P4.2 Assimilating satellite wind, moisture, and temperature for numerical forecast improvements during the PACific landfalling JETs (PACJET) experiment

John R. Mecikalski CIMSS/University of Wisconsin*,
Christopher Velden, Michael Morgan, Daryl Kleist, Dave Stettner,
Katherine Goodstein, Hyun Mee Kim, and Bryan Baum
University of Wisconsin - Madison
Madison, Wisconsin

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 drop sonde 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) will 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 2 discussed in 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 plan on assimilating GOES-10 wind and temperature. Before assimilating these observations, we first will 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 certain aspects of the model forecast 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. 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).

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* Corresponding author address: John R. Mecikalski, CIMSS/University of Wisconsin - Madison, Department of Atmospheric and Oceanic Sciences, 1225 W. Dayton Street, Madison, Wisconsin 53706
email: johnm@ssec.wisc.edu

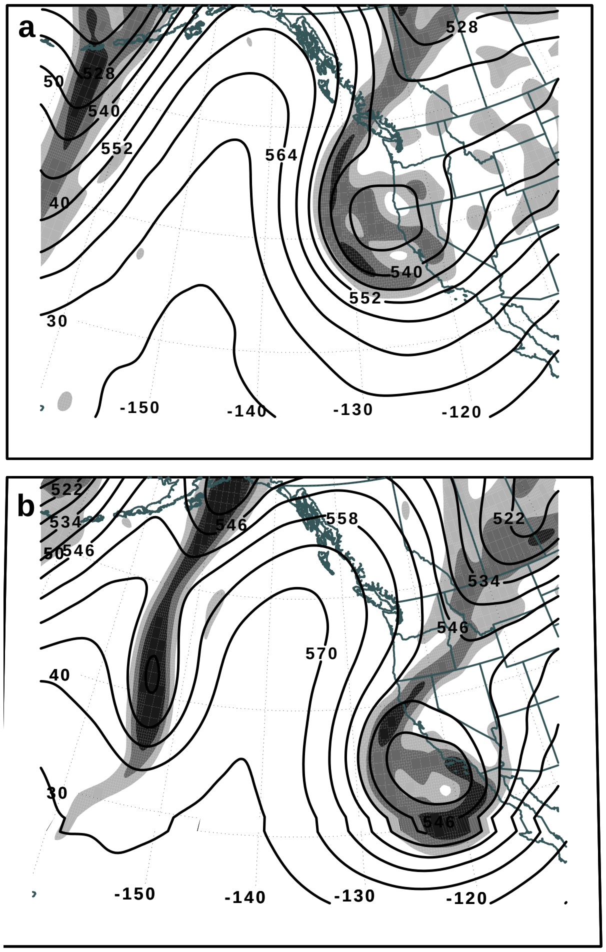


Figure 1. 500 hPa geopotential height (solid contour, interval 6 dam) and absolute vorticity (shaded above $12 \times 10^{-5} s^{-1}$, interval $6 \times 10^{-5} s^{-1}$) analyses for (a) 0000 UTC 12 February and (b) 1200 UTC 13 February.

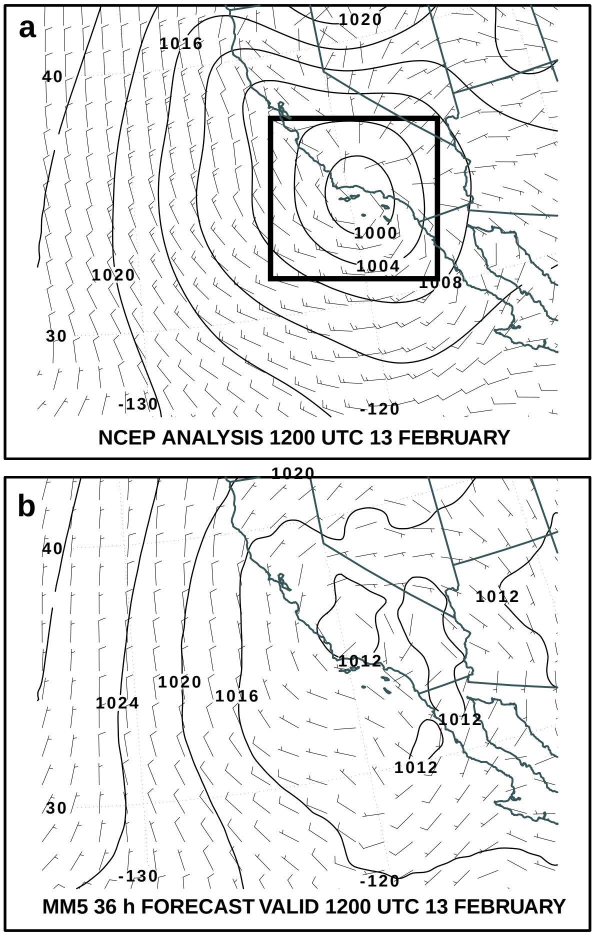


Figure 2. Mean seal level pressure (contour interval 4 hPa) and wind (ms^{-1}) from (a) NCEP final analysis and (b) 36 h MM5 forecast valid 1200 UTC 13 February. The box in (a) denotes the domain in which the area weighted vorticity was calculated.

12 h pressure changes offshore of the “bight” of southern 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 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). The model, initialized with NCEP AVN model final analyses, was run with 10 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. 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.

4. FORECAST SENSITIVITY

The adjoint of a numerical forecast model is a powerful tool to assess the sensitivity of various functions of the model forecast output to changes in the initial conditions (Errico, 1997). These functions of the model output, referred to as *response functions*, must be differentiable functions of the model output. The response function presented below, the area-averaged vorticity surrounding the cyclone in the lowest two sigma levels of the MM5 model in a 36 h forecast from 0000 UTC 12 February, is a measure of the intensity of the cyclone.

The sensitivity fields show considerable barotropic and baroclinic upshear tilt and appear to be maximized in the vicinity of and west and south of the precursor upper trough. 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 in which the sensitivity is positive correspond to regions in which a positive meridional perturbation to the wind in the initial analysis will lead to an increase in the circulation about the cyclone at 36h. 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 ini-

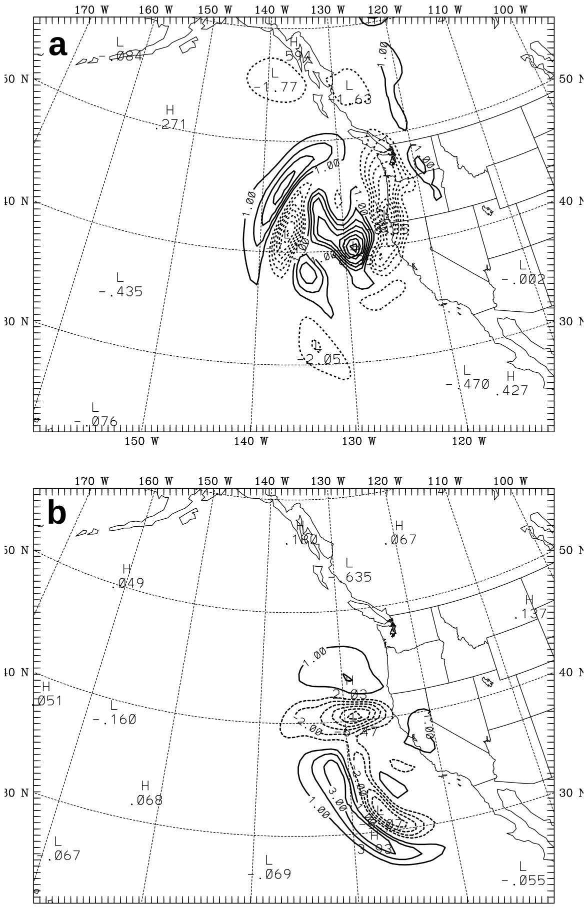
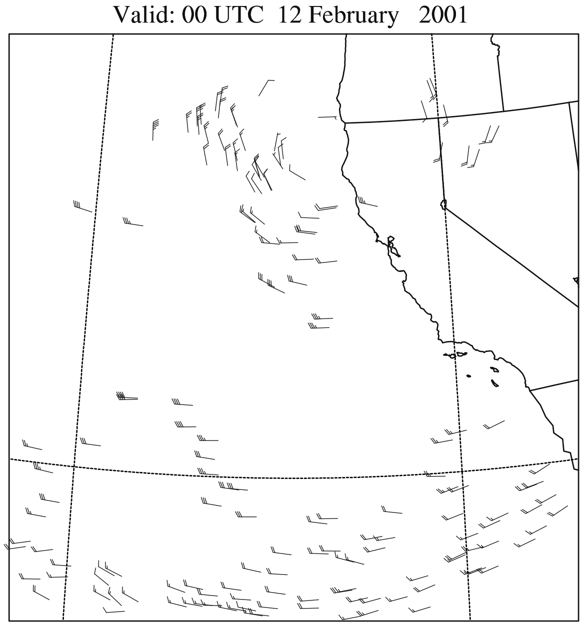


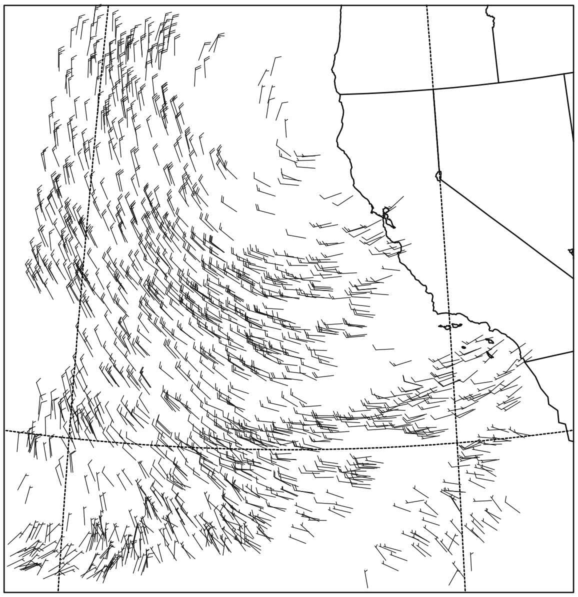
Figure 3. Gradient of response function (defined in text) with respect to initial model distribution of (a) meridional wind at 500 hPa and (b) zonal wind at 850 hPa.

tial 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 for the pressure perturbation in the lowest sigma level of the model at a grid point near the cyclone center is associated with a similar sensitivity field.

We will also explore response functions measuring the forecast error. In principle, given a perfect model, and the gradient of a response function that measures forecast error in a particular norm, it is possible 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.



GWINDEX Winds -- PACJET 500 hPa Cloud-Drift Winds: ms^{-1}



GWINDEX Winds -- PACJET 850 hPa Cloud-Drift Winds: ms^{-1}

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

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. Comparisons of the satellite winds with the wind analyses used in initializing the model suggest that in some regions, the analysis increments associated with these additional observations are of the proper sign to lead to an increase in the cyclone intensity. A more revealing comparison would be one in which analysis increments were compared with the sensitivity of a measure of the forecast error.

5. ASSIMILATION OF GWINDEX DATA

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

$$J = J_b + J_o$$

where J_b measures the degree of misfit of a background (or first guess) analysis with the desired analysis and 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. Each of these '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.

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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