Advancing the global observation of air-sea fluxes and linking these observations to global surface observing

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1. Introduction

The oceanographic community, with the OOPC providing leadership, has moved forward to develop oceanic surface heat flux and oceanic surface wind stress as Essential Climate Variables (ECVs)/Essential Ocean Variables (EOVs) to be measured under the Global Climate Observing System (GCOS) and Global Ocean Observing System (GOOS). Development of a strategy to accomplish the goal of global ocean observations of the surface fluxes and their state variable ECVs/EOVs has been laid out in a set of Community White Papers prepared for the Ocean Obs 19 meeting to be held in September 2019. The overall strategy (Cronin et al., 2019) will draw upon remote sensing methods, in-situ observations, and surface fields from numerical weather prediction (NWP) models that integrate these observations in a dynamically consistent way. There are many challenges to be addressed, including learning how to sample the strong spatio-temporal variability of the surface meteorological and air-sea flux fields, optimizing remote sensing of surface atmospheric fields, continuing development of the parameterizations used to estimate the fluxes from the bulk observables, and finding the support to sustain the in-situ observing systems. As a first step, there is the need to develop robust observing requirements for both the air-sea fluxes (wind stress, sensible and latent heat flux, short and longwave radiation) and the meteorological variables used in their parameterisation (hereafter related ECVs: primarily wind speed and direction, near surface air and sea temperatures, humidity, precipitation, surface currents, and sea level pressure). There is also a desire to ensure, where possible, the consistency of requirements across ocean, land and ice-covered regions. Each OceanObs 19 Community White paper (see refs) details strategies envisioned by a worldwide community of experts. Bringing the lead authors for air-sea flux and flux state variable EOV together into a team of experts could provide an unique opportunity to leverage across disciplines to achieve common goals for observing accurate air-sea fluxes. The following recommendations represent near-term activities identified by these CWP as high priority.

2. Building blocks

In the face of the daunting challenges in achieving these goals, it is proposed that obstacles be identified and addressed in a series of workshops that draw diverse participation from land, ocean, and atmospheric disciplines, from scientific and technical experts, from in-situ and remote sensing observers, and from modelers and assemblers of hybrid fields. A goal of the meeting of the joint panels in Marrakech in March will be to further develop this list of such building block workshops and activities to initiate progress.

Necessary steps:
1) Review accuracy and sampling requirements for surface ECVs.
2) Identify how best to sample fields in regions characterized by strong signals and rapid temporal and/or spatial variations.
3) Motivate improvements to the methods of making and assembling global fields of surface state variables and fluxes, building off the efforts of Ocean Obs19.

The goal of each workshop is to improve cross-disciplinary interactions and the state of the art in the topic area, with the hope of removing an obstacle from the paths toward global oceanic surface fluxes and all-earth fields of surface state variables and fluxes.

2.1. Review accuracy and sampling requirements for surface ECVs:

Goal: Review accuracy and sampling requirements for surface ECVs measurements using satellite and in situ approaches.

This is core business for the GCOS panels who should take a lead on this effort. In general, the following steps are required:

1) Review flux and related surface ECV accuracy and spatial/temporal resolution requirements for relevant applications .
2) Assess the accuracy of existing ECV and flux products, identifying regions, conditions, periods etc. that need particular attention. Identify where consistent products do not presently exist.
3) Review accuracies of existing and proposed measurement systems (gap analysis)
4) Define observing strategy to include:
    a) High quality in situ reference stations with extended timeseries of co-located full flux and related ECVs
    b) Baseline in situ measurements providing extended timeseries of radiation fluxes and metocean state.
    c) short intensive measurement campaigns to understand variability
    d) dedicated flux campaigns (ship or mooring based) in regions/conditions of high uncertainty in turbulent flux parameterisations.

    e) requirements for satellite and in situ observations to e.g. constrain reanalyses, fill gaps or provide calibration and validation
5) Evaluation of observing system adequacy

There are opportunities to compare approaches across ocean-atmosphere and land-atmosphere domains. Priorities include:

- **Surface radiation:** In situ and remote sensing observations of surface radiation, over the earth surface, land, ocean, and cryosphere
- **Other near surface state variables:** In situ and remotely sensed near surface wind, pressure, humidity and air temperature
- **Surface Temperature**: in-situ and remotely sensed surface temperature over the earth surface
- **Other surface variables:** In situ and remotely sensed observations of wind stress and surface currents
- **Other marine surface variables:** sea state

Among the possible variables, it is proposed that surface radiation be the focus of an early workshop.

2.2 Understanding and measuring fluxes in different regimes:

GOAL: How best to observe a region characterised by strong Temporal and Spatial Variability and signals.

To properly observe air-sea fluxes, the temporal and spatial variability must be understood. Strategies must then be developed for how to sample without contributing a bias to the global fields;

To tackle these topics, working through WCRP, WWRP and other research groups will be essential. Consider opportunities such as the Year of the Maritime Continent, and Year of Polar Prediction and other big experiments, leveraging upswing in interest in experiments in support of coupled forecast systems development, and the opportunities presented by the UN Decade of Ocean Science for sustainable development; with the aim of delivering a legacy for the sustained observing system. Potential priorities include:

- Temporal variability: Where and when does diurnal variability need to be resolved? What sampling is required in regions of extreme storms that are short duration and sporadic?
- Spatial variability: Air-sea fluxes in frontal and cold air outbreak regions

For the temporal variability questions, we can encourage that upcoming and planned CLIVAR workshops and satellite science team meetings specifically address the relative importance and challenges of observing the diurnal cycle. For addressing the spatial variability questions, a new workshop is proposed below.

3. Product development

GOAL: To motivate improvements to the strategies and methods to assemble global fields of surface state variables and fluxes.

The WCRP/CLIVAR Global Synthesis and Observation Panel (GSOP) is mandated to 1. Develop, promote and seek to implement strategies for the synthesis of global ocean, atmosphere and coupled climate information. Methods will include observation-based syntheses and model-based syntheses e.g. Reanalyses. We will therefore work with GSOP to develop strategies for using the flux EOV and ECV observations to produce, test, and improve gridded flux products. As a first step, the team will engage the model community with a set of reference data sets that could be used to develop and test the model bulk flux algorithms.

4. Broader engagement

GOAL: To motivate the community to develop and implement strategies for producing high quality, high resolution global fields of surface state variables and fluxes.

It will be necessary to engage with a wide range of specialists and stakeholders. Examples include the modeling community, air-sea interaction researchers, satellite experts and developers of new technology.

As part of OceanObs 19, more than a dozen CWP have been submitted related to air-sea fluxes that aim to provide strategies and methods to assemble global fields of surface state variables and fluxes. In an effort to synthesize their goals and recommendations, the authors of the CWP listed below have joined together to propose a conference breakout session titled **"Gateway Between Water and Air: Observing Atmosphere-Ocean Fluxes".**

Through this breakout session, recommendations and roadmaps for these CWP will be reviewed, highlighting areas of synergy, where communities can work together and leverage each other's efforts. Synthesizing the goals and strategies from these groups will be a major task, however, that will go beyond what can be accomplished at a conference breakout session. For this reason, this team of leaders is looking for a mechanism for forming a longer-lived working group. It is expected that this team will produce an integrated set of recommendations reflecting cross-disciplinary community priorities aimed to improve observations of interactions and exchanges across the air-sea interface. As this team will have members from many different communities, they will be in position to help organize implementation of these recommendations.

5. Proposed actions

5.1 Workshop on surface radiation

Oceanographic platforms provide incoming shortwave and incoming longwave radiation, and net shortwave radiation is estimated using either a fixed value or parameterization of the albedo, which quantifies the amount of shortwave reflected from the ocean surface. Net longwave is usually estimated using a modified black body formula for the emission of longwave radiation from the sea surface. The oceanographic community supports arrays of surface moorings in many regions, and the remote sensing community has used the in-situ observations to quantify the accuracy of new surface radiation product for the global ocean. While in the past there were some interactions between land-based observers, such as the Baseline Surface Radiation Network (BSRN), and ocean-based observers, it would be timely to now refresh the dialog about observing techniques and uncertainties and how best to establish the provenance and accuracies of ocean as well as land-based surface radiation observation. How should shortwave radiation be measured from a non-stationary platform? How best should radiation sensors be calibrated and how, by exposure to the sky or to a halogen lamp? And against what standard? It would also be of use to investigate together where, from remote-sensing and modeling perspectives, additional, new surface observations should be established. Would surface moorings, for example, in the region of the Atlantic Ocean where Saharan dust is seen be of use? Additionally, should in-situ radiation observations be provided in real time, either to calibrate remote sensing methods or to initialize models? More generally, is there a pathway towards improving surface radiation in models?

5.2 Workshop on observations in frontal regions and cold air outbreak regimes

Another topic for consideration for an early workshop would be how to meet the challenge of properly sampling the surface fluxes in a cold-air outbreak region such as the western North Atlantic Gulf Stream region. During the winter, cold and dry air can flow over the warm Gulf Stream and very large latent and sensible heat fluxes contribute to net heat loss from the ocean that approaches 2,000 W m^{-2} in places. Because the Gulf Stream itself is spatially complex, with thin filaments and eddies and because internal boundary layers and clouds develop in the atmosphere above the Gulf Stream, the resultant spatial field of air-sea fluxes is also very complex. How does one best sample such a region? And how can it be sampled by limited in-situ and other resources so that resultant sample averages are not biased in comparison to a true spatial average? Of concern is that undersampling of such a complex field of strong signals may contribute a significant bias to Atlantic basin averaged fluxes, which are much smaller. More generally, as ocean, land, and atmosphere investigators work together to examine issues such as the earth’s energy imbalance, how does uncertainty in regional energy balances in such a cold-air outbreak region compromise our understanding of the processes that maintain the global energy balance? Would modeling and representation of such regions be improved by more in-situ resources?

5.3 Resolving diurnal cycles and rapid temporal variability associated with extreme weather events

This topic could be leveraged in existing and planned workshops. Upcoming WCRP/CLIVAR meetings include the workshop on Atmospheric Convection and Air-Sea Interactions in the Tropical Oceans, to be held in Boulder CO USA May 7-9, 2019.

5.4 Working group on Air-Sea Fluxes: roadmap forward

The OceanObs19 conference, through their Community White Papers, provides a natural way to find the forward-thinking leaders within each community. There are roughly a dozen CWP related to air-sea fluxes and their state variables. Lead writers for each of these CWP have come together to form a group proposing a breakout discussion at the conference. In particular, they plan to review goals and recommendations in each of their CWP and find areas of synergy, where these different communities can work together and leverage each other’s efforts. The expected outcomes will be a synthesized set of recommendations that reflect cross-disciplinary community priorities aimed to improve observations of interactions and exchanges across the air-sea interface. Such an effort is laudable but is more likely to be successful if the group has a longer time horizon and more forums than just a breakout session at a conference. This team of leaders could be more successful as a GOOS task team or project, similar to Deep Ocean Observing System (DOOS). It is expected that such a team would be particularly useful for coordinating activities in space agencies of different countries and interoperability across different observing networks.

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