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Numerical Simulation of Precipitation over the Southwestern United States during the 1994-1995 Winter Season

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10.2 Numerical Simulation of Precipitation over the Southwestern United States during the 1994-1995 Winter Season

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1. INTRODUCTION

Accurate assessments of precipitation and surface snow budget during winter seasons are crucial for managing water resources in the western United States. This region receives most of its annual precipitation during winter months and relies on water stored in snowpack and reservoirs for water supply during dry summer seasons. Rainfall directly affects water inflow into reservoirs while snowmelt determines it during spring and summer.

Precipitation and snow budget result from interactions among large-scale forcing, mesoscale processes, and surface energy balance. Interaction among these elements is highly nonlinear and includes various processes such as large-scale water vapor and temperature advection, precipitation physics, orographic forcing, turbulence, solar and terrestrial radiative transfer, and snow-albedo feedback. Hence, one need to take these processes into consideration in order to obtain accurate assessments of regional water resources over time scales longer than a season.

A regional model that interactively couples atmospheric and land surface processes is a cost-effective tool for an assessment of precipitation and surface hydrology over large areas at a relatively fine resolution. Such models can include complex physical and dynamical processes involved in the interaction between the atmosphere and land surfaces. Another advantage of coupled atmosphere-land surface modeling is that simulations, when verified against local observations, can provide area-integrated values. Area-integrated values are useful for computing overall budgets, but they are somewhat difficult to obtain directly from local observations. Hence, a coupled atmosphere-surface model is especially useful for computing area-weighted values for areas of interest.

2. Model and Experimental Design

The regional model employed in this study couples Mesoscale Atmospheric Simulation (MAS) model and Coupled Atmosphere Plant Snow (CAPS) model (Mahrt and Pan, 1984). MAS and CAPS models have been successfully applied to studies of regional precipitation (Soong and Kim, 1995) and long term surface energy budget (Kim and Ek, 1995).

The model domain (Fig. 1) covers an area of 1300 x 1600 km^2. This model domain is resolved by a 20 km x 20 km grid mesh in the horizontal and 14 layers in the vertical.

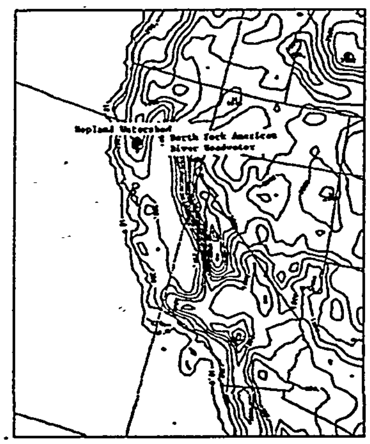

Fig. 1 Terrain of the model domain.

This seasonal simulation covers a period of seven months from 00UTC 3 November 1994 to 00UTC 1 June 1995. It was initialized using the 80km-resolution, NMC ETA model initial fields at 00UTC 3 November 1994 and continued for the next seven-month period by updating only the lateral boundary values as a function of time. The time-dependent lateral boundary conditions were obtained from the twice-daily, ETA-model initial fields to prevent forecast errors from contaminating the simulated regional flow fields.

3. Seasonal precipitation

Precipitation in the region closely follows local terrain as shown by many previous observational and numerical studies of various time scales (California Dept. of Water Resources, 1988; Giorgi, 1990; Roads et al., 1994; Soong and Kim, 1995). Fig.2 illustrates the season-total precipitation (cm) that combines rainfall and snowfall. Heavy precipitation occurred at upslopes and ridges of the Coastal Range and the Sierra Nevada. Rain shadow effects were clearly indicated by the precipitation minima within the Central Valley and at the eastern side of the Sierra Nevada. The peak season-total precipitation occurred at the northern Sierra Nevada with a value of 320 cm. Maximum values of rainfall and snowfall also appear at the northern Sierra Nevada, with secondary maxima at the northern and southern Coastal Range (not shown). Snowfall maxima occurred along the ridge of the Sierra Nevada, above 2 km elevation level.

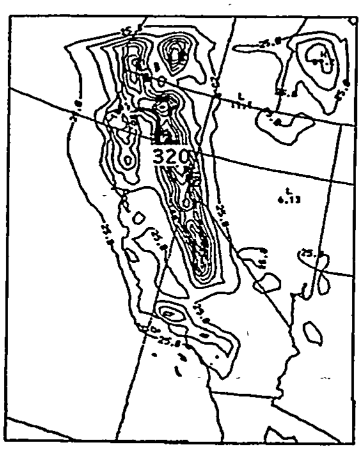

Fig. 2 Season-total precipitation (cm)

Fig. 3 shows the daily-mean precipitation over California obtained from raingauges and grid points containing at least one of the raingauges. The number of raingauges and grid points used to calculate daily-mean values ranges from 300 to 400 and it varies each day depending on the number of missing observations. Fig. 3 shows that MAS model closely simulated the temporal variation of the observed precipitation in California. Heavy precipitation associated with intense storms during January (days 60-90) and March (days 119-149) was especially well simulated by MAS model. Results of January 95 storm simulation are presented by Miller and Kim (1995).

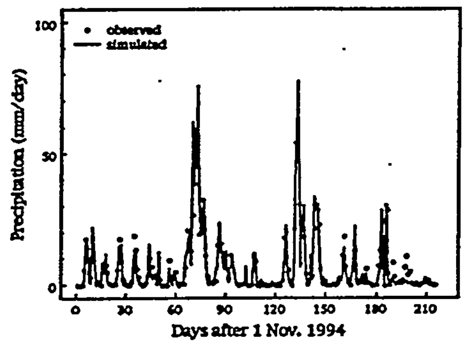

Fig. 3 Daily-mean precipitation within California during 1994 winter season.

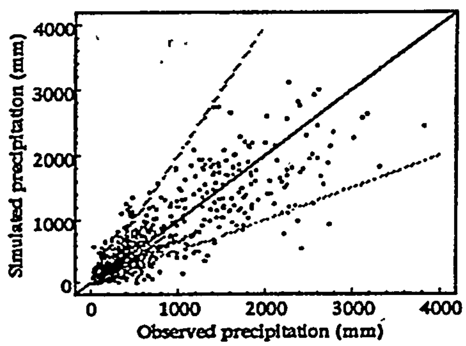

Fig. 4 Season-total precipitation within California.

Fig. 4 compares season-total precipitation at 420 raingauges within California and at the grid points which contain at least one raingauges. The spatial distribution of the simulated season-total precipitation well agrees with observation with a correlation coefficient of 0.8 between the simulated and observed values. When monthly values are concerned, best agreement between the simulated and observed precipitation was obtained during January and March (not shown).

The simulated precipitation shows strong dependence on terrain elevation. In Fig. 5, monthly-mean precipitation intensity at three elevation intervals is compared. The most intense precipitation occurred at elevations above 2 km level. Note that, the maximum area-integrated precipitation, which is obtained by multiplying intensity of precipitation by land area, occurred below 2 km elevation (not shown). Also, over 90% of total precipitation within the domain occurred at the west of the Sierra Nevada.

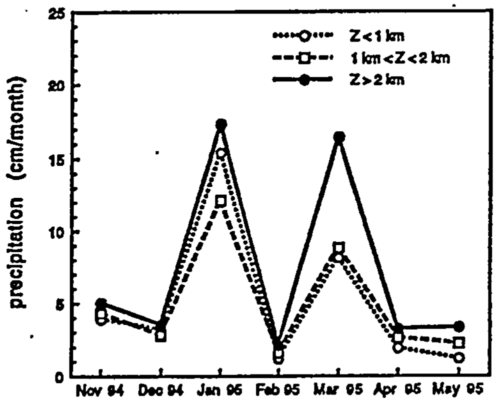

Fig. 5 Monthly-mean precipitation intensity as a function of elevation.

When type of precipitation is concerned, over 90% of precipitation at elevations above 2 km was snowfall while over 90% of it below 1 km elevation was rain (Fig. 6a and b). At elevations between 1 and 2 km, total precipitation was closely divided into rainfall and snowfall.

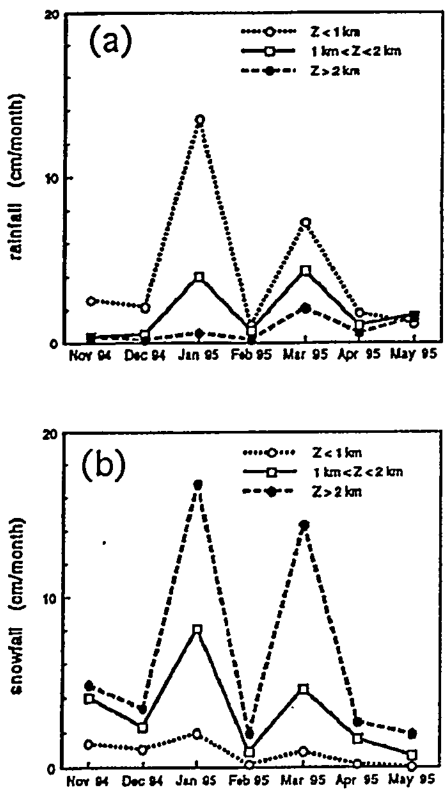

Fig. 6 Monthly-mean precipitation intensity as a function of terrain elevation:(a) Rainfall and (b) Snowfall.

4. Surface snow budget

The simulated monthly-total snow budget over the entire model domain is presented in Fig. 7 as a function of terrain elevation. Heavy snowfall during January and March caused large accumulation of snow at high elevations, mostly above 1 km level.

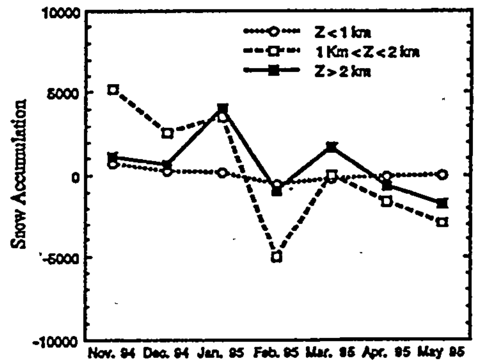

Fig. 7 Area-integrated monthly snow accumulation within model domain as a function of terrain elevation. Unit of the vertical coordinate is 4×10^7 kg/month.

Snow accumulation depends on a balance between the snowfall and snowmelt. Like snowfall, monthly snowmelt (not shown) strongly depends on terrain elevations due to the decrease of air temperature and increased availability of snow with height. At elevations below 2 km, peak snowmelt occurred during January while snowmelt increased toward spring (March and May) at elevations above 2 km. Peak snowmelt period largely coincides with the period of heavy snowfall at all elevation levels. The ratio between the snowmelt and snowfall during heavy snow periods decreases with elevation.

As a result of this balance between fresh snowfall and snowmelt, snow continued to accumulate above 2 km level until March, except during February which was an unusually dry month. On the other hand, the amount of snow remaining below 2 km level decreased continuously starting from February.

5. Conclusions

Precipitation and snow budget during the 1994-1995 winter within southwestern United States are simulated using a coupled atmosphere (MAS)-land surface (CAPS) model. Using twice-daily NMC ETA model initial fields to initialize and update time-dependent lateral boundary condition, this coupled model closely simulated the spatial and temporal variations of the observed precipitation in California. The maximum season-total precipitation was 320 cm and occurred at the northern Sierra Nevada, over the Feather River basin. Maximum rainfall occurred at 1.5 km level at the northern Sierra Nevada, over the Feather River basin. The maximum season-total snowfall appeared along the ridge of the Sierra Nevada. Below 1 km elevations, more than 90 % of total precipitation was rainfall while over 90 % of precipitation was snow at elevations exceeding 2 km.

Surface snow budget strongly depended on terrain elevation as a result of increased snowfall and decreasing temperature with terrain height. Most of snow accumulation occurred during January and March when precipitation was heavy. This simulation indicates that snowmelt above 2 km level is an important source of surface water during spring and early summer seasons.

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