Evaluation of the Timing and Strength of MM5 and Eta Surface Trough Passages over the Eastern Pacific

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1. INTRODUCTION

Recently, there has been a growing number of model verification studies evaluating National Centers for Environmental Prediction (NCEP) and research mesoscale model forecasts (e.g., Colle et al. 2001; Mass et al. 2001 Colle et al. 1999; White et al. 1999). Most of these studies use objective error statistics such as bias, mean absolute error, and root mean square (RMS) error to verify model temperature, wind, geopotential height, humidity, and precipitation at model grid points or at observation locations. Although such verification techniques are useful, they provide little information on the timing errors and structures of transient meteorological phenomena such as troughs, fronts, or cyclones.

The goal of the present study is to complete the first long-term verification of surface trough passages upstream of the U.S. West Coast during the cool season, evaluating both the timing and strength of the PSU-NCAR MM5 and NCEP Eta trough forecasts. Forecasting surface trough passages along the U.S. West Coast is particularly challenging because of the data-sparse Pacific upstream. In addition, the steep coastal topography substantially modulates trough/frontal strength and timing. Quantifying timing errors is important beyond short-term West Coast forecasting, since these errors can propagate inland and affect longer-term forecasts over the remainder of the U.S. and North Atlantic.

This study utilizes the 36- and 12-km resolution forecasts from the University of Washington (UW) real-time MM5 as well as the NCEP Eta interpolated to a 80-km grid. Colle et al. (1999) provides more details on the UW real-time MM5 system. Initial and boundary atmospheric conditions for the MM5 were obtained from the 3-hourly NCEP Eta model analyses bilinearly interpolated to the MM5 grid. All MM5 simulations used the “simple ice” moisture scheme, the Kain-Fritsch cumulus parameterization, and the Medium Range Forecast (MRF) planetary boundary layer.

2. METHODS

Since September 1997 a long-term verification dataset has been collected at UW by comparing the 3-48 hour MM5 forecasts with all available surface and rawinsonde observations within the model domains (Mass et al. 2001). This was done by bilinearly interpolating the model forecasts to each observation site, so that for each station and forecast time there are corresponding observation and model values for sea-level pressure, temperature, winds, relative humidity, and precipitation. The NCEP-104 grids (80 km resolution) were used to construct the Eta verification files at 3-h forecast intervals.

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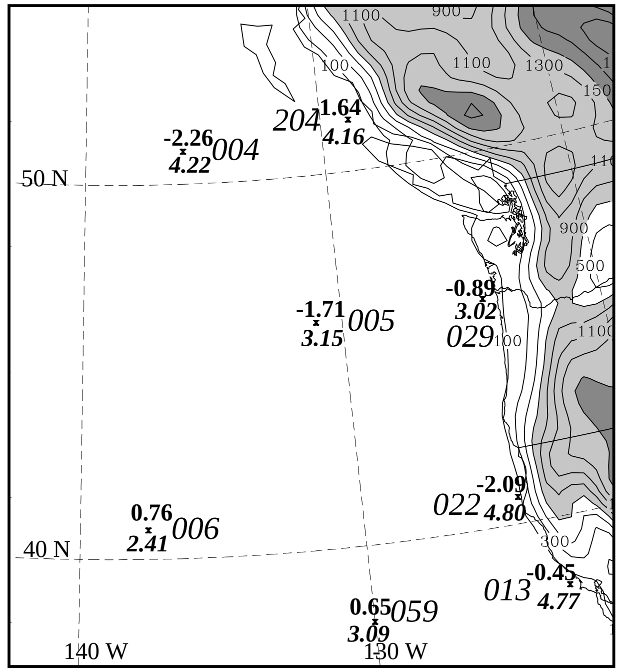

Figure 1. Mean (top number) and mean absolute (bottom, italics) surface trough timing errors (hours) in the MM5 for the 1998-2000 cool seasons (September through March). A negative mean error indicates the MM5 troughs are early on average. The buoy number (004, 005,...) is given by the large italic numbers.

The surface trough passages were screened using 3-hourly model forecasts interpolated to each buoy site for the same time intervals (ending at 0, 03, 06, 09 UTC ...). Since the temperature changes associated with surface trough passages over the Pacific Ocean are often masked by highly modified near-surface air which had spent days over a relatively uniform ocean, only winds and pressure were used to identify the cases. The surface trough passages were identified by a 30^{o} cyclonic windshift (5 kt windspeed minimum) accompanied by a 0.5 mb 3-h sea-level pressure rise. If consecutive 3-h periods met this criteria, only the first period was selected. These thresholds were chosen based on their ability to select events identified on NCEP surface charts. The 30^{o} windshift threshold could not be used for the Eta since the 80-km resolution “104” grids led to smoother and more gradual windshifts (20-30^{o} in 3-h) for many cases. Therefore, the 3-h windshift threshold for the Eta events was reduced to 20^{o}; each of these cases was carefully checked against NCEP charts to insure that it involved a surface trough. Finally, in order to directly compare the Eta and MM5, the trough events from the Eta and MM5 were matched by selecting the same cases for each initialization time.

3. VERIFICATION OF MM5 AND ETA

Figure 1 shows the MM5 mean frontal timing errors (in hours) for the 1998-2000 cool seasons (September through March). The timing errors were computed as the forecast trough passage time minus the observed so that a positive (negative) error (or bias) indicates that the modeling timing was late (early). The 36-km MM5 surface troughs tended to be early (1-2 h) to the north of ~42 ^{o}N and along the coast. In contrast, the troughs were approximately 0.75 h late over the offshore waters to the south of 42 ^{o}N. A two-tailed Student’s t-test found that the mean errors are significant at the 95% level to the north of 42 ^{o}N (buoys 204, 004, 005, and 029) and near the steep northern California coastal terrain (buoy 022), and at the 90% level offshore to the south of 42 ^{o}N (buoy 006).

Mean absolute timing errors were also calculated to determine the average timing error without error cancellation between the early and late events (Fig. 2a). Mean absolute errors are considerably larger than the mean errors, and are smallest over the southern offshore waters (2.5 to 3.0 h) and increase to 4-5 h to the north or along the steep northern California coastal terrain.

Overall, an analysis of the 36-km MM5 forecasts suggests that large-scale and terrain influences as well as the intensity of the troughs affect frontal timing errors. The large early biases towards the north are located within the mean synoptic storm track, where the zonal winds tend to be large. Increasing early biases near the coast suggests that the 36-km MM5 is not capturing trough deceleration associated with terrain blocking.

Does model resolution influence timing error? To address this question the 36-km MM5 timing errors at buoy 29 (just offshore of the Oregon/Washington border) were compared to the 12-km MM5 timing errors using the same trough passages (not shown). It was hypothesized that the early timing errors would be reduced going from 36- to 12-km resolution since greater flow blockage produced by higher and steeper 12-km terrain might slow the simulated surface troughs. However, the early timing errors were only reduced by 5-10% in the 12-km domain, and the difference in timing compared to the 36 km domain was not significant at the 90% level. This lack of significant improvement may be the result of troughs not having enough time to adjust and decelerate after they enter the 12-km domain. Alternatively, the 12-km resolution may still not be sufficient in this region, and/or the model may have physics deficiencies such as insufficient surface drag over land and/or water.

It is not only important to understand the average timing error for each station but also the distribution of the errors. Figure 2 presents the frequency of various timing errors at buoys 004, 006, and 022 based on forecasts from the 1998-2000 cool seasons. The number of occurrences are separated into three forecast hour periods: 3-18h, 18-33h, and 33-48h. For all buoys many of the simulated fronts are on-time (within 3 hours of the observation); however, the overall distribution of timing errors changes dramatically both in the north-south (Figs. 2a,b) and east-west (Figs. 2b,c) directions.

At the northern offshore buoy 004 (Fig. 2a), the distribution is skewed towards early trough passages, with more than 18 forecast trough passages having early biases greater than 3 h. In contrast, at the offshore buoy 006 to the south (Fig. 2b), most of the forecasts are within 6 hours of the observed and there is a tendency to be late, with almost as many 3-h late forecasts as on-time predictions. The timing errors are much earlier at the southern coastal buoy 022 (near the mountainous coast of northern California) than buoy 006 offshore.

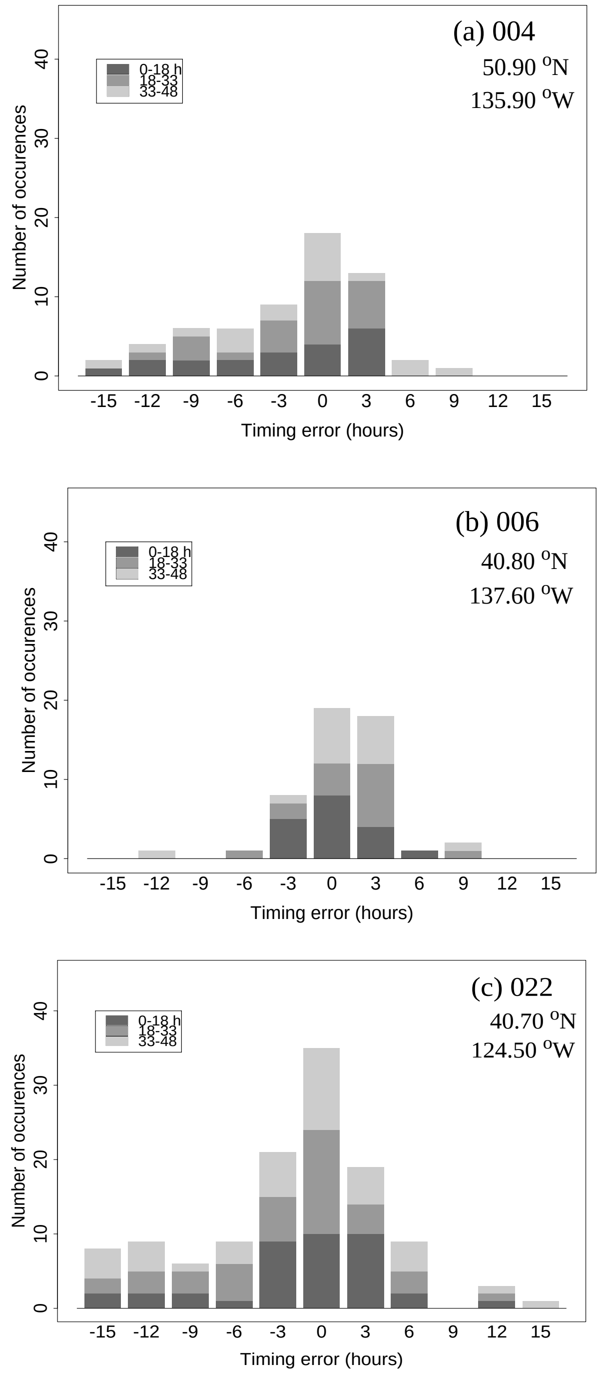

Figure 2. MM5 histograms for the 1998-2000 cool seasons showing the number of occurrences of timing errors (every 3 hours between -15 h and 15 h) for buoys (a) 004, (b) 006, and (c) 022. The number of occurrences are separated into 0-18, 18-33, and 33-48 forecast periods.

Figure 3a shows a spatial map of the mean timing errors for the same Eta and MM5 trough events; in addition, the differences in the errors between the models is also displayed.The Eta results are similar to the MM5; however, for the sites north of buoy 006 and near the coast, the troughs in the MM5 arrive 0.03 to 0.65 h earlier than the Eta. In contrast, the MM5 troughs are later than the Eta for the southern offshore buoy (006). The mean absolute timing errors for the Eta are 0.25-0.50 h larger than the MM5 for offshore buoys (Fig. 3b), while the MM5 absolute errors are 0.25-0.75 h larger than the Eta near the coast.

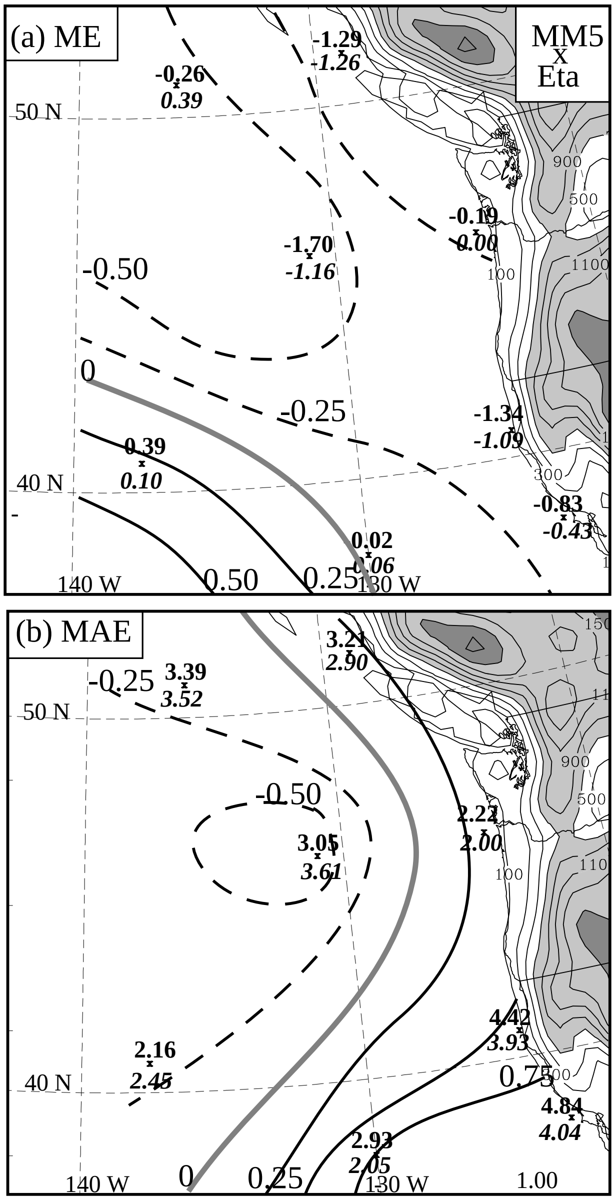

Figure 3. (a) Mean surface trough timing errors (bias) in the MM5 (top) and Eta (bottom, italized) for the identical events during the 1998-2000 cool seasons. The difference between the MM5 and Eta (MM5 -Eta) is contoured every 0.25 h with negative values dashed (MM5 troughs arrive earlier than Eta). (b) Same as (a) except for the mean absolute error. Dashed (solid) lines indicate areas where the MM5 (Eta) are more skillful.

In order to explore the reasons for these differences between the MM5 and Eta, verification of the simulated 3-h pressure tendencies, sea-level pressure, and wind speed (reduced logarithmically to 5 m ASL) were calculated (not shown). The MM5 wind speeds at most buoys are generally stronger than observed for the early events and weaker than observed for the late events. The Eta wind speed biases are similar to the MM5 for the early events, except that the Eta winds are .5 to 3 m s^{-1} weaker than the MM5. This result, which is significant to the 95% level, suggests that the Eta has more surface drag or less vertical mixing from aloft, which favors the slower trough movement than the MM5 at most buoys (cf., Fig. 3). Both the MM5 and Eta have the greatest trough underdevelopment at buoy 006 (4.0 mb). Overall, the pressure errors are similar between MM5 and Eta; therefore, most of the timing error differences between the MM5 and Eta appear to be related to differences in windspeed.

4. COMPOSITE STUDY

Both a time series analysis (not shown) as well as the verification of sea-level pressure suggest that there may be large-scale flow differences between the early and late events. For example, at most stations (except 004 and 029) the observed sea-level pressures are lower for the late events, which suggests that stronger troughs or cyclones are associated with the late events. To explore this further, composites of the 1000 and 500 mb geopotential heights were constructed for the early and late events using the daily-averaged NCEP reanalysis fields, which are on a 2.0^{o} lat. x 2.0^{o} lon. grid and include all mandatory levels from 1000 to 100 mb (Kalnay et al. 1996). This composite study for the MM5 extends from October 1997 through December 1999.

Using the MM5 trough events a composite of the 500 mb geopotential heights was created for the late and early trough passages at each buoy. The results are similar for each buoy so only buoy 005 is shown (Fig. 4). For the early events (Fig. 4a), the 500 mb composite shows a large-scale ridge over the western U.S., a weak upper-level trough approaching the coast, and a broad trough is situated over the northern Pacific. In contrast, the 500 mb trough is better defined for the late events and is centered over the Gulf of Alaska (Figs. 4b). The late events are also associated with more 500-mb ridging south of the Aleutians than the early events. With exception of the weak trough approaching the coast during the early events, all of the structures noted above have 50-120 m anomalies with respect to climatology and are significant at the 95-99% level (not shown). The composite was repeated for the Eta early and late trough events, and the results were similar to the MM5. Overall, these results suggest that the early and late events are episodic in nature, since clusters of early and late trough forecasts are sustained over 2-4 week periods and there are different large-scale flow structures associated with late and early trough events.

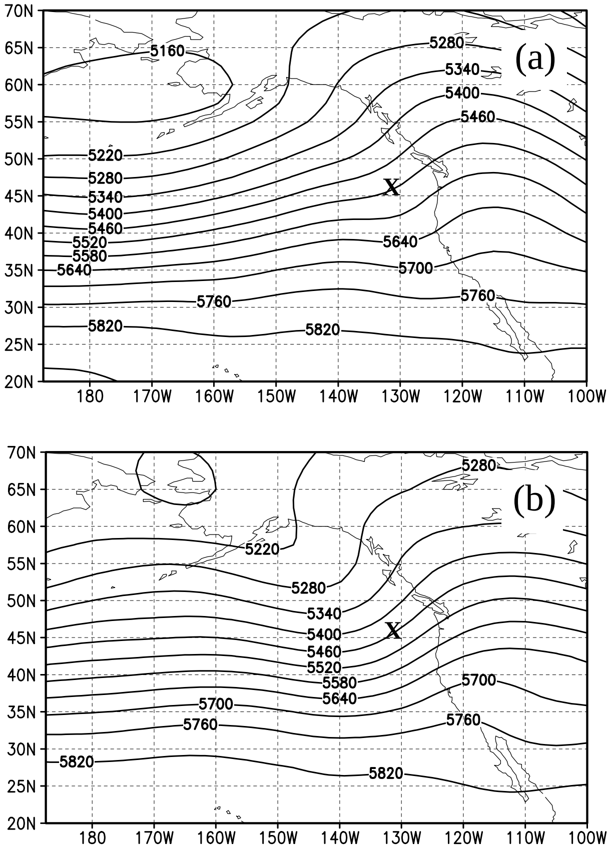

Figure 4. NCEP reanalysis composite of the 500 mb geopotential heights (contoured every 60 m) during trough passage for the (a) early and (b) late MM5 events at buoy 005. The "X" in the panel indicates the location of the buoy.

5. SUMMARY AND CONCLUSIONS

The goal of this study is to complete the first long-term model verification of surface trough passages upstream of the U.S. West Coast during the cool season. Both the timing and strength of the MM5 and NCEP Eta model trough passages were evaluated from September through March of 1998-2000, comparing observations from 8 offshore buoys with 48-h model forecasts.

Overall, the results suggest that a number of factors-- ranging from proximity to terrain and synoptic flow configuration, to the amplitude of the propagating troughs-- influence trough timing errors associated with the MM5 and Eta models. The large early biases over coastal waters adjacent to significant terrain suggest that the models are not fully capturing trough deceleration associated with terrain blocking. Errors in the strength of the predicted flow appear to have a significant influence on timing error, with early timing errors associated with stronger than observed surface wind speeds, and late timing errors associated with wind speeds less than observed. For late events, the model sea-level pressures are greater than observed, with sea-level pressure errors reaching 4 mb for the southern offshore buoy 006. However, the 3-h pressure rises, which is a measure of the trough amplitude/sharpness, are only slightly under-predicted (10-20% of observed) at most buoys. This suggests the amplitudes of the well-defined troughs in the late composite are actually well-simulated, but the weaker than observed flow results in slower troughs than observed. In contrast, it appears that when the model significantly underpredicts the amplitude of a trough (3-h pressure rise), there is a tendency for early trough passage. It has been noted both empirically and theoretically that stronger upper-level troughs (which are dynamically linked to surface troughs) tend to move westward more slowly within the background flow. Thus, underpredicted troughs are more likely to result in early timing errors.

It is beyond the scope of this study to determine more precisely whether most of the trough errors originate from initialization problems over the Pacific, model physics, or resolution. Poor initialization of trough location would result in more random trough timing errors with equal cancellation between late and early events. However, since the timing errors have a distinct bias, either the magnitude of the troughs are poorly initialized or forecast, the model PBL parameterizations have significant problems, or the model physics/resolution as a whole has difficulty simulating trough evolution. Future studies should investigate some individual case studies more closely as well as verify trough forecasts in other regions.

6. ACKNOWLEDGEMENTS

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