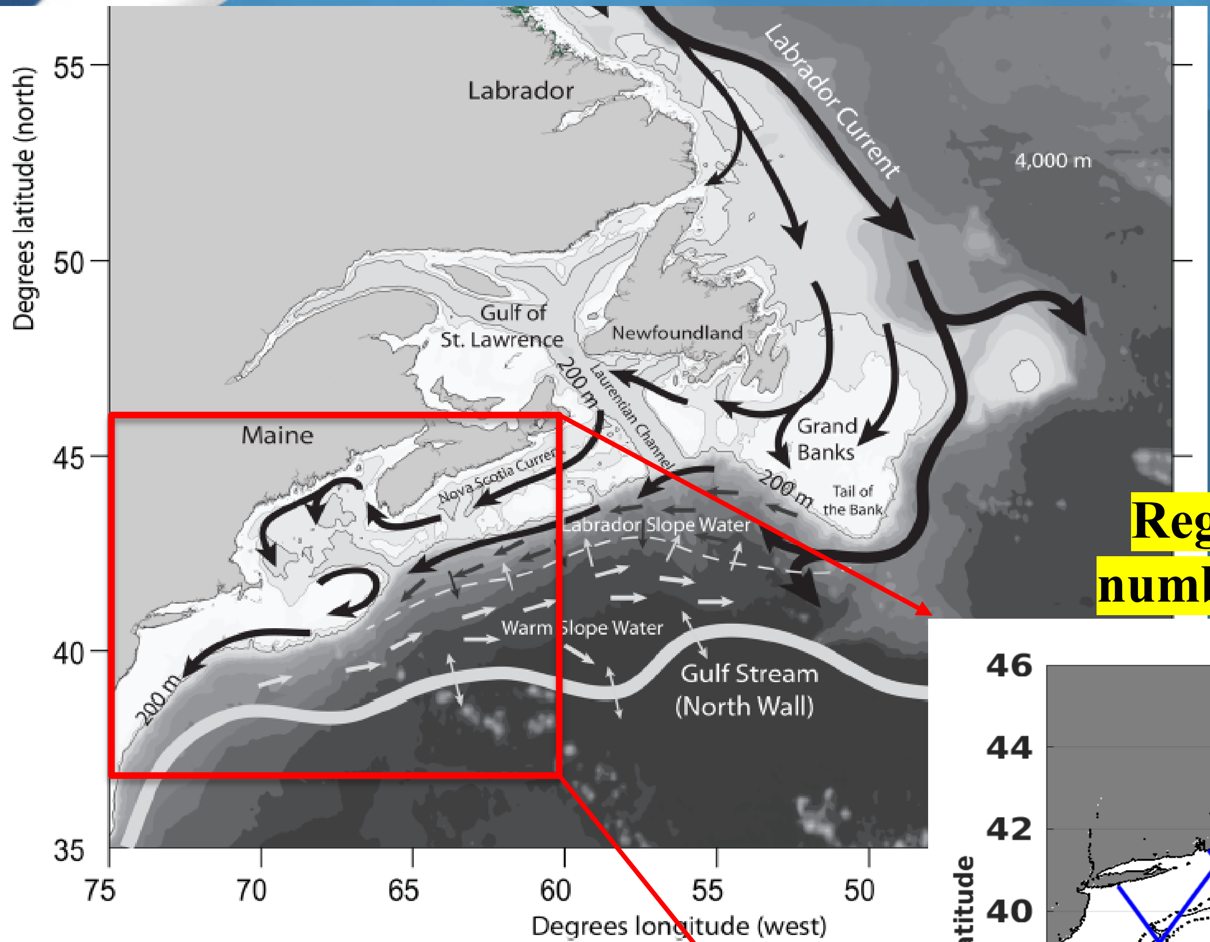
Assessment of S6 altimeter data along the Northwest Atlantic shelf

Hui Feng[1,2] and Doug Vandemark[1]

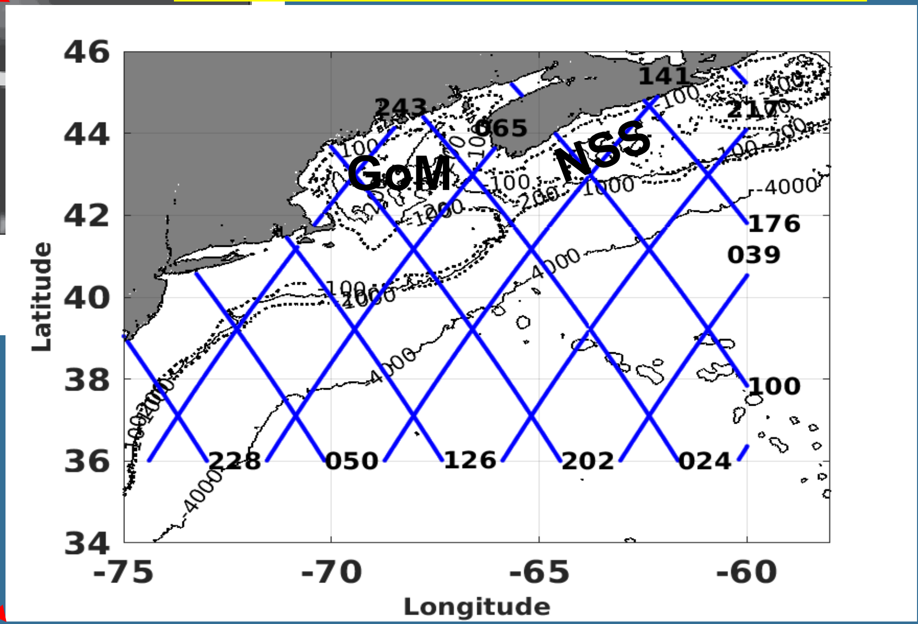
[1] University New Hampshire, NH, USA, [2] GST Inc., MD, USA.

Ocean Surface Topography Science Team meeting, Oct 31- Nov.3 , 2022

Region of Interest: NW Atlantic shelf



Regional map with the pass numbers labeled for S6 and J3



Goal and Objectives

Goal is to provide an assessment of Sentinel-6A altimeter products along the northeastern US and Nova Scotian coast and shelf seas

Objectives:

- analyze S6A products (range, SSHA, SWH, and sig0) in the Commissioning Phase (J3-S6 tandem)
- quantify data quality (bias and noise), particularly near the coast, using comparison of S6 LR (Low-Resolution) and HR (SAR) mode to Jason-3 LR reference data
- assess the quality of the altimeter SSH and SSH-derived geostrophic velocity estimates, both nearshore and offshore
- explore potential applications - monitoring Gulf of Maine subsurface salinity variation using altimeter current data over the Scotian Shelf

Data and methods

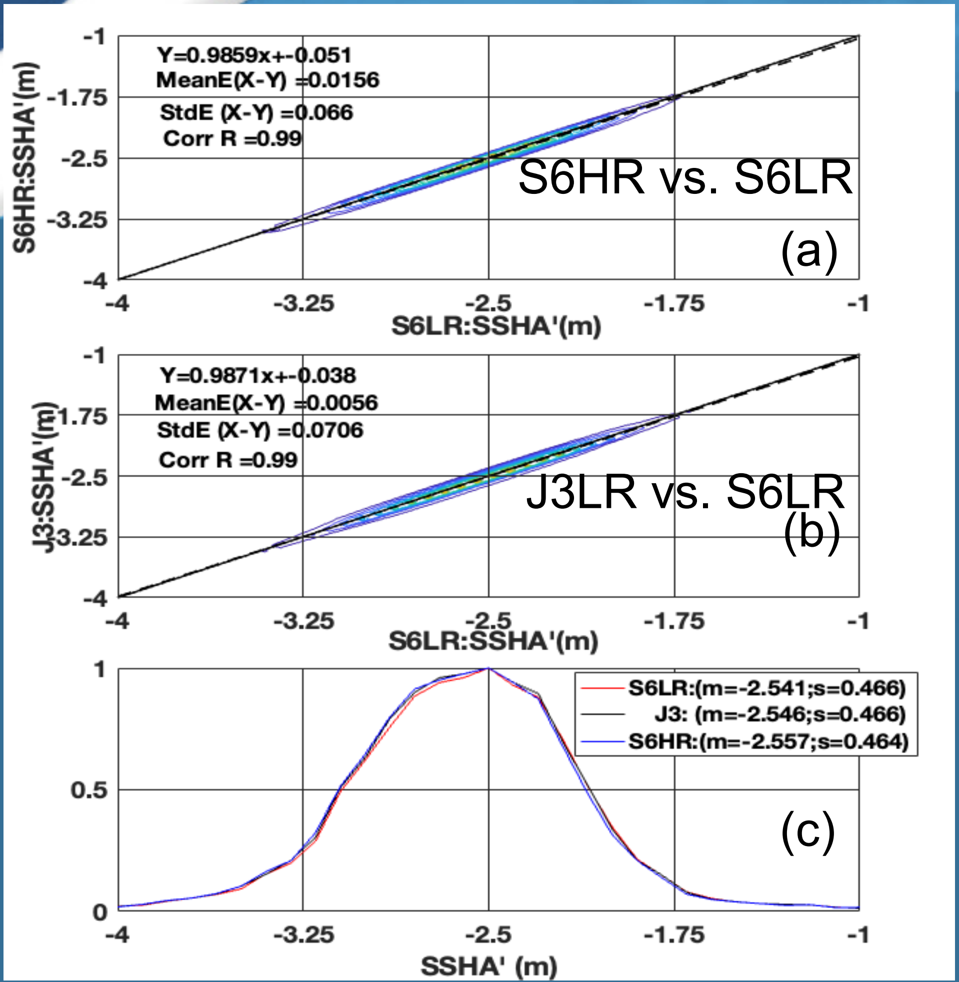
- Datasets: J3 is the GDRF, S6A LR/LR is Baseline F06; both at 1Hz rate and as extracted from RADS on collinear tracks
- Cycles: J3 (179-226) and S6A (4-51) (17 Dec 2020 to 7 April 2022) during J3-S6 tandem phase
- Spatial co-registering of the data along track to allow matchup evaluation

Variables for assessment in both Ku and C band (if available) include

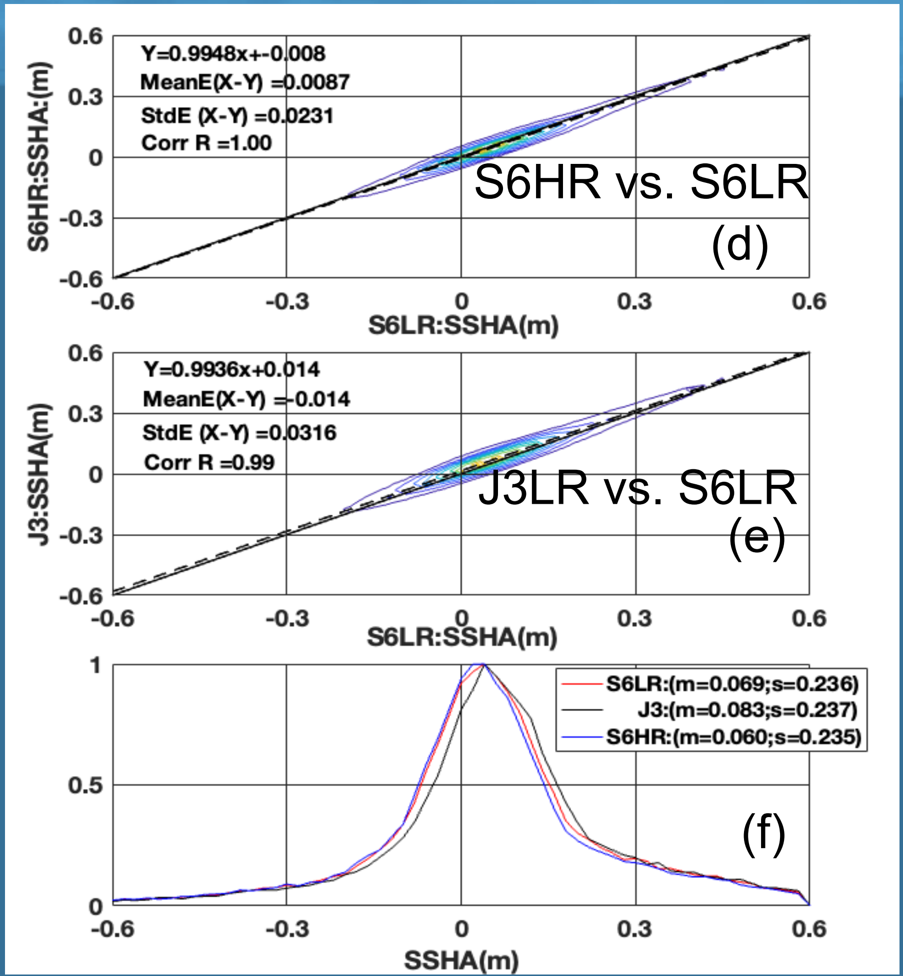
- Sea Surface Height Anormly SSHA
  - SSHA'= AltOrb-range-mss,   (w.o. geophysical corrs applied)
  - SSHA = AltOrb-(range+corrs)-mss, (w. geophysical corrs applied)
- SWH and Sig0
- SSH-based cross-track geostrophic current Vg

I. Bias analyses: Scatterplots and pdfs

Result 1a:Sea Surface Height Anomaly (SSHA) in Ku: S6HR/S6LR/J3



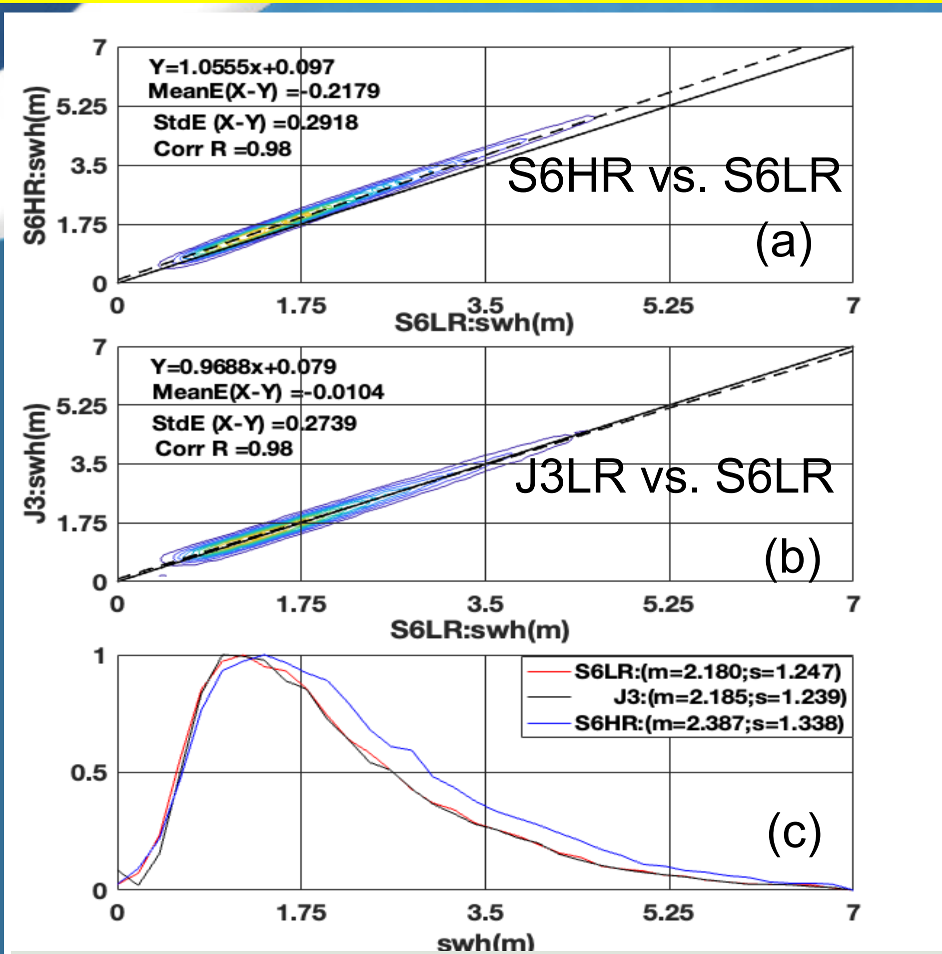
SSHA'=AltOrb-range'(no geophys. Corr.) -MSS
(a) S6HR vs. S6LR, (b) J3 vs. S6LR, and (c) pdfs



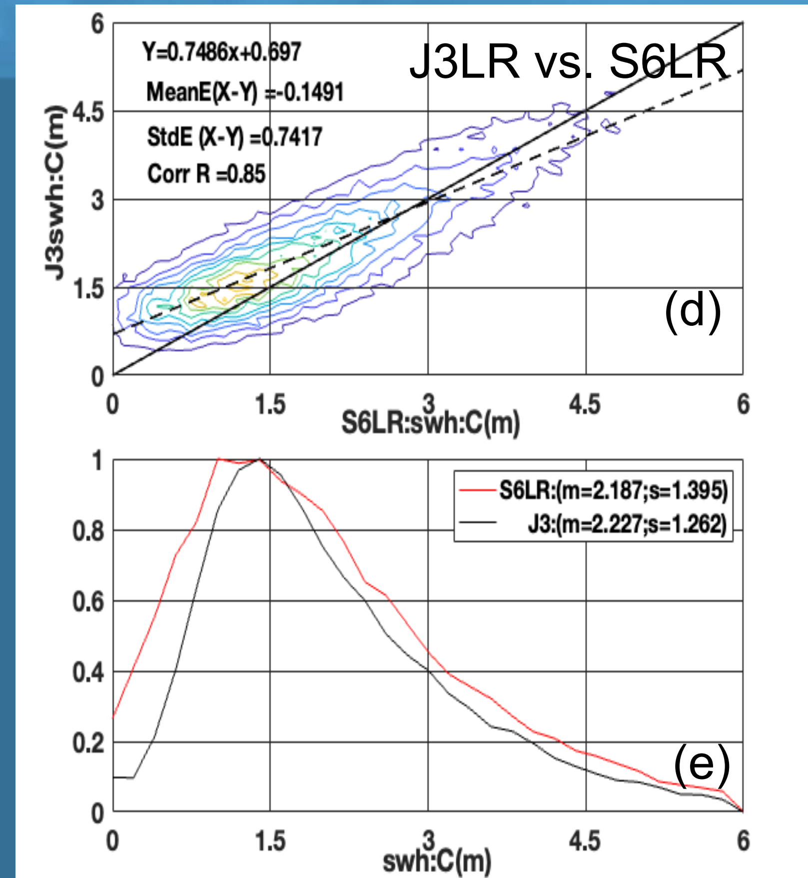
SSHA=AltOrb-range(geophy. corr) -MSS
(d) S6HR vs. S6LR, (e) J3 vs. S6LR, (f) pdfs

- Look well consistent among S6LR(or J3) and S6HR SSHAs either case

Result 1b: SWH in Ku and C : S6HR/S6LR/J3



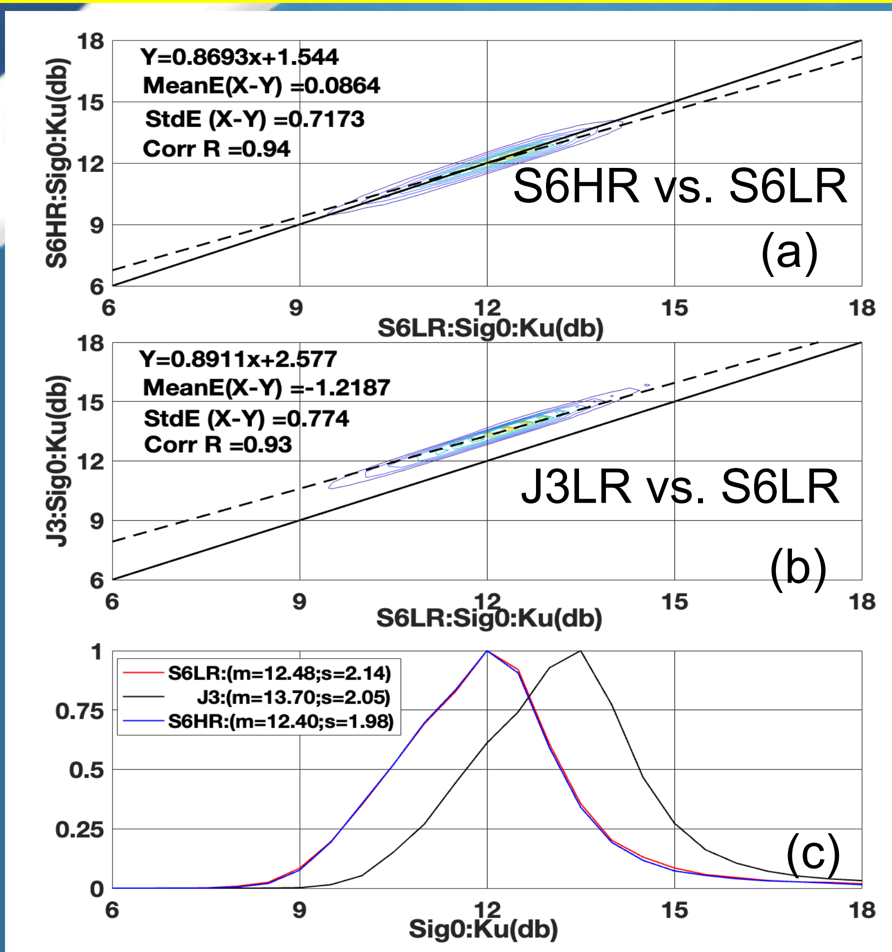
Scatter plots SWH in Ku, (a) S6HR vs. S6LR (b) J3 vs. S6LR, and (c) pdfs of these.



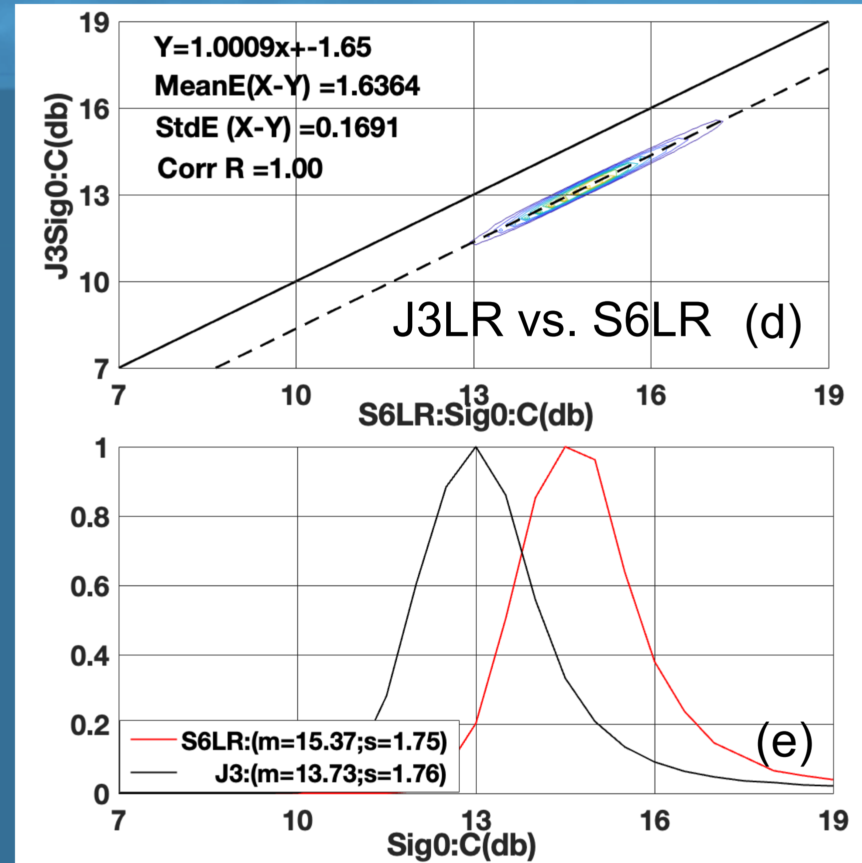
Scatter plots SWH in C, (d) J3 vs. S6LR, and (e) pdfs of these.

- As reported also elsewhere, bias exists between S6LR and S6HR SWH in Ku, increasing with S6LR SWH (a) and little bias between S6LR and J3 SWH in Ku (b)
- S6LR SWH in C is noisier than J3 SWH (d-e)

Result 1c: Sig0 in Ku and C : S6HR/S6LR/J3



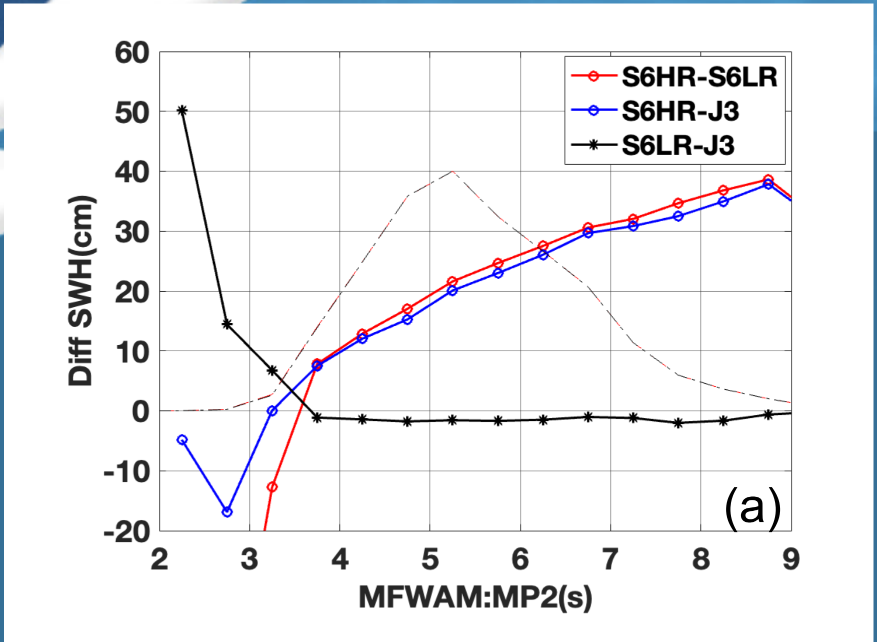
Scatter plots Sig0 in Ku, (a) S6HR vs. S6LR (b) J3 vs. S6LR, and (c) pdfs of these.

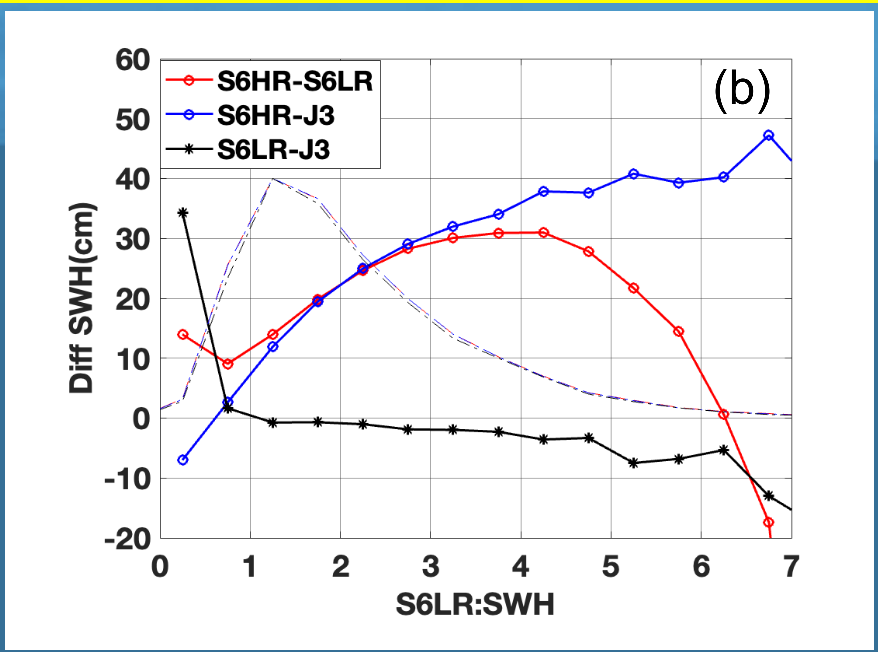


Scatter plots Sig0 in C, (d) J3 vs. S6LR, and (e) pdfs of these.

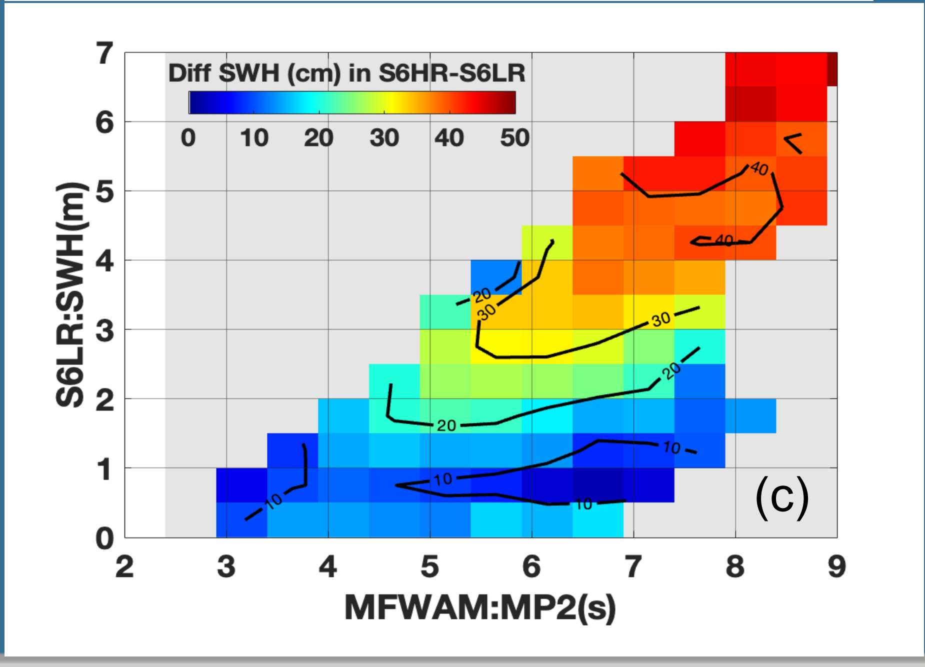
- Sig0 bias in Ku between S6LR and S6HR is relatively small (~0.086db) (a,c) , but appears much higher (1.22db) between S6LR and J3 (b,c)
- Sig0 bias in C between S6LR and J3 is there (~1.64db) (d-e)

Result 1d: the sea state related difference between HR and LR SWH in Ku

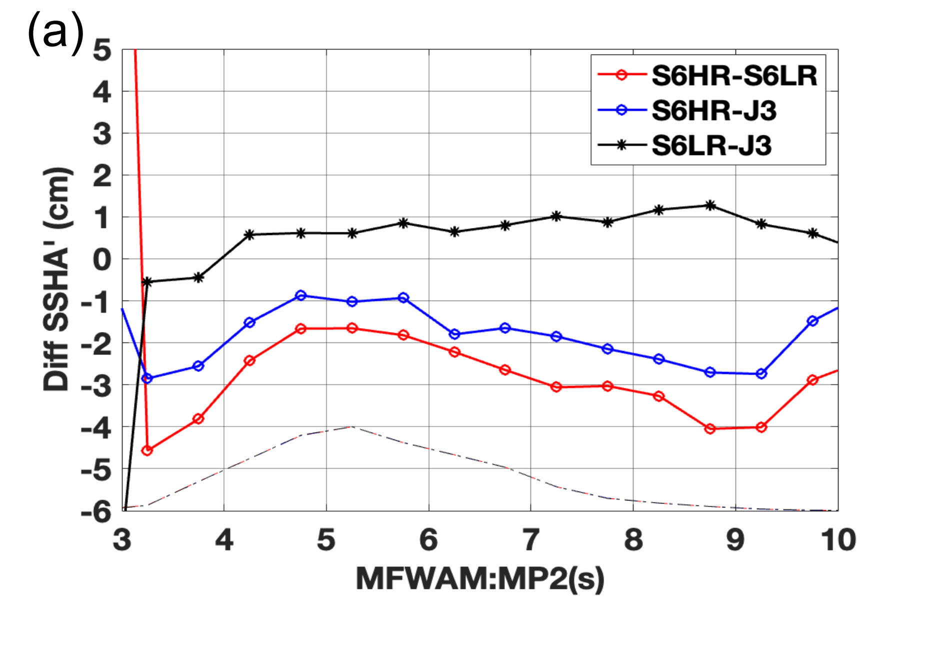


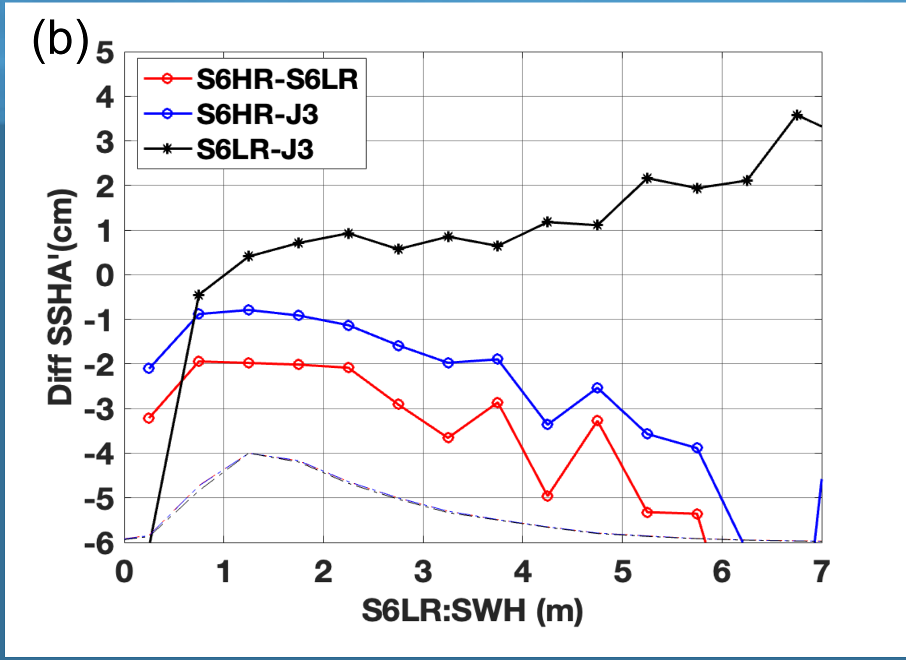


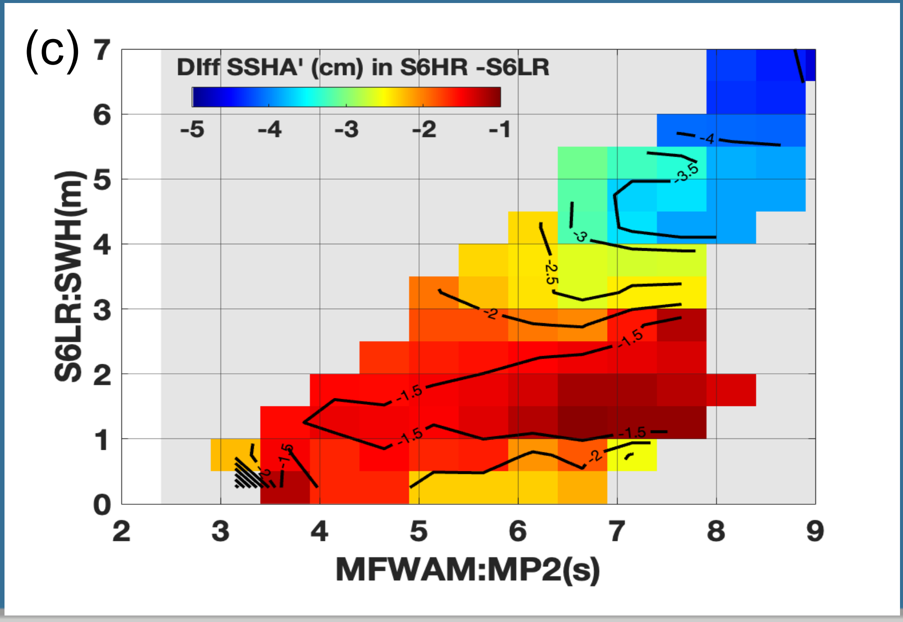
- Biases in S6 HR SWH at Ku-band can be explained by wave conditions, such as (a) mean wave period MP2 (MFWAM) , (b) S6LR SWH, or (c) by 2D (MP2,S6LRSWH)
- Empirical correction (2D) to remove the MP2-depended bias is available (c).
- There is little difference between S6LR and J3 SWH (black) in (a) and (b), and it is NOT related to the mean wave period or sea state



Result 1e: the sea state related difference bet. HR and LR SSHA' (=orbit-range'-mss)



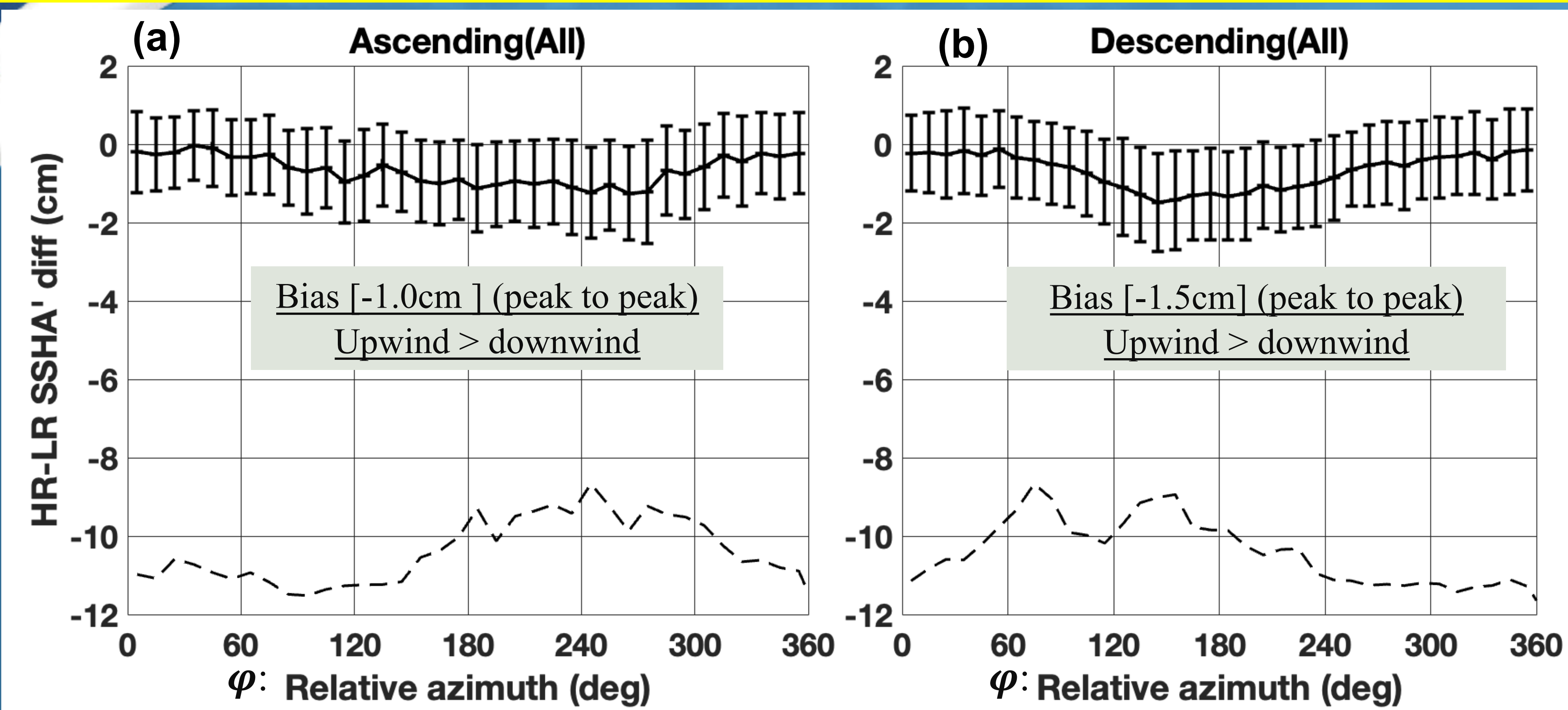




- There is some bias between S6HR SSHA' and S6LR (and J3) SSHA' in Ku at <u>low sea states</u>, partially explained by wave conditions, such as (a) mean wave period MP2(MFWAM) , (b) S6LR SWH , and (c) by 2D (MP2,S6LRSWH)

- Difference in LR mode data, J3 vs. S6 SSHA' is small and nearly unrelated to these wave conditions

Result 1f: the impact of relative angle φ between wind direction and satellite heading on the difference of S6 HR and LR SSHA' in Ku (see Buchaupt et al. OSTST talk)



Notes:

- For φ= 0 ; upwind (wind blowing is at the same direction in which satellite heading to
- For φ=180 ; downwind (wind blowing is at the opposite direction in which satellite heading to
- For φ=90 or 270 (±90): crosswind (wind blowing is at the direction on right/left 90 in which satellite heading to
- This impact may also be corrected by HR retracking (Buchhaupt et al. OSTST 2022 talk)

II. Along-track variable rms analysis for S6 Cycle 26 data

the ratio of along-pass noise (1hz rms) of of Variable 1 to Variable 2

V1_rms	to	V2_rms
S6LR v_rms	to	S6HR v_rms in Ku
J3 v_rms	to	S6LR v_rms in Ku
J3 v_rms	to	S6LR v_rms in C

(Note: ratio > 1 means 2nd V2 outperforms 1st V1)

Analysis stimulated by this figure (Donlon, 2020)

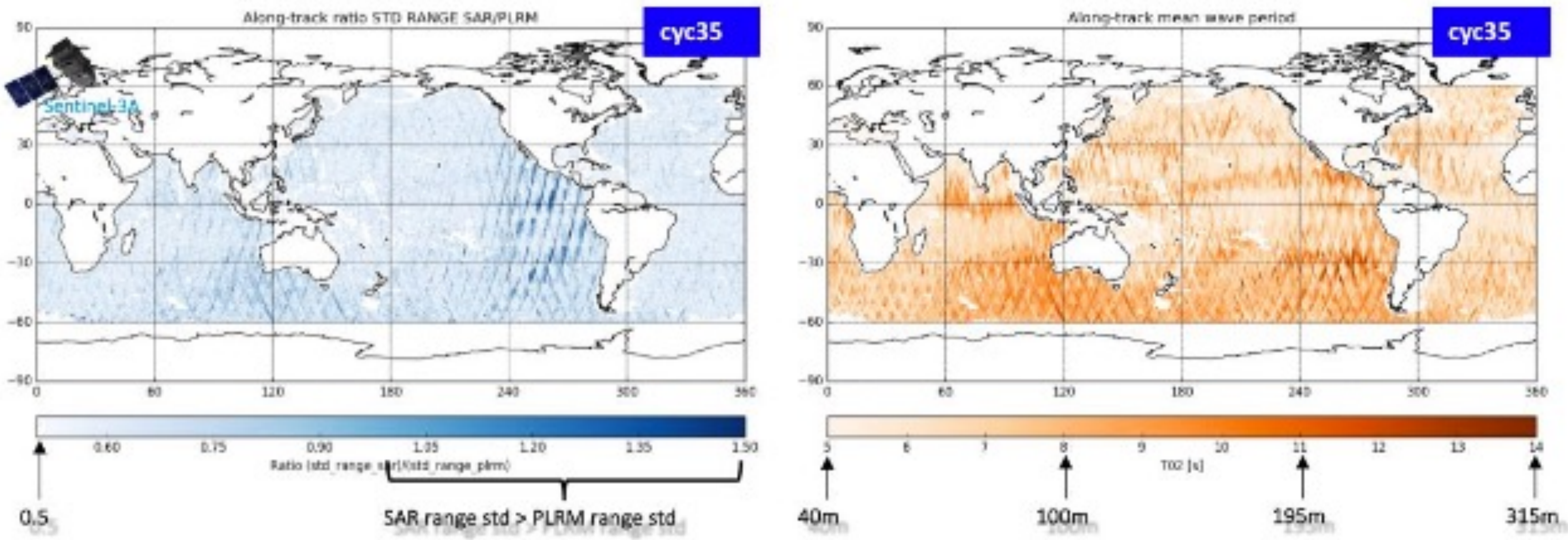
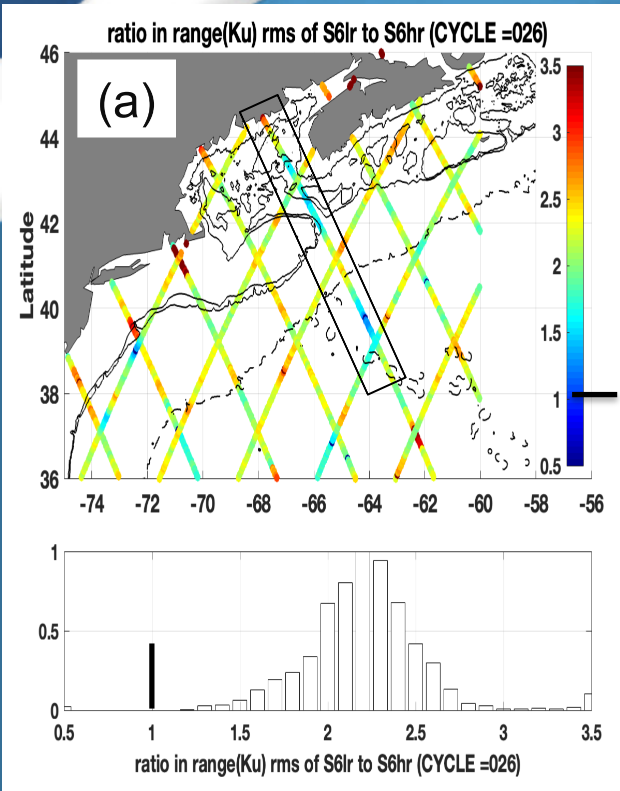
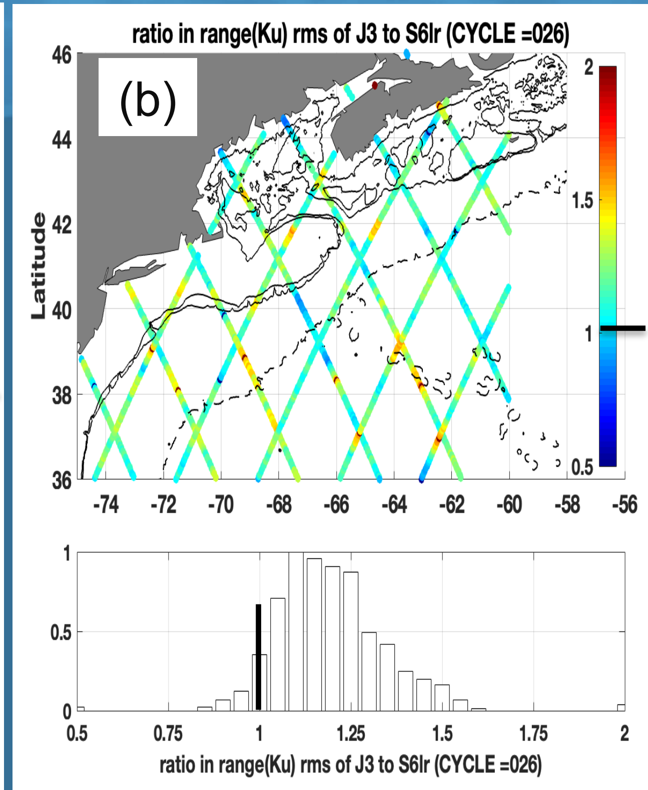


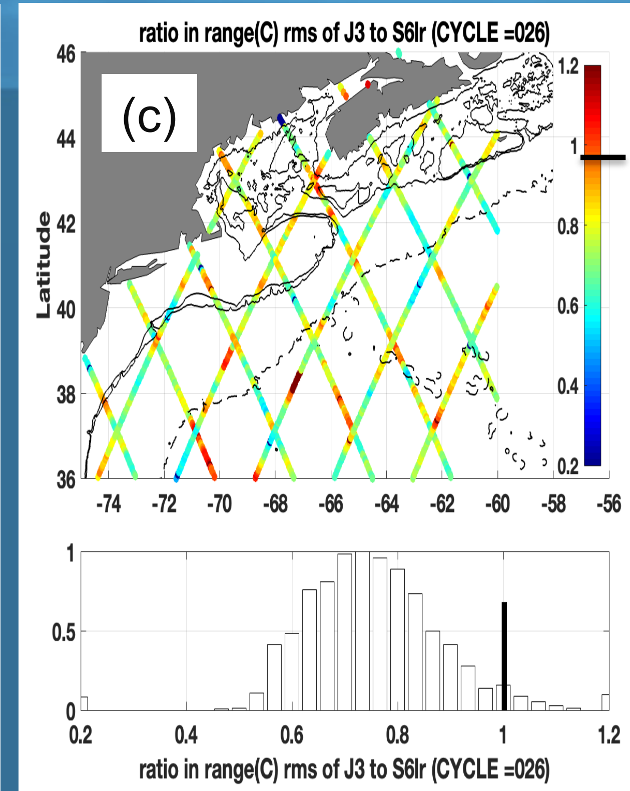
Figure 3. ***Left:*** **Sentinel-3A standard deviation of range SAR/PLM. Analysed under swell conditions.** ***Right:*** **waves model (MFWAM) provides the mean peak period, mean propagation angle, and mean wave height at the data locations (credit: CLS as part of the ESA Sentinel-3 Tandem for Climate study).**

Figure 3 from ”Sentinel-6A/B/Jason-3 Tandem Phase Justification and Requirements”, By Craig J. Donlon, ESA-EOPSM-S6-TN-3773: 02/10/2020.

Result 2a: range rms comparisons (Cycle 26)







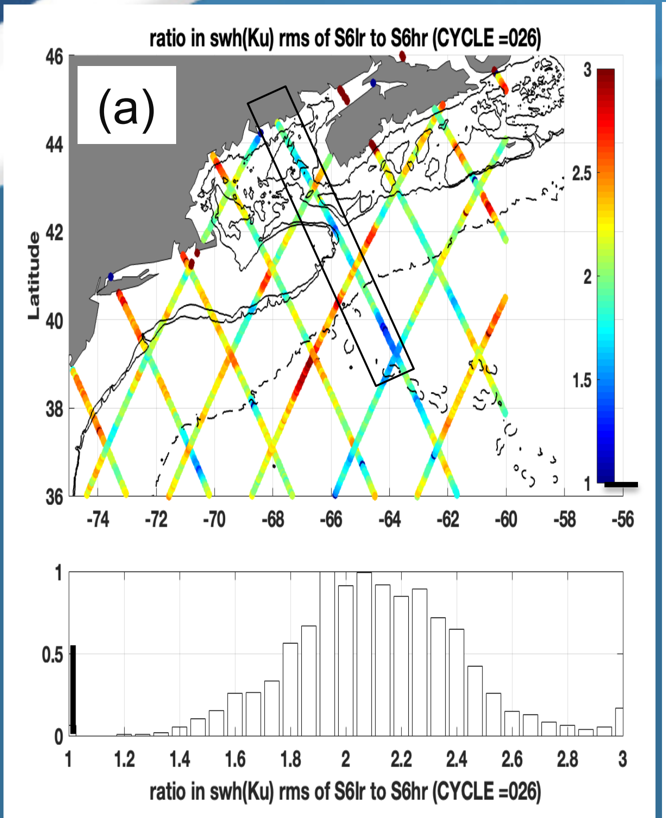
(a) The ratio of S6LR rms to S6HR rms in Ku-band range, showing >1 regionwide, S6HR range noise reduced vs. S6LR

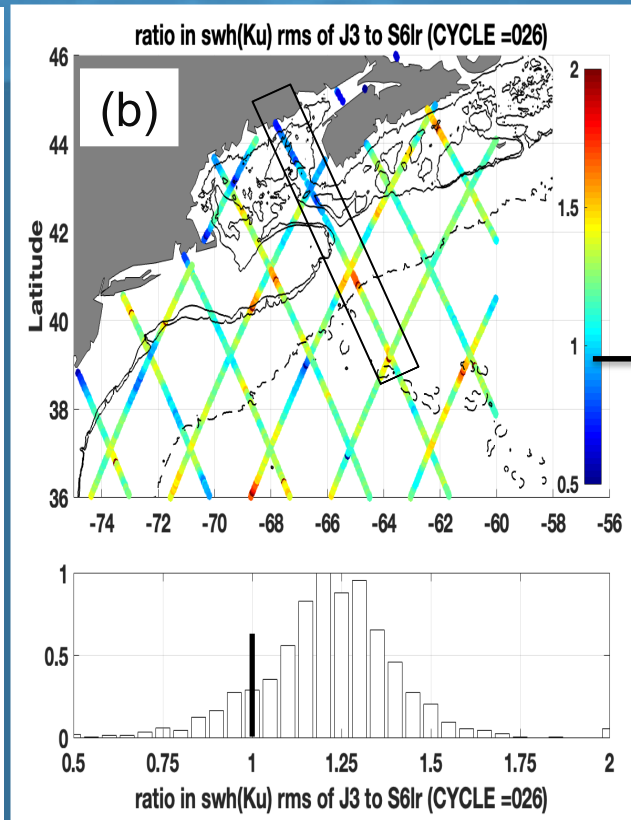
(b) The ratio of J3 rms to S6LR rms in Ku-band range, showing >1 at nearly all locations. J3 range is noisier than S6LR

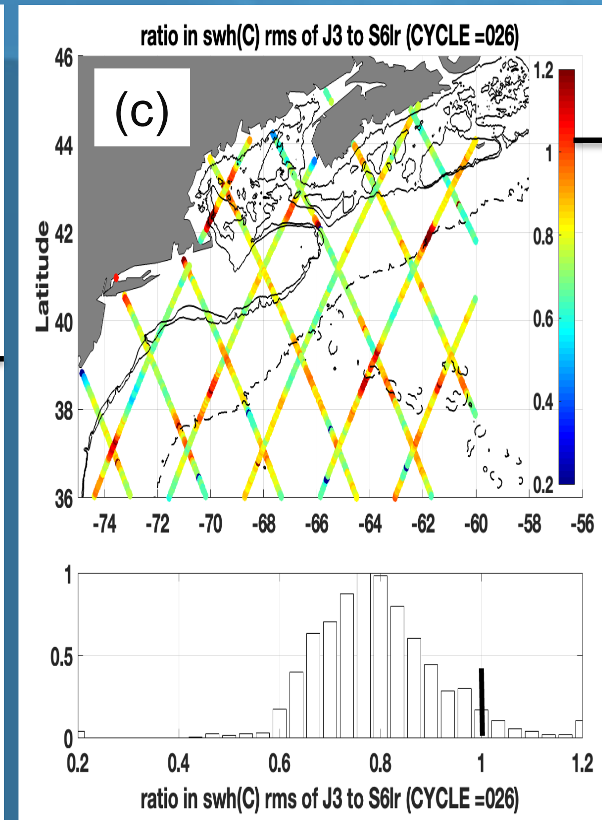
(c) C-band range rms ratio for J3 rms to S6LR rms shows < 1 almost everywhere. **C-band S6 range is noisier than J3.**

There are some spatial patterns in the ratio for S6 LR to HR range (a)

Result 2b: SWH rms comparisons (Cycle 26)







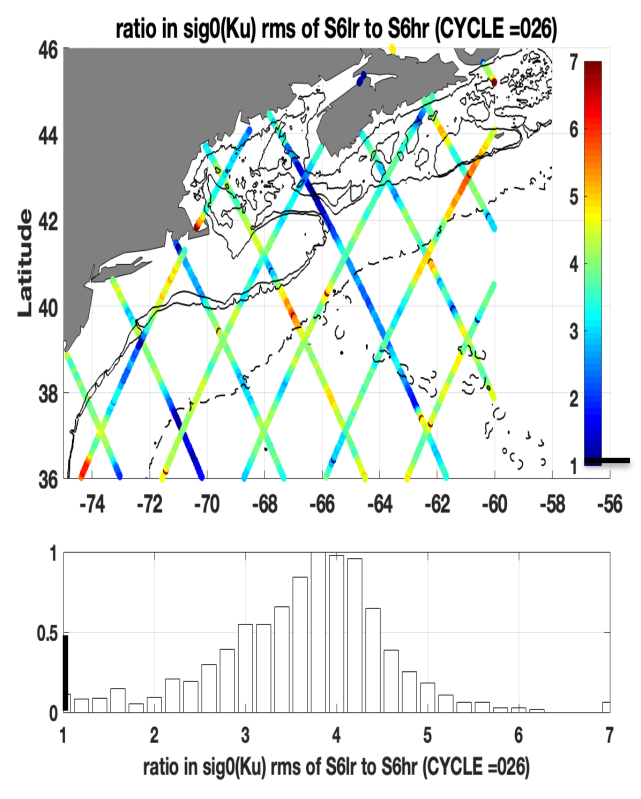
(a) The ratio of S6LR rms to S6HR rms in Ku-band SWH, >1 at nearly all locations.
S6LR SWH is noisier than S6HR

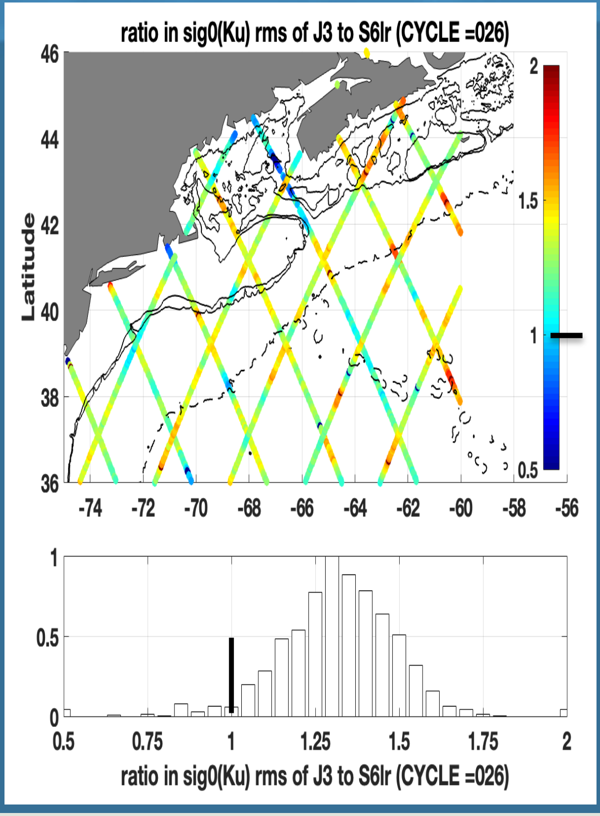
(b) The ratio of J3 rms to S6LR rms in Ku-band SWH, >1 at nearly all locations. J3 SWH is noisier than S6LR

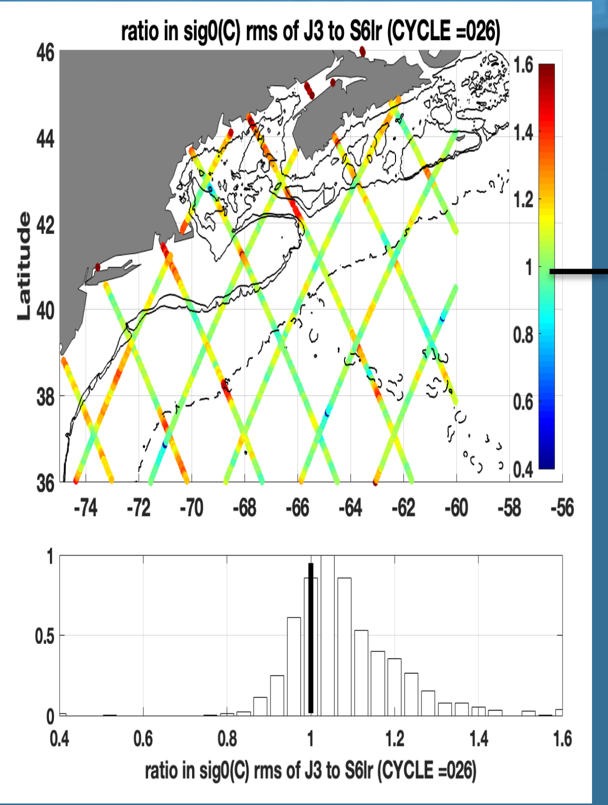
(c) The ratio of J3 rms to S6LR rms in C-band SWH, <1 nearly all locations.
S6 SWH in C is noisier than J3.

Similarly ,there are some spatial SWH pattern in both (a), and (b)

Result 2c: Sig0 rms comparisons (Cycle 26)







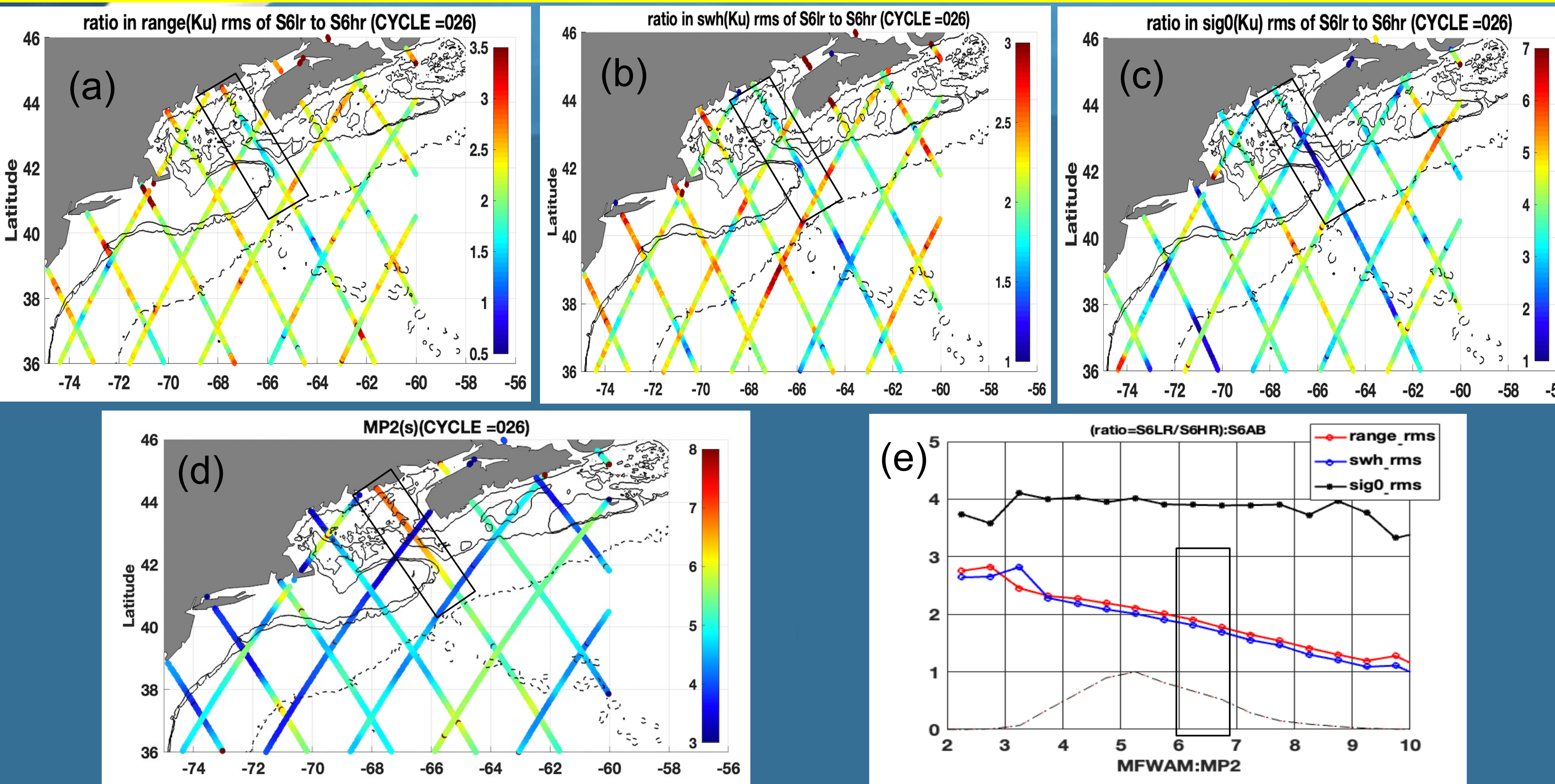
(a) The ratio of S6LR rms to S6HR rms in Ku-band Sig0, >1 at nearly all locations. S6LR Sig0 is noisier than S6HR

(b) The ratio of J3 rms to S6LR rms in Ku-band Sig0, >1 nearly all locations. J3 Sig0 is noisier than S6LR

(c) The ratio of J3 rms <S6LR rms in C-band Sig0 , >1 nearly 3/4 locations. **S6LR Sig0 in C is noisier than J3.**

Generally, similar spatial patterns in Sig0 to those in range and SWH (see above)

Result 2d: S6LR vs. S6HR rms @Ku, compared against regional wave period (cycle 26)

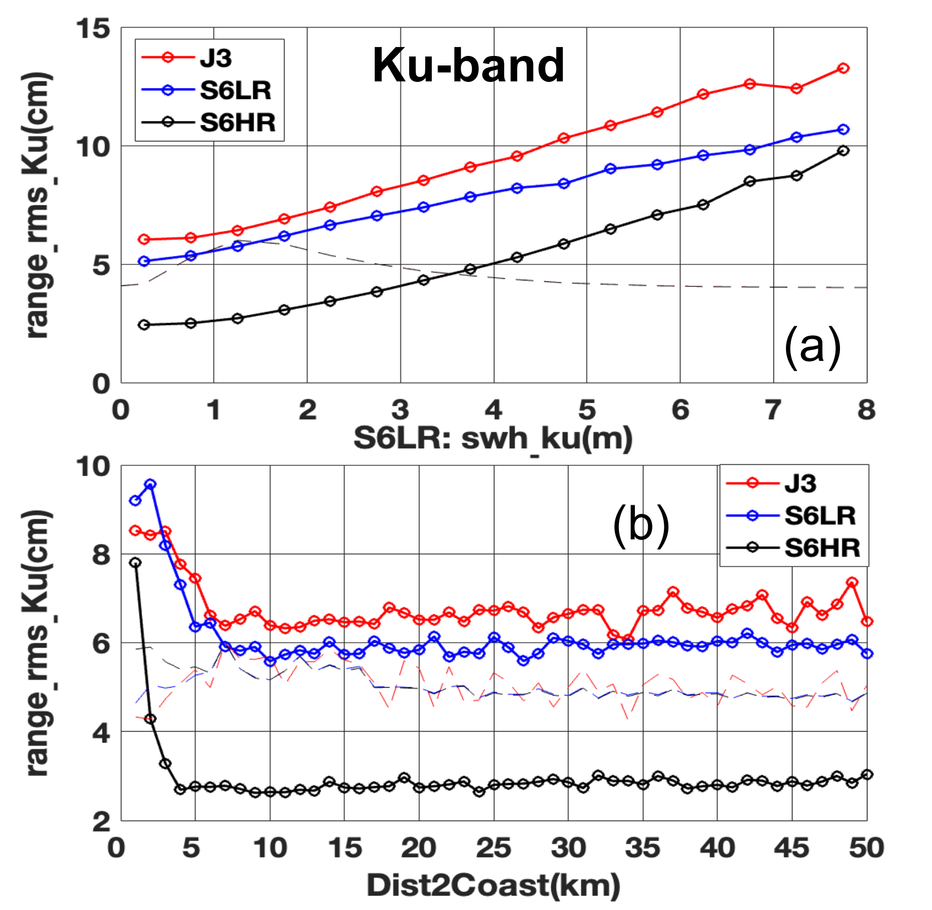


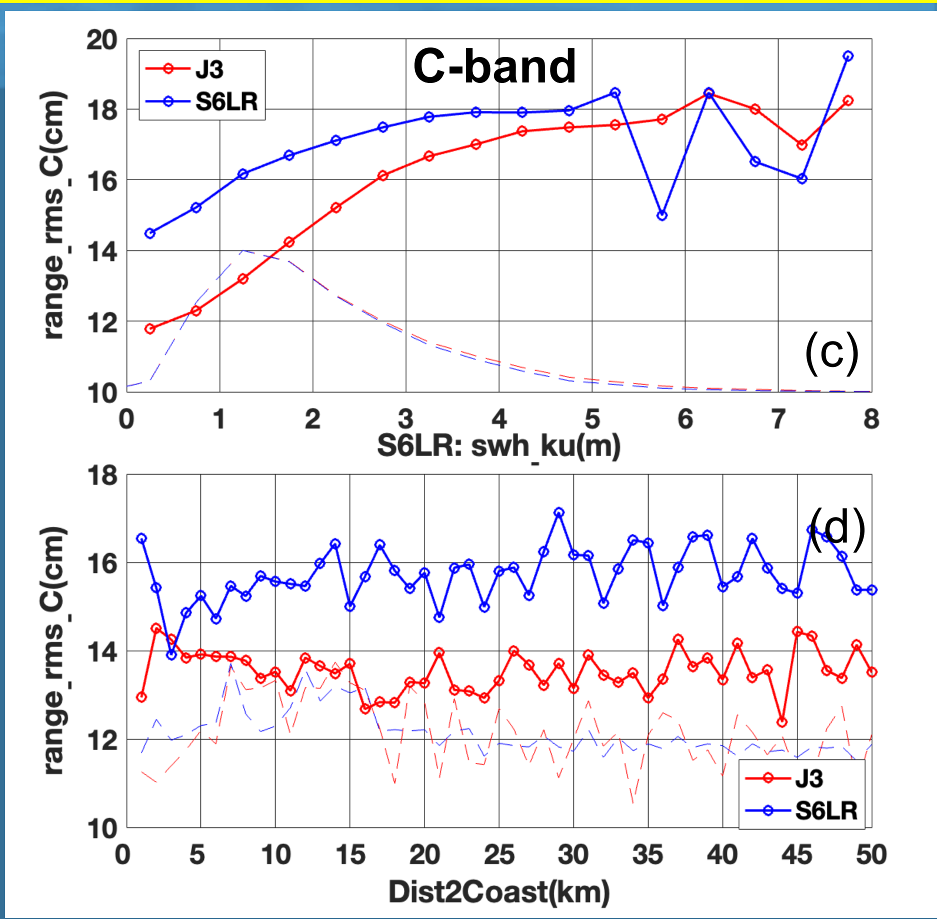
The along-track ratio of (a) range rms (b) swh rms , and (c) Sig0 rms in S6LR to S6HR in Ku band, compared with (d) mean wave model MP2 ((MFWAM), and (e) the bin-averaged ratio of variable (range, swh and sig0) rms in S6LR to S6HR vs. MP2

Spatial patterns are swell – dependent !

III. Bulk statistical comparison of 1 Hz measurement rms

Result 3a: Range rms of J3, S6LR/S6HR





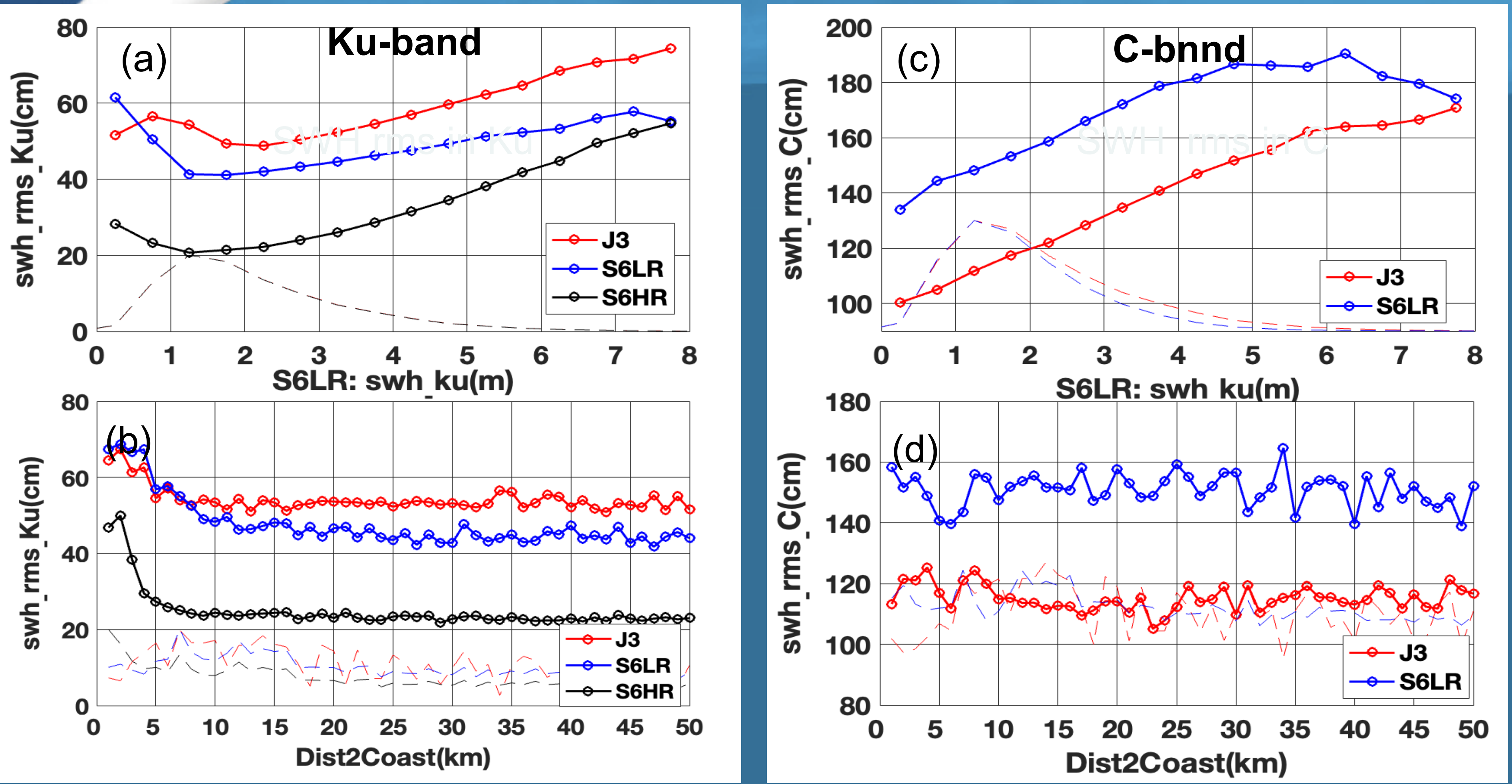
Range rms in Ku vs. (a) S6LR SWH and (b) Distance to Coast (D2C).

- S6HR rms < S6LR < J3, increasing with S6LR SWH and with D2C within 5km

Range rms in C vs. (c) S6LR SWH and (d) distance to coast (D2C).

- **C-band S6LR range rms > J3, increasing with S6LRSWH , not changing with D2C**

Result 3b: SWH rms of J3, S6LR/S6HR



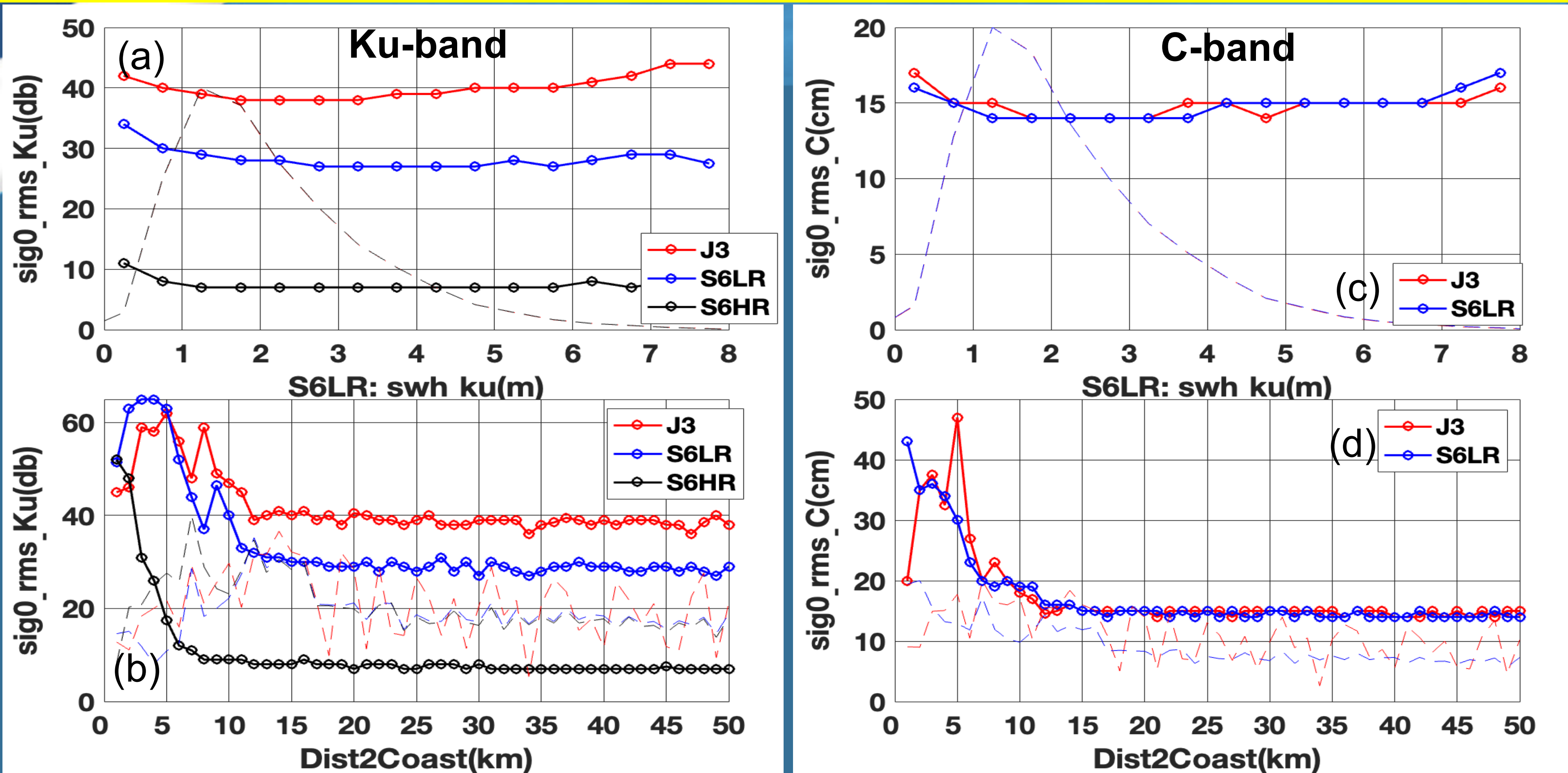
SWH rms in Ku vs. (a) S6LR SWH and (b) distance to coast.

- S6HR rms < S6LR < J3, increasing with S6LR SWH(>1. 5m) and with D2C within 5km

SWH rms in C vs. (c) S6LR SWH and (d) distance to coast.

- **C-band S6LR SWH rms > J3, increasing with S6LRSWH (c) , not change with D2C(d)**

Result 3c: Sig0 rms of J3, S6LR/S6HR



Sig0 rms in Ku vs. (a) S6LR SWH and (b) distance to coast.

- S6HR rms < S6LR < J3, not change with S6LR SWH much, and increase with D2C within 5km for S6HR, 10km for SRLR and J3

Sig0 rms in C vs. (c) S6LR SWH and (d) distance to coast.

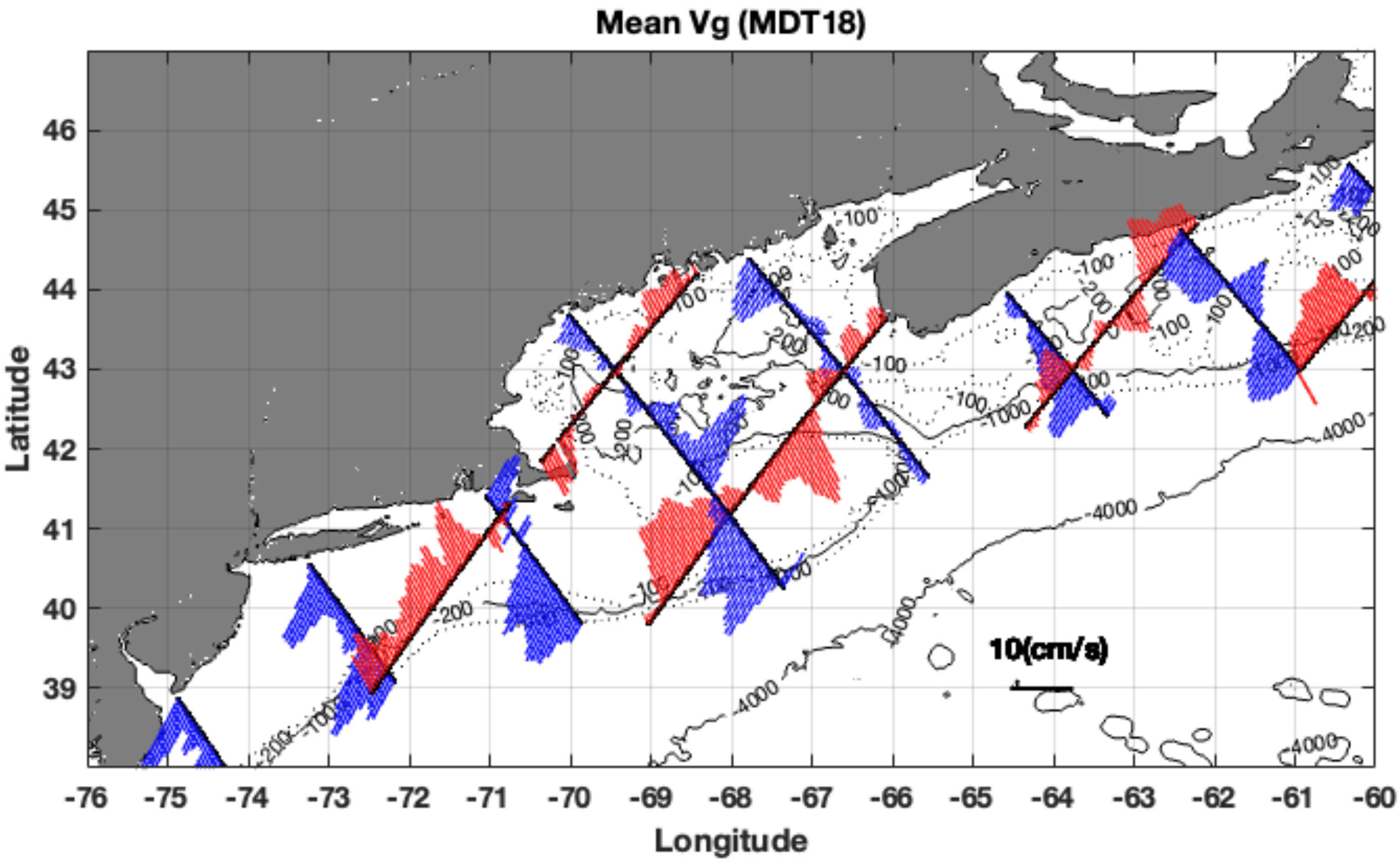
- **C-band S6LR rms ~=J3, not change with S6LR SWH much, but increase with D2C within 10km for SRLR and J3**

IV. Comparison of cross-track geostrophic currents derived from along-track SSH gradient

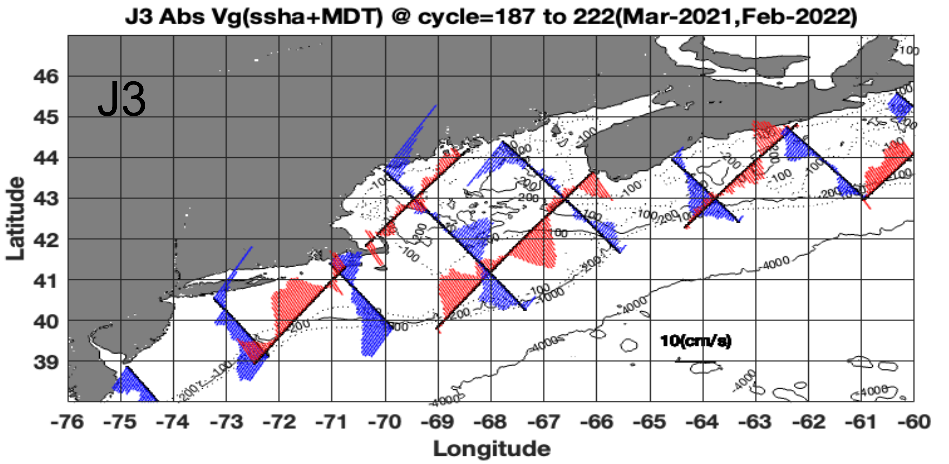
- Across-track yearly and seasonal mean absolute geostrophic current Vg derived from MDT+SSHA in S6LR and S6HR (cycles 012 – 047) and in J3 (cycles 187-222) during one year period Mar21-Feb22

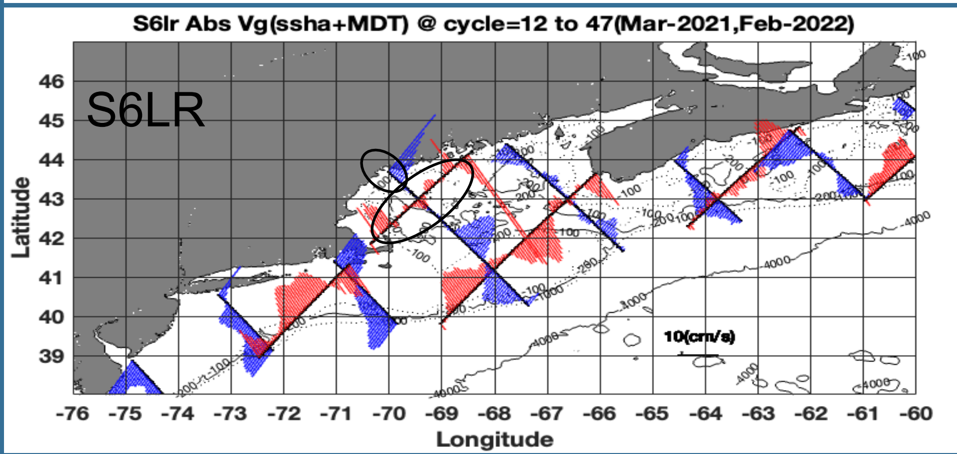
- Mean Vg from MDT (CNES/CLS18)

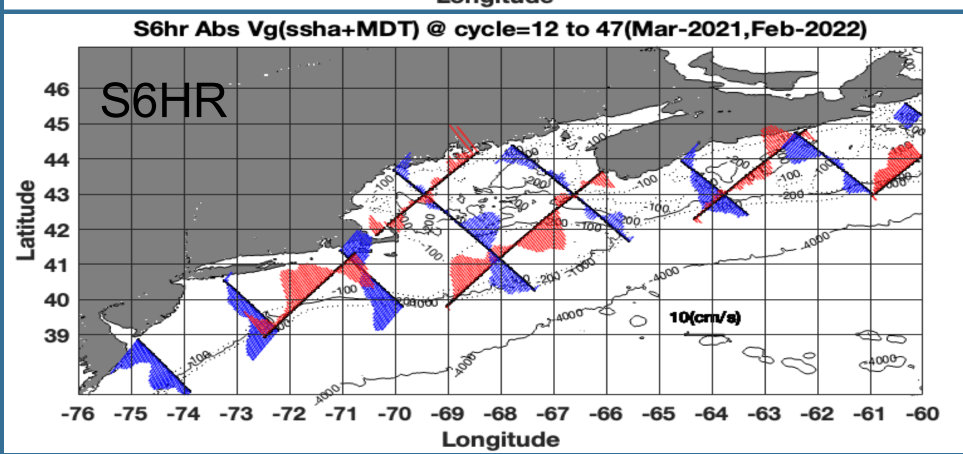
Result 4a: Mean Vg from MDT (CNES/CLS18)



Result 4b: a mean year Vg (SSHA +MDT) in Mar21-Feb22

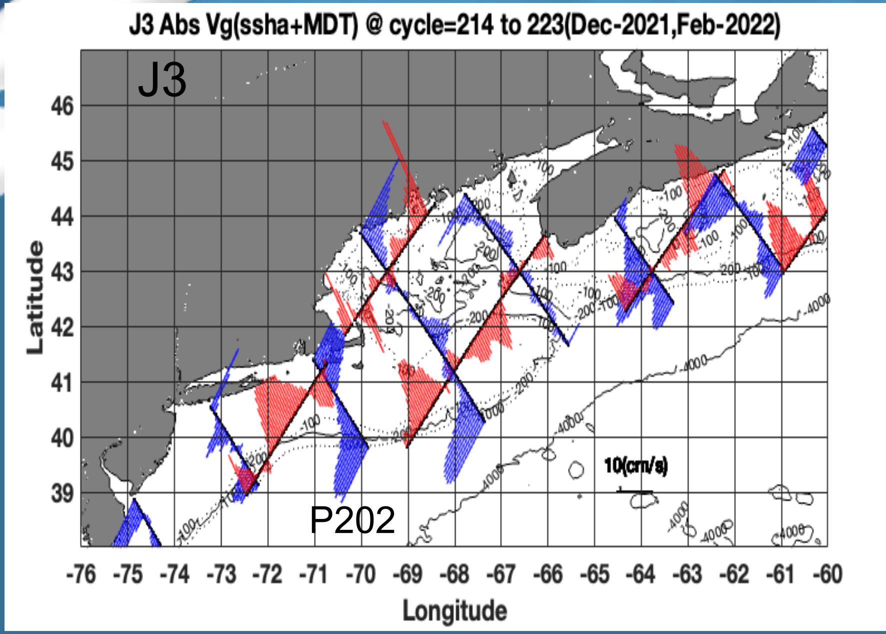


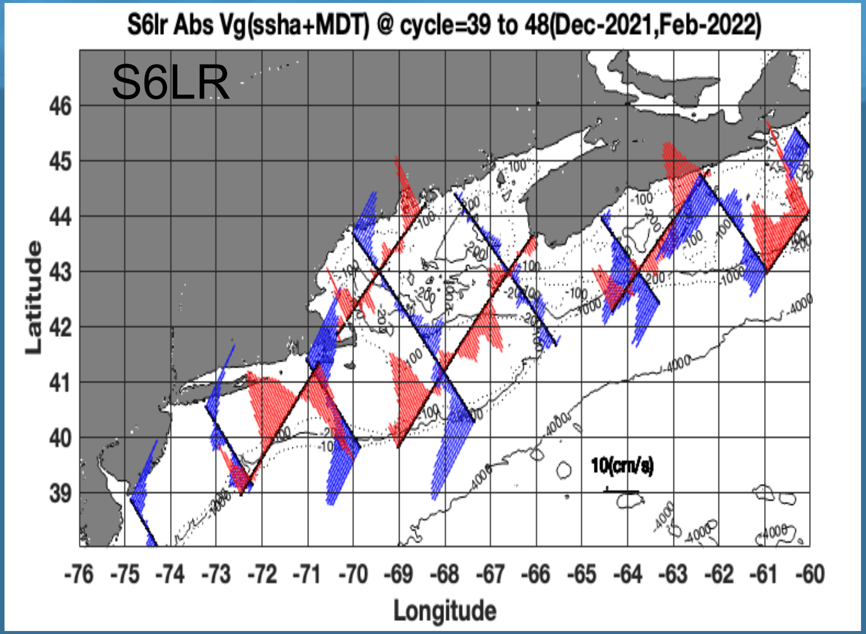


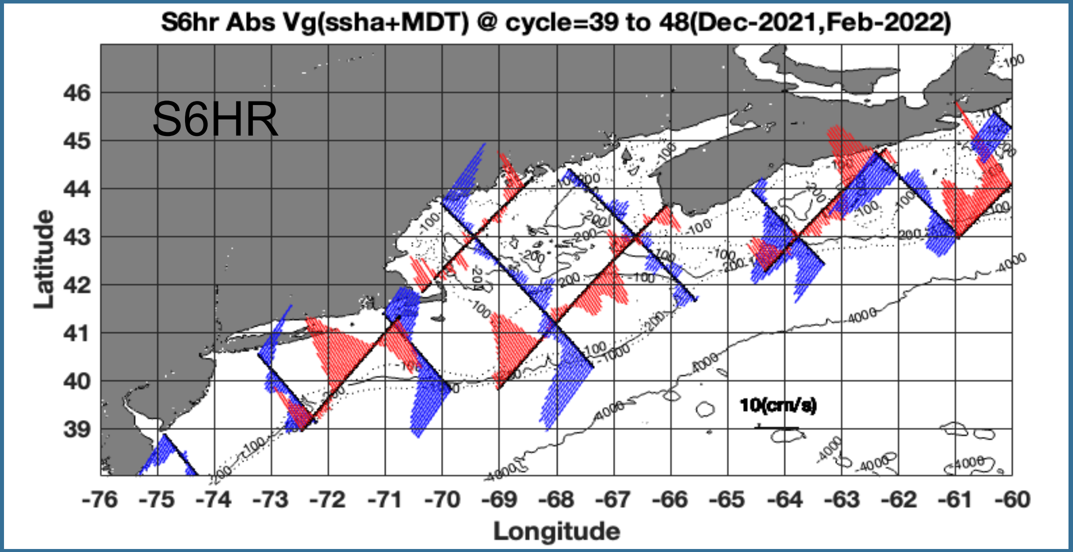


- Across S6LR , S6HR, and J3 Vg , they looks all generally consistent over the shelf region, with visually apparent lower noise in Vg S6HR
- There seems some issues seen in GoM coastal shelf, particularly in the western coastal zone, occurring in J3 and S6LR
- The issue is less significant for S6HR. Because the geophysical corrections (tides, DAC, etc.) are identical for LR and HR, any improvement in HR is likely related to cleaner HR range.
- The updated range-related duel-freq. IONO and SSB corrections may improve the quality of SSH and SSH-inferred Vg

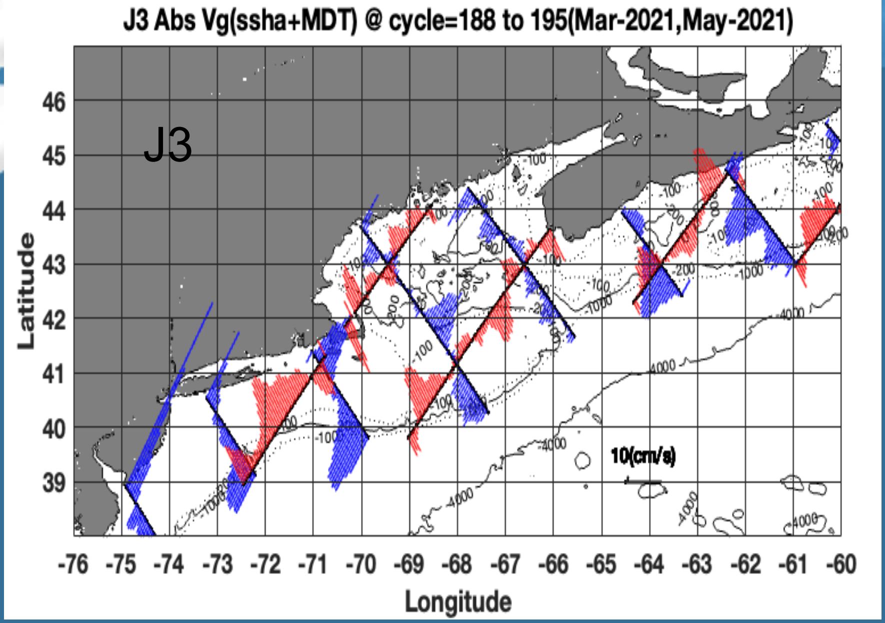
Result 4c Seasonality: mean winter Vg (Dec2021-Feb2022)

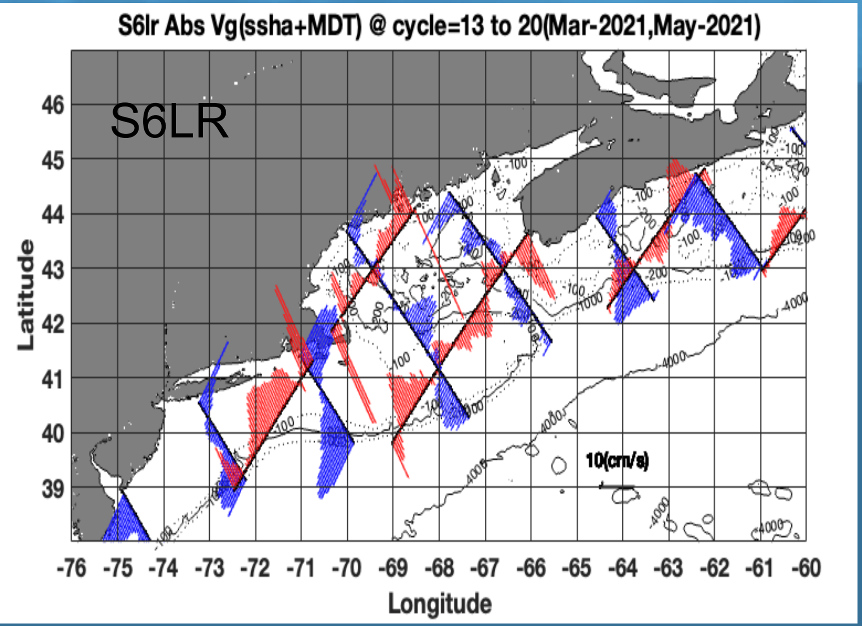


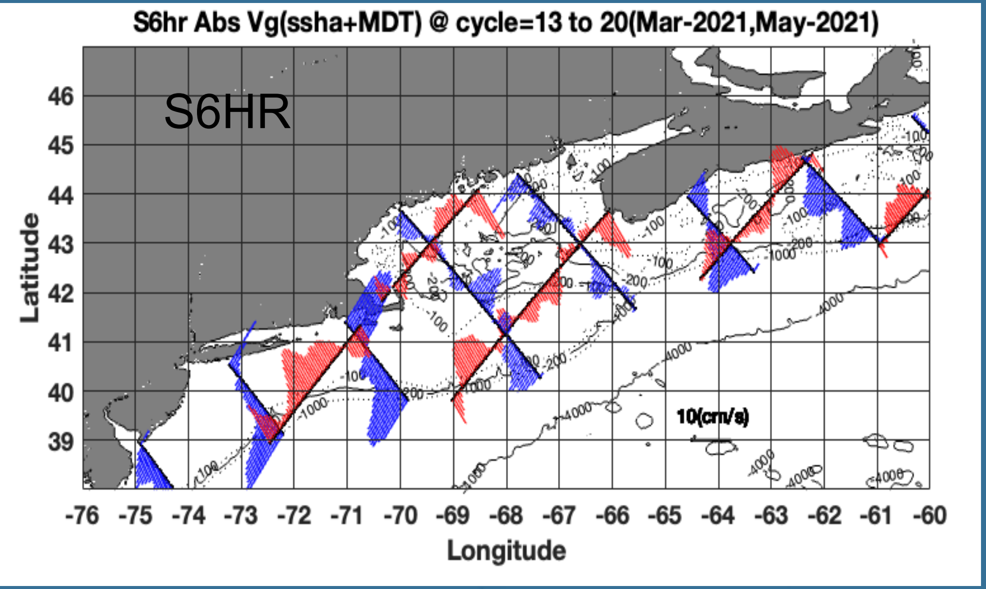




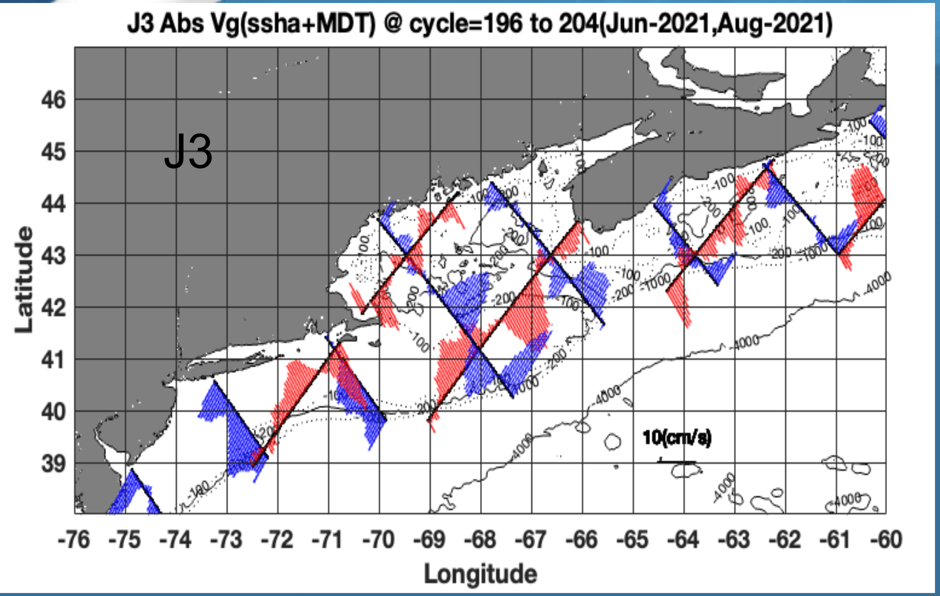
Result 4d Seasonality: mean Spring Vg (Mar2021-May2021)

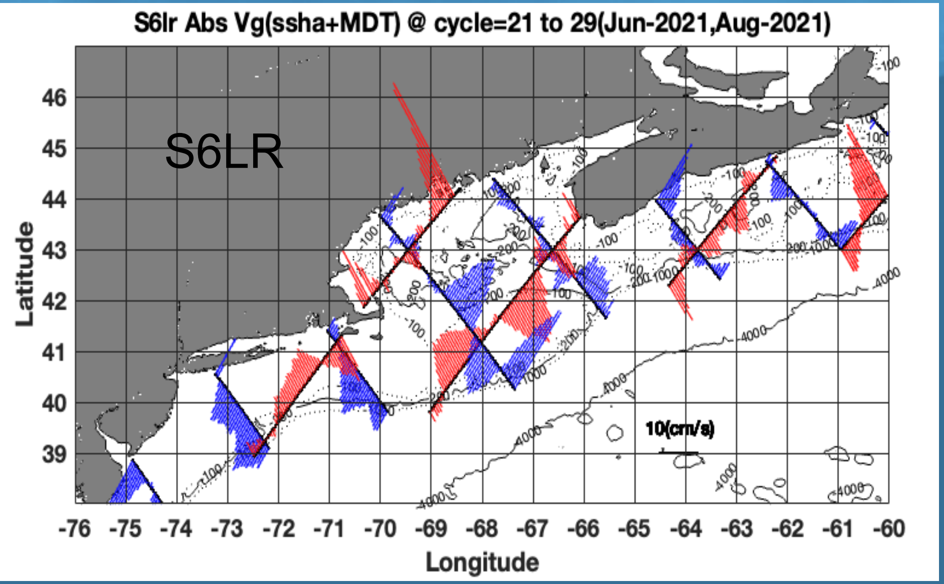


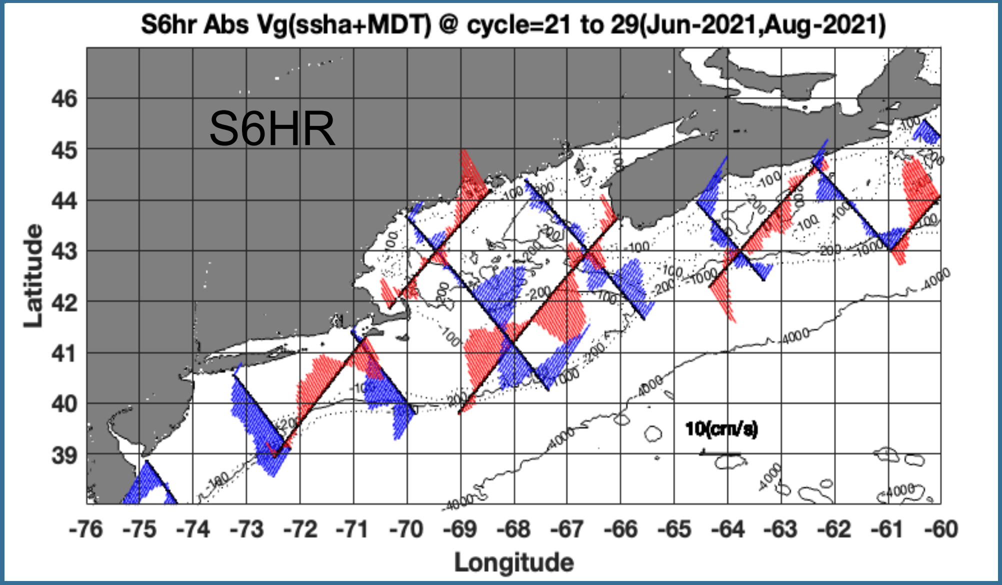




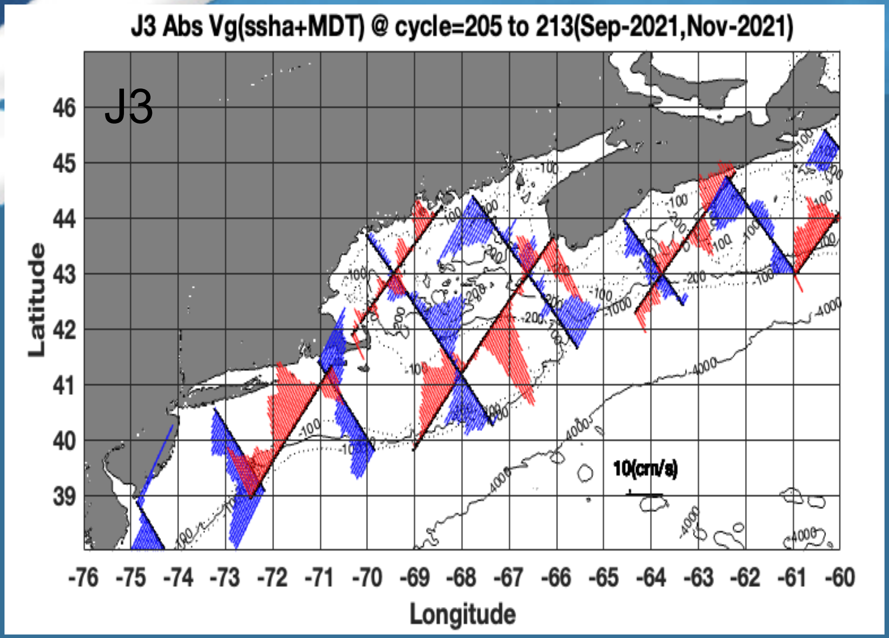
Result 4e Seasonality: mean Summer Vg (Jun2021-Aug2021)

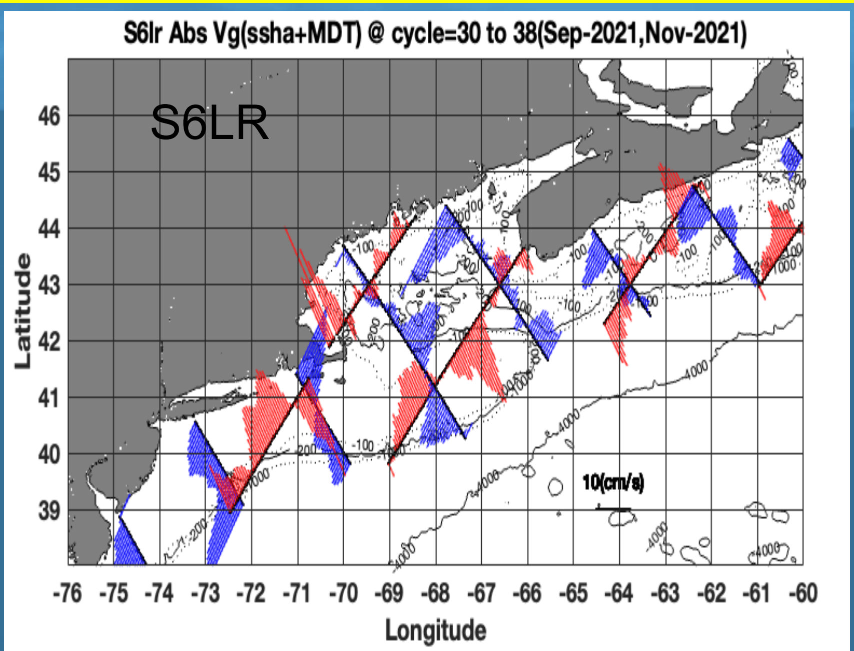


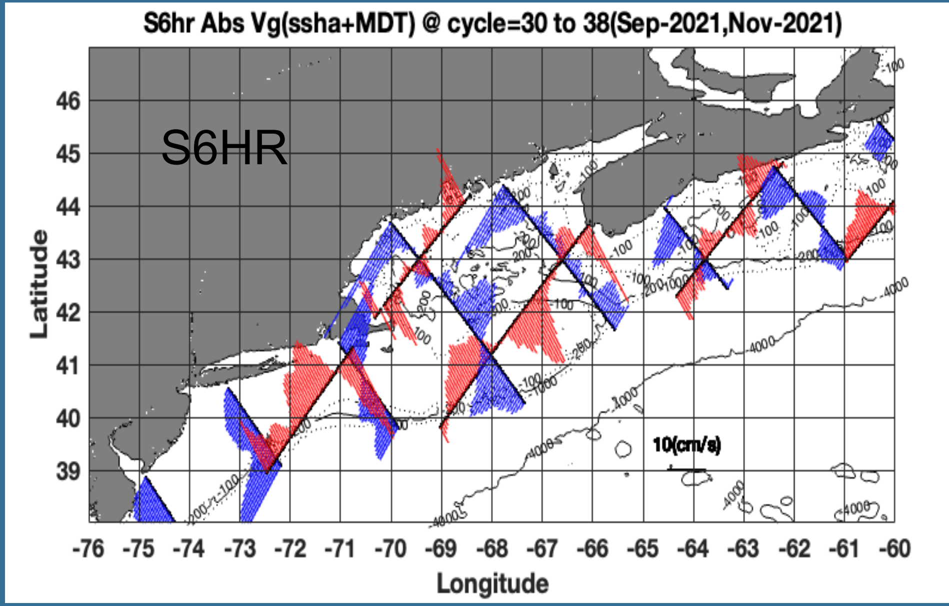




Result 4f Seasonality: mean Fall Vg (Sept2021-Nov2021)



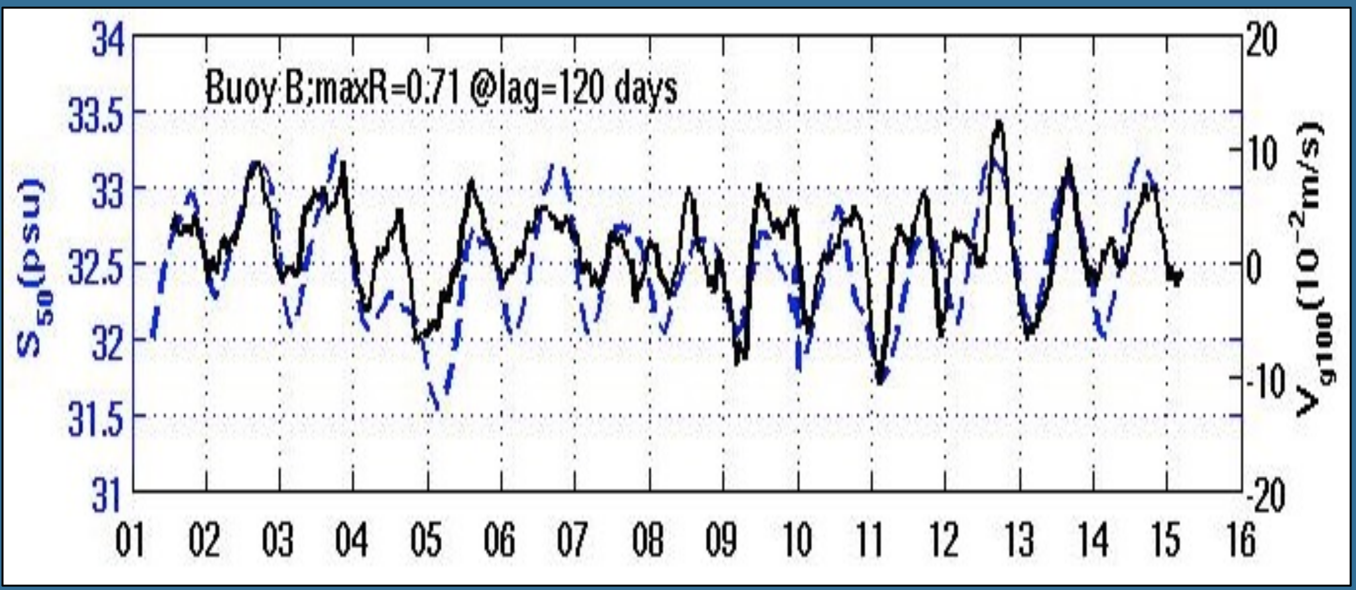


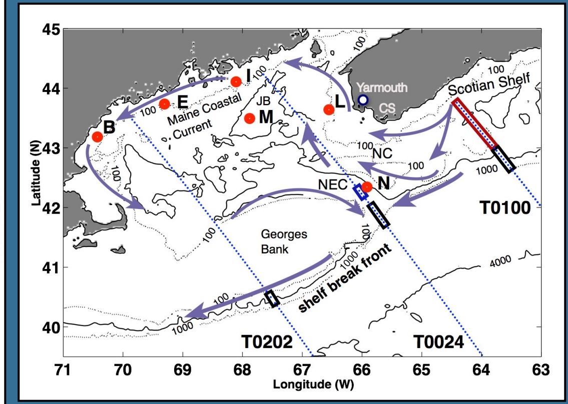


V. Application

In Feng et al. (2016), it was shown that long-term altimeter-derived currents and buoy salinity measurements indicate:

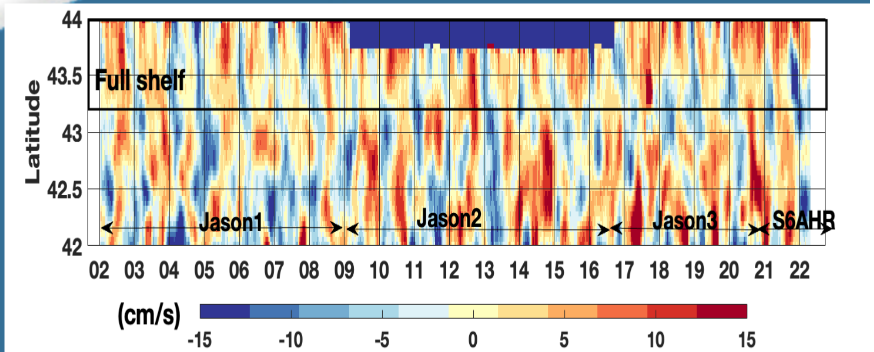
- Strong inverse correlation exists between subsurface Gulf of Maine salinity variation and upstream altimeter-inferred current anomaly in the Scotian Shelf inflow to the Gulf
- **Scotian shelf current modulation is a potential surrogate for variation of freshwater flux into the Gulf of Maine - extend this to 2022 using new J3 and S6 data**





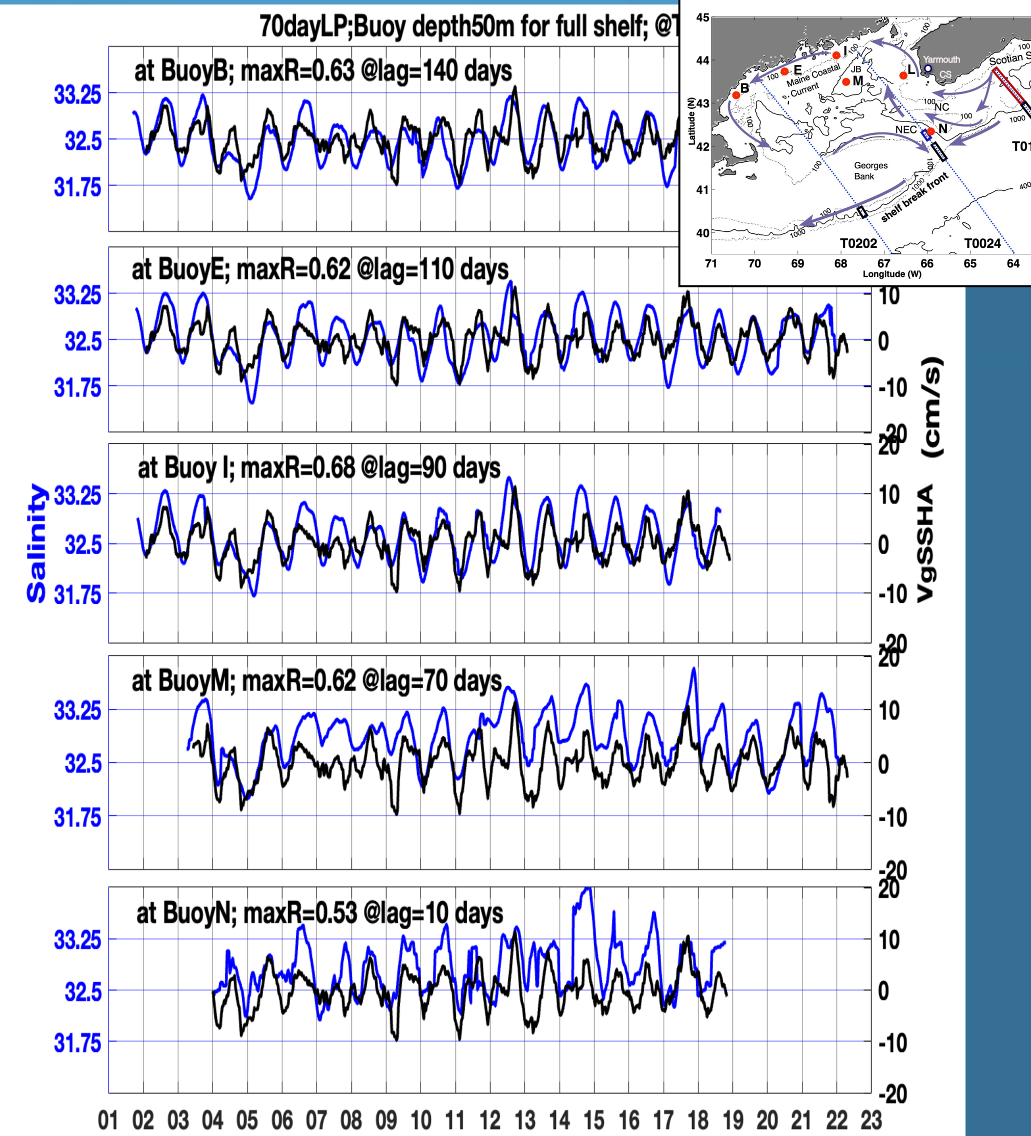
Comparison of buoy-B measured salinity at 50m depth (S50) with along-shelf geostrophic current anomaly V_{g100} inferred from track T100 altimeters Jason 1-2 on the SS with the time lags=120 days for maximum correlation (indicated as maxR) between S50 and V_{g100} (2001-2016), The time lags indicates the advection scale.

Seasonal linkage of GoM buoy-measured salinity S50 to upstream altimeter (J1/J2/J3/S6A) inferred cross-track geostrophic current anomaly Vg_{100} by SSHA in T100 on SS (2002-2022). (smoothed with a 70 day moving average low-passed filter)



Time-latitude representation of altimeter-based cross-track geostrophic current anomaly (Vg_{100}) computed (negative/positive values in Vg_{100} represent relative increase/decrease in mean downstream flow)

- There is an apparent linkage between Vg and S50 in the seasonal scale, similar to what was seen by (Feng et al., 2016)
- The noted time lags indicate the advection time scale.



Comparison of buoy-salinity S50 with altimeter (J1/J2/J3/S6A)-based current anomaly Vg_{100} from T100 on the Scotian shelf for buoys B,E, I, M, and N from the top to the Bottom, after offsetting S50 by the time lags as indicated.

Conclusions: from S6HRM, S6LRM and J3

Results I. Bias analyses

- SSHA in S6HR is highly consistent with S6LR and J3 with little bias and R=~1.0.
- The difference between S6 HR and LR SSHA in Ku is impacted by relative angle ***φ*** between wind direction and satellite heading.
- The bias between S6LR SWH and S6HR SWH in Ku is there, explained by wave conditions (e.g. wave period, and wave height), and little bias between S6LR and J3 SWH in Ku.
- Sig0 bias in Ku between S6LR and S6HR is small, but higher between S6LR and J3.

Result II (along-track rms analysis)

- Along-track rms in Range and SWH in Ku, S6HR is lower than in S6LR; S6LR is lower than J3 in Ku while in C is opposite !
- Along-track S6HR rms vs S6LR in Range, SWH and Sig0, increases with increasing wave conditions.

Result III (bulk statistics of variable rms)

- Range , SWH and Sig0 rms in Ku S6HR < S6LR < J3, increasing with SWH and toward the coastal zone (<5km)
- Range and SWH rms in C, S6LR >J3, increasing with SWH,
- Sig0 rms in C, S6LR is similar to J3 increasing toward the coastal zoon (<15km)

Result IV (Cross-track absolute geostrophic current Vg)

- The yearly and seasonal mean Vg fields have been resolved by S6HR, S6LR and J3.
- S6HR-based Vg is seen in the first time, generally consistent with S6LR and J3 over the shelf region, with visually recognized lower noise!
- Issues look there in the western GoM coast in S6LR and J3, less significant in S6HR. IT IS ENCOURAGING !
- Further validations should be carried out in terms of buoy measurements

Result V Application using long-term geostrophic current Vg

- Able to extend regional altimeter time series using S6 to at least one previously developed coastal application