SENSITIVITY OF MODEL SIMULATED LOW-LEVEL WINDS IN THE CENTRAL VALLEY OF CALIFORNIA TO UNCERTAINTIES IN THE LARGE-SCALE FORCING AND SOIL INITIALIZATION

Jian-Wen Bao[1], Sara A. Michelson[1, 2]

[1]NOAA/Earth System Research Laboratory, Boulder, Colorado, USA
[2]CIRES, University of Colorado, Boulder, Colorado, USA
E-mail : *Jian-Wen.Bao@noaa.gov*

Abstract: The sensitivity of the WRF model simulated low-level winds in the Central Valley of (CV) California to uncertainties in the atmospheric forcing and soil initialization is investigated using scatter diagrams. It is assumed that the uncertainties in the atmospheric forcing and soil initialization can be approximated by two independent operational analyses. First, the sensitivity is illustrated using scatter diagrams and measured in terms of the linear regression of the output from two simulations which differ in either the atmospheric forcing or the soil initialization. The spatial variation of the sensitivity is investigated and linked to the dominant low-level flows within the CV. The results from this study indicate that the WRF simulated low-level winds in the northern CV (the Sacramento Valley, SV) are more sensitive to the uncertainties in the atmospheric forcing than to those in the soil initialization. The simulated low-level winds in the southern most part of the San Joaquin Valley (SJV) are more sensitive to the soil initialization than they are in the SV. In the northern SJV, which is more directly under the influence of the incoming marine flow than either the SV or the southern SJV, the winds are overall more sensitive to the atmospheric forcing than to the soil initialization. This distribution of sensitivity indicates the important roles that the large-scale forcing specified by the lateral boundary conditions and the local forcing associated with the soil state play in controlling the incoming marine flow through Carquinez Strait.

Keywords: *Sensitivity study, WRF model, Central Valley of California, large-scale forcing, soil initialization,*

1. INTRODUCTION

This paper presents a case study to illustrate a method for measuring the relative sensitivities of a numerical weather prediction model to the uncertainties in the lateral boundary forcing and to those in the physics parameterizations, particularly in the land-surface parameterization. In this case study, simulations of the low-level winds in the Central Valley of California (CV) are performed using the Weather Forecasting and Research (WRF) model (Skamarock et al. 2005), and the results of the simulations are compared with the wind profiler and surface observations during an IOP of the 2000 Central California Ozone Study (CCOS). These comparisons are intended to reveal the sensitivity of the simulated low-level winds in the CV to the large-scale atmospheric forcing and soil initial conditions that are derived from the National Centers for Environmental Prediction (NCEP) and the European Centre for Medium-Range Weather Forecasts (ECMWF) analyses.

2. CASE STUDY

The analysis of both the observations and the simulations (Bao et al. 2007) has revealed several mesoscale low-level flow features in the CV (see the left panel of Fig.1): (1) the incoming low-level marine air flow through the Carquinez Straight into the Sacramento River delta, (2) the diurnal cycle of upslope/downslope flows (3) the up- and down-valley flow in the northern CV or hereafter referred to as the Sacramento Valley (SV), (4) the nocturnal low-level jet in the southern CV, or hereafter to as the San Joaquin Valley (SJV), and (5) the Fresno and Shultz Eddies. All these flow features interact with each other on the scales of the entire CV and the local dominant slope of the topography.

The WRF simulations are carried out on three one-way nested domains at 36-, 12- and 4- km resolution. There are 50 vertical stretched levels with 30 levels within the lowest 2 km and the lowest model level at about 12 meters above the surface. The 4-km domain encompasses the CCOS field study area, which extends from the Pacific Ocean in the west to the Sierra Nevada in the east, and from north of Redding, CA, to south of the Mojave Desert. Two simulations are carried out in which the initial and boundary conditions for the 36-km domain are generated using the 6-hourly 40-km Eta AWIP analysis from NCEP and the 0.5-degree ECMWF analysis. The simulations are initialized at 12 UTC 29 July and run for 120 h, ending at 12 UTC 3 August 2000. Two more WRF simulations are conducted to investigate the sensitivity of the simulated low-level winds to the uncertainties in the atmospheric forcing and soil initialization. In these two simulations, the initial and boundary conditions are created by changing the atmospheric information and the soil information from the NCEP and ECMWF analyses (see Table 1).

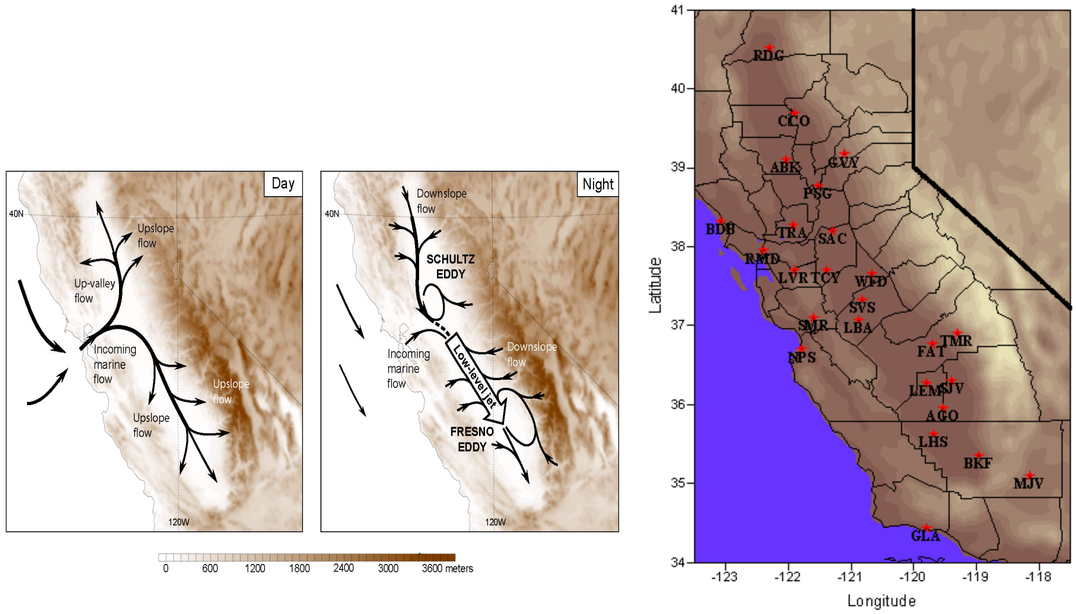

Figure 1: Left: Conceptualization of the daytime and nighttime low-level wind regimes during the 5-day episode. Right: Map of California with the location of the 25 profiler sites in the CCOS field study.

Table 1: Naming conventions for the WRF simulations. The first row and the first column indicate how each simulation is initialized (e.g., in the AWIP AIR ECMWF SOIL simulation, the 40 km Eta AWIP analysis is used to initialize the atmosphere and provide the lateral boundary conditions, while the soil is initialized using the 0.5-degree ECMWF analysis).

	AWIP ATMOSPHERE	***ECMWF ATMOSPHERE***
AWIP SOIL	AWIP	ECMWF AIR AWIP SOIL
ECMWF SOIL	AWIP AIR ECMWF SOIL	ECMWF

3. METHODOLOGY

Our method requires the use of scatter diagrams. In each scatter diagram, the abscissa is the prognostic variable from the AWIP simulation, and the ordinate is the counterpart from a perturbed simulation (i.e., either the AWIP AIR ECMWF SOIL or the ECMWF AIR AWIP SOIL simulation). Each data point in the scatter diagram corresponds to one of the 120 hours in the simulation. The interpretation of the scatter diagrams can be given in terms of simple linear regression (see Wilks 1995, section 6.2), in which the slope parameter (a) indicates the linear response of the prognostic variable to the change in either the atmospheric forcing or the soil initialization; the intercept parameter (b) measures the overall bias of the prognostic variable from the simulation in which either the atmospheric forcing or the soil initialization is different from the AWIP simulation; and the coefficient of determination (R^2) provides a measure of the nonlinear response of the prognostic variable to the change in the atmospheric forcing or soil initialization. The linear response to the perturbation is greater (less) when the slope parameter is farther (closer) from (to) one. The nonlinear response is greater (smaller) when the coefficient of determination is smaller (greater). In their statistical meaning, scatter diagrams provide a measure of the correlation between two simulations. We use this correlation to quantify the sensitivities of the simulations to the uncertainties in the analysis used to specify the atmospheric initial/boundary conditions and the initial soil conditions

4. RESULTS

Overall, the sensitivity illustrated by scatter diagrams varies with different locations in the CV. Such variation demonstrates a noticeable trend from south to north in the CV, depending on where the location is relative to the San Francisco Bay area and the foothills. In this presentation, only the scatter diagrams at three representative locations in the CV are shown and discussed.

Figure 2 contains the scatter diagrams for the u- and v-components of the winds averaged from the surface to 300 m above ground level (AGL) at Bakersfield, which is located in the southern SJV (labeled as BKF in the right panel of Fig. 1). It is seen that the slope parameters associated with the u-component of the wind for the change to the soil conditions (in blue) are closer to one (0.8077) than those for the change to the atmospheric conditions (in red**,** 0.7176), indicating the sensitivity to the soil initialization is smaller than the sensitivity to the atmospheric forcing. For the v-component of the wind, the slope parameters are comparable (0.5708 for the change to the soil initialization and 0.5879 for the perturbation to the atmospheric forcing), indicating that the sensitivity to the soil initialization and the sensitivity to the atmospheric forcing are similar. Thus, the low-level v-component of the wind is more influenced by the combined effect of the soil thermal dynamics and the valley-scale flow than the u-component of the wind, which is more influenced by the orographic blocking of the valley-scale flow. The nonlinear response of the winds averaged from the surface to 300 m AGL at this particular location, as measured by the size of the coefficient of determination, is stronger for the change to the atmospheric forcing than to the soil initialization.

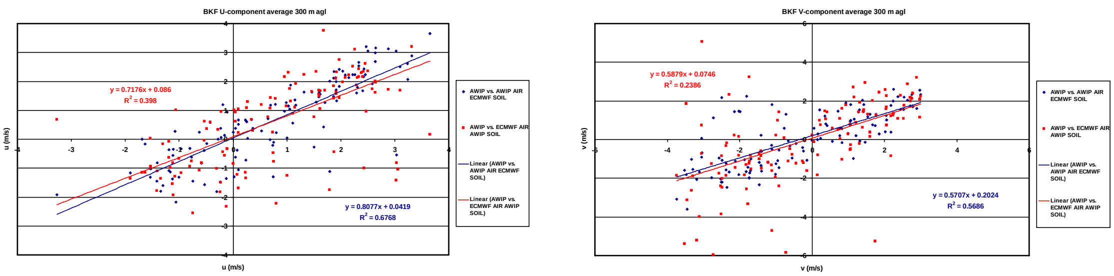

Figure 2: Scatter diagrams of the AWIP run vs. AWIP ECMWF AIR AWIP SOIL run (in red) and AWIP run vs. AWIP AIR ECMWF SOIL run (in blue), with linear regression information (i.e., the slope and the intercept parameters, and the coefficient of determination) for the winds averaged between the surface and 300 m AGL at Bakersfield, CA (BKF). Left: for the u-component. Right: the v-component.

The scatter diagrams for the winds averaged between the surface and 300 m AGL at Redding, which is located in the SV (labeled as RDG in the right panel of Fig. 1), are presented in Fig. 3. For both the u- and v- components of the wind, the slope parameters are closer to one for the change to soil initialization than the change to the atmospheric forcing (0.8641 versus 0.3492 for the u-component and 0.9117 versus 0.8158 for the v-component) indicating that at Redding, the low-level winds are more sensitive to the atmospheric forcing. However, the difference between the slope parameters for the change to the atmospheric forcing and change to the soil initialization for the u-components is smaller and the slope parameters are closer to one than for the v-component, indicating that the v-component of the winds is not as sensitive to both the soil initialization and atmospheric forcing as the u-component. This can be explained by the fact that the dominant flow at Redding in this case is caused by the diurnal

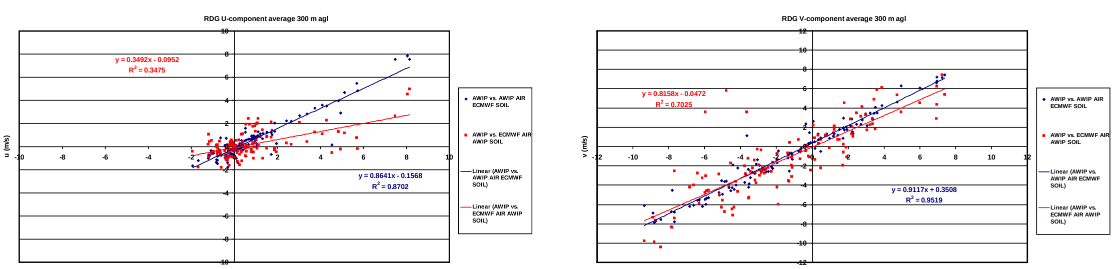

Figure 3: Scatter diagrams of the AWIP run vs. AWIP ECMWF AIR AWIP SOIL run (in red) and AWIP run vs. AWIP AIR ECMWF SOIL run (in blue), with linear regression information (i.e., the slope and the intercept parameters, and the coefficient of determination) for the winds averaged between the surface and 300 m AGL at Redding, CA (RDG). Left: for the u-component. Right: the v-component.

change of the up-valley, down-valley flow, which is dynamically influenced by the topography to the north. Since this flow is predominately in the v-direction (along the valley), it is sensible that the v-component would not be as sensitive to either the atmospheric or the soil conditions in the CV as the u-component. It is also interesting to note that the slope parameters for both the u- and v- components of the 300-m AGL averaged winds are closer to one for the change to the soil initialization in Redding than they are at Bakersfield, indicating that at Redding the 300-m AGL averaged winds have less influence from the soil thermal dynamics than at Bakersfield. The nonlinear response at Redding for both the u- and v- components of the 300 m AGL averaged winds is greater to the change to the atmospheric forcing.

However, the non-linear response to the change to the soil initialization is less at Redding than at Bakersfield**,** therefore there is more of a non-linear response to the soil initialization at Bakersfield that at Redding.

Figure 4 presents the scatter diagrams of the winds averaged between the surface and 300 m AGL at Sacramento (labeled as SAC in the right panel of Fig. 1). The overall sensitivity at this location is different from that at either Bakersfield or Redding. For the winds averaged over the lowest 300 m AGL, the slope parameter of the u-component of the wind is farther from one for the change to the soil conditions than for the atmospheric forcing (0.6301 for the change to the soil initialization and 0.7429 for the change to the atmospheric conditions), while the slope parameter of the v-component is closer to one for the change to the soil initialization (0.8987) than for the atmospheric forcing (0.3154). Given that Sacramento is just east to the San Francisco Bay area, the u-component at this location is representative of the intensity of the incoming marine flow through the San Francisco Bay area, while the v-component is representative of the north-south branching of the incoming flow. This characteristic of sensitivity reveals that the intensity of incoming marine flow is more influenced by the change to the soil state within the CV, while the north-south branching of the incoming flow is more influenced by the atmospheric forcing. The non-linear response of both the u- and v- components of the 300-m AGL averaged winds at Sacramento is greater to the change to the atmospheric forcing than to the change to the soil initialization.

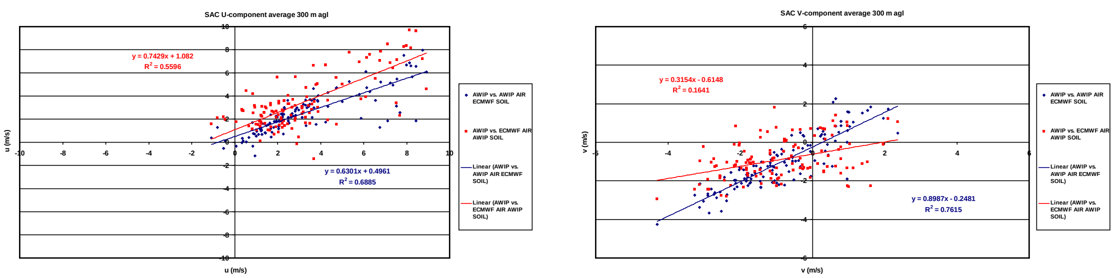

Figure 4: Scatter diagrams of the AWIP run vs. AWIP ECMWF AIR AWIP SOIL run (in red) and AWIP run vs. AWIP AIR ECMWF SOIL run (in blue), with linear regression information (i.e., the slope and the intercept parameters, and the coefficient of determination) for the winds averaged between the surface and 300 m AGL at Sacramento, CA (SAC). Left: for the u-component. Right: the v-component.

5. CONCLUSION

This paper demonstrates, by a case study, how scatter diagrams are used to measure the sensitivities of low-level wind simulations to the uncertainties in the large-scale forcing and the physics parameterizations. The results from this case study indicate that the WRF–simulated low-level winds in the SV are more sensitive to atmospheric forcing than to soil initialization, while the simulated low-level winds in the southern most part of the SJV are more sensitive to soil initialization than they are to atmospheric forcing. In the northern SJV/southern SV (east of the San Francisco Bay area), where the winds are more directly impacted by the incoming marine flow, the winds are more sensitive to atmospheric forcing than to the soil initialization. Furthermore, sensitivity to atmospheric forcing is greatest in the northern SJV and is least in the SV, while sensitivity to soil initialization is greatest in the southern SJV and least in the SV. In this case study, the distribution of sensitivity indicates the important role that the incoming marine flow through the San Francisco Bay area.

It is a widely accepted notion that an accurate soil initialization is important to the simulation of locally forced low-level winds. Our study not only reinforces this notion but also strongly suggests that it is the interaction of the valley scale wind associated with the incoming marine air and the locally forced winds along the foothills that determines winds in the CV and therefore the overall transport and dispersion of pollutants across the valley. Thus, future effort to improve the accuracy of the WRF simulated low-level winds in the CV should focus on the identification of not only the error sources of the simulated locally forced winds but also the error sources of the along-valley winds associated with the incoming marine flow through the San Francisco Bay Area.

REFERENCES

Bao, J.-W., S. A. Michelson, P. O. G. Persson, I. Djalalova, and J. M. Wilczak, 2007: Observed and simulated low-level winds in a high-ozone episode during the Central California Ozone Study. To be submitted to *J. of Appl. Meteor*.

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, W. Wang, and J. G. Powers, 2005: A description of the Advanced Research WRF Version 2. NCAR Tech Notes-468+STR.

Wilks, D. S., 1995: *Statistical Methods in the Atmospheric Sciences.* Academic Press, 467 pp.