2017
Salinity Workshop
Abstracts

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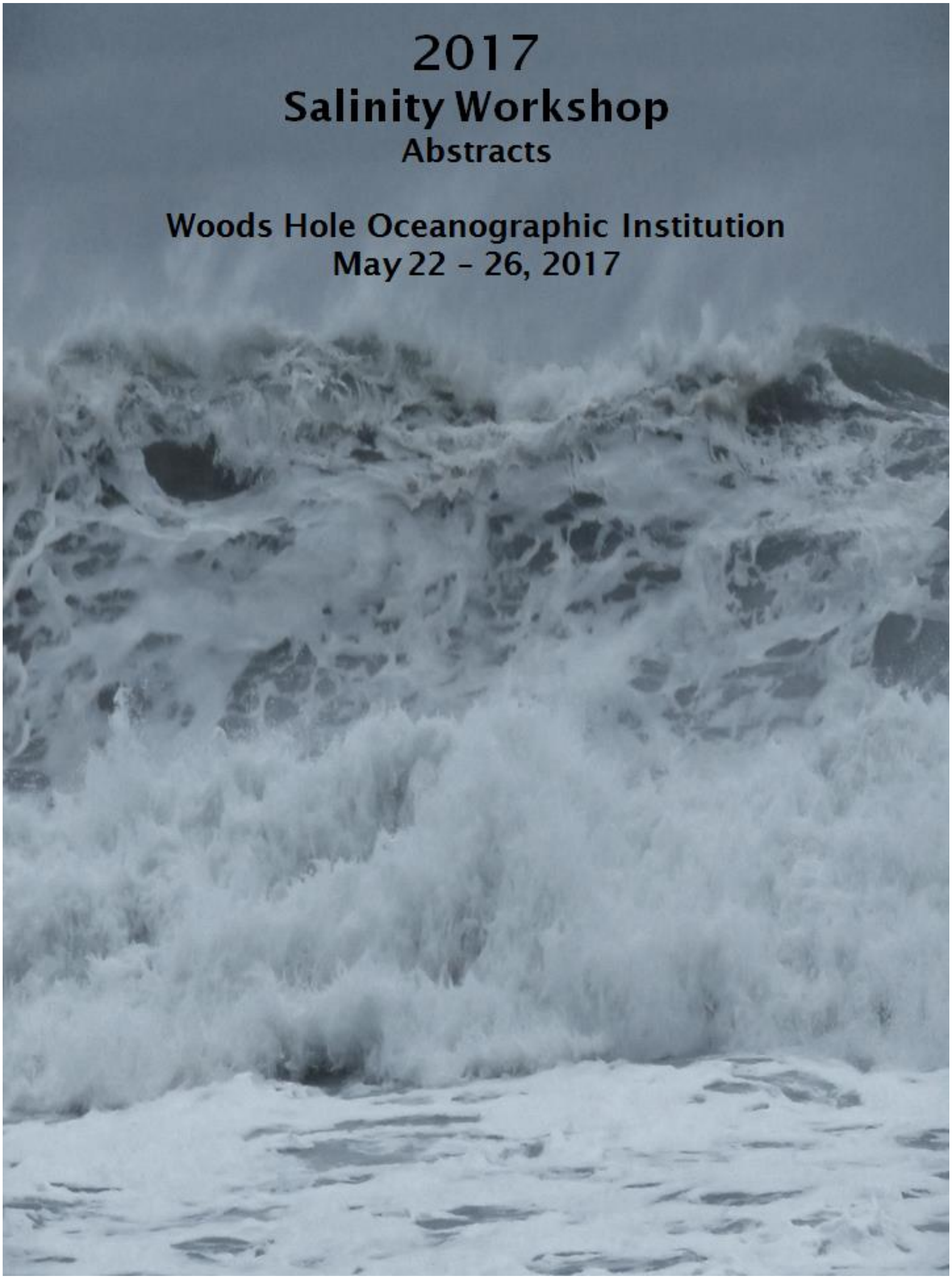

Jessica Anderson: University of Washington, jessea2@uw.edu
Presentation: Oral

Upper-ocean Responses to Rainfall: Observations from Profiling Floats

Rainfall over the ocean is an important component of the global freshwater cycle. Due to the small footprint and short lifespan of precipitation events, the upper-ocean responses to individual rainfall events remain difficult to observe. Using high vertical resolution (<10 cm) observations of temperature and salinity from Surface Temperature and Salinity (STS) enhanced Argo floats we examine the upper ocean responses to rainfall. Significant salinity drop events are observed to be associated with stratification, rainfall, and low wind speeds. Observations collected during fast cycle profiling (~2 hours) show the evolution of upper ocean temperature and salinity structure in response to rainfall for a variety of background conditions. In most cases, rainfall induced upper open stratification lasts less than 6 hours.

Manuel Arias: ARGANS Limited, marias@argans.co.uk
Presentation: Oral

OTT components analysis: Towards a better SMOS SSS retrieval

The analysis of MIRAS L1c TBs and L2 Ocean Salinity during commission phase of SMOS mission showed that simulated TBs from forward model do not match those from L1c input products. The mismatch appears to be systematic in the xi/eta antenna frame, at least in regions far from land, such as the Pacific Ocean. To correct for these errors in order for the L2OS processor to retrieve salinity, an Ocean Target Transformation (OTT) was proposed to be generated and applied to L1c TBs during L2OS processing. Each OTT contains TB offsets in a 2D array within the antenna frame, which are subtracted from L1c TBs in order to reduce the systematic instrumental biases. The so-called OTT is currently computed by averaging differences between forward ocean model and SMOS L1c TBs measurements, for each polarization, from 10 days before acquisition time, using only orbits passing through a specific region of the South Pacific Ocean, selected to minimize the influence of external sources of contamination like land/sea contamination or radio frequency interferences (RFI) from surface. The global idea behind it was that averaging errors would allow to disentangle the systematic errors of the antenna so far data were correctly filtered of external sources of contamination. This was meaning that level of noise of OTT would be related to the radiometry accuracy of the instrument and to geophysical variability; the last ones in the form of errors in the estimation of roughness contribution due to winds, sun signals and also to the actual changes of SSS happening in the region considered for the OTT computation.

More recently, it has been identified that OTT is not fully capable to only catch systematic errors. Specific patterns associated to TEC contamination and sun aliases within the Extended Alias Free Field of View (EAFFOV) have a major role in the temporal evolution of the offsets reflected by the OTT. Such seasonality of the OTT is, therefore, directly connected to sun activity (via TEC and its effect in the Faraday rotation) and also to annual sun cycle, as its specific geometry induces patterns of anomalies within the L1c TBs.

The present work is an exploratory approach intending to disconnect these signals from the true instrumental background. The technique approach that has been followed relies in the study of properties of time series of certain length, reason why this study could have not been carried out until recently, now that 7 years of data are available. The application of Singular Spectral Analysis (SSA), which operates well over non-linear signals, allows the determination of the main components of the times series constructed for each arbitrary position of the antenna frame. Application of Maximum Entropy Analysis over the filtered data also allows a fine study of the characteristic frequencies of some of the found signals. Results allow not only the isolation of a background component, but also to better understand the remaining sources of contamination (TEC and sun, mainly) appearing in both OTT and snapshots acquired by MIRAS, opening opportunities to deep the knowledge about these sources of errors, improve the OTT computation and hence, being an opportunity to increase the quality of SMOS SSS in the future.

Sabine Arnault: Laboratoire d'Océanographie et du Climat, sa@locean-ipsl.upmc.fr
Presentation: Poster

The intra-annual variability of the North Equatorial Counter Current eddies and of the instability waves of the tropical Atlantic Ocean using remote sensing

The intra-annual variability of the tropical Atlantic Ocean north of the Equator is investigated with satellite altimetry sea level anomalies, sea surface salinities and signal analysis methods such as the Empirical Mode Decomposition. Two regions of high variability are identified. The firstregion,between 3°N-11°N, is characterized by the presence of westward propagating eddies linked to the North Equatorial Counter Current (NECC) retroflection in the vicinity of the Brazilian coast. They show a strong annual cycle as expected. Our methods point out that this signal is frequency modulated shifting from large length scale structures in October to smaller ones in March. Consequently the number of "eddies" per year can be aliased, according to the time and location of sampling, and can impact the percentage they explain of the inter-hemispheric exchange of mass and heat associated with the meridional overturning circulation’s upper limb. The second region reveals the presence of westward propagating instability waves centered north of the Equator (3°N-7°N) between 50°W-10°W. These instability waves also show a strong seasonal cycle with maximum amplitude around August. They are clearly distinct from the NECC instabilities.

William Asher: University of Washington, asherwe@uw.edu
Presentation: Oral

Measurement of ocean surface turbulence generated by rain using the controlled flux method

Freshwater deposited on the sea surface as rainfall can produce a stable near-surface layer of fresher water with a lifetime of O(1–10) hours and a depth of O(1) meter. One-dimensional turbulence models show that the magnitude of the salinity decrease at the surface is a function of wind speed and rain rate, and that near surface turbulence is a critical factor in the formation and evolution of a fresh lens. Although it is known that rain generates surface turbulence, the role this turbulence plays in mixing the freshwater downwards is not well understood. Measurements of surface mixing in a rain simulator suggest that turbulence generated by raindrops impacting the water surface only mixes the top few centimeters, an order of magnitude shallower than the observed rain stratification. Whether or not rain-generated turbulence is relevant in terms of the formation or evolution of a fresh lens is an open question due to lack of field measurements of surface turbulence in rain. Direct measurement of surface turbulence and vertical profiles of salinity during rain are needed to understand whether the turbulence generated by rain in the upper few centimeters has an impact on fresh lenses generated by rain.

During the 2016 SPURS-2 field experiment in the eastern equatorial Pacific Ocean, the controlled flux technique (CFT) was used to infer surface turbulence before, during, and after rainstorms. CFT uses a carbon dioxide laser to heat a small patch of the ocean surface by a few degrees Celsius. An infrared imager then tracks the temperature decay of the patch, and the measured rate of the temperature decay can be related to the turbulence dissipation rate at the ocean surface. When combined with concurrent microstructure measurements made at a depth of 0.3 m, the contribution of rain to the dissipation rate at the ocean surface can be estimated. In this paper, preliminary results from the SPURS-2 CFT measurements will be presented to show the effect of rain on turbulence dissipation at the ocean surface. This data will be used along with concurrent measurements of salinity and temperature profiles in the upper meter of the ocean to better understand the generation and evolution of fresh lenses generated by rain.

Eric Bayler: National Oceanic and Atmospheric Administration, Eric.Bayler@noaa.gov
Presentation: Poster

Implementation of Operational Satellite Sea-surface Salinity Data Assimilation at NOAA

The assimilation of sea-surface salinity (SSS) data into numerical prediction models serves to extract value from the observations, as well as integrates those observations with other data to produce an optimal output. Sea-surface salinity observations from the European Space Agency's (ESA) Soil Moisture – Ocean Salinity (SMOS) mission and the National Aeronautics and Space Agency's (NASA) Soil Moisture Active-Passive mission are now sufficiently mature for assimilation into NOAA's operational models, in particular the Real-time Ocean Forecast System (RTOFS) and the Global Ocean Data Assimilation System (GODAS), the ocean component of NOAA's operational Climate Forecast System (CFS). The development of operational SSS data assimilation has now commenced full time. NOAA is operationally implementing the Navy Coupled Ocean Data Assimilation (NCODA) system; consequently, NCODA's SSS capability will be fully developed/refined and implemented. The development path is discussed.

Frederick Bingham: University of North Carolina Wilmington, bigkahuna@fredbingham.com
Presentation: Poster

Space and time scales of sea surface salinity and freshwater forcing variability in the global ocean (60S–60N)

Using Aquarius Version-4.0 data, we have investigated the time and space scales of sea surface salinity (SSS) over the global ocean between 60°S and 60°N. Decorrelation time scales of SSS were found to be divided among less than 80 days (covering 1/2 of ocean area), 80-100 days (1/3) and greater than 100 days (remainder). Once the seasonal cycle is removed, shorter time scales (less than 80 days) dominate. Spatial scales are largest in the tropics along the intertropical convergence zones of all oceans and the South Pacific convergence zone in the South Pacific. Time scales were also calculated for time-integrated (cumulative) surface freshwater forcing (CFWF) using precipitation from Tropical Rainfall Measurement Mission and evaporation from OAFlux data. These showed little spatial pattern, but a dominance of the seasonal and longer time scales over the globe. The lack of correspondence between dominant temporal and spatial scales of SSS and CFWF highlights the importance of ocean processes in regulating SSS variability.

Frederick Bingham: University of North Carolina Wilmington, bigkahuna@fredbingham.com
Presentation: Oral

SPURS-2 Data Management - Status and Plans

This is a short presentation on the data management efforts associated with SPURS-2.

Jacqueline Boutin: Laboratoire d'Océanographie et du Climat, jb@locean-ipsl.upmc.fr
Presentation: Oral

Measuring SSS with SMOS since 2010: Qualities and flaws

The Soil Moisture and Ocean Salinity (SMOS) mission monitors Sea Surface Salinity (SSS) from space since January 2010. This European Space Agency (ESA) Earth Explorer mission provided the first L-band radiometric observations of the Earth using interferometry. SMOS has demonstrated the feasibility of monitoring SSS and its variability from space with a precision of 0.15-0.3 (in regions free from radio frequency interferences and more than 1000km away from coasts). Some corrections however still need refinement such as the contamination by the land-sea emissivity gradient, the sun etc… (e.g. Boutin et al. 2016). Adjustments for systematic errors and radio frequency interferences have recently been successfully implemented on the level 2 and 3 SMOS operational chains. Empirical correction of the brightness temperatures in the ESA level 2 processing has indeed been made, adjusting better for land contamination. In the level 3 processing, a correction based on the self-consistency of SMOS SSS variations (Kolodziejczyk et al. 2016) has been implemented in Centre Aval de Traitement des Données SMOS (CATDS) for further correcting land contamination and systematic North-South seasonal errors. A particular attention has been put on preserving SSS natural variability in coastal areas, which was not well resolved by previous versions. These level 2 and 3 corrections greatly improve the SMOS-retrieved SSS. Systematic errors are reduced by more than 1 locally. The rms difference between the SMOS and Argo-derived SSS field (ISAS products; Gaillard et al. 2016) is reduced by more than 0.1 within 800km of the coast globally. The validation of this new retrieval method is however challenging due to the high natural SSS variability in coastal areas. We present a summary of the qualities and remaining flaws of these new retrievals, based on comparisons with SSS derived from SMAP (Soil Moisture Active/Passive), ISAS, ships of opportunity, surface drifters and TAO moorings.

James Boyle: Western Connecticut State University, boylej@wcsu.edu
Presentation: Poster

Development of an In-situ Instrument to continuously monitor near-surface salinity, temperature and sea state parameters

An in-situ instrument is under development with the goal of providing continuous and extended-duration monitoring of near-surface salinity (10 cm depth), near-surface temperature (2 cm depth) and directional wave parameters (i.e., significant wave height, peak spectral period and mean wave direction).

A small, low-mass and wave-following discus buoy is used. This buoy is designed to allow for capsize events, but generally remains top up because it is ballasted for self-righting. It has a small above-surface profile and low windage, resulting in near-Lagrangian drift characteristics. It is autonomous, with relatively low power requirements and solar panel battery recharging. Onboard sensors include an inductive toroidal conductivity probe for salinity measurement, an inexpensive, off-the-shelf motion package for sea state measurement and a thermocouple for bulk water temperature measurement. Data retrieval for this expendable buoy occurs using an onboard Argos transmitter.

This poster describes the sensor characteristics, calibration methods and uncertainty analyses for the scientific measurements. The physical model used to derive sea state parameters from buoy motion is provided along with data processing algorithms and laboratory validation results. Both the passive and a more recent design active anti-fouling system are discussed, including results from dock-side experiments. An assessment of the system-wide power budget is provided in support of long-term operation. Preliminary results from a short deployment during the SPURS-2 field campaign are shown. Finally, design and measurement issues which still need to be addressed are outlined.

When fully developed, it is anticipated this buoy could be used to support validation of satellite-based techniques to derive global-scale surface salinity. The advantages of this platform are: it provides measurements just below the surface which are important for L-band radiometric measurement of salinity, i.e., conductivity, temperature, surface roughness, and these measurements occur with high temporal resolution. In addition, the buoy has a relatively low cost and is easily deployed. This buoy would be most useful in regions with significant rainfall where horizontal inhomogeneity develops but is relatively short-lived and in high-latitude cold water regions where L-band radiometry is less accurate and deployment of valuable research-grade instrumentation may not be desirable.

Shannon Brown: Jet Propulsion Laboratory, shannon.t.brown@jpl.nasa.gov
Presentation: Oral

**A Next Generation Spaceborne Ocean State Observatory:
Surface Salinity, Temperature and Ocean Winds from Equator to Pole**

The advent of spaceborne L-band (1.2-1.4 GHz) passive and active microwave systems has unequivocally demonstrated the ability to measure salinity from low Earth orbit. But these first generation systems were limited to observing in just a single narrowband (<24MHz) portion of the microwave spectrum, in part due to the desire to operate in a band allocated for passive Earth observation and in part due to the relative immaturity of the required broadband RF components and power/mass efficient spectrometers. Observing only at L-band practically limits salinity observation to SSTs greater than 5C and also requires significant ancillary corrections in the salinity retrieval for the confounding contributions from surface roughness and water temperature. But, extending the passive microwave observations to a wider portion of spectrum (0.6-6 GHz) opens an entirely new capability to measure salinity with high precision in cold water and to also provide simultaneous retrievals of SST and wind speed; not only providing new complementary observations but also improving salinity retrieval globally. Significant technology development has taken place since the launch of the first L-band observatories making it now possible to conceive of a future series of ultra-wideband low-frequency passive microwave systems, coupled with narrowband active systems, to provide unprecedented observations of salinity in polar regions, sea surface temperature in all weather, winds in even the most extreme conditions and the thickness of both first-year and multi-year sea ice. In this presentation, we will highlight a new mission concept for a future ocean spaceborne observatory. We will discuss the expected capability in terms of measurement accuracy, precision and spatial resolution for simultaneous salinity, temperature and wind retrieval and highlight the technology that will get us there.

Subrahmanyam Bulusu: University of South Carolina, sbulusu@geol.sc.edu
Presentation: Oral

Investigating Interannual and Decadal Changes in Sea Surface Salinity in the Oceanic Subtropical Gyres and their connection to the Global Water Cycle

There is evidence that the global water cycle has been undergoing an intensification over several decades as a response to increasing atmospheric temperatures, particularly in regions with skewed evaporation – precipitation (E-P) patterns such as the oceanic subtropical gyres. Moreover, observational data (rain gauges, etc.) are quite sparse over such areas due to the inaccessibility of open ocean regions. We analyzed spatial and temporal salinity trends in five subtropical gyre regions over the past six decades using Simple Ocean Data Assimilation (SODA) reanalysis. It reveals that a positive rising trend in sea surface salinity in the subtropical gyres emphasizing evidence for decadal intensification in the surface forcing in these regions. Zonal drift in the location of the salinity maximum of the south Pacific, north Atlantic, and south Indian regions implies a change in the mean near-surface currents responsible for advecting high salinity waters into the region. Our results indicate an overall salinity increase within the mixed layer, and a salinity decrease at depths greater than 200m in the global subtropical gyres over 61 years, of which each individual gyre was analyzed in further detail. We determine that freshwater fluxes at the air-sea interface are the primary drivers of the sea surface salinity (SSS) signature over these open ocean regions by quantifying the advective contribution within the surface layer. This was demonstrated through a mixed layer salinity budget in each subtropical gyre based on the vertically integrated advection and entrainment of salt. Our analysis of decadal variability of fluxes into and out of the gyres reveals little change in the strength of the mean currents through this region despite an increase in the annual export of salt in all subtropical gyres, with the meridional component dominating the zonal. This study reveals that the salt content of E-P maximum waters advected into the subtropical gyres is increasing over time. A combination of increasing direct evaporation over the regions with increasing remote evaporation over nearby E-P maxima is believed to be the main driver in increasing salinity of the subtropical oceans, suggesting an intensification of the global water cycle over decadal timescales.

Julius Busecke: Lamont Doherty Earth Observatory, julius@ldeo.columbia.edu
Presentation: Oral

Temporal Variability in surface Eddy Mixing

Lateral mixing by mesoscale eddies is widely recognized as a crucial mechanism for the global ocean circulation and the associated heat/salt/tracer transports. The Salinity in the Upper Ocean Processes Study (SPURS) confirmed the importance of eddy mixing for the surface salinity fields even in the center of the subtropical gyre of the North Atlantic. We focus on the global salinity maxima due to their role as indicators of global changes in the hydrological cycle as well as providing the source water masses for the shallow overturning circulation.

A suite of observationally driven model experiments is used to investigate the contribution of near-surface lateral eddy mixing to the subtropical surface salinity maxima in the global ocean. Surface fields of salinity are treated as a passive tracer and stirred by surface velocities derived from altimetry, leading to irreversible water mass transformation.

In the absence of surface forcing and vertical processes, the transformation rate can be directly related to the integrated diffusion across tracer contours, which is determined by the observed velocities. The destruction rates of the salinity maxima by lateral mixing can be compared to the production rates by surface forcing, which act to strengthen the maxima. The ratio of destruction by eddy mixing in the surface layer versus the surface forcing exhibits regional differences in the mean - from 10% in the South Pacific up to 25% in the South Indian. Furthermore, the regional basins show seasonal and interannual variability in eddy mixing.

The dominant mechanism for this temporal variability varies regionally. Most notably, the North Pacific shows large sensitivity to the background salinity fields and a weak sensitivity to the velocity fields while the North Atlantic exhibits the opposite behavior. The different mechanism for temporal variability could have impacts on the manifestation of a changing hydrological cycle in the SSS field specifically in the North Pacific.

We find evidence for large scale interannual changes of eddy diffusivity in several ocean basins that could be related to large scale climate forcing.

Luca Centurioni: Scripps Institution of Oceanography, lcenturioni@ucsd.edu
Presentation: Oral

TBD: Joint presentation with V. Hormann, N. Maximenko and Y. Chao

Chris Chickadel: University of Washington, chickadel@apl.uw.edu
Presentation: Oral

Small-scale skin temperature variability affected by rain events during SPURS 2

High-resolution thermal imagery captured from a shipboard infrared camera during the SPURS 2 experiment shows development of small-scale skin temperature variability. These centimeter to meter wavelength features are typically elongate and linear, similar to classic Langmuir cells. They were observed over a range of wind and rain events, though their character varied. Previously, the characteristics and kinematics of these small features have been studied only from a small set of ocean and laboratory experiments. Our aim is to understand the significance of these small-scale features in upper ocean mixing, and to examine the degree they are affected by mechanical mixing of rain and shallow rain-caused stratification in open ocean conditions.

Thermal imagery is analyzed to determine the skin temperature variability, and spectral analysis is used to estimate the strength, scale, and orientation of the skin temperature features. Comparison of these derived parameters preliminarily reveals that the occurrence and orientation of the linear features is driven by the wind. However, the presence and degree of precipitation appears to modulate the relative feature strength (temperature signal above a background). We further explore the dependence of the feature length scales with ocean conditions and attempt to derive surface energy dissipation estimates associated with the features from the spatial content of the thermal imagery.

Allan Clark: Florida State University, aclarke@fsu.edu,
Presentation: Oral

El Niño Low Salinity Equatorial Jets

Fundamental to El Niño dynamics is the eastward movement of the western equatorial Pacific warm/fresh pool edge during El Niño and its westward movement during La Niña. Analysis of TAO/TRITON salinity and temperature measurements, as well as Aquarius sea surface salinity (SSS) and satellite altimetry, show that this zonal movement is mostly controlled by a shallow 23cm/s narrow jet. This zonal jet is confined to only a few degrees north and south of the equator in the top 50m-70m of the water column. The jet and its zonal movement result from a coupled ocean/atmosphere instability in which the jets are driven by westerly wind anomalies during El Niño and easterly wind anomalies during La Niña.

Preliminary work in the eastern equatorial Pacific suggests that there is also a shallow, narrow, low-salinity interannual zonal flow centered at 1 degree N that stretches for thousands of km and causes the interannual surface flow maximum to shift north of the equator. We are just beginning to examine its dynamics.

Carol Anne Clayson: Woods Hole Oceanographic Institution, cclayson@whoi.edu
Presentation: Oral

Near-surface stratification effects in the SPURS field campaigns

Stratification of the upper ocean in the tropics can occur under conditions of a positive heat flux from the atmosphere and/or positive freshwater flux. As such the strength of the stratification and the resulting changes in the surface temperature and salinity are highly sensitive to both the air-sea fluxes and the background initial stratification and mixing. In this talk, I shall discuss observations and modeling of the upper ocean stratification during the SPURS-1 and SPURS-2 field campaigns, including the variation in stratification seen as a result of diurnal warming, freshwater inputs, or both. The resulting mixing and temporal evolution of the stably stratified upper layers will also be discussed.

Rhiannon Davies: ARGANS Limited, rdavies@argans.co.uk
Presentation: Oral

Impact of a new bias correction on SMOS data

The European Space Agency's Soil Moisture and Ocean Salinity satellite mission uses a novel approach for retrieving brightness temperatures (TBs) of the Earth. The MIRAS (Microwave Imaging Radiometer using Aperture Synthesis) instrument is comprised of 69 separate sensors which are combined using a Fourier synthesis process to create one image, using interferometric techniques. Due to this retrieval method, any sudden change in brightness temperature (for example at the land-sea boundary) within the field of view (FOV) induces a Gibbs effect in the frequency domain. As a result, a bias is created in the reconstructed image of the alias-free field of view (AFFOV) generated by MIRAS. When associated with land/sea transitions, this bias is known as land-sea contamination (LSC). The effect appears in both land and sea but only has significant impact on the latter, due to the higher sensitivity required for ocean applications.

In SMOS, the LSC is seen in sea surface salinity (SSS) as a 'halo' around the continents that can bias retrievals both close to the coast and over 800 km away. SMOS L2 Ocean Salinity team has identified the parameter space associated to the problem, consisting of the geographical coordinates of the point, the fraction of land mass within the unit circle, the relative position of the point within the antenna frame, and the polarization. This means an empirical correction can be derived to mitigate the bias at TB level, prior to retrieval of SSS using the L2 Ocean Salinity processor. By considering 4 years of SMOS a systematic bias caused by LSC was estimated for the parameter space and used to correct the SMOS TBs in order to reduce this source of contamination.
The LSC has been extensively validated by the SMOS L2 Ocean Salinity team, against in situ data, such as ARGO, ISAS, ship data and WOA climatology. Validation showed an improvement in the retrieval of SSS in the areas affected by LSC, with a reduction in bias of between 0.2 and 0.3 pss when compared with ARGO . Comparisons with ship data showed a reduction in bias up to 0.5-0.7 psu on average, and a reduction of standard deviation by 0.3-0.7.

The introduction of the LSC correction in the SMOS L2 Ocean Salinity product has generally improved SSS quality around the affected areas, improving the exploitability of SMOS SSS. Nonetheless, the correction has some specific limitations that shall be addressed in future works.

Annette deCharon: ODYSEA LLC, avdecharon@gmail.com
Presentation: Poster

“NASA Salinity” Communication and Engagement

As a NASA pathfinder mission dedicated to public engagement, Aquarius made significant strides in broadening interest in salinity beyond the scientific community. Leveraging the infrastructure and thematic approach developed for Aquarius, new communication and public engagement endeavors are being conducted to align with the following scientific objectives:

1. Demonstrate clear linkages among ocean surface salinity variability, ocean circulation, Earth’s water cycle, and climate;

2. Highlight the synergistic value of NASA ocean surface salinity data in the broader context of other satellite and in situ measurements;

3. Provide insights into salinity variations within the upper water column in terms of environmental processes along with associated implications for “ground truthing” satellite-derived salinity data; and

4. Share the processes used to retrieve and refine salinity derived from satellite and other methods, including the ongoing efforts to improve data accuracy and consistency.

A variety of technical approaches and methodologies will be employed to reach a range of audiences in targeted, meaningful ways. For example, shareable media with eye-catching graphics and condensed text will be created to support social media campaigns. At the other end of the spectrum, online short courses will be offered to emergent scientists using effective practices that foster collaboration.

All of these outputs and opportunities will be showcased on the new, mobile-friendly “NASA Salinity” website. The activity will also include mining and repurposing other resources, such those generated for the Salinity Processes in the Upper-ocean Regional Study (SPURS) field campaigns. Content will highlight the synergies between satellite and in-water data while addressing concepts about today’s reliance on diverse technologies.

Through close coordination and interaction with the science community, these collective efforts will demonstrate how a better understanding of salinity science – and its ties to ocean circulation, climate, and the water cycle – can benefit society.

Shenfu Dong: National Oceanic and Atmospheric Administration (AOML), shenfu.dong@noaa.gov
Presentation: Oral

Near-surface Salinity and Temperature Structure Observed with Dual-Sensor Drifters in the Subtropical South Pacific

Three surface drifters equipped with temperature and salinity sensors at 0.2 m and 5 m depths were deployed in April/May 2015 in the subtropical South Pacific with the objective of measuring near-surface salinity differences seen by satellite and in situ sensors and examining the causes of these differences. Measurements from these drifters indicate that water at a depth of 0.2 m is about 0.013 psu fresher than at 5 m and about 0.024°C warmer. Events with large temperature and salinity differences between the two depths are caused by anomalies in surface freshwater and heat fluxes, modulated by wind. While surface freshening and cooling occurs during rainfall events, surface salinification is generally observed under weak wind conditions when there is strong surface warming that enhances evaporation and upper ocean stratification. Further examination of the drifter measurements demonstrate that (i) the amount of surface freshening and vertical salinity gradient heavily depend on wind speed during rain events, (ii) salinity differences between 0.2 m and 5 m are positively correlated with the corresponding temperature differences, and (iii) temperature exhibits a diurnal cycle at both depths, whereas the diurnal cycle of salinity is observed only at 0.2 m when the wind speed is less than 6 m/s. For wind speed less than 6 m/s, the amplitudes of the diurnal cycles of temperature at both depths decrease with increasing wind speed. The diurnal cycle in surface salinity is dominated by strong warming events under weak wind (≤2 m/s) conditions.

Kyla Drushka: University of Washington, kdrushka@apl.uw.edu
Presentation: Oral

Rain-driven turbulence in the upper meter of the ocean

Rain falling on the ocean produces buoyant surface layers of relatively fresh, cool water that are subsequently mixed laterally and vertically into the water column. Because it is difficult to make measurements near the sea surface, relatively little is known about the dynamics of this mixing — and as a result, our understanding of how rainfall affects upper ocean salinity is limited.

Here, we consider the response of the upper meter of the ocean using three months of measurements collected during the Friday Harbor Rain Experiment. Acoustic Doppler velocimeters, CTDs, and a suite of meteorological sensors were deployed over winter 2015-16 with the objective of quantifying the impacts of rainfall on the upper ocean. We examine how wind speed, rain rate and raindrop size, and background ocean conditions affect near-surface dynamics. In the upper few centimeters of the ocean, turbulence is dominated by wind forcing. Below 20 cm depth the impacts of rainfall are pronounced, with turbulent dissipation rate two orders of magnitude greater in in moderate rains compared to non-rain conditions. These observations are compared to outputs from a 1-d model, and the implications for parameterizations of near-surface turbulent mixing are discussed.

Paul Durack: Lawrence Livermore National Laboratory, pauldurack@llnl.gov
Presentation: Oral

Recent progress in understanding the global water cycle

Thanks largely to a boom in measurements and data, the research focus of the oceanic arm of the global water cycle has received considerable attention over the last decade. Due to this renewed interest, ocean salinity is now considered an Essential Climate Variable (ECV), its measurement is an integral part in the Global Climate Observing System (GCOS), and it provides an important metric of ongoing climate variability and change.

Recent work has highlighted the response of salinity to enhanced greenhouse gas concentrations over multidecadal timescales. In this context, salinity changes show a clear anthropogenic fingerprint of change and provide a suitable metric to compare observed and simulated change estimates. On shorter decadal timescales the fingerprint is less evident, and the impact of the sparse historical observing system, along with unforced modes of natural climate variability obscure a clear forced response. With the high-frequency measurements provided by salinity measuring satellites, and the sea-going SPURS campaigns, the direct relationship between salinity and rainfall has been further examined. These new assessments have uncovered relationships that occur over very short time and space scales, and which are unresolved by current modeling systems.

The presentation will provide an overview of current progress in understanding, and outline some ongoing work aimed at addressing the temporal disconnect between multidecadal and decadal analyses. While a long-term pattern of change appears robust both in available observational assessments and model simulations, there is further work required to better link these results with those captured over shorter timescales and smaller spatial scales.

James Edson: University of Connecticut, james.edson@uconn.edu
Presentation: Oral

Meteorological Quantification of P-E and Surface Fluxes during SPURS-2

A comprehensive set of meteorological instrumentation was deployed on the R/V Revelle and 3-m discus buoy during the SPURS-2 experiment in the tropical Eastern Pacific Ocean. These measurements are being used to quantify the amount of precipitation versus evaporation (P–E) that drives a freshwater flux into or out of the upper ocean, respectively. The salinity variability of the upper ocean is profoundly influenced by the freshwater flux at the surface, in combination with the effects of mixing and advection within the upper ocean. The mixing in the upper ocean is itself affected by the surface fluxes of freshwater, momentum, and heat. To quantify these fluxes, our measurements also include direct estimates of the heat, moisture, and momentum using Direct Covariance Flux Systems (DCFS) on the ship and buoy, as well as their related mean variables and radiative fluxes to estimate bulk fluxes.

The related means include four time daily launches of rawinsondes to provide atmospheric soundings of temperature, humidity, wind speed, and wind direction. These soundings provide the precipitable water available in the overlying atmosphere. These observations are being combined with remotely sensed data from satellites and models to investigate the relative importance of local evaporation, moisture storage, and moisture convergence using the vertically integrated moisture budget in the region of the Inter-Tropical Convergence Zone.

This talk will describe some of our initial efforts to quantify the surface fluxes and the sources/sinks of precipitable water over the SPURS-2 region. The principle hypothesis of this research is that the surface fluxes are a key factor in the evolution of salinity variability in this region, and that measurements of these parameters will greatly enhance our ability to simulate and predict the upper ocean salinity budget and resulting salinity structure in this region.

Tom Farrar: Woods Hole Oceanographic Institution, jfarrar@whoi.edu
Presentation: Oral

Surface layer salinity balance at the SPURS-1 central mooring

The Salinity Processes Upper-ocean Regional Study (SPURS) was a field campaign focused on understanding the physical processes affecting the evolution of upper-ocean salinity in the region of climatological maximum sea surface salinity (SSS) in the subtropical North Atlantic. An upper-ocean salinity budget provides a useful framework for guiding progress toward that goal. The SPURS measurement program included a heavily instrumented air-sea interaction mooring, which allows accurate estimates of the surface fluxes, and a dense array of measurements from moorings, Argo floats, and gliders. These data are used to estimate terms in the upper-ocean salinity and heat budgets during the SPURS campaign.

Brady Ferster, University of South Carolina, bferster@seoe.sc.edu
Presentation: Oral

Estimation of Salt Fluxes and Transports in the Southern Ocean

Sea surface salinity (SSS) derived from the multi-satellite missions, NASA's Aquarius/SAC-D, ESA's Soil Moisture and Ocean Salinity (SMOS), and NASA's Soil Moisture Active and Passive (SMAP), are used to estimate surface salt fluxes in the Southern Ocean (SO). Surface salt flux calculations produce similar estimations between the satellites, with anomalies resulting in changing the surface dynamics (buoyancy frequency). Depth-integrated salt and volume transports using Simple Ocean Data Assimilation (SODA) reanalysis are used to investigate the role of salt flux variation. The mean Drake Passage volume transport was calculated to be 143.3 0.2 Sv. Average inter-basin zonal salt transport is found to be > 5000 106 kg s-1 eastward, where mean Indian (566 106 kg s-1) and Atlantic (106 106 kg s-1) basins transport salt southward and the Pacific basin (589 106 kg s-1) transports salt northward. Seasonal variations in salt and volume transports suggest a net sink and source seasonally. Our results suggest that changes in salinity and salt transports are a major component of the SO warming. Based on these results, the use of satellite-derived salinity may prove to be a useful resource for observing salinity and surface salt fluxes within the SO.

Alexander Fore: Jet Propulsion Laboratory, alexander.fore@jpl.nasa.gov
Presentation: Oral

SMAP Sea Surface Salinity Retrieval Algorithm

The Soil Moisture Active Passive (SMAP) mission was launched January 31st, 2015. It is designed to measure the soil moisture over land using a combined active / passive L-band system. Due to the Aquarius mission, L-band model functions for ocean winds and salinity are already mature and may be directly applied to the SMAP mission. In contrast to Aquarius, the higher resolution and scanning geometry of SMAP allows for wide-swath ocean winds and salinities to be retrieved. In this talk we present the SMAP Sea Surface Salinity (SSS) dataset and algorithm. First we discuss the heritage of SMAP SSS algorithms from Aquarius, showing that SMAP and Aquarius show excellent agreement in regards to the ocean surface roughness correction. Next we discuss the particular strengths and weaknesses of a scanning radiometer like SMAP as compared to a push-broom system such as Aquarius. Then, we give an overview of some newly developed algorithms that are only relevant to the SMAP system, such as a new galaxy correction and a land correction enabling SMAP SSS retrievals to be done up to 40 km from coast. Finally we discuss the various L2B and L3 datasets available from SMAP and where they may be obtained.

Severine Fournier: Jet Propulsion Laboratory, severine.fournier@jpl.nasa.gov
Presentation: Oral

Satellite synoptic view of the Bay of Bengal post-monsoon "river in the sea"

The Bay of Bengal (BoB) is influenced by large freshwater input from the Ganga- Brahmaputra River and reversing monsoon-driven currents. Sparse in-situ observations and modelling studies suggest that the river-induced surface freshening is transported southward along the west coast of India in a narrow 100km strip by the East India Coastal Current (EICC) after the southwest monsoon. Our results demonstrate that sea surface salinity (SSS) retrieval from the Soil Moisture Active Passive (SMAP) satellite provides the first synoptic view of this coastal freshening. Satellite SSS agree well with in-situ measurements (correlation of 0.9) and display spatial contrast of up to 17 pss. Stirring by mesoscale eddies yields meanders of this coastal freshening. This freshening also extends further south in fall 2016 than 2015 because of the remote forcing from the negative 2016 Indian Ocean Dipole that drives a stronger southward EICC and hence transports the freshwater plume further south.

Severine Fournier: Jet Propulsion Laboratory, severine.fournier@jpl.nasa.gov
Presentation: Poster

Interannual variation in offshore advection of Amazon/Orinoco Plume water with impacts on regional upper ocean salinity and temperature

This study examines surface ocean interannual variability east of the Lesser Antilles, a region impacted by advected Amazon freshwaters and late-summer tropical cyclones (TC). The focus period was August, and largest differences were observed between 2011 and 2014 with an 840,000 km2 study area being 2 pss lower in surface salinity. Plume-impacted waters covered 92% of this area in 2011 against 60% in 2014, a 270,000 km2 difference. Lagrangian particle tracking based on satellite-derived ocean currents is used to diagnose Amazon and Orinoco freshwater transport impacts on surface salinity and temperature in the northwestern tropical Atlantic over 2010-2014. Northward freshwater flux is significantly weaker in summer 2014 than for 2010-2013. This anomaly is not due to interannual discharge variability but instead to significant changes in eddy-driven transport and in stronger cross-shore winds that restrict offshore freshwater flow in May 2014 compared to other years. We also show that the advected freshwater gradients are often associated with persistent sea surface temperature (SST) anomalies, contrasting with several modeling studies investigating salinity-impacted upper ocean barrier layer formation and SST feedbacks. One implication is the potential impact of these horizontal SST gradients on atmosphere ocean coupling during the convective TC summer periods. Basin-scale phenomena appear to be largely responsible for SST anomaly in 2010, which was 1C warmer than other years. Similarly, observed interannual variation in Amazon advective pathways and resulting salinity at the study site appears to follow from changes in the ITCZ position between 2011 and 2014.

Arnold Gordon: Lamont-Doherty Earth Observatory, agordon@ldeo.columbia.edu
Presentation: Oral

The Southern Hemisphere subtropical SSS-max regimes

The salty subtropical regimes of the world ocean display significant differences. Evaporation alone is not sufficient to explain the spatial and temporal characteristics of the salty subtropical regimes, the wind also shapes sea surface salinity maximum (SSS-max), both at seasonal and inter annual time scales. However, even the combination of regional air-sea water flux and the wind stress is insufficient to fully explain the SSS-max patterns. The SSS-max regimes are also influenced by their place in the global ocean system. This is particularly relevant to the southern hemisphere SSS-max regimes. The South Atlantic and the southern Indian Ocean SSS-max are affected by the Agulhas leakage around the southern rim of Africa, as well as the deflection of the South Equatorial Current into the northern hemisphere as part of AMOC. The southern Indian Ocean is also affected by the low SSS plume of Indonesian Throughflow water crossing the Indian Ocean between 10 and 15°S. The super wide South Pacific seems to have two distinct regimes, the 'normal' eastern SSS-max and the western regime shaped by a branch of the ITCZ in southern hemisphere. The difference of the SSS-max regimes is a sensitive indicator of the ocean and climate systems.

Virendra Goswami: Indian Institute of Technology, vk_goswami1@rediffmail.com
Presentation: Oral

Correlation of Regional Sea-level Variability Mechanism , Sub-Mesoscale Dynamics , Climate Variability & Development of Sea-Level Variability Predicting Models (SLVPM)

Lately, Researchers in University of Washington, USA & University of Edinburgh found that the pools underneath the glacier, Thwaites, are draining out at an unprecedented rate and emptying themselves. This unstoppably melting of the glacier into the ocean mainly, because of warmer seawater lapping at its underside. Thwaites is 4000m thick and is considered key to making projections of global sea level rise. Prof. Peter Clark, OSU attributed that the Glacier retreat was due to rising levels of Carbon Dioxide and other GHG, as opposed to other types of forces. If, this continues then the most of Glaciers would disappear in the next few centuries & the Glaciers loss in future will contributing to rising sea levels.

Hence, the present investigation aims to find out the correlation between the rise of GHG level & the Sea-Level rise vis-à-vis climate variability and can these be controlled through chemical processes e.g. creating the Temperature Absorption Sinks (TAS) to control Sea-Level rise & unstoppably melting of the glaciers into the ocean mainly because of warmer seawater lapping at its underside & Carbon Absorption Sinks (CAS),GHG Detoxifiers to check the rising levels of Carbon Dioxide and other GHG by developing the Sea-Level Variability Predicting Models (SLVPM)

Next, An attempt would be made through SLVPM to study the Correlation of Regional Sea-level Variability Mechanism , Sub-Mesoscale Dynamics ,Climate Variability & its impact on Sea-Level rise. Regional Variability of the Sub-Mesoscale Dynamics study includes to examine satellite imageries with emphasis on the large scale kinematic and thermodynamic behavior of selected mesoscale convective systems, e.g. intense cloud clusters depressions and thunderstorms to study vertical structure of these system. The values of characteristics, e.g. lifetime, distribution, trajectories, size and three dimensional structure, i.e., vertical extent of these systems would be computed.

Next, the kinematic features of the mesoscale convective systems would be correlated with sea-level variability on time & Space Scales; at the local, regional and global levels through the extracted Sea Surface Temperature (SSTs) over the grid box , attributing the regional change to natural and anthropogenic radiative forcing agents & to bring out a few optimum values of these to develop (SLVPM)

It would be endeavor to check the melting of glaciers and rise of sea level through Magnetic Refrigeration Techniques (MRT),Magnetic Reactors & harnessing of Lunar Energy to reduce the temperature at the glaciers and that of sea surface through chemical processes by making use of the correlation of physico-chemical Characteristics of catalysts & Climate variability as well as through the developed Sea-Level Variability Predicting Models (SLVPM).

Semyon Grodsky: University of Maryland, senya@umd.edu
Presentation: Poster

Interannual salinity in the Amazon plume and adjacent areas

The main mode of interannual near surface salinity in the tropical western Atlantic is related to ENSO teleconnections and is produced by changes in precipitation over the ocean and Amazon. The ocean rainfall has an almost immediate impact on underlying salinity in contrast to the land rainfall that leads to a delayed impact related to the hydrology of Amazon system. Due to the need for longer time records to resolve interannual signal, our investigation relies on historical syntheses of in-situ observations mainly focusing on the JAMSTEC analysis. The inferred patterns of variability are compared to those from relatively short AQUARIUS records.

Sébastien Guimbard: Ocean Data Lab, sebastien.guimbard@oceandatalab.com
Presentation: Oral

SMOS Pilot-Mission Exploitation Platform (Pi-MEP): Datasets, tools and case studies

The global database of Sea Surface Salinity (SSS) observations is rapidly expanding now as a result of new satellite measurement capabilities (ESA's Soil Moisture Ocean Salinity, SMOS, and the NASA Aquarius and SMAP missions) and other enhancements to the global observing system (e.g., the Argo float array, TSG, drifters...). Given the novelty of the satellite SSS data, the current user and science communities being interested in these data over the ocean are mostly connected to the mission expert team and centers. The main reason of the currently limited growth of the user community for this important Essential Climate Variable (ECV) first estimated from space is linked to the fact that these complex data are rather new and that data quality still needs to be improved and/or to be better understood, and characterized, for applications.

In that context, the recent SMOS Pilot-Mission Exploitation Platform (Pi-MEP) project principal objective will be to perform a systematic assessment of SMOS SSS data quality (at L2, L3 & L4) by systematically compare each product with relevant in situ data (ARGO, TSG, moorings, drifters...). Production of match-up database products of SMOS/in situ data and intercomparison reports between products (bias, RMS difference, spectral analyses, correlation with other variables, pdfs…) at different time and spatial scales (seasonal, interannual, regional, global, …) will be provided via user interface tools allowing visualization and/or user-driven extractions.

The Pi-MEP is also thought to be a dedicated hub for the SMOS (SSS) mission providing links and access to other satellite (Aquarius, SMAP), in situ SSS (ISAS, EN4, JAMSTEC…) and other thematic datasets (precipitation, evaporation, currents, sea level anomalies, SST…). The platform will also provide a monitoring of SSS for selected oceanographic « case studies »:

- Horizontal salinity transport and mesoscale structure signature in western boundary currents (Gulf Stream, North Brazilian Current, Kuroshio and/or Agulhas)
- Large tropical river plumes monitoring: Amazon, Congo and Mississippi
- Important fresh water cycle area (salinity, E-P, vertically integrated fresh water content…) under the intertropical convergent zones (Pacific, Atlantic and Indian ocean) and subtropical gyres evaporative zones
- SSS variability with Climate indexes: El Niño/La Niña, Indian Ocean Dipole
- Upwelling areas: Equatorial upwelling, Costa Rica dome, and Panama
- Tropical instability waves monitoring (eastern Pacific and Atlantic)
- Bio-geochemistry processes (ocean acidification, pCO2…) in key areas (e.g., Bay of Bengal, Barent sea and Amazon plume influence)
- High latitude (southern ocean) and semin-enclosed seas (Mediterranean sea).

In this talk, the current state of the initial phase of the Pi-MEP project regarding the collected datasets, visualization and extraction tools and a non-exhaustive list of oceanographic process studies will be presented.

Audrey Hasson: Laboratoire d'Océanographie et du Climat, audrey.hasson@locean.upmc.fr
Presentation: Oral

SMOS and simulated Sea Surface Salinity Anomalies in 2015: the imprint of a singular El Niño event

The El Niño Southern Oscillation (ENSO) is the dominant mode of variability of the Pacific Ocean at interannual timescales. Many studies have investigated the signal in salinity associated with ENSO and its importance in the ocean dynamics during the oscillation. Since 2010, sea surface salinity (SSS) is monitored from the satellite mission Soil Moisture Ocean Salinity (SMOS) with an unprecedented spatial and temporal resolution. It revealed the SSS patterns associated with the three interannual states of the tropical Pacific Ocean: La Niña (2010-2011), El Niño (early 2010, 2015-mid 2016) and almost 3 years in a “neutral state” (2012-2014). This study focuses on the latest El Niño event. October 2015 is described as the peak of the El Niño in terms of SSS. A negative anomaly (below -0.5) lays between 160ºE-160ºW and 8ºS-8ºN with a “tail” extending all the way to 90ºW and 10ºN, forming a “sigma-shaped” pattern. This is consistent with the ENSO-associated SSS pattern described in the literature. A distinct secondary basin-wide anomaly lower than -0.5 is present between 10 and 25ºN, which is not represented by the canonical ENSO SSS patterns. The two large-scale anomalies are separated by a band of weaker anomalously fresh waters centred around 10ºN.

A wide range of observations (in situ and space-borne) and a validated model simulation (NEMO) is used to characterize and understand the mechanisms leading to this singular SSS signal. The numerical simulation enables the quantification of the mixed layer salinity budget terms that cannot be resolved with observations solely. Results show that the equatorial anomaly results from mainly anomalous zonal advection in the west and anomalous precipitations in the east. The extra-equatorial signal is on the other hand a superposition of a persisting SSS anomaly from the 2014 aborted El Niño, advected north by the mean Ekman currents and the 2015 SSS anomaly transported in the tropical current system.

Ben Hodges: Woods Hole Oceanographic Institution, bhodges@whoi.edu
Presentation: Oral

Wave Gliders in SPURS-2

Three Wave Gliders were deployed in August 2016 to commence sampling for SPURS-2. They measure temperature and salinity at 2-minute intervals at depths of 30 cm and 6.5 m, and return the data in real time via satellite link. Additional temperature observations at 30-second intervals are made at other depths, the shallowest being 10 cm. Together with measurements of wind speed, these observations begin to form a picture of the formation conditions, size, frequency, duration, and seasonality in the SPURS-2 study area of the shallow "fresh puddles" which form when rain falls on a calm ocean surface. One Wave Glider carried an additional sensor suite for a brief period: a "rake", which measured temperature and salinity at 1-Hz at every 10-cm depth increment of the upper meter. These higher-resolution observations offer a more detailed view of the formation and decay of a few fresh puddles.

Verena Hormann: Scripps Institution of Oceanography, vhormann@ucsd.edu
Presentation: Oral

Lagrangian drifter observations of near-surface circulation and sea surface salinity during SPURS-2

The salinity distribution in the world ocean is a poorly understood part of the global water cycle. To improve understanding of the role of near-surface currents in defining the salinity distribution and location of minimum salinity in the northeastern tropical Pacific, a Lagrangian drifter study with about half the drifters fitted with salinity sensors has been designed as part of the SPURS-2 experiment. First results of the ongoing drifter deployments in the eastern Pacific fresh pool under the ITCZ will be presented, highlighting the observed large spatiotemporal variability in near-surface circulation and sea surface salinity.

Shijian Hu: Institute of Oceanology, sjhu@qdio.ac.cn
Presentation: Oral

Salinity effect in the interannual to decadal variability of the Indonesian Throughflow

The Indonesian Throughflow (ITF) region possesses strong mixing and experiences significant freshwater input, but the role of salinity variability in the Indonesian Seas remains unclear. The goal of this study is to understand how salinity variability influences the ITF transport on interannual to decadal time scales. The ITF transport is calculated using observations and assimilation datasets and verified using direct ITF transport estimates. We find that the halosteric component of the ITF transport contributes (36±7)% of the total interannual variability of ITF, in contrast to (63±6)% by the thermosteric component. Correlation analysis indicates that the interannual variability of the total ITF transport is mainly influenced by the El Niño-Southern Oscillation (ENSO) rather than the Indian Ocean Dipole. Under the ENSO cycle, the Walker Circulation shifts longitudinally resulting in fluctuations in precipitation over the Indonesian Seas that modulates salinity and subsequently influences the interannual variability of ITF transport. During the past decade, the ITF transport shows a significant strengthening trend due to a freshening and subsequent increase in the halosteric component of the ITF transport associated with enhanced rainfall over the Maritime Continent over the same period. The strengthening of the ITF transport leads to a significant change in heat and freshwater exchange between the Pacific and Indian Oceans and contributes to the warming and freshening of the eastern Indian Ocean. Our results suggest that the combined effect of the ITF transport of mass and freshwater along with tropical rainfall plays a very important role in the climate system.

Venkata Subba Reddy: GITAM University-Hyderabad, isubbareddy@rediffmail.com
Presentation: Poster

Global Variation of water vapor using Different observational platforms

The COSMIC mission was launched on April 15, 2006 it is a Global Positioning System (GPS) radio occultation (RO) and it includes six microsatellites. The main purpose of this mission is to provide ~2500 real-time soundings per day with a global coverage. This can potentially have major impacts on weather, climate, space weather research and forecasting. The COSMIC satellite data is most useful to study the variation of water vapor (WV) because of global coverage with high spatial resolution of about 100 m in the troposphere. The objectives of the study are to retrieve the WV from the RO satellite data and to study the annual and year-year variability of WV over the globe. To retrieve the WV from the COSMIC post processed data we used 1D-var analysis with Global Spectral Model of Japan Meteorological Agency (GSM-JMA) as an initial value. The retrieved WV is compared with the AQUA-AIRS satellite as well as the Model (NCEP and ECMWF) data sets. The difference between these observations and their latitudinal and longitudinal variation of WV are studied. The Global variation of water vapor and its impacts on climate change are studied by using the above different data sets and its strengths, limitations are discussed.

Benjamin Johnson: North Carolina State University, bkjohns2@ncsu.edu
Presentation: Oral

Accounting for Autocorrelation in Estimates of Salinity Sample Variances and Trends

Classical statistical methods require data in a sample distribution to be independent of one another (e.g. flips of a coin, trials of an experiment, decay of atomic nuclei). Analyses of salinity trends violate this requirement since time series data are autocorrelated. We examine the autocorrelation structure of salinity time series and demonstrate how low-frequency variability is typically unaccounted for when estimating sample statistics. We explain how to account for autocorrelation when estimating the magnitude of sample variances, the significance of epochal differences, and the significance of linear trends. We critically examine three recent studies by replicating their methodologies and demonstrating the extent to which these studies overestimate the significance of their results.

Julia Köhler: Center for Earth System Research and Sustainability, julia.koehler@uni-hamburg.de
Presentation: Oral

Mechanisms for seasonal and interannual sea surface salinity variability in the Indian Ocean

Through a combined analysis of an ensemble-mean sea surface salinity (SSS) product based on SMOS and Aquarius data, in situ ocean observations and a high-resolution model simulation, the forcing terms of the Indian Ocean mixed layer salinity are examined, including key processes for the seasonal (annual and semiannual) variability, such as surface salinity fluxes, horizontal and vertical salinity advection and mixed-layer entrainment.

Almost half the total Indian Ocean SSS variability can be explained by the annual cycle, specially in the southern Arabian Sea, northern Bay of Bengal and the Intertropical Convergence Zone (ITCZ) region. It was found, that the freshwater flux controls annual and semiannual salinity tendency in the western Indian Ocean, where the ITCZ has a strong seasonal cycle. There, surface fluxes account approximately for 70% (40%) of the annual (semiannual) salinity tendency variance. In contrast, advection is the dominant contribution in the northern and equatorial Indian Ocean, accounting for approximately 80% of the annual and semiannual salinity tendency. The influence of entrainment on the salinity tendency is enhanced in mid-ocean upwelling regions and the southern Arabian Sea but remains small. The inferred dominant salinity budget terms are confirmed by results obtained from a high resolution NCAR (National Center for Atmospheric Research) Community Earth System Model (CESM) run driven by CORE II forcing fields. For that, monthly model output fields were averaged over the simulated mixed layer to mimic the vertical and temporal resolution of the observations and to verify the approximations done by using the vertically averaged budget equation. The model shows that the different temporal resolutions contribute to the residual, but the main differences between model budget terms and observational budget terms come from differences in horizontal velocity fields, resulting in a misrepresentation of advection.

Some percentage of mixed layer salinity variance is related to interannual variations in the central Indian Ocean, associated with the Indian Ocean Dipole (IOD) climate mode. Correlation patterns of SSS anomalies and the IOD index show a meridional tripolar structure in the eastern Indian Ocean, which differs clearly from the IOD-dependent zonal SST pattern found in previous works. Horizontal advection dominates the interannual salinity tendency in this region due to the strengthening and weakening/reverse of wind and currents during, respectively, negative and positive IOD events.

Nicolas Kolodziejczyk: L'institut Universitaire Européen de la Mer, nicolas.kolodziejczyk@univ-brest.fr
Presentation: Oral

Resolving SSS from BASIN SCALE TO MESOSCALE: A SMOS Optimal Interpolation

The Soil Moisture and Ocean Salinity (SMOS) mission (European Space Agency) launched in November 2009 provides measurements of Sea Surface Salinity (SSS) over the global ocean at 45 km resolution every 3 to 5 days. Thus, the SMOS SSS products can be used to monitor the distribution of mesoscale features of SSS (larger than 50-100km, with 10 day to monthly averages). However, SMOS SSS still experiences large biases and noise on various time and space scales, related in particular to instrument calibration, to image reconstruction, and to radiofrequency interferences. Using a SMOS SSS L2 data (mid-2010 to now) available at Centre Aval de Traitement des Données SMOS and the global Argo array of in situ measurements as reference data base, a statistical approach and Optimal Interpolation are used to characterize and to correct a large part of the biases and reduce the noise. First, a coastal bias correction method comparable to Kolodziejczyk et al. (RSE, 2016) is implemented. Then, we use In Situ Analysis System (ISAS), an Argo interpolated product, to characterize and adjust large scale and seasonal varying differences. Finally, a 75-km and weekly Optimal Interpolated (OI) mapping provides improved SMOS SSS L4 global fields. We present a validation of this new OI product based on comparisons with SSS derived from thermosalinograph measurements from ships of opportunity.

Gary Lagerloef: Earth & Space Research, Lager@esr.org
Presentation: Oral

Aquarius Mission Summary and Overview

Conceived in the late 1990s, and proposed to NASA's Earth System Science Pathfinder (ESSP) Missions program in 2001-2002, the Aquarius mission was selected to resolve missing physical processes that link the water cycle, the climate, and the ocean by measuring sea surface salinity (SSS). The satellite was developed in partnership with Argentina as the joint Aquarius/SACD mission, and included complementary sensors provided by Argentina, Italy, France and Canada. The primary salinity sensor, Aquarius, provided global coverage every 7 days at 150 km spatial resolution for at least three years to resolve the global mean, seasonal and interannual variability. While the scientific focus was basin-scale, the capability to resolve smaller scale features exceeded expectations; such as tropical instability waves, river plumes and ocean fronts. Other key science achievements include improving tropical Pacific SST forecast skill, linking SSS changes to terrestrial rainfall, estimating total alkalinity, and discovering the range of temporal variability of the SSS field. Various examples will be presented.

Gary Lagerloef: Earth & Space Research, Lager@esr.org
Presentation: Oral

Verifying Aquarius Calibration Drift Using In Situ Data

Key Aquarius science objectives were to (1) map the mean SSS field, (2) measure the annual SSS cycle, and (3) document interannual variations, within a three-year minimum duration. This presentation addresses objectives (2) and (3) by analyzing the radiometer calibration drift on these time scales using co-located in situ data. The analysis converts the in situ data to an expected radiometer brightness temperature (Tb), and differences these from the Aquarius radiometer Tb. The crux of the analysis is separating the sensor drift from the varying environmental corrections in the retrieval algorithm. The approach is to take differences between geographical zones and regression analyses to isolate the sensor variations from the environmental ones. I will explain this calculation and present the results achieved until now with this work-in-progress. Calibration curves for each of the six Aquarius radiometer channels are derived, and are sensitive to the calibration method used in the processing for a few algorithm test versions being evaluated for the new V5.0 data release. Understanding the residuals due to environmental model errors remains more problematic. The future goal will be to adapt the technique to SMAP, and eventually SMOS measurements to enable a systematic cross-calibration of the different satellite systems and obtain a reliable combined multi-year time series for studying ocean trends.

Tong Lee: Jet Propulsion Laboratory, tlee@jpl.nasa.gov
Presentation: Oral

Perspectives for future enhancement of spaceborne salinity observing capabilities

The L-band (~ 1.4-GHz) SMOS, Aquarius, and SMAP missions have pioneered salinity remote sensing from space. Sea surface salinity (SSS) products from these missions are significantly improving our understanding of regional SSS variability, the associated ocean dynamics, and the linkages with climate variability and water cycle. The satellite SSS help resolve scales and monitor regions not adequately sampled by in-situ systems. The qualities of the SSS retrievals are continuing to improve. This presentation describes the perspectives for future SSS missions based on community inputs during 2015-2016 to the "2017-2027 Decadal Survey for Earth Science and Applications from Space" organized by the U.S. National Academies. The community inputs recognized three major areas for strengthening spaceborne salinity observing capabilities: (1) improvement of high-latitude SSS accuracy, (2) enhancement of spatial resolution (thereby getting closer to the coasts), and (3) mission continuity. In particular, the need to improve high-latitude satellite SSS stems from the fact that L-band radiometers have poor sensitivity to SSS in cold waters (<5C), and from the importance of high-latitude SSS to deep-water formation, heat and carbon sequestration, and global ocean circulation as well as the related property transports. A measurement concept has been proposed to improve high-latitude SSS by augmenting the L-band with P-band (~0.5 GHz) radiometry because the latter provides nearly three times better sensitivity than L-band for cold waters. Moreover, the dual-frequency L/P-band radiometry can improve the measurements of the thickness of seasonal sea ice, which is becoming more prevalent in the Arctic Ocean as the multi-year sea ice are declining. The enhanced capability to measure seasonal sea-ice thickness complements the existing capability of radar-based measurements of sea-ice thickness that have lower signal-to-noise radio for seasonal than for multi-year sea ice. More accurate sea-ice thickness measurements in turn help improve the correction of sea-ice effects on high-latitude SSS retrieval. The status for the ongoing technological development for the L/P-band radiometer will be discussed.

Sam Levang: Woods Hole Oceanographic Institution, slevang@mit.edu
Presentation: Oral

Improving the ocean rain gauge: a quantification of global mixed-layer salt transports

The time-mean salinity field in the upper ocean develops as a balance between forcing at the surface, which generates variance, and interior transports, which work to restore salinity towards homogeneity. Because the ocean is in constant motion, salinity is influenced by non-local forcing and non-isotropic transports, meaning the steady-state field does not align identically with the surface forcing. These oceanic transports involved in the steady-state balance are relevant to understanding the response of the system to forcing change, including changes associated with global warming. We present a quantification of the steady-state salinity budget for the surface mixed-layer, calculated from both an ocean state estimate and directly from observations. The budget is used to contextualize projected salinity changes in coupled climate models, which show significant deviations from the classical view of water-cycle intensification. One hypothesis is that oceanic regions with strong lateral transports are likely to exhibit the most influence from non-local forcing, since the surface layer adjusts more quickly than the abyss. The steady-state budget suggests that lateral transports are largest on the equatorial side of the subtropical gyres, where strong meridional Ekman and Sverdrup flows transport water across salinity gradients. This argument is supported by CMIP5 simulations, which indicate that changes in forcing are relatively well stirred within the subtropical gyres, making inter-basin contrasts the most prominent signal there. Such behavior has implications for the idea of an 'ocean rain gauge' as used to monitor long-term water cycle variability.

Laifang Li: Duke University, laifang.li@duke.edu
Presentation: Oral

Ocean salinity as a predictor of terrestrial precipitation

The global water cycle is fueled by water evaporating from the oceanic source regions. Over the global oceans, these sources are primarily located in the subtropics, where evaporation exceeds precipitation resulting in a net moisture export from the local oceans. About a third of the subtropical water is transported to the land and becomes an indispensable water source for terrestrial precipitation. Thus, the amount of terrestrial precipitation is significantly modulated by the availability of oceanic moisture. At the same time, the net ocean-to-land moisture transport leaves an imprint on sea surface salinity (SSS), suggesting that the variation of subtropical SSS can provide predictive value for terrestrial precipitation. In this presentation, we provide observation-based evidence that springtime salinity in the subtropical North Atlantic can be a very useful predictor of terrestrial precipitation with a one season lead. Specifically, high springtime SSS in the northeastern portion of the subtropical North Atlantic is followed by excessive monsoon precipitation in the African Sahel, whereas high SSS in the western North Atlantic is indicative of extreme summer precipitation in the US Midwest. The physical mechanism is established through an increased ocean-to-land moisture transport, and a positive soil moisture feedback process which preserves the initial oceanic moisture inflow for 3 months. In the African Sahel, the soil moisture influences monsoon-season precipitation by enabling the region to draw more moisture from the ambient oceans. In the US Midwest, the soil moisture exerts both thermodynamic and dynamic effects on summer precipitation. Thermodynamically, soil moisture itself is a moisture source for summer precipitation. Dynamically, the spatial distribution of soil moisture intensifies the Great Plains Low-level jet to transport more moisture into the Midwest. Due to the close relationship between subtropical North Atlantic SSS and ocean-to-land moisture transport, and the active role of soil moisture in the regional water cycle, seasonal forecasts of Sahel and Midwest precipitation can be improved by incorporating the North Atlantic SSS into prediction models. We will further show that the improvement in the precipitation is most significant for extreme precipitation. In addition, SSS is shown to provide superior predictive value than preseason SST for these regions. Our studies suggest that expanded monitoring of ocean salinity is likely to contribute to more skillful continental precipitation predictions.

Zhijin Li: Jet Propulsion Laboratory, zhijin.li@jpl.nasa.gov
Presentation: Oral

Meso/submesoscale Processes in the Subtropical North Atlantic Surface Salinity Maximum Region

Using a high resolution model of the sea surface salinity maximum (SSS-max) region in the subtropical North Atlantic Ocean, we show that meso/submesoscale flows (with spatial scales < 100 km) are more energetic than reported in previous studies. This flow involves vortices and elongated fronts, and may explain 40-50% of the total kinetic energy in this region. Water masses of relatively low salinity that converge into the SSS-max region are dispersed by the meso/submesoscale features, offsetting the air-sea surface fluxes that increase salinity. We conclude that the meso/submesoscale flow significantly impacts the salinity budget in the upper layers by both vertical and horizontal dispersion, acting to attenuate the SSS-max. The dynamics of the SSS-max spans a wide range of scales.

Chao Liu: University of South Florida, chaoliu@mail.usf.edu
Presentation: Poster

Vertical Redistribution of Oceanic Salt Content and Its Implications for the Upper Ocean Salinity Change

Ocean salinity is an important proxy for change and variability in the global water cycle. Multi-decadal trends have been observed in both surface and subsurface salinity in the past decades, and are usually attributed to the change in air-sea freshwater flux. Although air-sea freshwater flux, a major component of the global water cycle, certainly contributes to the change in surface and upper ocean salinity, the salt redistribution inside the ocean can affect the surface and upper ocean salinity as well. In addition, the mechanisms controlling the surface and upper ocean salinity changes likely vary on timescales. Here we examined the upper ocean salinity changes as well as the contribution of the vertical redistribution of salt with a 20-year dynamically consistent and data-constrained ocean state estimate (ECCO: Estimating Circulation and Climate of the Ocean). Preliminary results show an upward salt flux inside the ocean, indicating that the vertical redistribution of salt contributes positively to the upper ocean salinity change over the 20-year period (1992-2011). Between advection and diffusion, the two major processes determining the vertical exchange of salt, the advective term at different depth shows a downward transport, while the diffusive term is the dominate upward transport contributor. These preliminary results suggest that the salt transport in the ocean interior should be considered in interpreting the observed surface and upper ocean salinity changes, as well as inferring information about the changes in the global water cycle.

Christophe Maes: L'Institut de recherche pour le développement, christophe.maes@ird.fr
Presentation: Poster

Ocean Salinity Stratification during the 2002-2012 period as derived from the ISAS13 Argo atlas

Among the different physical processes contributing to the present climate changes and their impact on the ocean productivity and marine ecosystems, little attention has been paid to the large-scale contributions of stratification changes within the water column. Stratification, which is associated with the density difference between the surface and the deeper layers, characterizes the stability of the water column, and therefore influences the potential for vertical exchange of properties such as nutrients or dissolved oxygen. Due to the lack of in situ observations the salinity effect on stratification has often been neglected as compared to its thermal counterpart. Consequently, the differential effect resulting from the atmospheric forcing in terms of the temperature and salinity variability remains mainly unexplored. Rather than focusing on the classical halocline vs. thermocline definitions, the present study takes into account the respective thermal and saline dependencies in the Brunt-Vaisala frequency (N2) in order to isolate the specific role of the salinity stratification in the layers including the main permanent pycnocline. The role of salinity is differentiated through its stabilizing or destabilizing effect on stratification along the water column.

The Ocean Salinity Stratification (OSS, as defined by Maes and O'Kane, JGR 2014) is derived from monthly gridded temperature and salinity fields (0-2000m) based on the Argo measurements (ISAS-13 temperature and salinity gridded fields, Pôle Océan, http://doi.org/z77, F. Gaillard, 2016) and is analyzed in terms of large-scale variability patterns on seasonal to interannual time scales during the 2002–2012 period.

Amala Mahadevan: Woods Hole Oceanographic Institution, amahdevan@whoi.edu
Presentation: Oral

The Role of Freshwater in the Bay of Bengal: Lessons from ASIRI

Large riverine inputs and monsoonal rain make the Bay of Bengal one of the freshest tropical oceans in the world. Intensive observations and process modeling conducted through ONR's Air-sea interaction regional initiative, ASIRI, have shed light on the structure, processes, and air-sea fluxes in this ocean. The upper 50 m exhibit strong horizontal and vertical gradients in salinity, with density fronts and stratification that generate dynamical instabilities at multiple scales within the surface mixed layer. A rich set of submesoscale processes is embedded within a mesoscale eddy field and a seasonally reversing basin circulation that responds to monsoonal winds and buoyancy forcing. Together, these processes help disperse the freshwater input to the bay. This talk will highlight the freshwater's influence on the structure and dynamical processes, and its role in modulating interactions between the surface mixed layer and atmosphere.

Thomas Meissner: Remote Sensing Systems, meissner@remss.com
Presentation: Oral

Salinity Remote Sensing from SMAP

Remote Sensing System's (RSS) SMAP Version 2 sea surface salinity (SSS) data have been released on September 13, 2016. The release contains a Level 2 swath product and Level 3 maps of 8-day running averages and monthly averages.

Our talk discusses the major steps of the SMAP salinity retrieval algorithm, including updates and improvements from the Version 1 (BETA release).

Though designed for measuring soil moisture, the SMAP radiometer has excellent capabilities to retrieve SSS with a similar accuracy as Aquarius. However, the calibration accuracy of the SMAP brightness temperatures on which the SMAP soil moisture product is based, is itself not sufficient for retrieving SSS, but additional steps need to be taken. These steps will be discussed in our presentation.

Other than Aquarius, the SMAP antenna is slightly emissive. The value of the emissivity is approximately 1%, which is 4 times as large as anticipated from ground calibration. This causes significant spurious biases in the SMAP salinity data that correlate with the physical temperature of the antenna, which depends on solar heating. It is necessary to develop a correction for this spurious emissivity signal.

Due to the demise of the SMAP radar, SMAP does not provide valuable L-band scatterometer wind speeds at the same location and time as the radiometer observation as Aquarius did. Therefore, the SMAP salinity retrieval algorithm needs to use wind speeds from WindSat and F17 SSMIS for correcting the surface roughness effect.

The full 360-deg look of SMAP makes it possible to take observations from the forward and backward looking direction basically at the same instance of time. This two-look capability strongly aids the salinity retrievals. It is possible to observe some of the spurious contamination sources such as the reflected galaxy from different directions and thus determine the size of these spurious contamination signals.

We will provide validation results for the RSS SMAP salinity against ground truth measurements from ARGO drifters.

Finally, we will present our plans for upcoming SMAP SSS releases. After the algorithm for the Aquarius Version 5 release has been finalized, we need to make the retrieval algorithms for SMAP and Aquarius as consistent as possible. The correction for emission from land surfaces that is currently used in SMAP Version 2 needs to be improved. We also plan to include uncertainty estimates with all of the SMAP SSS retrievals.

SMAP has a much better filter for Radio Frequency Interference (RFI) than Aquarius or SMOS had. Nevertheless, likely intrusion of undetected RFI is observed in the Western Pacific near China, Korea and Japan and in the Gulf of Bengal, which manifests in fresh biases on the SMAP SSS in these regions. The RFI intrusion varies with looking direction. A mitigation for this undetected RFI can involve analyzing and comparing the SMAP SSS that are observed from different look directions.

Oleg Melnichenko: University of Hawaii, oleg@hawaii.edu
Presentation: Oral

The vertical structure of eddy freshwater transport inferred from satellite observations and Argo profile data

Satellite observations and Argo profile data are used to investigate the vertical structure of meridional eddy freshwater transport in the interiors of the subtropical gyres. To overcome limitations arising from the relative sparseness of in-situ profile data, an eddy composite analysis is utilized; namely, the mean vertical structure of mesoscale eddies and their transport properties are evaluated by synthesizing all available data in the framework of the eddy tracking technique.

In each of the five subtropical gyres, the role of mesoscale eddies is to pump freshwater into the gyre: the transport is poleward on the equatorward side of the gyre and equatorward on the poleward side. There are marked differences between the oceans, however. For example, in the North Pacific, North Atlantic, and the South Indian Ocean, the eddy freshwater transport is equally important on both sides of the gyre, while in the South Pacific and the South Atlantic the poleward side dominates. There, the role of eddies is not only to pump freshwater into the gyre but also to push the gyre center (determined as the SSS-maximum) equatorward.
In the vertical, the eddy freshwater transport is largely confined to the upper 200 m of the water column. Exceptions are in the South Indian Ocean, where the eddy flux penetrates as deep as 400 m depth, closely following the subsurface “river of salt”, and along the major oceanic fronts such as the Azores Current in the Atlantic and the Kuroshio extension in the Pacific. Relatively strong fluxes at depth are also observed in the subtropical North Atlantic at the level of the Mediterranean Water (MW) at around 1000 m depth, exemplifying the role of eddies in MW spreading. In the surface mixed layer, a good correspondence is found between the transport estimates made from the Argo profile data and from completely independent satellite SSS data, adding confidence to our results.

Viviane Menezes: Woods Hole Oceanographic Institution, vmenezes@whoi.edu
Presentation: Oral

Dynamics of the Sea Surface Salinity Maximum Pool in the Indian Ocean

Subtropical salinity maximum regions are particularly important because the salty subtropical underwater (STW) is formed by subduction of surface waters in these areas. In all oceans, the STW is transported equatorward from the formation region and are tightly related to the Subtropical-Tropical Cell. In the South Indian Ocean (SIO), the salinity maximum is further poleward (25S-38S) and eastward (60E-120E) compared to those in other oceans, and significantly impacts the circulation of the eastern basin. The STW forms a strong haline front with the fresh Indonesian Throughflow waters. This haline front overwhelms the temperature contribution to density gradients and establishes the eastward Eastern Gyral Current, an important upstream source for the Leeuwin Current. In the present work, we analyze the variability of the Sea Surface Salinity (SSS) maximum using multi-source datasets. These datasets include Aquarius, SMAP and SMOS satellite data, an Argo-based gridded product and the ECCO Ocean State Estimate v.4. The SIO salinity maximum pool is characterized by a strong oscillatory seasonal cycle of contraction and expansion. The pool reaches minimum area in October and maximum in April. Most of this seasonal oscillatory pattern occurs in the poleward side of the pool, with oceanic processes (advection and entrainment) controlling the contraction phase. From 2004 to 2014 a clear reduction in the pool area is identified in Argo data, mostly due to a freshening in the equatorward side of the pool. To get a better understanding of interannual to decadal variations in the pool area, ECCO outputs are presently being analyzed.

Sidharth Misra: California Institute of Technology, sidharth.misra@jpl.nasa.gov
Presentation: Oral

Enabling the Next Generation of Salinity, Sea Surface Temperature and Wind Measurements from Space: Instrument Challenges

NASA's Aquarius mission demonstrated the capability of space-borne microwave active and passive sensors to successfully measure sea-surface salinity at a very high precision. The Aquarius mission had a scatterometer at 1.2 GHz and radiometer operating at 1.4 GHz. The Aquarius radiometer operation was within a narrow protected bandwidth of 24 MHz that limited the radiometer noise performance, reduced sensitivity to cold-water salinity retrievals and prevented concurrent retrievals of SST and WS. In order to mitigate these limitations the spectrum of operation of the microwave sensors need to be expanded to lower frequencies such as 500 MHz, with continuous coverage up to 1.5 GHz.

In order to achieve the state objectives there are unique instrument design challenges that need to be addressed. The first challenge is developing a continuous ultra-wideband radiometer in order to be sensitive to different oceanographic geophysical phenomenon and be sensitive to cold-water salinity at lower frequencies. This involves a wideband digital backend capable of ingesting >1GHz bandwidth, RF electronics and wideband antenna. The second challenge is the instrument's ability to perform on-board radio frequency interference (RFI) detection and mitigation. Even though the measurements are made over the ocean, most of it is made in an unprotected spectrum, requiring an advanced RFI mitigation capability. The instrument also presents a unique challenge of integrating an active radar spectrum allocation within the passive radiometer bandwidth requiring a common radar/radiometer receiver chain. The final challenge is developing an antenna system capable of covering the band required at a high gain.

In this presentation we will discuss a JPL developed prototype active/passive microwave sensor airborne instrument that currently operates from 500 MHz to 1.5 GHz with a fully polarimetric digital backend and on-board RFI detection and mitigation capabilities as well as an integrated active channel for surface roughness correction. We will present the instrument architecture, instrument performance and test measurements that can validate and enable the next generation of physical oceanographic measurements from space.

Estrella Olmedo: Institute of Marine Sciences, olmedo@icm.csic.es
Presentation: Oral

Improvements in SMOS SSS: retrieval in marginal seas, coastal areas and river discharges

The Soil Moisture and Ocean Salinity (SMOS) mission provides a unique remote sensing capability for observing key variables of the hydrological cycle, and particularly Sea Surface Salinity (SSS). However, estimating SSS in coastal regions is still a challenging task, mainly due to the presence of Radio Frequency Interferences and Land-sea contamination.

Recently developed image reconstruction algorithms [1,2] have proven to reduce the impact of riples and tails on Brightness Temperatures . This reduction has led to a decrease of the noise in the SSS retrievals almost a factor 2. On the other hand, the combination of image reconstruction techniques with improved calibration methods [3] results in a strong mitigation of the Land-sea contamination biases [4].

Besides, non-Bayesian retrieval [5] has allowed improving the filtering criteria and empirically removing systematic biases, which has allowed to obtain SMOS SSS in regions where until now there were few or almost no valid data.

All together has opened new oceanographic oportunities, such as monitoring SSS in marginal seas like the Mediterranean [6] and the Black Sea, and also the study of coastal dynamics and fresh water discharges from rivers.

In this talk we will summarize the main ideas of these advanced processing methods and we will illustrate their improvements showing the performances in marginal seas and coastal areas.

Aaron Paget: University of Connecticut, aaroncpaget@gmail.com
Presentation: Oral

Evaluating the role of seasonal freshwater flux variability on the anomalous 2016 seasonal freshening of ocean surface water in the SPURS-2 region

The upper ocean waters in the SPURS-2 region undergo an annual cycle of seasonal freshening. From 2011 through 2015, the annual range of these variations was from 33 to 35 PSU; however, during 2016 the range extended from 31 to 34 PSU. In particular, the October and November of 2016 are fresher than the previous years, and, even more striking, the salinity values during that period are nearly 1 PSU fresher than the previous years. This freshening is confirmed by Argo floats, the SPURS-2 Buoy, and SMAP observations. The goal of this work is to understand the reasons for this increased freshening in 2016.

Contributing factors to the variations in the salinity come from precipitation, evaporation, mixing, and advection. The role of each of these contributing factors in this event are discussed, using a combination of satellite, reanalysis, and in situ data.
Sea surface salinity (SSS) observations from satellites are available from Aquarius, SMAP, and SMOS. The NASA Aquarius/SAC-D mission was developed with the goal of measuring sea surface salinity (SSS) with the Aquarius instrument on the SAC-D satellite observatory platform. Aquarius launched in 2011 and provided data from August 2011 – May 2015 (shown from 2013). The Aquarius L3 data are a weekly SSS product on a 0.25° x 0.25° grid and are available from NASA JPL PO.DAAC. Satellite-based SSS observations are also produced by the NASA Soil Moisture Active Passive (SMAP) instruments with data as an 8-day running mean of SSS starting in April 2015 on a 0.25° x 0.25° grid and are available from NASA JPL PO.DAAC. The European Space Agency (ESA) Soil Moisture and Ocean Salinity (SMOS) provides SSS observations starting in January 2010.

In situ data comes from the Argo floats and from the SPURS-2 Buoy. The Argo float data comes as a 10-day value for the mixed layer salinity gridded globally and are available from the Japan Argo Delayed-mode Data Base (Argo JAMSTEC, JAMSTEC.GO.JP/ARGO). For this analysis, periods without Argo floats near the SPURS-2 Buoy location are 2-D linearly interpolated from the surrounding Argo observations for the same date. The Argo data record covers the entire time period of available satellite observations. The SPURS-2 Buoy, located at 10 N, 125 W, provides a full suite of in situ observations of the ocean surface and near surface including SSS. Hourly values of SSS from the SPURS-2 Buoy are analyzed in this record starting late August 2016.

Morgan Paris: University of South Carolina, mparis@email.sc.edu
Presentation: Oral

Role of ENSO events on Salinity and Temperature Variability in the Agulhas Leakage Region

The Agulhas Current, a western boundary current, is a limb of the wind driven anti-cyclonic circulation of the south Indian Ocean. Near the tip of Africa, the current retroflects shedding warm saline waters into the Atlantic Ocean. This phenomenon, referred to Agulhas leakage, feeds the upper arm of the Atlantic Meridional Overturning Circulation. Fluctuations in this highly dynamic system impact the strength of overturning sequentially altering climate patterns. This study explores the relationship between small-scale fluctuations in sea surface salinity (SSS) and sea surface temperature (SST) of Agulhas leakage in response to ENSO events classified by the Oceanic Niño Index. In this study we used SSS derived from the multi-satellite missions, NASA's Aquarius/SAC-D, ESA's Soil Moisture and Ocean Salinity (SMOS), and NASA's Soil Moisture Active and Passive (SMAP), and SST derived from NOAA's AVHRR. Simple Ocean Data Assimilation (SODA) reanalysis 1960-present is used to study interannual and decadal variability of these fluctuations. It is predicted that there will be a connection between SSS and SST in which higher temperatures will be accompanied by higher salinity while cooler waters will be fresher. Combination of SSS observations with altimetry derived currents helped to better understand leakage process. Our findings suggest Agulhas retroflection sheds anomalously warm waters in response to El Niño and anomalously cool waters due to La Niña. Starting at the peak of an ENSO event the signal is transmitted at 12°S and 25°S from the Pacific Ocean into the Indian Ocean basin by Rossby waves. These waves travel westward until they reach Madagascar where they interact with source currents to complete the transfer of an ENSO signal into the Agulhas leakage region. The process occurs during a timescale spanning two years. Changes in the region of Agulhas leakage can be seen as early as 16 months after the peak of an ENSO event but the continued impact lasts no longer than 2 years following the event. The strength of an ENSO event and interactions with other events appear to affect the rate and strength of transmission of the ENSO signal to the point of Agulhas leakage.

Luc Rainville: University of Washington, rainville@apl.uw.edu
Presentation: Oral

Early Results from SPURS-2: multi-months timeseries of Salinity, Rain, and Turbulence from Autonomous Gliders

The SPURS-2 field program aims to understand the structure and variability of upper-ocean salinity in the Eastern Tropical Pacific Ocean over more than one complete annual cycle. Since their deployments in August 2016, Seagliders have resolved salinity, temperature, density, and their lateral gradients, in the top 1000 m of the water column on horizontal scales of 20 km and time scales on the order of the inertial period in the central SPURS-2 region. Shear and temperature microstructure sensors provide near real-time estimates of turbulence in the upper ocean for every dive. All SPURS-2 gliders are equipped with passive acoustic recorders, which will be used to infer rain rate and wind speed. In colse collaboration with the other SPURS PIs, we aim to understand how precipitation and atmospheric forcing act to govern the ITCZ upper ocean variability.

James Reagan: Earth Systems Science Interdisciplinary Center, james.reagan@noaa.gov
Presentation: Poster

Global and Regional Amplifications of Near-Surface Salinity Patterns from 1951-2014

Multiple studies have shown that since the mid-twentieth century salty regions of the ocean have become saltier and fresh regions fresher. These trends represent an amplification of the mean salinity pattern, which has been directly related to an amplification of the global hydrological cycle. Many studies that have linked changes in near-surface salinity patterns to changes in the hydrological cycle analyzed long-term (~50 years) salinity changes. However, the question remains whether or not changes in near-surface salinity over time periods less than 50 years can be used as an accurate proxy for estimating secular changes in the hydrological cycle. Does decadal to multi-decadal climate variability act to dampen and/or enhance salinity pattern amplifications? At what time period can other dominant terms of the mixed layer salinity budget, namely advection (Ekman and geostrophic) and vertical entrainment, be insignificant? To begin to address these questions we investigated salinity pattern amplifications, both globally and regionally, over time periods spanning 10 to 50 years. This study primarily utilized the National Centers for Environmental Information global pentadal (5-year) salinity anomaly fields from 1951 through 2014 derived from in situ data in the World Ocean Database. Additionally, a full error analysis was conducted that investigated the robustness of the salinity pattern amplifications by performing calculations with a range of starting pentads as well as taking a deeper look into the evolving salinity observation network since the 1950's and the potential impact that could have on this and other similar studies.

Nicolas Reul: IFREMER, nreul@ifremer.fr
Presentation: Oral

Seven years of ocean observation from SMOS: an overview

The Soil Moisture and Ocean Salinity (SMOS) mission, launched in November 2009, is the European Space Agency's (ESA) second Earth Explorer Opportunity mission. Significant progress has been made over the course of the now 7-year life time of the SMOS mission in improving the ESA provided level 1 brightness temperatures and level 2 soil moisture and sea surface salinity data products. The paper will provide an overview on the mission status and a performance assessment of the SMOS Sea Surface Salinity data products. The key scientific findings with a special emphasis on ocean salinity will be summarised.

Stephen Riser: University of Washington, riser@ocean.washington.edu
Presentation: Oral

Making Useful Salinity Measurements from Profiling Floats: Past, Present, and Future

The Argo program began in 1999 with the goal of making high quality, global observations of temperature and salinity in the upper 2000 m of the water column, but with little actual experience in measuring unattended salinity at the requisite accuracy and stability of 0.01 PSU over multi-year deployments. Yet within a few years such a measurement capability was developed, resulting from a strong collaboration between commercial manufacturers of sensor hardware and users in the research and academic communities. By 2011, the quantity of high-quality measurements made from such floats since the beginning of Argo exceeded the total number of temperature and salinity observations in the World Ocean Database collected in the entire 20th Century, allowing new inquiries into the relationship of climate change and the global hydrological cycle. In the coming decade it is hoped that these measurements will continue, with technological advancements in float hardware and salinity measurements opening important new areas of research.

Laura Ruiz Etcheverry: University of Hawaii at Manoa, laurare@hawaii.edu
Presentation: Oral

Climatology of salinity fronts in the Tropical Atlantic Ocean

Marine fronts are narrow boundaries that separate water masses of different properties. These fronts are caused by various forcings and believed to be an important component of the coupled ocean-atmosphere system, particularly in the tropical oceans. In this study, we use three years of sea surface salinity (SSS) observations from Aquarius satellite to investigate the spatial structure and temporal variability of six main frontal SSS features in the tropical Atlantic, their evolution between seasons and differences between individual years. Our results show that the strongest SSS fronts occur on edges of freshwater plumes from Amazon and Congo rivers. The patterns of the SSS gradients reveal a marked seasonal cycle, resulting in strong interaction between different fronts. Impacts of Aquarius SSS and Reynolds SST on variability of density gradients are also discussed. Insights into the dynamics of the fronts are obtained from analysis of vertical Argo profiles.

Roberto Sabia: European Space Agency, roberto.sabia@esa.int
Presentation: Oral

SMOS Pilot-Mission Exploitation Platform (Pi-MEP): Project overview

The SMOS Pilot Mission Exploitation Platform (Pi-MEP) for Salinity is a recent initiative to support and widen the uptake of ESA SMOS data over ocean. The Pi-MEP for Salinity has a twofold motivation:

i) To serve as an enhanced validation platform, complementing and expanding the efforts of the SMOS Expert Support Laboratories (ESLs) through, for example, exploring satellite performances at different spatial/temporal scales, applying different filtering criteria, or verifying SMOS outputs against various ground-truth data;

ii) To offer a testbed to enable oceanographic process studies in different domains, capitalizing on SMOS salinity data in synergy with additional satellite products (e.g., SST, WS, currents, rain estimates). The platform will offer a series of statistical and computational tools in a user-oriented scientific environment to foster an increased uptake of SMOS salinity data in combination with other relevant oceanographic parameters.

The project started in January 2017. The first task consists of consolidating the user requirements baseline, before proceeding to the technical design of the platform. In the subsequent period, the implementation and pre-operation phase will give way to the platform operations in mid-2018.

Instrumental to the activities of the SMOS Pi-MEP Salinity is a dedicated Scientific Advisory Group (SAG), which will provide valuable inputs to the scientific/industrial team in charge (led by IFREMER and OceanDataLab). The SAG inputs will allow to set up this platform by helping to define the requirements of the user community and by providing scientific expertise and advice. The SAG will also serve as super-user of the platform functionalities before the opening to the wider oceanographic community.

A SAG one-day workshop is currently foreseen for May 3rd, 2017 at ESA-ESTEC premises in Noordwijk, the Netherlands. A second SAG meeting is foreseen at the beginning of 2018 to follow-up Pi-MEP activities.
This paper will summarize the core elements and objectives of this project and will report on the feedback gathered at the first SAG workshop, concerning both scientific advice and also insights into the technical design and functionalities of the platform.

Julian Schanze: Earth & Space Research, jschanze@esr.org
Presentation: Oral

Sources and Sinks of the Global Water Cycle

Though a very large water cycle occurs over the oceans, with a total evaporation of ~13 Sv, much of the water is locally recycled due to the short residence time of atmospheric moisture (~10 days). Here we focus on the net export or import of water from different climatological regimes based on best estimates of evaporation-precipitation (E-P), and explore the relationships in the framework of surface temperature, salinity, density, and spiciness. Both evaporation and precipitation are enhanced at high surface temperatures, with the enhancement being larger for evaporation. The subtropical high pressure systems are identified as the overall source of atmospheric water, exporting a net of 4.5 Sv to other parts of the climate system. The major oceanic sinks for water are the ITCZ, which takes in about 1.2 Sv and the subpolar gyres, which take in about 1.7 Sv. An additional 1.5 Sv is transported onto land, where it also experiences much local recycling. To illustrate this, we further separate these components by the major ocean basins.

The net export or import of water of course has direct consequences for ocean salinity, with the subtropical highs experiencing high salinity, the ITCZ and subpolar gyres having low salinity. Such net exports of water also represent large transfers of latent heat energy. That is, when E-P > 0, there is a significant export of energy from the region, when E=P there is no export of water and only a local energy supply to the atmosphere, and when E-P<0 there is a net import of both water and latent heat energy. Latent heat fluxes are generally at least an order of magnitude larger than sensible heat fluxes and represent the major mode of energy transfer from ocean to atmosphere. Thus, there are significant climatological consequences of the processes affecting the net E-P in the subtropical high pressures systems. This helps to explain the recently discovered teleconnections between seasonal sea surface salinity variations and rainfall on land. E-P is a measure of net export or import of water and energy and the concomitant salinity changes provide a direct record of their variability and are thus a key indicator of the climate system.

Ray Schmitt: Woods Hole Oceanographic Institution, rschmitt@whoi.edu
Presentation: Oral

Remote Salinity Predictors of Terrestrial Rainfall

We have discovered that sea surface salinity (SSS) is a better seasonal predictor of terrestrial rainfall than sea surface temperature (SST) or the usual pressure modes of atmospheric variability. In many regions, a 3-6 month lead of SSS over rainfall on land can be seen. While some lead is guaranteed due to the simple conservation of water and salt, the robust seasonal lead for SSS in some places is truly remarkable, often besting traditional SST and pressure predictors by a very significant margin. One mechanism for the lead has been identified in the recycling of water on land through soil moisture in regional ocean to land moisture transfers (Li *et al*, 2016a, __, 2016b). However, a global search has yielded surprising long-range SSS-rainfall teleconnections for other areas. It is suggested that these teleconnections indicate a marked sensitivity of the atmosphere to where rain falls on the ocean. That is, the latent heat of evaporation is by far the largest energy transfer from ocean to atmosphere and where the atmosphere cashes in this energy in the form of precipitation is well recorded in SSS. SSS also responds to wind driven advection and mixing. Thus, SSS appears to be a robust indicator of atmospheric energetics and moisture transport and the timing and location of rainfall events is suggested to influence the subsequent evolution of the atmospheric circulation possibly through the generation of Rossby waves. In a sense, if the fall of a rain drop is at least equivalent to the flap of a butterfly's wings, the influence of a billion butterfly rainstorm allows for systematic predictions beyond the chaotic nature of the turbulent atmosphere. SSS is found to be particularly effective in predicting extreme precipitation or droughts (Li, *et al,* 2017), which makes its continued monitoring very important for building societal resilience against natural disasters.

Meike Sena Martins: University of Hamburg, meike.sena-martins@uni-hamburg.de
Presentation: Poster

Salinity from SMOS, comparison of bias corrected data products

Ocean salinity can be monitored by the ESA satellite SMOS since 7 years now and better retrieval algorithms lead to better data quality over this time. However, several caveats are still present in the data, the most prominent bias occurring especially due to land and ice contamination reaching 1000 km far off the coasts and ice edges. Therefore, the SMOS salinity maps have to be bias corrected. Several attempts have been carried out with slightly different approaches, however, in situ salinity fields have to be used for the correction, though in situ data are sparse and discontinuous. All data products ameliorate in terms of global means and statistics in comparison to the in situ salinity fields. Nevertheless, the data products differ in the remaining salinity variability and the performance of salinity bias correction. Here, an overview is given about the different data sets, and where they still differ from the in situ salinity fields. First analysis show that the subtropical salinity maxima are pictured by the different products with different mean salinity maxima and annual amplitudes, reflecting the uncertainty of the satellite derived salinity fields.

Andrey Shcherbina: University of Washington, ashcherbina@apl.uw.edu
Presentation: Oral

Multi-platform Lagrangian observation of ocean boundary layer shear and stratification during SPURS-2

During the first part of SPURS-2 experiment, a cluster of autonomous instruments was deployed for a 100-day 1,800-km coordinated quasi-Lagrangian drift through the North Pacific intertropical convergence zone (ITCZ). A total of 25 instruments participated in the drift during various stages of the experiment: a WHOI Wave Glider, an APL Seaglider, an APL Lagrangian float, a UW Profiling APEX float, 3 AOML Salinity drifters, and 18 SIO SVP(-S) drifters. The cluster conducted multi-platform observations of the ocean surface boundary layer structure and dynamics in a quasi-Lagrangian frame of reference minimizing the effects of horizontal advection. We will present preliminary results of this coordinated study, focusing on the evolution of upper-ocean stratification and shear in response to storm-induced rainfall and wind bursts.

Shikha Singh: Indian Institute of Tropical Meteorology, 08.singhshikha@gmail.com
Presentation: Oral

Possible role of subsurface ocean biases in climate models in the simulated interannual variability

Analysis for the possible impacts of deep ocean biases in temperature and salinity on the large scale air sea interaction in the state of the art coupled models has been investigated. Two coupled models (CFSv2 and IITM-Earth System Model) and outputs from selected CMIP-5 models are analyzed. CFSv2 is a coupled ocean atmosphere model by NCEP and is the core-part of the IITM-ESM. The CFSv2, IITM-ESM and candidates of CMIP-5 develop internal warm bias in the ocean (approximately 100-800m) in long term simulations. We believe that these internal biases could have implications in large scale ocean dynamics via its possible linkage to the baroclinicity of the ocean and subsequent interannual variability (eg: Indian Ocean Dipole & El-Niño Southern Oscillation). The possible role of internal biases in ocean dynamics is hypothesized using the relation between the Brunt-Väisälä frequency and baroclinic wave speeds using Sturm-Liouville equations and WKB approximations. The results indicate that the models analyzed here have a higher baroclinic speed compared to the observations. An examination of the annual propagating modes in the Indian Ocean suggests that the phase reversal in the models is taking place at a lead or a lag by a month or more as compared to the observations. This phase shift may be attributed to various reasons, one of them being the subsurface biases. Further, sensitivity studies based on a simple coupled ocean atmosphere model indicate that the evolutions of large scale events (for example ENSO) are highly dependent on the dominant baroclinic speeds and its bias. Thus the study suggests that the faster wave dispersions in climate models have a potential to affect the simulated planetary scale events such as IOD or ENSO in terms of their life cycle, periodicity and seasonality.

Gualtiero Spiro Jaeger: Woods Hole Oceanographic Institution, gvsj@mit.edu
Presentation: Oral

Layering of the pycnocline: spice and stratification in the Bay of Bengal

Salinity in the northern Indian Ocean is marked by the contrast of very salty Arabian Sea and very fresh Bay of Bengal water, associated gradients are both an active driver of density-driven flows and a useful tracer of the circulation. Recent observations in the Bay of Bengal (ASIRI cruises) paint a rich picture of the upper ~100m of the ocean, with two distinct water-masses revealing the effect of eddies and internal waves stirring and straining the strongly stratified pycnocline. Sections of b_z (vertical gradient of buoyancy) show distinctly layered bands coherent over 10's of kilometers with a thickness ~10m. Simultaneously, sections of a tracer (isopycnal spice) show the same thin layers, with a steady coherence between spice and b_z. While internal waves are expected to create bands in b_z (due to vertical strain), and isopycnal stirring by sheared geostrophic currents is expected to create thin spice layers, the mechanism coherently creating both is unclear. We present an analysis of observations of such layering, and proposed mechanisms responsible for it, with the help of numerical models of several spice-buoyancy fronts. Knowing what type of dynamics creates the observed layering can give insight into both the prevalence of this dynamic, and the process of isopycnal mixing or vertical re-stratification.

Janet Sprintall: Scripps Institution of Oceanography, jsprintall@ucsd.edu
Presentation: Poster

Upper Ocean Variability during the SPURS-2 Field Campaign under the ITCZ

A major goal as part of the SPURS-2 field campaign is to understand the characteristics and variability of the upper ocean salinity stratification in the vicinity of the ITCZ and identify the main mechanisms that are responsible for this variability. Our contribution focused on the “mesoscale” box (10-300 km) spatial scale, undertaking upper ocean stratification and velocity measurements that will help provide some regional context for the nested small-scale and single-point moored measurements. In all, we completed 50 CTD-O2/LADCP stations and 260 uCTD stations during the SPURS-2 cruise in August-September 2016. Salt-stratified barrier layers were observed during the cruise where the warm layer extends deeper than the fresh surface layer. Their formation mechanism in the eastern Pacific is not as yet clear but likely candidates include rainfall and advective processes (current shear and S-gradients). Other stratification profiles were characterized by very thick (>20 m) temperature inversions occurring at the base of the isohaline layer. These temperature-inversions appeared to be ubiquitous at the base of the fresh pools in the halocline, especially in the vicinity of strong fronts. It is as yet unknown if these are transient features or indeed what their time scales might be. Numerous mechanisms might be responsible for their formation including wind forced advection of cold water over warm water; net heat loss at the sea surface; advection of cold less saline water over warm saline water; fronts; and water mass interleaving.

Paul Spurgeon: ARGANS Limited, paul.spurgeon@argans.co.uk
Presentation: Poster

Eight years of Ocean Salinity from SMOS: selecting data

The new recently reprocessed SMOS data set of 8 years of ocean salinity (mid-2010 to mid-2017) is now available, with a number of significant improvements to data quality including better retrievals at high wind speeds, bias correction near to land, enhanced contamination filtering, a new sun glint model, and an experimental anomaly product. This reprocessing used the new Level 2 Ocean Salinity processor v662, and will continue to be used for the next 2 years, providing a unique 10 year continuous data set of sea surface salinity for oceanographers. This poster will describe the new salinity products, optimal criteria for user selection of high quality data, sources of contamination and how to avoid them, observed seasonal variations, long-term trends, and remaining biases.

Detlef Stammer: Universität Hamburg, detlef.stammer@uni-hamburg.de
Presentation: Oral

Dynamical Ocean Response to Projected Changes of the Global Water Cycle

Change in the global ocean will occur over the next century as a consequence of the acceleration of the hydrological cycle and the associated surface net freshwater fluxes under global warming. The paper is concerned with the dynamical response to those projected surface volume flux anomalies. Based on ocean model runs driven by RCP8.5 surface freshwater flux anomalies over the period 2081-2100 relative to 1986-2005, we show that the adjustment of the circulation involves a barotropic circulation as predicted from the Goldsbrough-Stommel theory. The corresponding barotropic circulation intensifies by approximately 20% with a stronger intensification of about 50% in the southern ocean. The barotropic circulation anomaly induced by intensified freshwater flux reaches to 0.6 Sv in the ACC region. The adjustment also involves changes in the meridional overturning circulation mirroring the basin-wide averages of changes in the convergence and divergence of the mass transport driven by the surface freshwater flux. The subsequent pathways of fresh water match with the spreading of volume flux in the shallow cells but diverge substantially with depth. Associated with changes of the flow field are changes in meridional heat and fresh water transports. Associated with the change in the circulation is also a response in temperature and salinity based on which a significant contribution to the regional sea level changes results in form of steric change. These changes can be largely attributed to the displacement of the isopycnals. The typical amplitude of sea level changes to the projected freshwater flux anomalies is of the order of 1/2 cm.

Alexandre Supply: Laboratoire d'Océanographie et du Climat, alexandre.supply@locean.upmc.fr
Presentation: Oral

Precipitation Estimates and L-Band Sea Surface Salinity (PEALS)

Two L-Band (1.4 GHz) microwave radiometer missions, SMOS (Soil Moisture and Ocean Salinity) and SMAP (Soil Moisture Active and Passive) currently provide Sea Surface Salinity (SSS) measurements from space. At this frequency, salinity is measured in the first centimeter below the sea surface, which makes it very sensitive to the presence of fresh lenses linked to rain events. A relationship between salinity anomaly (DS) and rain rate (RR) is derived in the Pacific Inter Tropical Convergence Zone based on SMOS SSS measurements and space-borne RRs from the Special Sensor Microwave Imager/Sounder (SSMIS) provided by Integrated MultisatellitE Retrievals for GPM (IMERG) that also provided rain merged product combining various instruments. The relationship is then used to provide an algorithm estimating RRs from SMOS SSS measurements. A heuristic corrective function is developed to correct the unphysical SMOS-estimated negative RR due to measurement noise. The correlation between SMOS and SSMIS RR and between SMOS and IMERG RR are both high when SMOS and SSMIS passes are less than 15min apart (r=0.7 at 1°x1° resolution), showing a good capability of SMOS to retrieve RR estimates. The RR retrieval is also successfully tested on SMAP SSS. As the time-lag between SMOS and SSMIS increases, the correlation between SMOS and IMERG RR diminishes. This suggests that L-band radiometry can provide information that could complement GPM missions in order to improve high temporal resolution interpolated RR products. The capacity of the algorithm to provide reliable RR estimates when averaged monthly is also shown.

R. Dwi Susanto: University of Maryland, dwisusa@umd.edu
Presentation: Oral

Comparisons of Seasonal Variability of Satellite Sea Surface Salinity and In Situ Measurements in the Karimata Strait, Indonesia

This study compares seasonal variability of satellite-derived sea surface salinity (SSS) and sea surface temperature (SST) with in situ measurements in the Karimata Strait, Indonesia, from November 2010 to June 2016. Karimata Strait flow is strongly affected by the Asia-Australia monsoon. During the boreal winter monsoon, northwesterly winds draw low salinity water from the South China Sea (SCS) into the Java Sea and at the same time, the Java Sea receives an influx of the Indian Ocean water via the Sunda Strait. Conditions are reversed during the summer monsoon. The SCS low salinity water also affects a vertical structure of water properties in the main ITF. It is desirable to have long-term salinity measurements or satellite salinity data as a proxy. The amplitude and phase of the Soil Moisture Active and Passive (SMAP) satellite salinity match field measurements well. Interannual variability of SSS and SST is remarkable. However, there is no apparent direct relation to the ENSO or the Indian Ocean Dipole events.

Wenqing Tang: Jet Propulsion Laboratory, Wenqing.Tang@jpl.nasa.gov
Presentation: Oral

Validating SMAP SSS with in SITU Measurements

Sea surface salinity (SSS) retrieved from SMAP radiometer measurements is validated with in situ salinity measurements collected from Argo floats, tropical moored buoys and ship-based thermosalinograph (TSG) data. SMAP SSS achieved accuracy of 0.2 PSU on a monthly basis in comparison with Argo gridded data in the tropics and mid-latitudes. In tropical oceans, time series comparison of salinity measured at 1 m by moored buoys indicates that SMAP can track large salinity changes occurred within a month. Synergetic analysis of SMAP, SMOS and Argo data allows us to identify and exclude erroneous jumps or drift in some real-time buoy data from assessment of satellite retrieval. The resulting SMAP-buoy matchup analysis leads to an average standard deviation of 0.22 PSU and correlation coefficient of 0.73 on weekly scale; the average standard deviation reduced to 0.17 PSU and the correlation improved to 0.8 on monthly scale. SMAP L3 daily maps reveals salty water intrusion from the Arabian Sea into the Bay of Bengal during the Indian summer monsoon, consistent with the daily measurements collected from floats deployed during the Bay of Bengal Boundary Layer Experiment (BoBBLE) project field campaign. In the Mediterranean Sea, the spatial pattern of SSS from SMAP is confirmed by the ship-based TSG data.

Elizabeth Thompson: University of Washington, eliz@apl.uw.edu
Presentation: Oral

Predictability of tropical freshwater lenses due to convective and stratiform rain during SPURS-2

This study seeks to understand the impact of convective and stratiform rainfall on salinity stratification observed during the 2016 SPURS-2 experiment. Previous observational studies have demonstrated a wind-speed-dependent correlation between in-situ salinity stratification and maximum rain rate. However, questions remain about the temporal lag between the maximum rain rate and evolution of the freshwater lens, and how rain intensity impacts the lifetime of a freshwater lens. Radar and disdrometer measurements have shown that a majority of local rain accumulation variability can be explained by differences in rain intensity, spatial heterogeneity, and drop size distributions between stratiform and convective precipitation features. The frequency and predictability of stratiform and convective precipitation has been addressed in numerous previous studies. However, observations are still needed to understand whether convective or stratiform rain elements are more efficient in creating and maintaining freshwater lenses, and what that may imply about tropical freshwater lens frequency, duration, and predictability.

To address these questions about freshwater lenses, we have analyzed oceanic and atmospheric data from the 2016 SPURS-2 field campaign in the tropical eastern Pacific. Specifically, we consider wind speed (ship-based and reanalysis), raindrop size distribution (ship-based disdrometer), rain rate/accumulation/spatial extent (satellite, ship-based gauge, and ship-based marine navigation radar), and in-situ ship-based salinity profiles in the upper 5 m. Using ship-based data, we estimate both the overall probability that a freshwater lens will form, and also its lifetime, following a convective or stratiform rain event. After comparing ship-, reanalysis-, and satellite-based wind and rain estimates, freshwater lens probabilities are recalculated using these routinely available global datasets.

Corinne Trott: University of South Carolina, ctrott@seoe.sc.edu
Presentation: Oral

Interannual and Decadal basin-scale exchange of fresh and salt water in the Northern Indian ocean

The Indian Ocean shows significant variability in the distribution of Sea Surface Salinity (SSS), especially in the Arabian Sea (AS) and Bay of Bengal (BoB) in association with seasonal climate variations. The seasonal reversal of monsoon winds and the differences in precipitation (P), evaporation (E) and river runoff (R) make the BoB a net precipitation basin and the AS a net evaporative basin. Also the northern Indian Ocean shows larger SSS variability than the Southern Indian Ocean. Also, high salinity waters from the Persian Gulf and Red Sea circulate at subsurface and intermediate depth ranges as high salinity water masses in the AS and BoB. In order to balance the salt and mass, there is a need for exchange between these northern basins. The dynamics of ocean salt distribution is quite complicated. On annual time scale, there is a considerable exchange of salt from one basin to the other. However, the pathways of these high salinity waters are speculated only through watermass analysis using the hydrographic data, and the limits of extent of high salinity waters from one basin to the other are not yet clearly delineated. This research work address the role of surface salinity from satellite measurements of Aquarius, SMOS, and SMAP, Argo floats, and model simulations from Hybrid Coordination Ocean Model (HYCOM), German Estimating the Circulation and Climate of the Ocean version 2 (GECCO2), and Simple Ocean Data Assimilation (SODA) re-analysis. The dominant spatial and temporal patterns of fresh and salt water fluxes are identified using satellite derived salinity and depth integrated transports using hydrographic observations, HYCOM simulations and SODA re-analysis. As such the response of ocean circulation to varying mean salinity needs to be investigated on the long term. Understanding salt transport (and by inference freshwater transport) especially on a long-term basis is important for climate modeling as it affect sensitivities.

Vardis Tsontos: Jet Propulsion Laboratory, vardis.m.tsontos@jpl.nasa.gov
Presentation: Poster
(Tony Lee will present)

Tools, Services and Support of NASA Salinity Mission Data Archival and Distribution through the PO.DAAC

The Physical Oceanography Distributed Active Center (PO.DAAC) serves as the designated NASA repository and distribution node for all Aquarius/SAC-D and SMAP sea surface salinity (SSS) mission data products in close collaboration with the projects. In addition to these official mission products, PO.DAAC archives and distributes high-value, principal investigator led satellite SSS products, and also datasets from NASA's "Salinity Processes in the Upper Ocean Regional Study" (SPURS 1 & 2) field campaigns in the N. Atlantic salinity maximum and high rainfall E. Tropical Pacific regions. Here we report on the status of these data holdings at PO.DAAC, and the range of data services and access tools that we provide in support of NASA salinity. These include user support and data discovery services, OPeNDAP and THREDDS web services for subsetting/extraction, and visualization via LAS and SOTO. Emphasis is placed on newer capabilities, including PODAAC's advanced L2 subsetting tool called HITIDE and a generalized satellite-in situ data collocation service (DOMS) that is under development.

Antonio Turiel: Barcelona Expert Center, turiel@icm.csic.es
Presentation: Oral

Analyzing the balance equation of SSS using SMOS data

The introduction of the advanced SMOS Sea Surface Salinity (SSS) products distributed by the Barcelona Expert Center (BEC) has enabled a more detailed analysis of the dynamics of SSS, with improved time and spatial resolutions and at regions where remote observation was so far impossible. This improvement has rendered possible to analyze the evolution of SSS in detail, assessing the relative importance of the terms contributing to its evolution equation.

Three kinds of contribution to the balance equation of SSS have been analysed: the transport term (advection), the dispersive term (diffusion), and the forcing term (interaction with atmosphere and land masses). By combining BEC SSS products with other satellite products, each term has been isolated, quantifying its magnitude and compared to known estimates.

Sea Surface Currents provided by OSCAR have been used to compute the advective contribution and so evaluate the first term, assessing the overall conservation of salt in the most superficial layers of the ocean. This allows to establish an overall balance between horizontal salt diffusion, that tend to destroy salinity gradients, and the sources of salinity variability, associated to evaporation, precipitation, river runoff and up- and down- welling, that tend to create salinity gradients.

A good correlation between evaporation, precipitation and river runoff and the partial time derivative of SSS has been observed. For example, in the Indian Ocean, strong positive derivatives are found just before strong episodes of rain (in summer and monsoon seasons) and coastal salty-fresh phases are observed in the post-monsoon season, when river discharges are still present but strong dry Himalaya winds flows to the southwest of the country.

The average horizontal turbulent diffusivity of salt has been also evaluated by a direct comparison with the diffusive term. Although computing horizontal diffusivity at different scales is difficult given SMOS spatial resolution, a first estimate of the related scaling exponent has been obtained.

Nadya Vinogradova: Cambridge Climate Institute, nadya@camclimate.org
Presentation: Oral

Surface freshening and salinification — decadal fluctuations versus secular trends

In recent decades, noticeable decadal salinity trends have emerged at the ocean surface, reflecting the changes in the ocean water cycle, strength of the ocean circulation, and changes in the ocean transports of salt. A number of potential causes for the observed changes have been suggested, including those related to anthropogenic aerosol forcing as well as natural climate fluctuations. Here we explore how the recent decadal salinity trends fit into the long-term picture, focusing on those ocean regions where the decadal changes oppose the long-term trends. For such regions, we estimate the likelihood of “unusual” decadal salinity changes in the context of the historical record, contemporary estimates, and future projections. The analysis is based on a large suite of salinity estimates, including data from the modern satellite salinity observations missions, multi-decadal historical in situ observations, ocean model/data synthesis, and centennial realizations from global climate models. We test a hypothesis that under the influence of internal variability the likelihood of strong salinification (or freshening, depending on a region) is plausible in the presence of an opposing secular trend due to anthropogenic forcing. Computed probabilities that are close to zero indicate that the internal variability is negligible compared to the background trend. Alternatively, if the internal variability is large and the background trend is negligible, the chance for a decadal salinity trend of an opposite sign is random, with probability around 0.5. For example, we find that the chance of occurrence of the strong decadal salinification recently observed in the subpolar North Atlantic, despite an increase in freshwater supply and long-term freshening, is about 0.1 — a plausible, although rare, event. Finally, contrasting changes in salinity with those in freshwater fluxes, our findings suggest that the time of emergence for anthropogenic trends in the ocean water cycle might be substantially earlier than that for surface salinity. In particular, for the ocean water cycle twenty years might be sufficient for the anthropogenic signals to rise above the “noise” level of natural variability.

Nadya Vinogradova: Cambridge Climate Institute, nadya@camclimate.org
Presentation: Oral

Synergistic use of satellite and in situ observations for production of new, multi-platform salinity estimate for climate research

The modern salinity observing system includes an expansive network of in situ and space-borne measurements. Today, salinity data from multiple sources, such as automated Argo profiles, repeat hydrographic section sampling, and satellite observations from Aquarius, SMOS, and SMAP, provide a multi-platform estimate of near-global salinity fields. Reconciling salinity estimates from these different platforms into a coherent picture is one of the objectives of the NASA Ocean Salinity Science Team and the Satellite & In Situ Salinity (SISS) working group. Here we introduce a new salinity estimate based on the synthesis of information from various sources over the 1992-2015 period. The salinity estimate is based on the latest release of the ECCO ocean state estimate (v4 Release 3) and reconciles salinity information from multiple platforms, including satellite observations from Aquarius and in situ data from Argo, CTD, and ITP (ice-tethered profilers). The resulting estimate is close to the observations within data uncertainties that are estimated a priori for each dataset. An important advantage of this new salinity estimate with respect to common ocean reanalyses (e.g., ECMWF ORA-family, SODA, etc.) is the physical consistency among the resulting salinity fields, corresponding ocean transports of salt, and exchange of freshwater within the land-ocean-atmosphere system via processes of evaporation, precipitation, run off, and sea-ice dynamics. The fit and dynamical consistency of the solution is achieved by virtue of optimized atmospheric forcing fields and oceanic turbulent transport parameters within the ECCO framework. We discuss main characteristics of the produced salinity estimates, place it in the context of other existing salinity estimates, and assess the value of satellite salinity versus in situ measurements in terms of their ability to improve the end-product ocean synthesis.

Zhankun Wang: National Oceanic and Atmospheric Administration, zhankun.wang@noaa.gov
Presentation: Poster

In-situ sea surface salinity and temperature observations from the NCEI Global Thermosalinograph Dataset (NCEI-TSG)

The newly developed NCEI Thermosalinograph Dataset (NCEI-TSG) is the world's most extensive collection of uniformly-formatted, quality-controlled, thermosalinograph (TSG) data available without restriction. TSG data are in-situ high resolution measurements of sea surface salinity (SSS) and temperature (SST) from ships. Measurements of other oceanographic variables, such as oxygen, chlorophyll etc are often measured concurrently with sea surface salinity and temperature and included in the dataset. The NCEI-TSG contains observations of TSG from more than 330 ships from 1989 to present. Compared to other datasets, the NCEI-TSG has several advantages: 1) It is the most complete TSG dataset, containing all data from the major TSG data assembly centers with more historical data from NCEI's archive to be added. 2) When different versions of a dataset are available, the dataset with the highest resolution is always chosen. 3) All data are converted to common netCDF4 format, following Climate and Forecast (CF) and Attribute Convention for Data Discovery (ACDD) conventions. 4) All data are processed using the same 11-step quality control procedures and criteria and flagged using a two-level flag system to provide a well-organized, uniformly quality-controlled TSG dataset for the user community. The NCEI-TSG servers as a significant resource for establishing match-ups with satellite SSS and SST observations for validation and comparisons. It will significantly contribute to the in situ component of the NOAA Satellite SSS Quality Monitor (4SQM) project (under development). This dataset facilitates assessments of global SST and SSS variability and the analysis of patterns and trends at various regional and temporal scales, enabling new insights in climate change, the global water cycle, air-sea interaction, etc. The NCEI-TSG database is freely accessible via the NCEI thredds server (https://data.nodc.noaa.gov/thredds/catalog/ncei/tsg/) and will be maintained with newly received TSG data, as well as further expanded with more historical data from NCEI archive.

Oliver Wurl: University of Oldenburg, oliver.wurl@uni-oldenburg.de
Presentation: Oral

Skin Surface Salinity: First in situ measurements in the tropical Ocean

With recent scientific and technological advancements, the sea surface is pushed into the global extent of biogeochemical processes and climate regulation, and here we report the first field data of the ocean's skin surface salinity and compelling evidence that the sea surface is a highly dynamic interfacial boundary layer. We observed salinity anomalies with a mean difference of $\Delta S = 0.250 \pm 0.494$ PSU (practical salinity unit) at the surface (< 1 cm depth) compared to reference data at 1 m depth. 80% of our observations confirmed the presence of a saline skin layer, e.g. increase salinity at the sea surface compared to the underlying water. We discuss the influence of precipitation and evaporation on the dynamics of the skin surface salinity. Such in situ data are crucial for the continuing efforts in remote sensing of the ocean for the purpose of calibration and quality assurance of satellite data. For this purpose, we will present the first truly in situ data (28362 data points) for the skin surface salinity, e.g. salinity in the SML.

Jie Yang: University of Washington, jieyang@apl.washington.edu
Presentation: Oral

Analysis of STS/PAL float data in SPURS-2 study area

Rain over the ocean is a central process in the global freshwater cycle. For SPURS-2 study area in the ITCZ, the annually averaged precipitation is approximately 10 mm dy^{-1}, with daily values tripling during the rainy season. Rainfall in this area is also known to be characterized by high spatial and temporal variability. Detailed study of the effect of rain on salinity requires in situ measurements of rain rate and total accumulation that capture this short-term, long-term, and spatial variability in the rain field to achieve the goals of SPURS-2. A total of 15 Argo profiling floats were deployed for SPURS-2 in the time period of Aug. 31 – Sep. 14, 2016. Among them, ten are regular US Argo floats and the other five are US Argo floats equipped with Surface Temperature and Salinity (STS) and Passive Aquatic Listener (PAL) sensors. The PAL sensors provide a continuous time series of rainfall and wind speed estimated from ocean ambient sound with a spatial footprint of 1 km and a temporal resolution of 1 min when the floats are at their park depth of 1000 m. In this talk, a preliminary analysis of the Argo and PAL data from the SPURS-2 deployment from Sep. 2016 – April 2017 are presented. In general, the PAL wind speed is consistent with wind speed measured by surface anemometers on the central mooring, while rainfall exhibits strong spatial variability. Salinity and temperature profiles from the 15 floats are presented as well to investigate their correlation with rainfall. (Work supported by NASA.)

Lisan Yu: Woods Hole Oceanographic Institution, lyu@whoi.edu
Presentation: Oral

From the tropical freshwater to the subtropical saltwater zones:
Ocean dynamical control on the relationship between the ocean water cycle and salinity

The rapid augment of the global surface and subsurface salinity database by Argo and satellite missions (e.g. Aquarius, SMOS, and SMAP) has fueled the long-held interest in using ocean salinity as a rain gauge to improve the detection and quantification of the marine branch of the global water cycle, namely, the ocean evaporation (E) and precipitation (P). However, the studies of recent years have led to an increasing recognition of the challenge faced by the direct inference of the E-P variability from sea surface salinity (SSS), because E-P and SSS are not directly linked but through various upper-ocean processes. Two fundamental characteristics define the complex relationship between SSS and E-P. First, E-P is a mass flux and does not stay locally. For instance, when rain adds to the mass of the water column, it causes a pressure perturbation and fast oceanic responses in terms of gravity waves and barotropic Rossby waves. Secondly, E-P does not have a feedback relationship with SSS. This is in stark contrast to surface heat flux that serves as both forcing and damping mechanisms for SST. E-P forces SSS anomalies but does not dampen them. As a consequence, SSS anomalies tend to be more persistent, and influenced more strongly by oceanic advection/mixing. SSS anomalies are carried out by oceanic processes and can circulate around for a period of time.

Here we present our recent study of ocean dynamical control on E-P generated SSS anomalies in two contrasting regimes. One is the tropical freshwater zone where P dominates E, and the other is the subtropical saltwater zone where E dominates P. In the tropical salinity-minimum zone, we show that there exists a near-surface salinity minimum zone (SMZ) in the vicinity of the Inter-tropical Convergence Zone (ITCZ). We find that, although the SMZ is sourced from the ITCZ, the generation mechanism is the oceanic Ekman convergence that pushes down the rain-freshened surface waters up to the depth of 50-80 meters. Unlike the ITCZ that migrates north and south seasonally, the SMZ is marked by seasonal monotonic poleward propagation at an average speed of ~3,500 m day-1, with a persistence timescale of O(12-15 months). A linkage of the SMZ and the tropical barrier layer is also suggested, indicating an intertwined relationship between the Ekman induced convergence of the rain-freshened surface water and the formation of a salinity-stratified barrier layer. In the subtropical salinity maximum zones, we find that the decadal trends of the satellite-derived E-P forcing are opposite to the trends of the observed surface salinity. By using a mixed-layer salinity model that is forced by satellite-derived surface wind and E-P forcing products, the observed salinity variability is simulated. We find that vertical entrainment and mixing are two main processes that offset the effect of the E-P forcing. In particular, the balance between the ocean processes and the E-P flux led to a unique pattern of change of the near-surface salinity in the subtropical North Atlantic, namely, the freshening of the salinity maximum center in the presence of the basin-scale salinification. The causes of the salinity pattern change are diagnosed, and the influence of the decadal change of surface wind pattern is elucidated.

Lili Zeng: South China Sea Institute of Oceanology, zenglili@scsio.ac.cn
Presentation: Oral

Decadal variation and trends in subsurface salinity from 1960 to 2012 in the northern South China Sea

Understanding the long-term salinity variations and underlying mechanisms, especially the signals below the sea surface, is essential to explain the effects of natural variability and climate change on the regional water cycle. Moreover, the signature of salinity changes below the surface is subjected to greater uncertainty than that of surface salinity. As part of the Indo-Pacific warm pool, the characteristics of water masses in the largest tropical marginal sea, the South China Sea (SCS), show remarkable open ocean and local properties. Observations suggest that subsurface waters in the northern SCS exhibited substantial low-frequency variability, with a striking decadal change in the southern limit of the 34.6 practical salinity unit (psu) isohaline. Long-term freshening of the subsurface waters, started in 1960, was followed by salinification from 1975, and freshening occurred again from 1993 to 2012. The linear trends were 0.0076, 0.0100, and 0.0078 psu/yr, respectively. An analysis of the subsurface salinity budget reveals that the main underlying contributors to subsurface salinity are horizontal advection and vertical entrainment. In particular, advection driven by the Luzon Strait transport and vertical entrainment from the mixed layer are the key factors controlling variations on subsurface salinity. Diagnosis of the salinity budget further suggests that entrainment from the mixed layer played a more important role in the freshening periods than in the salinifying period.