Progress Report and Lessons Learned from Developing a DORIS POD Software

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Dionysos DORIS Beacon

Dionysos Satellite Observatory (DSO) has been hosting a DORIS beacon in its facilities since 1989. First setup equipped with an `Alcatel` antenna, upgraded in May 2006 to `Starec` (1a).

(a) DORIS Beacon DIOB (Starec)

Orthophoto of Dionysos Satellite Observatory's Landscape Post-Fire
Produced by the Laboratory of Photogrammetry, School of Rural Surveying & Geospatial Engineering, National Technical University of Athens (NTUA)

(b) That was close . . .

Involvement in IDS & Motivation

Since late 2021, DSO has decided to expand its involvement in the DORIS community by developing its own, in-house processing software for POD and positioning using the DORIS system.

The software is designed and build from scratch, adopting recent developments in DORIS analysis and Satellite Geodesy.

- expand out knowledge-base and expertise (research activity & academic services),
- follow and apply state-of-the-art technologies in Satellite Geodesy and expand & modernize our research activity,
- contribute to the DORIS/IDS community, and get involved ongoing/future projects

Plan Outline

Our goal is to develop a DORIS free and open-sourceanalysis software for POD & positioning.

We follow an incremental approach, integrating one component at a time. As a first step, we are targeting:

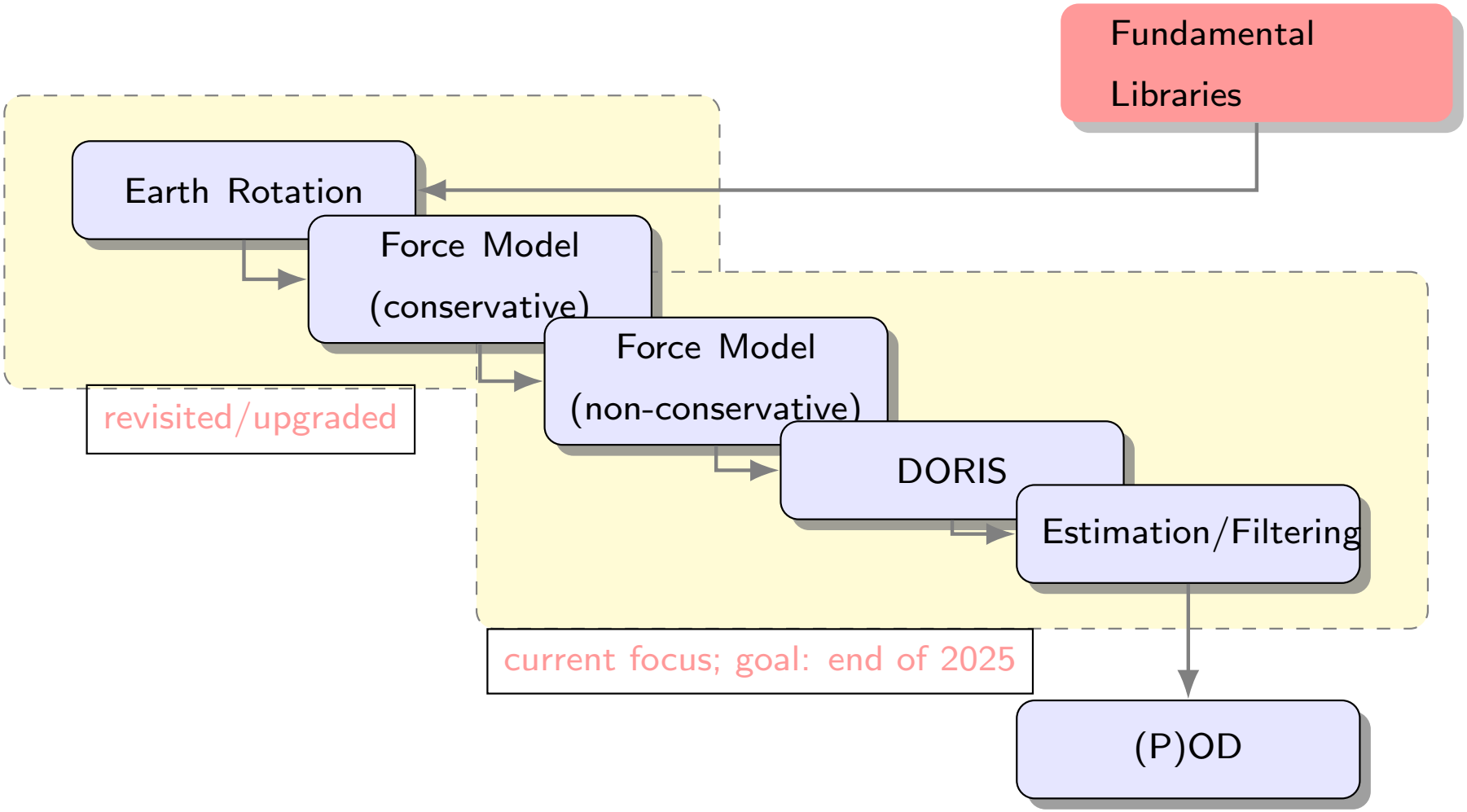
- (P)OD-only
  - Jason-3 satellite
    - adopt & implement simple models initially; gradually increase complexity

  ✓ gradually incorporate more satellites . . .

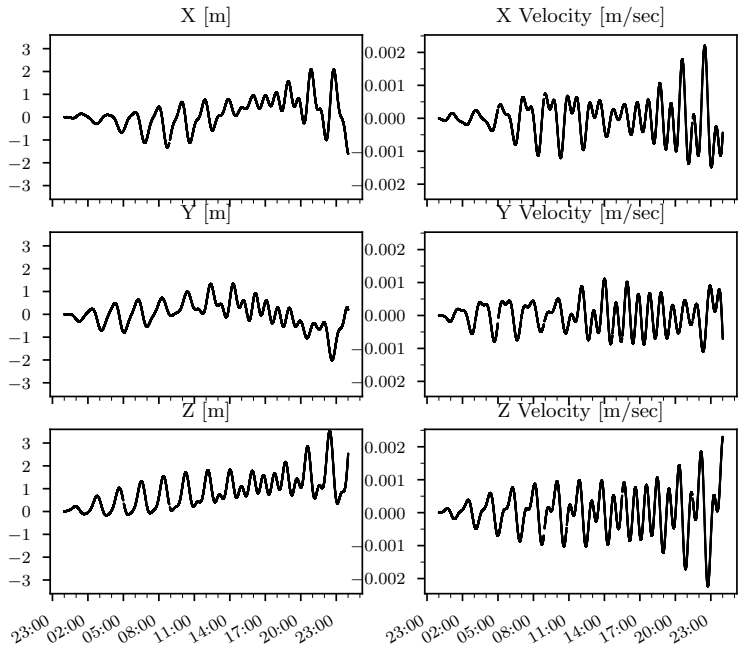
✓ introduce positioning once POD is acceptable

Workflow

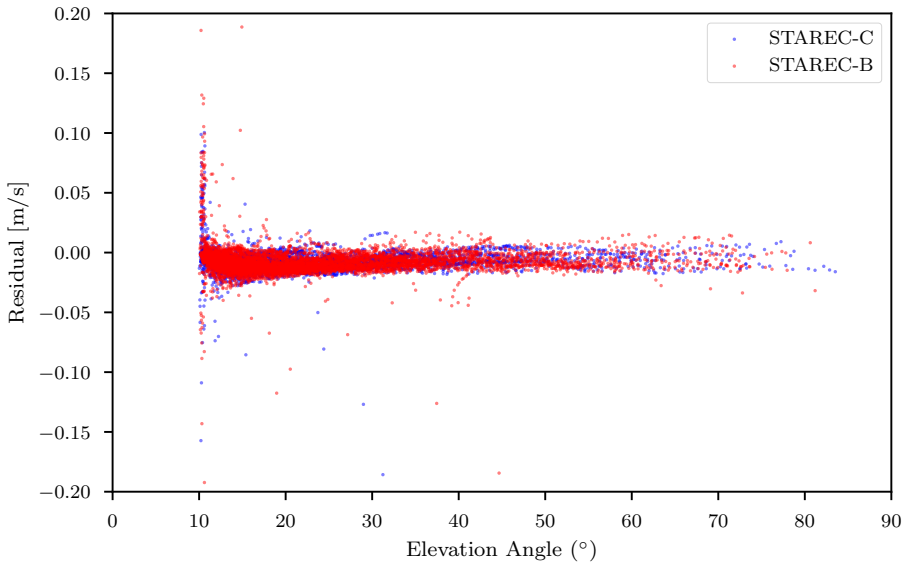
Development Plan & Milestones



Phase-I Results



(a) State differences w.r.t CNES/SSALTO orbits, Jason-3.



(b) Residuals w.r.t Elevation, per antenna type.

Figure 2: Preliminary results for Jason-3, at 05/09/2022

Design Considerations (1/3)

- Core software development using the **C++** programming language (exploiting its speed, robustness & versatility)
- Various minor, peripheral parts developed using **Python**, allowing development speed and ease of use (for developers & users)
- Follow a **modular** design pattern, with different parts developed individually, serving specific needs, thus favoring composability & reusability
- Strive for **minimum dependencies**; when unavoidable, we only use open-source software
- Developed in an "**open**" fashion, using public repositories on `github`

Design Considerations (2/3)

- RINEX-only processing
- We try to follow, as close as possible, the latest IDS recommendations published as "*IDS Recommendations and suggestions for ITRF 2020 reprocessing*"[1] or design for their easy adoption later on
- In general, consulting the extensive documentation on the IDS website "*Documents for the data analysis*"[2]
- Handling of DORIS observations follows the approach outlined in Lemoine et al. (2016) (range-rate)
- Estimation performed via Extended Kalman Filtering, Tapley et al. (2004) (later adopt a more sophisticated approach)

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[1] `https://ids-doris.org/images/IDS_RecommendationsITRF2020_04.02.2020.pdf`

[2] `https://ids-doris.org/analysis-coordination/documents-related-to-data-analysis.html`

Design Considerations (3/3)

- Comply with the IAU 2000/2006 resolutions (consistenly)
- "CIO-based" ITRS to GCRS via quaternions (Bizouard and Cheng (2023))
- Tidal indexing convention using Doodson numbers[3]
- Strive for adherence to the latest IERS standards (*IERS2010*, Petit and Luzum (2010))
- Fine concepts hard to grasp "mean tide", "zero tide", "tide free", ...

[3] R. Ray (GSFC), Indexing and argument conventions for tides, Ad Hoc Working Group on HF-EOP, 2017.

Software Components

Modular Design

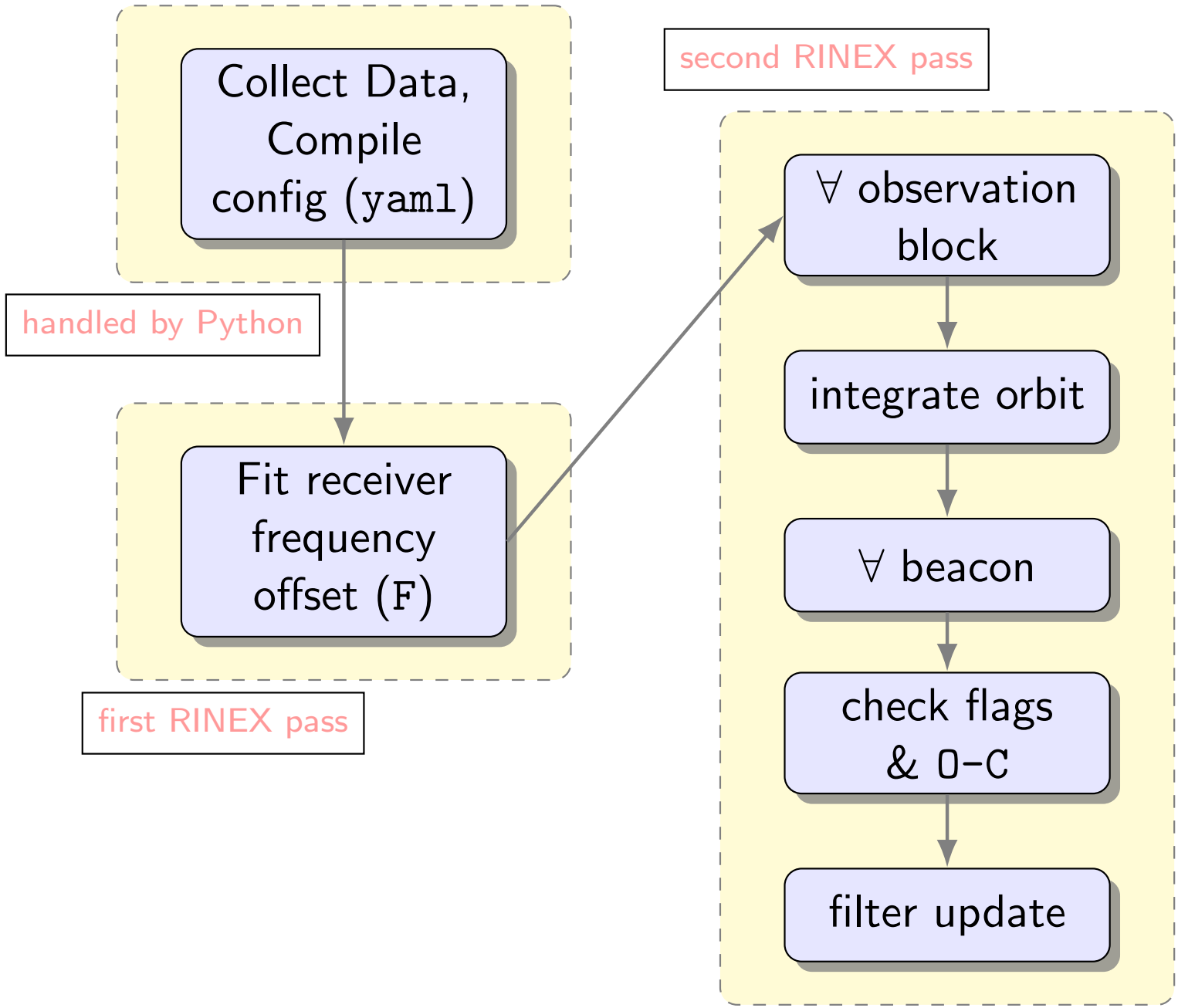
Library	Language	Comment
iers2010	C++, C, Python & Fortran	IERS2010 standards and Earth attitude
doris	C++, Python	DORIS system processing
sp3	C++	SP3 i/o and operations
geodesy	C++	coordinate transformations, ref. ellipsoid, etc
sinex	C++, Python	SINEX i/o and operations
datetime	C++	Datetime, time scales & transformations
rwatmo	C++	Radio-wave atmospheric models
eigen3[4]	C++ (header-only)	Matrix operations & linear algebra
cspice[5]	C/Fortran	Planetary ephemeris
yaml-cpp[6]	C++	Serialization/parsing of yaml files

[4] https://eigen.tuxfamily.org/
[5] https://naif.jpl.nasa.gov/naif/toolkit.html
[6] https://github.com/jbeder/yaml-cpp

Config File (yaml)

```yaml
---
data:
  doris-rinex: data/Jason-3/ja3rx22248.001
  sp3: data/Jason-3/ssaja320.b22238.e22258.DG_.sp3.001
reference-frame:
  station-coordinates: data/dpod2020_01.snx
eop-info:
  eop-file: data/eopc0420.1962-now
naif-kernels:
  spk: data/jpl/de421.bsp
  pck: data/jpl/gm_de431.tpc
  lsk: data/jpl/naif0012.tls
ocean-tides:
  harmonics: data/oceanTide_FES2014b.potential.iers.txt
  degree: 120
  order: 120
  blq: data/fes14b.blq
pole-tide:
  model: data/desaiscopolecoef.txt
  degree: 80
  order: 80
gravity:
  # model: data/gfc/GOCO02s.gfc
  model: data/gfc/EIGEN-GRGS.RL04.MEAN-FIELD.gfc
  degree: 120
  order: 120
troposphere:
  gpt3:
    grid: data/gpt3_5.grd
  vmf3:
    grid: data/2022248.v3gr_d
```

Flowchart


Collect Data, Compile config (yaml)
handled by Python
Fit receiver frequency offset (F)
first RINEX pass
second RINEX pass
∀ observation block
integrate orbit
∀ beacon
check flags & O-C
filter update

Revisited/Upgraded

Force Model

Available	**Update**	**Model**
Earth's gravity	generic, v2 & v3	ICGEM/gfc (Ince et al. (2019))
Solid Earth Tides	potential plus	IERS 2010
(potential)	displacement	
Ocean Tide	potential plus	FES2014
(potential)	displacement	(Lyard et al. (2021))
	Atmospheric Tide	AOD1B (Dobslaw et al. (2017))
	Solid Earth Pole Tide	IERS 2010
	Ocean Pole Tide	Desai (2002)
	De-Aliasing	AOD1B
Third Body		JPL DE
Relativity		IERS 2010

- ! Extensive testing against cost-g benchmark test (Lasser et al. (2020))
- ! Consistent use of Doodson numbers
- ! Identifying tidal constituents can be challenging ...

Current Development Focus

Force Model (Non-Conservative)

Available	**Update**	**Model**
Atmospheric Drag	NRLMSISE-00 to DTM-2020	Picone et al. (2002) Bruinsma and Boniface (2021)
Solar Radiation Pressure	only direct part	CNES macromodel
	Empirical Accelerations	

- ! Generic representation of attitude
- ! Pre-processing measured attitude (Bloßfeld et al. (2020))
- ! Refine SRP (albedo, CERES) ...
- ! Hard to test

Imminent Next Steps

- Generic attitude representation if possible,
- refine SRP,
- revisit DORIS analysis,
- revisit filtering (process noise/stochastic properties)

Thank you

Thank you for your attention!

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