Towards Improved Estimates of Ocean Heat Flux (TIE-OHF)

Chapter 1 : Technical Proposal

In response to ESA ITT ESRIN/AO/1-7712/13/I_AM

(***Reference: Improvement and Calculation of Global Long Time Series of Ocean Heat Fluxes from Satellite Remotely Sensed Data***)

Tender Reference: ESA/II/IFREMER/Tender/Tch

Issue No.: 2.0

Date of Issue: 25 May 2014

TABLE OF CONTENTS

Contenu

Applicable documents

The following table lists the applicable documents to this proposal.

Id	Title	Reference	Issue	Rev.
LET	Letter-Invitation to Tender	Act.Ref.: 13.155.28	15 Nov. 2013	
SOW	Statement of Work	EOP-SA/0261/PPM-ppm	1	1.
SCOT	Special Conditions to Tender	Appendix 3 to AO/1-7712/13/I-AM		
DC	Draft Contract OHF	Appendix 2		

Table 1 : Applicable documents

Reference documents

The [SoW] contains a large number of documents and web sites that our consortium confirms it is familiar with.

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 CO_2 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
SRR	
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 Institu
WGSF	Working Group on Surface Fluxes
WP	Work package
1D	One dimensional
3D	Three dimensional

Table 2 List of abbreviations and acronyms

1 Introduction

The consortium offers a skilled approach to conducting the appropriate flux research, method developments, and analyses of the resulting flux estimates, design, and implementation, as well as operational calculations of the ocean heat flux and related variables. We build upon proven expertise in flux estimation and validation, using of remotely sensed data for the surface parameter retrieval, calibration and validation of satellite radar and radiometer measurements and observations, cross-sensor comparisons, developing multiple sensor match-up databases, developing web interfaces for ocean data visualization and analysis, developing data processing infrastructure, and routine operations for GMES. The consortium includes experts in Earth observations such as surface wind, sea surface temperature (SST), specific air and surface humidities, turbulent flux determination and validation, sea state. Collectively we will provide a cost effective solution and deliver validated long time series of the ocean heat flux as well as of the main requested and related parameters.

Our group is pleased to provide this fully compliant Technical Proposal in response to ESA's requirement for the "Ocean Heat Flux" as described in ESA's Invitation to Tender ESA ITT ESRIN/AO/1-7712/13/I-AM. This is Chapter 3 of the proposal, containing our Technical Proposal in response to the requirements included in the Statement of Work (SoW).

The Technical Proposal responds to §3 of the Special Conditions of Tender. It describes our understanding and analysis of the technical and functional requirements, state of the art of turbulent and radiative fluxes, description of the scientific and technical work and anticipated results aiming to meet the proposal requirements, and a description of how we will conduct the necessary work activities. This technical proposal is organized as follows:

- **Section 1, Introduction**: a general introduction to the Technical Proposal document, with an overview of the proposal key points.
- **Section 2, Proposal Summary**:
- **Section 3, Background**
- **Section 4, Understanding of requirements**: an overview of the ocean heat flux scientific and technical requirements giving our group's understanding of their significance, an outline of the strength aspects and weaknesses of the available fluxes derived from EO data, and of the methods leading to the improvement of the calculation of flux long time series over global oceans.

- **Section 4, Background:**
- **Section 5, Goals**: presents our work objectives to meet OHF requirements.
- **Section 6, Detailed Description of the Proposal**: describes the approaches and methods that will be used to tackle the main issues of the TIE-OHF project. It provides details about scientific and technical methods to fulfill each SoW task requirements. For instance, it provides details of the methods aiming to assess the flux quality at various space and time scales. It also considers approaches to overcome the main known weaknesses of the surface turbulent fluxes and net OHF, to determine the reference data sets, and to estimate new ensemble flux data.
- **Section 7, References**
- **Section 8, Collaboration**: presents our approach to link with the expert user community for the system to fulfill its needs and requirements. It also takes advantage of existing experiences and fosters the uptake of the OHF by the user community.
- **Section 9, Compliance**: demonstrates our commitment in providing a fully compliant proposal.

2 Proposal summary

The heat exchange between ocean and atmosphere has four components. The turbulent flux is normally partitioned into the two components: latent heat flux component associated with the heat loss due to evaporation from the sea surface and sensible heat flux supported by atmospheric heat conductivity.. The radiative flux is also partitioned into two components, net shortwave (solar) and net longwave . The resulting amount of heat being exchanged determines the net air-sea heat flux. Investigation of the distributions of heat flux over the global oceans as well as over regional oceanic basins is a key element of climate research. Accurate air-sea heat flux estimates are required to establish air-sea feedback mechanisms, to provide guidance and motivation for modeling studies, to verify individual or coupled atmosphere-ocean general circulation model runs, and to serve as forcing functions for ocean model simulations.

Recommendations and priorities for ocean heat flux researches are for instance outlined in the latest CLIVAR and WCRP 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.

TIE-OHF project does not attempt to meet all requirements. It aims at meeting the following:

- Determination of accuracy of existing satellite and NWP fluxes through direct pointwise comparisons with selected high accurate flux measurements such as derived from OCEANSITE and from dedicated experiments.
- Characterization of flux accuracy depending on atmospheric and oceanic conditions.
- Investigation of the impact of uncertainties of input variables and bulk parameterizations on the flux accuracy.
- Determination of the effect of spatial and temporal sampling on the resulting flux quality at global and regional scales.
- Development of an innovative *ensemble* approach to generate multiple realizations of EO based flux products. It should combine the existing data sets, the latest improvements in bulk formulations and associated input data, and the most recent efforts in the climate quality (e.g. CCI) re-processing of EO data.
- Assessment of the new flux quality based on the comparison with in-situ data.
- Development of Web-based interfaces to facilitate access to daily averaged and higher resolution heat fluxes and meteorological state variables from mooring sites and satellites.

The main scientific challenges are the evaluation and improvement of turbulent fluxes including momentum and especially turbulent heat fluxes. The TIE-OHF project will first provide the evaluation of fluxes over the global ocean as well as at regional scales. Several global flux products derived from in-situ, satellite, and NWP data are currently available and widely used by the community. Although these products exhibit qualitative similarities of global spatial distributions and of the temporal variability patterns, they also show significant quantitative differences at regional scales. It has also been shown that the uncertainties in the net radiative heat flux at the sea surface can be as large as the variations in the turbulent heat fluxes. The reasons for these differences relate to the differences in input data as well as to the differences in inverse and direct methods used for the retrievals of geophysical parameters from remotely sensed measurements. There are difficulties in comparing surface flux estimates (both turbulent and radiative) due to inconsistencies in methodology and data input.

An obvious one is the mismatch of reference heights in NWP models, buoy and satellite estimates of surface variables. More uncertainties may result from different time constants explicitly or implicitly used for the derivation of surface state variables from different data sources. The TIE-OHF project will first address these differences and hence attempt to characterize the associated uncertainties. For instance, the uncertainty related to bulk parameterization will be first quantified using moored buoys which provide both atmospheric (surface wind, air temperature, air humidity, SW, rain) and oceanic (SST, wave characteristics, such as heights, directions, periods, SWH, currents (magnitude and direction)) measurements. 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 atmospheric and especially oceanic parameters, which are not directly entering the estimation of turbulent fluxes. Most flux producers also provide bulk state variables such as SST, air temperature, winds, and humidity. Differences between flux estimates will be analyzed with respect to the differences in bulk variables at global and regional scales. The third validation activity will deal with the impact of spatial and temporal sampling on the resulting satellite flux estimates. To assess this uncertainty, the synthetic satellite data (e.g. Bentamy *et al*, 2013) derived by sub-sampling of NWP will be used to simulate EO data coverage. The objective is to determine the sampling errors and to assess how particular atmospheric and oceanic conditions such as high winds, strong spatial gradients, as well as diurnal variations might resulting fluxes.

This proposal is aimed at obtaining and analyzing all heat flux components (turbulent and radiative) over the global ocean using multiple satellite sensors in combination with *in situ* measurements and numerical model analyses. The fluxes will be generated daily and monthly for the 20-year (1992-2011) period, for the ice-free ocean between 80 ^{o}N and 80 ^{o}S and at spatial resolution ranging between 0.5° and 0.25° in longitude and latitude.. Simultaneous estimates of all surface heat flux terms have not previously been calculated at such fine scale and long time period. Such an effort requires a wide range of expertise and data sources that only recently have become available. We focus on developing necessary methods and tools for integrating these data sources and calculate momentum and heat fluxes across the air-sea interface. We have access to all relevant satellite data to perform such computations. Our team possesses the required expertise to address the broad scope of these challenges. A requirement will be modifications of our methods to accommodate new sensors and new science derived from the latest research.

The specific objectives emphasize the assessment of the quality of available EO satellite data (retrievals), especially those derived from European and ESA satellite missions, and their use to improve the determination of a new multi-satellite ocean surface heat turbulent flux over the global ocean. To meet this objective, the uncertainties of bulk variables (e.g. wind speed, zonal and meridional components, air and sea temperatures, specific air and sea humidity) as well as of turbulent fluxes will be investigated and characterized with respect to the oceanic and atmospheric parameters and bulk parameterization. Expected results will lead to the determination of accurate EO input dataset that will be used as a reference for the community. Detailed proposal topics and their relationship to ITT tasks are provided below in the following sections.

This project will fully utilize satellite, ESA CCI, in-situ, and numerical model data. The remotely sensed data will be derived from scatterometers (ERS-1/2, NSCAT (onboard ADEOS-1), SeaWinds (QuikSCAT, ADEOS-2), ASCAT(Metop-A and –B), OSCAT (OceanSat2), and HY2), radiometers (SSM/I (F10-F18), AMSR (Metop-A and –B), AMSU (NOAA15-18, Metop), AMSR-E (Aqua), WindSat (Coriolis)), and ocean-colour sensors (MODIS, SeaWiFS and MERIS), The available satellite data will be collected and validated over the global ice-free ocean with available in situ measurements using same statistical procedures (or exploit validation work already undertaken in CCI projects). The project will perform consistency studies of surface parameters retrieved from several satellites. The basic variables (surface winds, surface and air specific humidities, and air and sea surface temperatures, chlorophyll concentration) will be used to estimate turbulent fluxes based on the methods previously published by our team. Global flux analyses will be then calculated with spatial resolutions varying between 0.5° and 0.25° in longitude and latitude. To enhance the space and time resolution of the parameter fields, the blending scheme (Bentamy *et al*, 2011) creating daily fields with a spatial resolution of 0.25° from satellite and atmospheric numerical model analysis data will be performed as a component of this proposal.

The resulting data will be used for:

(1) methodology development;

(2) assessing the quality of retrievals as well as of atmospheric estimates;

(3) Calculation of daily and monthly air-sea heat flux estimates over global ocean with spatial resolution at least of 0.50°×0.50° and

(4) Characterization of air-sea heat flux uncertainties including their dependency on environmental conditions.

In addition to improvement of OHF data and associated parameters, this proposal also aims to improve the processing scheme for satellite-derived surface variables and refinement of the operational component. For the purposes of this proposal "processing" is interpreted broadly and include all aspects of dataset development that do or do not require research. For some items we would be able to start immediately (if resources are available). In particular, to address data reclamation, work on dataset homogenization, improving dataset accessibility, and metadata availability.

The main added values of the TIE-OHF project are:

1. Better characterization of uncertainty sources dealing with bulk parameterizations, bulk variables, spatial and temporal sampling. Identification of specific areas for which improvements are needed and feasible.
2. Quality assessment of the input data (e.g. winds, air and sea surface temperatures, humidity) at various scales
3. Assessment of the consistency of input data derived from various satellites
4. Reprocessing of input data with respect to results obtained above
5. Use of the most updated input data and parameterization for the calculation of newly flux products over global ocean with high space and time resolutions
6. Determination of the accuracy of the newly flux products through comprehensive comparisons with high accurate in-situ data including buoy, ship, and dedicated experiment data.
7. Availability of input and flux data through dedicated portal with various facilities.

This proposal will further demonstrate the value of historic and ongoing satellite missions for studying the air-sea interactions. It will contribute to the calibration, validation, and usage of existing and new products needed for the global heat exchange between the ocean and atmosphere, and thus works towards the objectives of the ocean flux scientific community. It will combine EO data from scatterometers, altimeters, and radiometers with *in* *situ* data, numerical simulations and atmospheric re-analyses. Our data synergy approach could be used for cross validation of algorithms that will be developed by scientists associated with the present ESA project.

3 Background

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

For over a decade, several scientific groups have been developing air-sea heat flux datasets, including the Japanese Ocean Flux datasets with the Use of Remote sensing Observations (J-OFURO) (Kubota *et al.*, 2007), the Goddard Satellite-based Surface Turbulent Fluxes (GSSTF) (Chou *et al*, 2003), the Objectively Analyzed Air-Sea Fluxes (OAFLUX) (Yu *et al*, 2007), the Institut Français pour la Recherche et l'Exploitation de la MER (IFREMER) (Bentamy *et al.*, 2003, 2008, 2013), and the Hamburg Ocean Atmosphere Parameters and fluxes from Satellite Data (HOAPS) (Anderson *et al.*, 2010). These groups have developed direct and inverse methods, algorithms, and procedures to calculate long time series of surface winds, wind stress, specific humidity, and latent and sensible heat fluxes. These satellite-based fluxes are widely used by the scientific community for various purposes such as forcing ocean circulation models (e.g. Ayina *et al.*, 2006), analyzing the spatial and temporal variability associated with El Niño-Southern Oscillation (ENSO) (e.g. Mestas-Nuñez *et al.*, 2006, 2013), or employing an enhanced spatial and temporal sampling provided by remote techniques to evaluate the intra-seasonal variability (e.g Grodsky *et al*, 2009). Even though the results of these investigations have increased our understanding of air-sea interaction processes, further improvements of satellite-based fluxes are still required.

A number of studies aiming at assessing the quality of turbulent fluxes have been published in recent years. By comparing latent heat fluxes (LHF) from buoys and satellites Bourras (2006) has found that the overall accuracy is of the order of 20%-30%, whereas the required error for a quantitative use over the global oceans should be lower than 10%. He has concluded that the main LHF error sources are related to the accuracy of the specific air humidity (Qa) and surface wind speed (W). Tomita *et al.* (2006) have investigated the accuracy of satellite-based LHF through comparisons with buoy and NWP estimates. In the tropics, the main source of buoy and satellite LHF discrepancy is attributed to the accuracy of satellite Qa, whereas around Japan the LHF discrepancy is associated with the accuracy of both W and Qa. They have concluded that the improvement of satellite LHF estimation requires improvements of the remotely sensed W and Qa at global and regional scales. Santorelli *et al* (2011) have conducted detailed accuracy investigations of Ifremer and OAFlux latent and sensible heat fluxes as well as of basic bulk variables (10 m wind speed, W_{10}; 10m specific air humidity, Qa_{10}; 10 m air temperature, Ta_{10}; and SST) using standard moored buoy and dedicated-experiment scientific data. Recently Pinker *et al* (2014) investigated the spatial and temporal variations of the ocean heat fluxes derived from remotely sensed observation (Ifremer for turbulent fluxes and University of Maryland for radiative fluxes) and from blended product (Woods Hole Oceanographic Institution(WHOI) and ISCCP) (Figures 3.1 and 3.2). Although these products exhibit quite similar spatial and temporal variability patterns, regional differences between the two prototypes of flux estimates can be significant. It has been also shown that the uncertainties in the net radiative heat flux at the sea surface can be as large as the variations in the turbulent heat fluxes. The reasons for the differences observed relate to differences in input data as well as to differrences in inverse and direct methods used to retrieve geophysical parameters from remotely sensed measurements. There are difficulties in comparing surface flux estimates (both turbulent and radiative) due to inconsistencies in methodology and data input. An obvious one is the mismatch of reference heights in NWP models, buoy and satellite estimates of surface variables. This problem was addressed by Santorelli et al. (2011), whose conclusions generally agree with the studies mentioned earlier and emphasize that the improvement of satellite fluxes should include the improvement of the interpolation method used to calculate gridded fields over the global ocean to better reflect conditions during synoptic-scale storms and fronts. However, the further standardization of the pre-processing of satellite retrievals, model output and buoy data would be helpful for creating more consistent climate records. In particular, of a special importance would be development of well justified guidance on co-location of buoy, satellite based, VOS and NWP flux values accounting for different space-time scales behind the estimates from each individual source.

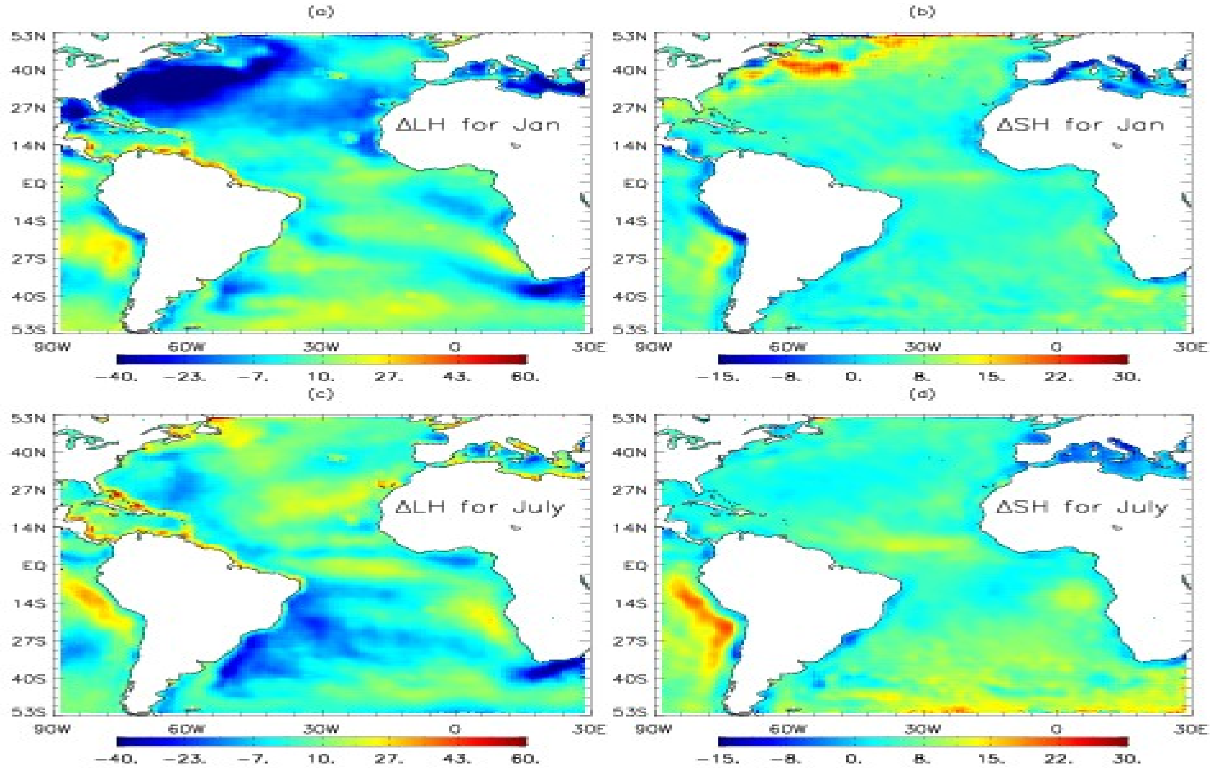

Figure 3.1 : Differences in a) latent and b) sensible heat fluxes for January and c) latent and d) sensible heat fluxes for July as available from IFREMER (*Bentamy et al.*, 2013) and WHOI OAFlux (*Yu et al*., 2007) for 2003-2005 (Pinker *et al*, 2014)

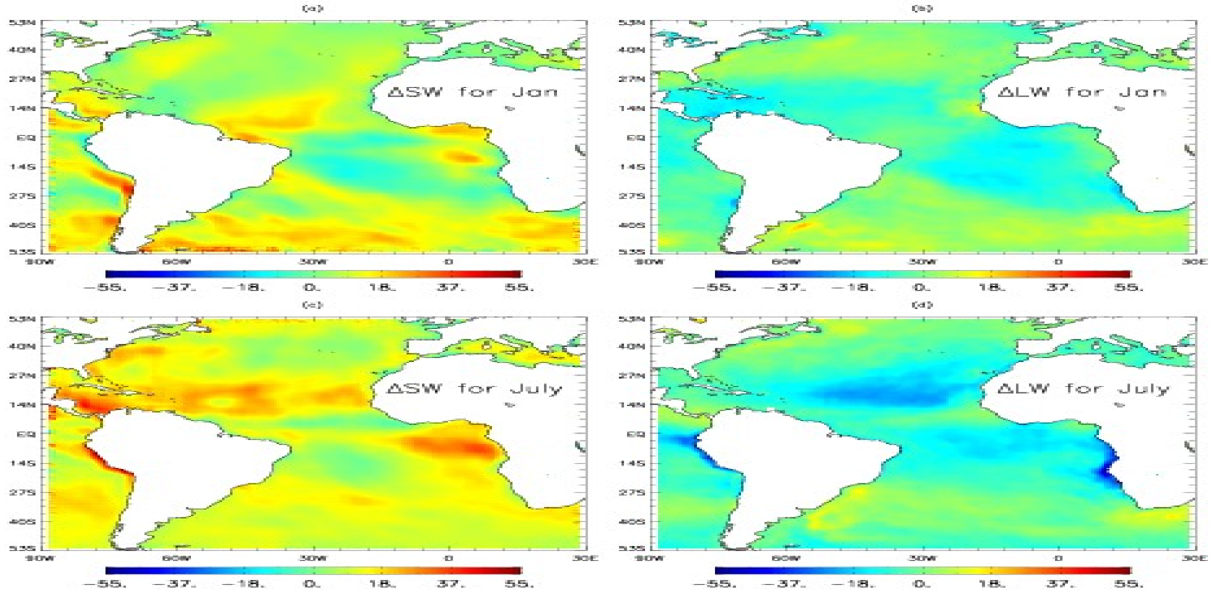

Figure 3.2 : Differences in short wave (SW) and long wave (LW) fluxes as derived from UMD/SRB_DX_SW v3.3.3 minus UMD/SRB_MODIS_SW and UMD/SRB_DX_LW minus UMD/SRB_MODIS_LW for 2003-2005: a) January SW; b) January LW c) July SW; d) July LW (Pinker *et al*, 2014)

The recommendations outlined in the World Climate Research Program (WCRP) and the associated programs deal with the improvement of turbulent flux determination, the spatial and temporal resolutions, the accuracy of flux fields, the characterization of the spatial and temporal errors of each flux component, and the analysis of the comparisons between satellite and numerical model analyses and re-analyses. In a report by the Joint WCRP/SCOR Working Group on Air-Sea Fluxes (WGASF, 2000) the desired accuracy requirement for climate studies is formulated to be "a few W/m²" for the flux components, resulting from a required accuracy of the large scale net heat flux of 10 W/m² (e.g. WGASF, 2000, Bradley and Fairall, 2007). Further recommendations given in the Oceanobs'09 White Paper on surface fluxes (Gulev *et al*., 2010) include new challenges targeting development of new parameterizations, achieving global and regional heat budget closure, accurate estimation of sampling uncertainties and scaling parameters for surface flux estimates.

One of possible strategies for inter-comparison of various parameters, including the total net flux, from a set of 19 model simulations has been developed by the GODAE and CLIVAR GSOP Workshop on Observing System Evaluation and Inter-comparison (Oke *et al*., 2011). Results have been presented at the CLIVAR GSOP/GODAE Ocean Reanalyses Inter-comparison Workshop (Balmaseda *et al.*, 2013) with a set of papers in CLIVAR Exchanges #64.

An ad hoc pragmatic way of measuring the current uncertainty of the satellite flux products is to conduct an intercomparison leading to a multi-parameter approach at interannual to decadal time scales and regional to global space scales, in particular by including OHC estimations as a constraint. Regional and global OHC estimations of the upper layer can be obtained from the Argo global observing system (http://www.argo.ucsd.edu/) delivering a view of the ocean interior heat storage at an unprecedented coverage in space and time. Since 2000, Argo delivers temperature and salinity measurements of the upper 2000m of the global ocean. Ocean reanalyses potentially provide more accurate information than observation-only estimates by combining ocean models, atmospheric forcing fluxes and ocean observations via data assimilation methods. They should be used in any multi-analyses approach when comparing OHC with OHF estimates (e.g. Balmaseda et al., 2014).

Following the concept of “Cages” (Bretherton et al., 1982), the “World Ocean Circulation Experiment” (WOCE) proposed using the hydrographic transects. More recently, a new prospect (WHICH ONE?) for heat budget constraints has emerged through the advent of new high quality measurements (Yu et al., 2012), in particular from the Argo profiling floats and from ocean reanalyses. The combination of OHC estimates with EO data can provide scientists with an estimate of changes in OHC induced either through surface exchanges or lateral transport, thus enabling evaluation of the fidelity of OHF products. As recommended by the recent GSOP workshop in Woods Hole (Yu et al., 2012) this methodology complements the traditional local evaluation methods (based on comparison with point-wise measurements) with regional approaches using area average heat budget .

To meet the scientific community requirements reported in ITT “Ocean Heat Flux” (ITT ESRIN/AO/1-7712/13/I_AM), the general area of focus of this proposal is towards developing, validating, and evaluating satellite-based estimates of surface turbulent fluxes, particularly derived from ESA satellite/mission EO data, of all the components of the turbulent fluxes over global ocean. It is important to have well-sampled purely observation-based estimates of all flux terms obtained independently of reanalyses. These observation-based estimates will be based on data provided by CM SAF, GEWEX and/or from University of Maryland teams (Pinker *et al*, 2009). The accuracy of the individual surface flux components as well as of the net heat flux will be first investigated through the comprehensive validation against flux estimates from state variables measured in-situ at buoys, including Flux reference OceanSites network (http://www.oceansites.org/), dedicated scientific experiments (http://seaflux.org/), and from ship measurements (Berry and Kent , 2009). At global scale, the satellite fluxes will be compared to the main climatological products OAFlux, HOAPS, IFREMER, ERA Interim, MERRA, and CFSR. To achieve all project tasks, we have assembled a team of experts with different specialties dealing with remotely sensed, in-situ, and numerical model data acquisition, processing, archiving, analysis, dissemination, and use towards scientific and operational issues. One of the novel aspects of the proposed work is that it will incorporate a sensitivity analysis of the estimated heat budget and fluxes of the upper ocean and the lower atmosphere to changes in the optical properties of the water derived from ocean-color data (OC-CCI).

To highlight preliminary results related to this proposal, we present our recent analysis of accuracy and variability of daily and monthly satellite wind, latent and sensible heat fluxes at global and regional scales (e.g. Bentamy *et al*, 2013; Pinker *et al*, 2014). For instance, these data illustrate that using scatterometer winds and radiometer Qa data along with Ta estimated from atmospheric simulations enables global daily turbulent fluxes mapping onto a 0.25°x0.25 grid. Their accuracy has been evaluated against in-situ fluxes from the tropical moored buoys. RMS difference from daily TAO, PIRATA, and RAMA fluxes is about 30W/m^2 and 10W/m^2 for the latent and sensible heat fluxes, respectively. On interannual time scales our estimates of turbulent fluxes display an apparent ENSO-related variability (Figure 3.3). Warm (cold) SSTs in the eastern tropical Pacific are phased with increases (decreases) in latent heat lost to the atmosphere. Therefore, changes in the latent heat flux act as a damping mechanism for anomalous SST. With daily fluxes we also expect to see the phase propagation related to the equatorial Rossby and Kelvin waves, which may provide additional insights of roles the air-sea interactions play in the ENSO genesis.

The improvement of surface flux estimates requires scientific skills relied on the understanding of the air-sea interaction processes at various space and time scales, the aerodynamic bulk parameterization, the physics of satellite and in-situ measurements, the methods dealing with the combination and comparisons of oceanic and atmospheric parameters, development of synergy between the available sensors and sources. In addition, technical skills are also required towards flux improvement. Advanced tools are also needed to collocate the data from multiple observational platforms, to justify most appropriate inter-comparison metrics and to quantify them. In addition, expertise on OHC quality for validation purposes are strongly needed, as uncertainties of the Argo ocean observing system, sampling issues, and systematic biases, still causes significant spread among the more recent estimates of OHC (Abraham et al., 2013; von Schuckmann and Le Traon, 2011). In particular, the detection of systematic biases represents a significant challenge for the Argo community as they are associated with a coherent signature over large areas and are difficult to identify with current regional quality control procedures (von Schuckmann et al., 2014). Tremendous efforts by the community are under way to overcome these issues and Argo data have a high potential to deliver accurate data for validation of global OHF products. Moreover for end-to-end product development, adequate processing, archiving, and dissemination capacities are highly required.

Our team possesses the required expertise to address the broad scope of this challenge dealing with OHF improvement. They published a number of scientific papers describing the methods of flux estimations (*e.g.*, Anderson *et al*, 2010; Bentamy *et al*, 2003, 2008, 2013, Fennig *et al*, 2012; Klepp *et al*, 2008) the calibration and validation of in-situ and satellite sensors and data(e.g.; Bentamy et al, 1999, 2002, 2007, 2010, 2012, 2013; Grodsky *et al*, 2012; Winterfeldt *et al*, 2010), the examination of the accuracy of flux estimates(*e.g*. Anderson *et al*, 2012, Bentamy *et al*, 2013; Gulev *et al*. 2007, 2012, Pinker *et al*, 2014), the characterization of the spatial and temporal flux patterns(*e.g*. Gulev *et al*. 2013, Grodsky *et al*, 2009, Katsaros *et al*, 2002; Mestas *et al*, 2006, 2013), the determination of flux errors (*e.g*. Gulev *et al*. 2007, 2010, Santorelli *et al*, 2011), the evaluation of the quality and uncertainties of Argo and ocean reanalyses OHC data (e.g. von Schuckmann and Le Traon, 2011; von Schuckmann et al., 2014, Balmaseda et al., 2014, Valdivieso et al., 2014), the use of flux as forcing function for ocean and atmosphere simulations (*e.g*. Ayina *et al*, 2006; Desbiolles *et al*, 2014; Grima *et al*, 1999; Brodeau *et al*. 2010), and the importance of optical properties of the water as a modulator of upper ocean heat budget and heat fluxes (Sathyendranath et al. 1991; We et al. 2007, Zhai et al. 2011). Furthermore, the team members have relevant expertise in working for several national, European, and international projects. We may mention the projects that have scientific and/or technical connections with OHF proposal: SeaFlux, GEWEX, WCRP/WGSF, DRAKKAR, MyOcean, GHRSST, GlobColour, GlobWave, GlobCurrent, SAF OSI, CM SAF, EuroArgo ERIC, WCRP/CLIVAR, GOOS, and NASA IOVWST.

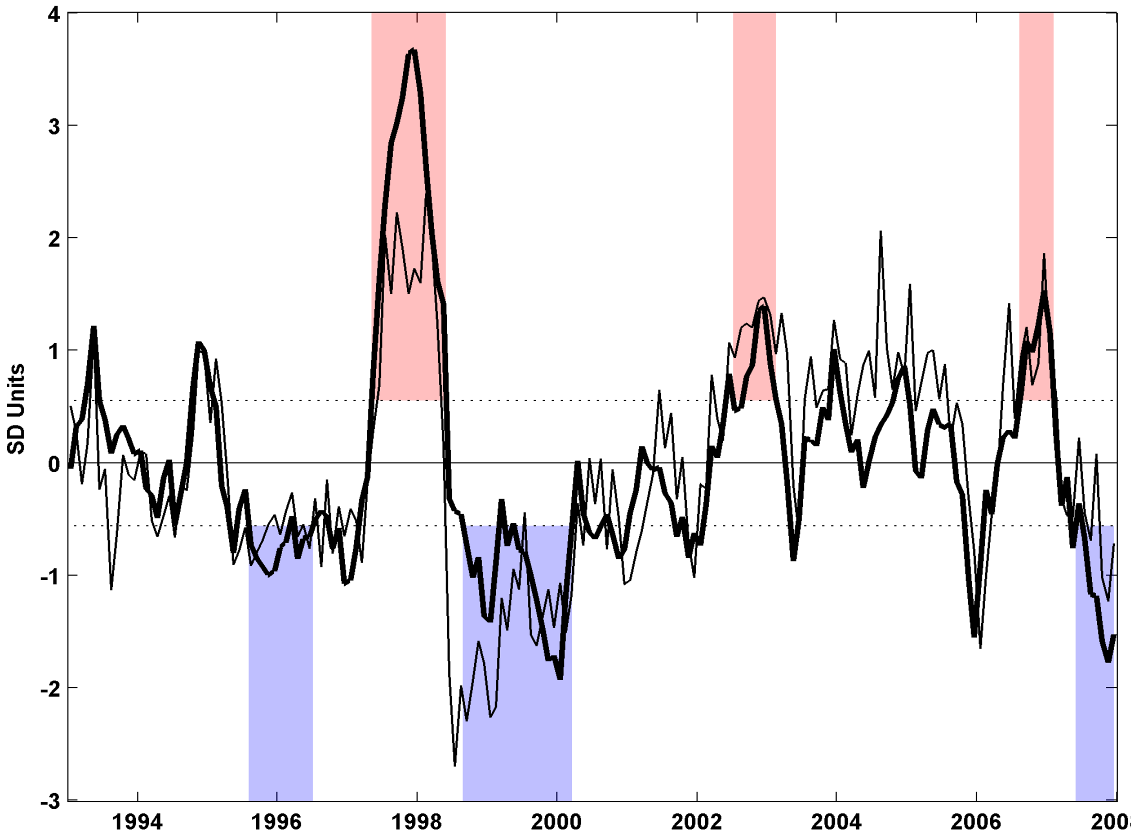

Figure 3.3 : Standardized, monthly SSTA (thick) and LHFA (thin) time series in the Niño-3 region. 273 The standard deviations of these time series are 0.90 ºC and 15 W/m2, respectively, and their 274 correlation is 0.79 with a 95% critical correlation of 0.36. The dotted, horizontal lines indicate 275 ±0.5 ºC temperature thresholds used to define ENSO events using the 5-month running means of 276 Niño-3 SSTA (not shown) following *Trenberth's* [1997] criteria. The resulting warm (El Niño) 277 and cold (La Niña) ENSO periods are indicated with the red and blue shadings, respectively (Mestas-Nunez *et a*l, 2013).

Both Ifremer and HOAPS groups generated and made available long time series of latent and sensible heat fluxes and the related bulk variables (wind speed and components, specific air humidity, air temperature and SST). Their projects are ongoing and will be continued through several satellite generations. Such products are used by several groups for different scientific issues. To overcome the latent and sensible heat flux weakness (e.g; Grodsky *et al*, 2009; Santorelli *et al*, 2011) associated with their accuracy and their spatial and temporal resolutions, Ifremer team (Bentamy *et al*, 2013) has developed and implemented a new method including a new model relating SSM/I brightness temperatures to 10m air specific humidity, and new objective method allowing the estimation of global daily fluxes and basic variable with spatial resolution of 0.25°×0.25°.

Ifremer, through its satellite data center - CERSAT, has dedicated for many years tremendous efforts to provide both software and infrastructure capability to cross-validate and intercompare surface flux and state variable observations from multiple sources, historical archives or near real time data. This constitute the primary expertise of its engineering team and has largely supported the cal/val activities, the development of new inversion algorithm or multi-sensor synergy product of the research team from the Ifremer Laboratory of Oceanography From Space. We have implemented a proper engineering machinery, methods, tools and resources to support such activities which have clearly shown the benefit of a tight transversal approach bringing together various technical skills and teams (system engineering, data management, operations) and a scientific expertise to achieve efficient, generic, user oriented and scientifically grounded applications and services. . For Argo and OHC reanalyses, our partners have strong expertise on the evaluation and validation issues, in particular use of ensemble and multi-parameter approaches. We propose to transfer this valuable background into the TIE-OHF project context and advance to the new generation of flux product and associated tangible and intangible deliverables,

The implemented system will also be a core element of our future activities and systems, and we feel therefore directly committed to deliver a successful and long-term sustained system matching tightly science user requirements.

3.1 OHF consortium

Our group brings together a number of teams with strong scientific and technical expertise in the air-sea interactions; flux parameterization; remote sensing data retrieval, validation, and visualization; ocean and atmosphere data analysis; and satellite sensors calibration and validation.

- **Institut Français de Recherche pour l'Exploitation de la MER (Institute of Research for the Exploitation of the Sea) (Ifremer,** France**)**, which has deep and internationally renowned experience in calibration and validation of remotely sensed data, development of air-sea data, modeling, ocean EO data management, processing, archiving, and dissemination.
- **Plymouth Marine Laboratory** (**PML, UK):** PML brings expertise in ocean-color data processing and interpretation, and in modeling the light transmission underwater as a function of satellite-derived information, such as chlorophyll concentration. PML is the science lead for the ocean color component of the Climate Change Initiative of ESA.
- **Nansen Environmental and Remote Sensing Center (NERSC, Norway):** Focus areas include a) climate processes, variability and change, b) marine and Arctic remote sensing studies, and c) ocean modeling and data assimilation. NERSC has long experience in physical retrieval modeling and validation of ocean surface currents, winds, and waves. It has also pioneered coupled turbulence resolving model to simulate interactions between the atmospheric boundary layer and the ocean mixed layer. With Ifremer and PML, NERSC presently coordinates the DUE GlobCurrent project.
- **University of Toulon (MIO):** Institut Méditerranéen d'Océanologie (Mediterranean Institute of Oceanography, MIO, France), which as a fundamental experience in ocean in situ data validation, processing and analysis as well as assimilation systems

The European consortium will be supported by experts of OHF data and analyses. They will support with their knowledge of the physics, parameterization, determination, characterization, and scientific use of turbulent and radiative fluxes.

Dr Carol Anne Clayson (WHOI, USA; Senior scientist), Dr Sergey Gulev (IORAS, Russia; Senior scientist), Dr Axel Anderson (CM SAF; Senior scientist), and Dr. Rainer

Hollmann (CM SAF, Senior scientist) will participate in the evaluation and validation of existing and newly developed flux products. Their expertise in satellite retrievals and computation of surface fluxes from VOS and reanalyses state variables will contribute to the validation activities making them more comprehensive.

The internal expert group is composed of Dr Rachel Pinker (UMD, Professor); Dr Carol Anne Clayson (WHOI, USA; Senior scientist), Dr Sergey Gulev (IORAS, Russia; Senior scientist), Dr Axel Anderson (CM SAF, Senior scientist), Dr Semyon Grodsky (UMD, Senior scientist), and Rainer Hollmann (CM SAF, Senior Scientist). They will support TIE-OHF project and partners in the definition of the methods dealing with the analysis of the input and flux data, and in the assessment of the results characterizing the quality of TIE-OHF products.

4 Understanding of the requirements

This section is in response to §3.3.1 of the Special Conditions of Tender. We present a summary of our understanding of the scientific work required (section 5.1), and of the work needed to meet each SoW task objective (section 5.2).

Our consortium involves partners having successful achievements in scientific and engineering dedicated frameworks and tools for the development of flux estimation methods, the calibration and validation of *in situ* and satellite sensors and data, the examination of the accuracy of flux estimates, the characterization of flux errors, the inter-comparison of fluxes derived from satellite, *in situ*, and NWP sources, and for the use of flux as forcing function for ocean and atmosphere simulations.

We fully understand and share ESA ambition to provide to the users, including a large scientific community, a long time series of global OHF updated and accurate components (surface winds, specific air and surface humidities, air temperature and SST, latent and sensible heat fluxes, radiative fluxes, OHF estimates). We think our consortium is best placed to develop a shared understanding of the requirements with ESA, and to sustain and expand in the future for user benefit.

4.1 Summary of understanding

Estimating global fluxes poses formidable challenges. It is therefore not surprising that most of the flux data sets available today suffer from systematic biases and fail to satisfy energy constraints. At the same time, this supports the case for major research efforts to address this key issue. ESA's overall requirements for the Ocean Heat Flux contract is to make available long term time series of the accurate and properly validated OHF components estimated from remotely sensed data maximizing the use of ESA EO data. This supports the new CLIVAR research focus (http://www.clivar.org/science/clivar-research-foci#six) and ts main objective to better understand the role of the ocean energy uptake by analyzing consistency of heat budget components as seen by independent global observing systems, including (i) "Earth Observation" (EO) satellite data, (ii) in-situ measurements of ocean heat content storage changes, and (iii) Ocean reanalysis for heat transports and exchanges.

The project results will address the development of new methods for estimation of surface turbulent fluxes and their adaptation to the satellite-based state variables, determination and characterization of all sources of associated errors, generation of bulk variable and turbulent flux reference dataset, extensive inter-comparison and validation of the developed flux product with the major recognized alternative surface flux products derived from in-situ observations, satellite measurements, NWP (reanalyses), and synthesis of different flux sources using blending approaches. The further application of the results will be an assessment of the regional heat balances and quantification of the constraints based on the use of altimetry and/or Argo data. The project includes the technical objective aiming at providing data producers and users community with an open access, flexible and reusable tool to easy access and use data towards further inter-comparisons, accuracy assessment, or model simulation studies.

Figure 4.1 summarizes the project flow, which is required to meet TIE-OHF project requirements, as provided in SOW. In our understanding, the required data should be first developed from satellite remotely sensed data, in particular from the ESA missions and projects such as CCI. However, in-situ data from moored buoys, scientific experiments, or from VOS are required to assess the quality of bulk surface parameters derived from EO sources, as well as of the estimated fluxes. In-situ data are also of great interest for the analysis of the accuracy and skills of different flux parameterizations, related algorithms, and approaches for the development of gridded products. To meet one of the main OHF requirements, namely generation of the reference data set, the surface parameters should be first gathered and homogenized to similar space and time resolutions and transformed into unified data format (netcdf). These parameters include (but are not limited to) surface wind, air and sea humidities, air and sea temperatures, latent and sensible heat fluxes available for at least 10 year period from various sources and platforms including EO, in-situ, NWP, and from L3 and L4 satellite products. The resulting data set should be made available to scientific community on OHF dedicated portal in order to facilitate the community's activities in generation and evaluation of turbulent heat fluxes at various spatial and temporal scales. In the next instance, further significant improvements of the reference data set will be undertaken in the TIE-OHF project. The latter project aims to make available new input data and algorithms to improve turbulent fluxes. The new input data will be estimated from remotely sensed data and especially from ESA EO sources. To overcome the sampling limitations, we will first quantify sampling uncertainties and then minimize them by combining ESA EO data with contemporary satellite data. The former data should be first inter-calibrated to assess their consistency. The retrievals will be combined to form consistent long time series (at least two year long) of the required surface parameters. Their accuracies will be determined through the comprehensive comparisons with high quality in-situ data, particularly derived from OceanSites and flux dedicated experiments. The reference data set will be used to perform the comparisons between available satellite, ship, NWP, and blended turbulent flux products and, thus, provide comprehensive assessment of the developed data set. The inter-comparisons should be performed against the atmospheric (Surface wind speed, specific air humidity, stratification) and oceanic (sea surface temperature, sea state) parameters. Based on the use of bulk reference dataset, sensible and latent heat fluxes should be estimated over satellite swaths using the most advanced bulk parameterization COARE-4.0 (Fairall *et al*, 2011). To perform comparisons with available satellite, ship, NWP, or blended flux products, an objective methods, including techniques of co-location and estimation of scaling ratios, will be adapted in the project in order to provide the best possible global daily and monthly gridded turbulent fluxes.

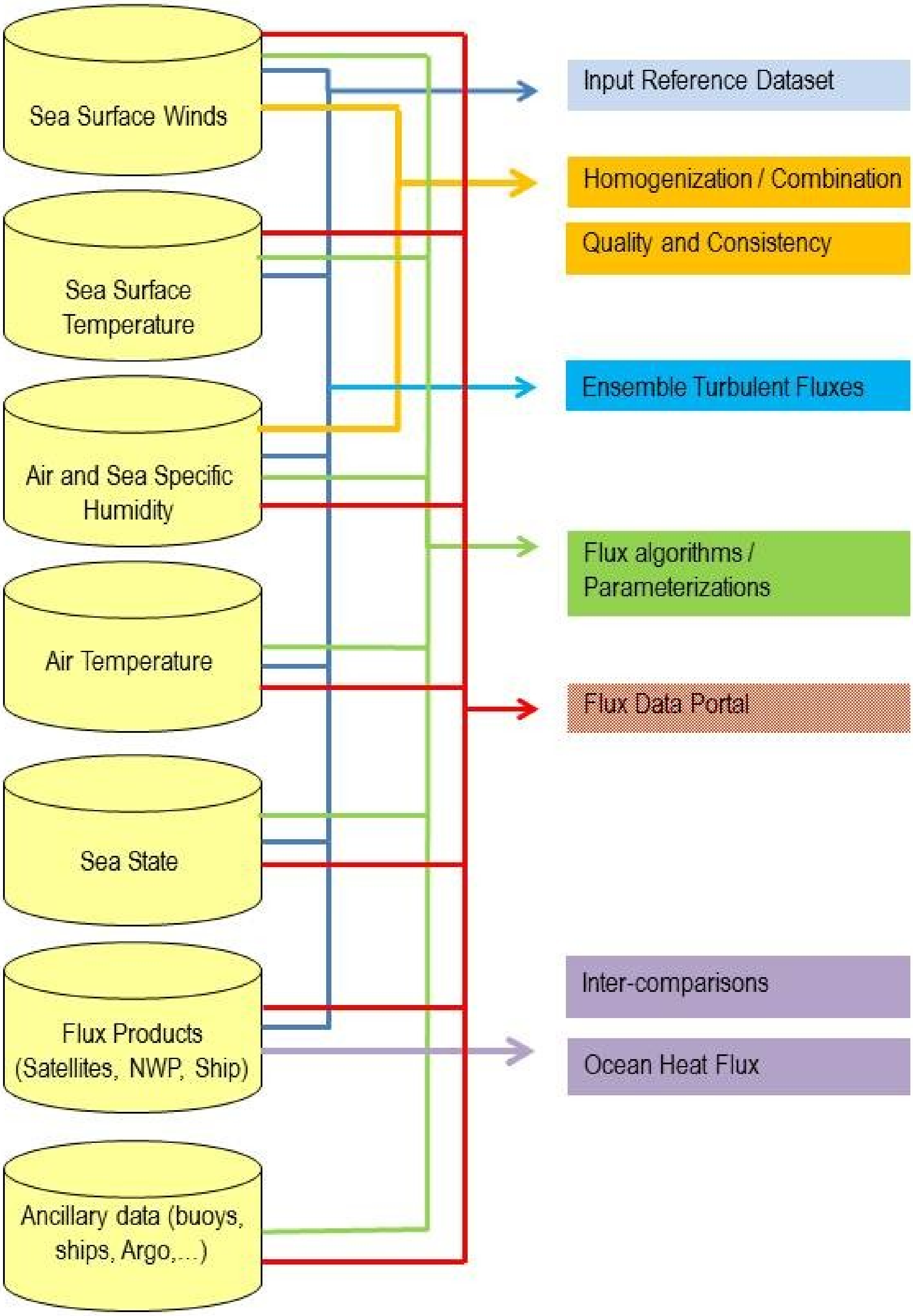

Figure 4.1 : Main data and task flow

4.2 Understanding of proposal tasks

We have reviewed the technical and functional requirements contained in the statement of work and present a general overview of our understanding of them.

Task 1: Scientific Requirements

The deliverable for Task 1 is a document describing the project in detail and providing the rationale for the data, methods and algorithms to be used and the products that will be delivered. The rationale will be based on scientific and user requirements and will focus on the quantification of complete estimates of data uncertainty.

Task 2: Reference Data Set Generation

The main objective of this task is to gather EO, especially those from ESA missions, *in situ* as well as L3 and L4 satellite turbulent and radiative fluxes to setting up reference data set. The latter should be available for scientific community, on dedicated portal, as common input data dealing with the generation and evaluation of ocean heat fluxes and its components.

The consortium has experience with most of data sources mentioned in the SoW for calibration, validation, analyses, and simulations. Most of these data are already available to the project, although with varying spatial and temporal resolutions and formats. Furthermore, they were estimated based on the use of different bulk variable inputs, parameterizations, and analysis methods. The main work that should be performed within this task:

- Collecting and archiving EO (especially from ESA sources) and non EO data as well as satellite L3 and L4 and NWP flux products available during common period of at least 10 years.
- Assessment of the data quality. It will be determined through comprehensive comparisons with *in situ* flux data
- Homogenization of the spatial and temporal resolutions among the selected products.
- Determination of product differences at various spatial and temporal scales, and according to atmospheric and oceanic parameters of interest.
- Making the reference data set available through the dedicated portal.
- Checking for consistency of the ensemble based on the assessment of the heat budget closure for different regions ("cage" approach).

- Process studies to validate ad hoc space time variations (e.g. El Nino Southern Oscillation, North Atlantic Oscillation patterns, etc) which can be observed with Argo and reanalyses OHC by using statistical signal analyses (e.g. lagged correlation of the surface fluxes and SST in mid latitudes, etc).
- Process validation of global OHF products by a multi-parameter approach including Argo and ocean reanalyses OHC to achieve quality improvement of the global OHF product. This methodology allows identification of regions with large discrepancies and uncertainties, thus allowing improvements through regional process studies.

Task 3: Product generation, Inter-comparison and Uncertainty Characterisation

This main requirement associated with this task is development and testing new data and algorithms. Several available flux products used non updated version of bulk variables and/or bulk parameterization. For instance, a number of variables such SST are now available with finer resolutions and better accuracy from ESA CCI.

Our work plan aiming to meet the requirement is as follows:

- Reprocessing of satellite sources to include the best available delayed mode datasets
    - Use of different SST data (including ESA CCI)
    - Use of different SSM/I input data
    - Use of improved retrieval methods for wind speed and humidity as well as improved flux parameterizations
- Generation of an ensemble of realizations through “smart perturbations” (e.g. based on reprocessing to above point).
- Evaluation of data sets using comparative assessments with alternative flux data sources and estimation of all sources of errors and uncertainties inherent in the generated data set, discrimination of error types and sources,
- Checking for consistency of the generated ensemble based on the assessment of the heat budget closure for different regions ("cage" approach), process studies (El Nino, lagged correlation of the surface fluxes and SST in mid latitudes, etc).

- Examine the sensitivity of estimated fluxes and the oceanic heat budget to changes in the optical properties of the water, using ocean-colour data and a light transmission model, combined with a General Ocean Turbulence model.

Task 4: Data Portal development

The portal development intends to meet existing needs in the user community for the validation and cross comparisons of various heat flux products versus reference data. Therefore, the portal should provide easy access and use of flux products, including collocated data, generated within this project, documentations (technical and scientific reports, newsletter, references to related scientific papers), links to relevant web sites (e.g. ESA, Eumetsat (SAF), NOAA, ECMWF, NCEP, NDBC, PMEL, SeaFlux, IFREMER, CLIVAR, GEWEX, WCRP, GSOP, ICOADS). The portal should also provide users reading, display, and basic statistics facilities. Similar portals such as GODIVA and OceanFlux, both developed for ESA CCI projects, are available and would be useful for OHF portal development.

Task 5: Strategic Development

This task aims to identify the most relevant methods and ways for fostering further developments of OHF products and their transition for potential operational use.

Task 6: Outreach & Coordination

The main purposes are the promotional of the resulting flux products and of the scientific and technical results, and the coordination with scientific user communities including CLIVAR, WCRP, GSOP, and SeaFlux groups. Newsletters and brochures will support the promotional of TIE-OHF project. Communities will be informed thanks a mailing list maintained and enhanced by the consortium.

5 Detailed description of the Proposal

The main focus of the proposal is on the detailed assessment of current latent and sensible heat flux estimates from satellite data and the generation of improved estimates of these parameters. A second focus of the proposal is the examination of the OHF by regional consistency checks using the improved turbulent flux data along with additional data sets. The proposal objectives constitute a very ambitious project, but are doable. Most of the work is well advanced, and thus new efforts will be in the category of enhancements and integration of previous efforts, which have relied on shorter and/or incomplete spatially or temporally sub-sampled data.

The overall objectives of this proposal are:

- the rigorous assessment of current ocean surface latent and sensible flux estimates from satellite data and associated environmental parameters.
- the results of the assessment will be used to derive a data set of improved air-sea flux flux estimates from satellite data
- to put the heat flux estimates in the context of the overall ocean heat flux (OHF)
- To contribute to the final consensus air-sea flux product acceptable to the community (work with CLIVAR Atlantic, GEWEX SRB, SEAFLUX and others.)

To meet the main project requirements, the present proposal aims to contribute to evaluating various estimates of surface parameters important to investigate the air and sea interactions at various spatial and temporal scales and to determine accurate estimation of ocean heat flux. The specific objectives emphasize the assessment of the quality of numerical weather prediction (NWP) reanalyzes dealing with climate studies, and of the available earth observations (EO) satellite data (retrievals) and their use to improve the determination of turbulent and radiative fluxes evaporation over the global ocean, with a focus on some specific oceanic basins such as the Mediterranean sea, North Atlantic, the Pacific Warm pool, and the inter-tropical zones.

This project will fully utilize data derived from scatterometers onboard ERS-1/2, ADEOS-1, QuikScat, ADEOS-2, Metop A and B, and OceanSat2, and from radiometers on board DMSP F10 through 17, and WindSat onboard Coriolis satellite. The results (Bentamy *et al*, 2008; 2009; 2012; Grodsky *et al*, 2010) assessing the consistency between C-band (ERS-1/2 and ASCAT) and Ku-band (Seawinds and OceanSat2) retrievals will be adapted. Global scatterometer surface wind retrievals that are now improved in the presence of rain can also be accommodated (e.g., Stiles and Dunbar 2010). More accurate estimates of wind stress by accounting for surface current can also be addressed using the current analyses being developed in the ongoing GlobCurrent project (given that GlobCurrent is expected to begin a reanalysis of the years prior to 2012 during 2015). The newly reprocessed SSM/I brightness temperature records (Berg, 2012; Fennig, 2013; Wentz, 2013) will be utilized for surface wind speed and air specific humidity estimations. Recently, SST data sets based on the Along-Track Scanning Radiometers (ATSRs) have been released from the ESA SST CCI. The available satellite data will be collected along with available *in situ* measurements. A large number of moored buoys will be used. They are located off the French and England coasts and 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. Furthermore, DWD and GEOMAR have developed a framework ("KollSat") to collocate ship and buoy measurements with satellite observations. The carefully quality controlled data from the DWD Marine Meteorological Service (Seewetteramt) and ICOADS (Woodruf *et al*., 2011).

The project will perform consistency studies of surface parameters retrieved from several satellites. The resulting consistent satellite data will be used to characterize the regional spatial and temporal patterns of each bulk variable and of the associated fluxes. Two NWP reanalyzes are of interest for the project: The European Centre for Medium Weather Forecasts (ECMWF) model ERA-Interim, and the National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR). Both provide the main requested parameters with their own specific space and time resolutions. The proposal aims to assess the comparisons between satellite-based and reanalysis-derived bulk variables and turbulent and radiative fluxes over the Global Ocean. The differences between the two types of flux estimates will be investigated at regional as well as at local scales, and with respect to atmospheric and oceanic conditions. In addition to these comparisons, an investigation of the heat flux spatial and temporal variability will be performed. The main objective of these assessments is to estimate error functions characterizing the differences between various satellites and reanalyzes. To enhance the space and especially the time resolutions of the parameter fields, the blending scheme creating daily fields with a space resolution of 0.25° from satellite and atmospheric re-analysis data will be performed as a component of this proposal. Calculations will involve the space and time structure function determined from remotely sensed data, and the error functions.

More specifically, the main expected results of this proposal are the enhancement of off-line requested satellite-based surface variable processing, the improvement of the resolution and the quality of the surface parameters involved in air sea interactions and requested for ocean heat flux determination over the global ocean, the characterization of the spatial and temporal errors of basic variables as well as of turbulent fluxes, calculation of long time series of global gridded fields of bulk variables and turbulent fluxes, assessment of the comparisons between the resulting flux fields and available satellite and NWP products, refinement of the operational component. For the purposes of this proposal "processing" is interpreted broadly to include all aspects of dataset development that do or do not require research, i.e. those we would be able to start immediately if resources are available, and including: data reclamation, dataset homogenization, improving dataset accessibility, and improving metadata availability.

The specific objectives and the methods that will be developed to achieve the objectives are described bellow accordingly to SoW tasks.

5.1 Task 1: Scientific Requirements Consolidation

Deliverable:

D1.1: Requirement Baseline Document: This document shall provide the user with a complete description of the suite of products delivered to meet the specific needs of the scientific community, their input data, meta-data, error statistics, validation protocol, strengths and weaknesses, and briefly describes the selected algorithms (e.g. Algorithm Theoretical Basis), methodologies (e.g. generation of ensemble perturbation), and workflows as well as the data portal to deliver and share them. As such this document shall constitute the backbone for activities in the following tasks.

WP	Who
Write Requirement Baseline Document	IFREMER, DWD, NERSC, PML, UR, UT,

Detailed Description of WP:

• Compiling the Requirement Baseline document shall provide the consortium with an opportunity to focus and justify its overall requirements early in the project. An example of the elected requirements (TBC with ESA following kickoff) that may satisfy users' needs is given in Table 4:

ID	*Type*	Requirement Description	*Trace/ Source*	*Valida-tion*
[PEΘ–10]	System	The V1 prototype system ***shall***: ι. Develop and implement algorithms and approaches to derivation of OHF measurements from EO data ιι. Develop and implement data merging strategies and methods ιιι. Produce new error and uncertainty estimations for OHF measurements ιϖ. Develop and implement a data management system ϖ. Develop and implement a data delivery system for users ϖι. Implement version control for all aspects of the system ϖιι. Produce new OHF products ϖιιι. Support Cage Studies ιξ. Provide metrics and other information describing the quality and availability of each product ξ. Produce a preliminary output data set addressing Requirements.	SoW	INSP
[PEΘ–20]	System	The V2 prototype system ***shall***: i. Develop and implement algorithms and approaches to derivation of	SoW	INSP

		OHF measurements from EO data ii. Develop and implement data merging strategies and methods iii. Produce new error and uncertainty estimations for OHF measurements iv. Develop and implement a data management system v. Develop and implement a data delivery system for users vi. Implement version control for all aspects of the system vii. Produce new OHF products viii. Support Cage Studies ix. Provide metrics and other information describing the quality and availability of each product x. Produce a 20-year output data set addressing Requirements.		
[PEΘ–30]	System	*OHF* software and systems ***shall*** be maintained under configuration control.	SoW	INSP
[PEΘ–40]	System	*OHF* ***shall*** provide a data management system for all data products within the project.	SoW	TEST
[PEΘ–50]	System	*OHF* ***shall*** provide tools for extracting time series of products over a given geographical location, as well as statistics of match-ups with in-situ and other (*e.g.,* model output) data held by *OHF*. Other tools ***shall*** be defined and implemented based on user requirements as required.	SoW	INSP
[PEΘ–60]	System	*OHF* ***shall*** provide a capability to re-process all data within the system using a consistent set of algorithms. *Note: the emphasis of this requirement is to produce a final data set at the end of the project.*	SoW	TEST

[PEΘ–70]	System	The primary mechanism for product delivery to users ***shall*** be ftp/sftp.	SoW	TEST
[PEΘ–80]	System	The secondary mechanism for product delivery to users ***shall*** be OpenDAP.	SoW	TEST
[PEΘ–90]	System	The project ***shall*** develop, operate and maintain a central web portal that ***shall*** provide a single entry point to all aspects of the project. The aim of the web portal is to provide users with a resource to make full and easy use of the *OHF* data products and services facilitating their application. An example of a typical web portal can be found at http://www.storm-surge.info The web Portal ***shall*** conform to the following specification: • Be operated in a robust manner with an availability[1] of >95%. • All data and information accessible via the portal ***shall*** by default be provided publicly and without restriction. • All sources of data and information products ***shall*** be fully acknowledged. • Contain introductory information about the project, including background, objectives, work plan and schedule, latest project news and news archive, dates/venues/presentations of all open meetings, list of OHF team. • Provide relevant links to related activities. • A reference bibliography of relevant scientific papers and reports. • Description and links to processing and sources of data used	SoW	INSP

1

		in the project. • An interactive geographical interface to visualise data products. • Web-accessible tools to manipulate and work with *OHF* data. • FTP access to all products. • Access to all public project documentation. • A password protected *OHF* project section containing project internal documentation, such as all draft document deliverables, monthly reports, etc. • Any other service or function required to implement the *OHF* project.		
[PEΘ–100]	AOI	*OHF* ***shall*** provide regional cage products for specific areas of interest. Regional AOI ***shall*** be chosen to maximise the user interest in *OHF* activities.	SoW	INSP
[PEΘ–110]	AOI	*OHF* ***shall*** provide global coverage products.	SoW	INSP
[PEΘ–120]	Visualisation	*OHF* ***shall*** provide maps of input parameters for all products suitable for use on the web portal and for download by users *Note: Versions of these maps may also provide a data product quick-look capability*	SoW	INSP
[PEΘ–130]	Product	All products ***shall*** be provided in NetCDF v4 format, be fully self-describing and complaint with Climate Forecast (CF) metadata (see http://cf-pcmdi.llnl.gov). *Note: Sufficient metadata **shall** be provided to allow a reasonable number (TBC) of freely available netCDF readers to read and display the data with no ad-*	SoW	TEST

		ditional tools.		
[PEΘ–140]	Product	All products ***shall*** include ancillary data as "dynamic flags" (based on auxiliary data) to interpret the quality of OSC data as required by users to interpret and apply the product.	SoW	INSP
[PEΘ–150]	Product	L4 products ***shall*** be built from L2 products.	SoW	INSP
[PEΘ–160]	Product	L4 products ***shall*** include uncertainty estimates for every grid-point in the data file. Uncertainty estimates ***shall*** include those from the data and those from the analysis system.	SoW	INSP
[PEΘ–170]	Product	L4 products ***shall*** be produced for a period of at least 10 years using archive data.	SoW	INSP
[PEΘ–180]	Product	*OHF* products ***shall*** provide as separate variables, significant components of the flux field (i.e., radiative fluxes) when appropriate.	SoW	INSP
[PEΘ–190]	Product	All *OHF* products ***shall*** include precise geo-location information.	SoW	INSP
[PEΘ–200]	Products	All products ***shall*** be freely and openly available to the user community without restriction.	SoW	TEST
[PEΘ–210]	Document	The *OHF* project ***shall*** develop and maintain tailored versions of EO product handbooks along the line of the Climate Data Guide [URL-08] (Schneider et al., 2013). Product handbooks ***shall*** include: (ι) Glossary of terms, a table of acronyms (ιι) Introduction and summary of	SoW	INSP

		product use in typical user applications (ιιι) Relevant background material describing the product, (ιϖ) Description of the precise algorithms applied to generate the product with links to other reference material, (ϖ) A description of the Processing Model that explains how data were processed end-to-end for each product. (ϖι) Relevant scientific and engineering journal paper and report references, (ϖιι) Any other material required by beginner users to successfully understand, read and apply the product.		
[PEΘ–220]	Document	All project documents ***shall*** be available to the users via the Web Portal.	SoW	INSP
[PEΘ–230]	Document	Apart from project management reports to ESA, all documents ***shall*** accessible to the user community in an open and transparent manner.	SoW	INSP
[PEΘ–240]	Data	The project ***shall*** use SST data.	SoW	INSP
[PEΘ–250]	Data	The project ***shall*** use SSH data.	SoW	INSP
[PEΘ–260]	Data	The project ***shall*** use ocean colour data.	SoW	INSP
[PEΘ–270]	Data	The project ***shall*** use sea-state data.	SoW	INSP
[PEΘ–280]	Data	The project ***shall*** use ocean current data.	SoW	INSP
[PEΘ–290]	Data	The project ***shall*** use wind stress data.	SoW	INSP

[PEΘ–300]	Data	The project ***shall*** use geoid data.	SoW	INSP
[PEΘ–310]	Data	The project ***shall*** make full use of other relevant satellite and *in situ* data as required to fulfil the aim and objectives of the project.	SoW	INSP
[PEΘ–320]	Data	A database of in-situ OHF validation data ***shall*** be collected, from a validation sites that cover different ocean regimes and sample different seasons.	SoW	INSP
[PEΘ–330]	Validation	The *OHF* system ***shall*** include a database of near contemporaneous *in situ* data for validation purposes including: • *In situ* OHF measurements • Satellite measurements • Any other data required by validation	SoW	INSP

Table 4: Preliminary set of baseline requirements for TIE-OHF

5.2 Task 2: Reference Data Set Generation

Deliverable:

D2.1: Reference Data Set: This data set shall provide the user with an integrated data set to generate and evaluate ocean heat flux products, and perform sensitivity to algorithms and assess product quality. As such, this data shall provide the backbone of all data related tasks.

The consortium presenters are used to use most of data sources mentioned in SOW for calibration, validation, analyses, and simulations purposes. Most of these sets outlined in SOW are already available to the project. However, there are available with different spatial and temporal resolutions and format. Furthermore, they were estimated based on the use of different bulk variable inputs, parameterizations, and analysis methods. The main work that should be performed within this task:

WP	Who
• Gathering and archiving EO (especially from ESA sources) and non EO data as well as satellite L3 and L4 and NWP flux products available during common period of at least 10 years. • Homogenize data to common (NetCDF) data format, resolution etc	DWD, IFREMER, NERSC, UR, PML
• Generate regional heat constraints for the cage study. Requires additional radiation data (CM SAF, GEWEX, Univ. of Maryland).	IFREMER, DWD, UT, UR, DMUM
• Make data available to project members through (preliminary) portal	IFREMER, UR
• Checking for consistency of the generated ensemble based on the assessment of the heat budget closure for different regions ("cage" approach). • Process studies to validate ad hoc space time variations (e.g. El Nino Southern Oscillation, North Atlantic Oscillation patterns, Hurricanes, etc.) which can be observed with Argo and reanalyses OHC by using statistical signal analyses (e.g. lagged correlation of the surface fluxes and SST in mid latitudes, etc)	MIO, UR

Detailed Description of WPs:

The main objective of this WP is the generation of reference data. To meet WP requirement, we will collect all needed basic variables (surface winds, air and sea surface temperatures, specific humidity, surface pressure, rain, sea state, current, sea surface salinity) derived from scatterometers, radiometers, and altimeters onboard satellites, moored buoys (NDBC, MFUK, TAO, PIRATA, RAMA), selected sites (e.g. OceanSites), in-situ (ICOADS/NOCS2), and from ESA Climate Change Initiative (CCI) projects, and from NWP re-analyses. Figure 5.1 shows the main sources of remotely sensed data expected to be used in this proposal. Further information relied on satellite sources, archives, product levels, swath characteristics, and cell spatial resolutions are provided in Table 5.1.

Most surface parameters will be derived from available L2b products. However, for consistency and reprocessing purposes, L2a will be utilized. The bulk variables such surface winds and air humidity, derived from satellite products, will be used, in combination with ancillary data from ESA CCI, NOAA analyses, and from NWP re-analyses, for the calculations of turbulent fluxes. Table 5.2 summarizes the characteristics of the required bulk variables. All are already available for TIE-OHF partners.

Satellite L2a and L2b will be used as observations of surface parameters required for the calculation of turbulent fluxes over satellite swaths. However, further input data from satellite products of level L2a and/or L2b are provided. L3 and/or L4 products such SST and sea state, including those derived from CCI projects, are not shown. The latter will be used without further reprocessing.

Table 5.1 : Summary of remotely sensed data attributes.

	Agency	Archive	Product	Time span	Swath	Resolution (Swath cell)
ERS-1	ESA / IFREMER	IFREMER	L2a and L2b	Aug91-May96	1×500km	50km
ERS-2	ESA / IFREMER	IFREMER	L2a and L2b	Apr 96 – Jan 01	1×500km	50km / 25km
QuikSCAT	NASA/JPL	IFREMER	L2b	Jul 99 – Nov 09	1800km	25km / 12.5km
ASCAT	EUMETSAT / KNMI	IFREMER	L2b	Dec 06 - Present	2×550km	25km / 12.5km
OceanSat2	ISRO	IFREMER	L2b	Dec 09 – Feb 14	1800km	25km / 12.5km
WindSat	NAVY / RSS	IFREMER		Feb 03 - Present		25km
SSM/I (F10 – F18)	EUMETSAT CM SAF / Univ. Colarado	IFREMER	L2a	Dec 90 - Present	1400km	25km
AMSR-E	JAXA / NASA	IFREMER	L2a	June 02 - Present	1445km	25km

The reference data are summarized in Table 5.3 of the proposal. To provide the user with an integrated data set for the further generation and evaluation of ocean heat content products, data will be made available at daily temporal resolution. For each day of the period 1992 – 2011, atmospheric surface state variables (wind speed, specific air humidity) derived from satellite measurements (L2b), atmospheric and oceanic data from in-situ (moored buoy measurements and ship analyses), and daily averaged products (SST, air temperature, Wind Stress, Latent Heat Flux, Sensible heat flux from producers such as ESA, IFREMER, OAFlux, SeaFlux, HOAPS, NWP) falling within a grid cell of 1°×1° around the analyzed location will be collocated. Data will be provided in NetCDF/CF files. Table 5.2 hereafter provides further details of TIE-OHF reference data that will be made available for the scientific community dealing with the evaluation and validation of turbulent fluxes.

Table 5.2 : Reference data. They include bulk variables and turbulent fluxes. Data will be provided at daily basis

	EO	Buoy	Ship (NOCS2)	NWP (e.g. ERA Interim)	Flux Products (L3 or L4 products)				ESA CCI / NOAA	ISCCP / UM/ CM SAF
					IFREMER	OAFLUX	SeaFlux	HOAPS		
Spatial Res.	0.25°/ 0.50°	MC	1°	0.70°	0.25°	1°	0.25°	0.50°	0.05° / 0.25°	0.25° / 1°
Wind Speed										
Zonal and Meridional Wind										
Specific Air Humidity										
SST										
Air Temperature										
Sea State										
Surface Current										
Sea surface salinity										
Short Wave Long Wave										
Wind Stress										
Latent Heat										
Sensible Heat										

Table 5.3 : Characteristics of inputs and resulting TI-OHF products

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
Delivered products																
Sensible	DP1	SH	25 km	Daily	1992 - 2011	19 yrs	Global	error bar	30W/m²	Scatteromters and radiometers	ERS1/2; QSCAT; ASCAT-A/B; OceanSat; HY-2; SSM/I F10 - 18, AMSR-E	EO (merged)	L3 and L4	IFREMER	Netcdf 4	Will be reprocessed from IP4, introducing new …
Latent	DP2	LH	25 km	Daily	1992 - 2011	19 yrs	Global	none	10W/m²	Scatterometers and radiometers	SCAT; ASCAT-A/B; OceanSat; HY-2; SSM/I F10 - 18, AMSR-E	EO (merged)	L3 and L4	IFREMER	Netcdf 4	Recomputed by combining IP1, IP2
Radiative SW	DP3	SW	25 km	Daily	1999 - 2011	19 yrs	Global	error bar	30W/m²	Modis, MSG; SSM/I	Aqua; MSG; ADEOS	EO (merged)	L3 and L4	SAF Clim; Univ. Maryland	Netcdf 4	Availble
Radiative LW	DP4	LW	25 km	Daily	1999 - 2011	19 yrs	Global	covariance matrix	30W/m²	Modis; MSG; SSM/I	Aqua; MSG; ADEOS		L3 and L4	SAF Clim; Univ. Maryland	Netcdf 4	
EO Input Products																

Wind stress	IP1	wind speed	50 km / 25km / 12.5 km	Orbits	Mar 1992 - Feb 2011	20 yrs	80S-80N		1m/s - 2m/s	Scatterometers	ERS1/2; QSCAT; ASCAT-A/B	EO (merged)	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 ; AMSR-E onboard Aqua; ADEOS-2; Metop		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 State	IP6	Ocean State	7km - 25km	Orbits/ Daily	Mar 1992 - Feb 2011	20 yrs	80S - 80N		0.50m	ESA CCI / Altimters	ESA CCI (GlobWave); ERS-1/2; TP; Envisat; Jason-1/2	EO (merged)	L2 and L3	ESA; IFREMER	Netcdf 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
Inter-comparison products (Satellite Products)																
IFREMER data set	SP1	Wind; Hum; SST; Air Temp; LHF; SHF	25km	Daily	Oct 1999 - Nov 2009	10 yrs	80S - 80N						L3 and L4	Netcdf 3		
HOAPS data set	SP2	Wind; Hum; SST; Air Temp; LHF; SHF; LW;	100km	Daily	Jan 1988 - Dec 2007	20 yrs	80S - 80N						L3	Netcdf 3		

		SW; RR														
SeaFlux data set	SP3	Wind; Hum; Air Temp.; LHF; SHF	25km	Daily	Jan 1992 - Dec 2007	15 yrs	80S - 80N						L3 and L4	Netcdf 3		
J-OFURO data set	SP4	Wind; Hum; SST; Air Temp; LHF; SHF; LW; SW;	100K km	Daily	Jan 1988 - Dec 2007	20 yrs	80S - 80N						L3 and L4	Netcdf 3		
In-Situ data (Validation/ Quality Process)																
Surface Winds	IN1	wind speed and directi on	Local / 1°	Hourly/ Daily	Mar 1992 - Feb 2011	20 yrs	Regional buoy networks / Global VOS		1m/s - 2m/s	Moored buoys / VOS	MFUK, NDBC, TAO, PIRATA, RAMA buoys ICOADS / NOCS		Hourly / Daily	Meteo-France/UKMet Office/NOAA/IRD/INPE/NOCS /(Archive at Ifremer)	Netcdf	
Humidity	IN2	air humidi ty	Local / 1°	Hourly/ Daily	Mar 1992 - Feb	20 yrs	Regional buoy networks		0.10 - 1g/kg	Moored buoys / VOS	MFUK, TAO, PIRATA,		Hourly / Daily	Meteo-France/UKMet Office/NOAA/I	Netcdf	

					2011		/ Global VOS				RAMA buoys ICOADS / NOCS			RD/INPE/NOCS /(Archive at Ifremer)		
Sea Surface Temperature	IN3	SST	Local / 1°	Hourly/ Daily	Mar 1992 - Feb 2011	20 yrs	Regional buoy networks / Global VOS		0.10°- 0.50°	Moored buoys / VOS	MFUK, NDBC, TAO, PIRATA, RAMA buoys ICOADS / NOCS		Hourly / Daily	Meteo-France/UKMet Office/NOAA/IRD/INPE/NOCS /(Archive at Ifremer)	Netcdf	
Air Temperature	IN4	Air. Temp.	Local / 1°	Hourly/ Daily	Mar 1992 - Feb 2011	20 yrs	Regional buoy networks / Global VOS		0.10° - 1°	Moored buoys / VOS	MFUK, NDBC, TAO, PIRATA, RAMA buoys ICOADS / NOCS		Hourly / Daily	Meteo-France/UKMet Office/NOAA/IRD/INPE/NOCS /(Archive at Ifremer)	Netcdf	
Pressure	IN5	Pressure	Local	Hourly	Mar 1992 - Feb 2011	20 yrs	Regional buoy networks			Moored buoys	MFUK, NDBC, TAO, PIRATA, RAMA buoys		Hourly	Meteo-France/UKMet Office/NOAA/IRD/INPE / (Archive at Ifremer)	Netcdf	
Sea Temperature	IN6	Temperature at depth (10-2000 m)	0.50°	Monthly	2005 - 2012	8yrs	60°N – 60°S	Error Bar / Covariance	0.005°C / ±5M for deptth	Argo profiling floats	Argo; Coriolis data center		Monthly	Argo; Coriolis data center	Netcdf	

Ocean State	IN7	Ocean State	Local	Local	Mar 1992 - Feb 2011	20 yrs	Regional buoy networks			Moored buoys	MFUK, NDBC, TAO, PIRATA, RAMA buoys		Hourly	Meteo-France/UKMet Office/NOAA/IRD/INPE / (Archive at Ifremer)	Netcdf	
Ocean Current	IN8	Ocean Current	Local	Local	Mar 1992 - Feb 2011	20 yrs	Regional buoy networks			Moored buoys	NDBC, TAO, PIRATA, RAMA buoys		Hourly	NOAA/IRD/INPE /(Archive at Ifremer)	Netcdf	

To assess the regional heat balances and quantification of the constraints based on the use of altimetry and/or Argo/reanalyses, two products will be used. Argo OHC will be evaluated using a re-qualified product from the Coriolis data center (http://www.coriolis.eu.org/) where Argo data have undergone a careful quality control that includes comparison of profiles from individual floats and optimal estimation of profiles using the entire Argo dataset (e.g. Gaillard et al., 2009; von Schuckmann et al., 2009). This product is freely available from the MyOcean catalogue. In addition, monthly gridded fields of temperature and salinity properties of the upper 2000 m over the period 2005–2012 (D2CA1S2 re-analysis) will be used. These fields were obtained by optimal analysis of the large in situ data set provided by the Argo array along with complementary measurements from drifting buoys, CTDs and moorings from the CORIOLIS data center (von Schuckmann et al., 2009). These data have undergone the same thorough quality control procedure as described above. In total, the Argo measurements account for more than 95% of data available for use in the optimal analysis since 2005. For OHC estimations from ocean reanalyses, the ERA GSOP reanalyses will be used, see for example Palmer et al (2014). The ensemble of OHF products allows signal and noise to be identified in the ensemble mean fluxes and in the variability at seasonal and interannual timescales, based on agreement between 15-20 different products. The reanalyses will also provide a second means of assessing the OHC budget through assessment of heat flux divergences. This methodology has been used previously for atmospheric reanalyses but is new for ocean reanalyses, but it will indicate on a regional basis, where advective heat flux transports are more reliable through agreement between different reanalysis products and therefore indicate where CAGE based estimates should be more reliable.

The principal idea is to generate a set of regional heat constraints to perform consistency tests of ocean heat products, covering at least three regions capturing different oceanic regimes/processes, including a semi-enclosed sea (e.g. Mediterranean Sea), the Pacific Warm Pool and a suitable open-ocean CAGE (which could be identified by ocean syntheses as above). The radiative components of the Net Heat Flux will be taken as given (along with its uncertainty) from existing data sets, as they are available from for example ISCCP.

More precisely, the analysis of regional heat budgets will be achieved

- by estimating the local heat storage and horizontal advection of heat based on a simultaneous re-analysis of ocean temperature and currents (Wang and Carton, 2002), based on data gathered through the CLIVAR GSOP intercomparison program (CLIVAR Exchanges 64).
- by comparison to the heat budget at fixed mooring sites available mainly in the tropics (e.g. Foltz et al., 2003), and
- by comparison with steric sea level estimates from satellite altimetry (e.g. von Schuckmann et al., 2014).

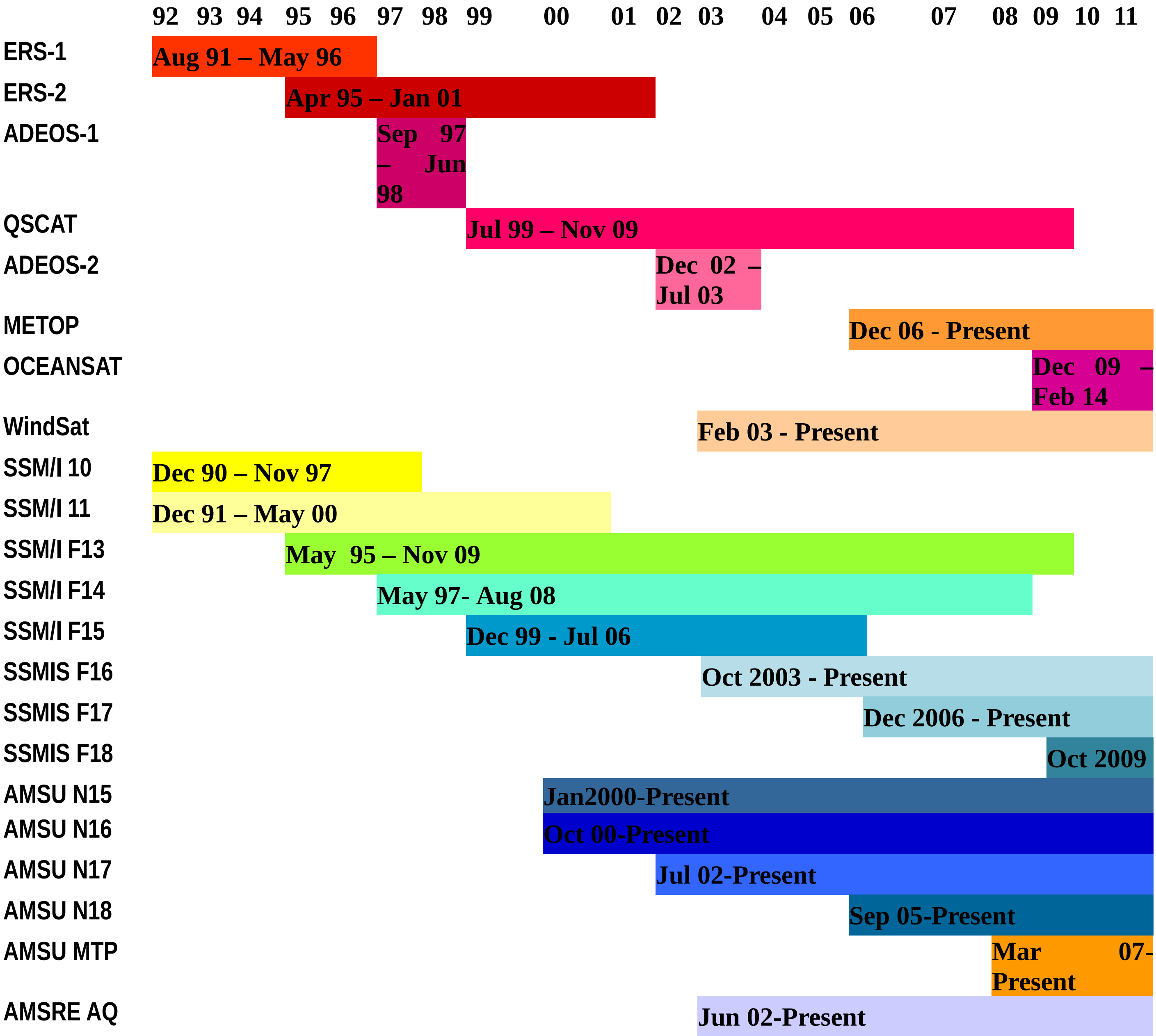

Figure 5.1: ESA and non European EO missions of interest for TIE-OHF project.

5.3 Task 3: Product generation, Inter-comparison and Uncertainty characterization

Deliverables:

D3.1: Flux Assessment Report: This document shall describe the results of the sensitivity study of the input data and algorithms, the output of the validation activities with in-situ and regional heat constraints and the outcome of the inter-comparison exercise.

D3.2: Product Handbook: This document shall include a comprehensive description of the products, and their strengths and weaknesses, along the line of the Climate Data Guide [URL-08] (Schneider et al., 2013).

D4.3: Flux Product Dataset: This data base shall include all the data used in the inter-comparison exercise and the related output ensemble products.

WP	Who
1. Sensitivity studies and algorithm improvement • Use different SST data (including ESA CCI) • Use different SSM/I input data • Impact of sea state on flux parameterization • Use improved retrieval methods for wind speed and humidity as well as improved flux parameterizations • Study sensitivity of flux calculations to optical properties of the sea, using ocean-colour data from ESA CCI	IFREMER, UR, DWD, WHOI, IORAS IFREMER, IORAS, WHOI, DWD. PML
2. Evaluation of data sets, Error characterization • Comparison against in-situ data • Characterize specific deficiencies in the algorithms to derive the geophysical parameters, particularly cross relations between the individual variables (e.g. SST dependent biases of near surface humidity)	DWD, IORAS, WHOI, DMUM, IFREMER
3. Ensemble generation	

• Generation of an ensemble of realizations through "smart perturbations" (e.g. based on reprocessing to above point).	DWD, IFREMER, IORAS, DMUM
4. Process validation of global OHF products by a multi-parameter approach including Argo and ocean reanalyses OHC to achieve quality improvement of the global OHF product. This methodology allows to identify regions of large discrepancies and uncertainties, therefore helps their improvement through regional process studies.	MIO, UR, NERSC

Description:

This WP is one the main crucial among the project WPs. Hereafter, the associated components (sub-tasks), provided in SoW document, are reported and the proposed work aiming to meet the requirements are summarized.

- *Develop and test new input data and algorithms, or combine strengths of existing ones, to improve quality of ocean turbulent heat flux products. The sensitivity tests shall focus on a short period of time (e.g. 2 years), being data rich and capturing processes of interest,*

Surface flux errors depend sensitively on the accuracy of surface wind, specific air humidity, sea surface temperature (SST), air temperature, and on the bulk parameterization. To meet the project requirements, momentum and heat fluxes will be estimated based on the use of newly reprocessed scatterometer and radiometer retrievals (e.g. Bentamy *et al*, 2012 and 2013, Fennig *et al*, 2013). Furthermore, new input data derived from ESA CCI such as SST and OC will also be tested for obtaining better flux estimates. The publications referenced in the proposal clearly stated that these new remotely sensed data are improved with respect to previous retrievals. The new flux parameterization COARE4.0 (Fairall *et al*, 2011) will be tested and the results will be compared to fluxes estimated from COARE3.0 (Fairall *et al*, 2003). The latter is utilized for the calculation of the recognized existing flux data sets. Comparisons will be performed according to the 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, midlatitude North Atlantic regions bounded by oceanic cross-sections, the Pacific Warm pool, and the inter-tropical zones.

- *Evaluate the quality and suitability of the new products, assess added-value compared to existing products, and describe the strengths and weaknesses of the different approaches,*

The quality of the new flux products will be determined first through comprehensive comparison with measured and/or buoy-estimated experimental sources. The main statistical parameters characterizing the differences between satellite and in-situ products will be calculated and analyzed. The former will also be investigated as a function of wind conditions, SST, air temperature, stability, current, and sea state. Similar statistical calculations will be performed for existing turbulent fluxes. The objective is to highlight the added-value of the new products compared to the existing ones. A specific sub-task here will be to derive estimates of sampling uncertainties as well as their impact on the representation of the statistical distribution of surface turbulent fluxes according to the guidelines of Gulev et al. (2007) and Gulev and Belyaev (2012).

- *Based on the recommended approach, generate an ensemble of realizations following the methodology defined in D1.1, which through smart perturbations should further sample the sensitivity and uncertainties of the different input parameters and algorithms. The ensemble product should address a longer time period (e.g. decade),*

The ensemble realization will be generated during the reprocessing of the newly updated input data such as SST data (including ESA CCI), SSM/I brightness temperature data, wind speed, and humidity retrievals. For instance the TIE-OHF project will investigate the assessment of the parameters with respect to their sensitivity regarding different microwave brightness temperature data records. For instance, the bulk variables derived from passive microwave data, wind speed and near surface humidity will be analyzed in order to reveal specific uncertainties with respect to the calibration of the brightness temperature input data. This is particularly important for the long term stability of the resulting data sets and hence for climate applications. The ensemble realizations will be first performed for the QuikSCAT period October 1999 through November 2009.

- *Perform a series of consistency checks of the ensemble by examining heat budget in different regions, including the semi-enclosed Med-Sea, the Pacific Warm Pool and one suitable open-ocean Cage. 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).*

The consistency of the reprocessed turbulent fluxes will be first investigated through the determination of error functions characterizing differences between satellite and NWP reanalyses: ERA-Interim and CFSR. The focus will be on some specific regions such as the North Atlantic, tropical areas, and the Mediterranean Sea. Examinations will include, but will not be limited to, the comparison between LHF and SHF versus available estimates from HOAPS, Ifremer, OAFlux, and SeaFlux. In particular, the difference analysis will be performed according to the variables that enter the bulk formulae for computing fluxes (wind speed, sea surface and air temperatures, specific air humidity). Also the comparative assessments will be performed to quantify the differences in the parameters that give realistic statistical distributions of surface fluxes.

As mentioned above (see Table 5.2 and Table 5.3), turbulent flux determinations require the knowledge of accurate surface wind speeds. In this project, the former will be mainly derived from scatterometer measurements. Previous studies (e.g. Quilfen et al, 2001; Kelly et al., 2001; Plagge et al., 2012) stated the dependency of scatterometer retrievals on the local sea state. Indeed, ocean waves have significant indirect effects via their influence on the atmospheric and oceanic boundary layers. In the atmospheric boundary layer the waves act as roughness elements, influencing the turbulent flow and the vertical wind speed profile, potentially modulating low-level baroclinicity. Below the water surface, the air-sea momentum flux mediated by the waves and wave-generated turbulence, initiates the mixing mechanisms and affects the vertical structure of ocean current, temperature, and salinity. The challenging issue here is associated with a better estimation of the kinetic energy balance of the surface ocean layer, in particular the fraction of energy available for local mixing and other ocean processes compared to the fraction propagating away as wave parcels and dissipating elsewhere. The impact of sea state on the accuracy of turbulent flux estimation will be investigated using the collocation of satellite and buoy estimates. The differences between buoy-based and satellite fluxes will be characterized as a function of significant wave height and current (when available) derived from moored buoys such as TAO, PIRATA, RAMA, in tropical areas, NDBC and MFUK in the North Atlantic and the North Pacific. Furthermore, the calculation of turbulent fluxes, based on the COARE4.0 flux algorithm, will be performed with and without sea state scheme (and thus, inputs dependent on sea state) providing ground for the further intercomparison and quantifying the role of sea state modulated fluxes. The latter will be handled using buoy data to characterize the impact of sea state as a function of geographical location and/or of wind and wave conditions.

An ad hoc but pragmatic way of measuring the current uncertainty of the satellite flux products is to including Ocean Heat Content (OHC) estimations as constraints. This idea of regional constraints as the concept of “Cages” (Bretherton et al., 1982) was already introduced decades ago in the context of the “World Ocean Circulation Experiment” (WOCE). The realization of this concept is now possible through the advent of new high quality measurements, in particular from the Argo profiling floats, delivering a view of OHC with an unprecedented coverage in space and time. By identifying some “suitable” regions (for example where changes in transport would either be relatively negligible, or can be directly derived from current measurement (mooring) arrays or other methods, e.g. from satellite altimetry or ocean reanalyses), the estimate of OHC anomalies should enable scientists to check the fidelity of the Net surface Heat Flux. Suitable regions could also be “pre-defined Cages”, where hydrographic transport is well known or measured (e.g. RAPID programme for ocean overturning circulation for the North Atlantic), “natural Cages” such as semi-enclosed seas, where outgoing transport of heat is known, or in a near surface “bubble” volumes such as the Western Pacific Warm Pool (Song & Yu, 2013).

- *Produce a product handbook describing the product, specifications and strengths and limits for specific applications*.

The TIE-OHF project will develop and maintain tailored versions of EO product handbooks along the lines of the Climate Data Guide [URL-08] (Schneider et al., 2013). They will include:

- Glossary of terms, a table of acronyms
- Introduction and summary of the product use in typical user applications
- Relevant background material describing the product,
- Description of the precise algorithms applied to generate the product with links to other reference material (metadata),
- A description of the Processing Model that explains how data were processed end-to-end for each product.

- Relevant scientific and engineering journal paper and report references,
- Any other material required by beginner users to successfully understand, read and apply the product.

Detailed Description of WPs:

More specifically, the work aiming to meet the WPs requirements will be performed following three main components as detailed hereafter.

5.3.2.1 Development, Generation and Quality assessment of OHF products

The tasks aim to perform an accurate evaluation of existing air-sea flux data sets as well as relevant input data sets for the period of 20 years (1992 – 2011). The evaluation will include comparisons with data from in-situ (buoys, ships, and scientific experiments), numerical atmospheric numerical model analyses and re-analyses, and other satellite products. The goal of these comparisons is the identification and quantification of different sources of uncertainty and structural errors in the flux estimates. These uncertainties may be caused e.g. by the:

- Assessment of the parameters with respect to their sensitivity regarding different microwave brightness temperature data records. Similar to the above task, the bulk variables derived from passive microwave data, wind speed and near surface humidity are analyzed in order to reveal specific uncertainties with respect to the calibration of the brightness temperature input data. This is particularly important for the long term stability of the resulting data sets and hence for climate applications. The result of this evaluation are important for the selection of the brightness temperature data sets for the reprocessing of the improved time series.

The rigorous assessment of the existing flux data sets and components allows to reveal potentials for improvements of the derived geophysical parameters.

Derive improved turbulent flux products based on the results of the previous evaluation through and optimal combination of existing products and newly developed algorithm and/or parameterizations. Fluxes will be calculated as L2 and L3 products. The estimation of L3 analyses will use a valuable objective method aiming to calculate regular in space and time flux fields over the global ocean with high spatial and temporal resolutions. The resulting data set will be extensively evaluated against in-situ data, yielding an uncertainty characterization of the data set.

- Generation of collocated data base aiming to investigate satellites/buoys, satellites/ships, satellites/satellites, satellites/NWP, and NWP/in-situ comparisons. The collocations procedures would consider the spatial and temporal patterns of each bulk variable (Table 5.3) (e.g. Covariances/correlation lengths).

- Assessment of the quality of surface parameters through comprehensive comparisons with available measurements from moored buoy and high quality in-situ data. This task aims to characterize the quality of remotely sensed and NWP. For each bulk variable the main statistics characterizing differences versus in-situ will be estimated globally and as a function of geographical location, sea surface temperature, sea state, current, and stratification. For instance, it expected to analysis the differences (satellite versus surface parameters) based on the calculation of conventional and linear statistical moments including the estimation and comparisons of probability density functions (pdf). Based on the derived statistics, an attempt will be performed to improve the quality of the remotely sensed surface parameters. Furthermore the bulk flux parameterizations itself may be improved, e.g. by considering the effect of sea state in the algorithm.

- Characterization of the resulting flux field error associated with the objective method used to calculate flux analyses. It will be performed using simulated data from numerical model interpolated onto satellite swaths. Daily fluxes will be calculated from simulated data. Difference between the resulting fields and daily averaged fields calculated from raw NWP data will be investigated to assess the error mainly relied on the sampling satellite schemes. The error results will be used to enhance the objective method.

- Assessment of the parameters with respect to their sensitivity regarding different microwave brightness temperature data records. Similar to the above task, the bulk variables derived from passive microwave data, wind speed and near surface humidity are analyzed in order to reveal specific uncertainties with respect to the calibration of the brightness temperature input data. This is particularly important for the long term stability of the resulting data sets and hence for climate applications. The results of this evaluation are important for the selection of the brightness temperature data sets for the reprocessing of the improved time series.

- Data from the global and regional reanalyzes will be directly used in the project activities. For example 17 global ocean reanalysis flux products and several atmospheric flux products have been gathered and compared as part of the recent GSOP ORA-IP program, http://www.clivar.org/sites/default/files/Exchanges/Exchanges_64.pdf see in particular the surface flux article. These data will be used for intercomparison and validation of satellite-based flux products developed under the project. A general approach for these intercomparisons will include comparing both, surface fluxes from ERA-Interim, NCEP-CFSR, MERRA and JRA reanalyses from the new generation products as well as re-computation of surface fluxes using reanalysis state variables. This will help to discriminate between the impact of parameterizations and of the state variables in the differences between the NWP products and satellite products. More advanced evaluation activities will include using reanalyses for estimation of sampling errors inherent in satellite data and VOS products (given that VOS will be also used for validation activities'). Finally, we will use also wind stress and wind wave products currently available from ERA-Interim for analyzing the effects associated with surface roughness in satellite-based products of kinetic energy fluxes

- Reprocessing of long time series of high space and time surface parameter resolutions. The satellite products will be available over the global ocean with a spatial resolution of 0.25° in longitude and latitude, and with two temporal resolutions: daily and monthly. They will be estimated for a period of 20 years (March 1992 – March 2011). This task includes inter-comparisons between various sources at global and regional scales, and development of methods to ensure data coherency and to determine the request quality control for data use. The results will be used for merging data and for objective analysis purposes. The calculation of gridded surface parameter will be performed based on the method previously used for daily ASCCAT and QuikSCAT wind fields (Bentamy *et al*, 2011).The resulting surface parameter field data will be considered as "reference data".

- Calculation of latent and sensible heat fluxes from reference input data and based on the use of bulk aerodynamic parameters. Following previous studies (e.g. Bentamy et al, 2013), COARE4.0 (Fairall *et al*, 2011) bulk parameterization (including possible improvements from above analysis) will be utilized. As for reference data, daily and monthly gridded will be calculated. The latter assume the determination of the spatial and temporal structure functions of LHF and SHF requested by the objective method.

- Characterization of the resulting flux field error associated with the objective method used to calculate flux analyses. It will be performed using simulated data from numerical model interpolated onto satellite swaths. Daily fluxes will be calculated from simulated data.

Difference between the resulting fields and daily averaged fields calculated from raw NWP data will be investigated to assess the error mainly relied on the sampling satellite schemes. The error results will be used to enhance the objective method.

- Validation of the derived satellite turbulent fluxes through comprehensive comparisons with daily and monthly buoy estimates. The expected results are the determination of LHF and SHF field accuracy as a function of some atmospheric and oceanic parameters: wind condition, SST, air temperature, and stability, current, and sea state.
- Determination of error function characterizing differences between satellite and NWP reanalyzes: ERA-Interim and CFSR. Focus on some specific regions such as western boundary current regions, tropical areas, and the Mediterranean Sea will be preformed.
- Examining the comparisons between LHF and SHF versus available estimated from HOAPS, Ifremer, OAFlux, and SeaFlux. In particular, the difference analysis will be performed according to the variables that enter the bulk formulae for computing fluxes (wind speed, sea surface and air temperatures, specific air humidity).

5.3.2.2 Heat budget examination

An ad hoc but pragmatic way of measuring the current uncertainty of the satellite flux products is to including Ocean Heat Content (OHC) estimations as constraints. According to the recommendations by the recent GSOP workshop in Woods Hole (Yu et al., 2012) this methodology complements the traditional local evaluation method (based on comparison with point-wise measurements) with a more regional approach using heat budget constraints in some suitable “reference” areas, either at the basin, regional or even global scale for flux calibration, validation and evaluation. The realization of this concept is now possible through the advent of new high quality measurements, in particular from the Argo profiling floats, delivering a view of OHC with an unprecedented coverage in space and time. As illustrated in Figure 5.2, by identifying some “suitable” regions (for example where changes in transport would either be relatively negligible, or can be directly derived from current measurement (mooring) arrays or other methods, e.g. from satellite altimetry or ocean reanalyses), the estimate of OHC anomalies should enable scientists to check the fidelity of the Net surface Heat Flux. Suitable regions could also be “pre-defined Cages”, where hydrographic transport is well known or measured (e.g. RAPID programme for ocean overturning circulation for the North Atlantic), “natural Cages” such as semi-enclosed seas, where outgoing transport of heat is known, or in a near surface "bubble" volumes such as the Western Pacific Warm Pool (Song & Yu, 2013).

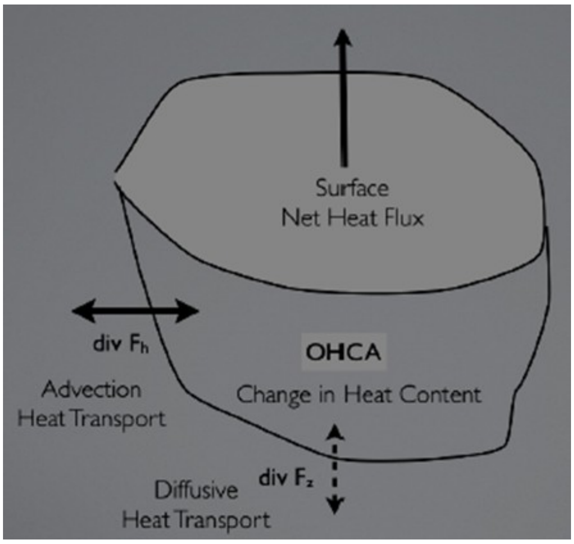

Figure5.2: *Illustration of a potential CAGE, highlighting a heat budget, where changes of OHC are compensated by lateral transport, and surface heat flux (WCRP, 2013).*

The methodology for the selection of appropriate "cage" regions will become one of the project tasks and well justified requirements with the uncertainty estimates will become one of the important project deliverables. Very preliminary, the selection of the so-called CAGES for the project should be based upon the following basic requirements -

(i) The chosen cages should reasonably represent the variety of sea-air interaction processes and ocean dynamics conditions. In this respect we will look on the regions with relatively high lateral advection, relatively strong storage terms and the weak potential changes of the ocean heat content. From air-sea interaction view point we will focus on the areas with dominating turbulent fluxes, and the regions where radiative fluxes are equally important compared to the turbulent exchanges. Finally, we will give a special consideration to the role of synoptic and mesoscale processes in forming space-time variability of surface fluxes. This issue is critical for estimating of space-time averaging effects in integrated fluxes and also for the accurate estimation of uncertainties of heat and moisture budgets. All these imperatives suggest provisionally few potential locations of the cages in mid and subpolar latitudes (including those covering the Western Boundary Current regions and central parts of the subpolar gyres), in the subtropical subduction regions and in the tropical warm pools.

(ii) Another important imperative for the selection of cages should be based upon the data coverage. Here several types of data should be considered:

- ⇒ ARGO buoys
- ⇒ full depth hydrology
- ⇒ meteorological buoys
- ⇒ VOS meteorology
- ⇒ research vessel (RV) meteorology

Assessment of the availability and amount of these data should be put in the context of the availability of satellite data on which the project is focused, but which have relatively homogeneous coverage. This concern implies preliminary focus on the Pacific Warm Pool (TAO buoys, many RV campaigns), midlatitude regions of the North Atlantic (RAPID array, 54N and 60N, good coverage with VOS and RV data), several enclosed seas, such as Mediterranean and Red Seas characterized by relatively known mass balances (while the river and ground water discharges need to be still estimated) and the large amount both VOS and RV data.

With these imperatives in mind we will design and test several competitive approaches for the selection of "cages" of the project. For now we can definitely say that the emphasis will be given to the Pacific tropical warm pool, subtropical and midlatitunal North Atlantic, Mediterranean and Red Seas along with probably Persian Gulf. A second order priority might be Kuroshio region (where highly accurate time series from the KEO and JKEO buoys are available) and consideration of the tropical belts of the Atlantic and Indian Oceans (with RAMA and PIRATA buoys). For all these regions the actual size of the potential "cages" will be investigated during the project, accounting for the potential of matching imbalances between satellite - based and in-situ - based flux estimates on one hand and of ocean state estimates fro different sources on the other.

We illustrate this methodology with the example of the Mediterranean Sea, which is an ideal « natural cage » for which lateral heat and freshwater fluxes include changes at the Gibraltar Strait, the Black Sea and river runoff (Figure 5.3), in a first assumption Black Sea and river runoff heat flux can be neglected due to their relatively small contribution). Direct estimates of the net heat transport through the Strait of Gibraltar have been derived from mooring measurements, giving a commonly used reference value (e.g. Criado-Aldeanueva et al., 2010). Also the Mediterranean Sea benefits from an increased observational effort during the recent decades as well as from the traditionally high sampling density of VOS observations. In particular, large improvements of temperature and salinity measurements have been predominantly achieved through the Argo observing system (MedARGO as regional component for the Mediterranean Sea), the use of gliders (http://www.groom-fp7.eu, with particular activities in the Mediterranean Sea), the MOOSE observing network (http://www.moose-network.fr/) and hydrographic sections from the PERSEUS FP7 project (http://*www.**perseus-fp7**.eu)*. In addition, other initiatives are underway to increase the sampling of hydrographic measurements in the Mediterranean Sea as for example the TRANSMED program (http://www.ifremer.fr/lobtln/TRANSMED, high-resolution spatio-temporal monitoring of the surface using ferries and cargo ships) and the CIESM Hydro-Changes initiative (http://www.ciesm.org/marine/programs/hydrochanges.htm).

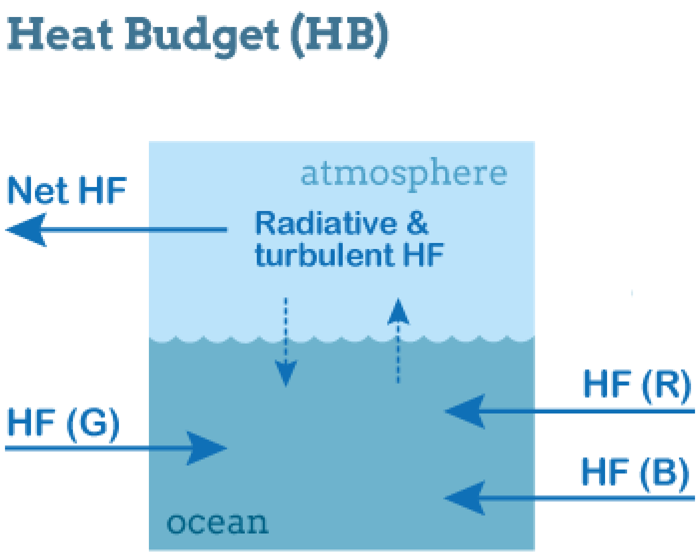

Figure5.3**:** Schematic representation of the Mediterranean Heat Budget (HB), where HF is the heat flux at the different boundaries (G=Gibraltar; B=Black Sea; R=River runoff) and the netHF = radiative + turbulent HF.

OHC will be evaluated using pre-qualified products from the Coriolis data center, in particular the COriolis dataset for reanalysis (CORA, www.coriolis.eu.org), where in situ temperature data have undergone a careful quality control that includes comparison of individual profiles and optimal estimation of profiles using the entire Argo dataset (Cabanes et al., 2012). This product is freely available from the MyOcean catalogue (www.myocean.org). Regional estimates (Mediterranean Sea) of OHC will be performed using the method based on a box averaging scheme as developed by von Schuckmann and Le Traon (2011). This method has the advantage that it can be applied easily within validation procedure systems, and can be adapted to any regional basin-scale.

Expected results will consist in a robust estimation of the Mediterranean Sea heat budget which in turn will help to understand the nature of current large uncertainties in surface heat flux estimates based only on satellite data over the Mediterranean for example. The latter is aiming to enhance the community and scientific exchange on the Mediterranean Heat Budget. The same methodology has the strong potential to be implemented as a validation procedure for surface heat flux products in similar CAGES elsewhere. In particular, we propose to develop a recommendation framework as well as to refine the scientific framework for a cage study in the North Atlantic Ocean (lateral transport to the south given by the RAPID array) based on our results obtained from the Mediterranean Sea cage experiment (for example we could test alternative methods (e.g. from satellite altimetry or ocean reanalyses) to derive the lateral transport if current arrays for a direct estimate are not available). In addition, the potential of other regions are thought to be discussed such as the Southern Ocean region. This concept is in coherence with the 6th Clivar research opportunity, and at regional scale with the MISTRALS/ENVIMED MED-MaHb (HYMEX) program (http://www.hymex.org/) for the Mediterranean Sea cage experiment.

Verification of the newly generated ensemble flux data set and determine uncertainties on regional and global using constraints from OHF data..

- Analysis of regional heat budgets including the Ocean heat content. This will be done for certain regional “Cages” as well as for relevant processes, such as El Nino or Hurricanes.
  - by estimating the local heat storage and horizontal advection of heat based on a simultaneous re-analysis of ocean temperature and currents (Wang and Carton, 2002),
  - by comparison to the heat budget at fixed mooring sites available mainly in the tropics (e.g. Foltz et al., 2003), and

- by comparison with steric sea level estimates from satellite altimetry alone (….)

5.3.2.3 Enhancement of OHF products

Further investigations will be performed to assess the importance of the penetrating component of the short-wave radiation for the marine heat budget, and the role of phytoplankton as a modulator of the distribution of this component of the solar energy. These factors have many implications for the heat budget of the ocean, and for air-sea fluxes (See Table 5.4 for some examples). More specifically, about 40 – 45% of shortwave solar energy is in the visible domain, capable of penetrating up to several tens of meters into the ocean. Depending on the optical properties of the water, this energy may be absorbed in the top ten meters of the water column, or in a hundred meters or more. If the depth over which the light energy is absorbed (the photic layer) lies within the surface mixed layer, the heat may re-distributed through mixing. This energy would then be available for exchange with the atmosphere. If, on the other hand, the photic depth is greater than the mixed layer, then the energy is trapped inside the ocean, and is insulated from exchange with the atmosphere, unless localized heating leads to vertical instability and enhanced mixing. In the open-ocean, phytoplankton are the primary agents responsible for modifying the optical properties of the water column. In coastal waters, other agents (such as suspended sediments, or color dissolved organic matter run off from rivers or land drainage) may also modify optical properties of the water independently of phytoplankton. Dynamics of these materials are complex and remote-sensing of ocean-color, in combination with optical models, provides an avenue for monitoring globally the diffuse attenuation coefficient for visible light in the ocean. Thus we are proposing to use ocean color to examine how optical properties of the ocean modify the distribution of a significant fraction of the short-wave radiation reaching the sea surface.

This task will 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 ocean-colour products from the Climate Change Initiative of ESA.

Table 5.4

Method	Some Relevant Results	Reference
Mixed layer model	Increase, at times over 3ºC/month, in the heating rate of the oceanic mixed layer,	Sathyendranath et al. 1991
Optical, physical, and biological oceanographic observations in the warm water pool of equatorial Pacific Ocean	A tripling of phytoplankton in the mixed layer reduced the penetrative flux at 30 m in the ocean from a mean of 23 Wm^{-2} to 5.6 $W\ m^{-2}$. Estimated biologically-mediated increase in the heating rate of the mixed layer by 0.13ºC per month.	Siegel et al. 1995
Mixed layer heating and solar penetration	Penetrating component of solar radiation can be important source (20 $W\ m^{-2}$)of heating to depths below the permanent pycnocline in tropical oceans.	Ohlmann et al. 1996
Bulk mixed-layer model embedded in an isopycnal general circulation model	Increase in phytoplankton concentration results in increased heating rate in the upper ocean, decreased mixed-layer depth and decreased temperatures in deeper layers.	Nakamoto et al. 2000
Ocean general circulation model	Presence of phytoplankton leads to loss of radiation to the subsurface and enhanced SST in Equatorial Pacific.	Murtugudde et al. 2002
Atmospheric general circulation model forced by SST changed due to phytoplankton	Phytoplankton amplify the seasonal cycle of the temperature in the lowest atmospheric layer.	Shell et al. 2003
Regional ocean circulation model of the Labrador Sea	Bio-optical heating of the oceanic mixed layer can be as high as 2.7ºC in areas of high chlorophyll and shallow mixed layer. Bio-optical heating can also increase stratification, and reduce mixed-layer depth (20 – 50%).	Wu et al. 2007

Ocean circulation model of the Gulf of St. Lawrence	Light absorption by phytoplankton in surface layers cools temperatures below the mixed layer by up to 2ºC.	Zhai et al. 2011

Satellite measurements of ocean colour provide global data on the distribution of phytoplankton in the ocean. This data, when combined with a model of light penetration in the ocean, provide an avenue for modeling the distribution of solar radiation in the surface layers of the ocean, and its contribution to the heat budget and to heat fluxes across the air-sea interface.

In this work package, we propose to:

1. Use satellite-derived data on phytoplankton concentration from the OC-CCI project, combined with a spectrally-resolved model of light transmission underwater (Sathyendranath and Platt 1988), to compute the distribution of solar radiation in the surface of the ocean.
2. Combine these results with a one-dimensional general ocean turbulence model (Burchard et al. 1999) to study the sensitivity of the oceanic heat budget within the mixed layer and below the mixed layer, and of the air-sea exchange of heat, to the parameterization of light penetration in the ocean and to air-sea exchange of heat.
3. Combine satellite-derived surface chlorophyll with parameterization of vertical structure in chlorophyll, for example as in Longhurst et al. 1995), to study the impact of vertical structure in optical properties on upper-ocean stability and heat budget, using the turbulence model.

   Examine the impact of optical properties of the sea and of optical processes at the air-sea interface on the diurnal variations in SST and hence on the heat budget of upper ocean and lower atmosphere and on air-sea fluxes.

5.4 Task 4: Data Portal Development

D4.1: Data Portal: This web site shall include open and password-protected areas. The open part shall provide users with access to information, data and tools, and the protected part shall provide ESA with access to management documents and information.

WP	Who
Setup and operate project data portal	IFREMER, UR

Deliverable:

D4.1: Data Portal: The TIE-OHF Project Portal will be developed and hosted by Ifremer. Ifremer currently operates several other portals providing ocean related data or for ESA projects.

We will setup and run a central TIE-OHF website and portal. In addition to the project documentation, product catalogue and online tools, a number of outreach components will be included such as a project blog and/or Twitter feed, hyper-links to related resources, project related journal papers and the project brochure. We describe here our design and development solution for the TIE-OHF project portal and provide summary evidence of long-term sustainability.

Introduction:

The TIE-OHF portal will be based on a content management system currently in use in Ifremer (Joomla 2.5), which provides a workflow allowing all consortium members to work together to provide clear and structured information for the benefit of users.

The Central Project Portal will be the single entry point to all TIE-OHF information, products and resources:

- **project documentation** (requirements, technical specifications, etc.) in a protected area only accessible to partners and ESA (or other authorized users)
- **overview of the project** together with system user manual, catalogue of input and TIE-OHF datasets, and guidelines, description of champion users and use cases, bibliography, a section on related activities, product and services
- **outreach resources** : video, papers, brochure,...
- a **blog** area where project members and contributors can post information on the project progress but also examples of their own system usage. The blog area will also be opened to users for comments and exchanges.
- product **catalogue** and **discovery**

- **tutorials**
- **online tools** for data visualization and quality assessment (refer to the overview of the data management and processing system)
- **registration of users** for priviledged acces or direct broadcasting of information
- regular update of the service availability (disrupted products,) and operational news through a **performance board**

Web Portal Development

The TIE-OHF web portal will be hosted and managed by Ifremer, and based on the widely used Content Management System ‘Joomla 2.5’ allowing shared access and edition to all partners. Joomla provides natively many content objects to set up quickly and easily web portals (news, FAQ, documents, articles, newsletters, etc.). It also implements different level of secured access (depending on user profile) as well as an internal mechanism for edition workflow (from edition of content to validation and publishing).

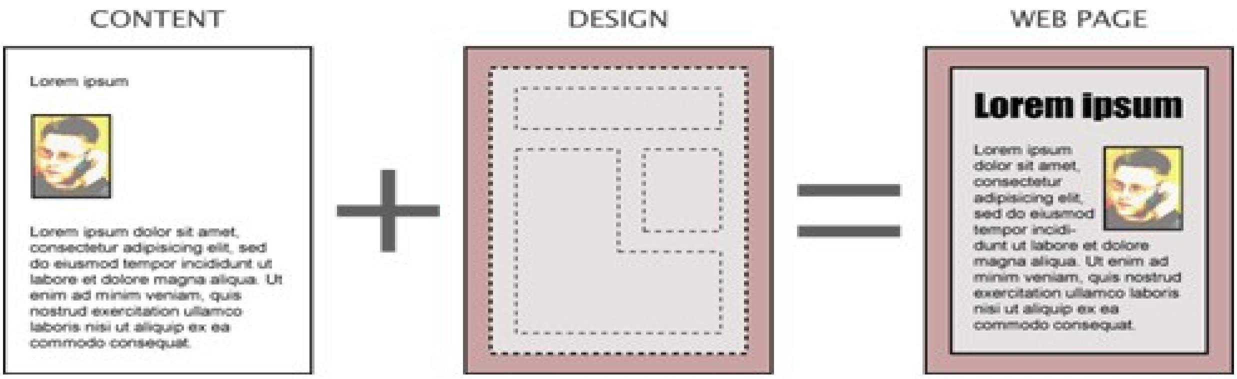

Figure 5.3 : TIE-OHF Web Portal Development

Content Management Systems are an established best practice for the implementation of web portals, allowing the content to be authored independently of the design of the web pages, and of the logical structure of the web site.

The initial version of the portal will be available at KO+1 and will feature:

1. A general project overview (goals, partners, schedule, etc.)
2. A password restricted area for the project documentation

3. The TIE-OHF portal will then be incrementally developed throughout the rest of the project.

It can be noted that all the Web Portal features rely on existing or ongoing developments (for multiple projects) which guarantees the robustness and sustainability (and increasing improvement) of our solution, as well as a cost-effective development process.

User registration

TIE-OHF portal will offer registration to users. Registration will allow :

- access to TIE-OHF products
- access to some restricted resources of the portal
- direct broadcasting through email of TIE-OHF information to the registered users (operational news such as production issues, alerts, outages,...)

Registration will rely on third party authentication services (several accounts will be usable : google, facebook, openId,...). This approach has the following advantages:

1. no security issues with authentication and password storage in TIE-OHF system, relying on highly secured services instead
2. cost effective solution (nothing to implement)
3. avoid the plague for users of having to remember another login/password.

Product catalogue

The TIE-OHF portal will allow browsing and discovering the project products through a catalogue, allowing for faceted search (using predefined search criteria such as sensor, resolution, area,...) or free-form search text box. The catalogue will display all the products corresponding to the current selection of search criteria. Clicking on a product will open a detailed view giving all the characteristics of the product (abstract, contact information, documentation, ATBD, link to provider, metadata,...).

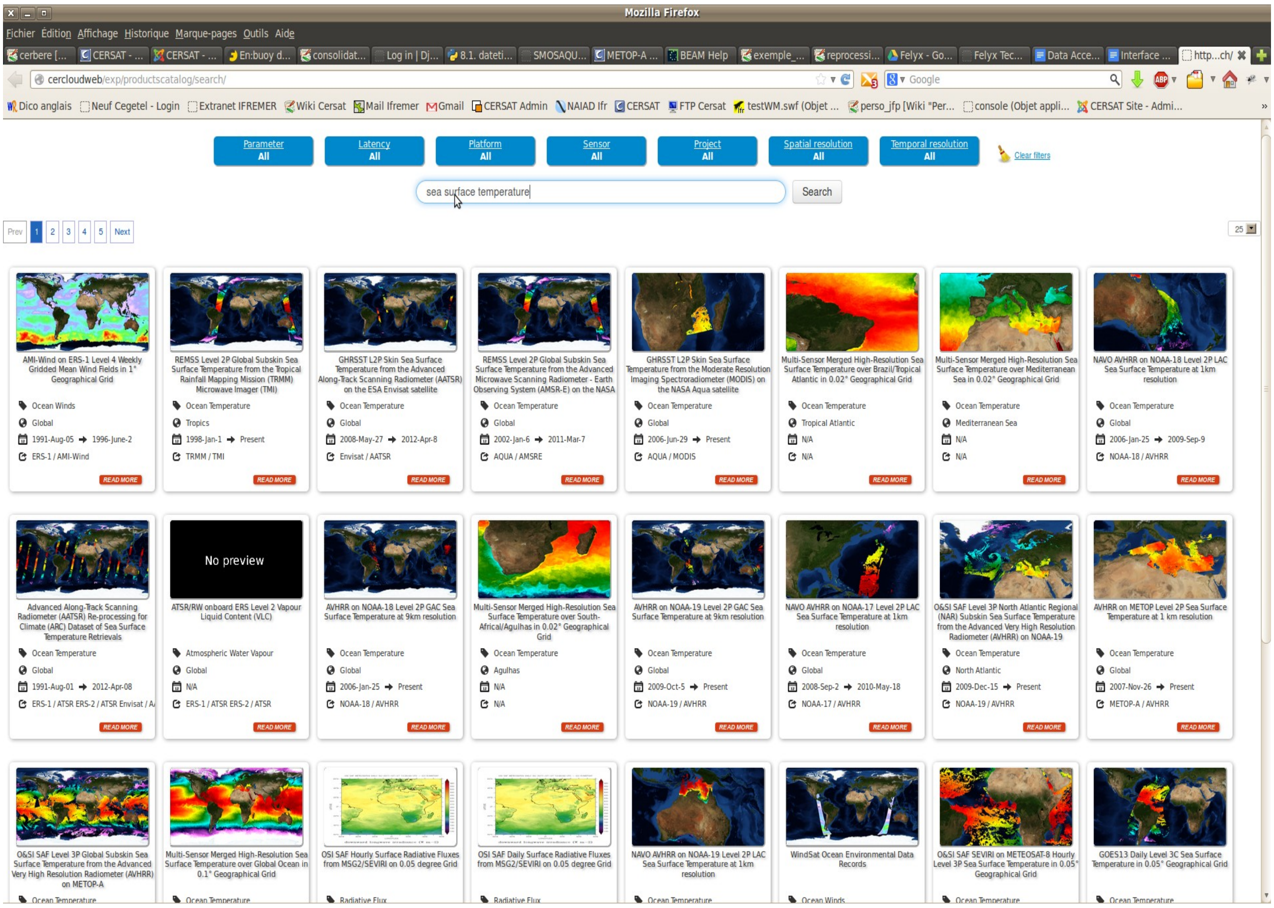

Figure 5.4: View of the product catalogue

The catalogue for TIE-OHF will rely on a technical solution developed by Ifremer for its product catalogue and also used in felyx or OceanFlux project.

It will also be possible to visualize any product featured in the catalogue through a link that will directly open the product in the *Calypso* visualization and analysis web interface (refer to data access in general architecture).

Data visualization

Data visualization will be possible in an interactive manner through various means, described in more details in the « data access » section of the « general architecture of the data management and processing system » chapter. This will include:

- Calypso, a tool implemented at Ifremer that allows multi-dimensional inspection of datasets (as maps, sections, time series) including different data patterns (stations such as moored buoys, buoy/ship trajectories, swaths, along-track or gridded data)
- Google Earth

- WMS servers

Data Access

The data catalogued within TIE-OHF (L2P, L3, L4, demo products, in-situ and model data, match-ups, validation data) will be made available to users over a selection of standards-based query and data access mechanisms, as shown on the general architecture figure. Each data access mechanism used in the TIE-OHF web portal is explained below, with the necessary justification for its selection.

FTP: Experience gained with the Medspiration or GlobWave projects has confirmed that the FTP protocol is the preferred user mode for users to retrieve data, especially for operational applications or usage (such as model assimilation). In push mode, users connect to an FTP server and initiate the download of the files. All TIE-OHF data will be available on a single FTP server, located at Ifremer. A login/password for each user will be requested (and obtained from TIE-OHF help desk). Login is requested in order to improve tracking of users and data download[2]. In push mode, data are automatically uploaded to user through FTP protocol. It is intended for operational applications where users want the data as soon as they are produced. The user has to provide an FTP address with write permission.

HTTP: An integrated server provides bulk file access through the HTTP protocol.

OpenDAP: this standard protocol allows client programs to access selected parts of a file (e.g. some header attribute, or a subset of some selected data parameters), without downloading the whole file. It is supported by IDL, Matlab, and by the latest versions of the NetCDF API.

OGC: these web service interfaces (e.g. WMS, WCS) allow OGC compliant client programs (Geographic Information Systems, e.g. ArcGIS) to access the data resulting from a geographic query. TIE-OHF gridded products will be available through WMS (Web Map Server) for intregration into GIS applications.

Google Earth: TIE-OHF gridded data will be available to Google Earth users by developing a tool to automatically generate ‘kml’ files for gridded data and display them through a web page (recent and past images).

2 Anonymous access was provided within Medspiration but proved to be very unsatisfying to extract relevant and meaningful statistics on service usage. Other experiences prove that having to request explicitly a login has no impact on the number of potential users.

Naiad: this ocean data mining tool was developed by Ifremer and funded by ESA and EUMETSAT. It allows on-line data search on space/time and content criteria, satellite-to-satellite collocation, on-the-fly computation of additional parameters, visualisation and product subscription. Naiad is particularly intended for satellite swath data, whose sampling pattern makes search and sub-setting over specific regional areas difficult, and includes also interactive satellite-to-satellite collocation functionalities for cross-mission inter-comparison or merging. Naiad now provides a WMS interface allowing integration of swath, along-track and image data in GIS applications, which is not possible with most of the existing WMS servers (serving only gridded datasets).

Thredds: several of the mechanisms above (HTTP, OpenDAP, OGC interfaces) are provided through the open source product THREDDS (Thematic Real-time Environmental Distributed Data Services). This project is developing middleware to bridge the gap between data providers and data users. The goal is to simplify the discovery and use of scientific data and to allow scientific publications and educational materials to reference scientific data. The THREDDS server will also be a requirement for GMES/MyOcean especially for its cataloguing component and its high integration level with OpenDAP protocols. It is already deployed at Ifremer and GlobWave products will then also be seen and accessible through this service.

Calypso: Calypso is the new focal point of CERSAT for visualizing and analyzing data from multiple source (EO, in situ, model,...) and multiple patterns (swath, grids, time series, trajectories, sections...). Calypso is an interactive application whose implementation started for GlobWave and is currently being extended (http://www.ifremer.fr/cersat1/exp/calypso/). It is extensively described in our management proposal and basically will provide the following services :

- visualization of maps of TIE-OHF products, either at global scale or on regional zooms (for quicklooks of products)
- overlay of in situ and other validation data
- comparison of maps as split-screen or transparency of layers
- extraction and visualization of time series, sections, histograms, directional histograms,...
- calculation and display of virtual drifters (from a user defined starting point) for dynamic assessment of products quality

Support

In order to ease uptake by the user community, IFREMER will provide user support through its help desk (cersat@ifremer.fr), managing the user requests concerning system usage, access to products, expert information, during the full project duration. The help desk will forward inquiries to the relevant expert within TIE-OHF consortium.

5.5 Task 5: Strategic Development

Deliverable:

D5.1: Scientific Roadmap: This document shall define strategic actions for fostering a transition of the target products in the project from research to more operational activities. In particular, it shall describe the potential developments for establishing long-term multi-mission data records, as well as identifying further relevant issues to be addressed by future activities in support to the CLIVAR community. It shall also provide recommendations on the observing systems to be developed to track the energy balance, and flux in particular (e.g. Flux Train). It shall also articulate the requirements for the development of a flux exploitation platform.

WP	Who
1. Develop and setup Scientific Roadmap	IFREMER, DWD, NERSC,PML, UR, UT

The deliverable could be prepared/defined during a workshop.

5.6 Task 6: Outreach and Coordination

Deliverables:

D6.1: Outreach Material: This document shall include all the material produced for promotion including brochures, newsletter, scientific publications. It shall be revised during the project.

D6.2: Workshop Report: This document shall describe the final workshop, its format, participation and major findings and recommendations

WP	Who
1. Outreach and Coordination	Project Office / IFREMER with support from all TIE-OHF partners.

The products and results of TIE-OHF project will be actively promoted to the scientific community and user activities. This will be done specifically through:

- Publications of our TIE-OHF project results obtained in peer review journals. At least three papers are expected. They will be dealing with the determination and accuracy of the reference data, the analysis of the inter-comparisons results, and the investigations of the spatial and temporal characteristics of the resulting ocean heat fluxes.
- Disseminations of scientific reports summarizing the OHF results.
- Dissemination of OHF internal workshop report and presentations.
- Organization of workshops and/or meeting sessions (e.g. EGU, AMS, OCEAN, PORSEC, and IOVWST) dedicated to the estimation, validation, and use of ocean heat fluxes.
- Participation to CLIVAR, GEWEX, GSOP, SeaFlux meetings
- Collaboration with climate and modeling communities (NEMO, MERCATOR, MyOcean, DRAKKAR, ROMS)
- Online publications of newsletters and brochure. They will useful information about the project description, aims, and progress. The brochure will be advertised through the blog and at conferences.

5.7 *Expected Results*

The work detailed in tasks above is summarized in the figure 5.5 (See Table 5.3)

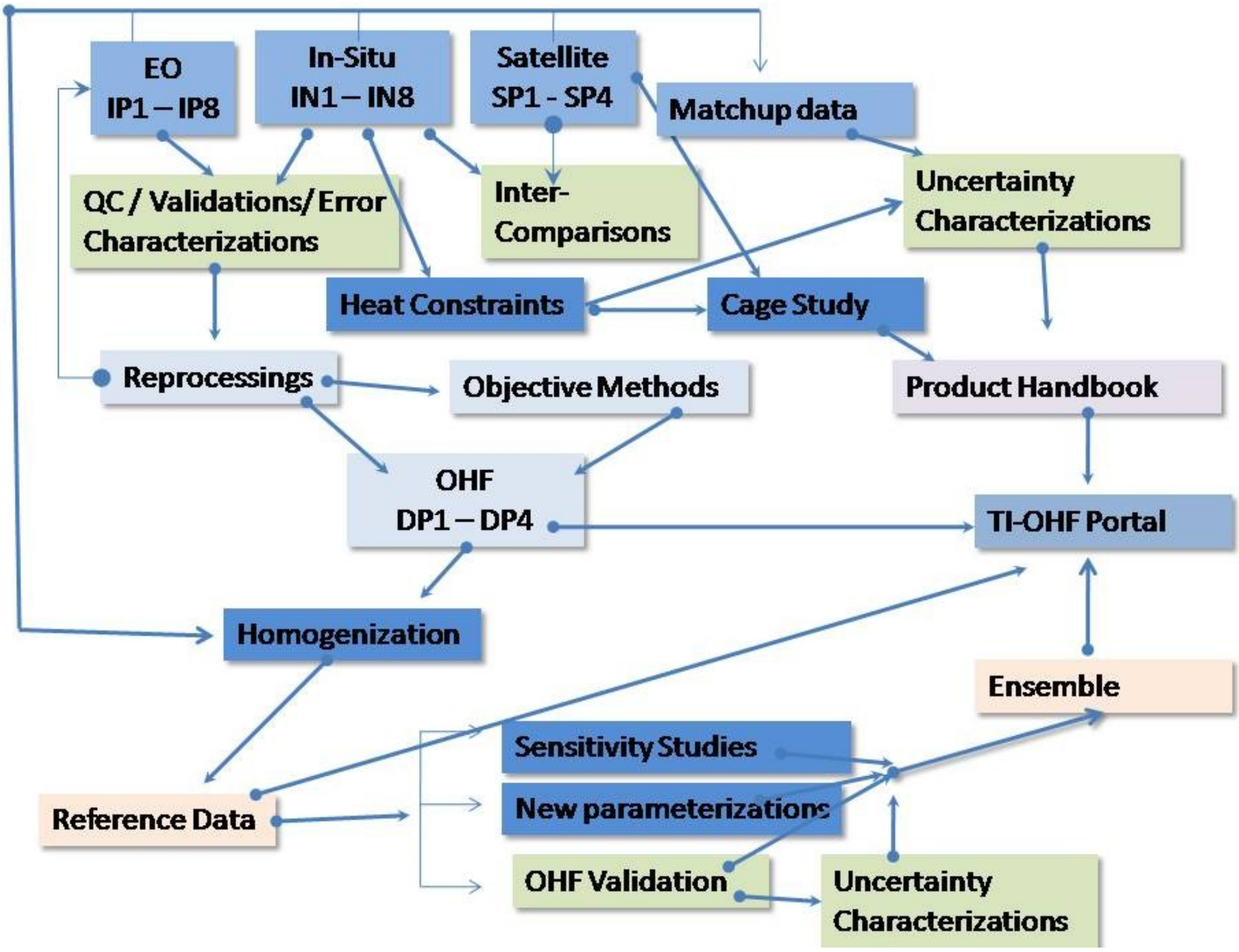

Figure 5.5: Simplified overview of significant components and their potential linkages within TI-OHF R&D demonstration system. The different colored boxes indicate the key tasks/studies of the project. Arrows denote data flows within and between these key ingest, (re)processing and product delivery sub-systems.

One the main results of the proposed work will provide daily and monthly estimates of the main terms needed for ocean heat flux estimations. About 20 year time series of wind bulk variables (wind speed and components, sea surface and air temperature, surface and air specific humidities) and of turbulent fluxes including wind stress, latent, and sensible heat fluxes will be provided. The error related to each variable will also be provided. It will indicate the error relied on sampling scheme impact on the spatial and temporal variability of the variable. The accuracy of the bulk variables as well as of LHF and SHF will be provided as statistics characterizing differences between satellite and *in situ* estimates. Ocean heat flux will be calculated from the combination of the resulting turbulent heat fluxes and radiative fluxes from CM SAF, ISCCP and/or University of Maryland. OHF accuracy as well the results characterizing the comparisons between the newly OHF and available OHF products will be setting up. Since the terms of the energy budgets will be estimated on a daily and monthly basis, the main analysis of the entire energy budget will be done daily and mostly monthly. Analysis of the annual cycle of heating and cooling in the latitude band over the global ocean or over some specific areas such tropical regions, north Atlantic area, and the Mediterranean Sea in terms of all the energy terms, radiative, latent, and sensible heat fluxes, will be provided at least 0.5° grid. The resulting fluxes will be compared to similar products based on ship data, numerical model estimates, and individual buoy time series for quality evaluation. While there are differences in the space-time resolution of the various components of the net heat flux, and the final product will have to be degraded to the lower resolution, it is believed that the finer resolution of the radiative fluxes will impact the quality of the other components. The 20+ -year analysis will contribute to the information needed in the future collection of data from satellites for evaluation of long-term climate variability.

6 Collaborations

We fully understand that in order for the community to take over the project outcomes and achievements, targeted users needs to be involved from the beginning of the project – from the requirements collecting and technical specifications – up to the demonstration on a few target domains and the delivery and sustained support of the system source code for further deployment and specialization.

Our focus and objective in the proposed study is to investigate, characterize, and determine the global ocean heat fluxes and the associated parameters mostly retrieved from satellite measurements. We plan on synergistic collaborations that will benefit other complementary flux studies and projects, as well as ours. We are planning to work closely with members of scientific groups dealing with flux determinations and characterizations such as WCRP, CLIVAR, SCOP, SEAFLUX, GEWEX. Members of consortium are member of these groups. This will allow the interaction easier. We will also continue collaborations with investigators of the programs aiming at studying ocean-atmosphere interactions at local and/or regional scales such as the International Indian Ocean Field Campaign known as the Dynamics of the Madden-Julian Oscillation (DYNAMO)) and the African Monsoon Multidisciplinary Analysis (AMMA) project. Both deal with the investigations of flux effect on monsoon dynamics on intra-seasonal to inter-annual time scales. We are also expecting a strong collaboration with colleagues of the International Ocean Vector Wind Science Team (IOVWST) to investigate the OHF quality, content, and errors. TIE-OHF partners are involved in ESA projects such as GHRSST, GlobeWave, and GlobeColor, OceanFlux will promote the project products for further scientific and technical collaborations.

In order to be successful, the involvement of the user community must follow a few guidelines:

- Must not be seen as duplicating existing efforts by the user community for which important investment may have been performed by various organizations
- User community must assess and feel the benefit of supporting such effort, which must be seen as a key asset for their own planned activities and so that they build on it

7 References

Abraham, J.P., M. Baringer, N.L. Bindoff, T. Boyer, L.J. Cheng, J.A. Church, J.L. Conroy, C.M. Domingues, J.T. Fasullo, J. Gilson, G. Goni, S.A. Good, J. M. Gorman, V. Gouretski, M. Ishii, G.C. Johnson, S. Kizu, J.M. Lyman, A. M. Macdonald, W.J. Minkowycz, S.E. Moffitt, M.D. Palmer, A.R. Piola, F. Reseghetti, K. Schuckmann,K.E. Trenberth, I. Velicogna, J.K. Willis, A review of global ocean temperature observations: Implications for ocean heat content estimates and climate change, Reviews of Geophysics, 51, 450-483.

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

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

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.

Balmaseda, M.A., F. Hernandez, A. Storto, M. Palmer, L. Shi, G. Smith, T. Toyoda, M. Valdivieso,O. Alves, B. Barnier,T. B o y e r, Y. Chang, G. A. Chepurin, N. Ferry, G. Forget, Y. Fujii, S. Good, S. Guinehut, K. Haines, Y. Ishikawa, S. Keeley, A. Köhl, T. Lee, M. Martin, S. Masina, S. Masuda, B. Meyssignac, K. Mogensen, L. Parent, K. A. Peterson, Y. Yin,G. Vernieres, X. Wang, J. Waters, R. Wedd, O. Wang, Y. Xue, M. Chevallier, J-F. Lemieux, F. Dupont, T. Kuragano, M. Kamachi, T. Awaji, K. Wilmer-Becker, F. Gaillard, 2014: The Ocean Reanalyses Intercomparison Project (ORA-IP), CLIVAR Exchange, 64, 3-7.

Balmaseda M. A., K.E. Trenberth, and E. Källén, 2013: "Distinctive climate signals in reanalysis of global ocean heat content", *Geophysical Research Letters*, vol. 40, pp. 1754-1759. http://dx.doi.org/10.1002/grl.50382

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

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.

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.

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.

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).

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.

Bentamy A., D. Croizé. Fillon, 2011: Gridded Surface Wind Fields from Metop/ASCAT Measurements. *International Journal of Remote Sensing*, 33, pp 1729-1754.

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.

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.

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

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.

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).

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.

Brodeau, L., B. Barnier, A. Treguier, T. Penduff, and S. Gulev, 2010 An ERA40-based atmospheric forcing for global ocean circulation models. Ocean Modelling, 31, 88?104, doi:10.1016/j.ocemod.2009.10.005

Bourras D., 2006: Comparison of Five Satellite-Derived Latent Heat Flux Products to Moored Buoy Data. *Journal of Climate*, Vol. 19, 2006, pp. 6291-6313. doi:10.1175/JCLI3977.1

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.

Burchard H., Bolding K., Villarreal M.R., GOTM - a general ocean turbulence model. Theory, applications and test cases, Tech. report. EUR 18745 EN, European Commission, 1999

Chou, S.-H., E. Nelkin, J. Ardizzone, R. M. Atlas, and C.-L. Shie, 2003: Surface turbulent heat and momentum fluxes over global oceans based on the Goddard satellite retrieval, version 2 (GSSTF2). *Journal of Climate*, **16**, 3256–3273.

Davis, X. J., F. Straneo, Y.-O. Kwon, K. A. Kelly, and J. M. Toole, 2013: Evolution and formation of North Atlantic Eighteen Degree Water in the Sargasso Sea from moored data, *Deep-Sea Res.*, 91, p. 11-24. doi: 10.1016/j.dsr2.2013.02.024

Fairall, C. W., T. Uttal, D. Hazen, J. Hare, M. F. Cronin, N. Bond, and D. E. Veron, 2007: Observations of Cloud, Radiation, and Surface Forcing in the Equatorial Eastern Pacific. J. Climate, Volume 21, Issue 4 (February 2008) pp. 655-673 doi: http://dx.doi.org/10.1175/2007JCLI1757.1

Fairall, C. W., M. Yang, L. Bariteau, J. B. Edson, D. Helmig, W. McGillis, S. Pezoa, J. E. Hare, B. Huebert, and B. Blomquist, 2011: Implementation of the COARE algorithm with O3, CO2 and DMS. *J. Geophys. Res.*, 116, C00F09, doi:10.1029/2010JC006884.

Fennig, K., Andersson, A., Bakan, S., Klepp, C., Schroeder, M., 2012: Hamburg Ocean

Atmosphere Parameters and Fluxes from Satellite Data - HOAPS 3.2 - Monthly Means / 6-Hourly Composites. Satellite Application Facility on Climate Monitoring. doi:10.5676 / EUM_SAF_CM / HOAPS / V001.

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

Gaillard, F., E. Autret, V. Thierry, P. Galaup, C. Coatanoan, and T. Loubrieu (2009), Quality control of large Argo data sets, J. Atmos. Oceanic Technol., 26, 337–351.

Grodsky S. A., A. Bentamy, J. A. Carton, R. T. Pinker, 2009: Intraseasonal Latent Heat Flux Based on Satellite Observations. *Journal of Climate*, 22(17), 4539-4556. http://dx.doi.org/10.1175/2009JCLI2901.1

Grodsky, S. A., V. N. Kudryavtsev, A. Bentamy, J. A. Carton, and B. Chapron , 2012: Does direct impact of SST on short wind waves matter for scatterometry?, *Geophys. Res. Lett.*, *39*, L12602, DOI: 10.1029/2012GL052091.

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.

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.

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

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.

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.

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.

Mestas-Nuñez A., A. Bentamy, K. Kristina, 2006: Seasonal and El Nino variability in weekly satellite evaporation over the global ocean during 1996-98. *Journal of Climate*, 19(10), 2025-2035. http://dx.doi.org/10.1175/JCLI3721.1

Mestas-Nuñez, A.M., F.J. Kelly**,** A. Bentamy, and K.B. Katsaros, 2013. The ENSO footprint in monthly satellite evaporation over the global ocean during 1993-2007. *Remote Sensing Letters*, **4,** 706-714, doi:10.1080/2150704X.2013.788259

Murtugudde, R, Beauchamp, J, McClain CR, Lewis, M, Busalacchi, AJ (2002) Effects of penetrative radiation on the Upper Tropical Ocean Circulation. J. Climate, 15: 470-486.

Nakamoto, S, Prasanna Kumar, S, Oberhuber, JM, Muneyama, K, Frouin, R (2000) Chlorophyll modulation of sea surface temperature in the Arabian Sea in a mixed-layer isopynical general circulation model. Geophys. Res. Let. 27: 747-750.

Ohlmann, JC, Siegel, DA, Cautier, C (1996) Ocean mixed layer radiant heating and solar penetration: A global analysis. J. Climate, 9: 2265-2280.

Oke, PR, O'Kane, TJ 2011, Observing system design and assessment, in A Schiller, GB Brassington (eds.), Operational Oceanography in the 21st Century, Springer, Amsterdam, pp.123-151

Palmer, M. and Co-authors (2014) Ocean heat content from ocean and coupled reanalyses. Clivar Exchanges Issue 64.

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.

Pinker R. T., A. Bentamy, K. B. Katsaros, Y. Ma, and C. Li, 2014: Estimates of net heat fluxes over the Atlantic Ocean. J. Geophy. Res. VOL. 119, 1–18, doi:10.1002/2013JC009386, 2014

Santorelli, A., R. T. Pinker, A. Bentamy, W. Drennan, K. Katsaros, J. Carton, and A. Mestas-Nunez, 2011: Differences between two estimates of air sea turbulent heat fluxes over the Atlantic Ocean. *Journal of Geophysical. Research*., 116, No. C09028 doi: 10.1029/2010JC006927

Sathyendranath, S, Gouveia, AD, Shetye, SR, Ravindran, P, Platt, T (1991) Biological control of surface temperature in the Arabian Sea. *Nature* 349: 54-56.

Shell, KM, Frouin, R, Nakamoto, S, Somerville, RCJ (2003) Atmospheric response to solar radiation absorbed by phytoplankton. J. Geophysical Res. 108, doi:10.1029/2003JD003440.

Shie, C.-L., K. Hilburn, L. S. Chiu, R. Adler, I-I Lin, E. Nelkin, J. Ardizzone, and S. Ga, 2012:Goddard Satellite-Based Surface Turbulent Fluxes, Daily Grid,version 3, Edited by Andrey Savtchenko., Greenbelt, MD, USA:Goddard Earth Science Data and Information Services Center (GES DISC), doi: 10.5067/MEASURES/GSSTF/DATA301

Siegel, DA, Ohlmann, JC, Washburn, L, Bidigare, RR, Nosse, CT, Fields, E, Zhou, Y (1995) Solar radiation, phytoplankton pigments and the radiant heating of the equatorial Pacific warm pool. J. Geophysical Res. 100 (C3): 4885-4891.

Stephens, G. L., et al, (2012): An update on Earth's energy balance in light of the latest global observations, Nat. Geosci., 5, 691–696, doi: 10.1038/ngeo1580.

Stiles, B. W., and R.S. Dunbar 2010: A neural network technique for improving the accuracy of scatterometer winds in rainy conditions, *IEEE Trans. Geosci. and Remote Sensing*, 48, pp. 3114-3122.

Tomita,H. and M. Kubota, 2006: An analysis of the accuracy of Japanese Ocean Flux data sets with Use of Remote sensing Observations(J-OFURO) satellite-derived latent heat flux using moored buoy data, *Journal of Geophysical Research*, 111, C07007, doi:10,1029/2005 JC003013, 2006.

Trenberth, Kevin E., John T. Fasullo, Jeffrey Kiehl, 2009: Earth's Global Energy Budget. Bull. Amer. Meteor. Soc., 90, 311–323. doi: http://dx.doi.org/10.1175/2008BAMS2634.1

WCRP, 2013: Report from the World Climate Research Program (WCRP). May 2013 (http://www.wmo.int/pages/prog/sat/meetings/documents/ET-SUP-7_Doc_08-03_WCRP.pdf)

von Schuckmann, K., Gaillard, F., and Le Traon, P. Y., 2009: Global hydrographic variability patterns during 2003–2008, J. Geophys. Res., 114, C09007, doi:10.1029/2008JC005237.

von Schuckmann, K. and Le Traon, P.-Y.: How well can we derive Global Ocean Indicators from Argo data?, Ocean Sci., 7, 783–791, doi:10.5194/os-7-783-2011, 2011.

von Schuckmann, K., J.-B. Sallée, D. Chambers, P.-Y. Le Traon, C. Cabanes, F. Gaillard, S. Speich, M. Hamon, 2014: Monitoring ocean heat content from the current generation of global ocean observing systems, Ocean Sci. Discuss., 10, 923-949, www.ocean-sci-discuss.net/10/923/2013/, doi:10.5194/osd-10-923-2013

Valdivieso, M. and Co-authors (2014) Heat fluxes from ocean and coupled reanalyses. Clivar Exchanges Issue 64, 28-31.

WCRP, 2013: Report from the World Climate Research Program (WCRP). May 2013 (http://www.wmo.int/pages/prog/sat/meetings/documents/ET-SUP-7_Doc_08-03_WCRP.pdf)

Wentz, F. J., (2013), "SSM/I Version-7 Calibration Report", report number 011012, Remote Sensing Systems, Santa Rosa, CA, 46pp.

WGASF, 2000: Intercomparison and validation of ocean-atmosphere energy flux fields - Final report of the Joint WCRP/SCOR Working Group on Air-Sea Fluxes. WCRP-112, WMO/TD-1036. P. K. Taylor, Ed., 306 pp., http://eprints.soton.ac.uk/69522/1/wgasf_final_rep.pdf

Winterfeldt, J., Andersson, A., Klepp, C., Bakan, S., & Weisse, R., 2010: Comparison of HOAPS, QuikSCAT, and buoy wind speed in the Eastern North Atlantic and the North Sea. *IEEE Transactions on Geoscience & Remote Sensing*, *48*, 338-348.

WOAP, 2012: Report action plan for WCRP activities on surface fluxes, WCRP informal report (http://www.wcrp-climate.org/documents/woap_fluxes_report_01_2012.pdf)

Woodruff SD, Worley SJ, Lubker SJ, Ji Z, Freeman JE, Berry DI, Brohan P, Kent EC, Reynolds RW, Smith SR, Wilkinson C., 2011: ICOADS release 2.5 and data characteristics. International Journal of Climatology 31(7): 951–967, doi: 10.1002/joc.2103.

Yu, L., X. Jin, and R.A. Weller, 2007: Annual, seasonal, and interannual variability of air–sea heat fluxes in the Global Ocean. Journal of Climate, 20, 3190-3209, doi: 10.1175/JCLI4163.1.

Yu, L., X. Jin, and R. A. Weller, 2008: Multidecade global flux datasets from the objectively analyzed air–sea fluxes (OAFlux) project: Latent and sensible heat fluxes, ocean evaporation, and related surface meteorological variables. Tech. Rep. OA- 2008-01, Woods Hole Oceanographic Institution, OAFlux Project, 64 pp.

Yu, L., K. Haines, M. Bourassa, S. Gulev, S. Josey, T. Lee, M. Cronin, A. Kumar, 2012: CLIVAR GSOP WHOI Workshop report on Ocean Syntheses and Surface Flux

Evaluation Woods Hole, Massachusetts, 27-30 November 2012

Zhai, L, Tang C, Platt, T, Sathyendranath, S (2011) Ocean response to attenuation of visible light by phytoplankton in the Gulf of St. Lawrence, *J. Mar. Syst.*, doi:10.1016/j.jmarsys.2011.05.005