The Antarctic Atmospheric Energy Budget: Observation and Model Simulation

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CERES Science Team Meeting

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Outline

Part 1: Climatology and Intraseasonal-to-Interannual Variability

Part 2: Multidecadal Trends


The atmospheric energy budget... 

...is tightly coupled with the surface energy budget, and, therefore, with the surface climate.

...can be used as a test of climate model performance.

...responds to anthropogenic forcing.

Previdi et al., 2013
Mathematical expression

Energy budget of an atmospheric column:

$$\frac{\partial E}{\partial t} = F_{\text{TOA:NET}} + F_{\text{SFC:NET}} + F_{\text{WALL}}$$

where:

$$\frac{\partial E}{\partial t} = \frac{1}{\partial t g} \int_0^{p_{SFC}} (c_p T + k + Lq + \Phi_{SFC}) dp$$

$$F_{\text{TOA:NET}} = F_{\text{TOA:SW}} + F_{\text{TOA:LW}}$$

$$F_{\text{SFC:NET}} = F_{\text{SFC:SW}} + F_{\text{SFC:LW}} + F_{\text{SFC:LH+SH}}$$

$$F_{\text{WALL}} = -\nabla \cdot \frac{1}{g} \int_0^{p_{SFC}} (c_p T + k + Lq + \Phi) v dp$$

$$= F_T + F_k + F_q + F_{\Phi}.$$
Part 1: Climatology and Intraseasonal-to-Interannual Variability
Datasets

• Focus on the period 2001-10 (first full 10 years of CERES satellite measurements)

• Primary observational datasets: CERES EBAF ($F_{\text{TOA}:SW}, F_{\text{TOA}:LW}$) and ERA-Interim reanalysis ($\partial E/\partial t, F_{\text{SFC}:SW}, F_{\text{SFC}:LW}, F_{\text{SFC}:LH+SH}, F_{\text{WALL}}$)

• CMIP5 model data: 11 models so far; 1 realization from each model of the Historical +RCP4.5 scenario
Observed climatological mean energy budget

Previdi et al., 2013
Comparison with the Arctic

Porter et al., 2010
Comparison with CMIP5
Observed intraseasonal-to-interannual variability

Previdi et al., 2013
Correlations with ENSO/SAM

Table 2. Linear correlations between energy budget components and ENSO/SAM during 2001–10 based on monthly mean data for DJF and JJA. The mean seasonal cycle was removed from the data prior to computing the correlations. Boldface values are statistically significant at the 95% confidence level.

<table>
<thead>
<tr>
<th></th>
<th>$\delta E/\delta t$</th>
<th>$F_{TOA,SW}$</th>
<th>$F_{TOA,LW}$</th>
<th>$F_{TOA,NET}$</th>
<th>$F_{SFCSW}$</th>
<th>$F_{SFCLW}$</th>
<th>$F_{SFCLH+SH}$</th>
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Previdi et al., 2013
Annual-mean relationships

Previdi et al., 2013
The SAM & horizontal energy transport

Previdi et al., 2013
The SAM & horizontal energy transport

Fig. 7. Regression of $F_{\text{WALL}}$ and its components onto the SAM index.

Previdi et al., 2013
Part 2: Multidecadal Trends
WACCM simulations

3-member ensembles of CESM1-WACCM integrations:

1) 20C: 1960-2000 period; CMIP5 Historical scenario for surface concentrations of GHGs and ODSs

2) 21C: 2001-2065 period; GHG/ODS forcing for 2001-2005 (2006-2065) based on CMIP5 Historical (RCP4.5) scenario

3) FixODS: 2001-2065 period; identical to 21C, except that surface concentrations of ODSs are held fixed at year 2000 levels

Smith et al., 2013
Interannual $F_{\text{TOA:NET}} / F_{\text{WALL}}$ relationship

Fig. 4. Scatterplot of WACCM annual mean, piecewise, linearly detrended polar cap averaged (70°–90°S) $F_{\text{TOA:NET}}$ and $F_{\text{WALL}}$ anomalies for 1960–2065 (20C and 21C). Solid black line indicates the least squares linear fit to the data.
Multidecadal trends

(a) Annual Mean $F_{\text{TOA:NET}}$

- Black: 20C + 21C
- Red: FixODS

(b) Annual Mean $F_{\text{WALL}}$

Smith et al., 2013
Multidecadal trends

Smith et al., 2013
Role for the SAM?

(b) DJF SAM Index

- **20C + 21C**
- **FixODS**

Smith et al., 2013
Role for the SAM?

Previdi and Polvani, 2014
Conclusions

• The observed Antarctic atmospheric energy budget is characterized by an approximate balance between the TOA net radiation and the horizontal convergence of the atmospheric energy transport. This balance is maintained both in the climatological mean, and in association with interannual (largely SAM-related) variability.

• CMIP5 models, on average, do well in simulating the observed climatological mean Antarctic energy budget. However, large biases exist in individual models during certain seasons (e.g., TOA SW radiation during summer).

• Multidecadal trends in the Antarctic mean TOA net radiation are simulated by CESM1-WACCM during 1960-2065, primarily in response to stratospheric ozone depletion and recovery. As was the case for the climatological mean and interannual variability, these multidecadal trends are balanced by opposing trends in the horizontal energy transport into the polar region.
TABLE 1. The climatological mean Antarctic atmospheric energy budget (W m$^{-2}$) for 2001–10. TOA radiative fluxes are based on CERES satellite measurements, surface energy fluxes and $\partial E/\partial t$ are from ERA-Interim, and $F_{\text{WALL}}$ is estimated as a residual. Positive values signify a gain of energy for the atmospheric column.

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<th>Month</th>
<th>$\partial E/\partial t$</th>
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<th>$F_{\text{TOA,LW}}$</th>
<th>$F_{\text{TOA,NET}}$</th>
<th>$F_{\text{SFC,SW}}$</th>
<th>$F_{\text{SFC,LW}}$</th>
<th>$F_{\text{SFC,LH+SH}}$</th>
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(c) Annual Mean SAM Index

![Diagram showing time series of SAM Index from 1960 to 2060. The y-axis represents the SAM Index ranging from -6 to 4, and the x-axis represents the years from 1960 to 2060. The trend over time shows fluctuations around the mean with a downward trend towards the end of the period.]
TABLE 2. DJF and JJA correlations between piecewise, linearly detrended Antarctic energy budget components and the SAM for 1960–2065 (20C and 21C). Bold font indicates correlations that are statistically significant at the 95% level.

<table>
<thead>
<tr>
<th></th>
<th>$\frac{\partial E}{\partial t}$</th>
<th>$F_{\text{TOA:SW}}$</th>
<th>$F_{\text{TOA:LW}}$</th>
<th>$F_{\text{TOA:NET}}$</th>
<th>$F_{\text{SFC:SW}}$</th>
<th>$F_{\text{SFC:LW}}$</th>
<th>$F_{\text{SFC:LH+SH}}$</th>
<th>$F_{\text{SFC:NET}}$</th>
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