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5.6 A COMPUTATIONALLY EFFICIENT METHOD FOR OBTAINING MODEL FORECAST WINDS IN THE VICINITY OF COMPLEX COASTAL OROGRAPHY

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1. INTRODUCTION

Advances in computers have provided the means for generating fine resolution mesoscale numerical weather predictions (NWPs). Each computer advance brings demands for forecasts on ever smaller scales, especially by such disciplines as air pollution modeling and fire weather forecasting. Weather forecasts and observations on very small scales are essential for driving the models used in these important decision-making processes. Even with the improvements in mesoscale NWPs, the horizontal scales desired by these communities are still too small to be treated by current computer technology in a timely and practical fashion. Even if the computer resources were adequate, mesoscale model parameterizations are not necessarily appropriate for these small scales, thereby potentially introducing significant model error in mesoscale NWPs.

One possible solution to the problems outlined above is to use a mesoscale model to predict on the scales for which it is both appropriate and practical, and supplement those forecasts with a diagnostic model to address the smaller scale topographic effects. This approach has already been implemented on an experimental basis, using the forecasts from a mesoscale model run at a moderate horizontal grid spacing (12 km) as input into the Winds on Critical Streamline Surfaces diagnostic model (WOCSS, see Ludwig et al. 1991 for a description). The WOCSS approach is used to adjust the mesoscale forecast winds to fine resolution orography. This system has proven quite practical in preliminary tests. This study extends recent work by Mohammed (2000), who used the composite mesoscale model-WOCSS system to obtain fine scale (~3 km) results. He showed that the combination provided better results in the coastal region of the California Bight than could be obtained by running the mesoscale model itself for a similarly fine grid. We will expand Mohammed's tests to case studies of the central California coastal zone for the model grid configuration shown in Figure 1 and examine the potential shortcomings and biases of the mesoscale model-WOCSS system. The quality of the diagnosed winds will be compared to a baseline fine-scale mesoscale model forecast using a consistent resolution of the complex coastal orography. The Navy's Coupled Ocean/Atmosphere Prediction System (COAMPS, version 2.0.15, Hodur 1997) and the National Center for Atmospheric Research/Penn State's Mesoscale Model Version 5 (MM5, version 3.3, Grell et al. 1995) are the mesoscale models which are used to drive the WOCSS diagnostic model in this study, although the approach should work with most mesoscale models.

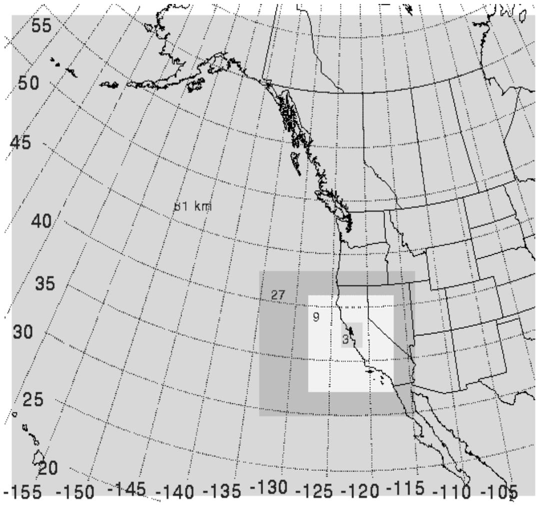

Figure 1: *Grid configuration of nested mesoscale model domains with grid spacings decreasing from 81 to 3 km in multiples of 3.*

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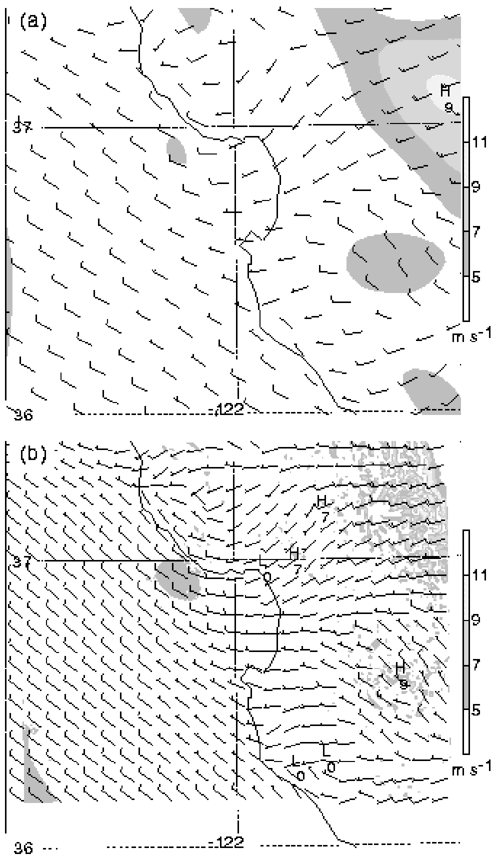

Figure 2: A 27-h *wind forecast at 22m above ground level valid at 0300 UTC 9 August 2001 as simulated by (a) MM5 at 12 km grid spacing and as diagnosed by (b) WOCSS at 1 km grid spacing. Isotachs are shaded in m s^{-1}. Every wind barb is plotted in (a) and every sixth wind barb is plotted in (b).*

2. METHODOLOGY

The WOCSS model has traditionally been applied by including as input available surface and upper-air observations of winds and temperature within a specified domain along with a fine-scale topographic database in order to generate a three-dimensional flow field which is consistent with the local topography and static stability on a given day (Ludwig et al. 1991, Ludwig and Sinton 2000). The flow field is determined by forcing the conservation of total (kinetic and potential) energy for the given static stability conditions which, given a highly stable environment, means that the flow field will generally be *around* orographic obstacles rather than *over* them.

The new approach presented in this study has been implemented whereby mesoscale model output is converted to the surface and upper-air format expected by WOCSS and is used by the WOCSS model to diagnose the flow field in the vicinity of complex orography on finer scales than those resolved in the “mother” mesoscale model. An example from the quasi-operational Naval Postgraduate School MM5/WOCSS flow field at 22m above ground level centered over Monterey Bay is shown in Figure 2. The mesoscale model wind and temperature forecasts at 12 km grid spacing (Fig. 2a) have been input into WOCSS along with topographic elevation information at 1 km grid spacing for grid points located over the Monterey Bay region. The result, shown in Fig. 2b, is greater detail in the wind structure in the far northeast corner of the domain as well as a wind speed enhancement as the air flows near Santa Cruz around the mouth of northern Monterey Bay. Evaluation of the realism of such structures is an emphasis of this study. The challenge in verifying MM5/WOCSS wind forecasts over the Monterey Bay region is the generally low observation data density.

A 36-h MM5 forecast with a triple nest configuration (108, 36, and 12 km grid spacings) requires three hours of wallclock time on a four processor SGI Origin 2000. The entire WOCSS diagnosis for 13 time periods (MM5 output is dumped at a three hourly forecast interval) requires 30 minutes on a single SGI 300 MHz processor. The requirement for running a 36-h MM5 forecast for a configuration having a innermost nest of 1 km grid spacing would result in a leap of at least an order of magnitude in forecast generation wallclock time, clearly impractical given quasi-operational time constraints.

The purpose of this study is to validate the mesoscale model/WOCSS (MM/WOCSS) approach for a variety of case studies using forecasts from two types of mesoscale models. The case studies have been chosen for periods when special observations are available. Furthermore, the domain of interest has been expanded to include the San Francisco Bay region which will allow a comparison to a larger number of observations for model verification. Using forecasts from two types of mesoscale models will provide an estimate of the variability in the mesoscale model/WOCSS approach due to the “mother” mesoscale model forecast error.

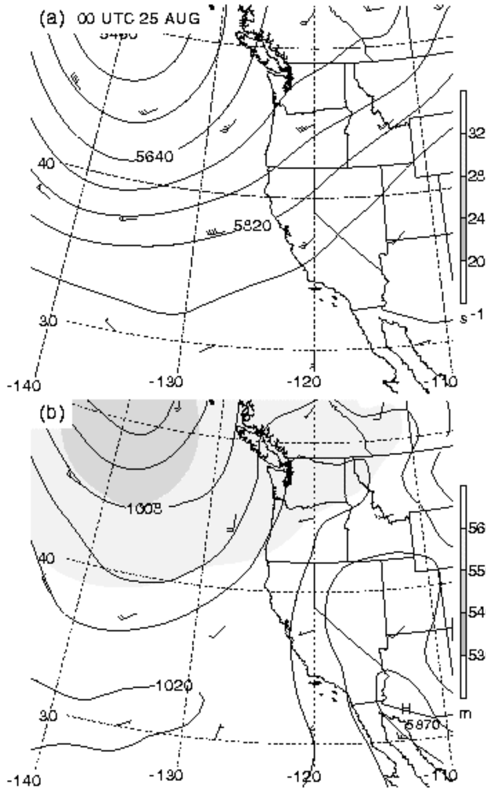

Figure 3: *Analyses from the NAVY NOGAPS model of [a] 500 mb geopotential height (m, contours) and absolute vorticity ($x10^{-5}$ s^{-1} , shading) and [b] mean sea level pressure (mb, contours) and 1000-500 mb thickness (m, shading) valid at 0000 UTC 25 August 1997.*

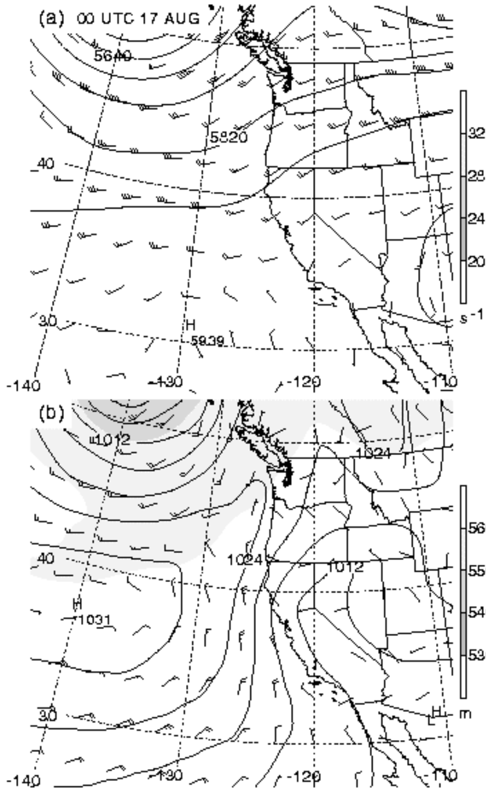

Figure 4: *Analyses from the NCEP ETA model of [a] 500 mb geopotential height (m, contours) and absolute vorticity ($x10^{-5}$ s^{-1} , shading) and [b] mean sea level pressure (mb, contours) and 1000-500 mb thickness (m, shading) valid at 0000 UTC 17 August 2000..*

3. CASE STUDY DISCUSSION

The summertime case studies have been included to investigate the sensitivity of MM/WOCSS results to relatively stagnant synoptic-scale weather regimes. In such situations, the MM/WOCSS wind diagnoses may prove to be very sensitive to the accuracy of the fine-scale details forecast by the “mother” mesoscale model.

The synoptic pattern as derived from the NAVY NOGAPS model analyses valid at 0000 UTC 25 August 1997, shown in Figure 3, indicates a cut-off low pressure system over the Gulf of Alaska with a relatively flat geopotential and pressure gradient at 500 mb (Fig. 3a) and at sea level (Fig. 3b), respectively. This particular case was a situation in which a controlled burn located near Monterey, California quickly became uncontrolled when the mesoscale weather conditions suddenly changed as the marine boundary layer inversion strengthened and marine air moved inland, thereby trapping smoke and fumigating the Salinas Valley. Such a case is ideal for testing an approach with potential applications for fire weather forecasting and decision aids.

The synoptic pattern for the 0000 UTC 17 August 2000 case (Figure 4) indicates a similar cut-off low pressure system over the Gulf of Alaska. However, the sea level pressure gradient over northern California is moderate resulting in wind speeds of 10-15 m s^{-1} offshore, more typical of coastal summertime conditions. Although the surface pressure gradient is significant, the change in the synoptic-scale features proved to be gradual over the successive 36 hours, making the case ideal for evaluation of mesoscale effects on the accuracy of the MM/WOCSS approach. Special aircraft observations are available over Monterey Bay for the period 17-1800 UTC 17 August.

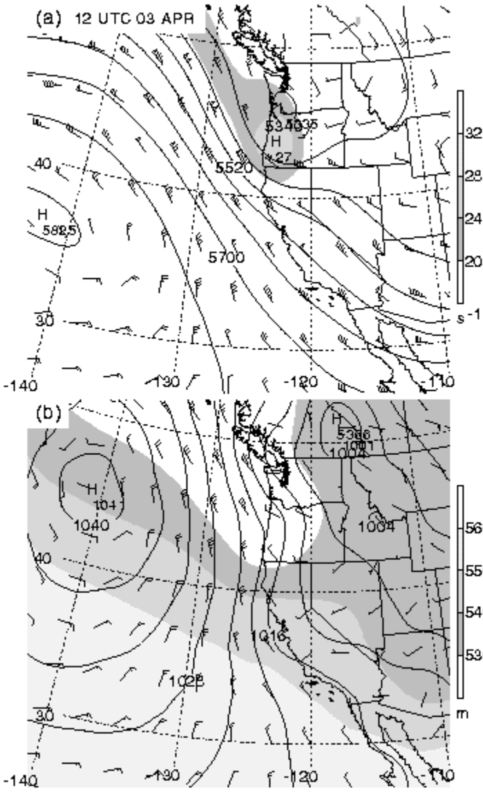

Figure 5: *Analyses from the NAVY NOGAPS model of [a] 500 mb geopotential height (m, contours) and absolute vorticity (x10*$^{-5}$ *s*$^{-1}$ *, shading) and [b] mean sea level pressure (mb, contours) and 1000-500 mb thickness (m, shading) valid at 1200 UTC 03 April 1999.*

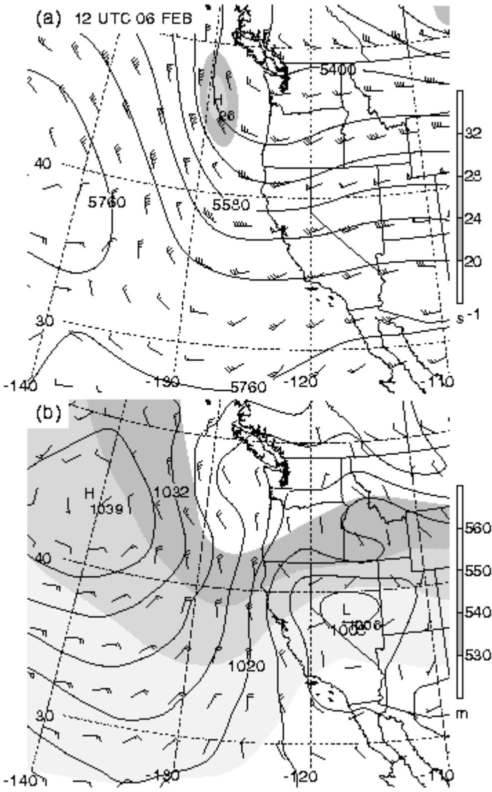

Figure 6: *Analyses from the NAVY NOGAPS model of [a] 500 mb geopotential height (m, contours) and absolute vorticity (x10*$^{-5}$ *s*$^{-1}$ *, shading) and [b] mean sea level pressure (mb, contours) and 1000-500 mb thickness (m, shading) valid at 1200 UTC 06 February 2001.*

The cold season case studies have been included to investigate the sensitivity of MM/WOCSS results to strongly forced synoptic-scale weather regimes. In such situations, the MM/WOCSS wind diagnoses may prove to be more sensitive to the accuracy of the phase and propagation of the synoptic-scale features forecast by the “mother” mesoscale model.

The synoptic pattern valid at 1200 UTC 3 April 1999 (Figure 5), as derived from NOGAPS, indicates a cold trough and 500 mb shortwave digging southward toward California. The surface winds along coastal central California intensified through the day, reaching speeds which caused significant damage and a fatality just inland from the coast (Miller et al. 2002). The quasi-operational Naval Postgraduate School MM5 12km forecast captured larger mesoscale features, but was unable to accurately replicate precisely the wind evolution in the mouth of the Salinas Valley (Miller et al. 2002). Generation of wind diagnoses for this case using the MM/WOCSS approach will help determine if details missing from the 12 km mesoscale model wind forecast is due to poorly resolved coastal terrain features.

The final case study occurred during the Pacific Landfalling Jets (PACJET) Experiment in February 2001. Note the similarity with the 3 April 1999 case; a cold trough digging toward California. The upper trough and associated vorticity maximum (Fig. 6a) were not as intense as the April 1999 case, however, coastal wind speeds along northern and central California are significantly above the climatological mean associated with the strong surface pressure gradient (Fig. 6b). In both cold season case studies, strong high pressure dominates offshore at the surface while cyclogenesis occurs inland over Nevada. These conditions, in addition to the upper-level vorticity maximum, are prime ingredients for strong surface wind events along the California coast (Miller et al. 2002). Special observations were taken during the February 2001 case in conjunction with the PACJET experiment which will provide a unique verification dataset.

4. SUMMARY

Each case study has been simulated for the nested domain configuration depicted in Figure 1 using MM5 and COAMPS as the mesoscale model drivers for the WOCSS model. A challenge to the MM/WOCSS approach is how to separate error originating in the mesoscale model from error arising from the imperfect WOCSS approach. Results presented in Ludwig et al. (1999), Ludwig and Sinton (2000), and Mohammed (2000) have suggested the potential weakness of the WOCSS methodology in regimes of neutral and unstable flow conditions as well as the tendency of WOCSS to underestimate rather than overestimate wind speeds. It is hoped that close examination of both cold and warm season case studies will provide a variety of flow stratification conditions which will better illuminate the strengths and weaknesses of the MM/WOCSS approach.

In summary, results will be presented for an approach which uses forecasts from a mesoscale model resolving features on a moderate horizontal scale as input to the WOCSS model which adjusts the mesoscale forecast winds to fine horizontal scales using high resolution topographic information. The advantage to this approach is; (1) the savings in computation time required to generate wind forecasts at very fine scales and (2) to provide an alternative to applying mesoscale models on horizontal scales for which their physics parameterizations are not appropriate. The accuracy of the MM/WOCSS approach will be evaluated for four case studies to determine its applicability over a wide range of weather regimes.

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