THREE DIMENSIONAL SNOW TRANSPORT MODELING OVER MOUNTAINOUS TERRAIN

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ABSTRACT

The Snow Accumulation and Numerical Transport Algorithms (SANTA) modeling system integrates a Mountain Windfield Model (MWM), a sophisticated Transport and Diffusion Model (TDM), and a bulk Cloud Microphysics Model (CMM). The SANTA modeling system treats atmospheric transport, cloud microphysics, snow deposition, and resuspension at comparable levels of sophistication. In its general formulation, SANTA is a three-dimensional, time-dependent, multispecies hydrometeorological model that simulates the time evolution of solid, liquid, and water vapor fields within cold orographic storms over complex mountain topography. It may be applied for both local scale and regional scale analyses.

Comparison of hourly and daily average snowfall and water equivalent precipitation predictions for the destructive 30 March 1982 Sierra Nevada storm shows that the SANTA model predictions match observations closely. From these preliminary verification exercises, the SANTA model shows potential as a tool in avalanche hazard forecasting.

INTRODUCTION

Techniques for numerical modeling of orographic snow storms have improved over the last decade. As a result of the enormous increase in scientific computing power, modeling of orographic storms has matured from the early pioneering attempts to simulate the dynamics and microphysics of winter snowfall (e.g., Fraiser, et al., 1973; Colton, 1976). The present research attempts to simulate intense winter orographic snow storms with sufficient accuracy to be of use in avalanche hazard forecasting. To succeed, it is essential that the three-dimensional, time-varying snow formation, transport, deposition, and drifting processes over mountain terrain are treated in a realistic manner.

Use of numerical models for avalanche forecasting was first described by Rhea (1978) and Tesche and Yocke (1976, 1978).

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The latter workers emphasized the problem of windfield prediction over two- and three-dimensional mountainous terrain while Rhea studied the moisture supply and snowfall formation processes. Results from Rhea's two-dimensional model have been used for many years by the Colorado Avalanche Warning Program (Judson, 1976; Williams, 1980). Recently, Hayes (1986) described a new two-dimensional orographic model developed for the Pacific Northwest which offers significant potential for highway maintenance decision-making and avalanche hazard forecasting.

The orographic precipitation models developed to date generally emphasize a restricted set of physical processes, treating others simply or ignoring them altogether. Young (1974), for example, developed a detailed cloud microphysics model, but coupled it with a simplified wind flow description. Hayes' (1986) model, in contrast, employs a detailed, two-dimensional diagnostic windfield model and a simple precipitation scheme.

MODEL FORMULATION

The Snow Accumulation and Numerical Transport Algorithms (SANTA) modeling system combines a Mountain Windfield Model (MWM), a sophisticated Transport and Diffusion Model (TDM), and a bulk Cloud Microphysics Model (CMM). The SANTA modeling system is formulated to treat atmospheric transport, cloud microphysics, snow deposition and resuspension at comparable levels of sophistication. In its general formulation, SANTA is a three-dimensional, time-dependent, multispecies hydrometeorological model. It simulates the time evolution of solid, liquid, and water vapor fields within cold orographic storms over complex mountain topography. It may be applied for both local scale and regional scale analyses.

The SANTA modeling system, as shown in Figure 1, depicts the relationships between the component meteorological, transport, and cloud microphysics models. Time-dependent, three-dimensional transport, dispersion, deposition, and snow resuspension processes are treated by the TDM code. Meteorological fields are supplied by the Mountain Wind Model. Description of ice phase nucleation, the growth of ice crystals by vapor deposition, and collection of water droplets is treated by the Cloud Microphysics Model. Technical descriptions of each component model are given by Tesche (1988).

SANTA MODEL EVALUATION

The SANTA model was exercised using data collected by the Sierra Cooperative Pilot Project (SCPP) program for the 26-31 March 1982 storm which deposited record precipitation totals in the central Sierra Nevada mountains of California. Between 0600 on 26 March and 0600 on 31 March, a total of 225 cm (89 inches) of new snow fell at the Alpine Meadows Ski Area adding to an existing base of 2.3 meters. During this period, wind gusts at the Sierra crest were reported in excess of 180 meters/sec (125 mph). The storm closed highways and ski areas due to high winds and heavy snowfall and initiated a widespread cycle of avalanche activity (Penniman, 1986). On 31 March, a massive slab avalanche destroyed a lift terminal and the ski patrol headquarters at the Alpine Meadows Ski Area, killing seven people, including Mr. Bernie Kingery, a noted avalanche researcher.

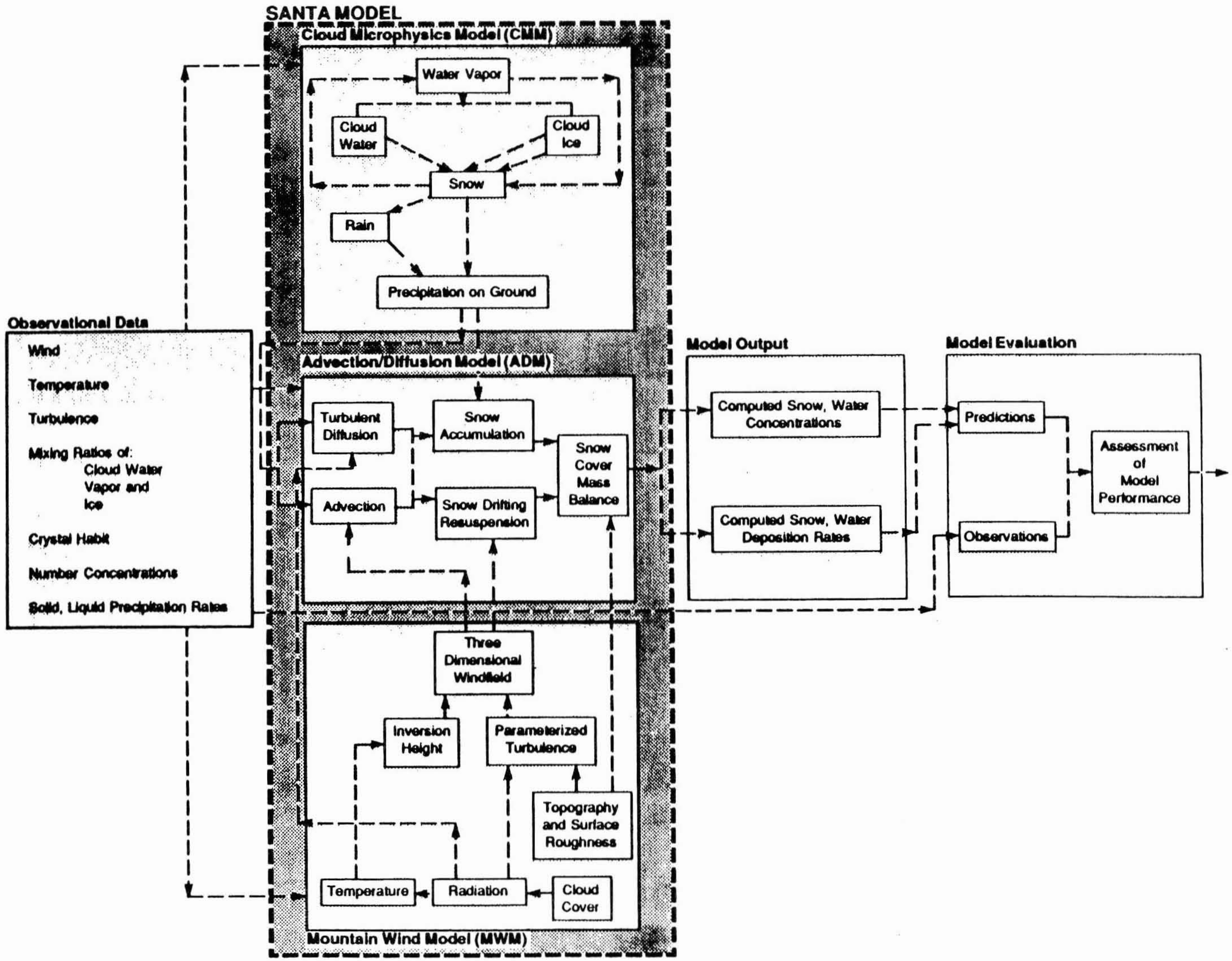

Figure 1. Overview of the Snow Accumulation and Numerical Transport Algorithms (SANTA) Model.

The SANTA modeling domain for the March 1982 storm consists of a 35 x 40 grid mesh with 2 km horizontal resolution. Eight vertical levels of 250 meter thickness are used. University of Wyoming (UW) aircraft soundings on the 30th revealed a neutrally stable layer up to the 0°C level (870 mb) with stable conditions aloft. Surface winds were southerly, veering to southwesterly at 3,000 meters, slightly above the height of the Sierra crest. Wind speeds increased to approximately 25 meters/sec near the crest. Measured vertical winds were of order 0.2 to 0.4 meters/sec. Figure 2 depicts the surface flow field over the mesoscale domain for 1200-1300 PST, computed by the Mountain Wind Model. Data from the UW aircraft flights were used to initialize the cloud water fields. Representative mixing ratios for cloud ice and cloud water were 4×10^{-4}gm gm^{-1} and 1×10^{-4}gm gm^{-1}, respectively. The concentration of ice particles within cloud upstream of the Sierra barrier was estimated at 30 ℓ^{-1}.

More than three dozen SCPP precipitation stations were in operation during the storm, 26 of which are contained within the mesoscale modeling grid. The agreement between predicted and observed total water equivalent precipitation on 30 March is quite close. Specifically, the average observed and predicted daily precipitation rates throughout the 31 station network were 38.8 mm and 36.6 mm of water, respectively. This represents a six percent error in total daily precipitation. The model underestimated the average daily snowfall (54.2 cm) across the six snow measurement sites by 30 percent. The overall bias and error in hourly average water equivalent precipitation rates (paired in time and space at 30 stations) are +10.8 percent and 52.5 percent, respectively. In Figure 3, the total predicted water equivalent precipitation for 30 March 1982 is presented; bold numerals directly above the station names indicate the observed precipitation totals in mm of water for the day.

SUMMARY

We reach the following conclusions:

- Grid-based, three-dimensional hydrometeorological model has been developed to simulate regional orographic snowstorms.
- The SANTA modeling system has undergone preliminary evaluation with detailed surface and aircraft measurements made during the 1981-82 SCPP field program in the California Sierra Nevada.
- The model closely replicates the total daily precipitation (i.e., within 6 percent) on 30 March 1982.
- The accuracy in simulating daily snowfall at six mountain weather stations is -30 percent.
- Overall accuracy in predicting hourly precipitation rates throughout the SCPP network on 30 March 1982 was 52.5 percent. Small positive bias (10.8 percent) in model predictions was found.
- The SANTA Model has potential as a tool in avalanche hazard forecasting. Use of numerical snowfall simulations coupled with synoptic forecast data, local observations, and multiple regression formulas may provide useful quantitative information for forecasting direct-action avalanches.

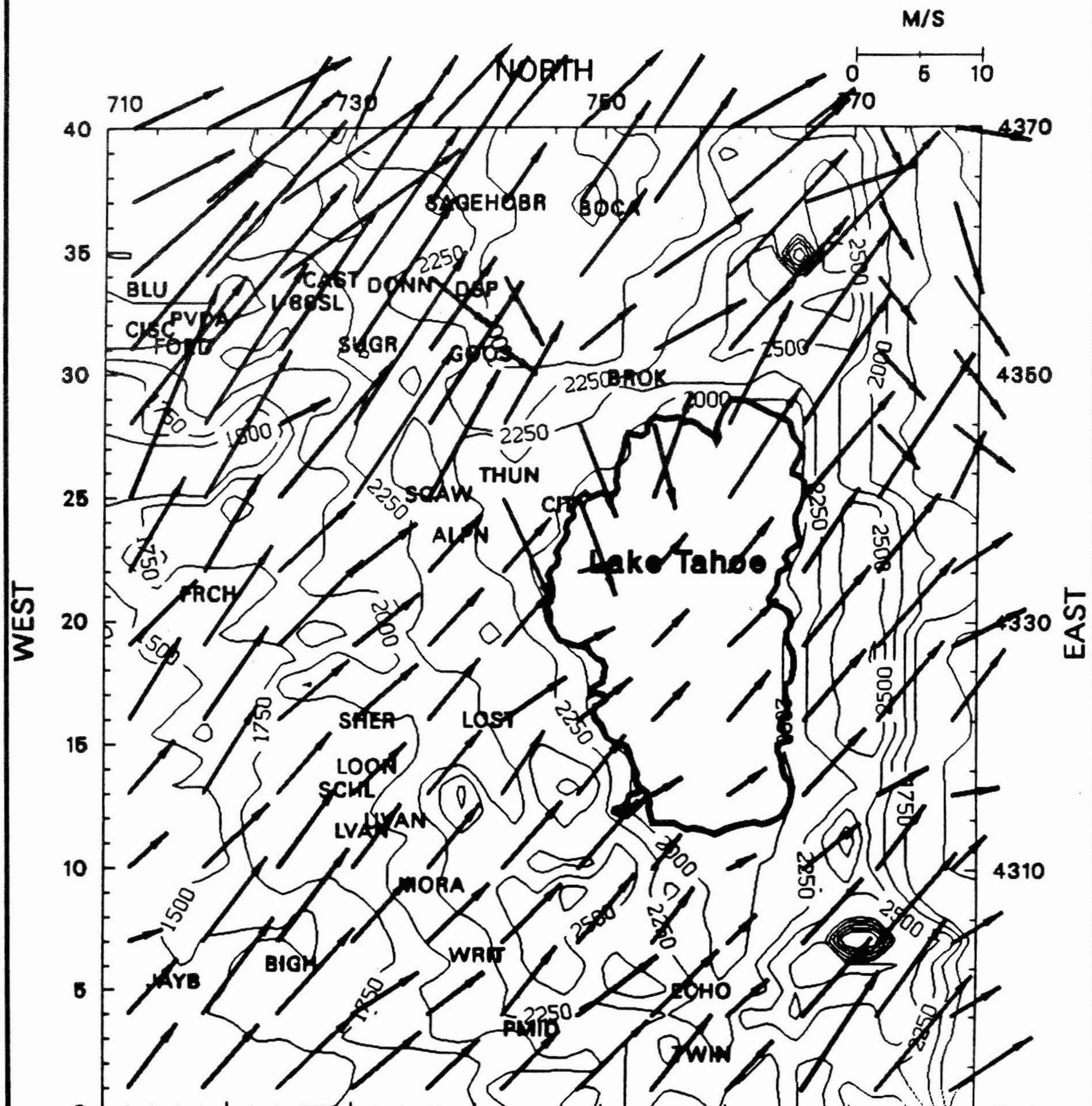

Figure 2. Surface Flow Field From the Mountain Wind Model For 1200-1300 PST on 30 March 1982--Mesoscale Domain. (Elevation contours in meters.)

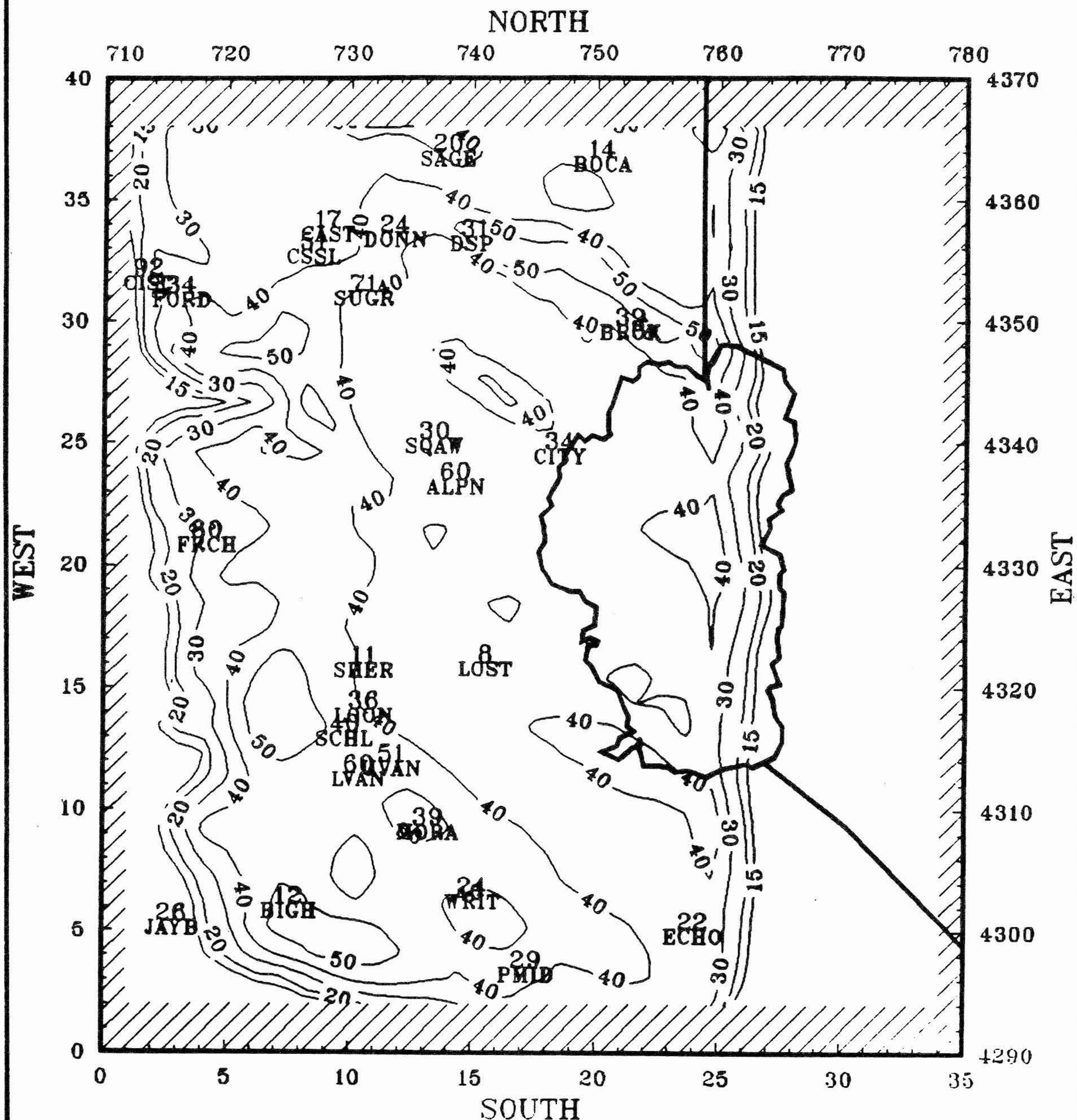

Figure 3. Computed Daily Precipitation (mm Water Equivalent) During the Period 0000-2400 PST on 30 March 1982--Mesoscale Domain.

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