DORIS-Derived Geocenter Motion for Precise Orbit Determination of Altimetry Satellites

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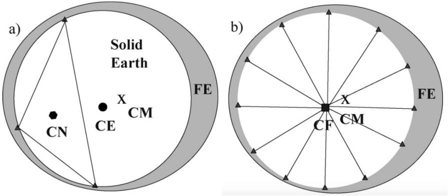
Background

GEOCENTER MOTION DEFINITION

- Motion of the center-of-mass (CM) of the whole Earth w.r.t. the center-of-figure (CF) of the solid Earth surface (Ray 1999)
- Deviation of motion between CF and the center of network (CN) contributing to apparent geocenter motion have been termed network effect (Tregoning and van Dam 2005)
  ⇒ Complicates a direct comparison of the different tracking techniques

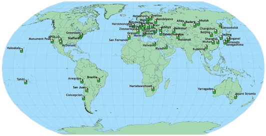


- ITRF origin approximately located at a point with a fixed offset from CF with no motion between them (Wu et al. 2002)

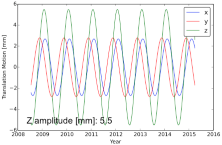
WHY DETERMINING NON-TIDAL GEOCENTER FROM DORIS ?

- Current non-tidal (seasonal) geocenter displacement estimates are uncertain (small amplitude, background models not robust enough, affected by noise/systematic effects in measurements)
- Use of annual geocenter models may not be sufficiently precise for accurate determination of mean sea level (MSL) rise

SLR network



RIES SLR model



DORIS network

- SLR is considered the best technique to sense geocenter but operational stations are sparse and poorly distributed (limited to night-time/cloudless weather observations)

  ⇒ Need independently determined geocenter time series

Approach

METHODS

- Dynamic approach (degree-one coefficients of the geopotential)
- Kinematic or network shift approach (translation parameters in fixed or fiducial-free networks, respectively)
- Degree-one deformation approach (degree-one mass load coefficients, thus not sensitive to geocenter offset and drift)

- The geocenter translation is estimated here simultaneously with the orbit, force and measurement parameters from DORIS data
  - Jason-2 GDR-E DORIS-only solutions (1/10-day orbit arcs)
  - 2008.5 – 2016.5

Mitigation Strategies

- Station height inaccuracy
- Making the most of low-elevation DORIS data
  - Data down to as low elevation angles as possible (e.g. 5°)
  - Estimation of tropospheric horizontal gradients
  - Use of an elevation-dependent weighting of the observations
- Draconitic effects
- Problem of lumped harmonics
- ITRF/DPOD residual errors (fiducial-free network)
- Dynamic vs reduced-dynamic solutions

STATION HEIGHT INACURACY

> Height will always be less accurate than horizontal positions
>
> Rothacher

- Error sources affecting the station height estimation
  - Non-tidal (atmospheric, hydrological) loading models
  - Correlation with troposphere zenith delay parameters
  - Multipath
  - DORIS USO frequency drift
  - Observation limited above the horizon
  - ...
- If not taken into account, the troposphere zenith delay estimates will absorb most of these errors
  $\Rightarrow$ Aliased while estimating geocenter motion

Station Height Correction

Solution	Bias [mm]	Drift [mm/y]	Ann. [mm] (Ph. [doy])
Heights fixed			
X	0.9	-0.4	$0.5(20)$
Y	7.2	0.3	$5.5(361)$
Z	-7.5	-3.5	$13.2(40)$
Heights est.			
X	5.3	-0.3	$0.8(303)$
Y	3.0	0.5	$5.8(362)$
Z	-10.3	1.7	$4.9(31)$

Low-Elevation Data

- Advantage
  - Get a better decorrelation of height and troposphere parameters
- Drawback
  - Accurate mapping functions have to be used (GPT/GMF and VMF1 provide comparable geocenter motion estimates)
  - Noise level and systematic effects (multipath, azimuthal asymmetries of the tropospheric delay) are more pronounced
    $\Rightarrow$ Hence the elevation-dependent weighting and estimation of troposphere gradients

Solution	Bias [mm]	Drift [mm/y]	Ann. [mm] (Ph. [doy])
$> 10°$			
X	3.0	-0.4	$1.2(287)$
Y	2.4	-0.1	$6.3(362)$
Z	-12.4	2.2	$0.9(358)$
$> 5°$			
X	5.3	-0.3	$0.8(303)$
Y	3.0	0.5	$5.8(362)$
Z	-10.3	1.7	$4.9(31)$

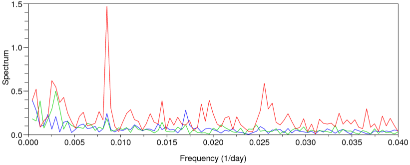
Draconitic Effects

- Cross-track bias modeling errors (SRP, phase center offset, ...) should be minimized to prevent draconitic signal from modulating the annual signal of geocenter motion along the Z axis (mainly cross-track observability)

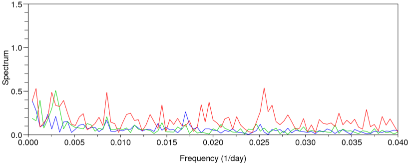
$$Z = \frac{C_{N_0} r^3}{GM \cos i} \tag{1}$$

SOLAR RADIATION PRESSURE MODEL TUNING

$C_r = 1.00$



$C_r = 1.04$



Solution	Bias [mm]	Drift [mm/y]	Ann. [mm] (Ph. [doy])
$C_r = 1.00$			
X	5.3	-0.3	$0.9(298)$
Y	3.1	0.5	$5.7(364)$
Z	-10.3	1.7	$7.1(25)$
$C_r = 1.04$			
X	5.3	-0.3	$0.8(303)$
Y	3.0	0.5	$5.8(362)$
Z	-10.3	1.7	$4.9(31)$

Problem of Lumped Harmonics

- Estimating the geocenter coordinates ($X = C_{1,1}$, $Y = S_{1,1}$, $Z = C_{1,0}$) is in fact the estimation of *lumped* harmonics
  - Residual errors in higher odd-degree order-0 and order-1 terms ($C_{3,1}$, $S_{3,1}$, $C_{3,0}$, $C_{5,1}$, $S_{5,1}$, $C_{5,0}$, ...) of the mean gravity field model may reflect in the recovered geocenter time series
  - *Caveats* should be associated with the phase estimates (lack of data in GRACE time series)

Solution	Bias [mm]	Drift [mm/y]	Ann. [mm] (Ph. [doy])
CSR RL05			
X	6.7	0.6	$1.2(10)$
Y	4.1	-0.6	$3.4(2)$
Z	-10.0	2.0	$6.5(62)$
GDR-E TVG			
X	5.3	-0.3	$0.5(6)$
Y	3.0	0.5	$5.5(22)$
Z	-10.7	2.0	$5.4(51)$

ITRF/DPOD Residual Errors

- Instead of directly estimating the geocenter motion and station heights, station displacements in the three directions can also be estimated for the entire DORIS network (completely free)

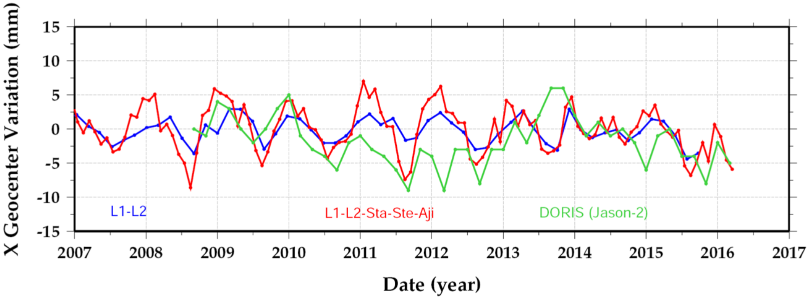
Solution	Bias [mm]	Drift [mm/y]	Ann. [mm] (Ph. [doy])
Fiducial-free			
X	-0.7	-0.3	$0.7(355)$
Y	7.8	0.3	$6.3(364)$
Z	-5.8	1.6	$6.1(25)$
Heights est.			
X	5.3	-0.3	$0.8(303)$
Y	3.0	0.5	$5.8(362)$
Z	-10.3	1.7	$4.9(31)$

DYNAMIC VS REDUCED-DYNAMIC SOLUTIONS

Solution	Bias [mm]	Drift [mm/y]	Ann. [mm] (Ph. [doy])
Dynamic			
X	-0.7	-0.3	$0.7(355)$
Y	7.8	0.3	$6.3(364)$
Z	-5.8	1.6	$6.1(25)$
Red. dyn.			
X	-1.7	-0.3	$0.8(70)$
Y	6.4	-0.1	$5.2(2)$
Z	-6.5	1.6	$5.7(30)$

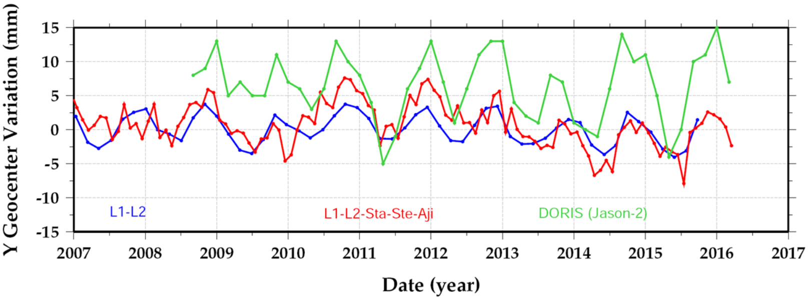
Comparison to SLR-Based Estimates

- 60-day DORIS-derived geocenter motion model to be used for POD of altimetry satellites
  - The geocenter motion model has to be consistent with the modeling that will be used for POD
  - Preferably dynamic solutions since network centering errors tend to affect only the Z component of the orbit (modulated by Earth rotation)
- The annual geocenter motion along the X axis has a particularly small amplitude ($< 1mm$, as in Haines et al. 2015)



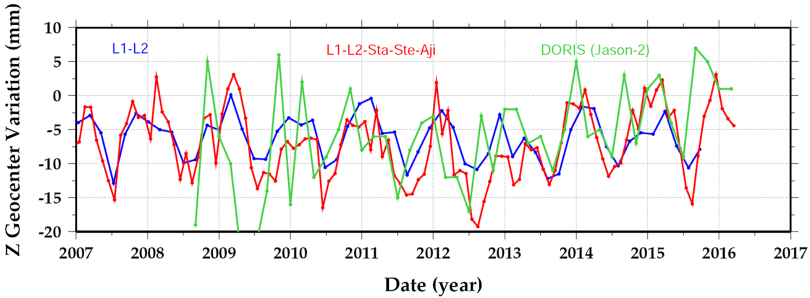
Comparison to SLR-Based Estimates

- Stronger annual signal along the Y axis (network effects ?)



Comparison to SLR-Based Estimates

- Good overall agreement in the North/South direction



Summary

CONCLUSION

- Jason satellites are <u>unique</u>
  - Inclination much below $90°$
  - Draconitic period not close to one solar year
  - No fixed attitude (yaw steering motion)

- Currently not possible to benefit from combining other satellites (most altimeter missions are sun-synchronous) with Jason-2/3 for DORIS-based geocenter motion estimates

$\Rightarrow$ The future consecutive launches of Jason-CS/Sentiel-6 and SWOT (inclination of $78°$, draconitic period of 78.5 days) will make possible this combination