The poleward deflection of midlatitude storm tracks-
from idealized GCMs to comprehensive climate prediction models

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poleward deflection of storm tracks

Eddy kinetic energy (EKE)

\[ EKE = \frac{1}{2} (\bar{u}^2 + \bar{v}^2) \]

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

The average cyclone in a zonally symmetric GCM propagates \( \sim 7.9^\circ \) 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

Cyclones

Pressure and vorticity anomalies

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 \( q = \bar{q} + q' \) and plug into \( \frac{dq}{dt} = Q \) where \( q = \frac{1}{\rho} \xi_a \cdot \nabla \theta \) is the Ertel PV.

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

Transient PV tendency \( L_y \)  
Horizontal advection \( L_x \)  
Latent heat release \( L_x \)
Composites of PV tendency

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

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

Horizontal advection
Composites of PV tendency

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

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

Horizontal advection

nonlinear advection
Composites of PV tendency

Decompose $q = \bar{q} + q'$ and plug into

$$\frac{dq}{dt} = Q$$

where

$$q = \frac{1}{\rho} \bar{\zeta} \cdot \nabla \theta$$

is the Ertel PV

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

Horizontal advection

Meridional nonlinear advection from UPV
Composites of PV tendency

Decompose \( q = \bar{q} + q' \) and plug into into
\[
\frac{dq}{dt} = Q
\]
where \( q = \frac{1}{\rho} \zeta_a \cdot \nabla \theta \) is the Ertel PV

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\]

Meridional nonlinear advection from UPV

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 $\frac{dq}{dt} = Q$ where $q = \frac{1}{\rho} \xi_a \cdot \nabla \theta$ is the Ertel PV

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

Latent heat release

Equivalent potential temperature

Meridional Velocity

Vertical velocity

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*

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:

$$\overline{v^*}$$

$$\overline{v'T'}$$
The dominant terms in the poleward deflection now include also a \textit{stationary wave}.

- PV tendency from the stationary wave advection is \textit{southeastward upstream} and \textit{northeastward downstream}
- Poleward deflection is \textit{suppressed upstream} and \textit{enhanced downstream}
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The dominant terms in the poleward 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.

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

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

Possible relation between cyclone track and the poleward shift:

- Lat increases
- Lon increases
- Tilt angle increases

- 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-

- **Atlantic**
  - Positive shift
  - No obvious signal

- **Pacific**
  - No obvious signal

- **NH**
  - No obvious signal

- **SH**
  - Negative shift

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**
  
  ![Advection by upper level PV](image1)

  ![Latent heat release](image2)

  +

- 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:

\[ q = \frac{1}{\rho} \zeta_a \cdot \nabla \theta \]

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**
- **PV tendency due to latent heat release and horizontal advection**
- **Mean PV intensity**
- **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)