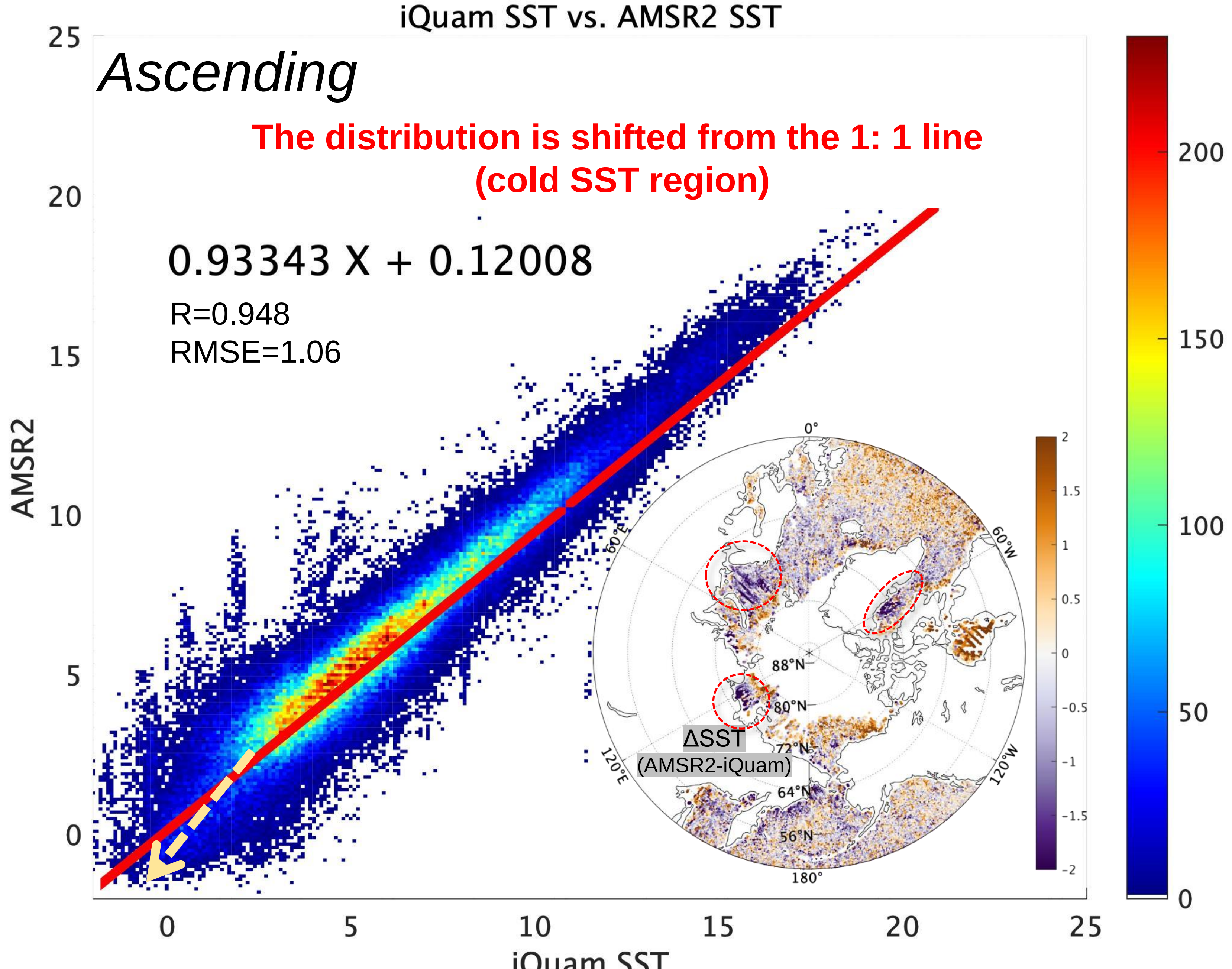
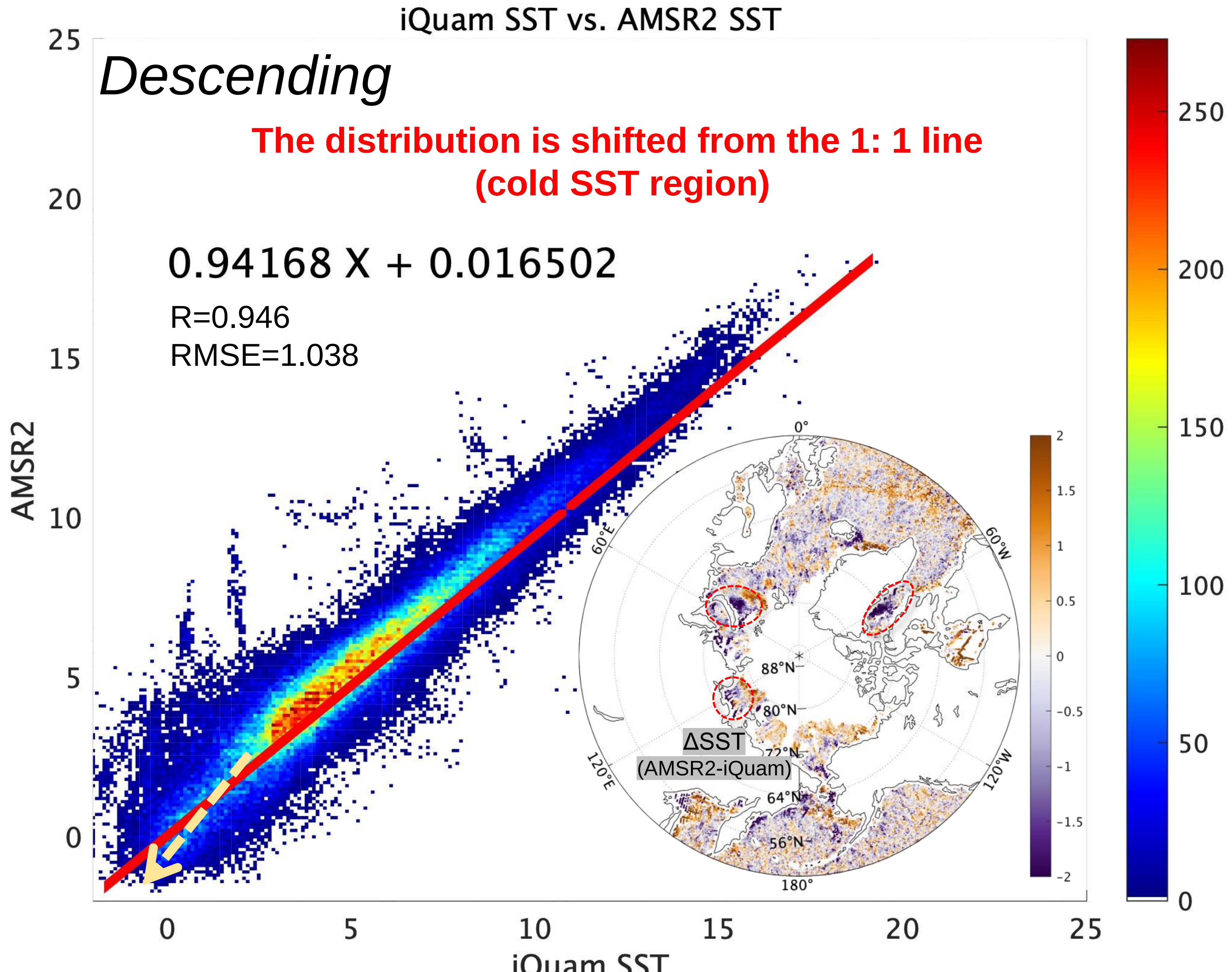
The Validation of the AMSR2 sea surface temperature in the polar oceans

Kohei Mizobata[1], Atsushi Matsuoka[2], Minami Arai[1] and Shintaro Takao[3]

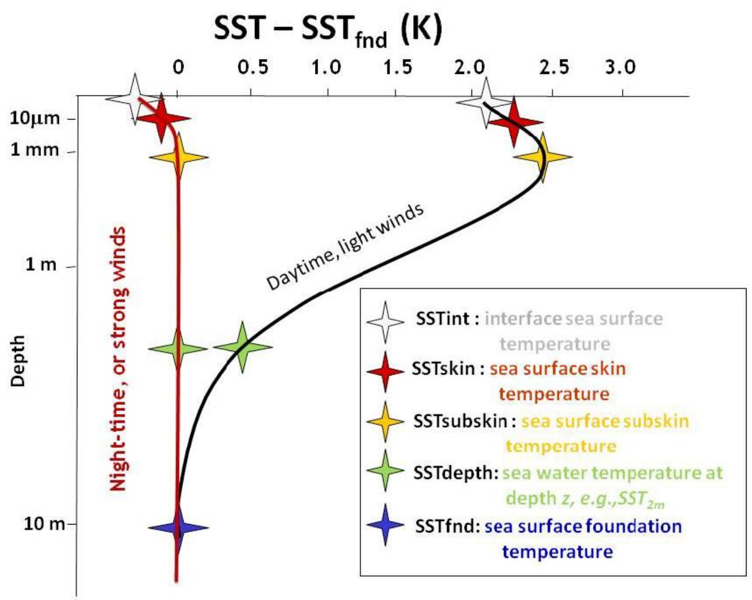
1: Department of Ocean Sciences, Tokyo University of Marine Science and Technology, JAPAN
2: Takuvik Joint International Laboratory (CNRS-ULaval), Université Laval, Canada
3: Center for Global Environmental Research, National Institute for Environmental Studies, JAPAN

Results (JFY2019-2020) : **Diff. SST between AMSR2 and iQuam v2.1**

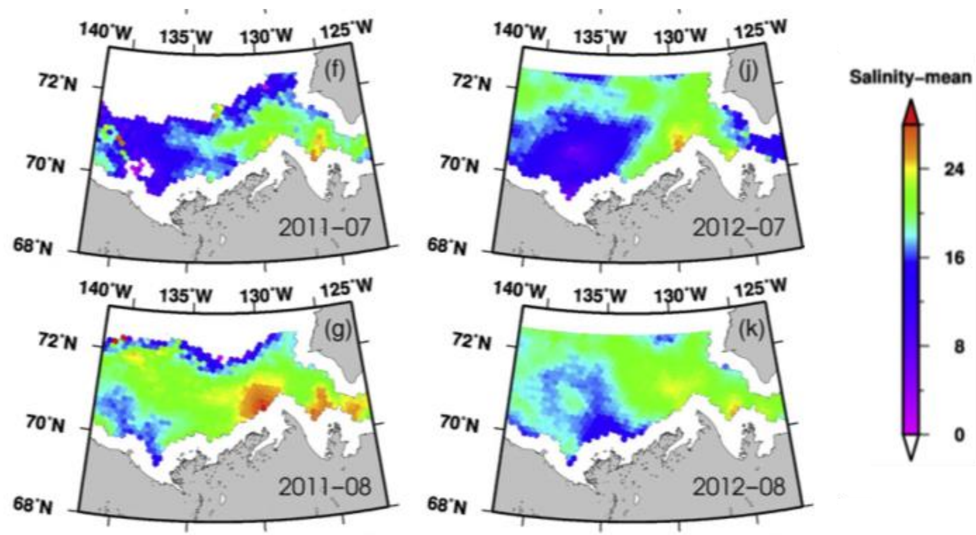




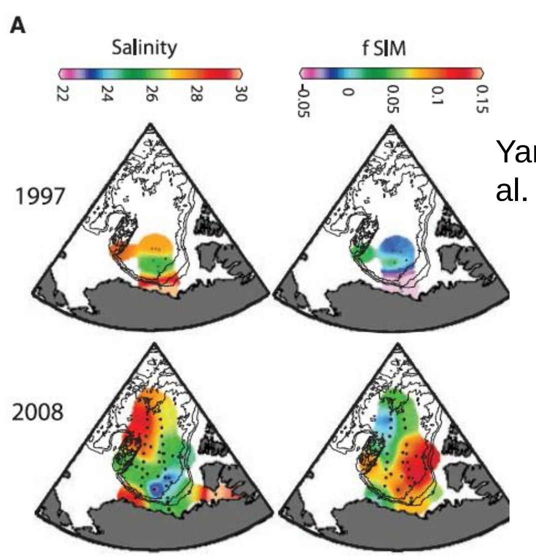
iQuam SST vs. AMSR2 SST
Descending
The distribution is shifted from the 1: 1 line
(cold SST region)
0.94168 X + 0.016502
R=0.946
RMSE=1.038
AMSR2
iQuam SST
ΔSST
(AMSR2-iQuam)
0°
60°E
60°W
120°E
120°W
180°
88°N
80°N
72°N
64°N
56°N



Minnett, P.J., Kaiser-Weiss, A.K., 2012. Group for High Resolution Sea-SurfaceTemperature Discussion Document: Near-Surface Oceanic Temperature Gradients (7pp.)



Matsuoka et al. (2016, Remote Sensing of Environment)



Yamamoto-Kawai et al. (2009, Science)

- ✓ Wind mixing
  Strong wind → skin temperature ≒ SSTdepth
  → AMST SST will be same as in-situ SST
- ✓ Freshwater due to river discharge and sea ice melt
  Salinity stratification induce efficient uptake of shortwave radiation
  → AMSR SST > in-situ SST

Level-3 AMSR2 SST and iQuam SST showed
- ✓ Underestimation of SST in the polar ocean
- ✓ This underestimation is not related to bulk-skin problem nor salinity stratification

Objectives

In JFY2021, we conducted analyses below.

✓ Level-2 AMSR2 SST vs. iQuam v2.1

Level-2 AMSR2 wind speed is used as the threshold. We made a strict comparison in the spatiotemporal direction.

✓ Revisit theoretical equations for emissivity and brightness temperature

We investigated the dependency of emissivity and TB on temperature and salinity.

✓ Estimation of Surface Mixed Layer Depth and Ocean Heat Content

SMLD and OHC were estimated using corrected AMST2 SST based on the methods described by Mizobata and Shimada (2012).

ΔSST (AMSR2 – iQuam) vs. Wind speed

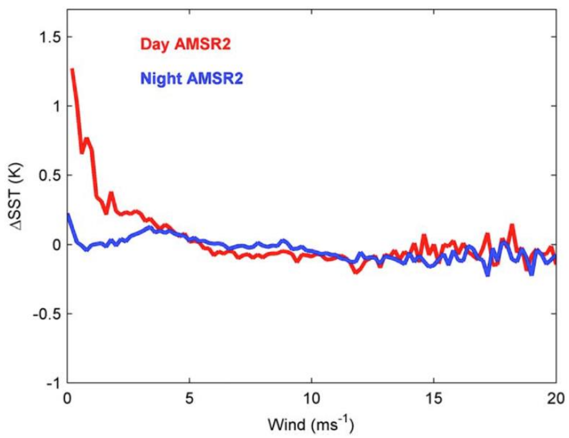


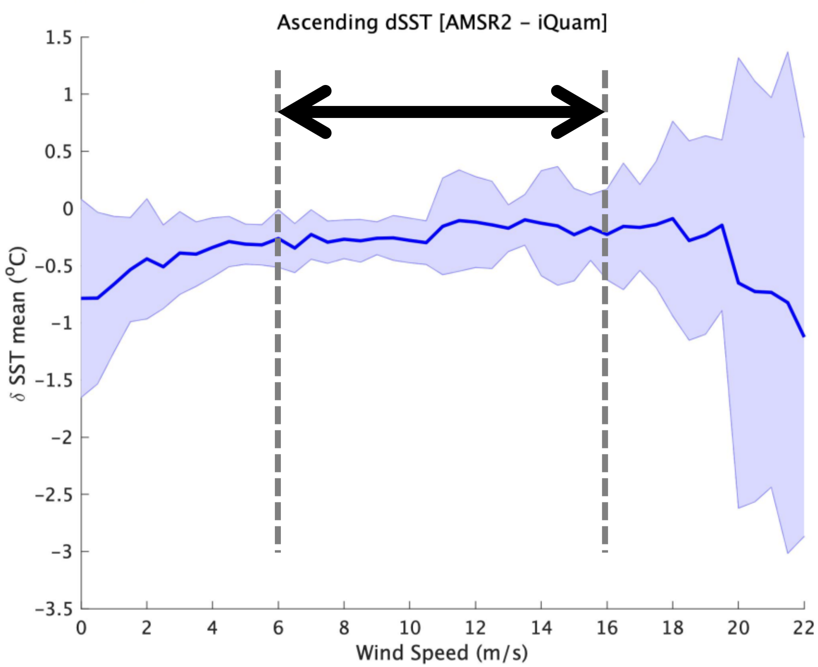
Figure 6. The bias (AMSR2 minus in situ SST) as a function of wind speed, separated into day and night observations.

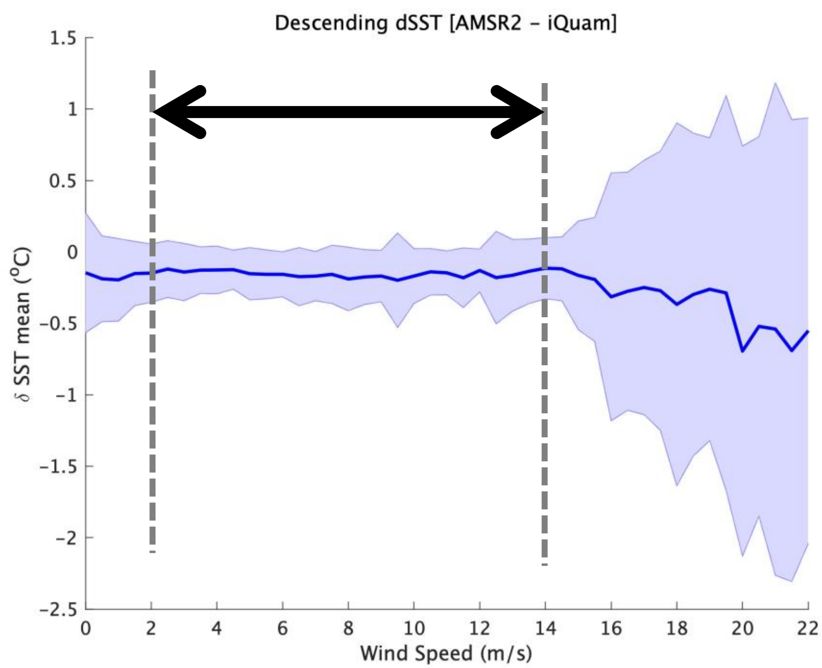
Gentemann and Hilburn (2015)

"At winds below 6 m/s the nighttime bias stays close to 0 K while the daytime bias increases at decreasing wind speeds, reaching a maximum of over 1.25 K at 0 m/s. This is a typical of diurnal warming [Gentemann and Wentz, 2001]. Therefore, to avoid collocations with diurnal warming, all collocations between 10 a.m. and 4 p.m. (local time) with wind speeds less than 6 m/s are excluded from the analysis."

This study

The variability of the water temperature error becomes larger when the wind speed is small. However, unlike Gentemann and Hilburn (2015), we cannot conclude that this is diurnal warming in the observed time.



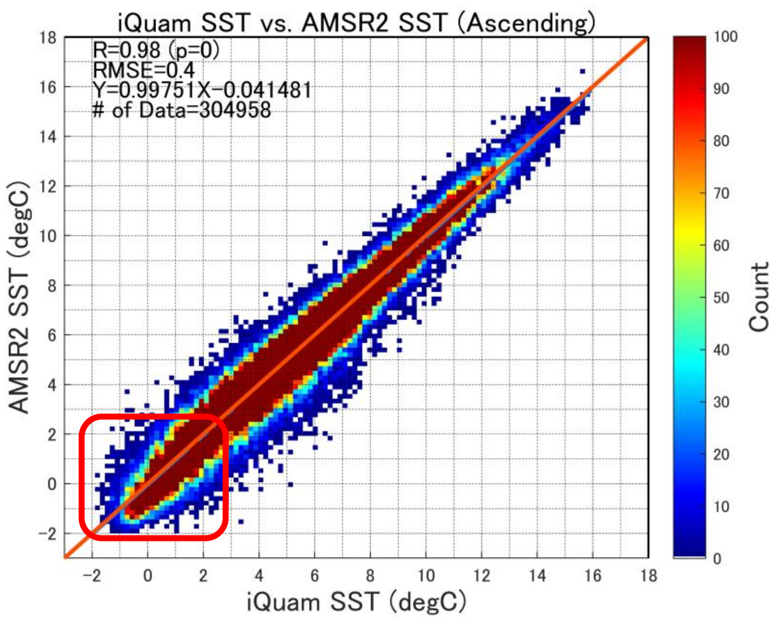


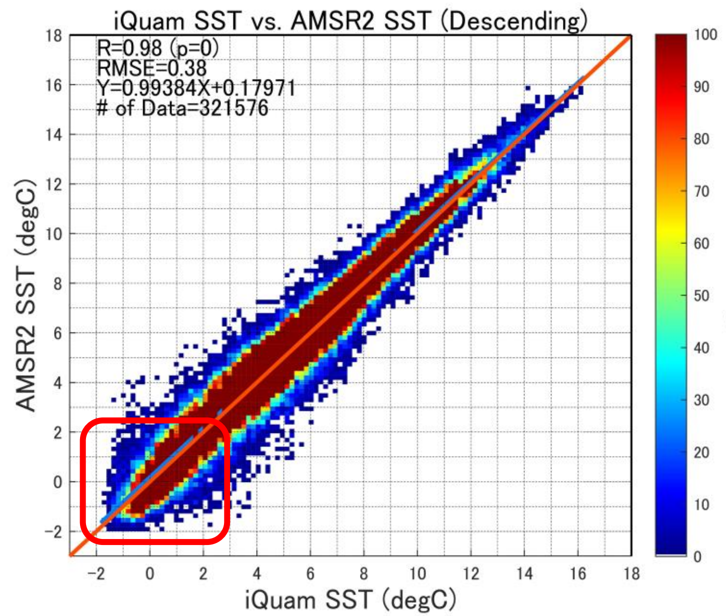
In this range (double-edged arrow), the SST error is assumed to be independent of the wind speed and is used in the subsequent analysis.

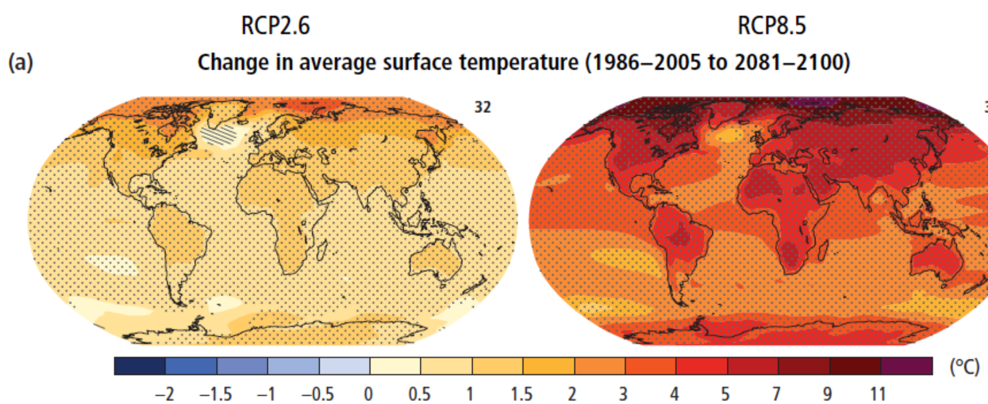
Difference of SST between AMSR2 and iQuam v2.1

Distance between iQuam and AMSR2 L2 Ver. 4 : Max. 12km

Difference in observation time : within 2 hours







Although the RMSE was within 0.5 K, the underestimation bias in the low temperature region will need to be resolved for evaluation of the global warming, especially in the polar oceans.

$$E = E_0 + \Delta E_w + \Delta E_\varphi$$

“**the isotropic wind-induced emissivity**” depends on wind speed *W, f (radiation frequency) and* θ_i*(Earth Incidence Angle).*

“**the wind direction signal**” depends on wind direction φ relative to the azimuthal look, *f and* θ_i.

“The emissivity of the specular ocean surface E_0 **depends on** f, θ_i, T_s **and** S**. The emissivity of the specular ocean surface** E_0 **is by far the largest part.”**

Meissner and Wentz (2012)

Ocean Surface Emissivity, E_0 & Dielectric constant

Emissivity $$E_{0p} = 1 - |r_p|^2$$

Reflection coef.

$$r_v = \frac{\varepsilon \cos(\theta) - \sqrt{\varepsilon - \sin^2(\theta)}}{\varepsilon \cos(\theta) + \sqrt{\varepsilon - \sin^2(\theta)}}$$

$$r_h = \frac{\cos(\theta) - \sqrt{\varepsilon - \sin^2(\theta)}}{\cos(\theta) + \sqrt{\varepsilon - \sin^2(\theta)}}. \qquad (1)$$

Dielectric constant with a double Debye relaxation law

Static dielectric constant for pure water; Intermediate frequency dielectric constant; Dielectric constant At infinite frequencies

$$\varepsilon(T,S) = \frac{\varepsilon_S(T,S) - \varepsilon_1(T,S)}{1 + i\nu/\nu_1(T,S)} + \frac{\varepsilon_1(T,S) - \varepsilon_\infty(T,S)}{1 + i\nu/\nu_2(T,S)} + \varepsilon_\infty(T,S) - i\frac{\sigma(T,S)}{(2\pi\varepsilon_0)\nu}. \qquad (6)$$

frequency; Relaxation frequency

Meissner and Wentz (2004)

Ocean Surface Emissivity : Dielectric constant

$$\varepsilon(T,S) = \frac{\varepsilon_S(T,S) - \varepsilon_1(T,S)}{1 + i\nu/\nu_1(T,S)} + \frac{\varepsilon_1(T,S) - \varepsilon_\infty(T,S)}{1 + i\nu/\nu_2(T,S)} + \varepsilon_\infty(T,S) - i\frac{\sigma(T,S)}{(2\pi\varepsilon_0)\nu}. \quad (6)$$

$$\begin{aligned}
\varepsilon_S(T,S) &= \varepsilon_S(T,S=0) \cdot \exp[b_0 S + b_1 S^2 + b_2 TS] \\
\nu_1(T,S) &= \nu_1(T,S=0) \cdot [1 + S \cdot (b_3 + b_4 T + b_5 T^2)] \\
\varepsilon_1(T,S) &= \varepsilon_1(T,S=0) \cdot \exp[b_6 S + b_7 S^2 + b_8 TS] \\
\nu_2(T,S) &= \nu_2(T,S=0) \cdot [1 + S \cdot (b_9 + b_{10} T)] \\
\varepsilon_\infty(T,S) &= \varepsilon_\infty(T,S=0) \cdot [1 + S \cdot (b_{11} + b_{12} T)]. \quad (17)
\end{aligned}$$

$$\varepsilon_S(T,S=0) = \frac{3.70886 \cdot 10^4 - 8.2168 \cdot 10^1 T}{4.21854 \cdot 10^2 + T}. \quad (7)$$

$$\begin{aligned}
\varepsilon_1(T,S=0) &= a_0 + a_1 T + a_2 T^2 \\
\nu_1(T,S=0) &= \frac{45 + T}{a_3 + a_4 T + a_5 T^2} \\
\varepsilon_\infty(T,S=0) &= a_6 + a_7 T \\
\nu_2(T,S=0) &= \frac{45 + T}{a_8 + a_9 T + a_{10} T^2}. \quad (8)
\end{aligned}$$

Meissner and Wentz (2004)

Ocean Surface Emissivity: Conductivity of Seawater

$$\varepsilon(T,S) = \frac{\varepsilon_S(T,S) - \varepsilon_1(T,S)}{1 + i\nu/\nu_1(T,S)} + \frac{\varepsilon_1(T,S) - \varepsilon_\infty(T,S)}{1 + i\nu/\nu_2(T,S)} + \varepsilon_\infty(T,S) - i\frac{\sigma(T,S)}{(2\pi\varepsilon_0)\nu}. \quad (6)$$

Conductivity of seawater

$$\sigma(T,S) = \sigma(T,S=35) \cdot R_{15}(S) \cdot \frac{R_T(S)}{R_{15}(S)} \quad (11)$$

$$\sigma(T,S=35) = 2.903\,602 + 8.607 \cdot 10^{-2} \cdot T + 4.738\,817 \cdot 10^{-4} \cdot T^2 - 2.991 \cdot 10^{-6} \cdot T^3 + 4.3047 \cdot 10^{-9} \cdot T^4 \quad (12)$$

$$R_{15}(S) = S \cdot \frac{(37.5109 + 5.452\,16 \cdot S + 1.4409 \cdot 10^{-2} \cdot S^2)}{(1004.75 + 182.283 \cdot S + S^2)} \quad (13)$$

$$\frac{R_T(S)}{R_{15}(S)} = 1 + \frac{\alpha_0(T-15)}{(\alpha_1 + T)} \quad (14)$$

$$\alpha_0 = \frac{(6.9431 + 3.2841 \cdot S - 9.9486 \cdot 10^{-2} \cdot S^2)}{(84.850 + 69.024 \cdot S + S^2)} \quad (15)$$

$$\alpha_1 = 49.843 - 0.2276 \cdot S + 0.198 \cdot 10^{-2} \cdot S^2. \quad (16)$$

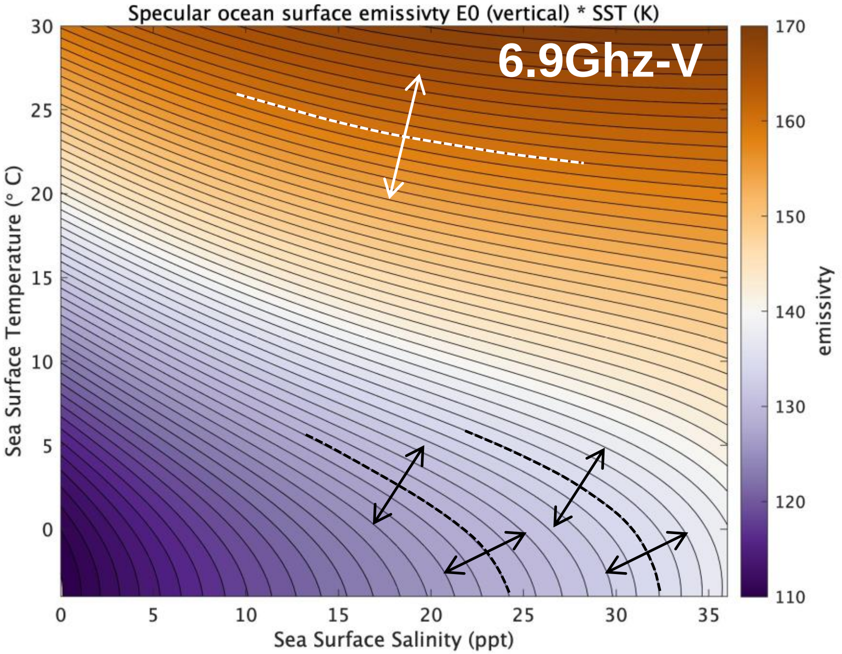
Meissner and Wentz (2004)

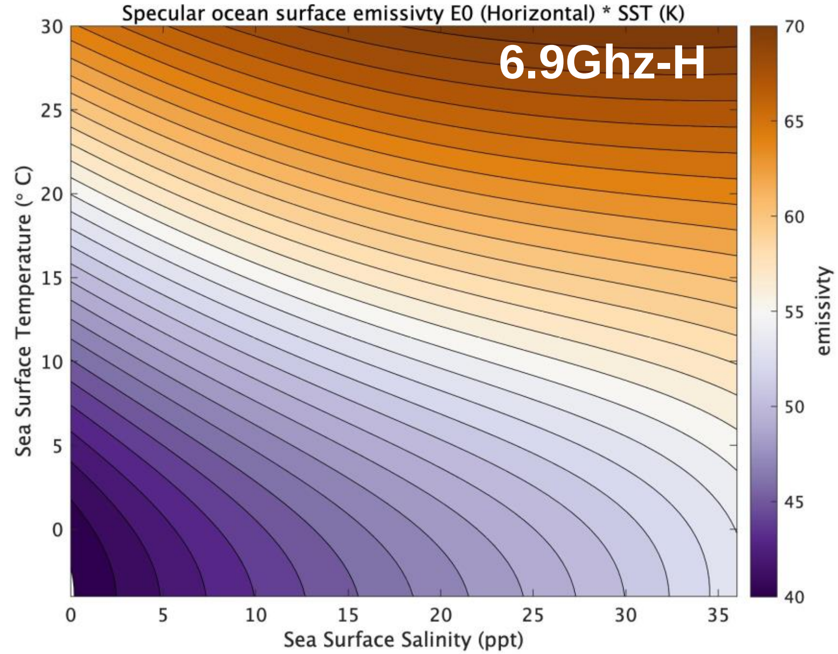
*We checked conductivity of Seawater from the Thermodynamic Equation Of Seawater - 2010 (TEOS-10), but there is NO big difference.

Ocean Surface Emissivity in T-S plane

$$E = E_0 + \Delta E_w + \Delta E_\varphi$$

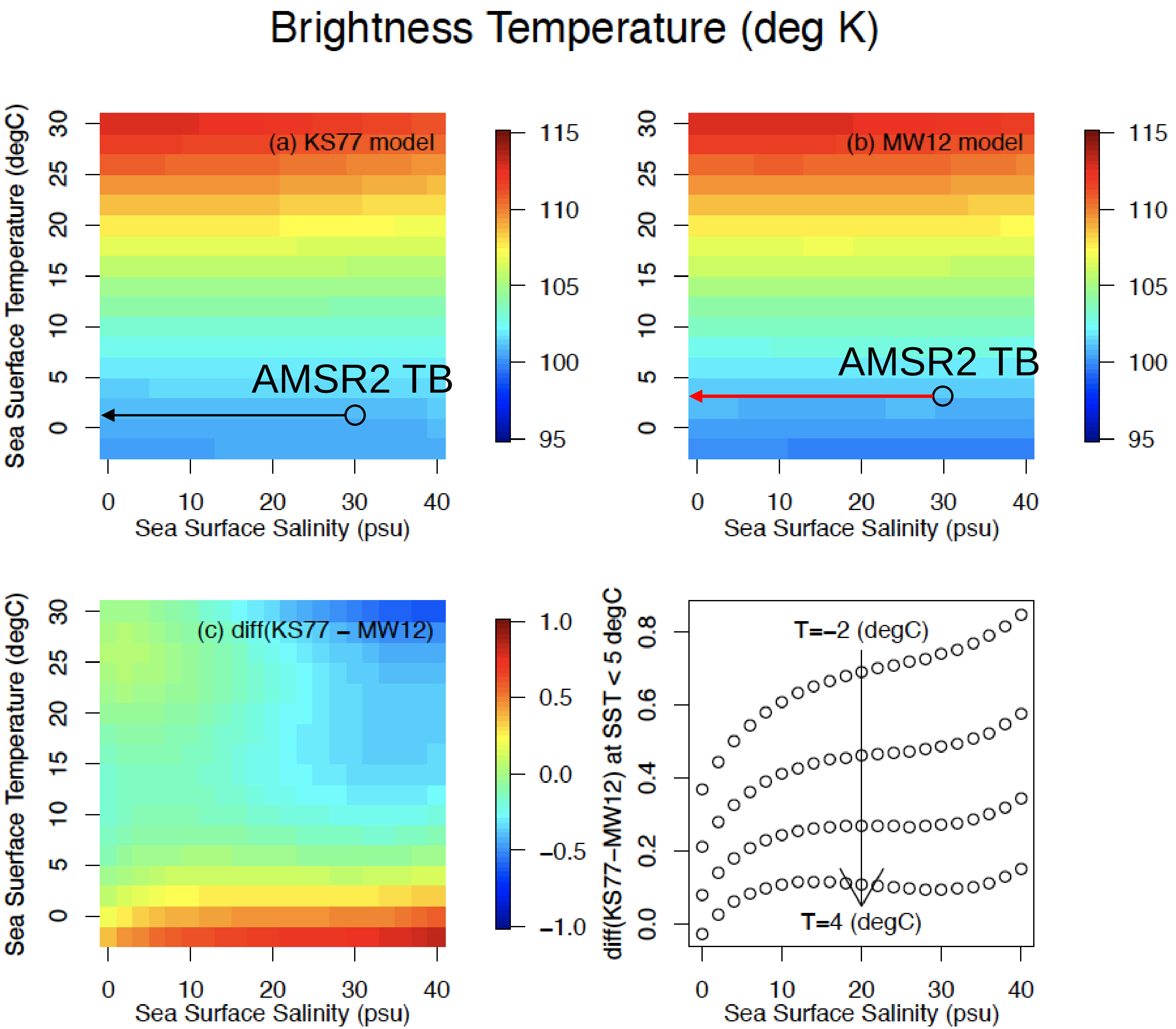
The emissivity of
the specular ocean surface
in T-S plane





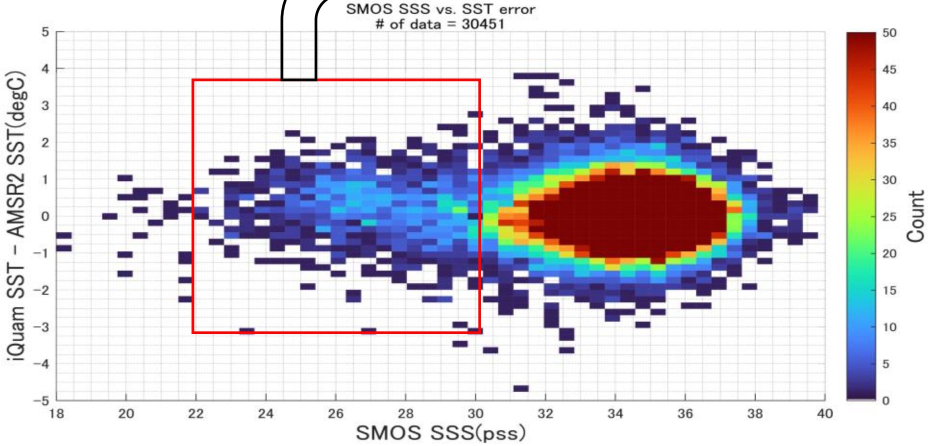
In the cold region like polar ocean,
the effect of salinity change on the change in E_0 becomes large.

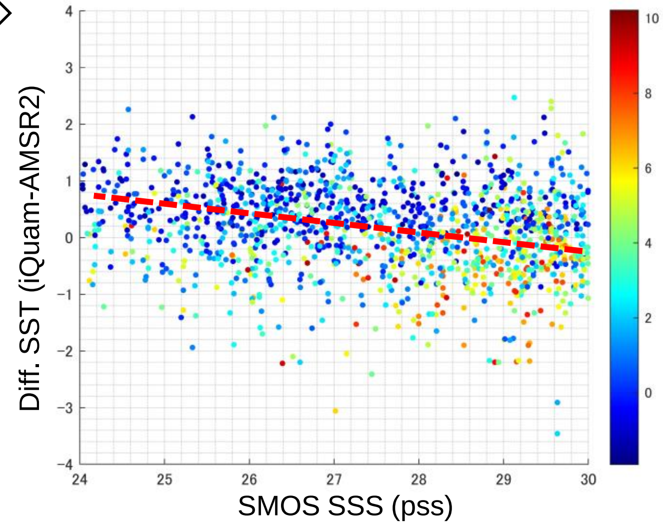
Brightness Temperature in T-S plane



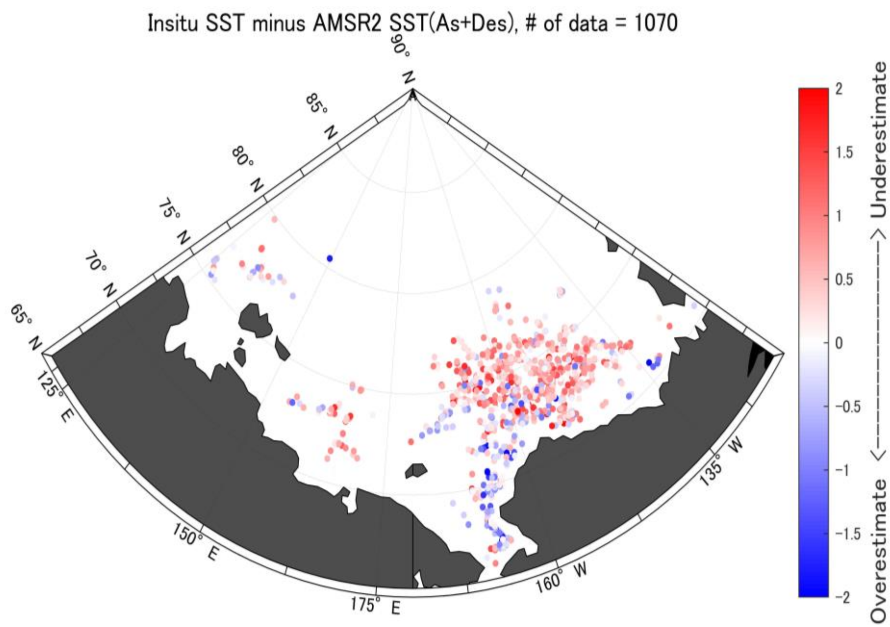
KS77-based LUT leads underestimation of SST.

Dif. T (iQuam – AMSR2) vs. SMOS Sea Surface Salinity



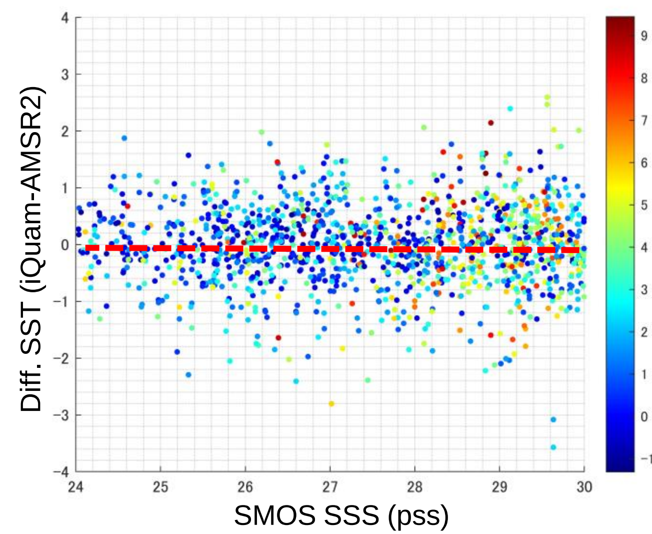


Diff. SST @ SSS < 30



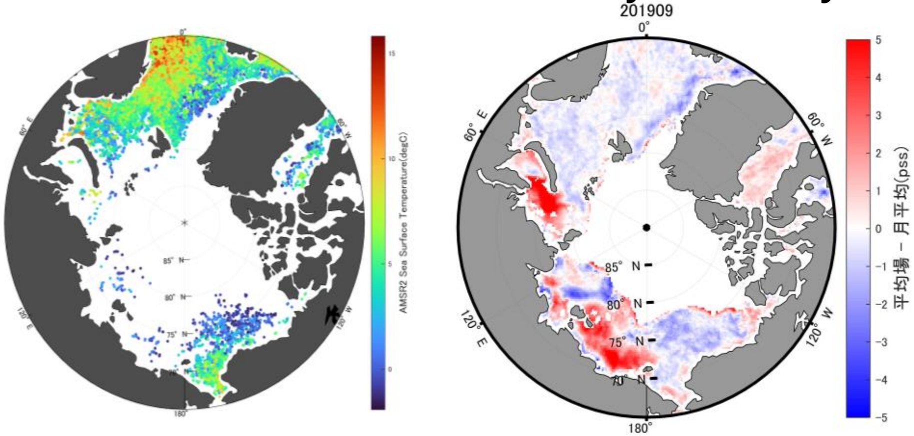
Attempt to modify using T(AMSR) and S(SMOS),

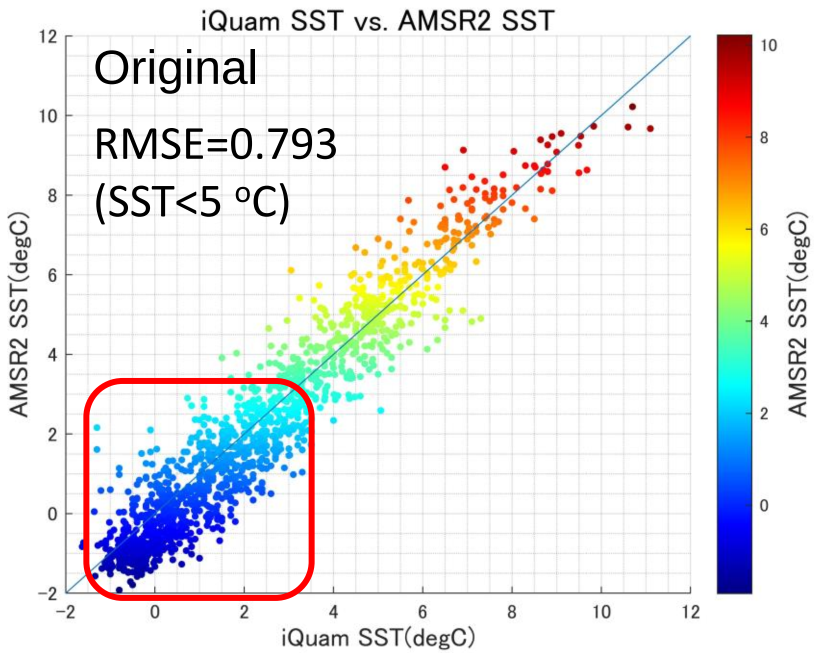
Diff. SST (iQuam – AMSR2)
= −0.013*SSS − 0.1147*SST + 0.77

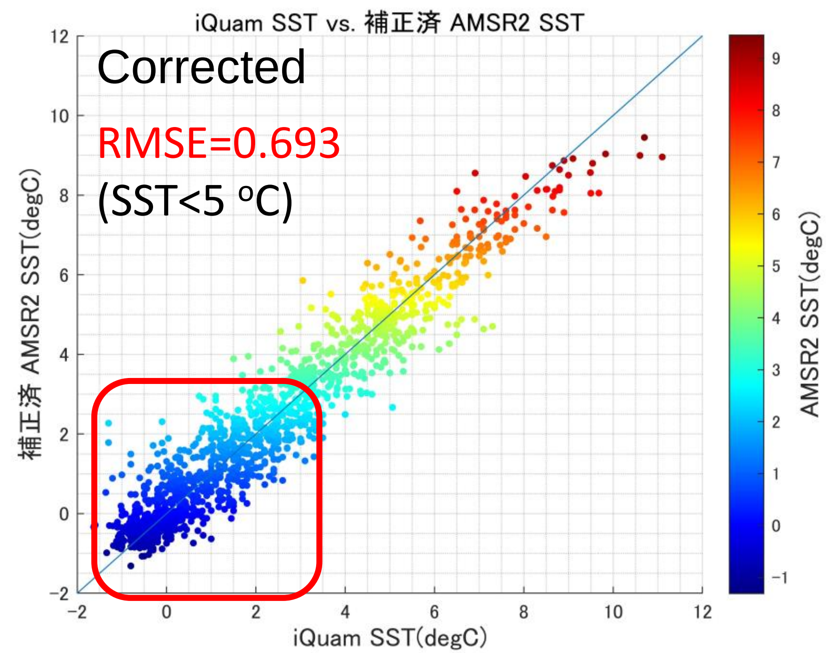


Corrected AMSR2 SST in the Arctic Ocean using SMOS SSS

Salinity anomaly







By adding corrections, we were able to improve SST in the low temperature region.

Estimation of Surface Mixed Layer and Ocean Heat Content

Deep-Sea Research II 77–80 (2012) 62–69

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Deep-Sea Research II

journal homepage: www.elsevier.com/locate/dsr2

East–west asymmetry in surface mixed layer and ocean heat content in the Pacific sector of the Arctic Ocean derived from AMSR-E sea surface temperature

Kohei Mizobata*, Koji Shimada

Department of Ocean Sciences, Tokyo University of Marine Science and Technology, 4-5-7 Kounan, Minato-ku, Tokyo 108-8477, Japan

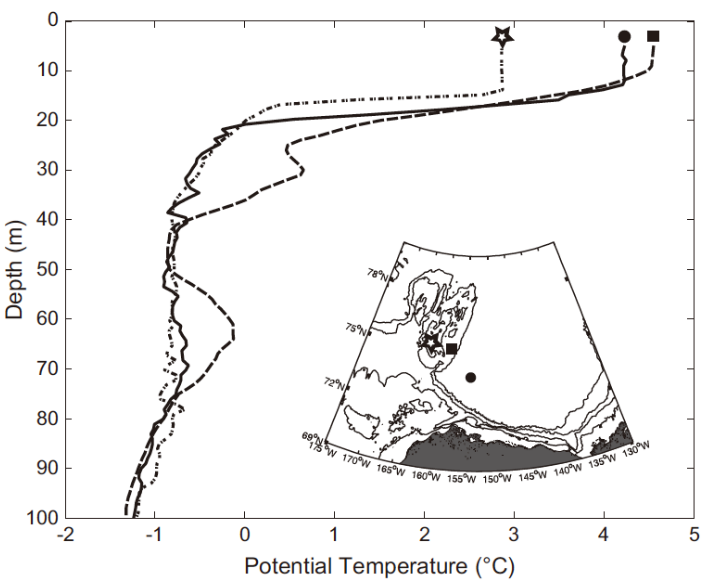
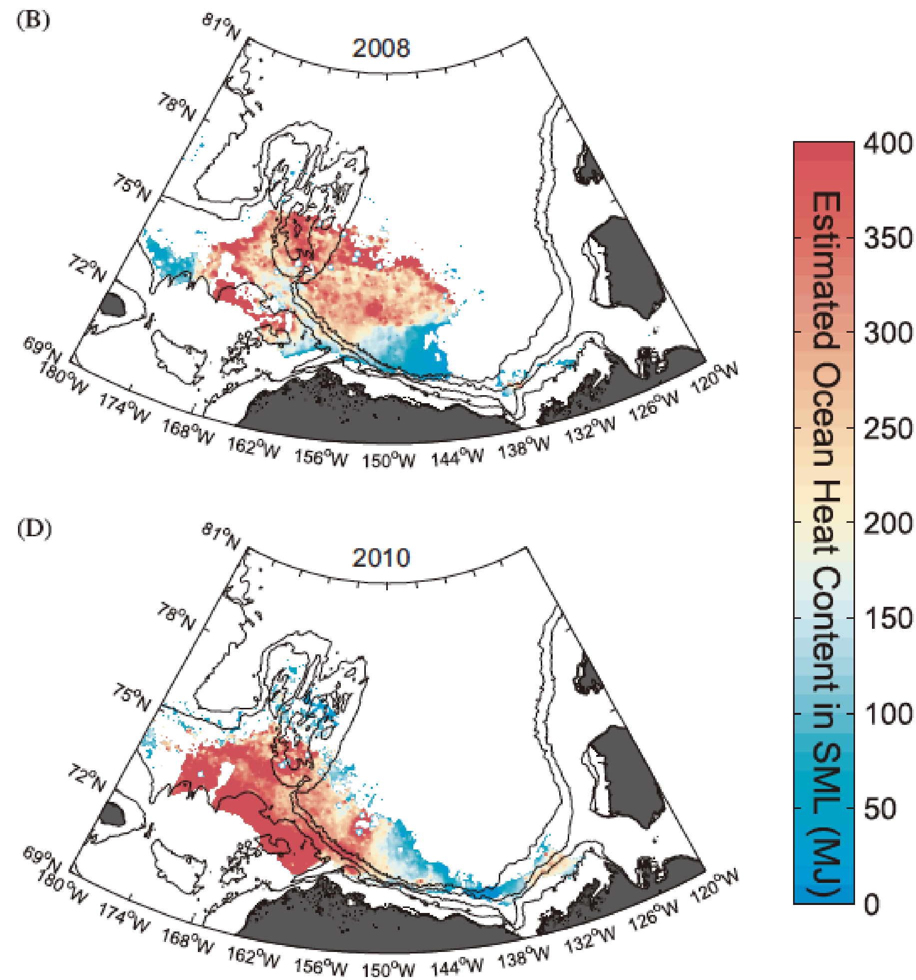
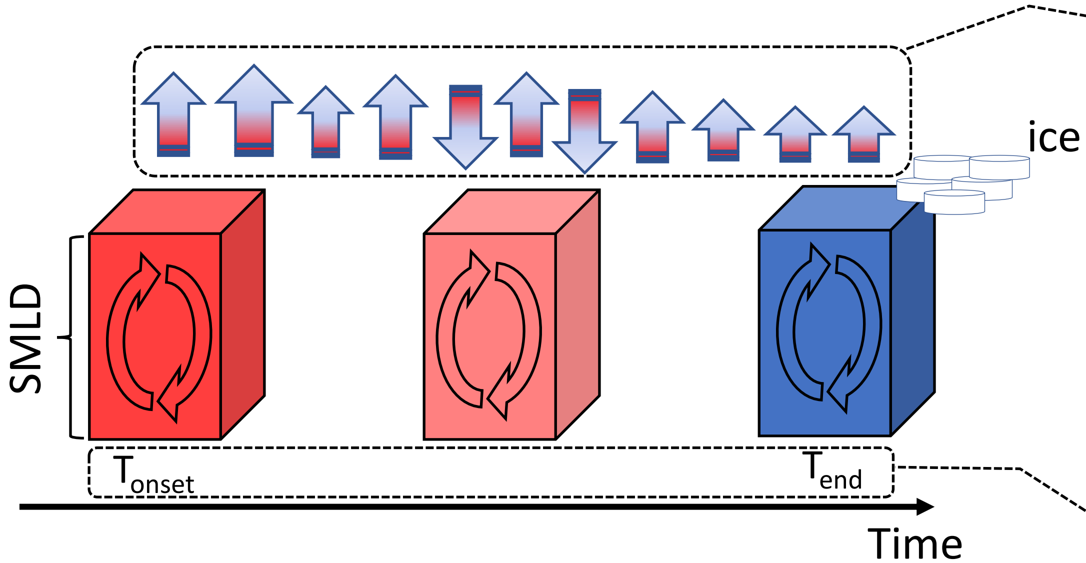


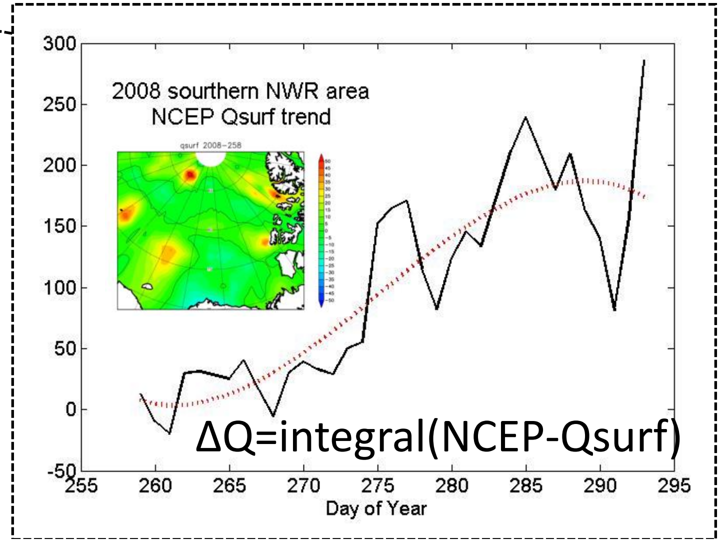
Fig. 3. Vertical profiles of potential temperature obtained in September, 2008, during the R/V Mirai cruise. Dotted, dashed, solid lines indicate the temperature profile at the southern Northwind Ridge, Northwind Ridge and western Canada Basin.

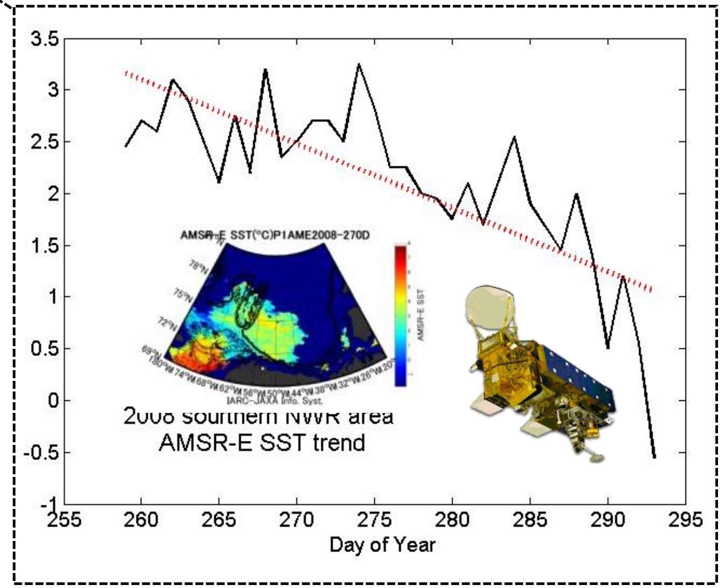


and NCEP/NCAR heat budget in (A) 2007, (B) 2008, (C) 2009 and (D) 2010.

Estimation of Surface Mixed Layer and Ocean Heat Content







$$OHC_{onset} = \rho \times Cp \times SMLD(T_{onset} - T_{freezing}) \quad (1)$$

$$OHC_{end} = \rho \times Cp \times SMLD(T_{end} - T_{freezing}) \quad (2)$$

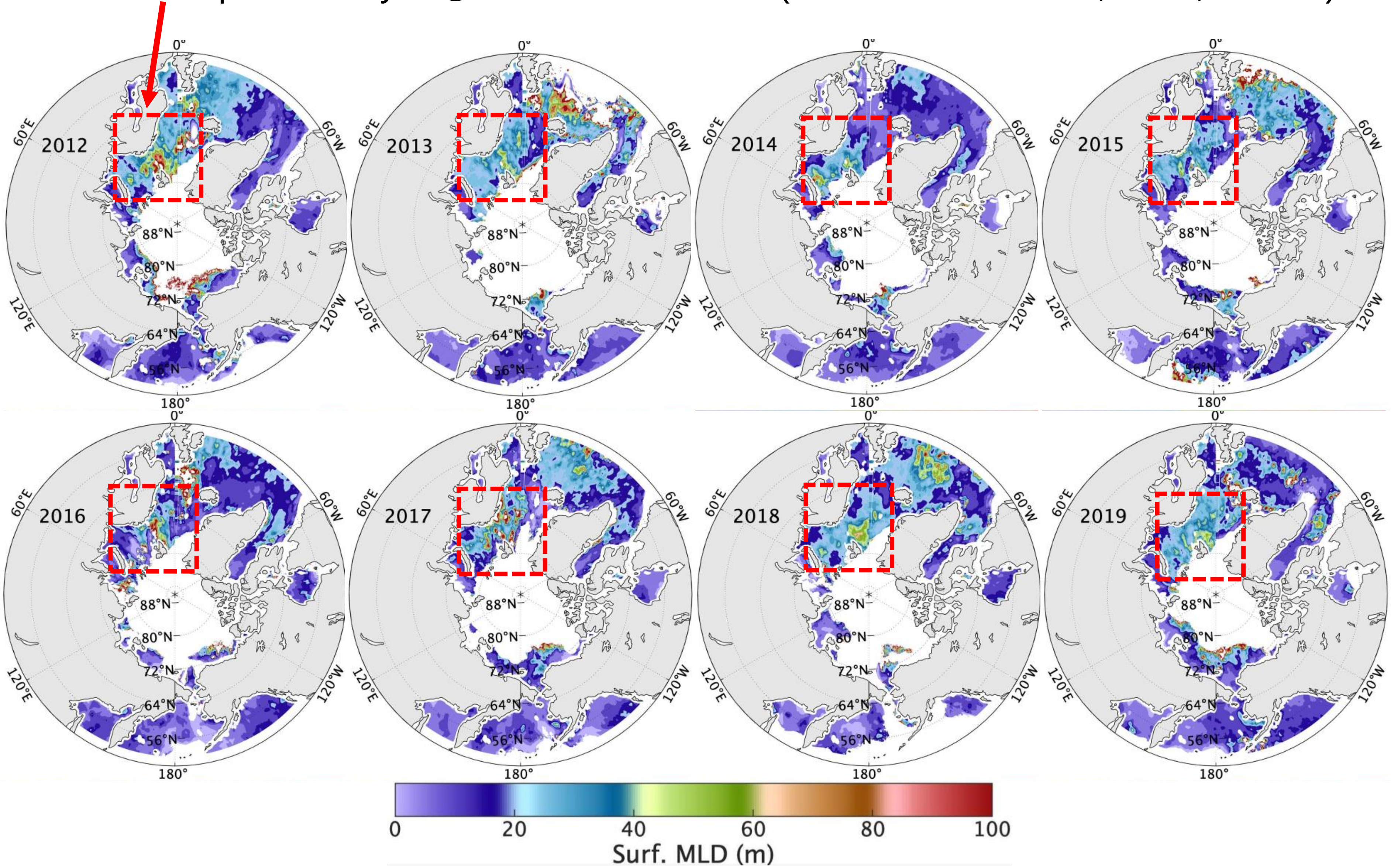
$$\Delta OHC = \rho \times Cp \times SMLD(T_{onset} - T_{end}) \quad (3)$$

$$\Delta OHC = \int_{onset}^{end} (SHTFL + LHTFL + NSWRS + NLWRS) \quad (4)$$

Mizobata and Shimada (2012, DSR2)

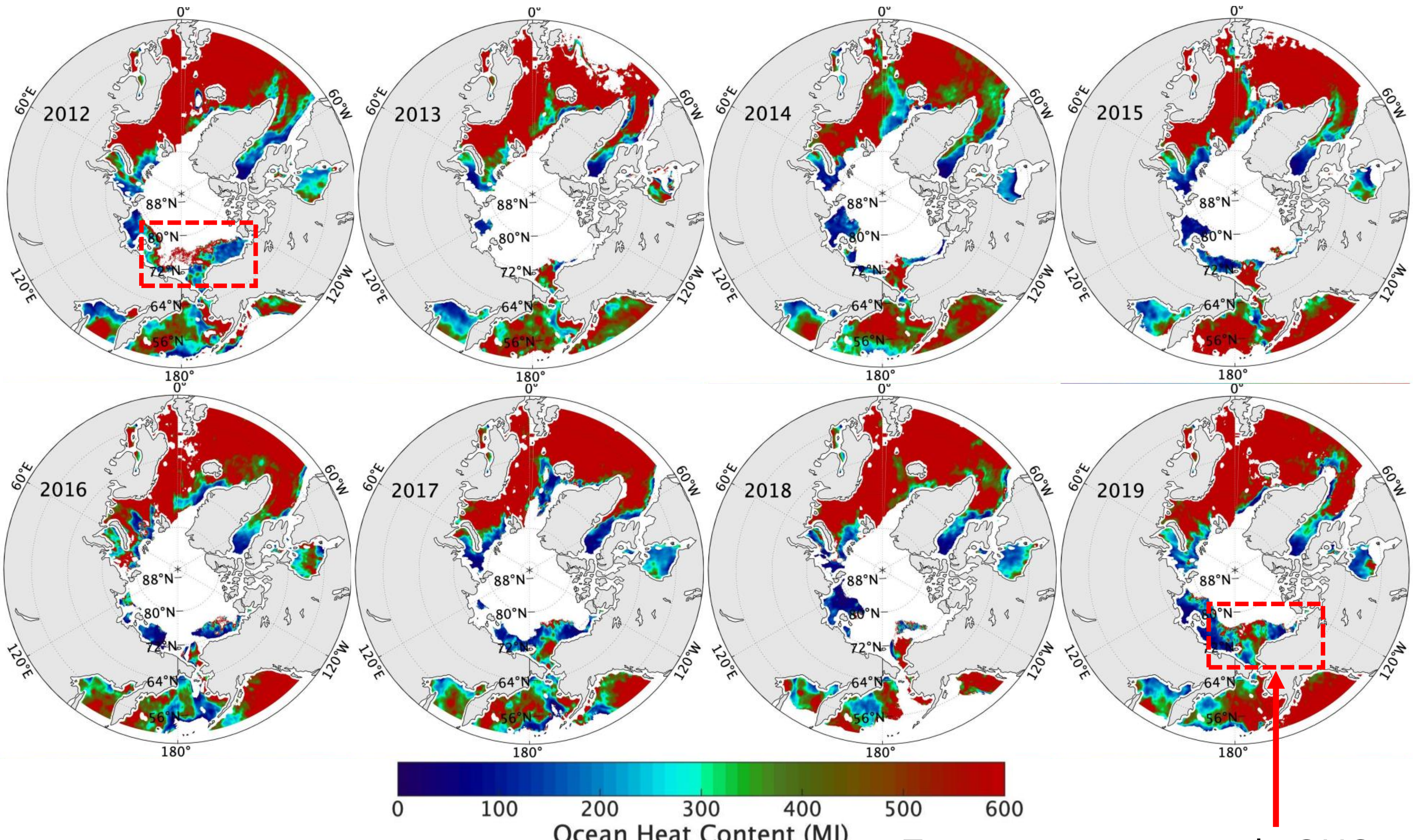
Estimated SML depth and OHC from 2012 to 2019

Deep mixed layer @ M2 critical latitude (Furevik and Foldvik, 1996, JGR-O) ?



Estimated SML depth and OHC from 2012 to 2019

Using corrected AMSR 2 SST & NCEP/NCAR Reanalysis



East-west asymmetry in OHC

Summary

- AMSR2 SST (A & D, after the impact of wind was removed) tends to be lower than the in-situ water temperature in the low-temperature region.

- The emissivity of the specular ocean surface ($\boldsymbol{E_0}$) was examined. In the cold region, the dependency of $\boldsymbol{E_0}$ on salinity change is expected. Underestimation of SST in areas where sub-pixel contamination of sea ice is expected may also suggest dependence on sea surface salinity.

- Current SST algorithm is based on a model for the dielectric constant of seawater (Klein and Swift , 1977). In this study, TB based on KS77 and MW12 was examined. Our result suggests KS77 will lead to underestimation of SST due to the impact of salinity in low-temperature region, such as the Arctic Ocean.

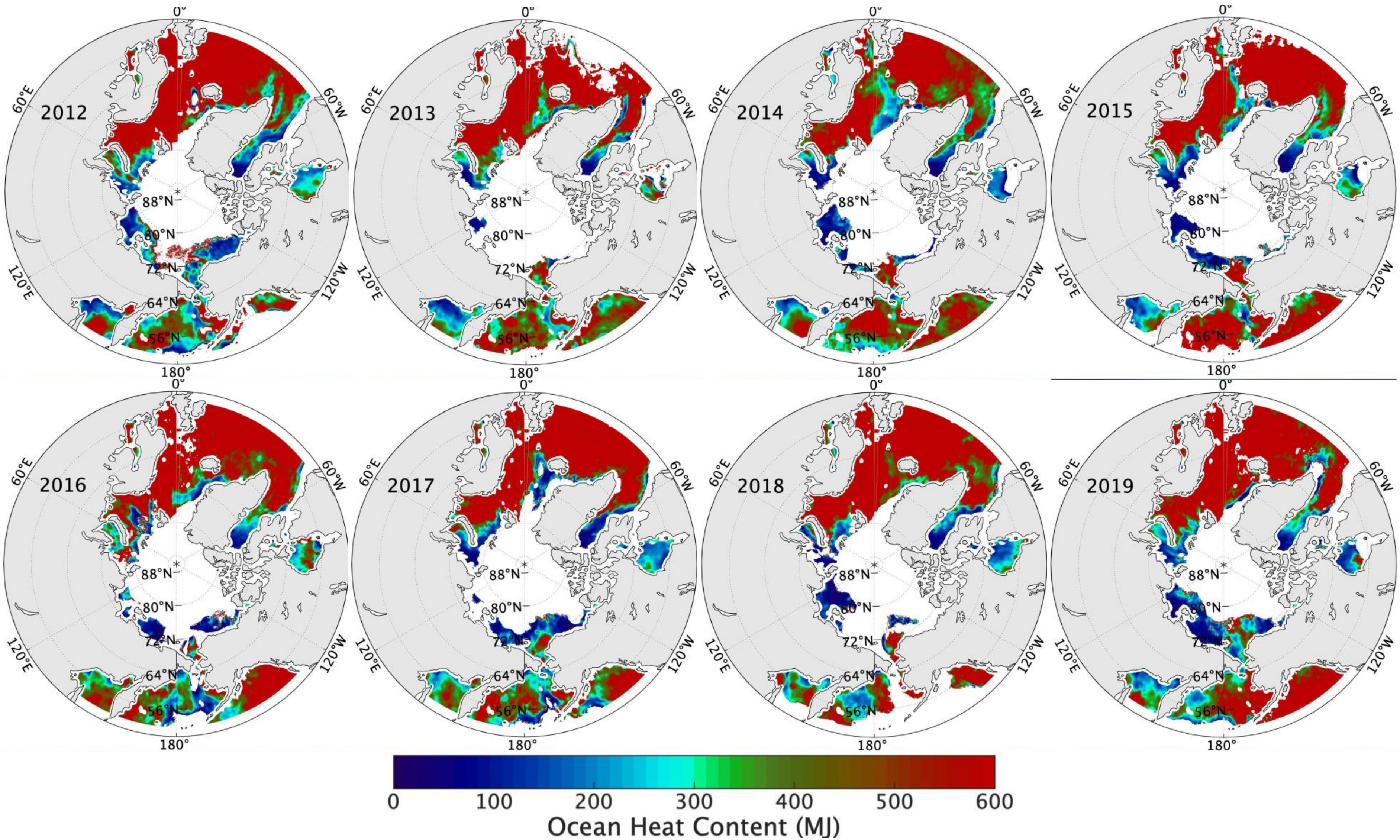
- Empirical correction using AMSR2 SST and SMOS SSS was applied.

- Using corrected AMSR2 SST and NCEP/NCAR reanalysis dataset, realistic surface mixed layer depth and ocean heat content were estimated based on Mizobata and Shimada (2012).

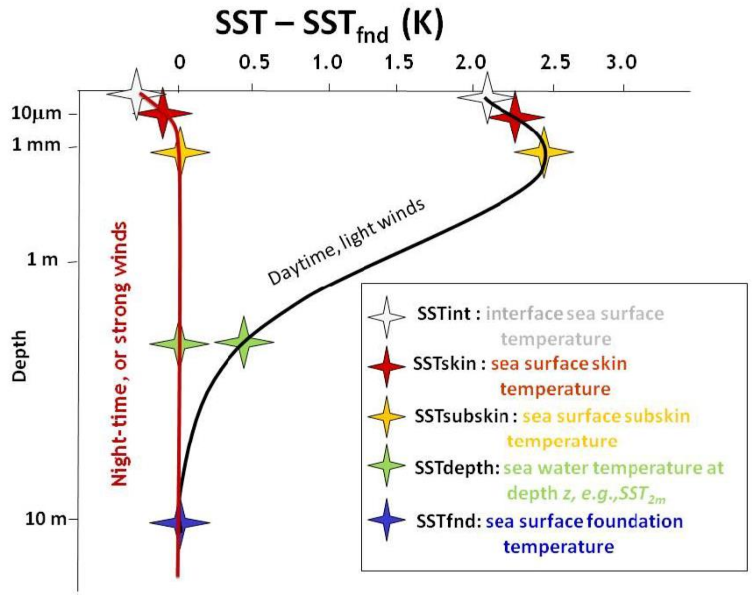
Supplemental information

Estimated SML depth and OHC from 2012 to 2019

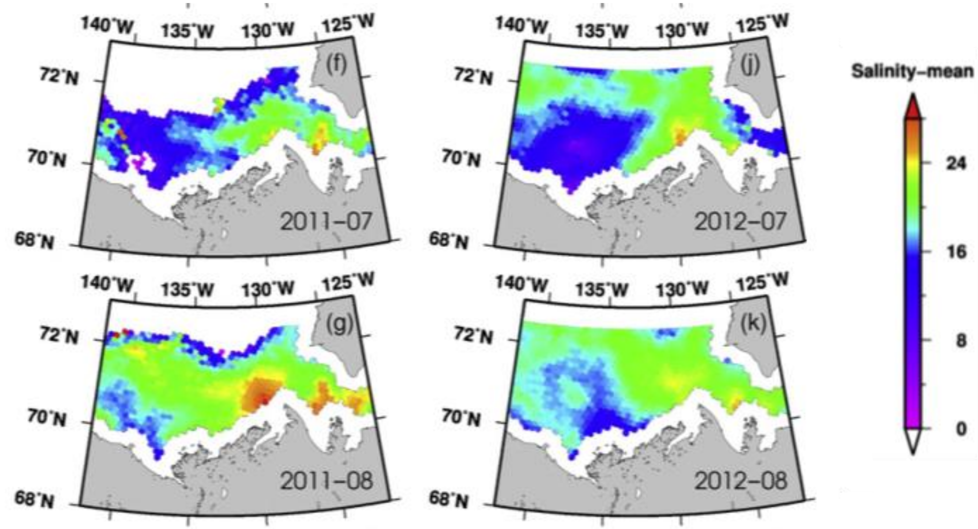
Using original AMSR 2 SST & NCEP/NCAR Reanalysis



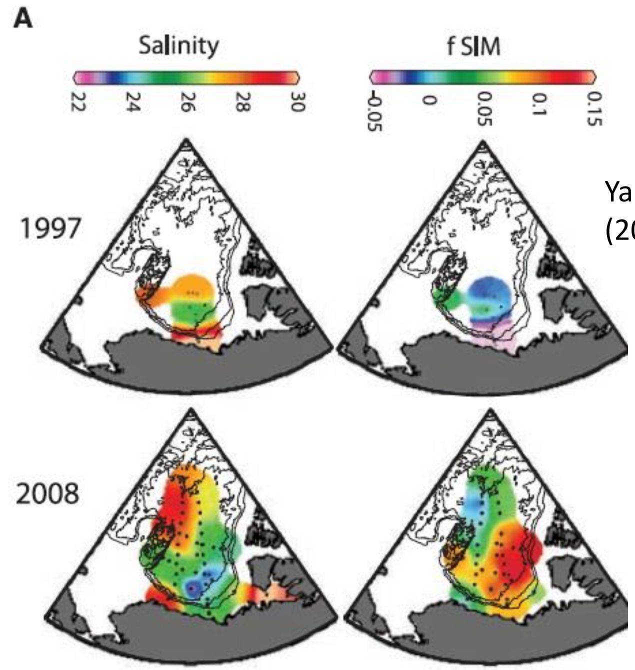
Possible suspects for scattering in cold area



Minnett, P.J., Kaiser-Weiss, A.K., 2012. Group for High Resolution Sea-SurfaceTemperature Discussion Document: Near-Surface Oceanic Temperature Gradients (7pp.)



Matsuoka et al. (2016, Remote Sensing of Environment)



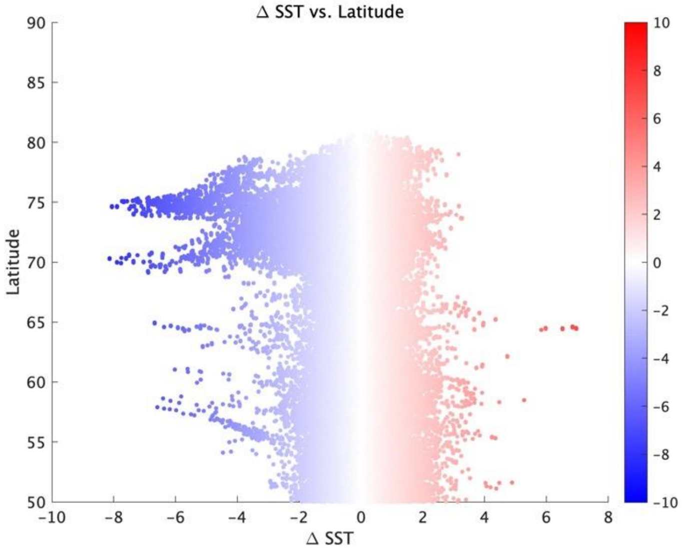
Yamamoto-Kawai et al. (2009, Science)

- ✓ **Wind mixing**
  Strong wind ➔ skin temperature ≒ SSTdepth
  ➔ AMST SST will be same as in-situ SST

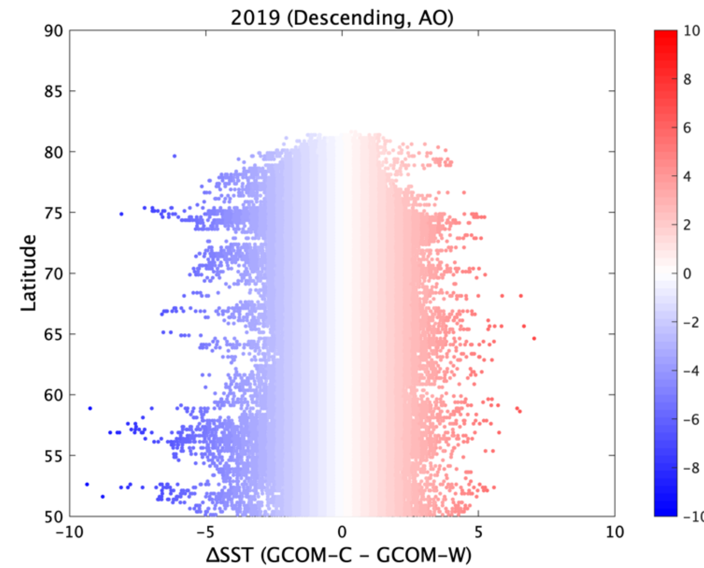
- ✓ **Freshwater due to river discharge and sea ice melt**
  Salinity stratification induce efficient uptake of shortwave radiation, i.e., enhancement of skin temperature vertical gradient of temperature ➔ AMSR SST > in-situ SST

Difference of SST between AMSR2 and iQuam v2.1

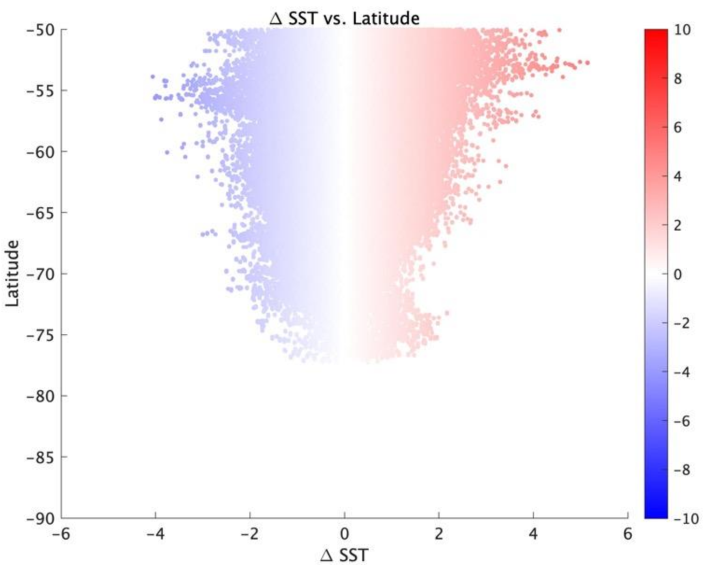
Northern Hemisphere



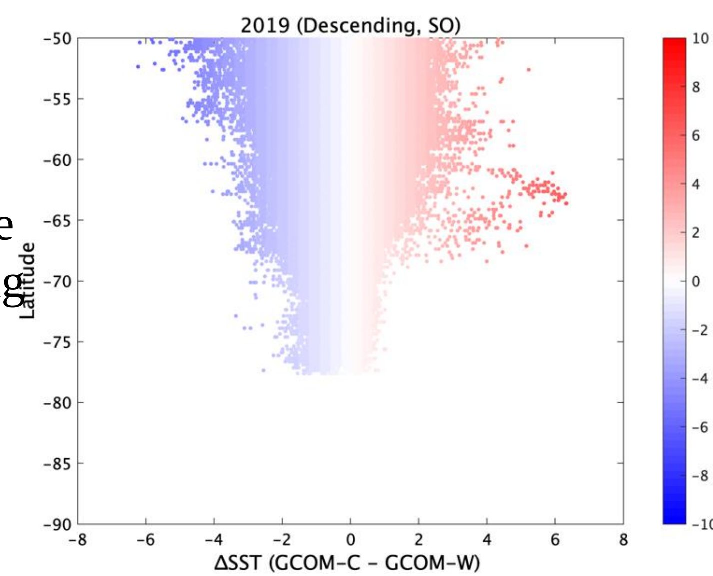
There is no latitude dependence in the Northern Hemisphere. SST (Ascending Path) tends to be underestimated.



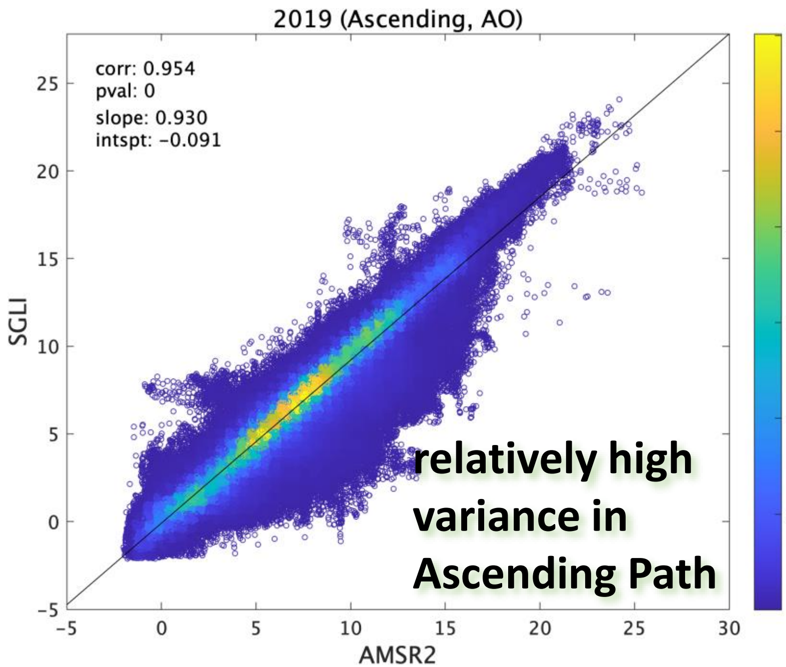
Southern Hemisphere

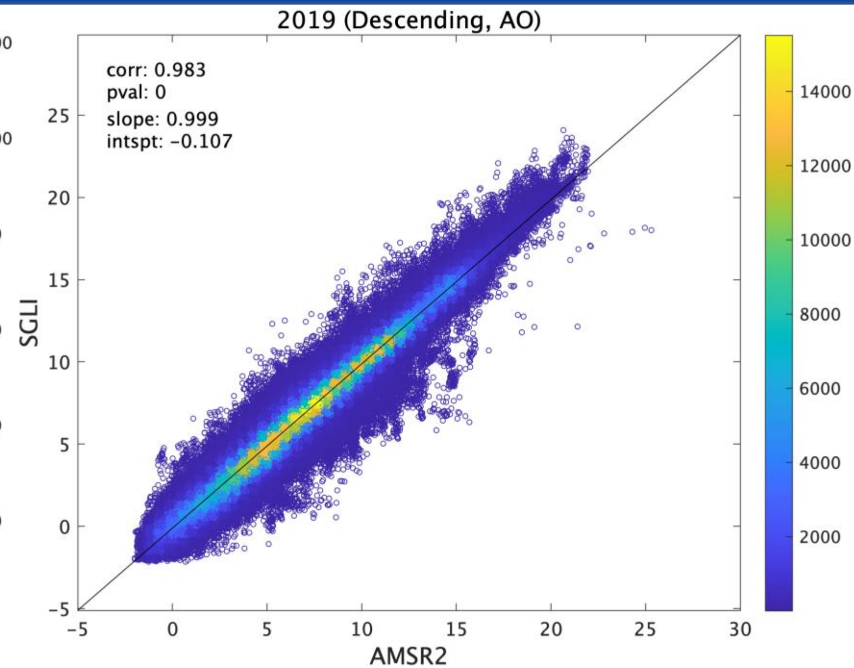


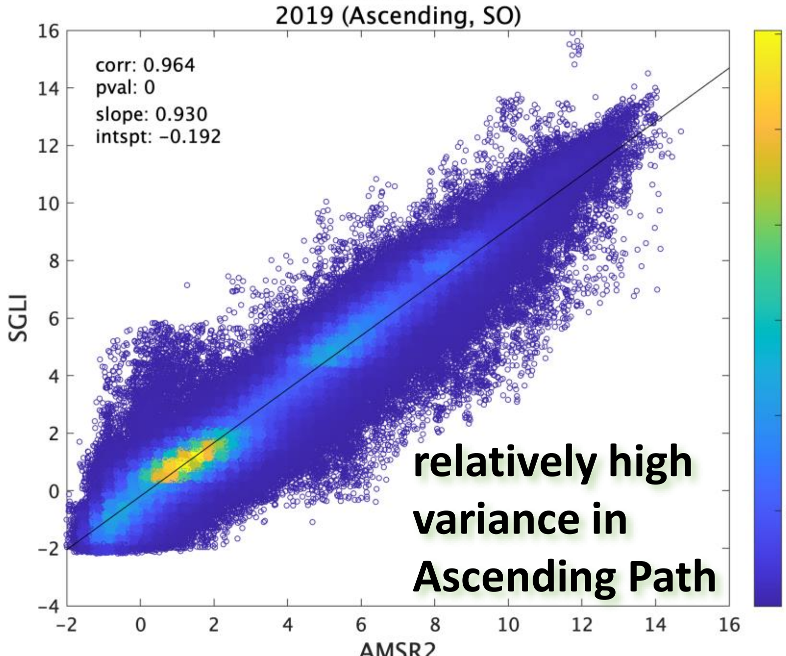
In the Southern Hemisphere, the error tends to increase in the lower latitude implying wind dependence.

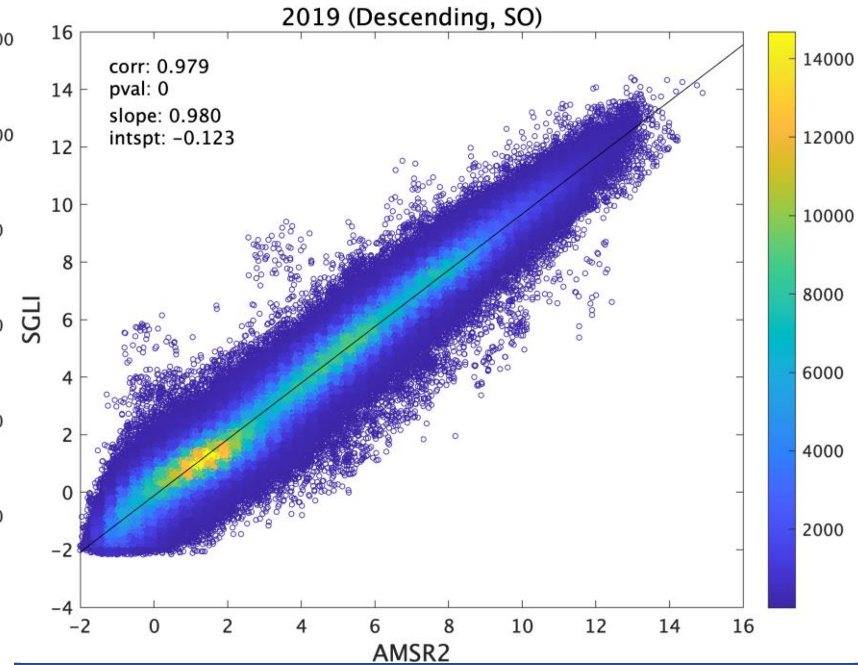


Introduction

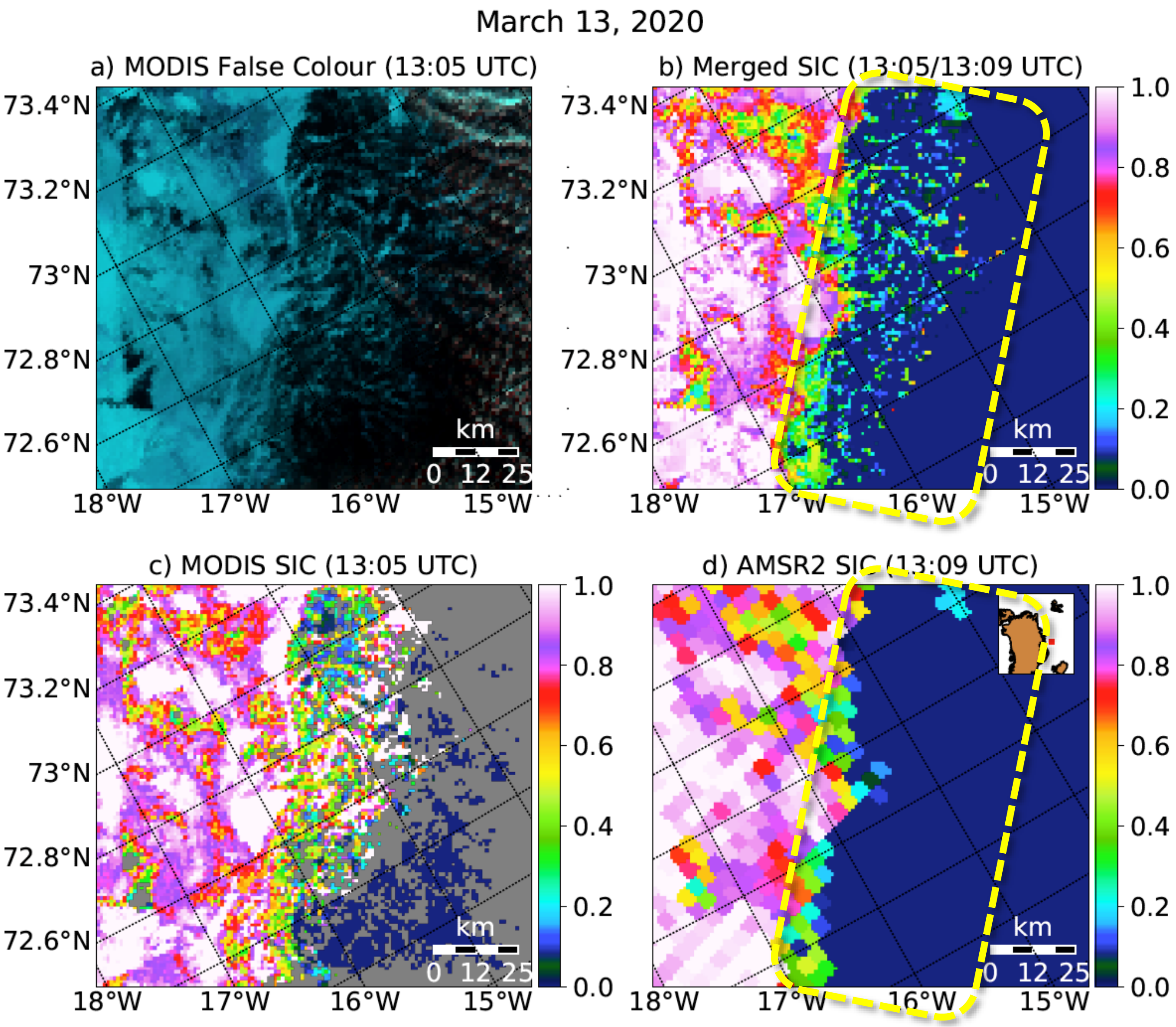






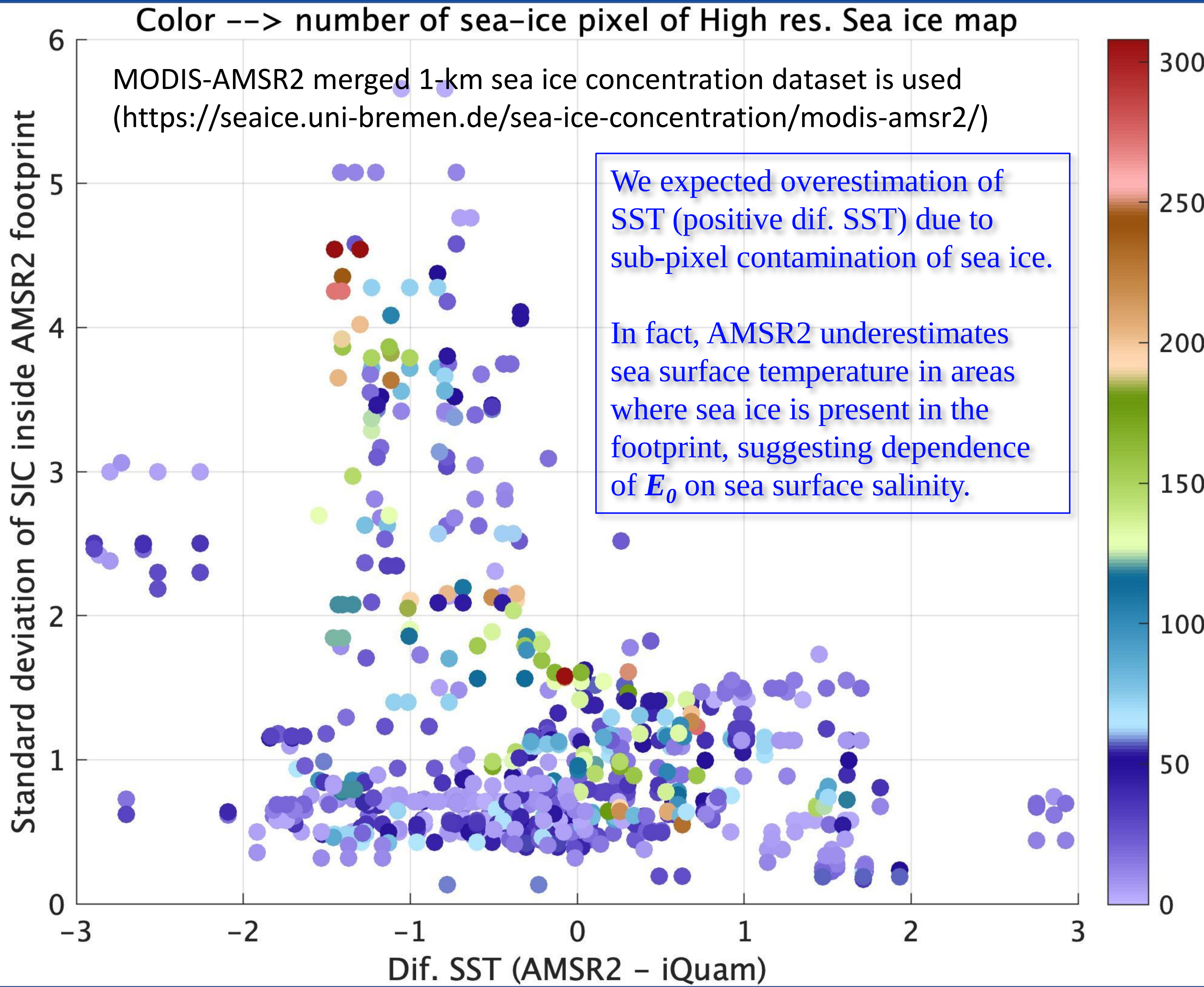


Sea ice distribution in AMSR2 footprint



Courtesy of Valentin Ludwig, University of Bremen

Sea ice distribution in AMSR2 footprint



Sea ice distribution in “pseudo” AMSR2 footprint