ORBIT ACCURACY AT THE 12TH YEAR ANNIVERSARY OF CRYOSAT-2 MISSION

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Content

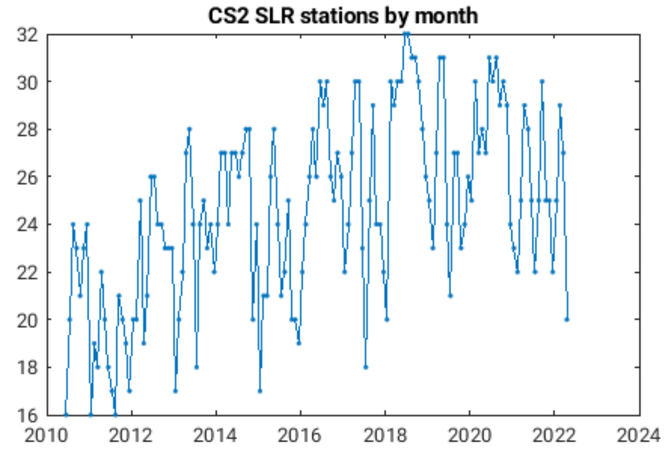
- Launched in April-2010, S/C still going strong after 12+ years
- Precise Orbit Determination for CryoSat-2
  - Tracking with DORIS and SLR
  - Reference models
  - Some parameters are estimated by us
- Problem statement / Motivation
  - GRACE to GRACE FO transition
  - Data gap in GRACE is from 23-5-2017 to 15–6-2018
  - GRACE-FO: 15-6-18 -> 19-7-18;   31-10-18 -> today
- Is the TVG transition between GRACE and GRACE-FO affecting POD?
- Is there an optimal strategy on combining GRACE and GRACE-FO?

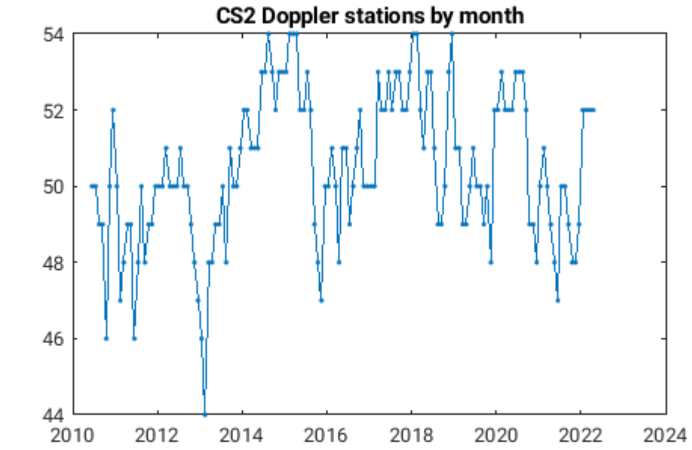
Orbit Determination of CryoSat-2

- Orbit determination is based mostly on Doppler tracking and somewhat on satellite laser ranging,
- Over the last 12 years there are 49 beacons/month, 24 SLR stations/month
- All tracking data from June 2010 to Sep-2022 all data is acquired.
- POD is done in arcs: average length is 6 days with a 12h overlap
- CS2 depends on realistic dynamic modelling:
  - DORIS tracking is not like GNSS tracking, there is less geographic coverage
  - SLR data is used to validate the POD process independently
- CS2 POD is a test case for evaluating GRACE to GRACE-FO TVG modelling

Statistics of Laser and Doppler tracking of CryoSat-2

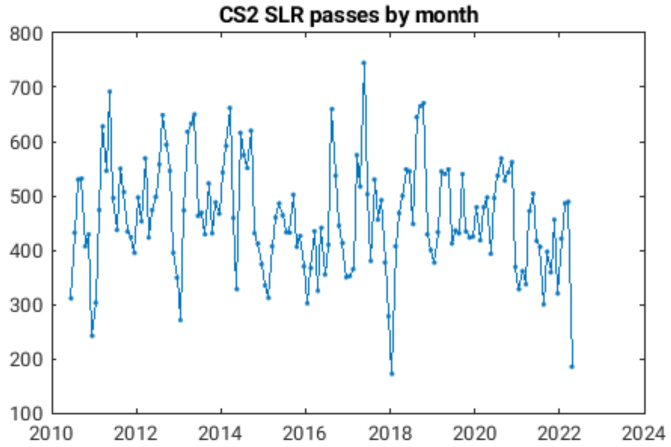
24 stations/month

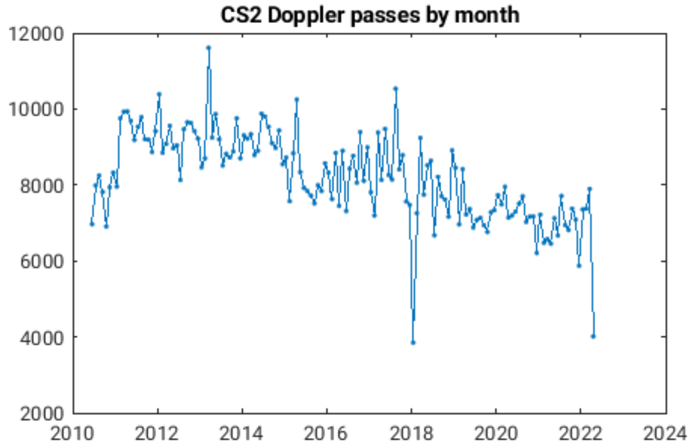




49 beacons/month

450 passes/month





8000 passes/month

Satellite attitude reconstruction

- Attitude and Orbit Control Sub-system (AOCS):
  - Three star cameras are available, normally 2 or 1 camera’s are used by the AOCS
- There are mode changes
  - We only want to produce orbits when it is not maneuvering
  - Nominal attitude mode: 4 degree yaw, 6 degree pitch up steering mode
  - In between orbit maneuvers the AOCS goes to an Earth pointing mode
  - Short and long orbit maneuvers, thruster geometry is relevant
  - Long orbit maneuvers come with a yaw flip
- Quaternion sets and status file
  - Since the start of the mission made available to IDS community
  - On 25/10: 4579 daily quaternion sets and 156 attitude events logged in a status file
  - Monthly updates via FTP server, documentation is on the IDS website
  - More extensive status file with satellite health information is available from ESA.

Modelling (1)

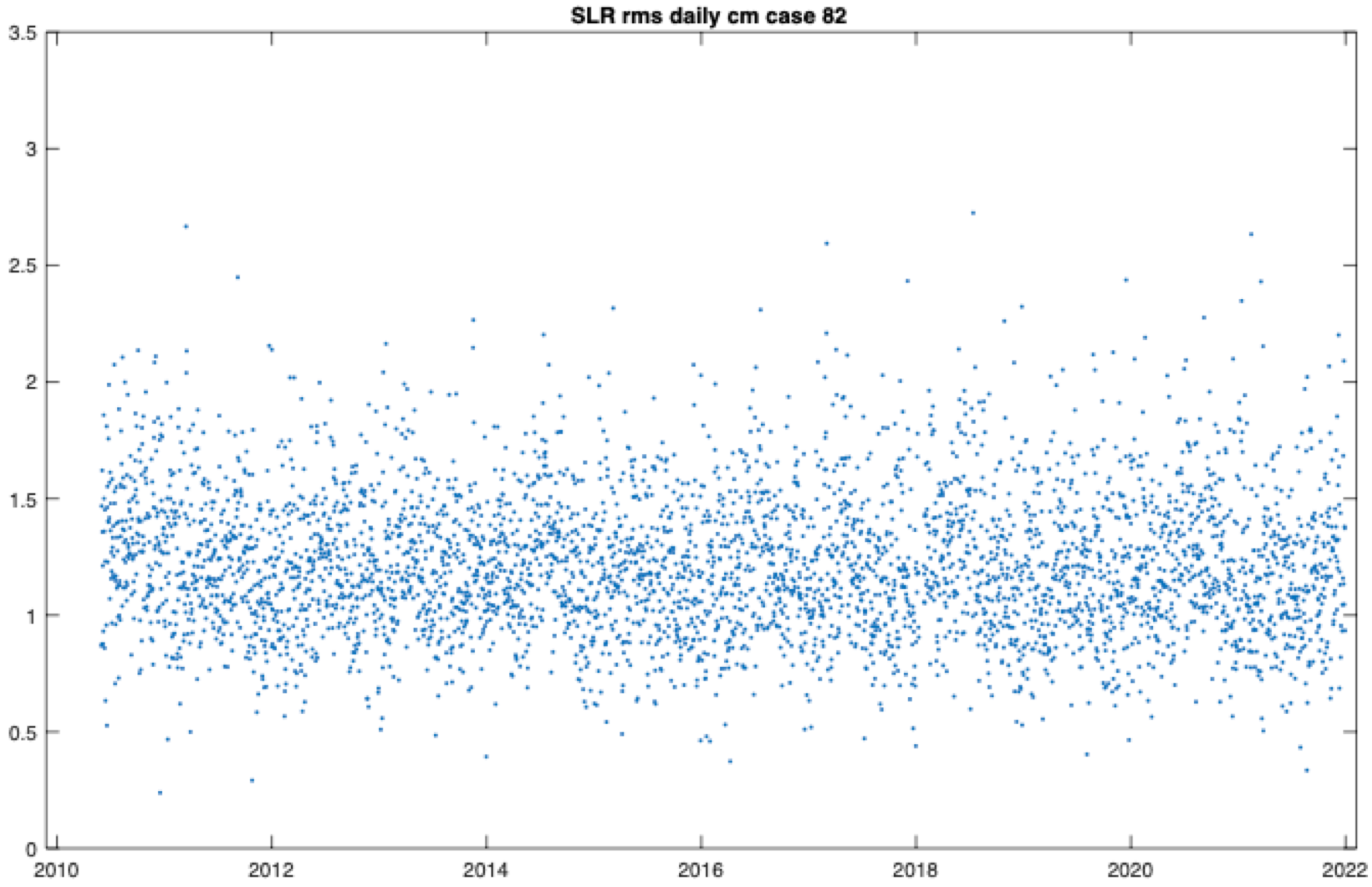
- DORIS beacon and SLR station coordinates come from ITRF2020p
- Chalmers ocean loading calculator based op FES2014
- Doppler beacon frequency offset estimated by pass
- Tropospheric zenith delay parameters estimated by pass
- Earth rotation parameters from IERS EOP 14 C04
- IAU recommendations for planetary constants and default models
- JPL planetary ephemeris DE/LE 403
- Initialization first state vector from DIODE navigator orbits

Modelling (2)

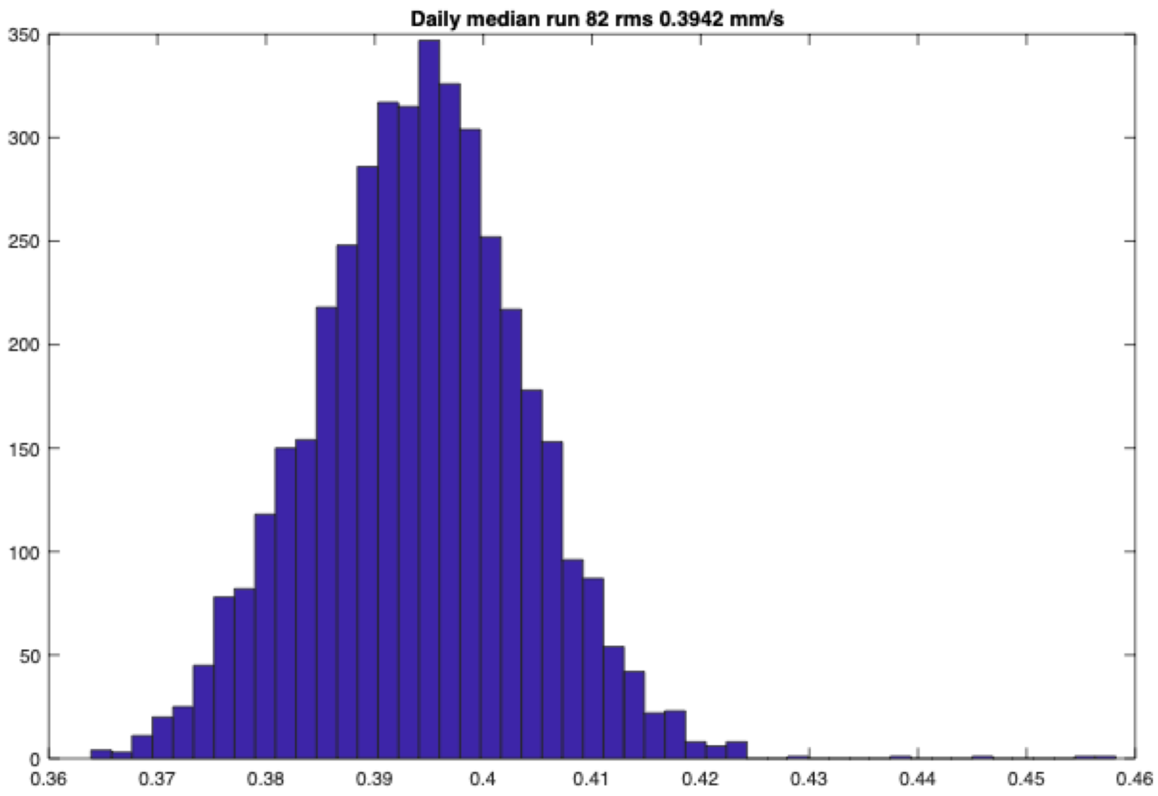
- Gravity model static: eigen5c
- Time variable gravity
  - Atmospheric and Oceanic : AOD1B average over an arc
  - Cryosphere and Hydrology part : derived from GRACE and GRACE-FO
- Solar radiation pressure modelling,
  - Scaling constant estimated once,
  - CNES model for specifying the panels
- Drag modelling, MSIS reference model, 3 hourly patches with constraints
- Ocean tides affecting the orbit: via FES 2004 model
- Empirical accelerations
  - along-track and cross-track: bias and once per revolution terms
  - 6 hourly piecewise modelling.

Daily mean Doppler residuals

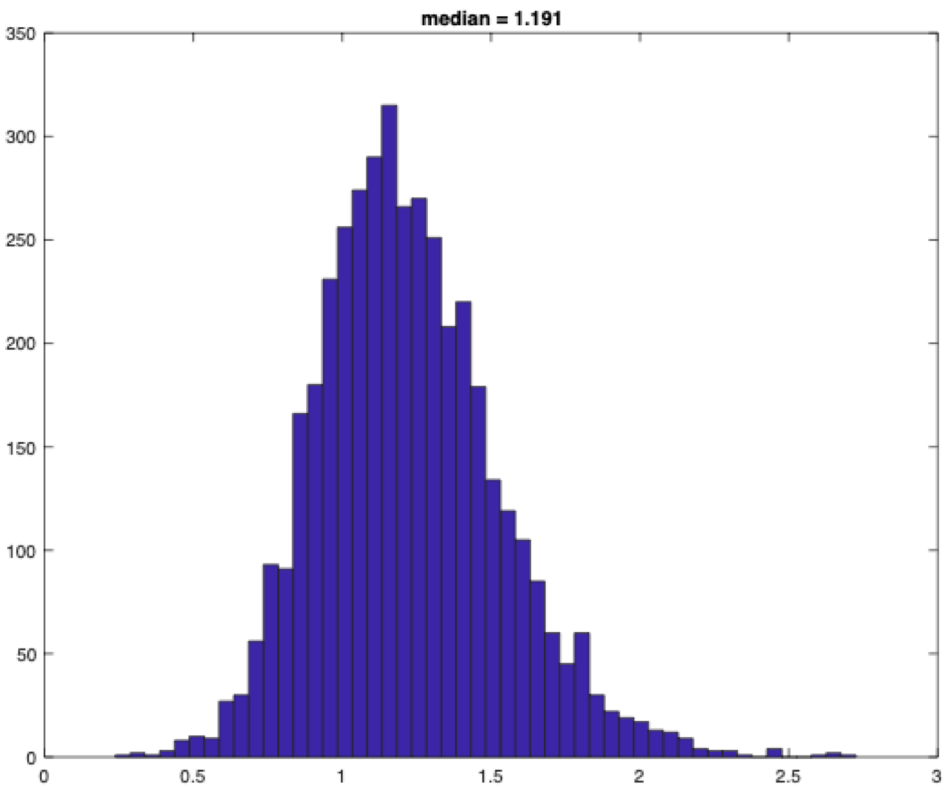
Daily mean laser residuals



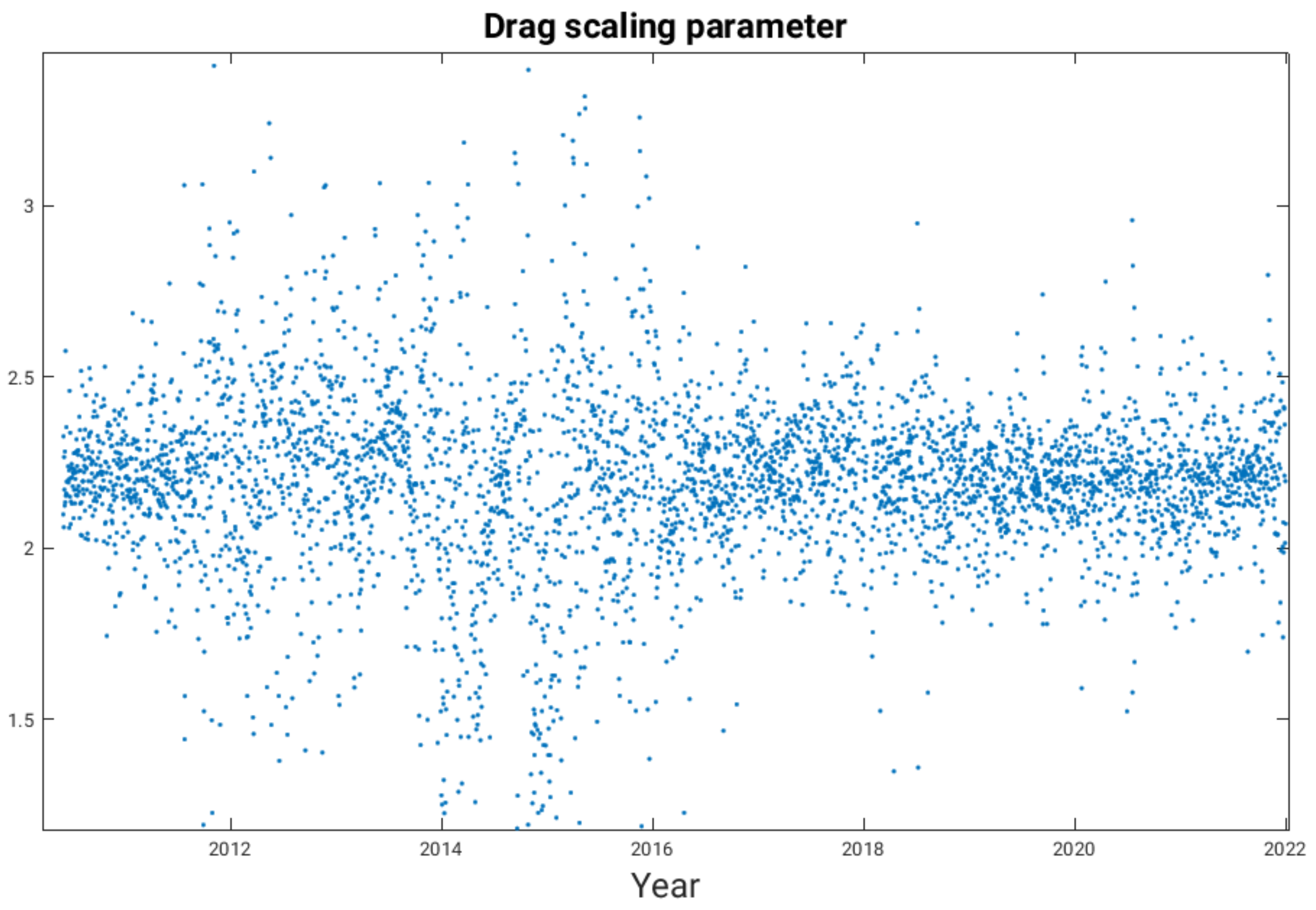
Tracking residual histograms



mm/s



cm



Drag scaling parameter
3
2.5
2
1.5
2012
2014
2016
2018
2020
2022
Year

Temporal gravity models used

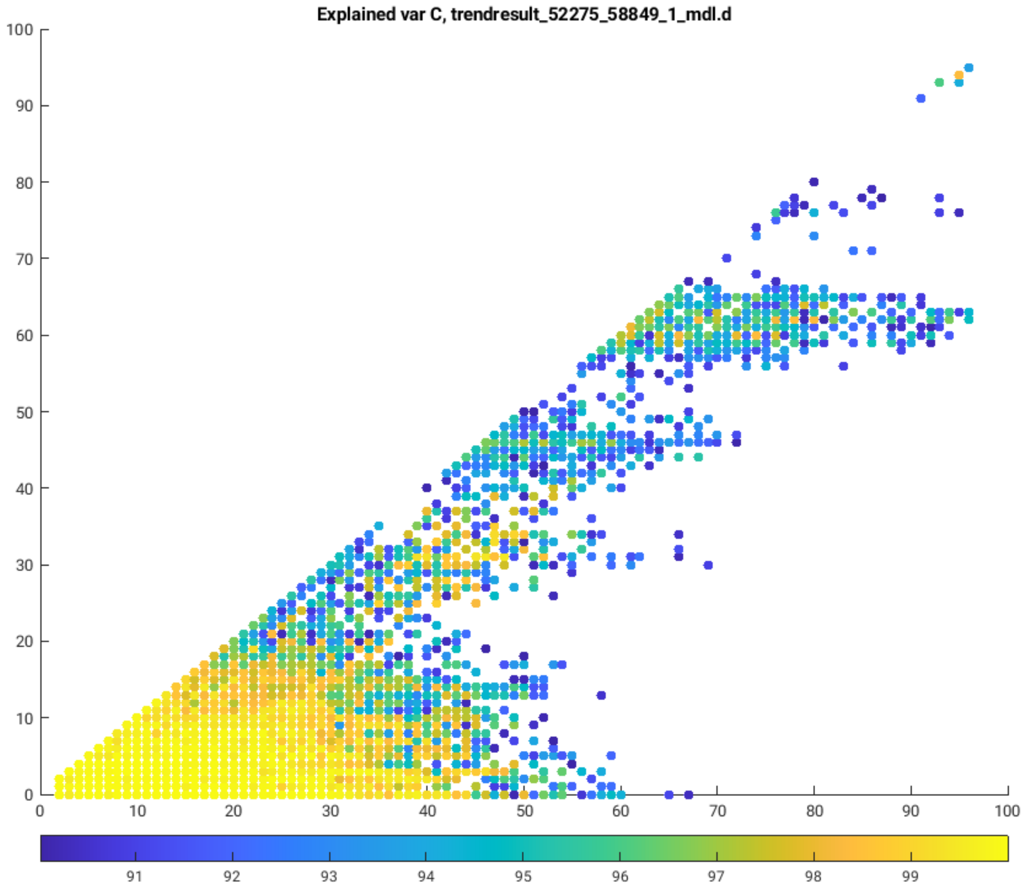
RUN	O+A	TVG	#NP	Dopper fit mm/s median	Laser fit cm median	Initialize new pass editor
81	AOD1B	02-22	14	0.3939	1.181	N
82	AOD1B	10-22	14	0.3941	1.191	N
83	AOD1B	02-17	11	0.3937	1.183	N
84	AOD1B	02-22	11	0.3938	1.182	N
85	AOD1B	10-22	11	0.3988	1.191	N
86	AOD1B			0.3940	1.165	Y
87				0.3943	1.176	N

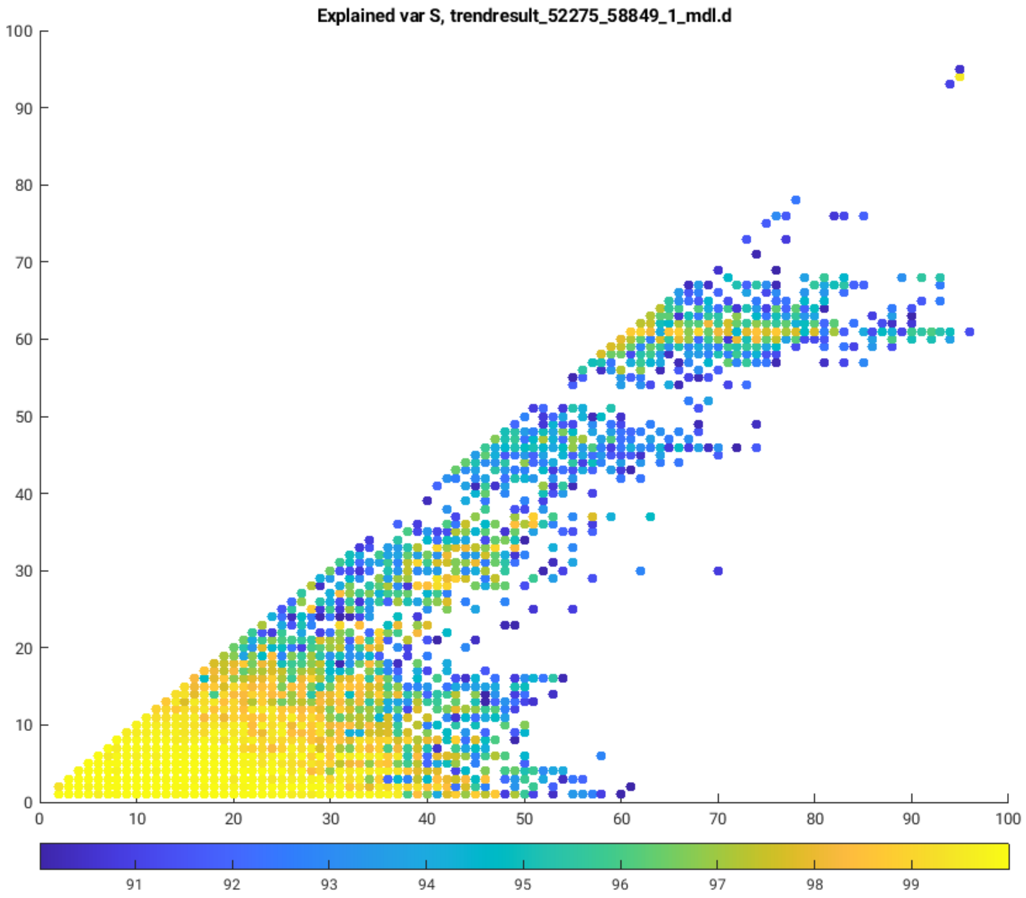
As far as tracking residuals are concerned we do not see significant differences

Differences TVG model strategy

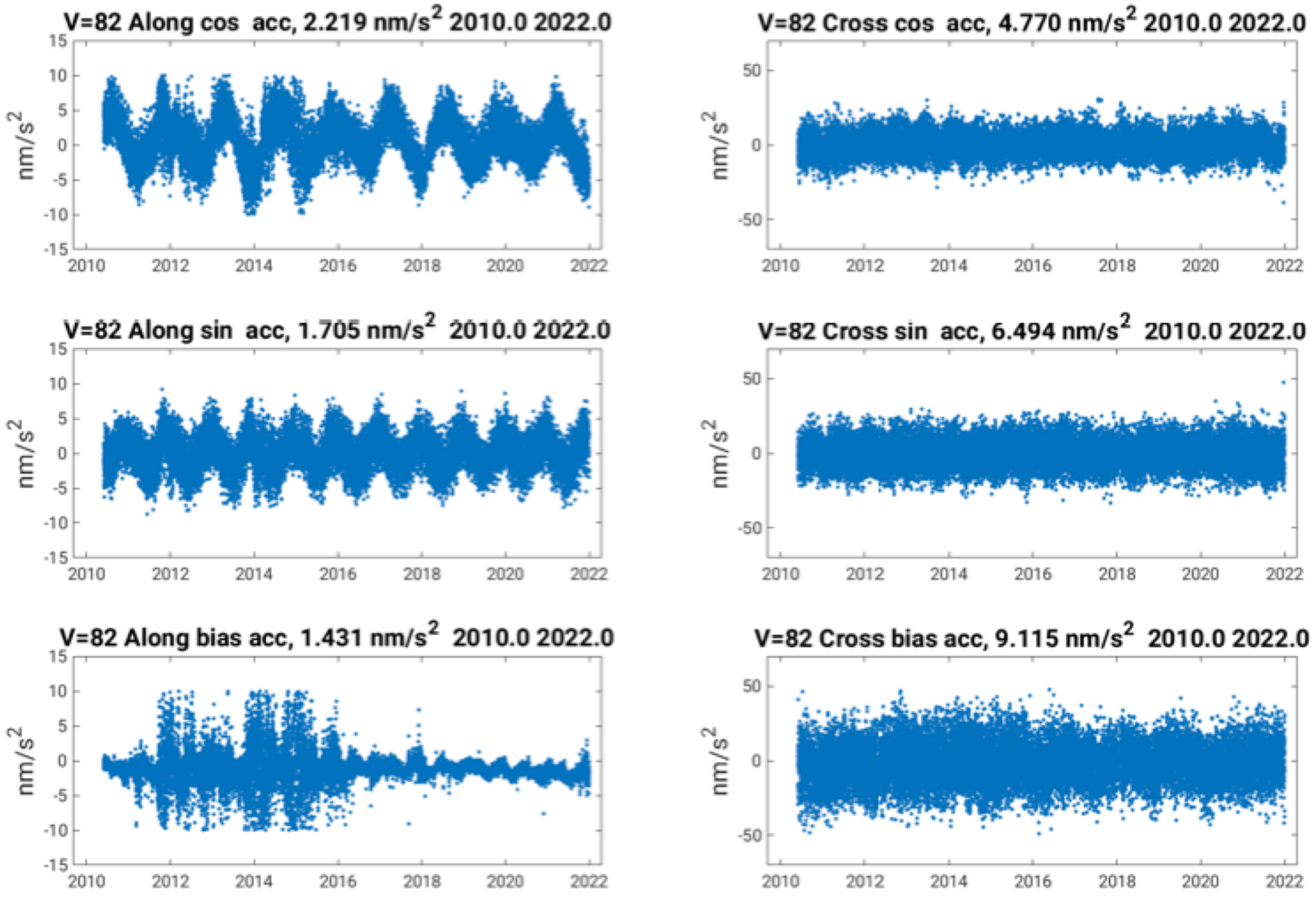
- In our 2017 paper all TVG SH potential coefficients were approximated with a trend/annual semi-annual model
- New approach is to only select those TVG SH terms where the explained variance of the model is greater than 99%
- Most of the TVG information is contained up to degree and order 36 with some resonant bands at higher degree

Variance explained example (window 2002-2019)





Empirical accelerations for run #82

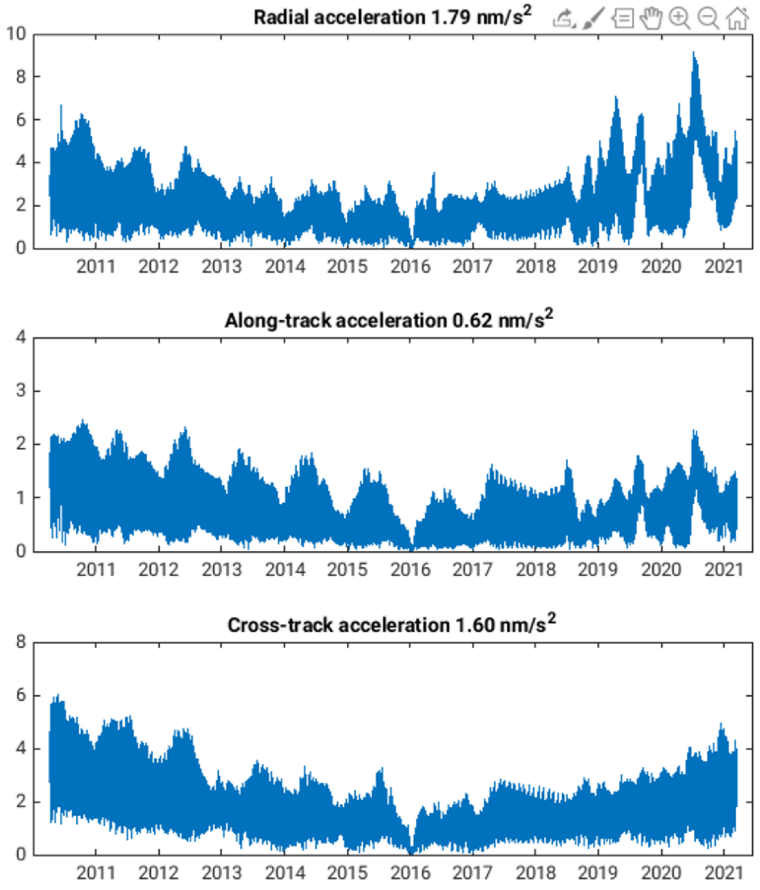


Empirical accelerations

ID	A cos	A sin	A bias	C cos	C sin	C bias	Tot Var	A wrt86	C wrt86	TVG	AOD1B	cmnt
81	2,146	1,696	1,433	4,859	6,735	9,192	163,0	0,9238	6,1070	02-22 14	Yes	
82	2,219	1,705	1,431	4,770	6,494	9,115	157,9	0,7140	6,5384	10-22 14	Yes	Best
83	2,292	1,684	1,431	4,871	6,472	9,117	158,9	0,5017	6,4827	02-17 11	Yes	
84	2,251	1,708	1,433	4,871	6,839	9,207	165,3	0,5923	5,9574	02-22 11	Yes	
85	2,262	1,702	1,432	4,964	7,444	9,183	174,4	0,5696	5,1358	10-22 11	Yes	
86	2,505	1,454	1,414	4,660	8,854	9,521	201,1				Yes	
87	2,481	1,454	1,418	4,697	9,157	9,563	207,6					Worst
								0,6603	6,0443			Average

All accelerations in nm/s^2

What do we expect at CS2 altitude from TVG (Hydrology and Cryosphere only)



- We simulated what one could see at altitude relative to a month in the center of CS2 window
- Calculate the effect in three directions, and subject it to a piecewise presentation
- We only parameterize two directions: 0.62 nm/s^2 and 1.60 nm/s^2 are expected

Conclusions

- POD depends on TVG, bridge the GRACE to GRACE-FO transition gap
- Ocean[1]/Atmosphere is a separate activity: AOD1B availability
- Cryosphere/Hydrology/Ocean[2] effect comes from GRACE/GRACE-FO,
- Ocean[1] : barotropic ocean effect at periods < 30 days,
- Ocean[2] : barotropic ocean effect at periods > 30 days
- Differences between TVG model #83 and others suggest that we can easily bridge the transition period,
- Number of parameters in TVG model seems less important
- GRACE and GRACE-FO are compatible for TVG modelling within POD
- Empirical accelerations reduce in case AOD1B and TVG are implemented
- SLR and Doppler residuals are not yet convincingly reduced (pass editor)