A-Train and Reanalysis Data: An Evaluation of the Arctic Energy budget

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\textbf{Goal:} Describe the COMPrehensive ARctic Energy budget DataSet (COMPARES) and use it for product evaluation and scientific inquiry.
Arctic Melting

- IPCC 5th Assessment report stated that it is very likely that the rise of CO₂ and other greenhouse gases has led to the dramatic decline of sea ice and snow extent across the Arctic.

- Sea ice extent has a substantial seasonal cycle with a minimum occurring in September.

- September 2012 had the lowest sea ice extent on record.
Arctic Amplification

2000 – 2009 GISS Surface Temperature Anomaly

- Greater temperature increases in the Arctic compared to the earth as a whole.
- Ice-albedo feedback: Bright snow and sea ice melt giving way to darker ocean which absorb more solar radiation causing greater heating.

NASA image by Robert Simmon

Warmer temperatures

Less snow and ice

More sunlight absorbed by land and sea
The ice-albedo feedback has a competitor: *clouds*

Questions

1) Do these trends hold up using a longer record?
2) Are these trends identified in other datasets?

Source: Kato et al. 2006, GRL

- MODIS Cloud coverage increased between 2000 and 2004.
- Increase in clouds cancel out the impact of melting snow and ice on polar albedo.
# Overview of Products

## Satellite Observations

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Primary Variables</th>
<th>Product</th>
<th>Period</th>
<th>Resolution spatial &amp; temporal</th>
<th>Note</th>
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</thead>
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<tr>
<td>AIRS</td>
<td>meteorology &amp; cloud</td>
<td>AIRX3STM</td>
<td>2002 – 2013</td>
<td>14km → 1°; month</td>
<td>high spectral resolution spectrometer</td>
</tr>
<tr>
<td>CERES</td>
<td>radiation</td>
<td>EBAF V2.7</td>
<td>2002 – 2013</td>
<td>20km → 1°; month</td>
<td>broadband scanning radiometer</td>
</tr>
<tr>
<td>CloudSat</td>
<td>cloud, radiation, &amp; precipitation</td>
<td>geoprof, flxhr, cldclass, rain &amp; snowprofile</td>
<td>2006 – 2011</td>
<td>1.4km → 2.5°×2.5°; instantaneous</td>
<td>radar &amp; lidar (CALIPSO)</td>
</tr>
<tr>
<td>CloudSat-L3</td>
<td>radiation</td>
<td>FLXHR-LIDAR</td>
<td>2006 – 2011</td>
<td>1.4km → 2.5°; month</td>
<td>radar &amp; Lidar (CALIPSO)</td>
</tr>
<tr>
<td>MODIS</td>
<td>cloud</td>
<td>MYD08_M3</td>
<td>2002 – 2013</td>
<td>1km → 1°×1°; month</td>
<td>scanning spectroradiometer</td>
</tr>
<tr>
<td>GEWEX-SRB</td>
<td>radiation</td>
<td>REL3.1 LW REL3.0 SW</td>
<td>1983-2008</td>
<td>1°; month</td>
<td>ISCCP cloud and GMAO input to radiation algorithm.</td>
</tr>
<tr>
<td>GRACE</td>
<td>water storage</td>
<td>CSR, JPL, GFZ</td>
<td>2003 – 2013</td>
<td>1°; month</td>
<td>ranging polar orbiting twin-satellites</td>
</tr>
<tr>
<td>NSIDC</td>
<td>snow &amp; ice</td>
<td>EASE-Grid</td>
<td>2002 – 2013</td>
<td>25 km; week</td>
<td>passive microwave: Nimbus-7, SMMR, and SSM/I</td>
</tr>
<tr>
<td>CMAP</td>
<td>precipitation</td>
<td>standard</td>
<td>1979-2011</td>
<td>2.5°; month</td>
<td>GPI, OPI, SSM/I scattering, SSM/I emission and MSU</td>
</tr>
<tr>
<td>GPCP</td>
<td>precipitation</td>
<td>V2.2</td>
<td>1979-2010</td>
<td>2.5°; month</td>
<td>gauge + GPI, OPI, SSM/I, &amp; MSU</td>
</tr>
</tbody>
</table>
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<tr>
<td><strong>Reanalysis Products</strong></td>
<td></td>
<td></td>
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<tr>
<td>MERRA</td>
<td>Interim</td>
<td>1979-2013</td>
<td>1.25°; 6xdaily</td>
<td></td>
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<tr>
<td>NCEP</td>
<td>DOE-Reanalysis 2</td>
<td>1979–2013</td>
<td>1.25°; 6xdaily</td>
<td></td>
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<tr>
<td>ECMWF</td>
<td>IAU 2D_rad_Nx</td>
<td>2002-2013</td>
<td>1.25°; 6xdaily</td>
<td></td>
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<tr>
<td>ASR</td>
<td>Interim</td>
<td>2000-2010</td>
<td>30 km; 3hr</td>
<td>WRF-VAR &amp; PWRF</td>
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<tr>
<td><strong>Assimilated (satellite + reanalysis) Products</strong></td>
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<tr>
<td>MACC</td>
<td>ECMWF</td>
<td>2006-2013</td>
<td>1.25°; 6xdaily</td>
<td>For aerosol data</td>
</tr>
<tr>
<td>GLDAS</td>
<td>NOAH025_M.020</td>
<td>2002-2013</td>
<td>0.25°×0.25°; month</td>
<td>NOAH model + Obs [CMAP, GDAS, MODIS, &amp; AGRMET]</td>
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<tr>
<td><strong>Ground Observations</strong></td>
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</tr>
<tr>
<td>ARM</td>
<td>ARMBE ARSCL</td>
<td>1998-2011</td>
<td>hour</td>
<td>Barrow, AK</td>
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<tr>
<td>GPCC</td>
<td>Full V6</td>
<td>1901-2010</td>
<td>0.5°; month</td>
<td>network of gauges</td>
</tr>
<tr>
<td>AMVER</td>
<td>ship inventory</td>
<td>2006-2010</td>
<td>0.25°; day</td>
<td>ship vessel density</td>
</tr>
</tbody>
</table>
Orbit: CloudSat is in a sun synchronous orbit with latitude range 82degS/N. Consecutive swaths are 2752 km apart at the equator. Return cycle is every 16 days. Makes 14 – 15 orbits per day.

- Temporal Resolution: Monthly average data
- Spatial Resolution: 2.5°×2.5°
- Range: 60 N to 90 N
- Each region contains a minimum of 700 CloudSat profiles.
- Boxes at higher latitudes are smaller but get more satellite passes per area.
Region Mask

- Land Mask
- Greenland
- Arctic Ocean
- Eurasia
- North America
- Baffin Bay
2B-Geoprof-Lidar merges cloud layer detection from CloudSat and CALIPSO to produce the most accurate quantitative description of hydrometeor layers in the atmosphere that is possible.
Vertical Cloud Fraction
Greenland

- 125 vertical levels at 240 m resolution.
- Clouds are included if they span the depth of the vertical bin.
- Cloud fraction was greatest in 2006. Largest variability occurs at 4 km.

*Count number of clouds that fall into each vertical bin to obtain vertical cloud fraction.
Total Water Storage Anomaly (GRACE)

Products: CSR.LAND University of Texas, GFZ Helmholtz Center, & JPL Pasadena.

- 1°x1° averaged monthly
- Total water storage can only be inferred over land.
- Total water storage decreases over Greenland during the CloudSat period.
Polar Region Anomaly (70° – 82° N)

Negative trend: snow & sea-ice melt caused by rising temperature over the arctic.

Positive trend: more clouds tend to occur as stronger evaporation rates over more open water become available as sea-ice melts (Wang and Key, 2005).

Warming trend: despite increase in cloudiness, less sea-ice is likely having the dominant effect on the top of atmosphere shortwave albedo anomaly.
Polar Anomalies: Comparison with Reanalysis

**Cloud thinning:**
Mean cloud water paths are decreasing. → Weaker shortwave cloud radiative effect.

**Inconsistent trends:**
MODIS, CloudSat, & ECMWF show a positive trend while SRB, MERRA, and NCEP show a negative trend. (SRB may be prone to substantial biases caused by snow/ice and steep viewing angles).

Next question: How well do these products compare with ARM surface observations?
ARM
North Slope of Alaska
Barrow: 71° 19’ 23.73” N, 156° 36’ 56.7” W

• BOA Radiative fluxes
  • ARM Best Estimate data products (ARMBE)
    – Pyranometer (shortwave)
    – Pyrgeometer (longwave)

• Cloud properties
  • Actively Remotely-Sensed Cloud Locations (ARSCL)
  • Ceilometer
  • micropulse lidar
  • cloud radar (35 GHz)
  • Cloud base height, precipitation, fall velocity, reflectivity.

• Meteorology
  • Radiosondes
  • ARM standard meteorological instrumentation at surface.
ARM Comparisons

All-Sky Downwelling Longwave Radiation

Greatest overlap of data occurs between 2007 – 2010.
Largest variation in surface downwelling longwave radiation occurs during winter.
• Longwave bias is two times larger using **reanalysis** data.

• Shortwave bias is large for both satellite observations and reanalysis data.

• CloudSat significantly overestimates absorbed solar radiation.
  – Cloud microphysical properties (water and particle size) and cloud thickness are the largest contributors to uncertainty [Kay and L’Ecuyer, 2013, JGR].
• Cloud cover fraction bias is three times larger using reanalysis data.

• Cloud cover fraction significantly varies amongst reanalysis products.

• Best agreement amongst satellite observations in summer.
  • MODIS product incorporates optical retrievals during polar summer.

• CloudSat/CALIPSO systematically detects more clouds than MODIS.
  – Lidar is sensitive to thin clouds.
Arctic Radiation Budget
70° – 82° N

CERES
CloudSat
SRB
MERRA
NCEP
ECMWF
ASR

Illustration by Graeme Stephens
Conclusions

• The COMPrehensive Arctic Energy budget dataSet (COMPARES) combines multiple datasets into one easy-to-use framework.
  – Can be used for inter-comparison, validation, and evaluation studies as well as for scientific inquiry.

• ARM Comparisons (Barrow, AK)
  – Satellite estimated surface radiation fluxes are within 7, 11 W/m^2.
  – The bias is 2 – 3 times larger using reanalysis data.
  – CloudSat derived shortwave flux are in poor agreement with CERES because the a priori value used as inputs where the lidar fails to retrieve optically thick clouds is probably too small.

• Polar cloud coverage has increased according to MODIS & CloudSat in recent years presumably due to the loss of sea ice. However, absorbed solar radiation continues to increase and the loss of sea ice dominates the change in reflected radiation
  – These relationships are generally not supported by reanalysis data.

• Dataset is currently available online via Colorado State University
  [http://reef.atmos.colostate.edu/~chrismat/arctic_html/arctic.html](http://reef.atmos.colostate.edu/~chrismat/arctic_html/arctic.html)