Response of the North Atlantic atmospheric circulation to increasing LGM ice-sheet elevation

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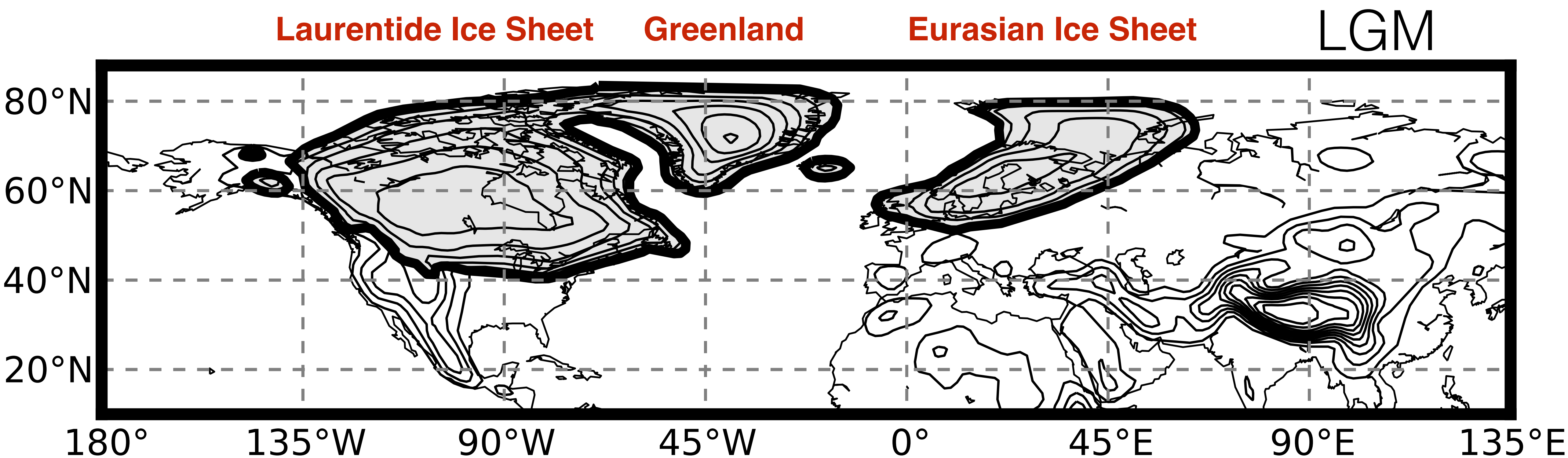
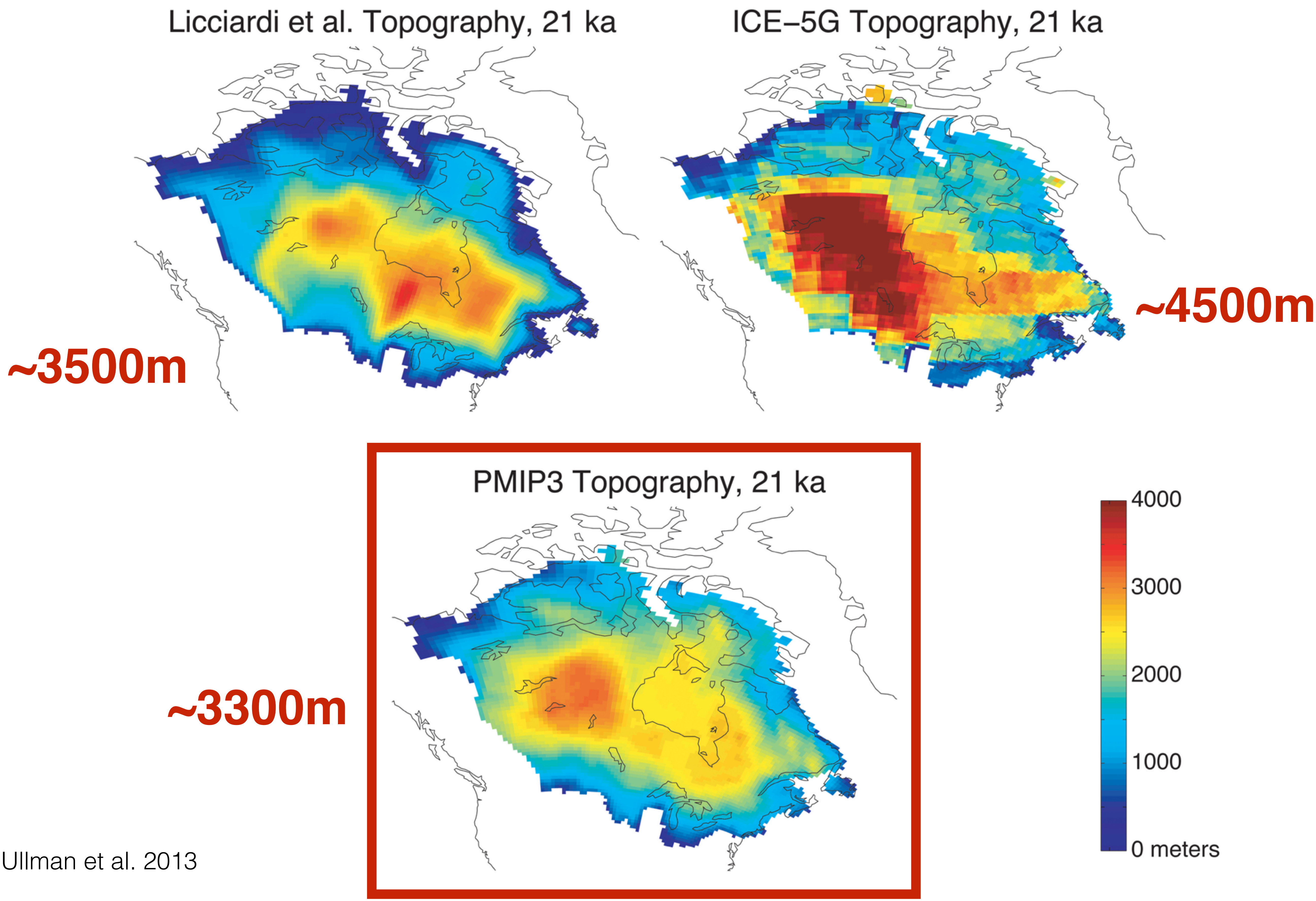
The Northern Hemisphere LGM topography

- Two major ice sheets (+ Greenland)
- Larger ice sheet in North America than in Eurasia



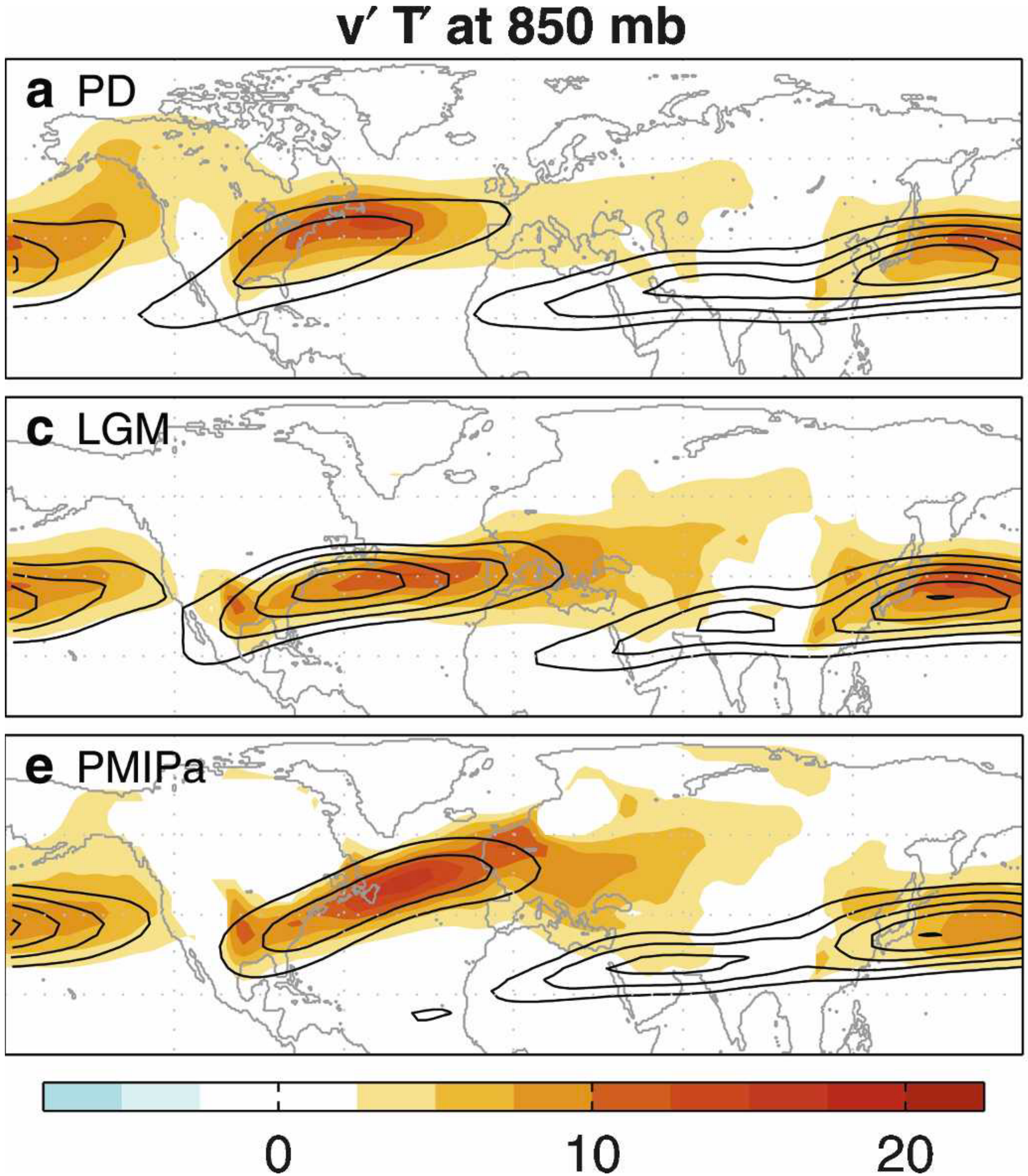
Kleman et al. 2013, Löfverström et al. 2014

Laurentide extent known, elevation debated



Ullman et al. 2013

Circulation differences: high vs. low ice sheet



Modern — Weak & tilted Atlantic jet

PMIP2 (high LIS) — Strong & zonal Atlantic jet

PMIP1 (low LIS) — Weak & tilted Atlantic jet

Li & Battisti 2008

Experiments and simulations

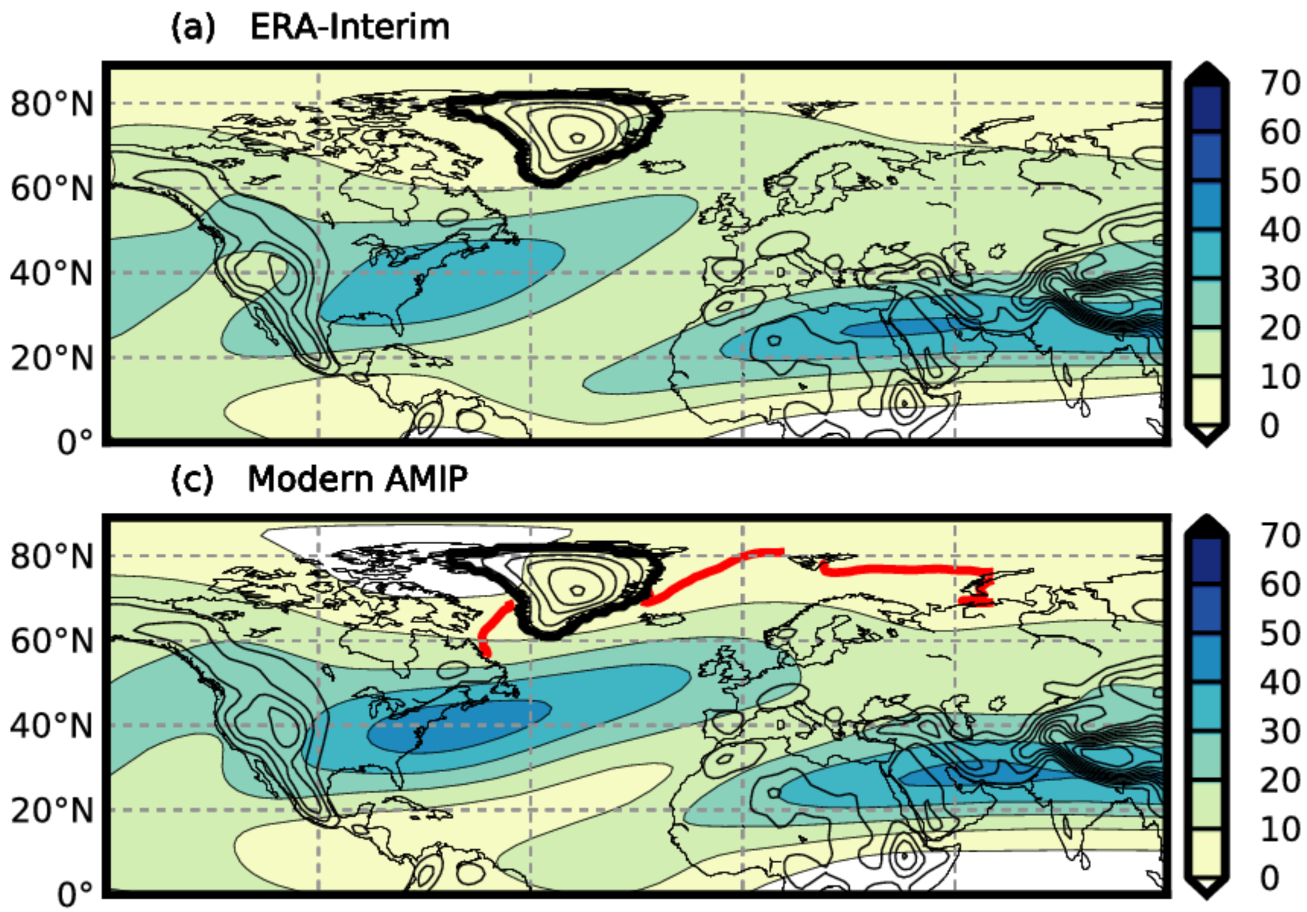
- Slab-ocean CAM3 (T85 L26), ocean heat flux convergence calculated from Brandefelt & Otto-Bliesner (2009)

- Eight LGM simulations with increasing ice sheet elevation from 0 m to 5100 m

- Sensitivity simulations with prescribed sea-surface conditions (*not discussed here*):
  (i) the importance of the ice-sheet topography **(very important)**
  (ii) the importance of the SST/sea-ice field **(important)**

- Analysis based on 30 years of DJF data after the model climate has reached statistical equilibrium

300 hPa wind and 300 K potential vorticity



- PD: Weak and meridionally tilted jet, similar to ERA-Int

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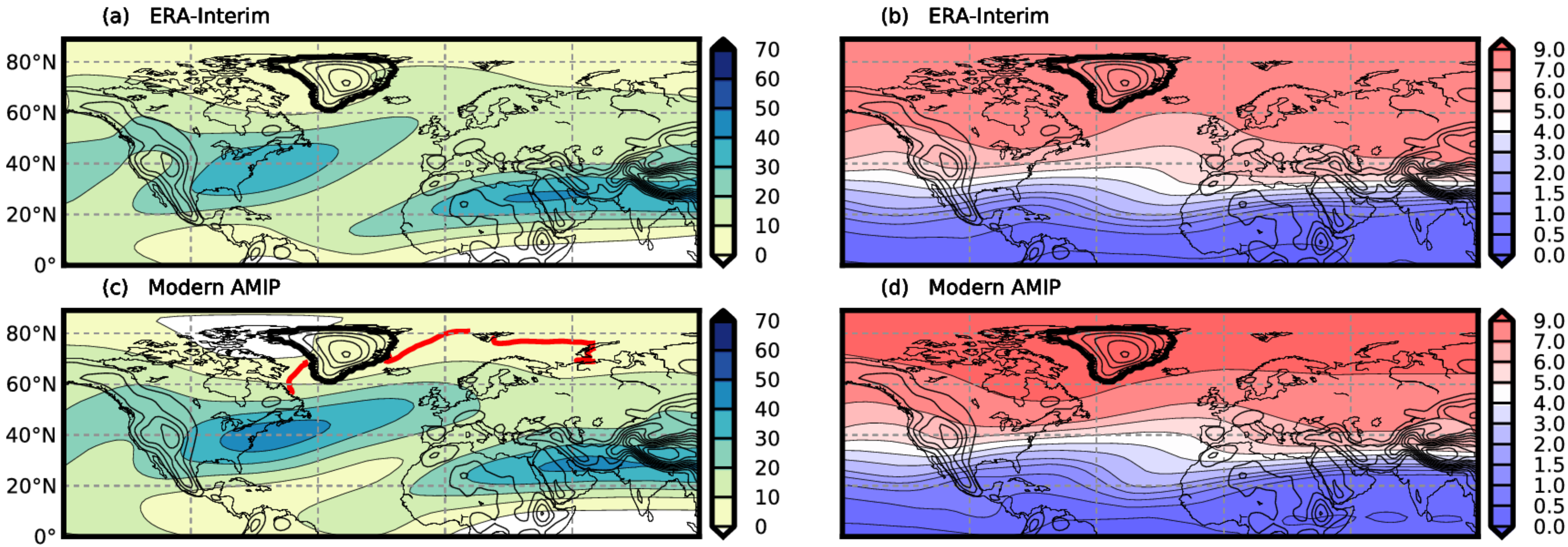

$$P = -g(f + \zeta_\theta)\partial_p \theta$$

- PD: Weak and meridionally tilted jet, similar to ERA-Int
- PD: Relaxed PV gradient in mid latitudes

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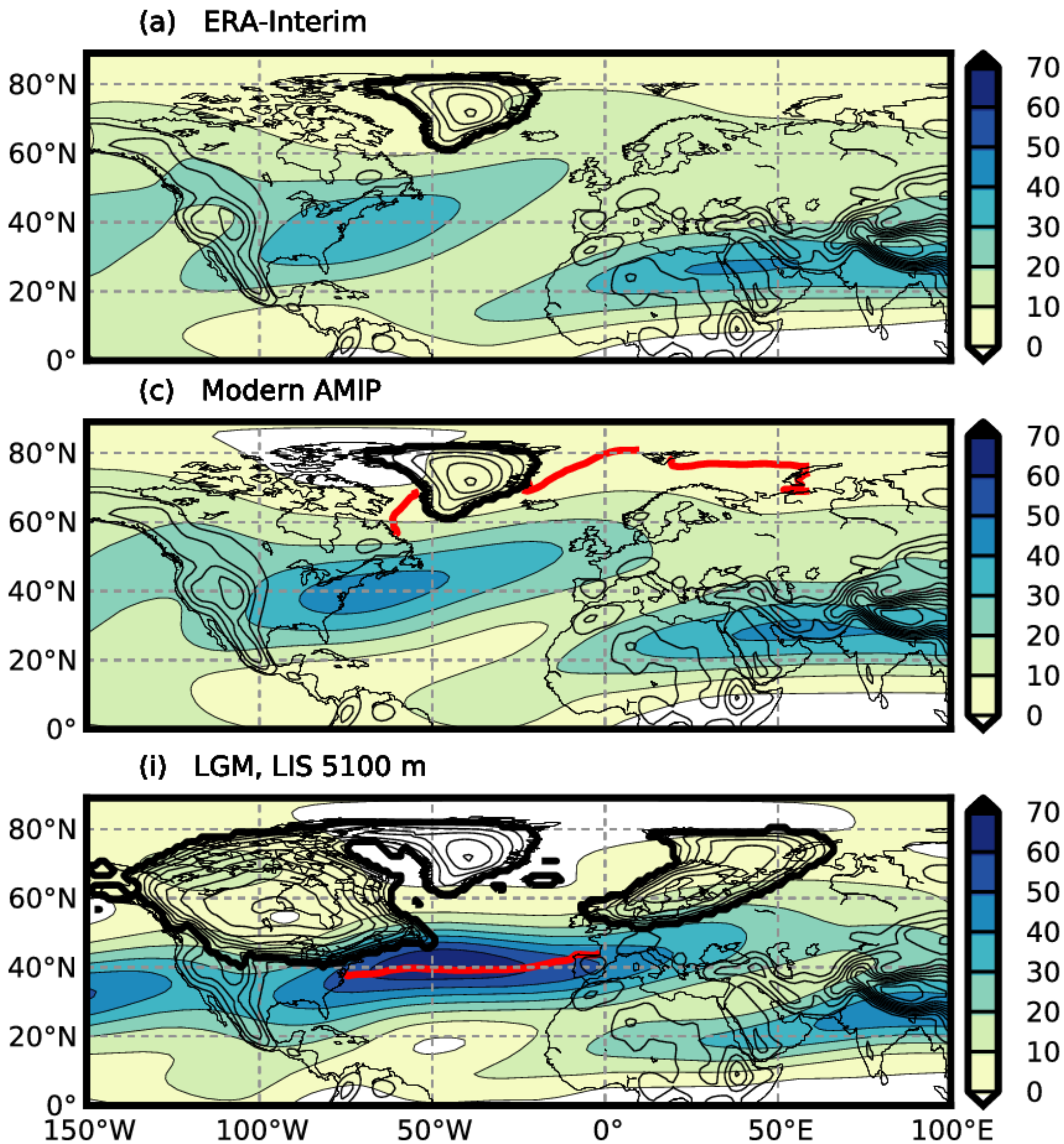

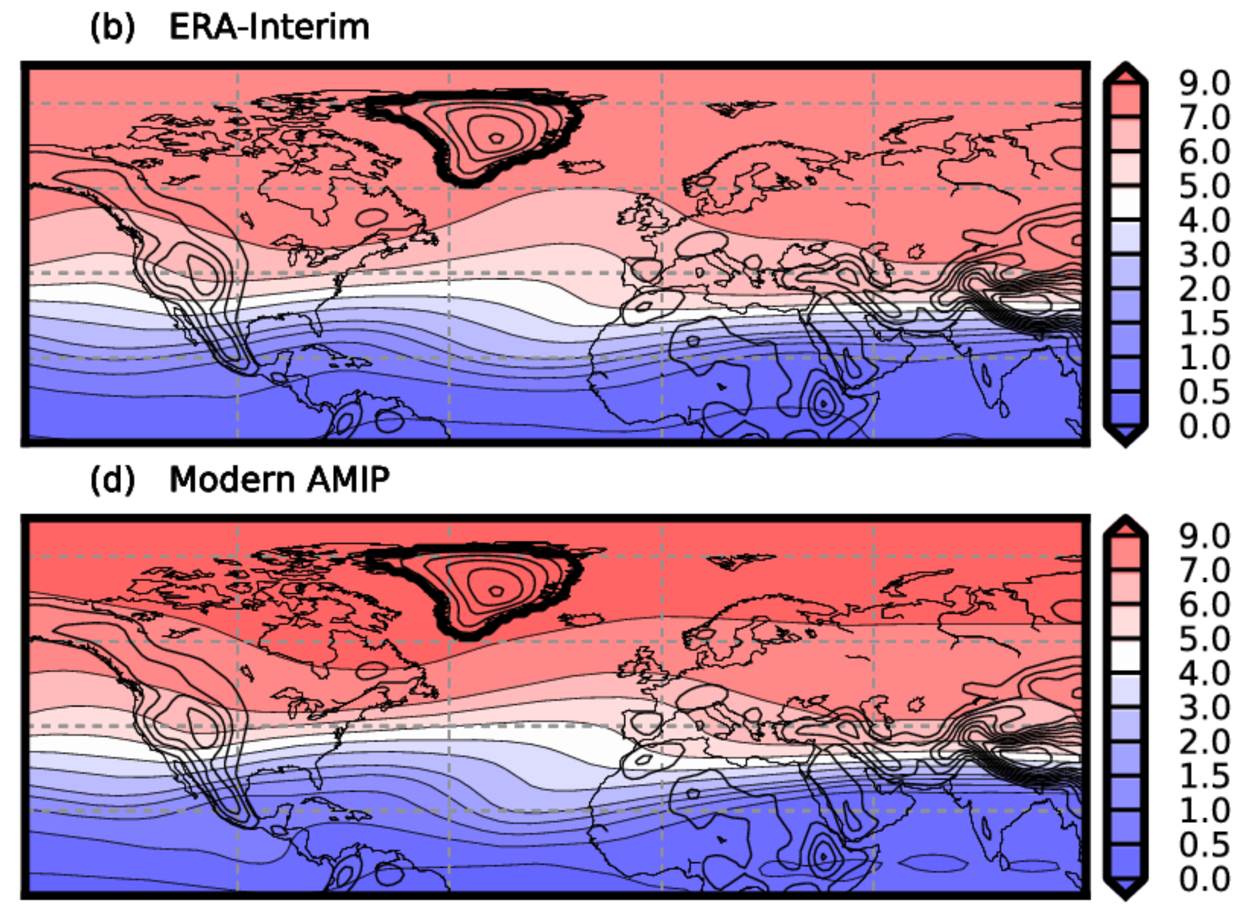

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- High LIS: Strong, narrow and zonal jet

- PD: Relaxed PV gradient in mid latitudes

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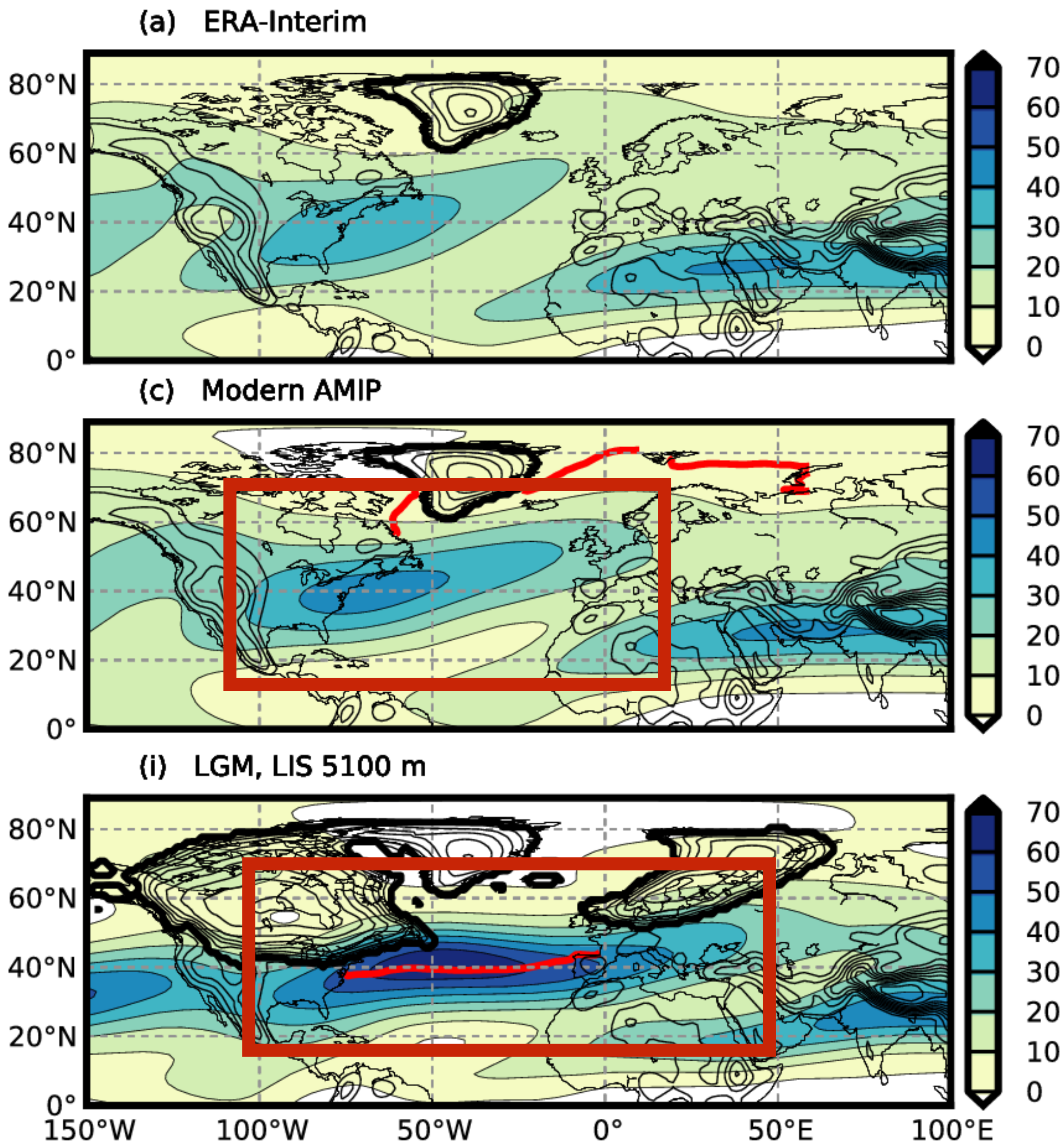

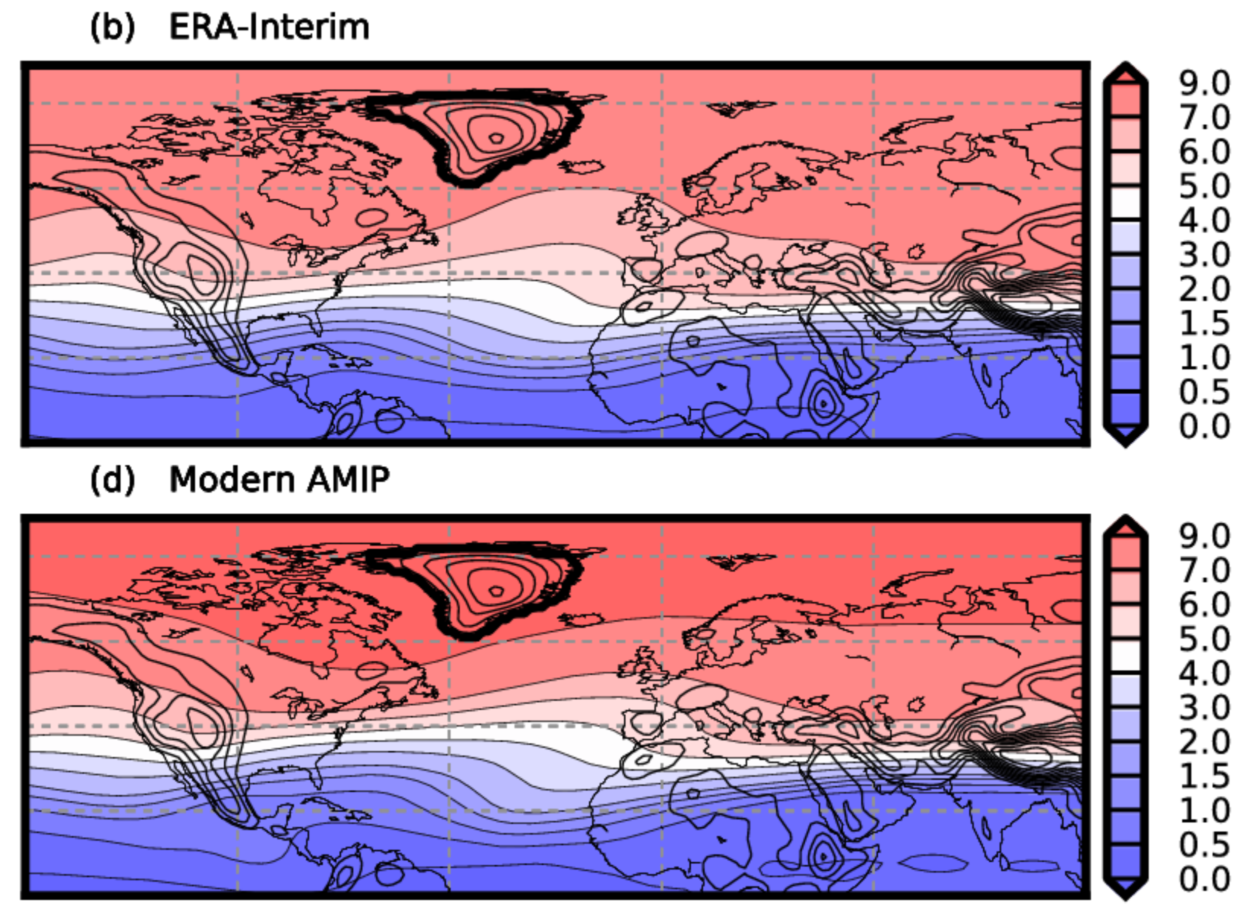

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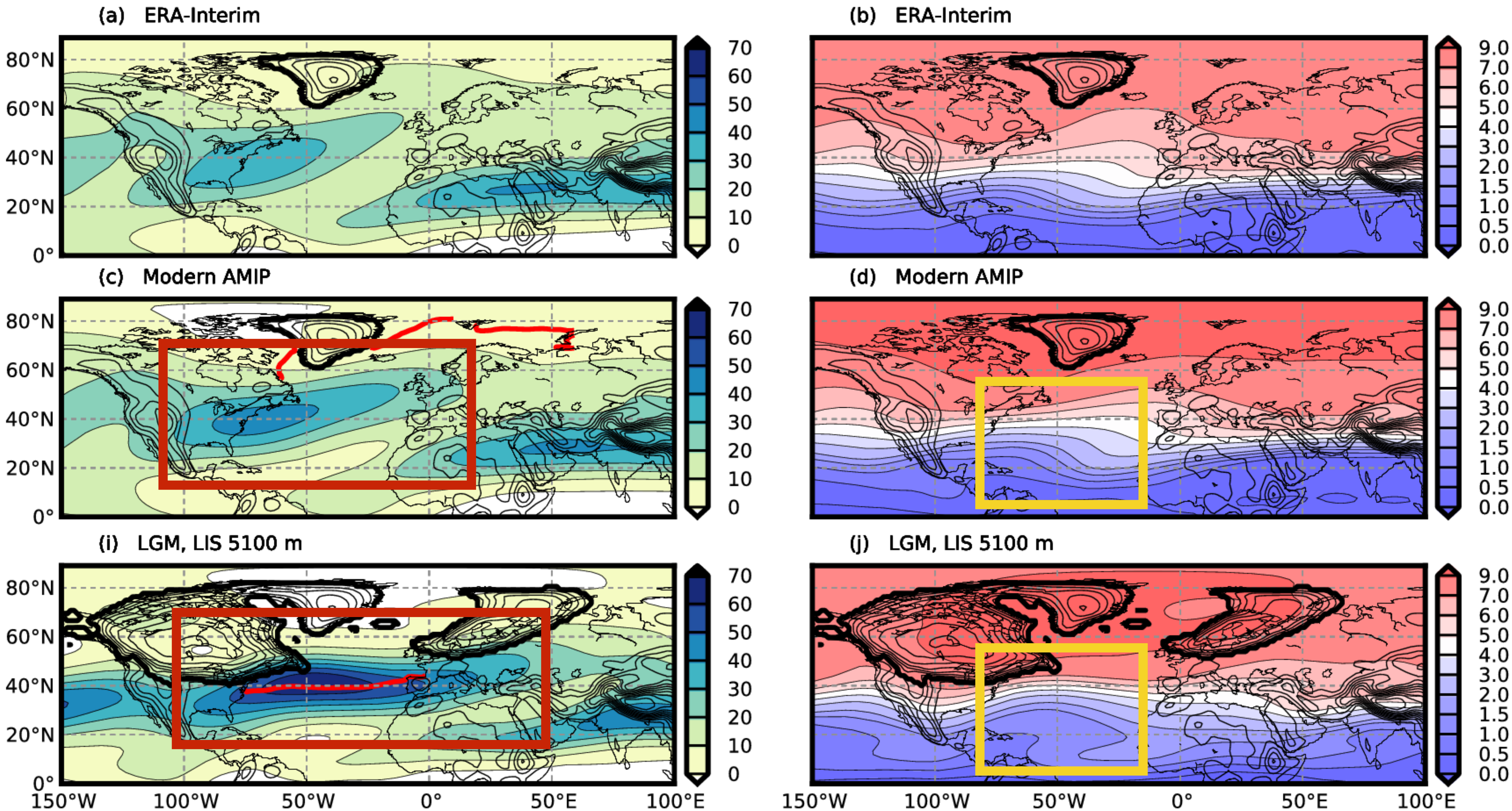
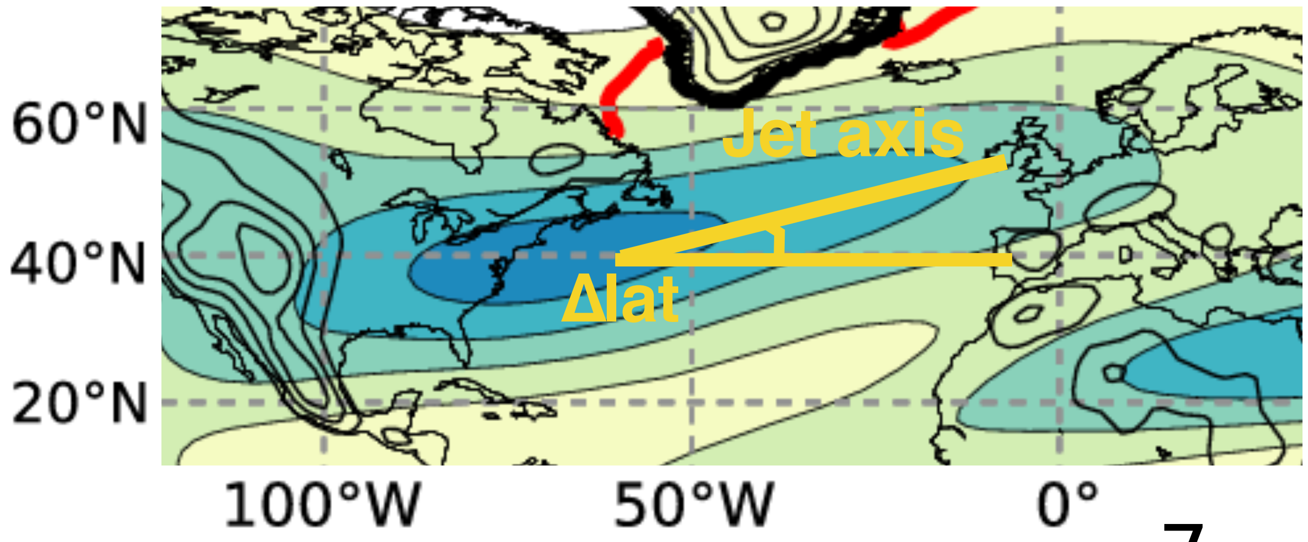
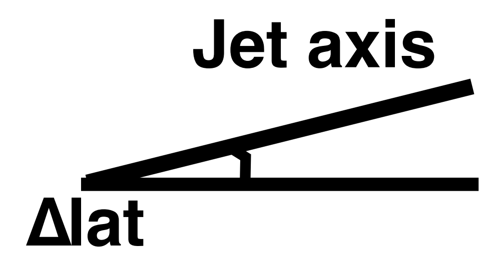


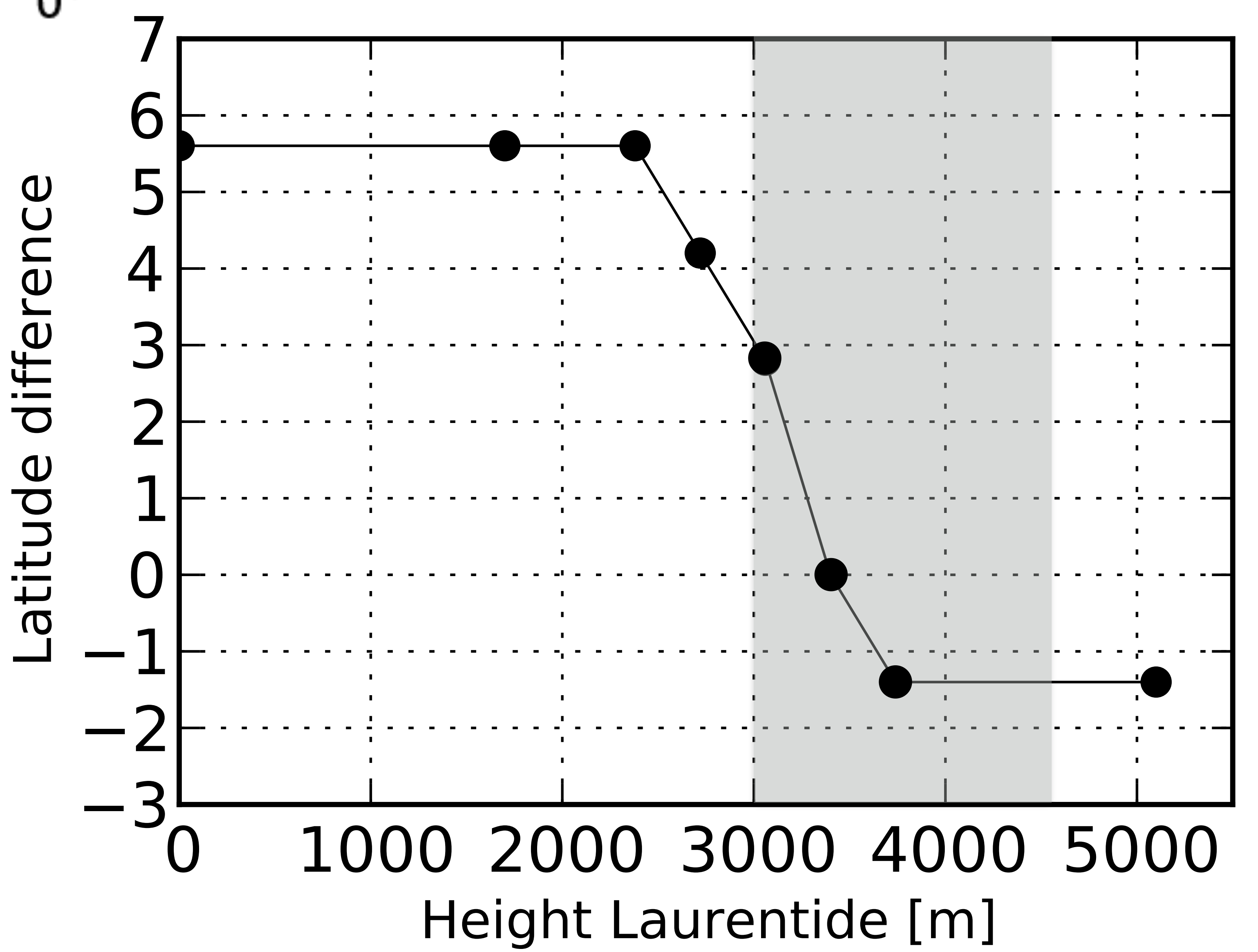
- PD: Weak and meridionally tilted jet, similar to ERA-Int
- High LIS: Strong, narrow and zonal jet

- PD: Relaxed PV gradient in mid latitudes
- High LIS: No PV gradient in low latitudes
- High LIS: Tight PV gradient in mid latitudes

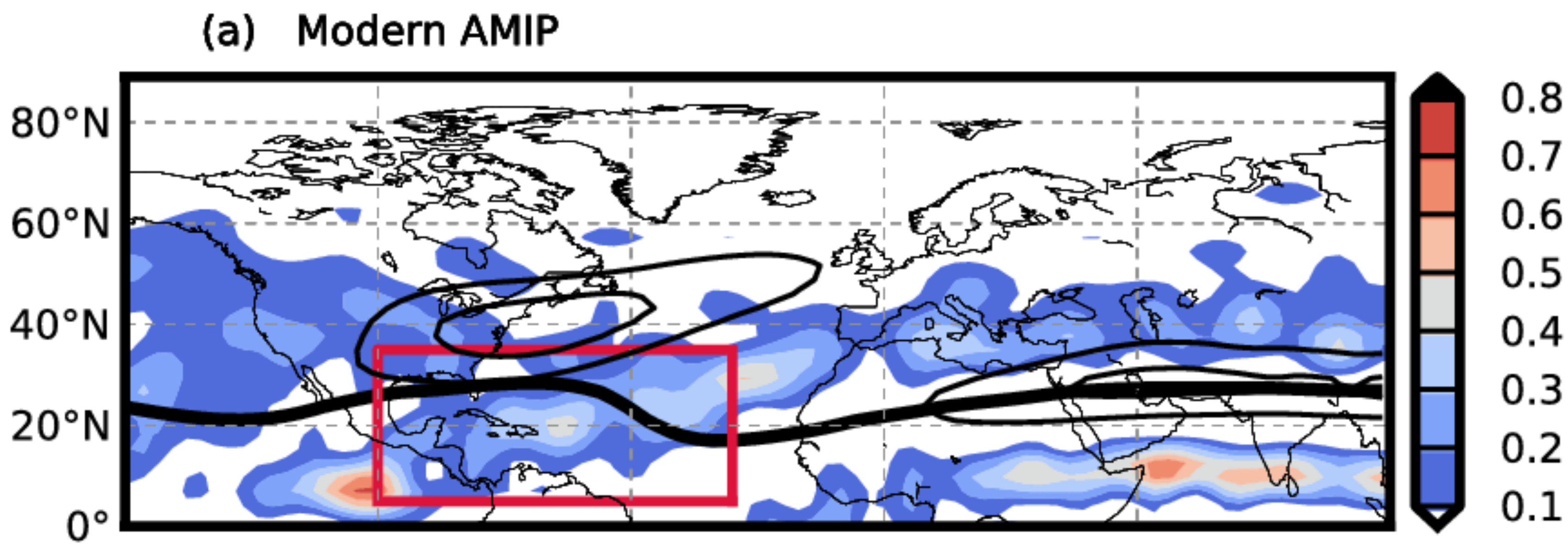
Meridional tilt of 500 hPa jet (55°–10°W) as function of ice sheet height



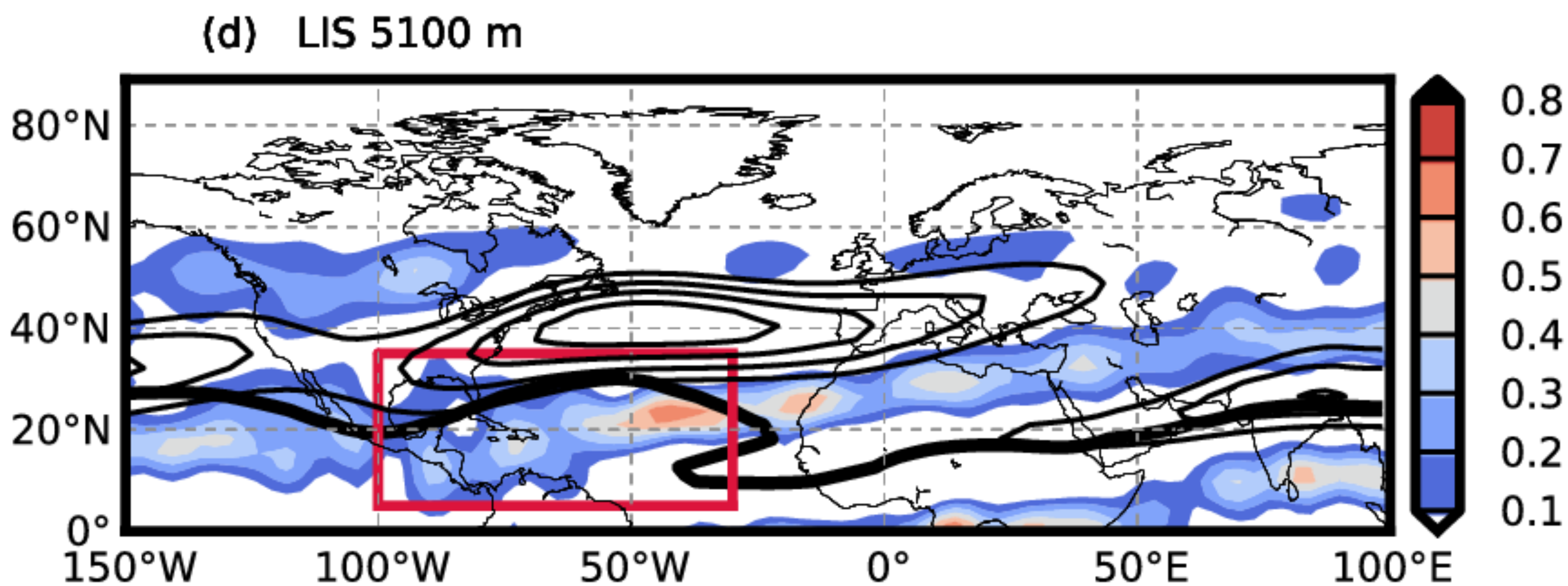




300 hPa Rossby wave breaking [(lat,lon)$^{-1}$ season^{-1}]
(old interpretation)



- AWB spread out
- Almost no CWB
- Tilted jet



- Concentrated AWB on equatorward flank
- Increased CWB on poleward flank
- Overturning subtropical PV
- Zonal jet

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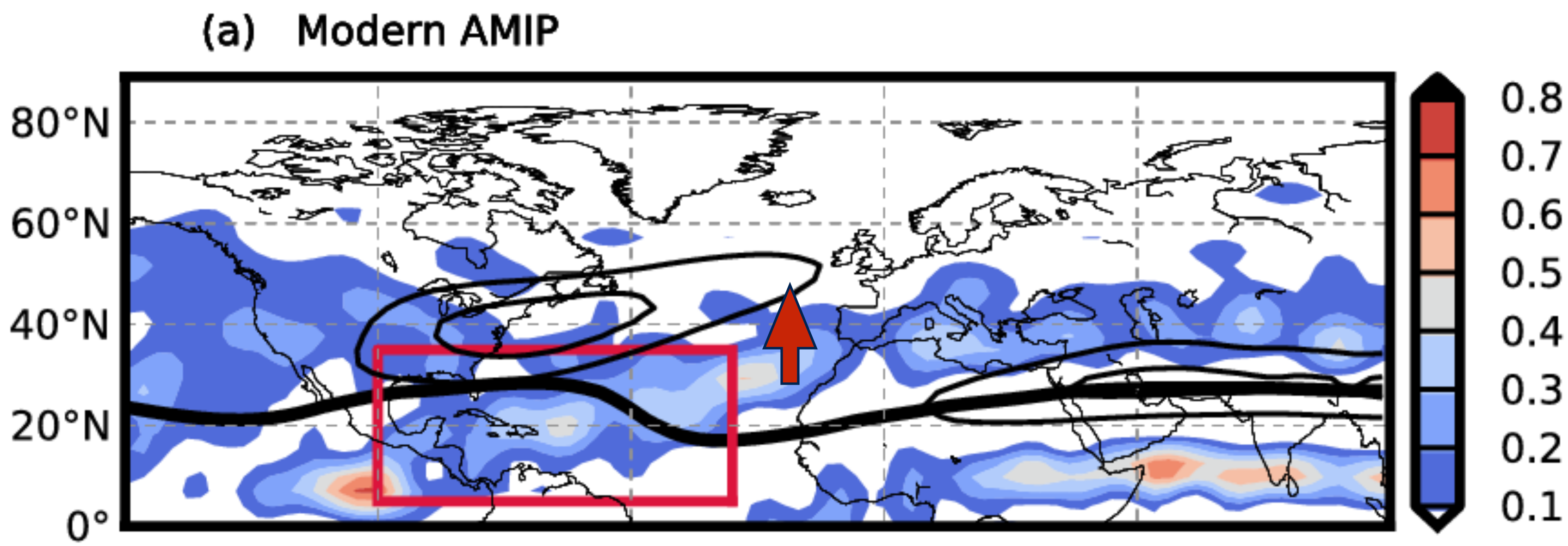

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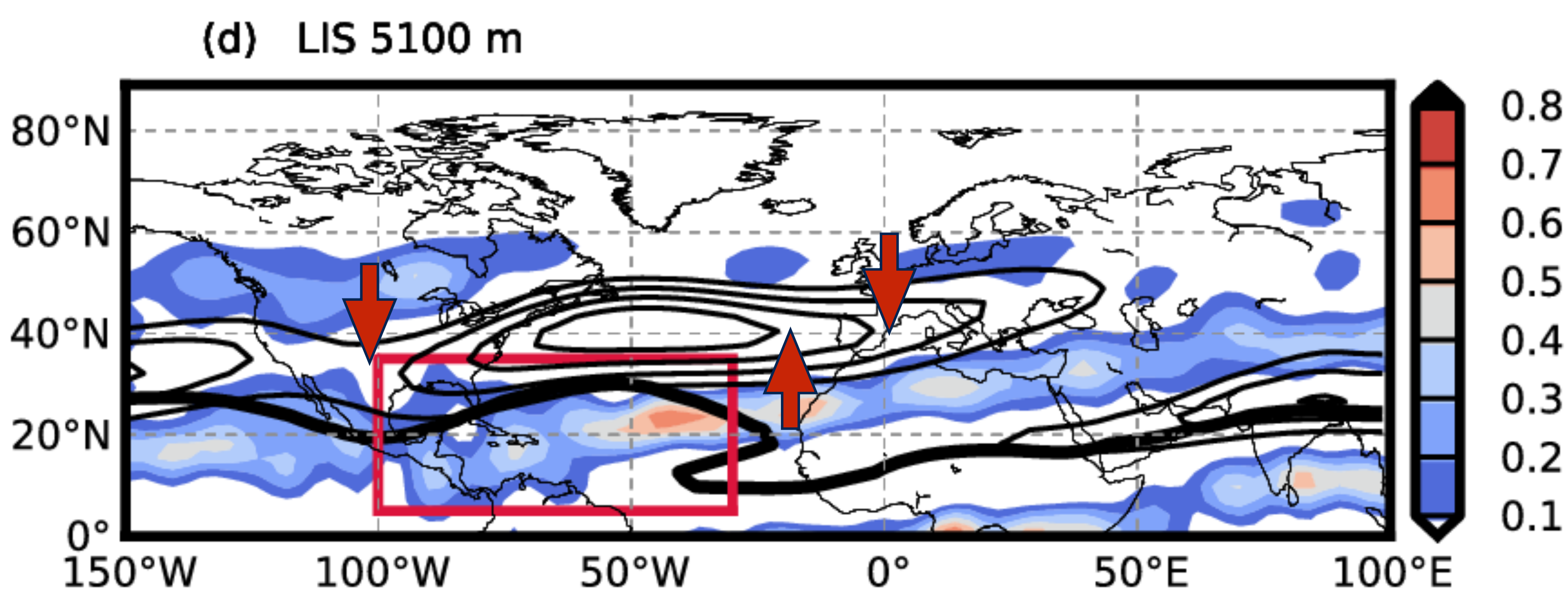

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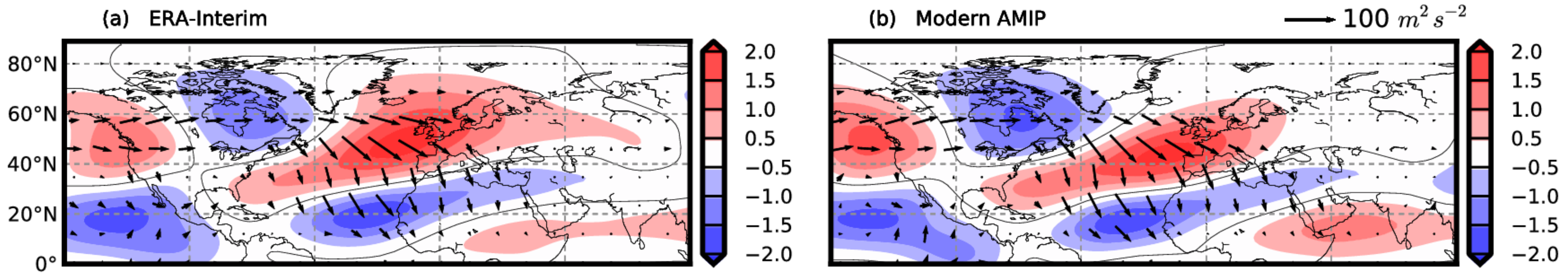
Stationary wave reflection (new interpretation)



Atmospheric stationary waves:

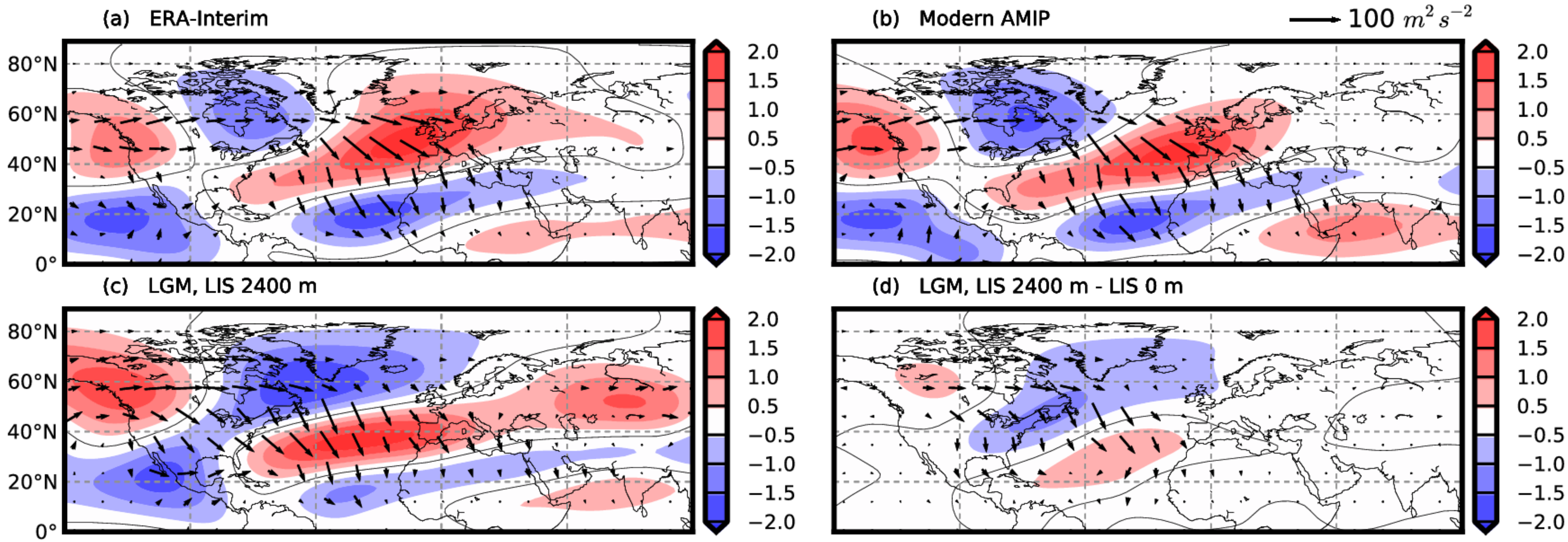
- Zonally asymmetric component of climatological atmospheric state
- Can be seen in almost all dynamic fields, typically upper troposphere eddy streamfunction [m^2s^{-1}]
- Driven by flow-top. interactions, diabatic heating, stat. and trans. eddy fluxes

Wave activity flux (Plumb flux):

- Indicates propagation direction of stationary waves
- Vector quantity almost parallel to the group velocity (energy propagation) in the WKB limit
- Orthogonal to phase lines of stationary waves

$$\mathbf{F}_{s(\mathbf{x},\mathbf{y})} \sim \begin{pmatrix} \frac{1}{2a^2\cos^2\phi}\left(\left(\frac{\partial \psi^*}{\partial \lambda}\right)^2 - \psi^* \frac{\partial^2 \psi^*}{\partial \lambda^2}\right) \\ \frac{1}{2a^2\cos\phi}\left(\frac{\partial \psi^*}{\partial \lambda}\frac{\partial \psi^*}{\partial \phi} - \psi^* \frac{\partial^2 \psi^*}{\partial \lambda \partial \phi}\right) \end{pmatrix}$$

300 hPa eddy streamfunction and wave activity flux



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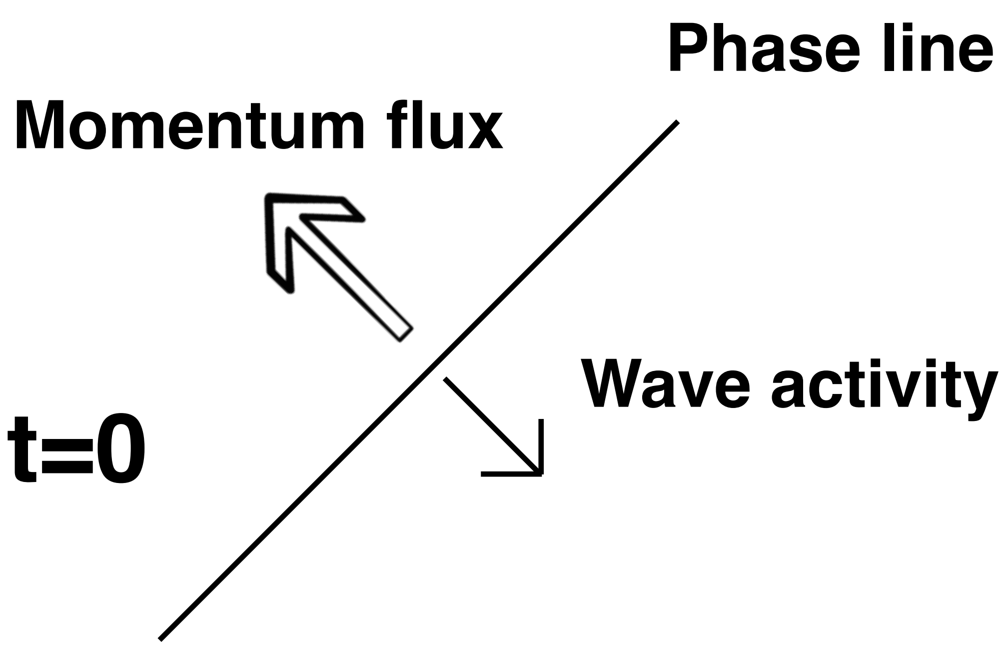
300 hPa eddy streamfunction and wave activity flux

Stationary wave absorption



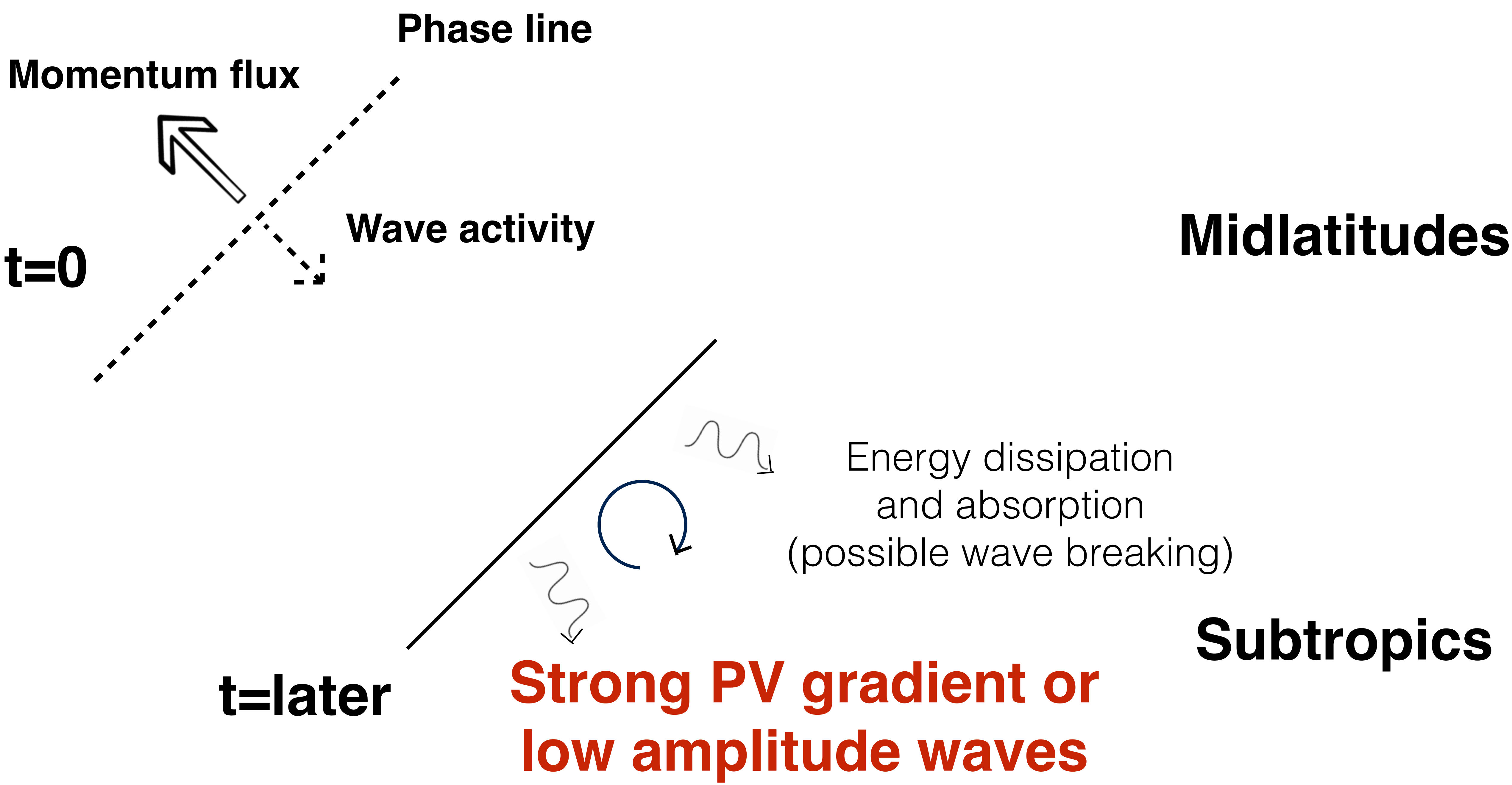
Midlatitudes

Subtropics

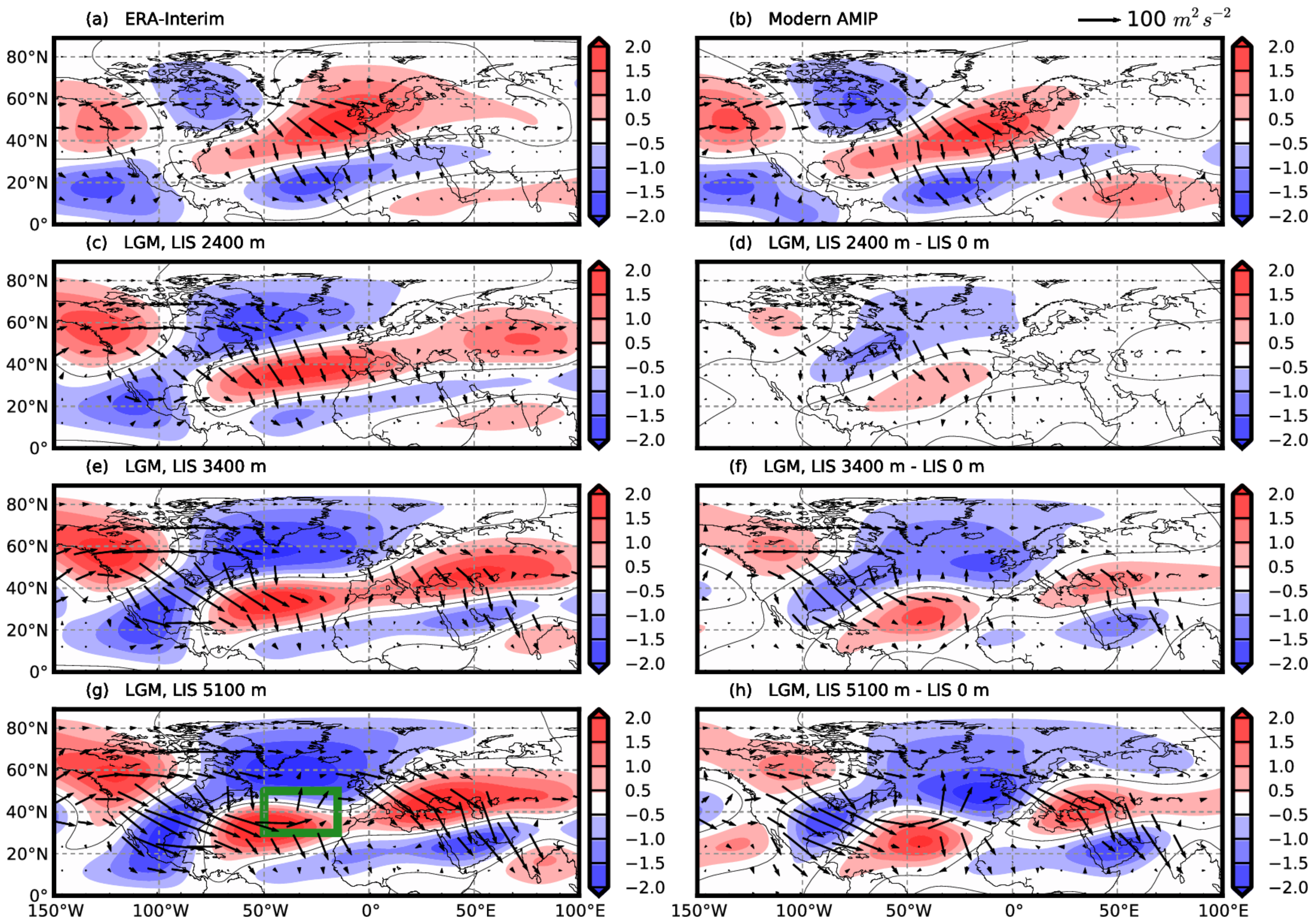
Strong PV gradient or
low amplitude waves

300 hPa eddy streamfunction and wave activity flux

Stationary wave absorption



300 hPa eddy streamfunction and wave activity flux



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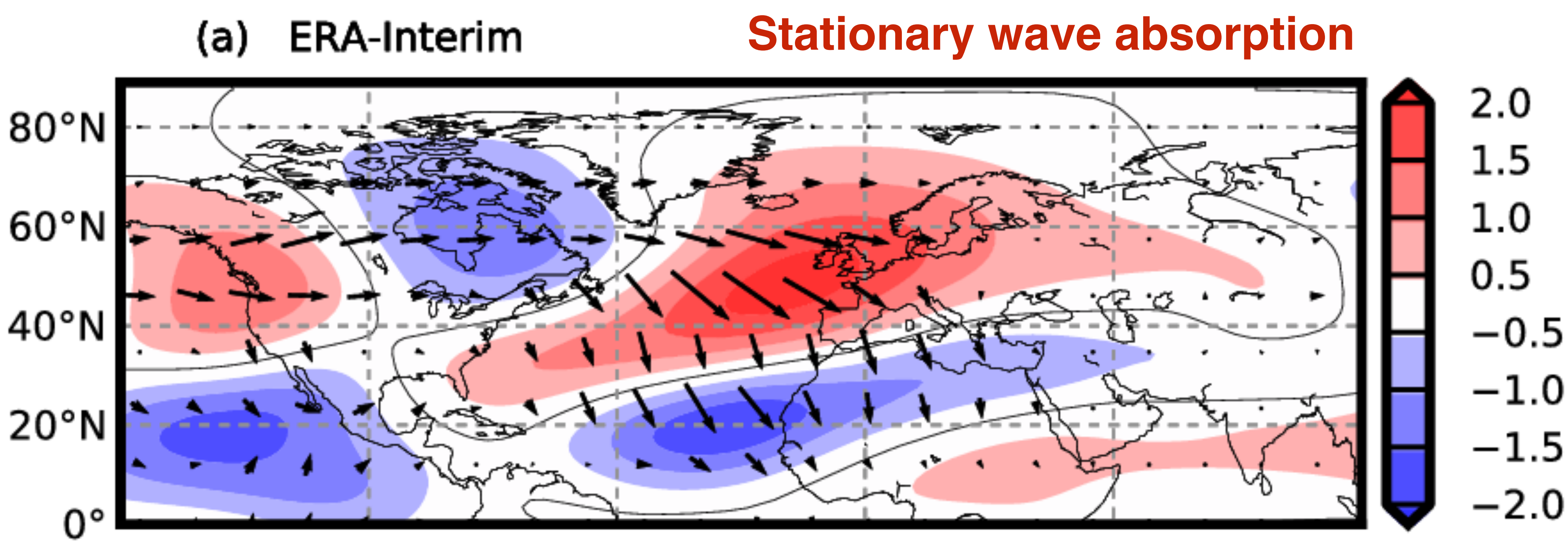

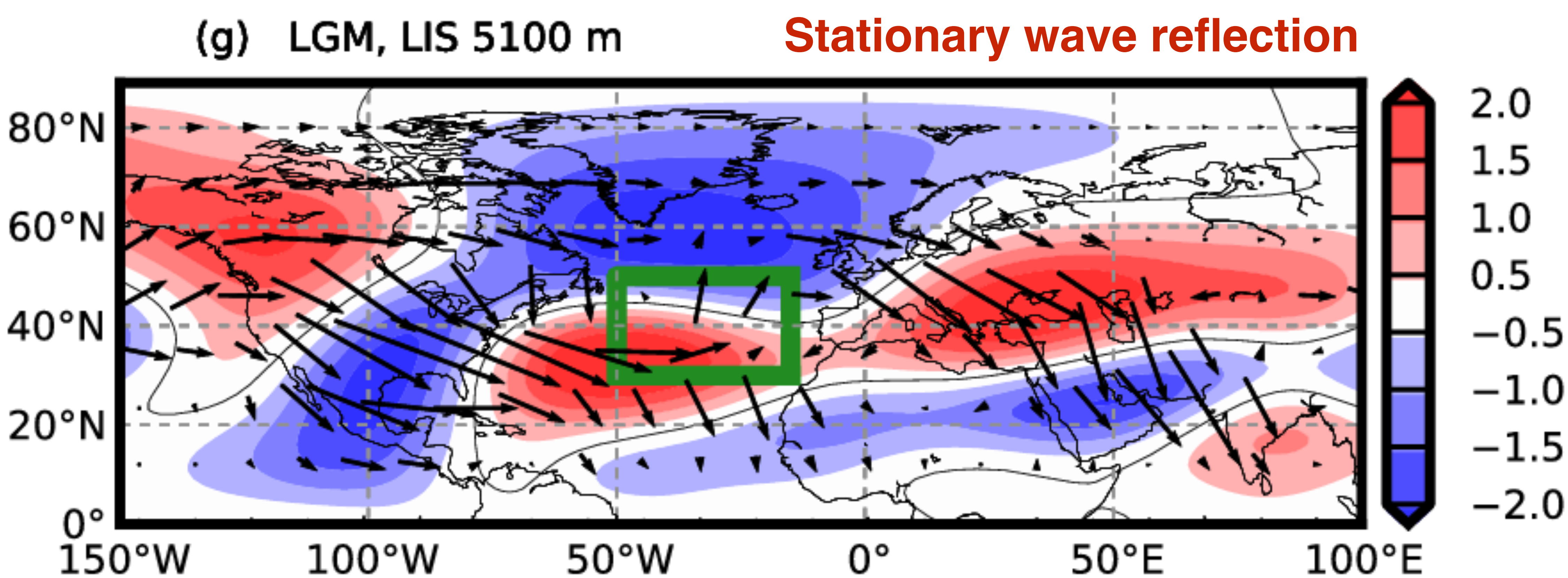

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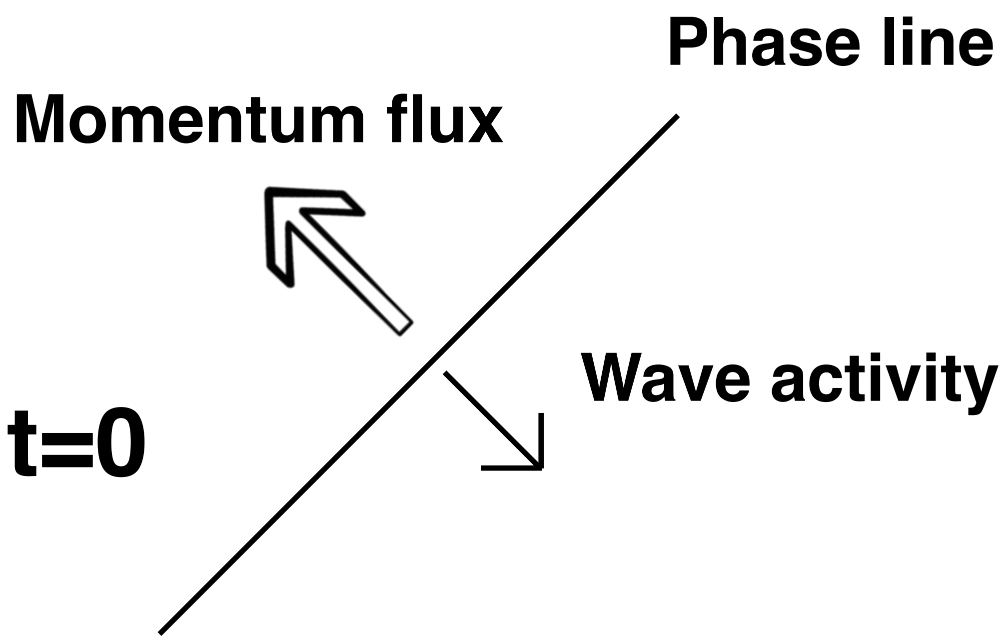
Stationary wave reflection



Midlatitudes

Subtropics

Weak PV gradient or
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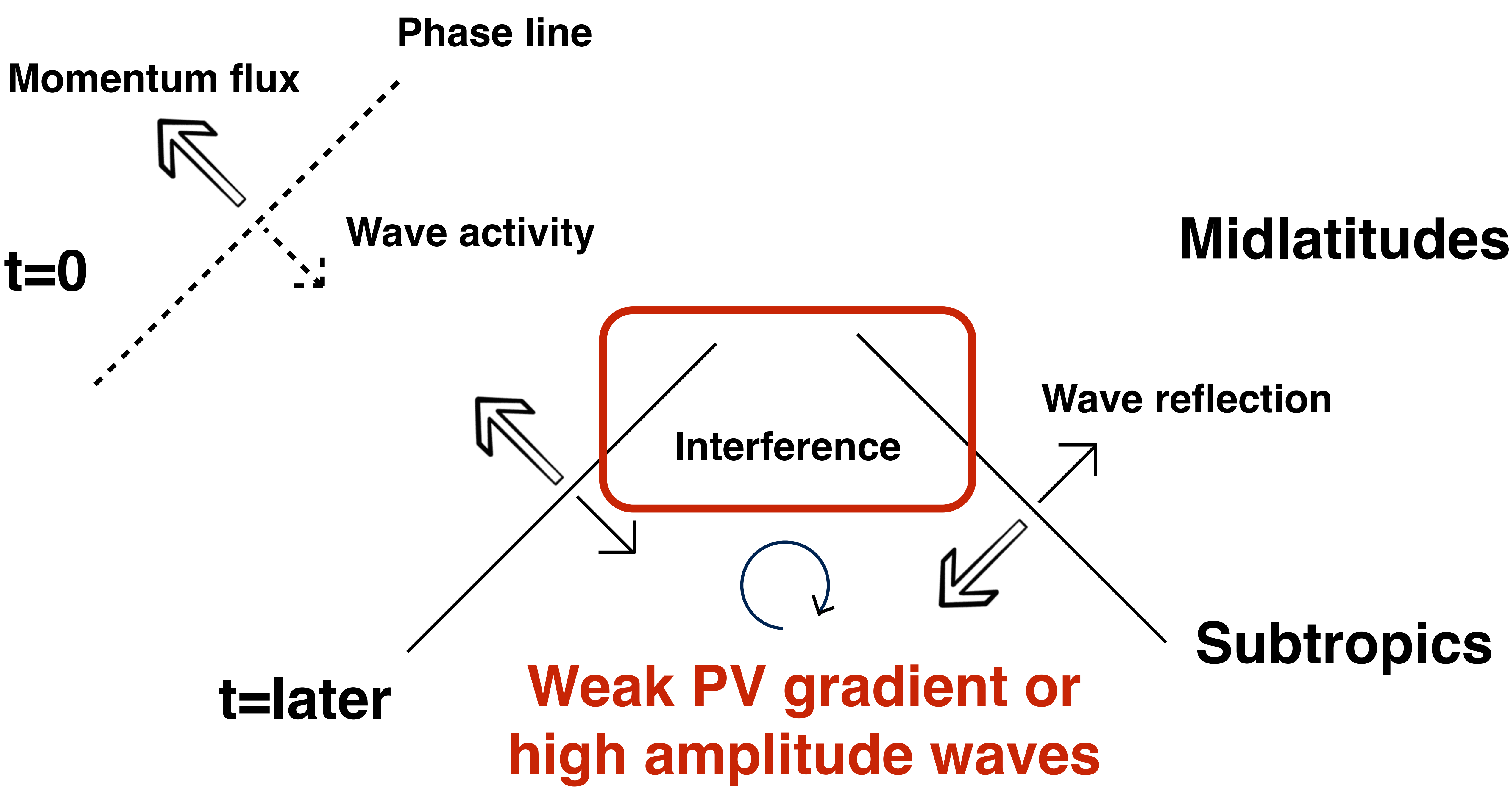
300 hPa eddy streamfunction and wave activity flux

Stationary wave reflection



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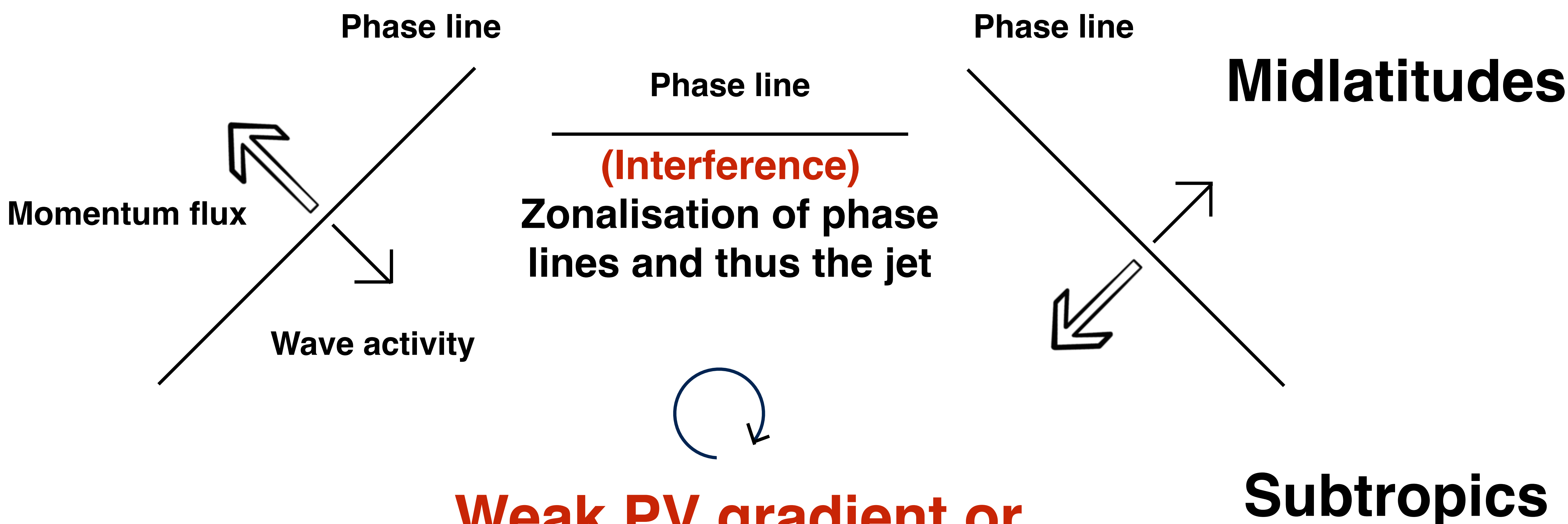
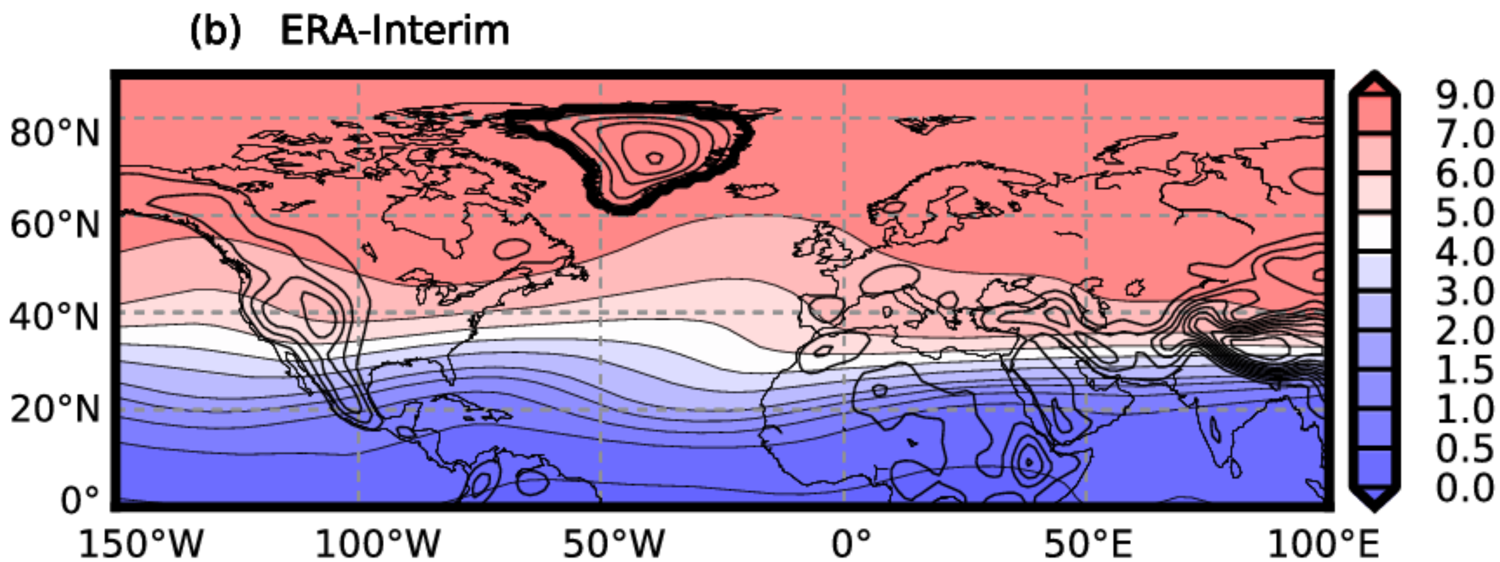
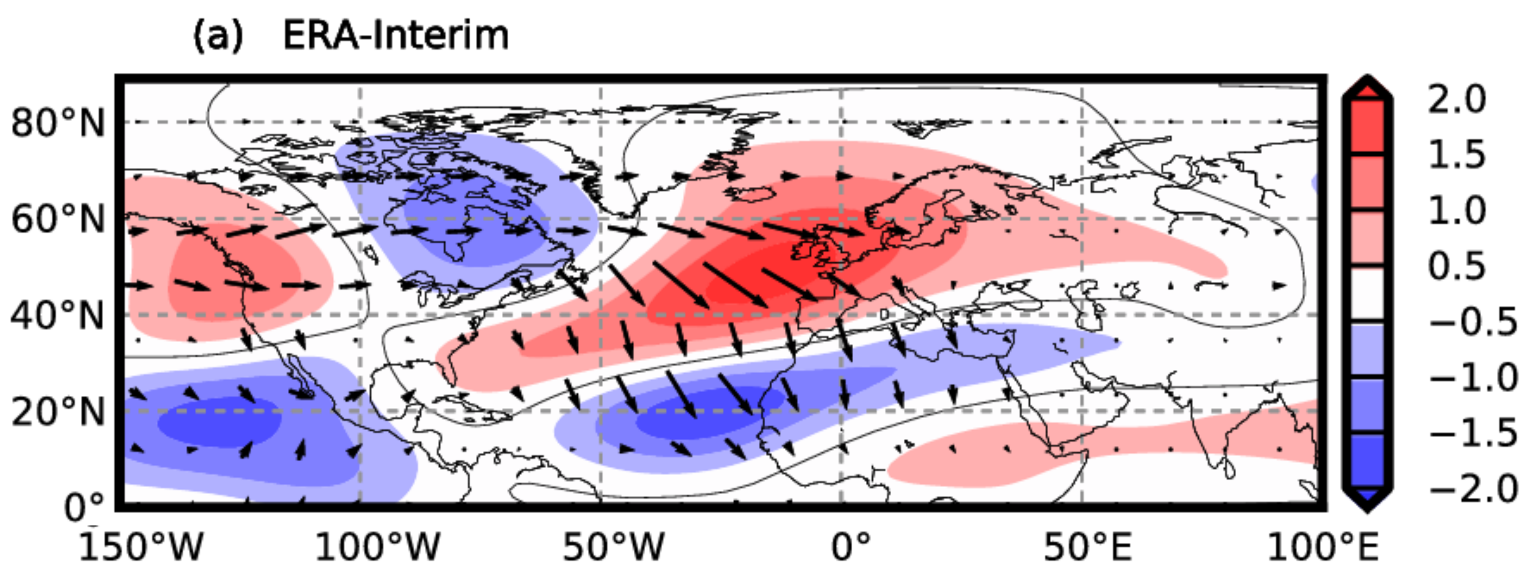


Weak PV gradient or high amplitude waves

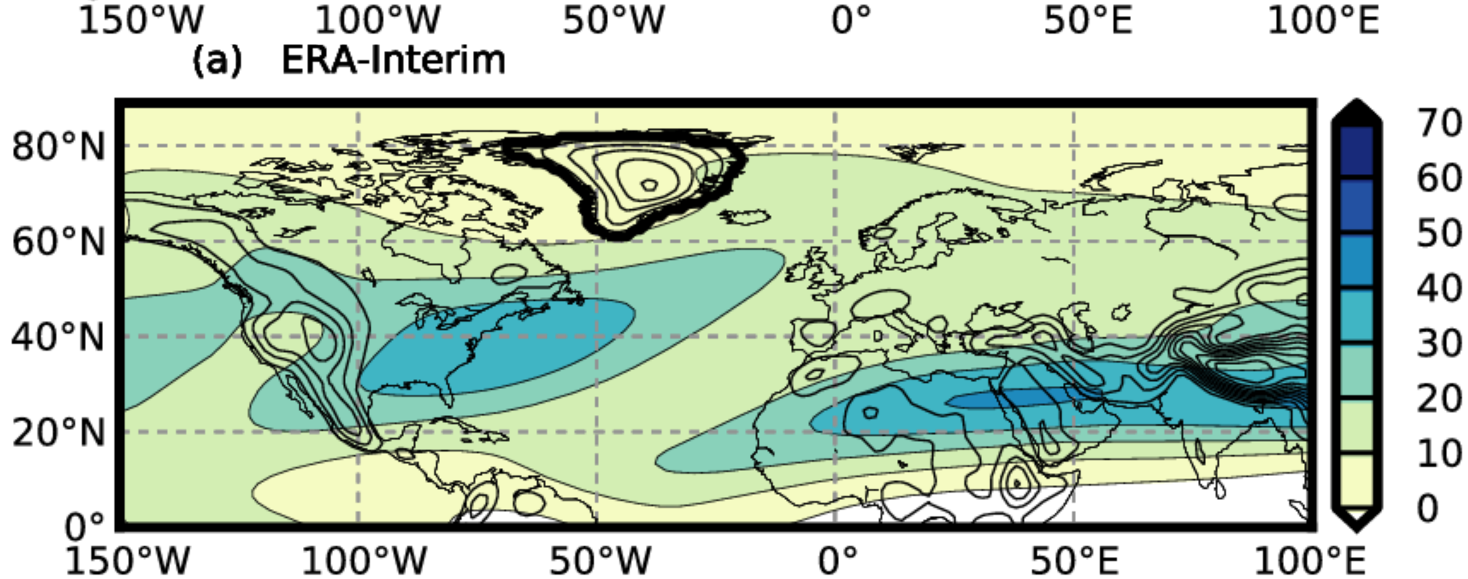
Everything put together
Climatologically non-reflective case



Strong subtropical PV gradient

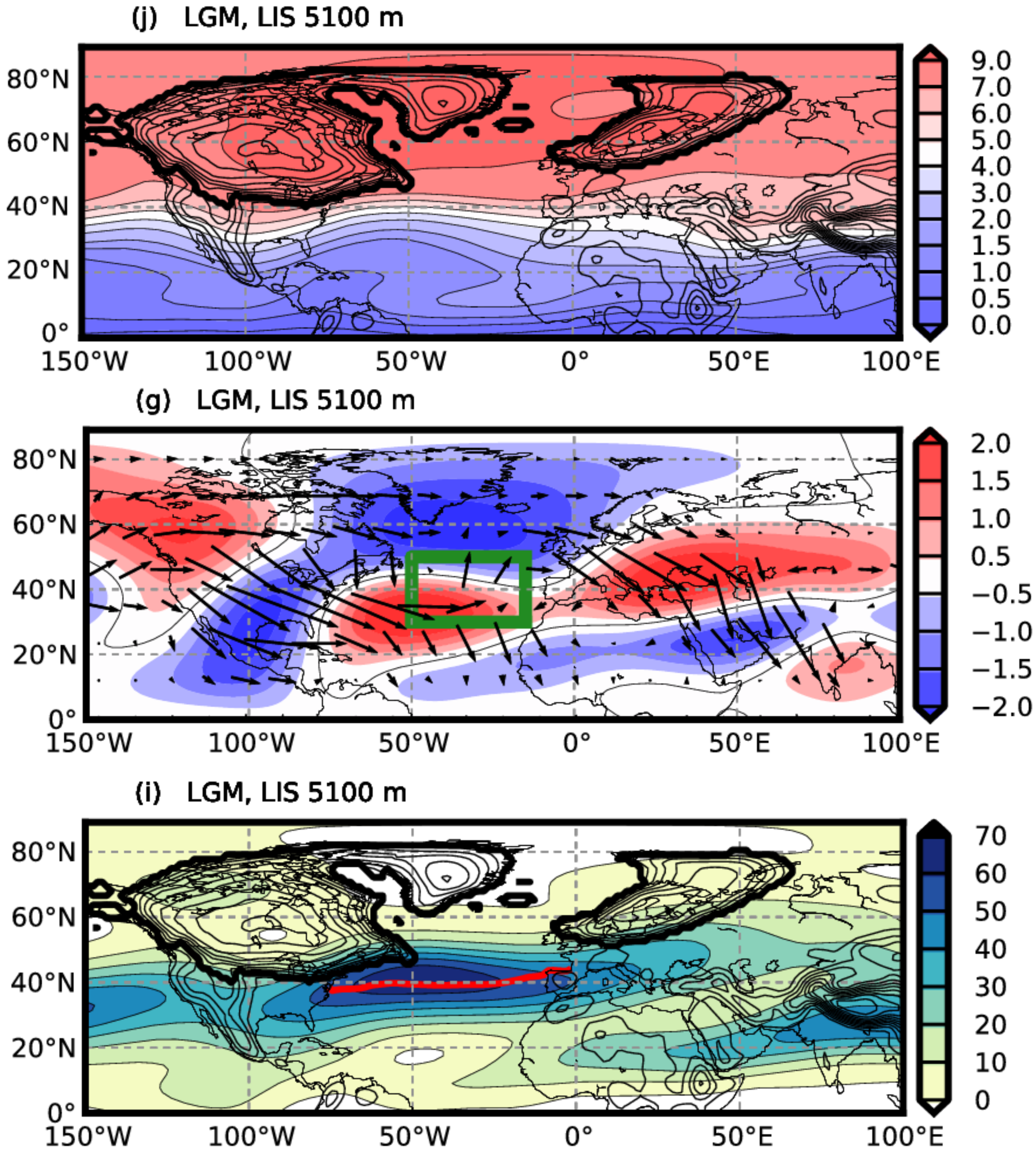


Predominant absorption of stationary waves in the subtropics. Equatorward wave activity flux in Atl. basin



Weak and meridionally tilted Atlantic jet

Everything put together
Climatologically reflective case



Homogenized subtropical PV & strong mid-lat. PV gradient

Predominant reflection of stationary waves in the subtropics. Poleward wave activity flux in E. Atl. basin

Strong and zonal Atlantic jet

Summary and conclusions

Modern climate & low LIS LGM

- Weak stationary waves
- Strong subtropical PV gradient that resists stationary wave reflection
- Weak and meridionally tilted Atlantic jet

High LIS LGM

- Strong mechanical stationary wave forcing in North America
- Organization of planetary waves (Rossby wave breaking)
- PV gradients expelled to mid-latitudes, weak subtropical PV
- Predominant stationary wave reflection that helps zonalise the Atlantic jet
- Reflected stationary waves tend to break cyclonically, which helps zonalise the jet even further