WCRP workshop

"The Earth's Energy Imbalance and its implications"

13 – 16 November 2018, Toulouse, France

Sponsors:

ABSTRACT BOOK - KEYNOTES

SESSION 1: Global estimates of Earth's Energy Imbalance

KEYNOTES:

Measuring the Surface Energy Imbalance from Space *(Tristan L'Ecuyer, Benoit Meyssignac, , and the NASA NEWS science team)*: It is essential to measure Earth Energy Imbalance (EEI) in order to monitor and understand the perturbation of the water and energy flows in the climate system in response to external forcing and in particular to anthropogenic forcing. Over 93% of the excess energy that is gained in response to the EEI is stored in the ocean. For this reason the global ocean heat content (OHC) places a strong constraint on the EEI and the ability to determine the global ocean heat storage change is essential to assess the changes in the global water energy cycle. Two different approaches are currently available to measure the OHC changes from space. The first approach is to measure the net ocean surface fluxes with satellite-based surface radiative and turbulent fluxes. The second is to estimate the thermal expansion of the ocean which is linearly related to the OHC changes. This can be achieved from space by combining satellite altimetry and space gravimetry observations. Both approaches have advantages and disadvantages. The first approach provides all components of the heat exchanged between the atmosphere and ocean, which enables errors in the net regional flux to be computed based on the error in each component. For this reason, the error is traceable and can reveal systematic errors in component fluxes. The disadvantage of this method is that, since component fluxes are typically generated from independent algorithms, the net flux computed by summing up all components over the ocean can be significantly biased from the true EEI. The second approach is intrinsically global and enables to estimate the EEI and its variations at annual time scales with an accuracy of a few tenths of a W.m-2. But it does not, at present, allow regional estimates of the changes in OHC to be derived. In this presentation we summarize the principles of both approach to estimate EEI from space, review the progresses achieved in both methods to date, and provide some perspectives on how they may be advanced or even combined in the future.

Global ocean heat content - From historical to contemporary estimates *(Tim Boyer, Karina von Schuckmann, Lijing Cheng)*: Past and contemporary observing systems for the direct evaluation of global ocean heat content (OHC) can be separated into three periods. The first is linked to historical shipboard in situ ocean temperature measurements. The second period, which starts with satellite altimetry in 1993, includes more complementary observing systems, from remote sensing techniques, fixed stations, modern shipboard measurements to autonomous in situ platforms (http://www.goosocean.org). This era also saw the development of reanalysis systems for data assimilation. The third period, an ongoing "golden era" for OHC, is characterized by a surge in temperature measurements with near global ocean data coverage for the upper 2000 m, mainly from Argo profiling floats and the availability of information for planetary/sea level budget constraint evaluations. This keynote talk will deliver insight in the current state of OHC evaluation based on different approaches, discuss associated uncertainties and challenges, and provides recommendation for improved future OHC estimates.

Net flux at the top of the atmosphere *(Norman Loeb, Seiji Kato, Fred G. Rose, David A. Rutan, Norman G. Loeb, and John T. Fasullo)*: The regional surface energy budget consists of net downward shortwave and longwave radiative fluxes, surface turbulent heat fluxes (latent and sensible heat), and internal energy flux associated with water mass transfer. The sum of these components provides the energy input to the oceans. However, when these flux components are inferred from satellite observations, there is an imbalance of 10 to 15 Wm-2 in the global annual mean net surface energy flux (downward positive), which is more than an order-of-magnitude larger than the Earth energy imbalance. As a result, satellite-derived regional surface energy balance has significant uncertainty. The aim of this analysis is to identify the causes of the surface energy budget residual by examining the regional distribution of the surface energy balance and by using surface observations to quantify the uncertainty in the radiative components. We use satellite products produced by the Clouds and the Earth's Radiant Energy System (CERES) for surface radiation, Global Precipitation Climatology Project (GPCP) for precipitation, SeaFlux for turbulent fluxes, and ERA-Interim for energy divergence in the atmosphere. We show that the annual global mean ocean surface energy balance residual computed with these data sets is substantially larger than the annual mean water mass balance residual at the global ocean surface. While surface net radiative flux is used to calculate the surface energy balance, it is not used in the computation of the mass balance. The regional surface energy balance residual indicates that the largest contribution to the global energy balance residual occurs over the tropical oceans. The bias in monthly mean downward shortwave and longwave radiative flux over ocean is, respectively, 4.7 Wm-2 and 1.0 Wm-2 compared with radiative flux measured at 46 buoys that are predominately located in tropics. We estimate the uncertainty in the annual global mean surface net radiative flux over ocean to be 8.6 Wm-2 with an assumption that errors in shortwave and longwave upward and downward radiative fluxes are uncorrelated, which gives an upper bound of the 1-sigma uncertainty. These results suggest that the surface energy balance residual over ocean cannot entirely be explained by a bias in surface radiative flux. Uncertainties in the surface turbulent fluxes likely contribute substantially to the excessive surface energy budget residual.

The role of cryosphere in the Earth Energy Imbalance (heat for melting ice) *(Fiammetta Straneo)*: Multiple components of the Earth's cryosphere have undergone rapid change over the last few decades. These include mass loss from the Greenland and Antarctic ice sheets, mass loss from ice caps and glaciers in polar and mountain regions, loss in Arctic terrestrial snow and sea-ice, polar and mountain permafrost thaw, and a reduction in the seasonal snow-cover of mountain regions. The reduction in mass of these different cryosphere components implies a supply of heat to melt the ice (or the ground) and thus represents a heat sink for the Earth System which must be accounted for in assessing the Earth's Energy Imbalance (EEI). The contribution of the cryosphere to the EEI was assessed to be about 4% in the Fifth Assessment Report. Here, we present observationally-based, updated estimates for changes in the major cryosphere components and present understanding of energy exchanges associated with ice loss. An updated contribution of the cryosphere to the EEI will be presented based on published literature and activities of the Climate and Cryosphere Project (CliC) of the World Climate Research Program.

SESSION 2: Regional Energy Budgets and Energy Transports

Keynotes:

Regional energy budget constraint approach *(Kevin Trenberth)*: The Earth's energy imbalance is caused by increasing greenhouse gases in the atmosphere and its partitioning between atmospheric, ocean, cryosphere and land heat reservoirs govern the rate at which the global climate evolves. Most of the imbalance, over 90%, goes into the ocean and accordingly ocean heat content (OHC) provides a primary indicator of climate change, along with sea level rise. Natural variability, especially El Niño, plays a small role globally, but can be significant locally. Regional energy and water imbalances drive heat transport, in part through ocean currents, evaporation, precipitation, and runoff. By adopting a holistic approach that includes top-of-atmosphere (TOA) radiation, vertically-integrated atmospheric transports, surface fluxes, and ocean transports, closure of the energy and water cycles on regional scales can be achieved. A new formulation of the energetics of the atmosphere and the climate system will be described and it is used to refine estimates of the surface energy fluxes as a residual of TOA and atmospheric energetics. When the surface flux is combined with OHC estimates, we can explore the meridional ocean heat transports during ENSO and AMOC in new ways.

Regional Earth system view from the cryosphere perspective *(Andrew Shepherd)*:

Covariance and structural error in regional heat budgets *(Keith Haines, Bo Do, Chris Thomas)*: Correlated errors are always likely to be present in EO based datasets as shared retrieval methods are used over large areas and also potentially due to the spatial structures of state dependent biases. When EO based fluxes are then combined in inverse models, as in the NASA Energy and Water cycle Study, the results may be very sensitive to the regions chosen, and to the specified covariance errors between regions. We will review ongoing work to assess correlated and state-dependent errors in EO based datasets, and look at ways of estimating error covariances using multiple EO flux products in combination with in situ, and reanalysis based datasets. Turbulent fluxes over the oceans, have been a focus for some of this work. Large-scale spatially coherent patterns are evident in error reconstructions based on EOFs of the differences between these products and against ICOADS in situ observations and ocean flux buoys, indicating that the uncertainties of the satellite-derived data are often composed of spatially correlated biases. These methods may provide a way to define more accurate error covariance representations of EO flux products. We will also use the NEWS inverse model to show the impact of correlated errors in ocean turbulent fluxes, on the global and regional heat and water budget solutions, and suggest better ways to test and constrain these analyses. Further inverse model results are described in the abstract of Thomas et al.

The role of land in the Earth Energy Imbalance *(Sonia I. Seneviratne, Pierre Gentine, Hugo Beltrami, Edouard Davin, Almudena Garcia Garcia, Mathias Hauser, and Francesco J. Cuesta Valero):* Land processes play an important role in the climate system1. While the largest amount of heat accumulated through greenhouse gas forcing is stored in the oceans2, it is uncertain how large the contribution of land heat storage for the overall Earth Energy Imbalance is. Multiple lines of evidence based on ground heat flux plate measurements across the globe and deep boreholes (>700m) suggest that in the recent decade continental heat storage is much higher than previous estimates at about 0.25W/m2. In addition, land heat storage is shown to play an important role for the diurnal cycle of temperature and to be likely not well constrained in current climate models.

SESSION 3: Earth energy imbalance evaluation and budget closure for climate models and reanalyses

KEYNOTES:

The challenge of Energy budget closure in Earth system models *(Peter Lauritzen)***:** A closed total energy (TE) budget is of utmost importance in coupled climate system modeling; in particular, the dynamical core or physics-dynamics coupling should ideally not lead to spurious TE sources/sinks. To assess this in a global climate model, a detailed analysis of the spurious sources/sinks of TE in NCAR's Community Atmosphere Model (CAM) is given. This includes spurious sources/sinks associated with the parameterization suite, the dynamical core, TE definition discrepancies and physics-dynamics coupling.

Evaluation of the Earth's Energy Imbalance in ocean reanalyzes *(Matt Palmer, Magdalena Balmaseda, Marie Drevillon, Michael Mayer, Simona Masina, Andrea Storto):* Ocean reanalyses and ocean state estimates (hereafter "ORAs") combine observations with a dynamical ocean model using a variety of model configurations and data assimilation approaches. ORAs are increasingly being used to gain insights into the time-evolution of Earth's Energy Imbalance (EEI) and also regional ocean changes. This presentation will review recent and ongoing ORA activities relevant to EEI, with example applications. A key strength of ORAs is their ability to synthesize a large number of observational data streams into a dynamically consistent estimate of the ocean state and propagate information into unobserved regions of the ocean and/or parameters (e.g. integrated heat transports). However, care must be taken around factors such as model drift, heat/freshwater conservation and inhomogeneities in the input observations and/or their sampling characteristics. Ensemble approaches are useful means to assess uncertainties across a range of ORA products, highlight the improvement in systems over time and contribute to the characterization of the error bars of energy budget terms.

Ice sheets and their coupling in Earth system models: a little energy could go a long way *(Sophie Nowicki)*: Ice sheets in the contemporary climate system are not in steady state: they exchange energy and mass between the atmosphere, ocean, and underlying bedrock. An adequate assessment of these processes is important for predicting future sea level change for example. Current ice sheet models have evolved rapidly in the last decades to provide a sophisticated representation of ice flow, and are now being coupled to Earth System Models. Adequate treatment of the exchanges of heat and mass at the ice sheet boundaries significantly affect model simulations, and is the subject of current research. Here, we review the current methods, recent development and limitations for coupling ice sheets in Earth System Models, and explore some of the challenges with regards to ice sheets and the Earth Energy Imbalance.