Where — Software for Geodetic Analysis

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https://github.com/kartverket/where

Where is currently being developed at the Norwegian Mapping Authority (Kartverket). The software is written in Python, which has proved very fruitful. The code is quick to write and the architecture is easily extendable and maintainable, while at the same time taking advantage of well-tested libraries like the SOFA and IERS packages. Where is an open source project.

Where

Geodesy in Norway

The Norwegian Mapping Authority has increased its contributions on global reference frames over the last decade. We are currently building a new fundamental station at Ny-Ålesund supporting VLBI, SLR, GNSS and DORIS. We have been involved in the establishment of a UN resolution on global geodesy and reference frames [11], and will work on the establishment of a Global Geodetic Centre of Excellence, as proposed by the UN Subcommittee on Geodesy.

The Where software project completes the norwegian contribution, by giving us a new tool for the analysis of geodetic data and giving us more insight into such analysis along the way.

How Where works

Where is mainly implemented in Python. The Python ecosystem for data science is very rich and Where utilizes several well known packages such as `numpy`, `scipy` and `matplotlib`, as well as more specialized packages like `jplephem` [10]. In addition, Python easily interfaces with other languages like C and Fortran, and Where uses the `SOFA` [2] and `IERS` [3] Fortran libraries directly.

Using Python has several advantages, including rapid development, flexible and easy to read code. Where is a command line tool, and comes with a configuration file that can be used to customize the behavior of the program. This makes the program quite easy to use, while at the same time having the possibility to use different models and input for the analysis.

The results can be inspected using the graphical tool called There that has been developed alongside Where (Figure 1).

The Where Workflow

First, observation data are read and edited, and stored in an internal data format. We use hdf5, which is a hierarchical data format compatible with the dictionary structure in Python. Next, for SLR, the orbit and the theoretical range observations are calculated, before station positions and EOP's are estimated on the basis of those theoretical ranges.

The implementation of the individual models follow the 2010 IERS Conventions [9], and when possible we have used software libraries made available at the IERS web page [3]. Table 1 gives an overview of the models implemented in Where. The estimation of EOP parameters and station positions is done using a Kalman filter [7]. We use continuous piecewise linear functions for the estimation.

Orbit determination

We have implemented all models for orbit determination, see Table 1. Force models, variational equations and orbit estimation is computed following [6], and we have implemented a Cowell orbit integrator following [8]. The observation equation for SLR is following [1].

Computation time

The original Python program was slow, but we have done some improvements. Using `numpy`, doing most operations on vectors (instead of sequentially) and caching results when possible gives us a fairly fast program. Running Where for one week of SLR analysis with the four satellites Lageos1, Lageos2, Etalon1 and Etalon2 now takes about 18 minutes. We have programmed the orbit computation in Cython, a programming language which gives us the combined power of Python and C. It lets us tune readable Python code into plain C performance by adding static type declarations in Python syntax.

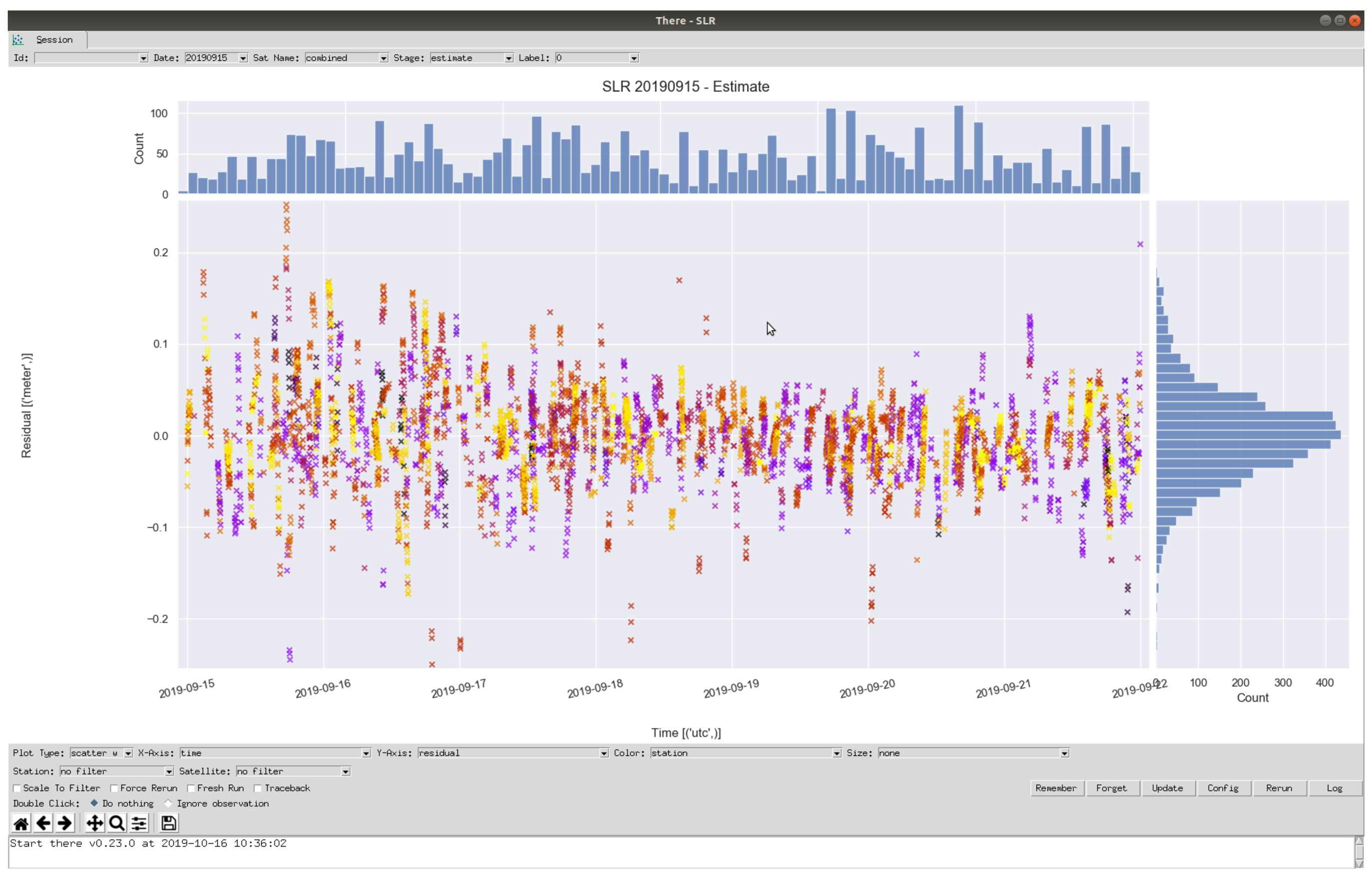

Figure 1: A screenshot of There - a graphical tool developed to look into the results and analysis done by Where. The plot shows the observation residuals for the four satellites Lageos1, Lageos2, Etalon1 and Etalon2, in meters, for a one week run.

Future Analysis Centers for VLBI and SLR with Where

The Norwegian Mapping Authority (NMA) is an associated analysis center within the IVS and ILRS. Both the NMA and the Instituto Geográfico Nacional, Spain, are in a test phase of deliveries of VLBI analysis results to the IVS with the Where software. Some of our activities in VLBI is documented in [4] and [5].

Our goal is to be able to contribute to the ILRS after some improvements of the software, and in the future recieve full status as operational analysis center for both VLBI and SLR.

Sharing and cooperating with other institutions is made possible by making Where an open source project on GitHub.

Orbit models	Earth gravity field EGM2008 (with Solid Earth and Ocean Tides), Gravity field of Sun, Moon and planets, Solar radiation pressure, Relativistic effects, Empirical accelerations: Constant and once-per-rev along track and cross track
Ephemerides	DE405, DE421, DE430
Displacement models	Atmospheric loading, Eccentricity vector, Ocean loading, Ocean pole tides, Solid Earth tides, Solid Earth pole tides
Delay models	Mendes-Pavlis troposphere models, Center of mass corrections from ILRS Data Handling file, Relativistic corrections
Estimation	Continuous piecewise linear Kalman Filter: EOP, Station positions, Range- and Time bias.

Table 1: Models and apriori data supported by Where

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