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Evaluating the potential impact of the assimilation of satellite derived products on a mesoscale forecast of PACific landfalling JETs experiment (PACJET) IOP 10

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1. INTRODUCTION

As part of the PACific landfalling JETs experiment (PACJET), the GOES rapid scan WINDs EXperiment (GWINDEX) was conducted with the objective of demonstrating improved quantity and quality of cloud-motion winds using 7.5 minute rapid-scan visible and infrared imagery from the GOES-10 satellite. The goals of PACJET are to develop and test methods to improve short-term (0-24 h) forecasts of damaging weather on the U. S. West Coast in landfalling winter storms emerging from the data sparse Pacific Ocean. The goals of the GWINDEX component of PACJET are to provide improved remotely-sensed data over the Eastern Pacific (EPAC) domain for National Weather Service (NWS) forecasters, support PACJET and THORPEX initiatives, and assess data impact on the RUC model short-term forecasts. PACJET was designed to test new ways to observe approaching storms, develop better ways to use existing data, improve our understanding of key physical processes, explore the linkages between climate variability and extreme weather, and work with forecasters to develop new forecasting tools.

GWINDEX, conducted during PACJET, took place from 10 January through 31 March 2001 over the EPAC and west coast of North America, and brought together participants within NOAA/NESDIS/ORA and FPDT, the University of Wisconsin-CIMSS, the NWS, NOAA/FSL/NSSL, and the U.S. NAVY. Data collected during PACJET/GWINDEX included, in addition to GOES-10 data, special dropsonde soundings, ocean surface flux measurements, and wind profiles on the U.S. west coast.

This study, using data collected during February 2001, intends to assess how well these special satellite and sounding observations may be used to improve forecasts of landfalling winter storms. We focus on improving how the assimilation of these data into the Pennsylvania State University-National Center for Atmospheric Research (PSU-NCAR) non-hydrostatic mesoscale model (MM5) may improve forecasts made with a numerical weather prediction model, one main focus of PACJET/GWINDEX.

The four-dimensional variational (4DVAR) assimilation system to be used in this study is developed from the MM5 Adjoint Modeling system based on the PSU-NCAR MM5 version 1 (Zou et al., 1997) and used in a set of assimilation experiments including Guo et al. (2000). As the first part of this study, we diagnose the sensitivity of the forecast (error) to changes in the initial conditions using the MM5 adjoint model. This will provide insight into where assimilation of observations may have the largest effect in improving the MM5 forecast and will serve as a basis for the study of the impact of the analysis increment attributed to the assimilation of wind and temperature on particular aspects of the model forecast.

In the presentation to follow, we briefly describe the synoptic characteristics of the case to be studied and provide a description of the model errors and the sensitivity of the forecast error to the initial conditions. We conclude with an outline of the proposed experimental design.

2. SYNOPTIC OVERVIEW

For this study, we focus on a cyclogenesis event that occurred between 0000 and 1200 UTC 13 February 2001 southwest of Los Angeles, CA. This event occurred during intensive observing period 10 (IOP 10) of the PACJET experiment. The precursor to the event was a vigorous upper tropospheric trough that was located west of the Oregon coast 0000 UTC 12 February (Fig. 1a). During the next 24 h, the vorticity maximum associated with this trough moved southward around a nearly stationary geopotential height minimum situated just offshore the northern and central California coasts. Following 0000 UTC 13 February the vorticity maximum moved eastward to a position just west of the northern Baja Peninsula of Mexico (Fig. 1b) by 1200 UTC 13 February.

During this 12 hour period a surface cyclone developed west-southwest of 32N 119W and moved east-northeast, making landfall east of Santa Barbara, CA after 1500 UTC 13 February. In the 6 h period ending at 1200 UTC 13 February, the cyclone deepened nearly 10 hPa to 992 hPa (Fig. 2a, close scrutiny of the surface observations reveals a cyclone deeper than analyzed). 12 hour pressure changes offshore of the bight of south-

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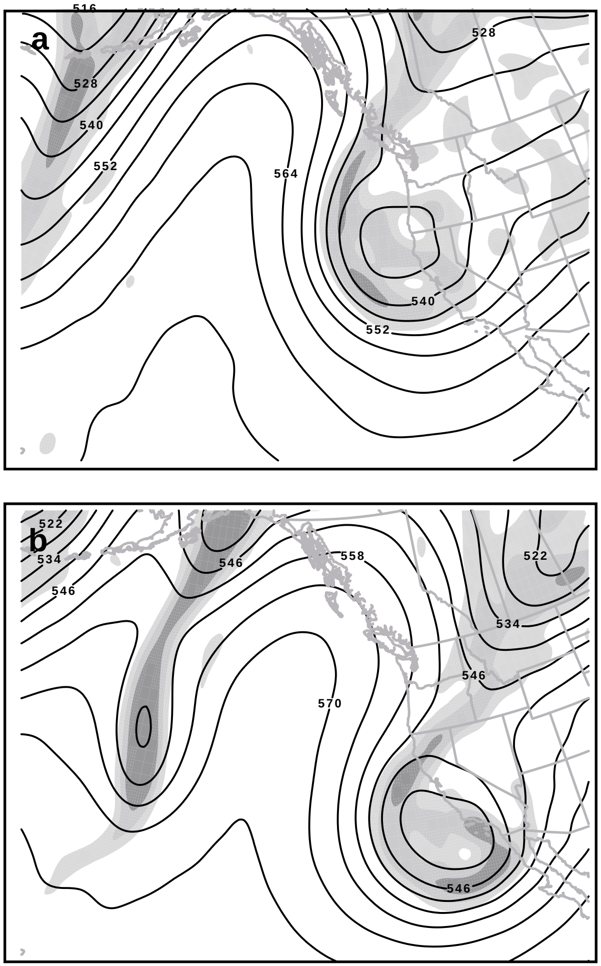

Figure 1. 500 hPa geopotential height (solid contour, interval 6 dam) and absolute vorticity (shaded above 12 x $10^{-5}s^{-1}$, interval 6 x $10^{-5}s^{-1}$) analyses for (a) 0000 UTC 12 February and (b) 1200 UTC 13 February.

ern California were as much as 17 hPa ending at 1200 UTC 13 February. This cyclone was accompanied by heavy precipitation (rain in the coastal areas and snow in the mountains) and wind.

3. MODEL FORECAST ERROR

A 36 h MM5 simulation of the event was performed. The model, initialized with National Center for Environmental Prediction (NCEP) ‘final analyses’, was run with 16 vertical levels, on a 68x85 60 km grid. The model physics included a bulk planetary boundary layer scheme, Kuo cumulus parameterization, and simple iced physics. The rather crude physics and resolution were chosen to make the run compatitble with the physics available for the MM5 Adjoint Modeling System. The 36 h MM5 forecast of this event was associated with an underforecast of the cyclone intensity and also a cyclone position error (compare Fig. 2b with Fig. 2a). In addition, the lower tropospheric wind field was poorly forecast. The poor forecast of the wind in regions of significant orography can lead to poor precipitation forecasts.

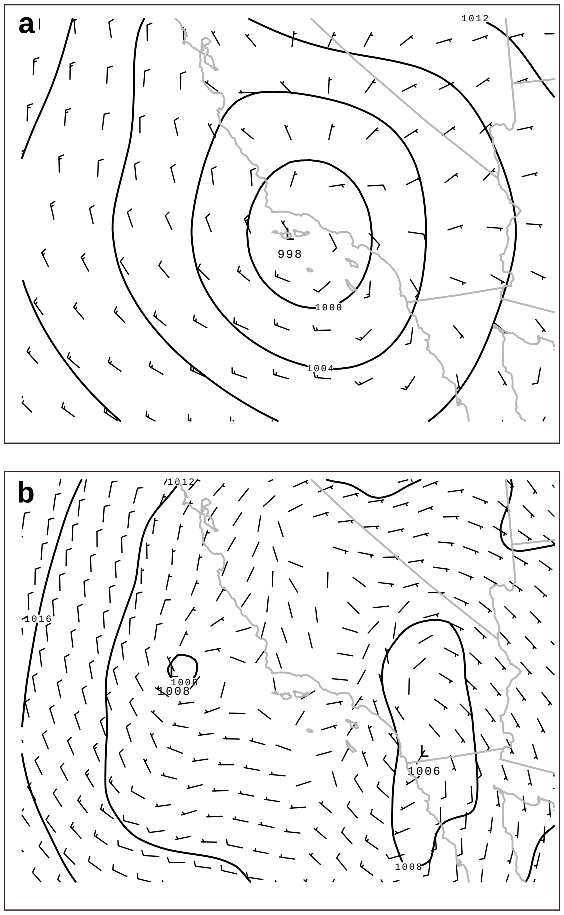

Figure 2. Mean seal level pressure (contour interval 4 hPa) and wind (ms^{-1}) from (a) NCEP final analysis and (b) 36 h MM5 forecast valid 1200 UTC 13 February. The box in (a) denotes the domain in which the area weighted vorticity was calculated.

4. FORECAST SENSITIVITY

For the purposes of assessing the potential impact of assimilation of the GOES-10 derived winds on the forecast of the PACJET 1OP 10 event, we conduct an adjoint sensitivity study. The response function chosen is the “energy-weighted forecast error” (e.g., Rabier 1996 and Gelaro et al. 1998) in a 10 degree latitude by 10 degree longitude box centered on the analyzed position of the surface cyclone. We define the forecast error as the difference between the 36 h forecast of the model state and the NCEP ‘final analysis’ interpolated to the model grid at the same time (1200 UTC 13 February 2001).

An examination of vertical and horizontal cross sections along the vertical and horizontal shear (not shown) reveals that the sensitivity fields show considerable barotropic and baroclinic upshear tilt. In the upper troposphere, the sensitivity fields appear to be maximized in the vicinity of the precursor upper tropospheric vorticity maximum. Fig. 3a shows the sensitivity of the response function with respect to the initial distribution of the meridional component of the wind at 500 hPa. Regions

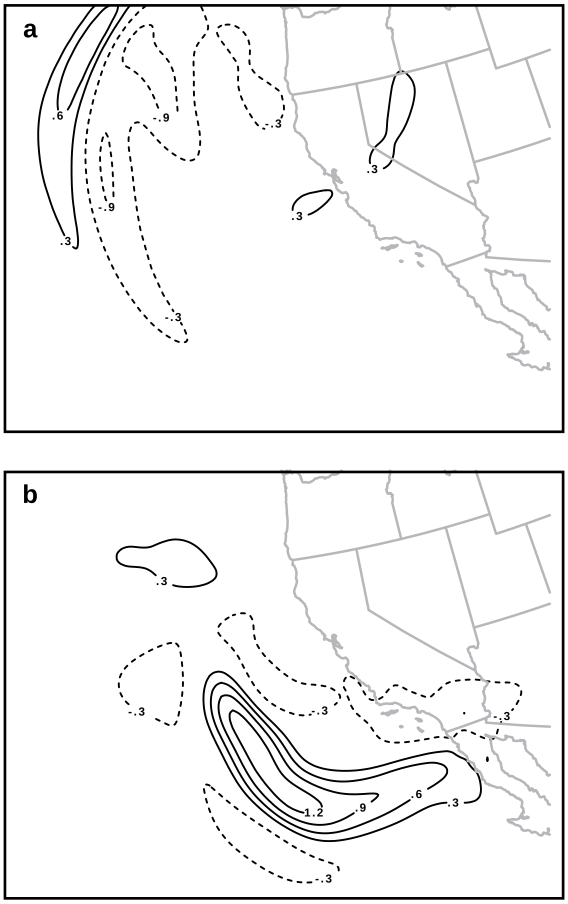

Figure 3. Gradient of response function (defined in text) with respect to initial model distribution of (a) meridional wind at 500 hPa and (b) zonal wind at 850 hPa on 0000 UTC 12 February 2001.

in which the sensitivity is positive correspond to regions in which a positive meridionalperturbation to the wind in the initial analysis will lead to an increase in the weighted forecast error at 36 h. The larger the sensitivity, the larger the change in the response function. Regions of low sensitivity correspond to regions where changes in the analysis will have a small effect on the response function at 36h. Fig. 3b shows the gradient of the response function at 850 hPa with respect to the initial zonal component of the wind. Note that the maximum sensitivity at this level is further to the southeast of the maximum at 500 hPa. A response function defined as the circulation about the same box defined for the energy-weighted forecast error is associated with sensitivity fields which would yield a consistent interpretation.

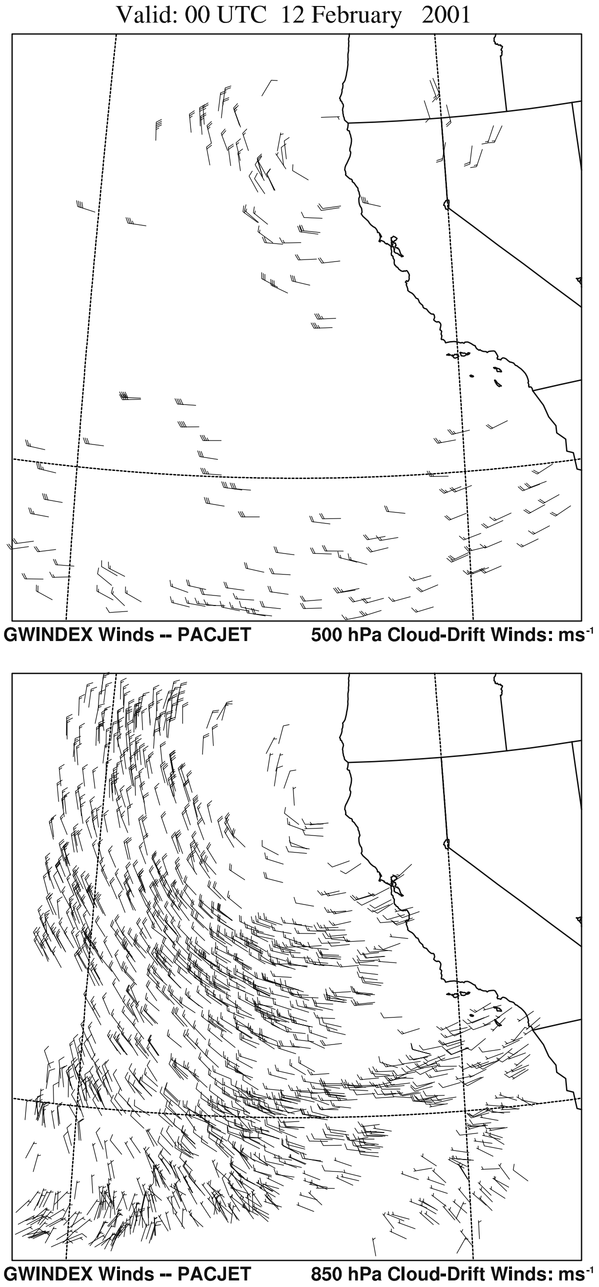

Figure 4. Distribution of GWINDEX winds (ms^{-1}) at 0000 UTC 12 February 2001 in a 35 hPa layer centered about 500 hPa (top) and 850 hPa (bottom).

A comparison of the distribution of GOES wind data available from GWINDEX at 0000 UTC 12 February (Fig. 4) with the sensitivity fields in Fig. 3 reveals that the 850 hPa winds best overlap the sensitivity fields at 850 hPa. This overlap suggests that the analysis increments associated with assimilating these winds will have an impact on the forecast of area weighted vorticity in the box shown. A calculation of the observational increments determined by interpolating the model analysis to the satellite wind vector locations, (not shown) suggests that the implied *analysis increments* for both the zonal (*u*) and meridional (*v*) components of the wind associated with these additional observations are of a sign which would lead to an *increase* in forecast error. Thus assimilation of these winds would be detrimental to the forecast.

In addition we note that a comparison of the distribution of the satellite derived winds as a function of height with the sensitivities of forecast errors with respect to *u* and *v* as a function of height (Fig. 5) reveals that the satellite data is most plentiful in regions for which the sensitivities of the forecast error with respect to the initial

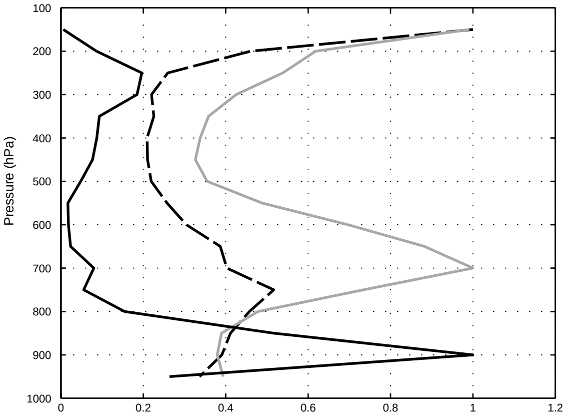

Figure 5. Vertical distribution of normalized area averaged forecast sensitivities with respect to initial *u* (grey) and *v* (dashed) components of the wind. Also shown is the normalized number of satellite derived wind vectors as a function of pressure (solid). The count of wind vectors is normalized by the maximum count of 3020 at 900 hPa. Note that the level of the largest number of satellite derived winds does not coincide with the level at which the sensitivities are maximized.

conditions are relatively small.

5. SUMMARY AND FUTURE WORK

The initial results of the study thus far suggest that the impact of the satellite data on the forecast of the PACJET IOP 10 cyclone would be detrimental (as measured by the energy-weighted forecast error). We further observe that, for this case, the satellite winds are not found in regions that would have the largest impact on the forecast error - though we note that assimilation of these winds may result in a 'spreading' of the observational information to these sensitive regions.

While our longer term goal is to assimilate the GOES-10 winds into the MM5, our more immediate objectives are to understand from an observational and dynamical perspective the relationship between the forecast sensitivities and the synoptic precursor, and to determine an "optimal" initial condition which would yield a reduced forecast error. This improved initial condition may be viewed as the upper limit of any improvements in the initial analysis which could be obtained from four-dimensional data assimilation.

We will use the MM5 adjoint modeling system to conduct a 4DVAR assimilation of the GWINDEX winds. 4DVAR assimilation over a time window (τ) involves the minimization of a cost function, *J*

$$J = J_b + J_o + J_p$$

where J_b measures the degree of misfit of a background (or first guess) analysis with the desired analysis, J_o measures the misfit of the observations to be assimilated distributed in time and interpolated to the model grid with the model forecast initialized with that analysis, and J_p (a penalty term) is a measure of the degree of dynamical imbalance the analysis possesses. Each of the 'misfits' is weighted by the corresponding uncertainties in the background field or the observations. The weightings are in fact the inverses of error covariances of the background and the observational error. Thus in order to assimilate the GOES winds, we must specify the length of the assimilation window and the background and observational error covariances. In addition, we must develop an interpolation operator to interpolate the observations to the model grid. Finally, if we seek a balanced initial state, we need to determine a proper formulation for the penalty term J_p.

We will assimilate the observations over 3 and 6 hour time windows beginning at 0000 UTC 12 February 2001. In order to calculate the background error covariances, we will accumulate the 6 h error statistics of MM5 forecasts during GWINDEX and employ the technique of Parrish and Derber (1992) to determine the diagonal elements of the background covariance matrix.

Having assimilated the GWINDEX winds, we will diagnose the changes to the 36 h forecasts by re-running the model, and by examining the analysis increments and their relationship to measures of forecast error sensitivity to initial condition perturbations.

6. REFERENCES

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Acknowledgments

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