Simulation of a Precipitation Event in the Western United States

Jinwon Kim
P.O. Box 808, L-262, LLNL, Livermore, CA 94551
S.-T. Soong
Dept. LAWR, UC Davis, Davis, CA 95616

1. Introduction.

Wintertime precipitation is the major water resources in the western United States. Thus correct assessment of the wintertime precipitation is important in planning the summertime water supply and the development of future water resources. Precipitation forecast is also important for early warning of flood.

Regional precipitation depends chiefly on the large scale flow and local topography. Large scale moisture influx determines the amount of moisture available for the precipitation. Topography affects two major factors in the local precipitation: Low-level vertical motion and local water vapor transport. Topography also affects partitioning the total precipitation into rain and snow since the snow line is usually lower than the peaks of major mountain ranges during wintertime.

Modeling the features of regional precipitation has been intensely studied (Giorgi 1991, Dickinson *et al*. 1989). Previous studies show that limited area models nested within large scale models or analysis can capture realistic features of storms. The simulated structure of individual storms and precipitation vary significantly depending on the parameterized precipitation processes (Zhang *et al.* 1988). As limited area models usually have much finer spatial resolutions than large scale models, parameterized precipitation processes developed for large scale models may not be adequate for limited area models (Frish and Chapel 1980).

We present a simulation of twelve-day precipitation over California from Feb. 11 to Feb. 23 1986. We focus on features of precipitation such as the local distribution, total amount, and the occurrence of snowfall and rainfall. The simulation is carried out using a primitive-equation limited-area model developed jointly by University of California at Davis and Lawrence Livermore National Laboratory.

2. Model

The model predicts the horizontal wind, surface pressure, potential temperature, and the mixing ratios of the water vapor, cloud ice, cloud water, snow, rain, and graupel. The governing equations are the flux-form of the primitive equations written in the σ-coordinates. The governing equations are discretized on the c-grid using the finite difference formulation by Takacs (1987) and, later modified by Hsu and Arakawa (1990), which ensures third order accurate advection in space and time. This finite-difference formulation yields no phase error, and causes minimal oscillation. It is an important advantage for this modeling study since steep orography tend to generate spurious oscillations. The model has 14 vertical layers with the domain top pressure of 50 mb (Fig. 1).

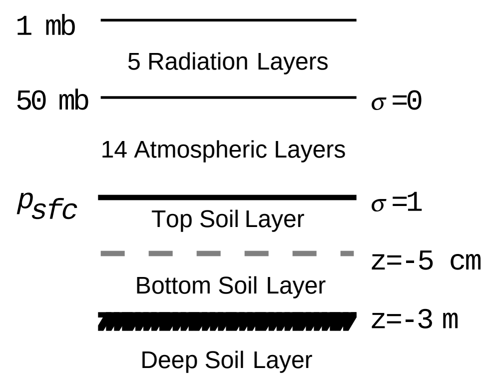

Fig. 1 Vertical structure of the atmosphere-soil model.

The source/sink of hydrometeors, heating/cooling due to the phase change of water substances, and precipitation are computed by combining a Kuo-type cumulus scheme with parameterized cloud microphysics (Cho and Iribarne 1987). The cloud microphysics model includes ice-phase processes as well as warm rain process. This approach appears to be crucial for the precipitation simulation in this study. In addition, inclusion of the cloud microphysical processes eliminates the need for separate estimation of cloud to compute the radiative transfer.

The solar and terrestrial radiative transfer processes are computed using the parameterizations by Davies (1982) and Harshvardhan and Corsetti (1984), respectively. Vertical profiles of the temperature, ozone, and water vapor mixing ratio in the layer between the top of the model domain (50 mb) and the top of the radiation domain (1 mb) are prescribed from the mid-latitude winter profiles by Ellingson *et al.* (1991).

A soil-snow-canopy model developed at Oregon State University (Mahrt and Pan 1984, Ek and Mahrt 1991) is used to compute heat fluxes at land surfaces. This soil-canopy-snow model predicts the soil temperature, soil water content, canopy water content, and snow depth. It also provides the temperature and water vapor mixing ratio at land surfaces to compute sensible and latent heat fluxes from the surface. The two-layer soil model (Fig. 1) uses a single-species big-leaf model to treat vegetation. The soil texture and initial soil water content are obtain from 1^o-by-1^o resolution climatology (Zobler 1986).

3. Observed precipitation

The total precipitation in California during the 12-day period is shown in Fig. 1. The precipitation is heaviest over the western slope of the Sierra-Nevada and Coastal Range. Precipitation is light in the Central Valley and decreases toward the southern California.

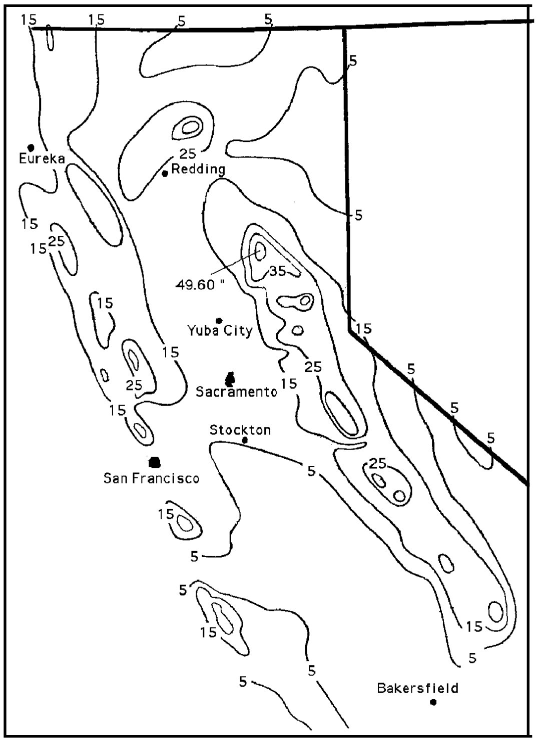

Fig. 2 Total precipitation from Feb. 11 to Feb. 22, 1986. The contours start from 5” with 10” interval.

The daily precipitation varies closely with the large scale water vapor convergence as heavy precipitation events occur during the periods of strong large scale water vapor convergence in the region (Fig. 3).

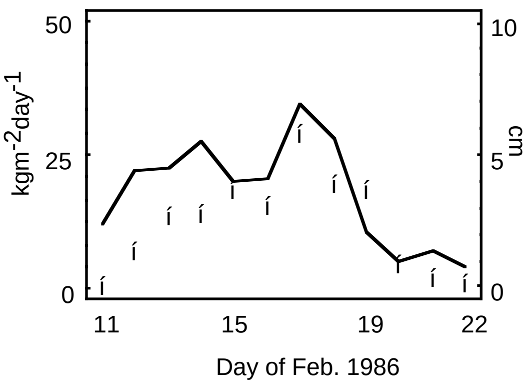

Fig. 3 Daily precipitation averaged over 165 stations in California (circles) and vertically-integrated water vapor flux convergence in the model domain (solid line).

4. Simulated precipitation

The simulation is initialized using the NMC analysis at 00Z Feb. 11 1986. the model is driven by updating the lateral boundary conditions for every 12 hour intervals. The domain of 1140 km x 1260 km covers much of the state of California, Nevada, and southern Oregon. This domain is divided with 20 km x 20 km grid mesh. The topography in the region is characterized by two major mountain ranges, the Coastal Range and Sierra-Nevada, with the Central Valley between these mountain ranges. At the northern end of central valley, the Coastal Range joins the Sierra-Nevada, forming a mild upslope toward the north. Such features of topography in the region is not only favorable for the orographic lifting of the low-level westerly but also plays an important role in the local transport water vapor in the low atmosphere.

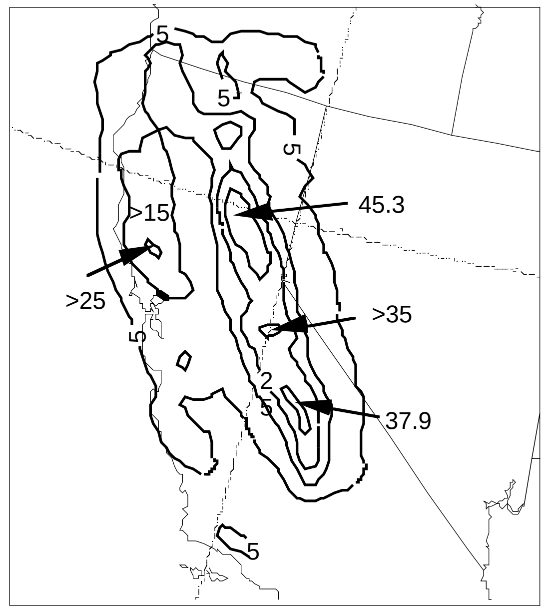

Fig. 4 Simulated total precipitation during the 12-day period. The contour interval is the same as in Fig. 2.

Simulated precipitation (Fig. 4) agrees well with the observation. It clearly reflects the effects of topography on the local precipitation. The location and magnitude of the observed precipitation maxima at the western slope of the northern Sierra-Nevada is well reproduced in the simulation. Despite good agreements, fine structures in the observed precipitation along the coast is missing from the simulation which indicates the importance of small scale features such as the narrow mountain barrier along the coast in local precipitin.

Fig. 5 shows the daily precipitation averaged over 165 stations in California (circles) and over the model grids containing one or more of those stations (solid line). Again, the simulation appears to have reproduced the general features of the observed daily precipitation. The large discrepancy between the observed and simulated precipitation on Feb. 14 1986 indicates the importance of the large scale information in simulating regional flow. The large scale water vapor flux convergence (Fig. 3) computed from the NMC analysis in the domain is large on the day. As a result, the model is forced to remove more water vapor within the model domain. This error may have been caused by the large scale analysis or during the interpolation. Thus, improvement of large scale information is crucial for simulating local flows.

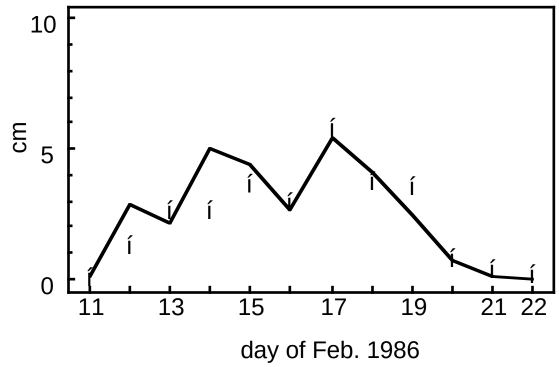

Fig. 5 Observed (circles) and simulated (solid lines) daily mean precipitation at 165 California stations.

The sea-level pressure perturbation due to topographic slope causes the low-level wind in the valley to turn north-eastward, approximately parallel to the Sierra-Nevada range. This perturbation in the low level wind appears to provide significant amount of water vapor to the northern Sierra-Nevada and northern California where orographic lifting produces precipitation. The isolated precipitation maxima near Redding, appearing both in the observation as well as in the simulation, is thought to be caused by such local transport of water vapor.

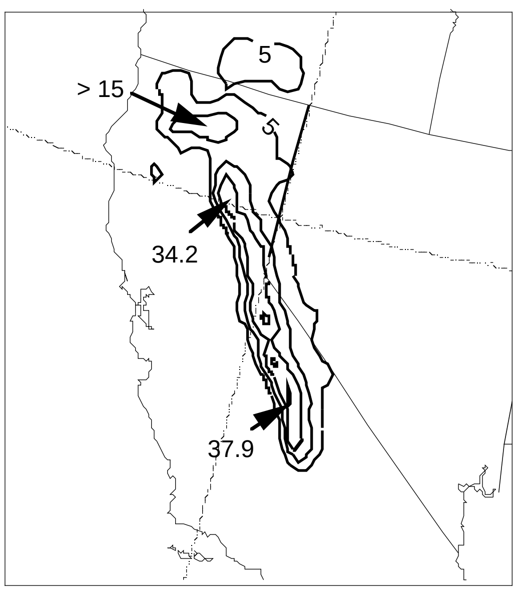

Fig. 6 Simulated total snowfall during the 12-day period. The contour interval is the same as in Fig. 2.

Explicit treatment of cloud microphysical processes in the model appears to be crucial in modeling precipitation in this study. Much of the precipitation in the valley and over the eastern slope of the Sierra-Nevada appears to be due to the precipitating particles formed over the Coastal Range and Sierra-Nevada and transported downstream by the upper level wind. The run with the cumulus scheme alone yields precipitation much less than observed. It also fail to simulate the local distribution of precipitation as the precipitation is confined within narrow bands of area at the western slopes of the Sierra-Nevada and Coastal Range. On the other hand, a simulation only with cloud microphysics (but without cumulus parameterization) produced almost same results as reported here.

The cloud microphysics parameterization also includes the ice phase process as well as the warm rain process. This feature enables the model to predict rainfall and snowfall separately without any further assumption. More importantly, the simulated precipitation depends strongly on the ice phase parameterization. The snow line is located about 1.8 - 2 km above sea level during the period, and most of the rainfall in the Sierra-Nevada and valley due to the melting snow. Warm rain process seems the major source of rainfall over the Coastal Range. The snowfall is confined in the high land of the Sierra-Nevada Mountains and in the northern California (Fig. 6) The precipitation in the valley and over the Coastal Range is almost entirely rain (Fig. 7).

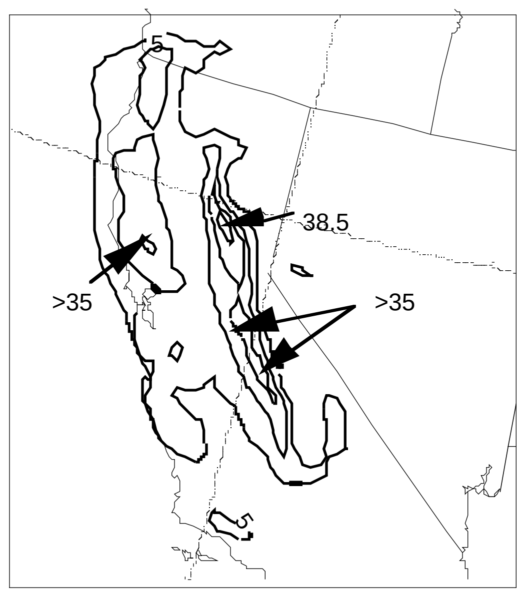

Fig. 7 Same as Fig. 5 except total rainfall.

5. Accumulated snow

Snow pack over high lands is especially important for the summertime water supply. The spring runoff from melting snow pack can cause flood in the western United States. Therefore accurate assessment and prediction of snow cover at the end of the wet season is an important information for planning short- and long-term water supply for industries, environment, and urban areas.

The soil-canopy-snow model also separately computes accumulated snow over land surfaces as the difference between the fresh snowfall and snow melt. Snowfall is computed by the atmospheric model and snow melt is computed as a part of the surface energy balance at the snow-covered land. Since the amount of snow cover at the beginning of the simulation is not available, only the net accumulation during the simulated period is computed. The results show that most of the fresh snow on high lands of the Sierra-Nevada is added to the snow pack at the end of the simulated period. On the other hand, much of the fresh snow in the northern California has been melted.

6. Conclusions

A twelve-day episode of heavy wintertime precipitation in the western United States is simulated using a limited area model nested within the NMC operational analysis. Combination of a Kuo-type cumulus scheme with cloud microphysics parameterization successfully reproduced important features of the observed precipitation.

The observed and simulated precipitation shows that the local topography and large scale water vapor flux are the two major factors in the local precipitation. The low level south-westerly from the Pacific ocean turns into south-easterly in the central valley probably due to the low level pressure perturbation caused by the Sierra-Nevada. The water vapor transport associated with this wind perturbation appears to be an important source of water vapor for the precipitation in northern Sierra-Nevada and northern California. The cloud droplets and precipitating particles transported downstream out of the upslope regions of the major mountain ranges caused the most of the light precipitation at the lee side of the major mountain ranges, including the Central Valley.

Parameterized cloud microphysics, or explicit moisture scheme, appears to be essential for simulating local precipitation in this case. A Kuo-type cumulus scheme alone severely underestimated the observed precipitation since most of the precipitation in the simulated case is from stratiform clouds or shallow convective clouds.

Acknowledgment

The authors wish to express great appreciation to Prof. John Roads of Scripps Institute of Oceanography for providing the station precipitation data over California and for useful discussions. This work is supported by National Institute for Climate Change (NIGEC) under the grant W/GEC0017, Institutional Collaborative Research (INCoR) Program of Univ. of California, and Laboratory Directed Research and Development (LDRD) Program of Lawrence Livermore Nat. Laboratory. Work performed under the auspices of the U. S. Dept. of Energy by the Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Reference

Cho, H.-R. and J. Iribarne, 1987: The role of clouds and precipitation in long-range transport and acid rain in Canada. Phase II: Programming, testing and refining of cloud dynamics, microphysics and chemistry models. Vol. 2, Appendix I: Cloud Microphysics., Report for the Canadian Electrical Assoc., Res. and Development.

Dickinson, R., R. Errico, F. Giorgi, and G. Bates, 1989: A regional climate model for western United States., *Climate Change,* **15**, 383-422.

Ek, K. and L. Mahrt, 1991: *OSU 1-D PBL Model User's Guide*., Dept. of Atmos. Science, Oregon State Univ., Corvallis, OR., 118 pp.

Ellingson, R. G., J. Ellis, and S. Fels, 1991: The inter-comparison of radiation codes used in climate models: Long wave results., *J. Geophys. Res*., **96**, No. D5, 8929-8953.

Frisch, J. and C. Chappel, 1980: Numerical prediction of convectively driven mesoscale pressure systems. Part I: Convective parameterization., *J. Atmos. Sci*., **37**, 1722-1733.

Giorgi, F., 1991: Sensitivity of simulated summertime precipitation over the western United States to different physics parameterizations., *Mon. Wea. Rev*., **119**, 2870-2888.

Harshvardahn and T. Corsetti, 1984: *Longwave radiation parameterization for the UCLA/GLAS GCM*., NASA Tech. Memo. 86072.

Hsu, Y. and A. Arakawa, 1990: Energy conserving and potential-enstrophy dissipating schemes for the shallow water equations. *Mon. Wea. Rev*., **118**, 1960-1969.

Mahrt, L. and H.-L. Pan, 1984: A two-layer model of soil hydrology., *Bound.-Layer Met*., **29**, 1-20.

Takacs, L. L., 1985: A two-step scheme for the advection equation with minimized dissipation and dispersion errors. *Mon. Wea. Rev*., **113**, 1050-1065.

Zhang, D.-L., E.-Y. Hsie, and M. Moncrieff, 1988: A comparison of explicit and implicit predictions of convective and stratiform precipitating weather systems with a meso-b-scale numerical model., *Q. J. Roy. Met. Soc*., **114**, 31-60.

Zobler, L., 1986: A world soil file for global climate modeling., NASA Tech. Memo. #87802.