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OceanFlux GHG

Workshop Minutes v1.4

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STSE OceanFlux GHG

Workshop Minutes v1.4

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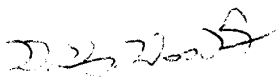
Prepared by/Lead Author (NHC)	David Woolf	Signature 
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1.1	17/02/2014	Main content written.	Peter Land David Woolf Fanny Girard-Ardhuin
1.2	18/02/2014	Added in missing info and tidied formatting.	Jamie Shutler
1.3	14/03/2014	Updated based on feedback from Craig Donlon.	Jamie Shutler
1.4	17/03/2014	Minor updates and corrections.	David Woolf.

DISTRIBUTION

Name	Company
Craig Donlon	ESA
David Woolf	NHC
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1. Introduction

1.1 OceanFlux GHG Overview

The air-sea flux of Greenhouse gases (GHGs) is a critical part of the climate system and a major factor in the development of the oceans (e.g. ocean acidification). More accurate and higher resolution calculations of these fluxes are required. We propose to deliver that improvement by bringing together expertise and capability in

- The physics of air-sea interaction and ocean waves.
- Marine Earth Observation
- Operational modelling of the oceans

A highly skilled and experienced international team was constructed under the leadership of Dr. David Woolf from the Environment Research Institute, which is part of North Highland College (NHC, UK) an Academic Partner within University of the Highlands and Islands. Dr Woolf is now at Heriot-Watt University but continues to lead the project.

The main output from the project will be a global $1^{o}\times1^{o}$ spatial resolution climatology and a higher spatial resolution subset of data for the European Shelf. This datasets will include information on data uncertainties and will be for the international SOLAS community to access and exploit**.**

Additional results and outputs from this project will include:

- Validated algorithms for studying air-sea gas interactions using Earth Observation.
- A number of key peer reviewed publications.

An end of project workshop and a clear framework for future ESA involvement in SOLAS related studies are also important outputs and this document encapsulates the achievements of the workshop.

1.2 Purpose and Scope of the scientific workshop minutes

This is the OceanFlux Greenhouse Gases scientific Workshop minutes (GHG-WS). It aims to provide an overview of the workshop, the work that was presented at the workshop, a list of the participants and a concise summary of the discussion sessions that took place during in the workshop. Some conclusions are then drawn.

1.3 Structure of this Report

The report is structured as follows:

- Section 1 (this section) the introduction gives an overview of the document aims and structure.
- Section 2 summarises the aims and outcomes of the workshop.
- Section 3 (annex 1) contains the discussion session minutes.
- Section 4 (annex 2) contains the list of participants.

1.4 Contributions

Table details the people who contributed to this report and the sections that they contributed to.

Table 1 Table of contributions.

Section	Primary author(s)	Contributing author(s)
Section 1	Jamie Shutler (PML)	
Section 2	Jamie Shutler (PML)	Jamie Shutler (PML) David Woolf (Heriot Watt) Fanny Girard-Ardhuin (IFREMER) Francine Loubrieu (IFREMER)
Section 3	Peter Land (PML)	Jamie Shutler (PML) David Woolf (Heriot Watt) Fanny Girard-Ardhuin (IFREMER) Francine Loubrieu (IFREMER)
Section 4	Fanny Girard-Ardhuin (IFREMER)	Jamie Shutler (PML) Francine Loubrieu (IFREMER)

1.5 Definitions and acronyms

CFOSAT	Chinese-French Oceanic SATellite
CO_2	Carbon dioxide
delta-C	Air-sea CO_2 concentration difference
DMS	Dimethyl sulphide
EGU	European Geophysical Union
EOS	Earth Observing System
ESA	European Space Agency
EU	European Union
Eumetsat	European Organisation for the Exploitation of Meteorological Satellites
GHG	Greenhouse gas
ICOS	Integrated Carbon Observation System
IFREMER	Institut Français de Recherche pour l'Exploitation de la Mer (France)
IPCC	Intergovernmental Panel on Climate Change
k	Gas transfer velocity
N_2	Nitrogen
NOAA	National Oceanographic and Atmospheric Administration (US)
NOC	National Oceanography Centre (UK)
O_2	Oxygen
OC-flux	ESA STSE project – Open ocean and Coastal CO_2 fluxes in support of carbon cycle monitoring
OLCI	Ocean Land Colour Instrument
OVOC	Oxygenated volatile organic compound
pCO_2	Partial pressure of CO_2
PML	Plymouth Marine Laboratory (UK)
Quikscat	Quick scatterometer, satellite sensor
S	salinity
SAR	Synthetic Aperture Radar
sigma0	Radar backscatter cross-section
SMOS	Soil Moisture and Ocean Salinity satellite sensor
SOCAT	Surface Ocean CO_2 Atlas
SOLAS	Surface Ocean and Lower Atmosphere Study
SOOP	Ship Of Opportunity Program
SST	Sea surface temperature
STSE	Support to Science Element
T	temperature
UHI	University of Highlands and Islands

2. Workshop

The scientific workshop was held at IFREMER, Brest, France on 24-27 September 2013, it was called "Air-sea Gas Flux Climatology, Progress and Future Prospects Science Workshop". The workshop was chaired by David Woolf (Heriot Watt University) and Bertrand Chapron (Ifremer).

The scientific workshop was jointly organized by the OceanFlux Greenhouse Gases project team, European Space Agency, Ifremer, and the Internataionl SOLAS community. It was funded within the OceanFlux Greenhouse Gases project with co sponsorship by the European Geophysical Union. We also had local sponsors such as Conseil Général du Finistère, Brest Métropole Océane, and Région Bretagne.

2.1 Aims and purpose

The air-sea transfer of gases is a major part of the budget of carbon dioxide and several other radiatively-important gases. While there are other methods for constraining global and basin budgets of the air-sea transfer, we depend on an air-sea gas flux equation for regional and sub-seasonal resolution of fluxes across the surface of the world's ocean.

That flux equation requires accurate values of transfer velocity, in addition to the concentrations of the dissolved gas in the upper ocean and in the lower atmosphere. This endeavour requires the maintenance of major observing systems (shipboard and satellite-borne) and deep understanding of transfer processes. It is a challenging task that will require interdisciplinary collaboration and cost-effective solutions.

Key aims will include

- Identifying key challenges facing the air-sea gas flux community
- Maintaining the ship-based observing system
- Maintaining the marine earth observation capability
- Addressing remaining gaps in fundamental knowledge
- Understanding and addressing the full set of uncertainties
- Identifying opportunities and setting priorities
- The requirements of the climate science and policy communities
- New earth observation technologies and missions
- New measurement techniques and opportunities for more autonomous measurements
- New modelling and statistical techniques

- The rapidly expanding capacity of cloud and other computing architecture

2.2 Organisation

The workshop has been organized at IFREMER, Brest, France. The main tasks of the organization were to:

- identify key participants and advertise them (through other workshops, email lists, etc…),
- find sponsors
- organize the local organization (booking of the facilities, logistical issues, accommodation and travel options…),
- manage of the registration and communicate with the participants
- organize the programme of the workshop
- select awardees among several grant applicants
- organize a press conference during the workshop
- made available the presentations available on the website

A dedicated website was setup for the workshop:

http://www.oceanflux-ghg.org/Workshop

and an email : oceanflux-workshop@ifremer.fr

2.3 Sponsors

EGU sponsorship was independently gained and was used to invite key participants. Other local sponsors, such as Brest Métropole Océane, Conseil Général and Région Bretagne, have been used to support partly the bus used daily between Brest city center (hotels) and the IFREMER institute and the bus needed for the diner of the conference.

Note that there were no registration fees for this workshop.

2.4 Invitations

Thanks to the EGU support and through the OceanFlux project budget for the conference, we were able to invite:

- An international expert on the CO_2 fluxes: Prof Andrew Watson
- The chair of International SOLAS: Dr Eric Saltzman
- A US expert in air-sea interaction: Dr Douglas Vandermark
- Five post-doctoral and/or early career scientists (one from USA, others from Europe): Mr Paget, Mrs Parard, Dr Bell, Mr Fiedler, Mr Steinhoff

2.5 Programme

The finbal programme and all presentations are available on the project website at:
http://www.oceanflux-ghg.org/Workshop/Agenda/

Day 1 - Sept 24 – Tuesday		
9:00 - 9:30	*Registration in the Hall*	
Welcome - Lucien Laubier Conference Room		
9:30 - 9:45	Welcome	David Woolf
9:45 - 10:00	Welcome to Ifremer	Bertrand Chapron, Ifremer, Brest center
Session 1 ESA & SOLAS ***Chair : Bertrand Chapron, Ifremer***		
10:00 - 10:20	ESA and SOLAS	Craig Donlon, ESA
10:20 - 10:40	International SOLAS and OceanFlux	Eric Saltzman, Chair of International SOLAS
10:40 - 11:00	The OceanFlux Greenhouse Gases project	David Woolf Heriot-Watt Univ., UK
11:00-11:30	*Coffee break & posters in the Hall*	
Session 2 Related projects ***Chair : David Woolf, Heriot-Watt University***		
11:30 – 11:50	OceanFlux Sea Spray	Gerrit de Leeuw FMI & UHEL Netherlands
11:50 - 12:10	OceanFlux Upwelling	Christoph Garbe Univ. of Heidelberg, Germany
12:10 - 12:30	An overview of the Takahashi air sea CO2 flux climatology	Richard Wanninkhof, NOAA/AOML
12:30 - 13:50	SOCAT- A global data product for quantification of air-sea exchange of CO2	Are Olsen Univ. of Bergen, Norway
13:00 - 14:00	*Lunch at Ifremer restaurant*	

Session 3; Air-Sea Fluxes (Context and OceanFlux) ***Chair : Andy Watson, Univesity of East Anglia***		
14:00 - 14:20	A flexible processing system for calculation of air-sea gas fluxes	Jamie Shutler PML, UK
14:20 - 14:40	Using satellite altimetry to measure air-sea transfer velocity	Lonneke Goddijn-Murphy ERI, UK
14:40 - 15:00	Enhancement of the oceanic turbulent fluxes estimated from remotely sensed data	Abderrahim Bentamy Ifremer, France
15:00 - 15:20	Extracting fluxes of GHGs at the air-water interface from satellite remote sensing	Christoph Garbe IWR, Germany
15:20 - 15:40	Towards super resolution of air-sea CO2 fluxes at the air-sea interface in the EBUS	Véronique Garçon CNRS/LEGOS, France
16:00-16:45	*Coffee break & posters in the Hall*	
Session 4; Futures ***Chair : Jamie Shutler, Plymouth Marine Laboratory***		
16:50 - 17:10	High Wind Gas Exchange Study, HiWinGS	Chris Fairall NOAA, USA
17:10 - 17:30	An ensemble approach to gas flux climatology	David Woolf Heriot-Watt Univ., UK
17:30 - 18:10	Discussion	
Day 2 - Sept 25 - Wednesday		
Session 5 Climatology and Carbon Dioxide ***Chair : Are Olsen, University of Bergen***		
9:00 - 9:20	The northern hemisphere air-sea CO2 flux - its variability and uncertainty	Ute Schuster Univ. of East Anglia, UK
9:20 - 9:40	Prediction of oceanic carbon dioxide levels at observational time series nodes using satellite ocean remote sensing products	Doug Vandemark

		UNH/EOS/OPAL, USA
9:40 - 10:00	Remote sensing algorithms for sea surface CO2 in the Baltic Sea	Gaëlle Parard Uppsala Univ., Sweden
10:00 - 10:20	Effect of mixing and stratification on the summertime carbonate chemistry of the northwestern European shelf	Dorothee Bakker Univ. of East Anglia, UK
10:20 - 10:40	Impact of coastal upwelling on the air-sea exchange of CO2 in a Baltic Sea basin	Sindu Raj Parampil Uppsala Univ., Sweden
10:40 - 11:00	Ocean-atmosphere CO2 flux variability estimated from SOCAT pCO2 observations	Christian Roedenbeck MPI Biogeochemistry, Germany
11:00-11:30	*Coffee break & posters in the Hall*	
Session 6 Slicks and Fluxes ***Chair : Helen Czerski, University of Southampton***		
11:30 - 11:50	Impact of climatology data geometry on the results of Empirical Orthogonal Function analysis	Ge Chen Ocean Univ. of China
11:50 - 12:10	The effect of surfactants on near-surface concentration fluctuations due to turbulence and wind stress	William Asher Univ of Washington, USA
12:10 - 12:30	Altimeter sigma0 bloom and surface slick	Jean Tournadre Ifremer, France
12:30 - 12:50	Air-sea gas exchange and bio-surfactants; low and high wind speed extremes	Alexander Soloviev Nova Univ., USA
13:00 - 14:00	*Lunch at Ifremer restaurant*	
13:45	*Group photo near Ifremer restaurant*	
Session 7 Fluxes and k ***Chair : Anna Rutgersson, Uppsala University***		
14:00 - 14:20	Uncertainty and ambiguity in gas transfer coefficients	David Woolf

		Heriot-Watt Univ., UK
14:20 - 14:40	The relationship between wind speed and gas exchange over the ocean revisited	Richard Wanninkhof NOAA, USA
14:40 - 15:00	Concurrent measurements of DMS and CO2 air/sea gas transfer by eddy correlation in the North Atlantic	Tom Bell PML, UK
15:00 - 15:20	Comparison of air-sea gas flux data from three tropical cyclones	Craig McNeil APL/UW, USA
15:20 - 15:40	Air-sea exchange of oxygenated volatile organic compounds over the Atlantic Basin	Mingxi Yang PML, UK
15:40 - 16:00	A perspective of the high surface-wind remote sensing capability with SMOS sensor	Nicolas Reul Ifremer, France
16:00-16:45	*Coffee break & posters in the Hall*	
Session 8 The bubbly ocean ***Chair : Craig McNeil, APL/UW***		
16:50 - 17:10	Dissipation source terms and whitecap statistics	Fabrice Ardhuin, Ifremer, France
17:10 - 17:30	Remote processing of Ocean Flux climatology on Nephelae	Jean-François Piollé Ifremer, France
17:30 - 17:50	Parameterising the bubble-mediated air-sea flux of a non-ideal gas, DMS	Penny Vlahos Univ. of Connecticut, USA
17:50 - 18:10	Estimating global active and total whitecap coverage for air-sea gas exchange using satellite-derived winds	Aaron Paget Brigham Univ., USA
18:15 19:30	Bus for Pointe Saint Mathieu Dinner at Pointe St Mathieu Restaurant	
Day 3 - Sept 26 - Thursday		
Session 9 Turbulent processes		

Chair : Fabrice Ardhuin, Ifremer		
9:00 - 9:20	Do we need to consider water-side convection when calculating air-sea gas transfer?	Anna Rutgersson Uppsala Univ., Sweden
9:20 - 9:40	Vertical and horizontal distributions of wave-induced turbulence	Nicolas Rascle Ifremer, France
9:40 – 10:00	Statistical properties of breaking waves in field condition; A Gaussian field approach	Alexey Mironov Ifremer, France
10:00 - 10:20	Numerical modelling of the air-sea interaction in wave breaking and consequences in terms of the air-sea gas exchanges	Alessandro Iafrati INSEAN-CNR, Italy
10:20 - 10:40	The effect of temperature, salinity and natural ocean surfactants on bubble fragmentation and coalescence	Helen Czerski Univ. of Southampton, UK
11:00-11:30	*Coffee break & posters in the Hall*	
Session 10 Freshwater, rain and ice ***Chair : Dorothee Bakker, University of East Anglia***		
11:30 – 11:50	Rain	Jamie Shutler PML, UK
11:50 – 12:10	Large tropical river plume monitoring with SMOS to better estimate Land-Sea freshwater fluxes	Séverine Fournier Ifremer, France
12:10 – 12:30	Air-sea gas exchange at ice surfaces	Wade McGillis Columbia Univ., USA
12:30 – 12:50	Precipitation and the global air-sea CO2 flux	Christopher Zappa, Columbia Univ., USA
13:00 - 14:00	*Lunch at Ifremer restaurant*	
Session 11; Perspectives on future research ***Chair : Eric Saltzman, University of California***		
14:00 - 14:20	When chemical oceanographers go robotic - towards accurate pCO2 measurements on novel autonomous platforms	Bjorn Fiedler

		GEOMAR, Germany
14:20 - 14:40	Progress on direct air/sea CO2 flux observations: results from DYNAMO2011 and TORERO2012	Ludovic Bariteau CIRES & NOAA, USA
14:40 - 15:00	Interfacial transport and turbulent statistics from thermography	Christoph Garbe Univ. of Heidelberg, Germany
15:00 - 15:20	Sensitivity of CO2 fluxes in a shelf environment	Ricardo Torres PML, UK
15:20 - 15:40	The observational platforms of PML for air-sea exchange	Tim Smyth PML, UK
16:00-16:45	*Coffee break & posters in the Hall*	
Session 12 Discussion I: The future of air-sea interaction research ***Chair : Chris Fairall and Craig Donlon***		
16:50 - 17:10	Air-sea exchange in strong winds	David Woolf Heriot-Watt Univ., UK
17:10 - 18:10	Discussion	
Day 4 - Sept 27 - Friday		
Session 13 Discussion II: Maintaining the CO2 Observing System ***Chair : Richard Wanninkhof and Diego Fernandez***		
9:00 - 9:30	Introduction	Andy Watson Univ. of East Anglia, Uk
9:30 – 11:00	Discussion	
11:00-11:30	*Coffee break & posters in the Hall*	
Session 14 : Discussion III: ESA and SOLAS; the continuing relationship ***Chair : Véronique Garçon and Christoph Garbe***		

11:30 – 13:00	Discussion
13:00	*End of the meeting*
13:00 - 14:00	*Lunch at Ifremer restaurant*

Posters have also been presented:

- ARCHER Stephen: Investigation of the influence of the sea surface microlayer on ozone deposition rates

- BOZEC Yann : High Frequency Monitoring of pCO2 using a CARIOCA sensor on a Marel buoy in a temperate coastal ecosystem: The Bay of Brest (2003-present)

- BRION Emilie : Estimating the CO2 fluxes over the North Atlantic subtropical basin

- GODDIJN-MURPHY Lonneke : The derivation of a CO2 fugacity climatology from SOCAT's global in situ data.

- HANAFIN Jenny : Comparison of WAVEWATCH-III ® model output whitecap fraction with in situ observations

- HARTMAN Susan : Controls on CO2 flux variation at a sustained observatory (PAP-SO) in the northeast Atlantic Ocean

- HO David : Rain-induced gas exchange: When and where does it matter?

- Dr JONES Steve : Decadal trends in surface ocean pCO2

- LOURANTOU Anna : On the assignment of prior ocean flux errors in CO_2 atmospheric inversions

- MARANDINO Christa : Interpretation of eddy covariance measurements of CO2 and DMS fluxes and gas transfer coefficients using outputs from the OceanFlux Greenhouse Gases project

- MARREC Pierre : Spatio-temporal dynamics of air-sea CO2 fluxes in the Western English Channel (WEC) based on FerryBox measurements

- WANNINKHOF Richard : The NOAA Ship of opportunity pCO2 project

- WOOLF David : Uncertainty and ambiguity in air-sea gas fluxes; a flexible system in response to a debate on transfer velocity.

2.6 Publications

The abstract book of the workshop is also available on the website. Publications on peer-reviewed journals are scheduled for 2014 in the EGU cross-journal special issue (Biogeosciences, Atmospheric Chemistry and Physics, Ocean Sciences) for the

workshop and is now open for submissions. Details of this special issue can be found on the workshop website and the EGU website of each journal.

2.7 Key issues of discussion

The chair of International SOLAS (Eric Saltzman, US) gave a key note talk (his travel was supported by the EGU) and the EGU ambassador Professor Andy Watson (University of Exeter, UK) gave a presentation and chaired a discussion session. Detailed minutes from these discussion sessions and all of the other discussion sessions (there were opportunities for discussions are each set of oral presentations – please see the timetable) that occurred during the workshop are given in Annexes (Section 3) of this document. Here follows an analysis of the issues that either provoked intensive discussions and/or issues that came up in discussion multiple times. The evidence for this analysis is found in the minutes for the discussion sessions in the Annexes (Section 3) of this document.

1. There is a need to understand and evaluate air-sea exchange in high winds (> 15 ms^{-1}) and related uncertainties. Empirical relationships have been developed for estimating k in hurricane conditions, however the impact of such systems on net-integrated fluxes in the Atlantic and Pacific have yet to be fully studied as most global flux studies concentrate on monthly fluxes that may miss such events (examples of high wind phenomena include hurricanes and polar lows). The limited understanding of air-sea exchange in strong winds was discussed and it seems timely to address the remaining uncertainties with the wide range of tools (ranging from Earth Observation through in situ measurement, physical modelling and numerical modelling to new theoretical paradigms) now available.
2. There is a need for a marine carbon observing system i.e. as part of the International Carbon Observing System (ICOS). EO has a clear role to play in developing this capability. The OceanFlux-GHG data processing system (FluxEngine) could be a component of such a system. The continued development of a "marine carbon observing system" was strongly endorsed by delegates. It was noted that the marine component lags behind other elements of the global carbon observing system, while accurate estimates of the North Atlantic sink, for example, are a realistic goal and can provide tight constraints on the terrestrial budget.
3. Air-sea gas flux work needs to exploit EO, models, and in situ data. In situ data from fixed platforms is a limited yet under exploited resource. Environmental monitoring platforms exist in the Gulf of Mexico. Offshore oil rigs and wind farms also offer great potential.
4. There is a need to study other gases and not just CO_2. e.g. behaviour or characteristics of gases other than CO_2 can help to interpret CO_2 fluxes or indirectly infer carbon cycling. Some research cruises are now addressing a multiplicity of gases including in situ data collection and process studies.
5. There is a clear need for the community to support the SOCAT initiative. This initiative is already producing very valuable outputs and it needs the community support (both time and funding) to continue.
6. Different mapping and interpolation methods can hide and/or create problems when interpreting data. The impacts of this on global net integrated air-sea

fluxes are unclear as yet. The SOCAT community have begun to look at this by organising a community inter-comparison.

7. It was identified that very little EO work has concentrated on Ocean acidification. This could be an opportunity for future work. Note: ESA STSE have a funding call open at the time of the workshop focussed on developing novel EO ocean acidification products.
8. The issues of freshwater inputs from large river systems and rain and their impact on CO_2 other gases was discussed. This also links with the Ocean Acidification case already discussed. This is one area where EO could clearly help. E.g. use of SMOS or Aquarius data, use of GPM data (and in the future the NASA SMAP mission) for freshwater inputs from large river systems.
9. There is a clear need for the community to use standard techniques and data formats. Other scientific communities are doing this, whereas the flux community has been slow to take this up. OceanFlux-GHG is using Climate Forcing (CF) compliant NetCDF format data.
10. There is a need to develop clear routes for communication of scientific developments and results through to policy.
    There is a clear need to identify the sources of and reduce the size of uncertainties in current air-sea flux estimates and approaches. OceanFlux-GHG has been working on this aspect and David Woolf gave a presentation of the approach at the workshop. The use of ensembles can be used to study uncertainties in air-sea gas fluxes. This is an approach that has been used with some success in the climate modelling community. It is not always possible to quantify all of the uncertainties, but it is still important to provide a reasonable range in the values on those that can't be quantified.
11. A number of communities are interested in the air-sea flux of CO2. There is a clear need for the broader air-sea CO2 flux community to meet frequently to learn from each others work and advances. This workshop has highlighted the benefit of such communication. This approach can be used to help pool resources and focus effort (and to avoid duplication).
12. The in situ gas flux community needs to start collecting SSTskin data and mean square slope data. The skin data should be used for the air-sea flux calculation and the mean square slope data will help support efforts to investigate more physically explained methods to parameterise the gas transfer velocity. If we want to exploit EO more, then we need to collect in situ data that is directly comparable to the EO data and the processes of interest.

2.8 Conclusions

The workshop was attended by more than 75 participants from all over the world, including the US, the UK, Sweden, France, Finland, Italy, Germany, China and The Netherlands. Within the participants there was a mixture of scientists, from EO specialists through to in situ scientists and modellers, and both senior scientists and PhD students.

The European Space Agency (ESA) were very happy with the overall scientific workshop, the quality of the work presented the discussion sessions. They were particularly happy with the amount of interaction and involvement from the wider international SOLAS community.

The discussions during and at the end of the workshop have provided clear avenues for future work that fit both within the International SOLAS plans and aims, and are within the scope of work that the European Space Agency are keen to support.

There was Strong International support for OceanFlux-GHG work, the gas-flux workshop and the OceanFlux-GHG data processing capability that is available for the community to exploit.

An EGU cross-journal special issue (Biogeosciences, Atmospheric Chemistry and Physics, Ocean Sciences) for the workshop is open for submissions.

3. Annex 1 - Minutes from discussion sessions

3.1 Tuesday discussion following David Woolf's talk (high winds)

Alex Soloviev: consider a simple dimensional analysis. The flux is not dependent on density or viscosity, this leaves surface tension, which breaks down at ~30m/s.

David Woolf: Importance of bubbles/droplets?

Alex Soloviev: Droplets not important for flux at low U, maybe more at high U, airside dominates. Tanks have small fetch, can run for a long time. Computational fluid dynamics small scale, short time, complementary.

?: North Sea storms look different from open ocean.

David Woolf: Could be wave/current interaction.

Craig McNeil: Need to use modelling, will never get many hurricane data, need to also look at eg Southern Ocean.

?: Miami have built a tank that can model a Cat 5 hurricane.

?: currents in shelf seas are important and wave/current interaction

?: Close water side by planting Argo floats with O2 sensors ahead of hurricanes.

Craig McNeil: Hit & miss getting the track location right.

McNeil: simulations are the way forward as a tool for interpreting data and better parameterisations. Field study opportunities are limited so need to look elsewhere for inspiration.

Veronique Garcon: high resolution wind time series are needed.

?: SOLAS needs new 10 year plan.

?: Satellite winds – what spatial scale & timeseries length?

?: As small, long & consistent as possible.

David Woolf: Do we need DMS?

Tom Bell: More compounds allow us to know whether we're really understanding the system. So its good to study multiple gases at the same time.

Tom Bell: looking at other gases can help understand CO2. Ie DMS including ancillary data.

?: What about HiWings? Should pin down 12-18m/s.

Tom Bell: We need ancillary data. Surface looks shredded even at 15-18m/s.

Alex S: How about DMS sensors in storm tracks?

?: Range of gases is important (we used O_2 and N_2, need more for calibration of parameterizations).

Ming Yang: CO_2, DMS, acetone, other OVOCs. Air injection more important for O_2 and N_2 because high air concentration.

Solieviev: Use of fixed platforms to collect data.

?: Towers in Gulf of Mexico instrumented already. Wind farms are coastal sites with strong winds.

Aaron Paget: platforms in the gulf of Mexico exist. What experiments could these be used for ?

Aaron Paget: platforms and wind farms. Why not use these ?

Jamie Shutler: need to be aware (and find a solution for) of health and safety issues as these can block the use of platforms for research. We put in two bids for instrumenting wind farms but logistical problems. Research platform in N Sea but funding issues.

Craig Donlon: Climatologies of other gases?

?: Dissolved O_2.

?: Importance of mapping, drivers and complexity from Christoph Garbe's talk. Learn from methods, strengths and weaknesses.

?: When is a trend a trend? Need clear definition.

Tom Bell: Climatologies of trace gases work with many fewer points than CO_2 (DMS second with 40k points).

David W: Need to try other mapping techniques. Tough to fill gaps for other gases. Gridding and interpolation may be harmful as viewed from an outsiders perspective. Ie may look like we have more data than we do!

Craig Donlon: Global maps are good but don't kid yourself – maybe move away from gridded data and acknowledge lack of data. Show politicians a full map, they say no need to do more!

Craig McNeil: use different gases and look at them together to understand gas exchange. The HiWinds project has started this.

Eric Salzman: Oceanflux for other gases would have the support of SOLAS.

Tom Bell: DMS climatology has associated errors – essential. Good to provide gridded data so that it is clear where the holes are.

Alex S: parameterizations without physics is shooting in the dark – unlikely to have global applicability.

Craig Donlon: Need to define some regions for study, carve up the oceans.

?: Rain synergy between satellites and in situ, eg stratification, high resolution rain measurements.

Doug Vandemark: issues of rain, what can be done here ? is CO2 the main gas of interest for rain ?

?: SST and rain could be important, but no in situ data exist to get a handle on this.

Wade McGillis: Dilution effect based on carbonate chemistry, dearth of data during rain, challenging environment and can lose sensors. CO_2 nonlinear due to carbonate chemistry, O_2 likely to be linear.

David Woolf: Would SMOS be useful?

Craig Donlon: SMOS can see fresh water pools, but there are diffuculties with using it.

Wade McGillis: Lots of bin averaging. Evaporation competes with mixing, probably dominates SMOS signal.

David Woolf: could SMOS be used to study amazon plume and freshwater influence. Interest in the input from large rivers ?

Dorothee Bakker: SMOS would be useful for sea ice melt and river plumes

Arre Olsen: Alkalinity and freshwater can influence ocean acidification in coastal environments.

Jamie Shutler: Need in situ sensors for SST effect of rain.

Christoph Garbe: Can we achieve closure? Are the errors too big?

Alex S: Most models assume whitecap coverage approaches 100% at high wind, untrue.

Craig Donlon: use T-S diagrams, alkalinity impacts on CO_2 flux.

David Woolf: Look at impact of great rivers on CO_2 exchange: SMOS can see them.

?: That and sea ice melt are good SMOS applications, need carbonate chemistry, rivers can have significant alkalinity.

Tim Smyth: SMOS low spatial and temporal resolution, need T-S upscaling, eg N Sea has many river inputs and storm events. need to be aware of the spatial and temporal resolution of SMOS.

Christoph Garbe: Big river plumes have had little carbonate work done on them, SOLAS opportunity?

Jamie Shutler: How useful is SMOS in the Arctic?

Roberto Sabia: Low emissivity in cold waters, ice/land contamination

Craig Donlon: Need to agree regions to do different things (CO_2, others), agree protocols, validate climatologies with independent data, decide on consistent presentation. Generate alternatives to current version. Gridding techniques. Global versus regional parameterizations. Going beyond climatologies. Rain – could do more with SMOS and rain radar. Ice edge, blooms. Rivers. ESA needs input on what the project should do.

David Woolf: Tool is community owned, it's up to you to make it what you want it to be.

Eric S: SOLAS discussion document is on SOLAS website (white paper), please do contribute and give feedback and comments.

3.2 Friday session 1 discussion following Andy Watson's talk about ICOS

David Woolf: Need for ocean observing network rather than ships and stations. Should include satellite data.

Andy Watson: Satellite SST and chlorophyll taken for granted, wouldn't work without them. Floats and gliders significant in ~5 years.

Dorothee Bakker: no connection in ICOS between land and ocean.

Andy Watson: Ocean didn't exist in ICOS for first 4 years (2008-12).

Anna Rutgersson: Is micrometeorology included in ICOS? What region does it cover?

Andy Watson: Yes, but few data available so it's in a research context rather than operational. Area covered is N Atlantic and marginal seas (Med, Baltic, Norwegian, Greenland), but need to integrate globally.

Craig Donlon: European Community integrated projects decimated small science – need to empower individual scientists, who can then help improve the system as a whole. ICOS looks very top down.

Andy Watson: ICOS top management has very top down attitude.

3.3 Discussion following Rik Wanninkhof's talk about NOAA SOOP/CO_2 effort

Rik W: Who are our customers/stakeholders?

?: Ocean acidification community are interested.

Craig Donlon: Governments have a statutory requirement through IPCC process, with that comes the climate modelling community.

Rik W: How do we communicate with policy makers?

Craig Donlon: Through scientific papers, so we have confidence in our conclusions and knowledge of the uncertainty.

Anna R: The scientific community are the stakeholders.

Rik W: Yes, but beware of isolation.

Craig Donlon: Term is 'user/producers'.

?: Need to constrain models, very important users.

Rik W: Overriding scientific goals?

David Woolf: Constrain N Hemisphere sink. Need credible k with possible local parameterizations.

?: Biogeochemical changes also affect global circulation, not just T and S.

Andy Watson: Need to understand how the oceanic food source for humanity will change over the next 100 years, including the role of carbonate chemistry.

?: Need to quantify ecosystem services.

Rik W: Can we form better connections between the k and delta-C communities? Do we need to?

Ming Yang: Distinction is artificial. Better to compare directly measured flux with climatology.

David Woolf: Comparison is not meaningful. The mean of lots of flux measurements doesn't necessarily converge on the climatological mean, it's a sampling problem. Might be better to use a time series at a given location.

Rik W: What about ships of opportunity?

David Woolf: Need time series with few gaps to make meaningful comparison. Even fixed stations have data gaps.

Rik W: k, delta-C approach gives gap filling potential.

Andy Watson: Comparing direct flux measurement is the terrestrial situation, very difficult. Nature has given us a way of measuring a very small flux using k and delta-C, we should use it.

Ute Schuster: Definition of climatology 10-30 years of data, how is a 2005 map a climatology?

David Woolf: Our climatology is a long term average referenced to a particular year to allow for long term trends. K and delta-C communities need to interact more meaningfully than just using each other's data. Should we meet again to set ourselves goals?

?: We can get insights into k and delta-C using direct fluxes.

Rick W?: global k's are constrained. Regional k's aren't constrained enough.

Craig Donlon: Useful discussion. Rationale to meet is to define next version of OCFlux – we can look at ensembles, but how do we say how useful they are? Brilliant people are often quite shy, we need to bring them together to forget about work and talk.

Veronique Garcon: this workshop has demonstrated that the k and delta-C communities need to meet regularly and keep talking, eg at SOLAS meetings.

Craig Donlon: Yes, but bridges are still needed.

Andy Watson: EU Horizon 2020 program needs a project to put numbers on eg N Hemisphere land and ocean fluxes. Carbochange community just uses Wannikhof 92, insufficient. Need to get together and propose project.

Rik W: Space agencies need feedback about the utility of their products for fluxes.

?: Straightforward to add other gases.

Christoph Garbe: Need to measure air side concentration.

Jamie Shutler: Skin temperature from ship using a radiometer would be very useful.

Craig Donlon: We have 10 autonomous radiometers [IR sensors] on ships around the world. Need N-S and E-W coverage to avoid aliasing. Role of surface currents in k, divergence and convergence…

?: team up with these IR sensor operators ?

?: new sensors for atmospheric gases. SCHIAMACHY has gone. Need something else. Vertical integrated gases are good to have.

?: how about a community goal to reduce uncertainty by 25%. ie to work towards isolating ways in which we can reduce the uncertainties. E.g. can EO help in specific ways (e.g. can EO help in specific regions to help bring down regional and thus global uncertainties ?)

Jamie Shutler: OceanFlux is collating uncertainty information for the climatology work. We're keen to get community generated ensemble to support this work.

?: needed [uncertainties] for development of model and its evaluation for ICOS.

? vertical column CO2 information is important.

Rik W: In regions with sparse pCO2 coverage, eg S Ocean, delta-C is the dominant error, while in eg N Atlantic, k is dominant.

?: Mixed layer depth is a key variable for mapping pCO2.

Jamie Shutler: Mixed layer depth is included in quality layers.

Rik W: Are we happy with satellite winds?

Anna R: Need higher resolution round coastlines.

Tom Bell: wind is from backscatter and mean square slope, so why do we measure wind at sea ? (and not MSS or backscatter?). Can mean square slope (MSS) data be made available to the community.

Jamie Shutler: MSS is in the climatology and can be accessed using the flux data processing system.

Craig Donlon: Sentinel 1 will improve this when it goes up, though you'll need a big internet connection. It'll be revolutionary, challenging, exciting.

Rik W: Satellite products can be customised for the community.

?: need community to recognise these data products and get someone to generate useful products for the community.

Bertrand Chapron: It's a challenge to unite small and large scales using satellites. Improve understanding of heat and momentum transfer including models.

?: Quikscat gives winds at 1km resolution, but dynamic problems near coast. Interested in validation efforts near coast, huge step to get realistic retrievals.

Rik W: There are lots of meteorological buoys around the coast measuring wind.

?: Insufficient coverage, data processing issues.

Ming Yang: Interesting to get mean slope from a geostationary satellite with in situ measurements below.

Bertrand Chapron: Remote sensing electromagnetic data that must be interpreted, interpret directly in terms of bubbles, spray etc. rather than through models of wind speed. Altimeter sampling rate is low, but could be tractable.

David Wool: Large arrays, direction relative to wind. Swell development important to whitecaps/bubbles, hard to quantify. Focus on large waves, could introduce regional bias to k parameterizations.

Bertrand Chapron: CFOSAT French/Chinese. Need to go beyond forecast winds using eg SAR to study relaxed seas. W band can be used to retrieve mean square slope, 1km pixels, altimeter 7-20km. We average small scale phenomena but don't understand them.

Rik W: Ensembles generally rigidly defined, this is more ad hoc.

David Woolf: Can't quantify all uncertainties, more a scenario approach like IPCC. Don't assign uncertainty, just range.

Jamie Shutler: Community needs to decide what goes into ensemble.

Dorothee Bakker: More techniques for gap filling? Alternative mappings are needed in the ensemble.

David Woolf: Yes, with more ESA money we can include other options.

Rik W: Options for forecasting?

David Woolf: Forecast eg SST and trust we can establish a relationship with CO_2, or try to forecast CO_2, eg Riqui's (Torres) modelling. Very hard, need to wait for improvement.

Craig Donlon: Show of hands to help generating climatology? Some, need more.

(autonomous sensors)

Rik W: Ocean acidification community has made a huge push, flux not there yet. Not enough standardization techniques.

Jamie Shutler: Key to filling in gaps, even if poorer quality.

Rik W: Bias is the killer. Need to measure pCO_2 in air.

Jamie Shutler: Autonomous sensors need characterizing.

Rik W: This is critical.

Jamie Shutle: Not a huge workload to define a climatology.

Dorothee Bakker: SOCAT Version 3 deadline end 2013, earlier is better.

3.4 Discussion following Veronique Garcon and Christoph Garbe's talks

?: Need to present forward (5 year) plan to member states. Concepts of missions. Another opportunity is Changing Earth Science annual small pot for postdocs.

Jenny Hanafin: Each year we get 12-13 hurricane force winds southeast of Greenland. Synthesis of satellite/in situ/model. Model and RS close in extent and magnitude. Used Wavewatch 3 to model evolution.

Rik W: Want to use Christoph's [Garbe's] list to improve gas flux parameterizations.

Notes: Christoph's Garbe's list (compiled from workshop attendees and discussions over the past few days)

- Better instruments for gas measurements over water bodies
- Fluxes of mass, momentum and energy
- Regional focus (not only global inventories etc.)
- Applications to sea ice
  - –Characterization, fluxes etc.
- Salinity and alkalinity
- Detection and quantification of organic matter
- Wide range of gases
  - –Different diffusivity and solubility
- Climatologies for other gases
- Process studies of drivers of interfacial transport
- Rain effects
- Bubble effects
- Derive better parameterisations

Tom B: Is ESA supportive of new directions or evolution of what's gone before?

Christoph Garbe: Biological effects important to SOLAS, not really covered by meeting. Is ESA open to these?

Craig Donlon: In principle, yes – need right projects. OLCI operated by Eumetsat, not ESA. ESA funds limited for this, may be better to seek EU funding. Phytoplankton functional types limited by packaging etc.

Tim Smyth: Phytoplankton functional types not clearly related to function, can do size which might be related to function. Forward planning for new sensors to deliver fluxes.

Craig Donlon: Earth Explorer programme suitable, need white paper with clear outputs. Need community to sign up to it.

Tim Smyth: Needs STSE to exploit existing RS with in situ.

Diego Fernandez: STSE includes new missions – Earth Explorers right.

Bertrand Chapron et al: Quikscat higher winds over blooms – changes surface tension and wave response to winds.

Christoph Garbe: Please send new satellite ideas to me and Veronique or Craig and Diego.

4. Annex 2 – List of participants

The participants to the workshop are listed in the following table.

Title	Family_Name	First_Name	InstituteCompany	Country
Dr	Adjou	Mohamed	IUEM	France
Dr	Ardhuin	Fabrice	IFREMER	France
Dr	Asher	William	University of Washington	USA
Mrs	Autret	Emmanuelle	IFREMER	France
Dr	Bakker	Dorothee	University of East Anglia	UK
Mr	Bariteau	Ludovic	CIRES and NOAA	USA
Dr	Bell	Tom	Plymouth Marine Laboratory	UK
Dr	Bentamy	Abderrahim	IFREMER	France
Dr	Bozec	Yann	Marine Chemistry Unit-SBR/CNRS	France
Ms	Brion	Emilie	ALTRAN Ouest	France
Dr	Caulliez	Guillemette	Mediterranean Institute of Oceanography	France
Dr	Chapron	Bertrand	IFREMER	France
Dr	Czerski	Helen	Institute for Sound and Vibration Research, University of Southampton	UK
Dr	Donlon	Craig	ESA	The Netherlands
Dr	Fairall	Chris	NOAA	USA

Dr	Fenglin	Tian	University of Quigdao	China
Dr	Fernandez	Diego	ESA	Italy
Dr	Fiedler	Bjorn	GEOMAR Helmholtz Centre for Ocean Research Kiel	Germany
Ms	Fournier	Séverine	IFREMER	France
Dr	Garbe	Christoph	IWR / University of Heidelberg	Germany
Dr	Garcon	Véronique	CNRS/LEGOS	France
Pr	Ge	Chen	Ocean University of China	China
Dr	Girard-Ardhuin	Fanny	IFREMER	France
Dr	Goddijn-Murphy	Lonneke	Environmental Research Institute	Scotland
Mrs	Hanafin	Jenny	UBO-LPO	France
Ms	Hartman	Susan	NOC-UK	UK
Dr	Ho	David	University of Hawaii	USA
Dr	Iafrati	Alessandro	INSEAN-CNR	Italia
Dr	Jessup	Andrew	Applied Physics Laboratory, University of Washington	USA
Dr	Jones	Steve	University of East Anglia	UK
Dr	Land	Peter	Plymouth Marine Laboratory	UK
Dr	Langmann	Baerbel	Institute of Geophysics, University of Hamburg, KlimaCampus	Germany
Mr	Leckler	Fabien	IFREMER	France
Pr	de Leeuw	Gerrit	FMI & UHEL	Finland

Ms	Loubrieu	Francine	IFREMER	France
Dr	Lourantou	Anna	Laboratoire des Sciences du Climat et de l'Environnement	France
Dr	Marandino	Christa	GEOMAR	Germany
Mr	Marrec	Pierre	Station biologique de Roscoff	France
Mr	Matei	Adrian	University of Southampton	UK
Dr	McGillis	Wade	Columbia University	USA
Dr	McNeil	Craig	APL/UW	USA
Dr	Mironov	Alexey	IFREMER	France
Dr	Olsen	Are	Geophysical Institute, University of Bergen	Norway
Dr	Paget	Aaron	Brigham Young University	USA
Dr	Parampil	Sindu	Uppsala University	Sweden
Dr	Parard	Gaëlle	Uppsala University	Sweden
Mr	Paul	Frédéric	IFREMER	France
Mr	Piollé	Jean-François	IFREMER	France
Dr	Prytherch	John	NOC, Southampton	UK
Dr	Rascle	Nicolas	IFREMER	France
Mr	Rawat	Arshad	IFREMER	France
Dr	Reul	Nicolas	IFREMER	France
Dr	Richier	Laurent	Altran Ouest	France

Dr	Roedenbeck	Christian	MPI Biogeochemistry	Germany
Pr	Rutgersson	Anna	Uppsala University	Swden
Dr	Sabia	Roberto	ESA	Italy
Dr	Saltzman	Eric	University of California	USA
Dr	Schuster	Ute	University of East Anglia	UK
Dr	Shutler	Jamie	Plymouth Marine Laboratory	UK
Mr	Sims	Richard	Plymouth Marine Laboratory	UK
Dr	Smyth	Tim	Plymouth Marine Laboratory	UK
Pr	Soloviev	Alexander	Oceanographic Center, Nova Southeastern University	USA
Dr	Steinhoff	Tobias	GEOMAR Helmholtz Centre for Ocean Research, Kiel	Germany
Mr	Sudre	Joël	LEGOS/CNRS	France
Dr	Torres	Ricardo	Plymouth Marine Laboratory	UK
Dr	Tournadre	Jean	IFREMER	France
Dr	Tynan	Eithne	NOCS, University of Southampton	UK
Dr	Vandemark	Doug	UNH/EOS/OPAL	USA
Dr	Vlahos	Penny	University of Connecticut	USA
Dr	Wanninkhof	Richard	NOAA/AOML	USA
Dr	Watson	Andy	University of East Anglia	UK
Dr	Woolf	David	Heriot-Watt University	UK

Dr	Yahia	Hussein	INRIA	France
Dr	Yang	Mingxi	Plymouth Marine Laboratory	UK
Pr	Zappa	Christopher J	Lamont-Doherty Earth Observatory of Columbia University	USA

Table 1 : list of participants

This was an international workshop with 21% of the participants who are non European people (USA and Chinese participants). European institutes have been represented at 60% by UK and French people.

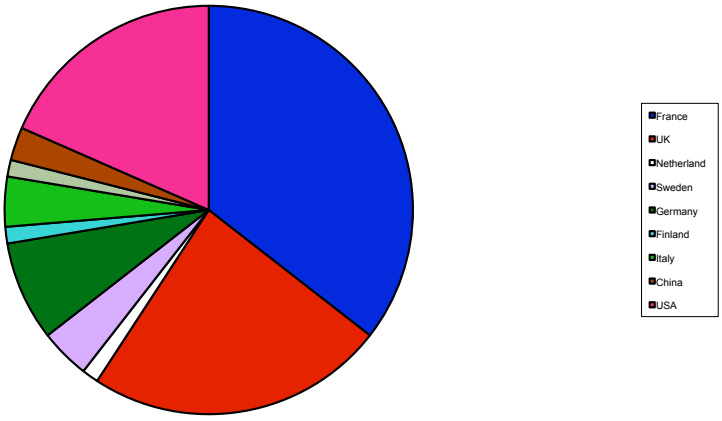

Figure 1 : participants

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