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Plausible ranges of observed TOA fluxes

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Plausible ranges of observed TOA fluxes

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(Note: all flux units are W m^{-2}; albedo is unitless.)

Deriving the ranges

We want a range of values for global- and time-averages of both FLUT and FSNTOA such that any model-simulated value outside a range makes it extremely likely that the simulation is fundamentally wrong, and therefore should be rejected. In IPCC Working Group 1 reports the term "extremely likely" is defined as > 95% probability (2007 SPM, p. 3). Adopting this definition, we seek two-sigma error bars because 95.45% of a Gaussian PDF lies within ± 2 standard deviations of the mean.

Norm Loeb is the chief PI for CERES (nominally he's co-PI with Bruce Weilicki, but Weilicki has gone on to other things according to Jerry Potter). Loeb et al. (J. Climate 22: 748, 2009) say that the dominant error source for CERES observations is absolute calibration of the CERES instrument: ±2% at the 95% confidence level. In their Table 2 they quantify all important error sources. Later they adjust the fluxes to conform to known constraints on the net heat input at the top of the atmosphere. Presumably this adjustment removes most of the original errors, but Loeb et al. give no error estimates for the final adjusted fluxes. We will be conservative and assign ±2% error bars to the adjusted fluxes:

```
LoebFLUTOA = 239.6 ; LoebFSNTOA = (340.0 - 99.5);

LoebFLUTOArange = {Floor[0.98 * LoebFLUTOA], Ceiling[1.02 * LoebFLUTOA]}

{234, 245}

LoebFSNTOArange = {Floor[0.98 * LoebFSNTOA], Ceiling[1.02 * LoebFSNTOA]}

{235, 246}
```

Note that these estimates apply to the first 5 years of CERES observations, March 2000 - February 2005 (Yuying Zhang has downloaded adjusted fluxes for the time period March 2000 - October 2005 and put these into the PCMDI observational database). The convenient summary statistics (ASCII files) produced by our AMIP runs, on the other hand, cover years 1995 - 2004. Fortunately there seems to be little year-to-year difference in the globally averaged numbers. For example, using Yuying's archive to get the numbers for January 2003 - December 2004, we find no difference in the final ranges:

```
LoebFLUTOA = 239.6 ; LoebFSNTOA = (340.0 - 99.3);

LoebFLUTOArange = {Floor[0.98 * LoebFLUTOA], Ceiling[1.02 * LoebFLUTOA]}

{234, 245}

LoebFSNTOArange = {Floor[0.98 * LoebFSNTOA], Ceiling[1.02 * LoebFSNTOA]}

{235, 246}
```

Kevin Trenberth's group at NCAR independently assesses observations of energy flows in the climate system. Trenberth, Fasullo and Kiehl (BAMS 90: 311, March 2009) estimate the following fluxes for the CERES time period March 2000 - May 2004, saying that the "values are known within about ±3% or better" :

```
TrenbFLUTOA = 238.5; TrenbFSNTOA = 239.4;
```

Applying ±3% error bars gives

```
TrenbFLUTOArange = {Floor[0.97 * TrenbFLUTOA], Ceiling[1.03 * TrenbFLUTOA]}

{231, 246}

TrenbFSNTOArange = {Floor[0.97 * TrenbFSNTOA], Ceiling[1.03 * TrenbFSNTOA]}

{232, 247}
```

so that each of Trenberth's ranges includes all of the corresponding Loeb range.

Expressing the estimates of shortwave flux as planetary albedo, we must use Loeb's and Trenberth's separate estimates of the solar constant:

```
LoebFSDTOA = 340.0;

TrenbFSDTOA = 341.3;

                  LoebFSDTOA - Interval[LoebFSNTOArange]
LoebAlbedoRange = ──────────────────────────────────────
                               LoebFSDTOA

Interval[{0.276471, 0.308824}]

                   TrenbFSDTOA - Interval[TrenbFSNTOArange]
TrenbAlbedoRange = ────────────────────────────────────────
                                TrenbFSDTOA

Interval[{0.276297, 0.320246}]
```

Again Trenberth's range includes all of Loeb's range, so we will continue to be conservative and adopt Trenberth's -- with rounding to three significant places --

```
albedoRange = {0.276, 0.320};

                  %⟦1⟧ + %⟦2⟧
bestGuessAlbedo = ───────────
                       2

0.298

albedoErrorBarHalfLength = %%⟦2⟧ - %

0.022
```

The albedoRange provides observational limits, for comparison with model simulations, that are more "fair to the model" (Pat Michaels' expression) than shortwave fluxes, since the model assumes rather than computes a value for the solar constant. The albedo defined here says nothing about longwave fluxes; we choose to study the latter by looking at . . .

Total net downward shortwave + longwave flux

For both Loeb's and Trenberth's estimates, the range of FSNTOA is 1 W m^{-2} higher than the range of FLUTOA because in recent times, net heat input at the top of the atmosphere was ~ 1 W m^{-2}. This number is independent of the original CERES observations and was used by both Loeb's and Trenberth's groups to adjust CERES observations. It comes mainly from in situ observations of increasing ocean heat content. Hansen et al. (Science 308: 1435, 2005) use these observations together with their climate model to infer that net heat input at the top of the atmosphere during 2003 was 0.85 ± 0.15 W m^{-2} (1-sigma errors). Trenberth et al. (Science 328: 316, 2010) show this quantity rising from about 0.6 to 1.0 W m^{-2} between 2003 and 2005 but do not show error bars. (Stopping the time period at 2005 eliminates most of the "missing energy" problem that Trenberth et al. discuss in this paper.) We apply 2-sigma versions of Hansen's error bars to Trenberth's estimate, which was already somewhat broader than Hansen's because of time variation. The result is

```
totalFluxTOArange = {0.6 - 0.3, 1.0 + 0.3}
```

```
{0.3, 1.3}
```

The totalFluxTOArange seems reasonable, even though the way we got it is rather eclectic. For example, the most recent estimate of ocean heat content changes (Levitus et al. GRL 36: L07608, 2009, Figure 1) exhibits an average rate of ocean heat content increase of 0.40×10^{22}J / yr since about 1970. Converting this to Watts per square meter by dividing by Earth's *total* surface area gives

```
<< PhysicalConstants`
```

```
R = EarthRadius
```

```
6 378 140 Meter
```

```
Δt = 86 400 * 365.25 Second
```

$$3.15576\times10^{7}\ \texttt{Second}$$

$$\texttt{fluxIntoOcean} = \frac{0.40\times10^{22}\ \texttt{Joule}}{\Delta\texttt{t} * 4\,\pi\,\texttt{R}^{2}}$$

$$\frac{0.247947\ \texttt{Joule}}{\texttt{Meter}^{2}\ \texttt{Second}}$$

but this number pertains only to the uppermost 700 meters of the ocean. In Hansen's climate model an average of 85% ocean heat storage occured here, implying

$$\texttt{fluxIntoOcean} = \frac{\texttt{fluxIntoOcean}}{0.85}$$

$$\frac{0.291702\ \texttt{Joule}}{\texttt{Meter}^{2}\ \texttt{Second}}$$

which more or less coincides with the lower limit of our estimated range. A low value is expected due to (1) neglecting other components of the climate system that store heat and (2) using a multi-decadal average for the rate of ocean heat content increase, which may have been larger in recent years.

Very recently Lyman et al. (2010: Nature 465, 304; see also Trenberth's News and Views commentary) found an ocean heat content trend over the period 1993-2008 of $+0.64 \pm 0.29$ W m^{-2} :

```
totalFluxTOArangeLyman = {0.64 - 0.29, 0.64 + 0.29}
```

```
{0.35, 0.93}
```

Lyman's numbers are averaged over Earth's entire surface area and their uncertainties are 2-sigma errors, so this range may be compared directly with our `totalFluxTOArange` above. Lyman's range is somewhat contracted from ours. For the moment, we will stick with our more "generous" error bars on `totalFluxTOArange`.

■ Comparing with CAM output

An additional problem arises in comparing these observations with CAM output. CAM accidentally recorded outgoing LW at the top of the model (FLUT) rather than at the top of the atmosphere (FLUTOA) in its output history files. This introduces errors up to 1 W m^{-2} locally; also, there are globally averaged errors ~ 0.3 W m^{-2} from CAM's -- and most if not all other climate models' -- incomplete accounting of energy sources and sinks (Trenberth, K. E., and J. T. Fasullo, 2010: Simulation of present day and 21st century energy budgets of the southern oceans. J. Climate, 23, 440-454. http://www.cgd.ucar.edu/cas/Trenberth/trenberth.papers/TF_JCLI_Jan-2010.pdf)