FUTURE ALTIMETER CONSTELLATIONS: CAPABILITIES AND ADVANTAGES

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1 - Abstract

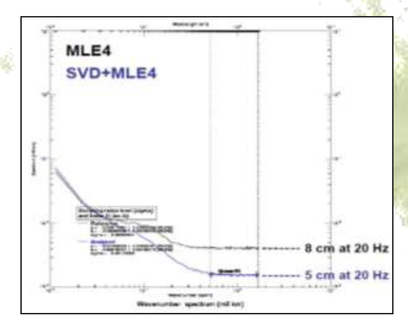
The upcoming IRIDIUM-NEXT constellation has the ability to host 66 payloads of opportunity, and among them conventional Nadir altimeters. Leveraging effect of scales and synergies with Jason-3, the routine exploitation costs of each sensor could be as low as 10% of a Jason-like mission with no synergy.

Beyond cost considerations, this work highlights the advantages of the concept: unprecedented temporal sampling, ability to complement SWOT in multi-sensor products with SSH-derived parameters (geostrophic or vertical velocities), and external cross-calibration to minimize SWOT errors for medium and large scale.

2 – Constellation size and payload

Although the mass and power left for IRIDIUM-NEXT passengers is relatively modest, it is compatible with a mono-frequency Nadir altimeter (Ku, and possibly Ka) without SAR capability, 2-frequency radiometer, and GPS + Laser reflector (no Doris).

Out of the 66 satellites of the IRIDIUM constellation, up to 24 can be accommodated with altimetry payload of opportunity.



F1: Noise level on traditional altimetry product (black) and on noise-minimized products from the CNES project SLOOP (blue). Courtesy of P.Thibaut

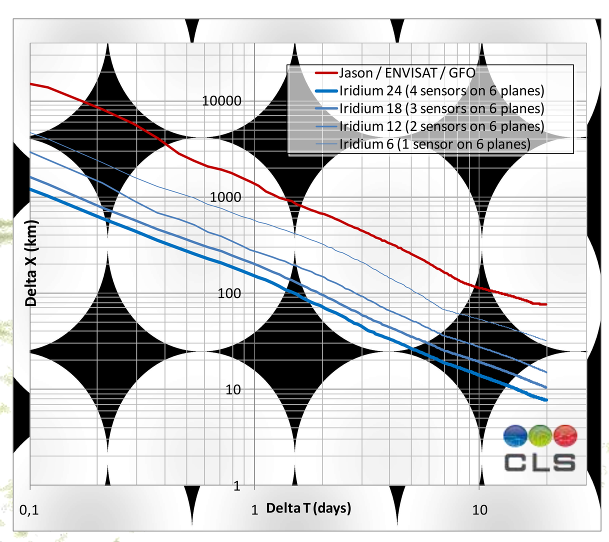
The lack of IRIDIUM-related program from any Agency will probably limit the number of such altimeter to 6 at best. Adding the upcoming Jason-3 & CS, Sentinel-3A & 3B, or GFO2, it would be possible to have up to 10 conventional altimeters by 2019 (i.e. SWOT launch).

Extrapolating improvements expected on external corrections (e.g. ionosphere) and reference surfaces (e.g. MSS), and altimetry processing (F1), it would be possible to have less than 3cm error at 1km in Ku-band (vs 3cm for 7km in GDR-C) and less in Ka-band. Doppler altimeters hosted on a dedicated constellation could reduce noise level almost to SWOT level.

3 – Temporal sampling

SWOT will provide an unprecedented observing capability in a 120km wide swath. But its temporal sampling capability is limited to the observation from a single sensor on a 22-day orbit.

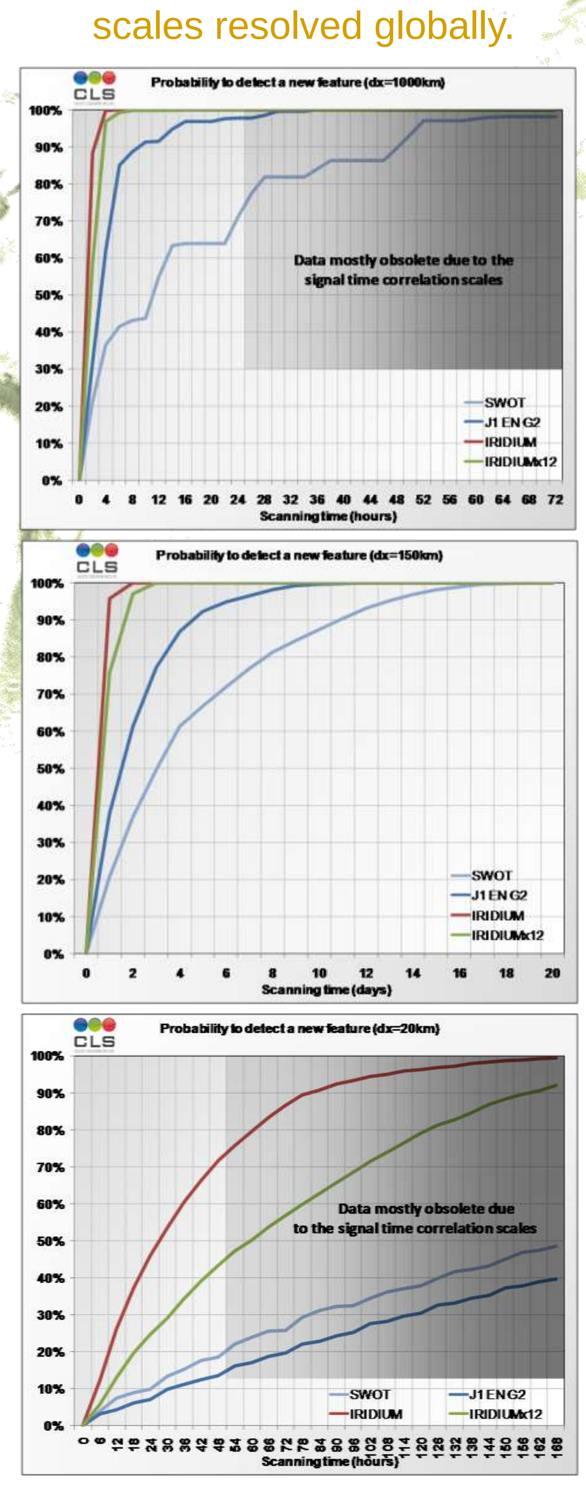
Conversely, a constellation of standard altimeters has a much better temporal sampling. It is naturally improved with more sensors (F2). The observation is still 1D and limited to the Nadir.



F2: RMS of the cross-track distance as a function of time for different constellations, i.e. scales resolved globally.

A large constellation of 20 altimeters has the ability (F3) to provide a synoptic view of 1000km structures in a few hours, and a global NRT obs of mesoscale every day. It can also track about 70% of all 20 to 50km structures in Near Real Time whereas SWOT alone can "refresh" its perfect 2D error-free observation in 48h (temporal decorrelation limit) for only 20% of the features it will observe in a full cycle.

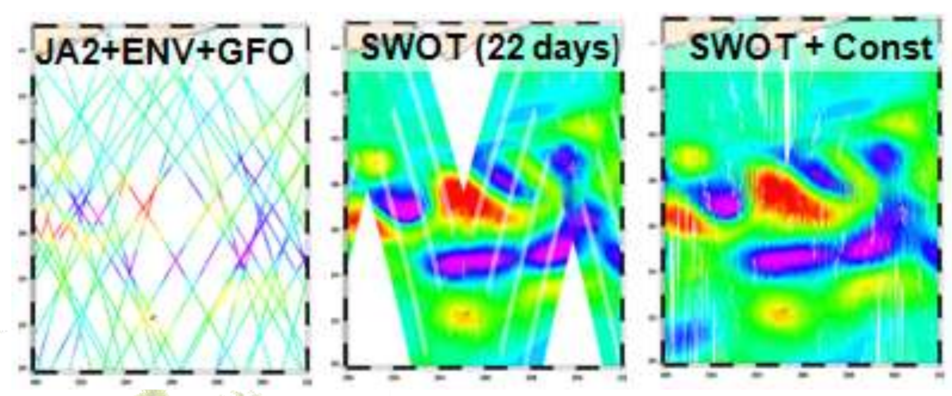
The same complementarities between high-precision 2D images and high-frequency 1D information exists for hydrology measurements: global mapping every 22 days vs high-frequency tracking of Nadir-limited virtual stations.



F3 : Percentage of oceanic features detected in Near Real Time by the constellation (i.e. correlation of 0.7 or more) as a function of scanning time: SWH/storm surge applications (top) mesoscale (middle) and large sub-mesoscale (bottom). The red curve is a constellation of 24 altimeters on Iridium, and the green curve is a constellation of 12 altimeters on Iridium

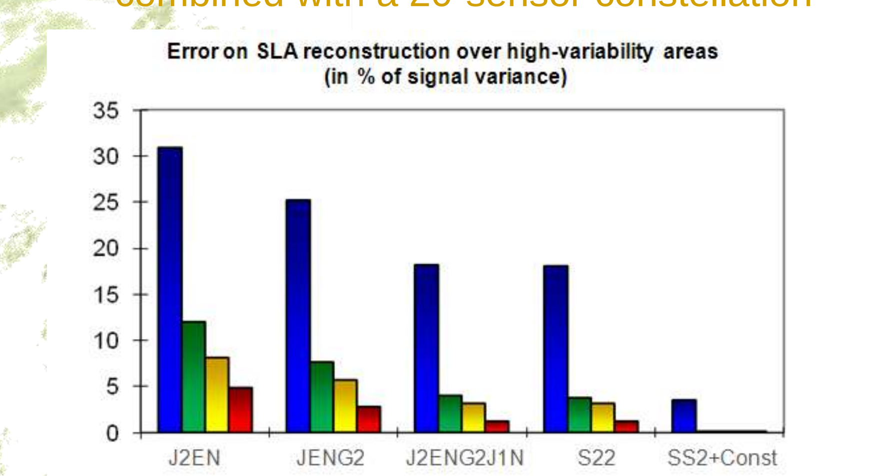
4 – Complementing SWOT observations

To assess the complementarity between SWOT and a constellation, various OSSE-like analyses were used in a mapping context. The ocean "truth" is the Earth Simulator output from Ifremer (courtesy of P.Klein). Simulating the nadir / swath observation with or w/o errors (F4) , the "reconstructed – truth" differences allows to infer the sampling impact on SSHA, geostrophic velocities, vorticity or vertical velocities derived from SSH.



F4: 10 days of SSH observations from a 3-satellite constellation, from SWOT and from SWOT combined with a 20-sensor constellation

The constellation provides a stable observable of mesoscale (50 to 100km, 10 days or more) that can complement the sampling from SWOT alone (F5). Even a couple of Nadir altimeters still provide useful information in the swath for derivative quantities (F6).



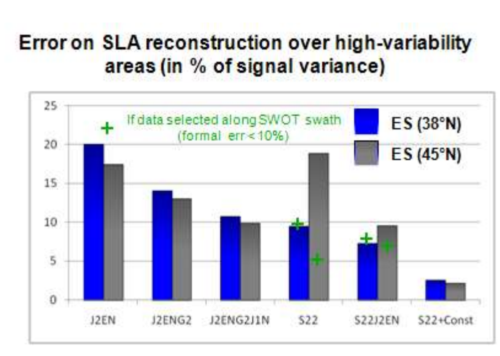
F5: Reconstruction error of Earth Simulator SSHA outputs. Blue is for total signal, Green is for low frequency (>10d), yellow is for large scale (>100km), red is for low frequency and large scale. In this case, all observations taken are error-free (pure sampling assessment).

	S22(opti)	S22 (pessi)	S22J2EN (pessi)
W (-100m)	45	55	50
W (-500m)	36	43	39
W (-1000m)	27	33	30

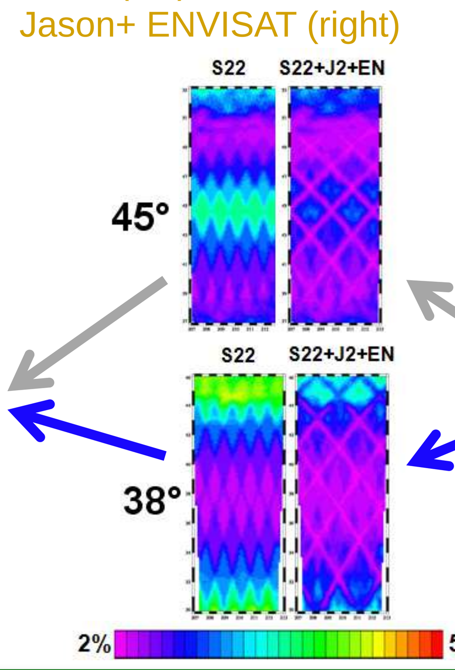
F6: Reconstruction error of vertical velocities (% of signal variance) derived from gridded SSH fields. The signal is limited to scales larger than 50 km, and the reconstruction is performed only in the SWOT swath. Left is for SWOT with optimistic error budget, middle is for a pessimistic error budget, and right is for the combination of SWOT and 2 conventional altimeters.

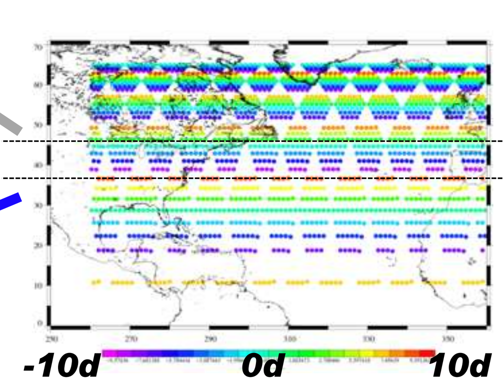
The constellation is most useful away from the swath or at specific latitude bands (F7), as it is the only surrogate for SWOT observation. For instance, at 45 N, ascending and descending arcs will be separated by only a few days (F8), leaving a 20-day gap until the next cycle. Nadir altimetry can provide the complement, albeit not a 2D kilometric image with 1cm precision.

F7a: Reconstruction error for scales >100km at two different latitudes (blue is 38 N and gray is 45 N). SWOT alone (S22) is limited by the 22-day sampling pattern (see F8), whereas adding 2 Nadir altimeters (S22J2EN) or more (S22+Const) gives a more homogeneous sampling capability (see F7b).



F7b: Formal mapping error at 45 N (top) and 38 N (bottom) for swot alone (left) and SWOT+ Jason+ ENVISAT (right)



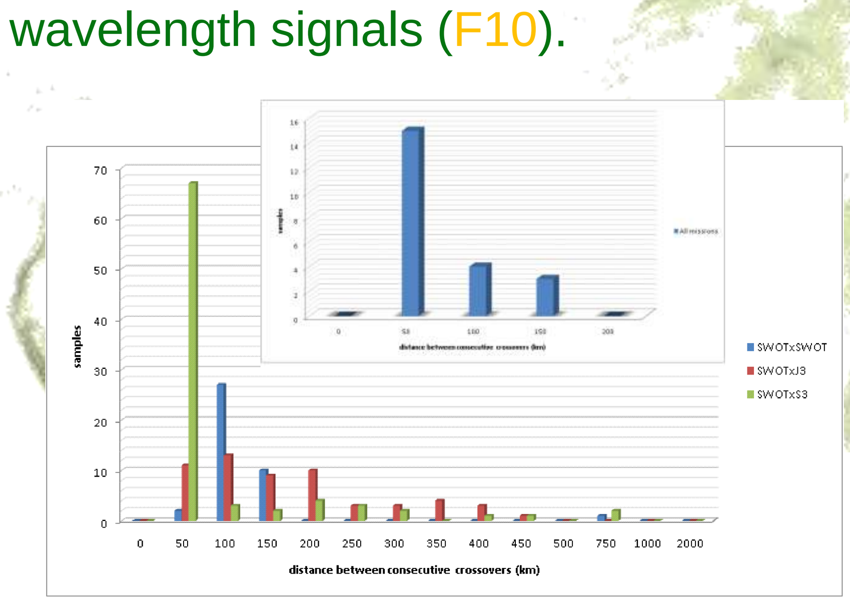


F8: Delta time of SWOTxSWOT crossovers. At 38 N asc/desc arcs are separated by ~1/2 SWOT cycle. At 45 N both arcs are almost on the same day of the cycle.

5 – Cross-calibration zones and SWOT error reduction

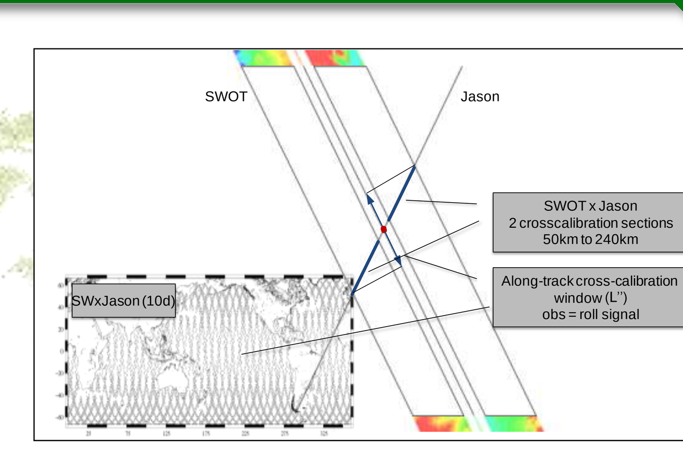
The SWOT error budget is ambitious and a lot of effort is put on hardware and processing constraints to ensure that the whole error spectrum is controlled.

Traditional altimeters provide the most trustworthy source of external error reduction through DUACS-like empirical cross-calibration methods (e.g. post-processing of L2 products). Each time the SWOT swath crosses a Nadir track, it is possible to use cross-calibration segments of 50 to 250km with a dense worldwide distribution (F9). With only 2 – 3 altimeters, it is possible to use such co-located data to observe low frequency / long wavelength signals (F10).



With 10+ Nadir altimeters it would be possible to observe shorter scales, either to relax Level2 error budget constraints, or to use the constellation as a risk reduction technique, or as a way to better understand the first years of SWOT data, comparing them with well-known Nadir altimetry data.

F10: Typical scales that can be cross-calibrated from Nadir altimetry. Expressed as a distribution of the distance between consecutive (along-track) crossovers. If Jason and Sentinel-3 are used only 20% of SWOT data are in cross-calibration gaps larger than 50km. With a large constellation, calibration zones are everywhere and they overlap making high-frequency cross-calibration possible.



F9:Geometry of a SWOT x Jason cross-calibration zone. The length of the segment is dictated by orbit geometry and latitude. The bottom left map shows the global coverage of calibration zones (delta time is less than 10days).