Moist formulations of the Eliassen-Palm flux and their connection to the surface westerlies

in comprehensive and idealized GCM simulations

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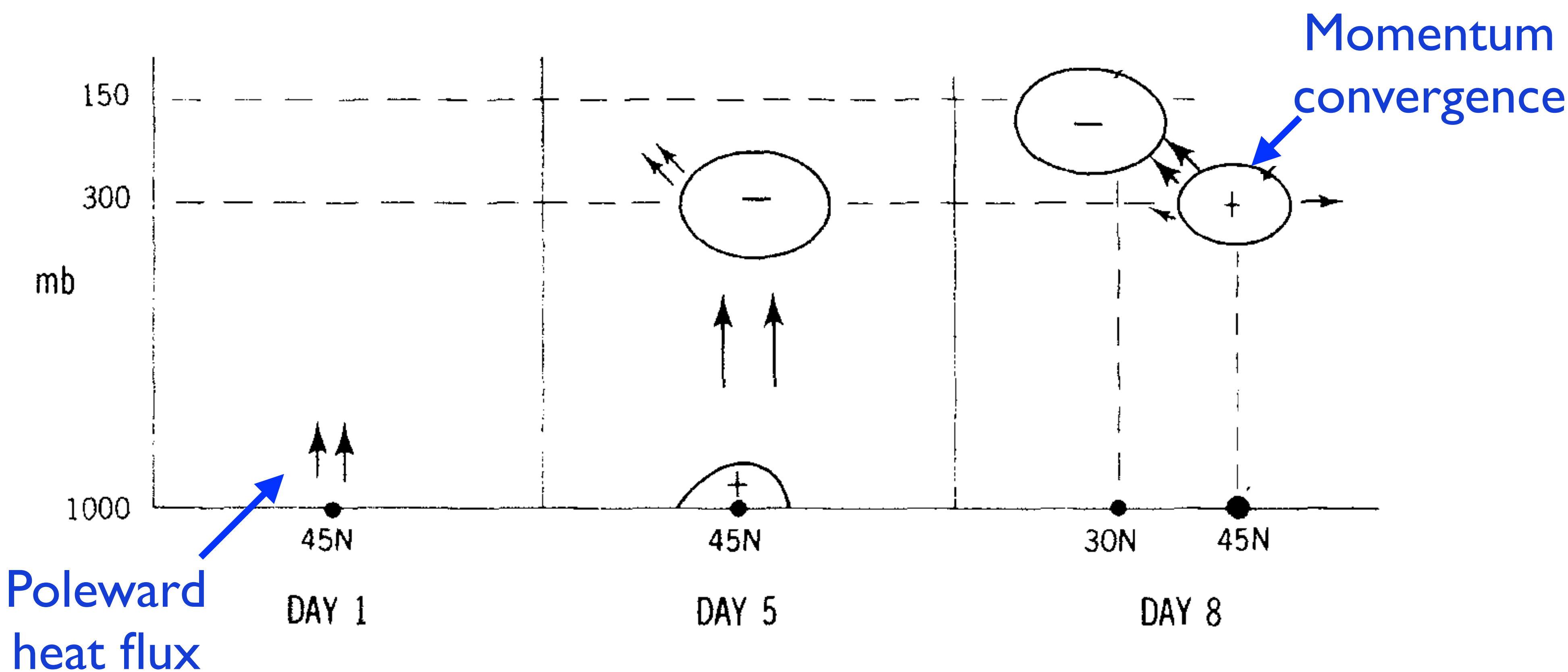
In collaboration with
John Dwyer (postdoc at MIT)

Eliassen-Palm (EP) flux is flux of wave activity, and has been used to connect surface westerlies to poleward heat flux



Schematic of baroclinic eddy lifecyle
Arrows: EP fluxes
Ovals: EP flux divergence

Figure: Held and Hoskins, Adv. Geophys., 1983 (see also Lu et al JAS, 2010 and Donohoe et al Clim. Dyn., 2014)

But EP fluxes typically do not account for water vapor even though eddy latent heat fluxes important to the general circulation…

Two approaches to including moisture in EP fluxes

$$F^{(\phi)} = -a\cos\phi\,\overline{u'v'}$$

$$F^{(p)} = a\cos\phi\, f\,\frac{\overline{v'\theta'}}{\overline{\theta}_p}$$

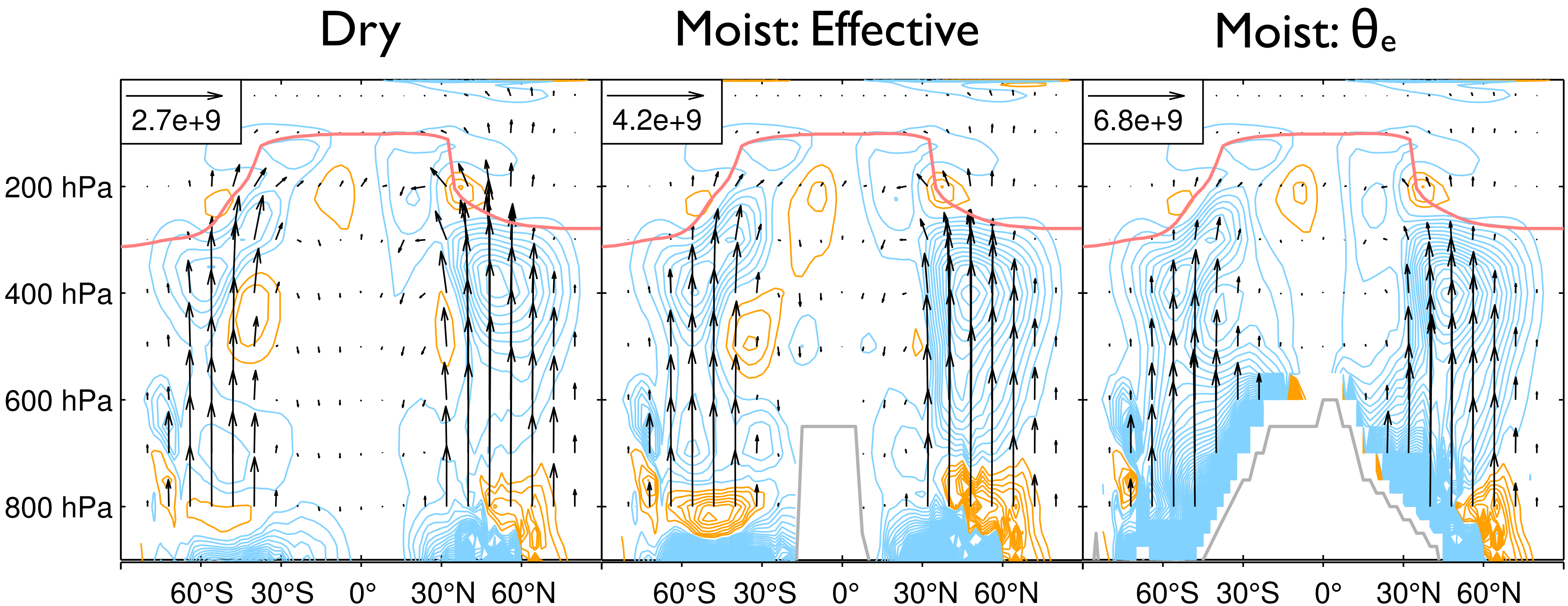
Effective EP flux: Replace dry static stability with effective static stability (cf. O'Gorman, JAS, 2010)

θ_e EP flux: Replace potential temperature with equivalent potential temperature (cf. Stone & Salustri, JAS, 1984)

See also Yamada and Pauluis, JAS, 2016 and Chen, JAS, 2013

Dwyer and O'Gorman, JAS, revised

Moist EP fluxes have stronger upward component that peaks further equatorward



ERA-interim reanalysis 1980-2013 DJF

Arrows: E-P fluxes (m^3/s^2)

Contours: convergence or divergence (75 m^2/s^2)

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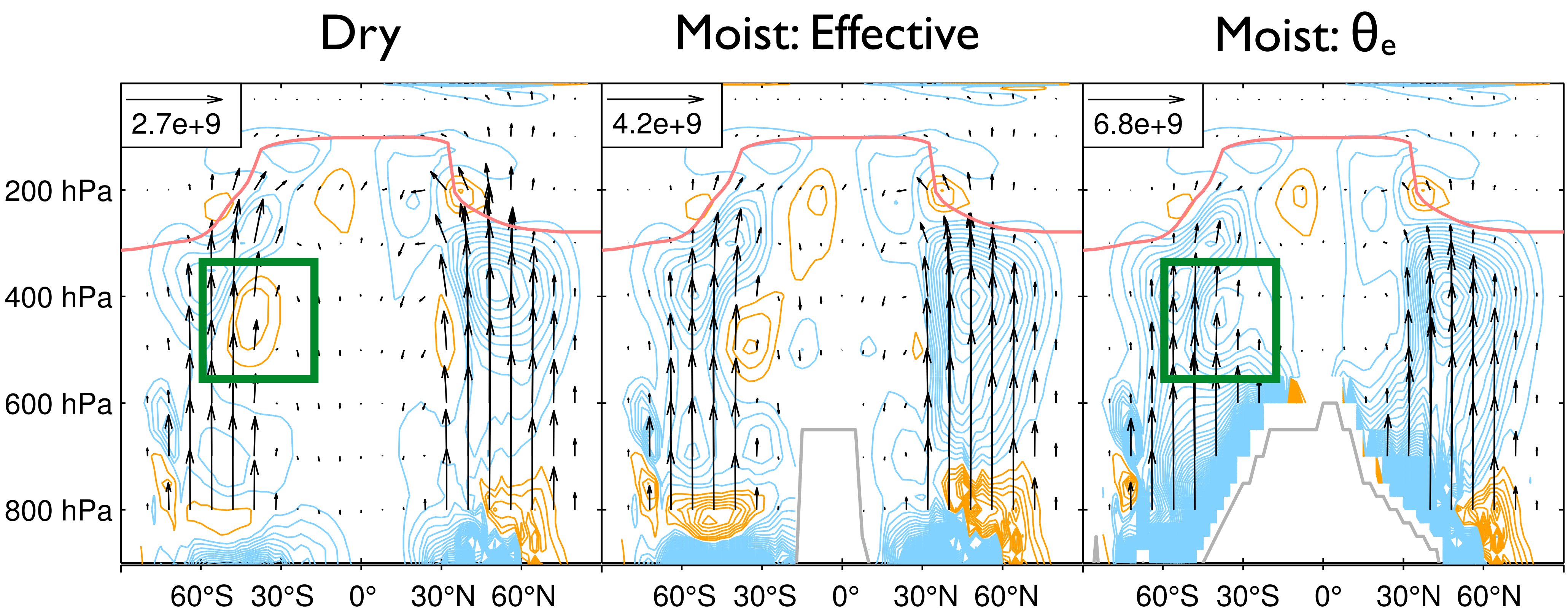

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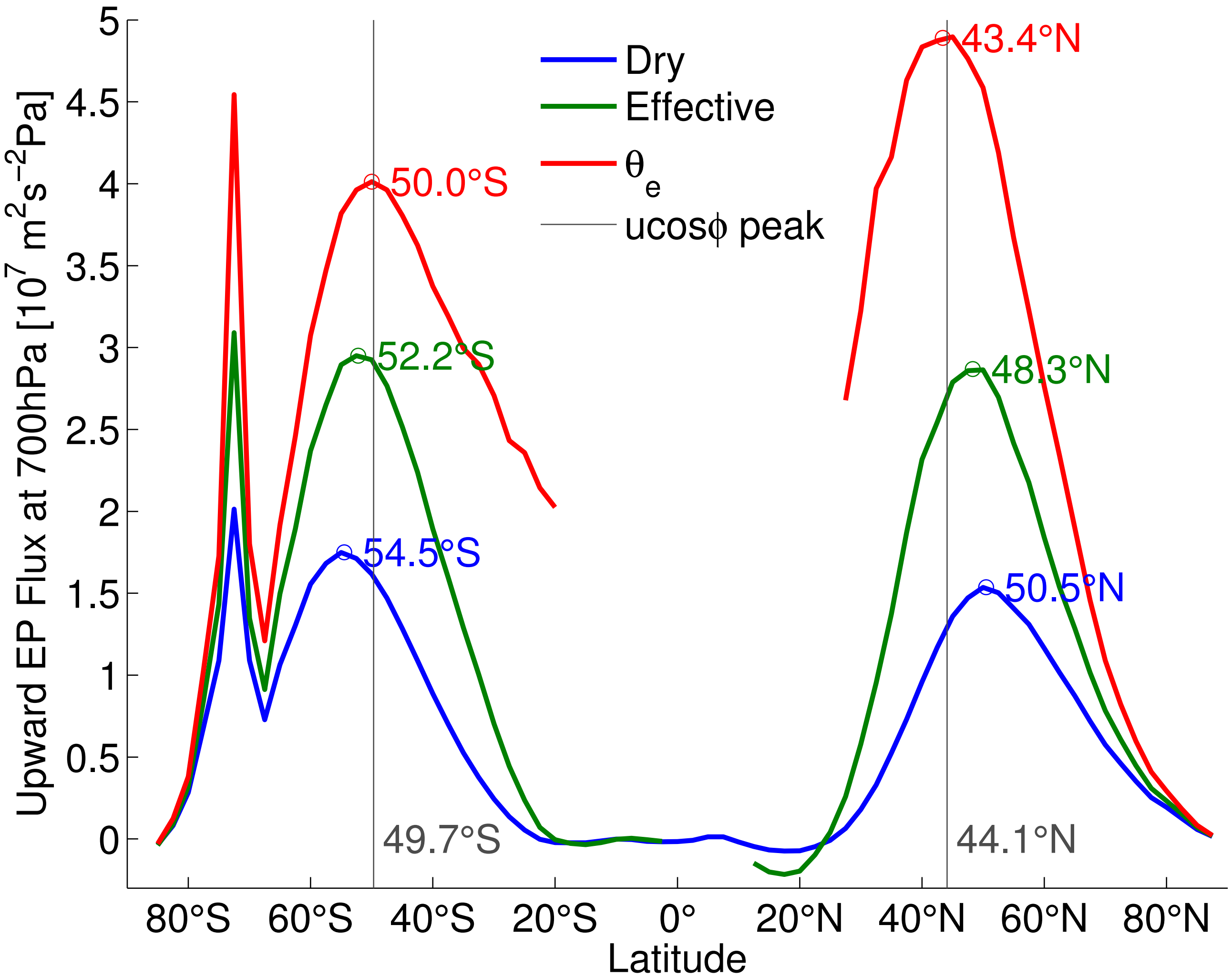
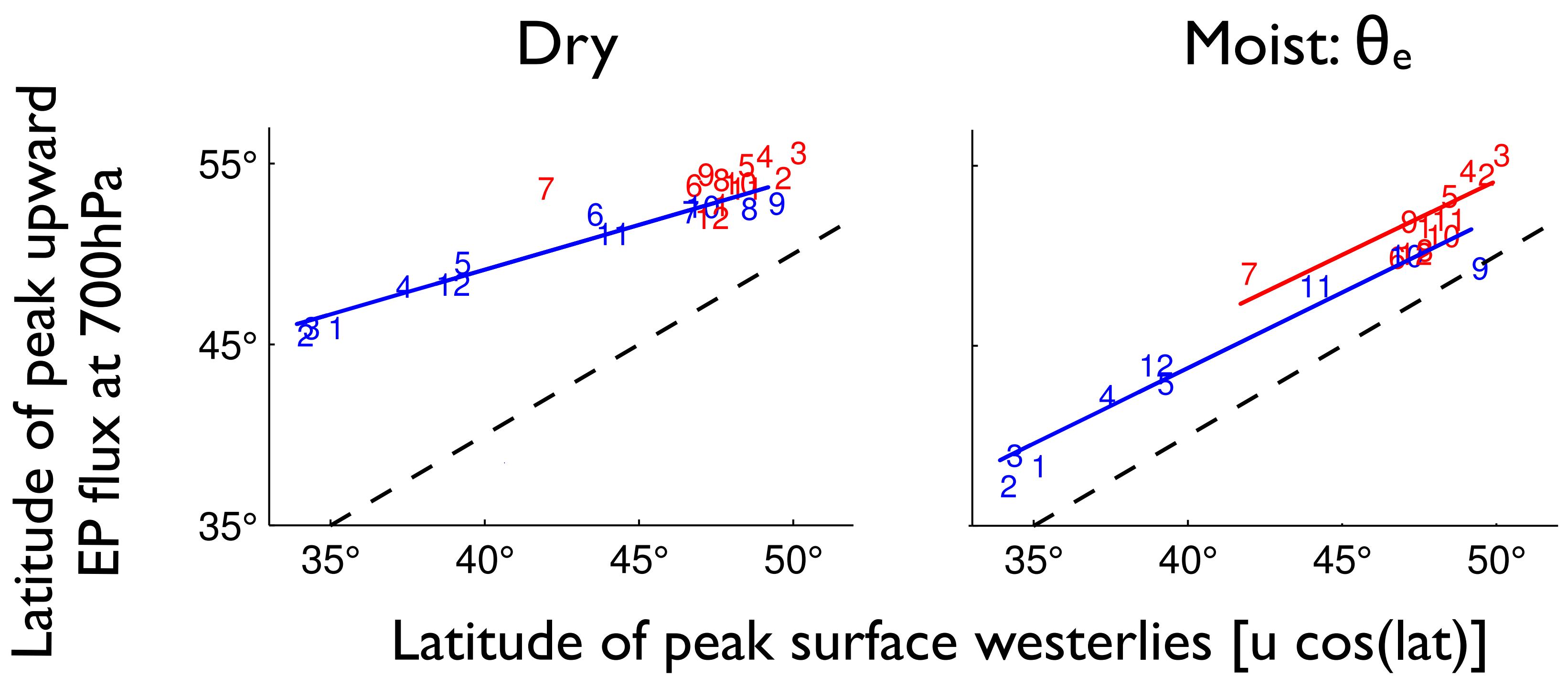
Moist EP fluxes peak further equatorward, closer to peak in surface westerlies



Upward EP flux at 700hPa
ERA-interim reanalysis, annual mean

Dwyer and O'Gorman, JAS, revised

Peak upward EP flux stays much closer to peak surface westerlies over seasonal cycle when moisture included



Northern or Southern Hemisphere
Numbers (1-12) are different months
GFDL-CM3 historical simulation 1980-1999

Dwyer and O'Gorman, JAS, revised

Dry and moist EP fluxes shift poleward by similar amount under climate change (RCP8.5 scenario)

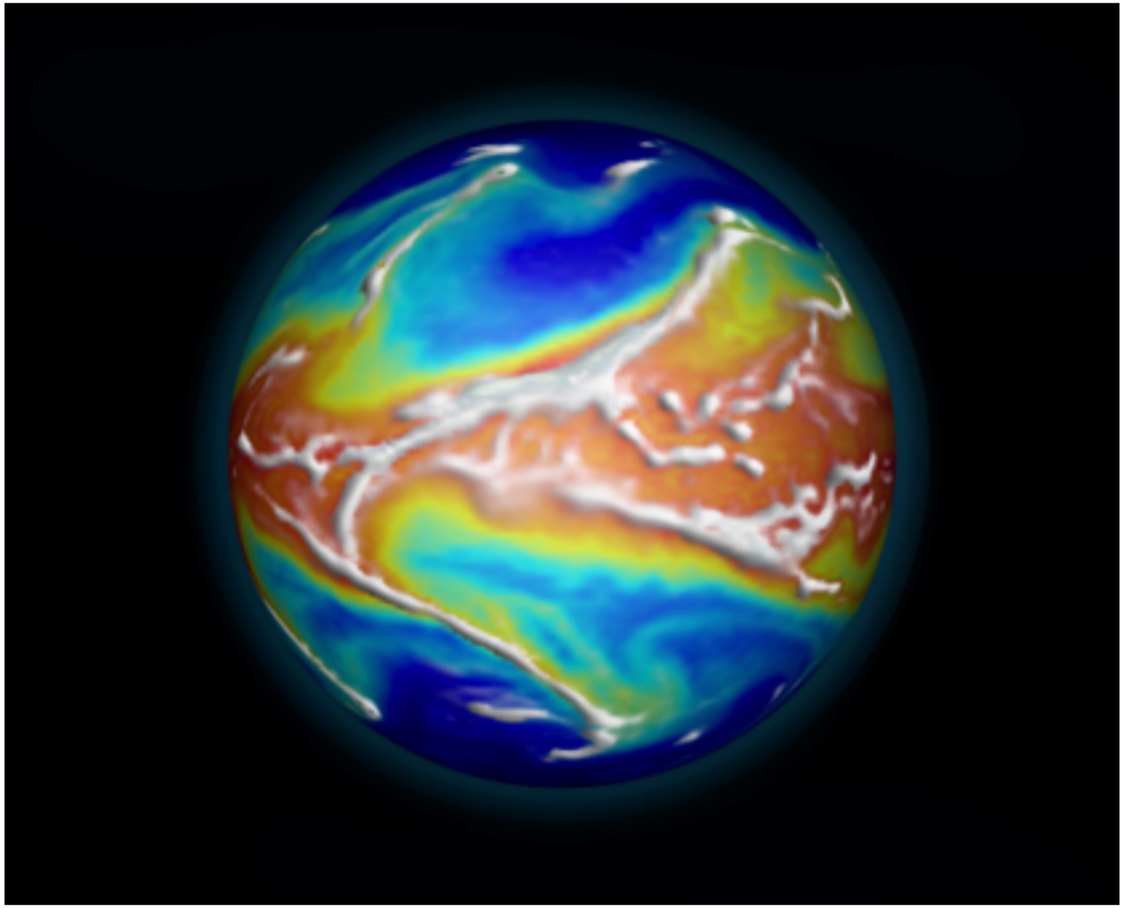
Shift in peak latitude of upward EP flux at 700hPa

	Dry	Moist θ_e
Northern Hemisphere	2.8°	2.8°
Southern Hemisphere	1.5°	1.6°

GFDL-CM3 2080-2099 minus1980-1999
Calculated for each month of the year and then averaged

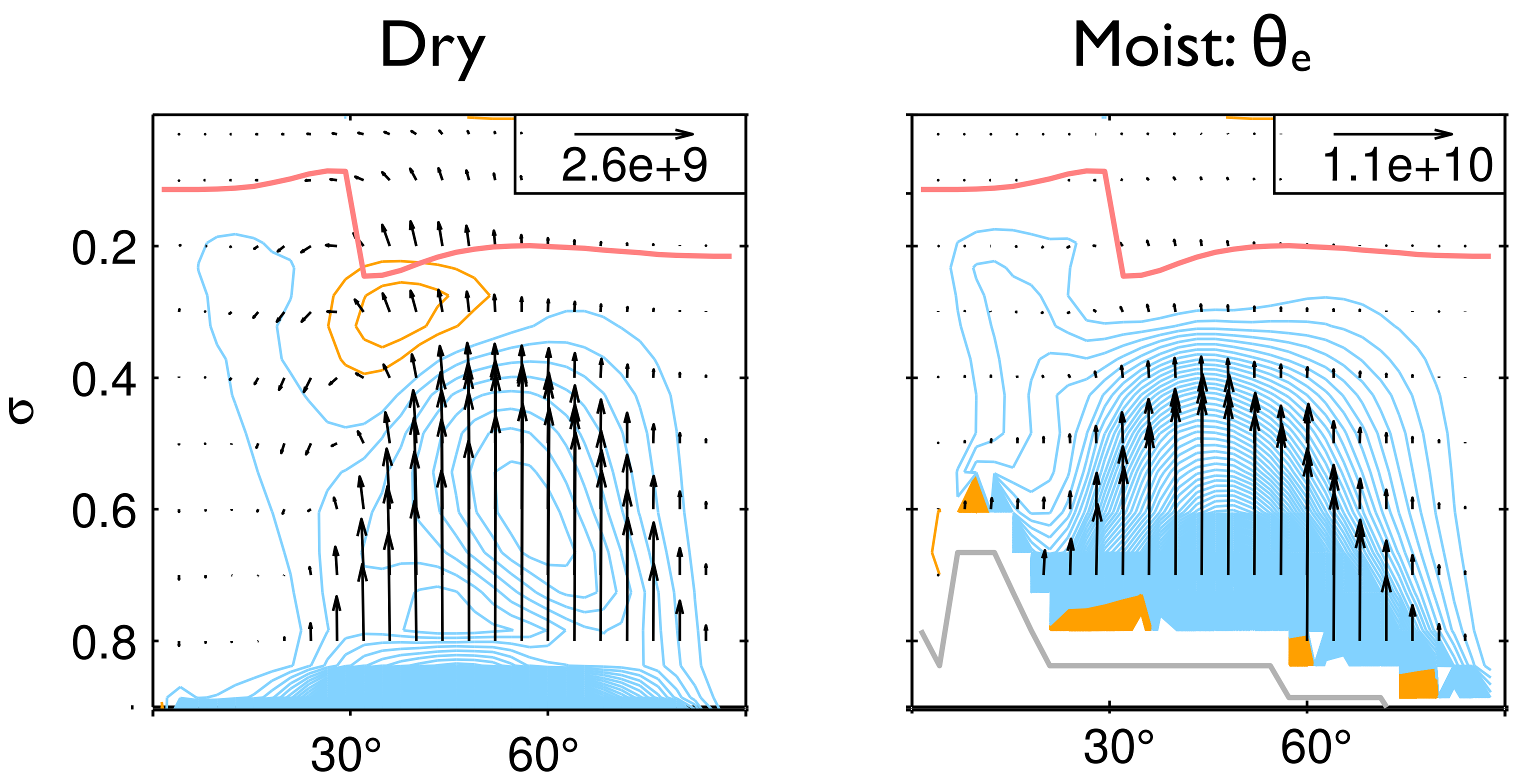
Dwyer and O'Gorman, JAS, revised

Study moist EP fluxes over wider range of climates in idealized 'aquaplanet' GCM simulations



Idealized GCM simulations (see Frierson et al 2006, Frierson 2007, O'Gorman & Schneider 2008)

Idealized 'aquaplanet' GCM: Using moist EP fluxes weakens anomalous divergence feature near subtropical jet



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Global mean surface air temperature 294K

Dwyer and O'Gorman, JAS, revised

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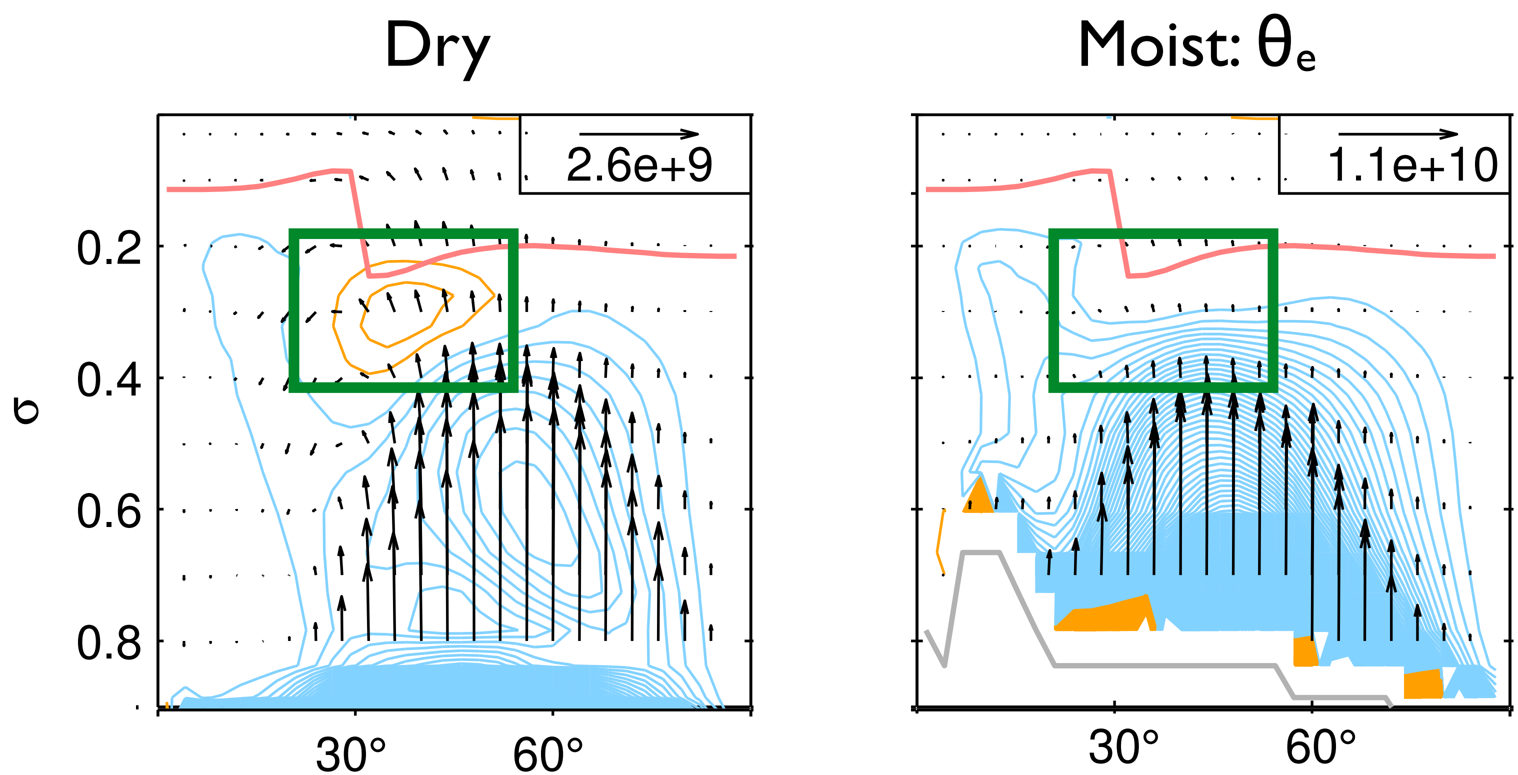

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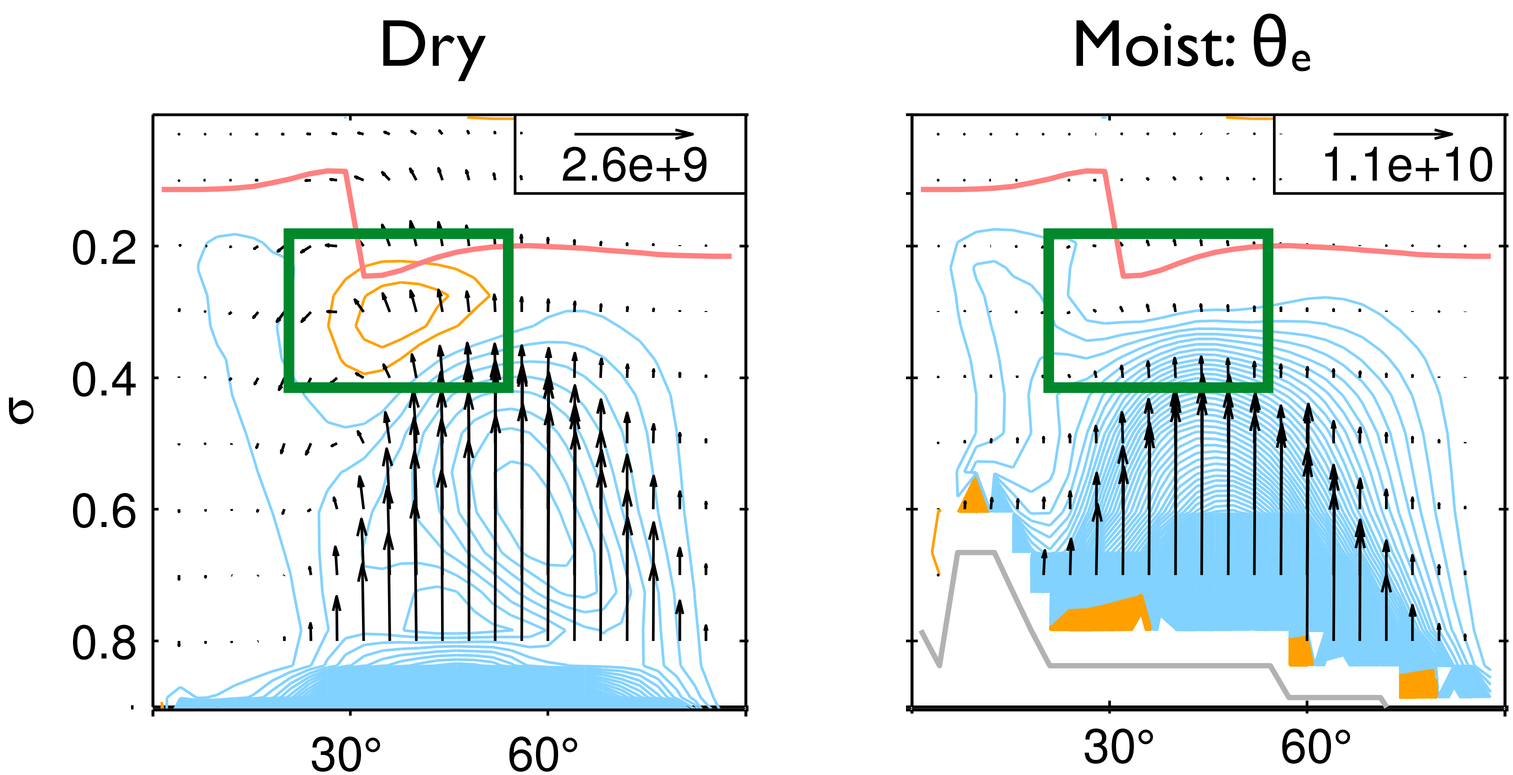
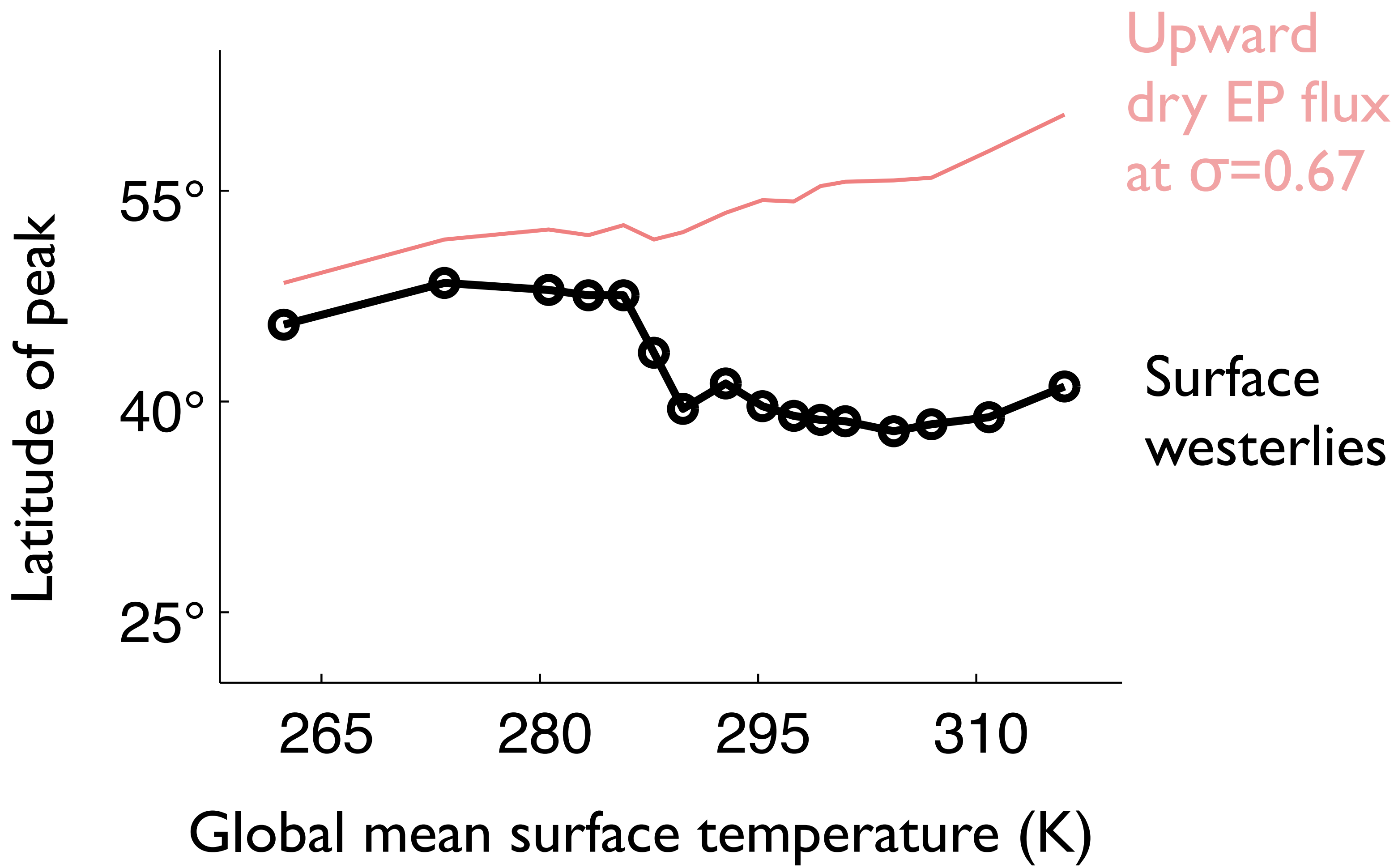


Potential enstrophy analysis: anomalous divergence is dry wave activity source due to condensational heating in this idealized GCM

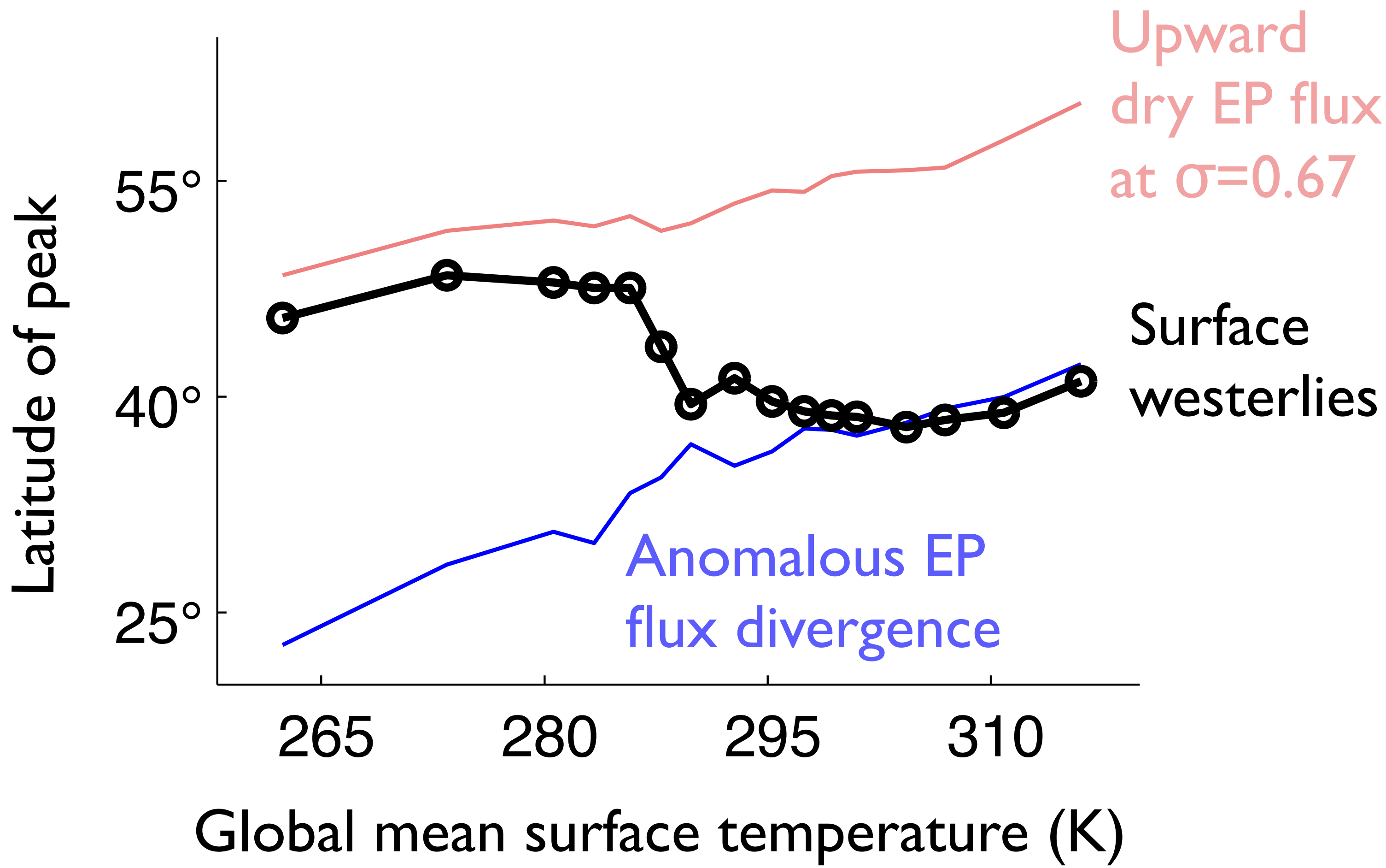
(cf. Birner et al, 2013)

Surface westerlies shift equatorward with warming and do not follow dry EP flux!



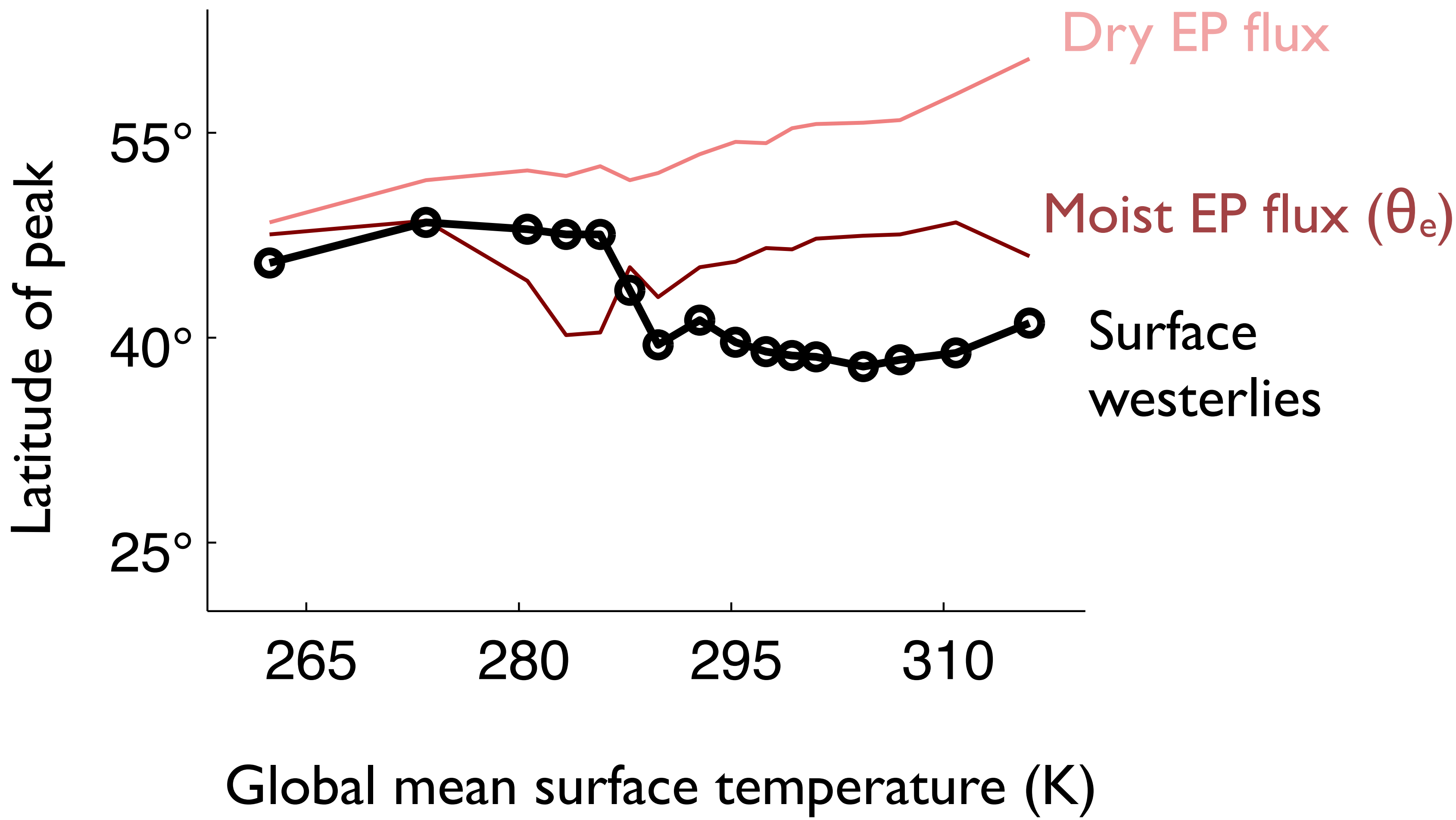
Dwyer and O'Gorman, JAS, revised
See also Schneider, O'Gorman & Levine, 2010

Dry EP flux perspective: Surface westerlies align with anomalous dry EP flux divergence feature in hot climates



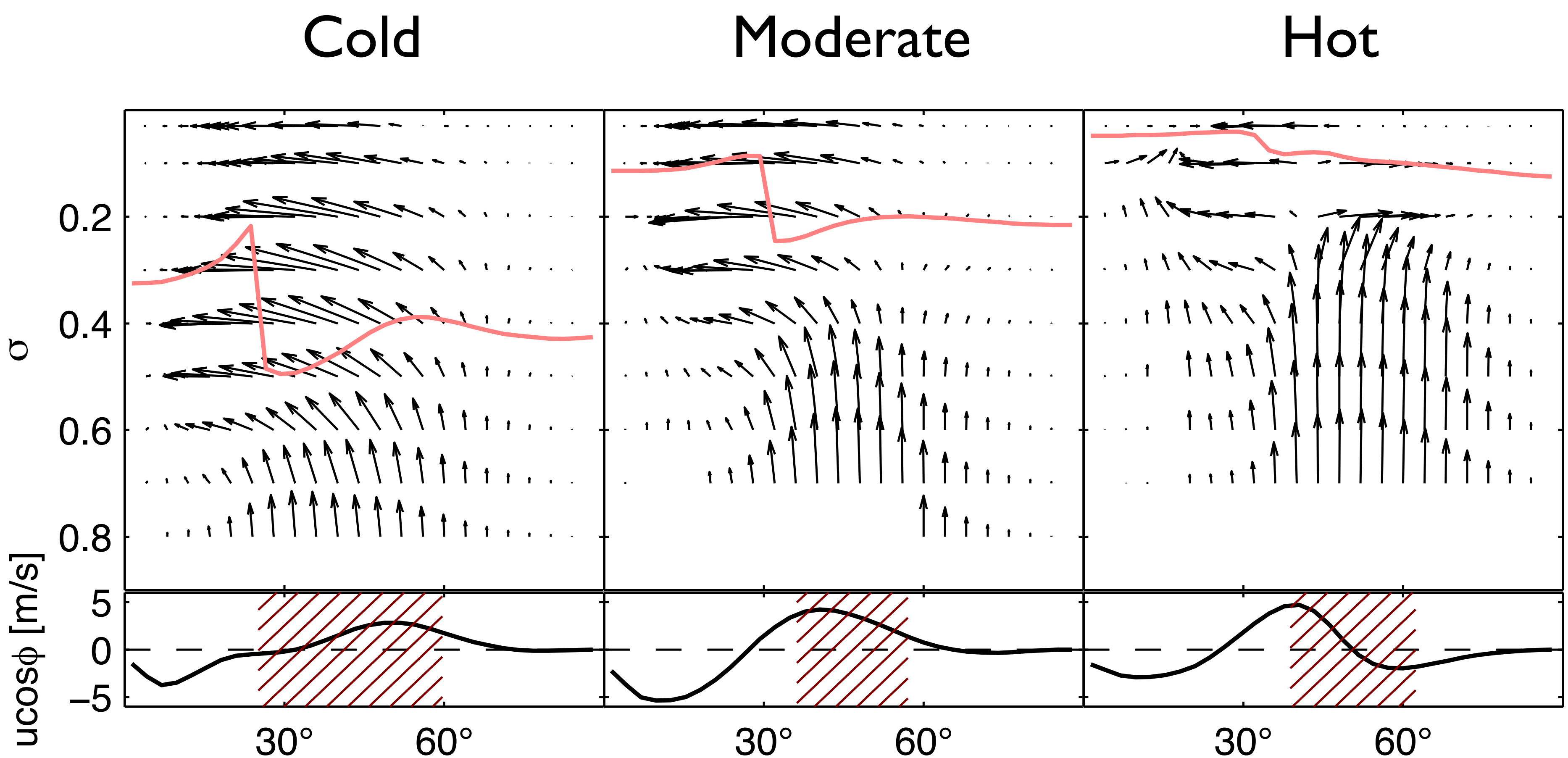
Dwyer and O'Gorman, JAS, revised

Moist EP flux perspective:
Peak upward EP flux is much closer to surface westerlies
(and anomalous divergence feature unimportant)



Dwyer and O'Gorman, JAS, revised

Surface westerlies can be understood with moist EP flux: Combination of broad upward EP flux and transition to poleward wavebreaking as climate warms



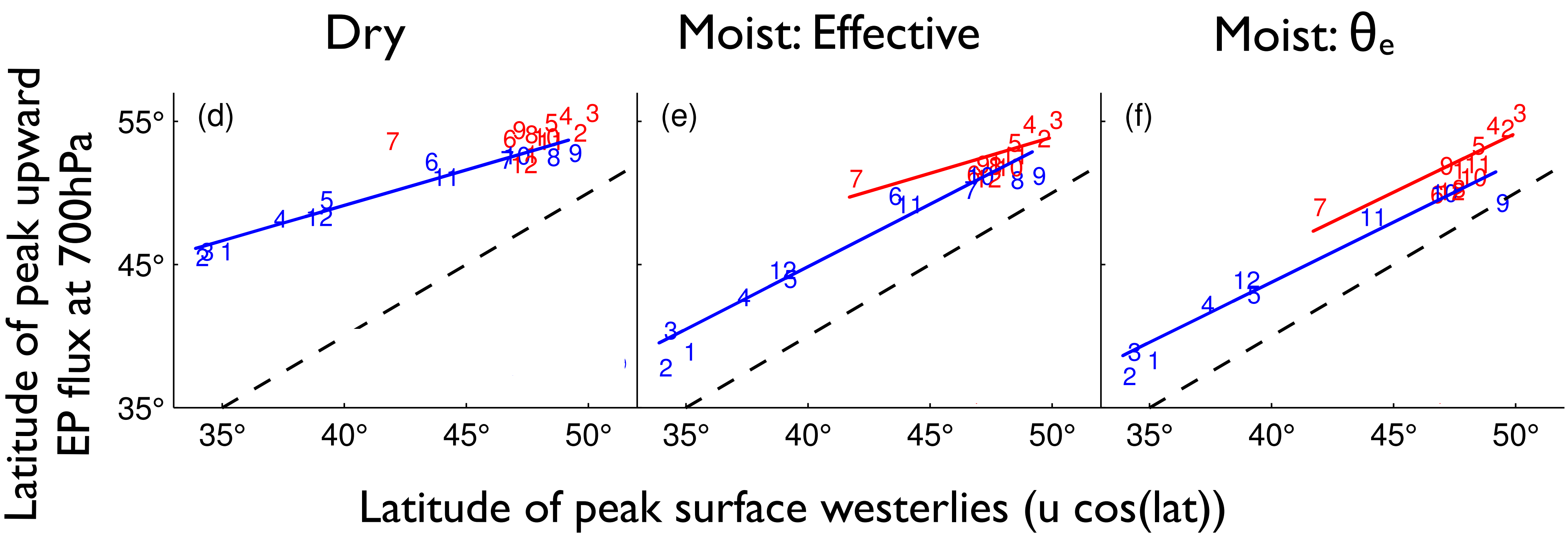
Arrows: E-P fluxes scaled to emphasize upper troposphere
Brown hatching: area of strong upward EP flux
Red: tropopause

Dwyer and O'Gorman, JAS, revised

Conclusions

- Moist EP fluxes are stronger and peak further equatorward than conventional dry EP fluxes
- Advantages:
  - Tighter connection to surface westerlies over seasonal cycle
  - Make it easier to understand surface westerlies in idealized GCM
- Idealized GCM simulations illustrate how moisture can influence wave-mean flow interaction

Peak upward EP flux stays much closer to peak surface westerlies over seasonal cycle when moisture included



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Idealized 'aquaplanet' GCM:
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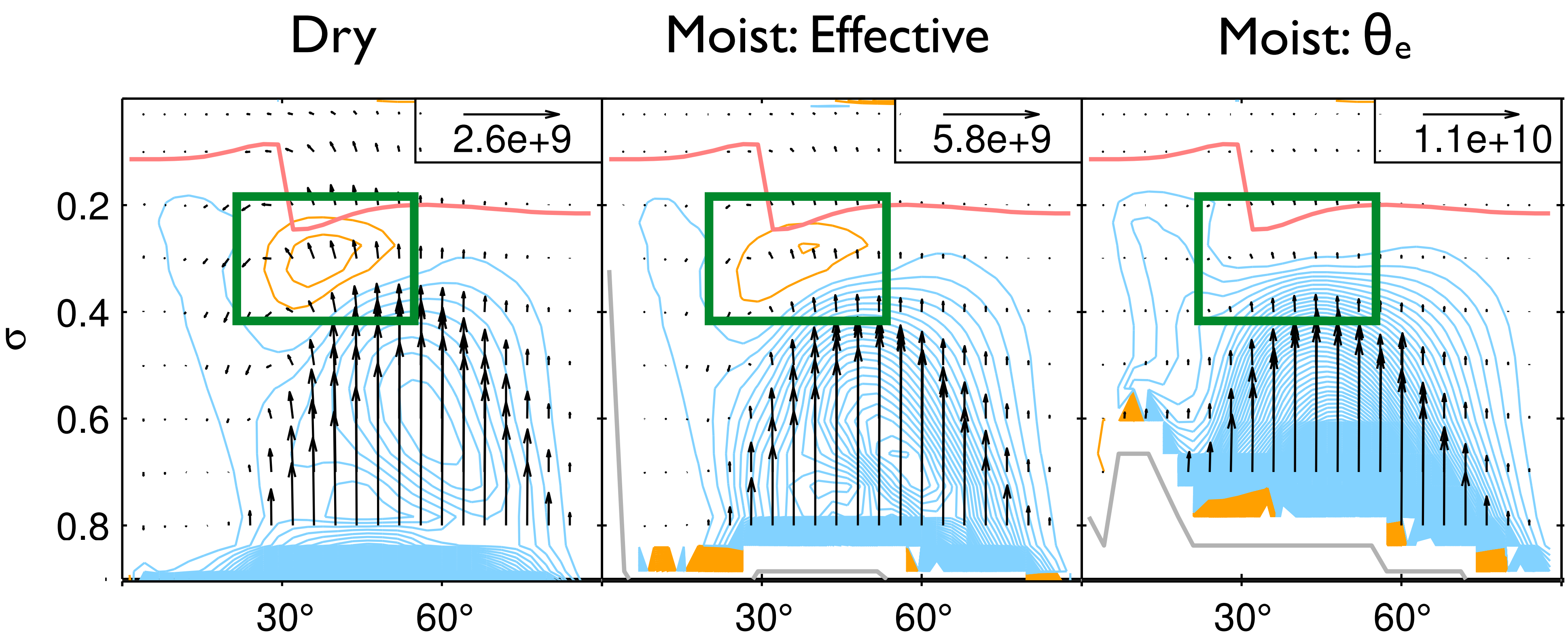

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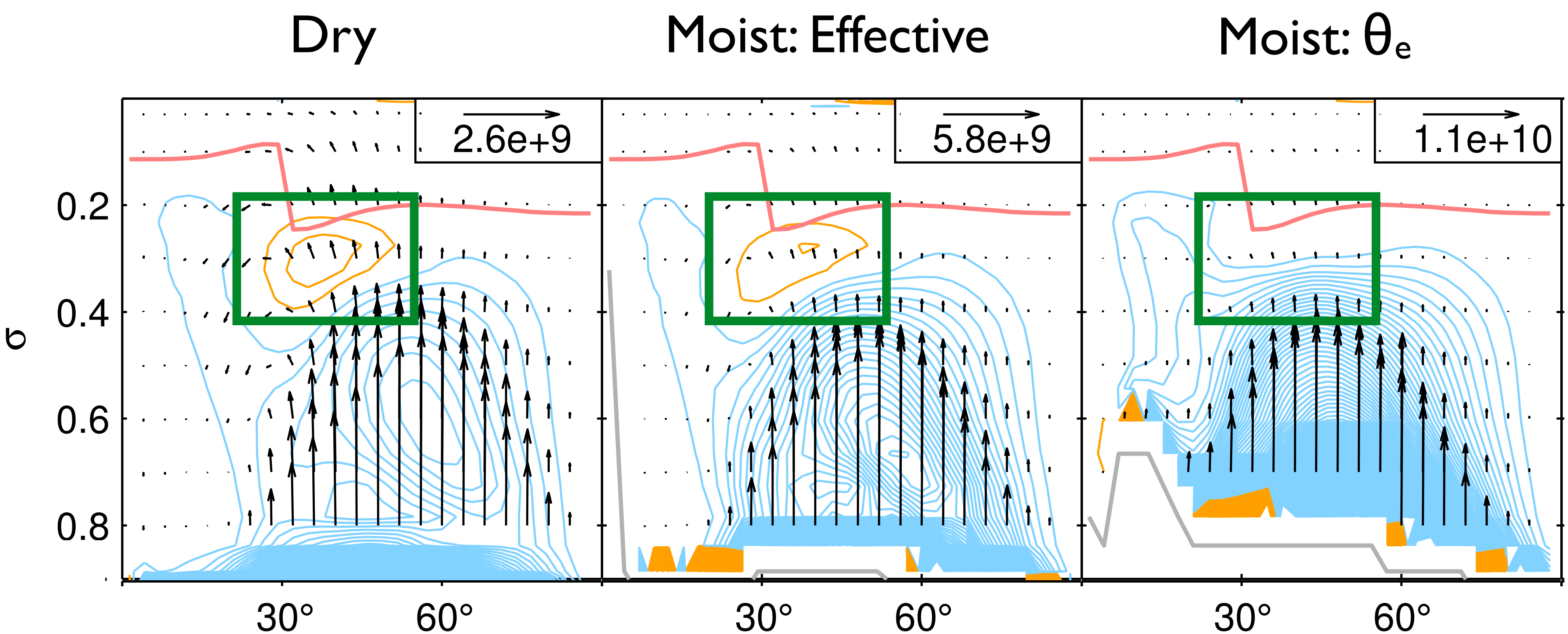

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(Different from what Birner et al, 2013 found for ERA-interim)