

ISENTROPIC FLOWS AND MONSOONAL CIRCULATIONS

Olivier Pauluis (NYU)

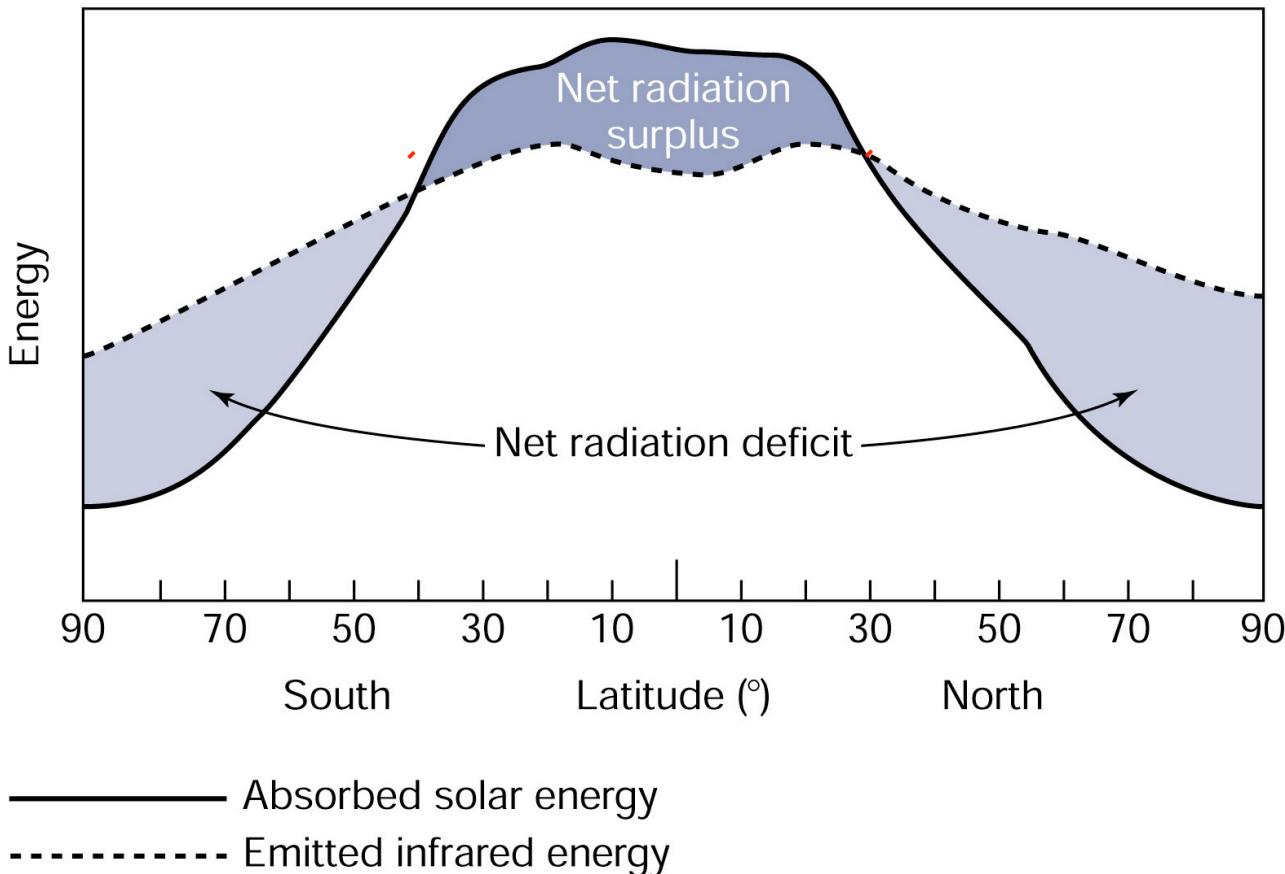
Monsoons- Past, Present and future
May 20th, 2015
Caltech, Pasadena

Outline

- Introduction
- Global monsoon in isentropic coordinates
- Dry ventilation
- Moist ventilation
- Role of deserts

The general circulation

Annual Radiation Budget

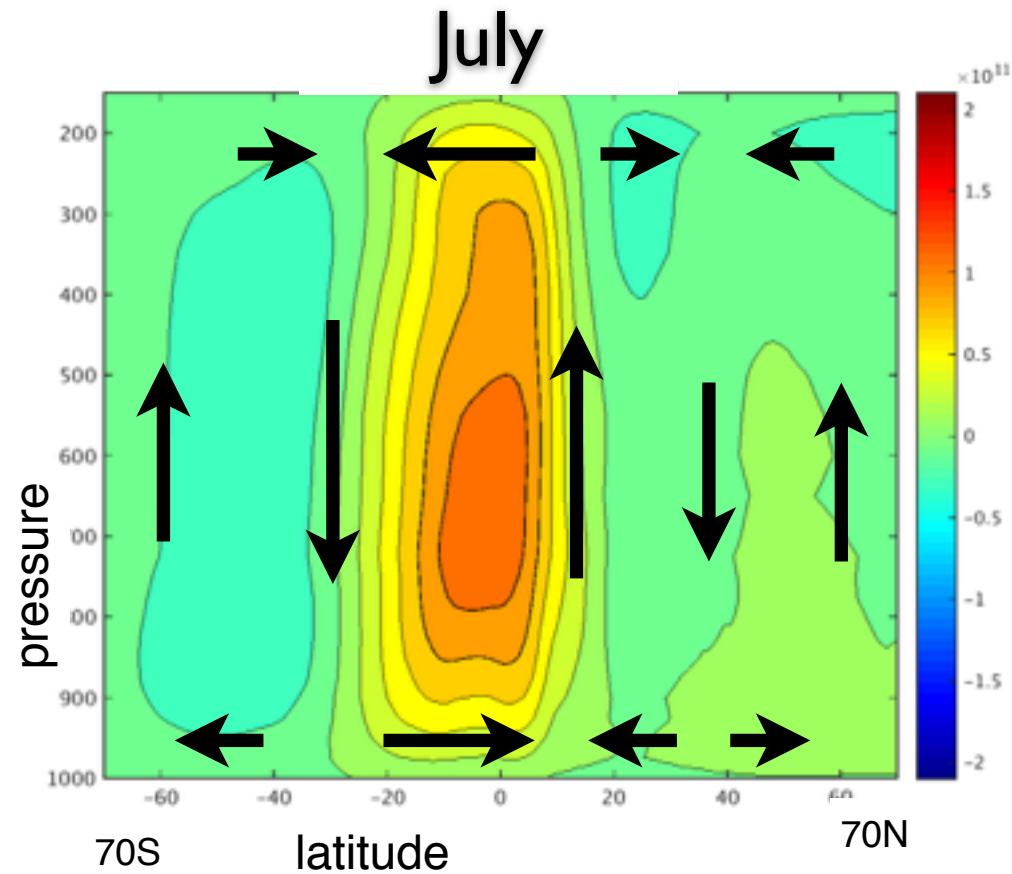
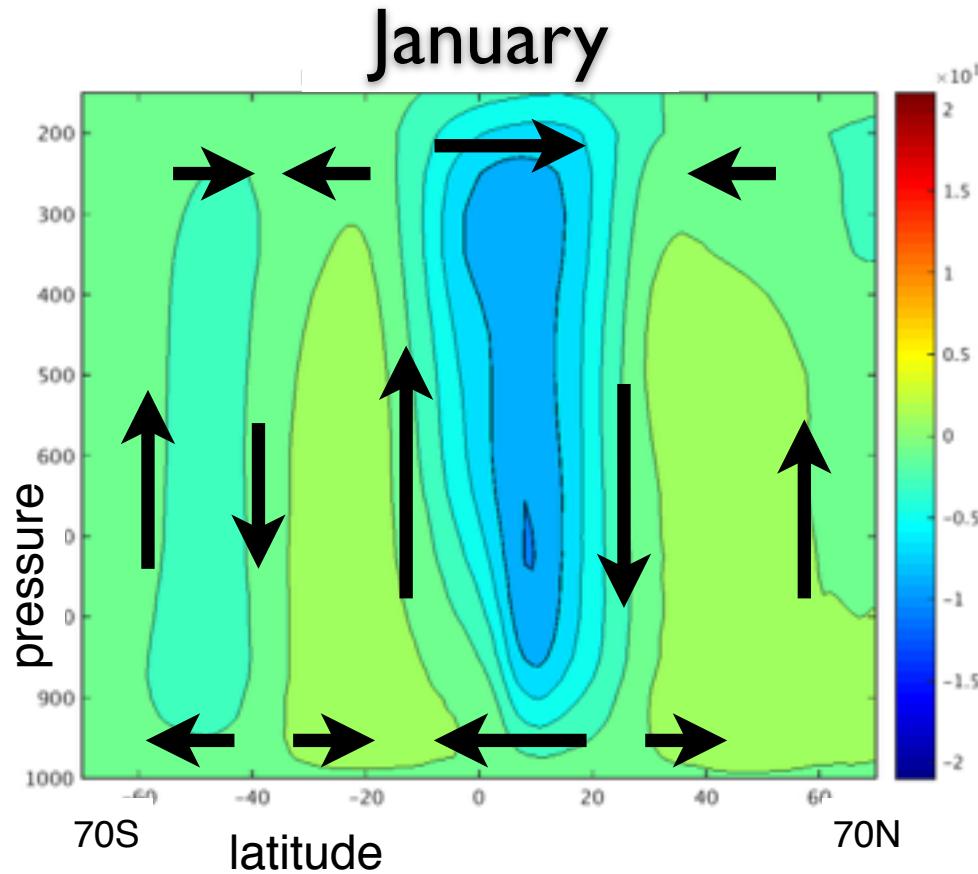


- The atmosphere (and ocean) act to transport energy poleward to balance the imposed latitudinal radiation imbalance.

Quizz: Where is the meridional circulation at its strongest?

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Eulerian-mean circulation

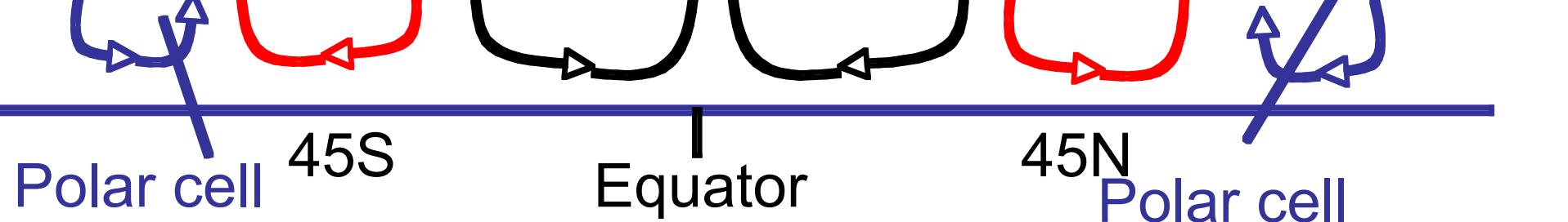


cint = $2.e10$ kg/s

$$\Psi_{mean}(\phi, p, t) = \int_0^p \bar{v}(\phi, p', t) \frac{dp'}{g}$$

Ferrel cells

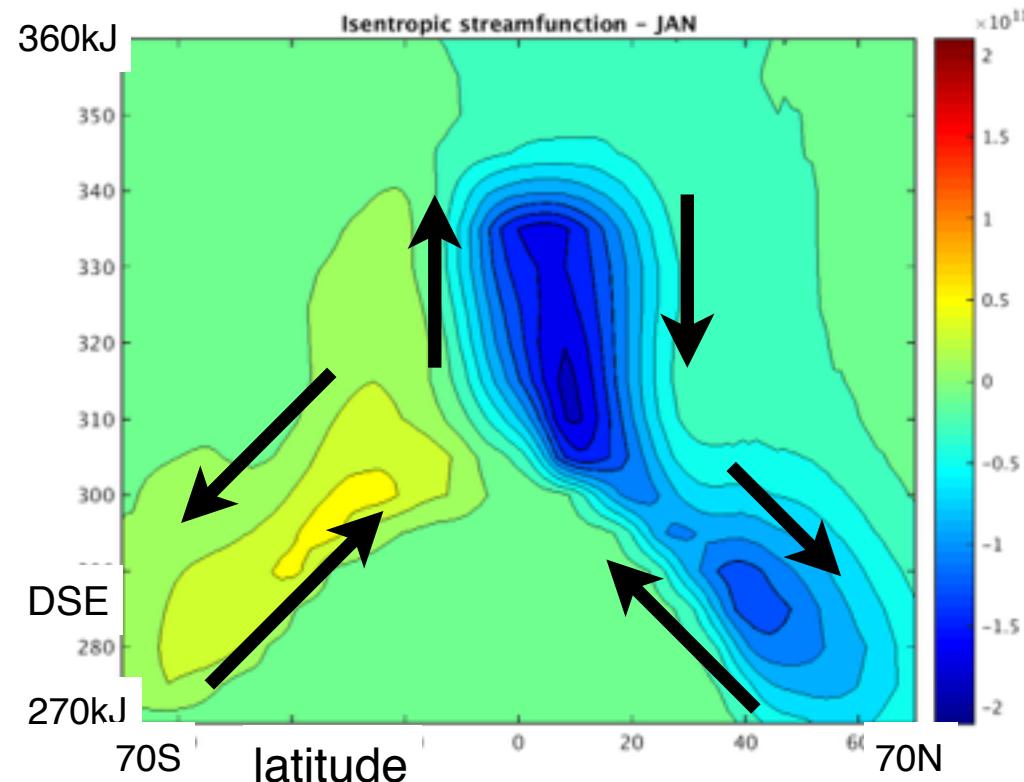
Hadley cells



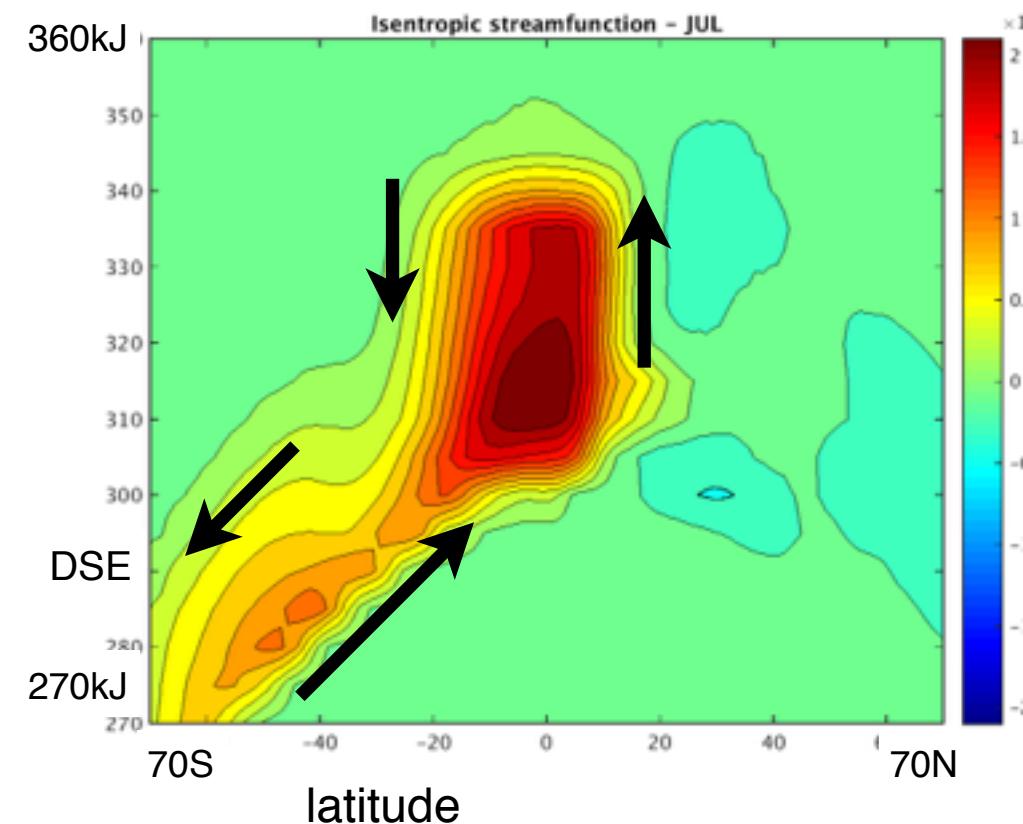
- Exhibits three cell structure
- Cross-equatorial Hadley dominates
- It implies a separation between tropics and extra tropics

Dry isentropic circulation

January



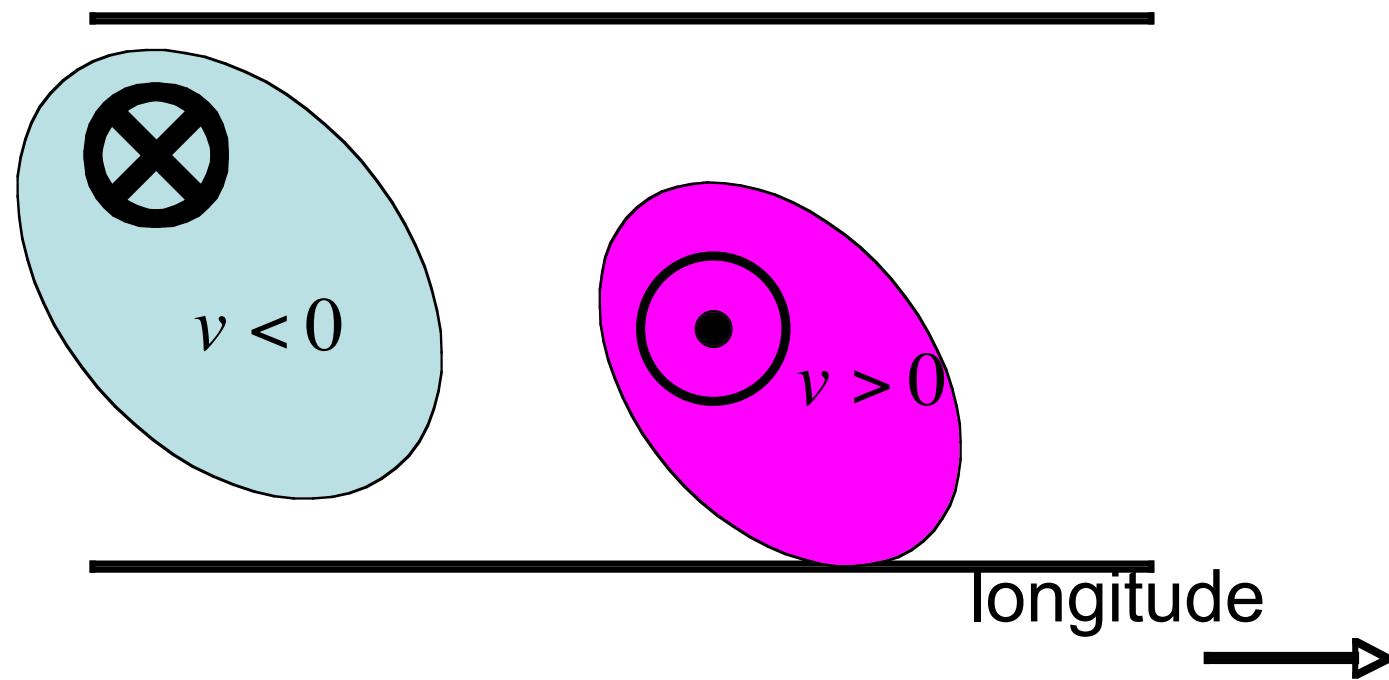
July



$$c_{int} = 2.e10 \text{ kg/s}$$

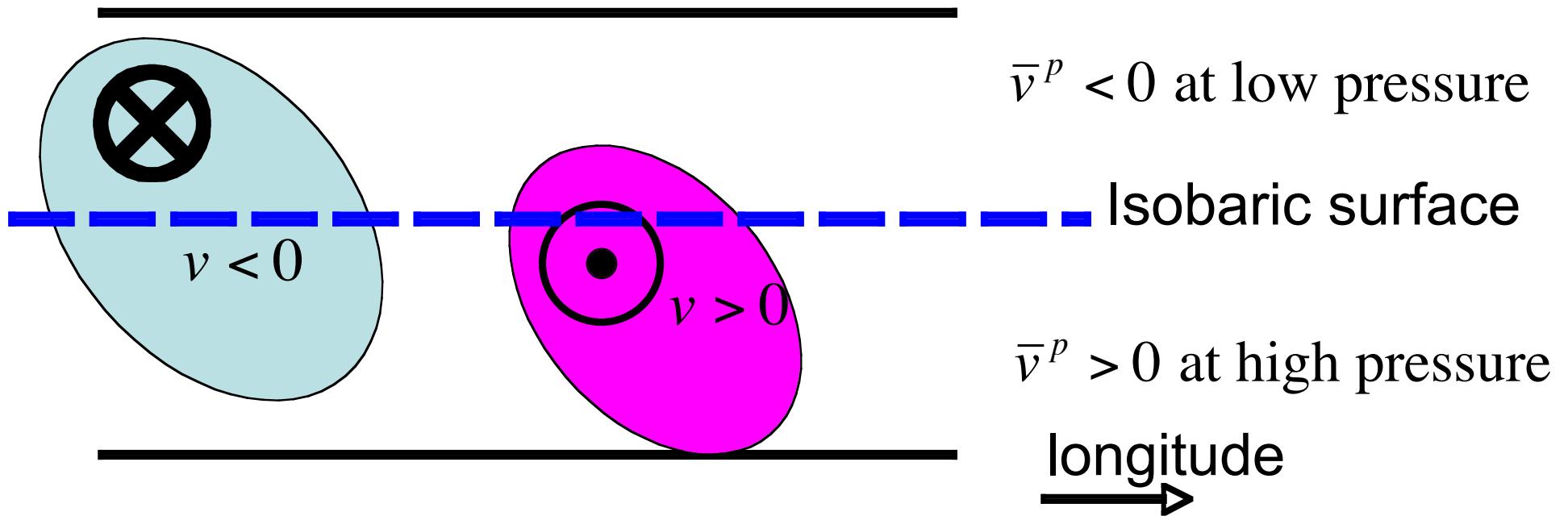
$$\Psi_\theta(\phi, \theta_0) = \frac{1}{T} \int_0^T \int_0^{p_{surf}} \int_0^{2\pi} \frac{a \cos \phi}{g} v H(\theta_0 - \theta(\lambda, \phi, p, t)) d\lambda dp dt$$

Why the circulation in eulerian and isentropic coordinates are in the opposite direction?



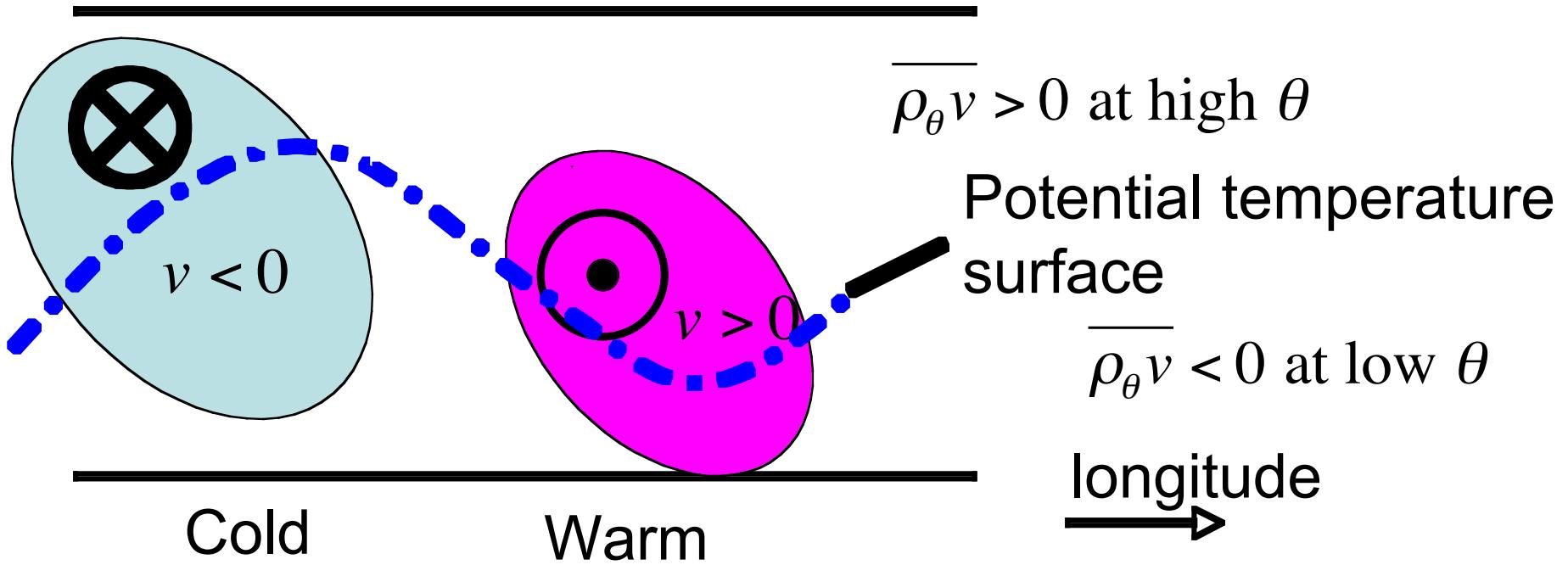
- In the midlatitudes, the flow is highly turbulent: the meridional velocity alternates between poleward and equatorward at all levels.

Eulerian-mean circulation



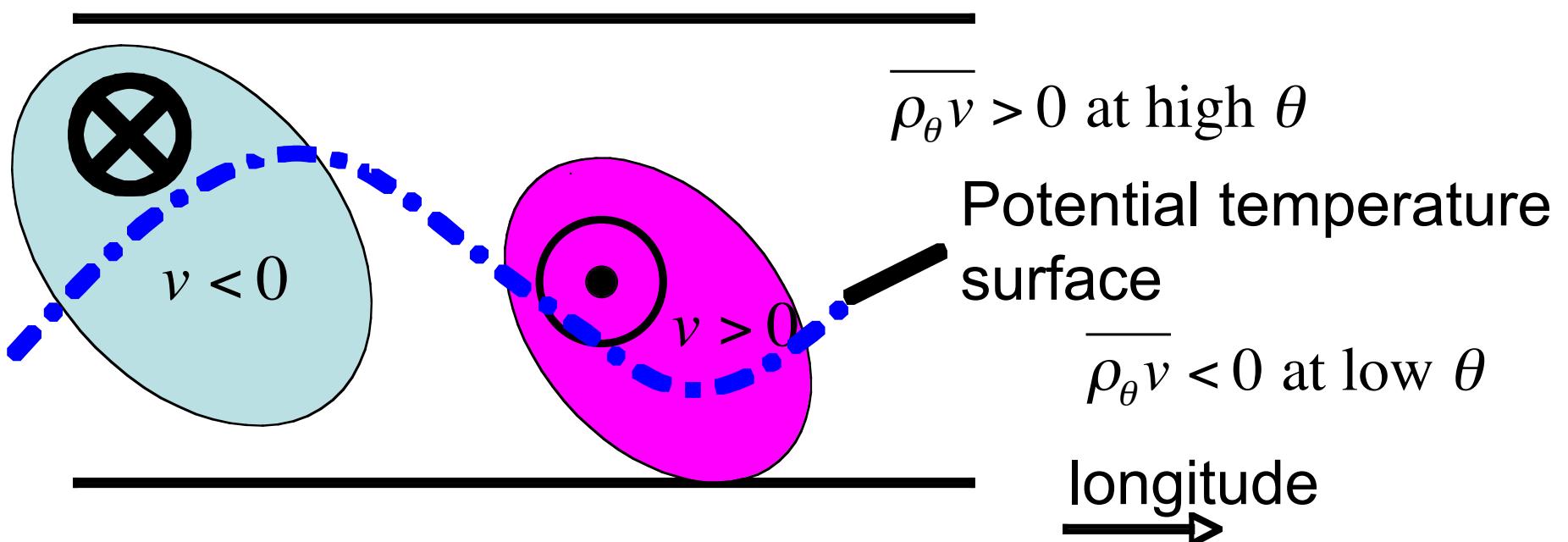
- In the midlatitudes, the flow is highly turbulent: the meridional velocity alternates between poleward and equatorward at all levels.
- This idealized eddies is associated with a poleward flow at high pressure/low level, and equatorward flow at high level

Isentropic circulation



Thickness variations are such that the upper isentropic layer encompasses larger fraction of the poleward flow.
Such pattern also corresponds to a net poleward energy mass transport.

Isentropic flow and eddy mass transport

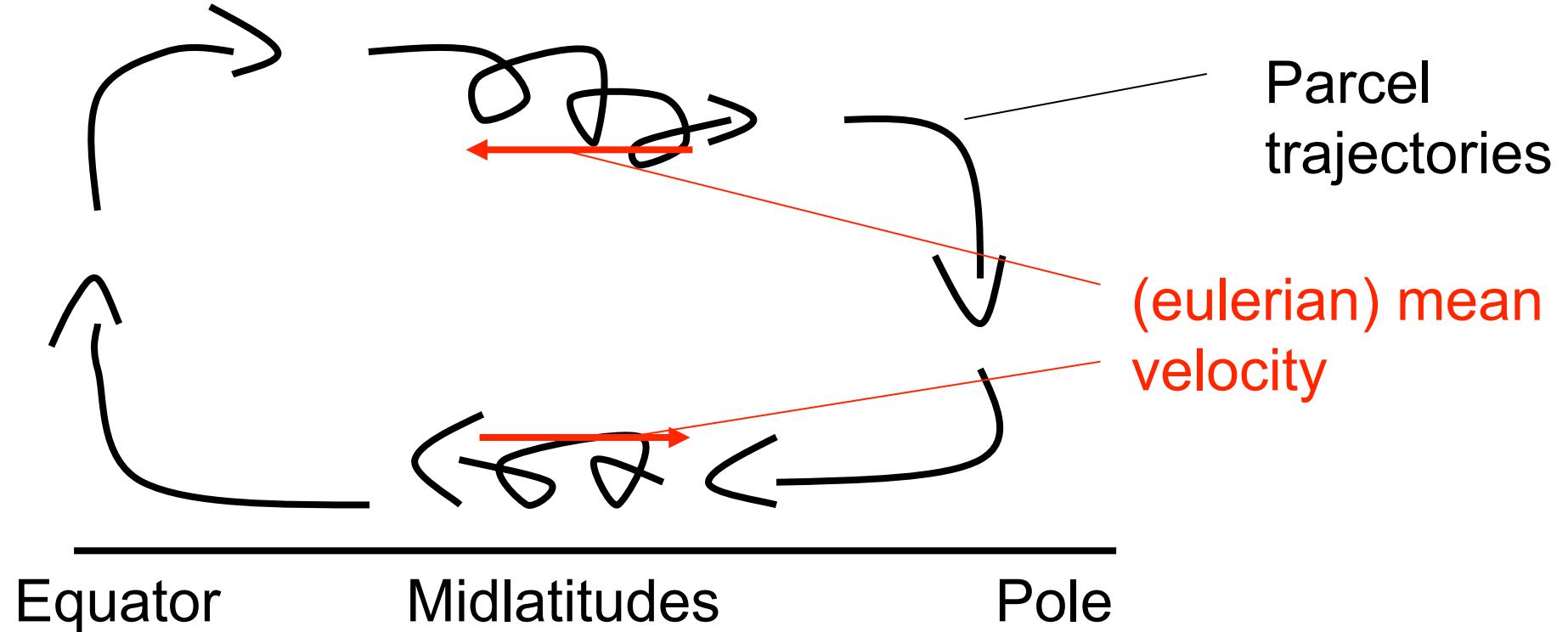


- The mass flux on isentropic surfaces can be written as:

$$\overline{\rho_\theta v}^\theta = \overline{\rho_\theta}^\theta \overline{v}^\theta + \overline{\rho_\theta' v'}^\theta$$

Total mass flux Transport by mean circulation Eddy transport

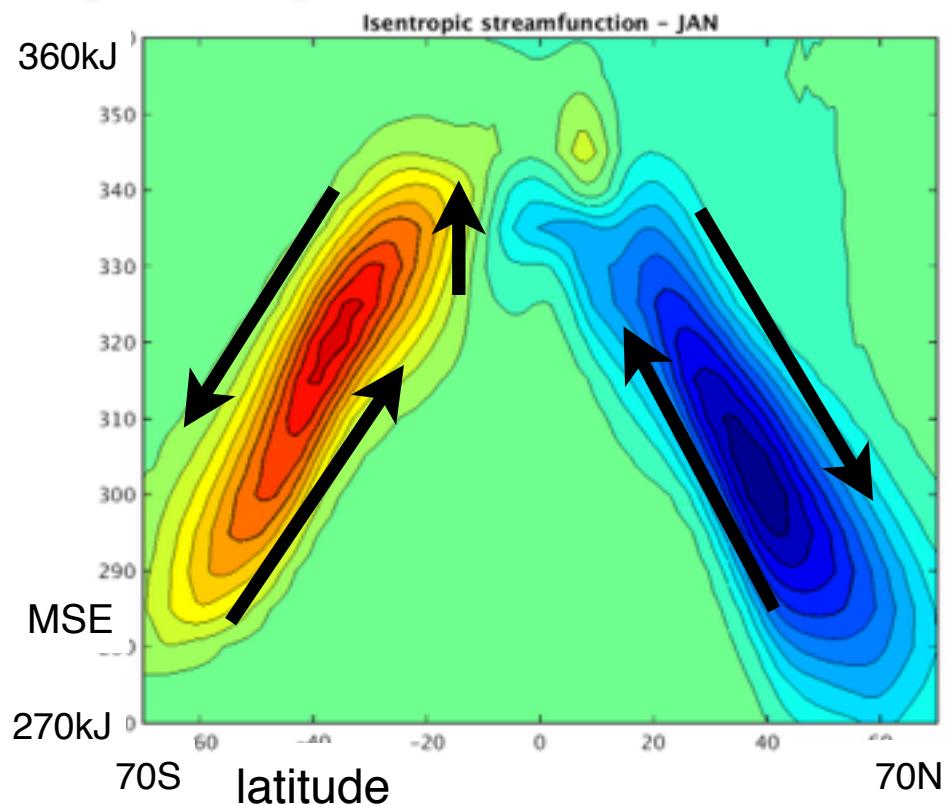
- The mass transport by the eddies is in the opposite direction to the mean wind.



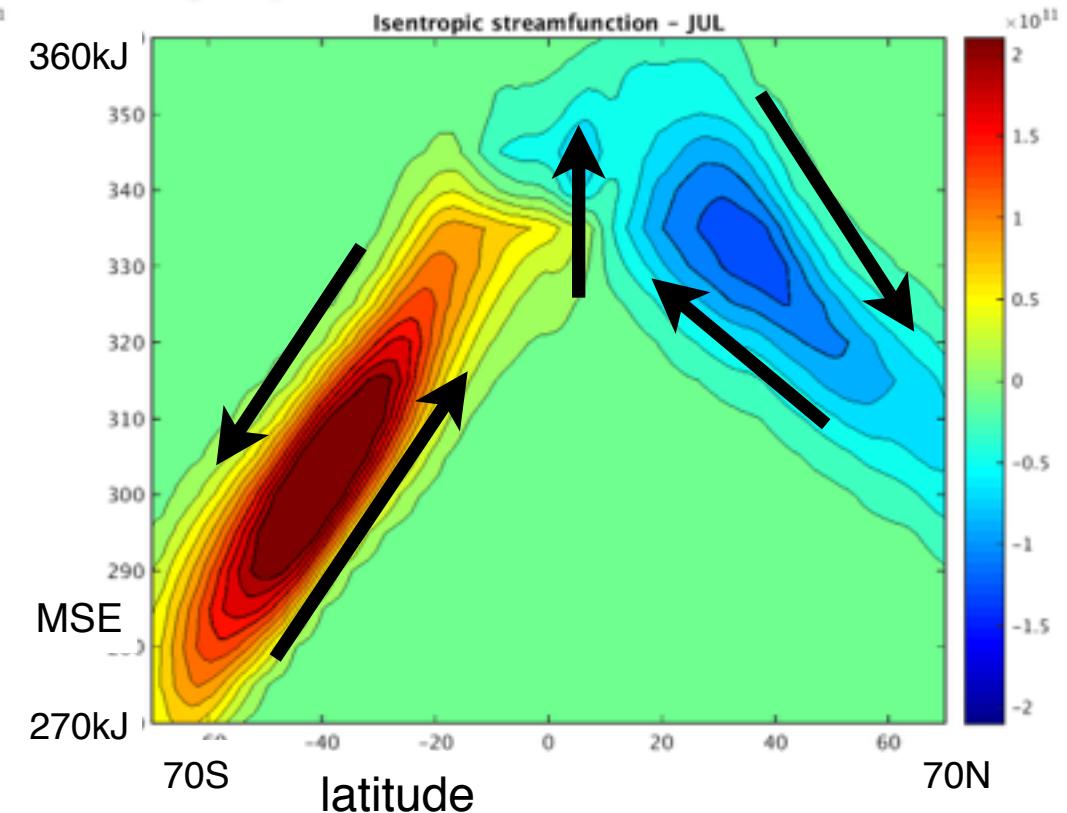
- The isentropic circulation better capture the parcels trajectories in presence of eddies.
- There is no artificial separation between tropics and midlatitudes
- It directly relates mass transport and transport of dry static energy (enthalpy + geopotential).
- but it does not include water vapor transport.

Moist isentropic circulation

January



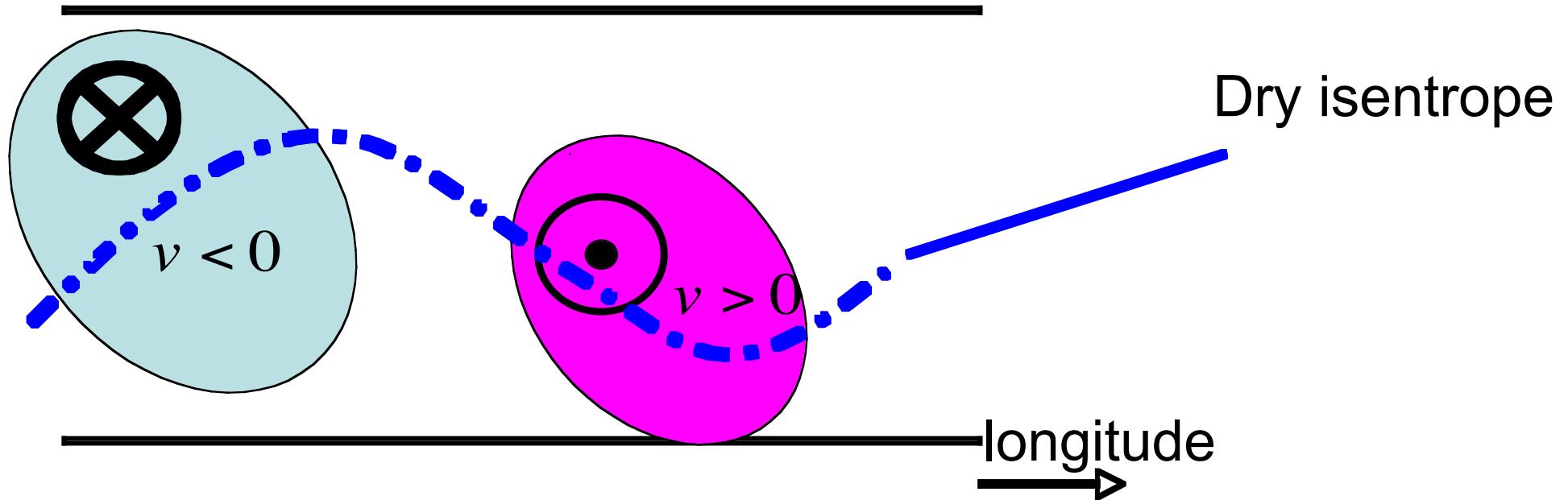
July



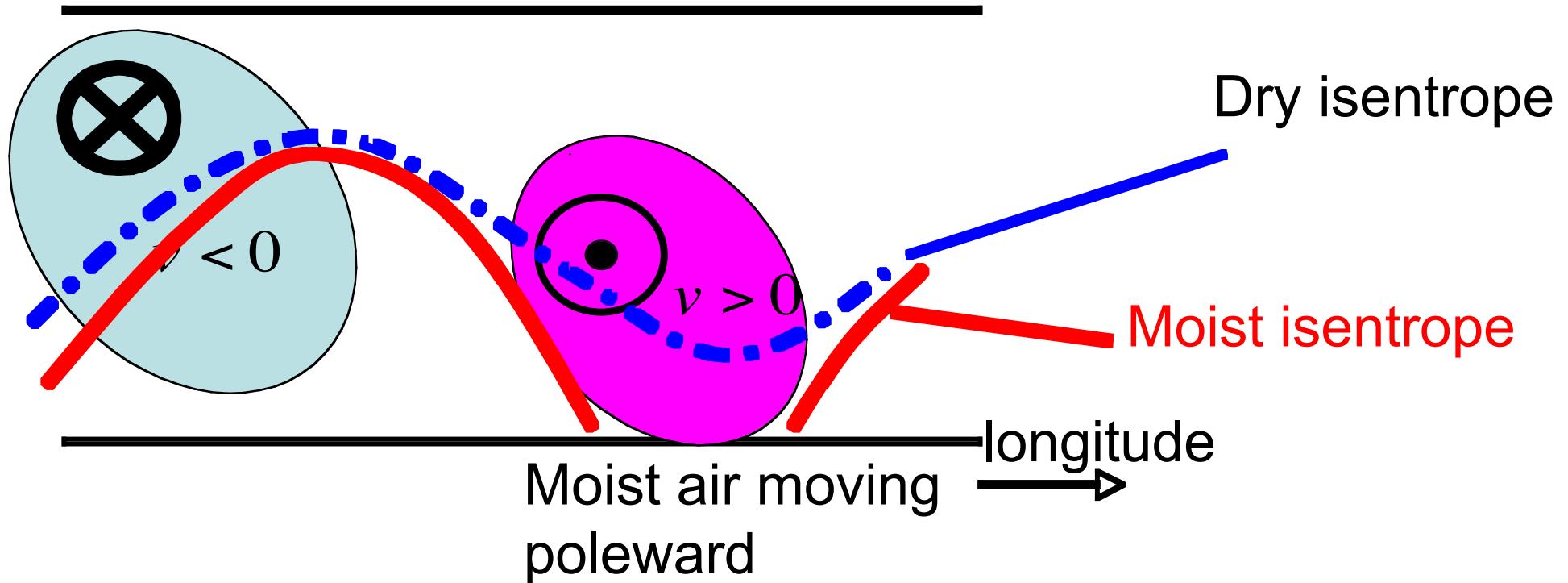
$$c_{int} = 2.e10 \text{ kg/s}$$

$$\Psi_\theta(\phi, \theta_0) = \frac{1}{T} \int_0^T \int_0^{p_{surf}} \int_0^{2\pi} \frac{a \cos \phi}{g} v H(\theta_0 - \theta(\lambda, \phi, p, t)) d\lambda dp dt$$

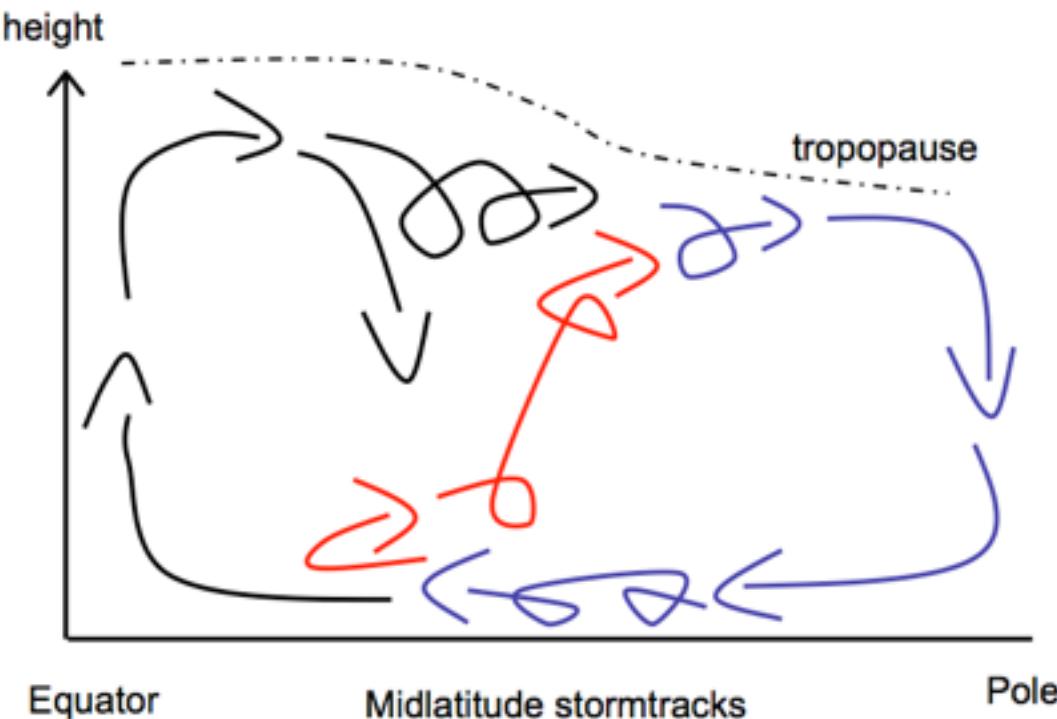
Why the circulation on moist isentropes is larger?



In the stormtracks: Circulation on moist isentropes



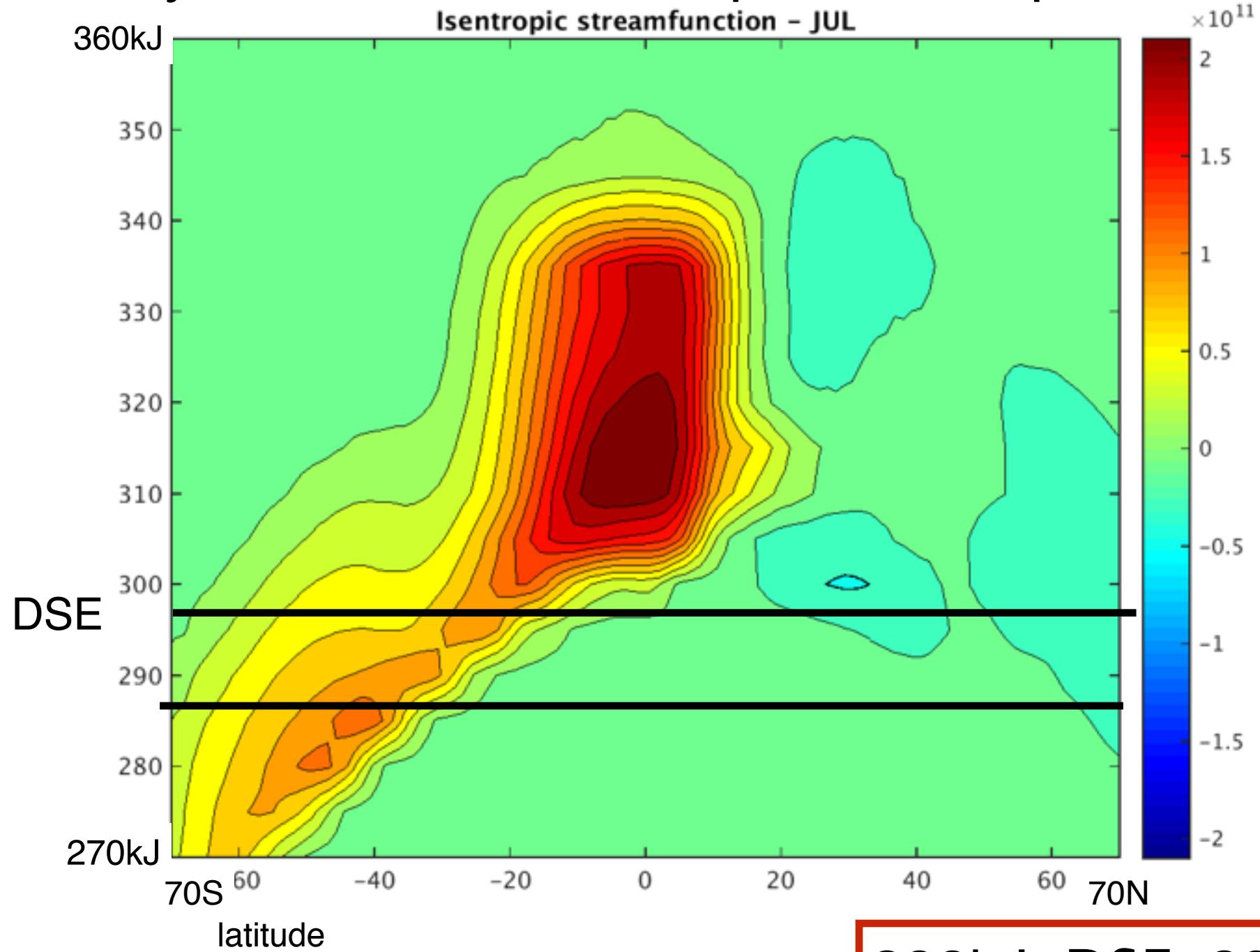
- Moist isentropes found in the upper troposphere also intersects the Earth's surface.
- Such situation corresponds to a poleward flow of warm, moist air near the surface.



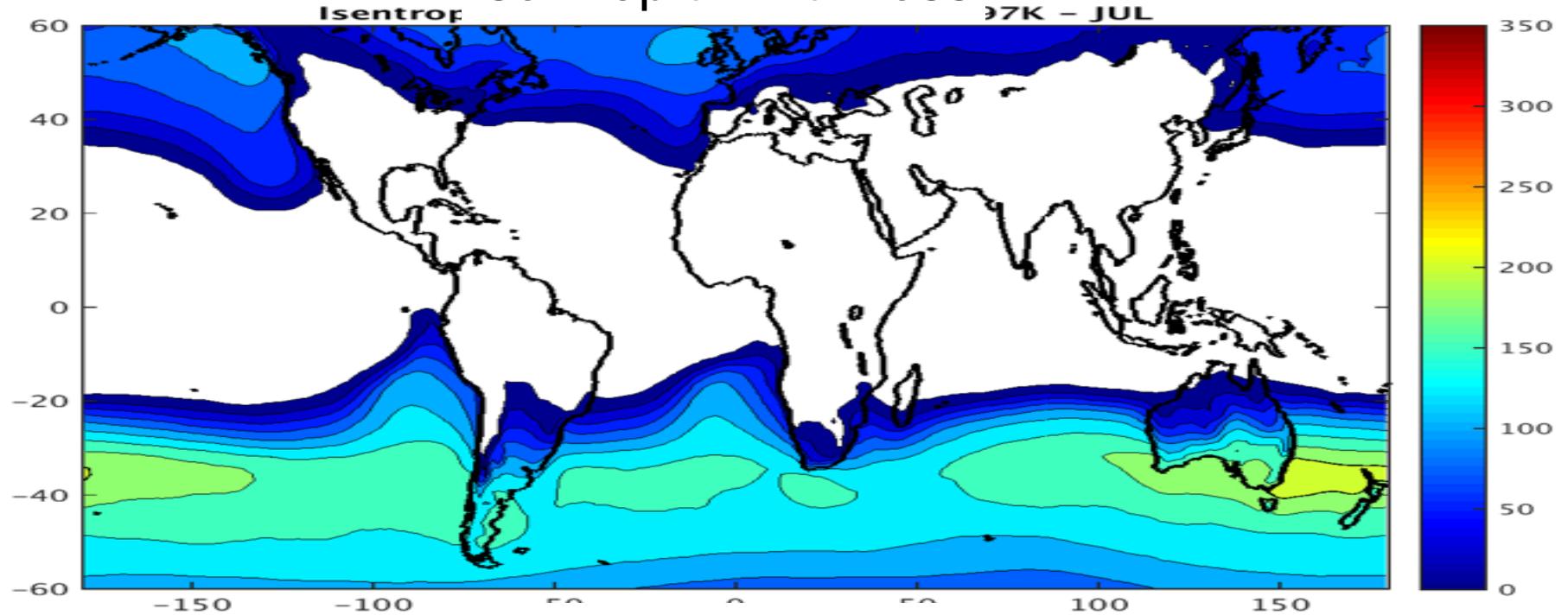
- Circulation on dry isentropes
- 'Moist' branch:
additional mass flow on moist isentropes

- The global circulation has two poleward components in the midlatitudes:
 - an upper tropospheric branch of high $\theta_e - \theta$;
 - an a lower branch of warm, moist air with high $\theta_e - \theta$, which ascent into the upper troposphere within the stormtracks.
- Mass transport is comparable in each branch.

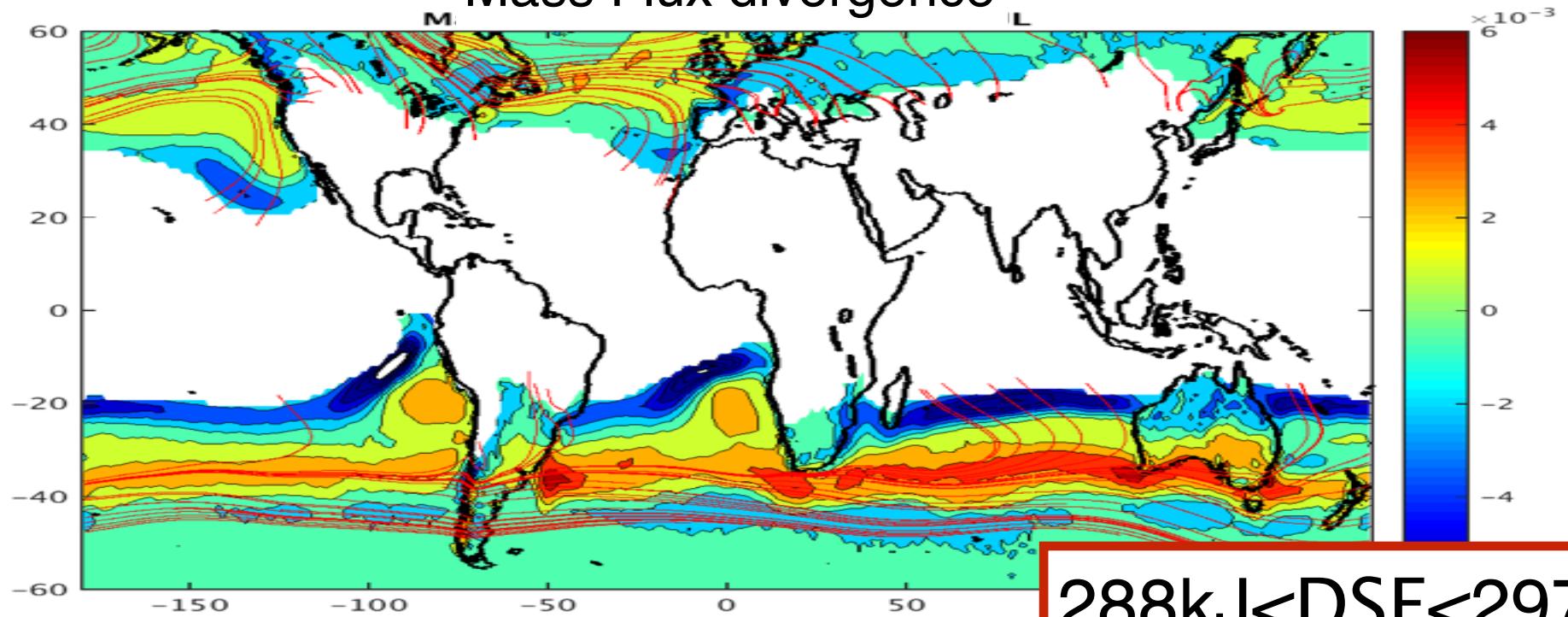
Dry ventilation of the tropical atmosphere



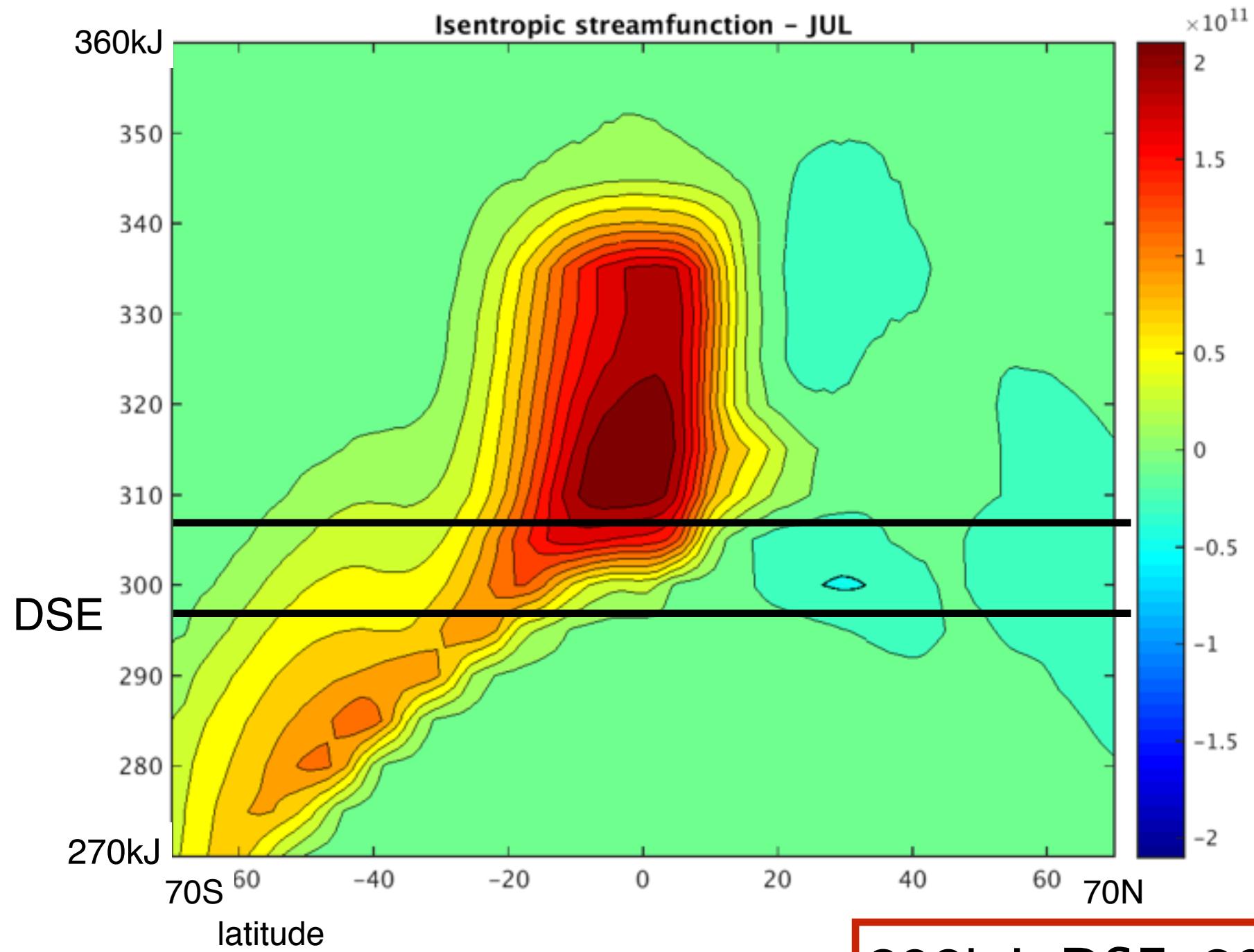
Isentropic Thickness



Mass Flux divergence

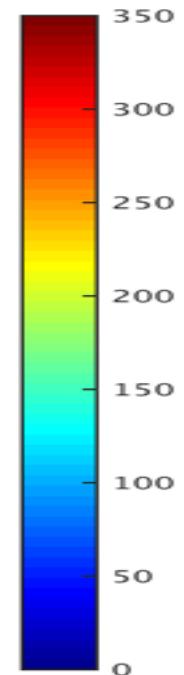
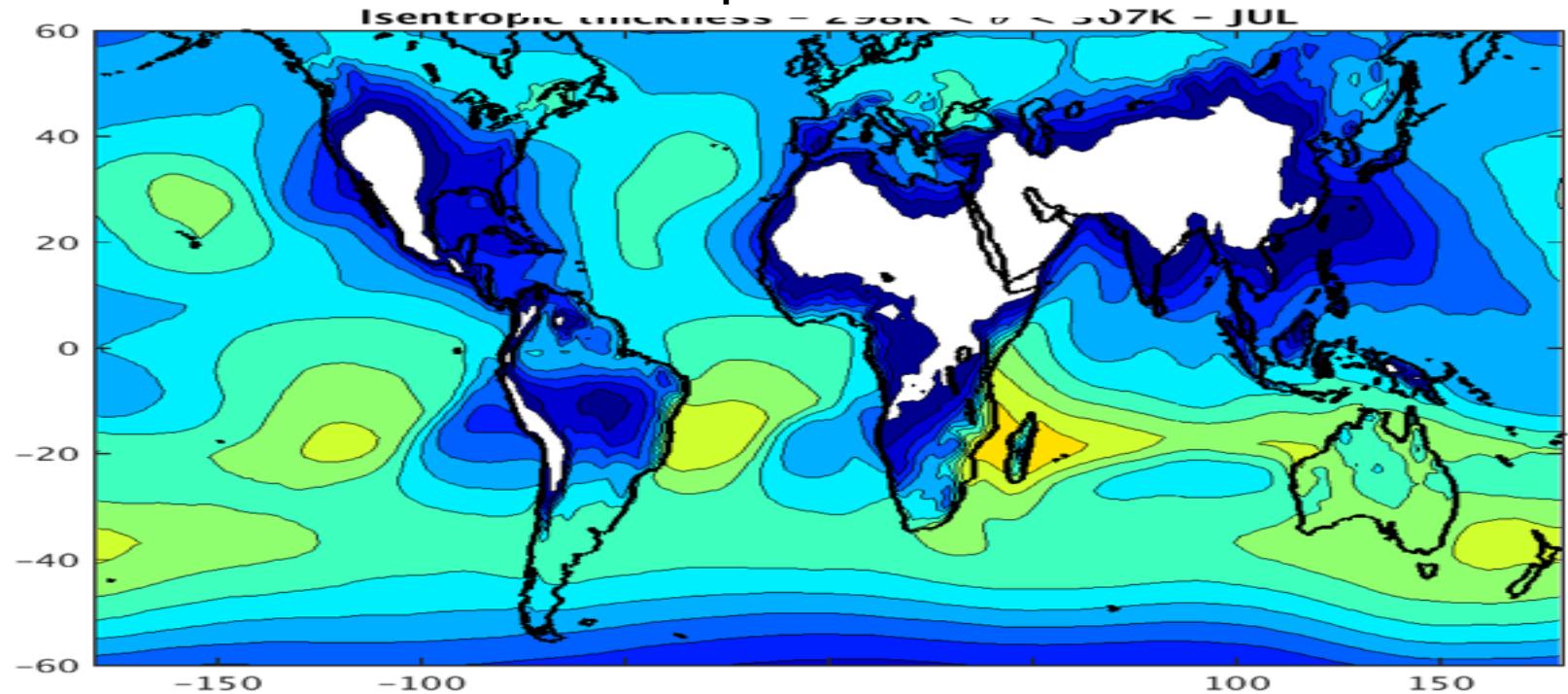


288kJ < DSE < 297kJ

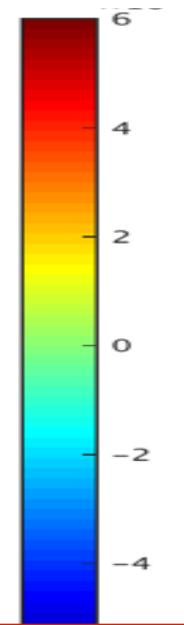
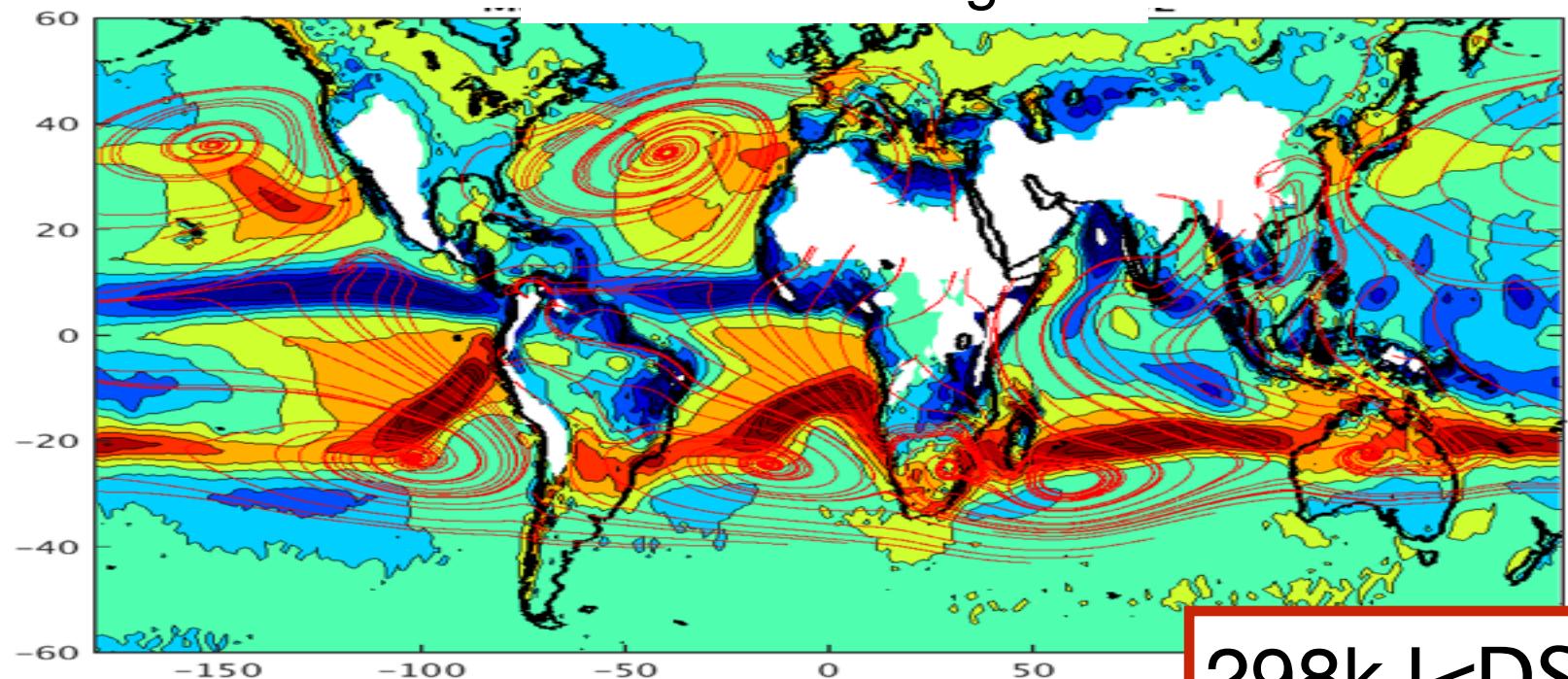


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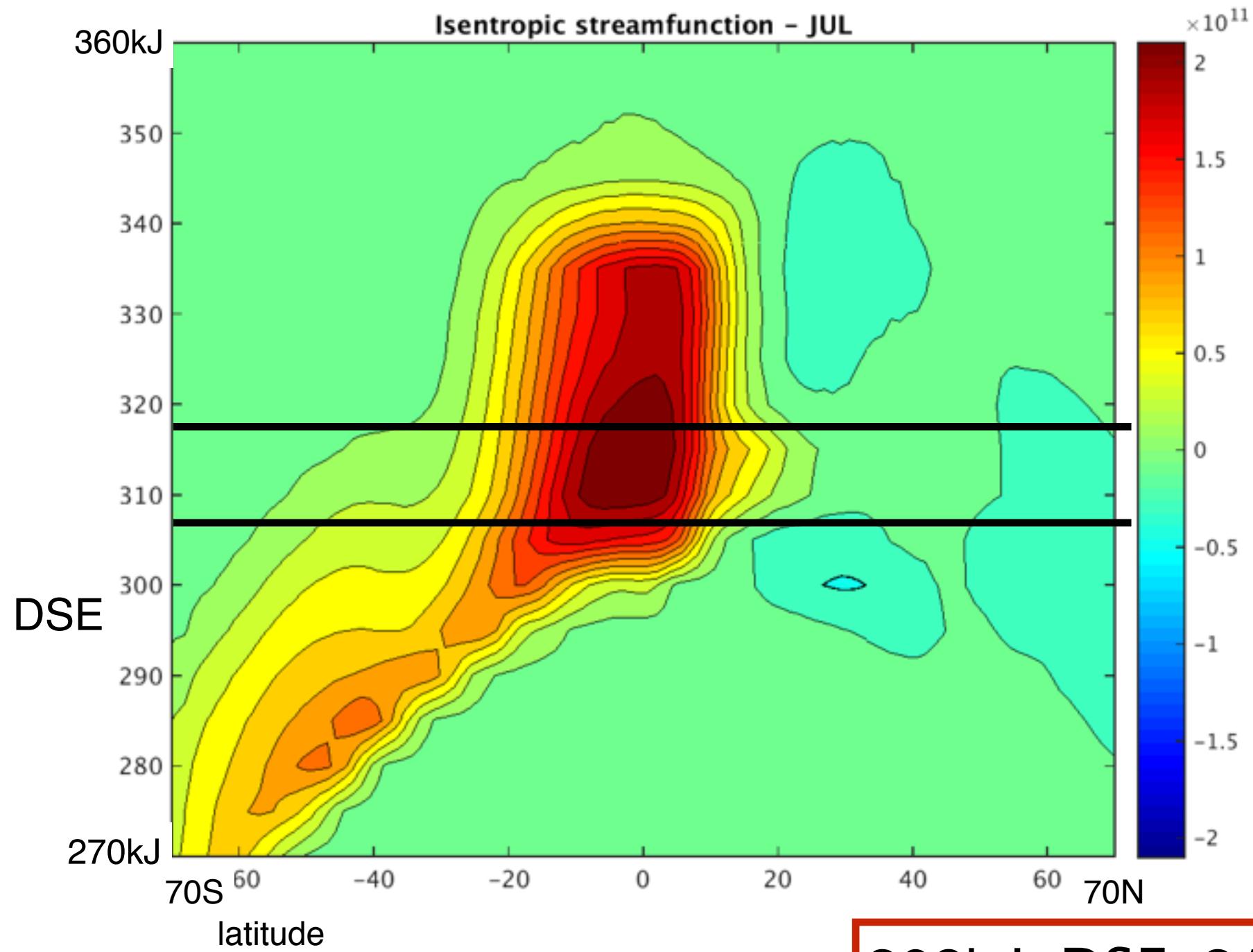
Isentropic Thickness



Mass Flux divergence

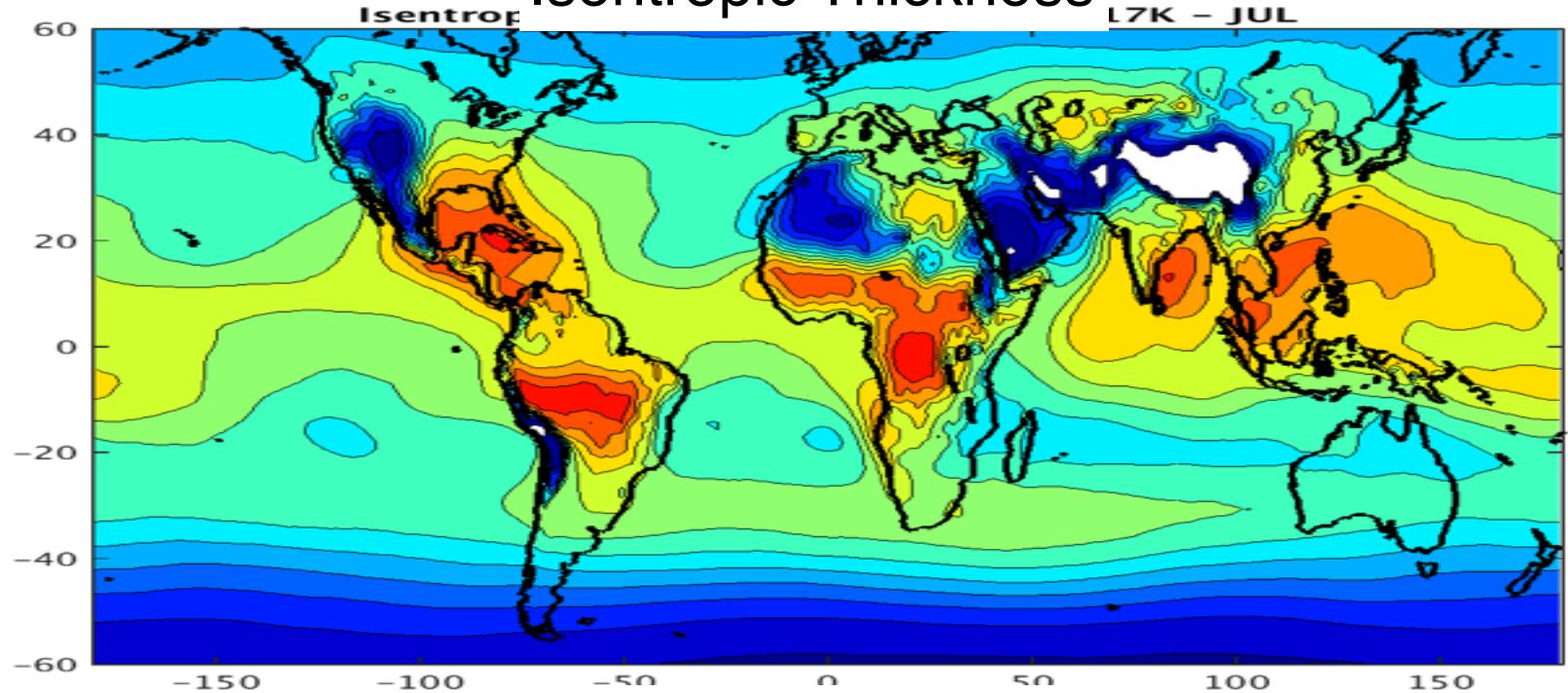


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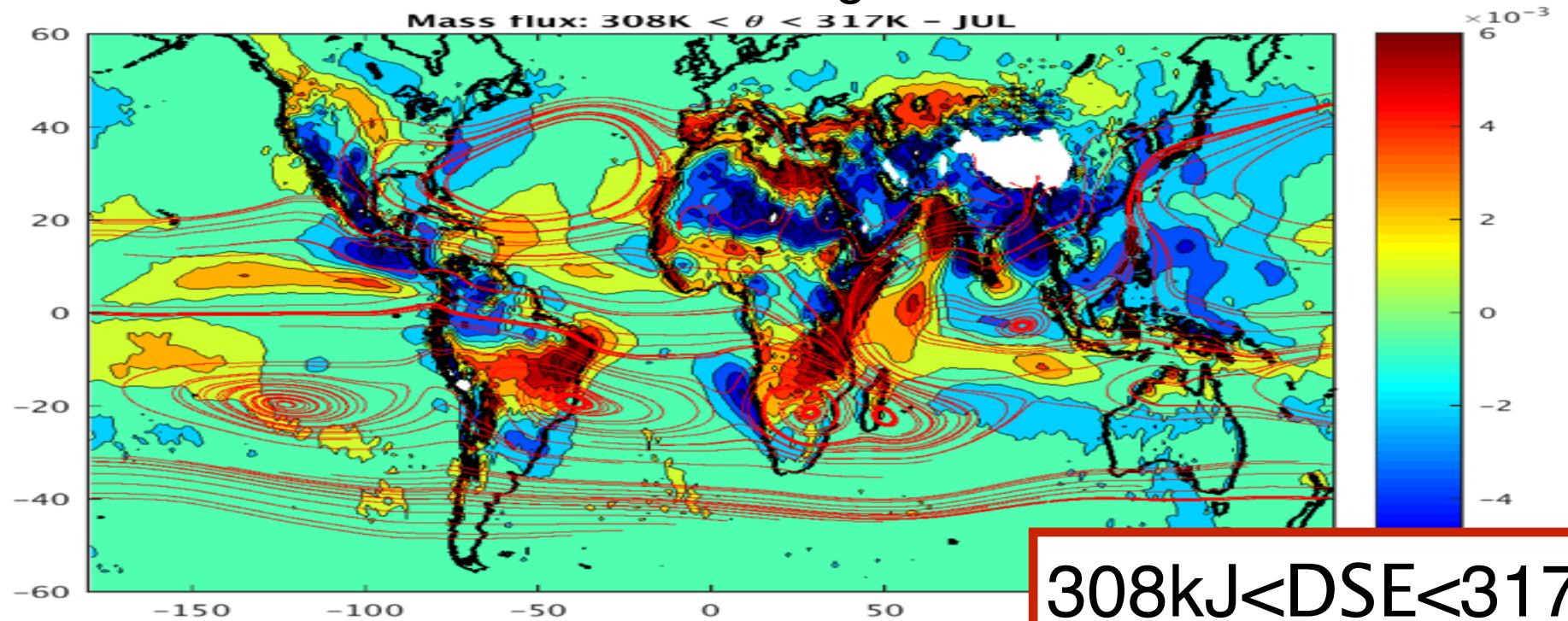


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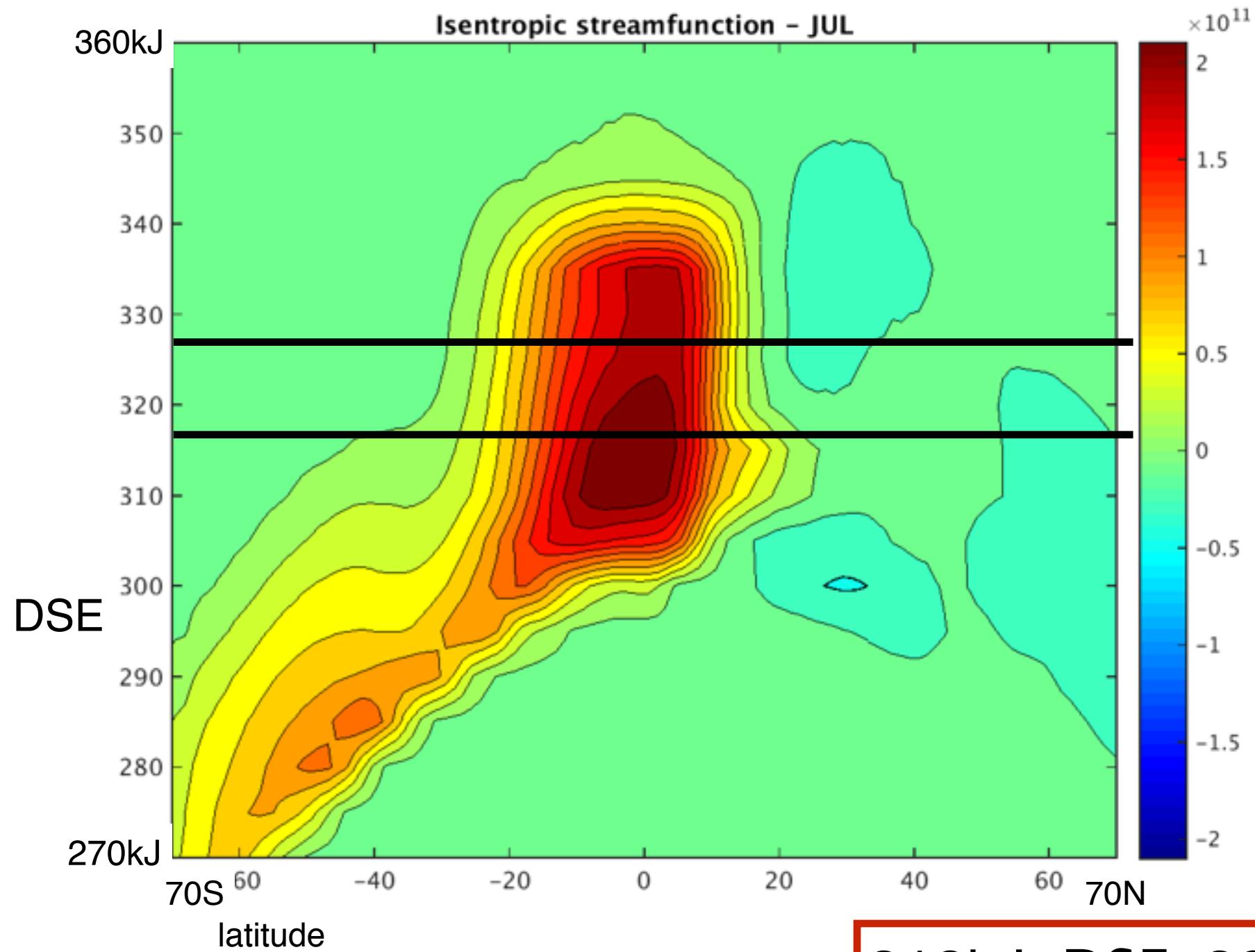
Isentropic Thickness



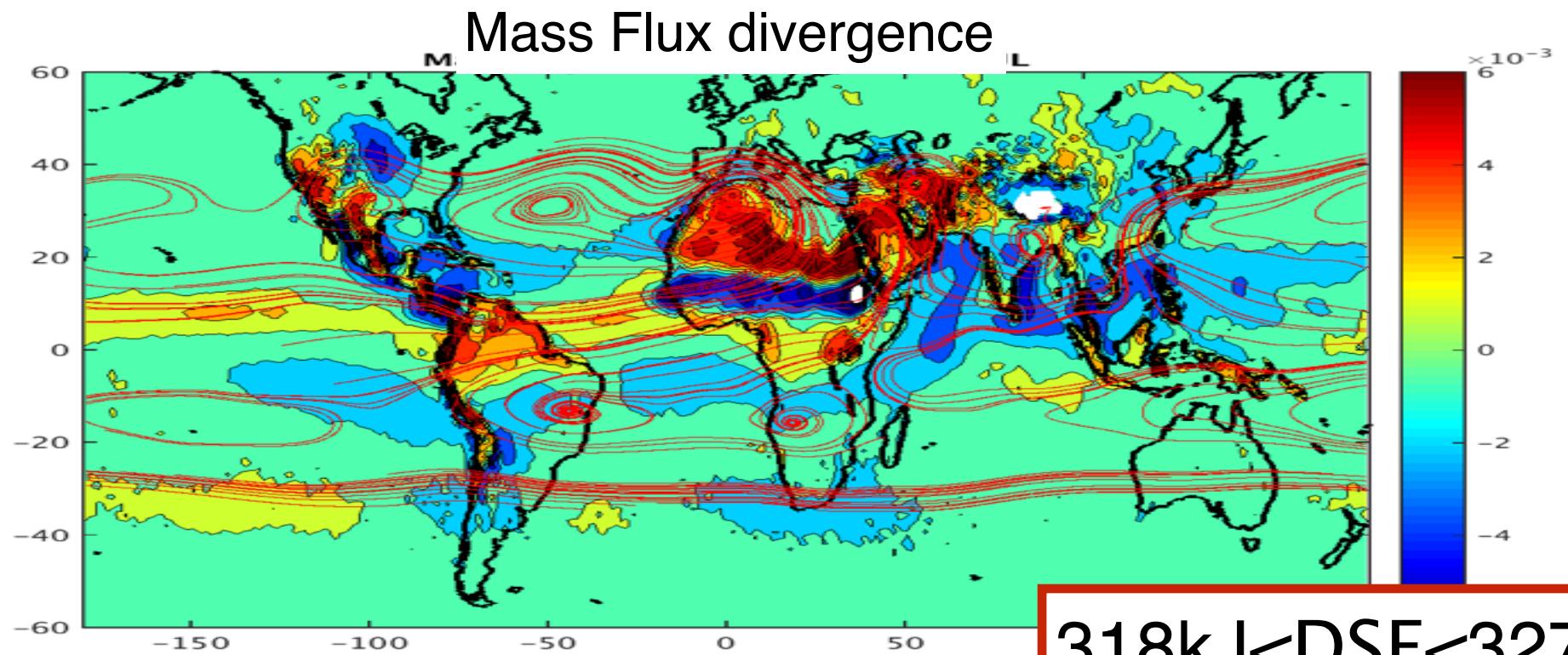
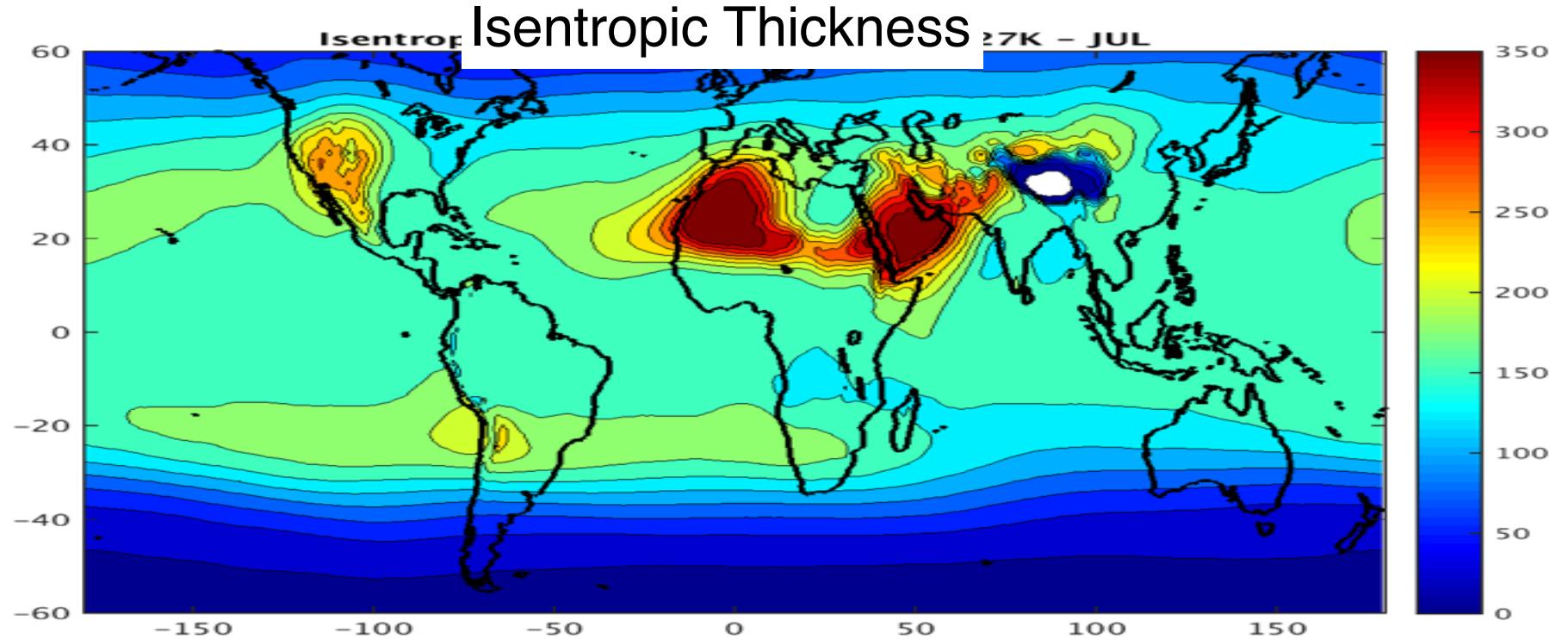
Mass Flux divergence



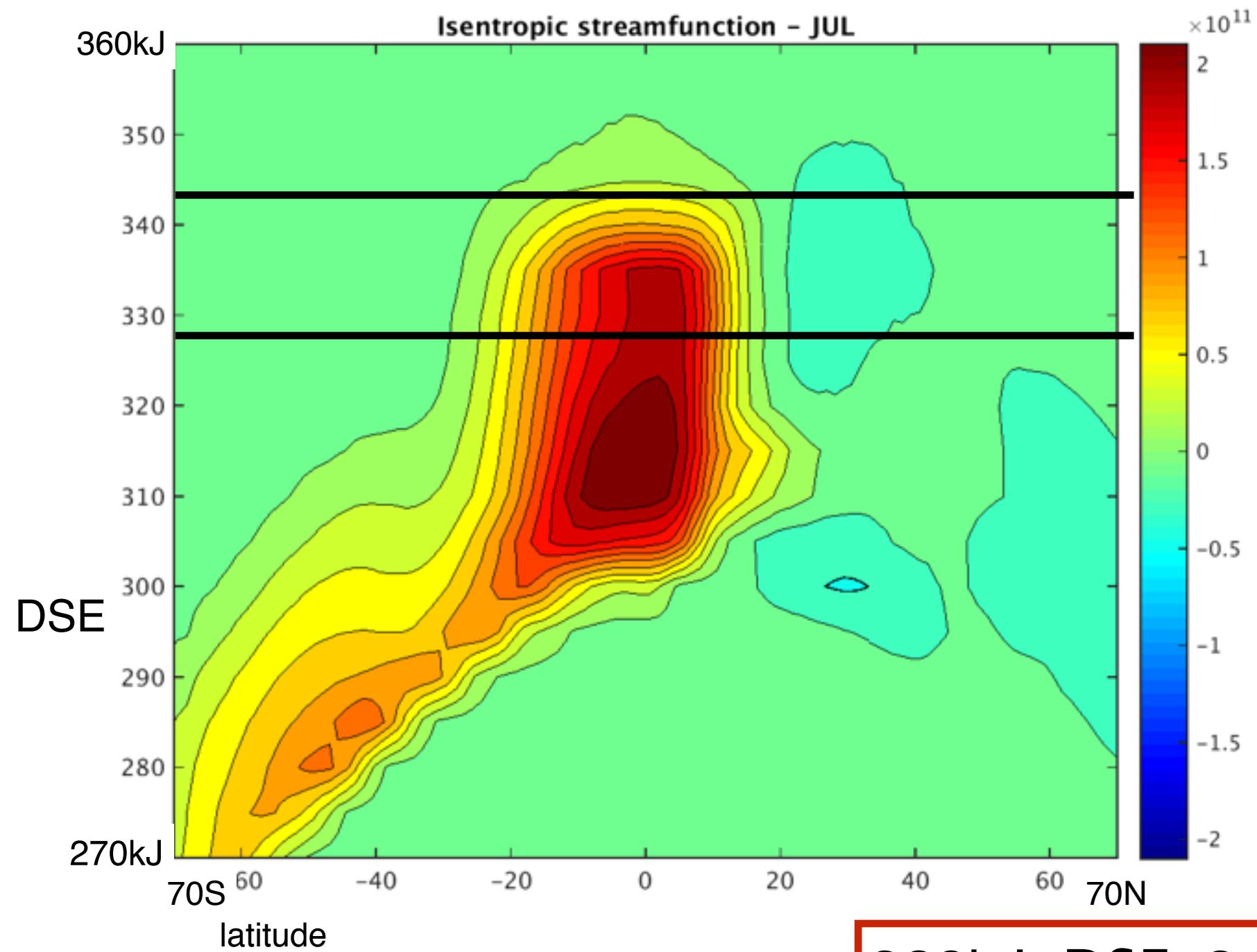
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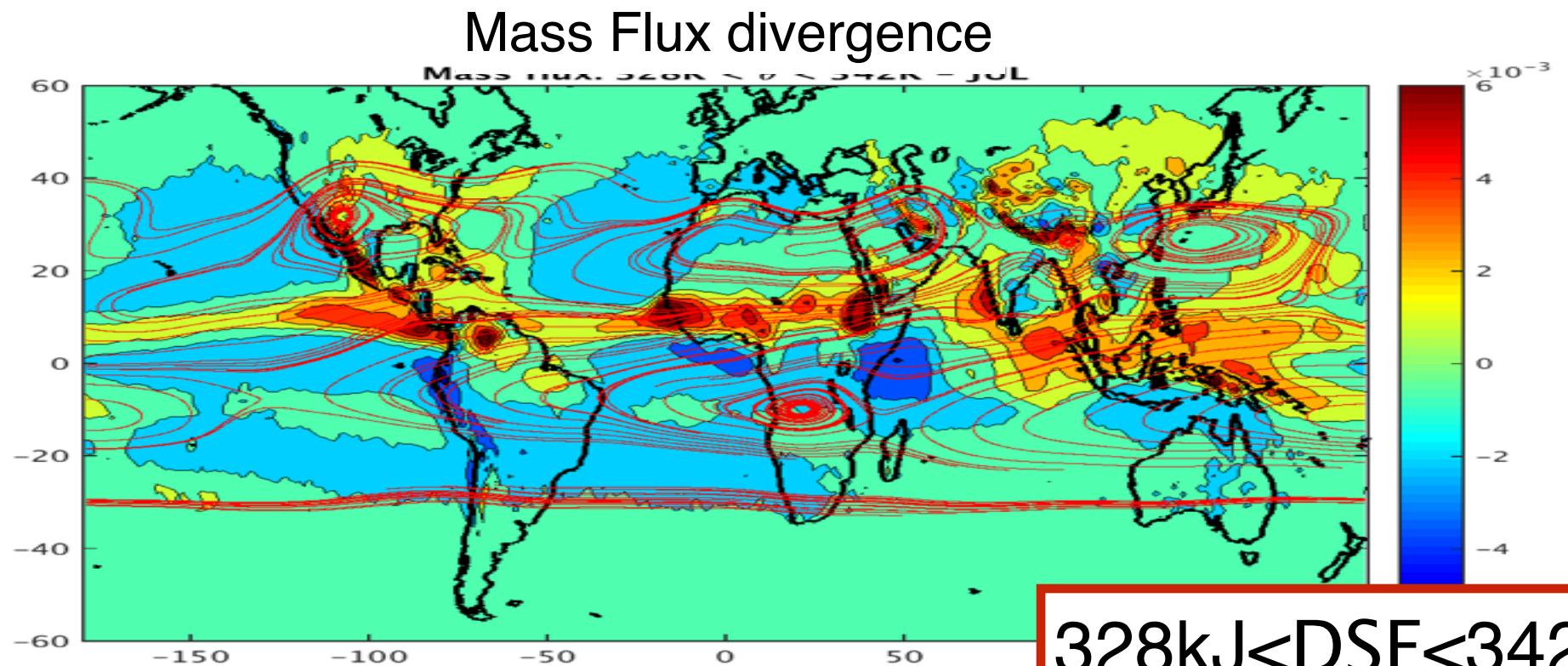
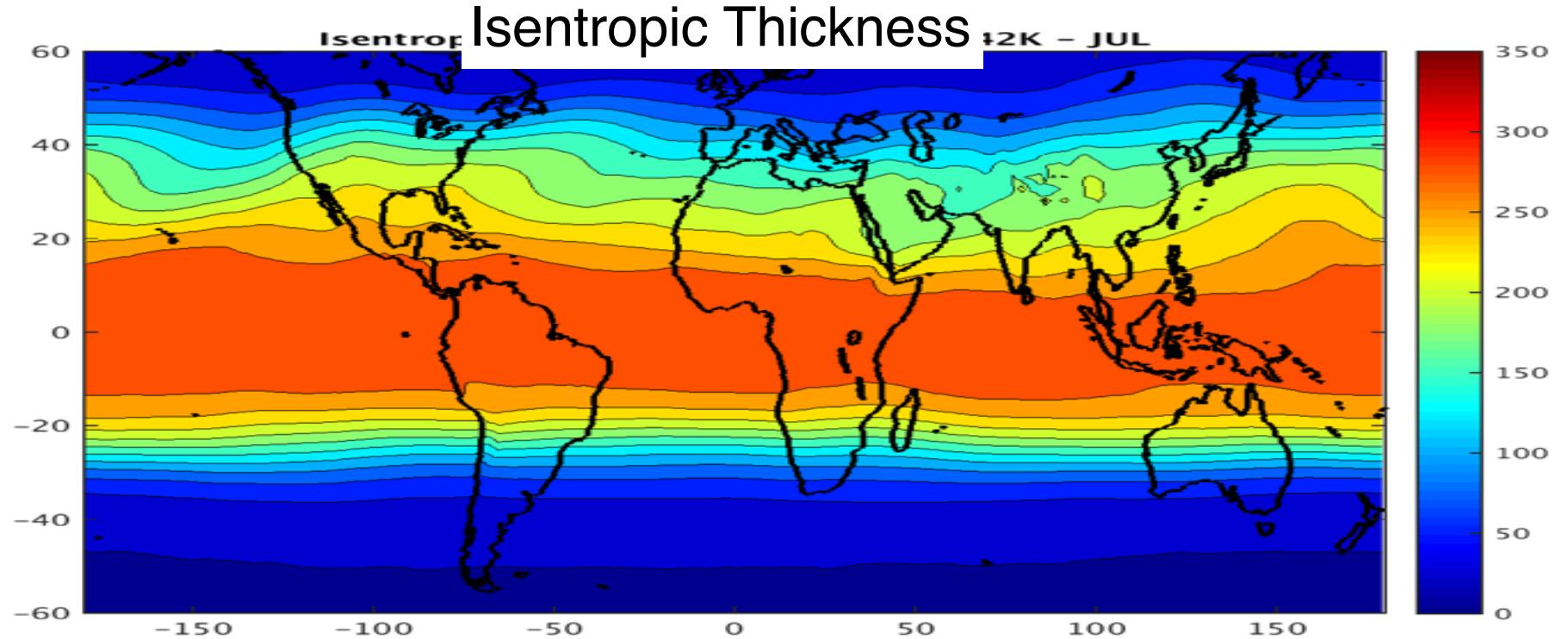
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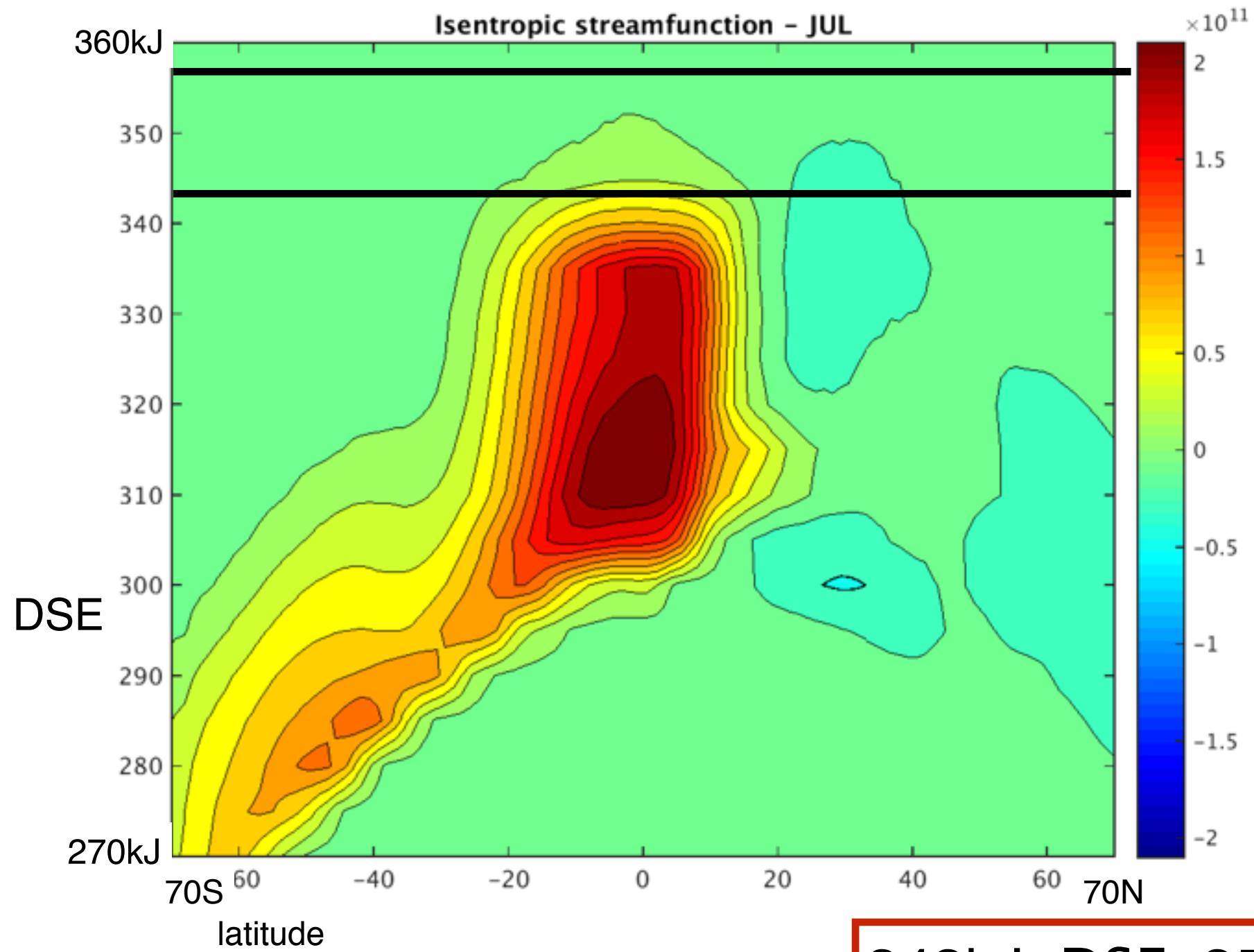
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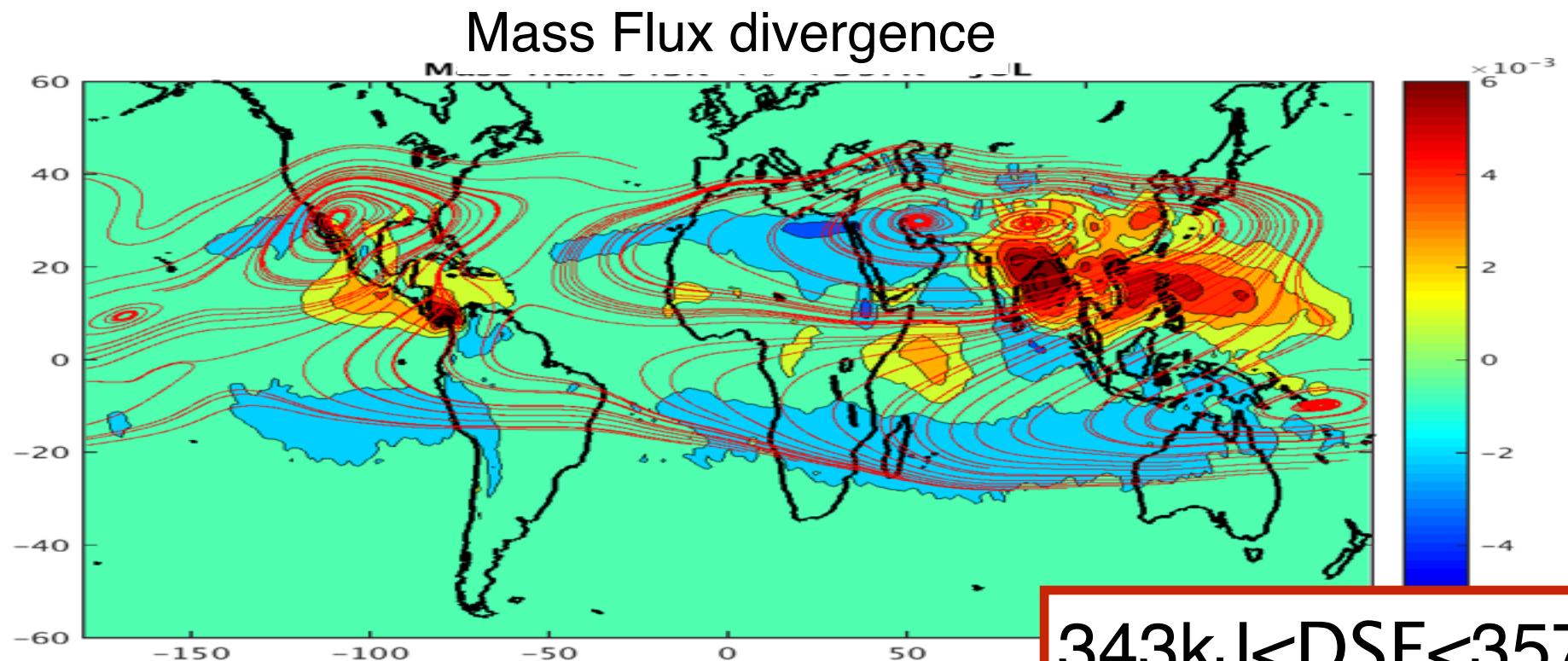
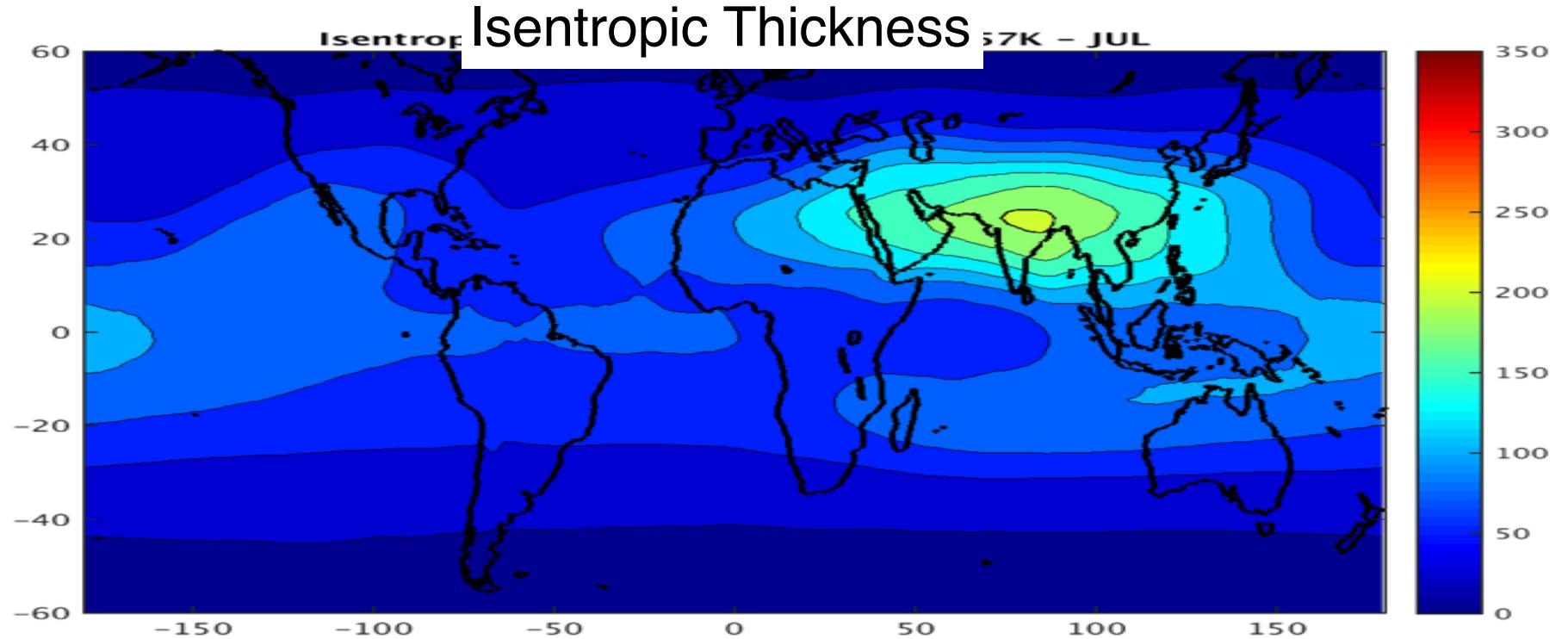
328kJ < DSE < 342kJ



328kJ < DSE < 342kJ

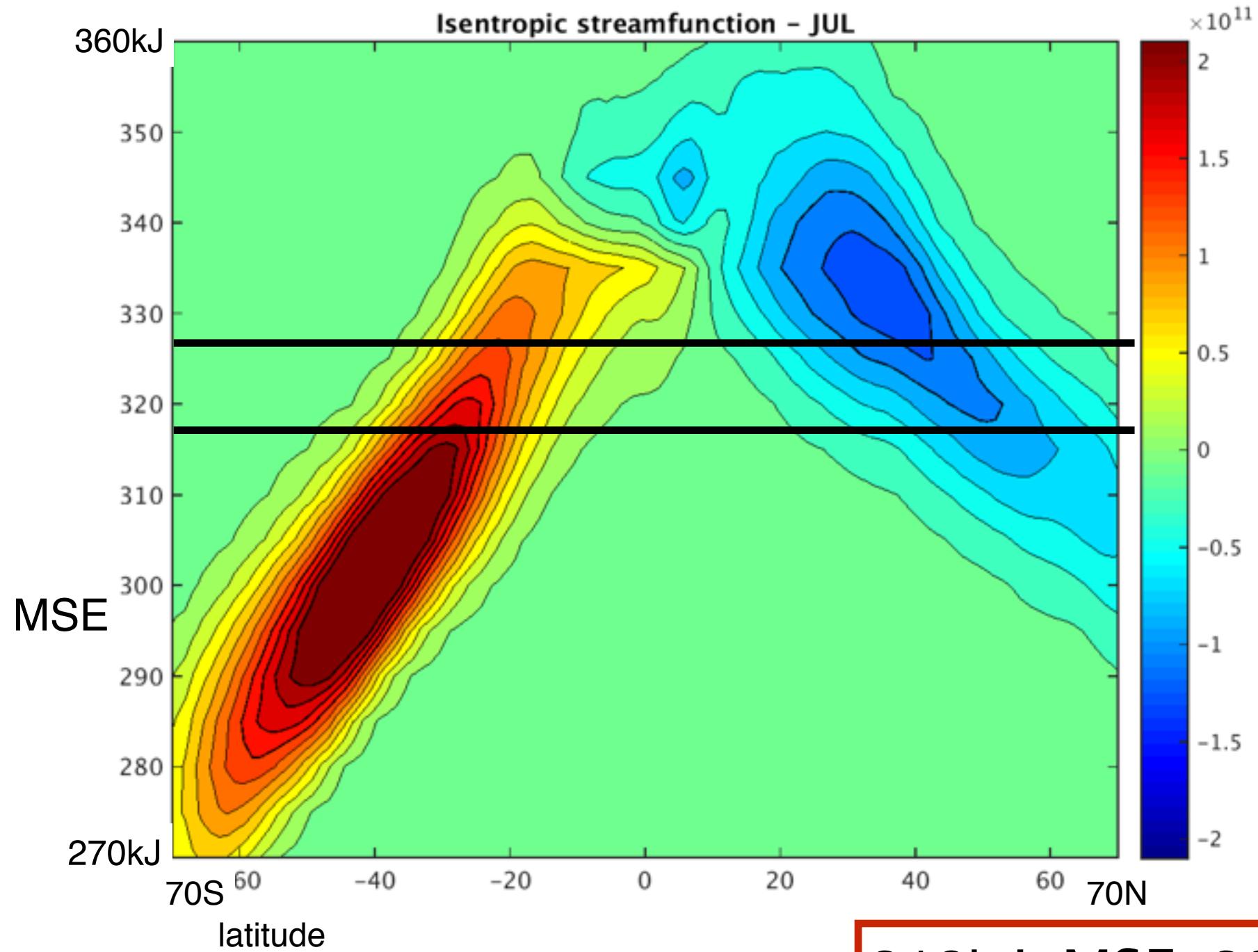


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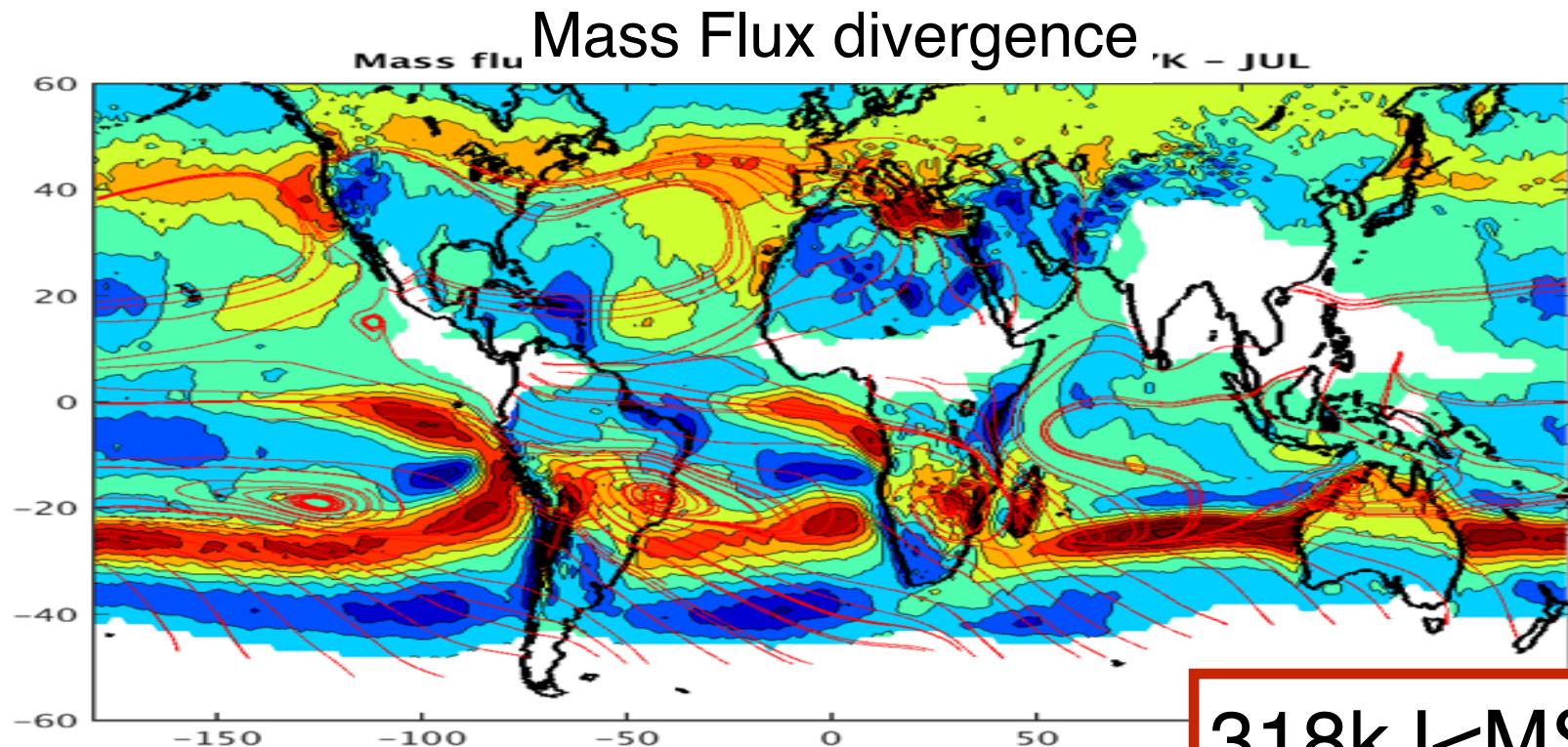
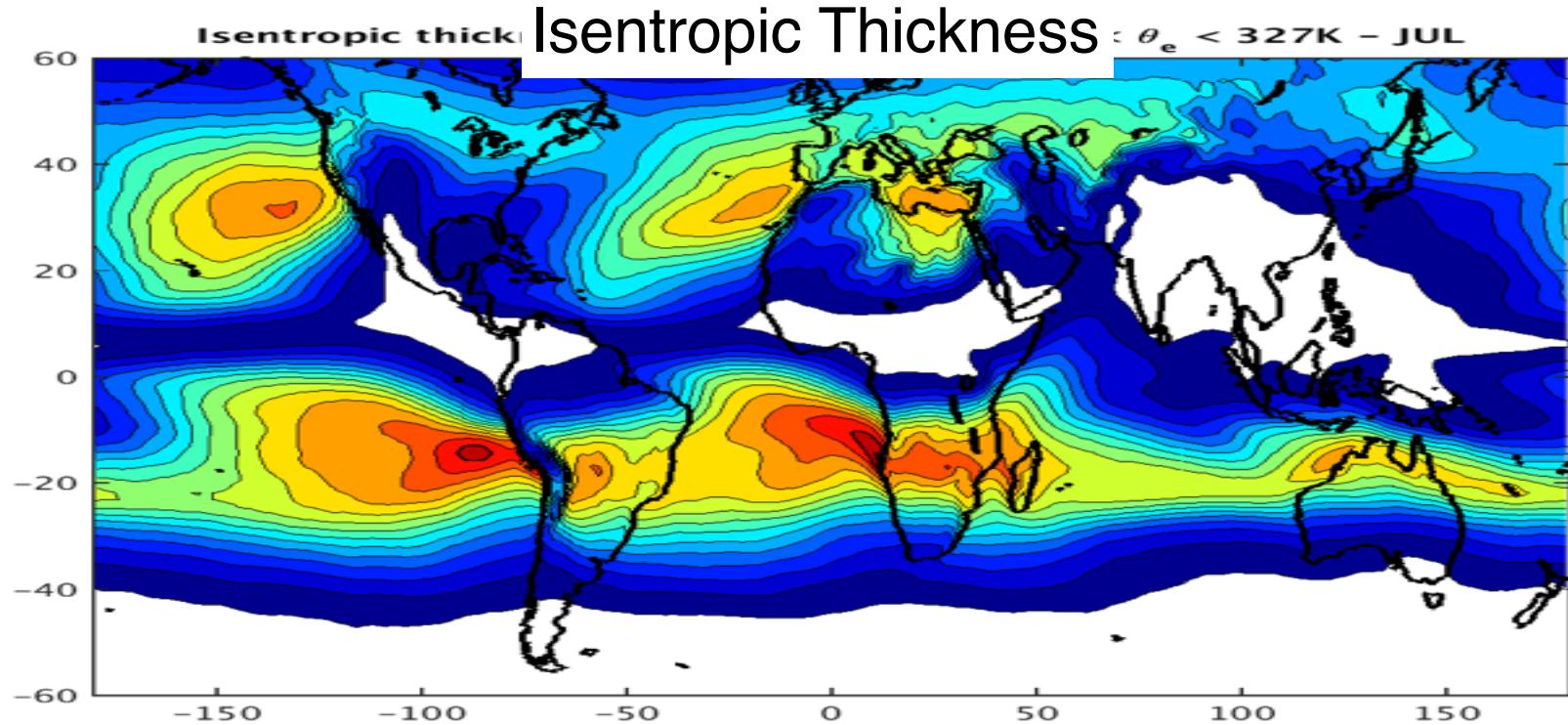


343kJ < DSE < 357kJ

Moist ventilation of the tropical atmosphere

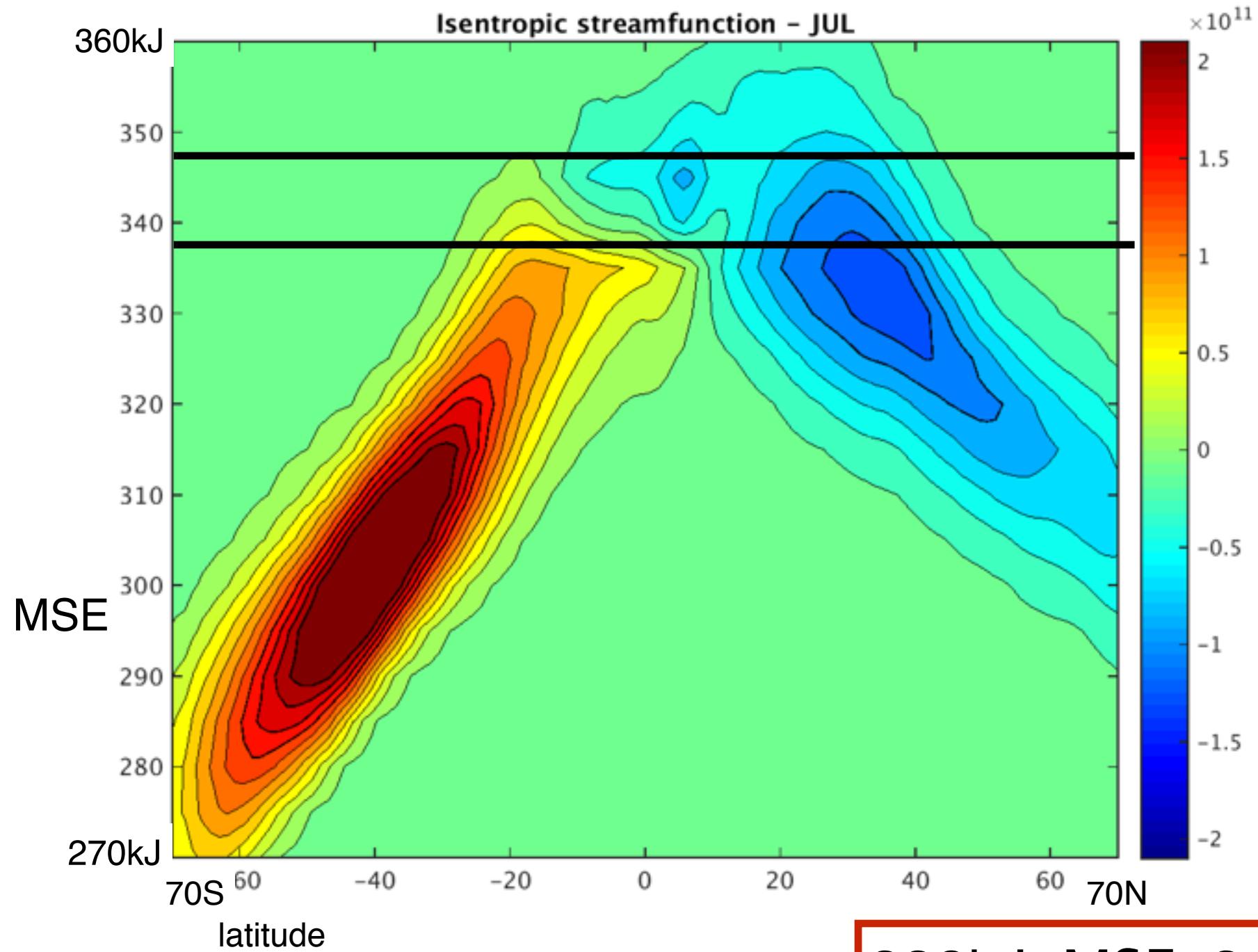


318kJ < MSE < 327kJ

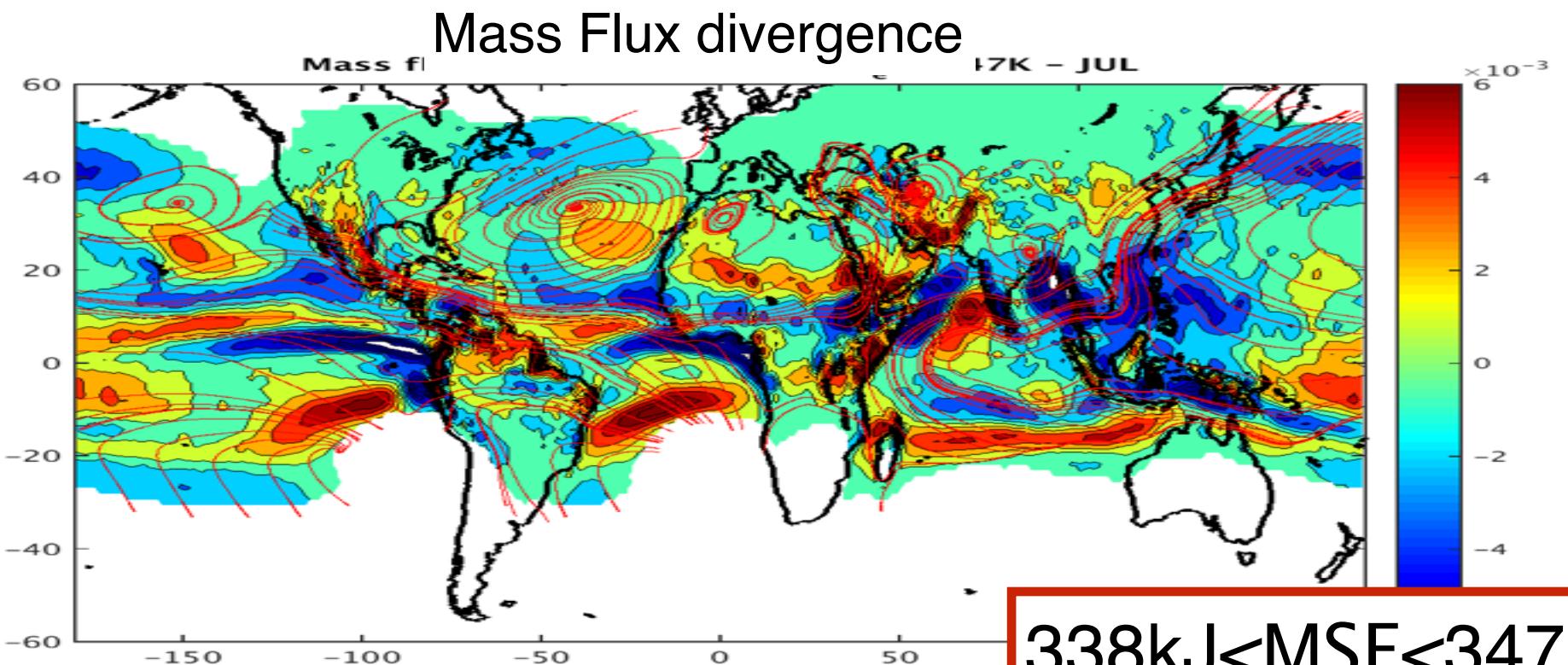
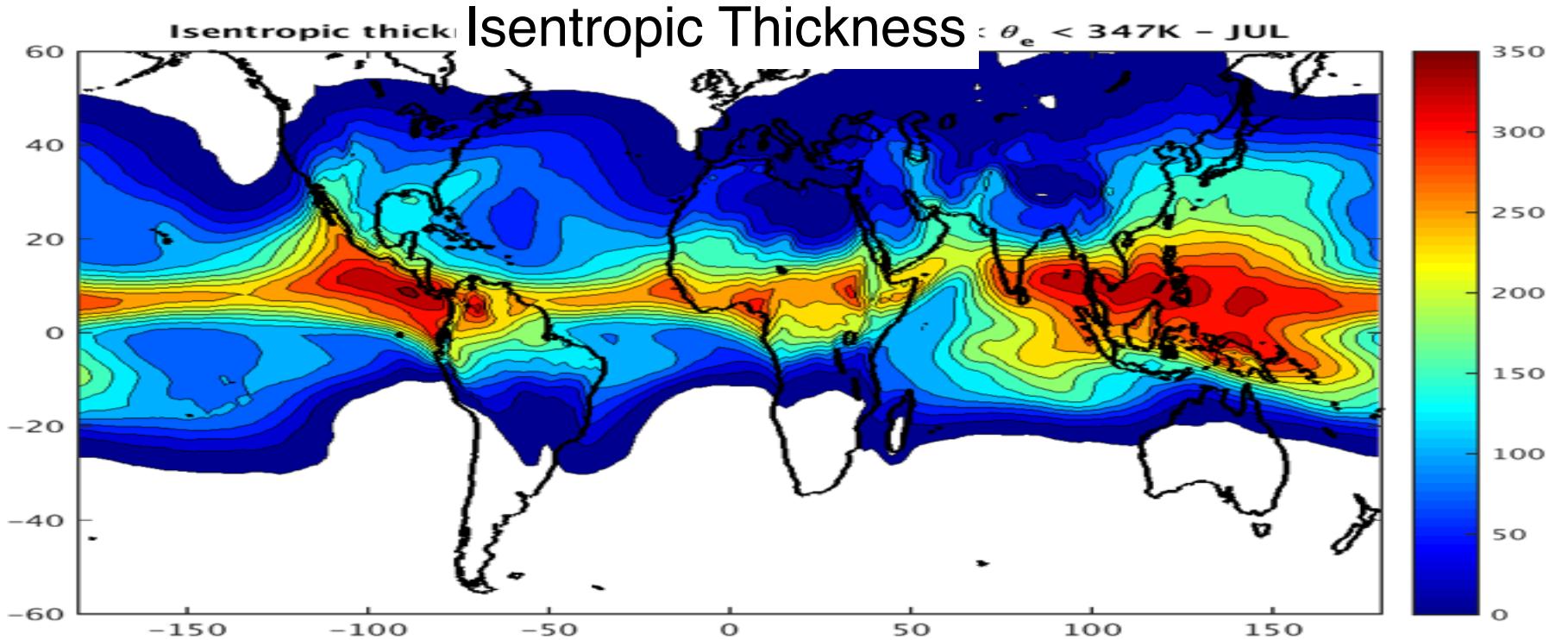


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Moist ventilation of the tropical atmosphere

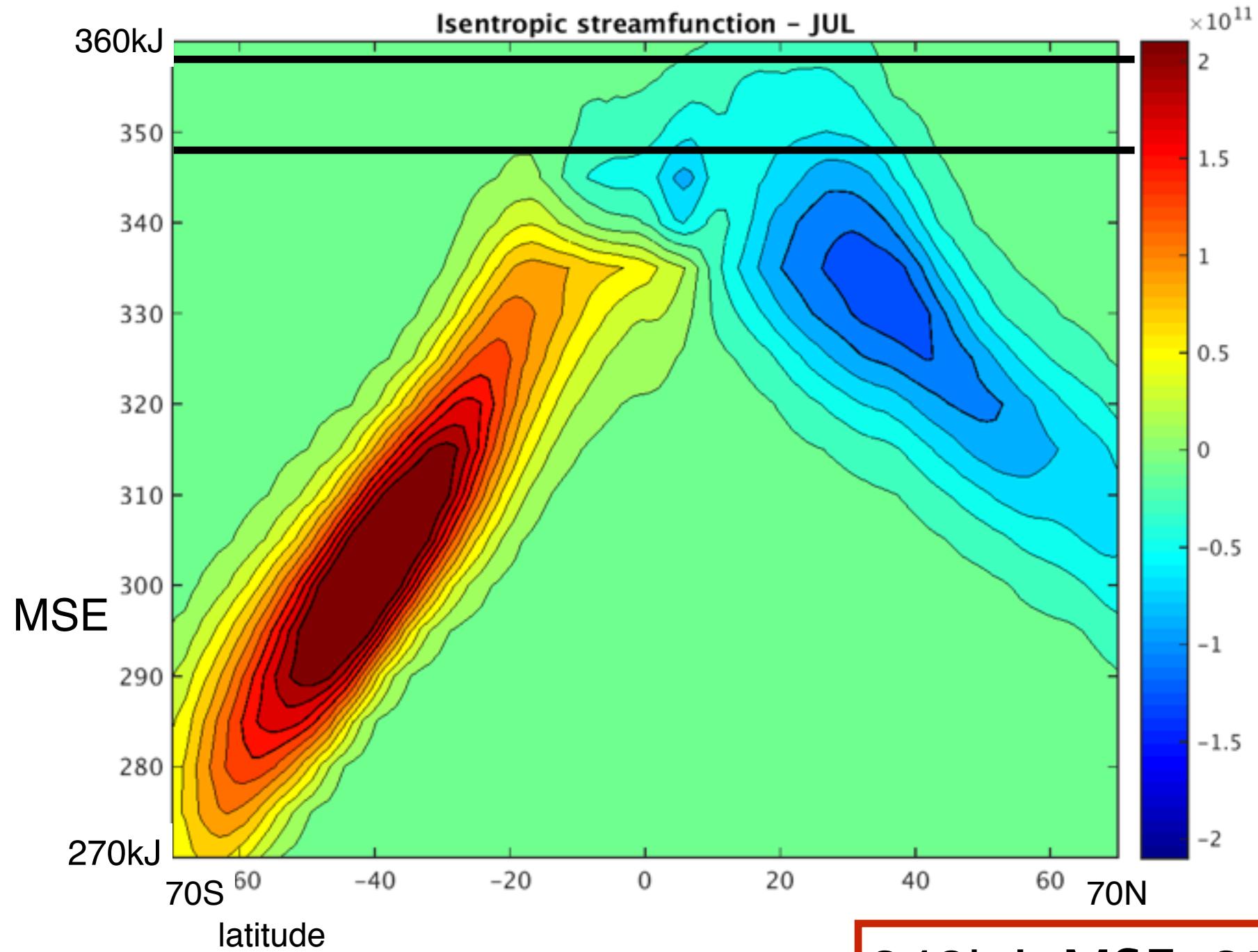


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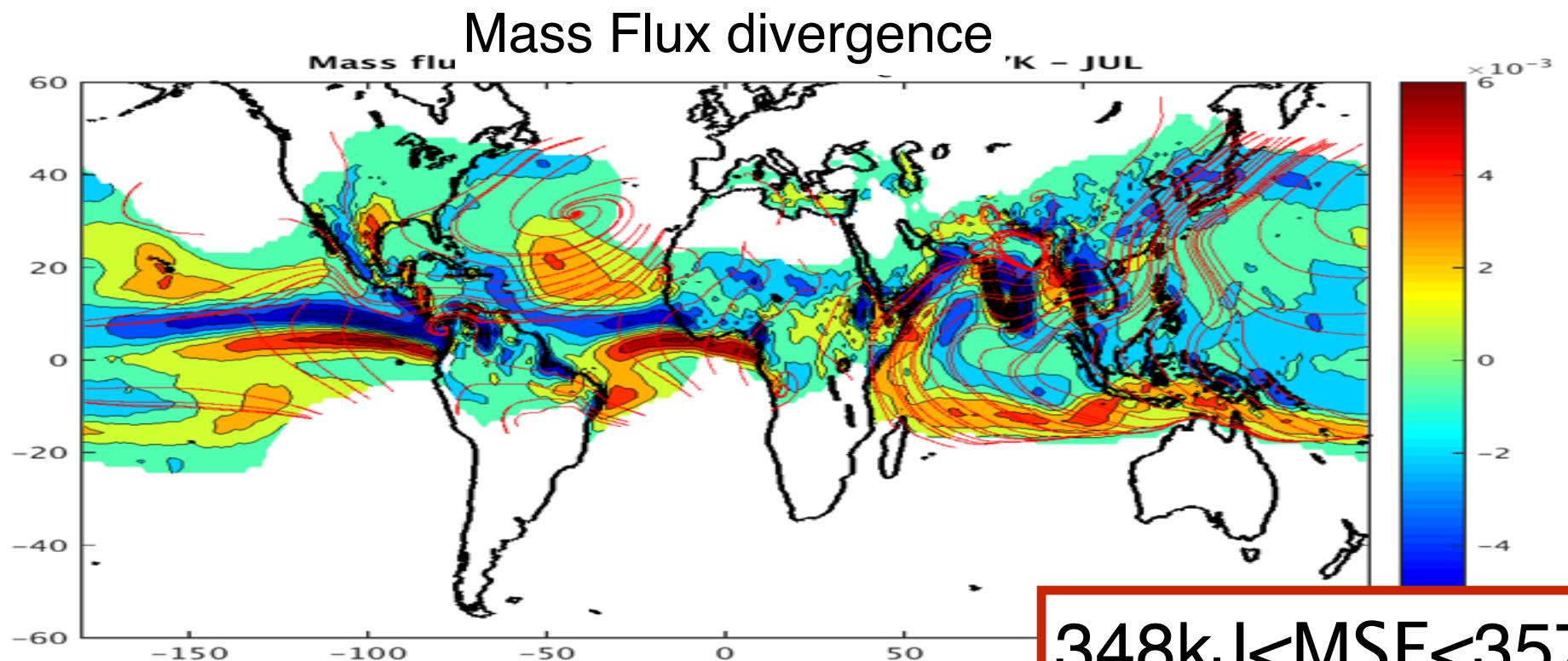
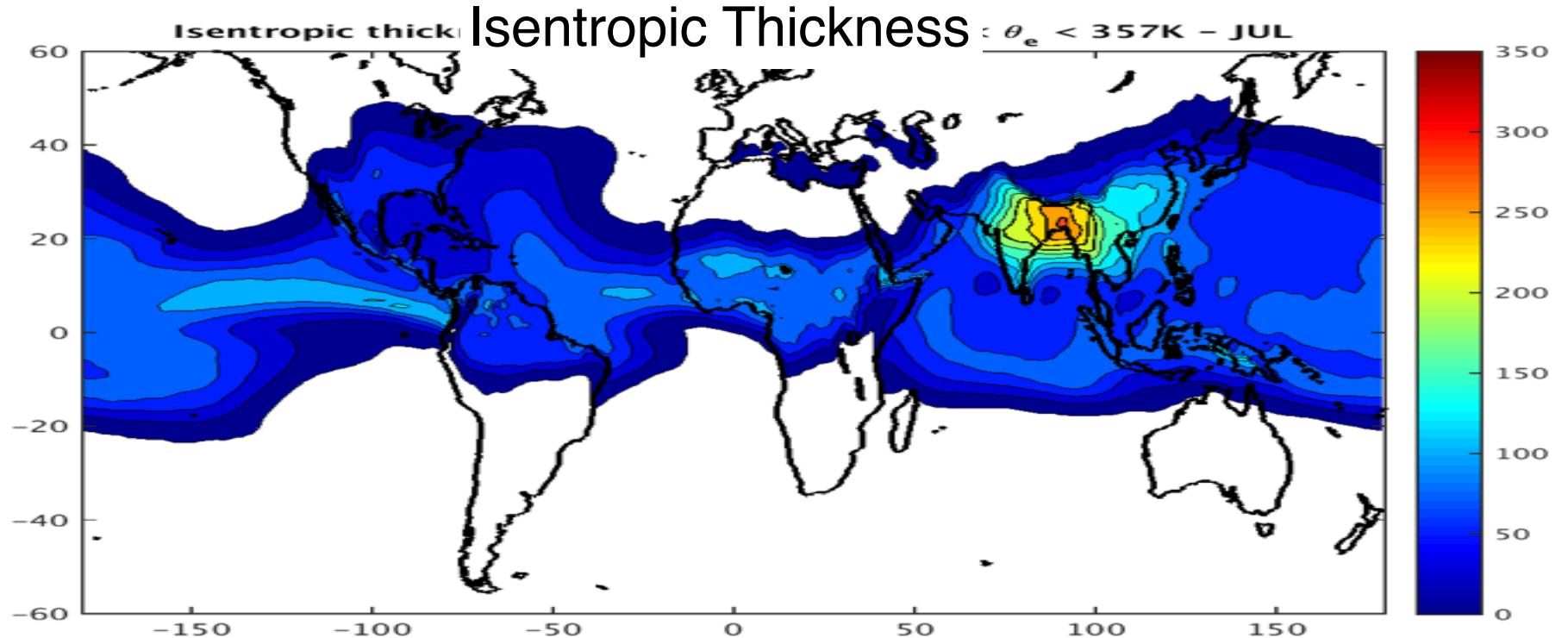


338kJ < MSE < 347kJ

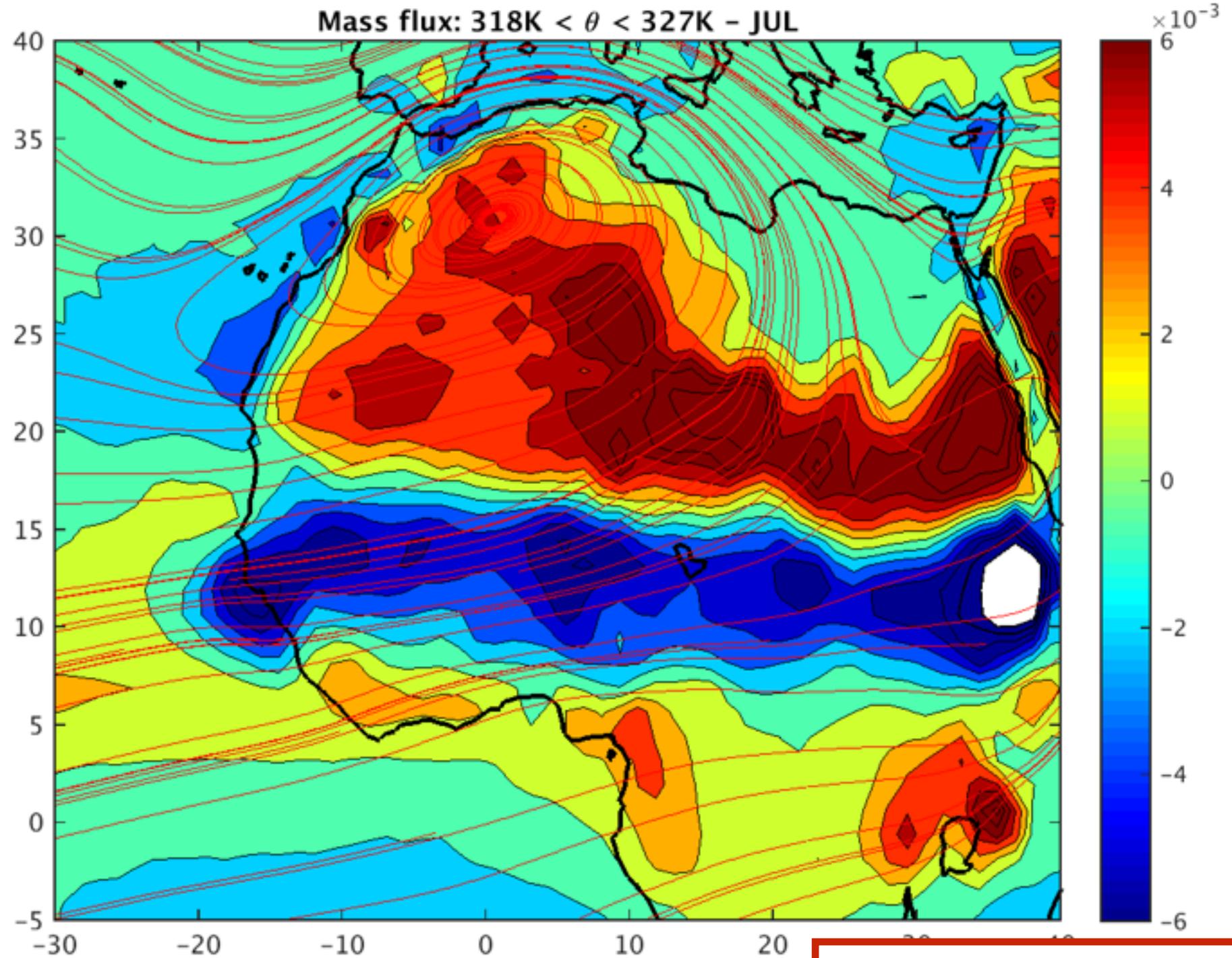
Moist ventilation of the tropical atmosphere



348kJ < MSE < 357kJ

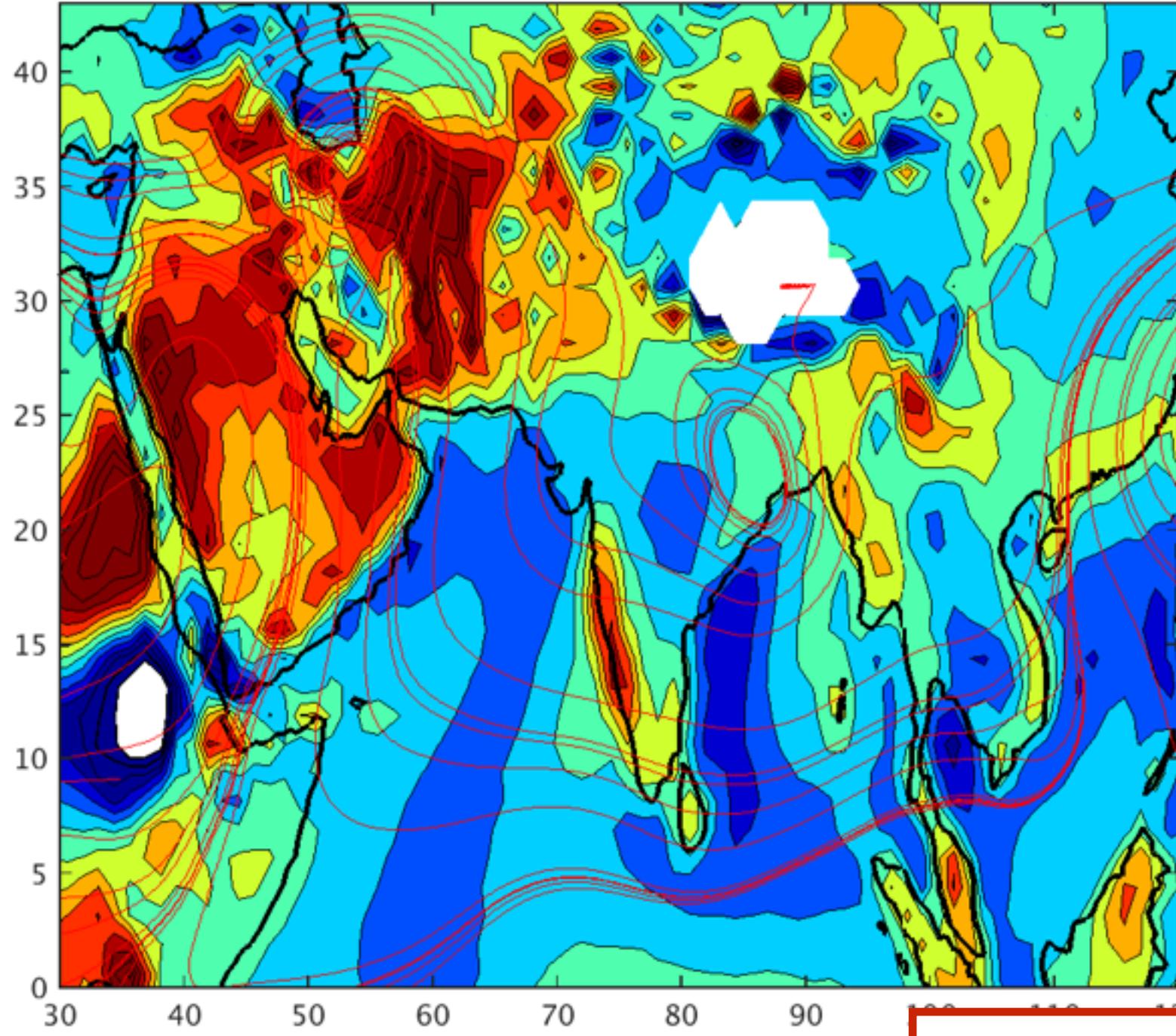


348kJ < MSE < 357kJ

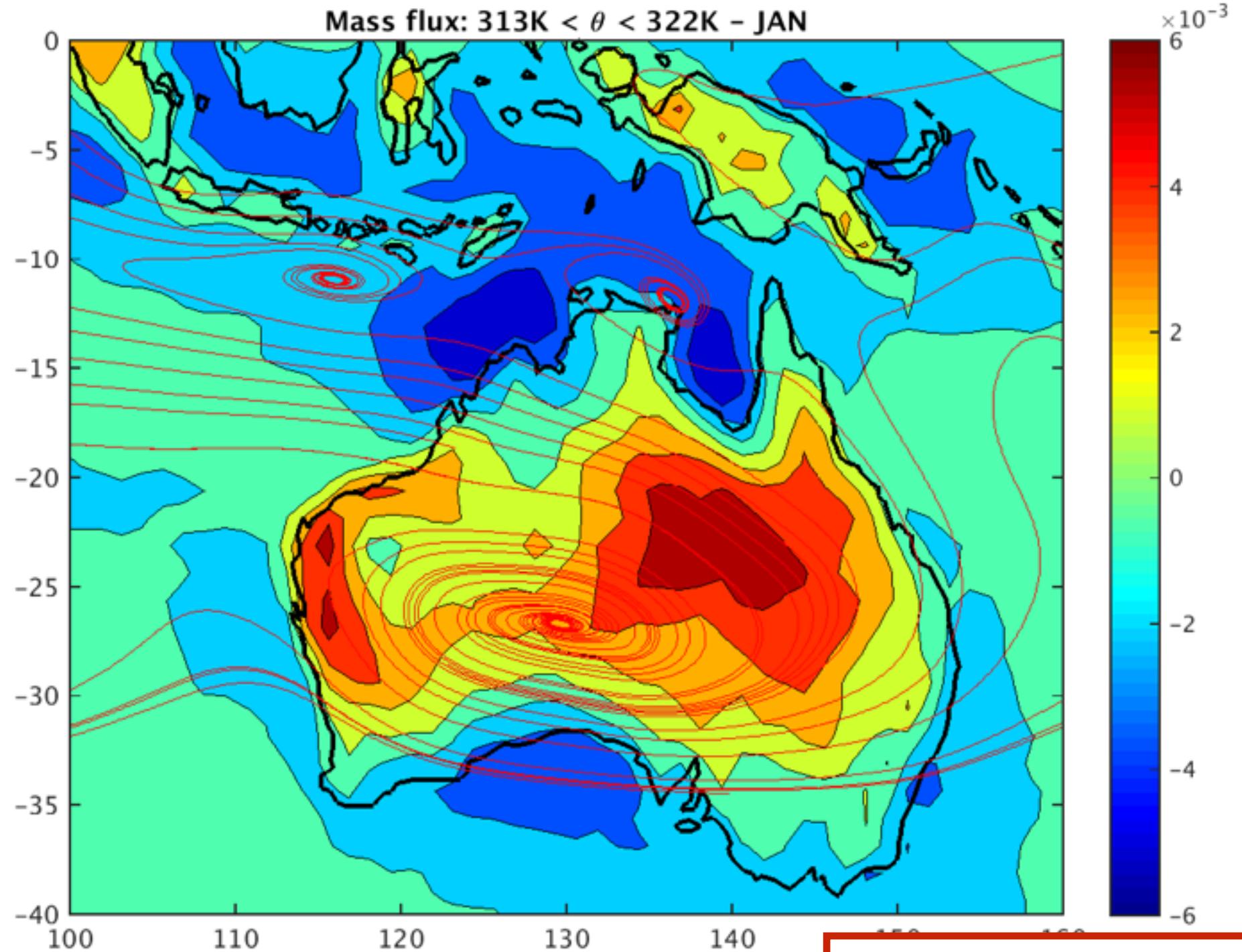


318kJ < DSE < 327kJ

Mass flux: $318K < \theta < 327K$ - JUL



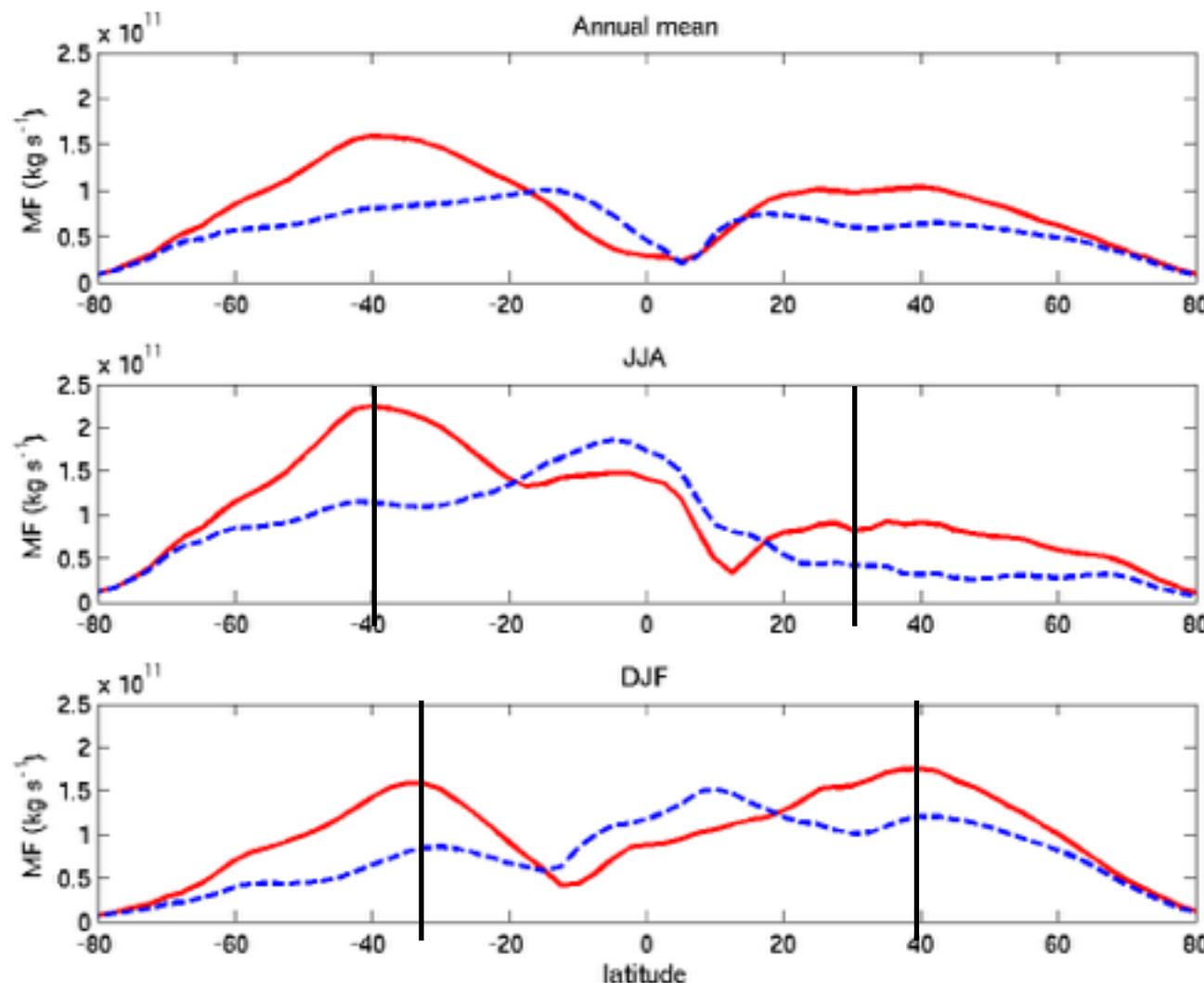
$318kJ < DSE < 327kJ$



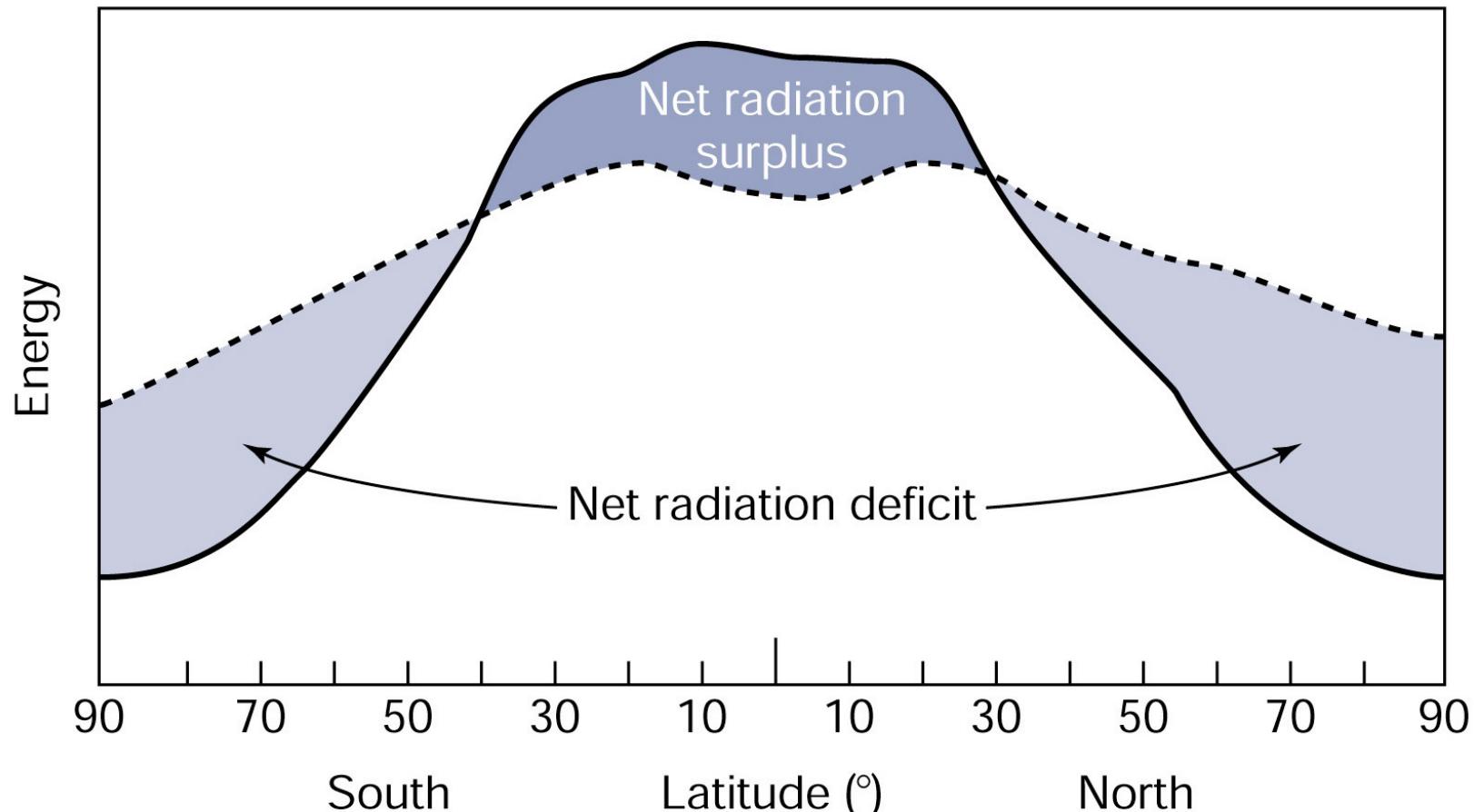
313kJ < DSE < 322kJ

Quizz: Where is the meridional circulation at its strongest?

Quizz: Where is the meridional circulation at its strongest?



At about 30 latitude in Summer hemisphere and 40 latitude in winter hemisphere



— Absorbed solar energy

- - - Emitted infrared energy

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Conclusion

- Computing circulation on isentropic surfaces offer a way of connecting mass and energy transport.
- Zonally averaged circulations tend to oversimplify the actual flows. This is especially true for Monsoonal circulations.
- Tropical ventilation is very different over land and oceans:
 - Ocean: equatorward transport of cold dry air, poleward transport of warm, moist air.
 - Land: moisture transport from cross-equatorial flow combined with dry air inflow₄₀ from nearby deserts...