Storm Tracks and Jet Streams Pt. 1

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Shifting of Storm Tracks

- It has been suggested that in a warming climate, extra-tropical storm tracks will shift poleward (IPCC, 2007)
- This shift can be generalized as a positive feedback on the climate system (IPCC, 2013)
Trends in Cloud LWP from 1988-2013
What Variables Determine Storm Tracks?

- Water Vapor
- Static Stability
- Horizontal Temperature Gradients
Water Vapor

Source: http://cimss.ssec.wisc.edu/
Static Stability

● Tropical upper tropospheric warming -> increased static stability
● Greater increases on tropical flank of storm track -> suppression of baroclinic eddy generation
● Region of largest baroclinic eddy generation shifts poleward
Horizontal Temperature Gradients

- Equator-pole T difference increases aloft, decreases near surface
- Stronger meridional temperature gradients -> more energy for storm tracks
- Focus of Harvey et al.

Harvey et al. Fig 1
Equator-to-pole temperature differences and the extra-tropical storm track responses of the CMIP5 climate models (Harvey et al. 2013)

- Paper’s main goal is to understand physical processes that cause large spread in CMIP5 storm track projections
- Relationship between 2-6 day mean sea level pressure variance (proxy for storm track activity) and upper- and lower-tropospheric equator-to-pole temperature differences examined
What Did They Find?

- Large regions in the Southern Hemisphere where the temperature difference responses were well correlated with storm track responses
- Linear regression model based on temperature differences explains 30-60% of inter-model variance in storm track responses
What Did They Find?

- Northern Hemisphere correlations were significantly different.
- In the summer, lower-tropospheric temperature differences dominate spread of storm track responses.
- In the winter, both upper- and lower-tropospheric temperature influence storm track responses.
- Due to the fact that the Northern Hemisphere is much more complicated than Southern Hemisphere (more land, mountains, etc…).
Methodology

- Harvey et al. uses 24 models from the CMIP5 dataset
- 1 ensemble run from each model
- Uses the June 1976-August 2005 historical run (HIST) and June 2070-August 2099 RCP8.5 and RCP4.5 scenarios
Methodology

- Storm track defined as the standard deviation of the 2-6 bandpass filtered MSLP
- Storm track response is defined as the difference between the seasonal storm track values between RCP and HIST runs
- Equator-to-pole temperature differences defined as the difference between the temperature in the tropics (30S-30N) and the temperature at the poles (60-90 N/S) for both the 850hPa and 250hPa pressure levels
Results

- Figure displays multi-model mean HIST storm tracks (contours) and multi-model mean storm track response in RCP 8.5 (shading) in panels (a) and (c)
- Standard deviation in panels (b) and (d)
- Areas of warmer (cooler) shading indicate areas of increased (decreased) storm track activity

Harvey et al. Fig 2
Results - Winter

- Weakening of storm track activity in N.H. winter everywhere except North Atlantic
- Significant strengthening of storm track activity in most of S.H. in the winter

Harvey et al. Fig 2
Results - Summer

- Weakening of storm track activity in N.H. summer everywhere except Arctic
- Poleward shift of storm track appears to occur in S.H. summer (decrease in activity in subtropics, increase in high latitudes)

Harvey et al. Fig 2
Methodology: Regression

- inter-model spread of SLP response regressed against T response
- Linear regression, \( \beta \) is slope
- Remember, for \( \beta > 0 \), positive association b/w T response and ST response
Regression Results

- Figure shows regression slope of storm track responses on equator-to-pole temperature difference responses.
- Regions of positive values indicate storm track activity increasing with increasing equator-to-pole temperature difference responses.

Harvey et al. Fig 4
In the winter, 850hPa regression is positive almost everywhere -- stronger in S.H.

Wintertime S.H. 250hPa looks similar to the 850 hPa. N.H. only has positive slope in ocean basins at 250hPa

Harvey et al. Fig 4
Regression Results - Summer

- Narrower band of positive regression slope in S.H. at both 850hPa and 250hPa levels
- High correlation between storm track responses and 850hPa temperature differences in N.H.
- Almost no correlation at 250hPa level in N.H.

Harvey et al. Fig 4
Differencing Method
Differencing Method
Northern Hemisphere Wintertime

- Used aforementioned, longitudinally confined, equator-to-pole temperature differences to create new regression map shown in figure
- Paper concludes that Atlantic basin equator-to-pole temperature differences are more strongly associated with storm track responses than zonal mean temperature differences

Figure 8, Harvey et al.
A Different Method...

- Baroclinic eddy generation depends on $\frac{dT}{dy}$
- Is that really what we are measuring here?

NO
dT/dy vs. Eq-Pol T Difference
Jet correlated with dT/dy

Jet correlated with hemispheric T difference
Back to the Northern Hemisphere...

Figure 5, Harvey et al (2013)
Steady-State Circulation Response to Climate Change-Like Thermal Forcings (Butler et al 2010a)

What does the time-mean, zonal-mean circulation in an idealized GCM look like when perturbed by:

- upper tropospheric tropical warming (greenhouse gas forcing)?
- polar stratospheric cooling (ozone loss)?
- polar surface warming (Arctic amplification)?

-note: all of these results are for equinoctal conditions
Response: Tropical Heating
Response: Polar Stratospheric Cooling
Response: Polar Surface Warming
Response: Multiple Forcings
Response: Multiple Forcings
Jet Shifts in CMIP5

Figure 1, Barnes and Polvani (2013)

- RCP8.5 also shows a poleward shift
- Narrowing of the histogram -> contraction of storm track
Jet Shifts in CMIP5

Southern Hemisphere  
North Atlantic  
North Pacific

Figure 2, Barnes and Polvani (2013). Mean jet position vs. historical jet position; arrows connect different experiments in same model.
Possible Physical Mechanisms for Jet Shifts

● Two we discussed:
  ○ Increases in static stability in tropics
  ○ Changes in horizontal T gradients (dT/dy)

● Changes in Rossby wave phase speeds and Rossby wave wave breaking
  ○ Complicated, but cool!

● ???
References

Backup Slides
Response: Tropical Heating
Response: Polar Stratospheric Cooling
Response: Shallow Polar Stratospheric Cooling
Response to Combined Forcing

(c) Sum of Individual Forcings
Response: Winter vs. Spring, Tropical Heating
Response: Winter vs. Spring, Polar Cooling
Equinoctial Wintertime
Physical Mechanisms for Jet Shifts

Rossby wave phase speed:

\[ c = U - \frac{\beta}{k^2 + l^2} \]

If \( U \) increases, \( c \) will increase

Assuming \( k \) is constant, as \( c \rightarrow U, l \rightarrow \infty \) (wave breaks)

\[ (k^2 + l^2) = \frac{\beta}{U - c} \]

So, if \( U \), and thus \( c \), are increasing, waves break anomalously poleward, shifting \( u'v' \) divergence (and conv.)