WINTER SNOW EVENTS OVER THE HIMALAYAS: OBSERVATIONS AND SIMULATIONS DURING CEOP EOP-3

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The major mechanism responsible for wintertime snowfall events over the Himalayas is the strong dynamical interaction between the Range and the prevailing westerly circulation related to the southern shift of the sub-tropical jet stream during winter. The understanding of the spatial and temporal scales of this interaction is not complete and the simulation of these weather systems is a challenging tasks for models. The purpose of this study is to present a preliminary analysis of a snowfall event occurred during winter 2002/2003 by means of observations and model simulations.

INTRODUCTION

Due to their extension and extremely high elevation, the Himalayas and the Tibetan Plateau exert an important influence on the dynamics of winter westerly flows. Winter precipitation in these regions is very important because anomalous high winter Eurasian snow has been linked to low rainfall in the following summer Indian monsoon, thus influencing water resources and water availability. A major mechanism affecting the occurrence of snowfall over the Himalayas is the blocking of synoptic waves as they interact with the complex topography, with the generation of a cyclonic circulation over the eastern Himalayas and an induced predominant south-westerly flow toward the Range. These winds cause orographyc precipitation. The goal of this study is to analyze a significant and widespread snowfall event occurred on 31 December 2002 over the Himalayas and the Tibetan Plateau. This analysis is developed within the framework of the Coordinated Enhanced Observing Period (CEOP), with the aim of better understanding the physical processes influencing the variability of the water cycle over the monsoon regions by means of observations and numerical simulations.

DATA AND METHODS

This preliminary analysis was conducted integrating different sources of data: *in situ* observations, remote sensed data, model output (reanalysis and simulations).

Surface observations

The surface data used here were collected every hour at the Pyramid automated weather station (AWS). This AWS is the highest point of observation of the CEOP Himalayas Reference Site (HRS), a network of 5 AWSs located in the Khumbu Valley, Eastern Himalayas (Nepal), from 2660 m to 5035 m a.s.l., over a distance of about 40 km. The Pyramid AWS has been established by a collaboration effort among the Ev-K^2-CNR Project, the Epson Meteo Center and the Water Research Institute/CNR.

Satellite data

The Tropical Rainfall Measuring Mission (TRMM, Kummerow *et al.* [1]) is a joint mission between NASA and the Japan Aerospace Exploration Agency (JAXA). The TRMM dataset used is the 3B42RT, which consists of three-hourly precipitation estimated from TRMM and other satellites available on a 0.25° x 0.25° grid.

EUMETSAT controls the Meteosat geostationary satellites. In particular, the Meteosat-5, positioned over the Indian Ocean at 63°E, provides infrared (IR) images every half hour.

The spatial extension of snow cover over the Himalayas and the Tibetan Plateau was investigated by means of images from the Moderate Resolution Imaging Spectroradiometer (MODIS). Global snow cover is mapped daily over the Earth’s land surfaces at 500 m resolution using an algorithm called SNOMAP [Klein *et al.* [2]].

Reanalysis

The NCEP/NCAR Reanalysis data [Kalnay *et al.* [3]], available every 6 hours on global 2.5° x 2.5° grid, were used to analyze the large-scale atmospheric circulation.

Numerical models and experiments configuration

A multi-nesting, fine resolution modeling system was used.

The general circulation model (GCM) is derived from the National Centers for Environmental Prediction (NCEP) Global Spectral Model (GSM). Model physics is for example described in Roads et al. [4].

The regional models nested in the GSM are based on the Regional Spectral Model (RSM; Juang and Kanamitsu, [5]). The RSM uses the same physics and has the same code structure as the GSM and uses a spectral representation with two-dimensional sine-cosine series for perturbations. The RSM version used has the possibility to be run as non-hydrostatic (called MSM, meso-scale spectral model).

Several simulations at different resolutions were run for the snow storm occurred on 31 December 2002, also initializing the GCM at different leading times to better study the performance of the modeling system. In all cases, the analysis data came from the NCEP Operational Analysis data at 00 UTC. Here, we will present the results of a case study with the models configured as in Table 1.

Table 1. Characteristics of the models for the case study described below. The GSM was truncated at T62. All models had 28 sigma vertical levels.

	GSM	RSM	MSM
Hor. Res. (km)	~ 200	60	15
Nx	192	97	129
Ny	95	72	78
Δt (s)	1800	300	30

A CASE STUDY

One typical case representative of the interaction between the westerly flow and the Himalayas occurred at the end of 2002. A trough approached the western Himalayas at 06 UTC of 30 December 2002, carried by strong westerlies. Impacting on the Range at a latitude around 32°N, the trough slowed down and partly separated from the westerly flow northern of the Plateau (Fig. 1). The trough remained almost stationary until 12 UTC of 31 December, then it weakened and moved north-eastward.

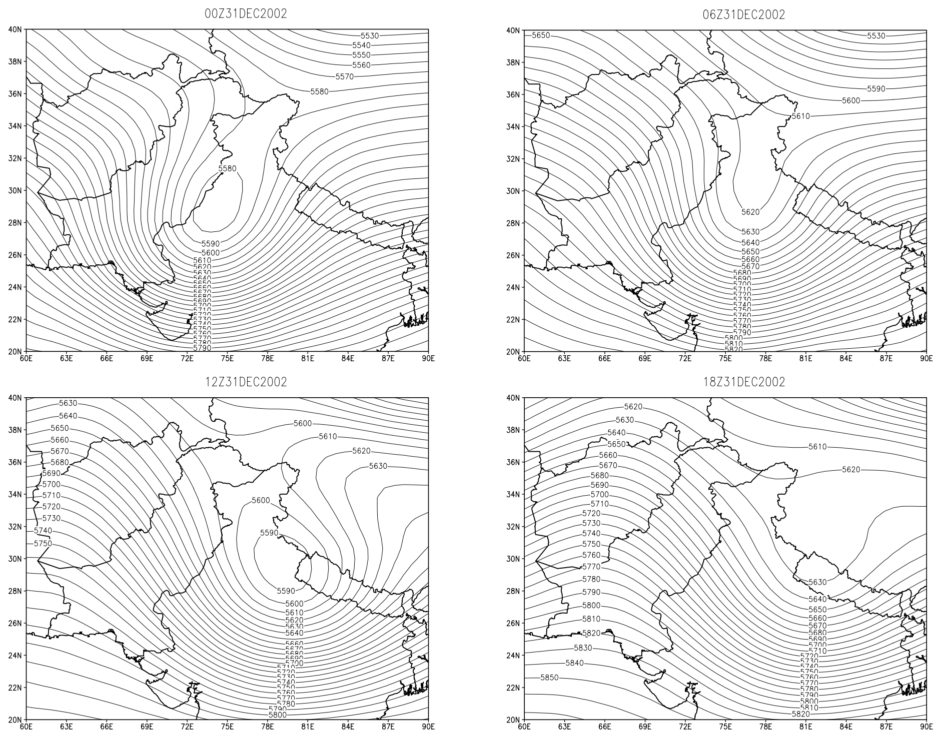


Figure 1. Evolution of the 500-hPa geopotential height from NCEP/NCAR Reanalysis

(a) (b)

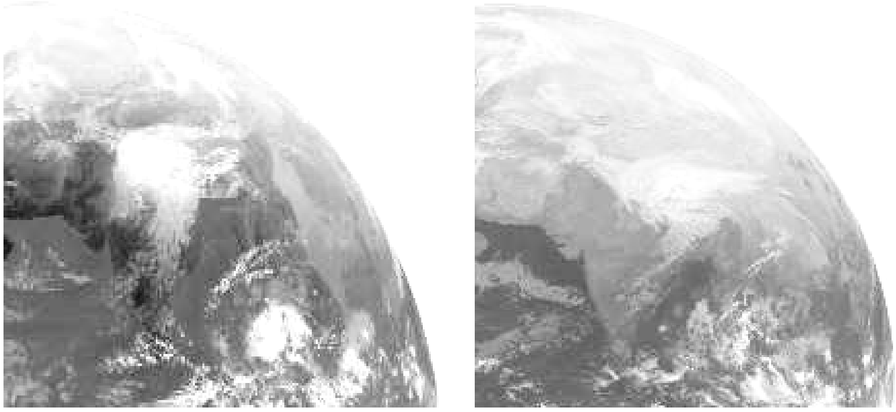
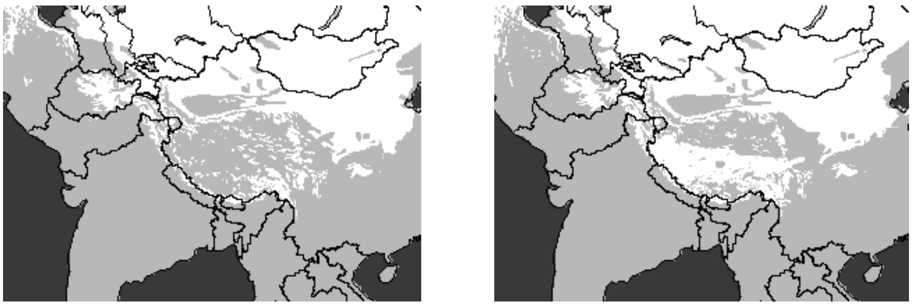


Figure 2. Meteosat-5 IR images on 31 December 2002 at 09 (a) and 21 UTC (b).

(a) (b)



(c) (d)

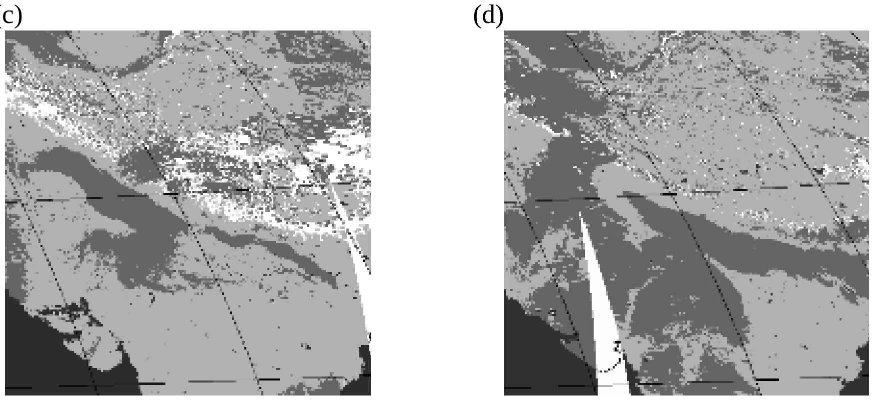


Figure 3. Satellites images of the daily mean snow cover before (29 December; (a) and (c)) and after (2 January; (b) and (d)) the snowfall on 31 December 2002

Images from NOAA DMSP on (a) and (b) (sea in black, land is light gray, snow is white), from MODIS on (c) and (d) (sea in black, land is light gray, clouds are dark gray and snow is white).

The Meteosat-5 IR-images (Fig. 2) clearly show the westerly disturbance associated to the snow event. In Fig. 2a, corresponding to the time of maximum development (09 UTC of 31 December), a large cloud system is pushed toward the Himalayas and the Tibetan Plateau.

The system moved slowly eastward and twelve hours later (Fig. 2b) it is leaving the Range. The overall effect of the disturbance was a widespread snowfall over the greatest part of the Himalayas and the Plateau, which is recognizable from satellites images (Fig. 3) taken just before (29 December) and after (2 January 2003) the event.

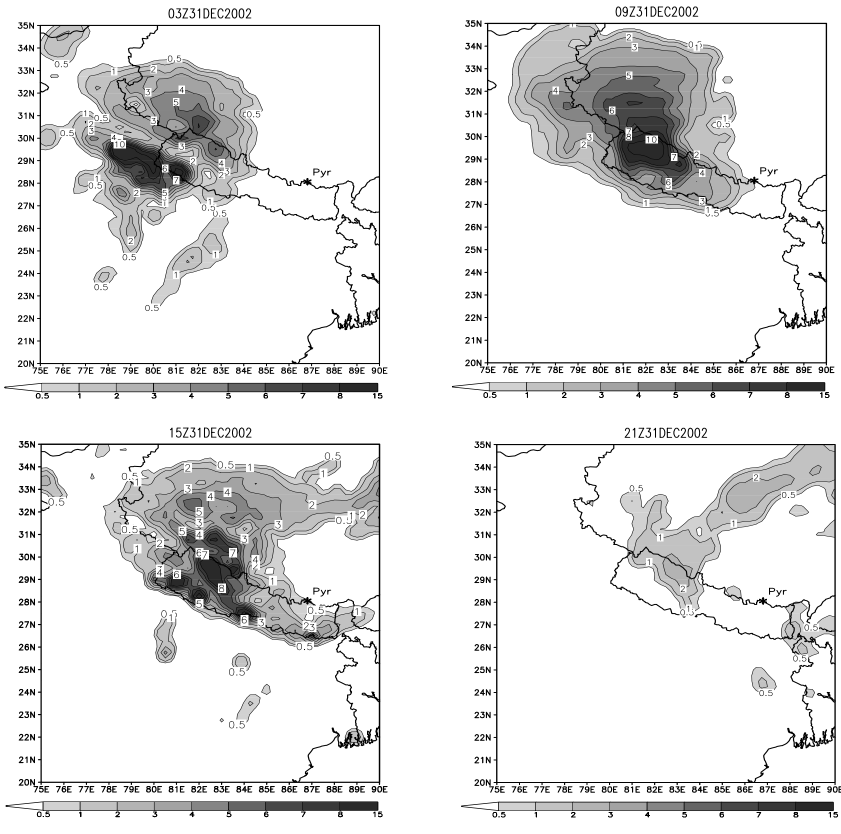


Figure 4. Sequence of TRMM 3-hourly precipitation

TRMM data (Fig. 4) depict the development and evolution of the disturbance. A large area of precipitation is evident over the southern slopes of western and central Himalayas, prolonging over Tibet. The system extended eastward at 15 UTC, causing a short event of precipitation over the Everest area. By 21 UTC of 31 December, the system is weaker and spatially confined.

There is very good correspondence in the timing of the event between TRMM and surface observations at the HRS. A cross-comparison between different sensors (Fig. 5), reveals that snow occurred from 14 UTC to 21 UTC. Actually, it was the first significant snow event of winter 2002/2003. The snow depth sensor measured about 18 cm of fresh snow, which persisted for some days later and clearly confirmed by the different sensors. The albedo raised from about 0.2 to above 0.6, then gradually decreased. The soil temperatures at two levels lost their typical variation due to the diurnal cycle of the heating of the ground. In particular, the deeper sensor measured a higher temperature.

(a) (b)

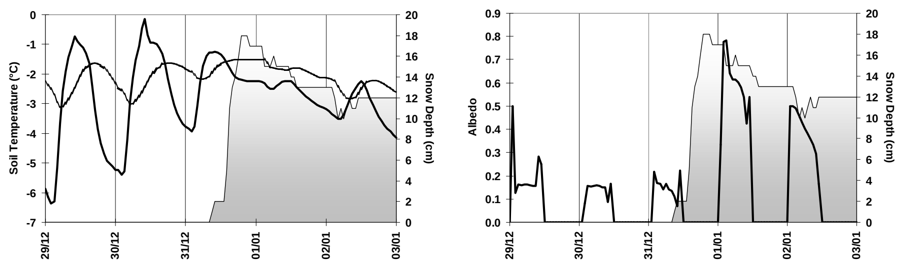


Figure 5. Hourly observations during the snow event at the Himalayas Reference Site (a): soil temperature at 5 cm (thick line) and 20 cm (thin line) below the surface and snow depth (shaded); (b): albedo (line) and snow depth (shaded).

Simulation of the snow storm

Some results from the model experiments are shown in Figs. 6 and 7. The GCM was initialized at 00 UTC of 30 December 2002. The GCM (Figs. 6a and 6b) was able to capture the development of the disturbance over the western Himalayas, even if the trough is placed northward with respect to Reanalysis. The separation of the flow in Fig. 6b is clear. The model predicted a westerly flow over eastern Nepal, while Reanalysis gives a southwesterly wind.

The overall performance of the RSM is good, even if this model, as the GCM, did not completely reproduce the return flow south of Nepal associated to the trough. As a consequence, the model predicted precipitation extends also over northern India (Fig. 6d) due to wind convergence at low levels and it not confined only to the mountains. Precipitation over Tibet is also much more reduced than TRMM estimates.

Finally, the MSM quite well reproduced the forced upward velocity over the southern slopes of the Himalayas with a downward motion immediately north of the ridges. The pattern of relative humidity also reflects the forced uplift.

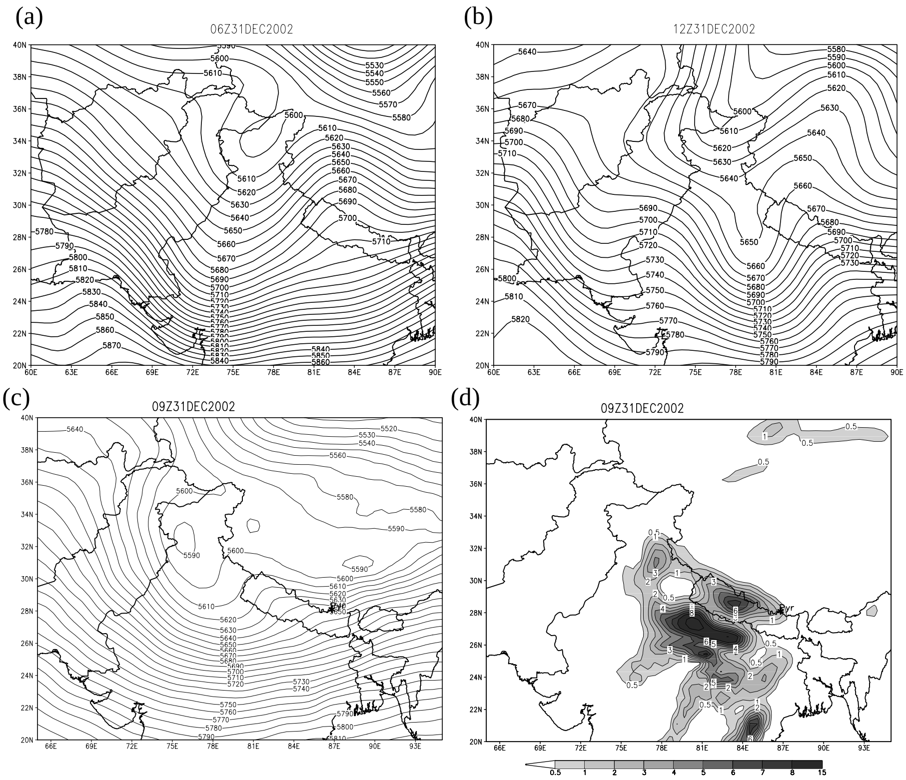


Figure 6. Geopotential height at 500 hPa simulated by the GCM on 31December 2002 at 06 UTC (a) and 12 UTC (b). Geopotential height at 500 hPa (c) and 3-hour precipitation (d) simulated by the RSM on 31 December 2002 at 09 UTC.

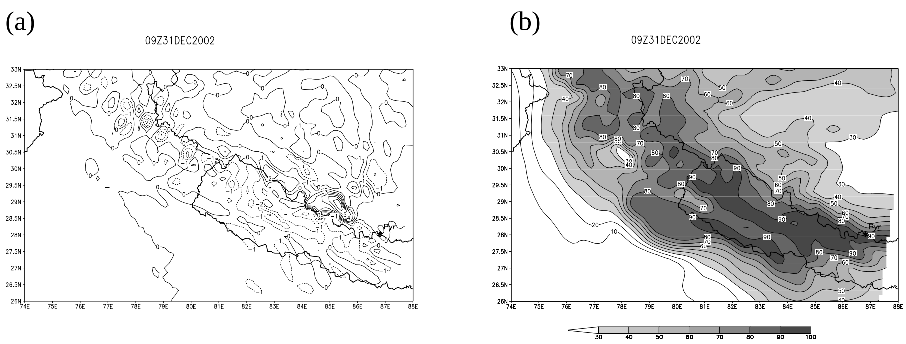


Figure 7. Vertical p-velocity (Pa s^{-1};a) and relative humidity (%; b) at 500 hPa simulated by the MSM on 31 December 2002 at 0900 UTC.

CONCLUSIONS

The preliminary analysis of a significant snow storm over the Himalayas and the Tibetan Plateau described above has outlined many aspects of the dynamical interaction between the Range and the westerly flow. An integration among different sources of data, which is the strategy behind CEOP, is essential for a more complete description of the mechanism of the event. Also, the results of regional-scale simulations demonstrated the importance of correctly reproducing the characteristics of the flow against the mountains, thus being a good test for model validation.

ACKNOWLEDGMENTS

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