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The Asian monsoon anticyclone and water vapor transport

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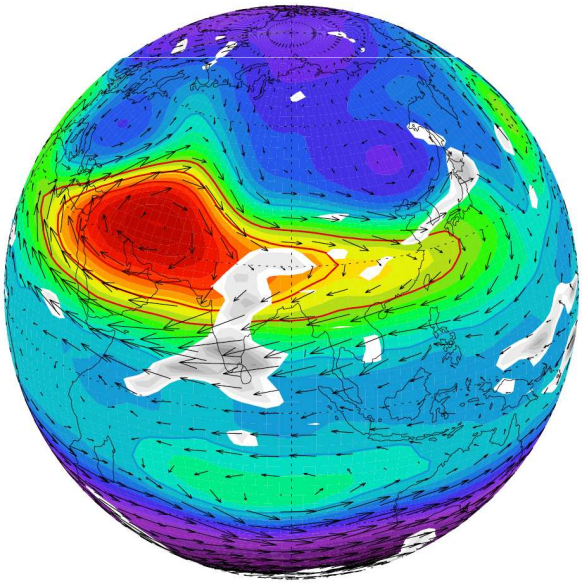
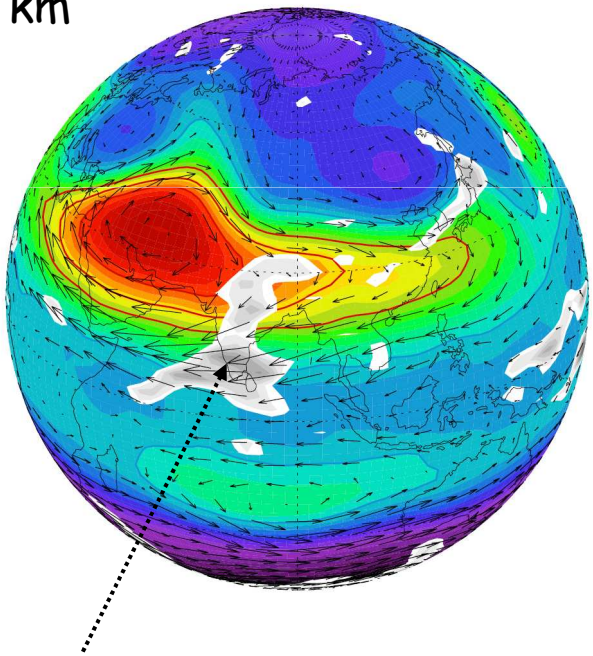
Atmospheric Chemistry Division
NCAR



Thanks to: Mijeong Park, Louisa Emmons

What is the monsoon anticyclone, and why is it interesting?

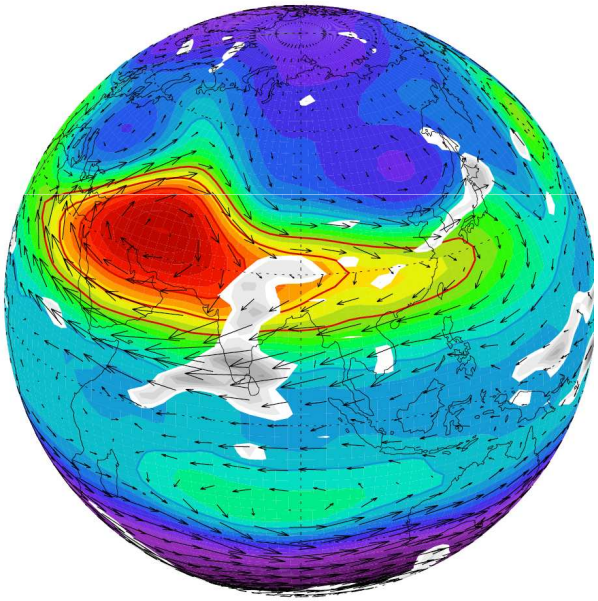
monsoon circulation near 15 km



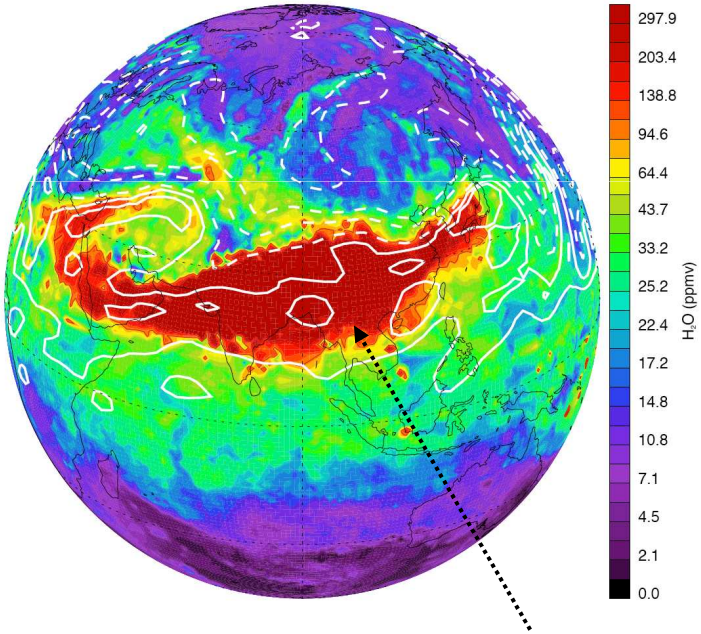
deep convection

- dominant circulation feature of NH summer UTLS
- forced by deep convection over India and Bay of Bengal
- associated with local maxima in trace constituents (water vapor in particular)

monsoon
circulation
near 15 km

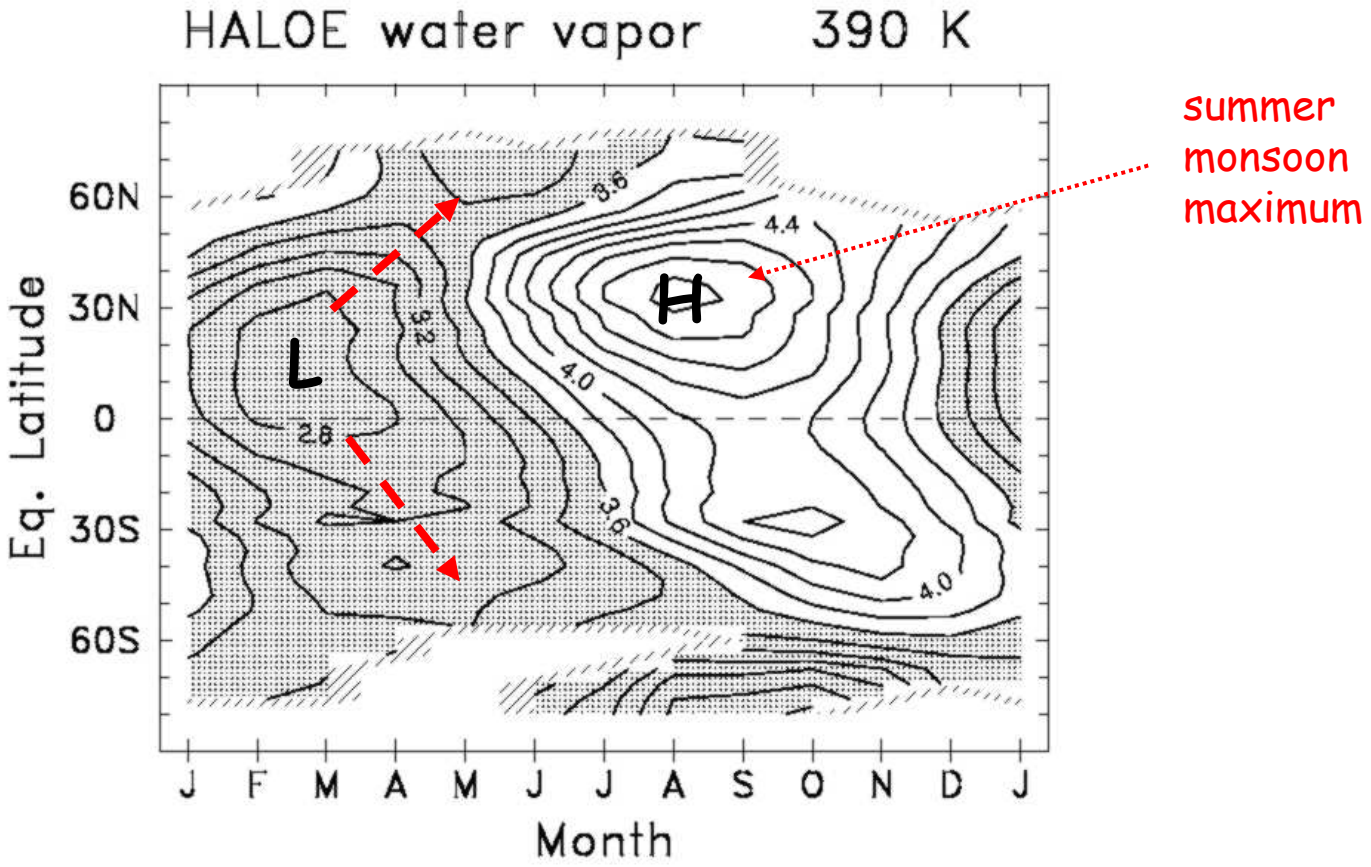


water vapor near 10 km
observed by
AIRS



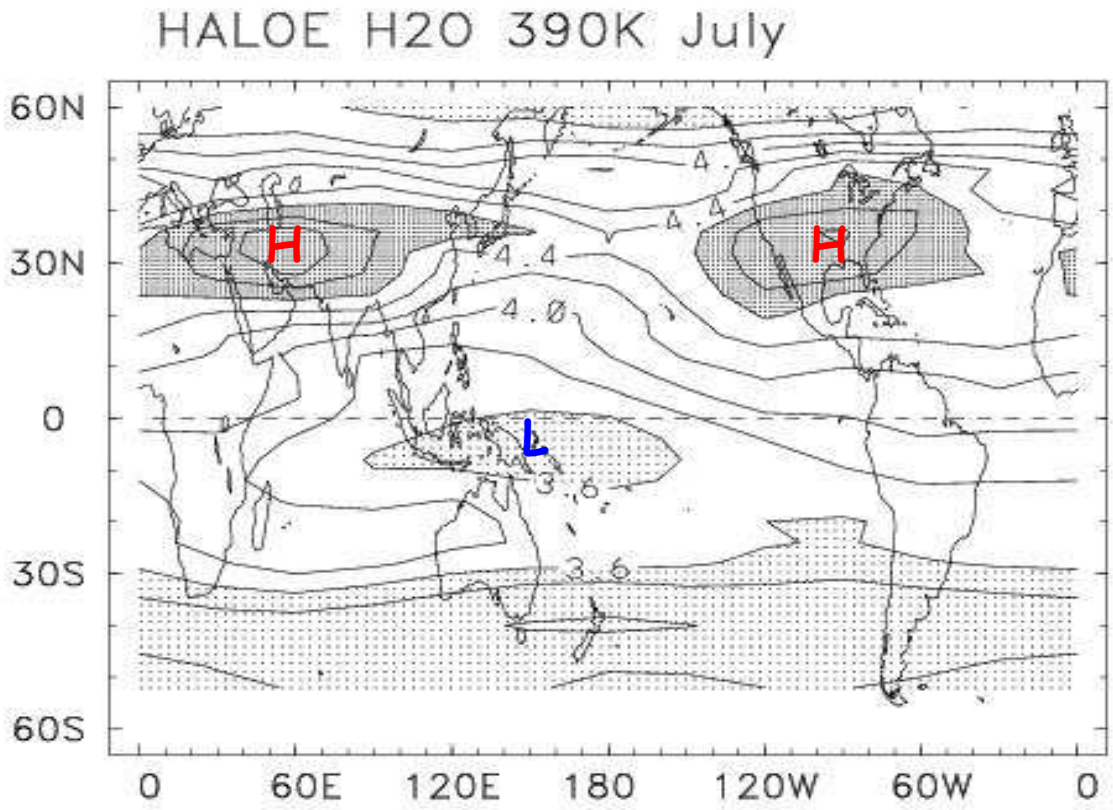
moist air within
monsoon anticyclone

Seasonal cycle of lower stratosphere H_2O



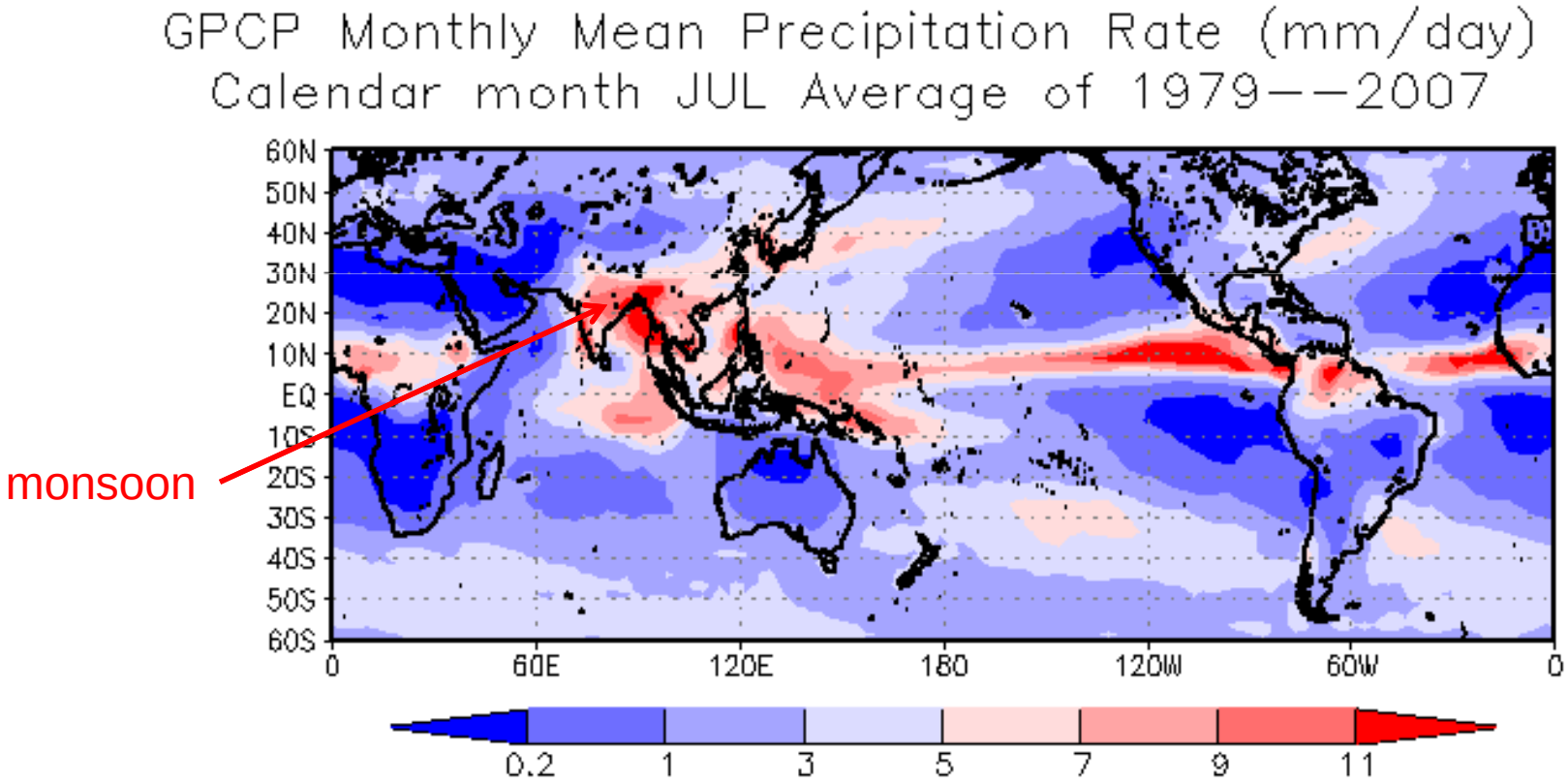
summertime lower stratosphere
maxima linked to
Asia and North American monsoons

Rosenlof et al 1997
Jackson et al 1998
Dethof et al 1999



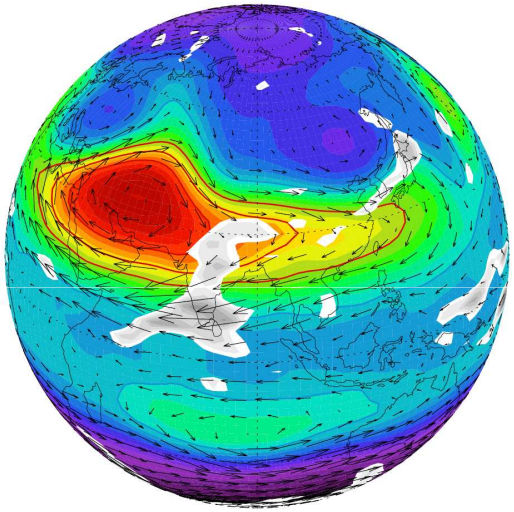
Dynamical Background

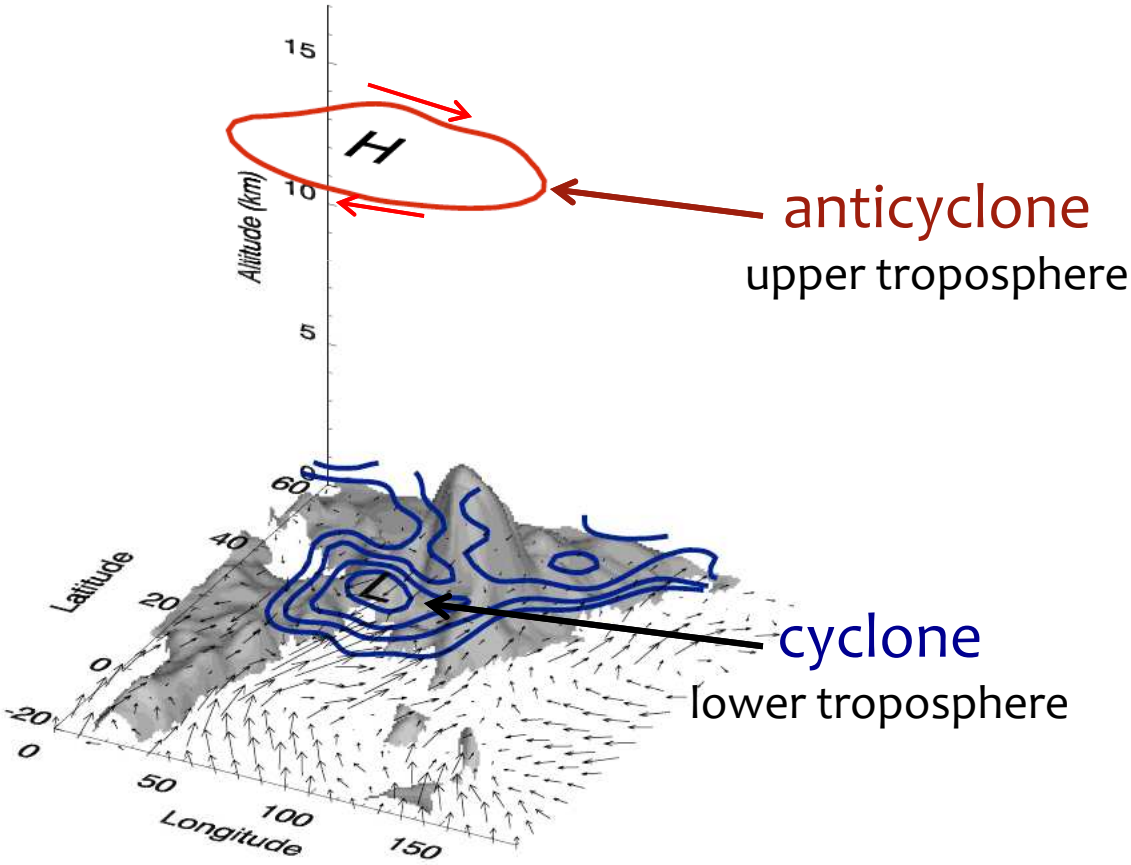
Climatological precipitation in NH summer



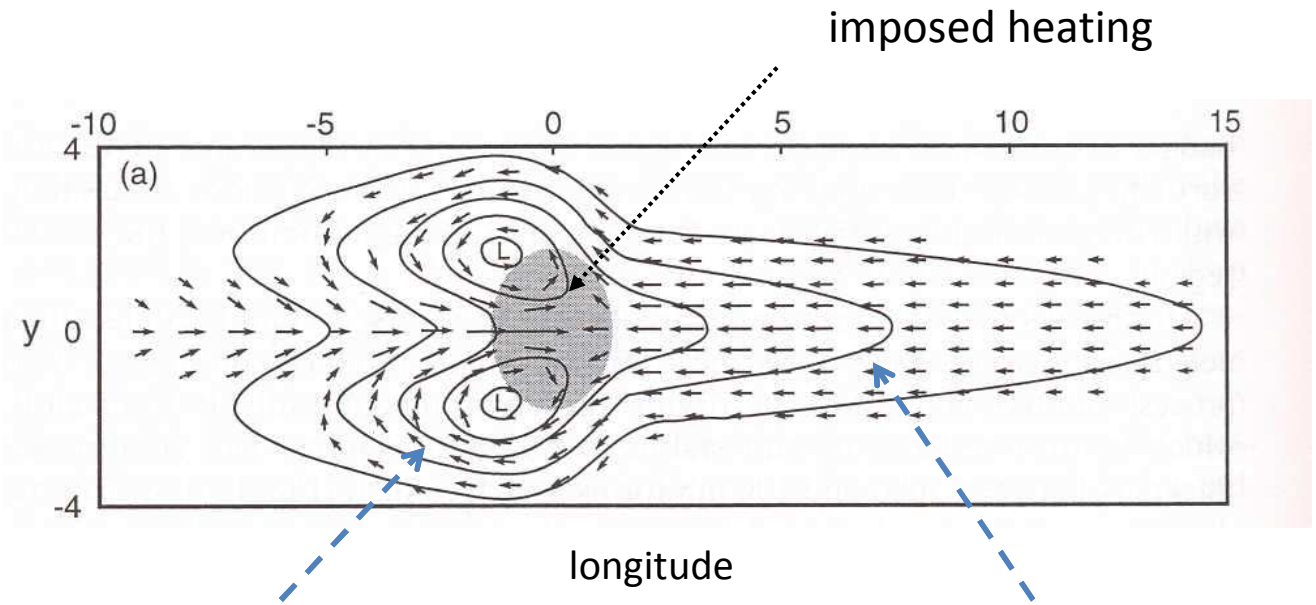
Dynamical Background

Cyclone at the surface, anticyclone in the upper troposphere

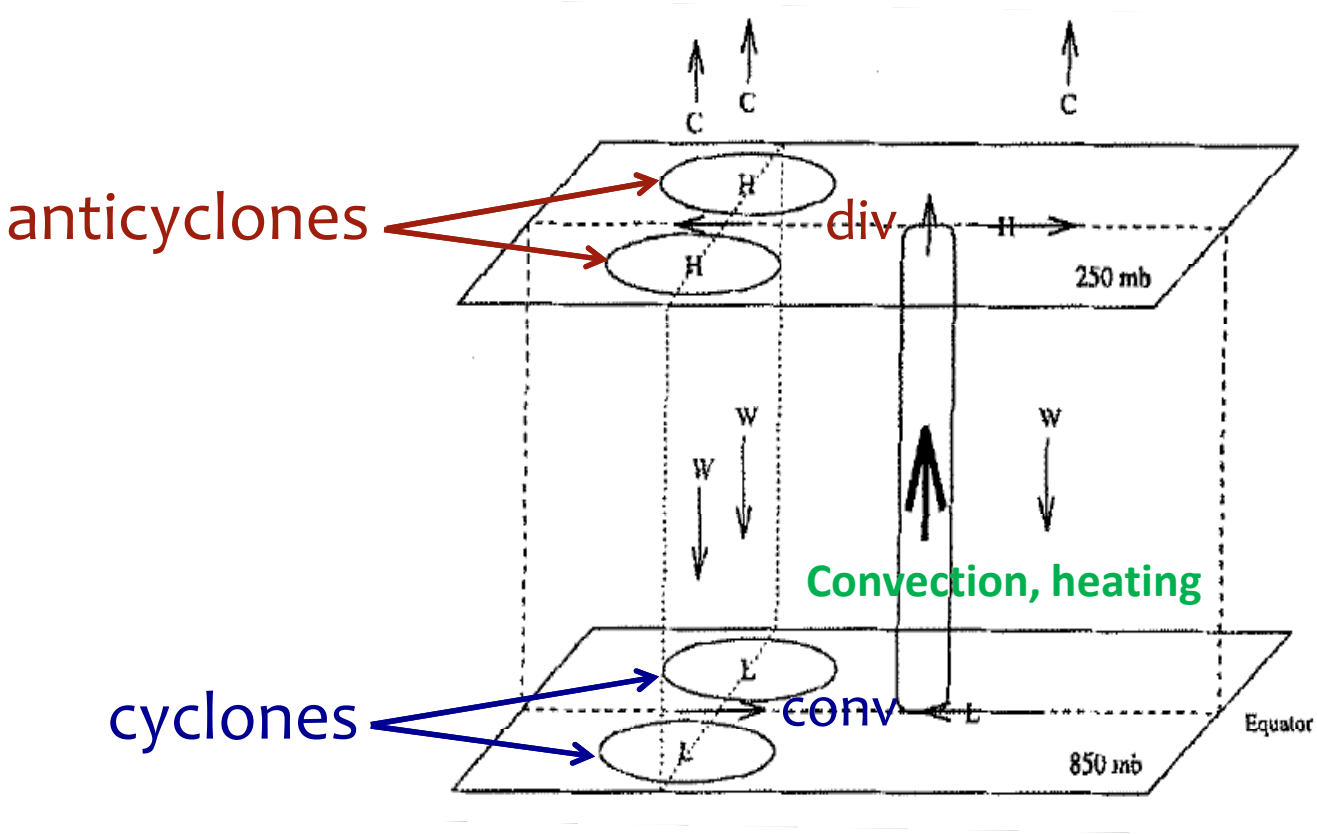




atmosphere response to steady tropical heating (Gill, 1980)



idealized vertical structure

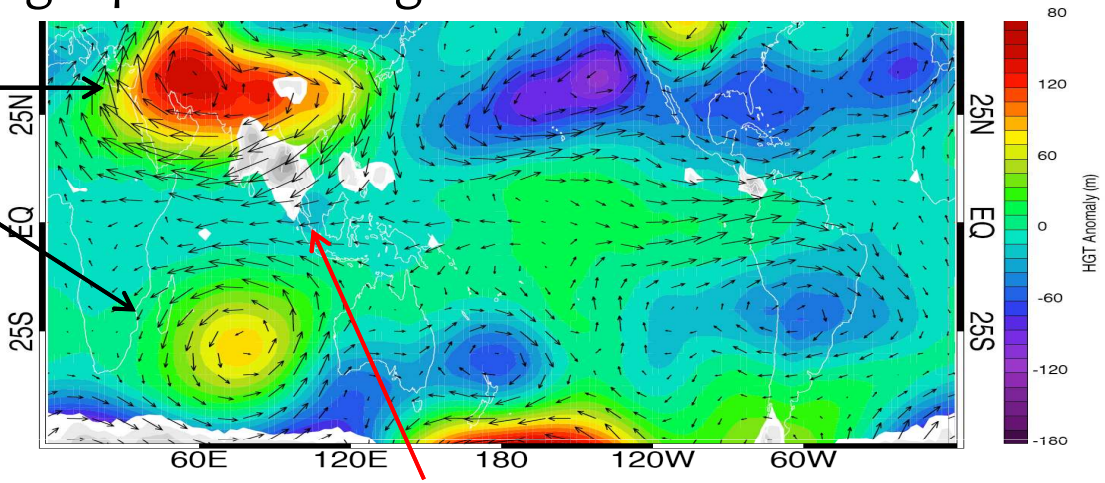


Highwood and Hoskins (1998)

Anticyclones in the UT

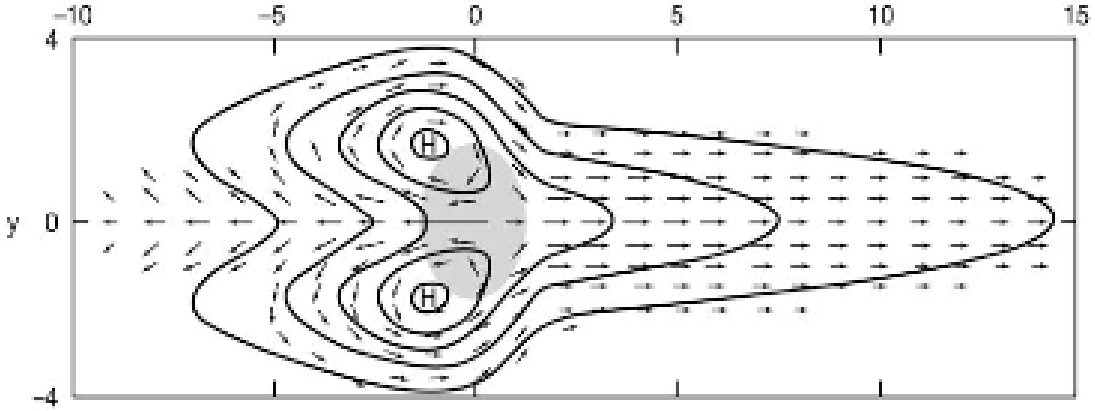
geopotential height and winds 100 hPa

anticyclones



Note that the anticyclone does not lie on top of the deep convection

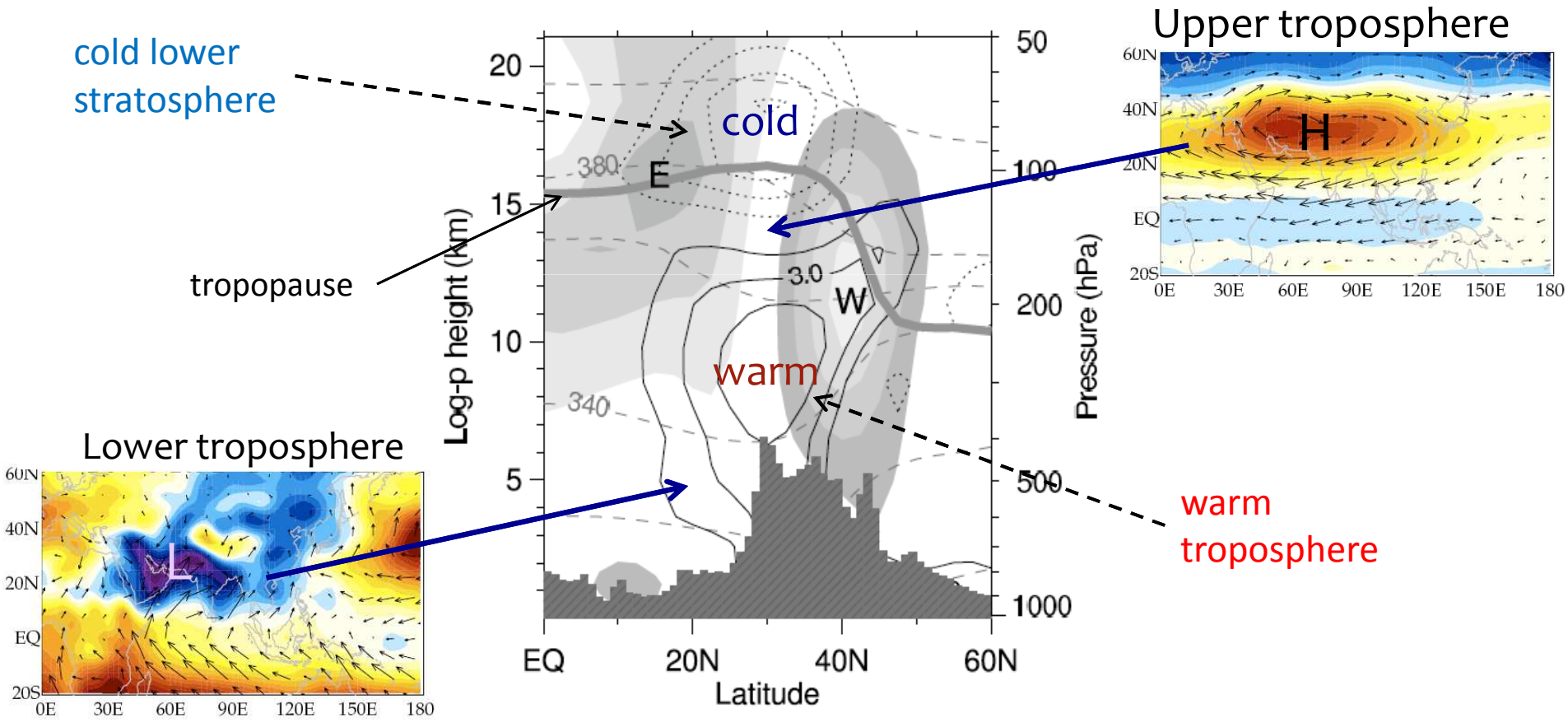
Convection (heating)



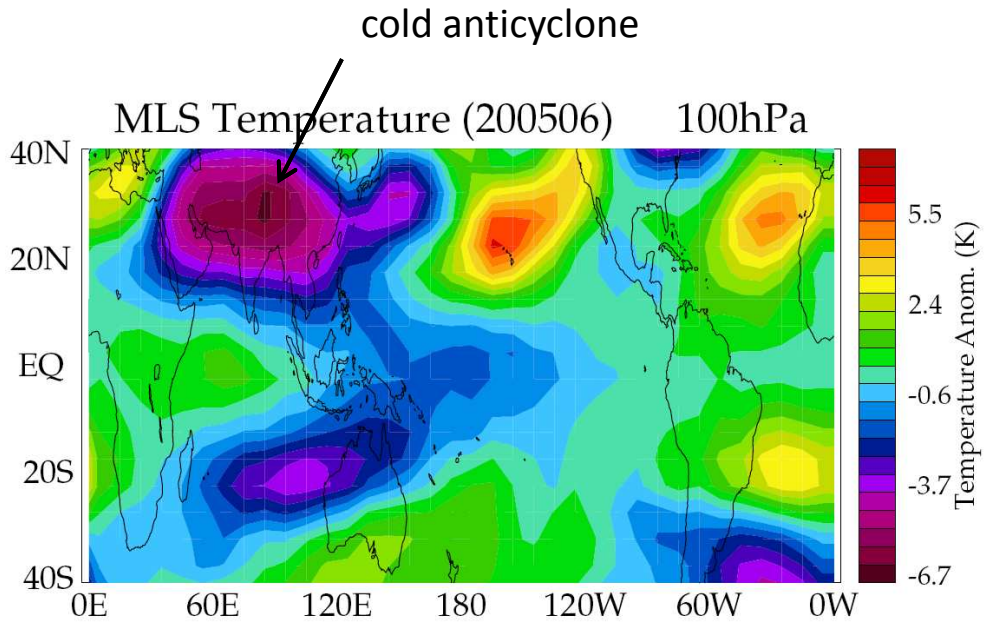
'Gill-type' Solution

Dynamical Background

Anticyclonic circulation extends into lower stratosphere

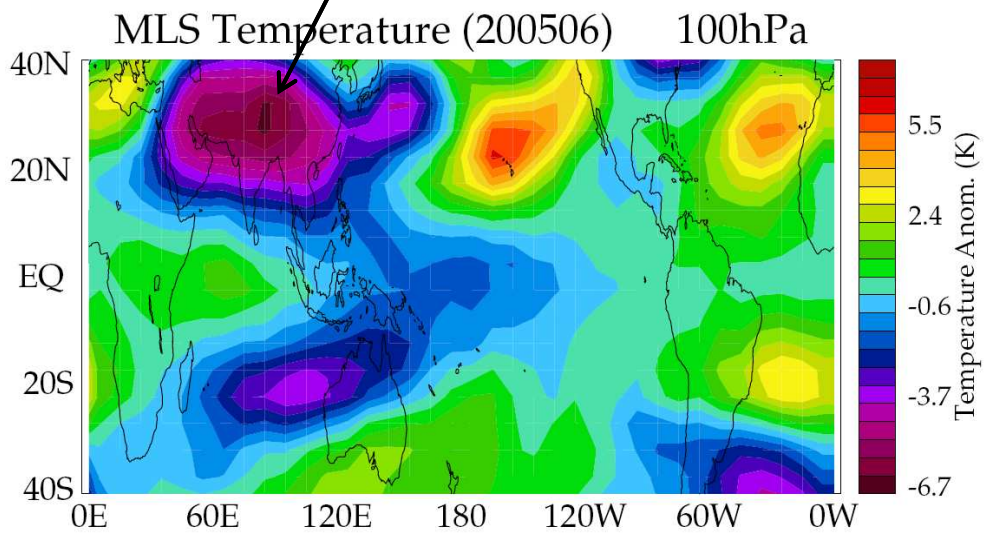


Randel and Park (JGR, 2006)



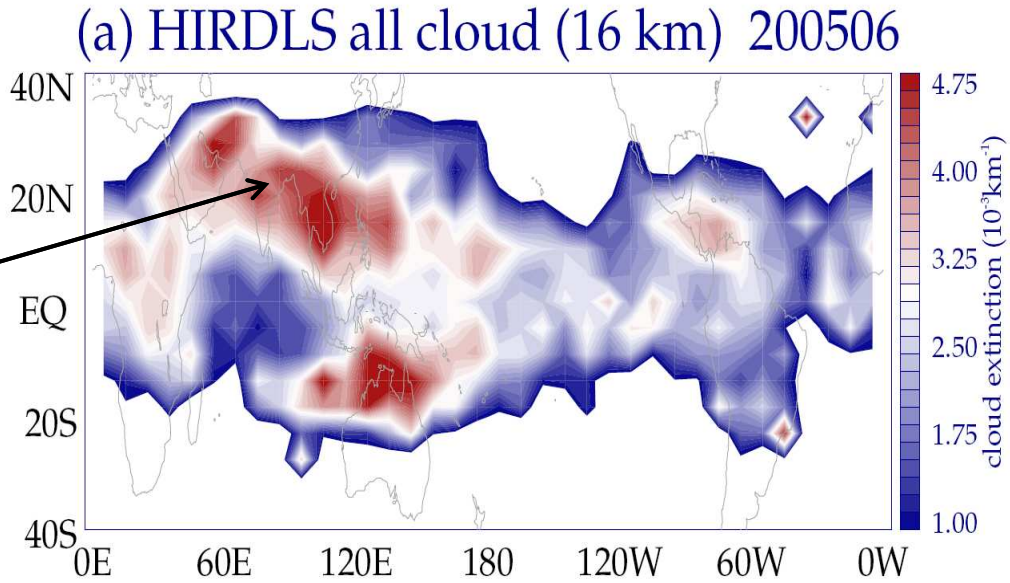
Temperatures (anomalies) at 100 hPa

cold anticyclone



Temperatures (anomalies) at 100 hPa

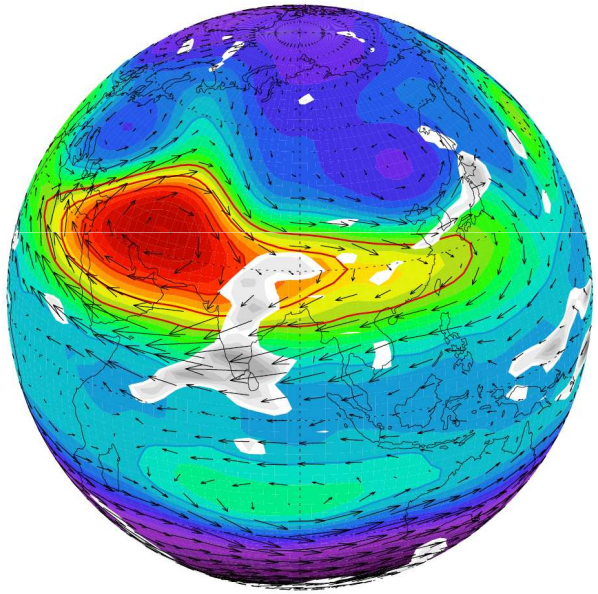
persistent cirrus clouds near tropopause



Cirrus clouds from HIRDLS satellite (Steve Massie)

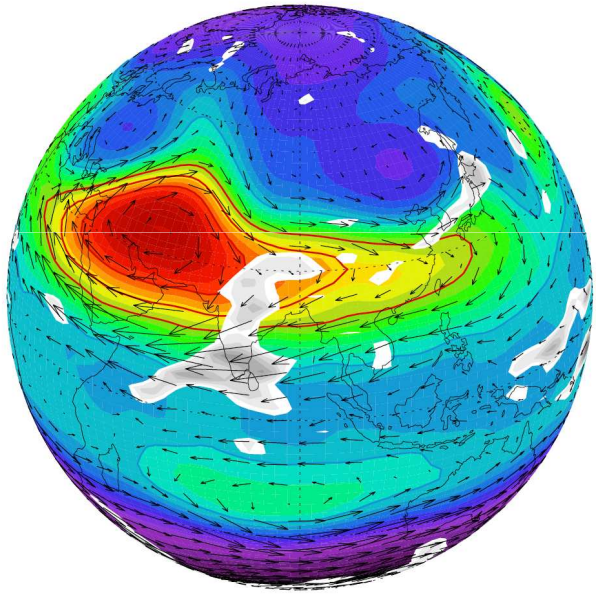
Persistent anticyclone (Great Red Spot)

Earth

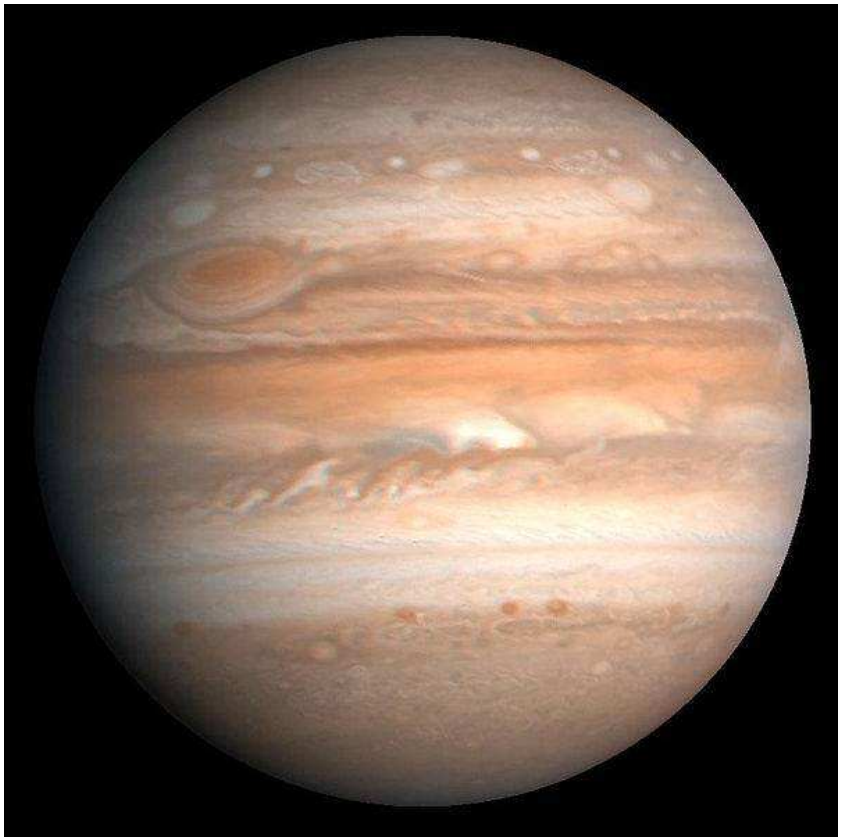


Persistent anticyclone (Great Red Spot)

Earth

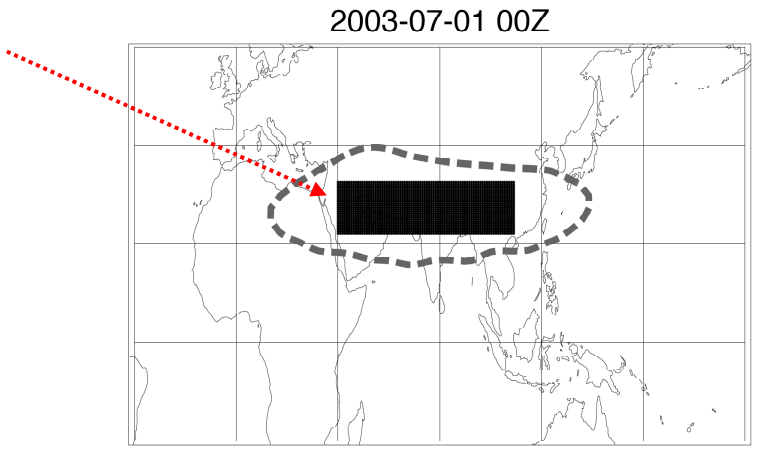


Jupiter

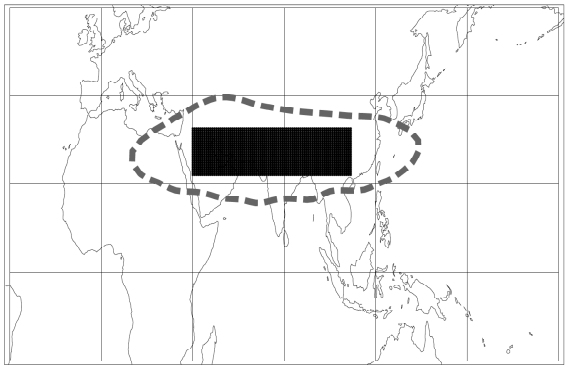


Confinement within the anticyclone: idealized transport experiments

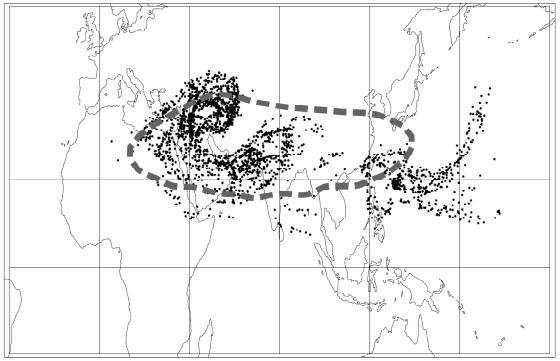
- initialize 2400 particles inside anticyclone
- advect with observed winds for 20 days
- test different pressure levels



transport
simulation
at 150 hPa

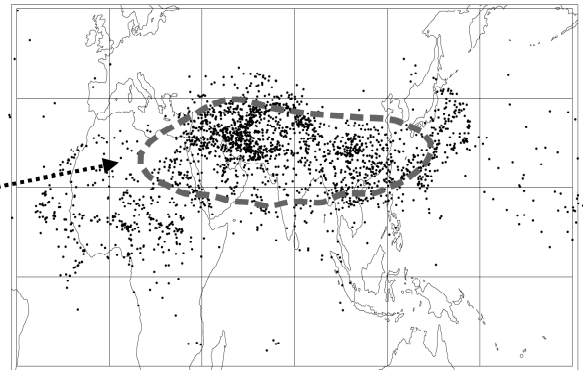


day 0



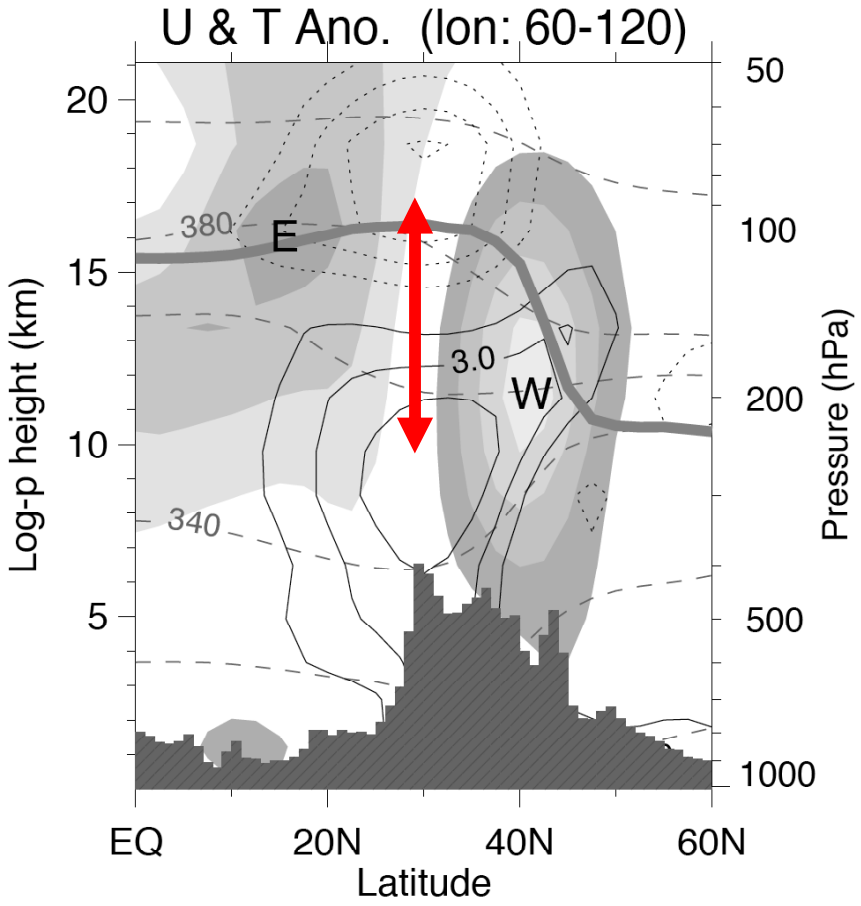
day 10

large fraction
remain inside
anticyclone



day 20

Confinement within region of strongest winds



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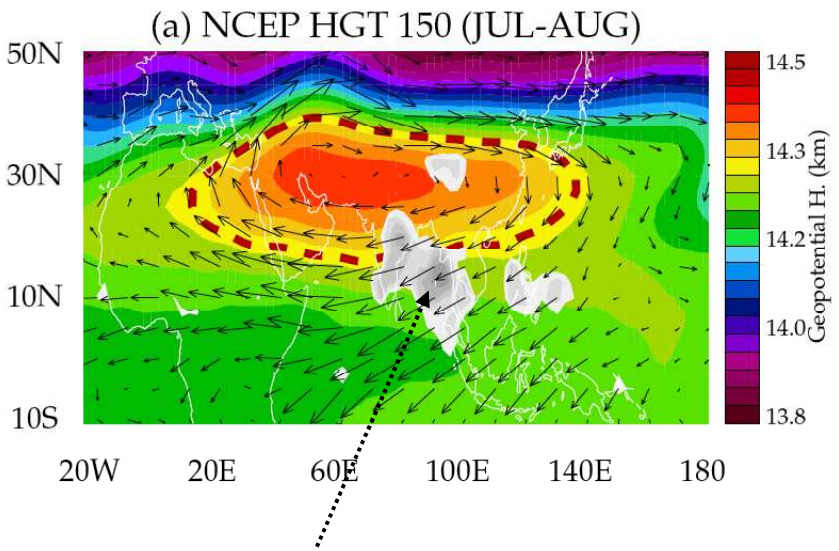
This talk:

- Variability of convection, dynamics and water vapor (AIRS observations)
- Transport pathways and links to the stratosphere

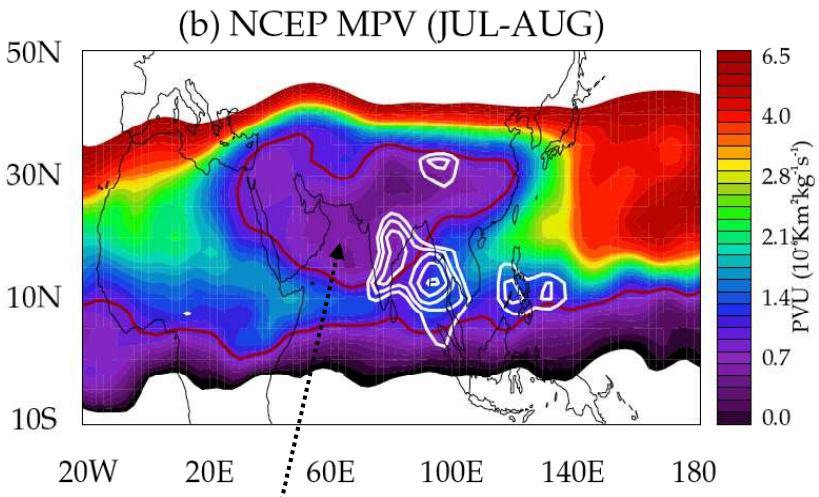
Anticyclone structure in terms of:

150 hPa height and winds



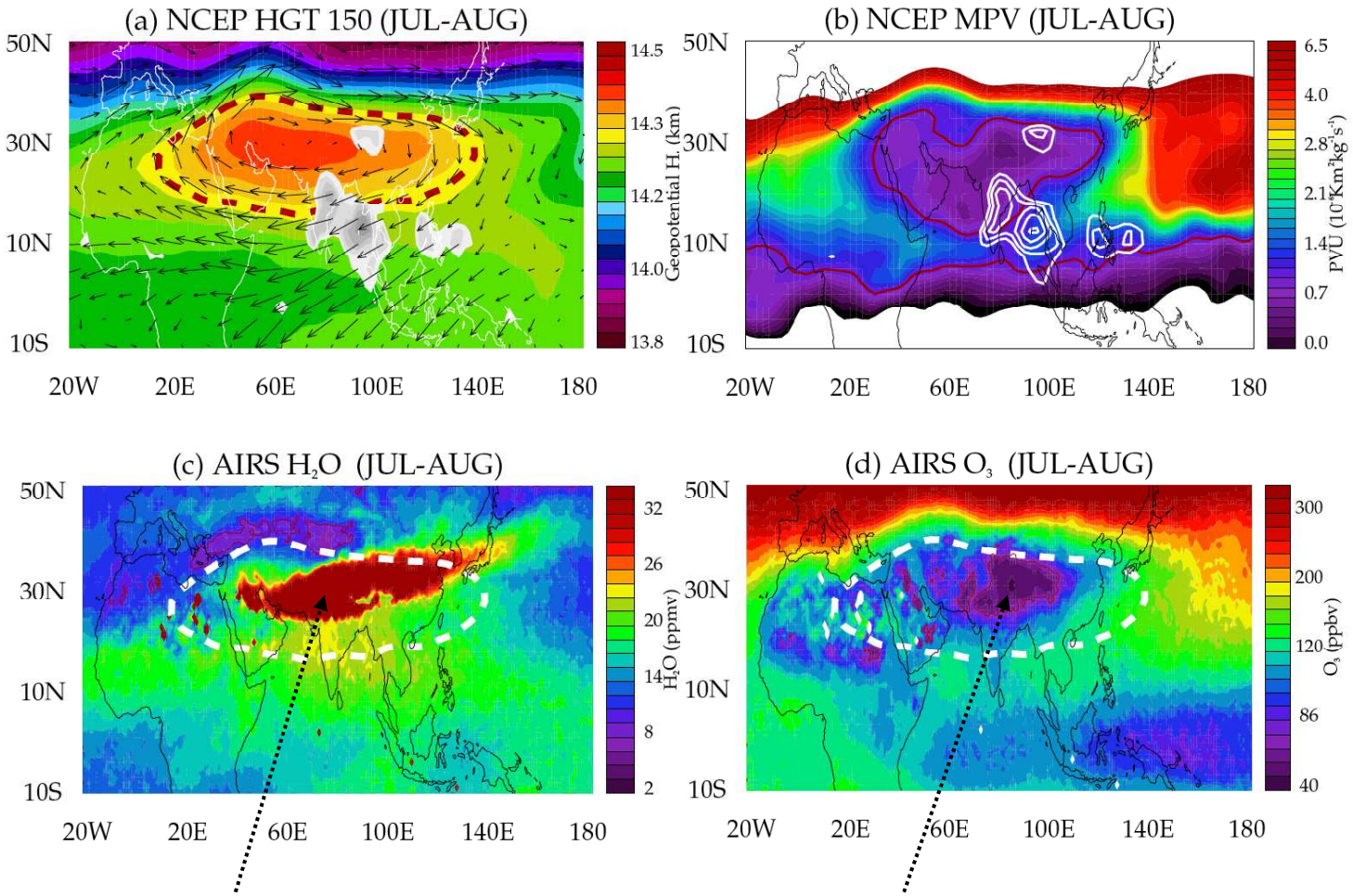
convection typically over SE region of anticyclone

Potential vorticity at 360 K



anticyclone is region of <u>low</u> PV

Time average structure (July-Aug 2003)



AIRS water vapor

AIRS ozone

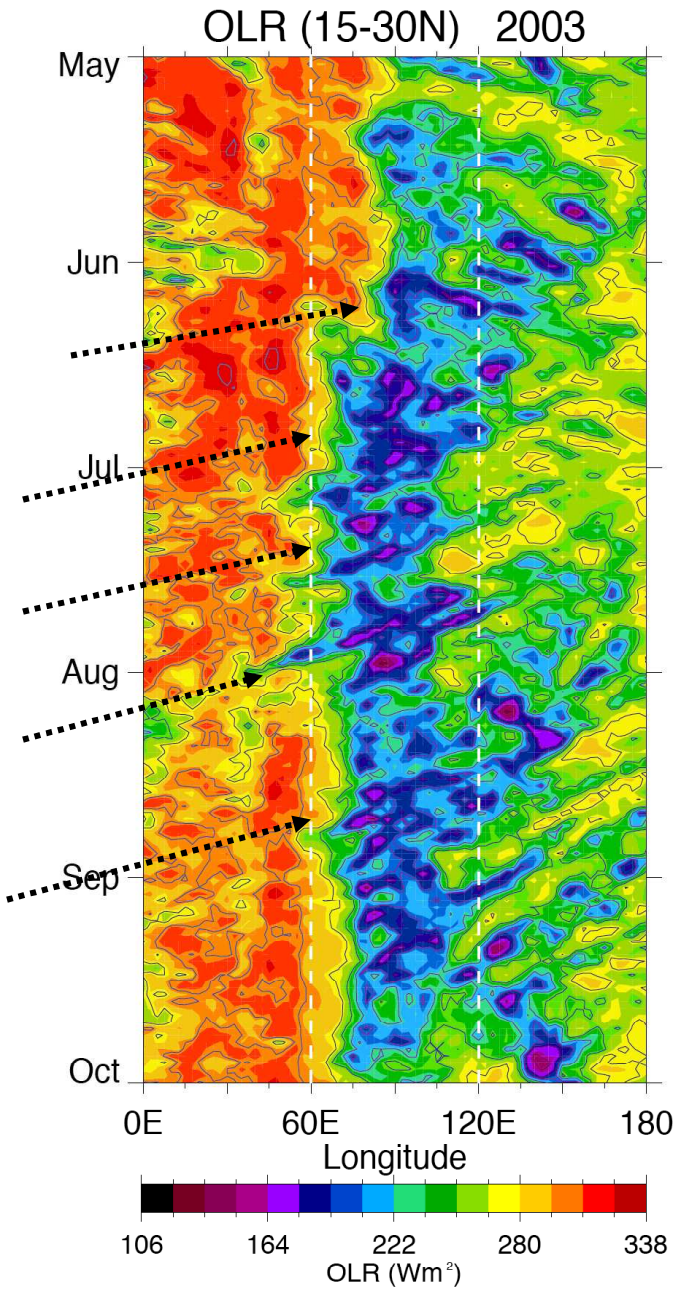
high water vapor

low ozone

Deep convection within monsoon region

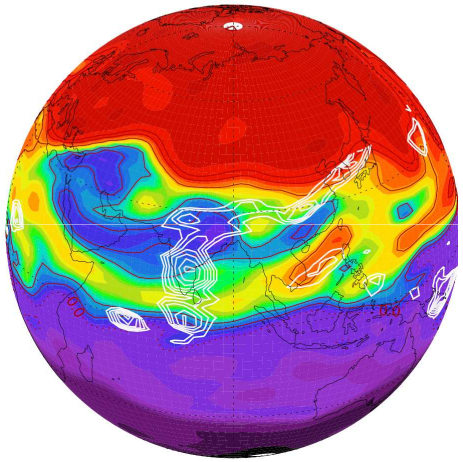
variations in convection
with time scales
of ~10-20 days

active/break cycles
of the monsoon



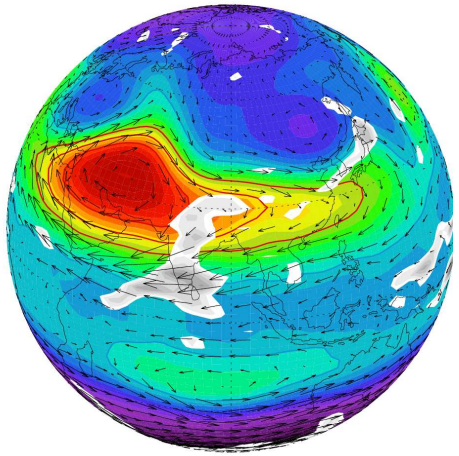
Two diagnostics for strength of anticyclone:

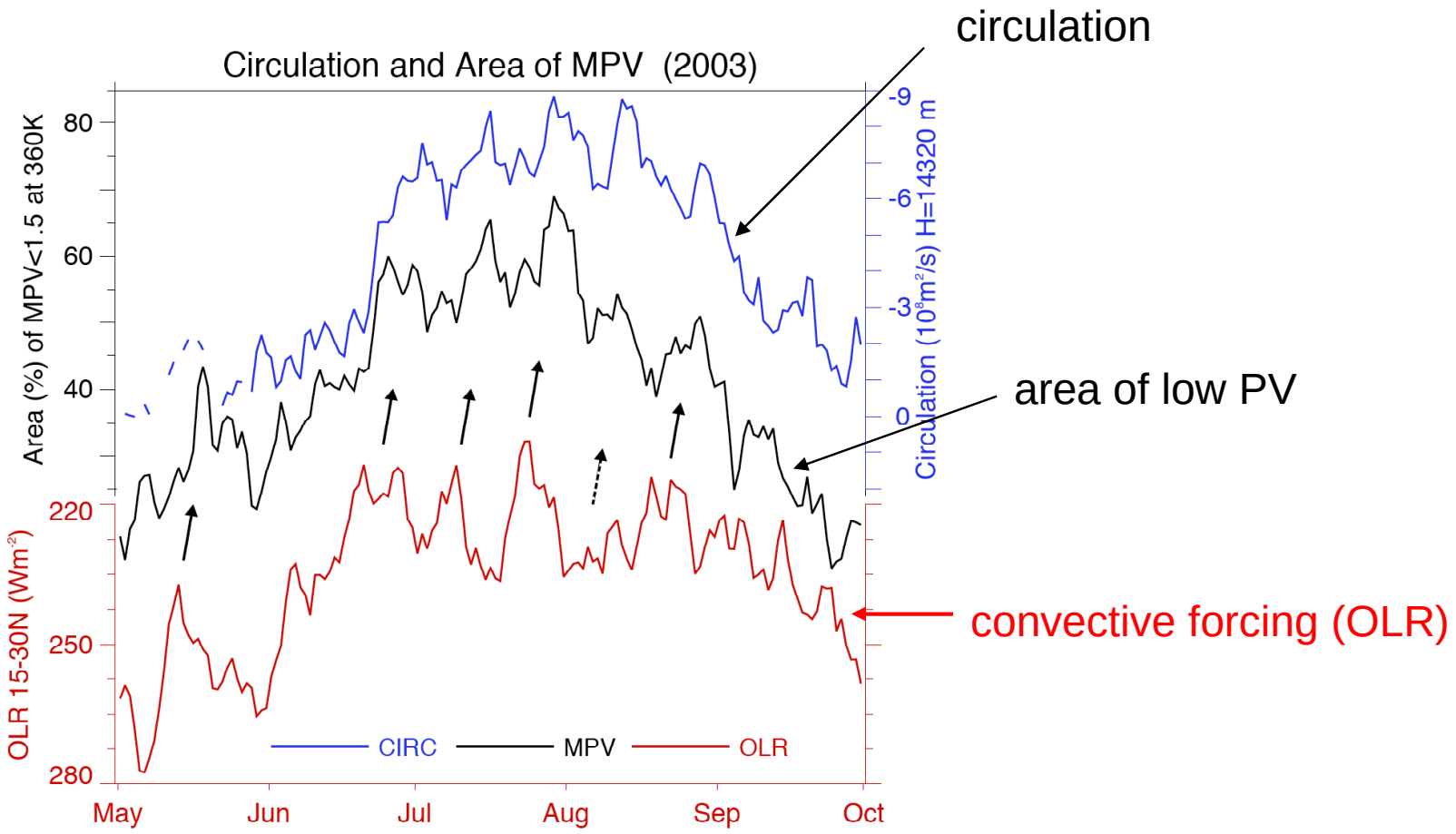
1) area of low potential vorticity (PV)

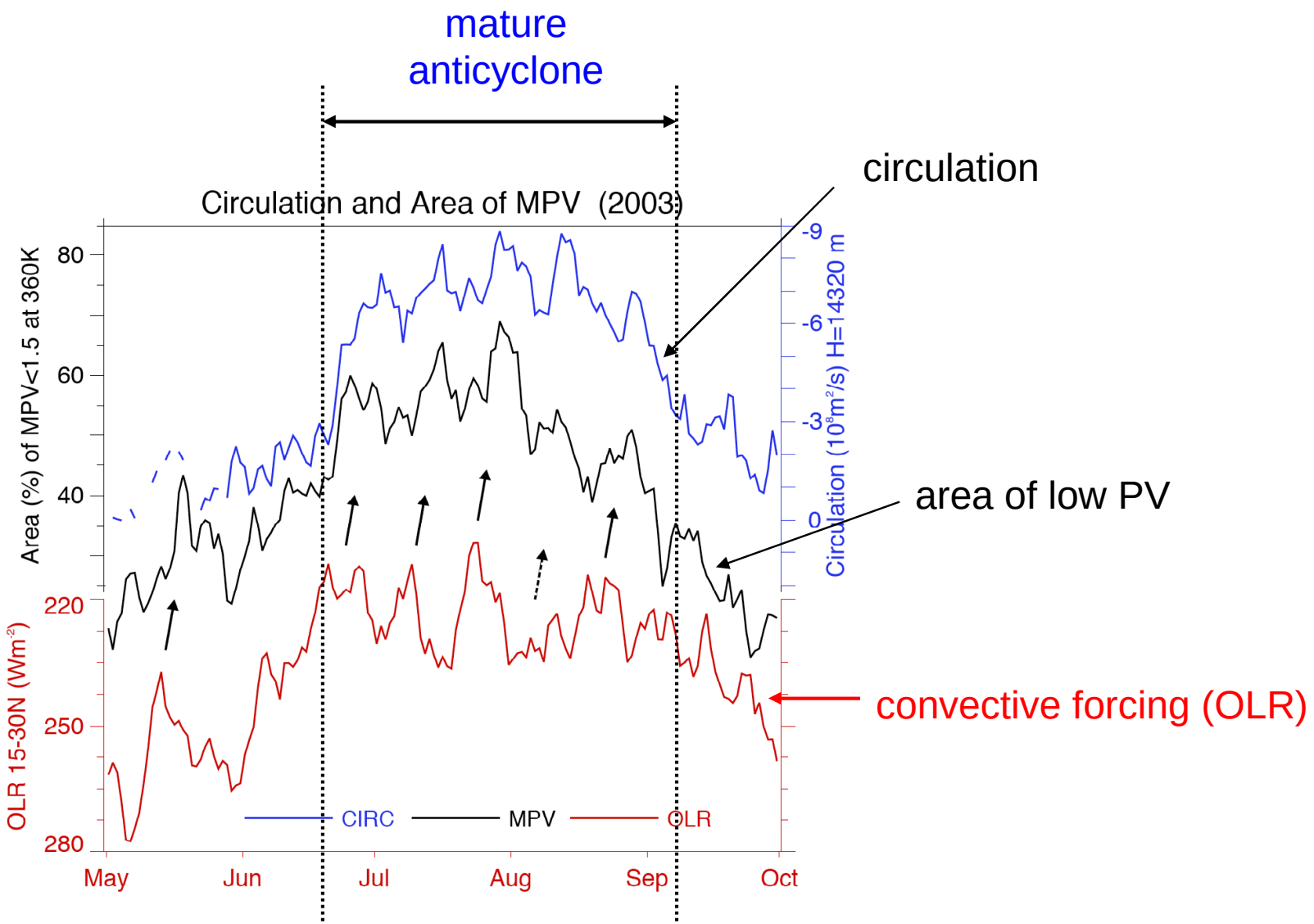


2) circulation in the upper troposphere

$$\oint_C \mathbf{u}\cdot d\mathbf{l}$$




Circulation and Area of MPV (2003)
Area (%) of MPV<1.5 at 360K
80
60
40
Circulation (10⁶m²/s) H=14320 m
-9
-6
-3
0
OLR 15-30N (Wm⁻²)
220
250
280
CIRC
MPV
OLR
May
Jun
Jul
Aug
Sep
Oct
circulation
area of low PV
convective forcing (OLR)


mature
anticyclone
circulation
Circulation and Area of MPV (2003)
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area of low PV
OLR 15-30N (Wm⁻²)
220
250
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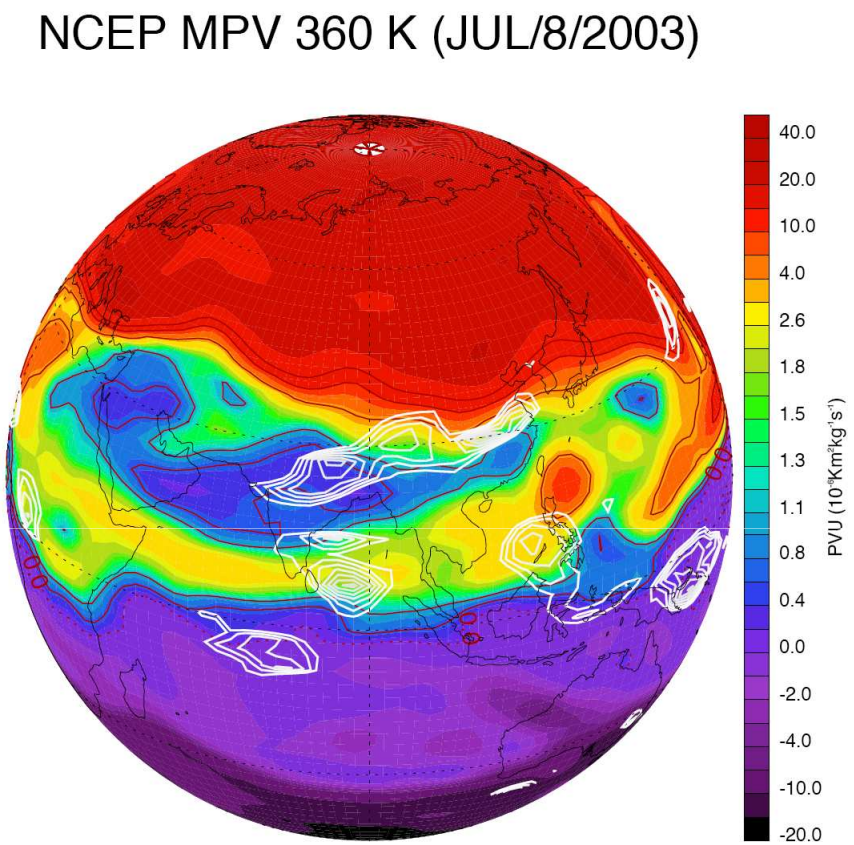
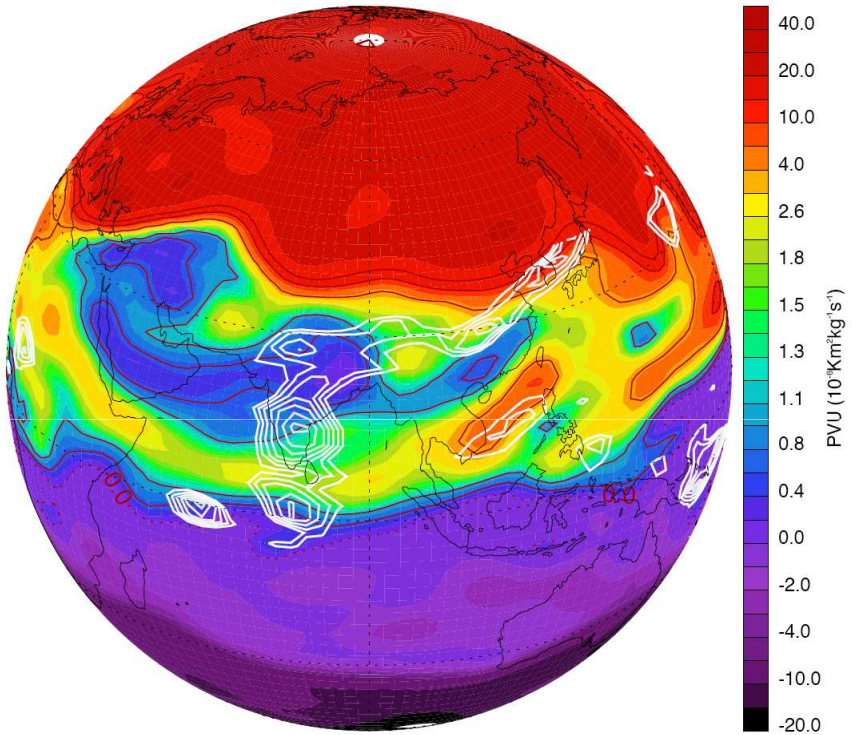
CIRC
MPV
OLR
convective forcing (OLR)
May
Jun
Jul
Aug
Sep
Oct

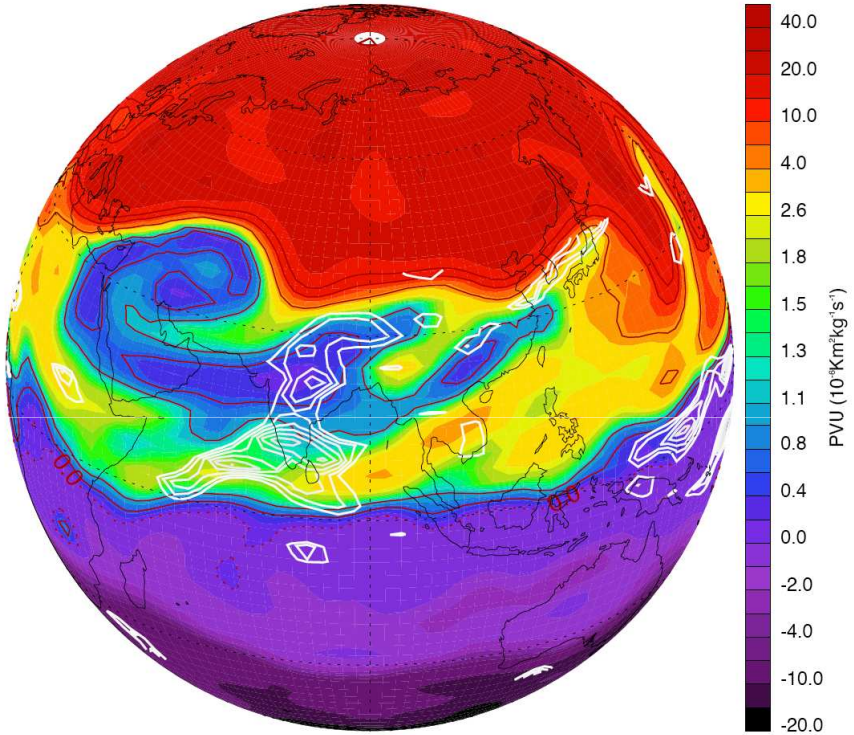
Life cycle of deep convective event



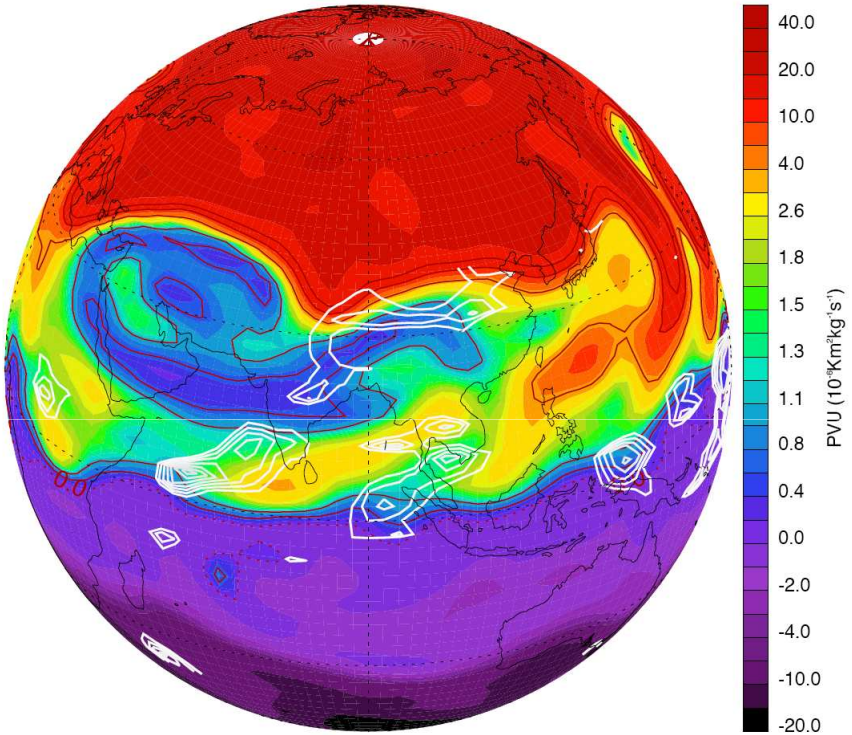
NCEP MPV 360 K (JUL/9/2003)



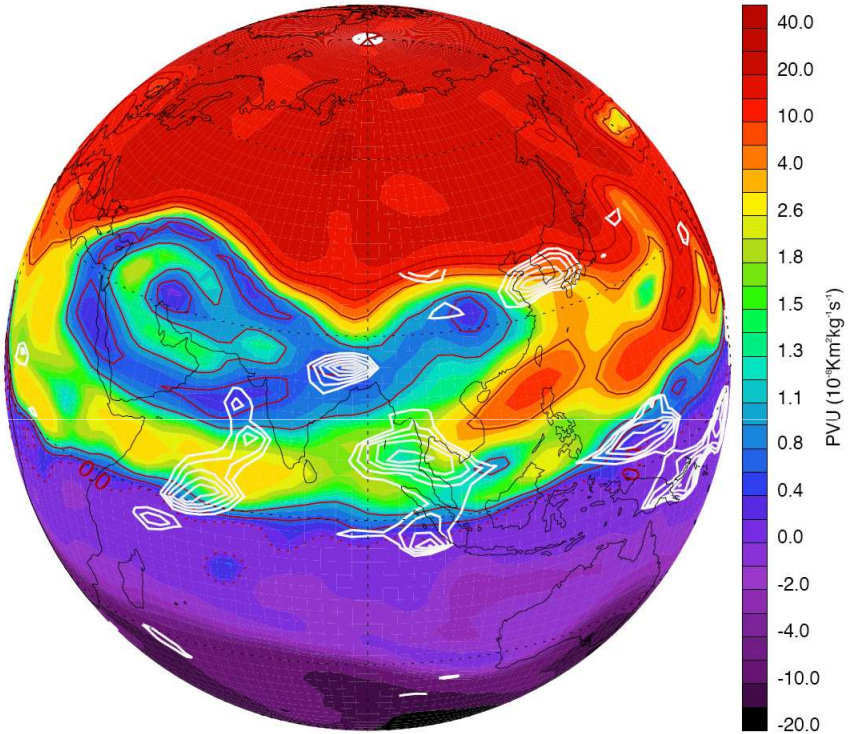
NCEP MPV 360 K (JUL/10/2003)



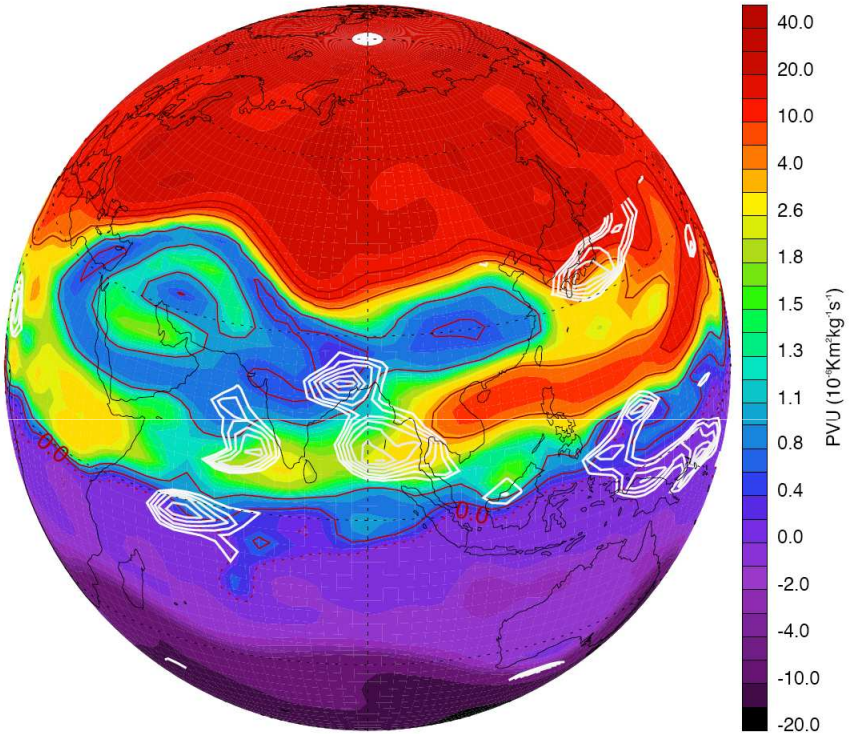
NCEP MPV 360 K (JUL/11/2003)



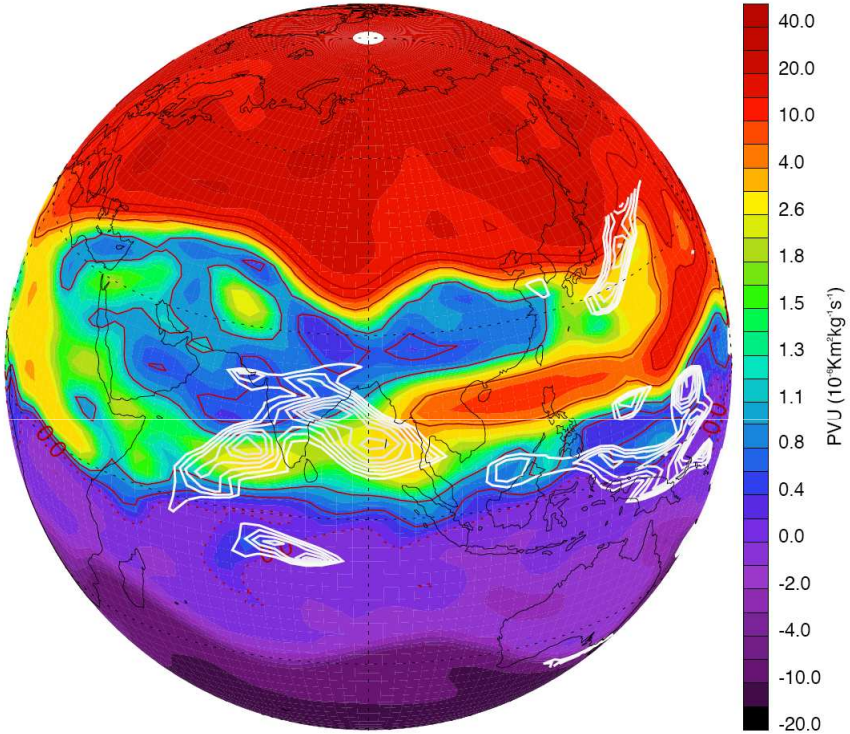
NCEP MPV 360 K (JUL/12/2003)

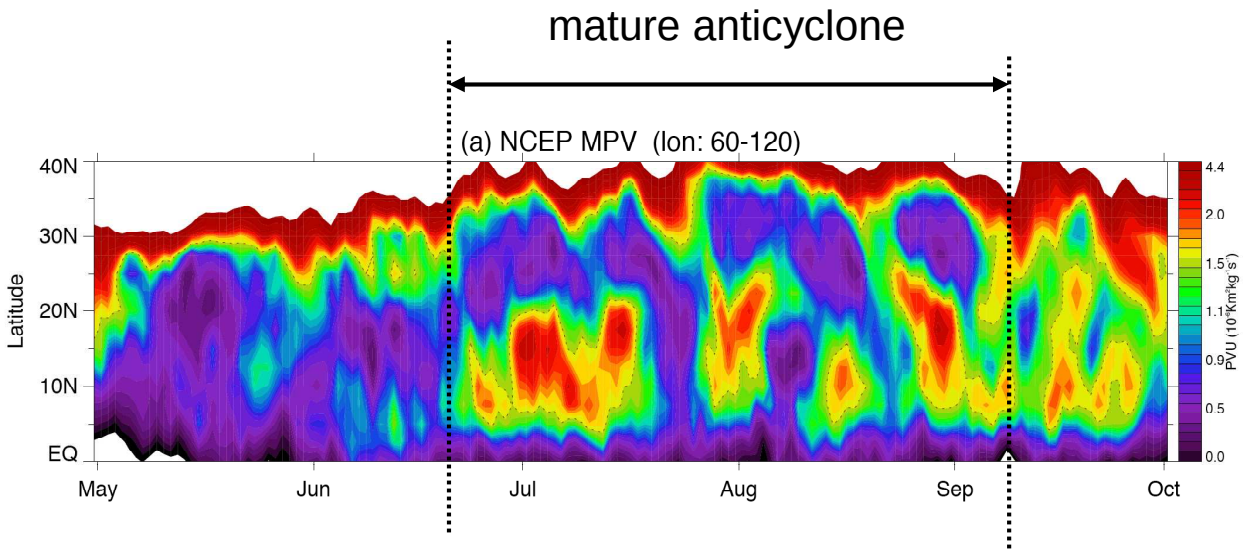


NCEP MPV 360 K (JUL/13/2003)

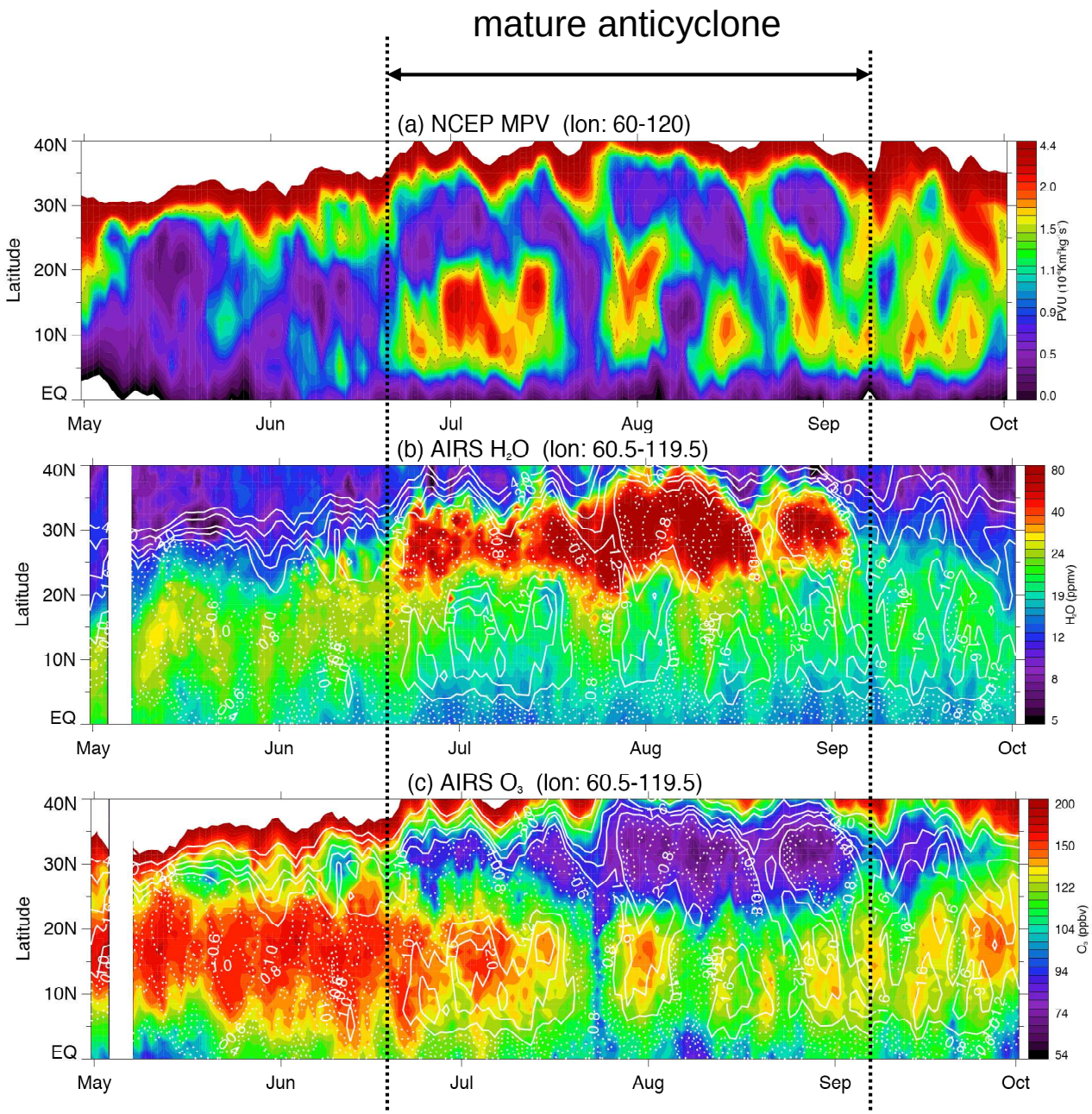


NCEP MPV 360 K (JUL/14/2003)




mature anticyclone
(a) NCEP MPV (lon: 60-120)
40N
30N
20N
10N
EQ
Latitude
May
Jun
Jul
Aug
Sep
Oct
4.4
2.0
1.5
1.1
0.9
0.5
0.0
PVU (10⁻⁶Km²kg⁻¹s⁻¹)

PV at
360 K



PV at 360 K

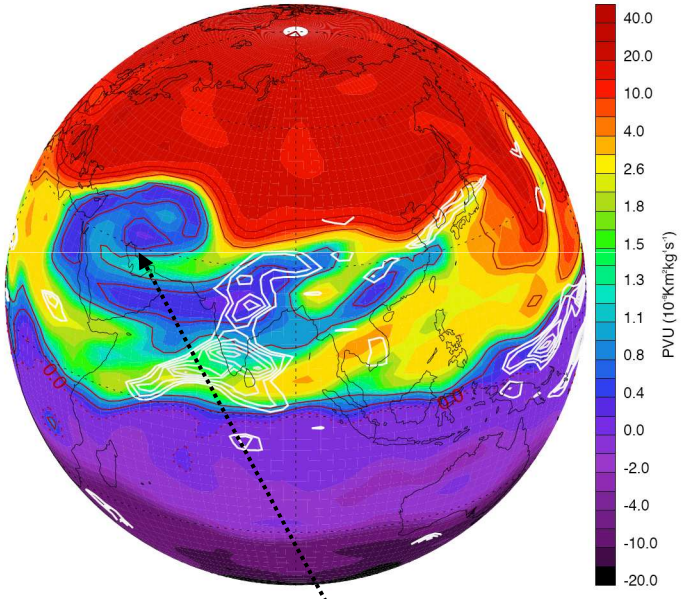
AIRS water vapor

AIRS ozone

Correlation of PV and tracers: July 10

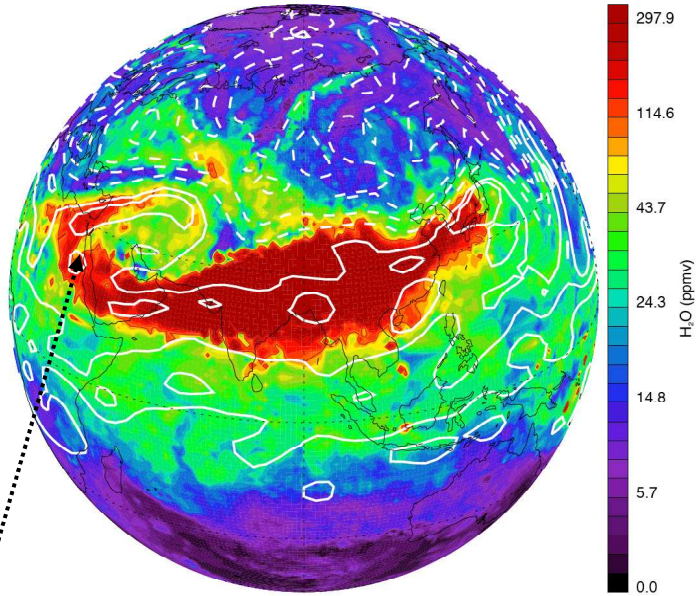
360 K PV

NCEP MPV 360 K (JUL/10/2003)



AIRS water vapor

(b) AIRS H_2O 350K (JUL/10)

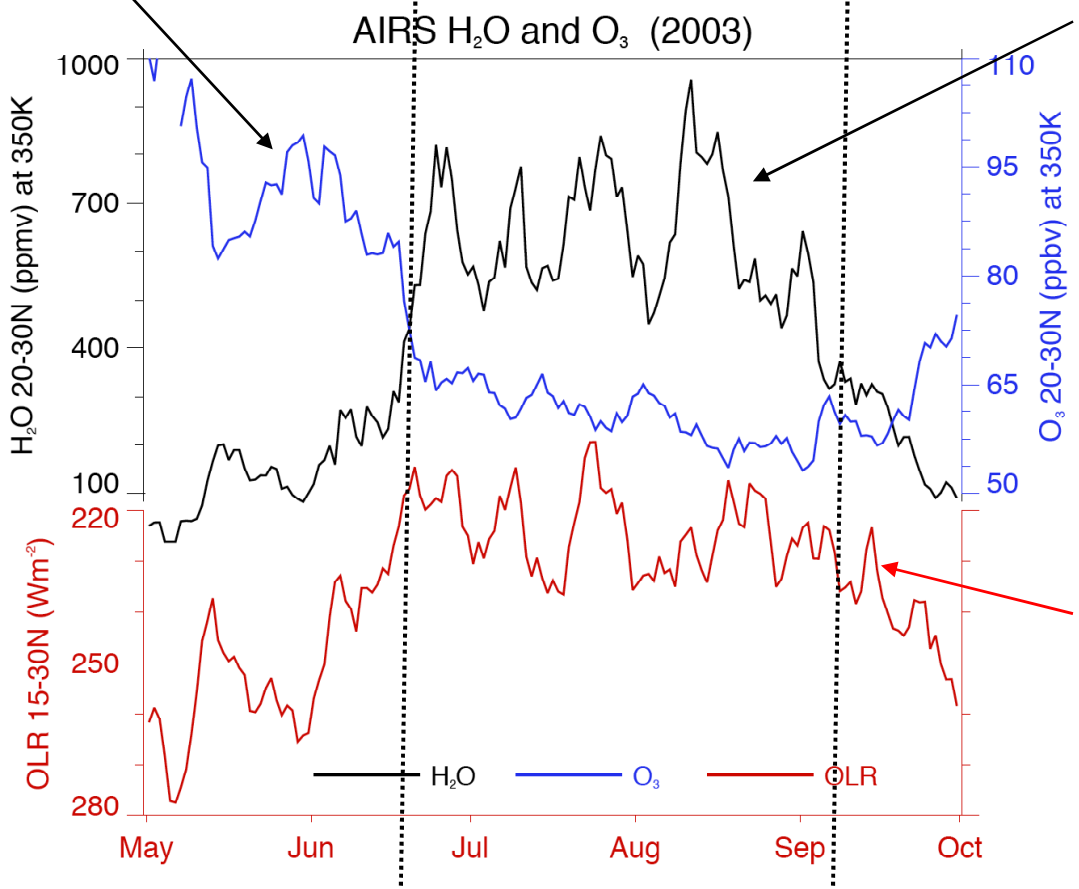


note coherent
wrapped structure

AIRS ozone at 350 K

mature anticyclone

AIRS water vapor at 350 K



convective forcing (OLR)

Key points:

1) Deep convection in monsoon region varies on 10-20 day time scale. (well-known active/break cycles).

2) Transient deep convection is linked to variations in circulation and constituents:

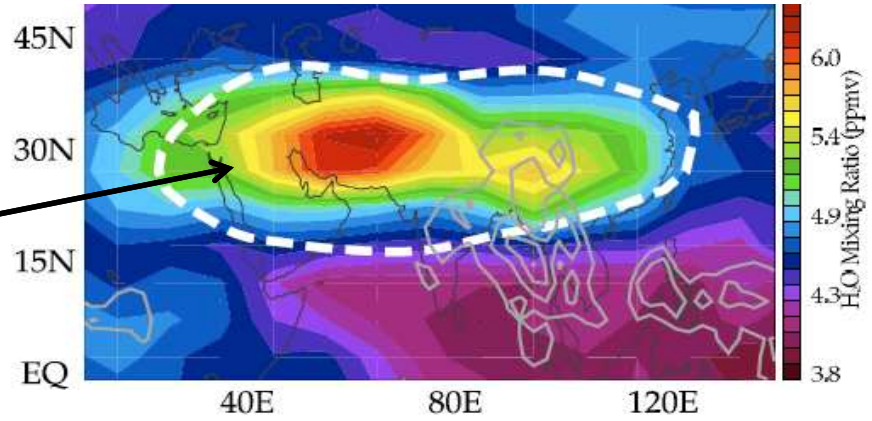
   Episodic convection: * stronger anticyclonic circulation
   * increased water vapor
   * decreased ozone

3) Constituents are confined within anticyclone

4) Monsoon effects extend into lower stratosphere

Water vapor from Aura MLS

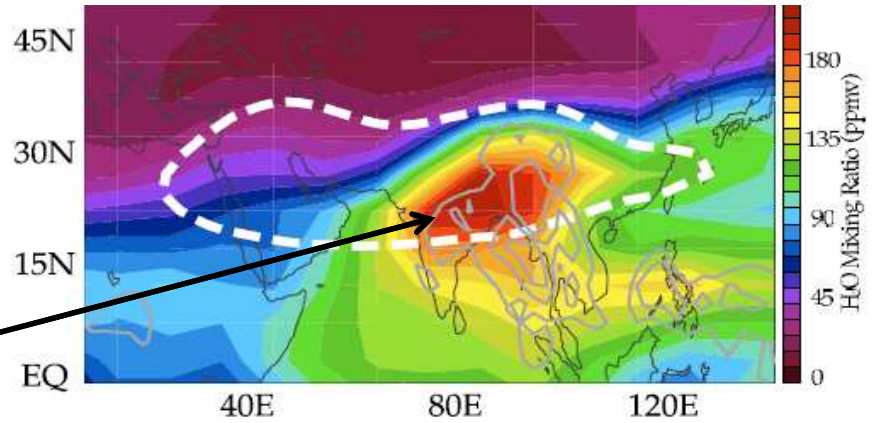
MLS H2O (Jul-Aug) 100 hPa



max inside the anticyclone

100 hPa

MLS H2O (Jul-Aug) 216 hPa



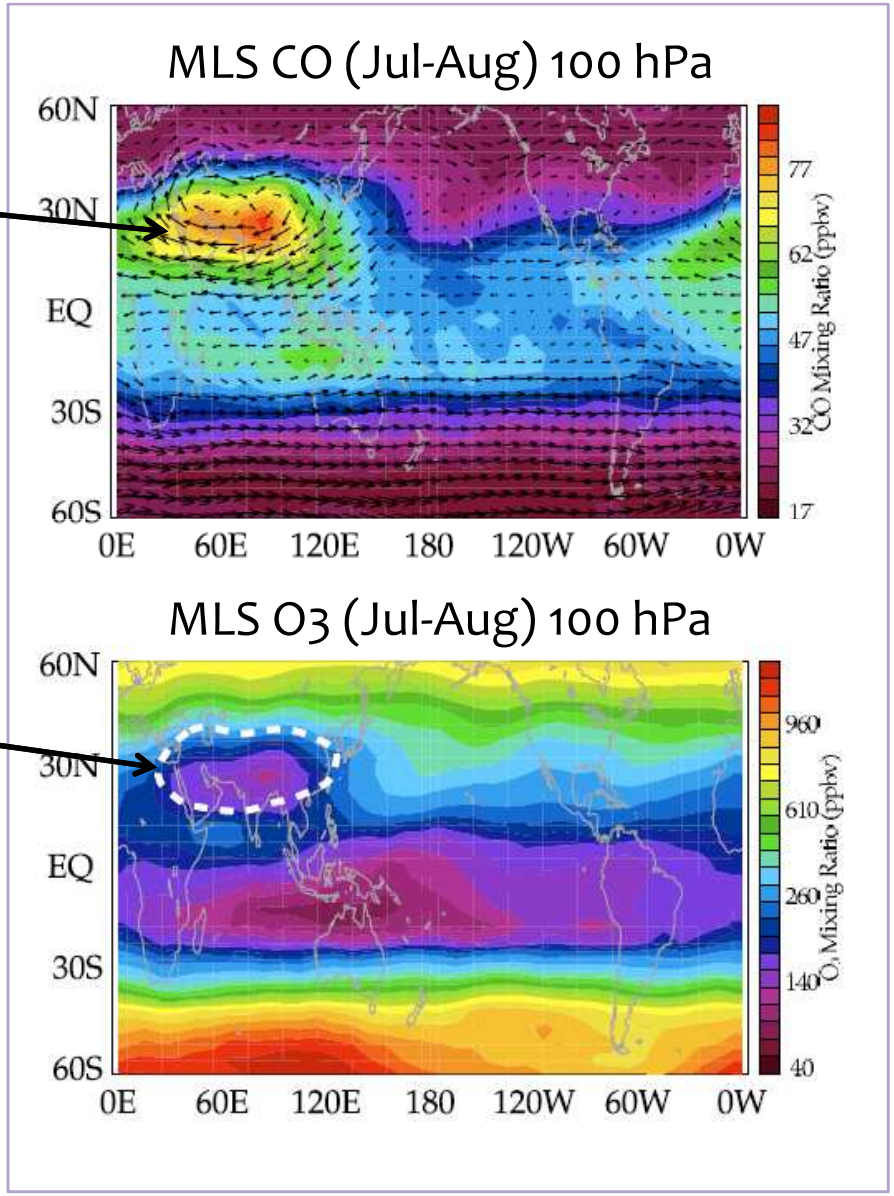
max over deep convection

216 hPa

Other tracers from MLS

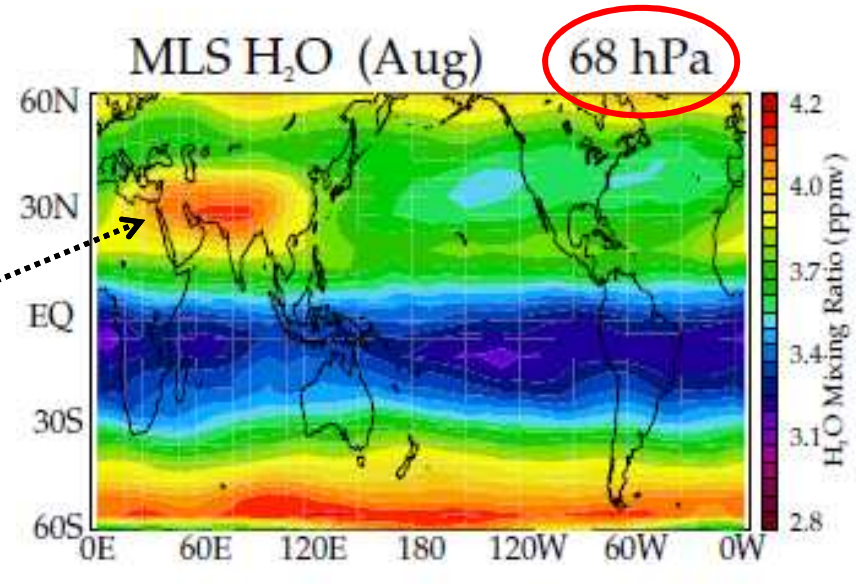
anticyclone
high CO

low ozone

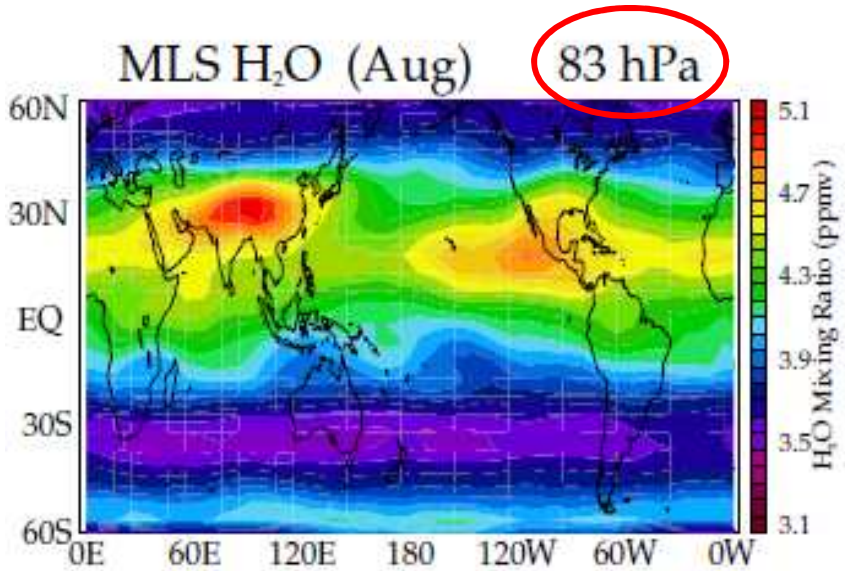


Water vapor from Aura MLS

Asian monsoon extends deeper into stratosphere



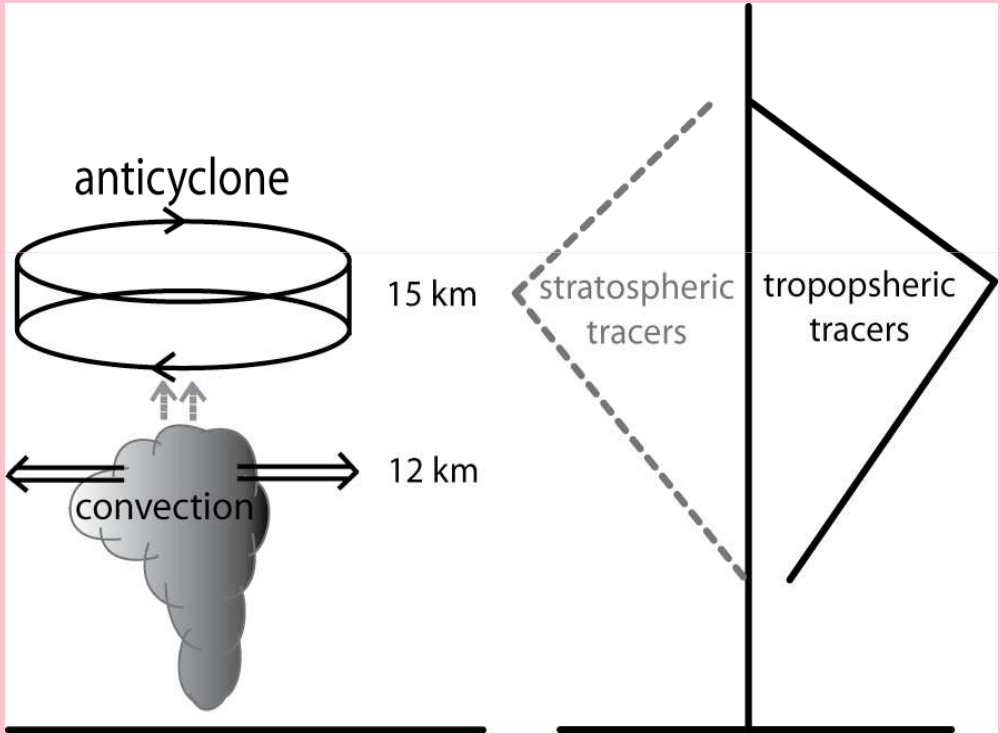
maxima associated with Asian and North American monsoons



How do tracers reach the tropopause?

convection

tracers



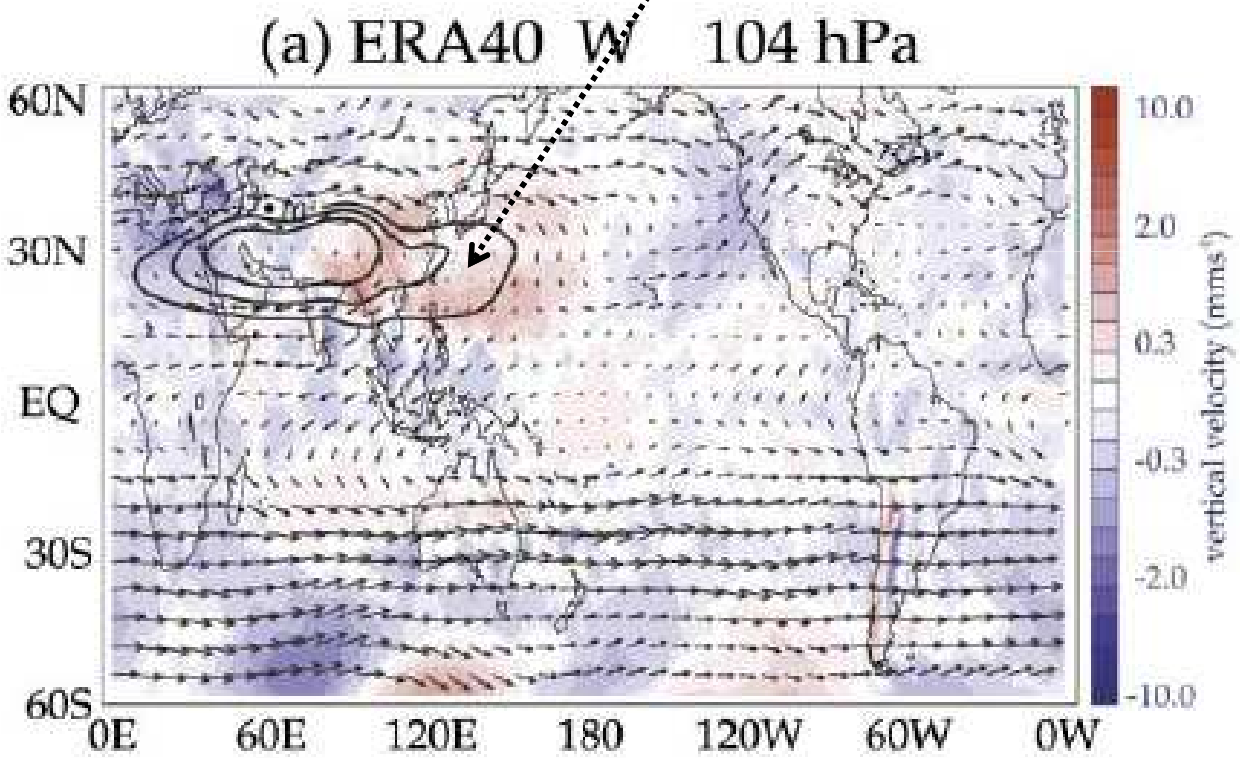
tracer max (min)

convective outflow (near ~12 km)

- large scale circulation ?
- convective overshooting ?

100 hPa vertical velocity from ERA40 reanalyses

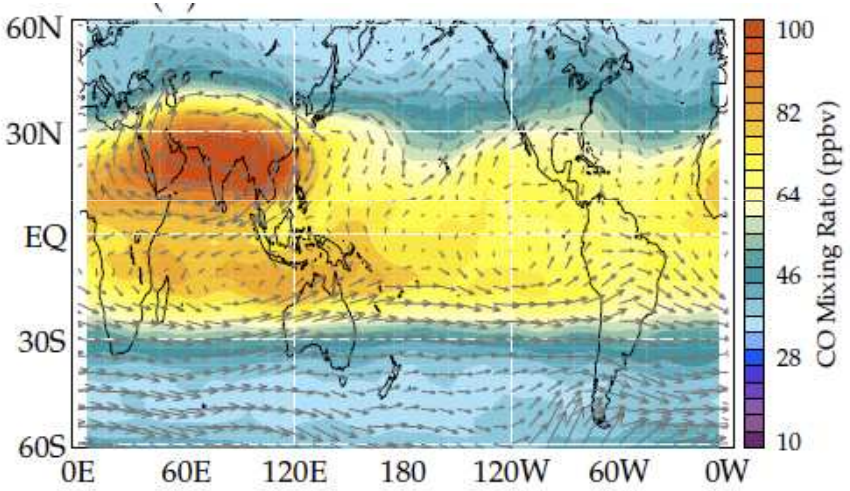
Large-scale upward motion on east side of anticyclone



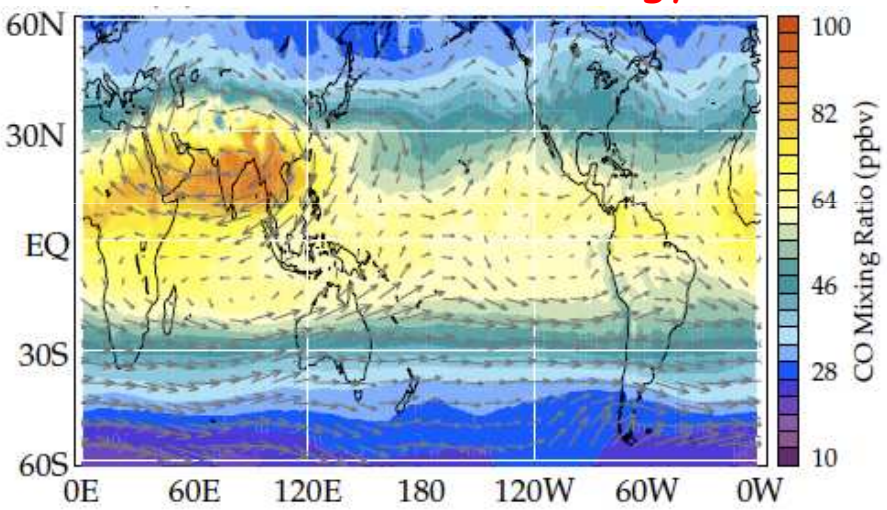
Park et al, JGR, 2007

Simulation of CO transport though monsoon

MLS observations 100 hPa



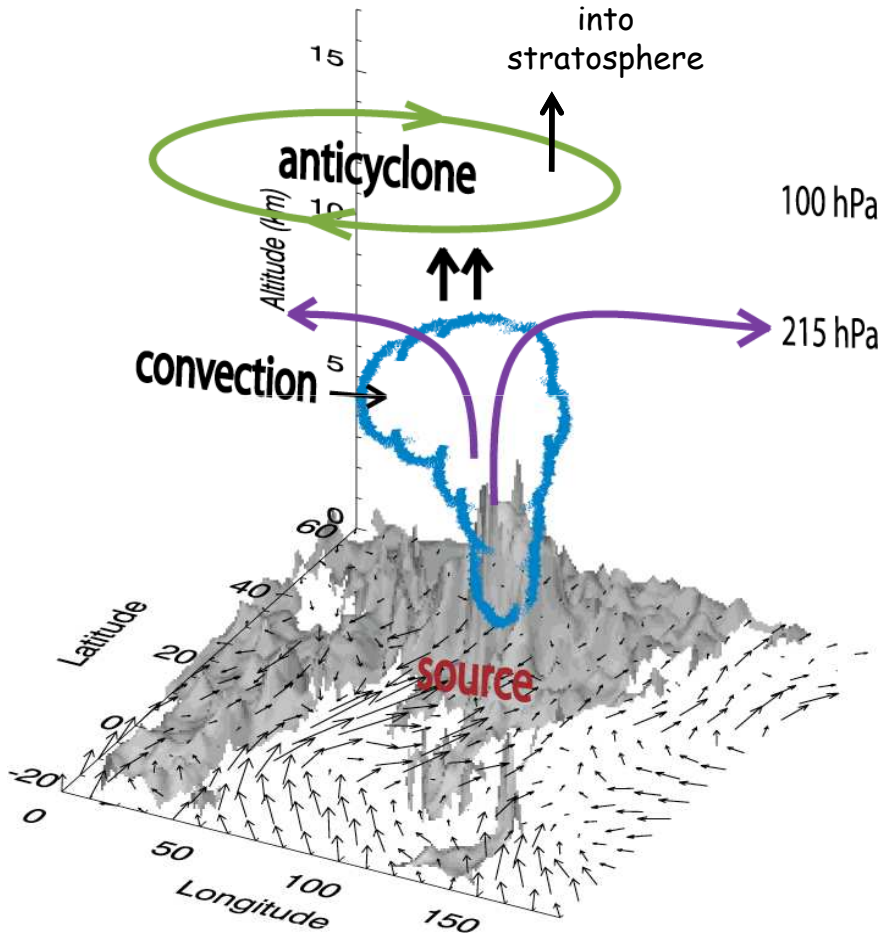
MOZART CTM simulation
using climatological CO sources
and NCEP meteorology



Result: Large-scale circulation can account for observed CO transport into the lower stratosphere

Park et al, 2009 JGR

Transport pathways (over monsoon region)



confinement by anticyclone

transport to west of convection

Transport above 200 hPa
by large-scale circulation

convective transport

(main outflow near 200 hPa)

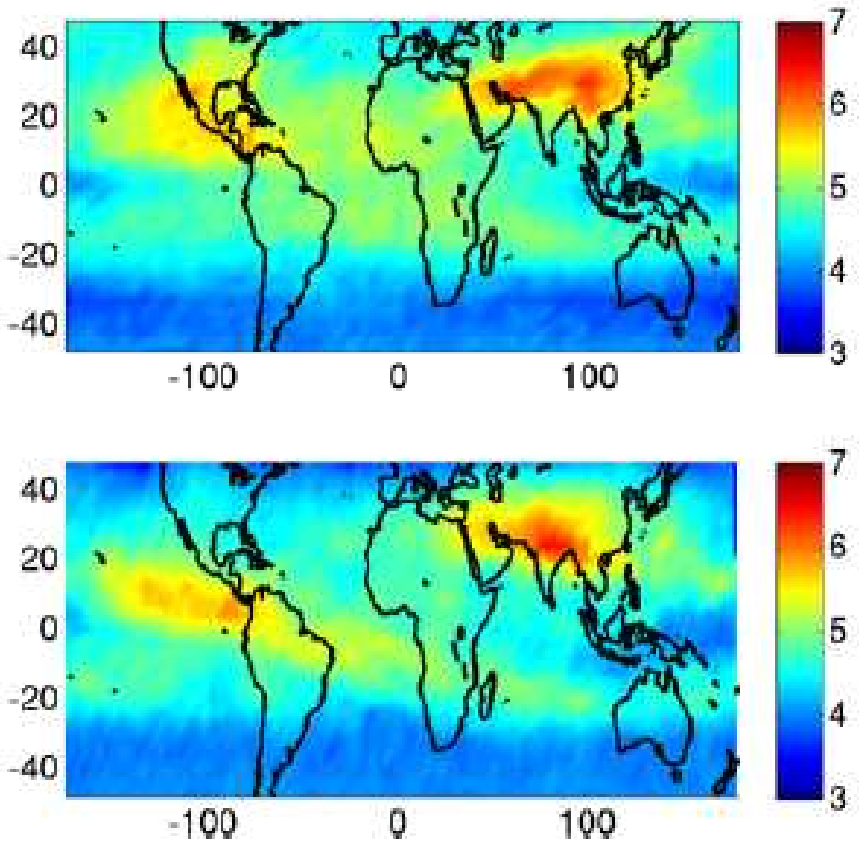
CO surface emission

(India and South China)

Refs: Park et al, JGR, 2007; ACP, 2008; JGR, 2009

Water vapor transport and dehydration above convective outflow during Asian monsoon

R. James,[1] M. Bonazzola,[1] B. Legras,[1] K. Surbled,[1] and S. Fueglistaler[2]



MLS observations
100 hPa

Trajectory
simulation

Note: small impact of convective moistening or overshooting convection

Key points:

- Monsoon anticyclone acts to confine air transported upwards in deep convection (high water vapor, surface pollution, etc.)

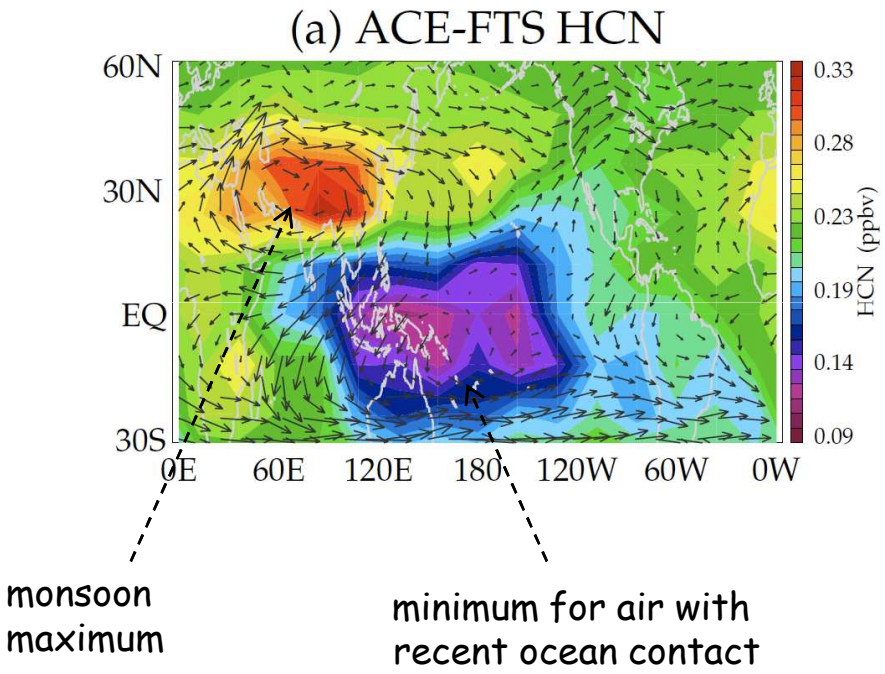
- Upwards transport above convective ourflow associated with large-scale circulation (part of the balanced Rossby gyre response to monsoon convective heating)

- Circulation extends into lower stratosphere

Evidence of monsoon transport to stratosphere from HCN

HCN observations from ACE-FTS satellite

HCN source: biomass burning
HCN lifetime: ~4 years in free atmosphere, but sink from contact with ocean



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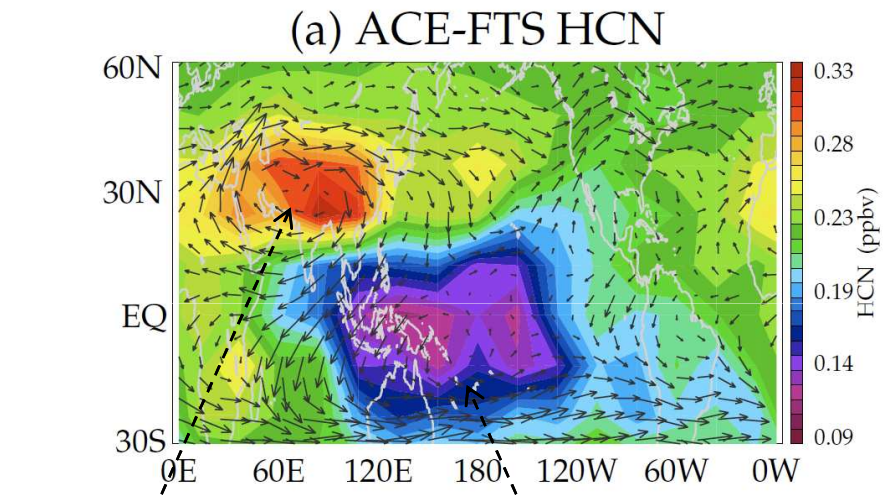
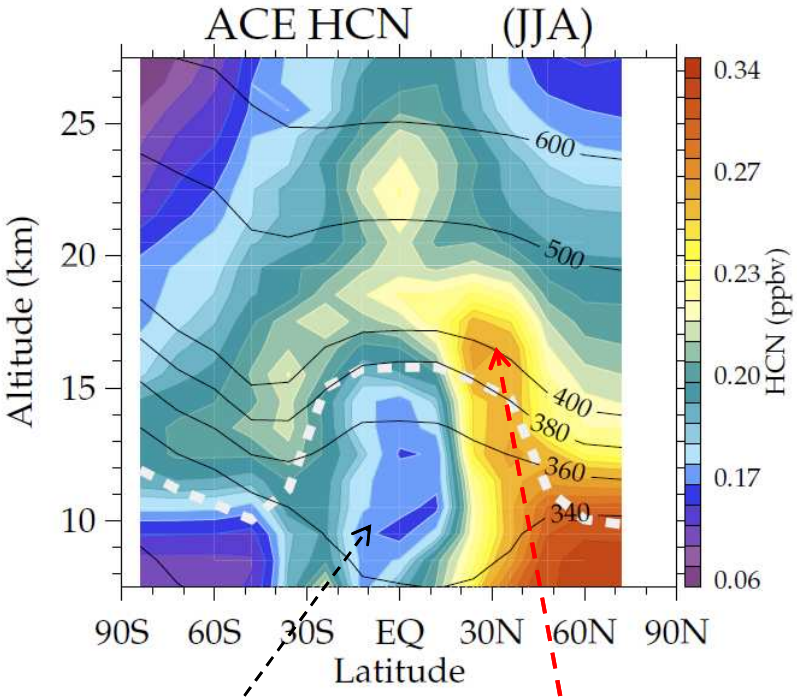


monsoon maximum

minimum for air with recent ocean contact



tropical minimum

transport to stratosphere via monsoon

Questions?