The Synergy of Satellite Laser Ranging (SLR) and DORIS as Space Geodesy Techniques

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Global Geodetic Observing System

21ST INTERNATIONAL WORKSHOP ON LASER RANGING
5 – 9 NOVEMBER 2018
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DORIS (Overview)

- **DORIS: (Doppler Orbitography and Radiopositioning Integrated by Ranging).**
- CNES (*French Space Agency*) &
  IGN (*Institut Géographique National*)

Ground Network:

- **55-60 stations, around the world.**
- **Dual-frequency beacons: 401.25 MHz + 2.036 GHz.**

Satellite Constellation:

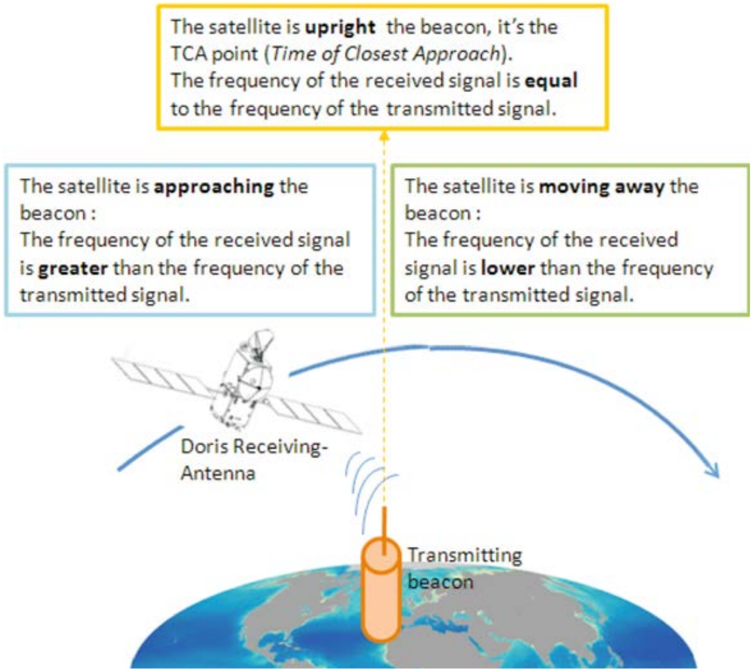
- **DORIS Receivers on LEO satellites.**

DORIS Data:

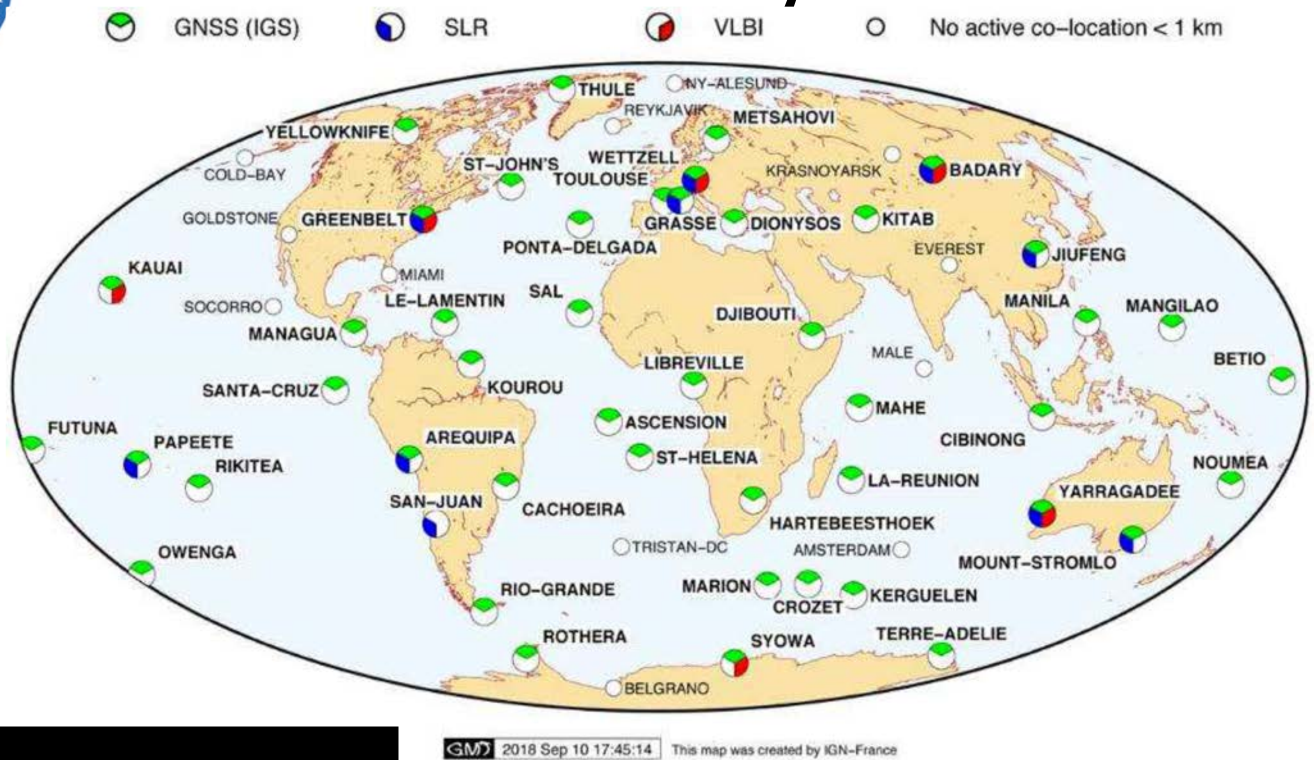
- **DORIS Doppler (**V2 format: historic**)**
- **DORIS/RINEX (**pseudorange and phase data**). All current & new DORIS satellites.**
- **Archived at NASA CDDIS & IGN Data Centers.**

Products & Contributions:

- **POD for LEO satellites – including Near-Real-Time (DIODE).**
- **Reference Frame (e.g., ITRF2008, ITRF2014).**
- **Ionosphere (NRT Working Group, Chair: Denise Dettmering, denise.dettmering@tum.de))**



DORIS Network: 25+ years of service



SLR/DORIS colocations	
Arequipa	12/1988
Badary	11/1991
Yarragadee	09/1992
Papeete	07/1995
Mt. Stromlo	10/1998
Greenbelt	06/2000
Jiufeng	12/2003
Grasse	08/2008
Wettzell	09/2016
San Juan	10/2018

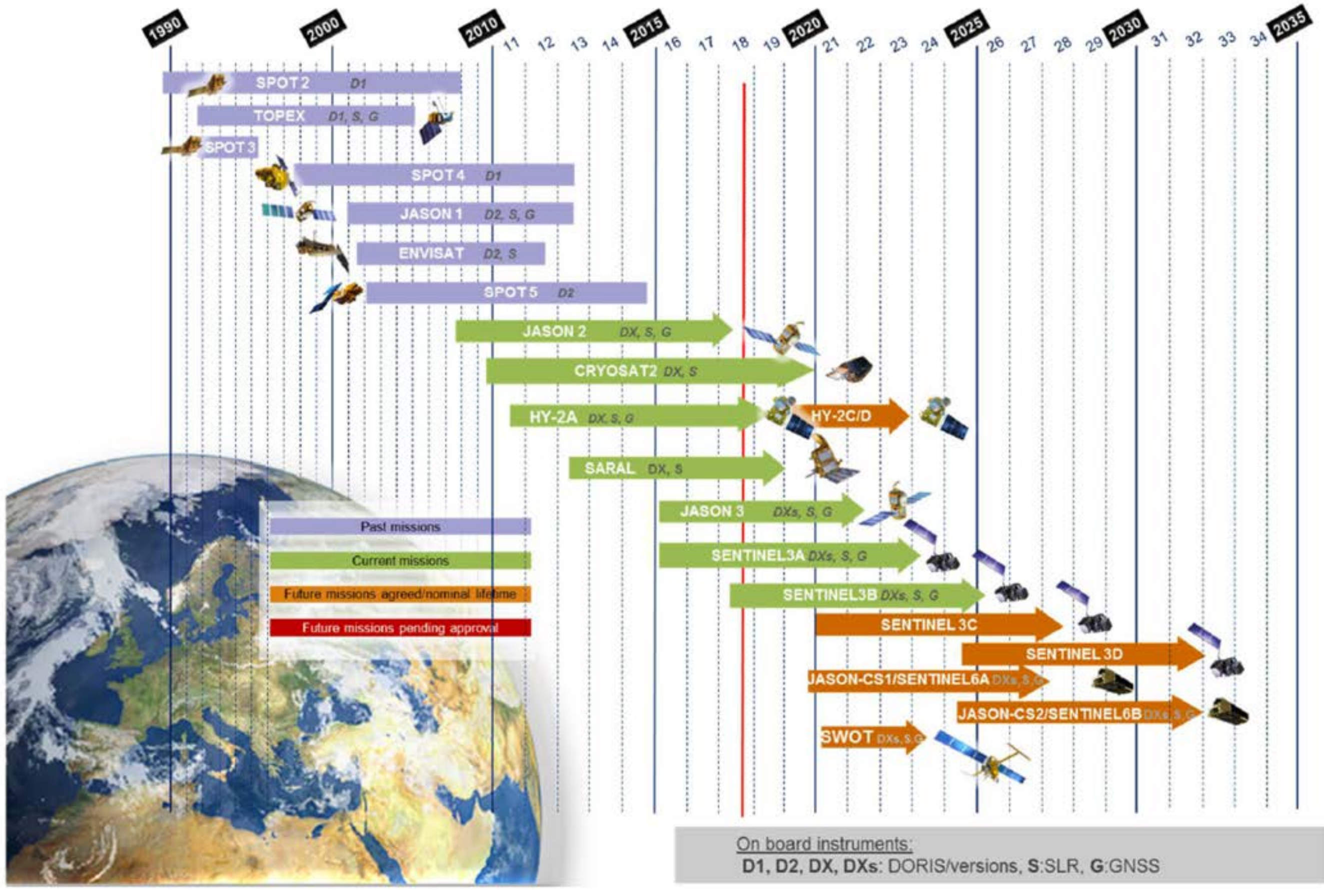
Today:
47 colocations out of 59 DORIS sites.

Colocations w. SLR: 10 sites.

- DORIS @ Hartebeesthoek since 03/1988.
  SLR & VLBI are ~2.1 km from the DORIS antenna.
- DORIS @ Metsahovi since 06/1988.
  (New) SLR & VLBI will be ~2.7 km from the DORIS antenna.

Future SLR/DORIS Colocations:
Changchun (China): awaiting approval.
Ny Alesund (Svalbard): ~2022.
Papenoo (Tahiti): Planning underway.

DORIS Satellite Constellation: 28 years on-orbit



SLR/DORIS: On-orbit colocations

Past Altimeter Satellite Missions:

TOPEX (1992-2005)

Jason-1 (2001-2013)

ENVISAT (2002-2012)

Only SLR/DORIS (no GNSS data):

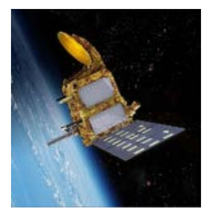
- **TOPEX (1994-2004).**
- **ENVISAT, CRYOSAT-2, SARAL.**
- **Jason-1 (after 2009).**

Current On-Orbit Ocean (& Cryosphere) Radar Altimeter Satellite Constellation:

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

CRYOSAT-2, 2010->

HY-2A, 2011->

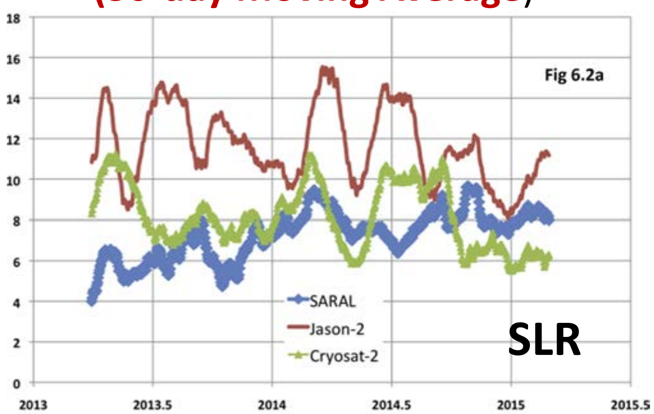


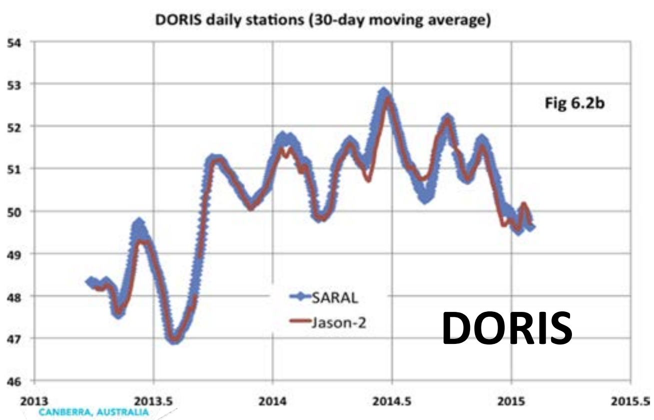
SARAL, 2013->

Sentinel-3A, 2016->
Sentinel-3B, 2018->

SLR/DORIS data jointly used for POD: (Jason-2)

Average Stations Tracking Per Day (30-day Moving Average)



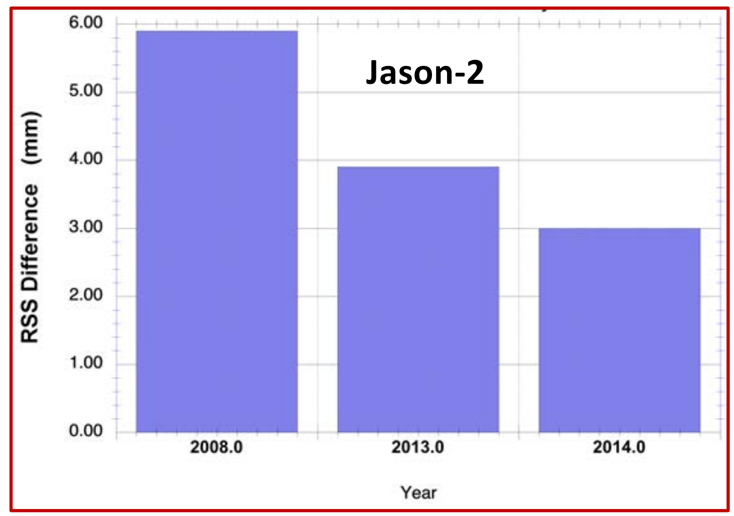


1. SLR Data Anchor the orbit to the TRF.
2. DORIS data have the geographic tracking coverage and data density to support a denser modeling parameterization for POD, which allows for superior orbit modelling.

(e.g. Increased estimation of OPR's, & For Lower altitude satellites Increased frequency of estimation for Cd, Coefficient of drag).

Results from:
Zelensky N et al.,
"Towards the 1-cm SARAL orbit",
Adv. Space Res. 58(12), 2651-2676, 2016,
doi:10.1016/j.asr.2015.12.011

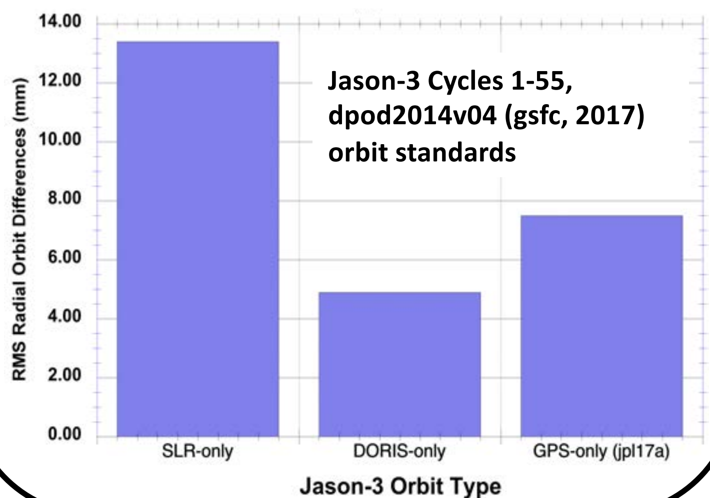
RSS Improvement (mm) of Altimeter Crossover Fits for SLR+DORIS orbits vs DORIS-only orbits.



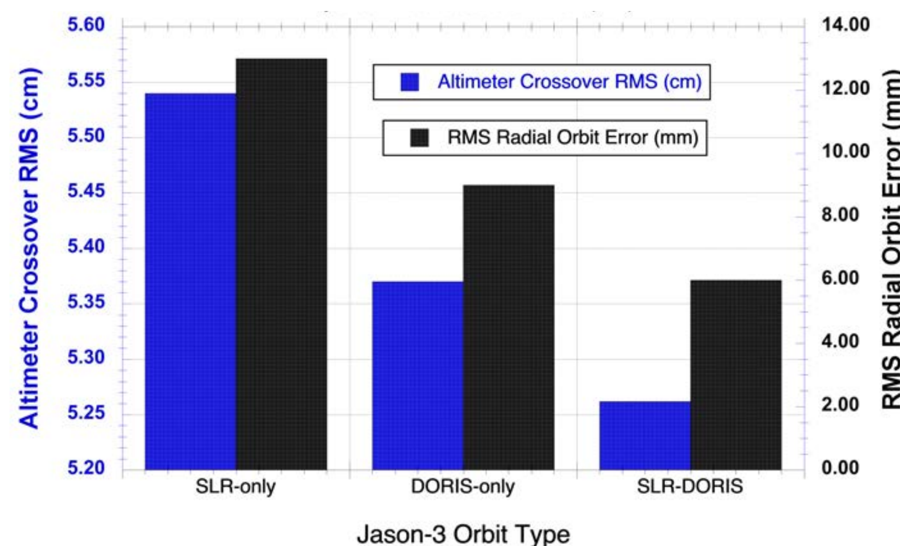
Lemoine, F. et al. "The Synergy of DORIS & SLR"

SLR/DORIS data jointly used for POD: (Jason-3)

Avg. RMS Radial Orbit Differences to Reference SLR/DORIS Orbit (2016.1 – 2017.6)



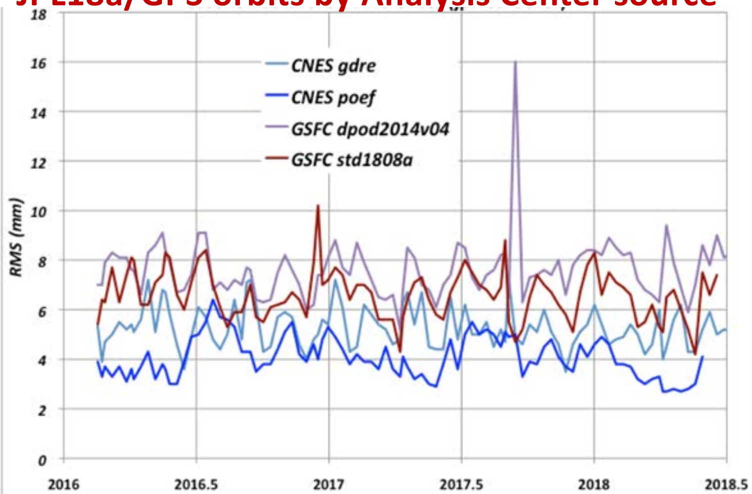
Jason-3 Altimeter Crossover Fits (cm), and Projected Radial Orbit Error (mm)



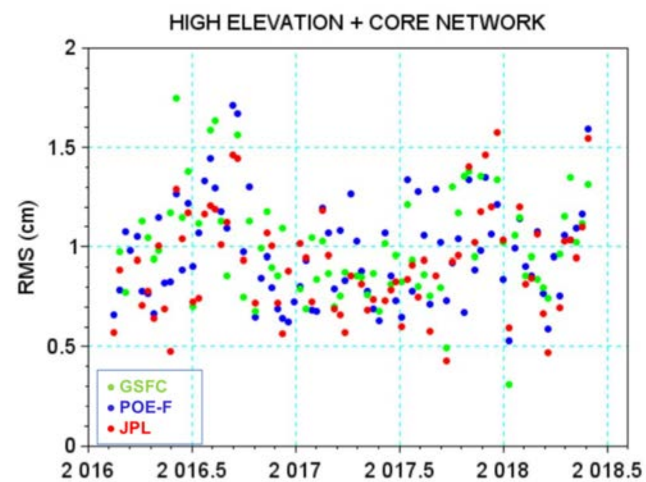
For Jason-3, SLR+DORIS orbits combine the best attributes of both tracking systems to produce lower projected radial orbit error and, lower independent altimeter crossover fits.

Verification of Orbit Quality for Reference Altimeter Missions: (TP, J1,J2,J3)

Jason-3 RMS Radial Orbit Differences (mm) vs. JPL18a/GPS orbits by Analysis Center source



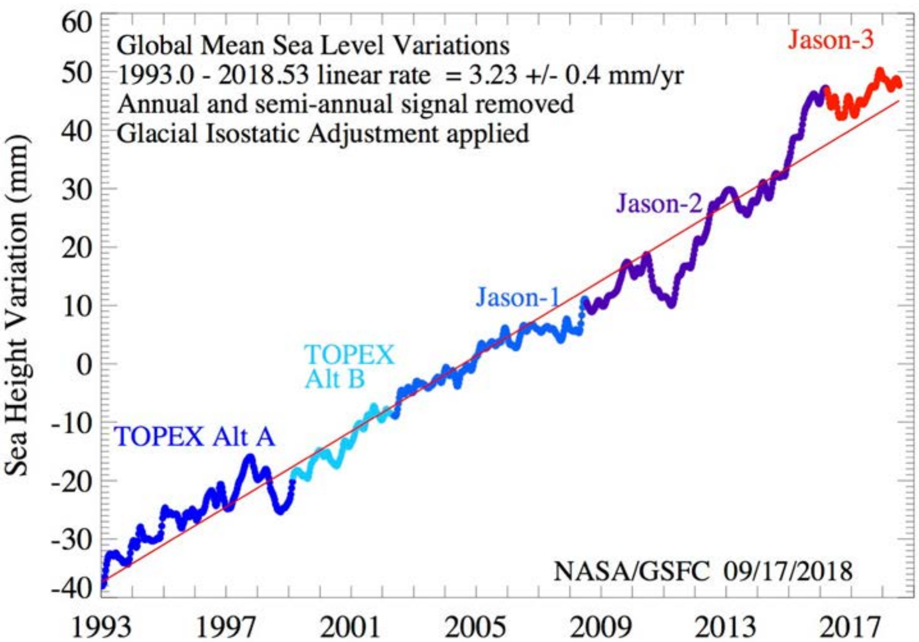
Jason-3 RMS High Elevation SLR fits (core network) for GPS orbits (CNES/POE-F, JPL), and SLR/DORIS)

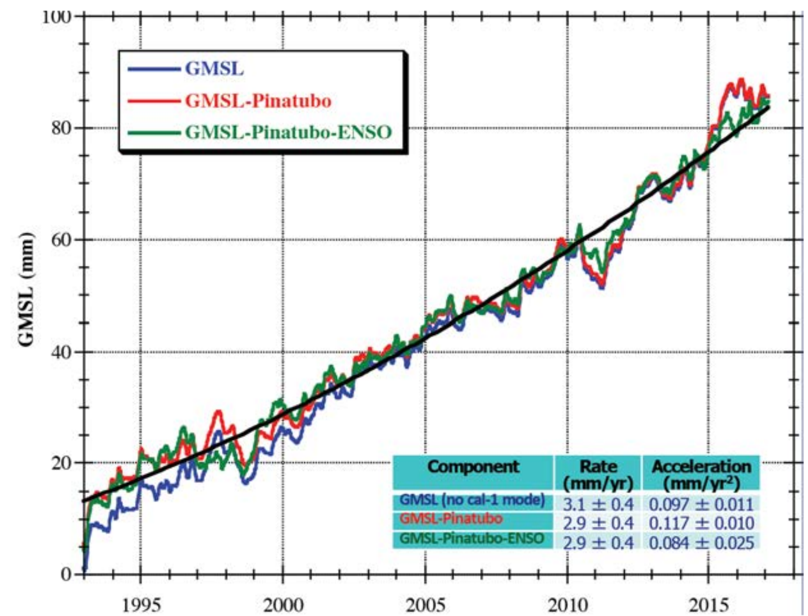


The intercomparison of SLR/DORIS-derived orbits (NASA GSFC), and independent GPS-derived orbits (JPL & CNES/POE-F) allow us to validate the radial orbit accuracy for missions such as Jason-2/Jason-3. This helps to guarantee the stability of the derived orbits for computation of sea surface height, and especially for the determination of Mean Sea Level.
For Jason-2 and Jason-3 we are confidant from this analysis that the RMS radial orbit accuracy is 8-10 mm.

SLR+DORIS Orbits Enable computation of the Global Mean Sea Level (GMSL) rate and its acceleration from sea surface height observations using 25+ years of ocean radar altimetry data

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

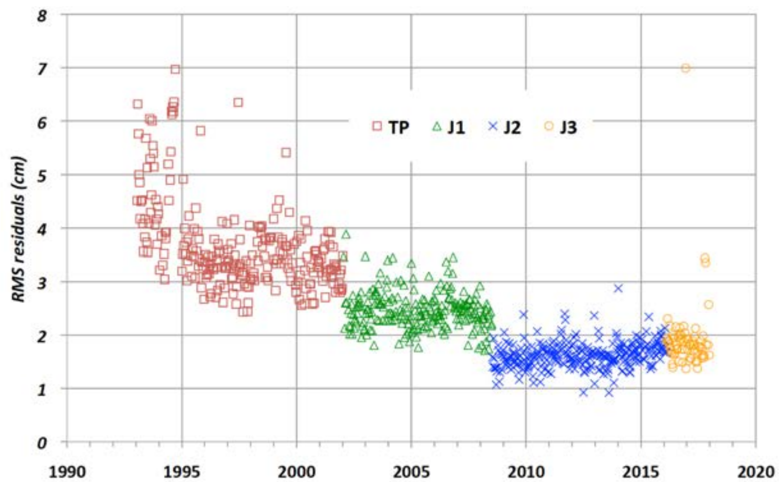




- **Nerem, R.S., et al. "Climate-change driven accelerated sea level rise detected in the altimeter era", PNAS, 2018, doi/10.1073/pnas.1717312115.**
- **Beckley, B.D. et al. "Monitoring Jason-3 Sea Surface Height Stability for Global and Regional Sea Level Estimates", Ocean Surface Topography Science Team (OSTST) Meeting, Ponta Delgada, Portugal, Sept. 2018.**

Independent SLR data & DORIS POD System improvement

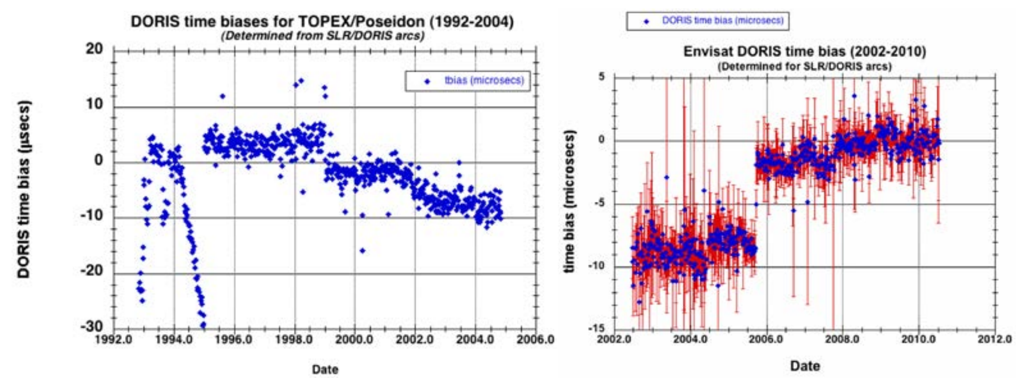
Independent SLR data Illuminates Improvement In DORIS-only POD performance over time



(DORIS system time biases w.r.t SLR not applied)

The SLR data illuminate improvements in the DORIS system:
~ June 2002: **Expansion of DORIS satellite constellation, & Availability of two-channel DORIS receivers.**
2008: **Launch of first satellite with an seven-channel DORIS Receiver (Jason-2)**
(from Nikita Zelensky, NASA GSFC & SGT Inc., 2018)

SLR data allows estimation of DORIS-system time biases wr.t. to SLR network "time system" for TOPEX (left), and Envisat (right)



Early in the TOPEX mission it was realized that a time bias had to be estimated for DORIS data to bring th DORIS and SLR time systems and data into alignment. On more recent missions the time biases are still estimated per arc but are typically of the order of 1-2 μsec (compared to 10-20 μsecs during some parts of the Envisat and TOPEX missions).

****** WITHOUT EXTERNAL (e.g. SLR) DATA IT WOULD BE IMPOSSIBLE TO ESTIMATE THIS DORIS SYSTEM TIME BIAS.**

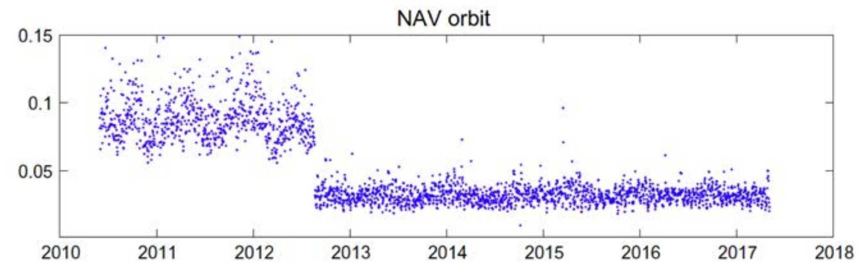
SLR data Assesses quality of DIODE (DORIS-Real-time) orbits.

DORIS Immediate Orbit Determination System. (DIODE).

- **On-orbit Kalman filter that processes DORIS dta in real-time to produce a real-time DORIS orbit.**
- **This real-time orbit is used by the altimeter processor to decide on the altimeter operating mode as it flies over land, oceans, or ice-covered regions.**

- **The DORIS/DIODE orbits are distributed on the OGDR's (within < 3 hrs) for Jason-2, Jason-3 and other altimeter missions, and feed into operational ocean analyses.**

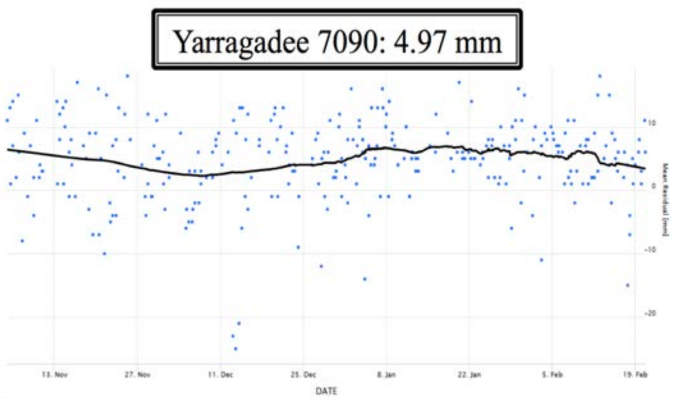
Radial Orbit Differences (cm)
between the DORIS/DIODE (real-time) orbit
and the post-processed SLR/DORIS Orbit for CRYOSAT-2

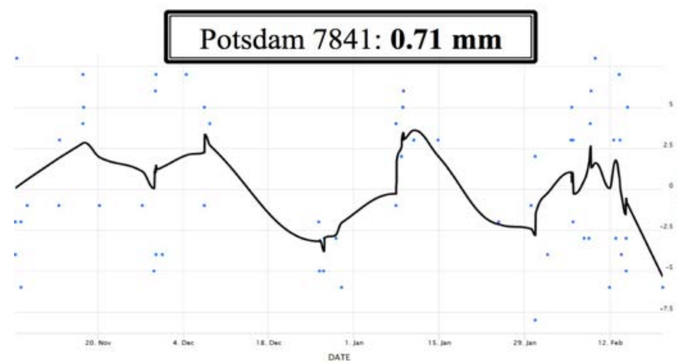


Cryosat-2 DIODE radial orbit differences with TU Delft (SLR+DORIS) *a posteriori* **orbit.**
The radial RMS orbit differences after mid-2012 ***(date of a software change on the DIODE receiver)*** **are 3.57 cm.**
(Schrama, EJO, "Precision orbit determination for CryoSat-2", Adv Space Res., 61, 235-247, 2018, doi: 10.1016/j.asr.2017.11.00)

SLR Station Range Biases Monitoring Using GNSS+DORIS Orbits from Jason-2

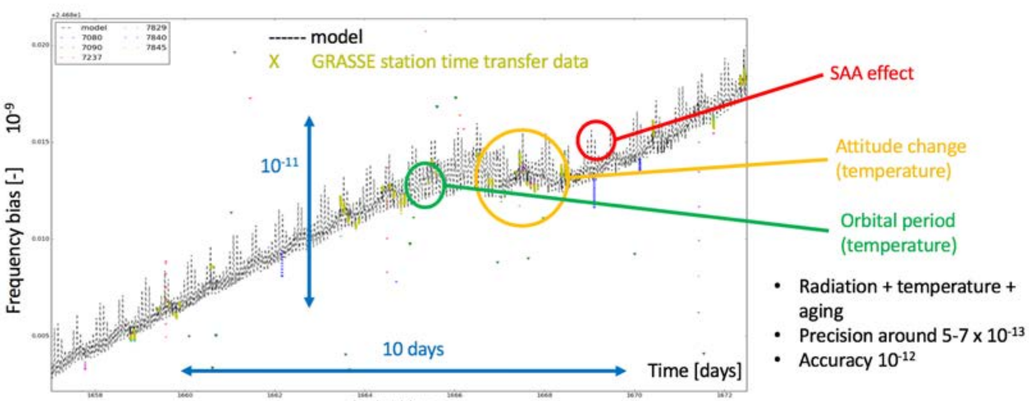
- *Independent* validation of long-term SLR station biases can be obtained from looking at SLR residuals w.r.t. DORIS+GNSS-based orbits for Jason-2.
- CNES releases reports of these SLR residuals to the ILRS QCB (since April 2017): Available at: ftp://cddis.gsfc.nasa.gov/pub/reports/slrcnes/jason2
- The available biases can be explored at the Station Performance Tool, Available at geodesy.jcet.umbc.edu/QC.

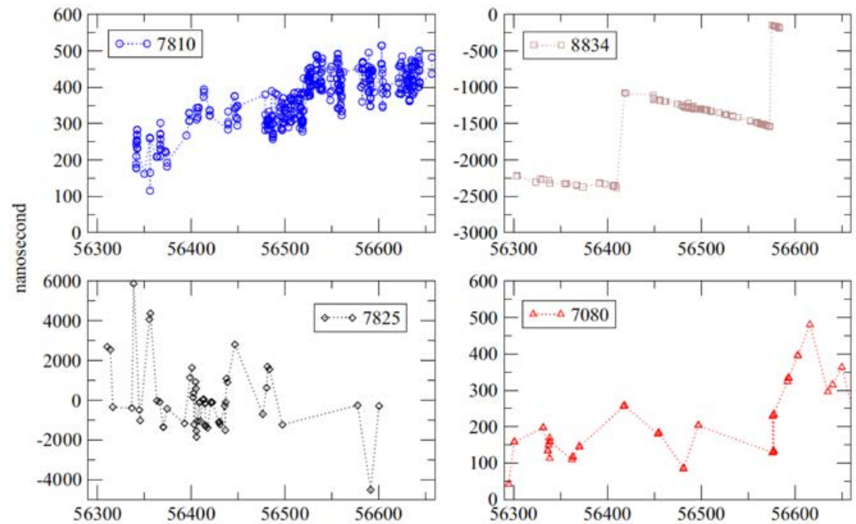




(Alexandre Couhert/CNES)

Through Jason2/T2L2, a path to reduce systematic error for both the SLR & DORIS techniques





Data from Jason-2/T2L2 reveal the behavior of the DORIS USO, and unmodeled effects on the DORIS/USO frequency, e.g. due to passage through the South Atlantic Anomaly (SAA), attitude changes, and USO temperature changes.
Belli, A. et al., Adv. Space Res., 58, 2589-2600, 2016,
doi: 10.1016/j.asr.2015.11.025.

Clockwise from Upper Left.
Time biases for SLR stations relative to Grasse, for Zimmerwald (7810), Wettzell (8834), Yarragadee (7090), and Mt Stromlo (7825) from Exertier et al. (2017). Units are ns.
Exe*rtier et al.,* "Time biases in laser ranging observations: A concerning issue of Space Geodesy", Adv. Space Res., 60, 948-968, 2017,
doi: 10.1016/j.asr.2017.05.016.

Summary

1. Eleven SLR & DORIS stations are collocated provided important ties to the ITRF. Up to four more stations in the near future. The DORIS community favors SLR colocations when feasible because of the stability, and reliability of the site and the intrinsic understanding of geodetic requirements.
2. Right now (Nov. 2018), Seven LEO satellites (altimeter missions) include both geodetic techniques (SLR & DORIS). On-orbit, the two data types complement each other for POD. The combination provides superior performance to each technique individually, as measured by altimeter crossovers.
3. SLR and DORIS data are used on the reference missions for altimetry (TP, J1, J2, J3) to measure the global mean sea level (GMSL) rate and its acceleration. They provide a vital validation and verification of radial orbit accuracy and stability (8-10 mm).
4. SLR & DORIS data can individually and jointly be used to study geophysical parameters other than the reference frame (e.g. time-variable low degree gravity field, geocenter).