CLIVAR research focus

Consistency between planetary energy balance and ocean heat storage (CONCEPT-HEAT)

Co-chairs:

K. von Schuckmann, K. Trenberth

Scientific steering team members:

C.-A. Clayson; C. Domingues; S. Gulev; K. Haines; N. Loeb; M. Palmer; P.-P. Mathieu; R. Weller; M. Wild; Y. Xue

1st CONCEPT-HEAT workshop at Met Office, Exeter, UK: 29.09.-01.10.2015
Climate is the result of energy transfer between the different components of the Earth's system.

Energy flows alter clouds, and weather and internal climate modes can temporarily alter the energy balance for periods of days to several decades.

The only practical way to monitor climate change at different time scales is to continually assess the energy, mainly in the form of heat, in the climate system.
Since the accelerated increased concentration of greenhouse gases from human activities, energy is not balanced, leading to an accumulation of heat in the climate system.
Positive Earth’s Energy Imbalance: accumulation and storage of heat

von Schuckmann et al., 2015, under review
“Symptoms” of positive EEI

von Schuckmann at al., 2015, under review
Different approaches determining Earth’s energy imbalance

**OCEAN: MAIN ENERGY RESERVOIR**

**GLOBAL ENERGY BUDGET AT THE SURFACE**

**NET RADIATION AT TOA: ASR - OLR**

**Surface flux**

- OAFlux+SRB
- OAFlux+ISCCP
- CFSR
- ERAI
- NO2
- ER40
- 20CR
- NCI
- NOC1.1
- Adj. COREv2

- Josey et al., 2015

**Radiation at TOA**

- Loeb et al., 2012

**Ocean heat content**

**Hindcast and climate projection**

- IPCC, 2013

- Upper ocean
- Deep ocean
- Ice
- Land
- Atmosphere
- Uncertainty

- 3D Grid box
- Back radiation
- Incoming solar radiation

- http://www.ias.ethz.ch
Different approaches determining Earth’s energy imbalance

Large uncertainties in our estimates challenge our ability to infer the absolute measure of the Earth Energy Imbalance and its changes over time.

An ongoing accounting of where heat goes and its manifestations is a great need and has implications for interpreting the recent past and immediate future.

Improving the knowledge and observational capability necessary to “track” the energy flows through the climate system is critical to better understand the relationships between climate forcing, response, variability and future changes.
An overall goal is to **bring together different climate research communities** all concerned with the energy flows in the Earth’s System to advance on the **understanding of the uncertainties through budget constraints**:

- Atmospheric radiation
- Ocean Heat Content
- Earth’s surface fluxes
- Climate variability and change
- Data assimilation & operational services (R&D)
- Climate projection
- Global sea level

**Remote sensing**

**In situ**

**Reanalysis systems**

**Numerical model**
More precisely, this CLIVAR research focus CONCEPT-HEAT has the main objective to build up a pluri-disciplinary synergy community for climate research aiming to work on two different issues:

1. Quantify Earth’s energy imbalance, the ocean heat budget, and atmosphere-ocean turbulent and radiative heat fluxes, their observational uncertainty, and their variability for a range of time and space scales using different observing strategies (e.g., in-situ ocean, satellite), reanalysis systems, and climate models.

2. Analyze the consistency between the satellite-based planetary heat balance and ocean heat storage estimates, using data sets and information products from global observing systems (remote sensing and in situ) and ocean reanalysis, and compare these results to outputs from climate models to obtain validation requirements (for model and observations).
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Consistency between planetary energy balance and ocean heat storage

“What are the expected outcome and who will use the info?”

**Outcome**
- refinement of the global climate research community
- Enhancement on uncertainty evaluation and assessment of the different components of the climate budgets by assessing already applied methods, developing new methods and inter-comparison initiatives (link to ongoing initiatives, and development of new priorities and initiate their realization)
- Insight into climate research topics, and link to socioeconomic impacts

**Use:**
- climate research community
- global observing system programs, institutions, initiatives and operational centers (using recommendations and perspectives for climate research applications)
- internationally organized scientific initiatives and programs
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Cross-cutting initiative
2012: Presentation of CONCEPT-HEAT (ideas, objectives): CLIVAR SSG meeting

2013: Joint CLIVAR-ESA scientific consultation workshop on: EO Measurement Constraints on OHC

2014-2015: ISSI international working group
The absolute measure of the Earth Energy Imbalance and its changes over time are vital pieces of information related to climate change as this is the single quantity defining the status of global climate change and expectations for continued global warming.

ISSI working group: “Consistency of Integrated Observing Systems monitoring the energy flows in the Earth System”

First meeting June 2014, Bern, Switzerland

K. von Schuckmann
A. Cazenave, D. Chambers,
J. Hansen, S. Josey, Y. Kosaka,
N. Loeb, P.P. Mathieu, B.
Meyssignac, M. Palmer, K.
Trenberth, M. Wild

Perspective paper NCC under review
(von Schuckmann et al., 2015)
CLIVAR CONCEPT-HEAT: Development

2012: Presentation of CONCEPT-HEAT (ideas, objectives): CLIVAR SSG meeting

2013: Joint CLIVAR-ESA scientific consultation workshop on: EO Measurement Constraints on OHC

2014-2015: ISSI international working group

2014-2015: ESA STSE OHF
www.oceanheatflux.org

2014 (July) Pan-CLIVAR: Break-out session: Scientific questions and white paper

2014 (November) Finalization of the CONCEPT-HEAT white paper

2015: Start of implementation phase after CLIVAR SSG 2014 meeting

2015: Establishment of the CONCEPT-HEAT scientific steering team

2015 (Sept./Oct.): 1st joint GSOP/CONCEPT heat meeting
1st CONCEPT HEAT workshop

... future development for the next 3-5 years ...
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Consistency between planetary energy balance and ocean heat storage

Key scientific questions

Question A: What is the magnitude and the uncertainties of our estimates of Earth's energy imbalance (EEI), and how does it vary over time?

Question B: Can consistency between planetary heat balance and ocean heat storage achieved and what are the major limitations?

Question C: How are TOA net radiation and ocean heating rate distributed in space and time?

Question D: How can we improve validation requirements for and from coupled climate models to improve estimates of EEI?

Question E: How can we better constrain the surface energy fluxes and their spatio-temporal variations at regional scale?
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<th>DAY 1:</th>
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| **Session 1** - The Earth’s energy budget  
  session convener: M. Palmer |
| **Session 2** - Energy flow as estimated from reanalyses and climate models  
  session convener: K. Haines |

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<th>DAY 2:</th>
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<td><strong>Session 3</strong> - Air-Sea fluxes; session convener: S. Gulev</td>
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| **Session 4** - OHC and atmospheric radiation  
  session convener: C. Domingues |

| **Evening**: common dinner (8 pm) |

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<th>DAY 3:</th>
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| **Synthesis-sessions** - Consistency between planetary energy balance and ocean heat storage  
  conveners: T. L’Ecuyer, K. Haines, M. Palmer, M. Cronin (rapporteur). |
Principal scientific question:

“What are the magnitude and the uncertainties of our estimates of Earth's energy imbalance (EEI), and how does it vary over time?”

• Each existing independent approach to determine energy flows in the Earth's system has advantages and drawbacks (sampling capability and accuracy) leading to different estimates, and associated uncertainties.

• Different communities are involved in delivering estimates of EEI from independent approaches. They have not worked closely together to allow different assumptions to be compared and ensure that uncertainties are reduced.

• Evaluating and reconciling the resulting budget imbalance is a key emerging research topic in climate science. It has the potential to bring different communities together to make a major contribution to reducing climate change uncertainties.
Recommendations/ Research priorities

- Develop framework to **develop and strengthen a CONCEPT-HEAT synergy community** joining expertise of all concerned with the energy flow through the Earth’s climate system. This requires funded collaboration initiatives (network funding for workshops, working visits at laboratories, summer school, etc…): NCAR ASP Colloquium? Session at CLIVAR OSC meeting 2016?, .. Others?

- Develop a **community review paper** on all components of EEI. Who? Maybe new ISSI proposal (for example “workshop”); other frameworks to develop? Or special issue as outcome of this workshop?

- **Improve accessibility and information content of products** to evaluate the different components of EEI for use by wider community. Develop improved evaluation of these products to quantify strengths and weaknesses and provide advice to a wider range of potential users. ➔ NCAR Climate Data Guide? EU Copernicus Programme (Copernicus Marine and Environmental Monitoring Service (CMEMS); Copernicus Climate Change Service (3CS)), others?

- Develop **platform for communication** and information exchange between different communities: CONCEPT-HEAT webpage (e.g. list of key publications, ..)?

- Develop **link to new WCRP Concept Team** on Near-Term Climate Prediction
Principal scientific question:

“How can we improve validation requirements for and from climate models and reanalysis systems to improve estimates of EEI?”

- Need to further understand the role of resolution of climate models and reanalysis models in resolving natural climate variability and providing accurate error estimates, as well as to understand the relevant model physics and parameterizations that need further improvements.
- The combination of ocean models, atmospheric forcing fluxes and ocean observations via data assimilation methods has the potential to provide more accurate information than observation-only or model-only estimations.
- A prerequisite is an adequate representation of the energy budget in climate models. This requires a careful validation process and adequate reference datasets.
Liaise with climate modelling community to define suitable EEI/OHC patterns/metrics for testing climate variability hypotheses emerging from climate modelling simulations and characterize range of model simulations of ocean heat uptake and mechanisms.

Assess the representation of the energy budgets in climate models with adequate reference datasets.

Controlled experiments to assess attribution of different processes on EEI and perform inter-comparisons of coupled climate model responses to radiative forcings and observed changes in different components of the TOA radiation budget.

Develop observational constraints on future sea level rise and transient surface temperature rise; develop process-based relationships between observable quantities and the emergent signals of change, net energy gain and the re-arrangement of energy within the system for an assessment of future climate projections.

Utilize experiments with coupled climate models with eddy resolving ocean blocks, in particular to assess how these phenomena are undercounted (poorly counted) in the existing climate models. The first pilot results can be generated at regional level (for key-areas), while in the future global assessment is necessary.
Session 2 - Energy flow as estimated from reanalyses and climate models, Session convener: K. Haines

Recommendations/ Research priorities

- Evaluate **OHC changes from the ensemble of current ocean reanalyses** and work with the OHC community to identify and understand differences, coming from different observations such as gap filling, data assimilation methodologies and parameter estimates (e.g. fluxes).

- Use of self-consistent models in **assessing and improving dataset homogeneity** and perform signal (from emergent patterns of OHC change) to noise (from internal variability) analysis to reveal fundamental information on the extension of the in situ observing system (e.g. test the importance of ice-covered ocean vs. shelf seas vs. deep ocean (> 2000m depth) and examine the role of mesoscale noise).

- Liaise with the reanalysis community to **define suitable climate variability and change patterns/metrics** for testing climate variability hypotheses and to develop improved validation frameworks for and from reanalysis systems ➔ link to ORA IP, COST EOS

- **Continue performance of multi-analysis reanalysis ensemble approach** to study the uncertainties [as successfully performed during the GSOP initiative (Clivar Exchanges No.64)] and quantify and reduce model biases by using recent well observed periods and any reanalysis estimates.
Principal scientific question:

“How can we better constrain the surface energy fluxes and their spatio-temporal variations at regional scale?”

- The **present level of uncertainties** in global ocean estimates of heat and moisture fluxes is **not adequate for many applications**, including global and regional mass and energy budget closure and variability on different time scales.

- **Biases in surface fluxes lead to the systematic errors in climate models** and preclude their efficient use in climate simulation. Without accurate estimates of surface fluxes it is difficult to engage the predictive potential of the ocean in weather and climate prediction.

- **Improvements in all aspects** of producing surface flux estimates, including parameterizations, measurement techniques and post-processing are required for further progress.
Quantify different types of uncertainties of surface fluxes, their correlation structure, sensitivity to uncertain parameters and satellite retrieval schemes to improve the usefulness of global flux products.

Develop an innovative ensemble approach to generate multiple realizations of flux surface products, combining the individual strengths of existing data sets, the latest knowledge in bulk formulations and associated input data, and the most recent efforts in re-processing flux data sets of climate quality (e.g. ESA CCI).

Exploit integral constraints (as suggested by Yu et al 2012) along with statistical approaches using reconstruction of probability density functions for surface fluxes (Gulev and Belyaev 2012) to check consistency of the Net Heat Flux product components and, in particular, by use of Argo data on a series of regional "Cages" (ESA-OHF).

Develop a community-led flux platform to share, access and inter-compare easily 6 different sets of flux climatologies, and their input data (e.g. different SSM/I data streams), thereby fostering close collaboration between different communities, as well as new ways of combining in situ measurements and flux data.
Complement the GSOP inventory of surface flux products with “assessment”-type information regarding the strengths and weaknesses of the various flux products, in an effort analogous to the “Climate Data Guide” (NCAR/UCAR, USA), to guide the in selecting the best product for their application across the multitude of flux products available on the web.

Evaluate potential for improving surface heat flux estimates based on ocean or coupled reanalysis products.

Ensure continuation and foster expansion of high quality in situ measurements in remote locations, such as on ocean platforms and small islands, as anchor sites for the assessment of modelling and remote sensing products.
Principal scientific questions:

“How are TOA net radiation and ocean heating rate distributed in space and time?”

“Can consistency between planetary heat balance and ocean heat storage achieved and what are the major limitations?”

• Continued **assessment and attribution studies** of regional natural climate variability are essential to improve our estimates of global changes. Observed climate variations such as the current hiatus or unresolved inconsistencies of climate observations underpin the need for fundamental research activities on the regional distribution of TOA and OHC (including vertical distribution), as well as their implication for their global estimates.

• There is also an urgent need to evaluate the **relative importance of currently under-sampled regions of ocean heat content change** (ice-covered ocean, marginal seas and deep ocean) and to understand how heat is transferred vertically. We have to evaluate how regional patterns change in time and if regional OHC tendency patterns can, along with other patterns e.g. regional sea level, be used to test/falsify model hypotheses.
Assessment of consistency between planetary heat balance and ocean heat storage as a multi-analysis approach to investigate uncertainties, quantify inconsistencies and understand their causes.

To benchmark our ability to monitor OHC changes at sub-annual to interannual time scales during the Argo era by using an agreed delayed-mode Argo input data set and ocean reanalyses and perform test of gap filling in space and time from ocean reanalyses (by using ocean heat transport).

Carry out a comparison of mapping methods using “pseudo profiles” in a “perfect model” experiment (including both high-resolution ocean model coupled climate model simulations) to get insights into the pros and cons of the different mapping methods and assumptions in a known system.

To utilize massively available SST (and potentially SSS) data along with mean sea level gauge records for the further cross-validation of estimates based upon data from different underwater systems. In addition, use of mean sea level from satellite altimetry corrected for ocean mass variations deduced from GRACE to analyze current biases from in situ sampling.
To achieve advancements in **commonly agreed data quality control issues and management of data and metadata archeology**: for the historical in situ database: joint activity with CLIVAR-GSOP Coordinated Quality-Control of Global Subsurface Ocean Climate Observations – the IQuOD initiative [www.iquod.org]; for the Argo era, in joint collaboration with the international Argo program.

- Evaluate the **relative importance of the ice-covered ocean, marginal seas and deep ocean (> 2000m)** of ocean heat content change and to understand how heat is transferred vertically, with the objective to develop recommendations for observing system design (GOOS).

- Use of ocean reanalyses to **analyze physical processes for exchanging OHC with the deep ocean** through mechanisms of diffusion and deep water formation and how regional patterns change in time

- Use of ocean reanalyses to **analyze processes and forcing (momentum and buoyancy) of regional natural climate variability** and their impact on the global budget

- Analyze if regional OHC tendency patterns can, along with other patterns e.g. regional sea level, be used to **test/falsify model hypotheses**.
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Three main objectives will be implemented in the review paper:

- report on the survey of scientific understanding
- develop an overview on recommendations for global climate observing systems and climate tools
- develop an overview on recommendations for future coordinated research through dedicated initiatives, well defined key questions and key challenges for climate research on the Earth’s energy budget