Jet Propulsion Laboratory
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Exploring the Synergy of Sea Surface Salinity, Ocean Bottom Pressure and Sea Surface Height to Study Arctic Ocean Freshwater Changes

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Motivations: Importance of studying Arctic Ocean freshwater changes and observing capability gap

- Arctic Ocean freshwater content and distribution are changing:
  - hydrological forcing (increased river runoff) - *Peterson et al., 2002*
  - cryospheric forcing (melting sea ice) - *Vaughan et al., 2013*
  - atmospheric forcing (accelerated winds and increased precipitation)
    Bintanja and Andry, 2017; Giles et al, 2012; Proshutinsky et al., 2002; Morison et al., 2012

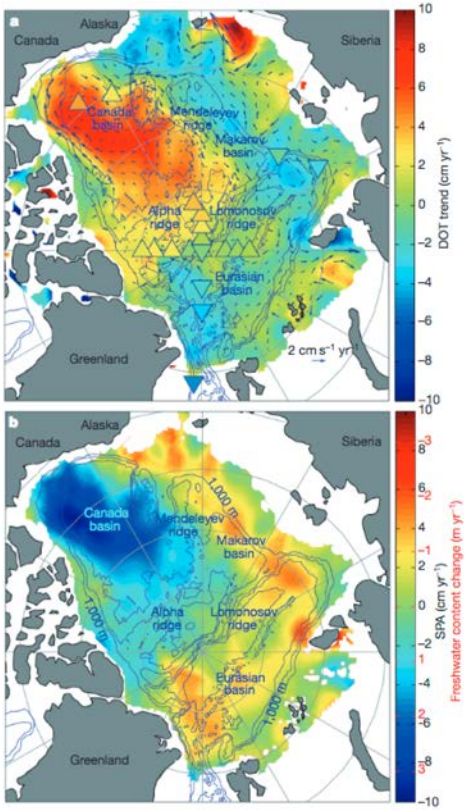
    -> potential impacts on:
    - North Atlantic and global ocean circulation and related redistributions of oceanic properties (heat, freshwater, carbon)
    - Arctic region air-sea interaction and Arctic-mid latitude interactions

- Observing system capability gap: paucity of in situ salinity measurements

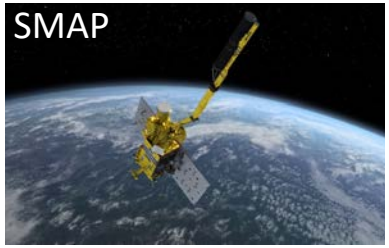
Synergistic use of satellite observations can enhance monitoring of Arctic freshwater changes

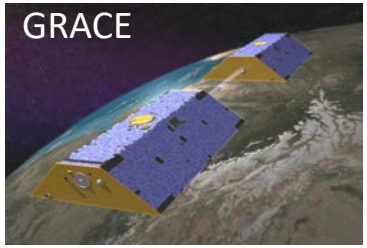
- Use of sea surface height minus ocean bottom pressure (SSH-OBP) to infer halosteric changes in the Arctic Ocean
  Morison et al., 2012; Giles et al., 2012; Armitage et al., 2016
  -> altimetry sampling limited compared to south of 66°N
  -> GRACE spatial resolution coarse

- Recent development of sea surface salinity (SSS) remote sensing (2010)
  -> better spatial and temporal sampling
  -> large uncertainties are expected at high latitudes
  Swift and McIntosh, 1983
  -> Arctic SSS signals are also large, S/N ratio needs to be assessed
  -> sparse in situ measurements for validation



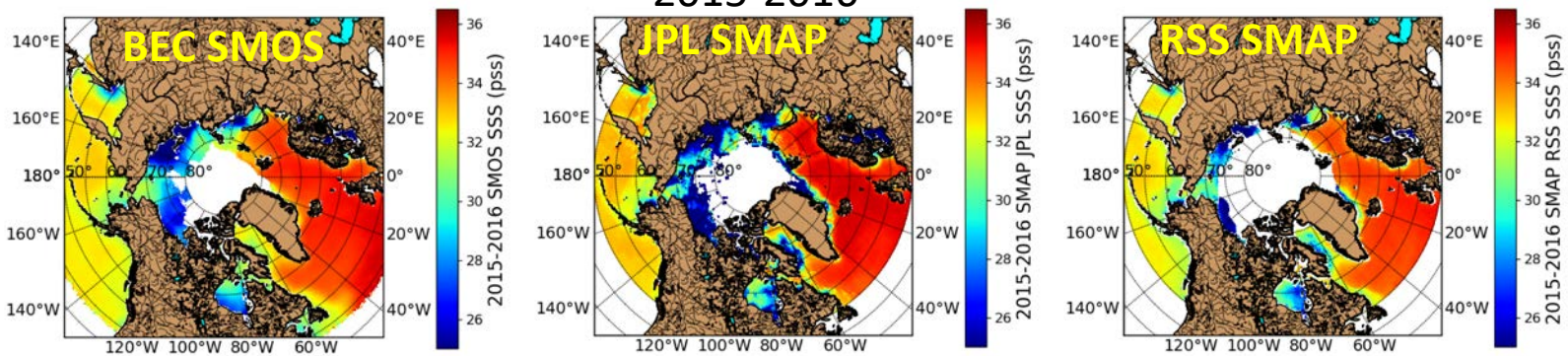
Morison et al., 2012

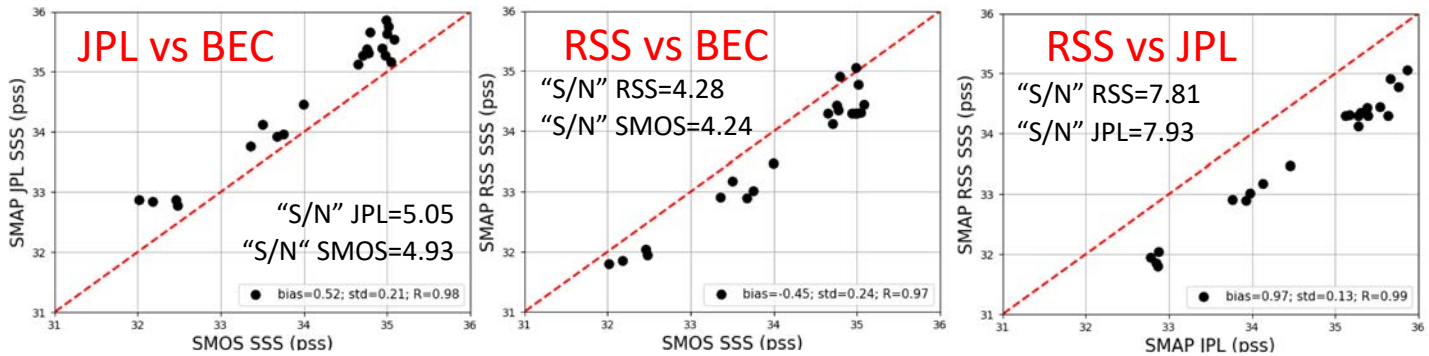




3 different SSS products in good agreement for Arctic Ocean average

2015-2016

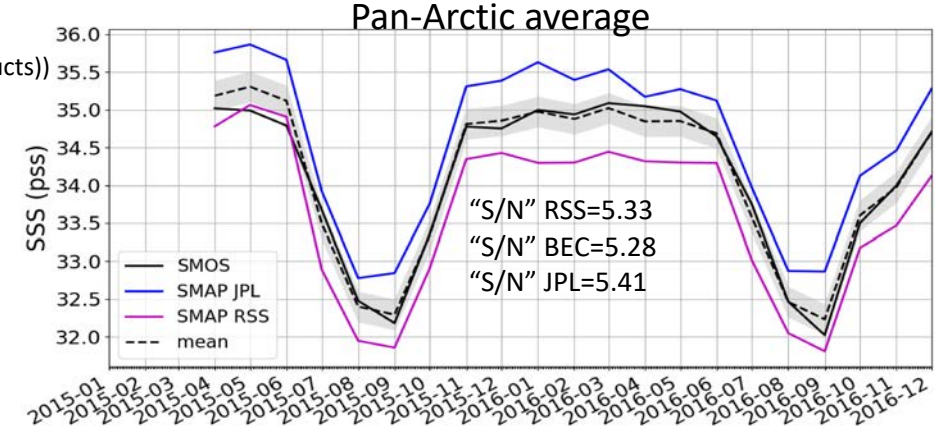




"Signal-to-noise" ratio: "S/N" = std(1 product)/std(difference between 2 products)
"Signal-to-noise" ratio: "S/N" = std(1 product)/mean(std(difference between 2 products))

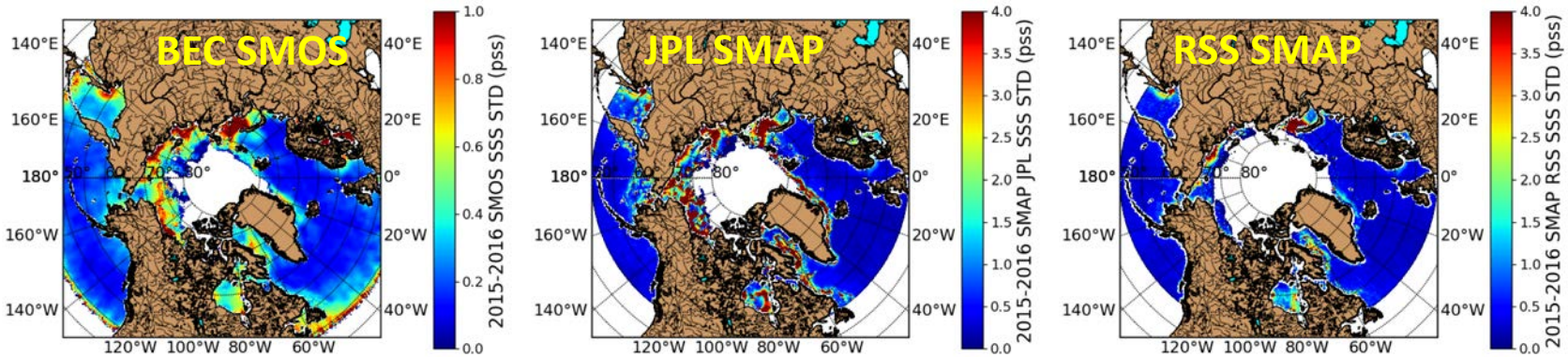
- 3 products in good agreement for Arctic Ocean average
- JPL SMAP saltier
- RSS ice mask more aggressive
- Large "S/N" ratio for Arctic average

Pan-Arctic average



3 SSS products have large differences in amplitude of variability

Temporal std (monthly)

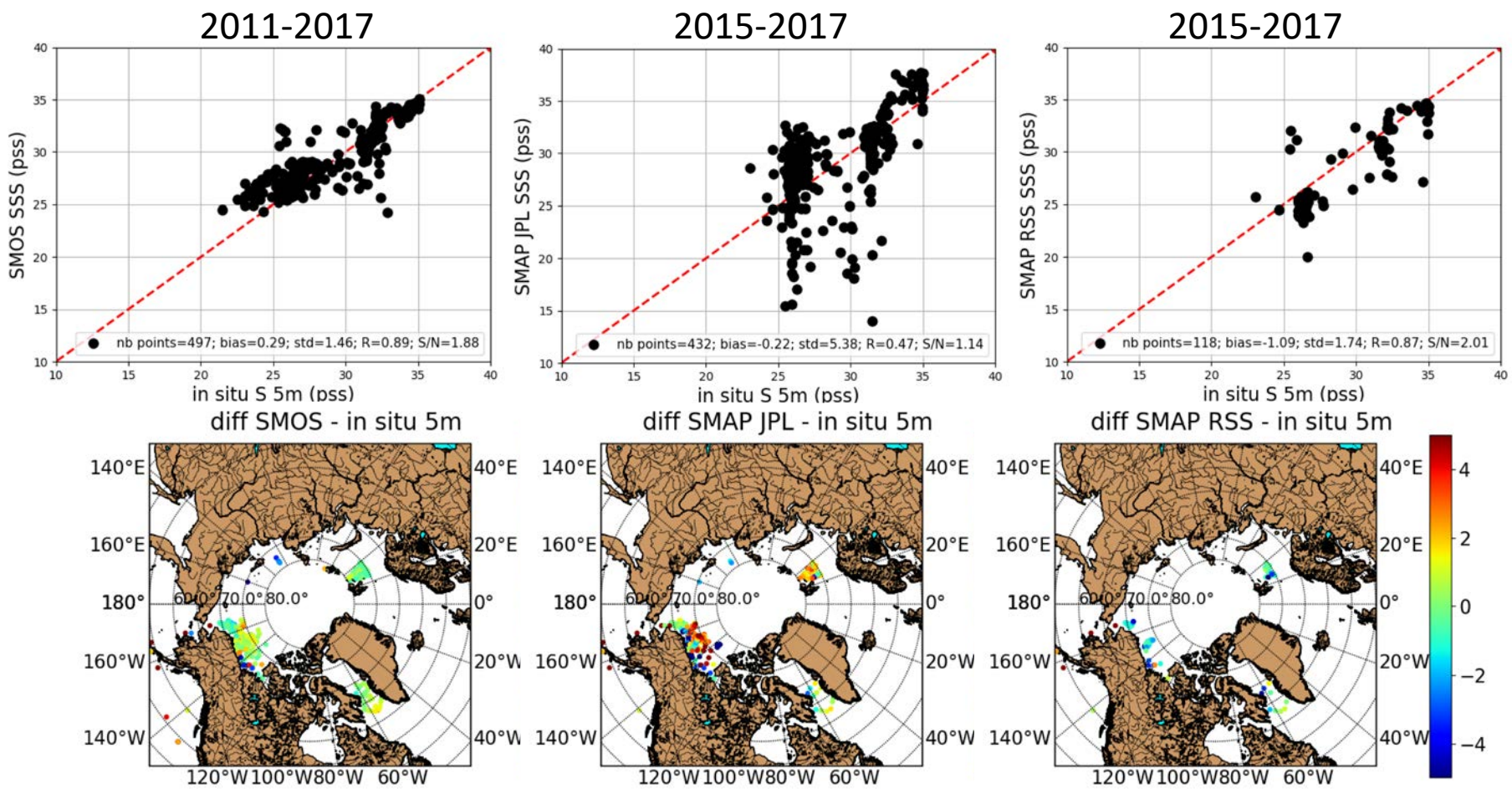


Different amplitudes!!

Similar regions of high SSS variability
But large difference in magnitude between SMAP & SMOS

Satellite-in situ comparisons

In situ data collected for the period 2011-2017 in the Arctic Ocean (M. Steele, S. Dickinson)



Limited in situ salinity data in the Arctic (Siberian Shelf, Kara Sea, Hudson Bay)
Important to understand satellite & in-situ sampling differences

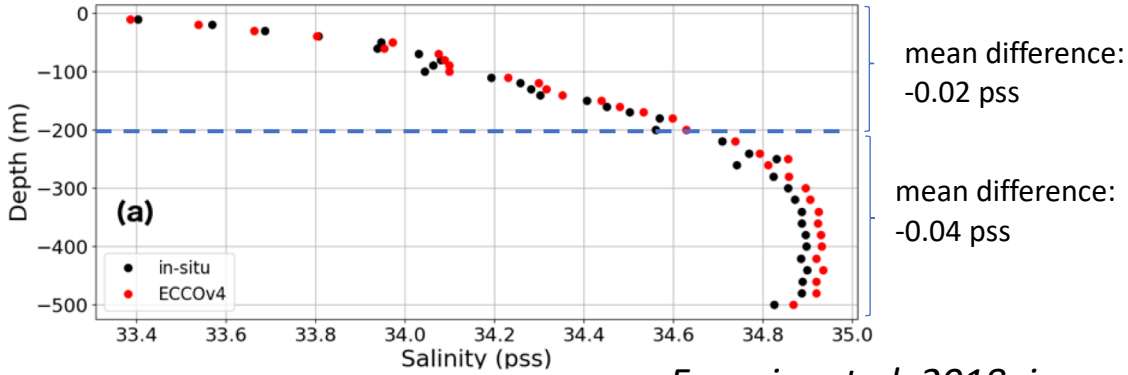
Questions:

- To what extent satellite SSS can serve as a proxy for freshwater changes in the ice-free Arctic Ocean?
- Can altimetry and gravimetry be used to evaluate SSS measurements in the ice-free Arctic Ocean?

Method:

- Examine relationships of SSS & SSH-OBP in ECCO-V4 ocean-ice state estimation product for a proof-of-concept study as a 1st step (1992-2015)
- Use altimetry and gravimetry to estimate freshwater content changes and compare with satellite SSS measurements
    - Examine consistency of Arctic altimetry and gravimetry products, respectively

ECCO-V4 ocean-ice state estimation reproduces very well the top 200 m salinity structure

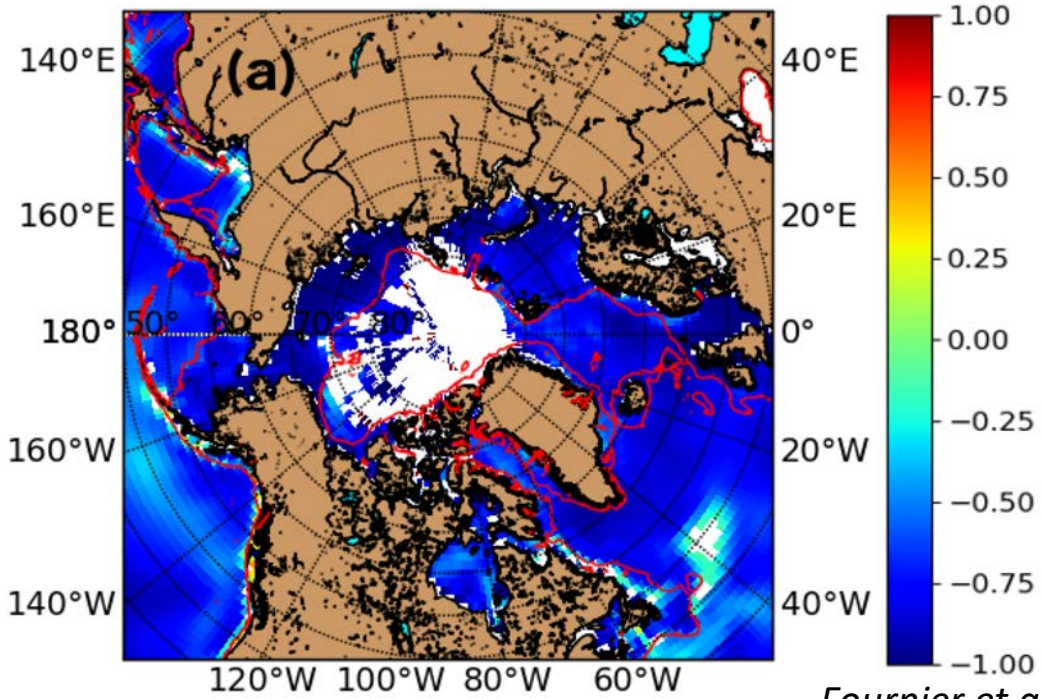


Fournier et al. 2018, in prep

- 1992-2015 time-mean daily salinity profile from in situ data (Ice-Tethered Profiler data) and co-located ECCO-v4 estimates (lat>65°N)
- The first 200 m dominate the steric changes

Sea Surface Salinity, a good proxy for freshwater changes above the halocline (ECCO-v4)

Local correlation of SSS & upper-200m halosteric height



Monthly
1992-2015

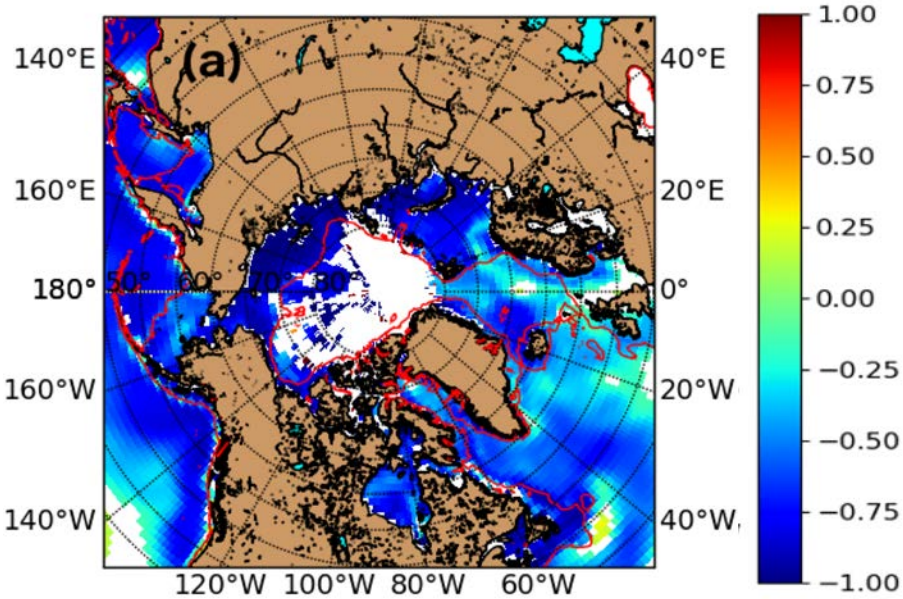
Fournier et al. 2018, in prep

- SSS/upper-200m halosteric height correlation, coherent over much of the Arctic Ocean
- Correlation coefficients of -0.80 averaged over the Arctic Ocean (lat>70°N)

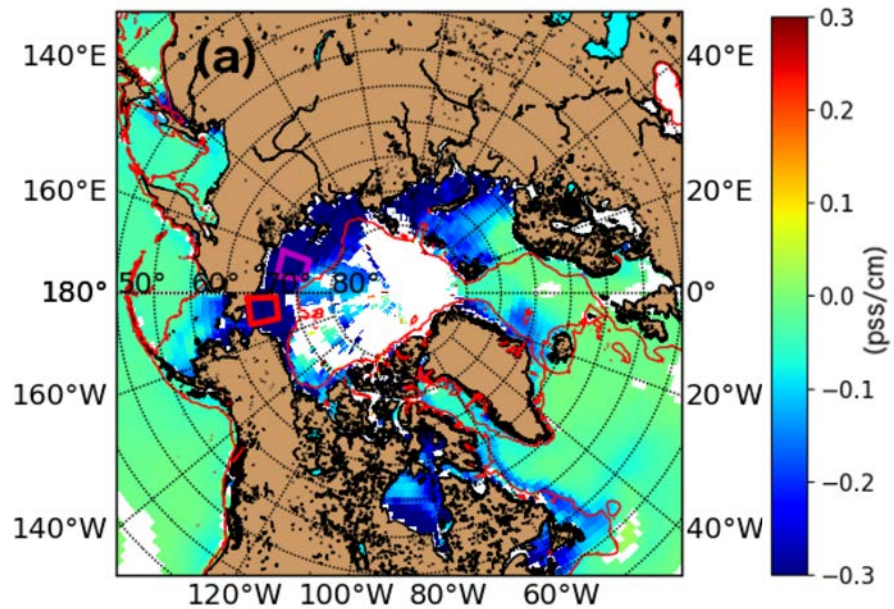
SSH-OBP (steric height mostly halosteric) and SSS are strongly anti-correlated especially in the shallow regions of the Arctic Ocean (ECCO-v4)

Monthly
1992-2015

SSS/SSH-OBP correlation coefficients



SSS/SSH-OBP regression coefficients

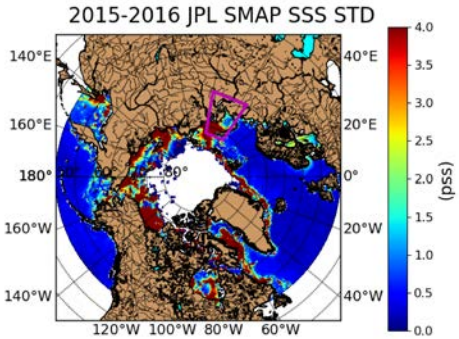


Fournier et al. 2018, in prep

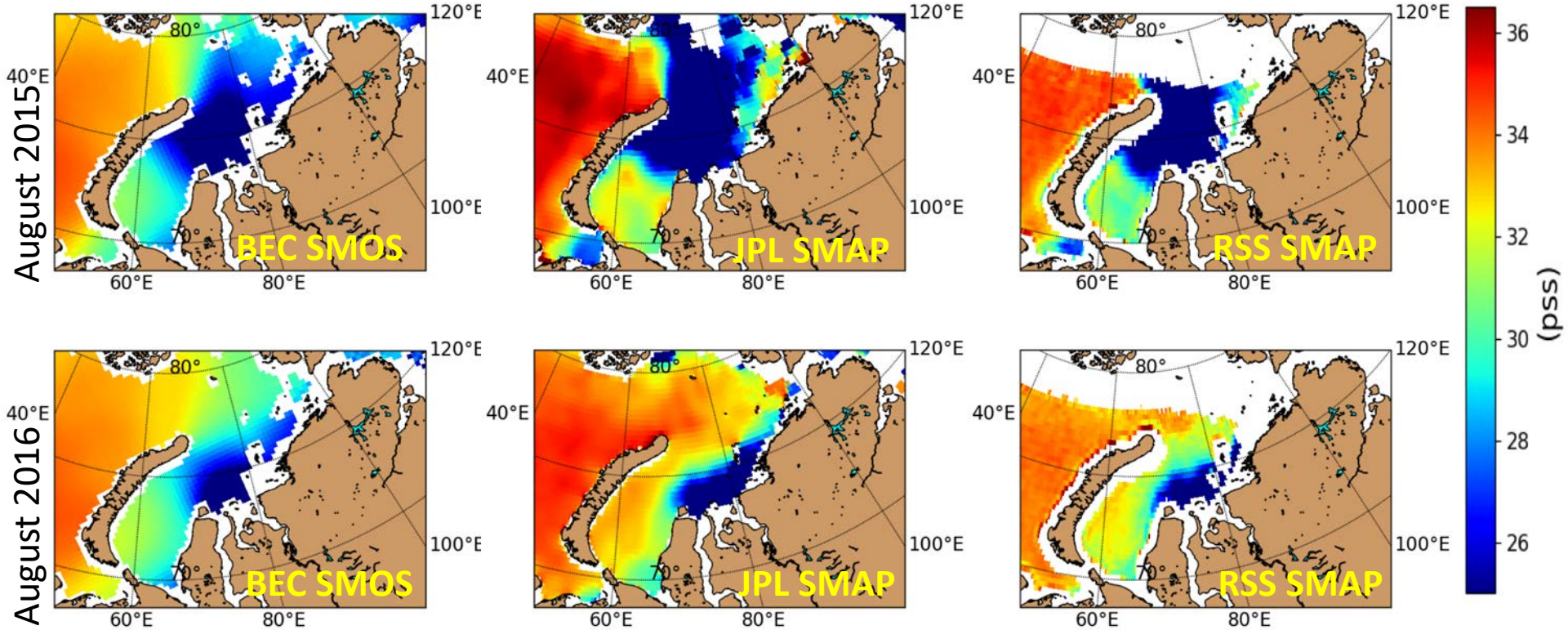
- Barents Sea: influence of the North Atlantic inflow of warmer and saltier waters
- Beaufort Gyre: steric changes are dominated by the fluctuation of the halocline depth due to Ekman pumping - *McPhee et al., 2009; Morison et al., 2012*

- Large regression coefficients ~-0.3 pss/cm or higher in magnitude in the shallower regions
- Deeper regions are also affected by wind-driven Ekman pumping, thermosteric effect, and deeper halosteric changes, not necessarily coherent with the SSS changes

Kara Sea, a case study – 3 SSS products observe fresher SSS in 2015 than 2016



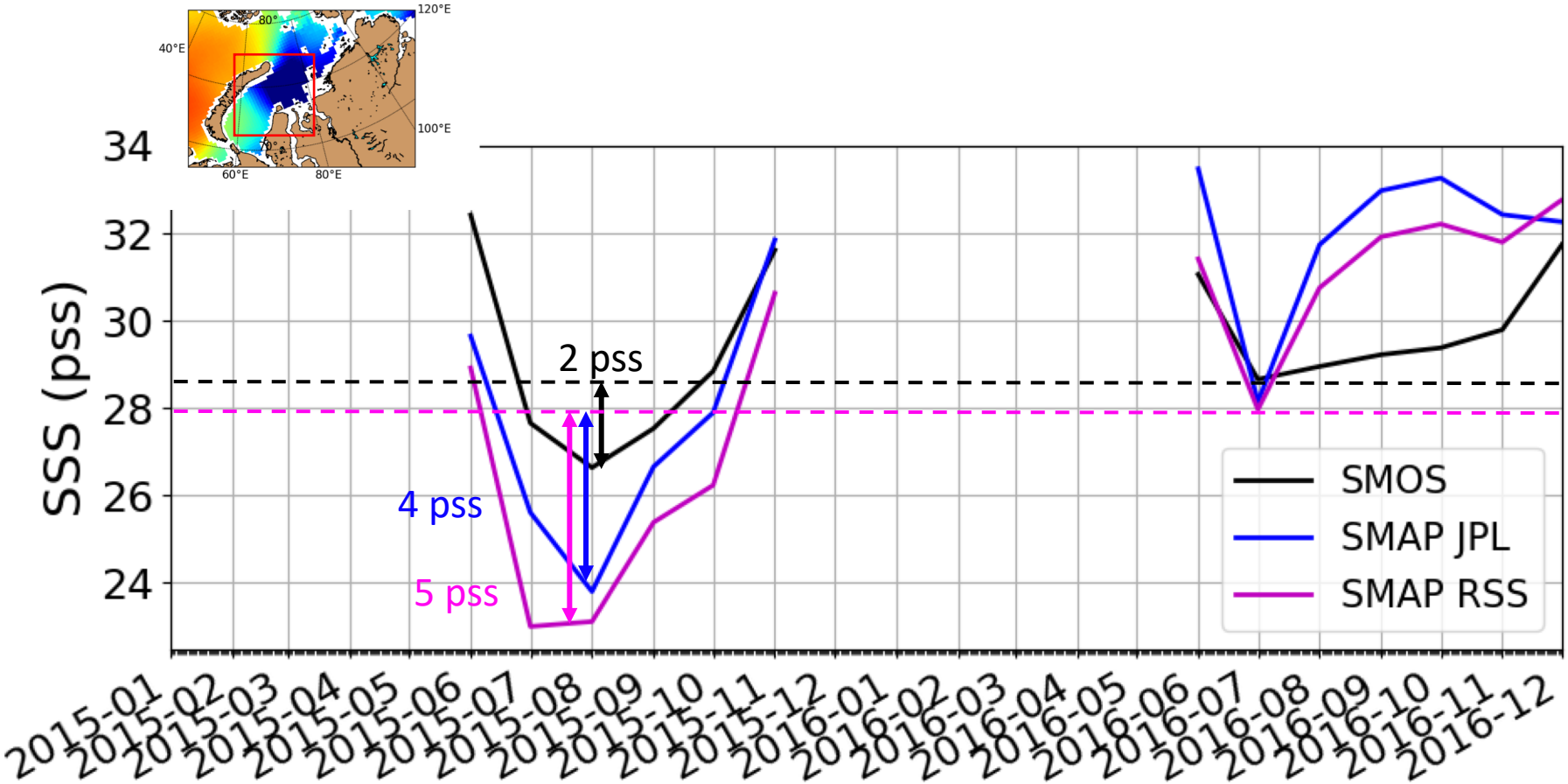
- SMAP SSS from Jet Propulsion Laboratory (JPL)
- SMAP SSS from Remote Sensing Systems (RSS)
- SMOS SSS specially processed for the Arctic Ocean from Barcelona Expert Center (BEC)



All 3 products capture fresher SSS in summer 2015 versus summer 2016 in the Kara Sea

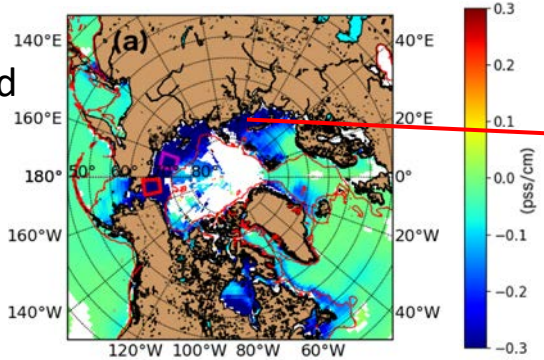
(as reported by Tang et al., 2018)

Different magnitude of the 2015 Kara Sea freshening among satellite SSS



Ongoing work: using altimetry and gravity to evaluate SSS, example of the Kara Sea

Regression coefficient between SSS and SSH-OBP based on ECCO-v4



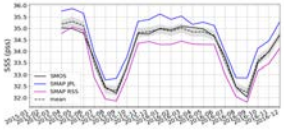
-0.45 pss/cm in this area in the Kara Sea (based on ECCO-v4)

Method:
Use the slope of the regression between SSS and SSH-OBP to evaluate the SSS change observed versus freshwater content changes observed by Altimetry and GRACE (SSH-OBP)

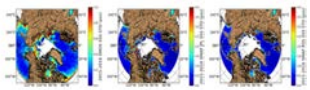
Example of the Kara Sea:
A 1 cm change observed in SSH-OBP should correspond to a -0.45 pss change in SSS
Uncertainties of SSH and OBP need to be taken into account

Ongoing work:
Evaluate consistency of Arctic altimetry products and Artic GRACE products

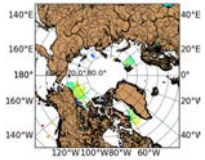
Summary



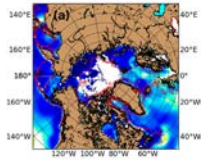
- Excellent Pan-Arctic consistency between BEC SMOS, JPL SMAP and REMSS SMAP products



- Spatial patterns of spatial variability consistent among products but the magnitude of the variability are very different

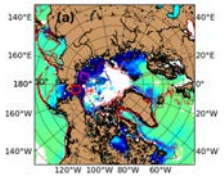


- Satellite-in situ salinity comparisons: in-situ observations are sparse in time and space in the Arctic Ocean region



- ECCO-v4 ocean-sea ice state estimation product illustrates the strong relationship of SSS and SSH-OBP variations around Arctic shelves

- This relationship shows that satellite SSS could be used to monitor freshwater changes and distribution in the ice-free Arctic Ocean along with altimetry and gravimetry data after validation of SSS measurements



- This relationship could be used to evaluate satellite SSS in the ice-free Arctic Ocean using altimetry and gravimetry data and improve SSS retrievals

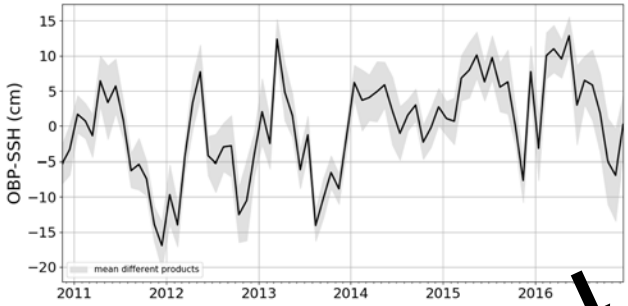
- Ongoing work: Evaluate the consistency of different altimetry and gravimetry products in the Arctic Ocean and the measurement uncertainties

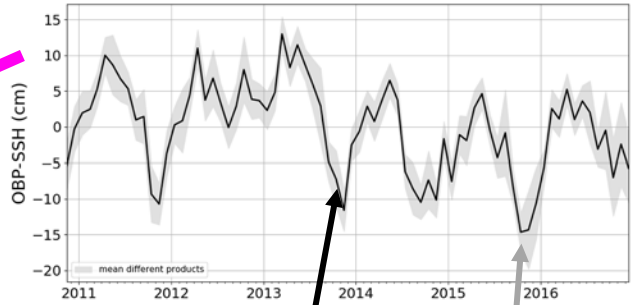
Relationships with only 3 or 10 years of ECCO data:

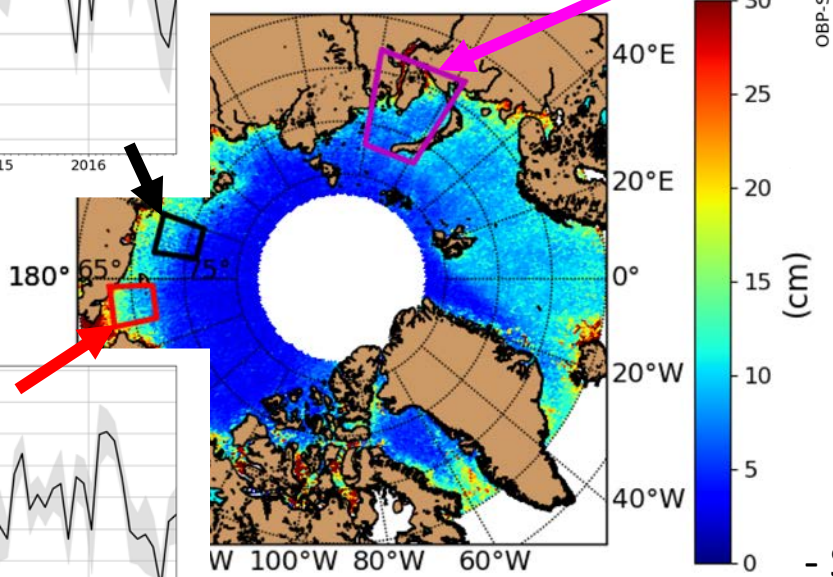
- SSS/HST not much changes anywhere
- SSS/SSH becomes not significant even on the Arctic Shelves
- SSS/SSH-OBP large changes in the Pacific and North Atlantic Ocean but not much changes on the Arctic shelves

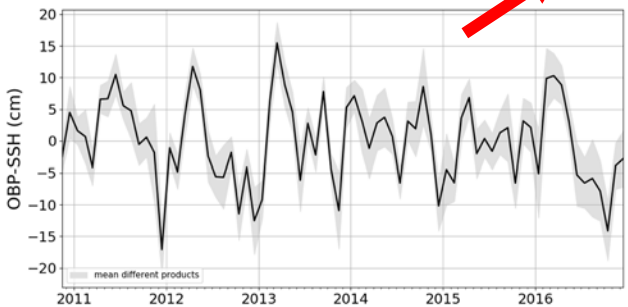
A need to evaluate the consistency of altimetry and gravimetry products

- Several altimetry/gravimetry products available (Cryosat-2/GRACE):
  - Dynamic Ocean Topography (DOT) - *Armitage et al., 2018*
  - DTU-TUM v2 2018
  - JPL RL05M_1.MSCNv02 monthly global mascons (https://grace.jpl.nasa.gov/data/get-data/jpl_global_mascons/)
  - UT-CSR RL-05 monthly global mascons (http://www2.csr.utexas.edu/grace/RL05_mascons.html)









Average OBP-SSH among different satellite products

- Spread among products
- Also need to account for SSH and OBP measurement uncertainties (ongoing work)