Observationally Closing the Gap Between IR Radiative Forcing and Changes in IR Radiation Climate 
or 
Is Atmospheric Infrared Radiation Doing What is Supposed to Do?

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With thanks to: 
Martin Wild (ETHZ- ECHAM), Norm Wood (CSU- NCAR/CCSM, B Collins), 
Stuart Freindenreich (GFDL-CM2, Delworth) for GCM results
Terminology:

- **Downward IR (LW) Irradiance at the Earth’s Surface** is quantity of interest in this talk

- **Downward IR (LW) Irradiance at the Earth’s Surface** is the integrated radiant power emitted downward by the atmosphere between about 3.5 μm – 100 μm and intercepted on a horizontal plane at the Earth’s surface. It is the combined natural and anthropogenic “greenhouse” radiation, \( f(T, \text{GHG}, \text{H2O}, \text{Clds}, \text{aerosols}) \) global annual mean ~ 350 W m\(^{-2}\)

- **Longwave (LW), infrared (IR), Terrestrial IR, Thermal IR, IR irradiance, and IR radiation** may be used interchangeably in this talk

- **IR anomalies** – Deseasonalized with long-term mean subtracted.

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**Global Mean Downwelling Longwave Radiation at the Earth’s Surface**

**ECHAM5 GCM**
Driven by different radiative forcings

Current GCM slope $\sim 2.5 \pm 1 \text{ W m}^{-2} \text{ dec}^{-1}$

Change in IR “radiation climate”

ESRL/GMD Observations?
1993-2008

Gap or feedback amplification

Increase due to additional GHG IR emission only, no feedbacks from system
Slope $\sim 0.3 \text{ W m}^{-2} \text{ dec}^{-1}$

“IR radiative forcing”

GCM results
Provided by Martin Wild / ETHZ

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ESRL-GMD Surface IR Observations: A few details
(G-Rad global baseline network, 1993 - 2008)

• Commercial pyrgeometers
• Albrecht & Cox calibration and data reduction methodology
• Calibration accuracy ~ 3 W m\(^{-2}\), traceable int’l
• Calibration stability < 0.2% (0.7 W m\(^{-2}\)) dec\(^{-1}\)
• Field calibration frequency once per 1 – 3 years
• Continuous sampling
• Manually edited and reviewed
• Subsequent analyses:
  – Deseasonalized 1-day averages → 20-day averages → AR-1 residuals
  – Two trend or analyses then applied:
    • Linear regression
    • Mann-Kendall tests on Sens slopes
  – Variance reduction from combining remote sample sites
GCM surface IR agreement with observations
M. Wild et al., 2001  (see Wild et al 2005 for update)

BEFORE

AFTER

BSRN OBS. (344 W m⁻²)
Model Avg. (329)

Global Means
Circa 1999

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GCM grid cell & GMD Obs averages 1993 – 2004 (W m⁻²)

<table>
<thead>
<tr>
<th></th>
<th>Barrow</th>
<th>Boulder (Erie)</th>
<th>Bermuda</th>
<th>Mauna Loa</th>
<th>Kwaj.</th>
<th>S. Pole</th>
<th>Global</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCSM</td>
<td>249.5</td>
<td>266.2</td>
<td>369.3</td>
<td>386.1</td>
<td>420.8</td>
<td>108.0</td>
<td>340</td>
</tr>
<tr>
<td>GFDL</td>
<td>243.5</td>
<td>289.1</td>
<td>372.1</td>
<td>390.3</td>
<td>420.9</td>
<td>107.2</td>
<td>338</td>
</tr>
<tr>
<td>ECHAM4</td>
<td>238.0</td>
<td>294.4</td>
<td>392.0</td>
<td>-</td>
<td>440.0</td>
<td>113.8</td>
<td>344</td>
</tr>
<tr>
<td>OBS</td>
<td>238.3</td>
<td>291.7</td>
<td>377.1</td>
<td>236.4</td>
<td>421.4</td>
<td>111.7</td>
<td>344</td>
</tr>
</tbody>
</table>

Within ~5 W m⁻² of Obs
Surface IR observations and GCM output for grid box containing the site

- Obs 20-day avg
- GCMs Month avg

BERMUDA
20-day Avg Desasonalized Surface IR Anomalies with Lowess Smoother (0.3)
ESRL-GMD Radiation Global Baseline Sites

BARROW

BOULDER

BERMUDA

MAUNA LOA

KWAJALEIN

SOUTH POLE

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Linear Trend Detection Times
(required data set duration for detection, B. Weatherhead et al., ’98)

Based on:
• Estimated variance
• Estimated autocorrelation (AR1)
• Expected trends

For the GMD deseasonalized IR data:

<table>
<thead>
<tr>
<th>Detectable trend</th>
<th>Uncertainty range in number of required years</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3 W m(^{-2}) dec(^{-1})</td>
<td>70 to 220 years</td>
</tr>
<tr>
<td>2.0 W m(^{-2}) dec(^{-1})</td>
<td>19 to 53 years</td>
</tr>
<tr>
<td>3.5 W m(^{-2}) dec(^{-1})</td>
<td>13 to 35 years</td>
</tr>
</tbody>
</table>

Currently have ~15 years of GMD data - It’s time to investigate!

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### Estimated Observed Changes in Surface Downward IR

**DESEASONIZED AR1 Residuals**

**Linear trends**

<table>
<thead>
<tr>
<th>Site</th>
<th>Method</th>
<th>Regress</th>
<th>Mann-Kendall</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRW</td>
<td>5.3</td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td>BLD</td>
<td>3.2</td>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td>BER</td>
<td>2.7</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>MLO</td>
<td>2.5</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>KWA</td>
<td>1.9</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>SPO</td>
<td>3.7</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>6AVG/SE</td>
<td>3.2/0.5</td>
<td>2.8/0.6</td>
<td></td>
</tr>
<tr>
<td>5AVG/SE</td>
<td>3.4/0.6</td>
<td>3.2/0.6</td>
<td></td>
</tr>
</tbody>
</table>

(W m\(^{-2}\) dec\(^{-1}\))

| AVG\(_6\) | ~ 3.0 (0.6 SE) W m\(^{-2}\) dec\(^{-1}\) |
| AVG\(_5\) | ~ 3.3 (0.6 SE) W m\(^{-2}\) dec\(^{-1}\) |

- Not significant at 95%
- Potentially significant at 95%, res uncorrelated, normality tests good to marginal
  - Avg Regress student’s \( t = 2.8\)
  - Avg Mann-Kendall **95% minimum** = 0.9 Wm\(^{-2}\) dec\(^{-1}\)
  - (SPO least sig.)

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# SURFRAD (CONUS) initial results
(Surface IR-down change $W \text{ m}^{-2} \text{ dec}^{-1}$)

<table>
<thead>
<tr>
<th>Site</th>
<th>Method</th>
<th>AR1 res Regress</th>
<th>AR1 res M-K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ft Peck, Montana</td>
<td></td>
<td>3.3</td>
<td>3.3</td>
</tr>
<tr>
<td>Bondville, Illinois</td>
<td></td>
<td>2.5</td>
<td>3.4</td>
</tr>
<tr>
<td>Goodwin, Miss.</td>
<td></td>
<td>3.4</td>
<td>2.8</td>
</tr>
</tbody>
</table>

**AVG = 3.1, Boulder (Erie) = 3.3**

Overall estimate of observed surface downward IR trend based on average for five globally remote sites (1993-2008)

$3.3 \pm \sim 1.5 \ W \text{ m}^{-2} \text{ dec}^{-1}$

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ECHAM5 GCM Means

Observed
~3.3 ± 1.5 W m⁻² dec⁻¹

“GHG only, no H₂O feedback”

GCM results
Provided by Martin Wild / ETHZ

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~3.3 ± 1.5 W m⁻² dec⁻¹

"GHG only, no H₂O feedback"

IR Irradiance: W/m²

GCM results
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Summary

- Using “best estimate” from GMD baseline data, surface IR growing near that predicted by GCMs

- Theoretical statistical estimates of trend detectability are marginally met.

- Maintaining calibration stability and extending the record are crucial

- Mauna Loa is not and should not show as certain a trend as other sites

- The somewhat higher than expected observed growth rates for 1993 – 2008, 3.3 vs 2.5, may be due to Pinatubo cooling recovery and is explicitly consistent with the GFDL fully-forced model run.

Future plans
- Continue and expand observational effort
- Extend analysis to existing but growing shorter data sets
- More detailed comparisons to fully-forced GCMs in a diagnostic mode
- Adequately determined IR climate could assist in assessing the validity and extent of multiple new and hypothesized feedback mechanisms