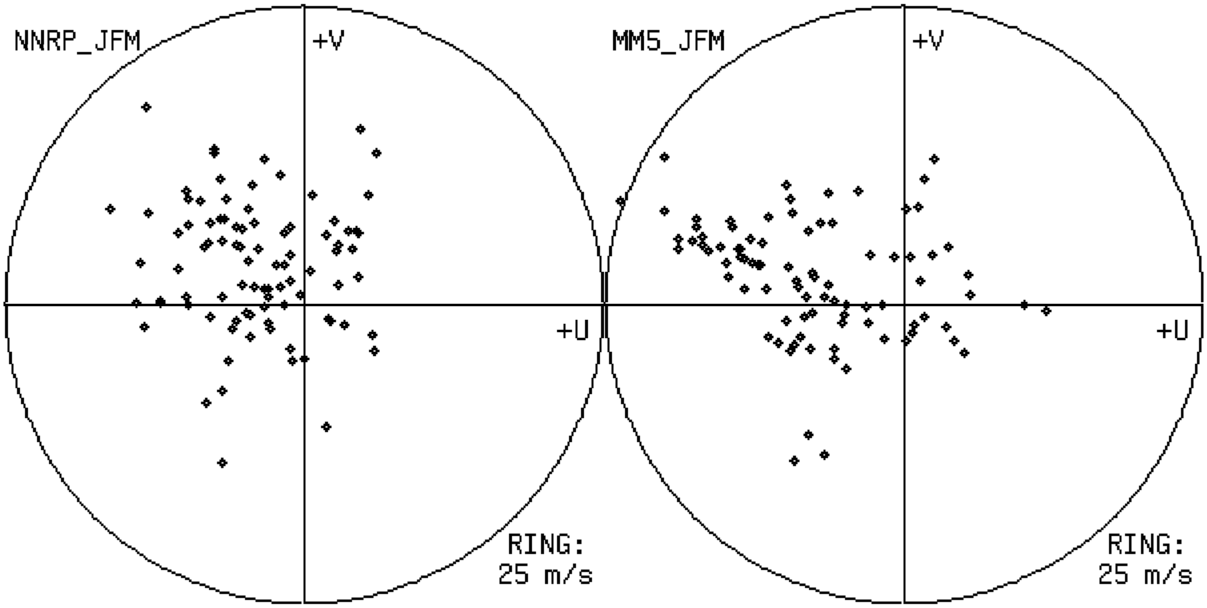

Figure 5. Polar composites of wind during January, February, and March, 2001. At left is NNRP and right MM5. Winds are from the near-shore point 25 km south of Cordova, AK. Points are plotted according to U and V component of wind, so a vector from the origin to a point would be in the direction the wind blows toward.

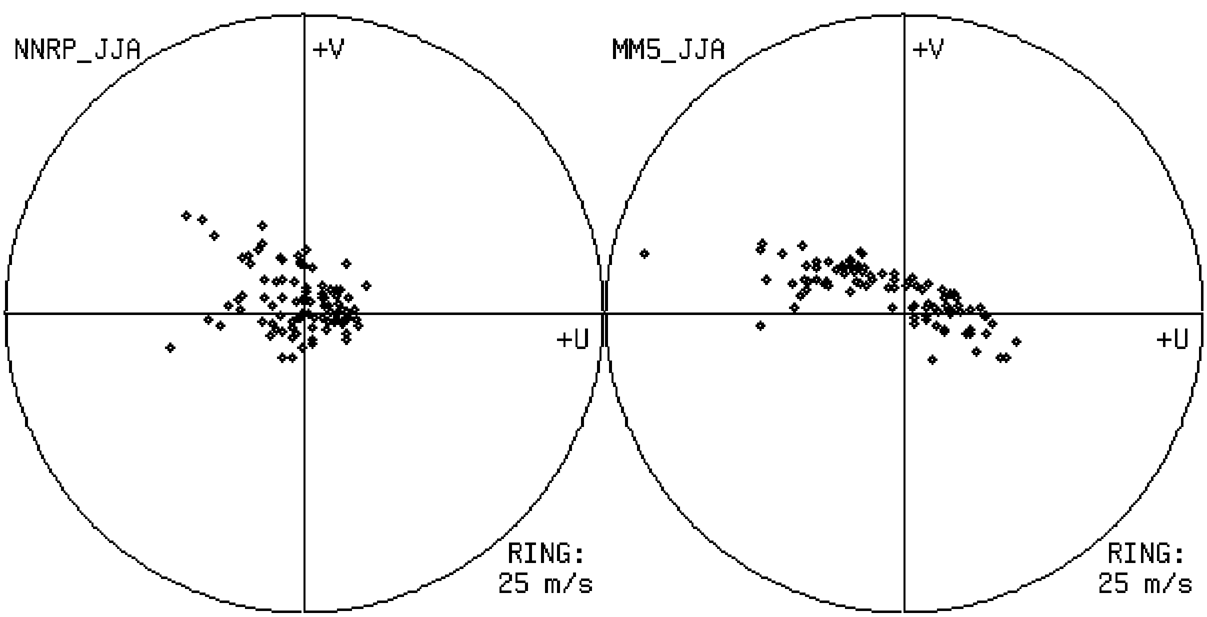

Figure 6. Polar composites of wind during June, July, and August, 2001. At left is NNRP and right MM5. Winds are from the near-shore point 25 km south of Cordova, AK. Points are plotted using same convention as in Figure 5.