SPURS-2

Diagnosing the physics of a rainfall–dominated salinity minimum

Report of a workshop in Pasadena, April 16-18, 2014

4 June 2014, revised 9 February 2015

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1. Introduction

One of the most important issues facing society is how the water cycle may change in the future. The exponential increase in the vapor-carrying capacity of the atmosphere with increasing temperature means that changes could be severe, with a tendency for dry areas to get dryer and wet areas to get wetter. The distribution of rainfall and drought is arguably the single most societally relevant aspect of weather and climate. Since most of the water cycle takes place over the oceans (the flow of all rivers sums to less than 10% of global ocean evaporation), an obvious place to look for change in the water cycle is in the ocean.

Sea surface salinity (SSS), being influenced by the evaporation that fuels atmospheric convection and the precipitation that removes water from the atmosphere, is a key indicator of water exchange between the atmosphere and ocean. The global database of SSS observations is rapidly expanding now as a result of new satellite measurement capabilities (Aquarius and the ESA's Soil Moisture Ocean Salinity, or SMOS, mission) and other enhancements to the global observing system (e.g., the Argo float array). However, improved understanding of the processes modulating SSS is critical to use of SSS as an indicator of air-sea exchange in the hydrological cycle. Besides air-sea exchange of water, SSS is also fundamentally affected by oceanic advection and mixing. "Oceanic advection and mixing" is a term that encompasses all of ocean dynamics, from large-scale subduction of surface waters beneath other water masses to eddy transport to centimeter-scale turbulence, and many different physical processes may influence SSS at different times and places.

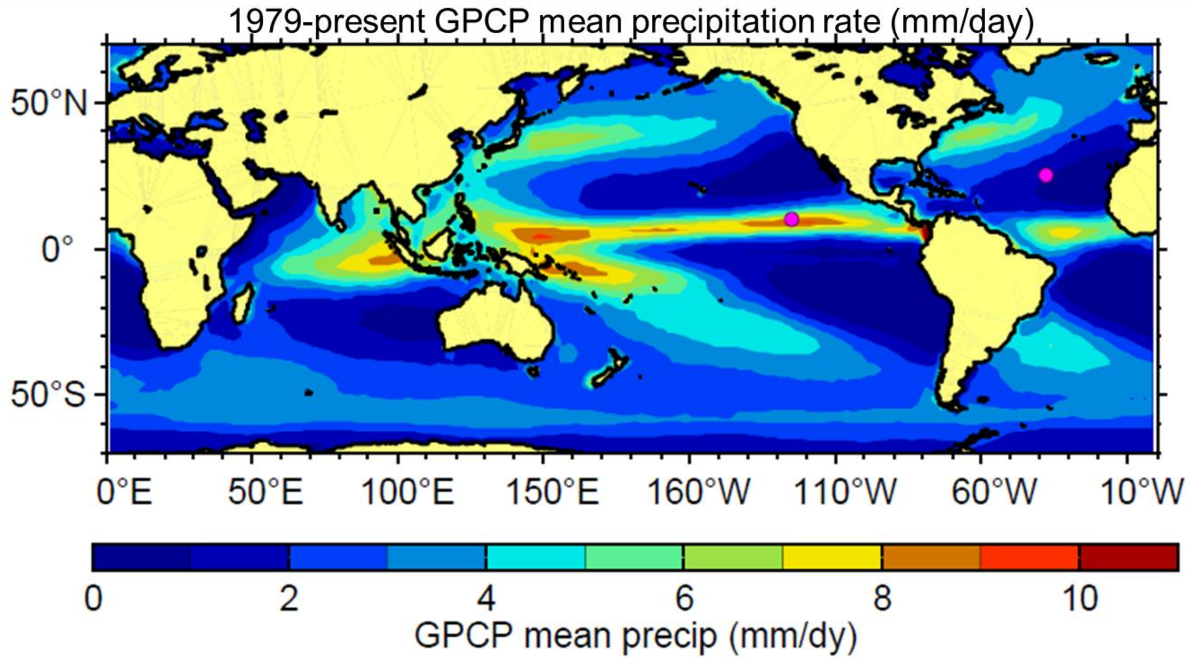


Figure 1. Annual average precipitation from GPCP. The Pacific ITCZ is seen to be the largest area of rainfall. The nominal locations of SPURS-1 (25°N, 38°W in Atlantic) and SPURS-2 (10°N, 125°W in Pacific) are indicated by pink circles.

The field program "Salinity Processes Upper-ocean Regional Study" (SPURS) was specifically designed to examine those processes affecting the near-surface salinity. SPURS was envisioned as a 2-phase effort with the first phase focusing on the salinity maximum of the North Atlantic during 2012-2013. This white paper develops the rationale behind the proposed second phase field effort in the low-salinity region of the eastern tropical Pacific. The low salinities in the area are driven by some of the largest rainfall rates on the planet (Figure 1).

Within the context of the global water cycle, SPURS focuses on both source and sink regions for ocean salinity and atmospheric freshwater. That is, the global water cycle is characterized by mid-latitude evaporation regions that supply moisture to high and low latitude precipitation-dominated regions. SPURS-1 focused on a subtropical high-pressure region where a dry, sinking and divergent atmospheric circulation, with its associated wind-stress curl field, drives a convergent Ekman transport and subducting oceanic circulation characterized by high salinity. Insights into the ocean dynamics and mixing processes there are readily transferable to the other subtropical gyres. The overall goal of SPURS-2 is to improve understanding of the physical processes that influence upper-ocean salinity and SSS in a precipitation-dominated regime with net freshwater and buoyancy fluxes into the ocean. The region chosen for SPURS-2 is under the inter-tropical convergence zone (ITCZ) in the eastern tropical Pacific, where the intensity of surface water flux is largest in summer (Figure 2).

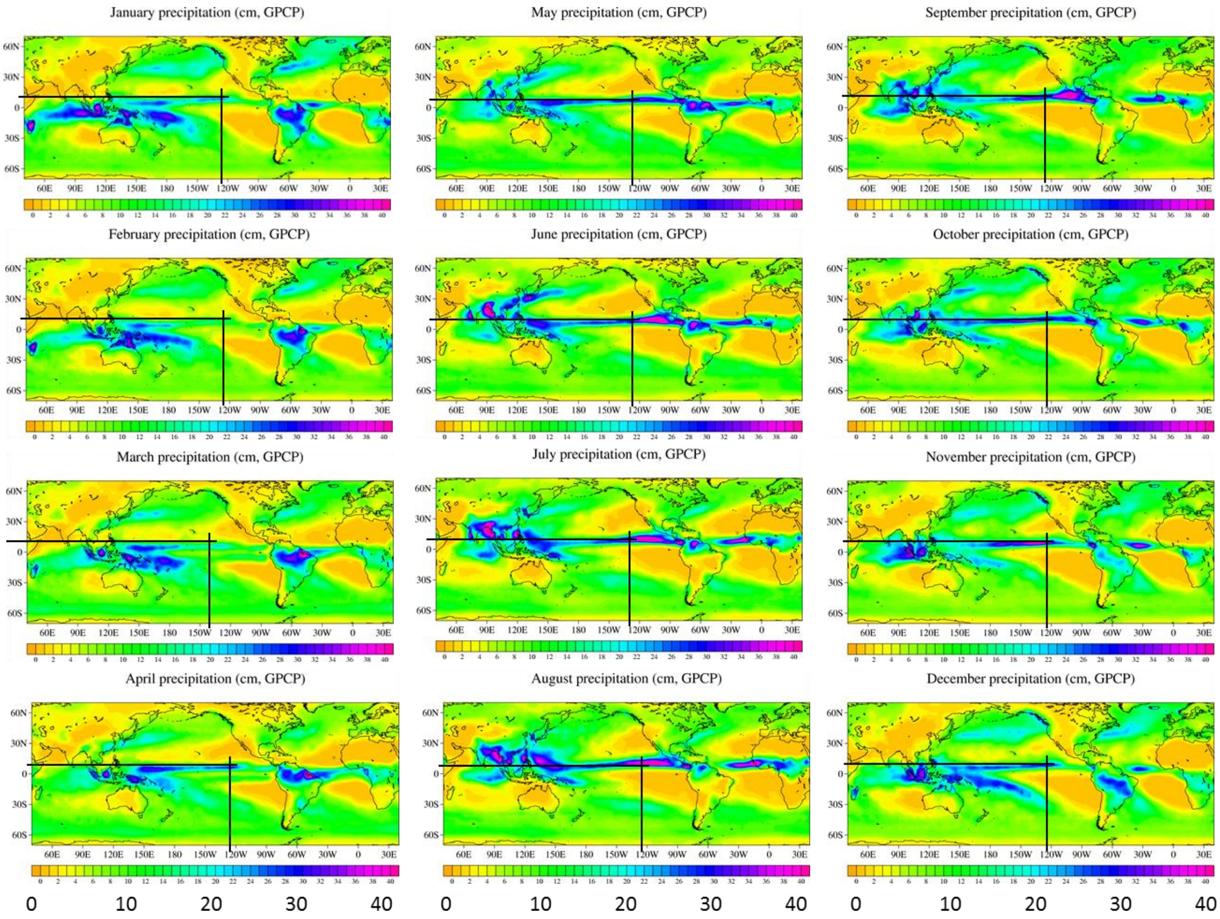

January precipitation (cm, GPCP)
May precipitation (cm, GPCP)
September precipitation (cm, GPCP)
February precipitation (cm, GPCP)
June precipitation (cm, GPCP)
October precipitation (cm, GPCP)
March precipitation (cm, GPCP)
July precipitation (cm, GPCP)
November precipitation (cm, GPCP)
April precipitation (cm, GPCP)
August precipitation (cm, GPCP)
December precipitation (cm, GPCP)

Figure 2. GPCP precipitation by month (Adler et al., 2003). The vertical line indicates 125°W. The rain band under the ITCZ migrates northward and intensifies during boreal summer at 10°N.

Some of the contrasts in the environments and processes targeted in each phase of SPURS are summarized in Table 1.

Table 1

SPURS-1	**SPURS-2**
Convergent ocean (Subducting) Divergent atmosphere	Divergent ocean (Upwelling) Convergent atmosphere
Salinity maximum	Salinity minimum
Evaporation dominated → Buoyancy loss	Precipitation dominated → Buoyancy gain
Deep mixed layer and thermocline	Shallow mixed layer and thermocline
Weak mean advection	Strong mean advection
Small annual cycle	Large annual cycle
Poleward limit of tropical-subtropical cell	Equatorward limit of tropical-subtropical cell
In the saltiest ocean basin, N. Atlantic	In the freshest ocean basin, N. Pacific
Positive long-term salinity trend	Negative long-term salinity trend

While most of these contrasts relate to the basic structure of the oceanic tropical-subtropical circulation, there is also an attempt to exploit one of the significant asymmetries of the global water cycle: the contrast between the salty North Atlantic as a net evaporation basin and the fresh North Pacific as a net precipitation basin (Figure 3). This is generally attributed to the narrowness and more land-surrounded nature of the North Atlantic, and the ready transport of moisture in the trade winds from the Atlantic to the Pacific across narrow Central America. SPURS-1 can be thought of a source region for the water that is freshening the SPURS-2 region, though individual water molecules do not travel that far in one evaporation/precipitation cycle.

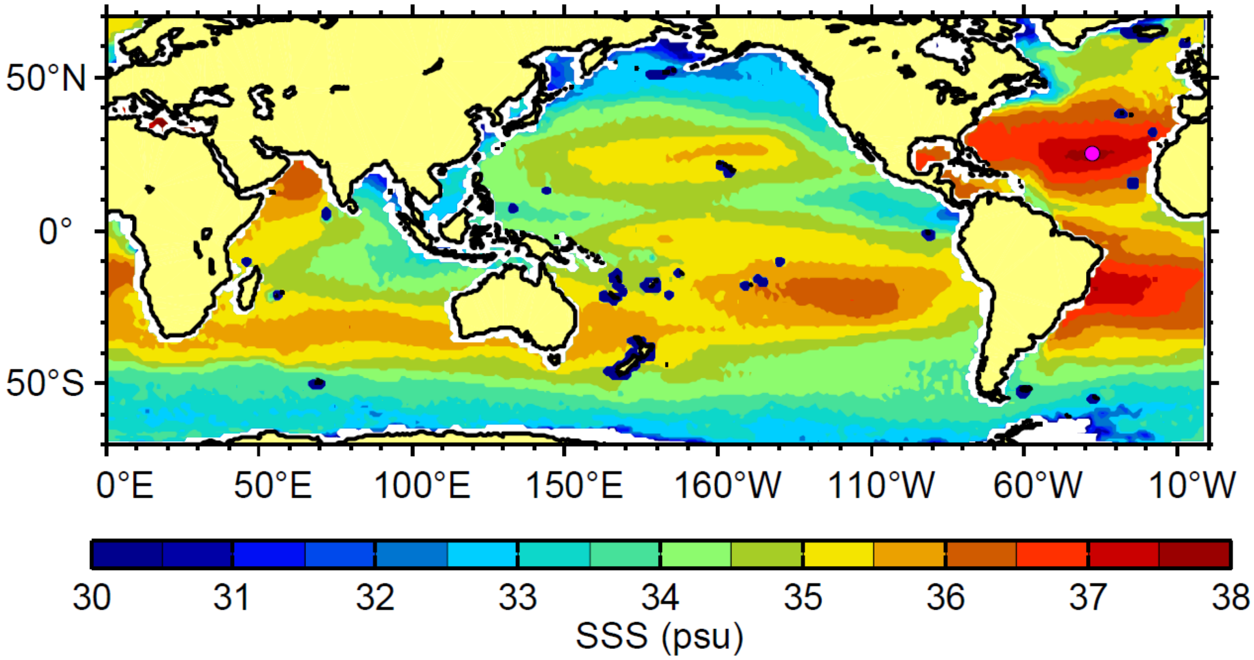


Figure 3. Mean sea surface salinity (SSS) from Aquarius during 2012-2013. The eastern tropical Pacific has some of the lowest salinities in the tropics and contrasts strongly with the high salinity of the SPURS-1 region in the North Atlantic (indicated by a pink circle near 25°N, 38°W).

Different physics

A key to understanding the differences between an evaporation-dominated regime and a precipitation-dominated regime is the opposite sign of the buoyancy flux. Evaporation leaves salt behind and therefore increases the density of near-surface waters, enhancing vertical mixing and deepening the mixed layer. Precipitation freshens surface waters and enhances stratification which tends to limit vertical mixing and leads to a shallower mixed layer. Also, the basic downwelling and subducting regime of the salinity maxima and the upwelling and obducting regime of the ITCZ lead to dramatically different thermocline depths.

The fundamental differences in how evaporation and precipitation affect ocean stratification and mixing are highly relevant to interpreting and understanding the long-term trends in ocean salinity that show the salty regions becoming saltier and the fresh regions becoming fresher (e.g., Durack and Wijffels, 2010). In the precipitation-dominated tropical regions, where SSS is freshening on decadal timescales, it is possible that the oceanic and atmospheric dynamics could reinforce one another with a positive feedback: enhanced precipitation can contribute to reduced vertical mixing in the upper-ocean, which can contribute to warmer SSTs, which can in turn contribute to enhanced atmospheric deep convection and precipitation. There is no reason to suspect any oceanic response by which increased evaporation and SSS could lead to conditions favoring further evaporation—this difference highlights the very different large-scale and small-scale physics of the evaporation and precipitation regimes. Measuring and modelling the ocean's response to surface water fluxes of both signs is the central goal of the SPURS field programs.

A SPURS workshop was held in Pasadena (April 16-18, 2014) to discuss the physical processes affecting SSS. The first part of the workshop focused on results from SPURS-1 and the Aquarius/SAC-D and SMOS satellite missions, and the second part of the workshop was devoted to discussion of the scientific context (goals and motivations) and plan for SPURS-2.

SPURS-1 was designed to be generalizable to the salinity maxima of other subtropical gyres, and SPURS-2 should have similarly wide applicability. Thus, planning has evolved so that the preferred site is representative of the open-ocean ITCZ regime, rather than one dominated by riverine inputs and other coastal processes. The region around 10°N, 125°W was discussed as a nominal site for SPURS-2 at the Pasadena workshop and prior SPURS meetings, in part because of prior knowledge and existing monitoring arrays, i.e. the TAO line to the south along 125°W. Figure 2 shows the monthly climatology of the precipitation and Figure 4 shows the climatology of surface wind divergence at 125°W. The latitude of 10°N is near the summer northward excursion of the ITCZ. This assures a strong seasonal cycle in rainfall. Such temporal variability in freshwater forcing will be an aid in discerning those processes that are most dependent on rainfall.

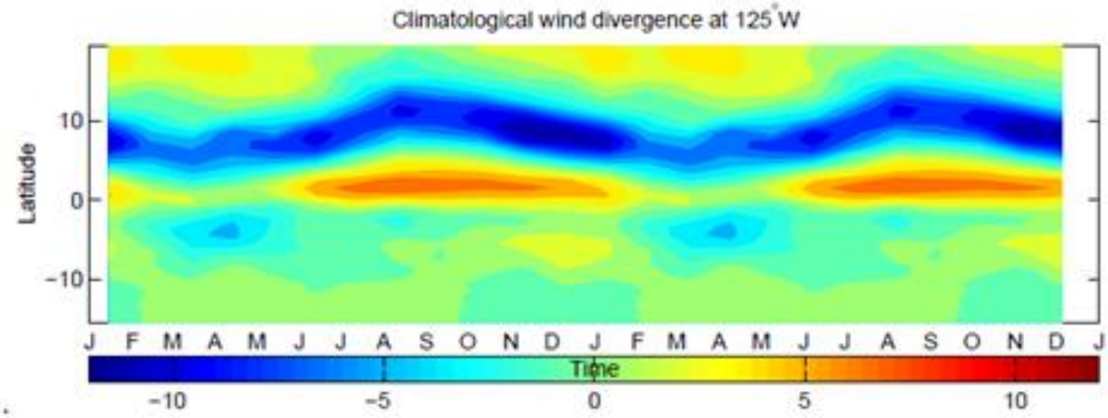
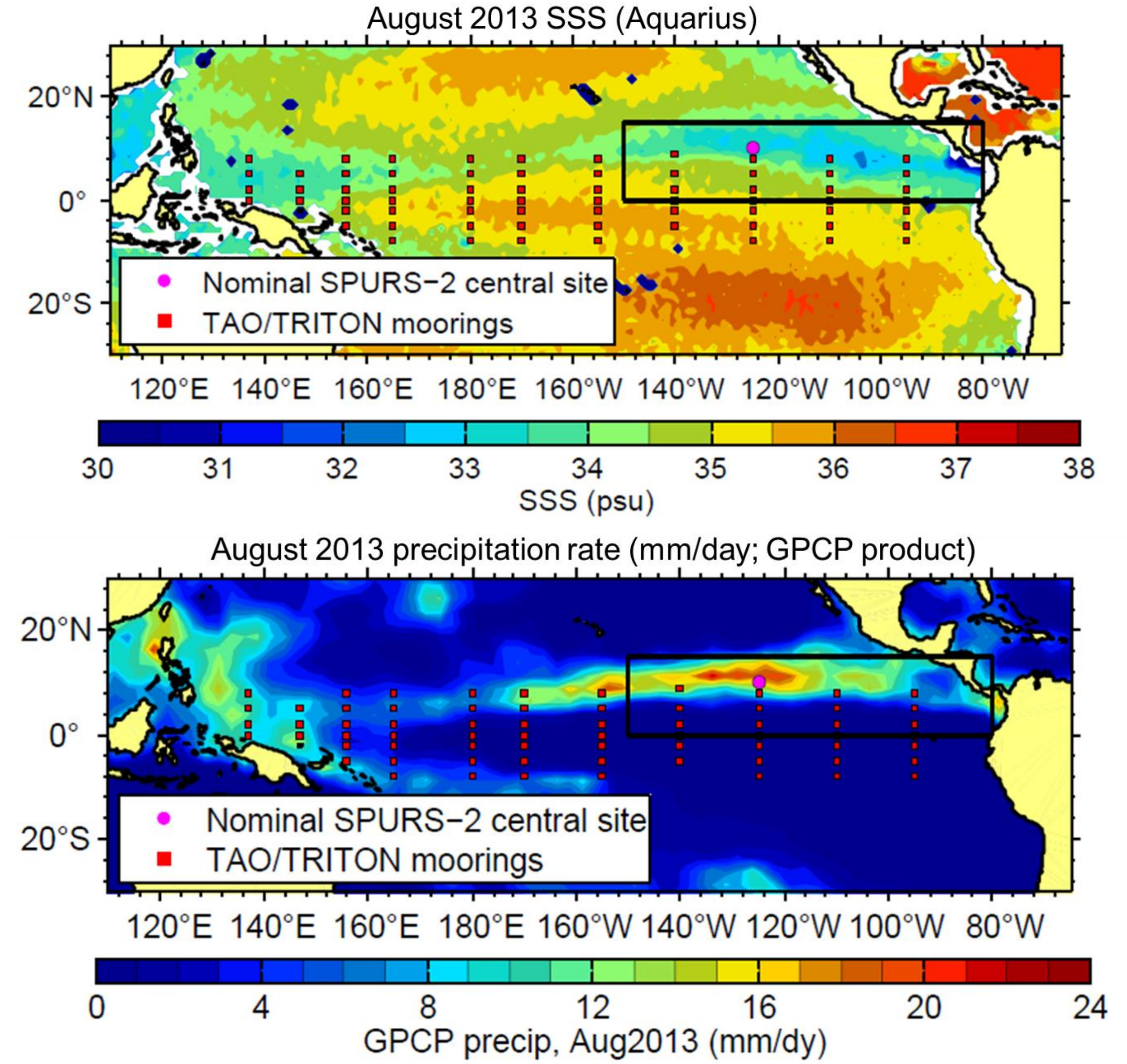


Figure 4: Latitude-time plot of climatological wind divergence at 125°W estimated from the IFREMER ERS scatterometer wind product. The band of wind convergence (negative divergence) is a measure of the location of the ITCZ. Units are 10^{-6} s^{-1}. (From Farrar, 2003)

The SPURS-2 experiment will focus on the region of low SSS found in the eastern Pacific ITCZ region (Figure 5). SPURS-2 is motivated by scientific questions and a need to better understand physical processes that involve scales ranging from centimeter-scale freshwater layers resulting from rainfall to the planetary scale of the tropical Pacific, so SPURS-2 scientific investigations cannot be limited to a particular point on the map. SPURS-2 will adopt a nested sampling strategy, with intensive sampling of a central region around 10°N, 125°W. The nested sampling is intended to observe the upper ocean in a cascading series of horizontal scales from meters to thousands of kilometers. The largest scales will be observed using data from the existing global observing array (Aquarius, SMOS, TAO/TRITON moorings, VOS observations, Argo floats, drifters, etc.).


August 2013 SSS (Aquarius)

August 2013 precipitation rate (mm/day; GPCP product)

Figure 5. Upper panel: Aquarius SSS from August 2013 (colored contours). Lower panel: GPCP precipitation for August 2013 (colored contours). The red squares mark TAO/TRITON mooring sites, and the pink circle at 10°N, 125°W marks the nominal location of the SPURS-2 central site. The black box delineates a broader SPURS-2 region—it is expected that SPURS-2 investigators will discuss and refine the SPURS-2 sampling regions after investigations are funded and as the detailed experimental plan is developed.

We can draw on climatological data to highlight the important features of the proposed site of the SPURS-2 field work. The CARS climatology (Fig. 6) shows the shape of the thermocline, more or less determined by the depth of the 20°C isotherm. The thermocline is the signature of the zonal current systems in this region, the south equatorial current (SEC) south of 5°N, the north equatorial countercurrent (NECC) between 5 and 10°N and the north equatorial current (NEC) north of that. The thermocline reaches a minimum depth around 10-11°N, as shallow as 50 m. At that latitude one can see the shallow surface freshwater pool that is the subject of SPURS-2. Note that the meridional surface salinity minimum is at 12-13°N in this climatology, and that the maximum temperature is around 7°N. Also note, the maximum rainfall (Fig. 4) occurs at 8°N. These offsets highlight the indirect nature of the relationship between air-sea interaction and SSS. Ocean processes as much as air-sea interaction determine the location and magnitude of the meridional SSS minimum.

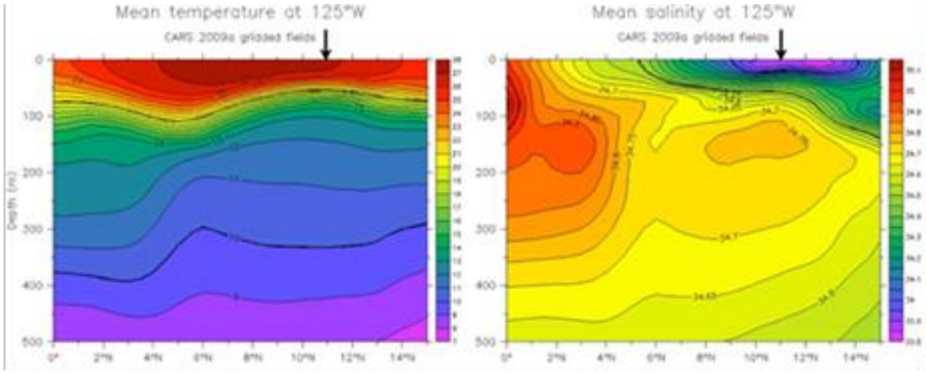


Figure 6. Mean Temperature (left) and Salinity (right) sections along 125°W from the equator to 15°N. From the CARS climatology.

2. SPURS-2 Scientific Questions

The overall goal of the SPURS-2 field program is to understand the structure and variability of upper-ocean salinity under the ITCZ. The Pacific ITCZ, with its frequent, heavy rainfall, is a major source of freshwater. Ultimately, this freshwater input contributes to the large-scale pattern of low SSS in the eastern tropical Pacific, but the initial input of freshwater is in “puddles” on the ocean surface with scales similar to the atmospheric mesoscale.

The 2014 workshop held in Pasadena identified several key scientific questions for the SPURS-2 field program:

- Where does the freshwater go? In other words, how does the ocean integrate the freshwater forcing and destroy the salinity variance created at the surface? By what oceanic processes is the freshwater transformed from shallow, patchy “puddles” of freshwater into the large-scale mean distribution of salinity that makes up the Eastern Pacific Fresh Pool?
- What impact will this horizontal and vertical variability have on the performance of satellite-based measurements of SSS?
- What are the local and non-local effects of the freshwater flux on the ocean?
- How does the ocean SSS impact the feedbacks on the atmosphere?

These are general issues that frame the interests of SPURS-2. More specifically, the program is expected to focus on certain physical processes, such as:

1. Barrier layers and the role of salinity in upper-ocean stratification

In high-precipitation regions, the vertical structure of salinity can be more important than that of temperature in setting upper-ocean stratification and mixed-layer depth. When the salinity stratification sets the base of the mixed layer, and the thermocline depth is at some deeper level, the resulting region between the mixed-layer base and the thermocline is called a “barrier layer”

(Godfrey and Lindstrom, 1987; de Boyer Montegut et al., 2007). The “barrier layer” label is used because the strong salinity stratification and weak temperature stratification at the mixed-layer base makes it difficult for mixed-layer entrainment to cool the mixed layer and SSTs. By the same token, the existence of a barrier layer provides favorable conditions for mixed-layer entrainment to increase SSS (because, by definition, salinity is larger beneath the mixed layer in a barrier-layer situation).

Barrier layers are commonly found in the tropical oceans beneath the ITCZ (e.g., Mignot et al., 2007; Figure 7), and they are typically present for about half of the year near 10°N, 125°W in the eastern Pacific (de Boyer Montegut et al., 2007). The persistent barrier layers observed by de Boyer Montegut et al. (2007) in the eastern Pacific ITCZ region, being only 5-10 m thick, are relatively thin in comparison to those in the western Pacific and Atlantic Oceans and the Bay of Bengal (Figure 7).

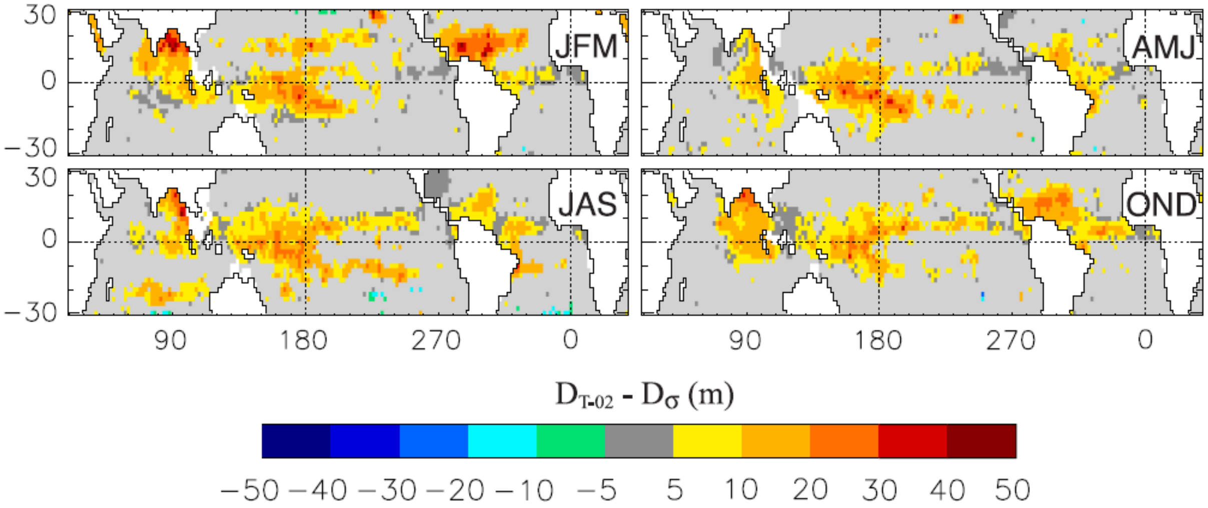


Figure 7. (From Mignot et al., 2007) Seasonal maps of barrier-layer thickness (positive values) and “compensated layer thickness” (negative values; not discussed here) estimated from available hydrographic data (from ship surveys and Argo floats).

The climatological significance of the eastern Pacific barrier layers and how they contrast with those in other areas are central concerns. A related and more fundamental interest is in understanding whether salinity stratification plays a role in contributing to the warm SSTs (and hence air-sea interaction) beneath the eastern Pacific ITCZ.

2. Surface fluxes

Evaporation and precipitation, the primary contributions to the surface freshwater flux, are expected to exert an important influence on the evolution of SSS on both the short timescale of rain events and on longer timescales (e.g., seasonal). These will thus be important measurements for SPURS-2. Precipitation measurements pose special sampling challenges.

Satellite precipitation products are expected to play an important role in SPURS-2. These products have matured greatly in recent years (e.g., TRMM) and are expected to improve as the international network of precipitation satellites, referred to as the Global Precipitation

Measurement (GPM) Mission, continues to improve and data become available from the recently launched GPM Core Observatory.

In situ techniques to measure rainfall would also be valuable. These could include point measurements from surface buoys and acoustic techniques that provide an area-averaged estimate of rainfall. Ship-based precipitation radars would be of high value for meeting the SPURS-2 goals, including rainfall estimation and mapping the spatial scales of rainfall. Perhaps such work can be supported by other agencies as SPURS-2 provides an exceptional research opportunity.

In addition to surface freshwater fluxes, measurements of surface heat and momentum fluxes are required in order to understand and interpret the evolution of the surface layer and SSS. For example, surface buoyancy fluxes are often (but not always) dominated by surface heat fluxes and mixed-layer entrainment is often driven by surface momentum fluxes.

3. Ocean/atmosphere Ekman layer coupling

As noted in Table 1, the ITCZ regime is one of convergence in the atmosphere and divergence in the ocean. The rising air drops its moisture as precipitation that freshens the upwelling ocean. The upwelled waters are saltier and have generally arrived in the tropics after subducting in the subtropical gyres. This is the tropical terminus of the shallow tropical-subtropical overturning cell that provides much of the low-latitude oceanic heat flux. Understanding this system is a central goal for SPURS-2. Many questions arise, such as: Why is the salinity minimum north of the rainfall maximum? How do the north equatorial currents and counter-currents influence the salinity budget and space-time structure of the salinity minimum? How close/different is the eastern Pacific ITCZ regime to/from other precipitation-dominated tropical regions (e.g., in the western and central Pacific, the Indian Ocean, and in the far-eastern Pacific)?

4. Salinity fronts and rainfall-induced ‘fresh pools’

The intermittency and spatial distribution of rainfall in the tropics leads to regions of low-salinity water at the ocean surface with sharp lateral and vertical boundaries. In the tropics, where rain rates can often exceed 10 mm/hr, these lateral and vertical gradients have been measured to be on the order of 1 psu over lateral scales of a kilometer and depth scales of a meter. Figure 8 shows a comparison of SSS sections at large spatial scales (i.e., a few hundred kilometers) and small spatial scales (i.e., a few tens of kilometers) measured as a function of depth in the upper few meters of the ocean. These measurements show that vertical and lateral gradients in SSS are observed at a range of rain rates and wind speeds. Furthermore, their scales in the horizontal direction can extend over a few tens of kilometers. In the vertical direction, the salinity profiles in the upper few meters can be complex, with instances where there is a gradient extending over a few meters (e.g., from 5320 km to 5340 km in the left-hand panel of Figure 8 and from 44 km to 45 km in the right-hand panel of Figure 8) and instances where the top few meters are well-mixed with a salinity gradient at deeper depths (e.g., from 47 km to 54 km in the right-hand panel of Figure 7).

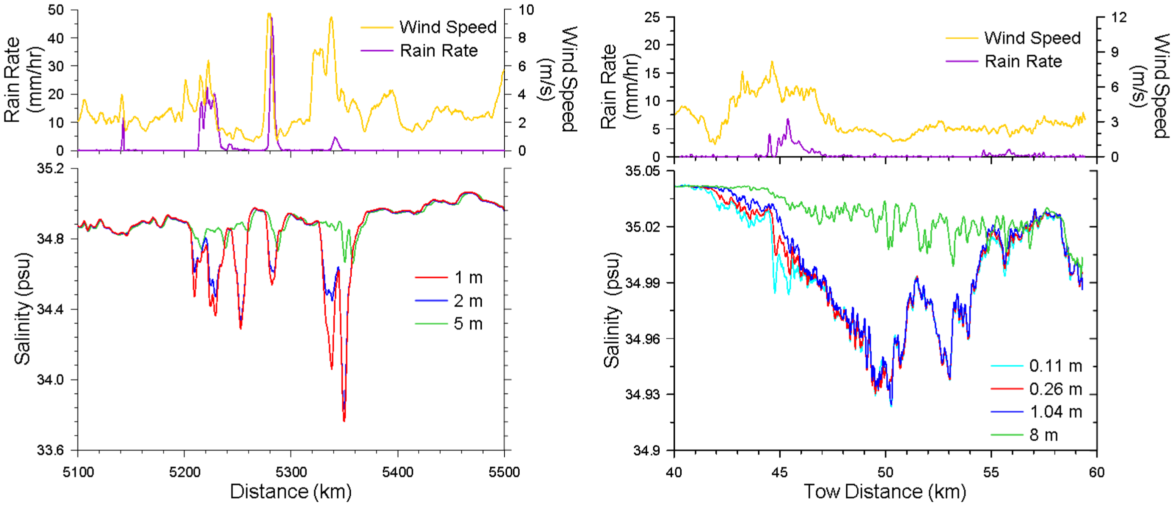


Figure 8. Observations of rain-induced salinity stratification in the upper few meters of the ocean at large and small scales as reported by Asher et al. [2014]. The left figure shows data recorded by the Underway Salinity Profiling System installed on the R/V T.G. Thompson in 2011 while underway in the North Pacific. The right figure shows data from the Surface Salinity Profiler recorded in the Equatorial Pacific Ocean during a cruise aboard the R/V Kilo Moana.

The current state of observational knowledge concerning how the freshwater influx from rain interacts with the dynamical processes to generate SSS variability in both time and space is insufficient to constrain models of ocean surface processes. The density anomalies associated with decreases in salinity of this magnitude and the surface mass fluxes from heavy precipitation events are expected to generate both baroclinic and barotropic responses in the ocean. For example, it is known that the freshwater influx must spread laterally across the ocean surface and mix downwards with the underlying higher salinity water. The interplay of baroclinic forces and surface currents that drive the lateral spreading with the vertical mixing due to waves and wind stress will determine the variability of SSS on scales of a few tens of kilometers shown in Figure 8. These same processes will also govern the evolution of the vertical gradients over scales of a few meters seen in Figure 8. However, although data such as these, and other data measured previously [Soloviev and Lukas, 1996], show that these features exist at the ocean surface, their spatial and temporal evolution has not been fully characterized. Some data on these shallow puddles was obtained during the SPURS-1 cruises using a special "salinity snake" that sampled the upper few centimeters of the ocean. Figure 9 shows a comparison of a SSS section across a rain puddle from the salinity snake compared with salinity a few meters down from the ship's thermosalinograph.

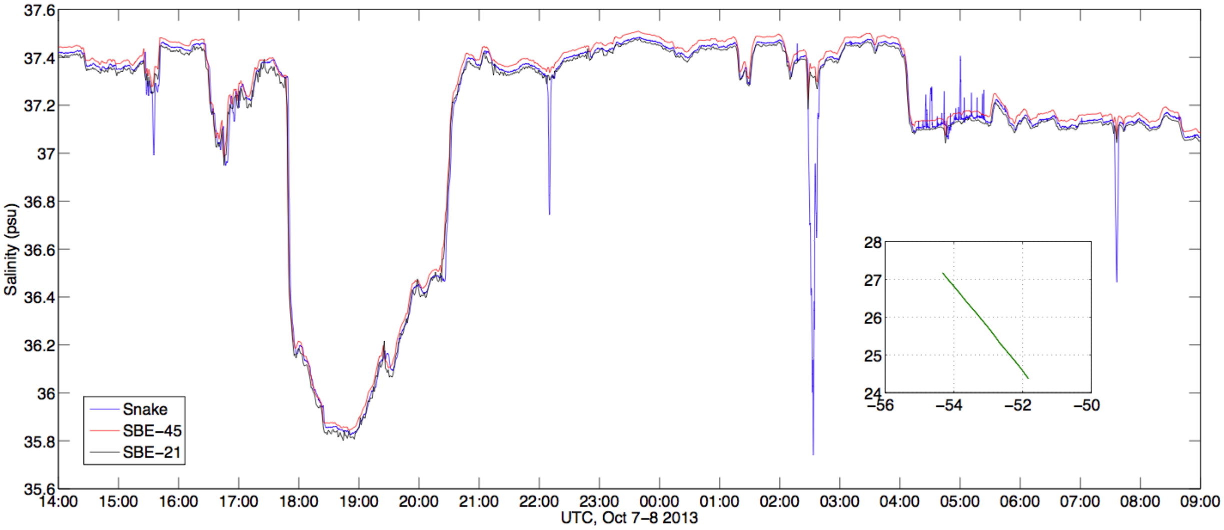


Figure 9. Nineteen hours of SSS data measured from the R/V *Endeavor* during SPURS-1 by a "snake" sampling at ~5 cm (blue) and two shipboard thermosalinographs sampling at ~5 m (red and black). Corresponding ship track, traversed from southeast to northwest, is shown in green. Four fresh "puddles" are visible.

We know that the buoyant fresh puddle must spread across the ocean surface while being mixed with underlying salty water and that the balance between these processes will determine how long they last and how far they spread.

Salinity fronts on larger scales will also be generated by interaction of the precipitation-induced salinity gradients with the strong regional current shear. Furthermore, evidence suggests that a seasonal pulse of freshwater may move west from the coastal fresh water pool that originates in the Gulf of Panama region. How these regional-scale effects combine to generate variability in SSS is also poorly known.

SPURS-2 will address the questions of how the spatial and temporal scales of rain combine with other upper-ocean forcing and dynamics to produce the observed distributions of salinity in time and space. Measurements that will be required include long-term monitoring (i.e., weeks to months) of salinity fields in the ocean mixed layer, with emphasis on measurements in the very near surface (i.e., upper 10 meters). Resolution of the short-timescale dynamics associated with formation and decay of rain-related salinity anomalies in the upper ocean will also require short-term measurements that are capable of resolving salinity gradients in the upper meter of the ocean. These measurements should ideally cover spatial scales on order of the known spatial scales of the rain events, so that the initial conditions for these lenses of fresher water are known.

5. Influence of rain on remote sensing

The right panel of Figure 8, as well as Figure 9, both show that salinity gradients in the top few meters of the ocean can exist over scales of a few tens of kilometers and have salinity anomalies on order of 1 psu. Rain-induced surface freshening on these scales would be significant in terms of its impact on salinity measured by L-band microwave radiometers. The surface salinity measurements described in Section 2.4 will also provide information required to determine if the fresh events caused by rain cause a bias that must be taken into account when extrapolating salinities measured by L-band microwave instruments at depths on order of 0.01 m to values that would be found at depths on order of 10 m.

3. SPURS-2: A Tropical Field and Modeling Program

In order to address the questions outlined in the previous section, an observational and modeling program will be carried out throughout an annual cycle, beginning during the 2016 calendar year. SPURS-2 is expected to fully capitalize on measurements from Aquarius/SAC-D and SMOS, as well as with other remote sensing products (altimetry, scatterometry, precipitation, etc.).

Measuring and interpreting processes occurring in a thin surface layer above the shallow and strong thermocline/halocline of the eastern tropical Pacific present a special challenge that needs to be squarely addressed by SPURS-2 measurements. This high-precipitation region differs greatly in this respect from the west Pacific warm pool (which has a much deeper permanent pycnocline), so it will be of interest for SPURS-2 to draw out the differences from the kinds of upper-ocean processes described in the TOGA-COARE experiment.

The field component is expected to maintain a persistent presence throughout the year. Intense ship-based measurements are likely to be required to resolve the small time and spatial scales of rain events and help the interpretation of long-term measurements. All the measurements will be guided and complemented by numerical modeling and data assimilation studies.

The scientific objectives of SPURS-2 can be rephrased in terms of time and space scales:

Large Scale: This scale covers the entire tropical ocean regime, with a focus the ITCZ region and the Eastern Pacific Fresh Pool. The proposed SPURS-2 area is the location of a strong annual cycle of salinity, one of the largest in the global ocean. The field campaign and modeling efforts should aim to characterize the processes contributing to the freshening and salinifying stages. An investigation of the similarities and contrasts with other ITCZ and high precipitation regions, as well as with the rest of the Pacific Ocean is expected. As SPURS-2 will sample only one realization of the annual cycle, some effort must be made to assess the extent to which the particular year of the SPURS-2 experiment is representative of the typical annual cycle in the region.

Mesoscale: A smaller region around the central SPURS-2 site would resolve scales of about 10 km to about 300 km. Within this “mesoscale box” or “inner nest”, gradients are expected to be larger in the north-south direction than in the east-west direction.

Small-scale: (<10 km), < 1 day. Precipitation is expected to be patchy in space and time, therefore providing the ocean with an input variance at small scales. The “rain puddles” need to be characterized over a short time scale, as they evolve rapidly. A variety of oceanic processes spread and integrate that variance, which might be described as an inverse cascade. At the same time, rain puddles and buoyancy fronts associated with patchy freshwater may lead to sub-mesoscale processes, generating mixed layer eddies and smaller structures. The strong stratification at the base of the mixed layer also supports internal waves, which modulate mixing and more generally play an important role in the mixed layer dynamics and its response to perturbations. It is expected that effort would be dedicated to estimation of the microscale dissipation parameters ε and χ in as many places as possible using gliders, profiling floats, and ship-based measurements to examine the role of processes at scales ranging from several hundred kilometers down to the dissipation scale in turbulent mixing of salinity and other properties.

In order to resolve the processes happening at different scales, a nested observational approach is likely necessary. For example, it could include a setup similar to what was used in SPURS-1, where year-long observations from flux buoys, underwater gliders, profiling and mixed-layer floats, surface wavegliders and drifters, were complemented by dedicated ship surveys (microstructure, AUV, profiler measurements) and historical observations.

Modeling Component: SPURS-2 will be a fully integrated observing and modeling program. Before the field experiment, SPURS-2 will use models to perform Observing System Simulation Experiments (OSSEs) to aid the observing system design. During the field experiment, investigators will have access to real-time assimilative/forecasting models at the spatial scales of observational data being collected. After the field experiment, models will be used to produce reanalysis to further address the SPURS-2 science questions. The model program may include:

- Process-oriented ocean models, including large-eddy-simulation (LES), to address specific SSS processes, e.g., mixing parameterizations
- Full 3D OGCMs: multi-scale models from global to regional
- Pre-field experiment: OSSE, observing system design, trade-off studies (e.g., how many gliders do we need to address a specific science question?)
- During the field experiment: real-time or near-real-time assimilation/forecasting, adaptive sampling (feature tracking: eddy, front)
- Post-field experiment: reanalysis, further process modeling, parameterization development
- Air-sea fluxes from global NWP models may not be accurate enough, so a downscaled WRF/COAMPS nowcast/forecast/reanalysis over the field experiment domain is likely to be needed; leverage on NCEP, NCAR and NRL-MRY may be required.

Given the scope of the scientific goals, the hope is to entrain multiple funding agencies and international partners, as was done successfully during SPURS-1.

Atmospheric component: Although SPURS-2 is framed as an oceanographic experiment, the atmospheric forcing of the upper ocean is of central importance for addressing the SPURS-2 science questions. Oceanic variability, at least immediately after a precipitation event, is likely to be tightly mirroring the scales of clouds and/or atmospheric storms. It is therefore important to characterize rainfall scales, although it is recognized that this may be different from the oceanic scales or those predicted by meteorologists. It is expected that rain rates can be estimated in-situ by a variety of instruments, and it would be useful to compare/relate these measurements with the rain scales estimated from satellite remote sensing (GPM, TRMM, and, if available, radar).

SPURS Information System: The success of the SPURS-2 field experiment depends on the collaboration of a network of institutions geographically spread across the country and from other countries. The objectives require quantitative analysis of interdisciplinary data sets and model output. Thus, observational data and model output must be exchanged between researchers. To extract the full scientific value, data must be made available to the scientific community on a timely basis.

A SPURS information system (SPURSIS) will be established well in advance of the field experiment to collect data/products, make them available through the web. Originators (observing elements or modeling groups) will be primarily responsible for quality control of their own data/products. As soon as data might be useful to other researchers, the data will be released, along with documentation that can be used by the user community to judge data quality and potential usefulness.

4. Experiment Design and Observational Requirements

It is premature to present a detailed experimental design prior to identification of the funded resources that will be able to contribute to SPURS-2. However, it is possible to identify the site and the preferred timing of the field program, and briefly identify anticipated contributions to the program.

a. Site: Eastern Tropical Pacific ITCZ in the region of 10°N 125°W.

b. Scheduling: The field campaign would take place over one full year, with the ship time arranged in three cruises about six months apart and an anticipated start date in the summer of 2016. Since interest is highest in the dynamics of rainfall events, it will be best to have the initial deployment cruise and final asset recovery cruise in the summer/fall rainy period. As such, these cruises could be also used for specific process studies, which would be an attractive option to encourage partnership between funding agencies.

c. Intensive Surveys: These should include shipboard surveys of basic T, S and velocity structure at a variety of scales, including the use of CTD sections, thermosalinographs, and special techniques to sample the surface layer. Microstructure measurements from ship and mobile assets are also encouraged. Flux measurements, especially of rainfall, would be valuable.

d. Moored Assets: We anticipate the use of one or more moorings, potentially arranged meridionally along 125°W, with priority on air-sea flux measurements (freshwater, heat, and momentum) and upper-ocean temperature, salinity, and velocity structure. The concentration of instruments can be more surface-focused than was required in SPURS-1.

e. Lagrangian Assets: Drifting or Lagrangian instruments such as floats and surface drifters must consider the stronger current regime of this site compared to SPURS-1. The potential for upstream seeding of drifters or active selection of the parking depth of floats should be considered.

f. Mobile Assets: Wavegliders, Seagliders or other mobile platforms (such as Sail-drones, if available) may be particularly useful in this high-current regime. Monitoring of the meridional thermohaline structure will be of most interest.

g. Ongoing regional measurements: Maintenance of the 125°W line of the TAO/TRITON array is highly desired for this project, as well as any enhancements such as improved flux measurements or higher resolution monitoring of T and S structure. Similarly, regional enhancements of VOS deployed XBTs or drifters would be most welcome.

h. Regional and local modeling: As in SPURS-1, we anticipate the use of ocean and coupled ocean-atmosphere models on a variety of scales to help understand and interpret our data and plan shipboard operations during the cruises.

i. Remote Sensing: Aquarius data was particularly useful during SPURS-1, and access to altimetry products and SST products also proved useful. Similar contributions would be beneficial to SPURS-2.

j. Data Management Plan: A data management project that includes real-time support of the cruises, data quality control and data archiving is expected.

k. Novel assets: Novel, mature technology and platforms would be welcome contributions to SPURS-2. For example, drifting buoys might capture some unique information of the spatial variability of the surface forcing. Use of non-conventional platforms such as FLIP and ASIS, and instruments such as ship-mounted rain radars would be valuable, though funding for activities that fall outside of the main focus of SPURS-2 or that would consume the funds needed to pursue the main goals of SPURS-2 must be sought from agencies other than NASA.

GPCP Precipitation data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/

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