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Pipeline optimization for space and ground based experiments (PSGE) – Pipeline for space gravity missions – MS7 KPI Status Update, 28 feb 2024

UC overview

Flagship UC: WP3.4 PIPELINE – Pipeline for space gravity missions

The main objective is the development of methodologies and expertise for the development, optimization and management of pipelines for precise orbit determination (POD) of Earth-orbiting satellites. The pipeline should make up an interface layer between the core POD code (assumed already existent and properly working) and the user / other analysis code / archive. A specific reference case is given by a widely used POD code written in Fortran 77/90 and essentially monolithic in its structure and used for research in geodesy, geophysics and fundamental physics (e.g., general relativity tests). An existing ensemble of interface codes (written in Bash and Python) would constitute the core for an analysis package able to manage complex analysis tasks (including Monte Carlo simulations), handle data and metadata, and manage archives. Due attention is foreseen to virtualization/containers (e.g. Docker).

POD – Scientific motivation

POD – Precise Orbit Determination

Set of algorithms and procedures to determine the orbit of a celestial body given a set of observations (angular, range, range-rate, …). It is a computationally intensive problem (especially if it involves the estimation of geophysically-related parameters), but for which multi-decade experience and tools are available.

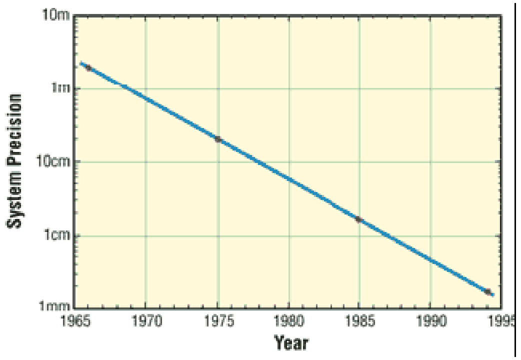
Use case

Improve/optimize a POD pipeline based on the Geodyn II (NASA-GSFC), a multi-purpose S/W dedicated to orbit propagation, orbit determination, geophysical parameters estimate. This pipeline has been locally developed to support scientific research in the fields of fundamental physics (tests of general relativity theory), space dynamics, geodesy, geophysics.

POD – Scientific motivation – Satellite Laser Ranging

Retroreflectors mounted on the satellite surface are the target of laser pulses, of which the travel time is measured

$$\Delta s = \frac{c\Delta t}{2}$$



ilrs.gsfc.nasa.gov

Photo Franco Ambrico; courtesy Giuseppe Bianco, ASI-CGS

POD – Scientific motivation – Models of satellite dynamics

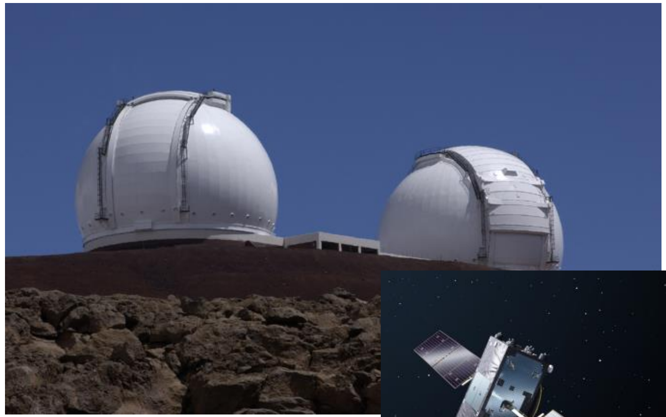
Gravitational

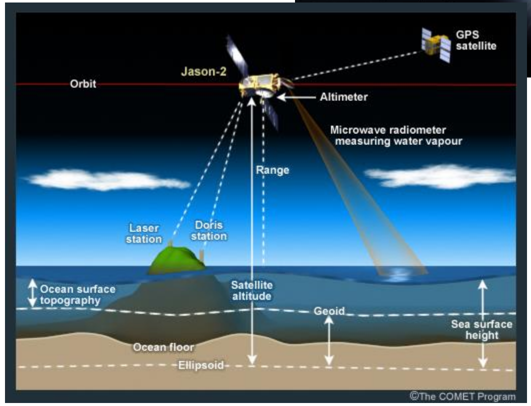
- Geopotential (static part)
- Solid Earth and ocean tides / Other temporal variations of geopotential
- Third body (Sun, Moon and planets)
- de Sitter precession
- Deviations from geodetic motion
- Other relativistic effects

Non-gravitational

- Direct solar radiation pressure
- Earth albedo radiation pressure
- Anisotropic emission of thermal radiation due to visible solar radiation (*Yarkovsky-Schach effect*)
- Anisotropic emission of thermal radiation due to infrared Earth radiation (*Yarkovsky-Rubincam effect*)
- Asymmetric reflectivity
- Neutral and charged particle drag

POD – Scientific motivation – reference frames





"Inertial"

ICRF

↕

Precession

↕

Nutation

↕

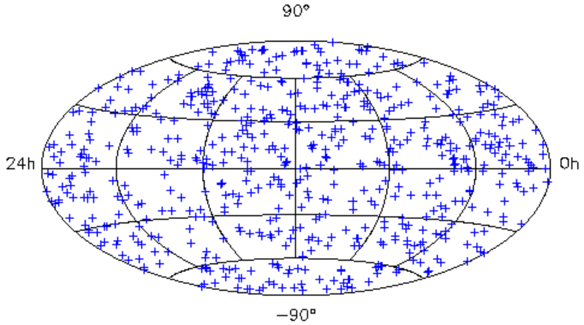
Length of day

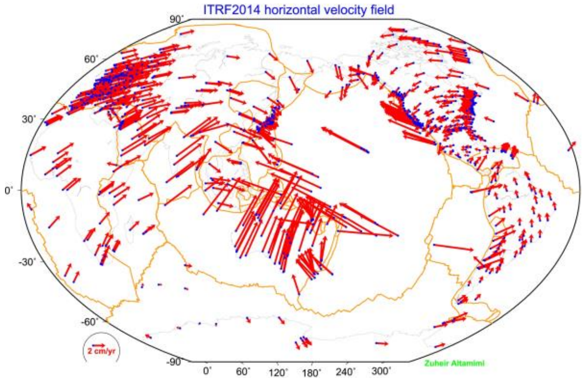
↕

Pole motion

↕

ITRF





POD – Scientific motivation – Typical science results

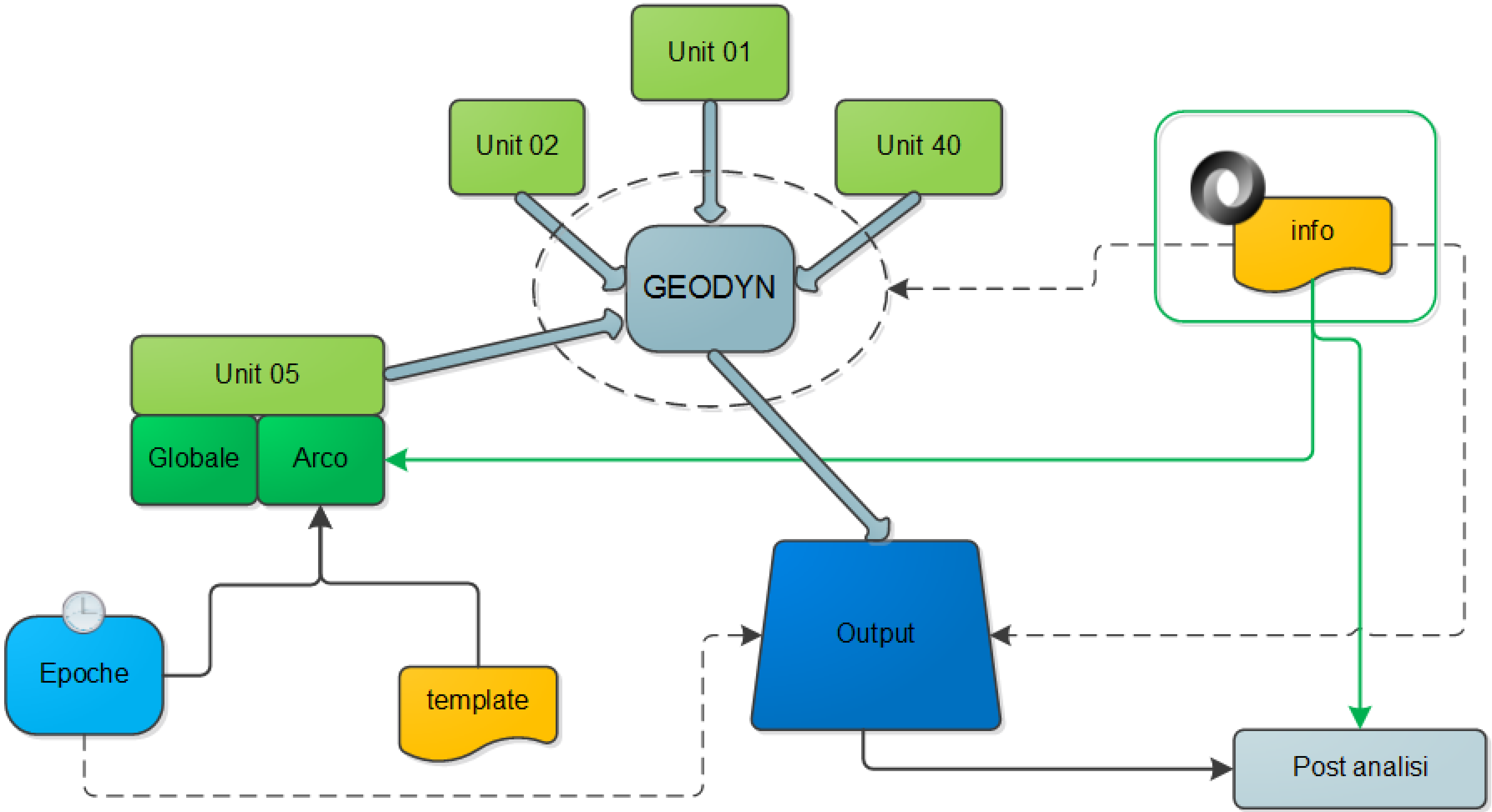
TABLE XVIII. Summary of the results obtained in the present work; together with the measurement error budget, the constraints on fundamental physics are listed and compared with the literature.

	Parameter	Values and uncertainties (this study)	Uncertainties (literature)	Remarks
	$\epsilon_\omega - 1$	$-1.2\times10^{-4}\pm2.10\times10^{-3}\pm2.54\times10^{-2}$	...	Error budget of the perigee precession measurement in the field of the Earth
PPN →	$\frac{\|2+2\gamma-\beta\|}{3} - 1$	$-1.2\times10^{-4}\pm2.10\times10^{-3}\pm2.54\times10^{-2}$	$\pm(1.0\times10^{-3})\pm(2\times10^{-2})$[a]	Constraint on the combination of PPN parameters
Yukawa →	$\|\alpha\|$	$\lesssim\|0.5\pm8.0\pm101\|\times10^{-12}$	$\pm1\times10^{-8}$[b]	Constraint on a possible (Yukawa-like) NLRI
ATGs →	$\mathcal{C}_{\oplus \mathrm{LAGEOSII}}$	$\leq(0.003\ \mathrm{km})^4\pm(0.036\ \mathrm{km})^4\pm(0.092\ \mathrm{km})^4$	$\pm(0.16\ \mathrm{km})^4$[c]; $\pm(0.087\ \mathrm{km})^4$[d]	Constraint on a possible NSGT
	$\|2t_2+t_3\|$	$\lesssim3.5\times10^{-4}\pm6.2\times10^{-3}\pm7.49\times10^{-2}$	3×10^{-3}[e]	Constraint on torsion

[a]From the preliminary estimate of the systematic errors of [166] for the perihelion precession of Mercury.
[b]From [167] with Lunar-LAGEOS *GM* measurements.
[c]From [5] and based on a partial estimate for the systematic errors.
[d]From [7] and based on the analysis of the systematic errors only.
[e]From [168] with no estimate for the systematic errors.

D.M. Lucchesi, R. Peron, *Accurate measurement in the Field of the Earth of he General-Relativistic Precession of the LAGEOS II Pericenter and New Constraints on Non-Newtonian Gravity*, Phys. Rev. Lett. 105, 231103, 2010
D.M. Lucchesi, R. Peron, *LAGEOS II pericenter general relativistic precession (1993-2005): Error budget and constraints in gravitational physics*. Phys. Rev. D 89, 082002, 2014

POD – Pipeline structure



POD – Pipeline structure

Geodyn II: written in Fortran 77/90
nearly monolithic (two executables) plus ancillary S/W
text (ASCII 'cards') / binary interface
high level of flexibility in processing strategies and data types

Control and interface scripts: written in Bash and Python
data and models pre-processing
run scheduling and execution
results extraction and post-processing

S/W local usage history: SPARC workstations
↓
PCs
↓
rack server (blade)
↓
virtual machine (24 cores / 64 GiB RAM / 140/600 GiB storage)

POD – Issues

Code heterogeneity Code written in several programming languages, at different times and with with differing levels of development. The parts are glued together in a case-by-case way, often necessity-driven.

Low portability The pipeline is somehow bound to a specific architecture. Current lack of a proper installation and initial configuration procedure. Limited degree of version control.

Hazy interfaces The current interfaces (between the pipeline modules and with the outside) are not always defined in a coherent way.

Bottlenecks The increasingly dependence on Python code for pre- and post-processing, good for flexibility and computational capabilities, is cause of current processing slow-downs that propagate in the entire pipeline.

Limited scalability Need for a better scheduling management, in view of advanced (e.g. Monte Carlo simulations) scenarios.

POD – Activity tasks

Git repository Development of a new, more coherent repository, in order to unify parts that are currently handled in a separate way.

Docker container Go towards a container environment to improve the pipeline portability and keep the dependencies under control.

Scheduling improvement Adopt better scheduling procedures, in order to optimize the resources usage and perform a more uniform handling of the various data processing routes.

Code optimization Optimize the data extraction Python code and related procedures, that currently are the cause of significant bottlenecks.

Scalability of procedures Review the processing flow, in order to make it more suitable to large scale (e.g. Monte Carlo) processing.