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Food for Thought

Developing an Observing Air–Sea Interactions Strategy (OASIS) for the global ocean

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The Observing Air–Sea Interactions Strategy (OASIS) is a new United Nations Decade of Ocean Science for Sustainable Development programme working to develop a practical, integrated approach for observing air–sea interactions globally for improved Earth system (including ecosystem) forecasts, CO_2 uptake assessments called for by the Paris Agreement, and invaluable surface ocean information for decision makers. Our "Theory of Change" relies upon leveraged multi-disciplinary activities, partnerships, and capacity strengthening. Recommendations from >40 OceanObs'19 community papers and a series of workshops have been consolidated into three interlinked Grand Ideas for creating #1: a globally distributed network of mobile air–sea observing platforms built around an expanded array of long-term time-series stations; #2: a satellite network, with high spatial and temporal resolution, optimized for measuring air–sea fluxes; and #3: improved representation of air–sea coupling in a hierarchy of Earth system models. OASIS activities are organized across five Theme Teams: (1) Observing Network Design & Model Improvement; (2) Partnership & Capacity Strengthening; (3) UN Decade OASIS Actions; (4) Best Practices & Interoperability Experiments; and (5) Findable–Accessible–Interoperable–Reusable (FAIR) models, data, and OASIS products. Stakeholders, including researchers, are actively recruited to participate in Theme Teams to help promote a predicted, safe, clean, healthy, resilient, and productive ocean.

Keywords: air-sea flux, carbon dioxide uptake, climate, global, multi-stressor, Observing Air-Sea Interactions Strategy (OASIS), observation, satellite, UN Decade of Ocean Sciences for Sustainable Development, weather.

Introduction

The sea surface supports maritime commerce and is the portion of the ocean viewed from space. The sea surface, and the interacting layers of ocean and atmosphere, has a profound influence on human and marine life. The ocean modulates the Earth's weather and climate through exchanges of heat, moisture, momentum, greenhouse gasses, and aerosols at the air–sea interface. These air–sea fluxes act as forces on the ocean's physical and living environment, without which the ocean would essentially be static, dark, and dead. Observations of air–sea interactions are used in forecasts of floods, droughts, marine heatwaves, severe storms, sea state, coastal inundation, climate variability, and other hazards with significant implications for regional and global economies and populations, especially those of coastal regions and Small Island Developing States (SIDS). Over the next decade, as nations meet or fail to meet the reductions of greenhouse gas emissions called for by the Paris Agreement, it will be ever more critical to monitor ocean CO_2 absorption and resulting impacts on the ocean carbonate system and marine life.

Co-designing the OASIS

The Observing Air–Sea Interactions Strategy (OASIS) has its roots in *OceanObs'19* (https://www.oceanobs19.net), a once-per-decade conference to build a community vision for transforming ocean observations and ocean information over the next decade. Of the 140 published community perspective papers from OceanObs'19, >40 were related to observing air–sea interactions. Three interlinked "Grand Ideas" emerged (Figure 1) for creating Grand Idea #1: **a globally distributed network of mobile air–sea interaction observing platforms built around an expanded array of fixed stations that provide long-term time-series in key regions**. At some point, these stations should each be enhanced with process studies and/or supersites, which would fully resolve interactions and feedbacks. These observations would then help to construct and validate satellite retrievals, develop new artificial intelligence modelling tools, and support "Grand Idea" #2: creating a **satellite network, with high spatial and temporal resolution, optimized for measuring air–sea fluxes.** Finally, "Grand Idea" #3, which depends on the first two, calls for **improved understanding and process representation of the air–sea coupling in a hierarchy of Earth system models.** Together, these expanded observing capabilities and improved representations of air–sea interaction will lead to more reliable weather, climate, and ecosystem forecasts and reanalyses.

The individual recommendations defining these transformational actions are now being harmonized by cross discipline Theme Teams (TT), and anchored to societal issues through a series of virtual workshops with stakeholder partners following the principles of co-design laid out by IOC-UNESCO (2021). These UN Ocean Decade Laboratories satellite events have included virtual workshops on air–sea observations for a Predicted Ocean (Cronin *et al.*, 2021), a Clean Ocean (Marandino *et al.*, 2022), a Safe Ocean (Venkatesan *et al.*, 2022), an Accessible Ocean, and Offshore Wind Energy. More information on past and planned workshops can be found on airseaobs.org.

Theory of change

It is clear that to realize these Grand Ideas, we must work together. A "Theory of Change" was proposed (Figure 2), which turns one of the most challenging aspects of measuring air–sea fluxes, the need to measure multiple co-located Essential Ocean Variables (EOVs), into a transformative opportunity to co-design an ideal and fit-for-purpose observing system. Multifunctional platforms are not only more economical than multiple single-function platforms, they also encourage collaborations across disciplines and areas of expertise. New sensors must be carefully tested and integrated into platforms to ensure interoperability and maximize utility. By developing best practices and technical readiness procedures, and fostering a culture of mentorship and partnership, the capacity of the observing system could be significantly expanded

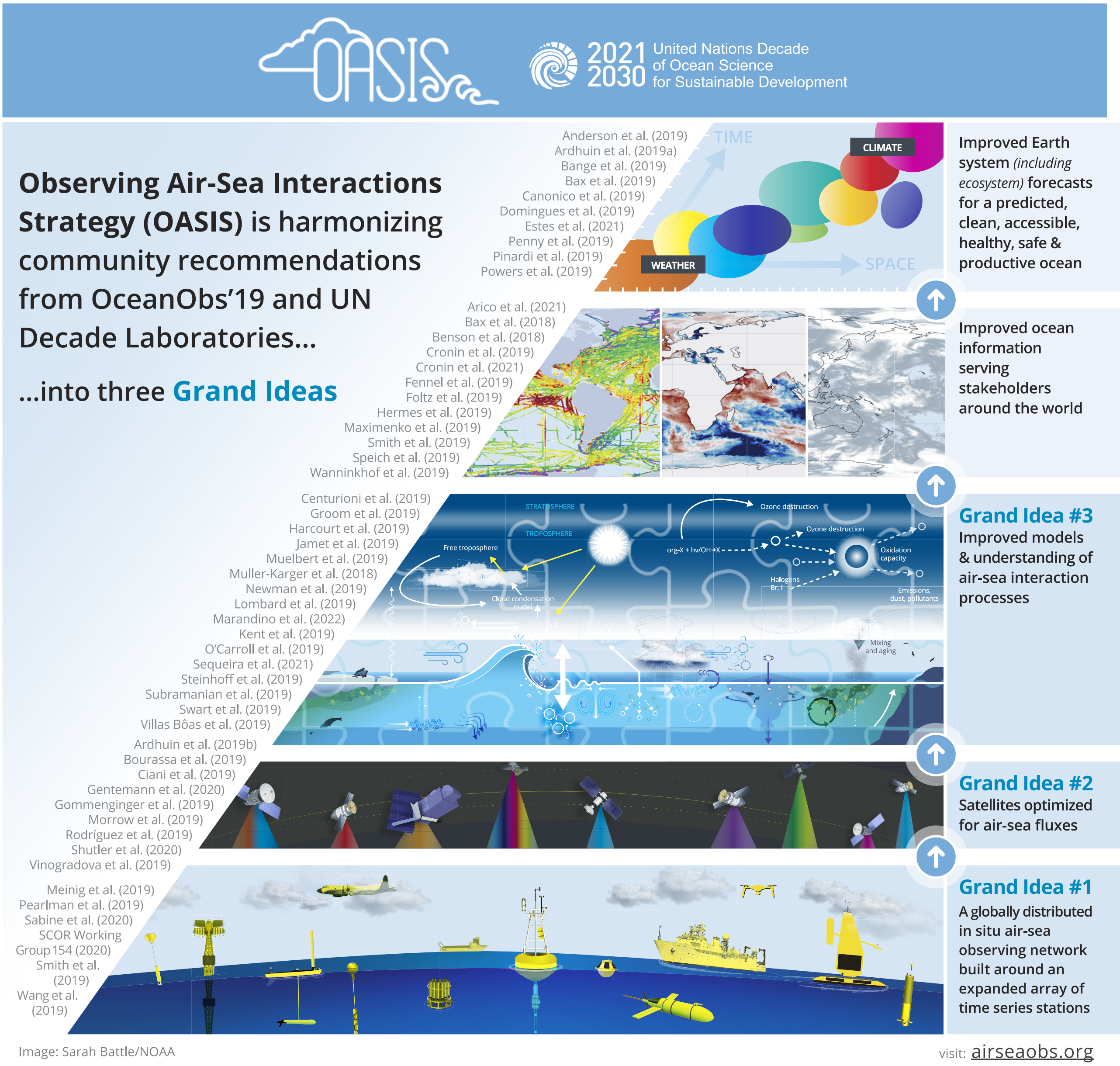

Figure 1. Three interlinked "Grand Ideas" of the OASIS and their relation to an end-to-end ocean information delivery for improved Earth system forecasts, including for ecosystems. Community strategy paper citations calling for the OASIS recommendations are shown here and in the reference list. Mapped fields in the second from the top layer, include (left) surface $p\mathrm{CO_2}$ from the Surface Ocean $\mathrm{CO_2}$ Atlas (Bakker *et al.*, 2016), (middle) daily average net downward heat flux on 3 September 2010 from prototype ORAS6 reanalysis, and (right) total cloud cover from ECMWF Reanalysis-5 (ERA5) reanalysis (Hersbach *et al.*, 2020) at 3 September 2010 T -12:00.

while providing opportunities for engagement by Early Career Ocean Professionals (ECOPs) and scientists from under-resourced nations and institutions. In addition, the co-location of multiple EOVs, including Essential Biodiversity Variables (EBVs), will revolutionize our ability to interrogate impacts from multiple stressors on ecosystems, from changes in biogeochemistry to components of the food web, and build robust state-of-the-art ecological forecasts.

OASIS SCOR working group #162 and TTs

Membership of the OASIS Scientific Committee for Ocean Research (SCOR) Working Group (WG) #162 covers multiple disciplines and methodologies, and spans data creators to information users (i.e. "end-to-end"). OASIS includes representatives from all Global Ocean Observing System (GOOS) panels (physics and climate, biogeochemistry, and biology/ecosystem). The WG spans the globe and is diverse in terms of gender and career level. Nearly all members were involved in OceanObs'19 either as lead or contributing authors with significant ties to user communities in their respective nations and regions.

One of the WG's first activities was to get OASIS endorsed as a UN Decade of Ocean Science for Sustainable Development Programme. OASIS will work with community members across five TT (Figure 3):

The "Observing Network Design & Model Development" TT will harmonize OceanObs'19 and other community rec-

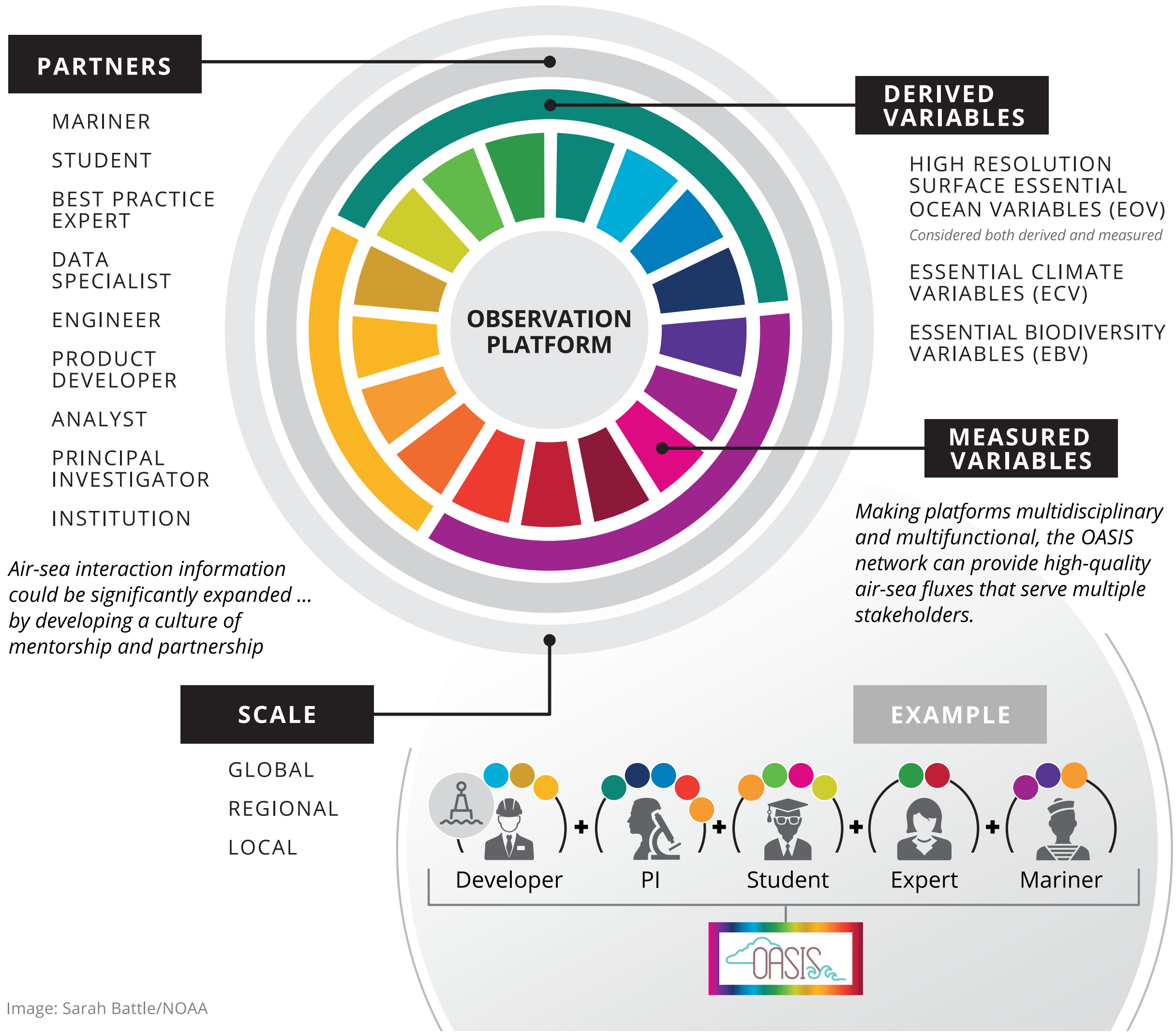

Figure 2. OASIS Theory of Change.

ommendations into a coherent strategy and will define process studies and transformational actions needed to reach our 2030 goals of a predicted, healthy, resilient, productive, clean, and safe ocean.

The "Partnership & Capacity Strengthening" TT will work with the other teams to offer curricula for a range of learners, from children to graduate students to mariners. Additionally, workshops, short courses, and mentoring programs will be initiated around the world.

The "UN Decade OASIS Actions" TT will work to implement OASIS projects by leveraging opportunities provided through the UN Ocean Decade and Ocean Decade National Committees.

The "Best Practices & Interoperability Experiments" TT will develop, document, and share best practices for collecting observations while simultaneously performing experiments to ensure that the air–sea interaction variables are interoperable across platforms.

The "Findable–Accessible–Interoperable–Reusable (FAIR) Data, Models & OASIS Products" TT will guide the development and accessibility of air–sea flux software toolboxes and gridded flux products, and work to make air–sea interaction information open and FAIR.

To get involved in any of these TTs, and/or sign up to receive the OASIS newsletter, go to: https://airseaobs.org/get-involved.

Looking forward to 2030, and back to 1972

OASIS hopes to make a major change in the observing and understanding of air–sea interactions through transformational actions, including an expanded *in situ* observing network, improved observations from space, improved understanding and representation in coupled models, and a significant increase in the capacity to make observations globally and have them used globally.

The famous photo of Earth (Figure 4) taken by the Apollo 17 astronauts en route to the Moon in 1972 changed our perspective of our place in the Universe. Fifty years later, anthropogenic global warming is undeniable, and our adverse impact on Earth must change.

OASIS can help build an observing network that would track the ocean's uptake of heat and carbon dioxide, and constrain numerical models for improved weather, climate, water, and ecosystem forecasts and reanalyses. Through OASIS, we hope that the world gains a better understanding of the deli-

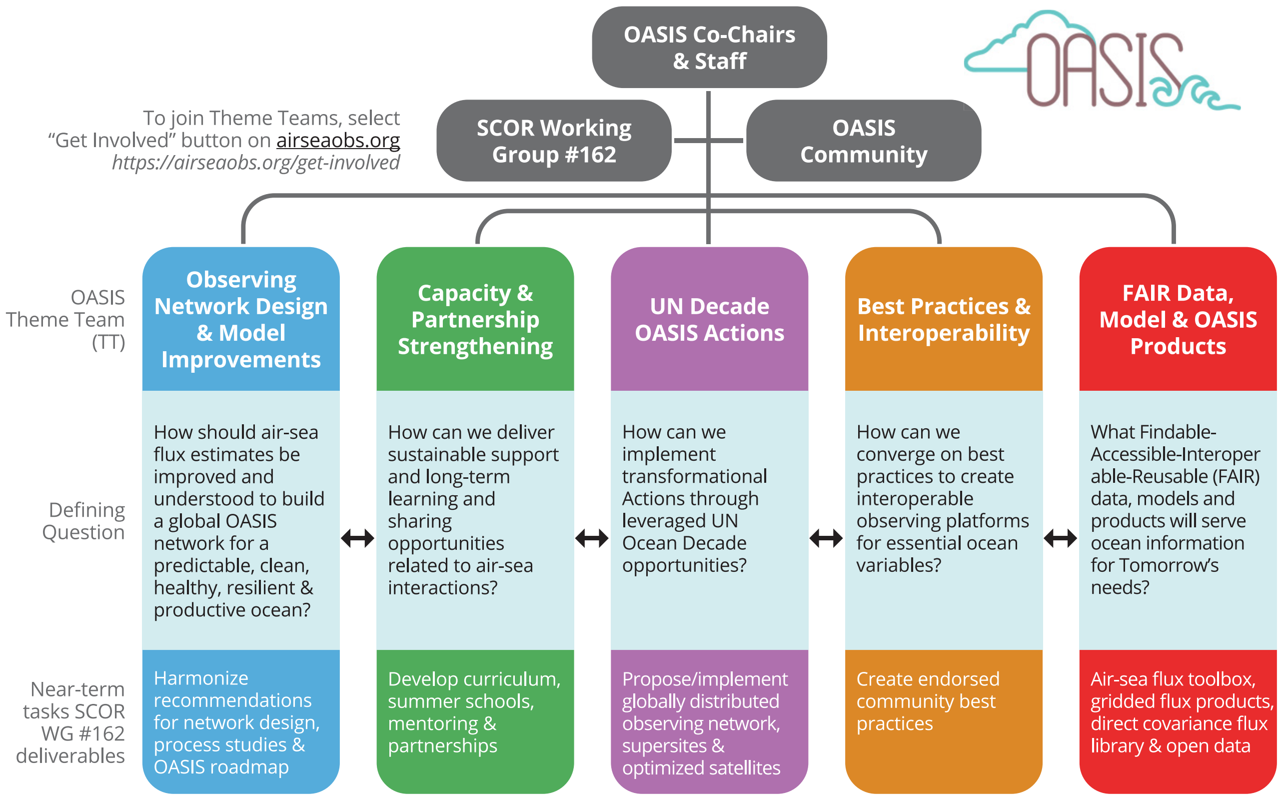

Figure 3. OASIS organization chart depicting the five community-based TTs.

Figure 4. The "Blue Marble" photograph of the Earth was taken by the crew of Apollo 17 en route to the Moon on 7 December 1972. Image courtesy: NASA (see: https://www.nasa.gov/topics/earth/features/astronauts_eyes.html).

cate balances that govern weather, climate, water, the carbon cycle, and the ocean environment, and a better understanding of how to maintain these balances for the benefit of all.

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Data availability

No new data were generated or analysed in support of this research.

Authors' contribution

OASIS was conceived by the SCOR WG #162 and lead authors of OceanObs19 papers included here as co-authors. MFC drafted the manuscript and finalized edits; all authors discussed ideas and contributed edits. SB created Figures 1–3. The manuscript is submitted with the approval of all the authors.

Conflict of interest

The authors declare no conflicts of interest.

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