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solas event report

Report 09 I May 2018

Workshop on:

“Remote Sensing for Studying the Ocean Atmosphere Interface”

13 - 15 March, 2018
Potomac, Maryland, USA

An international remote sensing workshop was held at the Bolger Center, Potomac, MD, USA, on 13 - 15 March, 2018, which brought together 43 experts and students from eight countries to discuss novel and new remote sensing techniques to study the ocean atmosphere interface (Figure 1). The workshop was sponsored by the European Space Agency (ESA), through Future Earth, the US National Aeronautics and Space Administration (NASA), the Scientific Committee for Ocean Research (SCOR), and the Surface Ocean - Lower Atmosphere Study (SOLAS). The objective of the workshop was to facilitate the exchange of ideas and information about developments in remote sensing that can provide new information and insights about the ocean-atmosphere interface, and will help forge collaborations among workshop participants and with the wider community.

The SOLAS community is in a very fortunate position in having both multi-decadal time series of relevant variables such as sea-surface temperature, surface winds and ocean colour, derived from measurements on earth observation satellites, and recently launched, new satellite sensors with improved capabilities such as better

In this report

Figure 1: Participants of the Workshop.
Front row left to right: Gary A. Wick, Ajoy Kumar, Johnson Zachariah, Alexander Gilerson, Kirk Knobelspiesse, Jack Kaye, Paula Bontempi, Prabhat K. Koner, Chris Ruf, Baijun Tian, Magdalena D. Anguelova, Diego Fernández Prieto, J. Vanderlei Martins, Rachel Pinker, Abderrahim Bentamy.
Middle row left to right: Malgorzata Szczodrak, Isaiah Lonie, Chelle L. Gentemann, Kyle Ehmann, Peter Cornillon, Robert Foster, Alexander Smirnov, Ivan Savelyev.
Back row left to right: Xiujun Wendy Wang, Lorraine Remer, James Carton, Diego Loyola, Peter Minnett, Lisa A. Miller, Brent A. McBride, Amir Ibrahim, Hiroyuki Tomita, Oliver Wurl, Phil Hwang, Hongbin Yu, Xuepeng Zhao, Eric C. Hackert, Santha Akella.
Missing: Santiago Gassó, Abhishek Chatterjee, Stéphane Saux Picart, Leonid Yurganov.

spectral resolution, spatial and temporal sampling. There are also many new missions under development for future launch. Many of these data sets support the major research themes of SOLAS, and these themes were presented during the opening session of the workshop in an overview presentation by Dr Lisa Miller, the Chair of the SOLAS Scientific Steering Committee.

To set the stage for the workshop, two invited presentations were given to describe 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 two MODerate-resolution Imaging Spectroradiometers (MODIS) on the NASA satellites Terra and Aqua, the Visible Infrared Imaging Radiometer Suite (VIIRS) on S-NPP (and a second version was recently launched on the NOAA-20 satellite), and the Soil Moisture Active Passive microwave radiometer (SMAP) that also measures ocean surface salinity. 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, launched on February 16, 2016, and its twin, Sentinel-3B, which was launched shortly after the workshop on April 25, 2018. 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).

Continuing to set the scene for discussions at the workshop, there were a series of oral presentations and many posters. The oral 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. Posters on these topics were available throughout the second day of the workshop, with a dedicated evening session.

The new sensors and missions included NASA's planned PACE (Phytoplankton, Aerosols, Clouds and ocean Ecosystems) mission, a hyperspectral imaging radiometer intended to extend key climate data records based on current and heritage sensors, and to address new and emerging science questions using advanced capabilities. Also presented was NASA's Cyclone Global Navigation Satellite System (CYGNSS), which consists of eight microsatellites, each with a four-channel GPS bi-static radar receiver to measure the sea-surface roughness, and hence wind speed, by using microwave illumination of the sea surface from the constellation of GPS satellites. An additional microsatellite of relevance to SOLAS is the Hyperangular Imaging Polarimeter (HARP) to measure aerosols, clouds and ocean surface properties in the visible range. HARP is expected to be launched from the International Space Station late 2018. European hyperspectral sensors, both on orbit (e.g. TropOMI) and planned (e.g. Sentinel 5) with primary applications for measuring atmospheric trace gasses and air sea interactions, were described along with innovative analysis techniques for extracting information from the "big data" they produce. Finally, a new, robotic Sea Surface Scanner (S3) was introduced as a device for sampling surface films that influence remotely-sensed signals.

To open the session on "Challenging properties and processes" Dr Kirk Knobelspiesse of NASA Goddard Space Flight Center gave an invited presentation entitled "Aerosol Remote Sensing: why is it so difficult?" which led into a series of presentations on satellite measurements of aerosols and their impacts on the ocean atmosphere system. Other SOLAS-relevant challenges are those of measuring gasses, such as methane and carbon dioxide, and air temperature very close to the sea surface; new techniques for such measurements were presented. Of particular note is the response of the carbon cycle to El Niño using data from the Orbiting Carbon Observatory-2. Additional remote sensing challenges discussed are assessing and correcting the effects of skylight reflected at the sea surface on measurements of ocean colour, determining the vertical temperature gradient within the sea-surface thermal skin layer, and measuring sub-surface turbulence.

The session on "Air-Sea Fluxes" was opened by Dr Abderrahim Bentamy from IFREMER in France with an overview presentation on "Remotely Sensed Data Requirements for Turbulent Heat Flux Determination". This was followed by presentations on improved measurements of near-surface humidity and latent heat fluxes, and the effects of sea-spray on remote sensing of the ocean surface, including the CYGNSS approach of using reflected GPS signals. Also in this session there was a presentation on a novel method to improve estimates of surface heat and moisture fluxes and the upper ocean heat budget with a case study of the Indian Ocean.

The final session focussed on "Challenging Conditions" and the two presentations were directed at the Arctic Ocean Marginal Ice Zone. Dr Phil Hwang, of the University of Huddersfield in the UK gave an invited presentation on "Observation of Arctic Sea Ice Breakup and Floe Size during the Winter-to-Summer Transition" and Dr. Chelle Gentemann of Earth and Space Research introduced a new collaborative study on improving remote sensing of surface temperatures and air-sea ice interactions in the marginal ice zone.

Additional background and discussion points on these topics were presented in the poster session.

The second part of the workshop comprised a series of break-out sessions involving subgroups of participants (Figure 2). The objectives of the breakout sessions were:

Figure 2: Breakout session on the “Low Hanging Fruit”. © Jessica Gier

- Discuss what has been presented here, and what has not
- Identify pressing research topics and who can collaborate
- Recommend next priorities for research and space agencies
- Recommend topics for future workshops and sessions at the SOLAS Open Science Conference 2019, Sapporo, Japan

These breakout sessions were focussed on the remote sensing of aerosols, remote sensing in the Marginal Ice Zone, and “Low Hanging Fruit”.

The problems associated with deriving aerosol properties at high latitudes were also discussed by the aerosol and Marginal Ice Zone breakout sessions. The merging of high resolution radar images of sea ice with optical measurements of reflected solar radiation and thermal emission was suggested, as was making better use of measurements at 1.6 µm that already exist and which will be in the PACE data stream. The objective is 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. At high southern latitudes, there needs to be a better focus on deriving aerosol properties over the Southern Ocean and at terrigenous dust source regions, such as Patagonia. Moving away from high-latitudes, the measurement from the new generation of geostationary visible and infrared imagers, the Himawari Baseline Imager (HBI) on the Japanese Himawari-8 satellite and the Advanced Baseline Imager (ABI) on the US GOES-16, provide much better spatial and spectral resolution as well as more rapid sampling than their predecessors and 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). On longer time scales, satellite data could be used to support studies on the response of aerosol generation and deposition to the changing conditions brought on by ENSO events, for example.

The Marginal Ice Zone (MIZ) breakout-group focused on questions related to improving estimates of air-sea fluxes in the MIZ, and discussions 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 in the MIZ

necessary 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 difficult. Furthermore, the processes and effects involved in the freeze-up and melting periods are not symmetric, unlike the major forcing: solar radiation. Some parameters needed to determine better vertical fluxes can only be measured using in situ devices; such parameters include pCO_2 in the water, under-ice fluxes including short-wave radiation, air temperature, and air-sea temperature differences for on-ice and off-ice winds. Other important features, such as melt ponds are more accessible to remote sensing through high resolution radar and optical sensors, but to help provide data to interpret and enhance the scientific value of the remotely-sensed data, in situ measurements are also needed such as pond salinity, depth of the ponds, and thickness of snow on the floes.

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, thereby stressing the ecosystem; accurate measurements are challenging using current remote sensing techniques. 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. As also identified by the aerosol breakout, 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.

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 in algorithm enhancement. Many new sensors have been developed for use on autonomous platforms, including drifters, gliders, Argo profilers, saildrones and wave-gliders, and aerial drones. Also, novel approaches to taking measurements in difficult conditions have been demonstrated, such as attaching instrument packages to sea mammals and large birds.

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?” An additional suggestion was to hold this, or another, SOLAS workshop in Asia to encourage involvement of more scientists from Asian countries.

An issue of great disquiet voiced by the aerosol group but which is if concern 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.

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Link to the event website:
http://www.solas-int.org/workshop-on-remote-sensing.html

The outcomes of this workshop contribute 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.

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Magdalena D. Anguelova studied engineering physics in Bulgaria. She received her PhD in oceanography from the University of Delaware, USA, and joined the Naval Research Laboratory in 2002 as a National Research Council postdoctoral fellow. Her interests include satellite-based studies of air-sea fluxes involving breaking waves, whitecaps, bubbles, and sea spray.

Radiometric measurements of whitecaps and air-sea fluxes

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Surface fluxes quantify air-sea transfers of momentum (Thorpe, 1992), heat (Andreas *et al*., 2015), gases (Wanninkhof *et al*., 2009), and particles (Veron, 2015). Breaking waves in the ocean entrain air into the water and create bubble plumes and sea spray, which enhance all air-sea fluxes. Oceanic whitecaps are the most direct manifestation of wave breaking with air entrainment. Whitecap fraction *W* -defined as the fraction of the ocean surface covered by whitecaps (sea foam)- quantifies the spatial extent of whitecaps. Therefore, *W* is a suitable forcing variable for parameterising the enhancement of the surface fluxes by breaking waves.

Different radiative properties of the whitecaps allow their detection with different measuring techniques. The high reflectance of the whitecaps in the visible portion of the electromagnetic (EM) spectrum affords measuring the whitecaps from photographs (Monahan, 1971). The high emissivity of the whitecaps in the microwave portion of the EM spectrum affords detection of whitecaps as changes of the ocean surface brightness temperature T_B (Bobak *et al*., 2011). Both reflectivity and emissivity of whitecaps are detectable in the infrared portion of the EM, which allows separation of the initial and decaying phases in the evo-

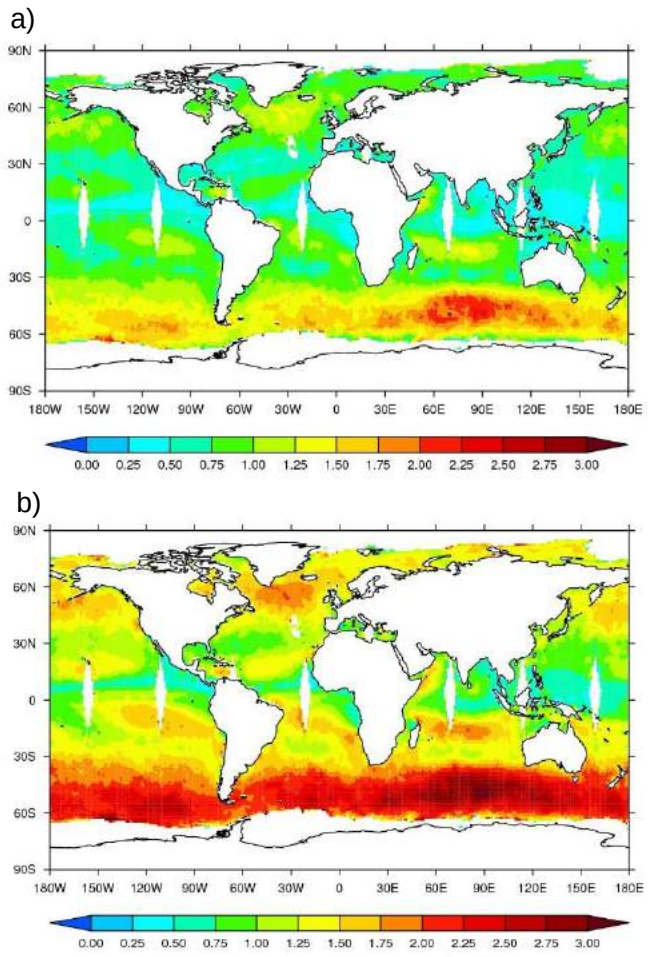

Figure 3: Mean whitecap fraction *W* for June-July-August 2014 from WindSat observations at frequency of: a) 10 GHz; b) 37 GHz.

lution of whitecaps (Potter *et al.,* 2015).
Within the framework of WindSat mission (Gaiser *et al*., 2004), we developed a method of estimating *W* from satellite-based T_B data. The algorithm uses the changes of the ocean surface emissivity at microwave frequencies from 6 to 37 GHz caused by the presence of sea foam on a rough sea surface. Satellite-based estimates of *W* (Figure 3) are useful for characterising and parameterising the geographical and seasonal variability of whitecap fraction (Salisbury *et al*., 2014). This, in turn, yields global estimates of sea spray production (Albert *et al*., 2016) and CO_2 transfer velocity (Anguelova, 2016).
We also work on expanding the utility of microwave radiometry to other frequencies. Observations at lower frequencies (below 1.5 GHz) combined with Global Positioning System (GPS) signals are useful for hurricane studies. Millimetre-wave frequencies (40-200 GHz) have the potential to measure *W* at high spatial resolution in coastal and polar waters.

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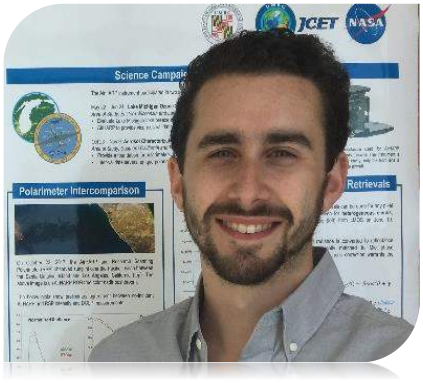

Brent McBride began his PhD at the University of Maryland, Baltimore County (UMBC) in 2015, investigating cloud microphysical properties with hyper-angular imaging polarimeter measurements. He leads optical characterisation, data analysis, and aircraft deployments of the Hyper-Angular Rainbow Polarimeter (HARP) in his role as an instrument scientist at the UMBC Earth and Space Institute.

Hyper-angular imaging polarimetry for microphysical retrieval of aerosol and cloud properties

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Aerosol-cloud interaction continues to puzzle climate scientists. It is among the most significant contributors to our climate but least understood: aerosol-cloud processes are poorly represented in climate models and efforts at measurement require high accuracy, narrow resolution, and cooperation between different instruments. Much of the issue stems from light scattering: while clouds are bright, aerosols reflect little to the top of the atmosphere. Molecular scattering, ice and desert cover, and land surface reflectance all complicate the retrieval of less reflective aerosol. Aerosol are well-known cloud condensation and/or ice nuclei, and their presence in a moist environment can drastically impact the extent of cloud or ice crystal growth, compared to a clean, unpolluted scene.

Radiometric satellites, with global coverage, wide spectral range, and long lifetime in space, greatly advance the way we attack this complexity. Fantastic strides made in the past three decades in data interpretation produced elegant microphysical retrievals by comparing signal from two wave lengths (for example Nakajima and King 1990a). Co-located multi-angle sampling helps constrain aerosol microphysical properties over land and ocean (Garay *et al*., 2017). The introduction of polarised remote sensing in 1999 deepened the connection between scattered light and the cloud or aerosol size distribution (Breon *et al*., 2005) and extended assumption-limited microphysical retrievals from radiometric satellites (Reidi *et al*., 2010). Several studies converge on the idea that a multi-angle imaging polarimeter, capable of high polarimetric accuracy and narrow spatial and angular resolution, is the strongest candidate to characterise cloud and aerosol properties at the level required for climate study (Polarimetry in the Plankton-Aerosol-Cloud-ocean Ecosystem (PACE) Mission, Science Team Consensus Document).

The Hyper-Angular Rainbow Polarimeter (HARP, Figure 4), is a wide field-of-view imaging polarimeter instrument designed and developed to fill this role. Built and operated by the Laboratory for Aerosol and Cloud Optics (LACO) at the Univer-

sity of Maryland, Baltimore County (UMBC) in Baltimore, Maryland, USA, HARP capitalises on well-resolved atmospheric measurements done from a compact, CubeSat platform; this advancement maximises science output at a fraction of the cost of current space satellites. HARP images the same scene on the ground from up to 60 unique viewing angles at 670nm, specifically for cloud targeting, and 20 angles at 440, 550, and 870nm for aerosol retrieval. The three polarised channels of HARP simultaneously image orthogonal states of linear polarisation, and linear combinations of these channels produce the first three Stokes parameters, I, Q, and U, and the degree of linear polarization (DOLP). The flagship instrument, the HARP CubeSat, is slated to fly as a stand-alone payload in the International Space Station (ISS) orbit for a mission lifetime of one year, beginning in 2018. To prepare our data algorithms and sampling strategy, the LACO group successfully deployed an airborne version, AirHARP, to the field twice in 2017: on-board the NASA Langley B200 during the Lake Michigan Ozone Study (LMOS) from May to June and the NASA Armstrong ER-2 during the Aerosol Characterization from Polarimeter and Lidar (ACEPOL) in October and November. The LACO group is also supporting early development of HARP-2, a modified HARP CubeSat instrument that will fly as part of the PACE mission in the 2020s.

Because the HARP instruments image the angular signature of light scattering, the HARP datasets will be used to (1) infer surface and ocean properties, (2) retrieve cloud and aerosol microphysics (effective radius, variance, refractive index, cloud thermodynamic phase, AOD, and size distributions), (3) validate and extend retrievals from radiometers and vertically-resolved lidar/radar instruments. The versatility of the HARP instrument, in both science output and physical size, provides an attractive platform for answering the toughest questions about how clouds and aerosols interact and their impact on climate evolution.

Figure 4: The HARP CubeSat spacecraft with solar panels fully deployed. Photo credit: Vanderlei Martins (UMBC/JCET)

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Hiroyuki Tomita is an assistant professor at Nagoya University. He holds a PhD from Tokai University and did a postdoc at the Japan Agency for Marine Earth Science and Technology (JAMSTEC). In 2012, he moved to Nagoya University and began research on global air-sea flux. He also serves as a project leader for the Japanese Ocean Flux Data Set with Use of Remote-Sensing Observations (J-OFURO) and a principal investigator for the Japan Aerospace Exploration Agency (JAXA) Global Change Observation Mission-Water Advanced microwave scanning radiometer 2 (GCOM-W/AMSR2).

J-OFURO3: A third-generation Japanese satellite-derived air-sea flux data set

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The air-sea fluxes of heat, momentum, and freshwater are essential physical quantities for understanding our climate system, so highly accurate quantitative global estimations are desirable. One possible answer to this challenge is the estimation of air-sea fluxes using multi-satellite remote sensing techniques.

A Japanese research project on satellite-derived air-sea flux, Japanese Ocean Flux Data Set with Use of Remote-Sensing Observations (J-OFURO), was established in the year 2000. Its initial public data set, J-OFURO1 (Kubota *et al*., 2002), was followed by a second-generation data set, J-OFURO2 (Tomita *et al*., 2010) in 2008, which featured improvements stemming from a pilot study's use of multi-satellite data. Following subsequent research and development, a third-generation data set, J-OFURO3, was released with significant further improvements (Tomita *et al*., 2018).

The use of multi-satellite observation is a distinct characteristic of J-OFURO3. As the number of available satellites increases, earth observations have commonly used multiple sensor platforms in recent years. As a result, current surface flux data have a higher spatial resolution with 0.25° grid size, significantly better than previous 1° grid data. This contributes to a better representation of complex flux variations related to oceanic fronts and mesoscale eddies.

Figure 5 shows spatial distribution of net heat flux over the Kuroshio extension region obtained from monthly mean of J-OFURO3 in January, 2013. This region is characterised by oceanic front and mesoscale eddies. J-OFURO3 can capture the fine-scale flux variations associated with these oceanic features.

Furthermore, in the course of development, we have improved a satellite algorithm to estimate near-surface humidity which is a key point to accurate estimation of surface heat flux. Recent research on the relationship between surface humidity, its vertical profile, and microwave satellite observations of brightness temperature allowed us to develop an algorithm for multi-satellite microwave radiometer instruments (Tomita *et al*., 2018b). The accuracy of the new satellite-derived humidity data is greatly improved, lead-

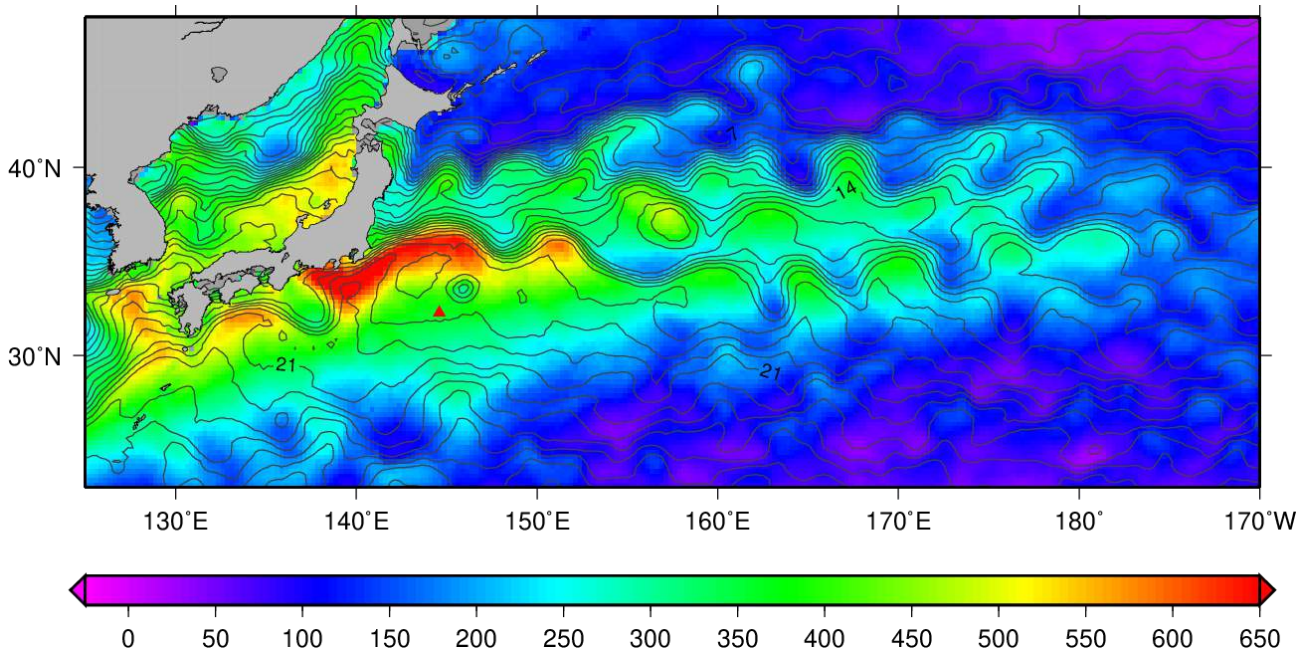

Figure 5: Spatial distribution of net heat flux [Wm-2] over the Kuroshio extension region obtained from monthly mean J-OFURO3 data for January, 2005. Positive values indicate upward flux. Contours are sea surface temperature at 0.7° K intervals. Red triangle marks the KEO buoy (32.3°N, 144.6°E) used for in situ comparison.

ing to better estimations of surface heat flux.

Comparisons with in situ observations at the KEO buoy (32.3°N, 144.6°E) confirmed that J-OFURO3's estimates are accurate, with a bias of +4.2 watt per square meter (Wm^{-2}) and root mean square (RMS) error of 45.3 Wm^{-2} in the net surface heat flux. These statistics are smaller than those obtained from previous products such as J-OFURO2 (biases of +13.5 to +68.9 Wm^{-2} and RMS errors of 60.5 to 106.8 Wm^{-2}).

J-OFURO3 offers data sets for surface heat, momentum, freshwater fluxes, and related parameters (including surface wind, humidity, and sea surface temperature) over the global oceans, excluding sea ice regions, from 1988–2013. Full data sets and documents can be accessed at https://j-ofuro.scc.u-tokai.ac.jp along with a newly designed logo symbolizing our project and data set (Figure 6).

J-OFURO

Figure 6: The new J-OFURO logo. Top and bottom portions represent the atmosphere and the ocean, respectively, while the circles and arrows represent air-sea interactions. The symbol at top right represents both a satellite sensor and "扇子 Sensu" in Japanese, meaning the increasing success of a project.

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Report 10 I August 2018

The 4th International Symposium on the Effects of Climate Change on the World Oceans

Session on: "Eastern Boundary upwelling systems: diversity, coupled dynamics and sensitivity to climate change"

2 - 8 June, 2018 Washington DC, USA

From 2 to 8 June 2018, the 4th International Symposium on the Effects of Climate Change on the World Oceans took place in Washington DC, USA, under the auspices of the International Council for the Exploration of the Sea (ICES), the North Pacific Marine Science Organization (PICES), the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO), the Food and Agriculture Organization (FAO), and the United States National Oceanic and Atmospheric Administration (NOAA), and sponsored by ICES, PICES, IOC-UNESCO, FAO, NOAA, Fisheries and Oceans Canada, COMPASS Science Communication, SOLAS, Integrated Marine Biosphere Research, International Atomic Energy Agency, Lenfest Ocean News, North Pacific Anadromous Fish Commission, Maine Coast Sea Vegetables, Monterey Bay Aquarium, Ocean Networks Canada, and Women's Aquatic Network (Figure 1). The Symposium focused on understanding and responding to climate impacts on ocean systems. The Earth's climate and oceans are rapidly changing, the impacts are already evident in some regions and more impacts are expected with continued changes in the

In this report

Figure 1: The ECCWO sponsor list at the Symposium venue. © Véronique Garçon

planet's climate system. There is much at stake. Future efforts to find solutions will include lessons learnt from the symposium to stimulate future science and to inform a range of societal options as people continue to adapt, adjust, and respond to these changes in the world's oceans.

The Symposium included invited plenary sessions, contributed paper sessions with extended periods for discussion, and workshops that explored topics in greater depth. A suite of theme sessions provided opportunities for scientific exchange within disciplines, as well as forums for the integration of knowledge of climate impacts from physics to society (e.g. from physical processes and their interaction with ecosystem dynamics, to food provision and ocean governance). Other theme sessions focused on comparing observed and projected changes in physical and chemical oceanography, the associated changes in the productivity, distribution, ecology and phenology of species, and the impacts of these changes on marine ecosystem structure and function, fisheries, and other socio-ecological systems. These included comparisons within a system under different scenarios and/or between systems under common scenarios. The Symposium has advanced understanding of the vulnerability and resiliency of ocean ecosystems and ocean-dependent human communities in a changing climate, and thereby informed societal consideration of risks, opportunities and actions concerning the world's oceans.

The Symposium in a few take home messages:

- The oceans and the social-ecological systems that depend on them are changing.
- Our understanding of social-ecological systems has improved allowing us to contrast the ecological and human impacts of different future scenarios. Opportunities for adaptation are more limited if society remains on a high emission scenario.
- Tactical and strategic opportunities for adaptation to climate change have been revealed through engagement.
- Extreme events provide an opportunity to assess human and ecological responses to climate change. Our ability to predict anomalous ocean conditions on seasonal to decadal time scales is improving.
- Research continues to reveal complex energetic and physiological trade-offs associated with adaptation to changing environmental conditions. There are energetic and physiological costs to adaptation that must be recognised.
- Coastal communities are turning to aquaculture, marine ranching, and fish attraction technologies to fill critical needs for food security. Research is needed to identify appropriate adaptation actions and good governance through stakeholder engagement and representation.
- Blue carbon solutions are emerging.
- More targeted measurements are necessary to better understand the oceanic carbon cycle and minimise uncertainties for both short-term prediction and long-term projection of the carbon uptake, ocean acidification, and

ocean deoxygenation. Global Observation networks with technological advancements for data collection will improve our understanding of key processes.
- International planning and assessment activities play a key role in guiding and informing our research.

The Symposium in numbers:
669 registrations, 51 countries, 18 sessions, 11 workshops and 3 Town Halls, 350 oral presentations, 158 posters, 102 students….and 4,103 tweets and 2,866 re-tweets!

All plenaries can be viewed at:
https://meetings.pices.int/publications/video#2018-ECCWO

SOLAS themes were covered by a couple of sessions but we would like to focus here on Session 7 entitled "Eastern Boundary upwelling systems: diversity, coupled dynamics and sensitivity to climate change", co-chaired by Ivonne Montes (Corresponding Chair, Instituto Geofísico del Perú, Perú) and Ryan Rykaczewski (Department of Biological Sciences and Marine Science Program, University of South Carolina, USA). The Eastern Boundary Upwelling Systems (EBUS) are the most productive areas of the world's oceans, supporting large populations of commercially important fish species. The basic forcing mechanisms are similar across the different EBUS. However, owing to differences in the relative strengths of potential stressors, a unified understanding regarding the sensitivity of individual EBUS to climate change remains evasive. In this session, talks on the different physical mechanisms occurring over different time scales (i.e., intradaily, intraseasonal, interannual, decadal, multidecadal) and their implications for water-column properties, biogeochemical cycles, biodiversity/ecosystem structure and functioning, and the regional climate in various EBUS were presented. Key feedback processes in EBUS, similarities and differences across systems and critical knowledge gaps that limit our current understanding of physical and ecological responses to natural and anthropogenic climate forcing in EBUS were discussed.

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CNRS/LEGOS, France, one of the four Symposium convenors

Rodrigue Anicet Imbol Koungue is from Cameroon. He studied Physics in Cameroon at the University of Yaoundé. He moved to Benin for his Master studies in Physical Oceanography at the University of Abomey-Calavi in Cotonou. Rodrigue Anicet joined the Department of Oceanography at University of Cape Town, South Africa, in September 2014 to start his PhD project which is funded by the Nansen Tutu Centre. He investigated the triggering mechanisms associated with the occurrences of coastal extreme warm and cold events along the Angola-Namibia coastline from 1998 to 2012 under the supervision of Prof. Mathieu Rouault and Dr. Serena Illig.

Role of Interannual Kelvin wave propagations in the equatorial Atlantic on the Angola Benguela current system from 1998 to 2012

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The Benguela Upwelling System (BUS) is one of the most productive marine ecosystems in the world, supporting a large marine ecosystem. Compared to the other Eastern Boundary Upwelling Systems (EBUS), one specific feature of the BUS is that it is encircled by warm waters at its northern and southern boundaries: tropical waters from the equatorial Atlantic in the north and warm-waters coming from the Agulhas current in the south. This is well observed in Figure 2 which illustrates the Sea Surface Temperature (SST) and wind stress in austral summer in the southeast Atlantic Ocean.

The BUS undergoes important variability at a wide range of frequencies and in particular at interannual timescales. Every few years, the BUS is indeed subject to the intrusion of anomalously warm waters from the tropical Atlantic. These events are called Benguela Niños (Shannon *et al.,* 1986) and are represented in Figure 3a. Benguela Niños typically manifest along the coast of Angola and Namibia in the southeast Atlantic Ocean. These anomalously warm events tend to reach their maximum during the late austral summer mainly during March-April and originate from the relaxation of zonal wind stress in the equatorial Atlantic in January-February (Florenchie *et al*., 2004). During a Benguela Niño event, the SST can peak up to 4°C above the seasonal average. The cool phase of Benguela Niño is called Benguela Niña (Figure 3b). Benguela Niños and Niñas are of great socio-economic importance for the countries of Southern Africa due to their impacts on climate, rainfall, marine productivity, and fisheries in the BUS. The forcing mechanisms responsible for the in-

terannual variability of SST in Angola-Benguela current system are still under debate. Two main forcing factors are identified in the literature: Firstly, the local atmospheric forcing mainly explained by variations in the coastal wind stress along the coast of Angola and Namibia (Richter *et al.,* 2010). Secondly, the remote oceanic forcing associated with the propagation of Interannual Equatorial Kelvin Waves (IEKW) along the equatorial Atlantic, which then, at the African coast, propagate poleward as Coastal Trapped Waves (CTW) (Bachèlery *et al.,* 2016; Imbol Koungue *et al.,* 2017). One of the key objectives of this study was to investigate the connection between the linear dynamics in the equatorial Atlantic and the coastal variability off Angola-Namibia from 1998 to 2012.

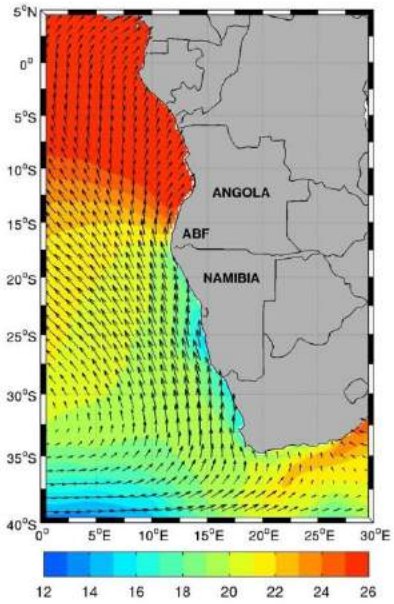

Figure 2: Left panel: AVHRR SST and SCOW wind stress averaged in austral summer (October to March) from September 1999 to October 2009.

Thereforediction and Research Moored Array in the Tropical Atlantic (PIRATA) buoy measurements were used to define an index of IEKW activity in combination with altimetric monthly Sea Surface Height Anomalies (SSHA) and SSHA calculated with a simple Ocean Linear Model. This IEKW index appears to be a skilful proxy to forecast coastal warm and cold events by about one month between October and April.

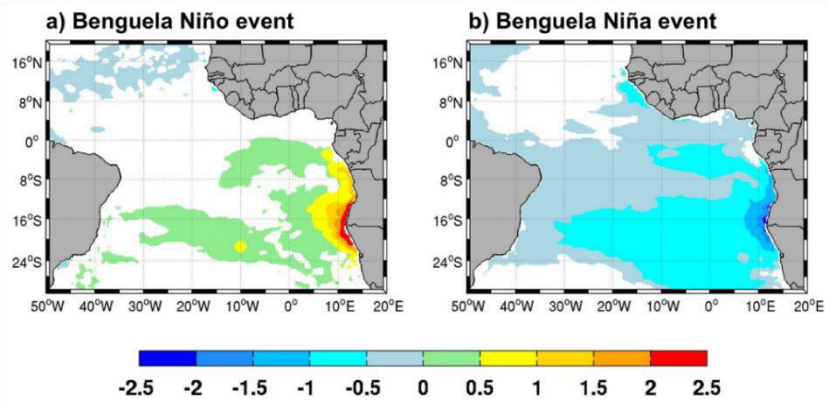

Figure 3: Composite maps of detrended anomalies of surface temperature (in colour, in °C) computed in March – April from: a) 5 selected extreme warm coastal events and b) 5 extreme cold coastal events. The shaded areas (detrended anomalies of T10) represent the 90% statistically significant areas.

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Nele Tim, meteorologist by training, finished her PhD in 2015 at Helmholtz-Zentrum Geesthacht on the atmospheric drivers and variabilities of the Benguela upwelling system. Currently, she is working as PostDoc at the University of Hamburg on the impacts of the Agulhas Leakage on the central water masses in this upwelling.

Origin and pathways of the central water masses in the Benguela upwelling system and the impact of the Agulhas leakage

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We analyse the origin, pathways, and age of the central water masses in the Benguela upwelling system (BUS) and the contribution of the Agulhas leakage to upwelling water masses in a high-resolution ocean simulation. The Agulhas Current flows along the east coast of southern Africa transporting warm and saline water southwestward. At the southern tip of the African continent, a small fraction (Agulhas leakage) leaves the Agulhas System and continues westward into the Atlantic Ocean (Gordon, 1986). The BUS, located off Southwest Africa, is one of the four important Eastern Boundary Upwelling Systems (EBUS) (Figure 4a) where trade wind induced

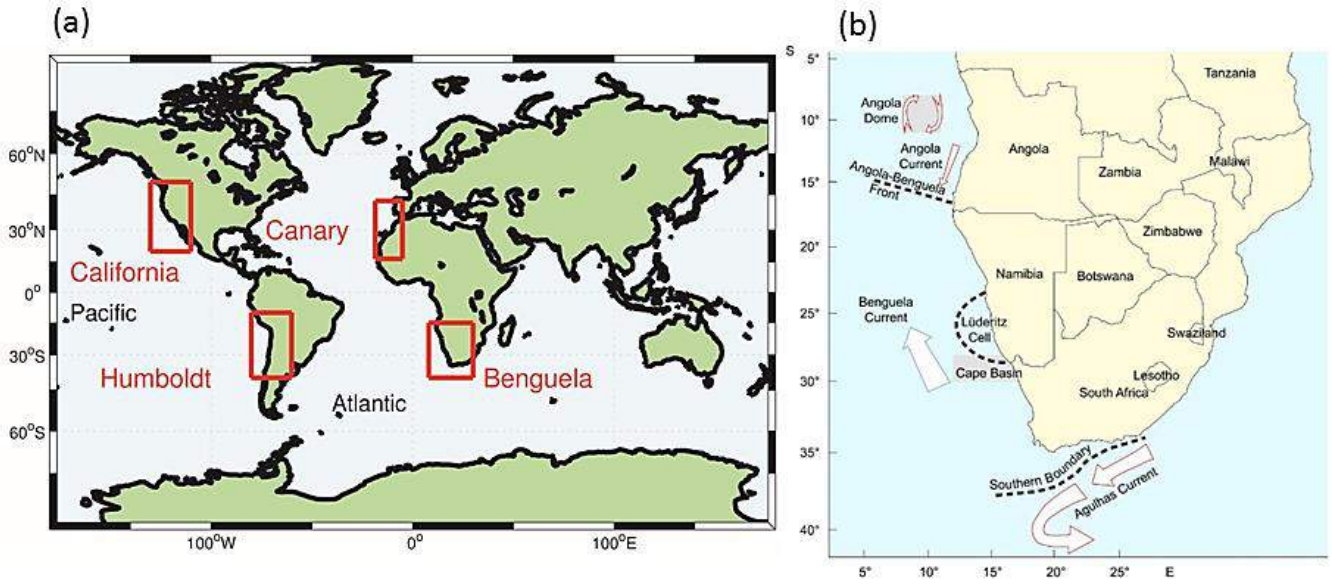

Figure 4: (a) Areas in red show the location of the four Eastern Boundary Upwelling Systems. (b) Schematic map of the Benguela upwelling system (Tim, 2016).

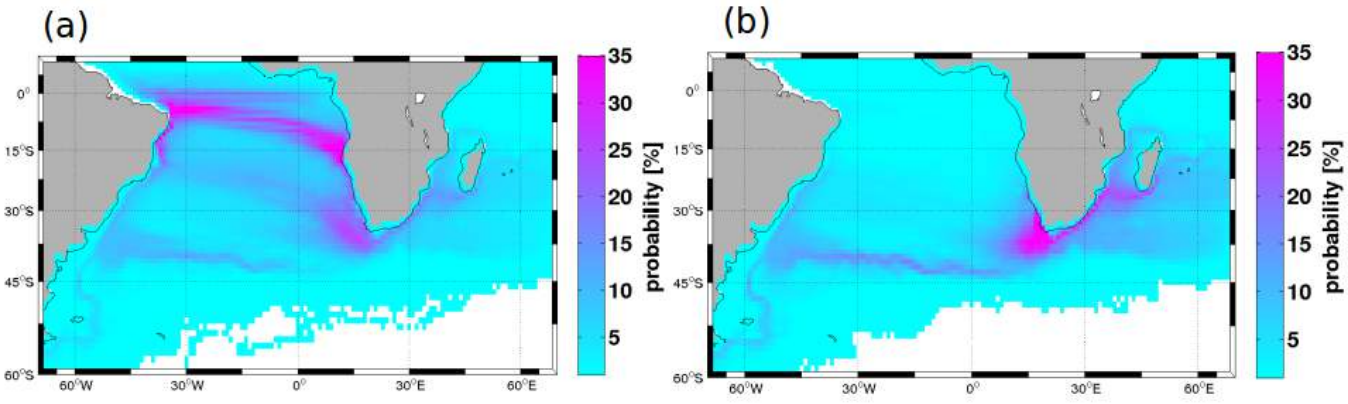

Figure 5: Percentage of parcels seeded in North Benguela (a) and South Benguela (b) calculated backward that pass a 1° grid box at least once during the simulation period (1958-2009).

upwelling of cold nutrient-rich water favours biomass growth. The BUS is separated at 27°S by the Lüderitz upwelling cell into North and South Benguela (Figure 4b) (Tim *et al.,* 2015). The water masses in the two subregions differ in nutrient and oxygen properties.

Observational studies (Mohrholz *et al*., 2008; Poole and Tomczak, 1999) suggest that the central waters of South Benguela are dominated by Eastern South Atlantic Central Water (ESACW), whereas South Atlantic Central Water (SACW) dominates in North Benguela. The SACW forms in the Brazil-Malvinas Confluence Zone (BMCZ) in the western South Atlantic. The ESACW forms when Agulhas leakage water mixes in the Cape region with the SACW. ESACW enters South Benguela rather direct, whereas the SACW takes a longer route through the equatorial current system before reaching North Benguela.

We test this hypothesis in a hindcast experiment (1958-2009) with the global nested ocean-only configuration INALT20 of the NEMO model (Madec, 2008). INALT20 has a global base model (ORCA025 (Barnier *et al*., 2006)) with a horizontal resolution of 1/4° and a nest over the South Atlantic and the western Indian Ocean with a resolution of 1/20°. In the nest, the simulation is eddy-resolving leading to a realistic simulation of the greater Agulhas system. Contributions, pathways, and age are studied with Lagrangian analysis of the trajectories of water volumes advected with the simulated ocean currents.

Our analysis shows that the Agulhas Current contributes more strongly to the central water masses in the BUS than the subduction region in the BMCZ. The contribution of Indian Ocean water is 70% of the water mass in South Benguela, and even 48% in North Benguela. The remaining percentages of the water masses originate from the BMZC (~25% for both regions) and only 1% for South Benguela, but 25% for North Benguela from the North Atlantic.

Furthermore, our study confirms the hypothesis based on observations that the central water masses in the North and South Benguela differ in their pathways into the upwelling regions: North Benguela SACW enters the upwelling region mainly by the equatorial current system, with only a small portion crossing the boundary between the two subsystems (Figure 5a) whereas ESACW flows directly with the Benguela Current into the upwelling region (Figure 5b). These different pathways lead to differences in water age and associated biogeochemical properties.

The location of last mixed-layer contact for both water masses is mainly in the Cape Basin. Thus, ESACW is younger than SACW with age of 6 years as travel times from last ventilation to North Benguela are twice as long. This leads to higher oxygen utilisation, carbon dioxide (CO_2) and nutrient build-up from remineralisation of

sinking organic matter in SACW than in ESACW. Thus, the distinct pathways cause age difference, with in turn can help explaining the contrasting nutrient, CO_2, and oxygen properties of the upwelling water masses in the North and South Benguela (Emeis *et al.*, 2017).

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Acknowledgements

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Carlos Conejero studied geophysics at the University of Concepcion, Chile. He started his PhD in 2017 at LEGOS, France, to investigate the impact of climate change on the oceanic circulation in the Eastern Boundary Upwelling Systems of the South Hemisphere.

Mechanisms associated to the global warming-induced sea surface temperature pattern in the South Eastern Pacific

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The Eastern Boundary Upwelling Systems (EBUS) are of particular interest because they connect the tropical ocean basins with the mid-latitudes. These regions share common characteristics (i.e. upwelling favourable winds, Figure 6) and contain very productive oceanic ecosystems and fisheries. The Humboldt System located in the South Eastern Pacific (SEP) is the most productive EBUS. Understanding how global warming will modify the oceanic circulation in this region remains a scientific challenge. Coupled Model Intercomparison Project (CMIP) -class models predict stronger warming in the equatorial region compared to the mid-latitudes of the South Hemisphere, resulting in a differential warming rate in the EBUS between the coastal and the off-shore ocean (Meehl *et al*., 2007).

In the SEP, the enhanced equatorial warming relative to the subtropics has been linked to changes in latent heat loss, negative shortwave

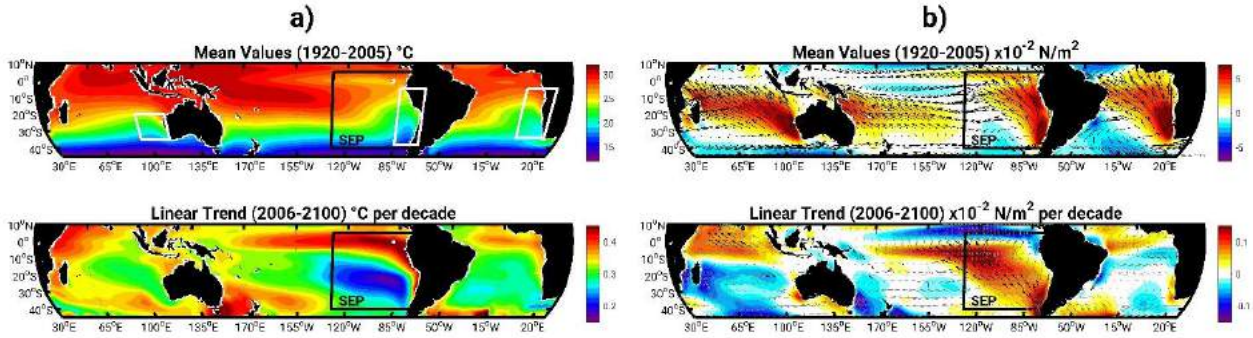

Figure 6: CESM-LENS 40 mean-ensemble of a) sea surface temperature, and b) meridional wind stress component. Mean values (linear trend) correspond to historical (RCP8.5) runs in upper (lower) panels. White rectangles correspond to the Eastern Boundary Upwelling Systems of the South Hemisphere and black rectangle indicates the South Eastern Pacific (SEP) region. Black vectors in b) correspond to wind stress.

cloud forcing, and ocean mixing (Liu *et al*., 2005) or changes in the southeast trade winds through the wind-evaporation-sea surface temperature (WES) feedback (Xie *et al*., 2010), suggesting that the role of ocean dynamics is minor. In addition, the mechanism involved in the minimum warming rate in the subtropics is yet to be elucidated.

Here we investigate the processes associated to the sea surface temperature (SST) climate change pattern in the SEP based on the Community Earth System Model Large Ensemble (CESM-LENS, Kay *et al*., 2015). To disentangle the complex of processes acting on SST, we carried out a heat budget analysis of the mixed layer (fixed at 50 m depth) associated to the long-term SST trend over the period 2006-2100 considering advection. We decomposed the tendency term associated to latent heat flux into a Newtonian cooling (αQLHm), wind speed, relative humidity and stability effects derive.

The SST trend pattern in the CESM-LENS simulations for which the radiative forcing levels yield 8.5 Wm^{-2} by 2100 (Representative Concentration Pathways (RCP) 8.5 scenario) consists in a region of minimum warming rate (~0.2°C/decade) off Central Chile that extends from the coast up to 130°W and between 40°S and 10°S. The warming rate is twice as large in the eastern equatorial Pacific and near the coast of Peru and Chile (Figure 6a). This pattern of minimum warming can be understood to the first order as resulting from the mean pattern of latent flux, which imposes that the SST tendency is minimum where the later is maximum, controlling the ocean's ability to limit SST warming by evaporation (αQLHm). However, the minimum warming is found at ~10°S to the south of the location of mean latent heat (Figure 7).

The heat budget analysis reveals that south of 10°S, the SST trend can be explained to a large extent by the summed-up contribution of heat flux and advection. Advection consists in a warming trend that compensate the excessive relative

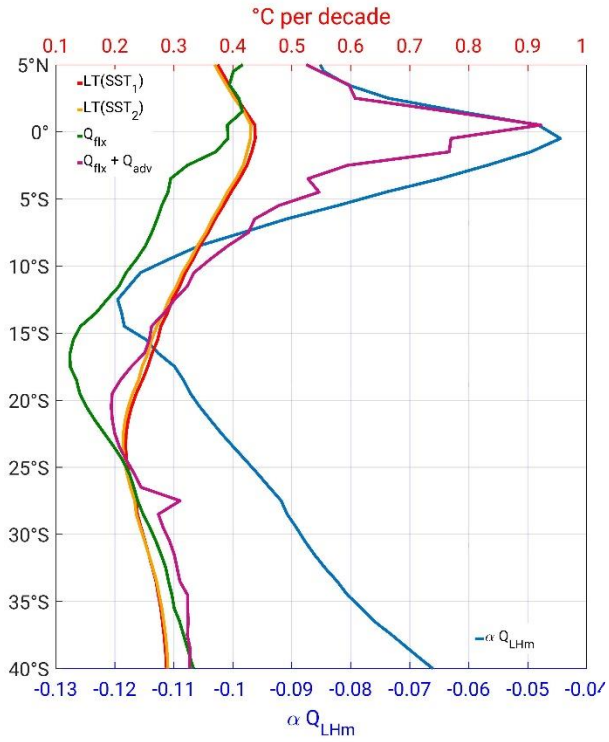

Figure 7: CESM-LENS 40 zonal mean-ensemble in the SEP region to Newtonian cooling coefficient (blue line, αQLHm) from mean value 1920-2005, and linear trend (°C per decade) from RCP8.5 runs to sea surface temperature directly from model (red line, LT(SST1)), SST from our heat balance (orange line, LT(SST2)), surface heat fluxes (green line, Qflx), and surface heat fluxes plus ocean heat advection (purple line, Qflx+ Qadv).

cooling by evaporation that is found north of 25°S so that the minimum warming rate is found around 24°S instead of 17°S if ocean advection was null. The warming trend of the advection term is associated to the meridional Ekman current owned to the increased in the southeast trade winds.

Our results suggest that the global warming pattern in the SEP is formed through the combined effect of the radiative forcing and the changes in the surface circulation associated to the expansion of the Hadley cell.

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Report 11 I December 2018

The 7th SOLAS Summer School

23 July - 3 August, 2018
Cargèse, Corsica, France

The 2018 mid-summer Mediterranean sunshine saw a gathering of 64 students and 17 lecturers and practical demonstrators in Cargèse, Corsica, France for the 7th SOLAS Summer School. The students came from 24 countries on all continents except Antarctica and were all either graduate students or recent post-docs in various fields of oceanography and atmospheric science. The lecturers were international experts on SOLAS science who also hailed from around the world. These people were brought together under the leadership of Christa Marandino, GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany, with the help of an organising

In this report

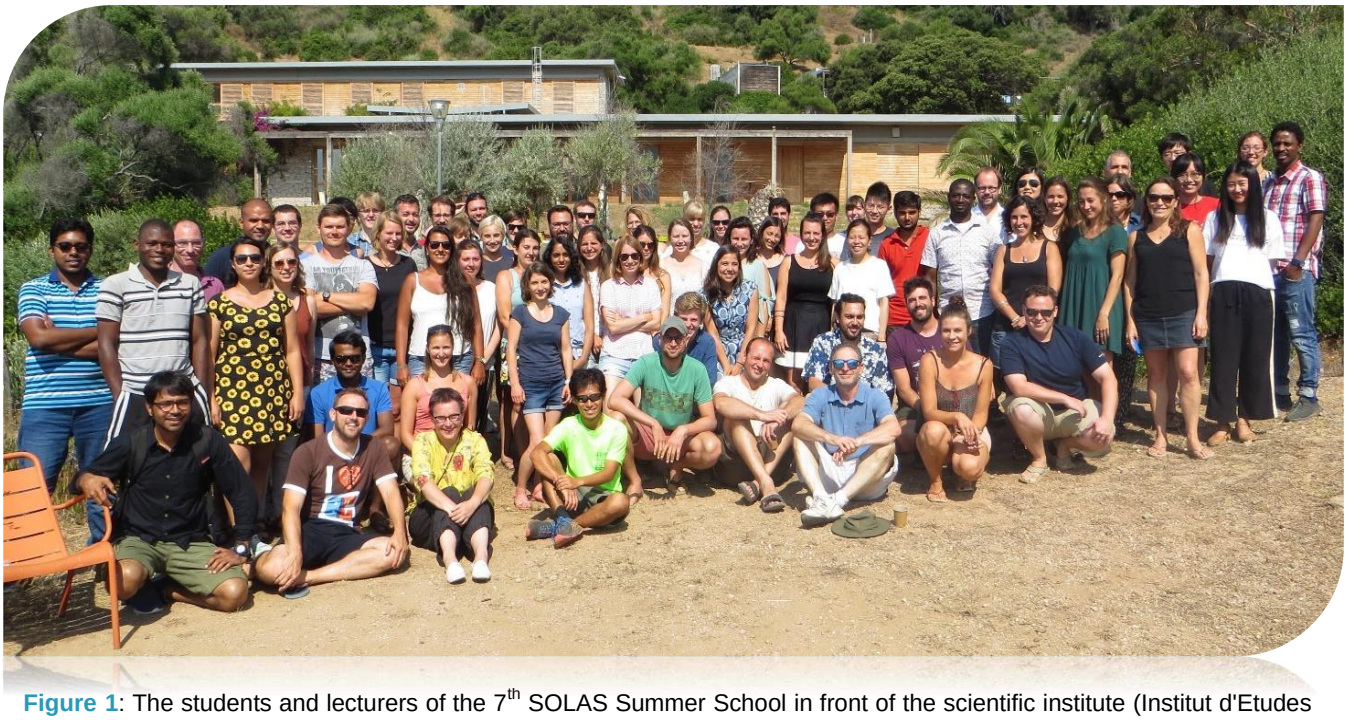

Figure 1: The students and lecturers of the 7th SOLAS Summer School in front of the scientific institute (Institut d'Etudes Scientifiques de Cargèse) in Cargèse, Corsica, France. © Jessica Gier

committee consisting largely of past summer school alumni and lecturers. Ultimately, skilled logistical support from Jessica Gier, SOLAS executive director, and Erik Ferrara assured everything went smoothly in the end. This summer school was dedicated to Roland von Glasow, alumni of the first SOLAS Summer School in 2003, later a member of the SOLAS Scientific Steering Committee, and a beloved colleague, who died in 2015.

As during the previous six summer schools, the lectures during the first three days presented fundamental - albeit often complex - information on the atmosphere and ocean sciences, to assure that all the students had basic knowledge of both sides of the air-sea interface. Poster sessions at the end of these first days also allowed them to share their own science with their colleagues and the lecturers. These three intense lecture-days were followed by three days of practicals which initiated the students into specific aspects of SOLAS science, including modeling, sea-air flux measurements, remote sensing, etc. These practical sessions also included a series of half-day cruises on-board the French research vessel Téthys II, a sought-after experience for those who had never been on a scientific ship. And certainly a good occasion to test their sea legs….

After a one-day rest, the students dove into a series of more specialised SOLAS-oriented lectures on topics such as the impact of atmospheric depositions on ocean biogeochemistry, the ocean biogeochemical control on atmospheric chemistry, SOLAS science and society, and geoengineering, to name a few. It was also during this second week that the students had the opportunity to improve their communication skills with short presentations of their research, as well as team reports on the practicals. All in all, two very busy but formative weeks for the students, who also found time to socialise and swim in the Mediterranean Sea! And how not to mention the lunar eclipse that graced the first week?! A memorable moment for all of us.

Those who had been involved with previous summer schools had forgotten how exhilarating and energising it is to share time with so many talented and determined students from different backgrounds and roots. The lecturers want to

personally thank all the students for their contribution to the success of the school. The experience has also reminded all of us of the challenge in bringing different disciplines together, oceanography and atmospheric science in our case; two components of the Earth system in constant interaction. Understanding the functioning of one of these two components is already an immense task. Understanding how they 'speak' to each other is, well, a life-time challenge, but a challenge that for all of us involved in organising the SOLAS Summer School has become a passion, a passion that we hope we have been able to transmit to all the students.

The following pages present articles written by a number of the students, summarising their research. Due to space restriction, we had the difficult task of picking only examples of the excellent research being conducted by these young scientists. Nonetheless, we feel these summaries reflect both the diversity of the research and the diversity of the participants, the two most powerful aspects of the SOLAS Summer School.

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Mohamed Ahmed is currently a PhD candidate in Geography Department at the University of Calgary, Canada. He got his Master degree in Geomatics from Lund University, Sweden. Ahmed's research project is focusing on combining field observations and remote sensing techniques to estimate the sea-air carbon dioxide fluxes in the Canadian Arctic.

Estimation of sea-air carbon dioxide fluxes in a changing Arctic system by using a combination of field observations and remote sensing techniques

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Whether using field measurements, sensors in the oceans, satellite images from the space, or simply talking with people who live in the Arctic, you will get the same answer: The Arctic climate is changing. Several studies report the significant impact of global warming on ecosystems and cultures in the Arctic region (e.g. Bates and Mathis, 2009; McGuire *et al*., 2009; Duarte *et al*., 2012), which may be irretrievable on long timescales and has a massive potential to cause striking consequences in our planet system.

The Arctic Ocean has been suggested to be a net sink for atmospheric carbon dioxide (CO_2) due to its cold temperature, low salinity, and relatively high biological production (e.g. Macdonald *et al.,* 2009). Although the Arctic Ocean is mostly ice-covered and occupies only 3% of the world's ocean surface area, the Arctic Ocean absorbs CO_2 on the order of -66 to -199 Teragram (Tg) carbon (C) year^{-1} (Tg C = 1012 g C) contributing to 5-14% to the global balance of CO_2 sinks and sources (Bates and Mathis, 2009).

However, the oceanic uptake of CO_2 in the Arctic Ocean is uncertain and controversial due to relatively field observations and expected variations as a result of rapid climate change. For example, Bates et al. (2006) estimated the sink of CO_2 in the Arctic Ocean has tripled over the last three decades due to sea ice loss. On the other hand, a slowdown in the CO_2 uptake in certain regions of the Arctic Ocean was found (Cai *et al*., 2010). Therefore, understanding the global carbon cycle along with the processes controlling air-sea CO_2 exchange is crucial to quantify the effect of the changing Arctic Ocean.

Figure 2 summarises the major processes affecting the organic and inorganic carbon flows in the Arctic Ocean. Generally, the major inputs that are affecting the Arctic marine carbon cycle are terrigenous inputs (river and underground water discharge, coastal erosion, and aeolian input), and biological processes (primary production, remineralization, and calcium carbonate formation). While, there are other important factors such as sea-ice processes, air-sea gas exchange, sinking and sedimentation, horizontal circulations, vertical mixing and upwelling between the polar mixed layer, halocline layer, and deep waters.

In Figure 2, including the temporal and seasonal

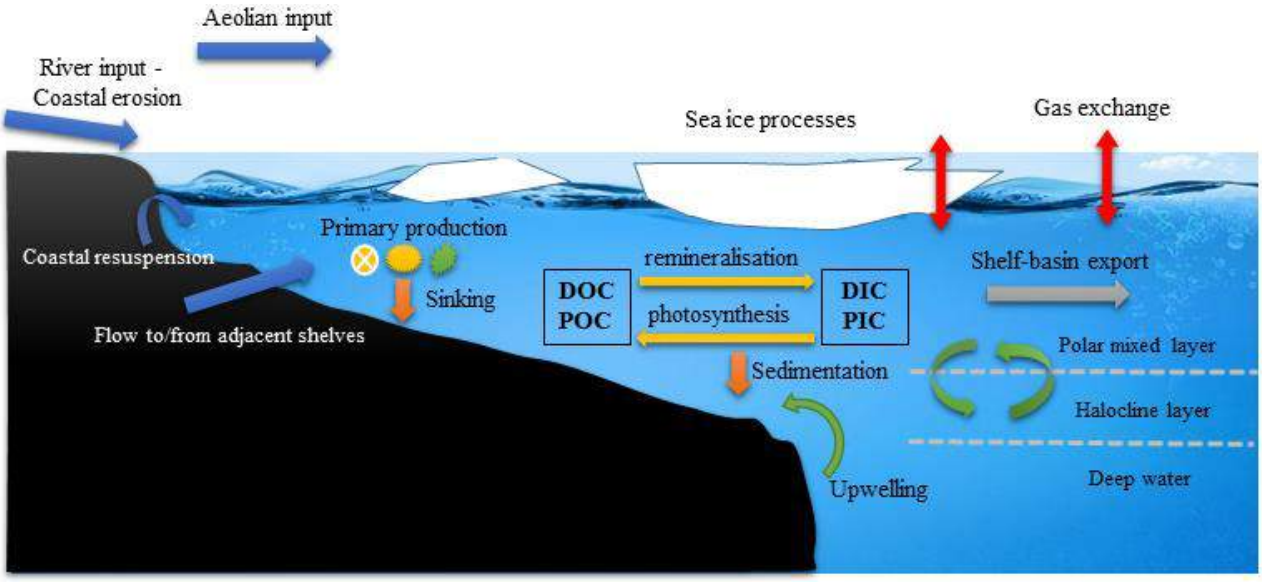

Figure 2: A schematic diagram summarising the factors controlling marine carbon cycle in the Arctic Ocean. Red arrows depict the air-sea gas exchange, while blue arrows represent the terrigenous and carbon stocks from rivers, coastal erosion, and adjacent shelves. DOC represents dissolved organic carbon, POC represents particulate organic carbon, DIC represents dissolved inorganic carbon, and PIC represents particulate inorganic carbon.

variations that will affect the transport and production of the Arctic marine carbon cycle have been neglected.

The fluxes of CO_2 across sea-air interface is a major concern and have potential effects on biogeochemical cycle in the ocean with fluxes averages about 2.2 Gigatons (Gt) C yr^{-1} into the ocean from the atmosphere (Takahashi *et al.*, 2009), and expected to increase in the future in response to the steadily increasing in the global atmospheric CO_2 concentration. This means that the oceans are absorbing around ~30% of anthropogenic emissions, and are responsible for more than half of the total global CO_2 sink. However, there is spatial and temporal variability in the ocean sink with some regions may act as strong sinks (absorbing atmospheric CO_2) such as North Atlantic Ocean, while others act as a minor sink or even as a source for atmospheric CO_2 such as the tropical regions in the Pacific Ocean (Figure 3). These significant regional variations could be accounted to physical, chemical, and biological processes, which are generally fluctuating seasonally and can cause a region to alter between a sink and a source over time (Takahashi *et al*., 2009). Therefore, it is important to study the marine carbon cycle at each region, separately, in the Arctic Ocean.

My research project seeks to overcome the spatial and temporal limitations of ship observations by using remote sensing products to assess air-sea CO_2 exchange in the regions of Canada's Arctic most likely to undergo rapid industrial development such as Hudson Bay and the Canadian Arctic Archipelago. This will be accomplished through collecting field datasets of surface salini-

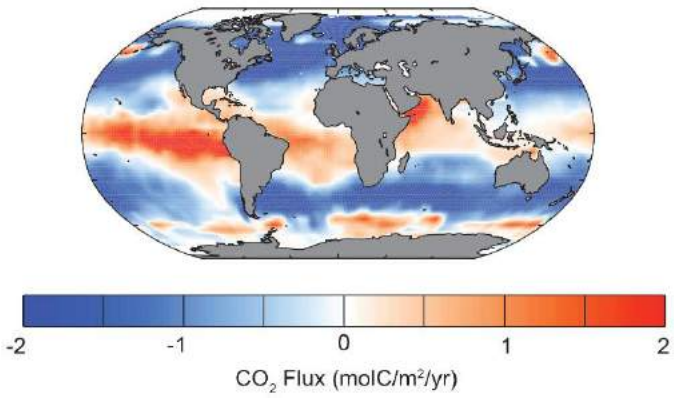

Figure 3: Annual mean air-sea CO_2 flux, estimated by Takahashi *et al*. 2009. Positive is from ocean to atmosphere, negative from atmosphere to ocean.

ty, sea surface temperature, ocean colour, and dissolved CO_2 in seawater and scaling it up by using remote sensing products from numerous sensors (e.g., MODIS, SMOS, MERIS, ASCAT) in order to provide weekly and monthly CO_2 flux maps, and describe the key factors of air-sea CO_2 exchange.

This study will benefit greatly from collaborations within the Hudson Bay System Study (BaySys), which aims to study the role of climate change and hydroelectric regulation of freshwater on Hudson Bay marine and coastal ecosystem. Broadly speaking, the results from this study will have a big significance for the scientific community by filling the current knowledge gaps about air-sea CO_2 exchange over Hudson Bay and the Canadian Arctic Archipelago in response to climate change.

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Kathryn Moore completed a Bachelor in Chemistry at Colby College in Maine, USA, in 2014. She started a Master of Science/PhD program at Colorado State University, Colorado, USA, in 2017, which is focused on ice nucleating particle production and cloud microphysical processes over the Southern Ocean.

Southern Ocean cloud phase modulation by ice nucleating particles

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Aerosols contribute the largest uncertainty to global radiative forcing estimates, with natural aerosols responsible for a significant portion of this (Carslaw *et al*., 2013). As the natural aerosol burden and its effects are largely unknown, our ability to constrain and predict the influence of anthropogenic aerosols on climate sensitivity, radiative forcing, and cloud processes has been hindered (Carslaw *et al*., 2013). An increased understanding of natural aerosol budgets is thus required to improve model simulations of aerosols and predict their effects on global climate in the future.

The limited anthropogenic and terrestrial aerosol sources impacting the Southern Ocean (SO) makes it a unique site to study the production of primary sea spray aerosols (SSA) and their role in cloud properties, such as phase, precipitation formation, lifetime, and radiative forcing. Ice nucleating particles (INPs), which are important for cloud glaciation, exhibit very different immersion freezing temperature spectra depending on their source (DeMott *et al*., 2016).

Thus, not only INP concentrations, but also their chemical and physical characteristics, affect the consequent aerosol-cloud interactions. Recent laboratory studies examining INP emissions from nascent SSA (DeMott *et al*., 2016) are in agreement with the lower bounds of the sparse existing INP measurements from the SO (Bigg, 1973). Observed low INP numbers, its remote location, and recent modeling work (Burrows *et al*., 2013) support the idea that the SO INP population is dominated by marine SSA and distinct from that found in the northern hemisphere, though direct field confirmation is still needed (Figure 4).

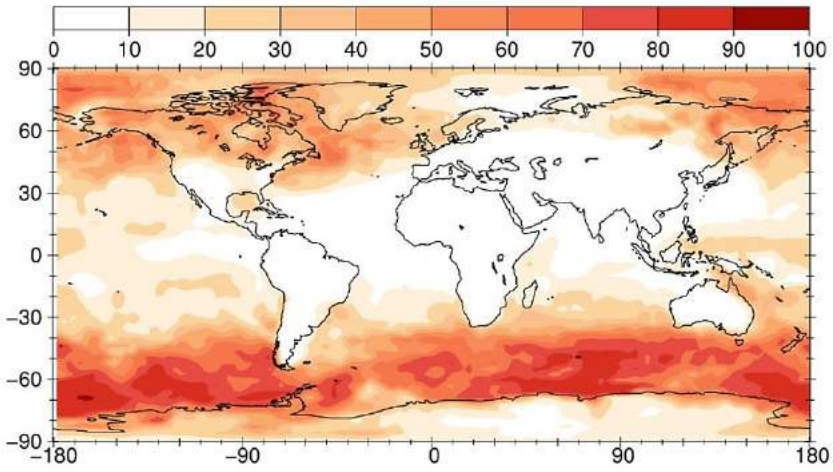

Figure 4: Modeled relative contribution of marine biogenic INPs to marine boundary layer INPs at -15 °C (Burrows *et al*., 2013).

Global climate model (GCM) simulations and satellite observations of SO clouds show poor agreement, including a systematic positive bias in model estimates of absorbed shortwave radiation poleward of 55°S, particularly during Austral summer (Trenberth and Fasullo, 2010). This leads to associated errors and uncertainties in predicting other model outcomes (Trenberth and Fasullo, 2010). The SO influences oceanic and atmospheric circulation on both local and global scales, and the poor representation of SO atmospheric processes in GCM simulations is a major limitation on our ability to accurately predict responses to future climate change.

Underestimation in the number and lifetime of supercooled clouds, particularly low and midlevel clouds in the cold sector of cyclonic storms appears to account for the bulk of GCM overestimation of absorbed shortwave radiation in the SO (Bodas-Salcedo *et al*., 2014). The unusually high proportion of supercooled liquid water (Morrison et al., 2011) is consistent with low numbers of INPs in this region and indicates that INP concentrations and composition may strongly control cloud phase and precipitation formation over the SO.

For my graduate studies, I am undertaking field (Figure 5) and laboratory measurements to better understand the source, composition, and variability of INPs over the SO, focusing on their climate implications. In particular, I aim to assess the extent to which marine INPs are responsible for cloud glaciation in the SO, in contrast to long-range transported aerosols, cloud dynamics, secondary ice formation, or other processes. Several research objectives will be undertaken to achieve this: 1) verify local SSA are the primary source of SO INPs, 2) determine the influence of the observed INPs on cloud phase in the SO, and 3) quantify the source production of SO INPs and collaborate with modelers to improve their representation in GCMs.

If SO INPs are indicated to strongly control SO cloud phase, their distribution, chemical, and physical properties would have significant implications for radiative forcing over high latitude regions, and so a more accurate representation in GCM simulations would be expected to improve model outputs of absorbed solar radiation and related properties. Knowledge of the SO INP number distribution in and out of clouds, and their sources, will provide much-needed and missing parameterisations and validation datasets for GCMs, while simultaneously reducing the significant model uncertainties attributed to aerosols (Carslaw *et al*., 2013).

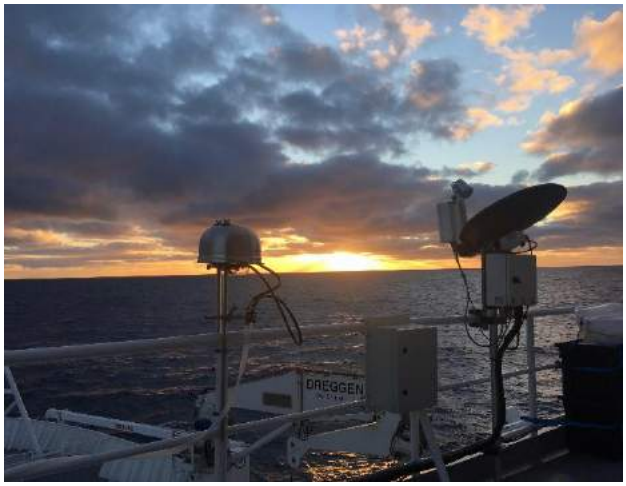

Figure 5: Filters for INP collection on the deck of the RV Investigator during the Southern Ocean Clouds, Radiation, Aerosol Transport Experimental Study (SOCRATES) field campaign. © Kathryn Moore

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Matias Pizarro-Koch obtained the degree in Marine Biology at the University Católica del Norte, Chile, in 2009. He is currently doing his PhD in Oceanography at the University of Concepción, Chile. His scientific interest are the physical/biogeochemical coupled numerical modelling of the ocean, particularly the spatio-temporal variability of the Oxygen Minimum Zone (OMZ) in the eastern South Pacific Ocean and the main drivers controlling its variability.

Temporal variability of the Oxygen Minimum Zone off Chile (30-38°S): a 3-D coupled physical-biogeochemical modelling approach

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Despite the large primary productivity that takes place along the coast off Central Chile during the upwelling season, surface waters are commonly undersaturated with oxygen (Letelier *et al.,* 2009). Near the coast, subsurface waters with very low dissolved oxygen (DO) are transported to the surface by upwelling circulation cells. In fact, the presence of an intense and relatively shallow oxygen minimum zone (OMZ) is one of the most striking oceanographic features along the eastern boundary of the Pacific Ocean (Wyrtki, 1962). Combined effects of the microbial decomposition of organic matter that is remineralised in subsurface waters (contributing to the subsurface DO depletion) and a sluggish subsurface circulation that prevents efficient ventilation, generate these oxygen-poor environments in different eastern ocean boundaries (Karstensen *et al.,* 2008).

In the eastern South Pacific (ESP) such conditions generate a large, shallow and very intense OMZ (Paulmier *et al*., 2006). This OMZ region in the Open Ocean may frequently reach values of DO in the suboxia range, which are lower than 40 µM, (Naqvi *et al*., 2010), and even anoxic zones (Ulloa *et al.,* 2012). Such oxygen-poor waters impact marine communities, the biogeochemical cycling of carbon and nitrogen, and the climate system (Helly and Levin, 2004; Stramma *et al*., 2011).

Most of OMZs studies have been carried out in the tropical zone, focusing mainly on the biogeochemical processes and bacterial communities, while the extra-tropical borders or the OMZ boundaries and its physical drivers are still unknown (Brand *et al*., 2010). Therefore, during my PhD study, I have been focusing on the extra-tropical OMZ off central Chile. In this region, the OMZ is related to the Equatorial Subsurface Water mass (ESSW), a water mass relatively warm (12.5°C), characterized by a subsurface salinity maximum (>34.9), nutrient rich and high phosphate content (Silva *et al*., 2009), and its southward transport along the continental slope through the Peru-Chile Undercurrent (PCUC).

The aim of my study is to analyse the seasonal

and interannual variability of the southern tip of the eastern ESP-OMZ (30°S to 38°S) using a coupled physical-biogeochemical model simulation between ROMS (hydrodynamic model) and BioEBUS (biogeochemical model) (Gutknecht *et al*., 2013).

Historical physical and biogeochemical in situ data from the study region were used for model validation. Based on this coupled simulation, the seasonal variability of the OMZ and its relationship with the meridional changes of the southward PCUC transport were analysed, together with the interannual variability and its association with EL-Niño-La Niña cycles.

Regarding the preliminary results and in light of the model assessment, the model has a fair skill in simulating the main features of the Eastern Boundary Upwelling System (EBUS; Figure 6), e.g. the upwelling dynamics, the subsurface poleward current (PCUC), the vertical structure of the OMZ associated with the ESSW and the eddy mesoscale variability, that allows the process studies focusing on seasonal and interannual timescale. The seasonal cycle of the OMZ off Chile showed during the first half of the year, which was associated with an intense southward PCUC transport and eastward-westward zonal jets. The OMZ volume is maximum (July) and the DO content (respectively, salinity) is minimum (maximum). Conversely, in the second half year, due to weakening of the PCUC transport, the volume decreased and the DO average content increased (Figure 7).

The interannual variability (2000-2008) also showed high consistency with the PCUC variability, i.e. high volume or positive anomalies (negative) were related with the intensification (weakening) of the PCUC. However, the PCUC showed better correlation r=0.8 with the DO content within volume than with the volume itself. Maximum and minimum values of the OMZ-volume anomalies were observed during 2001

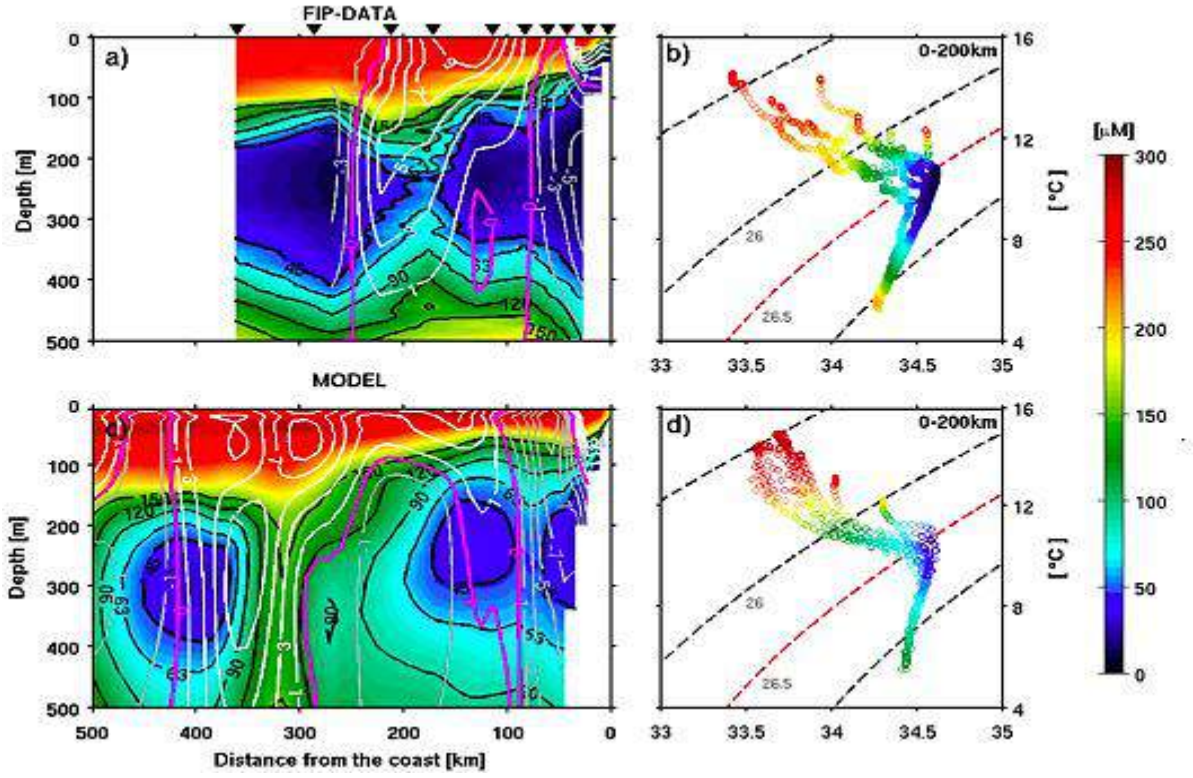

Figure 6: Cross-shore section comparison between dissolved oxygen (DO) modelled and cruise DO data during November 2004 (FIP cruise Letelier *et al*., 2009; a and c). The background colors show DO (inµM). The white (respectively, grey) contour indicate northward (respectively, southward) flows, while that magenta contour indicate zero velocity. The diagrams (b and (d) obtained from 0-200 km from the coast represent (b) in-situ data and (d) from ROMS/BioEBUS data. The colored dots represent the DO.

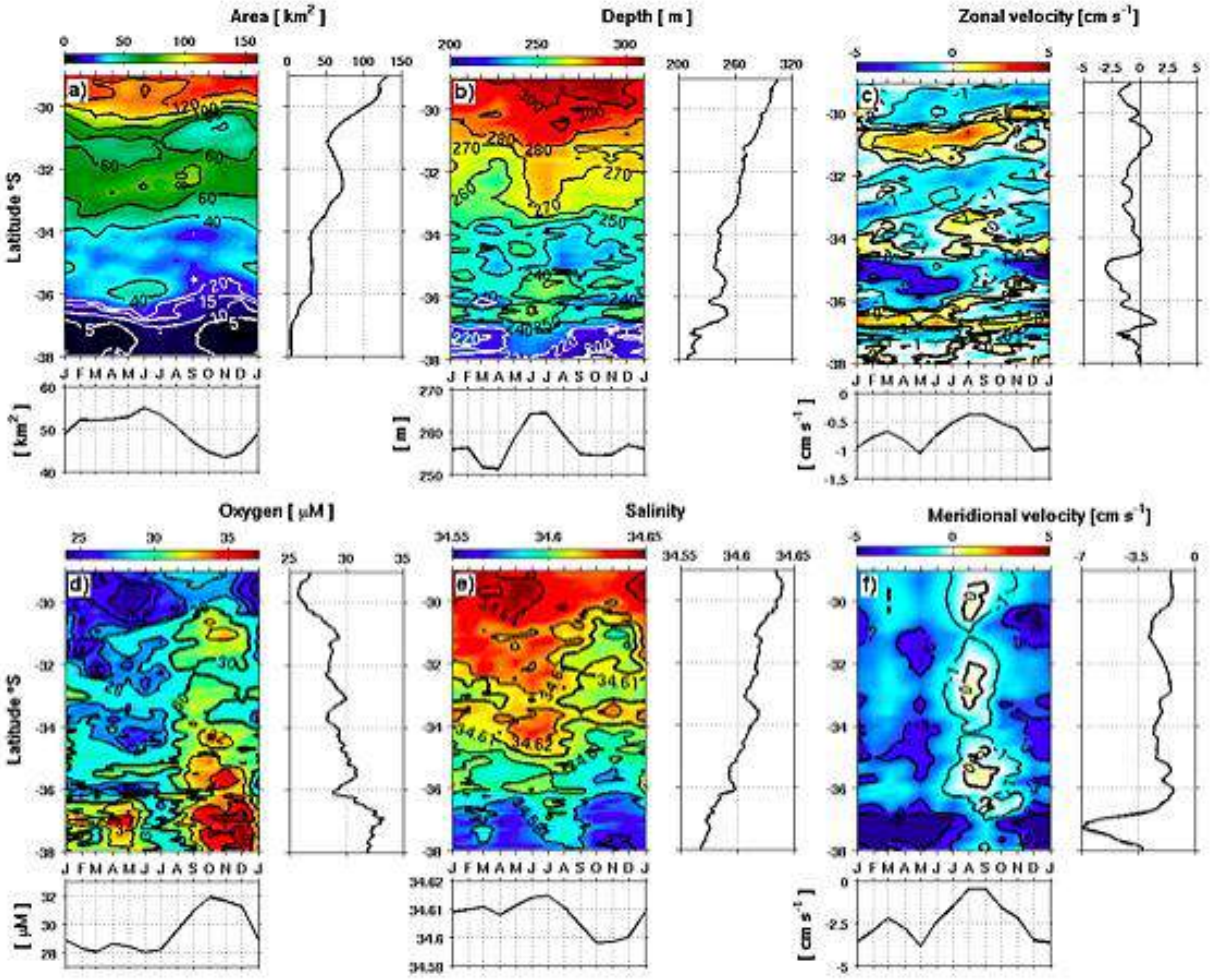

Figure 7: Seasonal cycle of different metrics that characterise the alongshore oxygen minimum zone (OMZ) southern tip (the OMZ was defined as the volume enclosed by the isopleth of DO $\leqslant$ 45 µM, see Figure 6). Whereas (a) is the area in km^2 (cross-shore extension), (b) mean depth (m), (c) zonal velocity (cm s^{-1}), (d) dissolved oxygen (DO) concentration (intensity; µM), (e) salinity and (f) meridional velocity (cm s^{-1}). The insets at the right and bottom of the main panels show the annual mean at different latitude and the mean seasonal cycle meridionally averaged of the corresponding variable, respectively.

and 2007, respectively.

In 2001, the OMZ- volume increased up to ~33% related to the mean value for the study period, displaying a large decrease in the mean oxygen concentration, together with a greater offshore and southward extension, as well as an increase in temperature and salinity. In contrast, in 2007 the OMZ volume was reduced by ~23% and became more oxygenated, showing a lesser offshore and southward extension, together with a decrease in temperature and salinity. These changes of the OMZ volume are related to changes in the PCUC transport, i.e., positive (negative) OMZ volume anomalies are associated with the intensification (weakening) of the PCUC (Figure 8).

Finally, the OMZ volume showed a significant correlation (r=0.6) with the equatorial index (ONI; Oceanic El Niño index). The seasonal and interannual DO budget analysis within OMZ reveals that the main drivers of its variability are the physical processes (90% contribution) and these in turn are dominated by the advective terms. In contrast, the biogeochemical fluxes and the mixing terms could be playing only a secondary role over the DO budget (~10% contribution).

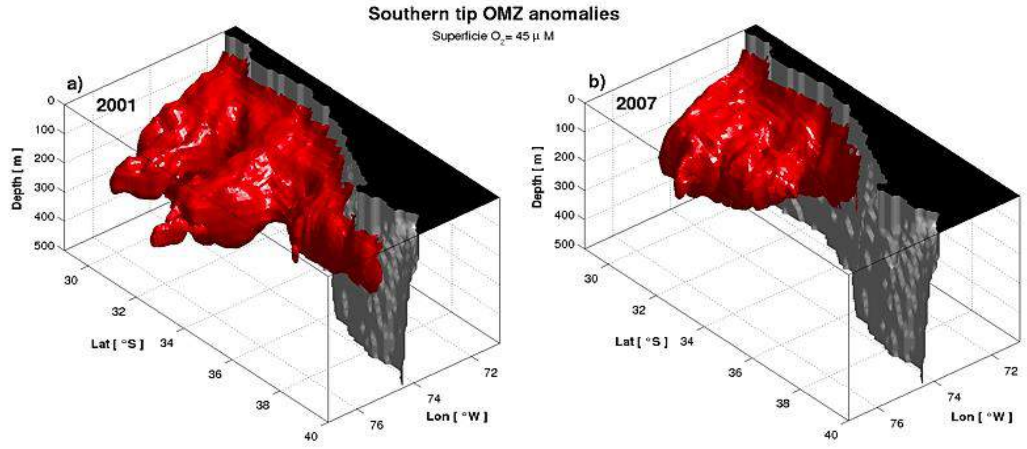

Figure 8: 3-D distribution of the southern tip of the Oxygen Minimum Zone. (Top panels) displays the whole OMZ volume (<45 µM) and (bottom panels) shows the OMZ core (<20 µM; bottom panels) during 2001 (positive anomaly; left panels) and 2007 (negative anomaly; rigth panels) periods.

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Yanjie Shen studied environmental science in Lanzhou University, Lanzhou, China, in 2016. In 2017, Yanjie started her PhD at the Ocean University of China, Qingdao, China, to investigate the new particle formation in atmosphere.

New particle formation events observed in remote tropical marine atmospheres over the South China Sea

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New particle formation (NPF) is a common atmospheric phenomenon which has been observed globally in various continental and marine environments (Gong *et al*., 2010). The grown newly formed particles are proposed to affect the climate by scattering sunlight directly or by affecting cloud formation indirectly (Kulmala *et al*., 2004). In the boundary layer of continental at-

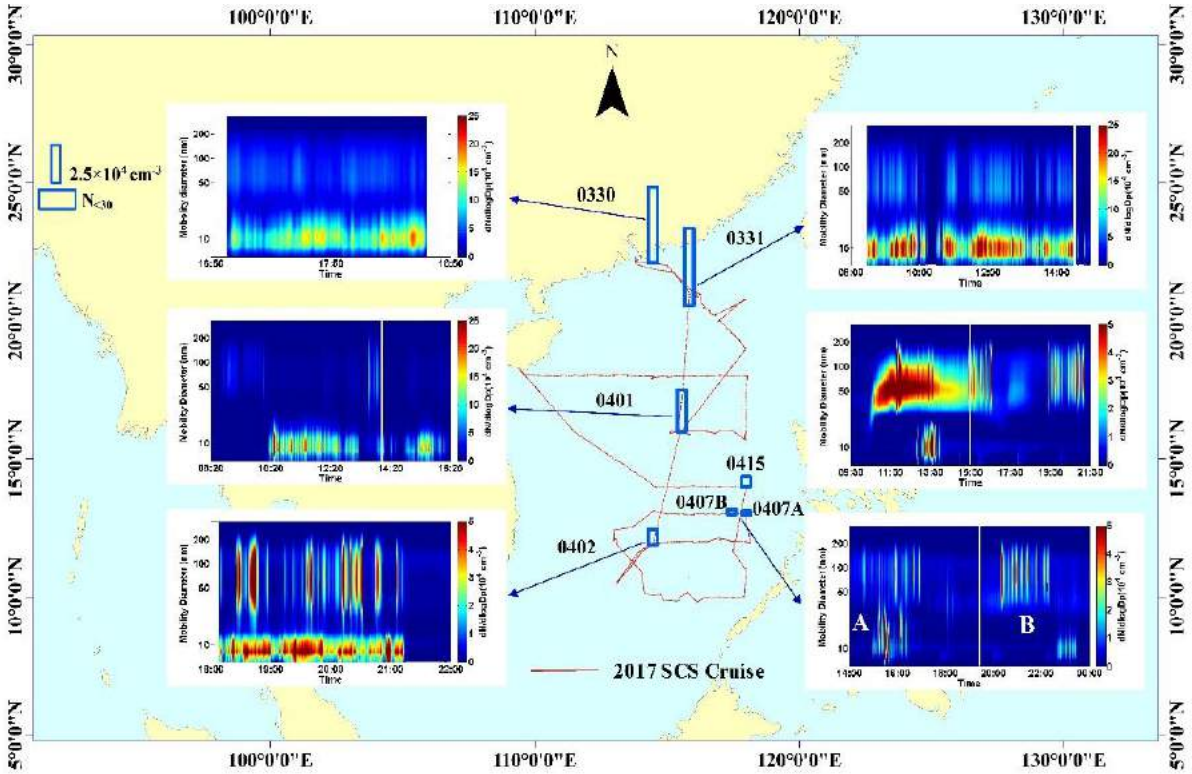

Figure 9: New particle formation (NPF) events observed in the atmosphere across South China Sea (SCS), the blue bars represent the number concentration of the 5.6-30 nm particles (N<30), the red line represents the cruise track across SCS during the period of 29 March to 2 May 2017.

mospheres, sulfuric acid vapor is widely recognised as the necessary precursor for atmospheric nucleation while ammonia (NH_3) and organics have been reported to greatly enhance atmospheric nucleation therein (Zhang *et al*., 2004).

In the boundary layer of marine and coastal atmospheres, the oxidation products of dimethyl sulphide (DMS) such as sulfuric acid as well as reactive iodine compounds are proposed to induce atmospheric nucleation (O'Dowd *et al.,* 2002). Relative to the abundant observations in the continent atmospheric boundary layer, the observations of the occurrence of NPF in the marine atmospheric boundary layer are scarce (Sellegri *et a*l., 2016), thus one of my PhD work is to study the NPF events across South China Sea (SCS).

In this study, a spring cruise campaign across the SCS was organised by National Natural Science Foundation of China using a search vessel Shiyan-1. The route is shown in Figure 9. During the whole cruise campaign, seven NPF events were observed (Figure 9). All seven NPF events occurred under clear weather conditions with ambient relative humidity (RH) exceeding 70%. This raised a possibility that these NPF events were not likely induced by sulfuric acid vapour. The observation of night-time NPF events supported this theory because of the lack of photochemical reactions. In addition, the typical "banana-shape" particle growth in any of the seven NPF events identified over the SCS was not observed. The geometric mean diameter (GMD) of newly formed particles remained invariant at ~10 nm in these NPF events. The 24-hour back trajectories during these NPF events showed that air masses travelled over the marine atmosphere (Figure 10). However, 24-hour back trajectories during the NPF events (grown up >10nm) across Northwest Pacific Ocean showed that air masses travelled over the continent.

Based on the comparison, it can be argued that the atmosphere over the SCS during the observational period lacks key precursors from the continent to support the growth of newly formed particles.

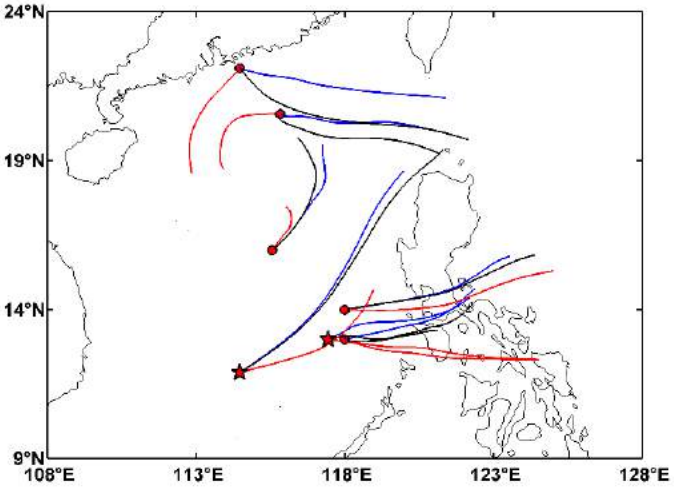

Figure 10: Air mass back trajectories in the latest 24 hours (100m, 500m and 1000 m) at the new particle formation (NPF) initial time on NPF days across South China Sea (SCS).

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Source characterisation of atmospheric trace metal deposition around Australia

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An important component of the Earth's carbon cycle system is the land-atmosphere-ocean transport of vital minerals and micronutrient trace elements (Jickells *et a*l., 2005). One part of this system is the biogeochemical cycle of iron (Fe), in which Fe-rich aerosols are delivered from the land masses to the oceans as aerosols from soils erosion, bushfire, and anthropogenic emissions. After deposition into the ocean some fraction of this Fe and other micronutrients contained in aerosols are available for marine biota consumption.

In some regions, such as the Southern Ocean, the scarcity of Fe controls marine phytoplankton growth with consequential effects for the ocean's drawdown of atmospheric carbon dioxide (CO_2) (Boyd *et al*., 2000). On the global scale, a high proportion of the CO_2 budget is consumed by photosynthetic organisms in oceans. This makes aerosols important for Earth's climate by influencing the atmospheric CO_2 concentration.

Deserts in North Africa and Central Asia are the most productive dust sources worldwide. The Southern Hemisphere is less abundant in mineral dust sources with the main active sources located in Australia, Patagonia and South Africa. Two main Australian dust sources are the Lake Eyre and Murray Darling Basins, both are supplied by inland river systems that deliver sediments to the arid zone of the continent. From there, dust is transported by two main atmospheric pathways: towards the south-east and the north-west of the continent (Bowler, 1976).

With an average 339 × 103 km^2 of land burned per year, Australia is the second largest source of biomass emission and contributes 11% of the global total direct carbon emission flux from wildfire or bushfire emissions (Ito and Penner, 2004). Bushfires are common especially in the northern tropics of Australia where significant areas of tropical savannah are burnt every year during the dry season (Russell-Smith *et al*., 2007).

Furthermore, since the Australian coast is inhabited by the majority of the Australian population, it is also the most industrially developed. For that reason, the coastline is a significant source of anthropogenic aerosols. Despite these signifi-

cant aerosol sources of both mineral dust and biomass burning emission, the aerosol data available for the Southern Hemisphere is still sparse. My results will assist with building up the trace metal (TM) database for Australia and thus will improve the accuracy of existing global models for ocean trace element and nutrient cycling.

A key question for studying the atmospheric TM deposition into oceans is the quantity of bioavailable TM forms that are supplied for photosynthesis and other bio-chemical processes. Bioavailability depends on nutrient solubility in sea water. Consequently, measuring total element concentrations in aerosols is not as important as determining what proportion of the total element concentration is bioavailable. Aerosol Fe solubility and bioavailability depend on its sources, particle size distribution and aging processes occurring during transport.

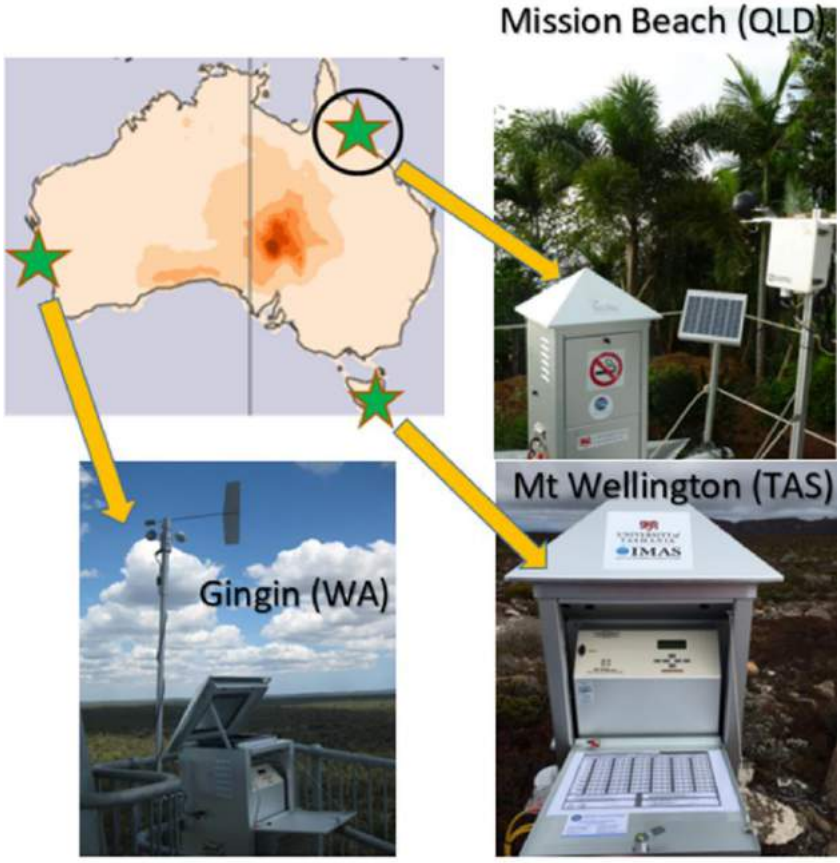

Figure 11: Dust dry deposition (left) and black carbon deposition (right) in Australia. Green Stars indicates sampling stations.
Source: https://giovanni.gsfc.nasa.gov/

Most of atmospheric Fe worldwide comes from dust where Fe is contained in a variety of minerals. However, the fraction of soluble Fe in mineral dust is generally low, below 1% for most Fe oxides and between 4 and 6% for most alumina-silicates (Journet *et al*., 2008). Desboeufs *et al*. (2005) found that Fe in alumina-silicate crystal clusters is much less soluble than Fe embedded in combustion products. They reported that Fe solubility for oil fly ash was as high as 36%. The high fractional solubility of combustion products was confirmed by Schroth *et al*. (2009) who reported Fe solubility from oil combustion reaching 81%, compared to much lower solubility of arid soils and glacial products: 1% and 2-3%, respectively.

Three sampling sites located in the proximity of the Australian coast are included in my research: Mission Beach (Queensland), Gingin (Western Australia), and Mount Wellington (Tasmania) (Figure 11). The last two stations are permanent sampling stations and allow observation of seasonal trends. Aerosol samples are collected on TM cleaned cellulose filters using air samplers. Leaching experiments followed by elemental analysis provide information about atmospheric concentrations of soluble, leachable and refractory forms of TM. Soluble TM data are correlated with markers of mineral dust, anthropogenic activity, and biomass burning to find their influence on soluble TM pool. Scanning Electron Microscopy analysis is used to study aerosol form and chemical composition.

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Thank you to SOLAS Summer School organisers, le, and students for a great scientific and social experience.

Valentina Giunta studied Physical Oceanography at the University of Buenos Aires, Buenos Aires, Argentina. She started her PhD in 2017 under the supervision of Dr Ward at the AirSea Laboratory, National university of Ireland (NUI), Galway, Ireland. She is currently involved in studying the characterisation of the ocean surface boundary layer, and its role in air-sea exchanges.

Lower atmosphere processes affecting the surface ocean: mixed and mixing layer depths

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The ocean surface boundary layer (OSBL) is typically well mixed as a result of different turbulent processes (due to the action of wind, waves, and buoyancy). The depth of the OSBL is controlled by the availability of turbulence and is characterised by vertically uniform temperature, salinity, and density. The OSBL controls relevant processes such as the transfer of heat, momentum, and trace gases between the ocean and atmosphere and represents an important element in the global climate system.

To investigate the OSBL, the Air-Sea Interaction Profiler (ASIP) was designed to study the surface layer of the ocean with an integrated suite of small-scale measurements from a single upwardly rising and autonomous platform (Figure 12) (for further details see Sutherland *et a*l., 2013, Ward *et al*., 2014, Esters *et al*., 2018). ASIP provides high-resolution vertical profiles of temperature, conductivity, and dissipation rates of turbulent kinetic energy (ε).

The base of the OSBL can be represented using the mixed layer depth (MLD) or the mixing layer depth (XLD) (Brainerd and Gregg, 1995). The MLD represents the limit of the layer at which

Figure 12: Image of the Air-Sea Interaction Profiler (ASIP) featured on the cover of the Journal of Geophysical Research (JGR) in March 2014.

temperature, salinity, and density are nearly constant with depth and the XLD represents the layer where turbulent processes are actively mixing the ocean surface. Using data collected with ASIP in the North Atlantic on board of the R/V Knorr from June 25 to July 6, 2011 (Figure 13), both parameters were estimated for the four deployments and then compared with local conditions.

The mixing in the OSBL is mainly produced by the contribution of three sources of turbulence: waves, wind, and buoyancy (Belcher *et al*., 2012). Under specific conditions one of the parameters could have more influence on mixing rather than others. For example, under positive strong buoyancy flux (B0) convection is favourable and therefore the mixing can penetrate deeper. In this case, both MLD and XLD are nearly equal (Figure 14, deployment 2) and are controlled by changes in B0. In deployment 3 (Figure 14), there are rapid changes in the energy flux (E10), and the energy increased until a certain point where it drops abruptly and subsequently increases. The XLD shows a strong positive correlation with E10 since it is increasing

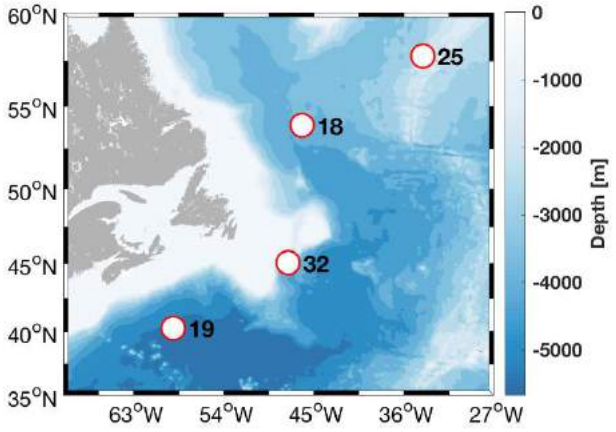

Figure 13: Bathymetry of the region of study. Red dots indicate the location of Air-Sea Interaction Profiler (ASIP) deployments and the total number of vertical profiles for each of them.

(and decreasing) at the same time that the energy is going up (or going down). The XLD is under the wind effects but the MLD seems to not have any relation to those changes. Since none of the turbulence sources takes over the others, the mixing in deployment 1 and 4 is a consequence of a combination among them.

Another relevant aspect of this is that the MLD and the XLD are not equal. Most of the time, the MLD is deeper and only under strong convection conditions both can be identical.

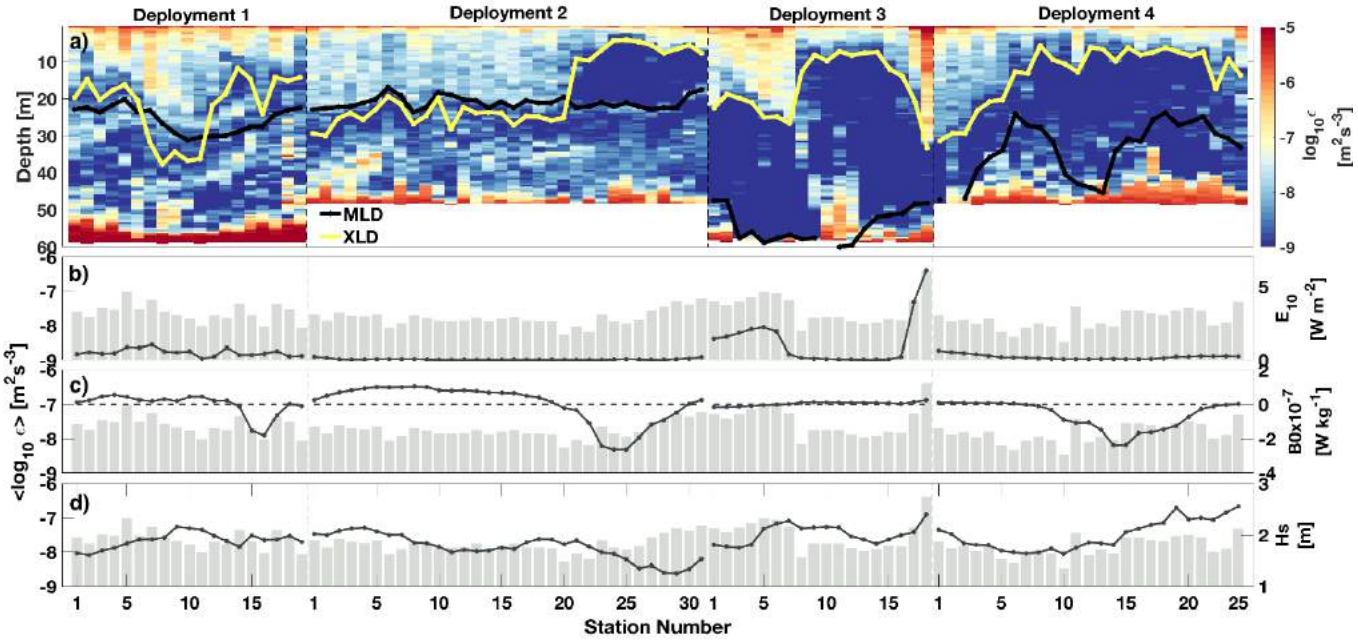

Figure 14: (a) Vertical profiles of log(ε) for the four deployments of the Knorr cruise. Wind energy flux (E10) (b), buoyancy flux (B0) (c), and significant wave height (Hs) (d) for all stations (black lines). The grey bar charts in b-d represent the average of log(ε) over the XLD.

The XLD is a better proxy of the turbulent mixing activity at the ocean surface.
Understanding the process that affects the air-sea exchanges is crucial to improving the climate and ocean general circulation models. Through the collection of on board measurements a better comparison between model outputs and in situ data can be made to reduce the lack of knowledge of physical processes at the ocean surface layer.

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Photo gallery of the SOLAS summer school

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solas event report

Report 12 I January 2019

Two consecutive workshops on SOLAS Core Themes 4 and 5

Workshop I: Influence of coastal pollution on marine atmospheric chemistry: effects on climate and human health.

Workshop II: Interconnections between aerosols, clouds, and marine ecosystems in contrasting environments.

27 - 29 November 2018, National Research Council, Roma, Italy

From November 27 to 29, 2018, two workshops took place at the Italian National Research Council (CNR) headquarters in Rome, Italy, organised by the Surface Ocean - Lower Atmosphere Study (SOLAS), in collaborations with the International Global Atmospheric Chemistry (IGAC) project, and CNR. These workshops focused on the SOLAS core themes 4 and 5.

The meetings featured presentations from experts and intense discussion sessions, exploring the multiple topics and feedbacks evident in air-sea interactions. The invited scientists were selected according to their expertise in the workshops topics and to provide a wide spectrum of knowledge. In fact, they included both experimentalists and modellers, representing the oceanographic and atmospheric science communities. Scientists from 17 different countries joined the workshops representing a wide range of career stages.

While workshop I was on “Influence of coastal pollution on marine atmospheric chemistry: effects on climate and human health”, workshop II

In this report

Figure 1: Presentation in the plenary room at the Italian National Research Council. © Jessica Gier

dealt with “Interactions between aerosols, clouds and marine ecosystems in contrasting environments”.

Workshop I focused on the importance of the coastal environment from the air-sea interaction point of view and on the different aspects of coastal pollution (air and water), with two main objectives:

1) discussing how coastal pollution affects gas and particles emitted over the coasts, and
2) understanding the effects of coastal pollution on the air quality-climate system and human health.

Presentations addressed various topics but with a clear focus on the peculiarities of atmospheric chemistry and air quality in coastal regions, with an emphasis on radical/halogen chemistry and on the oxidative properties of the coastal atmosphere. The role of sea-spray as a vehicle for transferring a variety of seawater components (biogenic organic matter, pollutants, bacteria, viruses and toxins) from the sea surface to the atmosphere has been intensively treated, evidencing a fundamental lack of knowledge on such processes and associated impacts. Emerging themes of crucial importance for the costal environment were also identified and discussed, such as the environmental and human health impacts of micro-plastics pollution and the increased occurrence of toxic (red) tides.

The discussion sections led to the definition of two major research areas for a better understanding of coastal air-sea interactions. The first need comes with the understanding of processes of sea-air exchange in the coastal environment, which in many cases are scarcely characterised. For instance, the exchange of particles, toxins, pollutants (including newly developed materials, such as engineered nano-particles and graphene) are scarcely understood in general and in the costal context in particular. Moreover, the role of the sea surface microlayer in this process has been pointed out as potentially important and warrants more detailed investigations. The second research area addresses the forcing and feedbacks between the sea and the atmosphere in the coastal environment. The importance of non-linear interactions between water biology, water and air composition, meteorology, human health, ecosys-

Figure 2: Plenary presentation of Spyros Pandis. © Jessica Gier

tems, economy, etc. was pointed out during the discussion, with a particular stress for the necessity of understanding these topics in a changing climate perspective.

Finally, the participants expressed a series of research needs for air-sea exchange investigation in the coastal environment. The necessity of linking different scientific communities (atmosphere, ocean, toxicology, and social) was considered of paramount importance in order to produce a significant advancement of science, through the development of a multidisciplinary investigation approach. The necessity of integrating laboratory and field observations, remote sensing and modelling was also highlighted, together with the importance of implementing integrated sea-atmosphere long-term observations in the coastal environment, which are almost non-existent at present.

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The outcomes of the workshop contribute to advance our knowledge of the Core Theme 5 “Ocean biogeochemical controls on atmospheric chemistry” of the SOLAS 2015-2025 Science Plan and Organisation.

Figure 3: Joint group picture of the workshops participants.
Front row left to right: Lin Du, Chiara Santinelli, Jurgita Ovadnevaite, Cristina Facchini, Michel Flores, Manuela van Pinxteren, Tiera-Brandy Robinson, Tim Bates, Francesca Malfatti, Karine Sellegri, Trish Quinn, Rafel Simó, and Karam Mansour.
Middle row left to right: Stefano Decesari, Emmanuel Boss, Kimberly Prather, Graham Jones, Ilan Koren, Maurice Levasseur, Aurelia Tubaro, Theresa Barthelmess, and Frédéric Gazeau.
Back row left to right: Manuel Dall’Osto, Jon Abbatt, Alfonso Saiz-Lopez, Matteo Rinaldi, Eric Saltzman, Christian Stolle, Richard Moore, Yinon Rudich, Oliver Wurl, Erik Hoffmann, 'Alcide Di Sarra, Karine Desbeoufs, Cliff Law, Thipsukon Khumsaeng, and Paquita Zuidema. , Kohei Sakata
Missing: Weidong Chen, Cécile Coeur, Erik van Doorn, Christian George, Roy Harrison, Monica Mårtensson, Michela Maione, Helge Niemann, Spyros Pandis, and Liselotte Tinel. © Jessica Gier

Workshop II was dedicated to bringing together scientists participating in eleven recent and current field programs that are addressing at least a part of the science of the ocean ecosystem-aerosol-cloud linkage, which is one of the key elements in the Surface Ocean - Lower Atmosphere Study (SOLAS) sciences. The aim of the workshops was that participants will:

1. be aware of what other programs are doing;
2. reach out to others to initiate cross-cutting studies.

SOLAS invited ten scientists to present eleven programs and the meeting was open to all interested scientists.

To set the stage, the first half-a-day of the workshop was dedicated to perspective talks associated with each program. We then moved to discuss cross-cutting themes on the second day. The meeting started with a quick introduction of all present. Maurice Levasseur than provided a short overview of SOLAS, its objectives, and the meeting objectives. He was followed by Rafael Simó who presented two relevant projects, the "Antarctic Circumnavigation Expedition" (ACE) and the "Plankton-derived Emissions of trace Gases and Aerosols in the Southern Ocean" (PEGASO), the first, circumnavigating the Southern Ocean sampling the oceans and a relatively pristine atmosphere and the second focused on Lagrangian following of high phytoplankton biomass patch and measuring their emissions. Karine Desboeufs discussed the "Process studies at the air-sea interface after dust deposition in the Mediterranean Sea" (PEACETIME), which focused on the Western Mediterranean sampling ocean/aerosols and interaction between the two using, among others, on-ship experimental chambers. Jon Abbatt presented the "Network on Climate and Aerosols: Addressing Key Uncertainties in Remote Canadian Environments" (NETCARE) project, focused on aerosol dynamics in the arctic and how they may be changing as a result of climate change. Study approach involved two cruises, airplane samplings, as well as a large modelling component. Manuela van Pinxteren presented the "Marine biological production, organic aerosol particles and marine clouds: a Process Chain" (MarParCloud) program that focused on organic matter originating in the ocean and its tracing in the micro-layer, aerosols, and cloud near Cape Verde (sampling on land as well as ocean). Cliff Law presented the "Surface Ocean Aerosol Production" (SOAP) project, which sampled ocean-aerosol relevant parameters near New Zealand in the fall of 2011 and 2012, and included sampling a variety of different oceanic blooms. He also mentioned an upcoming campaign called Sea2Cloud, a collaboration between New Zealand and France and which is planned for September-October 2019. Richard Moore presented the "North Atlantic Aerosols and Marine Ecosystems Study" (NAAMES), a four-cruise program to study the annual cycle of phytoplankton in the North

Figure 4: Maurice Levasseur is providing a short overview of SOLAS. © Jessica Gier

Atlantic and its linkages to aerosols and clouds, sampling with ship, airplane and a variety of in-situ and remote-sensing tools. Graham Jones presented the program “Reef to Rain Forest” (R2R) which focuses on the role of the Great Barrier Reef in aerosol and precursor production, sampling both water and overlying atmosphere at high temporal resolution. Michel Flores introduced the TARA Pacific project, covering the tropical and subtropical Pacific and associated ocean/aerosol sampling. Jurgita Ovadnevaite introduced the “Impact of Biogenic versus Anthropogenic emissions on Clouds and Climate: towards a Holistic UndeRStanding” (BACCHUS) synthesis project, a comprehensive program designed to understand the impacts of biogenic and anthropogenic emissions on clouds. The project involved process studies as well as compilation of a database of relevant measurements to improve parametrization in models. Finally, Paquita Zuidema presented “Variability of the American Monsoon Systems Ocean-Cloud-Atmosphere-Land Study” (VOCALS), a project focused on aerosols-clouds interaction in the Eastern South Pacific using ships and airplanes for sampling.

Figure 5: Breakout group discussion on “What are the cross-cutting SOLAS science questions that are common to many of the presented projects”, headed by Ilan Koren and Maurice Levasseur. © Jessica Gier

On the 2nd day, we reconvened as a group and each scientist discussed what they hoped to achieve on that day based on what they heard on the 1st day and stating common themes that were observed in many of the project presented. We then broke into two groups whose themes were:

1) What are the cross-cutting SOLAS science questions that are common to many of the presented projects - headed by Ilan Koren and Maurice Levasseur, and

2) What are the measurements necessary to study the ocean ecosystem-aerosol-cloud linkage and which require community effort to establish common practices - headed by Emmanuel Boss.

The two groups regrouped after lunch and several action items were decided on:

1. All the projects presented should be linked to the SOLAS website (some are, but not all).
2. A need was identified for method homogenisation and cross-comparison among SOLAS researchers to insure the inter-comparability between measurements and results conducted during different campaigns. The SOLAS website was suggested as a clearing house for community documents addressing SOLAS sampling issues (e.g. the SCOR working group report on how to sample the surface micro layer). The aerosol community has addressed this need with “Global Aerosol Synthesis and Science Project” (GASSP, Reddington *et al.*, 2017) but this effort does not reach to clouds and ocean variables.
3. The necessity to compile a table of measurements (and instruments) necessary to study the ocean ecosystem-aerosol-cloud linkage that will reside on the SOLAS website. The table will also include a wish list of measurements that are not essential (due to the significant efforts of costs associated) but that are encouraged. Such a table could be used to encourage global sampling programs (e.g. Global Ocean Ship-based Hydrographic

Investigations Program (GO-SHIP)) to add such measurements to increase systematic global sampling of ocean, aerosol, and clouds. This table will also reside on the SOLAS website and will be a living document that will be revisited every few years (perhaps in association with the SOLAS summer school).

4. Participants showed a clear interest to maintain contact and to exchange ideas on cross-cutting methodological and science topics.

We thank all the participants, the organisers as well as our funders, who supported this activity by funds and actions.

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The outcomes of the workshops contribute to advance our knowledge of the Core Theme 4 “Interconnections between aerosols, clouds, and marine ecosystems” of the SOLAS 2015-2025 Science Plan and Organisation.

Events sponsors

Kohei Sakata completed a PhD degree in geochemistry at Hiroshima University, Japan, in 2017. He started a postdoctoral position at the National Institute for Environmental Studies in 2017. His topic is chemical speciation of organic matter and their complexes in sea spray aerosol by X-ray spectroscopy.

Organic matters in sea spray aerosol: their role as a driving force of atmospheric chemistry in the marine boundary layer

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Great attention has been paid to organic matters (OM) in sea spray aerosol (SSA) as one of the factors controlling cloud condensation nuclei (CCN) and ice nuclei (IN) activities (Quinn *et al.,* 2015). Furthermore, OMs in SSA are related to various chemical reactions with oxidants and pre-existing particles (Figure 6). These reactions impact ozone formation/depletion, oxidation of methane and dimethylsulfide (DMS) and the promotion of primary production in the surface ocean by bioactive trace metals (BTM including iron (Fe)), and they are also important factors to regulate the marine climate and to control the biogeochemical cycle in the marine boundary layer (Mahowald *et al*., 2016). Therefore, a better understanding of the reaction processes of OMs in SSA is an indispensable task for further development of air-sea interaction research.

One of the challenges in improving knowledge about the atmospheric chemistry of OMs in SSA is the complexity of OM species in nascent SSA. Much effort has been made to clarify OMs in SSA based on mesocosm studies (Prather *et al*., 2013; Quinn et al., 2015) but field observations are still insufficient. Online analysis (e.g. aerosol mass spectrometry: AMS) has an excellent time resolution for chemical composition measurements in aerosol. However, accurate chemical speciation and morphological analyses are difficult to make due to fragmentation during ionization. By contrast, filter-based observation is suitable for OM speciation in SSA, even if the time resolution is inferior to online analysis, because various speciation techniques including X-ray spectroscopy can be applied. In addition, we recently developed a method for high time-resolution filter-based sampling of marine aerosols by dramatic decrease of the background of targeted elements in the filter (Sakata *et al*., 2018).

X-ray absorption fine structure (XAFS) spectroscopy, a non-destructive speciation method, can analyse bulk species in aerosol regardless of their physical state, and determine species on aerosol surface by combining the method with electron yield. Comparison of chemical species between bulk and surface species is useful for clarifying heterogeneous reactions on aerosol surface. Furthermore, micrometer/nanometer X-ray spectroscopy (e.g., scanning transmission X-

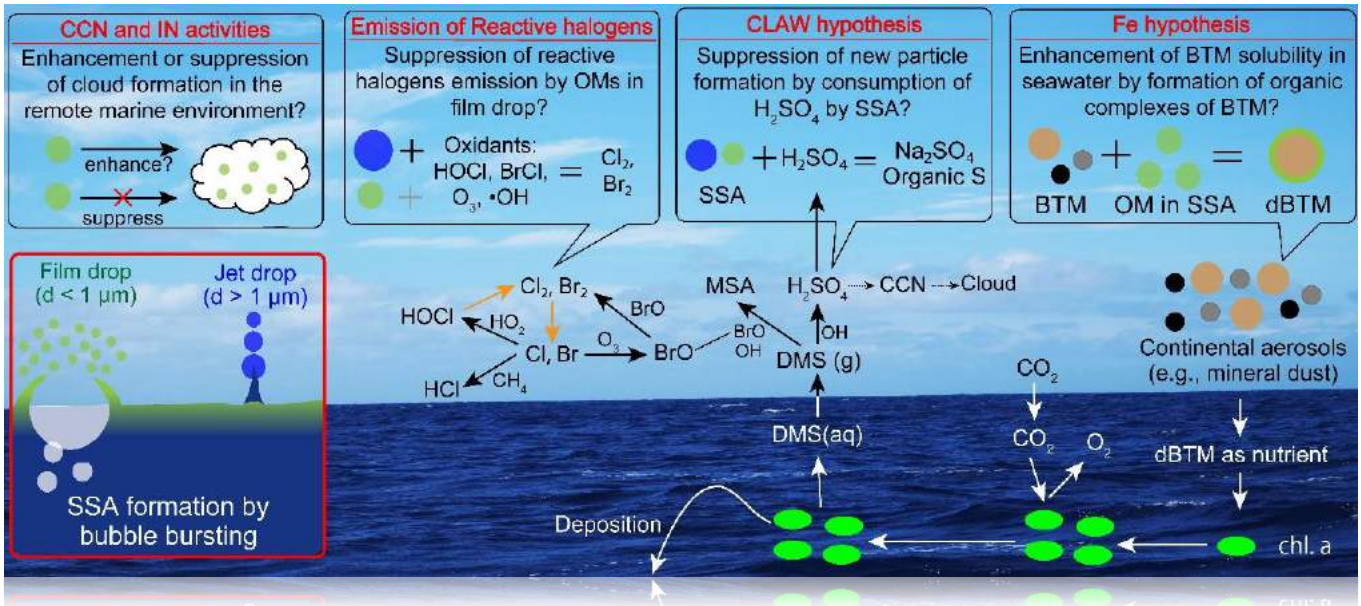

Figure 6: Schematic illustration of atmospheric chemistry related to sea spray aerosol (SSA). Abbreviations: cloud condensation nuclei (CCN), ice nuclei (IN), iron (Fe), organic matter (OM), dimethylsulfide (DMS), bioactive trace metals (BTM), methane sulfonate (MSA).

ray microscope: STXM) reveals chemical species with morphology in a single particle. However, there are only few cases where XAFS and STXM have been applied to marine aerosol. In our research, comprehensive analyses of chemical species of OMs and metals in size-fractionated marine aerosol collected in the Pacific Ocean were conducted.

We found (i) enhancement of atmospheric Fe solubility by complexation with OC in SSA, (ii) suppression effects of organic films on SSA for reactive halogen emission and oxidation reactions of reduced S including DMS, and (iii) formation of organic sulfates by reaction of organic films on SSA with H_2SO_4. In addition, we will optimize quantitative methods for water-soluble organic sulfur and semivolatile organic carbon by triple quadrupole inductively coupled plasma mass spectrometry (ICP-QQQ-MS) and proton transfer reaction time-of-flight mass spectrometry (PTR-ToF-MS). We believe that these novel data will lead to gaining new perspectives about the biogeochemical cycle and marine climate related to OMs in SSA, which in turn produces further development of air-sea interaction research through refinement of the experimental conditions for laboratory experiments and model calculation.

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After a master in linguistics, **Liselotte Tinel** discovered her love for science during a master in Environmental Chemistry in Marseille, France, followed by a PhD at the University of Lyon, France. Currently, as post-doc at the University of York, United Kingdom, she continues to work on interfacial reactions at the surface of the ocean.

Investigating ozone deposition at the sea-surface: the interplay of iodide and organics

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Oceans cover more than 70% of the surface of our planet; hence reactions at the sea-surface can have a significant effect on the atmospheric and oceanic chemical composition. The oceans can be a sink or a source for atmospheric gases. For ozone, a greenhouse gas influencing also air quality and human health, dry deposition at the surface of the ocean is an important removal route over the open ocean, and responsible for about a third of total global ozone deposition (Ganzeveld *et al.*, 2009). One of the major loss paths for ozone over the ocean is its reaction with iodide (I^-) at the sea-surface. Iodide is a naturally occurring sea salt and an essential element for many metabolisms, e.g. humans. It's the more reactive form of iodine present at low concentrations (10^{-7} - 10^{-9} M) alongside the more thermodynamically stable iodate (IO^{3-}) (Chance *et al.*, 2014). Ozone is very reactive towards iodide (k= 2 x 10^9 M^{-1} s^{-1} at pH 8, Magi *et al.*, 1997), and leads to the release of inorganic iodine into the atmosphere, mainly as hypoiodous acid (HOI) and iodine (I_2) (Carpenter *et al.*, 2013), where gas phase reactions of these species can lead to further ozone depletion and participate in particle nucleation (Figure 7). Recent modelling studies have shown that the iodine chemistry decreases the ozone burden in the marine troposphere by approx. 20%, thereby reducing ozone's radiative forcing (Sherwen *et al.*, 2016, 2017). However, the I_2climatology used in these models is based on rather sparse measurements of iodide concentrations in the surface waters (<20m depth). A part of my work has therefore aimed at improving the global coverage of sea surface iodide concentrations through

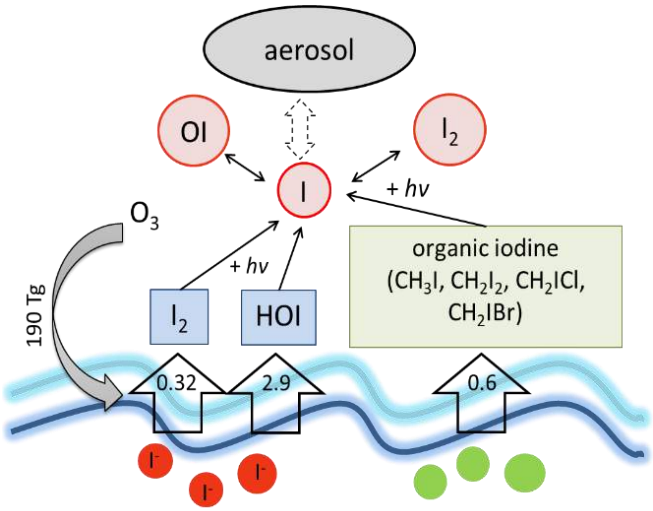

Figure 7: Simplified representation of iodine (I_2) chemistry at the sea-surface, with iodite (OI), ozone (O_3), hypoiodous acid (HOI), I iodide (I^-), hv Modelled fluxes from Sherwen *et al.*, 2016 (in Tg I yr^{-1}).

participation in a research cruise, the Indian Southern Ocean Expedition 9, in 2017 where I^- and IO^{3-} concentrations were measured in the under sampled region of the Indian & Southern Ocean (Figure 8). This data combined with simultaneous atmospheric observations of ozone and IO (performed by our project partner Dr. Anoop S. Mahajan, Indian Institute of Tropical Meteorology, India) should provide a better insight in the I_2 chemistry in that region and will be incorporated into a new I_2 climatology for atmospheric and oceanic modelling.

The interaction with dissolved organic carbon (DOC) is another major process believed to contribute to the dry deposition of ozone over the ocean. However, the nature of direct reactions of ozone with DOC at the sea surface is unknown, mainly due to the complexity of the nature of DOC. Emissions driven by the reaction of ozone with DOC at the sea surface are less well characterised, although potentially a significant source of functionalised and/or halogenated organic volatile compounds. By comparison, the reaction of I^- and ozone is relatively well characterised, but uncertainties remain and in particular the influence of natural DOC at the sea-surface on this reaction is not entirely understood. Therefore, a series of laboratory experiments were performed aimed at refining the estimate of the rate constant for the reaction of ozone with I^- at ambient or near ambient concentrations and at evaluating the influence of organics on this reaction. Emission fluxes of I_2 were measured using both organic-free artificial I^- solutions and natural seawater. Inorganic I_2 fluxes were measured using a Broadband Cavity Enhanced Absorption Spectrometer (BBCEAS and organic halogenated species by Thermo-Desorption Gas Chromatography Mass Spectrometry (TD-GC-MS). The first results from these studies indicate a significant suppression of inorganic I_2 emission in the presence of organics. Using real seawater samples, the fluxes of I_2 were 70-85% lower compared to artificial seawater with similar I^- concentrations and even less I_2 was observed above

Figure 8: Images of the Indian Southern Ocean Expedition in January - March 2017 to sample the Indian and Southern Ocean from Mauritius to Prydz Bay (Antarctica).

samples of the surface microlayer. These results underline the importance of DOC in air-sea gas exchanges. Our observations will be used to refine the I_2 flux model proposed in Carpenter *et al*., 2013.

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Tiera-Brandy Robinson studied marine biology in Alaska, USA, and then completed a Master of Research degree in Ocean Science at the University of Southampton, United Kingdom. In 2016 she moved to Germany to start a PhD with the University of Oldenburg in Oliver Wurl's sea surface group, investigating the role of transparent extracellular particles (TEP) in the formation and characterisation of the sea surface microlayer.

New depth profiles to understand biochemical parameters in the upper 1m of the ocean

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At the surface of the ocean, with a thickness between 1 µm and 1 mm, lies the sea surface microlayer. This layer is easily distinguished from the underlying water by its unique chemical, biological, and physical properties (Wurl *et al*. 2011) and has a large role to play as the boundary layer between the ocean and atmosphere. We understand this layer to be highly gelatinous, permeated with transparent extracellular particles (TEP) which hold the biological and chemical components together (Wurl *et al*. 2008). At high concentrations these can form biofilms at the sea surface (Wurl *et al*. 2016a) which affect air-sea exchanges and have been hypothesised to reduce gas exchange rates by 15% (Wurl *et al.* 2016b). For this reason, my PhD has three main focuses; 1, the effect of breaking waves and bubble scavenging on the enrichment and transport of TEP in the sea surface microlayer; 2, vertical and horizontal transport of TEP in the ocean; and 3, the relationship between primary production, TEP concentrations, and sea surface microlayer properties. Until now, the standard measuring procedure was to collect samples from the sea surface microlayer and 1 m depth as a reference. However, here I would like to introduce new techniques we have used to investigate what happens between the sea surface microlayer and 1 m.

We use a catamaran (Figure 9) for *in situ* measurements of the sea surface microlayer and underlying water at 1 m (Ribas-Ribas *et al*. 2017).

Figure 9: Our Catamaran "Sea Surface Scanner" which can collect in situ data on the SML and ULW at 1 m and can collect discreet water samples. Featured being deployed in the Baltic Sea. © Oliver Wurl

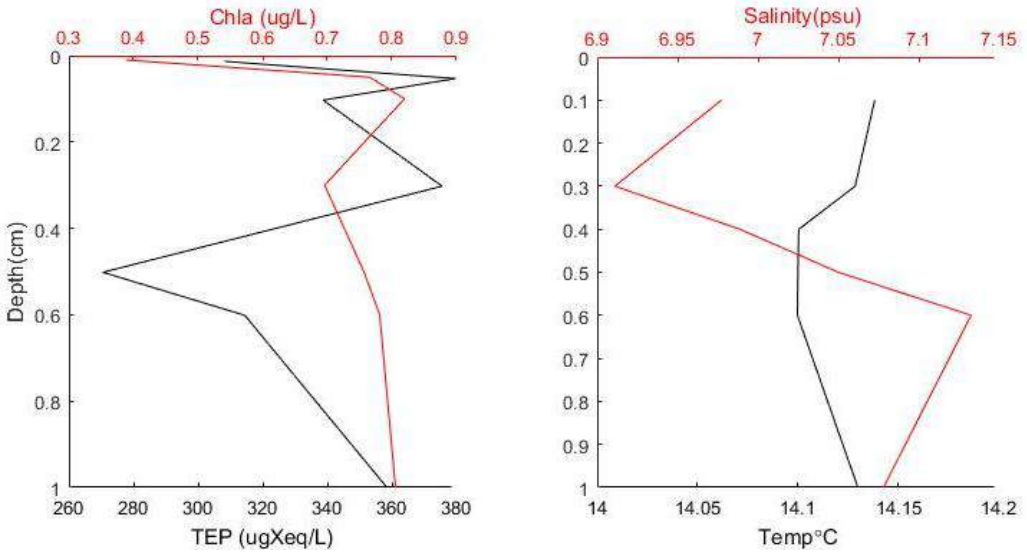

Figure 10: Data from a campaign in the Baltic Sea in July 2018, showing changes with depth of a) transparent extracellular particles (TEP), b) Chlorophyll (Chl) a, c) Temperature (°C), and d) Salinity (psu).

The catamaran uses 6 rotating glass plates to collect the sea surface microlayer and peristaltic pumps to collect underlying water from 1m depth. Recently we have attached multiparameter probes (Aqua TROLL) which measure *in situ* data at 5 depths between the sea surface microlayer and 1 m depth, in order to enhance the resolution of observed changes in the upper 1m. Additionally, we deploy a "vertical water sampler" which uses peristaltic pumps to collect discreet water samples from the same 5 depths as the probes.

Figure 10 shows data from a research cruise in the Baltic Sea in July 2018. There are noticeable changes in both biological and chemical properties within the upper 1m of the water. TEP and Chlorophyll (Chl) a show a negative enrichment with the highest concentrations in the underlying water rather than the sea surface microlayer. This finding is opposite to what is normally found in the ocean. There is a rapid increase for both TEP and Chl a at 5 and 10 cm below the surface, with concentrations increasing from 0.8 to 1.5 µg/m^3 for Chl a and 1400 to 4000 µgXeq/L (expressed as a standardised Xanthan equivalent in microgram (µg) per litre (L)) for TEP. Meanwhile temperature showed minimal changes of <0.05 °C and salinity rapidly increased >0.2 psu below 30 cm.

Only one station is shown here but multiple stations showed changes in biological and chemical parameters over both time and depth, while other stations showed minimal changes. Future analysis will be looking at the effect of wind speed on the homogeneity of parameters in the top 1 m. My hypothesis is that with higher wind speeds (>8 m/s) higher mixing will be seen, resulting in homogenous layers and lower wind speed (<8m/s) will result in less mixed layers and higher influence of physical parameters on biological ones. While negative enrichment is likely a result of sinking TEP/organic matter (OM) aggregates, photodegradation is a possible explanation for the observed rapid increase of TEP and Chl a just below the surface at 5 and 10 cm.

Within the air-sea interaction community, the role of the sea surface microlayer has slowly gained recognition as an important boundary layer, influencing all interactions. This new approach aims to further understand the formation of the sea surface microlayer and the role of biochemical processes not only at the sea surface microlayer and 1 m below but what is happening between, which is proving to be a dynamic environment that can no longer be considered homogenous. This type of high-resolution depth data will improve our understanding of process trends in the surface ocean and can help to explain effects like photodegradation or bubble scavenging on the sea surface microlayer.

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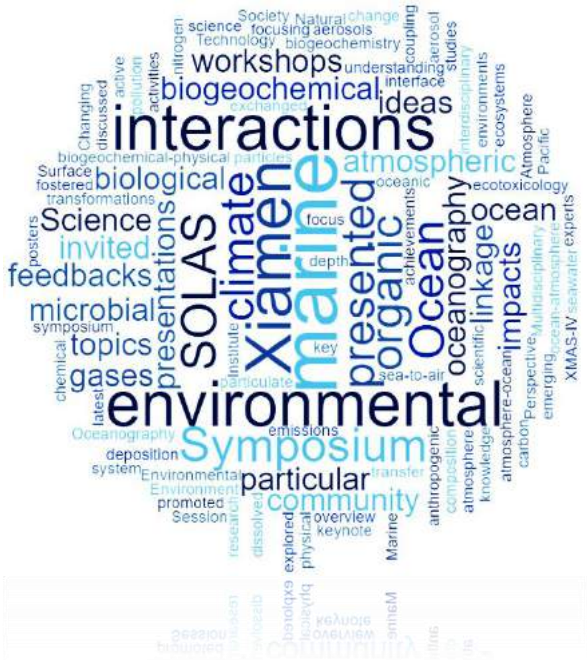
Report 13 I March 2019

The Fourth Xiamen Symposium on Marine Environmental Sciences (XMAS-IV)

Session on: "Surface Ocean and Lower Atmosphere Study - Air-Sea interactions and their climatic and environmental impacts"

6 - 9 January, 2019 Xiamen, China



From 6 to 9 January 2019, the fourth Xiamen Symposium on Marine Environmental Sciences (XMAS-IV) with the theme of 'The Changing Ocean Environment: From a Multidisciplinary Perspective' took place in Xiamen, China. It was organised and sponsored by the State Key Laboratory of Marine Environmental Science (Xiamen University), and the National Natural Science Foundation of China. SOLAS was one of the co-sponsors of this event. The symposium consisted of 33 sessions covering physical oceanography, marine biogeochemistry, biological oceanography, and marine ecotoxicology along with workshops for emerging topics in marine environmental sciences. It brought together 890 experts and students from 24 countries. The Symposium included 278 oral presentations (including 5 invited keynote talks), 352 posters, and workshops that explored topics in greater depth. The Symposium has fostered knowledge and ideas exchange within the marine environmental

In this report

Figure 1: A, The SOLAS session on “Surface Ocean and Lower Atmosphere Study - Air-Sea interactions and their climatic and environmental impacts” at XMAS-IV. B, Invited speaker, Yinon Rudich, Weizmann Institute of Science, Israel. C, Invited speaker, Yuzo Miyazaki, Hokkaido University, Japan. © Li Li

science community and, in particular, promoted interdisciplinary studies.

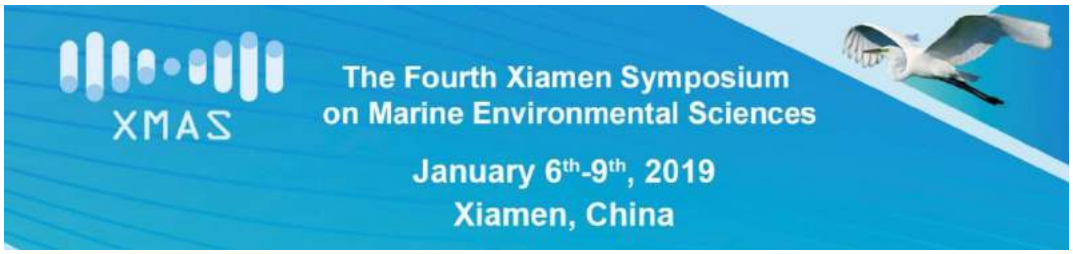
SOLAS themes were covered by a couple of sessions but we would like to focus here on session C4 entitled “Surface Ocean and Lower Atmosphere Study - Air-Sea interactions and their climatic and environmental impacts” (Figure 1), co-chaired by Guiling Zhang and Huiwang Gao (both Ocean University of China, China), Mohd Talib Latif (Universiti Kebangsaan, Malaysia), Jun Nishioka (Hokkaido University, Japan), Senchao Lai (South China University of Technology, China) and Bingbing Wang (Xiamen University, China). In this session, the SOLAS scientific community exchanged new ideas and discussed the latest achievements in our understanding of the key biogeochemical-physical interactions and feedbacks between the ocean and the atmosphere, and of how this coupled system affects and is affected by climate and environmental change.

Two invited presentations were given to overview recent research activities on biogeochemical linkage in the ocean-atmosphere interface via microbial activity and particulate organic matter. Prof. Yinon Rudich (Figure 1B) from Weizmann

Institute of Science presented coupling between oceanic microbial interactions and atmospheric biological aerosol composition. Assoc. Prof. Yuzo Miyazaki (Figure 1C) from Hokkaido University presented biogeochemical linkage between marine organic aerosols and surface seawater in the North Pacific, especially the sea-to-air transfer of dissolved organic carbon and nitrogen.

Studies focusing on atmosphere-ocean exchange of climate active gases, atmospheric deposition, chemical transformations of gases and particles, interactions between anthropogenic pollution with marine emissions, feedbacks from ocean ecosystems and impacts to environments and climate were also presented in particular.

Guiling Zhang, Ocean University of China, Qingdao, China
(guilingzhang@ouc.edu.cn),



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Jing Dou holds a Master of Science in atmospheric chemistry from Hong Kong University of Science and Technology since 2015. She started her PhD in 2016 at the Institute for Atmospheric and Climate Science, ETH Zürich, in Switzerland. She focuses on the feedbacks between microphysics and photochemical aging in viscous aerosols.

Photochemical aging processes in iron containing aerosols

Dou, J.[a]*, Krieger, U. K. [a], Luo, B. P. [a], Peter, T. [a], Alpert, P. [b], Ammann, M. [b], Corral Arroyo, P. [b]

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Iron (Fe) is not only abundant in the marine and terrestrial environments, but also quite important in the atmosphere. By wind erosion of soil or mineral dust, as well as anthropogenic emissions (e.g., traffic and combustion processes), Fe enters the troposphere in particulate form, and can be transported over long distances (Deguillaume *et al.*, 2005). In the atmospheric aqueous phase, Fe concentration can vary from 10^{-9} to 10^{-6} mol/L in raindrops and from 10^{-6} to 10^{-3} mol/L in cloud droplets, which are generally much higher than other transition metals (Hoigné *et al*., 1994). Depending on chemical parameters such as pH, ionic strength and concentration of involved substances, Fe can combine with organic (e.g., carboxylate ions) and inorganic ligands (e.g., sulfate (SO_4^{2-}) and nitrate (NO_3^-)) to form stable complex species. Fe-carboxylate complexes (e.g., Fe^{III}-oxalate and Fe^{III}-citrate) are photosensitive, potentially representing an important sink of organic acids in the troposphere (Weller *et al.*, 2013).

In my PhD project, we choose Fe^{III}-citrate as a model complex, since it plays an important role in aerosol aging processes, especially in the lower troposphere, with low intensities of ultraviolet light. The photochemistry of Fe^{III}-citrate has been widely recognised in both solution (Abida *et al*., 2012; Faust and Zapp, 1993; Pozdnyakov *et al*., 2012) and solid (Abrahamson *et al*., 1994) states. It can absorb light up to around 500 na-

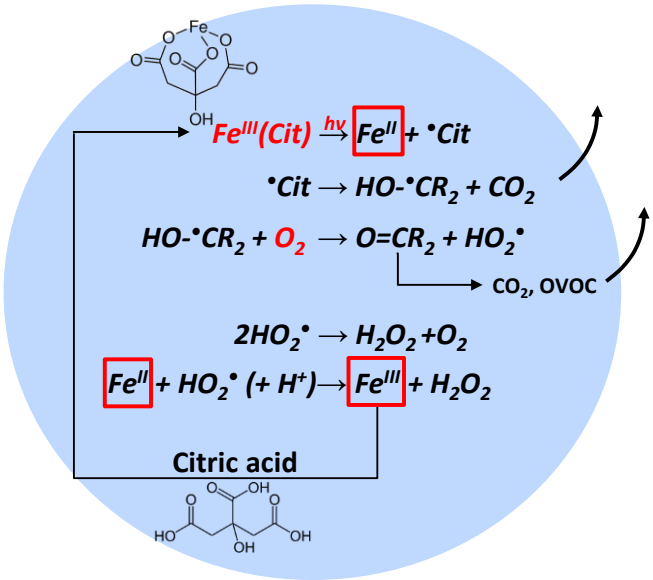

Figure 2: Photocatalytic cycle of FeIII-citrate/citric acid system.

nometre (nm), inducing the reduction of Fe^{III} and the oxidation of carboxylate ligands. In the presence of oxygen (O_2) ensuing radical chemistry will likely lead to more decarboxylation and production of peroxides (e.g., hydroxyl radical (OH•), hydroperoxyl radical (HO_2•) and hydrogen peroxide (H_2O_2)) and oxygenated volatile organic compounds (OVOC). The peroxides in turn allow the re-oxidation of Fe^{II} to Fe^{III}, closing this photocatalytic cycle, in which Fe acts as a catalyst (Weller *et al*., 2013) (Figure 2).

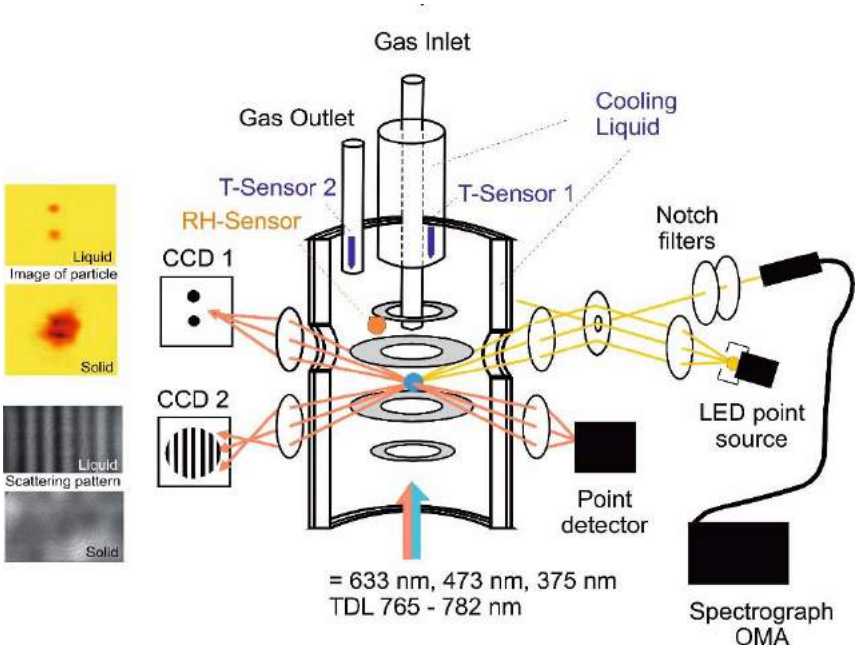

Figure 3: Schematic of the electrodynamic balance.
Abbreviations: Charge-coupled device (CCD), relative humidity (RH), Temperature (T), light-emitting diode (LED), optical multichannel analyser (OMA), tunable diode laser (TDL), and nanometre (nm).

Little is known about how the viscosity of an aerosol might slow these catalytic cycles. To investigate this question, the basic instrument we are using in the lab is an electrodynamic balance (Zobrist *et al*., 2011) (Figure 3). A single mixed FeIII-citrate/citric acid aerosol droplet (radius ~10 micrometre (µm)) is levitated in this balance with controlled temperature and relative humidity. During photochemical processing under irradiation in the visible (473 nm) light, the mass and size changes of the particle are tracked. We measure a substantial mass loss of the droplet during photochemical processing due to the evaporation of volatile (e.g., carbon dioxide) and semi-volatile (e.g., ketones) products. We focus the experiments on the high viscosity case (i.e., reduced molecular mobility and low water content), which slows the transport of products and thus affects chemical reaction rates. For a coherent description, we developed a numerical model, which includes main equilibria, chemical reactions, and transportations of major species. It allows to simulate the concentration gradients of each species inside of the particle, and to derive the size and mass changes. Comparing model output with experimental data enables us to determine some crucial parameters, such as equilibrium constants, chemical reaction rates, and liquid phase diffusion coefficients. With such well-defined and physically constrained parameters, we will predict the evolution of products as well as organic acid degradation in the condensed phase under atmospheric conditions.

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Yu Wang completed her Master's degree in Atmospheric Science at Peking University, Beijing, China, in 2017. Afterwards, she continues her research as a PhD student at The University of Manchester, Manchester, United Kingdom. She uses chamber experiments to investigate the behaviour of particles as seeds for secondary organic aerosol formation.

Aerosol Liquid Water and its influences on gas-particle conversion in North China Plain

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Water is ubiquitous in the atmosphere and it is one of the most important components of the atmospheric particles (Nguyen *et al*., 2016). Hygroscopic particles take up water as ambient relative humidity increases, in which this ability of water uptake depends on the chemical composition of the particles (Twomey, 1954). For example, water contributes ~67% of aerosol volume for a ammonium sulphate particle under relative humidity of ~80%; water dominates mass loading of most types of aerosols when relative humidity is over 90% (Kreidenweis and Asa-Awuku, 2014). Higher water content leads to larger light scattering, and hence greater visibility degradation. Thus, particle hygroscopicity plays a profound role in visibility degradation, cloud formation thereafter climate change (Figure 4) (Dusek *et al*., 2006; Kreidenweis and Asa-Awuku, 2014).

In addition, aerosol liquid water can act as a plasticiser and change the phase state of the particles, in which the molecular diffusion coefficient increase by several orders of magnitude as the particles transit from solid to liquid phase (Koop *et al*., 2011). Besides, aerosol liquid water provides a medium for multi-phase reactions throughout the atmospheric particles (Wu *et al*., 2018). These diffused gaseous precursors and the ongoing multi-phase reactions contribute to the formation of secondary inorganic and organic aerosols, accelerating the development and evolution of the haze events over North China Plain, especially during winter.

In my master's research, I focused on the influences of aerosol liquid water on the gas-particle conversion of gaseous precursors (e.g. sulfur dioxide (SO_2), nitric acid (HNO_3), glyoxal), and its further impact on particulate inorganic and organic formation in the atmosphere. In this study, a long-term measurement during 2014.05-2015.01 at PKUERS (PeKing University Environment monitoRing Station), Beijing, China and two intensive campaigns in Huairou (sub-urban site near Beijing), IAP (Institute of Atmospheric Phys-

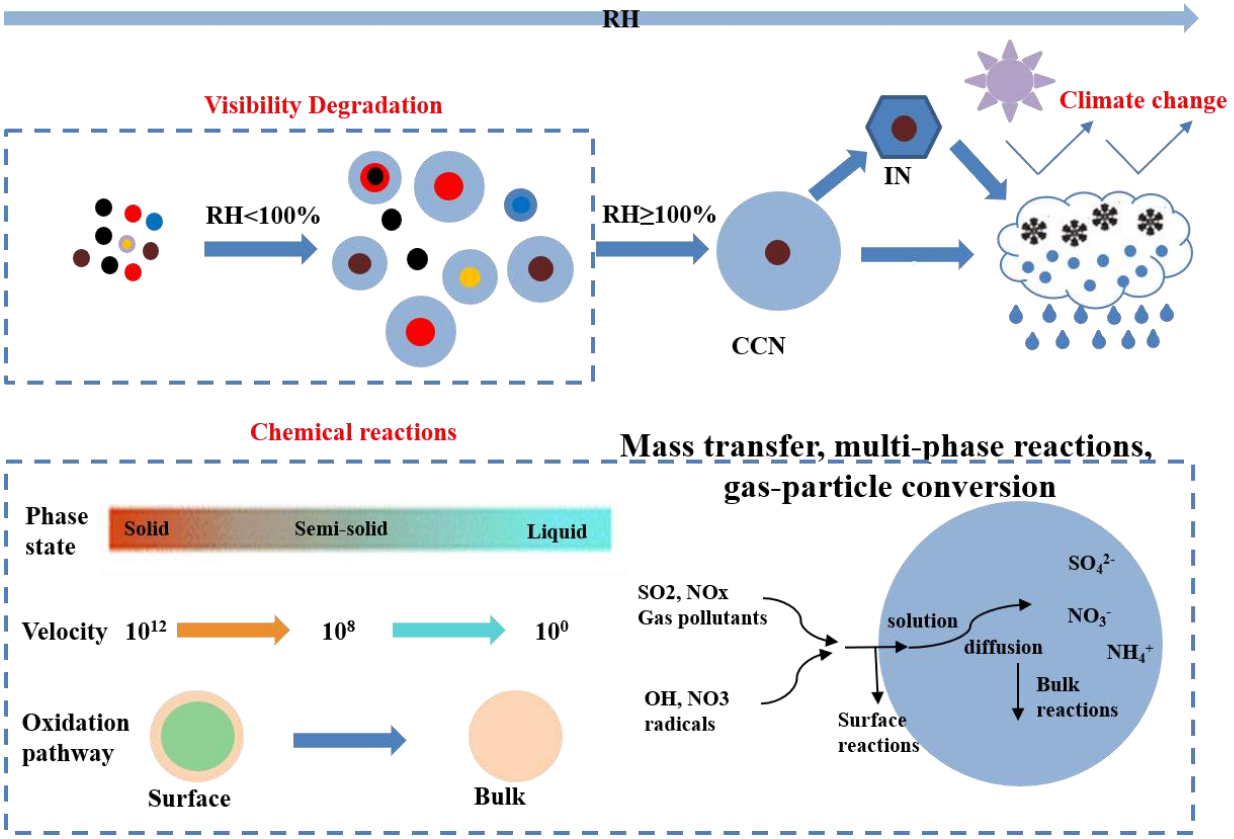

Figure 4: Environmental effects of interaction between aerosol and water.

ics, Beijing, China) in 2016 were conducted. A detailed dataset was obtained by a series of the-state-of-art instruments, including the measurements of chemical composition in both gas and particle phase, size-resolved particle hygroscopicity, particle number size distribution and meteorological parameters. By that, we have found a clear clue of the influences of aerosol liquid water on gas-particle conversion and quantified it. The calculated aerosol liquid water ranged from ~4 μg/m^3 to ~180 μg/m^3 in the long-term measurement, constituting up to ~50% of the total aerosol mass loading (PM2.5 + aerosol liquid water). The ambient relative humidity, as well as the mass fraction of aerosol liquid water showed a co-increasing trend with the elevated pollution levels. The molar fraction of particulate sulphate/nitrate in the sum of the particulate sulphate/nitrate and the gas precursors such as sulfur dioxide (SO_2) and nitric acid (HNO_3) and the formation rate of estimated aqueous secondary organic aerosol from glyoxal increased with the elevated aerosol liquid water via gas-particle conversion process. This indicates higher aerosol liquid water substantially accelerates the formation of particulate matter during the polluted episodes.

For future work, the potential influences of aerosol water uptake on visibility degradation will be evaluated and quantified. Advices on mitigation measures for government will be proposed based on our results. For my PhD study, I will investigate the interaction of aerosol liquid water influences and secondary organic aerosol formation from biogenic and anthropogenic volatile organic compounds, which are widely observed in the atmosphere.

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Short-term dynamics of sea surface pCO_2 in a large subtropical estuary system: The Pearl River estuary

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Estuarine systems feature highly dynamic short-term variability of sea surface partial pressure of carbon dioxide (pCO_2) (e.g., Yates *et a*l., 2007; Dai *et al*., 2009). Lacking of high-resolution samplings of sea surface pCO_2 could thus result in large uncertainties in estimation of air-sea CO_2 fluxes (Jiang *et al*., 2008; Bozec et al., 2011; Lanso *et al*., 2017). However, mechanistic understanding towards the diurnal to weekly dynamics of pCO_2 in estuarine systems remains challenging due to the complex interactions between biogeochemistry and physics therein. Here we examined the controlling factors on the short-term variability of sea surface pCO_2 recorded by a Battelle Seaology pCO_2 Monitor amounted on a buoy located in the outer Pearl River Estuary (PRE), a large subtropical estuary system in the northern South China Sea, from July 2 to August 11, 2015 (Figure 5).

Surface seawater pCO_2 in the PRE was highly

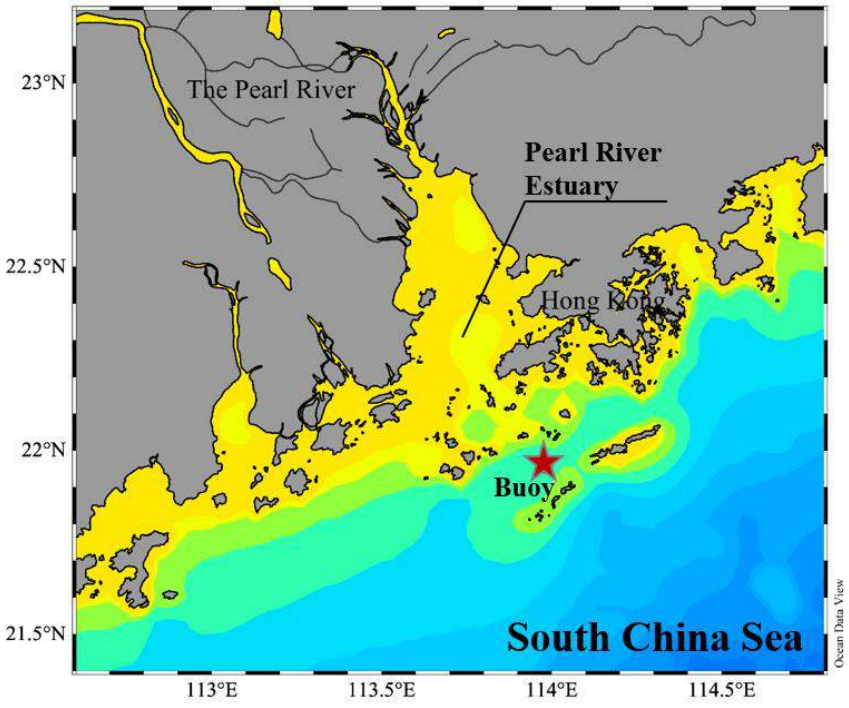

Figure 5: Location of the buoy in the outer Pearl River Estuary

variable, ranging from 78 to 640 micro atmosphere (µatm) with an average of 279 µatm, ~100 µatm lower than the atmospheric pCO_2 (Figure 6a). On diel timescales, pCO_2 changes of 50-90 µatm occurred in response to diurnal primary production and respiration; temperature and tidal effects played a minor role. Over weekly timescales, the low pCO_2 (~100-200 µatm) was strongly correlated with the eastward expanding of brackish water (salinity <25) under the favourable southwest winds (Figure 6), which had allowed for rapid phytoplankton production due to attenuated turbidity to the west of the estuary mouth. The low pCO_2 also corresponded well to the high river discharge despite of a time lag of nearly 7-10 days between the Wuzhou hydrological station and the estuary mouth (data not shown). In addition, large wind events were probably responsible for the pCO_2 increase, resulting from enhanced upward mixing of high-salinity, CO_2-enriched subsurface water as reflected in relatively low temperature, Chlorophyll a concentration and dissolved oxygen level (Figure 6).

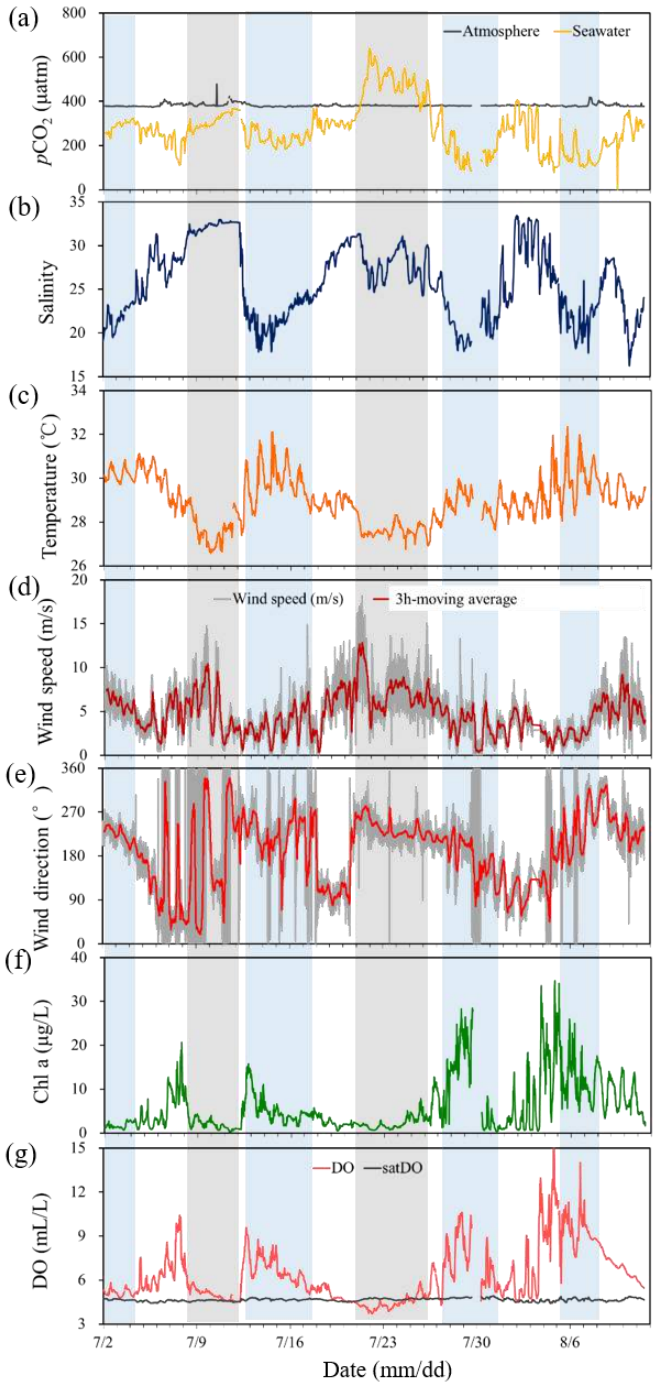

Figure 6: Time-series variability of (a) partial pressure of CO_2 (pCO_2, µatm), (b) salinity, (c) temperature °C), (d) wind speed (m/s), (e) wind direction, (f) chlorophyll a concentration (Chl a, µg/L), and (g) dissolved oxygen (DO, mL/L) in the outer Pearl River Estuary from July 2 to August 13, 2015. The blue and grey shadows denote the events of eastward expanding of brackish water and large winds, respectively.

Net fluxes of CO_2 for the observation period (-4.8 mmol CO_2 m^{-2} d^{-1}) were directed from atmosphere to ocean, but with a wide range from ~-30 to +20 mmol CO_2 m^{-2} d^{-1} depending largely on wind speeds. Therefore, careful consideration of the short-term variability of surface seawater pCO_2 and wind regimes was needed to accurately estimate air-sea CO_2 fluxes in the subtropical estuary system.

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