Model Analyses of Tracer Transport
Associated with the Dynamics of the Asian Monsoon

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NCAR

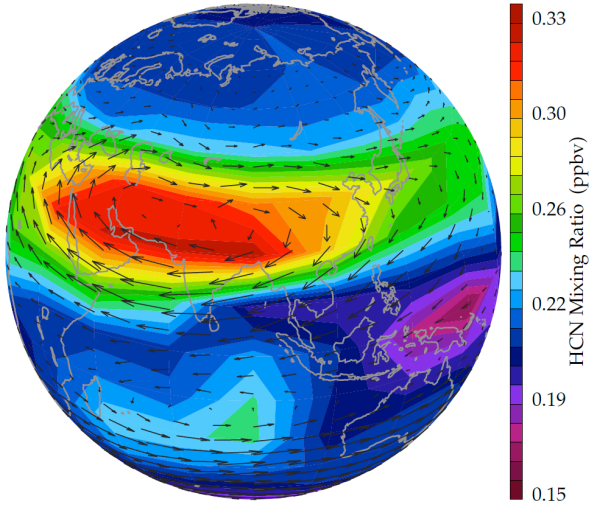
NSF

A few outstanding questions of ASM transport:

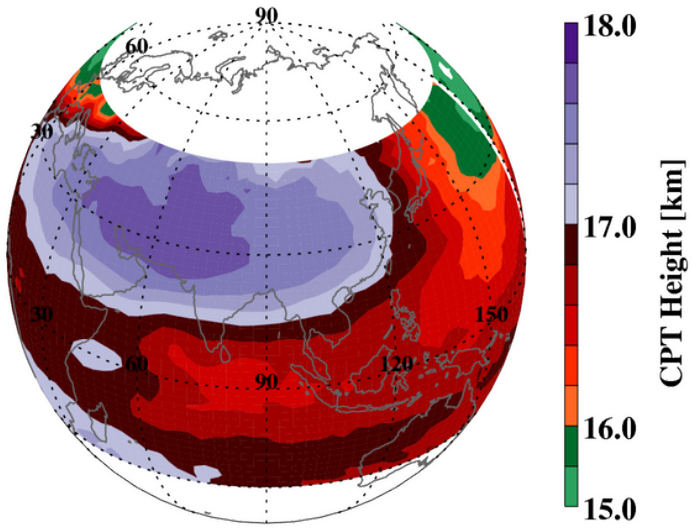
- **Preferred locations and the processes control the uplifting from the BL to the UTLS:**
  - Is there a conduit? If yes, how is it created?
- **The role of sub-seasonal scale dynamics in UT composition:**
  - How is the day-to-day variability of the UTLS composition related to the dynamical variability of the ASM anticyclone? (***confinement and shedding***)
- **The efficiency of ASM as a transport pathway into the stratosphere:**
  - What is the most effective mode of transport across the ASM tropopause? Vertical and diabatically or quasi-isentropically? (***chimney vs blower***)
  - What's the relationship between the ASM anticyclone and the B-D circulation?

Strong Tropospheric Tracer Signatures over the ASM AC

A "chimney" or a tropospheric "bubble" in the stratosphere background?



HCN from ACE Satellite (JJA, 16.5 km)
[Randel et al., 2010]

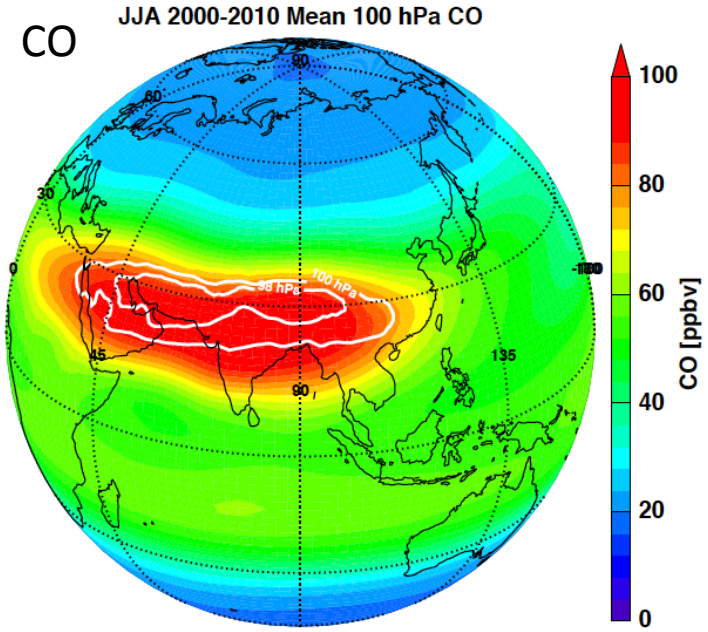


CPT Hgt from COSMIC GPS data JJA
[Munchak and Pan, 2014]

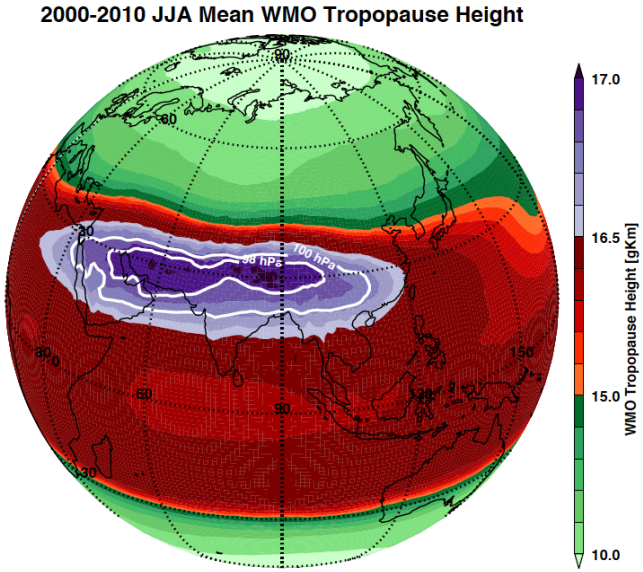
Highest Coldpoint Tropopause in JJA

11 year output from WACCM-SD 2000-2010

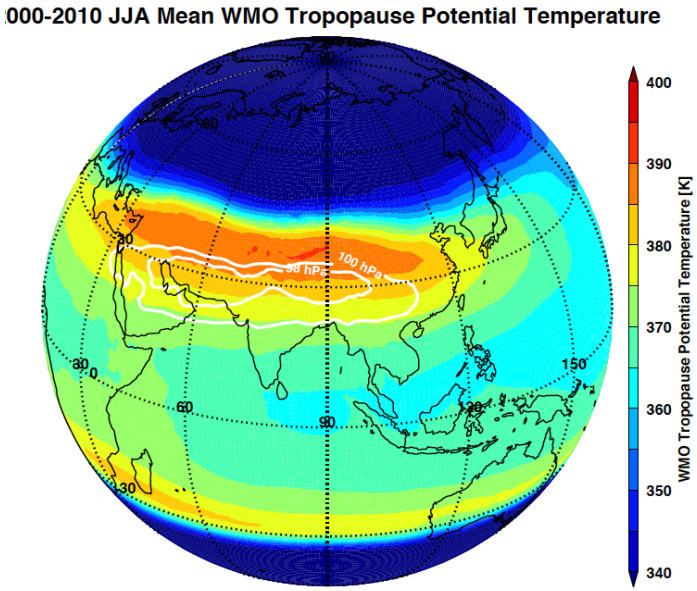
CO



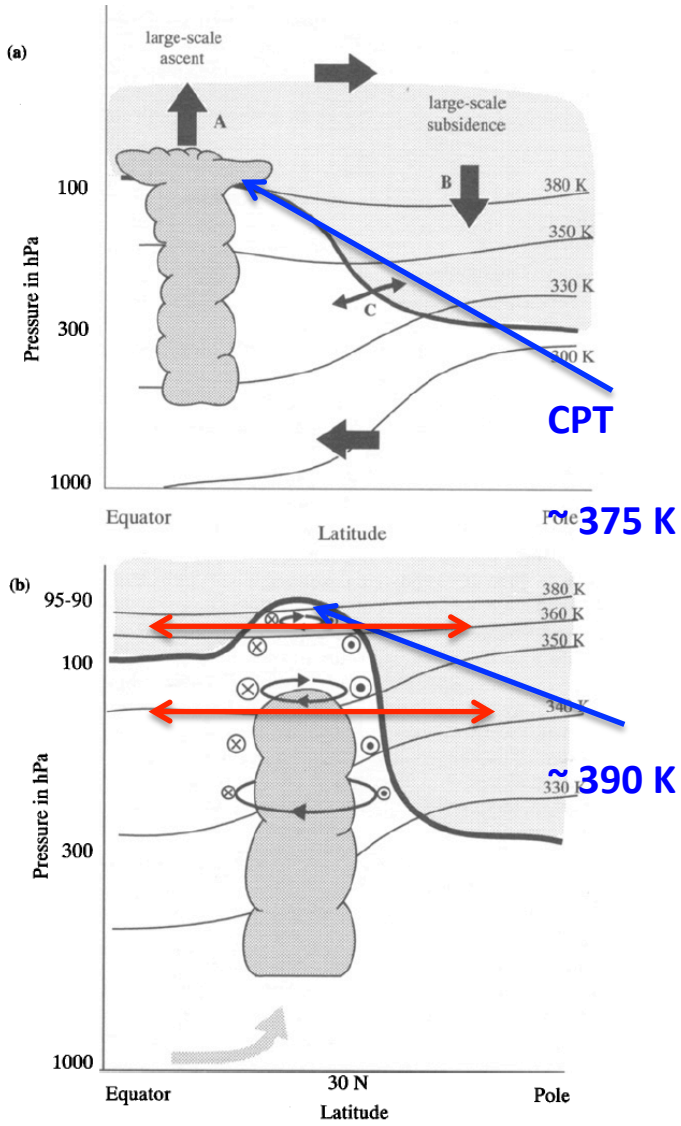
LRT



LRT θ

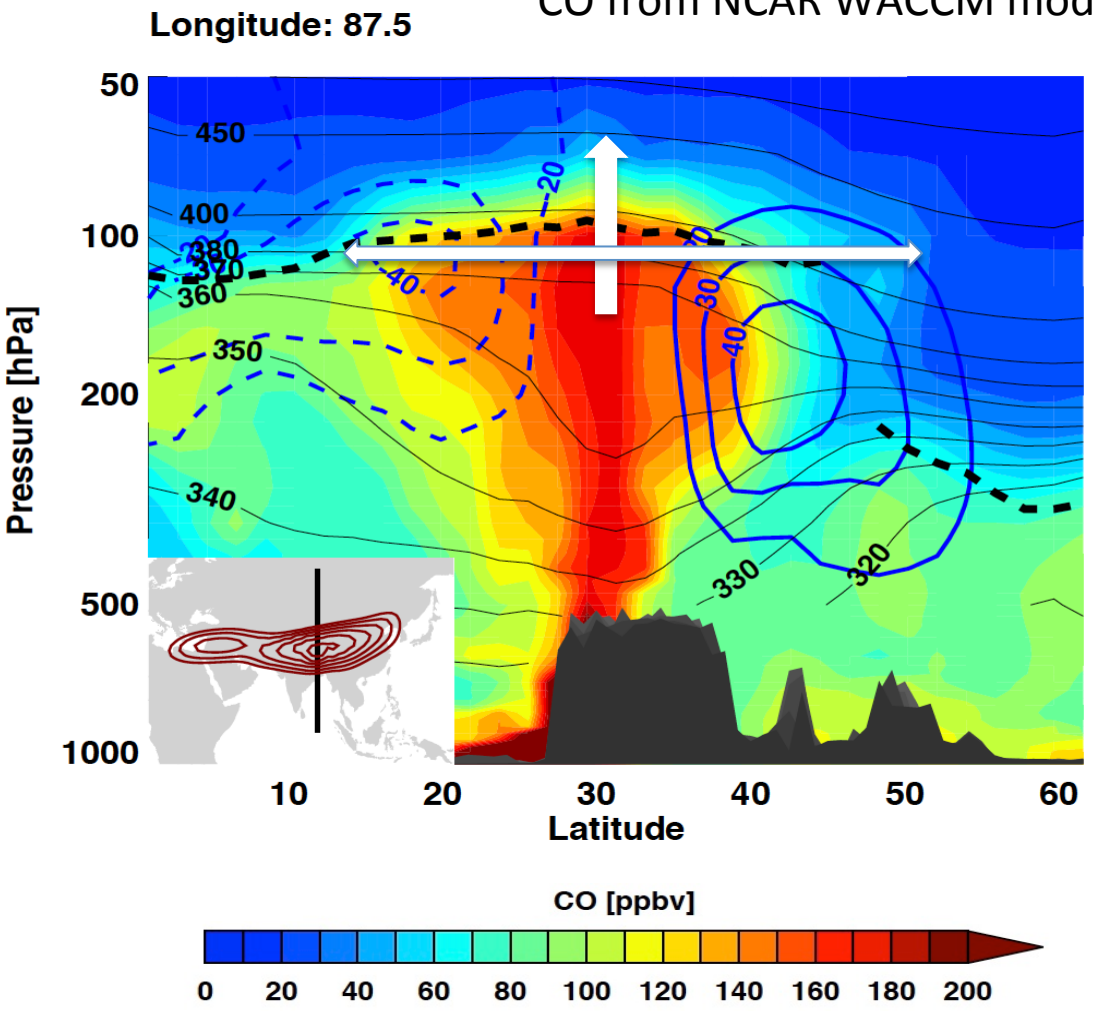


ASM transport: Chimney vs Blower



Dethof et al., 1999

CO from NCAR WACCM model



Tracer's intra-seasonal scale variability at the UTLS level
- the "blower model"

"Blower" model as seen from bi-modal oscillation

ASM anticyclone: Quasi-Bi-Weekly Oscillation between two modes

Zhang et al., 2002

Iranian Plateau Mode

Tibetan Plateau Mode

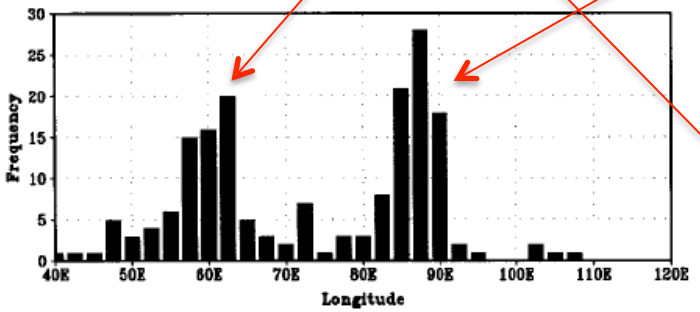


Fig. 2. The longitude-frequency distribution of the SAH major center during midsummer from the pentad mean data. For 15 summers there are totally 180 pentads involved in the statistics.

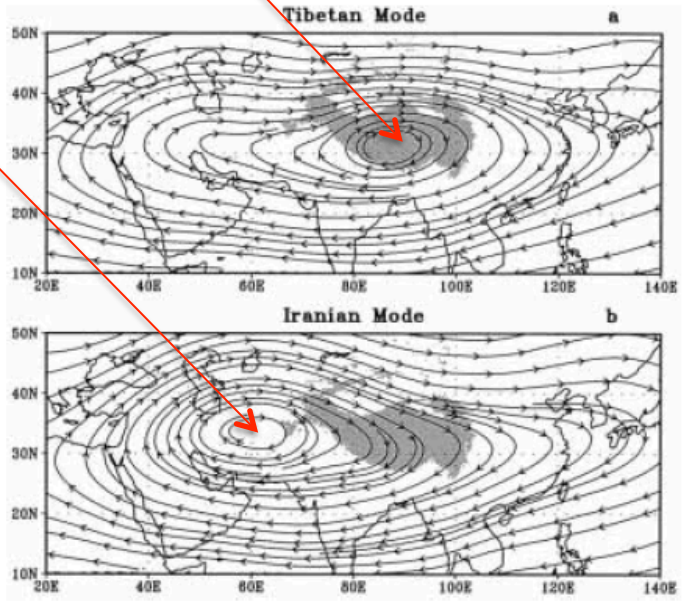
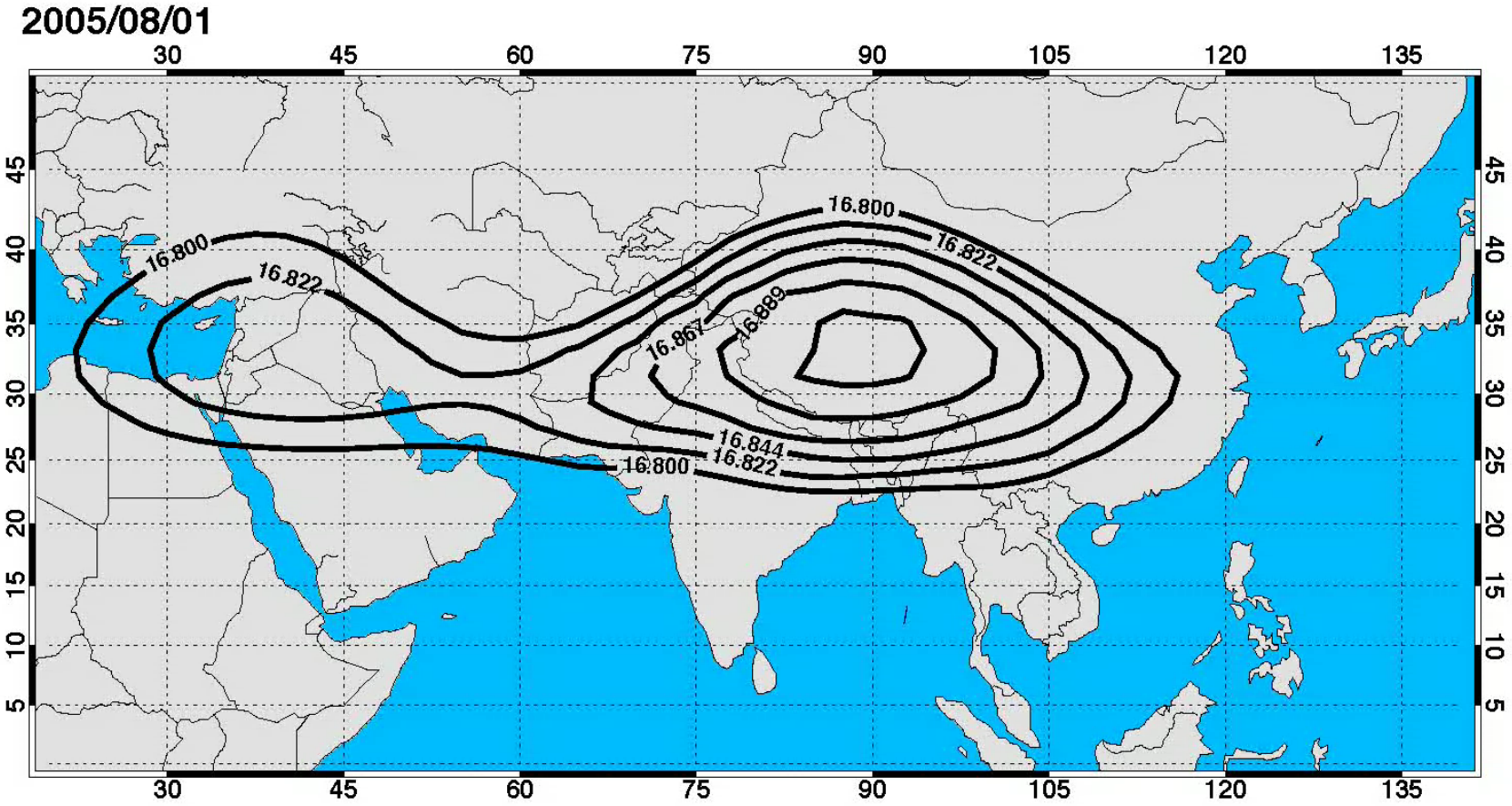


Fig. 3. The 100 hPa streamline composite corresponding to the TM (a) and

potential height along the ridge line is the greatest. Thereby the location of the SAH cen-

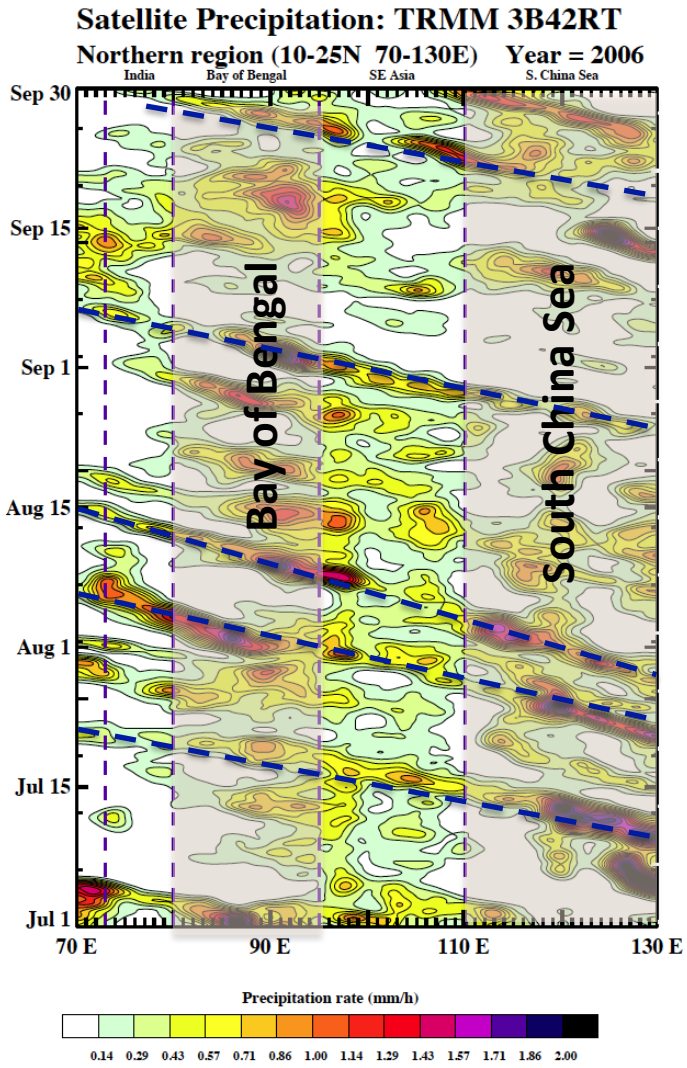
15-year composite, 100 hPa Streamline

Quasi-Bi-Weekly Oscillation of the Anticyclone



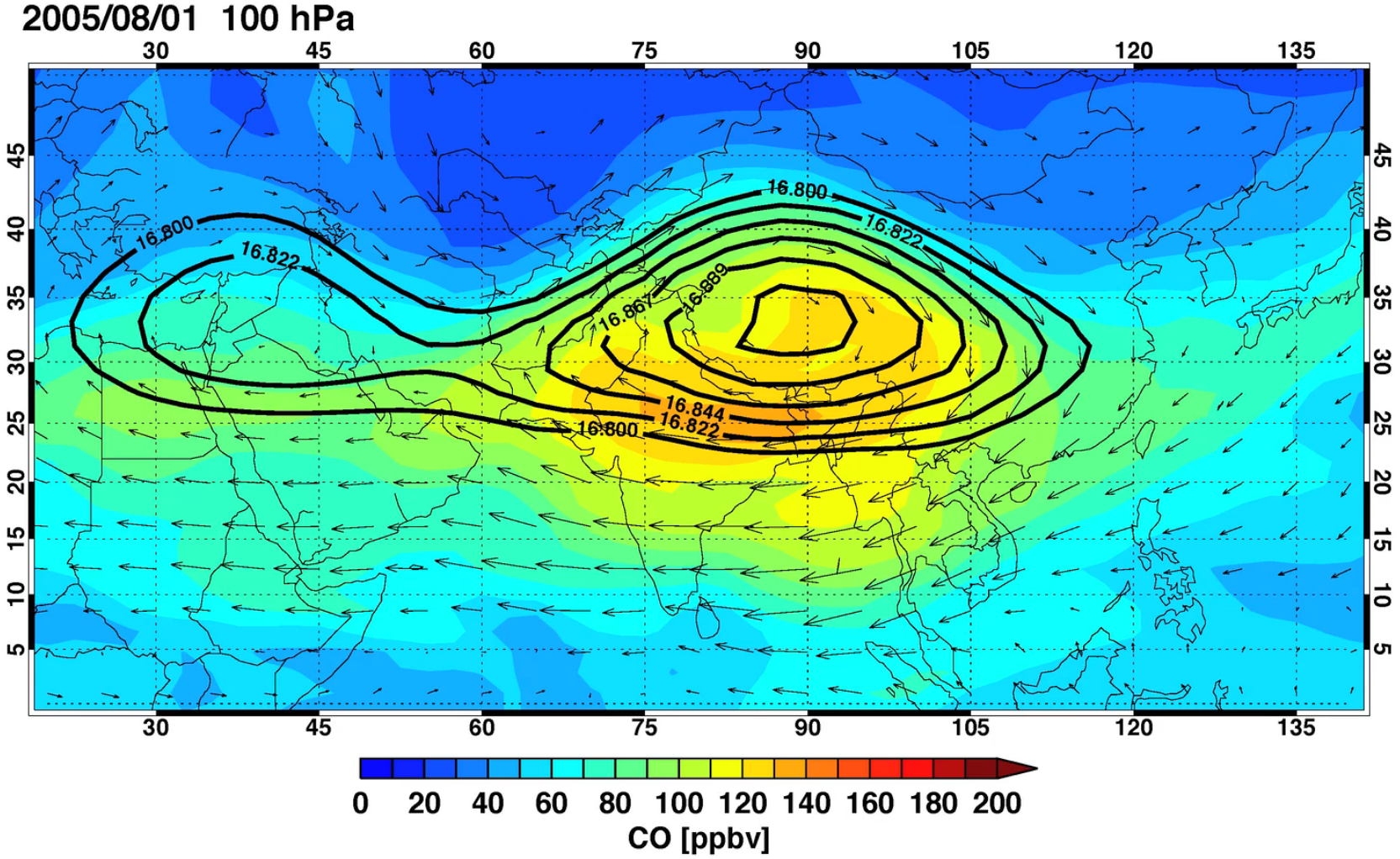
Note: A movie is replaced by its first frame for posting

10-15 day westward migration behavior also seen in TRMM Precip



John Bergman

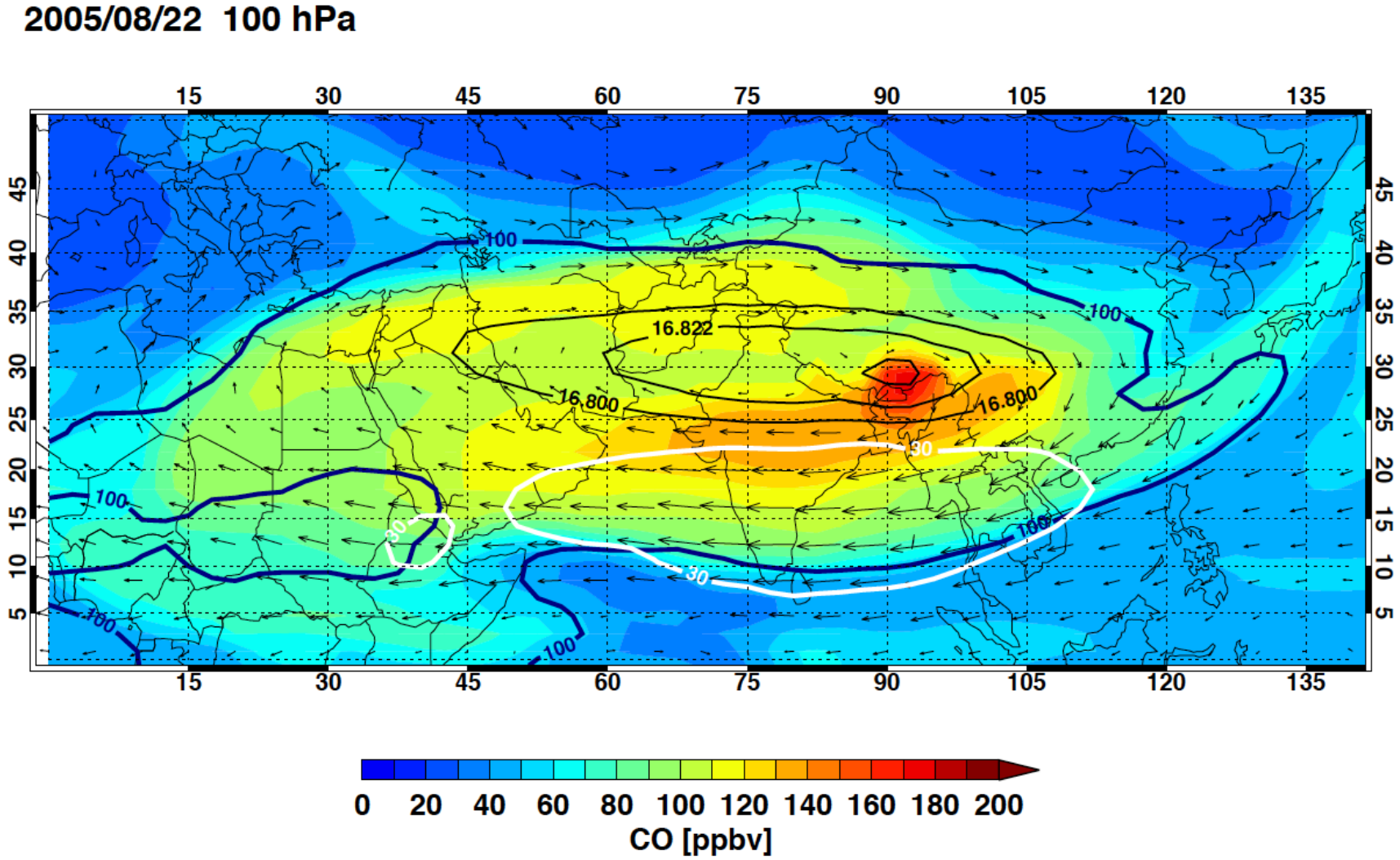
UT CO variability associated with the bi-modal oscillation



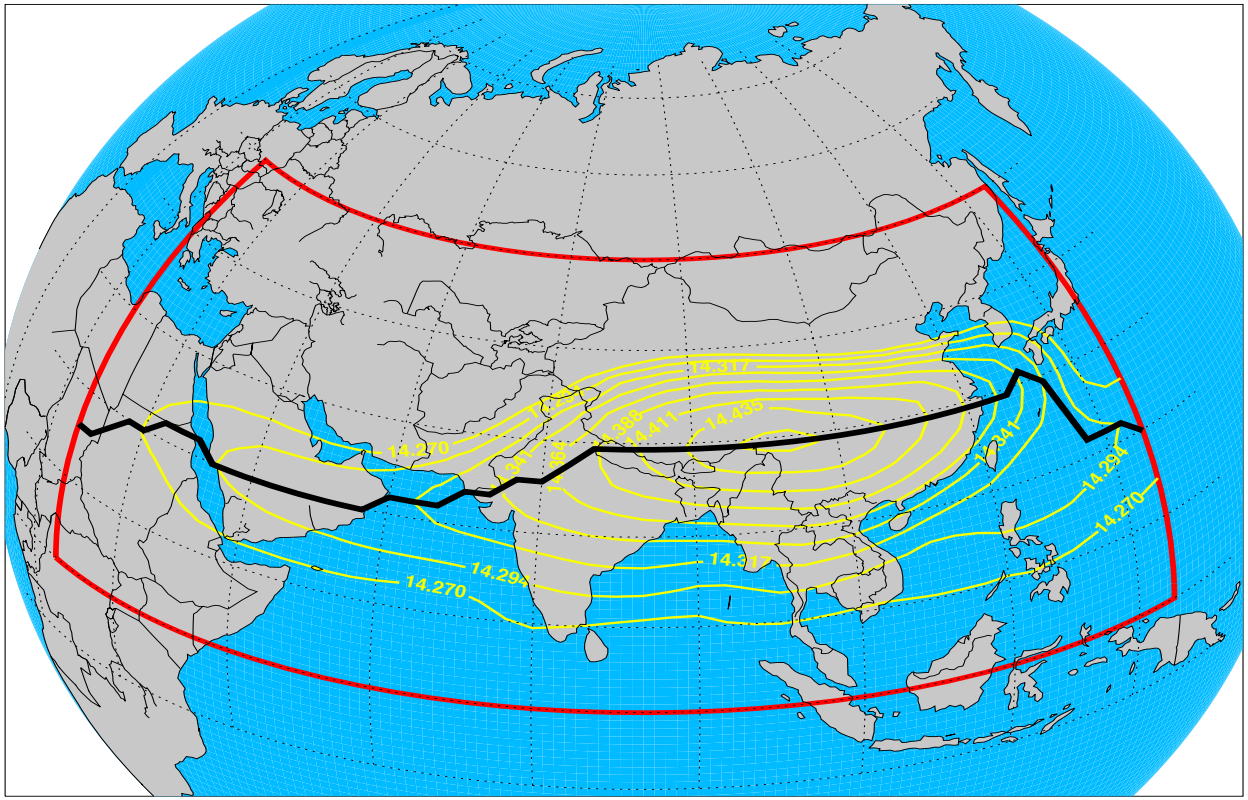
Note: A movie is replaced by its first frame for posting

"confinement and shedding"

Enhanced CO in relation to the tropopause and easterly jet

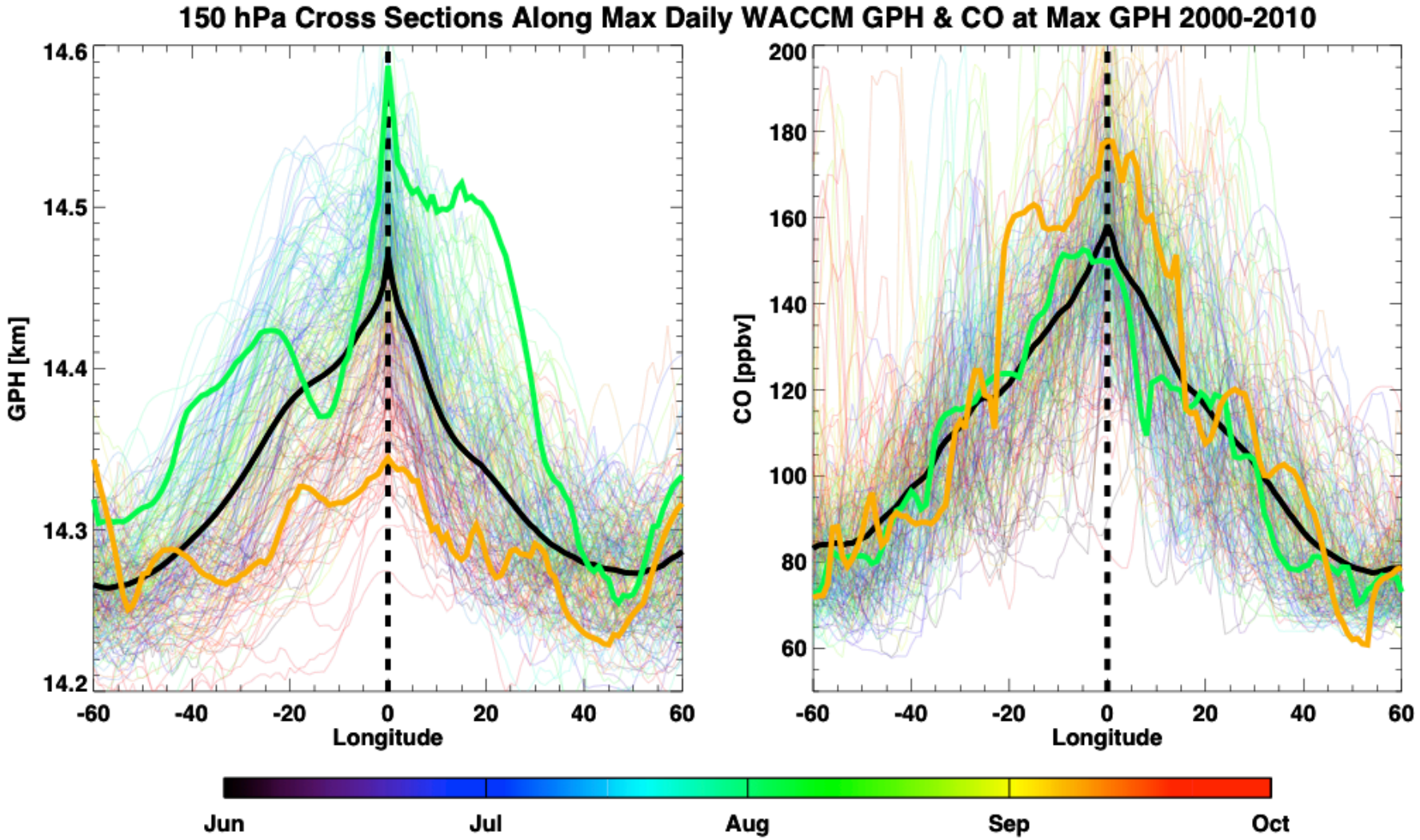


Characterization of the Anticyclone East-West Oscillation



150 hPa GPH, “ASM Box” (0°-70° N, 0°-140° E)

Statistically, CO maximum is aligned with the GPH maximum



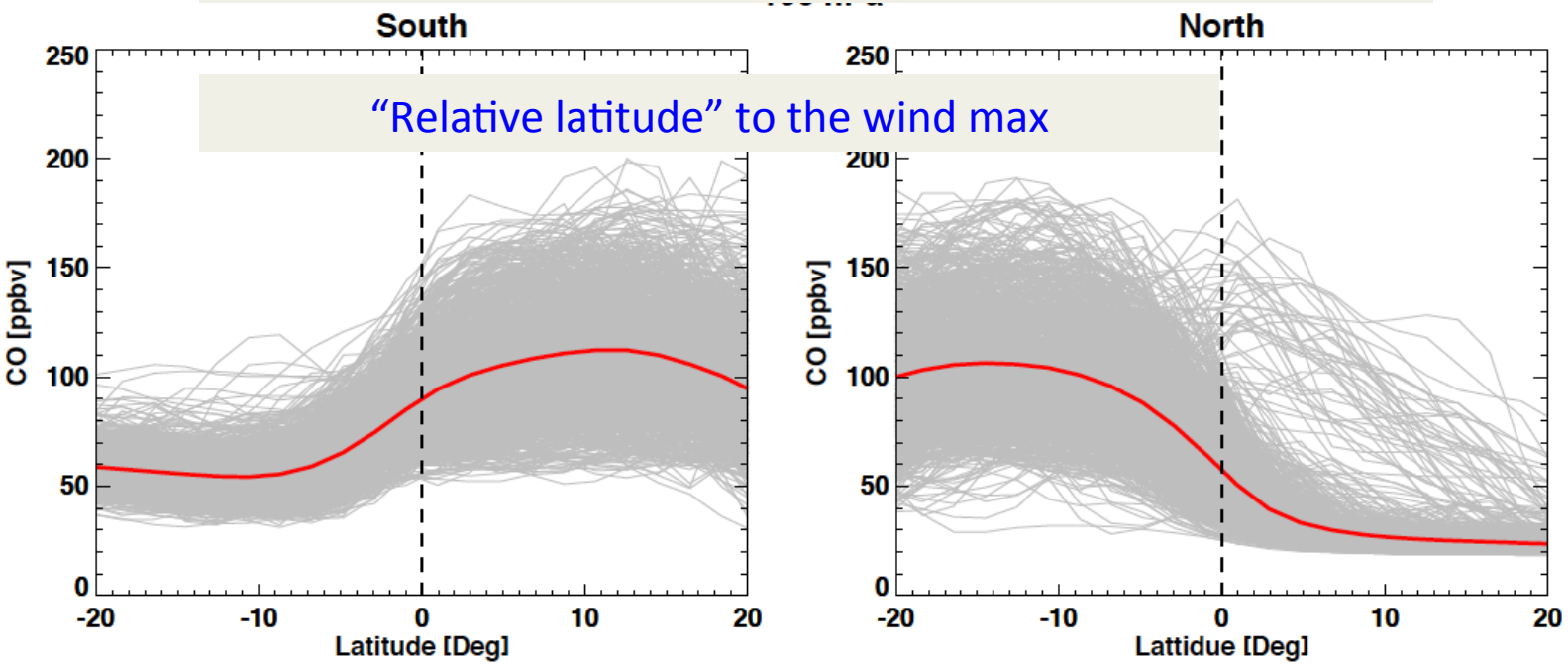
GPH and CO distribution along the ridge of GPH and in coordinates of longitude relative to the GPH maximum

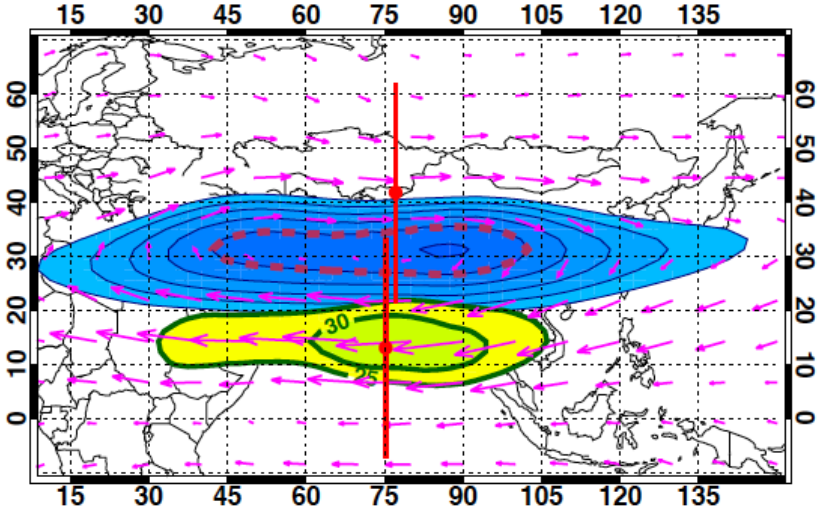
“Confinement and shedding”

Strong confinement

CO Gradient across the jet core (wind max) at 100 hPa

“Relative latitude” to the wind max

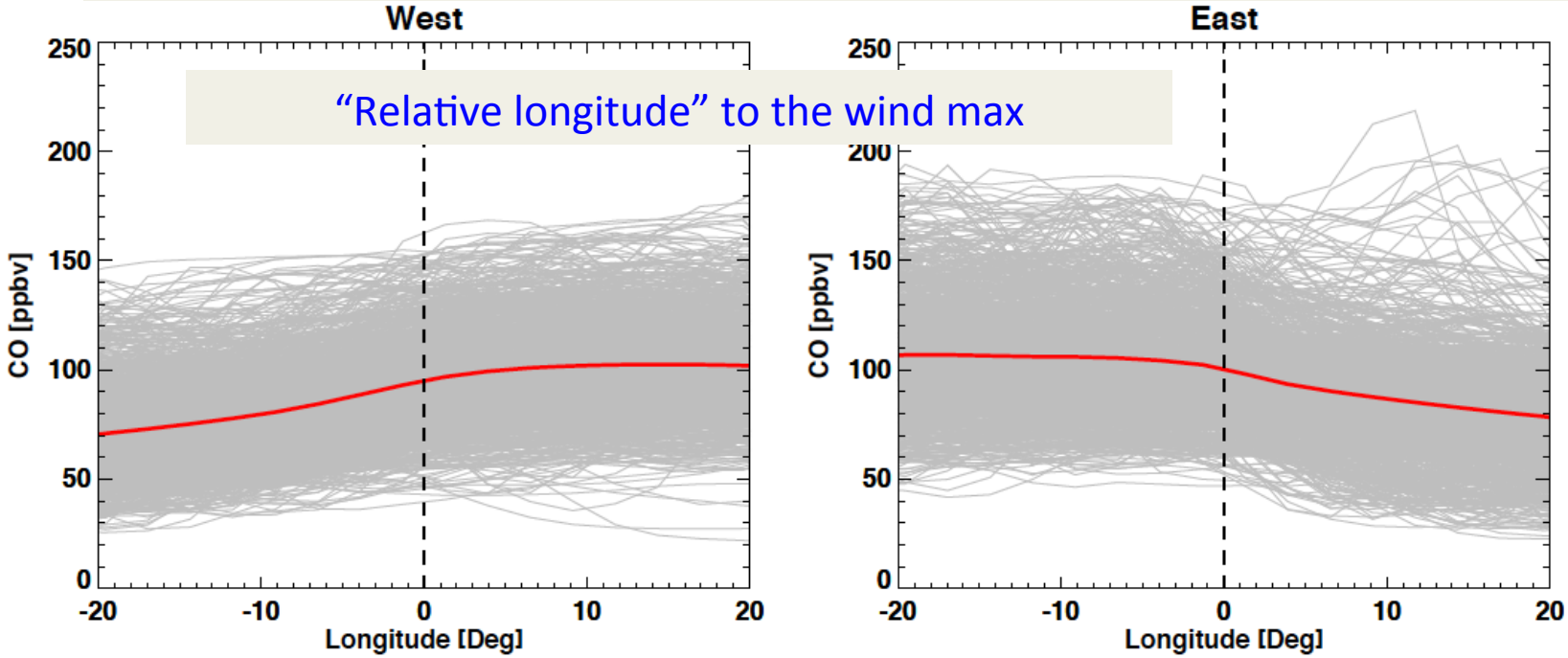


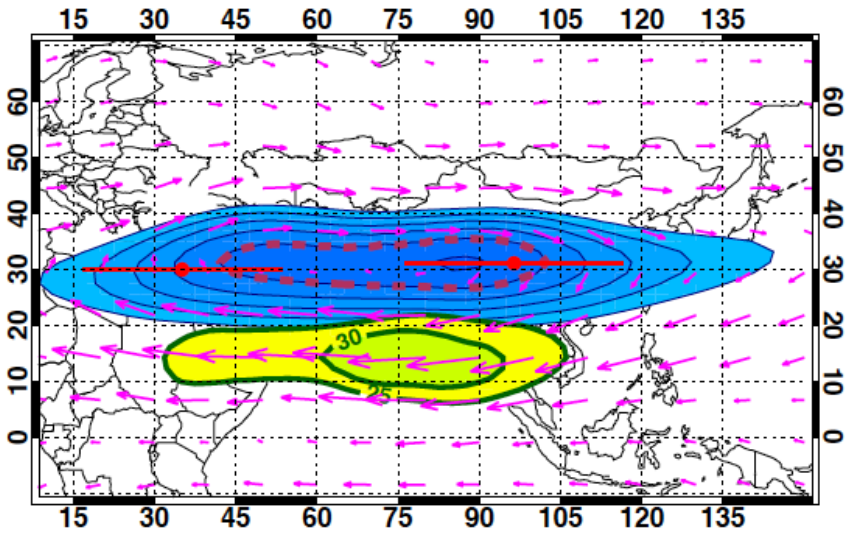


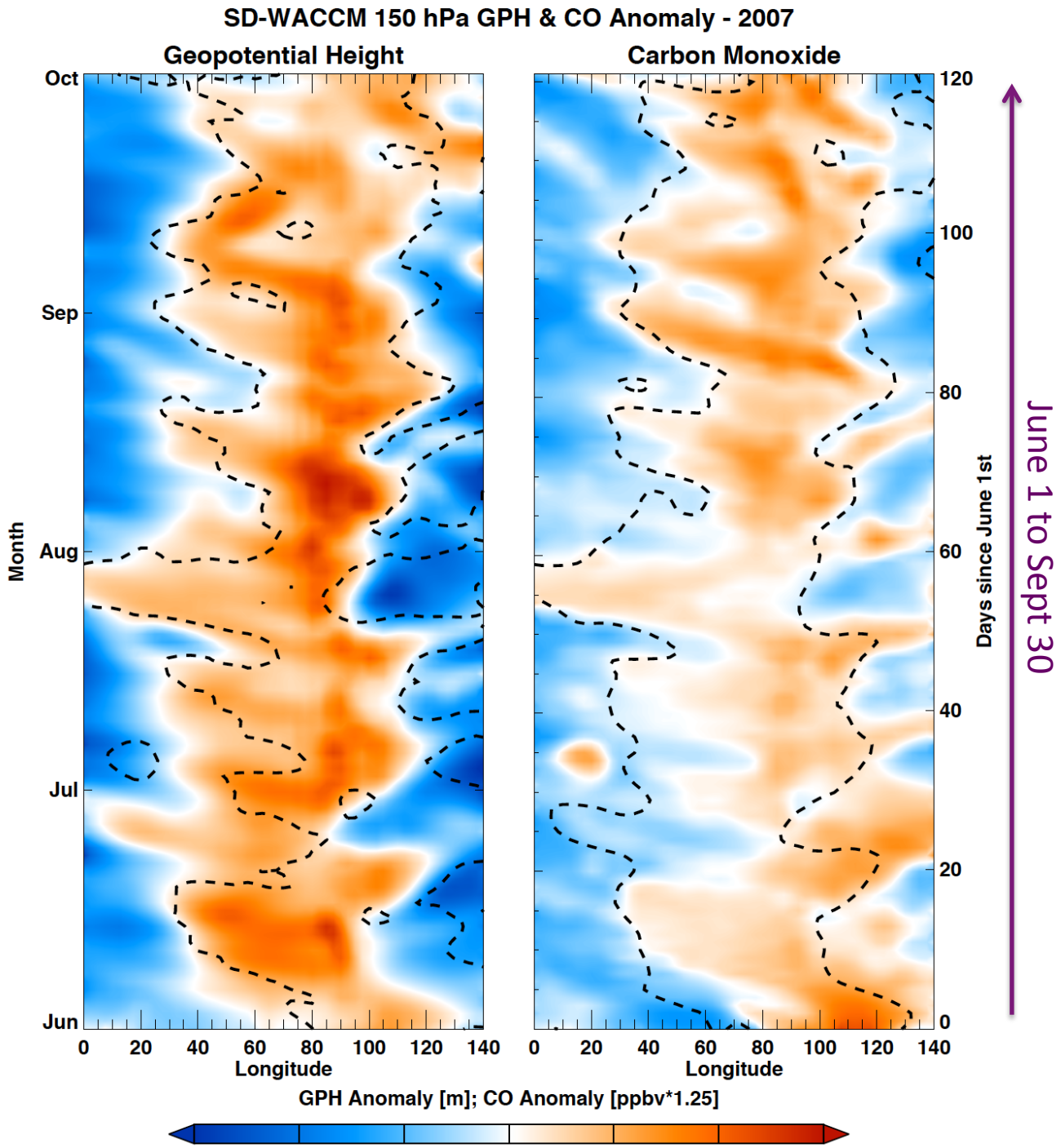
“Confinement and shedding”

Weak confinement

CO Gradient across the wind max at 100 hPa in the east-west direction

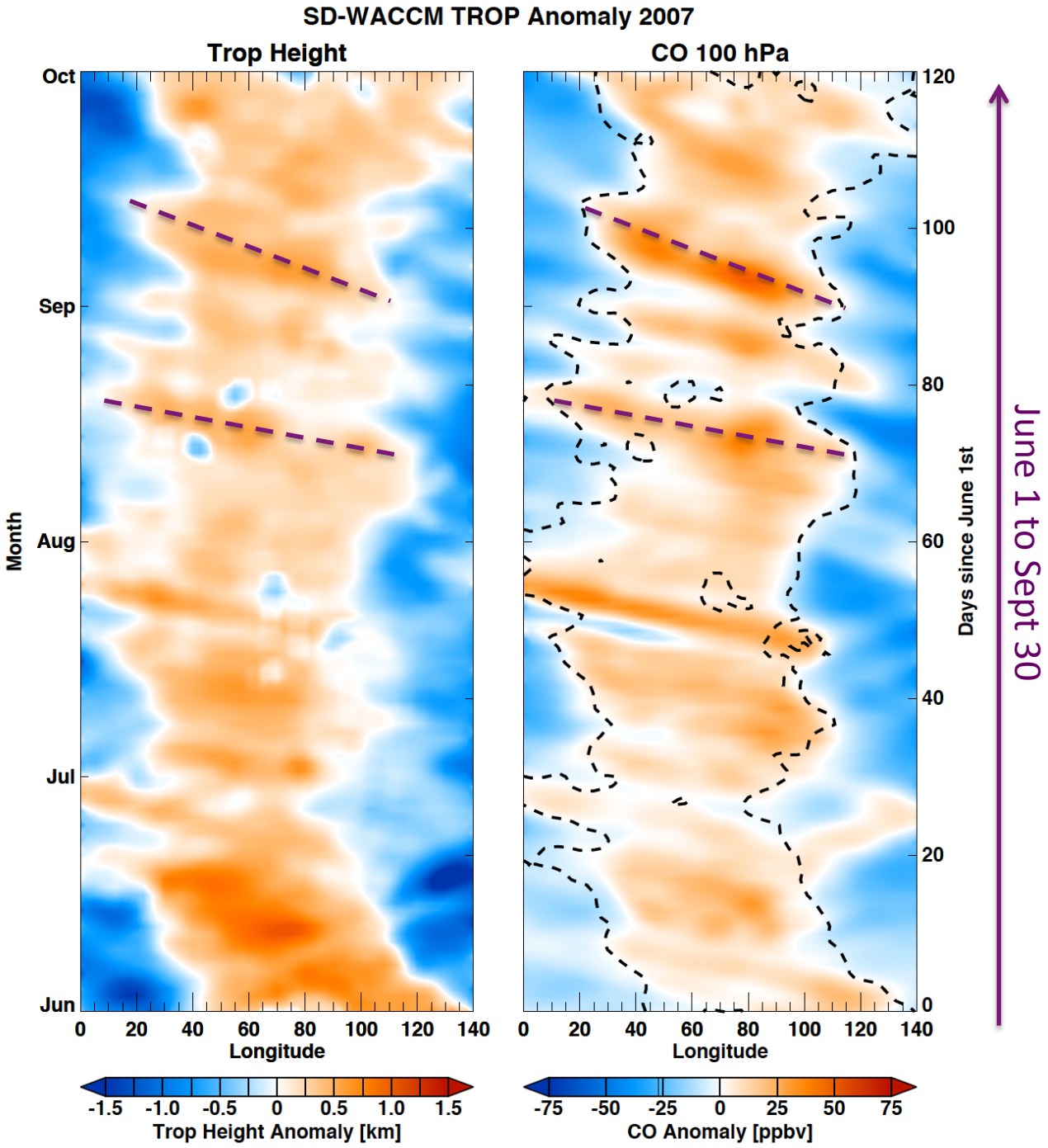






150 hPa GPH and CO anomaly fields along the GPH ridge

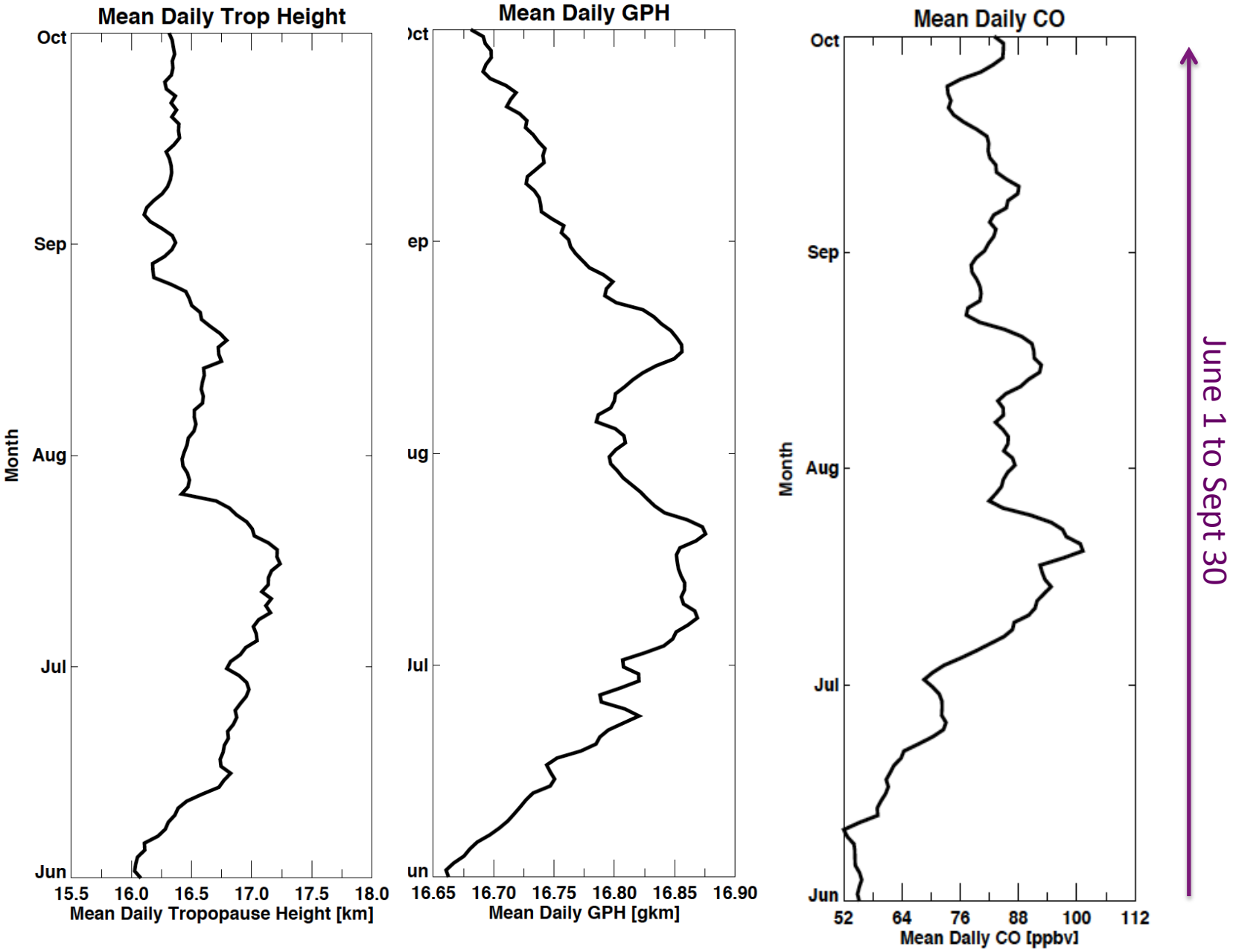
Dash lines indicate the zero line in the opposite anomaly field



Tropopause height (left) and 100 hPa CO mixing ratio anomalies 15°-35° N

Dash lines on the CO Hovmoller indicate the zero line in the tropopause anomaly field

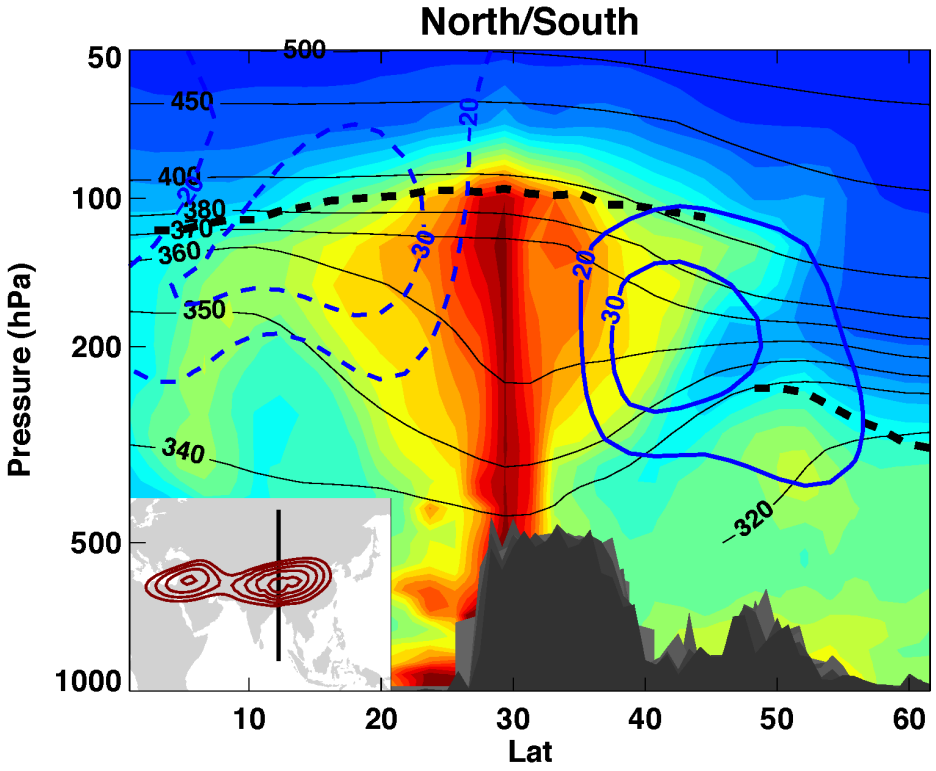
Variation of the means: Trop height (left), GPH (center), and CO (right)



Preferred path of vertical transport: "Conduit" or *"Chimney"*?

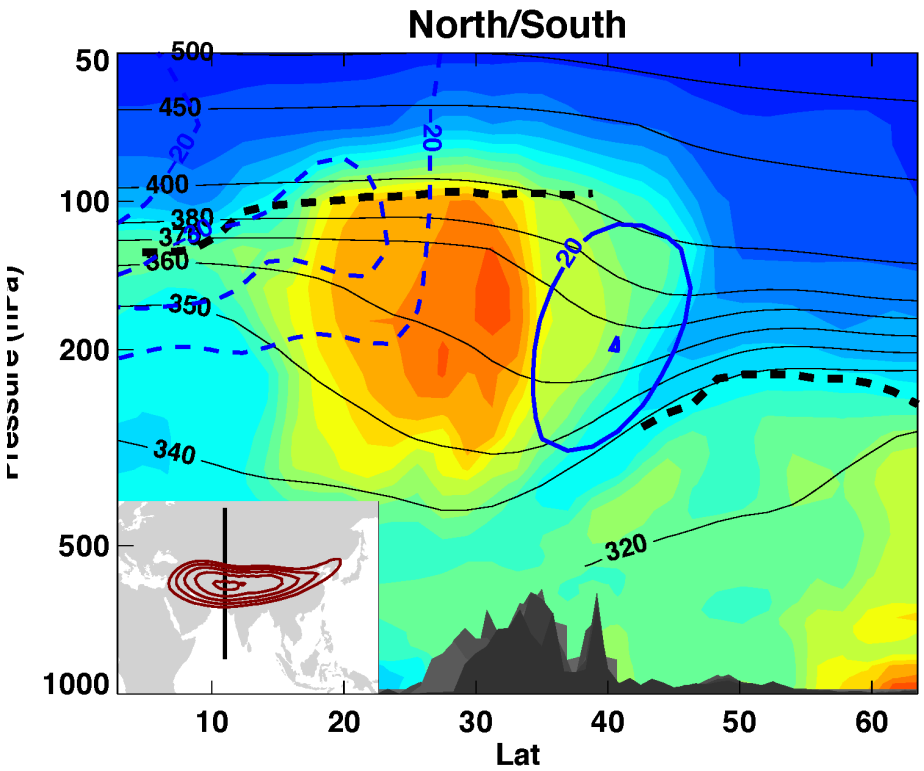
WACCM CO, Tibetan mode

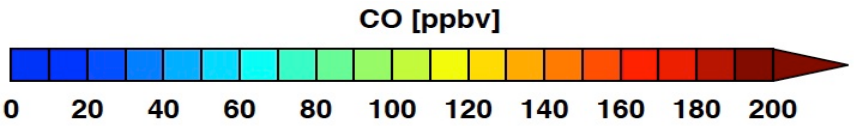
2005/08/11



WACCM CO, Iranian mode

2005/08/18

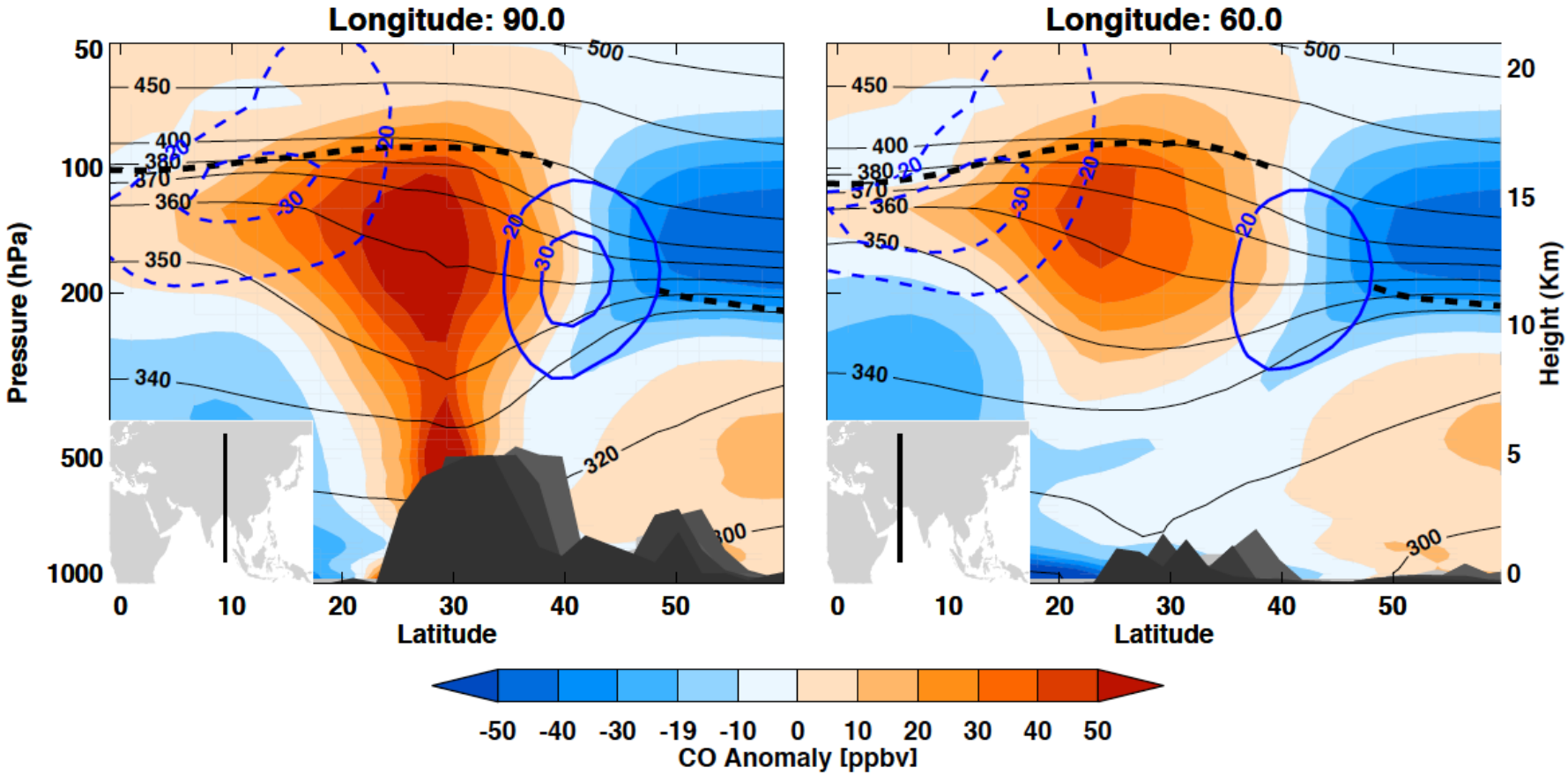




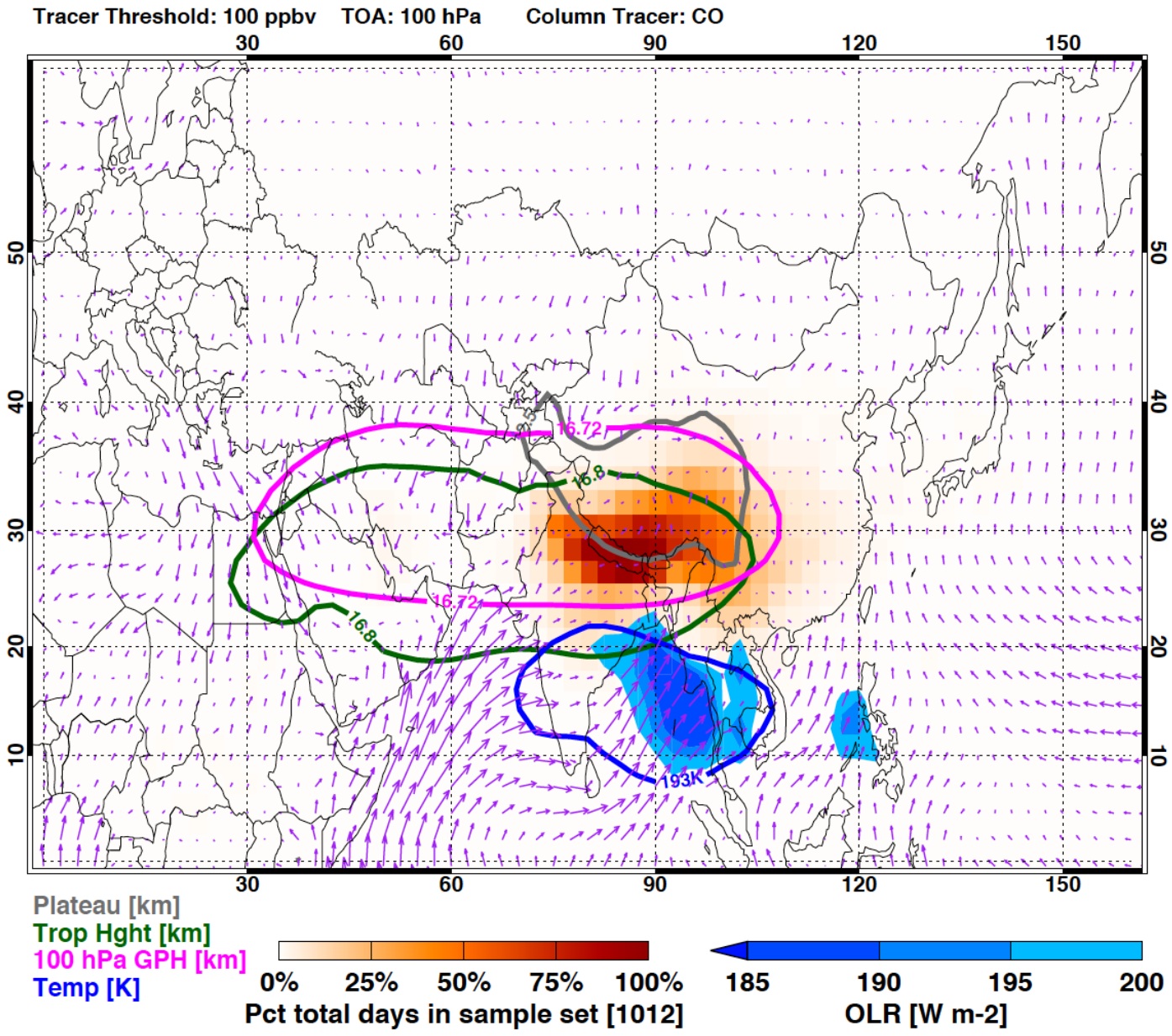
WACCM CO anomaly, 11 year mean (2000-2010)

Tibetan mode

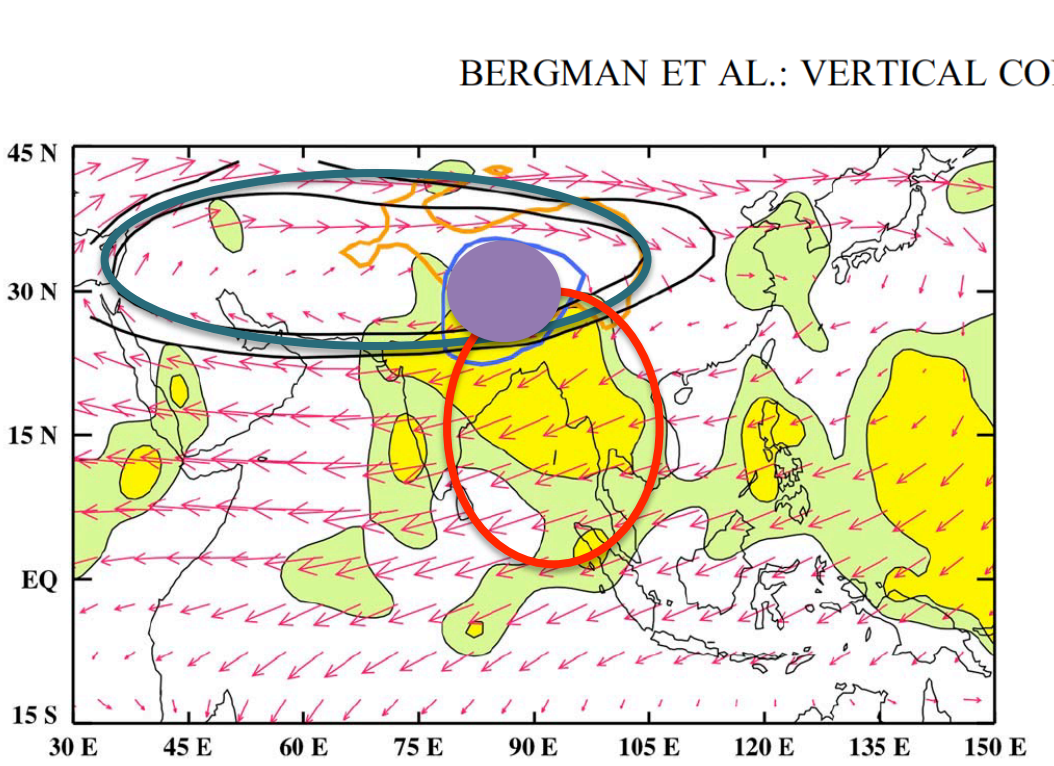
Iranian mode

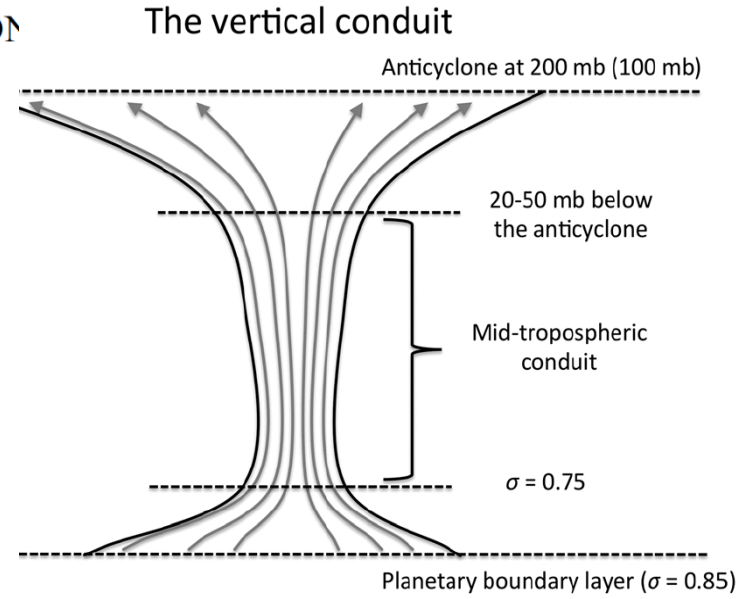


WACCM 11-year Frequency of Occurrence of CO>100 ppb at every level P> 100 hPa



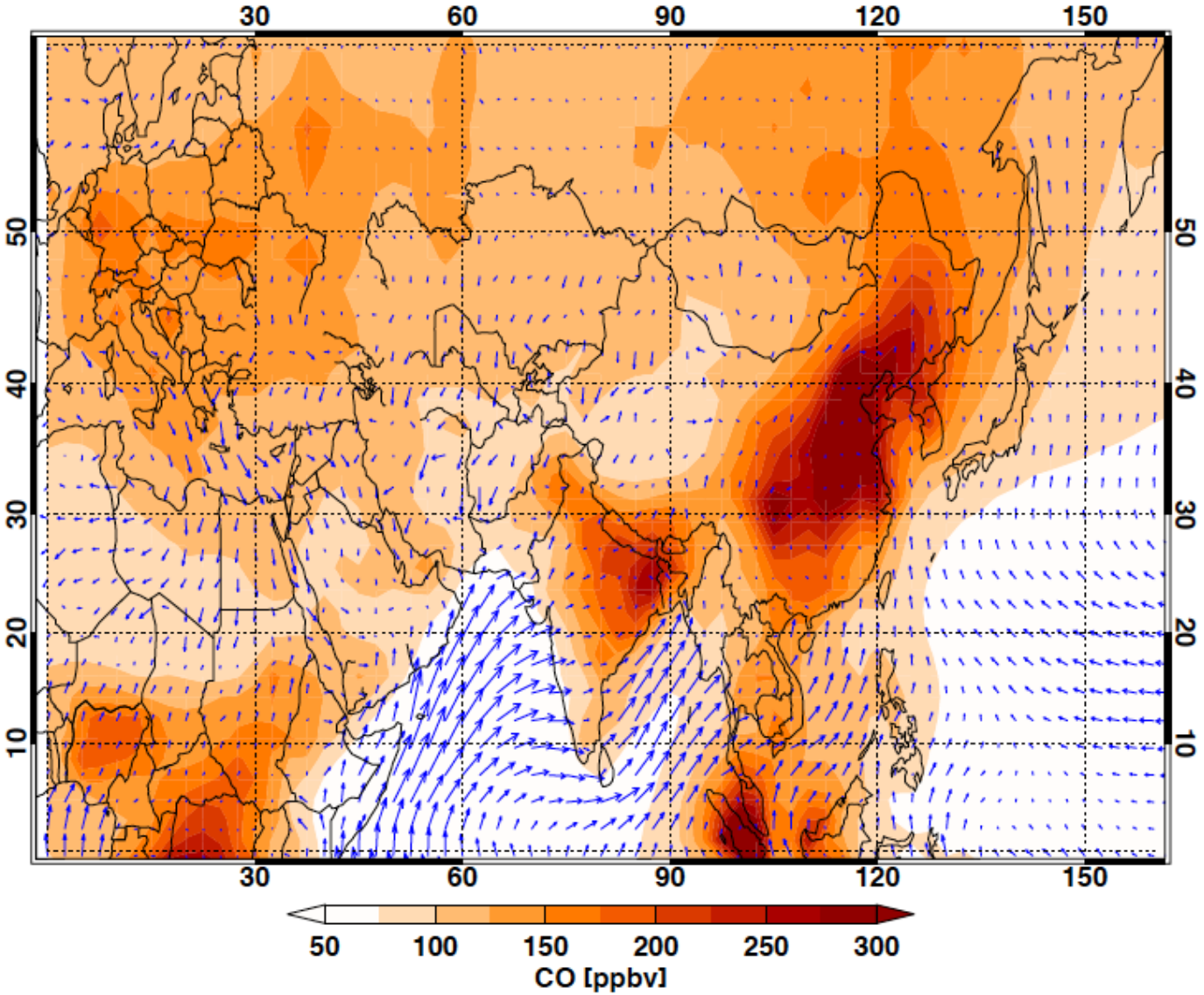
Is there a “conduit”? what are the leading physical processes that creates the “conduit”?





Bergman et al., 2013

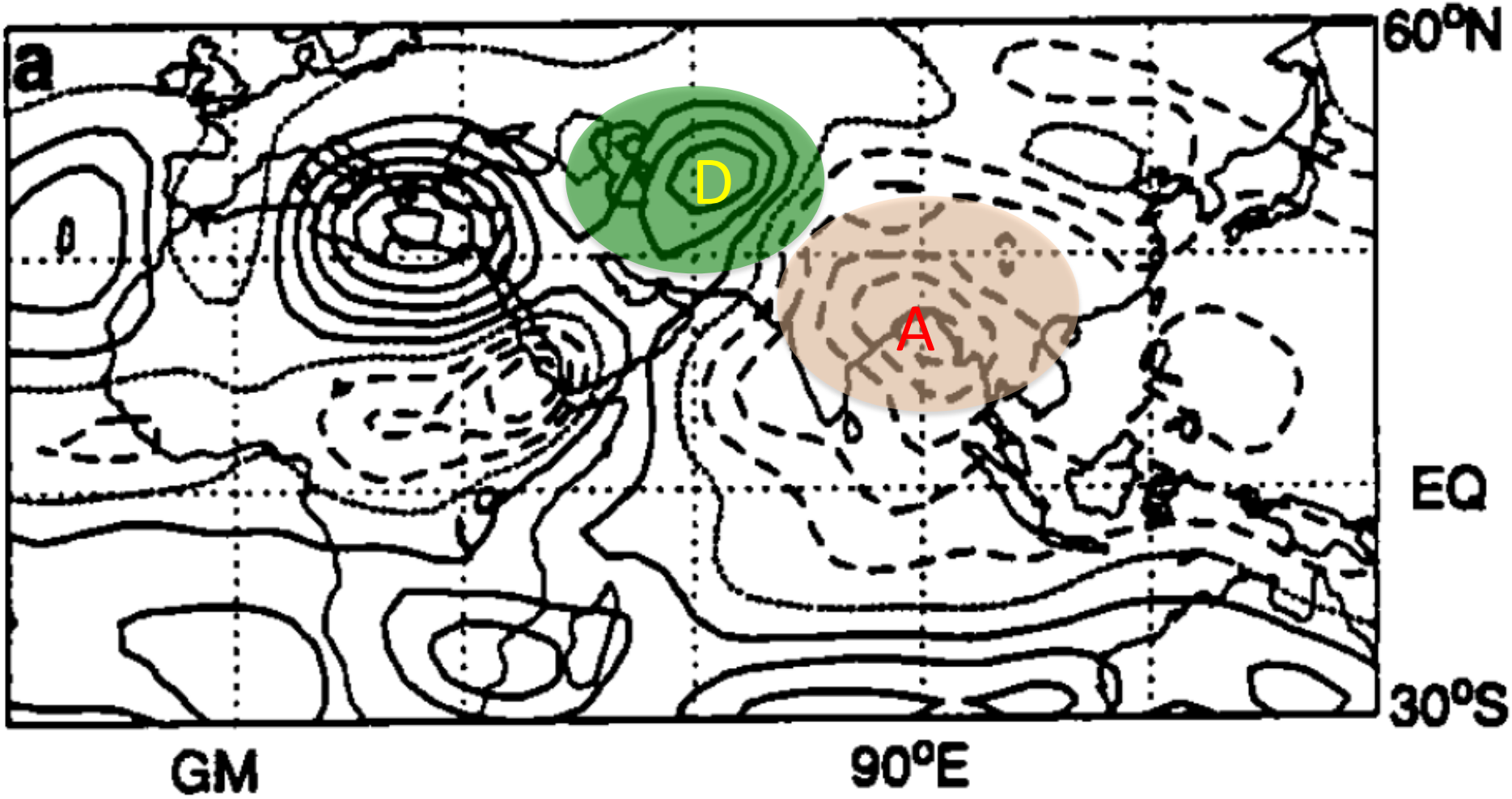
WACCM 11 year JJA Mean Surface CO



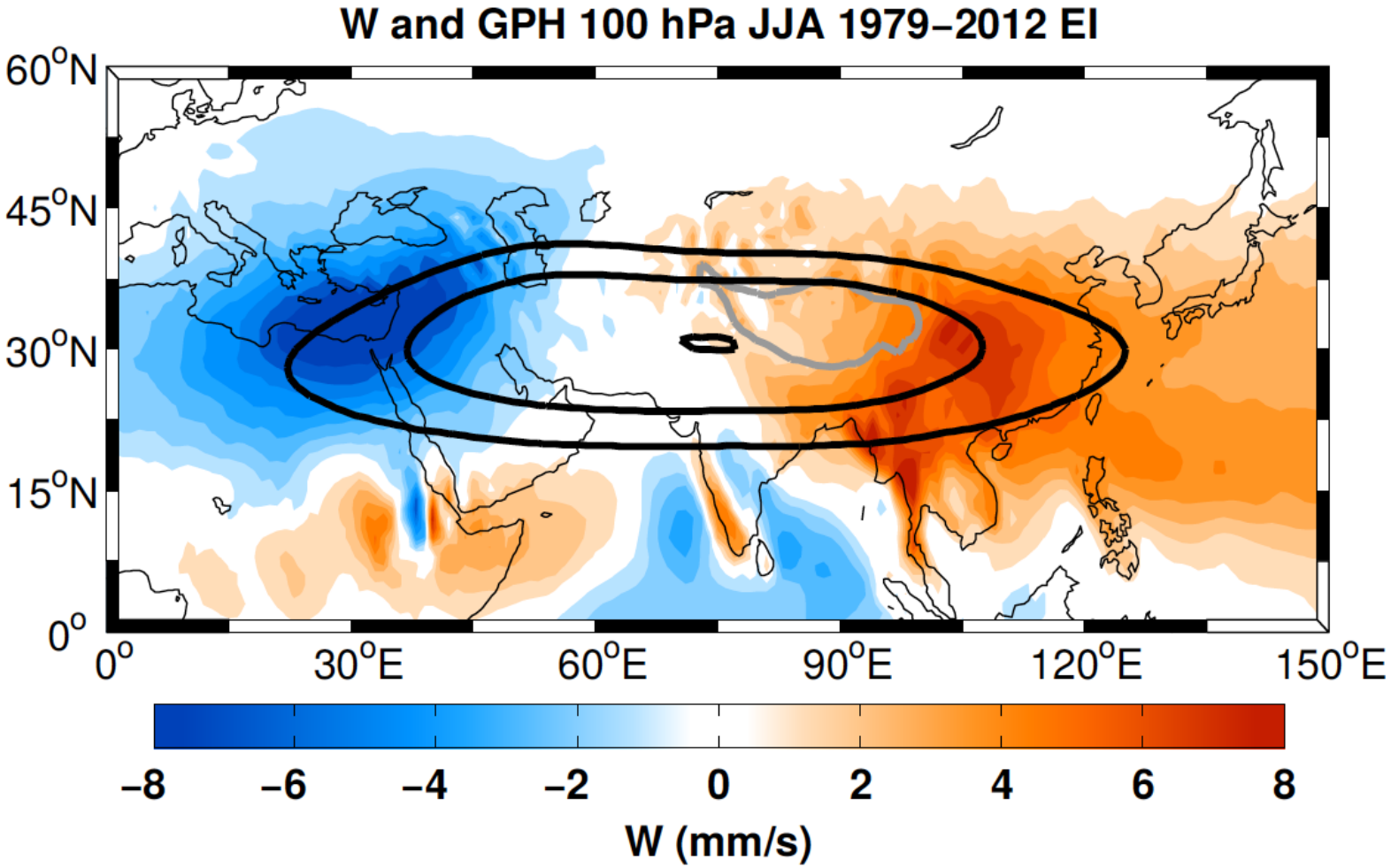
Vertical motion in the mid troposphere (477 hPa)

MONSOONS ANI

Rodwell and Hoskins 1996



Ascending/descending pattern at the tropopause level:



Implications:

- Boundary layer tracers are lofted to the UT preferably from the eastern side of the ASM anticyclone (Tibetan mode) ("chimney" or "conduit")

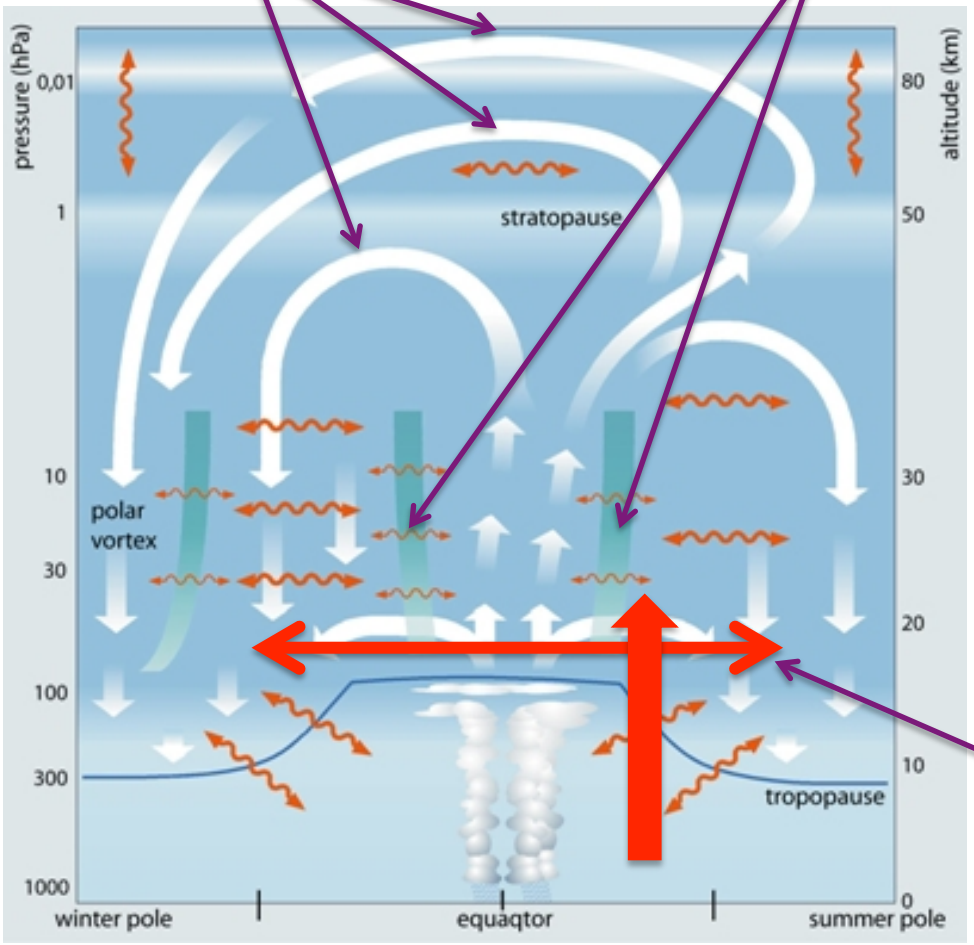
- Western side of the Anticyclone (Iranian mode) is filled by the eddy shedding associated with the intra-seasonal dynamical oscillation

Is the “Chimney” connected to the “tropical pipe” in the stratosphere?

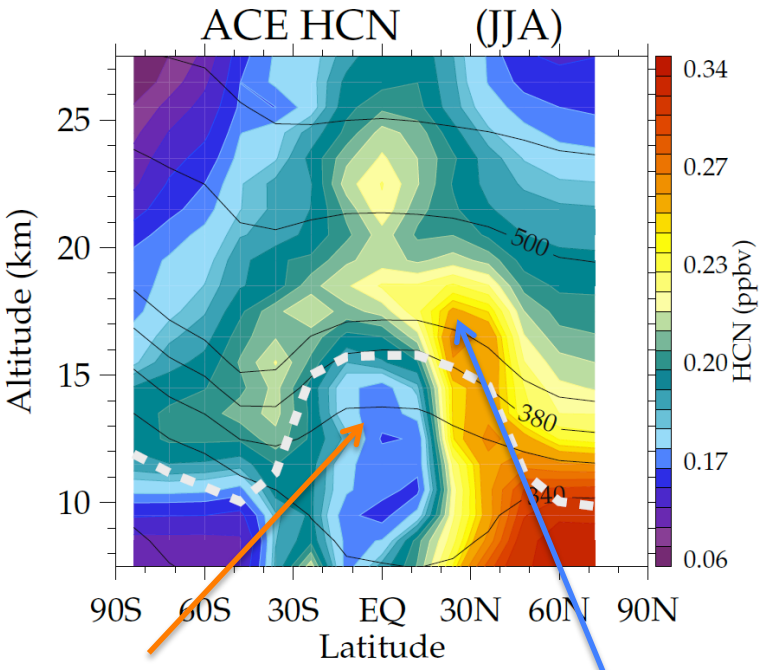
What's the relationship of ASM and the ascending branch of B-D circulation?

Overturning circulation "B-D"

"Tropical Pipe"



Randel et al., 2010



tropical minimum

transport to stratosphere via monsoon

Global diffuser

Is the “tropical pipe” shifting northward with the ITCZ in the monsoon season?

Lawrence and Lelieveld, 2010

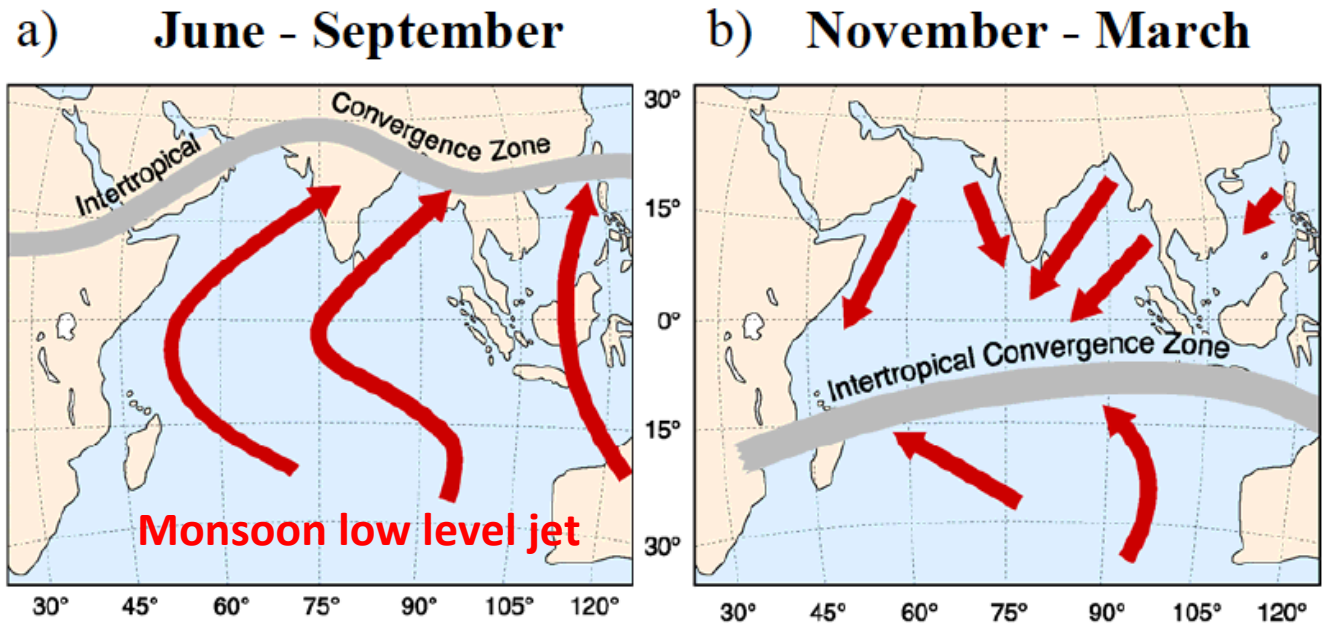
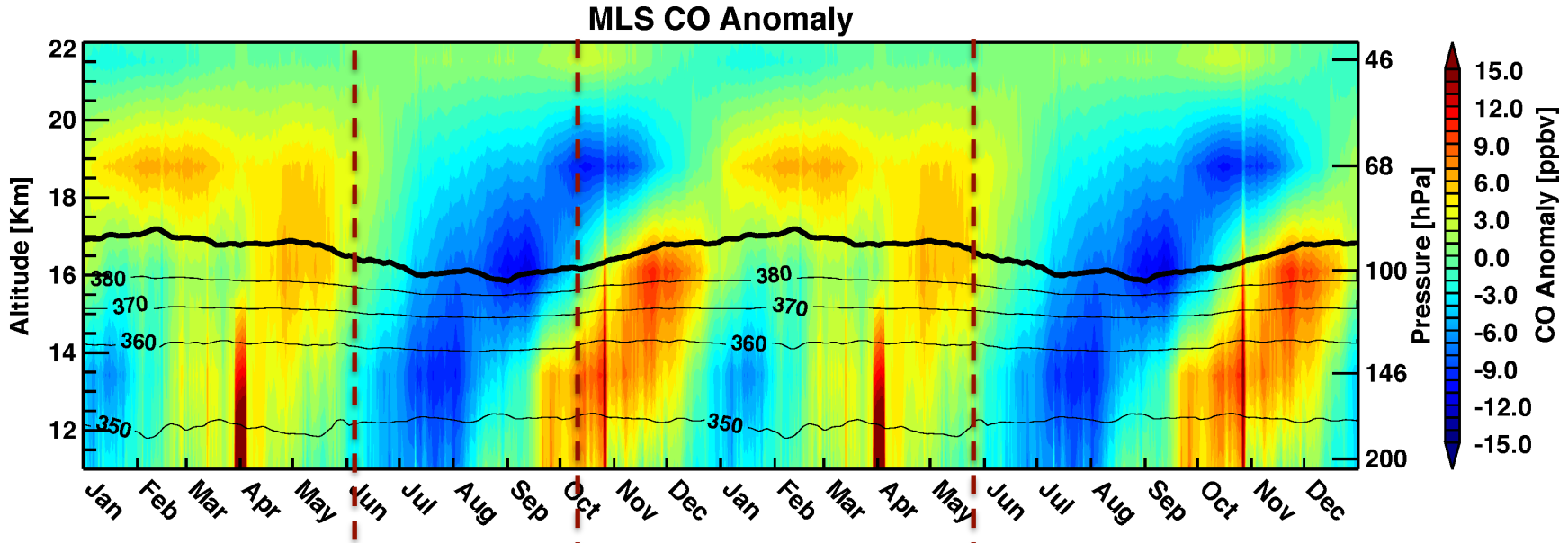
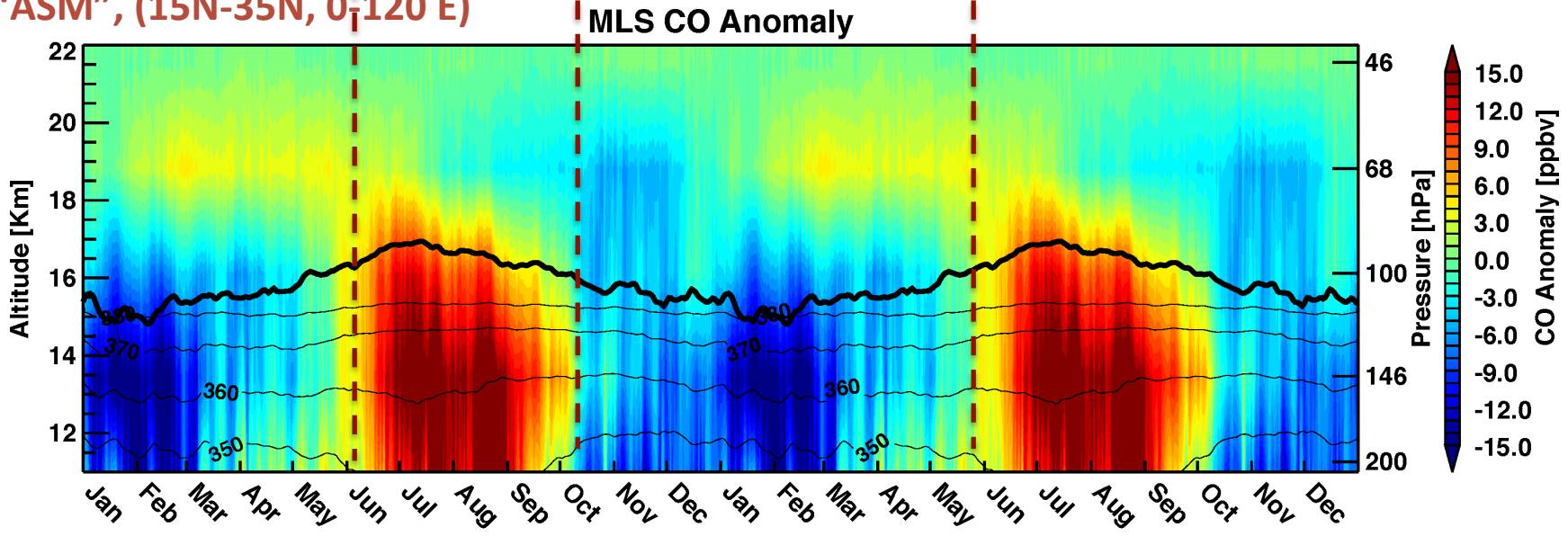


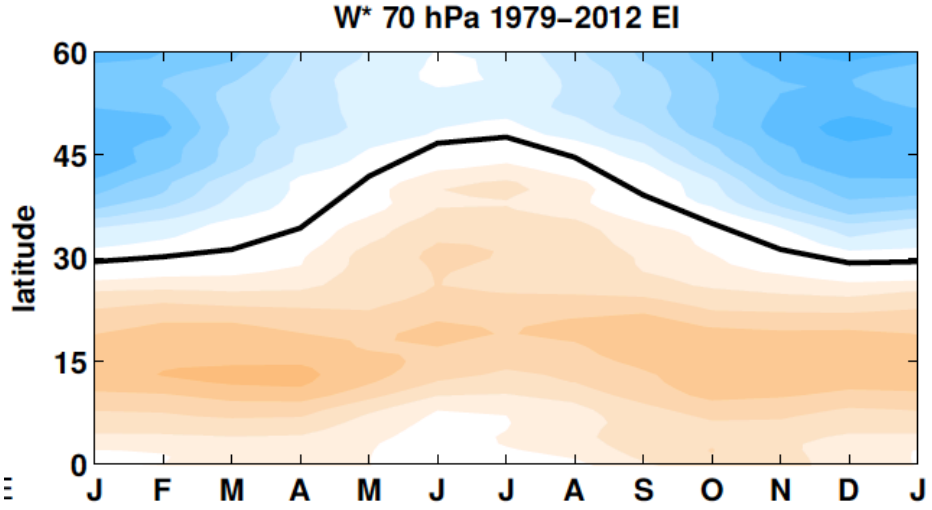
Fig. 5. Transport pathways for near-surface flow over the Indian Ocean during the **(a)** summer and **(b)** winter monsoon periods.

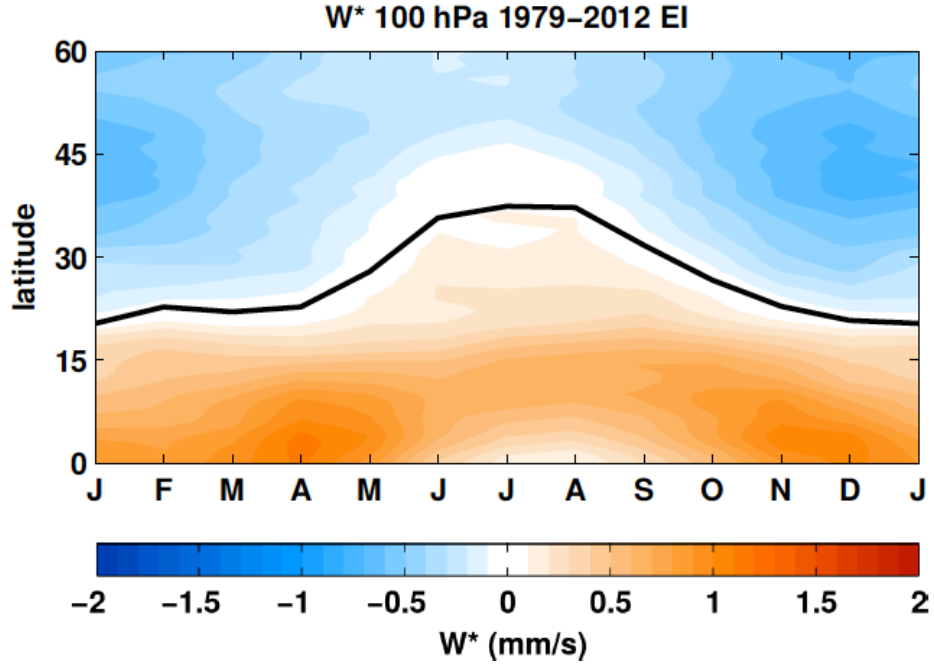
“Tropics” (12S-12N, 0-360E)



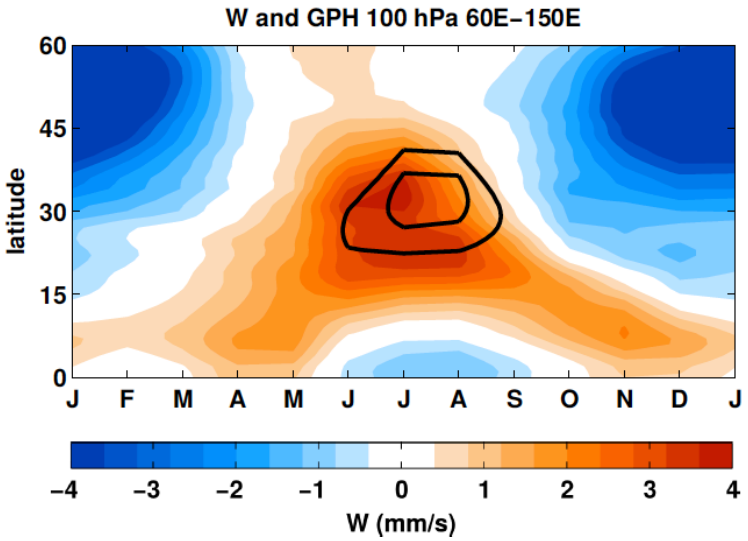
“ASM”, (15N-35N, 0-120 E)

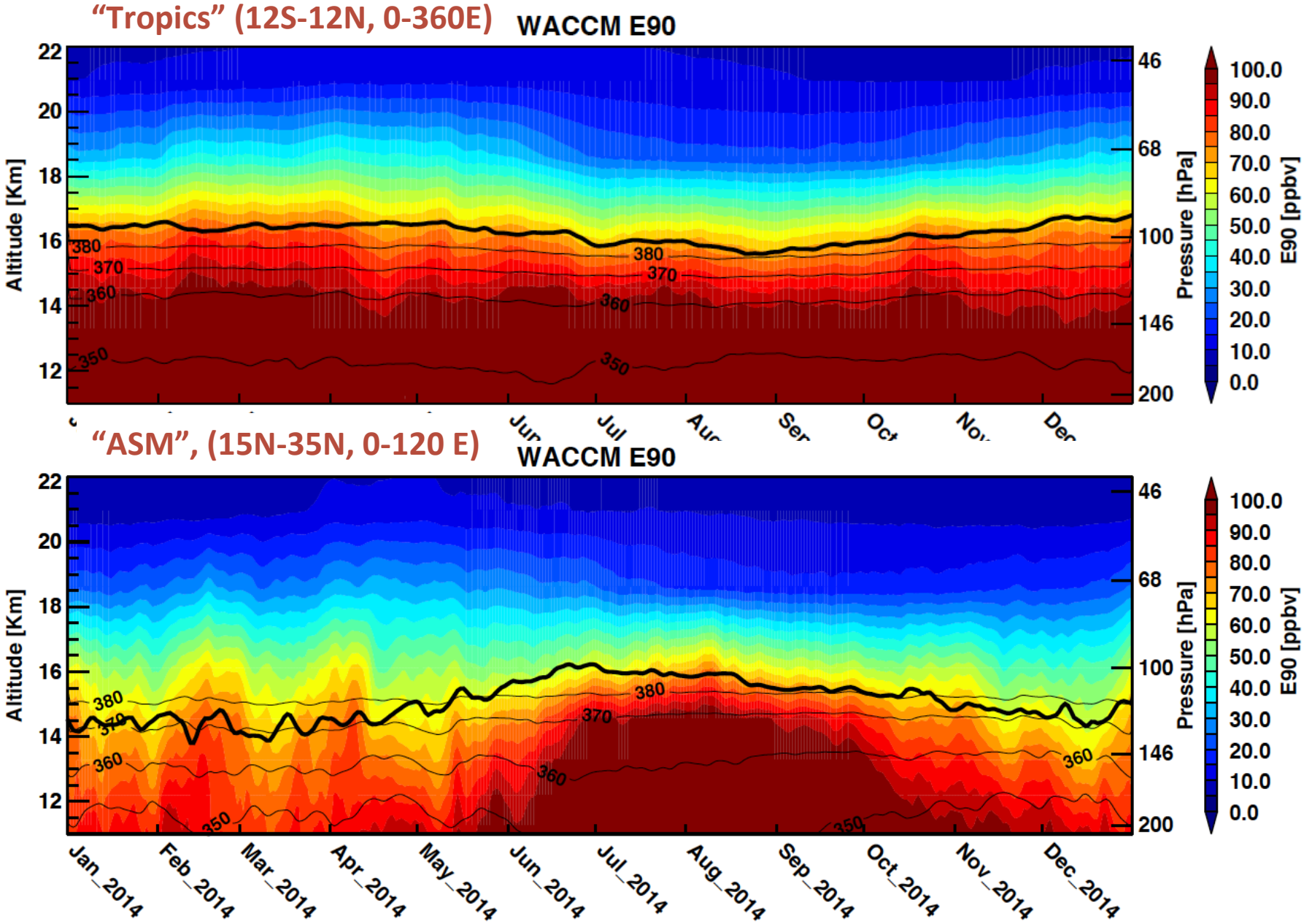




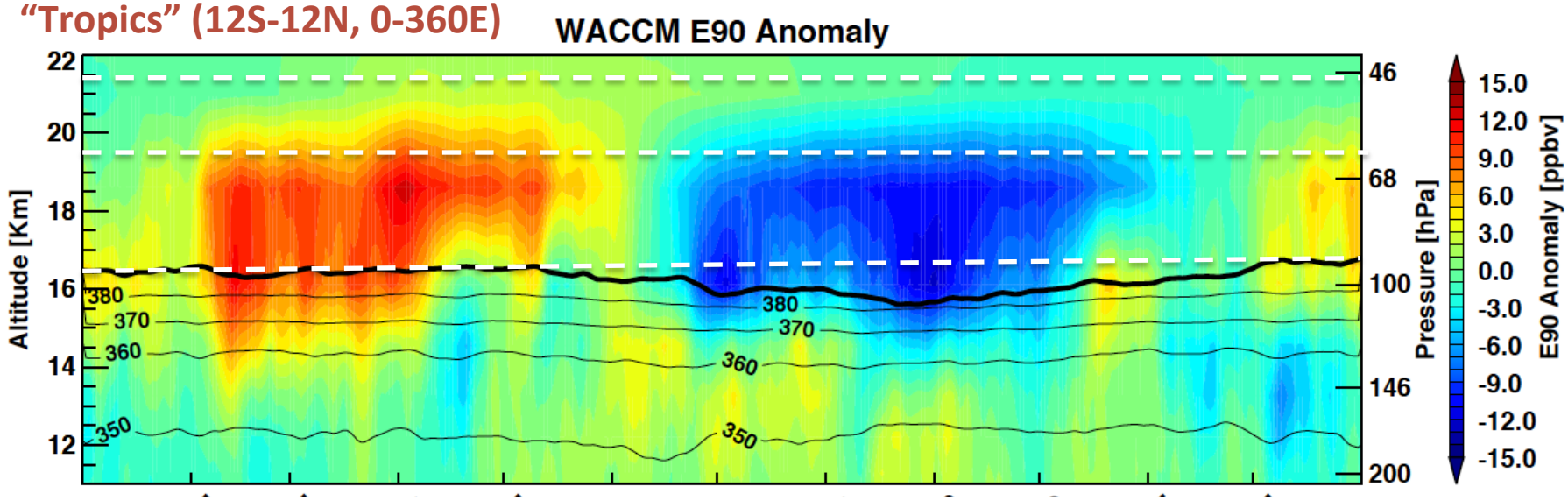


Seasonal variation of the “tropical pipe”

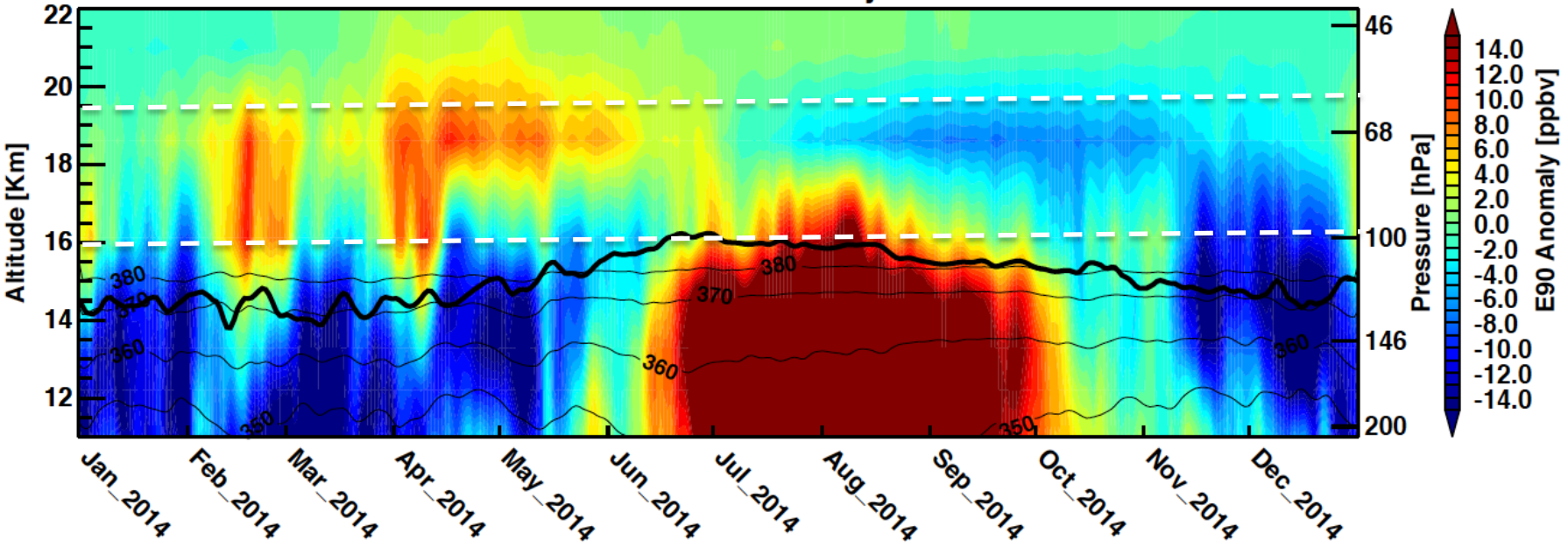



"Tropics" (12S-12N, 0-360E)
WACCM E90
Altitude [Km]
Pressure [hPa]
E90 [ppbv]
380
370
360
350
"ASM", (15N-35N, 0-120 E)
WACCM E90
Jan_2014
Feb_2014
Mar_2014
Apr_2014
May_2014
Jun_2014
Jul_2014
Aug_2014
Sep_2014
Oct_2014
Nov_2014
Dec_2014

"Tropics" (12S-12N, 0-360E)



"ASM", (15N-35N, 0-120 E)



Summary and Conclusions

- ASM creates **a "Bubble" of tropospheric air above the mean tropopause**. The potential temperature of the ASM tropopause is higher than that in the equatorial tropics, which allows the air in the bubble shed into overworld stratosphere isentropically
- **The uplifting of the BL pollutants to the tropopause level occurs primarily at the southern edge of the Tibetan plateau**, NE India and Nepal, directly north of the Bay of Bengal.
- Eddy shedding at UT associated with the **east-west oscillation is the primary mode** for filling the uplifted BL air mass into the entire anticyclone
- Although the ASM region connect directly with the Brewer-Dobson ascending branch in the stratosphere, the NH summer minimum in B-D vertical motion makes the vertical transport of ASM airmass inefficient. Quasi-isentropic transport maybe a primary mode for air from ASM anticyclone to enter stratosphere.