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COMPARISON BETWEEN OBSERVED AND SIMULATED PRESSURE DIFFERENCES FOR VERIFICATION OF NGM OUTPUT

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Introduction

Mountains and valleys induce mesoscale wind motions that often are not resolved correctly in models. When this occurs, simulated sea-level pressure fields can be underestimated, especially in valleys downstream from a mountain range. An example is the model terrain (NGM) in Oregon versus the actual topography (Fig. 1). This figure shows a west-to-east cross-section from about 50 miles west of Newport to slightly east of Pendleton. NGM model terrain does not recognize the Cascades, Columbia Basin, or any other major north-to-south oriented valleys. In addition, a similar west-to-east cross-section through Washington (Fig. 2) shows generally the same large model terrain inaccuracies.

With such large NGM terrain smoothing (basically no depiction of major Oregon and Washington topographic barriers and downstream basins), you would expect west-to-east pressure gradient forecast errors across this area. Of course, this would be more pronounced in certain synoptic environment than others. Most notable forecast errors in pressure gradient should occur when strong winds aloft are perpendicular to the Cascades. Also, a higher degree of error may be introduced when cool marine air is dammed west of the Cascades during summer and cold continental air is trapped east of the Cascades during winter.

Holton (1979) explained that westerly flow traveling over a major north-south oriented mountain barrier, induces a trough of low pressure on the lee side of the mountain to conserve potential vorticity. This weather phenomena is referred to as *Lee Side Troughing* and is an important key to surface pressure forecasting. Since the NGM does not resolve the Columbia Basin and Cascades, sea-level pressure forecasts east of the Cascades would become too high. This, in turn, should produce underforecasted pressure gradients across the Cascades.

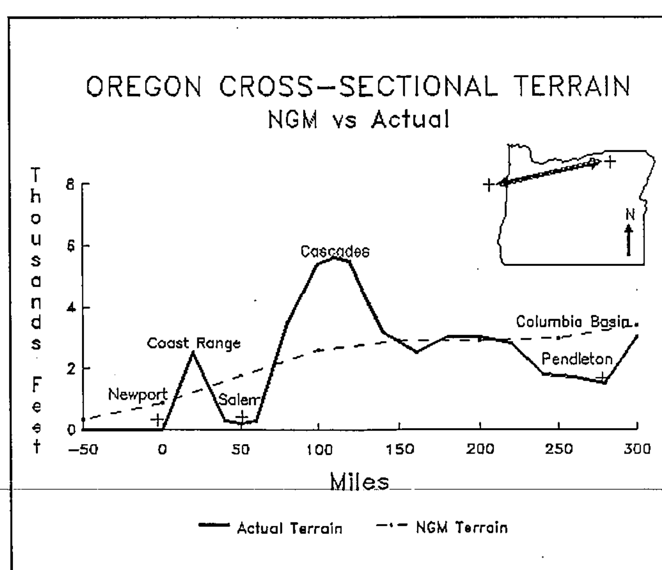

Fig. 1. Cross Section of Northern Oregon: NGM vs. actual terrain.

In the state of Washington, Hooker (1993) examined the Quillayute to Wenatchee pressure "gradient" (actually pressure difference) and showed that there were errors in the 48 hour verification of both the NGM and AVN models. Since both models have simplified topography, cool marine air is allowed to flood into eastern Washington resulting in high forecasted surface pressures. In reality, most marine air masses would be too shallow to cross over the Cascades.

This study will compare actual surface pressure differences with forecasted NGM pressure differences between the following sites: Portland (PDX) to Pendleton (PDT), Seattle (SEA) to Spokane (GEG), and Portland to Seattle during the late fall of 1991 and summer of 1993. It should be understood that these two data sets represent only a small portion of the sample space of all possible data. Nevertheless, the results of this study are intended to demonstrate the often unrealistic sea-level pressure forecasts by the NGM across the Cascades and into the Columbia Basin.

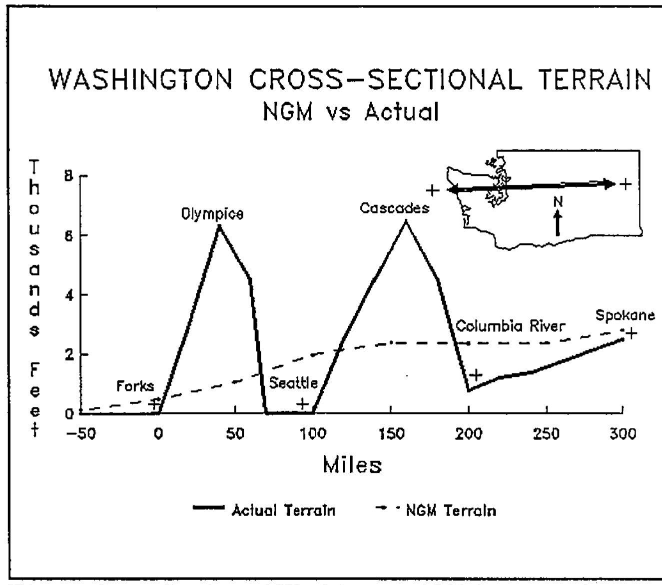

Fig. 2. Cross Section of Washington: NGM vs. actual terrain.

Methodology

Verification of the 12 and 24 hour NGM sea-level pressure forecasts were computed for the period mid-June through August 1993 and October through mid-December of 1991. These two periods were chosen because the National Weather Service forecasts wind speeds during these periods and utilizes the NGM model output for guidance. Actual 0000 and 1200 UTC surface pressures for the four stations were gathered along with their coinciding forecasted NGM pressures. Utilizing Quattro Pro software, sea-level pressure differences between PDX-PDT, SEA-GEG, and PDX-SEA were obtained and compared to NGM 12 and 24 hour forecasted pressure differences.

Summer Results

The NGM verification for summer 1993 showed that as the observed pressure difference between the west and east sides of the Cascades increased, the average NGM error increased. Due to the lack of easterly flows (offshore wind, negative gradient), only the positive onshore pressure differences will be discussed. Observed pressure differences less than 4 millibars (mb) correlated with only minor NGM errors across the Cascades (refer to Figs. 3a, 3b, 3c, 3d for NGM errors from PDX-PDT and SEA-GEG). In fact, a slight negative NGM error (NGM pressure difference too weak) between PDX and PDT was countered with a small positive error (NGM pressure difference to strong) from SEA-GEG. When observed pressure differences ranged from 4 to 6 mb, the NGM began to show substantial errors of -1.0 to about -1.6 mb. Once the pressure difference grew to 6 mb or more, errors began to double and triple in size (-2.87 to -3.83 mb). However, this may be somewhat deceiving. The relative error, or $(SLP_{fcst}-SLP_{obs})/SLP_{obs}$, remained nearly static (near 30%) as the observed pressure difference increased. During this study period, the actual peak observed pressure difference was 7.9 and 8.1 from PDX-PDT and SEA-GEG, respectively.

On the west side of the Cascades, Figs. 3e and 3f indicate a more accurate NGM pressure difference forecast between PDX-SEA, with the average less than 1 mb. The primary reason for the lower model error may be a better depiction of the relatively flat north-south terrain. In addition, this area is typically occupied by the same air mass.

Fall Results

The fall of 1991 sample study provided similar results to the summer of 1993 (refer to Figs. 4a-d). Generally, the larger the observed pressure differences from west to east across the Cascades, the larger the NGM error (a somewhat linear relationship). For observed pressure differences of 0 to 4 mb from PDX-PDT and SEA-GEG, the NGM error ranged from near zero to about -1.5 mb. Interestingly, a smaller NGM error was observed for pressure differences 2 to 4 mb than 0 to 2 mb. Substantial increases in the NGM negative bias occurred for observed pressure differences of 4 mb or greater. Values of the PDX-PDT pressure difference ranged from -3.18 mb to -3.80 mb, while SEA-GEG varied from -1.96 mb to -4.28 mb. Unlike the summer case studies, NGM errors increased significantly above 4 mb, rather than 6 mb. In fact, results showed similar errors for both the 4 to 6 mb and 6 mb or more observed pressure differences. The exception occurring on the NGM 24 hour SEA-GEG pressure difference (-4.28 mb) which was more than double the lower difference case (-1.96 mb). Largest pressure differences observed during this season were generally 6 to 8 mb (A peak value of 10.9 mb).

Due to a more stormy season, the fall results for the west side of the Cascades yielded a higher range of observed pressure differences and larger NGM errors from PDX-SEA in comparison to the summer results (Figs. 4e-f). NGM errors for observed pressure differences below 4 mb averaged near 0.35 mb. However, a notable underprediction of pressure differences (-1.5 to -1.7 mb) occurred for values 4 to 6 mb (relative error=30%). This may be partly due to a bias in the model to underestimate strong, bomb-type fall storms (Jannuzzi et al. 1991) as well as some Eastern Pacific cyclones (WRH Technical Attachment 1992). In addition, this may highlight the stronger discontinuity between the two air masses residing east and west of the Cascades.

Conclusion

Both the summer of 1993 and fall of 1991 results show a consistent correlation to a strong negative bias of forecasted NGM pressure differences between the west and east sides of the Cascades, especially when the observed pressure difference was large. Relatively cool, dense marine air is allowed to invade the eastern portions of Washington and Oregon due to the oversimplified NGM model terrain. This process would tend to raise the pressure in the lee of the Cascades and lower the west-east pressure gradient. To a lesser degree, lee side troughing east of the Cascades would become underforecasted, therefore, enhancing resultant pressure errors.

The overall verification of the 12 and 24 hour NGM pressure forecasts from this study manifests this expected deficit with an average error of 3 to 4 mb when the observed west-east pressure difference across the Cascades becomes 6 mb or greater (observed 16 times PDX-PDT and 20 times SEA-GEG). Consequently, the boundary layer geostrophic wind may, at times, be underforecasted due to its proportionality to the pressure gradient. In order to demonstrate this deficiency, we can apply the geostrophic wind equation:

$$V_g = \frac{\alpha}{f}\frac{\Delta p}{\Delta x}$$

where V_g is the geostrophic wind (m/s), α is specific volume of dry air (0.84 m^3 kg^{-1}), p is pressure (mb), f= $2\Omega \sin\theta$ is the Coriolis parameter, and x is the distance (km). Setting Δp_1= 4 mb (NGM forecast) and Δx= 330 km (PDX-PDT), then V_g= 9.9 m/s or 22 mph. Suppose the NGM underestimates the pressure difference by 3 to 4 mb, as shown in this case study. Then a more realistic forecasted pressure difference (Δp_2) would be about 7.5 mb. If Δp_2 = 7.5 mb, then V_g = 18.5 m/s or 42 mph, which is a 20 mph difference!

A negative bias in the NGM pressure difference forecast across the Cascades can also be shown statistically by a scatter plot (Fig. 5). This plot shows the relative number and location of the NGM pressure forecast compared to the perfect forecast. Points plotted below the perfect forecast (diagonal line) represent pressure difference forecasts that were less than observed values. The results yield a tendency for the model to underforecast pressure differences as the observed pressure difference increases. In addition, although larger errors occur as the observed pressure difference increases, the relative error increases linearly.

The main purpose of this research was to demonstrate the persistent NGM forecasted pressure bias across the Cascades and into the Columbia Basin during periods in which large pressure differences were observed. This case study does not necessarily verify the NGM performance when the model forecasted large pressure differences. The reader is also reminded that the study uses a limited data set and reports findings which are dependent on such.

As the previous example illustrated, a correction factor might involve increasing NGM MOS wind speeds due to its partial reliance on model geostrophic winds (Miller 1993). Therefore, when the forecaster is highly confident that large onshore west-east pressure gradients will be observed, some correction factor may need to be applied to the guidance to compensate for the NGM bias.

The Eta might be a preferable solution due to a better resolution of actual Northwest terrain. This model incorporates larger topographic features such as the Cascades and Columbia Basin better than the NGM (Fig. 6). A future study may analyze the verification of the Eta and compare it with the NGM.

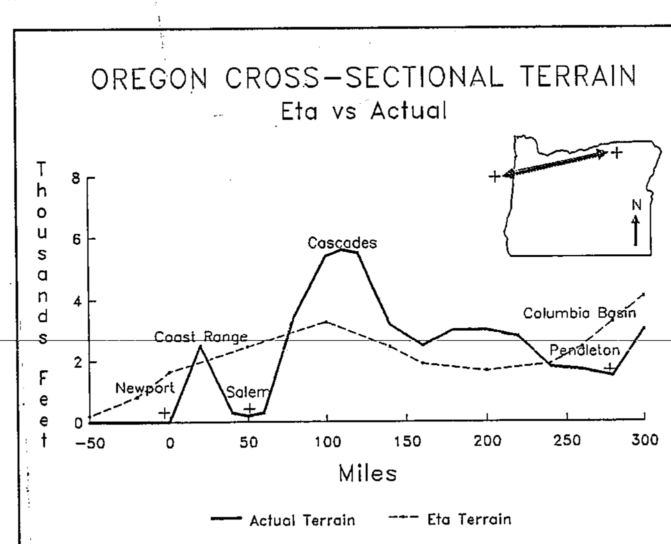

Fig. 6. Cross Section of Northern Oregon: Eta vs. actual terrain.

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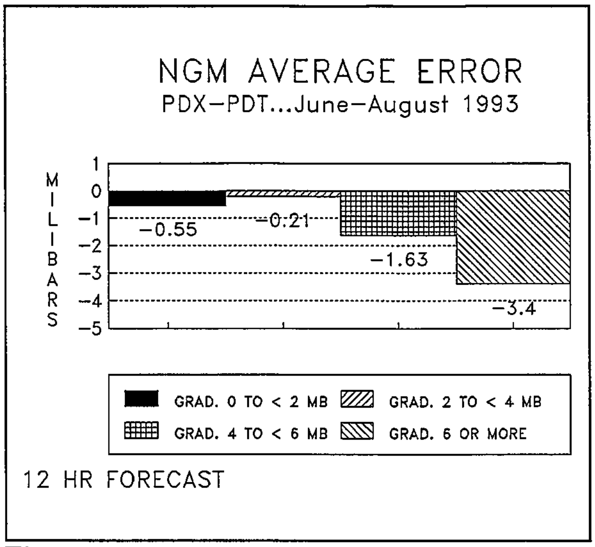


Fig. 3a.

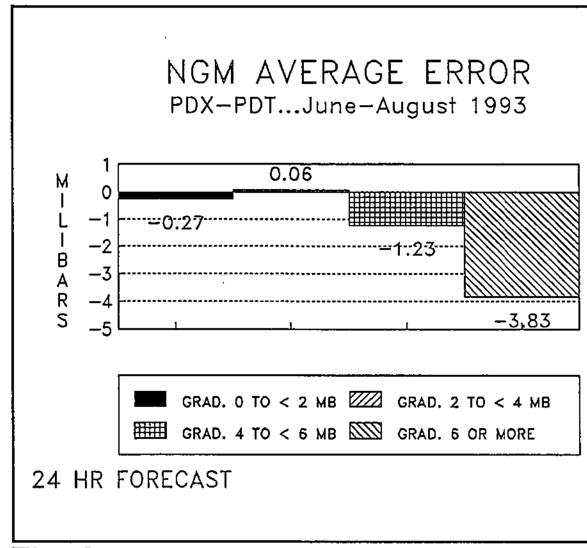


Fig. 3b.

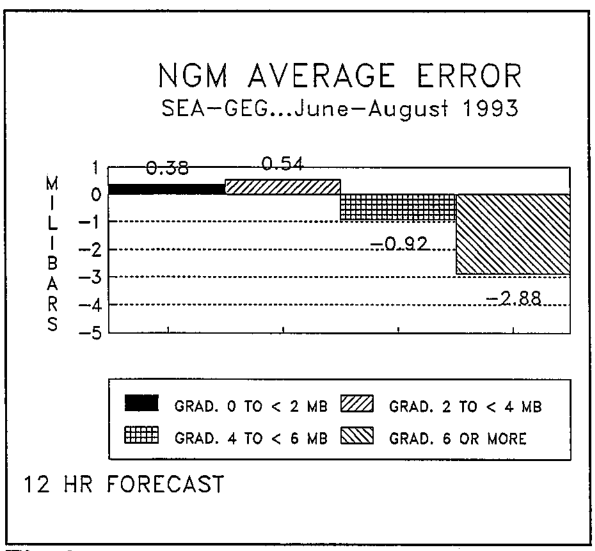


Fig. 3c.

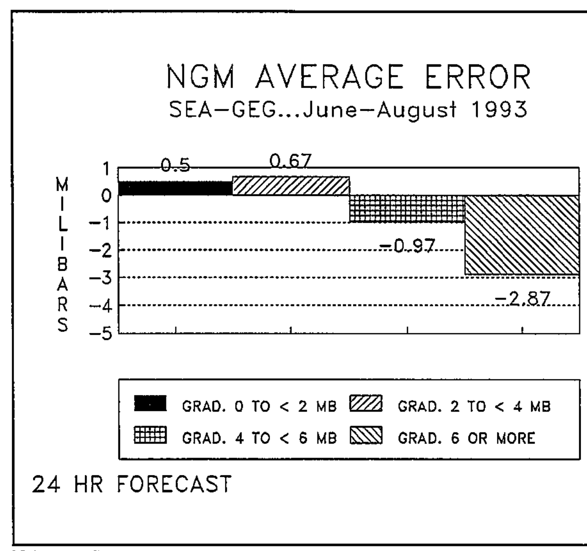


Fig. 3d.

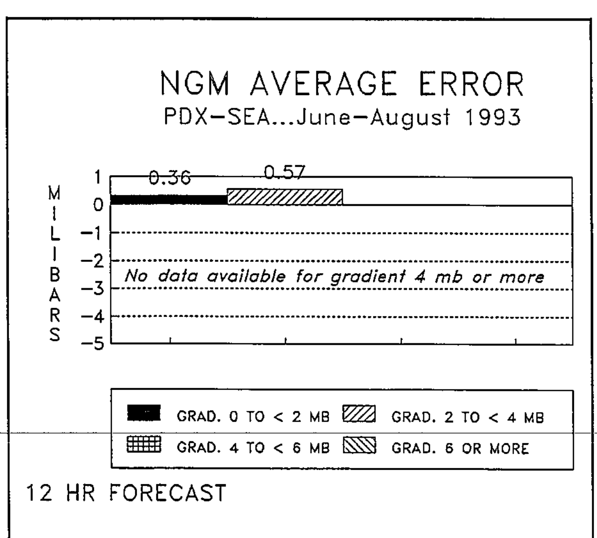


Fig. 3e.

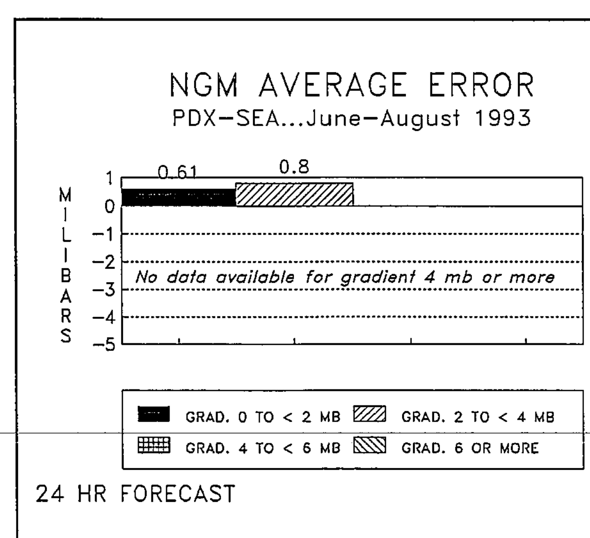


Fig. 3f.

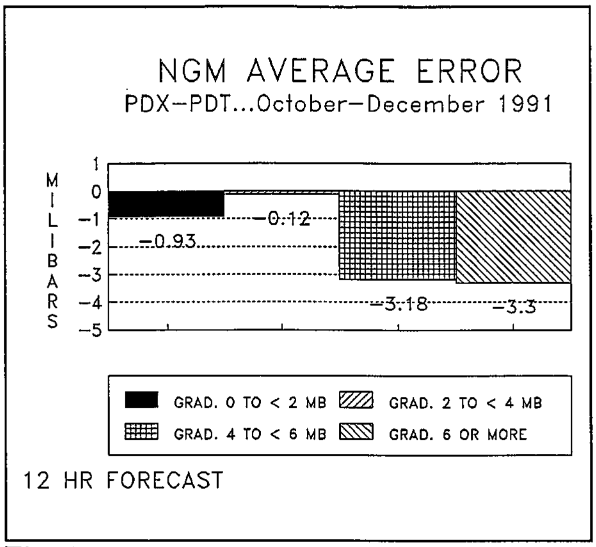


Fig. 4a.

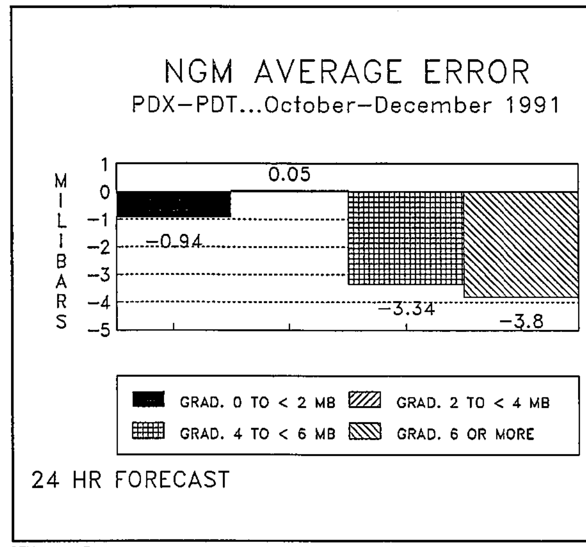


Fig. 4b.

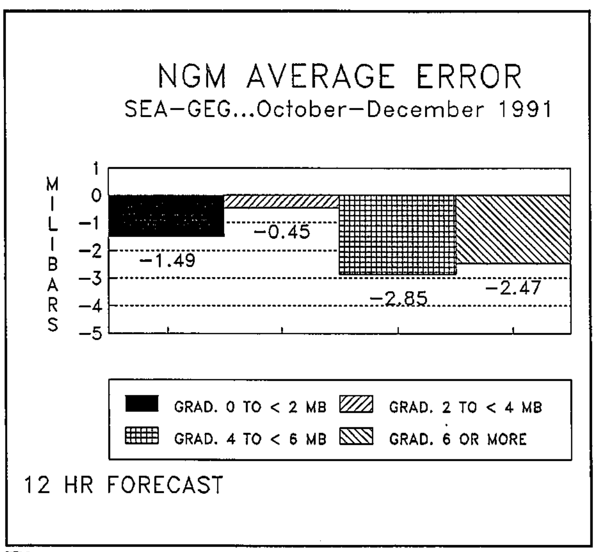
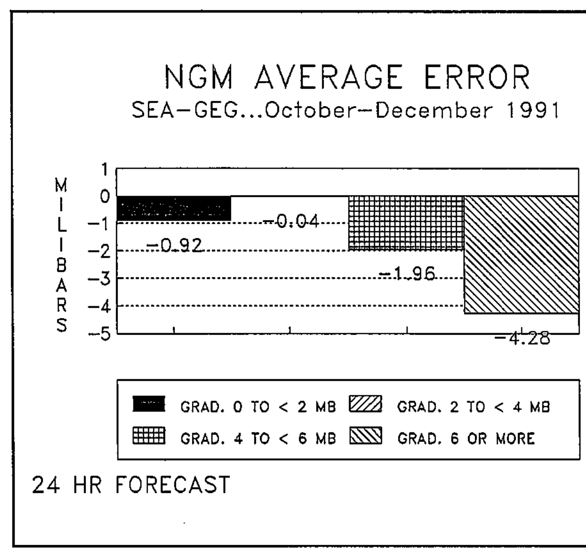


Fig. 4c.



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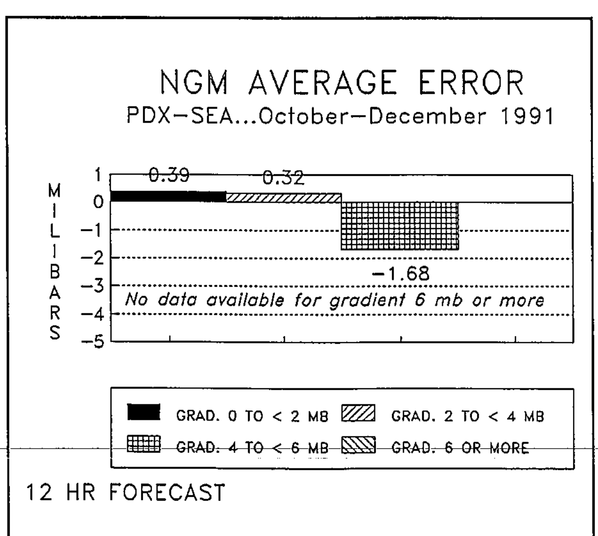

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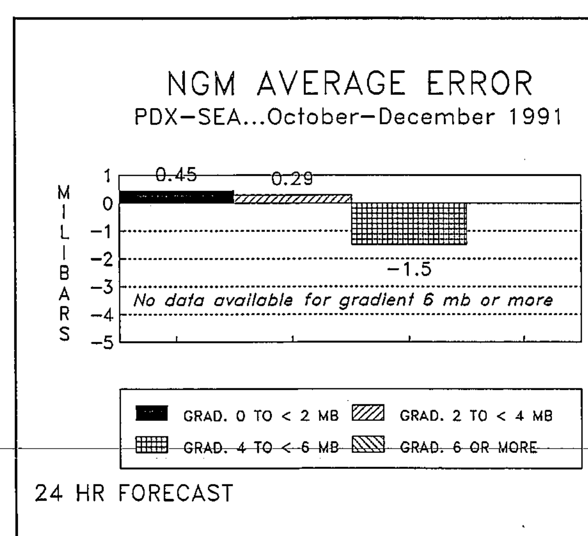

Fig. 4f.

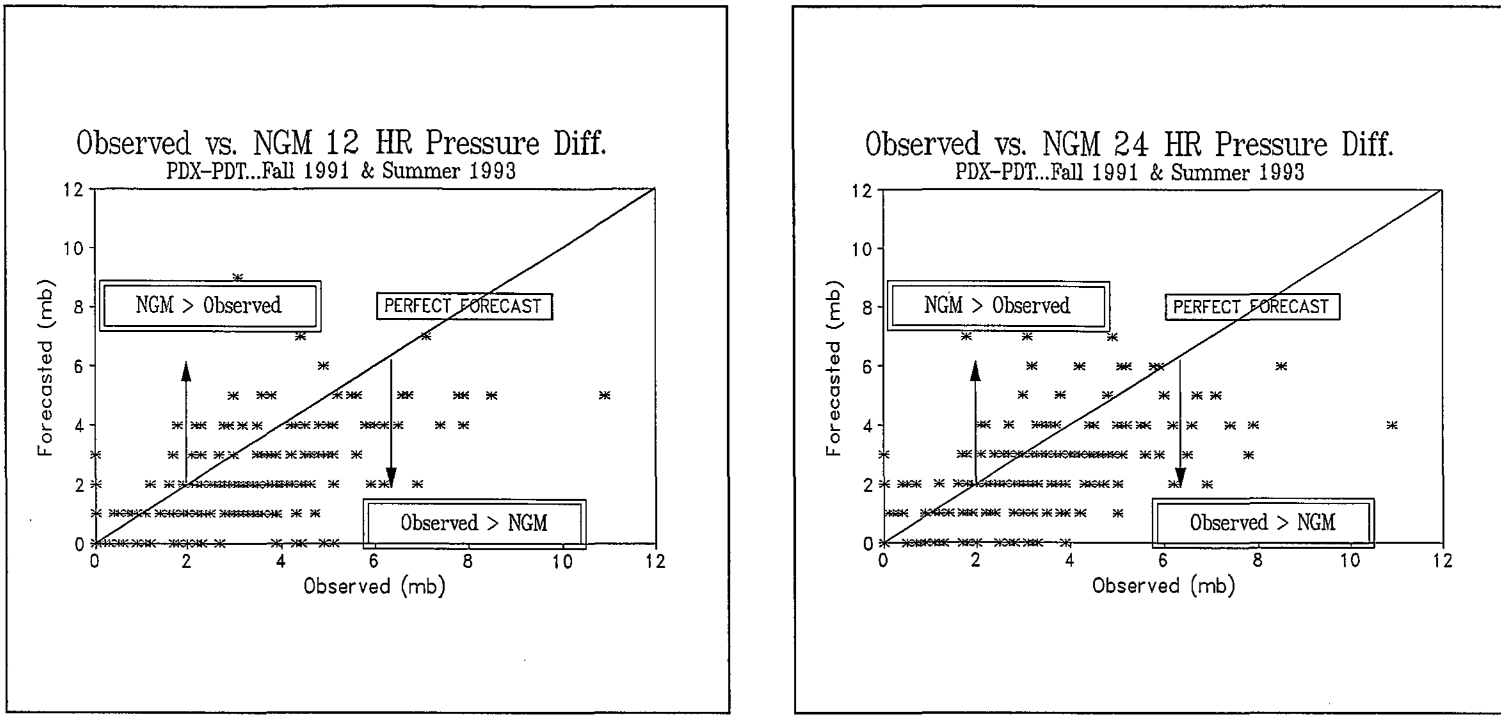

Fig. 5.A. Scatter plots showing observed versus NGM forecasted pressure differences at 12 and 24 hours between Portland and Pendleton (PDX-PDT). The perfect forecast is represented by the diagonal line on each graph.

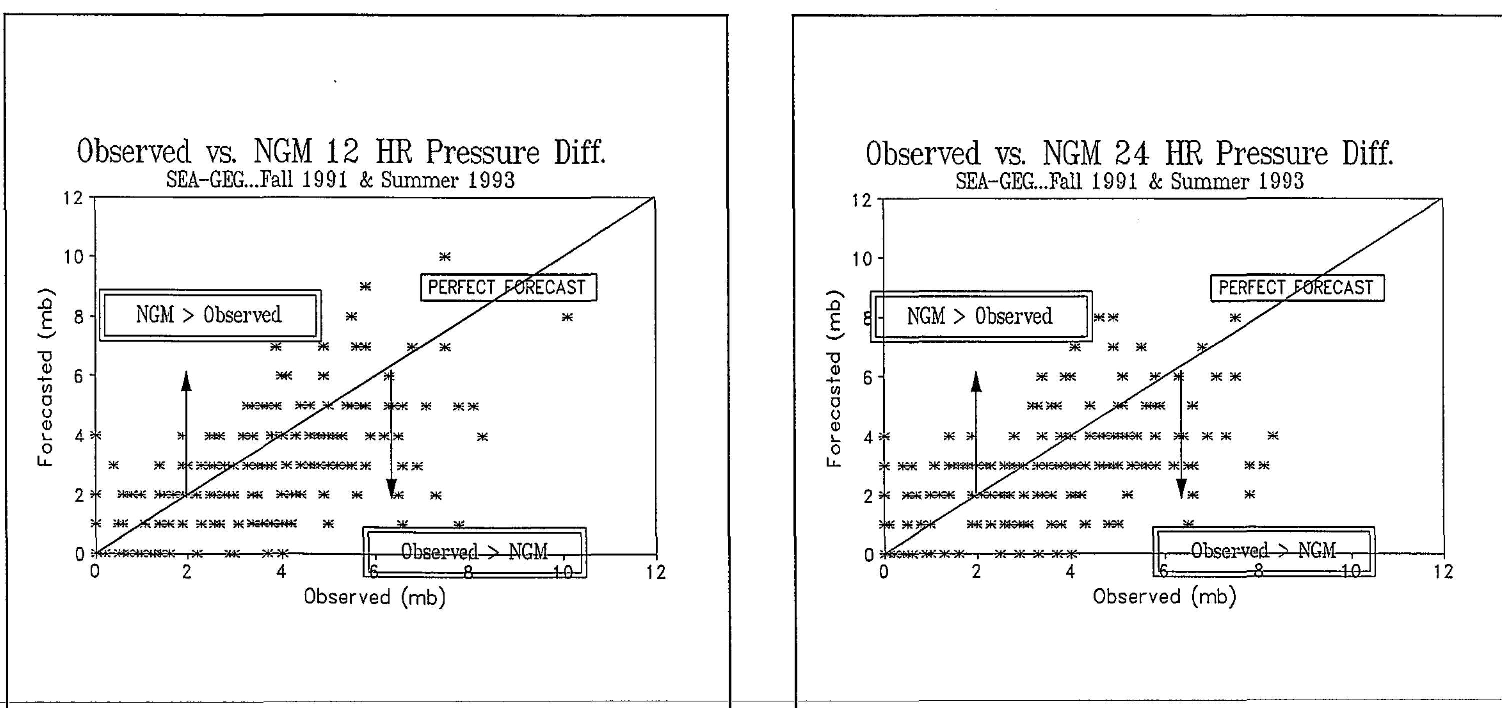

Fig. 5.B. Scatter plots showing observed versus NGM forecasted pressure differences at 12 and 24 hours between Seattle and Spokane (SEA-GEG). The perfect forecast is represented by the diagonal line on each graph.