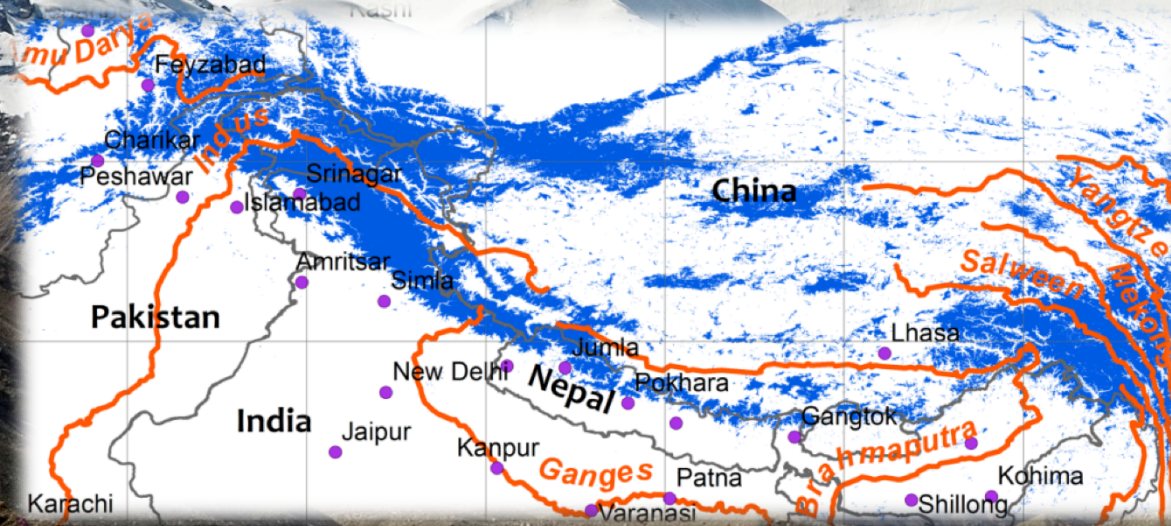


Impact of dust storms and anthropogenic emissions on the Indo-Gangetic Basin and melting of Himalayan Glaciers

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Menas Kafatos^{1,2} & Ashok Jaswal³



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¹School of Earth and Environmental Sciences, Schmid College of Science, Chapman University, Orange, CA 92866, USA

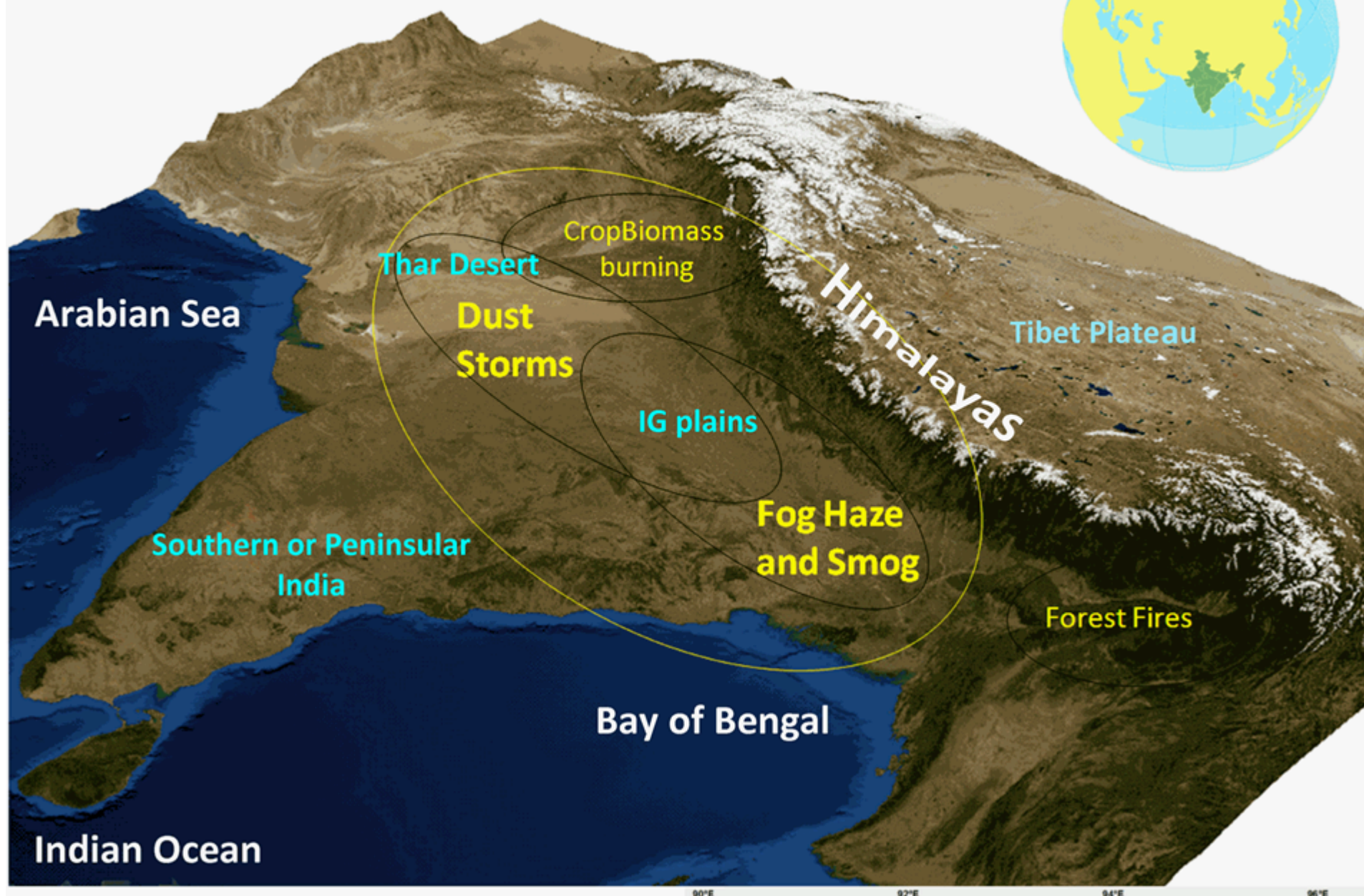
²Center of Excellence in Earth Observing, Chapman University, Orange, CA 92866, USA

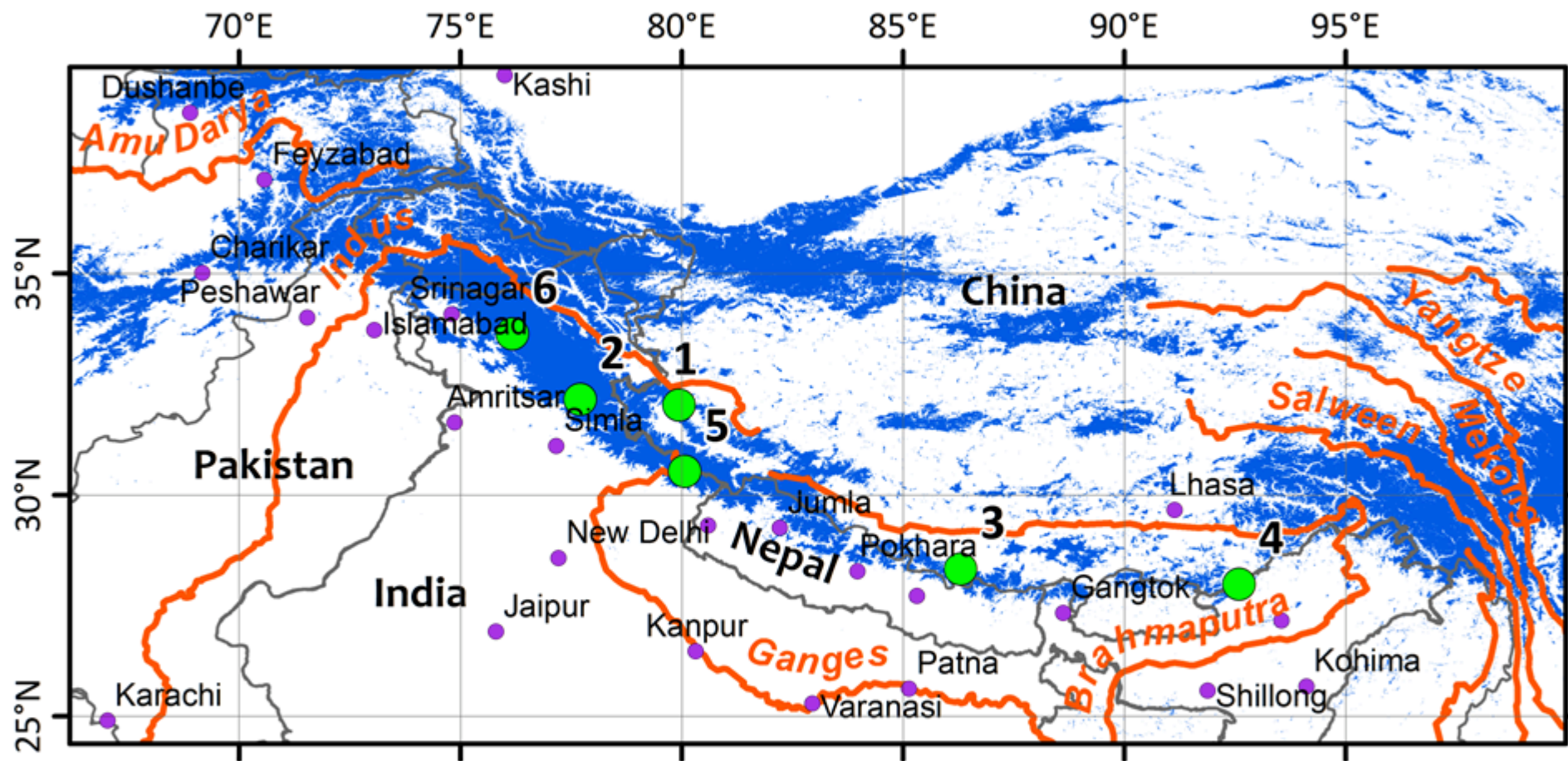
³India Meteorological Department, Pune, Maharashtra 411005, India

Outline

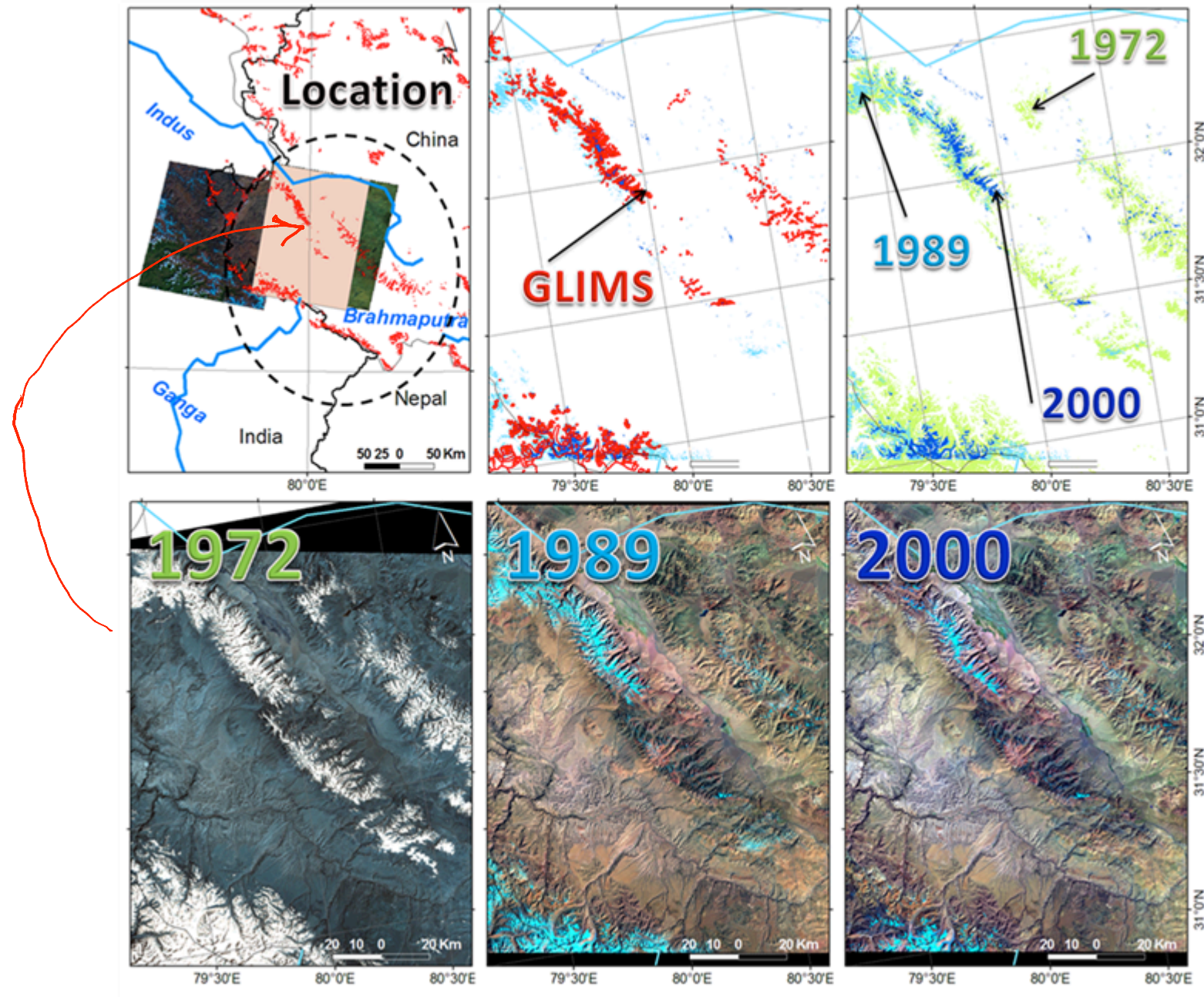
- 3D perspective of the study region
- Himalayan Snow and Glacier Cover (Change)
 - Landsat, ASTER, MODIS
- Evidences of transport of mixed aerosols (dust + anthropogenic emissions) over Himalaya (~5-6 km)
 - MODIS Terra, Aqua (column AOD and surface reflectance)
 - CALIPSO vertical profiles
- MSU tropospheric temperatures (TLT, TMT)
 - Himalaya
 - Indo-Gangetic plains
 - Other major deserts

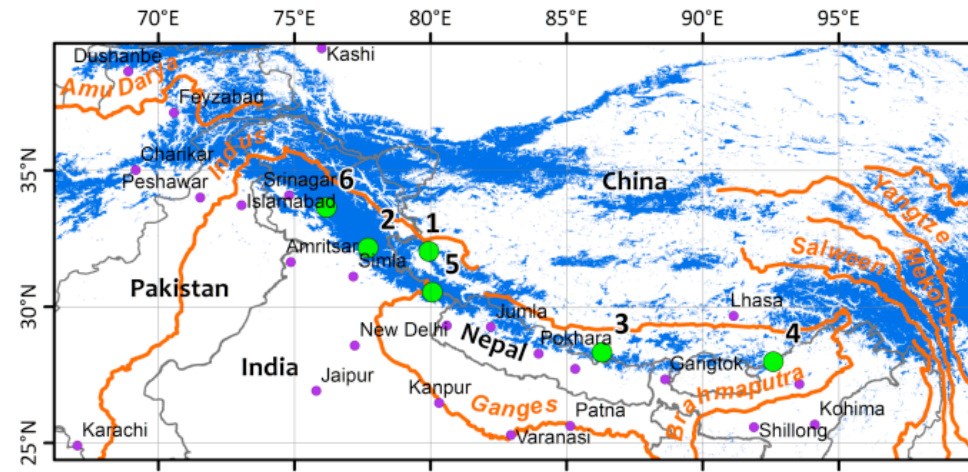
Indian sub-continent



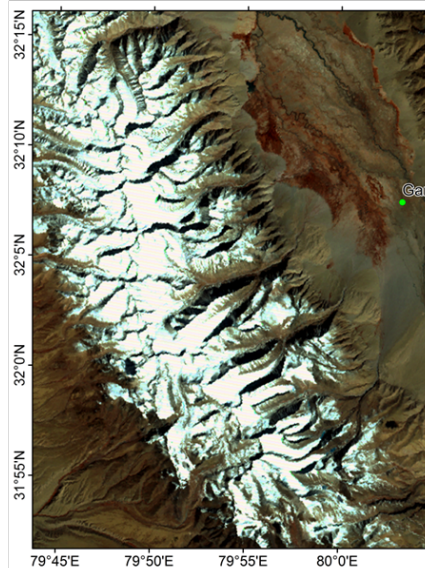


Major Rivers and Glacier-snow Extent

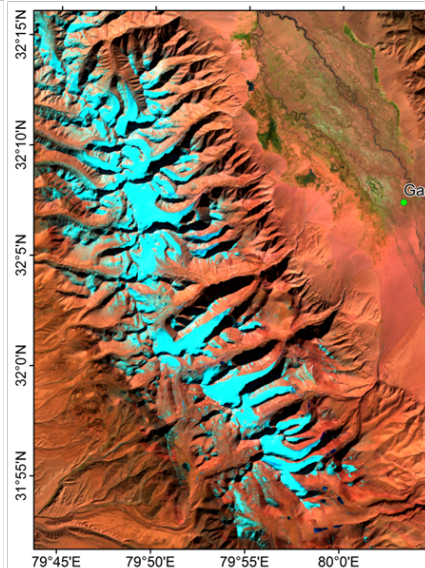




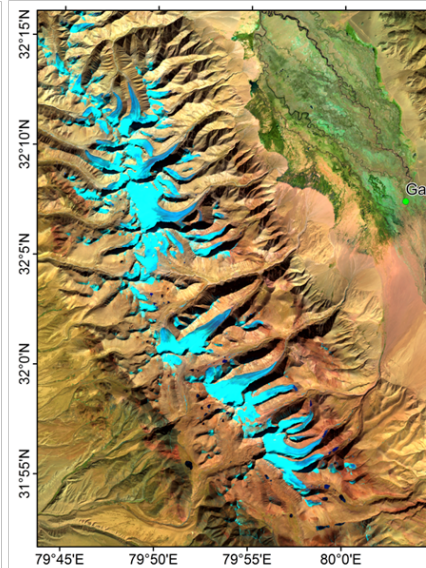
26 Oct. **1972**



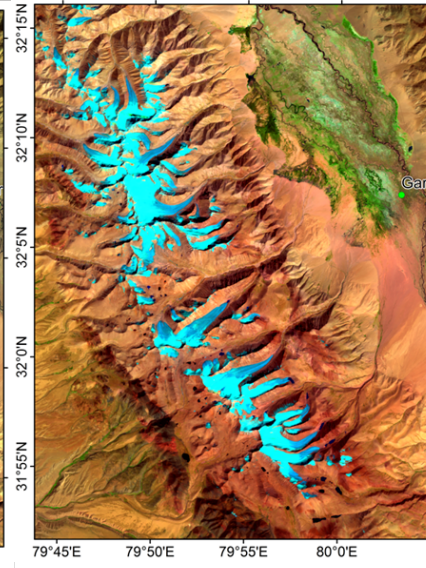
12 Nov. **1989**



2 Nov. **2000**



2 Oct. **2006**

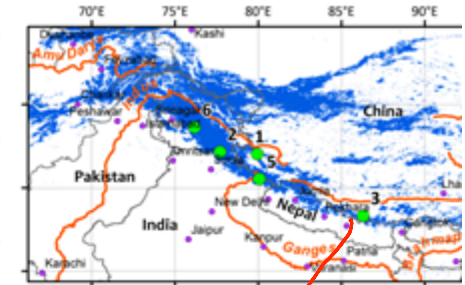
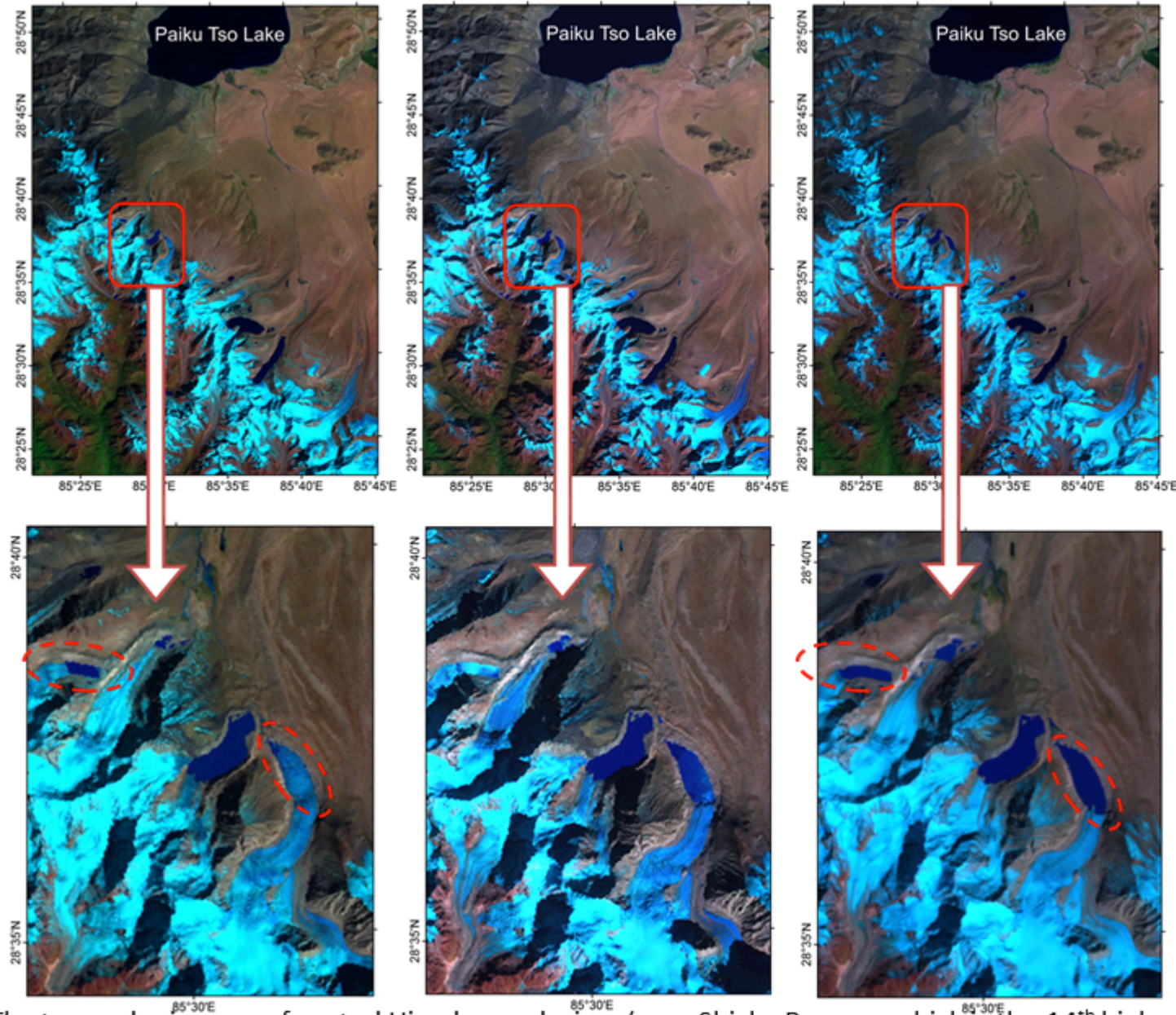


The true color images of Himalayan snow cover and glaciers, near the source of origin of three major rivers of Asia (Indus, Ganga and Brahmaputra), from the Landsat series (1972, 1989, 2000, 2006) and ASTER (2000, 2008). (*Location 1*).

12 Oct. **1988**

22 Nov. **2000**

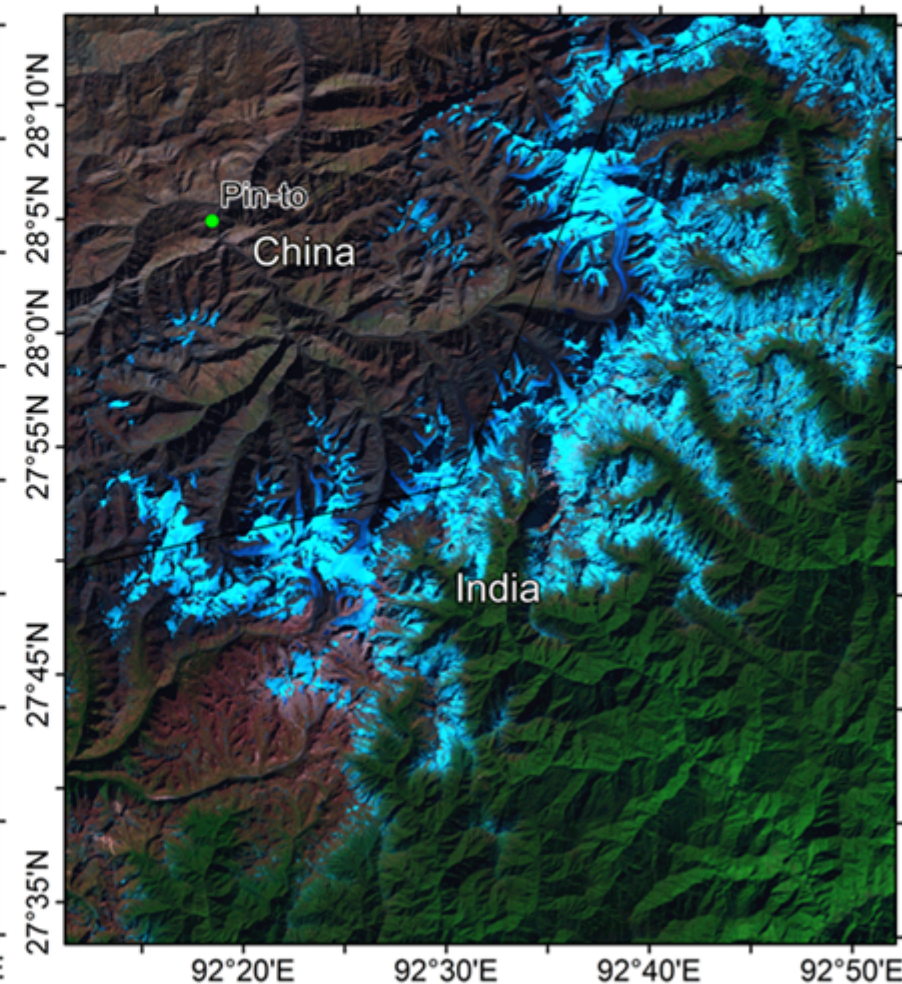
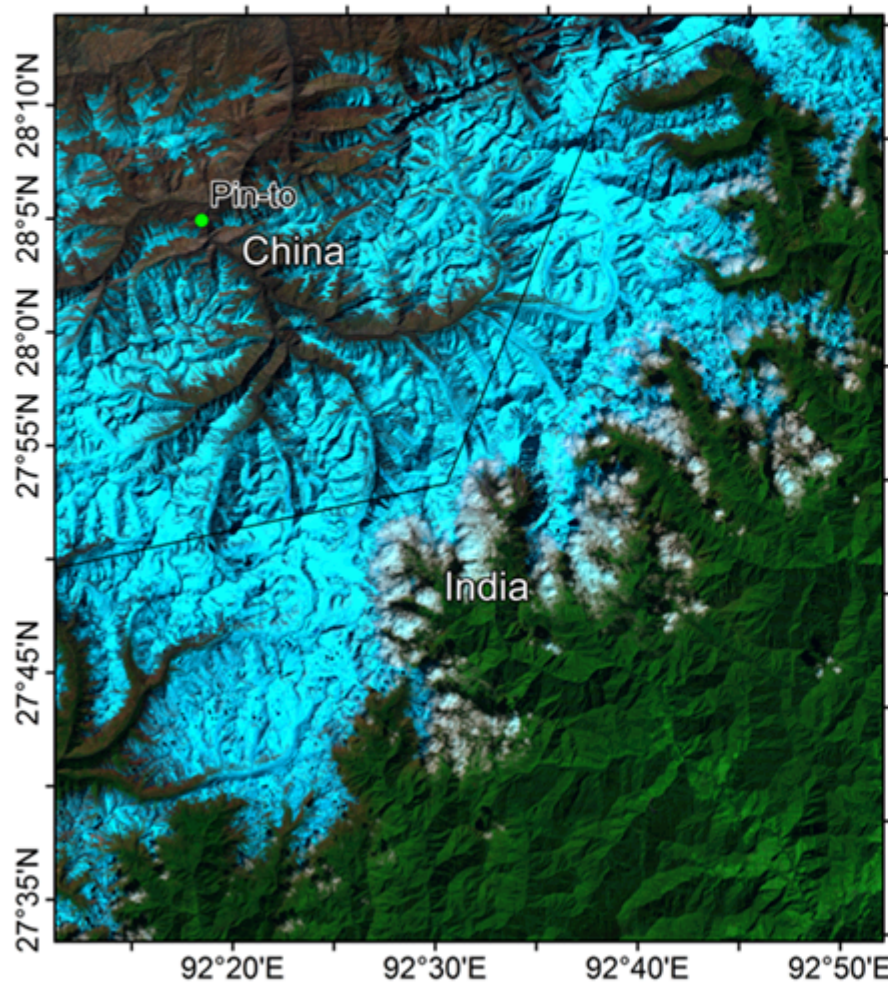
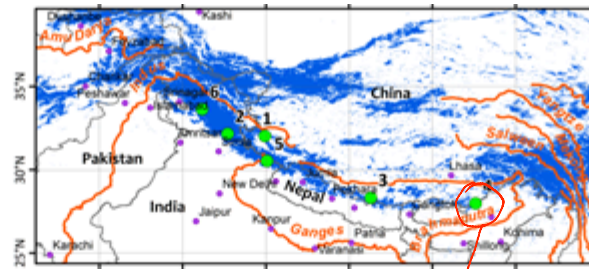
6 Oct. **2006**



The true color images of central Himalayan glaciers (near Shisha Pangma which is the 14th highest mountain in the world – 8013m) from the Landsat series (1988, 2000, 2006) show the melting and formation of new lakes in the region during 2000 and 2006 compared with 1988. (*Location 3*)

25 Oct. **1988**

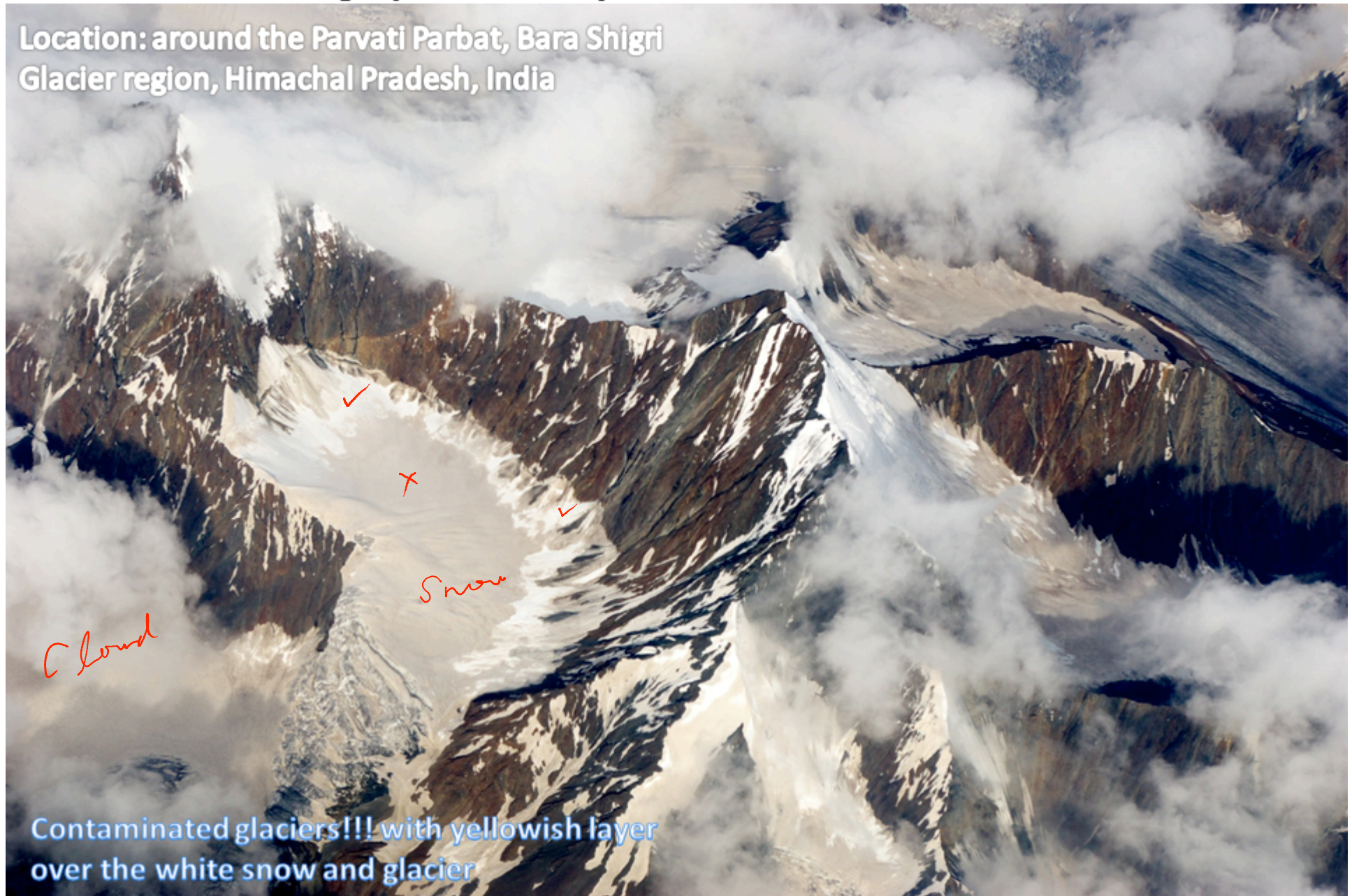
24 Dec. **2001**



The Landsat images during year 1988 and 2001 show a sharp decline in the snow cover and enhanced melting of glaciers in the eastern Himalayas near the state of Arunachal Pradesh (India) and Tibet (China) border. (*Location 4*)

Photographs: Himalayan Snow cover and Glaciers

Location: around the Parvati Parbat, Bara Shigri
Glacier region, Himachal Pradesh, India



Date: 28 Aug. 2010

Courtesy: A. Naumov

Photographs: Himalayan Snow cover and Glaciers

**Location: around the Parvati Parbat, Bara Shigri
Glacier region, Himachal Pradesh, India**

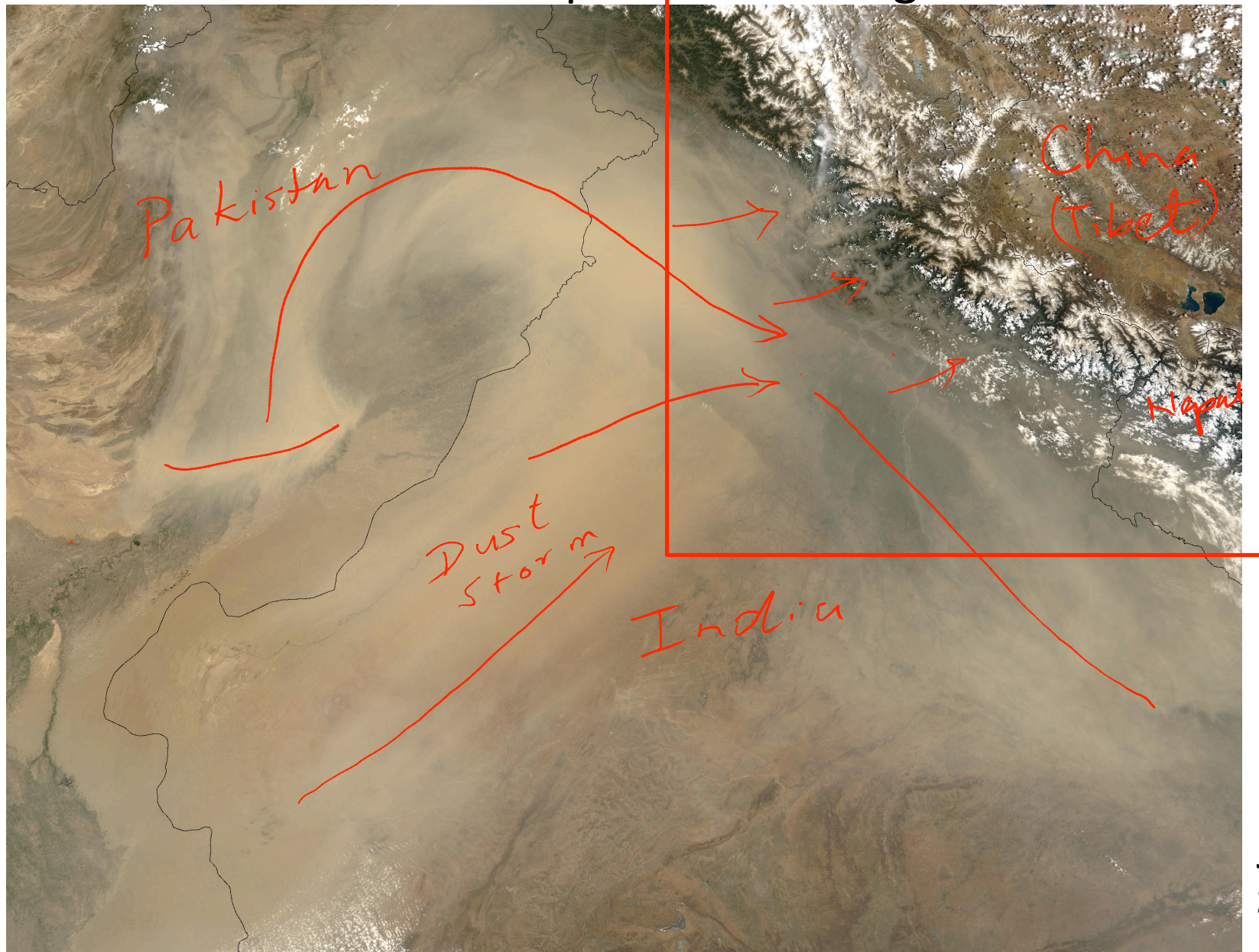


**Contaminated glaciers!!! with yellowish layer
over the white snow and glacier**

Date: 28 Aug. 2010

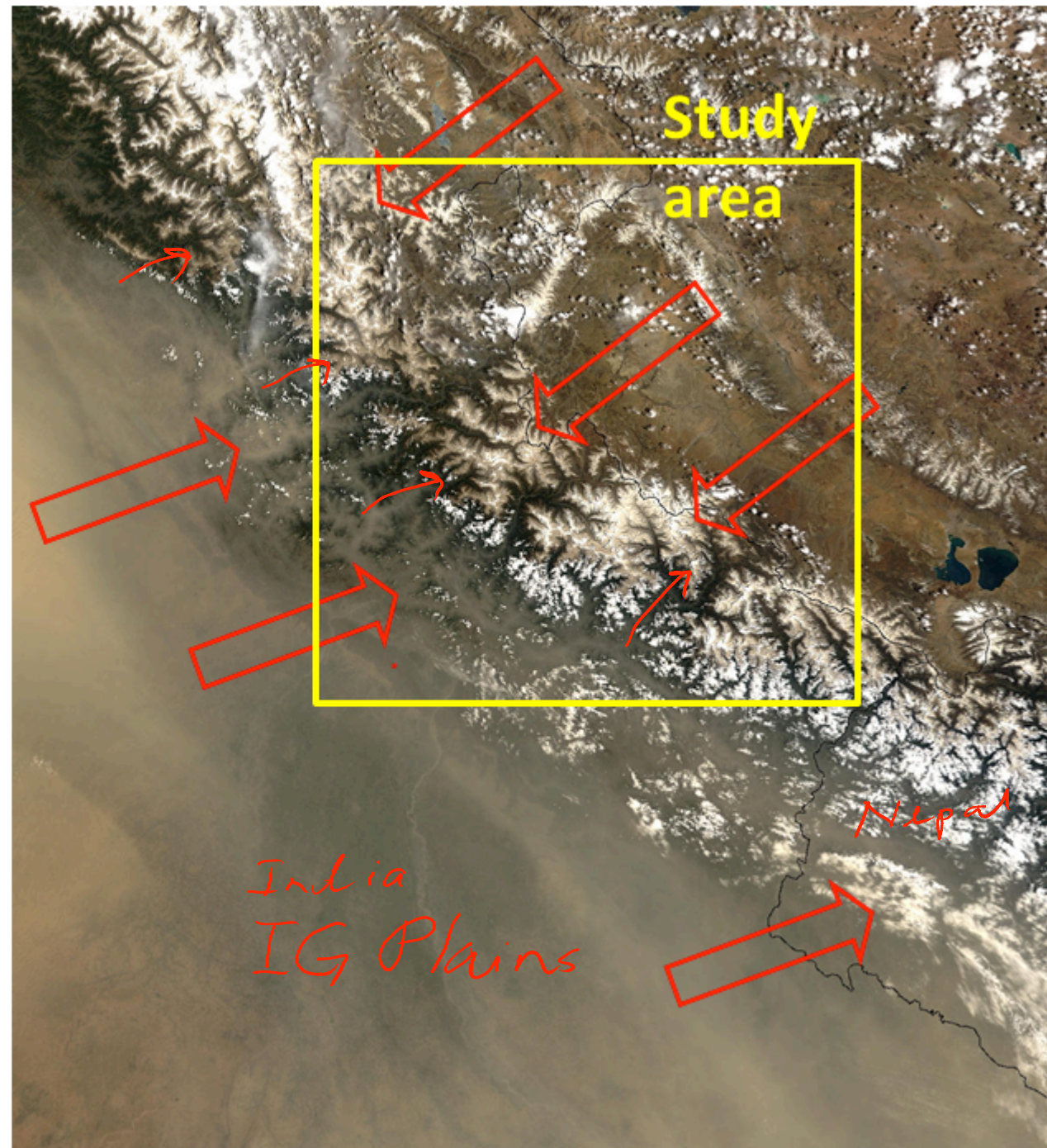
Courtesy: A. Naumov

Dust storms reach upto snow and glacier of Himalayas



June,
2003

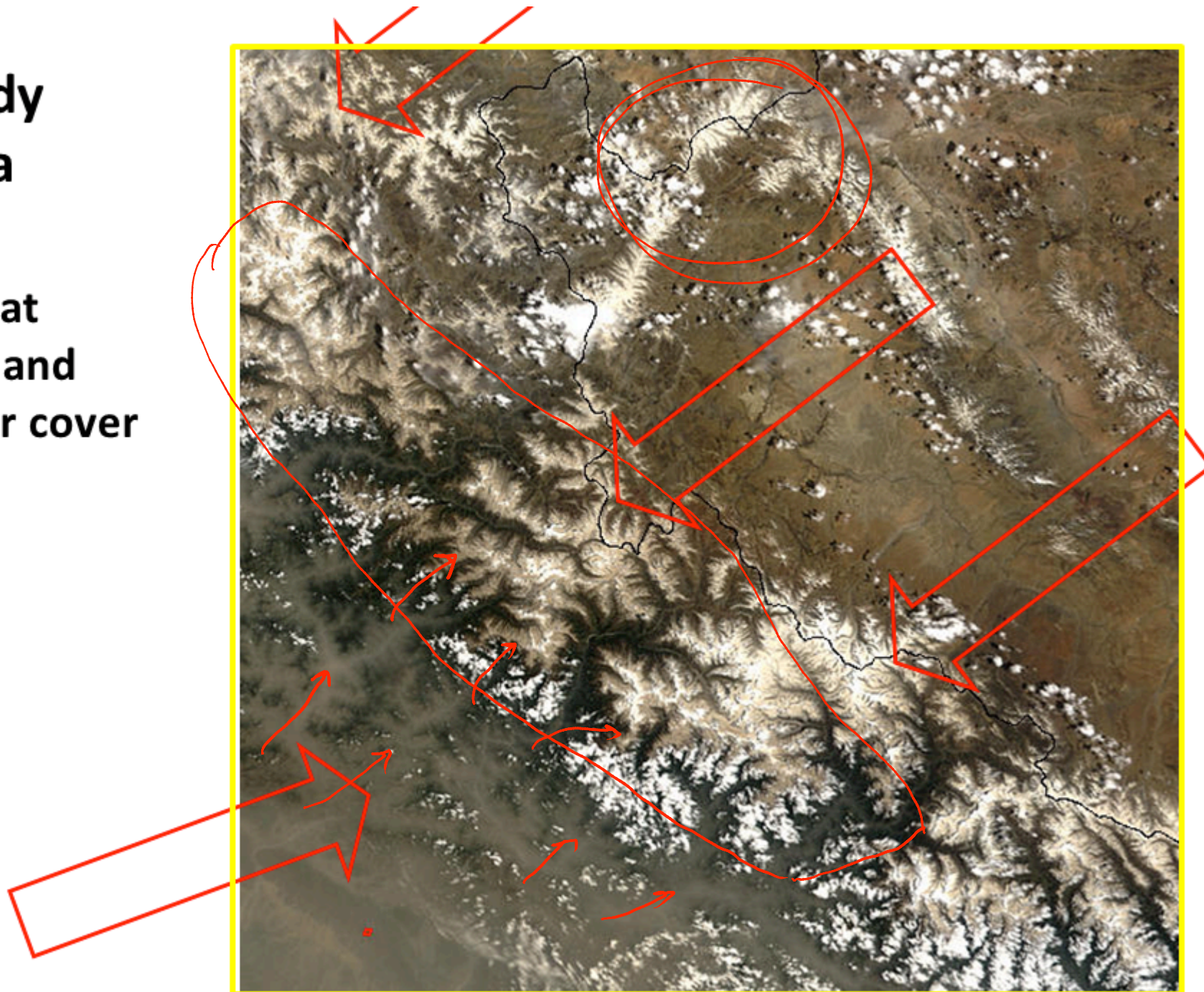
- Yellowish cover over “white” snow and glaciers
- Deposition of dust on snow

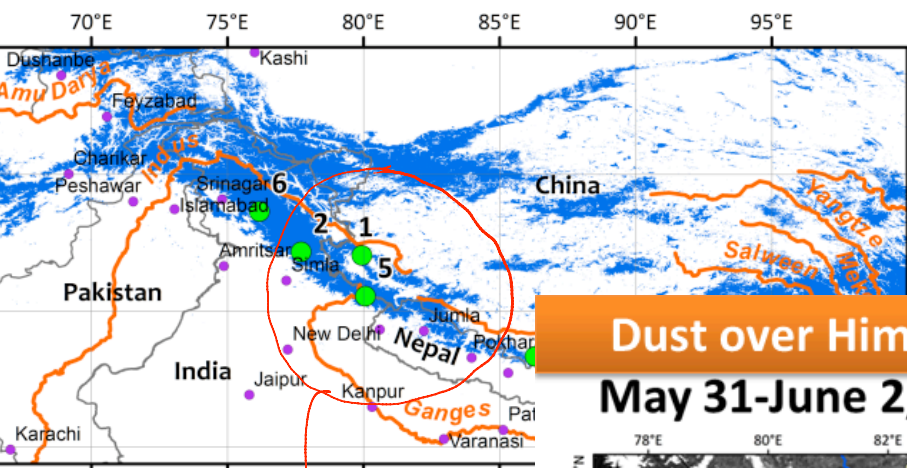


**Study
area**

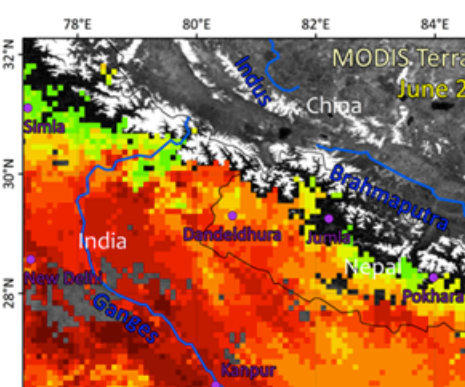
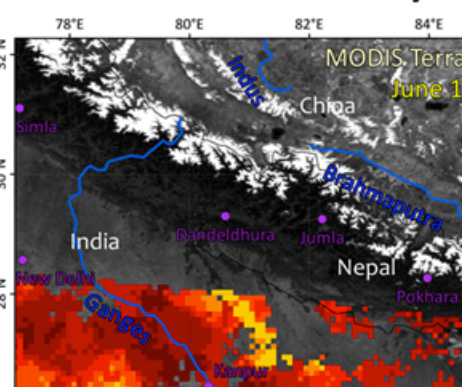
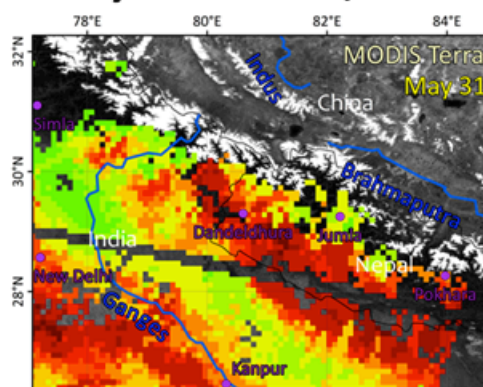
**Landsat
snow and
glacier cover**

**1972
1990
2000**

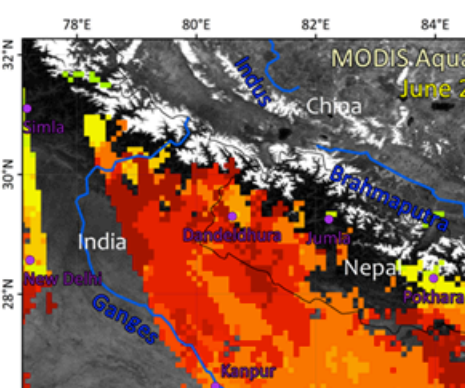
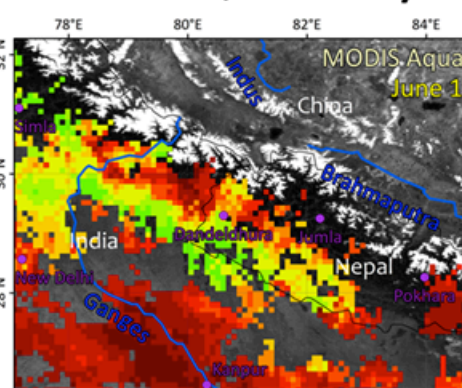
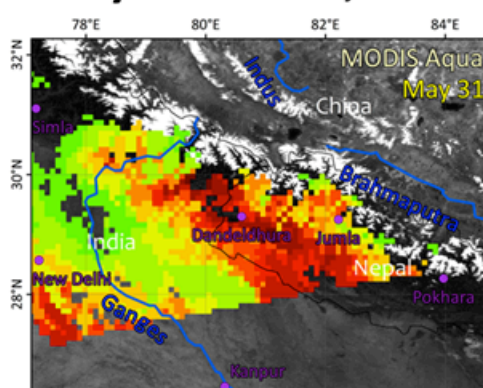




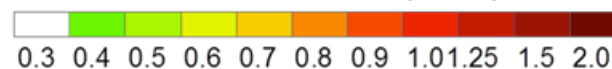
Dust over Himalayan Glaciers (Indus, Ganga, Brahmaputra Rivers) May 31-June 2, 2003 (MODIS TERRA AOD)



May 31-June 2, 2003 (MODIS AQUA AOD)

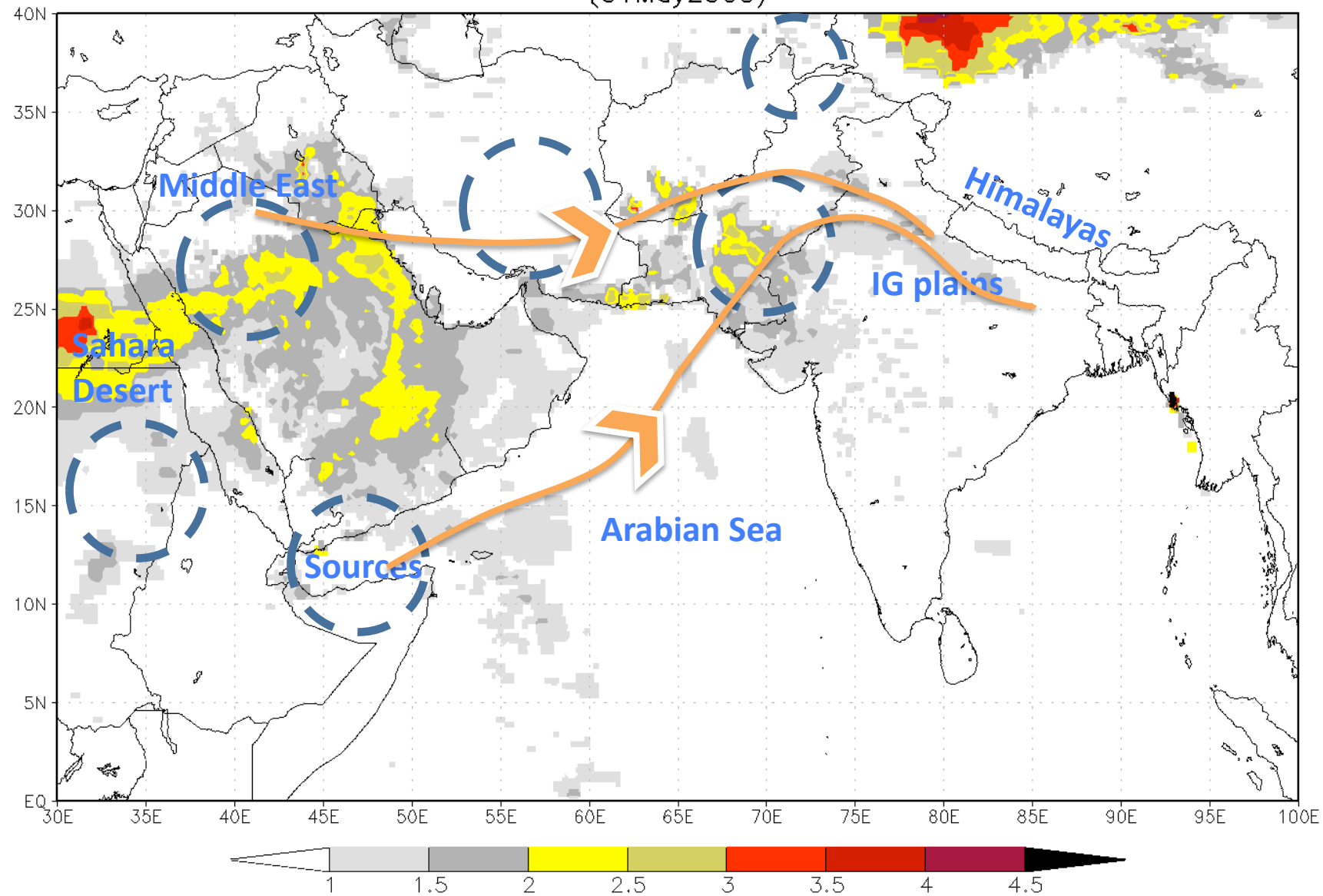


MODIS L2 AOD (max.)

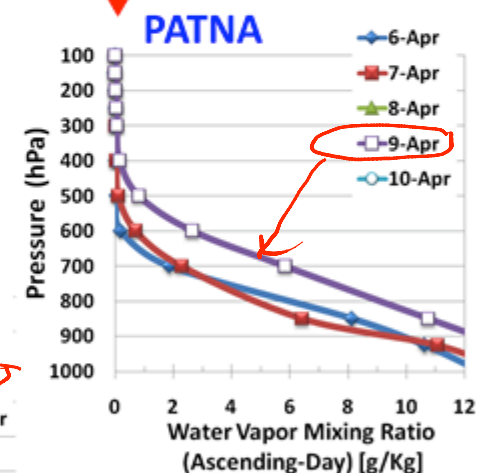
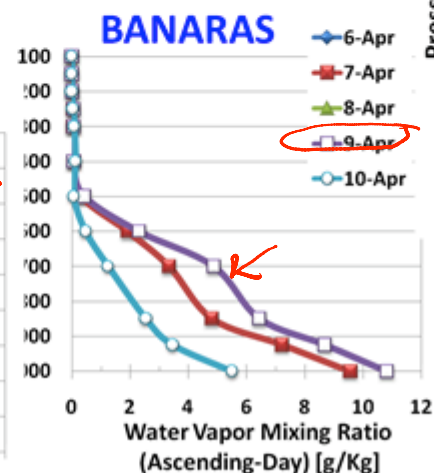
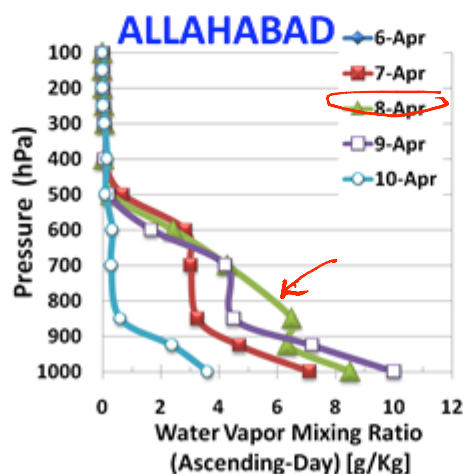
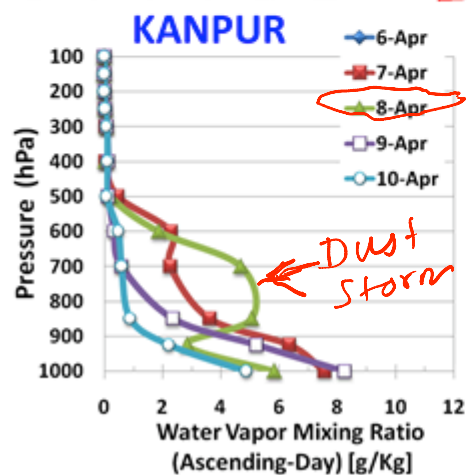
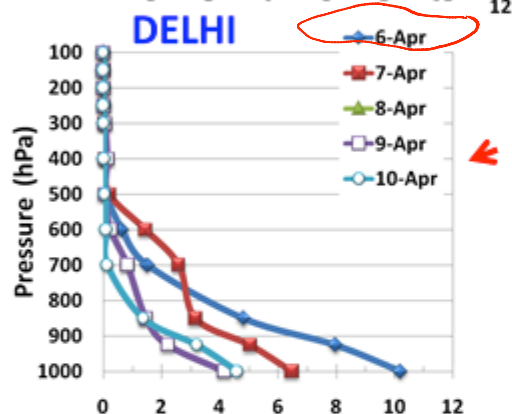
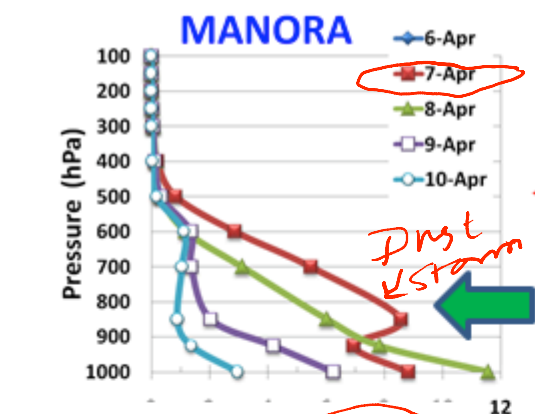


Dust storms (Mav 7-8-9. 2005)

OMT03E.002 UV Aerosol Index [unitless]
(01May2005)



Dust storm and AIRS – Water Vapor Mixing Ratio (g/Kg)



Ascending -
Day

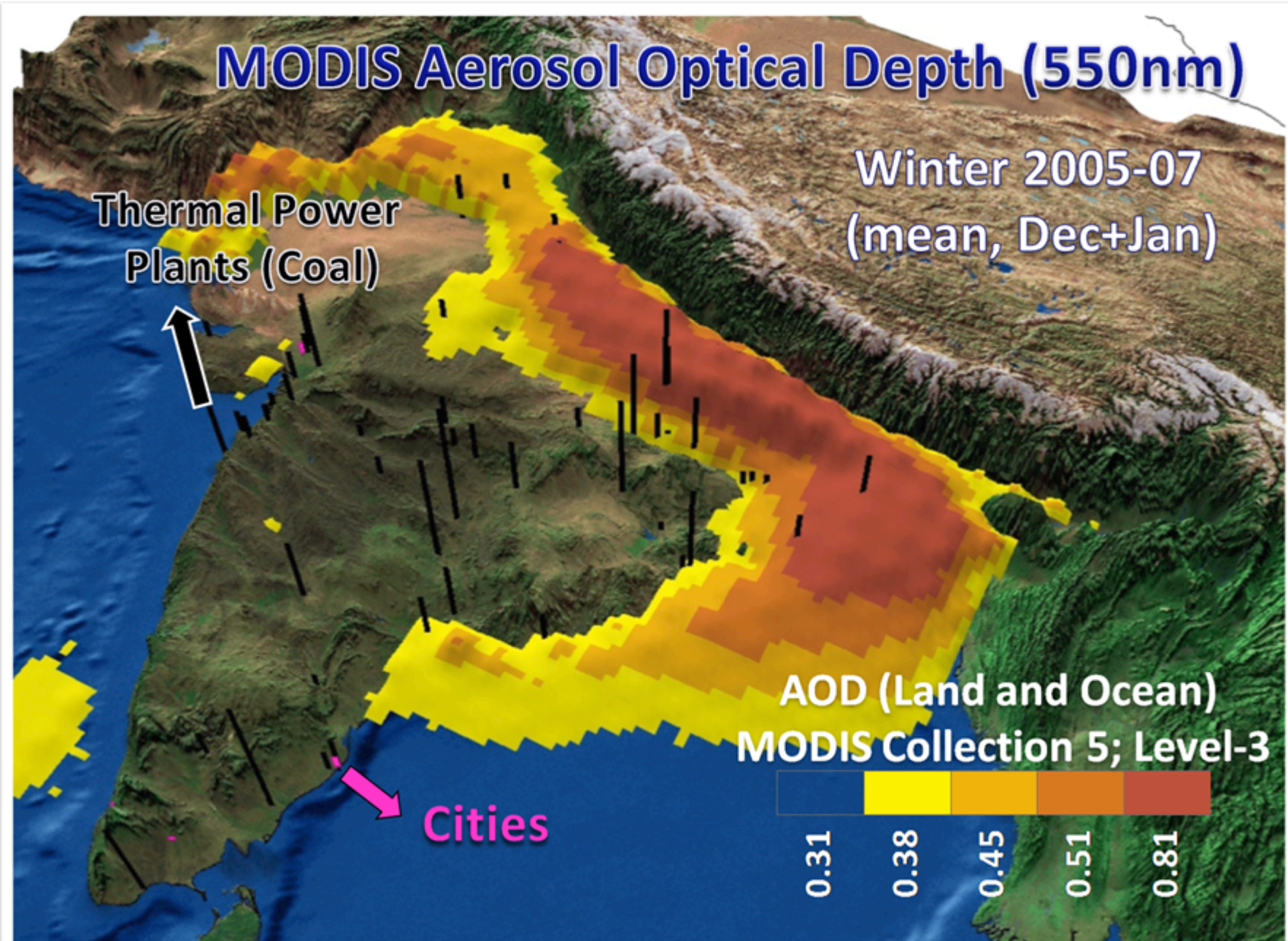
MODIS Aerosol Optical Depth (550nm)

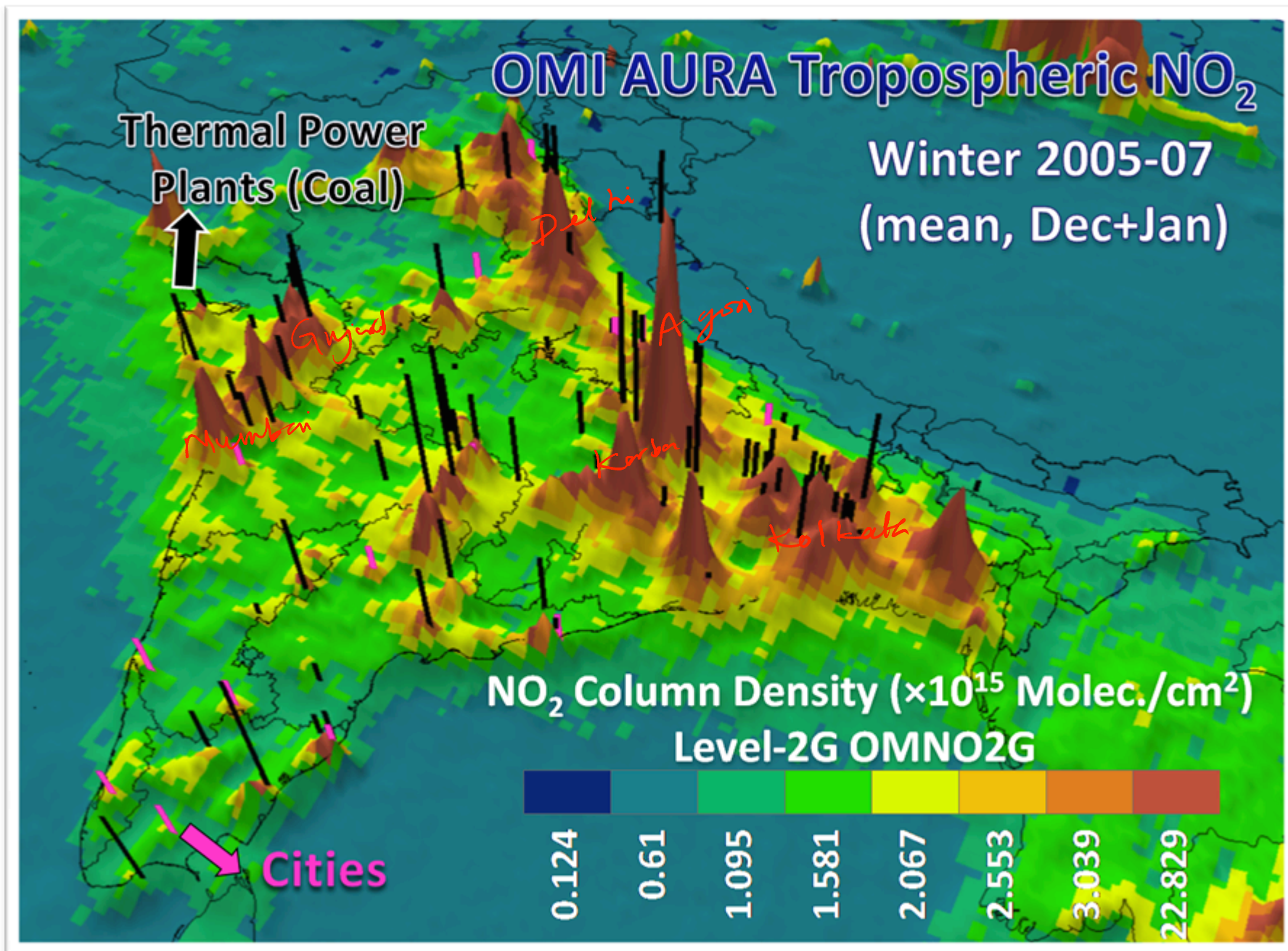
Winter 2005-07
(mean, Dec+Jan)

Thermal Power
Plants (Coal)

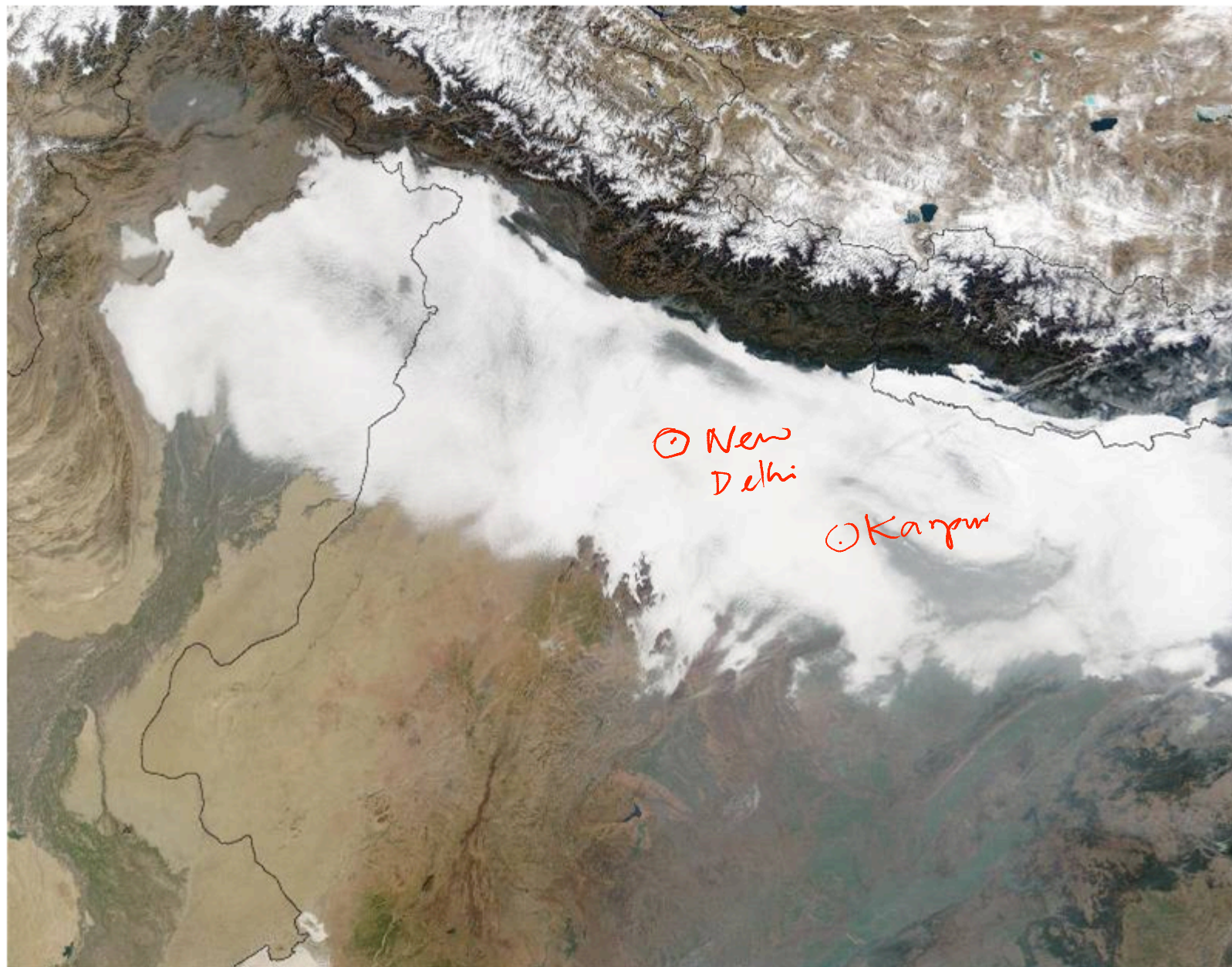
AOD (Land and Ocean)
MODIS Collection 5; Level-3

Cities

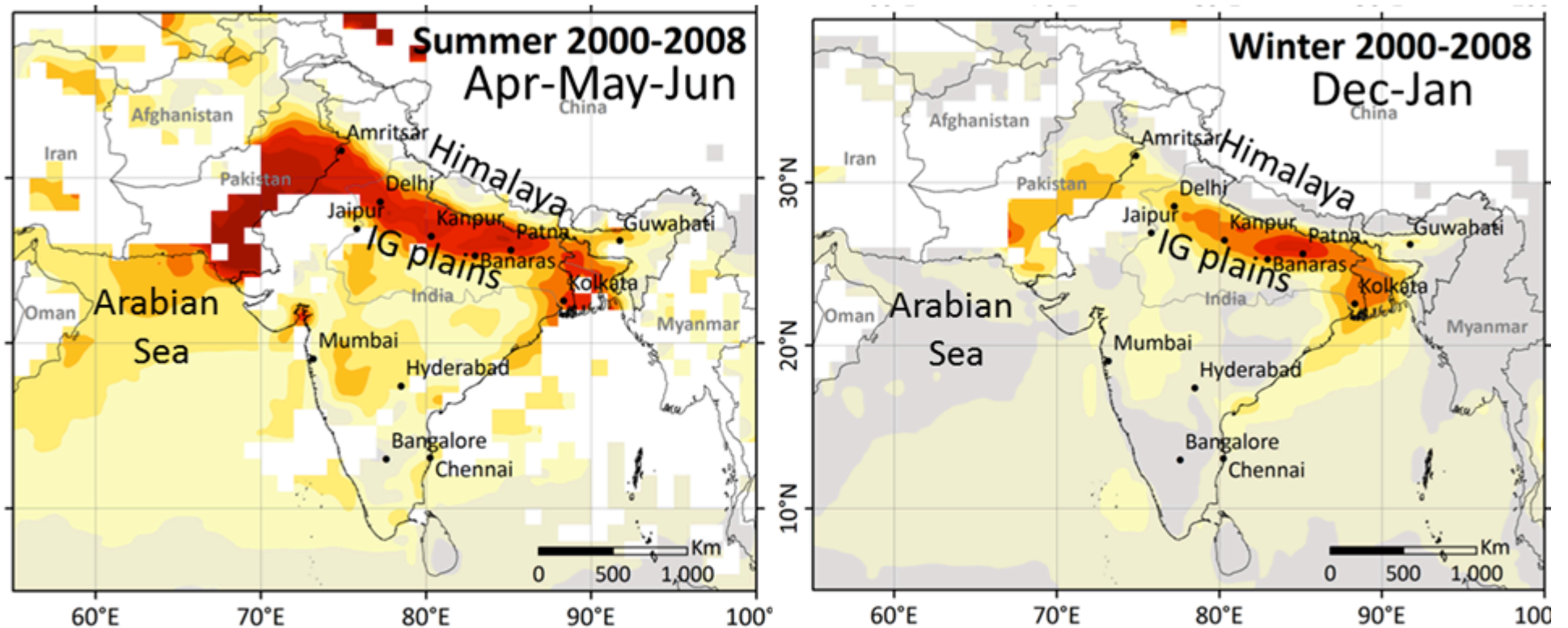


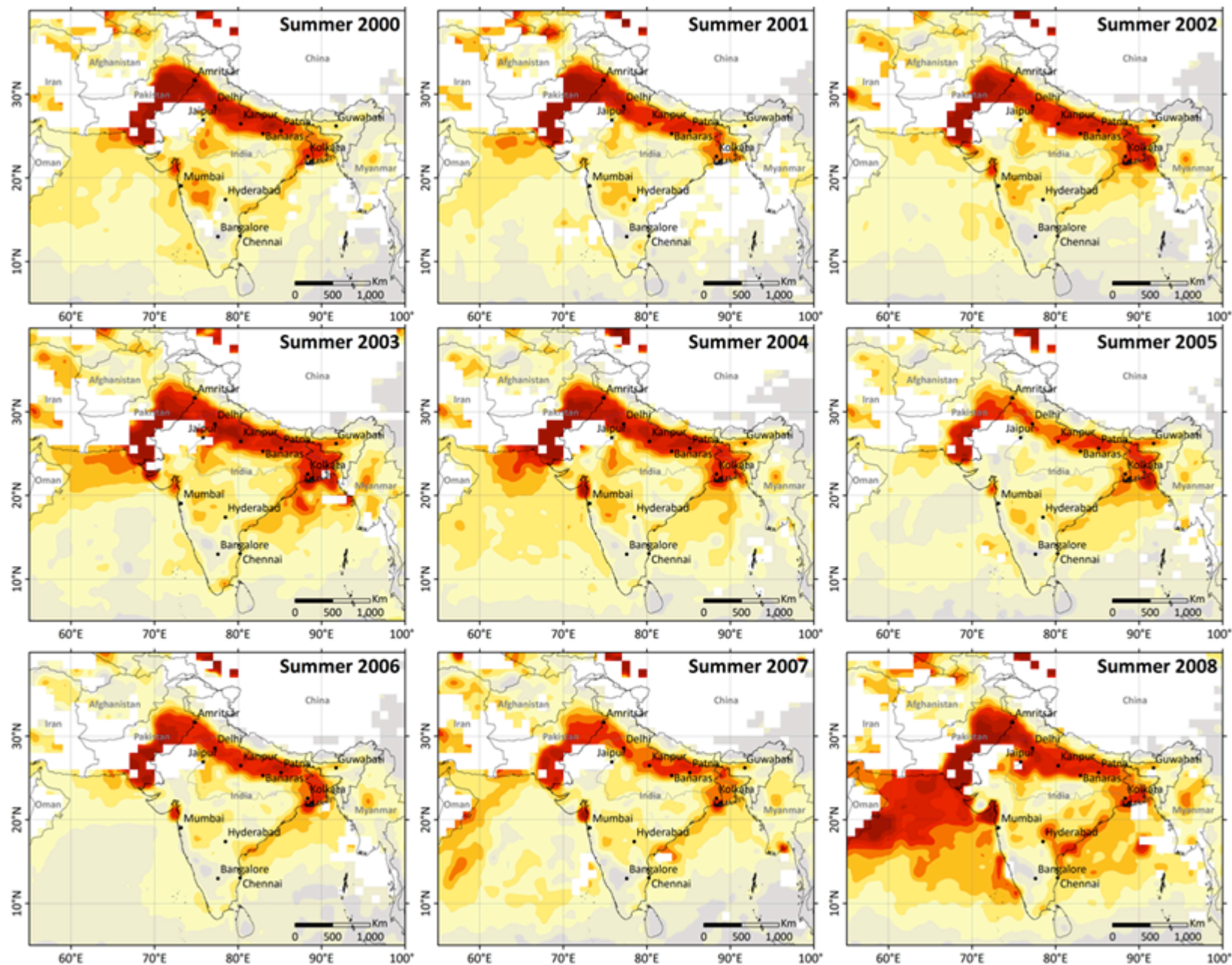


January 7, 2003 at 11 :25 local time, MODIS Terra

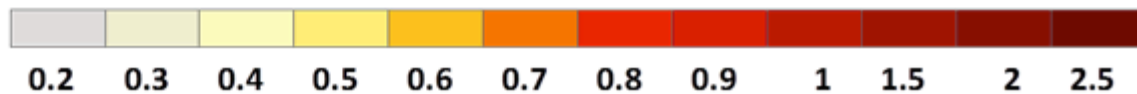


MODIS Aerosol Optical Depth (550nm)





AOD (unit less)

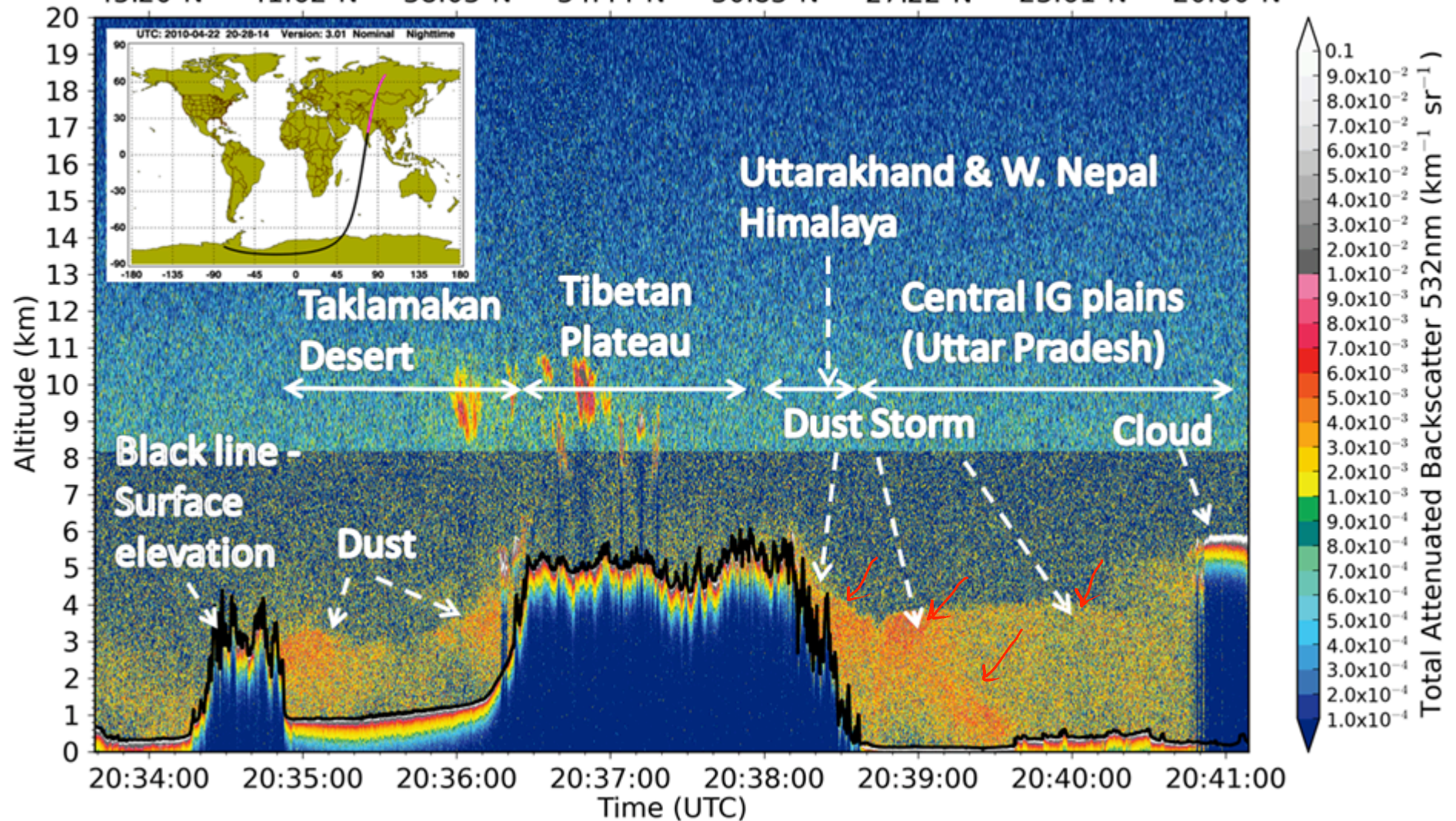


April 22, 2010 (CALIPSO vertical profile)

2:04 to 2:11 am
IST (local time)

CALIPSO Profile 2010-04-22T20:33:39Z/2010-04-22T20:41:09Z

86.32°E 85.09°E 83.96°E 82.92°E 81.94°E 81.01°E 80.13°E 79.27°E
45.20°N 41.62°N 38.03°N 34.44°N 30.83°N 27.22°N 23.61°N 20.00°N

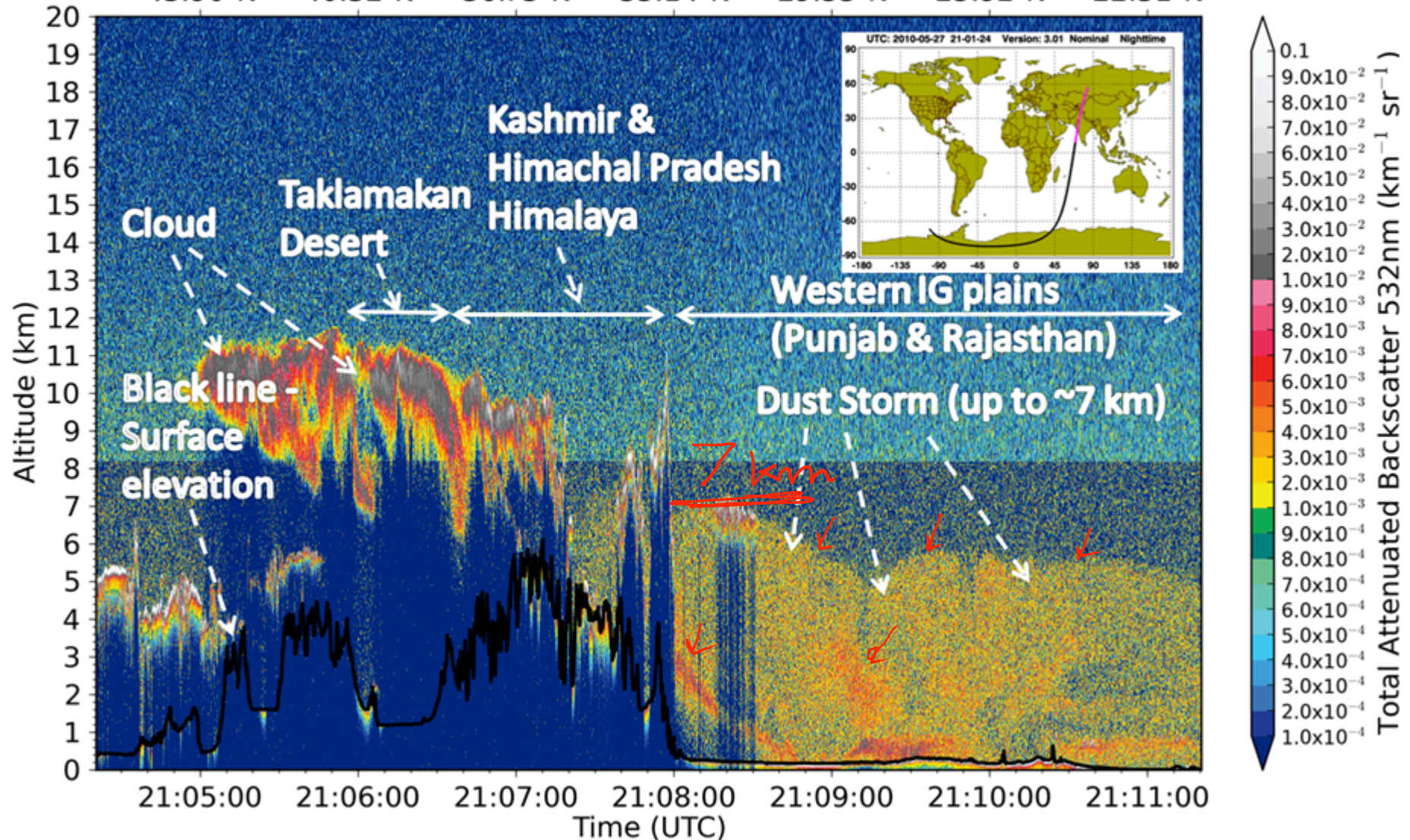


May 27, 2010 (CALIPSO vertical profile)

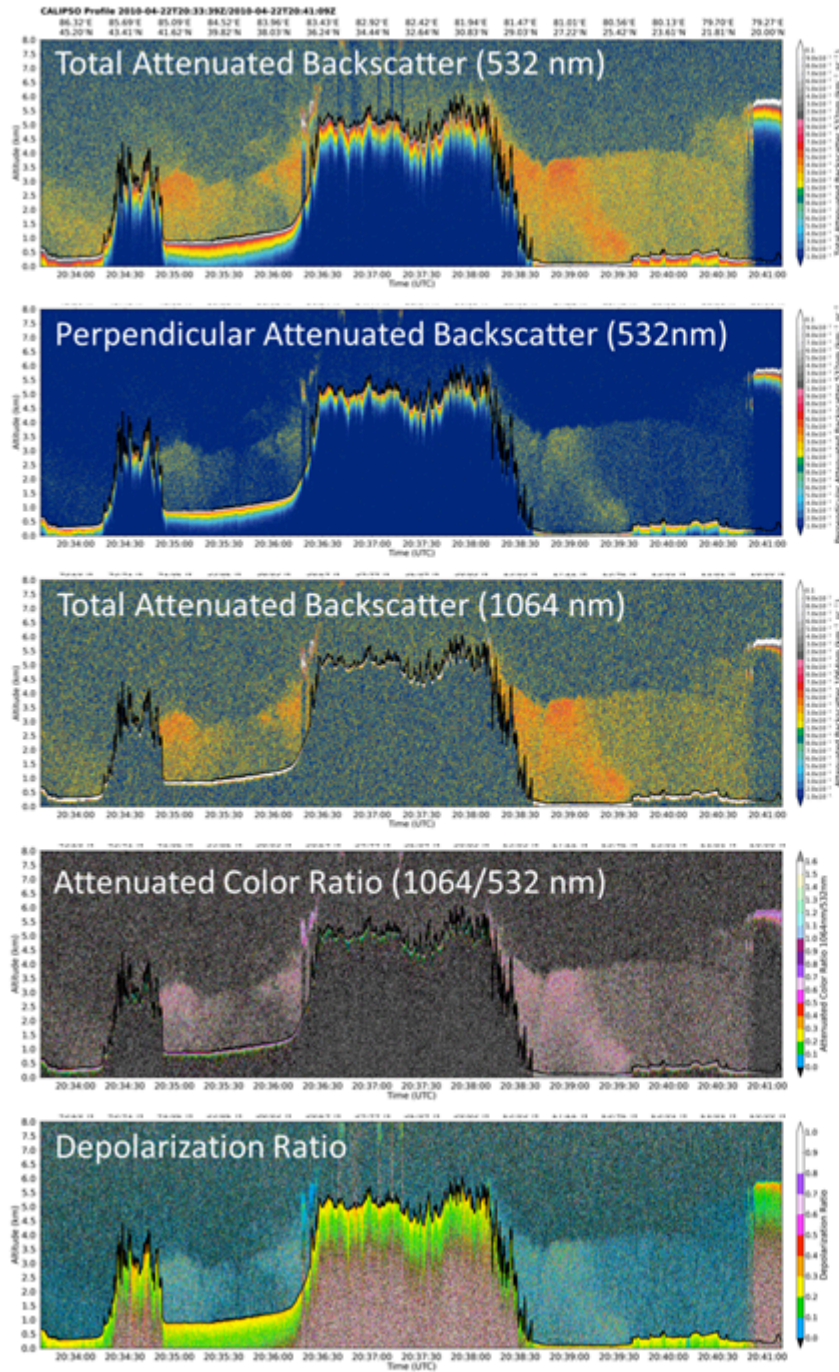
2:35 to 2:41 am
IST (local time)

CALIPSO Profile 2010-05-27T21:04:20Z/2010-05-27T21:11:20Z

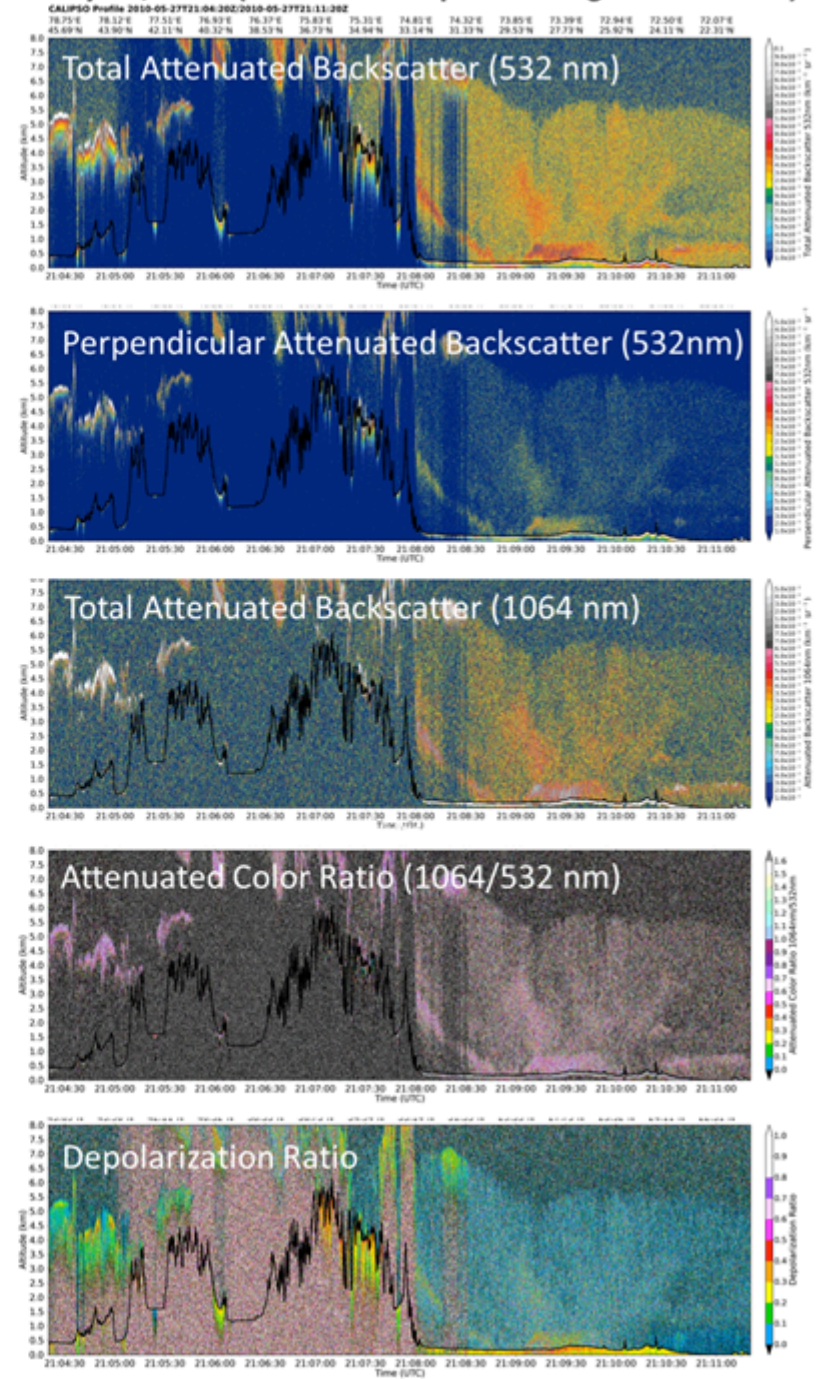
78.12°E	76.93°E	75.83°E	74.81°E	73.85°E	72.94°E	72.07°E
43.90°N	40.32°N	36.73°N	33.14°N	29.53°N	25.92°N	22.31°N



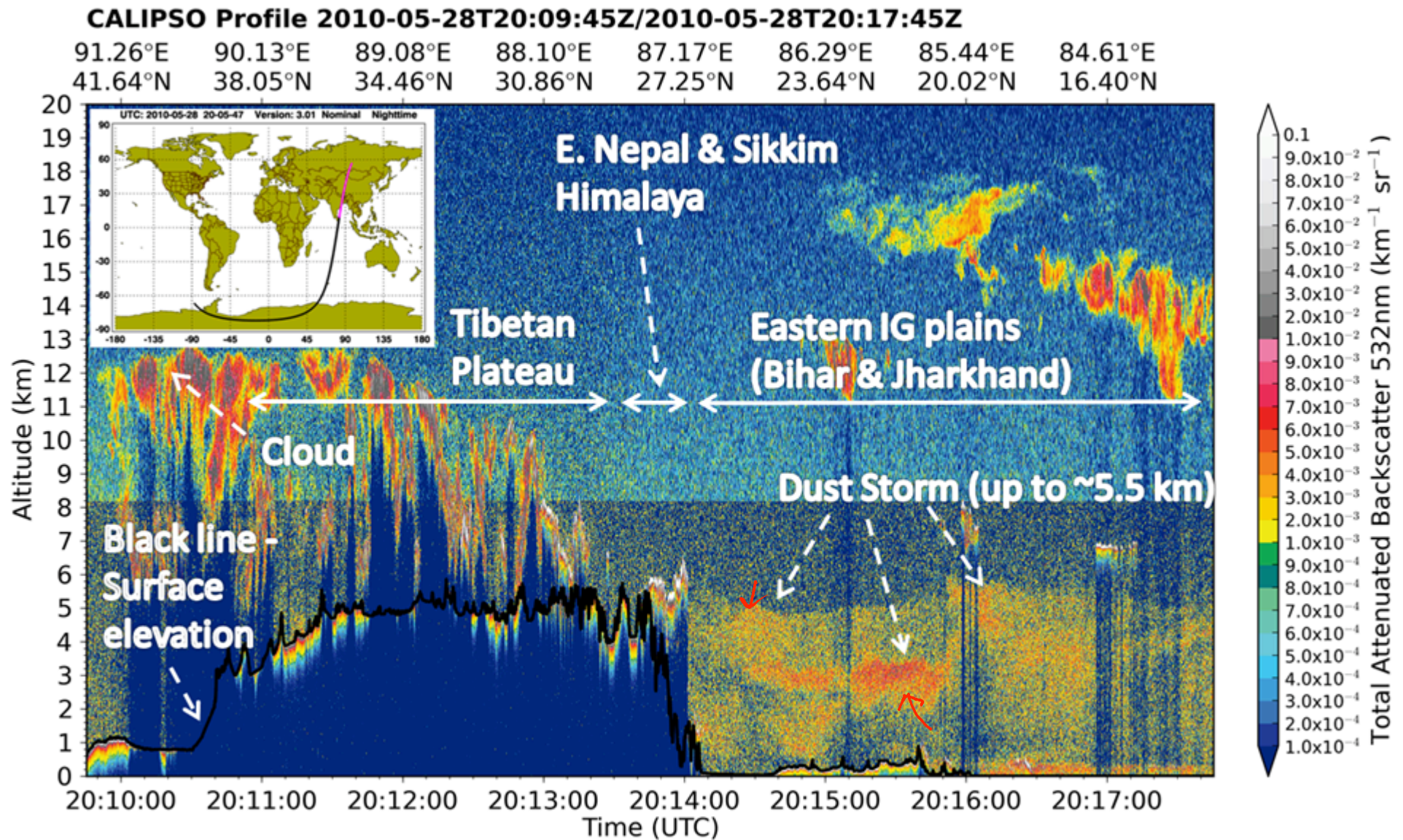
April 22, 2010 (CALIPSO overpass during a dust storm)



May 27, 2010 (CALIPSO overpass during a dust storm)



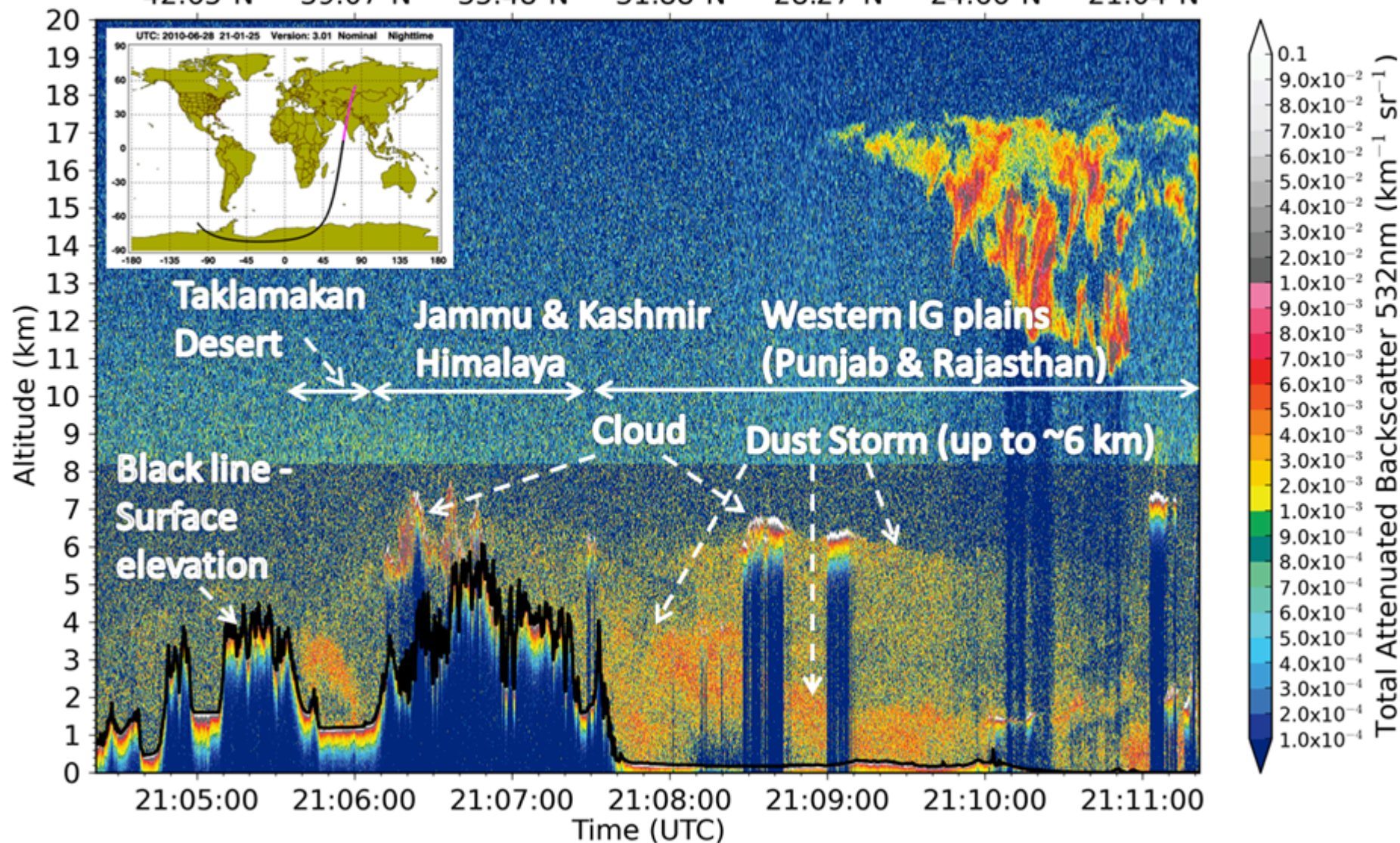
May 28, 2010 (CALIPSO vertical profile) 1:40 to 1:47 am IST (local time)



June 28, 2010 (CALIPSO vertical profile) 2:35 to 2:41 am IST (local time)

CALIPSO Profile 2010-06-28T21:04:21Z/2010-06-28T21:11:21Z

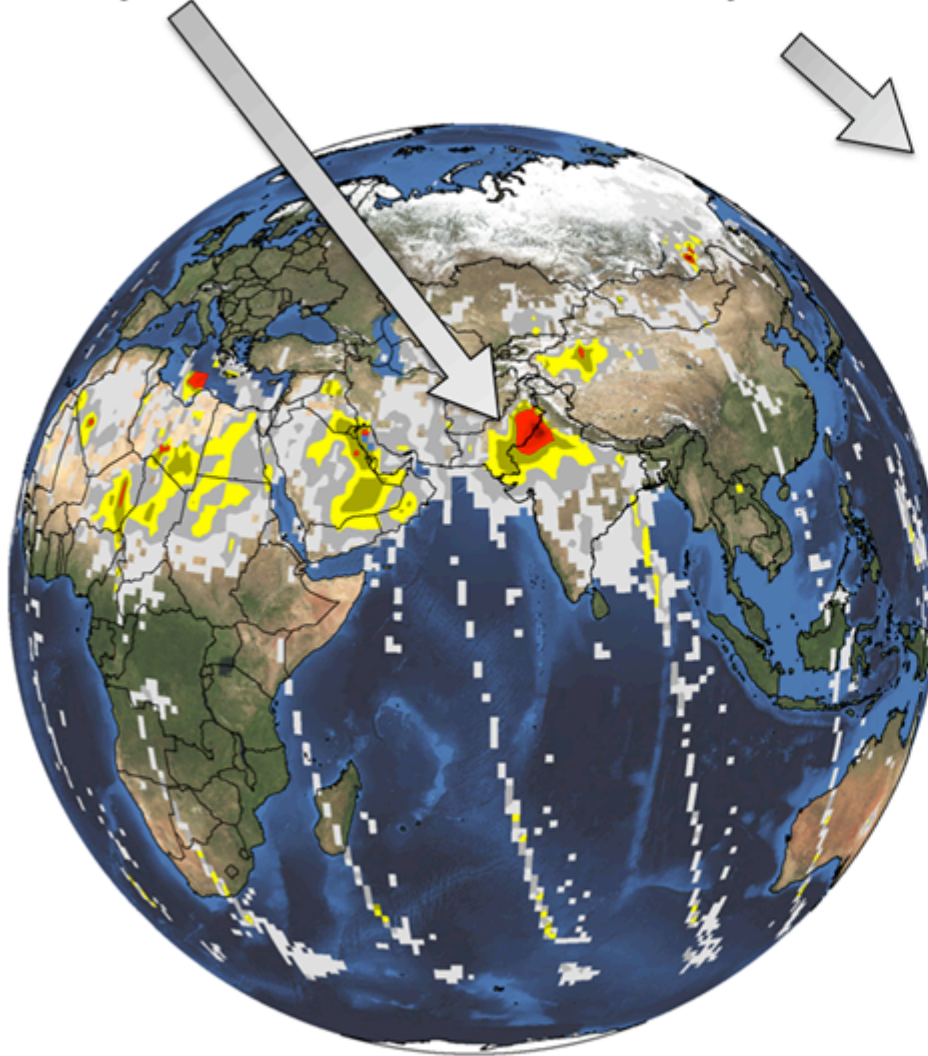
77.70°E	76.55°E	75.48°E	74.48°E	73.54°E	72.64°E	71.78°E
42.65°N	39.07°N	35.48°N	31.88°N	28.27°N	24.66°N	21.04°N



Dust Storm over Delhi (May 14, 2008)

May 13, 2008

May 14, 2008



TOMS Aerosol Index



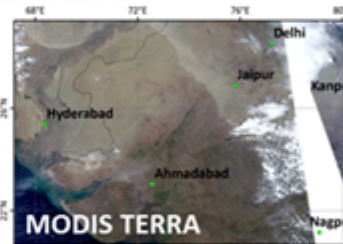
At 10 am, near-dark city paralyzes rush-hour rituals

HT Correspondent
New Delhi, May 14

THE WEATHER gods played havoc with the rush-hour rituals of the busy Capital on Wednesday with a sudden dust storm. Six people died and several were hurt even as a veil of dust made a mess out of the traffic. Parts of the city were left without power; cables snapped, and there was mayhem on the roads as Delhi witnessed a squall in morning on Wednesday.

Six dead, several hurt

A girl and a boy playing with friends and an elderly man out for a walk were among those who died in a wall of dust, said a police. "Two others died while travelling to work," he said. A three-year-old died in Kapashera after a wall on the terrace of a four-floor building came crashing down on her, the police said. Two other toddlers playing nearby were injured. "They



May 14, 2008

Strongest squall in 10 years kills six, hits flights

HT Correspondent
New Delhi, May 14

THE STRONGEST dust storm to hit the Capital in more than a decade tore away trees, blew down power lines and choked the city in a thick blanket of dust in the morning hours of Wednesday. Police said two children who were playing outside and two others were among those who died. At 10 am, a thick wall of dust and a squall started at 8:55 am and took off with a roar. The morning was overcast with thick clouds, but the visibility was not as bad as it was. During this period, the city also witnessed 1.2 mm of rain. Air traffic was the first to be hit by the storm. According to the meteorological department, the visibility at Indira Gandhi International Airport was less than 100 m at 9:55 am. The squall was the strongest summer dust storm to hit Capital in 10 years.

1 minute that shook city
9:55 am to 9:56 am

Storm kills 6, injures more than a dozen, uproots trees, electric poles, flattens partly-built structures, turns over container

THE DEAD

- A girl and a boy playing with friends
- An elderly man out for a walk
- Two men travelling to work
- A three-year-old girl. She was crushed as wall on terrace of four-floor building crashed down on her
- A 60-year-old, crushed by an uprooted tree

• Squall was the strongest summer dust storm to hit Capital in 10 years

90 mph wind speed the squall packed
9:55 am to 9:56 am: duration of squall

WHAT HAPPENED

- Thick, tall clouds engulfed city, plunging city into near-darkness
- Winds kicked up dust and a thick veil of dust hung in the air, making driving difficult for motorists

• Thousands, 1.22 mm of rain settled the dust. Soon after that, the mercury settled at a cool 21.2 degrees Celsius. Incidentally, it became the coolest May 14 in five years

• At the Palam observatory near the airport, the squall velocity recorded was much more, at 154 kmph, and it lasted longer than in the city, for two minutes, the Met department said

2003: Last time Delhi saw a squall of this magnitude at 17 kmph

Text: Anshuk G Bhatia, Ravi Bhatia

Kasturba Gandhi Marg 11:20 am



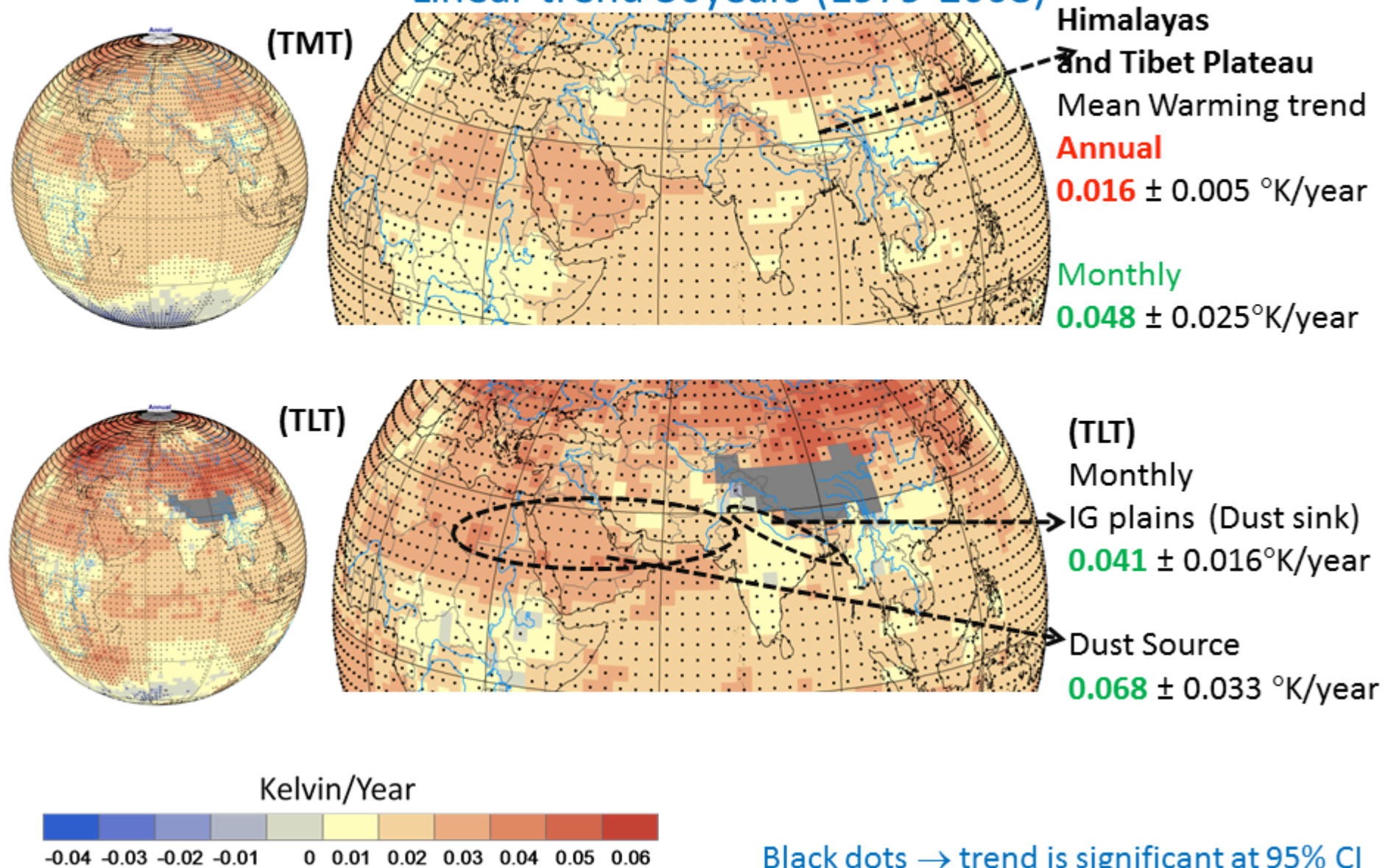
Motilal Nehru Road 12:10 am



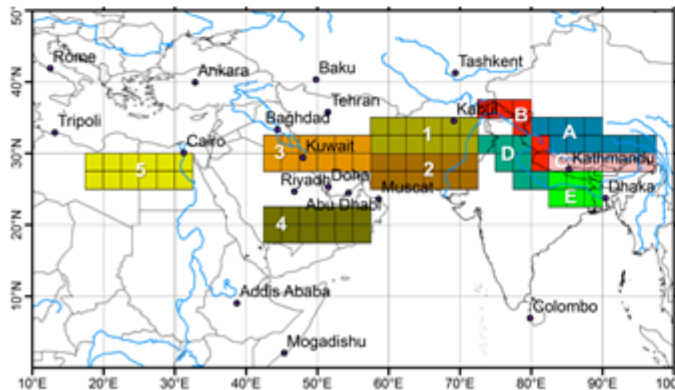
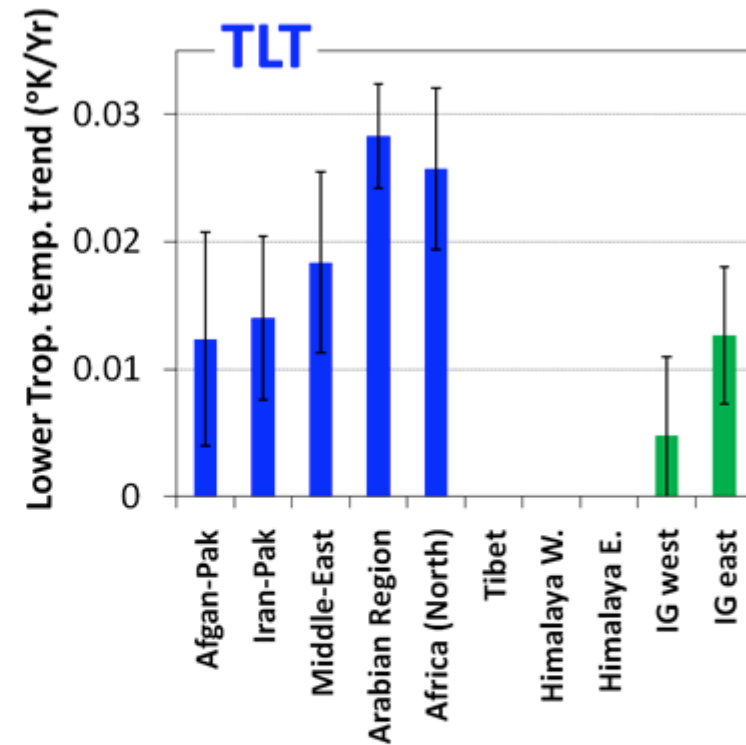
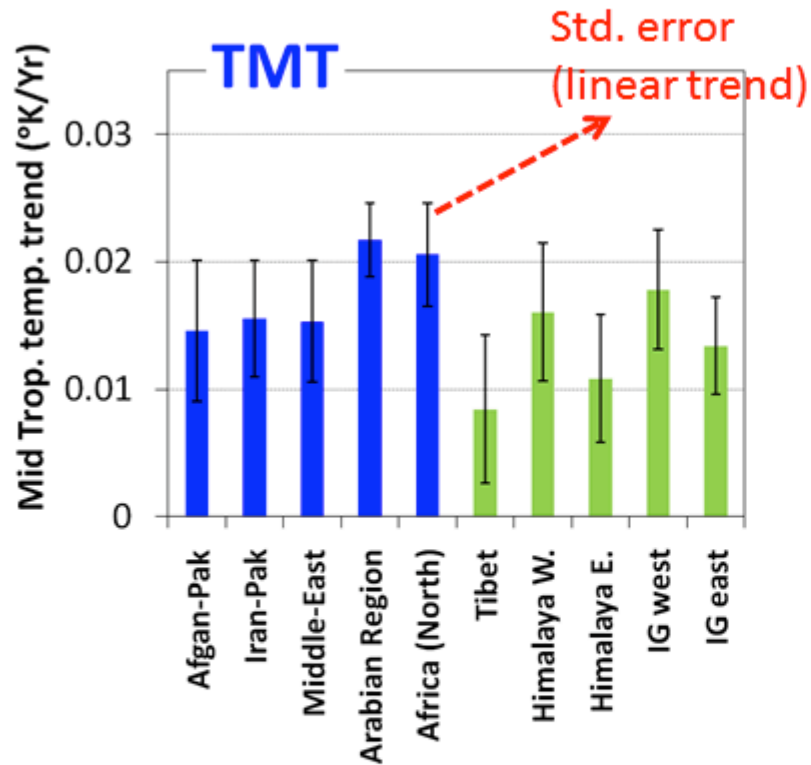
Sarvodaya Enclave 2 pm



Annual MSU trend lower and middle troposphere temperature Linear trend 30years (1979-2008)



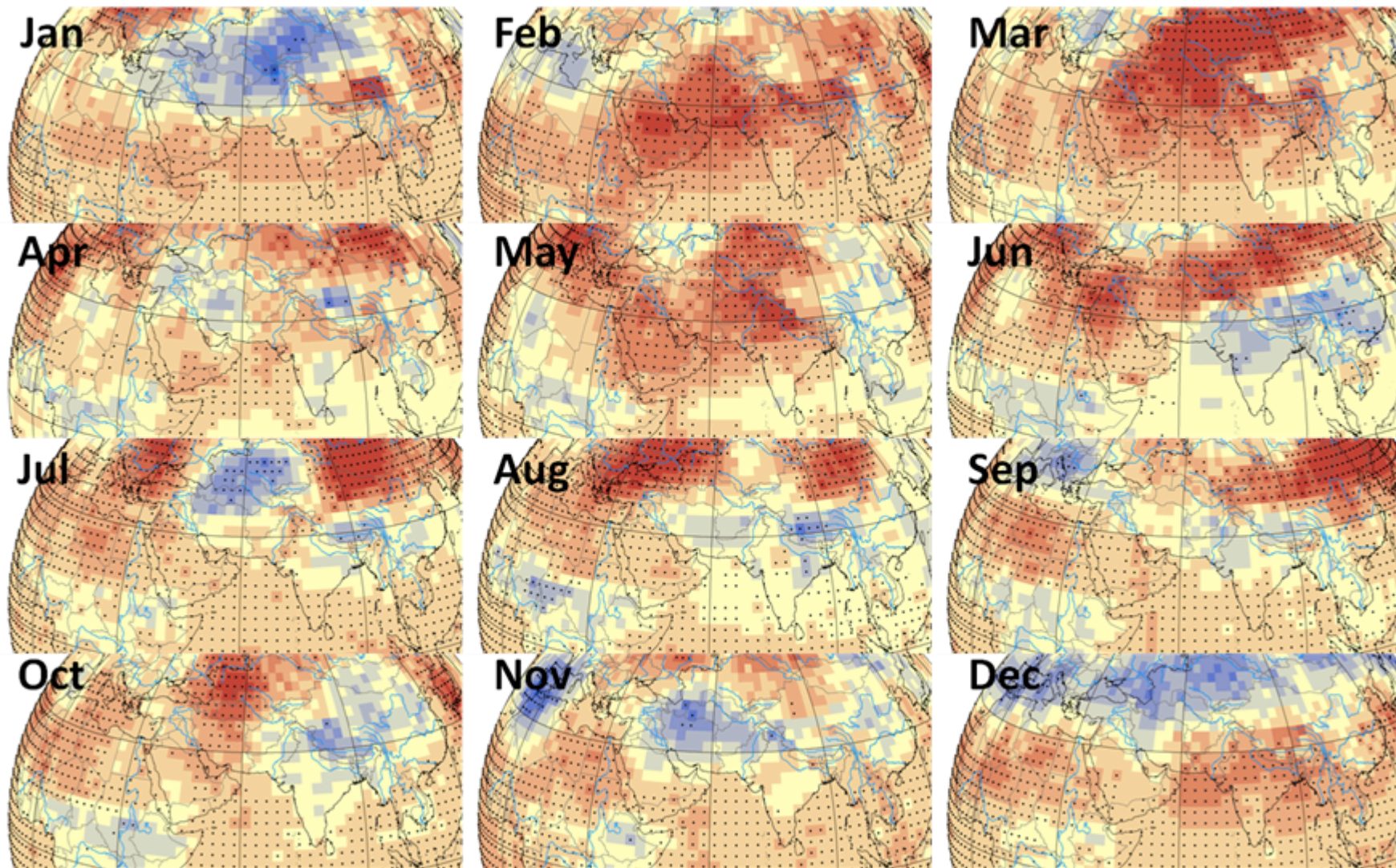
mean Lower and middle troposphere temp. trend ($^{\circ}\text{K}/\text{year}$) over Himalayas-Tibet, Dust Source, Sink regions



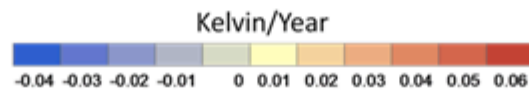
1 2 3 4 5 A B C D E

↕

Middle Troposphere (Trend for each month)



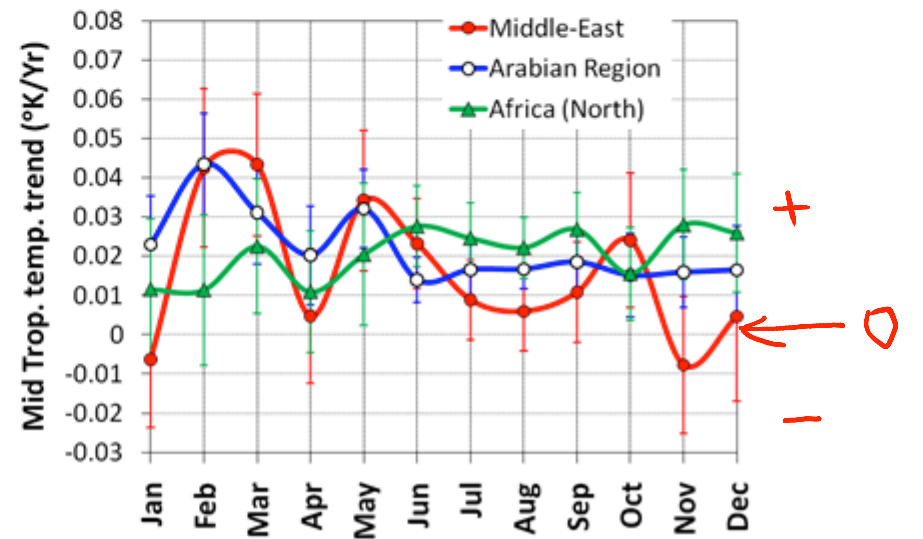
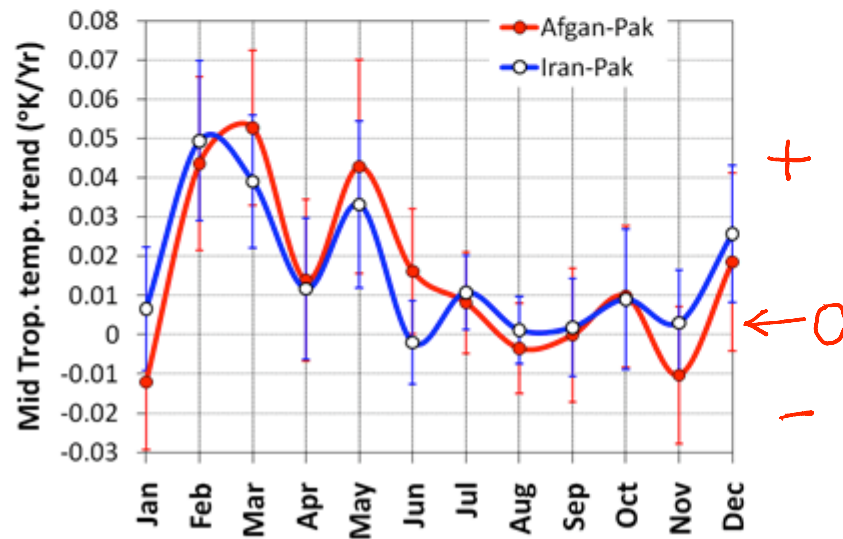
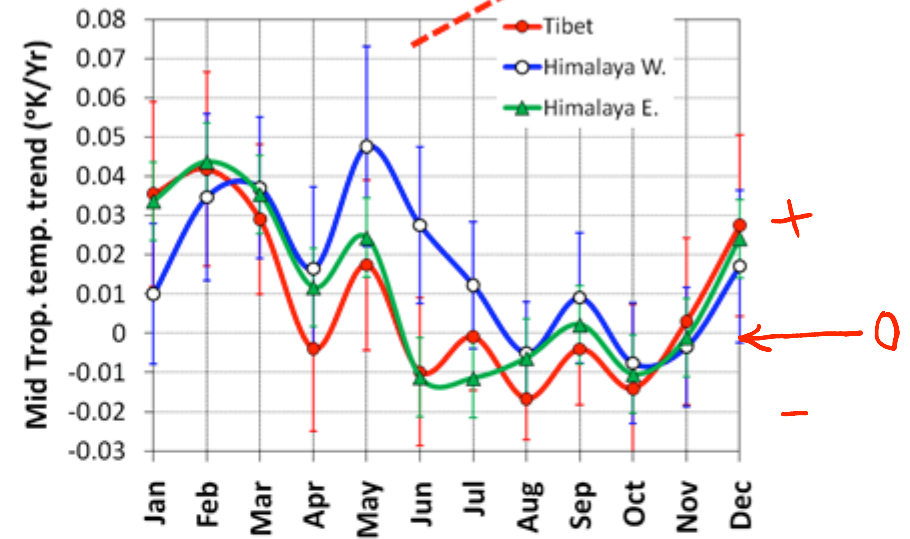
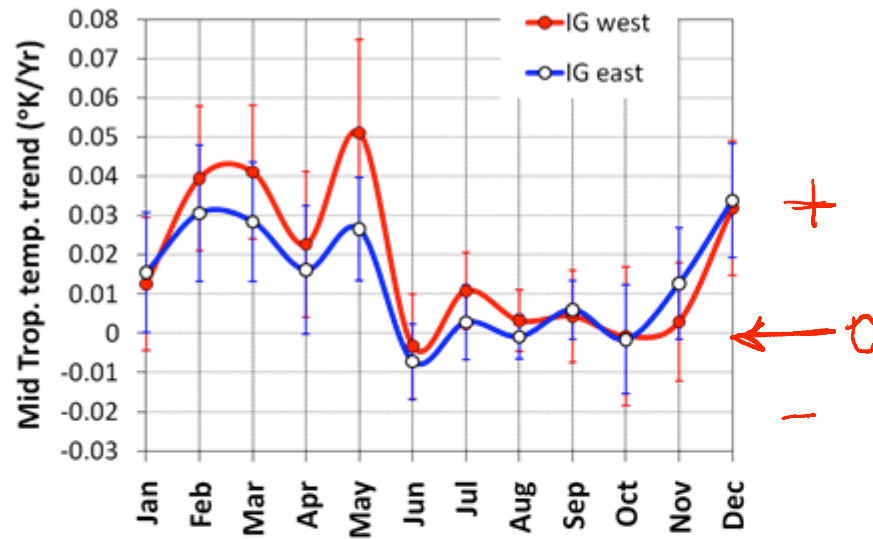
MSU TMT (middle Troposphere)



*Linear trend ($^{\circ}\text{K}/\text{year}$) of brightness
temperature anomaly (1979-2008, 30
years) for each month*

Mid Troposphere Mean Linear Trend over Regions

Error bar= Std. error
(linear trend)



Conclusions

- Historical Landsat and ASTER images since 1972 show evidences of glacier melting and formation of numerous melt lakes across the Himalayan Range.
- MODIS Terra and Aqua derived dark-target and deep_blue AOD retrievals, at 10 km grid resolution, show high aerosol loading over the Himalayas.
- CALIPSO vertical profiles during the major dust storms show that the mixed aerosols reach up to **7 km from msl**.
- The dust storms affect the western, central and eastern section of the Himalayas during **April-May-June (pre-monsoon season)**.
- MSU: The mean month-to-month warming (**up to $0.048 \pm 0.026\text{K/year}$ or 1.44K over 30 years**) of the mid-troposphere is prominent and statistically significant at a 95% confidence interval.
- MSU: Though the mean annual warming trend over the Himalayas ($0.016 \pm 0.005\text{K/year}$), and Tibetan Plateau ($0.008 \pm 0.006\text{K/year}$) is positive, the **month to month warming trend is higher (by 2–3 times, positive and significant)** only over a period of six months (**December to May**).

A satellite image of Earth from space, showing a curved horizon and a large landmass. A prominent snow-capped mountain range, likely the Andes, runs diagonally across the frame. The surrounding terrain is a mix of brown and green, with several dark blue lakes visible. The sky is a deep blue, and the overall image has a high-contrast, scientific quality.

Acknowledgements

- Support from SAIC and IGC
- Various NASA Science Teams (Terra, Aqua, Aura)
- Landsat and ASTER Science Team
- Data Centers

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- Prasad A.K., H. El-Askary, G.R. Asrar, M. Kafatos and A. Jaswal (2011), "[Melting of Major Glaciers in Himalayas: role of desert dust and anthropogenic aerosols](#)" In: **Planet Earth 2011 - Global Warming** Challenges and Opportunities for Policy and Practice, InTECH open access publisher. ISBN 978-953-307-733-8.

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thanks for your kind attention



Questions ?

