Super Sites for advancing understanding of the oceanic and atmospheric boundary layers

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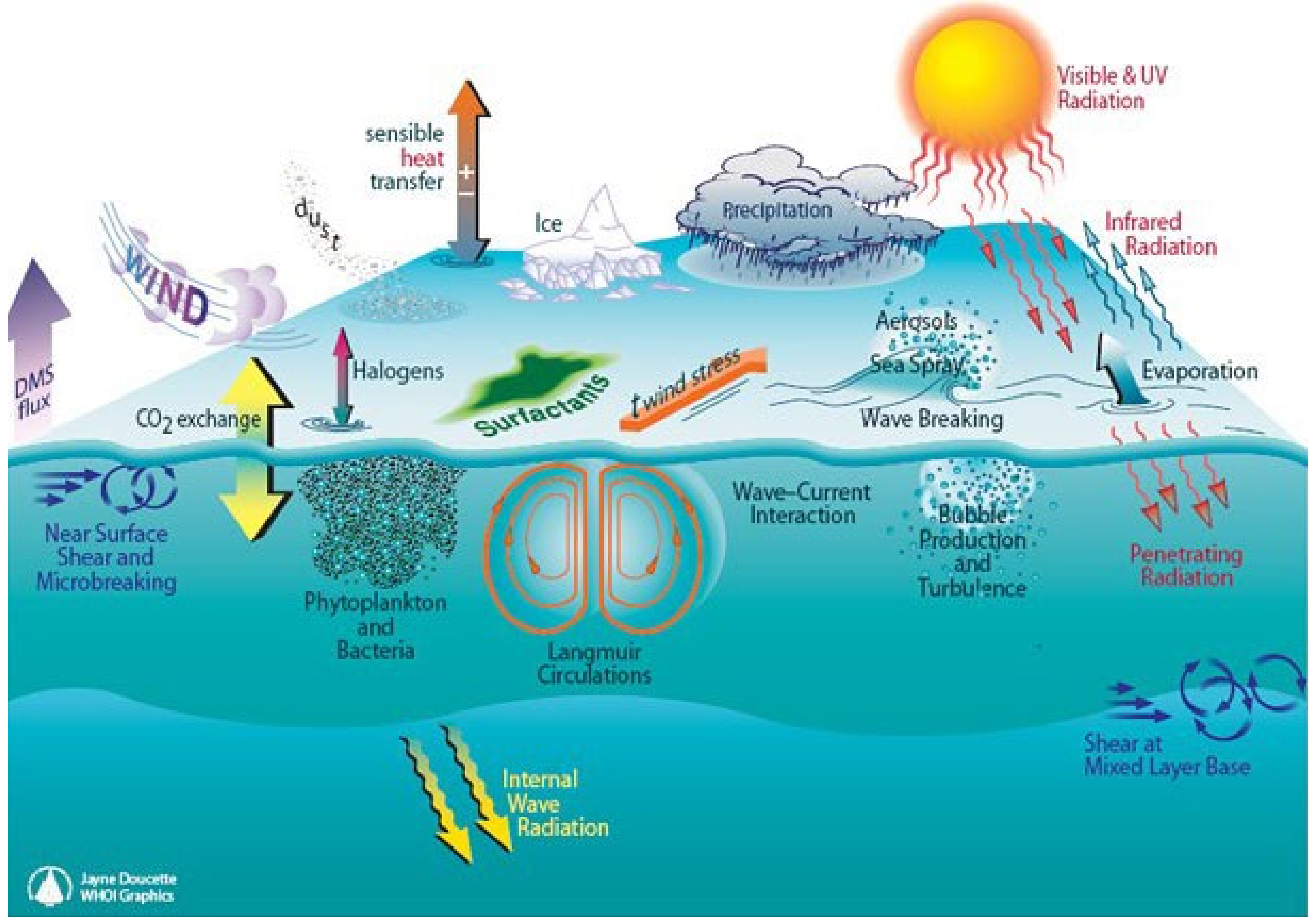
Abstract

Air-sea interactions are *critical* to large-scale weather and climate predictions because of the ocean's ability to absorb excess atmospheric heat and carbon and regulate exchanges of momentum, heat, water vapor and other greenhouse gasses. These exchanges are controlled by molecular, turbulent, and wave-driven processes across the *coupled atmospheric and oceanic boundary layers*. Improved understanding and representation of these processes in models are key for increasing Earth system prediction skill, particularly for sub-seasonal to decadal time scales. Our understanding and ability to model these processes within this coupled system is presently inadequate due in large part to a lack of data: contemporaneous long-term observations from the top of the marine atmospheric boundary layer to the base of the oceanic mixing layer.



We propose the concept of "Super Sites" to provide multi-year suites of measurements at specific locations to simultaneously characterize physical and biogeochemical processes within the coupled boundary layers at high spatial and temporal resolution. Measurements will be made from floating platforms, buoys, towers, and autonomous vehicles, utilizing both in situ and remote sensors. The engineering challenges and level of coordination, integration, and interoperability required to develop these coupled ocean-atmosphere Super Sites place them in an "Ocean Shot" class.

ABSTRACT
CHALLENGES
VISION
CONNECTIONS
OPPORTUNITIES
COLLABORATORS

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Challenges addressed

The coupled boundary layers are at the heart of weather and climate predictions

The Intergovernmental Panel on Climate Change (IPCC) has over multiple reports stated that clouds are at the heart of the most significant source of uncertainty in our climate projections. Clouds that form in the marine planetary boundary layer play a key role in this climate feedback. These clouds form as a result of atmospheric boundary layer variables including the temperature and humidity profiles, as well as aerosols such as salt and sulfate particles. The flux of heat, moisture, momentum, and particles between the ocean and atmosphere help set the structure of the atmospheric boundary layer (ABL), while being highly dependent on the ocean surface state, which is itself highly dependent on the turbulent processes in the oceanic boundary layer (OBL). In turn, processes in the OBL are intimately connected with these air-sea fluxes, and the atmospheric processes which affect them.

Thus, in order to better model this key component of the climate system, numerical weather prediction and climate models have increasingly turned to higher horizontal resolution, now approaching a resolution roughly equal to the depths of the ABL, the regime known as the “grey zone.” However, there is currently little theoretical and numerical modelling basis for how to represent this appropriately due to the lack of data.

A new approach is needed to provide long-term, high-resolution, coincident observations of the fully coupled atmosphere-ocean boundary layers at the atmospheric submesoscale, with an emphasis on understanding the processes connected to air-sea coupling. Such an approach should focus on the coupled boundary layers and their interface as a single entity, rather than as a sum of the three components. This approach should also span the many types of observations that are needed across the physical and biogeochemical systems.

Technology has been a traditional challenge

The advent of oceanographic Autonomous Surface and Underwater Vehicles (ASVs and AUVs) has revolutionized our ability to study the upper ocean. However, it has proven more challenging to observe the interface regions and especially the atmospheric boundary layer. Understanding the fluxes between the ocean and atmosphere requires many variables, including very accurate high-frequency near-surface atmospheric measurements, wave properties, and gas concentrations, typically over long time scales. Our technology for observing the atmospheric boundary layer has so far been limited to instruments on short-term ship deployments, and very infrequently on air-sea towers. Recently-developed tools can now collect better wave and wave boundary layer measurements, and ship-based platforms are ready to transition to an autonomous surface, sub-surface, and airborne platforms.

ABSTRACT

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CONNECTIONS

OPPORTUNITIES

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Vision & transformative impact

A new approach to long-term collection of innovative boundary layer data

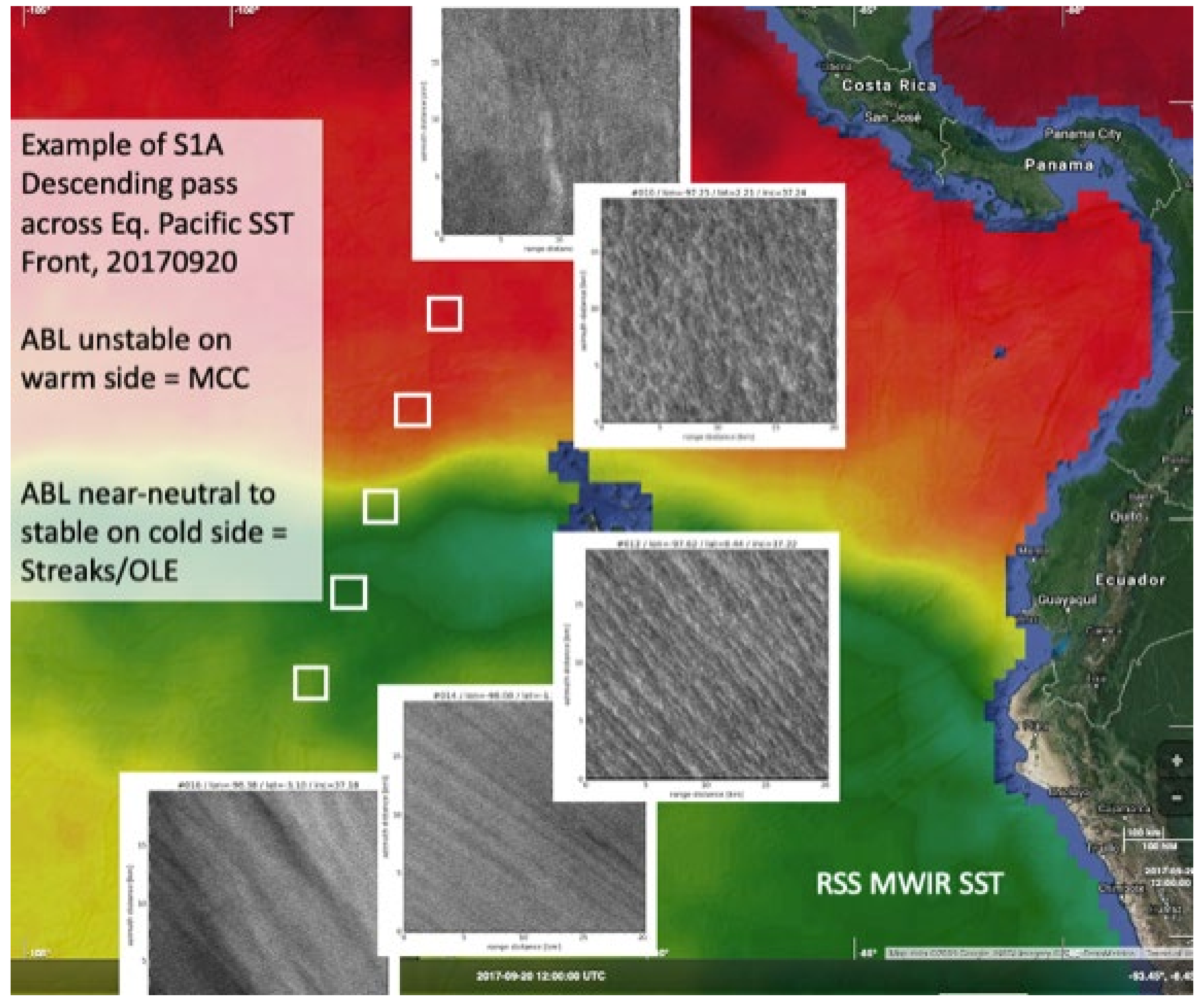
Super Sites will provide the long-term suites of state-of-the-art measurements that are critically needed to fully characterize coupled ocean-atmosphere boundary layer variability over a wide variety of weather and ocean states. This new measurement capability will provide the necessary data to allow us to improve and validate high-resolution atmosphere-ocean coupled models and satellite-based products; improve key process parameterizations for coarser-resolution models; and serve as a testbed for new and developing in situ and remote sensors.

Paradigm shift in observations

Multi-year process studies that fully characterize the turbulent coupled boundary layer system across the physical, chemical, and biological systems require significant platform, energy, and sensor needs. Platforms are being developed that can support masts that span the OBL and stable ABL and a large fraction of the convective ABL layer even over the open ocean. Moreover, these platforms will provide power to support newly developed remote sensors and autonomous vehicles in the ocean and atmosphere to allow better 3D characterization of the coupled boundary layers. Beyond sustained "core" observations the Super Sites platforms will enable testing and validation of new technologies, serving as a catalyst for new scientific and engineering development, and as hubs for national and international collaborations.

Needed data for satellite improvements

Satellite data is a key part of global ocean coverage. Many current, planned, or proposed satellite measurements could be significantly improved with the co-located, inclusive data sets from a Super Site including surface waves and currents; surface heat flux; and ABL profiles of temperature, humidity, and winds. Super Sites observations would provide additional data to improve continuing missions including precipitation; clouds; radiation; wind speed and direction; air-sea heat, moisture, and momentum fluxes; sea surface temperature, salinity, and ocean color; surface currents and waves. To reach the level of accuracy needed in long-term records for validating satellites and models requires platforms that enable testing and development of new measurement techniques.



Transformative data for model improvements

Testing and improving high-resolution models (which are essential for improving coarse-resolution climate simulations) requires statistically robust data samples over extended periods of time, which is not obtainable with typical short-term campaigns. Further, modeling needs require measurements that are often difficult to make due to platform, energy, or sensor inadequacies.

Long time-series data, combined with high frequency observations, can capture the coupled boundary layers and their fluxes during transient events, such as storms, ocean jets/eddies, and amplified sea state. The impacts of these transient events on net heat, water, and other budgets can then be understood and modeled. Platforms that can allow for extended masts will provide the capabilities of measuring fluxes within the ABL (i.e., not just at the surface), a "Holy Grail" measurement, particularly when coupled with corresponding surface and other measurements.

Data assimilation systems will also benefit from calibrated parameters using these new data. Super site observations can be highly integrated with data assimilative models, allowed for additional information on spatial and temporal decorrelation scales.

Air-sea flux parameterization improvements require information on oceanic processes and phenomena such as surface waves, cool-skin and warm layers, surface currents, breaking waves and bubbles, as well as atmospheric processes, all of which can be measured at Super Sites.

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CONNECTIONS
OPPORTUNITIES
COLLABORATORS

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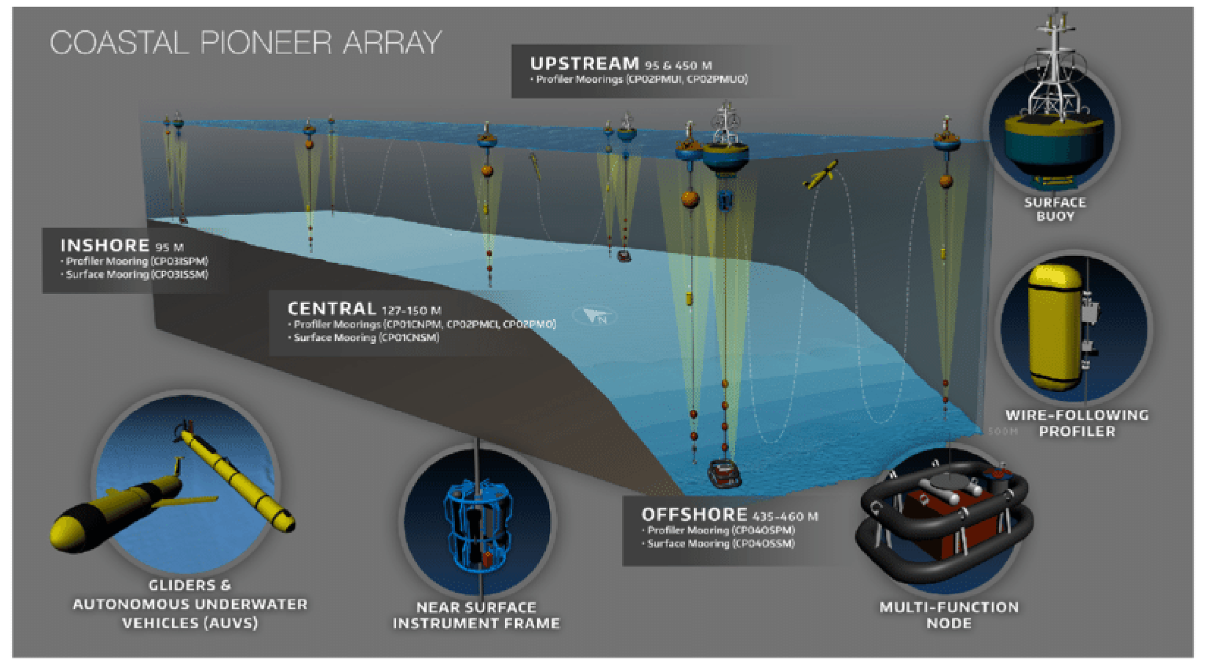
Carol Anne Clayson, WHOI, et al.

Connections to existing infrastructure, technology, and partnerships

Existing infrastructure and partnerships

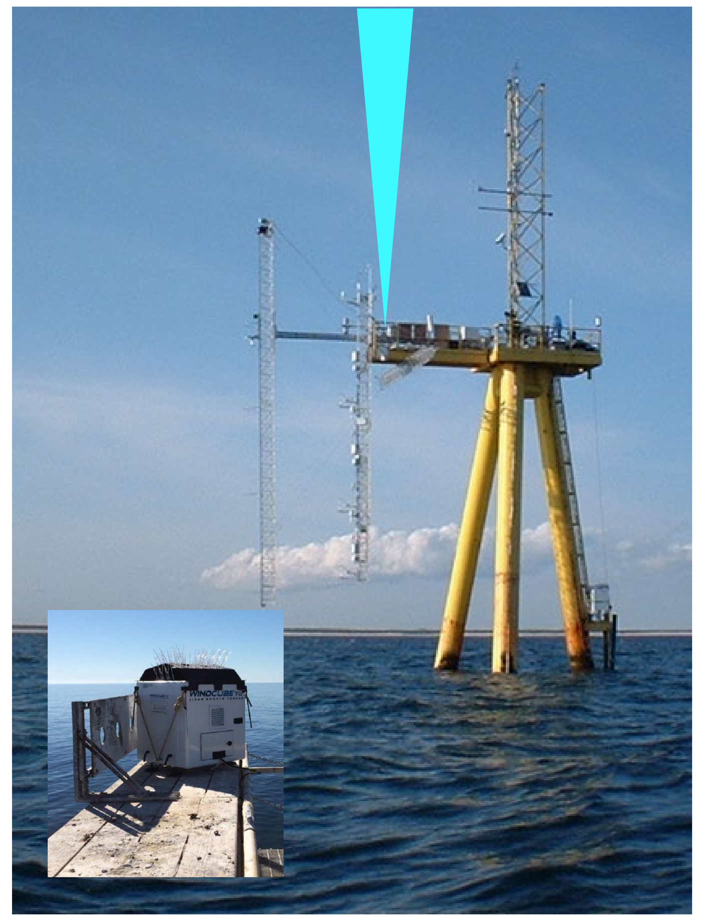


The U.S. oceanographic community has experience with various aspects of sustained observational capability. The NSF-funded Ocean Observatories Initiative (OOI) has made strides towards a combined, sustained mooring/glider program that samples the ocean and air-sea fluxes. The ONR-funded CBLAST program built a long-term Air-Sea Interaction Tower (ASIT) that continues to provide key coupled boundary layer observations for almost two decades. U.S. Research Vessels have provided platforms for many of the marine hardened remote sensors. NASA/NOAA satellites measure key components of the air-sea interface, and a satellite designed specifically for the ABL is in incubation phase. The DOE has deep investment in wind energy technology, with a developing focus on offshore installations. The offshore wind industry is a clear example of a possible public-private partnership, with expertise in developing large platforms and infrastructure for wind turbines and energy delivery, as well as a vested interest in marine conditions and forecasts.

Existing technology

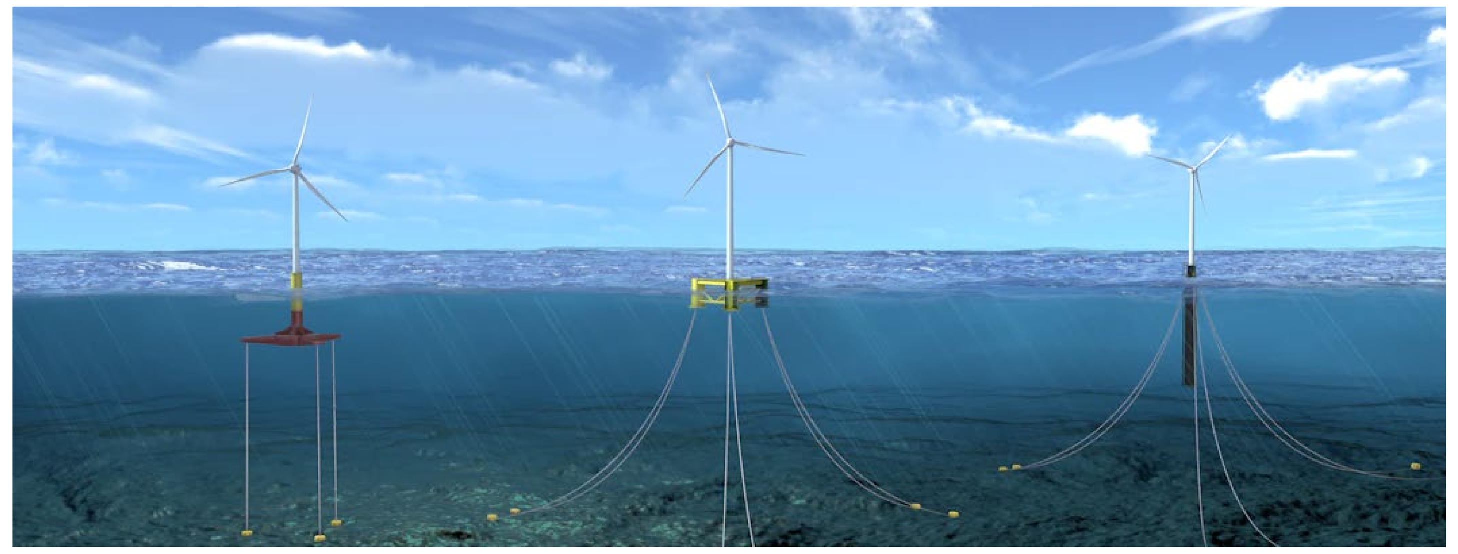
Examples of some current state-of-the art technology that could be adapted for use on a platform, or in or around a a series of platforms, with sufficient space and power capability are shown here. Oceanographic ASVs and AUVs and gliders and atmospheric Unmanned Aerial Vehicles (UAVs) will require continued development of docking stations with power; atmospheric remote sensing systems capable of long-term ocean deployments on small platforms (e.g., lidar buoys) are only now being developed and validated.

Water Vapor DIAL profiling system, courtesy of NCAR

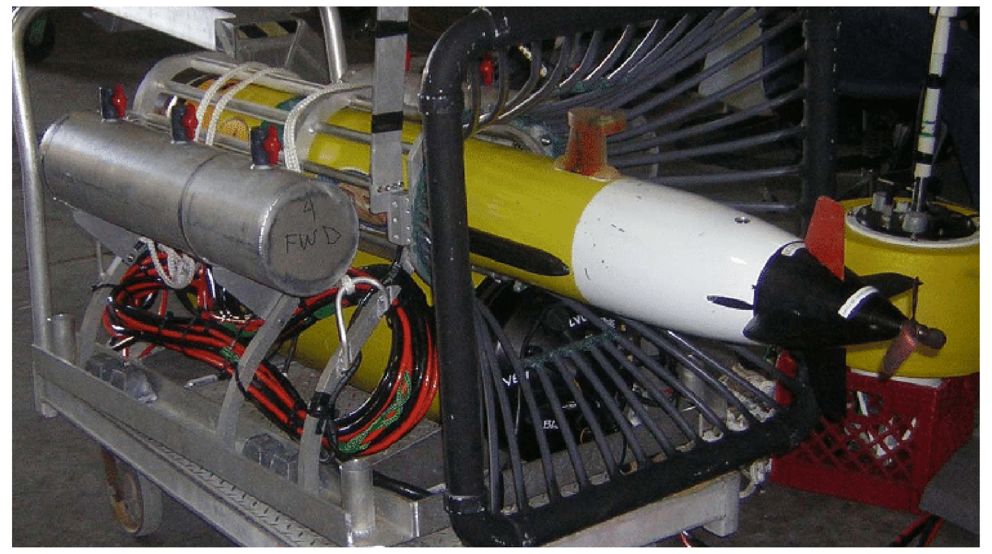


Air-Sea Interaction Tower (ASIT), WHOI, with LIDAR

Wave Glider with carbon system, from CSIR



Floating offshore wind turbines, courtesy AS Mosley



REMUS 100 docking station, courtesy of A. Kukulya

ARM SHIPRAD system on Moana Loa, from L. Riihimakia

ABL UAV, from C. Zappa

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ABSTRACT
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VISION
CONNECTIONS
OPPORTUNITIES
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Carol Anne Clayson, WHOI, et al.

Opportunities for international collaboration and capacity-building

A key program aspect will be to engage, utilize and enhance the scientific and technical expertise of international scientific communities, as well as provide more general public educational opportunities. As a testbed for new platforms and sensors, some capacity will be reserved for both early-career and local scientists to propose and develop novel capabilities. The science defining exchanges between the upper ocean and the atmospheric boundary layer is a leading-order challenge. Super Sites will provide the scientific opportunities needed to train the next generation of ocean and atmospheric scientists to tackle these problems.

Needed technology partnerships

- Creative engineering will be needed to envision and build all-new types of observing platforms with expanded power generation, data communications and asset deployment capabilities.
- The telecommunications and informatics industries will be needed for expertise with the resulting big data.
- Industries associated with the development of autonomous platforms, drones, and sensors will also be key to Super Site success.
- Current work on power generation on ocean surface platforms has been highlighted recently in an NSF Workshop on Advancing Underwater Cyber Infrastructure for Blue Science (BLUE UCI).

THE TIME IS NOW for the community to embark on an ambitious program that will provide transformative observations for the climate and weather communities, enable model developments in some of the most challenging and under-sampled regions in the Earth system, and enable significant technological and scientific development.

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ABSTRACT
CHALLENGES
VISION
CONNECTIONS
OPPORTUNITIES
COLLABORATORS

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Carol Anne Clayson, WHOI, et al.

Collaborators

Groups recommending the Super Site idea

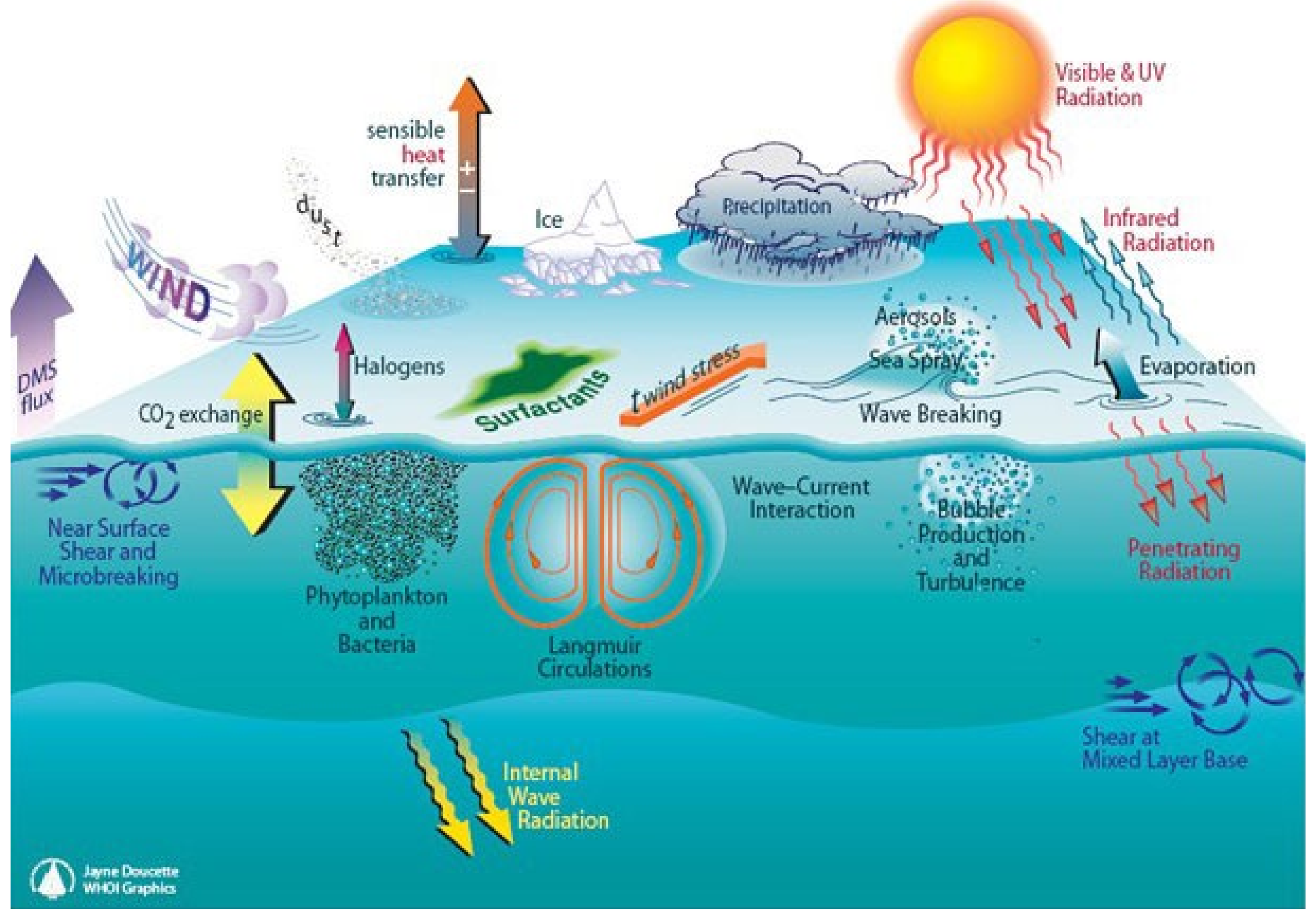
Super Sites have been recommended by national and international groups, including the World Climate Research Program-Data Advisory Panel (WCRP-WDAC) surface flux team, OceanObs19 Community Strategy papers, the Tropical Pacific Observing System (TPOS) Second Report, and the Observing Air-Sea Interactions Strategy (OASIS) SCOR Working Group. Super Site installations will be placed in carefully selected locations throughout the global oceans for several years and then relocated. Such a significant undertaking will require the expertise of the international community, working in partnership with local scientists, particularly for development and maintenance of the Super Sites, as well as any legacy observations.

OASIS Programme Partners

- GOOS Ocean Observations Physics and Climate (OOPC) Panel
- GOOS BGC Panel/International Ocean Carbon Coordination Project (IOCCP)
- GOOS-Biology-Ecosystem Panel
- Ocean Best Practice Systems
- CoastalPredict
- Marine Life 2030
- Deep Ocean Observing Strategy (DOOS)
- Ocean Corps
- EquiSea
- Consortium for Ocean Leadership
- NSF Regional Coordination Network

Wide variety of disciplines engaged

The atmosphere-ocean coupled modeling community will be a key partner in the development and design of these Super Sites. In addition, atmospheric chemists, boundary layer meteorologists, cloud and radiation physicists, and remote sensing experts will be involved in their design and use.



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