Modeling and forecasting the occurrence of ionospheric irregularities in mid-latitude regions

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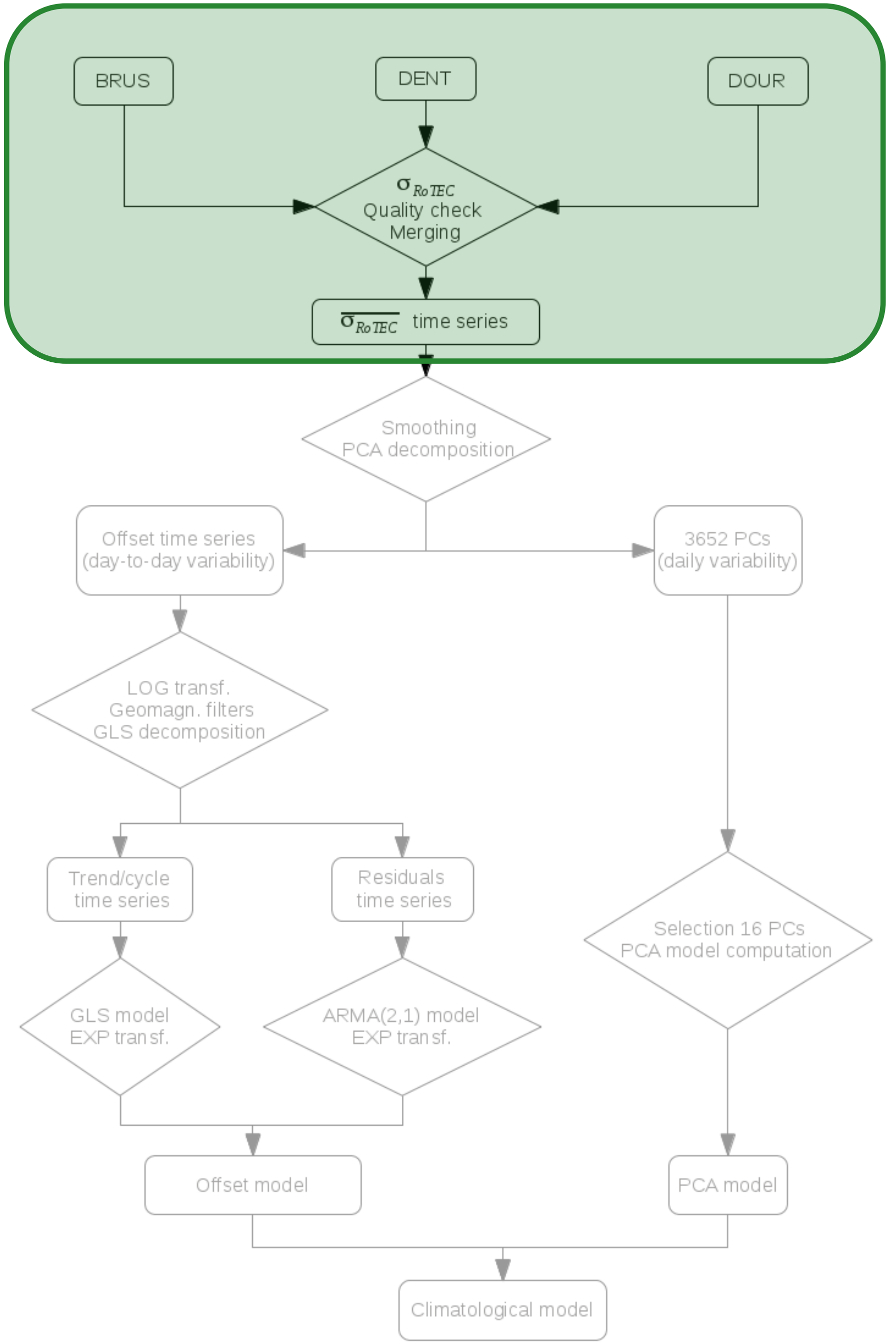
Ionospheric variability is a major error source for real-time, high-accuracy positioning techniques with GNSS

- Ionospheric models exist
  foF2, TEC models (IRI, Nequick)

- Models reproduce recurrent patterns
  Variability remains unmodeled and unpredicted

→ Develop a climatological model of the ionospheric variability that could be used by GNSS users in the field



1^{st} **step**: data acquisition

σ_{RoTEC} series

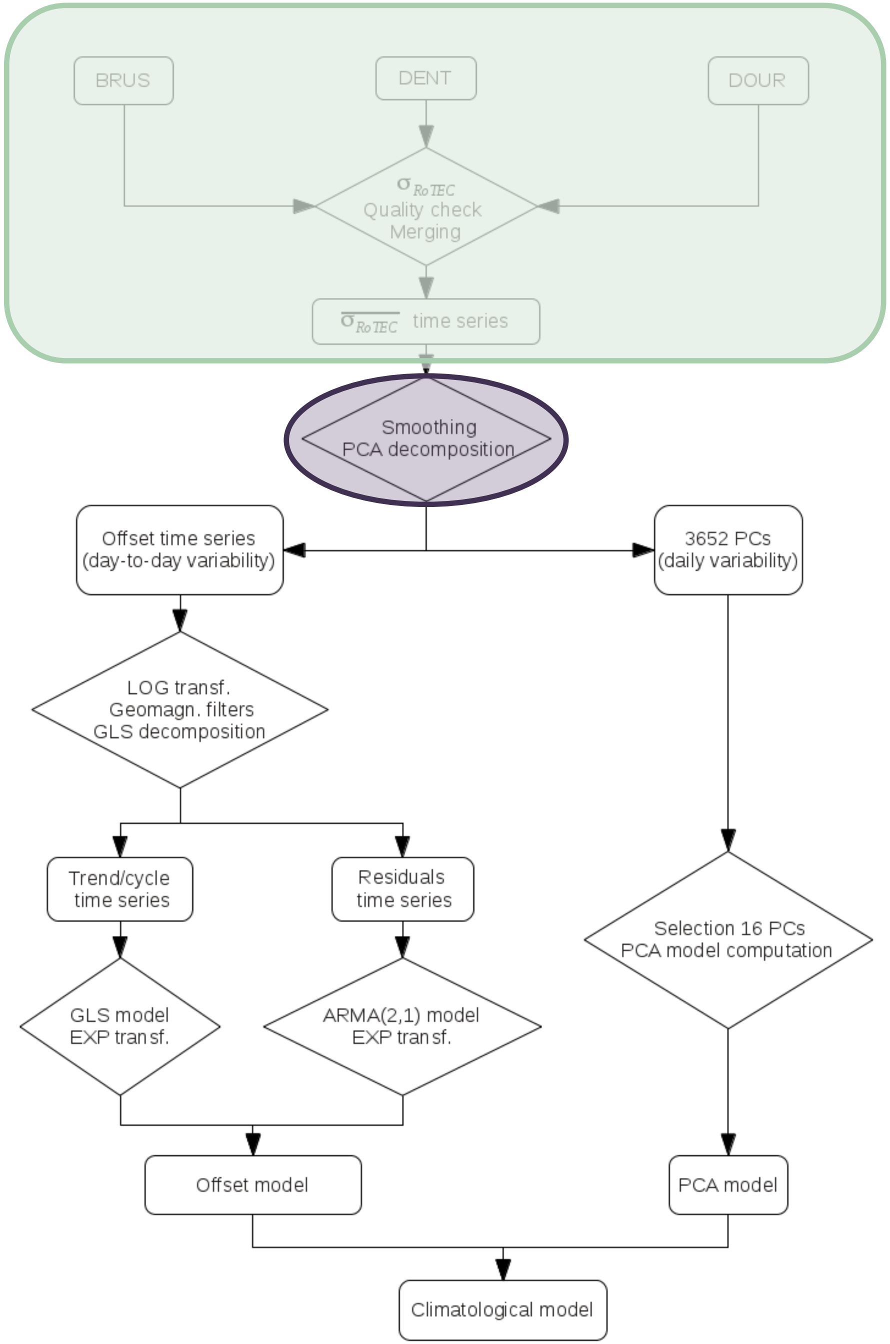
Wautelet et al. (2012), *Local climatological modeling of ionospheric irregularities detected by GPS in mid-latitude regions*, JASTP, 89:132-143.

Extraction of high-frequency variability using dual-frequency GPS observations

1. Extraction of the vertical ionospheric term
   Geometric-free combination on L1/L2 + mapping function
2. Compute TEC rate of change
   Time differencing, accuracy of phase measurements
3. High-pass filtering → Rate of TEC (RoTEC)
   Remove low-order effect of regular gradients
4. Variability computed every 15 min : σ_{RoTEC}
   For each satellite in view

Constituting the 10 year time series…

- From 2002 to 2011, Belgian observations only
  - As a prototype…
- Merges observations from 3 GPS stations
  - Reduce measurement noise
  - Mitigate local effects (multipath)
- Merges all satellites in view
  - Simulates a GPS user in the field



1st step: data acquisition

σ_{RoTEC} series

2nd step: decomposition

DailyVS long term

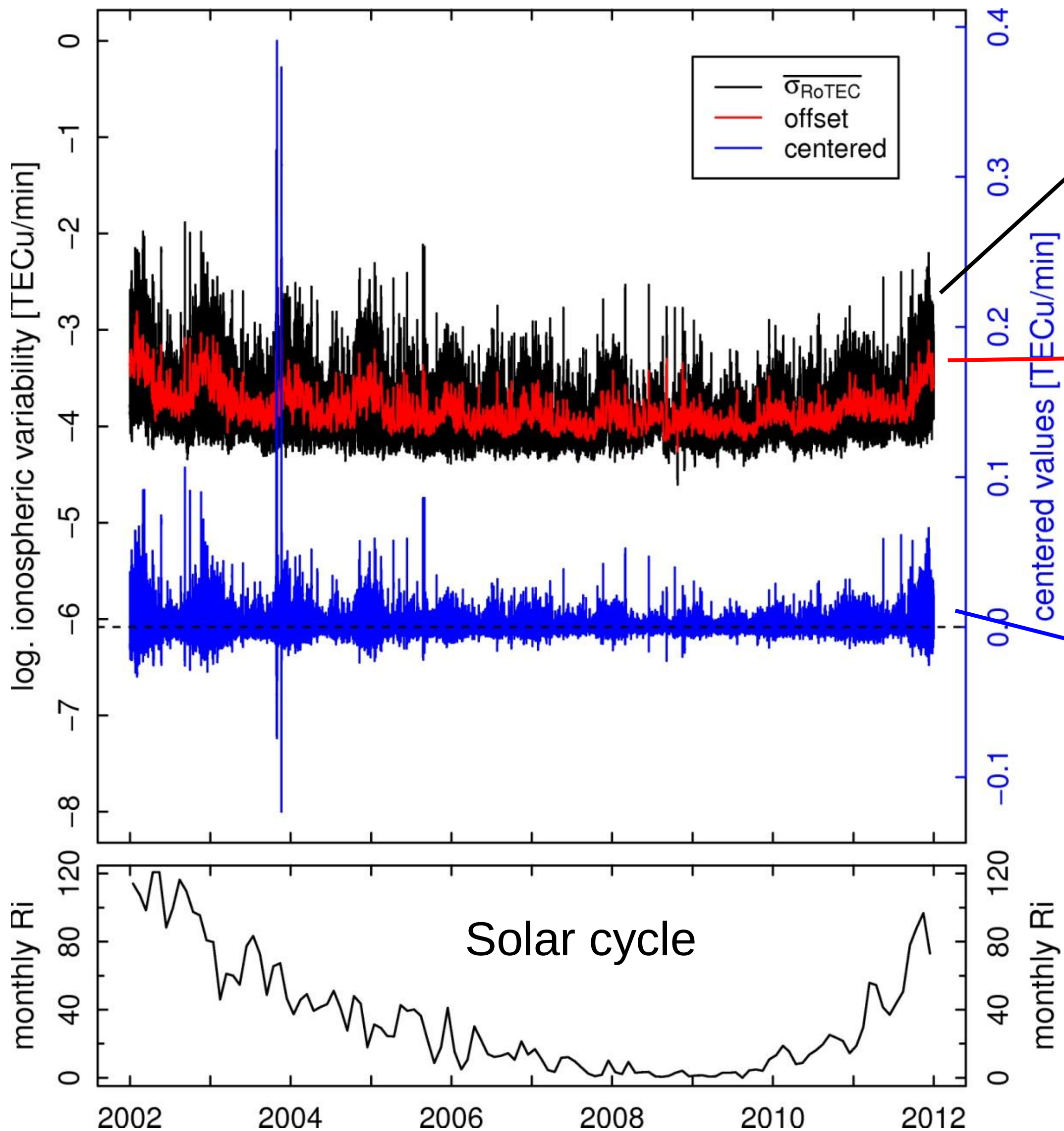
Wautelet et al. (2012), *Local climatological modeling of ionospheric irregularities detected by GPS in mid-latitude regions*, JASTP, 89:132-143.

- Because ionospheric variability is varying with…
  - Solar activity
  - Season
  - Local time
  - Geomagnetic activity

- The variability model is divided into 2 parts:
  1. Long-term component → solar cycle, season
  2. Daily component → local time dependence

- The model is climatological → filter out disturbed conditions

  $Kp < 4$ & $|DST| < 50$ nT & Xrays $< 10^{-5}$ W/m^2



Original series (σ_{RoTEC})

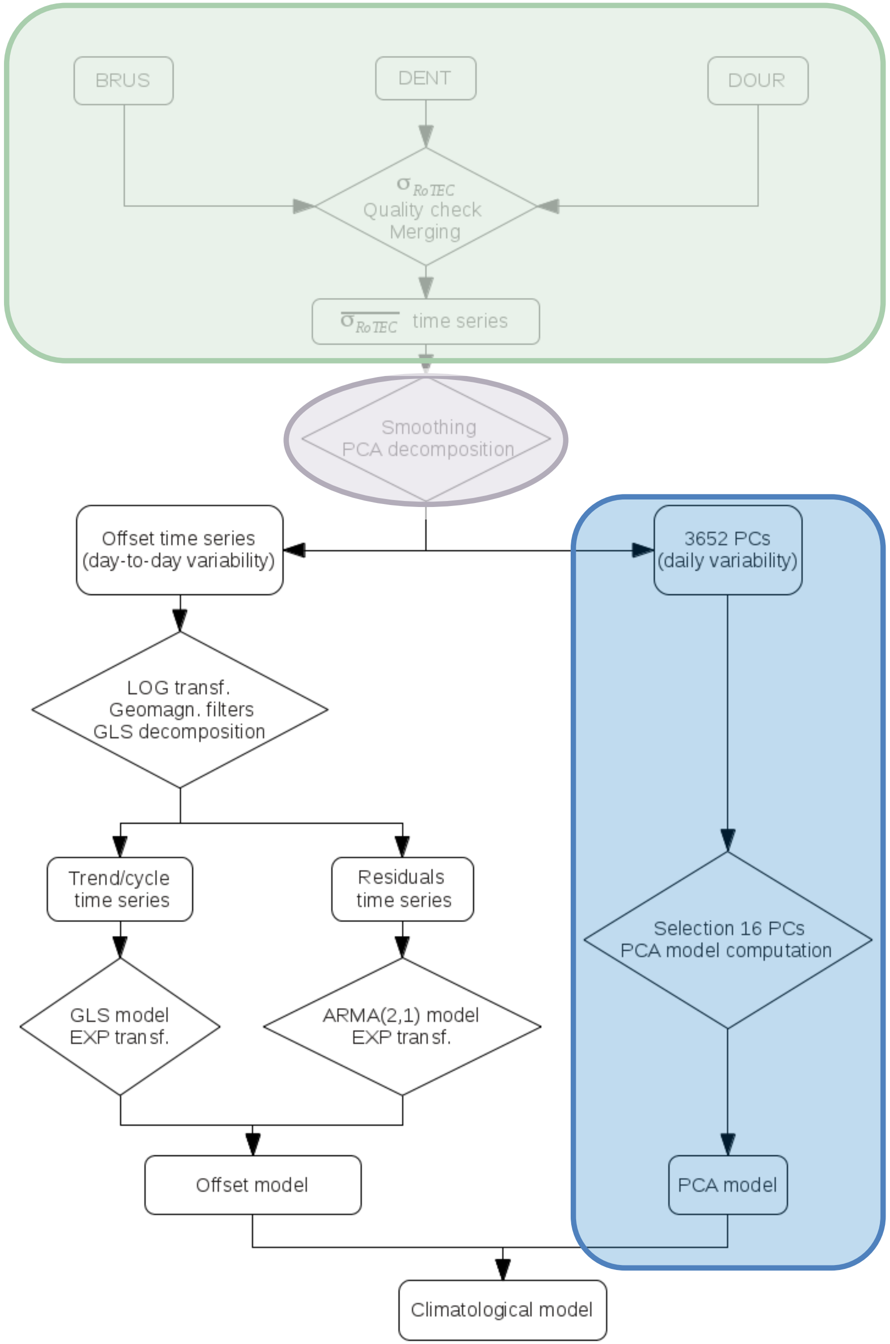
15 min resolution

Offsets = daily means

24h resolution → long term

Centered = original - offsets

15 min resolution



1st step: data acquisition

σ_{RoTEC} series

2nd step: decomposition

Daily VS long term

3rd step: Principal Component Analysis (PCA)

daily model

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Principal Component Analysis (PCA) – principles

Idea = extract the most recurrent patterns from the series

σ_{RoTEC} series : 3652 days with 15-min time interval

3652 variables (days)

96 observations (epochs)

	01/01/02	01/02/02	…	12/31/11
00:00	0.023	0.057	…	−0.004
00:15	0.023	0.064	…	−0.004
00:30	0.023	0.070	…	−0.005
⋮	⋮	⋮	…	⋮
23:45	0.052	0.018	…	−0.005

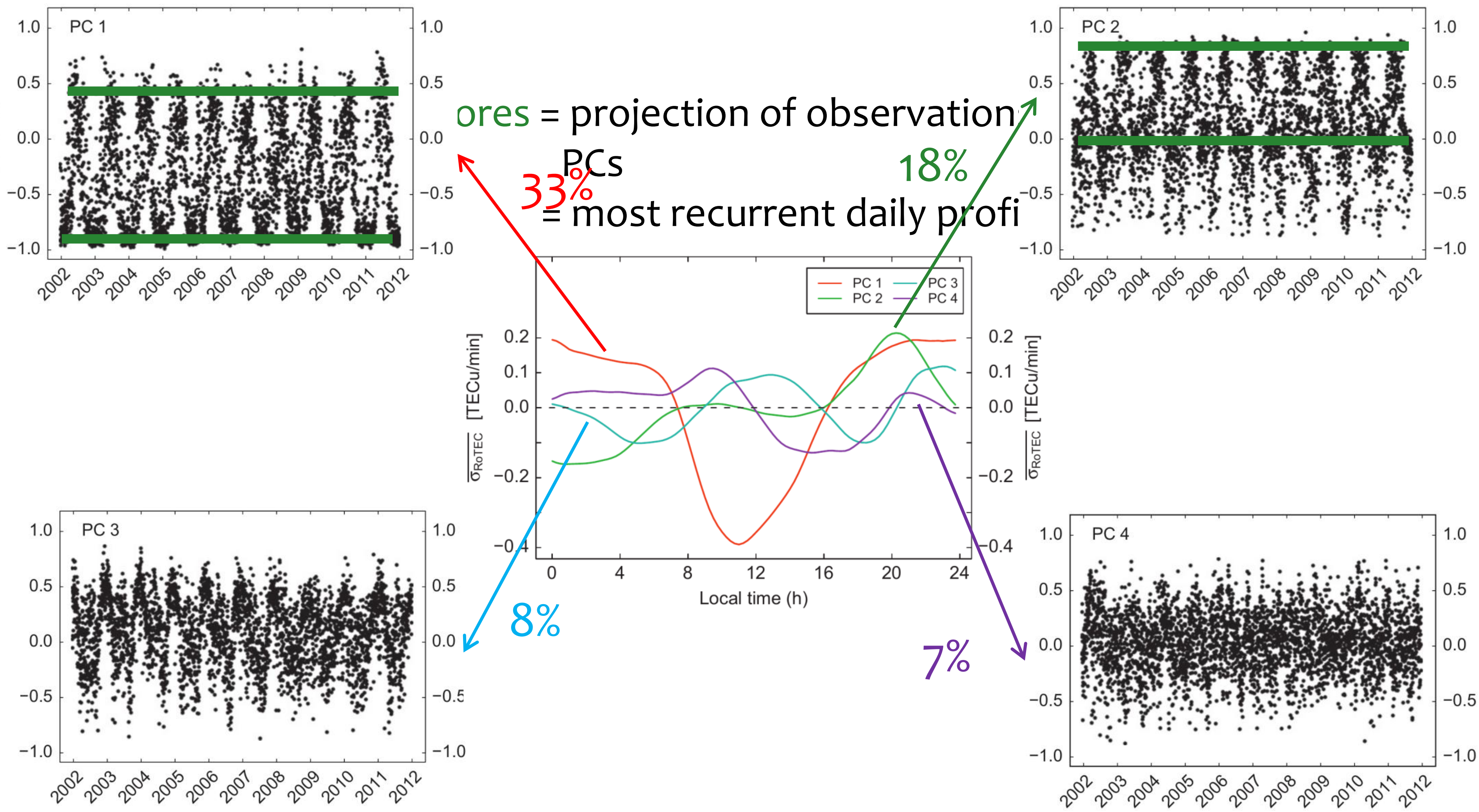
Principal Component (PC) = linear combination of variables
(eigenvectors)

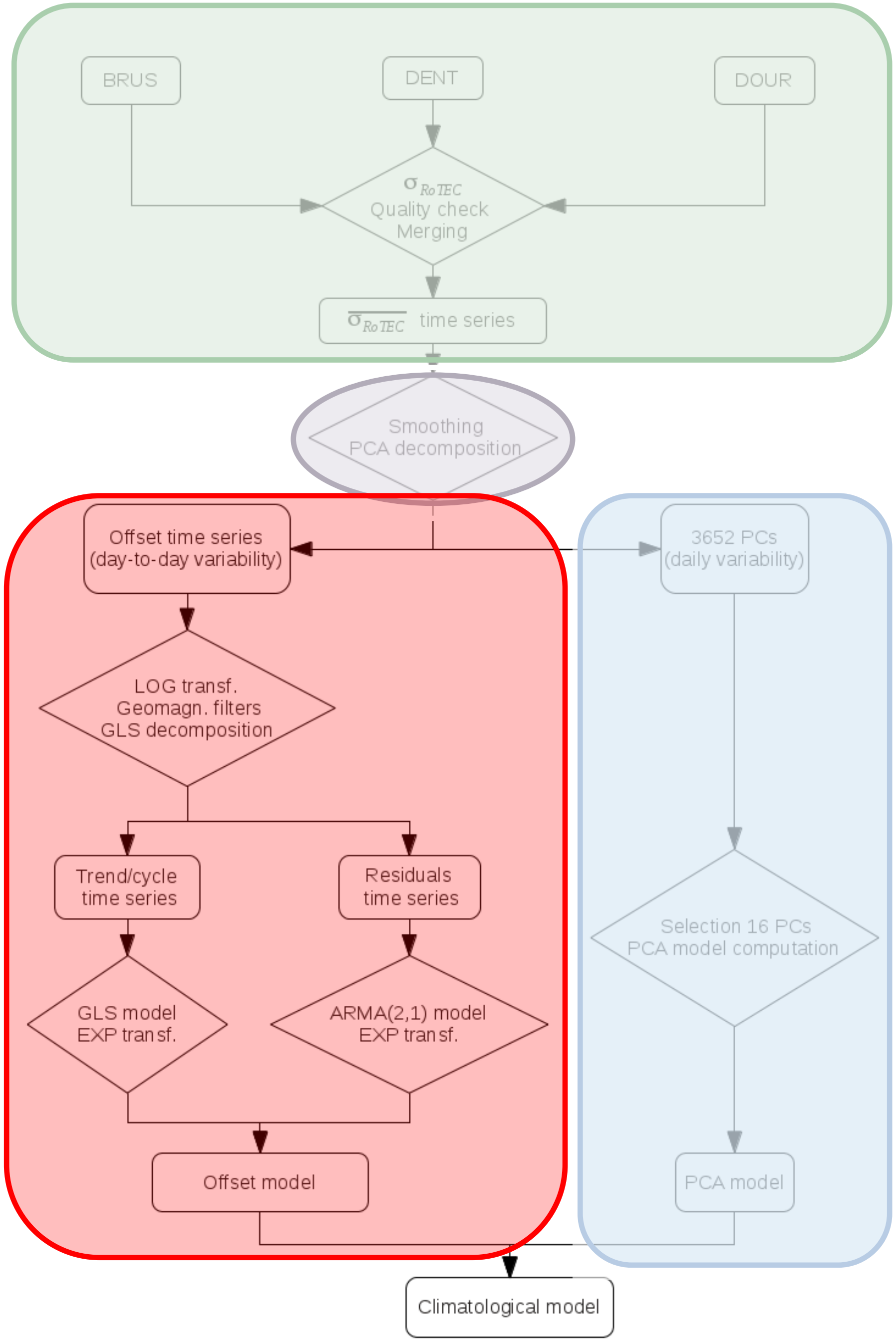
$$CX_i = \lambda_i X_i$$

C = inertial matrix (= correlation matrix, 3652x3652)
X_i = i^{th} PC
λ_i = eigenvalue related to the i^{th} PC

Principal Component Analysis (PCA) – analysis

Loadings = correlation between PCs and original variables





1st step: data acquisition

σ_{RoTEC} series

2nd step: decomposition

Daily VS long term

3rd step: Principal Component Analysis (PCA)

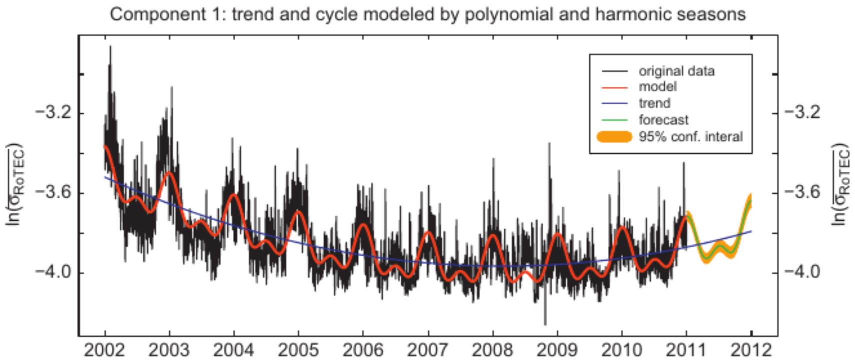
daily model

4th step: Generalized Least-Squares (GLS) and ARMA modeling

offset model

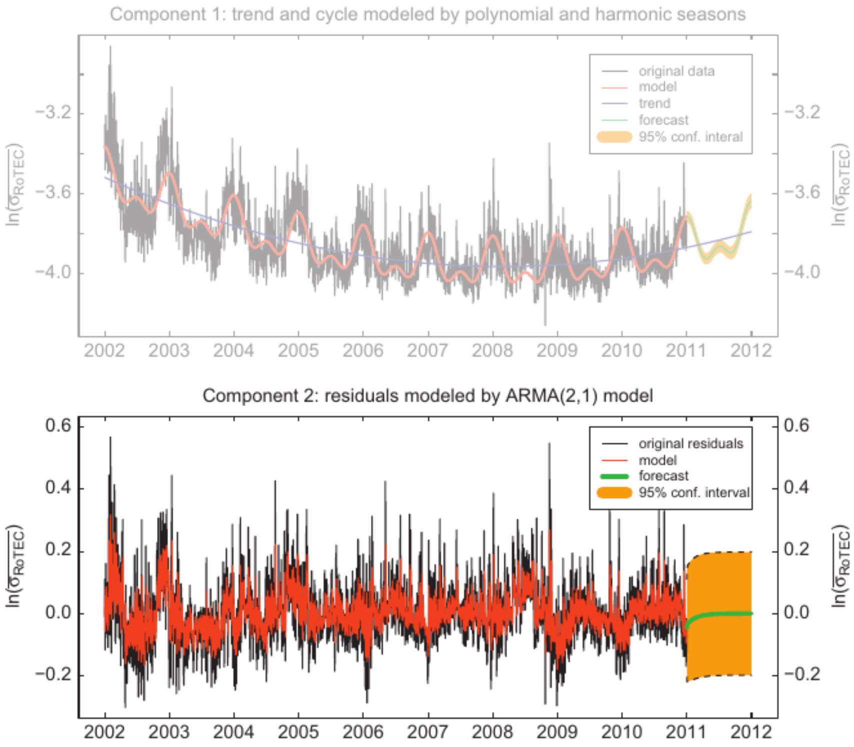
Wautelet et al. (2012), *Local climatological modeling of ionospheric irregularities detected by GPS in mid-latitude regions*, JASTP, 89:132-143.

Offset model: solar cycle and seasonal components



$$\text{Offsets}(t) = a_0 + a_1 t + a_2 t^2 + a_3 \cos\left(\frac{2\pi t}{T_1}\right) + a_4 \cos\left(\frac{2\pi t}{T_2}\right)$$

Offset model: solar cycle and seasonal components



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ARMA = Autoregressive and Moving Average

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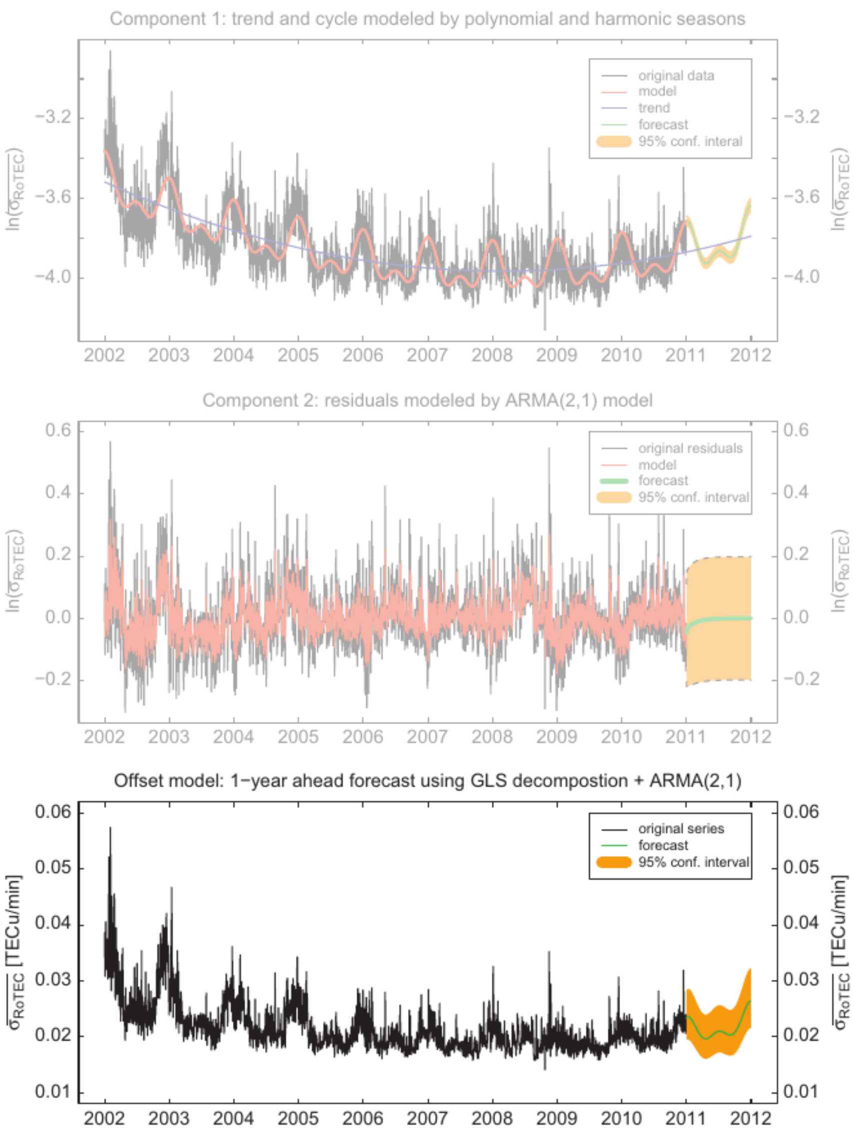

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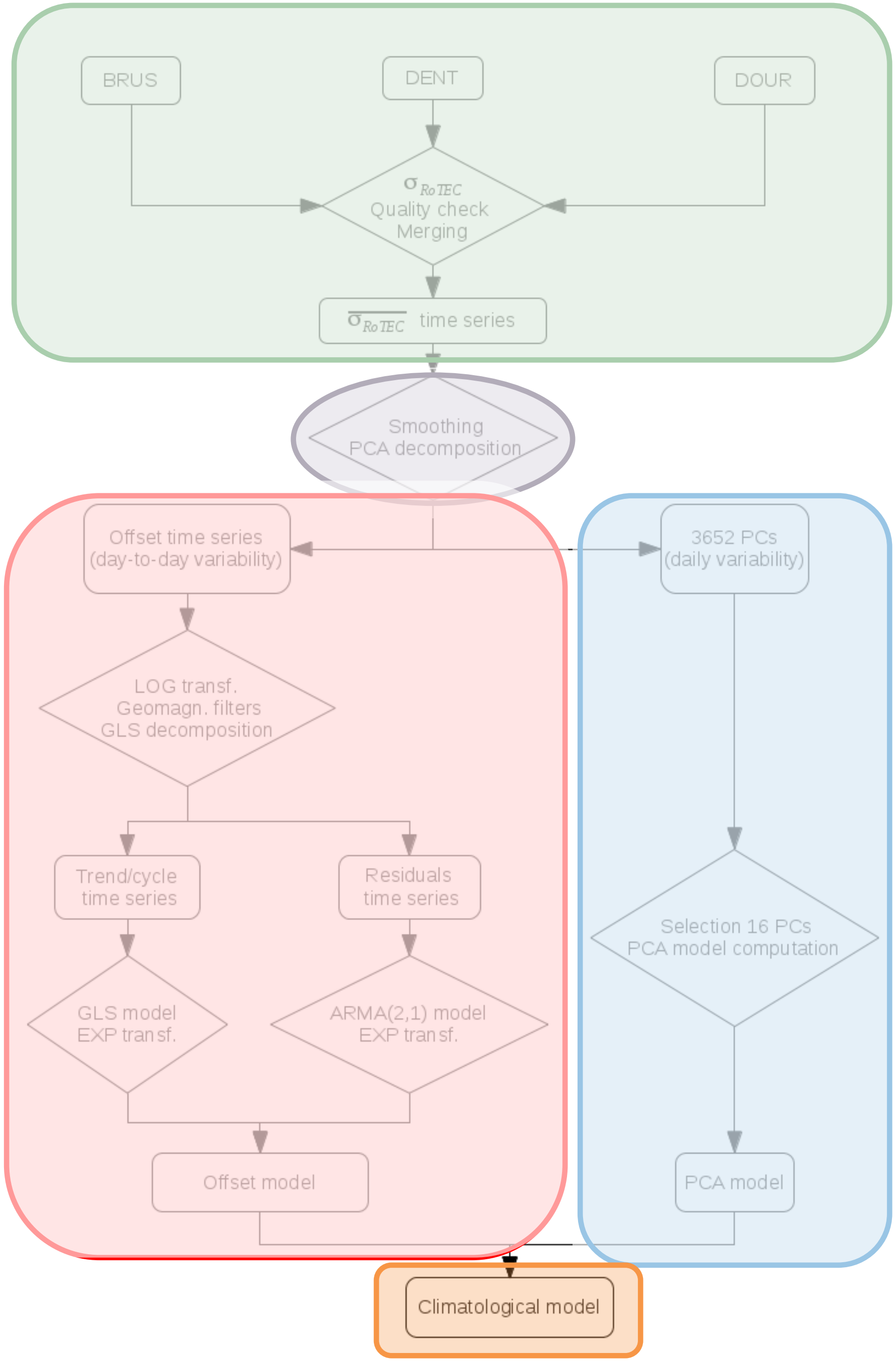
ARMA = Autoregressive and Moving Average

Offset model → solar cycle + seasons



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offset model

5th step: final model

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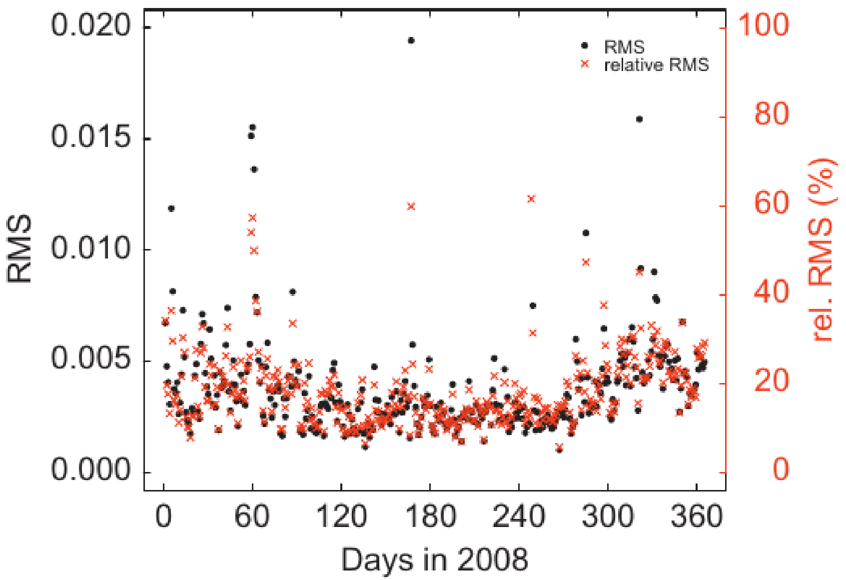
Final model: validation on low and moderate solar conditions

2008 (low solar activity)



Final model: validation on low and moderate solar conditions

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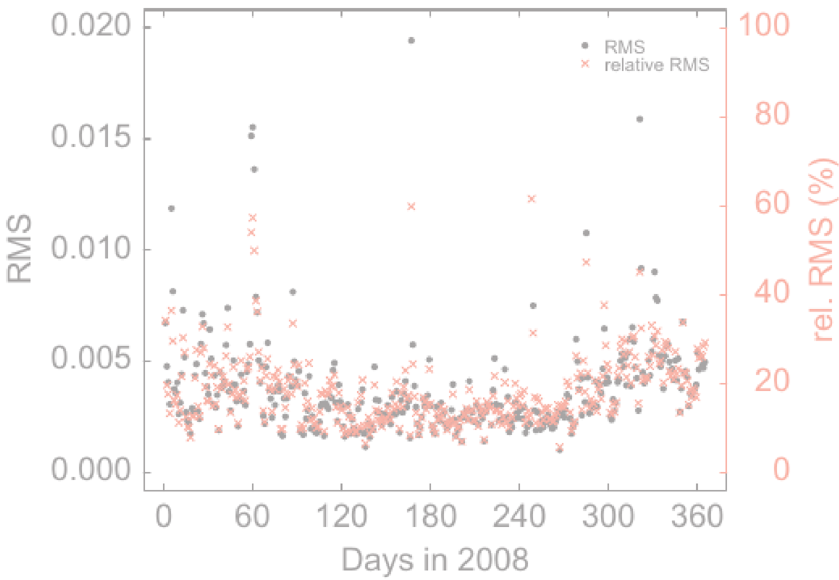
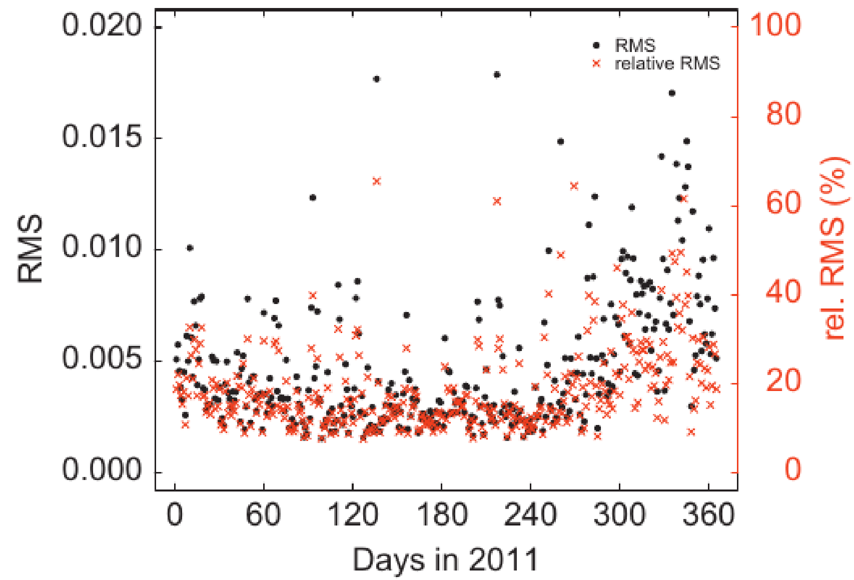


2011 (moderate solar activity)



In conclusion…

- Local climatological model divided into 2 components
  Daily, seasonal, solar cycle variations
- Performance of 10 - 15% (summer) and 20 - 25% (winter)
- Next steps :
  - Improve solar cycle modeling
  - Include geomagnetic component
  - Validation on other regions (lat/lon)

Thank you!

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