Some highlights on CLIVAR Energy Activities

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With some contribution of / many thanks to Karina VonSchuckmann, Aida Alvera, Abderahim Bentamy, Caroline Clayson, Lisan Yu, Bertrand Chapron, Raymond Zaharia, Axel Anderrson, Mark Bourassa, Michael Brunke, Chris Fairall, Sarah Gille, Simon Josey, Fennig Karsten, Liz Kent, Chris Merchant, Brent Roberts, Chung-Lin Shie, Andrea Storto, Keith Haines, Magdalena Alonso, Kathy Hill, Tony Lee & colleagues …
Why?
Climate science

A sensitive matter

The climate may be heating up less in response to greenhouse-gas emissions than was once thought. But that does not mean the problem is going away.

Source: The Economist, March 2013
Possible causes?.. Natural Climate Variability, Reduced Solar Variability, ENSO (La Nina), Increased Stratospheric Aerosols from Volcanoes, Asian Pollution, Deep ocean heat uptake, Sampling Bias in polar regions, Obs quality, ....
Heat as seen from Space through S-3

THERMAL SIGNATURE OF NAMIBIAN COASTLINE

S3A SLSTR
05.04.2016
Namibian coast
Positive Earth’s Energy Imbalance: accumulation and storage of heat

von Schuckmann at al., 2015, accepted in NCC
“Symptoms” of positive EEI

EARTH’S ENERGY IMBALANCE: ☀ < ☾

- Atmospheric temperature ↑
- Atmospheric moisture ↑
- Land ice ↓
- Sea ice ↓
- Global mean sea level ↑
- Global surface temperature ↑
- Ocean heat content ↑
- Ocean mass ↑
- Flooding ↑
- Drought ↑
- Coastal flooding, erosion ↑
- Snow cover, glaciers ↓

von Schuckmann at al., 2015, accepted in NCC
Integrated Earth System Approach

Ocean’s total heat content

Ocean is a big player in our understanding of climate variability as well as changing climate.

- Earth Energy Imbalance
- Water cycle
- Sea level

Demands high-quality, complete and consistent long-term ocean data

Rhein et al. (2013) IPCC AR5
Different approaches determining Earth’s energy imbalance

Radiation at TOA

Storage inventory (OHC)

Hindcast and climate projection

Loeb et al., 2012

Josey et al., 2015

IPCC, 2013
Different approaches determining Earth’s energy imbalance: TOA & OHC

Estimates of EEI

1993-2008: 0.8 to 0.9 Wm²
(Trenberth et al., 2011; Trenberth and Fasullo, 2011; Hansen et al., 2011; Balmaseda et al., 2013b)

1993-2008: 0.57 Wm²
(Hansen et al., 2001 with Levitus et al., 2009 OHC, or similar with Johnson et al., 2012 OHC)

2001-2010: 0.50 ± 0.43 Wm²
(Loeb et al., 2012 with Lyman et al., 2010 OHC (up-dated)).

2005-2010: 0.58 ± 0.15 Wm²
(Hansen et al., 2011 with Argo OHC, von Schuckmann and Le Traon, 2011)

2001-2011: 0.5-1 Wm² (Trenberth et al., 2014, range from different OHC estimates)

“Missing energy” remains at interannual timescales:
All OHC estimates show CERES 2007 cooling, all miss CERES warming in 2008/2009
⇒ unable to achieve closure at interannual scales
⇒ remaining errors either in CERES or OHC
How?
CONCEPT-HEAT
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
The Research Foci are proposed as crosscutting activities.
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
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 accepted
(von Schuckmann et al., 2015)
CLIVAR research focus CONCEPT-HEAT:
Consistency between planetary energy balance and ocean heat storage

First CONCEPT-HEAT workshop, Met Office, Exeter (29.09.-01.10.2015)
An imperative to monitor Earth's energy imbalance


Affiliations  Contributions  Corresponding author

Nature Climate Change 6, 138–144 (2016)  doi:10.1038/nclimate2876
Received 24 June 2015  Accepted 22 October 2015  Published online 27 January 2016
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).
CLIVAR research focus CONCEPT-HEAT:
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?
(a) Ocean Reanalysis
Different approaches determining Earth’s energy imbalance: OHC

Global OHC from an ocean reanalysis (ORS4)

Abraham et al., 2013

Historical measurements

Balmaseda et al., 2013

Argo era
ORCA-IP Objectives

- To quantify signal/noise from ensemble
- To gain insight into the ocean variability and trends
- To identify current deficiencies
- To measure progress
- To exploit existing multi-ORCA ensemble
  - For climate indicators
  - For model validation
  - For real-time monitoring
  - For initialization of coupled models
CLIVAR GSOP/GODAE Ocean View
Ocean Reanalysis Inter-comparison (ORA-IP)

- 6 Observation only products
- 13 Low resolution models
- 8 High resolution models (1/3 or ¼ degree)
- 4 Coupled DA products
- 6 Long reanalyses, starting 1950’s

Summary Paper
Balmaseda, M.A. et al., The Ocean Reanalysis Intercomparison project (ORA-IP) J. Op. Oceanogr. Volume 8, supplement 1, 9 June 2015

Special Issue Climate Dynamics:
7 papers accepted so far, 2 under revision
+ other papers with sensitivities

http://www.clivar.org/sites/default/files/documents/Exchanges64.pdf
## Table 1 List of ocean reanalysis products entering the inter-comparison.

<table>
<thead>
<tr>
<th>Product</th>
<th>Forcing</th>
<th>Configuration</th>
<th>Data Assim. Method</th>
<th>Analysis Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFDL/NOAA (ECDA)</td>
<td>Coupled DA</td>
<td>1°x1/3° MOM4 coupled</td>
<td>EnKF (T/S/SST)</td>
<td>1979-present</td>
</tr>
<tr>
<td>GMAO/NASA (MERRA Ocean)</td>
<td>Merra + Bulk</td>
<td>0.5° MOM4</td>
<td>EnOI (SLA/T/S/SST/SIC)</td>
<td>1979-present</td>
</tr>
<tr>
<td>NCEP/NOAA (GODAS)</td>
<td>NCEP-R2 Flux.</td>
<td>1°x1/3° MOM3</td>
<td>3DVAR (SST/T)</td>
<td>1979-present</td>
</tr>
<tr>
<td>NCEP/NOAA (CFSR)</td>
<td>Coupled DA</td>
<td>0.5°x1/4°</td>
<td>3DVAR (SST/T)</td>
<td>1979-present</td>
</tr>
<tr>
<td>CAWCR/BOM (PEODAS)</td>
<td>ERA40 to 2002; NCEP-R2 thereafter. Flux</td>
<td>1°x2° MOM2</td>
<td>EnKF (T/S/SST)</td>
<td>1979-present</td>
</tr>
<tr>
<td>ECMWF (ORAS4)</td>
<td>ERA40 to 1988; ERAi thereafter. Flux.</td>
<td>1°x1/3° NEMO3</td>
<td>3DVAR (SLA/T/S/SST)</td>
<td>1979-present</td>
</tr>
<tr>
<td>MRI/JMA (MOVE-G2)</td>
<td>JRA-55 corr+ CORE Bulk</td>
<td>1°x0.5° MRI.COM3</td>
<td>3DVAR (SLA/T/S/SST)</td>
<td>1979-present</td>
</tr>
<tr>
<td>UK MET (GloSea5)</td>
<td>ERAi+CORE Bulk</td>
<td>1/4° NEMO3.2</td>
<td>3DVAR (SLA/T/S/SST/SIC)</td>
<td>1993-present</td>
</tr>
<tr>
<td>MERCATOR (GLORYS2V3)</td>
<td>ERAi corr+ CORE Bulk</td>
<td>1/4° NEMO3.1</td>
<td>EnKF+3DVAR (SLA/T/S/SST/SIC)</td>
<td>1993-present</td>
</tr>
</tbody>
</table>

### Table 1: List of Ocean Variables Inter-compared

<table>
<thead>
<tr>
<th>Variable</th>
<th>Responsible</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steric Height</td>
<td>Andrea Storlo</td>
<td>CMCC</td>
</tr>
<tr>
<td>Sea Level</td>
<td>Fabrice Hernandez</td>
<td>Mercator Océan</td>
</tr>
<tr>
<td>Ocean Heat Content</td>
<td>Matthew Palmer</td>
<td>UK MetOffice</td>
</tr>
<tr>
<td>Depth of 20 degree Isotherm</td>
<td>Fabrice Hernandez</td>
<td>Mercator Océan</td>
</tr>
<tr>
<td>Mixed Layer Depth</td>
<td>Takahiro Toyoda</td>
<td>MRI-JMA</td>
</tr>
<tr>
<td>Salinity</td>
<td>Li Shi</td>
<td>BMRC</td>
</tr>
<tr>
<td>Surface fluxes and transports</td>
<td>Maria Valdiviesio</td>
<td>UoR</td>
</tr>
<tr>
<td>AMOC at 26N</td>
<td>Vladimir Stepanov</td>
<td>UoR</td>
</tr>
<tr>
<td>Sea Ice</td>
<td>Gregory Smith</td>
<td>En-Canada</td>
</tr>
</tbody>
</table>
Different approaches determining Earth’s energy imbalance: OHC

Global Ocean Heat Content: Historical data & Argo era

- Differences in upper-ocean heat storage between analyses/periods.
- Differences in “interannual to decadal variability” between analyses.
- All estimates show a multi-decadal increase in OHC in both, upper and deep ocean regions.

Abraham et al., 2013

Domingues et al., 2008

Ishii and Kimoto, 2009

Levitus et al., 2012

Palmer et al., 2007

von Schuckmann & Le Traon, 2011

Johnson et al., 2013
An overview of EOS

http://www.eos-cost.eu

Chair: Aida Alvera-Azcarate
Vice-chair: Keith Haines
COST Action “Evaluation of Ocean Syntheses”

November 2014 to November 2018

Main objective:

Establish and consolidate a network of European scientists working on the generation and evaluation of ocean synthesis products, data providers, experts in data assimilation and ocean modelling...

Support individual mobility, strengthen existing networks and foster collaboration between researchers.

↓

- compile an inventory of end-user requirements (quality and availability of ocean syntheses)
- improve the understanding of the value and use of ocean syntheses
- issue recommendations on which data products are the most suitable for which task.
- increase awareness of ocean synthesis products among end users
(b) In-situ
The mission of OceanSITES is to collect, deliver and promote the use of high-quality data from long-term, high-frequency observations at fixed locations in the open ocean.

http://www.oceansites.org/index.html
Integrated Earth System Approach

International Quality-Controlled Ocean Database

To maximize the quality, consistency and completeness of the long-term global subsurface ocean database.
(data | (intelligent) metadata | uncertainty)

To freely distribute for use in ocean, climate and Earth system research and services of societal benefit.

One of CLIVAR GSOP’s future plans/priorities (CONCEPT-HEAT)
Today’s big challenge: “Climate quality” ocean database

Need for IQuoD:
An effective globally-coordinated approach to maximise the quality, consistency and completeness of the long-term global subsurface ocean database (data/metadata/uncertainty)

Long-term subsurface ocean temperature data
Experts and users from various institutions across 17 nations

The IOC Committee on International Oceanographic Data and Information Exchange has established IQuOD as an IODE project and encourages all IOC member States, Programmes, relevant organizations and projects to collaborate with IQUOD.
www.iquod.org

mozilla
Science Lab

Join our software collaboration

Visit collaborate.mozillascience.org/projects/autoqc to find out more about our open source software development project with Mozilla Science Lab and to take part.
(c) Fluxes
Blended

Remote Sensing

Reanalysis

In Situ


ERA-15 NCEP-1 NCEP-2 ERA-40 JRA ERA-MERRA Interim CFSR 20CR ERA20C JRA-55

OAIflux DFS COREv2

SEAFLUX Reading Residual

## Ocean Heat Flux

<table>
<thead>
<tr>
<th></th>
<th>IFREMER</th>
<th>HOAPS</th>
<th>OAFlux</th>
<th>SeaFlux</th>
<th>J-OFURO</th>
<th>ERA Int</th>
<th>CFSR</th>
<th>MERRA</th>
<th>NOCS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spatial sampling</strong></td>
<td>0.25°×0.25°</td>
<td>0.50°×0.50°</td>
<td>1°×1°</td>
<td>0.25°×0.25°</td>
<td>0.50°×0.50°</td>
<td>0.70°×0.70°</td>
<td>0.38°×0.38°</td>
<td>0.50°×0.66°</td>
<td>1°×1°</td>
</tr>
<tr>
<td><strong>Wind</strong></td>
<td>QSCAT</td>
<td>SSM/I</td>
<td>SSM/I+QSCAT+NWP</td>
<td>CCMP</td>
<td>ERS2+QSCAT+AMSRE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SST</strong></td>
<td>OISST</td>
<td>NOAA/RSMAS</td>
<td>OISST+NWP</td>
<td>OISST</td>
<td>NCEP+METOP</td>
<td></td>
<td></td>
<td>ICOADS2</td>
<td></td>
</tr>
<tr>
<td><strong>qa</strong></td>
<td>SSM/I</td>
<td>SSM/I</td>
<td>SSM/I+AMSRE</td>
<td>SSM/I</td>
<td></td>
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</tr>
<tr>
<td><strong>Ta</strong></td>
<td>ERA Int</td>
<td>SSM/I+NWP</td>
<td>NWP</td>
<td>SSM/I+AMSRE</td>
<td>NCEP</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td><strong>Algorithms</strong></td>
<td>COARE3</td>
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<td>COARE3</td>
<td></td>
</tr>
</tbody>
</table>
Requirements depend on space scales, time scales, and applications.

- Century
- Decade
- Year
- Month
- Day
- Hours

- Convective precipitation
- Tropical cyclones
- Mesoscale and shelf processes, polynyas
- Boundary currents, ocean fronts and eddies
- Convection, surface water mass transformation
- ENSO, monsoon break
- Extratropical cyclones, diabatic heating
- Meridional ocean circulation
- Climate change, global ice mass balance

Required accuracy:
- 0.1 W/m²
- 1 W/m²
- 5 W/m²
- 10 W/m²
- 20 W/m²
- 50 W/m²
INPUT PARAMETERS

- Surface Wind
  - ERS, Envisat, SSM/I, QSCAT, ASCAT, AMSR-E, HY-2
  - Sea Temp
- SST (AATSR, AVHRR)
- Specific Humidity
- SSM/I, AMSR-E, ADEOS
- Air Temperature
- ERA-Interim
- Sea State
- Globwave (ERS, Envisat altimeter)
- Ancillary
  - ERA_Int CFSR MERRA
- Model data

OTHER FLUX DATA SETS

- Quality Inter-comparison (global)
  - NERSC
  - IFREMER
- J-OFURO HOPS SeaFlux IFREMER AOFlux
- Validation (point-based)
  - Buoys, Experiments, NOCS, SAMOS
  - NERSC, IFREMER
- Consistency Checks (regional assessment)
  - (Open Cage, Warm Pool Bubble, Med Sea)

REGIONAL HEAT BUDGET

- MIO
  - Argo
  - Glob C
  - Net Flux
  - ORA
  - Ocean Colour
- PML
  - OHC
  - Current
  - Rad Fluxes
  - Synthesis
  - CCI
  - Mixed Layer Depth derived from GOTM

PDF Turbulent Heat Flux
- 20yrs, 0.25deg
- Sensible Flux, Latent Flux, Uncertainty

State-of-the-art Bulk Formula
+ Ensemble Approach
Example of inter-comparison results from OHF reference data
2-parameter MFT PDF (Gulev and Belyaev 2012)

\[ P(x) = (\alpha \cdot \beta) \cdot e^{\beta x} \cdot e^{-\alpha \cdot e^{\beta x}} \]

How accurately captured by parameterizations and different data?

How can be accounted in large-scale integrations?
Collaborative Platform

Oceanheatflux.org
Revisiting “cage” concept

The CAGE accuracy requirements cannot be met, even over the North Atlantic, if the local fluxes are to be computed with data from the existing radiocarbon network alone and then analyzed and differentiated to give the flux divergences (Oort, 1978). The principal difficulty in using this technique lies in the lack of samples (stations) over the ocean. It is

The sea surface fluxes are very difficult to measure well. The best way at present is to “parameterize” the fluxes in terms of their bulk properties. Errors of up to 50% arise from poor sampling in time and space such as avoidance of heavy weather by most ships, inadequate parameterization and biases in the data themselves.

Over most of the ocean, the heat stored and released over the course of the year (at latitudes other than those where it is stored) is found in the top few hundred meters (Oort and Vonder Haar, 1976). To allow estimation of the heat storage trend over the five-year time scale of the experiment, however, the heat content of the water column to far greater depths must be measured at least twice, preferably at the beginning and the end of the experiment.
Evaluation of Ocean Heat Budget (OHB)

Lateral flux

\[ \frac{d(OHC)}{dt} \]

Budget

\[ OHC = \int_{z} \rho c_{p} T_{0}(z)dz \]

\[ \frac{d(HB)}{dt} = \frac{d(OHC)}{dt} - HF_{lateral} \]

\[ T_{0} = T - T_{\text{clim}} \]

\[ HB = (SW \downarrow - SW \uparrow + LW \downarrow - LW \uparrow) + Lhf + Shf \]

Lhf = latent heat flux; Shf = Sensible heat flux
Concluding Remarks
COMMENTARY:

1.5 °C and climate research after the Paris Agreement

Mike Hulme

The Paris Agreement contains an ambition to limit global warming to no more than 1.5 °C above pre-industrial levels, changing the context for policy-relevant research and extending a challenge to the IPCC and researchers.
Integrated Earth System Approach
CHARTING THE COURSE FOR CLIMATE AND OCEAN RESEARCH

18-25 SEPTEMBER 2016 QINGDAO, CHINA

18, 24-25 September: Early Career Scientists Symposium
19-23 September: Open Science Conference