**11B.6**

# COMPARISON OF SEA LEVEL PRESSURE ERRORS BETWEEN THE U.S. EAST AND WEST COASTS DURING THE COOL SEASONS OF 2000-2005

Lynn A. McMurdie[1*], Michael Curley[2], Brian A. Colle[2], and Cliff Mass[1]
[1]Department of Atmospheric Sciences, University of Washington, Seattle, Washington
[2]Stony Brook University, State University of New York, Stony Brook, New York

## 1. INTRODUCTION

Intense extratropical cyclones often develop off the East Coast of the U.S. with strong winds and heavy rain and snowfall, resulting in major societal impacts of human and economic losses. In the earlier days of numerical weather prediction, these storms were often completely missed by the numerical models of the time, with extremely large short-term forecast errors. Well known examples of these forecast failures include the QEII storm of 10 September 1978 (Anthes et al. 1983, Gyakum 1983a and b, Uccellini 1986), and the President's Day storm of 16 February 1979 (Bosart 1981, Bosart and Lin 1984, Uccellini 1984 and 1985) However, more recently, the so-called 'Superstorm' of 12-14 March 1993 that affected a large area of the eastern portion of the U.S. and Canada, was well forecast largely due to significant improvements in model resolution, parameterized physics and data assimilation (Uccellini et al. 1995, Caplan 1995). Models have continued to evolve since this storm and it is important to document the ability of current numerical models to forecast the development and movement of major storms.

A recent study focusing on model accuracy over the northeast Pacific has shown that large forecast failures still occur. For example, the 48-h forecast of sea-level pressure (slp) of an intense cyclone occurring 3 March 1999 had a cyclone central pressure error of 24 mb, and a position error greater than 500 km (McMurdie and Mass 2004). It is not known whether errors this large also occur over the Atlantic, and if there are large errors, it is not known whether these errors are associated with East Coast cyclogenesis. In this study, 24-h and 48-h slp forecasts from the National Centers for Environmental Prediction (NCEP) Eta model are verified with observed sea level pressure at several buoys along the East Coast and western Atlantic and along the West Coast and northeastern Pacific during the cool seasons (Nov 1 – Mar 31) of 2000 – 2004. Statistics of the errors for the two regions are then compared and composites of sea level pressure and 500 geopotential heights for those days with large errors are constructed to determine if large errors are associated with particular synoptic events such as offshore storm development.

## 2. DATASETS AND METHODS

Sea level pressure observations from offshore and coastal Canadian and NOAA buoys over the western Atlantic Ocean and eastern Pacific and the NOAA Coastal Marine Automated Network (CMAN) stations along the west coast are used to verify to Eta model forecasts. The locations of the buoy and CMAN stations are shown in Figs. 1 and 2. The period of study is from 1 November 2000 through 1 April 2005 which encompasses the five most recent winter seasons. During this time, the Eta was upgraded including changes in resolution and data assimilation (see Rogers et al. 2000, 2001a,b).

The 24- and 48-h Eta forecasts initialized at 0000 UTC of sea level pressure were compared to the observed slp at

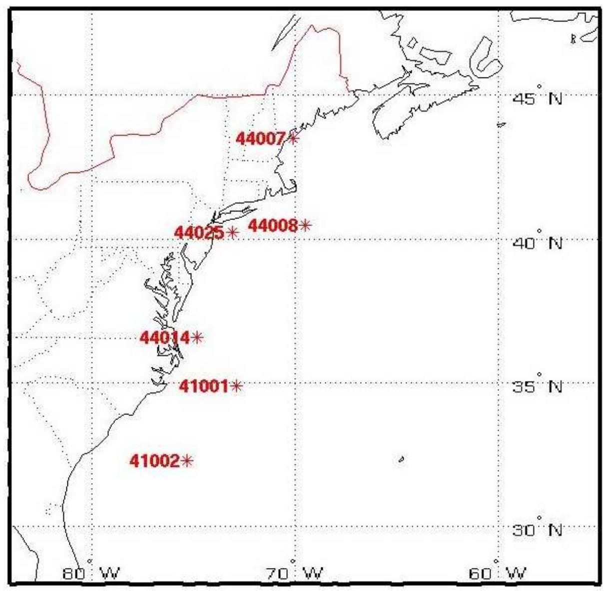


*Fig. 1. Map of buoy locations used for the western Atlantic portion of the study.*

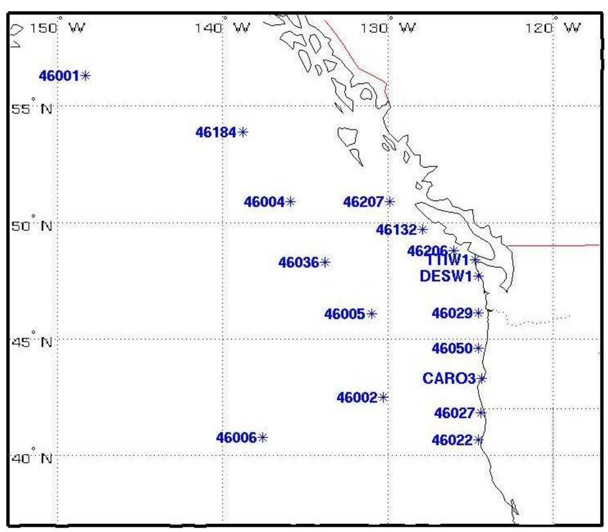


*Fig. 2. Map of buoy and CMAN locations used for the northeastern Pacific portion of the study.*

*Corresponding author address:* Lynn McMurdie, Department of Atmospheric Sciences, University of Washington, Box 351640, Seattle , WA 98195. email: mcmurdie@atmos.washington.edu

each buoy and CMAN location. To do this, the Eta forecasts were interpolated to observation sites using a bilinear interpolation scheme. Time series of mean SLP error at each station, defined as forecast sea level pressure minus observed, were calculated over the study period. In addition, the average error, the mean absolute error, and the standard deviation of the errors were calculated at each observation site. For each site, dates where the slp error exceeded two times the standard deviation were identified. Composites of slp and 500 mb heights were constructed using the dates where the errors at a western Atlantic buoy were two times the standard deviation and another set of composites of slp and 500 mb heights were constructed using dates where the errors at a northeastern Pacific station were larger than two times the standard deviation. The data for the composites were obtained from the NCEP reanalysis grids of daily averaged 500 mb heights and sea level pressure with a grid resolution of 2.5°lat and 2.5°lon.

**3. RESULTS**

*3.1 Buoy Statistics*

Time series of slp 24-h and 48-h forecast errors for the entire period at buoy 44025 in the western Atlantic (40.25°N 73.1°W) and at Tatoosh Island (CMAN station TTIW1 at 48.4°N 124.7°W) are shown in Figs. 11 and 12 (shown at end of paper), respectively. In addition, the average error (green line, Fig. 11) and two times the standard deviation (violet lines) for the entire period are provided. At both stations, the 48-h forecast errors are significantly larger than the corresponding 24-h errors. However, for both forecast lead times, the errors at Tatoosh Island are larger than at buoy 44025. In addition, the two times the standard deviation lines correspond to larger forecast errors at Tatoosh Island.

The differences in error characteristics between the Atlantic and the Pacific stations are further illustrated with histograms of 48-h forecast errors for all five winter seasons in Figs. 3 and 4. At buoy 44025 (Fig. 3), a vast majority of the forecast errors are between –5 and 5 mb with relatively few forecasts with absolute errors greater than 5 mb and less than 10 forecasts with absolute errors greater than 10 mb. On the other hand, Tatoosh Island (Fig. 4) exhibits a much larger spread in forecast errors with a significant portion of the forecasts with absolute errors greater than 5 mb and several forecasts with errors greater than 10 mb. Other stations in each ocean basin exhibit similar characteristics (not shown).

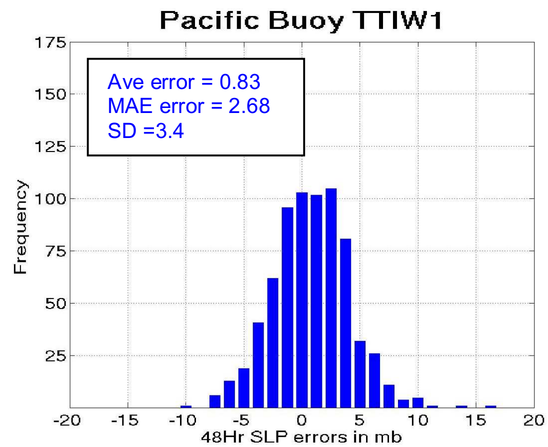


*Fig. 4. Histogram of forecast errors at Tatoosh Island along the west coast. There are more errors greater than 5 mb than for buoy 44025 in the Atlantic.*

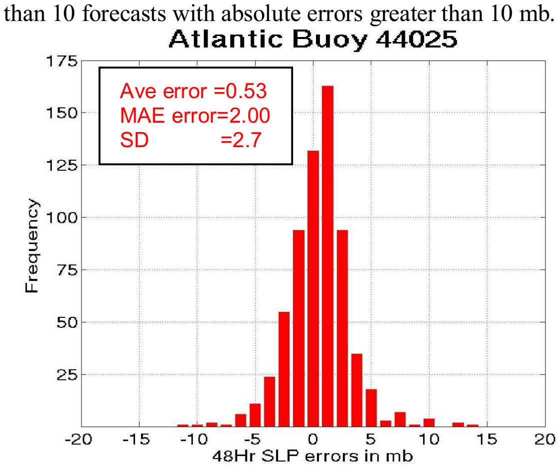


*Fig. 3. Histogram of 48h forecast errors at buoy 44025 in the North Atlantic for all five winter seasons together. A vast majority of the errors are less than 5 mb.*

To further quantify the differences in errors between the two basins, Tables 1 and 2 list the 48-h standard deviation of errors at all stations used in the study by season. In each basin, the standard deviations are larger for stations residing further north. However, most of the stations in the northeastern Pacific basin have standard deviations larger than those stations in the western Atlantic for most seasons. It is also clear from Tables 1 and 2 that there is considerable inter-annual variability of forecast errors. For most of the western Atlantic stations, the standard deviations are larger during the 2000-1 and 2002-3 seasons than the other three seasons. Whereas most northeastern Pacific stations exhibit larger standard deviations during the 2000-1, 2001-2 and some stations with large values during the 2003-4 season. Table 3 further summarizes the inter-annual differences in large forecast error frequency for each ocean basin. In that table, the number of forecasts where the error was larger than two times the standard deviation at a particular station was averaged for all stations for each season and each ocean basin. Again, the seasons with the greater number of large forecast errors are 2000-1 and 2002-3 for the western Atlantic and 2000-1, 2001-2 and 2003-4 for the Pacific.

| *Buoy* | *2000-2001* | *2001-2002* | *2002-2003* | *2003-2004* | *2004-2005* |
|---|---|---|---|---|---|
| ***44007*** | 3.19 | 2.56 | 2.65 | 3.06 | 2.77 |
| ***44008*** | 3.18 | 2.74 | 3.02 | 2.75 | 2.68 |
| ***44025*** | 3.07 | 2.44 | 2.83 | 2.61 | 2.43 |
| ***44014*** | 2.73 | 1.88 | 2.49 | 2.28 | 2.02 |
| ***44001*** | 2.23 | 1.80 | 2.53 | 2.24 | 1.97 |
| ***44002*** | 1.94 | 1.67 | 2.17 | 1.97 | 1.78 |

*Table 1. Standard deviations (in mb) of 48-h forecast errors for stations along the eastern U.S. and North Atlantic for each winter season.*

| Buoy | 2000-2001 | 2001-2002 | 2002-2003 | 2003-2004 | 2004-2005 |
|---|---|---|---|---|---|
| 46001 | 5.22 | 4.31 | 4.22 | 4.67* | 4.25 |
| 46004 | 4.76 | 5.19 | ** | 4.74 | 4.23* |
| 46184 | 5.08 | 4.81 | 4.37 | 4.26* | 4.03 |
| 46132 | 3.62 | 4.41 | 3.49 | 3.19 | 3.32 |
| 46207 | 4.10 | 4.57 | 4.14 | 3.83 | 3.86 |
| 46206 | 3.55 | 3.64* | 3.22 | 3.26 | 3.02 |
| 46036 | 4.71 | 5.16 | 4.51 | 4.28 | 4.08 |
| TTIW1 | 3.65 | 4.19 | 2.96 | 3.11 | 3.14 |
| DESW1 | 3.47 | 4.25 | 2.95 | 3.03 | 3.06 |
| 46005 | 3.62 | 4.14 | 3.44 | 3.67 | 3.98* |
| 46029 | 2.87 | 3.84 | 2.65 | 2.90 | 3.32* |
| 46050 | 2.95 | 3.17 | 2.52* | 2.95 | 2.69* |
| CARO3 | 2.69 | 3.24 | 2.63 | 2.64 | 2.58 |
| 46002 | 3.54 | 4.16 | 3.17 | ** | 2.77 |
| 46027 | 2.64 | 2.80 | 2.68 | 2.56 | 2.59 |
| 46006 | 3.52 | 3.35 | 3.25 | 3.67 | 3.03 |
| 46022 | 2.64 | 2.74 | 2.77 | 2.46 | 2.65 |

*Table 2. Standard deviations (in mb) of 48-h forecast errors for stations along the west coast and North Pacific for each winter season. Asterisks correspond to missing data for that season*

| Year | Atlantic (24-h) | Pacific (24-h) | Atlantic (48-h) | Pacific (48-h) |
|---|---|---|---|---|
| 2000-2001 | 8.75 | 7.00 | 10.5 | 9.2 |
| 2001-2002 | 4.25 | 10.12 | 4.25 | 11.4 |
| 2002-2003 | 7.50 | 5.25 | 9.00 | 5.19 |
| 2003-2004 | 5.25 | 8.07 | 7.00 | 6.00 |
| 2004-2005 | 6.25 | 5.77 | 4.00 | 5.07 |

*Table 3. Average number of 24- and 48-h errors greater than 2 std dev (SD) per year for those observing sites shown in Fig. 1 (Atlantic) and Fig. 2 (Pacific).*

An important question is whether the inter-annual variation of large forecast errors reflects changes in storm activity or model skill. To examine storm activity, the mean 500-mb heights and root-mean-square (rms) of time-filtered 500-mb heights (which retain periods within the 2-10 day band[1]) are plotted in Figs. 5 and 6. During the 2001-2 season (Fig.5), there is a weak ridge over the western states while the flow is nearly zonal over the eastern states. In addition, the storminess (as indicated by maximum values of rms) extends to the west coast and the rms is high north of 40°N along the east coast. However, the 2002-3 seasons has a significantly different upper-level flow pattern (Fig. 6). The west coast ridge has a much higher amplitude and the storminess is restricted to the western Pacific, whereas the east coast trough has higher amplitude than the previous season. The 2002-3 seasons stands out as one where the forecast errors were smaller for most of Pacific stations compared to other years and the errors were larger for the Atlantic stations compared to other years. Therefore it is likely that the observed

[1]The Lanczos filter used for the rms calculations is given by Duchon (1979)

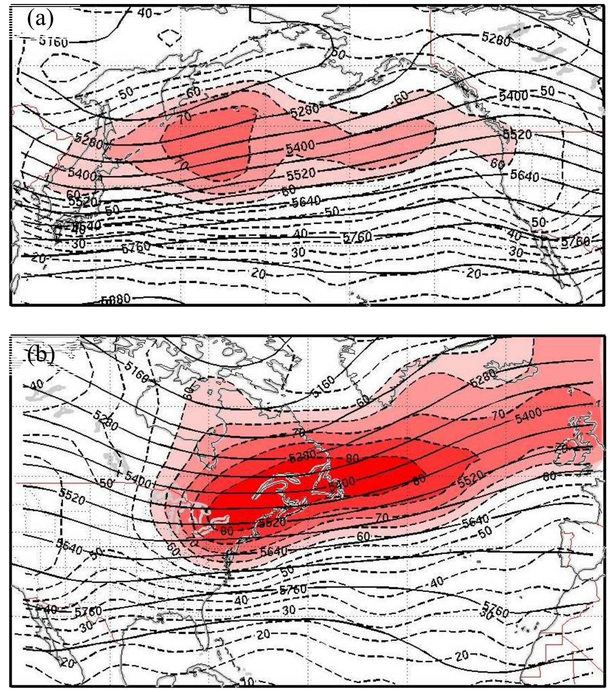

*Fig. 5. Mean 500 mb heights and rms in hPa for the 2001 – 2002 season, a) Pacific Ocean and west coast, b) Atlantic Ocean and east coast.*

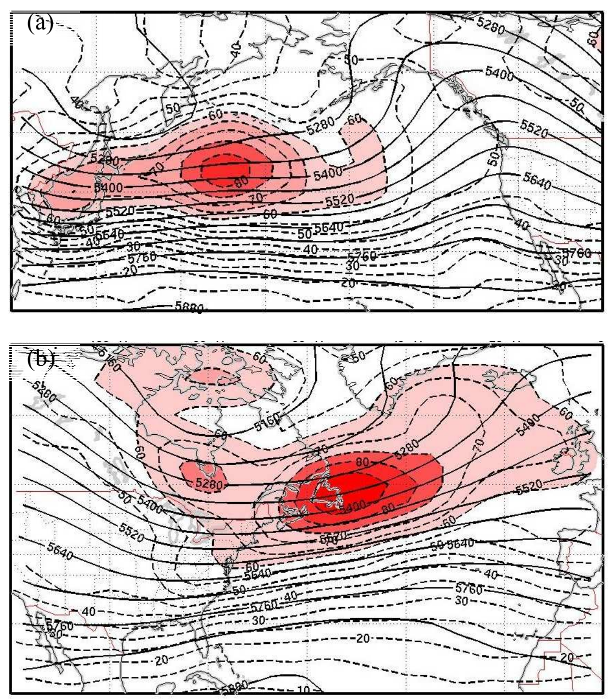

*Fig. 6. Mean 500 mb heights and rms in hPa for the 2002 – 2003 season, a) Pacific Ocean and west coast, b) Atlantic Ocean and east coast.*

inter-annual variability of forecast errors is more correlated with changes in large-scale flow pattern and storm activity.

*3.2 Composites*

As described earlier, dates where the forecast errors were larger than two times the standard deviation were identified for each station in both ocean basins. In Figs. 7 and 8, composites and anomalies of 500 mb heights and sea level pressure using the dates corresponding to buoy 44025 in the western Atlantic are shown. The anomaly fields are defined as the composite minus the mean field where the mean was calculated using the 5 winter seasons of the study. The composite 500 mb field shows a significant trough just upstream of the east coast where the heights are as much as 100 m below the mean heights. In addition there is a short-wave ridge downstream of the trough at about 60ºW and an additional trough further downstream. This indicates that large forecast errors at buoy 44025 are associated with a short-wave upper-level trough. The composite 500 mb height field for 24-h and 48-h prior to the time of large errors show the same features situated further upstream with somewhat less amplitude (not shown). The composite sea level pressure field (Fig. 8) has a significant low pressure center located at about 40ºN 75ºW reminiscent of a developing surface cyclone. In contrast, the mean sea level pressure field does not have any low pressure center along the east coast and the composite surface low is more than 6 mb lower than the

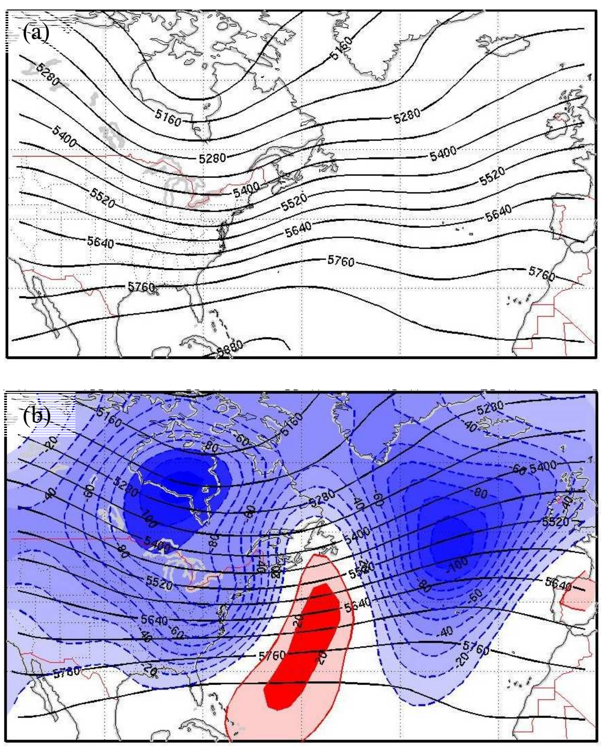


*Fig. 7. Composite and anomaly 500 mb heights in hPa for cases with large forecast errors at buoy 44025, a) composite, b) mean 500 mb height fields for 2000-2005 (black) and anomaly (shaded, blue negative), defined as composite minus mean.*

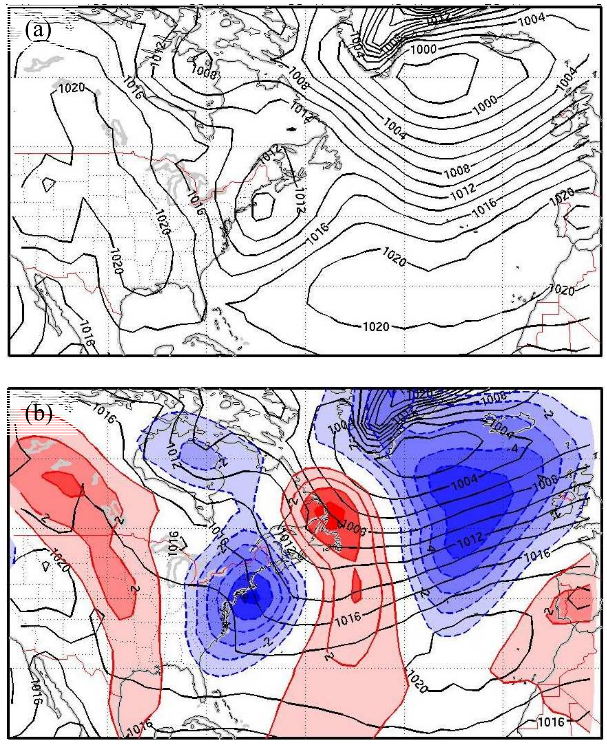


*Fig. 8. Composite and anomaly sea level pressure in mb for cases with large forecast errors at buoy 44025, a) composite, b) mean slp field for 2000-2005 and anomaly (shaded, blue negative), defined as composite minus mean.*

mean. The composite and anomaly sea level pressure fields at 24-h and 48-h prior to the time of maximum forecast errors show a weak low pressure area over the eastern states and over the Mississippi valley, but there is no close-low structure (not shown). This pattern is consistent with a developing off-shore cyclone such as a 'nor-easter' type of storm.

In contrast, the composite and anomaly 500 mb height fields using dates where the forecast errors are large at Tatoosh Island along the west coast are given in Fig. 9. In this case, the large forecast errors are also associated with a broad upper-level trough and significantly lower heights all across the Pacific, especially along the west coast. The anomalies indicate that large forecast errors at Tatoosh Island occur when the west coast ridge weakens and there is stronger zonal flow across the Pacific. In contrast to the composite for the Atlantic, the Pacific composite of sea level pressure field (Fig. 10) only exhibits a trough along the Washington Coast. However, the composite sea level pressure is up to 6 mb lower than the mean sea level pressure at that location. The composite fields at 24- and 48-h prior to the time of maximum forecast errors show the same features (a 500 mb trough and a sea level pressure trough) positioned upstream of those shown in Figs. 9 and 10 and of approximately the same magnitude. Therefore it is difficult to determine whether the errors are associated with developing or deepening cyclones or if cyclones at all stages of development can be associated with large forecast errors. Composites constructed using dates of forecast errors at other stations reveal the same patterns as Figs. 9 and 10 except the maximum deviation from the mean is centered at the station used for the composite (not shown).

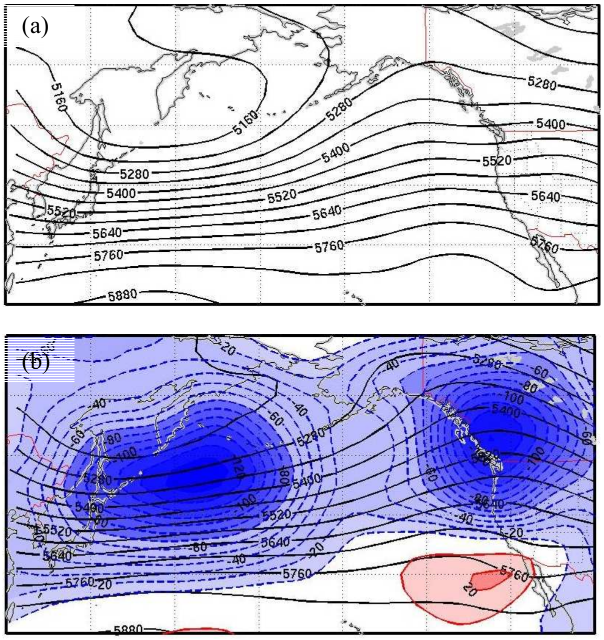


*Fig. 9. Composite and anomaly 500 mb heights for cases with large forecast errors at Tatoosh Island, a) composite, b) mean 500 mb height fields for 2000-2005 (black) and anomaly (shaded, blue negative), defined as composite minus mean .*

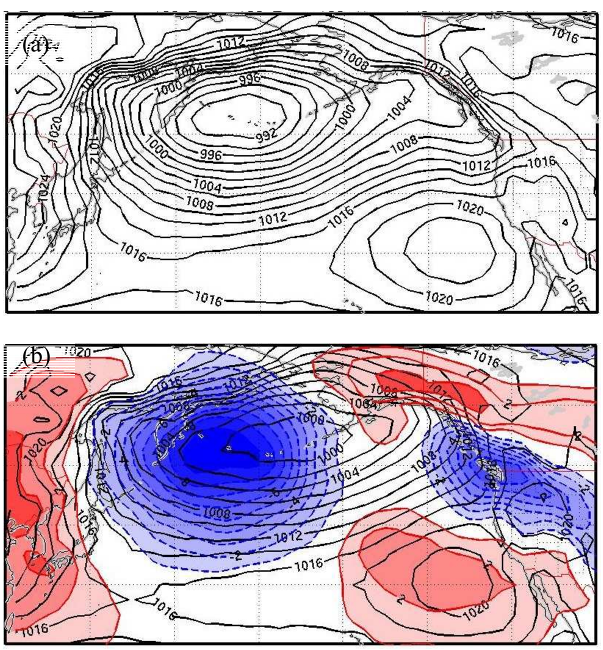


*Fig. 10. Composite and anomaly sea level pressure for cases with large forecast errors at Tatoosh Island., a) composite, b) mean slp field for 2000-2005 and anomaly (shaded, blue negative), defined as composite minus mean*

**4. CONCLUSIONS**

In this study, the magnitude and frequency of large forecast errors of sea level pressure over the western Atlantic and the northeastern Pacific were documented for the five most recent winter seasons. The findings can be summarized as follows:

- Large forecast errors of greater than 10 mb still occur in both the Pacific and Atlantic basins.
- Large forecast errors occur more frequently and are typically larger over the Pacific than the Atlantic.
- Inter-annual variability of large forecast errors is modulated by inter-annual variability of storminess.
- Large forecast errors over the western Atlantic occur in associated with cyclones developing off the east coast.
- Large forecast errors over the northeastern Pacific and along the west coast occur in association with upper-level troughs and general zonal flow across the Pacific and are also associated with sea level pressure troughs along the west coast.

These conclusions imply that despite continuing improvements in model physics, model resolution and data assimilation, the Eta model appears to struggle with short-term forecasts of developing cyclones. Although the Eta on average exhibited small forecast errors at buoys in the western Atlantic, when forecast errors were large, the composite and anomaly results indicated that those times were associated with offshore cyclones, similar to developing nor'easter type storms. On the other hand, for stations over northeastern Pacific and along the west coast, the eta model exhibited larger 24-h and 48-h forecast errors than at Atlantic stations over the entire 5-year study period encompassing a wide range of synoptic situations. However, when the forecast errors were large over the Pacific, the composite and anomaly results indicated that those times were also associated with offshore cyclones and upper-level troughs. Unlike the Atlantic, it could not be determined whether the large forecast errors were largely associated with developing cyclones or cyclones at any lifecycle stage. In the previous study by McMurdie and Mass (2004), they found that large forecast errors at Pacific buoys were associated with large errors of forecast cyclone position and to a lesser extent they were associated with errors of forecast cyclone intensity. In a future study, we will examine whether this is also true for the western Atlantic cases and for the Pacific cases of this study.

It is also important to note that these conclusions are only valid for the Eta model. It is not known whether the forecast errors are also as large for other models, such as the NCEP Global Forecast System (GFS) or whether large forecast errors are associated with developing cyclones for these other models. However, in a preliminary study by two of the authors (LAM and CM), it was noted that the GFS model typically has smaller errors than the Eta on average, yet large forecast errors occurred with the GFS also in association with offshore cyclones. Future work will include examining forecast error characteristics of several operational models over both ocean basins and across the North American continent.

## 5. ACKNOWLEDGMENTS

This work was supported partly by NSF grant ATM0450684 (LAM and CM) and UCAR Comet Grant S0238662 (MC and BAC). The NCEP reanalysis data was provided by the NOAA-CIRES Climate Diagnostics Center, Boulder, Colorado, from their Web site (http://www.cdc.noaa.gov).

## 6. REFERENCES

Anthes, R. A., Y. H. Kuo, J. R. Gyakum, 1983: Numerical simulations of a case of explosive marine cyclogenesis. *Mon. Wea. Rev*., **111**, 1174-1188.

Bosart, L. F., 1981: Presidents' day snowstorm of 18-19 February 1979: a subsynoptic-scale event. *Mon. Wea. Rev*., **109**, 1542-1566.

Bosart, L. F., and S. C. Lin, 1984: Diagnostic analysis of the Presidents'Day storm of February 1979. *Mon. Wea. Rev*., **112**, 2148-2177.

Caplan, P. M., 1995: The 12-14 March 1993 Superstorm: Performance of the NMC Global Medium-Range Model. *Bull. Amer. Meteor. Soc*., **76**, 201-212.

Duchon, C. E., 1979: Lanczos filtering in one and two dimensions. *J. Appl. Meteor*., **28**, 1016-1022.

Gyakum, J. R., 1983a: On the evolution of the QE II storm, Pt. 1, Synoptic aspects. *Mon. Wea. Rev*., **111**, 1137-1155.

Gyakum, J. R., 1983b: On the evolution of the QE II storm, Pt. 2, Dynamic and thermodynamic structure. *Mon. Wea. Rev*., **111**, 1156-1173.

McMurdie, L. A., and C. Mass, 2004: Major Numerical Forecast Failures over the Northeast Pacific. *Wea. Forecasting,* **19**, 338-356.

Rogers, E., T. Black, W. Collins, G. Manikin, F. Mesinger, D. Parrish, and G. DiMego, 2000: Changes to the NCEP Meso Eta Analysis and Forecast System: Assimilation of satellite radiances and increase in resolution. NWS Technical Procedures Bulletin 473, 10pp. [Available online at http://wwt.emc.ncep.noaa.gov/mmb/mmbpll/eta22tpb/ also available from National Weather Service, Office of Meteorology, 1325 East-West Highway, Silver Spring, MD 20910.]

-----,-----,B. Ferrier, Y. Lin, D. Parrish, and G. DeMego, 2001a: changes to the NCEP Meso Eta Analysis and Forecast System: Increase in resolution, new cloud and microphysics, modified precipitation assimilation, modified 3DVAR analysis. NSW Technical Procedures Bulletin 488, 15 pp. [Available online at http://www.emc.ncep.noaa.gov/mmb/mmbpll/eta12tpb also available from National W Weather Service, Office of Meteorology, 1325 East-West Highway, Silver Spring, MD 20910.]

-----, M. Ed., Y. Lin, K. Mitchell, D. Parrish, and G. DiMego, 2001b: changes to the NCEP Meso Eta Analysis and Forecast System: Assimilation of observed precipitation, upgrades to land-surface physics, modified 3DVAR analysis. NSW Technical Procedures Bulletin 479, 15 pp. [Available online at http://www.emc.ncep.noaa.gov/mmb/mmbpll/spring2001/tpb/ also available from National W Weather Service, Office of Meteorology, 1325 East-West Highway, Silver Spring, MD 20910.]

Uccellini, L. W., P. J. Kocin, R. A. Petersen, C. H. Wash, and K. F. Brill, 1984: The Presidents' Day cyclone of 18-19 February 1979: synoptic overview and analysis of the subtropical jet streak influencing the pre-cyclogenetic period. *Mon. Wea. Rev*., **112**, 31-55.

-----, D. Keyser, K. F. Brill, and C. H. Wash, 1985: Presidents' Day cyclone of 18-19 February 1979: Influence of upstream trough amplification and associated tropopause folding on rapid cyclogenesis. *Mon. Wea. Rev*., **113**, 962-988.

-----, P. J. Kocin, R. S. Schneider, P. M. Stokols, and R. A. Dorr, 1995: Forecasting the 12-14 March 1993 Superstorm. *Bull. Amer. Meteor. Soc*., **76**, 183-199.

.

.

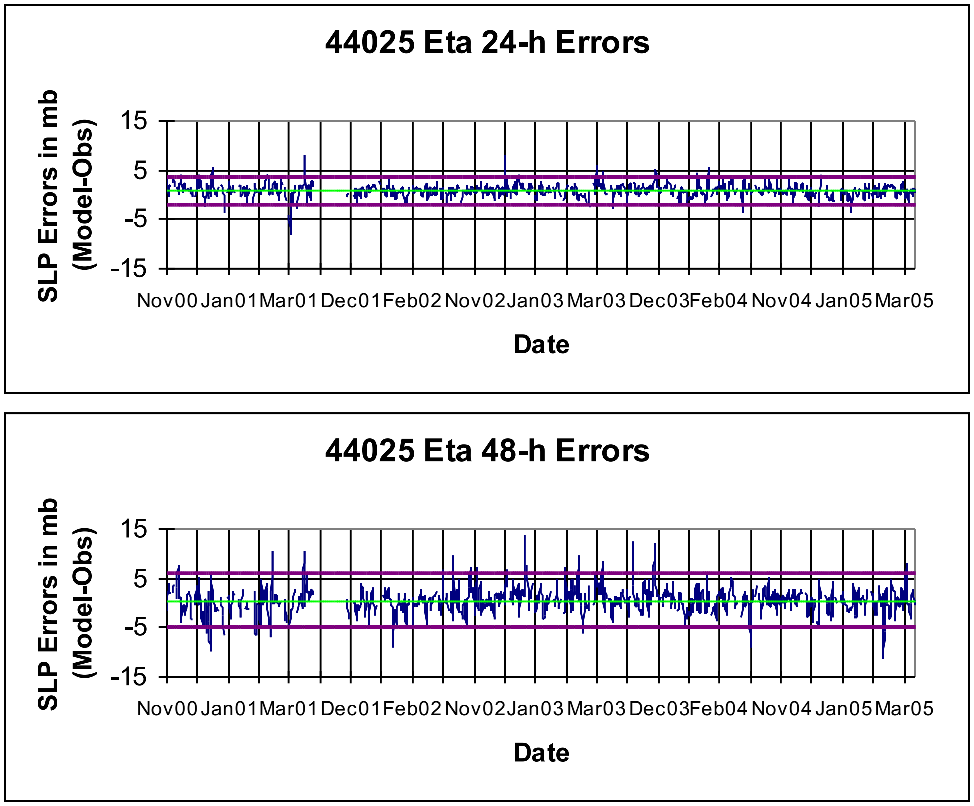


*Figure 11. Time-series of forecast errors of sea level pressure where error is defined as forecast sea level pressure minus observed sea level pressure for buoy 44025 at () in the northwest Atlantic for the period November 2000 through March 2005, a) 24-h forecast errors, b) 48-h forecast errors.*

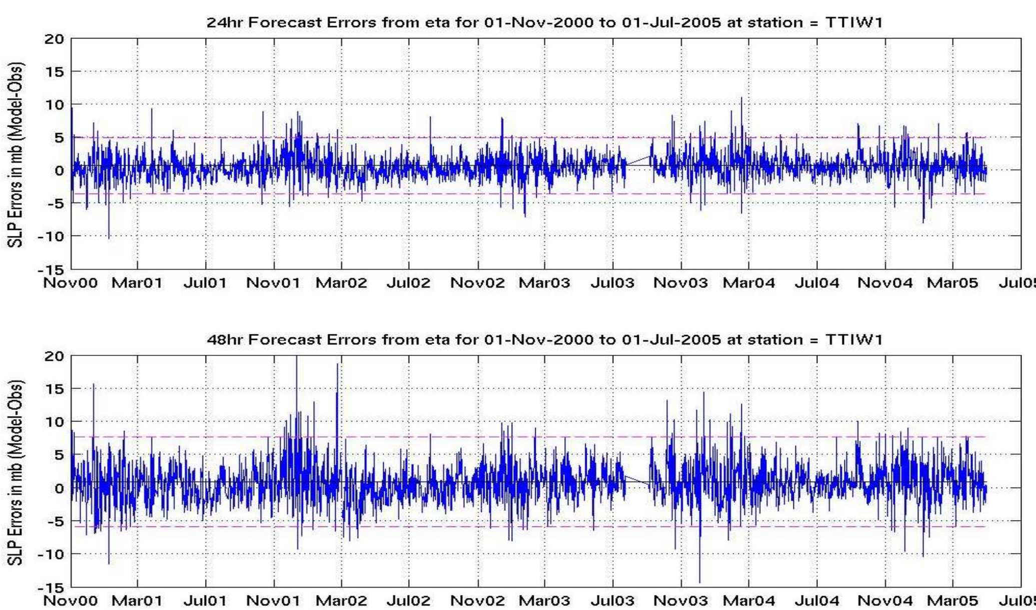


*Fig.12. Timeseries of forecast errors of sea level pressure where error is defined as forecast sea level pressure minus observed sea level pressure for CMAN station TTIW1 (Tatoosh Island) at (lat lon) along the west coast of the U.S. for the period November 2000 through March 2005. A) 24-h forecast errors, B) 48-h forecast errors.*