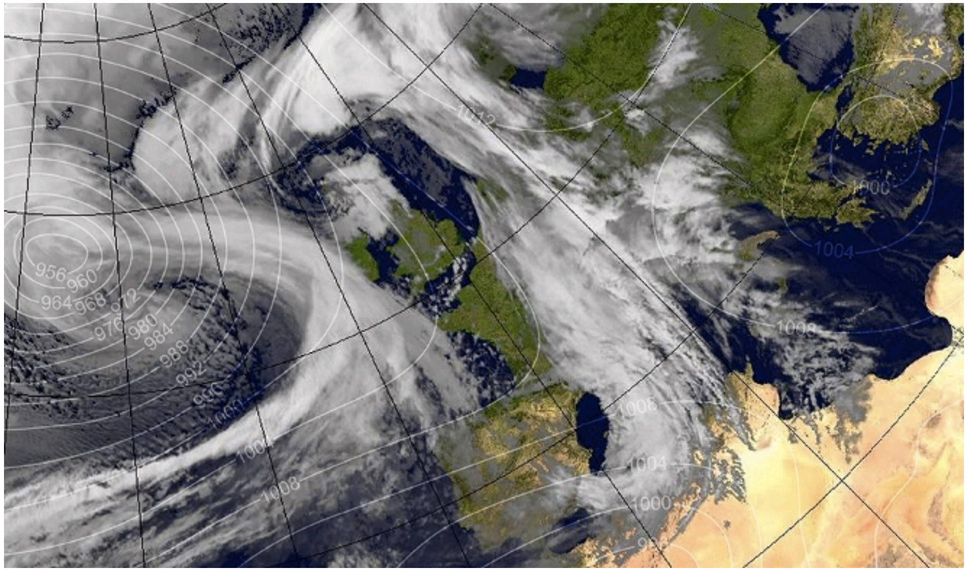
The poleward deflection of midlatitude storm tracks-

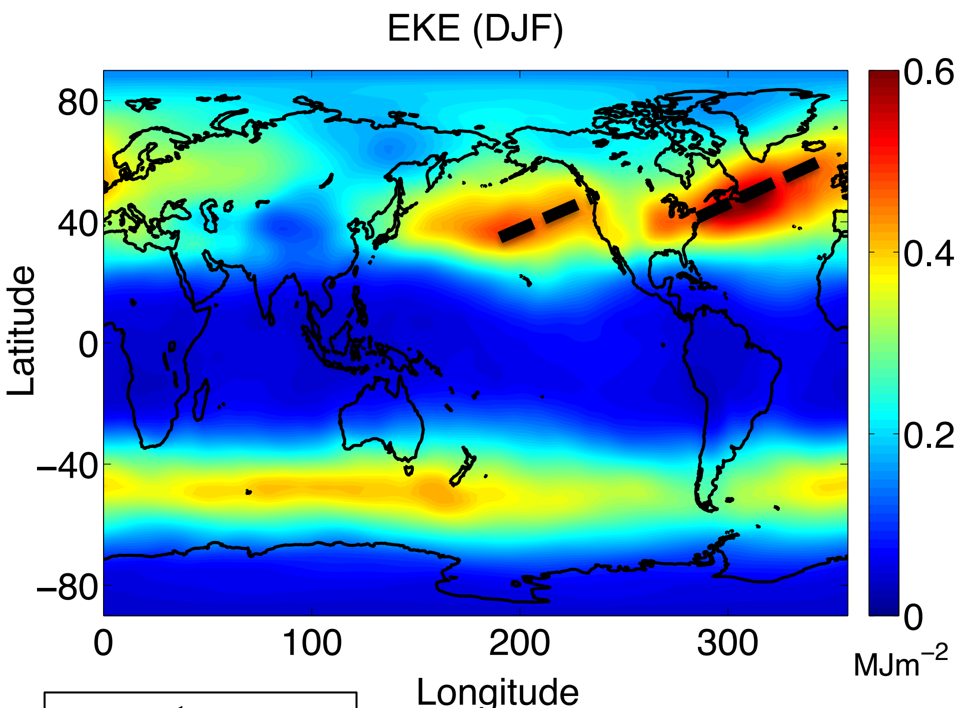
from idealized GCMs to comprehensive climate prediction models



Talia Tamarin and Yohai Kaspi
Weizmann Institute of Science,
Model hierarchies workshop, Princeton, 2016

poleward deflection of storm tracks

Eddy kinetic energy (EKE)



$$\boxed{EKE = \frac{1}{2}\left(\overline{u'^2} + \overline{v'^2}\right)}$$

Poleward tilt of the EKE

Cyclone tracks

Poleward propagation of cyclones

Key questions:

- *What controls the poleward deflection?*
- *What sets the differences between the Pacific and Atlantic storm tracks?*

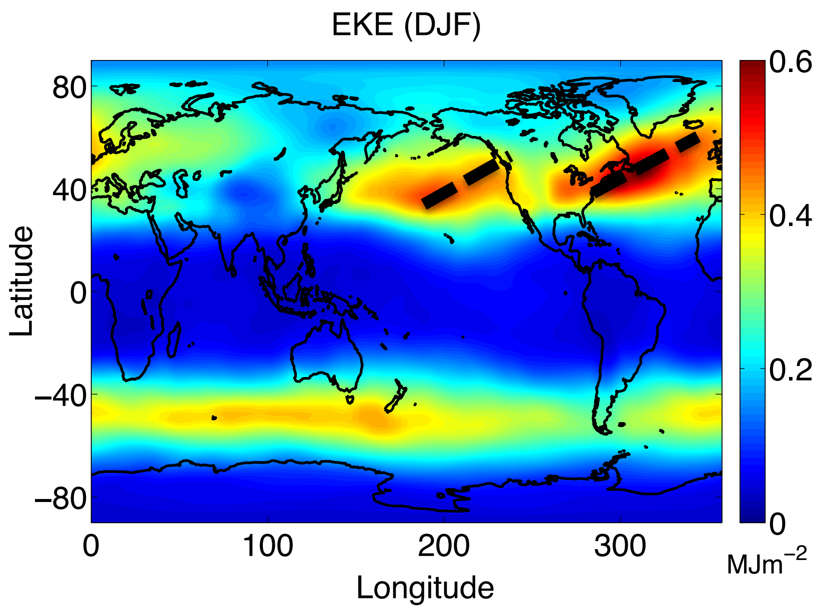
Idealized zonally *symmetric* GCM

⇩

Idealized zonally *asymmetric* GCM

⇩

Reanalysis data

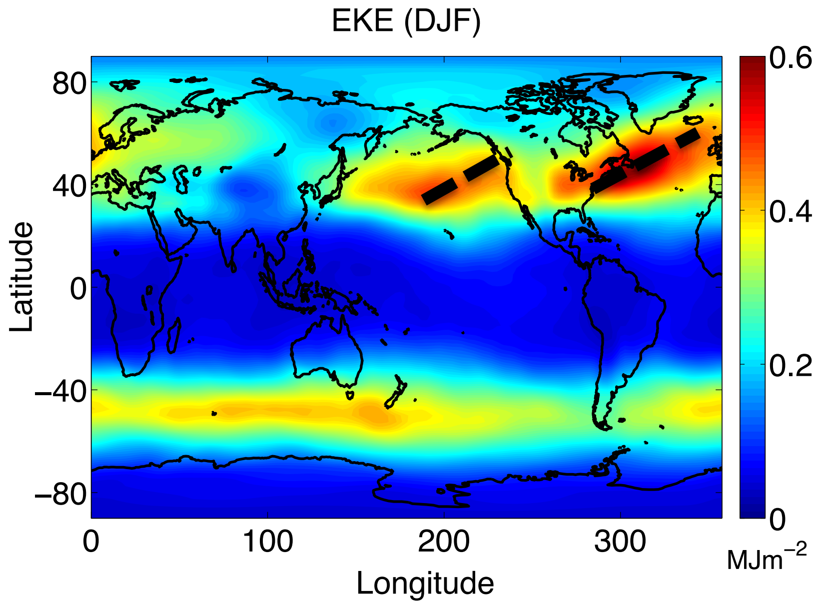


Key questions:

- *What controls the poleward deflection?*
- *What sets the differences between the Pacific and Atlantic storm tracks?*
- *How can climate change affect the poleward deflection of cyclones?*

Idealized *global warming* experiments

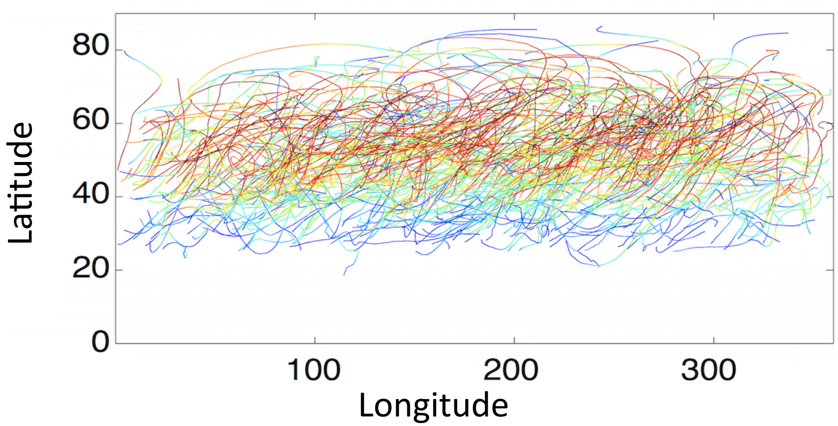
CMIP5 projection models



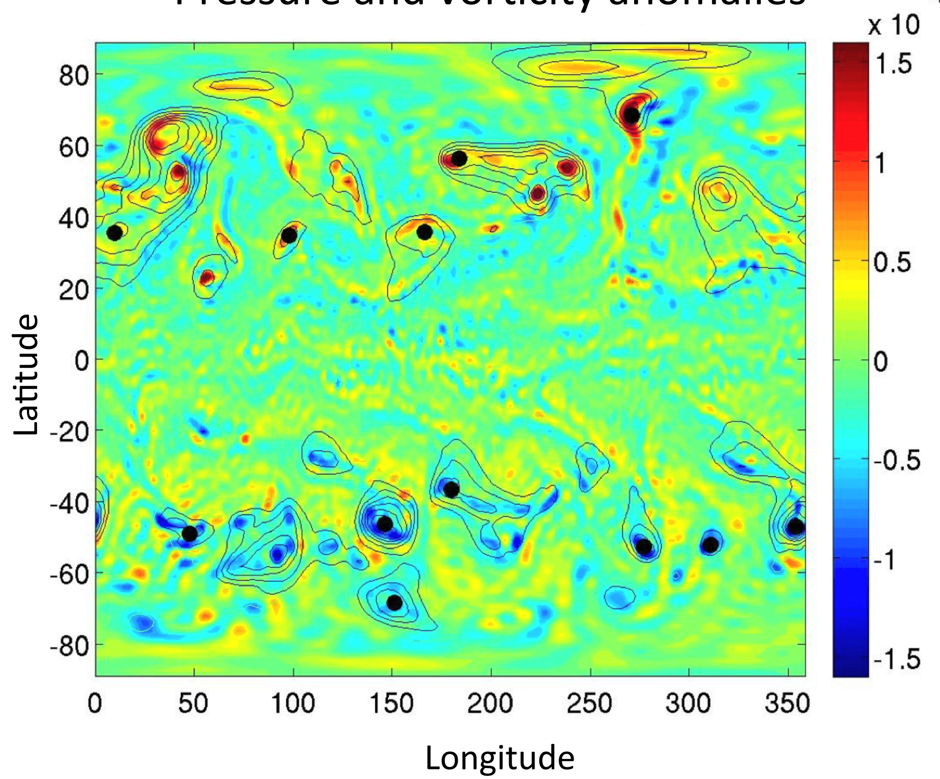
Storm-tracking algorithm in an idealized GCM

Zonally symmetric storm track

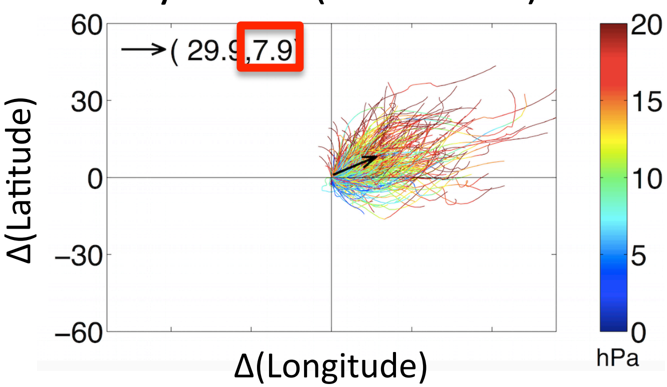
Cyclones



Pressure and vorticity anomalies



Cyclones (translated)



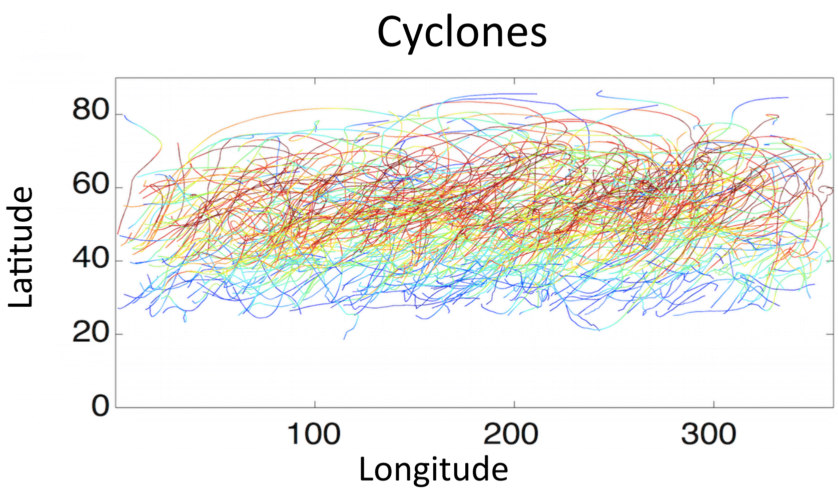
The average cyclone in a zonally symmetric GCM propagates ~7.9° poleward

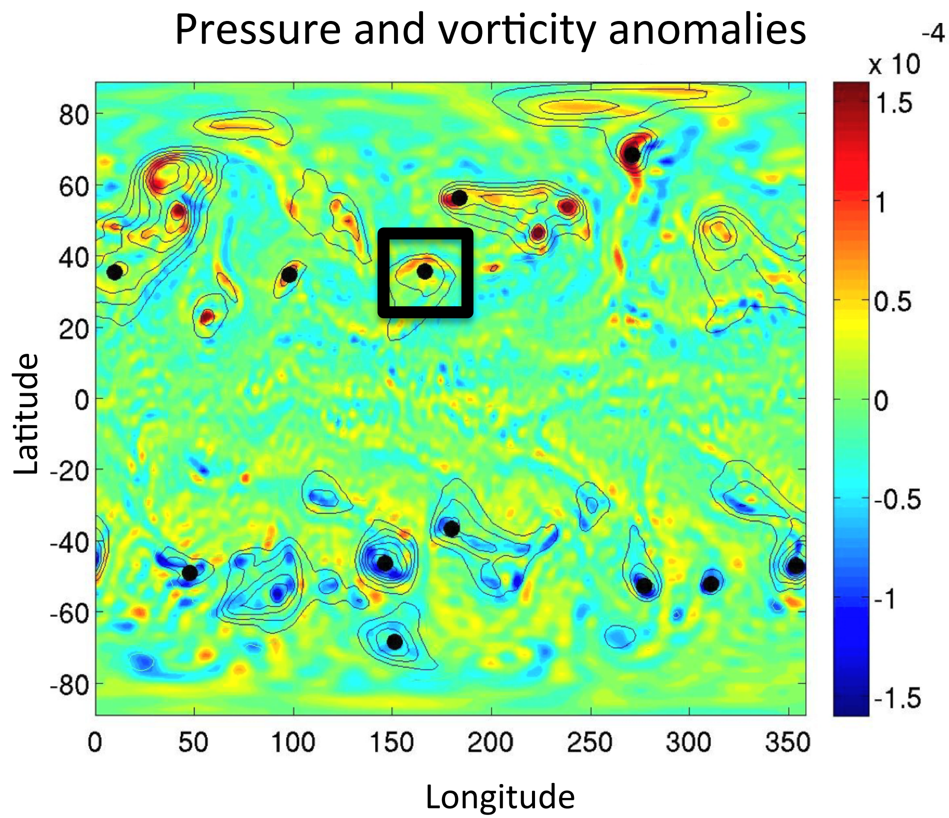
- Idealized moist aquaplanet GCM- FMS GFDL (Frierson 2006)
- Tracking algorithm: “TRACK”, by Kevin Hodges (Hodges, 1995)

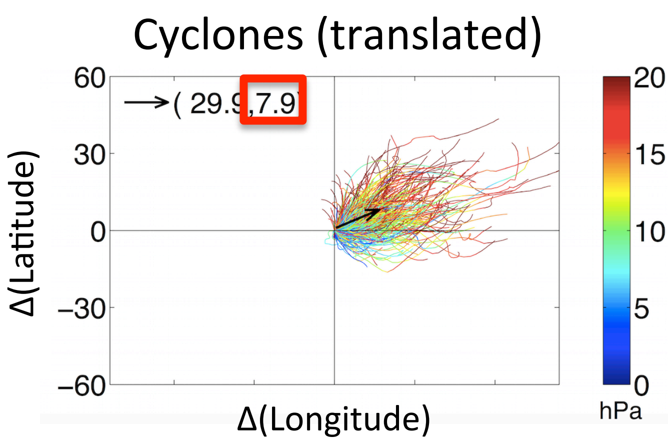
Tamarin and Kaspi, JAS (2016a)

Storm-tracking algorithm in an idealized GCM

Zonally symmetric storm track







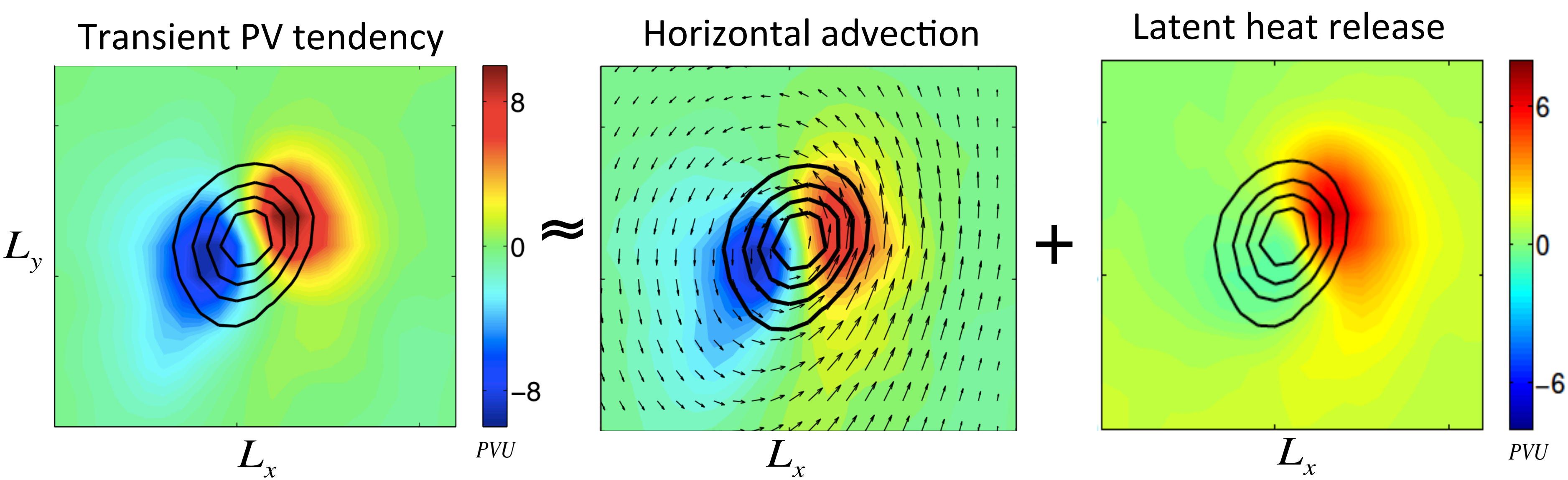
Cyclone composites:

- Put a box around each center.
- Average fields moving with the box until maximum intensity, and sum over all cyclones

Composites of PV tendency

Decompose $q = \overline{q} + q'$ and plug into into $\boxed{\dfrac{dq}{dt} = Q}$ where $\boxed{q = \dfrac{1}{\rho}\zeta_a \cdot \nabla\theta}$ is the **Ertel PV**

$$\boxed{\frac{\partial q'}{\partial t}} \approx \boxed{-\overline{u}\frac{\partial q'}{\partial x} - v'\frac{\partial \overline{q}}{\partial y} - u'\frac{\partial q'}{\partial x} - v'\frac{\partial q'}{\partial y}} - w'\frac{\partial q'}{\partial z} \boxed{+Q}$$

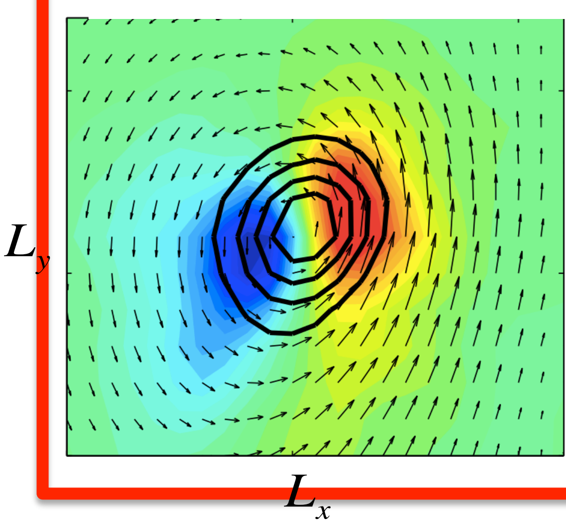


Composites of PV tendency

Decompose $q = \bar{q} + q'$ and plug into into $\boxed{\frac{dq}{dt} = Q}$ where $\boxed{q = \frac{1}{\rho}\zeta_a \cdot \nabla\theta}$ is the **Ertel PV**

$$\frac{\partial q'}{\partial t} \approx \boxed{-\bar{u}\frac{\partial q'}{\partial x} - v'\frac{\partial \bar{q}}{\partial y} - u'\frac{\partial q'}{\partial x} - v'\frac{\partial q'}{\partial y}} - w'\frac{\partial q'}{\partial z} + Q$$

Horizontal advection

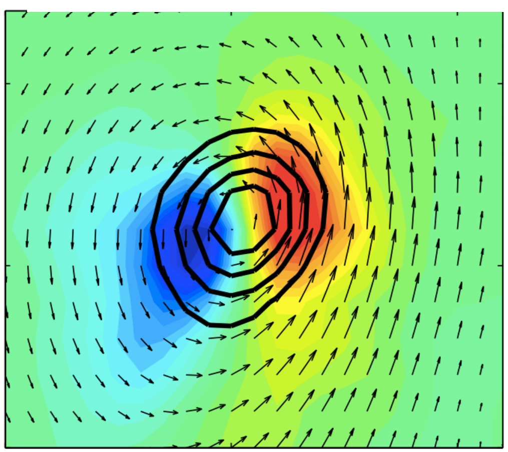


Composites of PV tendency

Decompose $q = \overline{q} + q'$ and plug into into $\boxed{\frac{dq}{dt} = Q}$ where $\boxed{q = \frac{1}{\rho}\zeta_a \cdot \nabla\theta}$ is the **Ertel PV**

$$\frac{\partial q'}{\partial t} \approx -\overline{u}\frac{\partial q'}{\partial x} - v'\frac{\partial \overline{q}}{\partial y} \boxed{- u'\frac{\partial q'}{\partial x} - v'\frac{\partial q'}{\partial y}} - w'\frac{\partial q'}{\partial z} + Q$$

Horizontal advection

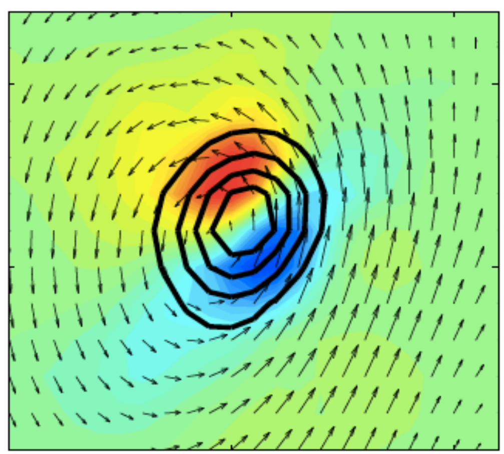


L_y

L_x

$\sim$

nonlinear advection



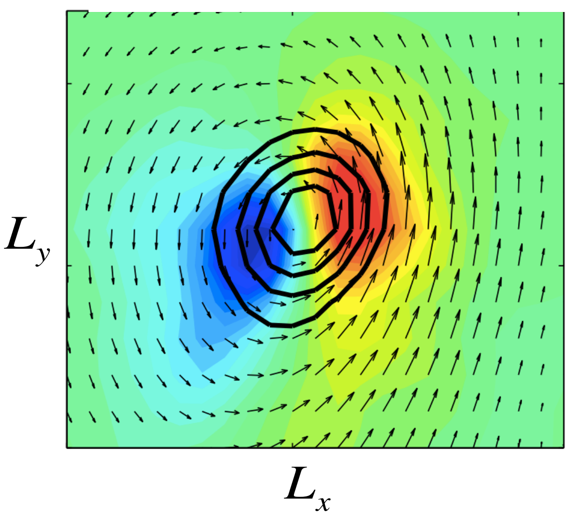
L_x

Composites of PV tendency

Decompose $q = \overline{q} + q'$ and plug into into $\boxed{\frac{dq}{dt} = Q}$ where $\boxed{q = \frac{1}{\rho}\zeta_a \cdot \nabla\theta}$ is the **Ertel PV**

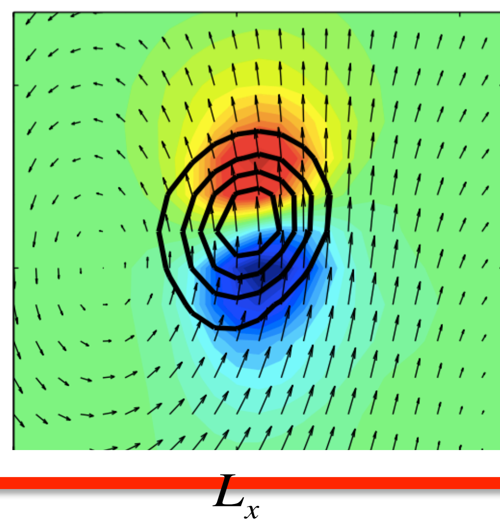
$$\frac{\partial q'}{\partial t} \approx -\overline{u}\frac{\partial q'}{\partial x} - v'\frac{\partial \overline{q}}{\partial y} - u'\frac{\partial q'}{\partial x} \boxed{- v'\frac{\partial q'}{\partial y}} - w'\frac{\partial q'}{\partial z} + Q$$

Horizontal advection



$\sim$

Meridional nonlinear advection from UPV

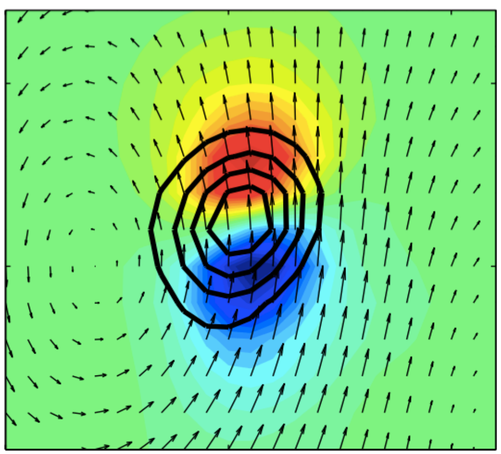


Composites of PV tendency

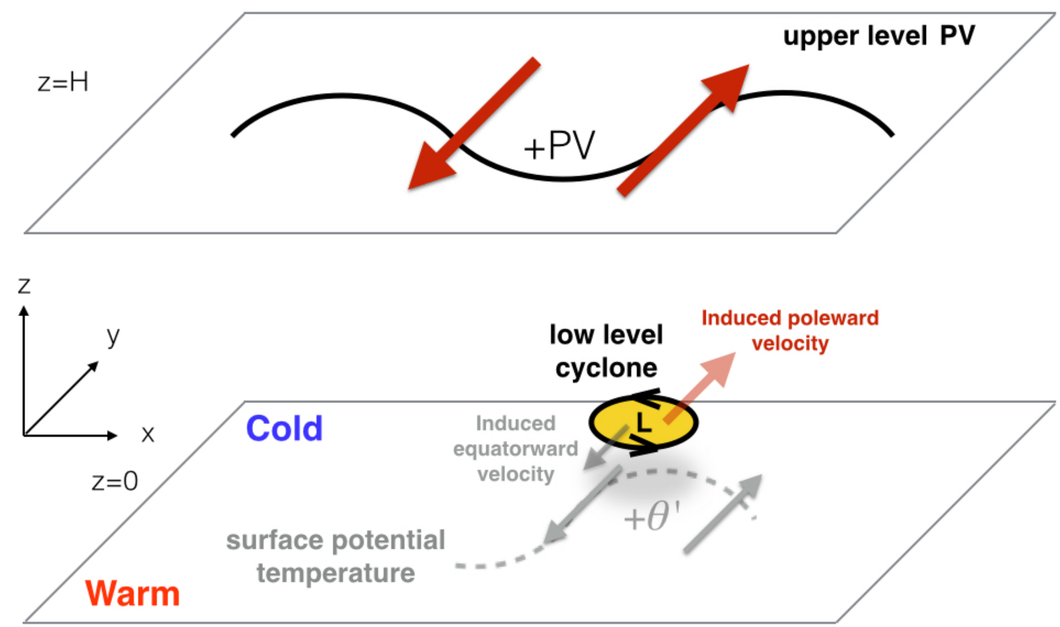
Decompose $q=\overline{q}+q'$ and plug into into $\boxed{\dfrac{dq}{dt}=Q}$ where $\boxed{q=\dfrac{1}{\rho}\zeta_a\cdot\nabla\theta}$ is the **Ertel PV**

$$\frac{\partial q'}{\partial t}\approx-\overline{u}\frac{\partial q'}{\partial x}-v'\frac{\partial\overline{q}}{\partial y}-u'\frac{\partial q'}{\partial x}\boxed{-v'\frac{\partial q'}{\partial y}}-w'\frac{\partial q'}{\partial z}+Q$$

Meridional nonlinear advection from UPV



L_x



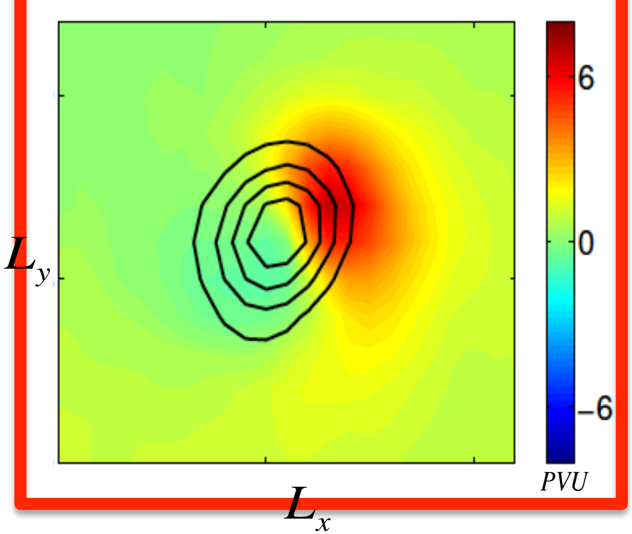
T. Tamarin and Y. Kaspi, "The poleward motion of extratropical cyclones from a PV tendency analysis", JAS (2016)

Composites of PV tendency

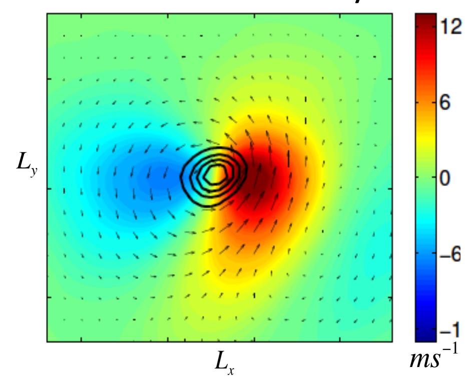
Decompose $q = \bar{q} + q'$ and plug into into $\boxed{\frac{dq}{dt} = Q}$ where $\boxed{q = \frac{1}{\rho}\zeta_a \cdot \nabla\theta}$ is the **Ertel PV**

$$\frac{\partial q'}{\partial t} \approx -\bar{u}\frac{\partial q'}{\partial x} - v'\frac{\partial \bar{q}}{\partial y} - u'\frac{\partial q'}{\partial x} - v'\frac{\partial q'}{\partial y} - w'\frac{\partial q'}{\partial z} \boxed{+Q}$$

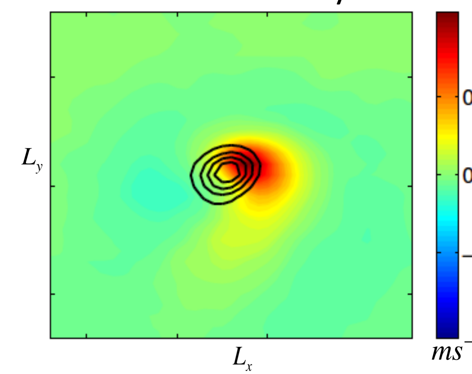
Latent heat release



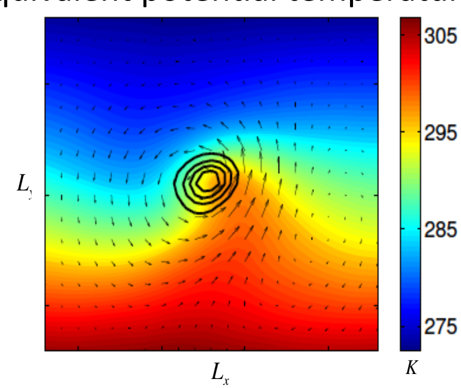
Meridional Velocity

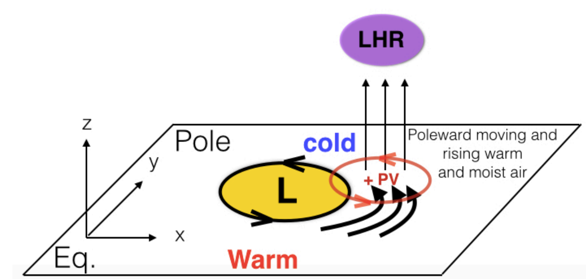


Vertical velocity



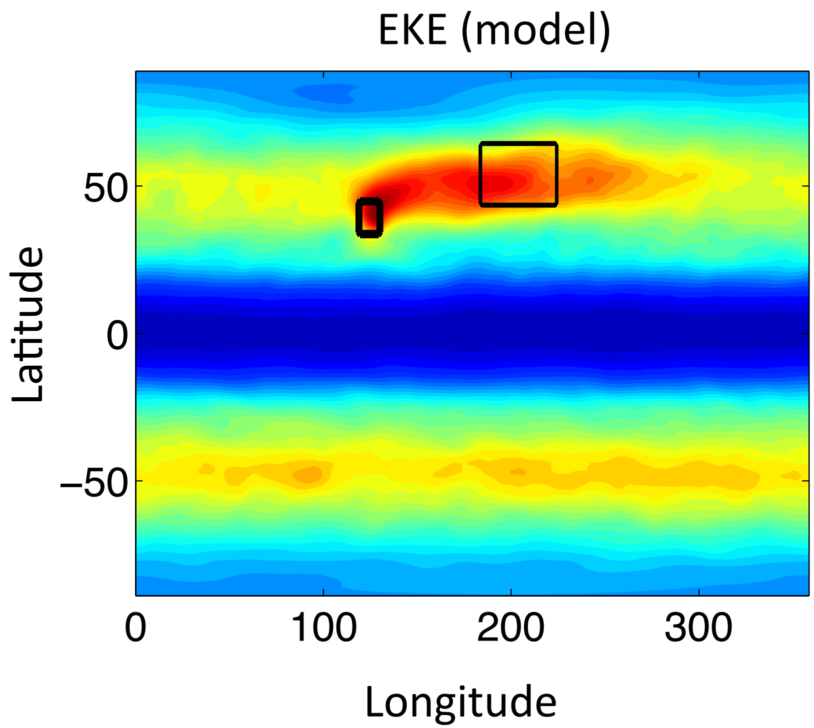
Equivalent potential temperature

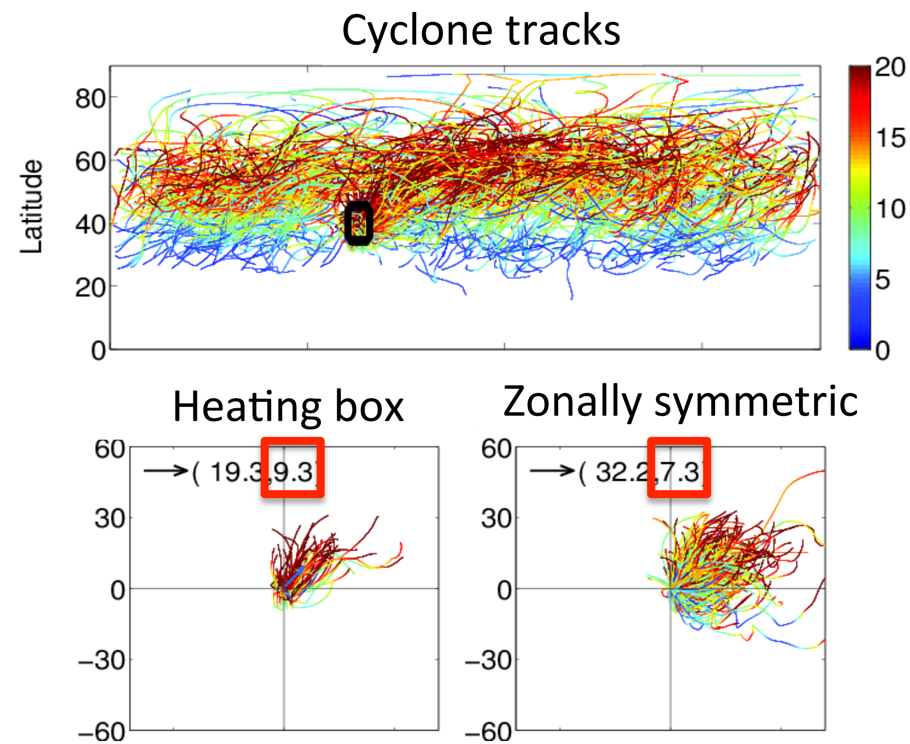




Tamarin and Kaspi, JAS (2016)

The poleward motion of cyclones in a zonally *asymmetric* storm track



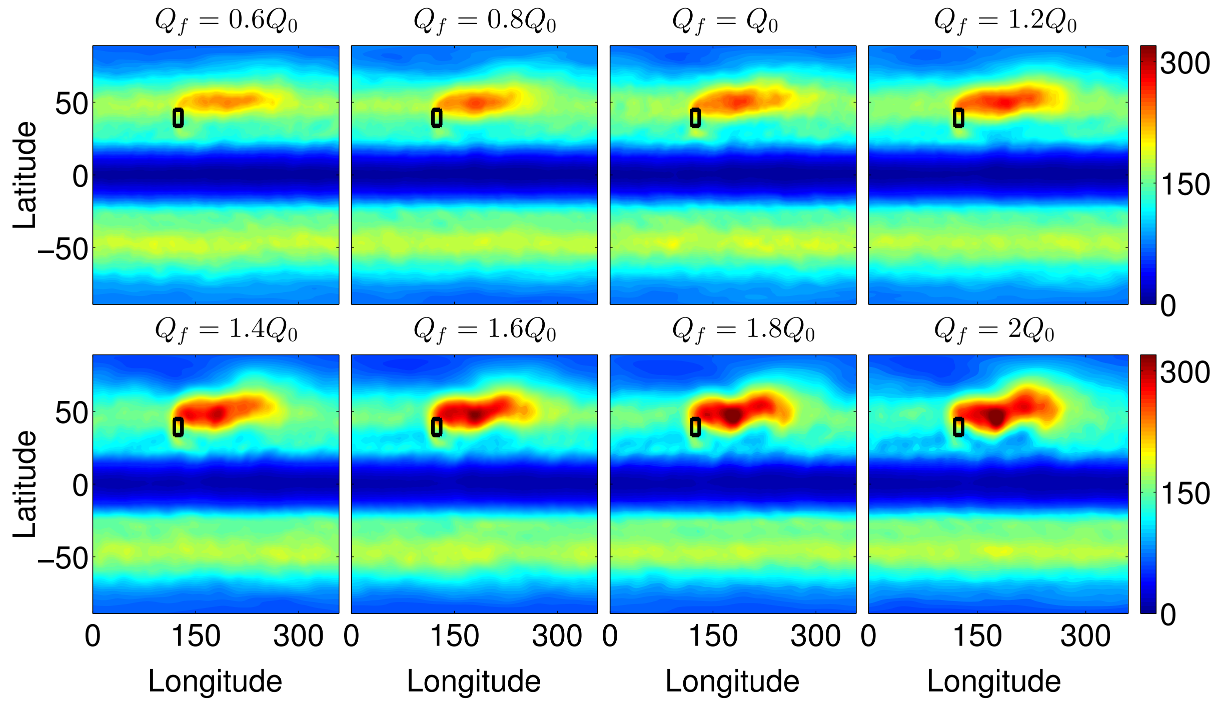


Downstream of heating box , the poleward drift of cyclones is enhanced

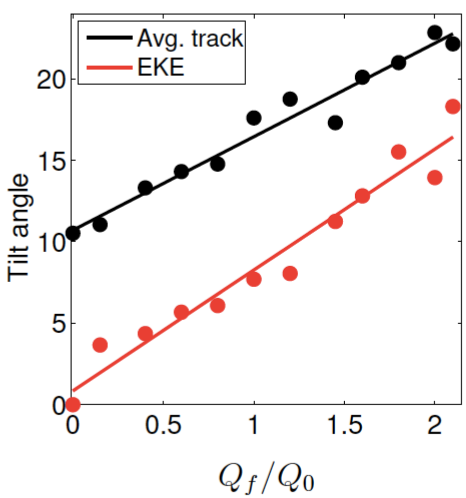
The poleward motion of cyclones in a zonally *asymmetric* storm track

Idealized GCMs with increased strength of heating:

The storm track becomes more tilted



Tilt angle



Both the poleward drift of cyclones and the tilt of the EKE increase as the heating increases

T. Tamarin and Y. Kaspi, "Mechanisms controlling the downstream poleward deflection of midlatitude storm tracks", JAS (2016b)

Composites in a zonally asymmetric system

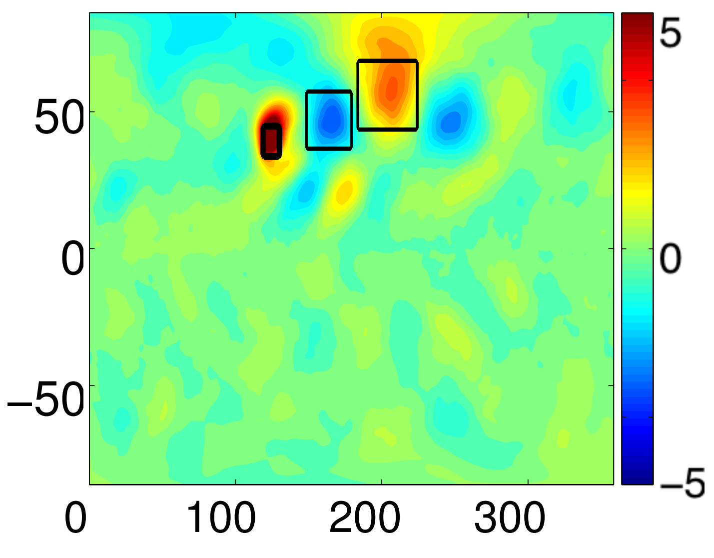
Each field is decomposed into three components:

$$a(x,y,p,t) = [\overline{a(y,p)}] + \overline{a(x,y,p)}^{*} + a'(x,y,p,t)$$

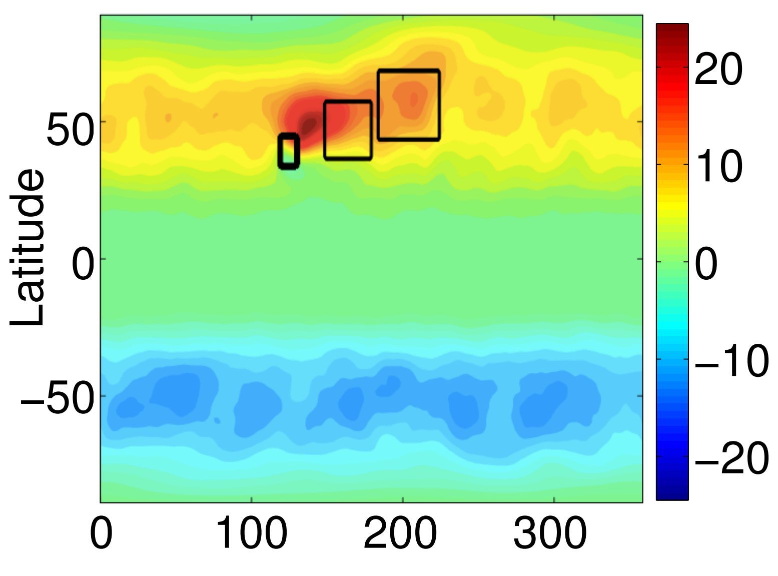
Time and zonal mean | Stationary wave | Transient eddy

Composites are done on the upstream and downstream boxes separately:

$\bar{v}^{*}$

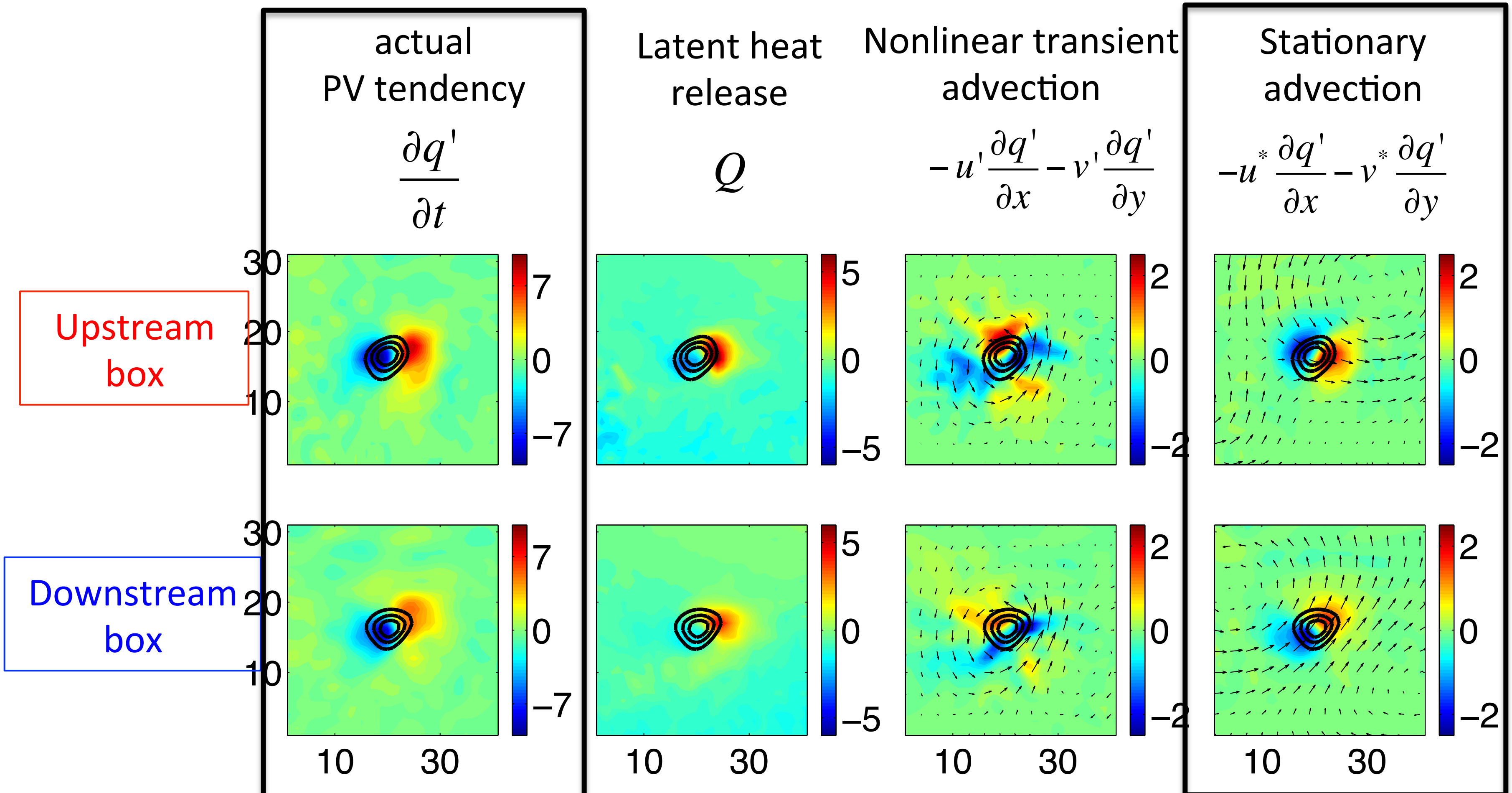


$\overline{v'T'}$



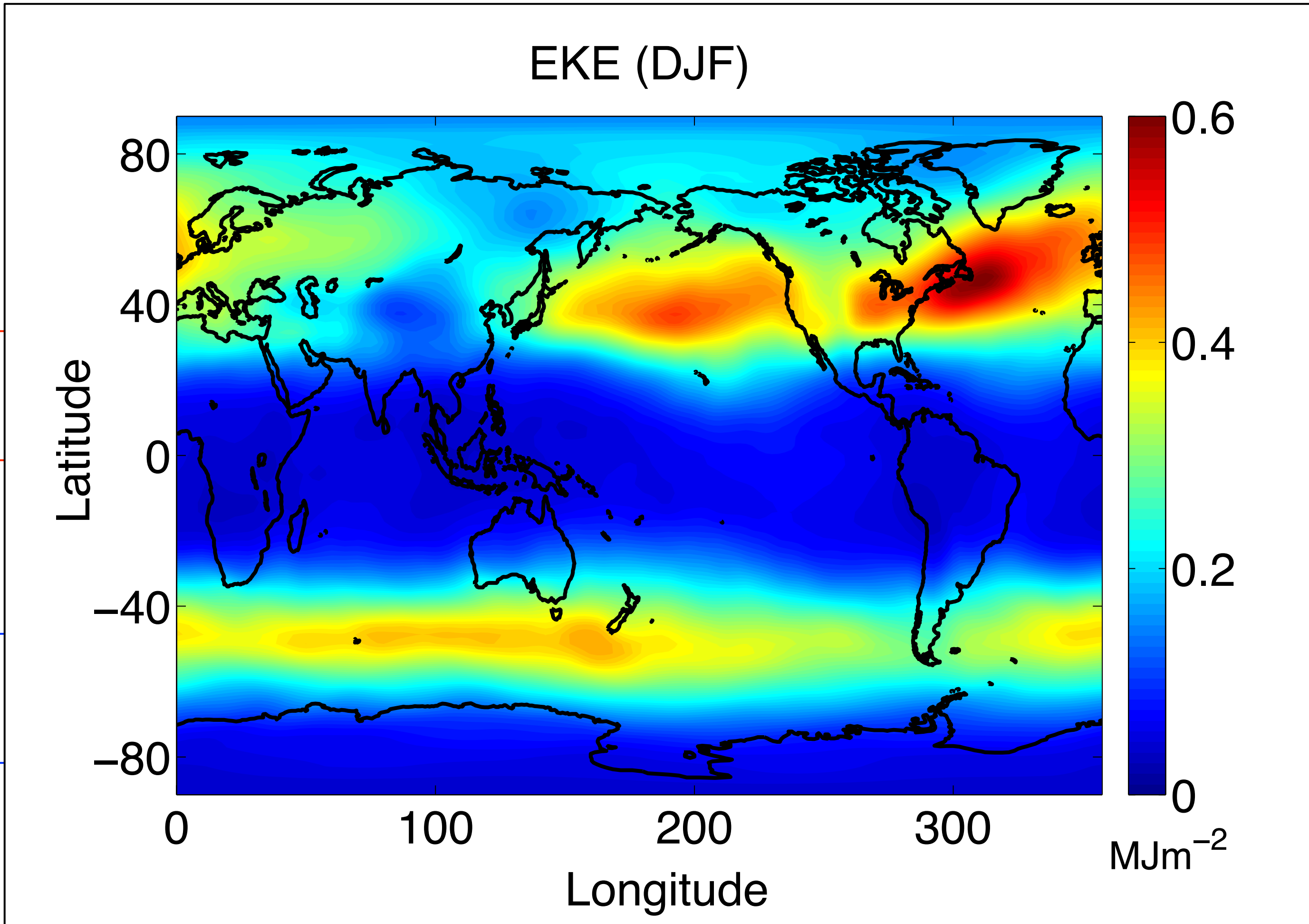
The dominant terms in the polewrad deflection-

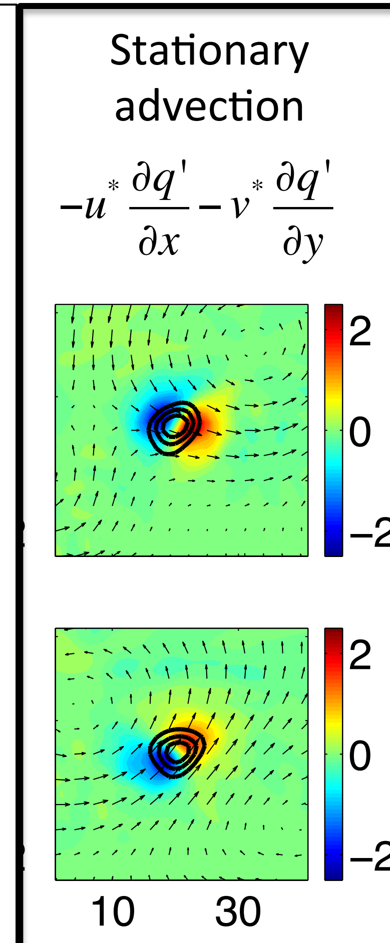
now include also a *stationary wave*



- PV tendency from the stationary wave advection is southeastward upstream and northeastward downstream
- Poleward deflection is suppressed upstream and enhanced downstream

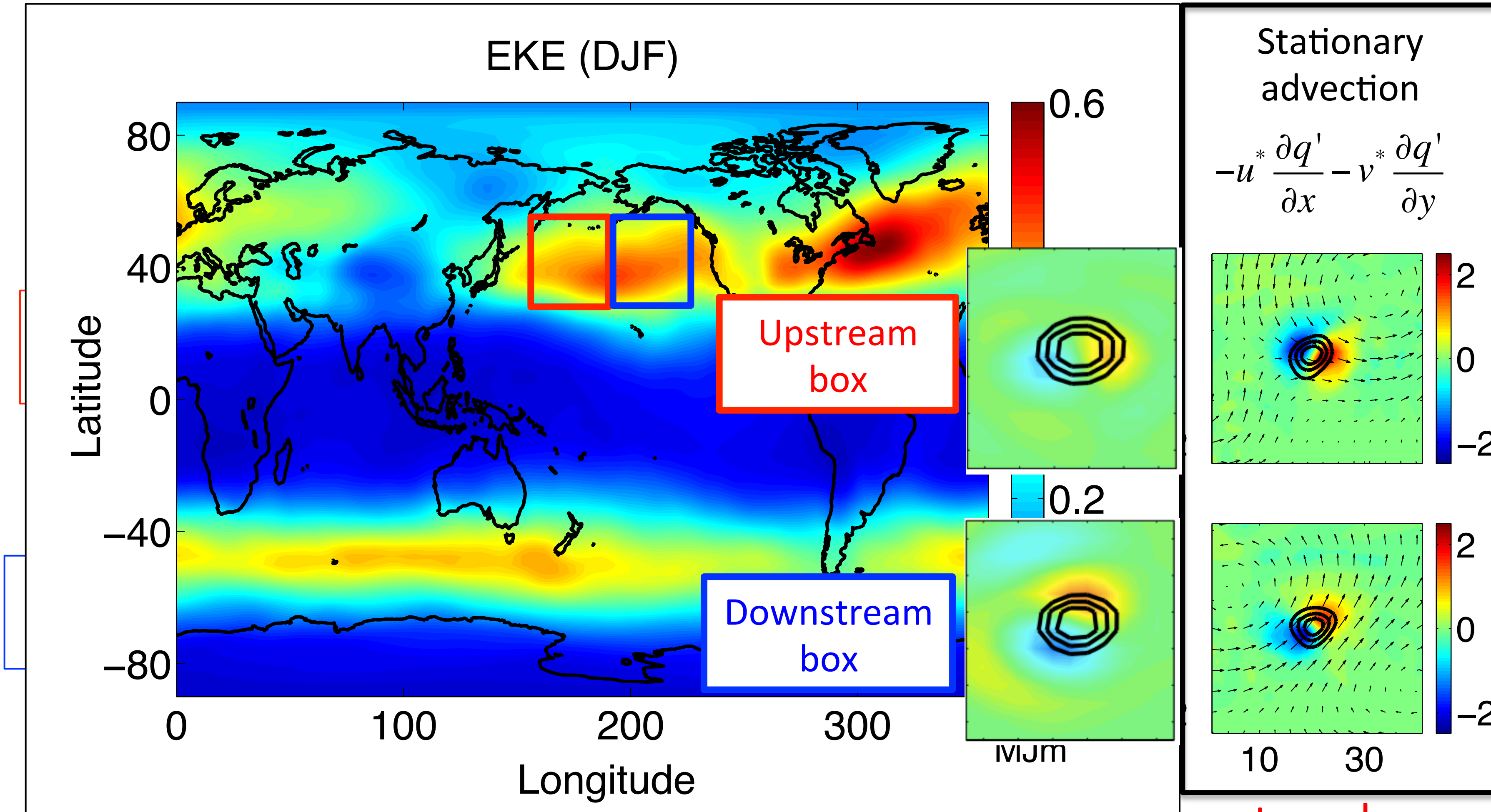
The dominant terms in the polewrad deflection- now include also a *stationary wave*





- PV tendency from the stationary wave advection is southeastward upstream and northeastward downstream
- Poleward deflection is suppressed upstream and enhanced downstream

The dominant terms in the polewrad deflection-
now include also a *stationary wave*



- PV tendency from the stationary wave advection is southeastward upstream and northeastward downstream
- Poleward deflection is suppressed upstream and enhanced downstream

How may climate change affect the poleward motion of cyclones

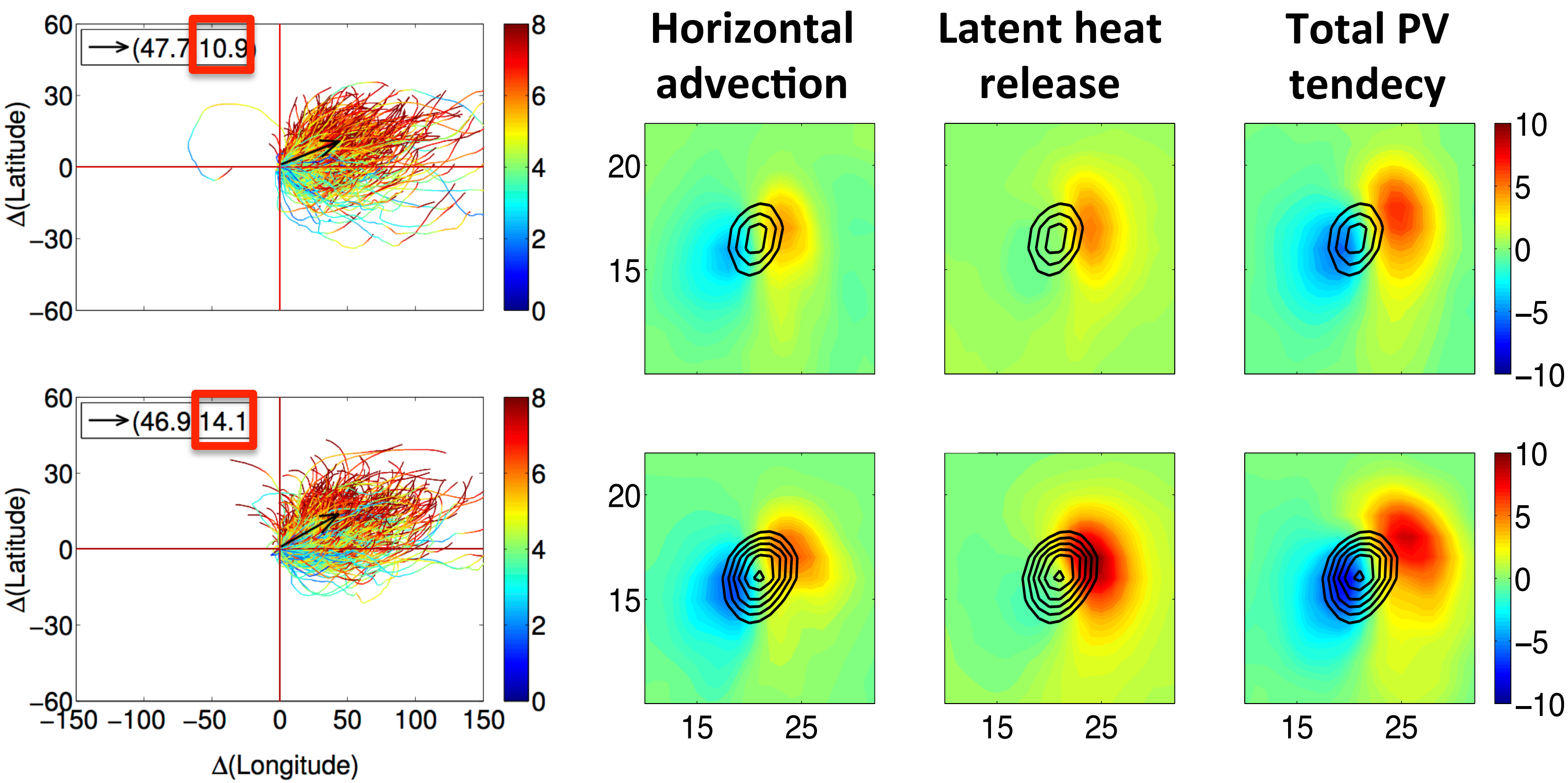
Idealized global warming experiments-

$T_S = 286\ K$

coldest simulation

$T_S = 299\ K$

Warmest simulation



In a warmer climate, the poleward propagation is intensified

- PV tendency due to horizontal advection and latent heat release increase
- Consistent with more water vapor and stronger upper level jet

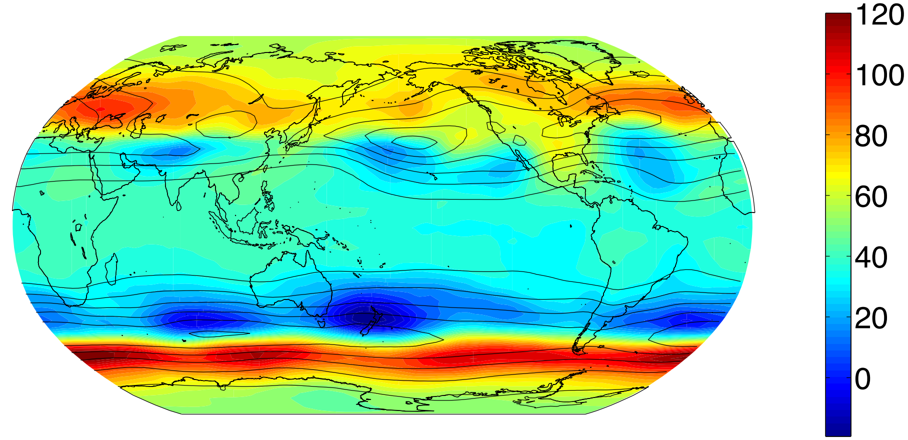
Possible implications- *the projected poleward shift of the storm tracks*

Global climate models predict that the latitudinal band of storms will shift poleward in a global warming scenario.

$$EKE = \frac{1}{2}\left(\overline{u'^2} + \overline{v'^2}\right)$$

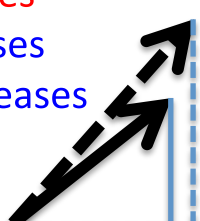
CMIP5 models
Full physics simulations
RCP8.5 (4xCO2 Scenario)

Projected EKE change

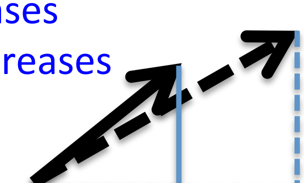


Possible relation between cyclone track and the poleward shift:

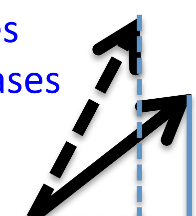
Lat increases
Lon increases
Tilt angle increases



Lat increases
Lon increases
Tilt angle decreases



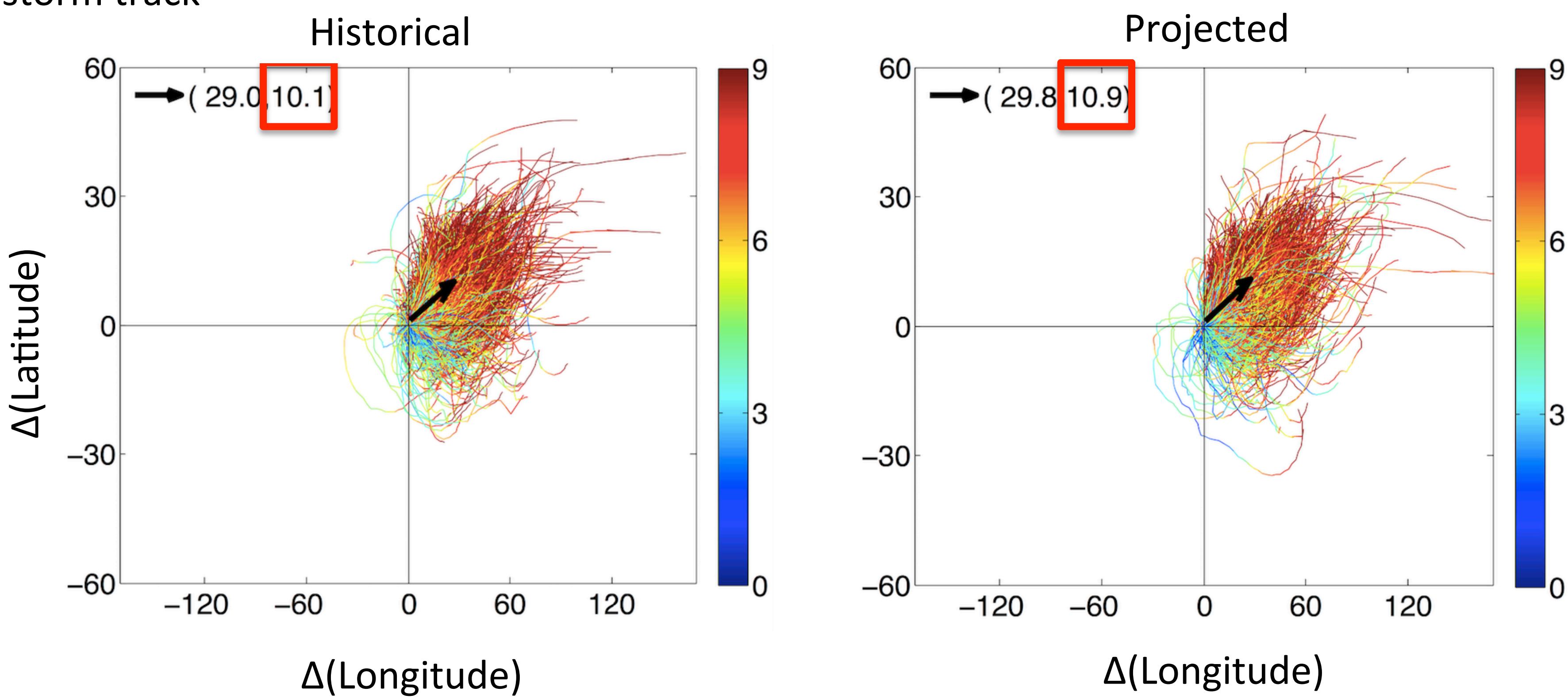
Lat increases
Lon decreases
Tilt angle increases



Enhanced latitudinal drift is associated with a poleward shift

Tracking cyclones in CMIP5

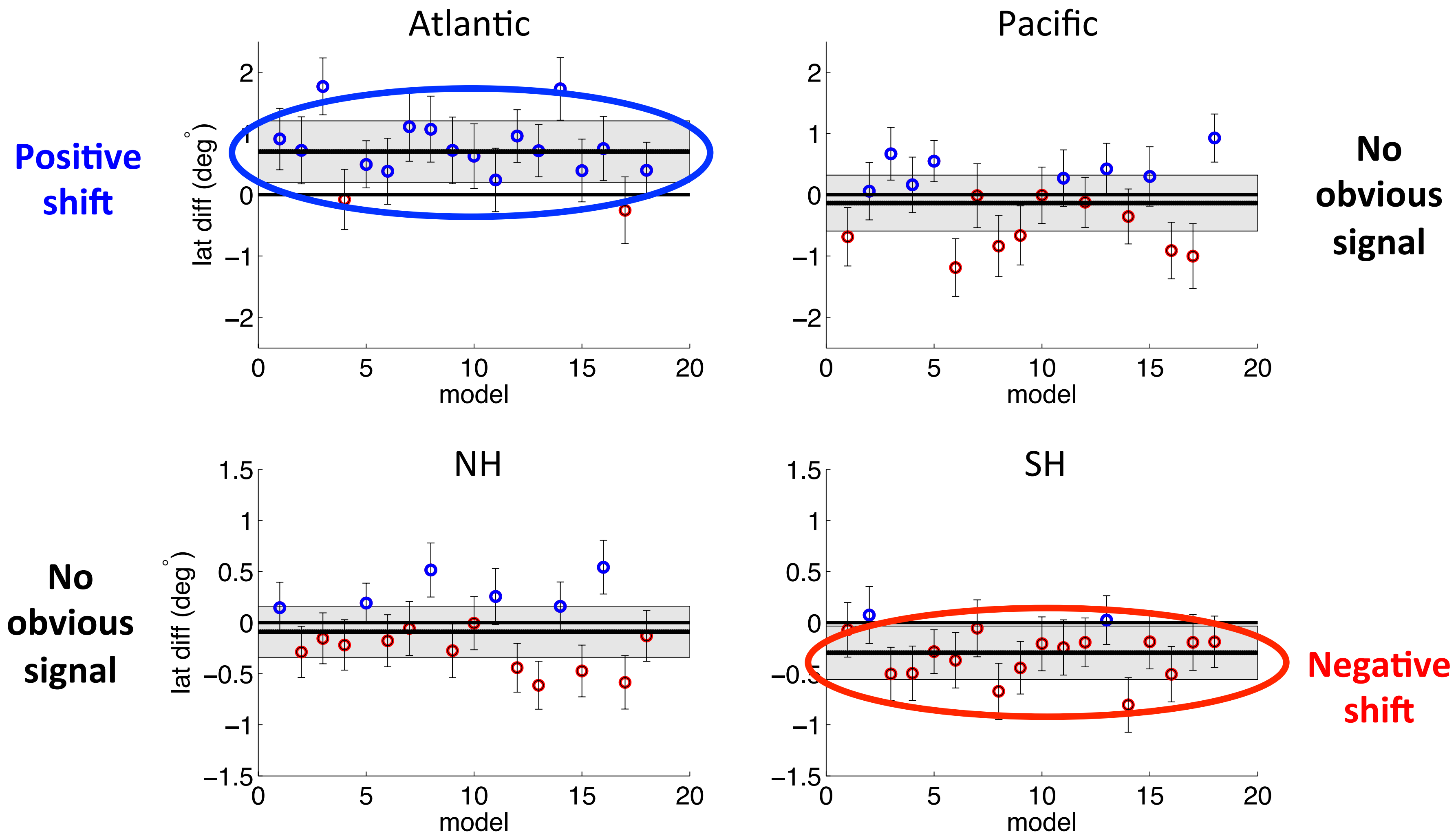
Taking the *strongest 200 cyclones* identified from each model in the Atlantic storm track-



Storms in the Atlantic will likely drift more poleward

Tracking cyclones in CMIP5

Taking *all cyclones* identified-

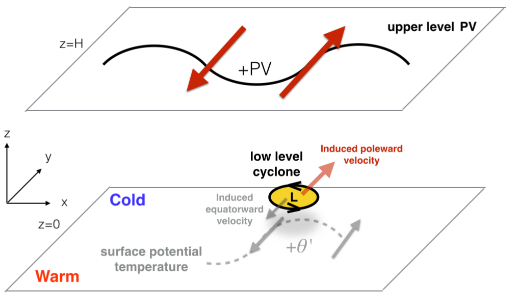


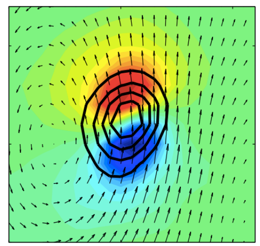
A poleward shift in the Atlantic and in the SH storm track

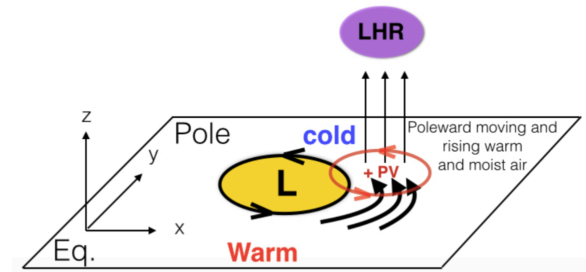
Summary and conclusions

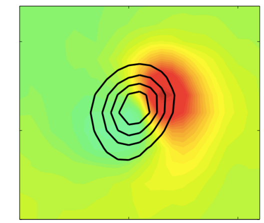
- zonally symmetric storm track- two mechanisms for poleward propagation

Advection by upper level PV + Latent heat release

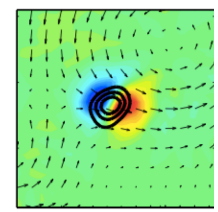


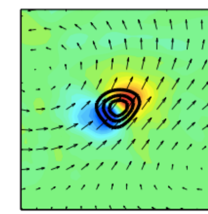






upstream downstream



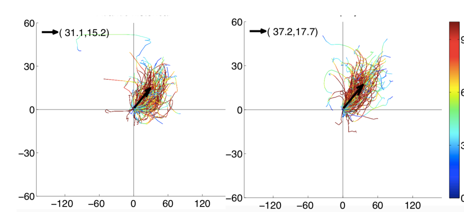


- Zonally asymmetric storm track- an additional stationary advection is enhancing the downstream poleward tilt

- May explain the observed downstream deflection of the Pacific storm tracks. Does not explain the structure of the Atlantic storm track.

- The poleward drift of cyclones increases in idealized global warming experiments- consistent with more water vapor and stronger jets

- Results from CMIP5 models show enhanced poleward drift in the Atlantic region and SH in projected runs



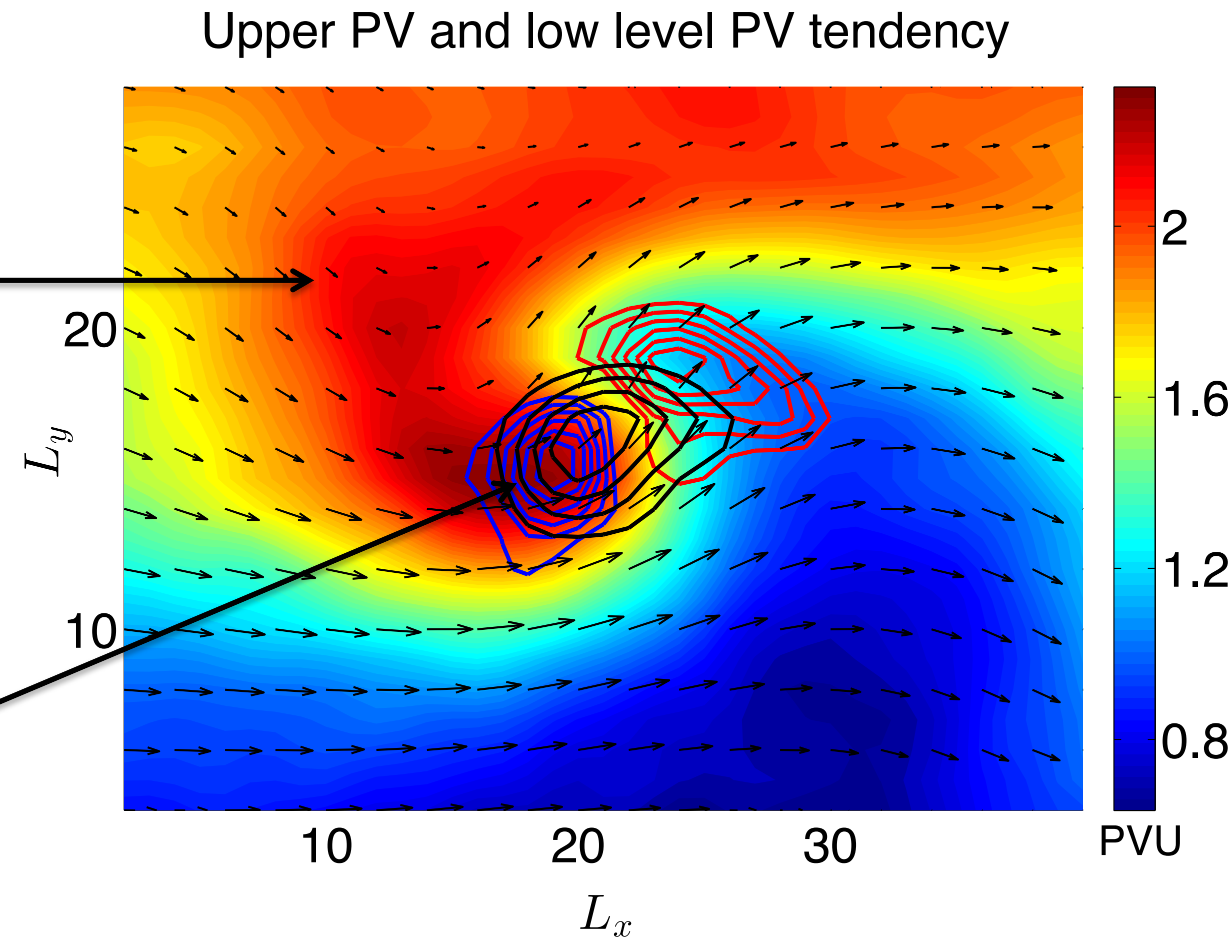
Thank you! ☺

Composites of PV and PV tendency $\frac{\partial q}{\partial t}$

Ertel PV: $\boxed{q = \frac{1}{\rho}\zeta_a \cdot \nabla\theta}$

Upper level PV (color) and upper level velocity field (arrows)

Low level PV (black) and low level PV tendency (red for positive and blue for negative)



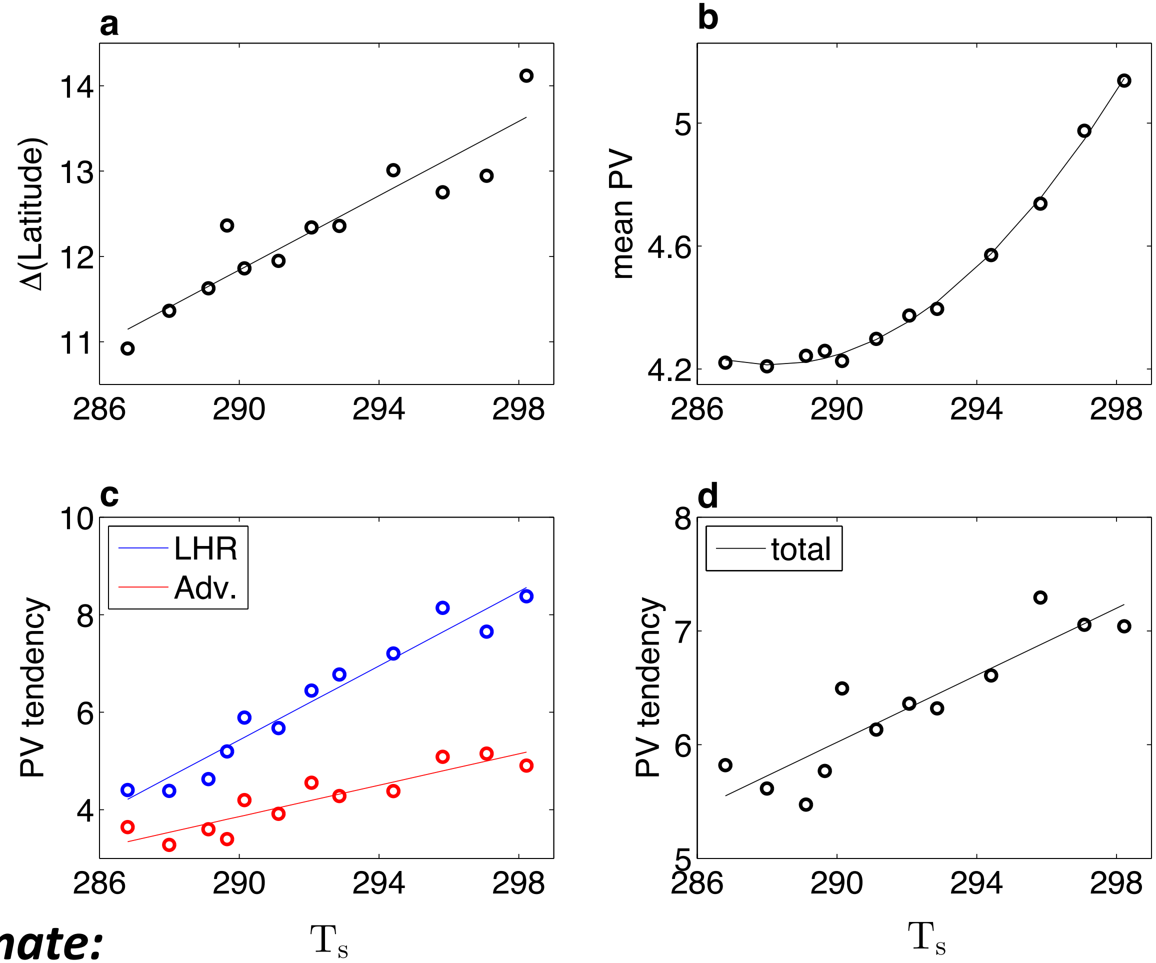
- *Positive PV tendency in the northeastern side of the surface PV and negative PV tendency in the southwestern side of the surface PV*
- *Strong indication for upper level advection*

Idealized global warming scenarios-

Enhanced poleward motion in warmer climates

Mean latitudinal drift

Mean PV intensity



PV tendency due to latent heat release and horizontal advection

Total PV tendency

In a warmer climate:

- Stronger upper level jet hence stronger nonlinear advection at low levels.
- Larger LHR is probably due to larger saturation water vapour content (given that relative humidity does not change significantly)