19th International Beacon Satellite Symposium, ICTP, Trieste, Italy, 27 June – 1 July, 2016
Session 4A : Polar (high-latitude) Effects on GNSS

Empirical statistical model relating scintillation indices with solar and geomagnetic activity for L band GNSS receivers at high latitudes

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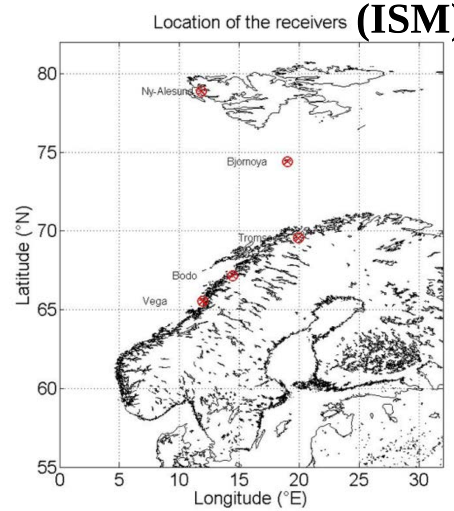
retour sur innovation

Introduction

- **Context of the activity :**
  - **French-Norwegian collaboration agreement :**
    - French Space Agency (CNES), French Aerospace Lab (ONERA)
    - Norwegian Space Centre (NSC) + Norwegian Mapping Authority (NMA)
  - **Goal : develop a forecast model of ionosphere-caused GNSS signal disturbances at high latitude, especially scintillation**
  - **PolaRxS Ionospheric Scintillation Monitors installed in Norway since 2012**
  - **Access to standard GNSS receivers long term database (SATREF)**



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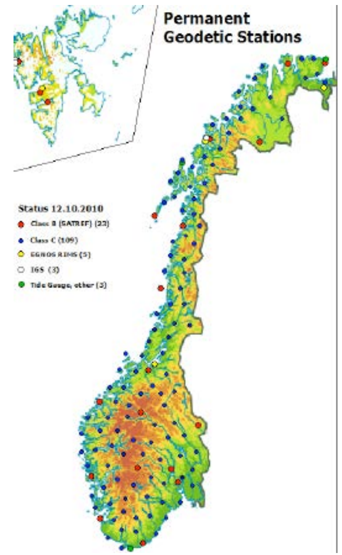


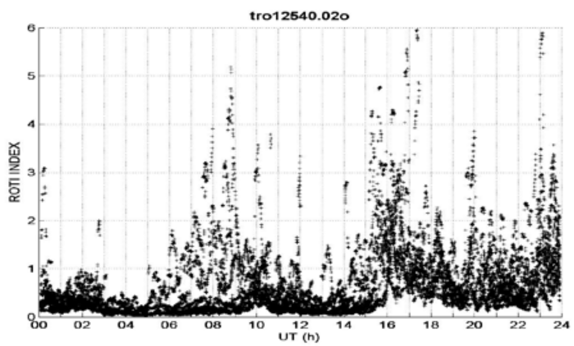
- **Outline of the presentation :**
  - **Models relating ROTI to geomagnetic indices**
  - **Empirical model relating σ_ϕ to ROTI**
  - **Conclusion and perspectives**

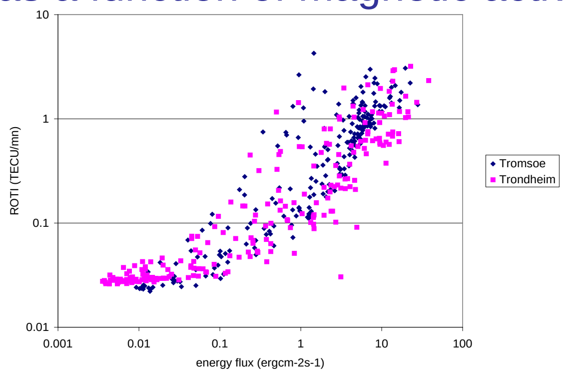
First attempt for a ROTI prediction model from geomagnetic activity [Boscher & al, EUCAP 2014]

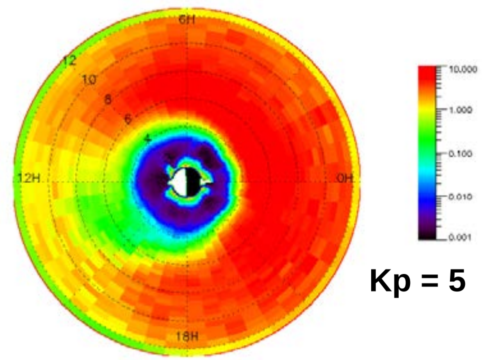
Step 1 : Ionosphere disturbances have been tracked from processing of ROTI for a data set from 2001 to 2011

Step 2 : Link between ROTI and particles energy fluxes (concurrently measured by NOAA POES for a large range of energy values)

Step 3 : Matrices of particles energy fluxes as a function of magnetic activity parameter Kp





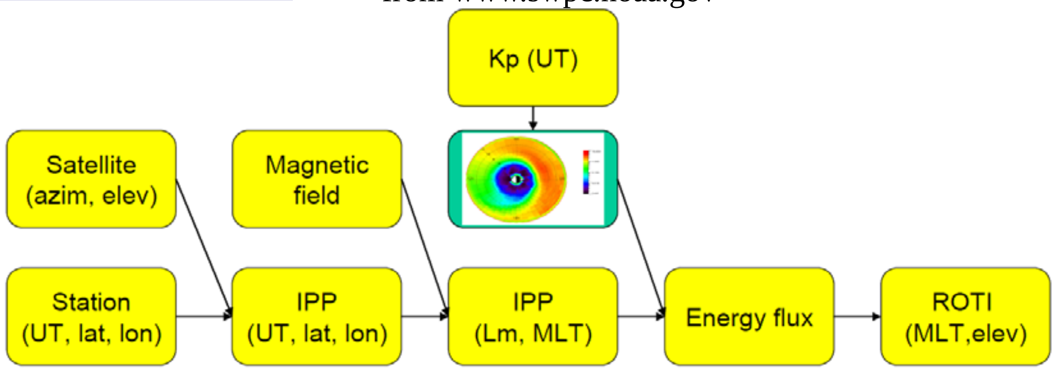


Kp = 5

$$\mathrm{ROTI} = \frac{0{,}025+0{,}005\sin(MLT+7{,}5)}{\sin(elev)^{1{,}5+0{,}5\sin(MLT+17)}} + 0.1294\ \text{Energy flux} * 1{,}0082^{elev-65{,}2} \quad \text{for } Kp \leq 6$$

Model Flowchart

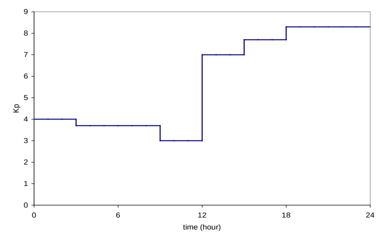
from www.swpc.noaa.gov

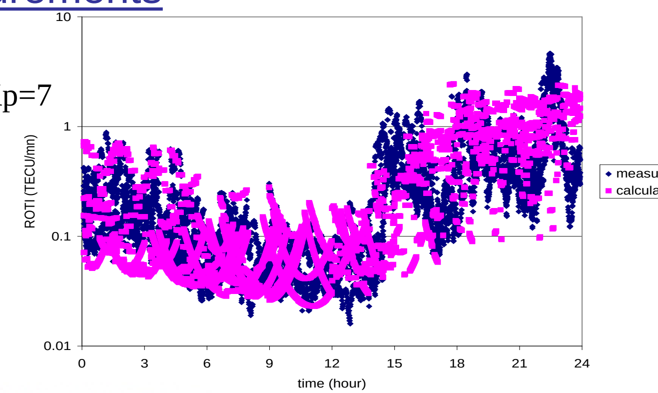


Comparison with measurements

Active day : May 29th 2003

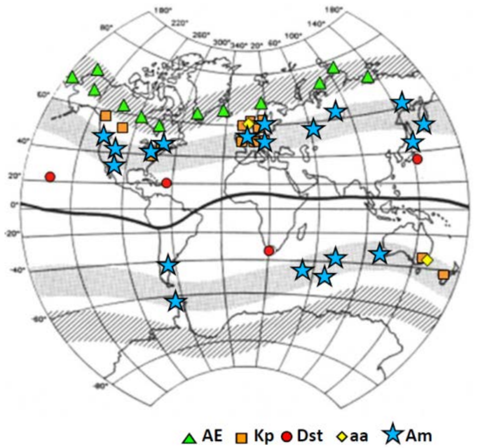
Kp switches from Kp=3 to Kp=7





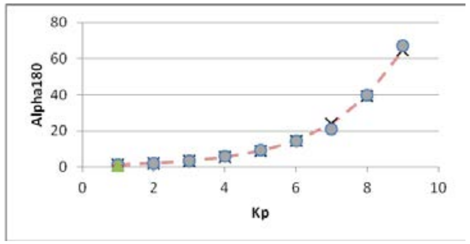
Improved ROTI prediction model

Step 4 : Looking for a better magnetic activity parameter, use of new alpha parameter (from International Service of Geomagnetic Indices). Alpha is a global magnetic activity index with up to 15 mn resolution.



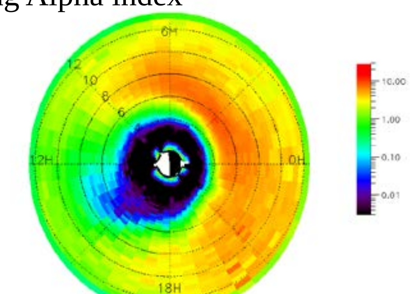
gamme	0	1	2	3	4	5	6	7	8	9
Kp	0,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	>9

gamme	0	1	2	3	4	5	6	7	8	9
Alpha 180	0,72	1,2	2	3,5	6	9,5	14,5	21	40	>67



$$Alpha180 = 0.72\, e^{0.50\, Kp}$$

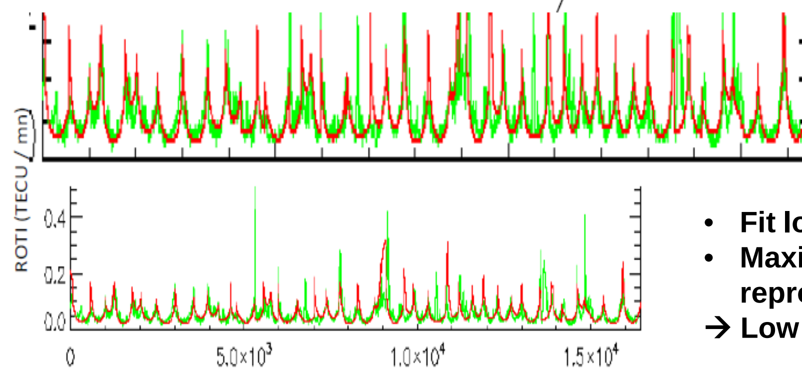
Analysis of energy fluxes using Alpha index



Gamme 5, Alpha60

Correlation coefficient between calculated and measured ROTI at Trondheim

	Alpha 15	Alpha 30	Alpha 60	Alpha 120	Alpha 180
Low activity level	37 %	37,04 %	48,72 %	48,63 %	45,22 %
Medium activity level	37,1 %	38,79 %	80 %	56 %	43 %
High activity level	2,4 %	8,81 %	7,8 %	6,3 %	-21,02 %



- Fit looks quite nice
- Maxima are not well reproduced

→ Low correlation coeff.

- Time resolution of the model has been improved (60 mn)
- Good representation of ROTI behavior for low/medium magnetic activity levels, but does not provide an accurate ROTI amplitude
- Preliminary study to define ROTI flag levels, but needs to be improved
- Alpha indices are not currently provided by ISGI, and is not yet IAGA endorsed

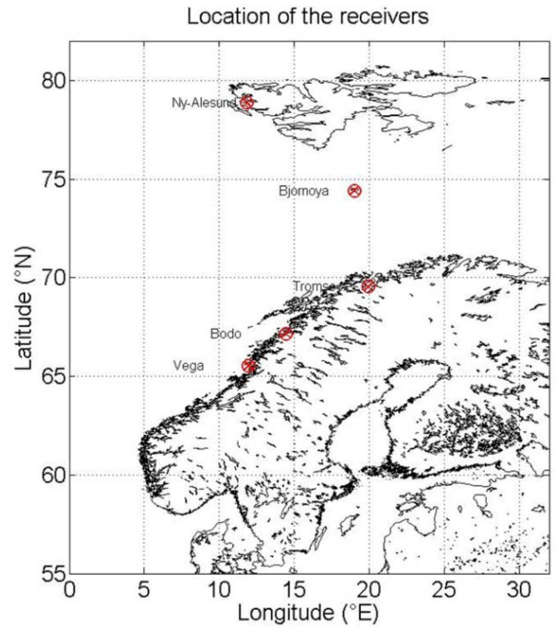
<u>Still the model is not as efficient as we need for a forecast model in every situation, especially for high magnetic activity !</u>

Prediction model of σ_ϕ from ROTI

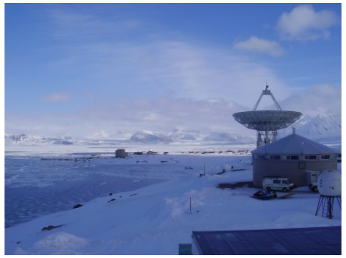
- **Objective :**
  - **Develop a prediction model to have directly access to ionospheric scintillation characteristics:**
    - S_4 related to amplitude scintillation (not relevant at high latitude)
    - **σ_ϕ related to phase scintillation (strongly relevant at high latitude)**
    - Turbulence spectrum

- **Scintillation monitors installed in Norway**

Site	Receiver ID	Latitude	Longitude
Tromso	TRO2	69.539917	18.938883
Vega	VEG2	65.531298	11.964081
Ny-Alesund	NYA2	78.860408	11.858982
Bjornoya	BJO2	74.406795	19.001955
Bodo	BOD2	67.153025	14.434391



- **3 steps for Data processing and sensitivity analysis**
  - Detrending of Signal Intensity and Carrier Phase
  - Computation of high temporal resolution ionospheric indices (S4, $\boldsymbol{\sigma_\varphi}$)
    - Influence of filtering
    - Comparisons with pre-computed low resolution indices
  - Computation of STEC, ROT and ROTI time series

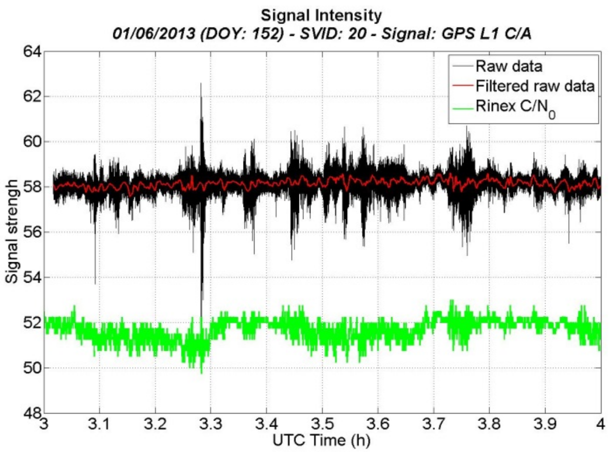


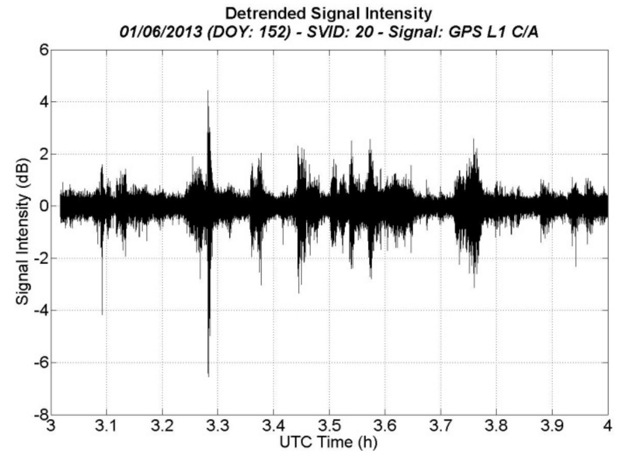
→ Empirical model of σ_ϕ knowing ROTI

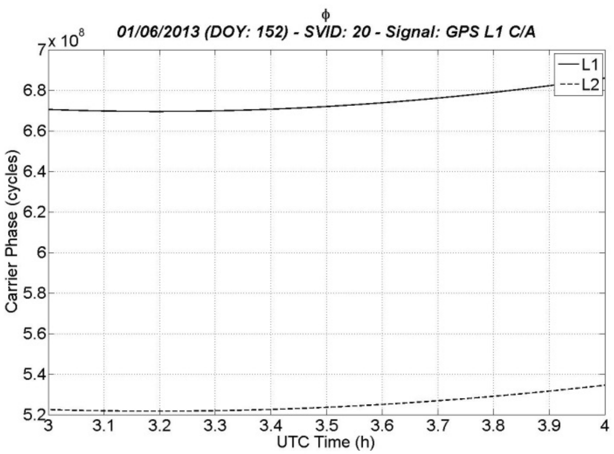
Prediction model of σ_ϕ from ROTI

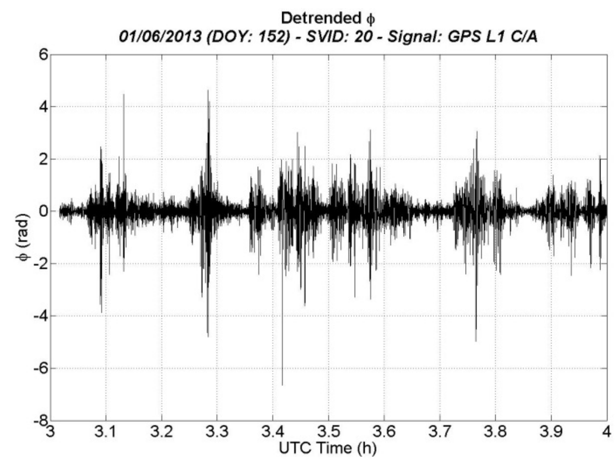
Data processing

- **Step 1**: Detrending Signal Intensity and Carrier Phase measurements



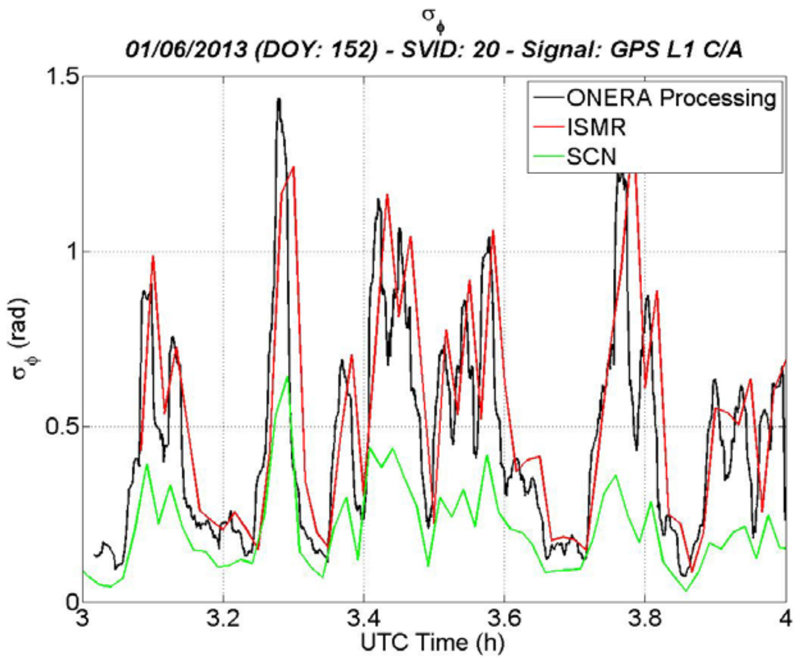


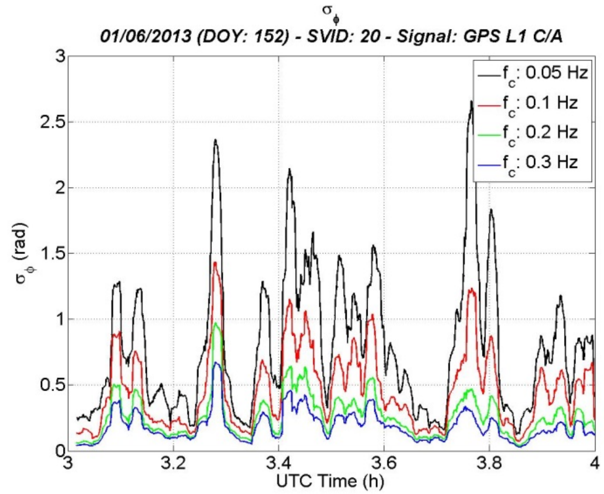




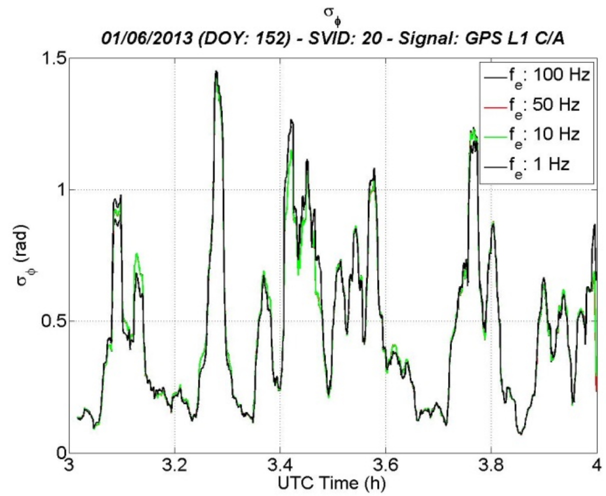
Prediction model of σ_ϕ from ROTI
Data processing

- **Step 2: Computation of high resolution ionospheric indices**





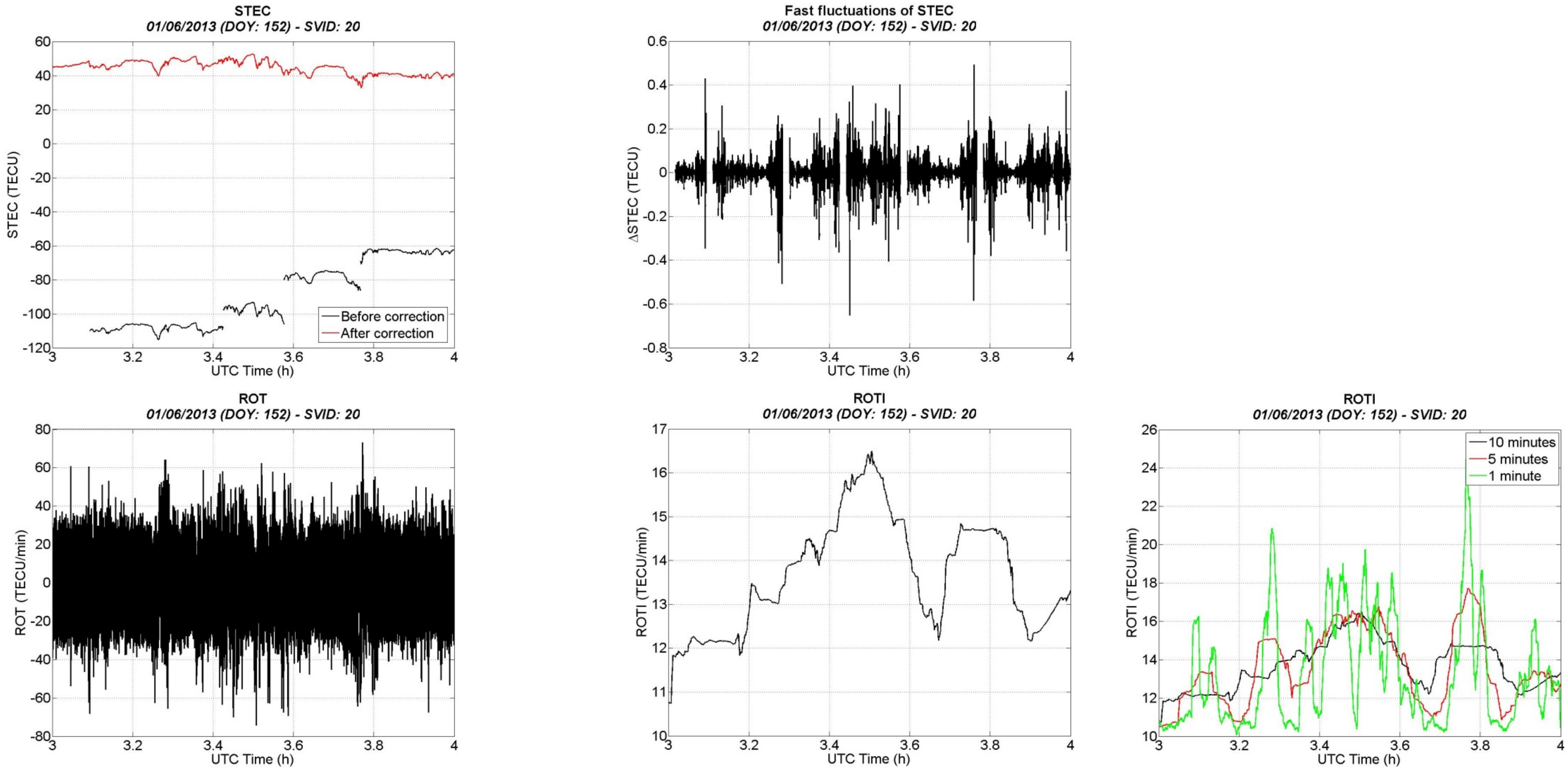
Influence of filtering



Influence of sampling rate

Prediction model of σ_ϕ from ROTI
Data processing

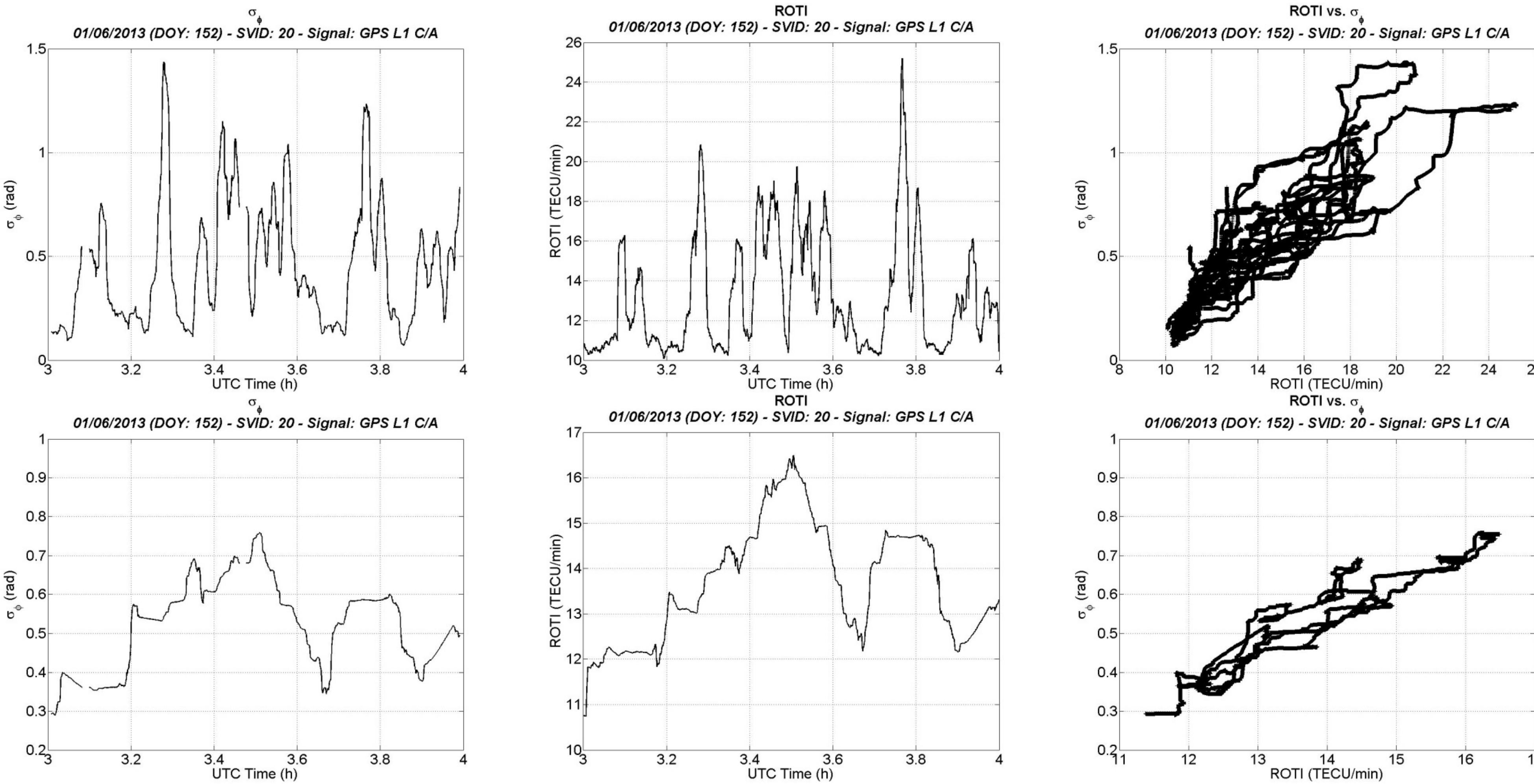
- **Step 3**: Computation of high temporal resolution STEC, ROT and ROTI



Prediction model of σ_ϕ from ROTI

Development of a new model of σ_ϕ

- **Start from the observation of the scatterplots of ROTI/σ_ϕ**



Fs = 100 Hz
Win = 60s

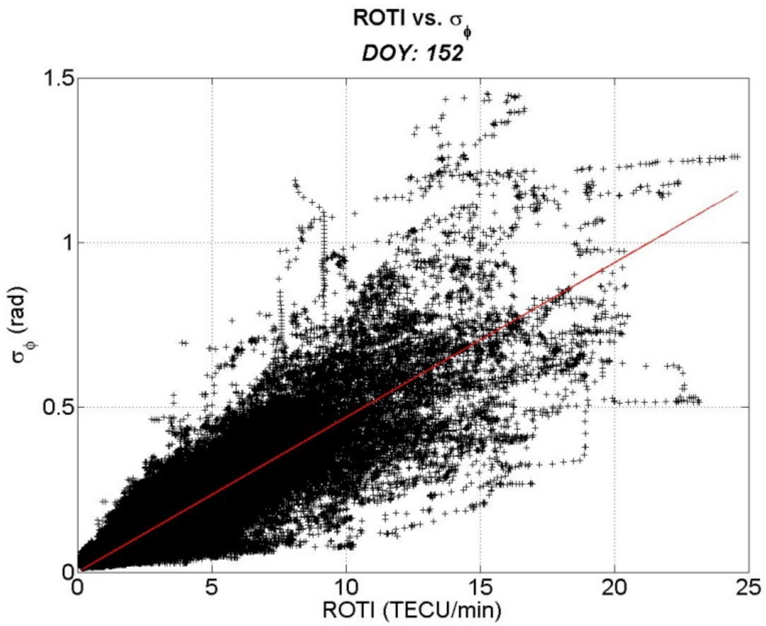
Fs = 100 Hz
Win = 10min

Prediction model of σ_ϕ from ROTI

Development of a new model of σ_ϕ

- **Strong correlation but not a direct relationship**
  - New model based on the conditional Probability Distribution Function (PDF) of σ_φ knowing the value of ROTI
  - Assumed to be log-normal with parameters μ and σ

$$p\left(\sigma_\varphi \middle| ROTI\right) = \frac{1}{\sigma_\varphi \sigma \sqrt{2\pi}} \exp\left(-\frac{\left[\ln(\sigma_\varphi) - \mu\right]^2}{2\sigma^2}\right)$$



$$E\left[\sigma_\varphi \middle| ROTI\right] = K \cdot ROTI$$

Prediction model of σ_ϕ from ROTI

Development of a new model of σ_ϕ

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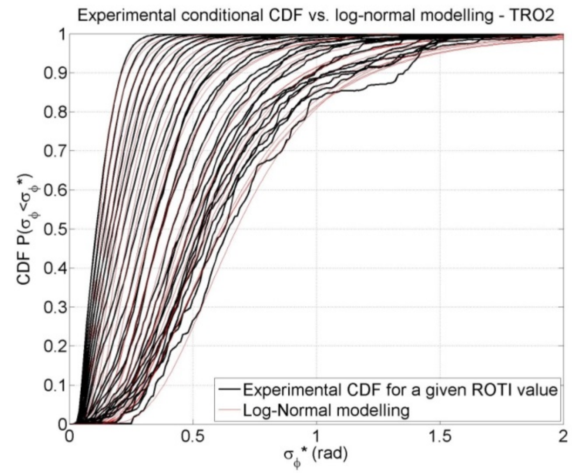
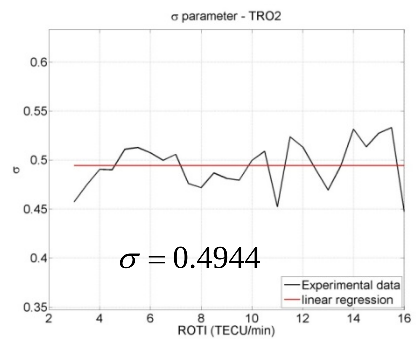
- **Parameterization**
  - **Due to the huge database and to avoid prohibitive computation time, it has been chosen to use data:**
    - collected at 5 sites (Tromsoe, Vega, Ny-Alesund, Bjornoya, and Bodo)
    - re-sampled at 1 Hz
    - concurrent to data analyzed in a previous NMA report for which the magnetic activity had been detected as moderate or strong.

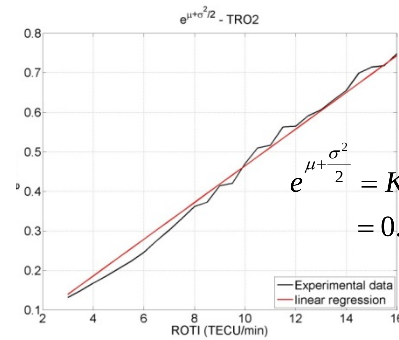
- **Parameters retrieval**



$$P\left(\sigma_\varphi > \sigma_\varphi^* \middle| ROTI\right) = \frac{1}{2} erfc\left(\frac{\ln\left(\sigma_\varphi^*\right) - \ln\left(K \cdot ROTI\right) + \frac{\sigma^2}{2}}{\sqrt{2}\sigma}\right)$$



$\sigma = 0.4944$



$$e^{\mu+\frac{\sigma^2}{2}} = K \cdot ROTI = 0.0464 \cdot ROTI$$

Prediction model of σ_ϕ from ROTI

Development of a new model of σ_ϕ

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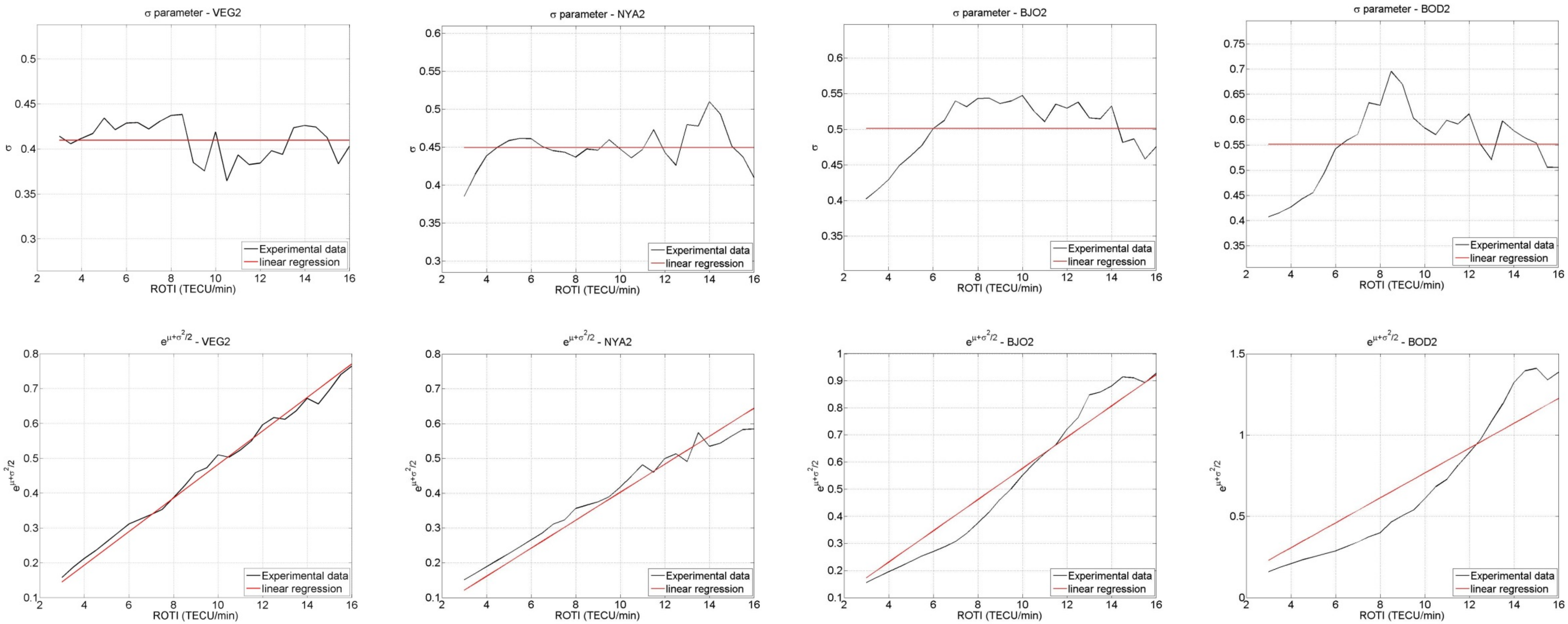
- **Other results**

Site	Receiver ID	σ	K
Tromso	TRO2	0.4944	0.0464
Vega	VEG2	0.4096	0.0482
Ny-Alesund	NYA2	0.4496	0.0402
Bjornoya	BJO2	0.5014	0.0576
Bodo	BOD2	0.5510	0.0766



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Risk estimation

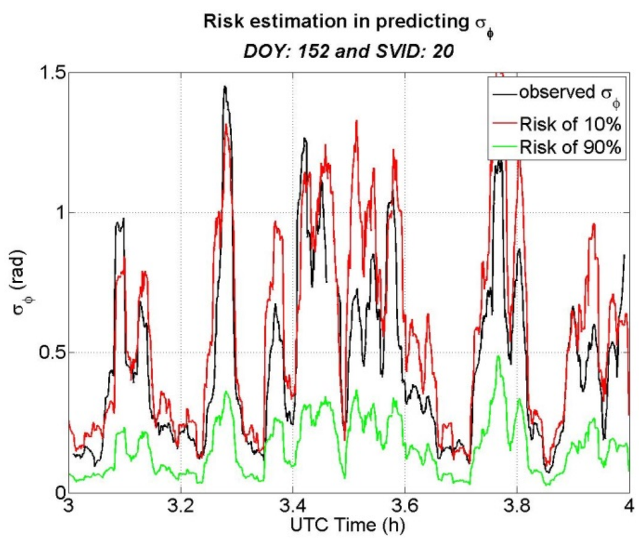
- Starting from a given value of ROTI (which can be predicted), the problem is now to estimate the risk, $\Re$, that the phase scintillation index on L1 exceeds the value σ_φ .

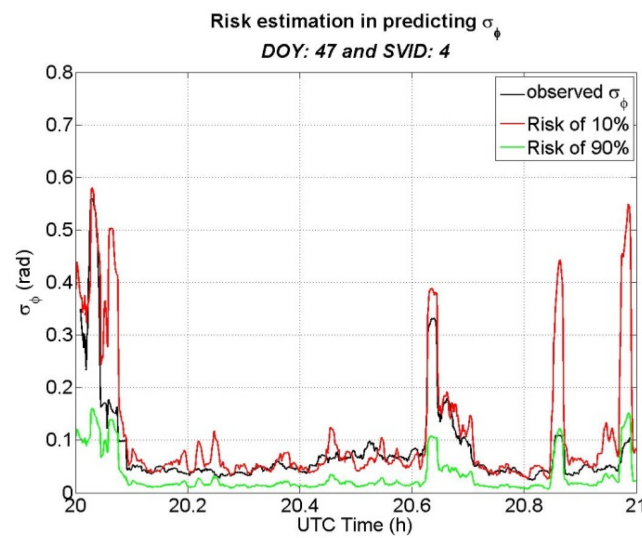
Recalling that the phase scintillation index is log-normally distributed, it follows:

$$\Re = P\left(\sigma_\varphi > \sigma_\varphi^* \middle| ROTI\right) = \frac{1}{2} erfc\left(\frac{\ln(\sigma_\varphi) - \ln(K \cdot ROTI) + \frac{\sigma^2}{2}}{\sqrt{2}\sigma}\right)$$

or equivalently,

$$\sigma_\varphi = \exp\left(\sqrt{2}\sigma erfc^{-1}(2\Re) + \ln(K \cdot ROTI) - \frac{\sigma^2}{2}\right)$$





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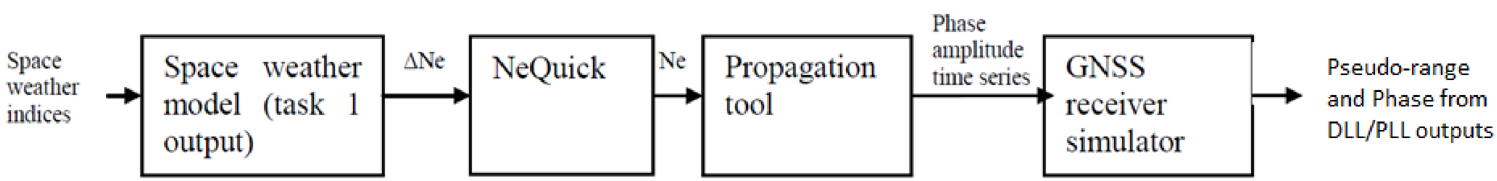
Conclusions and perspectives

- **ROTI prediction models based on geomagnetic indices (Kp and Alpha)**
  - **Statistical approach (fit between ROTI and geomagnetic indices thanks to energy flux maps)**
    - \+ Give a coarse prediction of the scintillation, Very simple to implement and very fast, No similar model in the literature
    - \- Not enough accurate and efficient for storm prediction and application (civil aviation)
- **A statistical link between ROTI and σ_φ**
  - **A prediction model of σ_φ on L1 has been proposed.**
    - The probability distribution function of σ_φ knowing concurrent values of ROTI has been derived.
    - Parameters have been extracted for raw data sampled at 1 Hz and an integration window of 60 s (common value for estimating σ_φ) or 10 minutes (common value for estimating ROTI).
  - **A methodology to estimate the risk in predicting the phase scintillation index has been proposed.** It allows people to be warned (with a probability threshold) when a value of σ_φ could be exceeded.

<u>Perspectives</u> : **try to make prediction from space weather indices** (during CME event)

- relation between solar wind and energetic particles coming in the ionosphere : coupling functions for assessing additional quantity of injected particles in the ionosphere $\Delta N_e(\varphi, \lambda, h)$, comparison of satellite in solar wind data (such as ACE) and low orbit satellite data (as POES) ?
- Put together effects of solar wind on ionosphere characteristics and navigation receivers response (in particular PLL and DLL), for instance :



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