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1. The new CLIVAR research opportunity on planetary heat balance

Climate is very much about exchange of energy in the Earth System, and in particular in the form of heat. Quantifying these exchanges, and in particular how much heat has been generated by human activities, and how it affects our climate system is one of the key challenges faced by the climate research community (IPCC). Over the last decades, many studies based on both models and observations have been performed, leading to significant advances in our understanding of the energy exchanges (Hansen et al., 2005; Bindoff et al. 2007; Hansen et al., 2011; Church et al., 2011; Trenberth and Fasullo, 2011; Bengtsson et al., 2012; Loeb et al., 2012; Stephens et al., 2012), while highlighting at the same time large uncertainties in the estimate of the energy flows (Trenberth, 2012).

The global ocean plays a critical role in regulating these energy flows, being by far the most important heat reservoir due to its enormous heat storage and transport capacity. Over the last 50 years, it is estimated that a large share (about 90%) of the extra incoming heat at the Top Of the Atmosphere (TOA) has penetrated the ocean through net surface heat fluxes, leading to an observed increase of the Ocean Heat Content (OHC) (von Schuckmann & Le Traon, 2011), accompanied by a regional redistribution of heat through lateral transport. The rest of the extra heat being used to melt continental ice and warm the atmosphere and land surface.

The role of the ocean in energy uptake, and in particular the deep ocean, has now become one of the hot topics in climate science following the emerging climate debate regarding the issue of an apparent "plateau" in global surface temperature over approximately the last 15 years. The issue is that over this so-called "hiatus" period, the global Earth surface temperature has remained around the same level, while the Greenhouse Gas emissions, the global OHC and the Sea Surface Height have all continued to rise, thereby raising the question of where the extra heat building up in the system is going. This puzzle of the so-called "missing energy" or "recent pause in warming" has now reached the public sphere (The Economist, 2013, Climate science: a sensitive matter) and is also exploited by climate deniers as a sign of global warming slow down. Intensive research efforts using data and model experiments are currently ongoing to explore the possible causes of the plateau (e.g. Guemas et al., 2013; Balmaseda et al., 2013; URL-13, URL-14). Scientists have suggested that the heat might be penetrating the deep ocean, beneath 700 meters, where there have not been reliable temperature measurements in the past (Palmer et al., 2011). Developing the knowledge, and observational capability, necessary to "track" the energy flows through the climate system is therefore critical to better understand the relationships between climate forcing, response, variability and future changes (Allan, 2011).

In this context, the Ocean-climate system - Variability, Predictability and Change (CLIVAR) project [URL-1] of the World Climate Research Programme (WCRP) has recently established a new research opportunity on "*Consistency between Planetary Heat Balance and Ocean Heat Storage*" [URL-2]. The main objective of the CLIVAR cross-cutting activity is to better understand the "*role of the ocean in energy uptake*" by analyzing consistency of heat budget components as seen by ***independent*** global observing systems, including (i) Earth Observation (EO) satellite data, (ii) *in-situ* measurements of ocean heat content storage changes, and (iii) Ocean reanalysis for heat transports and exchanges. Each of these independent approaches has its own advantages and drawbacks in terms of sampling capability and accuracy, leading to different estimates, and associated uncertainties of budget imbalance. *Reconciling* these different estimates to close the energy budget is a key emerging research topic in climate science.

To address the EO component of the CLIVAR research opportunity, the European Space Agency (ESA) is planning to start an activity on "Ocean Heat Flux" in partnership with CLIVAR within the framework of the ESA Support to Science Element (STSE)[1] programme [URL-3].

[1] STSE represents a pathfinder for science and innovation providing a flexible mechanism to address the scientific needs and requirements of the Earth System Science Community in terms of novel observations, new algorithms and products and innovative Earth science results.

2. Focus on Ocean Surface Flux Research

Air-sea fluxes are considered central to climate research given their key role in exchanges of energy. As such, air-sea fluxes have long been a *strategic* focus of the WCRP activities leading to the creation of several working groups, reviews, and publications. Also characterizing the uncertainty and biases in fluxes is essential to address the big scientific challenges related to the Earth Energy budget, energy flows and understanding the recent pause in global warming.

Taylor *et al.* (2010) performed a comprehensive review of the various flux data sets, as part of the Joint WCRP/SCOR Working Group on Air-Sea Fluxes (WGASF), describing their strengths, weaknesses, requirements, retrieval methods, and range of applications from constraining models (e.g. wave, ocean, forecast), to water/energy cycle and climate studies. Following this study, a research action plan regarding fluxes has been developed by the WCRP Ocean Atmosphere Panel (WOAP, 2012). More recently, the issue of air-sea flux has been addressed through the CLIVAR Global Synthesis and Observations Panel (GSOP) panel [URL-5], which hold a series of meetings to develop a flux inventory of air-sea fluxes and good practices for their "evaluation" (Josey & Smith, 2006). In particular, the recent meeting of GSOP in Woods Hole in 2012 led to a series of recommendations on how to use regional heat constraints to calibrate fluxes (Yu *et al.*, 2012). CLIVAR has also set-up a dedicated "Working Group on High Latitude Surface Fluxes", who established guidelines and recommendations (Bourassa et al., 2013) to address the unique challenges of flux measurements in high-latitude regions.

Air-sea interaction research is also by nature a "*cross-cutting topic*" addressing multiple international scientific programmes, such as the Surface Ocean Lower Atmosphere Study (SOLAS) for biogeochemical fluxes, and the Global Energy & Water Exchange Project (GEWEX) for LandFlux, as well as the long standing SeaFlux efforts.

Quantifying heat fluxes to the required level of accuracy needed to support the various applications identified by WGASF is a very challenging task as net fluxes are generally relatively *small*, being the difference of large diverse components, viz. from short and longwave radiation, latent and sensible turbulent fluxes. Different applications of air-sea fluxes require different resolutions, sampling and levels of accuracy (Taylor et al., 2010). For example, climate studies are one of the most demanding and challenging applications in terms of accuracy, as the global Net Heat Flux should be quantified within a few W/m^2 in order to close the energy budget (e.g. the IPCC (2007) estimated a global Radiative Forcing at the TOA of about +1.6 W/m^2, between 0.6 and 2.4 W/m^2), while the magnitude of the component fluxes is much larger (e.g. order a few 100 W/m^2), and can vary significantly in space and time.

Hence, estimating global fluxes poses *formidable challenges*. It is therefore not surprising that most of the flux data sets available today suffer from *systematic biases* and *fail to satisfy energy constraints*. At the same time, this supports the case for major research efforts to address this key issue.

Of particular interest for the new CLIVAR research activity, is the surface exchange of energy in the form of heat. The Net Heat Flux includes two radiative components of Short Wave Flux (SWF) (radiation whose source is the sun) and Long Wave Flux (LWF) (thermal infrared emissions), and two turbulent components of Sensible Heat Flux (SHF) (related to air-sea temperature differences) and Latent Heat Flux (LHF) (related to evaporation).

The surface radiative fluxes are generally derived from ground measurements and models, or estimated by satellites using Radiative Transfer Models in combination with observations of the TOA fluxes, composition of the atmosphere (e.g. amount of water vapour, ozone, cloud, aerosols) and surface properties (e.g. albedo) (Pinker *et al.* 1995).

In contrast, turbulent fluxes are indirectly estimated from a set of basic state variables and exchange coefficients using "bulk formulae", making their estimation a very specific problem differing from the estimation of the radiative fluxes. Today most of the basic state variables necessary for estimating turbulent fluxes, such as wind stress/speed, Sea Surface Temperature (SST), sea-state and surface humidity, can be derived from EO data, thereby making EO an essential tool to quantify fluxes at the global scale. One exception is the atmospheric surface air temperature, which affects air-sea exchanges, the atmosphere stability and transfer coefficients.

Over recent decades, major efforts have been made to generate a variety of flux data climatologies, including both the radiative component (e.g. International Satellite Cloud Climatology Project - ISCCP) driven by GEWEX efforts and the turbulent component. The turbulent flux climatologies available today are based on traditional bulk formulae based either on in-situ data alone, on EO data alone or on a mix of both along with models. In particular, representative data sets include:

- In-situ: (i) National Oceanography Centre (NOCS2.0) (Berry & Kent, 2010), (ii) Florida State University (FSU) (Bourassa et al., 2005) based on the International Comprehensive Ocean Atmosphere Dataset (ICOADS),
- EO: (i) Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data (HOAPS) (Fenning *et al.*, 2012; Anderson *et al.*, 2010), (ii) Institut Français de Recherche pour l'Exploitation de la MER (IFREMER) (Bentamy et al., 2003), (iii) Japanese Ocean Flux data sets with the Use of Remote sensing Observations (J-OFURO) (Kubota et al. 2002),
- Hybrid: (i) Objectively Analysed Fluxes (OAFLUX) (Yu et al., 2004), (ii) Common Ocean-ice Reference Experiments (CORE2) (Large & Yeager, 2009) modified to give global closure, (iii) Goddard Satellite-based Surface Turbulent Fluxes (GSSTF2) (Chou et al. 2003),
- Atmospheric Re-analysis: (i) the National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR, i.e. NCEP 1), (ii) NCEP/Department Of Energy (NCEP/DOE, i.e. NCEP2), (iii) the European Centre for Medium-Range Forecast (ECMWF) 40-yrs reanalysis ERA-40, (iii) the NASA Modern Era Retrospective-analysis for Research and Applications (MERRA), (iv) the new generation re-analysis for climate ECMWF ERA-Interim and ERA-Clim (Dee et al., 2011), and the Japanese JRA-25 (Onogi et al., 2005),
- Ocean Synthesis: (i) MyOcean products (Ferry et al., 2011), (ii) ECMWF Ocean Re-analysis System (ORAS) (Balmaseda et al., 2013) and (iii) Estimating the Circulation and Climate of the Ocean (ECCO).

  The EO-based fluxes are widely used by the scientific community for a variety of applications ranging from forcing ocean circulation models (e.g. Ayina et al. 2006), to study of climate variability and model evaluation. In particular, the use of fluxes for evaluation of coupled models is of increasing importance (and relevance for this project) given the emergence in Europe of the new generation of coupled reanalysis CERA-20C developed by ECMWF with support of ESA [URL-6].

It is worth noting that most of the current EO flux data sets are based on non-European sensors, such as the Advanced Very High Resolution Radiometer (AVHRR), QuikSCAT, and the Special Sensor Microwave/Imager (SSM/I). The current development of a new generation of climate quality observational products within the framework of the ESA Climate Change Initiative (CCI) [URL-7] is therefore very timely to derive from these a new air-sea flux dataset.

2.1 Evaluation of Fluxes

The various data sets have been extensively “compared” and “evaluated” against in-situ measurements within the framework of the “SeaFlux” inter-comparison exercise (Curry et al., 2004) and other assessments (Smith et al., 2011). Many studies have highlighted that the data sets suffer from *systematic biases* and *fail to satisfy energy constraints*.

A key element of the “*evaluation*” of these data sets is local comparison against in-situ measurements (Clayson et al., 1996), which include both direct measurements of the turbulent fluxes (eddy correlation) and collocated measurements of mean ocean parameters for calculation of the flux through bulk parameterisations. These meteorological and ocean data are available from a variety of research ships and high quality surface flux buoys. Although the number of buoys has increased significantly over the last decade, their sampling still remains quite limited and uneven, with concentration in the tropical regions with just a limited number of mid-latitude deployments and nearly *none* at high latitudes (poleward of 50deg latitude).

However, such traditional approach suffers from several shortcomings (Song & Yu, 2013). First, in-situ point-based measurements only provide a "local" view, and the results of local evaluation cannot necessarily be applied at basin or global scale. It is also not trivial to compare a point-based flux from buoys with a grid-area value from a satellite. Secondly, the in-situ observations are very sparse and their poor sampling *represents a major source of uncertainty* given the many key processes taking place in the under-sampled regions, and in particular in high-latitude regions (Bourassa et al., 2013), where dense water mass formation influenced by air-sea interactions is taking place. There are also some issues related to sampling in time such as diurnal variations (Clayson & Bogdanoff, 2013). Thirdly, there are only very few "direct" measurements of fluxes (made through eddy correlation methods), most in-situ observations are computed from bulk formulae, which brings an issue of independence when evaluating global fluxes constructed from similar algorithms.

To address these issues, the recent GSOP workshop in Woods Hole (Yu *et al.*, 2012) recommended to complement the traditional "*local*" evaluation method (based on comparison with point-wise measurement) with a more "*regional*" approach using heat budget constraints in some suitable "reference" areas, either at the basin, regional or even global scale. This idea of regional constraints is not new as the concept of "Cages" (Bretherthon et al., 1982) was already introduced decades ago in the context of the World Ocean Circulation Experiment (WOCE) using hydrographic transects. The concept is now coming back (Yu et al., 2012) as *new prospects for heat budget constraints emerge* through the advent of new high quality measurements, in particular from XBT and the Argo profiling floats, delivering a view of the ocean interior heat storage at an unprecedented coverage in space and time. The combination of Argo data with EO data can provide scientists with an estimate of the changes in heat content induced either, through surface exchanges, or lateral transport. As illustrated in Fig 1, by identifying some "*suitable*" regions (where changes in transport would be relatively negligible), the estimate of OHC anomalies should enable scientists to check the fidelity of the Net surface Heat Flux. Such suitable "test bed" regions, could be "*pre-defined* Cages", where hydrographic transport is well known or measured (e.g. RAPID programme for ocean overturning circulation), "*natural* Cages" such as semi-enclosed seas, where outgoing heat is known, or in a near surface "*bubble"* volume such as the Western Pacific Warm Pool (bounded by a specific isotherm 28°C), where a heat budget equation can be formulated. For example, Song & Yu (2013) have performed a bubble analysis on the warm pool, highlighting issue of inconsistency between OHC and SST variations for several climatologies of the Net Heat Flux at the surface.

3. Joint CLIVAR-ESA scientific workshop

In order to better define the scope of the ESA/STSE activity, ESA and the CLIVAR Project Office held a workshop on 3-4th July 2013 at the University of Reading in the UK. The meeting, supported by the World Meteorological Organisation (WMO), the National Centre for Earth Observation (NCEO), and ESA attracted more than 27 participants from Europe and the US, with additional presentations delivered from the US by videoconference.

The workshop aimed to define the EO requirements for a STSE activity. In particular, the objectives of the workshop were to:

- *Review* the status of current EO-based observations and methods used to derive air-sea fluxes,
- *Consolidate* the scientific requirements of the CLIVAR community in terms of data sets, and new methodology (using heat budget constraints) needed to improve ocean surface fluxes,
- *Identify* the main geographical areas of interest, and existing reference data sets that may contribute to the Ocean Heat Flux project,
- *Explore* the main research needs towards the development of the new CLIVAR research opportunity.

The meeting included four sessions addressing the (i) Assessment of current air-sea heat flux products from satellites and other sources, including their uncertainties and methods of calibration, (ii) Planetary energy balance measurements from TOA and from Argo, (iii) Availability of satellite products relevant to constraining surface fluxes and (iv) Ocean synthesis and ocean products as constraints on air-sea fluxes. Each discussion session was introduced by a seed talk representing the view of the community. All presentations are available from [URL-5].

The workshop led to a series of recommendations by the community regarding the EO component of the new

CLIVAR research opportunity (see below) as well as the wider planetary heat budget closure. The latter is discussed in a companion document under preparation by von Schuckmann et al. (2013).

In particular, regarding the EO component, the workshop has identified the need to:

- (R1) Quantify the different types of *uncertainties* of EO-based surface fluxes, their *correlation* structure, and *sensitivity* to uncertain parameters (e.g. input data, transfer coefficients) and algorithms (e.g. retrieval schemes) in order to improve the usefulness of global flux products, and make them more suitable to support scientific studies of climate variability, trends, and the global ocean heat budget closure problem that remains unresolved,

- (R2) Develop an innovative *ensemble* approach to generate multiple realisations of EO-based flux products (as illustrated in Fig 2), 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 EO data sets of climate quality (e.g. ESA CCI). The idea is that a well-designed ensemble of multiple realisations of fluxes would sample some of the uncertainties related to the flux product, in a similar way as is done for the SST within the HadSST3 data set.

- (R3) Exploit *integral constraints* as suggested by GSOP to check consistency of the Net Heat Flux product components, and in particular by use of Argo data on a series of Cages of interest, such as enclosed seas (e.g. Mediterranean Sea, Pacific Warm Pool).

- (R4) Develop a community-led *Flux Platform* to share, *access* and inter-compare easily different sets of flux climatologies, and their input data (e.g. different SSM/I data streams), thereby fostering close collaboration between different communities (e.g. meteorologists, oceanographers, climatologists, observationalists and modelers), as well as new ways of combining in situ measurements and EO data. Such a platform was regarded as a very useful tool to achieve R1, R2 and R3, and organize a global effort to coordinate the evaluation of flux products, improve their inter-operability and encourage their use.

- (R5) Complement the GSOP inventory with "assessment"-type information regarding the strengths and weaknesses of the various flux products, in an effort analogous to the "Climate Data Guide" [URL-8], to guide the users (in particular non-experts) in selecting the best product for their application across the multitude of flux products available on the web (Schneider et al, 2013).

In this context, ESA is considering these recommendations to initiate a potential new dedicated activity, capitalizing on the latest knowledge in algorithms and data sets from independent observing systems (e.g. satellites, Argo), with strong focus on ESA missions and related datasets.

By doing so, the project would contribute to the new CLIVAR initiative while complementing SeaFlux activities, also complementing other ESA flux activities, such as the Water Cycle Multi-mission Observation Strategy - Evapotranspiration (WACMOS-ET) project for land fluxes [URL-10] and SOLAS OceanFlux GHG and Upwelling projects for CO2 ocean fluxes [URL-11, URL-12].

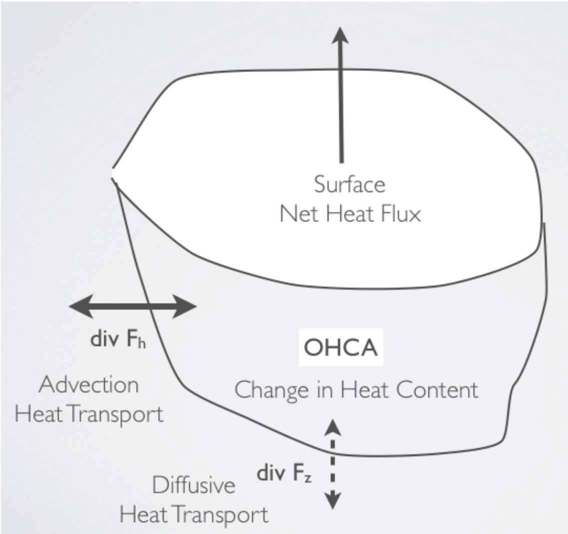

Figure 1: Illustration of a potential CAGE, highlighting a heat budget, where changes of OHC are compensated by lateral transport, and surface heat flux.

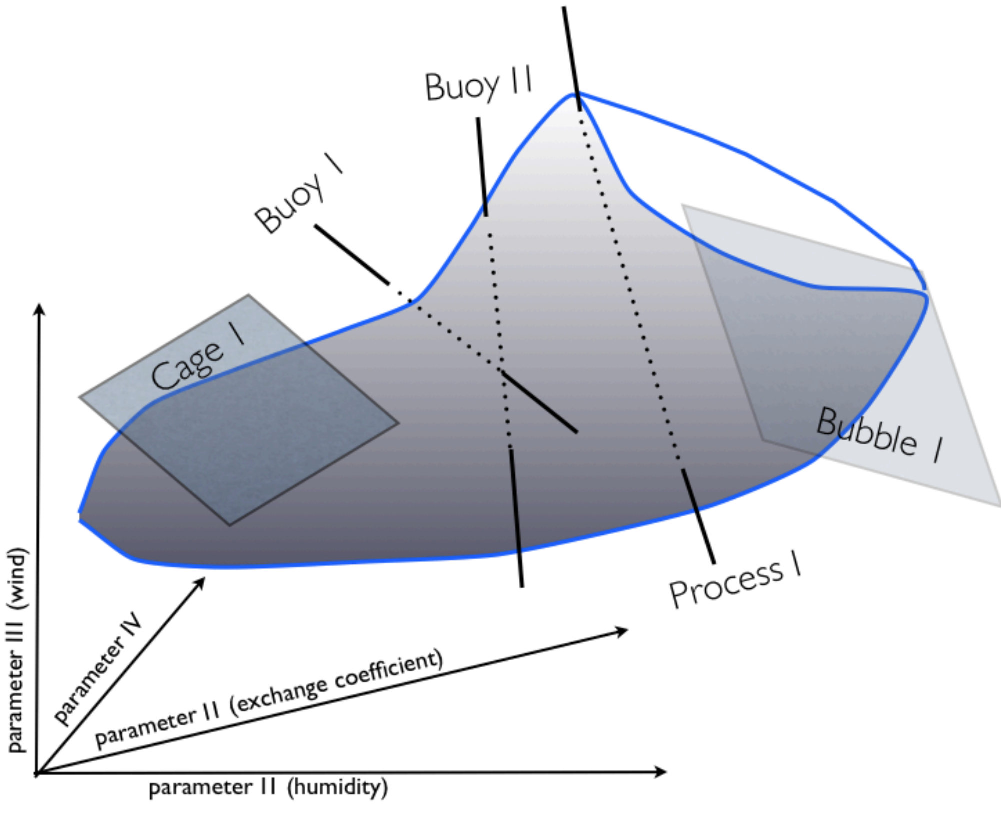

Figure 2: Ensemble of realisations of the Net Heat Flux in a multivariate space. The lines and planes represent the consistency checks base on point-wise in-situ observations, and regional heat constraints, respectively.

Acronyms

AVHRR	Advanced Very High Resolution Radiometer
CCI	Climate Change Initiative
CLIVAR	Ocean-climate system - Variability, Predictability and Change
CORE	Common Ocean-ice Reference Experiments
DUE	Data User Element
ECMWF	European Center for Medium-Range Forecast
ECCO	Estimating the Circulation and Climate of the Ocean
ENSO	El Nino Southern Oscillation
ESA	European Space Agency
FSU	Florida State University
GSSTF	Goddard Satellite -based Surface Turbulent Fluxes
GEWEX	Global Energy & Water Exchange Project
GODAE	Global Ocean Data Assimilation Experiment
GSSTF	Goddard Satellite-based Surface Turbulent Fluxes
GSOP	Global Synthesis and Observations Panel
GOOS	Global Ocean Observing System
GLORYS	Global Ocean Reanalysis and Simulations
HOAPS	Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data
ICOADS	International Comprehensive Ocean-Atmosphere Data Set
IPCC	Intergovernmental Panel on Climate Change
ISCCP	International Satellite Cloud Climatology Project
J-OFURO	Japanese Ocean Flux Data sets with Use of Remote Sensing Observations
LWF	Long Wave Flux
LHF	Latent Heat Flux
MERRA	Modern Era Retrospective-analysis for Research and Applications
NCEP	National Centers for Environmental Prediction
NCAR	National Center for Atmospheric Research
NCEO	National Centre for Earth Observation
NOC	National Oceanography Centre
NWP	Numerical Weather Prediction
OAFLUX	Objective Analyzed Fluxes
OGCM	Ocean General Circulation Models
OHC	Ocean Heat Content
ORAS	Ocean Re-Analysis System
SCOR	Scientific Committee on Ocean Research
SHF	Sensible Heat Flux
SOLAS	Surface Ocean Lower Atmosphere Study
SMOS	Soil Moisture Ocean Salinity
SST	Sea Surface Temperature
SSH	Sea Surface Height
SSS	Sea Surface Salinity
SSM/I	Special Sensor Microwave/Imager
STSE	Support to Science Element
SWF	Short Wave Flux
TOA	Top of the Atmosphere
VOS	Voluntary Observing Ships
WACMOS	Water Cycle Multi-mission Observation Strategy
WCRP	World Climate Research Programme
WGASF	Working Group on Air-Sea Fluxes
WMO	World Meteorological Organisation
WOAP	WCRP Observation & Assimilation Panel

Web Sites

URL-1	http://www.clivar.org
URL-2	http://www.clivar.org/science/clivar-research-opportunities#six
URL-3	http://due.esrin.esa.int/stse/
URL-4	http://seaflux.org
URL-5	http://www.clivar.org/organization/gsop/activities
URL-6	http://www.esa-da.org/
URL-7	http://www.esa-cci.org/
URL-8	https://climatedataguide.ucar.edu/
URL-9	http://www.globwave.org/
URL-10	http://due.esrin.esa.int/stse/projects/stse_project.php?id=160
URL-11	http://www.oceanflux-ghg.org/
URL-12	http://due.esrin.esa.int/stse/projects/stse_project.php?id=158
URL-13	http://www.metoffice.gov.uk/research/news/recent-pause-in-warming
URL-14	http://www.met.reading.ac.uk/~sgs02rpa/research/DEEP-C.html

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AGENDA

Venue: University of Reading, Building 56 ESSC, Room 175 Harry Pitt Blg, Reading, UK

DAY 1: Wed 03 July 2013 (13h30 – 18h30)

13h30-14h00 Introduction

13h30-13h45: "Welcome, and brief introduction to ESA programmes and objectives of the meeting" (PP. Mathieu, Keith Haines, Sergey Gulev, Diego Fernandez)

13h45-14h00: "New proposed CLIVAR research opportunity on "Consistency between planetary heat balance and ocean heat storage" (Karina von Schuckmann)

14h00-16h00: Discussion I:

Review of existing surface flux data sets and information products, their quality, global consistency, research challenges and opportunities related to the EO contribution to the new CLIVAR research opportunity. Chair: Carol-Anne Clayson

14h00-14h30: Seed talk on "Air-Sea Fluxes of Heat, Freshwater and Momentum over the global Ocean, including SeaFlux" by Carol-Anne Clayson, Sergey Gulev, Liz Kent, Abderahim Bentamy, Simon Josey and with input from the community

14h30-16h00 Discussion I: (see questions in Annex)

16h00-16h30 Break

16h30-18h30 Discussion II:

Refinement of a scientific framework on consistency between planetary heat balance and ocean heat storage. Chair: Norman Loeb

16h30-17h00: Seed talk on "Monitoring changes in Earth's Energy Imbalance and Global Ocean changes" by Norman Loeb, Richard Allen, Gregory Johnson, Karina von Schuckmann, Anny Cazenave, Josh Willis and with input from the community

17h00-18h30 Discussion II: (see questions in Annex)

18h30 END OF DAY 1, Community Dinner

DAY 2: Thu 04 July, 08h30-13h30

08h30-10h30 Discussion III:
Identify the scientific requirements of the CLIVAR community in terms of observational data needs dedicated to climate and heat budget studies. Review recommendations from the CLIVAR GSOP workshop (see report on clivar.org). Chair: Tony Lee

08h30-09h00: Seed talk on ”Earth Observation Measurement Constraints on Ocean Heat Budget” by Tony Lee, Pierre-Philippe Mathieu, Keith Haines, Carol-Anne Clayson, Bernard Barnier, Sergey Gulev, Norman Loeb, Simon Josey and with input from the community

09h00-10h30: Discussion III (see questions Annex)

10h30-11h00: Break

11h00-12h30 Discussion IV:
Ocean observational heat budget constraints for forcing ocean models and syntheses. Advancing our understanding of ocean surface heat balance and temporal changes to better achieve regional calibration/validation of surface fluxes. Chair: Bernard Barnier

11h00-11h30: Seed talk on “Upper ocean heat content, ocean state estimation and data assimilation in climate research” by Bernard Barnier, Mathew Palmer, Magdalena Balmaseda, Tony Lee, Catia Domingues, Karina von Schuckmann and with input from community

11h30-12h30: Discussion IV (see questions Annex)

12h30-13h30 Summary and discussion on workshop report documents including the “EO requirement” document for ESA and “Roadmap” document for CLIVAR.

13h30 End of the workshop

Annex

Key Questions for Discussion I on surface fluxes:

- What are the current flux data sets available? And plans to improve them?
- What is the current way to validate / evaluate their quality? How can it be improved using the diversity of communities addressing energy budget? Is there a need for some reference data sets to benchmark fluxes?
- What are the requirements on heat fluxes? For which applications? Which EO data are needed?

Key Questions for Discussion II on refinement of scientific framework:

- What are the key questions to address to close the ocean energy budget?
- What are the needs (in terms of observations), current capabilities and gaps?
- How can we benefit from the diverse of communities looking at different angles of the energy balance problem?

Key Questions for Discussion III on climate and heat budget studies:

- How to develop the strategy for regional heat/salt budget analysis and regional flux assessment?
- How to proceed with further direct pointwise comparisons of different ocean synthesis and atmospheric reanalysis products with flux buoy and OceanSITES measurements?
- How to evaluate surface fluxes and ocean transports inferred from ocean syntheses?
- How to identify regions that are suitable for regional heat/salt budget study and flux evaluation?.

Key Questions for Discussion IV on ocean heat content and ocean surface heat balance:

- How to adjust global wind products for consistency?
- Which OHC dataset/products are recommended to be used as reference dataset?

List of attendees:

Confirmed people:

1) Magdalena Balmaseda, , magdalena.balmaseda@ecmwf.int, ECMWF, UK
2) Matthew Palmer, matthew.palmer@metoffice.gov.uk, MetOffice, UK
3) Roger Barry, rogbar@noc.ac.uk, Director CLIVAR ICPO
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7) Christopher Merchant, c.j.merchant@reading.ac.uk, University of Reading, UK
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9) Tony Lee, tong.lee@jpl.nasa.gov, Jet Propulsion Laboratory, USA
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29) Catia Domingues, catia.domingues@csiro.au, CSIRO, Australia

People who cannot attend but could contribute to the report:

30) Joerg Schulz, Joerg.Schulz@eumetsat.int, Eumetsat, Darmstadt, Germany
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