Aerosol, Asian Monsoon and Climate Change

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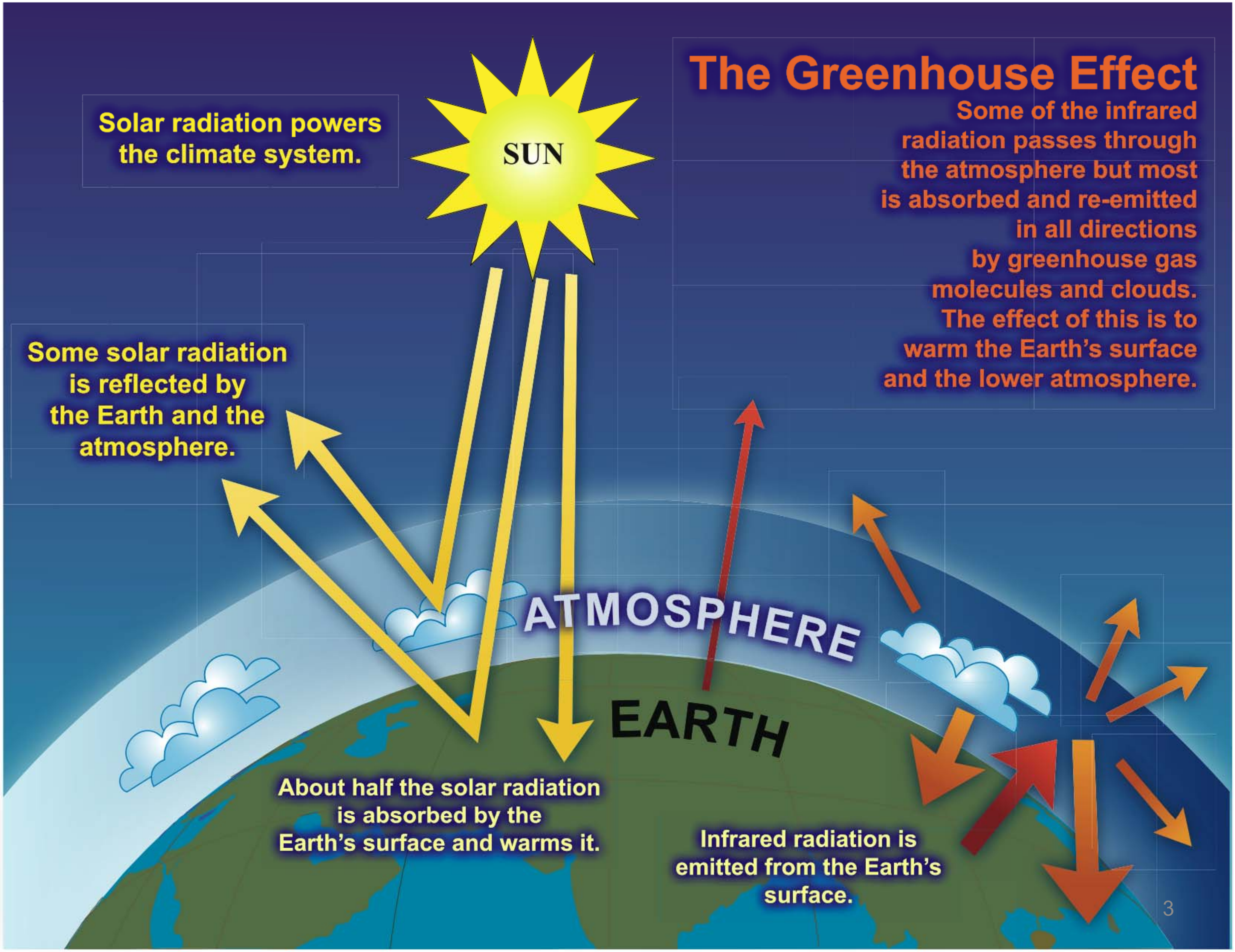
OUTLINE

- Aerosol-climate change primer
- Possible impacts of aerosols on
  - Asian monsoon water cycle
  - Accelerated melting of snowpack in the Himalayas and Tibetan Plateau
- Adaption and mitigation

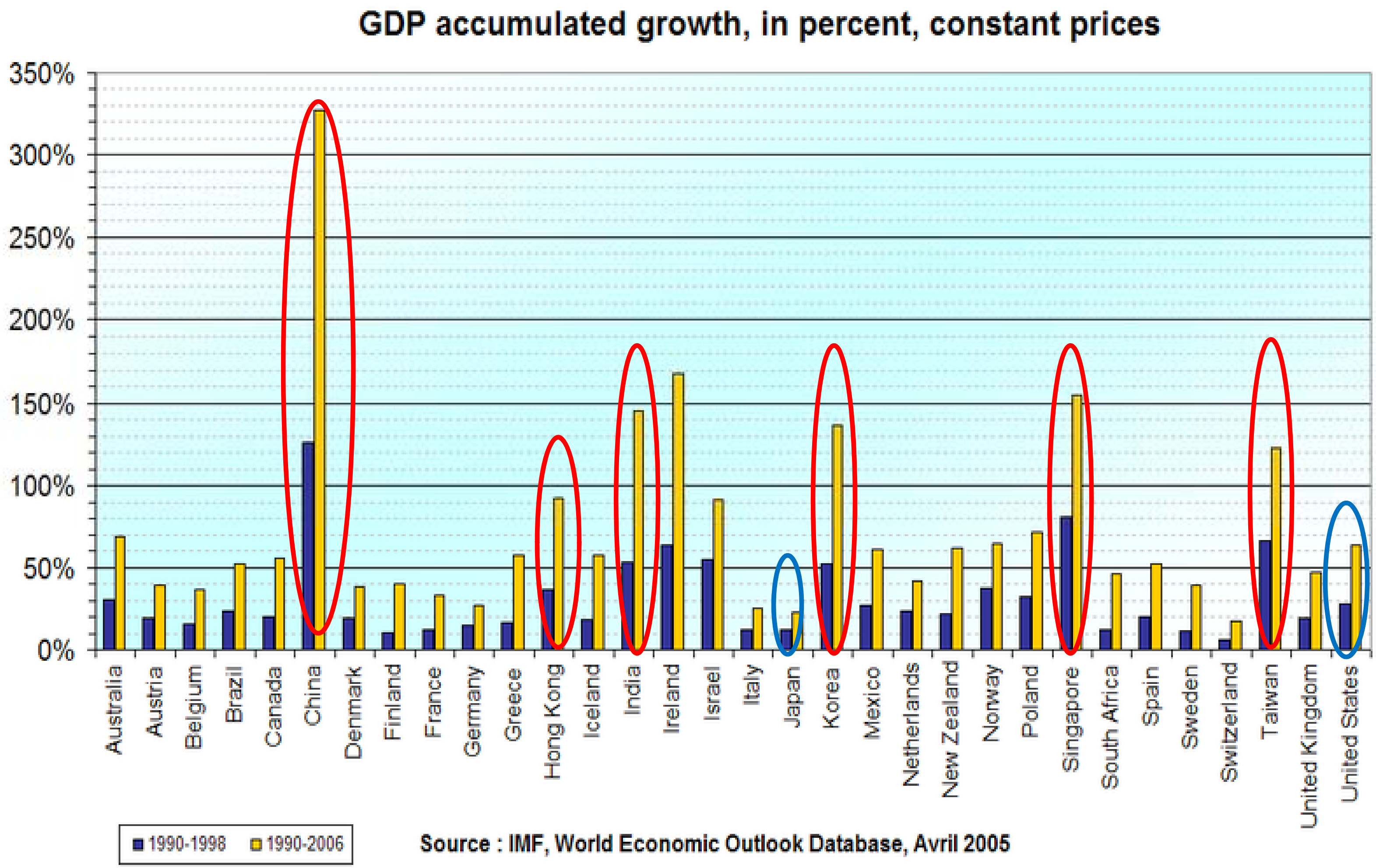

The Greenhouse Effect
Solar radiation powers the climate system.
SUN
Some of the infrared radiation passes through the atmosphere but most is absorbed and re-emitted in all directions by greenhouse gas molecules and clouds. The effect of this is to warm the Earth's surface and the lower atmosphere.
Some solar radiation is reflected by the Earth and the atmosphere.
ATMOSPHERE
EARTH
About half the solar radiation is absorbed by the Earth's surface and warms it.
Infrared radiation is emitted from the Earth's surface.

Global Warming ≠ Climate Change

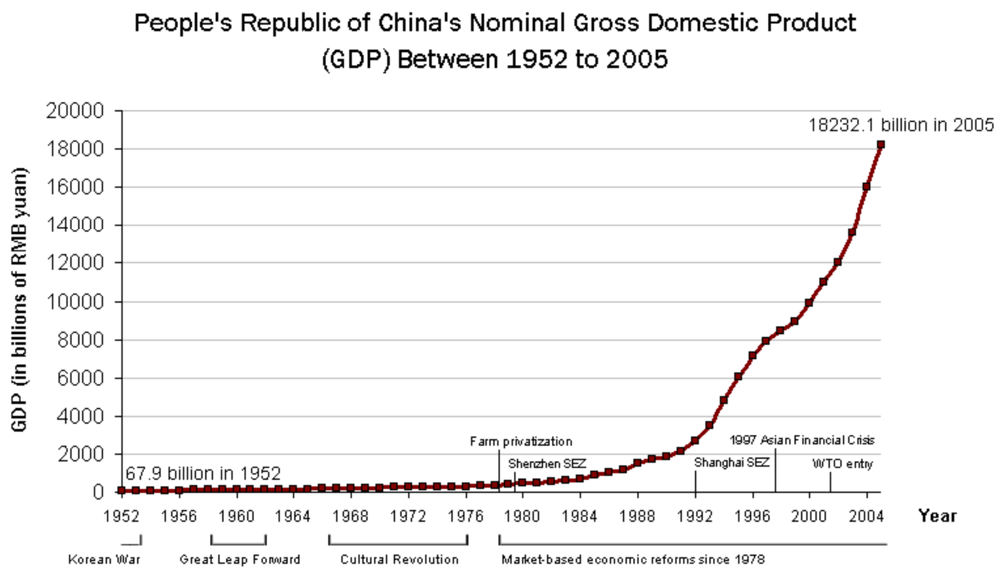
Climate change is a change in the statistical distribution of weather over periods of time that range from season, years, decades to millions of years. It can be a change in the average weather or a change in the distribution of weather events around an average (for example, greater or fewer extreme weather events). Climate change may be limited to a specific region, or an environment, or may occur across the whole Earth System

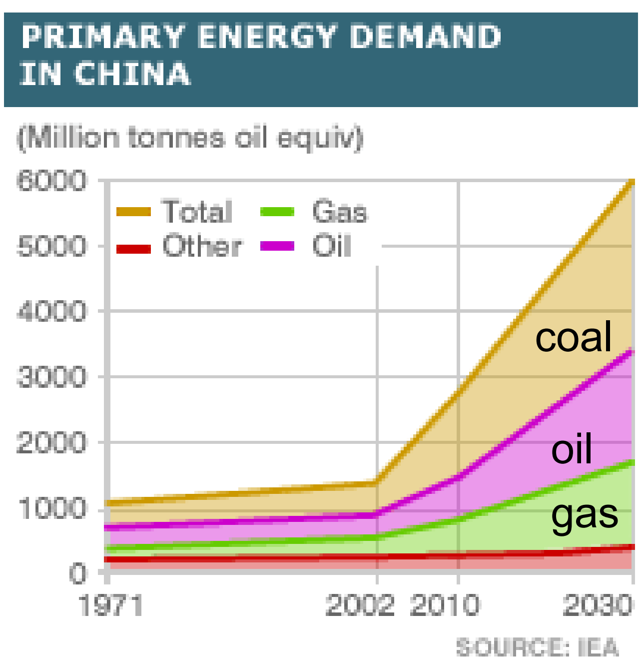
Global warming is a realization of the effects of well-mixed greenhouse gases associated with modern (approx. since the last two centuries) climate change

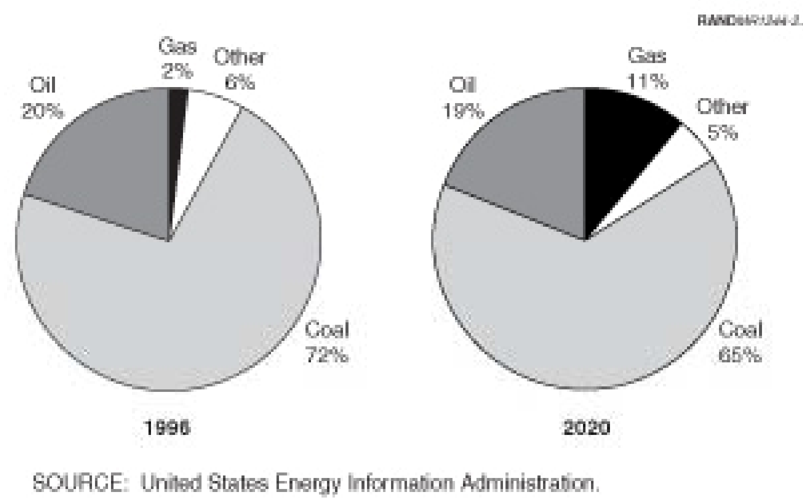
Rapid industralization in Asian countries



Energy demands by types in China







Climate Change in China

- Surface temperature over China has increased by more $2^{o}C$ since 1900, and increasing by more than 0.3 degree per decade since 1980.

- About 30-50% of the increase may have been masked by aerosols.

- The average depth of the permafrost over the Tibetan Plateau, and glacier coverage has shrunk by 5-10% in the last 30 years

- Temperature over Asia will rise by additional $3\text{-}5^{o}C$, depending on various emission scenarios, and even with stabilization (450 ppm by 2050), temperature will continue rise at about $1^{o}C$ per 100 years, in the next century.

Climate Assessment Report Bejing Climate Center, 2008

"……human influences are significant and involve a diverse range of first-order climate forcings, including, but not limited to the human input of well mixed greenhouse gases (CO_2, CH_4, N_2O etc.) The impacts of these other forcings are critically important in exciting climate feedbacks on regional and local scales, and in modulating the greenhouse warming effects."

Climate Change: The Need to Consider Human Forcings Other than Greenhouse Gases, EOS, American Geophysical Union, November issue

*By Roger Pielke Sr[1]., Keith Beven[2], Guy Brasseur[3], Jack Calvert[3], Moustafa Chahine[4], Russ Dickerson[5], Dara Entekhabi[6], Efi Foufoula-Georgiou[7], Hoshin Gupta[8], Vijay Gupta[1], Witold Krajewski[9], E. Philip Krider[8], **William K. M. Lau**[10], Jeff McDonnell[11], William Rossow[12], John Schaake[13], James Smith[14], Soroosh Sorooshian[15], Eric Wood[14]*

Aerosols and the Asian Monsoon

- Over 60% of world population live in the Asian monsoon regions
- Monsoon related droughts and floods, and aerosols are the two most serious environmental hazards in Asian monsoon regions,
- The monsoon water cycle is driven by atmospheric heating, through the dyn
amical interaction of wind, moisture, clouds and rainfall.
- Sea surface temperature, and land surface processes alter monsoon water c
ycle, through generation of surface heating gradients and atmospheric

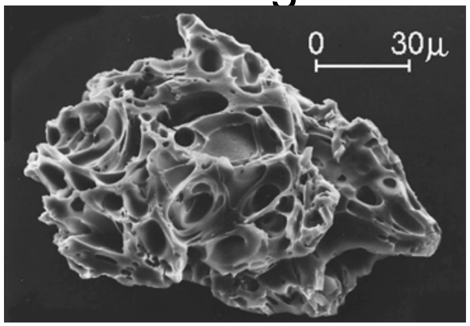
heat sources and sinks.

- Suspended particles (aerosol, clouds, precipitation) in the atmosphere
regulate and interact with heat sources and sinks, and alter the monsoon w
ater cycle

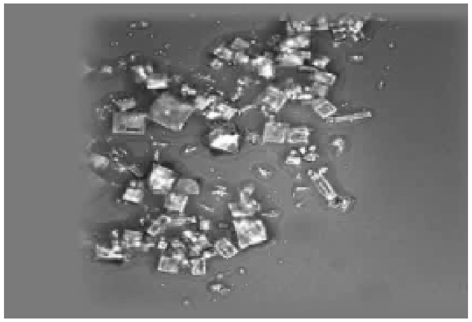
Definition of aerosol

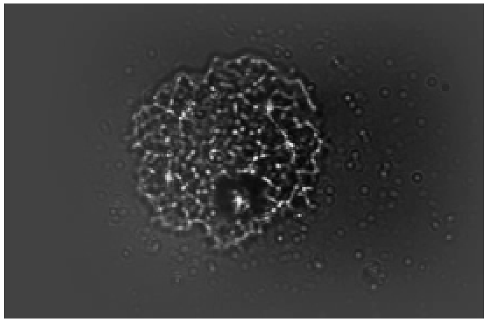
An **aerosol** is a suspension of fine solid particles or liquid droplets in a gas. Aerosols come from both man-made (industry, motor vehicles), and natural sources (forest fires, oceanic haze, deserts). *Examples are: sulfate, soot (black carbon), organic carbon, dust, sea salt.*

Soot is impure carbon particles resulting from incomplete combustion of a hydrocarbon *e.g.*, from internal combustion engines, power plants, heat boilers, waste incinerators, furnaces, fireplaces, slash and burn agriculture, forest fires.



Volcanic ash


Sea Salt


Tractor soot

Aerosols alter energy balance of the atmosphere-ocean-land system

Radiation (Direct) Effects

Back Scattering (Cooling)

Absorption (Atmospheric Column Warming by absorbing aerosols e.g. dust and soot)

Forward Scattering

Dimming of Earth Surface (Cooling)

Microphysics (Indirect) Effects

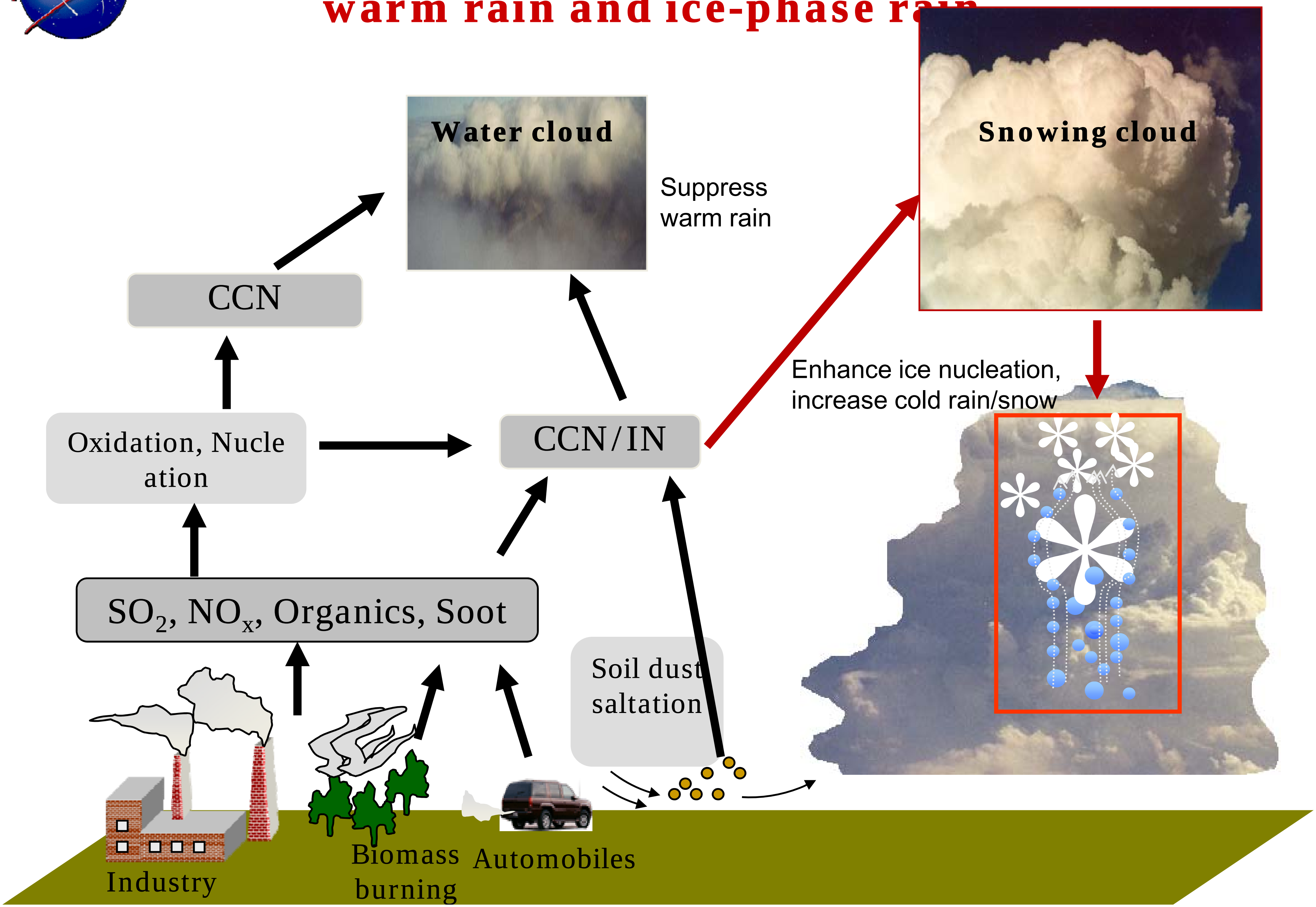
Warm Rain suppression, Increased cloud life time (cooling)

Increased ice nucleation, enhanced deep convection (warming)

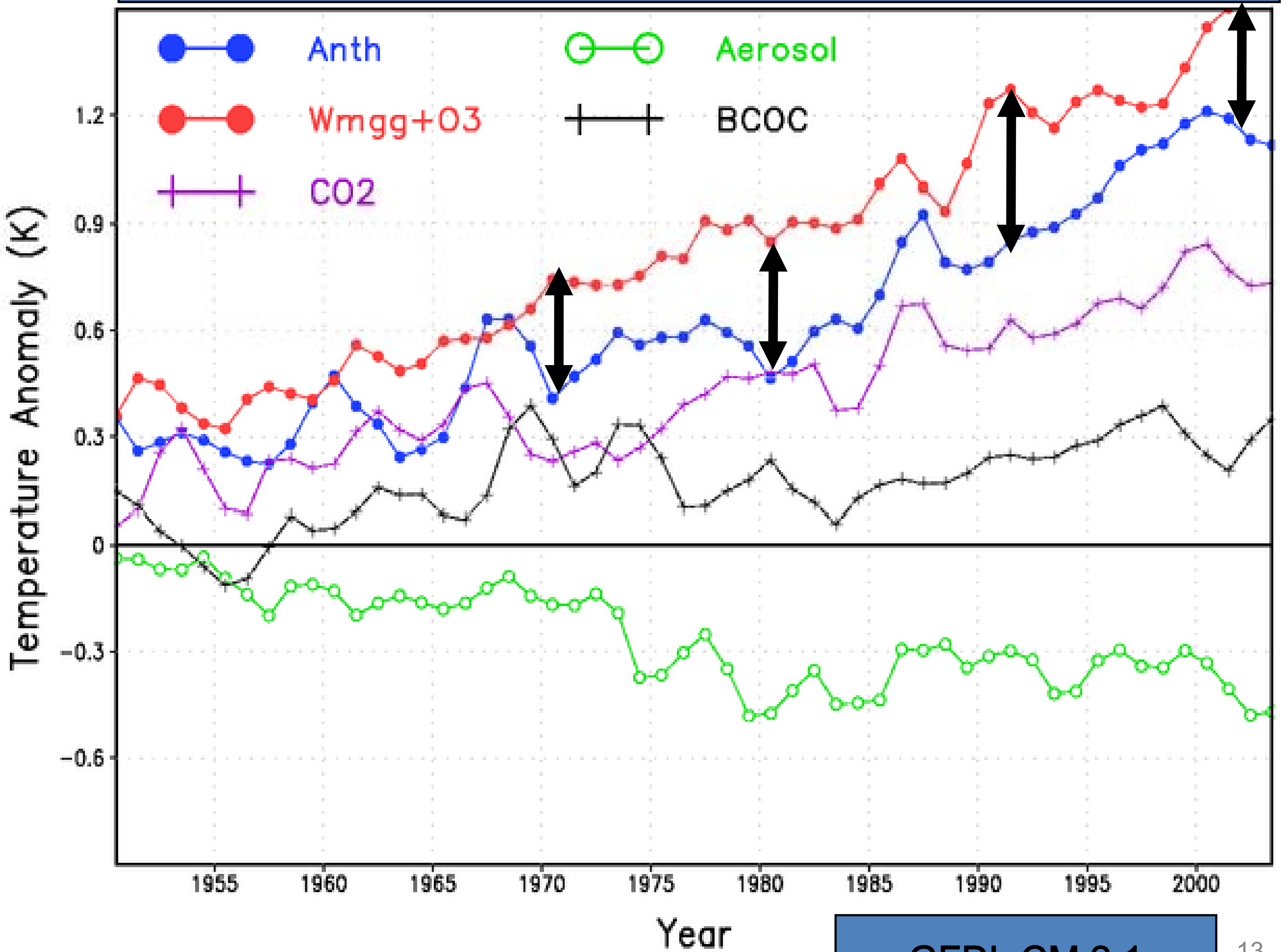
Aerosol induced cloud-shielding

→ Surface dimming

Microphysics (indirect) effects of aerosols on warm rain and ice-phase rain



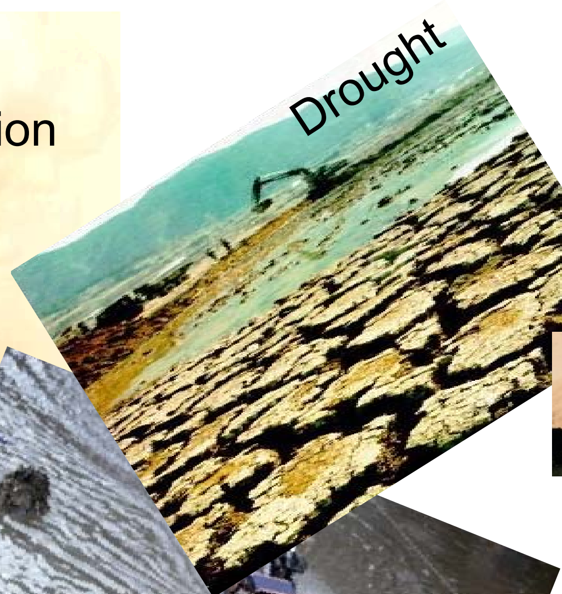
Aerosols mask global warming effects

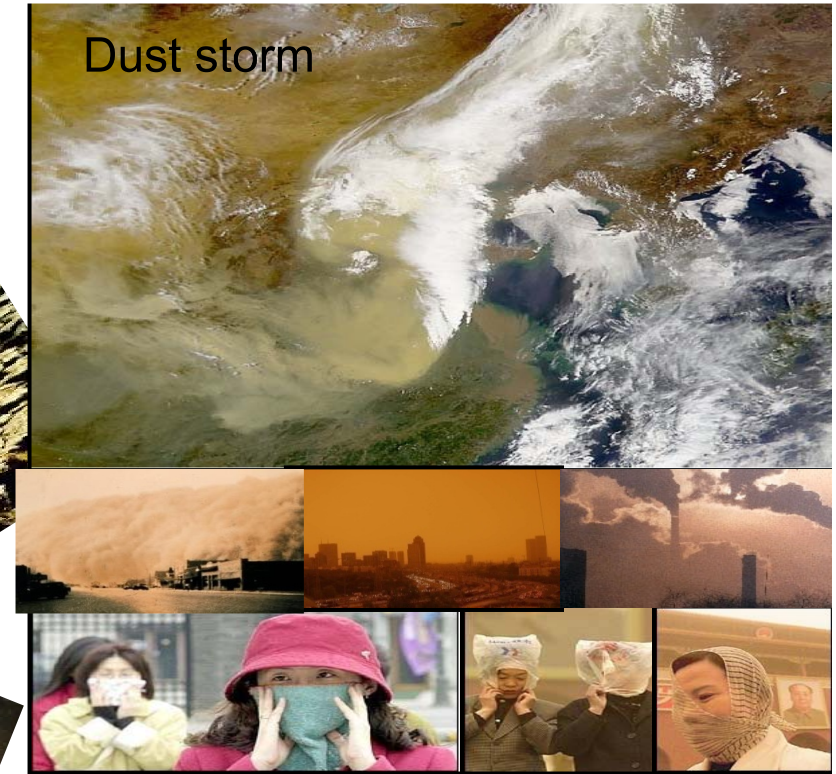


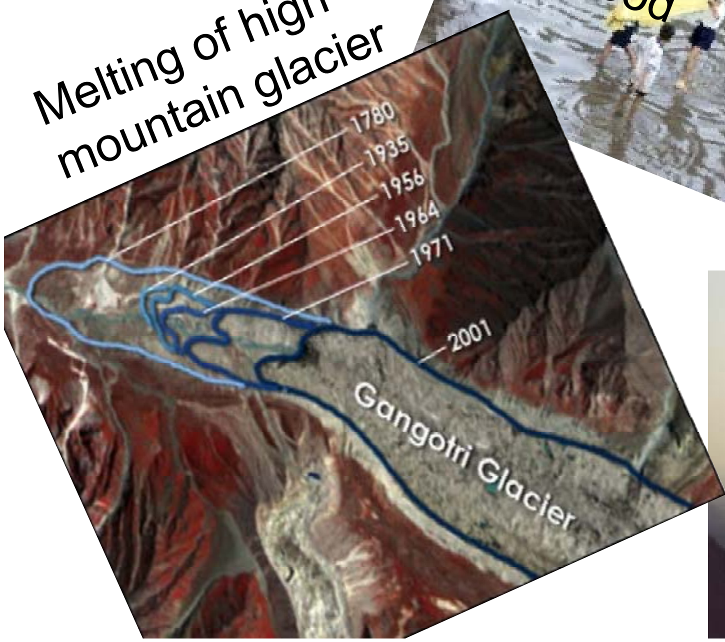
GFDL CM 2.1

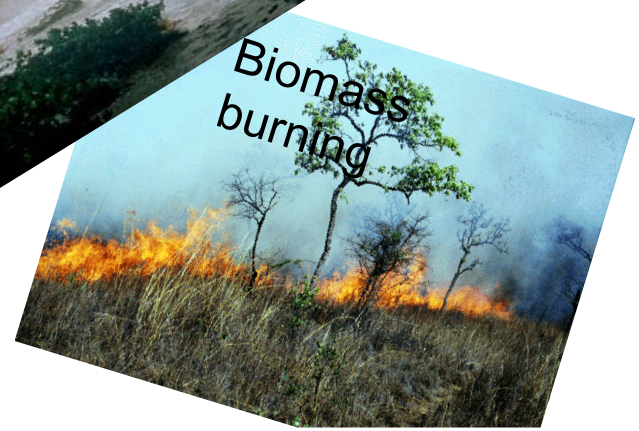
Aerosols have done a lot more than just "offset" the global-mean surface temperature due to Long-Lived Greenhouse Gases, but also altered regional water cycle and climate in ways that are still not understood, or even known!!

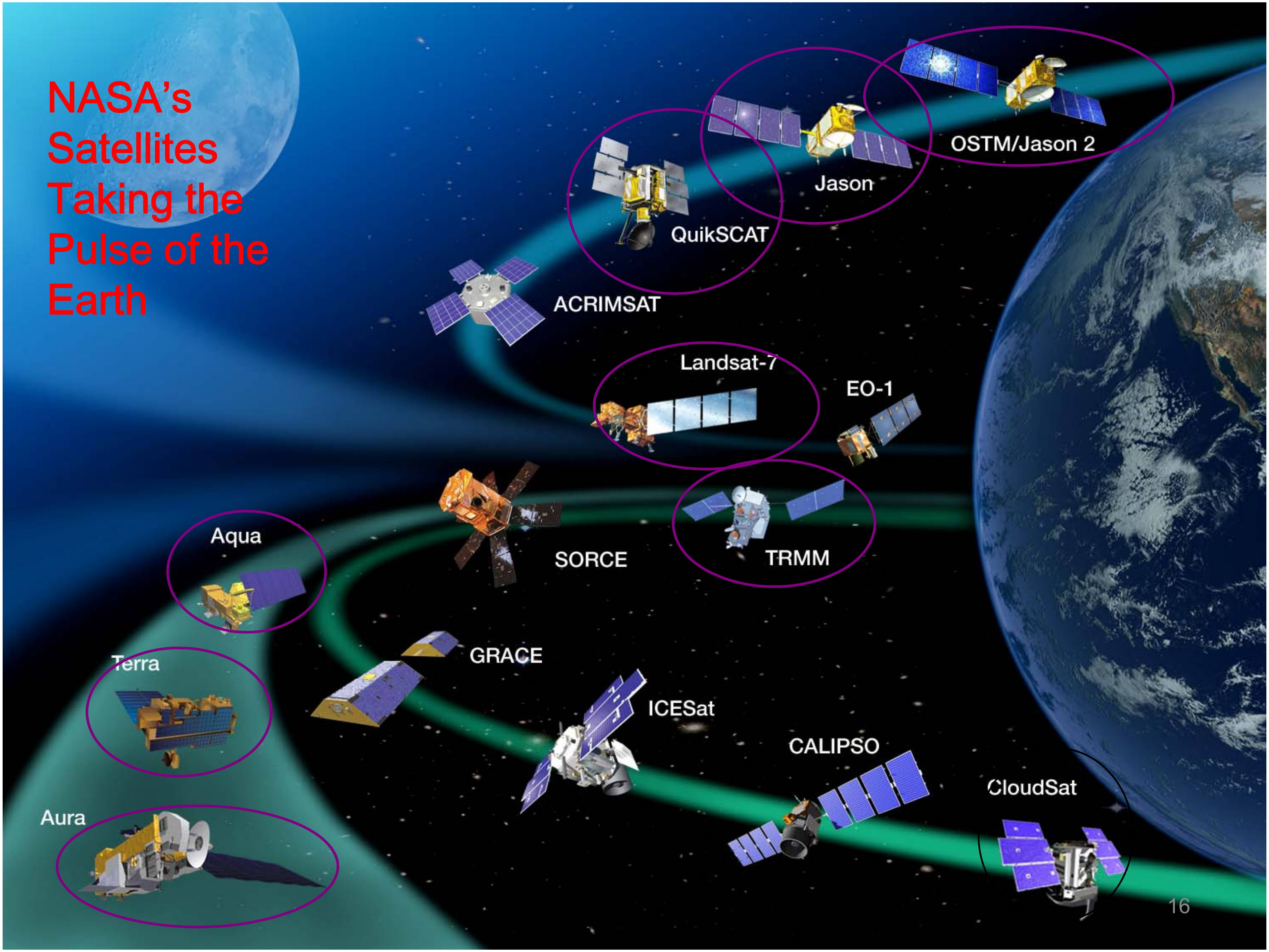
Climate change hazards in Asia





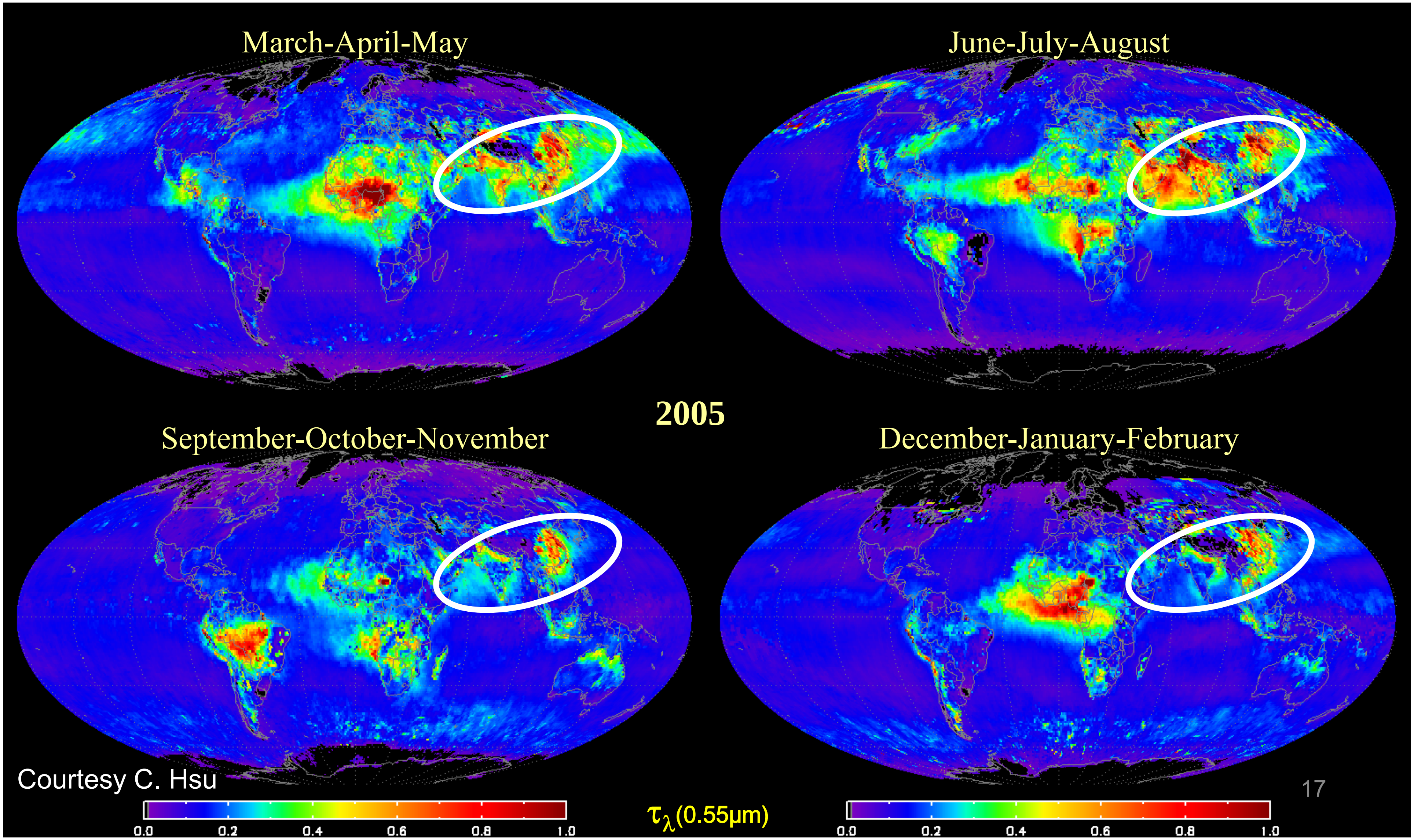




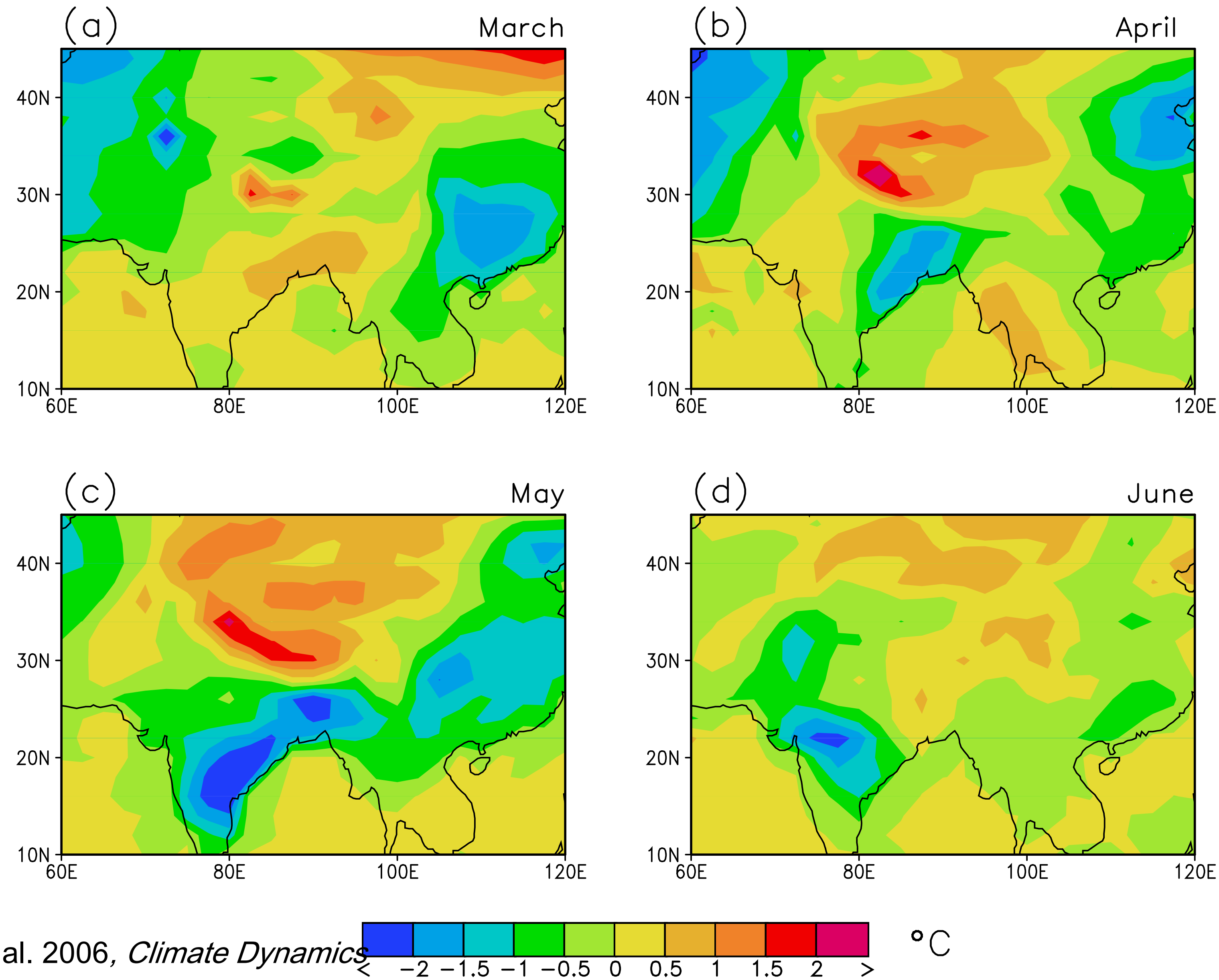

NASA's Satellites Taking the Pulse of the Earth
OSTM/Jason 2
Jason
QuikSCAT
ACRIMSAT
Landsat-7
EO-1
SORCE
TRMM
Aqua
GRACE
Terra
ICESat
CALIPSO
CloudSat
Aura

Aerosol-Hotspots

Aqua Collection-05 Aerosol (Deep Blue & MODIS Composite)

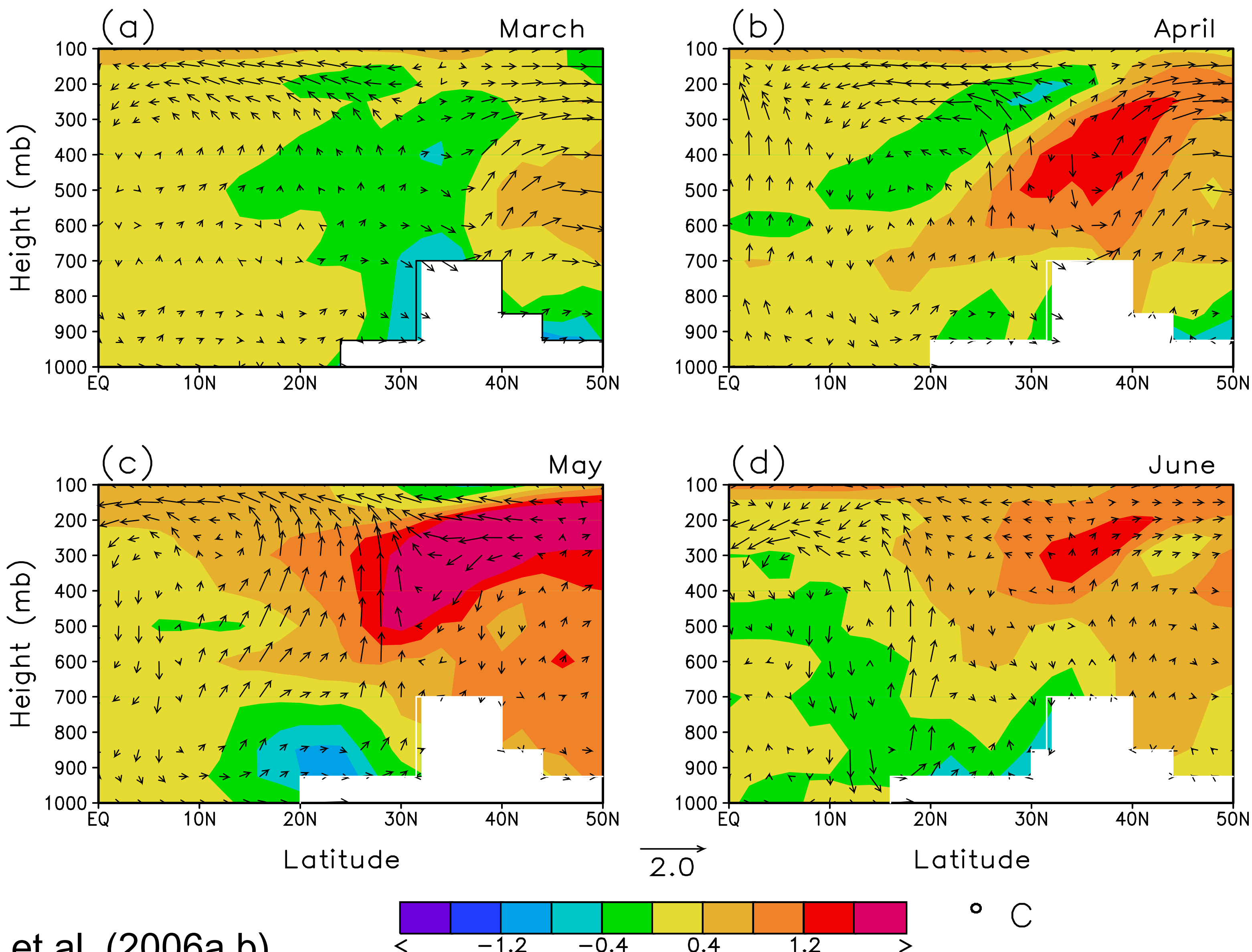


Aerosol-induced anomalies of surface air temperature in NASA fvGCM



Lau et al. 2006, *Climate Dynamics*

Anomalies of temperature and vertical motion (80-100E) induced by absorbing aerosols (dust and black carbon) in GCM simulations



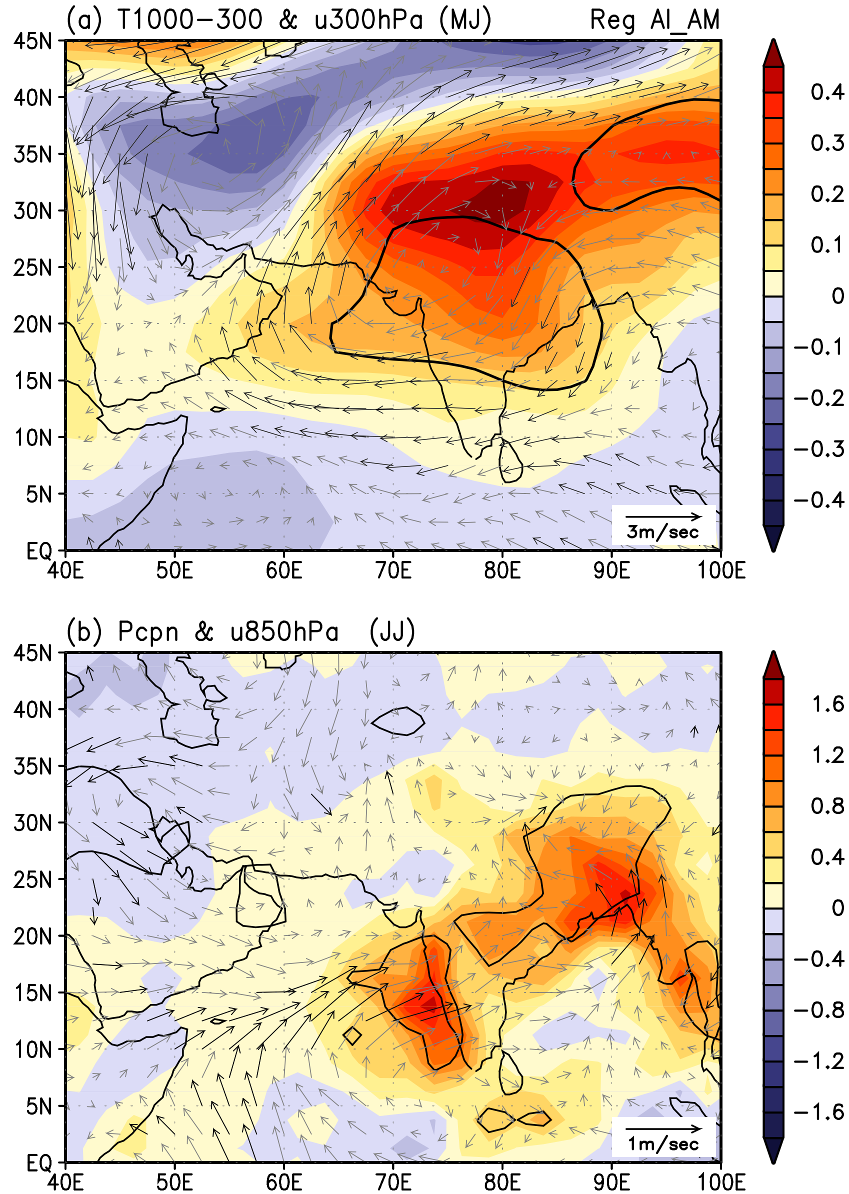
Lau et al, (2006a,b)

Characteristic EHP large scale pattern :

Enhanced tropospheric warming over the Tibetan Plateau and increased monsoon rainfall and winds in June-July, following major build-up of absorbing aerosol (dust and BC) over the Indo-Gangetic Plain in April-May

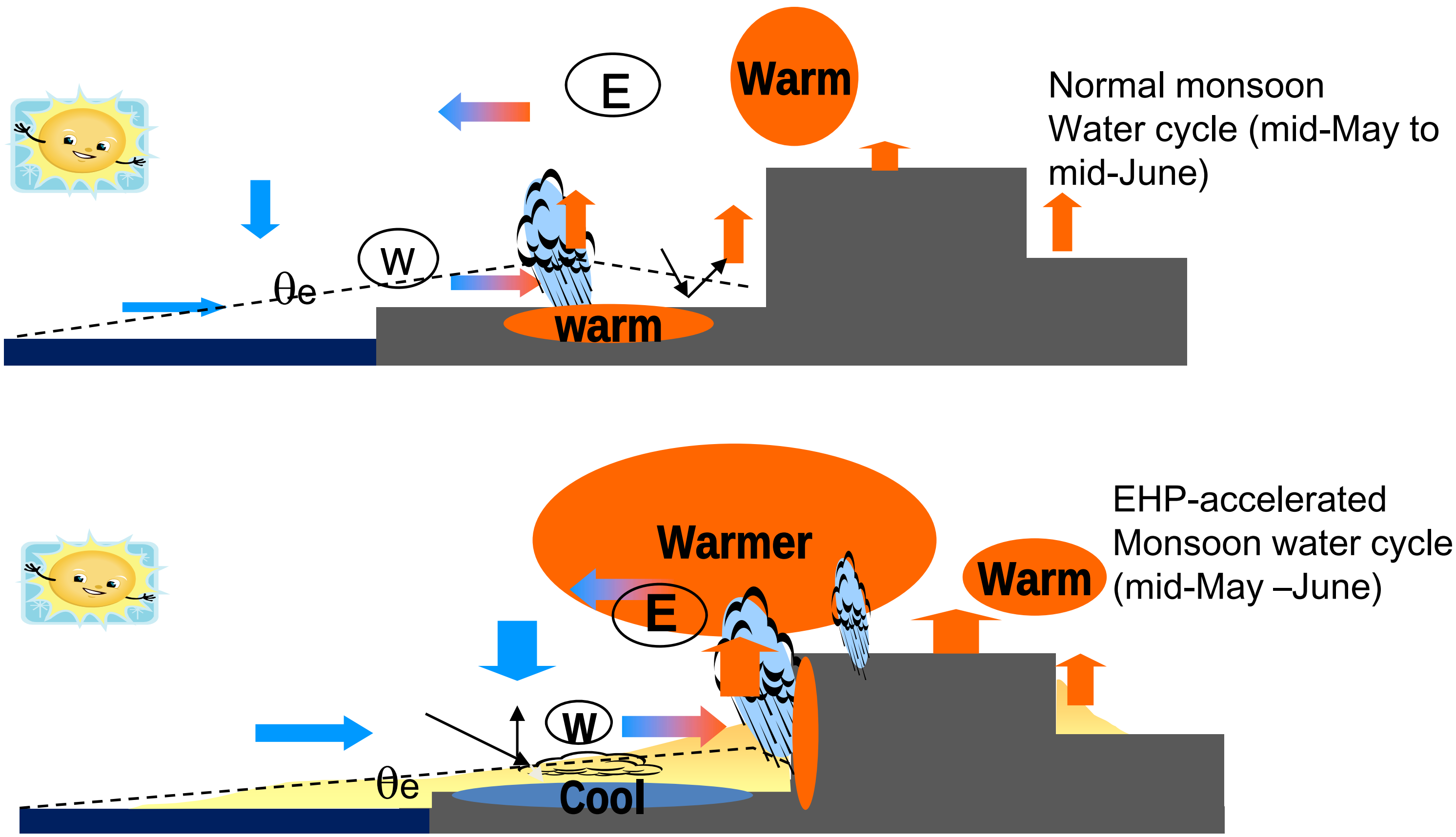
Data source: TOMS AI, GPCP, and NCEP re-analyses

Lau and Kim, 2006, *GRL*



The Elevated Heat Pump (EHP) hypothesis

(Lau et al. 2006, Lau and Kim 2006, Lau et al 2008)



EHP postulates:

a) Warming and moistening of the upper troposphere over the Tibetan Plateau

b) An advance of the rainy season in northern India/Napal region in May-June

c) The increased convection spreads from the foothills of the Himalayas to central India, resulting in an intensification of the Indian monsoon. in June-July

d) Subsequent reduction of monsoon rain in central India in July-August

e) Enhanced snowmelt and rapid retreat of mountain glacier

Climate Change is “a clear and present danger” in high-mountain regions

- Sixty-seven percent of glaciers are retreating at a startling rate in the Himalayas, and the major causes have been identified as global warming . *Ageta and Kadota 1992, Yamada et al. 1996, Fushinmi 2000)*

- Overall, Himalaya glaciers are losing mass rapidly at a rates about 500 -1000 kg m^{-2}/year, but rates are highly variable in space and time. However Himalaya glacier will NOT disappear by 2035, as previously reported by IPCC 2007 (J. Kargel et al. 2009).

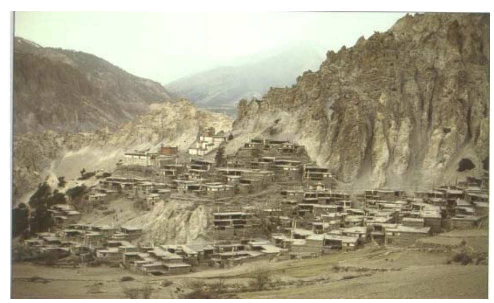
- Himalayas mountain regions are already suffering from major environmental degradation: floods from bursting of glacier lakes, soil erosion, shortage of water and power supply, loss of bio-diversity……

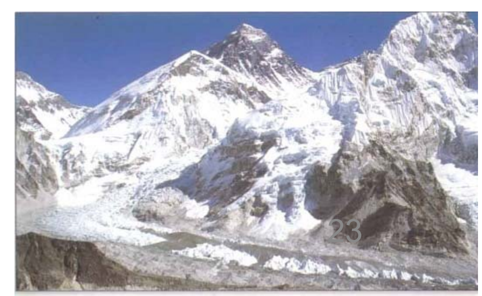
Climate Change is devastating high-mountain countries (Nepal, Bhatan, Pakistan-K2..)

- Diminished fresh water supply
- Increased flooding of river basins
- Reduced agriculture productivity
- Increased health hazards
- Increased Glacial lake outburst floods (GLOFs)
- Shortage of energy and power resources:
  hydro-electric, coal-burning, biofuel…
- Highly stressed eco-system,
  threatened biodiversity and wildlife


Tsho Rolpa Glacier Lake, Ne pal


Near Sundari Ghat, Bagmati, 2002 July

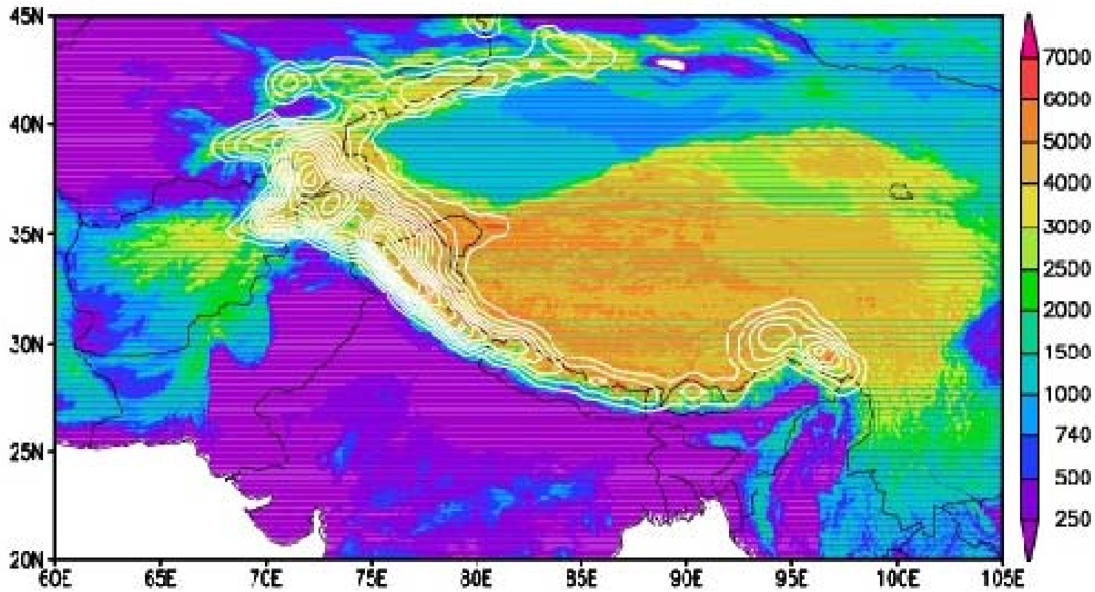




Accelerated melting of Himalaya-Tibetan Plateau glacier will endanger the water supply of the entire Asia!

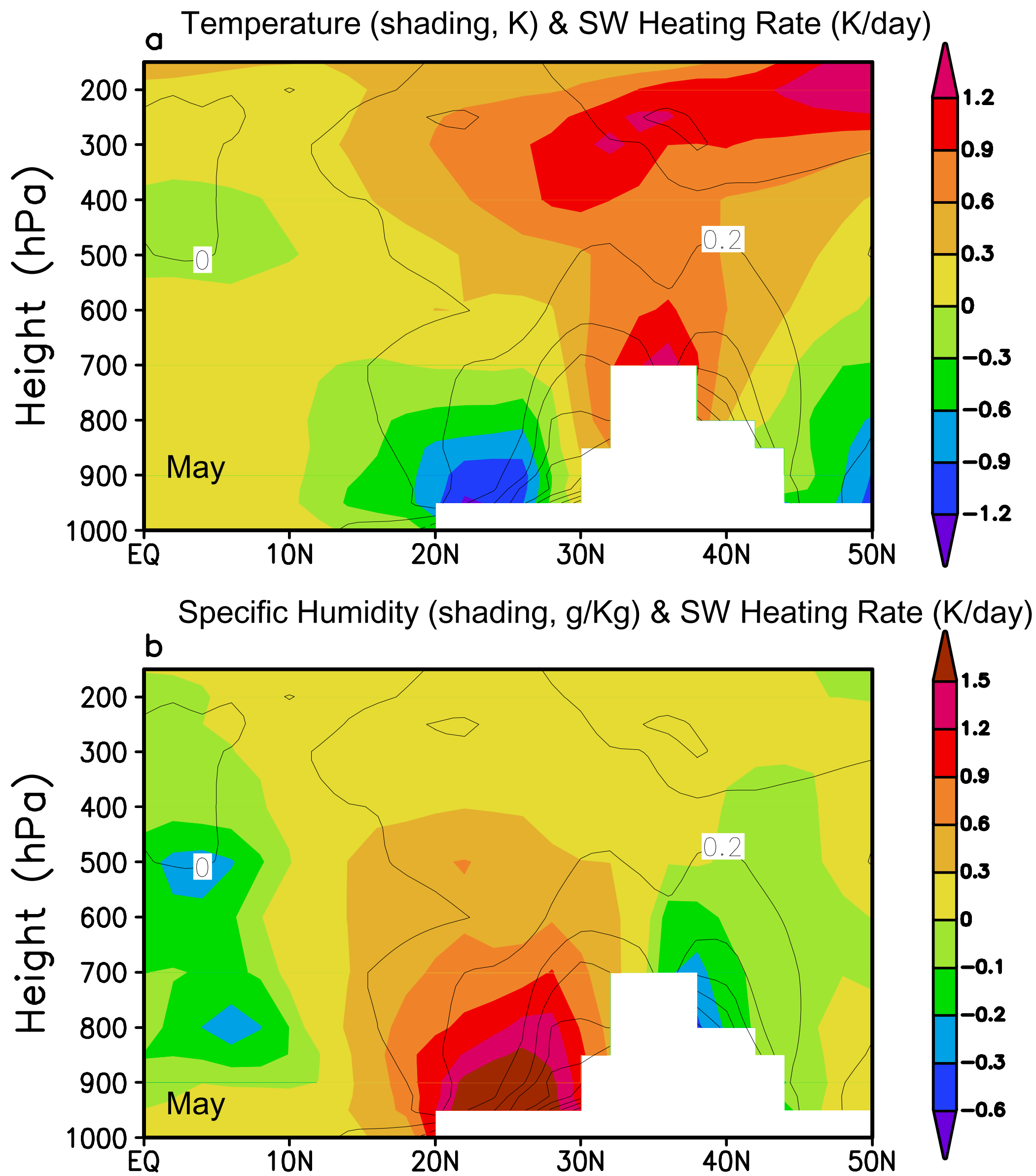
The Himalaya-Tibetan Plateau Glaciers feed seven of Asia's great rivers: the Ganga, Indus, Bramaputra, Salween, Mekong, Yangtze, and Yellow River that supply fresh water to many countries in Asia.

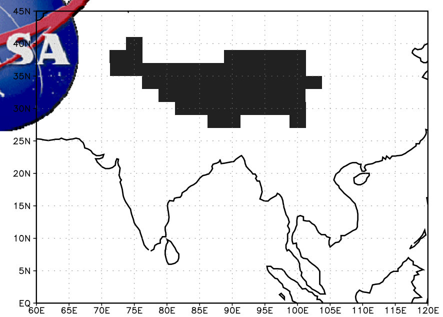
Possible causes of accelerated snowmelt and glacier retreat in the Himalayas and Tibetan Plateau



- Greenhouse Warming
- Atmospheric heating due to aerosols
- Snow-darkening effect from soot and dust

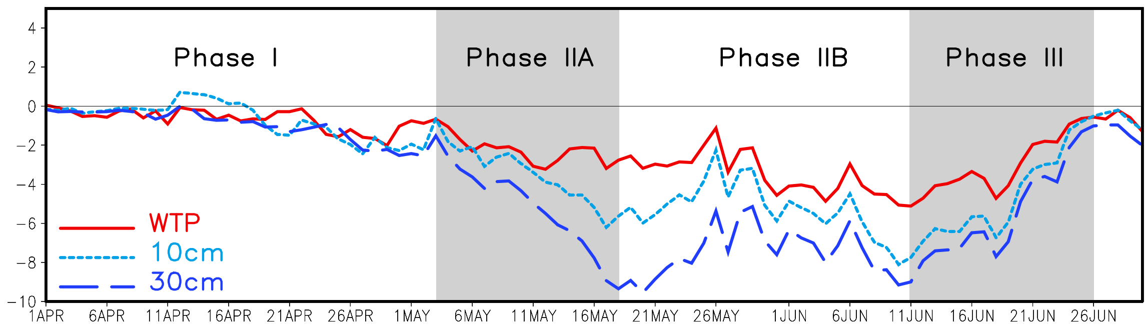
EHP induced heating and moistening along 80^{o}E

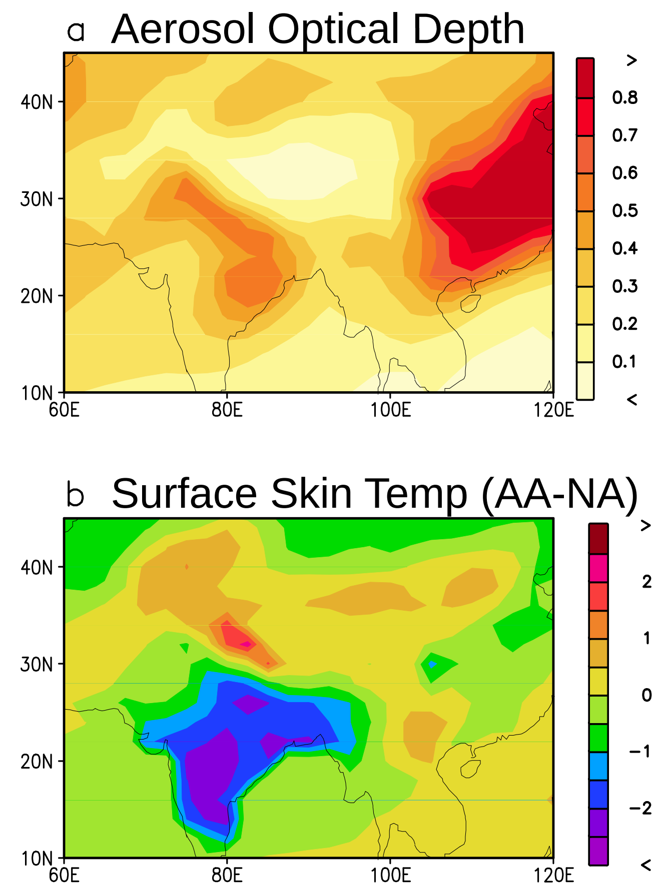




Effect of absorbing aerosols on snow melt over the Tibetan Plateau (EHP Effect)

(GEOS4-fvGCM with Slab Ocean Model)





1. Slow melting phase (I) in April is initiated by sensible heat transfer from warmer atmosphere to land.
2. Rapid melting phase (IIA) is due to an evaporation-snow-land feedback coupled to an increase in moisture over TP
3. Melting is slowed down by increasing surface evaporation in Phase IIB.
4. Partial recovery (Phase III)

Lau, K. M., M. K. Kim, K. M. Kim, and W. S. Lee, 2010: Enhanced surface warming and accelerated snow melt in the Himalayas and Tibetan Plateau induced by absorbing aerosols. Environ. Res. Lett.

“Snow Darkening Effect”:

Black Carbon and Dust deposited on snow surface make it darker. A darker surface absorbs more sunlight, and melts faster

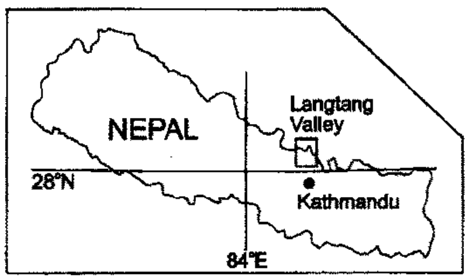
The highest aerosol observatory, NCO-P (ABC-Pyramid): the southern slope of the Himalayas (5079 m a.s.l.)

Meteorological parameters, Optical Particle Counter (OPC; 0.25-32 μ m), Scanning Mobility Particle Sizer (SMPS; 10.31-669.8 nm), and eq uivalent Black Carbon concentration (MAAP) data in 2006 at NCO-P s ite were observed (Bonasoni et al., 2008) and used in this study.

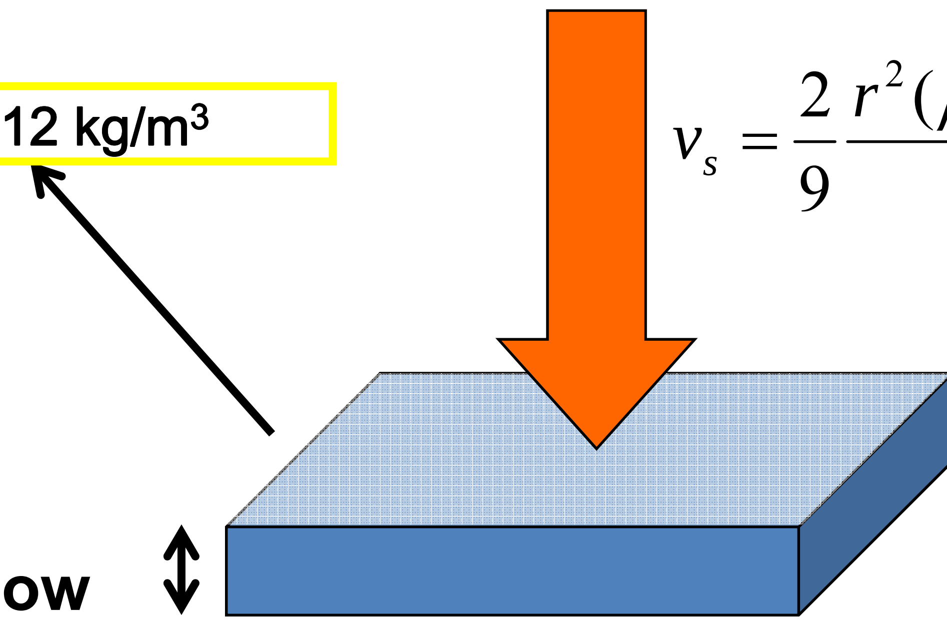
Estimated “lower limit” of BC deposition over Himalayan glaciers

BC deposition of **209** μg/m² by dry fallout du
ring March-May in 2006 (2.27 μg m^{-2} day^{-1})

Surface snow density
at Yala glacier: 195 to 512 kg/m³
(Fujita et al., 1998)



$$v_s = \frac{2}{9}\frac{r^2(\rho_{BC} - \rho_{Air})g}{\eta}$$

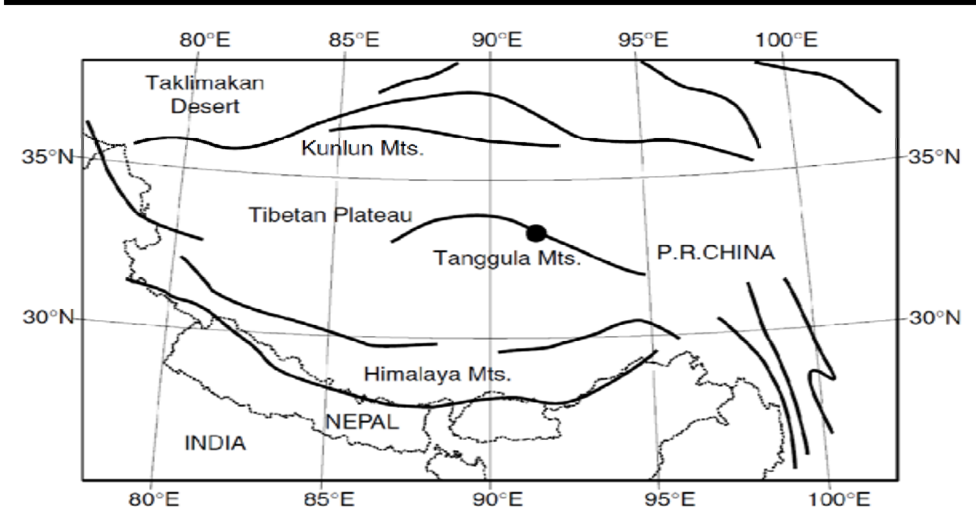


2cm surface snow

Yasunari et al (2010, *ACP*)

Estimation of additional annual runoff from snow-darkening effect

Figure 3. Photograph of the Da (left) and Xiao (right) Dongkemadi Glaciers



•Using a glacier mass balance model (Fujita, 2007, Fujita et al., 2007). with the same input data as used in p revious studies

• Over a typical Tibetan glacier (Dongkemadi glacier), continuous albedo reductions of 1.6 & 4.1% may increase by 9.0-24.8% the annual run off from discharge of melted snow

Building up the case for importance of absorbing aerosols (black carbon and dust) in impacting monsoon water cycle and climate.

Heating by absorption of solar radiation by soot and dust in the Hindu-Kush-Tibetan-Himalayas (HKHT) region initiates an atmospheric feedback via the EHP effect leading to:

- Increased mid-tropospheric radiative heating along Himalayas foothills enhances convection in northern India, leading to warming and moistening of the middle and upper troposphere over the HKHT region; enhancing the **early** summer monsoon…….
- The hotter and moister atmosphere transfers sensible and latent heat to the HKHT land surface, enhancing early spring snow melt

Snow-darkening effect with typical soot deposition, may lead to 1-4 % reduction in surface albedo; leading to 9-24% increase in annual runoff in a typical TP glacier.

- Both EHP and snow darkening effect may accentuate greenhouse warming, leading to early season snowmelt and accelerated glacier retreat.

Societal /Moral Dilemmas

1) Life Time of Greenhouse Gases effects are centuries or longer
   Doing nothing now, will cause us much more later!
   Should we let our grand children deal with it?
   Should climate change policies be based on equal shared burden for all or provide help for the under-developed first ?

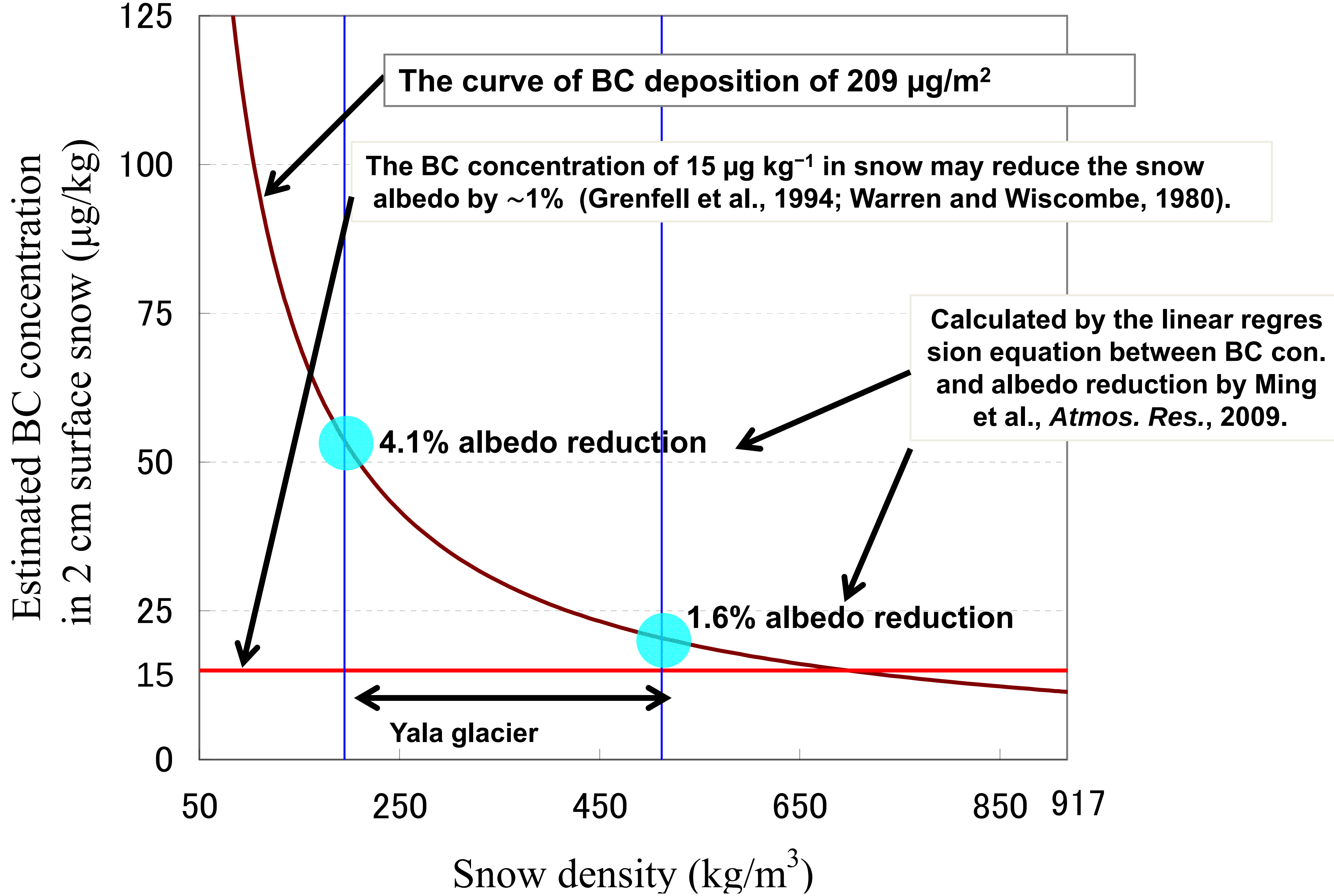
2) GHGs vs. Aerosols
   The warming that we are experiencing now is only a portion (~ 60- 70%) of what we expect from well mixed gas greenhouse effect , because of cooling (masking) effects by aerosols. *Air Pollution has shorter lifetime (days, weeks), compared to GHG (decadal, century time scale), and is easier to realize benefit, but global warming will be enhanced without it.*

3) Geo Engineering ?? e.g. injecting sulphate aerosols in lower stratosphere…
   Don't go there. *Beware of the "Law of Unintended Consequences" !.*

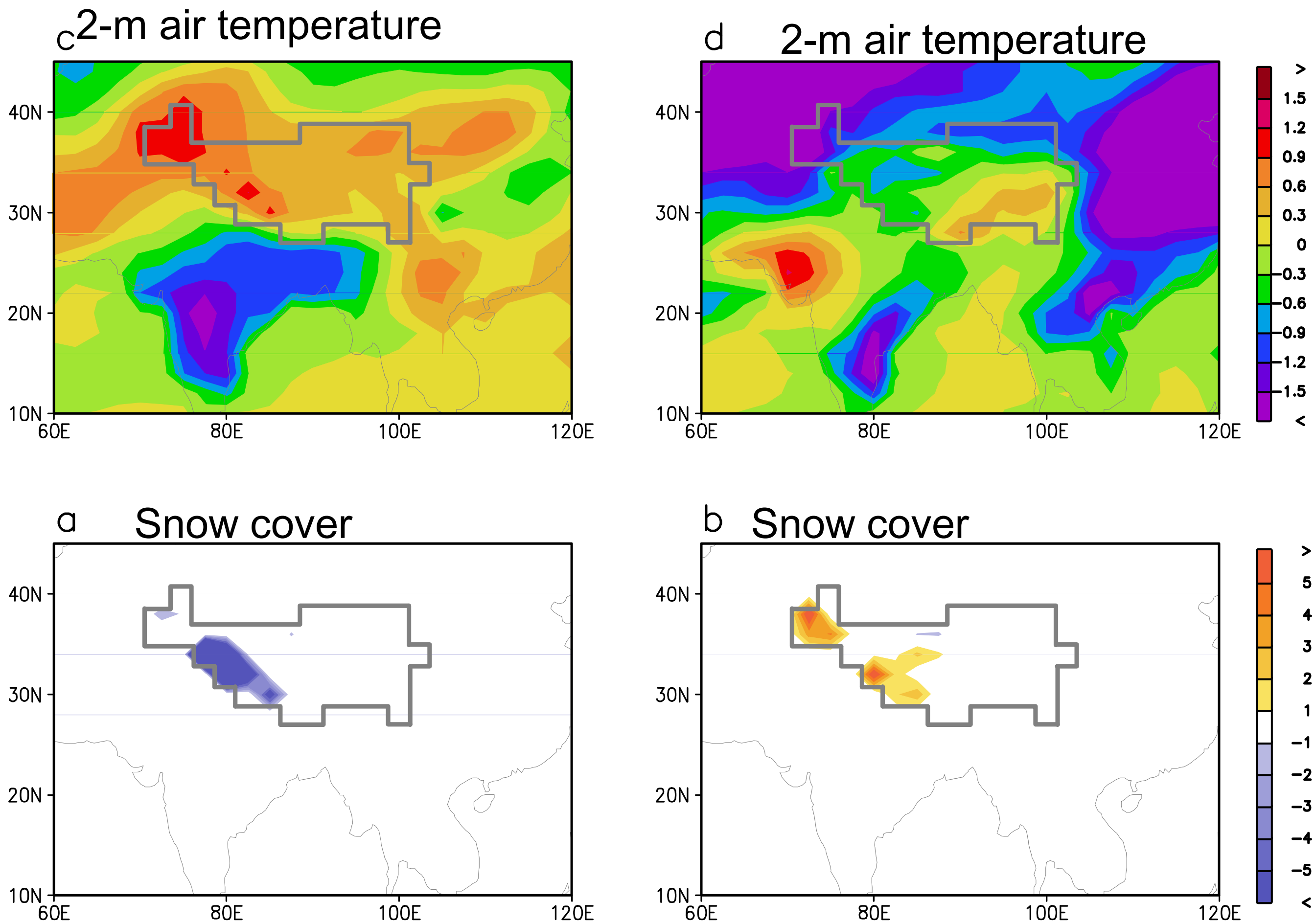
4) Regionally, the science is still unfolding, and Asia is potentially the most vulnerable region:
   Pollution may induce droughts and floods in Asian monsoon regions;
   Accelerated melting of high mountain glaciers caused by black carbon and dust
   Asian countries should adopt different priorities, compared to more industrialized countries

Back Up

Estimated BC concentration in 2 cm surface snow with surface snow density variations at Yala glacier



Absorbing aerosols (dust and BC) reduce snowcover but reflecting aerosols (sulphate) increase snowcover in western Himalayas

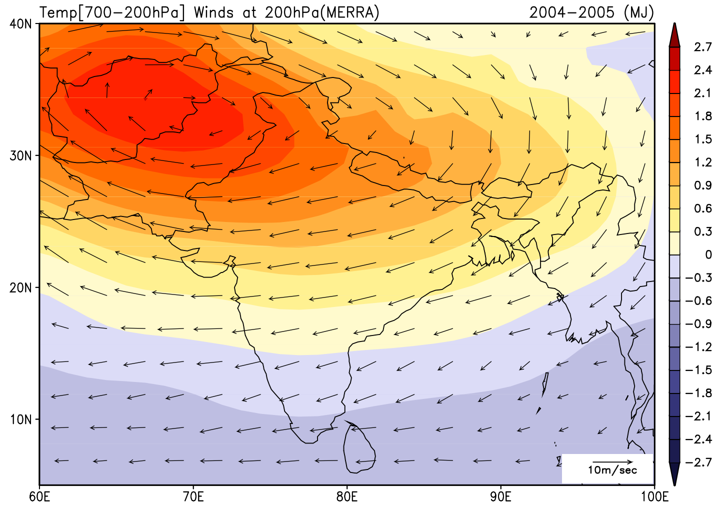


All Aerosols–minus-No Aerosols

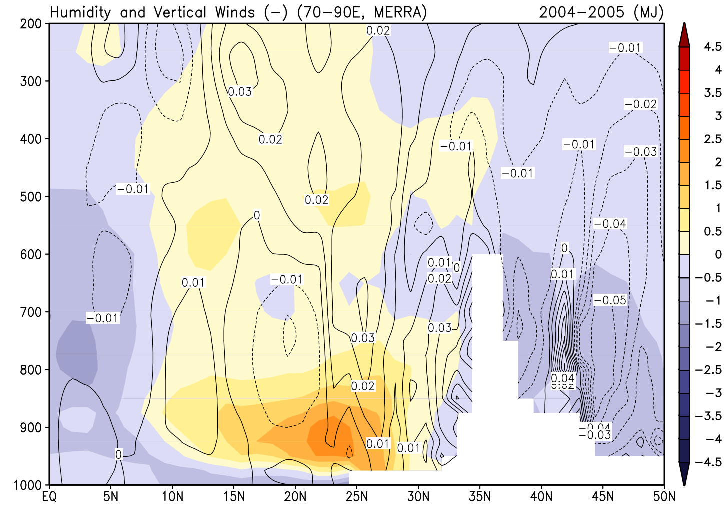
Sulphate only –minus-No Aerosols

May/June Difference between 2004 and 2005
Dirtier year minus cleaner year

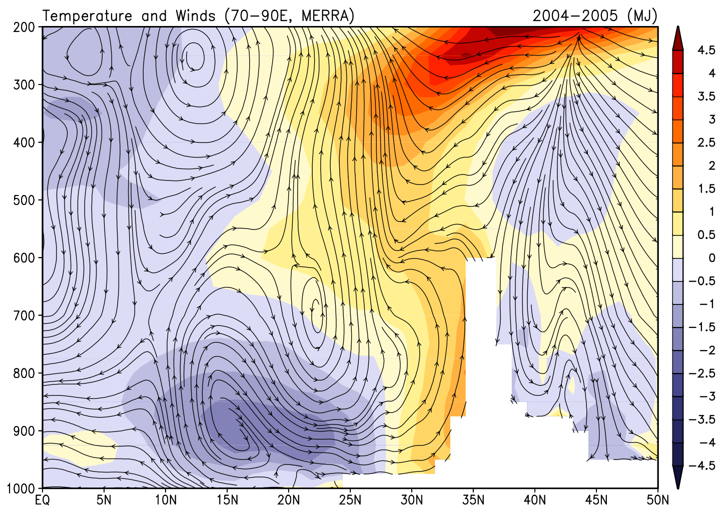
Upper level Temperature & Wind



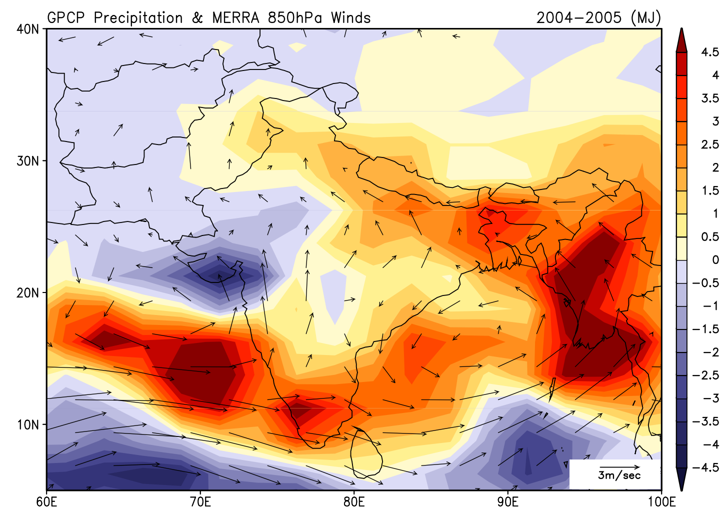
Moisture & Vertical Winds



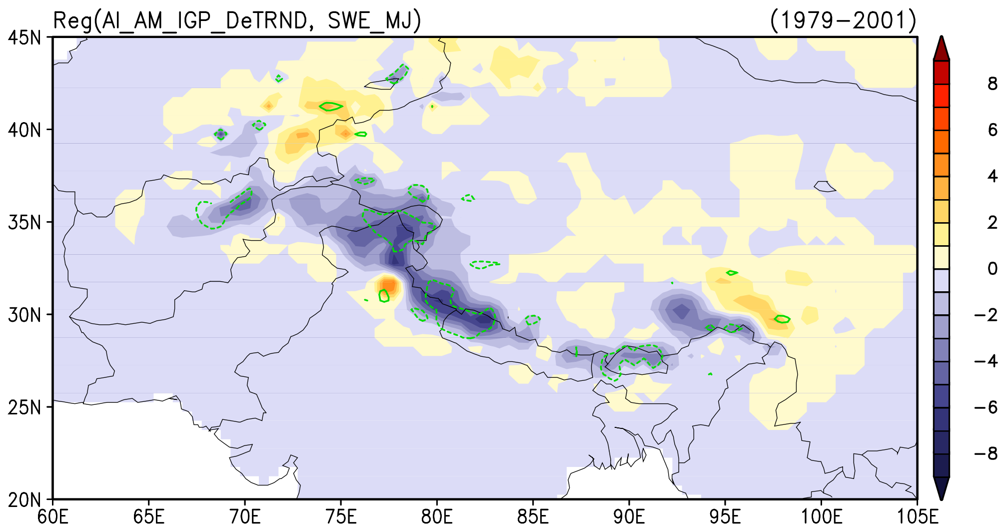
Temperature & winds (v-w)



Lower level Winds & Rainfall

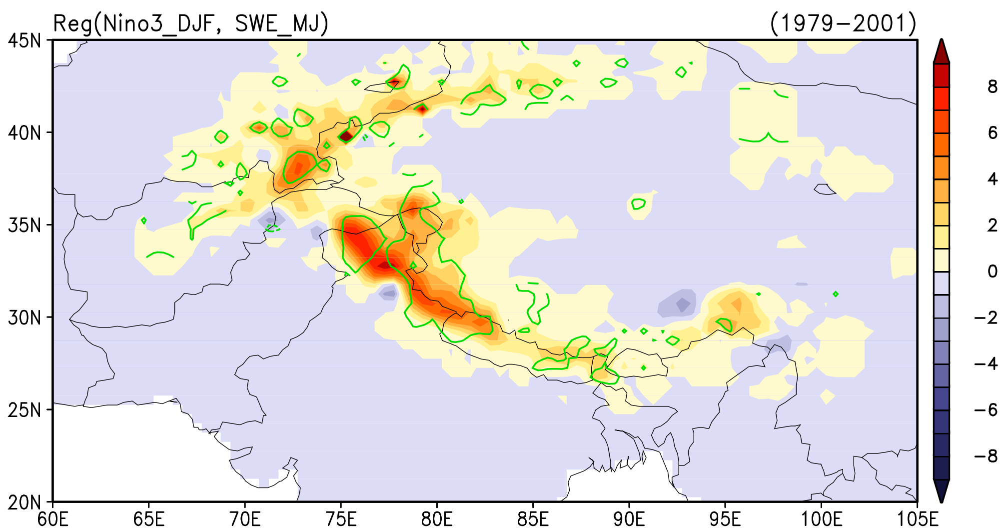


Interannual Variation of Snow Water Equivalent (Aerosol vs El Nino)



Aerosol Effect

Heating of the atmosphere by dust and BC can lead to widespread enhanced warming over the TP and accelerated snow melt in the western TP and Himalayas. (Lau et al. 2010) Decreased snow albedo due to BC/dust deposition can further accelerate snow melt (Yasunari et al. 2010)



El Nino Effect

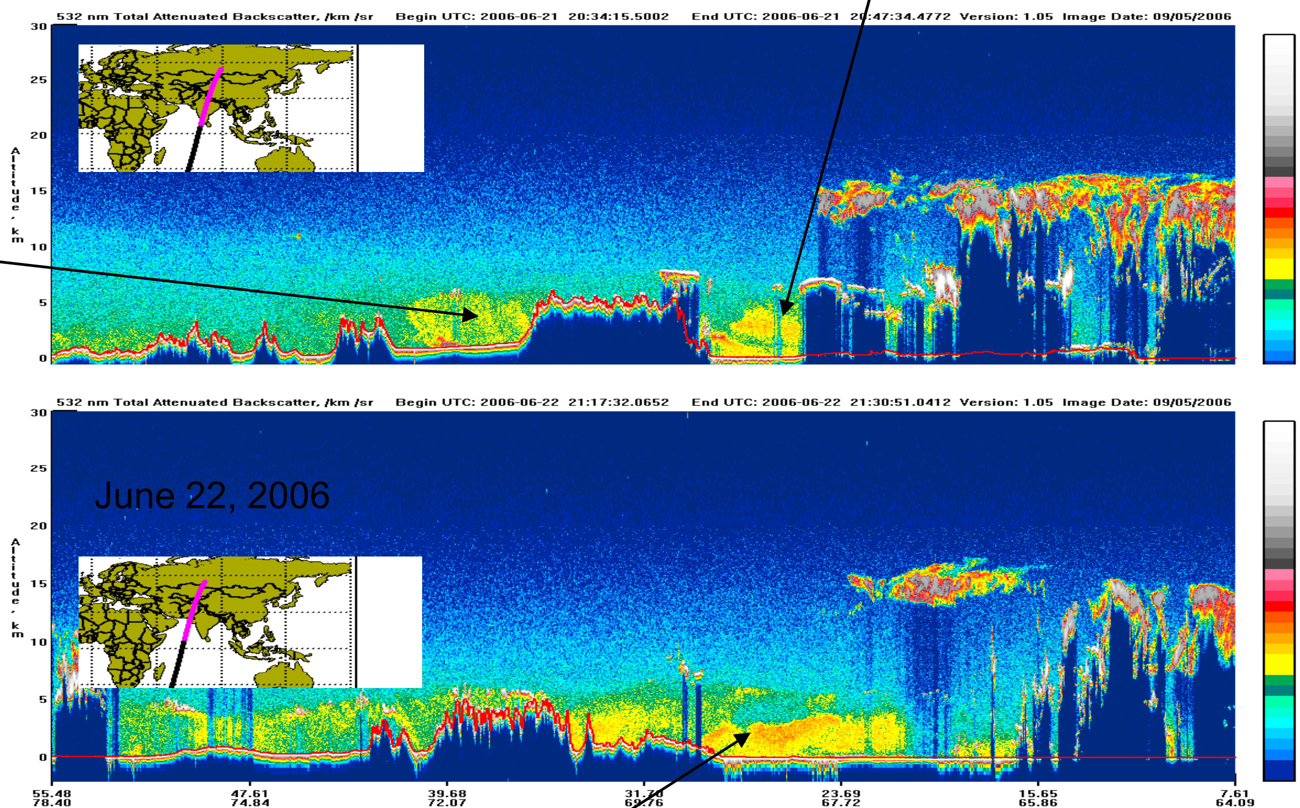
The atmospheric teleconnection pattern initiated by ENSO increase snowfall over TP during winter. The increased snowfall produces a larger snowpack which lasts through the spring and summer, and subsequently weaken the Indian monsoon (Shaman and Tziperman 2005).

Merdional cross-section of aerosol concentration from Calipso

June 21,2006

Indo-Gangetic Basin

Taklamakan Desert

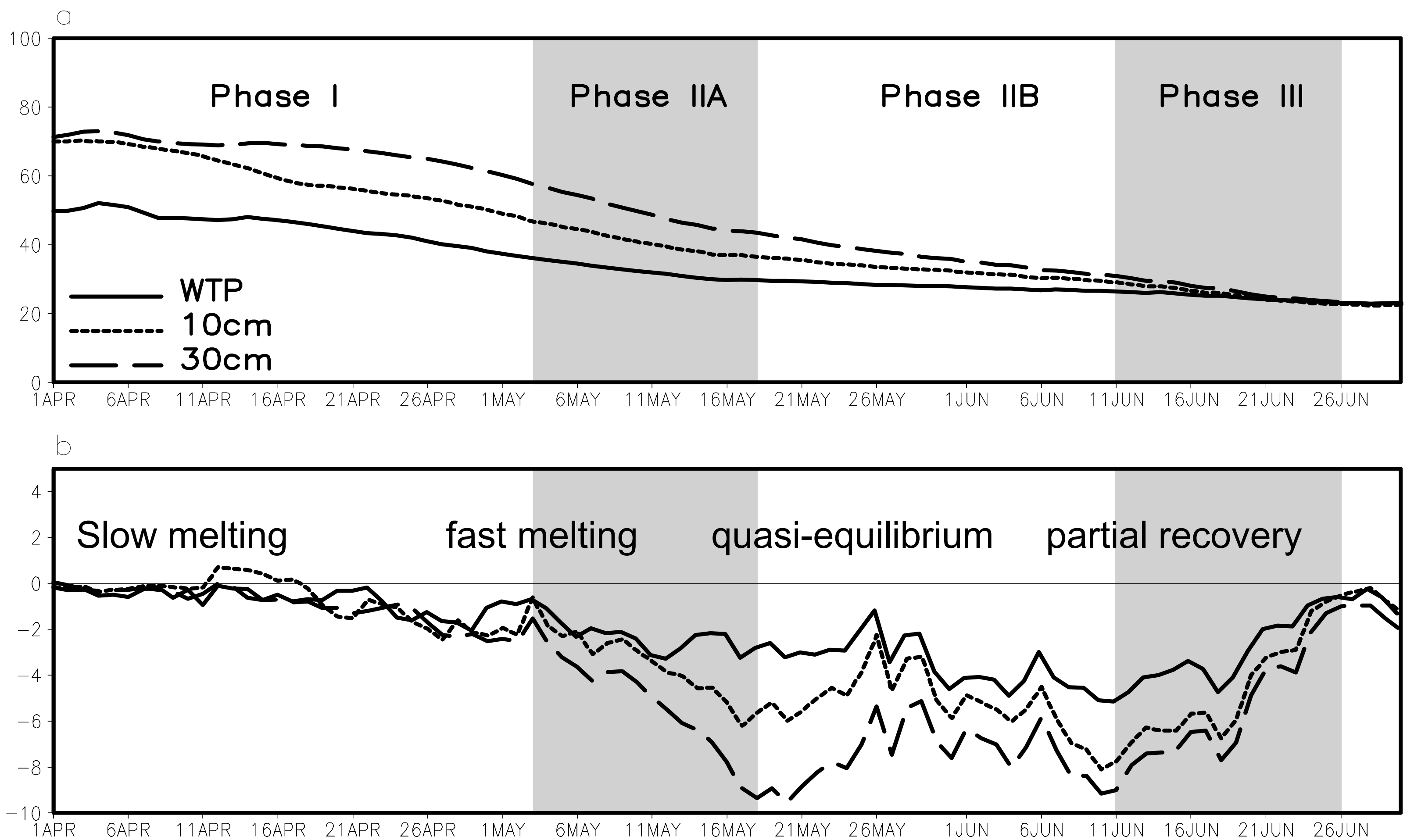


northeastern IGB

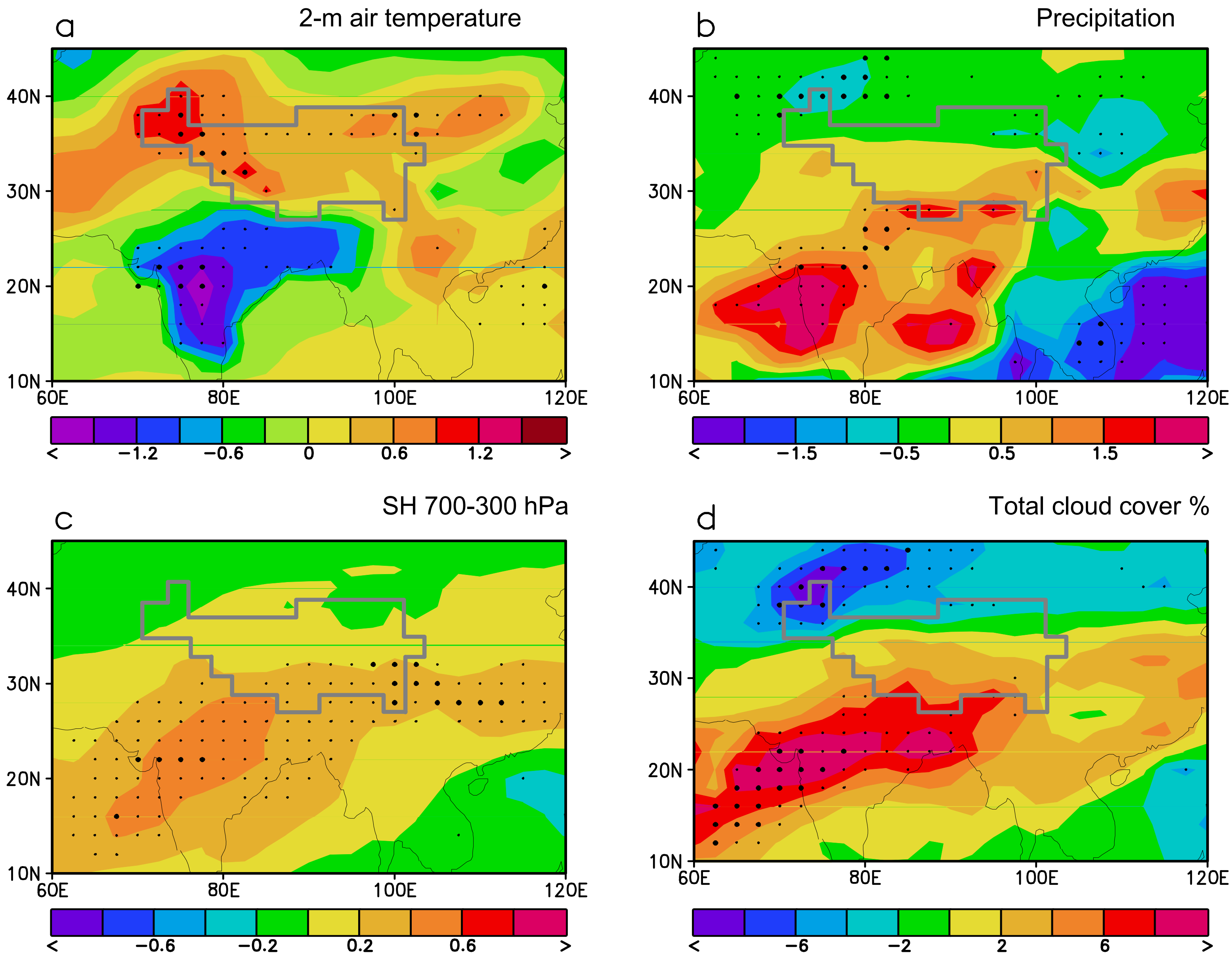
Reference"

Lau, K.-M., K.-M. Kim (2008), Absorbing aerosols enhance Indian summer monsoon rainfall. iLEAPS Newsletter, No. 5, 22-24.

Relative percentage change of surface albedo (due to changes in snow-cover, and exposure of underlying land surface)



GEOS GCM, Aerosol-minus-No Aerosol, for month of May



Enhanced surface warming and accelerated melting of snowpack in the Himalayas and Tibetan Plateau induced by absorbing aerosols

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National Geographic

Photo Gallery

Tibetan Plateau

Glaciers that feed great Asian rivers are shrinking. See photographs by Jonas Bendiksen.

Video

Behind the Photo

Sometimes called the Third Pole, the region is a lockbox of snow and glacial ice that supplies fresh water to nearly a third of the world's people.

Interactive

Freshwater 101

We live on a planet covered by water, but how much is freshwater?

Tibetan Plateau

Published: April 2010

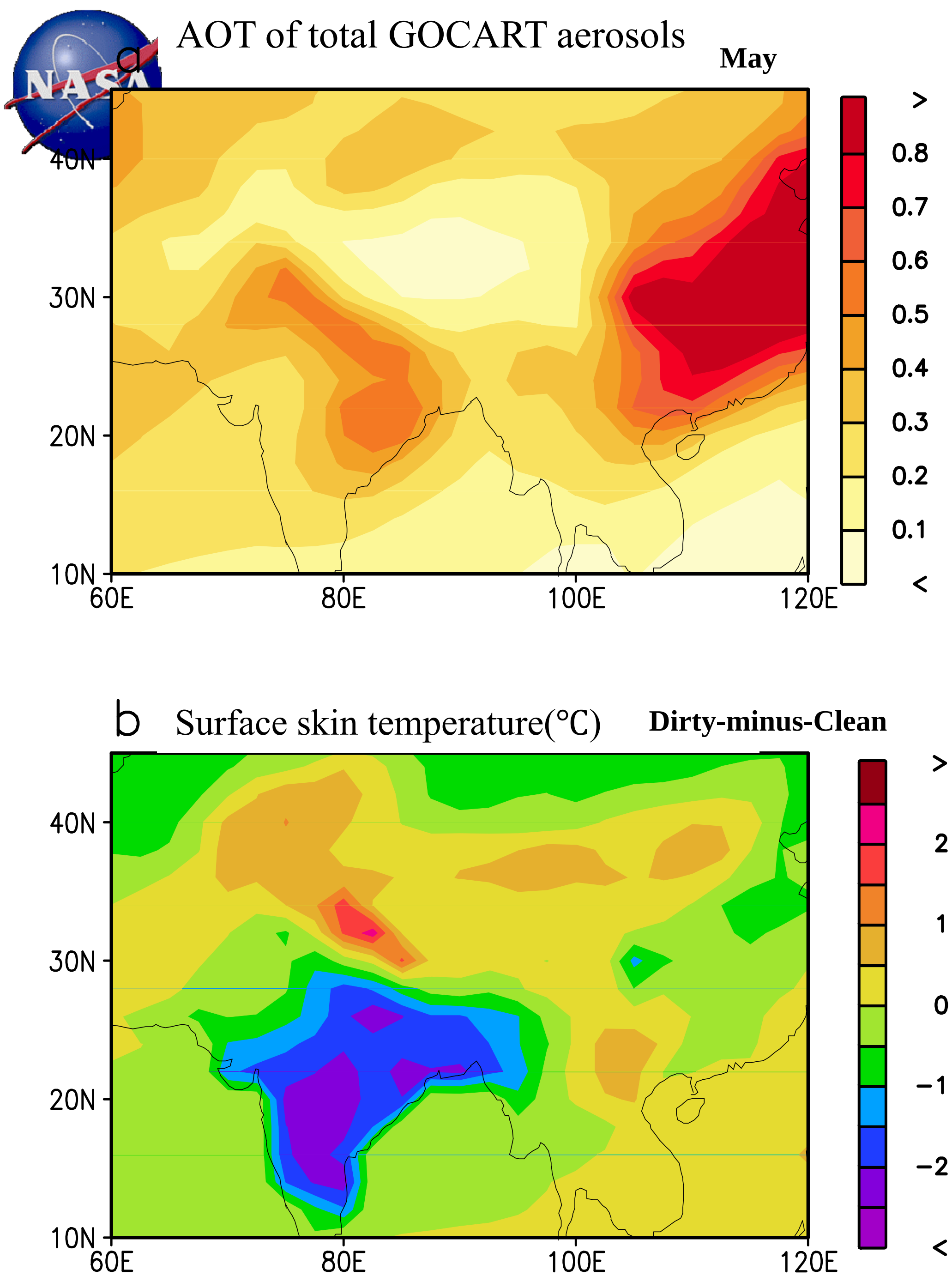
The Big Melt

Glaciers in the high heart of Asia feed its greatest rivers, lifelines for two billion people. Now the ice and snow are diminishing.

By Brook Larmer
Photograph by Jonas Bendiksen

The gods must be furious.

It's the only explanation that makes sense to Jia Son, a Tibetan farmer surveying the catastrophe unfolding above his village in China's mountainous Yunnan Province. "We've upset the natural order," the devout, 52-year-old Buddhist says. "And now the gods are punishing us."



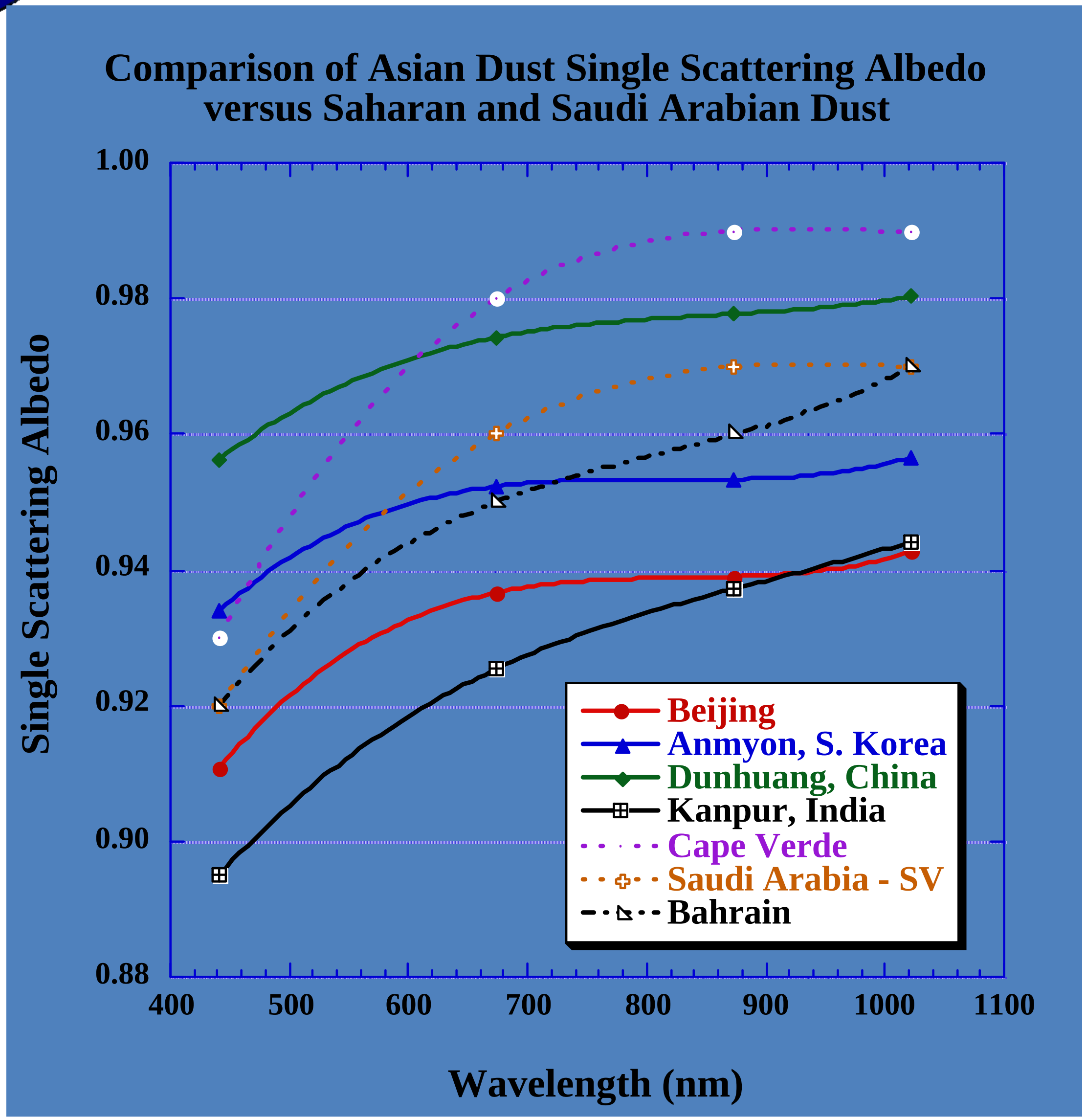
Area-averaged composition of aerosols in May

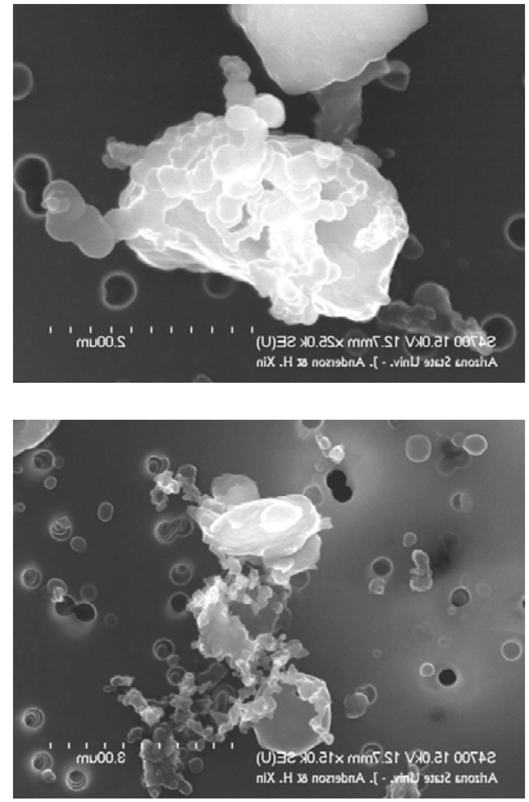
Region / Aerosol Type	IGP [75~90°E, 17.5~30°N]	TP [80~95°E, 30~35°N]	Central China [105~120 ° E, 25~35°N]
All aerosols	0.24	0.15	0.73
Black Carbon	(11.7%)	(10.7%)	(8.0%)
Dust	(41.9%)	(43.3%)	(15.8%)
Sulfate	(15.8%)	(22.3%)	(62.5%)
Organic Carbon	(26.5%)	(20.4%)	(12.4%)
Sea salt	(3.8%)	(3.0%)	(1.1%)

Lau et al. 2010 *ERL*

How absorbing are dust aerosols ????

More absorbing





Micrographs of
soot coating and aggregate
on mineral dust from Asian dus
t (courtesy of J. Anderson)

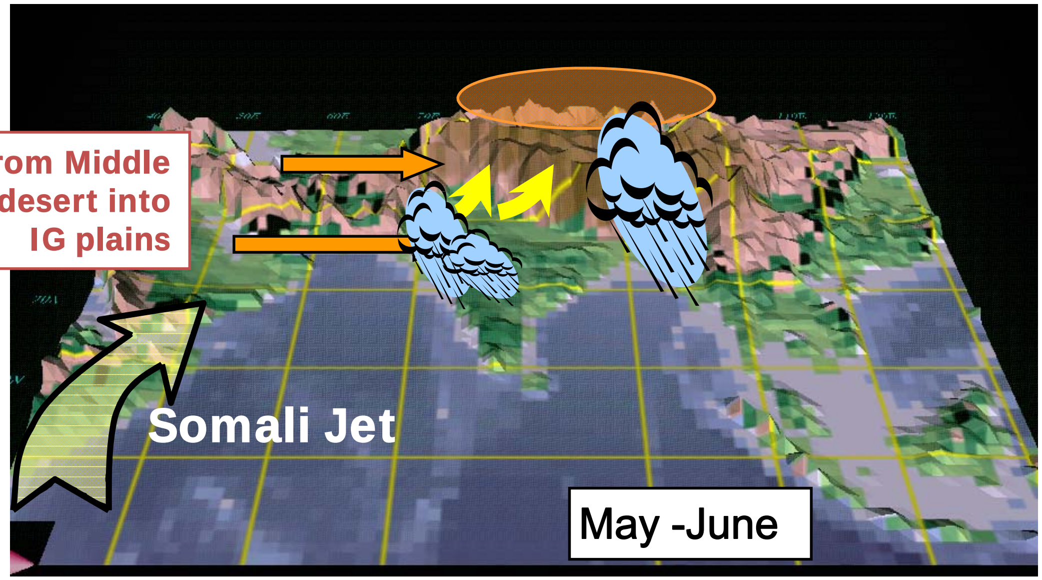
Dusts over major industrial cities are more absorbing (solar radiation)

T. Eck et al 2004

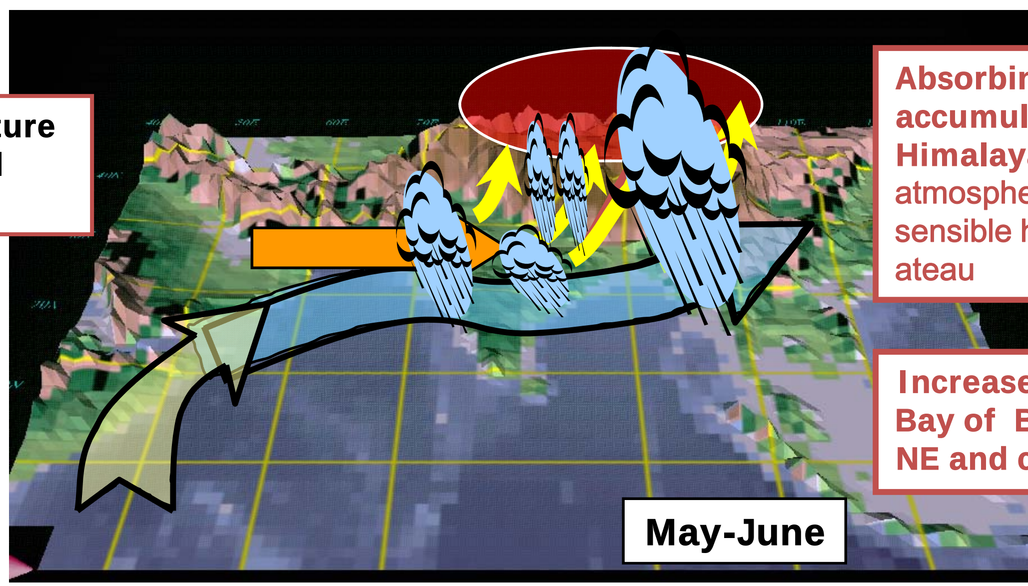
The Elevated Heat Pump Hypothesis

(Lau et al. 2006, Lau and Kim 2006)

Dust transport from Middle East and Thar desert into IG plains



Increase dust and moisture transport from low level monsoon westerlies

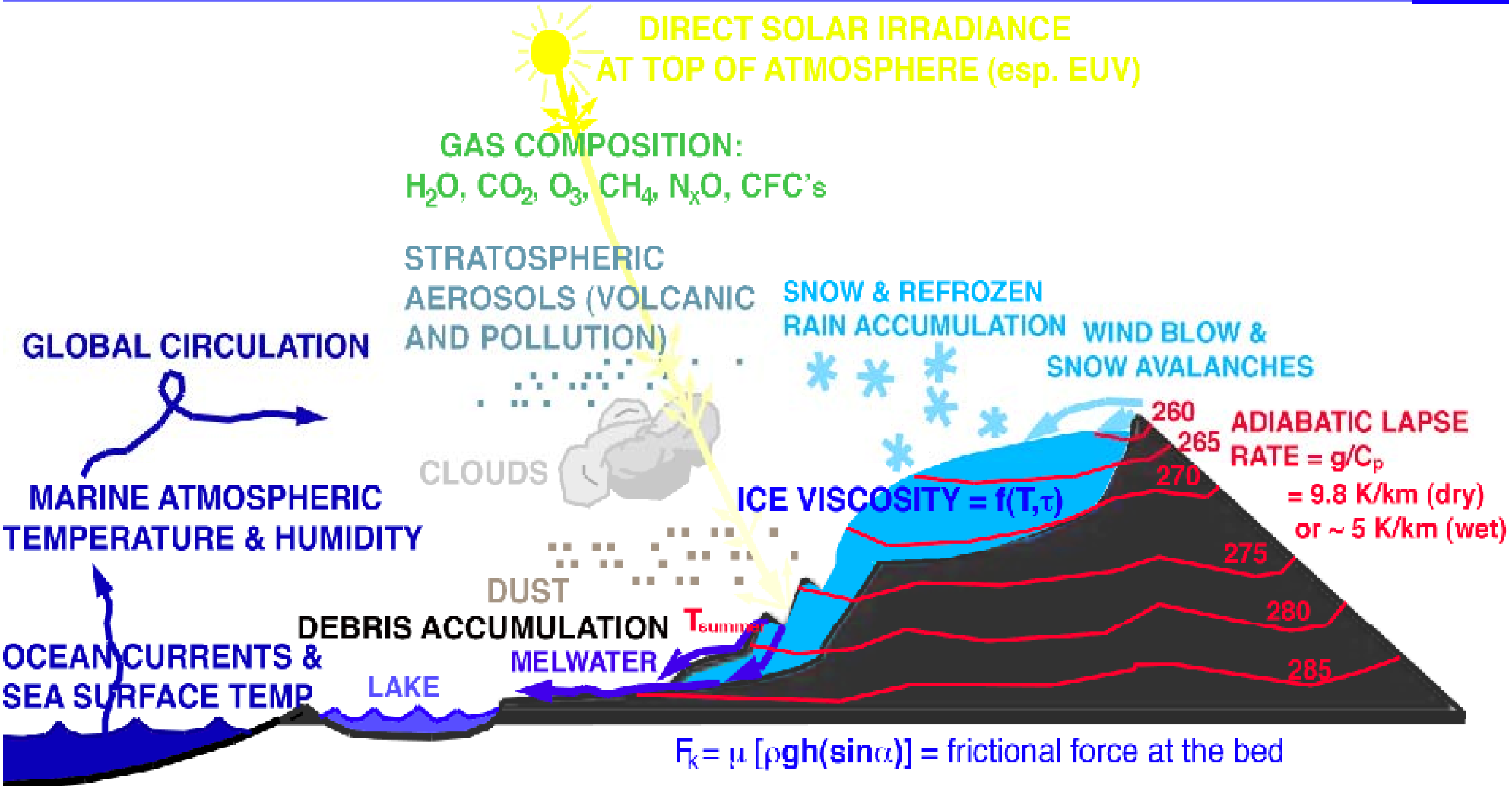


Absorbing dust and BC accumulated on foothills of Himalayas accentuate atmospheric heating by sensible heat flux over Tibetan Pl ateau

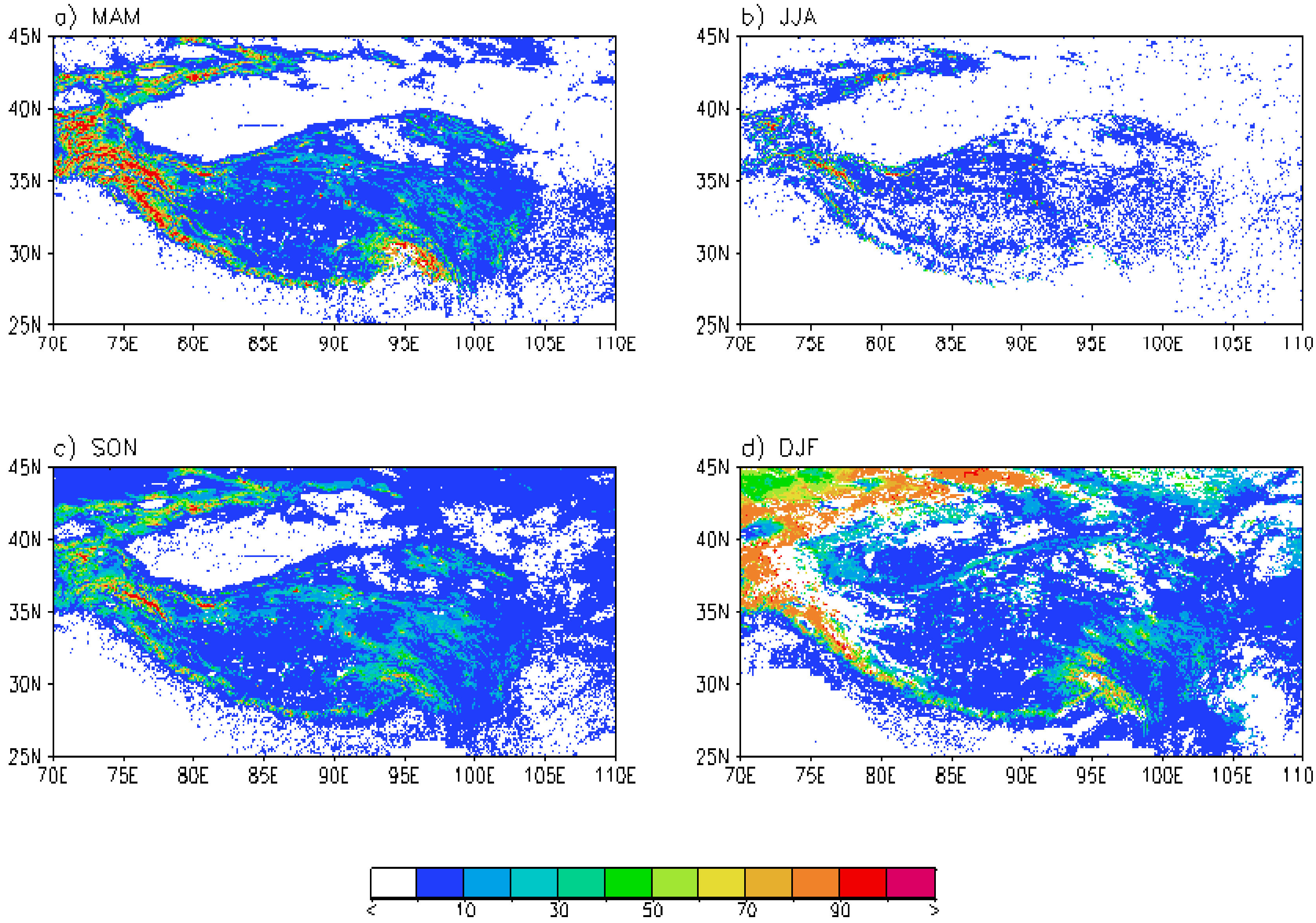
Increased convection over Bay of Bengal, eastern TP, NE and central India

Courtesy: Jeff Kargel

Climate and environmental change related to glaciers is more than about rising temperatures



Seasonal mean of snow cover fraction(%) over TP from 2000 to 2009



NASA fvGCM Experimental Set-up

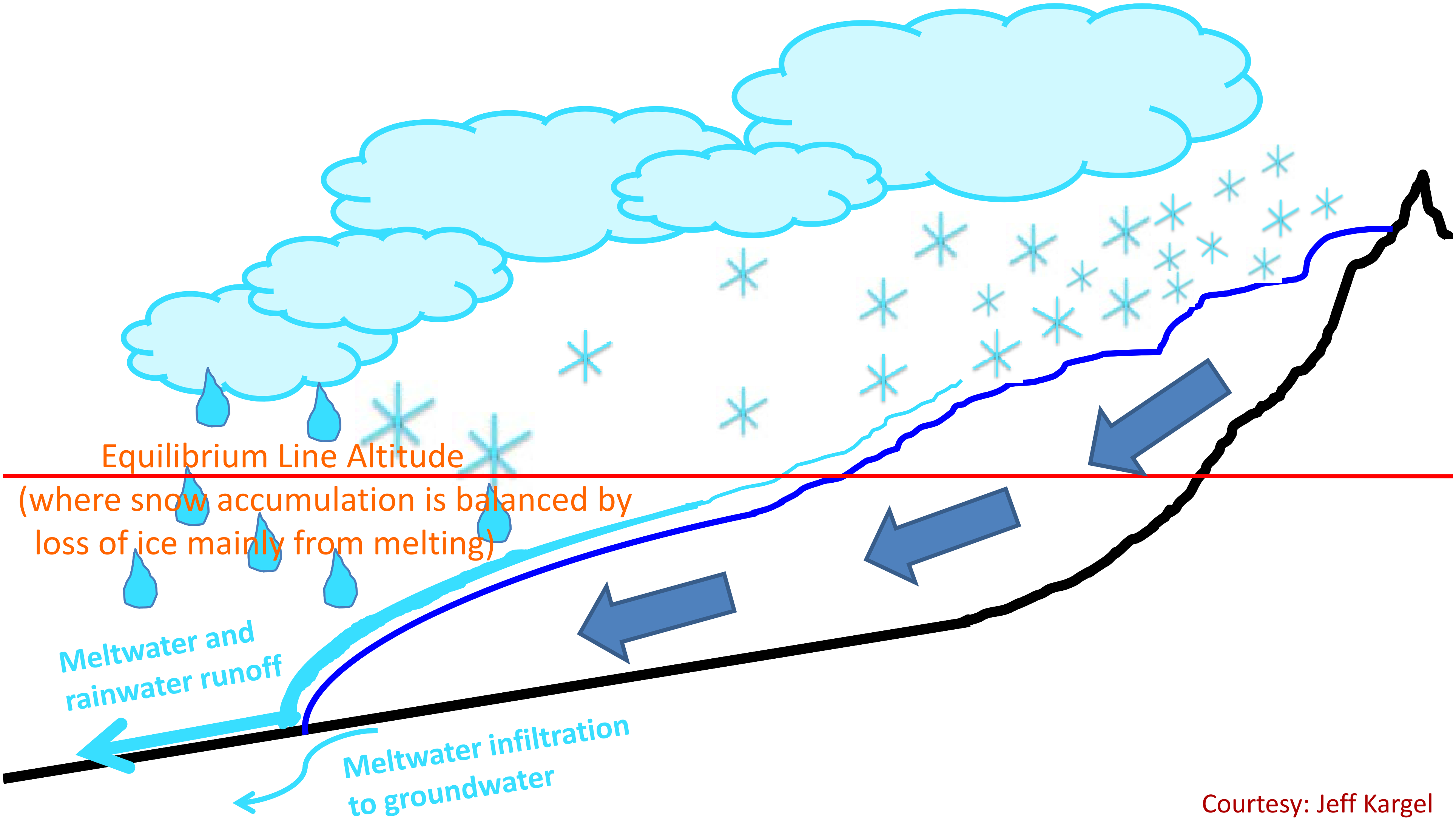
- Four sets of 8 year simulations (2000-2007), coupled to mixed layer ocean, and interactive land surface model, with same CO_2 forcing, for:

- Control (dirty) with prescribed seasonally varying aerosol loading (dust, BC, OC, sulfate, and sea salt), and computed radiative forcing, i.e., all aerosol (AA)

- Anomaly (clean world): with aerosol radiative forcing disabled, i.e., no aerosol (NA).

- Additional experiments: non-absorbing aerosol (sulphate) only

Generalized glacier

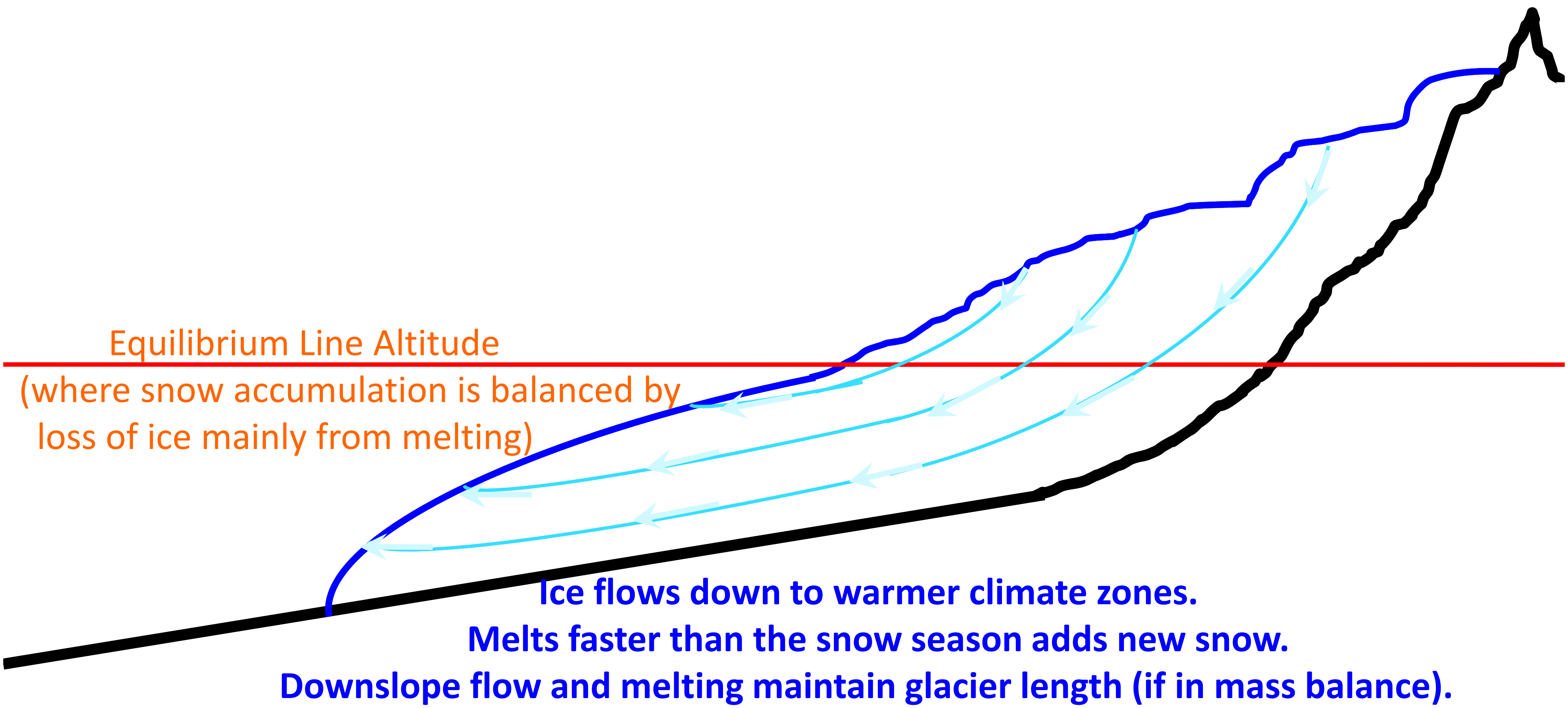


Courtesy: Jeff Kargel

CONTACT: Jeff Kargel

Generalized glacier

The Equilibrium Line Altitude is where snow accumulation (snowfall an
d any added snow avalanches) is balanced by melting and sublimation
losses. It is not the same as the elevation where annual average temp
erature is at the melting point (but there is a relationship).



Possible major causes of accelerated snowmelt and glacier retreat

- Sixty-seven percent of glaciers are retreating at a startling rate in the Himalayas, and the major causes have been identified as global warming . *Ageta and Kadota 1992, Yamada et al. 1996, Fushinmi 2000).* Overall, Himalaya glaciers are losing mass rapidly at a rates about 500 -1000 kg m^{-2}/year, but rates are highly variable in space and time.

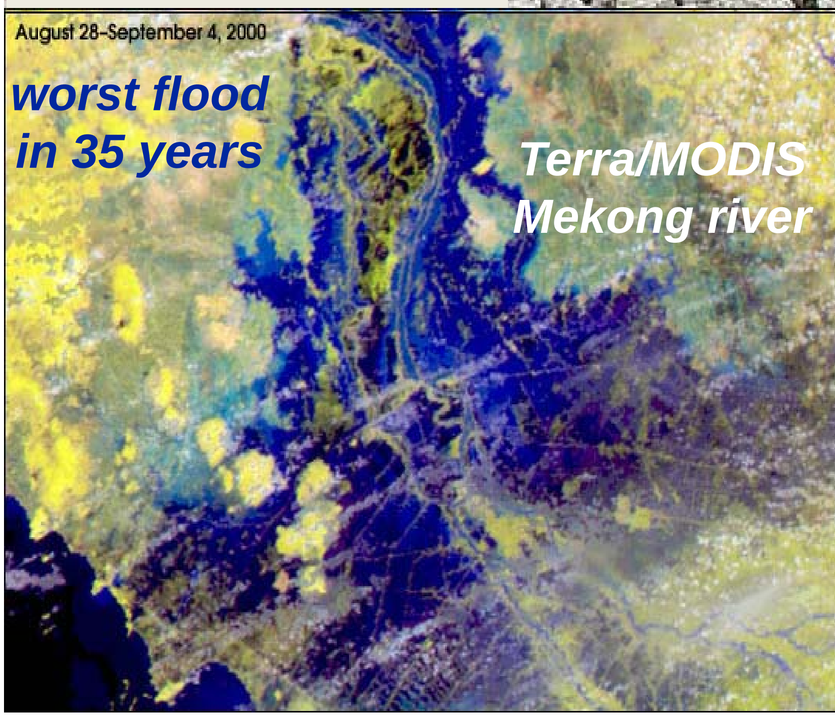
- Aerosols may accelerated snowmelt and glacier retreat.
  - <u>Atmospheric heating due to aerosols</u>
  - Snow darkening effect

Summary

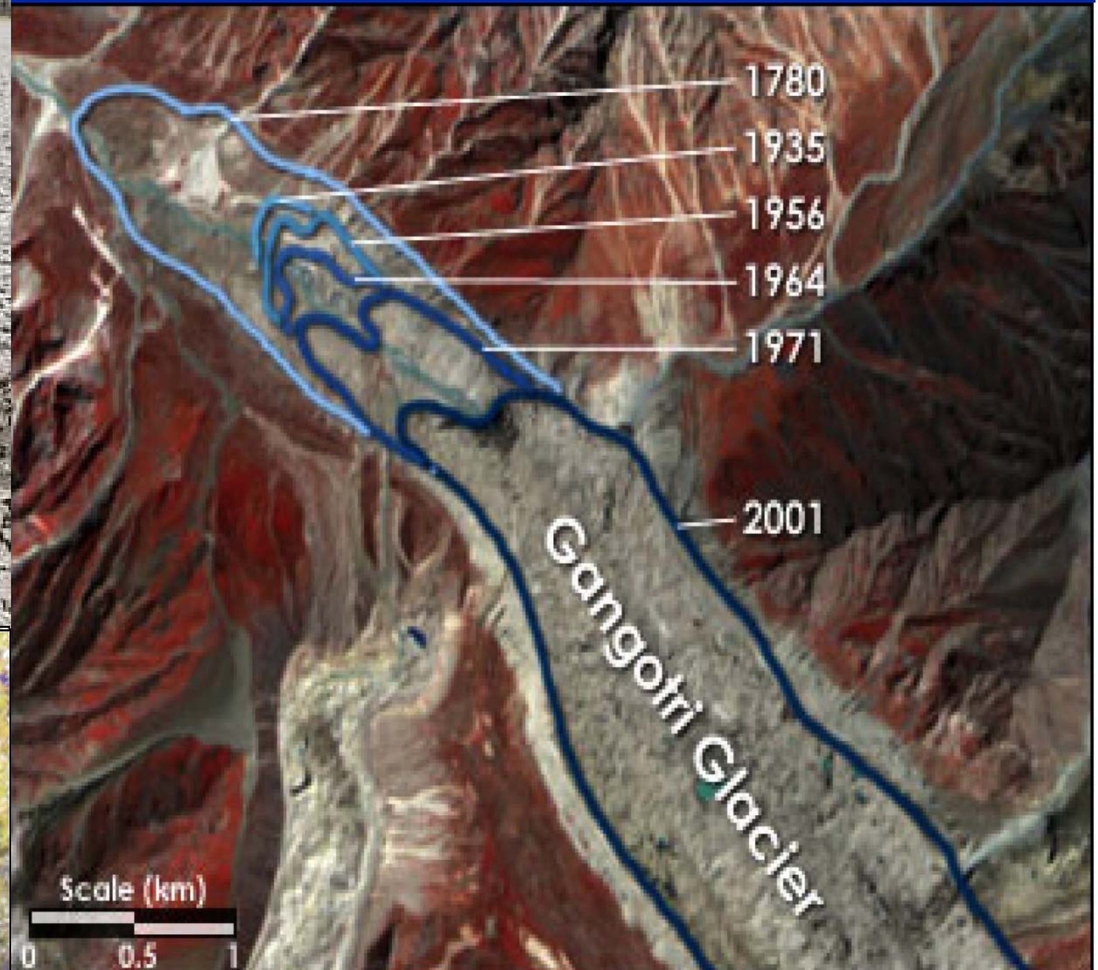
1. Previous results from GCM experiments shows that the heating by absorption of solar radiation by soot and dust in the IGP region initiates an atmospheric feedback via the EHP effect leading to:

- Increased mid-tropospheric radiative heating along Himalayas foothills enhances convection in northern India, leading to warming and moistening of the middle and upper troposphere over the TP and early snow melt

2. Observations show that mid to upper tropospheric temperature warming is prominent in the year (2004) with high aerosol loading over north-west India and IGP as compare to low AOD year (2005). Anomalous patterns of IGP rainfall, surface temperature at the TP , and the snow water equivalent are consistent with those from model simulation.



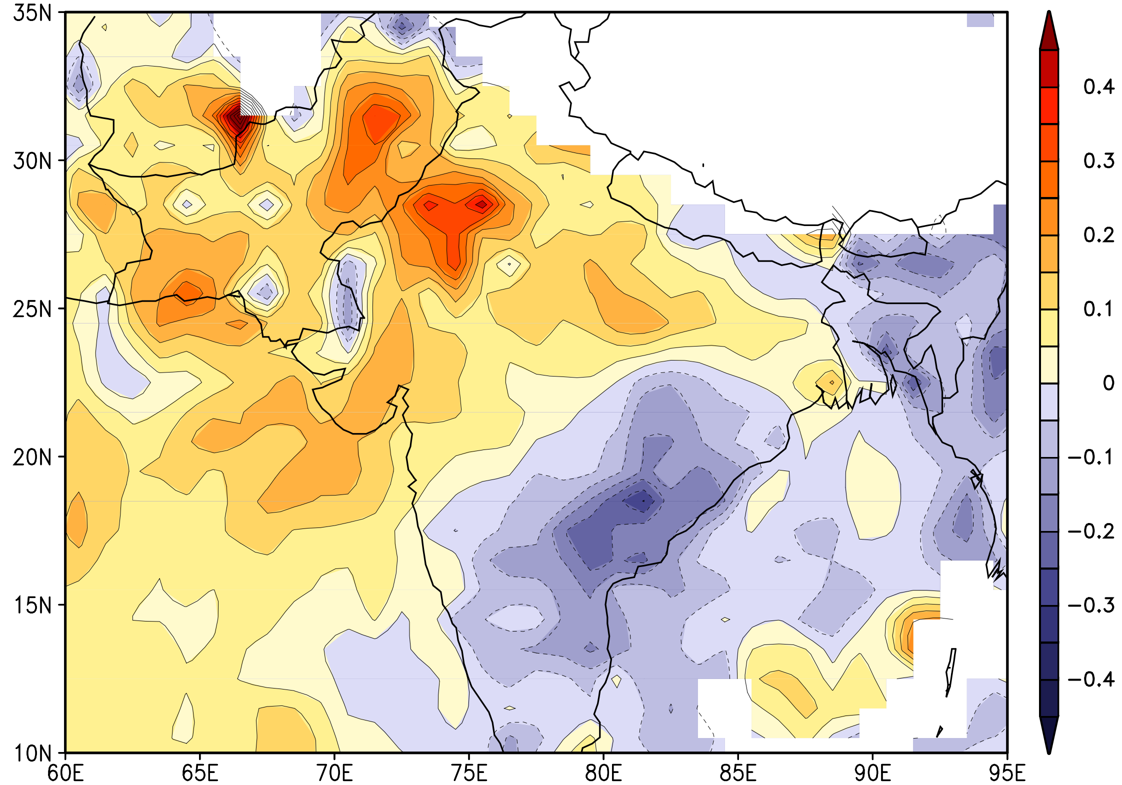
What cause these..



Composite of ASTER/Landsat images and h istorical photographs depicts how the Indian Gangotri Glacier terminus has retracted sinc e 1780 (the GLIMS project: Kieffer et al., 20 00, Global Land Ice Measurements from Sp

Observational Case Study
2004 vs 2005

Aqua AOD + DeepBlue
Apr-May (2004 minus 2005)



Data Used

MODIS AOD

Snow cover (MODIS/Terra)

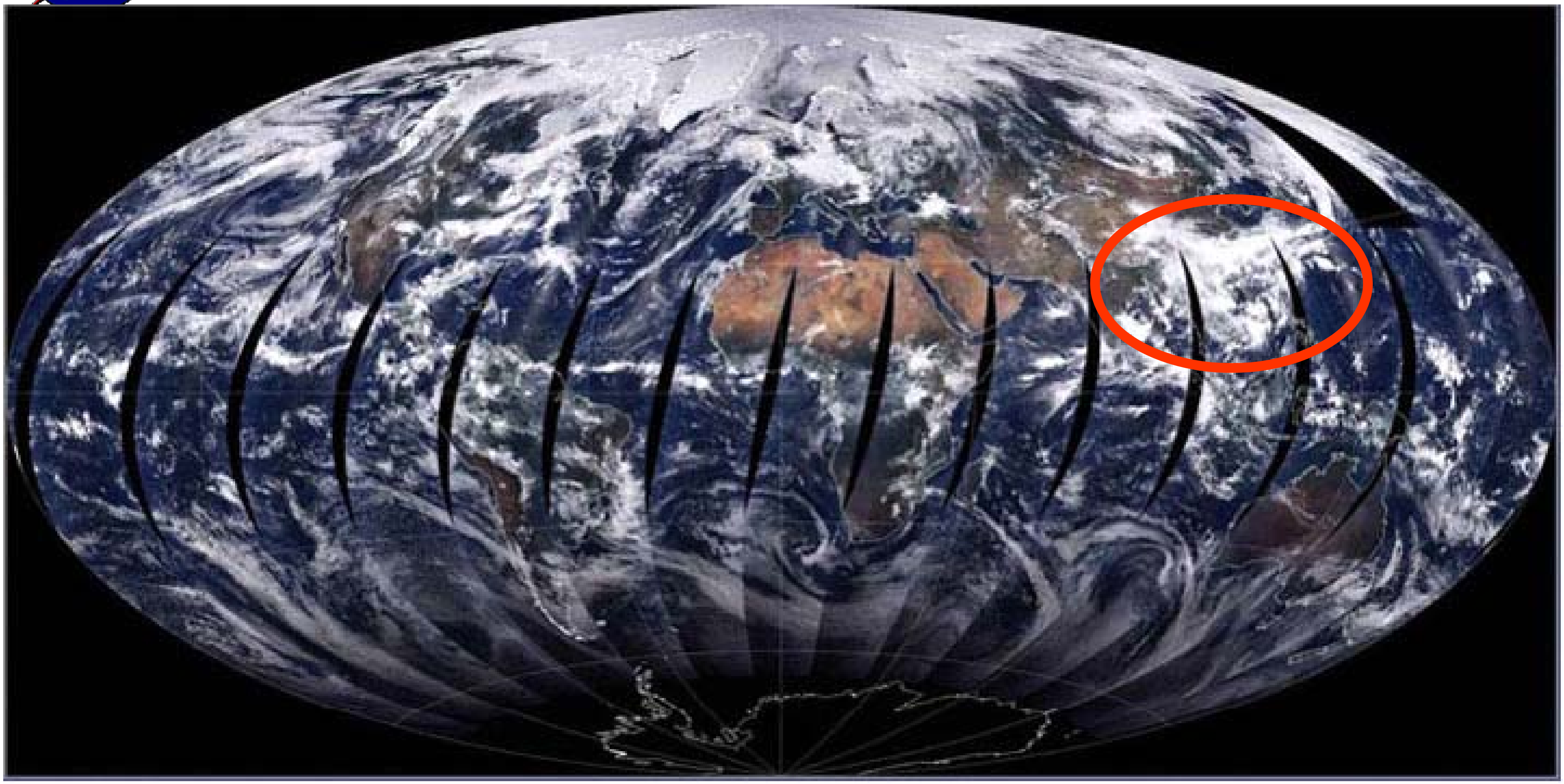
Snow Water Equivalent
(SSMR & SSM/I) & (AMSR-E)

MERRA Winds & Temperature

Surface Temperature (AIRS)

Nino3 SST Index

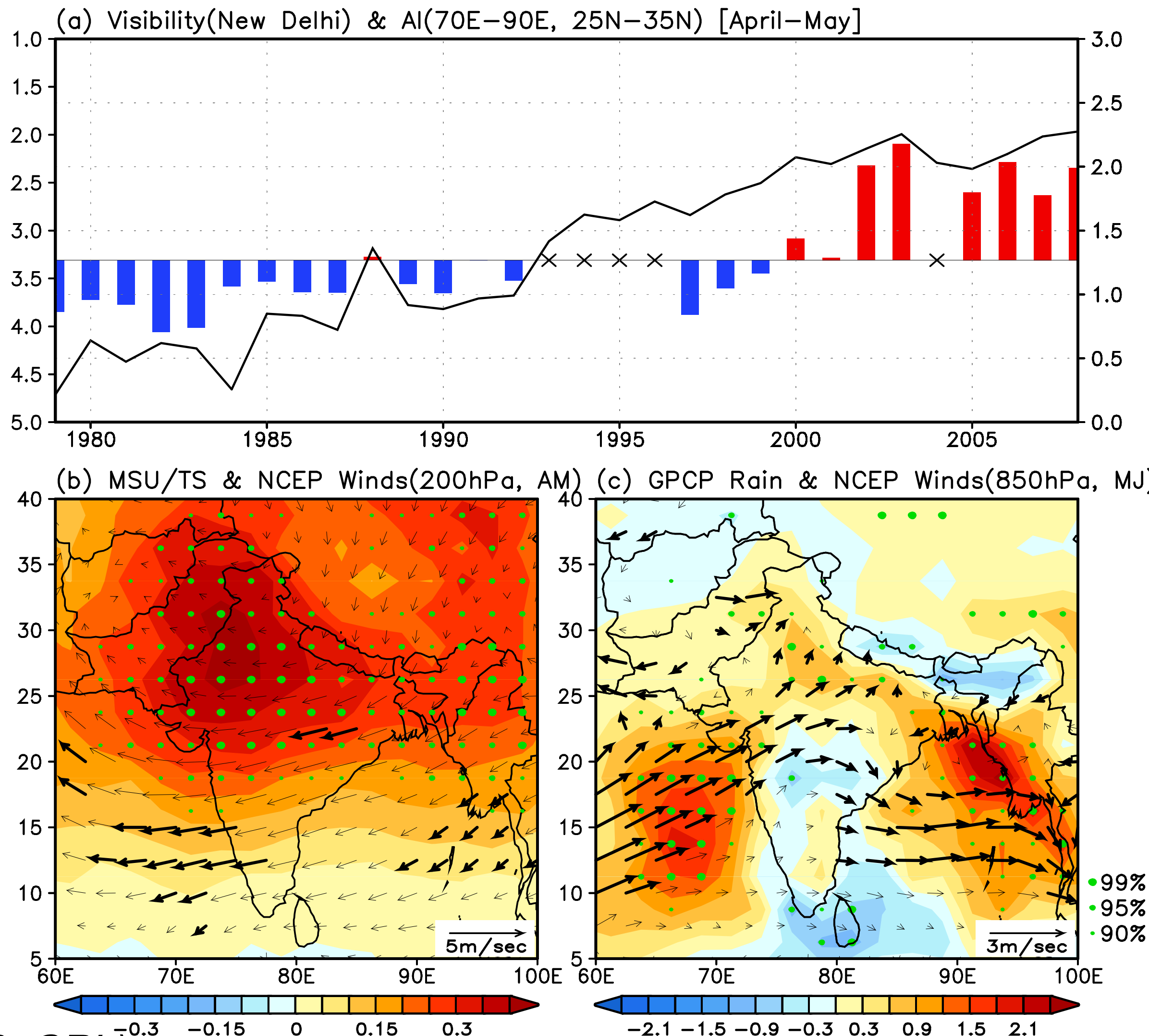
MODIS Terra true-color composite



The world is more than 60% covered by clouds on the average.

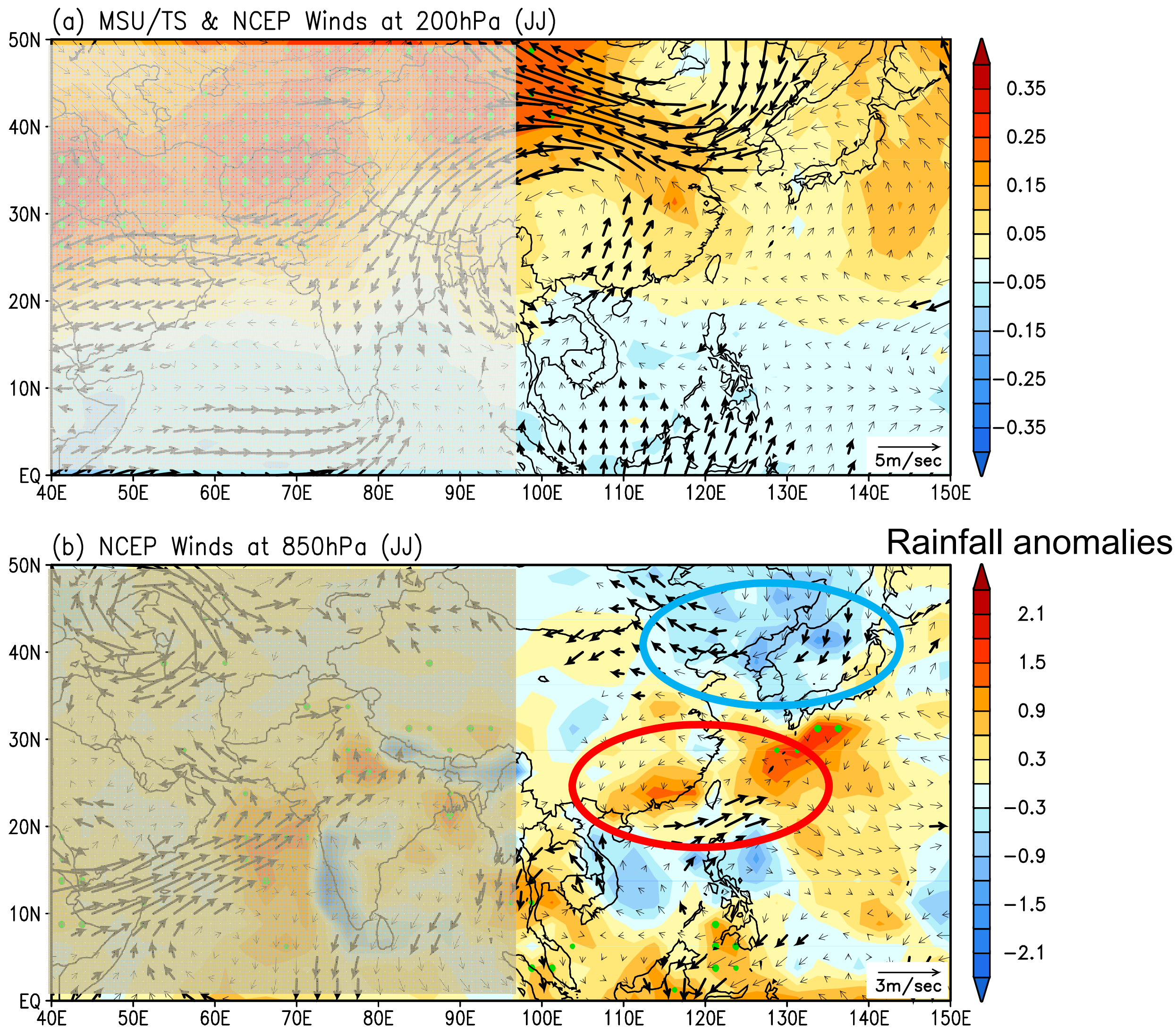
Clouds over subtropical East Asia/Southern China
in April-May are exceptionally bright. Why?

EHP signals are detected in observed long-term temperature and rainfall for the South Asian monsoon!



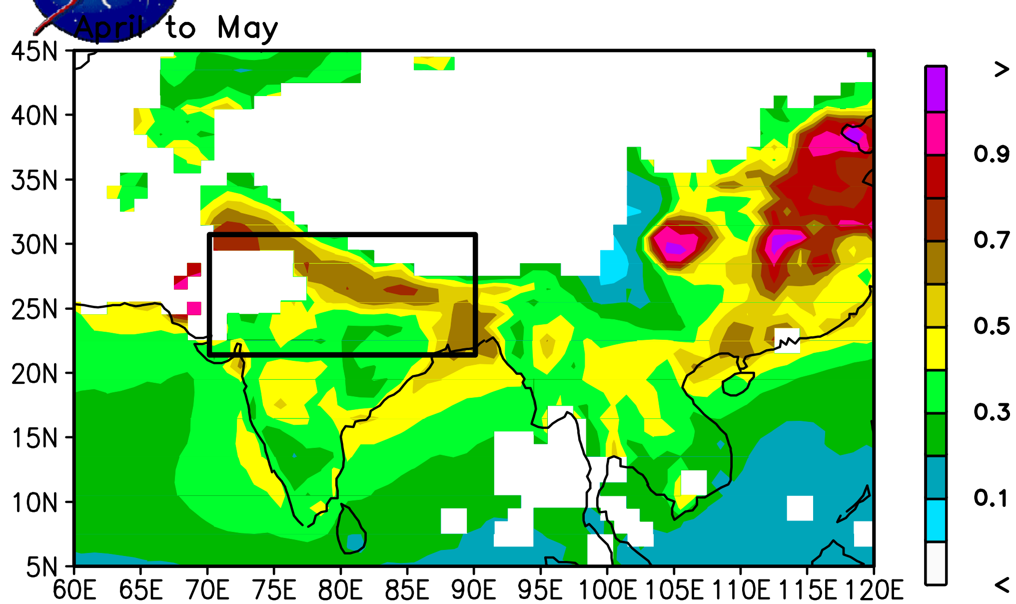
Lau and Kim (2010, GRL)

EHP associated teleconnection (1987-2009)

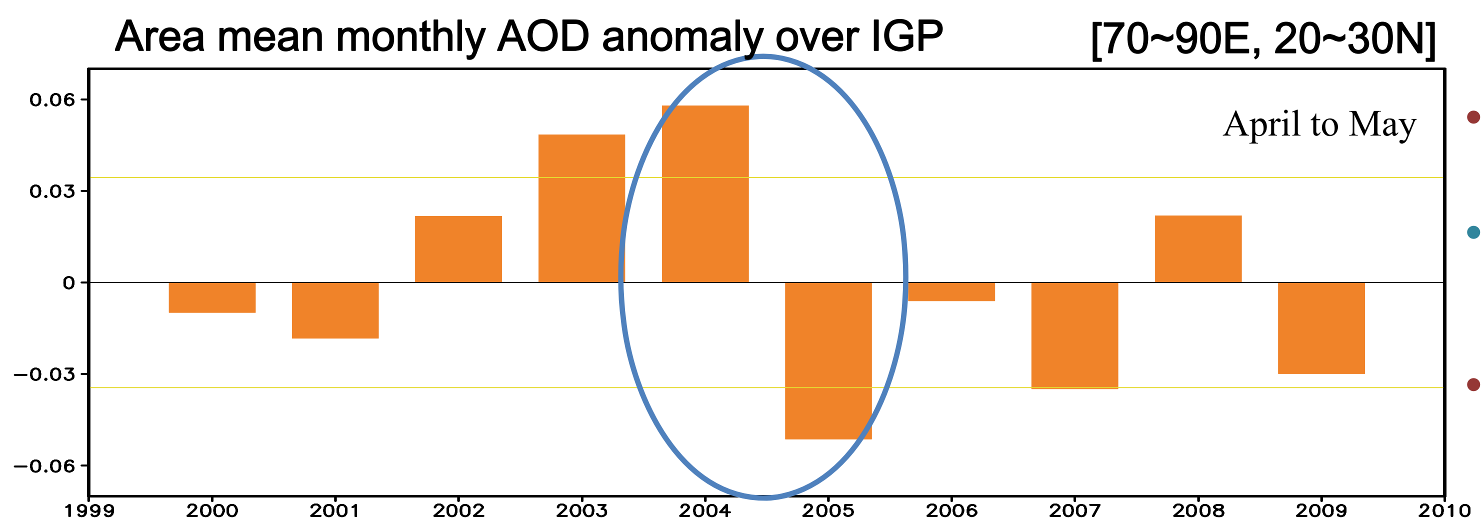


North/drought – South/wet rainfall dipole in East Asia in June -July

April-May mean aerosol optical depth(AOD) from 2000 to 2009



The dusts in IGP are coated with black carbon produced from local emissions and become a strong absorber of solar radiation and an efficient source of atmosphere heating(Lau and Kim, 2006).



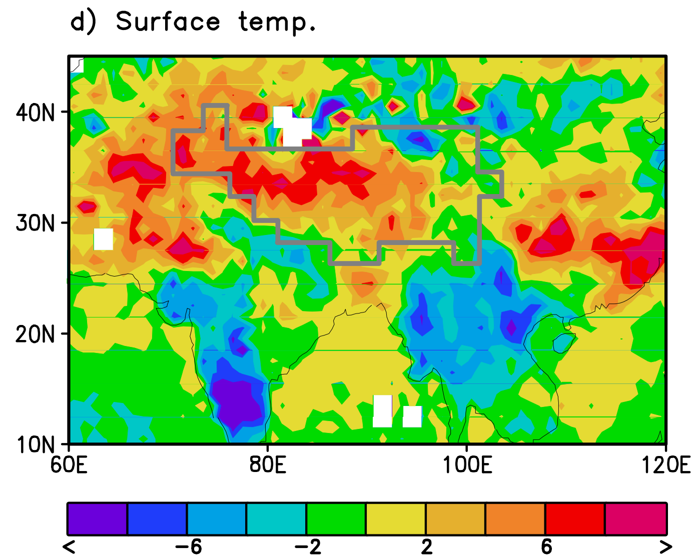
- High AOD : 2004
- Low AOD : 2005
- Nino3 Index

  DJF 2004: 0.29

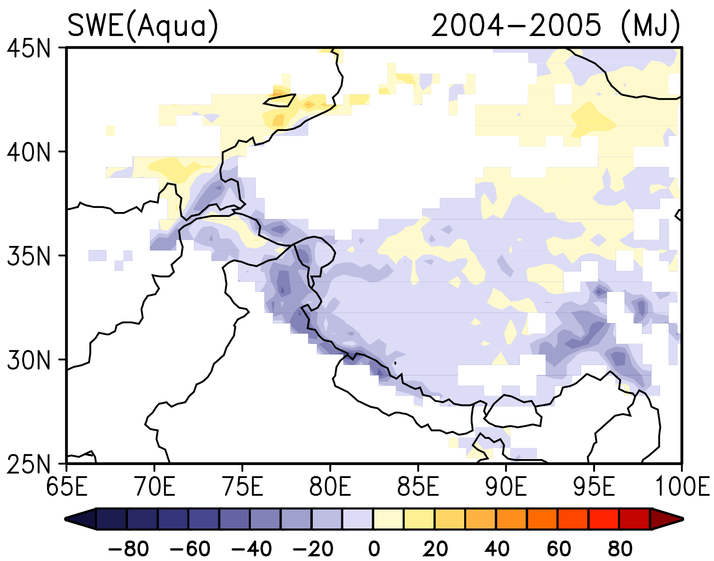
  DJF 2005: 0.26

  DJF 2003: 0.83

May/June Difference between 2004 and 2005
Dirtier year minus cleaner year



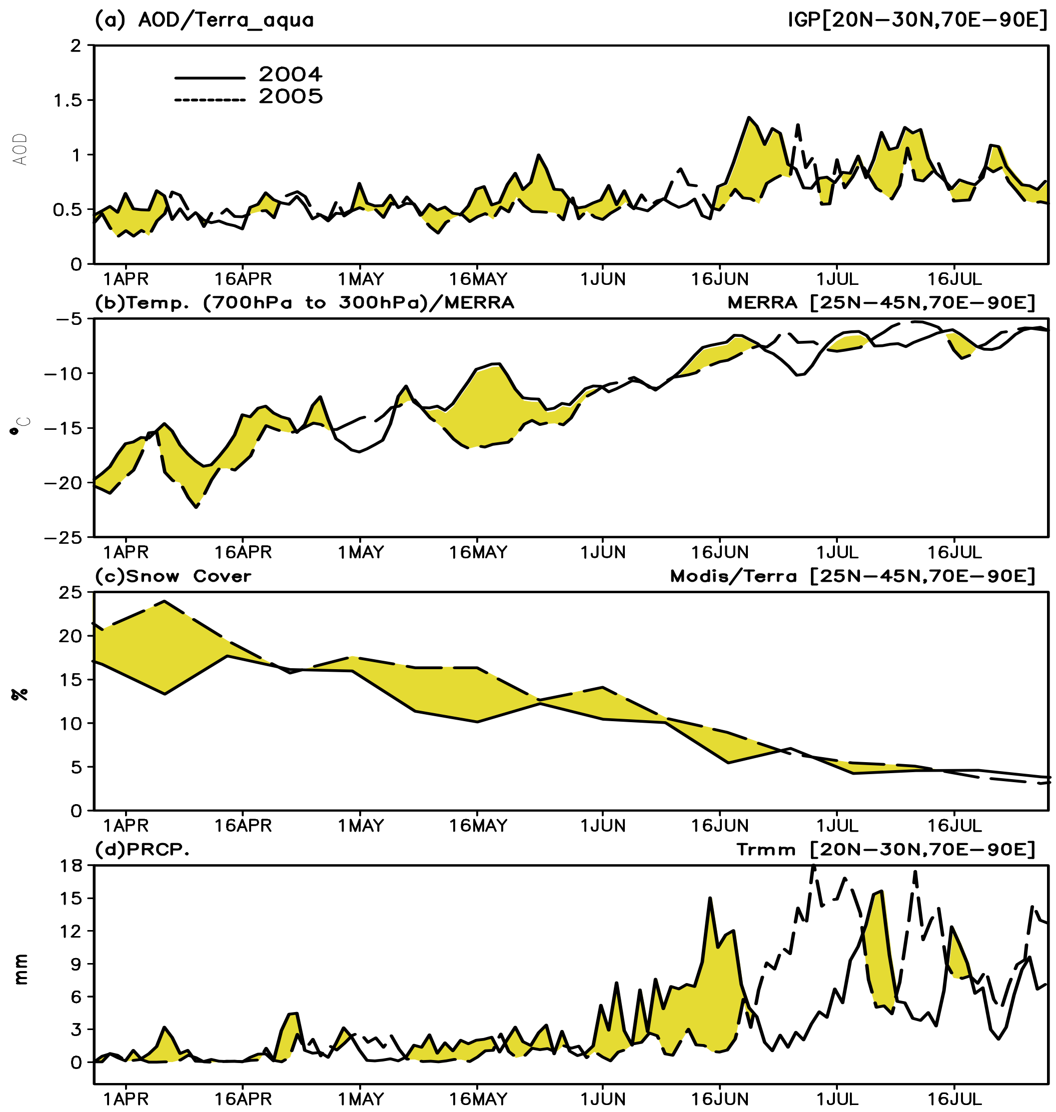
Increased surface temperature (AIRS) over NW India and HKHT



Reduced Snow Water Equivalent (Aqua) → more rapid snowmelt

Intra-seasonal variation

Dirtier year (MJ 2004) minus cleaner year (MJ 2005)



Increased AOD over N. India

Increased Upper level Temperature Tibetan Plateau

Decreased Snow Cover over TP

Increased Rainfall over N. India