Observing and Modelling Earth's Energy Flows

Introduction and Background

The Earth's climate system is controlled by the radiative energy balance of the solar radiation absorbed by the Earth and the terrestrial radiation emitted to space. The geographical and seasonal distribution of planetary radiation balance (or net radiation) depends on the astronomically determined distribution of the incoming radiation, but the time/space distribution of absorbed and reflected solar radiation is strongly affected by many components of the Earth-atmosphere system including clouds, absorbing gases in the atmosphere and the differences in albedo of the Earth's surface. At the same time, terrestrial radiation emitted to space depends on both surface and atmosphere properties, strongly varying in both time and space and increasingly modified by human activities. The time/space structure of planetary radiation balance is both a driver of and is driven by the state of the Earth's climate system, in particular the atmospheric circulation.

A complete understanding of the Earth's energy balance including the interactions between the surface (land and ocean) and the atmosphere is one of utmost complexity and requires a comprehensive and detailed understanding including the dynamics of climate processes and circulation systems. A recent update of the knowledge of the Earth's global energy budget can be found in Trenberth et al., (2009). Fig 1 from this paper is shown below. See also Kandel and Viollier (2010) to appear in Comptes Rendus – Géosciences.

During the last century the Earth's surface and troposphere has been undergoing a warming process amounting to some 0.7°C. As discussed in the IPCC 4th assessment report, increasing accumulation of greenhouse gases in the atmosphere has probably caused much of this warming. Although determinations of earlier climate variations by proxy evidence are subject to uncertainties, the warming of the last century appears distinctly stronger and faster than variations estimated for the previous two thousand years. However, the warming has been irregular, Fig 2, with two marked warming trends 1920-1945 and 1975-2000 with a minor cooling trend in between. During the last decade the global mean surface air temperature, while remaining well above temperatures prior to 1975, has broadly stayed constant.

To the extent that there has been significant accumulation of heat in the climate system, it has mainly been used to warm the oceans, but a minor part, some 10% or so, has gone into melting ice on land and sea as well as heating the lower atmosphere and the surface. To what extent the variations in the warming are due to variation in the heat balance caused by changes in solar irradiation, by clouds and aerosols or by exchange of heat with the deep ocean is not presently clear. Alternatively, the variation in warming can also be due to variations in the atmospheric/ocean circulation (such as ENSO events) and the efficiency of transporting excess heat into areas that are effective heat sinks such as the desert regions. Such variations can appear as variations in the geographical structure of the Earth's radiation balance

A common but somewhat simplistic metric for climate change is to determine the magnitude of climate sensitivity that is the ratio between the global surface temperature increase and the changes in radiative forcing due on the one hand to increasing greenhouse gases, on the other to forced changes in absorbed solar radiation. To empirically determine climate *sensitivity* from observations is extremely difficult, if not impossible, because it requires knowledge not

only of the changes in albedo and outgoing thermal radiation due to aerosol and greenhouse *forcing* but also ability to distinguish these from cloud and water-vapor *feedback* effects. It also requires an estimate of the energy imbalance of the climate system as it is slowly adjusting towards a quasi-steady radiative equilibrium (or alternatively jumping to a radically different state!). A value of the present planetary energy imbalance is probably of the order 0.5 Watt/m2 and too small to be reliably obtained from observations. The energy imbalance has been estimated from the trend in heat accumulation in the climate system dominated by the warming of the deep oceans.
There are considerable variations in the regional climate response with in general the largest warming at high latitudes of the Northern Hemisphere. This is interesting as the combined climate forcing from greenhouse gases and aerosols is smaller there than at high latitudes of the Southern Hemisphere where greenhouse gas forcing dominates. The regional response is consequently strongly influenced by the internal circulation of the atmosphere and the oceans.

Climate sensitivity depends on feedback processes involving changes in the water cycle, in particular atmospheric water vapor content and clouds, as well as surface albedo changes depending on snow and ice cover. Presumably slower processes involve surface albedo changing as a function of changing vegetation, itself dependent on changing surface temperatures and water balance. Strongly different representations of feedback processes in different climate models (and some are not even modeled) are the main cause of the wide range of the IPCC estimate of climate warming due to increasing greenhouse gases (almost by a factor of 3). By constraining the model calculations by observations such as the time evolution of sea surface temperatures and comparing model-generated energy and radiation fluxes with the same from observations, it may be possible to determine whether models (or for that matter which models) depict feedback processes realistically.

An important point to note is that the observed increase in surface temperature since 1900 (or since the beginning of the industrial era) is less than 40% of that expected if one considers only the observed increase in the long-lived greenhouse gases based on the best estimate of equilibrium climate sensitivity given by the IPCC 2007 assessment report, Fig.3.

This apparent discrepancy could be due to an overestimation of climate sensitivity including treatment of clouds in models, neglect of the imbalance factor, or omission of some of the forcing, in particular an offset by increased concentration of reflecting aerosols. This could involve "indirect" cloud radiative forcing, i.e. the role of anthropogenic sulfate aerosols in changing cloud droplet populations in the direction of smaller and therefore more strongly reflecting water aerosols. To understand this better is of central importance for climate change, because it may be that anthropogenic aerosols with short atmospheric residence times (and which therefore could be rapidly reduced by worldwide antipollution measures) are presently masking the warming due to anthropogenic increases in greenhouse gases with long atmospheric residence times (which therefore will be with us for many decades even after GHG emissions are reduced).

Key current satellite capabilities from instruments in low-Earth orbits provide global almost-simultaneous observations of radiance at multiple wavelength and scattering angles as well as vertical profiles by lidar. An effective system of systems for combining these observations with data from the family of geostationary meteorological satellites can provide complete space/time sampling and global coverage of changing cloud properties, a critical source of climate feedback. More advanced capabilities such as Glory Mission and deep space deployments, DSCOVR, the Deep Space Climate Observatory have been suggested but DSCOVR has very limited sampling and resolution capabilities.

Satellite measurements on their own are probably not sufficient to reduce the uncertainties in forcing due to sampling limitations and biases and current existing ambiguities in separating natural and anthropogenic effects. However, smoothing the net radiation anomalies with a 6-month filter (Harries and Belotti, 2009) leave for recent data from CERES only a modest variability, well centered on zero of 0.5-1 W/m^2. To what extent this reflects a real climate signal is not clear but the work of Loeb et al (2009) indicates that absolute uncertainty may be the dominant source of error.

In summary the following scientific objectives are suggested:

Scientific objectives

1. How accurately can we determine the Earth's radiation balance and what are the prospects for further improvements? What contribution can be expected from new space missions including CLARREO providing spectrally resolved radiances.

2. To revisit the issue of the absolute value of total solar irradiance, its possible variations since space data began to arrive and before, and the accuracy of the absolute value of the planetary radiation balance.

3. To revisit the issue of solar-activity-related variability of the spectrum of incoming solar radiation, and its possible influence on the Earth's climate. The signal is expected and observed to be strongest in the upper atmosphere, with some signal extending down to the stratosphere. How can we separate the effect of this in the troposphere towards the background on natural variability? How far back can we reliably reconstruct solar irradiation?

4. How accurately can we measure the effects of aerosols (tropospheric and stratospheric) on the radiation balance? To what extent can aerosol effects on cloud droplet distributions be accurately modeled?

5. How does the atmosphere and ocean circulation affect the heat budget of the Earth? How does heat transport out of the tropics depend on temperature and on the atmospheric and ocean circulation? How does it vary between tropical land and sea?

6. Why are the Earth's radiative fluxes responding so fast to ENSO events? Why does the cloud radiative forcing from the deep tropical clouds stay the same under changing conditions? How can better observations of radiative fluxes help improving modeling of tropical convection?

7. How can we effectively combine model information and space data to better understand atmospheric feedback processes?

Topics of the workshop

1. Solar total and spectral irradiance variations

2. Earth energy flows (atmospheric, ocean circulation and heat storage)

3. Water vapor feedback, distribution and spectra

4. Cloud forcing and feedbacks

5. Aerosol forcing

6. Synthesizing models and observations.

List of conveners

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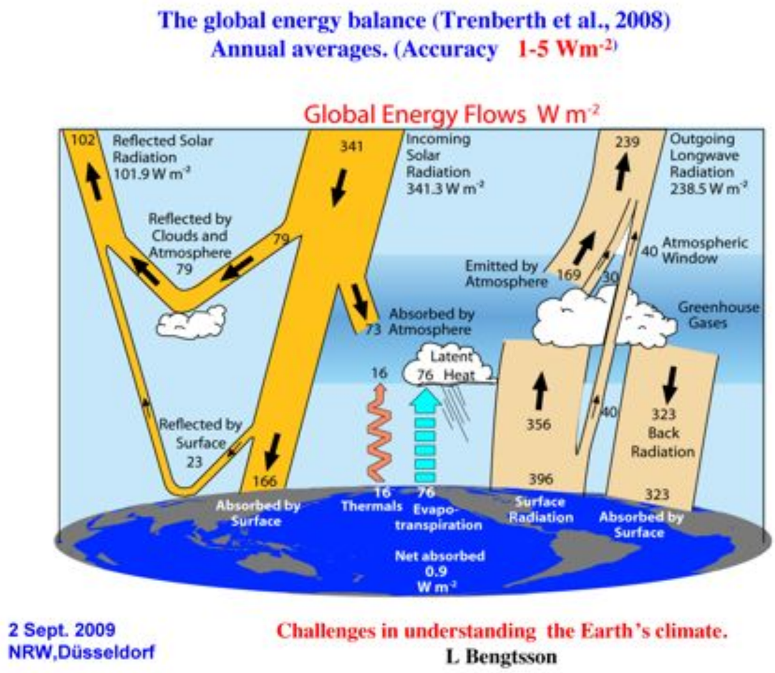
ISSI Book

The outcome of the workshop will be published by ISSI following the same procedure as used for its Space Science Series which are reprinted from Space Science Reviews or Surveys in Geophysics (See http://www.issibern.ch/publications/sssi.html)

Fig.1 The Global energy balance. K. Trenberth et al., 2009.



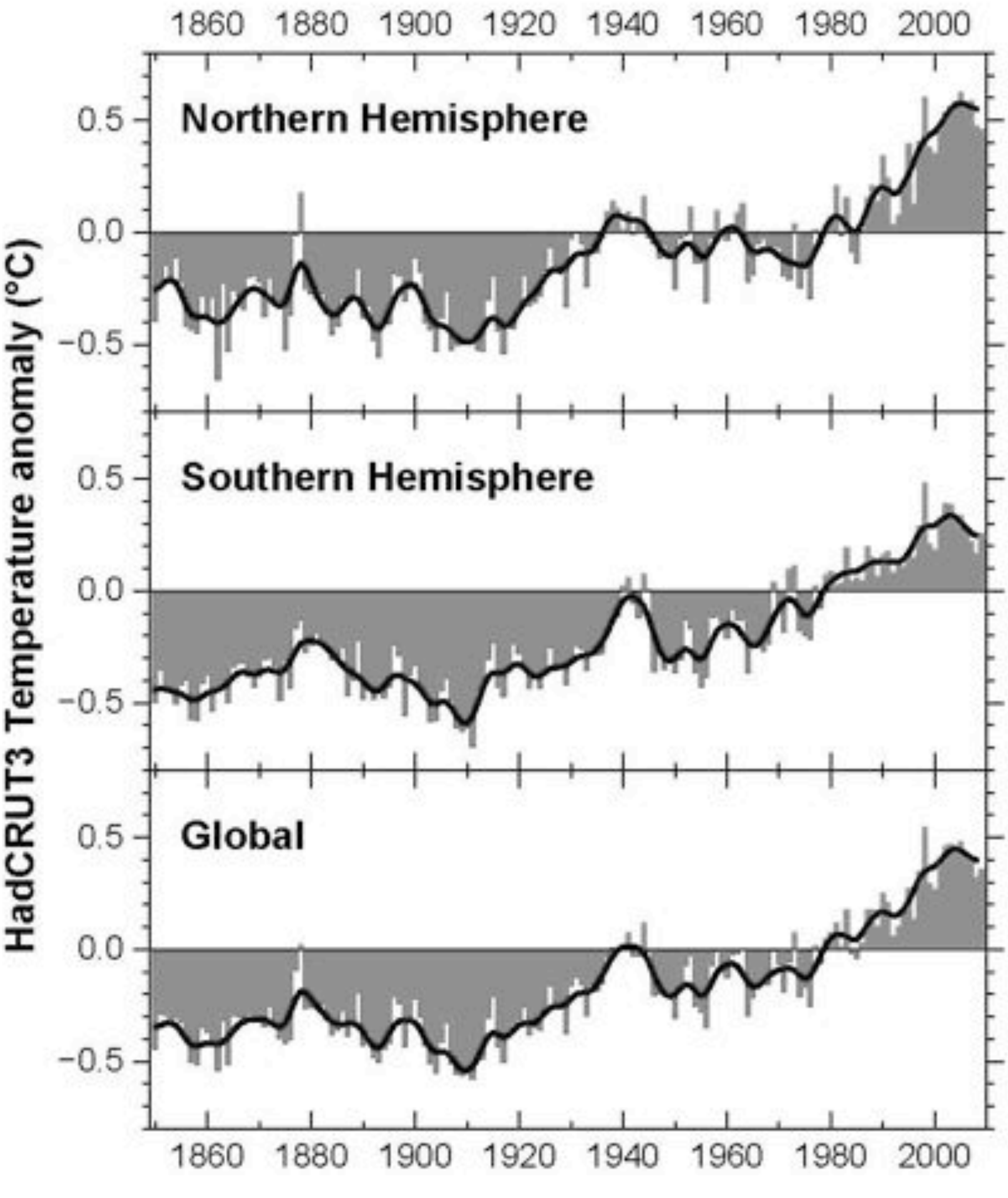


Fig.2 Surface mean temperature 1850-2009. Source: Hadley Centre

Fig. 3 Global mean surface temperature and greenhouse gas forcing 1850-2009. Courtesy S. Schwartz. Mod. L. Bengtsson