The Relationship Between Surface Temperature Anomaly Time Series and those of OLR, Water Vapor, and Cloud Cover as Observed Using Nine Years of AIRS Version-5 Level-3 Products

Joel Susskind, Gyula Molnar, Lena Iredell
NASA GSFC
Sounder Research Team

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Outline

1. Comparison of AIRS and CERES anomaly time series of OLR and $\text{OLR}_{\text{CLR}}$

2. Explanation of recent decreases in global and tropical mean values of OLR

3. AIRS “Short-term” Longwave Cloud Radiative Feedback
   - A new product
Significance of AIRS OLR and OLR\textsubscript{CLR}

AIRS OLR is a computed product for each AIRS FOR using an OLR RTA. Input data is AIRS retrieved $T_{\text{skin}}$, $\epsilon_\nu$, $T(p)$, $q(p)$, $O_3(p)$, $\alpha\epsilon$, and $p_{\text{cloud}}$.

AIRS OLR\textsubscript{CLR} is also computed for each AIRS FOR using same parameters but setting cloud fraction $\alpha\epsilon = 0$. Roughly 70% of all cases pass OLR\textsubscript{CLR} QC and are used to generate Level 3 OLR\textsubscript{CLR} product.

CERES products are derived from broad spectral band observations. Considered the “Gold Standard” of OLR and OLR\textsubscript{CLR} data. CERES OLR\textsubscript{CLR} represents CERES OLR values for scenes considered to be clear. Roughly 10% of all cases are used to generate Level 3 product.

If Anomaly time series of AIRS OLR products closely match those of CERES:
- This validates anomaly time series of both AIRS and CERES OLR products.
- This indirectly validates anomaly time series of AIRS retrieved products.
- In addition, anomaly time series of OLR and OLR\textsubscript{CLR} can now be attributed to those of their component parts.

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Comparison Data Sets

AIRS Science Team Version-5 monthly mean data obtained from Goddard DISC (Level 3)

- OLR, OLR$_{CLR}$, $T_{\text{skin}}$, $q_{500}$, cloud fraction
- Presented on a 1°x1° latitude-longitude grid
- 1:30 AM and 1:30 PM monthly mean values extracted separately and averaged together
- Data products extend to August 2011

CERES Science Team monthly mean data obtained from Langley ASDC

- All data presented on a 1°x1° latitude-longitude grid
- Edition-2.5 CERES Terra OLR and OLR$_{CLR}$
- Data products extend to June 2010
- We did not use Edition-2.5 CERES Aqua OLR and OLR$_{CLR}$
- Data products extend only to August 2009
AIRS Version-5 OLR and OLR_{CLR} are biased compared to CERES, with a small annual cycle.
Definition of Anomalies and ARC’s

Seven-year monthly climatologies were generated for each grid box by averaging data for seven Januaries, seven Februaries, ……

The monthly anomaly for each grid box is the difference of the monthly mean value for that month from its climatology

The Average Rate of Change (ARC) for a grid box is the slope of the straight line passing through the monthly anomaly time series

Values of ARC’s depend on the extent of the time series used
Spatial patterns are more important than precise values

An area mean ARC is the cosine latitude weighted average ARC over the area

Monthly anomalies and ARC’s of AIRS and CERES OLR can match well if there is a monthly bias between AIRS and CERES OLR but it is essentially constant in time.
September 2002 through August 2011

Global OLR

Tropical OLR

Global Clear Sky OLR

Tropical Clear Sky OLR

AIRS Version-5
CERES Terra
AIRS Version-5 minus CERES Terra

AIRS El Niño Index multiplied by 2

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## OLR Anomaly Time Series Comparison
### September 2002 through June 2010

<table>
<thead>
<tr>
<th></th>
<th>Global</th>
<th>Tropical</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AIRS ARC (W/m²/yr)</strong></td>
<td>$-0.088 \pm 0.015$</td>
<td>$-0.111 \pm 0.043$</td>
</tr>
<tr>
<td><strong>CERES Terra ARC (W/m²/yr)</strong></td>
<td>$-0.065 \pm 0.013$</td>
<td>$-0.100 \pm 0.040$</td>
</tr>
<tr>
<td><strong>AIRS Minus CERES STD (W/m²)</strong></td>
<td>0.108</td>
<td>0.139</td>
</tr>
<tr>
<td><strong>AIRS/CERES Correlation</strong></td>
<td>0.972</td>
<td>0.991</td>
</tr>
</tbody>
</table>

### OLRCLR Anomaly Time Series Comparison
### September 2002 through June 2010

<table>
<thead>
<tr>
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<th>Global</th>
<th>Tropical</th>
</tr>
</thead>
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<tr>
<td><strong>AIRS ARC (W/m²/yr)</strong></td>
<td>$-0.004 \pm 0.011$</td>
<td>$-0.017 \pm 0.023$</td>
</tr>
<tr>
<td><strong>CERES Terra ARC (W/m²/yr)</strong></td>
<td>$-0.069 \pm 0.012$</td>
<td>$-0.101 \pm 0.025$</td>
</tr>
<tr>
<td><strong>AIRS Minus CERES STD (W/m²)</strong></td>
<td>0.175</td>
<td>0.235</td>
</tr>
<tr>
<td><strong>AIRS/CERES Correlation</strong></td>
<td>0.821</td>
<td>0.922</td>
</tr>
</tbody>
</table>
OLR Anomaly Average Rate of Change (Watts/m²/yr)
September 2002 through June 2010

AIRS OLR

Global Mean = -0.088
STD = 0.597

CERES OLR

Global Mean = -0.065
STD = 0.586

AIRS Version-5 minus CERES Edition-2.5

Global Mean = -0.023
STD = 0.180
Correlation = 0.949

OLR

Global Mean = -0.023
STD = 0.180
Correlation = 0.949

OLR CLR

Global Mean = 0.065
STD = 0.187
Correlation = 0.762

OLR Region 1 and 2 are enclosed by rectangles
OLR Anomaly (Watts/m²)  
Tropics 5°N to 5°S  
Monthlies, September 2002 through June 2010

CERES OLR

AIRS minus CERES OLR
Correlation = 0.993

AIRS minus CERES Clear Sky OLR
Correlation = 0.913

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AIRS and CERES OLR Comparison Summary

AIRS and CERES OLR and OLR_{CLR} anomaly time series are in close agreement in space and time.

Agreement of AIRS and CERES OLR_{CLR} is remarkable given the sampling differences.

Both show the period September 2002 through June 2010 was marked by a significant drop in Global mean and Tropical mean OLR on the order of -0.075 W/m²/yr and -0.10 W/m²/yr respectively.

Both also show significant spatial structure of changes in OLR and OLR_{CLR}, especially in the tropics.

There is little question that these consistent findings are real.

The next set of charts explain recent changes in OLR in terms of ARC’s of AIRS derived products over the extended period September 2002 through August 2011.
AIRS Version-5 Surface Skin Temperature Anomaly
September 2002 through August 2011

Average Rate of Change (K/yr)  
Tropics 5°N to 5°S (K)  Monthly Anomalies

Global Mean = -0.01  
Standard Deviation = 0.10

Surface Skin Temperature vs. El Niño Index
Anomaly Correlation

Global Mean = 0.07  
Standard Deviation = 0.30

AIRS El Niño region is enclosed in the green rectangle: 15°N-15°S, 140°W-160°E

The AIRS El Niño index is the monthly mean SST anomaly averaged over this region.
AIRS Version-5 Anomaly Average Rates of Change
September 2002 through August 2011

Effective Cloud Fraction (%/yr)

500 mb Specific Humidity (%/yr)

OLR (Watts/m²/yr)

Clear Sky OLR (Watts/m²/yr)

OLR Regions 1 and 2 are enclosed by rectangles.
Anomaly Correlations  September 2002 through August 2011

Effective Cloud Fraction vs. El Niño Index

- Global Mean = -0.06
- Standard Deviation = 0.19

500 mb Specific Humidity vs. El Niño Index

- Global Mean = 0.04
- Standard Deviation = 0.24

OLR vs. El Niño Index

- Global Mean = 0.03
- Standard Deviation = 0.25

Clear Sky OLR vs. El Niño Index

- Global Mean = 0.04
- Standard Deviation = 0.24
AIRS Version-5 Regional Anomaly Time Series
September 2002 through August 2011

OLR Averaged over Region 1

OLR Averaged over Region 2

El Niño Index multiplied by 4
OLR lagged by 3 months
OLR_{CLR} lagged by 3 months

El Niño Index multiplied by 10
OLR
OLR_{CLR}
### Area Mean Average Rates of Change of OLR and OLR\(_{\text{CLR}}\) (W/m\(^2\)/yr)
September 2002 through August 2011

<table>
<thead>
<tr>
<th>Spatial Area</th>
<th>OLR ARC</th>
<th>OLR(_{\text{CLR}}) ARC</th>
<th>OLR Anomaly Correlation with El Niño Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global</td>
<td>-0.089 ± 0.012</td>
<td>-0.019 ± 0.010</td>
<td>0.582</td>
</tr>
<tr>
<td>Tropical</td>
<td>-0.172 ± 0.034</td>
<td>-0.065 ± 0.020</td>
<td>0.807</td>
</tr>
<tr>
<td>Region 1</td>
<td>-0.491 ± 0.064</td>
<td>-0.142 ± 0.030</td>
<td>0.755</td>
</tr>
<tr>
<td>Region 2</td>
<td>-1.486 ± 0.171</td>
<td>-0.435 ± 0.056</td>
<td>0.839</td>
</tr>
<tr>
<td>Global excluding Region 1</td>
<td>-0.039 ± 0.010</td>
<td>-0.005 ± 0.008</td>
<td>0.246</td>
</tr>
<tr>
<td>Tropical excluding Region 1</td>
<td>-0.028 ± 0.023</td>
<td>-0.023 ± 0.012</td>
<td>0.549</td>
</tr>
<tr>
<td>Global excluding Region 1 and 2</td>
<td>-0.010 ± 0.010</td>
<td>0.004 ± 0.008</td>
<td>-0.123</td>
</tr>
<tr>
<td>Tropical excluding Region 1 and 2</td>
<td>-0.001 ± 0.022</td>
<td>-0.014 ± 0.012</td>
<td>0.420</td>
</tr>
</tbody>
</table>

Anomalies in OLR Regions 1 and 2 are highly correlated with El Niño and account for the majority of the recent decreases in global and tropical mean OLR and OLR\(_{\text{CLR}}\) which result from a La Niña trend over the period under study.
Longwave Cloud Radiative Feedback (F) refers to the relationship between anomalies of Longwave Cloud Radiative Forcing (LCRF) and $T_{\text{skin}}$

$$F = \frac{\Delta \text{LCRF}}{\Delta T_{\text{skin}}}$$

LCRF is the effect of cloud cover on OLR

$$\text{LCRF} = \text{OLR}_{\text{CLR}} - \text{OLR}$$

Understanding F is of great significance to climate prediction

Processes related to cloud feedbacks are the most uncertain components in global climate models
Computation of F

Following the approach of Andy Dessler, we evaluate F as the slope of the linear least squares fit to the scatter diagram of monthly mean anomalies of LCRF and T_{skin}. We compute F_{i,j} for each grid point i,j

F_{i,j} should not in principle be time period dependent because time is not one of the coordinates

We generated AIRS F_{i,j} using 9 years of AIRS OLR, OLR_{CLR} and T_{skin} anomalies based on 9 year AIRS climatologies

We also generated TOVS F_{i,j} based on 22 year TOVS Pathfinder anomalies based on 22 year TOVS climatologies

TOVS products come from many different satellites. All products are adjusted to a common time of day

AIRS F should be much more accurate than TOVS, but we wanted to see the extent that the two data sets agreed with each other

The agreement is remarkable and lends credence to F_{i,j} derived from AIRS
Zonal Mean Longwave Cloud Radiative Feedback

Correlation = .96

AIRS Version-5  September 2002 through August 2011
TOVS  January 1980 through February 2002
AIRS minus TOVS Difference

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AIRS Version-5
Longwave Cloud
Radiative Feedback
\((W/m^2/K)\)
September 2002
through
August 2011

Global Mean = 0.98   Standard Deviation = 3.02

TOVS
Longwave Cloud
Radiative Feedback
\((W/m^2/K)\)
January 1980
through
February 2002

Global Mean = 1.38   Standard Deviation = 3.46

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