ESA Support to Science Element

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1 Introduction

1.1 Overview

The oceans have the largest heat capacity in the climate system and therefore control the rate of climate change (Levitus et al. 2005; Lyman et al., 2010; Trenberth and Fasullo 2010; Loeb et al. 2012). Ocean circulation redistributes heat and regulates air–sea fluxes on long time scales, thus influencing climate variability and change. The heat exchange between the ocean and the atmosphere (quantified through the net heat flux) consists of four components: latent heat flux associated with turbulent heat transfer by evaporation of sea water; sensible turbulent heat flux transfer short wave and long wave radiative fluxes. Being the crux of communication between the ocean and the 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), and are to assess the surface energy budget (e.g. Trenberth et al, 2009, Stephens et. al., 2012), and can be linked to changes in the Ocean Heat Content (OHC) especially of the upper ocean layers.

Improving estimation of air–sea fluxes is a critical issue for advancing our understanding of atmosphere–ocean interactions related to Earth's climate variability and change, and for accounting for the ocean signals in short- and long-term climate fluctuations due to natural variability and human influence. Accurate air-sea heat flux estimates are required to establish air-sea feedback mechanisms, to deliver forcing functions for ocean and atmosphere GCMs, to provide guidance and validation background for modeling studies. Recommendations and priorities for ocean heat flux research were developed at several WCRP and CLIVAR meetings and workshops and outlined in the corresponding reports (Yu et al, 2012; WOAP, 2012; WCRP, 2013). These include the need for improving the accuracy, the consistency, and the spatial and temporal resolutions of air-sea fluxes over both global and regional scales.

However, estimating surface fluxes at a global scale poses formidable challenges. Most of available surface flux data sets suffer from systematic biases and random uncertainties and fail to satisfy global and regional energy constraints. This supports the case for consolidated research effort to address this key issue. ESA's overall requirements for the Ocean Heat Flux (OHF) contract is to make available long term time series of the accurate and properly validated OHF components derived from remotely-sensed measurements with the use to a full extent of ESA Earth Observation (EO) data. This is naturally going hand in hand with the new CLIVAR research focus CONCEPT-HEAT (http://www.clivar.org/science/clivar-research-foci#six) which has the main objective to build a multidisciplinary synergy community for climate research aiming at the two issues:

- 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.

- 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).

To meet the scientific community requirements, the OHF project is aiming at the development, validation, and evaluation of satellite-based global estimates of surface turbulent fluxes, particularly derived from (but not limited to) ESA satellite/mission EO data. The main objectives of OHF project are:

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

- 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

1.2 Purpose and scope of the Baseline Reference

This is the Reference Baseline (RB) (deliverable D.1.1) for the OHF project. It is intended to satisfy the original requirements for a Reference Baseline specified by ESA [SoW]. Primary turbulent flux products - including ESA EO -, in-situ data sources and reanalysis outputs and systems are identified. The principal aim of this requirements baseline document is to provide users with a comprehensive inventory and description of the suite of products to be delivered to meet the specific needs of the scientific community. The major focuses will be on the input data, meta-data, error statistics, validation protocol, assessment of strengths and weaknesses, brief description of the selected algorithms, methodologies, and workflows as well as on the data portal to provide access to the data. This document will constitute the first milestone for further activities in the TIE-OHF project. More precisely, the purpose of this report is to

- Present a balanced view of key issues for ocean turbulent heat flux products as based on existing understanding, gaps in understanding and controversies significant to the evaluation of OHF products.
- Assess the reasonable expectation for the project (particularly the achievable outputs) given remaining gaps in understanding and the finite resources of this project
- Provide an analysis of requirements for the project in several sub-headings
- Clarifications of fundamental understanding that must underpin reliable and accurate outputs
- The data required to arrive at a reference data set
- Specifications on OHF outputs, including product, format and content
- Compile and analyze data output relevant to the project
    - Data type
    - Methodology
    - Accuracy

    - Temporal and Spatial Coverage
    - Availability and Restrictions on Use
- Outline the tasks involved in completing the project satisfactorily
- Identify specific products.
- Identify validation methods, and corresponding regional approaches.
- Identify delivery mechanisms.
- Identify routes for communication, outreach and collaborations.

1.3 Report structure

The report is structured as follows:

- Section 1 (this section) the introduction gives an overview of the project aims and objectives, including purpose and scope of the RB document.
- Section 2 is aiming to summarize the key requirements and objectives for ocean heat flux. In addition, trade-offs will be identified for this RB.
- Section 3 will deliver information on product specification, format and content for the OHF outputs.
- Section 4 will focus on the requirements on data and methods to generate the Ocean Heat Flux products.
- Section 5 will introduce the different methods and approaches for product evaluation and validation strategy, including the estimation of errors, the Triple Collocation Method, the Probability distribution, and the method of cages.
- Section 6 will give insight into strengths and limitations of the project objectives (?)
- Section 7 aims to develop requirements for OHF technical implementation
- Section 8 will describe the OHF data portal
- Section 9 shows up planned outreach and communication activities
- Section 10 will introduce requirements on the schedule

1.4 Applicable documents

The table list of the applicable documents to this document:

Table 1: Applicable documents

Id	Title	Reference	Issue	Rev.
SOW	Statement of Work	EOP-SA/0261/PPM-ppm	1	1.

1.5 Reference documents

Table 2: Reference documents

Id	Title	Reference	Issue	Rev.
[RD-1]	Climate Data Guide			

1.6 Web resources

Table 3: Web resources

Id	Title	Reference
[WEB-1]	OceanFlux GHG project climatology generator	http://www.ifremer.fr/cersat1/exp/oceanflux
[WEB-2]	Felyx software solution	http://felyx.org
[WEB-3]	Ifremer/Cersat	http://cersat.ifremer.fr/
[WEB-4]	HOAPS	http://www.hoaps.zmaw.de/
[WEB-5]	OAFlux	http://oaflux.whoi.edu/data.html
[WEB-6]	SeaFlux	http://seaflux.org/
[WEB-7]	J-OFURO	http://dtsv.scc.u-tokai.ac.jp/j-ofuro/
[WEB-8]	NOCS2	http://noc.ac.uk/science-technology/earth-ocean-system/atmosphere-ocean/noc-surface-flux-dataset
[WEB-9]	ERA Interim	http://www.ecmwf.int/en/research/climate-reanalysis/era-interim
[WEB-10]	CFSR	https://climatedataguide.ucar.edu/climate-data/climate-forecast-system-reanalysis-cfsr
[WEB-11]	JPL QuikSCAT L2B 12.5 km data	podaac.jpl.nasa.gov/OceanWinds/quikscat/preview/L2B12/v3/
[WEB-12]	Ifremer/cersat wave data	ftp://ftp.ifremer.fr/ifremer/cersat/products/swath/altimeters/waves/documentation/

[WEB-13]	Oceansites	http://www.oceansites.org
[WEB-14]	SAMOS	http://samos.coaps.fsu.edu/html/

1.7 Scientific publications

Table 4: Scientific publications

[SP-1]	Ayina L. H., A. Bentamy, A. Mestas-Nunez, G. Madec, 2006: The impact of satellite winds and latent heat fluxes in a numerical simulation of the tropical Pacific Ocean. Journal of Climate, 19(22), 5889-5902. http://dx.doi.org/10.1175/JCLI3939.1
[SP-2]	Andersson A., K. Fennig, C. Klepp, S. Bakan, H. Graßl, and J. Schulz, 2010: The Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data - HOAPS-3, Earth System Science. Data, 2, 215-234, doi:10.5194/essd-2-215-2010.1
[SP-3]	Andersson, A., Klepp, C., Fennig, K., Bakan, S., Grassl, H., & Schulz, J. , 2011: Evaluation of HOAPS-3 ocean surface freshwater flux components. Journal of Applied Meteorology and Climatology, 50, 379-398.
[SP-4]	Bentamy, A., P. Queffeulou,, Y. Quilfen, K. Katsaros,1999: Ocean surface wind fields estimated from satellite active and passive microwave instruments, IEEE T. Geoscience and Remote Sensing, 37 (5) , 2469-2486
[SP-5]	Bentamy A., K B. Katsaros, M. Alberto, W. M. Drennan, E. B. Forde, 2002: Daily surface wind fields produced by merged satellite data. American Geophys. Union, Geophysical Monograph Series Vol. 127, 343-349.
[SP-6]	Bentamy, A., K. B. Katsaros, A. M. Mestas-Nuñez, W. M. Drennan, E. B. Forde and H. Roquet, 2003. Satellite estimates of wind speed and latent heat flux over the global oceans. J. Climate, 16, 637-656.
[SP-7]	Bentamy, A., H.-L. Ayina, P. Queffeulou, and D. Croize-Fillon ,2007: Improved Near Real Time Surface Wind Resolution over The Mediterranean Sea, Ocean Sci., 3, 259-271.
[SP-8]	Bentamy, A., L-H. Ayina, W. Drennan, K. Katsaros, A. M. Mestas-Nuñez, and R. T. Pinker, 2008. 15 years of ocean surface momentum and heat fluxes from remotely sensed observations, FLUXNEWS, 5, World Climate Research Programme, Geneva, Switzerland, 14–16 (http://sail.msk.ru/newsletter/fluxnews_5_final.pdf).
[SP-9]	Bentamy, A., D. Croize-Fillon, and C. Perigaud , 2008: Characterization of ASCAT measurements based on buoy and QuikSCAT wind vector observations, Ocean Sci., 4, 265–274.
[SP-10]	*Bentamy A., D. Croizé. Fillon, 2011:* Gridded Surface Wind Fields from Metop/ASCAT Measurements. International Journal of Remote Sensing, 33, pp 1729-1754.
[SP-11]	Bentamy, A., S. A. Grodsky, J. A. Carton, D. Croizé-Fillon, and B. Chapron, 2012: Matching ASCAT and QuikSCAT winds, J. Geoph. Res., 117, C02011, doi:10.1029/2011JC007479.
[SP-12]	Bentamy, A., S. A. Grodsky, K. Katsaros, A. M. Mestas-Nuñez, B. Blanke and F. Desbiolles , 2013: Improvement in air–sea flux estimates derived from satellite observations, International Journal of Remote Sensing, 34 (14), DOI:10.1080/01431161.2013.787502.
[SP-13]	Bentamy A., Grodsky S. A., Chapron B., Carton J. A., 2013: Compatibility of C- and Ku-band scatterometer winds: ERS-2 and QuikSCAT. J. Marine System 117-118, 72-80
[SP-14]	Berg, W., C. Kummerow, M. Sapiano, N. Rodriguez-Alvarez, and F. Weng, A Fundamental Climate Data Record of Microwave Brightness Temperature data from 25 Years of SSM/I and SSMIS Observations, GEWEX Newsletter, August 2012.

[SP-15]	Berry, D.I. and E.C. Kent, 2011, Air-sea fluxes from NOCS2.0: the construction of a new gridded dataset with uncertainty estimates. International Journal Climatology. (CLIMAR-III Special Issue), 31, 987-1001 (doi:10.1002/joc.2059).
[SP-16]	Bretherton, F.P., D.M. Burrige, J. Crease, F.W. Dobson, E.B. Kraus and T.H. Vander Haar , 1982: The CAGE experiment, a feasibility study, UNESCO report.
[SP-17]	Bradley, E. F. and C.W Fairall, 2007: A Guide to Making Climate Quality Meteorological and Flux Measurements at Sea. NOAA Technical Memorandum OAR PSD-311, NOAA/ESRL/PSD, Boulder, CO, 108 pp.
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[SP-22]	Fennig, Karsten; Andersson, Axel; Schröder, Marc (2013): Fundamental Climate Data Record of SSM/I Brightness Temperatures - . Satellite Application Facility on Climate Monitoring. DOI:10.5676/EUM_SAF_CM/FCDR_SSMI/V001 http://dx.doi.org/10.5676/EUM_SAF_CM/FCDR_SSMI/V001
[SP-23]	Gulev, S.K., T. Jung, and E. Ruprecht, 2007: Estimation of the impact of sampling errors in the VOS observations on air-sea fluxes. Part II. Impact on trends and interannual variability. J. Climate, 20, 302-315.
[SP-24]	Gulev, S.K. and coauthors, 2010: Surface energy and CO2 fluxes and sea ice for ocean monitoring and prediction. ESA special volume on OceanObs'09 Plenary White Paper at Oceanobs-09, Venice, Italy, September 2010.
[SP-25]	Gulev, S.K., and K.P. Belyaev, 2012: Probability distribution characteristics for surface air-sea turbulent heat fluxes over the global ocean. J. Climate, 25, 184-206, 2012, doi: 10.1175/2011JCLI4211.1
[SP-26]	Gulev SK, Latif M, Keenlyside N, Park W, Koltermann KP , 2013: North Atlantic Ocean control on surface heat flux on multidecadal timescales. Nature, 499, 464–467.
[SP-27]	Kubota, M., and H. Tomita, 2007: Introduction of J-OFURO latent heat flux version 2. Proc. Joint 2007 EUMETSAT Meteorological Satellite Conf. and 15th Satellite Meteorology and Oceanography Conf., Amsterdam, Netherlands, EUMETSAT and Amer. Meteor. Soc.
[SP-28]	Klepp, C., Andersson, A., & Bakan, S. (2008). The HOAPS climatology: Evaluation of latent heat flux. Newsletter of the WCRP Working Group on Surface Fluxes, 5, 30-32.
[SP-29]	Pinker, R. T., H. Wang, and S. A. Grodsky, 2009. How good are ocean buoy observations of radiative fluxes? Geophys. Res. Lett., 36, L10811, doi:10.1029/2009GL037840.
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[SP-56]	Sapiano, M. R. P., W. K. Berg, D. S. McKague, and C. D. Kummerow, 2012: Toward an Intercalibrated Fundamental Climate Data Record of the SSM/I Sensors. IEEE Trans. Geosci. Rem. Sens., Vol. 51 , Issue 3, doi 10.1109/TGRS.2012.2206601
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57.1 Abbreviations and Acronyms

Table 5: List of abbreviations and acronyms

AATSR	Advanced Along Track Scanning Radiometer (ESA instrument)
ADB	Actions Data Base
AMSRE	Advanced Microwave Scanning Radiometer – E (of NASA's EoS Aqua)
API	Application Programming Interface
ATSR-1	Along Track Scanning Radiometer onboard ERS-1 (ESA instrument)
ATSR-2	Along Track Scanning Radiometer onboard ERS-2 (ESA instrument)
AMSR-E	Advanced Microwave Scanning Radiometer for EOS (NASA instrument)
AOD	Aerosol optical thickness

AOT	Aerosol optical depth
ASAR	Advanced Synthetic Aperture Radar
ASCAT	Advanced SCATterometer (of MetOp)
ATBD	Algorithm theoretical basis document
AVHRR	Advanced Very High Resolution Radiometer (NOAA instruments)
CCI	Climate Change Intiative
CDR	Critical Design Review
CEOS	Committee on Earth Observation Satellites
CERSAT	Centre de Recherche et d'Exploitation Satellitaire (IFREMER Satellite Data Center)
CLIVAR	Climate and Variability
DARD	Data Access and Requirements Document
DIR	Directory
DMSP	Defense Meteorological Satellite Program (of the USA)
DVP	Development and Validation Plan
DWD	Deutscher Wetterdienst
ECMWF	European Centre for Medium-Range Weather Forecasts
ENVISAT	Environment Satellite
EO	Earth observation
EOS	Earth Observing System
ERS	European Remote Sensing satellite (ESA instrument)
ERSEM	European Regional Seas Ecosystem Model
ESA	European Space Agency
EU	European Union
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FOAM	Forecast Ocean Assimilation Model
FR	Final Report
FP	Final Presentation
FTP	File transfer protocol
GCOS	Global Climate Observing System
GHRSST	Group for High Resolution Sea Surface Temperature
GMES	Global Monitoring for Environment and Security
GOCE	Gravity field and steady-state Ocean Circulation Explorer
GSICS	Global Space-based Inter-Calibration System
Hs	Significant Wave Height (also SWH)
ICD	Interface Control Document
IFREMER	Institut Français de Recherche pour l'Exploitation de la Mer
IOCCG	International Ocean Colour Coordinating Group
IOWAGA	Integrated Ocean Waves for Geophysical and other Application
IOVWST	International Ocean Vector Wind Science Team
IR	Infra-red (a piece of the electromagnetic spectrum)
ITT	Invitation To Tender
Jason-1	Altimetry mission (NASA/France instrument)

Jason-2	Altimetry mission (NASA/France instrument)
HOAPS	Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data
KO	Kick Off
LHF	Latent Heat Flux
LW	Long Wave
MERIS	Medium Resolution Imaging Spectrometer (ESA instrument)
MODIS	Moderate Resolution Imaging Spectrometer (NASA instrument)
MR	Monthly Report
NASA	National Aeronautics and Space Administration (US)
NCDC	National Climatic Data Center
NERC	UK Natural Environment Research Council
NetCDF	Network Common Data Form
NetCDF CF	NetCDF Climate and Forecast Metadata Convention
NOAA	National Oceanographic and Atmospheric Administration (US)
NOC	National Oceanography Centre (UK)
NOP	Numerical Ocean Prediction
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NRT	Near Real Time
NTC	Non Time Critical
NWP	Numerical Weather Prediction
NWC	Numerical Weather nowCasting
OAFlux	Ocean Atmosphere Flux
OC	Ocean colour
OC-flux	ESA STSE project – Open ocean and Coastal CO2 fluxes in support of carbon cycle monitoring
OHF	Ocean Heat Flux
OPeNDAP	Open-source Project for a Network Data Access Protocol
OSTIA	Operational Sea Surface Temperature and Sea Ice Analysis (UK Meteorological Office)
PaaS	Platform as a Service
PAR	Preliminary analysis report
PI	Principal Investigator
PML	Plymouth Marine Laboratory
PR	Progress Report
PMR	Passive Microwave Radiometry
RA2	Radar altimeter 2 (ESA instrument)
RB	Requirements Baseline
RD	Reference Document
RRS	Remote Sensing Reflectance
RUG	Reference User Group
SaaS	Software as a Service
SAP	Scientific Analysis Plan
SAR	Scientific Assessment Report

SAR	Synthetic Aperture RADAR
SeaWIFS	Sea-viewing Wide Field-of-view Sensor
SEVIRI	Spinning Enhanced Visible and Infrared Imager (of Meteosat Second Generation)
SIAR	Scientific and Impact Assessment Report
SOLAS	Surface Ocean and Lower Atmosphere Study
SoW	HR-DD Statement of Work
SR	Scientific Roadmap
SRR	System Requirements Review
SSH	Sea Surface Height
SSM/I	Special Sensor Microwave Imager (of DMSP)
SSS	Sea Surface Salinity
SST	Sea Surface Temperature
SST-VC	SST Virtual Constellation (of CEOS)
STSE	Support to Science Element
TBC	To Be Confirmed
TBD	To Be Determined
TDP	Technical Data Package
TDS	Test Data Set
TN	Technical Note (short report 10-50 pages)
TO	Technical Officer (of the Agency)
TOA	Top of Atmosphere
TR	Technical Report (long report > 50 pages)
TS	Technical Specification
TOPEX	TOPEX-Poseidon altimetry mission (NASA/France)
UM	User Manual
URL	Universal Resource Locator
VIIRS	The NOAA Visible Infrared Imager Radiometer Suite
WCRP	World Climate Research Programme
WGASF	Working Group on Air-Sea Fluxes
WHOI	Woods Hole Oceanographic Institute
WGSF	Working Group on Surface Fluxes
WP	Work package
1D	One dimensional
3D	Three dimensional

2 Summary of Ocean Heat Flux requirements

2.1 Overview

The requirements presented in this document come from the following sources:

- The original statement of work [SoW], issued by ESA,
- Internal discussions within the Ocean Heat Flux project team, a reference group of experts assembled by the project team and the ESA technical officer,
- The CLIVAR workshop recommendations
- The submitted project proposal.

2.2 Key requirements and objectives

OHF project objectives attempt to meet the main requirements reported in SoW:

- Consolidation of flux product requirements related to sampling, accuracy, input data, ancillary data, error characteristics
- Consolidation of flux product specifications related to the file format, metadata, projection
- Consolidation of flux method and algorithms
- Identification of the product algorithm strengths and limitations
- Consolidation the strategy of the flux product evaluation and validation
- Consolidation of the method aiming at the generation of a suitable ensemble of realization of turbulent fluxes
- Refine architecture
- Homogenization of turbulent flux data
- Generate regional heat constraints for the cage study
- Make data available to project members through (preliminary) portal
- Product Generation, Inter-Comparison and Uncertainty Characterizations
- Sensitivity studies and algorithm improvement

2.3 Key requirements from the research community

OHF requirements address the recommendations and priorities outlined in the latest CLIVAR and WCRP reports . These include the need for improving the accuracy, the consistency, and the spatial and temporal resolutions of air-sea fluxes over both global and regional scales

2.4 Trade-offs made for the requirements baseline

OHF does not attempt to meet all scientific community requirements. For instance, no significant effort is devoted for radiative short (SW) and long (LW) wave fluxes estimation and validation. It is expected to collect SW and LW data from university of Maryland and from DWD both collaborating to the project as experts. Therefore, OHF project will not provide any indicators related to Qnet. The project does not consider the merging in-situ and EO data for flux enhancement purposes. No further improvement of in-situ analyses calculated from ship measurements will be performed. Only available NOCS2 data is considered for inter-comparison issues. Number of ocean and atmospheric re-analyses (e.g. ERA Interim, CFSR, MERRA, JRA-25, NCEP NARR, are available would be used for the project. However, only ERA Interim and CFSR are considered.

3 Ocean Heat Flux data requirements

The OHF project will exploit the vast amount of EO, in situ and model data that its partners already hold. We will exploit the large amount of data storage and processing capability available at IFREMER. Any required datasets that are not already held by the partners will have to be obtained and stored in standardized formats. Most of L2b data (radar and radiometer retrievals) and in-situ raw measurements are available at IFREMER database. However, for OHF project purpose it is expected to use the most updated remotely sensed data. For instance, reprocessed and consistent datasets such as brightness temperatures (Tb) from SSM/I onboard DMSP satellites (F10, F11, F13, F14, and F15) will have to be collected from Colorado university group. Similarly, for the intercomparison and assessment step, the flux products mentioned in SoW and in the OHF proposal will be downloaded, in agreement with the providers, from the related databases. The in-situ data needed for further accuracy and quality investigation issues will also have to be collected. The following sections summarize the requirements for all these inputs to OHF project and the available sources considered.

3.1 Generation of a reference dataset

The whole project depends on the availability of input bulk variables and heat, (turbulent and radiative) flux data sets that will be used as reference for further investigations of air-sea interaction process at various space and time scales and/or for assessing the impact of various atmospheric and oceanic variables or bulk parametrization on the final flux accuracy.

A reference dataset shall therefore be assembled from EO L2, L3, and L4 products, and from in-situ measurements or estimates as well as model outputs. The resulting dataset shall aim at providing high quality bulk variables and the most updated bulk parametrization.

Accuracy of inputs for the generation of the reference dataset will be determined through comprehensive comparisons with “ground truth” data from moorings, ships and dedicated campaign that should be also comprehensive and of high quality.

<table>
<tr><th colspan="2">OHF-RB-REQ-3.1: Reference dataset</th></tr>
<tr><td colspan="2">The OHF project shall assemble a reference dataset containing:
• all necessary input bulk variables for turbulent flux computation
• all necessary data for validation and accuracy assessments
• existing turbulent fluxes
• existing radiative fluxes
The sources for each of these category may include EO and non EO (in situ, model) data.</td></tr>
<tr><td>Verification method</td><td>Inspection</td></tr>
</table>

Link to OHF SoW tasks	

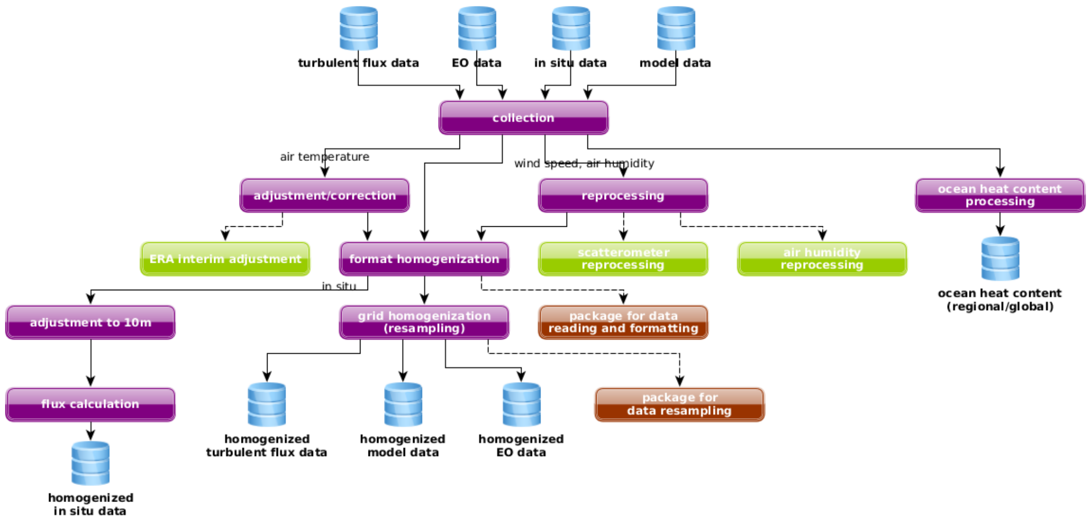
The list and sources for these data is detailed in section xxx to xxx.

All data selected for this reference dataset (where IPR agreements allow) will be made available through the project website by exploiting the IFREMER web based data access tools previously used within other ESA projects. These allow users to browse and access data and associated metadata easily using a web browser.

OHF-RB-REQ-3.2: data availability and access	
The OHF project will make all collected and generated data available through the project website. Data will be made available once all scientific work has been completed and the quality of these data have been verified.	
Verification method	Inspection
Link to OHF SoW tasks	

The generation of the reference dataset shall follow a set of activities, as illustrated in the workflow diagram 6

Figure 6: workflow for the reference dataset generation



In particular:

- the collection of the required EO (section 3.5.2) and model (section 3.7) input data for the generation of new turbulent fluxes (section 3.5.1), in situ data (section 3.6) and existing sets of turbulent fluxes (section 3.4)

- the homogenization of all data to the same format and content (section 3.3), and same spatial and temporal grid (section 3.10.1), following common OHF products specifications (section 3.2), applying in the same way to the all future flux products generated by the project.
- the adjustment and correction of the datasets for which it is required (section 3.9).
- the provision of the software developed for these operation as open source code for the community (section 7.4).

3.2 OHF product specifications

To allow consistency and complementarity throughout the project, all collected input products and generated output products shall cover a common time frame, and be available at the same spatial and temporal resolution over the same area.

Most of satellite flux products available for OHF project are daily and 0.25°×0.25° temporal and spatial resolutions. The latter are coherent with the satellite radar sampling schemes and with the remotely sensed observation spatial resolution. Furthermore, recent publications [e.g. [SP-53], [SP-54]) highlighted the impact of such resolution on the characterization of air sea interaction patterns.

The target temporal coverage for the reference dataset will be based on the availability of the input data required for the calculation of turbulent fluxes, in particular the availability (with sufficient daily sampling) of scatterometer (QuikSCAT, ASCAT), radiometer (SSM/I (F11, F13, F14, F15) and other relevant data (CCI sea surface temperature, and NWP air temperature reanalyses). A requirement is also to produce a at least 10 years long time series of fluxes. A quick analysis of the period where these sources are simultaneously available indicates the time frame 1999 to 2009 is the best suited.

The resulting products of the reference dataset will be available as daily analyses with a spatial resolution of 0.25° in longitude and latitude over ice free global ocean.

<table>
<tr><th colspan="2">OHF-RB-REQ-3.3: Reference dataset grid specifications</th></tr>
<tr><td colspan="2">The OHF project will produce a global reference dataset over the following grid specifications:
• Spatial coverage: global (80S to 80N, 180W to 180E) - 0.25° x 0.25° (regular geographic grid)
• Temporal resolution: daily
• Temporal coverage: 1999 to 2009
This will be referred to as “the OHF grid”.</td></tr>
<tr><td>Verification method</td><td>Inspection</td></tr>
</table>

Link to OHF SoW tasks	

OHF-RB-REQ-3.4: Conformity to OHF grid	
All OHF gridded data products, input bulk variables, validation products or output fluxes, shall be remapped to the same OHF grid.	
Verification method	Inspection
Link to OHF SoW tasks	Task1, Task2, Task3, Task4

Note: The OHF project will not generate any specific regional products, though some error and accuracy assessment or process study activities may be performed on regional areas.

3.3 Products format and content

3.3.1 Common format

Existing input datasets relevant for OHF shall not be re-formated if they are already available in NetCDF3 or NetCDF4 format.

All in situ data will be converted to NetCDF format. These data will follow and extend the data model defined by the ESA GlobWave project for ocean and meteorological buoy data.

The global datasets produced by OHF will use:

- Common grid specifications, as defined in section 3.2
- NetCDF4_CLASSIC (CF 1.6 compliant) format with internal compression. No usage of the new NETCDF4 features (such as groups etc...) shall be handled.
- Common content definition (variable naming, spatial and temporal dimensions,....)

OHF-RB-REQ-3.5: data types and formats	
The OHF project shall provide all fluxes, EO, model and in situ datasets in a consistent NetCDF-4 format complying to CF conventions.	
Verification method	Inspection
Link to OHF SoW tasks	Task4

All format conventions for dimension and variable naming, units, metadata, etc... will be summarized in a format and content document shared by all project partners.

OHF-RB-REQ-3.6: format document	
The OHF project shall provide a document for format and data content that will be be applied to all datasets produced by OHF.	
Verification method	Inspection
Link to OHF SoW tasks	Task2, Task4, Task6

3.3.2 Metadata requirements

The OHF products shall include global and variable attributes complying to the CF convention. The GHRSST GDS v2 specification will be used as a basis for the relevant list of metadata.

The OHF products shall include quality level information: the scale of quality levels (“good”, “suspect”, etc...) shall be the same for any dataset and comply with already existing community accepted and defined definitions (such as GHRSST).

OHF-RB-REQ-3.7: metadata	
The OHF project will follow the CF convention 1.6 for any NetCDF data that the project produces, in accordance with community standards. This will include quality level data.	
Verification method	Inspection
Link to OHF SoW tasks	Task4

3.4 Existing flux products

In accordance to task2 of SoW, the OHF project will collect the main existing turbulent fluxes to assess their homogenization over global ocean as well as at regional scales.

OHF-RB-REQ-3.8: Existing turbulent fluxes	
The OHF project will collect a set of existing turbulent flux products that will be used for evaluation, inter-comparison or ingestion into an ensemble reference dataset. This set of products shall include the products listed in table 7.	
Verification method	Inspection
Link to OHF SoW tasks	Task2, Task3, Task4, Task5

Table 7 summarizes the main characteristics of flux products (turbulent and radiative fluxes, and the associated bulk variables) to be used in OHF project. Four types of data, available over global ocean, are considered:

- fluxes estimated based only on remotely sensed observations such as:
  - 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),
  - J-OFURO (Japanese Ocean Flux Data sets with Use of Remote Sensing Observations; Japan).
- fluxes estimated as blended products such as:
  - OAFlux (Objectively Analyzed air-sea Flux (WHOI); USA)
- fluxes derived from numerical weather predictions centers such as:
  - the reanalysis performed and provided by the European Center of Medium Weather Forecasts (ECMWF), named ERA Interim,
  - the National Center for Environmental Prediction (NCEP) known as Climate Forecast System Reanalysis (CFSR) are used.
- fluxes determined from Voluntary Observing Ship (VOS) estimates as daily analysis are processed and provided by National Oceanography Centre Southampton and referred as NOCS.

In addition to turbulent fluxes, radiative fluxes (Long (LW) and short (SW) waves) from SAF Climate ([[WEB-3]) will be used to meet the project objective dealing with the investigation of net heat budget over global ocean as well as at some specific oceanic areas. Even though the OHF project does not aim at the evaluation of radiative flux accuracy, LW and SW from University of Maryland (USA) will be also used to assess the impact of radiative fluxes on net heat flux analyses.

Table 7: Characteristics of the existing flux products used in OHF

TIE-OHF Ocean Heat Products to be delivered	Ref	Parameter	Resolution	Frequency	Time Span	Coverage Time	Coverage Space	UncertaintyInformation	Error Size	Sensor Souces	Source	Nature Product	Level	Data Provider	File Format	Comments
IFREMER data set	FP1	Wind; Hum; SST; Air Temp; LHF; SHF	25km	Daily	Oct 1999 - Nov 2009	10 yrs	80S - 80N						L3 and L4	IFREMER	Netcdf 4	Version 4 calculated for OHF project.
HOAPS data set	FP2	Wind; Hum; SST; Air Temp; LHF; SHF; LW; SW; RR	50km	6-hourly Swaths	Jan 1988 - Dec 2007	20 yrs	80S - 80N						L3	DWD	Netcdf 3	Dailiy-avefaged estimates calculated fro OHF project issues
SeaFlux data set	FP3	Wind; Hum; Air Temp.; LHF; SHF	25km	Daily	Jan 1992 - Dec 2007	15 yrs	80S - 80N						L4	WHOI	Binary	Data are reformatted for OHF project.

OAFlux	FP4	Wind; Hum; Air Temp; LHF; SHF	100km	Daily	Jan 1985 - Dec 2014	30 yrs	80S - 80N						L4	WHOI	Netcdf 3	
J-OFURO data set	FP5	Wind; Hum; SST; Air Temp; LHF; SHF; LW; SW;	50km	Daily	Jan 1988 - Dec 2007	20 yrs	80S - 80N						L4	Univ. Tokai	Netcdf 3	
NOCS2	FP6	Wind; Hum; SST; Air Temp; LHF; SHF	100km	Daily	Jan 1992 - Dec 2010	19 yrs	80S - 80N						L4	SOC	Netcdf 3	
ERA Interim	FP7	Wind; Hum; Air Temp.; LHF; SHF	0.70°	6-hourly	Jan 1992 - Dec 2011	20 yrs	90S - 90N						Reanalyses	ECMWF	Grib	Data reformatted fro OHF project

CFSR	FP8	Wind; Hum; Air Temp.; LHF; SHF	0.38°	6-hourly	Jan 1992 - Dec 2011	20 yrs	90S - 90N						Reanalyses	NCEP	Grib	Data reformatted fro OHF project

3.5 Input data

3.5.1 Required parameters

Latent and sensible heat fluxes are not directly retrieved from satellite measurements. They are estimated from basic bulk variables such as 10m winds, 10m specific air humidity, air and sea surface temperature through bulk parameterization. To create the new global OHF reference dataset we will need the following parameters :

- surface wind speed and direction
- specific air humidity
- air temperature
- Sea skin temperature, foundation temperature,???
- sea state
- ocean color

The following sub-sections expand upon the above bullet points for each parameter. It discusses the various aspects discussed for the choice of the data sources with respect to their availability over the periods of interest, their accuracy, etc...

One of the key aspects is to select the best sources of synoptic observations provided by EO datasets, taking advantage in particular of the effort of ESA to make available long and consistent time series of essential variables measured by its satellites.

OHF-RB-REQ-3.9: Satellite input origin	
The products of basic bulk variables selected as input for processing and validating more than 10 years of turbulent fluxes estimations shall consider maximize the use of ESA products and satellites.	
Verification method	Inspection
Link to OHF SoW tasks	Task1, Task2, Task3

3.5.1.1 Surface wind speed and direction

Surface winds at 10m height (W) will be mainly derived from scatterometers on board QuikSCAT and METEOP-A (ASCAT). This study uses a new QuikSCAT wind retrievals indicated as QuikSCAT V3 ([WEB-11]). They are made available by Jet Propulsion Laboratory (JPL)/ Physical Oceanography Distributed Active Archive Center (PODAAC) scientific team ([SP-45]. QuikSCAT V3 products are calculated based on the use of a geophysical model function ensuring the consistency with winds retrieved from microwave radiometers such as Special Sensor Microwave Imager (SSM/I) and WindSat ([SP-46]). Wind retrievals are provided over QuikSCAT swath at Wind Vector Cell (WVC) of 12.5km spatial resolution. This new scatterometer product is assumed improving wind speed performance in rain and at high wind speed conditions. The accuracy of the QuikSCAT V3 data is determined through various comparisons with buoy wind measurements, QuikSCAT V2 retrievals, and with remotely sensed winds derived from the ASCAT scatterometer onboard Metop-A satellite. The main findings are that the comparison results meet those obtained previously ([SP-11]). QuikSCAT V3 and QuikSCAT V2 exhibit similar comparison results versus buoys. ASCAT and QuikSCAT V3 statistics are of the same order as ASCAT and QuikSCAT V2. Discrepancies characterizing ASCAT and QuikSCAT V2 comparisons are found for ASCAT and QuikSCAT V3. For instance, the most significant discrepancies are found at tropical and high latitudes. QuikSCAT V3 are corrected and improved when compared with ([RD-11]) results. To ensure the consistency between retrievals from QuikSCAT and ASCAT, the correction models described in [SP-11] will be applied.

The calculation of daily gridded wind fields from scatterometer wind observations is performed using the objective method described in ([SP-10]). The resulting wind field accuracy is investigated trough the comparisons with daily-averaged winds from MFUK, NDBC, PIRATA, RAMA, and TAO moored buoy estimates. The main statistics characterizing scatterometer and buoy daily wind speeds and direction comparisons indicate that overall statistics indicate that the daily scatterometer wind fields compare well to daily-averaged buoy data. The RMS differences do not exceed 2m/s and 20°, which are the scatterometer specifications for wind speed and direction, respectively. For in-situ and scatterometer daily winds higher than 3m/s no significant bias trend is found. For lower wind speed ranges, scatterometer winds tend to be slightly overestimated compared to buoys. The wind direction biases are relatively small. Despite of difference in buoy and scatterometer sampling schemes used for the estimation of daily winds, correlation values attest that satellite daily winds reproduce fairly well in-situ estimates. The lowest correlation value is found for Tropical buoy and satellite wind comparisons due to the low wind speed conditions distribution in these specific oceanic regions.

OHF-RB-REQ-3.10: Surface winds
OHF project shall reprocess a consistent and calibrated time series of surface winds from

existing scatterometer over the OHF period of interest and grid specifications.	
Verification method	Inspection
Link to OHF SoW tasks	

3.5.1.2 Specific air humidity

The specific air humidity (Qa) is one the main required input for latent heat flux estimation. It is estimated at 10m height based on the use of an existing model relating Qa and brightness temperatures (Tb) from radiometers.

In this project , the most updated Tb from SSM/I onboard SSM/I F11, F13, F14, and F15 are used for Qa calculation. They are provided by the University of Colorado ([SP-14]) and about twenty years of these global Tb measurements will be made on Ifremer OHF platform.

Details on the method of determination and validation of Qa retrieval are provided in ([SP-12]). Briefly, the new method aiming at the determination of Qa from Tb, improves the previous one ([SP-6]). Indeed, ([SP-12]) indicate that the RMS difference between in-situ (moorings and ship) and satellite Qa is lower than 1g/kg. Furthermore, no systematic or regional biases are found. More than ten years of Qa (1999 – 2011) over SSMI/ swath cells (0.25°×0.25°), referenced as L2b products, are calculated and are available at IFREMER. L2b Qa data are used to estimate daily analyses over global ice-free oceans with a spatial resolution of 0.25° in longitude and latitudes ([SP-12]). They are referenced as L3 products. Their accuracy is determined through comparisons with daily Qa estimated from moorings and from NOCS2 data. The RMS values are about 1g/kg while correlation coefficients exceed 0.85. Similar results are obtained from the comparisons versus daily NOCS2.0 not used in the development of the satellite Qa model.

OHF-RB-REQ-3.11: Specific air humidity	
The OHF project will estimate mean fields of specific air humidity (Qa) from radiometer brightness temperature.	
Verification method	Inspection
Link to OHF SoW tasks	Task1, Task2, Task3, Task5

3.5.1.3 Sea surface temperature

Sea surface temperature (SST) data are version 2 of OI daily analyses ([SP-47]) with a spatial resolution of 0.25° in longitude and latitude. Furthermore, to meet OHF objective dealing with the investigation of SST impact on turbulent flux estimation, the OSTIA reanalysis performed for ESA CCI SST project will be used. Both datasets are available at IFREMER. This project does not deal with the improvement of SST at global or regional scales.

OHF-RB-REQ-3.12: Sea surface temperature	
Verification method	Inspection
Link to OHF SoW tasks	Task1, task2, Task3

OHF-RB-REQ-3.13: Sources of sea surface temperature	
The OHF project will make use of different sources of SST to investigate the impact of turbulent flux estimation.	
Verification method	Inspection
Link to OHF SoW tasks	Task1, task2, Task3

3.5.1.4 Air temperature

Even though air temperature is needed for the three turbulent flux component estimations, it is highly required for sensible heat flux calculation through bulk parametrization. Air temperature at 10m (Ta_{10}) will be mainly derived from ERA Interim re-analyses. However Ta_{10} will come from CFSR re-analyses or estimated from radiometer brightness temperatures ([SP-48]).

Previous study ([SP-12]) aiming at the characterization of ERA interim Ta accuracy based on the comparisons with buoy estimates showed Era Interim Ta_{10} are underestimated for buoy Ta_{10} exceeding 20°C. A bias correction was determined from linear regression between Era Interim and buoy Ta_{10} estimates. The corrected ERA Interim Ta will be used in this project.

OHF-RB-REQ-3.14: Sources of air tempertaure	
The OHF project will make use of ERA Interim 2m air temperature	
Verification method	Inspection
Link to OHF SoW tasks	Task1, task2, Task3, Task4

3.5.1.5 Sea State

The significant wave height shall be used in particular to assess the sensitivity of OHF flux estimation to this parameter, in particular for its impact on wind stress (see 4.1.1.2).

The sea state will be derived from altimeter on-board satellites ERS-2, Topex/Poseidon, Jason-1, GFO, Envisat, and Jason-2. The Ifremer cross-calibrated multi-sensor database ([SP-49], [WEB-10]) is the most updated altimeter SWH product and will be selected as input for OHP project.

OHF-RB-REQ-3.15: Sea state	
Verification method	Inspection
Link to OHF SoW tasks	

3.5.1.6 Ocean color

OHF will make use of OC-CCI ocean-colour products. The information provided by ocean colour (chlorophyll concentration, inherent optical properties, diffuse attenuation coefficient at 490 nm) is not directly required to compute surface heat fluxes. It is an add-on, that can be used to compute penetration of solar radiation into different depth horizons in the ocean, for example, to compute solar heat flux reaching the base of the mixed layer.

Direct verification is not planned, but sensitivity analyses will be carried out using GOTM model to understand sensitivity of model-predicted heat fluxes to optical properties of the sea, under differing environmental conditions.

OHF-RB-REQ-3.16: Sea state
OHF project shall use OC-CCI data to evaluate the significance of optical variability in the

ocean, for estimation of solar heat flux below the mixed layer.	
Verification method	Inspection
Link to OHF SoW tasks	Task 3

3.5.1.7 Rain

As reported in [SP-52] rain through sensible cooling effect may impact the estimation of turbulent fluxes and their associated accuracy. OHF project will characterize the error of LHF and SHF estimations related to the rain. Samples of LHF and SHF will be estimated based on the use rain parameter trough bulk model. flux product. The results will be used to assess the error as a function of rain characteristics. Rain data will provided by DWD partner. They estimated from SS/M radiometers over global ocean with similar spatial and temporal resolutions ([WEB-4]).

OHF-RB-REQ-3.15: Rain	
The OHF project will collect rain rate from DWD for investigating the LHF and SHF related-error.	
Verification method	Inspection
Link to OHF SoW tasks	Task1, Task2, Task3, Task5

3.5.1.8 Sea surface salinity

To meet OHF objectives aiming at the assessment of heat flux content derived from the reference flux data (Task2) and/or from ensemble flux data set (Task3), and further improvements of flux estimations (Task5), the project will investigate the impact of salinity on latent heat flux variation at regional and global scales. Satellite products available for OHF project do not use salinity for LHF and SHF estimation. For instance, Ithe LHF calculation through bulk parametrization requires the knowledge of the saturation specific humidity (qs) at the air-sea interface. The latter is calculated as a function of sea surface temperature (SST). However, air in contact with a water surface is assumed to be saturated. Above sea water the saturated air has 98% of the value of water vapor density at saturation over a freshwater surface, due to the effects of the dissolved salts in the sea. The project does not aim to develop a new parametrization including salinity variable. It will investigate the spatial and temporal variability of LHF and of SHF as a function of sea surface salinity (SSS). The latter will be derived from available CCI SSS.

OHF-RB-REQ-3.16: Sea Surface Salinity	
The OHF project will collect monthly averaged SSS from available reference datasets for investigating LHF and SHF variability with respect to SSS patterns	
Verification method	Inspection
Link to OHF SoW tasks	Task2, Task3, Task5

3.5.2 Requirements for remote sensing data

The satellite provides the largest synoptic sampling of some of they quantities relevant for the estimation of fluxes and are therefore a key entry to OHF project. They must be available of the time period of interest defined for OHF project.

OHF-RB-REQ-3.17: Satellite input data time span and related platform	
The products selected as inputs for the basic variables requested for for reprocessing (when needed) and validating more than 10 years of turbulent fluxes shall consider the availability and concomitance of the different satellite missions measuring the required parameters, as summarized in table 8.	
Verification method	Inspection
Link to OHF SoW tasks	Task1, Task2, Task3

The assessment of the relevant satellite missions for OHF will be based in particular on the analysis of the time coverage of these missions, as presented in table 8.

Table 8: Satellite mission available for OHF project.

Type	Platform	Instrument	Period
Scatterometer	ERS-1	AMI	1992 - 1996
	ERS-2	AMI	1996 - 2001
	QuikSCAT	SeaWinds	1999 - 2009
	METOP-A	ASCAT	2007 - Present
Radiometer	DMSP F10	SSM/I 10	1990 - 1997
	DMSP F11	SSM/I 11	1991 - 2000

	DMSP F13	SSM/I 13	1995 - 2009
	DMSP F14	SSM/I 14	1997 - 2008
	DMSP F15	SSM/I 15	1999 - Present
Altimeter	ERS-1	RA	1992 - 1996
	ERS-2	RA	1995 - 2011
	TOPEX	NRA	1992 - 2005
	GFO	RA	1998 - 2008
	ENVISAT	RA-2	2002 - 2012
	JASON-1	Poseidon-2	2001 - 2013
	JASON-2	Poseidon-3	2008 - Present

The choice of the relevant datasets for OHF will also aim at maximizing the usage of ESA and European sources. This includes for instance:

- reprocessed datasets from ESA CCI projects, such as sea surface temperature or ocean colour
- multi-mission cross-calibrated datasets issues from ESA DUE projects, such as the wave altimeter products from GlobWave project, or OSI SAF such as the scatterometer L2 data reprocessed by KNMI

OHF-RB-REQ-3.18: Satellite input origin	
The products selected as input for the purposes of reprocessing (when needed) and validating more than 10 years of basic variables requested for turbulent estimations shall consider maximize the use of ESA products and satellites.	
Verification method	Inspection
Link to OHF SoW tasks	Task1, Task2, Task3

Table 9: Characteristics of OHF input data

EO Input Products	Ref	Parameter	Resolution	Frequency	Time Span	Coverage Time	Coverage Space	Uncertainty information	Error Size	Sensor Souces	Source	Nature Product	Level	Data Provider	File Format	Comments
Wind stress	IP1	wind speed	25km/ 12.5 km	Orbits	Mar 1992 - Feb 2011	10 yrs	80S-80N		1m/s - 2m/s	Scatterometers	QSCAT	EO	L2a	IFREMER; ESA; SAF OSI; JPL/NASA; KNMI; CNES; SAF Clim.	Netcdf 3 or 4	
Humidity	IP2	air humidity	25km	Orbits	Mar 1992 - Feb 2011	20 yrs	80S - 80N		1g/kg	Radiometers and ancillaries (SST; Air Temp.)	F10 - F15 SSM/I ;		L2a	IFREMER; ESA; EumetSat/SAF Clim; NOAA/Univ. Colorado	Netcdf 3	
Sea Surface Temperature	IP3	SST	25km	Daily	Mar 1992 - Feb 2011	20 yrs	IS THIS CORRECT	covariance matrix	0.20°C	AATSR; AVHRR; AMSR	Envisat; Metop; NOAA	EO (merged)	L3 and L4	ESA CCI and NOAA OI.	Netcdf 3 and/ or 4	
Air Temperature	IP4	Air. Temp.	0.35° - 0.70°	6-hourly	Mar 1992 - Feb 2011	20 yrs	80S - 80N		0.20°C	NWP re-analyses (ERA Interim; CFSR)	ECMWF; NCEP	Model	NWP re-analyses (ERA Interim; CFSR)	ECMWF; NCEP	Netcdf 3	
Pressure	IP5	Pressure	0.35° - 0.70°	6-hourly	Mar 1992 - Feb 2011	20 yrs	80S - 80N			NWP re-analyses (ERA Interim; CFSR	ECMWF; NCEP		NWP re-analyses (ERA Interim; CFSR)	ECMWF; NCEP	Netcdf 3	
Ocean	IP6	Ocean	7km	Orbits	Mar	20 yrs	80S -		0.50m	ESA CCI /	ESA CCI	EO	L2 and	ESA;	Netcd	

State		State	- 25km	/Daily	1992 - Feb 2011		80N			Altimters	(GlobWave); ERS-1/2; TP; Envisat; Jason-1/2	(merged)	L3	IFREMER	f 3	
Ocean Colour	IP7	Chlorophyll	25km	Daily	Mar 1992 - Feb 2011	20 yrs	80S - 80N			ESA OC CCI	ESA OC CCI		L3 and L4	ESA; PML	Netcdf 4	The Chlo will be used to see how the SW flux will penetrate the ocean in bubble analysis
Surface Current	IP8	Surface Current	0km - 50km	Hourly / Daily	Mar 1992 - Feb 2011	20 yrs	in-situ sites / Global		1m	Buoys and/or ocean n numerical models	NDBC; TAO; PIRATA; RAMA; OceanSites; Mercator; ROMS; MARS	In-situ	In-situ / L4	NOAA; PMEL; IRD; IFREMER; Mercator	Netcdf 3 and/or binary	Correction to quantify OHC

3.6 In situ data

Buoy measurements provide several oceanic (sea surface temperature (SST), column water temperature, current, sea state) and/or atmospheric (wind speed and direction, air temperature; air humidity (and/or dew point temperature), pressure) measurements required for turbulent flux estimation or validation.

There are more than 200 moored buoys of interest for this purpose. Twelve moorings located off the French and England coasts are maintained by UK Met-Office and/or Météo-France (MFUK), 96 buoys are provided by the U.S. National Data Buoy Center (NDBC) and located off and near U.S coasts, 66 buoys of the TAO array located in the equatorial Pacific, and 13 buoys of the PIRATA network located in the equatorial Atlantic. TAO and PIRATA will be hereafter referred as Tropical buoys. Buoy data are usually hourly available at heights varying between 3m and 10m. High quality bulk variable measurements are derived from OceanSITES buoy network ([WEB-11]). The moorings are an integral part of the Global Ocean Observing System (GCOS). Most of OceanSITES buoys are located in tropical zones of the Atlantic, the Indian, and the Pacific oceans. Only Kuroshio Extension Observatory (KEO) buoys are moored at extra-tropical. The OceanSITES buoy number increases from 7 in 1999 to 37 in 2009. In addition to moorings, in-situ data required for further investigation of flux quality issues, come from selected ship (SAMOS [WEB-12]) and campaign measurements. The latter are retrieved from SeaFlux web site ([WEB-4]).

All these data will be collected and made available on Ifremer OHF platform.

OHF-RB-REQ-3.19: In situ data	
The OHF project shall collect and make use of in-situ listed in Table 4 mainly as references for validation purposes.	
Verification method	Inspection
Link to OHF SoW tasks	Task1, Task2, Task3

Buoy wind speeds, specific air humidity, air temperature are converted to the values at 10m height by COARE3.0 model ([SP-52]). The latter is also used to estimate buoy turbulent fluxes from buoy bulk variables.

Turbulent fluxes are calculated from validated hourly buoy 10m wind speed, specific air humidity, and air temperature in combination with sea surface. The adjustment to 10 height of basic variables (W, Qa, Ta) as well the estimation of turbulent fluxes are performed using COARE4.0 algorithm ([SP-20]).

OHF-RB-REQ-3.20: In situ parameter estimation and adjustment	
The collected in situ shall be properly adjusted to 10m height. Turbulent flux calculation shall be applied when possible.	
Verification method	Inspection
Link to OHF SoW tasks	Task2, Task3, Task4

Table 10: Characteristics of the required OHF in situ data

In-Situ data (Validation/ Quality Process)	Ref	Parameter	Resolution	Frequency	Time Span	Coverage Time	Coverage Space	Uncertainty Information	Error Size	Sensor Sources	Source	Nature Product
NDBC	IN1	Wind; Hum; Air Temp.,SST, Pressure wave		10mn / 1 hour	Jan 1992 - Dec 2014	22 yrs	20°N – 67°N					
OceanSites					1999 - Present						IFREMER	
Campaigns					1999 - 2011						SeaFlux	
SAMOS					1999 - 2014						COAPS	

TAO/PIRATA/ RAMA	IN2	Wind; Hum; Air Temp.,SST, pressure current		10mn / 1 hour	Jan 1992 - Dec 2014	22 yrs	20°S – 22°N					
MFUK	IN3	Wind; Hum; Air Temp.,SST, Pressure, wave		1 hour	Jan 1999 - Dec 2014	15yrs	32°N – 65°N					

3.7 Required numerical model data

Era-Interim ([SP-51], [WEB-9]) refers to the re-analyses of atmospheric parameters produced by the European Center for Medium Weather Forecasts (ECMWF). It uses 4D-variational analysis on a spectral grid. This re-analysis covers the period from 1989 to the present day. The ERA-Interim data used in this study was obtained from the ECMWF data server on a fixed grid of 0.75°. The main parameters (Table 5) used in this study are specific air humidity and air temperature at 2m, available at synoptic times (00h:00, 06h:00, 12h:00, 18h:00 UTC), converted to Qa10 and to Ta10 , respectively, utilizing the COARE3.0 model ([SP-49]). The quality of Qa10 and of Ta10 is checked through comparisons with MFUK, TAO, and PIRATA buoy estimates. The main finding of interest for this study is that Era Interim Ta10 are underestimated for buoy Ta10 exceeding 20°C. A bias correction is determined from linear regression between Era Interim and buoy Ta10 estimates.

NCEP Climate Forecast System Reanalysis (CFSR) ([WEB-10], developed by the US NOAA NCEP. The data used for this study are from the NOAA's National Operational Model Archive and Distribution System (NOMADS), which is maintained by the NOAA's National Climatic Data Center (NCDC) ([WEB-10]). The coupled model consists of a spectral atmospheric model at a resolution of T382 (38km) with 64 hybrid vertical levels and the GFDL Modular Ocean Model. The atmosphere and ocean models are coupled with no flux adjustment. The NCEP-CFSR uses the GSI data assimilation system for the atmosphere. Flow dependence for the background error variances is included as well as first order time interpolation to the observation Variational quality control of observations is also included. An ocean analysis for SST is also performed using Optimal Interpolation (OI). A full range of observations is used as in the other re-analyses which are quality controlled and bias corrected, including satellite radiances. Observations of ocean temperature and salinity are also used.

OHF-RB-REQ-3.21: Model data	
The OHF project shall make use of numerical reanalyzes listed in Table 11 for the generation of reference data.	
Verification method	Inspection
Link to OHF SoW tasks	Task1, Task2, Task3, Task4, Task5

Table 11: Re-analyses to be used for OHF project

Models	Ref	Parameter	Resolution	Frequency	Time Span	Coverage Time	Coverage Space	Level	Data Provider	File Format	Comments
NOCS2	FP 6	Wind; Hum; SST; Air Temp; LHF; SHF	100k m	Daily	Jan 1992 - Dec 2010	19 yrs	80S - 80N	L4	SOC	Netcd f3	
ERA Interi m	FP7	Wind; Hum; Air Temp.; LHF; SHF	0.70°	6-hourly	Jan 1992 - Dec 2011	20 yrs	90S - 90N	Reanalyses	ECMWF	Grib	Data reformatt ed fro OHF project
CFSR	FP8	Wind; Hum; Air Temp.; LHF; SHF	0.38 °	6-hourly	Jan 1992 - Dec 2011	20 yrs	90S - 90N	Reanalyses	NCEP	Grib	Data reformatt ed fro OHF project

3.8 Ocean heat content

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.

As introduced in more detail in section 5.2(method development), the evaluation of ocean heat content (OHC) plays a key role in the physical budget constraint method. Estimates of OHC can be derived from the global ocean in situ observing system. Several key historical and modern subsurface measurement instruments exist for assessing ocean temperatures globally as required for climate assessment, i.e. the expendable bathythermograph (XBT), shipboard CTD measurements, the Argo floats and seal data for the Southern Ocean (see Roemmich et al., 2012 and Abraham et al., 2013 for an overview). Other measurement techniques such as mooring arrays from TAO, RAMA and PIRATA and the Ocean Buoy Network, drifting boys and Gliders complement the global ocean in situ observing system. In particular, with the inception of the Argo array of autonomous profiling floats (http://www.argo.ucsd.edu) in 2000, our ability to monitor global and regional ocean heat content variability and change significantly increased, owing predominantly to increased sampling density. Argo has now become the major contributor to the global ocean in situ observing system.

The collection, assembly, and quality control of a comprehensive data set as done by oceanographic data centers are invaluable for analyses of OHC. An additional quality control in delayed mode is indispensable when using the data base from the data centers (Coriolis, UK Met Office, US NODC) for OHC analyses, (coherence analyses to check for platform drifts, exclude black-listed Argo profiles and others, check for systematic biases, application of corrections (XBT, MBT, etc)). Largest challenges remain for the historical data, including the large gaps and the correction method for XBT data (e.g. Domingues et al., 2008). Despite independent efforts over the past few decades by a number of research organizations who have attempted to assemble, rescue and quality-control (QC) subsurface ocean profiles, the global historical profile database still contains a relatively large fraction of biased, duplicated and substandard quality data and metadata that can confound climate-related applications. The IQuOD (International Quality-controlled Ocean Database, http://www.iquod.org) effort is being organized by the oceanographic community, and includes experts in data quality and management, climate modelers and the broader climate-related community. The primary focus of IQuOD is to produce and freely distribute the highest quality and complete single ocean profile repository along with (intelligent) metadata and assigned uncertainties for use in ocean climate research applications. Developing and implementing an internationally agreed framework will achieve this goal.

We propose here to use a quality controlled in situ data set, i.e. the CORA data set of Coriolis (Ifremer, France, Cabanes et al., 2012). This data set is used in operational oceanography and is part of the MyOcean catalogue (www.myocean.eu). The CORA data set is up-dated regularly (every 6 month) which means that any changes in data quality and information (e.g. output from IQuOD, or from the PI) will be implemented into each new version of CORA (note that the Coriolis R&D group is contributing to IQuOD). We will implement the latest version of CORA in the end of this project, but develop the method with the current one.

Estimates of OHC will be then performed after the method of von Schuckmann and Le Traon (2011). This method differs from other OHC evaluations, as OHC is calculated at every profile position before averaging within large ocean boxes. Other methods for OHC evaluation from the in situ observing system are based on objective mapping techniques, and OHC is then calculated from these gridded fields. The use of the method from von Schuckmann and Le Traon (2011) has the advantage that it can be easily adopted to different regions/ocean boxes – a method which is needed for the proposed flux data uncertainty assessment as described in section 5.2.

Table 12: Characteristics of OHF data (IP, FP, IN, DP state for Input product, Flux product, In-situ, and Delivery product respectively.

Delivered products	Ref	Parameter	Resolution	Frequency	Time Span	Coverage Time	Coverage Space	UncertaintyInformation	Error Size	Sensor Souces	Source	Nature Product	Level	Data Provider	File Format	Comments
Surface Wind	DP 1	W, U, and V	25km	Daily	1999 – 2009	10yrs	Global	Error analysis	1m/s	Scatterometer	QSCAT	EO	L3	IFREMER	Netcdf4	Updated version
Wind Stress	DP 2	□, □x, □y	25km	Daily	1999 – 2009	10yrs	Global	Error analysis	0.01N/m2	Scatterometer	QSCAT	EO	L3	IFREMER	Netcdf4	Updated version
Specific Humidity	DP 3	Qa	25km	Daily	1999 – 2009	10yrs	Global	Error analysis	1g/kg	Radiometers	SSM/I F11 – F15.	EO (merged)	L4	IFREMER	Netcdf4	Updated version
Sensible	DP 4	SH	25 km	Daily	1999-2009	10yrs	Global	Error analysis	$10W/m^2$	Scatterometer and radiometers	QSCAT; SSM/I	EO (merged)	L4	IFREMER	Netcdf 4	Updated version
Latent	DP 5	LH	25 km	Daily	1999-2009	10yrs	Global	Error analysis	$30W/m^2$	Scatterometer and radiometers	QSCAT; SSM/I	EO (merged)	L4	IFREMER	Netcdf 4	Updated version

3.9 Improvement of inputs

One the main sources of flux errors relies on the accuracy of the input quantities (surface wind, specific air humidity, sea surface temperature, air temperature). This will require reprocessing of some of the input bulk variables whenever they can be improved.

OHF will also adjust the values of some existing inputs when known errors or bias have been estimated.

OHF-RB-REQ-3.22: Improvement of inputs	
The OHF project shall aim at providing the best input quantities to flux calculation, by the means of reprocessing of new datasets or correcting existing ones.	
Verification method	Inspection
Link to OHF SoW tasks	Task2, Task3, Task4

3.9.1 Reprocessing of input parameters

To meet the project requirement, momentum and heat fluxes will be estimated based on the use of newly reprocessed scatterometer for winds and radiometer retrievals for air humidity (e.g. [SP-11], [SP-20]). Some of these quantities will have to be reprocessed from L2A and/or L2B data. Indeed, the latest reprocessing QuikSCAT V3 ([WEB-11] retrievals are assumed providing better surface wind speed and directions with higher resolutions of 0.125°×0.125° over scatterometer swath of 1800 km width ([SP-45]). Further improvements deal with high winds determination based on the use of a new geophysical model function (GMF) and rain detection leading to an enhancement of rain flag determination.

During the period April 2007 – November 2009, in addition to QuikSCAT, ASCAT onboard METOP-A is also operating. ([SP-11]) showed that both QuikSCAT and ASCAT exhibit very similar wind patterns at various scales. However, differences have been pointed out especially at the tropical areas and high latitudes. ,Based on the results described in ([SP-11] and [SP-57]) QuikSCAT and retrievals will be corrected with respect to SST at high latitudes, whereas ASCAT will be corrected with respect to wind speed and radar azimuth. ASCAT and QuikSCAT V3 will be used to estimate gridded wind and stress vector over global ocean for the periods 2007-2009 and 1999 – 2009., respectively.

Specific air humidity is derived, over special sensor microwave imager (SSM/I) radiometer swaths , based on the use of the model relaying brightness temperature measurements (Tb) and Qa10 ([SP-13]). SSM/I are onboard the polar orbiting satellites DMSP F10, F11, F13, F14, and F15. For this project, a new reprocessing of Qa10 will be performed with respect to the use of the recently reprocessed fundamental climate data record (FCDR) brightness temperatures ([SP-55]). The latter are produced by the Colorado State University ([SP-56]) with NOAA funding support. Qa will be calculated over radiometer swaths with a spatial resolution of 0.25°×°0.25° from SSM/I 's onboard F11, F13, F14 and F15 DMSP satellites for the period 1999 – 2009.

OHF-RB-REQ-3.23: Reprocessing of wind speed	
QuikSCAT and ASCAT wind retrievals will be corrected regarding the results described in ([SP-11])	
Verification method	Inspection
Link to OHF SoW tasks	Task2, Task3, Task4

OHF-RB-REQ-3.24: Reprocessing of air humidity	
Specific air humidity will estimated over SSM/I swaths onboard F11, F13, F14, and F155 satellite with a spatial resolution of 0.25°×0.25° over global oceans and for the period 1999 - 2009.	
Verification method	Inspection
Link to OHF SoW tasks	Task2, Task3, Task4

3.9.2 Adjustment and correction of input datasets

Air temperature at 10m (Ta10) will be estimated from Ta2 derived from ERA Interim re-analysis based on COARE 3.0 parametrization ([SP-52]). Previous study ([SP-12]) aiming at the characterization of ERA interim Ta accuracy based on the comparisons with buoy estimates showed Era Interim Ta10 are underestimated for buoy Ta10 exceeding 20°C. A bias correction was determined from linear regression between Era Interim and buoy Ta10 estimates. The corrected ERA Interim Ta will be used in this project.

OHF-RB-REQ-3.25: Reprocessing of 1àm air temperature	
ERA Interim Ta_2 will be converted to Ta10 based on Coare3.0 parametrization. The resulting Ta_{10} will be corrected with respect to the results shown in ([SP-12]).	
Verification method	Inspection
Link to OHF SoW tasks	Task2, Task3, Task4

3.9.3 Calculation of in situ fluxes

Turbulent fluxes are calculated from validated hourly buoy and ship 10m wind speed, specific air humidity, and air temperature in combination with sea surface. The adjustment to 10m height of basic variables (W10, Qa, Ta) as well the estimation of turbulent fluxes are performed using COARE3.0 ([SP-52] and COARE4.0 ([SP-20]) algorithms. The resulting wind stress, latent and sensible heat fluxes will be used as "ground truth".

OHF-RB-REQ-3.26: In situ flux estimation	
The OHF project shall provide turbulent fluxes estimations from in situ measurements using COARE3.0 and COARE4.0 bulk parametrization.	
Verification method	Inspection
Link to OHF SoW tasks	Task2, Task3, Task4, Task5

3.10 Data homogenization

The project shall also aim at alleviating the burden of dealing with heterogeneous data coming in different format, content, units, or grid projections. It is a major objective of the OHF project to help users spending more time on science and less on programming or dealing with data issues.

3.10.1 Resampling

Data, including turbulent fluxes (wind stress, latent and sensible heat fluxes) and the associated bulk variables (wind speed, specific air humidity, air temperature, sea surface temperatures), derived from each available product will be used to generate global daily estimates over a grid map of 0.25°×0.25°.

To make flux evaluation easier with respect to some oceanic parameters, daily products of SST, sea state, ocean colour, current, derived respectively from CCI projects GHRSST, GlobWave, OceanColor, and GlobCurrent, will be interpolated over same grid of 0.25×0.25°. The reference dataset will be determined for a period of 10 years (1999 – 2009).

OHF-RB-REQ-3.27: Remapping method	
The OHF project shall investigate and select the most adapted remapping method required to to resample the input bulk variables and available fluxes over the targeted OHF grid.	
Verification method	Inspection
Link to OHF SoW tasks	

OHF-RB-REQ-3.28: Product grid specifications	
The different products to be inter-compared or combined with each other shall be on the same grid, at the same temporal and spatial resolution. It shall be a task of OHF project to implement a community remapping tool to allow this transformation to the common grid specification.	
Verification method	Inspection
Link to OHF SoW tasks	

3.10.2 Formatting

The resulting data sets will be made available in the same format Netcdf4. The objective is to generate reference data set allowing the users flux inter-comparisons, flux calculation over global and/or regional scales, and uncertainty evaluation with respect to atmospheric and oceanic parameters.

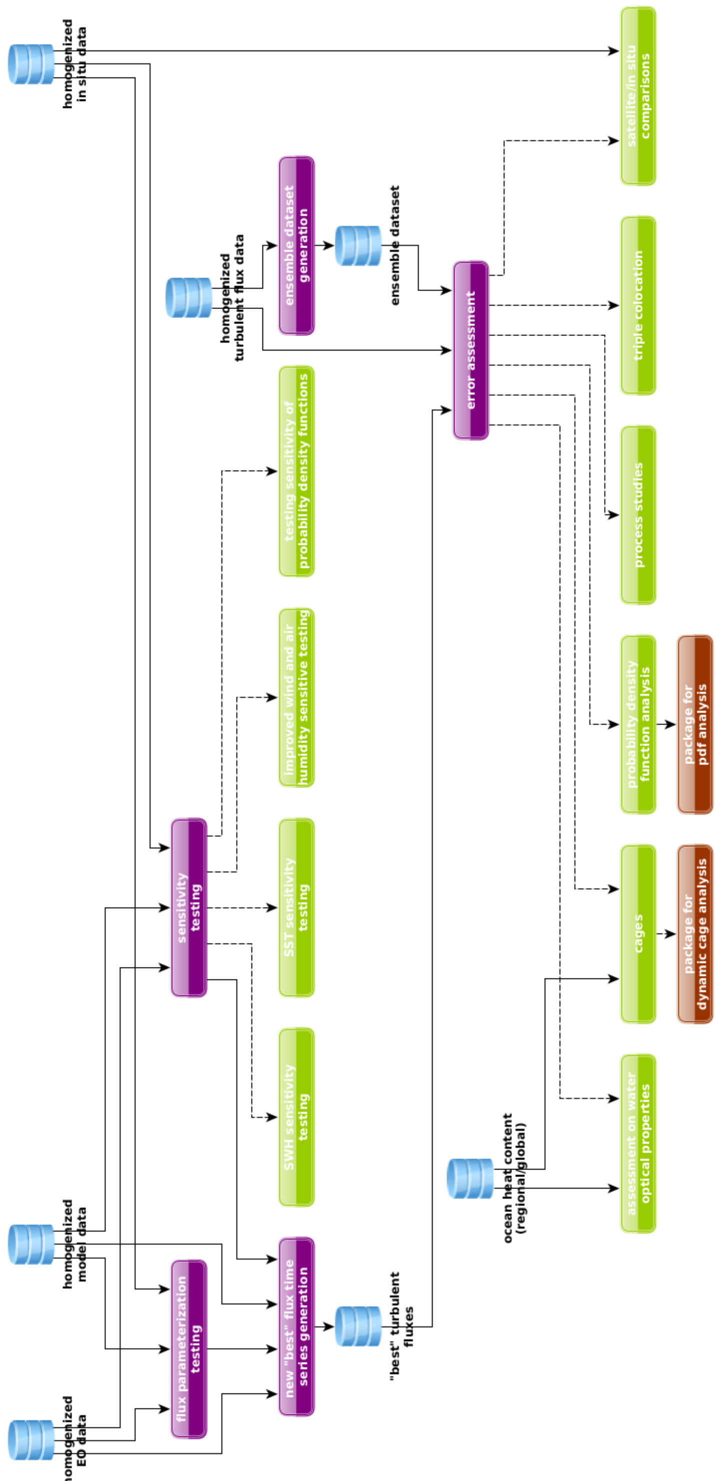
OHF-RB-REQ-3.29: Format and conventions
The data shall be provided in a consistent NetCDF format, following the Climate and Forecast convention CF 1.6 and similar conventions (ACDD), in line with other climate and EO related projects (GHRSST, CLIVAR, ...).

Verification method	Inspection
Link to OHF SoW tasks	

OHF-RB-REQ-3.30: Product content	
The different products shall be consistent in terms of content and follow common guidelines (variable naming, metadata, dimensions, quality flags, masks, etc...) as done in other community projects (GHRSST GDS, GlobCurrent Format and Content Document,...).	
Verification method	Inspection
Link to OHF SoW tasks	

4 Requirements on the generation of OHF products

4.1 Development of methodologies


homogenized in situ data
homogenized turbulent flux data
ensemble dataset generation
ensemble dataset
error assessment
satellite/in situ comparisons
triple colocation
process studies
probability density function analysis
package for pdf analysis
cages
package for dynamic cage analysis
assessment on water optical properties
ocean heat content (regional/global)
testing sensitivity of probability density functions
improved wind and air humidity sensitive testing
SST sensitivity testing
SWH sensitivity testing
sensitivity testing
flux parameterization testing
new "best" flux time series generation
"best" turbulent fluxes
homogenized model data
homogenized EO data

4.1.1 Sensitivity tests

One the main sources of flux errors relies on the accuracy of surface wind, specific air humidity, sea surface temperature (SST), air temperature, and of the bulk parametrization. Several publications (e.g. [SP-13], [SP-30], [SP-48]) clearly stated that new remotely sensed data improve the flux retrieval accuracy. It is therefore required to assess the sensitivity of flux calculation to some of these input variables to evaluate the impact of EO data accuracy on the flux estimation.

4.1.1.1 Sensitivity to sea surface temperature

OHF-RB-REQ-4.1: Sensitivity to different sources of SST	
The sensitivity to different sources of sea surface temperature data shall be investigated, in particular using newly reprocessed ESA CCI dataset as an alternative input. This shall be assessed over a period of at least three years (2005-2007).	
Verification method	Inspection
Link to OHF SoW tasks	Task2, task3, Task4, task5

4.1.1.2 Sensitivity to significant wave height (SWH)

To further investigate turbulent flux uncertainties, investigation will be performed with respect to sea state. In particular the OHF project will attempt to address the impact of significant wave height (SWH) on the estimation of wind stress, and somehow latent and sensible heat fluxes over global oceans. The impact will be mainly investigated through bulk parameterization used for estimating turbulent flux components. The objective is to quantify the differences between different bulk parameterizations used in the calculation of turbulent fluxes with respect to atmospheric and oceanic conditions. The expected results will provide a better understanding of the differences between existing estimates of surface fluxes at global and regional scales. Further investigations will be performed to assess the potential impact of wave, which are not directly entering the estimation of turbulent fluxes.

The SWH impact assessment will be based on the use of collocated scatterometer winds, radiometer Qa, SST analyses, and corrected Era Interim Ta for a period of one year.

OHF-RB-REQ-4.2: Assessment of sensitivity to significant wave height
Two turbulent fluxes datasets shall be estimated according to the use of SWH or not in the bulk parameterization. The resulting fluxes will be seasonally and/or regionally compared. Statistics characterizing the comparisons will be used to characterize the uncertainties of turbulent fluxes as a function of SWH ranges.

Verification method	Inspection
Link to OHF SoW tasks	Task2, Task3, Task4, Task5

4.1.2 Bulk parameterization testing and assessment

Several bulk parametrization are available. However, all turbulent flux products of interest for this project and estimated from remotely sensed data are calculated based on COARE3.0 model. The newly parametrization known as COARE4.0 ([SP-11]) will be tested and the results will be compared to flux estimated from COARE3.0 ([SP-52]). The latter is utilized for the calculation of the main existing flux data sets. The new turbulent fluxes will be calculated over global ocean with the spatial resolution of 0.25° in longitude and latitude. They will cover the period 2005 – 2007 when all existing products are available and both numbers of remotely sensed and in-situ data are higher. The accuracy of the newly fluxes will be mainly determined through comprehensive comparison with in-situ estimates. Further comparisons will be performed with existing fluxes. The latter will be performed according to various atmospheric and oceanic parameters such as wind and sea state conditions. with a focus on some specific oceanic basins such as the Mediterranean sea, North Atlantic, the Pacific Warm pool , and the inter-tropical zones.

OHF-RB-REQ-4.3: Assessment of bulk parameterizations	
Different bulk parameterizations (COARE4.0 and COARE3.0) will be evaluated at global scale over a 3 years test period (2005-2007). Intercomparison and assessment against in situ buoys will be performed.	
Verification method	Inspection
Link to OHF SoW tasks	Task3, Task4, Task5

4.2 Generation of the OHF “best” fluxes

According to the results relied on bulk variable (wind speed, air and sea temperatures, specific air humidity) quality and on bulk parametrization ([OHF-RB-REQ-3.20], [OHF-RB-REQ-3.21], [OHF-RB-REQ-3.22], [OHF-RB-REQ-4.1], [OHF-RB-REQ-4.2], [OHF-RB-REQ-4.3]), turbulent fluxes as well bulk variable fields will be reprocessed over global oceans as daily estimates with the spatial resolution of 0.25°×0.25°.

OHF-RB-REQ-4.4: Generation of improved fluxes
The OHF project will generate a new time series of turbulent fluxes on a daily grid at

0.25°x0.25° resolution over a period of three years (to be defined with respect to the available validation data, likely 2005-2007), using the best combination of inputs and bulk parameterizations assessed from the previous steps.	
Verification method	Inspection
Link to OHF SoW tasks	

4.3 Generation of the OHF ensemble dataset

OHF project considers several existing flux products (IFREMER, HOAPS, OAFlux, SeaFlux, J-OFURO, ERA Interim, CFSR, NOCS2). Following the homogenization method described above, each latent heat and sensible and related bulk variables will be perturbed based on statistical distributions determined from in-situ data. Such perturbations will provide a large number of realizations at each grid cell of 0.25°×0.25° over global oceans. They will allow the determination of the statistical conventional and linear moments of turbulent fluxes and of the related bulk variables at grid points. To assess the quality of the resulting statistical parameters, they will be compared to those obtained from in-situ data at mooring locations. At each grid-point a quality control will be applied for each realization. The main objective is to avoid the outliers in the ensemble determination. The latter will be defined as the median of the selected realizations at each grid point. The median is preferred over the conventional first moment, to further minimize the impact of possible outliers not detected through the quality control.

OHF-RB-REQ-4.5: Ensemble dataset	
An ensemble product shall be generated as daily global fields with the spatial resolution of 0.25°×0.25 for the period 1999 - 2009.	
Verification method	Inspection
Link to OHF SoW tasks	Task3, Task4

4.4 Product delivery

OHF-RB-REQ-4.6: Product handbook	
The OHF project shall provide a product handbook with the generated dataset describing the product content and specifications, and its strengths and limitations for different applications	
Verification method	Inspection

Link to OHF SoW tasks	

OHF-RB-REQ-4.7: Product handbook	
The OHF user handbook shall follow the guidelines from Climate Data Guide	
Verification method	Inspection
Link to OHF SoW tasks	

5 Requirements for products evaluation and validation strategy: Estimation of errors

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 interannual to interdecadal variability 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 present level of uncertainties in global ocean estimates of heat and moisture fluxes is not adequate for many applications, including global and regional mass and energy budget closure and variability on different time scales. This prevents understanding the mechanisms of ocean climate variability. Biases in surface fluxes lead to the systematic errors in climate models and preclude their efficient use in climate simulation. Without accurate estimates of surface fluxes it is impossible to engage predictive potential of the ocean into weather and climate prediction. Thus, improvements in all aspects of producing surface flux estimates, including parameterizations, measurement techniques and post-processing are required for further progress.

For this purpose, the CLIVAR research focus CONCEPT-HEAT has identified the key scientific question “How can we better constrain the surface energy fluxes and their spatiotemporal variations at regional scale?”. This project will significantly contribute to face this challenge through the development and application of methods for product evaluation and validation, which will in turn lead to a product assessment and error estimation. These analyses will be build on the themes and recommendations of the CLIVAR/WHOI Ocean Synthesis and Air-Sea flux evaluation Workshop (Yu et al., 2012: WCRP Report No. 13/2013), which took place in November 2012 at WHOI, US, as well as on recommendations of the CLIVAR-ESA scientific consultation workshop in June 2013 at University of Reading, UK. Given the gaps in present-day knowledge and understanding, a consensus was reached during both workshops that achieving globally balanced energy and freshwater budgets is a long-term challenge, and should be broken down into incremental steps with achievable targets at each stage, i.e. through regional budget analysis. Based on these discussions, a set of methods will be build up as part of this project, i.e. the triple collocation analysis, the concept of cages and surface turbulent flux probability density functions.

5.1 Triple collocation

A pointwise comparison that involves a collocation of multiple platforms (e.g., satellite, in situ, and model-based) is a familiar technique in the evaluation of bulk variables used to calculate surface heat flux (SOW). Its application to heat flux itself provides a novel complement to the cages and probability density function approaches. Although bulk variables can be assessed using this technique, we target an assessment of heat flux analyses including the reference TIE-OHF time series. The approach is predicated on a hypothetical target (the so-called true) analysis (t) that is performed at the temporal and spatial resolution of the TIE-OHF grid. Following Stoffelen (1998), collocations of buoy, TIE-OHF (satellite) analysis, and model (e.g., ECMWF interim) are assumed to have an associated bias (α), slope (β), and error (δ) relative to t, according to

$$\begin{aligned} \text{buoy} \quad x &= \alpha_x + \beta_x t + \delta_x \\ \text{satellite analysis} \quad y &= \alpha_y + \beta_y t + \delta_y \\ \text{model} \quad z &= \alpha_z + \beta_z t + \delta_z \end{aligned} \tag{1}$$

Given that errors have zero mean and are uncorrelated with each other, the expected mean squared error over all available triple collocations (denoted by <·>) is

$$\begin{aligned} \langle \delta_x^2 \rangle &= \langle x^2 \rangle - \langle x \rangle^2 - \tfrac{(\langle xy \rangle - \langle x \rangle \langle y \rangle)(\langle xz \rangle - \langle x \rangle \langle z \rangle)}{\langle yz \rangle - \langle y \rangle \langle z \rangle} \\ \langle \delta_y^2 \rangle &= \langle y^2 \rangle - \langle y \rangle^2 - \tfrac{(\langle xy \rangle - \langle x \rangle \langle y \rangle)(\langle yz \rangle - \langle y \rangle \langle z \rangle)}{\langle xz \rangle - \langle x \rangle \langle z \rangle} \\ \langle \delta_z^2 \rangle &= \langle z^2 \rangle - \langle z \rangle^2 - \tfrac{(\langle xz \rangle - \langle x \rangle \langle z \rangle)(\langle yz \rangle - \langle y \rangle \langle z \rangle)}{\langle xy \rangle - \langle x \rangle \langle y \rangle} \end{aligned} \tag{2}$$

Additionally, the triple collocation method has been shown to provide a second metric of analysis performance (McColl et al. 2014). In the context of the error model (1), this is a proxy for the signal to noise ratio and is defined as the correlation between collocated and target data:

$$\begin{aligned} \rho^2(x,t) &= \tfrac{(\langle xy \rangle - \langle x \rangle \langle y \rangle)(\langle xz \rangle - \langle x \rangle \langle z \rangle)}{(\langle xx \rangle - \langle x \rangle \langle x \rangle)(\langle yz \rangle - \langle y \rangle \langle z \rangle)} \\ \rho^2(y,t) &= \tfrac{(\langle xy \rangle - \langle x \rangle \langle y \rangle)(\langle yz \rangle - \langle y \rangle \langle z \rangle)}{(\langle yy \rangle - \langle y \rangle \langle y \rangle)(\langle xz \rangle - \langle x \rangle \langle z \rangle)} \\ \rho^2(z,t) &= \tfrac{(\langle xz \rangle - \langle x \rangle \langle z \rangle)(\langle yz \rangle - \langle y \rangle \langle z \rangle)}{(\langle zz \rangle - \langle z \rangle \langle z \rangle)(\langle xy \rangle - \langle x \rangle \langle y \rangle)} \end{aligned} \tag{3}$$

These two metrics shall be applied to assess the relative quality of heat flux analyses, for which the reference analysis is expected to match the in situ observations, while allowing that in situ estimates are also fundamentally erroneous.

An important caveat is that the three datasets should be independent of each other. It follows that any satellite analysis that also employs in situ data on the day of collocation (this may include heat fluxes computed from ECMWF “bulk variables”, where applicable) must be interpolated from the adjacent 2-6 days (i.e., excluding the central day; a cubic spline or its equivalent will be evaluated to confirm that the interpolated and original daily heat flux value are essentially equivalent). The implication of this procedure is that the validation of analyses employs a temporal resolution which is slightly longer than daily (whereas the ECMWF Interim also may be given by a forecast interval that starts on the day of interest and represents a period slightly shorter than 24 h).

The PDF model of Gulev and Belyaev (2012) has been employed to simulate the validation by triple collocation. For error models of the form (1), such as

$$\begin{aligned}
\text{truth} \quad t &= \alpha\beta e^{-\beta x} e^{-\alpha e^{-\beta x}} \\
\text{buoy} \quad x &= t + 10 * \delta_x \\
\text{satellite} \quad y &= 1.1 * t + 20 * \delta_y + 5 \\
\text{model} \quad z &= 0.9 * t + 50 * \delta_z - 5 \\
\text{Gaussian errors} \quad \delta & \quad \text{(zero mean and standard deviation of 1)}
\end{aligned}$$

The resulting retrieval of error estimates are not distinguishable from the values above when a large number of simulations are performed (O[10^8]). (Specifically, all parameters α, β, and δ are obtained and the correlations to truth (Fig. xx) increase respectively from 0.75, 0.96, to 0.99 for model, TIE-OHF (satellite), and in situ (bouy), as might be expected.)

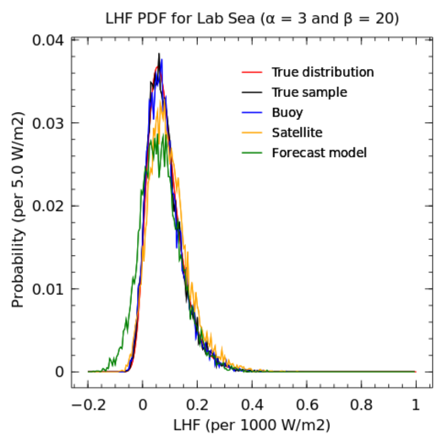


Fig. Xx: Simulated true latent heat flux PDF for the Labrador Sea and perturbations of this distribution (cf. Gulev and Belyaev 2012).

These simulations indicate that triple collocation appears to provide more than one metric of analysis quality that can be employed, as desired, to distinguish between heat flux analyses in a manner that is complementary to both the cage and PDF assessment methods. Although the strengths and weaknesses of the present method may be the most familiar, it is notable that the new metric of McColl et al. (2014) and applications to surface heat flux are relatively unexplored.

OHF-RB-REQ-5.1: Triple collocation
Validation of TIE-OHF reference surface heat flux data shall include estimates of root mean square error and signal to noise ratio by employing the method of triple collocation

Verification method	Inspection
Link to OHF SoW tasks	Tasks 2, 3, and 4 involve cage and PDF assessments of heat flux quality that are complemented by the triple collocation assessment method.

5.2 Method of cages

The surface heat energy budget consists of radiative fluxes (net shortwave, SW, and net longwave, LW, radiation), and turbulent fluxes (sensible and latent heat). Surface water budget is made by the precipitation and evaporation, the latter being directly related to the latent heat flux. Improving our estimates of the global surface energy budget, and producing reliable uncertainty estimates, is currently a significant challenge of the air-sea/land interaction community. Because the atmosphere has very small heat capacity, on annual and longer time scales the surface fluxes should match the TOA values to within about 0.1 W m-2 globally.

Air-sea net heat fluxes have on average local uncertainties of random and systematic nature of the order of 10 Wm-2, but these errors can vary significantly in space and time. Errors in extreme conditions such as hurricanes, or in regions with strong SST gradients, such as the Gulf Stream, can be much larger. Global and regional integration of surface heat fluxes derived from ship observations leads to mean errors of more than 20 Wm-2 (Josey et al. 2013). Hence, it is currently impossible to arrive to the imbalance equivalent to 1 Wm-2 via estimation of the surface energy budget. However, characterizing the uncertainty and biases in 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 (e.g., recent “hiatus” period) superimposed on the centennial-scale warming of the global ocean surface (e.g., Trenberth et al., 2010, Loeb et al., 2012, Cazenave et al., 2014; Trenberth and Fasullo 2013).

In July 2013 ESA and CLIVAR sponsored a workshop at the University of Reading in the UK under the framework of this research focus, aimed at scoping a Support for Science Element (STSE) project to improve satellite based air-sea flux products to make them more useful in OHC and Earth energy budget applications (WCRP report No: 26/2013). Based on these discussions, the integration of regional budget analyses is proposed here which has much in common with the CAGE concept envisaged in the early 1980s (Bretherton et al. 1982). The design of a CAGE experiment recognized:

- the importance of meridional heat transport in Earth's climate,
- the need for obtaining an accurate estimate of the mean state of the world climate and of the ocean's role in maintaining that state, and

- uncertainties in existing surface flux products and ocean observations that preclude realistic assessment of the changes in ocean heat transport and storage.

The CAGE experiment will be designed to inter-compare different flux products in a single basin/area under favorable circumstances to establish the random and systematic errors associated with each approach.

Moreover, a number of suggestions were made at the ESA/CLIVAR workshop (WCRP, 2013) and in Yu et al. (2012) to help in the selection of ocean regions for flux budget studies, which include:

1. Seek the areas away from boundary currents where the advective convergence is minimal. It is possible that ocean synthesis or other modeling products could be used to assess the likely transport magnitudes for such regions. Selected areas could also include enclosed and semi-enclosed basins such as the Mediterranean and the Red and Black seas.

2. Seek the areas that include within them one or more flux buoys (e.g., the OceanSITES flux buoys or an ongoing field program such as SPURS, particularly buoys associated with process study data (e.g., STRATUS and PAPA) to allow for a direct regionalization and cross-referencing. It has been also recommended that satellite data and other in situ data (ships and drifters) be used to observe and/or assess the regional variability around the buoys.

3. Analyze the areas of particular interest for ocean processes (e.g., areas of strong water mass formation).

4. Choose the areas with the best Argo buoy (www.argo.ucsd.edu) sampling over the longest available period.

The principal aim is to develop a method for product error assessment of the OHF project through the “cage approach”, which could become operational as part of the planned Flux Data Portal. More precisely, we plan to analyze how to partition the near global ocean (60°S-60°N) into large ocean boxes for the purpose of assessing different turbulent flux products of the reference data set within these different boxes through regional budget constraint. This analysis will be based on recommendations introduced above and will be performed in collaboration with MIO, Ifremer, University of Reading, IORAS and DWD. A scientific paper is planned to establish this collaboration. Main criteria for this analysis are introduced below.

Method development:

The time-varying equation for the heat budget (HB) can be written as:

$$\frac{d(HB)}{dt} = net\,HF + lateral\,HF\,, \qquad (1)$$

i.e. the sum of atmospheric heat flux (HF, turbulent and radiative component) and lateral HF in the ocean (i.e. the sum at the different ocean boundaries). Temporal changes of HB are directly linked to temporal changes in ocean heat content (OHC):

$$\frac{d(HB)}{dt} = \frac{d(OHC)}{dt} - lateral\,HF\,. \qquad (2)$$

OHC is calculated as the integral from the ocean surface to a given depth (normally chosen due to data availability, e.g. 700m depth):

$$OHC = \int_{z_1}^{z_2} \rho\, c_p T_0(z)\, dz\,, \qquad (3)$$

where T0 is the measured in situ temperature anomaly relative to a climatology, ρ is the density of seawater and cp is the specific heat capacity.

As obvious from equation (2), we need estimates of several components of the physical budget to implement the approach, and to apply this to different boxes of the global ocean. In particular, we plan to derive four components:

1. a reference estimates of box mean temporal changes for OHC
2. one reference of box mean radiative flux estimate
3. one reference estimate of lateral HF at the boundaries of each box
4. a set of box mean turbulent fluxes from the “OHF reference data set”

More precisely, for components i) to iii), one product for each component will be used for the assessment of the different products of the OHF reference data set (iv). The most power-full issue for the “cage approach” is that independent climate observing systems and tools are compared and set into the constraint of the physical budget for each defined ocean box. Table 13 shows details on the data sets and products used for the reference components of i)-iii). Details for turbulent flux products can be found in Table 7.

Table 13: Description of data sets and methods used to obtain reference estimates as part of the "OHF cage approach".

Budget component	Type of product	Product information
OHC (i)	Quality controlled in situ observations used for OHC estimates	Data set: Cabanes et al., 2012 OHC method: von Schuckmann and Le Traon (2011), and validated after method of von Schuckmann et al. (2014)
HFradiative (ii)		
HFlateral (iii)	Ocean reanalysis as part of the CLIVAR ORA-IP initiative (Balmaseda et al., 2015)	Valdivieso et al., 2014

The largest source of uncertainty for this method is the initial assumption that reference components of the physical budget i)-iii) are assumed to be robust estimates, i.e. low uncertainties. This is not the case, and large uncertainties are expected, in particular for component i) and iii). For this purpose, scientific analysis are needed aiming to reduce these uncertainties to a level that they do not introduce to much noise in the product assessment of iv).

In particular, a fundamental analysis on the box size to be chosen is vital following the criteria of WCRP (2013) and Yu et al. (2012). The box size needs to be chosen so that uncertainties are reduced through averaging processes. The size of ocean boxes are expected to vary depending on dynamical processes in the global ocean which increase rates of errors in component estimates of i) and iii) (such as boundary currents, fronts, ..). The use of ocean reanalysis (Valdivieso et al., 2014), altimeter data (ESA CCI product) and in situ data (Cabanes et al., 2012) are proposed to be used. In addition, the size of the ocean boxes will also depend on the in situ data availability based for the bow mean OHC estimates. We also plan to validate this method in two specific regions of the global ocean. The criteria for this choice depend on regions where estimates of direct measurements of lateral HF exists and during a time of most complete in situ ocean sampling. This will allow to compare our product assessment method for these two specific regions, where more robust measures of the reference component of iii) are available in order to test our assumptions on reducing noise through large-scale averaging.

The region of the north Atlantic between 26.5ºN and 60ºN was recommended to for this method validation procedure. In particular because lateral heat flux changes at the boundaries can be obtained from existing mooring arrays. These include the RAPID array at the southern rim with time series from 2004 to 2014 (http://www.bodc.ac.uk/projects/uk/rapid/). For 60ºN estimates of transports can be derived from the repeated sections carried out starting from 1997. These full depth sections with very high resolution of individual profiles were analyzed in e.g. Sarafanov et al. (2012) and many other publications. Another option might be the Greenland–

Portugal OVIDE section which is also densely sampled over the last 2 decades (Mercier et al. 2015). Labrador Sea transports can be derived from the multiply sections sampled in this region (Yashayaev and Loder 2009). These full depth precise observations synergized with the Agro array will provide good ground for obtaining accurate estimates and validation of budgets derived from surface fluxes.

A second region is suggested for the validation of the method, i.e. the Mediterranean Sea, which is an ideal natural cage. On average, the total heat budget of the Mediterranean Sea is negative, that is, the Mediterranean Sea loses more energy than it gains. It has an overall freshwater deficit, as the loss to the atmosphere by evaporation is larger than the gains by precipitation and runoff from the main rivers and input from the Black Sea. These losses of freshwater and heat are compensated by the two-layer exchange at the Strait of Gibraltar comprising a relatively warm and fresh upper water inflow and a relatively cooler and saltier outflow to the Atlantic (e.g. Tsimplis and Bryden 2000). The net heat transport through the Strait of Gibraltar has been estimated by using mooring-based measurements, giving a reference value of +5 W/m2 for HB estimations (e.g. Criado-Aldeanueva et al., 2010). These direct estimates of lateral heat exchange at Gibraltar serve as a benchmark for budget constraints, whereas the impact of river-runoff and Black Sea heat and mass changes are assumed to be of secondary order (e.g. Dubois et al., 2012). Estimates of basin wide Mediterranean Sea of OHC will is planned to be developed after the method of von Schuckmann and Le Traon (2011), taking into account the specific characteristics of the Mediterranean Sea ocean dynamics and bathymetry (von Schuckmann et al., 2015, in preparation).

Expected outcome: The final step of this method is to establish 2-D scatter plots showing “iv) plus ii)” (varying associated to “OHC reference data set”) versus “i) plus iii)” (not varying, reference component. We intend to develop this type of visualization for each defined ocean box at different temporal scales during the period 1999-2009 (period of “OHF reference data set), i.e. at seasonal, annual, interannual and decadal scale. This will allow the user to select region and scale of variability for his individual assessment of components of the “OHF reference data set” while indicating which product is better constraint within the respective regional heat budget.

OHF-RB-REQ-5.2: Regional cage consistency analysis	
The OHF project shall perform a detailed cage consistency analysis on at least the following pre-defined areas: • Mediterranean sea (semi enclosed sea) • North-Atlantic	
Verification method	Inspection

Link to OHF SoW tasks	

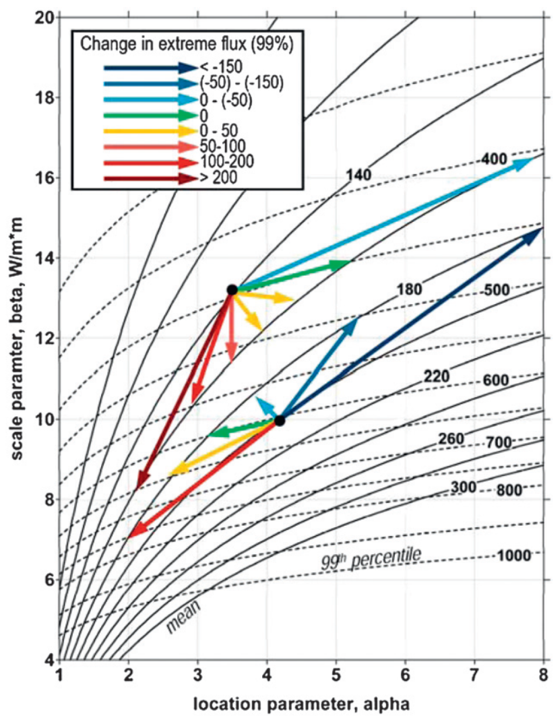
It is a project objective to make possible to easily repeat this analysis over another area, and that this capability should be offered to the user community:

OHF-RB-REQ-5.3: Generic cage consistency analysis	
The cage analysis software shall be made generic and provided to the user community so that other cages can be user defined and heat budget calculated over these cages.	
Verification method	Test
Link to OHF SoW tasks	

5.4.3 Surface turbulent flux probability density functions

Validation of different surface flux products cannot be limited to consideration of mean fluxes only, but requires also assessment of surface turbulent flux statistics. With this in mind we suggest to apply in the TIE-OHF project an approach based on consideration of surface turbulent flux probability density functions. Gulev and Belyaev (2012) developed the so-called Modified Fisher-Tippett (MFT) distribution, which accurately approximates synoptic and mesoscale variability of surface turbulent fluxes in a variety of conditions. MFT represents a two-parametric PDF steered by the location and scale parameters which determine the shape of PDF and its moments and allow for accurate estimation of extreme fluxes. Numerical procedures for estimation of parameters and derivation of MFT distribution are outlined in Gulev and Belyaev (2012). The advantage of the use of probability distributions (even not necessarily MFT) is that this framework allows for validating full distribution, including fluxes of very high order percentiles which (i) might exhibit quite strong differences in different datasets and also (ii) might demonstrate qualitatively different relations between the datasets compared to those for mean values. This holds for both spatial distributions and time variability patterns.

Figure 1: Hypothetical scheme, showing potential changes in the 99th percentile of turbulent fluxes, which are implied by the change is the mean flux by 20 W m-2 under different associated changes in a and b. Upper fantail of the arrows corresponds to the positive change of the mean flux by 20 W m-2 and the lower fantail to the negative. Colors of the arrows show the sign and the magnitude (W m-2) of the associated changes in the 99th percentile of surface fluxes under different tendencies in a and b. Solid black lines correspond to the mean values of turbulent fluxes and dashed lines stay for the 99th percentile.



The potential of MFT distribution is demonstrated in Fig XX which schematically shows changes in the 99th percentile of turbulent fluxes, which are, hypothetically, caused by the change in the mean flux by 20 W m-2 under different associated changes in the location (alpha) and scale (beta) parameters of MFT distribution. All changes are shown on the 2D diagram of parameters of MFT distribution (alpha and beta), where the corresponding nmean and extreme values are plotted. The value of 20 W m-2 gives a typical range of interannual variations of surface fluxes and also represents a reasonable estimate of the linear trends during the recent decades (e.g., Yu and Weller 2007; Yu 2007; Gulev et al. 2007b). According to Fig. XX, a positive change in the mean turbulent flux can be associated with both positive and negative tendencies in extreme fluxes and can vary from a few watts per square meter to several hundred watts per square meter, depending on the changes in a and b. Similarly, the decrease of the mean turbulent flux by 20 W m-2 under different tendencies in a and b may result in the change of the 99th percentile from 2150 W m-2 to more than 100 m-2.

Note that MFT (or similar) probability distributions have also quite a potential not only for validation and intercomparison of different flux products but also for the further integration of surface turbulent fluxes over time and space which is relevant for estimating surface fluxes over "cage" boxes. A simplified approach has been used by Gulev et al. (2013), but under TIE-OHF it can be extended and further specified. Of an interest will be to consider 2D distributions in the coordinates "sea-air temperature difference - surface wind" (the two parameters determining surface turbulent fluxes) and to further provide integration of surface flux in these coordinates.

OHF-RB-REQ-5.4: Generic Probability Density Function analysis software	
A generic software toolbox to perform the probability density function analysis on any flux dataset over any area and time frame shall be made available to the user community.	
Verification method	Test
Link to OHF SoW tasks	

5.3 Validation through the use of ocean colour data

The work proposed in this section cannot be considered true “validation”. The objective is to investigate the role of variability in optical properties of the sea as a modulator of the distribution of solar radiation within the surface layers of the ocean, and hence on the heat budget of the ocean. Two streams of work are proposed. In the first one, OC-CCI products, in conjunction with mixed-layer depth and surface irradiance will be used to compute the role of variable optical properties in determining the solar flux reaching the base of the mixed layer. In the second stream, a one-dimensional turbulence model (GOTM) will be used to study the sensitivity of modeled air-sea fluxes to the optical conditions, under varying physical conditions.

OHF-RB-REQ-5.5: Assessment on water optical properties	
The OHF project shall examine the significance of marine optical properties as a modulator of heat fluxes and heat budget in the surface mixed layer of the ocean, below the mixed layer and for air sea exchange of heat, using ESA CCI Ocean colour data.	
Verification method	Inspection
Link to OHF SoW tasks	

5.4 Process studies

[SoW] Other simple and quick consistency tests shall also be performed, examining coupled processes including significant air-sea exchanges, such as the El Nino Southern Oscillation (ENSO) and extreme events like hurricanes, e.g. examining relationships between flux and associated SST-induced variability and mixed layer (Clayson & Bogdanoff, 2013).

Contribution by Bertrand expected on consistency of flux with other quantities (for instance SST residual after advection).

6 Technical implementation requirements

The following sections specify the requirements for the OHF technical implementation.

6.1 Synergies with other projects

Some technical tasks of the project are already addressed in other frameworks that may be of interest for OHF too. They include for instance:

- collection of satellite, model and in situ data (wind, sea surface temperature, salinity, waves, ...)
- homogenization of data to a common reference format and convention (GlobCurrent, OceanFlux GHG, Ocean Acidification,...)
- development of community tools for data handling and remapping (library cerbere used for felyx, Ocean Virtual Laboratory – OVL -, GlobCurrent, OceanFlux GHG, Ocean Acidification,...)
- development of common exploitation platform focused on a particular thematic (cloud Nephelae of Ifremer/Cersat used for GlobCurrent, OceanFlux GHG, Ocean Acidification,...) with remote access by project partners
- online generation of new products (flux engine in OceanFlux GHG)
- development of data visualization and intercomparison tools (felyx, syntool,...)

OHF-RB-REQ-6.1: project synergies	
The OHF project shall seek synergies with other similar other ESA projects (GlobWave, GlobCurrent, OceanFlux GHG, Felyx, ...) in particular in terms of complementary datasets (e.g. currents), data formats or tools and services (OceanFlux engine, cloud *Nephelae*, colocation or resampling routines, felyx...)	
Verification method	Inspection
Link to OHF SoW tasks	

6.2 Cloud computing

OHF shall provide a processing capability for reprocessing datasets or testing new algorithms.

This processing capability shall be available, and restricted, to all members of OHF team, including the selected experts. The platform shall provide a suitable environment and tools to these members for them to read, analyze and process data.

Members of OHF (and a limited number of expert users) shall be able to initiate processing on the processing platform. Tools shall be provided to distribute and run any data processing (using an efficient batch approach) on a sequence of input data. This will include the capability to :

- Perturb input data and re-generate flux ensemble dataset (e. g. for evaluating uncertainties and error propagation).
- Reprocess the OHF turbulent fluxes data (using standard set of input data, uploading a python script e. g. plug in their own bulk parameterization, fixed spatial and temporal resolution).
- Perform the cage analysis on a new region

OHF-RB-REQ-6.2: cloud computing	
The OHF project will provide cloud computing capability to members of the OHF team and selected experts. This capability will allow these specific allowed users to analyze and reprocess the OHF products.	
Verification method	Inspection
Link to OHF SoW tasks	

6.3 Open source community tools

One objective of OHF is to develop and make available all the means to improve the turbulent fluxes through processing and analysis tools. It is obvious that OHF will not produce the ultimate set of turbulent fluxes and that many improvements will come in the future. However it is a key objective of OHF to support these future improvements by making available resources and tools. Therefore these tools and resources collected or implemented in the context of the project will be made available to the user community. They include for instance:

- data reading tools
- data homogenization and remapping tools
- data intercomparison tools

- data validation tools such as the calculation of probability density functions, 3-way validation or cage analysis.

Some of these intended tools are further described in section on OHF portal.

OHF-RB-REQ-6.3: community tools	
The OHF project shall make available to the user community the tools implemented for data manipulation, analysis and validation.	
Verification method	Inspection
Link to OHF SoW tasks	

All algorithm and tool development will promote the usage of Python language. Python is the language used for numerous data reading, collocation or resampling tools at Ifremer. Many open source packages are available in python for scientific computation. It is used also in many related ESA projects (felyx, GlobCurrent, GlobWave, OceanFlux GHG) and there is a growing usage in the research community.

All software developed within OHF will be made open source upon the completion of any scientific analyses. The source code will be available on a github server (or equivalent).

OHF-RB-REQ-6.4: software requirement	
All software algorithm development will use Python and be made open source on a git server upon the completion of the scientific work within the project.	
Verification method	Inspection
Link to OHF SoW tasks	

6.4 Toward a flux thematic platform

Though the project is a two year project, it shall aim at building the foundation of a research framework to be sustained in future, in particular anticipating at future evolutions and developments.

OHF-RB-REQ-6.5: scientific roadmap
The OHF project shall produce and deliver through a scientific roadmap document a strategic vision for the development and improvement of the assets developed in the project.

Verification method	Inspection
Link to OHF SoW tasks	

In particular, there is currently though ESA and H2020 initiatives a growing demand for the development of Virtual Research Environments (VREs) and Thematic Exploitation Platform (TEPs) associating infrastructure resources, data, tools and services. The OHF shall foster on the new big data technologies and these demonstration platforms to foresee and define a similar future framework for the ocean flux community.

OHF-RB-REQ-6.6:	
The OHF project shall specify the architecture and requirements of a research platform dedicated to ocean fluxes. It shall first assess the limitations of the platform set up in the frame of the OHF project life and propose improvements and additions in regard to other initiatives. This shall be included in the scientific roadmap delivered at the end of the project.	
Verification method	Inspection
Link to OHF SoW tasks	

7 Data portal

7.1 Overview

The OHF project shall develop, operate and maintain a central web portal that shall provide a single entry point to all aspects of the project. It will be maintained for at least 2 years after the completion of the project.

The aim of the OHF web portal is to:

- provide users with a resource to make full and easy use of the OHF products.
- establish and maintain connections with the CLIVAR community and other relevant project teams.
- actively promote the results of the project.

OHF-RB-REQ-7.1:	
The OHF web portal shall contain at least the following contents: • information about the OHF project, including objectives, work packages list, latest news and news archive, documents and presentation for all the project meetings in PDF format, list of OHF main team members, contacts of the project manager, links to international community linked to the project • a page announcing meetings • description and links to sources of data used in the project (satellite, in situ, models) and products developed during the project • access to project documentation	
Verification method	Inspection
Link to OHF SoW tasks	

OHF-RB-REQ-7.2:
The web portal shall be maintained and updated for the duration of the project and at least two years after the end of the project. The contents of the web portal shall be reviewed at least once per month.

Verification method	Inspection
Link to OHF SoW tasks	

7.2 Project documentation

All internal project documentation shall be made available on the website, however this should not be publicly available.

The web portal shall provide a restricted (and secure) project area containing internal documentation such as deliverables, meeting minutes, monthly reports, project management plan, etc… The project documents will be placed in the secure area as they become available.

OHF-RB-REQ-7.3: project documentation	
The web portal shall provide a password protected project section containing project internal documentation, such as all draft document deliverables, RIDs, meeting minutes, actions database, monthly reports, project management plan, etc.	
Verification method	Inspection
Link to OHF SoW tasks	

7.3 Data access

The OHF project will allow easy access to the project products and results. The OHF data information shall be available through the website. This will include links to any documentation and information on how to access any datasets.

OHF-RB-REQ-7.4: data access	
The OHF project will provide easy access to all project (output) datasets through the project web portal.	
Verification method	Inspection
Link to OHF SoW tasks	

The datasets produced by (or collected for) OHF shall be available through ftp access to all authorized users. A login/password shall be delivered by CERSAT help desk to any interested users.

Local access to the online archive will be possible from the cloud platform *Nephelae* of CERSAT allowing for direct remote processing without the need to download any data.

The gridded data will be displayed through a web visualization service, relying on standard protocols in Ocean community (ie WMS, Thredds/OpenDAP).

OHF-RB-REQ-7.5: data delivery	
The OceanFlux GHG project will make all OceanFlux GHG products available through a ftp and Thredds/OpenDAP servers.	
Verification method	Inspection
Link to OHF SoW tasks	

7.4 Online tools and virtual research environment

In the recent years, the large increase in the volume and diversity of the data has made it difficult for end users to collect, process and analyse them in their local premises on their own. In the meantime, the development of cloud computing platforms has increased the ability to remotely work with data without circulating them through networks, and with the collateral advantage of allowing improved data curation by centralizing consistent and consolidated datasets at thematically identified places ("Thematic Exploitation Platforms") together with a sandbox (user workspace, processing resources and tools) for users to connect and remotely play the data. Similarly the development of web services and back-end processing mechanisms has made possible to provide researchers with the ability to remotely design and execute complex processing workflows with less time spent on programming or data access. The development of crowd sourcing in the field of science also promises to ease scientific cooperation and bring data analysis and virtual experiments to a next level.

Early attempts to take advantages of these new capabilities have been undertaken, for instance with Gas Flux Climatology Generator developed for OceanFlux GHG project [WEB-1].

It shall be an objective of OHF to also foster on existing tools and capabilities to provide users with the ability to run online complex data analysis or production tasks and share them with each other.

In particular, flexible and generic tools shall be provided to:

- remotely reading and working with the data
- generate a flux dataset by perturbing inputs or using different datasets as input for a single parameter, or using different bulk formulations
- analysing and inter-comparing different datasets
- examining the heat budget over a user defined area (concept of cages)

7.4.1 Data remapping

The OHF project shall provide a python tool or routine to perform the remapping on the same OHF grid/projection.

It shall provide several methodologies adapted to the respective quantity and resolution of the remapped data. It shall assess and define the criteria and constraints to be taken into account to minimize the sources of error in later flux estimation or comparison.

OHF-RB-REQ-7.6: resampling tools	
The OHF project shall provide python tools to allow the homogenization of input and reference data to the same format and spatial grid. These tools shall provide different options for data resampling, depending on their nature and source vs target spatial resolution.	
Verification method	Inspection
Link to OHF SoW tasks	

7.4.2 Quick dataset intercomparison

Several software solutions have been developed to allow the inter-comparison of different data sources (such as ***felyx*** [WEB-2]). The OHF project shall assess these existing solutions and set up the more suitable tools to allow users to remotely analyze and inter-compare different flux products.

OHF-RB-REQ-7.7: online dataset inter-comparison	
The OHF project shall investigate and deploy technical solutions for users to assess and inter-compare the strengths and weaknesses of comparable products.	
Verification method	Inspection
Link to OHF SoW tasks	

7.4.3 Custom flux dataset generation

OHF-RB-REQ-7.8: custom flux dataset generation	
The OHF project shall offer a way for registered users to remotely define and generate a climatology of fluxes, perturbing input datasets or selecting different inputs.	
Verification method	Inspection
Link to OHF SoW tasks	

7.4.4 Heat budget examination (cage analysis)

OHF-RB-REQ-7.9: remote heat budget examination	
The OHF project shall offer a way for registered users to remotely define a cage and examine the heat budget within this cage.	
Verification method	Inspection
Link to OHF SoW tasks	

8 Outreach and communication

8.1 Promotion of the project

The OHF project intends to disseminate the results of the project to as wide a community as possible and a number of mechanisms are planned in order to achieve this including:

a) Develop and maintain a contacts directory of all members of the project.

b) Actively maintain connections with relevant international communities (e. g. CLIVAR).

c) Develop and maintain a web portal.

d) Actively promote the results through the web portal, publishing peer-reviewed papers and presenting results at international conferences.

e) Convene and hold an international workshop were the results from OHF are presented and the international community can present their work.

f) In conjunction with the international community collate and write a scientific roadmap to identify and focus future research activities.

The mechanisms by which the OHF project shall promote and disseminate the results of the project are detailed below.

OHF-RB-REQ-8.1: Directory and mailing list	
The OHF project will maintain a directory and mailing list which shall contain contact details of: • All members of the project team. • Potential users of the project output. • All project supporters.	
Verification method	Inspection
Link to OHF SoW tasks	

OHF-RB-REQ-8.2:Promote results of the study
The OHF project will actively promote the results of the study and distribute freely all data, reports and experimental output data to the relevant groups, project communities (CLIVAR)

and any project supporters.	
Verification method	Inspection
Link to OHF SoW tasks	

A joint workshop of CLIVAR CONCEPT-HEAT, CLIVAR GSOP (Global Synthesis and Observations Panel), ORA-IP (international reanalysis intercomparison project) and COST ES1402 (EOS: Evaluation of Ocean Synthesis) is planned to take place 29.09. to 02.10.2015 at MetOffice, Exeter, UK. Project members plan to attend this meeting for outreach, as well as scientific communication. It is an opportunity to convene there a dedicated session or joint meeting presenting the OHF project achievements and getting community attention.

OHF-RB-REQ-8.3: Convene and hold an international workshop	
The OHF project shall take the opportunity of an important community event such as CLIVAR to convene and hold a joint meeting or session where the results from the project will be presented. The workshop shall also provide a stage for the international community to present their work and open discussions to identify future avenues of scientific investigation.	
Verification method	Inspection
Link to OHF SoW tasks	

Further communications are planned, such as:

- EGU general assembly 2015: “Challenges of the surface energy budget and proposed ways forward”: K. Von Schuckmann, S. Josey, S. Gulev, K. Trenberth, C.-A. Clayson, P.-P. Mathieu, M. Wild
- Presentation at DWD (Germany) seminar: “Ocean Heat Content and CAGE Experiments”, K. Von Schuckmann

OHF-RB-REQ-8.4: Present results of the study	
The OHF project will present the study and results at relevant international events, including future ESA and other international symposia during the lifetime of the project and the project scientific workshop.	
Verification method	Inspection
Link to OHF SoW tasks	

It is also planned in the project to promote the project achievements through paper communication and publications, for which some of them are already in preparation:

- Presentation of OHF project for FLUX NEWS, issue 7 (http://www.met.reading.ac.uk/~sgs02rpa/REPORTS/FluxNews7.pdf): A. Bentamy, K. von Schuckmann
- Paper in preparation: "Regional ocean indicators in the Mediterranean Sea from in situ measurements during 2004-2012" Karina von Schuckmann, Giulio Notarstefano, Francisco Calafat, Pierre-Marie Poulain, Isabelle Taupier-Letage, Louis Prieur and Nicolas Reul

OHF-RB-REQ-8.5: Peer-reviewed publications	
The OHF project will develop and submit papers to appropriate international (peer-reviewed) science journals. The publications shall acknowledge the support of the ESA STSE programme and use of ESA data.	
Verification method	Inspection
Link to OHF SoW tasks	