Report of the Workshop on "Remote Sensing for Studying the Ocean-Atmosphere Interface" held at the Bolger Center, Potomac, Maryland, USA, 13-15 March 2018.

The Surface Ocean - Lower Atmosphere Study (SOLAS) community is currently in a very fortunate position in having both multi-decadal time series of relevant variables such as sea-surface temperature, aerosols, surface winds and ocean colour, derived from measurements on earth observation satellites, and new measurements from recently launched, satellite sensors with improved capabilities such as better spectral resolution, spatial and temporal sampling. Satellite remote sensing cannot provide all the measurements needed to support SOLAS research objectives, but increasing accuracies and global coverage, together evolving remote sensing techniques, lead to increasingly relevant contributions.

The international remote sensing workshop brought together 43 experts and students from nine countries (Canada, China, France, Germany, India, Italy, Japan, UK, and USA) to discuss novel and new remote sensing techniques to study the ocean atmosphere interface. Thus, the workshop was designed to advance our knowledge of the Core Theme 2 (Air-sea interface and fluxes of mass and energy) of the SOLAS 2015-2025 Science Plan and Organisation. The workshop was sponsored by the Europeans Space Agency (ESA), through Future Earth, the US National Aeronautics and Space Administration (NASA), the Scientific Committee for Ocean Research (SCOR), and SOLAS. The main objectives of the workshop were to facilitate the exchange of information and ideas about developments in remote sensing that can provide new knowledge and insights about the ocean-atmosphere interface, and to help forge collaborations among participants with the wider community.

To set the stage for the workshop, Dr Lisa Miller, Chair of the SOLAS Scientific Steering Committee, gave an overview presentation of SOLAS, and this was followed by two invited presentations which described current and planned missions of NASA and ESA. Dr Jack Kaye, Associate Director for Research, Earth Science Division of NASA's Science Mission Directorate described the current and planned missions that provide information relevant to the SOLAS objectives, and introduced new missions recommended by the recently completed Decadal Survey from the US National Academies. Of particular relevance to SOLAS are the four visible to Infrared polar sensors MODIS (Aqua and Terra satellites) and VIIRS (S-NPP and NOAA 20 satellites), and the Soil Moisture Active Passive microwave radiometer (SMAP). The overview of ESA's missions relevant to SOLAS objectives was given by Dr Diego Fernández-Prieto of the European Space Research Institute (ESRIN) in Frascati, Italy. The Sentinel satellites of the European Copernicus Programme are major contributors to the study of the ocean-atmosphere. Of special note are Sentinel-3A, and Sentinel-3B. Both Sentinel-3s have satellite oceanography as their prime focus, but all of the six Sentinel satellite types have the potential to contribute to SOLAS objectives, as have many of ESA's Earth Observation satellites, such as CryoSAT and SMOS (Soil Moisture Ocean Salinity).

Before the workshop participants formed smaller breakout discussion groups, a series of oral presentations and posters were given. The presentations were grouped into new and future sensors and missions, remote sensing of challenging properties and processes, remote sensing of air-sea fluxes, and remote sensing in challenging conditions. The workshop agenda and abstracts of presentations are available at https://bit.ly/2D1SLmo

The breakout sessions were focussed on the remote sensing of aerosols, remote sensing in the Marginal Ice Zone (MIZ), and "Low Hanging Fruit" concepts. The problems associated with deriving aerosol properties at high latitudes were discussed by both the aerosol and MIZ breakout sessions.

Discussions on air-sea fluxes in the MIZ fell into eight topics: major observations needed in the MIZ; timing of observations; clouds in the Arctic; missing observations; instrumentation; platforms; Arctic feedbacks; and emerging remote sensing needs. Measurements needed to characterise air-sea exchanges include gas fluxes, aerosols, and short- and long-wave radiative fluxes. The challenges to making these measurements are great, not only because of the harsh environment but also of the small scales on which they occur which renders merging in situ measurements with remotely-sensed data very problematic.

In terms of emerging remote sensing needs in the MIZ, those related to biogeochemical fluxes and

ecosystems were discussed. Ice edge plankton blooms occur early in the melt season but are difficult to characterise in satellite ocean colour data as the solar illumination levels are low. Accurate determination of the bloom properties is important for assessing the flow of carbon through the Arctic system and the de-oxygenation that can follow when the blooms decay. Remote sensing of methane is now feasible, and this opens up the prospect of studying the release of methane from gas hydrates that will result from increasing water and substrate temperatures, and this is a worrisome development as methane is a potent greenhouse gas linked to positive feedbacks for climate change in the Arctic. The remote sensing of clouds and aerosols in the MIZ is a formidable challenge, but nevertheless these are critical factors in understanding better the feedbacks in the Arctic. The improved quantification of feedbacks, both negative and positive, in the Arctic is a challenge to the SOLAS and remote sensing communities.

The merging of high resolution radar images of sea ice with optical measurements of reflected solar radiation and thermal emission, including making better use of measurements at 1.6 μm, was suggested to better characterise the reflection of solar radiation by bright surfaces in the retrieval of aerosol properties using spectral measurements of aerosol-scattered sunlight. The aerosol breakout group also recommended incorporating measurements from space-based lidars (e.g. the CALIOP lidar on CALIPSO) that provide information on the vertical distribution of aerosols.

Moving away from high-latitudes, the measurements from the new generation of geostationary visible and infrared imagers, the Himawari Baseline Imager (HBI) on the Japanese Himawari-8 and -9 satellites and the Advanced Baseline Imager (ABI) on the US GOES-16 and -17, provide much better spatial and spectral resolution as well as more rapid sampling than their predecessors. They offer the potential of much improved retrievals of aerosol properties, including better assessment of photochemical process, better understanding of aerosol-cloud interactions and aerosol removal processes (wet and dry deposition over the oceans).

In all cases, there is a pressing need to improve the accuracy and number of variables measured in situ to not only complement the remote sensing retrievals, but also to be used in validating the satellite data and support algorithm enhancement. In terms of “low-hanging fruit”, discussions focussed on deriving new information by the analysis of combination of sensors in different regions of the electromagnetic spectrum. For example, whitecap fraction derived from measurements in the microwave can be related to marine aerosol optical properties such as aerosol optical depth (AOD) derived from MODIS.

An issue of great disquiet for the SOLAS community as a whole is the likelihood of gaps in long time series of measurements when critical sensors fail. In the worst case, if there were no replacement sensor foreseen, this would lead to termination of the time series.

In his final remarks, Dr Fernández-Prieto stressed that SOLAS does wield influence in ESA in helping set the priorities for future earth observation missions and guide the specification and selection of future satellite instruments. Members of the SOLAS community should take advantage of opportunities to have a positive impact on relevant ESA missions.

A suggested topic for a future SOLAS workshop was made by the aerosol break-out group to be “How to encourage and support linkage of field studies and regional models to large scales via remote sensing?” Also, as a consequence of this workshop, a proposal has been submitted as reply to the ESA-Future Earth call 2018 to hold a follow-on workshop the first quarter of 2020, with the ESRIN in Frascati, Italy. As a direct result of the workshop, Dr Minnett and Dr Fernández-Prieto proposed a session to the organizing committee of the ESA Living Planet Symposium to be held in Milan, Italy, in May 2019. The proposal was accepted and the session “Remote Sensing of the Ocean Surface and Lower Atmosphere - a SOLAS Session” will be part of the symposium. The description of session A4.08 is available here: https://bit.ly/2skB37F. In addition, the workshop organisers and some of the participants are currently considering a review paper based on the outcomes of the workshop.

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