Study on optimal temporal approximation of meteorological and tropospheric parameters

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Abstract

Over the past few years, the attention was paid for an optimal modelling of tropospheric corrections in support of GNSS positioning and navigation. For this purpose, data from numerical weather models are more and more utilized. Because of a large volume of data, several approximations are commonly applied for an effective provision of meteorological and tropospheric parameters for a GNSS signal path delay calculation. First, vertical approximation is useful to significantly reduce the amount of NWM data to a two-dimensional field at a reference level. This approximation is usually based on model algorithms approximating the physics of the atmosphere. Second, the grid spatial approximation is commonly utilized. Although the horizontal resolution is progressively improving, it strongly depends on the available input data from numerical weather field. Third, an approximation in time enables to provide a closed form of the correction model that does not require any additional information about the actual state of the atmosphere. Such temporal approximation usually benefits from results of the individual parameter time-series analysd is using an effective data time-span.

Our study focuses on the temporal approximation of selected meteorological and tropospheric parameters in order to prepare data for other analysis such as tropospheric correction model for positioning and navigation development. First, an effective length of the time-span of input data was assessed. Second, we applied the methods of mathematical statistics on individual parameter time-series and identified those methods that could be helpful for an effective temporal approximation.

Impact of data time span for time-series approximation

By the length of the time series we understand the number ,N, of the measurements of which this time-series consists (not just the time span between the first and the last measurement). Thus with the time-series length increase the amount of information included in this series increases as well. Moreover, when a very long time-series is used, some of its characteristics may be significantly changed over the passing of time.

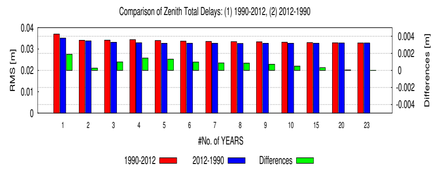


Figure includes the results of a simple study when the time-series span influence on the extrapolation procedure was studied. The time-series of several spans were fitted with appropriate mathematical model and then adjusted coefficients were applied to the extrapolation. The time-series span was extended in both directions: from 1990 to 2012 and the other way round, from 2012 to 1990. The differences of the RMS statistics, when extrapolated values and original IGS data were compared, shows how residuals decreases with data time span is increased for time-series approximations.

Gnut/Apep – objectives

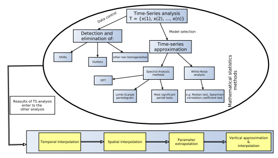
The software tool is being developed for performing the quality checking of meteorological data time-series before their final use, e.g. in climate research.

- G-Nut/Apep is an flexible application under the development supposed to be serve for QC, TS analysis and approximations of time-series of paramteers derived from positioning (coordinates), atmosphere monitoring (tropospheric zenith path delays, horizontal gradients), and other parameters.
- The application is implemented using the G-Nut core library developed at the Geodetic Obsevatory Pecny (GOP).
- G-Nut library (APEP) is foreseen as an independent tool with possibility to link to the GOP-TropDB tropospheric database.

Selected methods and procedures

The analysis includes methods and procedures sorted into the three main groups (also implemented within G-nut library):

1. (DQCH): Data Quality Control and time-series Homogenization algorithms, including SNHT, BckAvg, Kernel smoother, etc.
2. (TSAM): Time-Series Approximation Methods including LSQ or Levenberg-Marquardt method for model adjusting, interpolation methods, etc.
3. (MMS): Methods of Mathematical Statistics such as selected methods of spectral analysist: Lomb-Scargle Periodogram, Fourier Transformation, Informative Criterions, etc.

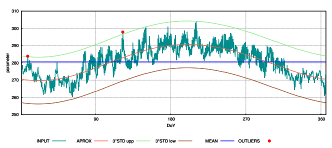


Additional functions:

1. For model fitting support:
   (a) Least-Squared method,
   (b) Levenberg-Marquardt method,
2. For time-series approximation support:
   (a) Linear interpolation,
   (b) Cubic Spline interpolation.

(DQCH): Outlier detection

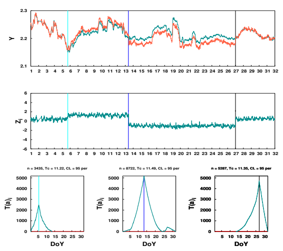
Selected methods and first results:
In statistics formalism, the outlier candidate is defined as an observation that differs from other observations of the statistical sample.



The majority of the methods related to the outliers detections is based on criterion of relative distance between the suspected point and the mean value of the sample. Our procedure is based on fitting of the data sample by appropriate regression model and using rule of $3\times\sigma$. Other procedure includes strategy based on Autoregressive model development.

Jump detection

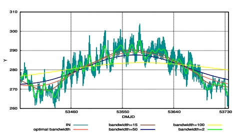
The jumps in GPS time-series are usually associated with the change of antenna. The identification of the shifts in time-series requires very sensitive analysis based on verified statistical methods and researcher's expertise.



Standard Normal Homogenity Test (SNHT) was introduced by Alexandersson and implemented within Gnut/Apep application. An algorithm depends on at least two time-series. One is given as a reference, where no jumps are expected. Second represents analysed series. An example and results are ploted in the figure placed on left. Alternative methods were implemented:

1. Block Average algorithm - BckAvg,
2. Cumultative Sum algorithm.

Kernel smoother



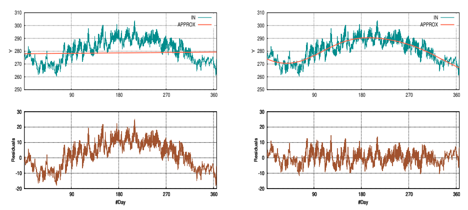
Kernel smoother with Gauss-normal kernel function. Plot shows applications with different bandwidth settings

Kernel density estimation represents density estimator with some positive properties: It is smooth (in contrast with the other simple density estimators) and is enought sensitive to local properties of the model function. Kernel smoother method is used when outliers in tested sample are analysed.

(TSAM): Time-Series Approximation

The idea is to test residuals (differences between input sample and fitted mathematical model), and to decide if residuals represent so-called white noise, which can be simply defined as:

$$E\varepsilon_t = 0 \ \ \forall t, \ \ t \in < a,b >$$
$$var\varepsilon_t = \sigma^2 \ \ \forall t, \ \ t \in < a,b > .$$



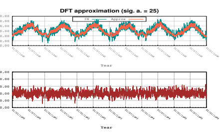
Plots related to time-series approximation show two scenarios.

1. Linear (trend, fig. on left) model was selected as regression model. Residuals plot clearly shows another period characteristic for the model.
2. Harmonic model with seasonal period (fig. on right) was selected as regressiom model.

(MMS): Methods of Mathematical Statistics

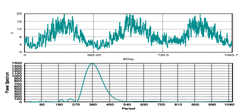
- Discrete Fourier Transformation

It allows us to test and study series in frequency domain. Using inverse transformation with selected (usually low) frequencies, DFT can be used as a smoother. Additionally, this method is used: (1) in support of outliers detection, (2) data sample approximation, … .



An example of Discrete Fourier Transformation. Plot shows inverse DFT, when 25-most significant Fourier frequencies were used

- Lomb-Scargle Periodogram



Plot clearly shows that the significant period equals to 365 days approx., whed L-S periodogram was applied

Method is widely used for the power spectral density estimation, especially when data are unevenly sampled. In our case is used when significant periods are to be estimated. Fisher test and Siegel test were implemented for testing of the most significant period(s), as alternative methods.

Conclusion

The development of time-series analysis tool (G-Nut/Apep) was motivated by performing quality control checking for data in GOP-TropDB database. Additionally, it is used to filter data before generating parameter approximation, like in the development of blind tropospheric model case.
Various additional methods and procedures are studied for this analysis, e.g.:

- Wavelet transformation for better understanding of time signal,
- Non-Fourier frequency analysis.

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