MERIDIONAL MOISTURE TRANSPORT BY EXTRA-TROPICAL CYCLONES IN THE SOUTHERN HEMISPHERE

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MOTIVATION

• Precipitation is strongly related to moisture flux convergence
• Heavy precipitation can lead to floods
• Changes to climatological moisture fluxes will alter precipitation patterns
• Vital to know how precipitation will change in the future
• In models precipitation is parameterized whereas v and q are often prognostic variables
• Transport moisture from the warm, moist tropics to the midlatitudes and high latitudes
• Warm Conveyor Belt
• Atmospheric Rivers
GRACE observations. Change in mass balance relative to 2002

Snow accumulation and snow rates in East Antarctica. Relates to Atmospheric Rivers - Gorodetskaya et al (2014)
MOISTURE TRANSPORT DUE TO CYCLONES MIGHT CHANGE IF:

• The number of cyclones changes
• The location of the storm track changes
• Or the characteristics of storms change
AIM

Identify which characteristics of synoptic-scale cyclones contribute the greatest amount to meridional moisture flux variability?
• Use ERA-Interim reanalysis data
• 35 years (1979 – 2012), ~80 km grid spacing, 6 hour resolution
• Calculate vertically integrated meridional moisture flux between 1000 and 300 hPa
• Negative sign so that poleward MMF is positive in SH

\[ \text{MMF}_{\text{tot}} = -\frac{1}{g} \int_{p_1}^{p_2} (vq) dp \]
• Peak between 42S and 45S
• Largest values in SH Autumn (MAM)
• In SH summer (DJF) MMF is smaller than in all other seasons poleward of 55S
HOW TO CALCULATE MOISTURE FLUX DUE TO CYCLONES?

• Traditional approach: decompose v and q into a mean, stationary eddy and transient eddy component
• Assume transient eddies are synoptic scale systems
• Disadvantage: cannot separate cyclones with different characteristics

\[
[qv] = [q][v] + [q^*v^*] + [q'v']
\]
AN ALTERNATIVE METHOD

- Combine cyclone tracks with a cyclone masking method
- Similar to the method applied by Hawcroft et al (2012) for precipitation
- Track all extratropical cyclones using TRACK
  - Find localized maxima of 850-hPa relative vorticity
  - Genesis latitude, meridional speed, maximum vorticity obtained
- Create a “mask” around each cyclone centre at all times the cyclone was identified
Snapshot of mean sea level pressure in the Southern Hemisphere

Lots of cyclones are present
Red dots are the cyclone centres identified with TRACK.

Not all are associated with a closed pressure contour.
Draw a mask with a radius of 12 degrees (11 degrees in DJF) around each cyclone.

Moisture flux inside this mask is allocated to the cyclone.

Mask = 1 inside the circular cap.

\[ \text{MMF}_{\text{ETC}} = \text{MMF}_{\text{TOT}} \times \text{mask}. \]
Most meridional moisture transport is associated with extra-tropical cyclones.
This cyclone tracking and masking method now allows us to identify the meridional moisture flux due to different types of cyclones.

Consider 3 characteristics: maximum intensity, speed of meridional propagation and genesis latitude.
ETCs with stronger vorticity will have:

- stronger system relative air flows
- Stronger warm conveyor belt
- More meridional moisture transport

Meridional speed = system relative winds + ETC propagation
Hypothesis 2

ETCs with more meridional tracks will have:
- stronger meridional propagation component
- More meridional moisture transport

Meridional speed = system relative winds + ETC propagation

\[ \text{MMF}_{\text{TOT}} = - \frac{1}{g} \int_{p_1}^{p_2} (vq) dp \]
Hypothesis 3

ETCs with more equatorward genesis regions

- Form and move through a climatological more moist region
- Will have higher values of $q$
- More meridional moisture transport

Meridional speed = system relative winds + ETC propagation

$$MMF_{TOT} = -\frac{1}{g} \int_{p_1}^{p_2} (vq)dp$$
BIN CYCLONES BY CHARACTERISTICS

<table>
<thead>
<tr>
<th>Bin</th>
<th>Max vorticity (s(^{-1}))</th>
<th>Genesis Latitude ((^{\circ})S)</th>
<th>Poleward Velocity (degrees per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0 – 5.0 (\times) 10(^{-5})</td>
<td>&gt; 67.5</td>
<td>0 – 2</td>
</tr>
<tr>
<td>2</td>
<td>5.0 – 6.5 (\times) 10(^{-5})</td>
<td>62.5 – 67.5</td>
<td>2 – 4</td>
</tr>
<tr>
<td>3</td>
<td>6.5 – 8.0 (\times) 10(^{-5})</td>
<td>55.0 – 62.5</td>
<td>4 – 6</td>
</tr>
<tr>
<td>4</td>
<td>8.0 – 9.5 (\times) 10(^{-5})</td>
<td>45.0 – 55.0</td>
<td>6 – 8</td>
</tr>
<tr>
<td>5</td>
<td>9.5 – 10.5 (\times) 10(^{-5})</td>
<td>35.0 – 45.0</td>
<td>8 – 10</td>
</tr>
<tr>
<td>6</td>
<td>&gt;10.5 (\times) 10(^{-5})</td>
<td>&lt;35.0</td>
<td>&gt;10</td>
</tr>
</tbody>
</table>

- For each 18 bins, calculate
  - an ETC mask at each time in ERA-Interim
  - The MMF associated with these ETCs
- Calculate the MMF per mask (per cyclone)
- Calculate the zonal / temporal mean

\[ |\text{MMF}_{ETC}| = \frac{\sum \text{MMF}_{ETC}}{\# \text{masks}} \]
• Recall the aim: which cyclone characteristic leads to the greatest variability in the MMF

• Standardize the 3 characteristics (subtract mean, divide by standard deviation)

• Maximum vorticity, poleward propagation speed and genesis latitude
The strongest relationship is between *genesis latitude* and MMF (closely followed by *speed*).

Changing the *intensity of cyclones* has a small impact on MMF.

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**RELATION BETWEEN CHARACTERISTICS AND MMF (50ºS)**

Graph:

- **X-axis:** 6 points, one per each bin.
- **Y-axis:** the zonal mean of MMF per mask.

- Solid lines: SH Winter
- Dashed lines: SH Summer
At 65S, variability in the maximum vorticity has little impact on MMF.

Speed has the strongest relation with MMF at 65S.
The radius of the cyclone does not affect the main result.

- Poleward propagation velocity: solid lines, triangle markers.
- Maximum cyclonic vorticity: dashed lines, circle markers.
- Genesis latitude: solid lines, square markers.
• Why does variability in cyclone poleward propagation speed lead to the largest variability in MMF?

• What is the structure of the cyclones in the different bins?

• Create cyclone composites to find out
  • For each of the 18 bins, create a composite (average) of the 200 cyclones at the “top” of each bin
  • Composites are created at different stages of the cyclone lifecycle
GENESIS LATITUDE

24 hours before time of maximum vorticity

- Black contours: mean sea level pressure
- Red contours: total column water vapour
- Shading: meridional moisture flux

62.5 – 67.5S
45 – 55 S
< 35S
MAXIMUM VORTICITY

24 hours before time of maximum vorticity

5 x 10^{-5} – 6.5 x 10^{-5} \text{s}^{-1}

8 x 10^{-5} – 9.5 x 10^{-5} \text{s}^{-1}

> 10.5 x 10^{-5} \text{s}^{-1}

Black contours: mean sea level pressure
Red contours: total column water vapour
Shading: meridional moisture flux
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PROPAGATION SPEED

24 hours before time of maximum vorticity

2 – 4 degrees Day\(^{-1}\)

6 - 8 Degrees Day\(^{-1}\)

> 10 degrees Day\(^{-1}\)

Black contours: mean sea level pressure
Red contours: total column water vapour
Shading: meridional moisture flux
CONCLUSIONS

• ETC poleward propagation speed has the strongest influence on ETC meridional moisture flux particularly at high latitudes.
• Variability in ETC maximum vorticity does not impact MMF much.
• Fast moving ETCs resemble a frontal wave and have no equatorward MMF.
• ETCs with lowest latitude genesis regions and highest maximum vorticities have closed low pressure center with a MMF dipole.
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