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INTERVIEW

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We welcome Professor Guy Brasseur as the new Chair of the World Climate Research Programme Joint Scientific Committee and are very grateful that he kindly agreed to answer our questions and share his views on promoting air-flux science.

Flux News: For many years the WCRP Joint Scientific Committee has been very supportive of air-sea flux science. For example, there were two WCRP working groups: WG for Surface Fluxes (co-sponsored by SCOR) and WG on Air-Sea Fluxes. How do you see this strategy in the future? What could be the means of integrating air-flux science into the work of the WCRP? Which issues of climate science are most closely related to air-sea fluxes?

G. Brasseur: WCRP is promoting a systemic approach for climate studies. In addition to investigating physical and chemical processes in individual components of the Earth, we are focusing also on global cycles of energy, water and carbon. In this respect, a deeper understanding of physical and biogeochemical air-sea interactions is crucial. WCRP remains, therefore, very supportive in promoting sea-flux science. An example that highlights the importance of such an issue is the recent "hiatus" in the observed global warming. This natural variability process is clearly linked to exchanges of heat between the atmosphere and the ocean. As the new Chair of the WCRP JSC, I would like to promote studies that focus on seasonal-to-decadal natural cycles in the Earth system.

> ***Guy Brasseur:** We would very much welcome a new and exciting research initiative integrating knowledge on air-sea exchanges produced by CLIVAR, SPARC, SOLAS and IMBER*

Flux News: Currently surface flux issues are addressed by the WCRP under CLIVAR and namely by the GSOP panel. Recently CLIVAR started to develop a new initiative focussed on ocean heat content where surface fluxes are crucial. If this initiative is launched, do you think this group might become the major surface flux body also serving the WCRP in other aspects of air-sea interactions?

G. Brasseur: CLIVAR should certainly be the place where air-sea exchanges are addressed. There are, however, other WCRP groups that will include these processes in their research activities. And some of our newly-defined Grand Challenges will include some aspects of atmosphere-ocean interactions.

Flux News: There was a long debate at the JSC on how to ensure synergy between physical fluxes and biogeochemical fluxes. SOLAS Project (co-sponsored by WCRP and IGBP) has always been a relevant platform for this. However, SOLAS cannot take on board all the problems of physical air-sea interactions, particularly those related to NWP and the validation of global satellite products. There were, however, a number of very successful cooperative activities between SOLAS and e.g. WGSF. Would the JSC consider a renewal of a close interaction between SOLAS and JSC flux groups?

G. Brasseur: We have initiated new discussions between the WCRP and IGBP to enhance scientific interactions between the two programmes. As a result of this process, we have asked IGBP and WCRP core projects to propose joint initiatives on challenging questions. We already see strong cooperation between, for example, IGAC and SPARC. We would very much welcome a new and exciting research initiative that integrates knowledge produced by CLIVAR, SPARC, SOLAS and IMBER on air-sea exchanges.

A PROSPECTUS FOR THE CLIVAR RESEARCH FOCUS "CONCEPT-HEAT"

(CONsistency between planetary energy balance and ocean HEAT storage)

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1. Introduction

As one of the four core projects of WCRP, CLIVAR's (Climate and Ocean: Variability, Predictability and Change, http://www.clivar.org/) mission is to understand the dynamics, the interaction, and the predictability of the coupled ocean-atmosphere system. The CLIVAR community has identified a number of scientific imperatives to better understand climate variability and dynamics, as well as predictability and change on various time-scales, through the collection and analysis of observations and the development and application of data sets and models of the coupled climate system to the benefit of society and the environment in which we live.

To achieve the overall CLIVAR objectives, the WCRP core project is working in cooperation with other relevant climate-research and observing activities and is developing seven research foci to work on specific challenges over the next 3-5 years. An overarching scientific challenge faced by the whole climate science community is related to achieving accuracy in the changes in storage and flows of energy throughout the climate system necessary for climate state and variability studies. For this purpose, CLIVAR is developing the research focus "Consistency between planetary energy balance and ocean heat storage (CONCEPT-HEAT)". Developing the knowledge, and observational capability, necessary to "track" the energy flows through the climate system is critical for better understanding relationships between climate forcing, response, variability and future changes. 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. Improved knowledge and understanding of the climate system will be translated into improved climate assessments and more reliable climate models, synthesizing the observations, performing attribution of what is happening and why, and in making predictions and projections on all space and time scales.

The only practical way to monitor climate change across time scales is to continually assess the energy, mainly in the form of heat, in the climate system. Quantifying these exchanges, and in particular how much heat has resulted from human activities (including feedbacks), and how it affects our climate system is one of the key challenges faced by the climate research community (IPCC, 2013, Fig. 1). Many studies based both on models and observations have been performed, leading to significant advances in our understanding of Earth's energy exchanges (Hansen et al., 2005; Hansen et al., 2011; Church et al., 2011; Trenberth and Fasullo, 2011; Loeb et al., 2012; Stephens et al., 2012, Balmaseda et al., 2013, Trenberth et al., 2014; Palmer et al., 2011; Palmer and McNeall, 2014; Allan et al. 2014; Katsman and van Oldenborgh, 2011), while highlighting at the same time large uncertainties in the estimates of the energy flows (Trenberth, 2009; 2010, Trenberth et al., 2011, Abraham et al., 2013, Trenberth and Fasullo, 2013 ; Trenberth et al., 2014). However, they all agree that 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.

Large uncertainties 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. Improved knowledge and understanding of the climate system will be translated into improved climate assessments and more reliable climate models, synthesizing the observations, performing attribution of what is happening and why, and in making predictions and projections on all space and time scales.

An overall goal of this research focus is to bring together seven 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
- Air-sea-fluxes
- Ocean Heat Content
- Ocean reanalysis
- Atmospheric reanalyses and NWP
- Climate models
- Global sea level.
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This will increase our capabilities to answer pressing issues of climate related research. More precisely, this CLIVAR research focus 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).

2. Key scientific issues

Climate dynamics is very much about exchanges of energy in the Earth System, in particular in the form of heat. To understand how the Earth's climate system balances the energy budget, we have to consider processes occurring at three levels: the surface of the Earth, where most solar heating takes place; the Top of the Atmosphere (TOA), where sunlight enters the system; and the atmosphere in between (Fig.1). At each level, the amount of incoming and outgoing energy, or net flux must, on average, be equal on longer time scales in an unchanging climate. Under the influence of external and/or internal climate forcing energy is not balanced anymore, and can hence, lead to a temporal positive or negative Earth's Energy Imbalance (EEI).

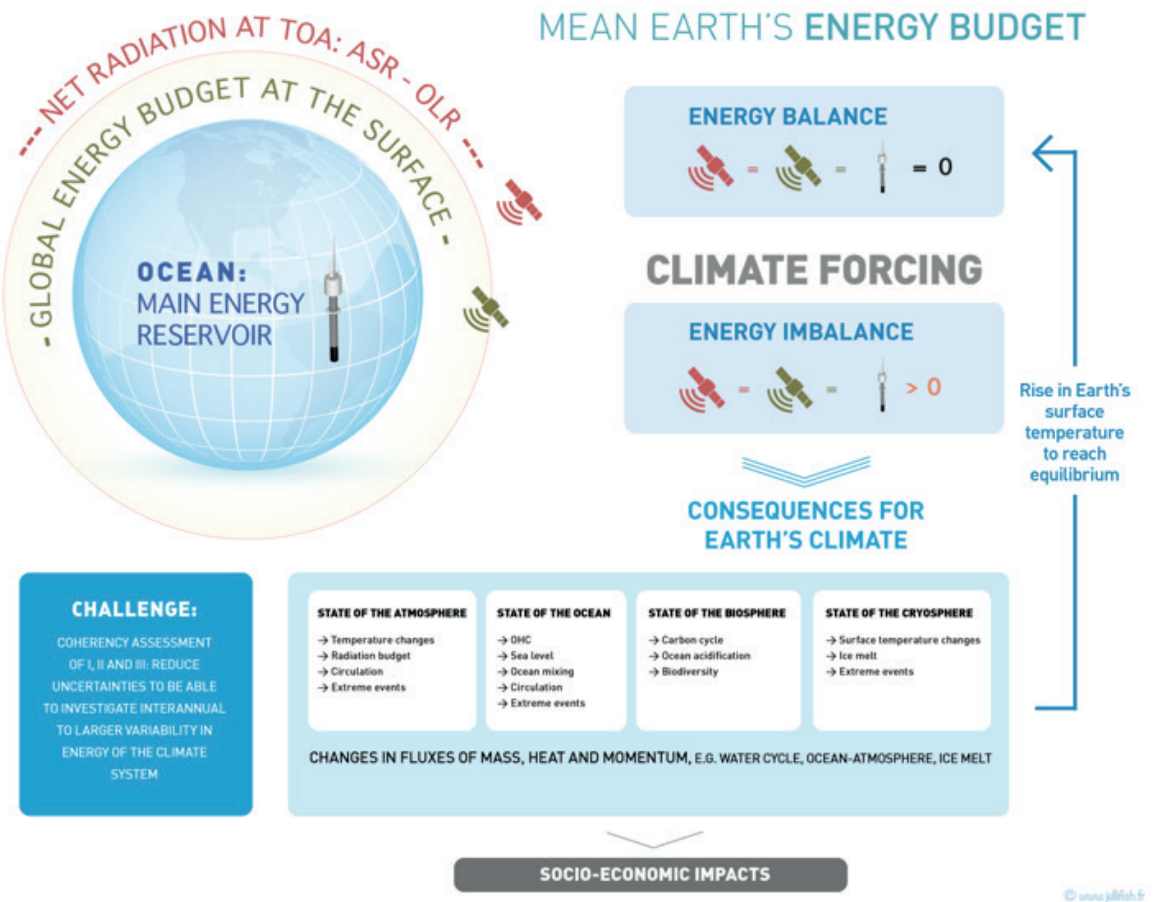

Fig. 1: Overview graphic summarizing the CLIVAR research focus CONCEPT-HEAT (CONsistency between planetary energy balance and ocean HEAT storage).

Temporary variations of EEI can occur naturally due to internal variability as well as external forcing. On short time-scales (months), natural fluctuations in clouds and atmospheric dynamics associated with synoptic and low-frequency variability can create a temporary EEI. Internal climate variations, in particular the El Niño Southern Oscillation (ENSO) can also lead to interannual fluctuations of EEI (e.g., Trenberth et al. 2014a; Allan et al., 2014; Palmer and McNeall, 2014; Brown et al, 2014). External forcing such as volcanic eruptions and variations of the sunspot cycle can also create such changes. All these influences occur superposed on the climate change signals associated with changes in atmospheric composition (Trenberth et al., 2014a).

Over the last few decades, increased emissions of Greenhouse Gases induced by human activities have significantly impacted our climate, forcing a positive net flux imbalance ranging from 0.5 to 1 Wm^{-2} at TOA during the last decade with considerable interannual variability (Earth's Energy Imbalance, Hansen et al., 2011; IPCC, 2013; Loeb et al., 2012; Trenberth et al., 2014a). The apportioning of this energy in the atmosphere, oceans, land and ice, and the exchanges among them along with the phase changes of water, on various time-scales are at the core of climate dynamics and how the climate system evolves. 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 accumulating heat at the ocean surface has penetrated into the top 700m (and deeper) layers through subduction and mixing processes, leading to an observed increase of upper Ocean Heat Content (OHC, Abraham et al., 2013; IPCC, 2013). CMIP5 model simulations suggest that full-depth global ocean heat content becomes the dominant term in Earth's energy budget on timescales of about 1 year (Palmer and McNeall, 2014). The remaining excess heat from planetary warming goes into melting of both terrestrial and and sea ice, warming the atmosphere, and the land surface (Trenberth, 2009; Hansen et al., 2011; Church et al., 2011; 2013a).

The positive energy imbalance apparent in both observations and climate model simulations suggests an ongoing accumulation of energy in the Earth climate system manifested primarily as a warming of the global ocean. Multiple studies show that there has been a multi-decadal increase in OHC of the ocean layer going down to at least 3000 meters, although the confidence in these estimates is higher for the upper ocean (700 meters) and decreases below due to the differences in measurement methods, input observations, and analyses techniques (Abraham et al., 2013). This clearly reflects the impact of anthropogenic warming on the Earth's climate system.

Despite this, Earth's surface temperature trends have slowed substantially over the last 15 years and the observed trends are very much at the lower end of model simulations (Smith, 2014; Forster and Rahmsdorf, 2011; Easterling and Wehner, 2009). This observed hiatus in global warming is challenging the prevailing view that anthropogenic forcing causes global surface warming. Various mechanisms have been proposed for this hiatus in global surface warming highlighting the role of internal climate variability forcing a redistribution of heat in the oceans (Meehl et al. 2011; Guemas et al., 2013; Watanabe et al., 2013; Trenberth and Fasullo 2013; Trenberth et al., 2014a; Yu and Xie, 2013; England et al., 2013; Meehl et al. 2013, 2014; see also Nature Geoscience special issue: www.nature.com/ngeo/focus/slowdown-global-warm/index.html).

Periods with little or no surface warming trend have occurred before in observations (Knight et al., 2009; Easterling and Wehner, 2009), and are seen as well in climate-model simulations (Santer et al., 2011; Meehl et al. 2011, 2014). Trenberth et al. (2014a) show in their estimates that the net energy imbalance at TOA varies naturally in response to weather and climate variations, the most distinctive of which is ENSO. It also varies with the sunspot cycle, affecting 15% of the climate change signal on decadal time scales. Moreover, the net TOA energy flux, as well as OHC is profoundly influenced by volcanic eruptions (Palmer et al., 2007; Domingues et al., 2008; Balmaseda et al., 2013). On multidecadal time scales strong intrinsic variability of the ocean affecting the Pacific (Meehl et al 2011; Kosaka and Xie 2013; Trenberth and Fasullo 2013; Trenberth et al. 2014a), and Atlantic (Latif et al. 2004, Knight et al. 2005; Chen and Tung 2014) may produce multidecadal signals in air-sea heat fluxes (Gulev et al. 2013). All of these influences occur superposed on the climate change signals (e.g. Cazenave et al., 2014) associated with changes in atmospheric composition. While heating continues during the recent upper-ocean-warming hiatus, but the heat is absorbed in the deeper ocean below 300-700 m (e.g. IPCC 2013; Abraham et al., 2013; Balmaseda et al., 2013). So the plateau in surface warming is not because heating from rising greenhourse gas concentrations has ceased. The evidence supports continued heating of the climate system as manifested by melting of Arctic sea ice and glaciers, as well as Greenland, but most of the heat is penetrating below the ocean mixed layers which influence surface temperature (e.g. Balmaseda et al. 2013; England et al., 2013; Chen and Tung, 2014), and thus contribute to observed increasing global mean sea level rise (e.g., Church et al., 2013b).

Some studies have shown that the closure of the observed energy budget over the hiatus period remains elusive for interannual variations pointing to an amount of "missing energy" in the system (Trenberth, 2009; Trenberth and Fasullo, 2010; Trenberth et al. 2014). Although some of this previously "missing energy" is accounted for within the substantial observational uncertainty range (e.g. Hansen et al., 2011; Loeb et al., 2012), the large inconsistencies between independent observations of Earth's energy flows points to the need for improved understanding of the error sources and of the strengths and weaknesses of the different analysis methods, as well as further development and maintenance of measurement systems to track more accurately Earth's energy imbalance on annual timescales (Trenberth et al., 2014; Loeb et al., 2012). A particular key science question of this research focus is concerned with the range of substantially different heating rates that have shown to be large.

Energy balance can also be estimated from climate models, which in turn require validation to provide confidence in their results (Hansen et al., 2011; Trenberth et al., 2014), but can play an important role in informing the observational requirements for improved estimates of Earth's energy budget (Meehl et al., 2011; Meehl et al., 2013, Katsman and van Oldenborgh, 2011; Palmer et al., 2011; Palmer and McNeall 2014). The key issues in this case relate to 1) how realistic the model is, 2) the external forcings that are specified, and 3) the integrity of the model in terms of internal variability. The external forcings are quite incomplete, especially in the 2000s in all CMIP5 model simulations (Santer et al 2013; Trenberth et al 2014; Allan et al 2014). Small volcanic eruptions are missed altogether, solar variability, especially as a function of wavelength is inadequate, and aerosols are generally poorly dealt with whether specified in concentrations or as emissions that are then interactively evolved within the model. The model must in turn represent realistic energy budgets regionally and the simulations of clouds remain a key issue (e.g. Trenberth and Fasullo 2010b). The internal variability in CMIP5 models remains inadequate, whether in terms of ENSO or multidecadal variability (such as NAO, SAM etc). All of these outstanding issues require the development of metrics for evaluating models and homogeneous datasets.

2.1 Key Science 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?

Advances made on this key science question are most fundamental for climate research as EEI is the single quantity defining the status of global climate change and expectations for continued global warming. We are able to obtain this information from current global observing systems, ocean reanalysis and climate models, but fundamental work is urgently needed to understand existing inconsistencies and unsolved issues of different products and estimates of EEI. This is necessary in order to adequately track where the energy is currently accumulating, how our climate is changing and what are the implications for the future. A proper accounting is needed of the absolute mean value, the temporal variability as well as the uncertainties in the EEI and we need to identify what is required to further reduce the uncertainties.

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

Each of the existing independent approaches (satellite measurements at TOA, in-situ observations and reanalysis outputs for ocean heat content, estimates of EEI from climate models) to determine values for energy flows in the Earth's system has its own advantages and drawbacks in terms of sampling capability and accuracy, leading to different estimates, and associated uncertainties. In addition different communities are involved in delivering these estimates and as yet these communities have not worked closely together to allow different assumptions to be compared and for some of the uncertainties to be reduced. Thus evaluating and reconciling the resulting budget imbalance is a key emerging research topic in climate science which has the potential to bring 6 different communities together to make a major contribution to reducing climate change uncertainties. Errors involved in deriving single components without a coupled context can accumulate and have major impacts on the accuracy of climate indicators, leading to large imbalances differences in estimates of Earth's budgets and climate. Reconciling the different approaches remains a challenge. Only by using conservation and physical principles can we infer the likely resolution.

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

Observed climate variations such as the current hiatus or unresolved inconsistencies of climate observations (e.g. “missing energy” in the climate system) 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. Continued assessment and attribution studies of regional natural climate variability are essential to improve our estimates of global changes. 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. We 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 which are the relevant model physics and parameterizations that need further improvements.

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

Models are self-consistent and accounting for any drifts and biases may therefore be useful in identifying inhomogeneity in observational datasets or in providing transfer functions between measurements and physical variable. Consideration of models in conjunction with observations is therefore essential in evaluating climate change processes. Addressing the energy budget in climate models is a powerful method for understanding future climate projections. A prerequisite thereby is an adequate representation of the energy budget in climate models, which requires a careful validation process and adequate reference datasets. They can be used to evaluate the main drivers for understanding the energy budget, more precisely to analyze the transient climate response and the role played by ocean heat uptake (i.e. ocean heat uptake efficiency). This can be achieved by focusing on the net energy accumulated in the Earth’s system and how that energy is redistributed in space and time. A large part of this energy will be found in the deep ocean heat uptake, and particular emphasizes should be given to projected OHC and accompanied uncertainties, including the uncertainty of projections of global thermal expansion, which is a large term in projections of sea level (of order 50% of the projected signal).

More work is needed to understand biases in specific terms of energy budgets in the models as derived from climate model energy imbalances. These biases depend on the way how the different models balance the terms, and their understanding in turn will shed light on biases in forcing terms from observations (e.g. surface fluxes). Here the effort is needed for understanding the role of eddy resolved ocean in forming new mechanisms of coupling and, thus, changing the picture of surface fluxes diagnosed by models. Moreover, more work is needed to assess the response of climate models to the radiative forcing, and a combined study of satellite observations with climate models will be particularly valuable to advance on this issues.

Question E: How can we better constrain the surface energy fluxes and their spatio-temporal variations at regional scale?

Characterizing the uncertainty and biases in surface fluxes is essential to address scientific challenges related to the Earth Energy budget, energy flows and understanding the observed shorter-term interannual to decadal fluctuations superimposed on the centennial-scale warming of the global ocean surface. Quantifying sea surface heat fluxes to the required level of accuracy needed to support the various applications is a very challenging task. The current level of uncertainties in global ocean mean and trends of heat and moisture fluxes remain higher than is required by many applications and improvements to these estimates are required for further progress. Many of the current global ocean products use local measurements for determination of methodologies and/or uncertainties. Given the relative paucity of local measurements, sampling issues and errors in flux algorithms and satellite retrievals under extreme wind or wave conditions between differing data sets cannot be resolved by comparisons with these in situ data alone. Also, a further critical issue is the scaling of surface fluxes because in-situ measurements of the fluxes and state variables are scale dependent. Regional and global energy budget assessments may help provide further constraints for the surface flux datasets to aim towards. Using constraints on energy budget considerations, and hence, inter-comparisons to other independent observing systems as well as to re-enforce interdisciplinary collaborations for climate research application will contribute to advances urgently needed for estimates of surface energy fluxes.

3. Expected outcomes

The main expected outcome of this initiative is to achieve refinement of a scientific framework on consistency between planetary heat balance and ocean heat storage aiming to build up a pluri-disciplinary synergy community for climate research (see 1.2):

- **Evaluation of existing data sets and information products and the assessment of their consistency.**

- **Recommendations on how to improve the observing systems, methods to derive surface flux products, data assimilation methods, ocean and climate models and development of new data sets, analyses and diagnostics that can be used to assess storage terms and energy flows in models, as well as future climate projections.**

- **Contributing insights to the understanding of interannual-to-decadal climate variability in Earth's Energy Budget as well as associated changes in the ocean heat storage and surface fluxes, thus, assessing changes in the climate system, and linking them to initiatives on predictability and detection of anthropogenic climate change.**

- **Quantitative constraints for climate models on heat budget imbalances at TOA, the air-sea interface as well as regional and depth limited accumulation rates of OHC.**

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TIE-OHF: TOWARDS IMPROVED ESTIMATES OF OCEAN HEAT FLUX

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Accurate estimates of the ocean surface turbulent and radiative fluxes are of great interest for a variety of air-sea interaction and climate variability interaction issues. Being the language of communication of the ocean and atmosphere, surface fluxes play a key role in the coupling of the Earth climate system, controlling most important feedbacks between the ocean and atmosphere (Gulev et al. 2013). Furthermore, accurate turbulent flux estimates are essential to assess the surface energy budget (e.g. Trenberth et al, 2009, Stephens et. al., 2012). Changes in the Ocean Heat Content (OHC) of the upper ocean layers can be quantified through the estimation of imbalance of surface flux components. The main source of the long-term time series of such fluxes over the global ocean are reanalyzes based on numerical weather prediction (NWP) models and data assimilation, voluntary observing ship measurements (VOS), and remotely sensed data.

For over a decade, several scientific groups have been developing air-sea heat flux datasets, including IFREMER (Institut Français pour la Recherche et l'Exploitation de la MER; France), HOAPS (Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite; Germany), SeaFlux (Woods Hole Oceanographic Institution, Woods Hole (WHOI); USA), and J-OFURO (Japanese Ocean Flux Data sets with Use of Remote Sensing Observations; Japan) or developed fluxes estimated as blended products such as OAFlux (Objectively Analyzed air-sea Flux (WHOI); USA). The third kind of flux product is derived from numerical weather predictions centers. For the TIE-OHF project the reanalysis performed and provided by the European Centre of Medium Weather Forecasts (ECMWF), named ERA Interim, and by the National Center for Environmental Prediction (NCEP) known as Climate Forecast System Reanalysis (CFSR) are used. Flux data determined from Voluntary Observing Ship (VOS) measurements as daily analysis are processed and provided by National Oceanography Centre Southampton and referred as NOCS2. These groups have developed direct and inverse methods, algorithms, and procedures to calculate long time series of surface winds, wind stress, specific humidity, and latent and sensible heat fluxes. Even though, these products contribute for increasing our understanding of air-sea interaction processes, further improvements of satellite-based fluxes are still required.

The recommendations outlined in the World Climate Research Program (WCRP) and the associated programs deal with the improvement of turbulent flux determination, the spatial and temporal resolutions, the accuracy of flux fields, the characterization of the spatial and temporal errors of each flux component, and the analysis of the comparisons between satellite and numerical model analyses and re-analyses. In a report by the Joint WCRP/SCOR Working Group on Air-Sea Fluxes (WGASF, 2000) the desired accuracy requirement for climate studies is formulated to be “a few W/m^2” for the flux components, resulting from a required accuracy of the large scale net heat flux of 10 W/m^2 (e.g. WGASF, 2000, Bradley and Fairall, 2007). Further recommendations given in the Oceanobs'09 White Paper on surface fluxes (Gulev et al., 2010) include new challenges targeting development of new parameterizations, achieving global and regional heat budget closure, accurate estimation of sampling uncertainties and scaling parameters for surface flux estimates.

To meet the scientific community requirements European Space Agency (ESA) supports a project called Ocean Heat Flux (OHF (http://www.oceanheatflux.org/)) aiming at the development, validation, and evaluation of satellite-based estimates of surface turbulent fluxes, particularly derived from ESA satellite/mission EO data, of all the components of the turbulent fluxes over the global ocean. The main objectives of OHF project are summarized hereafter:

- Establishing a reference input dataset maximizing the use of ESA dataset,

- Developing an ensemble of ocean heat turbulent flux products fostering the use of EO data, and in particular from European and ESA missions. The flux products shall be global, with a resolution of at least daily in time and at least 0.5deg x 0.5deg in space, covering a time period of about 10 years. Monthly composite shall also be generated,

- Quantifying regional heat constraints to assess consistency of the various flux products. The ocean heat constraints, estimated from observations (e.g. in-situ, Argo, altimetry) and/or models (e.g. reanalysis, ocean synthesis), shall cover at least 3 regions of interest representing different oceanic regimes,

- Generating an input reference dataset including EO data (maximizing the use of European and ESA data and relevant datasets, in particular from the Climate Change Initiative (CCI), http://ionia1.esrin.esa.int/) and other required data inputs (e.g. in situ and model based data), required to calculate ocean heat turbulent fluxes, and evaluate their quality and consistency (e.g. in-situ, regional heat constraints), being the basis for further analysis,

- Performing a cross-comparison of different algorithms and approaches based on the reference dataset, evaluating their impact, accuracies and sources of uncertainties, identifying key areas for improvement, and exploring and developing improved approaches to retrieve ocean heat turbulent fluxes from EO data,

- Generating an ensemble of turbulent fluxes, including multiple approaches, multiple products and “smart” perturbations of input data to better sample the different types of uncertainty,

- Evaluating the quality and consistency of ensemble realizations through confrontation with in-situ observations, and by exploiting integral heat constraints at local, regional and global scales,

- Developing a Flux Data Portal to access, share and foster the use of the reference data set and flux products with the scientific community, and to enable easy inter-comparison between products and observations,

- Coordinating with relevant partners, activities and international programs, such as CLIVAR, GSOP, GEWEX and SeaFlux.

Figures 1 and 2 illustrate the need for investigating differences between available flux products. The results are expected to be used for the determination of reference flux products. The inter-comparisons are performed over global oceans and for the period January 2000 through December 2007. Figures show the long-term average LHF (Fig. 1a) and SHF (Fig. 2a), and the associated variablities (Fig. 1b and Fig. 2b) estimated as standard deviations (STD). The LHF patterns are consistent with previous studies (e.g. Mestas et al, 2006 and Grosdky et al, 2009). Inter-comparisons of LHF and of SHF products are illustrated through the mean differences between IFREMER and NOCS2 (Fig. 1c; Fig. 2c), IFREMER and HOAPS (Fig.1d; Fig. 2d), IFREMER and AOFlux (Fig.1e; Fig. 2e), IFREMER and SeaFlux (Fig.1f ; Fig. 2f), IFREMER and ERA Interim (Fig1g; Fig 2g), and between IFREMER and CFSR (Fig.1h; Fig. 2h), are shown. One should notice, IFREMER is not considered as reference. Such differences should be analyzed with respect to various atmospheric (e.g. wind conditions, air humidity and temperature) and oceanic (e.g. sea surface temperature, sea state, current).

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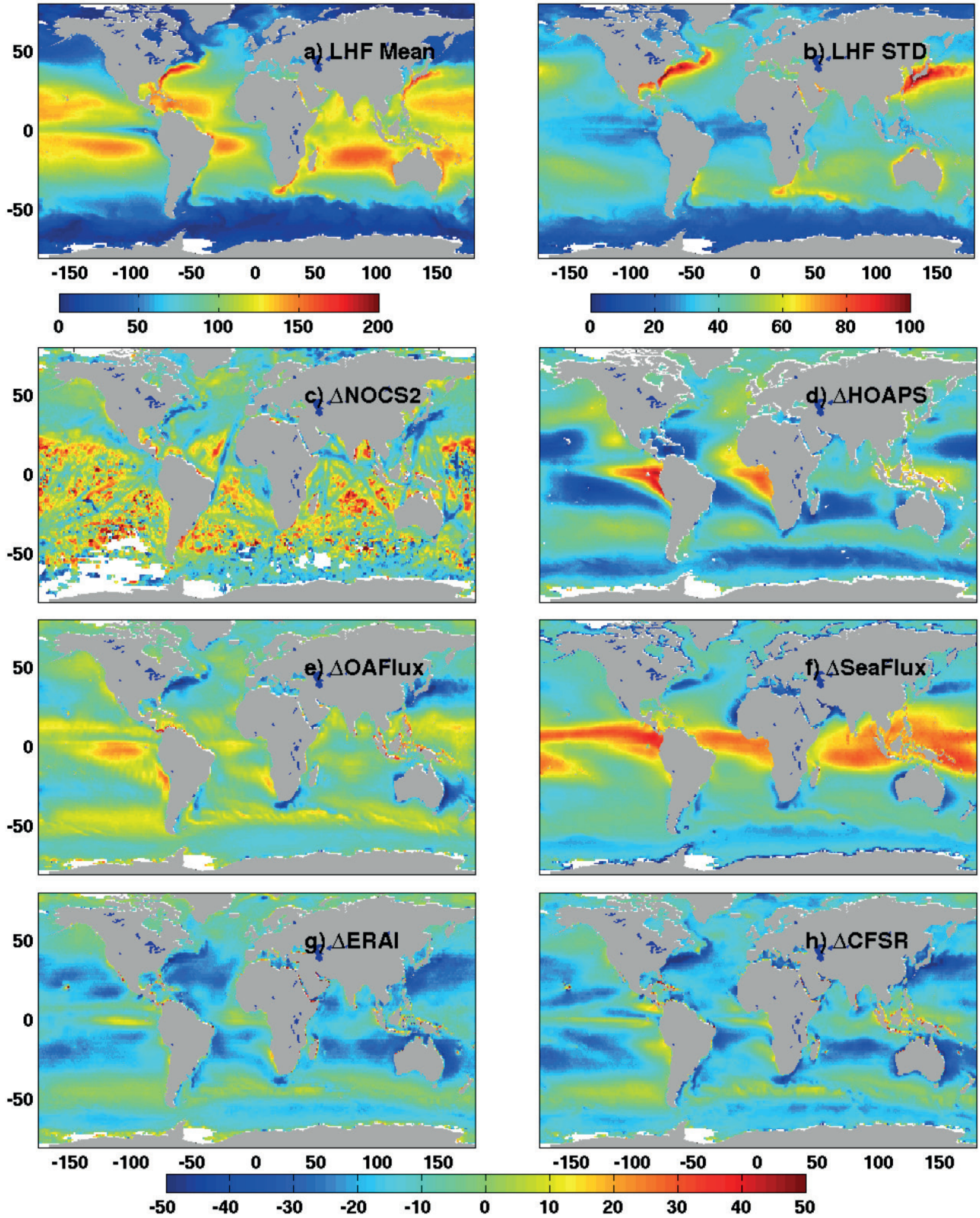

Fig. 1: Annual mean (a) of IFREMER LHF (2000 - 2007) and of the associated variability (STD) (b). Mean differences of LHF derived from IFREMER and from c) NOCS2, d) HOARS, e) OAFlux, f) SeaFlux, g) ERA Interim, and h) CFRS. Units are W/m².

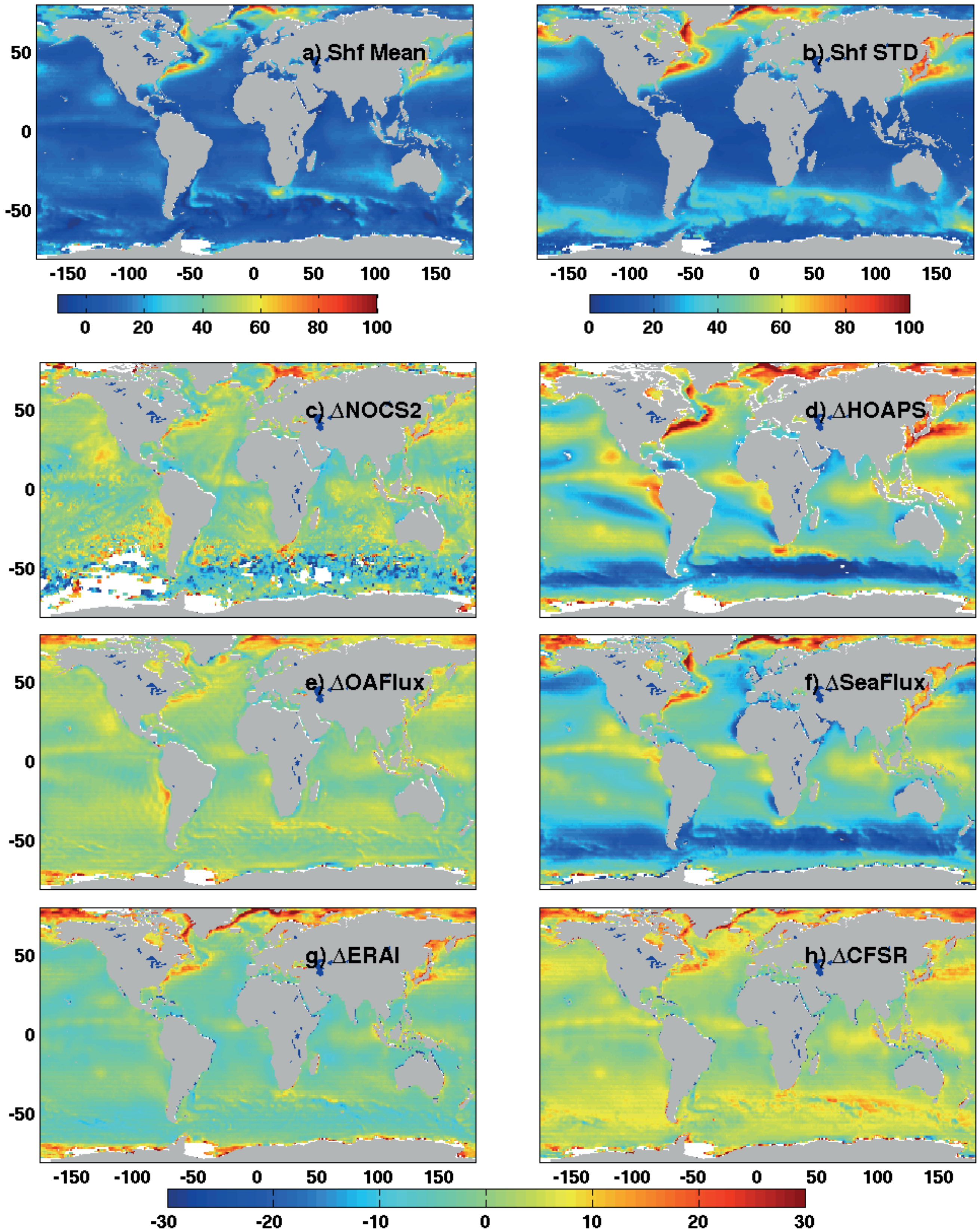

Fig. 2: Annual mean (a) of IFREMER SHF (2000 - 2007) and of the associated variability (STD) (b). Mean differences of SHF derived from IFREMER and from c) NOCS2, d) HOARS, e) OAFlux, f) SeaFlux, g) ERA Interim, and h) CFRS. Units are W/m².

OCEAN HEAT CONTENT IN CLIMATE CHANGE SCIENCE REFLECTED IN IPCC AR4 AND AR5 REPORTS

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It is of interest to reflect on the progress of ocean science since the Fourth Assessment Report from IPCC in 2007 (Bindoff et al. 2007). The experience between AR4 and AR5 has some important messages for the design of CLIVAR and the activities the ocean community should undertake.

In the Fourth Assessment Report we were confident that the oceans were warming. We were also confident that the heat increase in the oceans from 1961 to 2003 accounted for more than 90% of the total energy increase in the overall climate system (that is the atmosphere, oceans, ice sheets, glaciers, sea-ice and land). The estimate at that time of the air-sea flux needed to account for the stored energy over this 42-year period was 0.21±0.04 W/m^{-2} and emphasises the small size of the imbalance in the earth's energy budget. See the excellent prospectus in this issue on the CLIVAR research focus on energy balance and ocean heat storage (Schuckmann et al. 2015).

The headlines in IPCC 2007 are similar to the ones in the IPCC Fifth Assessment Report (Rhein et al. 2013). In the lead up to IPCC 2007 there were two outstanding issues in the global heat content. The first was the anomalous warming in the period 1970 to 1985 (Fig 5.1 in Bindoff et al, 2007). All of the available analyses of the observations of ocean temperature change were in agreement to within sampling error. The Ocean-Atmosphere-General-Circulation Models did not include internal variability of this size and scale during this period (e.g. Gregory et al. 2004) and thus the historical simulations and observational record were in disagreement. This disagreement between models and observations in the ocean heat content weakened the conclusions in the IPCC 2007 about the size of the warming signal and the level of decadal variability, and our capacity to attribute the observed long term warming to human influences from rising greenhouse gases (see Hegerl et al. 2007). Ocean heat content in the upper ocean was only likely (i.e. > 66% chance) to have had a contribution from Anthropogenic forcing.

The second issue was the apparent cooling in the ocean heat content record from 2003 to late 2006. This "apparent" downward trend for a period with very good ocean coverage caused concern in the chapter team about how well internal variability was understood in the oceans.

These two issues have mostly been resolved. The first issue with the discovery that the anomaly in global ocean heat content during the 1970s could be entirely explained by the systematic biases in XBT temperature profiles is that these biases evolved with time and that the large decadal variability was simply an observational artefact (e.g. Wijffels et al. 2008 and Domingues et al. 2008). The second issue was resolved when it was understood that there was a small pressure biases in some of the ARGO floats that led to an apparent cooling. Importantly none of these anomalies in ocean heat content were directly connected to sampling inadequacies of the overall observing network.

In the Fifth Assessment Report, the excellent meticulous science that had been undertaken since 2007 meant that the ocean heat content estimates had a much larger role to play in the overall conclusions, and in the understanding of the earth's energy budget, and the influence of man on the climate systems. For example, it was considered "very likely that anthropogenic forcing have made a substantial contribution to warming of the upper ocean", that is a

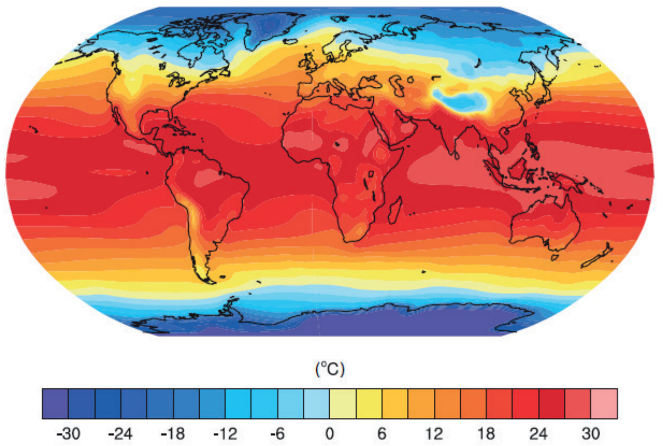

Fig.1: Multi-model (ensemble) annual mean surface (2 m) air temperature (°C) for the period 1980-2005 constructed with one realization of all available models used in the CMIP5 historical experiment. Adopted from Flato et al. 2013.

greater 90% chance of a substantial contribution. The ocean heat content had continued to rise since 1998 even though surface ocean temperature had a rate of rise over of about half that compared with the previous 15 years (Flato et al. 2013, see Fig.1), providing strong evidence that the climate change was not about to go into "reverse" and the earth was continuing to store more heat (Rhein et al 2013).

The key lessons for the ocean community and CLIVAR in particular is that the observational network must be maintained. It is urgent to develop and drive methods that ensure that the main source of errors in ocean heat content are progressively tested and validated (e.g. CLIVAR IQUOD project). Climate models have a key role in addressing the issue of observational artefacts and it is crucial that both data and models are evaluated together. This activity is very relevant to CLIVAR GSOP. It is the combining of theory, observations and models that allows scientific progress to be made. Understanding variations on short time-scales is becoming increasingly relevant to society (for example the recent hiatus in surface warming) and knowing how much of these changes has been caused by human or natural influences such as volcanic eruptions. Ocean heat content data is increasingly being used to explain and understand past changes and projections of the future climate, and thus becoming relevant to society and more often used to support global environmental decision making.

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THE 4TH JCOMM WORKSHOP ON ADVANCES IN MARINE CLIMATOLOGY AND THE 1ST ICOADS VALUE-ADDED DATABASE WORKSHOP, ASHEVILLE, 9–13 JUNE 2014

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The Fourth JCOMM Workshop on Advances in Marine Climatology (CLIMAR-IV) was held in Asheville, North Carolina on 9-12 June 2014 in conjunction with the First ICOADS Value-Added Database (IVAD) Workshop (13 June 2014). This CLIMAR workshop forms the latest in a series of science workshops on Advances in Marine Climatology (CLIMAR) and Advances in the Use of Historical Marine Climate Data (MARCDAT). The principle aims, following on from the previous workshops, were:

1. To highlight the societal benefits of the applications of marine climatology, including for climate services;
2. To review the needs of the scientific and operational communities for marine climate data and products;
3. To assess the state of the marine climate component of the global climate observing system, identify gaps, and provide guidance on how to address them;
4. To review ongoing developments in the integration of observations across multiple observing domains (land-lower atmosphere / surface ocean – deep ocean – space).
5. To encourage submissions to the Dynamic Part of the WMO *Guide to the Applications of Marine Climatology*.

The meeting was opened by Tom Karl, director of NCDC, with key challenges for the community noted. These included, inter alia, making appropriate connections to the users and the integration of observing systems. In order to address the aims of the workshop, eight thematic and three plenary sessions were convened. The plenary sessions focused on current hot topics, including *Applications of Marine Climatology, Extreme Indices* and *Future Priorities*. These took the format of panel discussions, led by Marjorie McGuirk, Val Swail and Scott Woodruff respectively. In addition to the sessions, there was a celebration of the 50th anniversary of the Marine Climatological Summaries Scheme (MCSS) on the end of the first day.

The first thematic session focused on *Applications of Marine Climatology* and the uses of marine climate data, with two invited talks. The first was on attribution of extreme events (Thomas Peterson) and a perspective from the land community. The second looked at the development of marine indices for risk management (Rodney Martínez). The remaining talks looked at: marine indices; adding value to marine climate data through national data centres and weather and climate services; and the use of marine climate data to understand changes to the atmospheric circulation. In a related session, the *Characteristics of the Global Observing System(s)* were examined, including an invited talk on Ocean Observing Panel for Climate related activities (Mark Bourassa).

Four of the sessions were domain specific, looking at advances in *Air – Sea Interaction, Waves and Storm Surges, Surface Temperatures* and *Oceanographic Data*. Invited talks included: recent progress towards deriving near surface air temperature and humidity estimates from satellites (Darren Jackson); advances towards developing a global storm surge climatology (Kevin Horsburgh); the Coordinated Ocean Wave Climate Project (COWCLIP) (Mark Hemer); the World Ocean Database (WOD)(Tim Boyer); progress on the ERSST (Boyin Huang) and HadISST (John Kennedy) datasets; and lessons that could be learnt from the International Surface Temperatures Initiative (ISTI)(Peter Thorne).

The final two sessions focused on *Data Recovery and Management Initiatives* and *Quality Control*. Invited talks included talks on the future of ICOADS (Eric Freeman), on the ICOADS Value-Added Database (IVAD) project (Shawn Smith) and on a high level quality control standard for marine atmospheric data (Gudrun Rosenhagen). The importance of data management and effective quality control, having been previously recognised, led to the development of the IVAD project.

The First IVAD Workshop provided a forum for members of the CLIMAR community to discuss and provide feedback to the developers of the prototype International Comprehensive Ocean-Atmosphere Data Set (ICOADS) value-added database. The IVAD project has the goal of establishing a system whereby external developers of adjustments (e.g., bias corrections, height adjustments, enhanced quality control) to parameters within individual ICOADS reports can attach their adjustments to the original ICOADS value within a structured database management system. IVAD is designed around serving these community-developed adjustments to the user community as part of the ICOADS. The session included a series of facilitated discussion sessions organized around seven primary topics: *Progress on IVAD prototypes, Status of the IVAD database management system, User access to adjusted data, Importing new marine records into ICOADS, Updates to the International Maritime Meteorological Archive (IMMA) format used by ICOADS, Future capabilities of ICOADS and IVAD and IVAD administrative activities.* Community input resolved a number of minor challenges with the IVAD prototype and laid the groundwork for future development. Decisions were made on how to manage unique record identifiers within ICOADS and the protocol for submitting new ICOADS and IVAD records to the respective projects. A proposal for a "how to" manual for translating original marine records to the IMMA format was discussed and several actions taken to move that manual forward. An additional proposal explored the structure and challenges associated with collaborative software development for ICOADS/IVAD and one option to be further explored is to establish a technical expert team under the ICOADS international steering committee. The final activity of the workshop was to outline potential future data adjustments recommended by the CLIMAR community including the following: height adjusting variables to standard measurement heights and bias adjustments for moisture, SST, measured winds, salinity, and sea level pressure.

A summary of the discussion had during the workshop, issues identified and recommendations made can be found in the meeting report, available from:

http://www.jcomm.info/index.php?option=com_oe&task=viewEventDocs&eventID=1384

The book of abstracts, presentations made and video celebration of the 50th anniversary of the MCSS are also available from this site.

REPORT ON HISTORICAL WAVE AND WIND OBSERVATIONS AT OCEAN STATION P

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Ocean Station Papa (OSP; 50°N, 145°W) was founded as an observation reference location by the United States military in the 1940s to develop better meteorological prediction models for the North Pacific. After the US abandoned the site in the early 1950s, the Canadian Coast Guard took over the meteorological observation program. Those measurements were later supplemented by oceanographic measurements that remained part of the overall program until continuous occupation of the site was terminated in 1981.

In 2007, continuous monitoring of some of the surface meteorology, physical and biogeochemical observations at OSP resumed with the deployment of a NOAA surface mooring. In 2010, continuous monitoring of surface waves resumed with the deployment of a moored directional wave buoy (Datawell Waverider) by the University of Washington Applied Physics Laboratory (UW–APL). The Canadian weather ship wave data have been quality-controlled into a robust scientific tool to provide an historical context for modern measurements. Additionally, the quality-controlled data product was used to determine the influence of known climate signals on wave development in the North Pacific.

In developing the quality-controlled dataset, several sources connected to the Canadian measurement program were obtained and cross-referenced. While numerous problems were discovered during the cross-referencing process, many were reconcilable, and the resultant data set was compared to four years (2010–2014) of modern data. This analysis primarily focused on wind speed, wave height, and wave period as bulk parameters for wave conditions. It was found that historic, mechanical anemometer wind speeds were almost statistically identical to modern, sonic anemometer wind speeds.

Historic wave height and period proved to be more problematic for analysis, primarily because a trained observer visually estimated both parameters. In addition, there is some evidence that the observer sometimes separated the wave field around the weather ship into wind–sea and swell, recording a height and period for each. This may explain why the distribution of wave period in the historic dataset was found to align more closely with the spectrally-averaged period than the peak period of modern waves at OSP. A significant low bias was also noted for historic wave heights, however a statistical comparison with modern significant wave heights indicated that the historic values were collected in a systematic manner and could be considered viable data when analyzed through statistical means.

The quality-controlled data was then subjected to a seasonal decomposition and statistical comparison to the Pacific Decadal Oscillation (PDO). The methods utilized in this analysis showed a very weak dependence of wind speed and wave height variability on phase of the PDO cycle. Notably, the PDO phase was determined to have a greater impact on the wave variability, with more extreme wave height measurements during the cool phase of the PDO.

A technical report (Belka et al. 2014) containing more detailed results is available for download through the UW–APL at http://www.apl.washington.edu/research/downloads/publications/tr_1407.pdf. The quality-controlled data and supporting documentation are also available for download in multiple formats through the University of Washington Library at http://hdl.handle.net/1773/25570.

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CALENDAR

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14TH INTERNATIONAL WORKSHOP ON WAVE HINDCASTING AND FORECASTING

November 2015, Key West, Florida, USA

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