Today:

**Me:**
- Overview of SH annular variability (context for later talks).
- Annular-like trends in the Southern Hemisphere. Possible causes.

**Laura Ciasto:**
- Linkages between the Equatorial Pacific and SH teleconnections.

**Ed Gerber:**
- The relative role of ozone vs. GHG forcing in circulation trends in the SH.
- Sensitivity of the responses. Implications for the dynamics.

**Francis Cordron:**
- Seasonality of the SAM. Relationship of SAM with mean state. Basic dynamics/feedbacks, model biases.

**David Schneider:**
- Tropical teleconnections over Antarctica and the Southern Ocean.
- Recent trends over Antarctica.

**John Fyfe:**
- Southern Ocean response to GHG increase.
- Southern Ocean role in response to ozone depletion. Antarctic sea response to ozone depletion.
• Structure/basic dynamics of SH annular variability.

• Why we care: Climate impacts. Trends.

• How GHGs and ozone depletion (might) force SH annular variability.
The Southern annular mode

850-hPa height and U regressed on the SAM

e.g., Kidson, Karoly, Trenberth, Hartmann, Thompson/Wallace, etc.
basic mechanism (Robinson 2000)

heat fluxes (upward wave fluxes) form in regions of large baroclinicity

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surface

Cool       Warm

South
momentum fluxes (meridional wave fluxes) accelerate the flow towards the east.
Momentum fluxes are balanced by meridional flow.

Adiabatic temperature changes reinforce baroclinicity.
heat fluxes (upward wave fluxes)
Correlations between the wind and forcing associated with the SAM. From Lorenz/Hartmann 2001.
why we care (I): Climate impacts

Regressions on the SAM during summer.
why we care (I): Climate impacts

Regressions on the SAM during summer.
why we care (II): Trends

Observed and simulated trends from the pre-ozone hole to ozone hole eras.
why we care (II): Trends

Observed and simulated trends from the pre-ozone hole to ozone hole eras
why we care (II): Trends

SAM indices from a coupled chemistry climate model forced with increasing ODSs and GHGs.

![Graph showing SAM Indices from McLandress et al. (2011)]

SAM indices from a coupled chemistry climate model forced with increasing ODSs and GHGs.
Why is the SAM response to anthropogenic forcing so robust? Increasing GHGs and ODSs can presumably influence the jet and its eddy fluxes of heat and momentum by:

• Altering the direction of wave propagation in the free troposphere.
  e.g., By changing the index of refraction (Chen and Robinson 1992; Simpson et al. 2009; etc); the eddy phase speed (Chen and Held 2007); the baroclinic lifecycle (Wittman et al. 2007); the eddy length scale (Kidston et al. 2011).

• Altering the generation of wave activity near the surface.
  e.g., Ring and Plumb 2008; Brayshaw et al. 2008; Chen et al. 2010; Butler et al. 2011.
...viewing response in terms of diffusive fluxes

e.g., Green 1970; Held 1999

Low PV  
*downgradient PV flux* \( \sim \frac{dPV}{dy} \)

High PV  
*downgradient eddy heat flux* \( \sim \frac{dT}{dy} \)

Warm  

Cool  

surface

tropics  

high latitudes
Application to tropical heating

Simulated changes in temperature due to increasing CO2 and O3 depletion: 1890-1999. Maximum is ~1K/century. IPCC FAR (Santer et al. 2003).
Application to tropical heating

Simulations with dry dynamical core of the CSU GCM run in the Held/Suarez configuration. Loosely resembles tropical heating in IPCC-class climate change simulations.

From Butler, Thompson, Birner 2011.
Heating and wind response

(a) Pressure Coordinates

response days 100-150. From Butler, Thompson, Birner 2011.
Heating and near-surface wind response

(a) Pressure Coordinates

(b) Zonal-wind response, 700mb
At lower levels

Generation of eddies (and thus eddy heat flux) is determined by the meridional slope of the isentropes

![Diagram showing eddy heat flux and temperature gradient between tropics and high latitudes.](image)

e.g., Eady 1948; Lindzen and Farrell 1980; Lu et al. 2010; Kushner and Held 1998; Held 1999
Support from ERA Interim

Isentropic slope and $[v^*T^*]_{850 \text{ hPa}}$ regressed on $[v^*T^*]_{50-90N, 850 \text{ hPa}}$

- Anomalously steep isentropic surfaces
- Anomalously poleward heat fluxes
- Anomalously flat isentropic surfaces
Butler, Thompson, Birner 2011

310K Isentropic Slope (contours) & 700mb Heat Flux (shaded)

Anomalously poleward heat fluxes (shading)

Anomalously steep isentropic slopes (contours)

Heating turned on

Butler, Thompson, Birner 2011
At upper levels:

Low PV  
\[ \text{downgradient PV flux} \sim \frac{dPV}{dy} \]  
High PV

e.g., Green 1970; Held 1999
(PV contours; $v^* PV^*$ shading)

Control

Response

Butler, Thompson, Birner 2011
Understanding the barotropic component

Response in terms of EP fluxes

EP flux divergence

EP flux convergence

decreased baroclinicity

increased baroclinicity (increased dθ/dy)

Westward surface flow

Eastward surface flow

poleward
Figure 7. The response to the heating as a function of time and latitude.

(c) Zonal Wind (contours) & eddy heat flux (shading), 700 hPa

Butler, Thompson, Birner 2011
Application to stratosphere/troposphere coupling

Regressions on an index of stratospheric variability (ERA Interim; daily data)

*isentropic surfaces are moving downwards to higher pressure*
flattening of isentropic surfaces at high latitudes (shading)

weaker than normal poleward heat fluxes (contours)

links to momentum fluxes are still under investigation
• Robust linkages between the tropospheric isentropic slope, wave generation and the near-surface flow (ie, the momentum flux convergence aloft).

• Linkages predict closely the response of the eddy fluxes of heat (and thus wave generation) to tropical heating and stratospheric variability.

• Linkages (likely) also relevant for atmosphere/ocean interactions in the Southern Ocean region.