Combined Active / Passive Retrievals of Ocean Vector Wind and Sea Surface Salinity with SMAP

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Abstract

We outline the algorithms for a radar-only salinity product, a radar-only vector wind product, and a combined active / passive vector wind and salinity product. We show SMAP can provide ocean vector winds with accuracy approaching that from traditional scatterometers using both the active and passive instruments. We demonstrate the novel ability of SMAP to make higher-resolution salinity estimates as compared to Aquarius while having accuracy approaching it. Next we show some promising results using only the radiometer channels to retrieve extreme winds.

Introduction

The Soil Moisture Active / Passive (SMAP) mission is a combined active / passive L-band microwave instrument designed to measure the soil moisture over land at 9 km resolution with a revisit time of 8 days. To meet these requirements, SMAP has included an L-band radar ($1.22-1.3$ GHz) and radiometer (1.41 GHz) which share a 6 meter rotating deployable mesh reflector. The full footprint 1-way resolution is 40 km while the radar also operates in a range-sliced and Synthetic Aperture Radar (SAR) mode giving resolutions of 30x6 km and 1-3 km, respectively. Due to data downlink constraints the SAR mode is generally only available over land and within 1000 km of the coastline.

While the mission goals of SMAP are solely over land, the similarities of SMAP to the Aquarius mission enable combined Ocean Vector Wind (OVW) and Sea Surface Salinity (SSS) measurements. Aquarius has paved the way of L-band combined active/passive estimations of ocean wind speed and salinity [2, 3] and the conically-scanning nature of SMAP, similar to RapidScat and QuikSCAT, enables wind direction retrieval as well due to the addition azimuthal looks afforded by the measurement geometry.

Algorithm Overview

The first stage of the combined active passive (CAP) processing is the radiometer-only portion which entails a residual T_B bias estimation as a function of time and polarization. Next the data are binned into a typical scatterometer L2A swath grid and we perform two retrievals using the radiometer-only data. First a combined wind speed and salinity retrieval where we use the following objective function:

$$F_{T_B} = \sum_i \left[\frac{T_{B,i} - T_{B,i}^m}{NEDT_i}\right]^2 + \left[\frac{spd - spd\_anc}{\delta_{spd}}\right]^2.$$

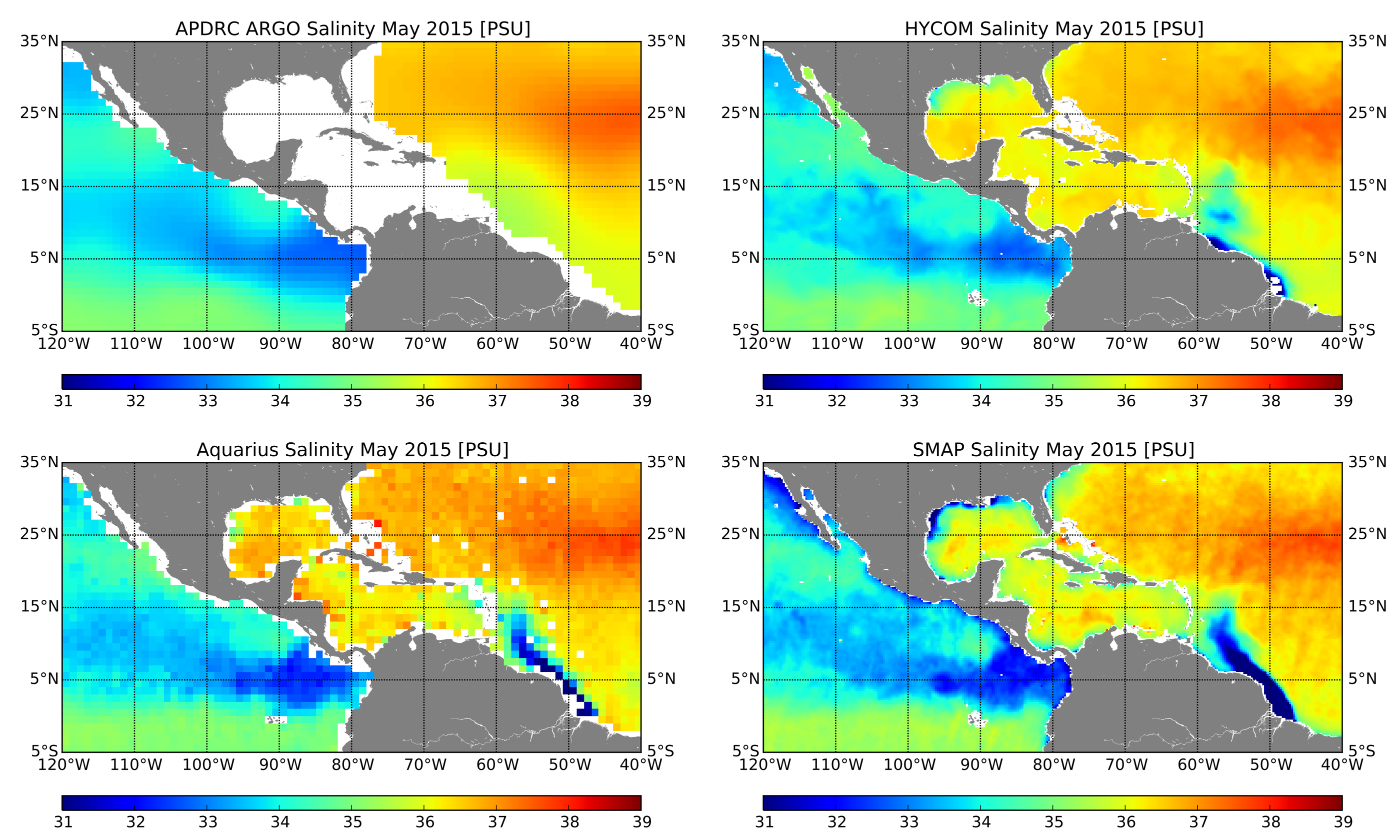
Here $T_{B,i}$ is one of the four flavors of T_B (H-fore, H-aft, V-fore, V-aft), $T_{B,i}^m$ is the model value of T_B which is a function of wind speed, relative wind azimuth, sea surface temperature, significant wave height, and incidence angle. The second term serves to impose a prior on the wind speed keeping it near the NCEP wind speed otherwise the problem has a continuous family of solutions in the wind speed and salinity space. We use $\delta_{spd} = 1.5$ m/s. For extreme winds we remove the prior term from the objective function and fix the salinity at the value from the ancillary data product. Then we retrieve wind speed and direction using algorithms developed for NSCAT, QuikSCAT, and RapidScat (i.e. DIRTH [1]). After performing the radiometer-only processing we perform the radar-only processing, which is a direct application of algorithms developed for QuikSCAT and RapidScat to the SMAP data with the only significant change being in the model function used. Finally, the CAP processing stage then combines the radar-only and radiometer-only retrievals to obtain the salinity and wind vector solution using the objective function:

$$F_{cap} = \sum_i \left[\frac{T_{B,i} - T_{B,i}^m}{NEDT_i}\right]^2 + \sum_i \left[\frac{\sigma_{0,i} - \sigma_{0,i}^m}{\sqrt{var\left(\sigma_{0,i}\right)}}\right]^2,$$

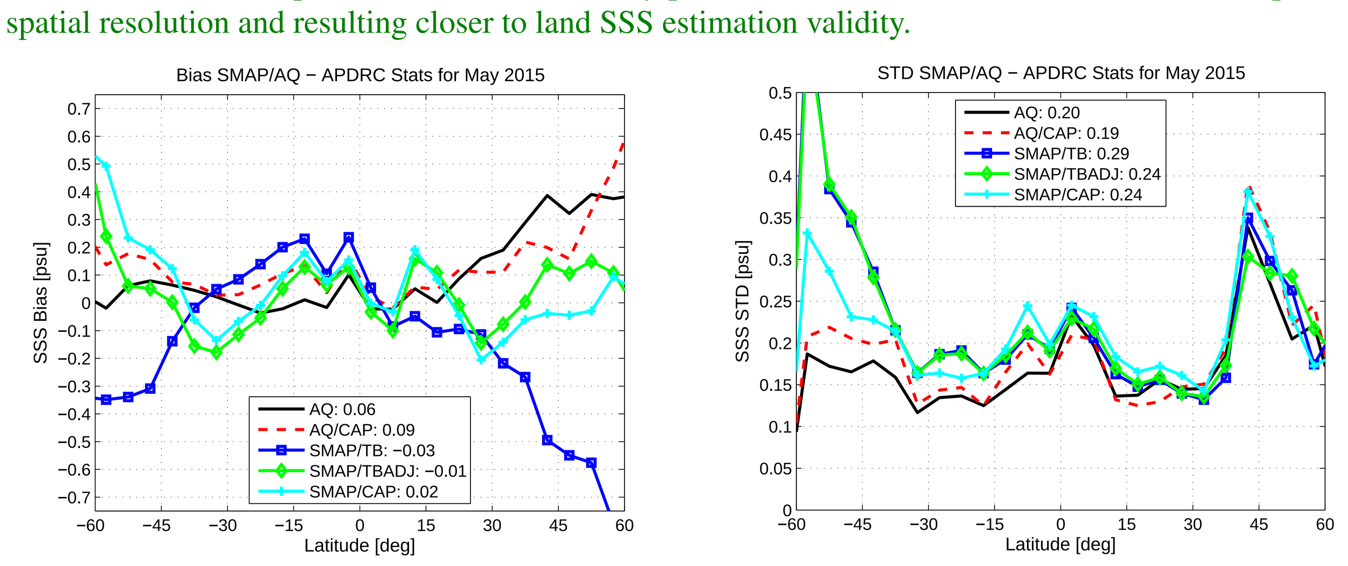
where $\sigma_{0,i}^m$ is the model σ_0, which is a function of wind speed, relative azimuth, and incidence angle. The CAP processing is an extension of the DIRTH processing to include salinity retrieval as well as wind speed and direction.

Results

Salinity

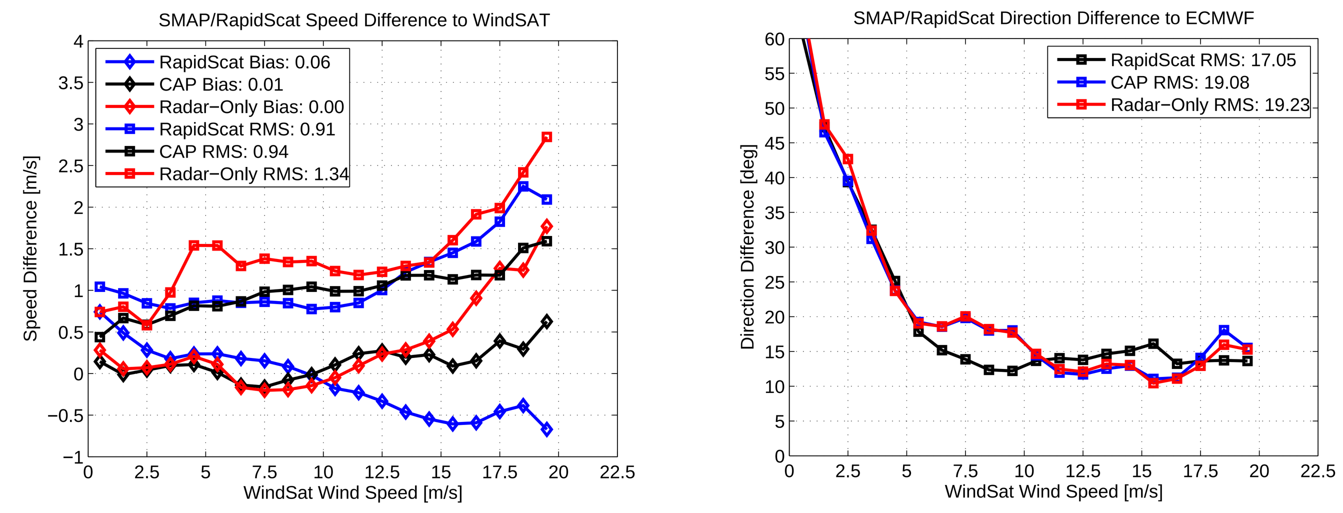


Monthly SSS maps for ARGO (upper-left), HYCOM (upper-right), Aquarius (lower-left), and SMAP (lower-right). This map illustrates the new level of detail that an instrument like SMAP is able to provide, even as compared to Aquarius which was designed for SSS. The Amazon river outflow is much more striking in the SMAP map than in the HYCOM or ARGO map, both of which vastly underestimate the magnitude and size of the localized freshening that is occurring during the rainy season. We also see noticeable differences in the major river outflows in the gulf of Mexico, which are not detectable in the Aquarius map due to its larger antenna footprint size. In addition we can see higher-resolution features than in Aquarius, such as in the East Pacific, and swirling diffusion patterns in the Amazon freshwater plume. The SMAP T_B-only product can enable novel science even as compared to Aquarius due to the higher spatial resolution and resulting closer to land SSS estimation validity.



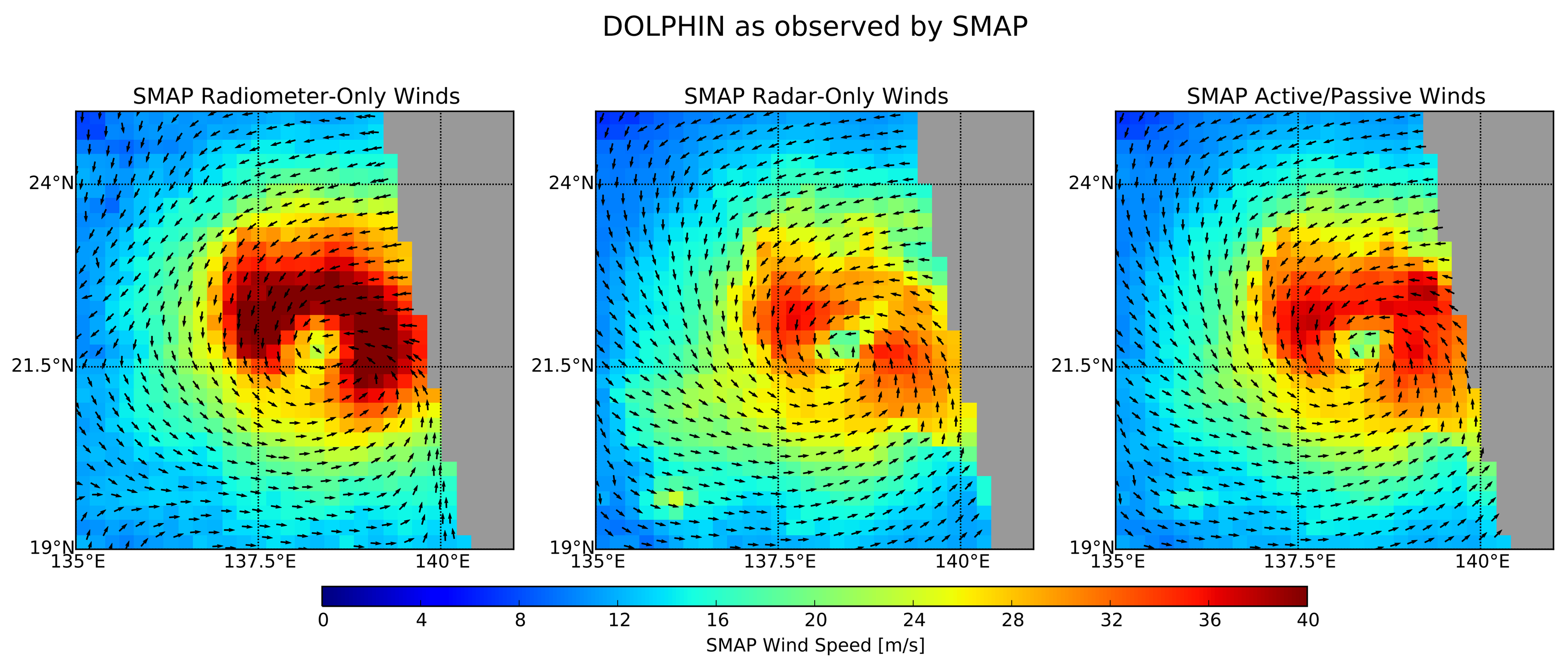
Various Aquarius and SMAP biases (left) and STD (right) of monthly Level 3 (L3) SSS products as compared to APDRC ARGO data for May 2015. For Aquarius we show the project products as well as the CAP (JPL produced) salinity products. For SMAP we show two types of T_B-only processing, one with an empirical T_B bias removal procedure applied and the combined radar / radiometer product. The legend of each shows the overall STD of SSS between $\pm 50°$ latitude. The SMAP CAP product is not significantly better than the T_B-only product due to the averaging criteria used to create the L3 data. The accuracy of the SMAP products is good, however, it is currently significantly worse than that from Aquarius and continues to have a bias issue at high/low latitudes.

Ocean Vector Winds

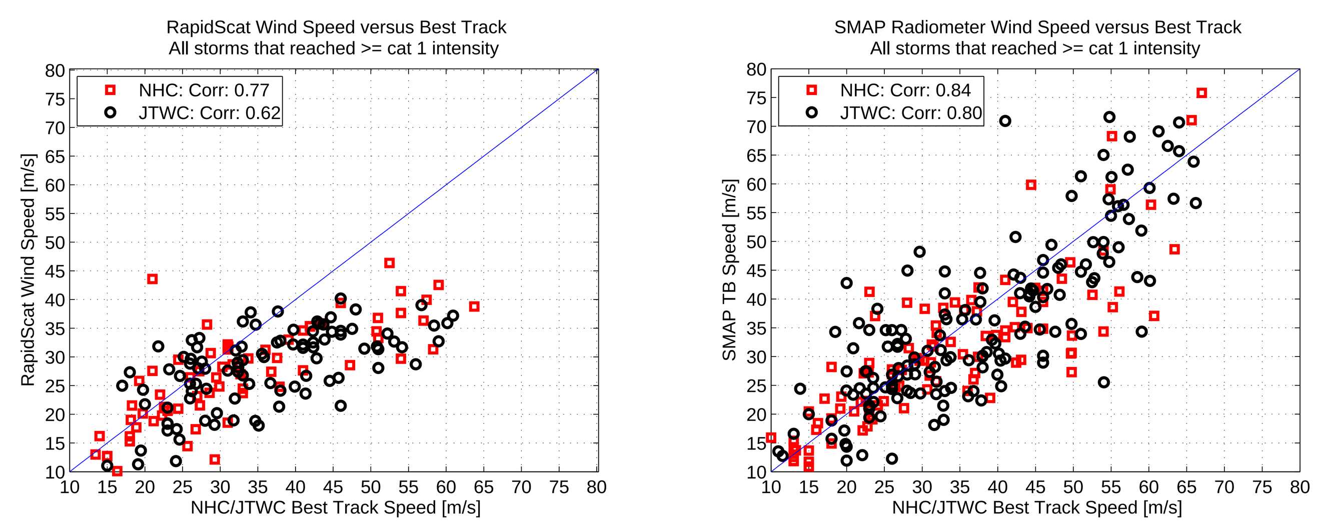


Joint collocation analysis of SMAP, RapidScat, and WindSat. (left) Speed mean difference (diamonds) and RMS difference (squares) of the RapidScat (blue), SMAP CAP (black), and SMAP radar-only (red) OVW data products versus WindSat / SSMI/S wind speed, conditioned on the WindSat / SSMI/S wind speed, (right) wind direction RMS difference (squares) as compared to ECMWF wind direction, conditioned on the WindSat / SSMI/S wind speed. Comparing the SMAP radar-only and SMAP CAP products, we find that the CAP product has a wind speed that is significantly better than the radar-only, about 0.4 m/s better in an RMS sense while the wind directions are only marginally improved by using the radiometer. Next comparing SMAP and RapidScat, we note that the SMAP CAP wind speed is worse than RapidScat for speeds between 6.5-12.5 m/s and direction is worse for speeds between 5.5 and 10.5 m/s, however, above 11.5-12.5 m/s it seems that the SMAP CAP wind speed and direction may be superior to that from RapidScat.

Extreme Winds



Various SMAP ocean vector wind retrievals in tropical cyclone Dolphin, where the best track speed indicated 41 m/s. (left) SMAP T_B-only wind vectors, (middle) SMAP radar-only wind vectors, and (right) SMAP CAP wind vectors. The T_B-only wind vectors are quite good in extreme winds and continue to be available after the failure of the SMAP radar.



(left) Scatter plot of peak RapidScat wind compared to best track wind speed for all hits on storms that reach category 1 intensity for RapidScat low SNR data, (right) same for the SMAP T_B-only extreme winds data product. The SMAP radiometer extreme winds product seems to maintain sensitivity to winds far past traditional scatterometers such as RapidScat, perhaps even as high as 70 m/s.

Summary

- SMAP active / passive ocean vector wind estimates approach the accuracy from traditional scatterometers and may out-perform for winds above 12-15 m/s.
- SMAP radiometer-only data has sensitivity to ocean surface winds far past that from traditional scatterometers, perhaps as high as 70 m/s.
- SMAP can continue the time series of ocean surface salinity data from Aquarius.
- Higher resolution of SMAP allows for new science as compared to Aquarius.

References

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