SLR Tracking Requirements for Satellite Altimetry

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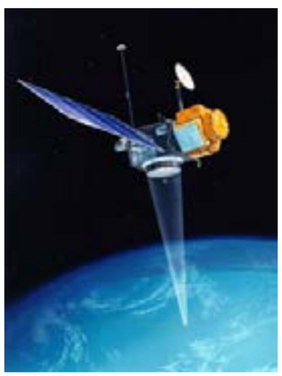
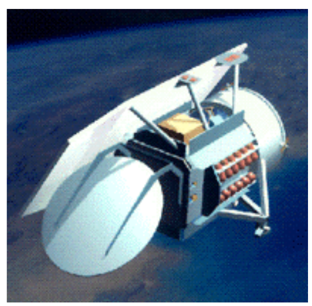
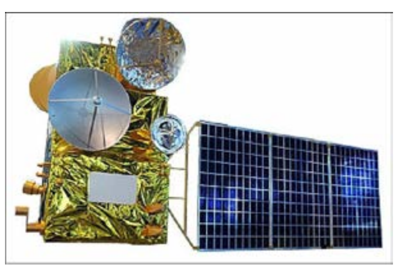




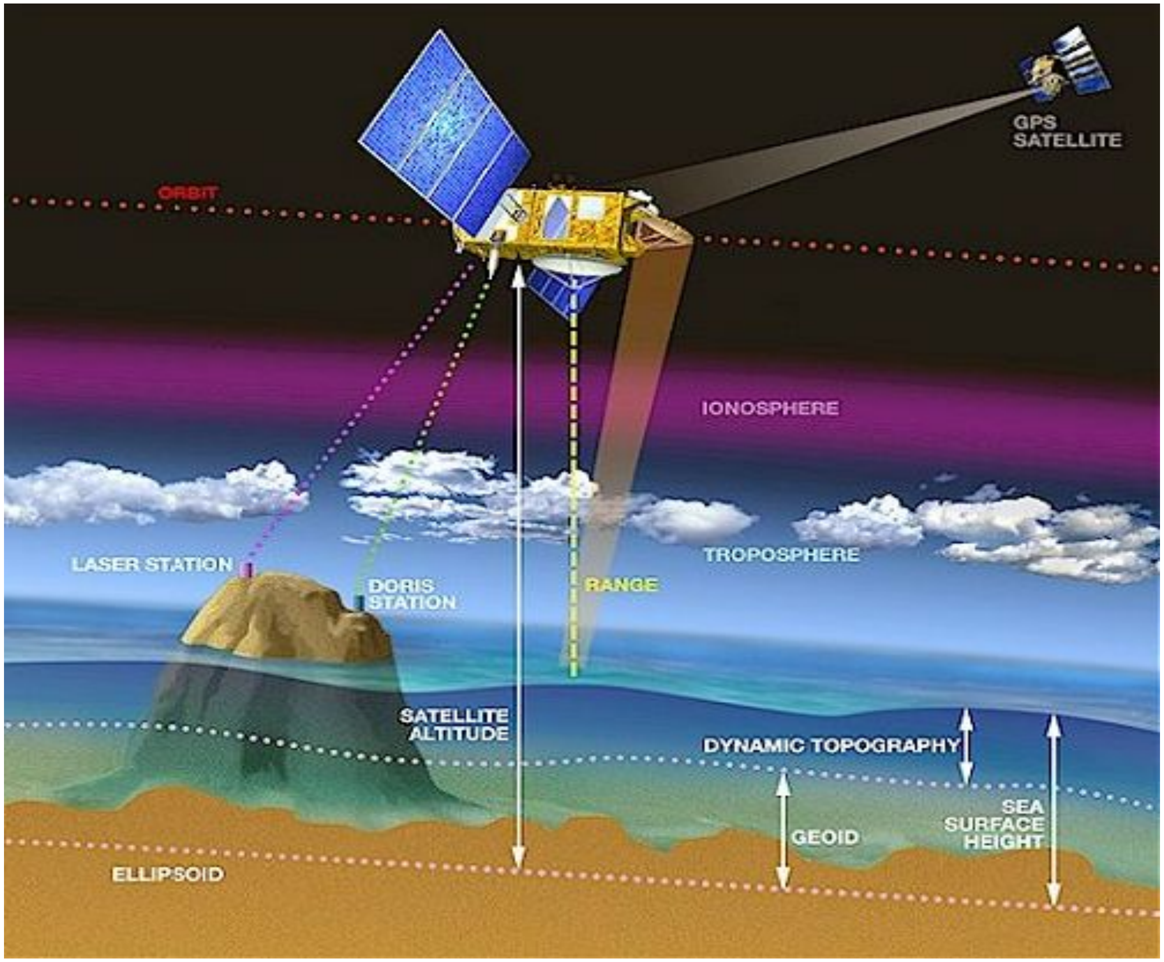





International Laser Ranging Service

- Introduction
- Examples of science from Satellite Altimetry.
- Role & Contribution of SLR.
  (1) POD.
  (2) Orbit Validation.
  (3) Verification of Radial Orbit Stability.

POD - Schematic

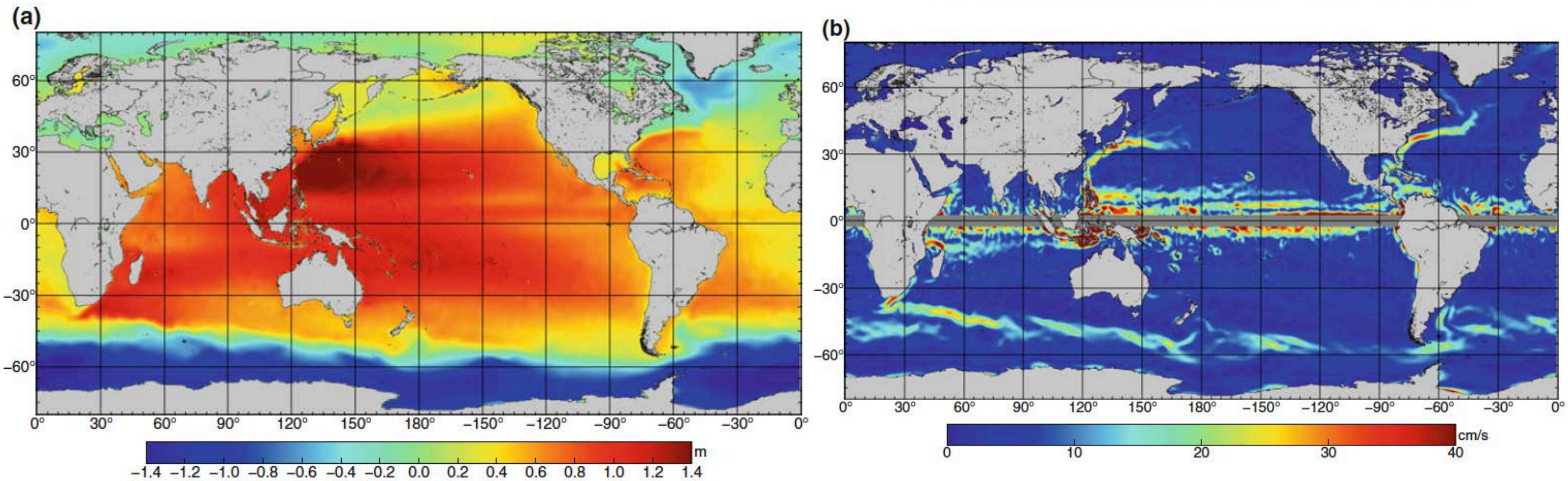


This example is for TOPEX, but the same principle applies for all altimeter satellites.

In order to determine the height of the sea surface, we must know the satellite position (meaning its orbital ephemerides) to a precision commensurate to or better than the accuracy of the altimeter

Science of Altimetry- I

Dynamic Ocean Topography / Global Ocean Circulation

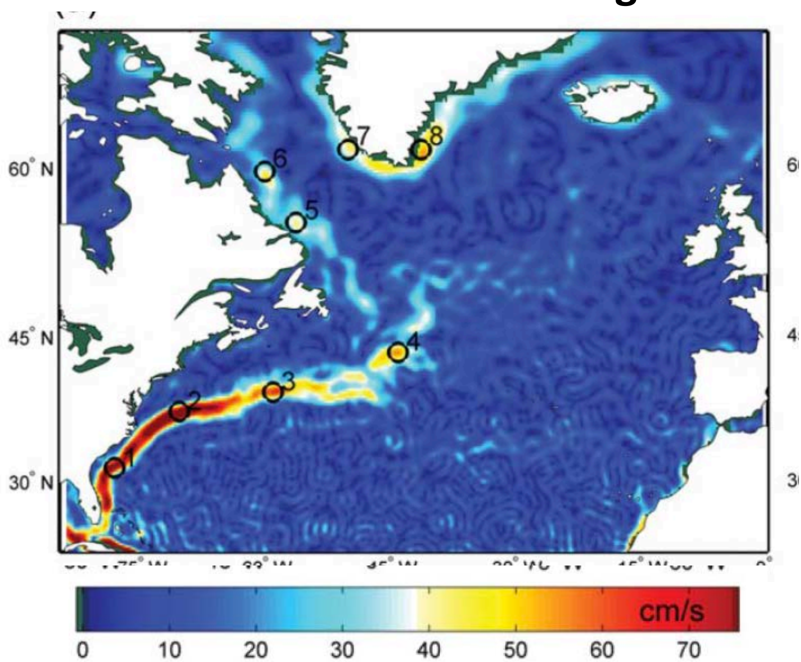


With independent information on the gravity field of the Earth (e.g. GOCE) it is possible to separate out the DOT contribution to a Mean Sea Surface and image the mean shape of the oceans caused by the ocean currents ... and also compute the mean geostropic velocities.

(a) GOCE DOT filtered with a 140 km Gaussian filter
(b) Surface geostrophic current speeds computed from the filtered GOCE DOT.
(Knudsen, P., et al., “A global mean dynamic topography and ocean circulation estimation using a preliminary GOCE gravity model”, J. Geodesy, 2011***)***

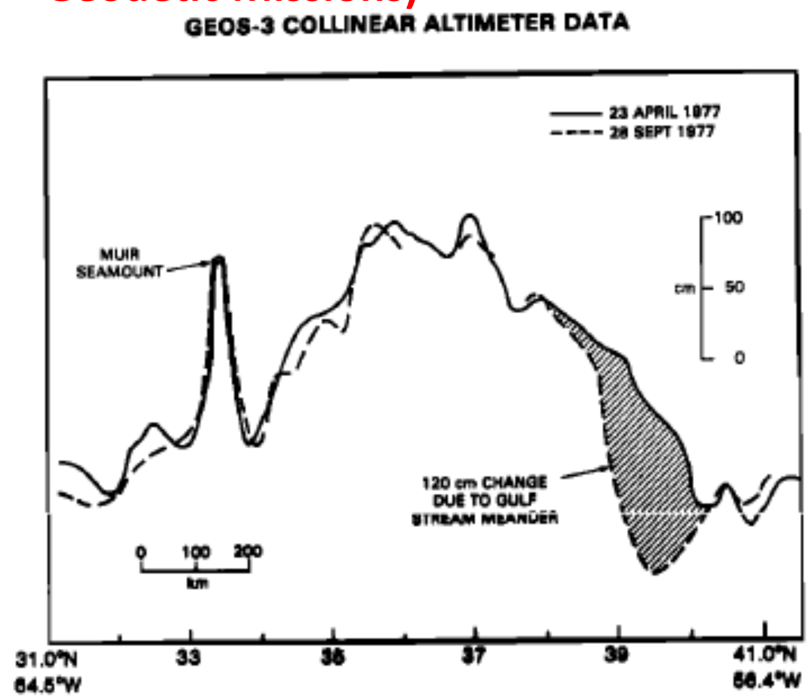
Science of Altimetry- II

Map Boundary Current Velocities: and how the currents change



Sanchez-Reales, et al., 2012, Marine Geodesy.

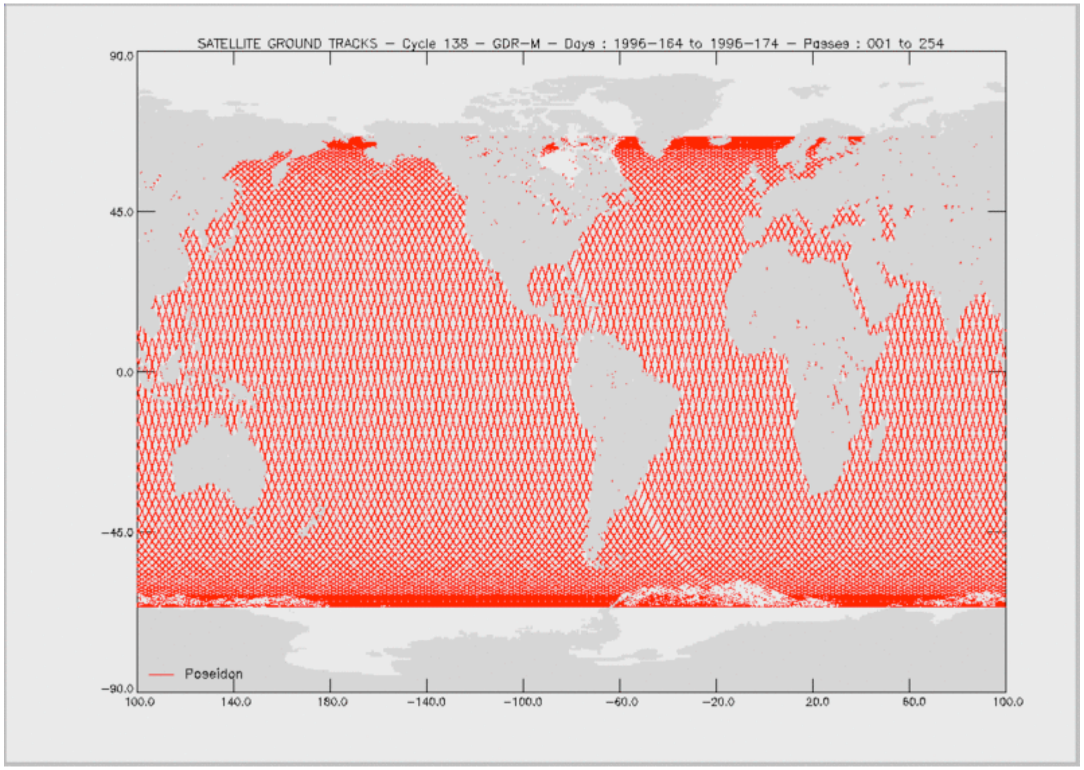
Map ocean geoid & indirectly map ocean bathymetry **e.g. (Jason1 & Jason2 Geodetic Missions)**

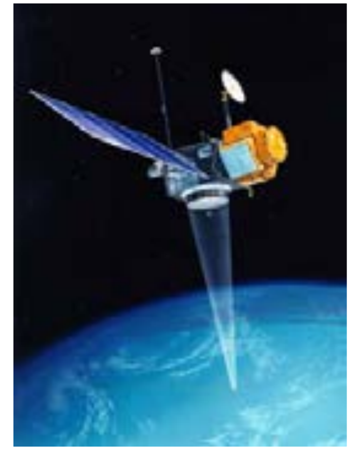


(Geodynamics and Earth Ocean Satellite: GEOS-3)
<u>Launched</u>: Apr. 9, 1975
Operated through July 1979.

B. Douglas et al., JGR, 1983,
http://dx.doi.org/10.1029/JC088iC14p09595

Example Ground Track Coverage for TOPEX (& Jason-1, Jason-2, Jason-3).





TOPEX/Poseidon
1992-2006

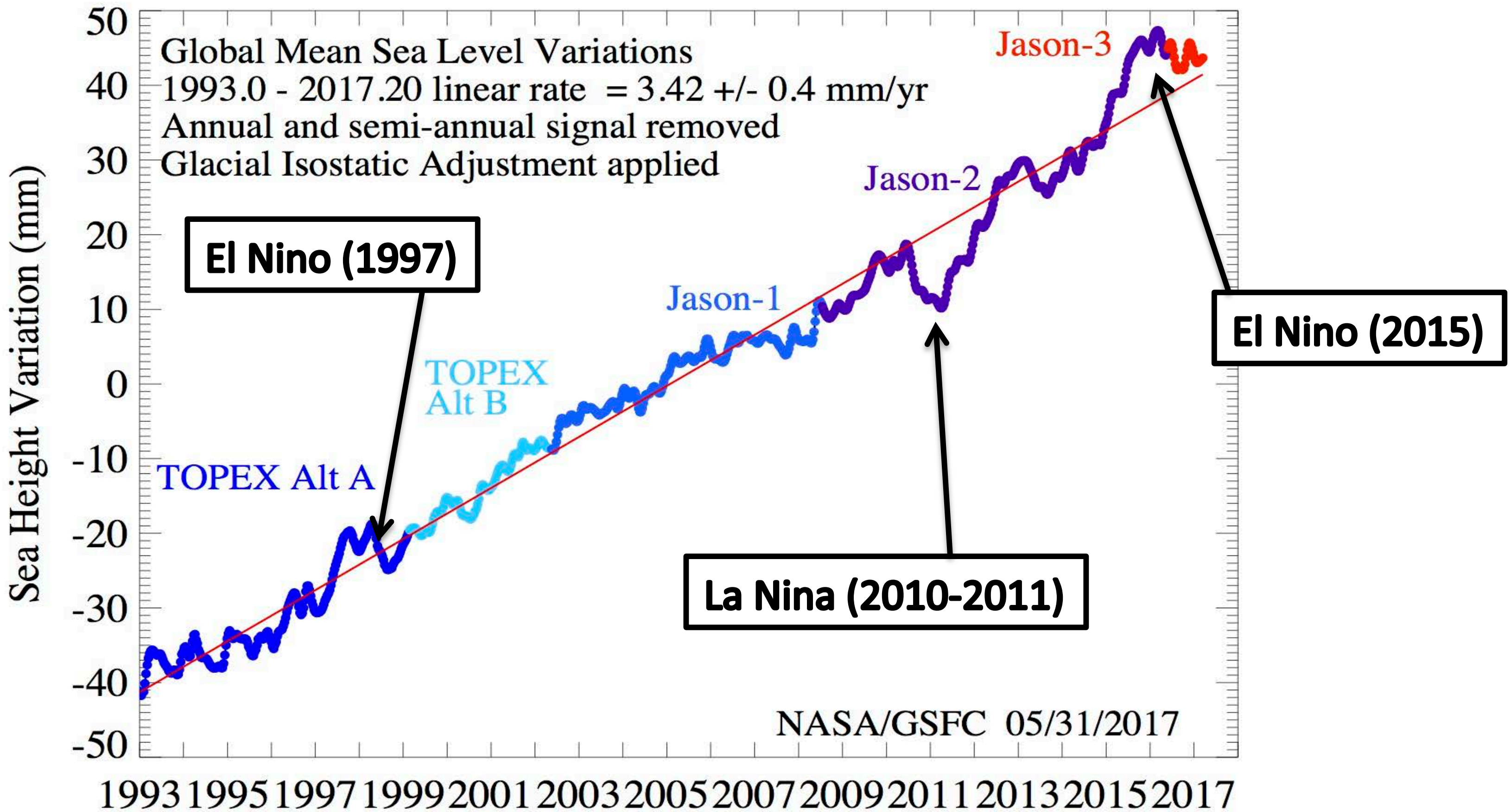
Image from AVISO (Toulouse, France)

Jason-3
2016 –

Think of these "Reference Mission" satellites as an orbiting tide gauge that regularly (every 9.9156 days) that provides a snapshot of the ocean surface.

Science of Altimetry- III

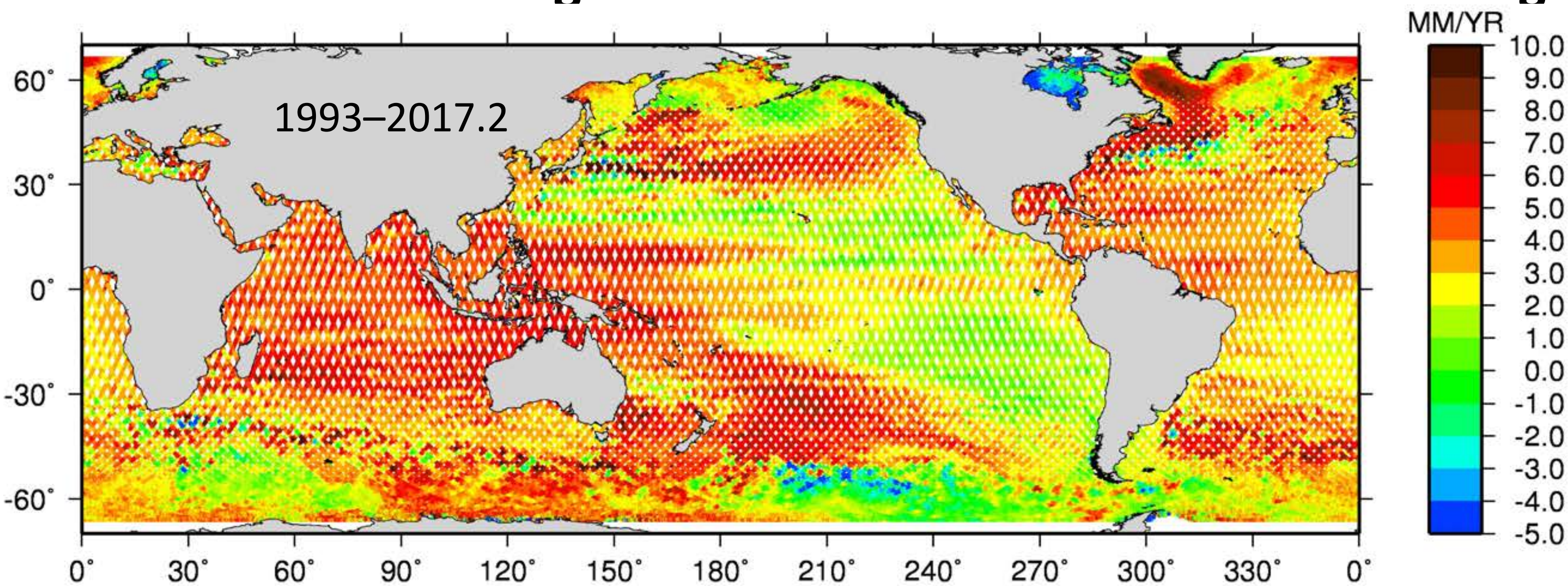
The precise orbits for TOPEX/Poseidon, Jason-1, Jason-2, all computed in a consistent reference frame (ITRF2008, and in future ITRF2014) are used to compute the global change in mean sea level from satellite ocean radar altimeter data.



http://podaac.jpl.nasa.gov/Integrated_Multi-Mission_Ocean_AltimeterData

Science of Altimetry- IV

Measurement of Regional and Global Mean Sea Level Change



Regional mean sea level variations from TOPEX, Jason-1, and Jason-2 with respect to 1993-2002 mean; http://podaac.jpl.nasa.gov/Integrated_Multi-Mission_Ocean_AltimeterData

TOPEX/Poseidon 1992-2002 (-2006)

Jason-1, 2001-2009 (-2013)

Jason-2, 2008-
Jason-3, 2016-

Oceanographic & Geophysical Signal Summary

Phenomenon	Amplitude	
Mean Sea Surface	± ~100 m	Geoid + Dynamic Ocean Topography
Global Dynamic Ocean Topography	± ~1.5 m	Only resolvable with independent satellite gravity information
Sea Level Change	~3.4 mm/yr (global average)	Regional variations − up to +6-8 mm/yr in some regions.
Warm Core Eddies	~50 cm	e.g. Hurricane Katrina
El Nino	± ~30 cm	
Ocean Tides.	e.g. 1 cm (Q1) to > 1 m (M2)	Many frequencies & constituents. Alias period is satellite-specific.

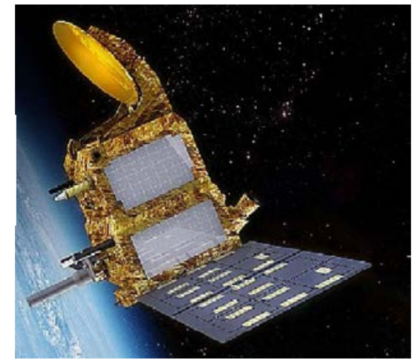
Current Ocean-radar mapping altimeter satellites (Oct. 2017)

EUMETSAT

SLR+DORIS+GNSS

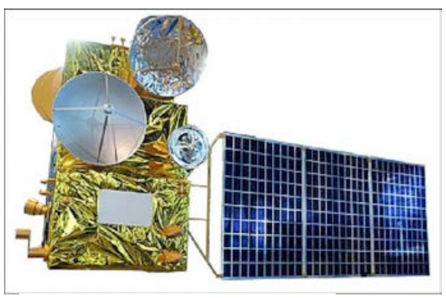
SLR+DORIS

ISRO (India)



SARAL, 2013-

SLR+DORIS



Haiyang (HY)-2A, 2011 (CNSA)

SLR+DORIS+ ... (GNSS*)

esa opernicus

Sentinel-3A 2016

(SLR)+DORIS+GNSS

These satellites form a “virtual” constellation that monitors the ocean surface topography.

Golden Age of Satellite Altimetry!!

SLR Data Applications for Altimeter Satellites (1)

Precise Orbit Determination:

• Compute orbits in combination with DORIS data

->Jason-2, Jason-3, SARAL, Cryosat-2, HY2A

(POD Centers (e.g.): GSFC, TU Delft, ESOC, GFZ, institutes in China**)**

Orbit Validation (on an ongoing basi**s):**

• Verify orbit performance by computing SLR residuals to orbits computed from other techniques (DORIS, GNSS).

->Jason-2, Jason-3, SARAL, Cryosat-2, HY2A, Sentinel-3A

(**POD Centers (e.g.): GSFC, CNES, Copernicus/Sentinel-3 POD Teams**)

Verify Radial Orbit Stability (<1 mm/yr):

• Driven by Requirement to determine Mean Sea Level on a regional basis with this accuracy.

–> Jason-2, Jason-3

SLR Data Applications for Altimeter Satellites (2)

Precise Orbit Determination:

➔ Data quality to compute orbits to better than 1 cm radial RMS accuracy

➔Sufficient global coverage on an-arc-by-arc basis to anchor the orbit to the geocenter in the ITRF; DORIS-only orbits (at present) have a weaker tie to the geocenter, and the orbit centering is subject to drifts when there are outages in the DORIS tracking network (see Zelensky et al. (2017, Adv. Space Res.)).

➔orbits must be anchored to geocenter to prevent spurious orbit drifts in "Z" which map directly into radial orbit drifts

(e.g. 1 mm/y "Z" drift maps to ~0.29 mm/y radial orbit drift, Morel & Willis (2005), Beckley et al., 2007))

SLR Data Applications for Altimeter Satellites (3a)

Orbit Validation (on an ongoing basis):
Good temporal and spatial Sampling from a global SLR network on a routine arc-by-arc basis.

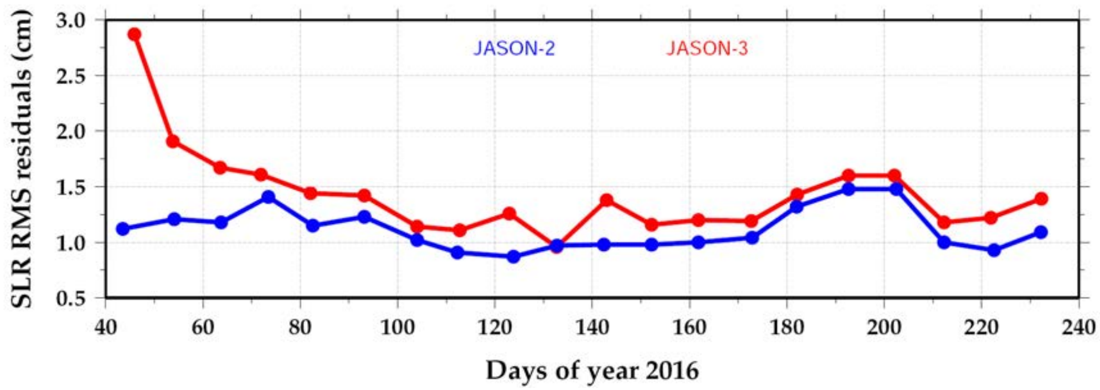
- **Given the precision of the radar altimeter data (~1cm), the SLR-derived orbits must be accurate at this level.**
- **For orbit validation, SLR data quality must of the highest accuracy (1 cm or better), because the orbit accuracy requirements for altimeter missions are generally 1-2 cm radial RMS.**

SLR Data Applications for Altimeter Satellites (3b)

Orbit Validation (Example):

SLR RMS of fit (Core stations, All elevations) for CNES GDR-E orbits (based on DORIS + GNSS, reduced-dynamic orbits)

(from Alexandre Couhert, CNES)



In these tests with DORIS & GPS data, Satellite Laser Ranging Measurements of Jason-2 are independent and directly measure orbit accuracy.

The fact that these orbits from different tracking systems agree at ~1cm radial RMS, is a reason why we can have such high confidence in the determination of Mean Sea Level change from satellite altimetry.

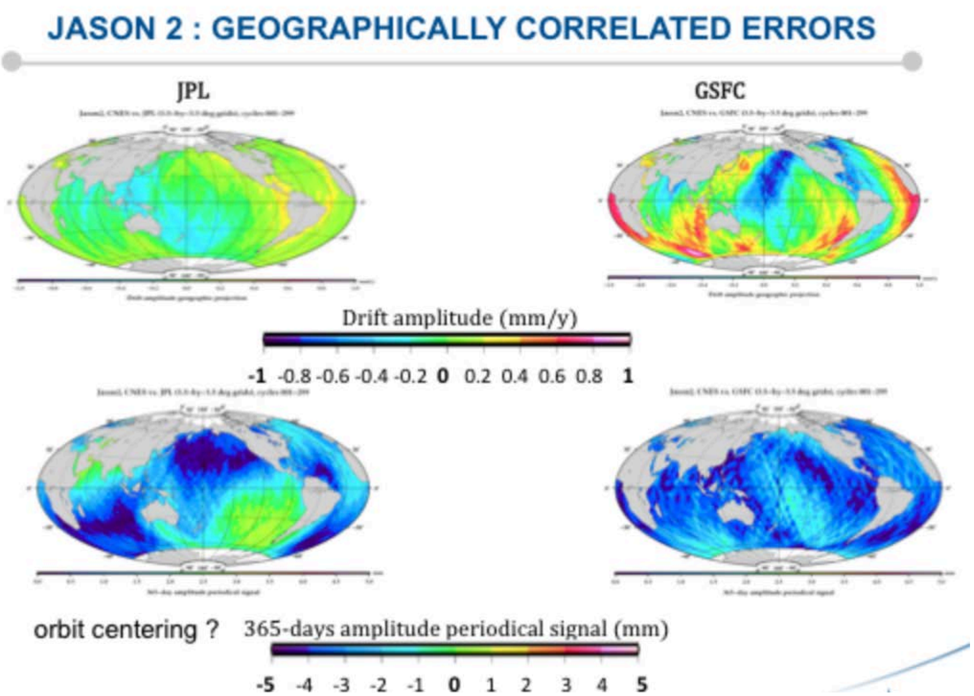
SLR Data Applications for Altimeter Satellites (4a)

Radial Orbit Stability :

This requirement is derived from desire to measure changes with precision in regional mean sea level to < 0.3 mm/y ; We must be able to detect drifts in orbits (determined by GNSS, DORIS).

Radial Orbit Stability: Observed Signals: Motivation:

In order to validate orbit quality, “we” (altimeter POD teams) systematically intercompare signals (drift, annual signals) in different types of orbits. See example below from Couhert et al. (2016, OSTST meeting) – intercomparing CNES orbits (GNSS, DORIS) vs JPL (GNSS-only, reduced dynamic), vs GSFC (SLR+DORIS-dynamic).



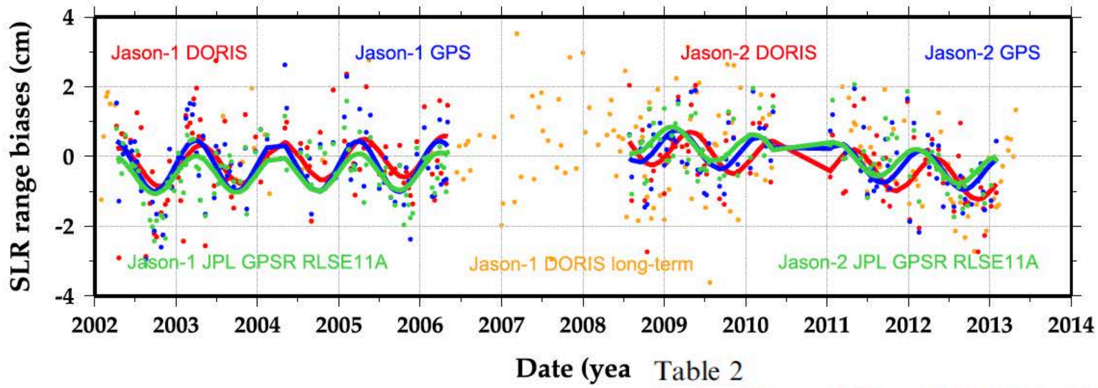
These orbit differences are caused by model differences, reference frame inconsistencies among analysis centers and techniques.

We want to be able to use SLR data (core stations) to monitor orbit drifts as a diagnostic tool of orbit quality - but SLR biases at mm level and how they change with time make this problematic.

SLR Data Applications for Altimeter Satellites (4c)

Radial Orbit Stability: Observed Signals: Some current results (Couhert et al., 2015):

Figure 5. Greenbelt (7105), Mean of Residuals > 70° elevation



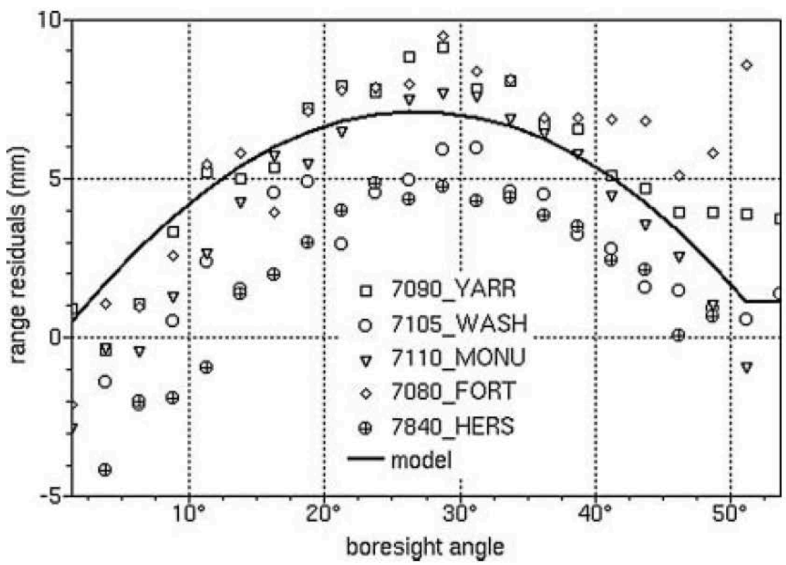
Differences include SLR target effects, biases in ranging system, unmodeled geophysical corrrections (e.g. hydrology, atmosphere loading). Still we would like SLR "biases" to be minimized and for systems to be stable as possible.

Table 2
Range biases, drifts and annual estimates of high-elevation mean SLR Greenbelt station residuals on independent Jason-1 and Jason-2 DORIS-only and GPS-based orbits.

Solution	Bias (mm)	Drift (mm/y)	Annual (mm)
Jason-1			
DORIS	-1.7 ± 1.2	0.9 ± 1.0	5.7 ± 2.4
GPS	-2.8 ± 1.1	-0.1 ± 0.8	7.3 ± 2.2
JPL	-4.9 ± 0.9	0.3 ± 0.7	5.3 ± 1.8
Jason-2			
DORIS	-1.9 ± 1.1	-2.5 ± 0.8	5.3 ± 2.3
GPS	-0.7 ± 1.0	-1.9 ± 0.7	5.0 ± 2.1
JPL	0.5 ± 0.9	-2.1 ± 0.6	4.4 ± 1.9
Jason-1 long-term			
DORIS	0.2 ± 0.8	-0.1 ± 0.2	5.2 ± 1.6

SLR – Current Challenges: Target Signature

Jason-1: SLR Residuals to GPS orbit vs. boresight angle



Cerri et al., 2010, Marine Geodesy (Figure 5)

SARAL: Arnold LRA model vs. mean correction & data distribution vs elevation

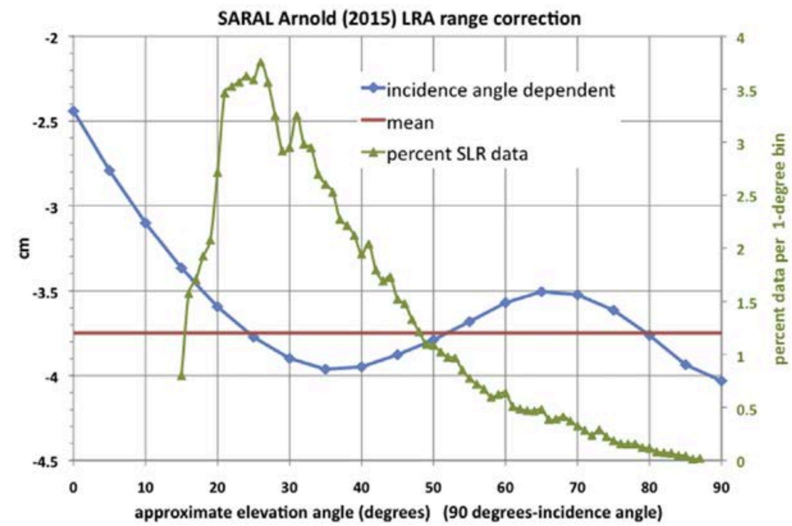


Fig. 3.2. Arnold LRA (2015) models and percent SLR data used in SARAL POD.

Zelensky et al., 2016, Adv. Space Res. (Figure 3.2)