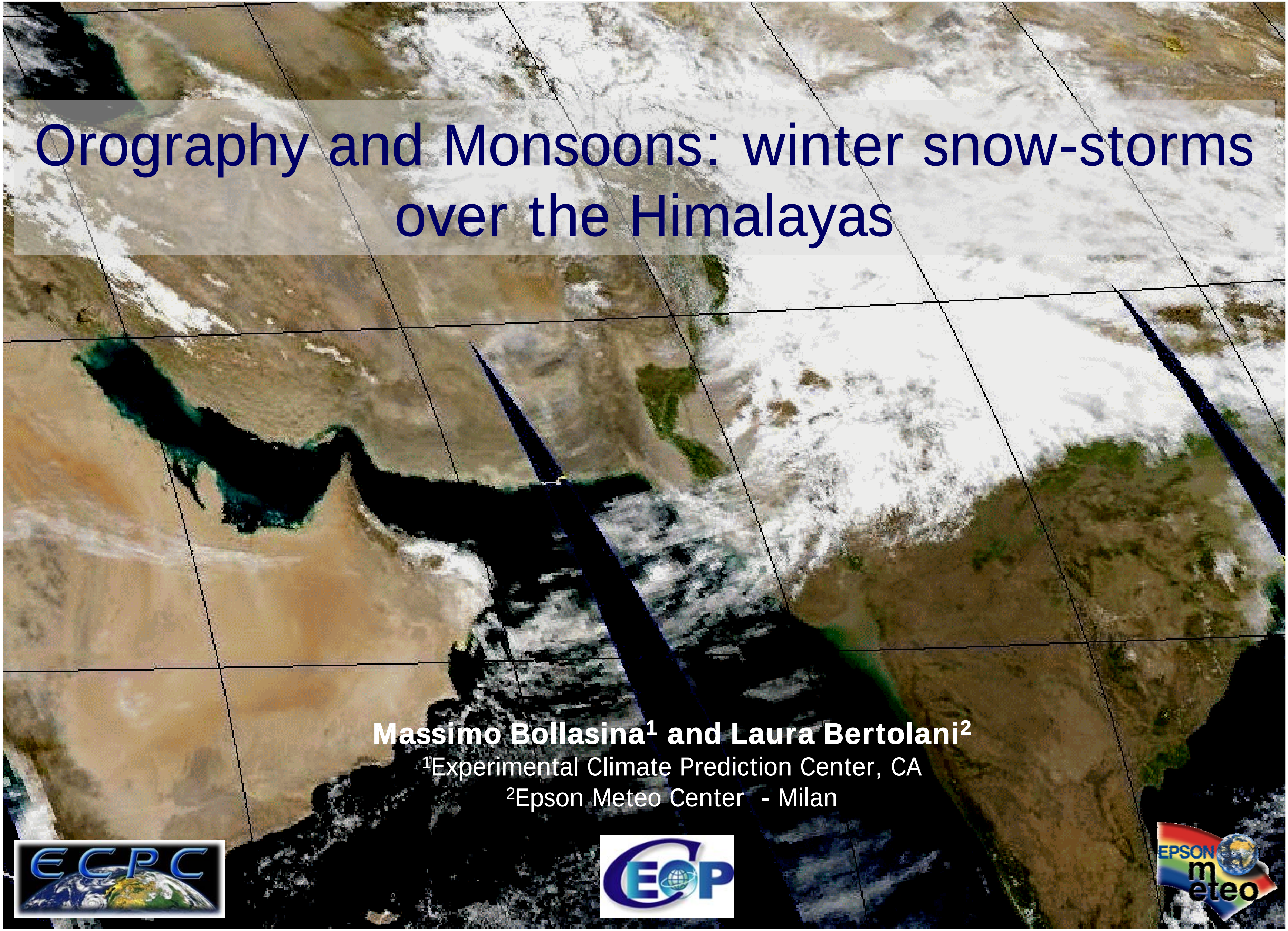
Orography and Monsoons: winter snow-storms over the Himalayas



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General Aims and Framework

Orography plays an important role in monsoons, especially for the Asian monsoon

In the general framework of understanding the fundamental physical processes driving the water cycle, it is important to focus and to study (*observations + simulations*) how the distribution of water resources is modified by the interaction between the atmospheric circulation and orography ("orographic forcing")

It is carried on within the framework of CIMS activity

CIMS (CEOP Inter-Monsoons Studies) is a CEOP initiative to assess, validate and improve the capabilities of climate models in simulating physical processes in monsoon regions around the world

Main Issues and Motivations of the Study

Why snow cover is so important:

Many OBSERVATIONAL and GCM MODELLING STUDIES have pointed out that SNOW COVER and SNOW DEPTH over EURASIA during WINTER/SPRING has an INVERSE INFLUENCE on the FOLLOWING ASIAN SUMMER MONSOON (albedo and hydrological effects)

The HIMALAYAS and the TIBETAN PLATEAU exert a PROFOUND THERMAL INFLUENCE on the SUMMER MONSOON, which depends on surface features (e.g., moisture availability)

The study of the occurrence of snow storms over the Himalayas involves several issues:

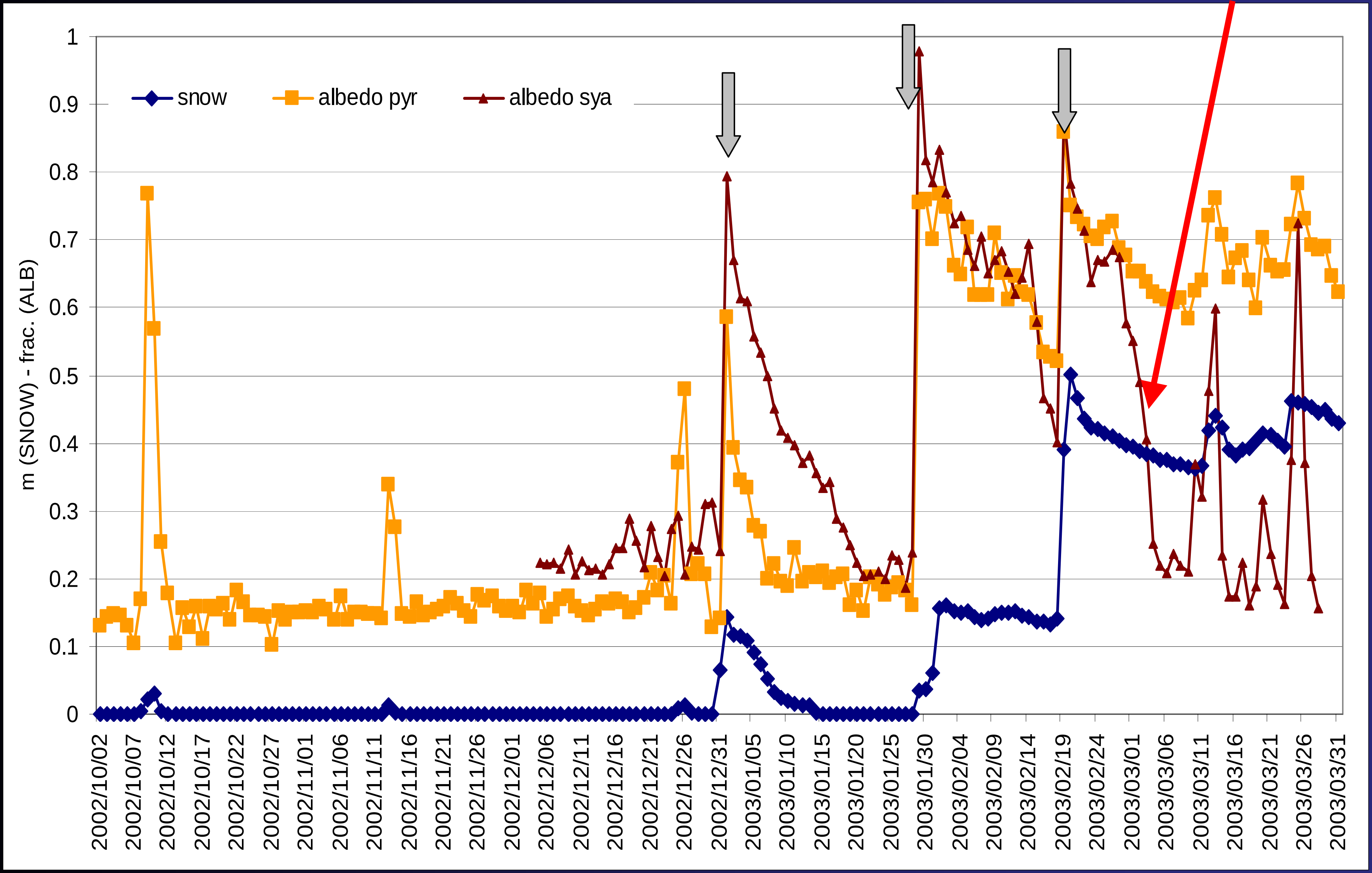
- **Impact of orography as a huge barrier to the flow (*blocking, deflection, friction*)**
- **Interaction of mesoscale-induced flow with the synoptic circulation**
- **Monsoon water budget and precipitation processes, snow accumulation and water balance**

IN DOING THIS, the MOTIVATIONS ARE:

- **To demonstrate the utility of the CEOP and CIMS integrated approach**
- **To evaluate the skill of downscaling models from global to sub-regional scale (dynamics, atmospheric vertical stratification, precipitation) in the prediction of the events**

Snow and radiation: daily ave variation @ Pyramid&Syangboche

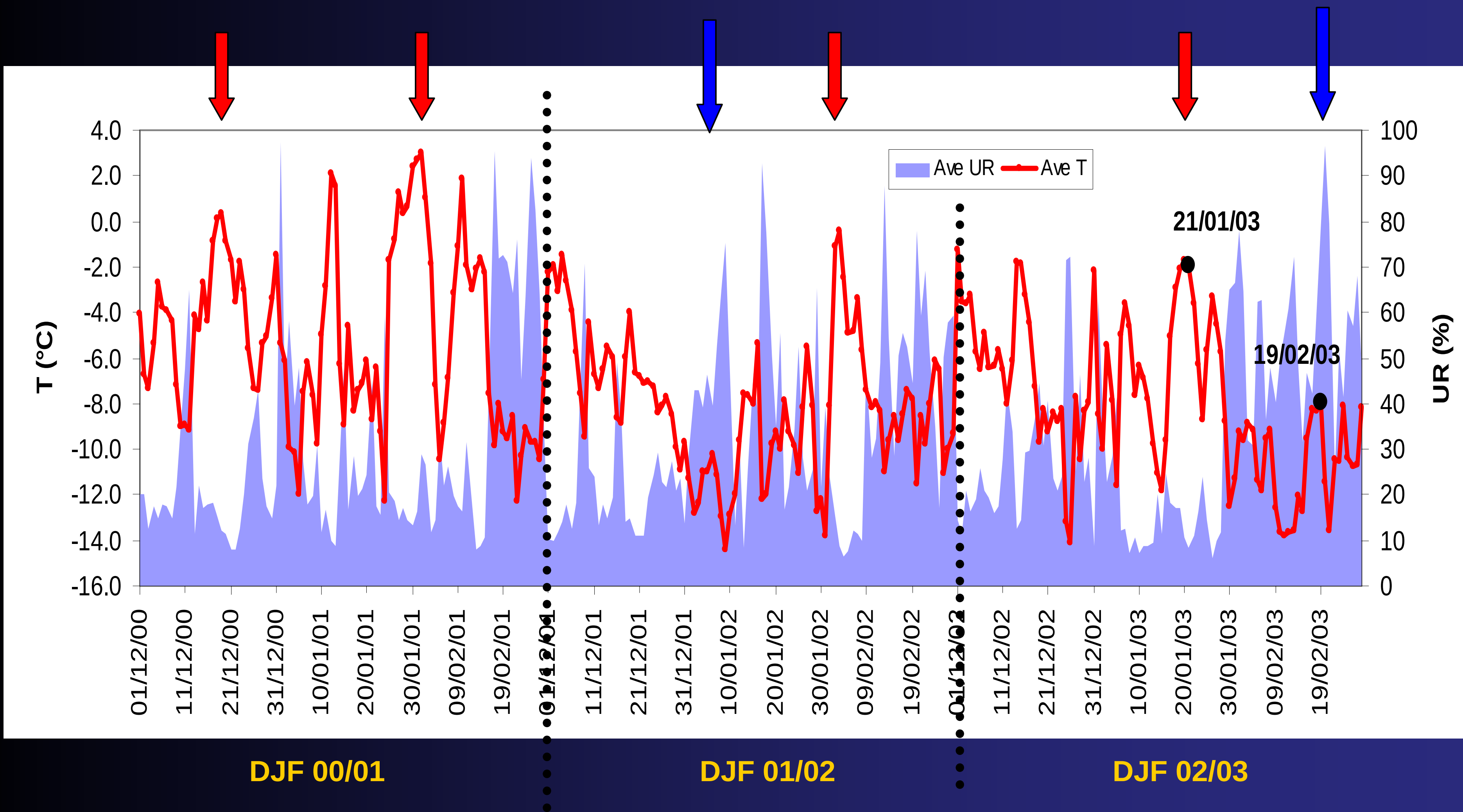
Snowfall events over the Eastern Himalayas during winter-early spring 2002/2003:
Faster snow melt at Syangboche from late winter due to lower altitude



Heat Waves during Winter @ Pyramid AWS (2000/2003)

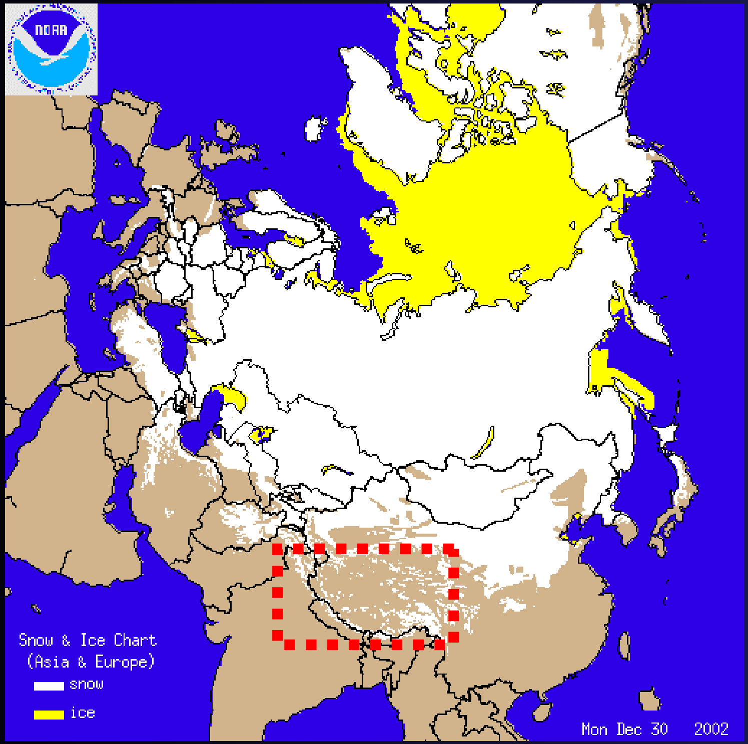
Warm episodes related to pressure ridges without snow fall: in the eastern Himalayas air temperature rises and humidity falls

This variability could have relations with the TBO!

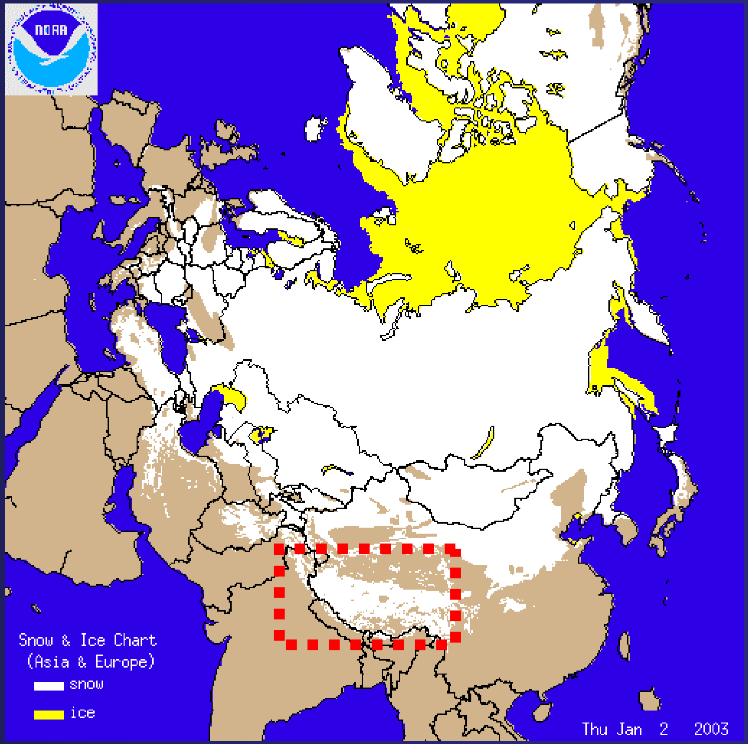


The selected events are significant due to their large-scale nature!

BEFORE (30 Dec 2002)



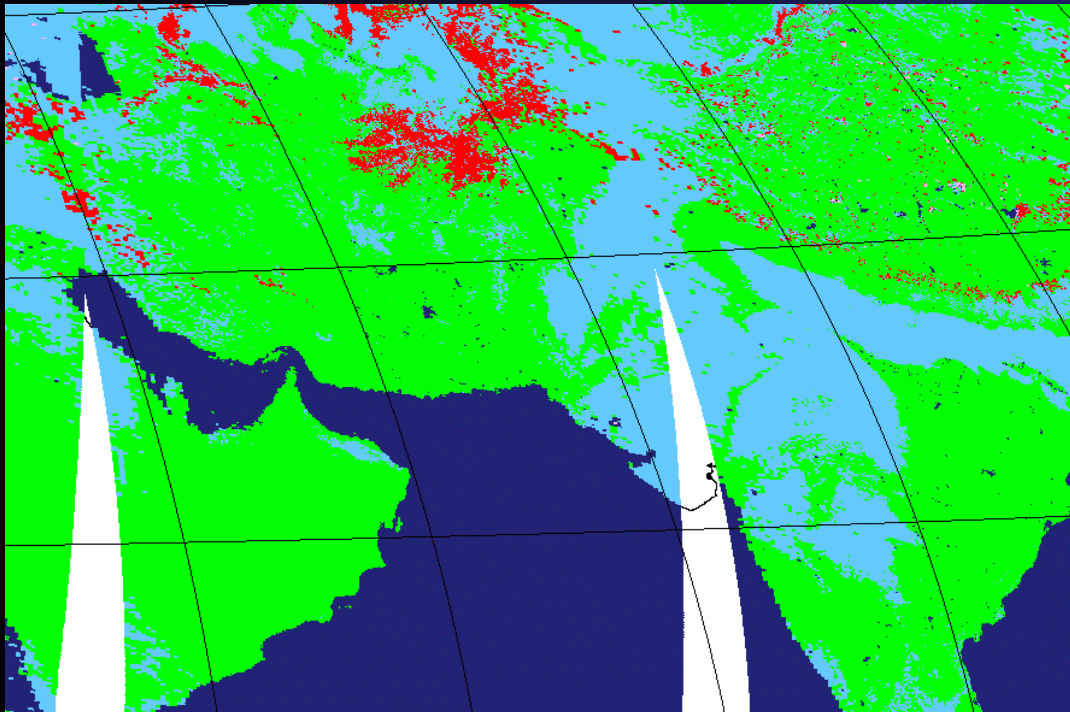
AFTER (2 Jan 2003)



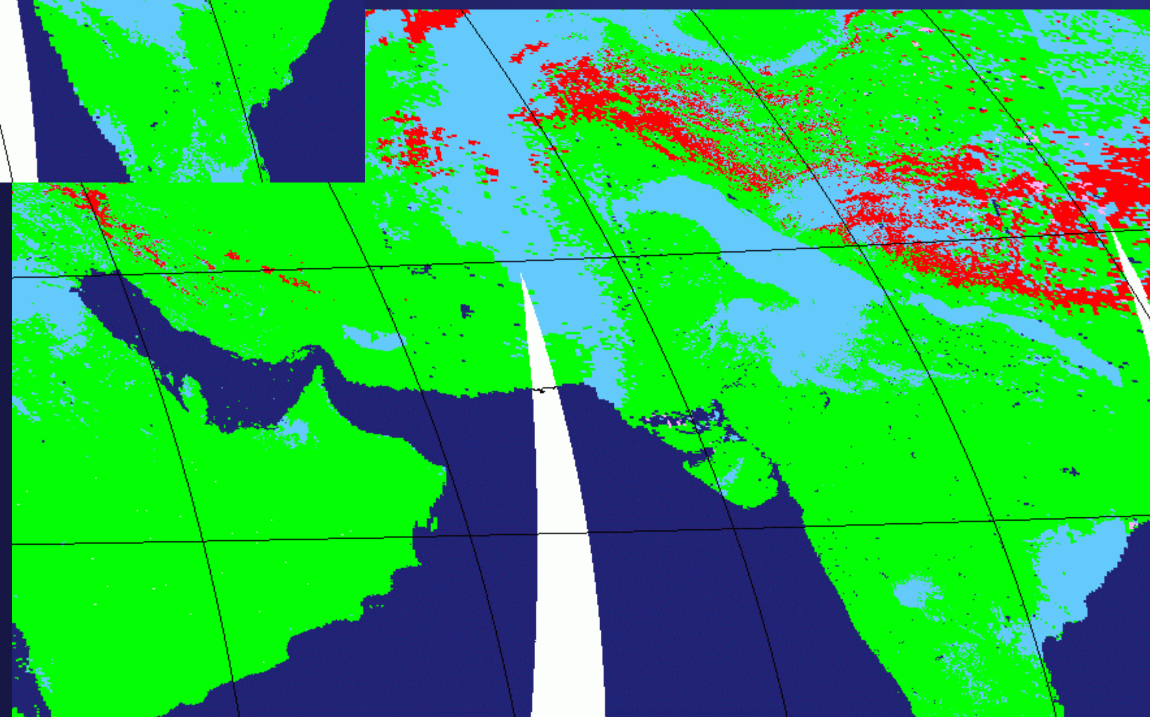
CASE 1 (end of December 2002): a snapshot from NOAA DMSP Satellites Operational Analysis – SSD NOAA/NESDIS

NOTE: actually, 2 consecutive troughs passed over the Himalayas

BEFORE (30 Dec 2002)



AFTER (2 Jan 2003)



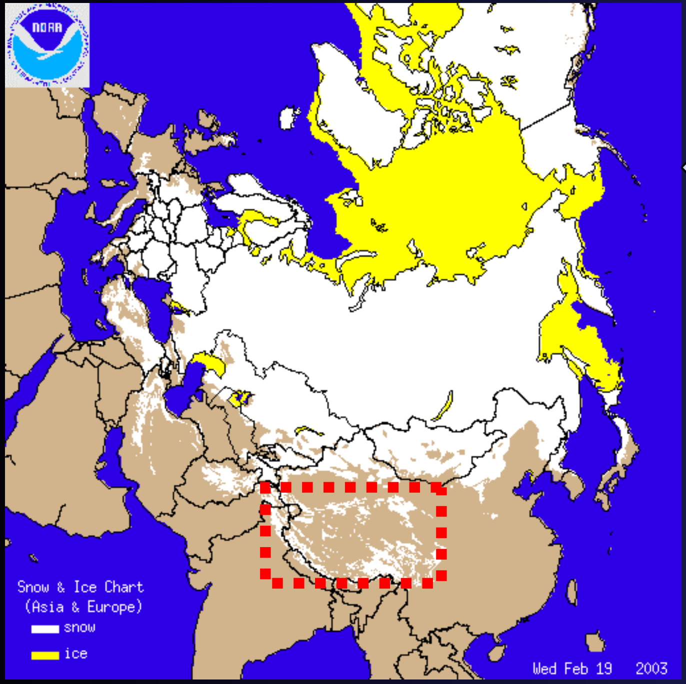
LEGEND:

Green : LAND

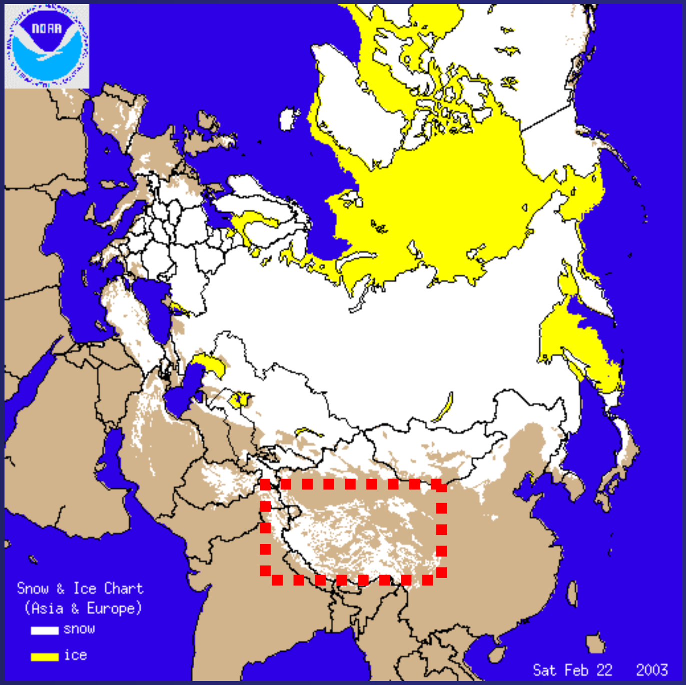
Light blue: CLOUDS

Red: SNOW

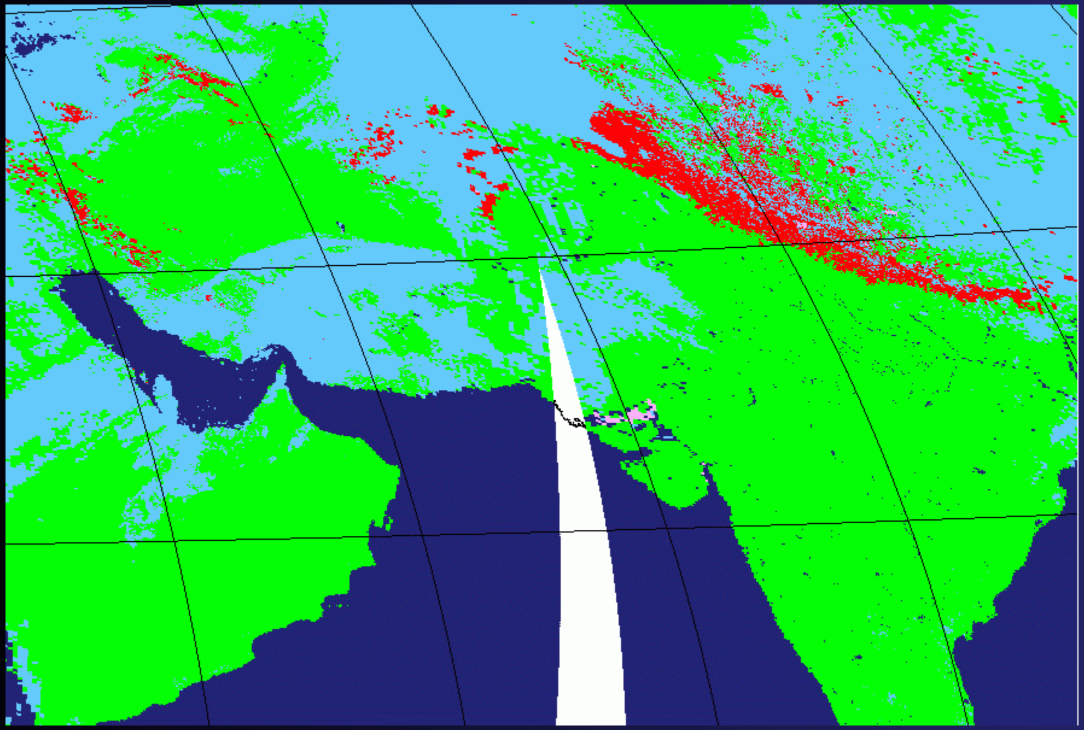
CASE 1: a snapshot from MODIS on Terra (GSFC/NASA)



19 Feb 2003



20 Feb 2003



CASE 3 (19-20 Feb 2003): a snapshot from DMSP (up; left=before; right=after) and MODIS (down=after).

What causes the Himalayan snow storms?

The major factor determining the occurrence of snow over the Himalayas is the interaction between the Range and westerly disturbances

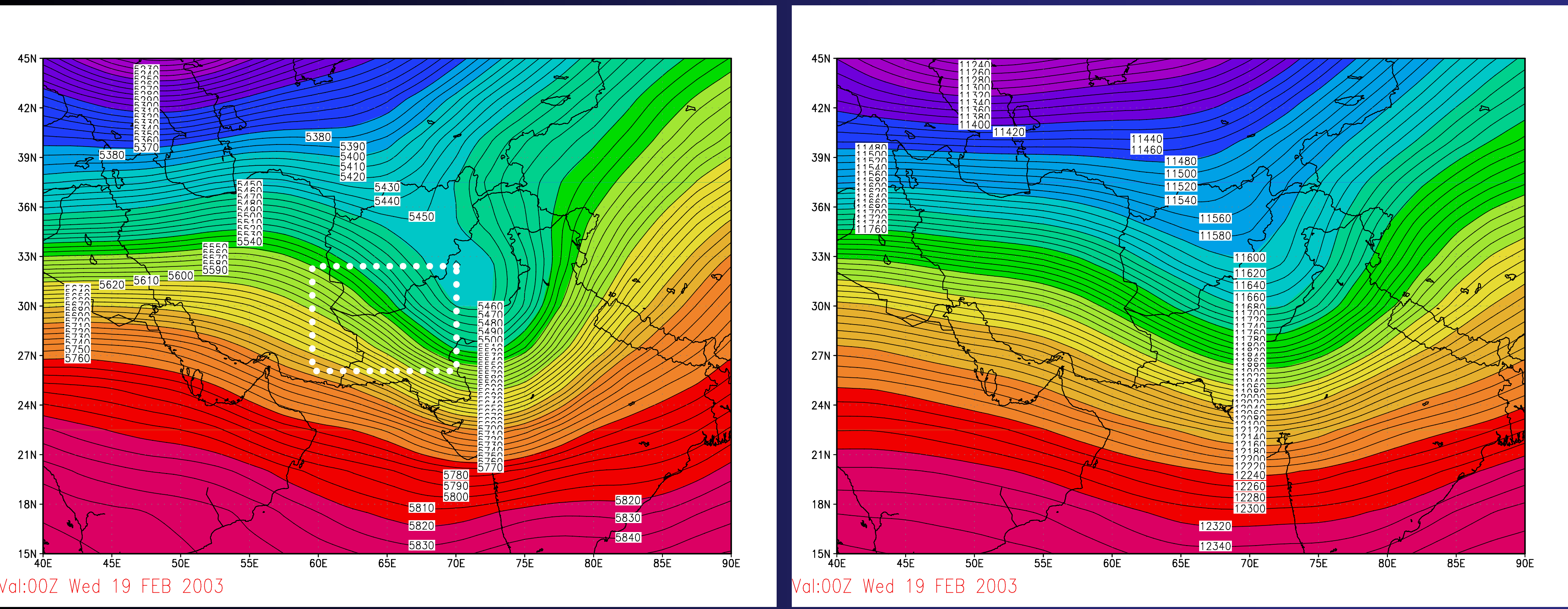
It is not the ONLY forcing, other factors could contribute and co-exist (tropical cyclone in the BoB (e.g., 14-15 December 2003), local dynamics, etc.) and can bring to heavy snowfall

But most cases are associated to this mechanism

Synoptic framework during snow storms over the Himalayas (1/3)

A midlatitude trough embedded in the westerlies: a southwesterly flow brings <u>warm and wet</u> air over the Himalayas

Tipical time for eastward propagation of the disturbance over the Tibetan Plateau: 2 days



Geopotential Height @ 500 hPa (left) and 200 hPa (right) during CASE 3 (data from NCEP/NCAR Reanalysis)

Synoptic framework during snow storms over the Himalayas (2/3)

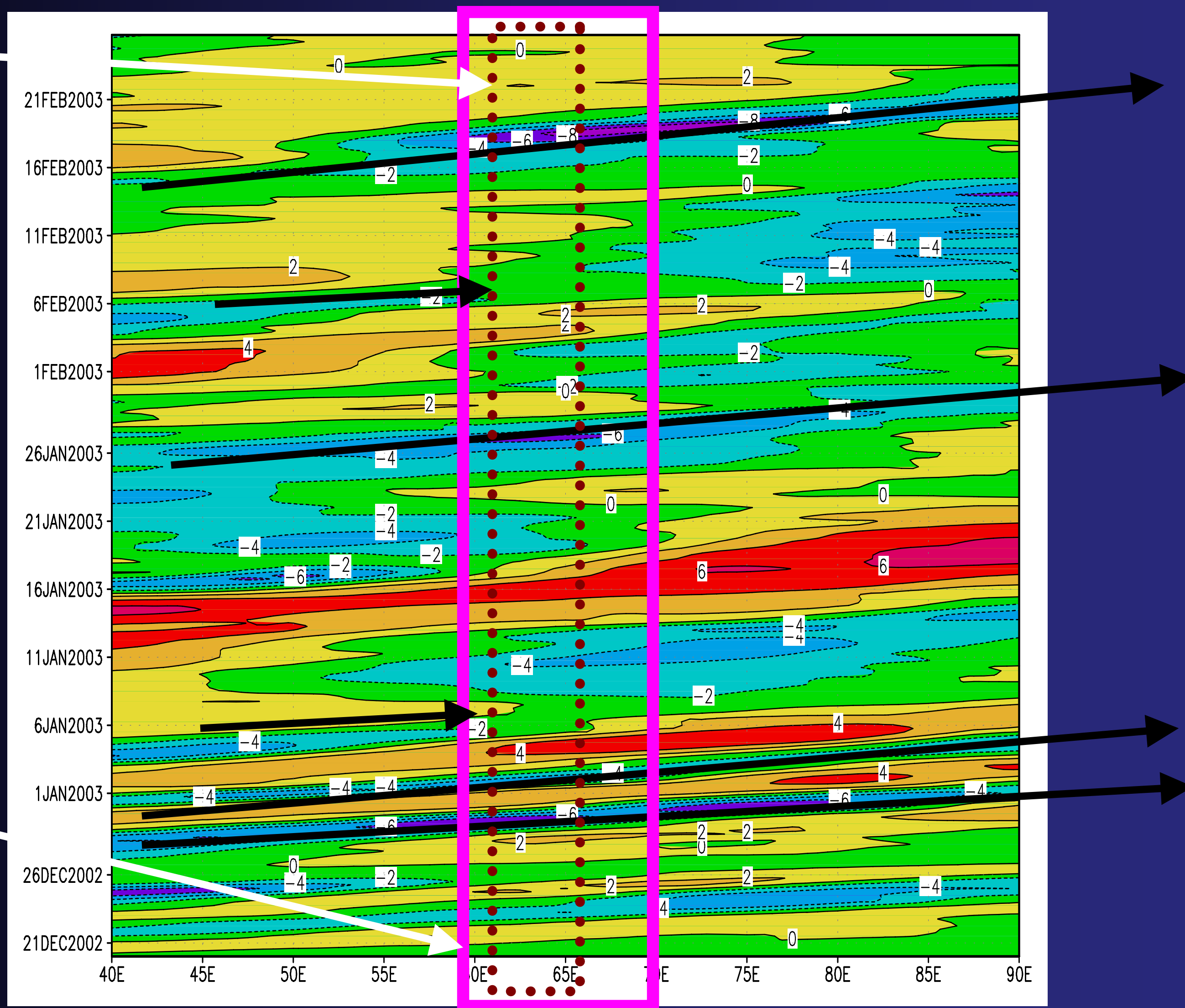
The trough originates in the Eastern Mediterranean area, then moves almost zonally toward the Himalayas. It then can deepen and slow down, causing snowfall.

Longitude/time variation of "anomalous" T at 500 hPa averaged over [26° -32° N]

(a rough estimate of origin and trajectory of the trough)

Barrier Effect

Deepening



CASE 3

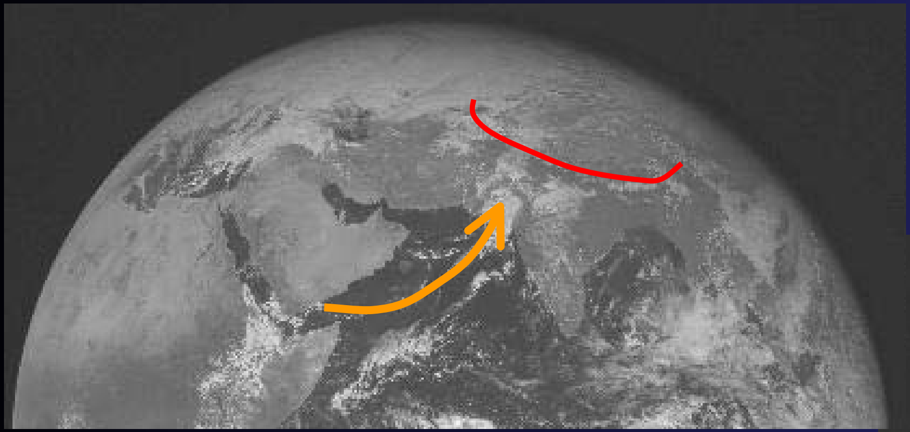
CASE 2

CASE 1

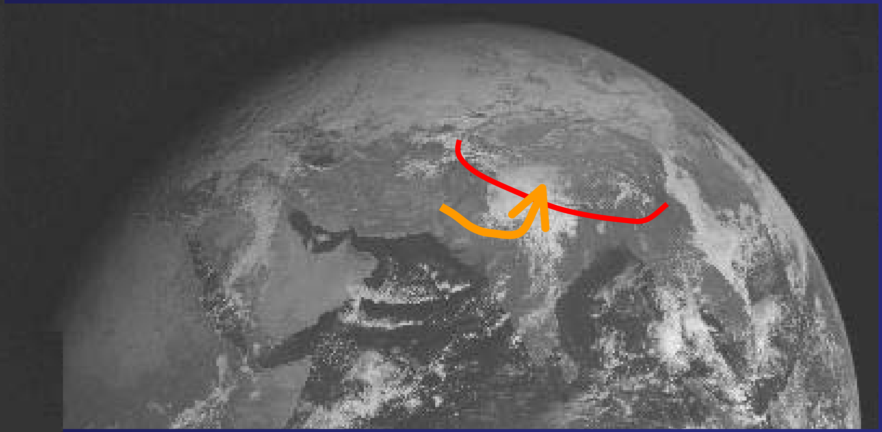
Synoptic framework during snow storms over the Himalayas (3/3)

Cloudness related to the depression (METEOSAT5 and GMS-5 IR and WV) :

A meso-scale system moves from SW carried by the depression and intensifies against the barrier



30 Dec 2002 06UTC VIS

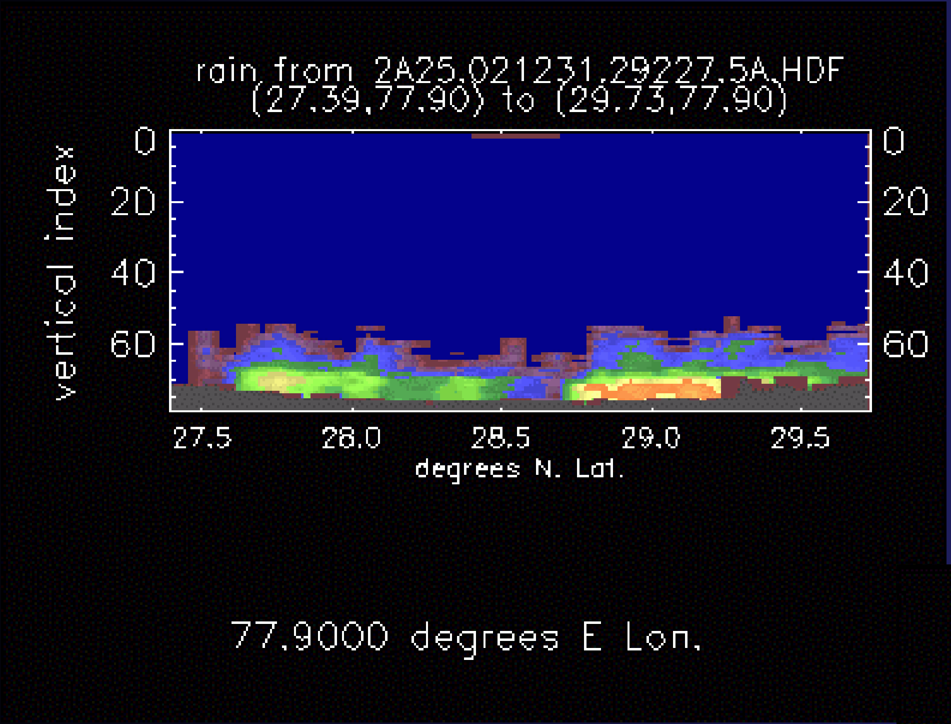


31 Dec 2002 06UTC VIS

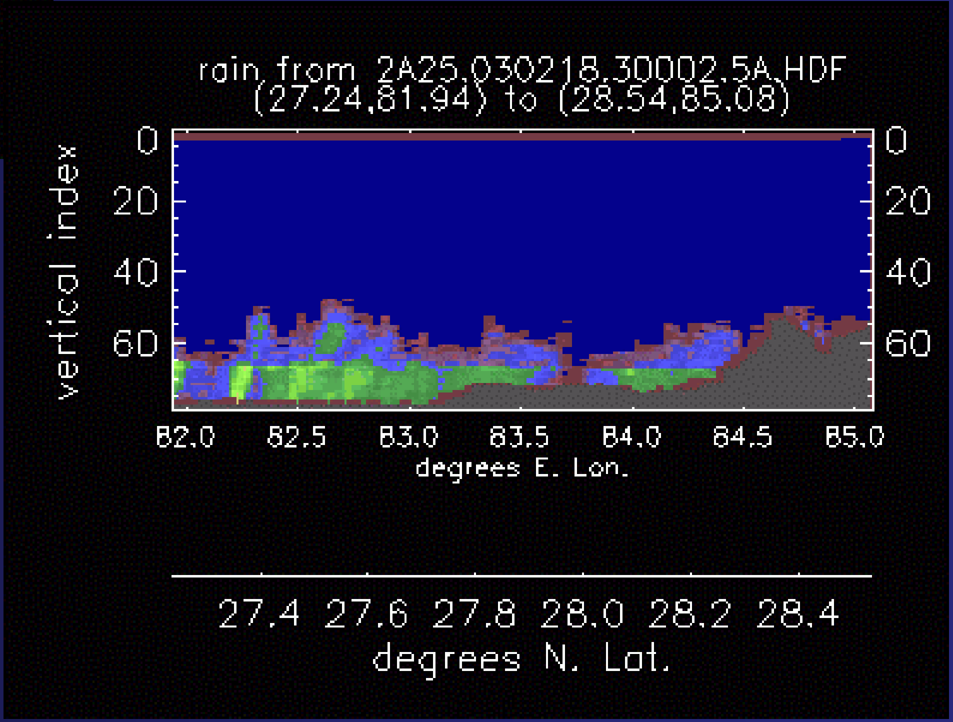
01 Jan 2003 06UTC VIS

An insight into clouds (lat/height cross section from TRMM)

31 dec 2002

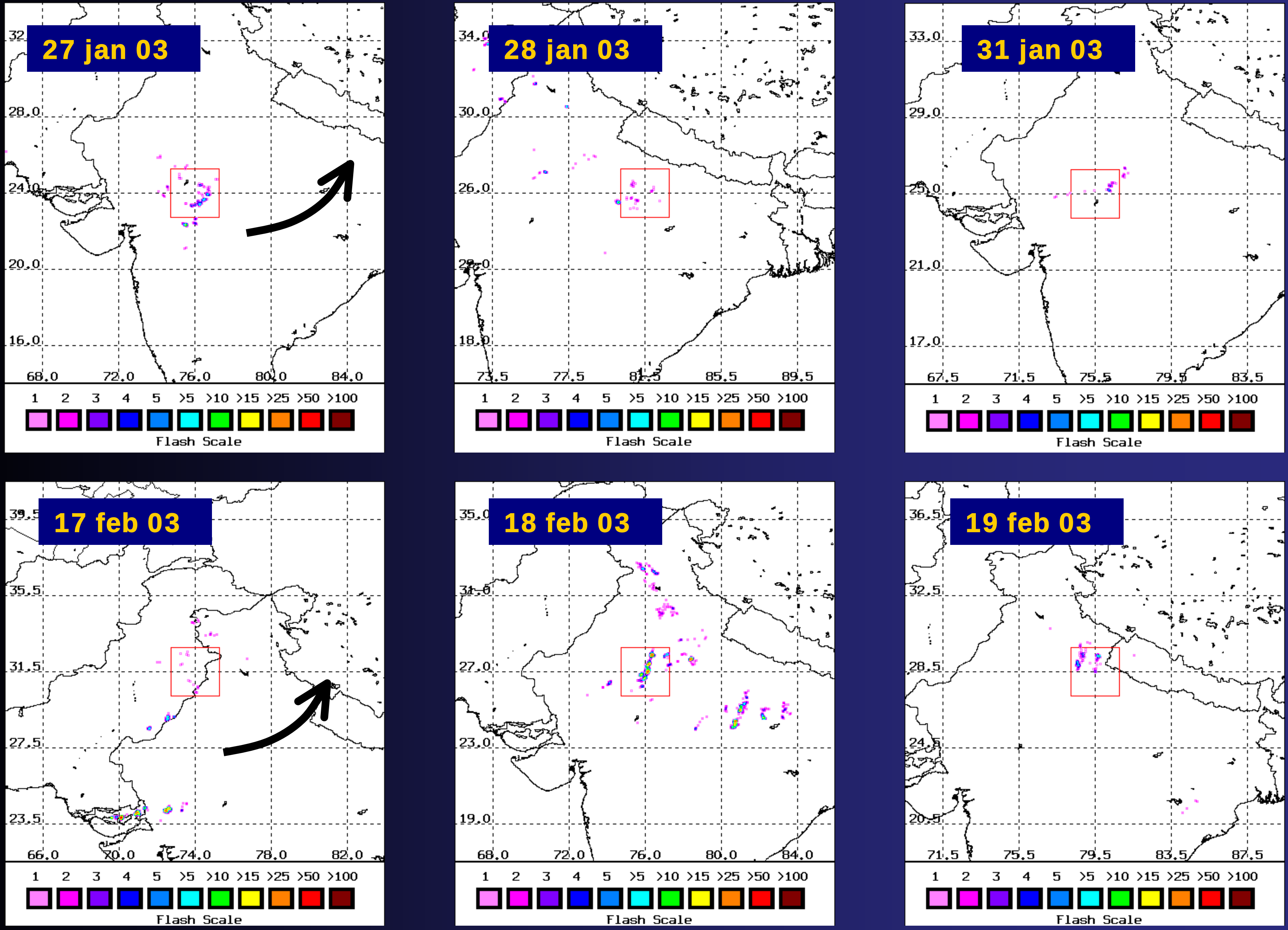


One or more structures with height below 7 km



18 feb 2003

The nearing of the trough and the intrusion of cold air could be accompanied by lightning over NW India (LIS on TRMM; by courtesy of MSFC/GHCC)



Prediction Experiments

Based on NCEP / ECPC GSM and RSM (Roads et al., 1999)

Heterogeneous boundary conditions at surface (vegetation and soil), full physics

Topography datasets: GSM: USGS GTOPO30; RSM: TOPO05 / GLOBE

A high degree of smoothing was necessary for GSM

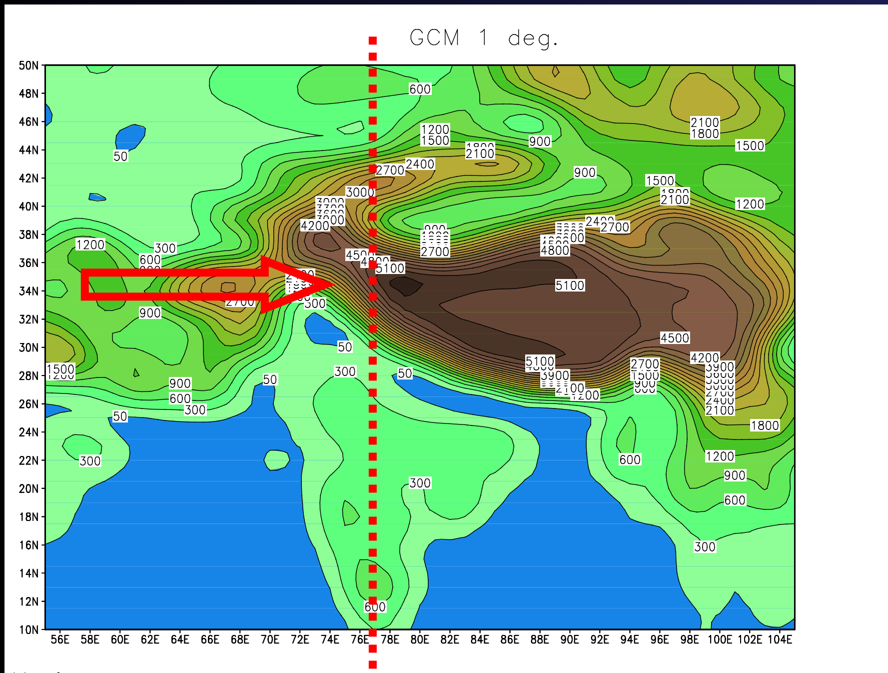
- Model Initializations: GCM initialized with NCEP/GDAS analysis at 00 UTC
- Simulation length: + 48/72 hrs (with about 12 hrs for spin-up)

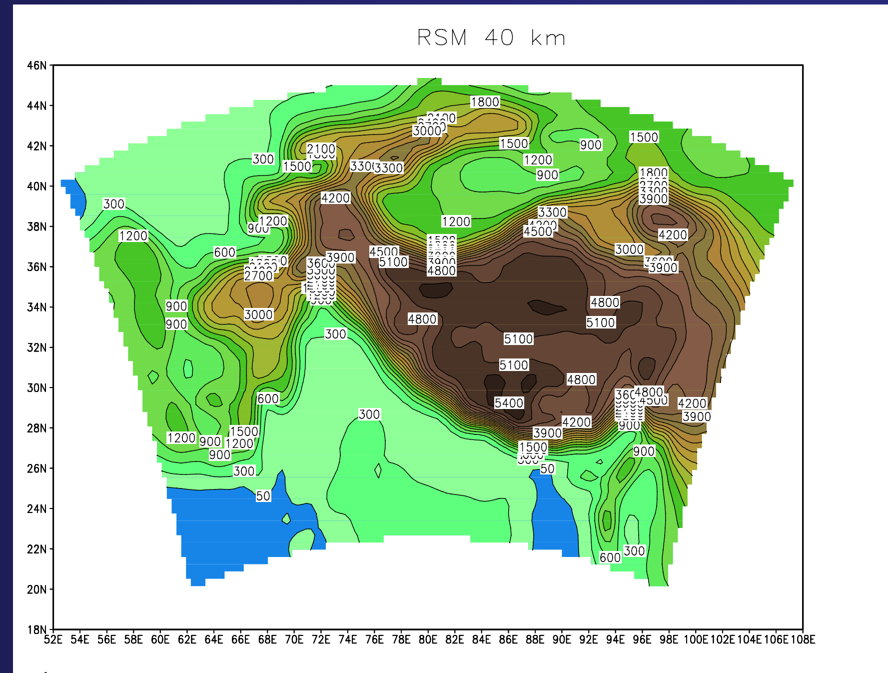
The storm cycle is centered between 18-42 hrs in the 2-day simulation

Self-Nesting Model Structure

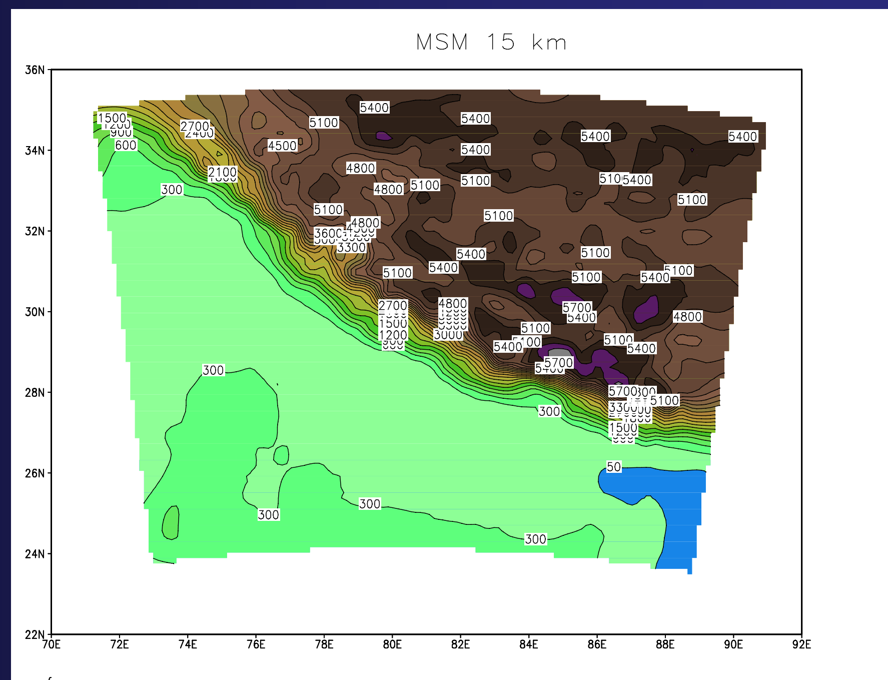
	Hor. Res. (km)	Time Step (s)	NX x NY	N. Levels
GCM	~ 100	1200	360 x 181	28
RSM	40	200	129 x 78	28
MSM	15	30	145 x 108	28

Models Domains and Topography





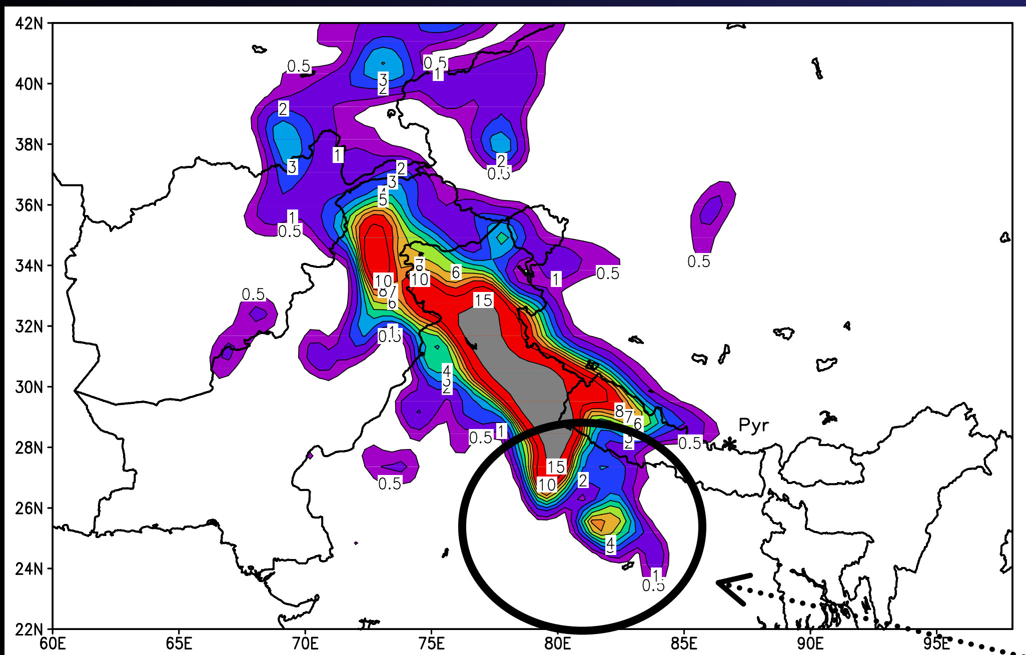
76 ° E

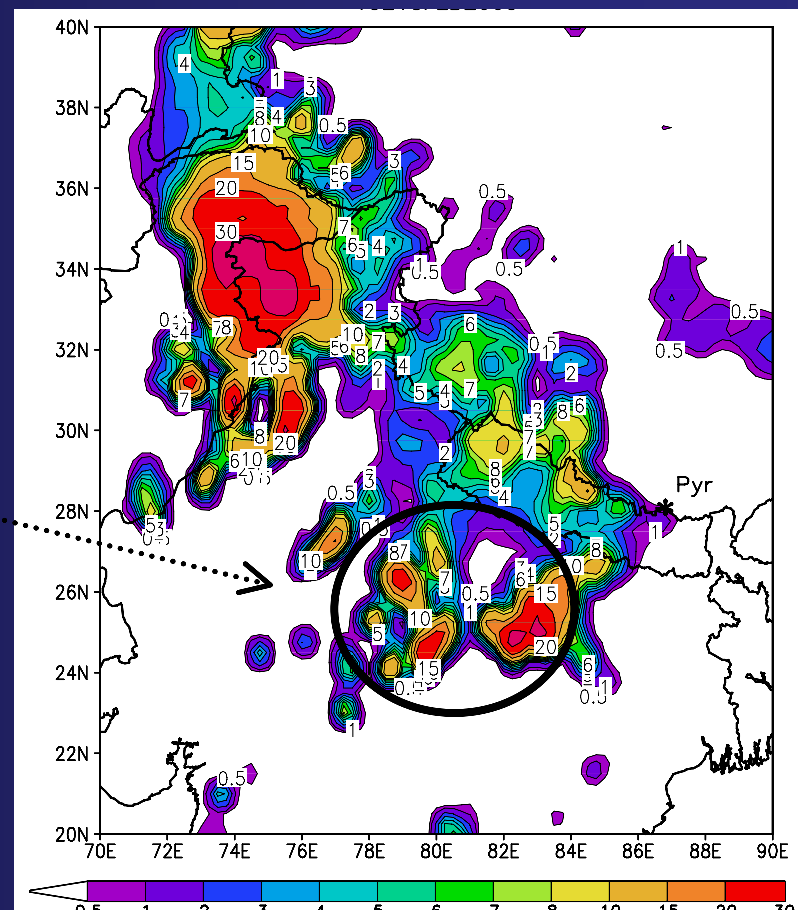


The tipical trajectory of the trough is indicated for cases of snow over the Himalayas

CASE 3 (18-19 Feb 2003)

There is an agreement with TRMM in the position of the precipitation; amounts are however locally different



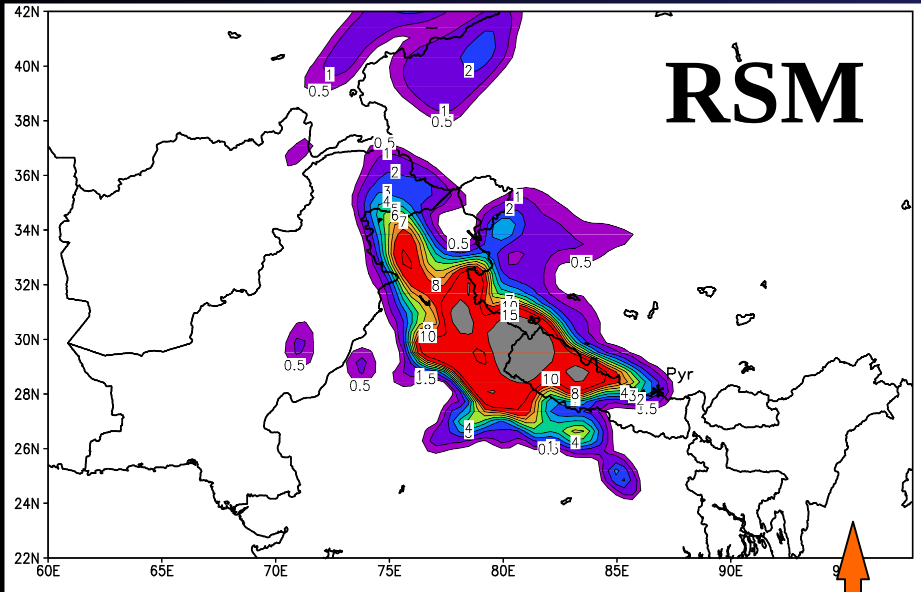


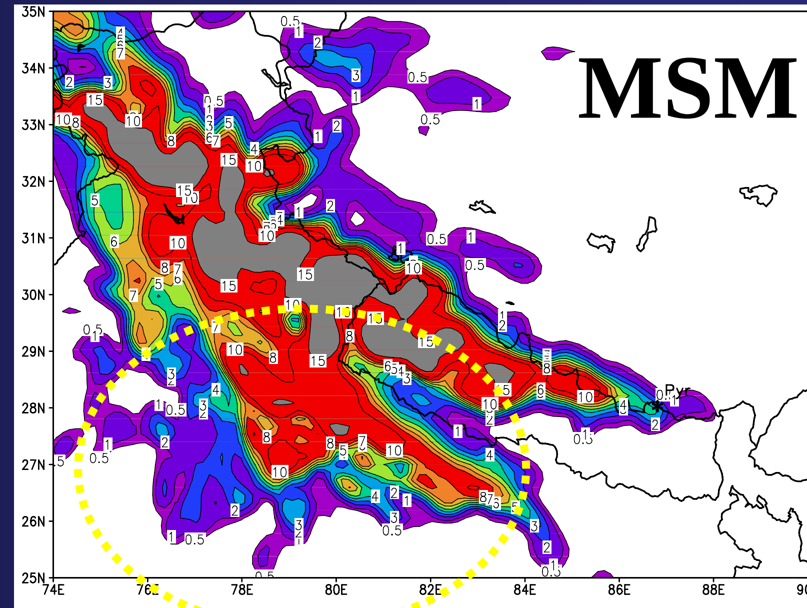
Southward protruding branch

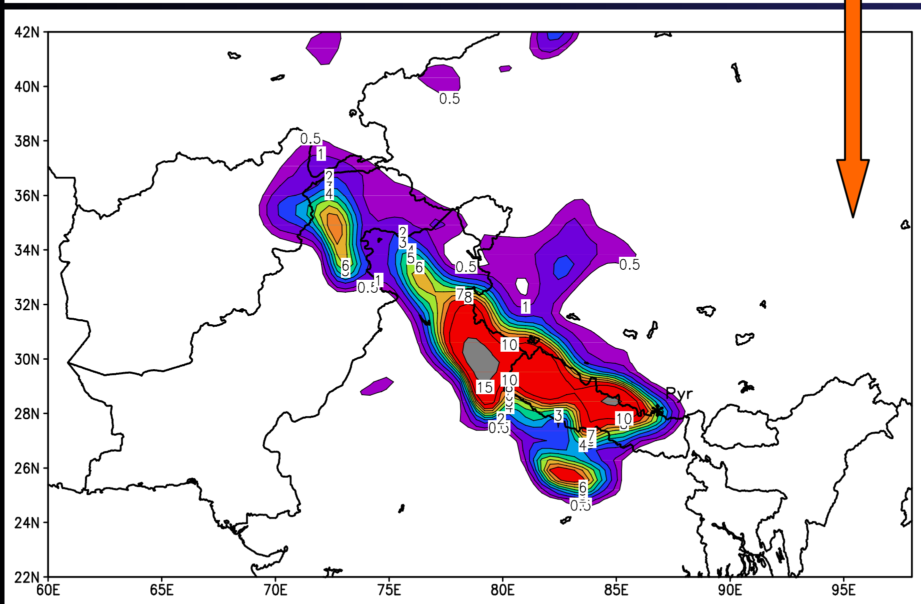
18 Feb 15 UTC: 3-hr precipitation from TRMM (right) and RSM (+39 hr, up)

A +24 hr simulation of precipitation by RSM (left) and MSM (right)

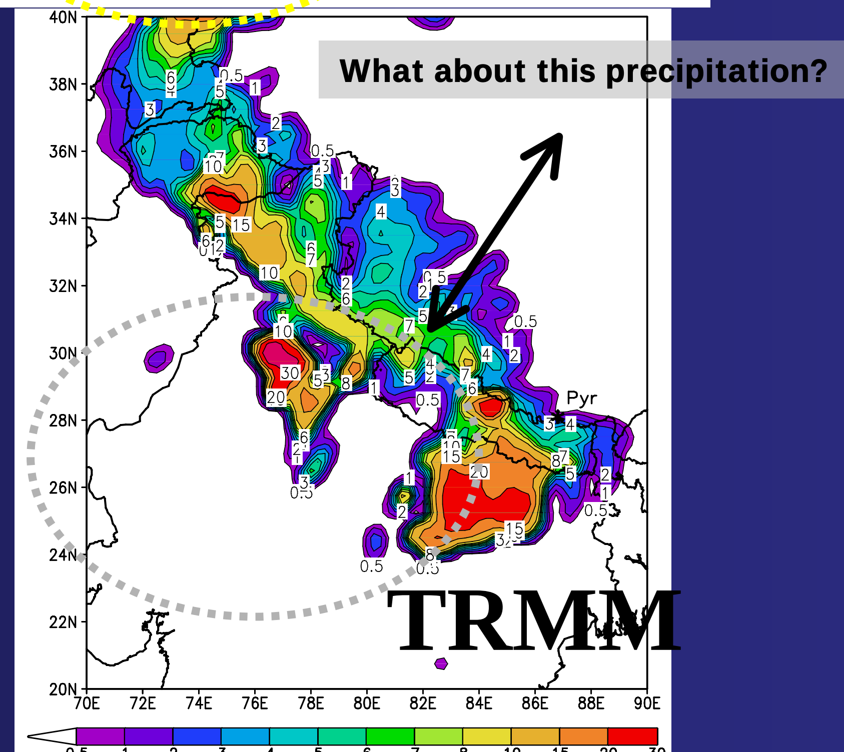
19 Feb 00 UTC





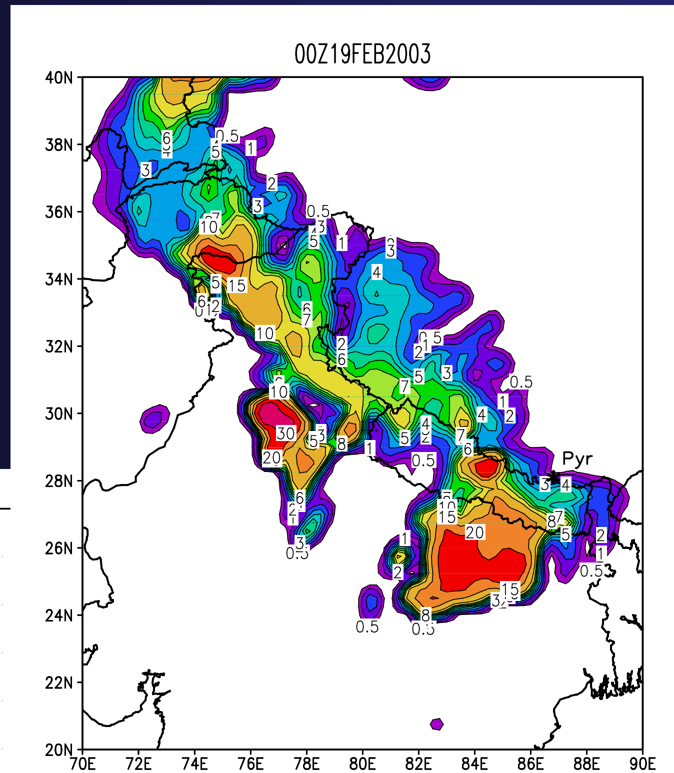


A + 48 hr simulation of precipitation by RSM (the results are very similar even if the model was initialized 1 day before)

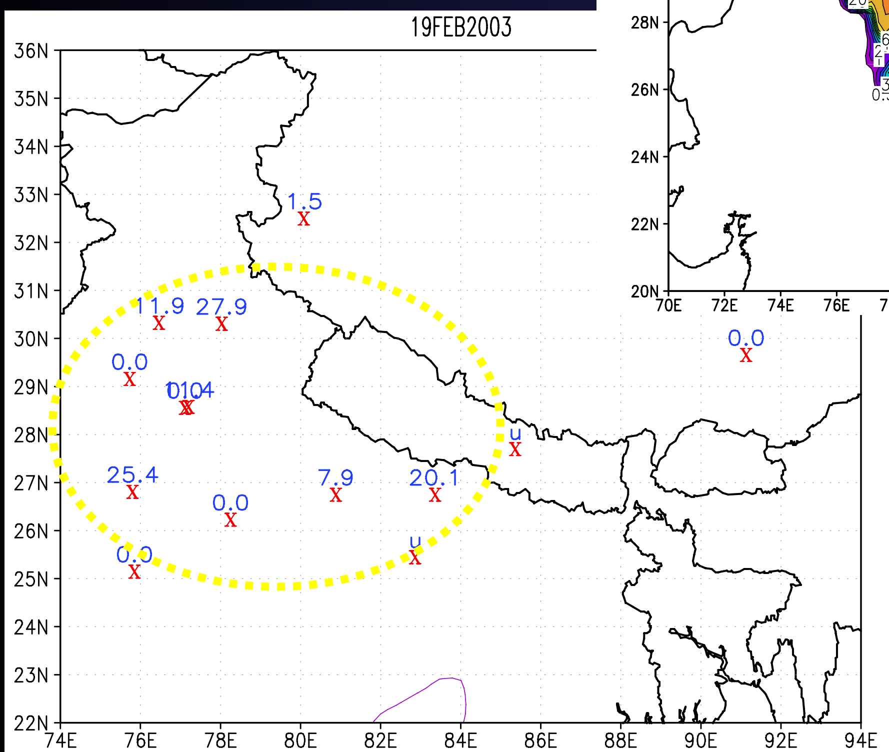


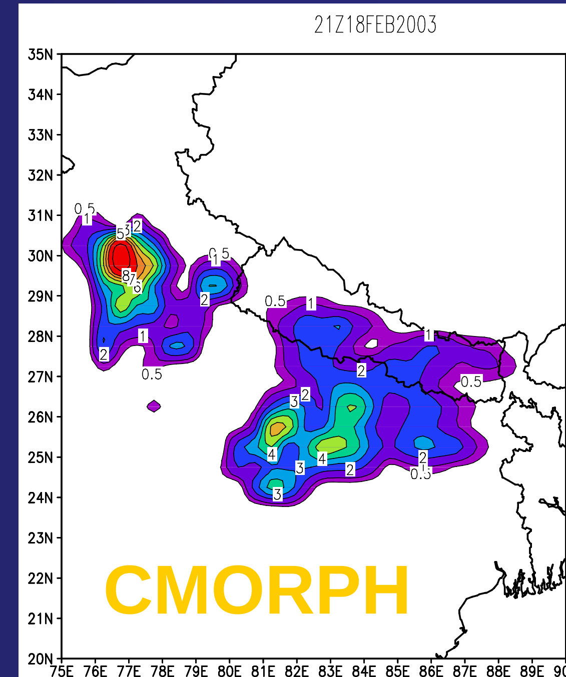
Different datasets→ Different distributions of precipitation (upwind/downwind of the Himalayas)

TRMM

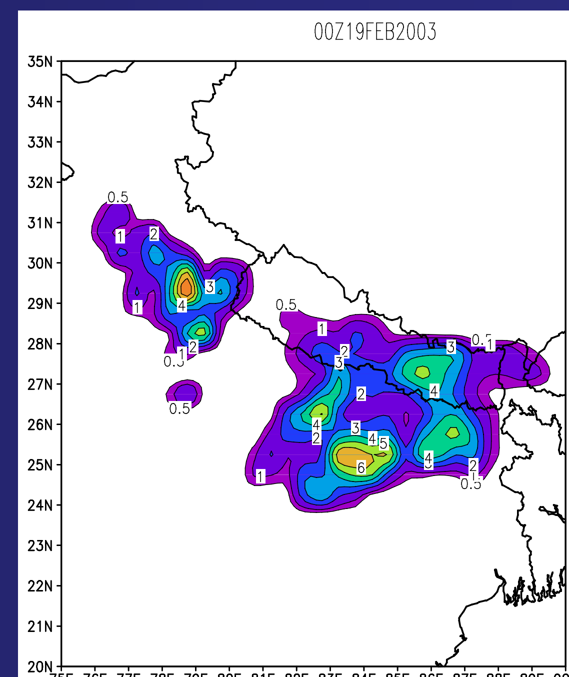


NOAA GLOBAL SOD



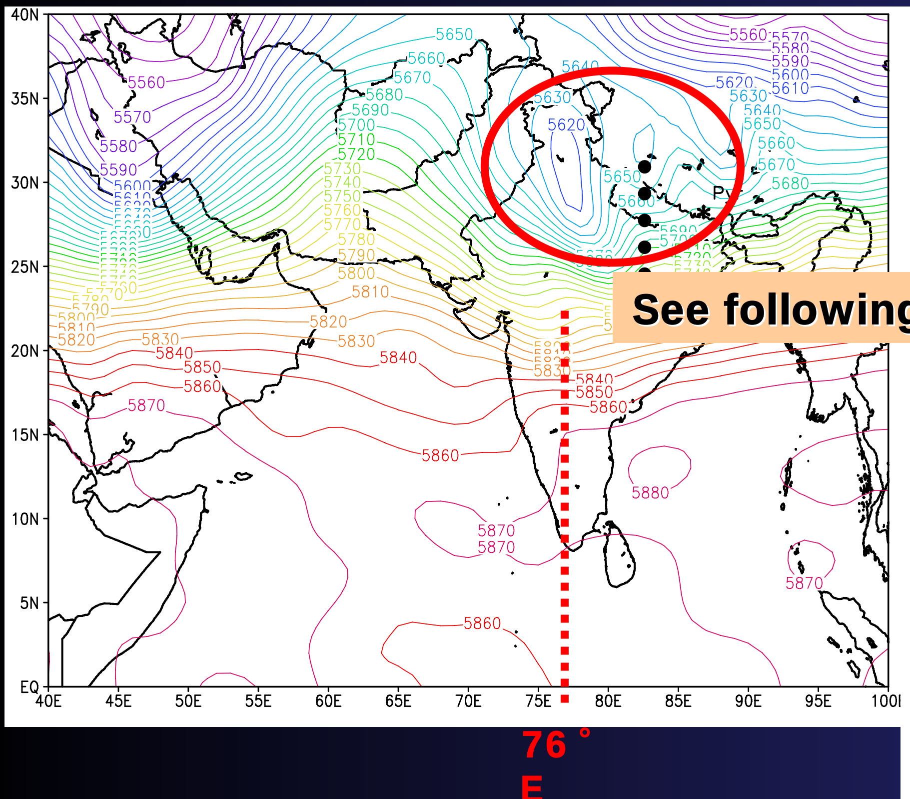


CMORPH



CASE 1 (31 Dec 2002)

The topography influences the movement of the trough in the GSM. The trough is partially blocked (trapped in the orography) and the flow cannot completed rise the steep mountains



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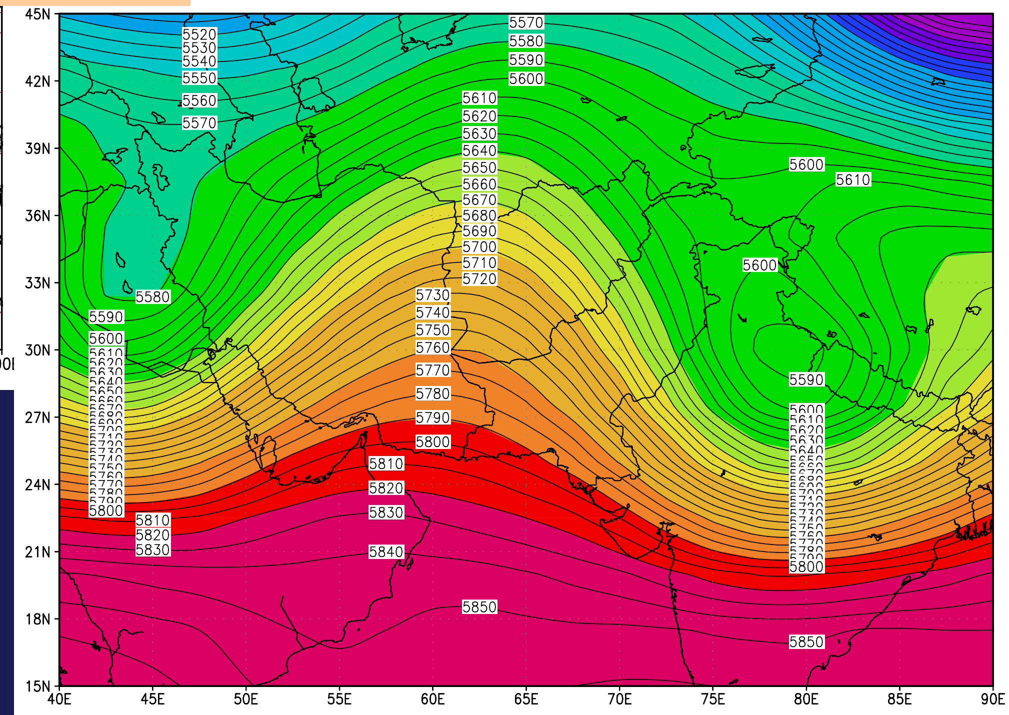
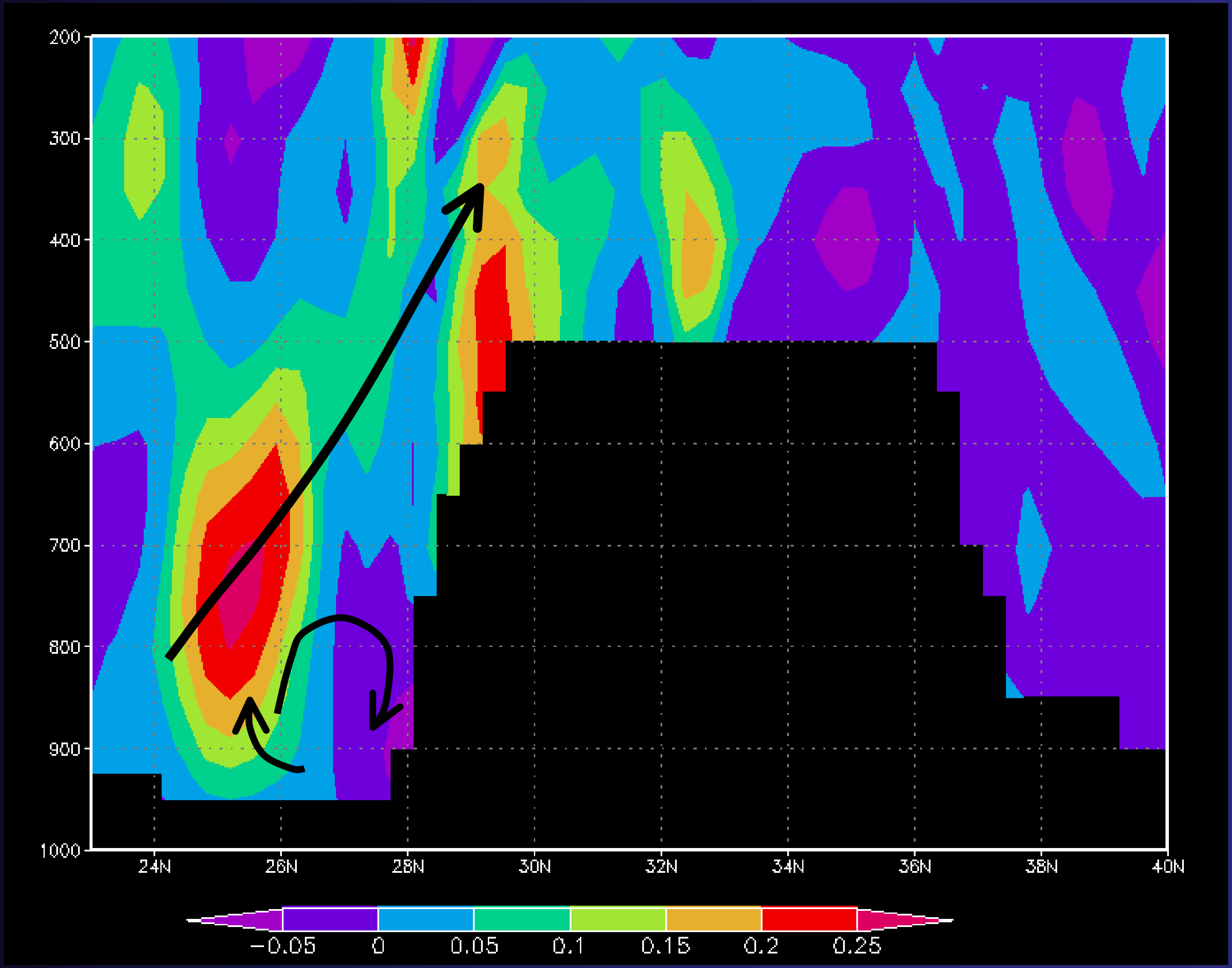


31 Dec 12 UTC: 500 hPa Geopotential Height observed (right) and simulated by GSM (up).

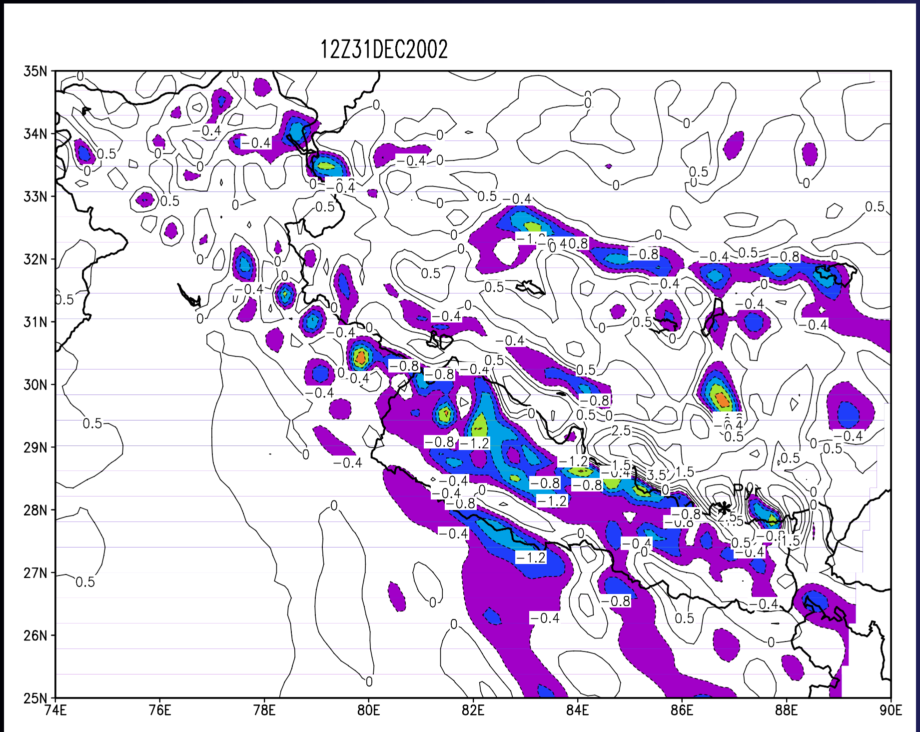
The impact of the flow against the mountains creates a small region of downward motion at low levels due to blocking, which converges with the upward flow



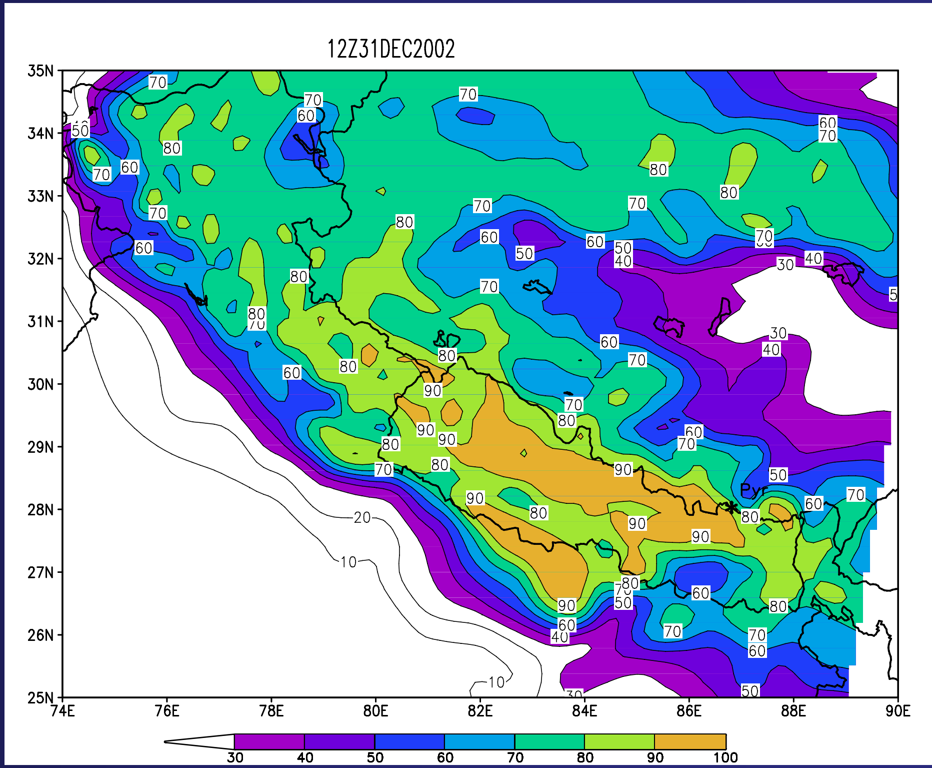
31 Dec 12 UTC: latitude/height cross-section of w (m/s) along 84° E from the RSM

A close look at the circulation up the mountains from the MSM

Vertical p-velocity @ 500 hPa

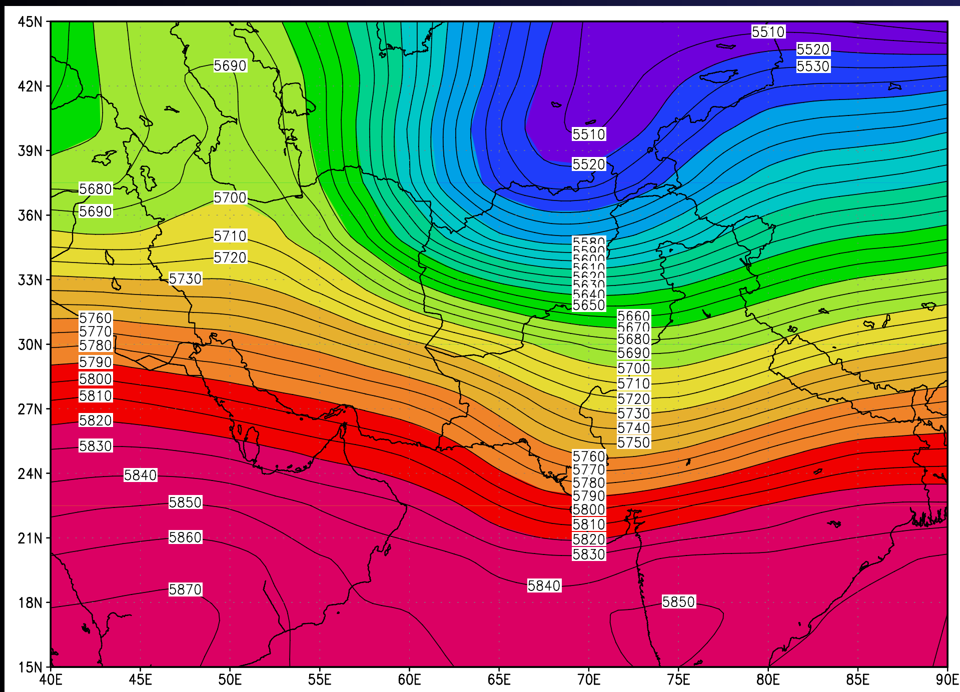


RH @ 500 hPa

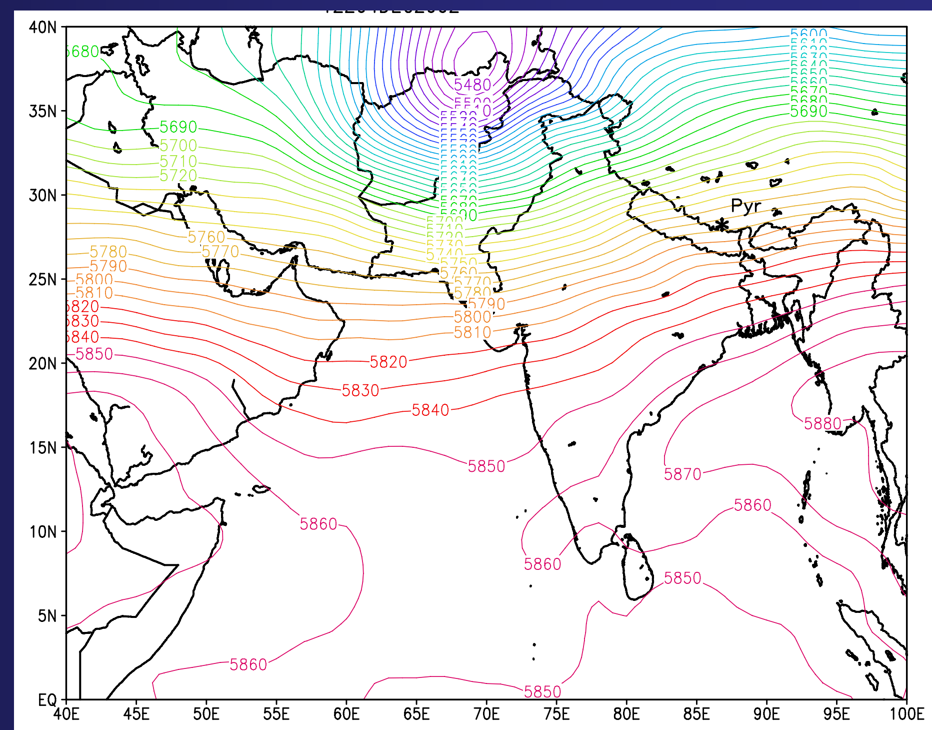


One interesting case (4 Dec 2002)

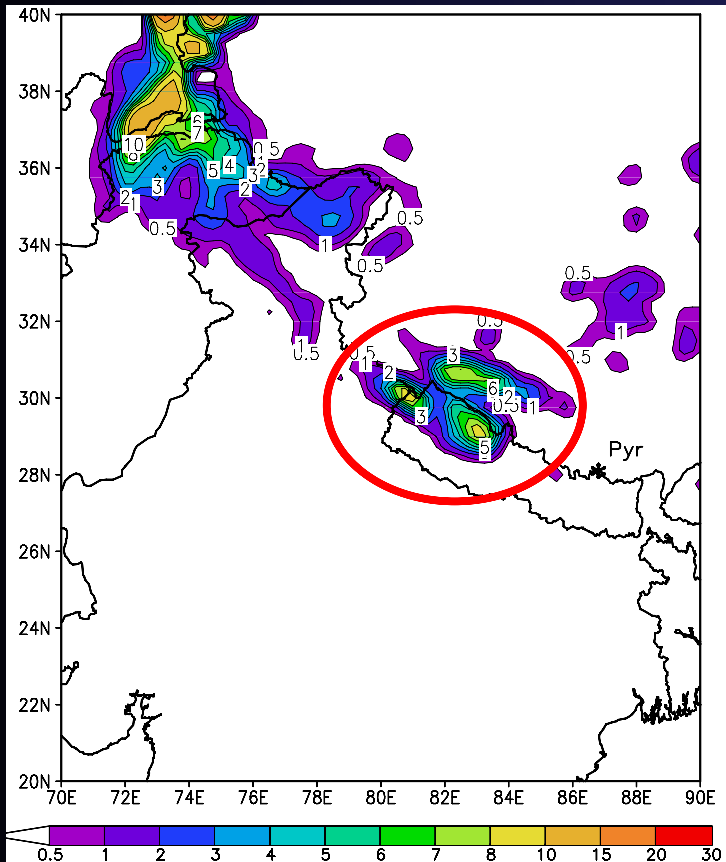
The trough is few degrees north ➡ precipitation mainly over the western Himalayas

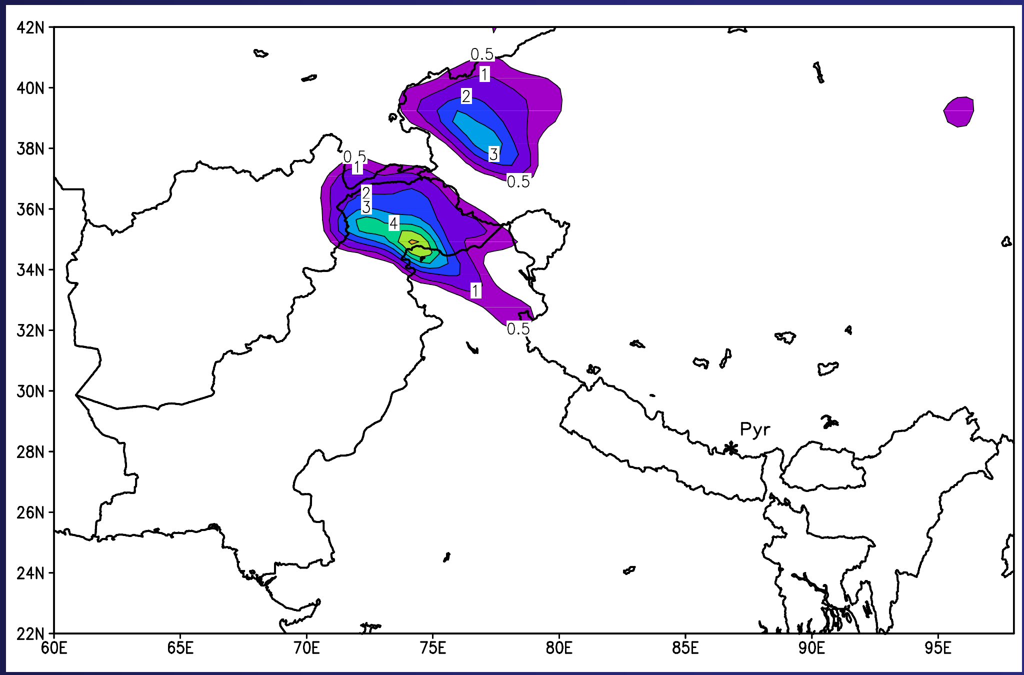


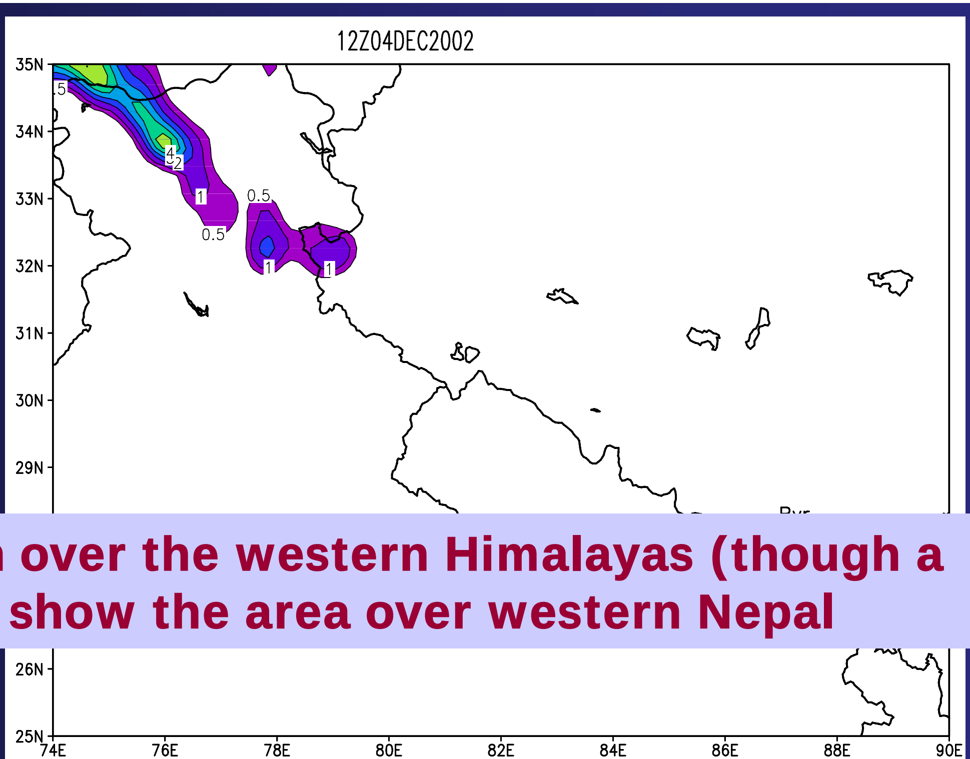
The model correctly reproduces the trough shifted to the north around 39° N and almost zonally flow over Nepal



04 Dec 12 UTC: 500 hPa Geopotential Height observed (up) and simulated by GSM (right).







04 Dec 12 UTC: 3-hr precipitation from TRMM (left), RSM (right up) and MSM (right, down)

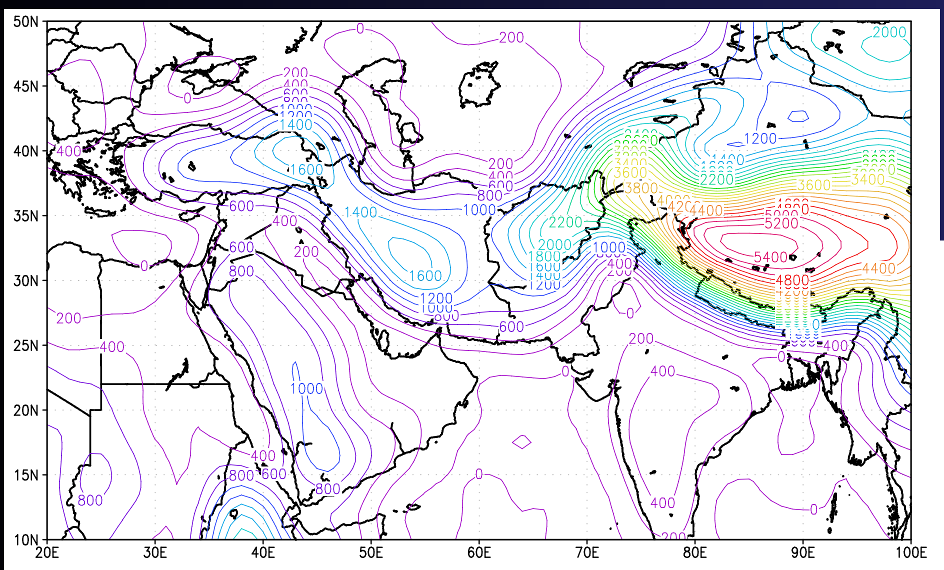
The RSM simulates precipitation over the western Himalayas (though a little reduced) but does not show the area over western Nepal

The evolution of the circulation : a sensitivity test

Question: do the Himalayas and the Tibetan Plateau play a role on the eastward movement of the disturbance (and to what extent)?

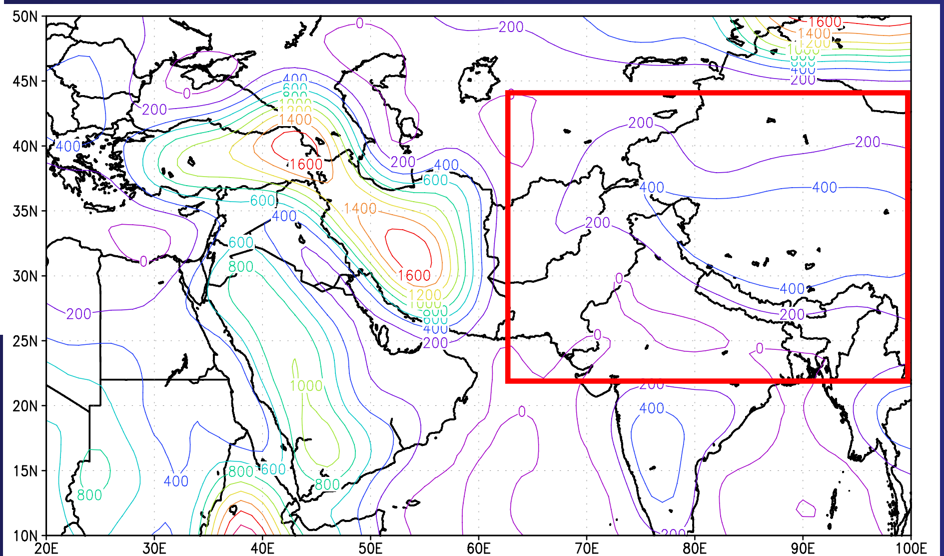
GSM(2°)/RSM(60km) experiments with reduced orography

Simulations started 3 days before precipitation over central Himalayas to follow the dynamics of the trough (i.e., for case 1 (31dec) init=00Z 28dec)

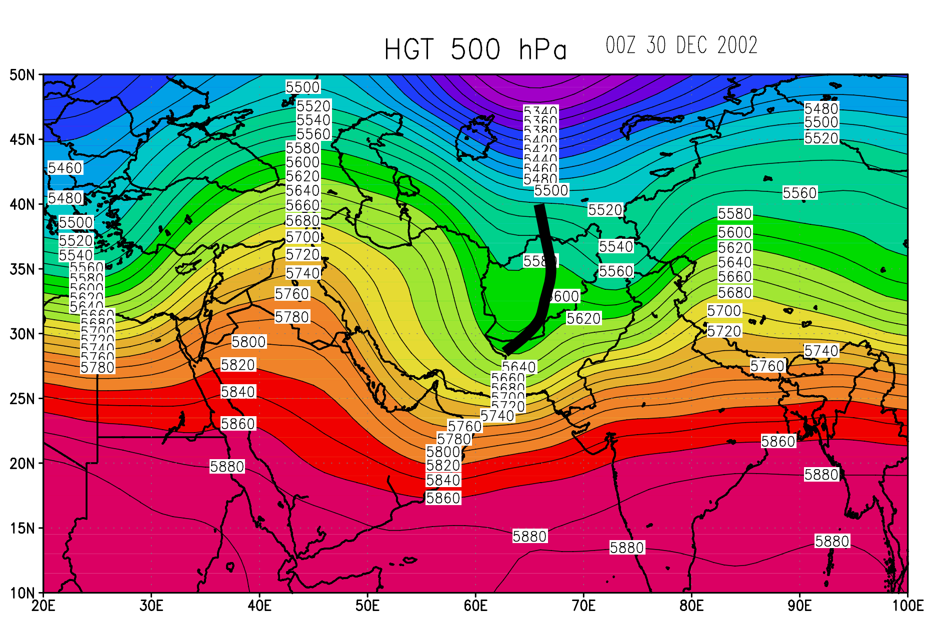


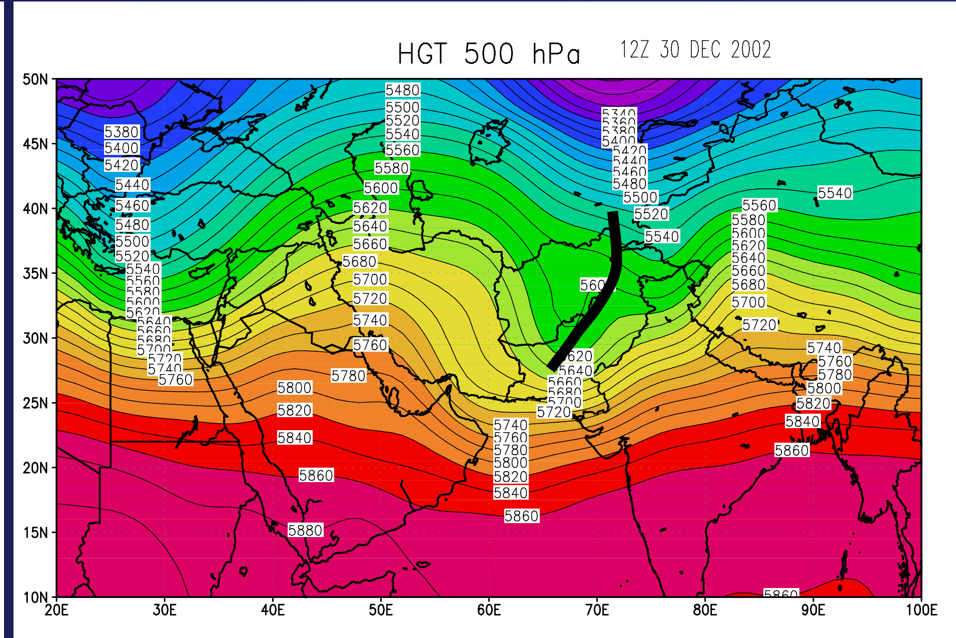
Control

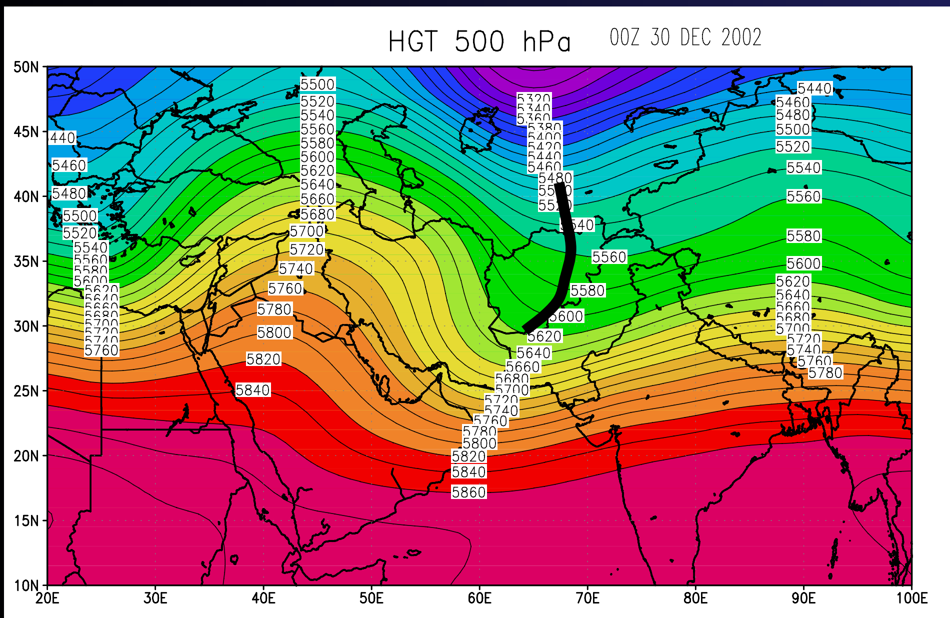
Reduced (10%)

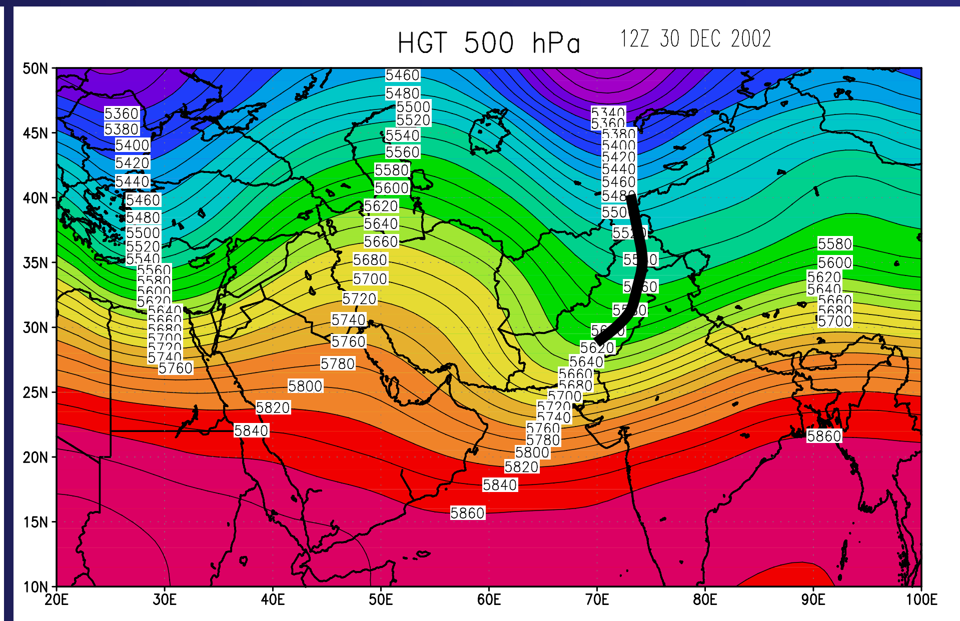


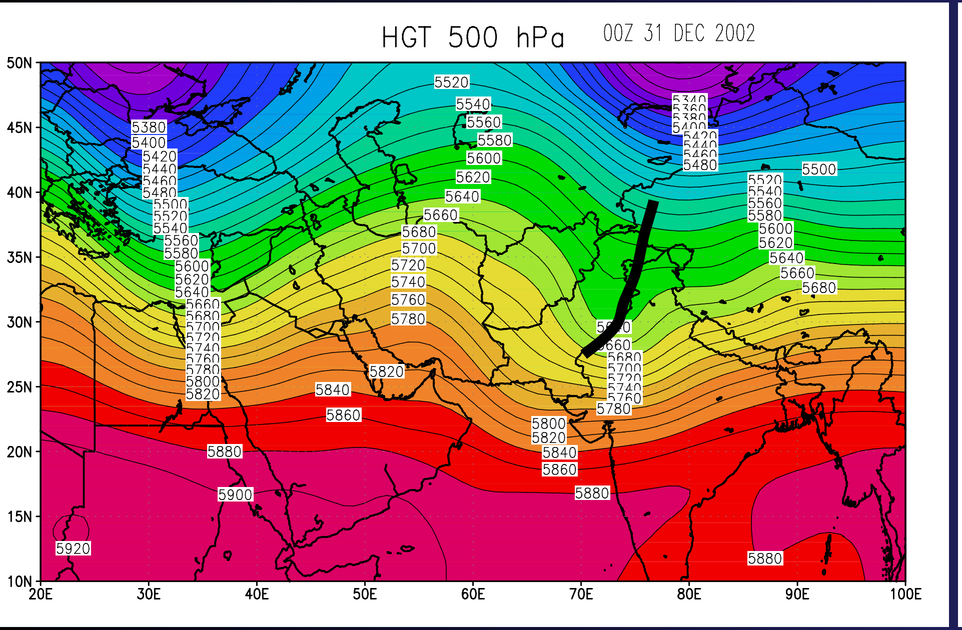
CASE 1

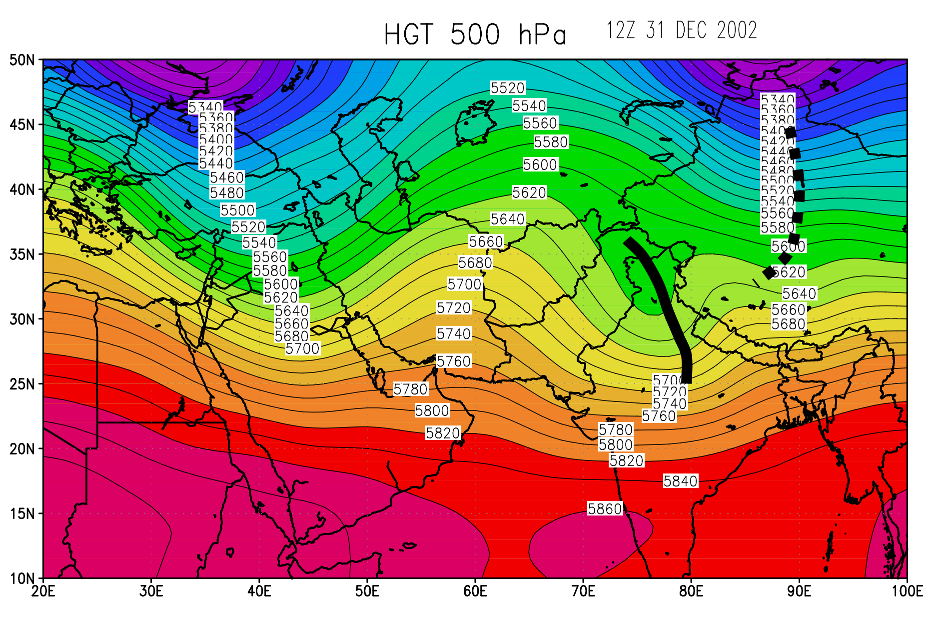

HGT 500 hPa 00Z 30 DEC 2002

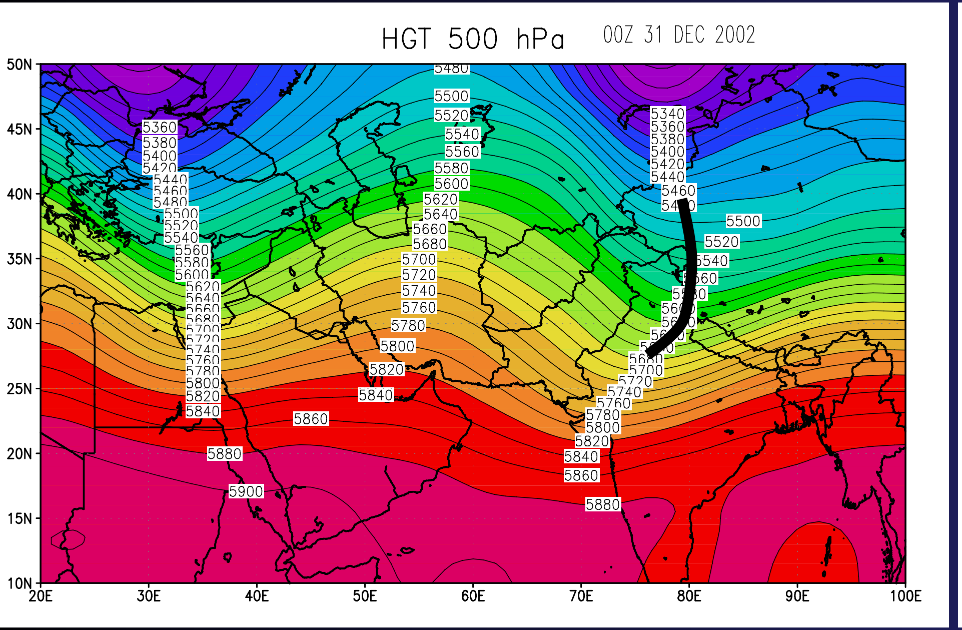

HGT 500 hPa 12Z 30 DEC 2002


HGT 500 hPa 00Z 30 DEC 2002


HGT 500 hPa 12Z 30 DEC 2002


HGT 500 hPa 00Z 31 DEC 2002
50N 45N 40N 35N 30N 25N 20N 15N 10N
20E 30E 40E 50E 60E 70E 80E 90E 100E


HGT 500 hPa 12Z 31 DEC 2002
50N 45N 40N 35N 30N 25N 20N 15N 10N
20E 30E 40E 50E 60E 70E 80E 90E 100E


HGT 500 hPa 00Z 31 DEC 2002
50N 45N 40N 35N 30N 25N 20N 15N 10N
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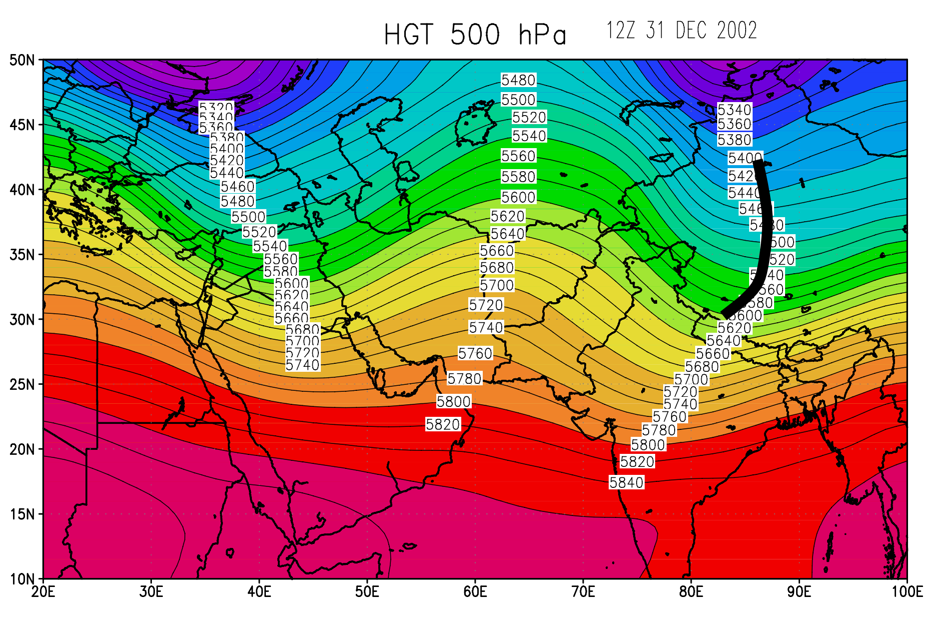
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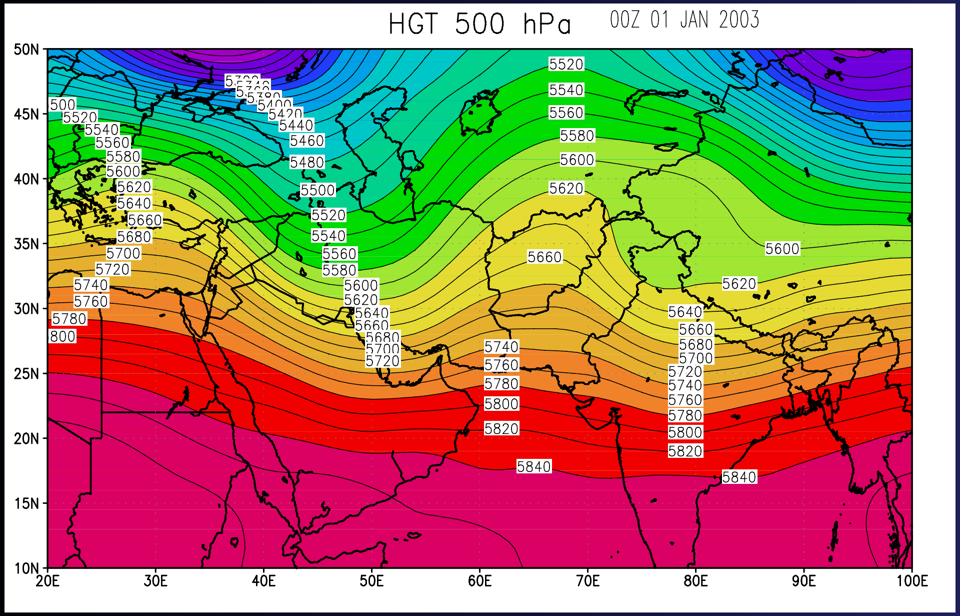

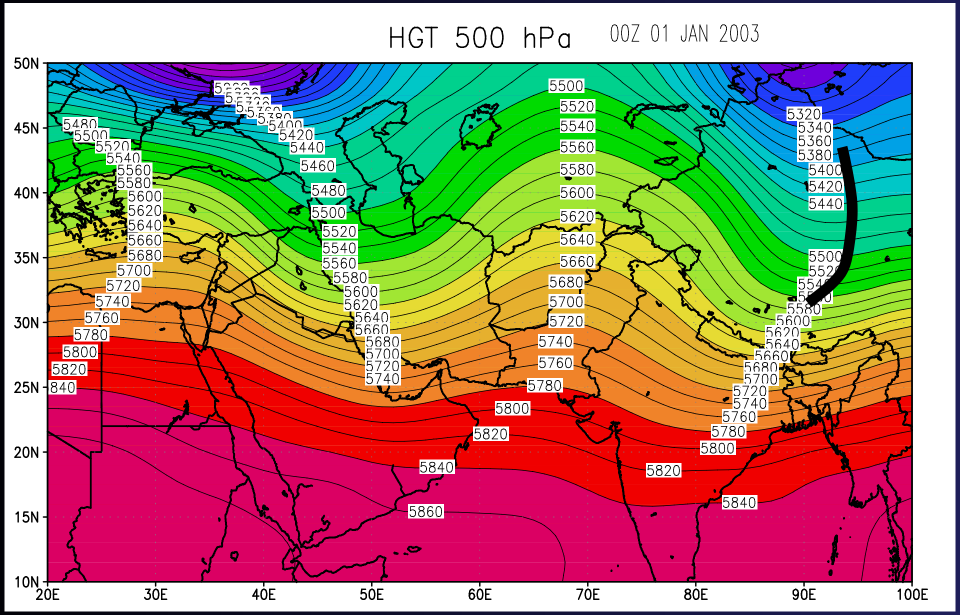

- The trough originates far from the mountains
- It is transported to about 60° E, where it interacts with topography
- The depression is trapped by the western Himalayas, its eastward propagation is reduced, a clear SW flow impinges against the Himalayas

Which is the overall skill of the model?

The performance of the models is globally pretty good

The GCM drives the evolution of the circulation, even onto the small scale

WHERE THE MODEL FAILS

- **Low level flow seems to be blocked and can create (depending on the cases) convergence in front of the mountains depending on the position of the trough**
- **Precipitation over Tibet seems to be reduced**

Conclusions

Using different instruments and sources of data it was possible to get insights in the origin, evolution and nature of the snow storms

The detailed characteristics of the impact of the flow with the Himalayas are fundamental for precipitation distribution, both in observations and model simulations

The first downscaling modelling effort shows interesting features: the dynamics is strongly influenced by the exact evolution / reprodution of the trough