South Asian High and Upper-troposphere Temperature Maximum in Summer

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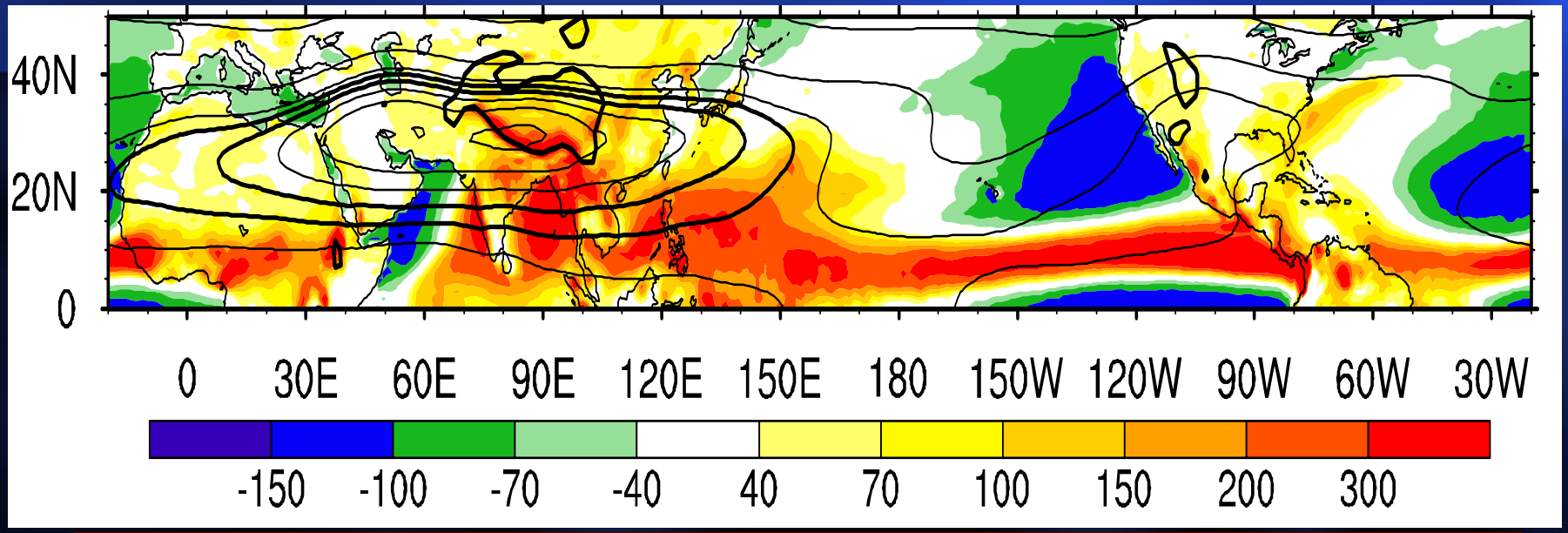
200-hPa H & vertical integrated Q



- Diabatic heating ~ formation of SAH (Liu et al., 2001, 2004; Wu and Liu 2003, Wu et al., 2009);

??: Location of UTTM

Variation of SAH

Outline

1. Introduction
2. Location of the UTTM
3. Variation of SAH – biweekly
4. Summary

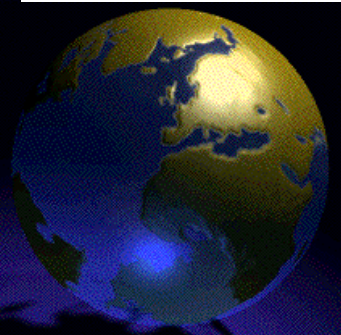
Overlapping of UTTM and ridgeline (u=0):

- geostrophic balance
- hydrostatic balance
- thermal wind relation

$$fu = -\partial\phi / \partial y$$

$$\partial\phi / \partial \ln p = -RT$$

$$\frac{\partial u}{\partial \ln p} = \frac{R}{f}\left(\frac{\partial T}{\partial y}\right)$$

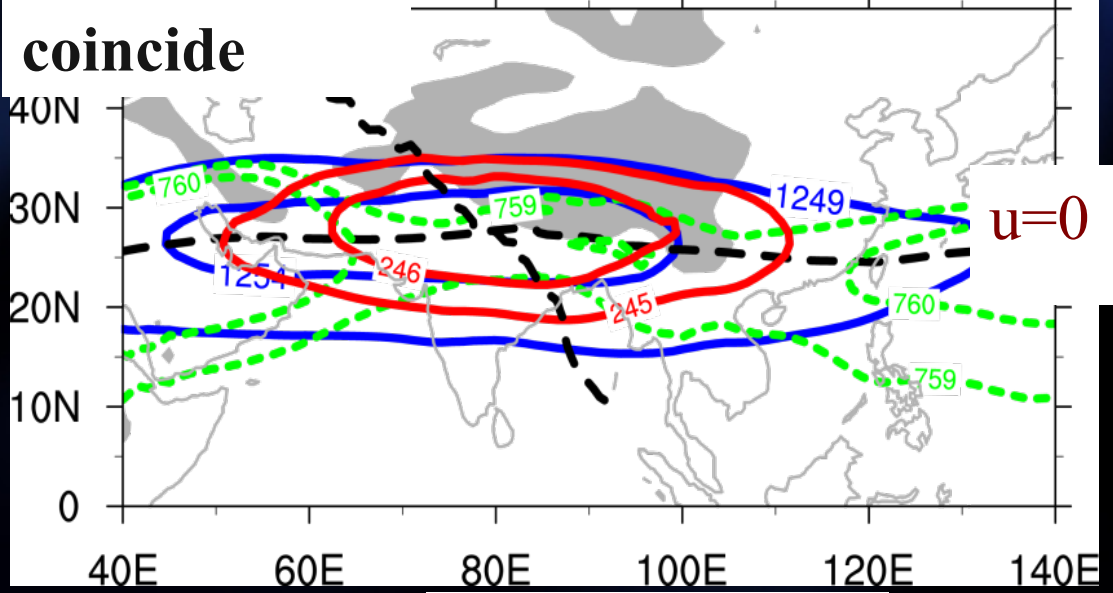


200 H

200-400 T

coincide

$$\frac{\partial u}{\partial \ln p} = \frac{R}{f}\left(\frac{\partial T}{\partial y}\right) < 0$$



$$\frac{\partial u}{\partial \ln p} = \frac{R}{f}\left(\frac{\partial T}{\partial y}\right) > 0$$

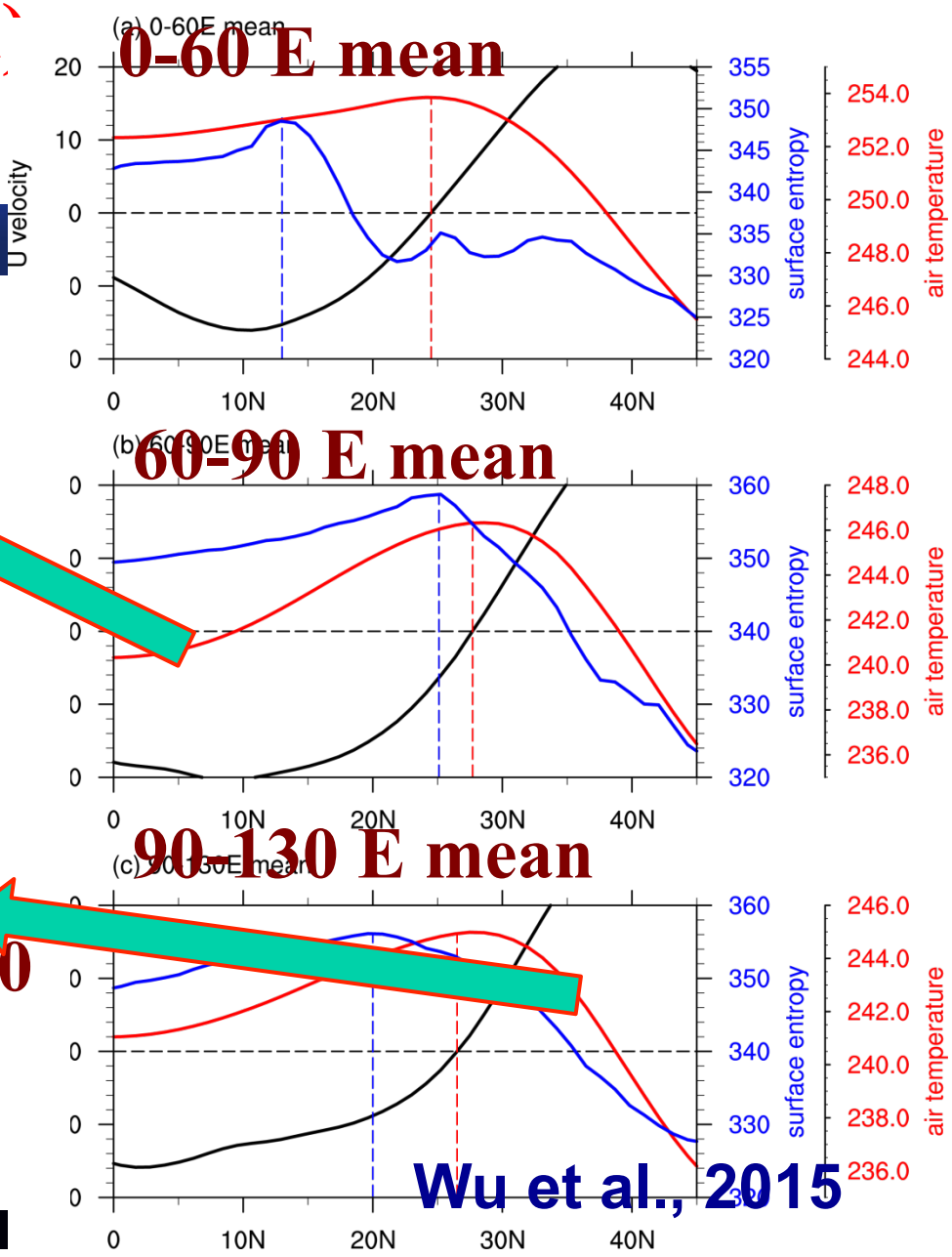
- **Latitude Location**

Hadley circulation demonstrated that in response to an axisymmetric diabatic heating, atmospheric circulation adopts two distinct regimes:

- **Thermal equilibrium (TE) regime in extra- tropics**
- **Angular momentum conservation (AMC) regime in the tropics.**

ERA40 July mean profiles of surface entropy θ_{SE} (blue), 200-400hPa T(red) 200hPa u (black)

- AMC: small planetary vorticity, large Rossby deformation radius ~ vertical easterly shear ~ $T_y>0$
- Thermal equilibrium: Large f, small Rossby deformation radius ~ $T_y<0$
- Max. θ_{SE} ~ easterly shear in upper troposphere



Modified Gill's Model

Original Gill model–in contrast to the PV theory at upper troposphere in the subtropics

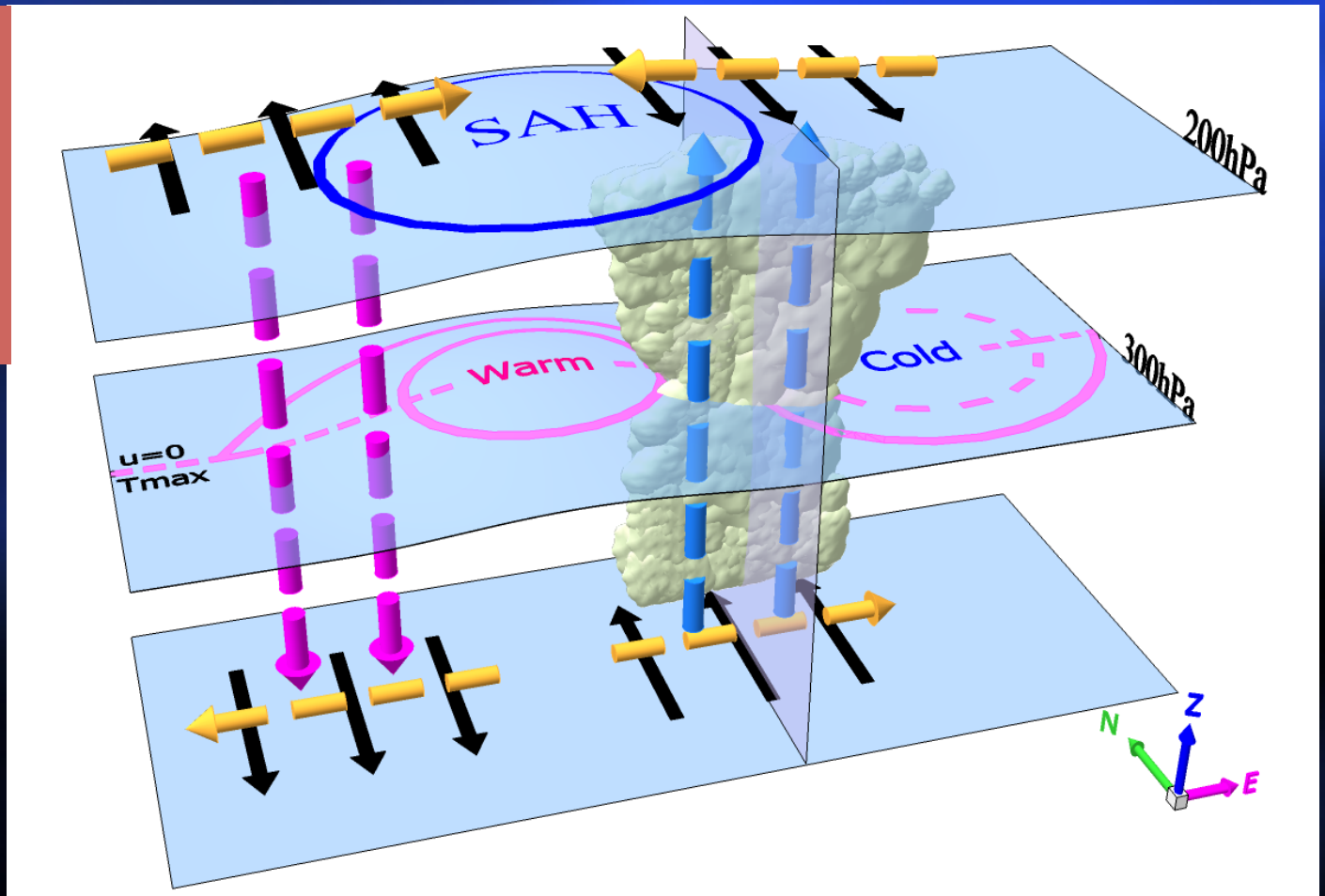
$$\begin{cases} \varepsilon u - \dfrac{y}{2} v = -\dfrac{\partial p}{\partial x} \\ \varepsilon v + \dfrac{y}{2} u = -\dfrac{\partial p}{\partial y} \\ \varepsilon p + \dfrac{\partial u}{\partial x} + \dfrac{\partial v}{\partial y} = -Q \end{cases}$$

Q – Vorticity forcing Qz

$$\begin{cases} \varepsilon u - \dfrac{y}{2} v = -\dfrac{\partial p}{\partial x} \\ \varepsilon v + \dfrac{y}{2} u = -\dfrac{\partial p}{\partial y} \\ \dfrac{1}{2} v = \dfrac{y}{2} \dfrac{\partial Q}{\partial z} + \dfrac{y}{2} \varepsilon p - \varepsilon \zeta \end{cases}$$

T-Q_Z Mechanism

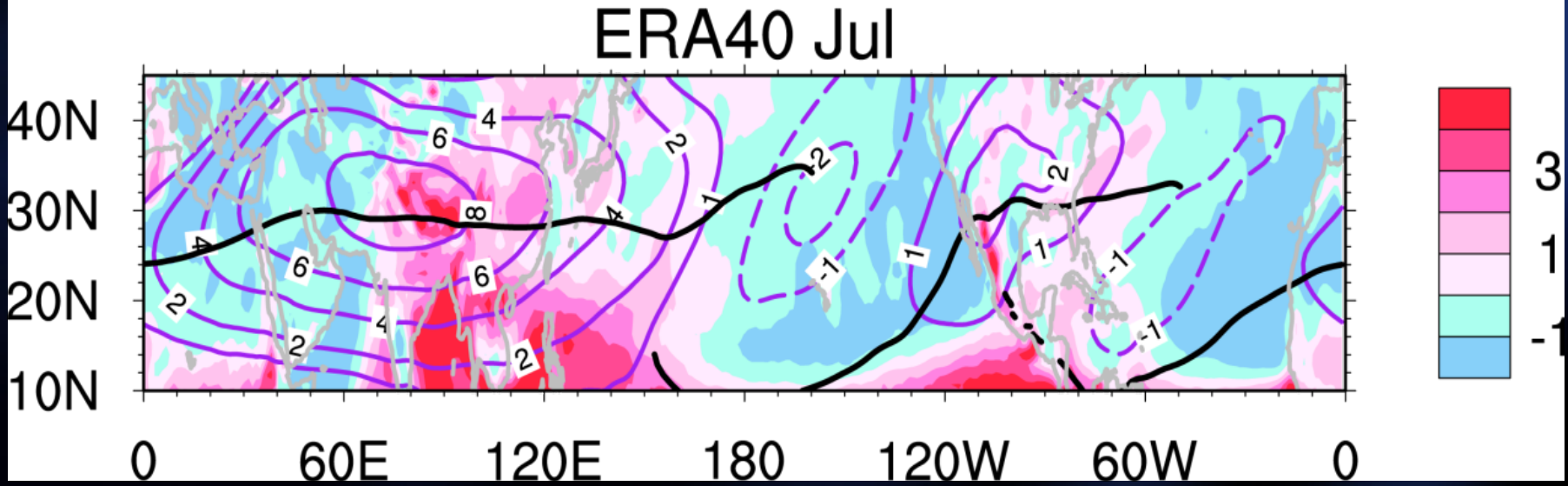
T-Q_Z Mechanism Schematic Diagram



EAST Eurasian Strong monsoon CO - vertical northerly shear - eastward **Tx<0** in upper troposphere - forming the UTTM and aloft SAH to the west of the heating. **WEST** vertical southerly shear - eastward **Tx>0** , due to surface SH and longwave radiation cooling - UTTM and SAH on the eastern end of the cooling.

T-Q_Z Mechanism

200-400 T deviation from 180-360 mean & Q



Summary 1

- In response to an axisymmetric diabatic heating, circulation adopts two distinct regimes: thermal equilibrium (TE) in extra-tropics; Angular momentum conservation, (AMC) in tropics, UTTM and SAH are located in subtropics;
- Longitude location of the UTTM is results of the circulation response to Q along the subtropics, and presents a T-Q_Z relation: a warm center is located between monsoon heating in its east and a longwave radiation cooling in its west.

Outline

1. Introduction
2. Latitude location of the UTTM
3. Variation of SAH – biweekly
4. Summary

Summer：Quasi-biweekly oscillation of Tibetan High Krishnamurti et al. ,1973; Krishnamurti and Bhalme, 1976; Shun, 1979; Tao and Ding, 1981;

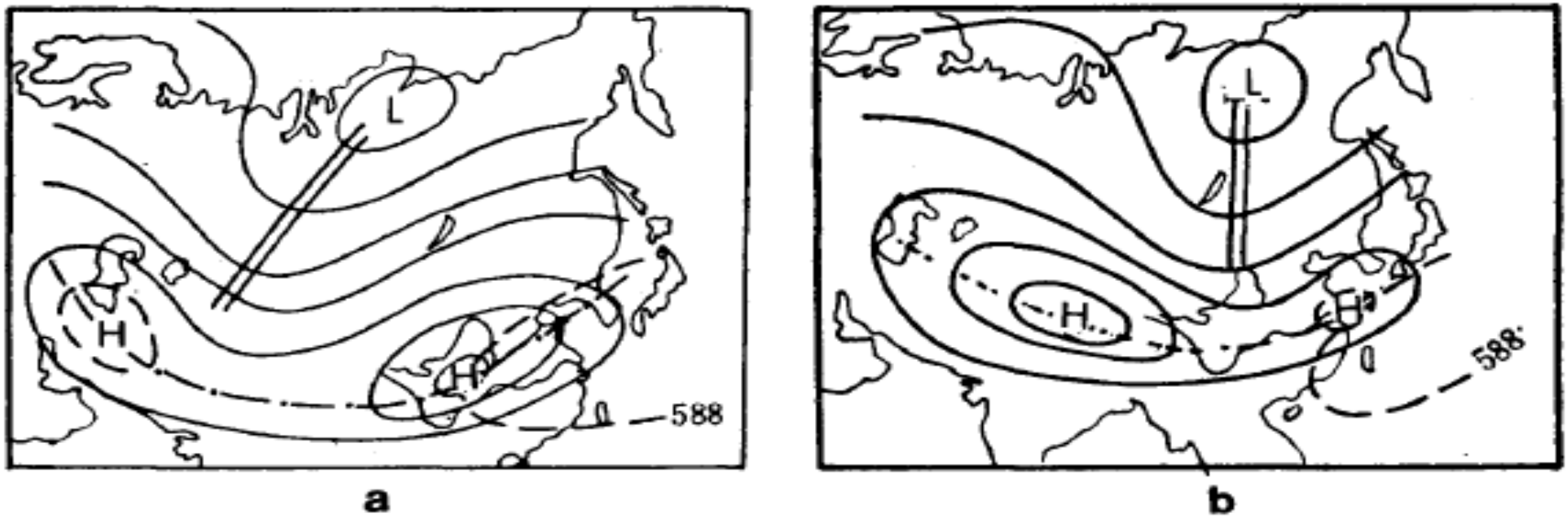


FIG. 6. Two major patterns of the Tibetan high at (a) 200 mb; and (b) 100 mb.

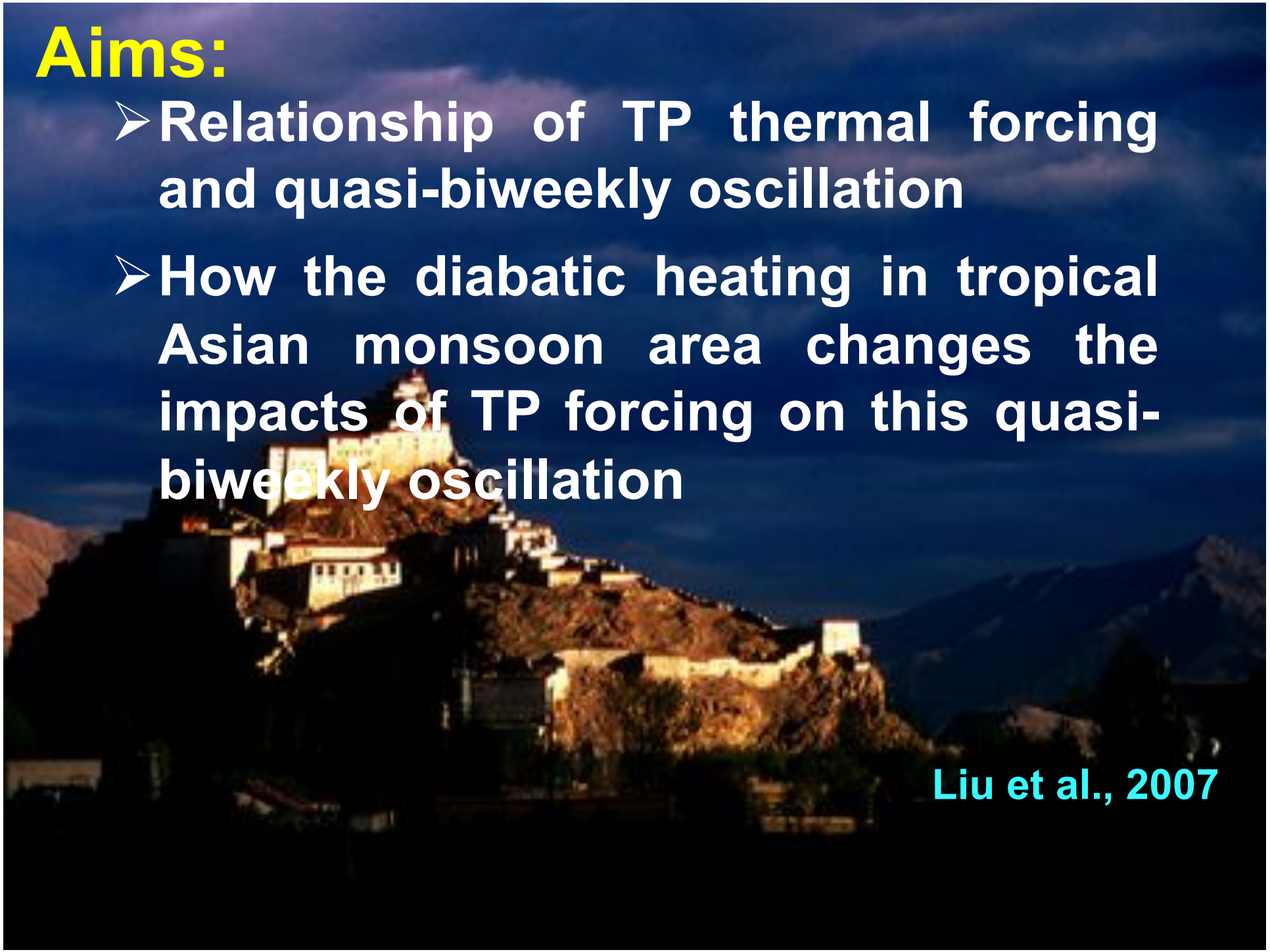
(Tao and Zhu, 1964)

Question:

What is mechanism of the Biweekly Oscillation of SAH?

Aims:

- Relationship of TP thermal forcing and quasi-biweekly oscillation
- How the diabatic heating in tropical Asian monsoon area changes the impacts of TP forcing on this quasi-biweekly oscillation



Liu et al., 2007

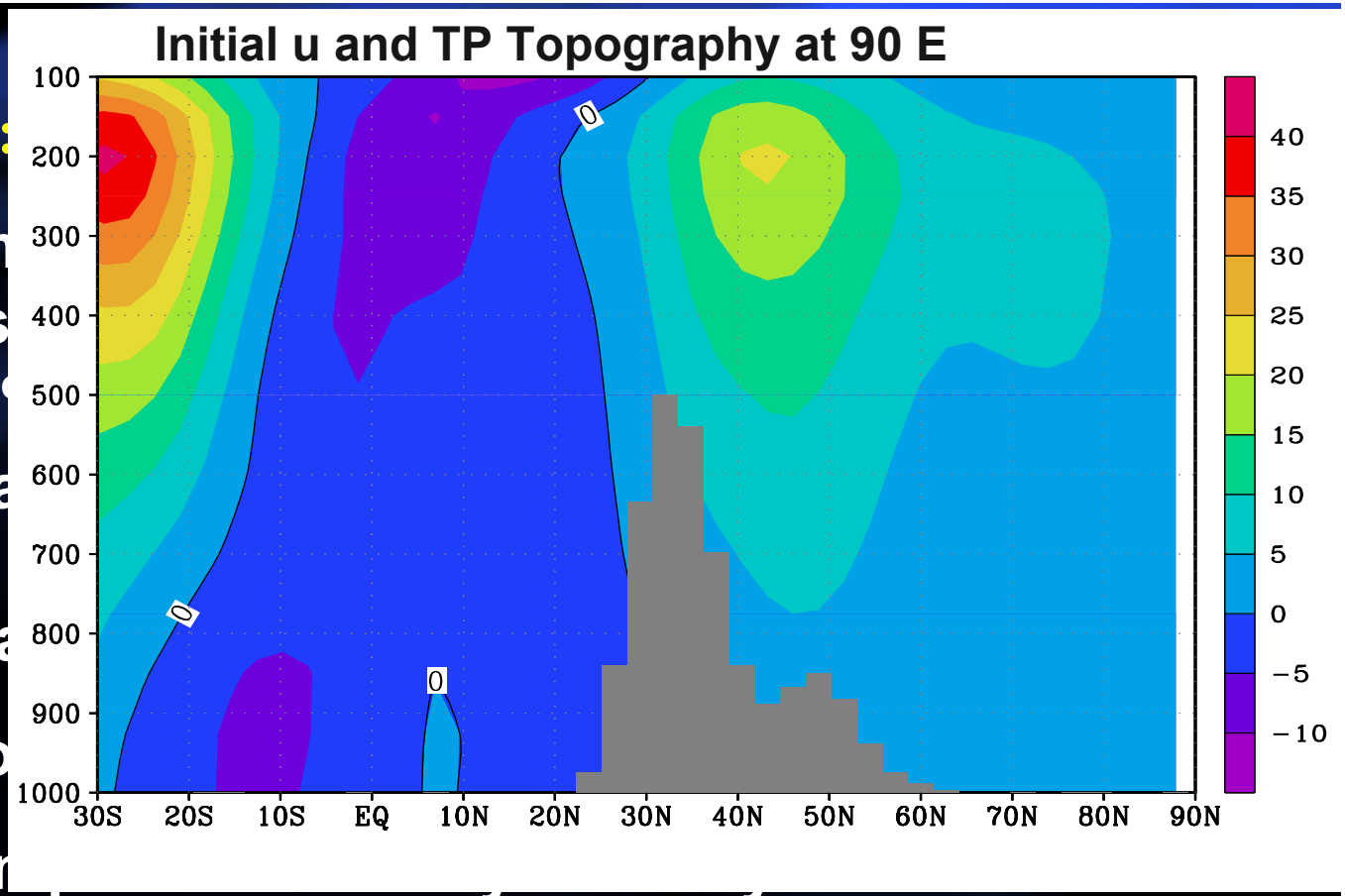
MODEL:

Interm
atmos
Meteorol

adiaba
in the
vertica

Fix zo

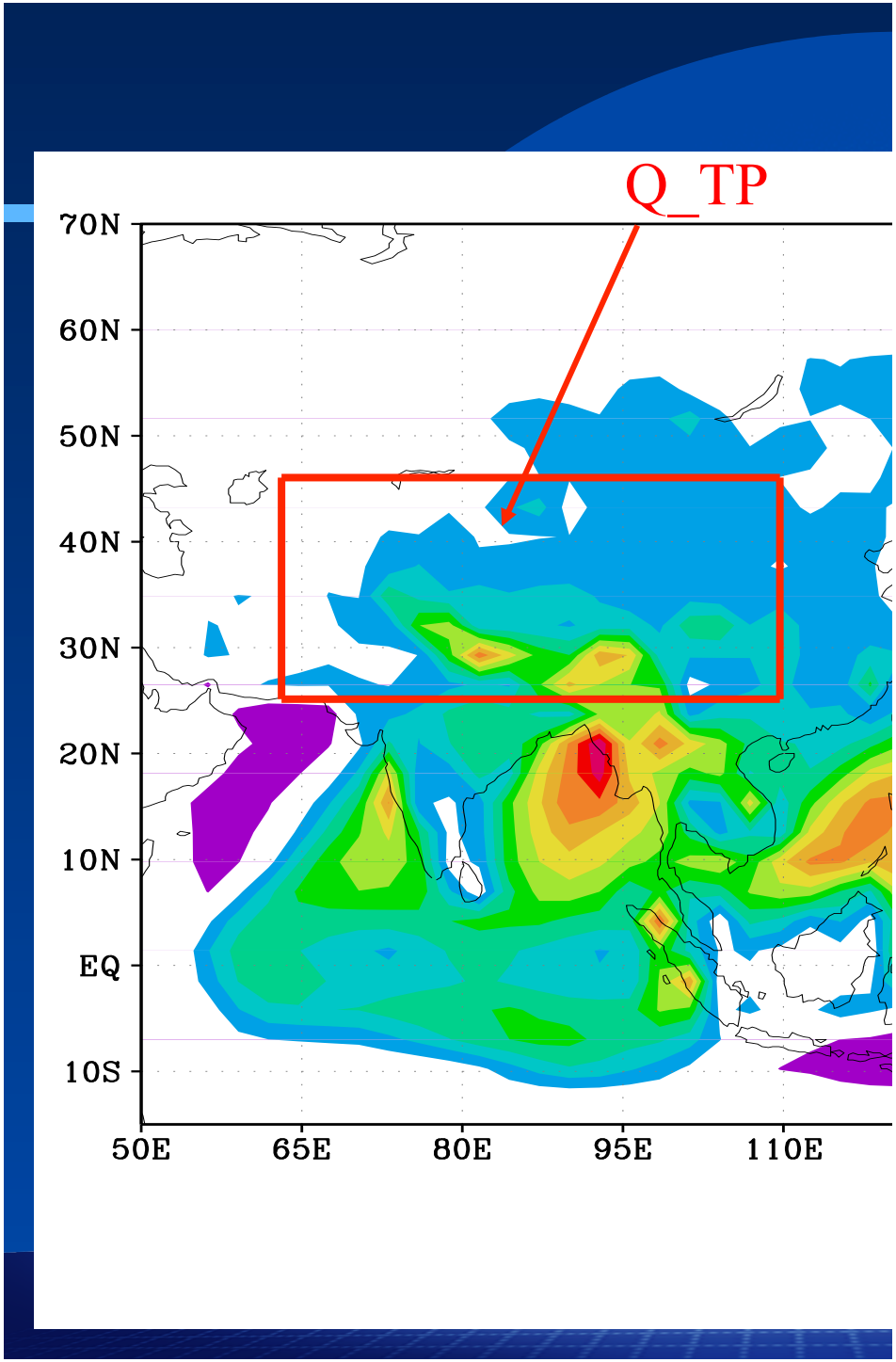
Q is ir

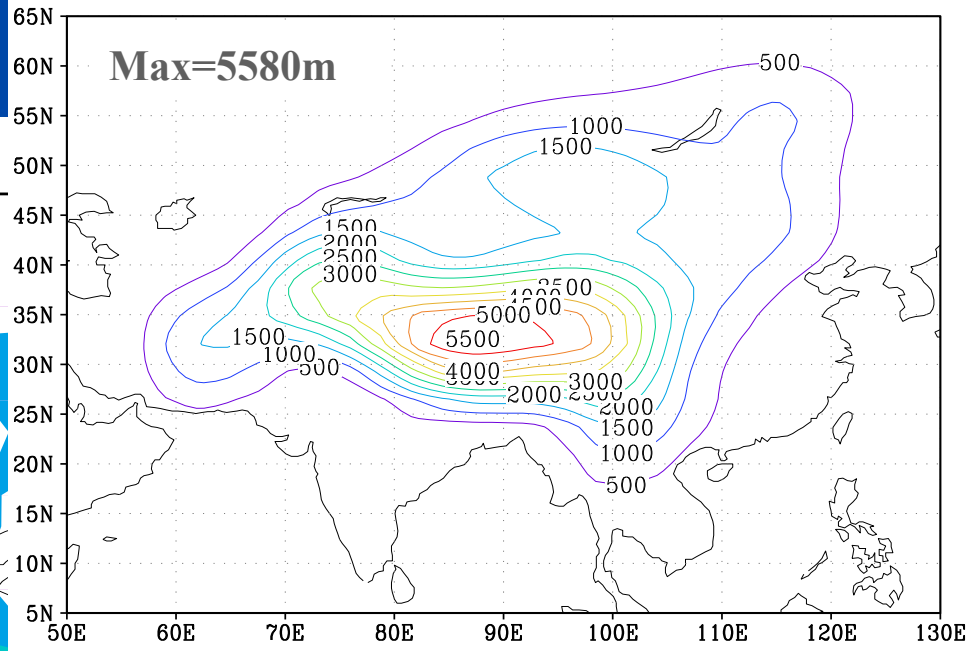


DATA:

Era-15 JJA climatology 1979-1993

Era-40 Diabatic heating JJA 1979-2001


Q_TP
70N
60N
50N
40N
30N
20N
10N
EQ
10S
50E
65E
80E
95E
110E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65N
60N
55N
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45N
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30N
25N
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15N
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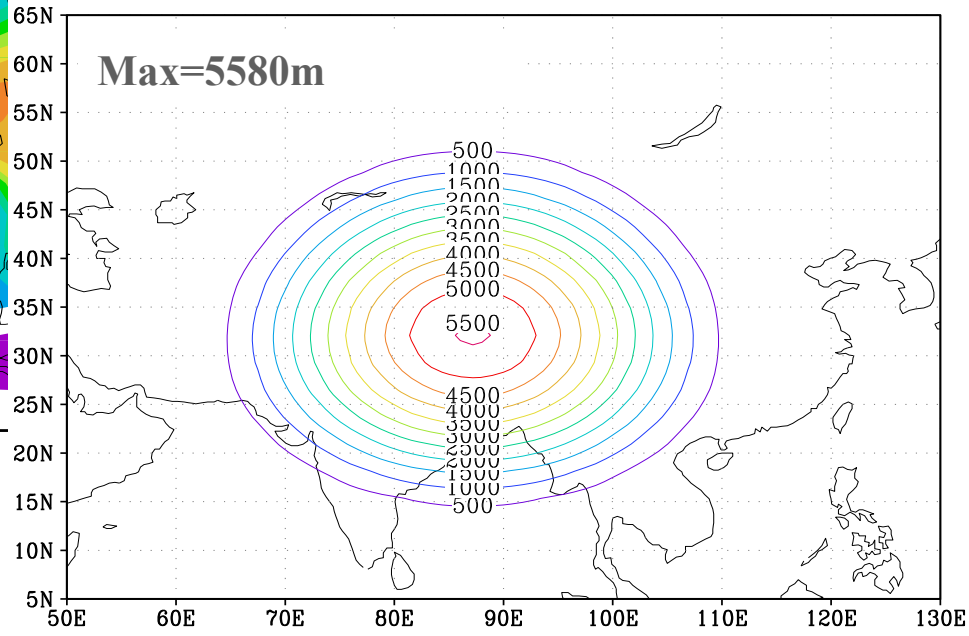
50E
60E
70E
80E
90E
100E
110E
120E
130E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35N
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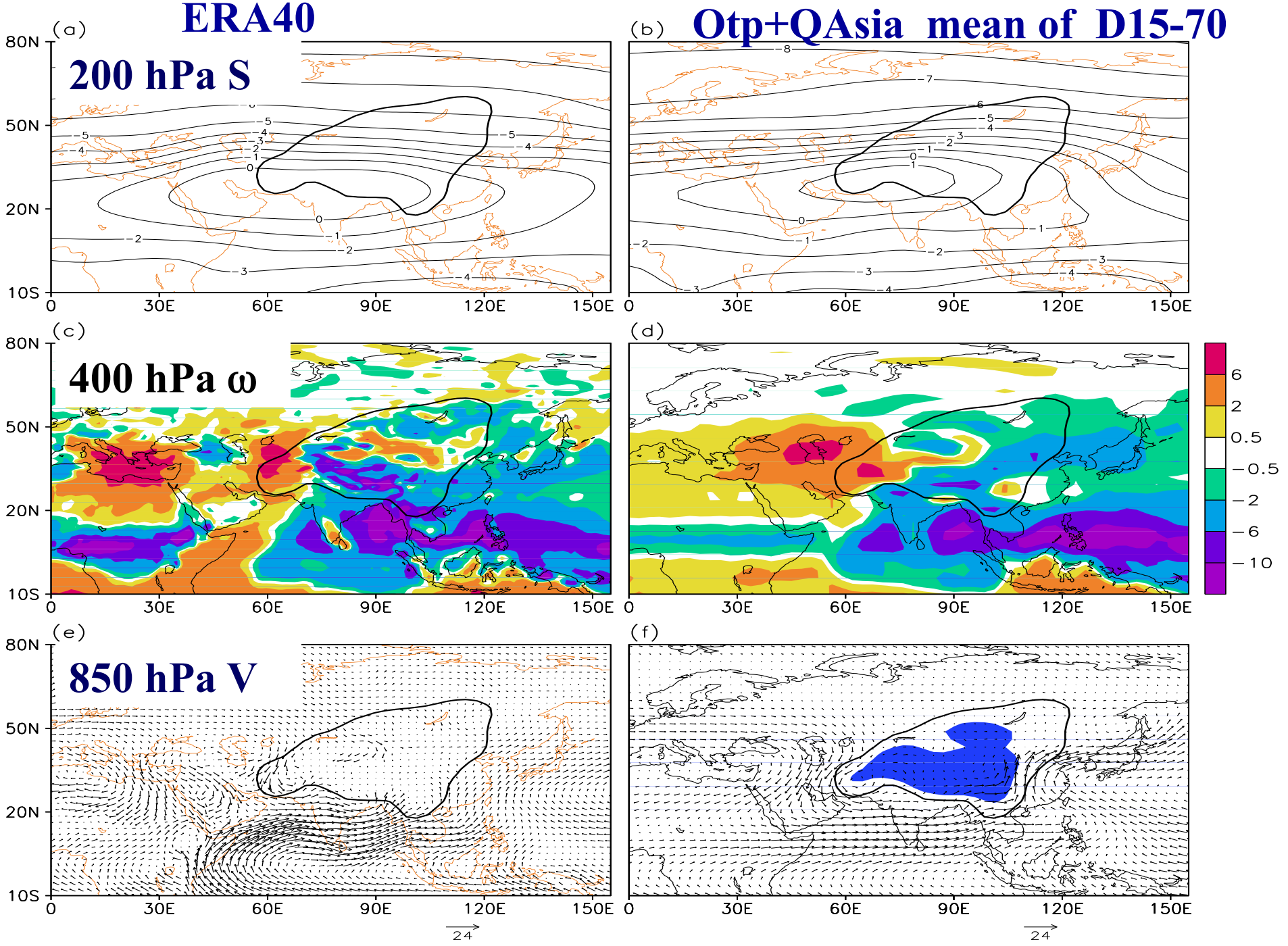
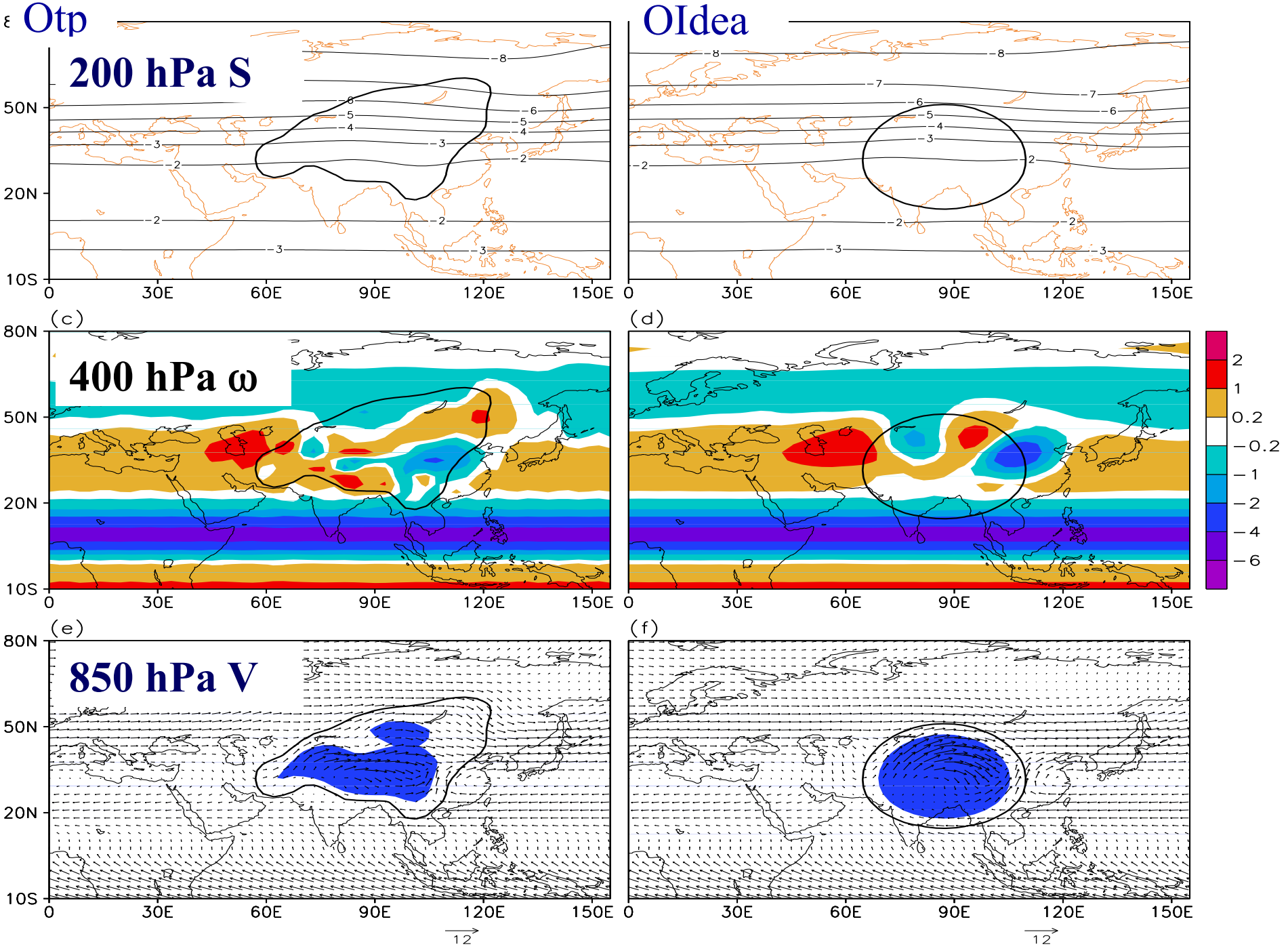
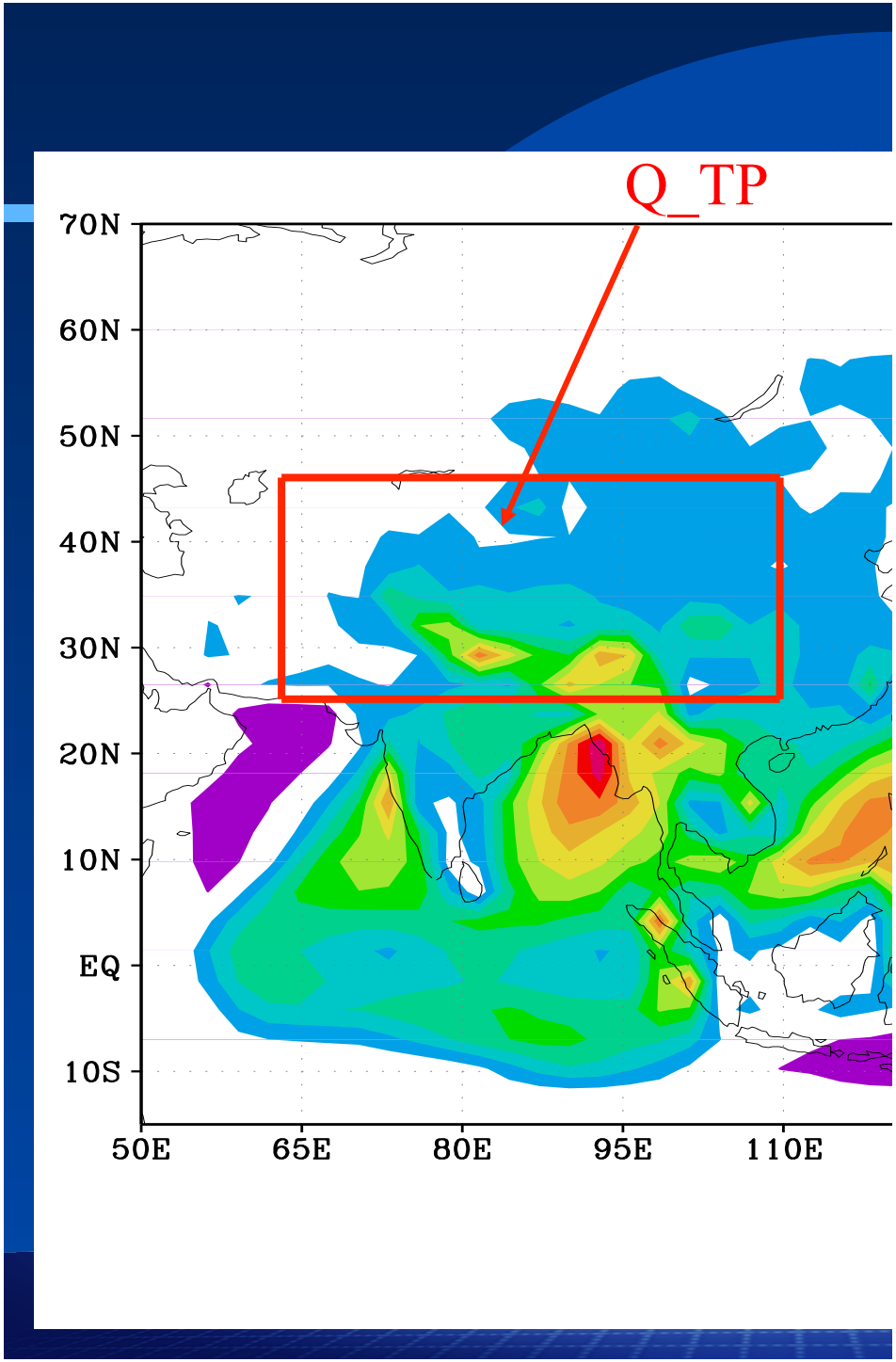
80E
90E
100E
110E
120E
130E


ERA40
Otp+QAsia mean of D15-70
(a)
200 hPa S
(b)
(c)
400 hPa ω
(d)
(e)
850 hPa V
(f)
80N
50N
20N
10S
0
30E
60E
90E
120E
150E
6
2
0.5
−0.5
−2
−6
−10
24
24


Otp
OIdea
200 hPa S
400 hPa ω
850 hPa V
(c)
(d)
(e)
(f)
50N
20N
10S
80N
0
30E
60E
90E
120E
150E
2
1
0.2
−0.2
−1
−2
−4
−6
12


Q_TP
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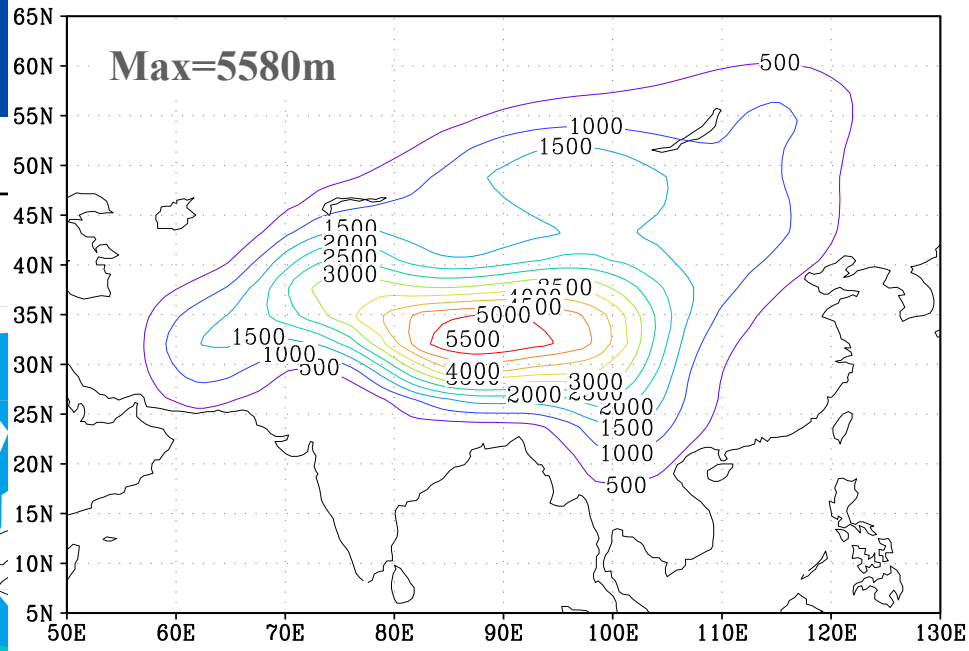
60N
50N
40N
30N
20N
10N
EQ
10S
50E
65E
80E
95E
110E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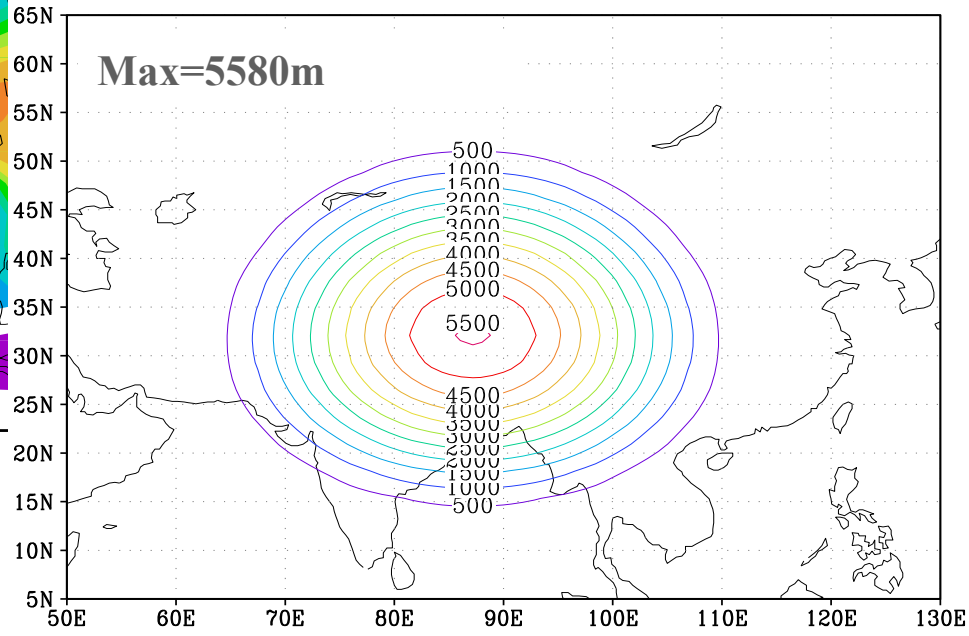
100E
110E
120E
130E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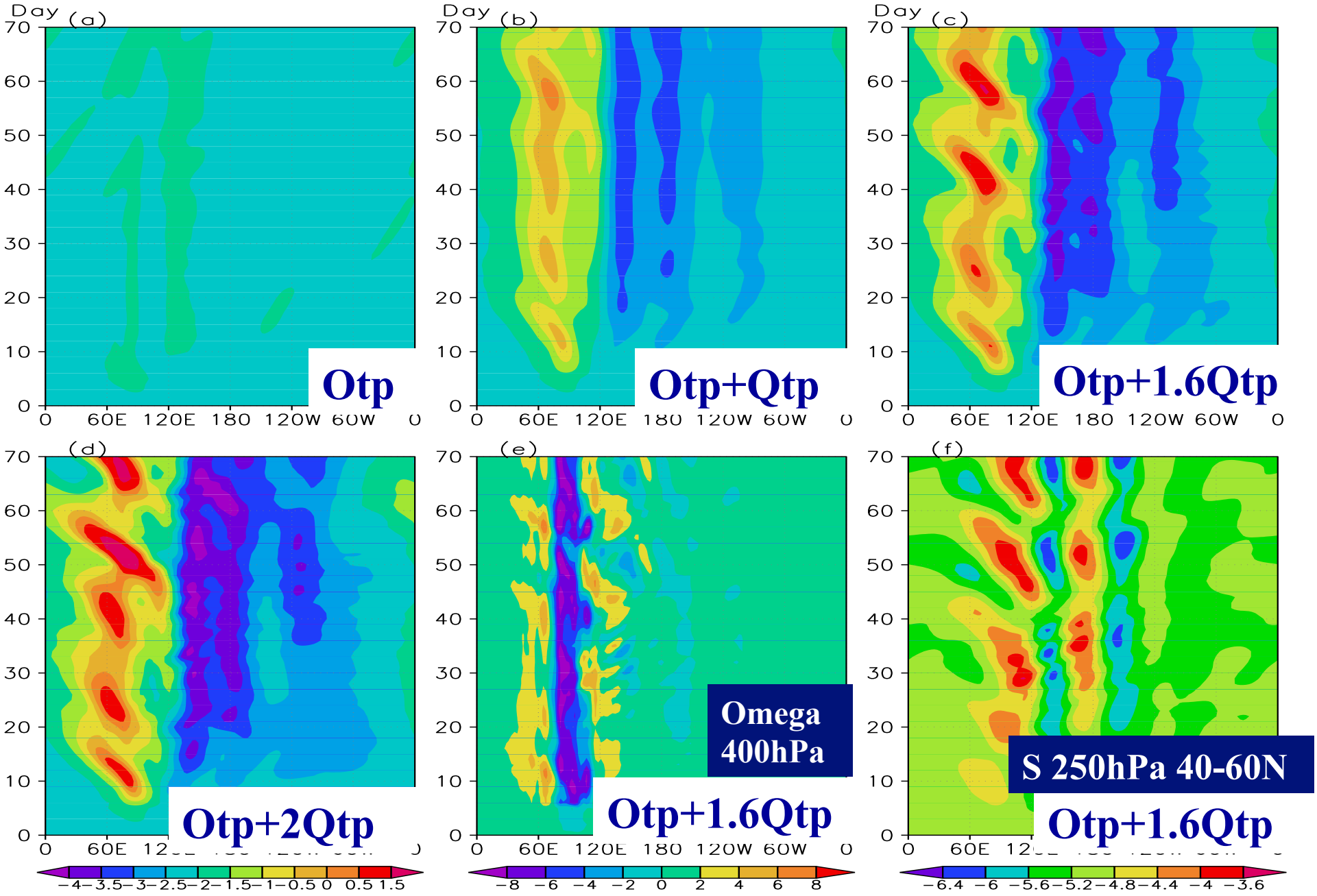
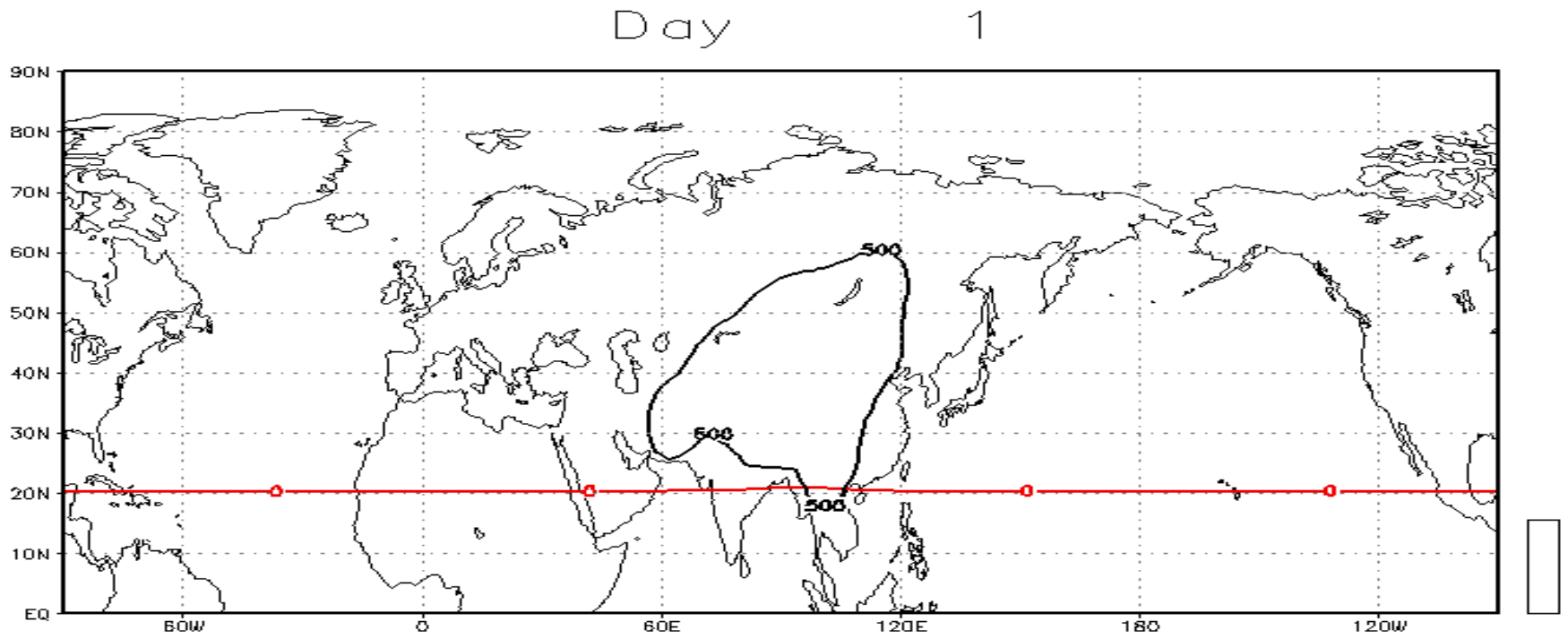
80E
90E
100E
110E
120E
130E

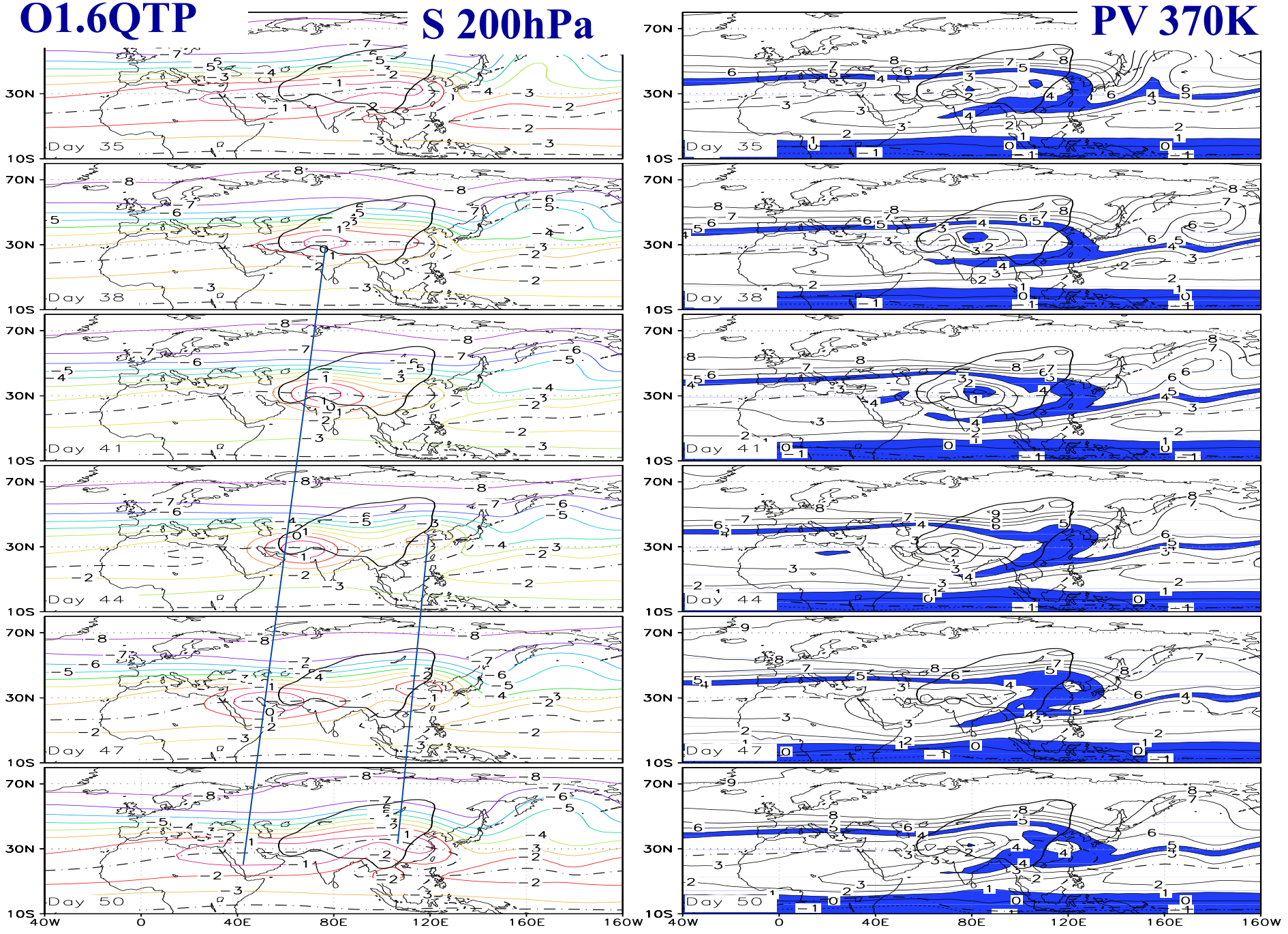
Streamfunction 200hPa Mean of 25-35N



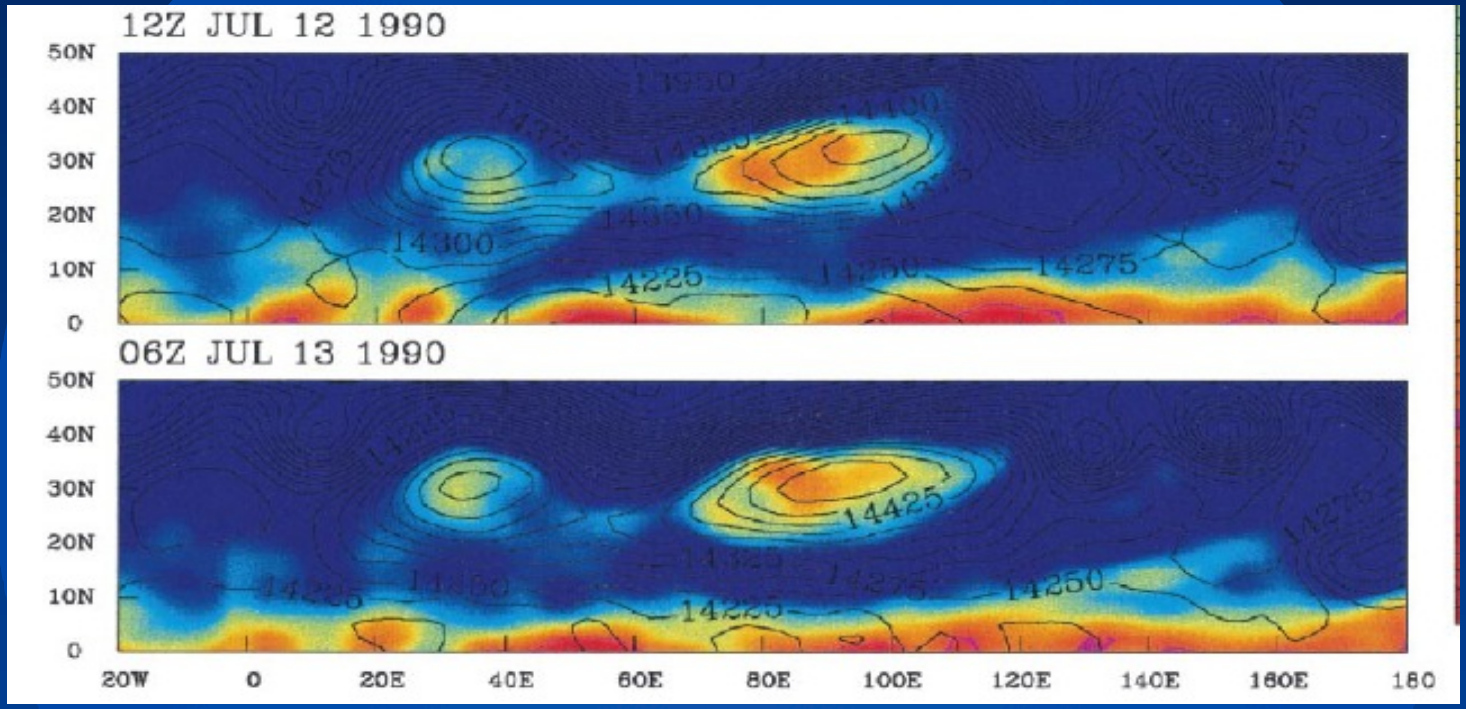
$O_{TP} + 1.6Q_{TP}$

StreamF. Deviation 200 hPa




O1.6QTP
S 200hPa
PV 370K
Day 35
Day 38
Day 41
Day 44
Day 47
Day 50
70N
30N
10S
40W
0
40E
80E
120E
160E
160W

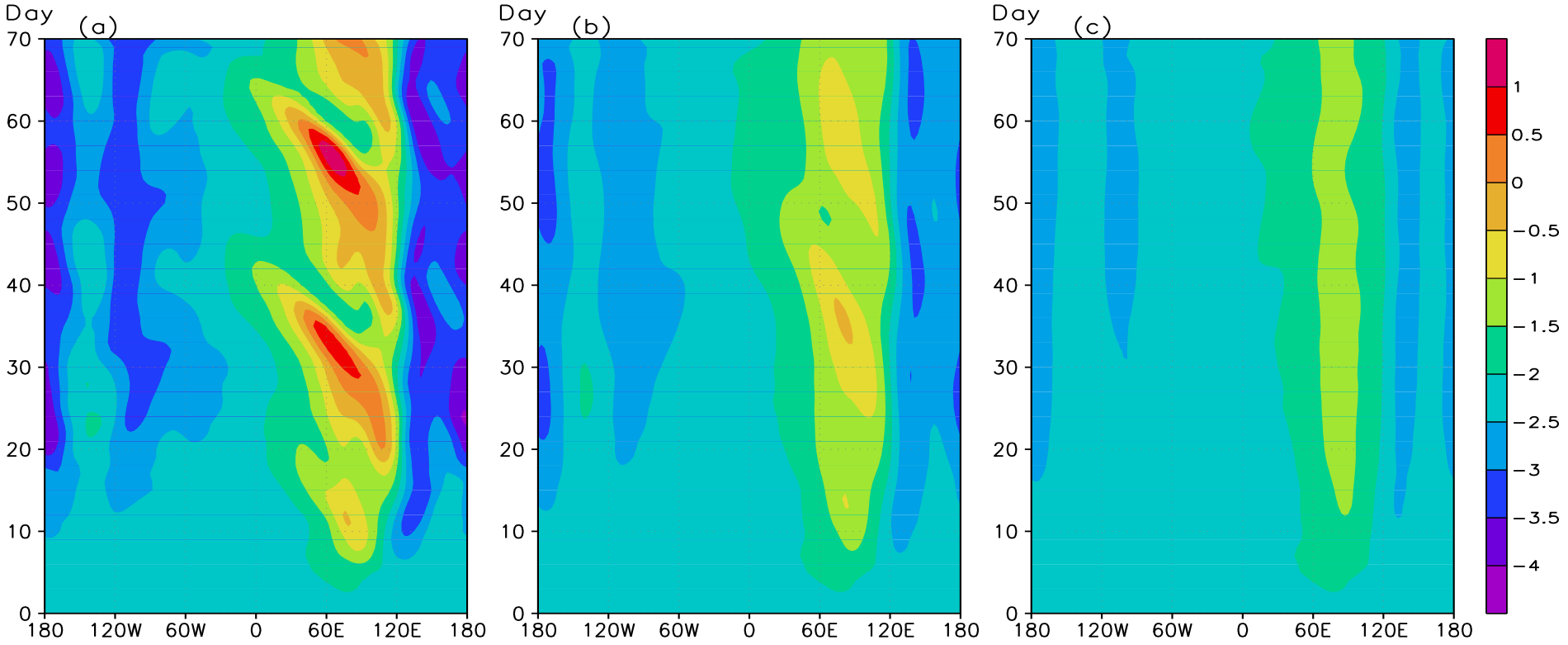
PV field at 370 K (shading) & H at 200 hPa (contours)



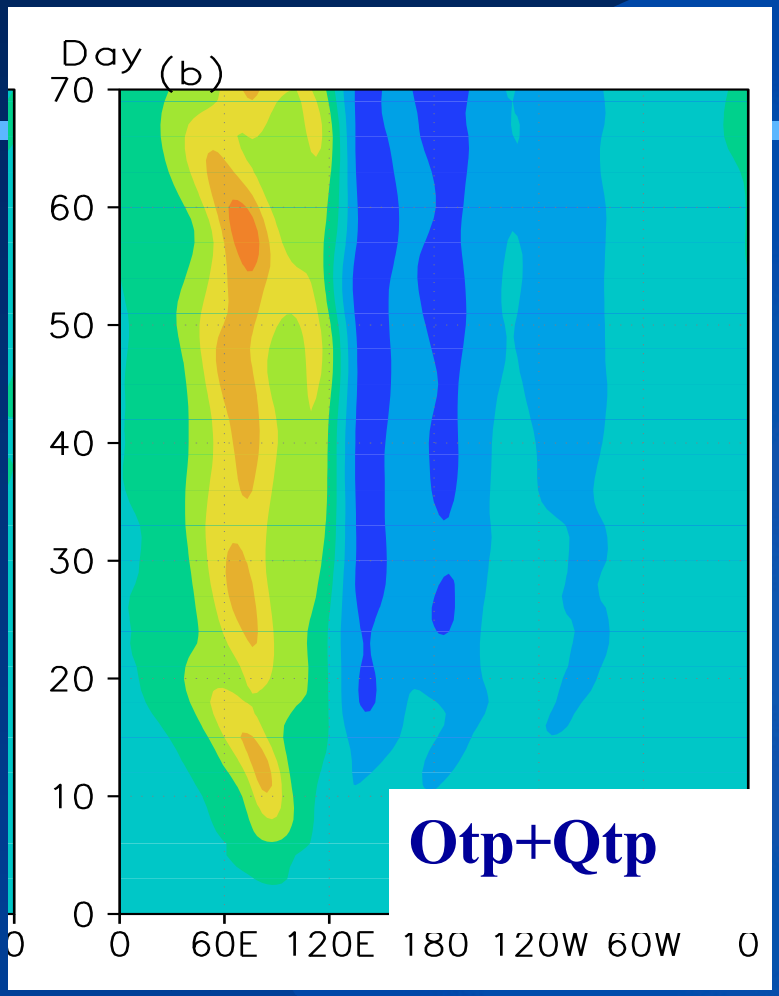
NCEP reanalysis: Westward shedding of anticyclonic eddies

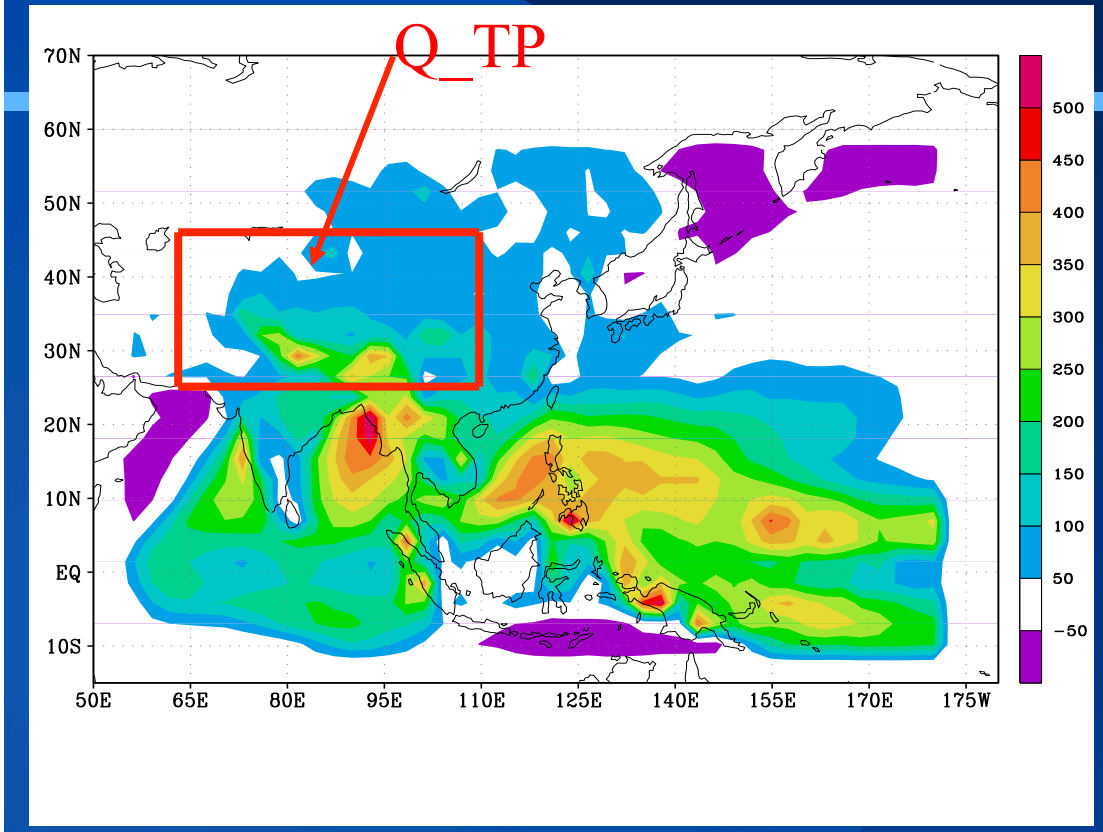
Hsu and Plumb (2000)

OideaTP+QideaTP **OideaTP+QideaTP/2** **OideaTP+QideaTP/4**

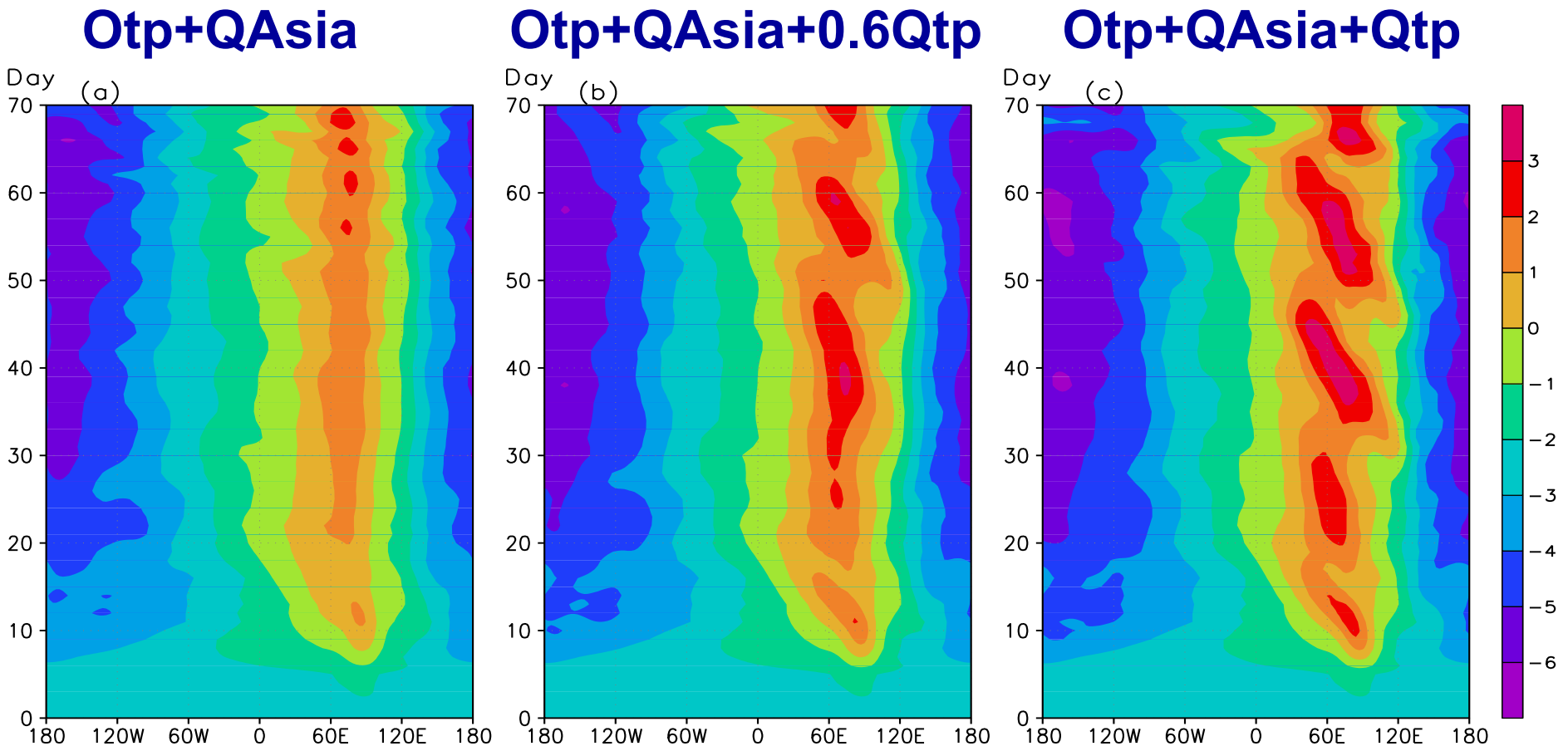


Streamfunction 200hPa **Mean of 25-35N**



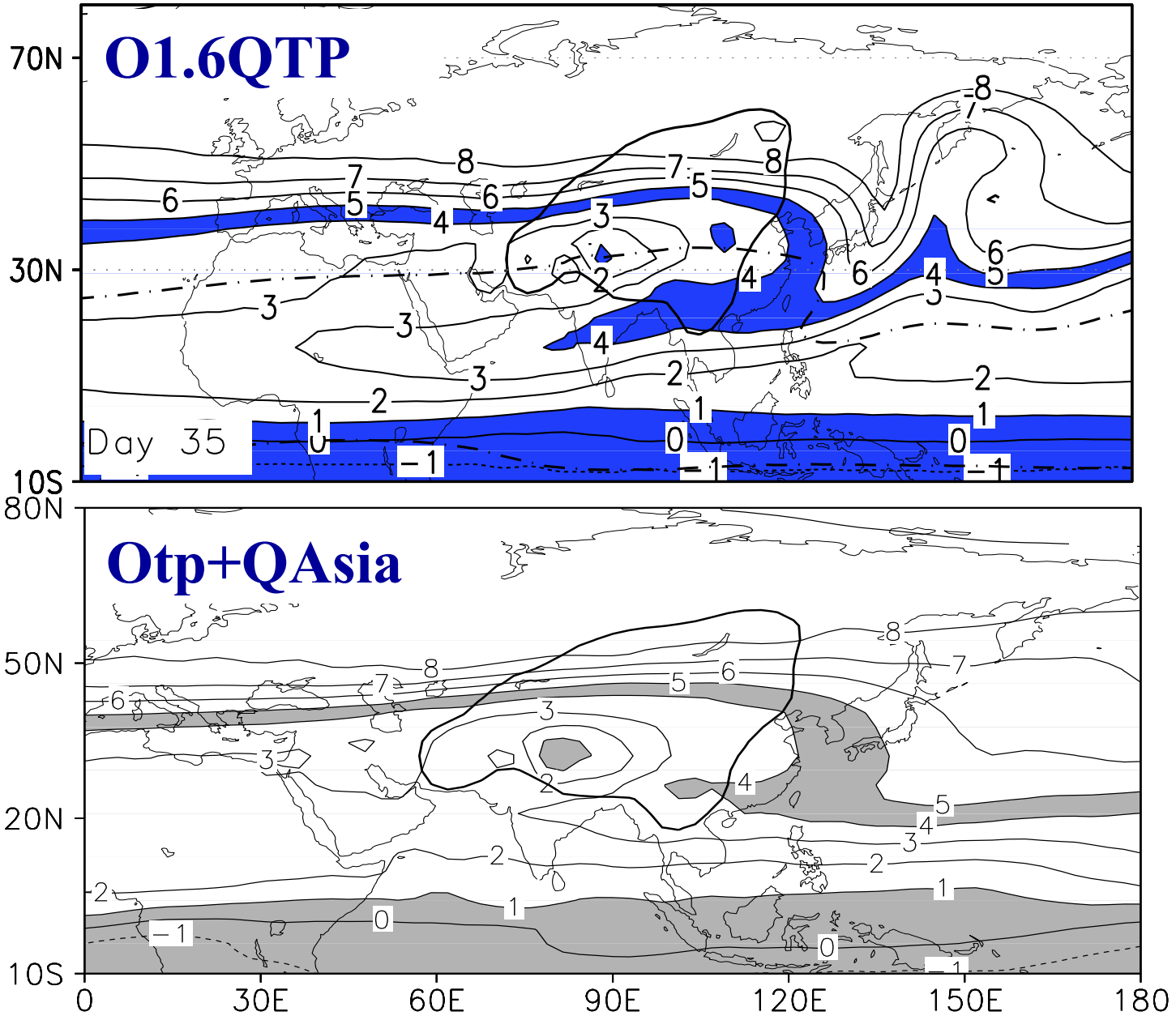


Streamfunction 200hPa
Mean of 25-35N



Stream Func. Mean of 25-35N

PV 370K


O1.6QTP
Day 35
70N
30N
10S
Otp+QAsia
80N
50N
20N
10S
0
30E
60E
90E
120E
150E
180

Oscillation of the South Asian High

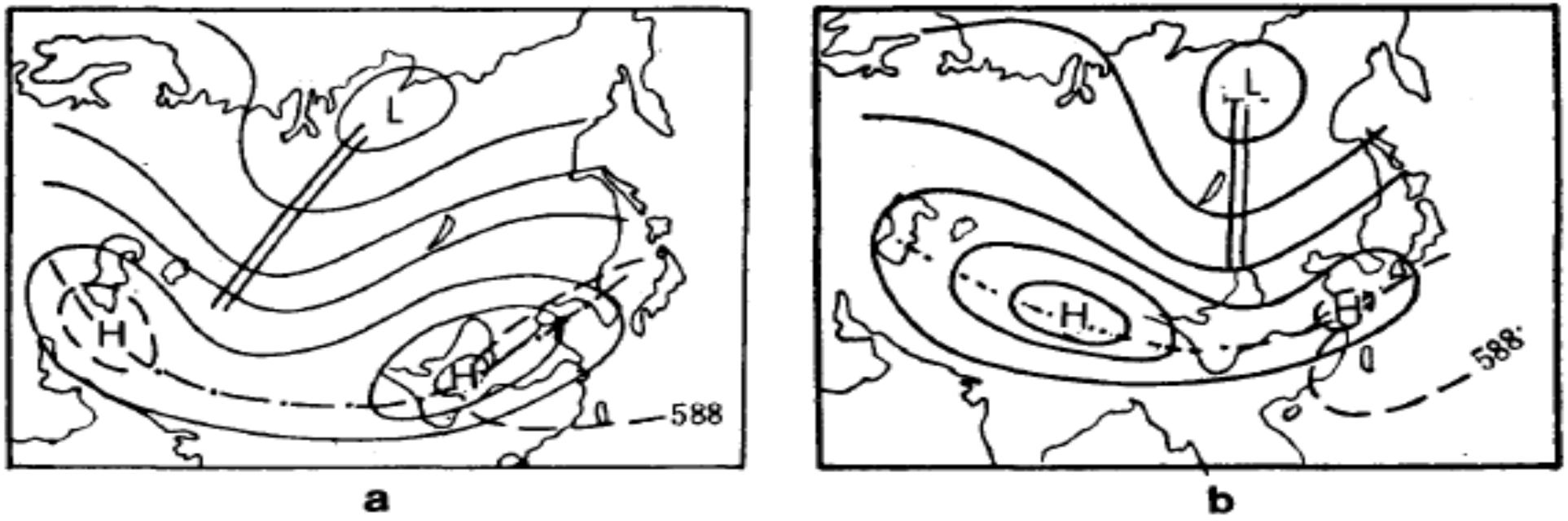
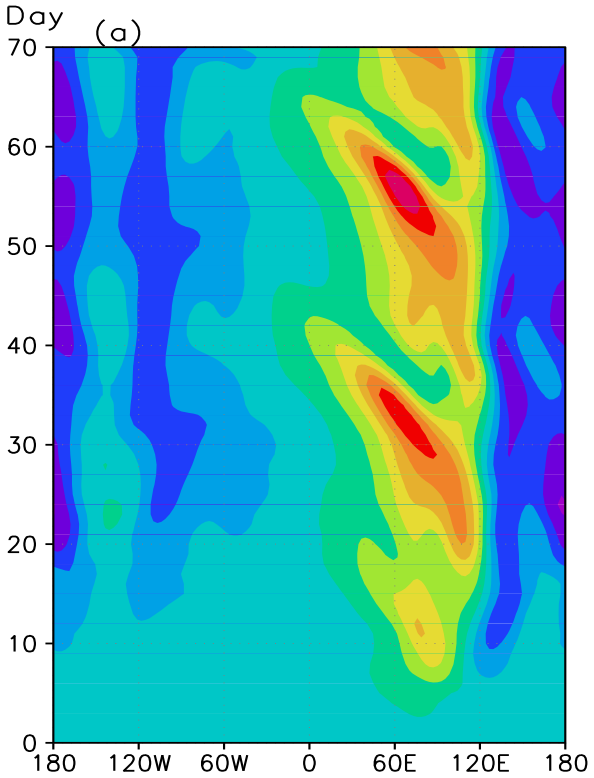


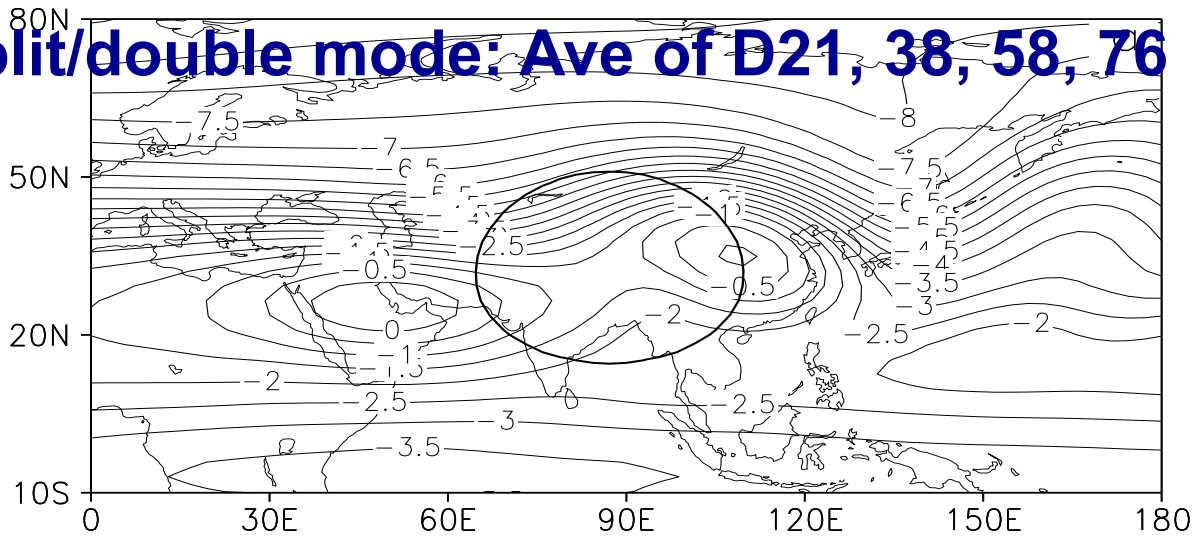
FIG. 6. Two major patterns of the Tibetan high at (a) 200 mb; and (b) 100 mb.

Composite based on phase of biweekly oscillation

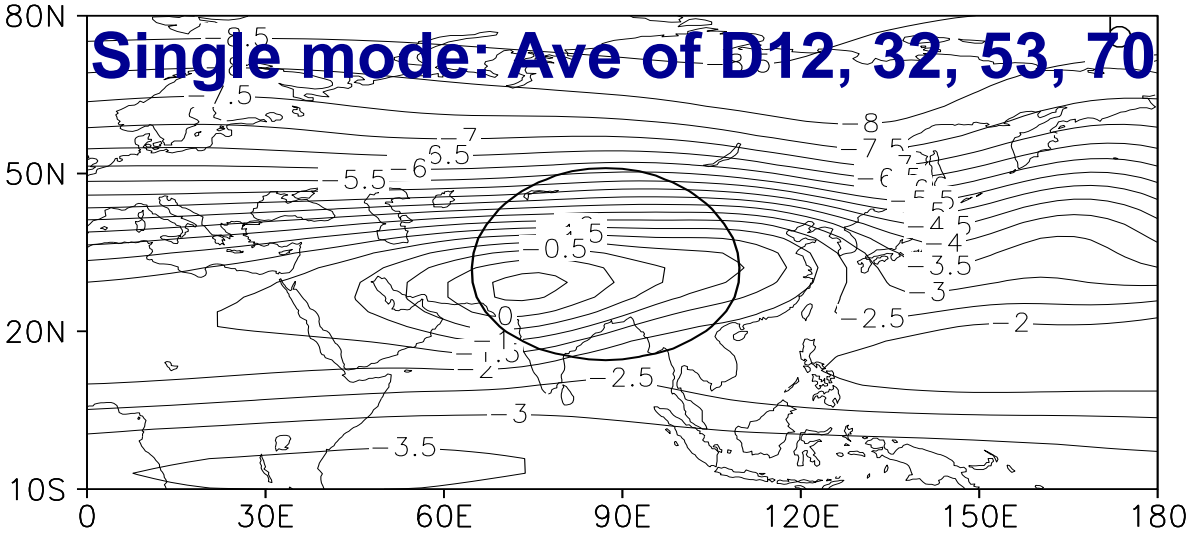
OideaTP+QideaTP



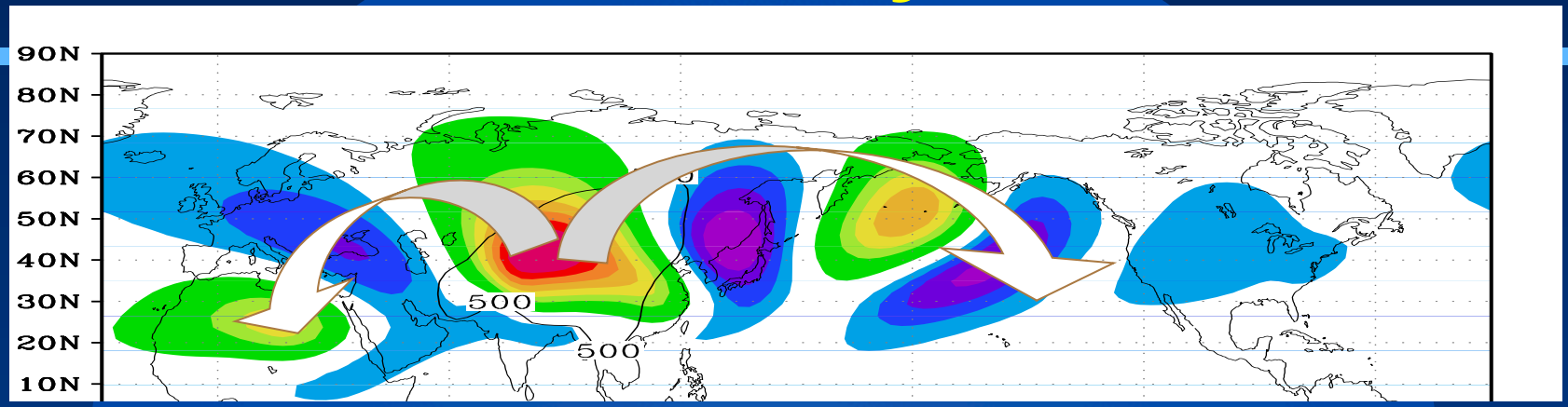
Split/double mode: Ave of D21, 38, 58, 76



Single mode: Ave of D12, 32, 53, 70



Summary 2



Faster **eastward** wave packet in westerlies

Slower **westward** propagation along weak winds and **quasi-biweekly oscillation** due to **stronger** TP heating

Liu et al., 2007

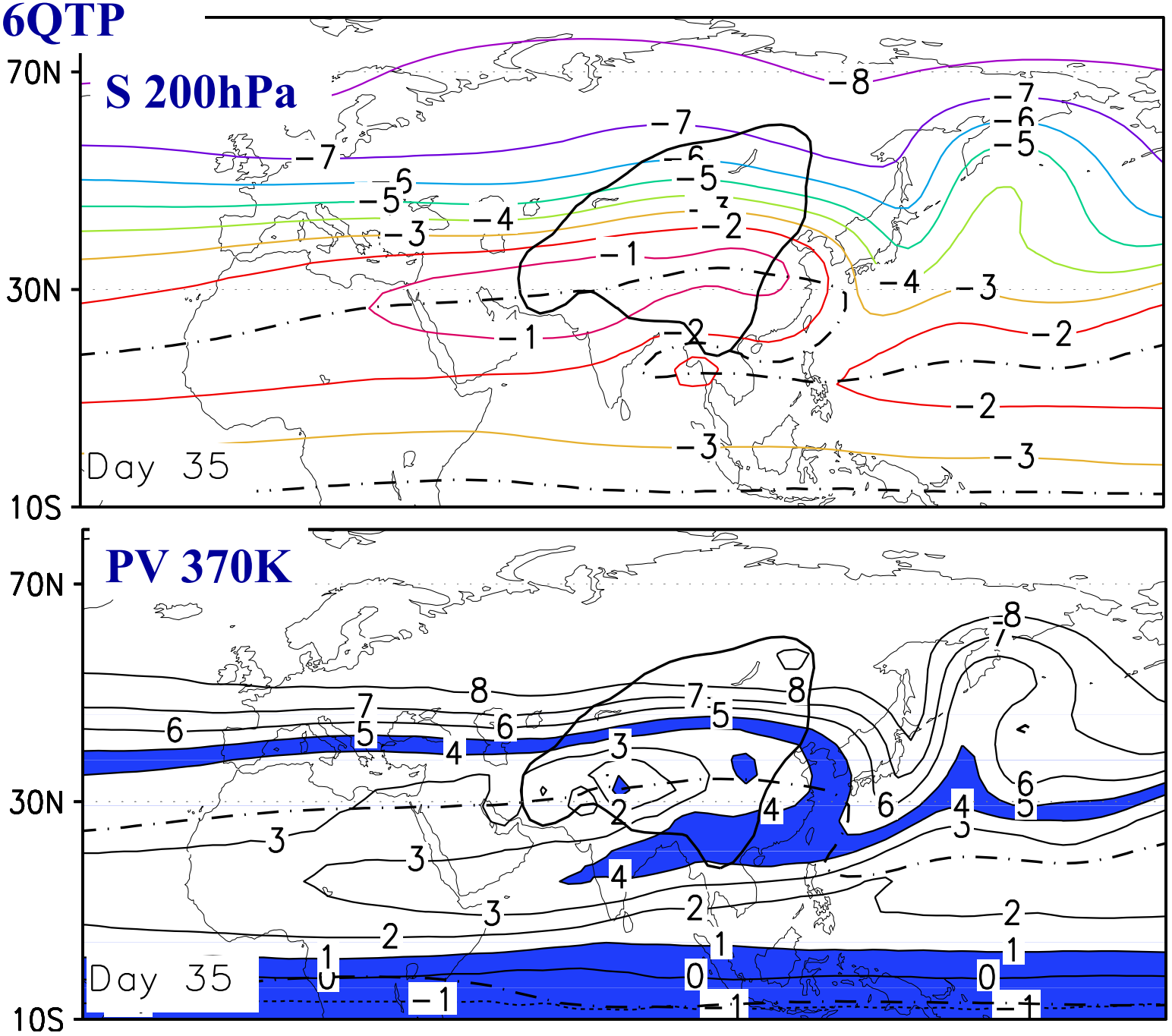
Thank You!

Ref:

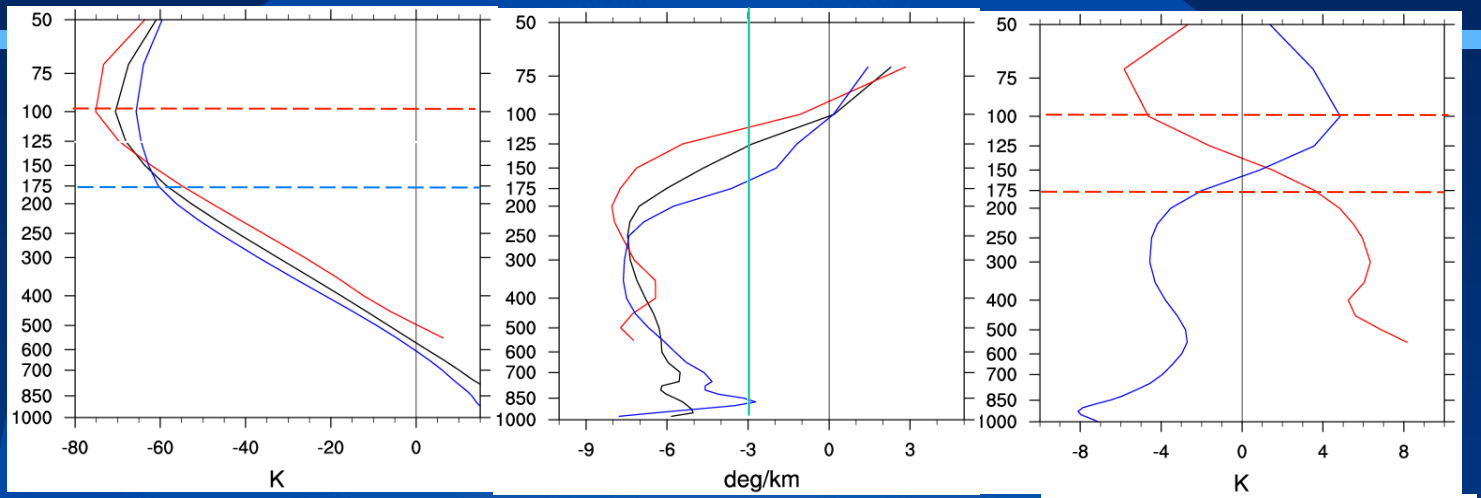
Liu，Hoskins, Blackburn, 2007: Impact of Tibetan Orography and Heating on the Summer Flow over Asia. J. Met. Soc. Japan, 85B: 1-19

Wu, He, Liu, Bao, Ren: Location and variation of the summertime upper troposphere temperature maximum over South Asia. Clim Dyn，45: 2757–2774

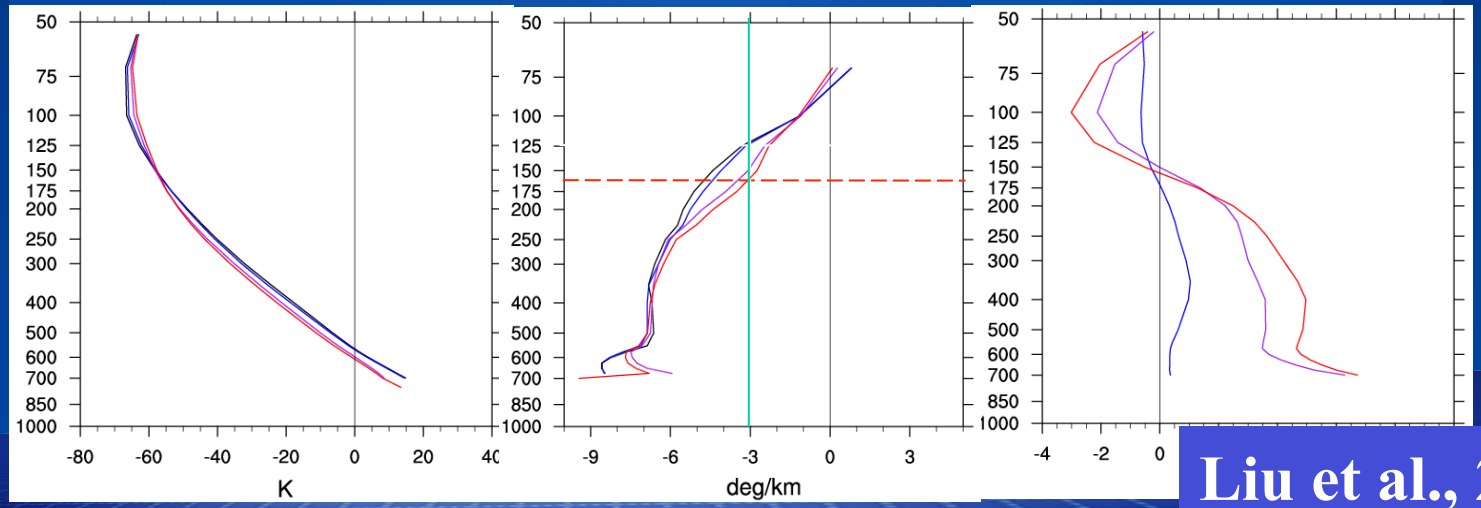
O1.6QTP



CFSR T dT/dz T- Tzonal-mean



WRF T dT/dz T_{CTL}- T_{noSH}



Liu et al., 2016

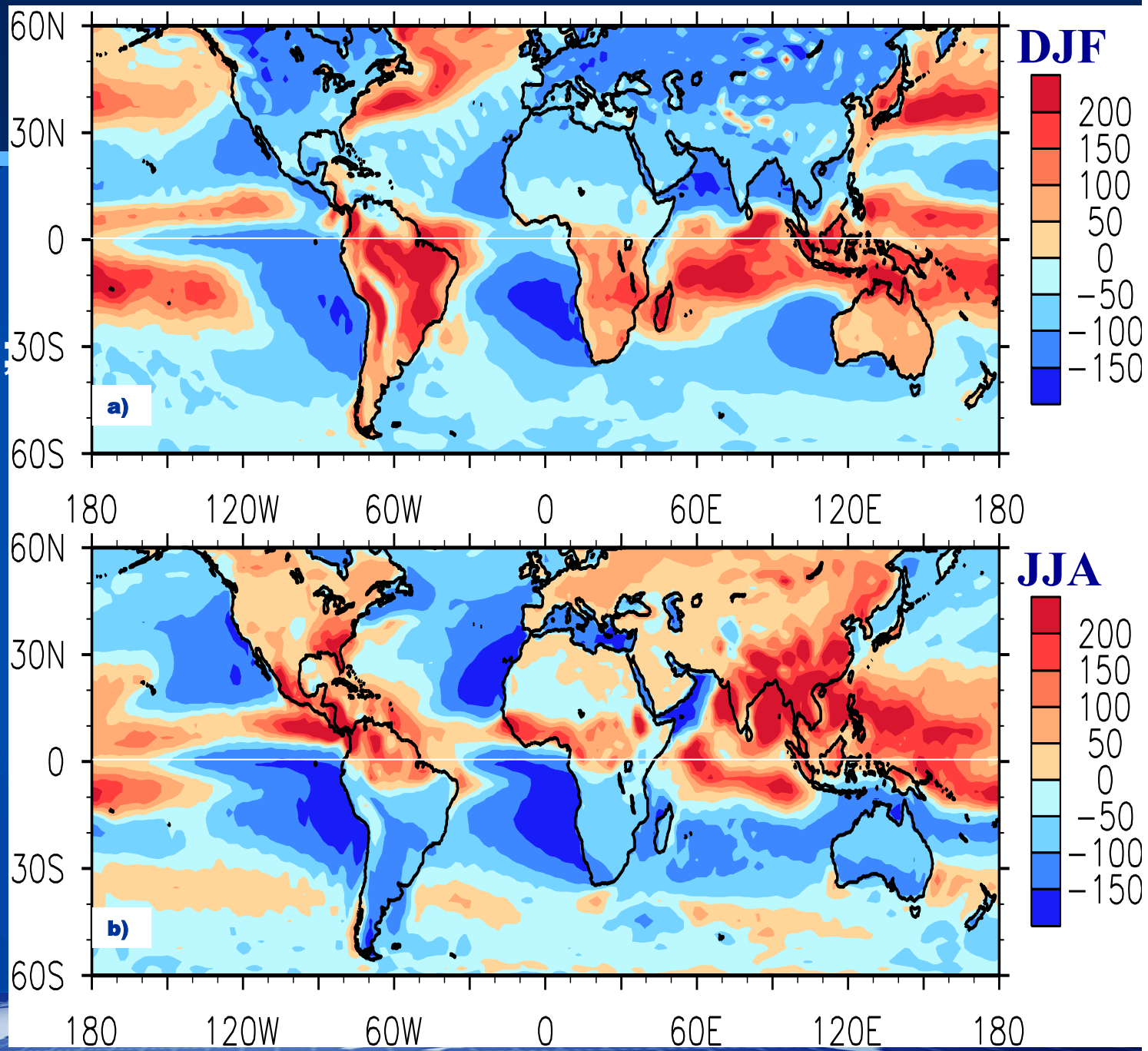
Large scale
Vertically integrated Q

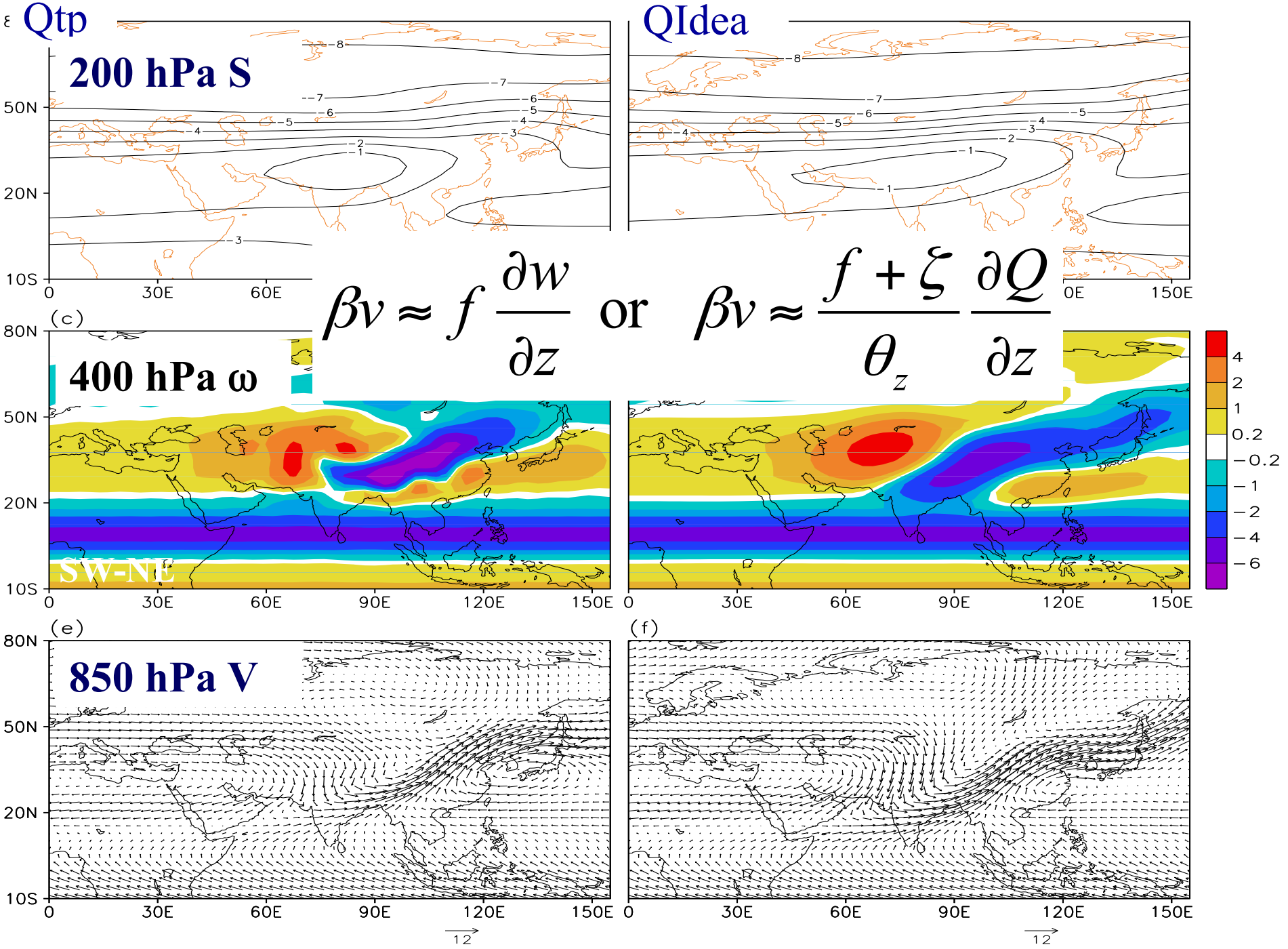
Winter:

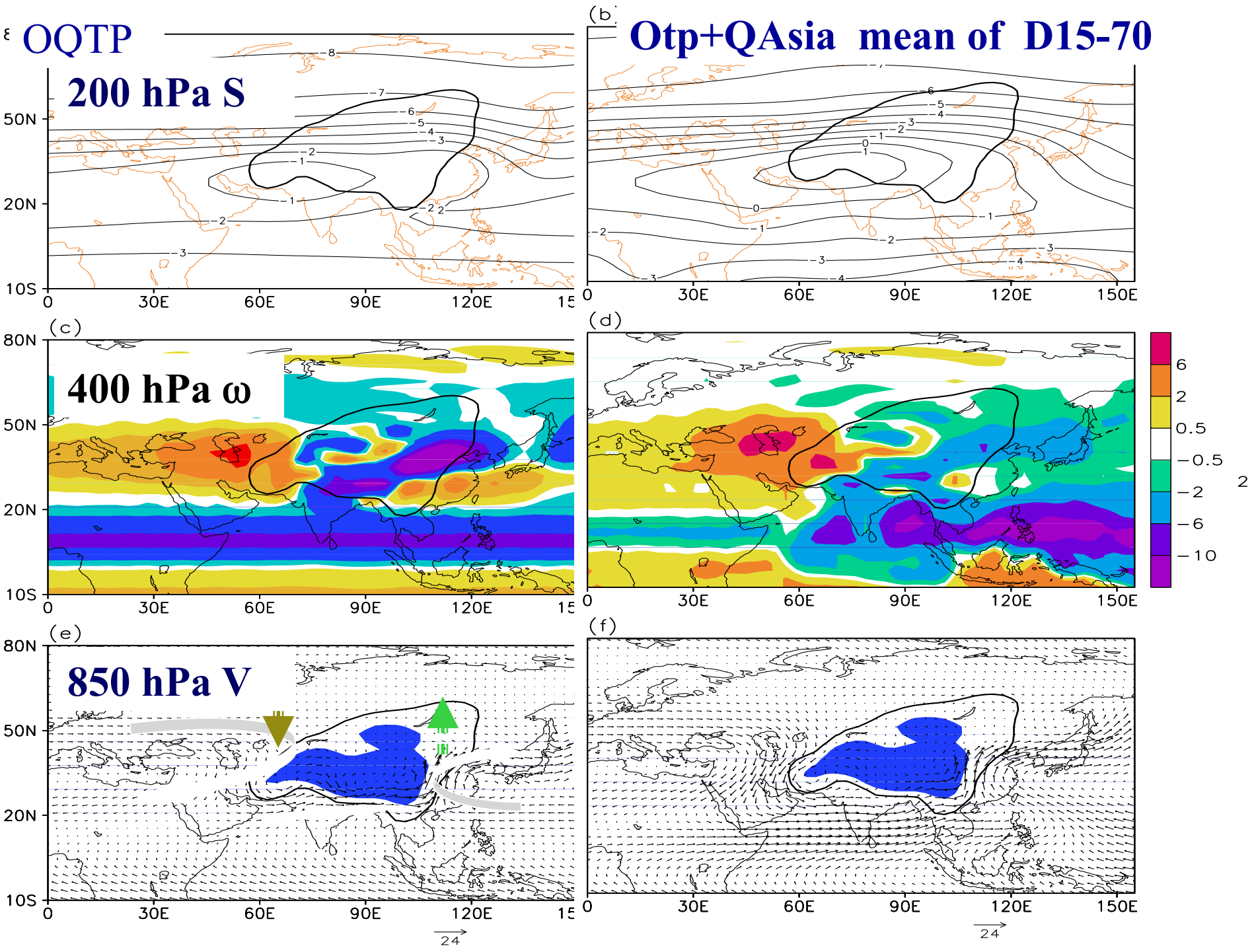
Source-ocean; sink-land

Summer:

Source-land; sink-ocean




Qtp
200 hPa S
QIdea
50N
20N
10S
0
30E
60E
150E
$\beta v \approx f \frac{\partial w}{\partial z}$ or $\beta v \approx \frac{f+\zeta}{\theta_z}\frac{\partial Q}{\partial z}$
(c)
80N
400 hPa ω
SW-NE
90E
120E
4
2
1
0.2
−0.2
−1
−2
−4
−6
(e)
(f)
850 hPa V
12


OQTP
200 hPa S
Otp+QAsia mean of D15-70
400 hPa ω
850 hPa V
(b)
(c)
(d)
(e)
(f)
80N
50N
20N
10S
0
30E
60E
90E
120E
150E
6
2
0.5
−0.5
−2
−6
−10
24