Measuring, Monitoring and Understanding Earth's Global Energy Balance

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- Global energy balance provides an excellent framework for Earth science
- Rigorous understanding of limitations in global datasets is required
- A broad remote sensing portfolio using a wide variety of emission sources and mission scenarios is enabling

Key Challenges:

Understanding the Earth's global energy balance, and whether human activities are causing large-scale changes, is a major scientific challenge. This challenge is important to address for intellectual and practical reasons. A gradual warming of the atmosphere, which is hypothesized to occur as a result of human-induced increasing green house gas (GHG) concentrations, may lead to significant impacts on human life, possibly affecting food and water security, natural disasters, weather extremes, and habitability of coastal areas. Warming is fundamentally due to an imbalance between incoming and outgoing energy that manifests itself globally at the top of the atmosphere. Increasing GHG concentrations leads to warming because the bulk emissivity of Earth is changed so that less energy is radiated, and temperatures must rise until a new equilibrium between incoming and outgoing energy is established at higher temperatures. The character of our environment under this new equilibrium is of major interest and concern.

While the factors affecting Earth's equilibrium temperature can and should be understood at ever-finer levels of detail, we must find alternative approaches that do not require the energy balance to be determined from detailed understanding of every contributing process. Fortunately, a series of papers, e.g. by Trenberth et al. (2009, doi:10.1175/2008BAMS2634.1) and Stephens et al., (2012, doi:10.1038/NGEO1580), demonstrate that an advanced understanding of energy balance is already achieved. These papers categorize and quantify the physical processes leading to imbalance, including: incoming and reflected short-wave radiation, atmospheric absorption, surface versus atmospheric reflection and absorption, sensible and latent heating of the atmosphere, and the role of clouds. Each of these categories can be further broken down to finer levels of detail that will occupy scientific investigations for many years to come.

As clearly shown by Stephens et al., (2012), uncertainties can be assigned to these major categories of energy flow. These authors find that the uncertainty of the imbalance as a whole is comparable to the imbalance itself. Thus, the current understanding of the imbalance is inadequate, and projection of future imbalances needs improvement. The uncertainties of individual contributors to the energy budget also exceed the uncertainty of the overall imbalance. Much more needs to be learned, and space-based observations will play a critical role in this research. In future Earth science research, a balance must be achieved between detailed process knowledge and quantifying the broad categories of energy transfer.

The global energy balance perspective involves a broad range of science areas from atmospheric dynamics, to the carbon and water cycles, to solid Earth (volcanic aerosols). Advances in all these areas will lead to reduced uncertainty in the contributors to the energy imbalance. Reducing these uncertainties by observational means will vastly improve our understanding of energy balance. Eventually, based on such observations, models may be constructed that could be more helpful in forecasting future climate.

On the other hand, if an observational focus on the global energy balance is not adopted, progress in understanding climate change may be long in coming. Requiring a detailed understanding of small-scale to meso-scale processes sufficient to constrain contributions to the imbalance is an excellent long-term goal. However, only emphasizing such detailed process knowledge will, in the near term, lead to increased uncertainties associated with individual contributors to the imbalance. The many contributing processes exhibit large variabilities with season, diurnal cycle, geographic location and geophysical condition. Intellectually, understanding this variability is an important goal, but practically, these variabilities are going to tax our intellectual capital to address them all.

The solution is to constrain the major contributors to Earth's energy imbalance using observations wherever possible. This can be done with the right combination of observational systems that gather and process radiant energy and measure thermodynamic quantities in the oceans, land and atmosphere. Our understanding is sufficient to identify the major contributors to balance, but our observational systems so far do not produce adequate constraints.

Timeliness:

The global energy balance as a framework for understanding Earth and climate is of significant practical value. A paper published in 2013 ("Value of information for climate observing systems", Cooke et al., doi:10.1007/s10669-013-9451-8) shows that higher accuracy observing systems reduce the time required to detect the magnitude of climate change, increasing the probability of near-term action by moving away from "business-as-usual" scenarios. Therefore a focus on global energy balance and its change over time, accurately measured, is of high priority.

Why Space?

It is inconceivable to address the global energy balance without space-based data. For example, in the paper by Stephens et al. (2012), satellite observations were used either directly or through gridded reanalysis products. The following satellites contributed data to the paper: CERES (multi-satellite), NASA A-Train low Earth orbiters Terra and Aqua, Geostationary satellites (critical for cloud inventories via the International Satellite Cloud Climatology Project), Cloudsat, CALIPSO (aerosol), MODIS (surface fluxes), TRMM (rainfall), microwave sounders onboard DMSP, NOAA, and MetOp satellites (humidity and precipitation), among others. Although ground based networks are critical for validation and for ocean and soil data at depth, it is not possible to understand the global energy balance without global observations from space.

Responses to the Questions:

a. Is there a capability gap?

Existing and planned programs do not focus on reducing the observational uncertainties in the global energy balance. These uncertainties can only be reduced with a concerted effort. The focus on energy balance need not preempt other scientific investigations, but an over-arching energy theme should influence a wide variety of future Earth science missions.

Even with such a focus, there exists a persistent problem that the Earth science community has not yet fully addressed: the issue of global sampling from satellite. The enormous benefits of space-based sampling in some cases leads to complacency and a lack of critical thinking regarding the products derived from satellites. Once gridded products are developed from satellite data, with the attendant efforts to validate and make them as accurate as possible, there is a tendency to ignore fundamental limitations of these products that hinder observing the global energy balance. Such limitations arise for several reasons that cannot be overcome easily. Examples are: 1) lack of sampling in cloudy regions by infrared remote sensing techniques; 2) poor characterization of surface emissivities particularly over land for microwave remote sensing, 3) insufficient sampling of the full range of precipitation intensity, 4) insufficient vertical resolution of humidity from all-weather sounders (e.g. microwave) 5) insufficient accounting for the episodic nature of precipitation and its impact on global inventories, 6) incomplete geographic coverage, 6) inadequate sampling of the diurnal cycle from slowly precessing or sun-fixed satellite platforms. Such limitations (among others) will bias the observational record of the global energy balance.

The community, therefore, must eschew complacency and embrace activism, to aggressively expand the remote sensing portfolio to include new platforms, new regions of the electromagnetic spectrum, new signal sources, higher spatial resolution and lower revisit times, and new approaches to missions that specifically address gaps that are persistent in the current record. In addition, international coordination should be embraced more aggressively than in the past. A comprehensive and detailed inventory of observational limitations and gaps should be undertaken. Fortunately, Earth science has sufficient first-order understanding of many processes that at least the gaps can be identified.

b. Linking space-based observations with other observations;

Programs are currently in place linking new satellite observations with ground-based observations that permit detailed understanding of physical processes locally. To improve our knowledge of global energy balance, such efforts connecting global observation to process understanding are critical and must continue.

c. Scientific and Societal Benefits

The study by Cooke et al. (2013, doi:10.1007/s10669-013-9451-8) shows that observational accuracies can significantly influence policy decisions. Higher-accuracy observing systems provide the means sooner to achieve the needed confidence to change practices and policies. The potential savings achieved by confidently deviating from "business as usual" practices is in the trillions of dollars.

d. The science communities that would be involved.

Given that we need global observations, and the challenges in bias and coverage that such observations pose, consideration must be given to a wide variety of methods of addressing global observation. This need not always involve space-based observations (e.g. Argo) but it is impossible to address these grand challenges without space as a major platform. The science communities involved in this endeavor encompass the remote sensing and radiative transfer communities, hydrology/water cycle, vegetation/carbon cycle, ocean scientists, and troposphere to stratosphere experts.

In this white paper we have specifically emphasized observations but it should not be inferred that modeling is not of critical importance also, particularly when climate projections are needed. The reason for our emphasis on observations is that observations undergird the scientific method and provide the needed rigor. Whereas theory and modeling are critical, they rest on a foundation of observations that, if incomplete, can only exacerbate our difficulties in understanding global change.