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Statement of Work for:

Ocean Heat Flux

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1 INTRODUCTION

1.1 Scope of the Document

This Statement Of Work (SOW) establishes the tasks to be performed, and the deliverables to be provided to the European Space Agency (ESA), within the project "Ocean Heat Flux".

The "Ocean Heat Flux" project is carried out in collaboration with the **Ocean-climate system - Variability, Predictability and Change** (**CLIVAR**), the ocean-atmosphere core project of the **World Climate Research Programme** (**WCRP**). The CLIVAR's mission is to facilitate observation analysis and prediction of changes in the Earth's climate system, with a focus on ocean-atmosphere interactions, enabling better understanding of climate variability, predictability, and change, to the benefit of society and the environment in which we live.

This activity is jointly motivated by the growing importance of investigating energy budget in the Earth System, as well as by the increasing multi-mission observational capacity provided by existing and upcoming ESA EO missions, Third Party Missions (TPM) and European EO missions.

1.2 Acronyms & Abbreviations

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

SWF	Short Wave Flux
TOA	Top of the Atmosphere
TPM	Third Party Missions
VOS	Voluntary Observing Ships
WACMOS	Water Cycle Multi-mission Observation Strategy
WCRP	World Climate Research Programme
WGASF	Working Group on Air-Sea Fluxes
WMO	World Meteorological Organisation
WOAP	WCRP Observation & Assimilation Panel

1.3 Reference Web Sites

URL-00	ESA EO	http://www.esa.int/eo
URL-01	CLIVAR	http://www.clivar.org
URL-02	CLIVAR RO	http://www.clivar.org/science/clivar-research-opportunities#six
URL-03	STSE	http://due.esrin.esa.int/stse/
URL-04	SEAFLUX	http://seaflux.org
URL-05	GSOP	http://www.clivar.org/organization/gsop/activities
URL-06	ESA DA	http://www.esa-da.org/
URL-07	ESA CCI	http://www.esa-cci.org/
URL-08	CLIM GUIDE	http://climatedataguide.ucar.edu/
URL-09	GLOBWAVE	http://www.globwave.org/
URL-10	OCEAN FLUX	http://due.esrin.esa.int/stse/projects/stse_project.php?id=160
URL-11	OCEAN GHG	http://www.oceanflux-ghg.org/
URL-12	OCEAN SPRAY	http://due.esrin.esa.int/stse/projects/stse_project.php?id=158
URL-13	EARTHNET	http://www.esa.int/earthnet
URL-14	FELYX	http://hrdds.ifremer.fr
URL-15	GODIVA	http://behemoth.nerc-essc.ac.uk/ncWMS/godiva2.html

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1.5 Background

Climate is very much about exchanges of energy in the Earth System, and in particular in the form of heat. Quantifying these exchanges, and in particular how much extra heat has been generated by human activities, and how it affects our climate system is one of the key challenges faced by the climate research community (IPCC AR5). Over the last decades, many studies based on both models and observations have been performed, leading to significant advances in our understanding of the energy exchanges (Hansen et al., 2005; Bindoff et al. 2007; Bengtsson et al., 2012; Hansen et al., 2011; Church et al., 2011; Trenberth and Fasullo, 2011; Loeb et al., 2012; Stephens et al., 2012), while highlighting at the same time large uncertainties in the estimate of the energy flows.

The global ocean plays a critical role in regulating these energy flows, being by far the most important heat reservoir due to its enormous heat storage and transport capacity. Over the last 50 years, it is estimated that a large share (about 90%) of the extra human-induced heat has penetrated the ocean through net surface heat fluxes, leading to an observed increase of the Ocean Heat Content (OHC) (von Schuckmann & Le Traon, 2011; Rosenthal et al., 2013), accompanied by a regional redistribution of heat through lateral transport. The rest of the extra heat is being used to melt continental ice and warm the atmosphere and land surface.

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

1.5.1 The new research opportunity of the WCRP CLIVAR programme

In this context, the WCRP CLIVAR has recently established a new research opportunity on "Consistency between Planetary Heat Balance and Ocean Heat Storage" [URL-02]. The main objective of the CLIVAR cross-cutting activity is to understand better 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. Each of these independent approaches has its own advantages and drawbacks in terms of sampling capability and accuracy, leading to different estimates, and associated uncertainties of budget imbalance. Reconciling these different estimates to close the energy budget is a key emerging research topic in climate science.

To address the EO component of the CLIVAR research opportunity, ESA is planning initiate the "Ocean Heat Flux" project in supporting CLIVAR within the framework of the ESA STSE programme [URL-03]. This activity aims at fostering the use of EO data and products, in particular from ESA EO missions to generate a new set of ocean heat flux products in support of the CLIVAR research opportunity.

1.5.2 Focus on Ocean Surface Flux Research

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

Taylor et al. (2010) performed a comprehensive review of the various flux data sets, as part of the Joint WCRP/SCOR Working Group on Air-Sea Fluxes (WGASF), describing their strengths, weaknesses, requirements, retrieval methods, and range of applications from constraining models (e.g. wave, ocean, forecast), to water/energy cycle and climate studies. Following this study, a research action plan regarding fluxes has been developed by the WCRP Ocean Atmosphere Panel (WOAP, 2012). More recently, the issue of air-sea flux has been addressed through the CLIVAR Global Synthesis and Observations Panel (GSOP) panel [URL-05], which hold a series of meetings to develop a flux inventory of air-sea fluxes and good practices for their "evaluation" (Josey & Smith, 2006). In particular, the recent meeting of GSOP in Woods Hole in 2012 led to a series of recommendations on how to use regional heat constraints to calibrate fluxes (Yu et al., 2012). CLIVAR has also set-up a dedicated "Working Group on High Latitude Surface Fluxes", who established guidelines and recommendations (Bourassa et al., 2013) to address the unique challenges of flux measurements in high-latitude regions.

Air-sea interactions research is also by nature a "cross-cutting topic" addressing multiple international scientific programmes, such as the Surface Ocean Lower Atmosphere Study (SOLAS) for biogeochemical fluxes, and the Global Energy & Water Exchange Project (GEWEX) for LandFlux, as well as the long standing SeaFlux [URL-04] efforts.

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

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

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

The surface radiative fluxes are generally derived from ground measurements and models, or estimated by satellites using Radiative Transfer Models in combination with observations of the TOA fluxes, composition of the atmosphere (e.g. amount of water vapour, ozone, cloud, aerosols) and surface properties (e.g. albedo) (Pinker et al. 1995; Ma & Pinker, 1995). In contrast, turbulent fluxes are indirectly estimated from a set of basic state variables and exchange coefficients using “bulk formulae”, making their estimation a very specific problem differing from the estimation of the radiative fluxes. Today most of the basic state variables necessary for estimating turbulent fluxes, such as wind stress/speed, Sea Surface Temperature (SST), sea-state and surface humidity (Yu et al., 2007; Clayson et al., 1996) can be derived from EO data (Table 1), thereby making EO an essential tool to quantify fluxes at the global scale. One exception is the atmospheric surface air temperature, which affects air-sea exchanges, the atmosphere stability and transfer coefficients.

Input Variable	Sensor Type	Sensor Examples
Wind Stress	Scatterometer	ASCAT, QuikSCAT
Sea Surface Temperature	Infrared / Microwave radiometer	AATSR, AVHRR, AMSR-E
Sea-state	Radar	RA, SIRAL, ASAR
Surface Humidity	Passive Microwave	SSM/I, AMSR-E

Table 1: Some examples (not comprehensive list) of potential input parameters derived from EO entering the calculation of turbulent ocean heat fluxes.

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

- In-situ data: (i) National Oceanography Centre (NOCS2.0) (Berry & Kent, 2010), (ii) Florida State University (FSU) (Bourassa et al., 2005) based on the International Comprehensive Ocean Atmosphere Dataset (ICOADS),

- EO data: (i) Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data (HOAPS) (Fenning et al., 2012; Anderson et al., 2010), (ii) Institut Français de Recherche pour l'Exploitation de la MER (IFREMER) (Bentamy et al., 2003), (iii) Japanese Ocean Flux data sets with the Use of Remote sensing Observations (J-OFURO) (Kubota et al. 2002),

- Hybrid data: (i) Objectively Analysed Fluxes (OAFLUX) (Yu et al., 2004), (ii) Common Ocean-ice Reference Experiments (CORE2) (Large & Yeager, 2009) modified to give global closure, (iii) Goddard Satellite-based Surface Turbulent Fluxes (GSSTF2) (Chou et al. 2003),

- Atmospheric Re-analysis: (i) the National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR, i.e. NCEP 1), (ii) NCEP/Department Of Energy (NCEP/DOE, i.e. NCEP2), (iii) the European Centre for Medium-Range Forecast (ECMWF) 40-yrs reanalysis ERA-40, (iii) the NASA Modern Era Retrospective-analysis for Research and Applications (MERRA), (iv) the new generation re-analysis for climate ECMWF ERA-Interim and ERA-Clim (Dee et al., 2011), and the Japanese JRA-25 (Onogi et al., 2005),

- Ocean Synthesis: (i) MyOcean products and re-analysis (Ferry et al., 2011), (ii) ECMWF Ocean Re-analysis System (ORAS) (Balmaseda et al., 2013) and (iii) Estimating the Circulation and Climate of the Ocean (ECCO).

The EO-based fluxes are widely used by the scientific community for a variety of applications ranging from forcing ocean circulation models (e.g. Ayina et al. 2006), to study of climate variability and model evaluation. In particular, the use of fluxes for evaluation of coupled models is of increasing importance (and relevance for this project) given the emergence in Europe of the new generation of coupled reanalysis CERA-20C developed by ECMWF with support of ESA [URL-06].

It is worth noting that most of the current EO flux data sets are based on non-European sensors, such as the Advanced Very High Resolution Radiometer (AVHRR), QuikSCAT, and the Special Sensor Microwave/Imager (SSM/I). The current development of a new generation of climate quality observational products within the framework of the ESA Climate Change Initiative (CCI) [URL-07] is therefore very timely to derive from these a new air-sea flux dataset.

1.5.2.1 Evaluation of Fluxes

This project focuses on evaluating and improving the turbulent component of the Net Heat Flux, taking its radiative components as given (along with their uncertainties). The various data sets have been extensively “compared” and “evaluated” against in-situ measurements within the framework of the “SeaFlux” inter-comparison exercise (Curry et al., 2004) and other assessments (Smith et al., 2011; Gulev & Taylor, 2000). Many studies have highlighted that the data sets suffer from systematic biases and fail to satisfy energy constraints.

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

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

To address these issues, the recent GSOP workshop in Woods Hole (Yu et al., 2012) recommended to complement the traditional “local” evaluation method (based on comparison with point-wise measurement) with a more “regional” approach using heat budget constraints in some suitable “reference” areas, either at the basin, regional or even global scale. This approach would extend the traditional concept of “super-site” to the new concept of “super-regions” for flux calibration, validation and evaluation. This idea of regional constraints is not new as the concept of “Cages” (Bretherthon et al., 1982) was already introduced decades ago in the context of the World Ocean Circulation Experiment (WOCE) using hydrographic transects. The concept (see Fig 1) is now coming back (Yu et al., 2012) as new prospects for heat budget constraints emerge through the advent of new high quality measurements, in particular from XBT and the Argo profiling floats, delivering a view of the ocean interior heat storage at an unprecedented coverage in space and time.

The combination of Argo data with EO data (e.g. altimetry) can provide scientists with an estimate of the changes in heat content induced either, through surface exchanges, or lateral transport.

As illustrated in Fig 1, by identifying some “suitable” regions (where changes in transport would be relatively negligible), the estimate of OHC anomalies should enable scientists to check the fidelity of the Net surface Heat Flux. Such suitable “test bed” regions, could be “pre-defined Cages”, where hydrographic transport is well known or measured (e.g. RAPID programme for ocean overturning circulation), “natural Cages” such as semi-enclosed seas, where outgoing heat is known, or in a near surface "bubble" volume such as the Western Pacific Warm Pool (bounded by a specific isotherm 28°C), where a heat budget equation can be formulated. For example, Song & Yu (2013) have performed a bubble analysis on the warm pool, highlighting issue of inconsistency between OHC and SST variations for several climatologies of the Net Heat Flux at the surface.

In order to ease evaluation of new flux products, this particular activity will generate a "reference input data set" including both the input data and flux buoys observations and regional heat constraints supporting assessment and evaluation of new products.

1.5.2.2 Uncertainties in Fluxes

In recent years there has been significant progress in our knowledge of ocean surface fluxes, including refinement of bulk formulae used for flux calculations, better quantification of uncertainty in the data, new retrieval schemes developed for relevant geophysical variables, and emergence of a new generation of re-analysis for climate (e.g. ERA-Clim). Unfortunately, despite these advances and the resulting better quality of flux data sets, the observational flux data remain limited and sparse, and there remain many sources of error and uncertainty, in particular with regard to:

• *Parameterisation Formulae*. Despite years of research there is still uncertainty with regard to the behaviour of the various "transfer coefficients" at very high (over 10 m/s) or low wind speed (Blanc, 1985), and dependence on sea-state in storm and swell conditions (Hanafin et al., 2012), leading to the development of a variety of algorithms incorporating specific treatments of physical processes (e.g. light wind phenomena, diurnal variations of SST, wind gustiness). As discussed by Bourassa et al. (2013), parameterisations including sea-state (Smith et al. 1992; Taylor & Yelland 2001) differ significantly from those not including sea-state (Large & Pond 1981; Large et al. 1994; Kara et al. 2005). Having to choose a bulk formulation introduces a structural uncertainty into derived flux products, which needs to be more systematically quantified.

• *Input data,* which have inherent noise and sampling characteristics. There are different sources for input data sets (e.g. in-situ, EO, reanalysis), which have their own error characteristics, coverage, quality and sampling (e.g. Kent et al., 2013 for humidity, Bentamy et al., 2011, 2012, 2013 for wind). The choice of input data set is therefore likely to have a critical impact on the quality of flux climatologies, and these sensitivities need to be better quantified. The characterisation of uncertainties in these input data streams and propagation of these to flux products is also not fully developed.

• *Structural uncertainty* associated with retrieval of geophysical variables from satellites. There is generally uncertainty in the "observation operator" functional relationship relating the EO raw data to the geophysical parameters of interest. For example, Fanghor & Kent (2012) presented differences between wind speed products derived using different retrieval methods from the same QuikSCAT sensor, which illustrates another contribution to the uncertainty in the flux estimation process.

• *Sampling uncertainty,* referring to error characteristics associated with under-sampling of natural variability. For example, EO satellites, due to orbital constraints, tend to pass at the same time of day at the equator thereby introducing potential aliasing into the data. Also, in-situ data only provide a local view of a rapidly varying flux. Hence, the spatio-temporal distribution of fluxes is not well known and a probabilistic approach might be needed (Gulev & Belyaev, 2012).

It is worth noting that the above list is limited and does not represent all the different types of uncertainty, other more suitable categorisation can be proposed according to needs.

2 WORK TO BE PERFORMED

2.1 Objective

The ESA "Ocean Heat Flux" activity will support the EO component of the new CLIVAR research opportunity by developing a new ocean surface heat turbulent flux multi-product ensemble capitalising on the latest knowledge in algorithms and data sets from independent observing systems, such as satellites, in-situ networks and Argo floats.

In particular, in line with the recommendations of the CLIVAR-ESA workshops [ULR-2], and other CLIVAR working groups (Yu et al., 2012, Bourassa et al., 2013), the project shall aim to:

- *Establish* a reference input dataset maximising the use of ESA dataset,
- *Develop* an ensemble of ocean heat turbulent flux products fostering the use of EO data, and in particular from European and ESA missions. The flux products shall be global, with a resolution of *at least* daily in time and *at least* 0.5deg x 0.5deg in space, covering a time period of about 10 years. Monthly composite shall also be generated,
- *Quantify* regional heat constraints to assess consistency of the various flux products. The ocean heat constraints, estimated from observations (e.g. in-situ, Argo, altimetry) and/or models (e.g. reanalysis, ocean synthesis), shall cover at least 3 regions of interest representing different oceanic regimes,
- *Generate* an input reference dataset including EO data (maximising the use of European and ESA data and relevant datasets, e.g. CCI), and other required data inputs (e.g. in-situ and model based data), required to calculate ocean heat turbulent fluxes, and evaluate their quality and consistency (e.g. in-situ, regional heat constraints), being the basis for further analysis,
- *Perform* a cross-comparison of different algorithms and approaches based on the reference dataset, evaluating their impact, accuracies and sources of uncertainties, identifying key areas for improvement, and exploring and developing improved approaches to retrieve ocean heat turbulent fluxes from EO data,
- *Generate* an ensemble of turbulent fluxes, including multiple approaches, multiple products and "smart" perturbations of input data to better sample the different types of uncertainty,

- *Evaluate* the quality and consistency of ensemble realisations through confrontation with in-situ observations, and by exploiting integral heat constraints at local, regional and global scales,
- *Develop* a Flux Data Portal to access, share and foster the use of the reference data set and flux products with the scientific community, and to enable easy inter-comparison between products and observations,
- *Coordinate* with relevant partners, activities and international programmes, such as CLIVAR, GSOP, GEWEX and SeaFlux,
- *Develop* a scientific roadmap to define future development and new needs.

The main outcome of this project will be the *reference data set*, the *ensemble data set*, and the *data portal* enabling easy *inter-comparison* of products. It is also expected that the project will provide data providers and scientists with a first building block towards a ***cross-disciplinary collaborative framework***, enabling them to rapidly share and access data, iteratively develop new products, and rapidly check their quality and consistency through confrontation with observations, and in particular regional heat constraints.

2.2 Work Logic

The project shall be carried out within *24 months* from the Kick-Off (KO) with strong interactions with the flux scientific community. The Contractor shall consolidate the preliminary scientific requirements for the activity in collaboration with the scientific community and define the characteristics of the target products and data portal platform. The Contractor shall then refine the methodology to generate and validate new products and produce an ensemble. Following a review with ESA on the type of algorithms and methodology to be implemented, the Contractor shall deliver the products, assess their quality, and make them accessible and inter-comparable through the data portal. The following tasks (see Table 1), including product development tasks (1-2-3) and cross-cutting tasks (4-5-6) shall be performed:

- ***Task 1:*** *Scientific Requirements Consolidation*
- ***Task 2:*** *Reference Data Set Generation*
- ***Task 3****: Product Generation, Inter-comparison and Uncertainty Characterisation*
- ***Task 4:*** *Data Portal Development*
- ***Task 5:*** *Strategic Development*
- ***Task 6:*** *Outreach & Coordination*

2.3 Tasks and Deliverables

2.3.1 *Task 1: Scientific Requirements Consolidation*

- **Input:**

  SOW, Contractor's Proposal, Workshop Recommendations [URL-02]

- **Task description:**

This task aims to consolidate the requirements with the scientific community to define the full specifications of the products and methodology in more details. In particular, the task shall:

- Review scientific requirements, existing activities, products, and needs related to ocean heat flux products across applications, from energy exchanges, climate, up to Numerical Weather Prediction,
- Consolidate the requirements for flux products, regarding their sampling, accuracy, input data, ancillary data from different sources (e.g. EO, in-situ, models) and error characteristics,
- Consolidate specification of flux products to be generated, including their format, quality flags, map projection, catalogue, and metadata convention, taking into account existing standard formats and available software tools for accessing data, (the output data shall be in NetCDF CF),
- Consolidate the algorithms needed, input data streams, workflows, diagnostics to be generated and inter-comparison strategy,
- Identify the potential strengths and limitations of the product and algorithms, such as inconsistencies in data streams, data policy restrictions, and missing input information preventing delivery of comparable data products shall be documented, and mitigation strategies proposed,
- Consolidate the strategy for evaluation and validation of products, including identification regional constraints at different scales (as illustrated in Fig 2): (i) Locally, using the traditional point-based in-situ measurements, (ii) Regionally, using heat budget constraints in a variety of carefully selected super-regions and (iii) Globally, using global heat and consistency constraints.
- Consolidate the methodology to generate a suitable ensemble of realisations of fluxes, discussing strategy to perform suitable perturbations. Ideally, the ensemble should explore the different components of the uncertainties (see examples in section 1.5.2.2), providing scientists with more insight scientists into the sensitivities to uncertain parameters (e.g. transfer coefficients), refined sampling (e.g. diurnal variation of SST; Clayson & Bogdanoff, 2013), and formulations (e.g. inclusion of sea-state, relationships between humidity and radiance; Bentamy et al., 2013).
- Refine architecture, content and functionality of the data portal, in coordination with the scientific communities, and in particular SeaFlux.

➢ **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 Theoritical 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.

2.3.2 Task 2: Reference Data Set Generation

➢ **Input:**

SOW, Contractor's Proposal, D1.1

➢ **Task description:**

This Task shall generate a reference data set (in Netcdf CF format) providing the community with a common input for the generation and evaluation of ocean turbulent heat fluxes over a period of 10 years. In particular the task shall:

- *Gather* all data needed as input to generation and evaluation of a multi-products ensemble of turbulent heat fluxes, including EO data and non EO data sets (e.g. Table 1), and other flux products derived from observations (in particular EO) and models available openly (see section 1.5, e.g. HOAPS, IFREMER, SeaFlux, OAFLUX, J-OFURO). 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,
- *Maximise* use of EO data, from European (and non European) missions. Of specific interest in this project is the use of re-processed data sets integrating data from ESA missions - including for example SST, SSH, Ocean Colour (from CCI), sea-state (from Data User Element DUE Globwave [URL-09]), current (from Data User Element Globcurrent), wind stress (from ERS-2), geoid (from GOCE), new generation reanalysis ERA-Clim, and possibly Soil Moisture & Ocean Salinity (SMOS) data (if deemed relevant for supporting flux calculation) - as input to the bulk flux calculations and/or integral constraints used for evaluation (e.g. CCI SSH to quantify OHC along with Argo, CCI Ocean Colour to quantify light attenuation in Cages or Bubbles).
- *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 synthesis). 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. The heat constraints will be based on Argo data combined with other in-situ and satellite data (Table 1).

- **Deliverable:**

- **D2.1: Reference Data Set:** This data set shall provide the user with a 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.

2.3.3 Task 3: Product generation, Inter-comparison and Uncertainty characterisation

- **Input:**

SOW, Contractor's Proposal, D1.1, D2.1

- **Task description:**

The task shall:

- 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,
- 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,
- Based on the recommended approach, generate an *ensemble* of realisations 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),
- 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).
- Produce a product handbook describing the product, specifications and strengths and limits for specific applications.

- **Deliverables:**

- **D4.1: 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.
- **D4.2: 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.

2.3.4 Task 4: Data Portal Development

- **Input:**

  SOW, Contractor's Proposal, Workshop Recommendations, D1.1, D2.1

- **Task description:**

This task shall develop a web-based data portal enabling to easily and quickly access and inter-compare ocean heat flux products with other reference data, such as in-situ data and reanalysis data. The portal, which will be developed incrementally, shall contain at least:

- General information about the project, including for example the technical documentation, the product handbook, data catalogue, newsletters, mailing list (with registration), discussion forum, Frequently Asked Questions, biography, calendar of meetings, list of presentations, Data portal facility giving access to the relevant data set, including the reference data set, the products and ensemble,
- A series of "light" tools (and links to existing relevant tools) to enable quick inter-comparison of different products and evaluation against observations. Examples of projects demonstrating useful web-based functionality for quick inter-comparisons are Felyx [URL-14], GODIVA [URL-15], Ocean Flux GHG [URL-11] and also the ECMWF Climate Monitoring Facility (CMF). The idea is that the portal could evolve in a longer term into a kind of "community platform" or "flux-e-laboratory" enabling easy processing (e.g. cloud computing, workflows) and inter-comparison of new climatologies in line with the Climatology Configurator developed within the Ocean Flux GreenHouse Gases [ULR-11], which offers to interested partners the ability to run their own climatology processing, selecting the parameterization and input data of their choices.
- A password-protected area containing an archive of internal project documentation (e.g. deliverables, minutes, presentations, etc.), and traceability of issues.

The web site is expected to evolve during the duration of the project and shall be maintained and regularly updated. It shall be hosted on contractor premises. Documents shall first be delivered to ESA for approval before being published on the web site.

- **Deliverable:**

- **D4.1: Data Portal :** This web site shall include an 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.

2.3.5 Task 5: Strategic Development

- **Input:**

SOW, Contractor's Proposal, Workshop Recommendations, D1.1

- **Task description:**

This task shall:

- Identify opportunities regarding potential development of products,
- Identify potential development paths, describing the needs and potential partnerships,
- Articulate a vision, and the requirements (e.g. needs, architecture) for the development of a "flux e-laboratory" enabling to test and deploy flux algorithms, enable scalable processing, analogous to the ESA Super Site Exploitation Platform and the OceanFlux GHG platform [URL-11].

- **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.

2.3.6 Task 6: Outreach & Coordination

- **Input:**

SOW, Contractor's Proposal.

- **Task description:**

This task shall:

- Coordinate with relevant networks, including for example CLIVAR, GEWEX, GSOP, and SeaFlux,
- Perform promotional activities, including a biannual newsletter, project brochures, and publications in scientific journals,
- Maintain a mailing list containing the email addresses of all known members of the user flux community, and the participants in workshops and promotional events,
- The newsletter shall be posted on the Flux Portal and circulated in electronic form to all email addresses on the mailing list,

- Present the project at relevant international events, including ESA events (e.g. Living Planet Symposium), and wider scientific events such as the GEWEX, CLIVAR, WCRP conferences and European Geophysical Union (EGU),
- Organise a final workshop with the user community to present the results of the workshop and discuss future development. The workshop can piggyback on major relevant conferences.

➢ **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.

2.4 Schedule & Milestones

The table 2 describes the schedule, deliverables, meetings and Milestones.

Ref	Tasks & Deliverable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Task 1	*Scientific Requirements Consolidation*																								
D1.1	Requirement Baseline Document				v1																				
Task 2	*Reference Data Set Generation*																								
D2.1	Reference Data Set						v1																		
Task 3	*Product Generation, Inter-comparison, & Uncertainty*																								
D3.1	Flux Assessment Report											v1													v2
D3.2	Product Handbook										v1													v2	
D3.3	Flux Product Data Set										v1											v2			
Task 4	*Data Portal Development*																								
D4.1	Data Portal			v1					v2						v3				v4						v5
Task 5	*Strategic Development*																								
D5.1	Scientific Roadmap						v1												v2						
Task 6	*Outreach & Coordination*																								
D6.1	Outreach Material											v1													v2
D6.2	Final Workshop Report																								v1
	Milestones	M1	M1	M1	M1	M1	M2	M2	M2	M2	M2	M2	M3	M3	M3	M3	M3	M3	M4	M4	M4	M4	M4	M4	M4
Duration	Meeting Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	Contract Meetings with ESA																								
1d	KickOff / Final meeting in ESA premises	X																							X
1d	Review Meetings							X											x						X
	Progress Meeting by Telecom									X															
	Final Workshop																								
1d	Workshop																						X		

Table 2: Schedule, meetings, deliverables and Milestones. For example, on the basis of the colour code, the milestone M1 includes D1.1, D2.1, D4.1v1.

Prior to all meetings, the Contractor shall prepare a report highlighting the status of the development. This report shall be delivered at least five days before the meeting takes place.

2.5 EO Data Procurement

The Contractor shall maximize the use of ESA data and products, such as the CCI and Glob data sets. The Contractor shall be entitled to acquire any ESA data required at conditions and prices for Category- 1 use [URL-00].

It is recognised that the provision of required EO-based products will require more than a single source of EO data. Therefore, the Contractor is encouraged to exploit both ESA TPM, and non-ESA EO mission data, as and where appropriate to the work to be carried out. In addition, and due to the needs for historical optical information, the Contractor is also encouraged to exploit the historical archives.

Data Procurement can be quoted but all satellite data procurement with the ESA budget will be property of ESA and will only be given at the disposal of the Contractor for the execution of the project. Terms and Conditions from the Data Distributors are to be understood and to be strictly fulfilled. Due to the Research and Development (R&D) nature of this contract, the Contractor shall explore the possibility to acquire the non-ESA data required for this project at an R&D compatible price.

3 REQUIREMENTS FOR MANAGEMENT & REPORTING

3.1 Management

3.1.1 Prime Contractor

The Prime Contractor shall appoint a Project Manager who shall provide the necessary administrative support to ensure the project remains within schedule, within budget and achieves its objectives. The Project Manager shall have a proven track record on managing large-scale international projects and an understanding of the technical and scientific issues being tackled in the project.

3.1.2 Project Manager

The Project Manager shall:

- Provide at KO and implement the “Project Management Plan” (PMP);
- Monitor progress of each task and identify, follow-up and close-out all problems or under-performance,
- Set up and maintain a project actions database,
- Organise internal quality review and ensure timeliness in submission of all deliverables,
- Compile monthly progress reports and minutes of meetings,
- Organize and attend progress meetings and ensure attendance by all necessary project team members.

- Update the Project Management Plan, which describes the plan for managing the activity, including project organization, analysis of risk factors, mitigation strategies, Work Breakdown Structure, Gantt charts, Work Package descriptions, identification of task leaders, Level of effort, quality procedure and plan to achieve quality.

3.2 Project Monitoring

Project monitoring is conducted through the generation and updating of the PMP and the delivery of Monthly Progress Reports.

3.2.1 Monthly Progress Reports

The contractor shall provide written status reports every month covering progress to date, schedule to completion, status of all minuted actions, issues affecting the project and proposed solutions.

3.2.2 Quarterly Progress Reports

The contractor shall provide written status reports every quarter, targeted at a non-technical audience, and presenting the main highlights of the projects, in particular related to products, communication, publications feedback of users and scientific impact.

3.3 Meetings

The list of major meetings detailed in Table 2 is as follows:

- KO meeting to be held at ESRIN,
- Progress Meetings to be held at the Contractor's premises or at ESRIN,
- Final Presentation to be held at ESRIN,
- Final workshop with the scientific flux community.

The Contractor shall make all organisational arrangements to prepare these meetings and shall circulate a draft agenda and meeting logistical information at least two weeks in advance. Choice of date, venue and agenda shall be subject to approval by ESA.

The Contractor shall chair all progress meetings, shall be responsible for all minutes and shall ensure all actions raised during the meetings are promptly recorded in the Actions Database.

Where progress is deemed by ESA to be unsatisfactory, recovery actions shall be identified and implemented.

3.4 Deliverables

3.4.1 Documentation

The contractor shall deliver the documents indicated in the Table 2. *Unless stated otherwise, no paper copies of the deliverables are required (only electronic).* Electronic documents shall be delivered in PDF.

It is recalled that the documents to be delivered are a *tool* to achieve the main *objectives* of the project and the delivery of a good *quality data set*. As such they shall be made as **concise** as possible and reviewed, before delivery to ESA, for:

- Scope, Completeness, Configuration control,
- Clarity, consistency, grammar, spelling,
- Scientific rigor

All documents delivered to ESA shall bear the following information:

- Document title; issue & version number; issue date
- Author(s) name & signature
- Reviewer(s) name & Signature
- Approver(s) name, organisation & signature Issuing Authority name & signature

All documents shall contain:

- Table of contents,
- Executive Summary,
- Change Record History with name of the various authors.

All documents shall refer to a single bibliography list that uniquely identifies each reference document.

All text revisions shall be recorded in change logs that provide information on the reason for the change, the issue number, revision number, date and pages and paragraphs affected.

All documents shall be clear, self-explanatory and self-contained.

A Final Report (as approved by the Technical Officer) shall be submitted at the end of project. The Executive Summary shall also be provided in searchable PDF format suitable for publishing on the Agency's Web Page.

Both documents shall be free of all commercial/ESA-authorised proprietary information, which should be provided under separate cover if necessary. No copyright nor dissemination restrictions shall be indicated.

3.4.2 Data Base

The contractor shall make sure the data shall be accessible and shareable by the community and in a widely format used format as Netcdf CF.

4 LIST OF FIGURES

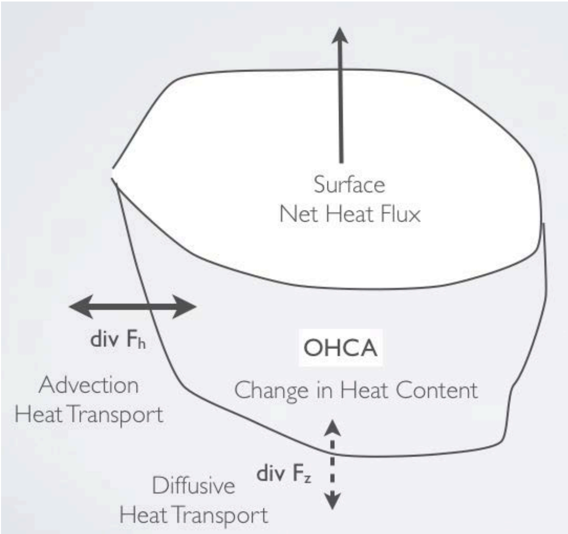

Figure 1: Illustration of a potential CAGE, highlighting a heat budget, where changes of OHC are compensated by lateral transport, and surface heat flux.

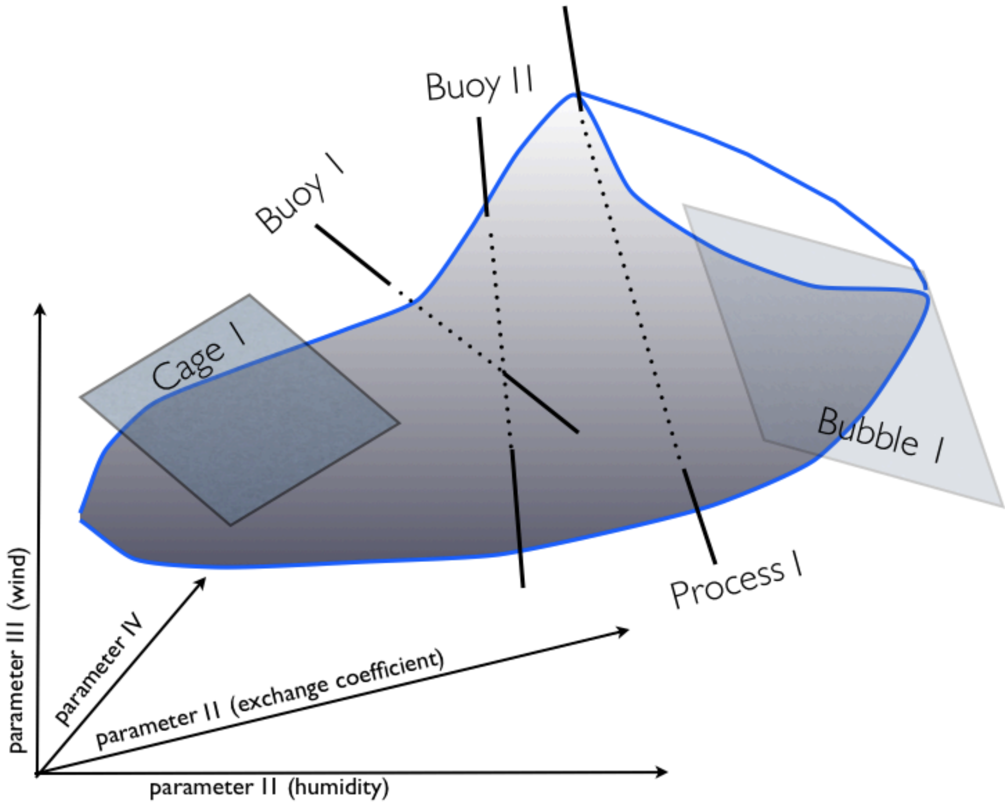

Figure 2: Ensemble of realisations of the Net Heat Flux in a multivariate space. The lines and planes represent the consistency checks base on point-wise in-situ observations, and regional heat constraints, respectively.