High-Resolution Modeling Applications

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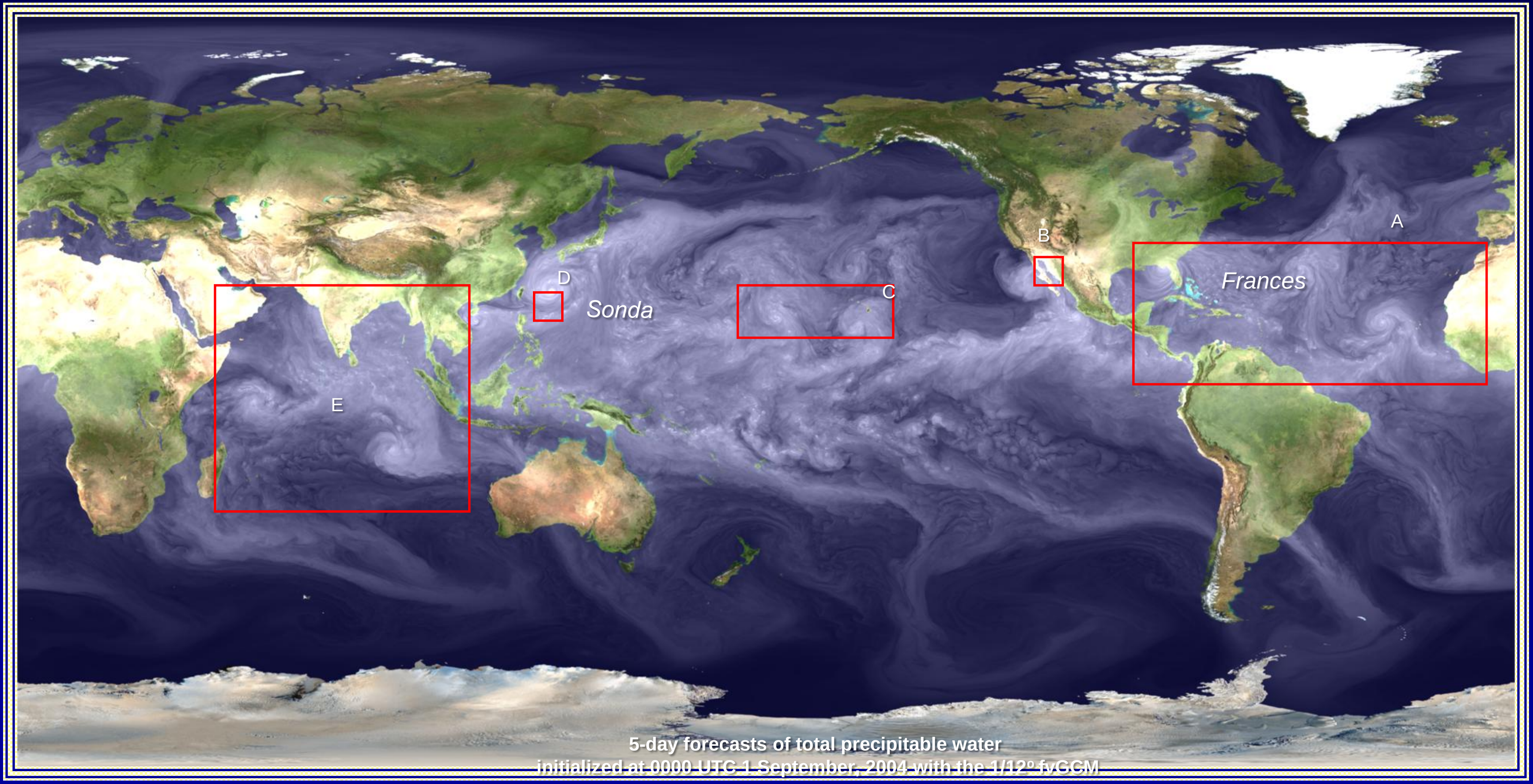
Outline

1. Forecasting convective organization of tropical systems using NASA GEOS4 global meso-scale model *(Atlas, et al 2006, Shen et al 2007, 2008)*

2. Impacts of Saharan Air Layer (SAL) and Saharan dust on tropical Atlantic weather and climate

3. Impacts of absorbing aerosols (dust and BC) on water cycle of the Asian monsoon

Global Mesoscale Modeling on the NASA fvGCM on the Columbia Supercomputer



D: Typhoon Sonda

E: Indian Twin Tropical Cyclones

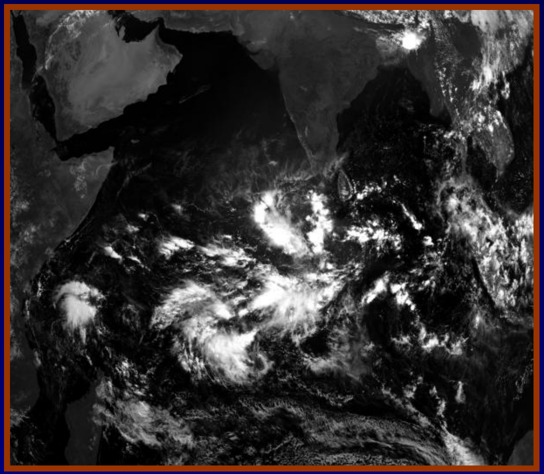
A: Atlantic Hurricanes

B: Catalina Eddy

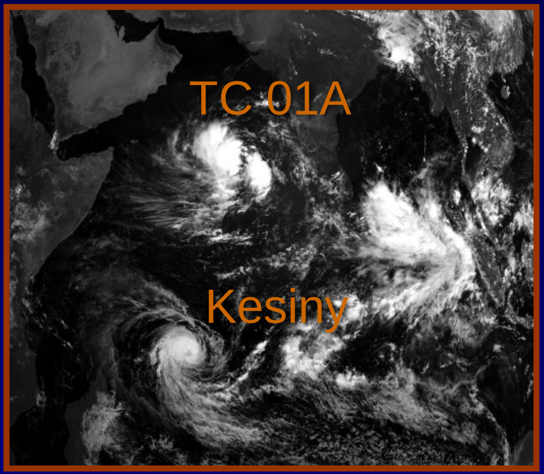
C: Hawaiian Lee Wakes

Atlas, et al. 2006, Shen et al. 2008

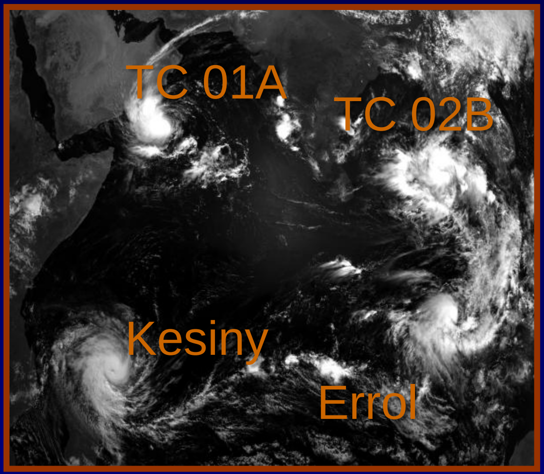
0630 UTC 1 May 2002



0630 UTC 6 May 2002

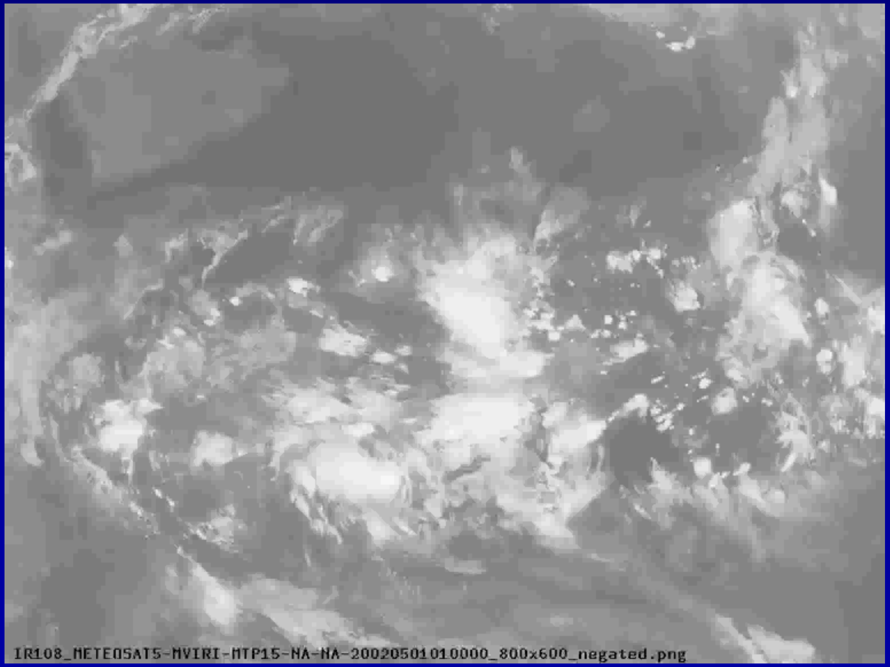


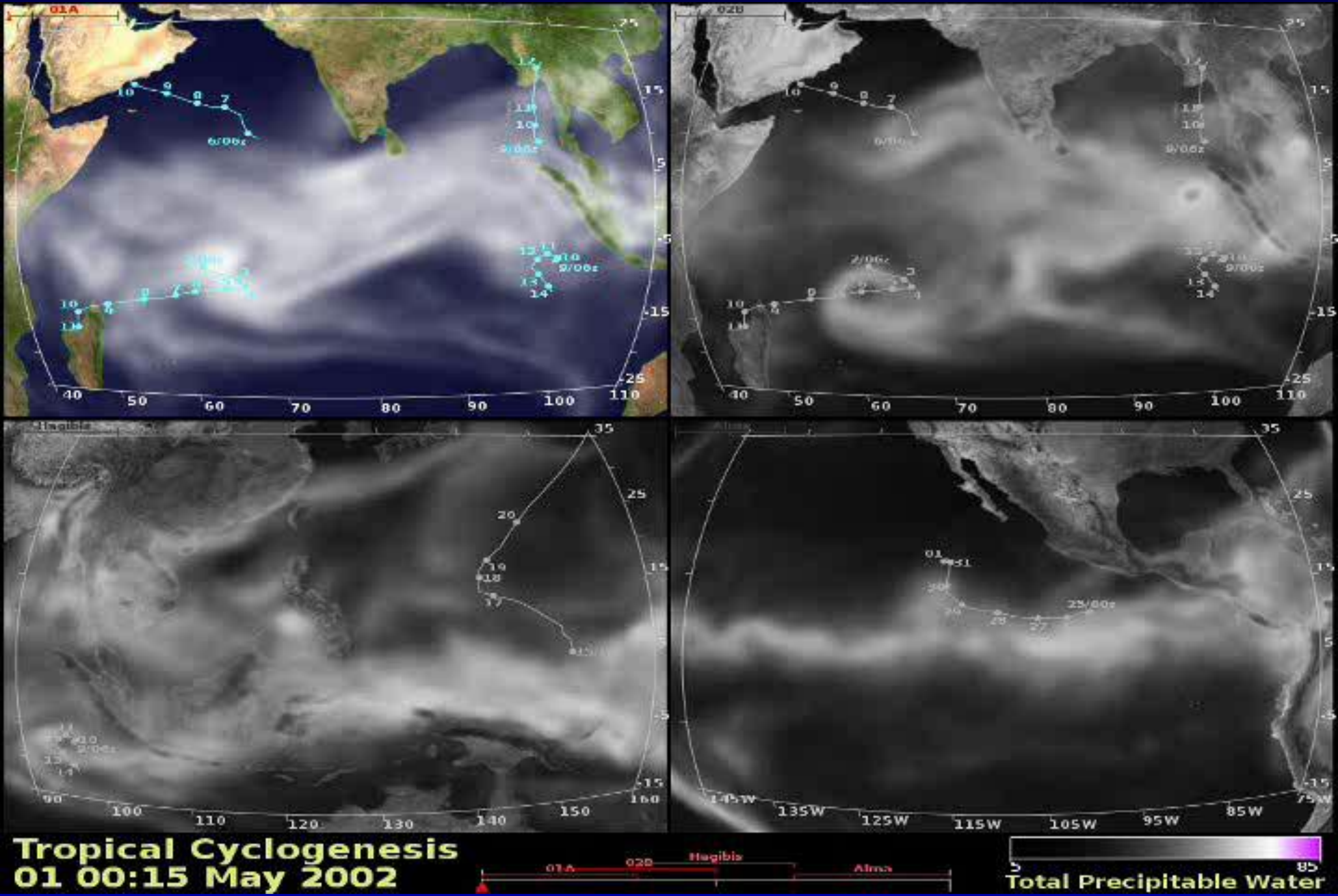
0630 UTC 9 May 2002



- Two pairs of twin TCs appeared sequentially after an Madden-Julian Oscillation (MJO) propagated eastward through these areas.

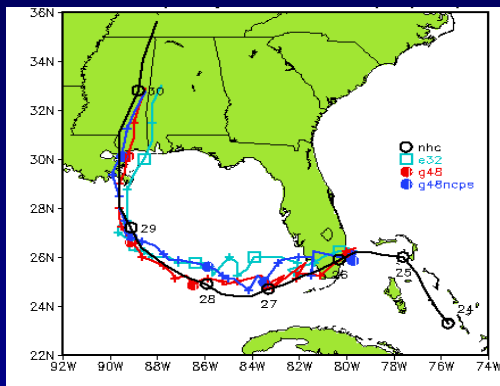
Kesiny (3-11) and TC 01A (6-10, May)
Errol (9-14) and TC 02B (9-12 May)
Supertyphoon Hagibis (15-21 May)
Hurricane Alma (25 May – 1 June)

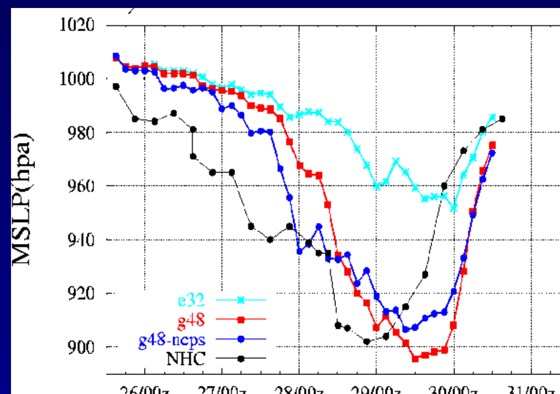


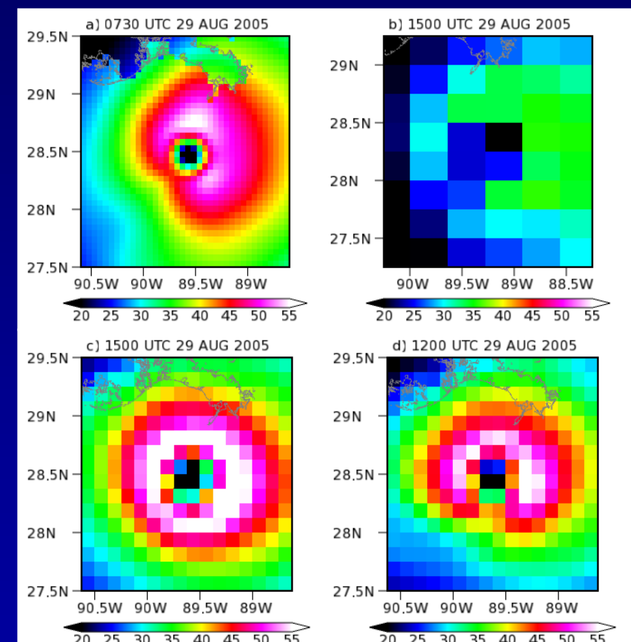

Tropical Cyclogenesis
01 00:15 May 2002
01A
02B
Hagibis
Alma
5
85
Total Precipitable Water

Forecasts of Katrina's Track, Intensity, Structures

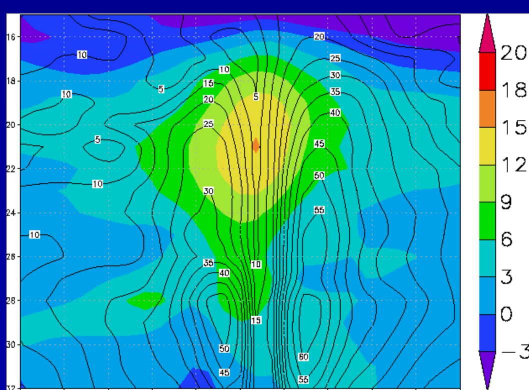
•Six 5-day simulations of Katrina at both 0.25º and 0.125º show comparable track forecasts, but the higher-resolution (0.125º) runs provide much better intensity forecasts, producing the center pressure with errors of only +- 12 hPa. Realistic near-eye wind distribution and vertical structure are also obtained as cumulus parameterizations are disabled.



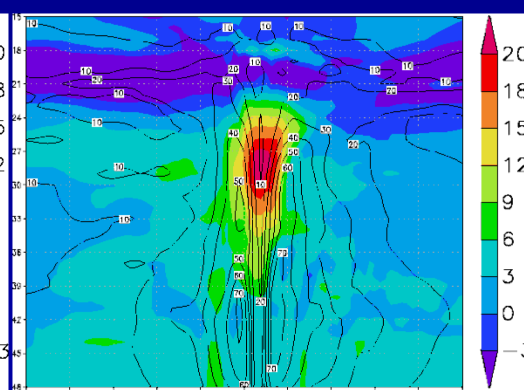




Landfall errors:
e32 (1/4º): 50km, g48(1/8º): 14km, g48ncps (1/8º w/o CPs): 30km



GFS Analysis (~35km) valid at 08/29/12z



96 h Simulations with no CPS

Near-eye Wind Distributions in a 2ºx2º box (a) AOML high-resolution surface wind analysis, (b) the 0.25º 99h simulations, (c) the 0.125º 99h simulations, (d) the 0.125º 96h simulations without convection parameterizations (CPs).

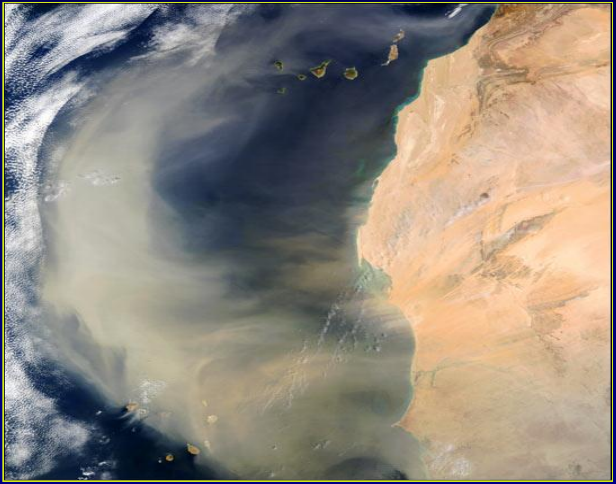
High-resolution runs simulate realistic intensity, RMW (radius of max wind) and warm core (shaded)

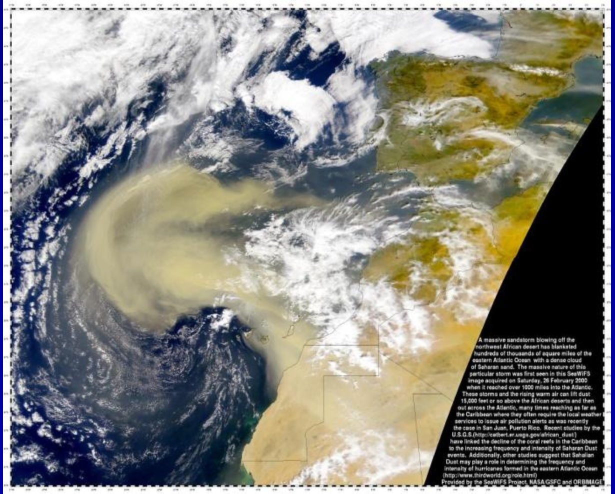
Possible effects of Saharan dusts on weather and climate over the Atlantic

- Annual emission of Saharan dust is estimated to be 1-2 billion tons
- Increased Saharan dust outbreak in 1970 – 1990's, associated with the prolonged drought in Sahel and increased dust storm over the Sahara desert; recent decade show partial recovery, with decreasing trend of dust outbreak

Possible weather and climate impacts:

- SAL dry air may suppress tropical cyclogenesis, and hurricane formation
- Microphysics effects: suppress warm rain; increase ice-nucleation and deep convection
- Solar Dimming Effect *(Lau and Kim 2007a, b)*
- " Elevated Heat Pump" Effect *(Lau et al , 2006, 2009)*

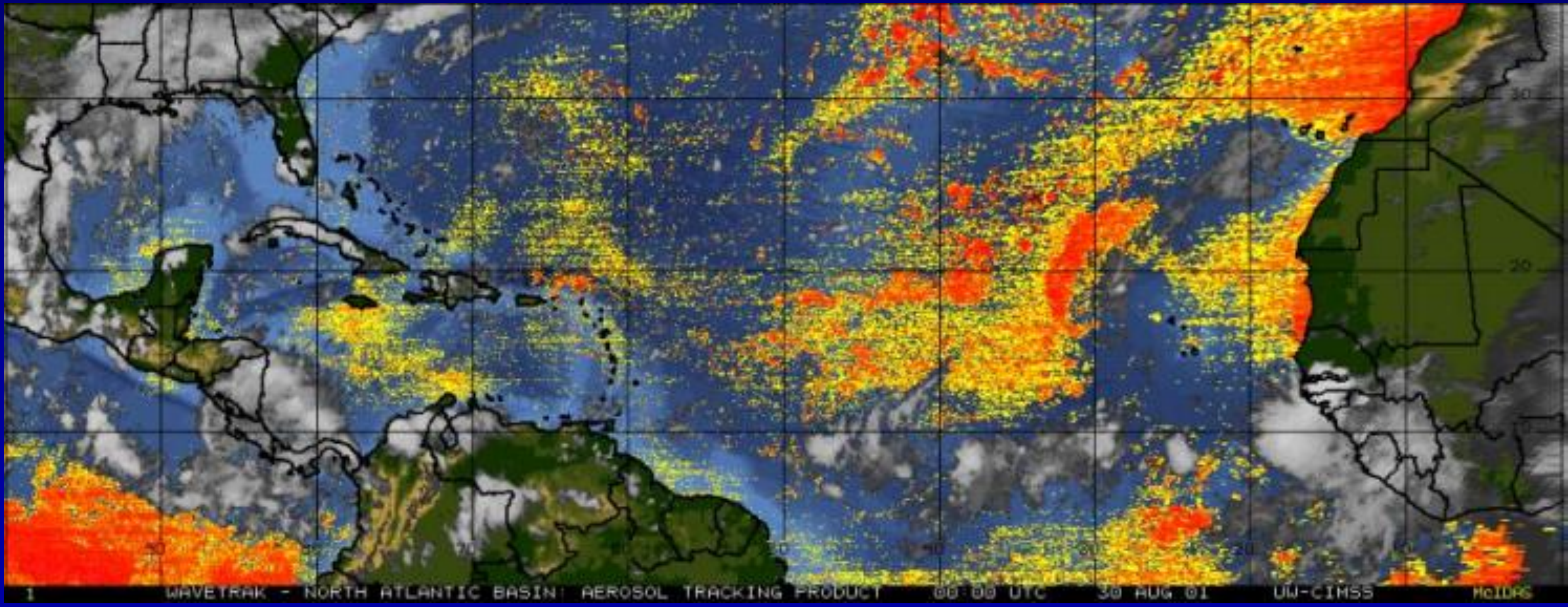




MODIS Images

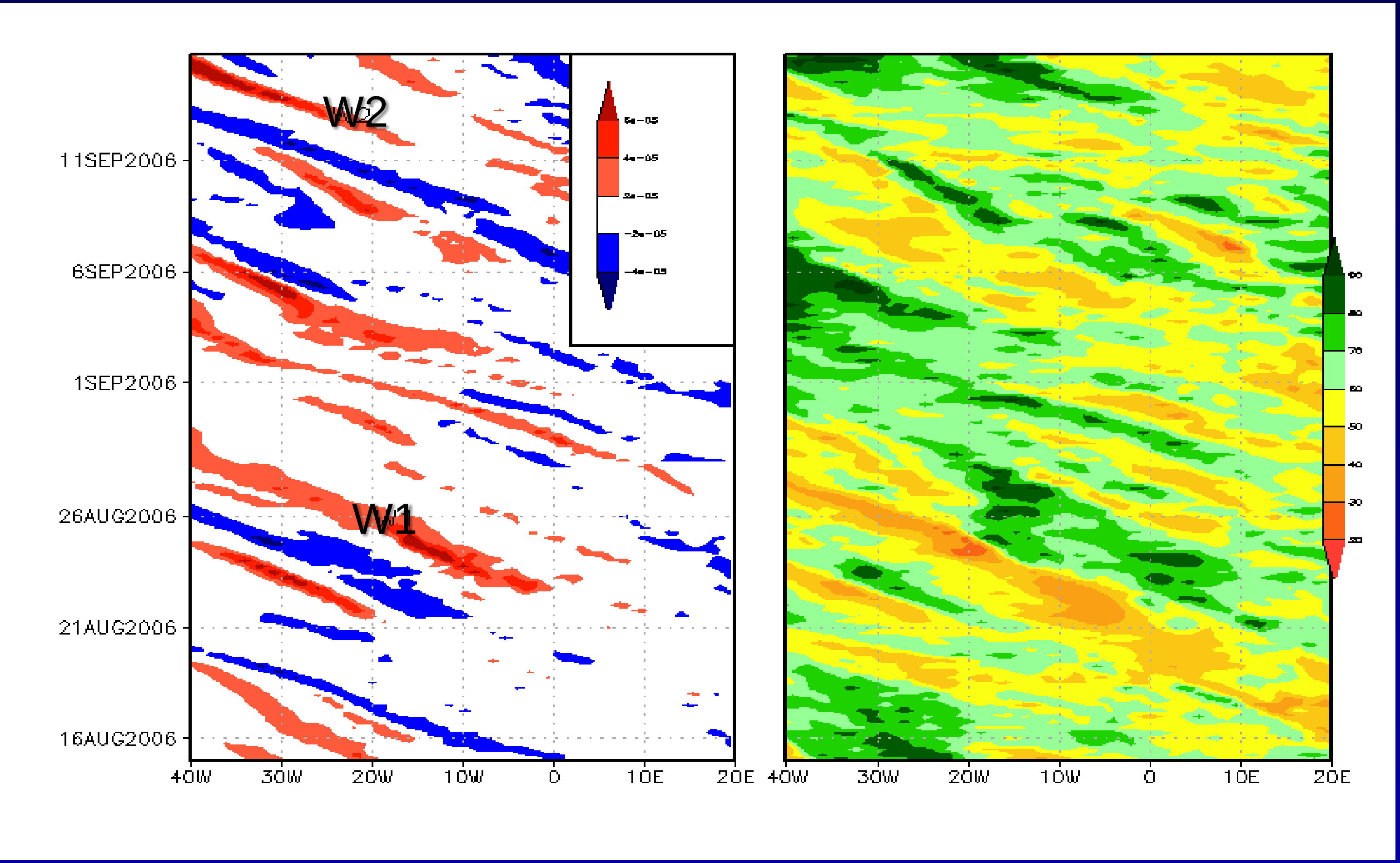
Saharan Air Layer (SAL) and tropical cyclone interaction:

- Cyclones developed from ITCZ which is always found immediately at the southern edge of dust layer
- Cyclones often spin down inside the dust layer
- Less than ~1 in 10 AEWS develop into TC, less than 1 TC in 2 develop into hurricanes



Courtesy: J. Dunion

Time-longitude section at 15N of AEWs from GEOS-5 analysis during NAMMA period



700hPa rel vorticity

Rel. Humidity

Oreste, Lau et al. 2009, *J. Atmos. Sci. NAMMA Special Issue*

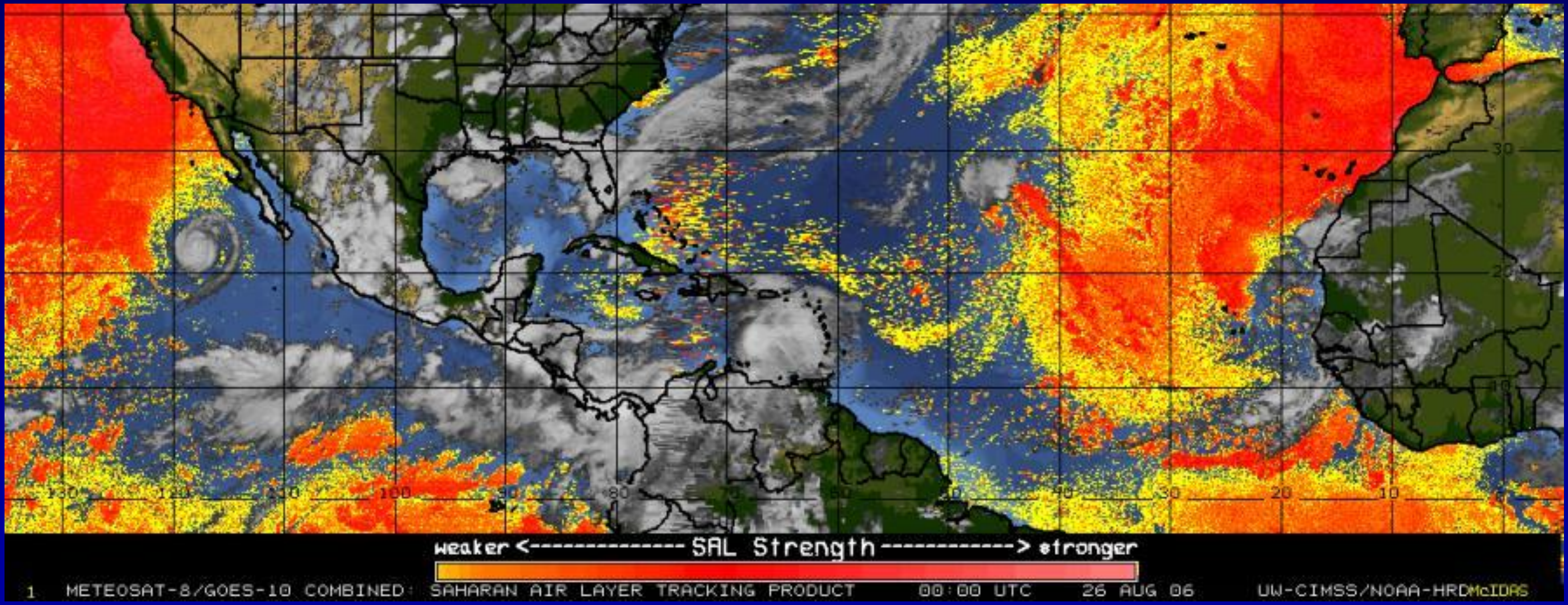
Experiments setting

- One month long assimilation run with all conventional and satellite data used operationally, and AIRS controlled cloudy retrievals at a global horizontal resolution of 0.5 degree, 72 vertical levels
- 2 sets of 30 5-day forecasts, at 0.25 degrees and 0.5 degrees, both with 72 vl
- Global Anomaly correlation skill at day 5 ranges from 0.76 to 0.80 – comparable to operational centers in boreal summer conditions

Focus of this study

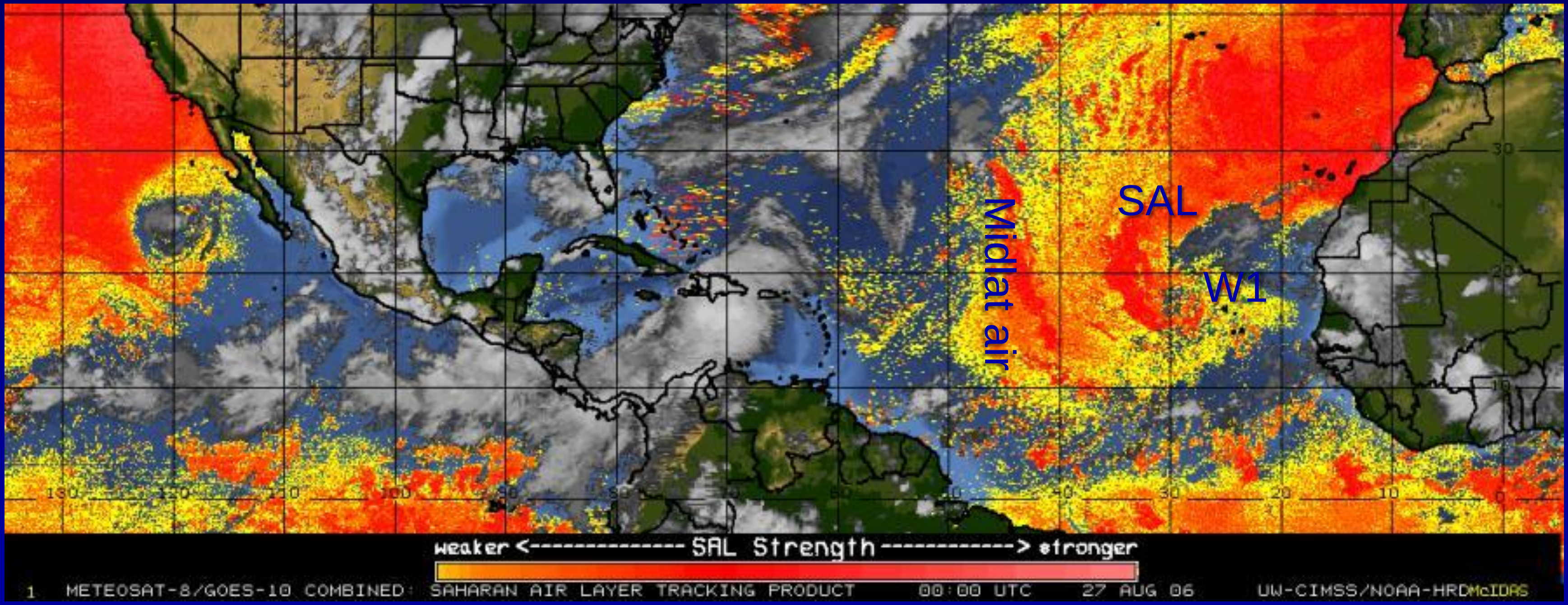
- Two waves (W1 and W2) are selected: one non-developing and one developing (precursor of Helene)
- Both interact with the SAL
- Environmental conditions (SST, large scale vertical shear, strength of the wave) are comparable
- We investigate why W1 does not develop

UWisc-CIMSS Imagery for validation



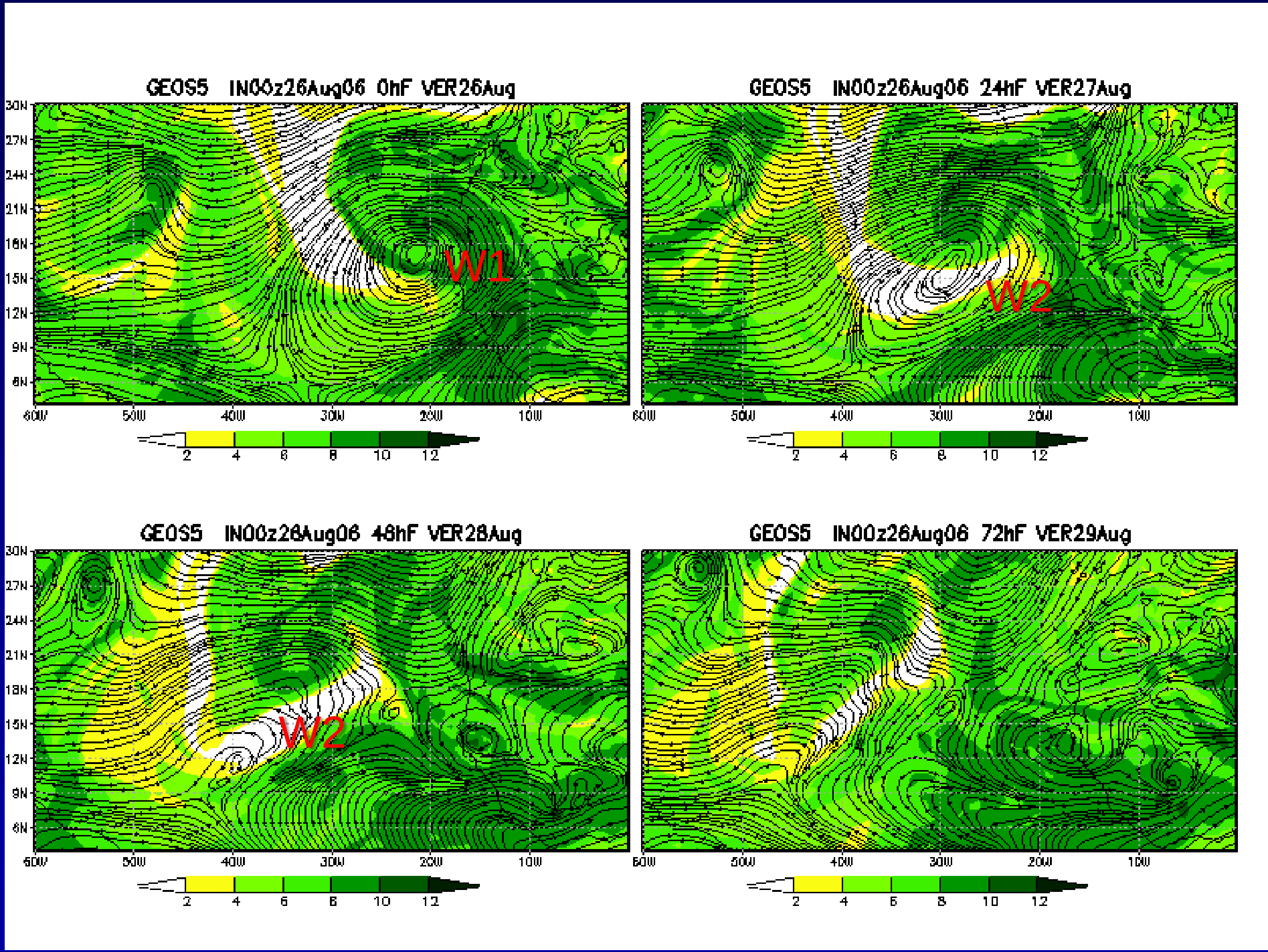
00z 26 August 2006

UWisc-CIMSS Imagery for validation



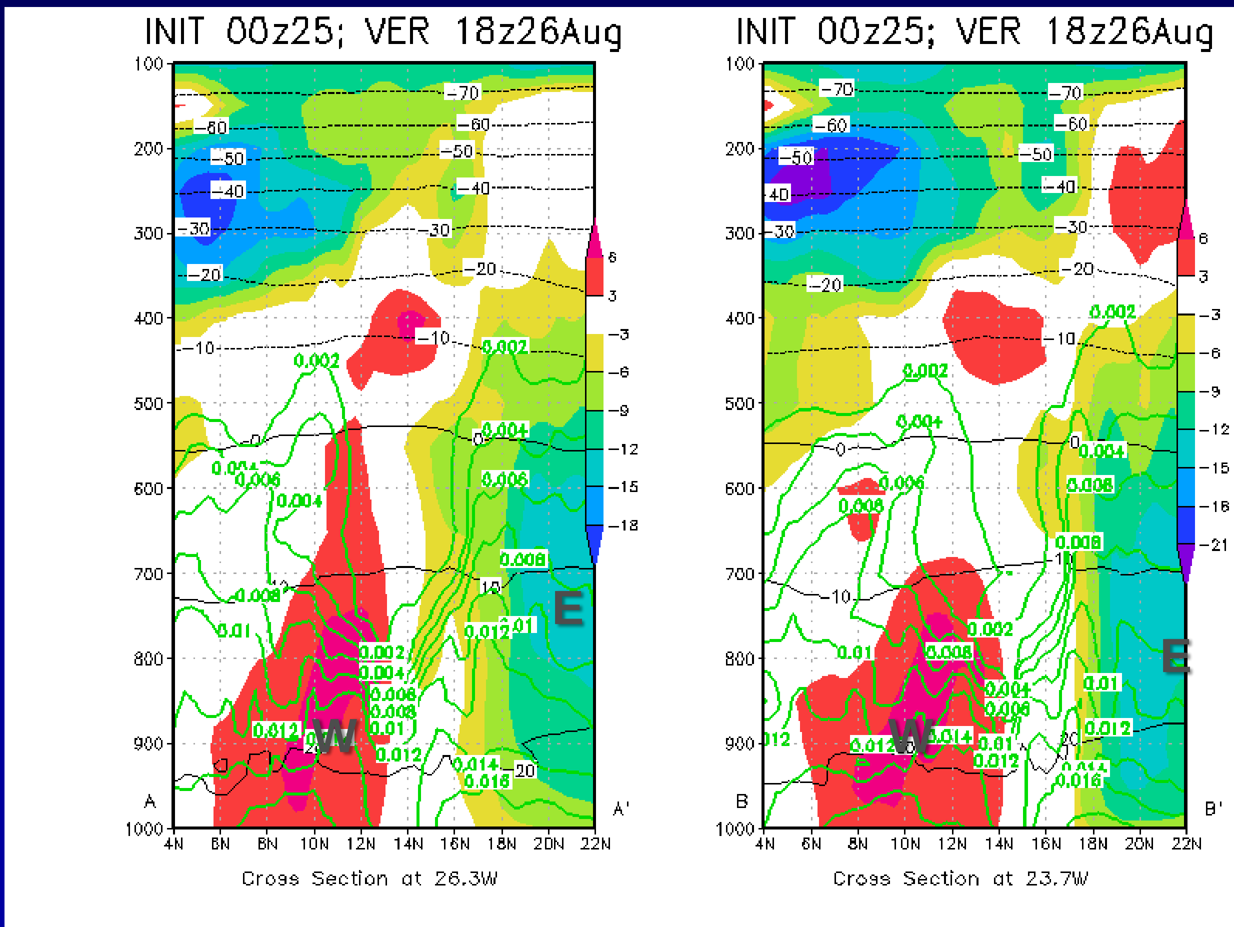
00z 27 August 2006

Non-developing Wave

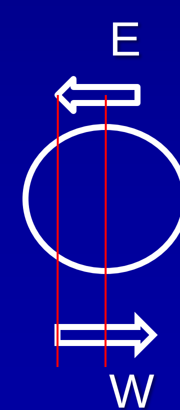


700 hPa Spec Hum (g/Kg) and 900 hPa wind (to emphasize low-level circulation). SAL gets entangled in the circulation and destroys it.

GEOS-5 forecast of dry air intrusion at 500-700 hPa suggestive of non-development in spite of very favorable dynamical condition



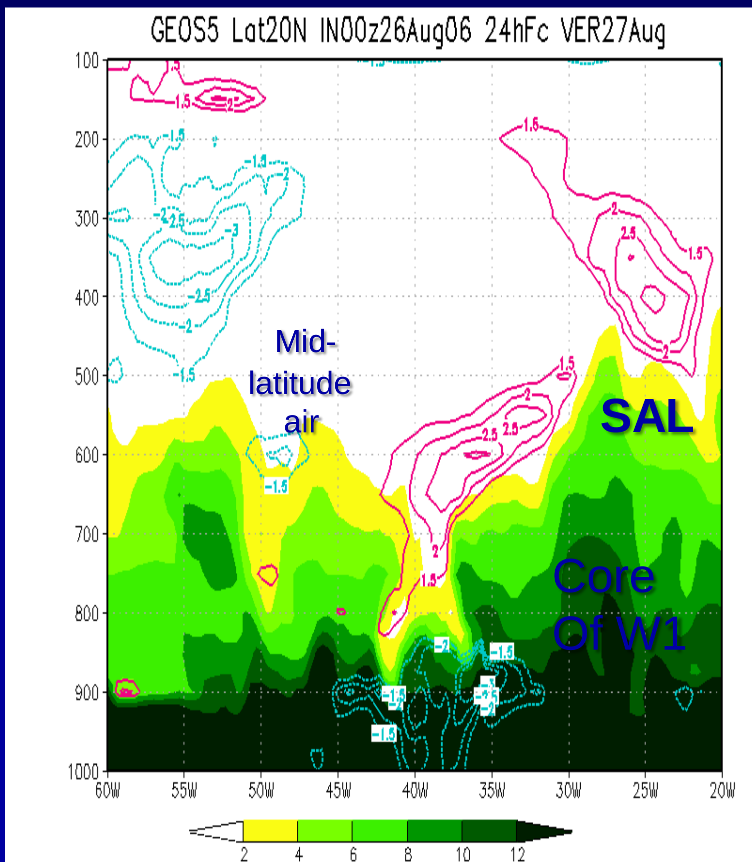
Zonal Wind (shaded)
Temp (black solid)
Spec hum (green thick)

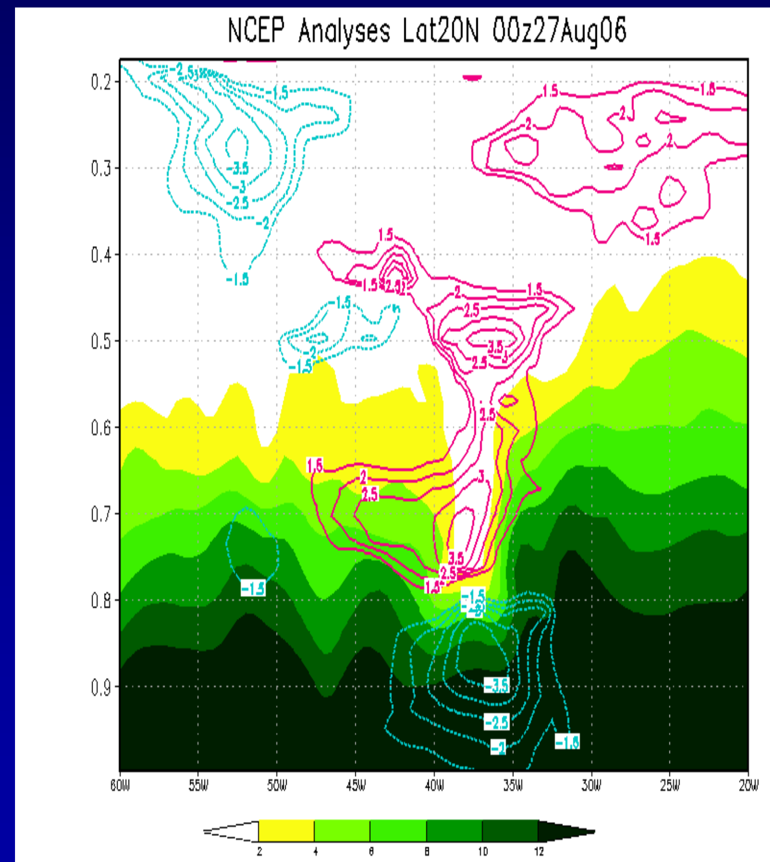


Evidence of SAL thermal structure in the 0.25 deg GEOS-5 forecast

Zonal cross-section at 20N. Spec Hum (g/Kg), Temp Anom (C)

NONDEVELOPING WAVE

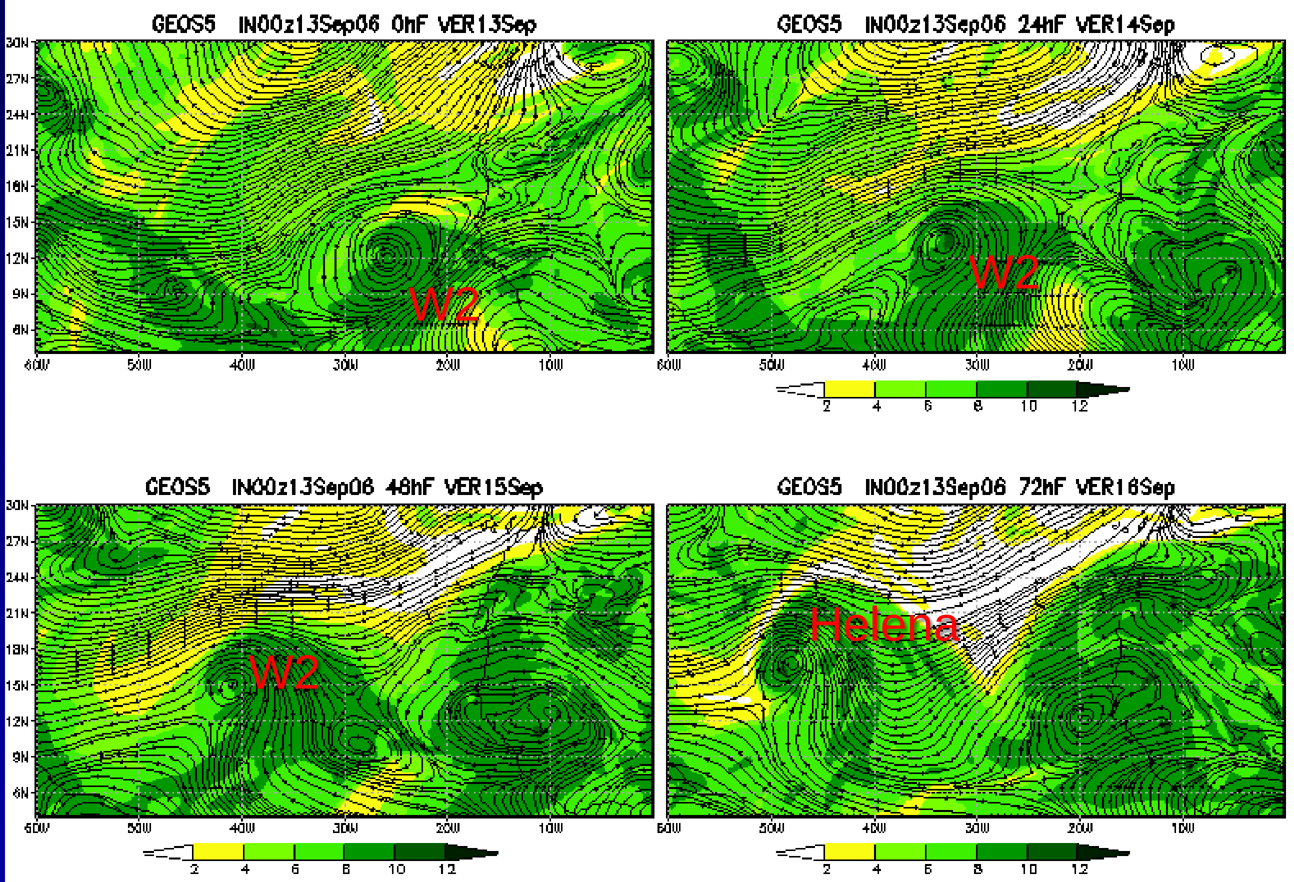




STRONG TEMPARATURE INVERSION IN THE SAL

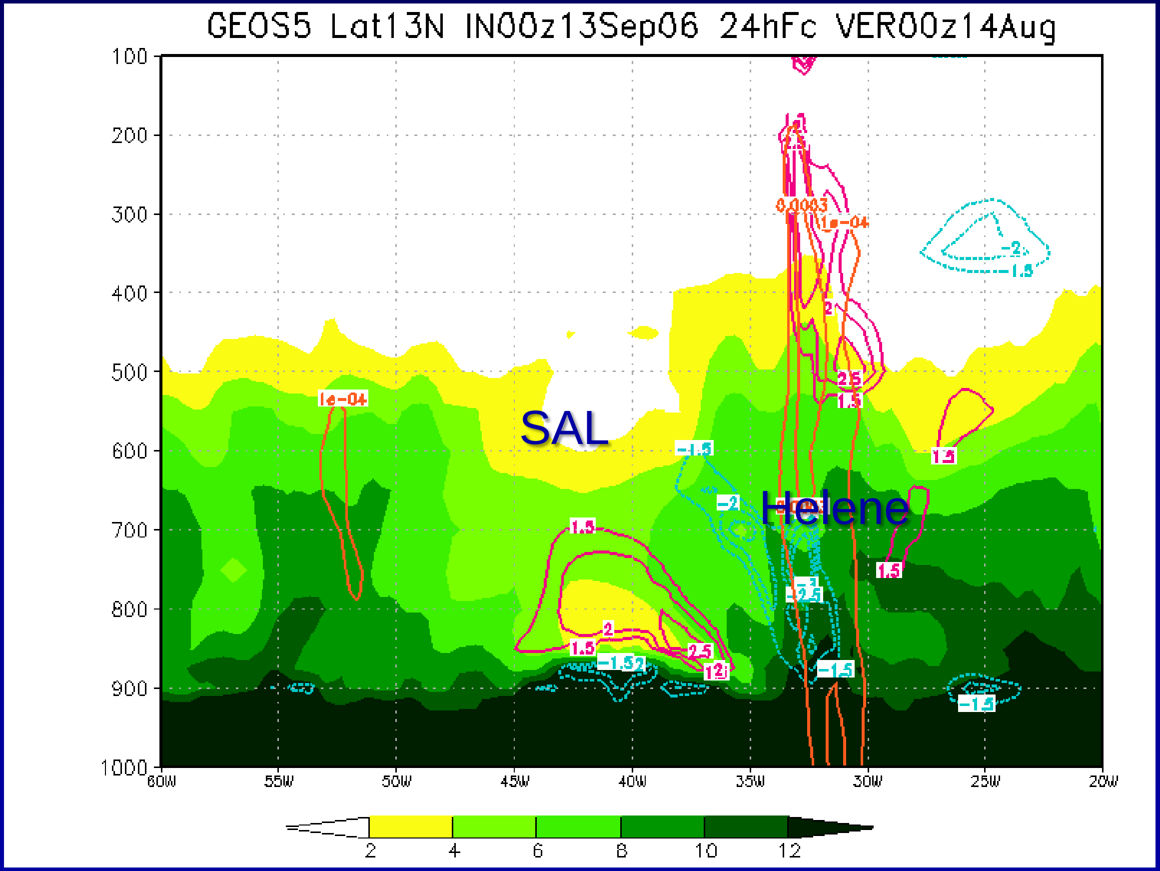
TIGHT MOISTURE GRADIENTSON THE BORDERS OF THE SAL

Developing Wave



This wave also interacts with the SAL but survives and becomes the precursor of Helene

Much weaker evidence of SAL thermal structure in the 0.25 deg GEOS-5 forecast for the developing case



Zonal cross-section
At 20N.
Spec Hum (g/Kg)
Temp Anom (C)
Vort (s-1)

DILUTED MOISTURE GRADIENTS ON THE BORDERS OF THE SAL

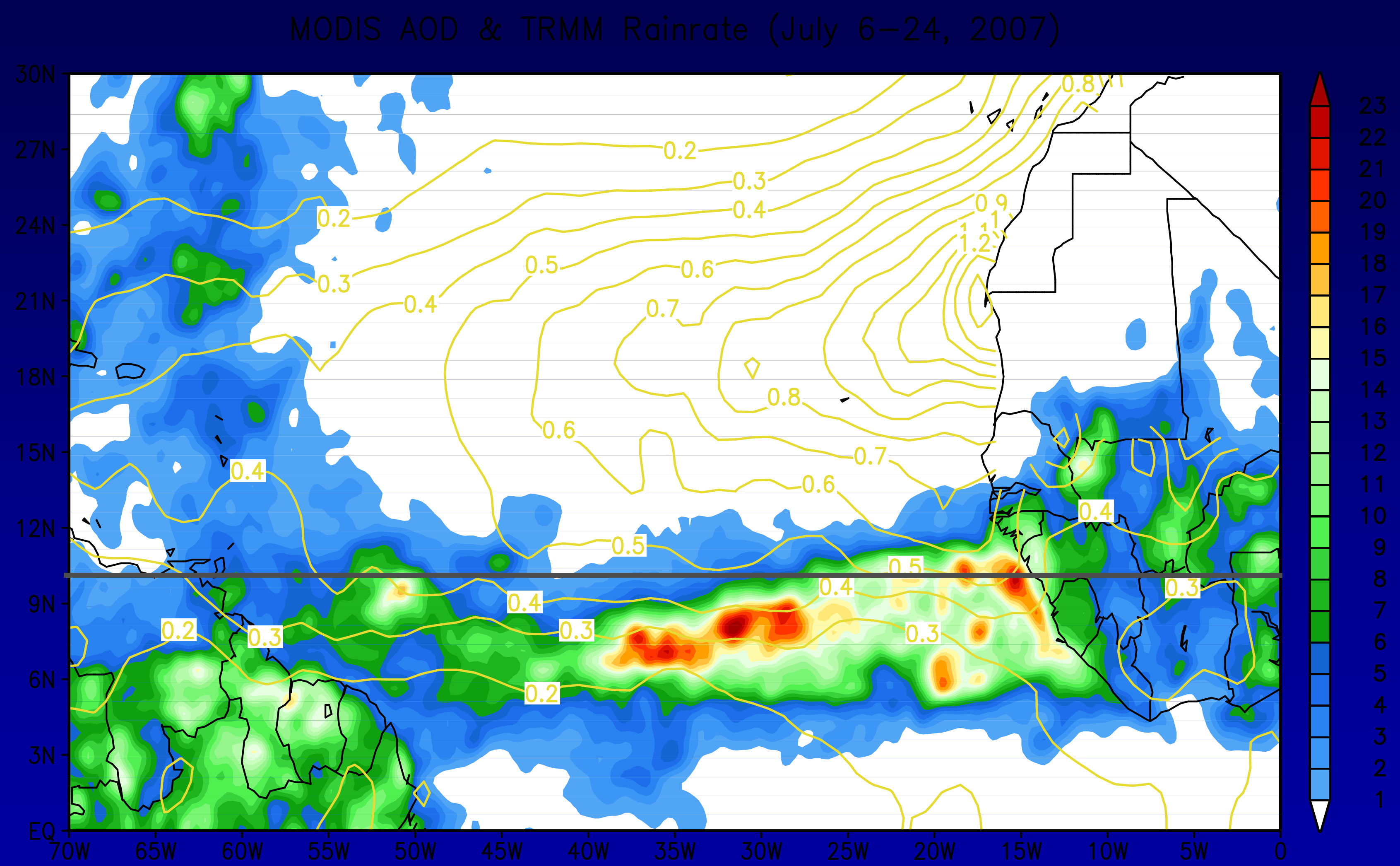
WEAK TEMPARATURE INVERSION IN THE SAL

Summary of present study (Oreste et al. 2009)

- Both GEOS-5 at horizontal resolution of 0.25 degrees and NCEP analyses agree that W1 and W2 are similar
- W1 failed to develop in TC (even though initial voriticity development is favorable), in part because of entrainment of dry air from SAL
- A strong thermal dipole is associated with the SAL in W1 case, suggesting possible signature of radiative effect of Saharan dust (thermal dipole) in the AIRS controlled initial condition, and preserved by the 0.25 degree resolution
- A much weaker dipole is found for the SAL associated with W2, which eventually developed into Helena

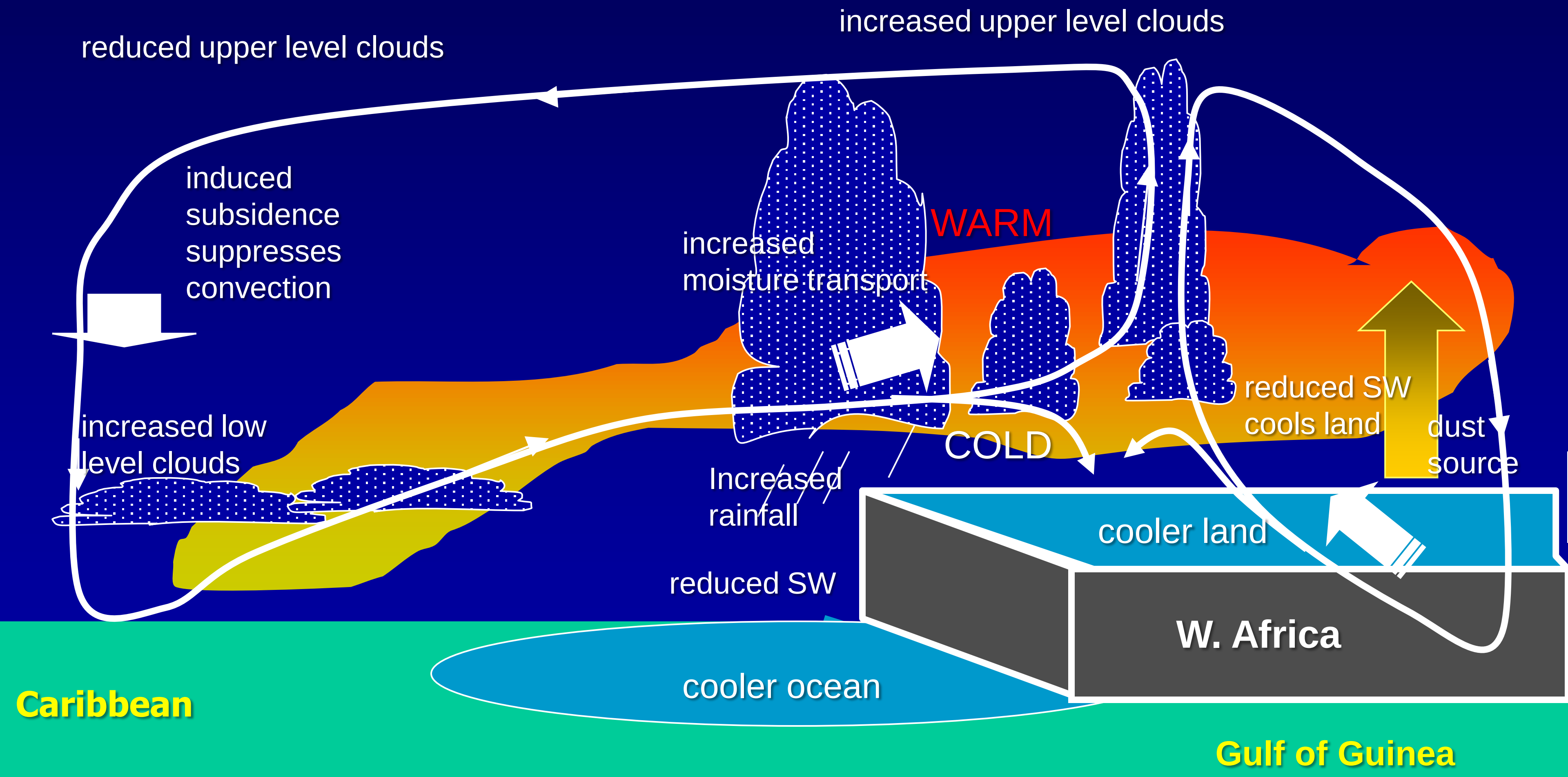
Ongoing and future work

- Design forecast experiments with HR coupled GOCART-GEOS5 model to untangle impacts of SAL vs. dust radiative effect for many more representative samples.

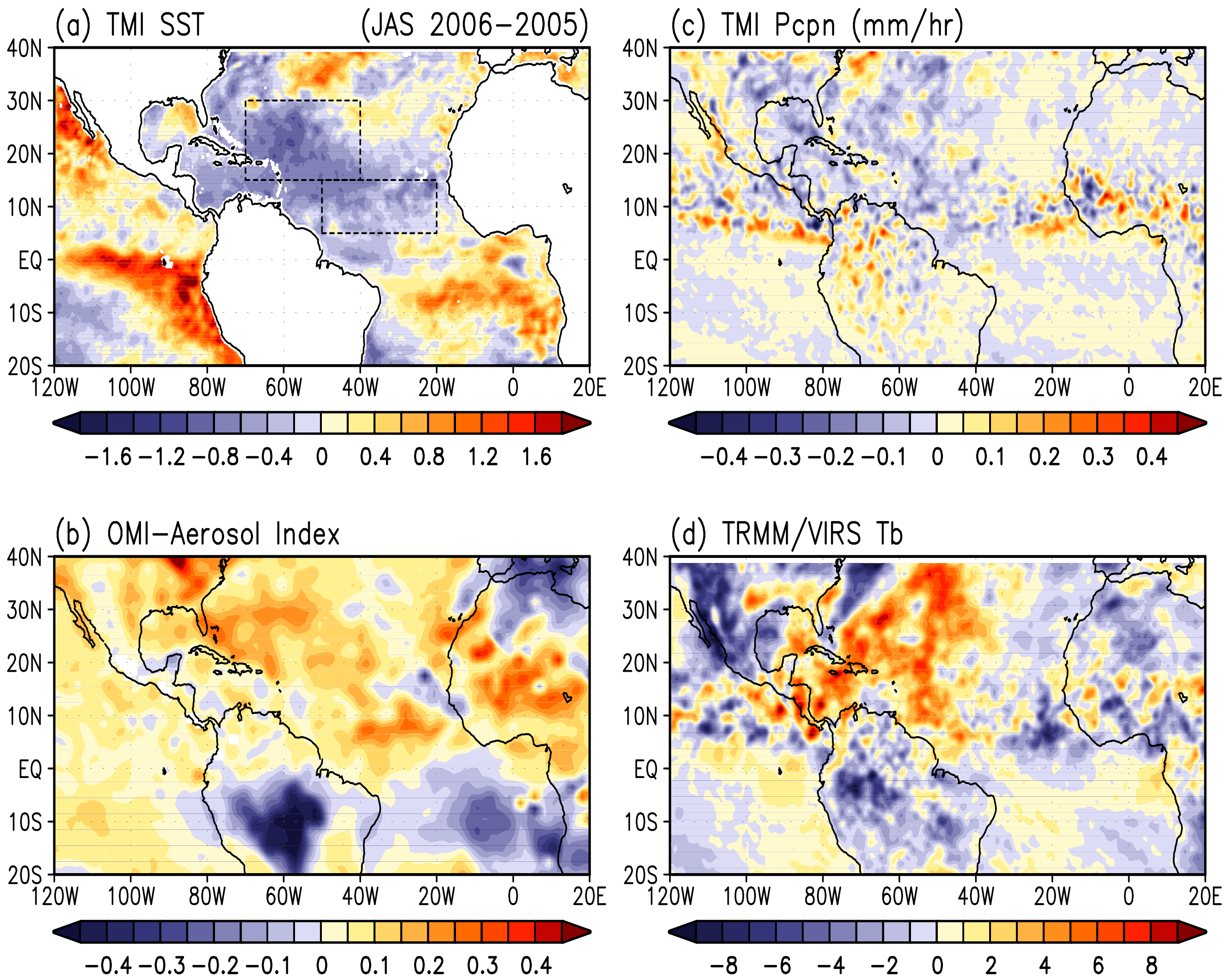


MODIS AOD & TRMM Rainrate (July 6-24, 2007)
30N
27N
24N
21N
18N
15N
12N
9N
6N
3N
EQ
70W
65W
60W
55W
50W
45W
40W
35W
30W
25W
20W
15W
10W
5W
0
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1

Anomalous atmospheric water cycle and surface temperature induced by the "Elevated Heat Pump" EHP effect of Saharan Dust over the West Africa/Atlantic region

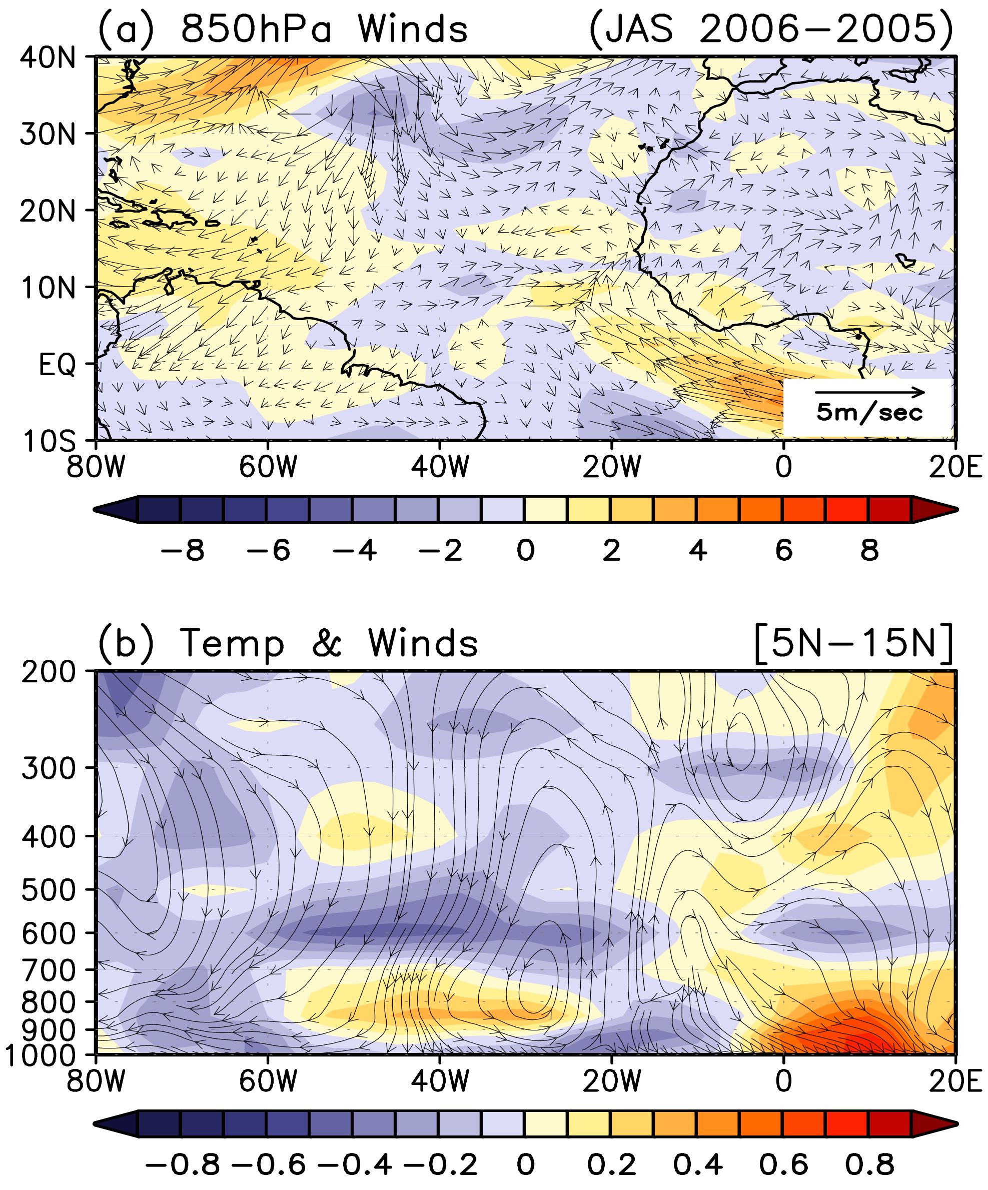


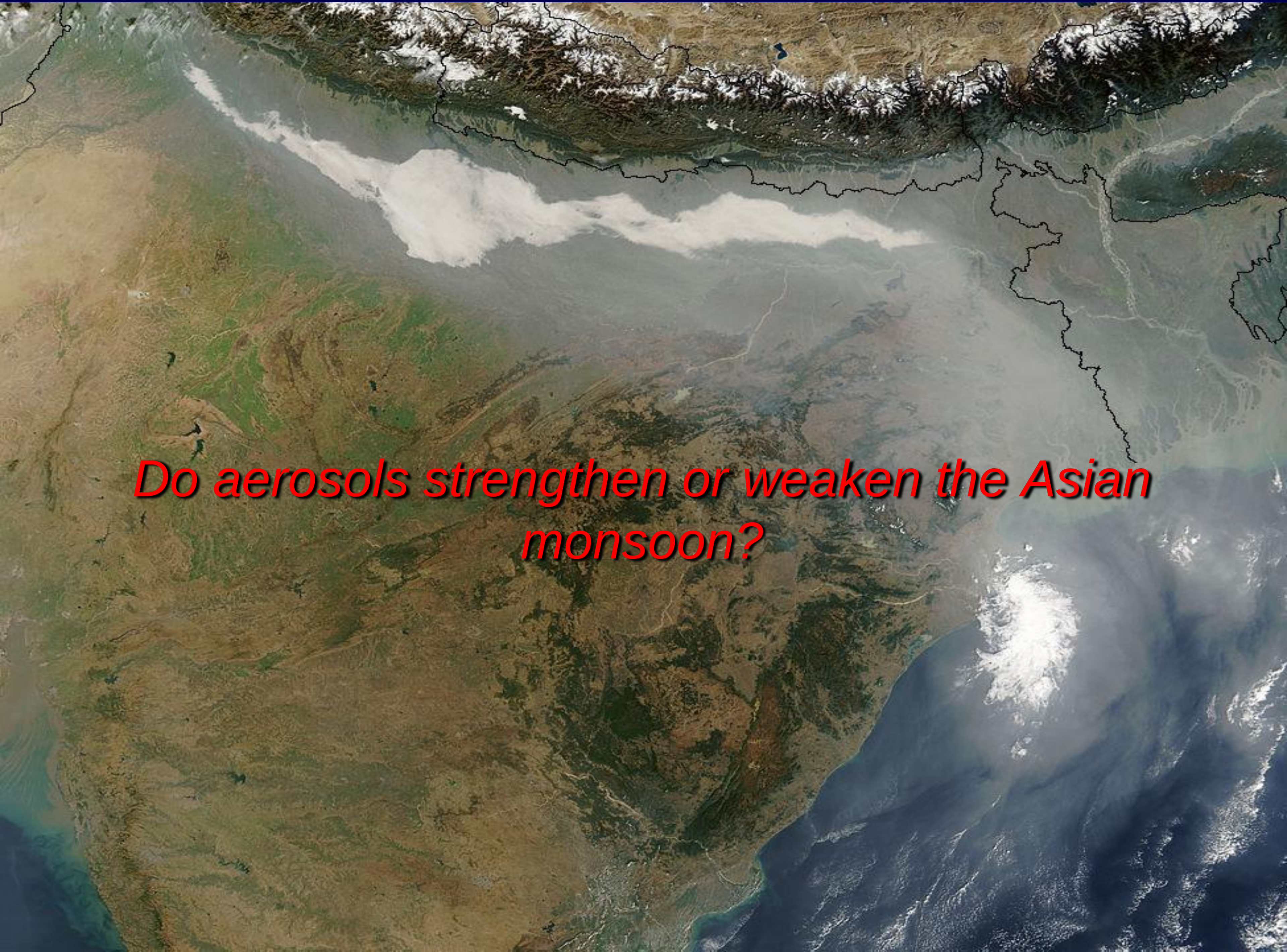
Lau et al. 2009, *Geophys. Annales (in press)*



Lau and Kim, 2007a. b)

JAS (2006 minus 2005) wind and circulation anomaly




Do aerosols strengthen or weaken the Asian monsoon?

Possible effects by aerosols on the large-scale monsoon water cycle

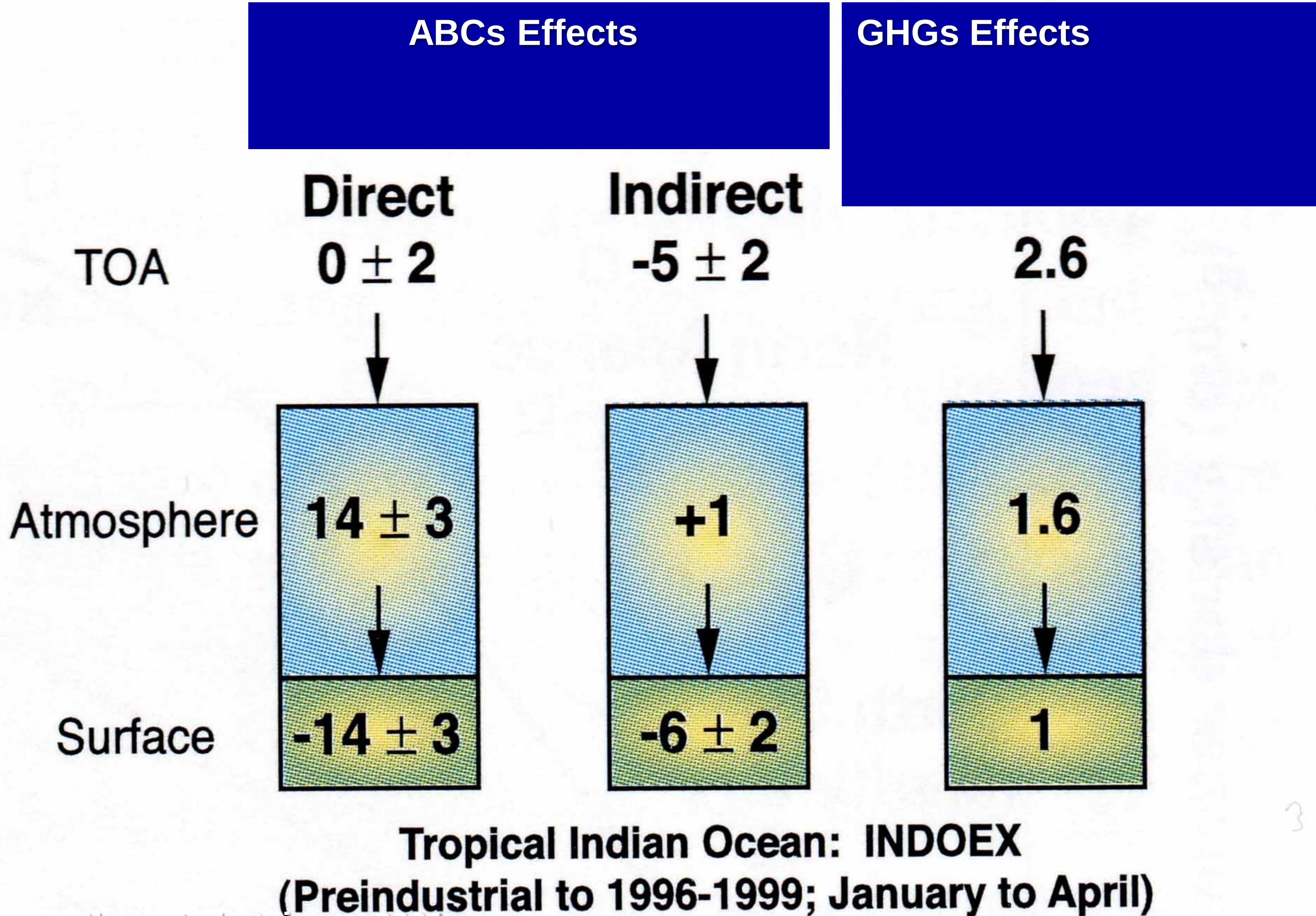
- The Solar Dimming (SDM) Effect : More aerosol cooling reduceds surface evaporation, reduce meridional SST gradient, causes a spin-down of the Hadley circulation, weakens the monsoon (Ramanathan et al 2005, Chung and Ramanathan, 2005..)

- The Elevated Heat Pump (EHP) Effect: Dust and black carbon piling up against the foothills of the Himalayas, heats up upper troposphere, producing a positive water cycle feedback, enhancing the monsoon (Lau et al. 2006, Lau and Kim, 2006, 2007, Meehl et al. 2007, Collier and Chung 2009…)

- Microphysics effects of aerosol – a wild card

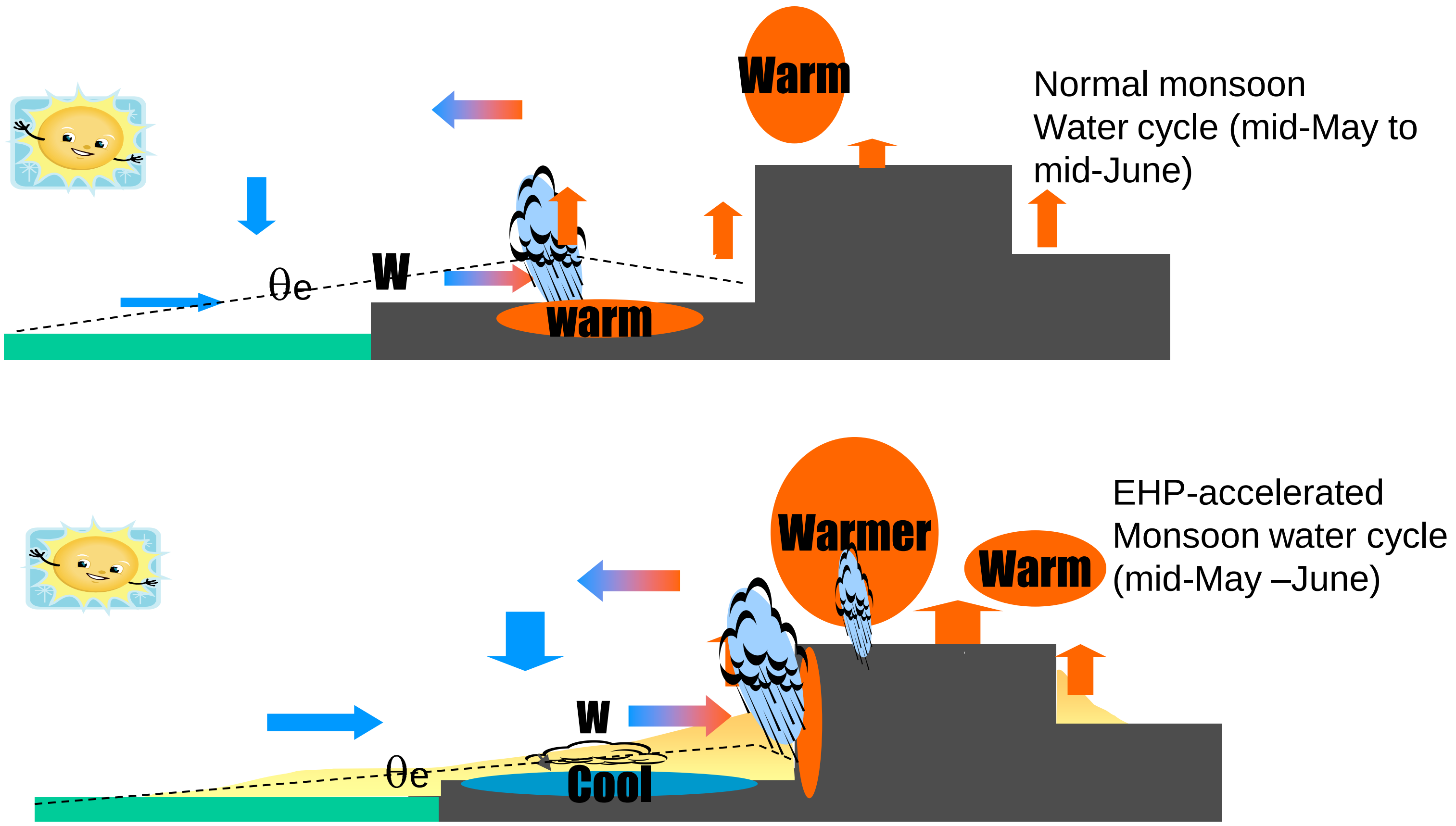
- Coupled Atmosphere-land-ocean dynamics: All aerosols effects are likely to be confounded, modulated by large-scale remote forcing, e.g., El Nino, NAO, Global warming…

ABCs and GHGs: Impact on Regional Radiation Budget



Ramanathan et al, Science 2001

The Elevated Heat Pump (EHP) hypothesis (Lau et al. 2006, 2007)



EHP postulates:

a) a warmer, and moister troposphere over the southern TP

b) an advance of the rainy season in Himalayas foothill region in May-June

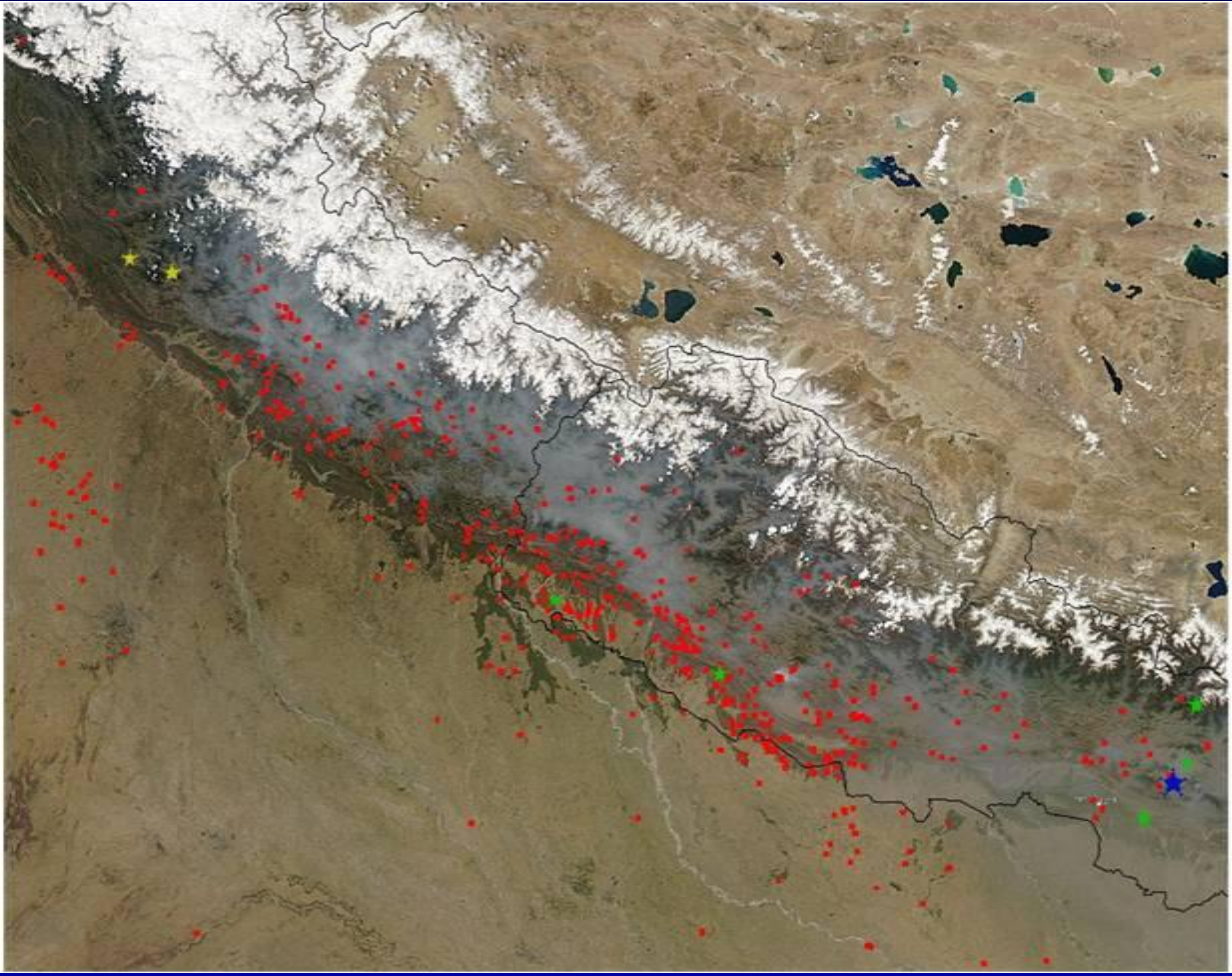
c) In June-July, the increased convection spreads from the foothills of the Himalayas to central India, resulting in an intensification of the Indian monsoon.

d) Possible related to long-term trend increased in rainfall over northwest India, and accelerated melting of Himalaya mountain glaciers.

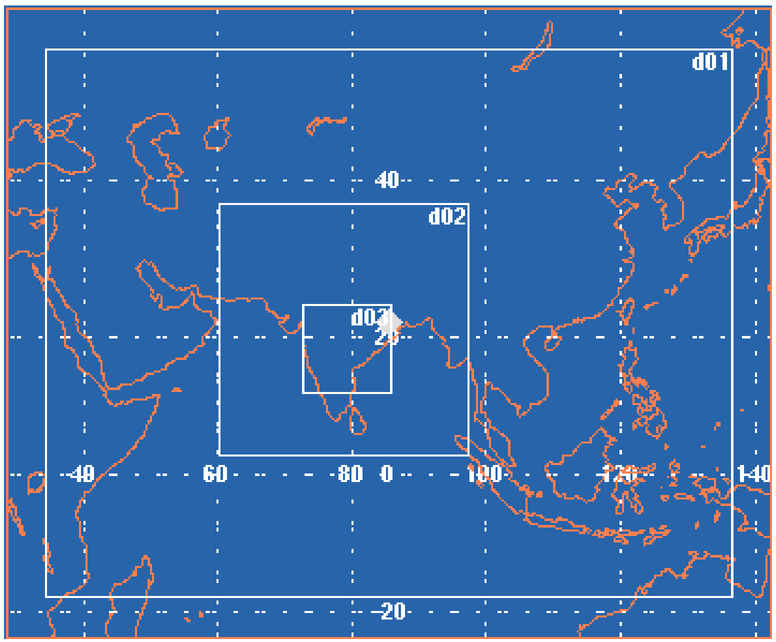
Possible consequences/signals of the "Elevated Heat Pump" effect

After major dust storm and/or as a long-term (decadal) trend:

- Warmer and moister upper troposphere over S. Tibetan Plateau
- Increased deep convection in the Himalayas foothills , and southern part of the TP, leading up to the monsoon onset
- Advance of monsoon rainy season, more rain in northern India/Nepal region in May-June; strengthening of Indian monsoon in June-July
- Weakening of the East Asian monsoon (Mei-yu rainfall), through large scale dynamical adjustment to EHP heating associated with a westward shift of the West Pacific subtropical high
- Accelerate the melting of mountain glacier→ expose land surface →surface warming → increased sensible heat flux → increased EHP
- Increased water vapor in the upper troposphere, and lower stratospheric, increased trend of reduction of stratospheric ozone over TP

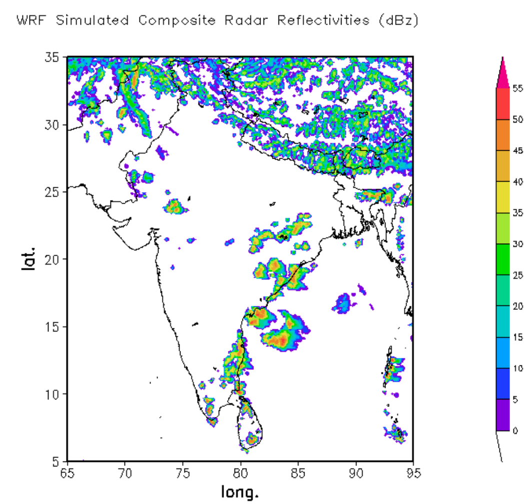


Aerosol-monsoon water cycle interaction

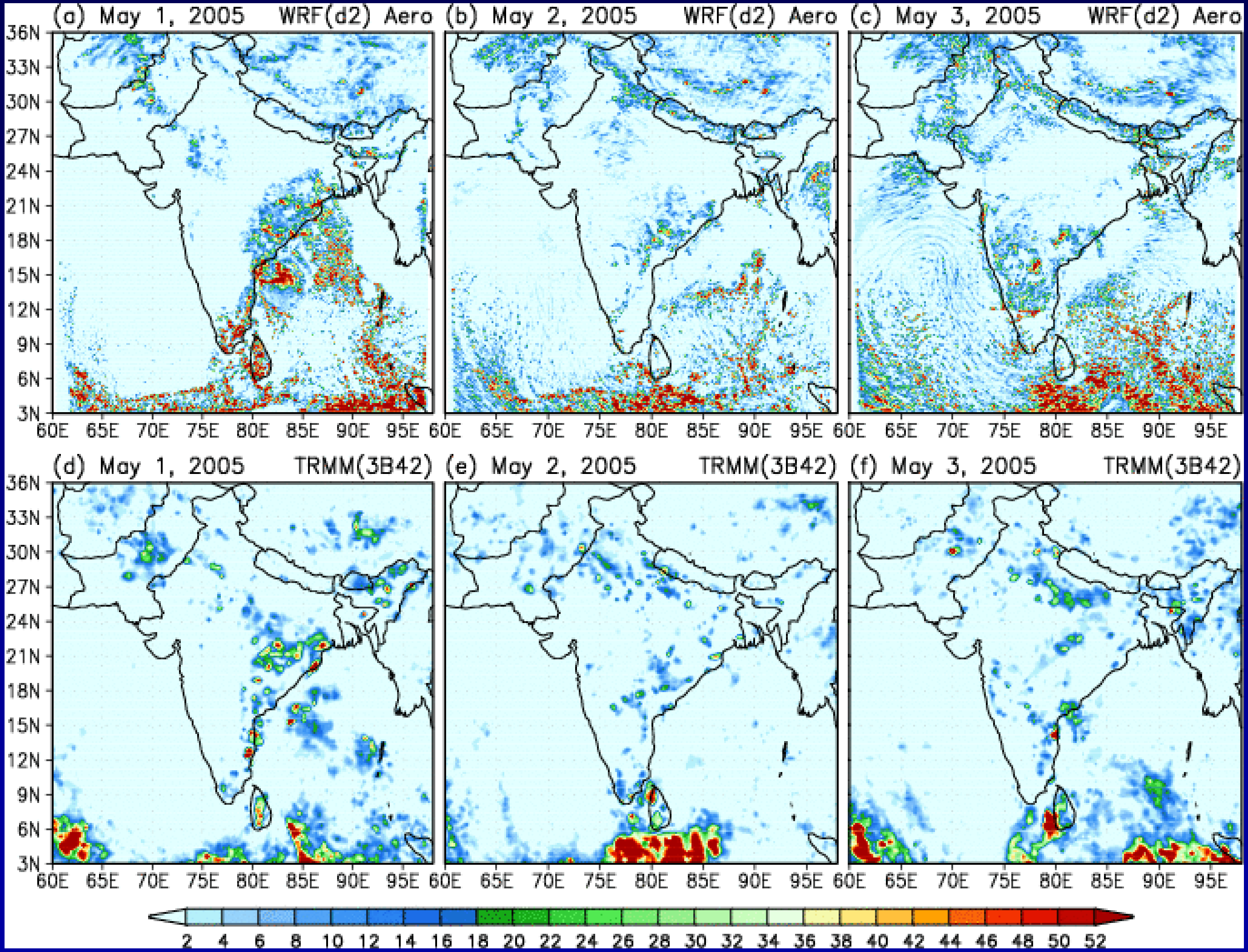


Resolutions: 27, 9 and 3 km
Grid size: 391x313, 427x427, 451x451, and 31 vertical layers
Δt = 9, 30 and 10 seconds
Starting time: 00Z 05/01/2005
Initial and Boundary Conditions:
  NCEP/GFS, no data assimilation

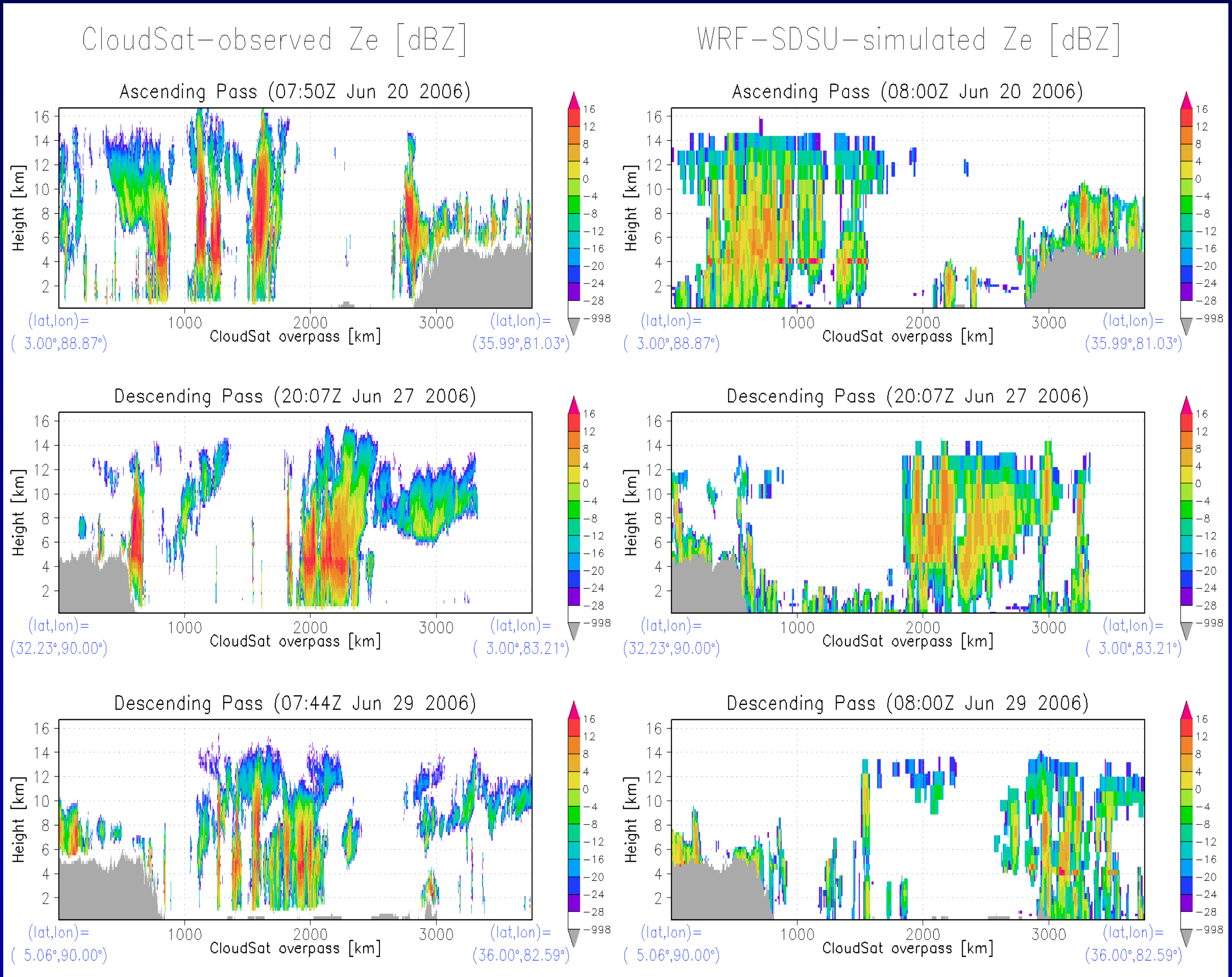
- Cu parameterization: Grell-Devenyi scheme (for the outer grid only)
- Cloud microphysics:
  Goddard microphysics 3ice-Graupel
- Radiation:
  shortwave: New Goddard
  longwave: New Goddard
- PBL parameterization:
  Mellor-Yamada-Janjic TKE scheme
- Surface Layer:
  Monin-Obukhov (Janic)
- Land Surface Model: Noah land-surface
- Aerosol physics (direct and indirect effects)

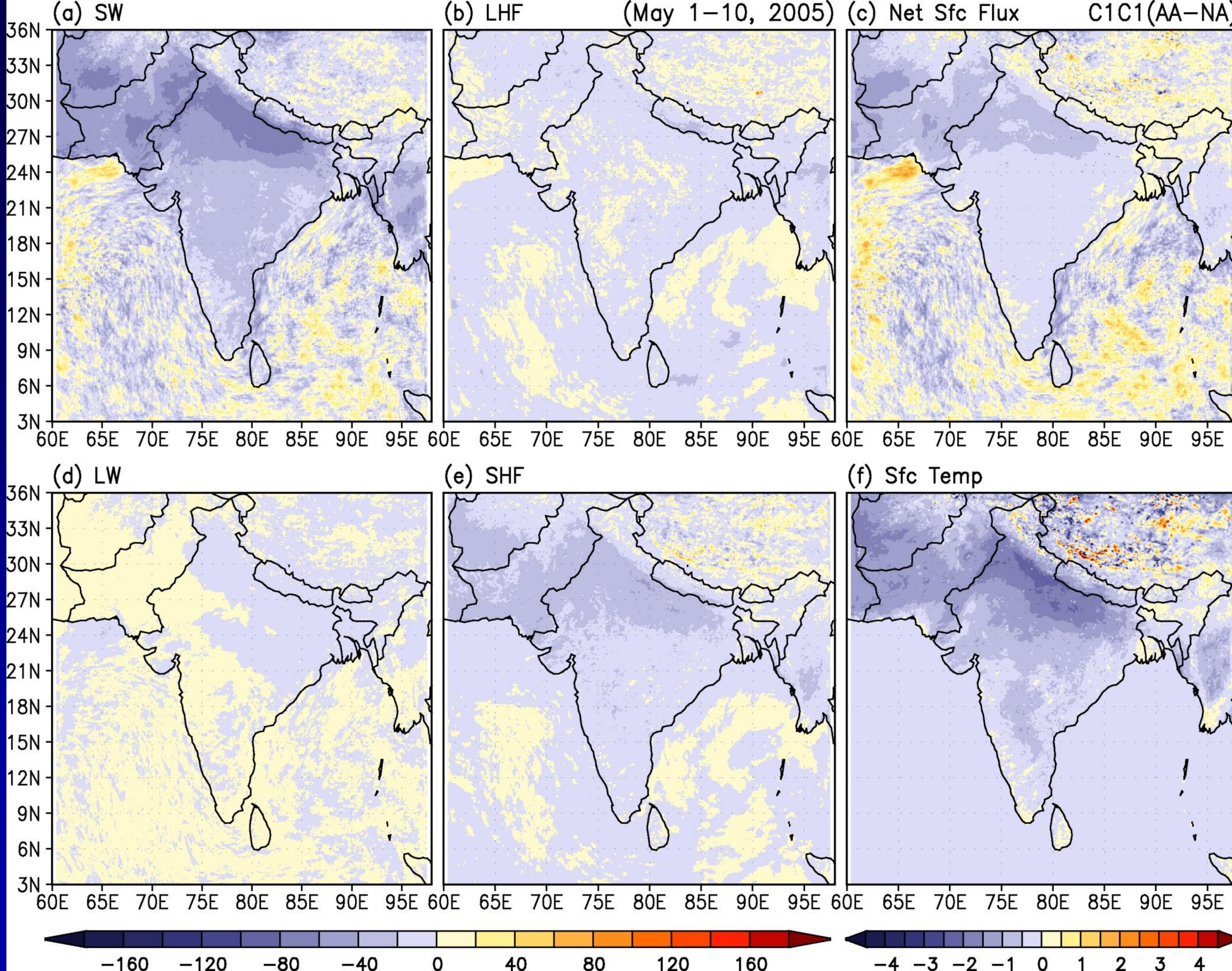


Daily Mean Rain Rate (Aerosol Run)

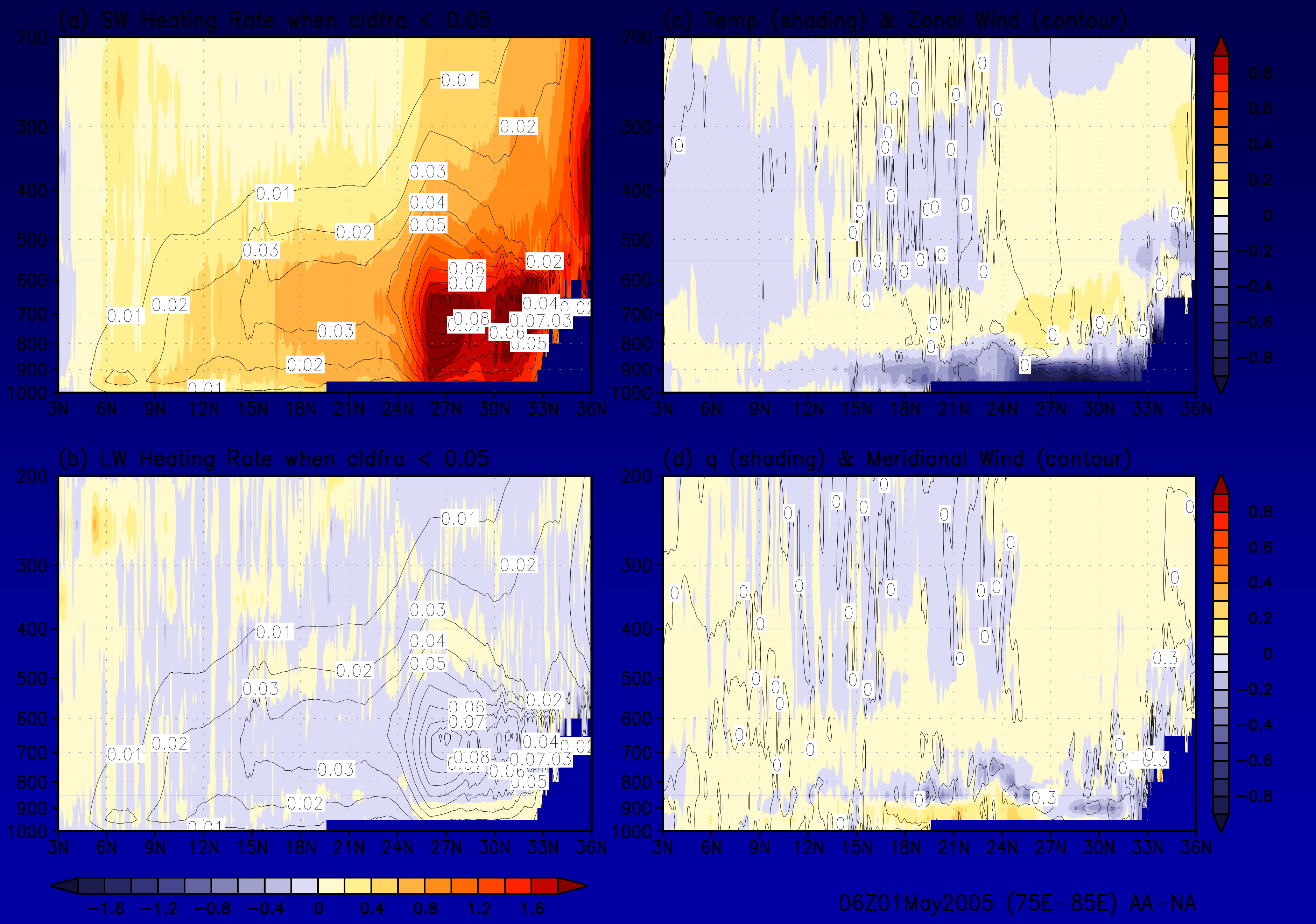


Satellite simulator, radiance-based validation of WRF model results,



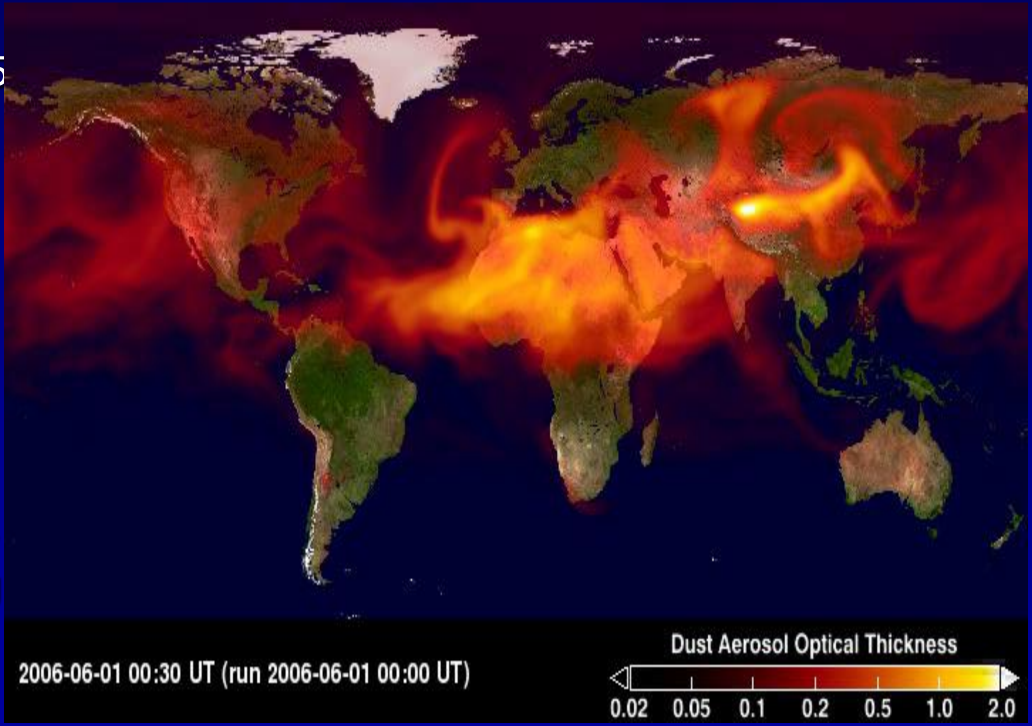


(a) SW
(b) LHF
(May 1–10, 2005)
(c) Net Sfc Flux
C1C1(AA–NA)
(d) LW
(e) SHF
(f) Sfc Temp
36N 33N 30N 27N 24N 21N 18N 15N 12N 9N 6N 3N
60E 65E 70E 75E 80E 85E 90E 95E
−160 −120 −80 −40 0 40 80 120 160
−4 −3 −2 −1 0 1 2 3 4


(a) SW Heating Rate when cldfra < 0.05
(c) Temp (shading) & Zonal Wind (contour)
(b) LW Heating Rate when cldfra < 0.05
(d) q (shading) & Meridional Wind (contour)
3N 6N 9N 12N 15N 18N 21N 24N 27N 30N 33N 36N
200 300 400 500 600 700 800 900 1000
−1.6 −1.2 −0.8 −0.4 0 0.4 0.8 1.2 1.6
−0.8 −0.6 −0.4 −0.2 0 0.2 0.4 0.6 0.8
06Z01May2005 (75E-85E) AA-NA

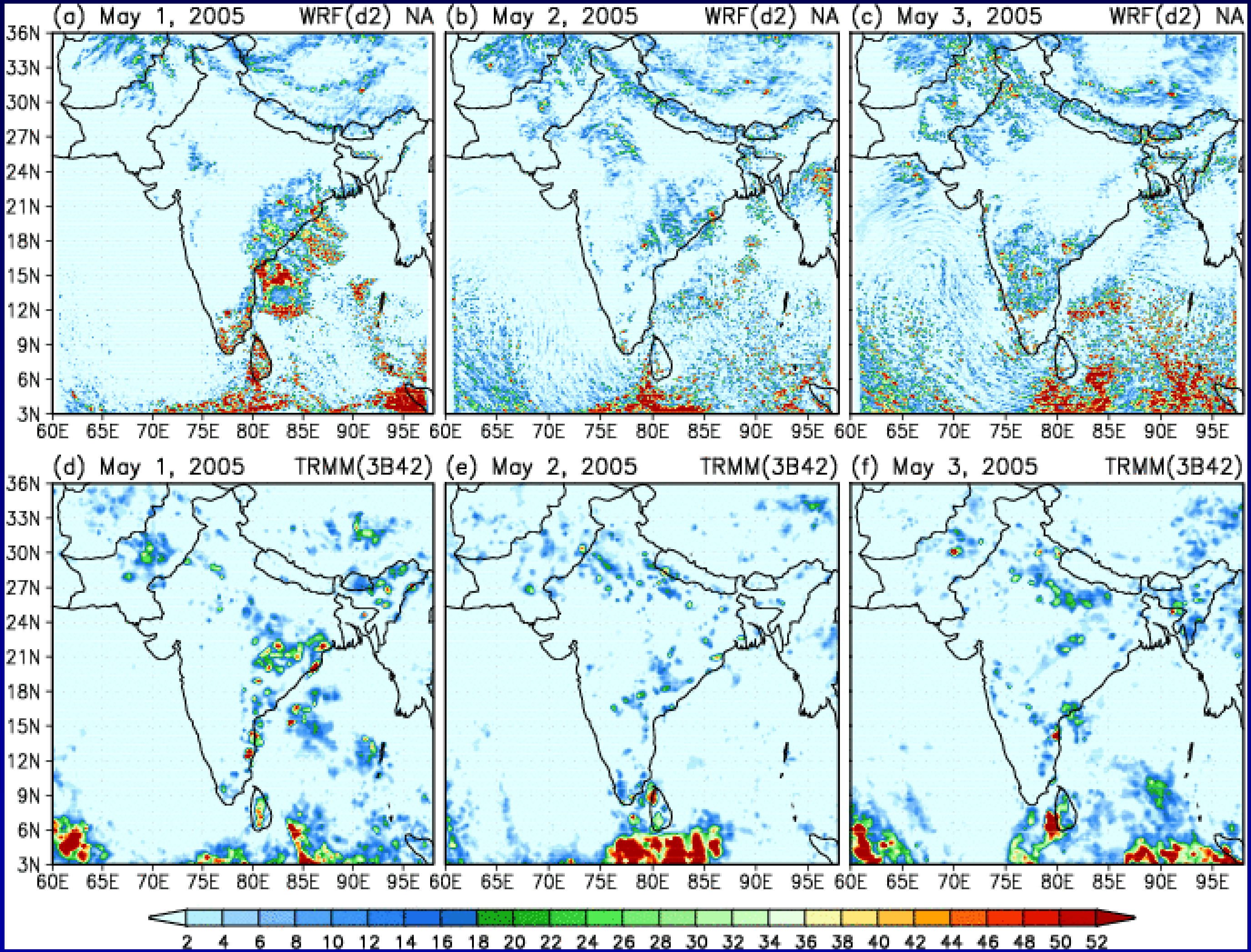
Proposed HR modeling experiments with Coupled GOCART-GEOS-5 with 1/4x1/4 degree resolution

1. Run ¼ x ¼ degree (or higher) resolution of GEOS-5 (with out aerosols) with specified SST for 2005 and 2006
2. Same as (1), but with GEOS-5 with interactive aerosols
3. Same as (2),but with specified aerosol forcing from (2)
4. Repeat (2) and (3) with mixed-layer ocean
5. Use HR global GEOS-5 as boundary conditions to run multiple-embedding WRF (with indirect effects of aerosols) over complex terrain of IGP/Himalayas to study regional aerosol-hydroclimate interactions

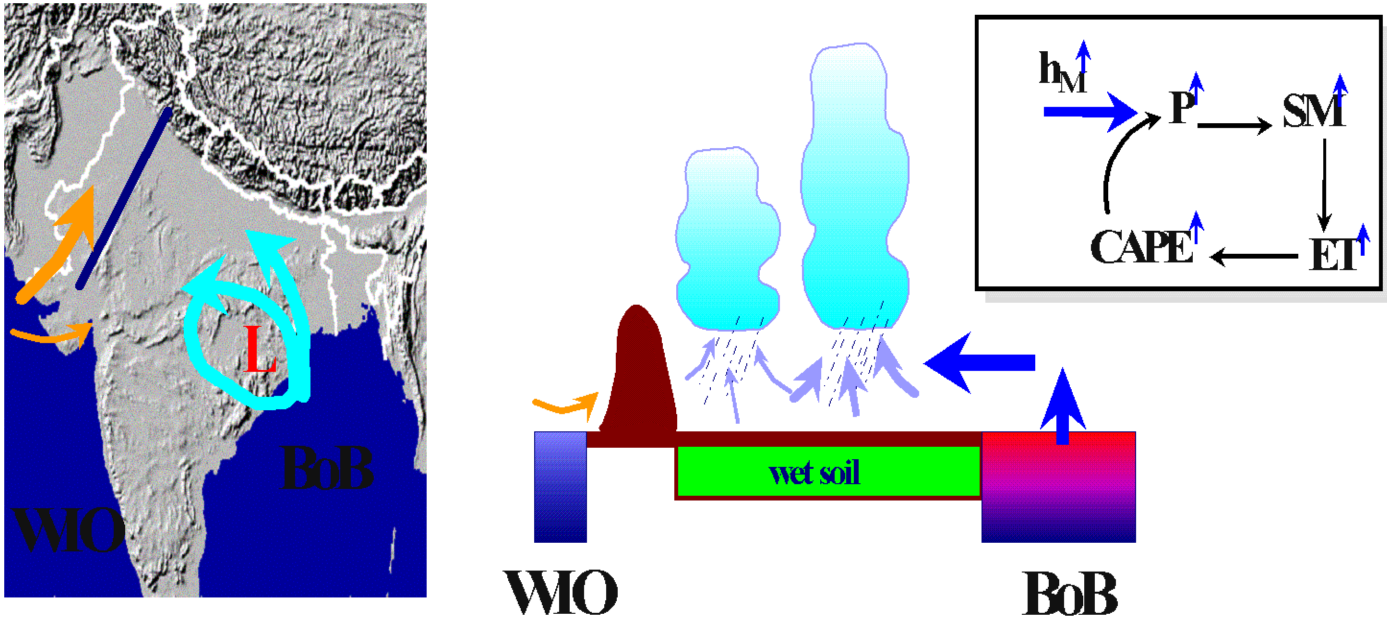


- Back up

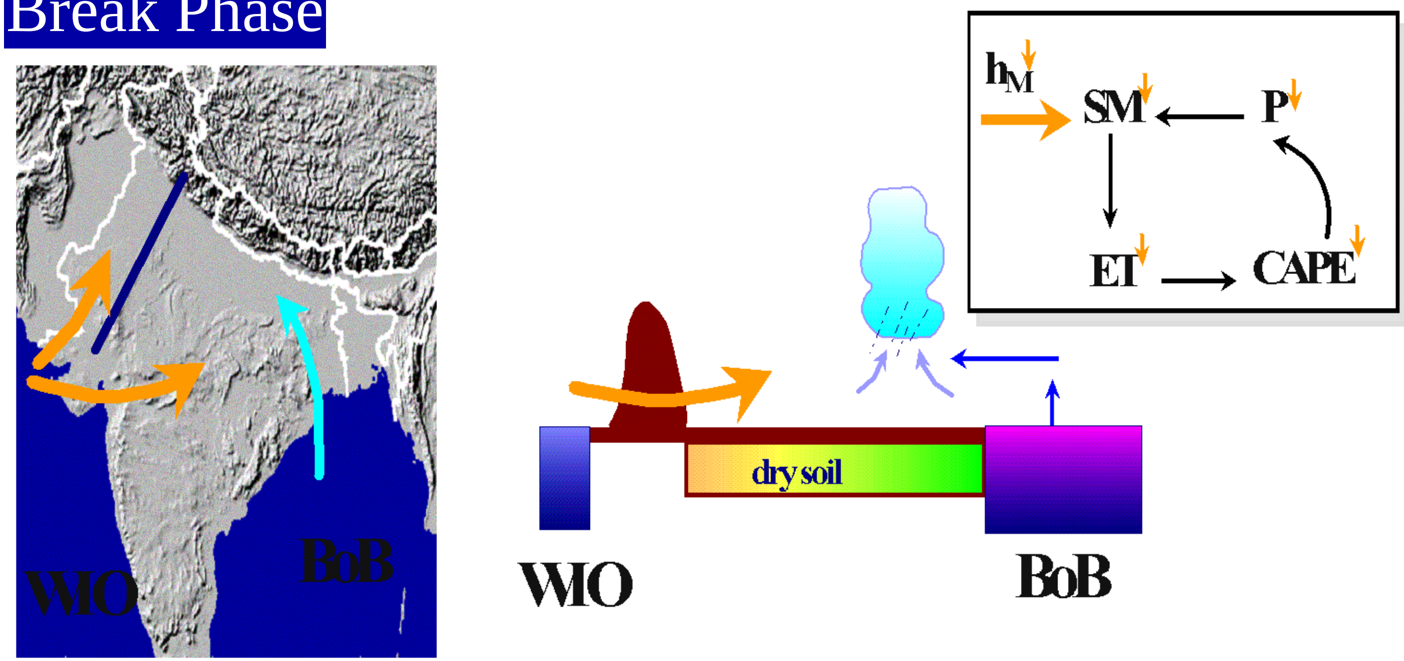
Daily Mean Rain Rate (No-Aerosol Run)



Active Phase



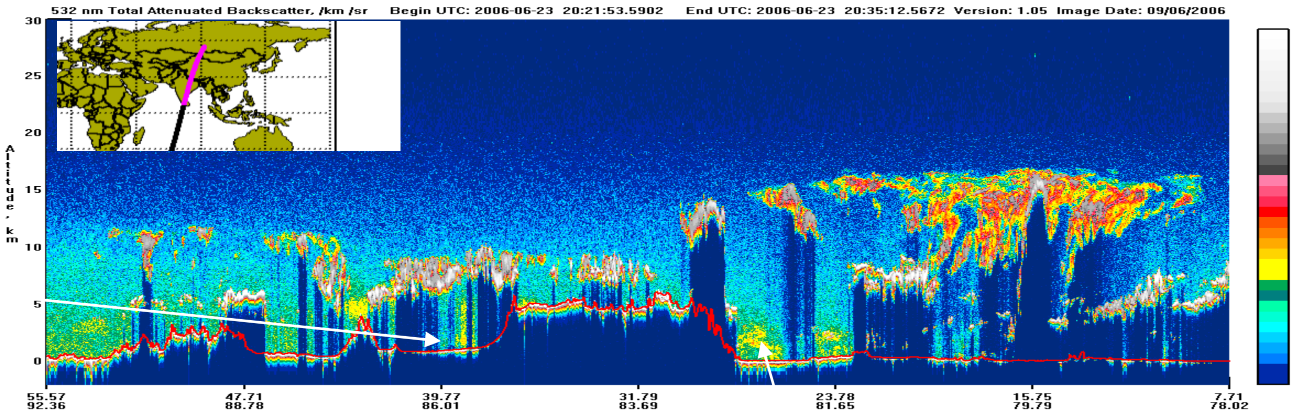
Break Phase



Merdional cross-section of aerosol concentration from Calipso

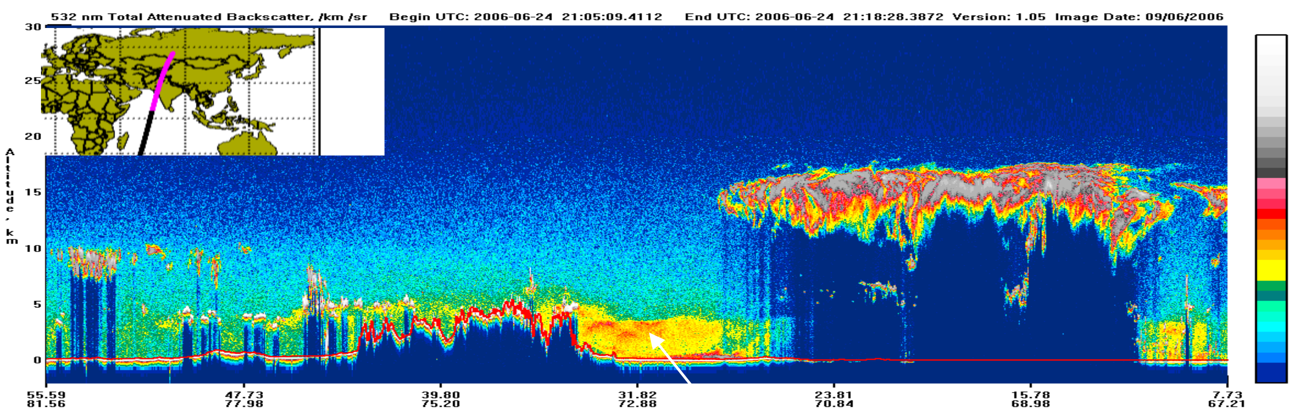
June 23 2006

Taklamakan Desert



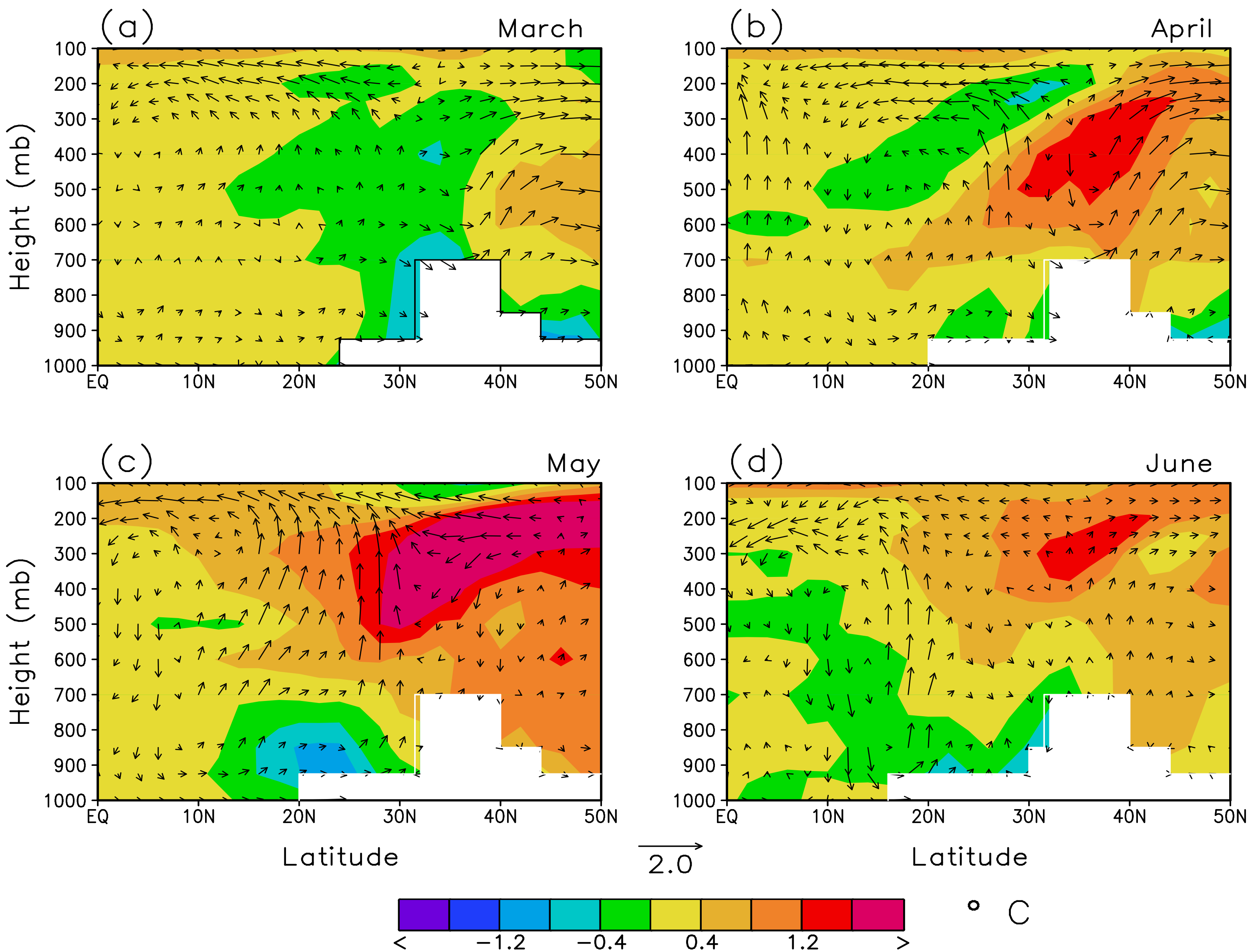
IGB

June 24, 2006



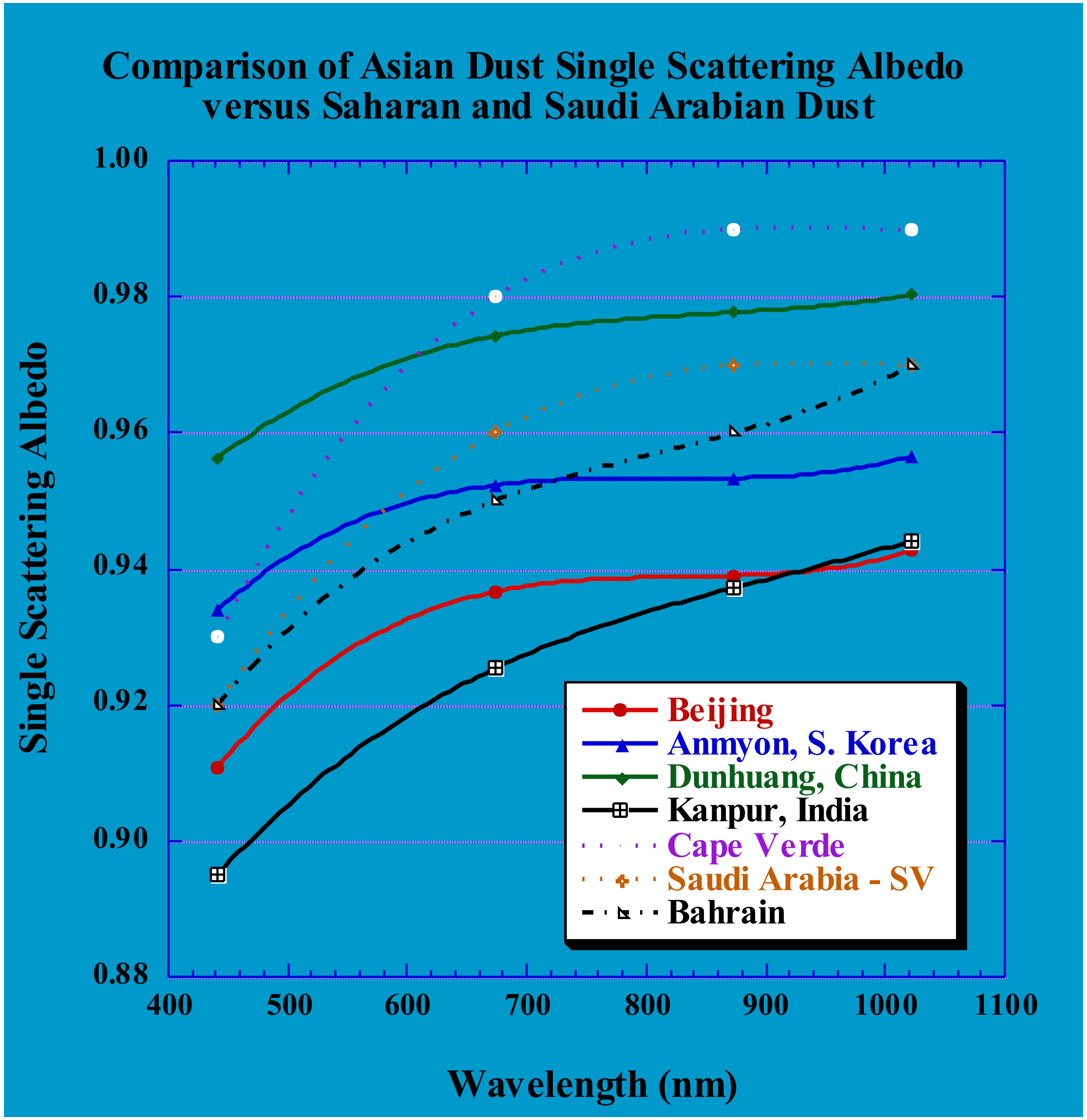
northeastern IGB

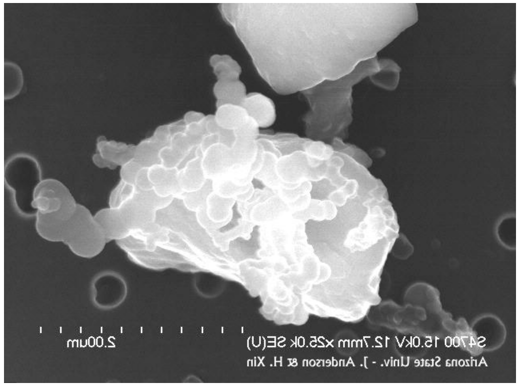
Anomalies (aerosol-minus-no aerosol) of vertical temperature (80-100E) simulated by the GEOS GCM

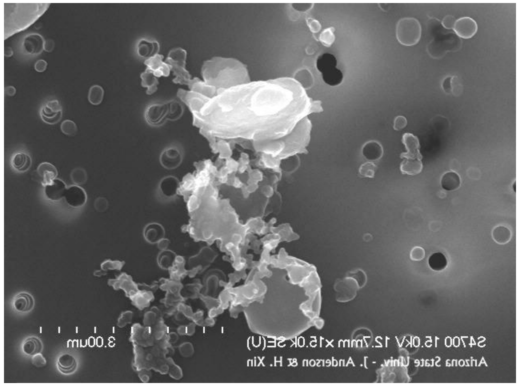


Dusts over major industrial cities are more absorbing (solar radiation)

More absorbing



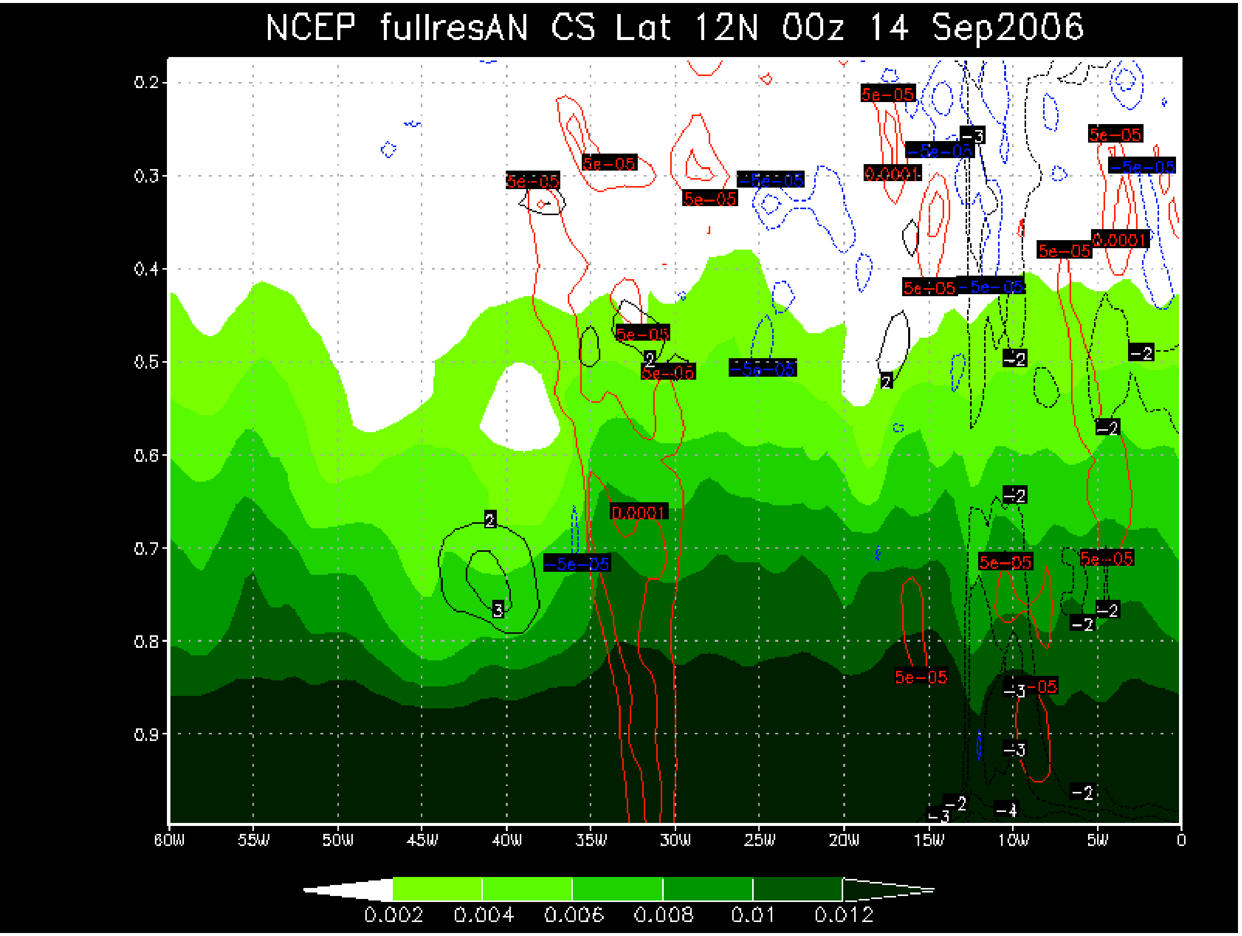




Micrographs of
soot coating and aggregate
on mineral dust from Asian
dust (courtesy of J. Anderson)

T. Eck et al 2004

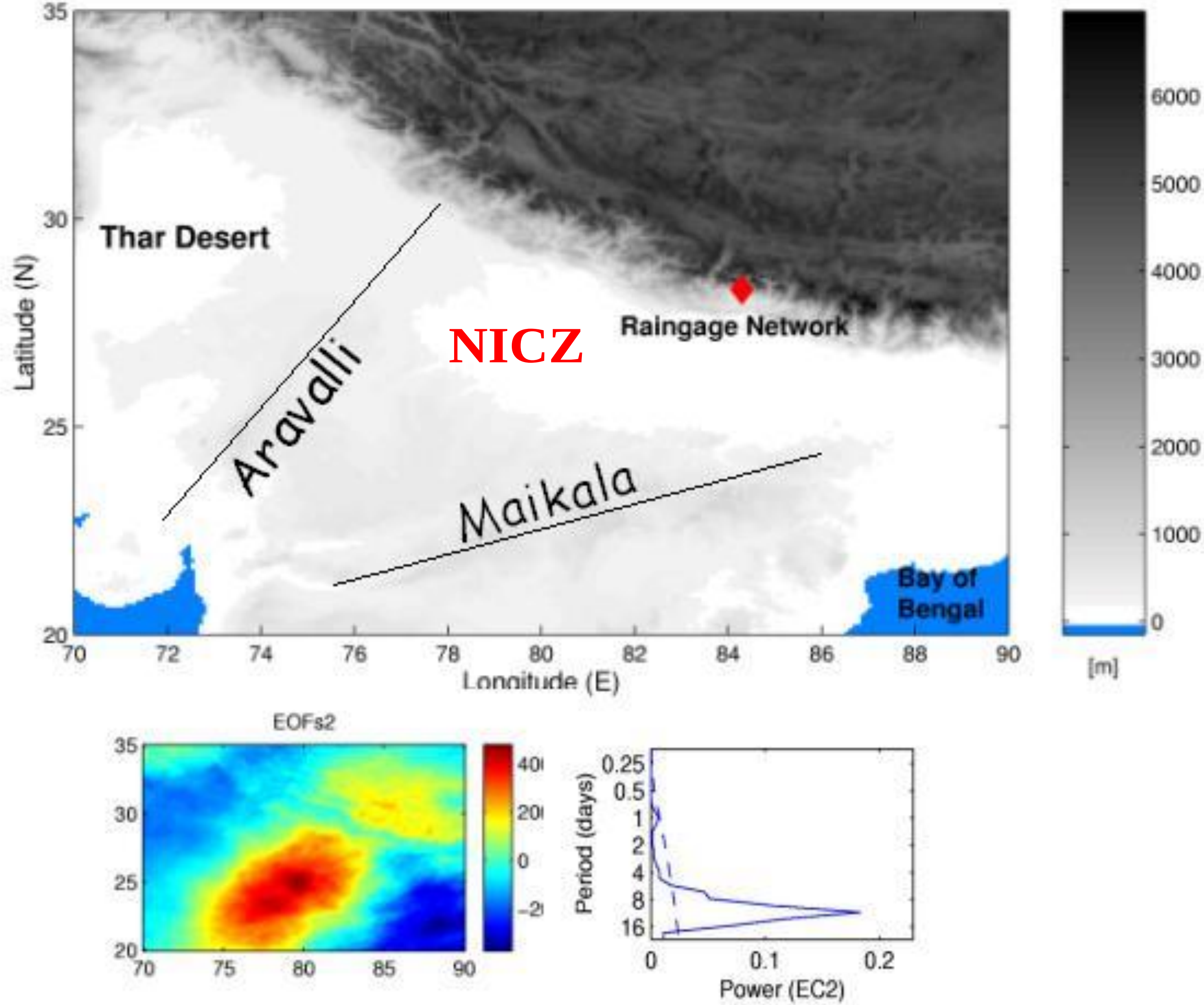
No evidence of dry air in a developing system (TS Helene)



Specific humidity,
Relative vorticity

The cyclonic vorticity Column represents the Developing system named Helene

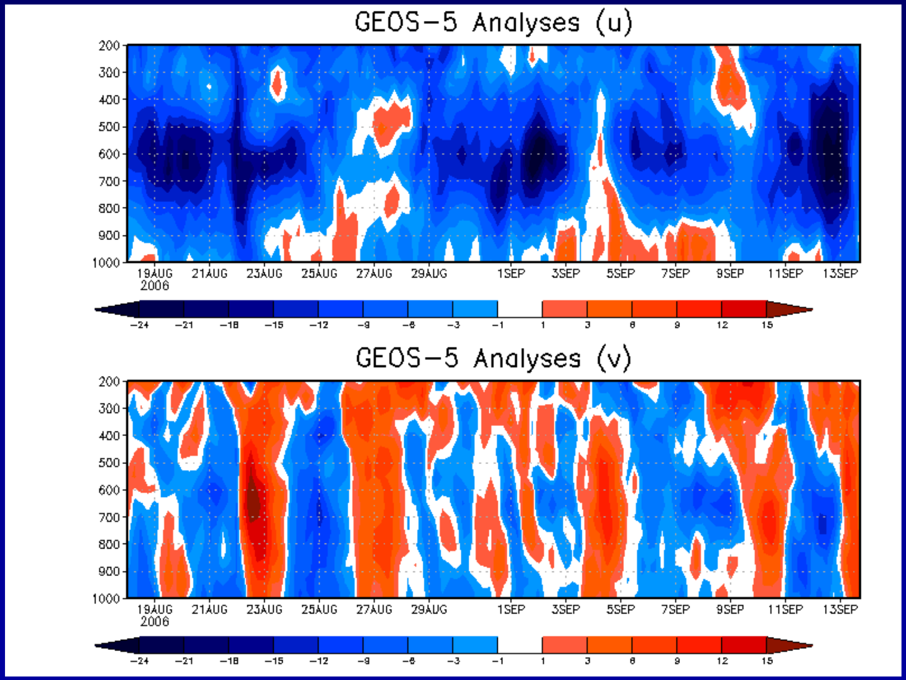
A much weaker thermal Anomaly associated to a Remnant of dry air to the W of Helene



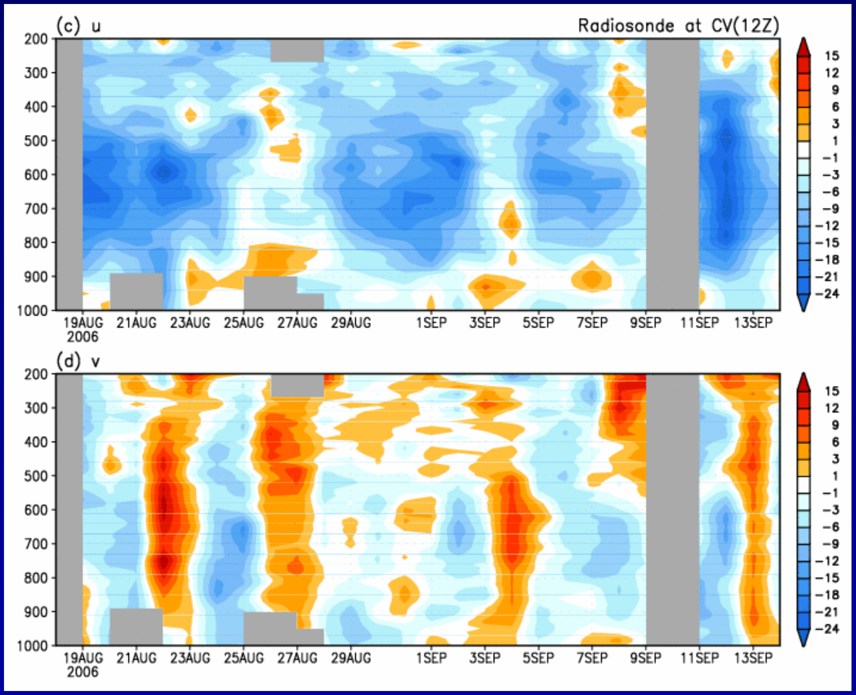
Thar Desert
Aravalli
NICZ
Raingage Network
Maikala
Bay of Bengal
Latitude (N)
Longitude (E)
[m]
EOFs2
Period (days)
Power (EC2)

Validation
GEOS-5 Analyses versus observations

Profiles extracted from GEOS-5 Analyses



Observed profile (12Z) At Cape Verde

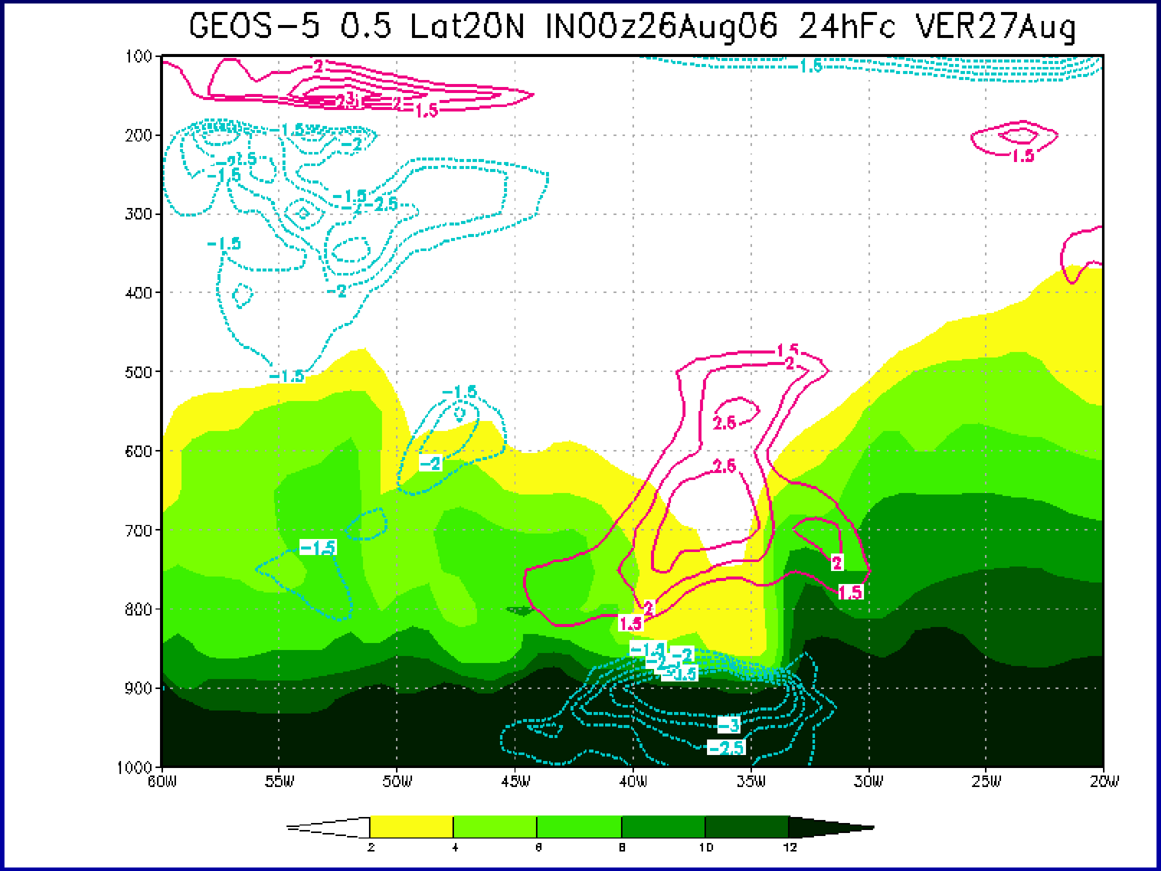


MAJOR WAVE PASSAGES **ARE** ALL REPRODUCED IN THE ANALYSES

To understand possible SAL (hot, dry air) and radiative effects of dust on TC, accurate representations of dust properties and transport processes are very important

- Very sharp moisture gradients advected into a circulation is critical for correct prediction of a non-developing wave
- Microwave imagery, high-resolution global analyses confirm that dry air can be driven into a tropical circulation with minimal mixing for at least 48-60 hours
- Very clear thermal signature detected in full resolution NCEP analyses and maintained in GEOS-5 short (up to 60 hours) integrations associated with Saharan air
- When the thermal anomaly associated to SAL is advected in the center of the storm, convection seems to immediately disappear.
- The fv dynamical core seems to have some advantage with respect to other types of dynamics
- Radiative properties of dust determines amount of heating/cooling in the atmosphere

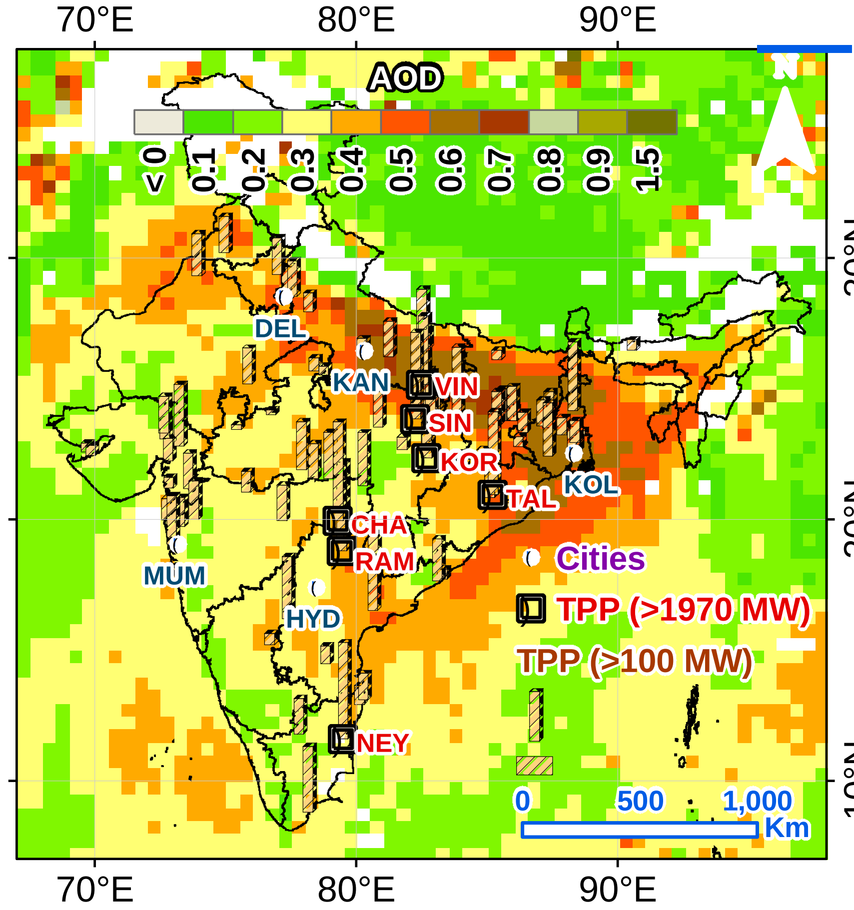
The importance of horizontal resolution Cross-section of W1 with GEOS-5 at 0.5 (low) horizontal resolution

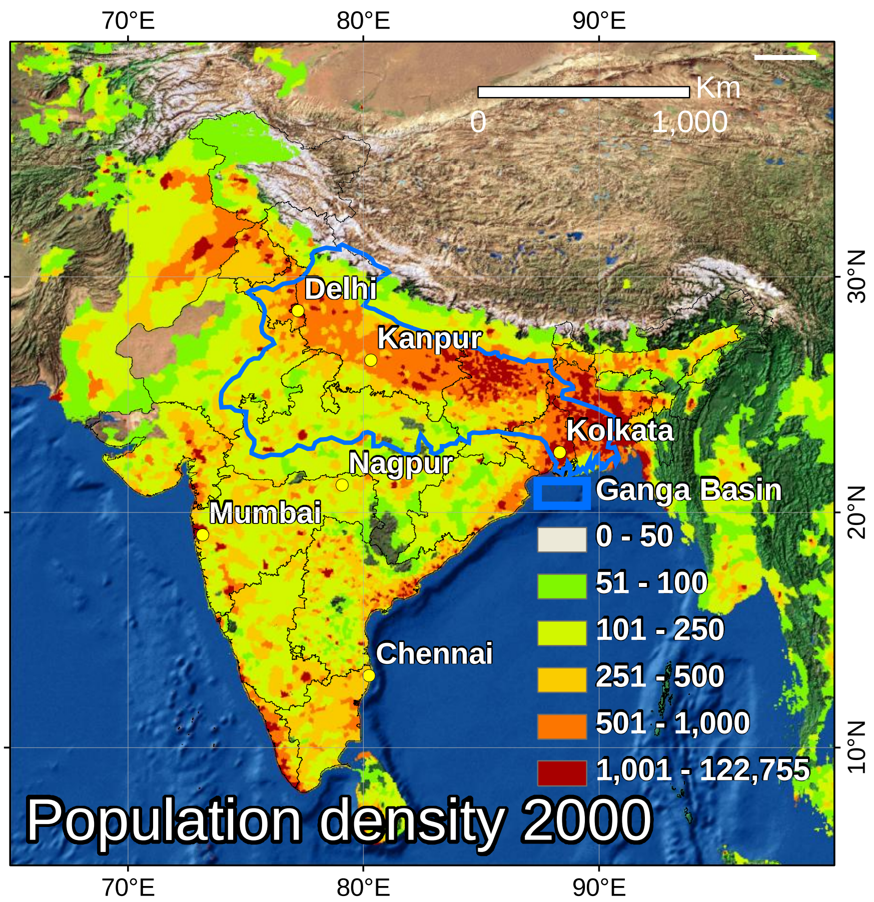


DILUTED MOISTURE GRADIENTS ON THE BORDERS OF THE SAL

No separation between the SAL and midlatitude intrusion

Sources and distribution of aerosols over India

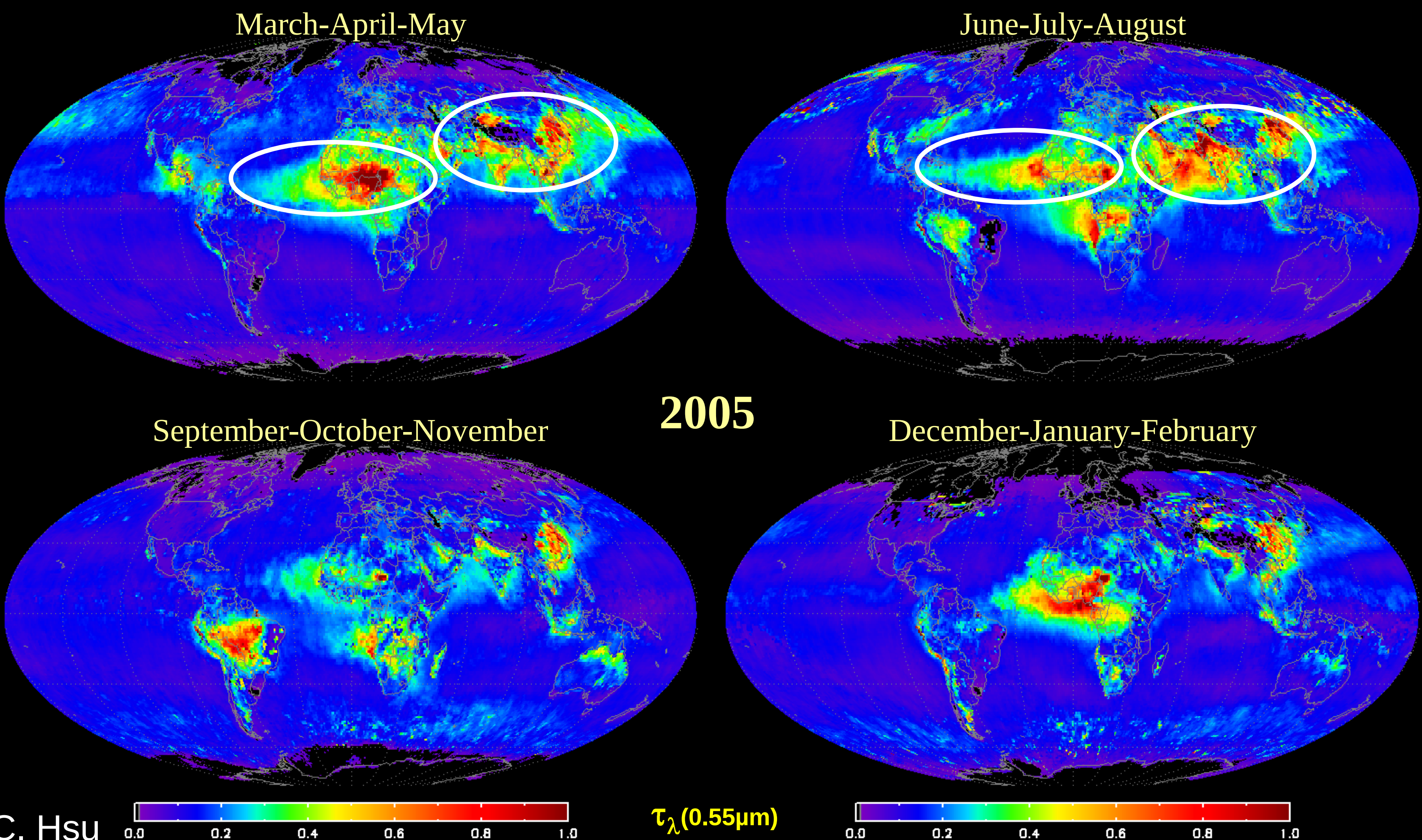




Courtesy R. Singh

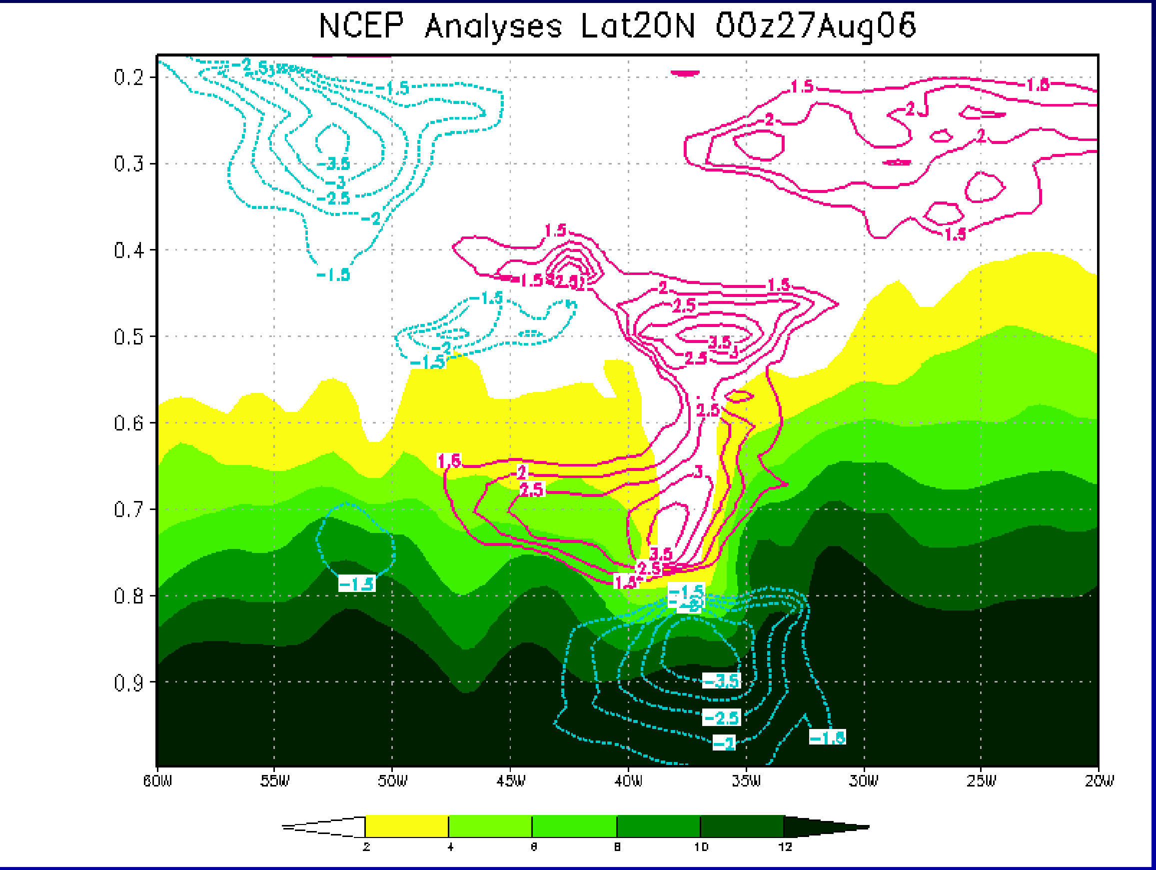
Global Aerosol Hotspots

- ***Year-round aerosols***
  - East-Southeast China, *mega-city*
  - Indo-Gangetic Basin dust, BC *mega-city*
  - Africa, Saharan dust (less in SON)
- ***Seasonal aerosols***
  - East Asia, dust (MAM)
  - Tropical Atlantic, dust (MAM, JJA)
  - Arabian Sea, dust (JJA)
  - Southeast Asia, smoke (DJF-MAM)
  - S. America, smoke (JJA-SON)
  - Africa, smoke (SON-DJF)
  - Southwest Asia, haze (MAM)



C. Hsu

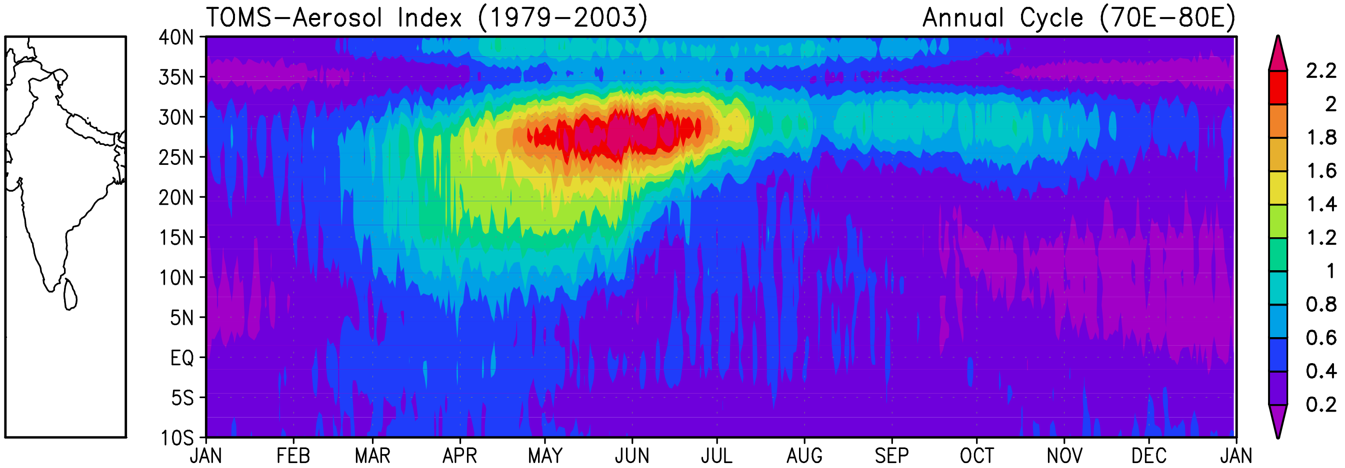
Similar structure in the NCEP Analyses

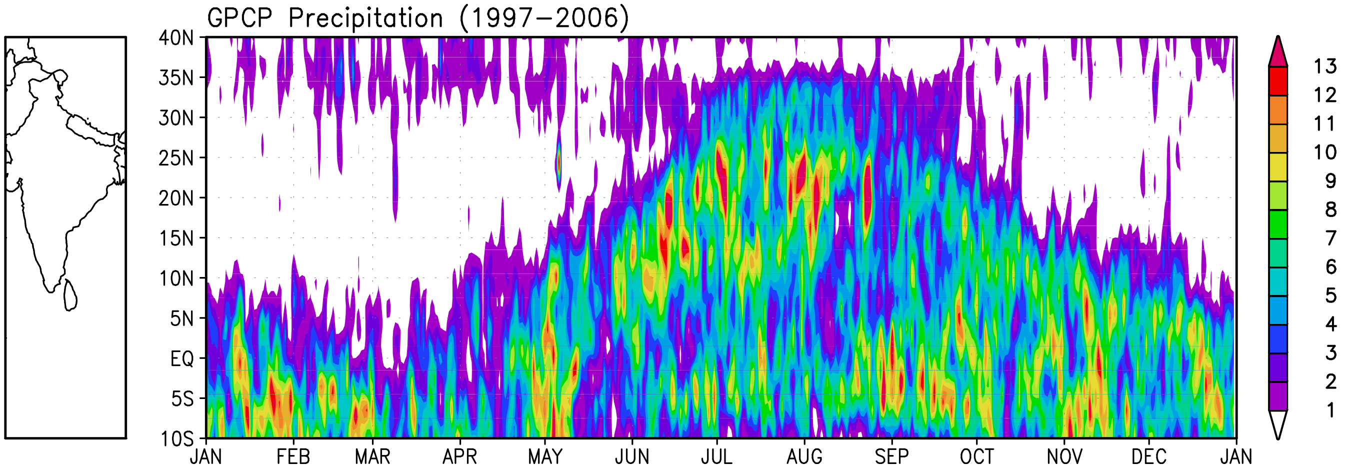


Less tight moisture gradients
Unrealistical diffusion of
Temperature anomalies
With respect to the GEOS-5

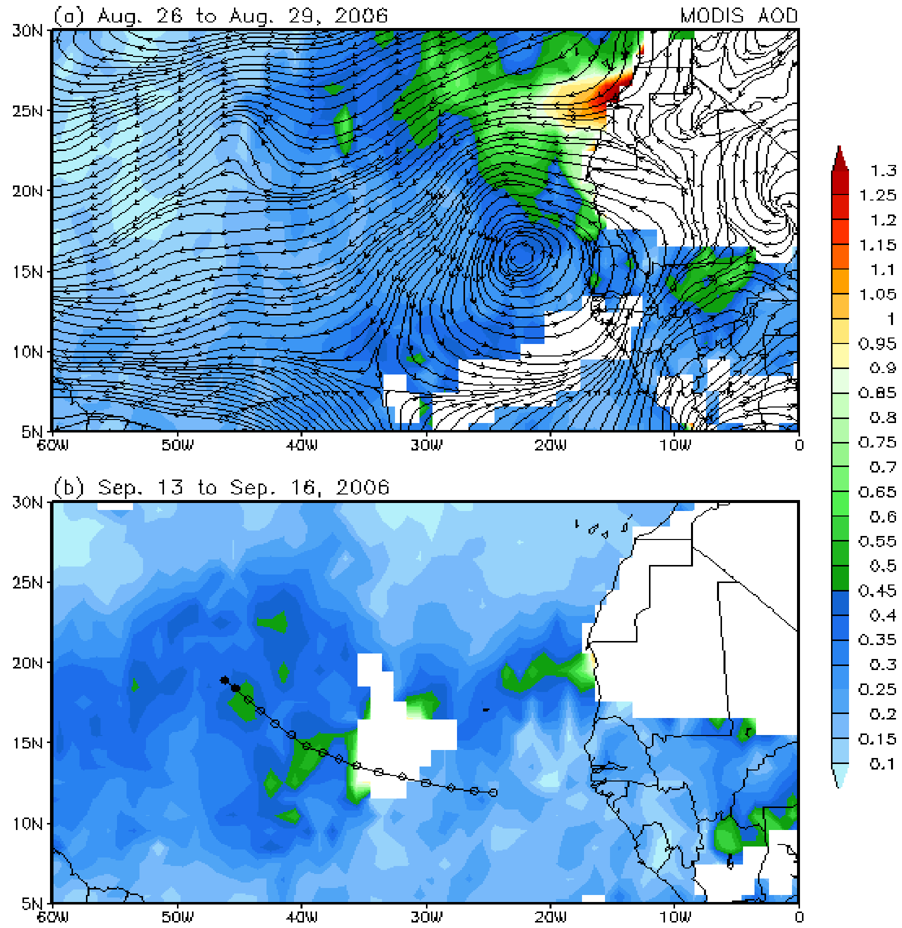
No detection of a thin
Intrusion of midlatitude
air (that can be seen
in the UWisc Imagery west
of W1)

Climatology of absorbing aerosol (dust and BC) and rainfall over India





Possible dust contribution

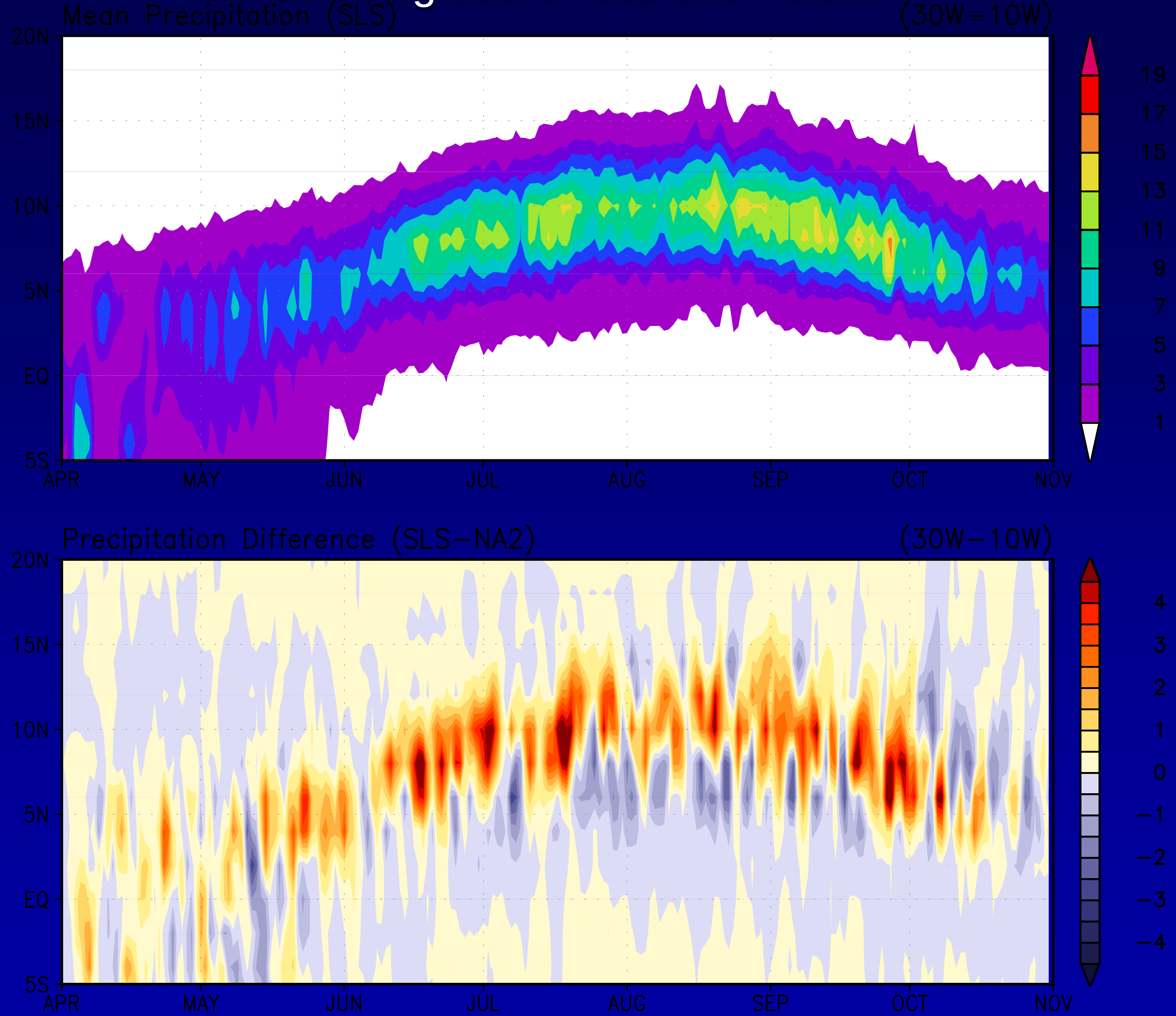


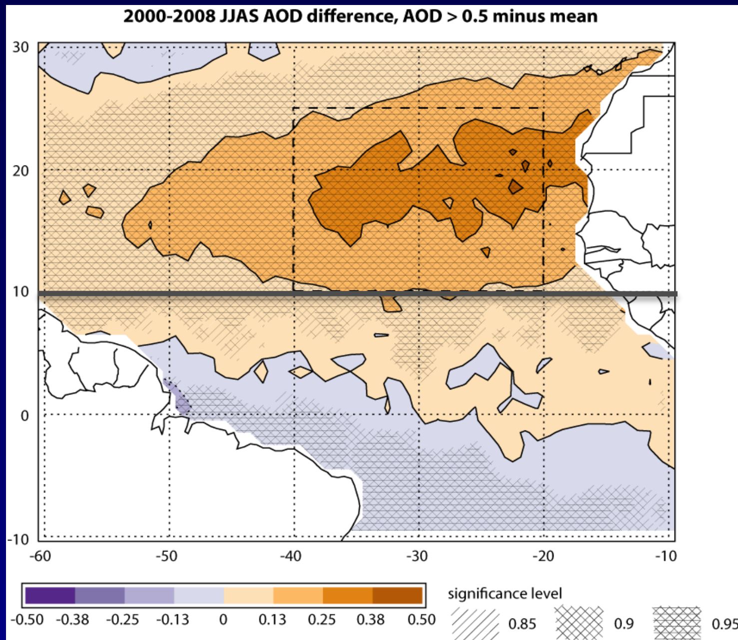
W1 at 00z 26Aug
Mean Aerosol Optical Depth 26-29 Aug
From MODIS

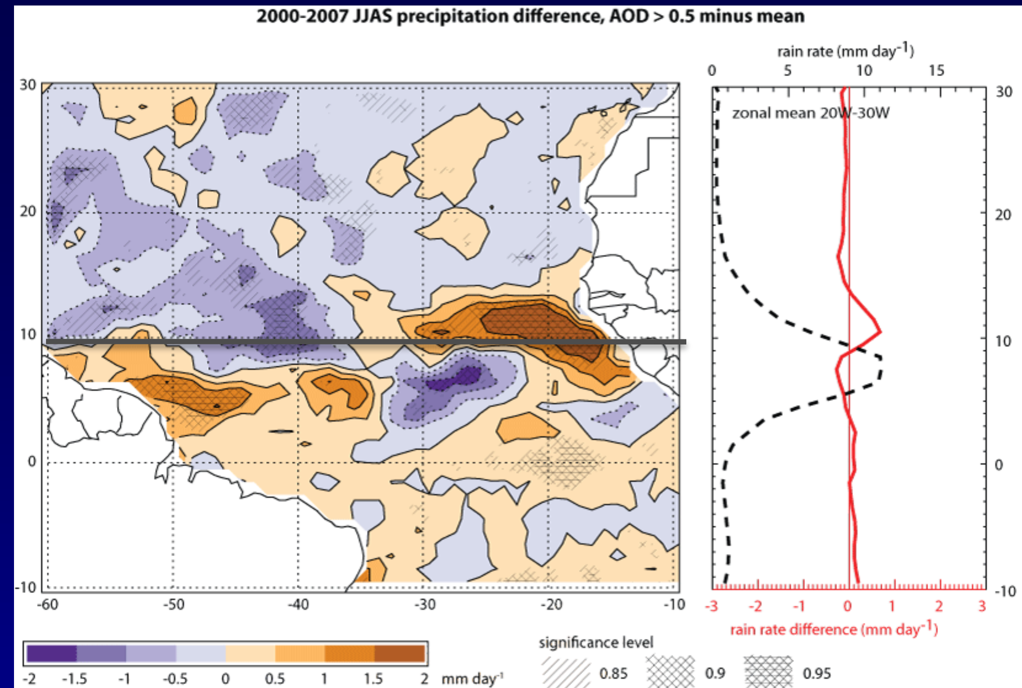
Helene's Track
Mean Aerosol Optical Depth 13-16 Sep
From MODIS

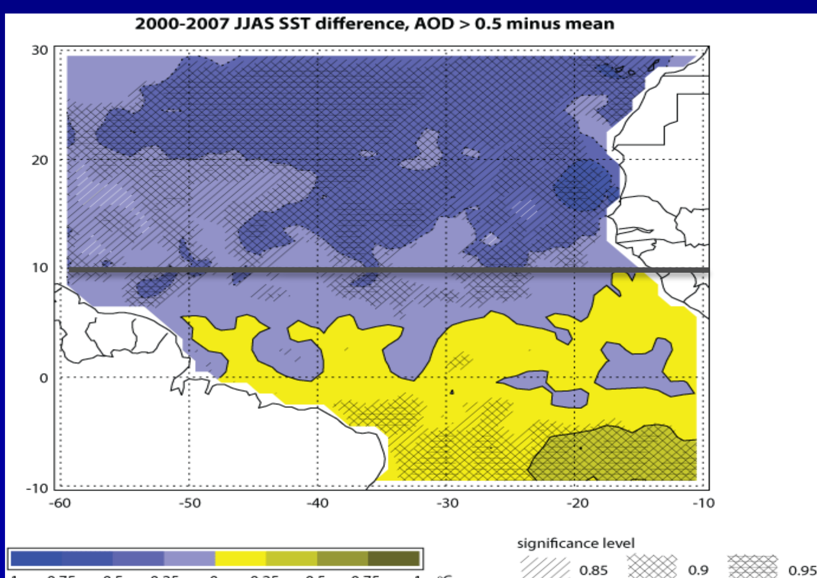
MUCH HIGHER AOD VALUES IN THE NON-DEVELOPING CASE

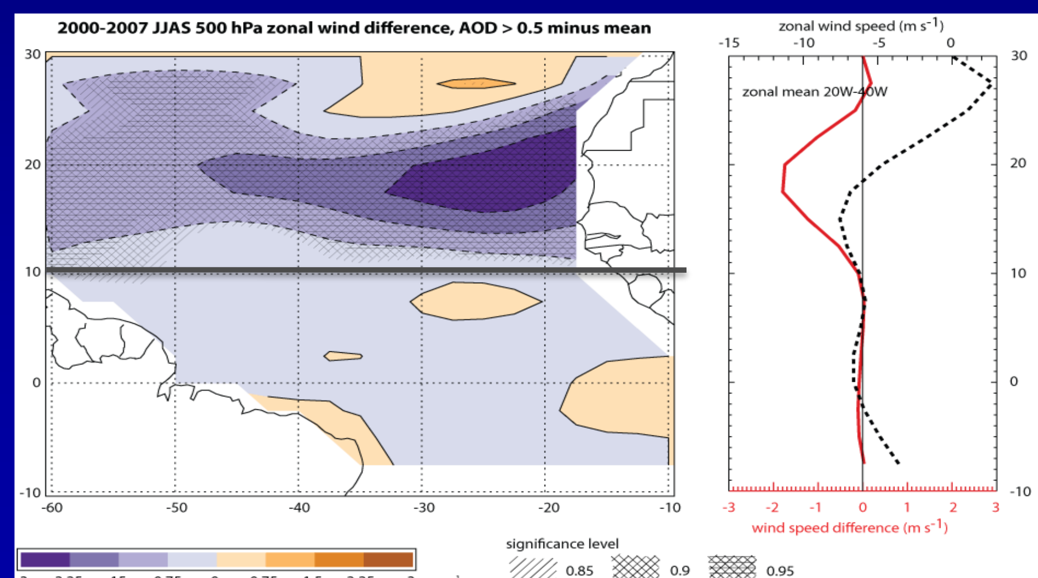
Impact aerosol forcing in affecting ITCZ rainfall using coare resolution GCM



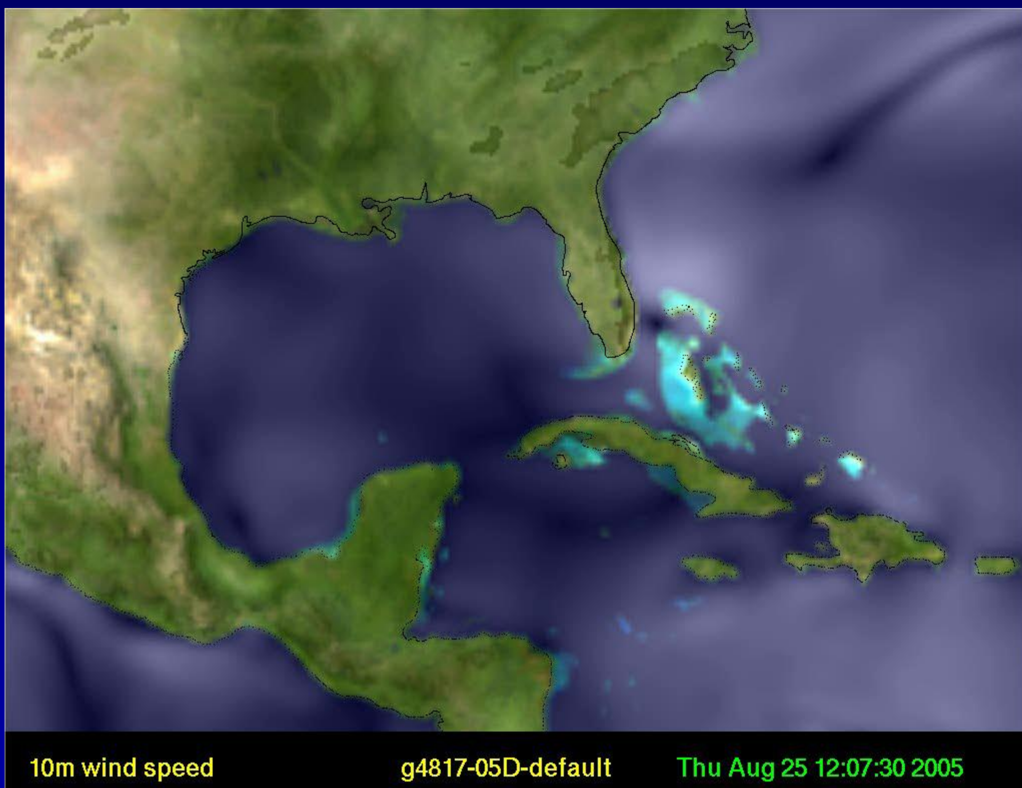

2000-2008 JJAS AOD difference, AOD > 0.5 minus mean
30
20
10
0
-10
-60
-50
-40
-30
-20
-10
-0.50 -0.38 -0.25 -0.13 0 0.13 0.25 0.38 0.50
significance level
0.85
0.9
0.95

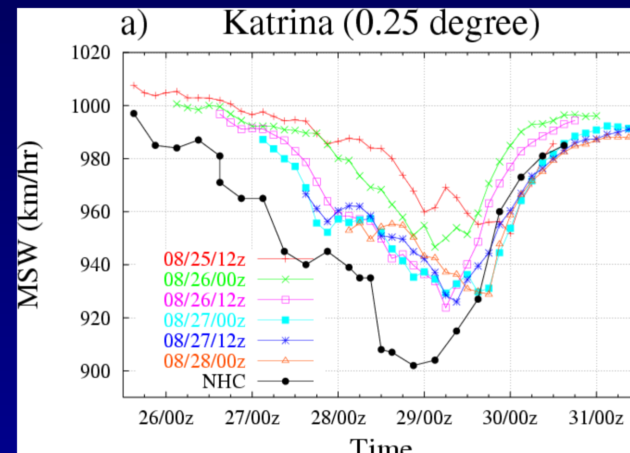

2000-2007 JJAS precipitation difference, AOD > 0.5 minus mean
rain rate (mm day-1)
0 5 10 15
zonal mean 20W-30W
30
20
10
0
-10
-60 -50 -40 -30 -20 -10
-3 -2 -1 0 1 2 3
rain rate difference (mm day-1)
latitude
-2 -1.5 -1 -0.5 0 0.5 1 1.5 2 mm day-1
significance level
0.85
0.9
0.95

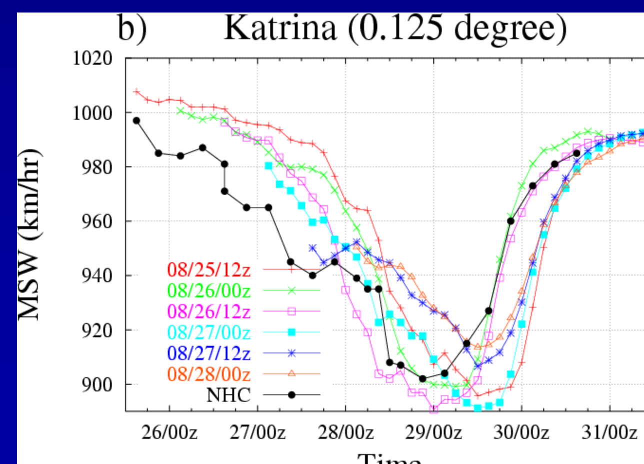

2000-2007 JJAS SST difference, AOD > 0.5 minus mean
30
20
10
0
-10
-60 -50 -40 -30 -20 -10
-1 -0.75 -0.5 -0.25 0 0.25 0.5 0.75 1 °C
significance level
0.85
0.9
0.95


2000-2007 JJAS 500 hPa zonal wind difference, AOD > 0.5 minus mean
zonal wind speed (m s-1)
-15 -10 -5 0
zonal mean 20W-40W
30
20
10
0
-10
-60 -50 -40 -30 -20 -10
-3 -2 -1 0 1 2 3
wind speed difference (m s-1)
latitude
-3 -2.25 -15 -0.75 0 0.75 1.5 2.25 3 m s-1
significance level
0.85
0.9
0.95

Katrina Intensity Forecasts







Aerosol sources and transport over the Indo-Gangetc Plain