



# Polar Ocean Tides Revisited

## - new look at the Arctic and Antarctic ocean tides from Cryosat-2

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Contribution to  
ESA ALBATROSS project

DTU Space  
National Space I



$$f(x+\Delta x) = \sum_{i=0}^{\infty} \frac{(\Delta x)^i}{i!} f^{(i)}(x)$$
$$\int_a^b \varepsilon \Theta + \Omega \int \delta e^{i\pi} = \{2.7182818284\}$$
$$\chi^2 \sum_i >$$

# Cryosat-2 Orbit parameters

With ESA official  
369 days repeat

	Jason-3	Saral AltiKa	Cryosat-2	Sentinel 3A/3B
M2	61.75	95.33	8487.00	155.25
S2	58.74	$\infty$	$\infty$	$\infty$
K1	179.00	341.86	4647.46	341.86
Annual	365	365	33671	365

Table 2: Alias periods given in days.

TABLE 1. *CryoSat-2* orbit parameters.

Orbit attribute	Value
Altitude	717.242 km
Inclination	92°
Repeat cycle	368.24 days
Orbits per cycle	5344
Track spacing at equator	7.5 km
Pseudosubcycles	28.33 days, 2.18 days
Orbit period	1.654 h
Mean local solar time drift	-179.21 s day <sup>-1</sup>
Longitude of ascending node	309.37°

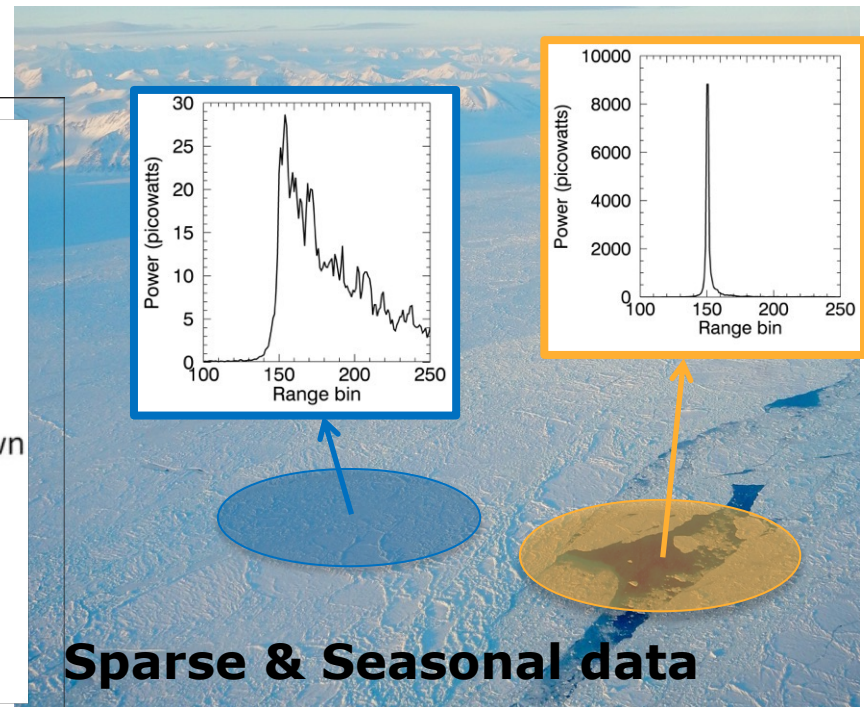
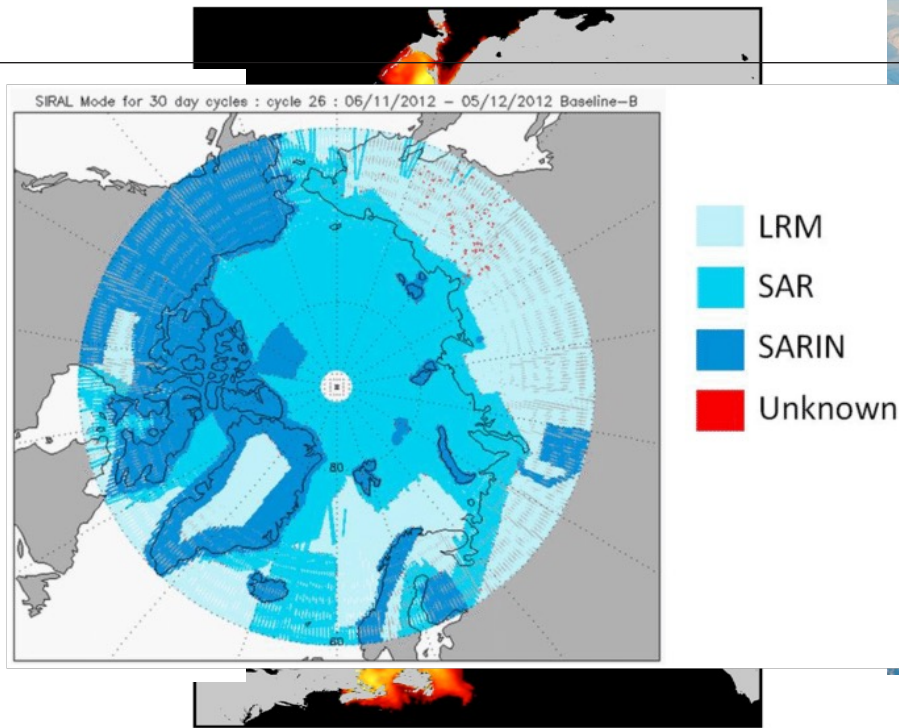
Zaron et al. 2018

## C2 – Real Tidal Aliasing

	Sample interval $\Delta t$ (days)				
	368.2396	28.9410	19.4246	7.5180	1.9983
M <sub>2</sub>	800	371	42	16	14
S <sub>2</sub>	768	245	129	209	576
K <sub>2</sub>	743	715	438	98	267
N <sub>2</sub>	2095	225	113	30	9
K <sub>1</sub>	1486	1430	41	16	535
O <sub>1</sub>	1262	294	347	638	14
P <sub>1</sub>	1591	209	52	15	277
Q <sub>1</sub>	5106	195	55	26	9
NO <sub>1</sub>	3170	962	86	28	29
MO <sub>3</sub>	2187	164	47	16	7
MK <sub>3</sub>	1734	500	1682	115	15
M <sub>4</sub>	4633	185	288	140	7

Zaron et al. 2018

# Cryosat -2 reprocessing using ESA GPOD



**SAMOSA+ modification to SAMOSA retracking model by Dinardo, S (2018)**

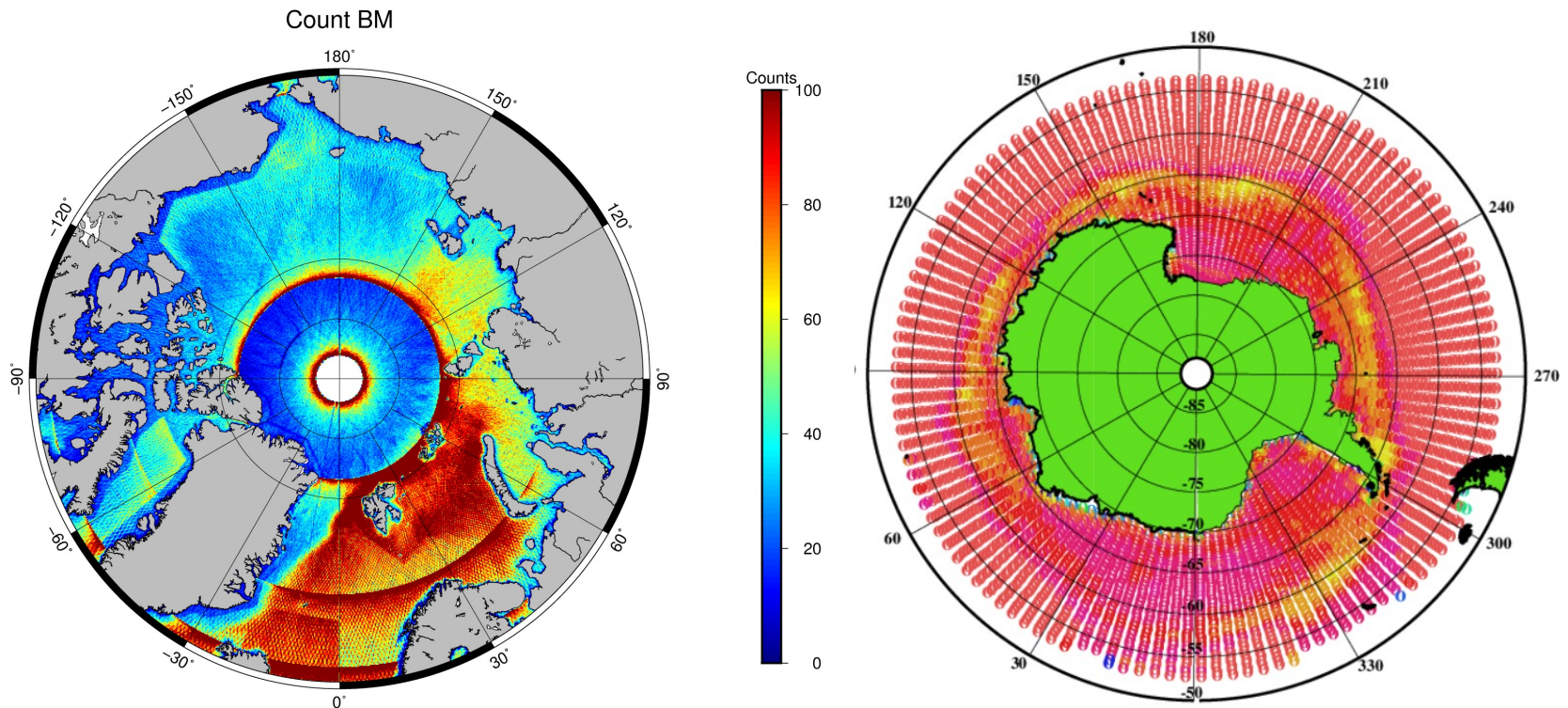
**Works over SAR and SARin region (most of Arctic and Antarctic)**

**Operate over specular scattering surfaces as ice and robust to off-nadir returns from ice**

**Solving for SSH, SWH and Wind Speed it enables the determination of SSB**



- SAR+SARin physical Retracked (>80% of the region) by ESA GPOD service
- We compute and apply Sea State Bias to SAR+SARin data
- LRM from RADS 1 Hz products
- Add other satellites when available and when it improve solution (SA/N1+Jasons)



- Remove/restore wrt FES2014b ocean tide model.
  - Remove Elastic Ocean tide.
  - Compute EO residuals
  - Restore loading residuals and FES2014b ocean tide constituents.
- Averaging 20 Hz SLA anomalies within 0.5 x 3 degree cells (shifted)
  - Use C2 (LRM,SAR,SARin)
  - Add SA,N1,JA1/2/3 nominal+interleaved)
- Accuracy of MSS is an issue (track to track)
  - We apply DTU21MSS to minimize (Based on SAMOSA retracked data).
- Harmonic method is problematic (Zaron, 2018).
- Use Response method (Added harmonic prediction of non-linear (M4, MS4)

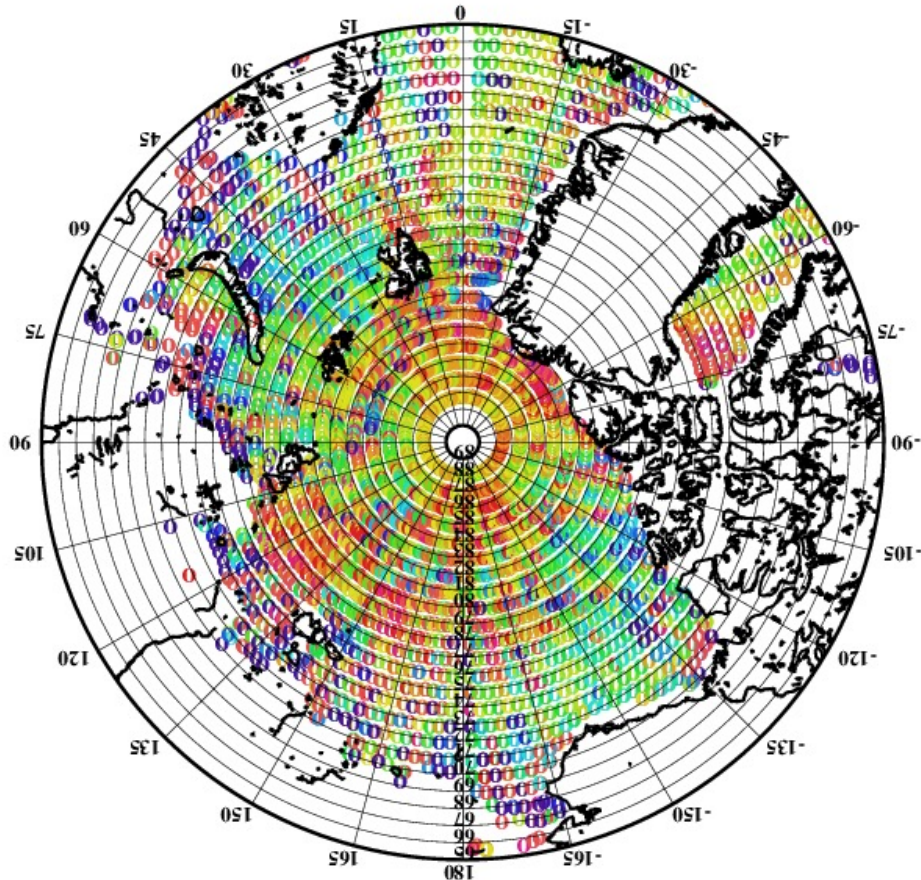
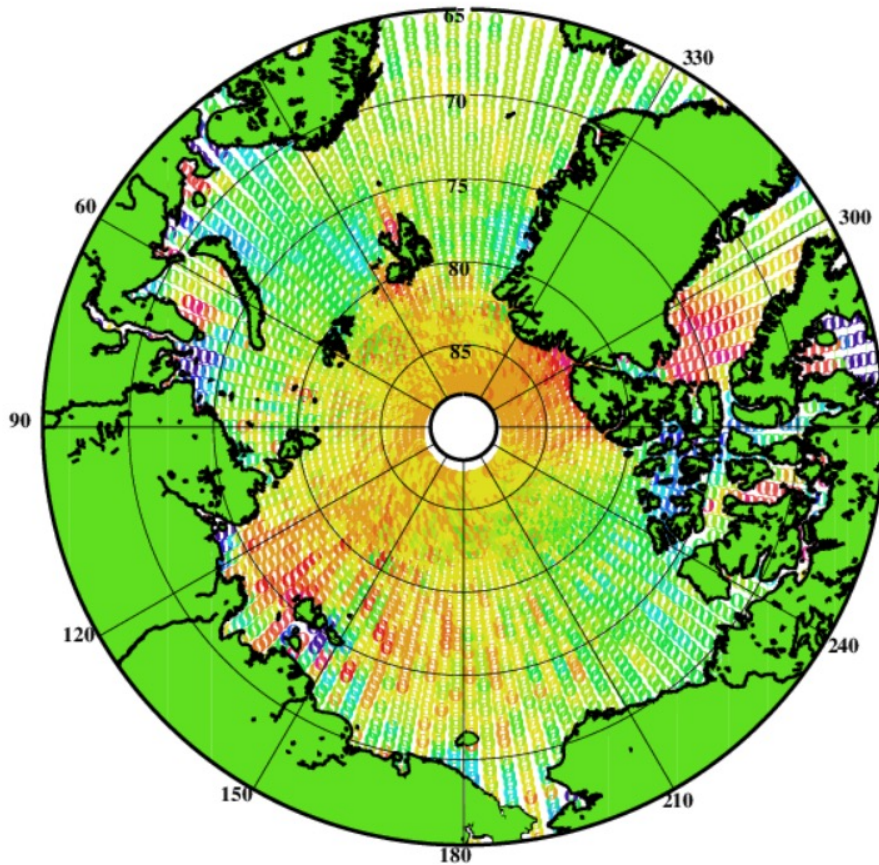
$$\begin{aligned}
 h(t) = & \sum_{m=1}^2 \sum_{k=-K}^K [u_k a^m(t - \Delta k) + v_k b^m(t - \Delta k)] & \text{(diurnal, semidiurnal)} & 12 \text{ param} \\
 & + \sum_{n=1}^N [H_{1n} \cos(\sigma_n t) + H_{2n} \sin(\sigma_n t)] & \text{(shallow water)} & 4 \text{ param} \\
 & + H_{1\text{ann}} \cos(\sigma_{\text{ann}} t) + H_{2\text{ann}} \sin(\sigma_{\text{ann}} t) & \text{(annual variation).} & 2 \text{ param}
 \end{aligned}$$



# Arctic Ocean M2 cosine FES2014 residuals

**Physical SAMOSA+.**

**Empirical Threshold rtrk**



Height (cm)



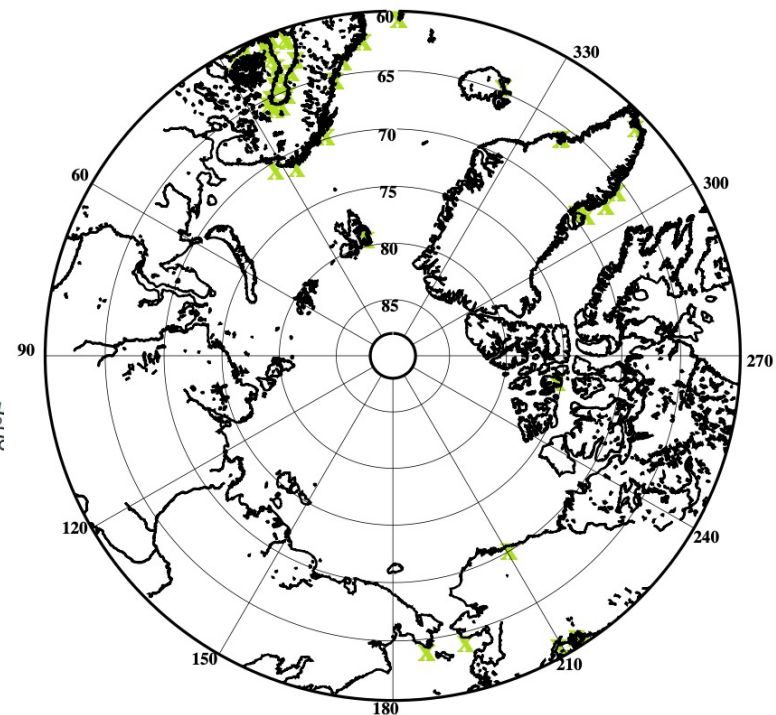
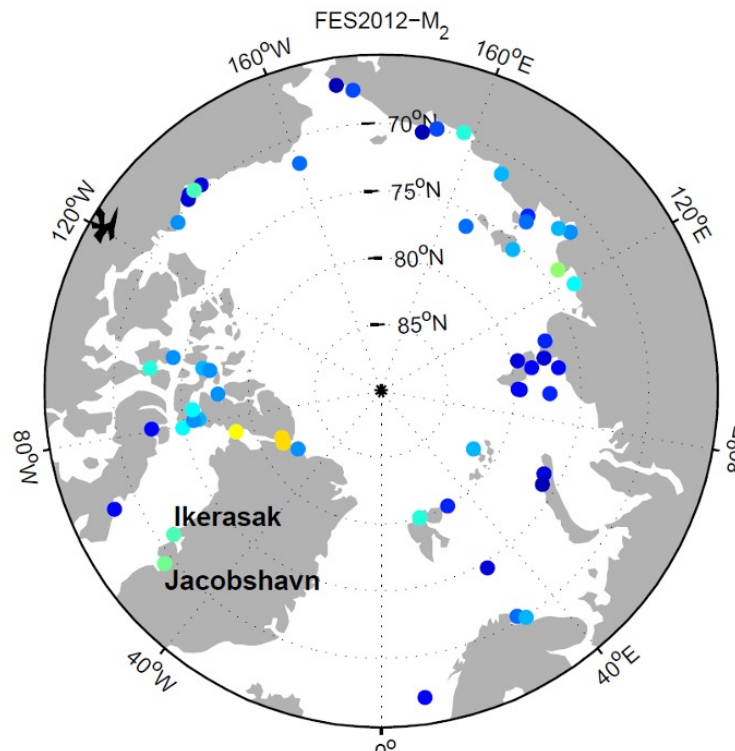
5.00

1.66

1.66

5.00

	Pre 1990 (56 TG)		TICON 2020 (65 TG)	
	FES 2014	"DTU22"	FES2014	"DTU22"
M2	4.74	<b>4.73</b>	2.43	<b>1.88</b>
S2	5.65	<b>4.94</b>	2.40	<b>1.80</b>
K1	<b>2.46</b>	2.47	1.21	<b>1.18</b>
O1	1.60	<b>1.55</b>	0.98	<b>0.80</b>

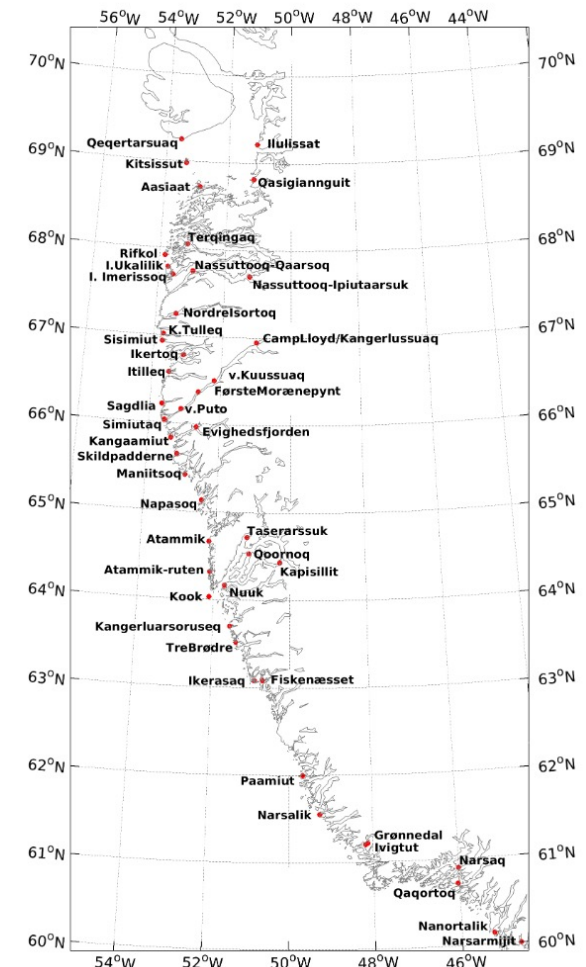
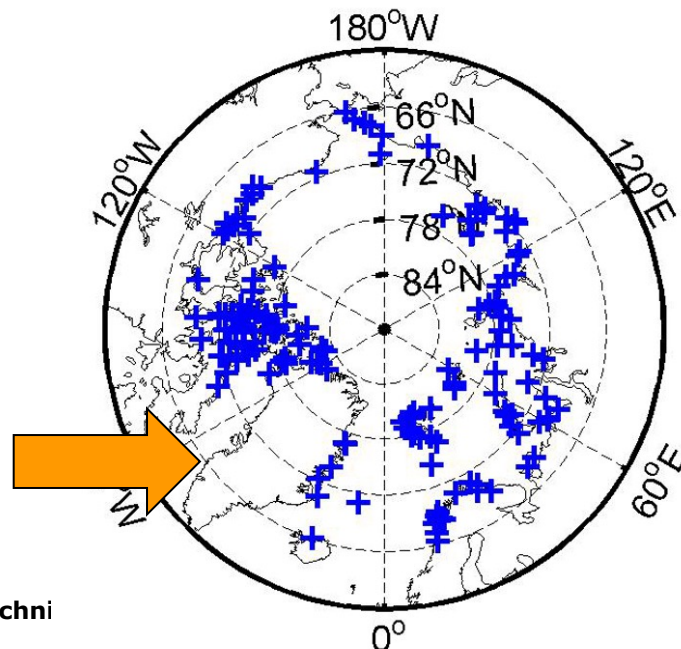




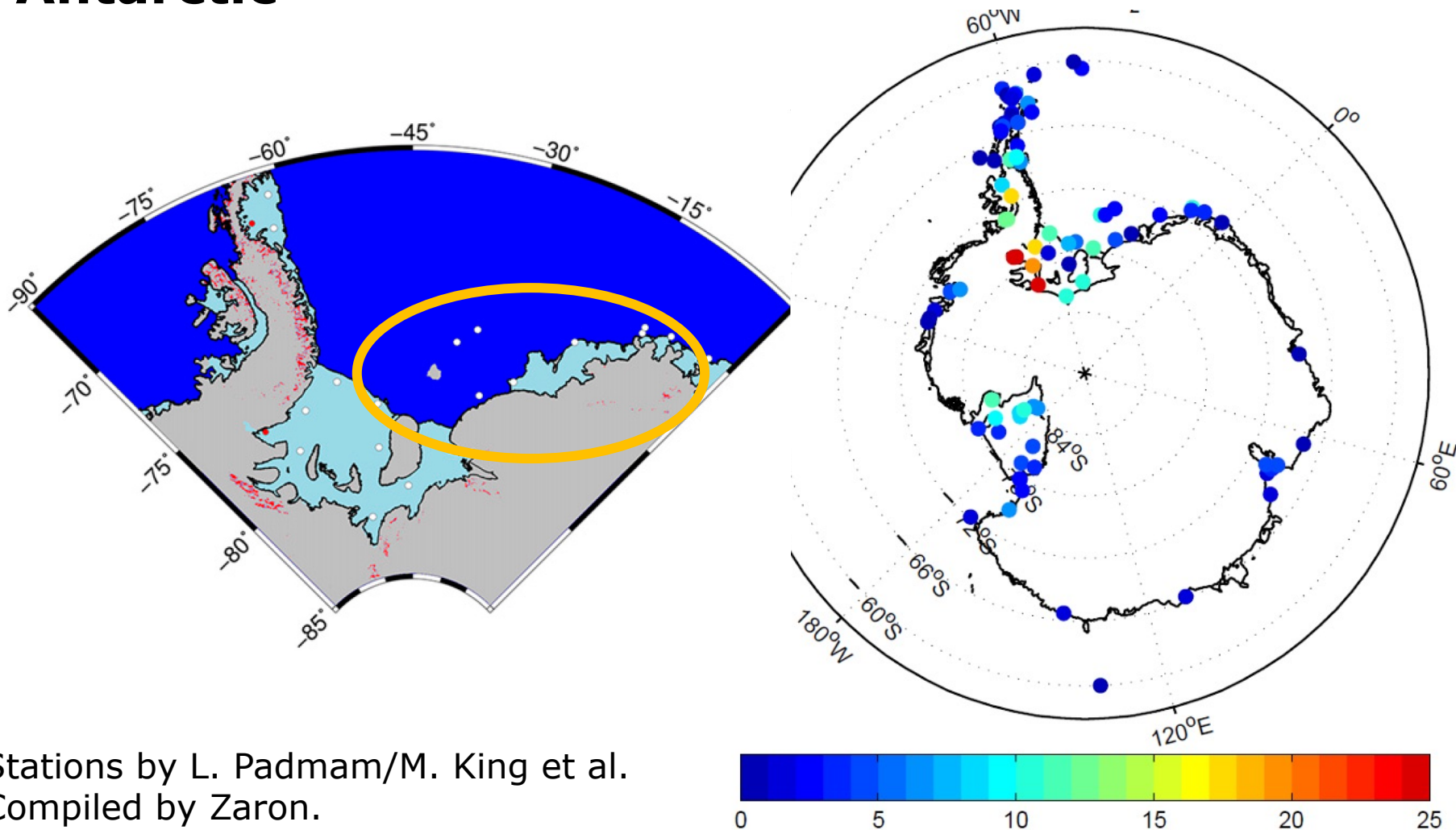
# Revisiting the Arctic Tide constituent set.

Constituent dataset compiled in Late 1980's.  
By Kowalik and Protushinsky  
Varying quality (Local phase/time zone problematic).  
Normally reduced empirically to 50+ stations.

Recompile new Arctic set + add TICON2020  
Number of new stations (e.g., 40+ in Greenland)



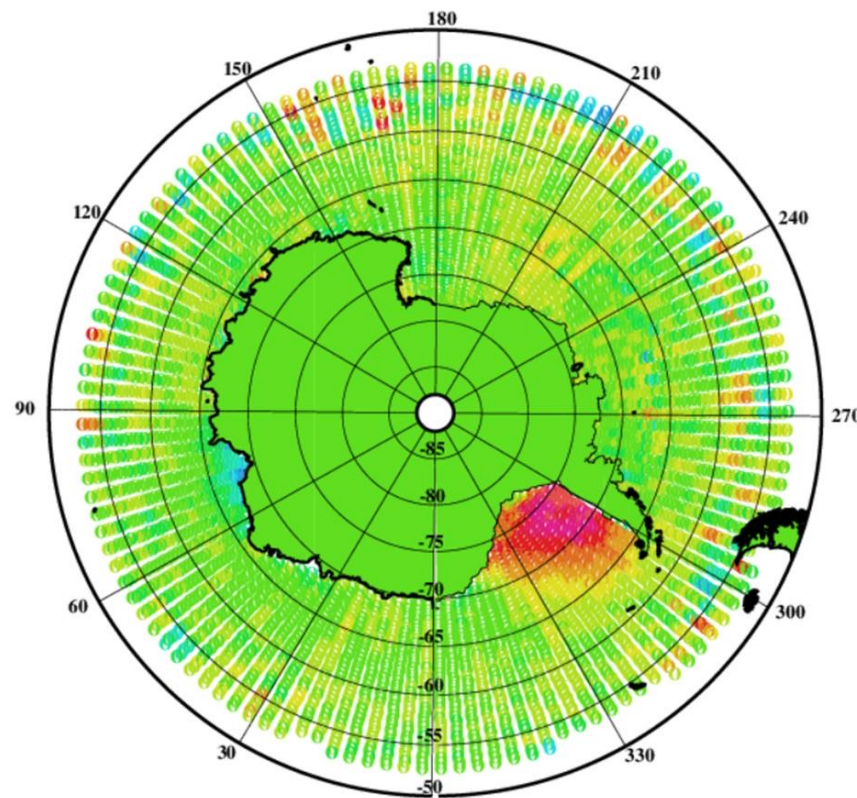
# Antarctic



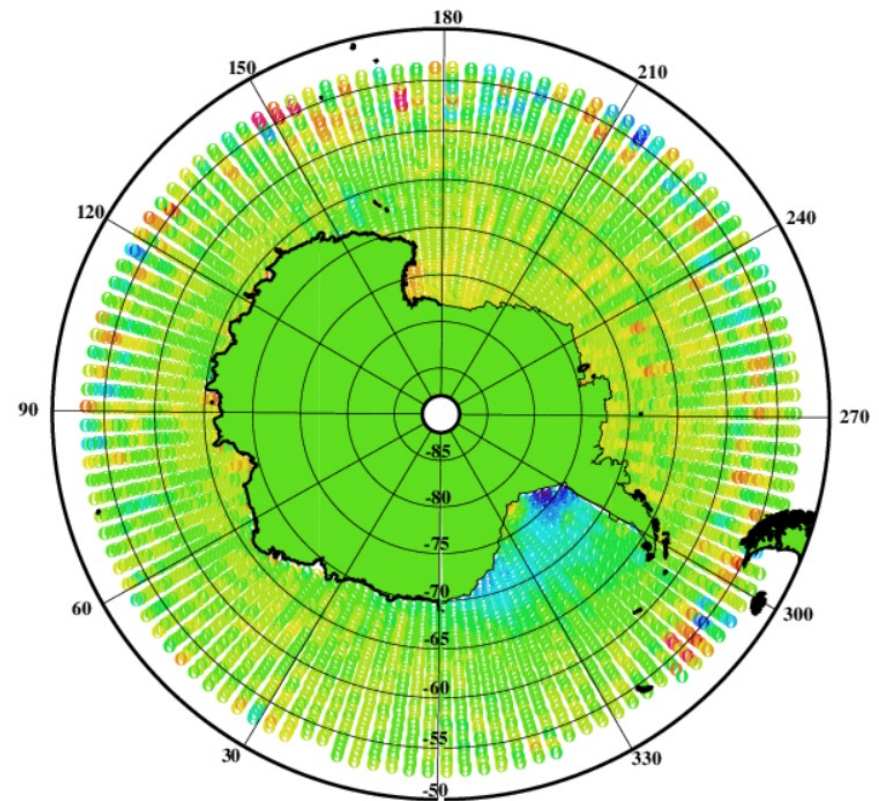
Stations by L. Padmam/M. King et al.  
Compiled by Zaron.

# M2 tidal constituent

M2 cos - C2 SAR(SAMOSA+)



M2 SIN - C2 SAMOSA



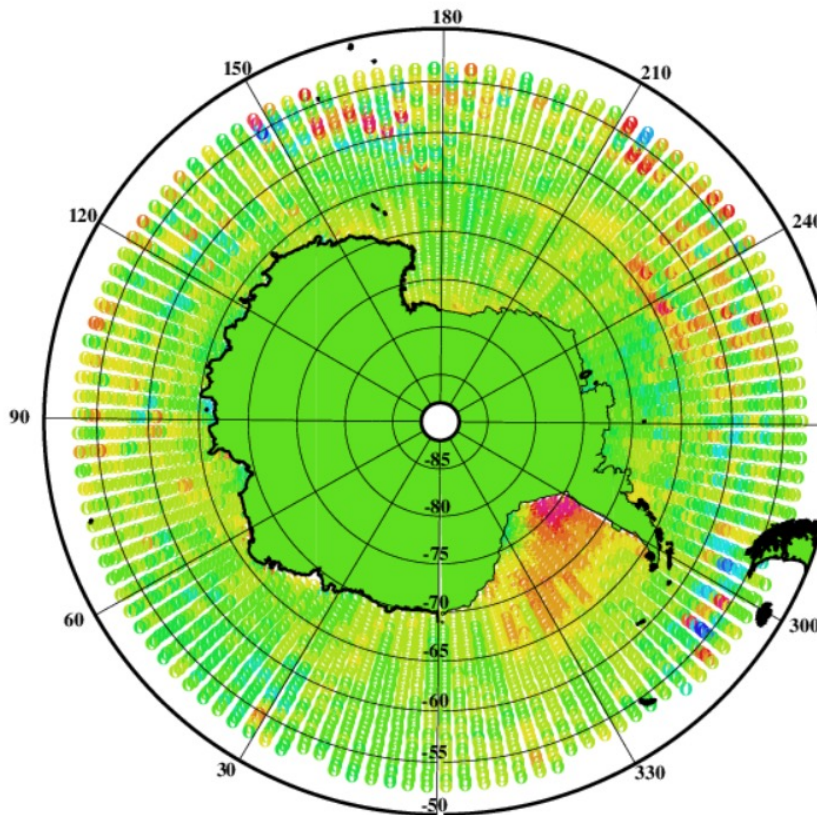
Height (cm)  
-5.00 -1.66 1.66 5.00

Height (cm)  
-5.00 -1.66 1.66 5.00

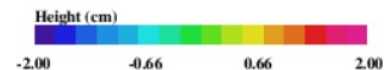
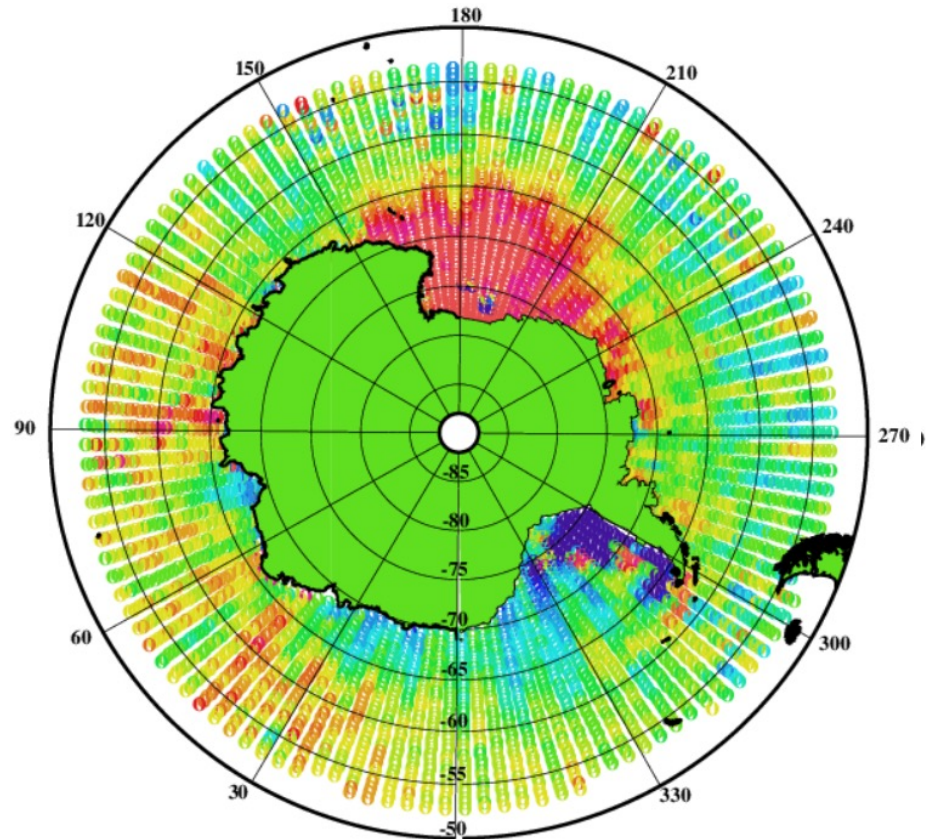


# The S2 + K1 constituents

S2 COS - C2 SAMOSA

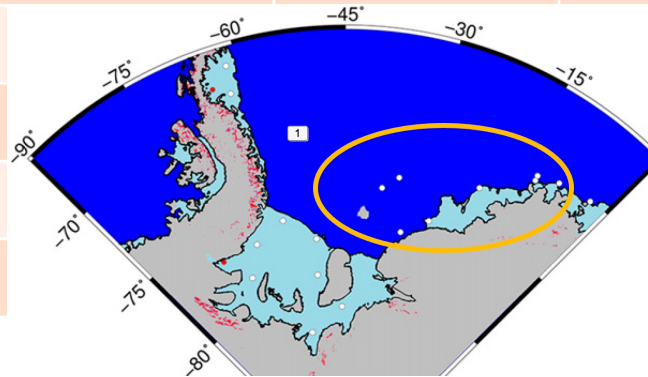
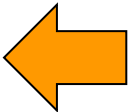


K1 SIN - C2 SAMOSA



# RMSVE. Comparison (30 stations). Zaron+King+Padman

	FES2014 (cm)	GOT 4.10	CATS08	Zaron 2018	"DTU22" (cm)
M2	4.51	4.3	4.5	3.9	3.88
S2	4.43	8.8	7.6	6.8	2.76
K1	6.04	4.5	2.4	2.8	2.43
O1	6.69	5.6	1.2	2.1	2.61
8 selected					
M2	4.65				2.39
S2	4.62				2.69
K1	5.19				2.51
O1	6.01				2.44



Numbers from GOT4.10/CATS08/Zaron are from Zaron et al. Table 5

# Conclusions

Cryosat-2's 3.68.24 days repeat is great for tidal prediction.

Important to maintain and develop independent validation dataset (e.g. Ticon2020)

I think we should recommend to ESA that Cristal is launched is not  
Launched in sun-synchronous orbit – Planned for 367.0 days

As SARAL and Sentinel 3 are Synsynchronous (Bad S2)

Thanks to ESA for supporting the the Albatross project.  
Thanks to fantastic ESA GPOD service -> Earth Console





# Data and model availability

Binned altimetric anomalies (DIY tide model and methodology)

Estimated constituents at point locations (24 major constituents)

DTU22 ocean tide model.

Data.dtu.dk (briefly).

