Climate feedbacks and relationships between TOA radiation and temperatures on Earth: CESM vs Observations

Why does the energy imbalance vary so much and so fast?

What does this imply

- For climate sensitivity analysis from data?
- For feedbacks?

EARTH’S ENERGY BALANCE REVISITED
Fifty shades of feedbacks

\[ R_T = F - \lambda \Delta T + \varepsilon \]
Global warming:

Under no climate change, the net flow of energy in from the sun is balanced by the net radiation out to space.

$$\text{ASR} = \text{OLR}$$

With global warming there is a net energy imbalance as heat trapping gases lower OLR:

$$\text{Net } R_{T} = \text{ASR} - \text{OLR}$$
Net TOA radiation anomalies

Standard deviation 0.64 W m\(^{-2}\):
Anomalies over 1 W m\(^{-2}\) common.

Base period:
Jan 2001-Dec 2010
Global Temperatures
Jan 1979 to Oct 2013

$r = 0.66$

$r = 0.81$

$0.72 \ (0.77 \ 2 \ mo)$

$0.37 \ (\text{lag} \ 4)$

$0.52 \ \text{detrend (5)}$
Global

Jan 1979 to Oct 2013

We use
From models: 1994-2005
From obs: 3/2000-10/2013
Correlation between tropospheric mean T and net TOA radiation

March 2000 through October 2013 (ERA-I w CERES)  
correlation = -0.57  
regression = -2.18  W m$^{-2}$/K

i.e. for a 1° C increase in T, there is 2.18 W m$^{-2}$ extra radiation to space.
CESM-LE and CAM-5.3 AMIP

CAM 5.1

Focus on 1994-2005: post Pinatubo
Large_ensemble: 30 members
AMIP: 1 member

About 40% too large
6 ensemble members
Dominated by 2 volcanoes: El Chichon and Pinatubo.

Model: “top heavy”
CAM5-AMIP run: specified SSTs
CESM-LE ensemble mean 1994-2005

- SST
- T2m
- Ttrop
- Total cloud
- Water vapor
- Precipitation
Correlations between $T_{2m}$ and precipitation

Over ocean: observed -ve vs +ve in model

This is mostly ENSO: Walker circulation does not adequately suppress precipitation in W Pacific during El Niño in model.
These change from strong +ve for global mean of local relationships to strong -ve for the global means.
### Feedbacks

$$R_T = F - \lambda \Delta T + \varepsilon$$

1994-2005

For $T_{trop}$ (1000-150 hPa) regression in W m$^{-2}$ K$^{-1}$

<table>
<thead>
<tr>
<th></th>
<th>RT=</th>
<th>ASR-</th>
<th>OLR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed</td>
<td>-2.18</td>
<td>-0.68</td>
<td>1.49</td>
</tr>
<tr>
<td>AMIP</td>
<td>-1.96</td>
<td>-0.05</td>
<td>1.91</td>
</tr>
<tr>
<td>CESM-LE</td>
<td>-1.71</td>
<td>0.08</td>
<td>1.79</td>
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</tbody>
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For $T_{2m}$

<table>
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<th></th>
<th>RT=</th>
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</tr>
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<tbody>
<tr>
<td>Observed</td>
<td>-1.17</td>
<td>0.58</td>
<td>1.76</td>
</tr>
<tr>
<td>AMIP</td>
<td>-0.87</td>
<td>0.92</td>
<td>1.78</td>
</tr>
</tbody>
</table>
| CESM-LE  | -0.98 | 0.81  | 1.78 | W m$^{-2}$ K$^{-1}$

Negative feedback in model not as strong as observed, mainly because of ASR (cloud).
Biases in model

The model does very well in many respects, but...

• ENSO too large, different.

• Vertical profile of temperature in CESM top heavy: is this because of enhanced ENSO or more generically related to deep convection?

• The dry zone in tropics is under represented.
Biases over warm pool

- Walker circulation plays a key role (non-local links between E and W Pacific)

- Over oceans, high SST $\Rightarrow$ more precip & more water vapor and cloud $\Rightarrow$ ASR, and OLR less. In model extends to warm pool (not in obs).
Biases in model

- Generally, Cloud $\uparrow \Rightarrow$ ASR $\downarrow \Rightarrow$ $T_{2m}$ $\downarrow$
- Hence ASR and $T_{2m}$ are +ve correlated over land and some places over ocean; **lot less in model**
- In model, over oceans, $T_{2m}$ $\uparrow \Rightarrow$ cloud and convection $\uparrow \Rightarrow$ ASR $\downarrow$ and -ve correlation
- Too much ASR as temperatures rise means total radiation feedbacks with temperatures are not negative enough.
- **Does this mean that climate sensitivity is too large in model?**