8th GEWEX Science Conference
Canmore, Canada, 6-11 May 2018

Tibetan-Iranian Plateau (TIP) – The elevated driver of water and energy cycle in Asia

Guoxiong WU

Yimin LIU, Anmin DUAN, Qing BAO, Bian HE

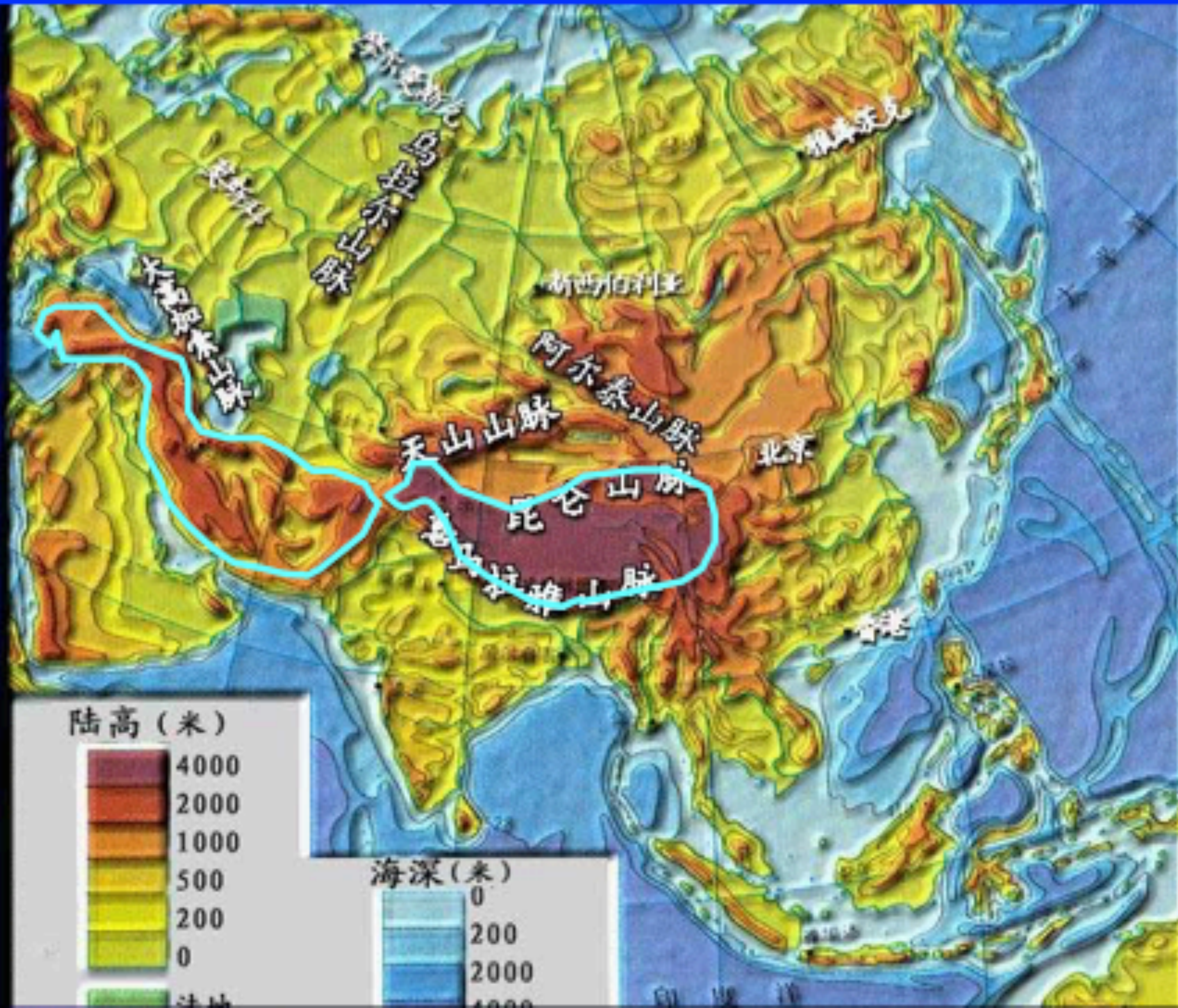
LASG, Institute of Atmospheric Physics (IAP), CAS, China

Outline

1. Introduction- SHAP
2. TIP-SHAP and vertical pumping of water vapor
3. TIP-SHAP and horizontal water vapor transport from ocean to land
4. TIP-SHAP, AMC and large-scale ascent
5. Conclusion

1. 科学意义（一）

尺度－横跨欧亚大陆、占1/4中国国土

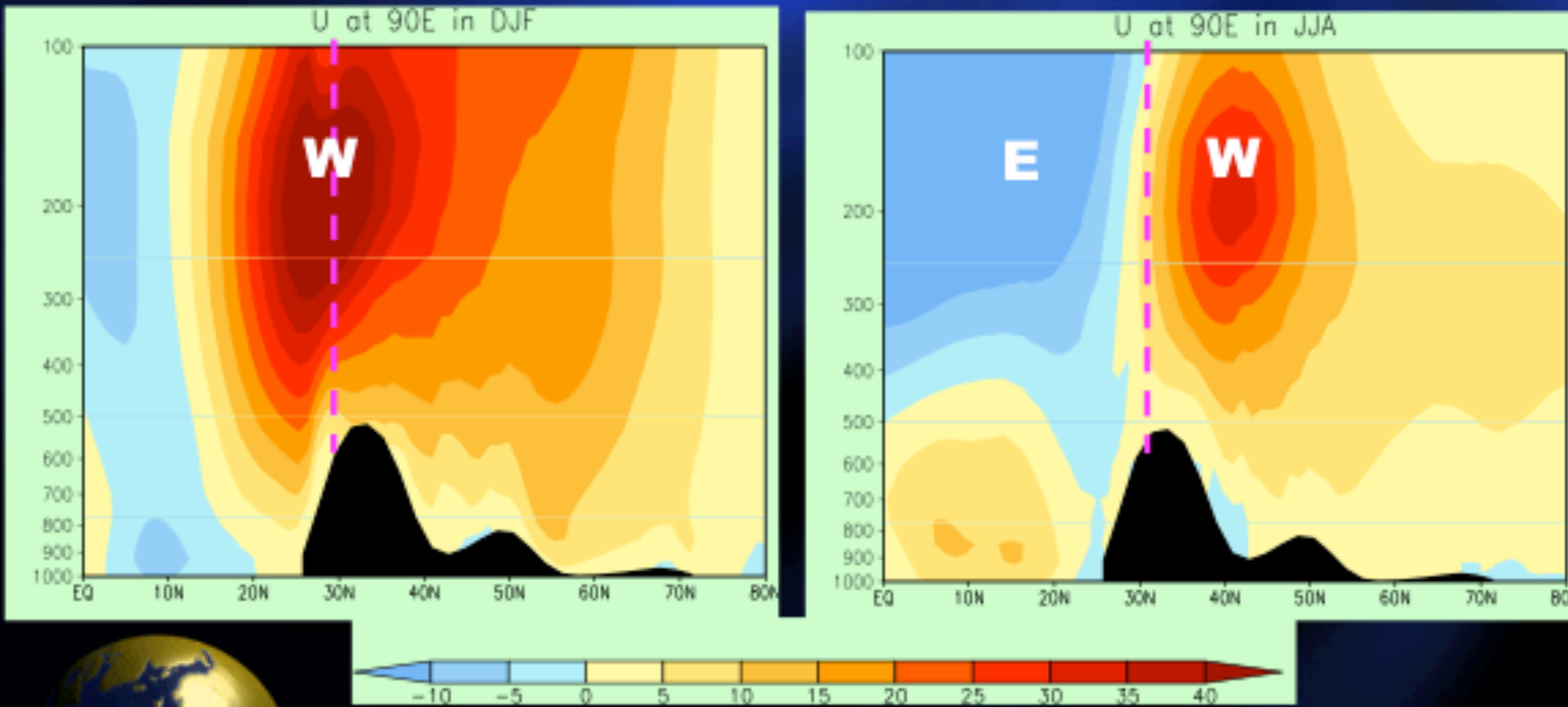


亚洲地形图

Zonal wind

Winter

Summer



纬度－欧亚大陆副热带－冬夏环流差异大

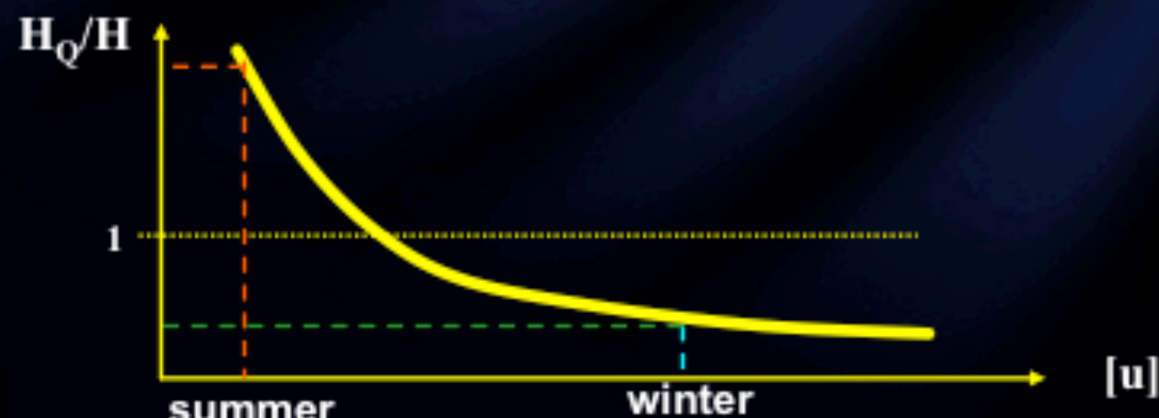
Linearized QG thermodynamic equation: (Held, I., 1983)

$$[u]\frac{\partial}{\partial x}\frac{\partial \psi^*}{\partial z}-\frac{\partial \psi^*}{\partial x}\frac{\partial [u]}{\partial z}+\frac{N^2}{f_0}W^*=\frac{\kappa Q^*}{f_0 H}\equiv R^*$$

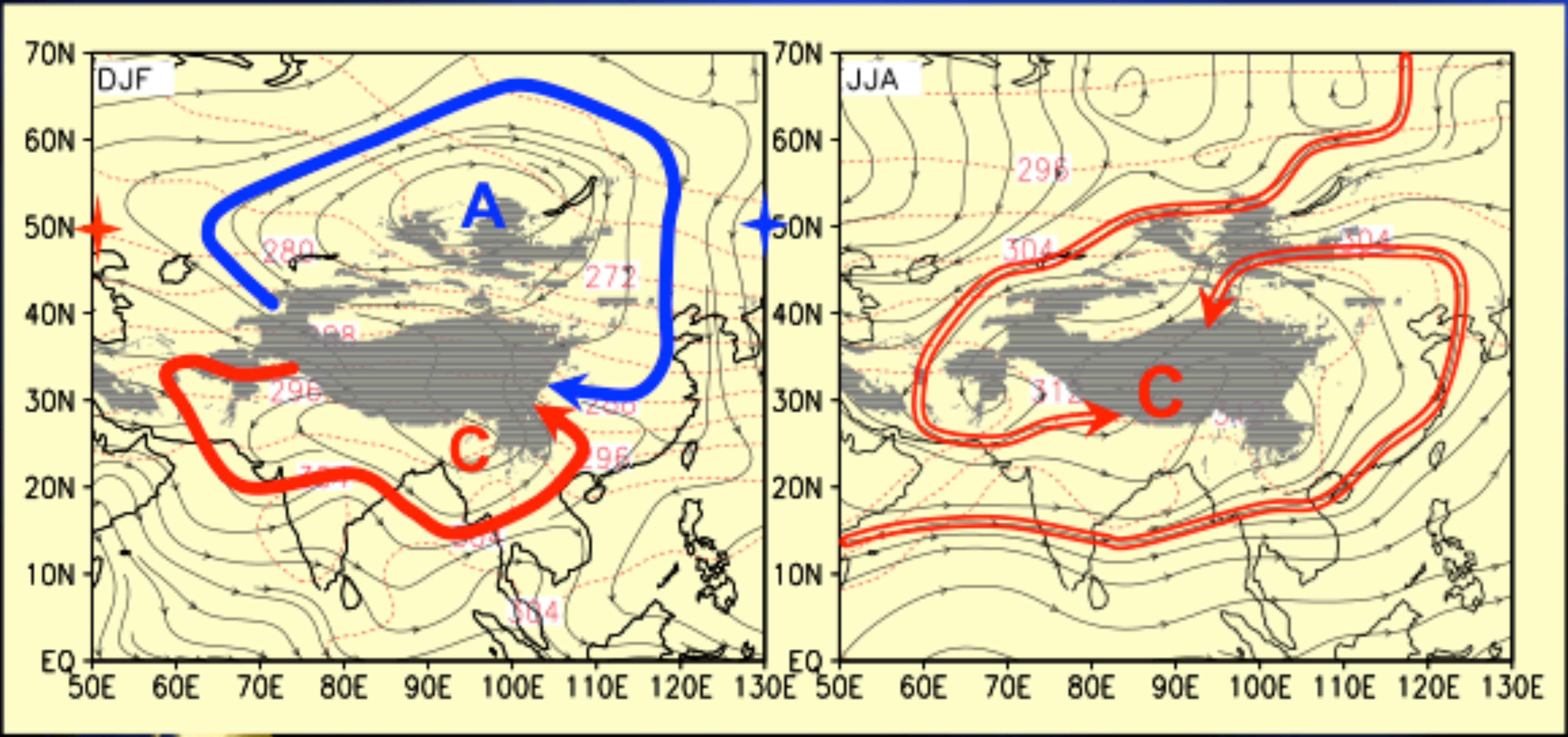
$$\tilde{\psi}_p=\frac{-if_0^2}{k\rho_0[u](K_s^2-K^2)}\frac{\partial}{\partial z}\left(\frac{\rho_0 R}{N^2}\right)$$

等效地形高度“Equivalent topography”示意图

$$\tilde{h}_T=\frac{if_0}{N^2k[u]}\tilde{R}(0)$$



850hPa zonal deviation of wind and potential temperature



Winter: Dipole Mode

冬季：偶极型流场

Summer: Warm Spiral

夏季：螺旋辐合流场

Wu et al; 2007

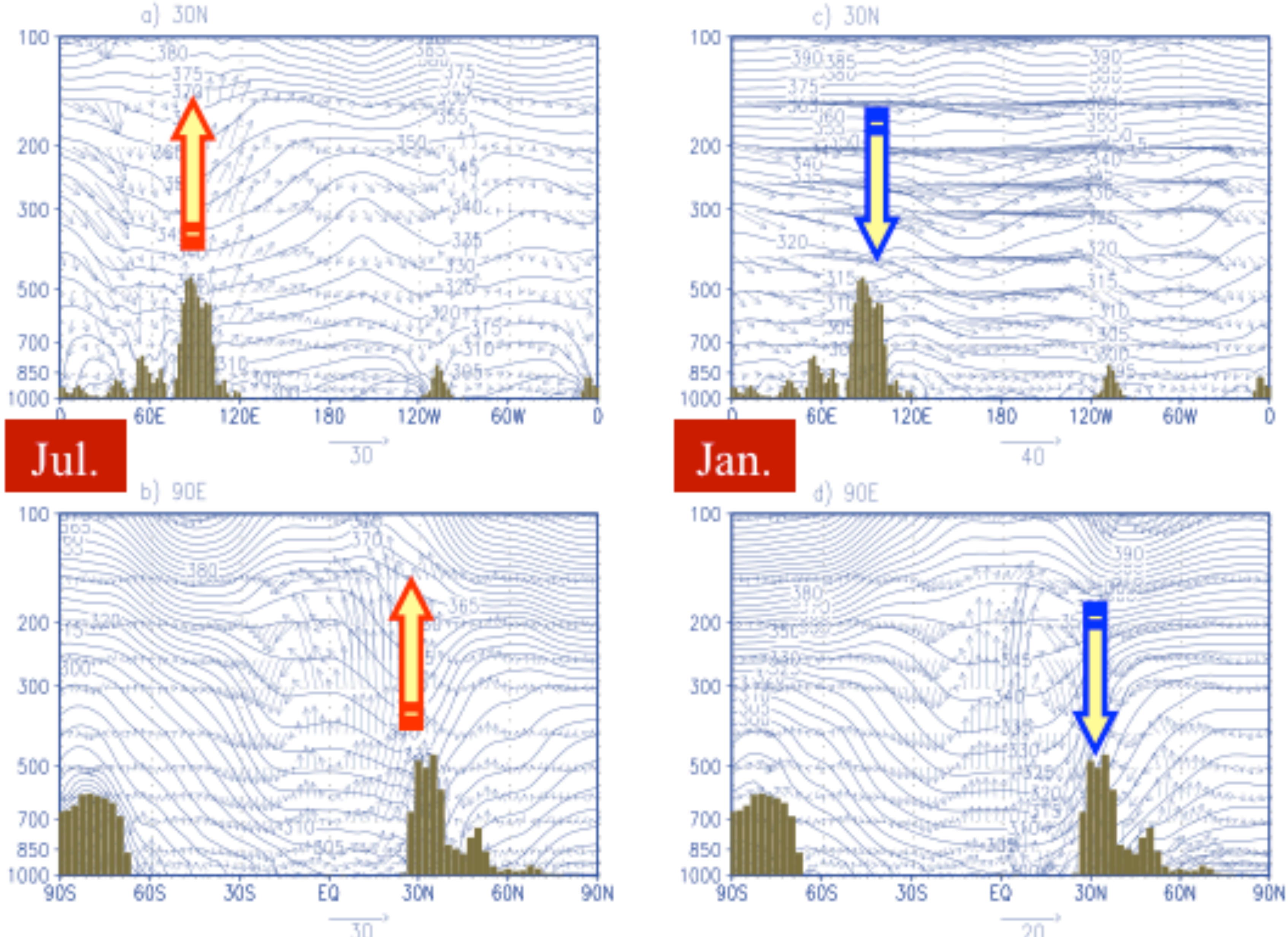
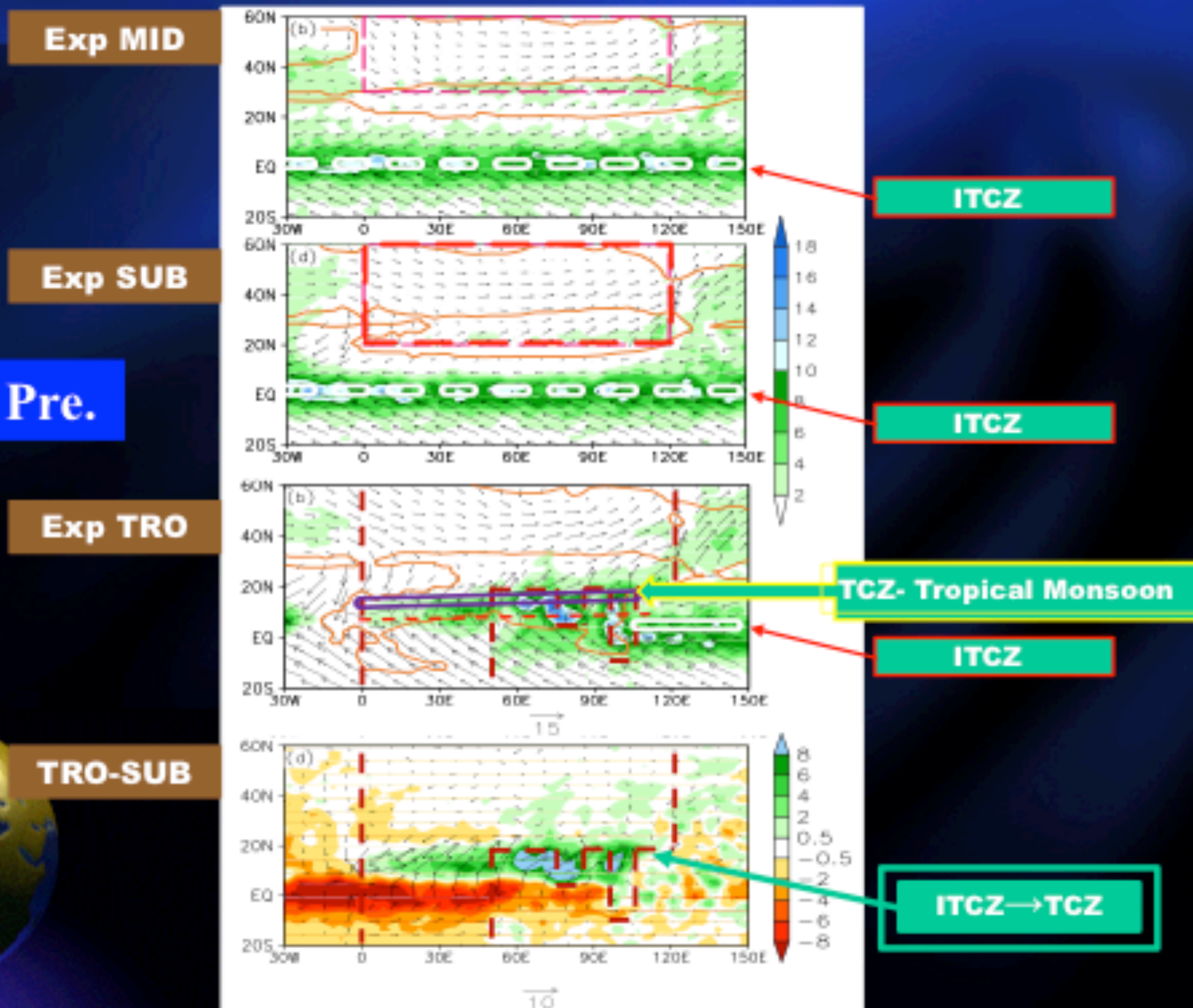


fig. 4; 1986-1995 10 years mean Jul. potential temperature and wind vector cross-section; theta(K) Wind(m/s)

1986-1995 10 years mean Jan. potential temperature and wind vector cross-section; theta(K) Wind(m/s)

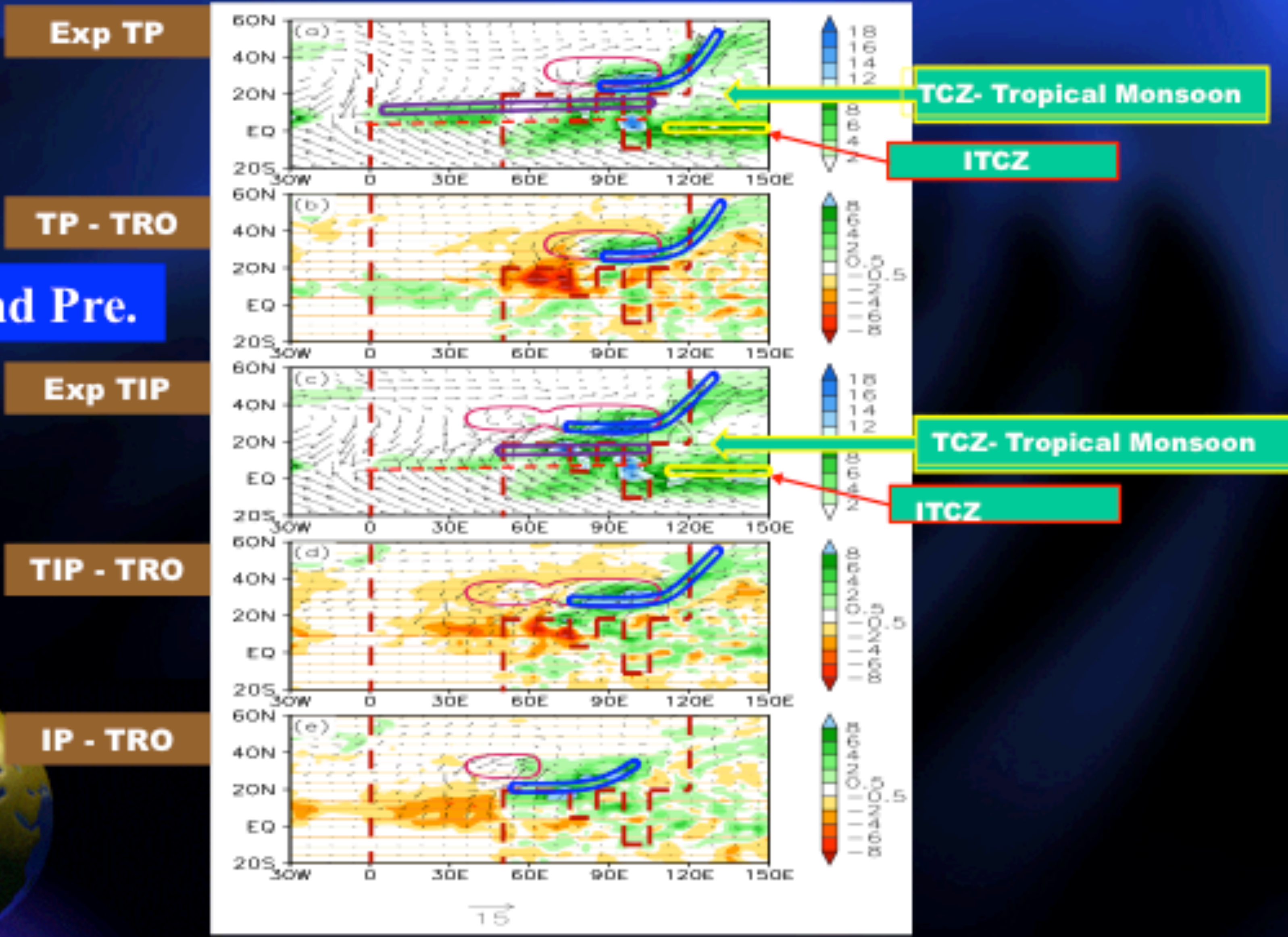
Aqua-Land/Sea experiment- ITCZ and TCZ

$V_{0.991}$ and Pre.



Aqua-Plateau experiment- ITCZ and TCZ

$V_{0.991}$ and Pre.



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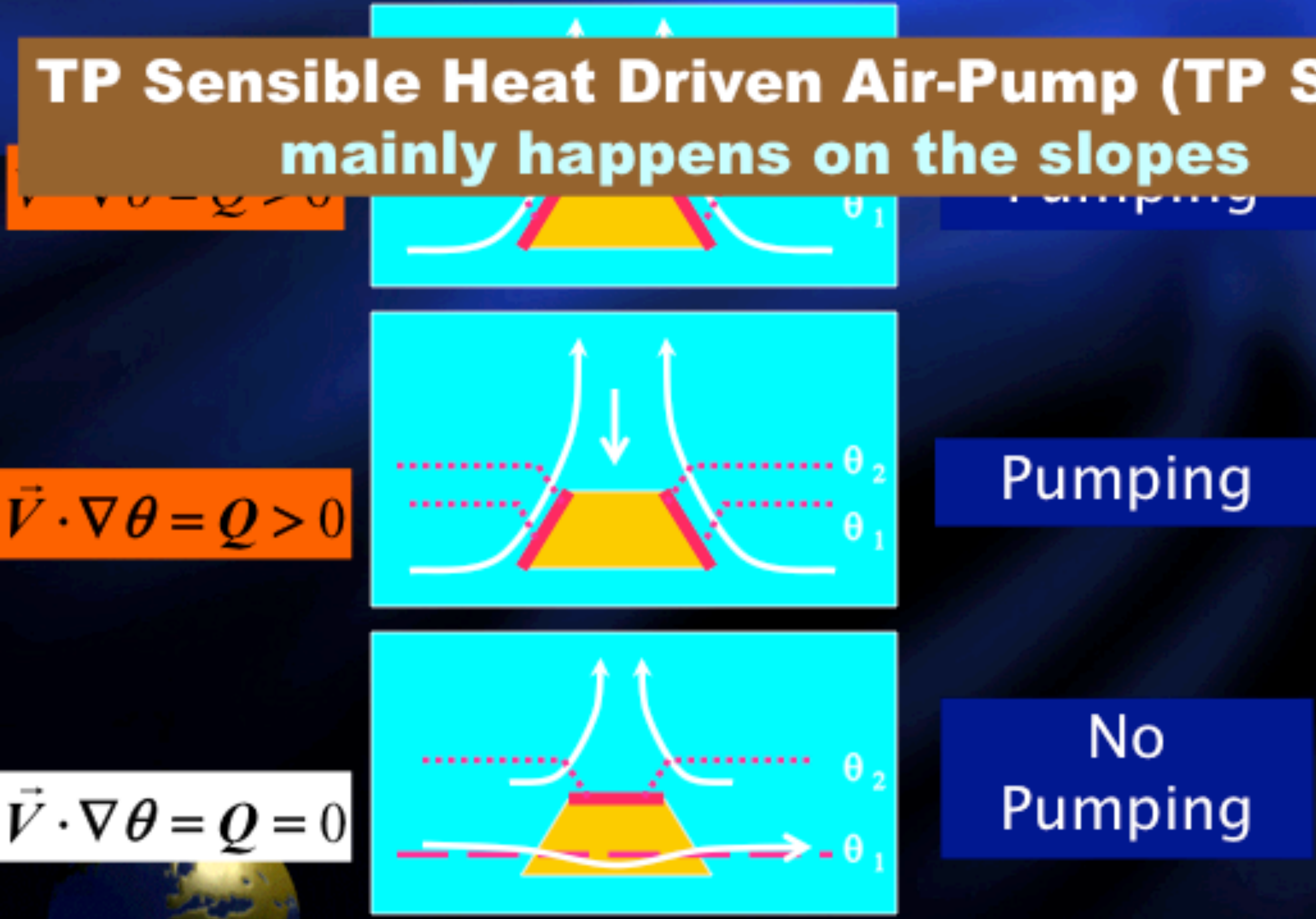
TP Sensible Heat Driven Air-Pump (TP SHAP)
mainly happens on the slopes

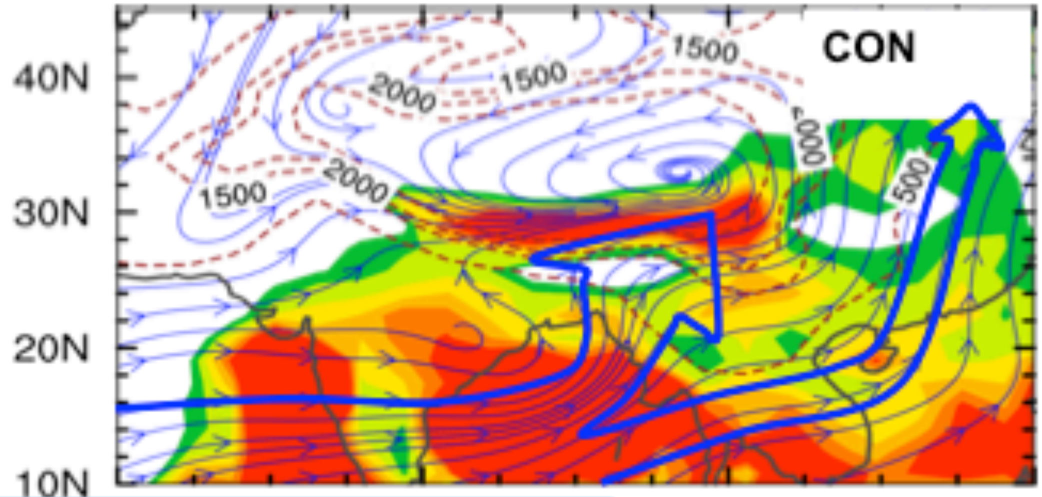


U , W and θ vertical cross- section

TP heating produce pumping

$$\vec{V}_s \cdot \nabla H_s \approx 0 \quad \vec{V} \cdot \nabla H \approx \vec{V}_n \cdot \nabla H_n$$

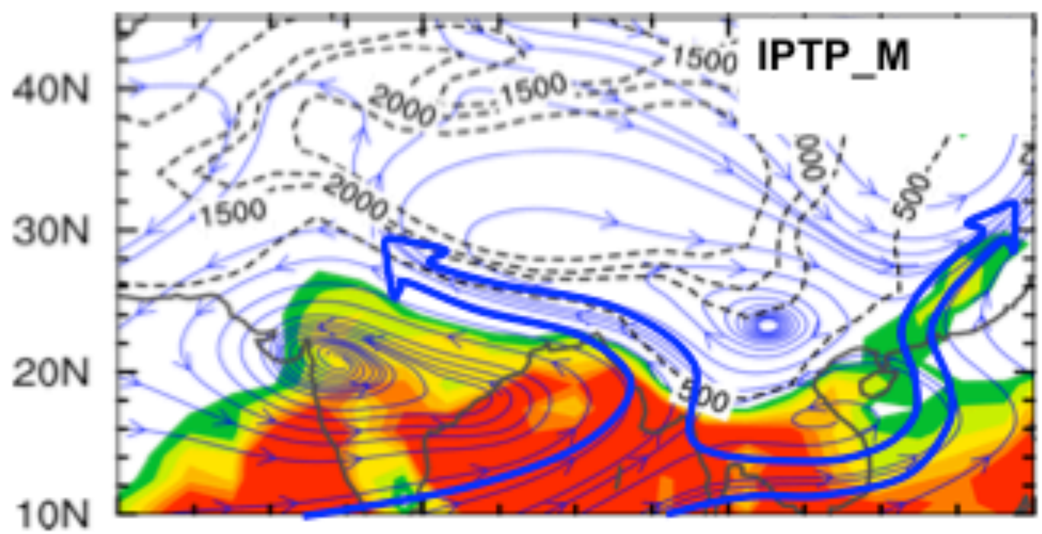
a



No TP heating, no pumping

$$\vec{V}_n \cdot \nabla H_n = 0 \quad \vec{V} \cdot \nabla H = \vec{V}_s \cdot \nabla H_s$$

b



Tibetan Plateau-
Sensible Heat driven Air-Pump
(TP-SHAP)

Heating on the mountain slope surface is crucial for uplifting water vapor from the surface to free atmosphere to form monsoon cloud and precipitation!

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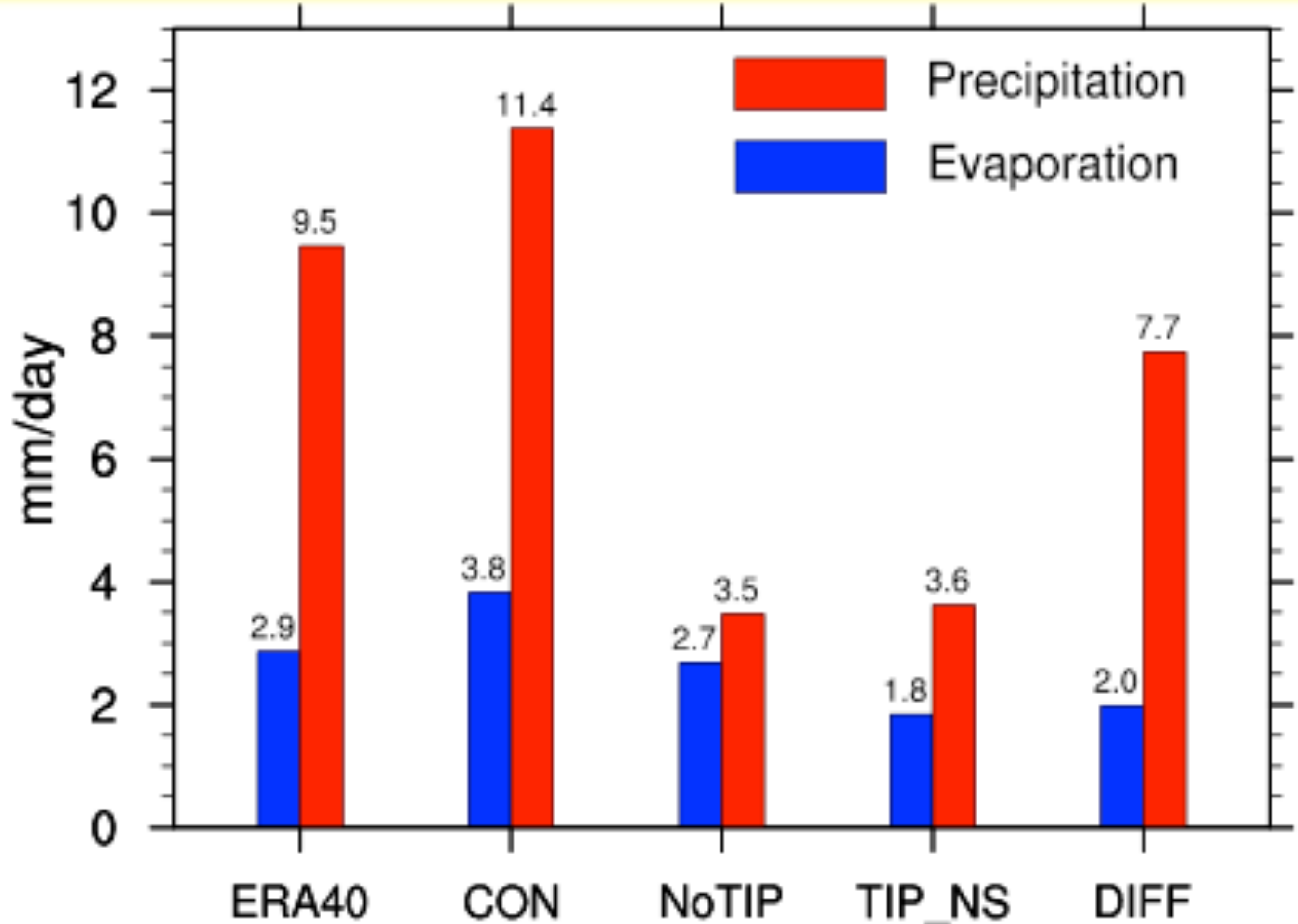
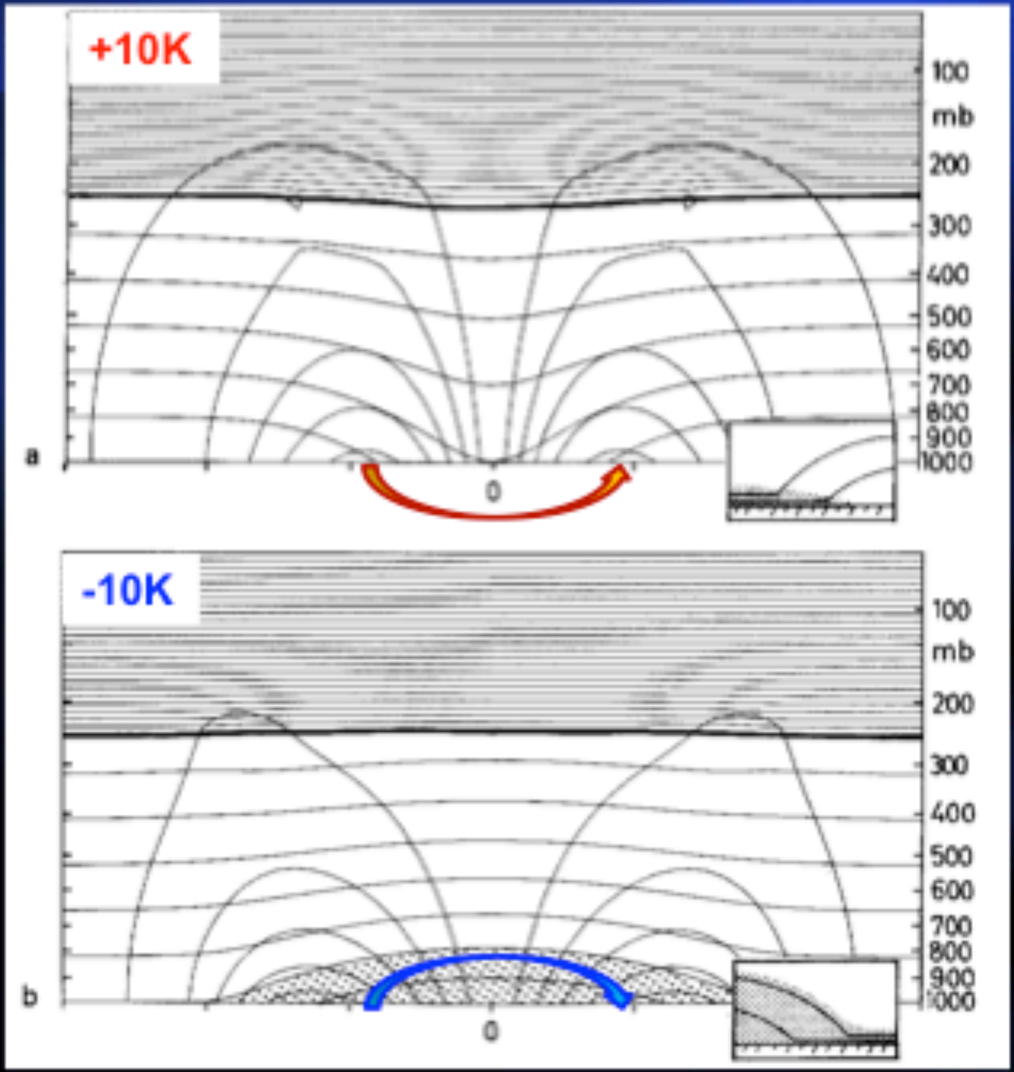
Water vapor transport is more important than evaporation in contributing to monsoon precipitation



Bar chart of hydrological budgets (unit: mm d^{-1}) in the region of (24–28° N, 75–100° E) as denoted by the box in Fig. 2f-o for the ERA-40 Reanalysis and numerical experiments CON, NoTIP, and TIP_NS. DIFF denotes the difference between CON and TIP_NS.

Circulation symmetric flows induced by boundary temperature anomalies



Thorpe AJ (1985) Diagnosis of balanced vortex structure using potential vorticity. *J Atmos Sci* 42(4): 397-406.

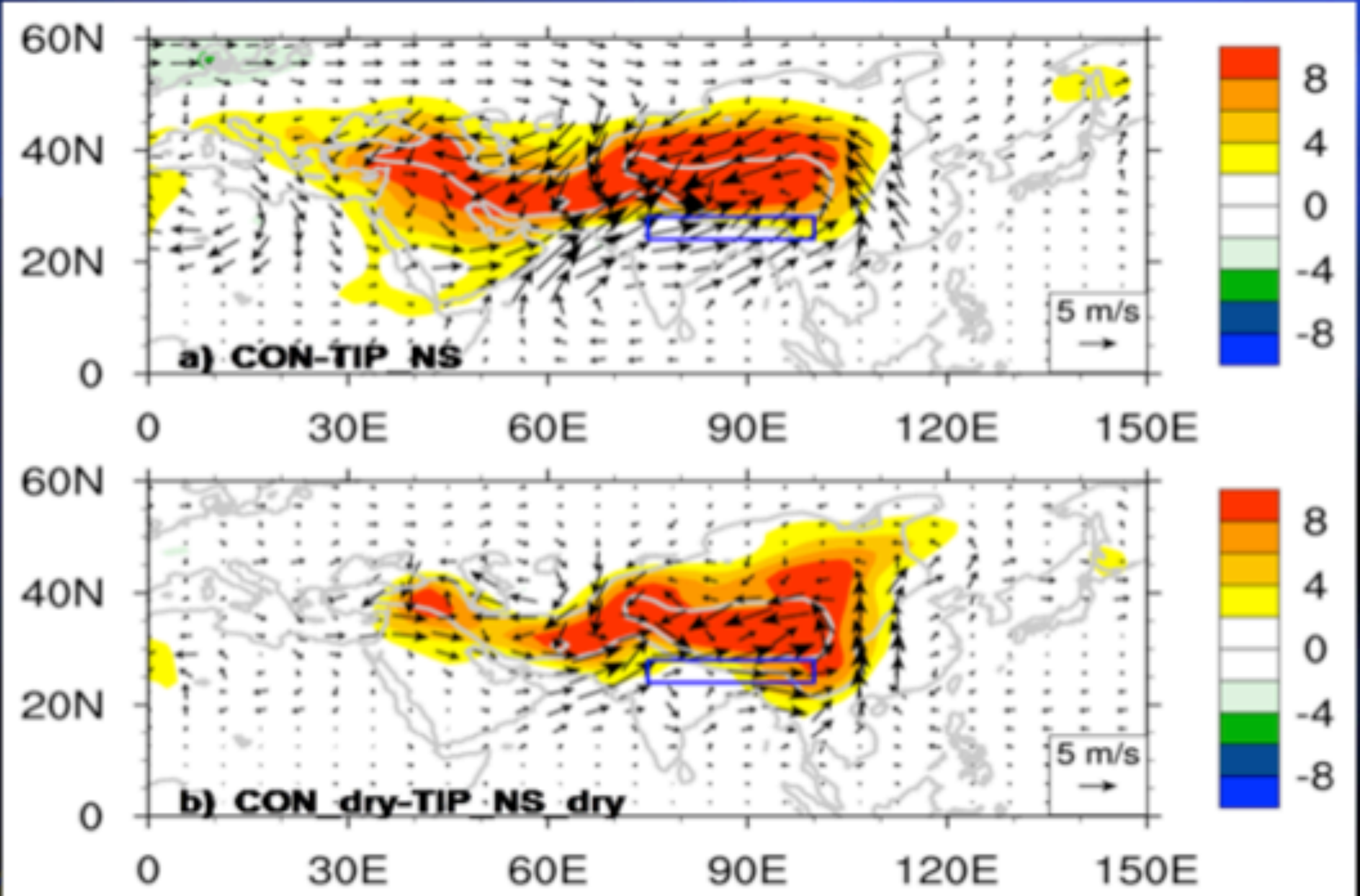
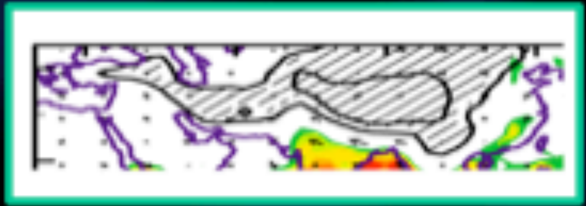


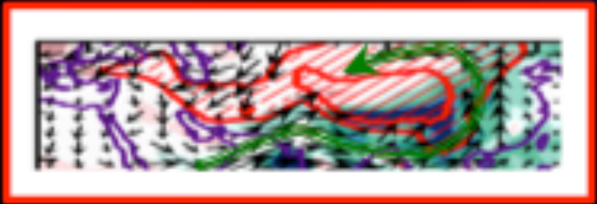
Fig. 4 JJA mean differences of near-surface (sigma=0.99) potential temperature θ (K, shading) and circulation (vectors, m s^{-1}) between (a) CON and TIP_NS, (b) CON_dry and TIP_NS_dry, (c) the difference between (a) and (b); (d) is the same as (c) but for precipitation (shading, unit: mm d^{-1}). The square indicates the South Asian summer monsoon region of (24–28° N, 75–100° E).

PV-Q perspective of the TIP impact on the Asian summer monsoon

IPTP_M



IPTP_SH



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In response to an axisymmetric diabatic heating, the meridional circulation adopts <u>two distinct regimes:</u>

- the thermal equilibrium (TE) regime in extra- tropics
- the angular momentum conservation (AMC) regime in the tropics.

Schneider, Linzen, Hou, Held, Plumb…

Dynamic forcing and W

$$W \propto \frac{\partial}{\partial z}[-\vec{V} \cdot \nabla(f+\zeta)]$$

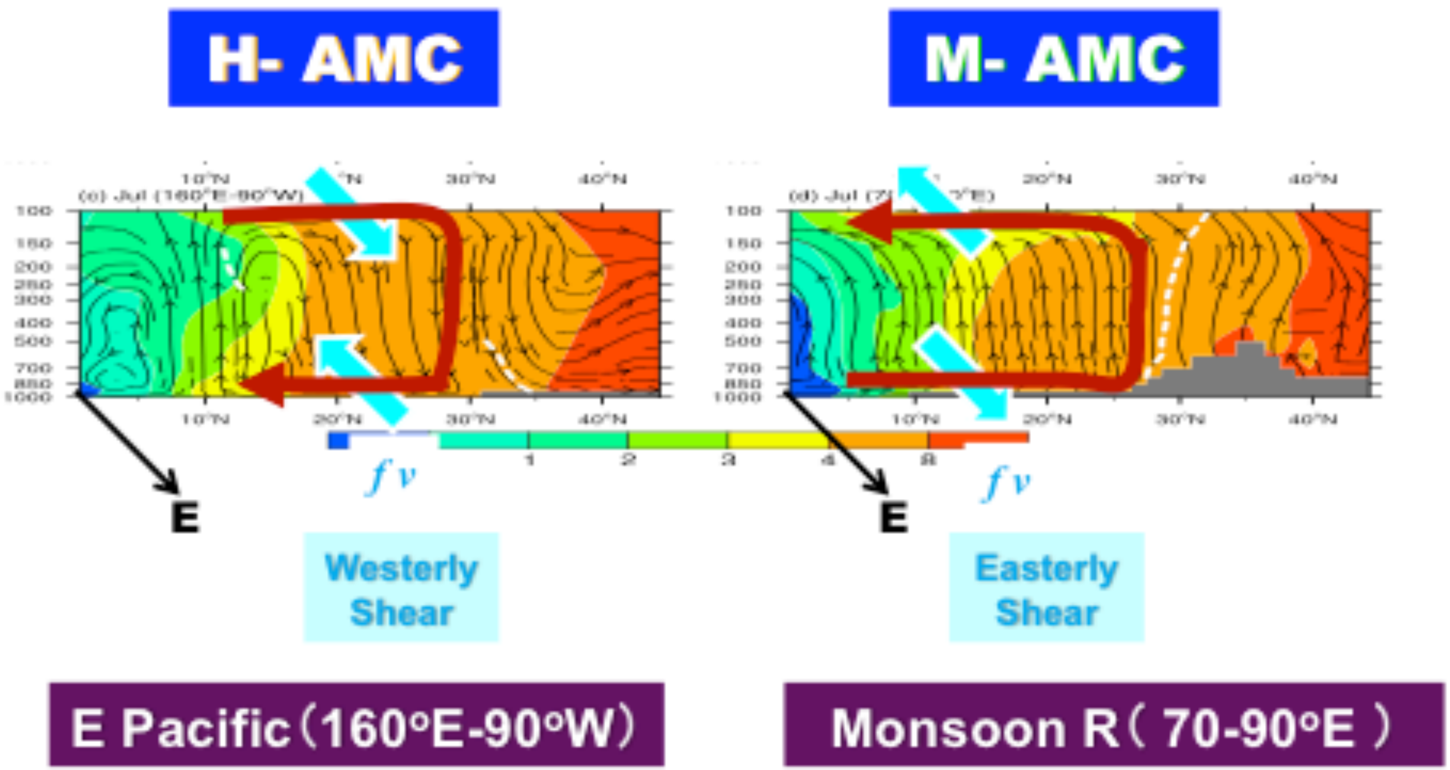


图4. 平均经圈环流(流线)、绝对涡度($10^{-5}\,s^{-1}$, 彩色)和纬向风零线(白断线)的气压-纬度分布的剖面图:(a)1月纬向平均;(b)7月纬向平均;(c)7月东太平洋(160°E-90°W)平均,(d)7月亚洲季风区(70-90°E)平均

Tibetan Plateau (TP) acts -

Enhance coupling between surface and upper tropospheric circulations, and between subtropical and tropical monsoon circulations

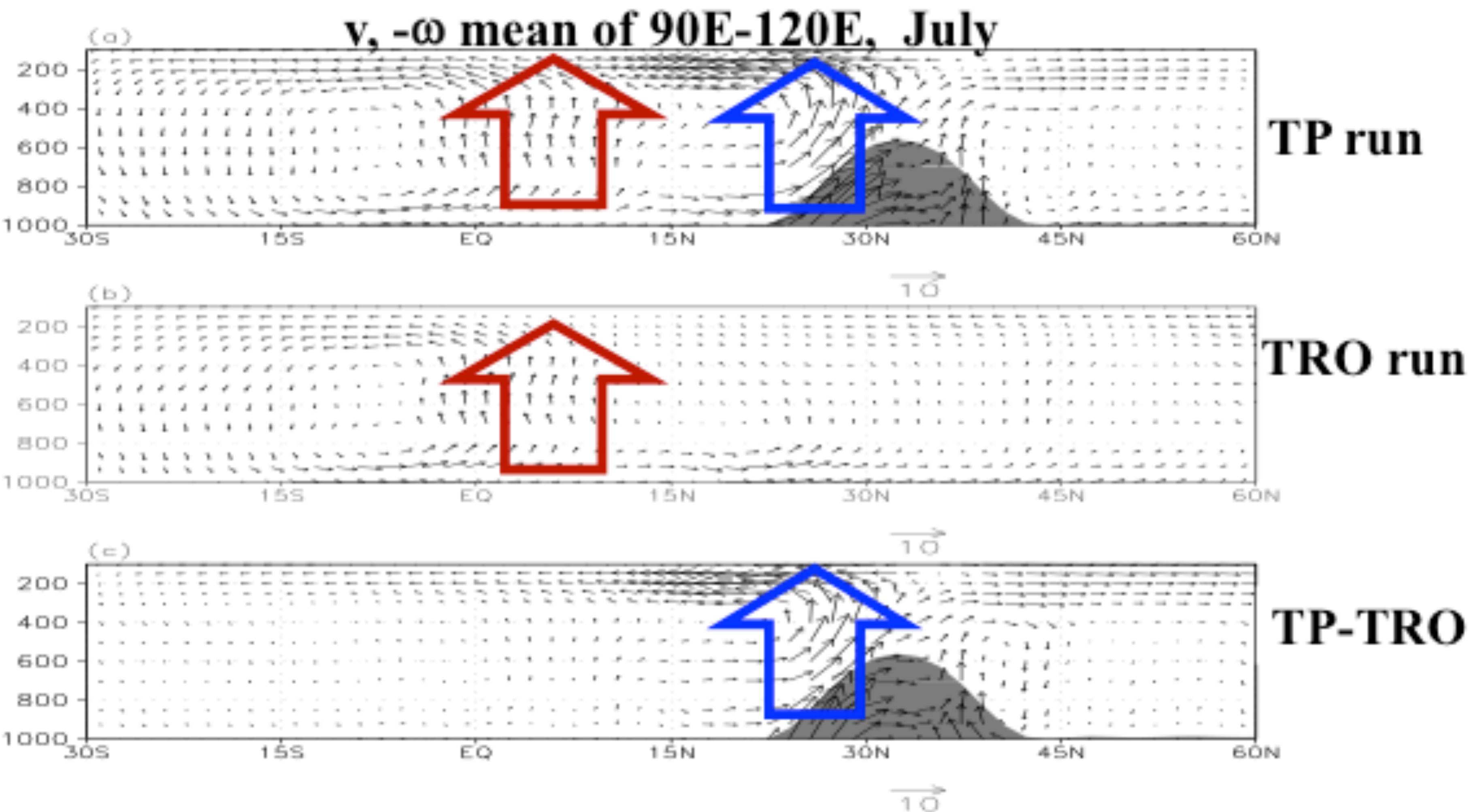
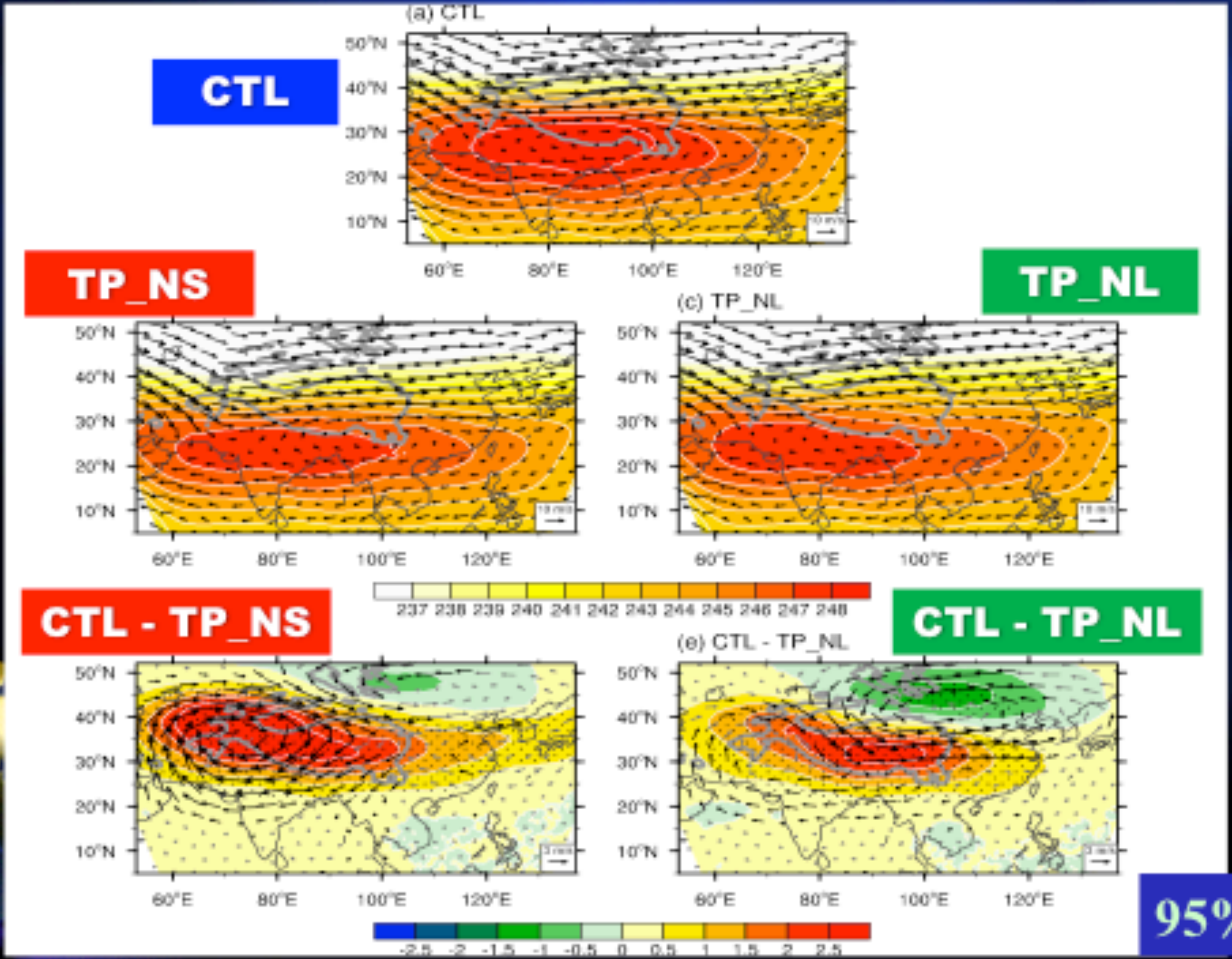


表1试验设计
Table 1 Experiment design

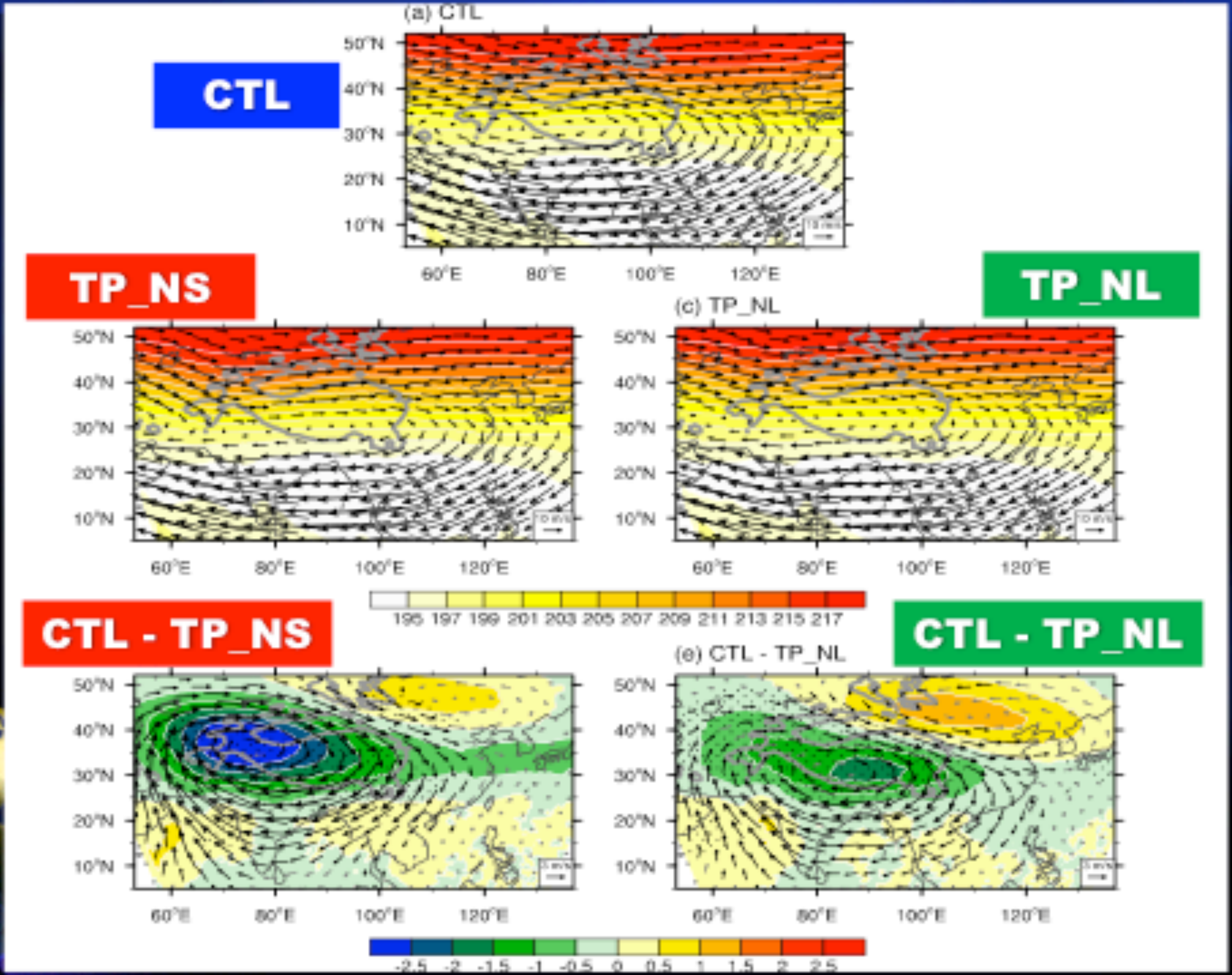
Experiment	Description
CTL	Control-climate mean
TP_NL	Main TP（≥ 2 km）No L-heating
TP_NS	Main TP（≥ 2 km）No S-heating
STP_NS	S slope of TP（≥ 2 km）No S-heating

JJA Air temperature and wind at 300 hPa



95% level

JJA Air temperature and wind at 100 hPa



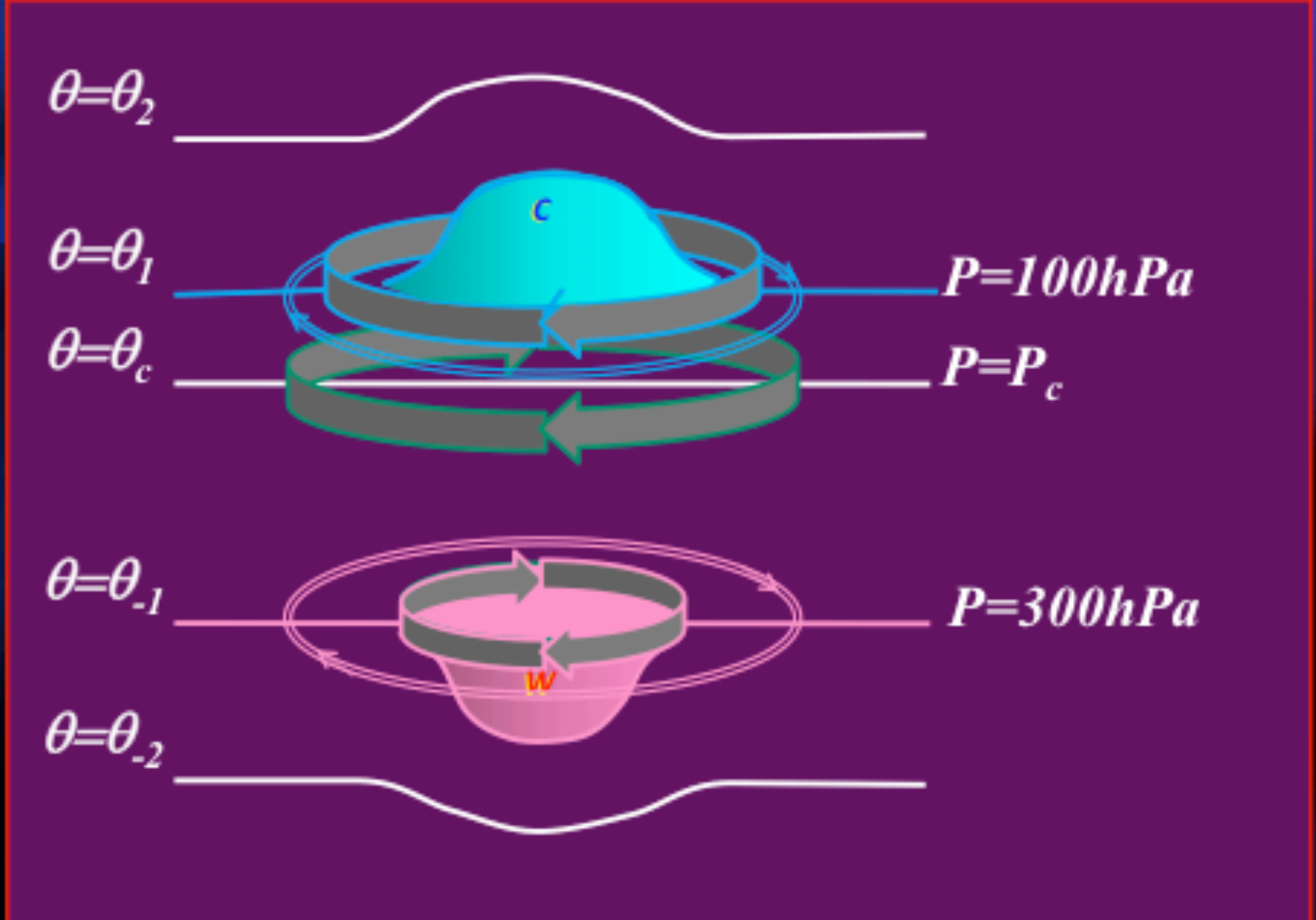


图9 青藏高原主体加热通过改变对流层上层的温度场和流场结构在近对流层顶形成最小位涡强迫的示意图

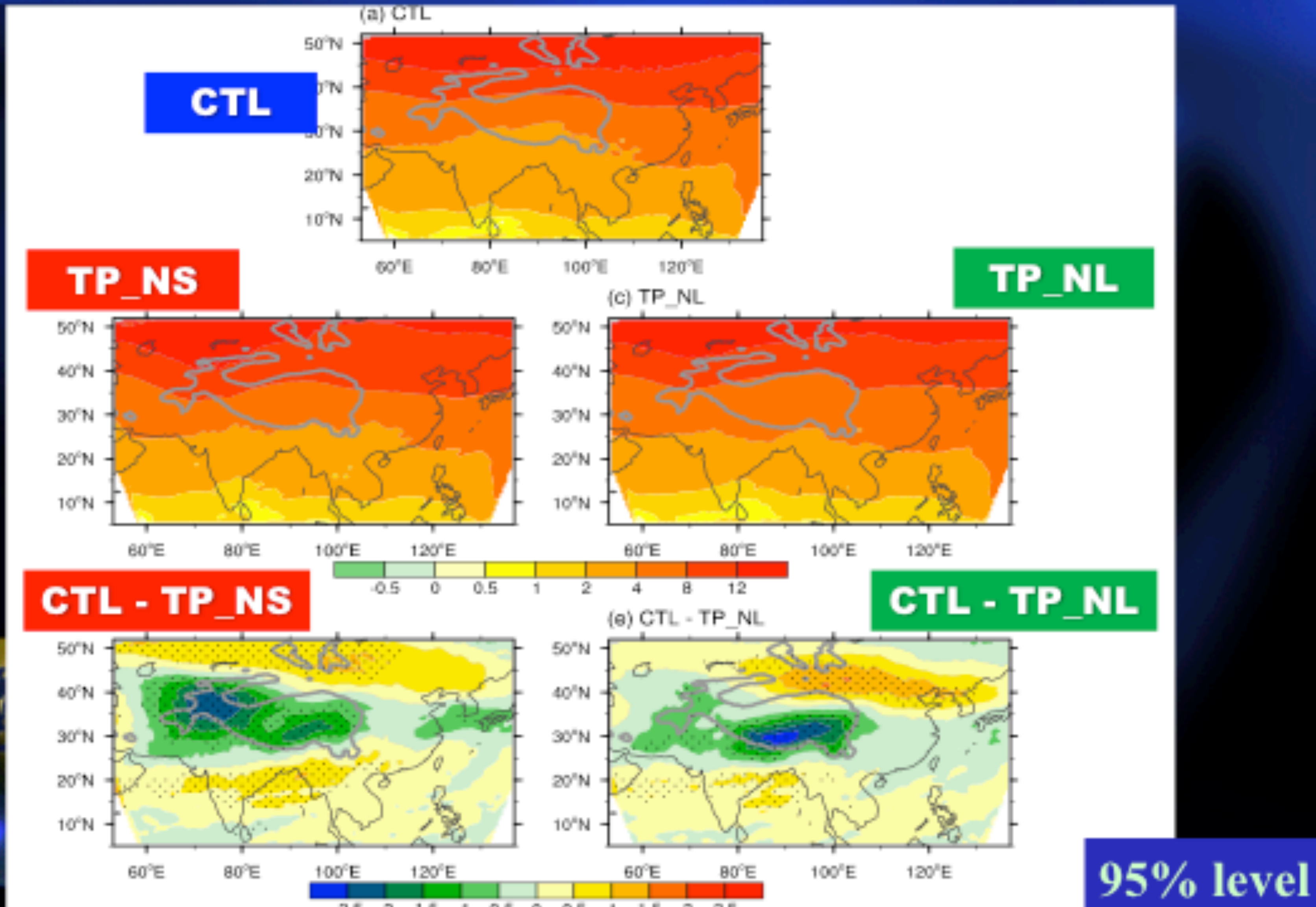
箭矢表示反气旋环流; “C”和蓝色表示冷性, “W”和粉红色表示暖性

Fig. 9 Schematic diagram indicating the formation of PV minimum forcing near the tropopause due to the thermal forcing over the main body of the Tibetan Plateau. Vector indicates anticyclone circulation; “C” and blue color denotes cold temperature, and “W” and pink color, warm temperature.

$$\boldsymbol{P} = \alpha(\,\boldsymbol{f} + \zeta\,)\frac{\partial\theta}{\partial \boldsymbol{z}} = \boldsymbol{Minimum}\,, \quad P = Pc$$

Minimum potential vorticity forcing is forced near the tropopause !

JJA Absolute vorticity（$10^{-5}s^{-1}$）at 150 hPa



JJA Potential vorticity difference（PVU）

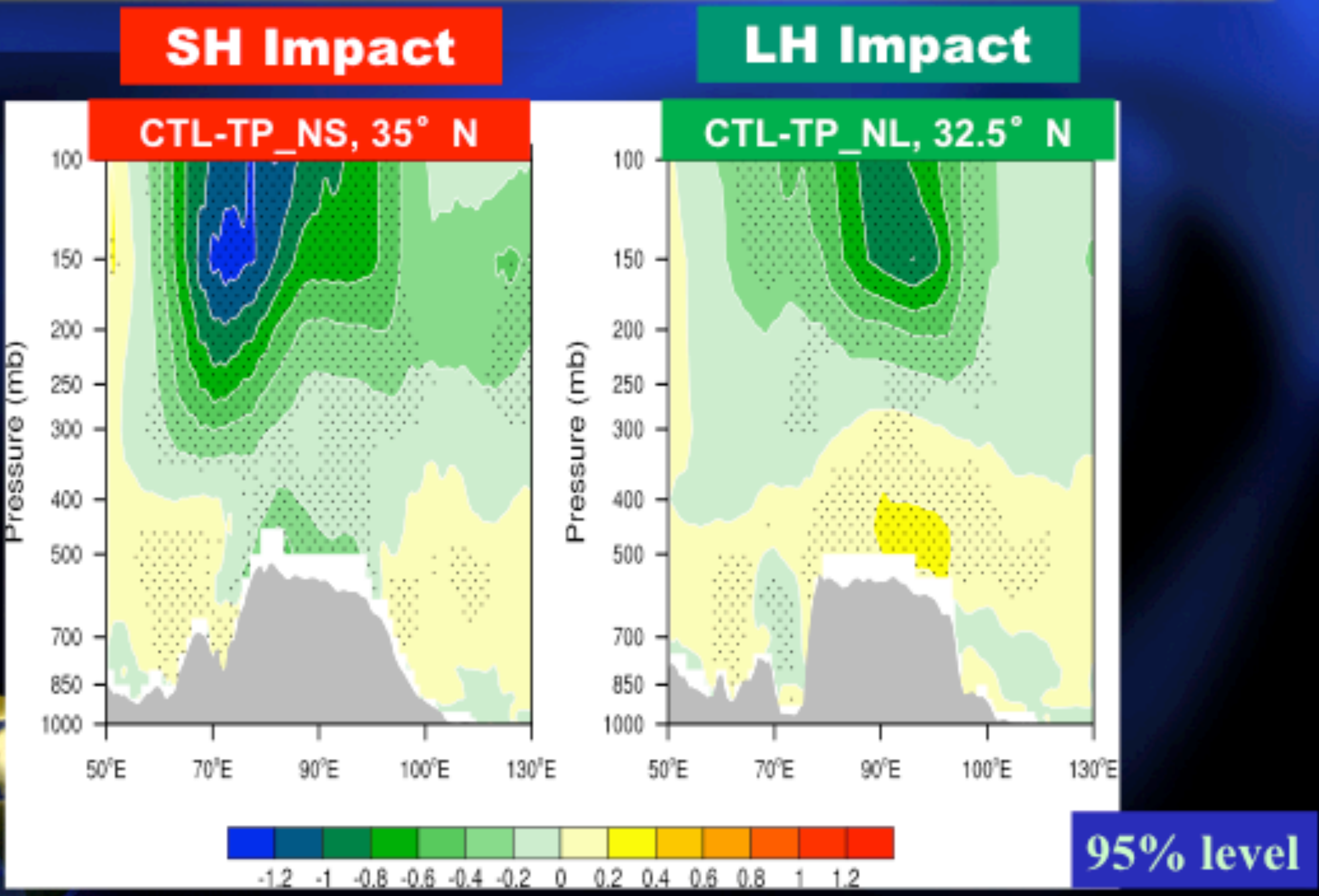
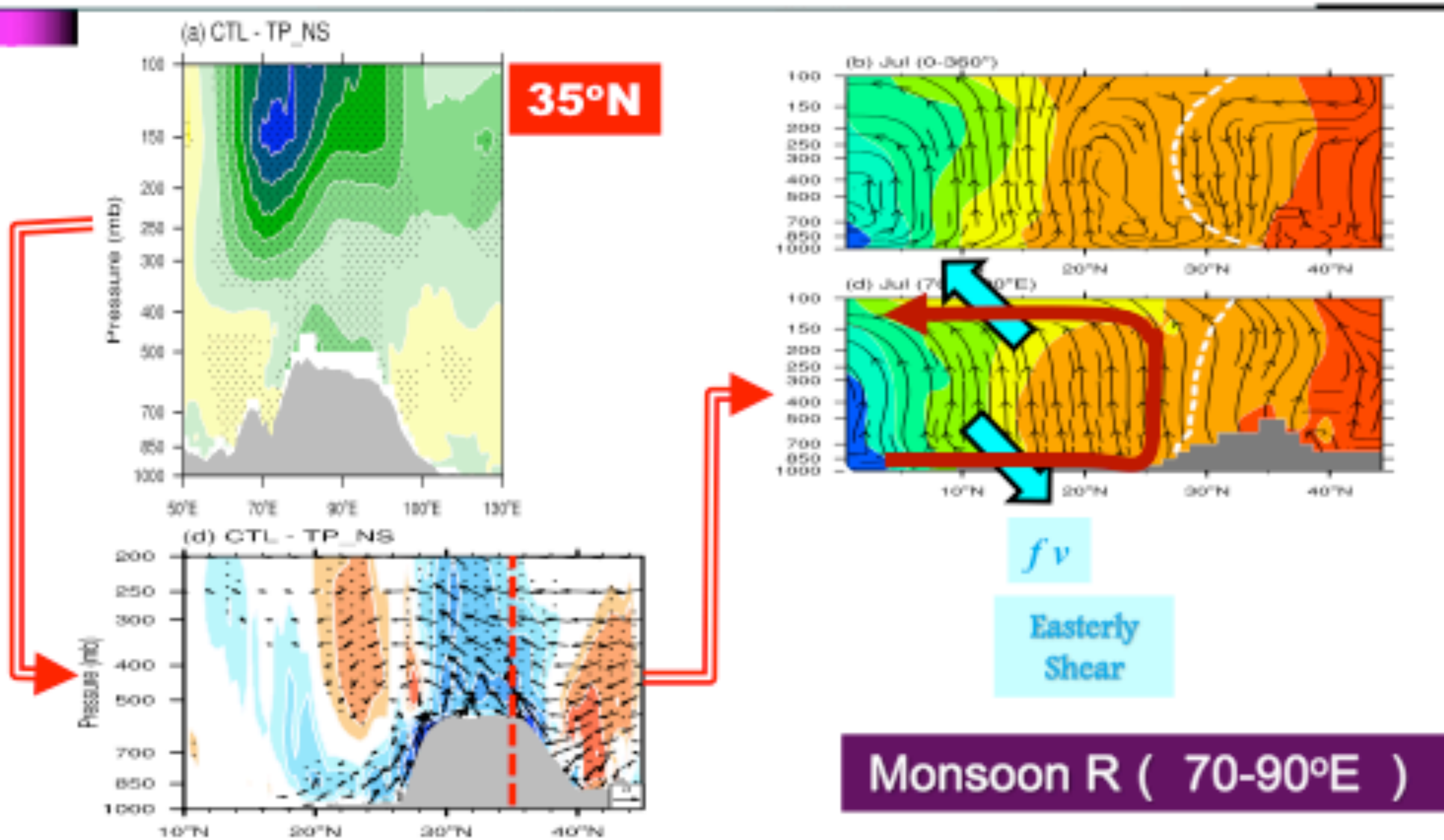


图11 高原主体加热所激发的位涡异常

(a) 感热加热（CTL-TP_NS）（35° N）; (b) 潜热加热（CTL-TP_NL）（32.5° N）. 单位:（PVU, 1 PVU=10^{-6} K m^2 s^{-1} kg^{-1}）

$$M_D \zeta_a = 2\Omega^2 a^2 \sin\varphi \cos^2\varphi + \frac{1}{2}\frac{gD}{T_0}\frac{1}{\cos\varphi}\frac{\partial}{\partial\varphi}\left[\frac{\cos^3\varphi}{\sin\varphi}\frac{\partial \hat{T}_e}{\partial\varphi}\right]. \quad (7)$$

Plumb and Hou 1992



How TP contribute to the development of monsoonal meridional circulation?

Summary

- Diabatic heating of TP can change temperature and circulation in the upper troposphere and <u>produce minimum PV and absolute vorticity forcing near the tropopause, monsoonal-type of meridional circulation is generated.</u>

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TIP-SHAP and Asian summer monsoon

- TIP Air- Pump is driven by its slope-surface sensible heating (SHAP), which regulates the surrounding circulation and affects at least circulation over the Northern hemisphere;
  - TIP-SHAP → vertical pumping of water vapor ;
  - TIP-SHAP → horizontal transport of water vapor from ocean surface to inland area ;
  - TIP-SHAP → large-scale air ascent
- TIP-SHAP → significant in energy and water cycle over ASM area!

Thanks for your attention!