Monitoring Climate Change from Space

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Why Monitor Earth’s Climate from Space?

- Global
- Spectrum
- Current
- Detection
- Understanding
- Prediction
The problem...

IPCC: www.ipcc.ch/ipccreports/ar4-wg1.htm
Link to animation
Earth’s Radiation balance in space

Absorbed Solar or Shortwave Radiation \((S/4)(1-\alpha)\)

\[\text{Thermal/Infra-red or Outgoing Longwave Radiation (OLR)=}\sigma T_e^4\]

- There is a balance between the absorbed sunlight and the thermal/longwave cooling of the planet:
  \[(S/4)(1-\alpha) \approx \sigma T_e^4\]

- How does it balance? Why is the Earth’s average temperature about 15°C? e.g. Lacis et al. (2010) Science
Earth’s global annual average energy balance

Solar: 240 Wm\(^{-2}\)

Thermal: 240 Wm\(^{-2}\)\(\varepsilon'\sigma T^4\)

390 Wm\(^{-2}\)

Surface Temperature = +15\(^\circ\)C

Efficiency \(\varepsilon' \sim 61.5\%\)

Radiating Efficiency, or the inverse of the Greenhouse Effect, is strongly determined by water vapour absorption across the electromagnetic spectrum.
Now double CO$_2$ - a “radiative forcing”

Surface Temperature = +15$^\circ$C

Radiative cooling to space through longwave emission drops by about 4 Wm$^{-2}$ resulting in a radiative imbalance
The climate system responds by warming

\[ \text{Surface Temperature} = +15^\circ \text{C} \]

\[ \text{Solar} > \text{Thermal} \]

\[ 240 \text{ Wm}^{-2} \quad \text{Solar} \]

\[ 236 \text{ Wm}^{-2} \quad \varepsilon' \sigma T^4 \quad \text{Thermal} \]

\[ 390 \text{ Wm}^{-2} \quad \sigma T^4 \]

Efficiency \approx 60.5\%
The 2xCO$_2$ increased temperature by about 1°C in this simple example. So what’s to worry about?
But it’s not that simple...

IPCC (2007)
Climate forcing and feedback: a natural experiment
Clouds affect radiation fluxes
Radiation fluxes affect clouds
Feedback loops or “vicious circles” amplify or diminish initial heating or cooling tendencies e.g. Ice “albedo” Feedback

\[ \uparrow \text{CO}_2 \]

\[ \uparrow \text{Temperature} \]

Melting ice and snow

Additional surface heating

Reduced reflection of sun's rays

\[ \text{Average Monthly Arctic Sea Ice Extent September 1979 - 2012} \]
One of the strongest positive amplifying feedbacks involves gaseous water vapour.
Cloud Feedback: a complex problem

- Clouds **cool** the present climate
- Will this cooling effect enhance or diminish in the future?
- Will clouds **amplify** or **reduce** future warming?
Monitoring Climate From Space

CloudSat
PARASOL
Aura
CALIPSO
Aqua
Remote sensing clouds and aerosol from space: Cloudsat and CALIPSO

- **Radar:** \( \sim D^6 \), detects large particles (e.g. ice)

- **Lidar:** \( \sim D^2 \), more sensitive to thin cirrus, low-level liquid clouds and aerosol pollutants but signal is attenuated

Work by Dr. Julien Delanoë and Prof. Robin Hogan, University of Reading
Energy from the Sun; stable over last 50 years

IPCC WG1 2.7.1 (p.188-193)

Lean (2000)
Y. Wang (2005)

See also: http://www.pmodwrc.ch/pmod.php?topic=tsi/composite/SolarConstant
Monitoring sea surface temperature
Monitoring Land Ice From Space

Above: results from Gravity Recovery And Climate Experiment (GRACE) mission

Right: NASA's ICE-Sat satellite - Ice, Cloud and land Elevation Satellite

Figure 2 | Rate of change of surface elevation for Antarctica and Greenland. Change measurements are median filtered (10-km radius), spatially averaged (5-km radius) and gridded to 3 km, from intervals ($\Delta t$) of at least 365 d, over the period 2003–2007 (mean $\Delta t$ is 728 d for Antarctica and 746 d for Greenland). East Antarctic data cropped to 2,500-m altitude. White dashed line (at 81.5° S) shows southern limit of radar altimetry measurements. Labels are for sites and drainage sectors (see text).
Arctic sea ice: Rapid decline in extent over satellite record since 1979, especially at ice minimum during Sept + Declining thickness

http://nsidc.org/news
Monitoring Sea level

IPCC 2007 Fig. 5.13 (p. 410)
Current rises in global sea level

Is sea level rising faster than projections made by numerical climate simulations?

Research by Rahmstorf et al. (2007) Science, 4 May
La Niña so strong the oceans fell

New satellite instruments including GRACE can “weigh” the mass of the oceans and ground water

Boening et al. (2012) Geophysical Research Letters
How will the water cycle change?

- Increased Precipitation
- More Intense Rainfall
- More droughts
- Wet regions get wetter, dry regions get drier?
- Regional projections??
Using microwave measurements from satellite to monitor the water cycle

Allan and Soden (2008) Science
Linking atmospheric rivers viewed from space with flooding

HydEF project: Importance of large-scale atmospheric precursors for flooding e.g. 2009 Cumbria floods

Conclusions

• Earth’s radiative energy balance drives climate change
• It also provides a rich spectrum of information
  - Monitoring and detecting climate change
  - Understanding physical processes
  - Enabling and evaluating prediction
• Challenges...
  - Clouds & Aerosol
  - Precipitation
  - Regional impacts