Perspectives for Future Enhancement of Spaceborne Salinity Observing Capabilities

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On behalf of a long list of US & international contributors to two community white papers in response to US Decadal Survey for Earth Science and Applications from Space (2017-2027) RFI1 and RFI2

Community white papers in response to Decadal Survey

Response to Decadal Survey RFI: Linkage of the Water Cycle, Ocean Circulation, and Climate

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Response to NRC 2017-2027 Decadal Survey Request for Information #2:

"Linkages of salinity with ocean circulation, water cycle, and climate variability"

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The three L-band (~1.4 GHz) satellite missions that have pioneered ocean salinity from space

Summary of satellite SSS achievements & ongoing challenges

See Monday presentations by Gary Lagerloef & Nicolas Reul:

- Oceanic features/processes (eddies, fronts, river plumes, Rossby waves, TIWs, SSSmax, SSSmin, etc.).
- Linkages with the water cycle (with atmosphere and land).
- Relationships with climate variability (MJO, IOD, ENSO, etc.).
- Emerging biogeochemical applications.
- Filling gaps in SSS observations (spatiotemporal scales & regions not resolved or inadequately sampled by in-situ platforms).

Three major requirements advocated by community response to Decadal Survey

- Improving high-latitude satellite SSS accuracies.
- Enhancing spatial resolution and getting closer to the coasts.
- Continuity of satellite SSS missions.

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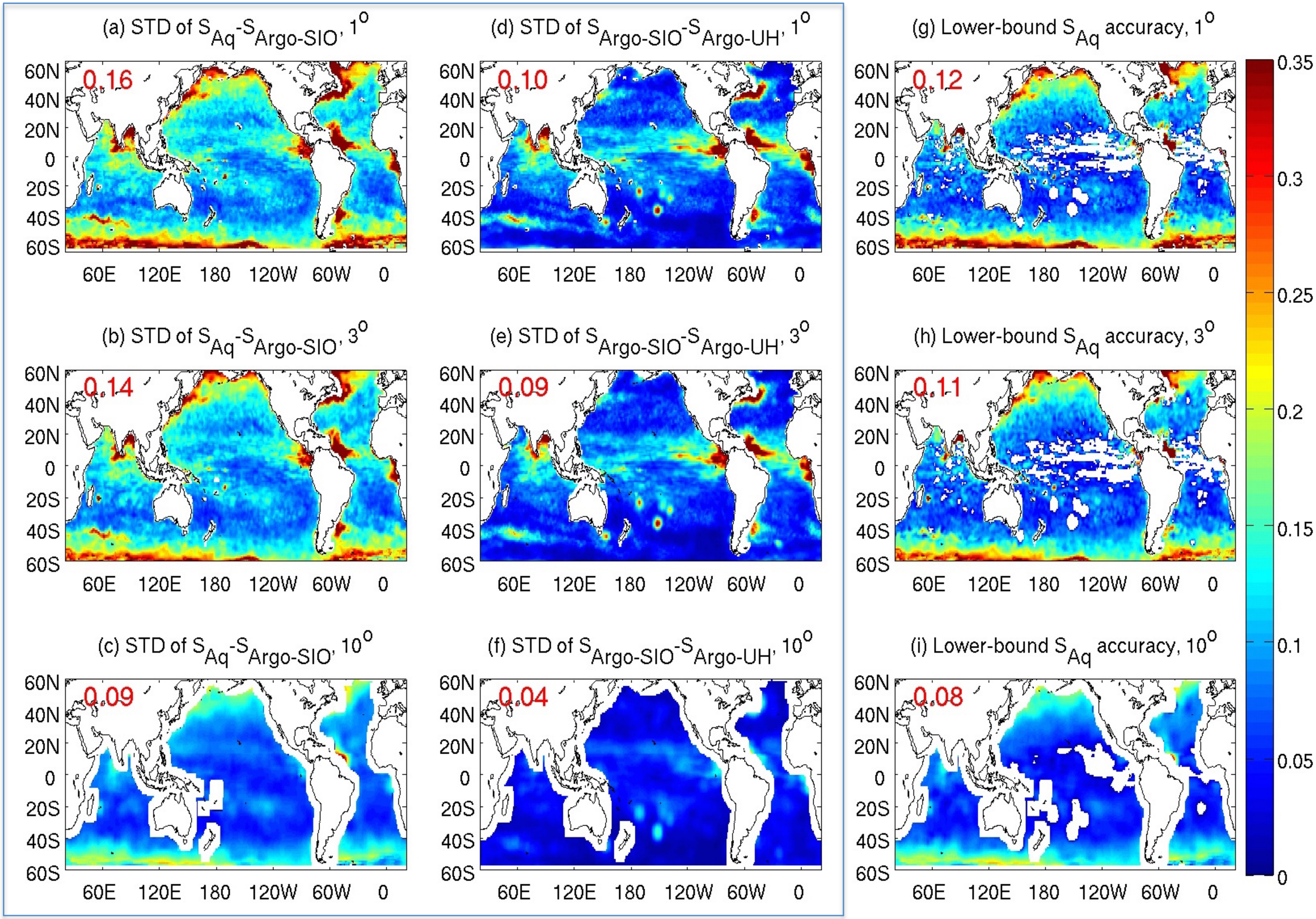
Improving high-latitude satellite SSS accuracies

Rationales:

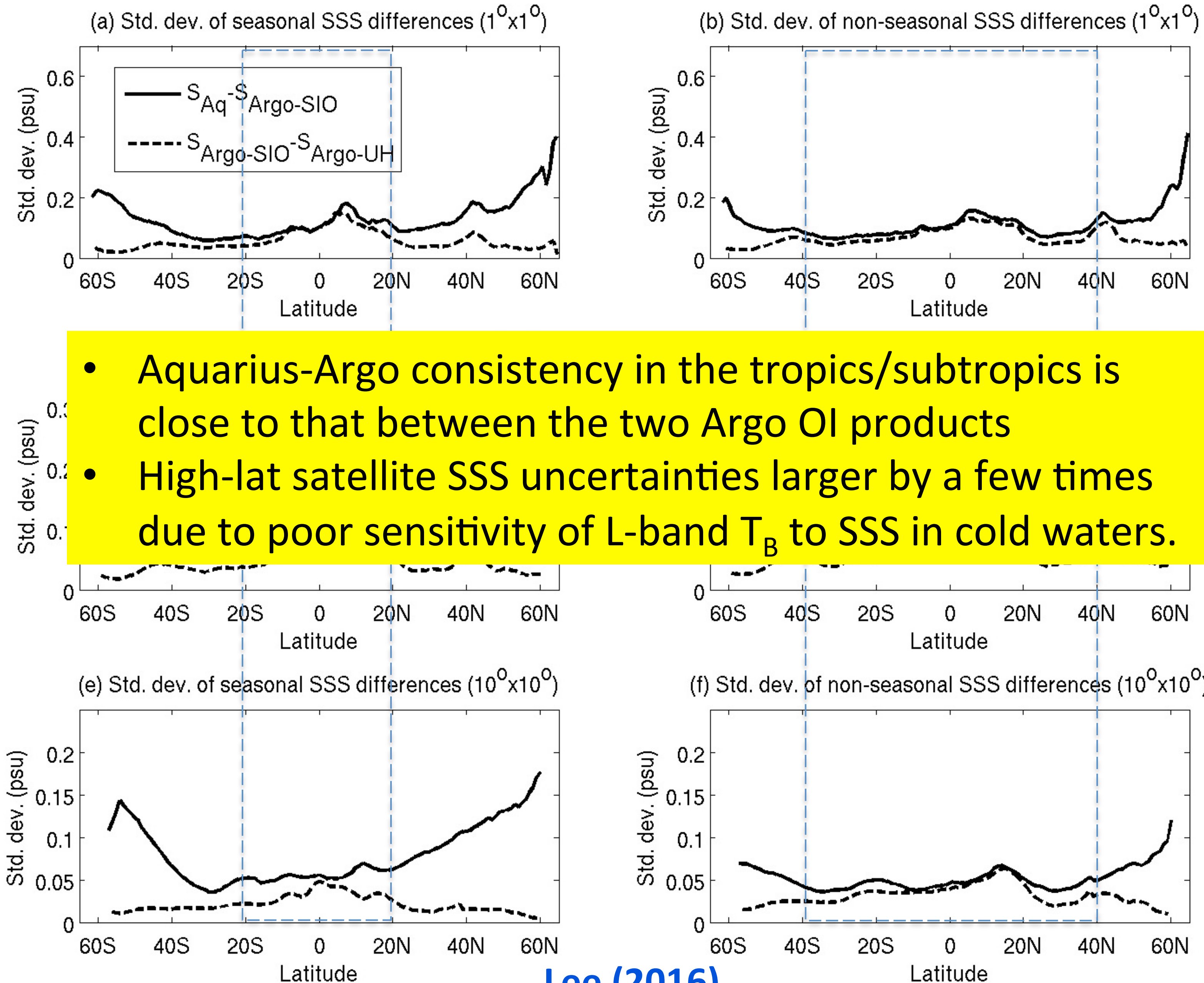
- Much larger uncertainties of high-latitude satellite SSS.
- Lack of in-situ salinity measurements, esp. in the Arctic Ocean.
- Importance of high-latitude SSS.

STD of SSS Difference for Aquarius - Argo-SIO & Argo-SIO vs. Argo-UH for different spatial scales (Lee 2016)



Zonally averaged STD of SSS differences for Aquarius vs. Argo-SIO & Argo-SIO vs. Argo-UH for different spatial scales (seasonal: left, non-seasonal: right)

Seasonal anomalies



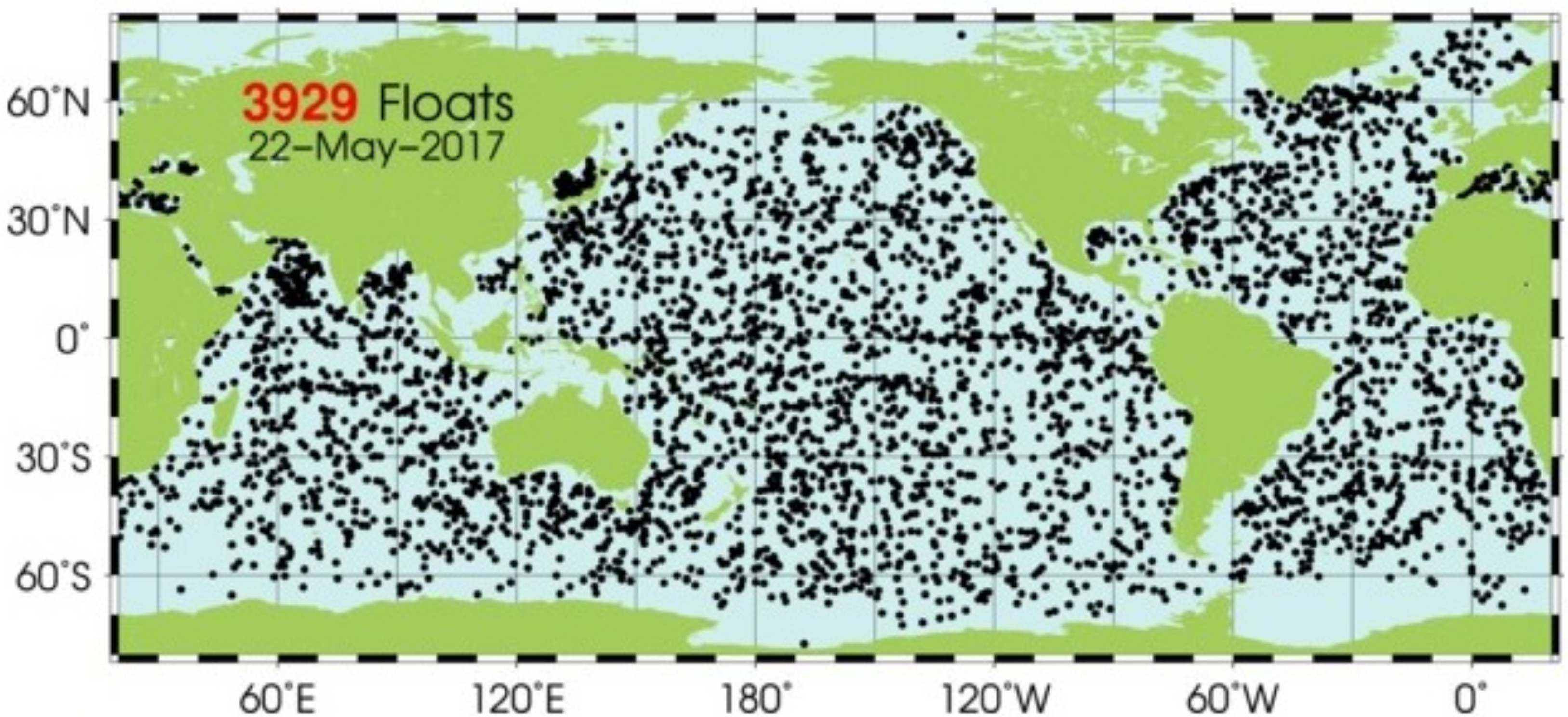
- Aquarius-Argo consistency in the tropics/subtropics is close to that between the two Argo OI products
- High-lat satellite SSS uncertainties larger by a few times due to poor sensitivity of L-band T_B to SSS in cold waters.

Non-seasonal anomalies

Lee (2016)

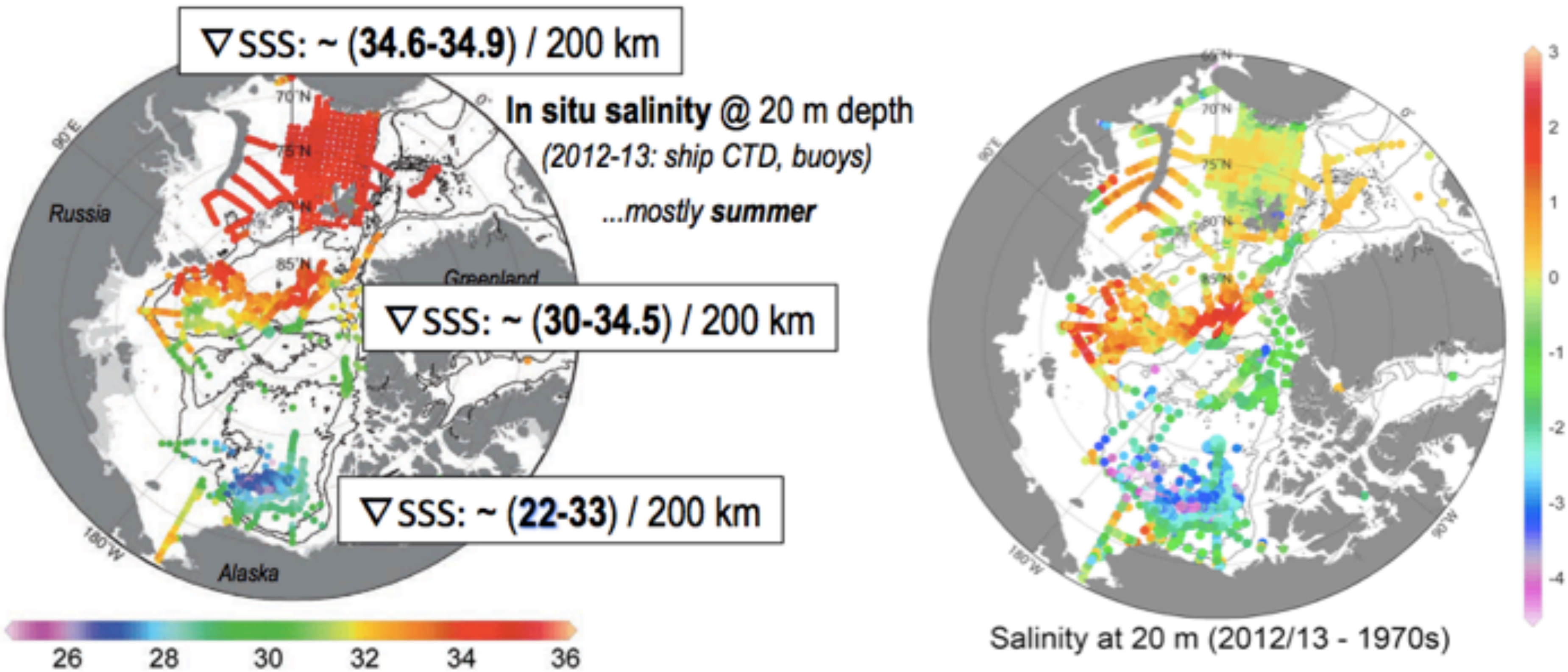
Importance of improving high-latitude satellite SSS

- Significant/dominant roles of salinity on density/stratification/steric height.
- Implications to water-mass formation.
- Monitoring Arctic freshwater pathways, redistribution, and interactions with subpolar North Atlantic.
- Potential effects on AMOC and the related transports (heat, freshwater, carbon, nutrients, …).
- …



Applicability of L-band SSS at high-latitude oceans

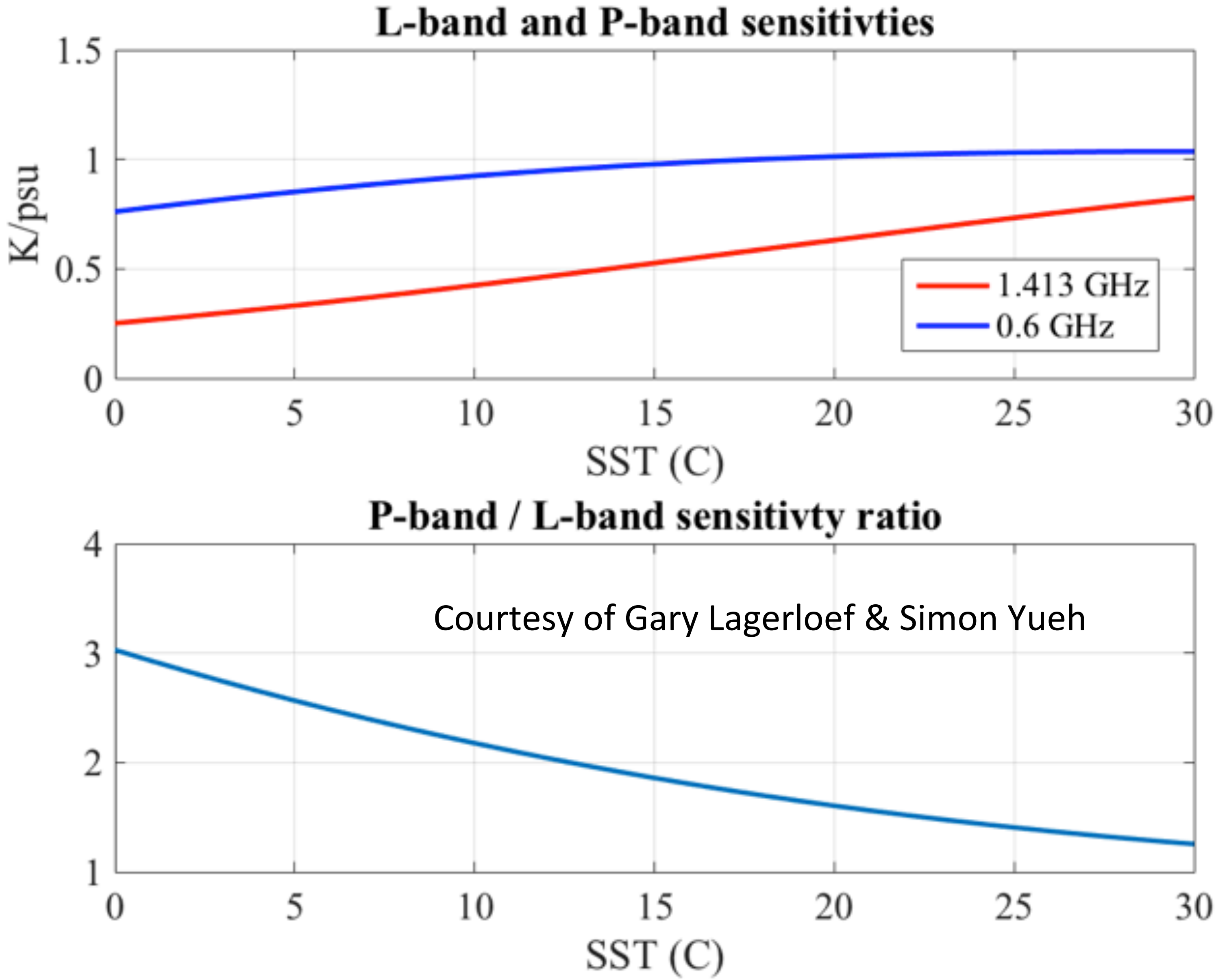
- Challenging for the Southern Ocean:
  e.g., the SSS gradient across the SAF & PF is below L-band SSS accuracy.
- Some potential for the Arctic Ocean due to the large SSS signals.



Timmermans et al. (2014) and NOAA Arctic Report Card 2013 Update.
Gradient estimates provided by Mike Steele of APL, University of Washington

The value of adding P-band radiometry:

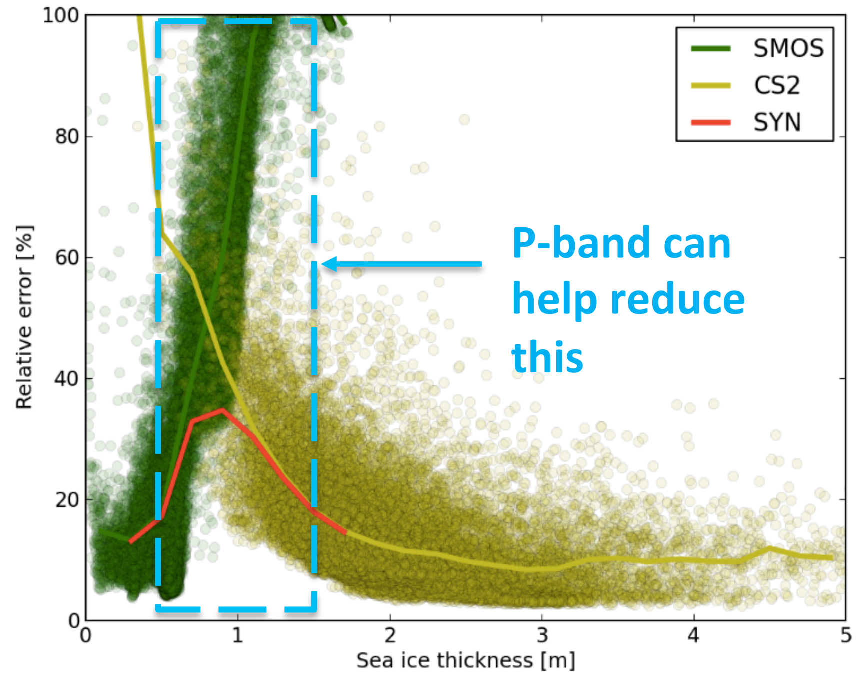
T_B at P-band has ~ 3 times better sensitivity to SSS than L-band

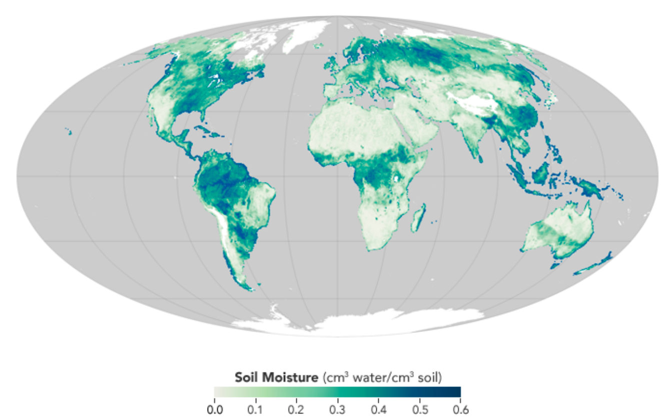


Additional values of P-band radiometry

- Improving sea ice thickness measurements by complementing radar and L-band radiometry measurements
- Better thickness measurements for 1st-year ice in turn help improve SSS retrievals near sea ice.
- Other values: measurements of ice shelf thickness, land applications (e.g., soil moisture, evapotranspiration, vegetation, …).

Sea-ice thickness measurement error (Kaleschke et al. 2015)





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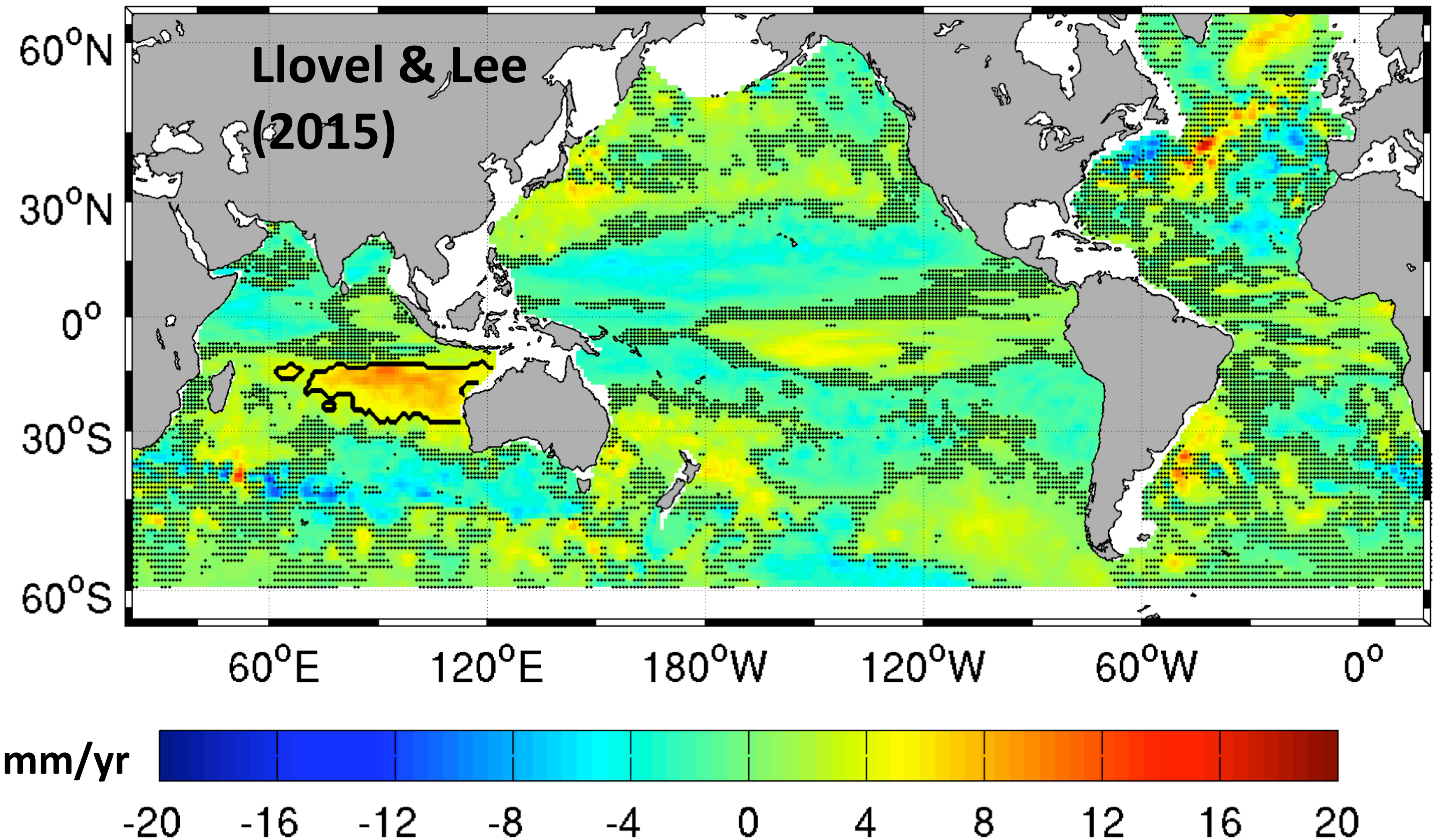
➢ **Enhancing spatial resolution and getting closer to the coasts.**

- Continuity of satellite SSS missions.

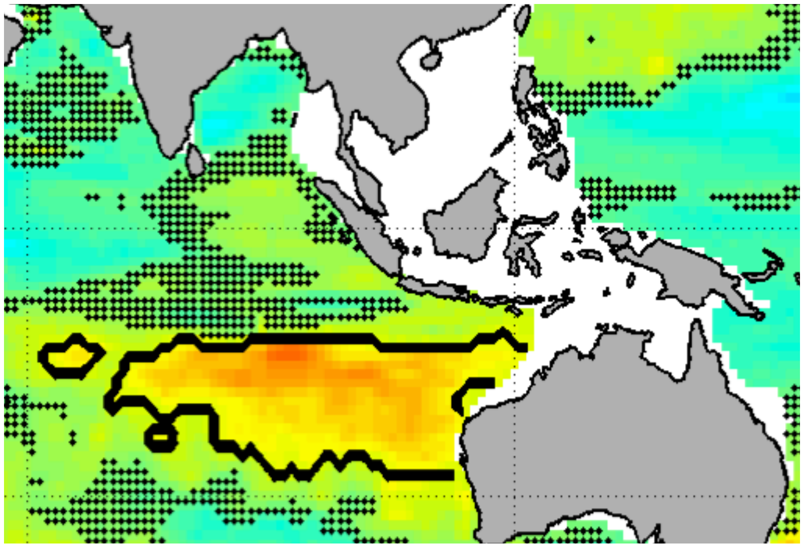
Enhancing spatial resolution and getting closer to the coasts

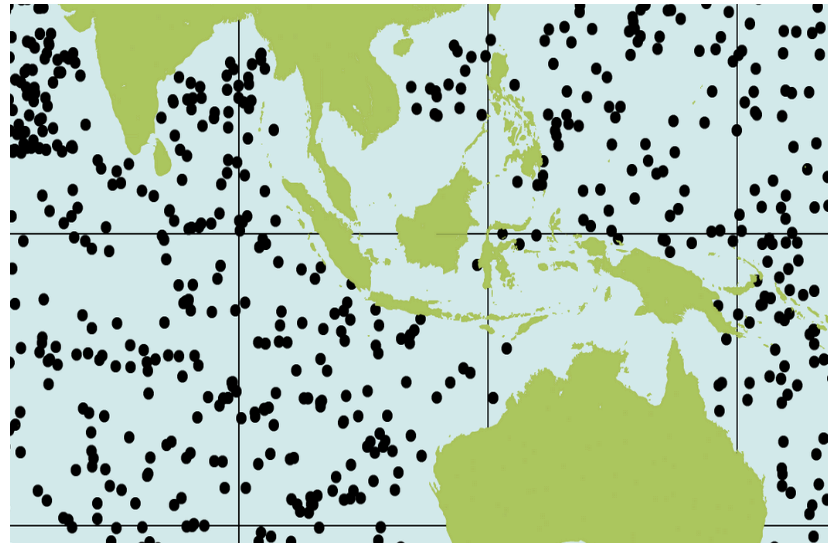
- Meso- & sub-mesoscale ocean dynamics (e.g., presentation by Amala Mahadevan).
- Linkage of ocean and terrestrial element of the water cycle.
- Importance to biogeochemistry.
- Implications to large-scale changes (example in the next slide)

Large trend of halosteric height (freshening) in the southeast Indian Ocean: implications to multi-decadal variability & climate change



SEIO freshening trend linked to possible changes in the Maritime Continent region *(Llovel and Lee 2015)*





Enhanced precipitation in the Maritime Continent ($V\,S\uparrow$ effect)?

Enhanced ITF transport ($V'S$ effect)? (e.g., Gordon et al. 2012)

Need good SSS in the Maritime Continent regions

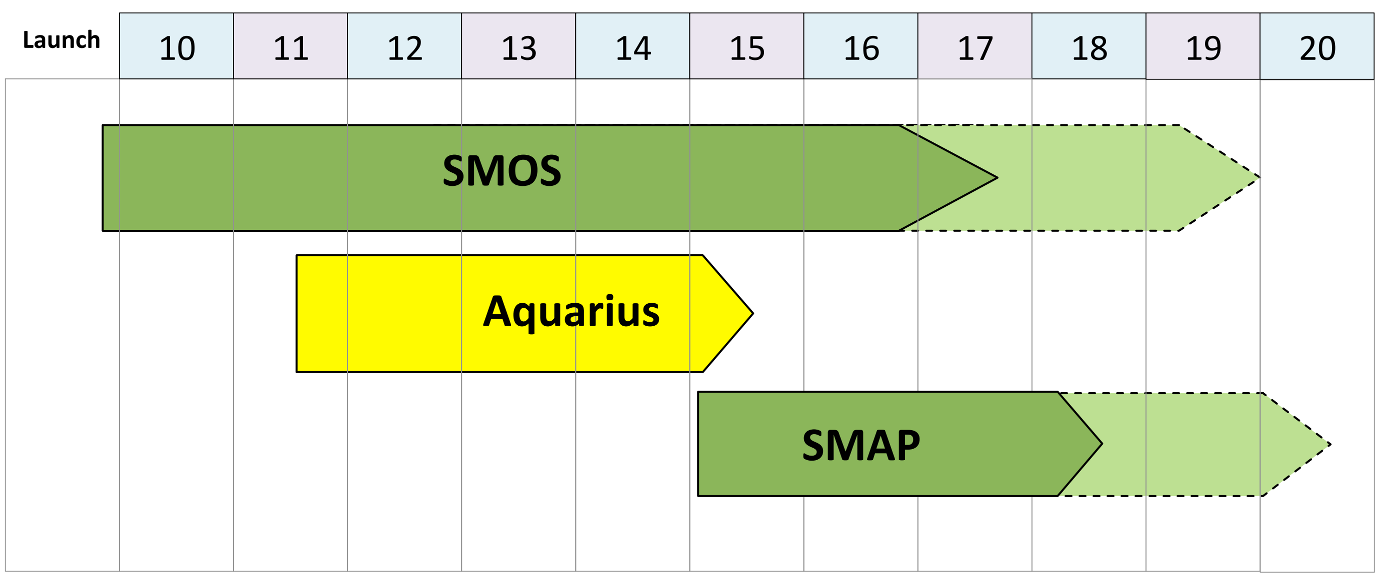
Three major requirements advocated by community response to Decadal Survey

- Improving high-latitude satellite SSS accuracies.
- Enhancing spatial resolution and getting closer to the coasts.

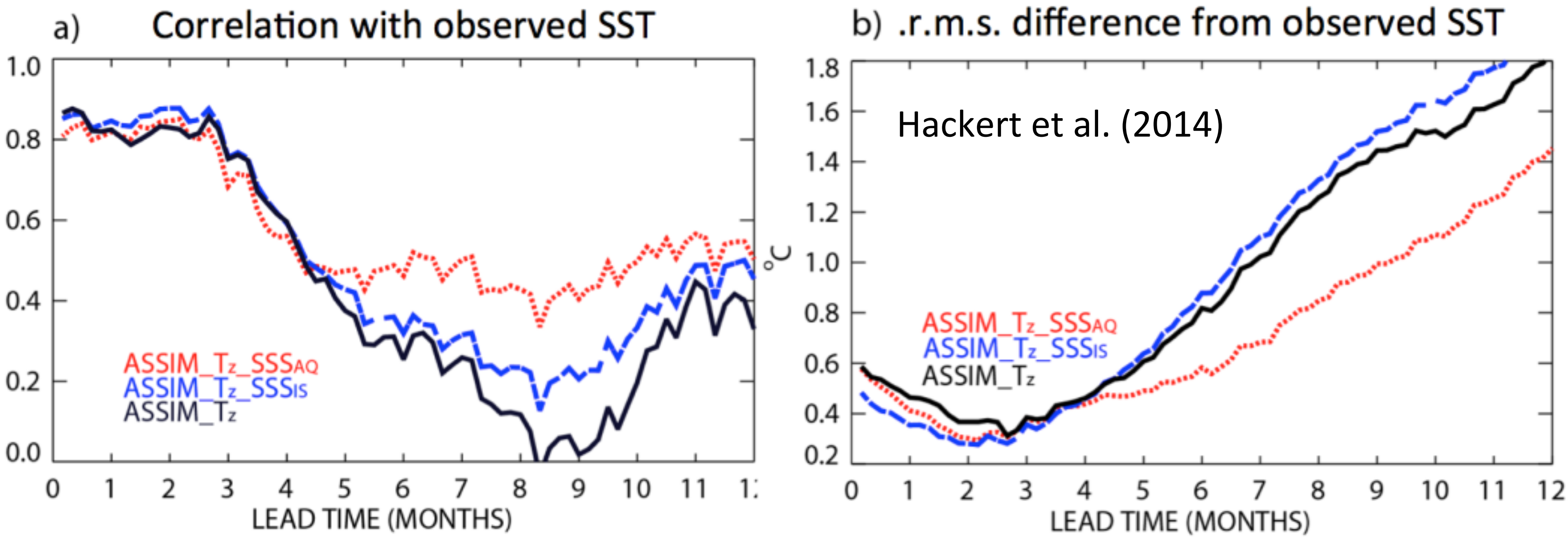
➢ Continuity of satellite SSS missions.

Continuity of satellite SSS missions

- Important for monitoring changes in the water cycle (emphasized by many presentations in this WS, e.g., Durack…)
- Necessary for studying and predicting seasonal, interannual, and decadal climate variability.



Impact of assimilating satellite SSS on SI prediction



$ASSIM\_T_Z$: baseline experiment, assimilation of all subsurface temperature data.

$ASSIM\_T_Z\_SSS_{IS}$: assimilation of all subsurface temperature and in-situ salinity data.

$ASSIM\_T_Z\_SSS_{AQ}$: assimilation of all subsurface temperature and Aquarius SSS data.

The latter has higher correlation & lower RMSE wrt observed SST for lead times > 4 months.

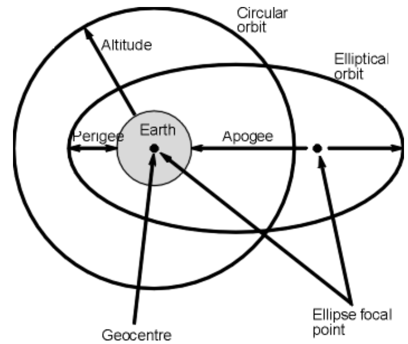
Need long data record (covering many ENSO events) to establish the robustness of impacts on prediction.

Other community advocacy for continuing satellite SSS

- US CLIVAR Phenomena, Observations, and Synthesis Panel.
- Tropical Pacific Observing System (TPOS) 2020, as part of the TPO2020 "Backbone System".
- WMO Integrated Global Observing Systems (WIGOS) Vision for 2040, as part of the "Backbone Component".

Additional considerations of future satellite SSS missions

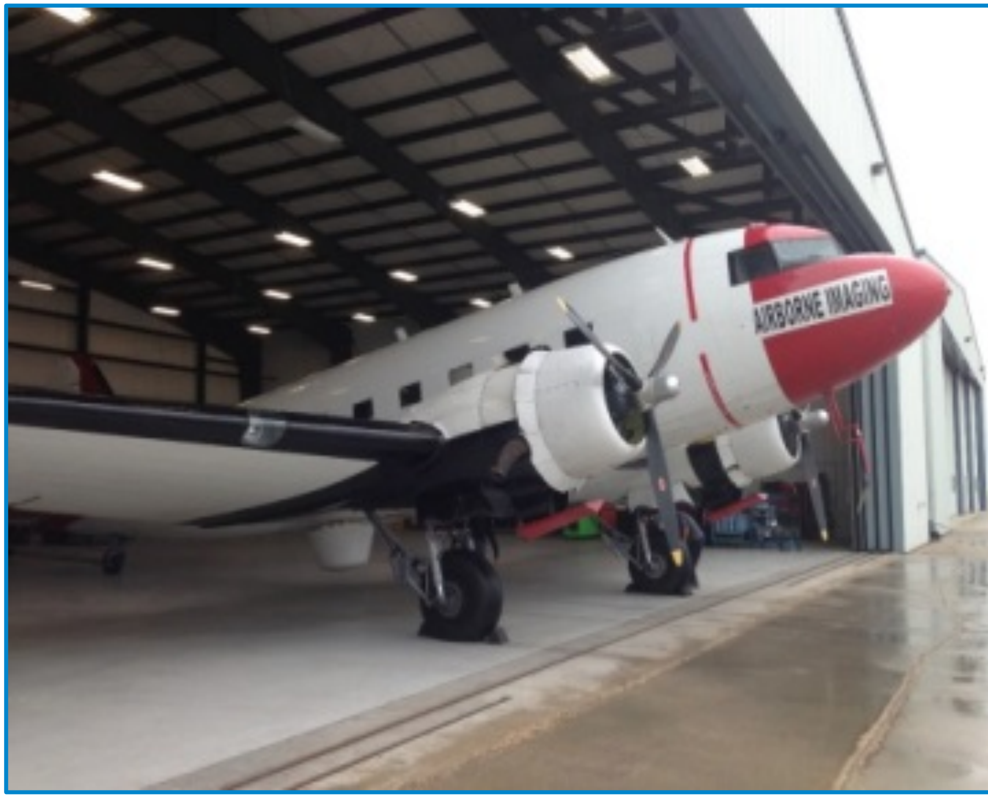
- Radio Frequency Interference (RFI) detection/mitigation.
- Retrieval algorithms (esp. corrections for contaminations by sea ice signals).
- Orbit consideration (e.g., circular vs. elliptical orbits).

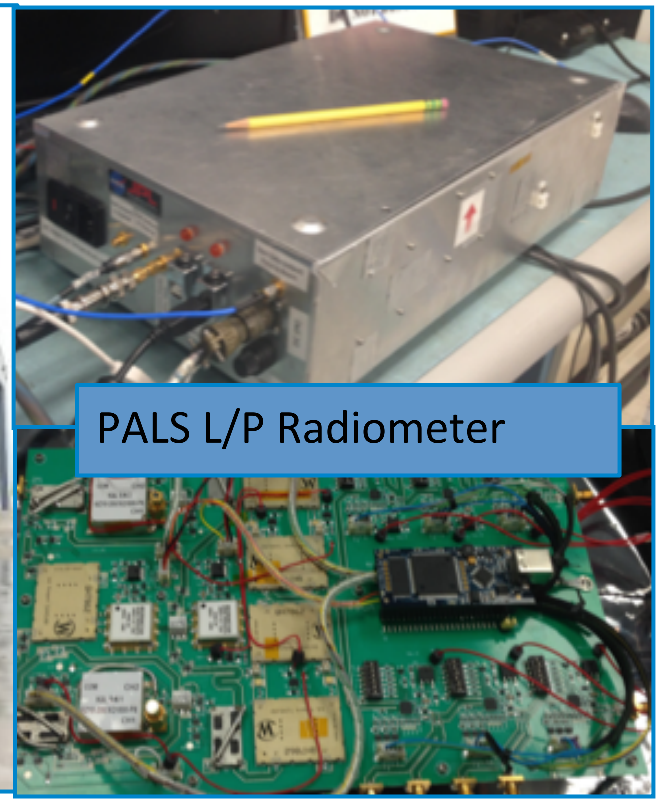


- Antenna technology (resolution vs. cost).
- Given cost constraint, how do we get sufficient resolutions to capture sub-mesoscale features and get close enough to the coasts and inland waters to maximize the benefit for biogeochemistry?

WMO Integrated Global Observing Systems (WIGOS) Vision for 2040 stated the need of satellite SSS as part of the "Backbone component", with sufficient resolutions to meet the need for coastal ocean/inland sea applications, esp. for biogeochemistry. The related technology needs to be developed.

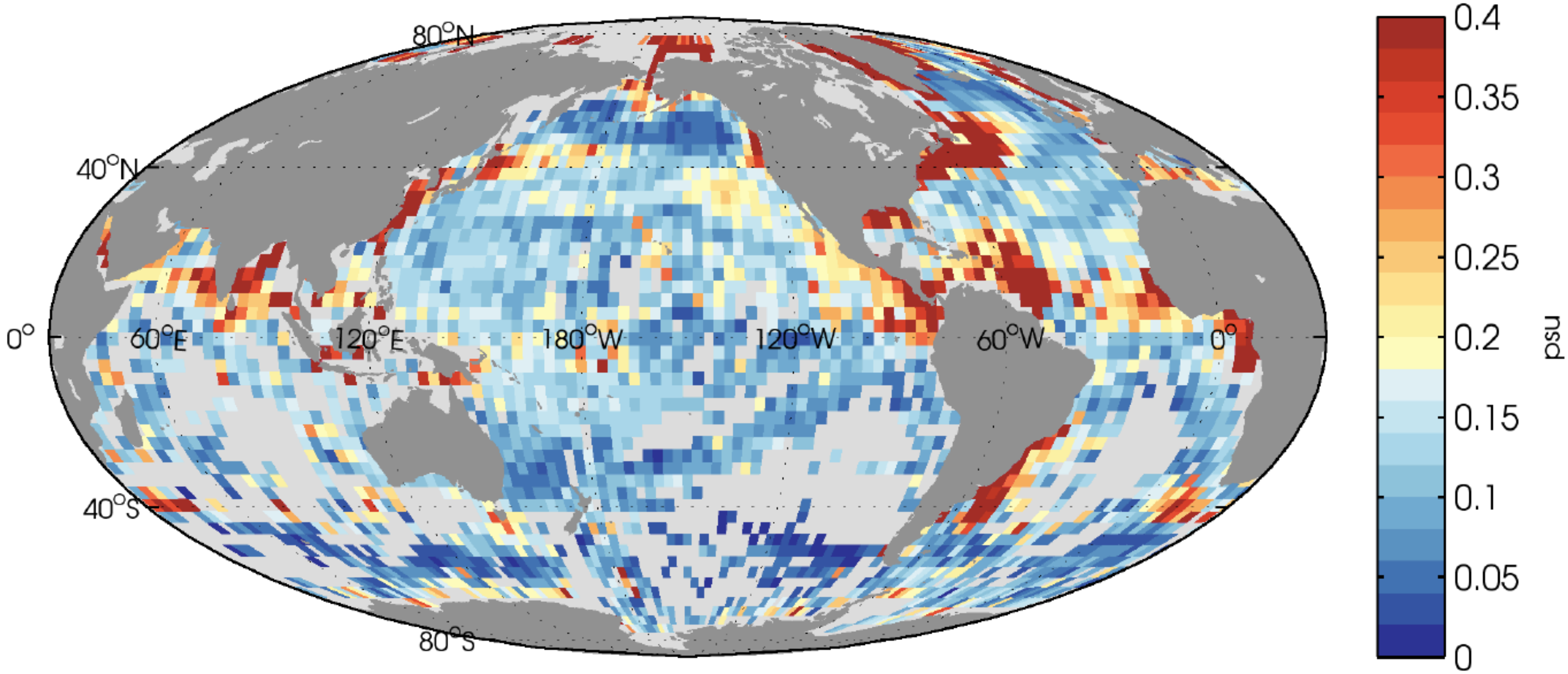
Examples of ongoing technology development:
next two presentations by Shannon Brown and Sid Misra





Variations of SSS within satellite footprints account for significant portion of differences between satellite SSS & in-situ point-wise measurements (Boutin et al. 2015, BAMS)

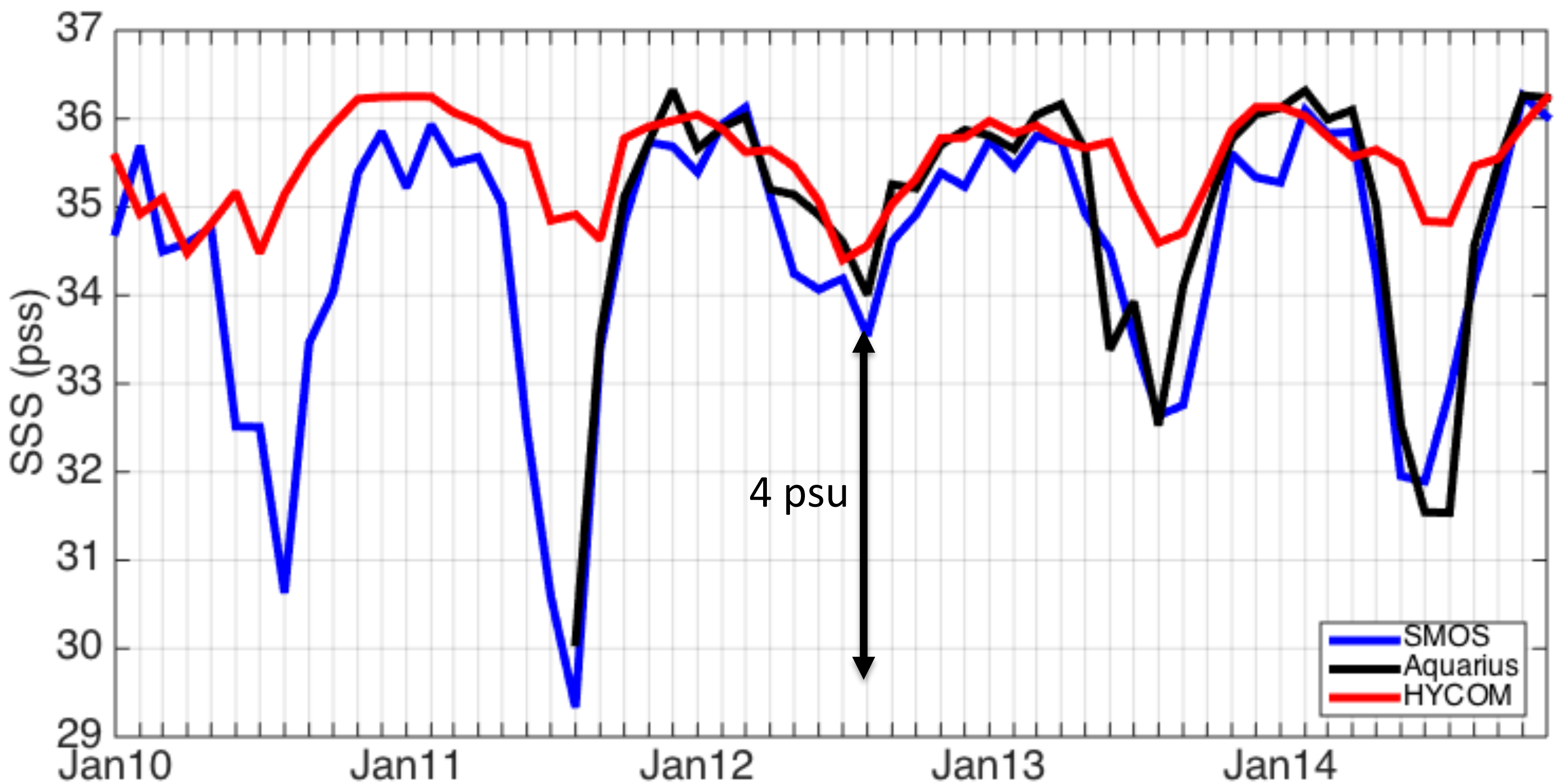
STD of SSS within 100-km increments along ship tracks, computed from high-density thermosalinograph (TSG) data



Courtesy of Kyla Drushka, APL/UW

Large interannual variations of SSS near Mississippi River mouth

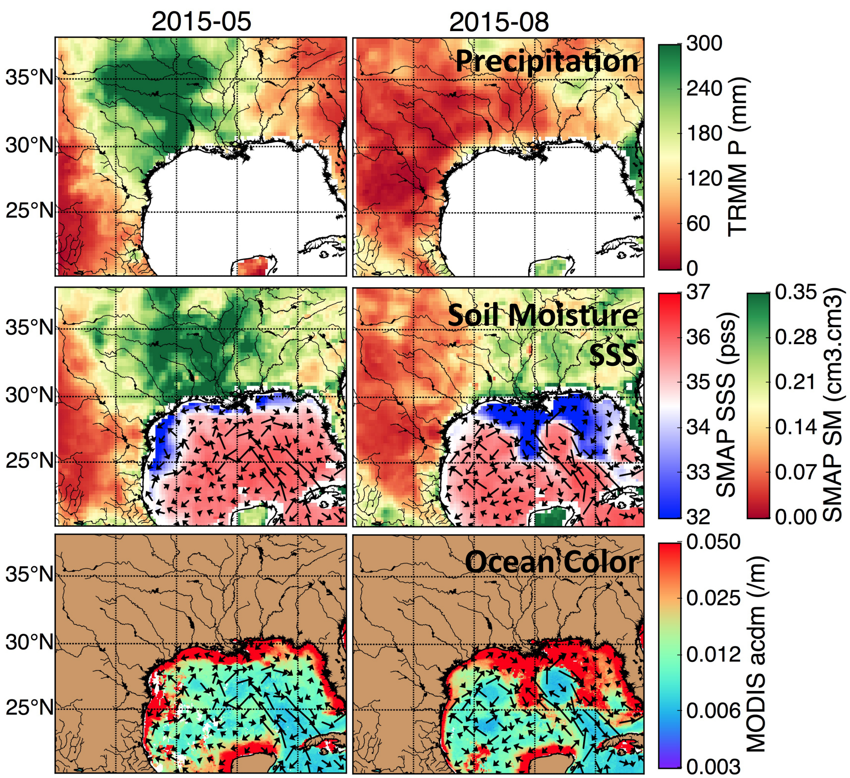
(Fournier, Lee, and Gierach 2016)



- Aquarius & SMOS revealed large interannual variations of SSS (up to 4 psu) near the M.R. mouth - not documented previously.
- Interannual changes of M.R. discharge found to be a major forcing.
- HYCOM analysis failed to capture the interannual variations.
  - Caused by climatological river discharge forcing & SSS relaxation to climatology
  - Underlines the importance of satellite SSS to constraint ocean state estimation

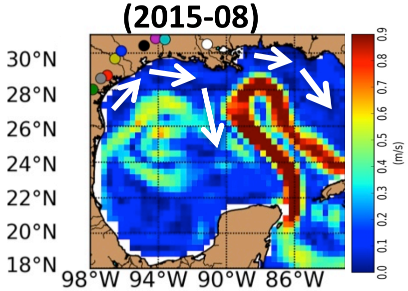
A combined land/sea assessment of the impacts of the May 2015 severe Texas flooding event

Fournier S., J.T. Reager, T. Lee, J. Vasquez, C. David, & M. Gierach (2016)



May and August 2015 GPM precipitation, SMAP soil moisture and sea surface salinity (SSS) and MODIS Ocean Color.. Vectors: JASON-2 surface currents.

Current Speed & schematics (2015-08)



August 2015 surface current speed (JASON-2) showing the Loop Current, its eddy, and schematics of the flow pattern that shaped the "horseshoe" freshwater plume

Problem: How does the May'15 severe flooding in Texas affect terrestrial hydrologic conditions, marine environment, and their linkage?

Finding: Intense rainfall in May'15 over Texas caused saturated soil & record river discharges into the Gulf of Mexico (GoM). The unusually strong Loop Current & its eddy shaped the freshwater into a "horseshoe" pattern, affecting thecentral GoM that's not normally influenced by river plume.

Significance: Implications to the extent of the GoM hypoxic zone and the Flower Garden Bank coral reef ecosystem. Multi-variate satellite observations (e.g., SMAP, GPM/TRMM, MODIS, JASON-2, GRACE, and SMOS) are essential to provide integrated assessment of land/sea impacts associated with flooding.