Jason-2 "Extension of Life" phase (EoL): orbits and timing

Summary of discussions from Jason-2 EoL working group

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An « Extension of Life » phase for Jason-2

- Jason-2 is 8 years old and performing (very) well
- Still an increasing risk of onboard failure due to ageing
- Need to protect the historical orbit for follow-on missions
- Scientific & operational merits of EoL seen with Jason1

but

- We cannot use the Jason-1 GM orbit for Jason-2

"Jason-2 EoL" OSTST working group created to discuss:

<u>where</u>: pick an orbit for the EoL

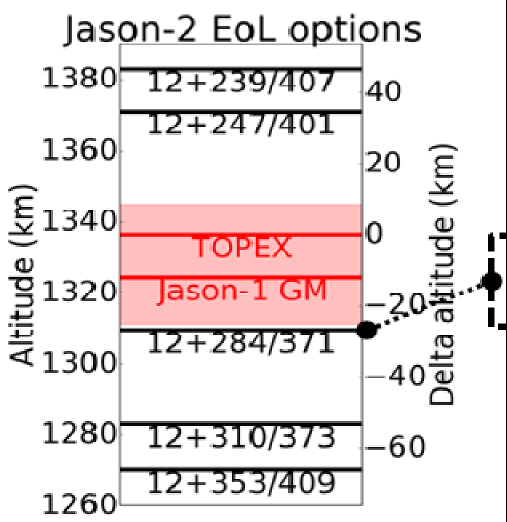
<u>when</u>: timing scenario for the EoL

Which EoL orbit for Jason-2

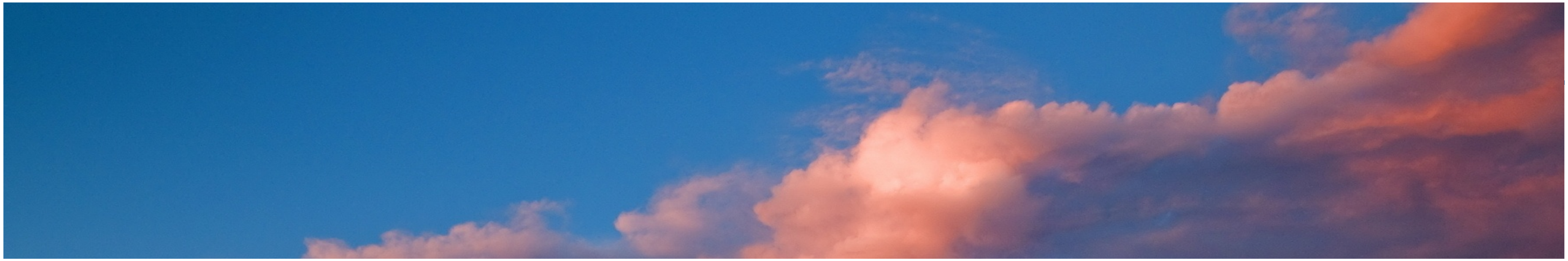
(Using Jason-1 GM orbit again is not an option)

Recommended orbits

- 6 good orbits found for Jason-2 EoL (Dibarboure & Morrow, 2016)
  - Minimize mesoscale sampling loss when interleaved is broken
  - Good geodetic grid (resolution increases after 6mo, 1yr, 2yr)
  - Good for debris avoidance (minimizes collision risk)
- Recommended target approx 27 km below Jason-3
- Ground track must be shifted by 4 km after 1 year (and 2 km after 2 years)



Altitude (km)	Delta Altitude (km)	Number of Revs per day	Sub-cycles (days, negative is westard)	A: Mesocale sampling uniformity (Jason-2 EoL + Jason-3)	B: Geodetic sampling uniformity (Jason 2 EoL + Jason1 GM)	C: Overlap event uniformity	D: Satellite debris (collision risk)	Tentative Priority
1383.0	46.7	12+239/407	-2, 5, -17, -63, -172, 407	Excellent	Good	Very Good	Medium	3
1371.0	34.7	12+247/401	3, -5, 13, 138, 401	Very Good	Good	Excellent	Good	2
1309.5	-26.8	12+284/371	-4, 17, 81, 145, 371	Excellent	Very Good	Very Good	Very Good	1
1282.9	-53.4	12+310/373	-6, -77, -148, 373	Good	Very Good	Very Good	Very Good	2
1277.3	-59.0	12+322/381	-6, 13, -71, 155, 381	Good	Very Good	Very Good	Very Good	2
1270.0	-66.3	12+353/409	-7, 22, -73, 168, 409	Very Good	Medium	Excellent	Very Good	3



Lessons learned from Jason-1 GM

And what should we expect from Jason-2 EoL?

GAIN: more geodetic data for bathymetry

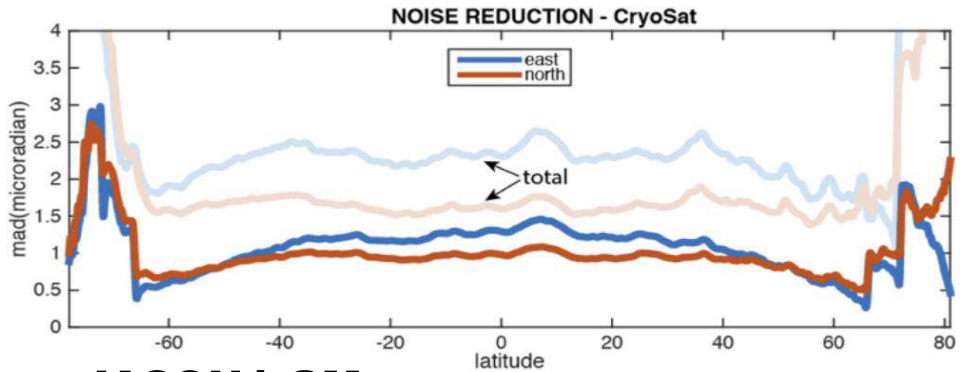
Jason-1

- Gravity noise reduction from Jason-1 GM is very good despite the short time series (4 times less than CS-2), thanks to the 66° orbit
- Greatest gravity improvement
  - at latitudes lower than 40°
  - in the east-west direction

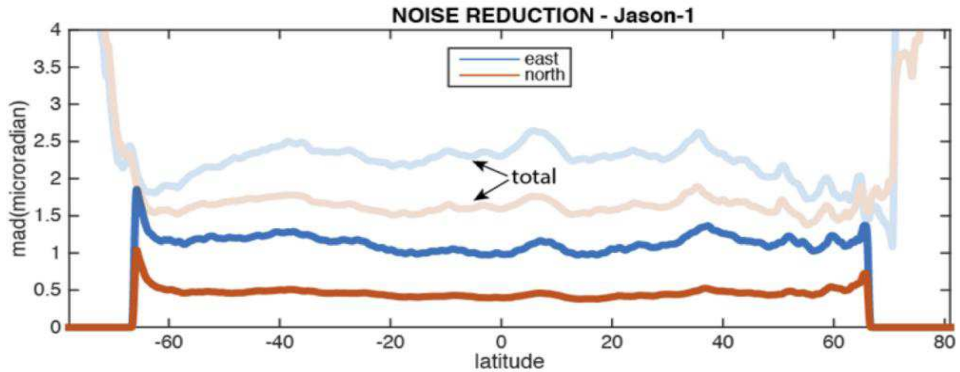
Jason-2

- Resolution of current gravity models is 12 km (6km features)
- Difficult to improve upon with CryoSat alone (8-km fixed grid) or AltiKa (uncontrolled drift)
- Jason-2 is the only mission that can yield a 4-km grid after 2 years (and a 2-km grid after 4-years)

CRYOSAT-2

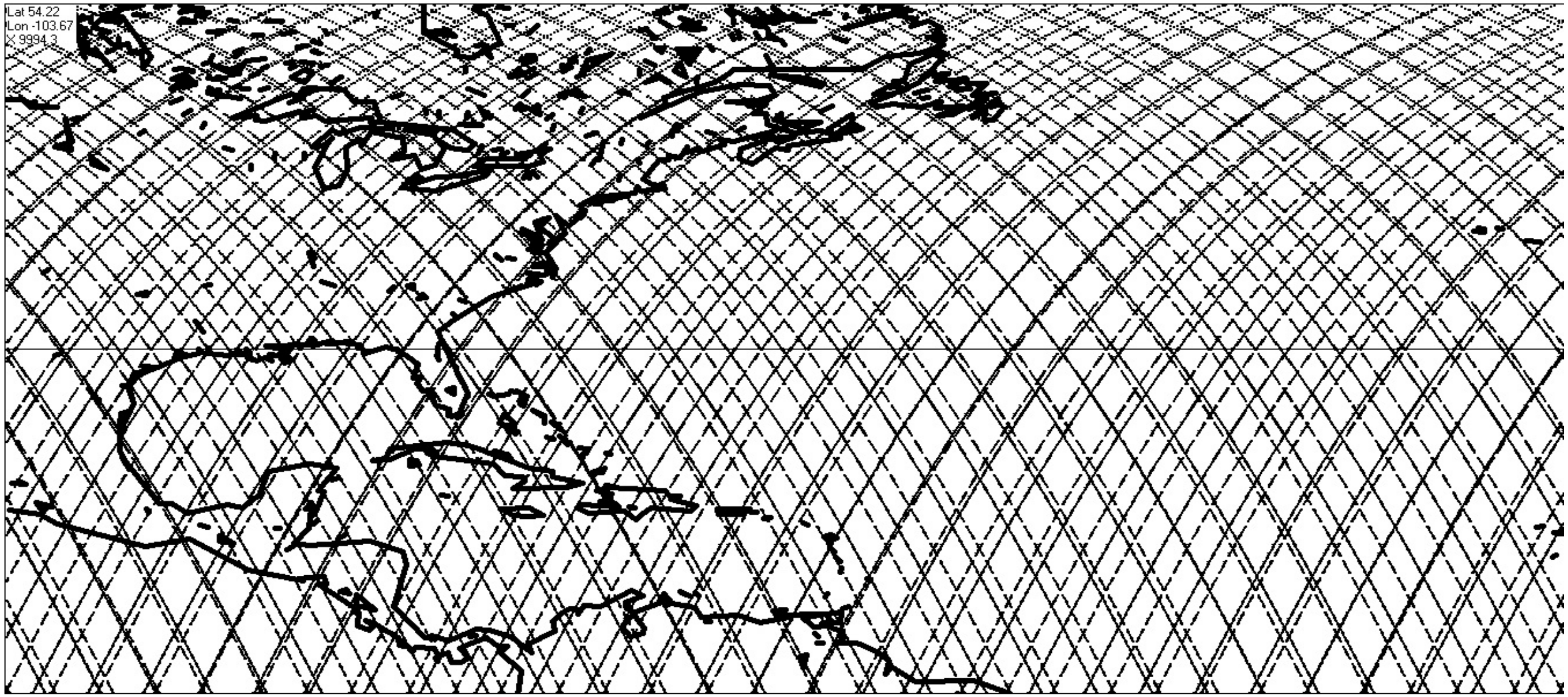


JASON1-GM



LOSS: breaking the interleaved sampling

- Interleaved orbit yields the best sampling for mesoscale & sea state
- Any EoL orbit generates sampling loss (25~30% duplicated tracks)
- Jason-1 GM mesoscale sampling patterns travel zonally
- Same effect is expected between Jason-2 EoL and Jason-3



Sampling of Jason-2 (plain) and Jason-1 GM (dashed) for subsequent 11 day-periods

LOSS: short-term degraded accuracy along uncharted tracks

- Sea level anomalies are obtained as :

$$SLA = SSH_{alt} - \langle SSH_{alt} \rangle$$

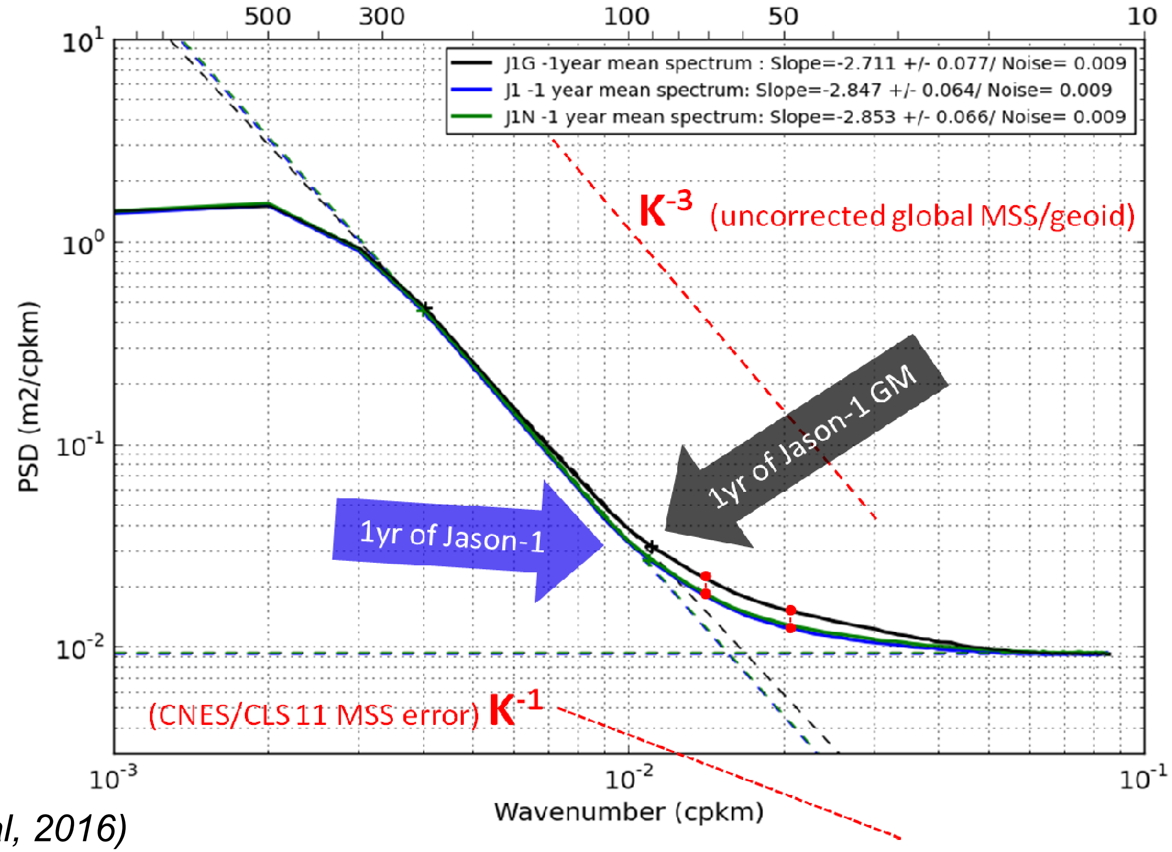
- Mean profile (repeat track)

or

- Mean sea surface model (global grid)

- The mean profile is well-known along the charted tracks of TOPEX/Jason
- For uncharted orbits (e.g. geodetic or S3), the mean reference is a 2D gridded MSS model
- Gridded models are less precise than MP

SLA degraded along uncharted tracks



Error from 2010 MSS models used for Jason-1 GM (Dufau et al, 2016)

GAIN: long-term improvement of gridded MSS

- The only way to reduce MSS errors is to collect more geodetic data
- Relevant for sensors with a focus on precision and small-scale (S3 & SWOT)

For the MSS, there is a trade-off between:

Resolution

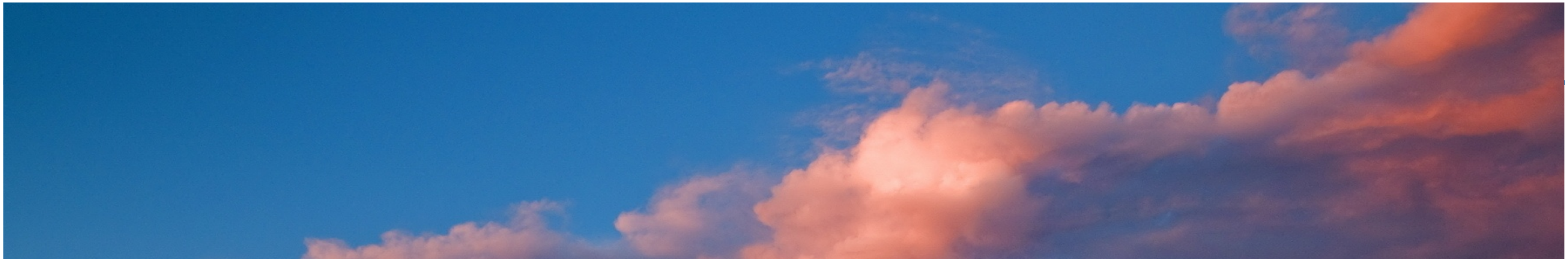
- Only Jason-2 EoL can collect a 4-km geodetic grid (up to 2 km)
- 2-year EoL phase is the minimum (4 years is very desirable)
- High-res MSS models needed by 2020 for SWOT's launch

➡ *EoL should start as soon as possible*

Mesoscale variability

- Large mesoscale is the main source of MSS error in certain regions
- Interleaved orbit useful to separate large ocean variability from MSS

➡ *EoL should start as late as possible*



Summary and possible compromise

Summary and timing trade-off

- Long-term gain
  - Protect historical orbit while Jason-2 platform is still healthy
  - Better resolution of bathymetry and gravity (4km, goal of 2km)
  - Better resolution of gridded MSS models (e.g. S3 and SWOT)

➔ **EoL should start as soon as possible**

- Short-term loss
  - Degraded sampling for mesoscale monitoring
  - More error in geodetic phase (gridded MSS models not perfect)
  - More difficult to separate ocean variability and geoid / MSS

➔ **Stay in interleaved orbit as long as possible**

Jason-1 VS. Jason-2

- Jason-1 in 2010: high priority on operational sampling & precision
  - ENVISAT was old, no ocean product from CryoSat-2, and no HY-2A
  - And the error of MSS models was still large at the time
  - ➡ Jason-1 stayed in interleaved orbit as long as possible
- Lessons learned from Jason-1 GM
  - Few surprises: anticipated changes (good & bad) were actually seen
  - Operational models *can* assimilate SSH from a geodetic mission…
    …but only if they double the altimeter error bar (weaker constraint)
- What changes for Jason-2
  - EoL must be 2 to 4 years to make a difference in geodetic resolution
  - New MSS models are 50% more precise (but still far from perfect)
  - 6 altimeters operated (but not 6 times the information, see backup)
  - Having only Jason-3 on a charted track is bad for mesoscale monitoring

Possible compromise

Long-term

- Guarantee high-resolution geodetic dataset
- Get new MSS model & bathymetry before SWOT (if EoL starts before 2018)

Short-term

- Use interleaved orbit for 1 year (better mesoscale sampling & precision)
- Tolerate a substantial toll on operational oceanography: all altimeters but Jason-3 will be on an uncharted track (error bar doubled in assimilation)
- Accept the loss of coverage and precision because there are enough altimeters in operations in the J2 EoL time frame (2016-2020)

Jason-2 should be moved to a geodetic orbit if either

a fixed deadline is reached (e.g. fall 2017), or

any significant onboard anomaly occurs on Jason-2

Thank you for your attention

REFERENCES

• Dibarboure.G. and D.Sandwell (2016): When should Jason-2 be moved to a geodetic orbit? Technical note circulated to the OSTST by the science leads

• Dibarboure, G., & R.Morrow (2016). Value of the Jason-1 geodetic phase to study rapid oceanic changes and importance for defining a Jason-2 geodetic orbit. Journal of Atmospheric and Oceanic Technology (in press).

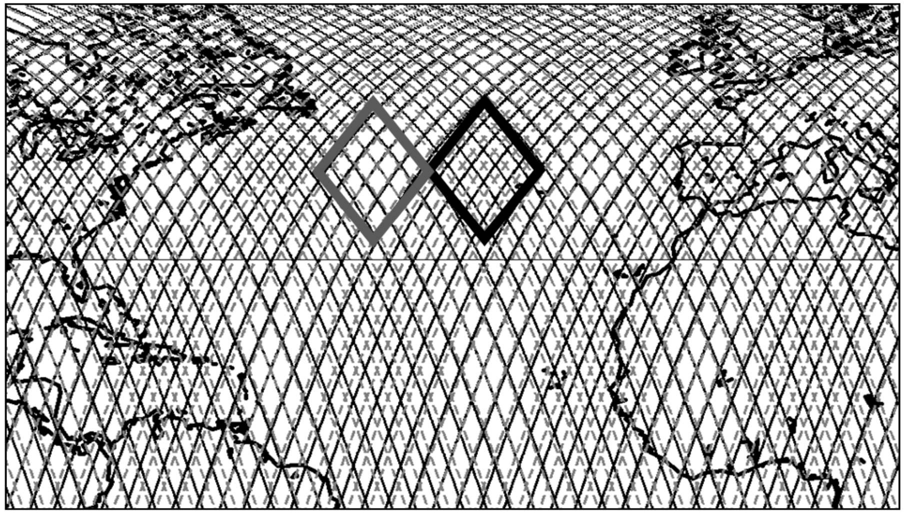
• Dibarboure et al (2012). Finding desirable orbit options for the “extension of life” phase of jason-1. Marine Geodesy, *35*(sup1), 363-399.

• Dufau, C., Orstynowicz, M., Dibarboure, G., Morrow, R., and La Traon, P.-Y.: Mesoscale Resolution Capability of altimetry: present & future, J. Geophys. Res, 121, 4910–4927, 2016.

• Sandwell.D, R.Dietmar Müller, W.Smith, E.Garcia, R.Francis (2014): New global marine gravity model from CryoSat-2 and Jason-1 reveals buried tectonic structure. Science 3 October 2014: Vol. 346 no. 6205 pp. 65-67

Can Jason-2 EoL be interleaved with Jason-1 GM tracks?

- Best geodetic sampling = interleaved with the tracks of Jason-1 GM
- This requires to put Jason-2 exactly at the altitude of Jason-1 GM
- Not possible because Jason-1 platform is uncontrolled and still orbitting at this altitude
- Any other EoL orbit will result in Moiré patterns (like mesoscale but on the 7 km grid and 400 days) Very local effects and impossible to optimize

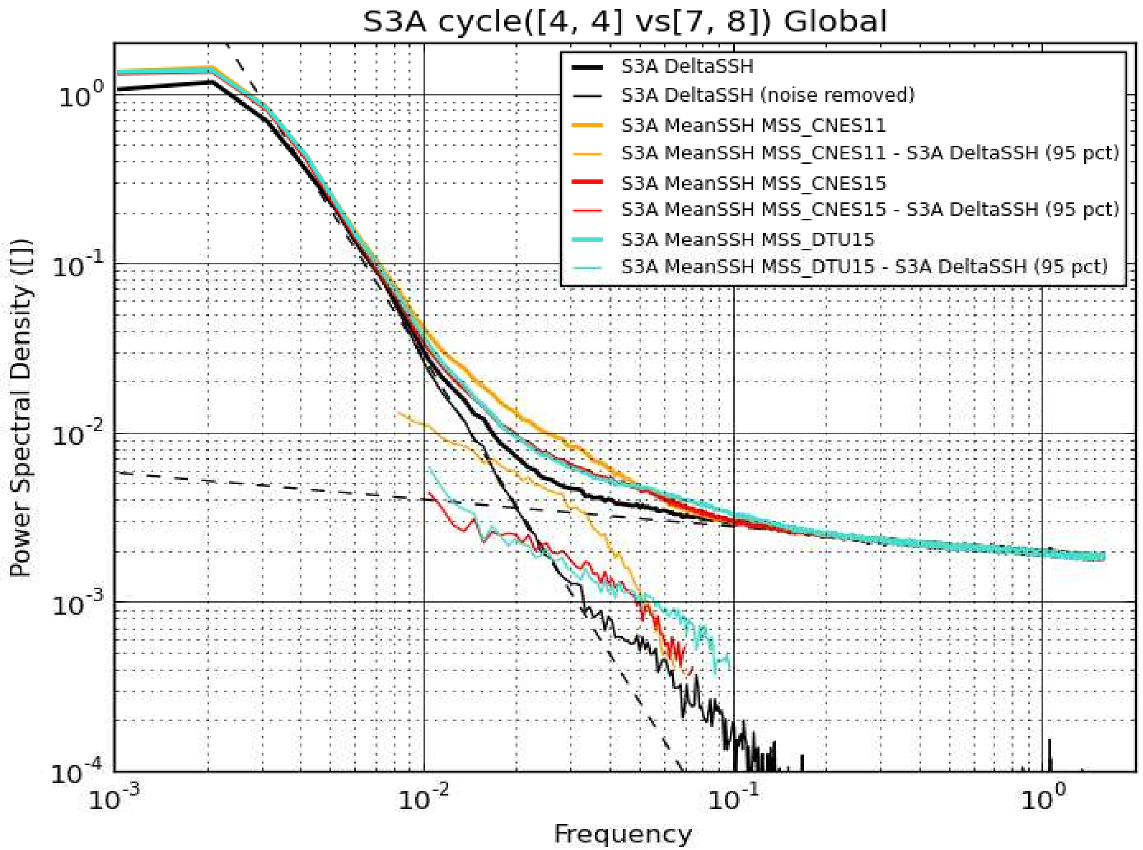


- If Jason-2 GM last for more than 400 days, it is possible to collect a second geodetic cycle exactly between the tracks of the first 7 km grid (i.e. grid less than 4 km)

Gauging the error of 2016 MSS models with Sentinel-3

- Black PSD: 90-day differences along S3 repeat track (MSS error cancelled out)
- Coloured PSD: spectra of SLA based on different models (MSS error included)
- The MSS error generates substantial undesirable extra energy from 10 to 100 km

➡ The MSS error is a limiting factor for the improved precision of Sentinel-3 in SARM



(see talk from Pujol et al about MSS errors)

6 altimeters ≠ 6 times the information

- Starting with Jason-3, as satellites are incrementally added in uncoordinated orbits, the marginal return of independent information diminishes for each subsequent satellite
  - Jason-2 in the interleaved orbit is coordinated so redundancy is minimal
  - Estimate of Jason-1 redundancy in geodetic orbit (uncoordinated) with Jason-2 was about 30%
  - No overall coordination between orbits of HY2, Jason-3, S3, AltiKa, J2-EoL
  - As additional uncoordinated orbits are added, the redundancy increases

- Observation impact on forecast systems is reduced as errors increase
  - Influence is simplistically $V_B/(V_B+V_O)$, where V_B is the background error variance and V_O is observation error variance
  - Emphasized by the systematic (stationary) nature of MSS errors
- An uncoordinated higher error data set can have less than half the impact of a coordinated accurate data set

6 altimeters on uncharted and uncoordinated orbits = only 3 times the information for models

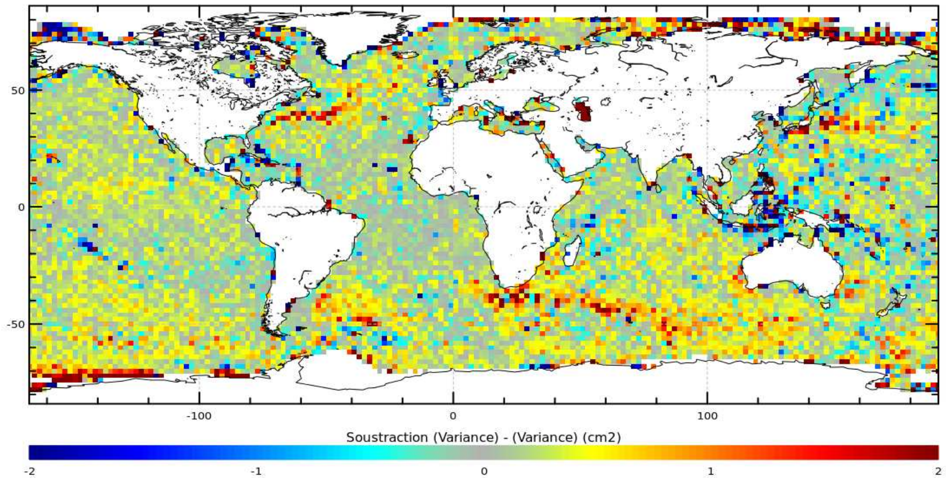
Jason-2 EoL = significant loss for mesoscale even now

Oceanic variability

- A small fraction of SLA dynamics may be misinterpreted and modeled as MSS content ➔ commission error affecting all altimeters using this MSS model
- One way of separating this dynamic signal from the mean surface is to use multi-altimeter SLA maps (based on repeat tracks, i.e. independent from gridded MSS)
- There are now 3 geodetic altimeters: Cryosat-2, HY2-GM, and AltiKa-DP
- To get these 3 geodetic datasets with as little large scale oceanic variability in them as possible, the interleaved orbit of Jason-2 is useful because it is the only charted repeat-orbit that can be merged with Jason-3

Variance difference for HY-2A SLA based on two MSS models

Var(SLA_MSS_DTU15) –
Var(SLA_MSS_CNES_CLS_2015)
Λ=[0, 250km]

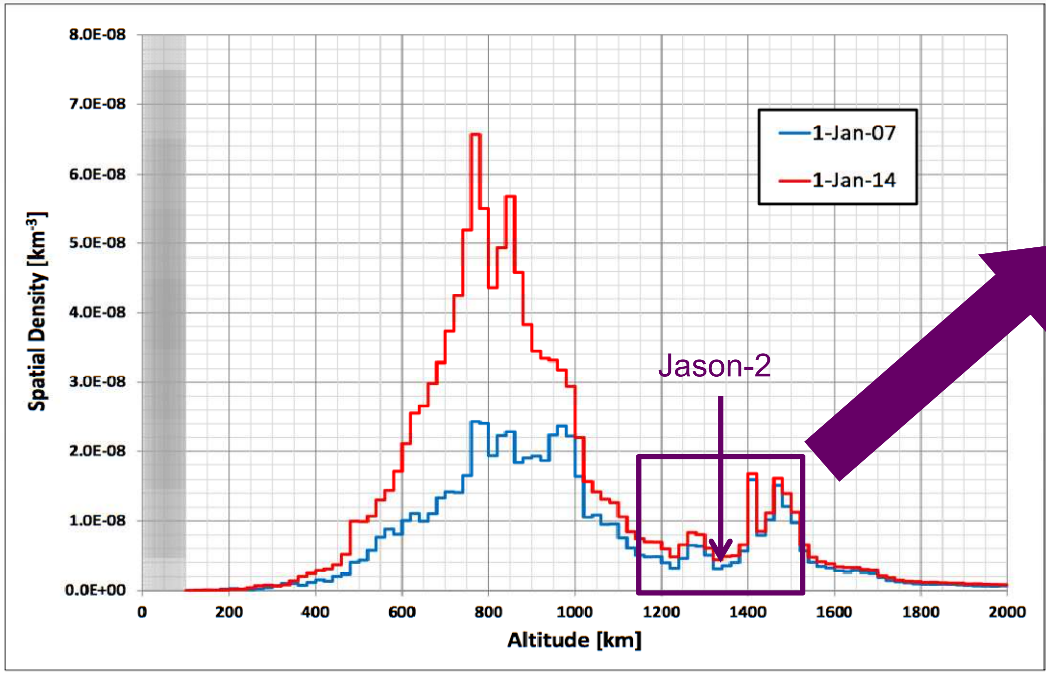


There is clearly oceanic variability in the latest MSS models

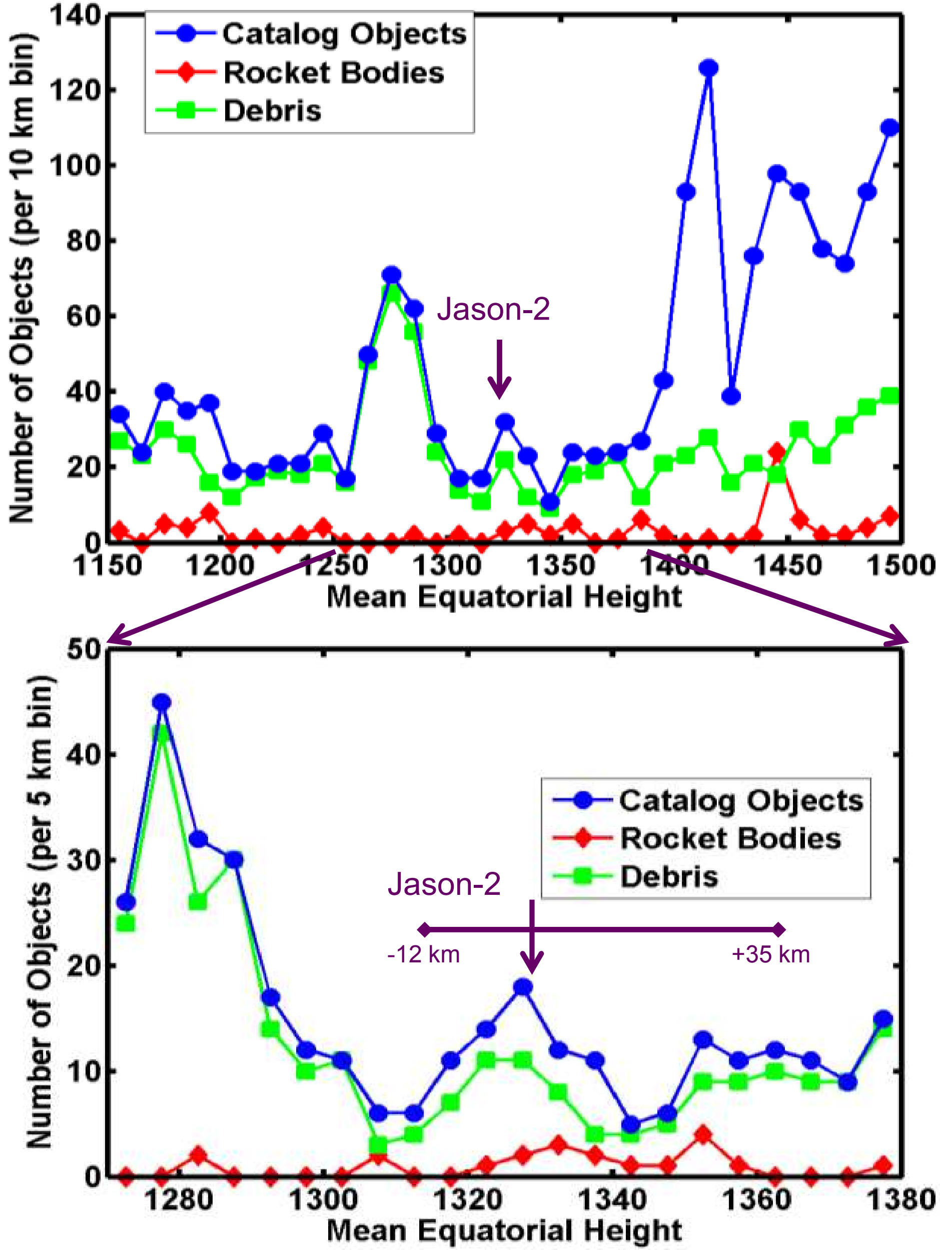
(see talk from Pujol et al. about MSS errors)

Debris and collision risk

From G.Shirtliffe (Spring 2016 REVEX meeting)



This chart compares the spatial density distributions of the tracked objects in low Earth orbit (LEO) for 1 January 2007 and 1 January 2014. The increase below 1000 km altitude is approximately 115.4%. Fragments generated from the Fengyun-1C anti-satellite test conducted by the People's Republic of China in 2007 and the accidental collision between Iridium 33 and Cosmos 2251 in 2009 account for most of the increase.



Density and Number of Objects
at End-of-Life orbits -12 km & +35 km