Transport, chemistry and aerosols in the Asian monsoon anticyclone

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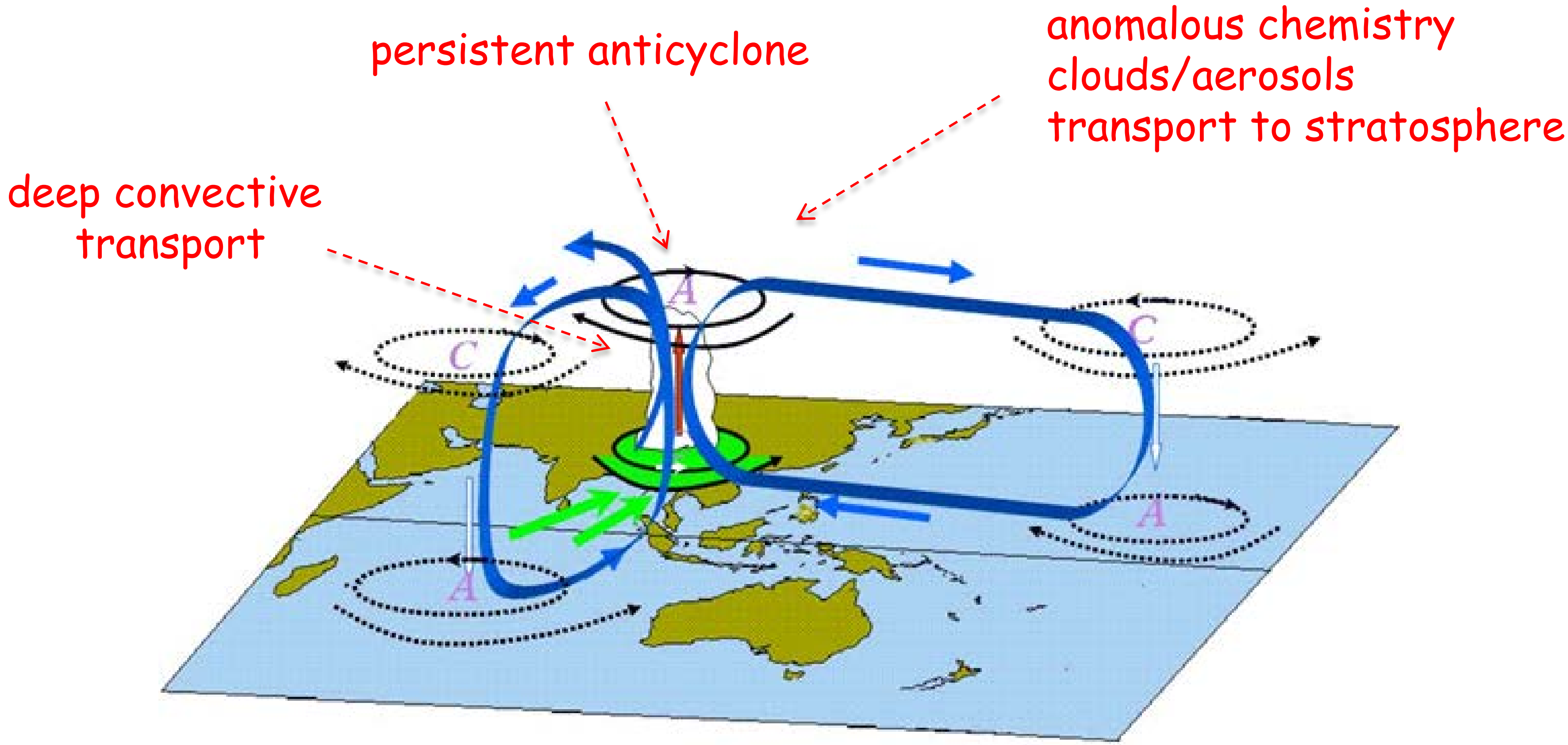
Thanks to: Mijeong Park, Laura Pan, Doug Kinnison, Hella Garney, others.

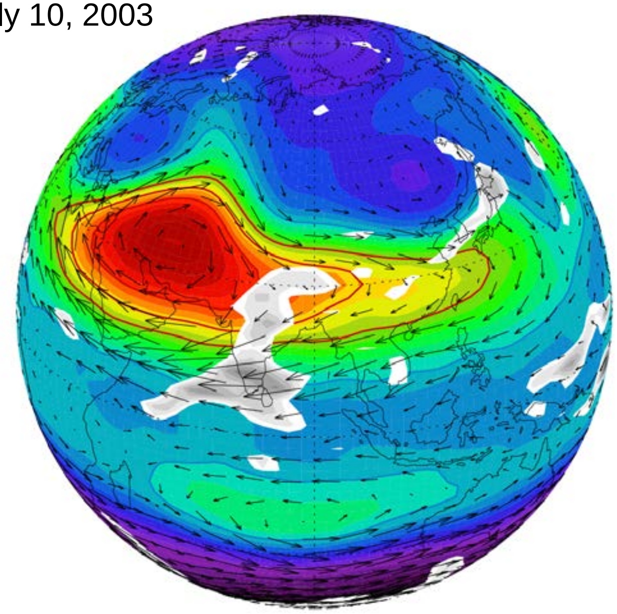
Summer Broad-Scale Circulations

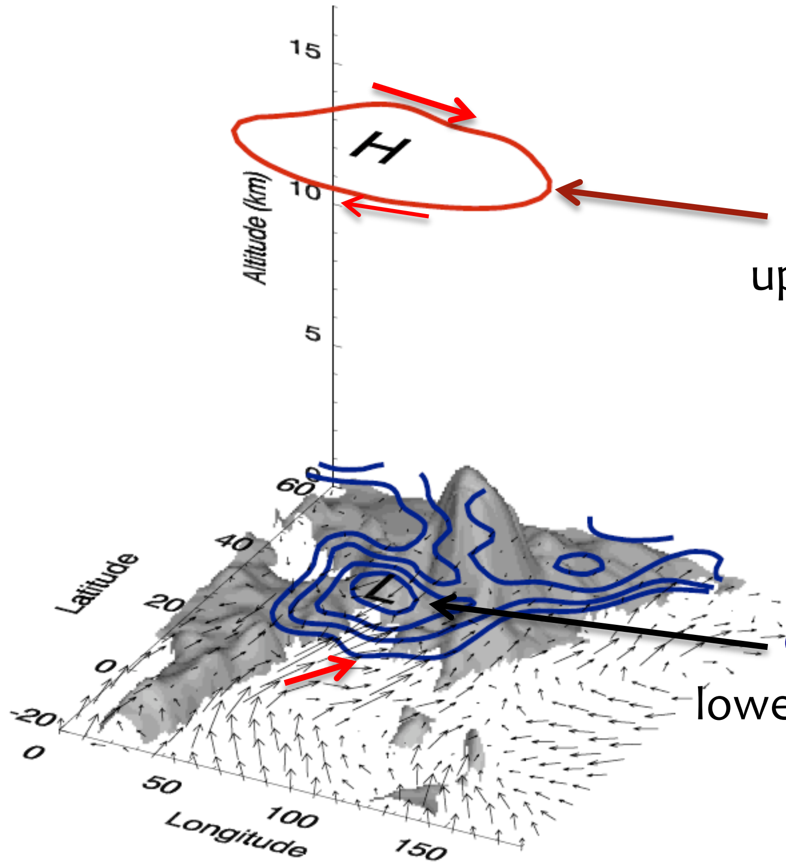


Dynamical Background

Cyclone at the surface, anticyclone in the upper troposphere

July 10, 2003



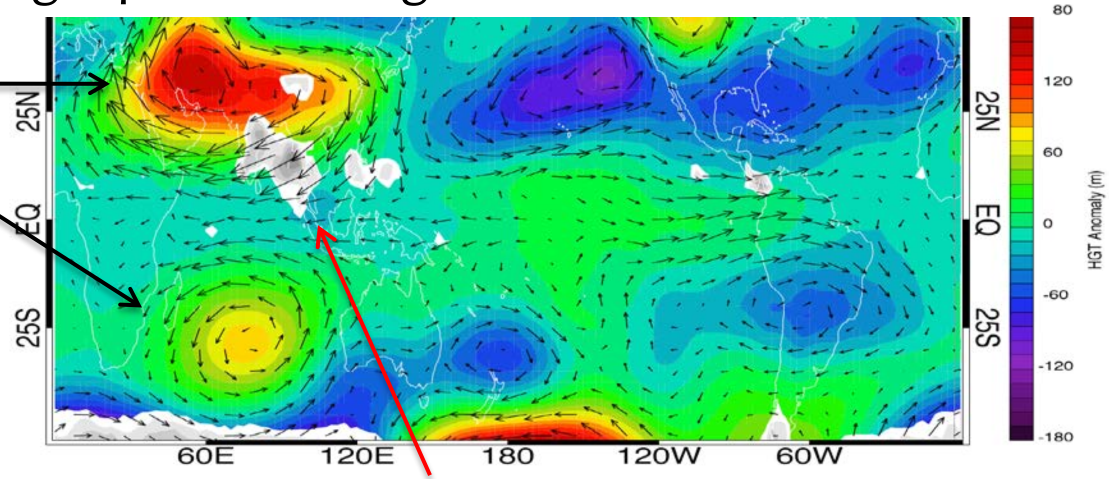


Hoskins and Rodwell, 1995
Highwood and Hoskins, 1998

Anticyclones in the Upper Troposphere

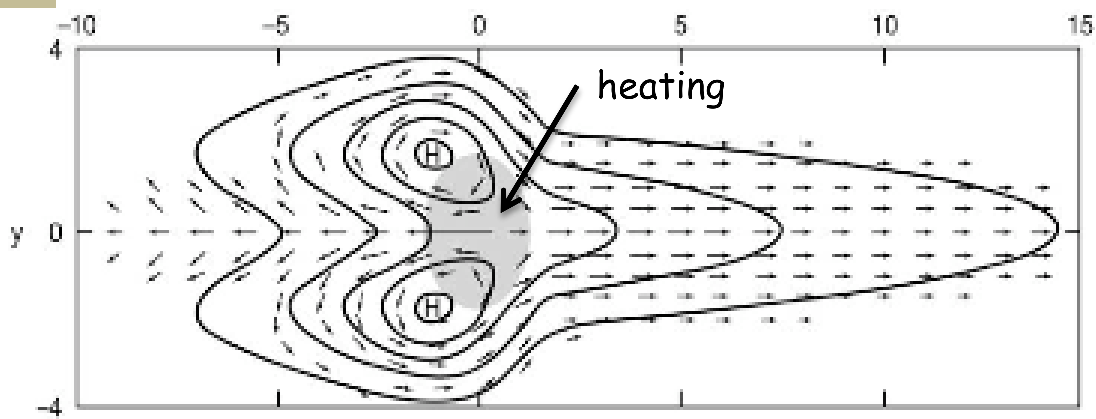
geopotential height and winds 100 hPa

anticyclones



Convection (heating)

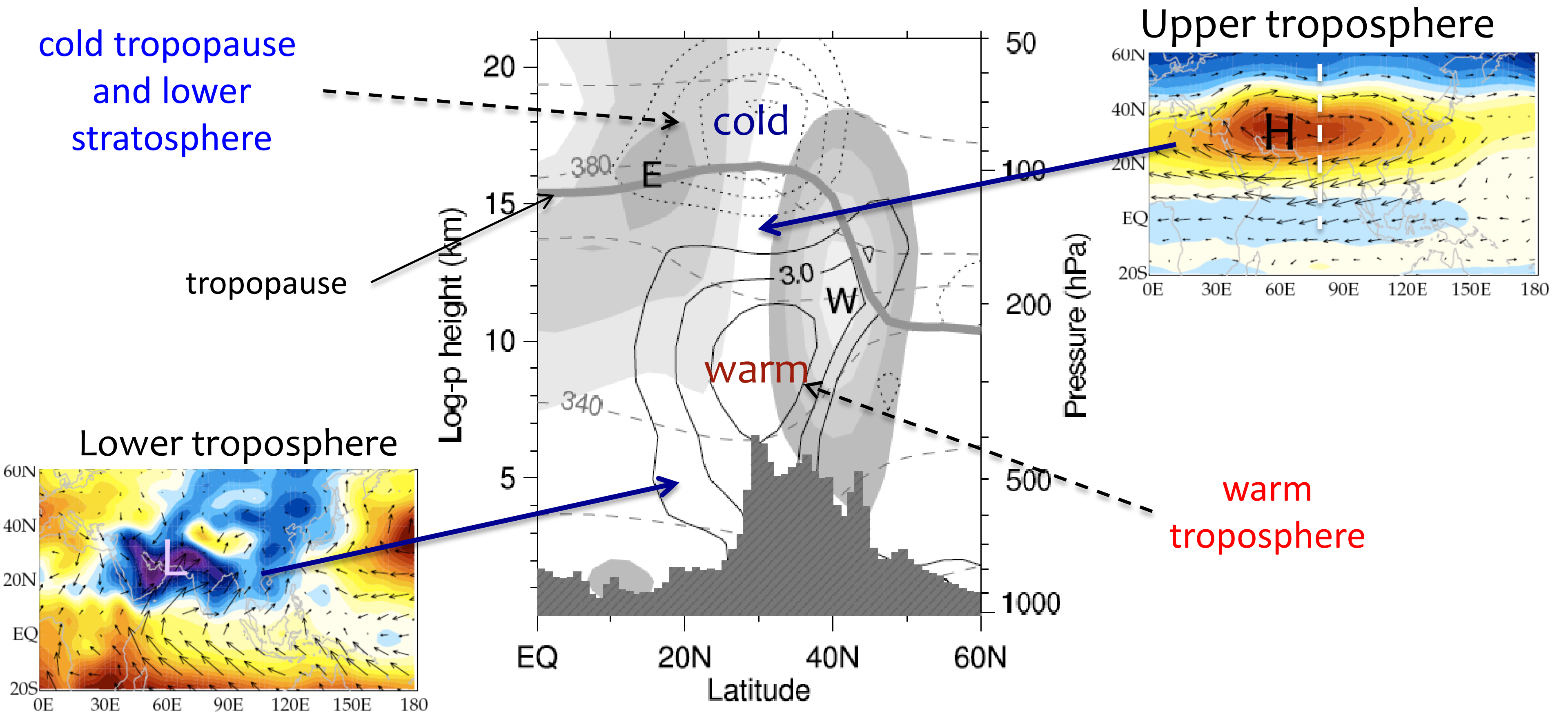
Note that
the anticyclone
does not lie
on top of the
deep convection



'Matsuno-Gill' Solution

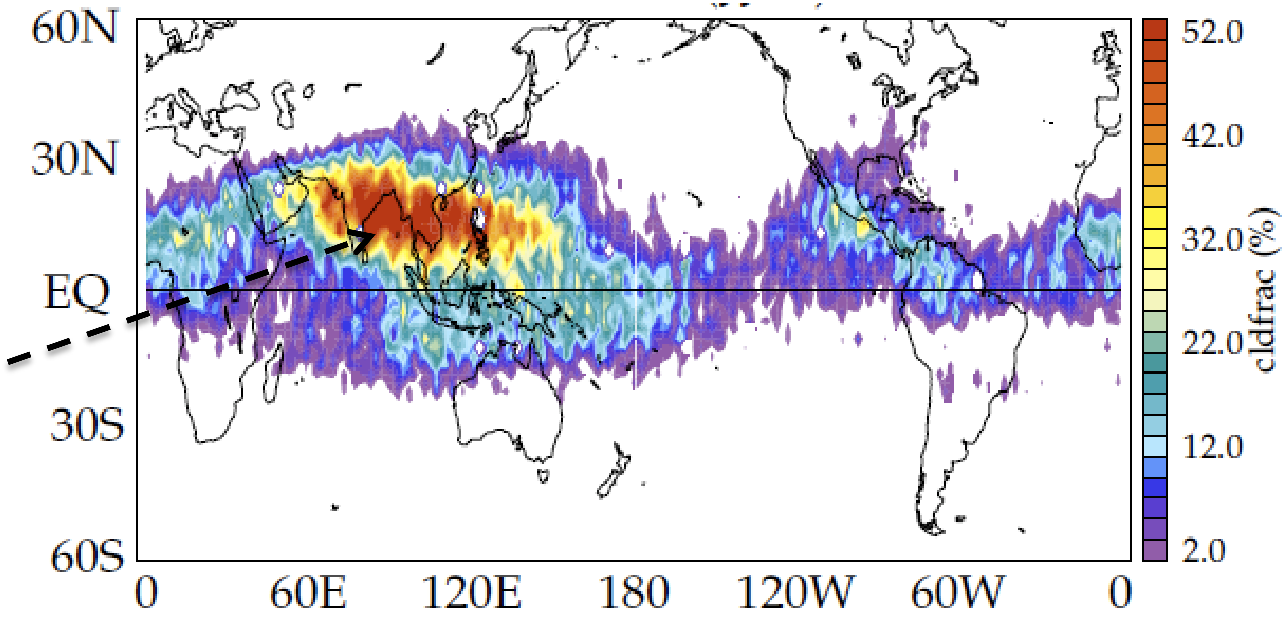
Dynamical Background

Anticyclonic circulation extends into lower stratosphere



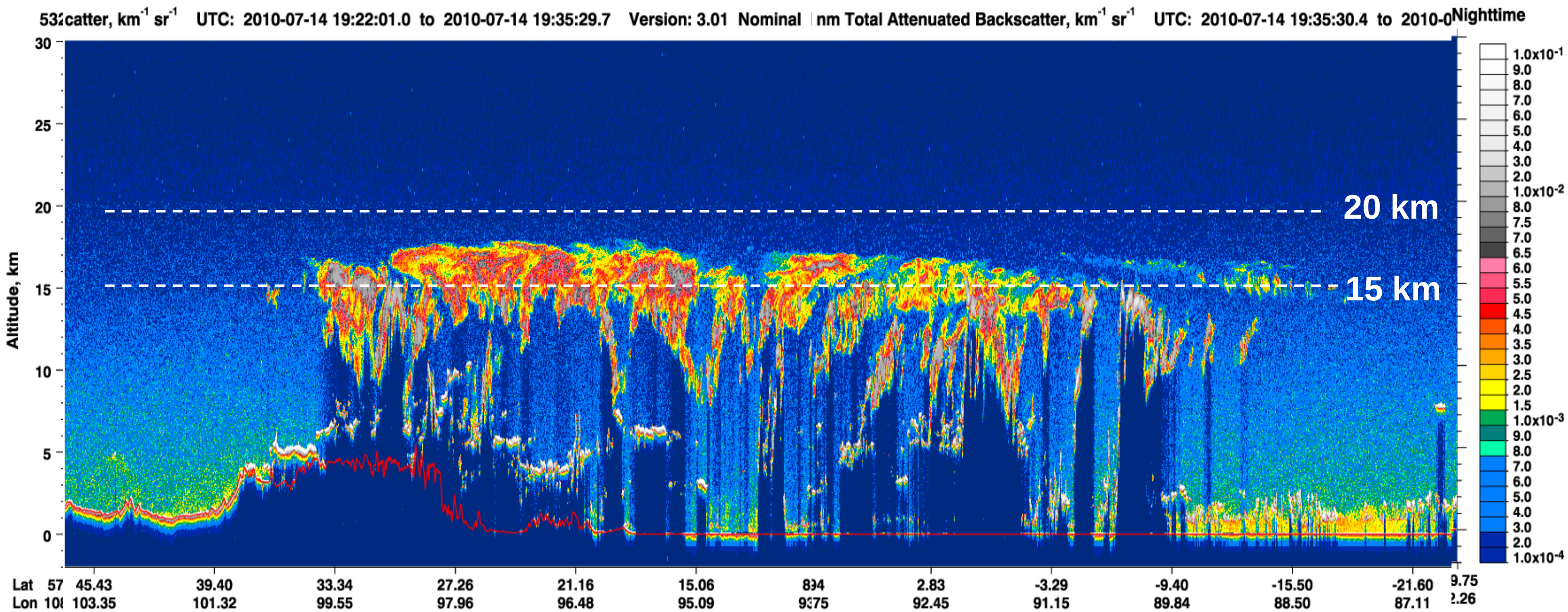
Randel and Park, JGR, 2006

CALIPSO cloud fraction near 16 km

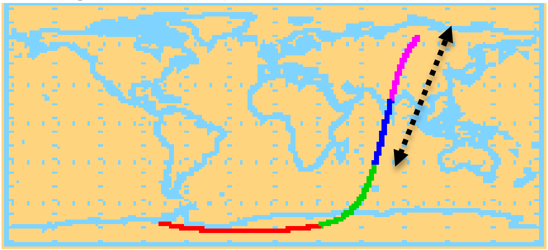


frequent cirrus
near tropopause

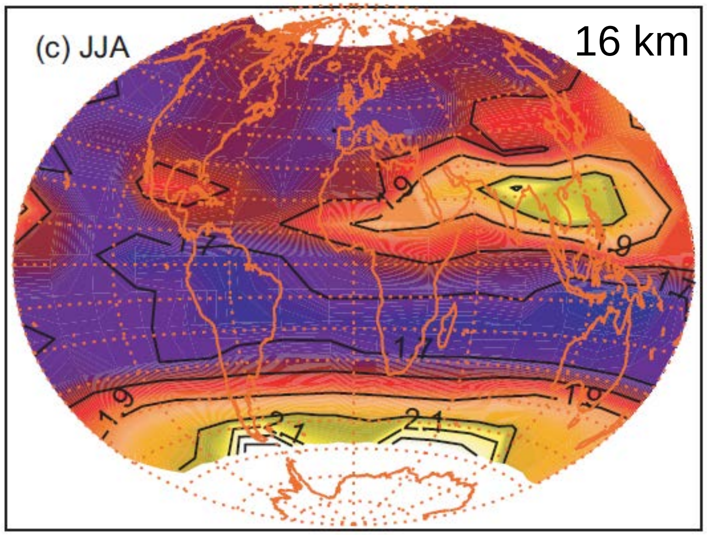
CALIPSO satellite lidar cloud observations



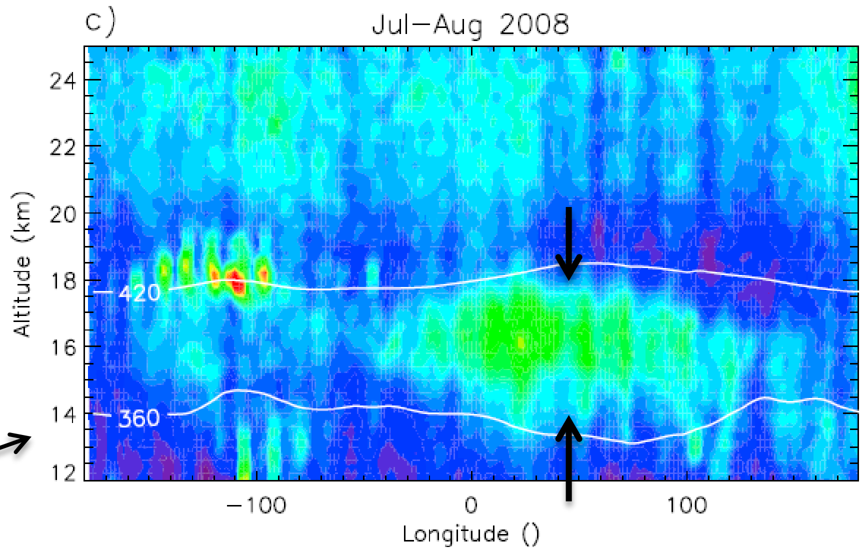
July 14, 2010



Monsoon aerosol layer near 16 km



SAGE II measurements 1999-2005
Thomason and Vernier, ACP, 2013

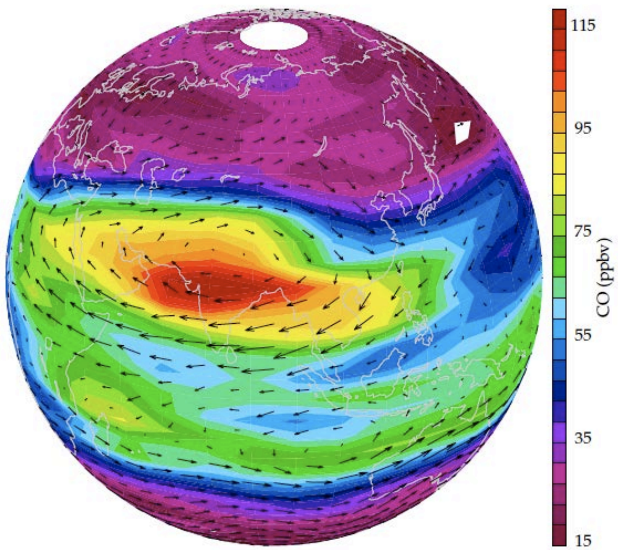


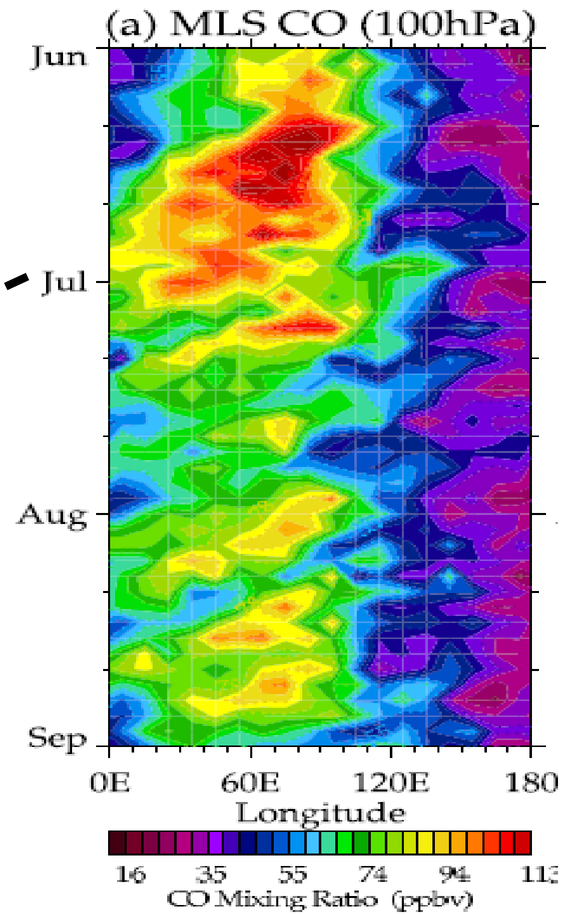
CALIPSO measurements
Vernier et al , GRL, 2011

Narrow layer near tropopause

strong chemical influence on summer UTLS

MLS 100 hPa
carbon monoxide (CO)

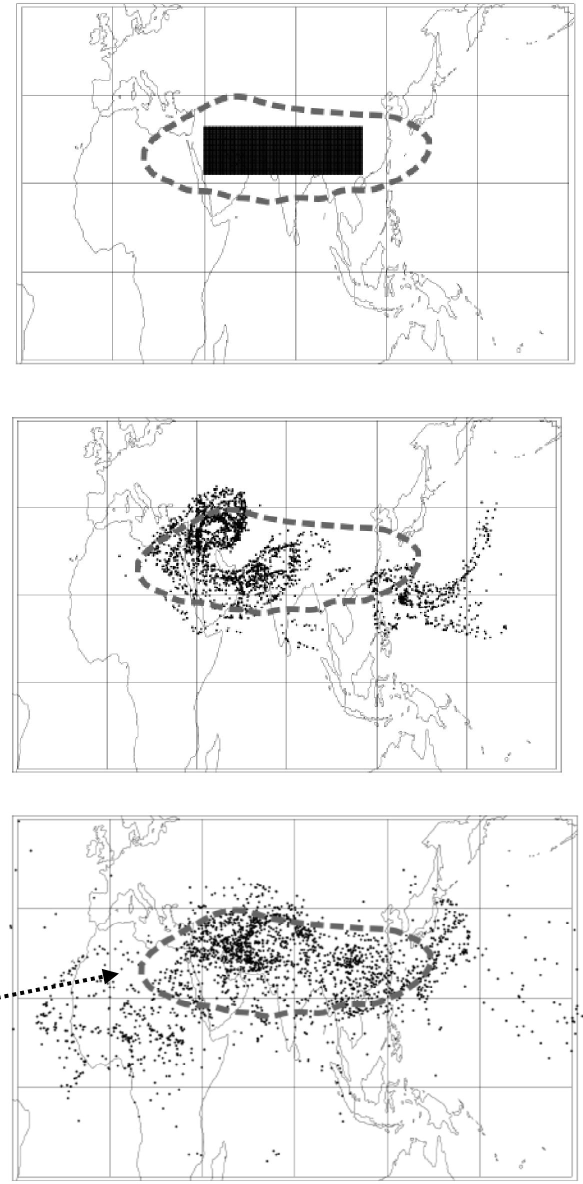




variability linked to monsoon convection

Park et al, JGR, 2008, 2009

transport simulation at 150 hPa



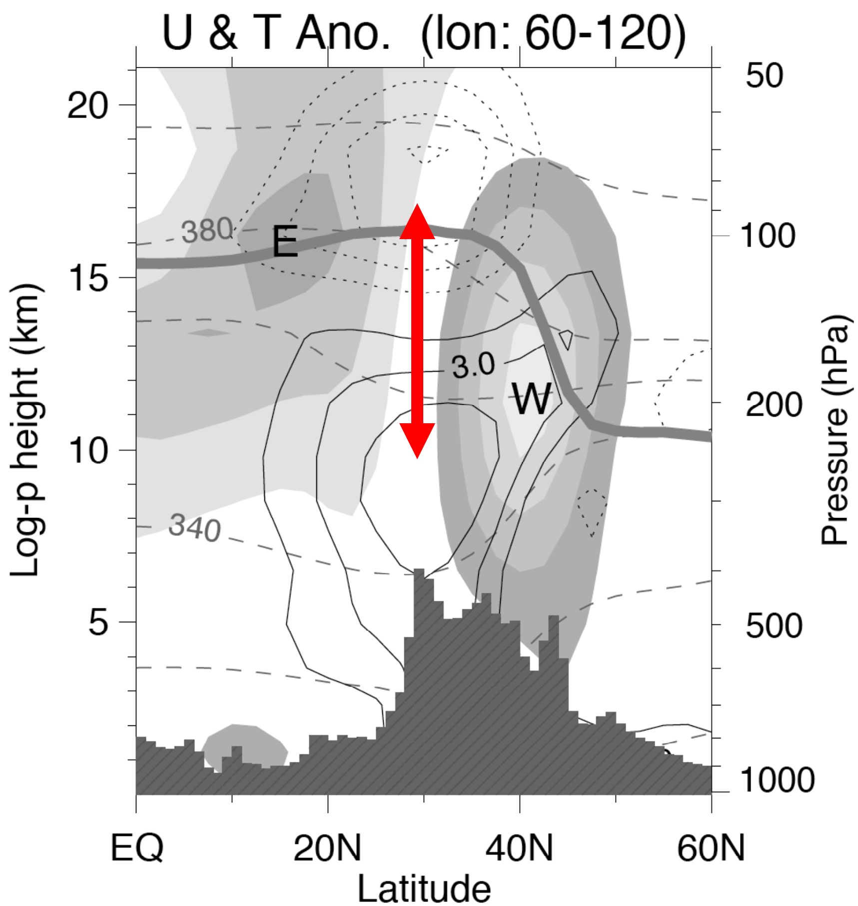
day 0

day 10

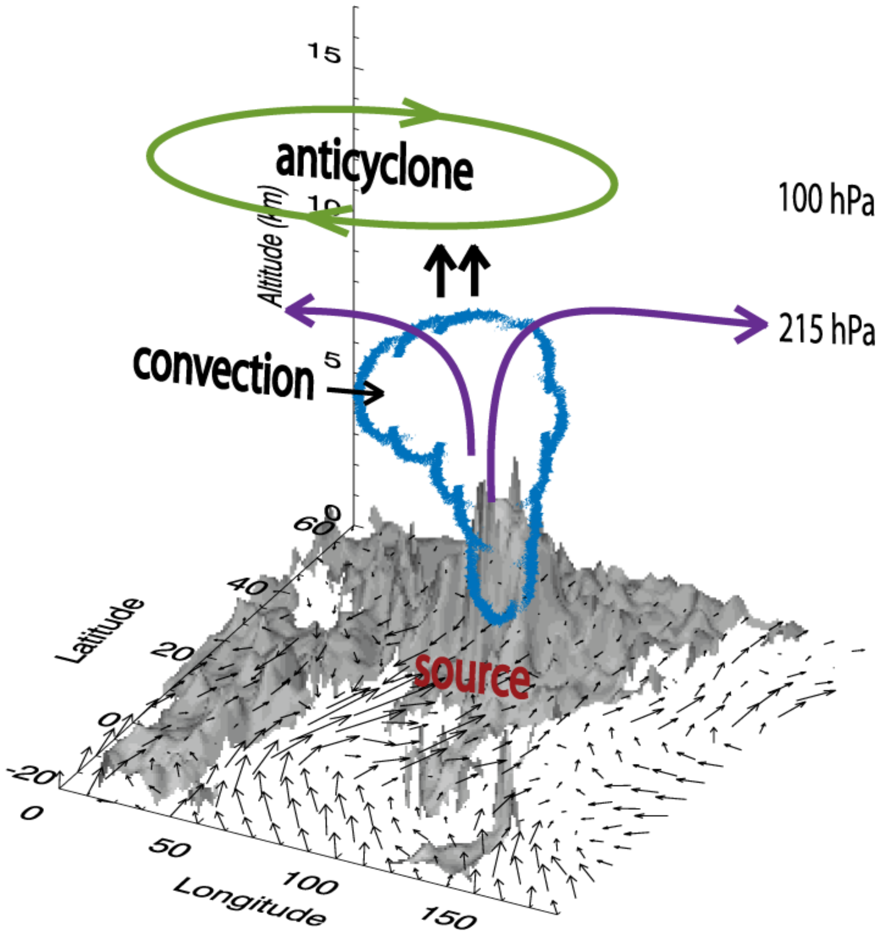
day 20

large fraction remain inside anticyclone

Confinement within region of strongest winds



Transport pathways



confinement by anticyclone
+ transport to stratosphere

Transport above 200 hPa
by convection / circulation

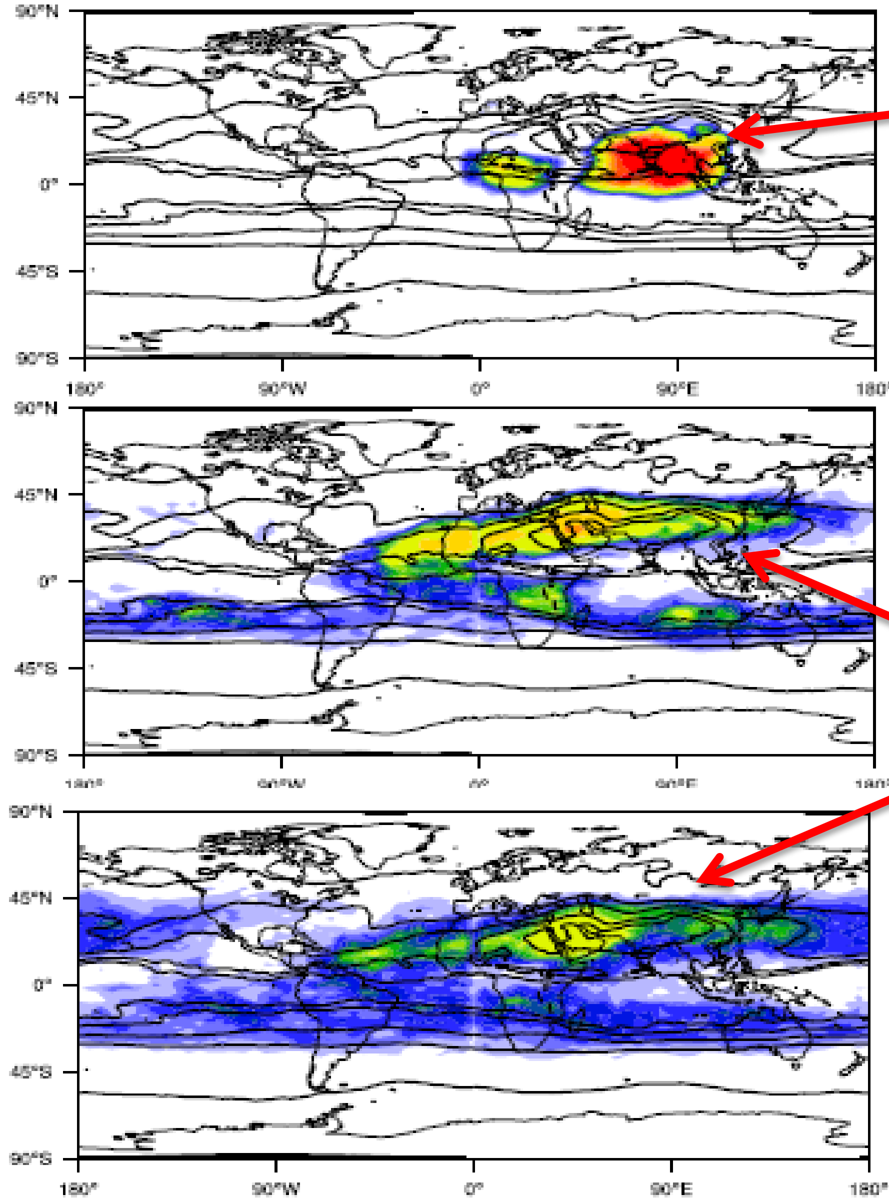
convective transport
(main outflow near 200 hPa)

surface emission
(India and Southeast Asia)

Park et al, JGR, 2008, 2009

What happens to the outflow from deep convection?

3D trajectories initialized at 200 hPa in regions of deep convection OLR < 160 K



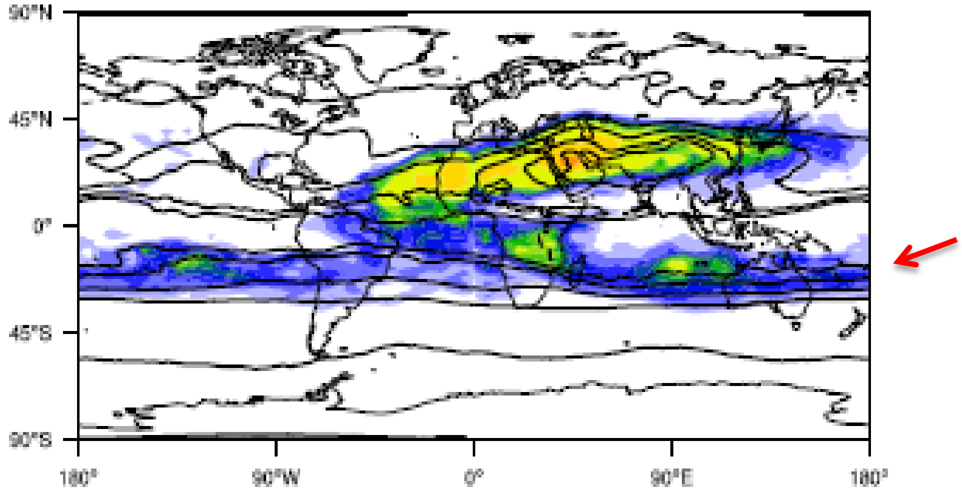
+ 10 days

+ 20 days

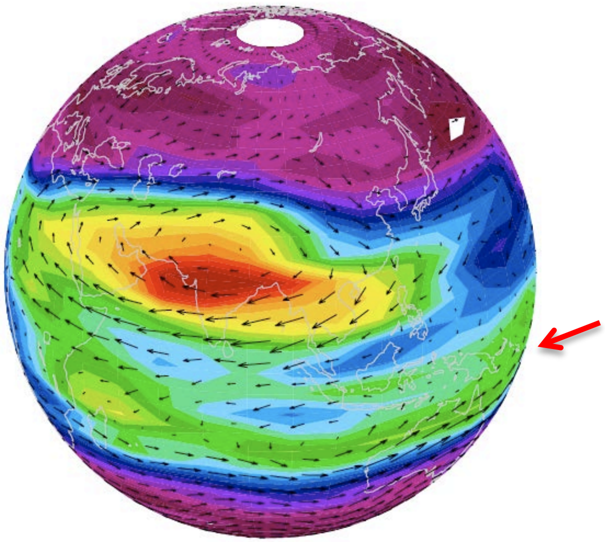
confinement within anticyclone + transport to SH

from Hella Garney

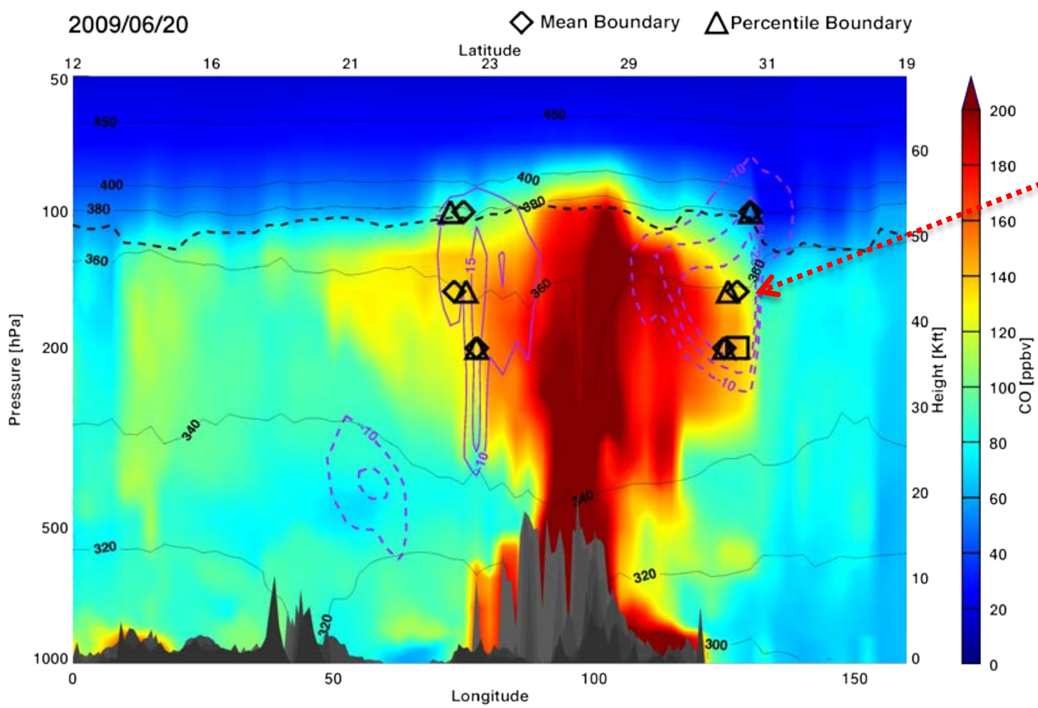
trajectories



MLS 100 hPa
carbon monoxide (CO)



Vertical structure of CO from model simulation



dynamical 'edge' of anticyclone

from Laura Pan

- How sharp is the 'chemical edge'?
- When and where does air 'escape' the anticyclone?

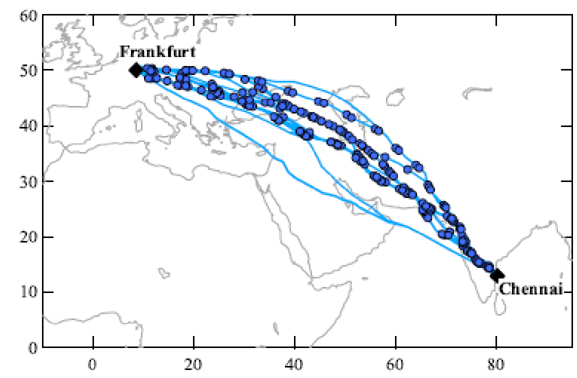
Atmos. Chem. Phys., 10, 3965–3984, 2010
www.atmos-chem-phys.net/10/3965/2010/

Atmospheric Chemistry and Physics

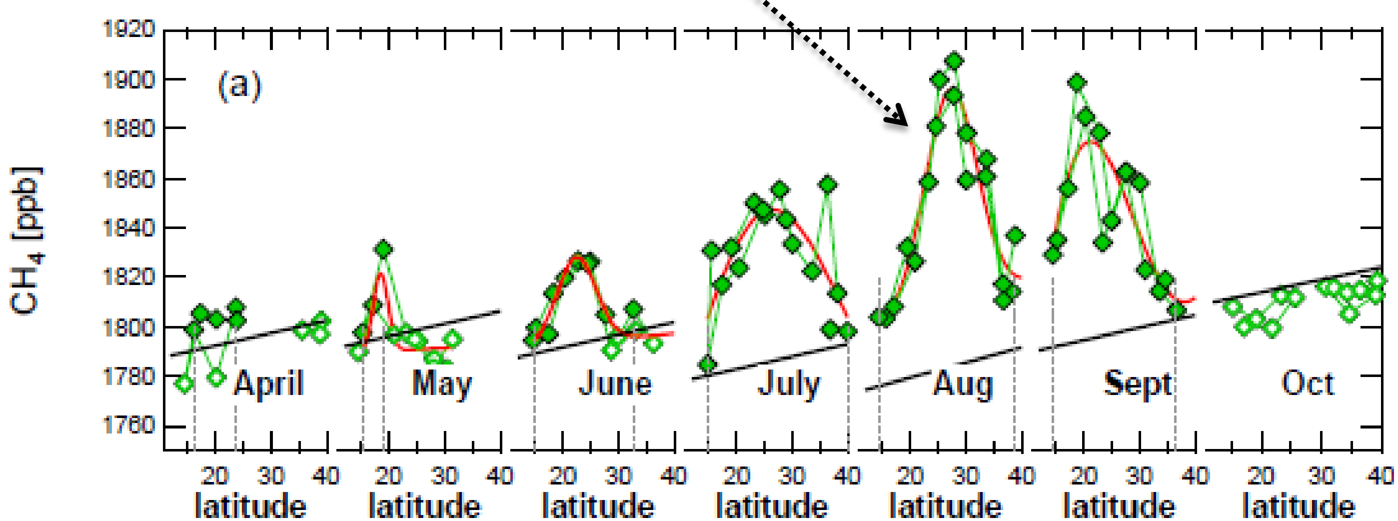
Aircraft measurements

Greenhouse gas relationships in the Indian summer monsoon plume measured by the CARIBIC passenger aircraft

T. J. Schuck[1], C. A. M. Brenninkmeijer[1], A. K. Baker[1], F. Slemr[1], P. F. J. von Velthoven[2], and A. Zahn[3]



Enhanced CH_4 within anticyclone

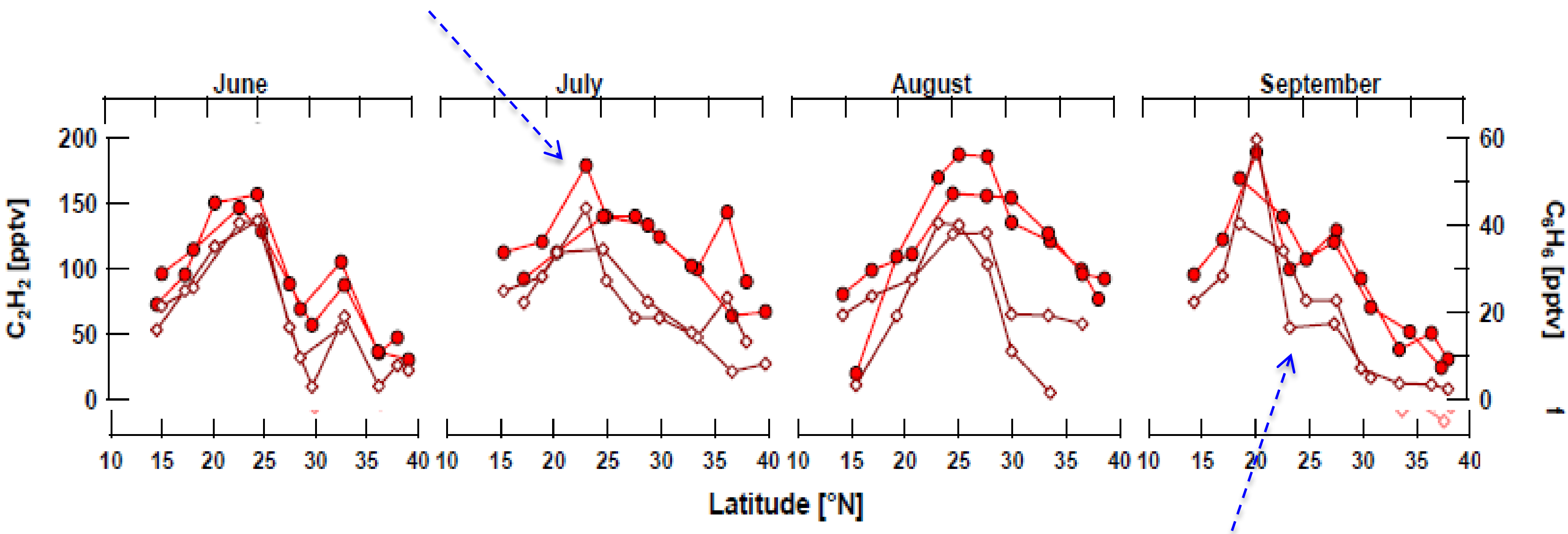


Characterization of non-methane hydrocarbons in Asian summer monsoon outflow observed by the CARIBIC aircraft

A. K. Baker[1], T. J. Schuck[1], F. Slemr[1], P. van Velthoven[2], A. Zahn[3], and C. A. M. Brenninkmeijer[1]

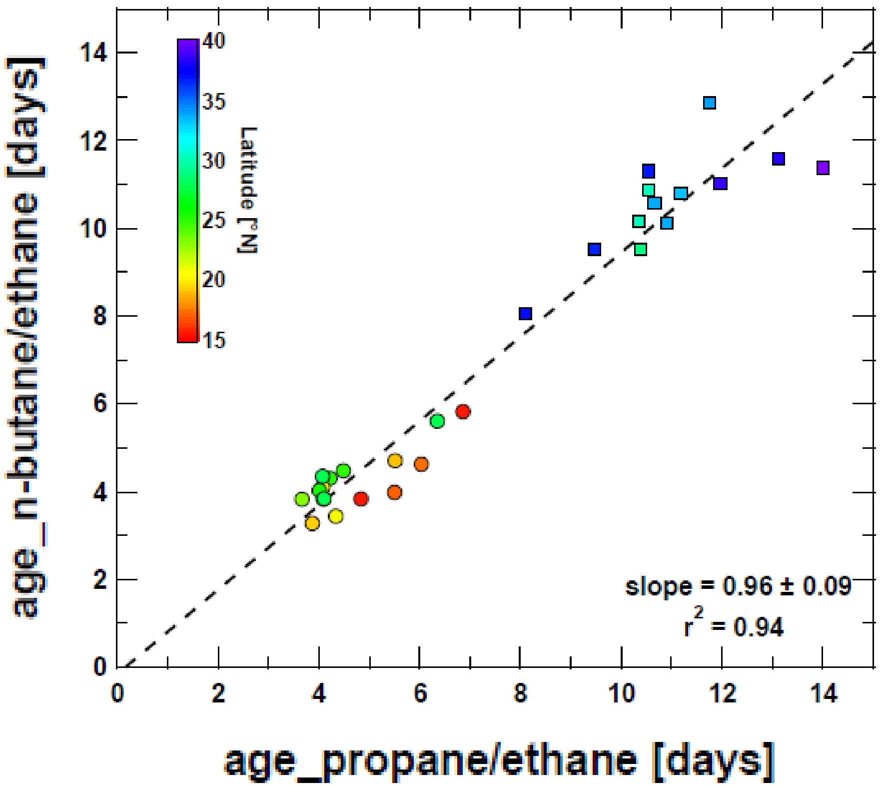
ACP, 2011

acetylene C_2H_2



benzene C_6H_6

Age of air estimated from short-lived hydrocarbons

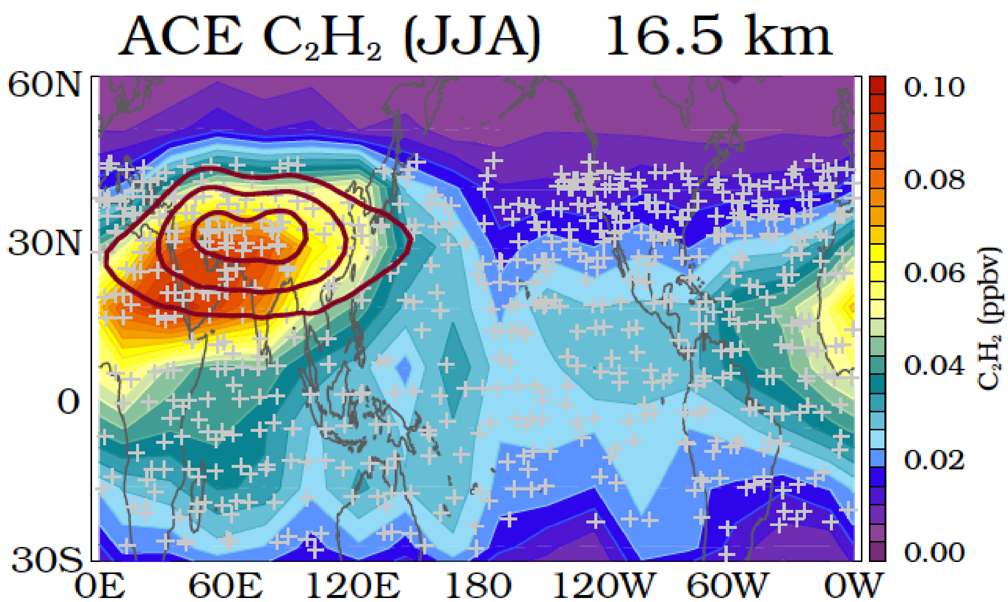


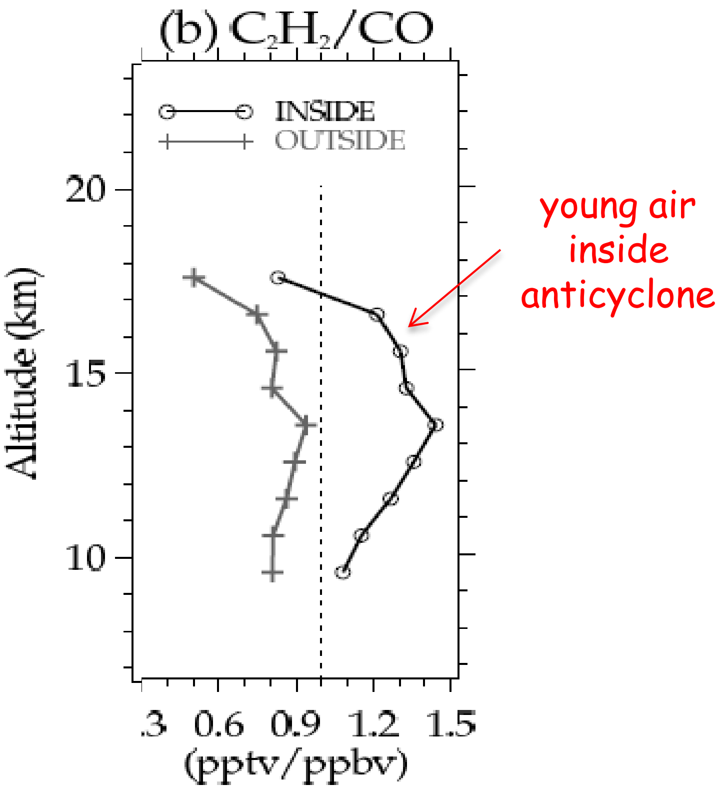
Baker et al, ACP, 2011

Result: air is relatively young: ~5-12 days

C_2H_2 measurements from ACE-FTS satellite

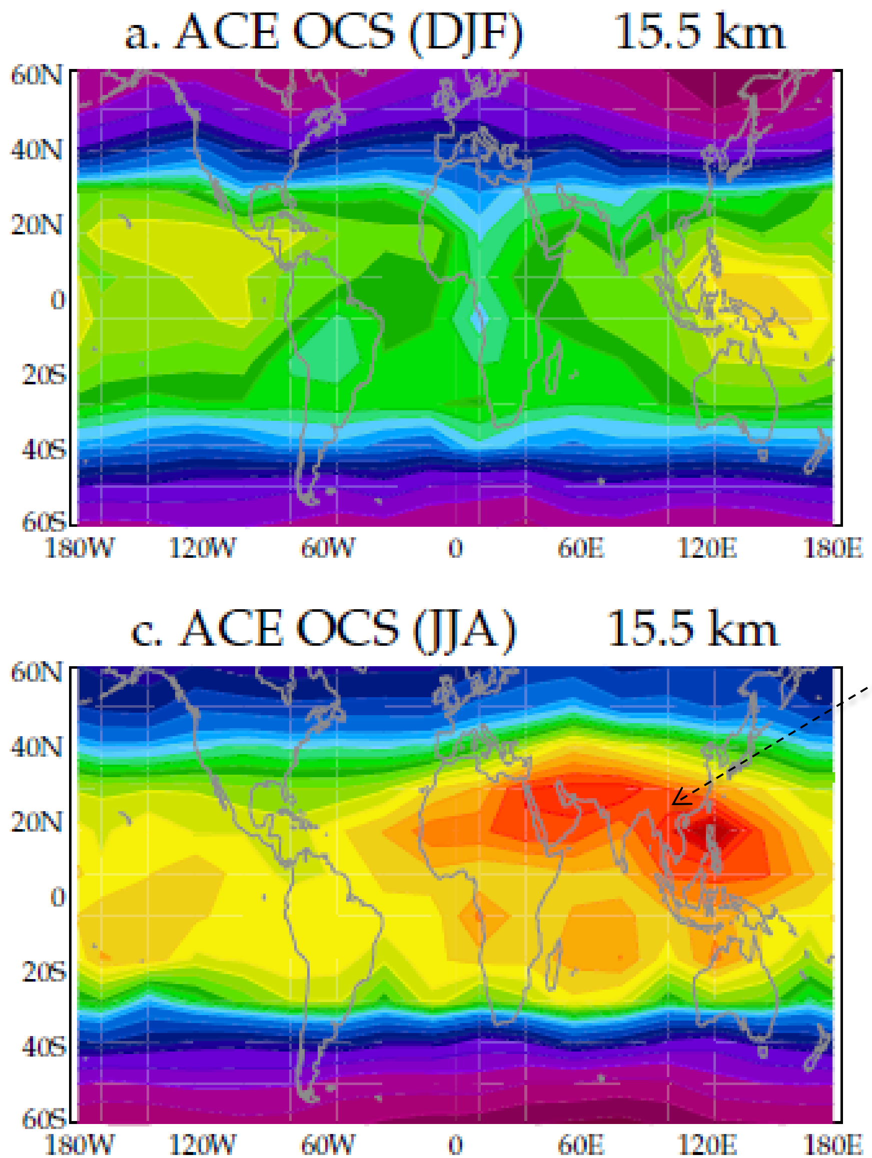
photochemical lifetime ~ 2 weeks





ACE measurements of OCS

Note the large annual cycle

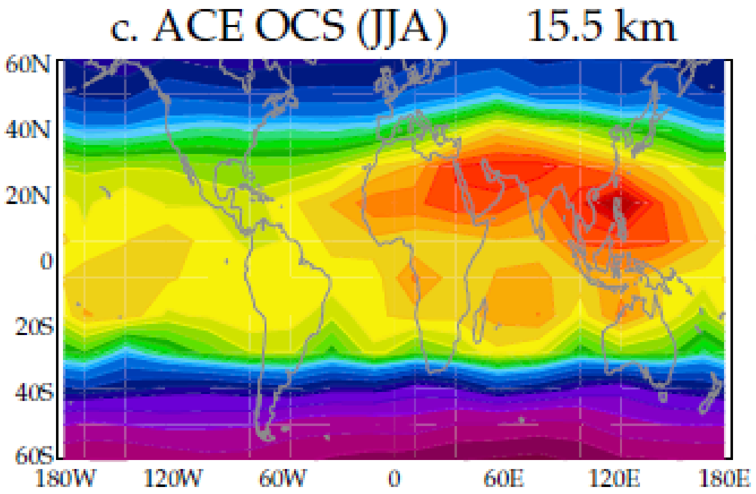


DJF

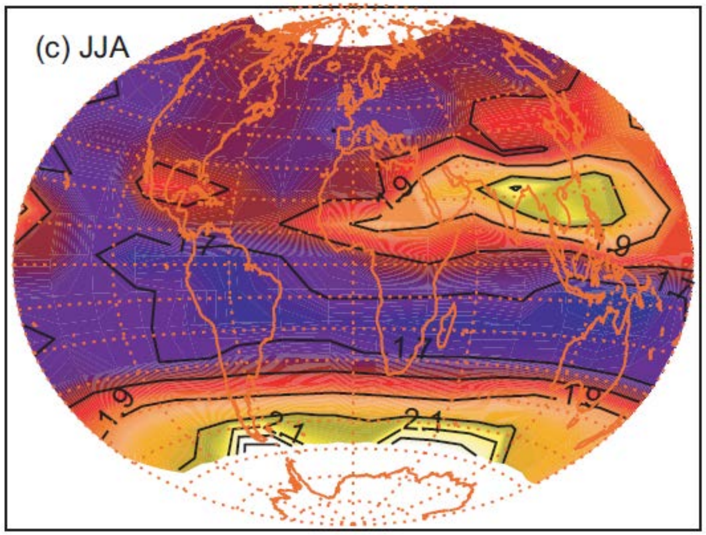
enhanced in monsoon region

JJA

Simple mechanism for ATAL?



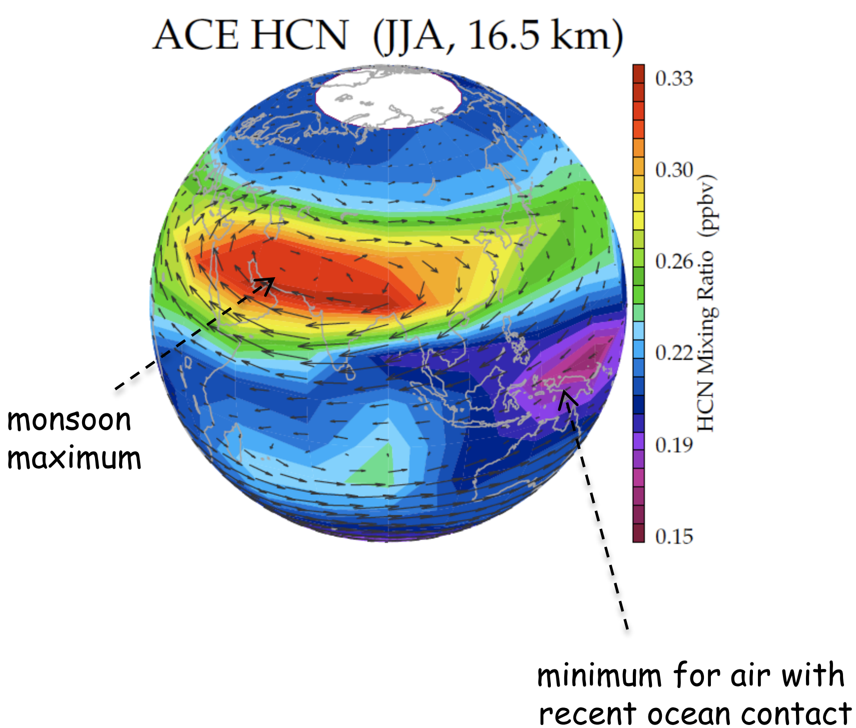
SAGE II aerosols
Thomason and Vernier, ACP, 2013

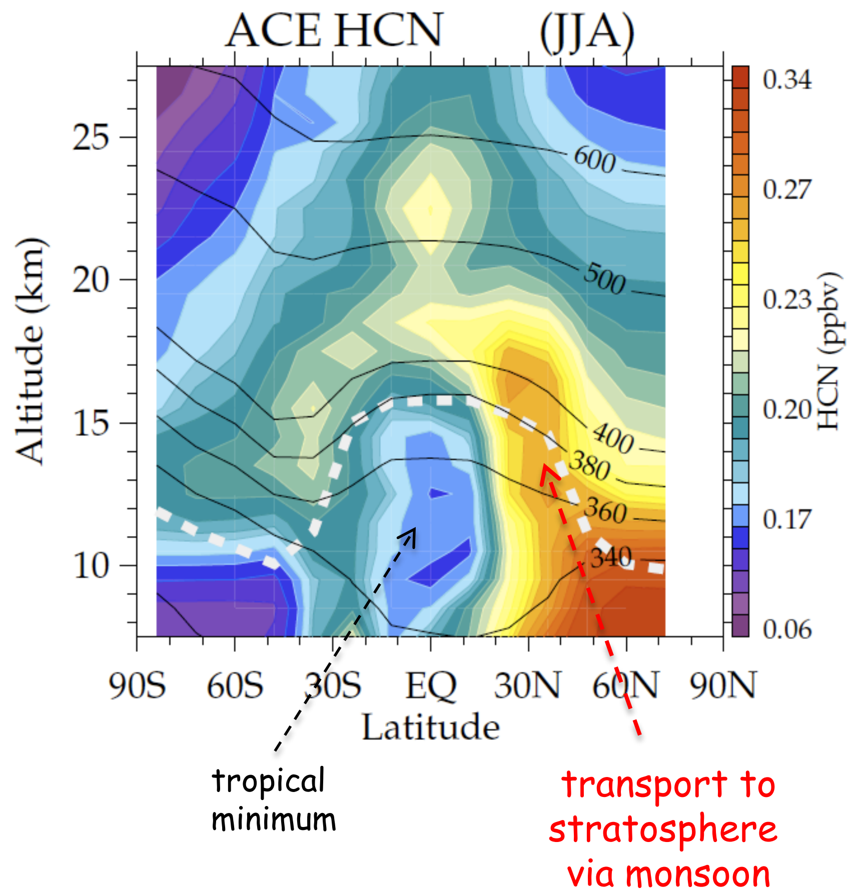


Transport to the stratosphere observed from ACE hydrogen cyanide (HCN)

HCN – biomass burning tracer

- Minimum in tropics (ocean sink)
- Long lived in free atmosphere



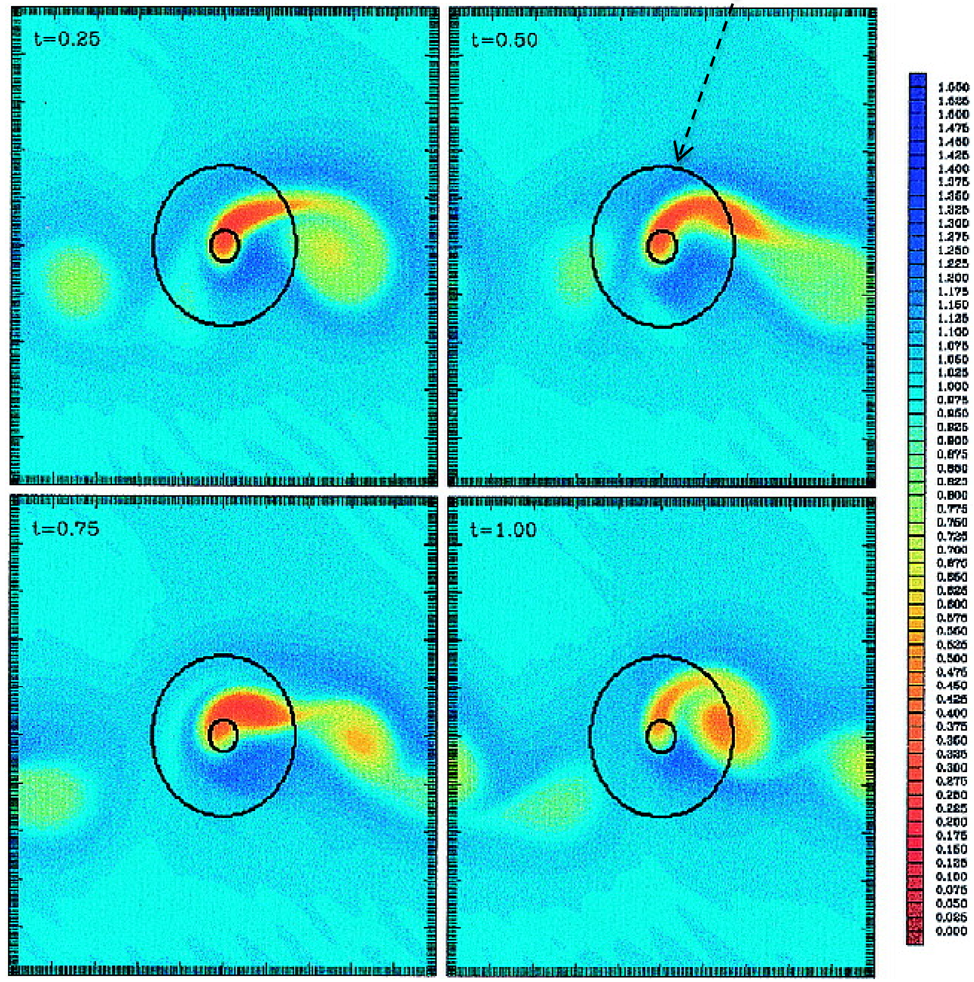


Monsoon circulation is inherently unstable

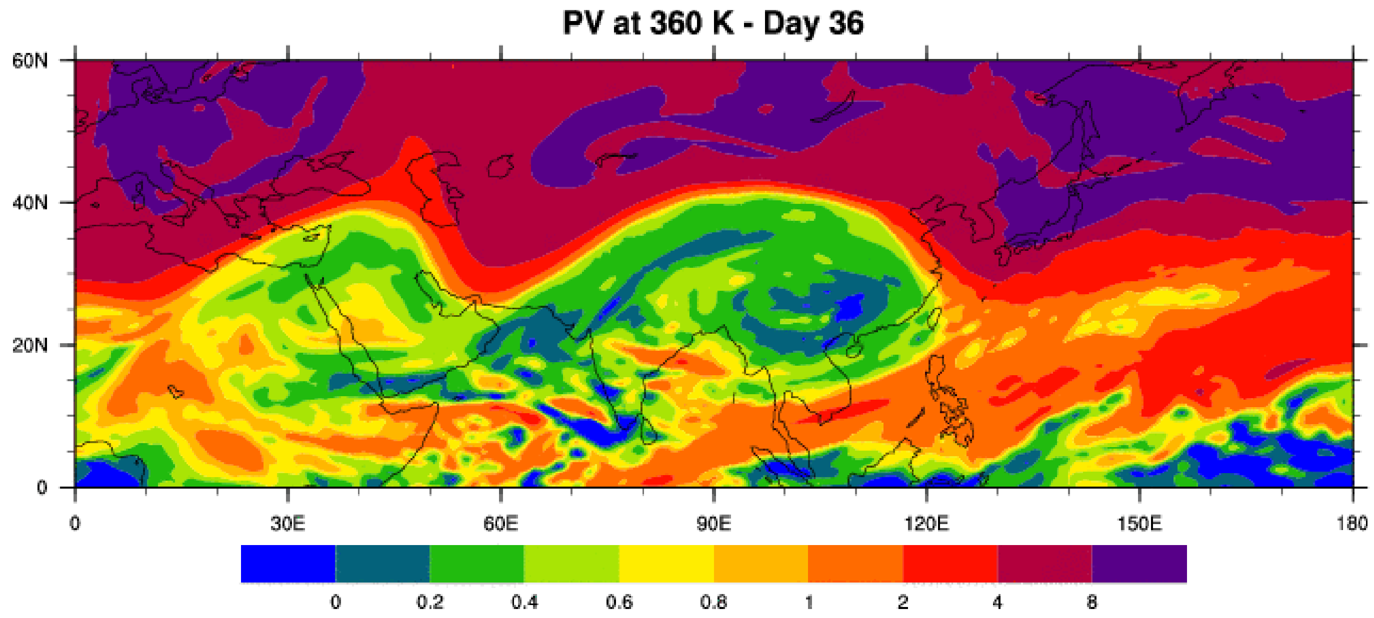
time-independent
forcing

Hsu and Plumb 2000

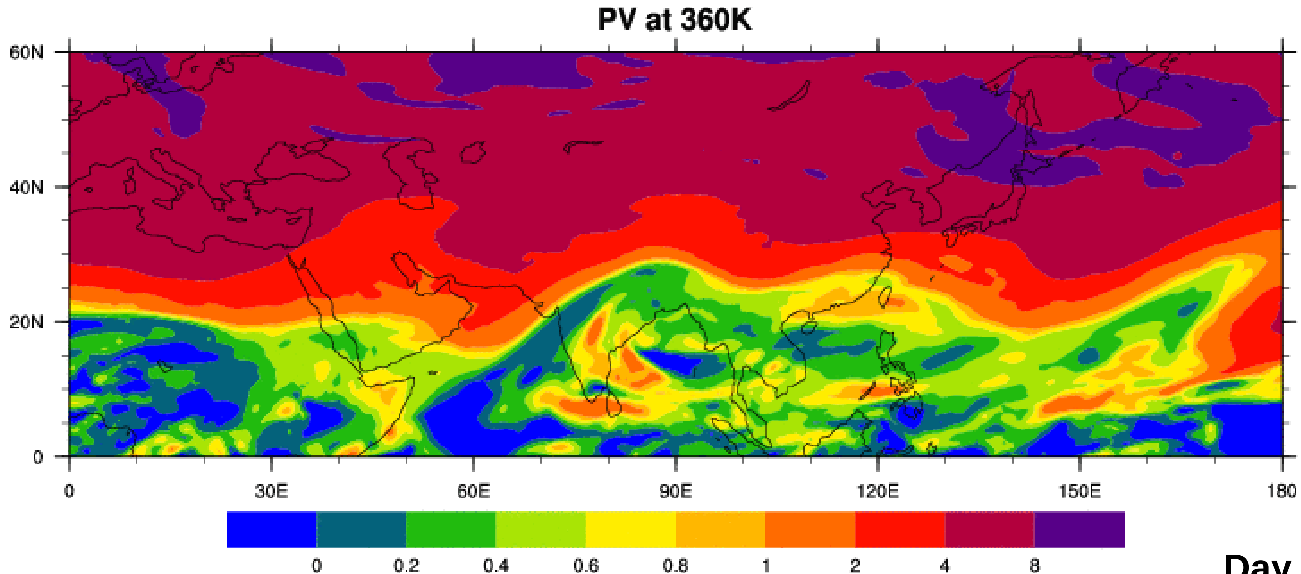
eddy shedding from
monsoon circulation



Anticyclone viewed in potential vorticity



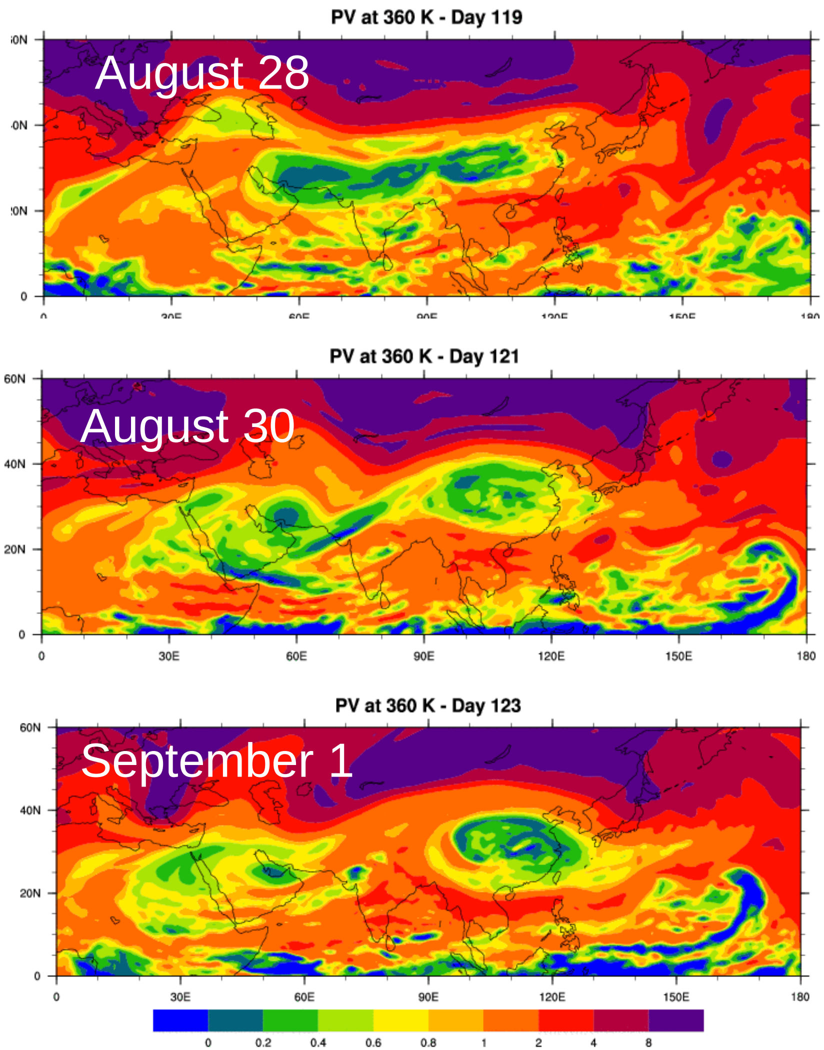
PV in monsoon region at 360 K May 1 – September 30, 2006

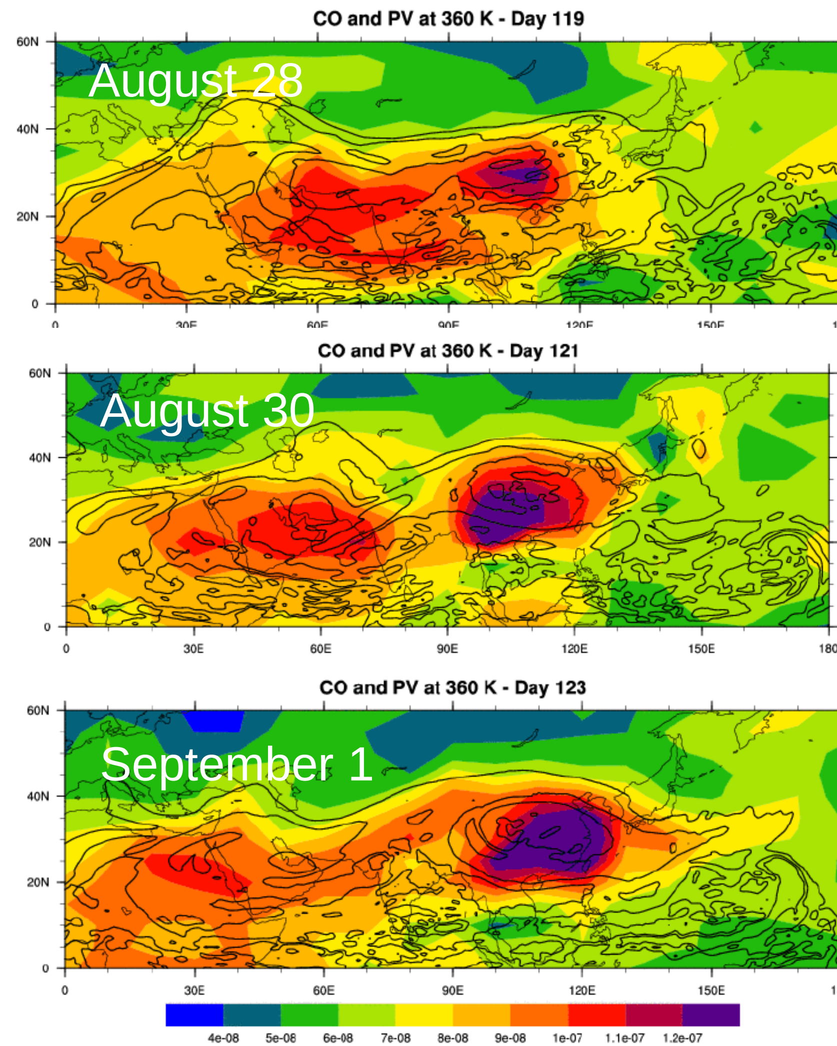


Day 1 = May 1
32 June 1
62 July 1
93 Aug 1
123 Sept 1

PV maps at 360 K

CO from Aura MLS





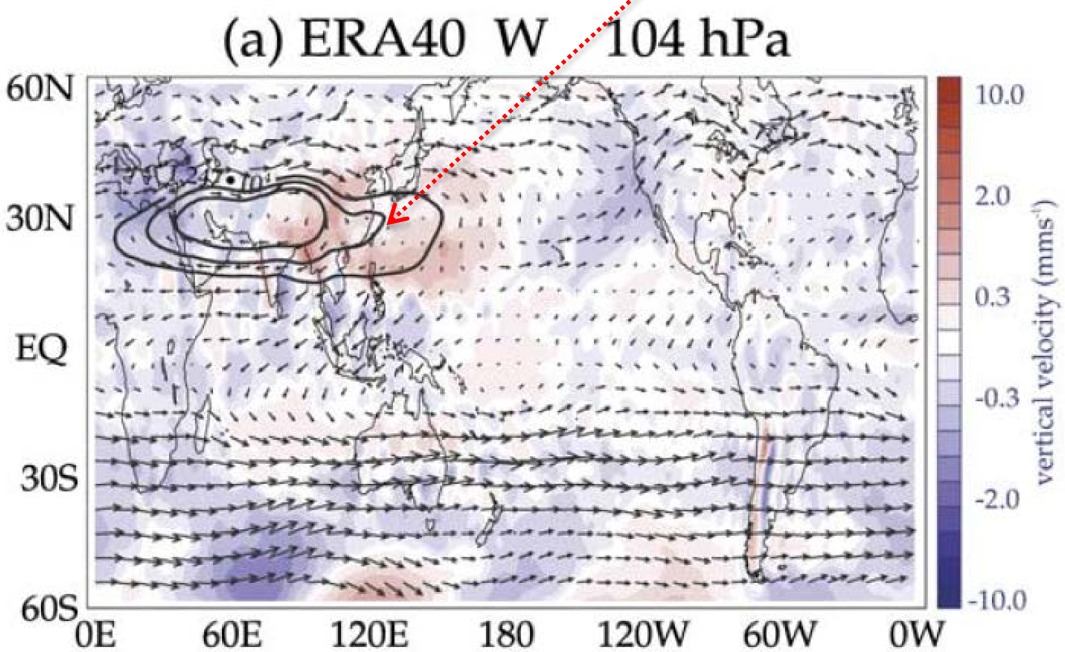
Garney and Randel, 2013

What controls transport to stratosphere?

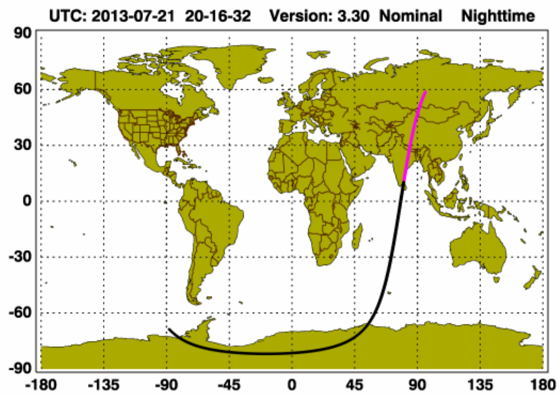
Deep convection and/or large-scale circulation?

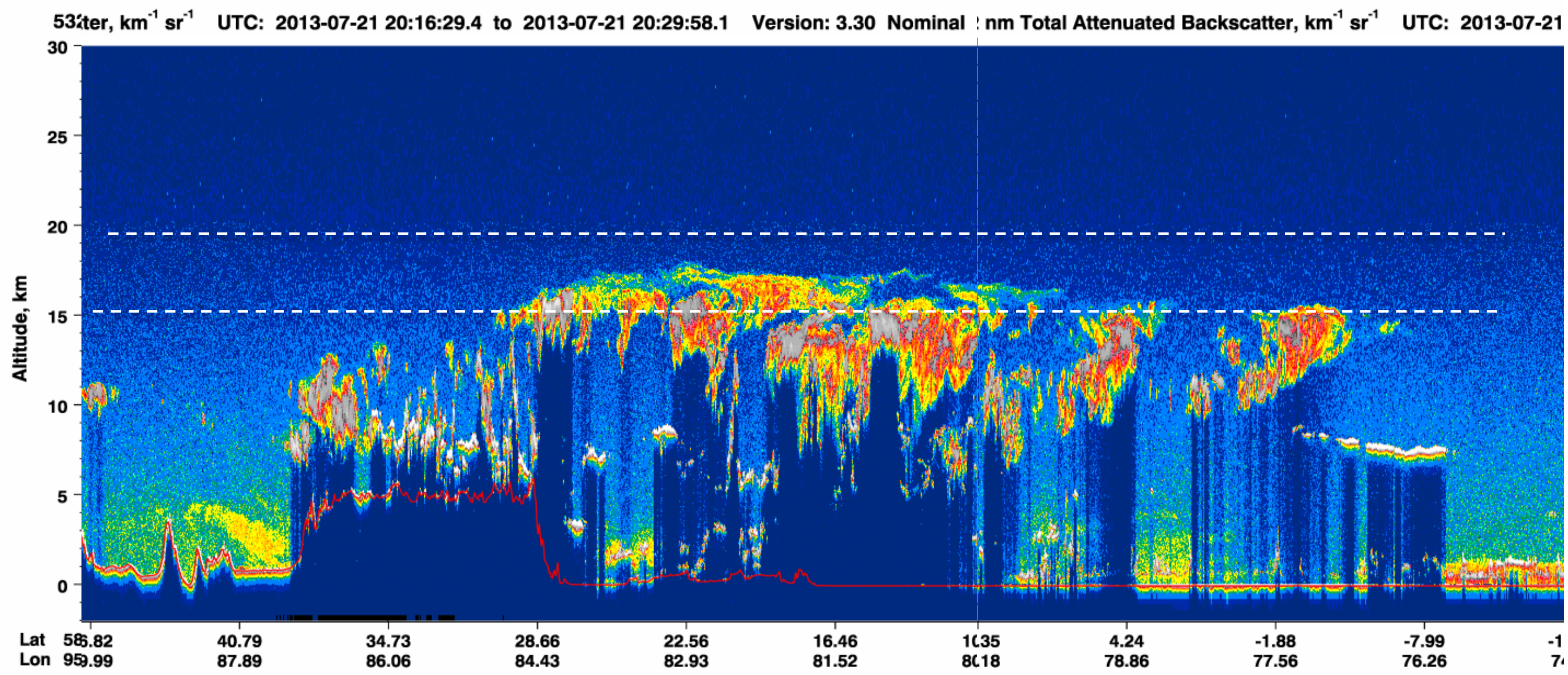
vertical velocity
from reanalysis

large-scale upwelling on
eastern side of anticyclone

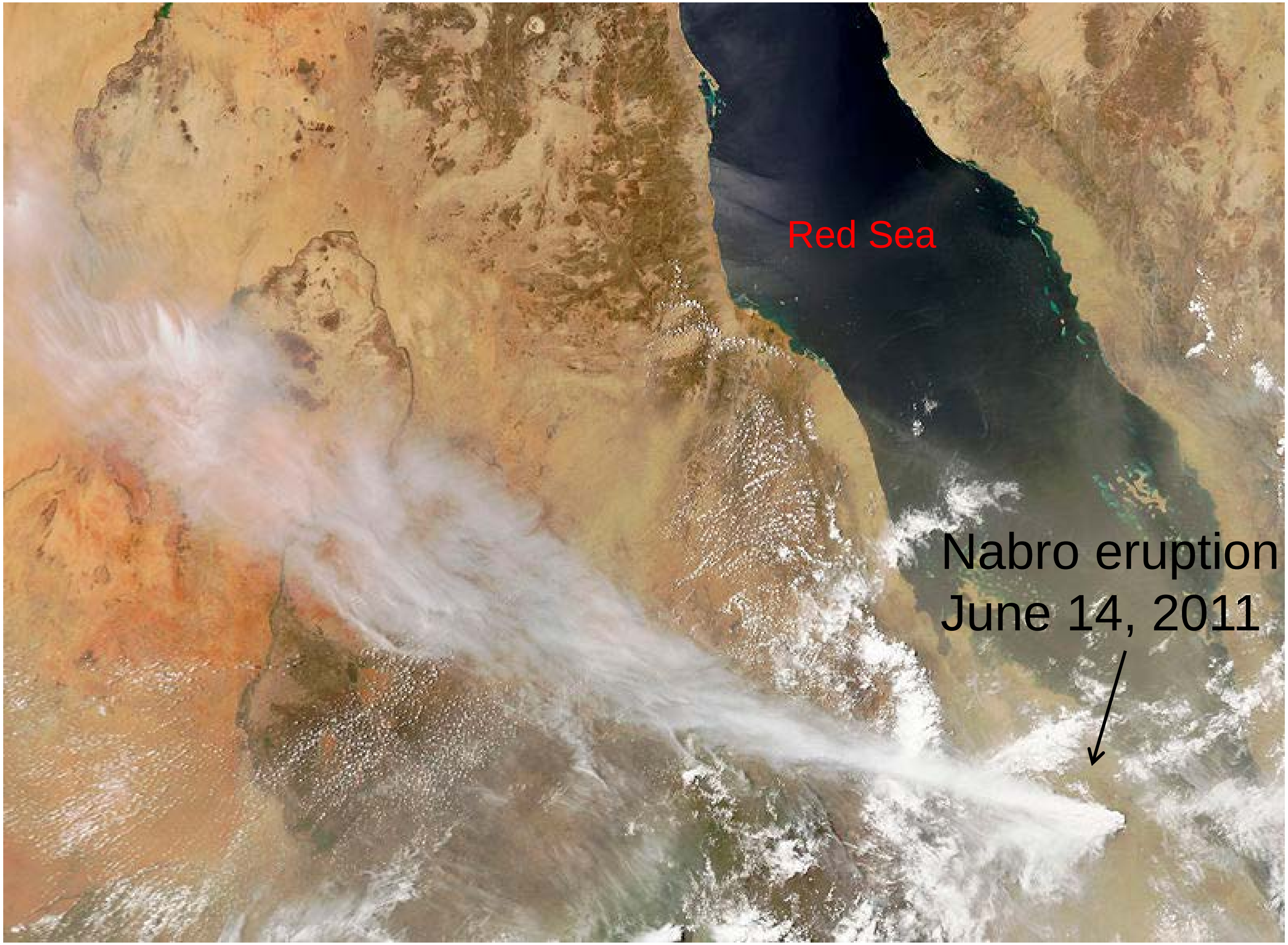


Deep convective transport near/above tropopause

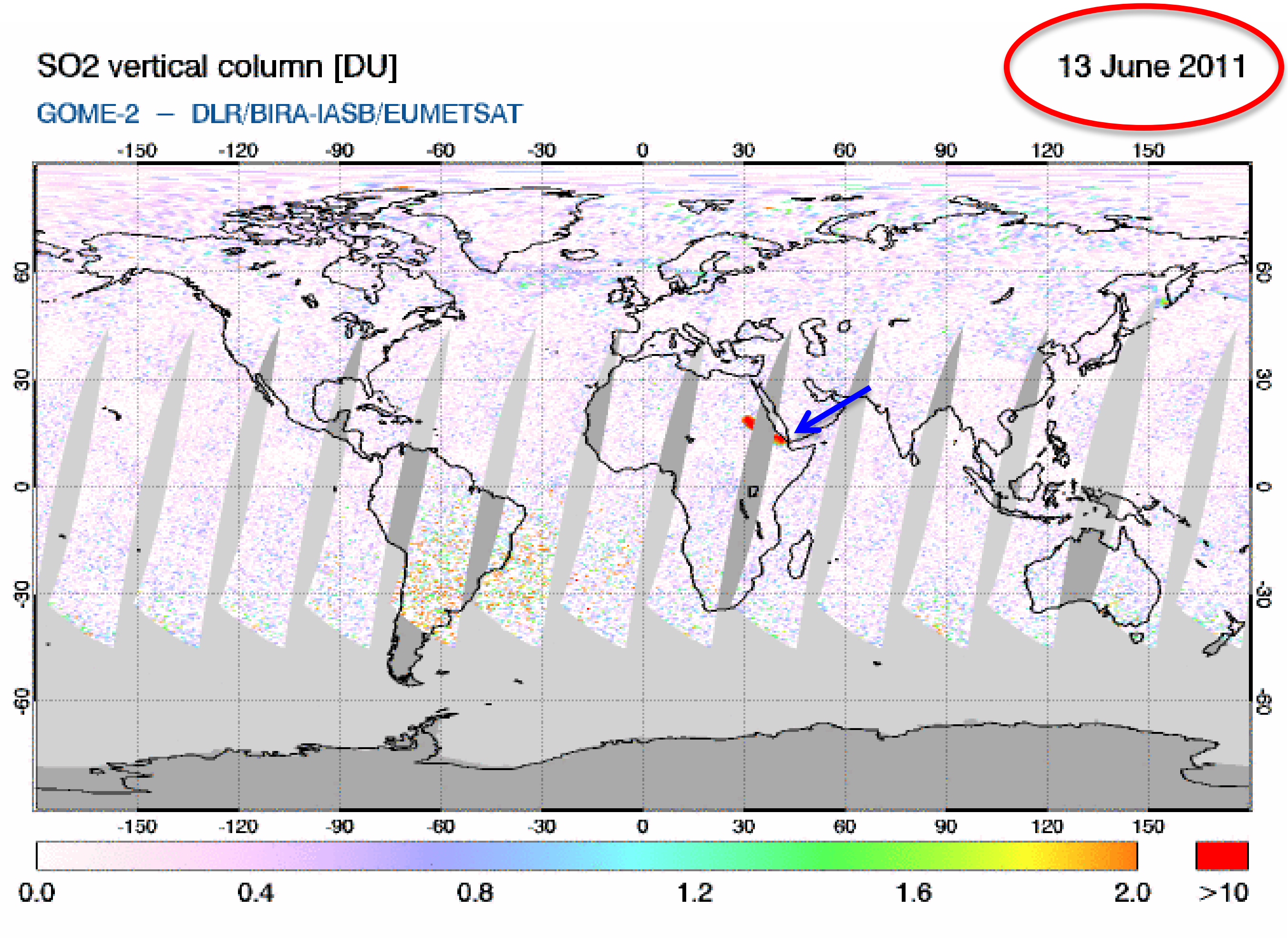




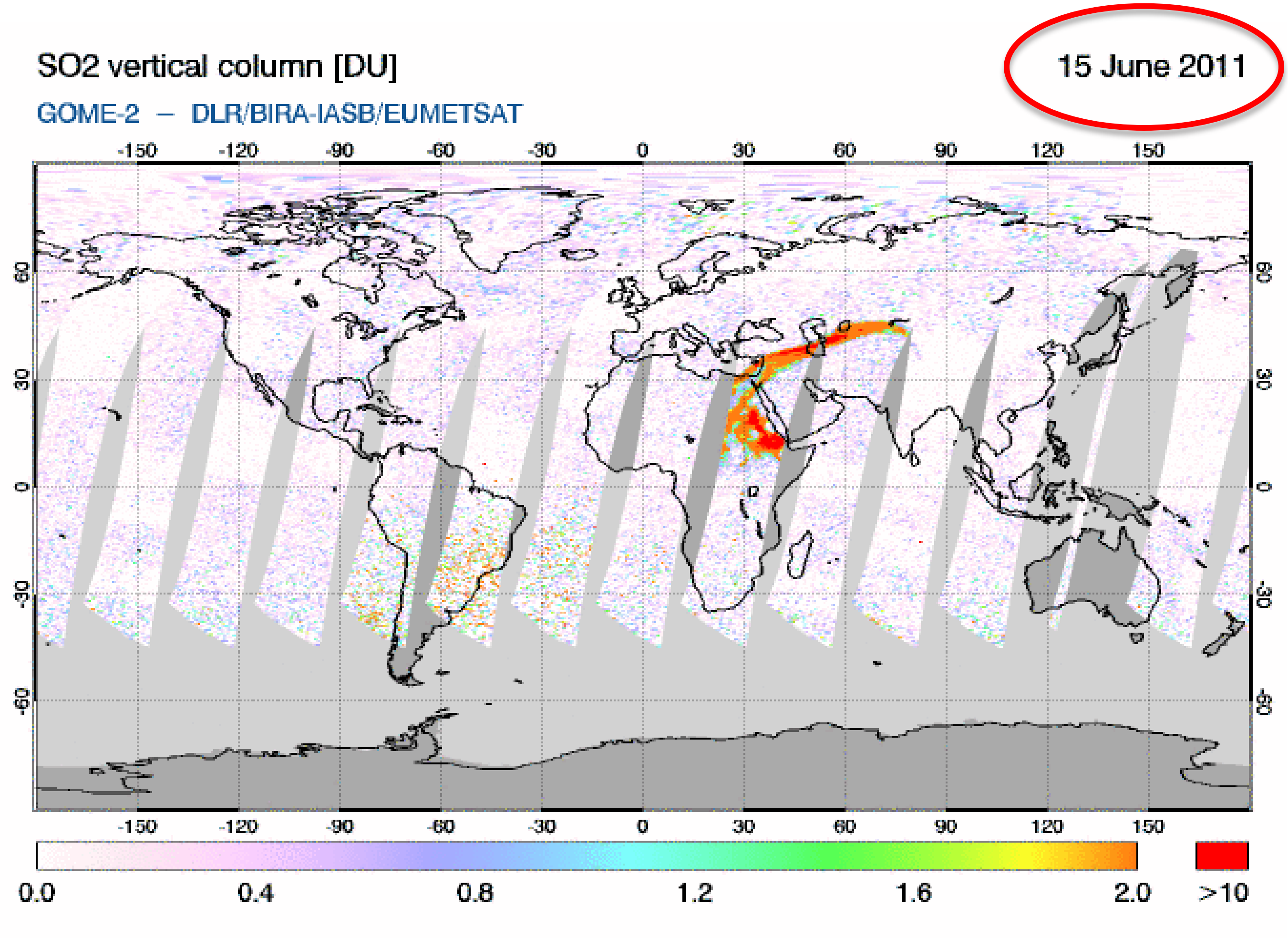
Eruption of Mt. Nabro June 13, 2011 Eritria, Africa


Red Sea
Nabro eruption
June 14, 2011

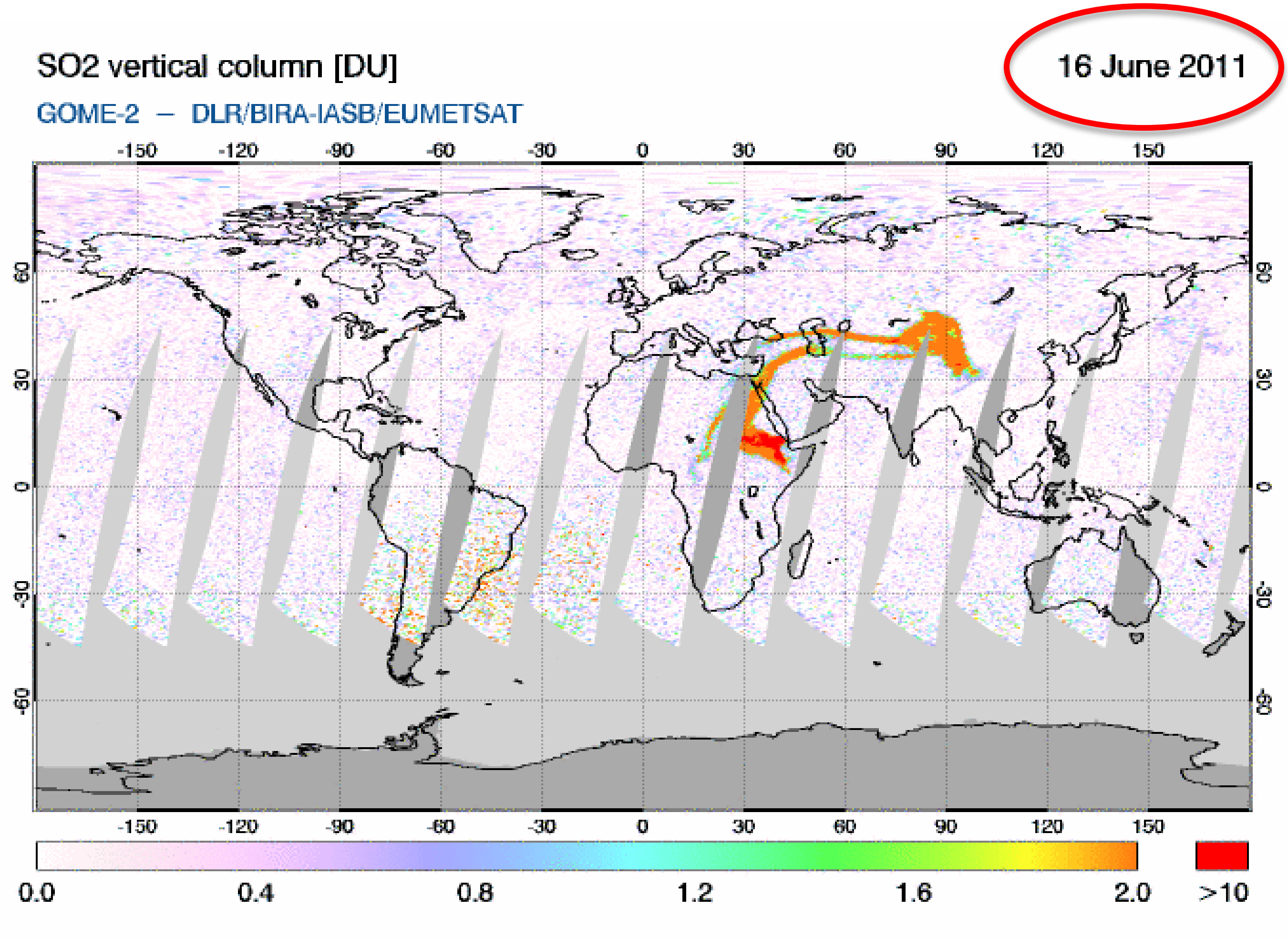
SO_2 plume from Nabro



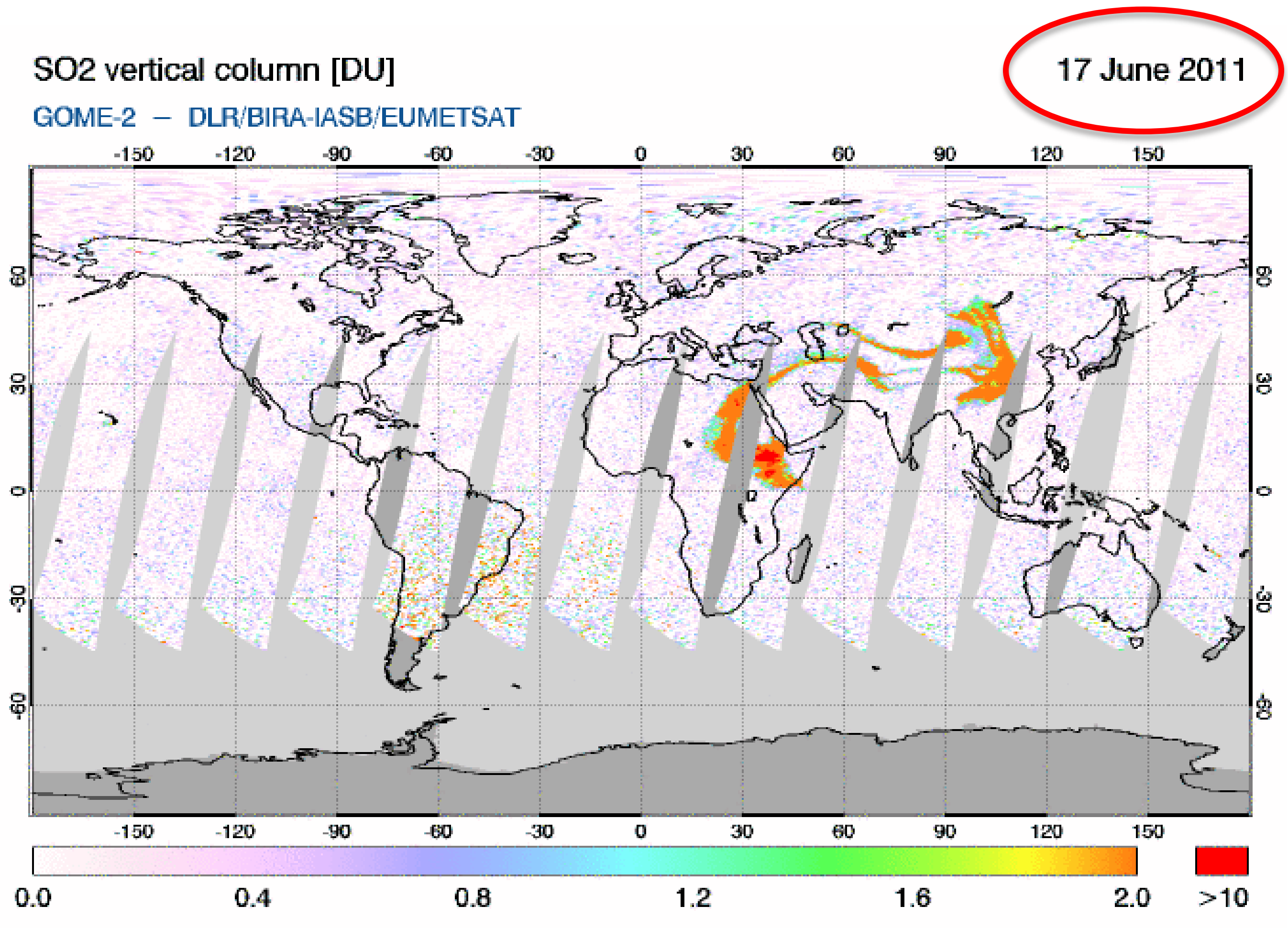
SO_2 plume from Nabro



SO_2 plume from Nabro

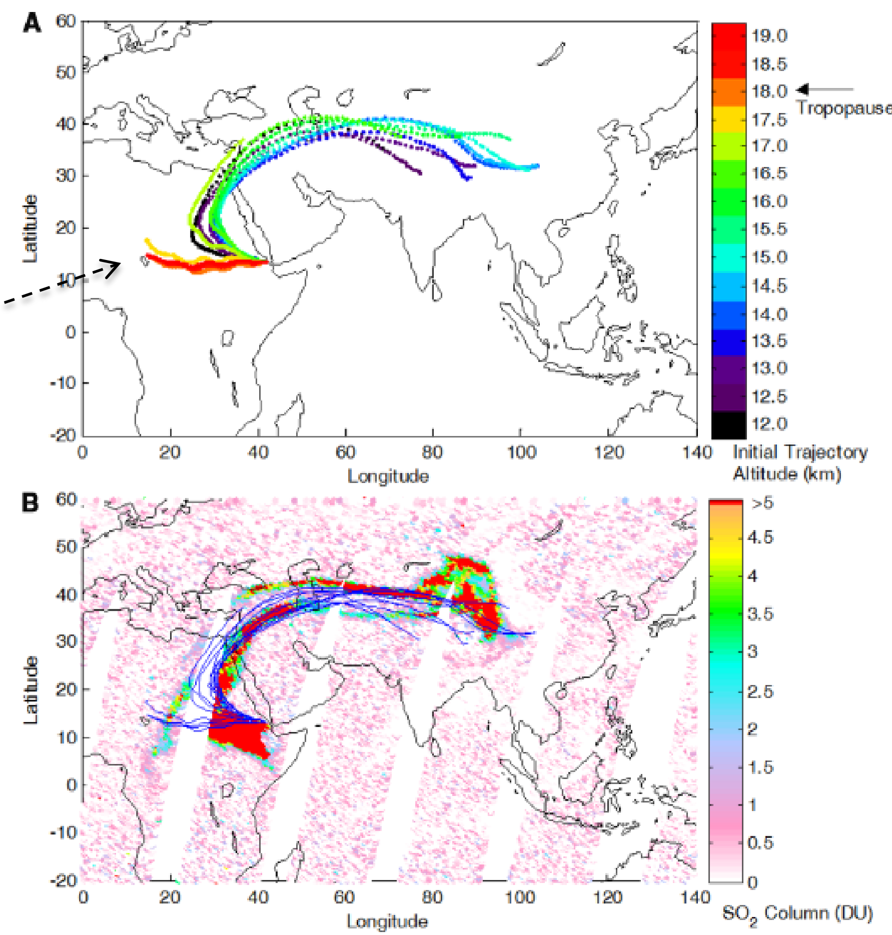


SO_2 plume from Nabro



How high did the eruption go?

westward movement for 17.5 km and above



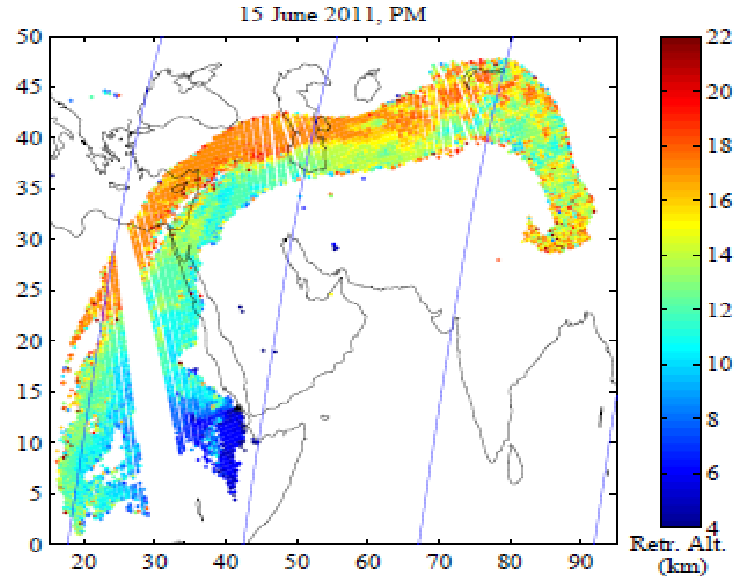
trajectories for June 13-16

trajectories overlaid with GOME SO_2

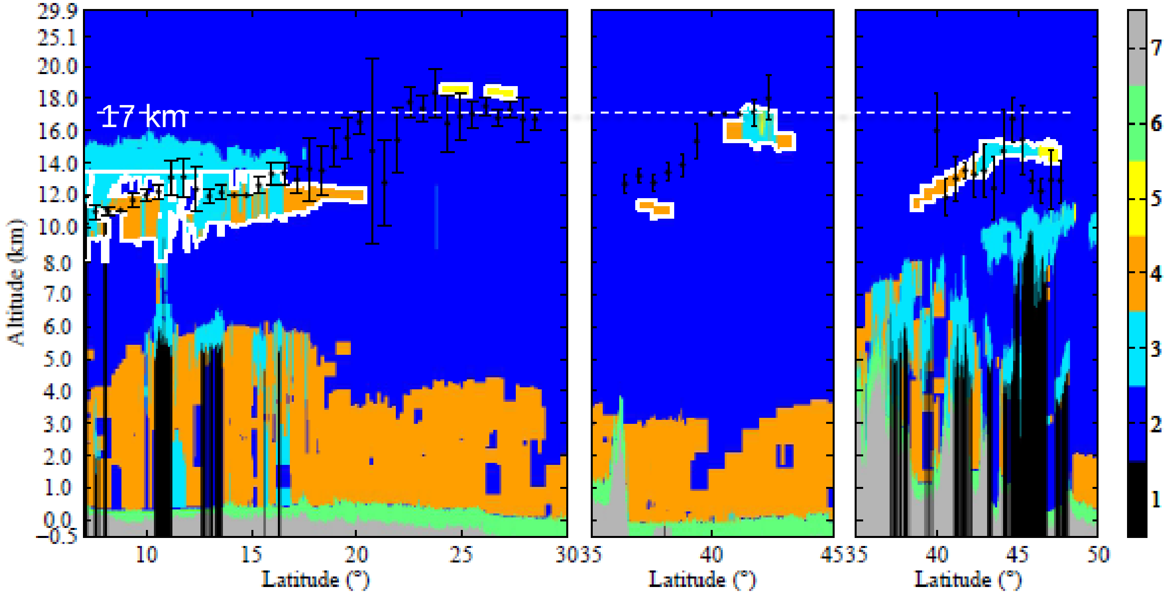
Bourassa et al, 2013

Nabro SO_2 plume height derived from IASI

Clarisse et al, submitted

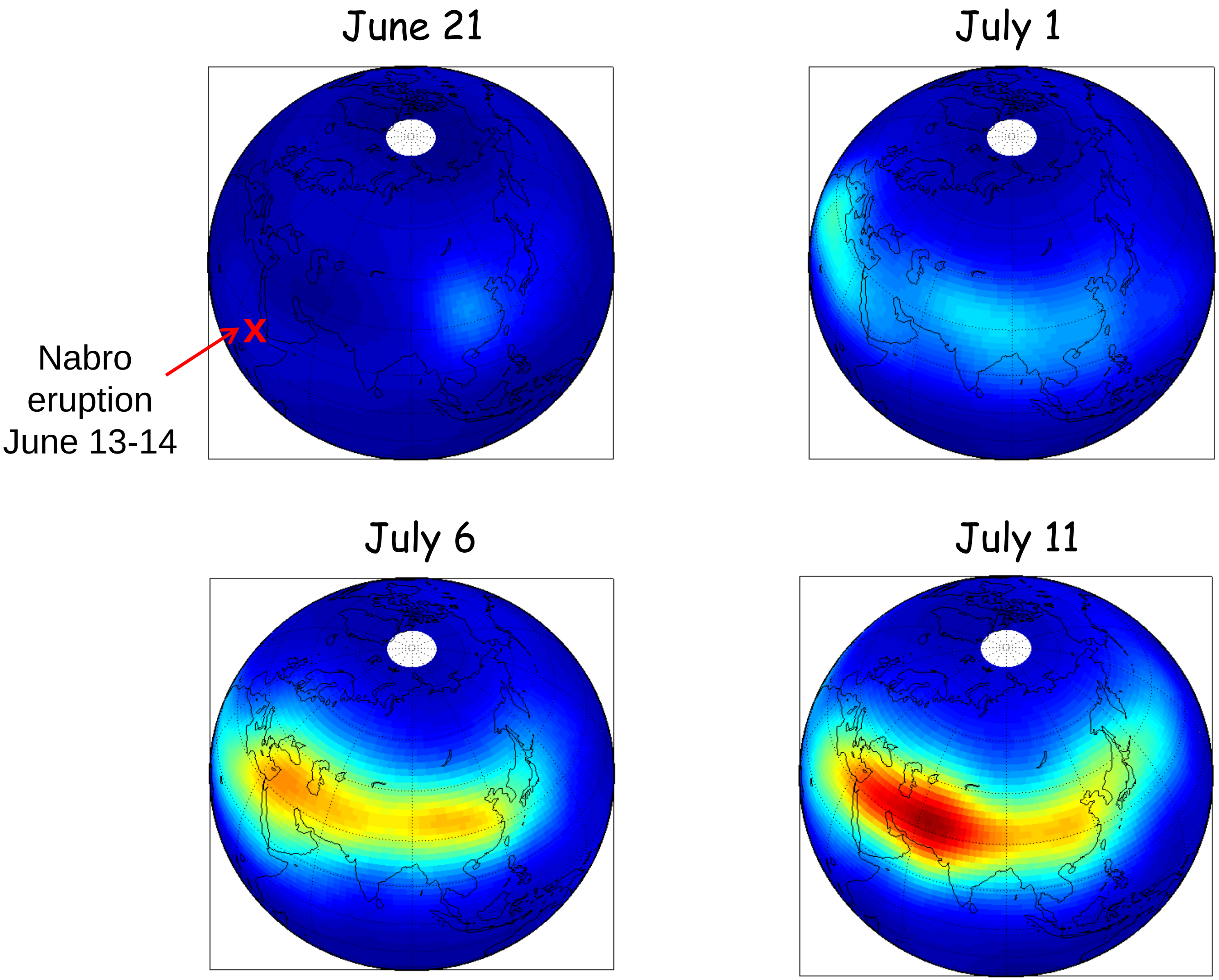


primary injection to ~12-17 km

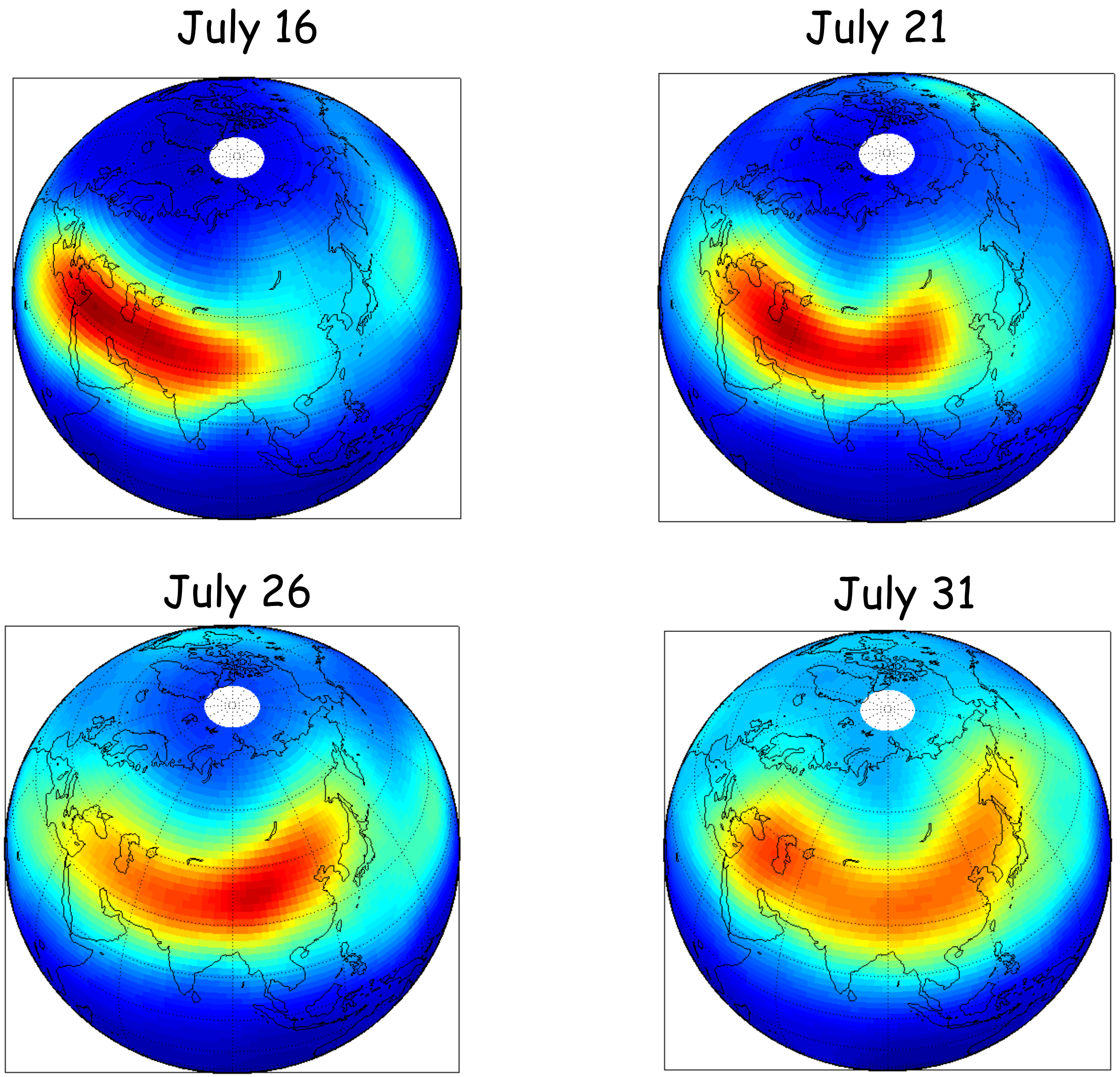


Stratospheric aerosols from OSIRIS satellite

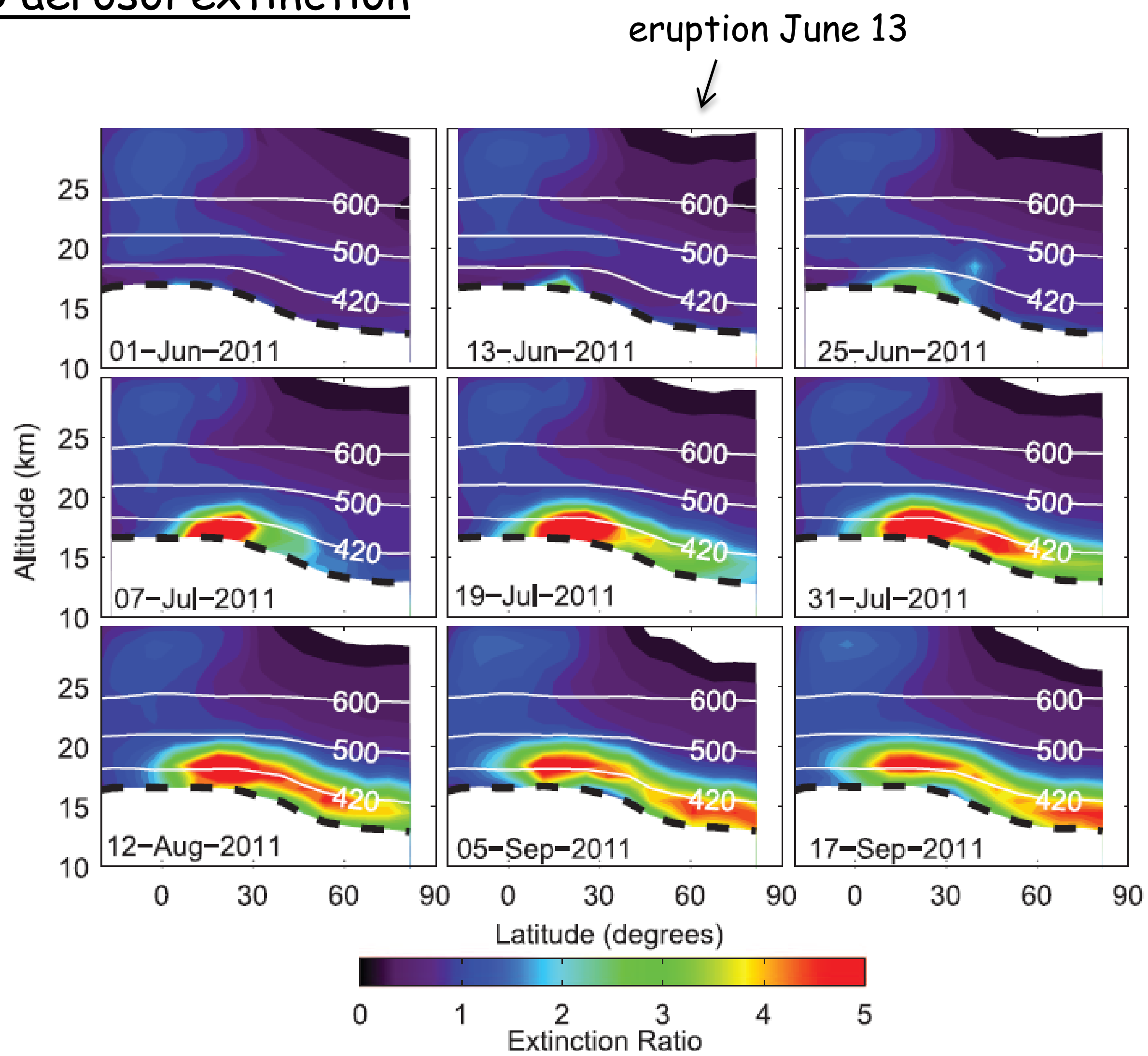
Bourassa et al, 2012



Bourassa et al, 2012



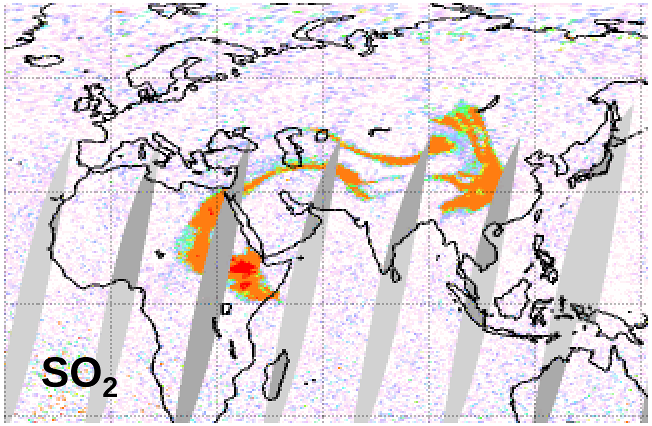
OSIRIS aerosol extinction



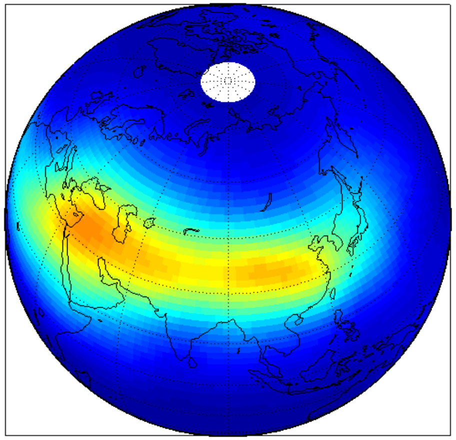
Interpretation:

- Nabro SO_2 plume in upper troposphere, transported around monsoon circulation to eastern side.
- Transport to stratosphere through circulation / convection (?)
- Confined to anticyclone, converted to stratospheric sulfate aerosol ~ 1 month
- Further evidence of transport to lower stratosphere via monsoon (Nabro in right place at right time)

June 17

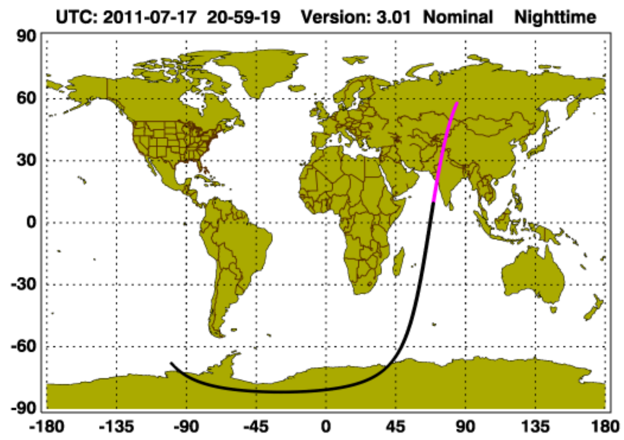


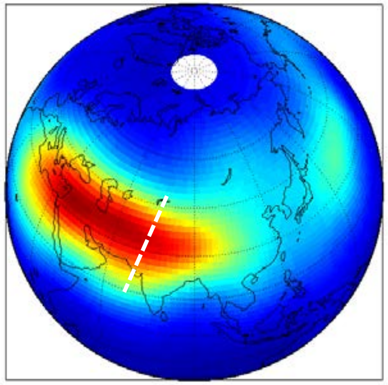
July 6

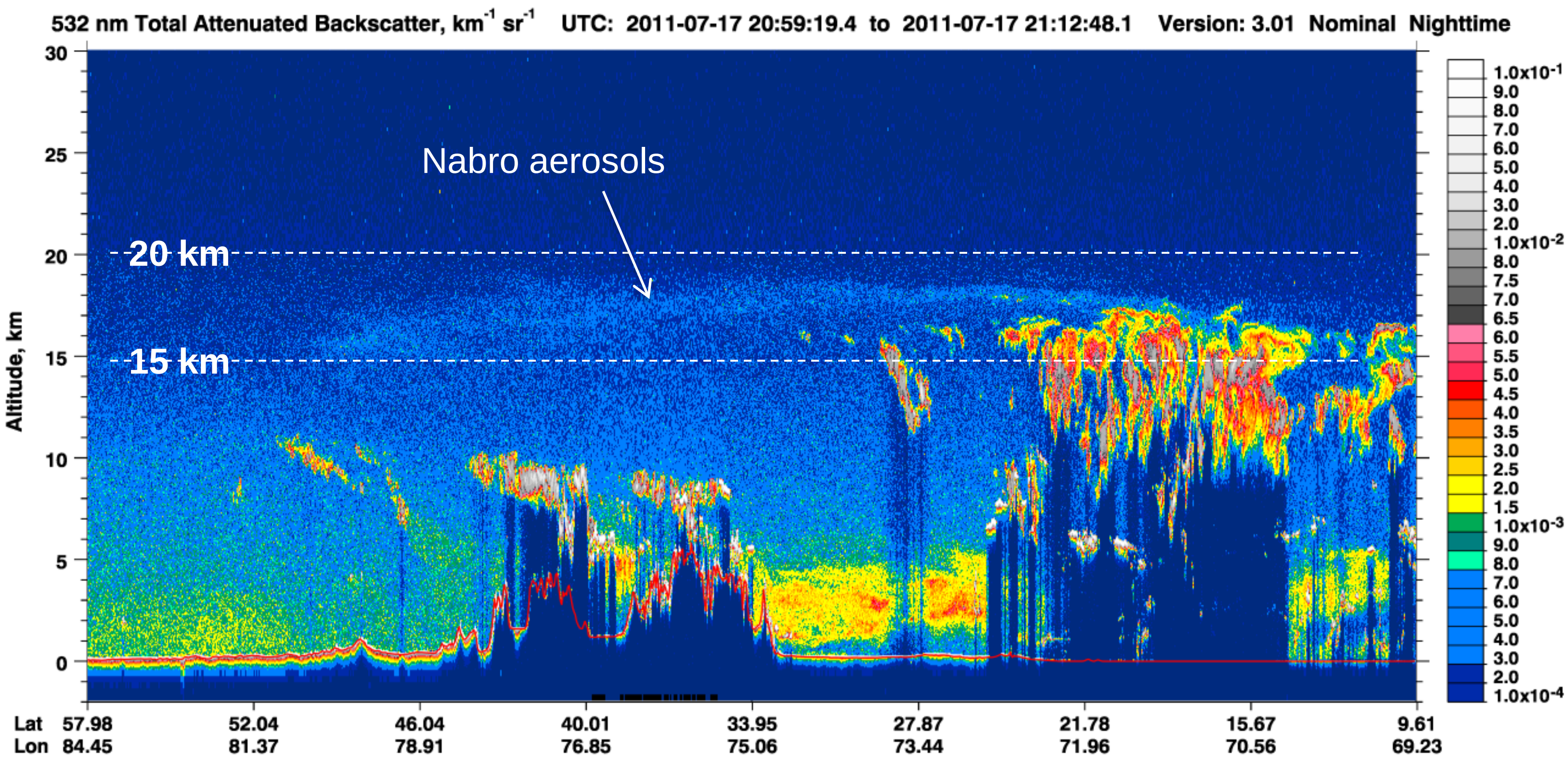


stratospheric aerosol

July 17
34 days
after eruption







Ongoing questions:

- What are the contributions of different chemical source regions to the upper troposphere? Is reactive chemistry important? How much reactive nitrogen is in the anticyclone?
- When and where does air escape the anticyclone? Are there sharp gradients across edges?
- What is the role of deep convection vs. large-scale upward circulation to the stratosphere? How important are diurnal variations in convection?
- What is the nature of the tropopause aerosol layer? Does it influence UTLS clouds?

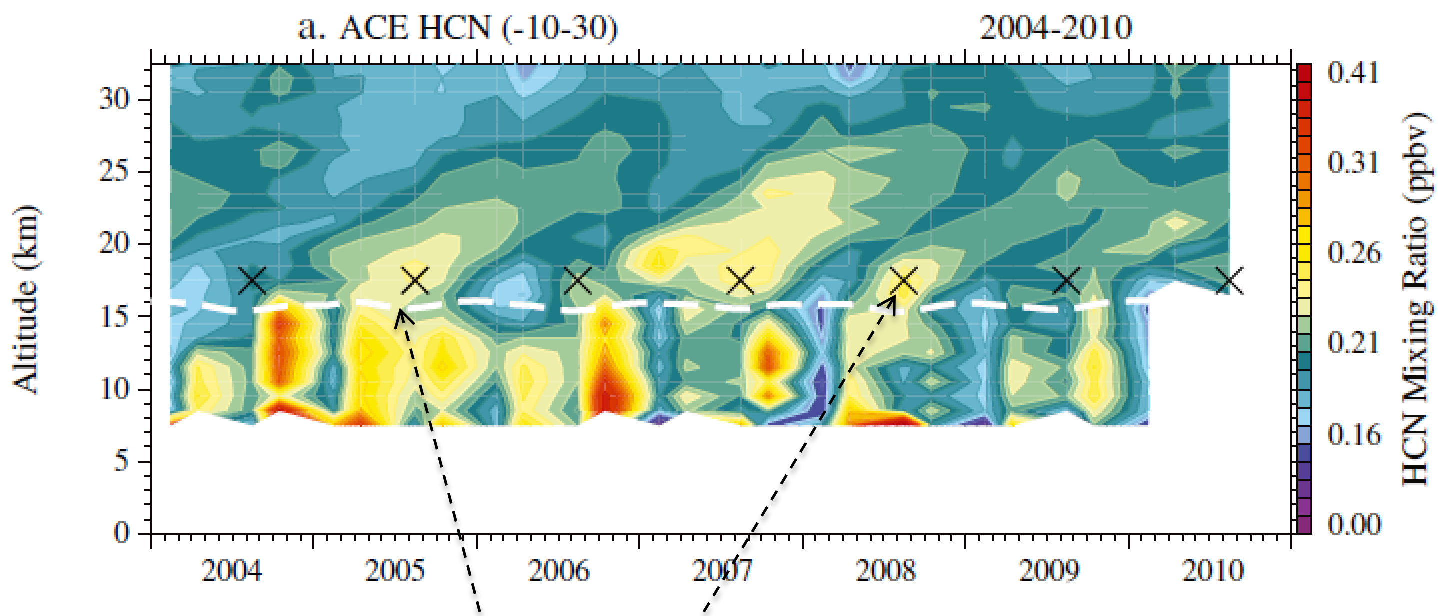

Thank you

Extra slides

HCN 'tape recorder' from ACE-FTS measurements

PARK ET AL.: HYDROCARBONS FROM ACE-FTS AND WACCM4

JGR, 2013



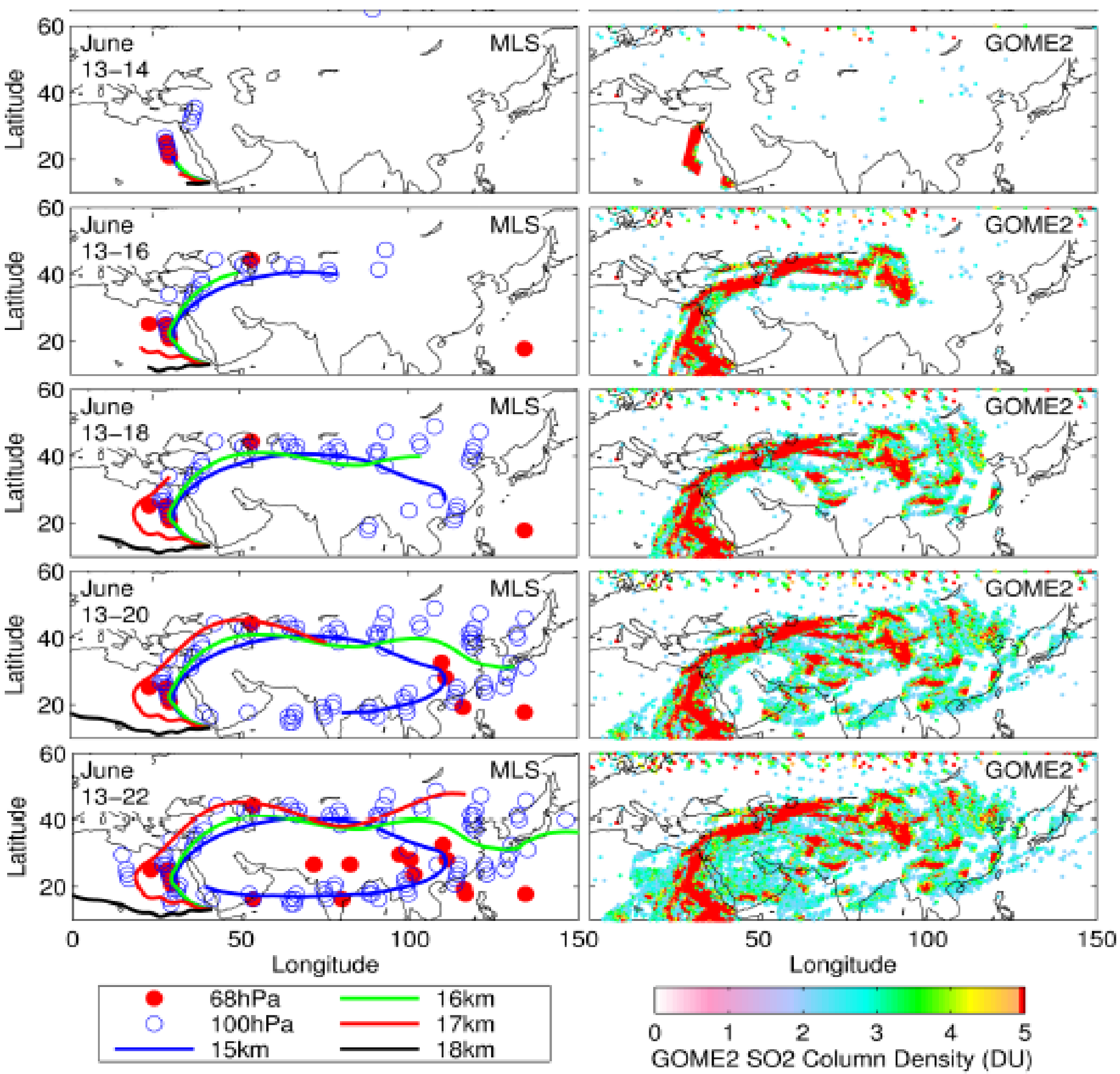
boreal summer maxima from
Asian monsoon circulation

MLS observations of SO_2

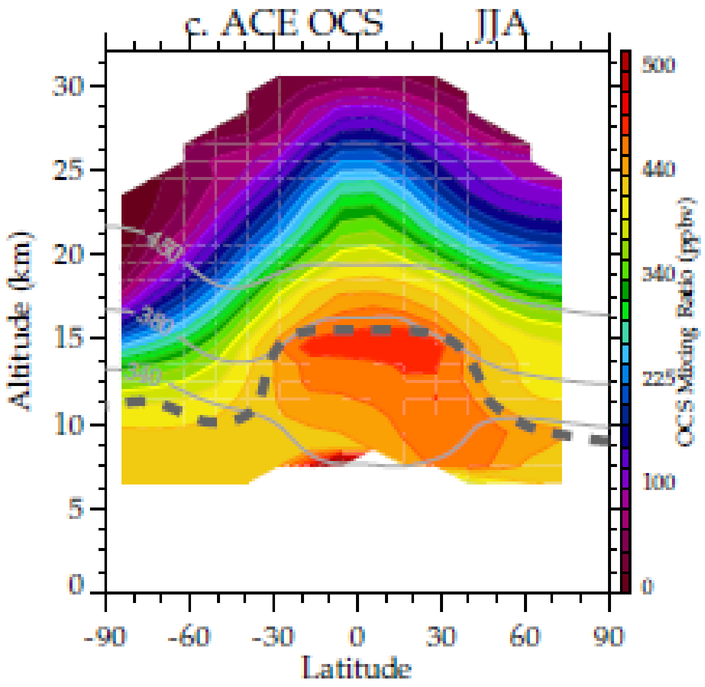
Bourassa et al, Science, 2013

blue dots: enhanced at 100 hPa

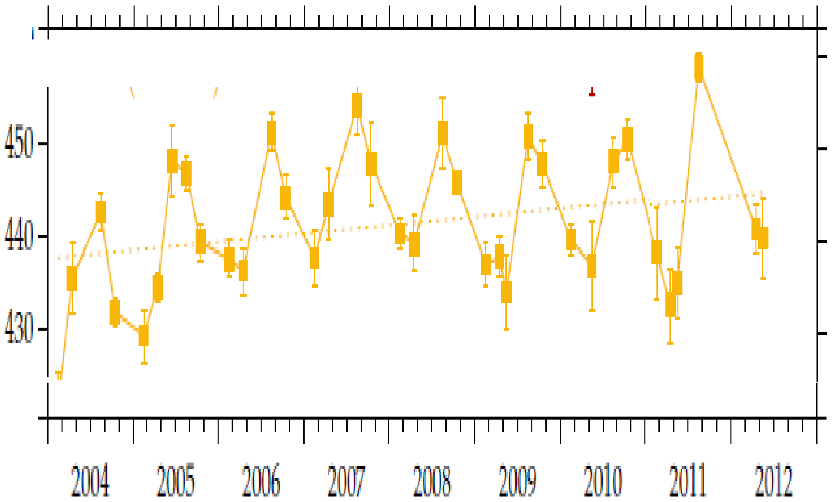
red dots: enhanced at 68 hPa



OCS climatology from ACE-FTS

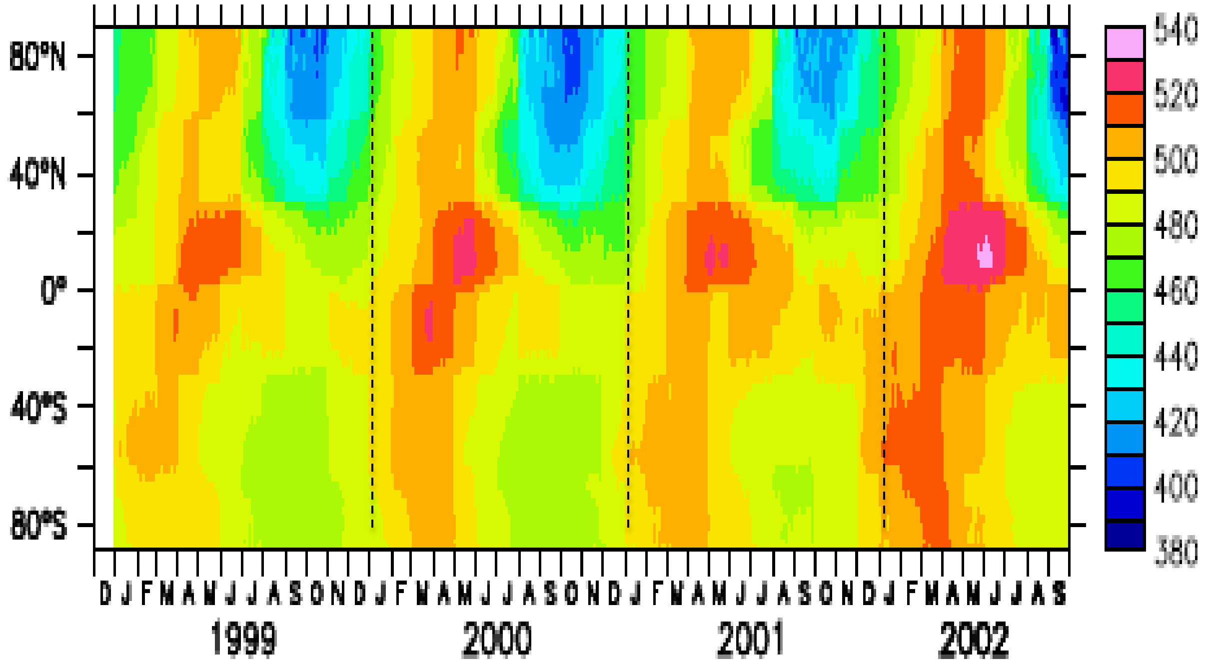


OCS at 16.5 km 30° N-S



increase of
~2% / decade
over 2004-2012

Boundary layer OCS Bruhl et al, 2012,

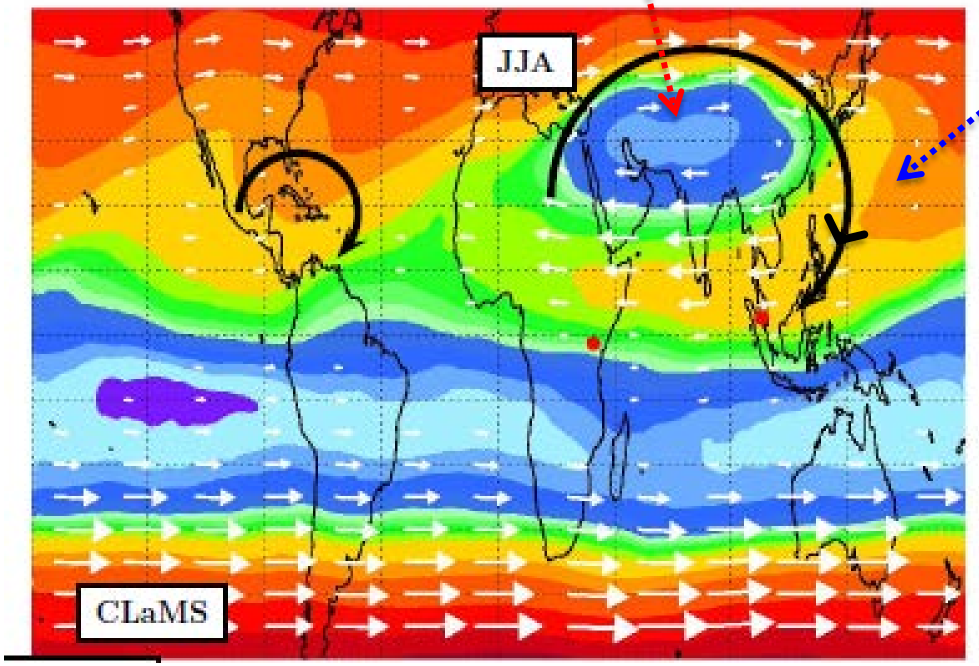


COS, pptv, boundary layer

Ozone at 380 K
(~17 km)

minimum within
anticyclone

transport into
the tropics
on eastern side
of anticyclone
influences
TTL ozone

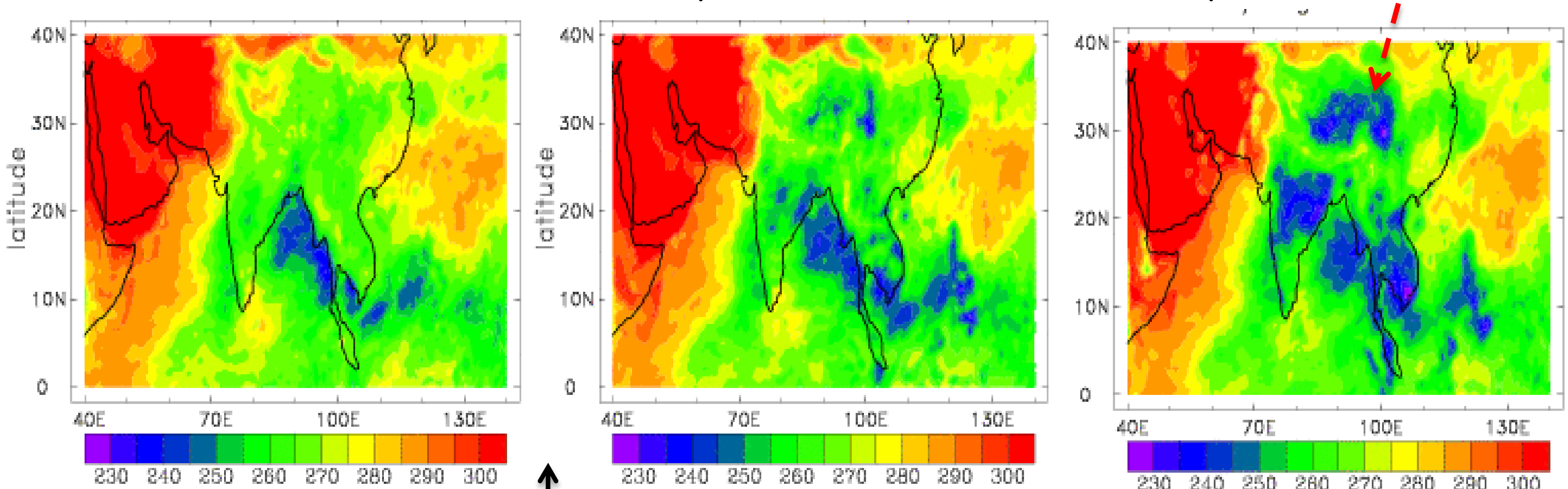


Konopka et al, 2009, 2010; Ploeger et al, 2012

convective cloud statistics from
3-hour geostationary (CLAUS) data

Tibet plateau convection
in late afternoon

12 noon   3 pm   6 pm

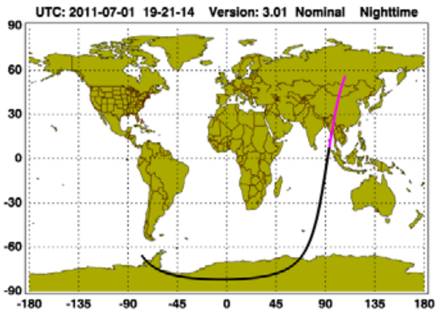


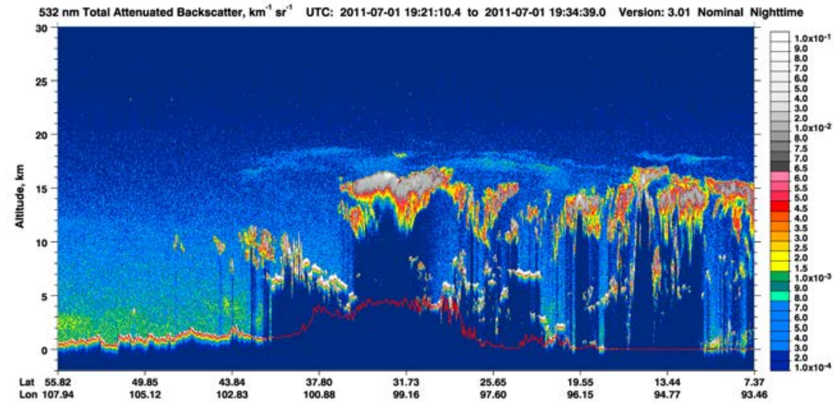
CALIPSO, Cloudsat
observations at 1:30

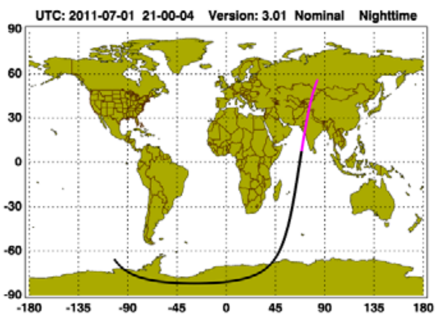
Blue = deep, high convective clouds

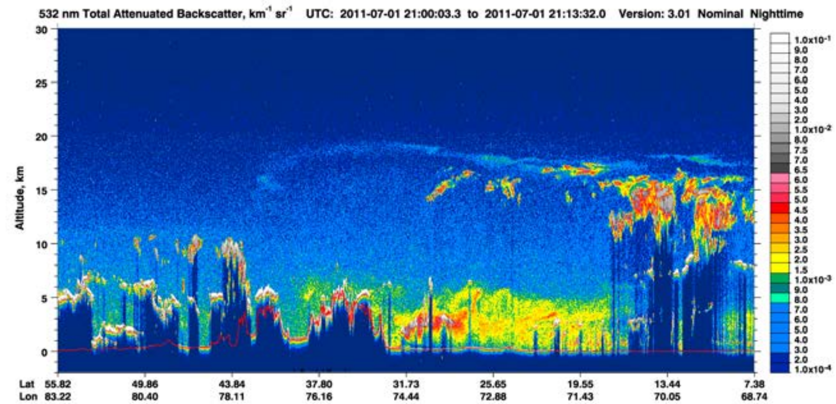
(Motivated from Jonathan Wright, Rong Fu)

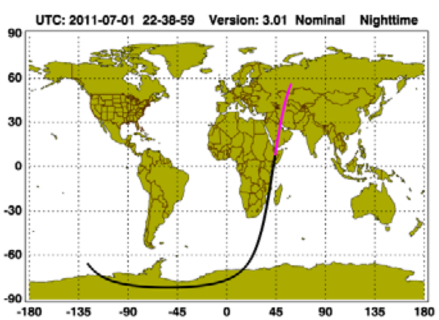
July 1: 18 days after eruption

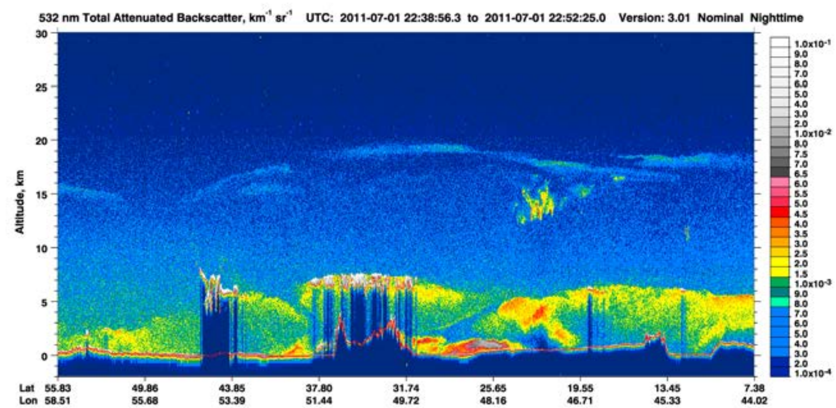




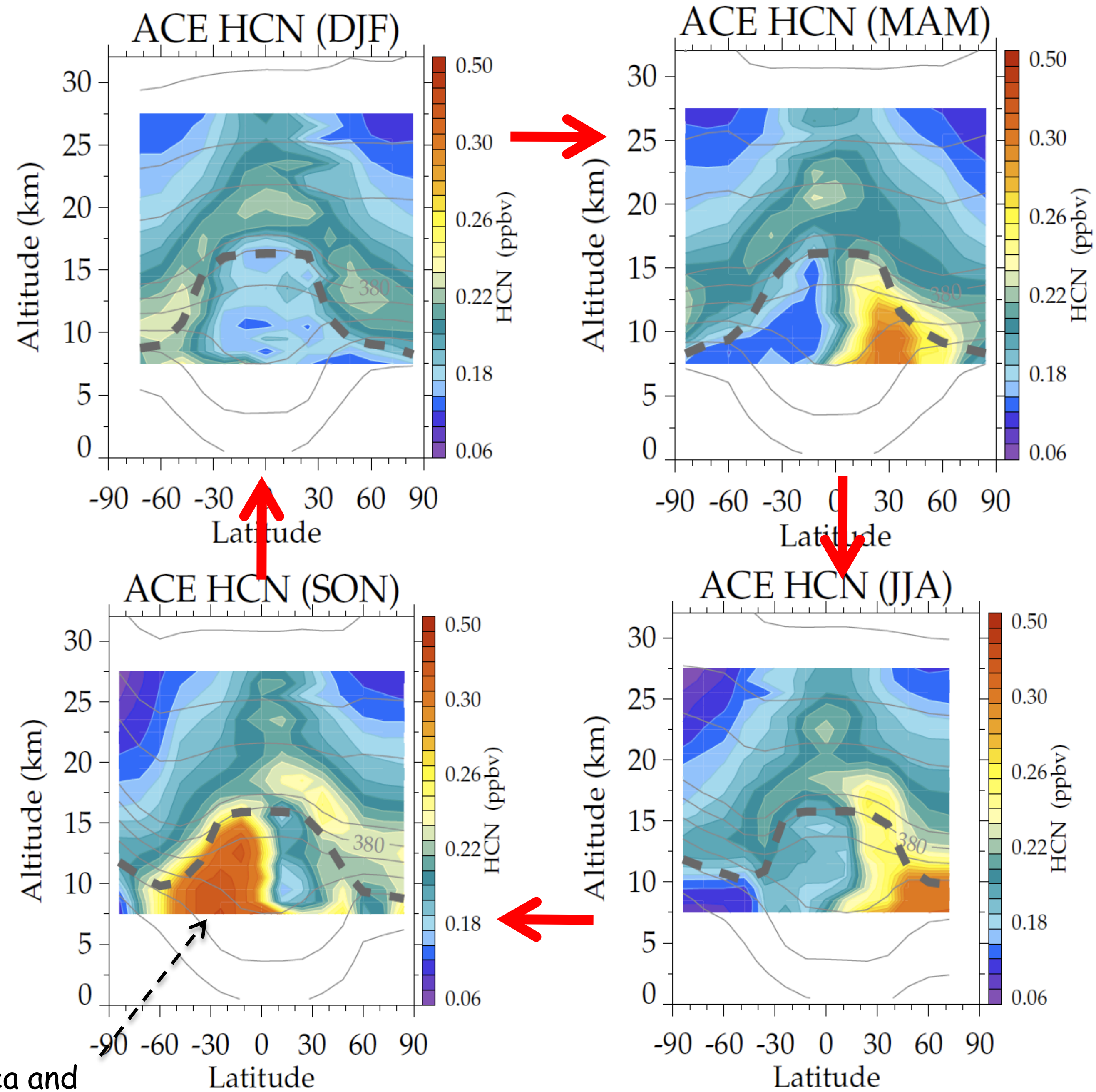






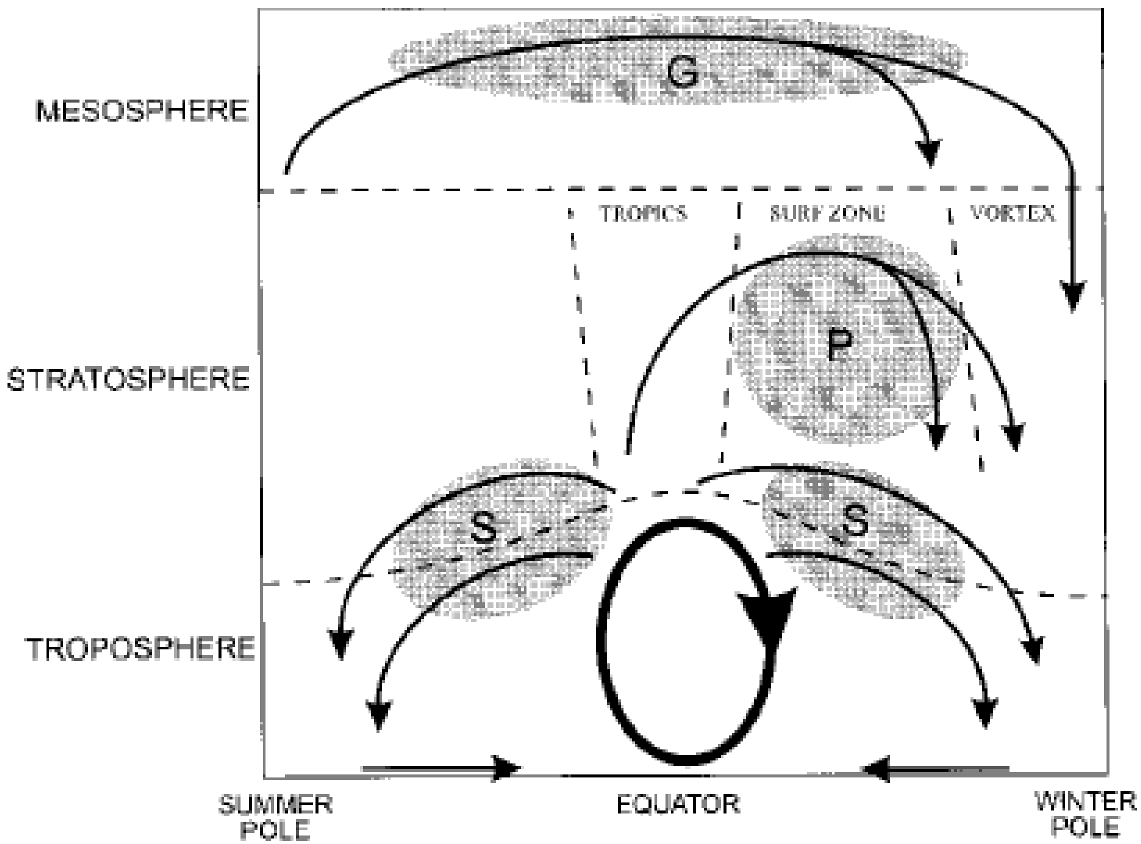


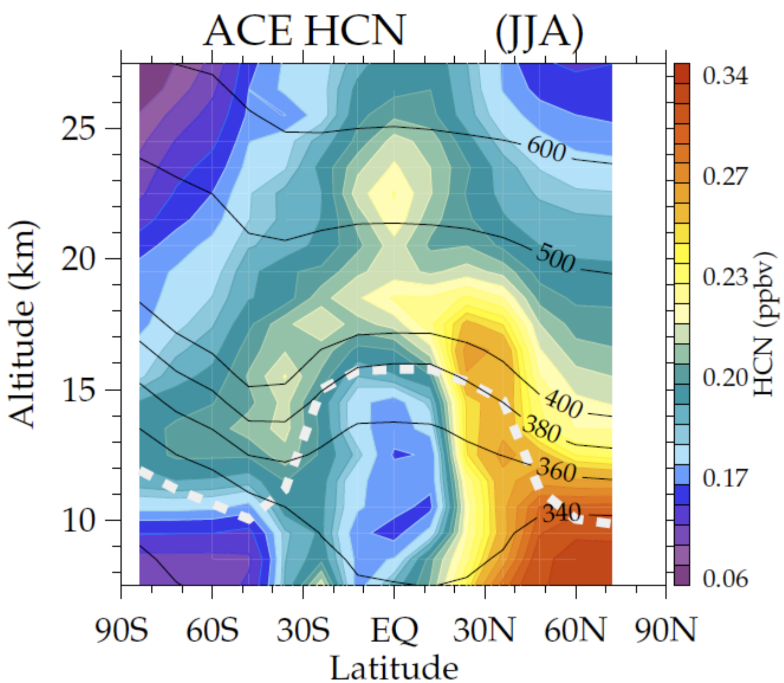
Seasonal cycle of HCN from ACE-FTS

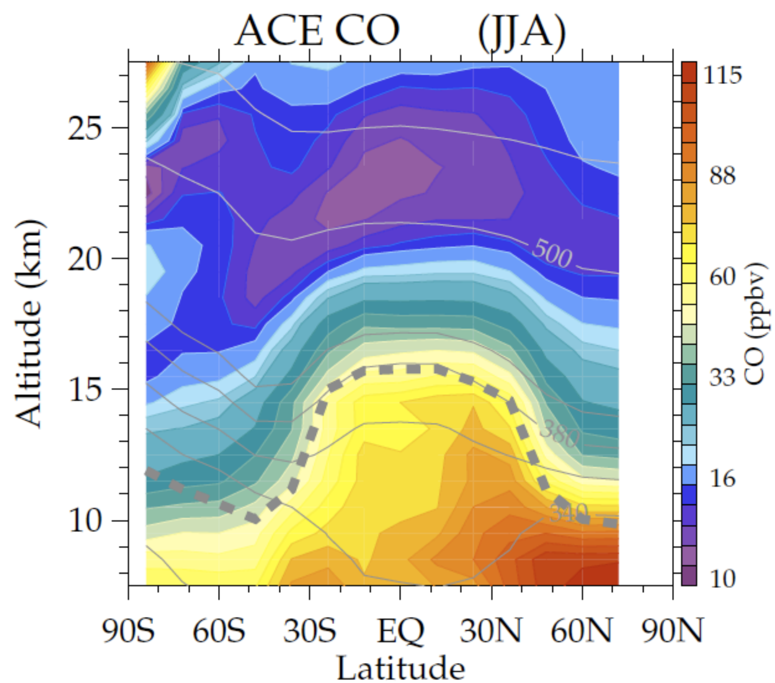


Africa and S. America

Plumb (2002) 'Stratospheric Transport'




ACE HCN (JJA)
Altitude (km)
25
20
15
10
90S 60S 30S EQ 30N 60N 90N
Latitude
600
500
400
380
360
340
0.34
0.27
0.23
0.20
0.17
0.06
HCN (ppbv)

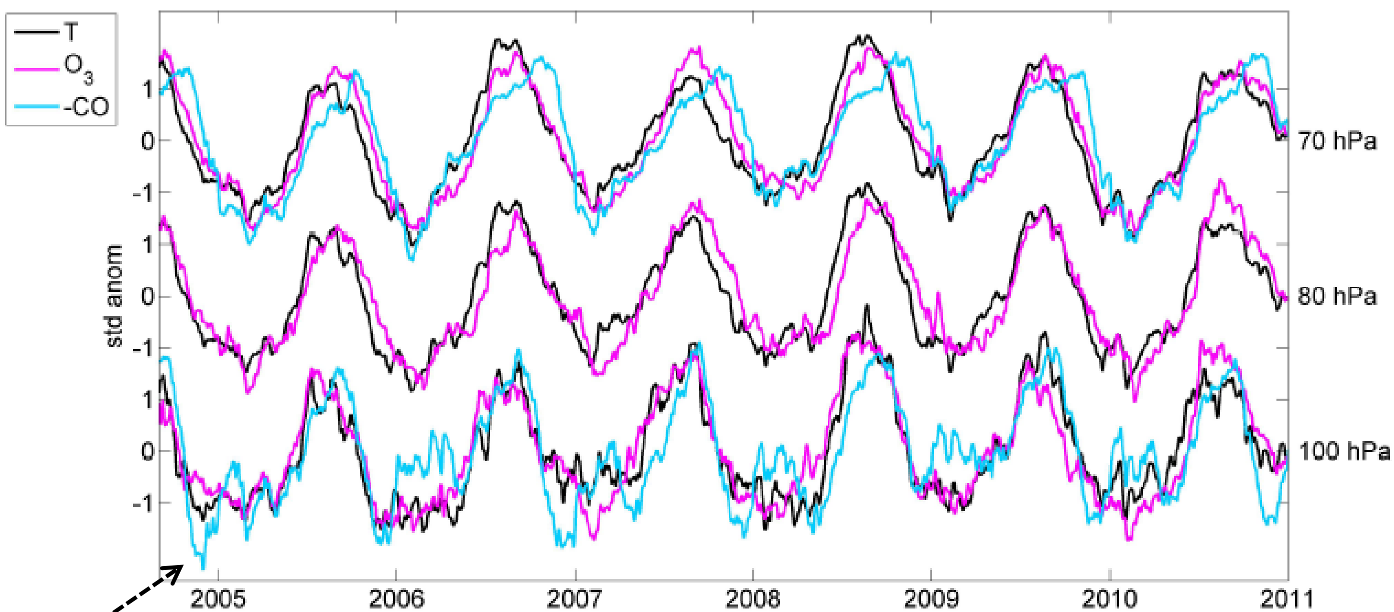

ACE CO (JJA)
Altitude (km)
25
20
15
10
90S 60S 30S EQ 30N 60N 90N
Latitude
500
380
340
115
88
60
33
16
10
CO (ppbv)

Variability in tropical upwelling drives temperatures and ozone and other tracers in tropical lower stratosphere

* large annual cycle

* sub-seasonal (week-to-week) variability

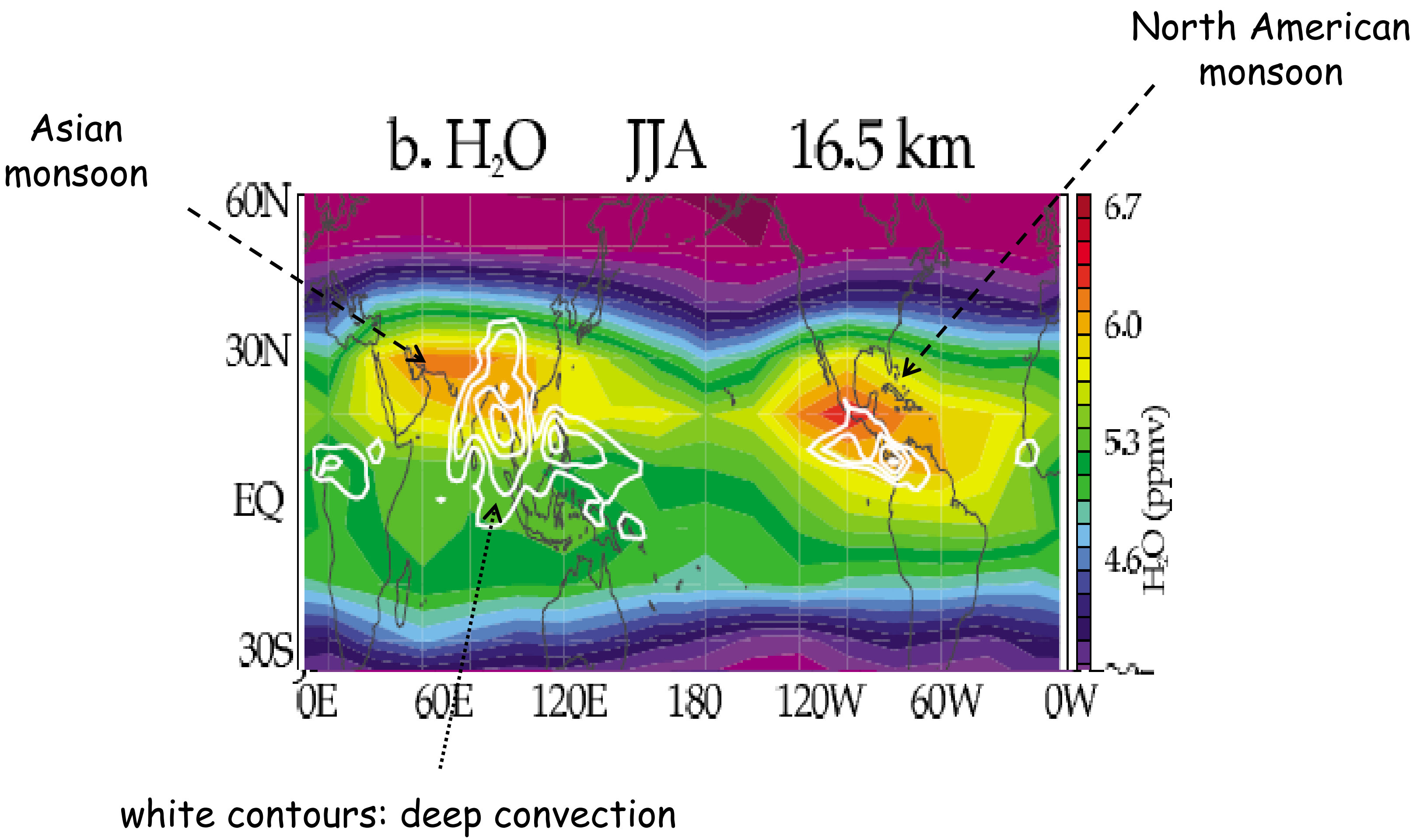
Zonal mean temperature, ozone and CO averaged 18° N-S



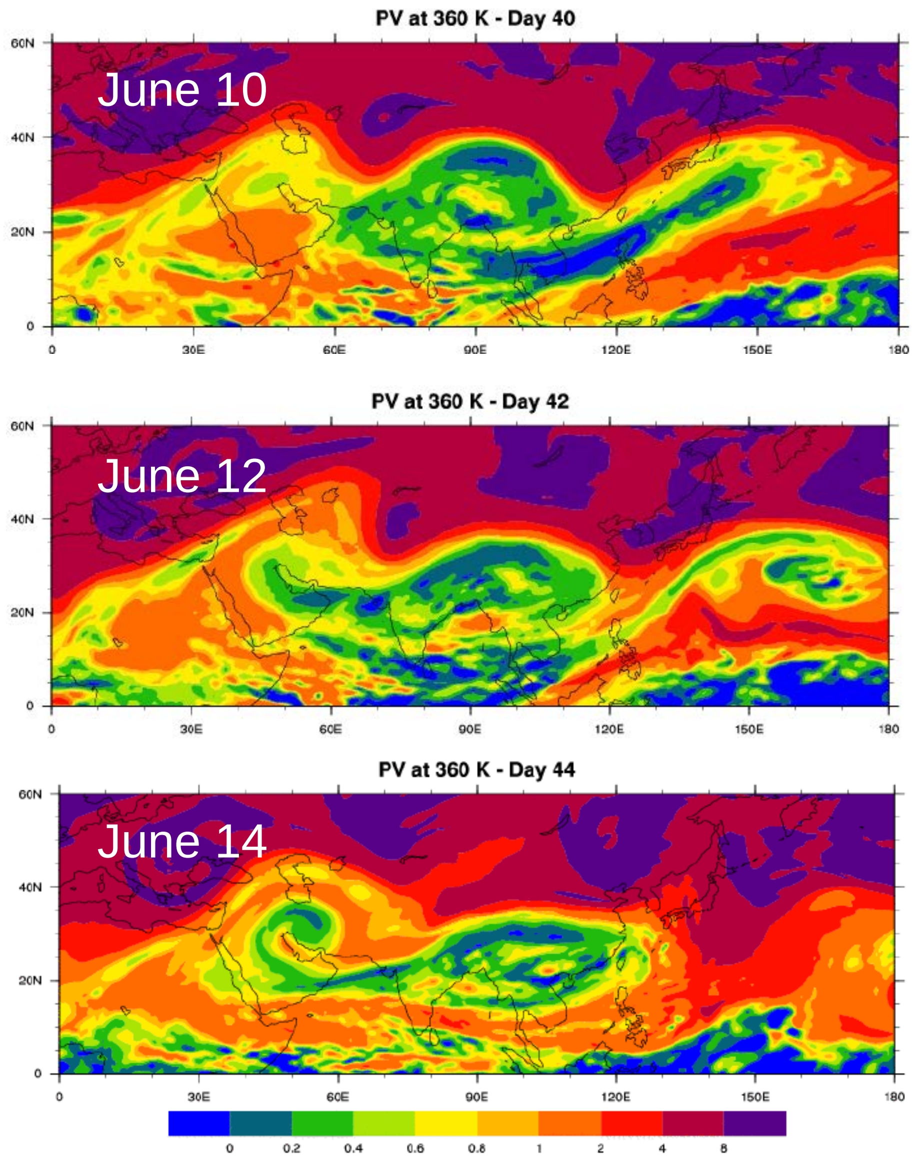
CO inverted scale

Abalos et al 2012 ACP

Also enhanced water vapor in monsoon regions



PV maps at 360 K



CO from Aura MLS