Comparison of Salinity and Freshwater Content in the Arctic Ocean and Beaufort Gyre using in situ, satellite and model simulations

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Data

Satellites

- **SMOS**: (Soil Moisture and Ocean Salinity) Version 3.1, BEC
  - 25 km EASE-Grid 2.0
  - 3 days temporal resolution
- **SMAP:** (Soil Moisture Active Passive) L3 V5.0 product, RSS
  - 0.25° × 0.25° daily gridded product with 8-day running mean
- **OISSS:** (Multi-mission SSS Optimum Interpolation Analysis) Level 4 V1.0, IPRC
  - 0.25° × 0.25° gridded product
  - 4-day temporal resolution

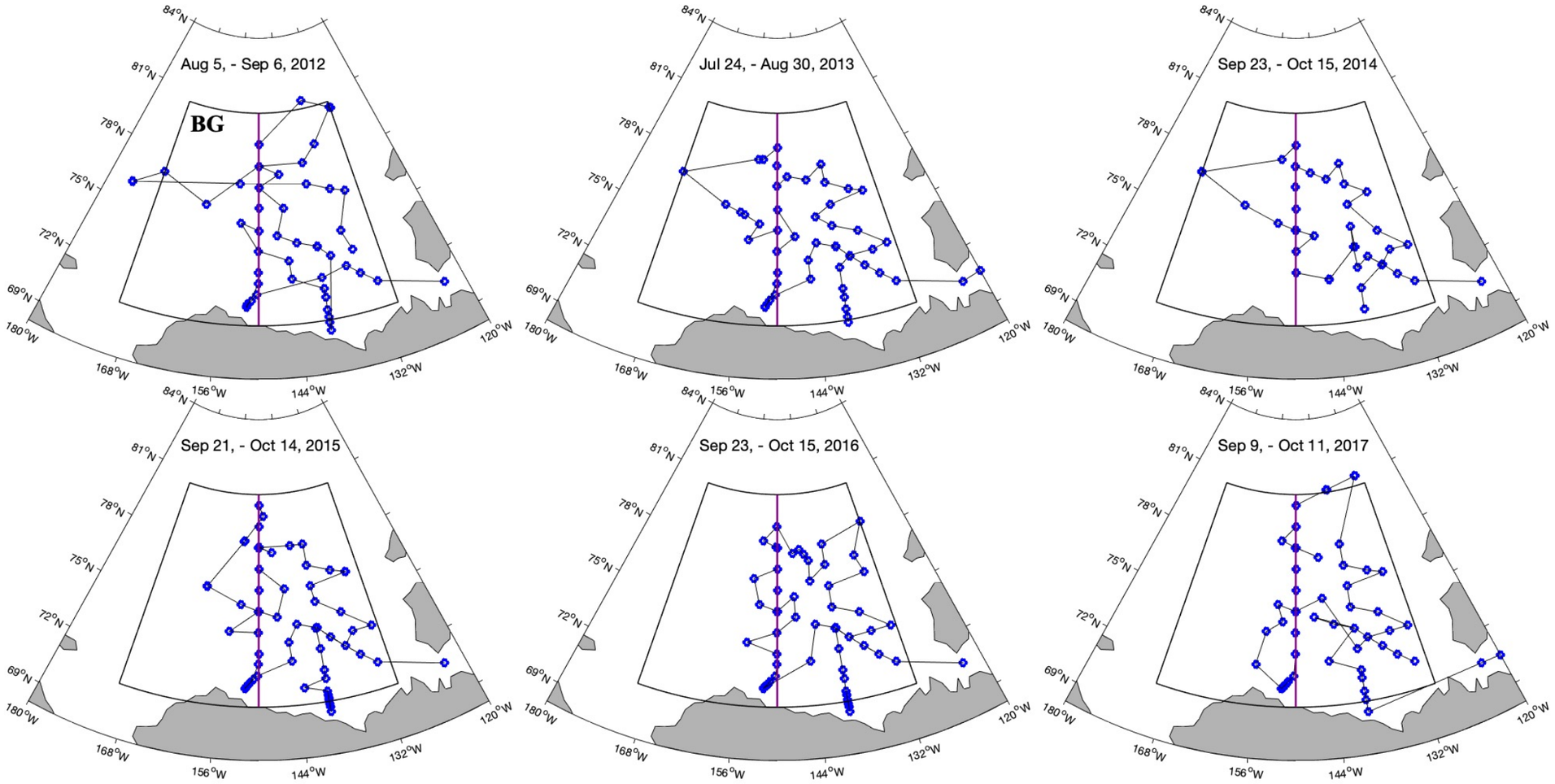
In Situ

- **SIZRS:** The Office of Naval Research sponsored Seasonal Ice Zone Reconnaissance Surveys
  - Monthly expedition, typically June – October (2012-2017)- 126 AXCTD drops
- **BGP:** Beaufort Gyre Exploration Project
  - Hydrographic profiles collected by annual CTD surveys
- **EN4**: Met Office Hadley Center "EN" series global reanalysis product's most recent version 4.2.1
  - 1° horizontal resolution (42 depth levels beginning at 5-m depth)
  - monthly temporal resolution

Ocean Models & Reanalyses

- **ECCO v4r4:** NASA's Estimating the Circulation and Climate of the Ocean
  - Lat-Lon-Cap 90 (LLC90) grid: horizontal resolutions 22-km in polar regions
  - Daily temporal resolution
- **MIZMAS:** Marginal Ice Zone Modeling and Assimilation System developed by the Applied Physics Laboratory Polar Science Center (APL/PSC)
  - 20km, daily resolutions
- **HYCOM+CICE**: Hybrid Coordinate Ocean Model is coupled with the Los Alamos Sea Ice model (CICE), NRL
  - 1/12° global spatial, daily resolutions
- **ORAS5:** Ocean Reanalysis System's version 5 from European Centre for Medium-Range Weather Forecasts (ECMWF)
  - Uses NEMOv3.4 model with a coupled sea ice model
  - 1/4° spatial resolution; monthly temporal resolution
- **GLORYS12:** Produced by Mercator Ocean International and based on the Copernicus Marine Service (CMEMS) forecasting system; Version 1
  - 1/12° spatial resolution, daily temporal resolution,

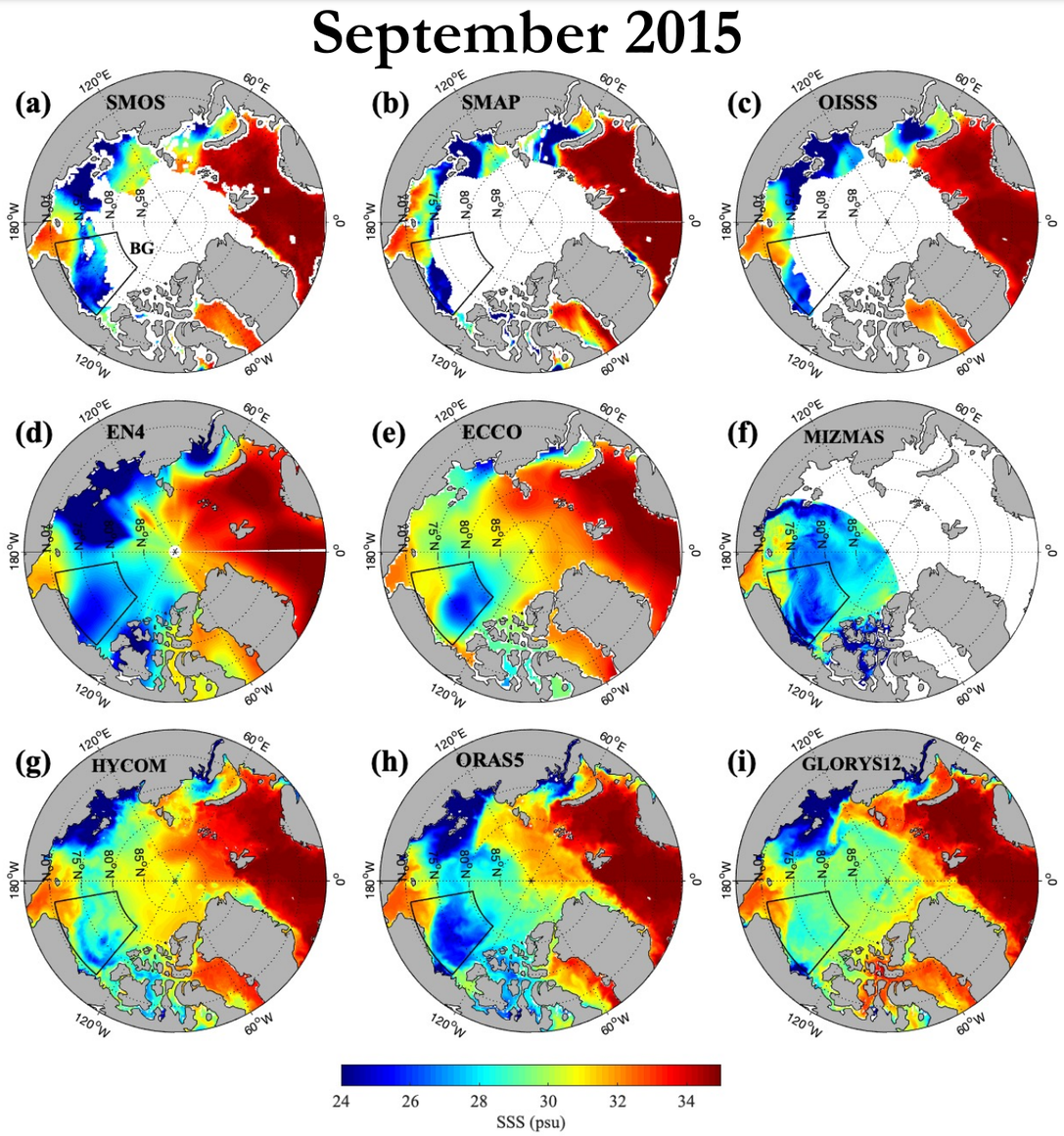
Beaufort Gyre Exploration Project CTD casts



Map of the Beaufort Gyre Exploration Project (BGP) CTD casts (blue dots) from 2012 – 2017 (**a-f**) in the (black outline) Beaufort Gyre (BG). The purple line delineates points along 150°W (along SIZRS section).

Intercomparison of Satellite Derived Salinity

- Satellites restricted by sea ice coverage
- Freshwater localized in:
  - Coastal regions of major river discharge (East Siberian and Laptev seas)
  - Beaufort Gyre (BG)

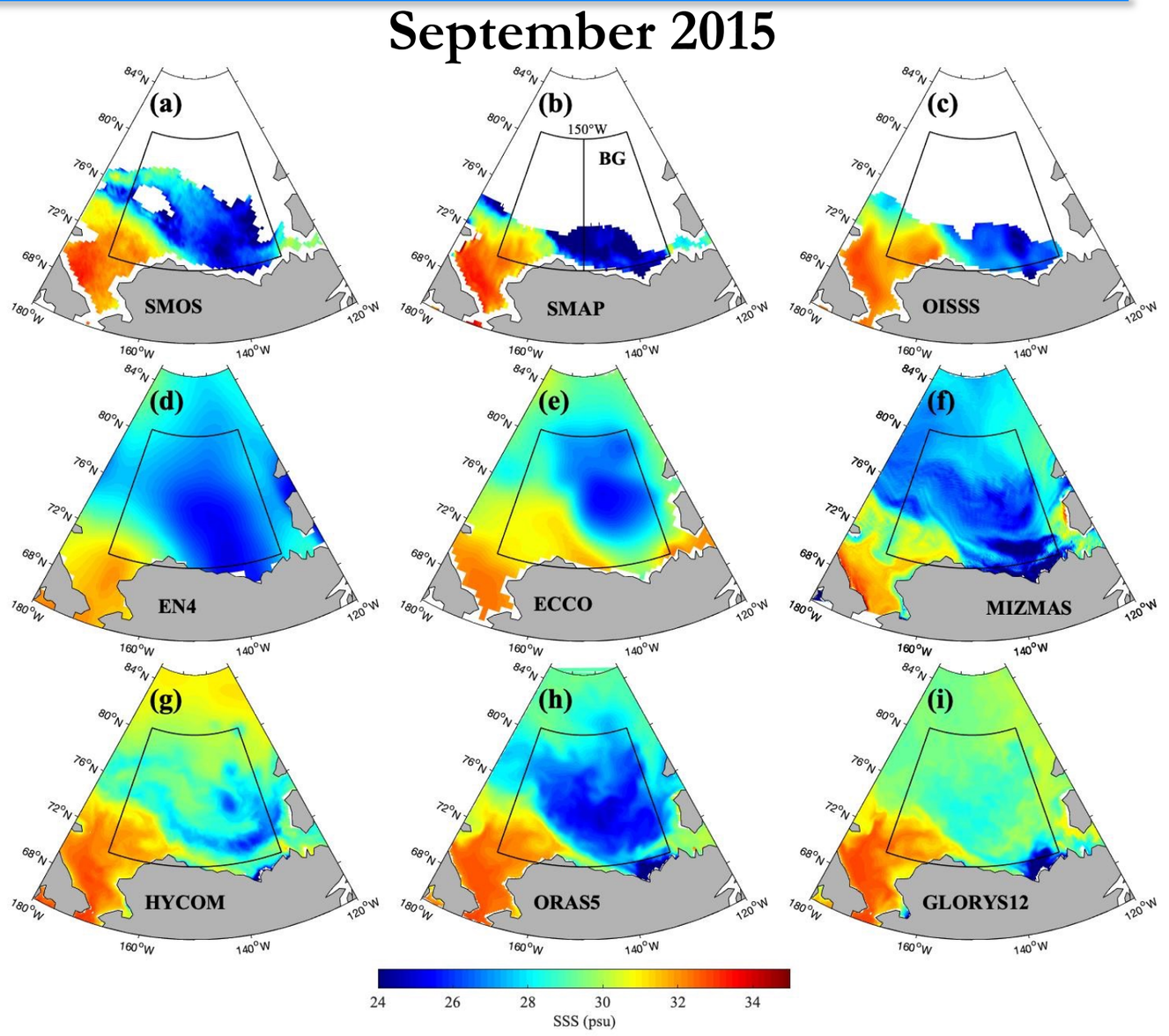


Arctic Ocean sea surface salinity (SSS) averaged over the month of September 2015 from satellites: (**a**) SMOS, (**b**) SMAP, (**c**) OISSS, *in situ* reanalysis product: (**d**) EN4, and ocean model simulations: (**e**) ECCO, (**f**) MIZMAS, (**g**) HYCOM, (**h**) ORAS5, and (**i**) GLORYS12.

Sea Surface Salinity from Observations & Models

Beaufort Gyre

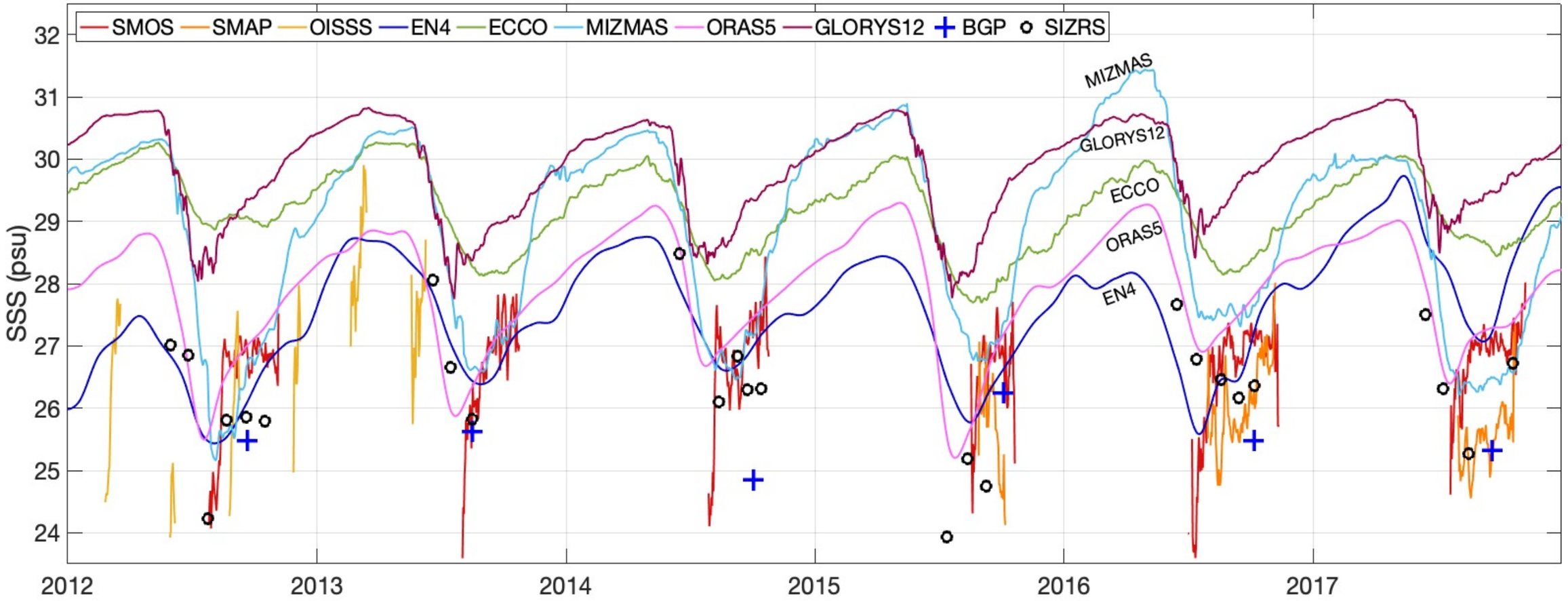
- SMOS: more coverage in BG region compared to SMAP or OISSS
- Ocean model estimations vary in salinity distribution and magnitude



Arctic Ocean sea surface salinity (SSS) averaged over the month of September 2015 in the Beaufort Gyre (BG) region derived from satellites: (**a**) SMOS, (**b**) SMAP, (**c**) OISSS, *in situ* reanalysis product: (**d**) EN4, and ocean model simulations: (**e**) ECCO, (**f**) MIZMAS, (**g**) HYCOM, (**h**) ORAS5 and (**i**) GLORYS12. 150°W transect is outlined for comparisons in this study.

Sea Surface Salinity along 150º W (SIZRS transect 70.5N-80.5N)

- Satellite products: SMOS(red), SMAP(orange), and OISSS(yellow) highly variable (seasonally) due to sea ice zone and lack observations of the entire transect

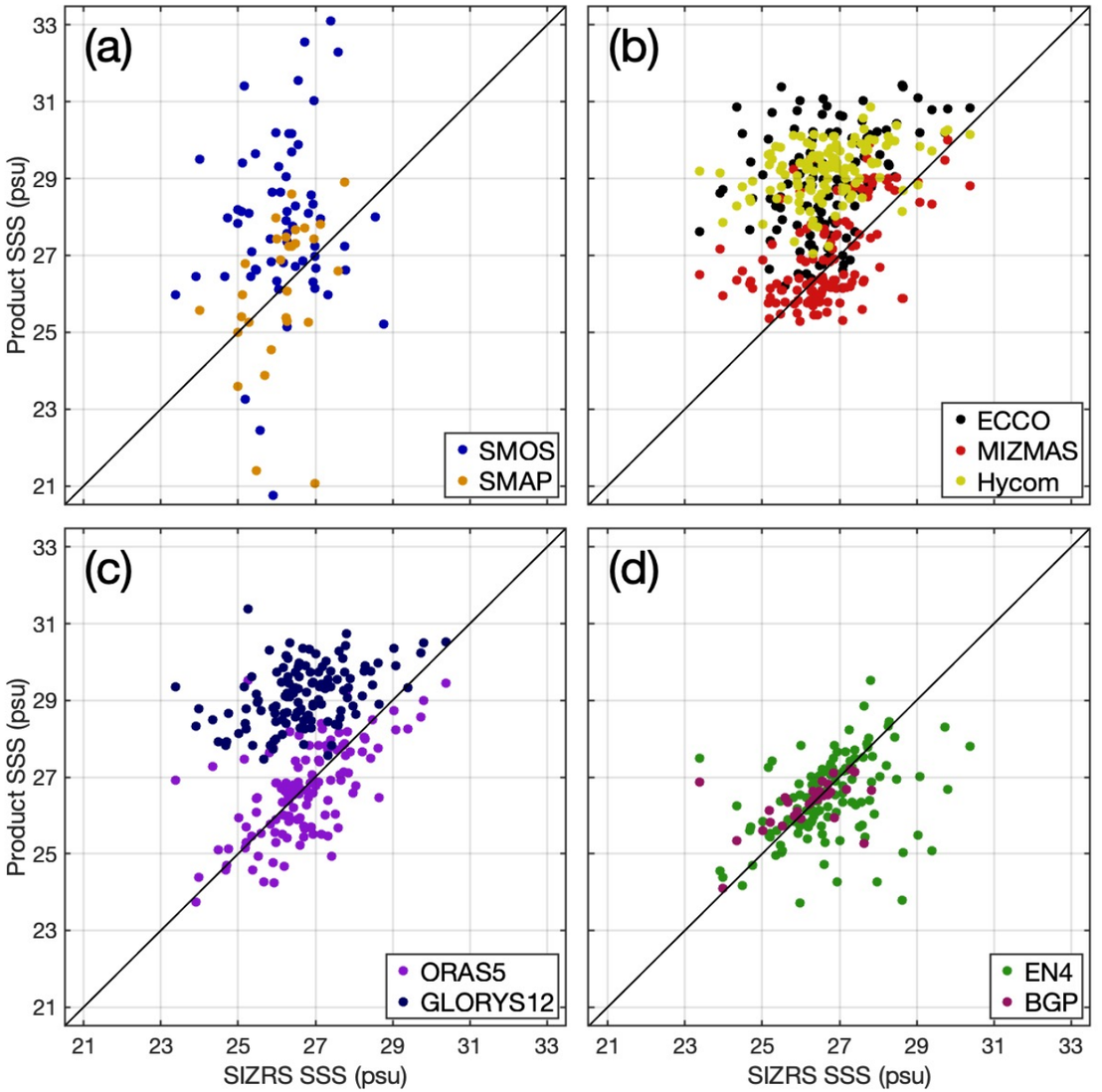


Transect average sea surface salinity (SSS) along 150°W from 70.5°N–80.5°N among ocean products between 2012–2017.

Scatter diagrams between observations & Models

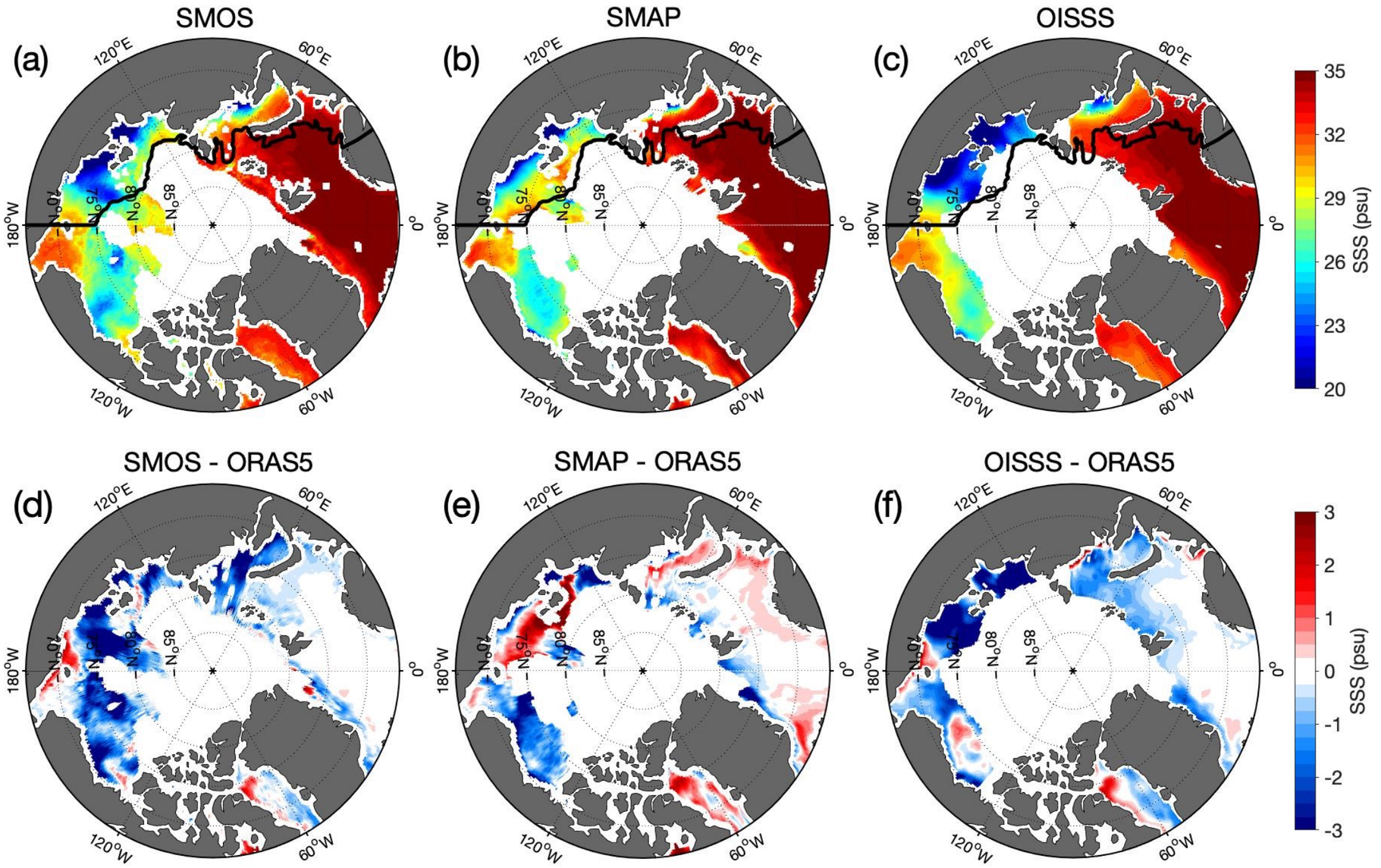
Salinity comparisons at every SIZRS (in situ) measurement

- Satellites: (excluding OISSS) more SSS variance, SMOS with more outliers
- Models: mostly more saline
  - ORAS5 has highest correlation (0.612) compared to other products



Sea surface salinity (SSS) of SIZRS (2 m) to (**a**) satellite missions, and of SIZRS (5 m) to (**b,c**) ocean model simulations, and (**d**) in-situ observations at each SIZRS AXCTD measurement. Black line signifies equivalent salinity values (psu).

Intercomparison of Satellite Derived Salinity

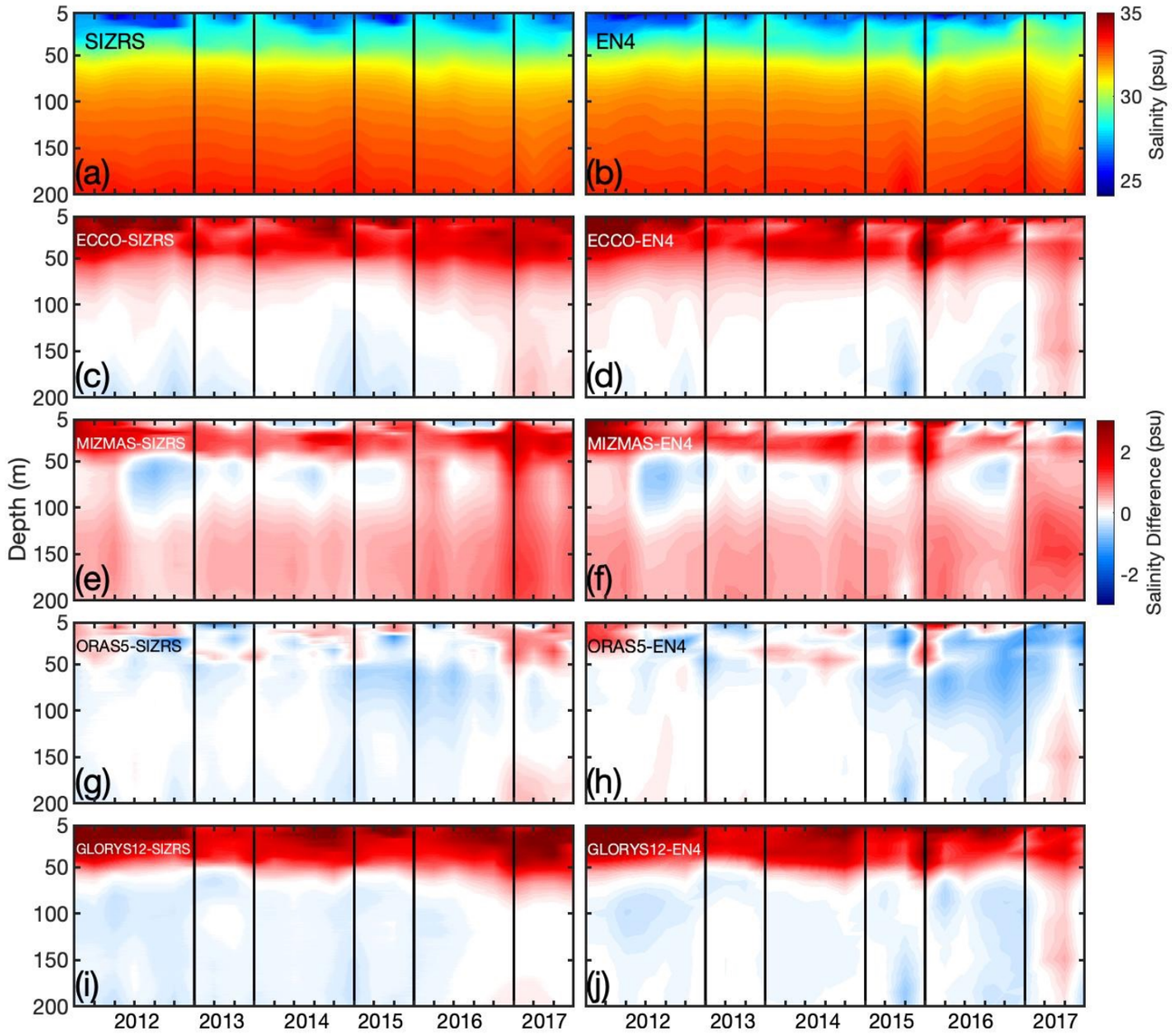


- Average 2016 SSS differences (Satellites – ORAS5)
- ORAS5 generally less (more) saline than SMAP (SMOS) in Arctic

Sea surface salinity (SSS; psu) in the Arctic Ocean from (a) SMOS, (b) SMAP, and (c) OISSS satellite observations averaged over the 2016 year with the Russian Shelf region's contour with the Russian Shelf region's contour. (d-f) Difference between satellites and ORAS5 data salinity at 0.5 m.

Salinity variations with depth at each SIZRS Latitude

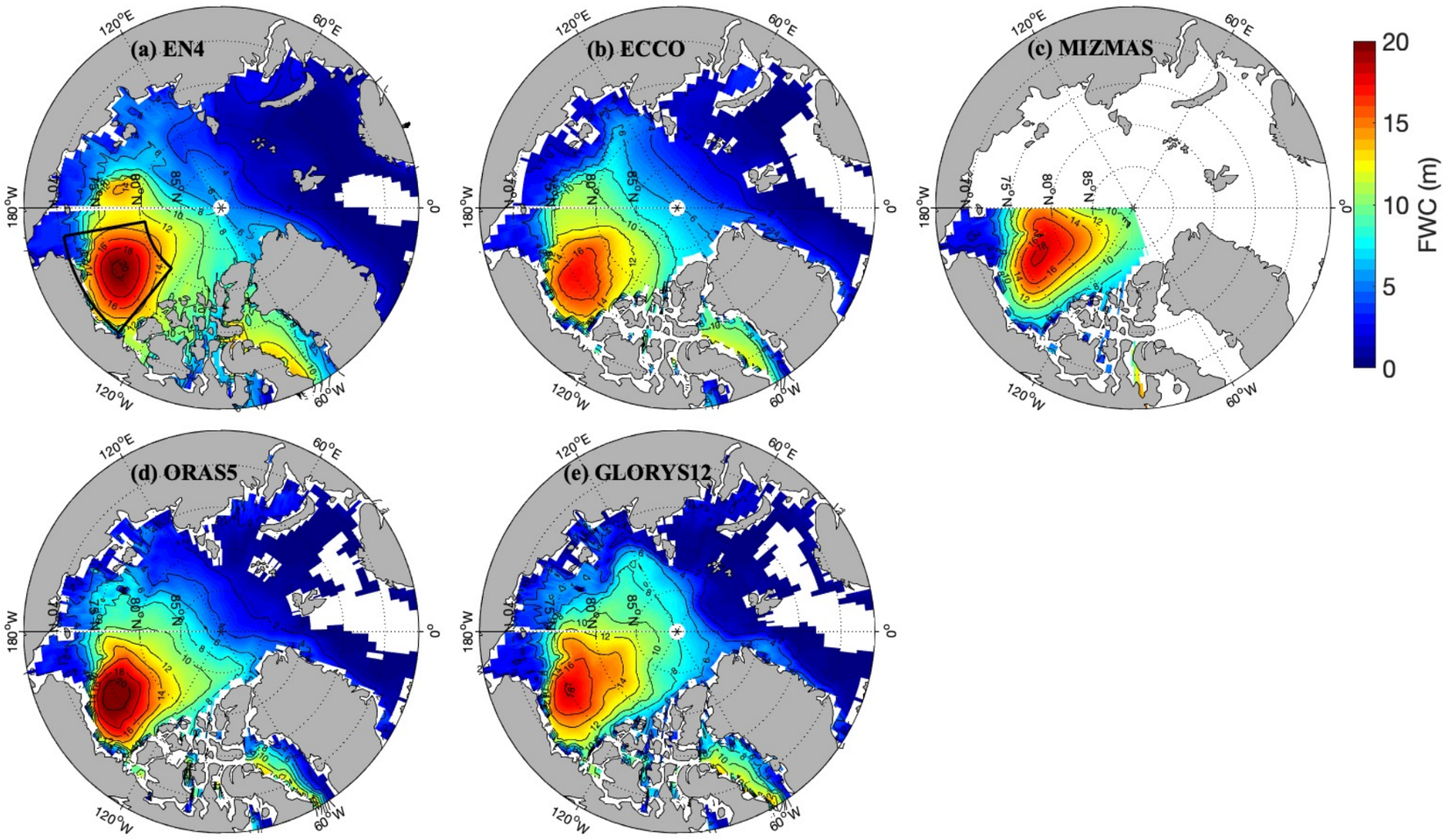
- Greatest differences among products are above 50-m depth layer
- Unlike other models, MIZMAS simulates higher salinities with 0.5-1psu differences below 100-m depth



Salinity (psu) versus depth profiles at each SIZRS latitude for **a**) SIZRS and (**b**) EN4 averaged monthly from 2012–2017, and the departure of salinity from SIZRS (left column) and EN4 (right column) for the ocean models (**c,d**) ECCO, (**e,f**) MIZMAS, (**g,h**) ORAS5, and (**i,j**) GLORYS12. Black vertical lines separate years where months are not consecutive.

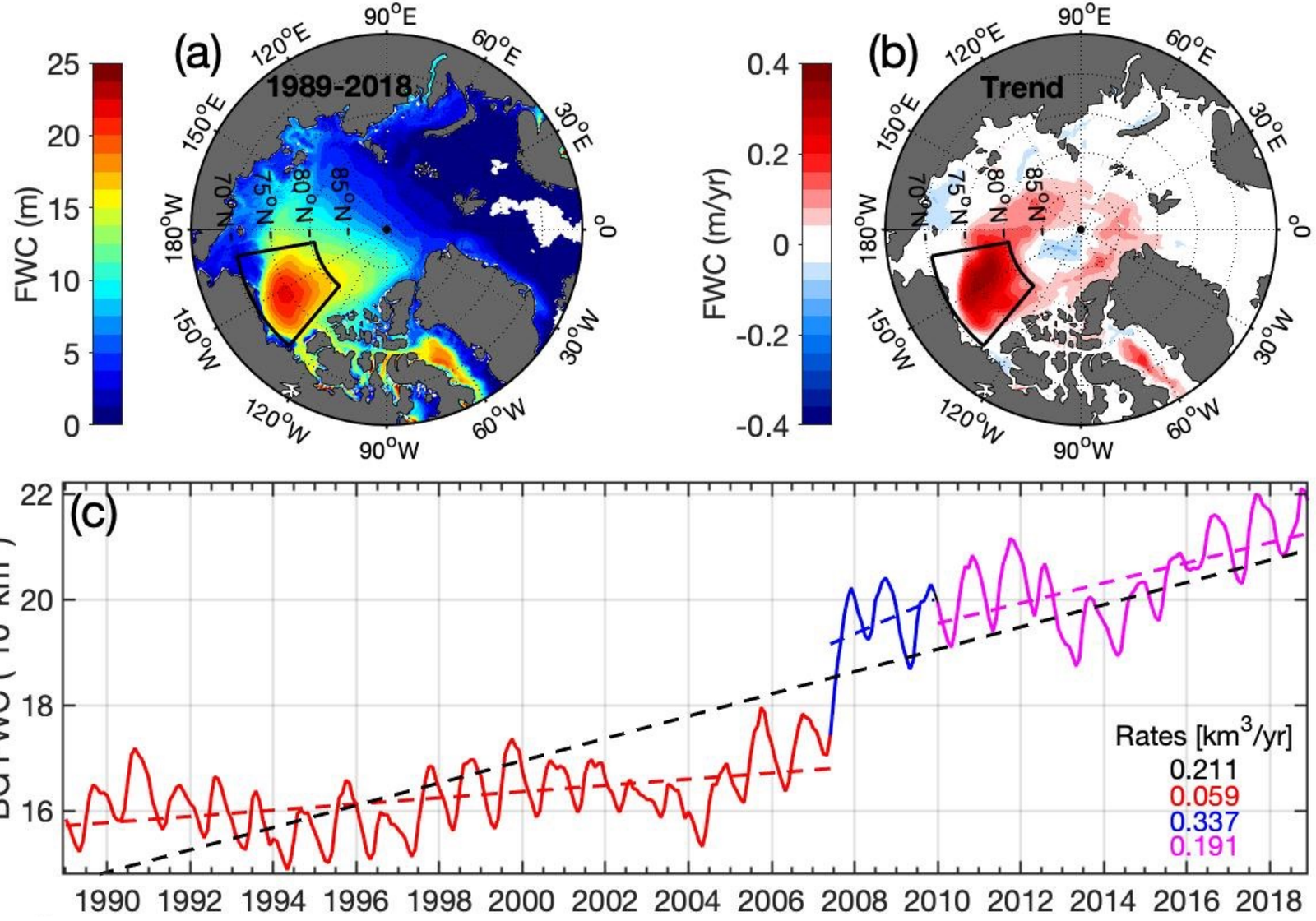
Freshwater Content

- BG region: ~1/4 of the total liquid FWC in Arctic Ocean
- Highest depth integrated FWC in BG for 2012-2017 average is ~20m, lowest in ECCO 16-17m



Freshwater content (FWC; km) of the Arctic ocean averaged from 2012-2017 from (a) EN4 reanalysis product and five models: (b) ECCO, (c) MIZMAS, (d) ORAS5, and (e) GLORYS12. FWC is contoured every 2m with a reference salinity of 34.8psu. Beaufort Gyre region is outlined in a black box.

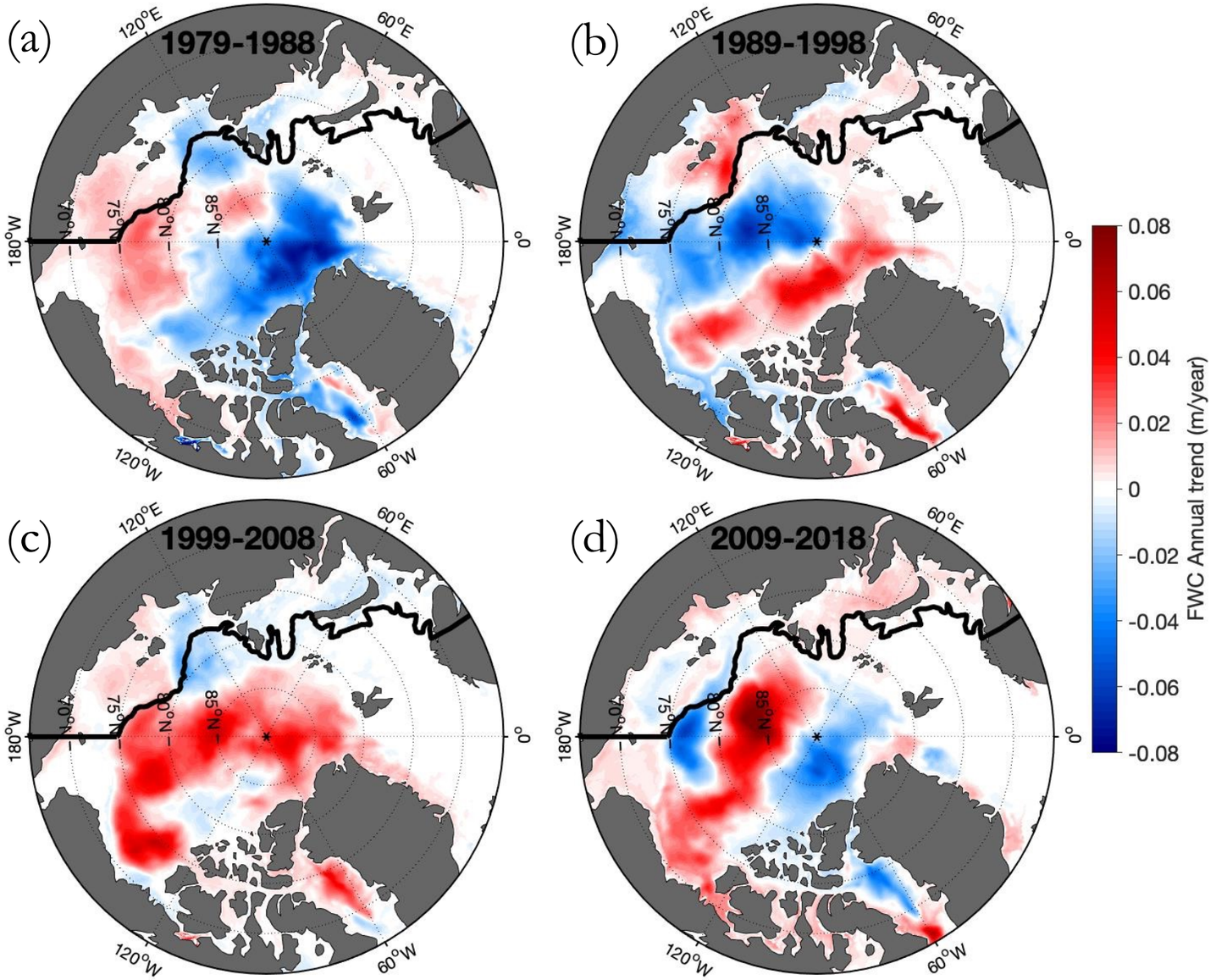
FWC Trend in BG (1989-2018)



- BG FWC: linear trend of 0.21 km^3/yr (1989-2018)
  - Concentrated northwest of BG region
  - Regime change during 2007 (local maximum of the Arctic Oscillation index)

Arctic Ocean (a) freshwater content (FWC) and (b) FWC trend spatial maps between 1989-2018 using ORAS5. The Beaufort Gyre (BG) region delineated by a black box. (c) Timeseries of the BG freshwater content with respective rates between (red) 1989-2007, (blue) 2007-2010, and (pink) 2010-2018.

FWC Trend in Arctic: last 4 decades

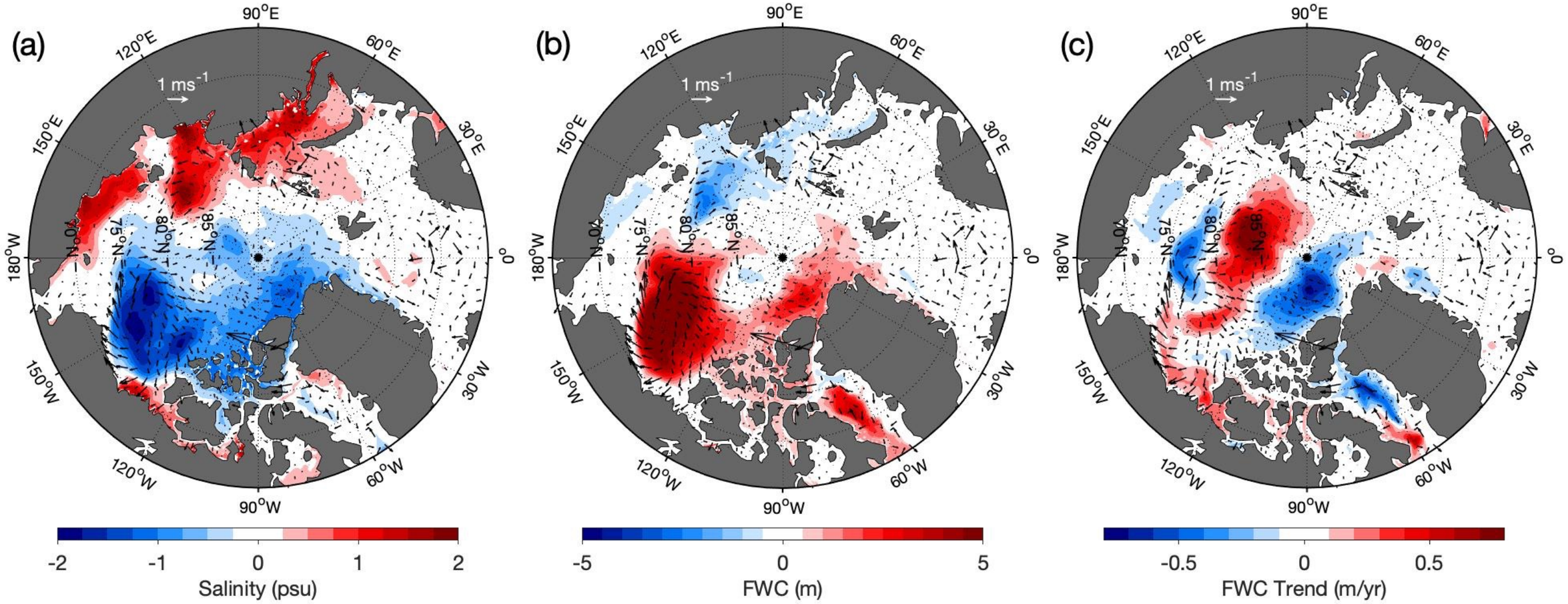


- Spatial differences/shifts in FWC trend in the last 4 decades
- Overall, FWC trend in the BG region is increasing, while parts of the Russian shelf are decreasing
- Need to analyze the Arctic as a whole when quantifying the freshwater budget

Arctic Ocean freshwater content (FWC) trend (m/year) between the decades of (a) 1979-1988, (b) 1989-1998, (c) 1999-2008, and (d) 2009-2018 using ORAS5. The Russian Shelf region delineated by a black box.

New (2008-2018) minus Old (1979-2007) Period

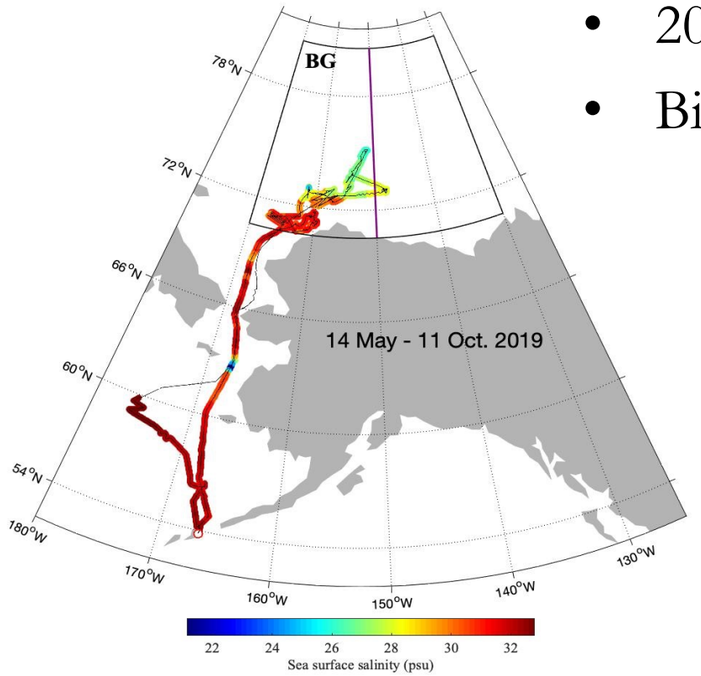
- Surface Current anomalies between different periods overlaid: Strong currents for Anticyclonic BG and transport from Laptev Sea into Eurasian basin where FWC trends are significant



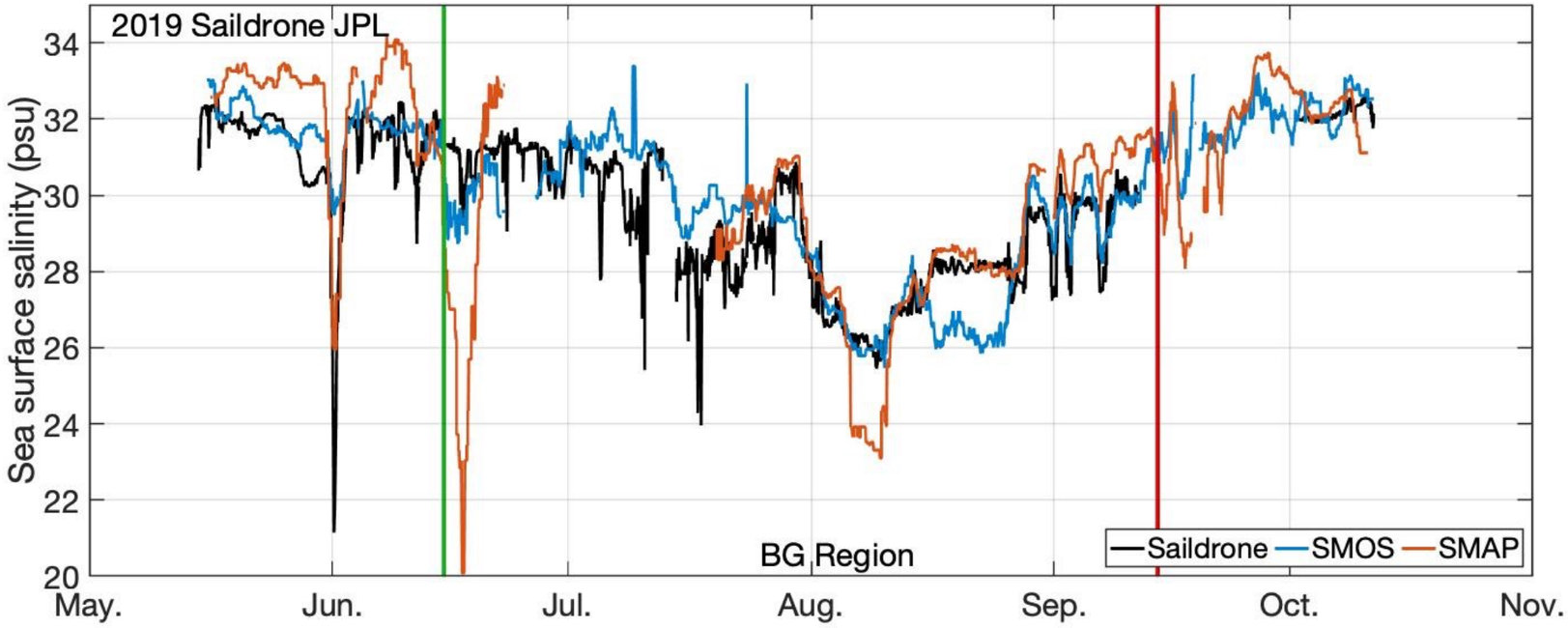
ORAS5 differences of new period (2008-2018) minus old period (1979-2007) averages of (a) salinity (psu), (b) freshwater content (FWC; m), and (c) FWC trend (m/year). Black arrows indicate new minus old period anomalies of surface current anomalies (m/s).

Saildrone data comparison with SMOS & SMAP Salinity in 2019

- The continuation of *in situ* missions is valuable to understanding changes in Arctic Ocean
  - 2019 Saildrone mission's salinity data (every minute) from JPL-PO.DAAC
  - Biases possibly originate from data obstruction by sea ice edge

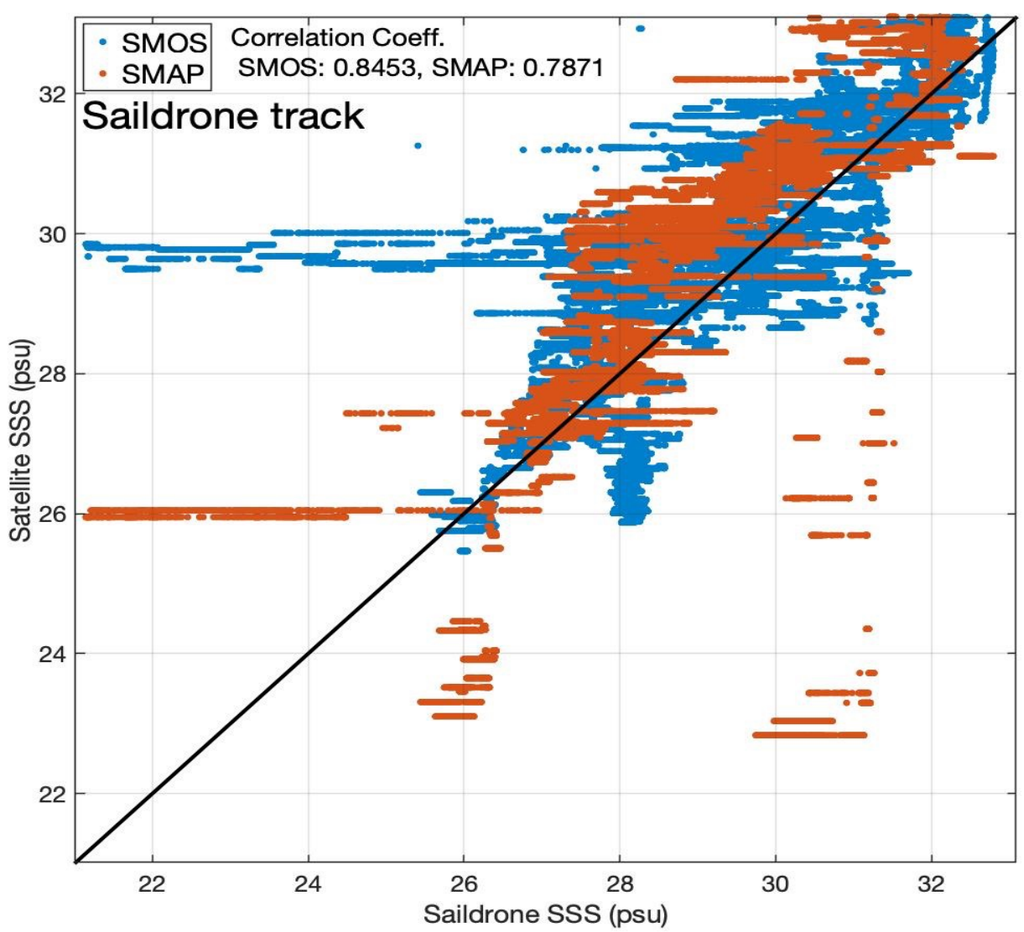


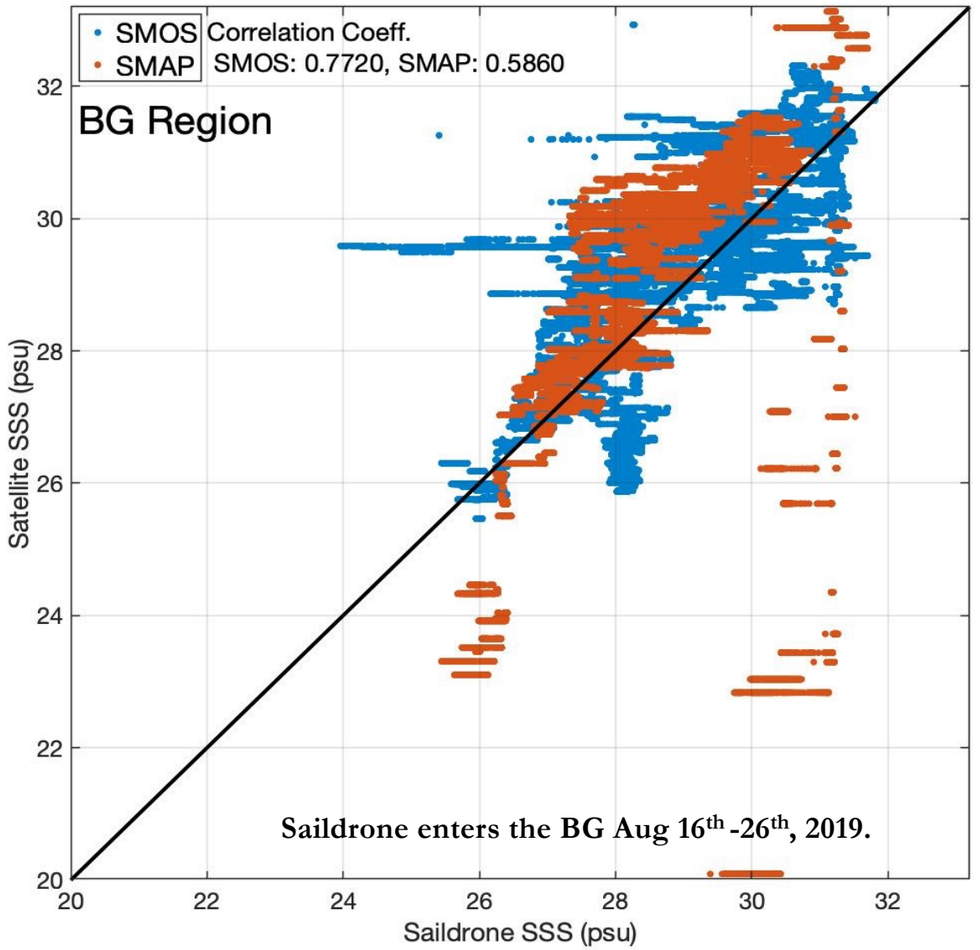
Schematic of sea surface salinity (psu) of 2019 Saildrone data deployed from 14 May until 11 October. Saildrone track is indicated in solid black line with salinity marked in color. The Beaufort Gyre (BG) region (black box) with associated 150°W transect (purple line).



Timeseries of sea surface salinity from Saildrone (black line), SMOS (blue line), and SMAP (orange line) between 14 May and 11 October 2019. Vertical lines indicate when the Saildrone entered (green) and exited (red) the Beaufort Gyre (BG) region.

Saildrone data comparison with SMOS Salinity in 2019





Scatterplot of sea surface salinity (psu) between Saildrone to Arctic SMOS (blue dots) and SMAP (orange dots) when available between 14 May and 11 October 2019 along the Saildrone track. Equal salinity values (black line) are overlaid. (Left) entire Saildrone track, and (right) BG region.

Summary

- Satellites & *in situ* data restricted from sea ice zone, models help fill this gap
- Of satellites, SMOS showed higher spatial coverage in the BG region but SMAP had more promising SSS comparisons to SIZRS *in situ* data
- The average difference of models at each SIZRS drop are greater than 2 psu with exception to ORAS5 (–0.052 bias) and MIZMAS (0.105 bias).
  - Compared to SMOS (SMAP), the ORAS5 ocean model has generally higher (lower) SSS during 2016 average
  - HYCOM (2.50 psu bias) and GLORYS12 (2.44 psu bias) show the greatest disagreement with SIZRS salinity
- Improving surface and subsurface measurements is important to understand changing freshwater content in the BG region
- The continuation of *in situ* data in the Arctic is valuable to understanding changes in the Arctic Ocean: ex. JPL's Saildrone deployments show strong correlation to satellites