4.4 WIND AND SEA SURFACE PRESSURE FIELDS FROM THE SEAWINDS SCATTEROMETER AND THEIR IMPACT IN NWP

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1. INTRODUCTION

Spaceborne scatterometers provide marine surface wind vector measurements with unprecedented coverage in space and time. As a result, these instruments can serve as invaluable tools in operational meteorology, and particularly in their contribution of valuable observations for use in the realm of numerical weather prediction (NWP). Recent work (Atlas et al. 2001) presents a clear review of previous studies, which have successfully demonstrated this result. However, these previous works focus solely on the direct assimilation of scatterometer surface winds. Scatterometer winds may also be used to directly calculate sea surface pressure fields (Endlich et al. 1981; Harlan and O'Brien 1985; Brown and Zeng 1994; Zierden et al. 2001). Here, the focus is devoted not only to evaluating the impact the scatterometer winds, but also to the impact of assimilated scatterometer-derived sea surface pressures.

Preliminary studies examining the impact of scatterometer data in weather prediction produced only mixed results. Baker et al. (1984) and Duffy et al. (1984) were amongst the first to establish that assimilated satellite scatterometer winds from SeaSAT-A provided significant improvements in the surface analyses over the oceans. This was particularly true in the case of major synoptic events over the Southern oceans, and other areas where the scarcity of marine observations was most severe. However, the improvements from the SeaSAT winds were less evident in the analysis of upper atmospheric levels, and demonstrated no significant impact on model forecasts. Similar impacts were observed using winds measured by ERS-1. Subsequent works (Hoffman 1993; Stoffelen and Anderson 1997) demonstrated that ERS-1 surface winds greatly enhanced the initial analysis in the wind fields of the ECMWF model but lacked sufficient influence overall to enhance the model's forecasts. Further studies revealed that the limited impact of scatterometer winds, when assimilated into NWP models, was primarily due to ineffective methods of assimilation. It was realize this was largely related to the unique characteristics of the scatterometer data.

Satellite surface winds differ from conventional surface wind observations and therefore, require specialized data processing (Atlas et al. 2000). Vertical correlation or adjustment schemes have been exchanged for the use of sea surface pressures generated from the scatterometers surface winds can vertically extend the influence of scatterometer observations (Tahara and Nomura 1999; Tahara 2001) and may perhaps impact the performance of atmospheric models in an even greater fashion than before. Sea surface pressures may be calculated from scatterometer winds using

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geostrophic relationships and a boundary layer adjustment that are in conjunction with numerical methods of to solve for either pressures or pressure gradients.

Assuming a relatively hydrostatic state in the atmosphere, surface pressures represent three dimensional columns of the atmosphere rather than the two-dimensional fields depicted by the wind vectors alone. Surface pressure fields affect the mass fields of the atmosphere directly and thus the impact of their assimilation could be much stronger than that of the winds alone (without additional model adjustments). With the use of pressures, many issues regarding complicated boundary layer physics can be circumvented and so too the need for any vertical extrapolation schemes to adjust the upper atmospheric levels in NWP models.

The calculation of sea-surface pressures from the scatterometer wind vectors (section 2.1) is made following the works of Harlan and O'Brien (1985), Brown and Zeng (1994) and most closely that of Zierden et al. (2001). One month of SeaWinds surface pressures and the same month of winds are assimilated into a global atmospheric model (section 3) at the National Aeronautics and Space Administration (NASA) Goddard Data Assimilation Office (DAO). Several case studies demonstrate the impact of assimilated SeaWinds sea-surface pressure fields as well as assimilated winds.

2. SEAWINDS INSTRUMENT

SeaWinds, like all scatterometers, measures backscattered microwave signals that are Bragg scattered by short wavelength water waves (capillary and ultra gravity waves) on the ocean's surface. These short wavelength water waves respond quickly to changes in wind. The backscattered cross section, σ^o (the fraction of transmitted radar signal energy reflected back to the instrument), are evaluated with an empirical geophysical model function that determines surface wind speed and direction relative to the scatterometer's position. Scatterometers acquire multiple, spatially and temporally co-located observations of σ^o, from different viewing angles and/or polarizations. This ensures greater accuracy in measuring wind speed and is necessary for the determination of the surface wind vector's direction.

2.1 SeaWinds Wind Vectors

Herein, wind vectors from the SeaWinds Level 2B (L2B) data set are used. These winds are processed at NASA's Jet Propulsion Laboratory (JPL) by the Physical Oceanography Data Acquisition and Archive Center (PODAAC). A subset of these vectors (and surface pressures) based on across swath position is assimilated into the model. Data (winds or sea-surface pressures) from the 'sweet spot regions" (250-700 km from nadir) are used exclusively in this experiment.

2.2 SeaWinds Derived Surface Pressures

The calculation of sea-surface pressures from the scatterometer wind vectors in this study is made following well-established variational methods (Zierden et al. 2001). Relative vorticity is computed from scatterometer observations, and blended with geostrophic vorticity obtained from a NWP model surface pressure field.

The Seawinds wind vector measurements are made on a regular grid aligned with the instrument's surface track, which is convenient for the computation of relative vorticity inside the scatterometer swath. Relative vorticity is computed using a centered finite-difference scheme. The wind vectors' speed and direction are decomposed into along track and cross track components for the calculation of relative vorticity, ζ_s (scatterometer vorticity). Delunay triangulation (Renka 1982) is employed to transfer the scatterometer's relative vorticity to a regular quarter degree grid. Grid points where neighboring wind vector data is missing are treated as points without any scatterometer-based relative vorticity.

The scatterometer-based relative vorticity is combined with a geostrophic vorticity obtained from the NWP model before solving for a new sea-surface pressure field. The determination of NWP geostrophic vorticity is made on the grid of the NWP pressure. All subsequent steps in the method are calculated on a finer 0.25° grid to maximize the benefit from the scatterometer resolution. Once both relative scatterometer and NWP geostrophic vorticities are obtained, they are blended together smoothly through the minimization of the cost function to find solutions pressures and vorticities.

3. MODEL

The NASA DAO and the Global Dynamics Division (GDD) of the National Center for Atmospheric Research (NCAR) have recently developed a global circulation model (GCM), the NASA-NCAR GCM, which is highly suitable to explore the impact of scatterometer data on NWP. This model was developed in hopes of producing a unified climate, numerical weather prediction, and chemistry transport model suitable for the global data assimilation and simulation of the physical and chemical state of the Earth's atmosphere. Its suitability for the experiments conducted here lies in its robust CORE data assimilation system (DAS) and it's Physical Space Analysis System (PSAS). These systems are designed with the assimilation of satellite observations in mind.

The NASA-NCAR GCM employs a Lagrangian vertical coordinate system. The general circulation model and the Core DAS of the NASA-NCAR model are both based on the finite volume dynamical core (Lin and Rood 1996; Lin 1997; Lin and Rood 1998). Further physical parameterizations were added to this foundation from the NCAR Community Climate Model 3 (Kiehl et al. 1996). The NASA-NCAR GCM also makes use of a Statistical Quality Control (SQC) System to screen observational data prior to assimilation. Essentially, the SQC system is comprised of simple checks of the observational against a background field. This is followed by an adaptive buddy check which adjusts the error bounds according to the flow of the day.

The analysis system for the NASA-NCAR GCM is an updated version of from the Phyiscal-space Statistical Analysis System (PSAS) (Cohn et al. 1998). In previous studies, the PSAS has proven to be highly successful in enhancing model performance using scatterometer wind observations (*Atlas et al.* 1999, 2000, 2001), functioning in conjunction with NASA's older GEOS model systems, which preceded the NASA-NCAR GCM. The PSAS combines a first guess from the model with observational data to provide an updated state of the atmosphere. The system works in both observation and finite-volume spaces, with no intermediate constant pressure transformation necessary (P to Φ interpolations are eliminated). The PSAS produces analysis increments directly on the model grid, thereby preserving the balance relationships implied by the error covariance formulations. Furthermore, the surface and the upper-air analyzes are unified in the system, thus ensuring the consistency between surface pressure and low-level geopotential height analysis, and maximizing the impact of surface wind observations on the upper-air fields.

For the experiments described here, the model assumed its standard configurations with some slight modifications. In place of the full vertical resolution of 55 layers, the model was run with 36 vertical layers, and its horizontal resolution was slightly reduced to 1.0°×1.25° grid spacing. This configuration is chosen to economize computational time and space.

4.SEAWINDS IMPACT EXPERIMENTS

A series of individual experiments are conducted to separately assess and compare the impact of assimilated SeaWinds-derived sea surface pressures and assimilated SeaWinds surface wind vectors. The method closely follows the procedures established by (*Atlas et al. 2001*). The experiments occurred in three separate stages. The first stage was comprised a control run (CR) of the model conducted without any assimilated scatterometer data. The second stage is the model run with assimilated SeaWinds wind vectors (WR). The third stage consists of the model simulation with assimilated SeaWinds surface pressures (PR). An approximately one-month period of study (November 2000) is selected from to examine the scatterometer data's impact on the model performance. During this period, 29 days of scatterometer data are separately assimilated into the model. Assimilations occurred at regular six-hour intervals. From these assimilations, 174 individual global analyses are made as well as 22 individual five-day forecasts. These 22 forecasts were made daily from November 4th to November 25th.

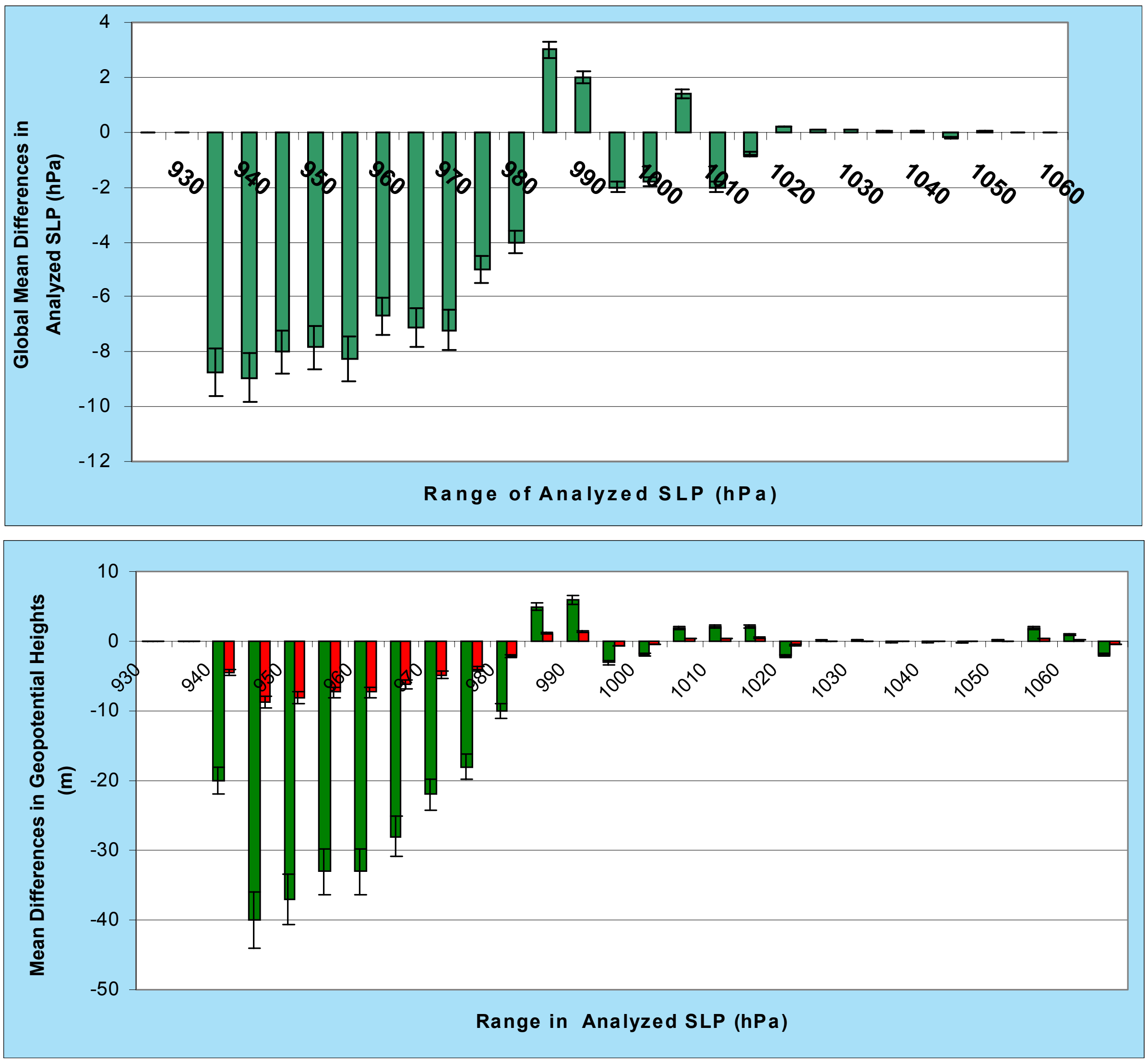

Figure 1. Mean point-to-point differences in analyzed PR-CR (top) SLP and (bottom) geopotential height (green: 850mb; red: 500 mb), as a function of WR SLP (there is little difference when plotted against PR SLP). For low pressures, the WR–CR differences (Fig. 2) are larger than the PR–CR differences.

5. RESULTS

The impact of the scatterometer data upon the NASA-NCAR's GCM's performance is evaluated in two phases. First, the influence of the SeaWinds data upon the model's analysis fields is investigated. Subsequently, the impact of both the assimilated pressures and winds upon the model's forecasts is explored.

5.1 SeaWinds Impact on the GCM's Analyses

Global averaged differences in the WR and PR analyses suggest that there is only a subtle difference between the impacts of the two data types. A point-to-point determination of differences in analyzed SLP, averaged as a function of pressure, reveals that the greatest differences in the analysis fields occur in the lower atmospheric layers and during particularly strong events (Figs. 1,2). The mean differences are greatest for the lowest pressures (stronger low pressure systems and fronts). These differences decrease with increasing analyzed SLP. A similar plot using PR analyzed SLP on the independent axis presents a similar distribution of differences.

Globally averaged statistical differences between the scatterometer-aided analyses and the control illuminate the general impact of the scatterometer data; however, it largely obscures much of the most beneficial the assimilated scatterometer data. In many particular cases, the impacts of the assimilated SeaWinds data are much stronger than the statistical comparison suggests. The use of the assimilated SeaWinds data significantly enhances the definition (i.e., relative fine scale features) of developing systems in the analysis fields. Many key features, such as the low pressure centers of developing storms or the frontal locations associated with such storms, can only be seen in the analyses rendered with the assimilated scatterometer data. One such case is taken as representative example from the experimental results, illustrates these strengths of the SeaWinds aided analyses.

Beginning at 12Z on November 22nd, the SeaWinds analyses show a strong low pressure system is observed at 60°S latitude with a central pressure of roughly 967 hPa centered

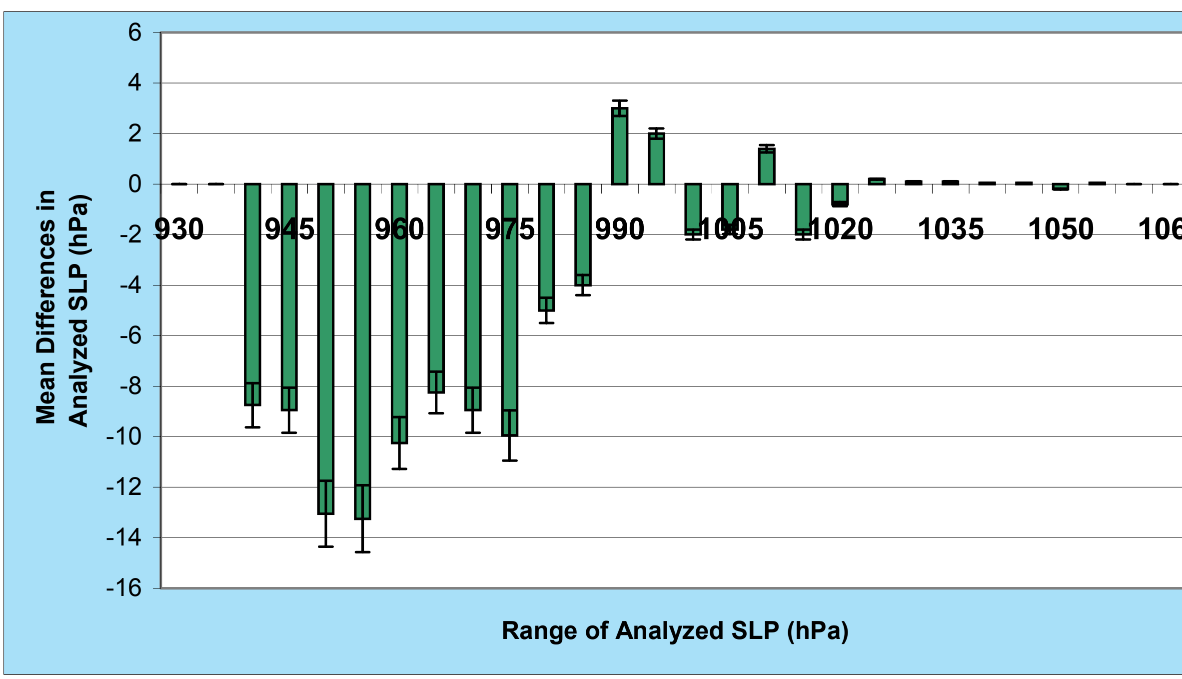

Figure 2. Mean point-to-point differences in analyzed WR-CR SLP.

about 155° W longitude. Associated with this large system are two smaller lows, emerging off the southeastern coasts of Australia and New Zealand respectively. In the 12Z analysis rendered by the CR, these smaller associated systems appear to be nearly identical to in location, size and developmental state to the same features in the PR and the WR. As the systems evolve, differences (PR-CR and WR-CR) increase. At 18Z, clearly defined pressure centers exist in the PR and WR SLP analysis fields; however, these centers are absent in the CR. In the 0Z and 6Z of the November 23rd PR and WR analyses show the small systems intensifying, whereas the CR analyses suggest a weaker development of theses systems. This remains true until the 18Z analysis of November 23rd. A shortcoming of the scatterometer aided analyses for this case is that a similar impact is not observed at either the 850 hPa or 500 hPa pressure levels for this case. This result is typical for the majority of cases without bias towards any particular latitudes.

5.2 *Impact of the Assimilated SeaWinds Data on the Model Forecasts*

Twenty-one five day forecasts were also made in each model run. Each forecasts was generated from the 18Z analysis the preceding day, commencing on November 5th and ending on November 25, 2000. An initial evaluation of the forecasts is made by computing anomaly correlations (ACS) over the five days of each forecast. Specifically, ACSs are computed for the forecasted SLP and 500 hPa geopotential height fields. The ACS evaluates the agreement between forecasted fields and analyzed fields. Verification for the ACS computation is based on the same model run's analysis (i.e. verification of the PR forecasts is made with the PR analysis fields). The higher the ACS value, the more accurate the forecasted field is deemed. It is generally accepted that ACS values of 0.60 and higher demonstrate useful forecast skill when applied in this manner.

The average of the results obtained through the anomaly correlation computations suggest that that the impact of the scatterometer pressures and winds is slight in the Northern Hemisphere and more pronounced in the Southern Hemisphere (Figure 3). The average ACS values further indicate that the WR forecasts are typically an improvement over the CR in both hemispheres. However, the PR forecasts only show a very slight improvement in the Northern Hemisphere. In the Southern Hemisphere, the assimilated SeaWinds pressures have a negative influence on the global statistics. There is considerable variability in the ACSs; therefore, the global statistics are a suspect indication of the

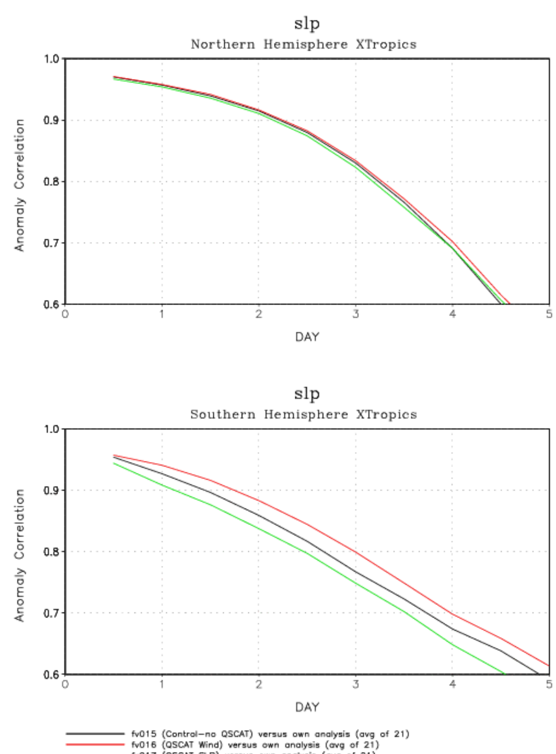

Figure. 4. Anomaly Correlation Scores (ACS) for sea level pressure fields for the (a) northern and (b) southern hemisphere extra-tropics, as a function of the time into the forecast period.

combined value of the data and the assimilation technique.

No control run was produced by for the forecasts; therefore, WR and PR results are compared directly (Fig. 4). As with the analyses, the two types of scatterometer assimilations provide similar results, and the WR low pressure systems have slightly lower pressures and sharper features.

6. CONCLUSIONS

This study of the impact of SeaWinds data indicates that satellite scatterometers can play a significant and positive role in the realm of NWP. This is true in the case of utilizing either SeaWinds derived pressures or SeaWinds surface wind vectors. The impact of the pressures is similar, but not identical to that of the winds. In the analysis phase of the model performance, the impact of both pressures and winds is manifested as an improved analysis of developing marine storms, fronts and strong low-pressure systems. It is in the analysis of strong systems that the differences in scatterometer pressure and wind products differ the most. These differences are of lesser magnitude in the model forecasts.

ACS analysis suggests that on average, the SeaWinds winds positively enhanced the model forecasts, particularly in the Southern Hemisphere. However, the use of the SeaWinds pressures produces a slightly negative average impact. However, it is evident that the performance of both the pressures and winds varies substantially on a case by case basis, indicating that the differences are likely to be of little significance.

The results of this study are highly dependent upon the atmospheric model used and the data assimilation method employed to incorporate the scatterometer data. Results from this experiment demonstrate the benefits of the DAO's analysis system when assimilating satellite, and in particular, scatterometer data into an atmospheric model. The assimilation of scatterometer pressures is a unique aspect of this study and results suggest that the assimilation of the pressures is nearly as effective as the assimilation of the winds in this setup. It would be interesting to see if this holds true or if the impact of the pressures may be greater in less sophisticated NWP assimilation and analyses systems.

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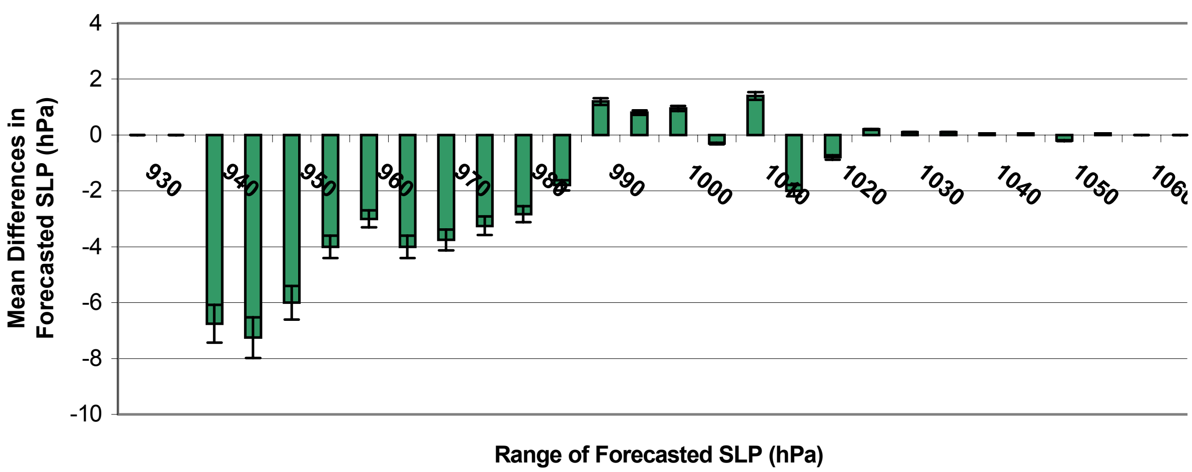

Figure 4. Mean point-to-point differences of forecasted SLP fields using scatterometer data (PR−WR) as a function of WR SLP (plotting with respect to PR SLP results in small changes).

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