Ionosphere Scintillation Mapping

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Contents

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- Input Data
- Algorithm
- Examples of results
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Calculation Technique

Kriging technique

- Well suited to random data processing

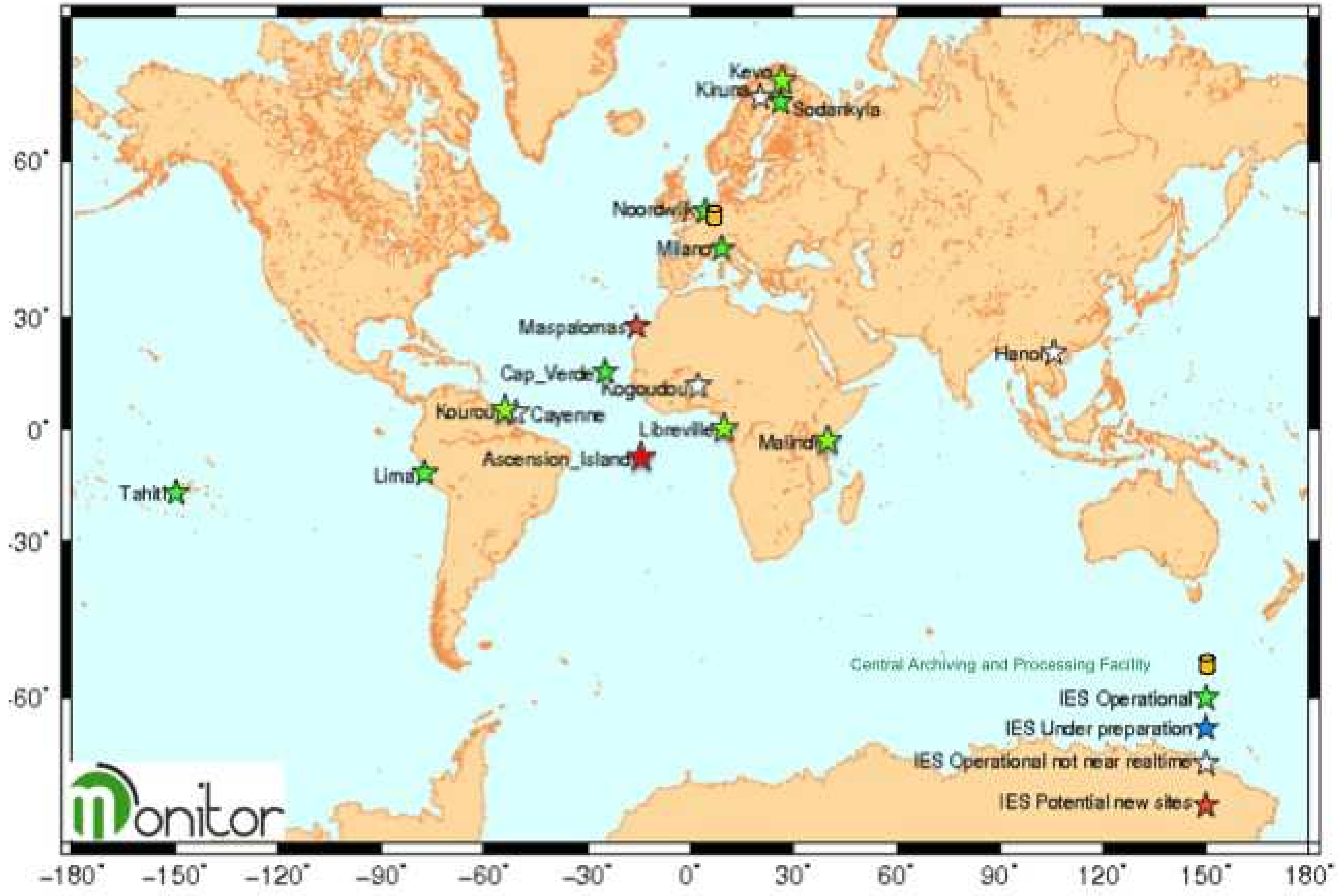
- Accuracy increases with the number of data

- Allows to produce a map and the corresponding error map

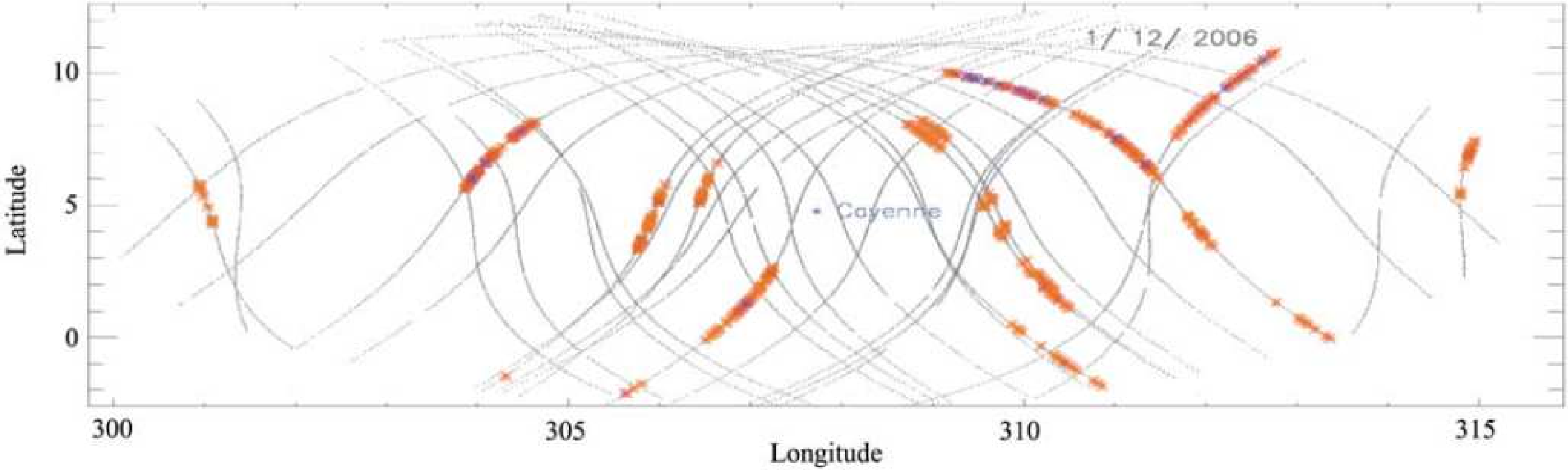
Input Data

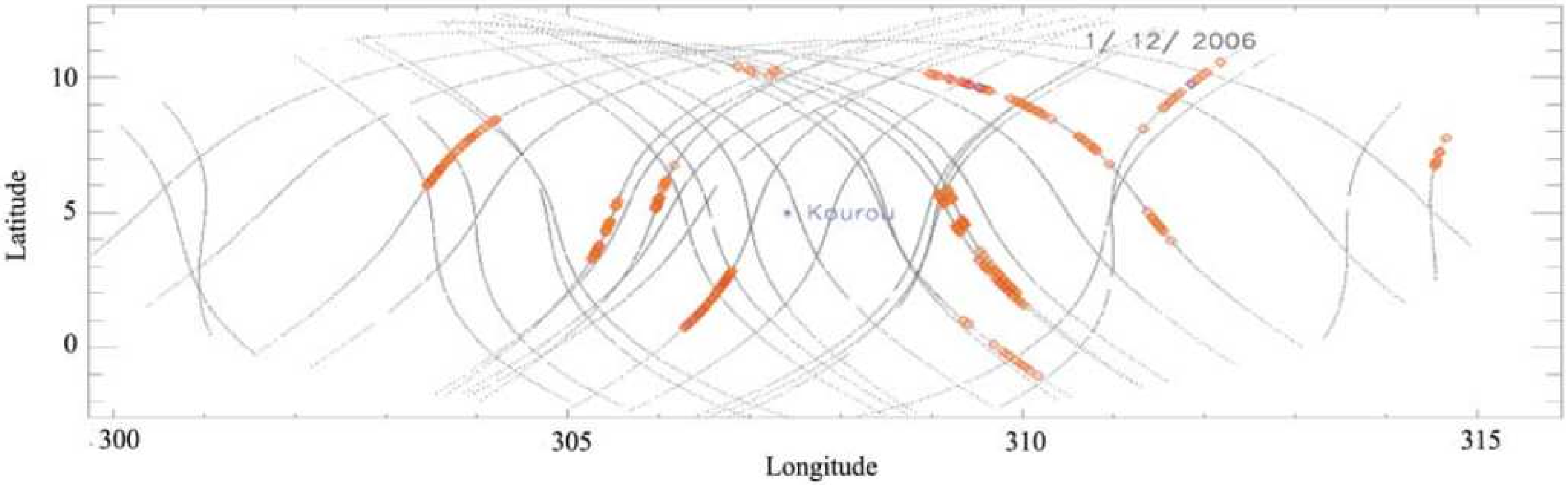
50 Hz receivers	⟶	Monitor Project
1 Hz	⟶	IGS Data
Simulated	⟶	GISM

Monitor Network
50 Hz receivers



Scintillation indices at 50 Hz (top panel) vs 1 Hz (IGS data: bottom panel)





Modelling
(GISM) MPS model

The model includes an orbit generator (GPS, Glonass, Galileo, …)

Inputs

Geophysical Parameters

Scenario

Intermediate calculation : LOS, Ionisation along the LOS

Outputs

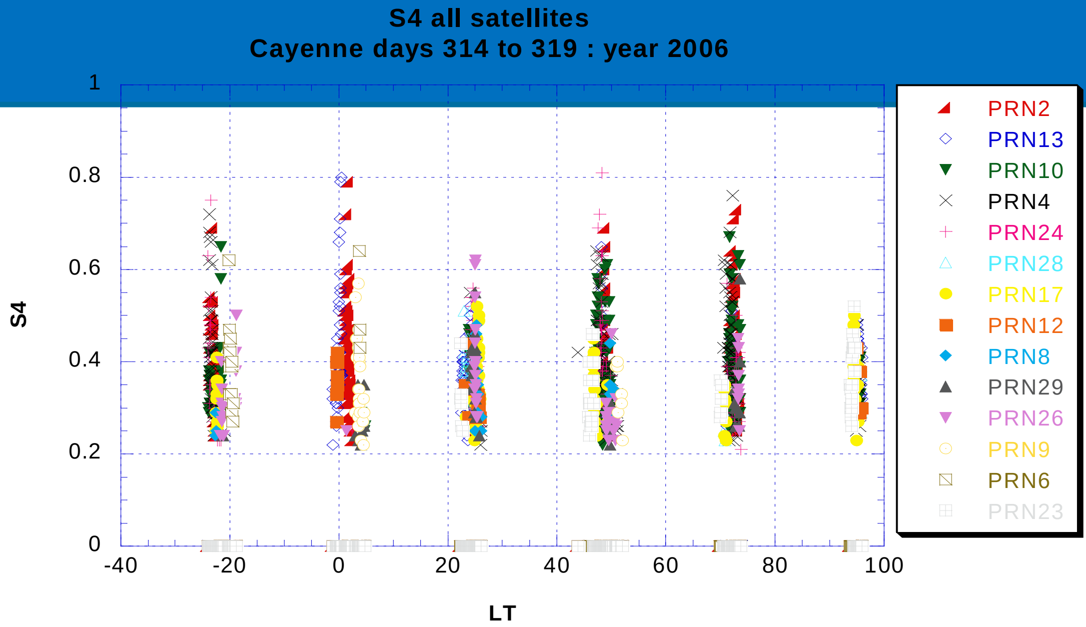
Time series, Scintillation indices, Correlation Distances

Scattering function

Béniguel Y., P. Hamel, "A Global Ionosphere Scintillation Propagation Model for Equatorial Regions", Journal of Space Weather Space Climate, 1, (2011), doi: 10.1051/swsc/2011004

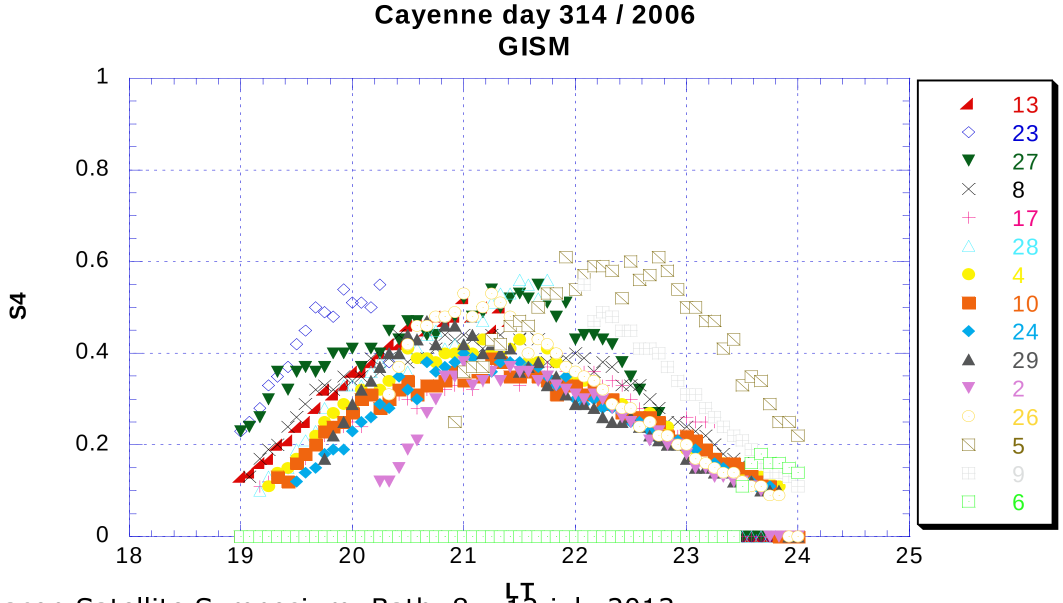
Modelling vs Measurements (Intensity)

Measurements



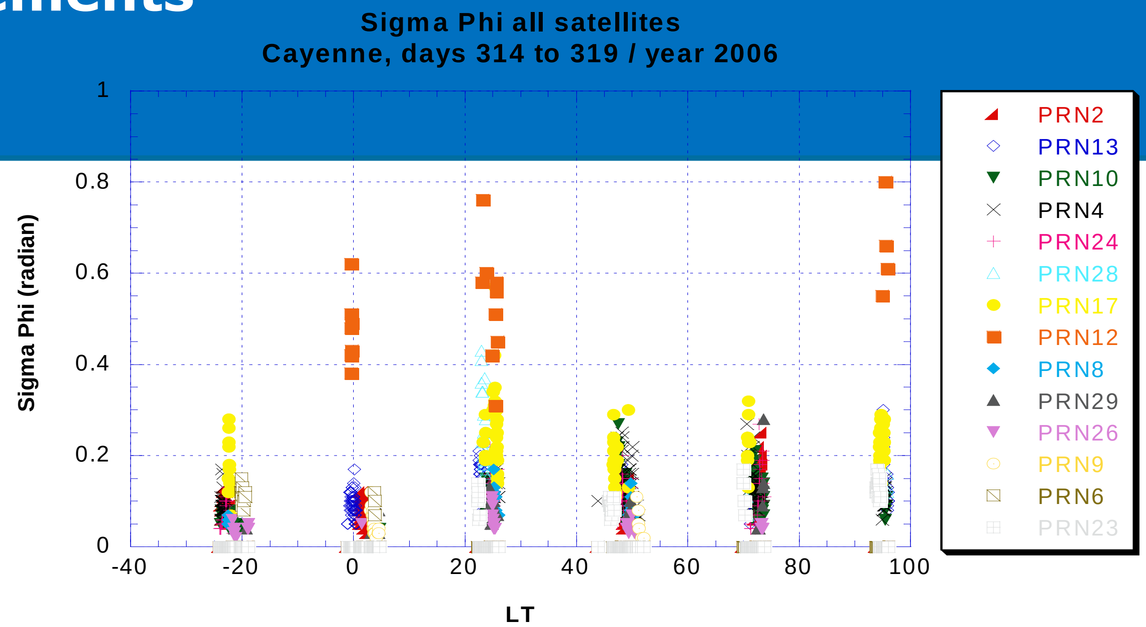
Samples with S4 < 0.2 were ignored (noise level)

Modelling



Modelling vs Measurements (Phase)

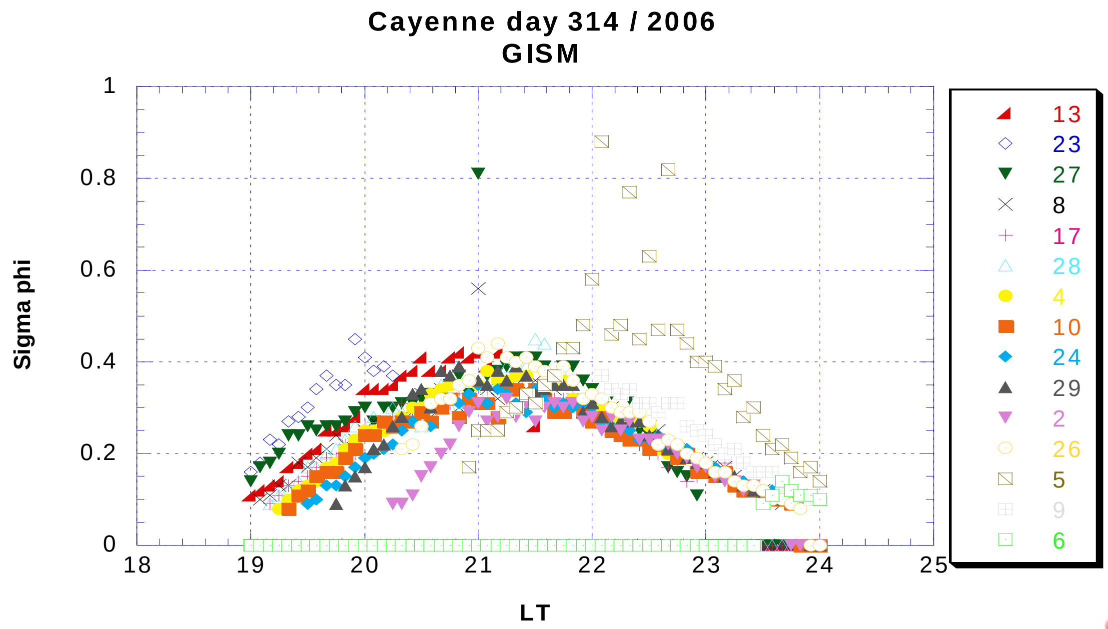
Measurements



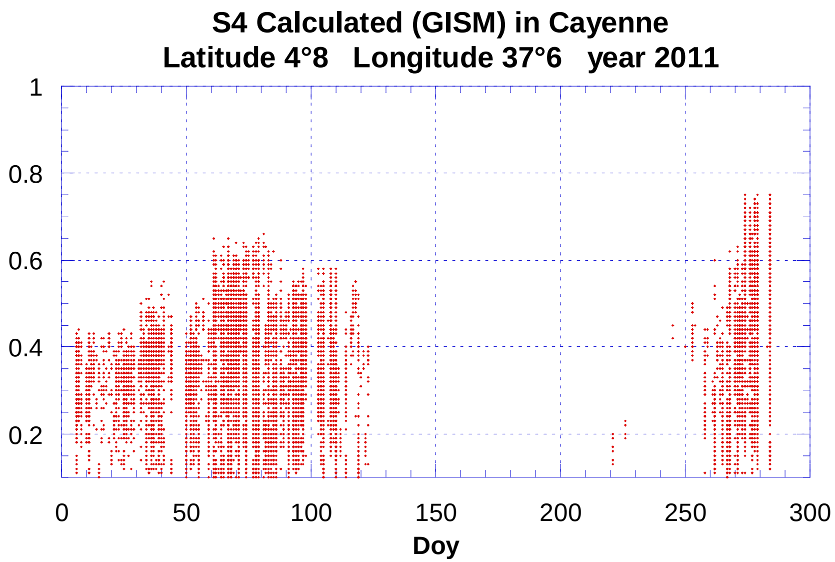
The phase RMS value is slightly lower than the S4 value

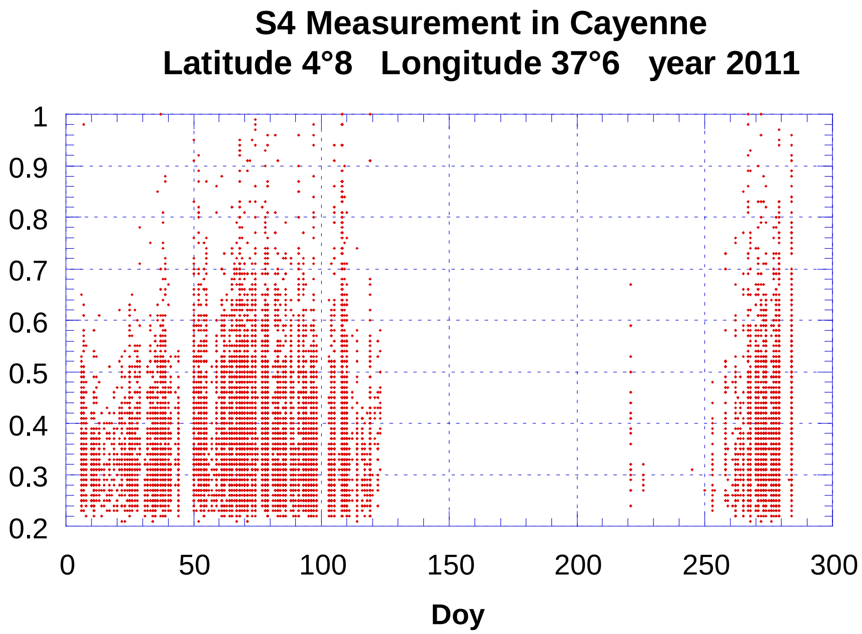
Some samples exhibit high values (both measurements and modelling) due to the phase jumps

Modelling



Comparison with Measurements
Year 2011 / Guiana / Novatel Measurements





Kriging Algorithm

Kriging Random Variables

Y the observable, f a vector of factors (location, …)

Y is the sum of a mean value and a random part

$$Y(f,\omega) = m(f) + \Gamma(f,\omega)$$

$$m(f) = \sum_{1}^{M} a_i \varphi_i(f)$$

Covariance function

$$c(f_i, f_j) = \left\langle \Gamma(f_i, \omega)\, \Gamma(f_j, \omega) \right\rangle = c(h)$$

Covariance Function

- **Many data points**

Computation of the experimental covariance

- **Few data points**

Choice of the covariance function among known models.

Kriging Interpolation Technique

A linear estimator is built with all data points

$$Y^* = \sum_{1}^{N} \lambda_j \; Y(f_j, \omega)$$

The outcome at f_0 is linear

$$Y^*(f_0) = \sum_{1}^{N} \lambda_j (f_0, f_j, c) \, Y(f_j)$$

The estimator gives an exact value at the data points
(Lagrange multipliers)

Variance Minimization

- Minimizing the variance $\left| Y^* - Y_0 \right|^2$

- Taking the inverse of the covariance matrix

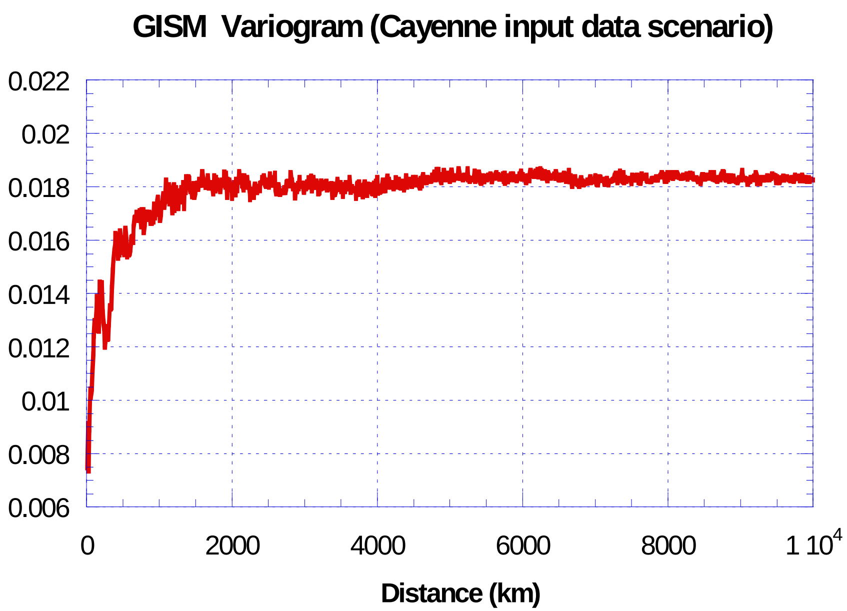
$$Y^*(f_0) = w^T \, Y$$

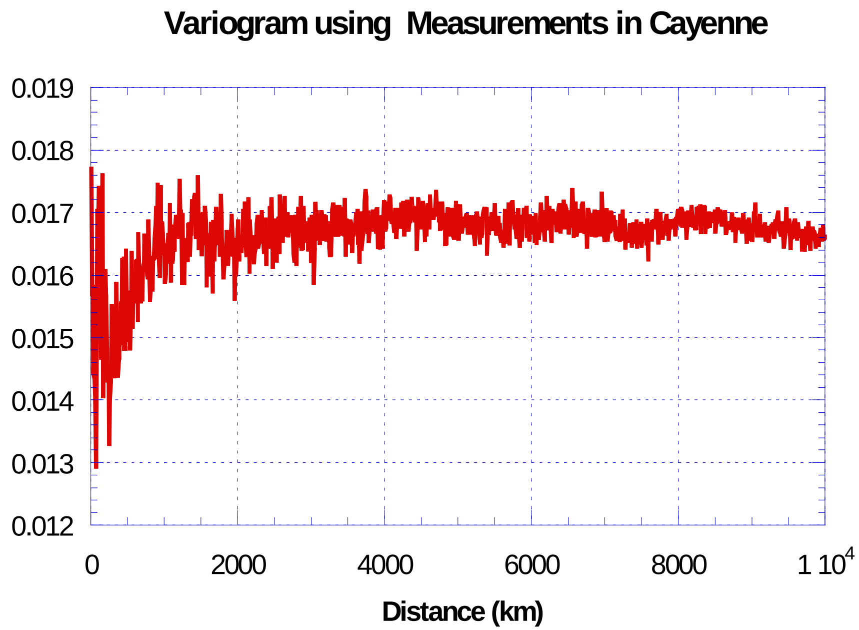
- It is an exact interpolator : no errors at data points

- Gives an estimate of the accuracy of the Kriged estimates

$$\mathrm{Min} \left\langle \left| Y^* - Y \right|^2 \right\rangle = \sigma^2_{\mathrm{Min}}$$

Variogram Estimation



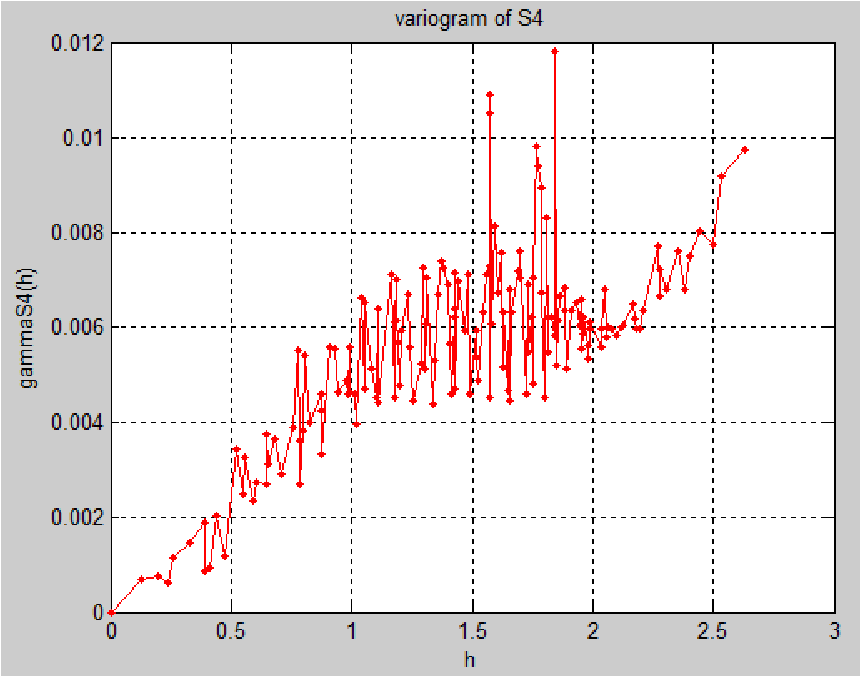


$$\gamma(h) = \left\langle \left| Y(\bar{r}_i) - Y(\bar{r}_j) \right|^2 \right\rangle$$

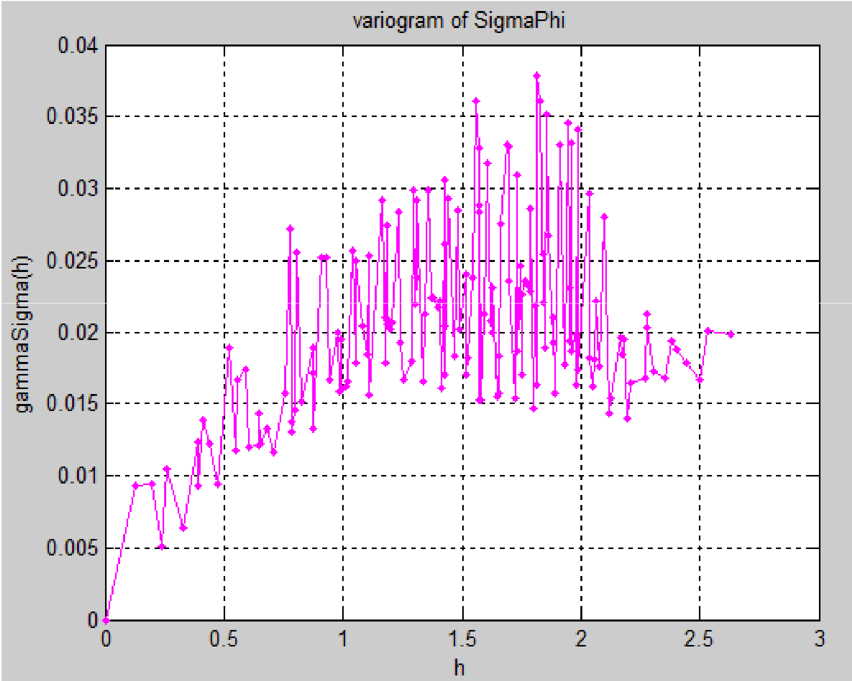
$$h = \left| \bar{r}_i - \bar{r}_j \right|$$

Variograms Estimated on a Reduced Time Duration

Experimental variograms based on GISM calculations



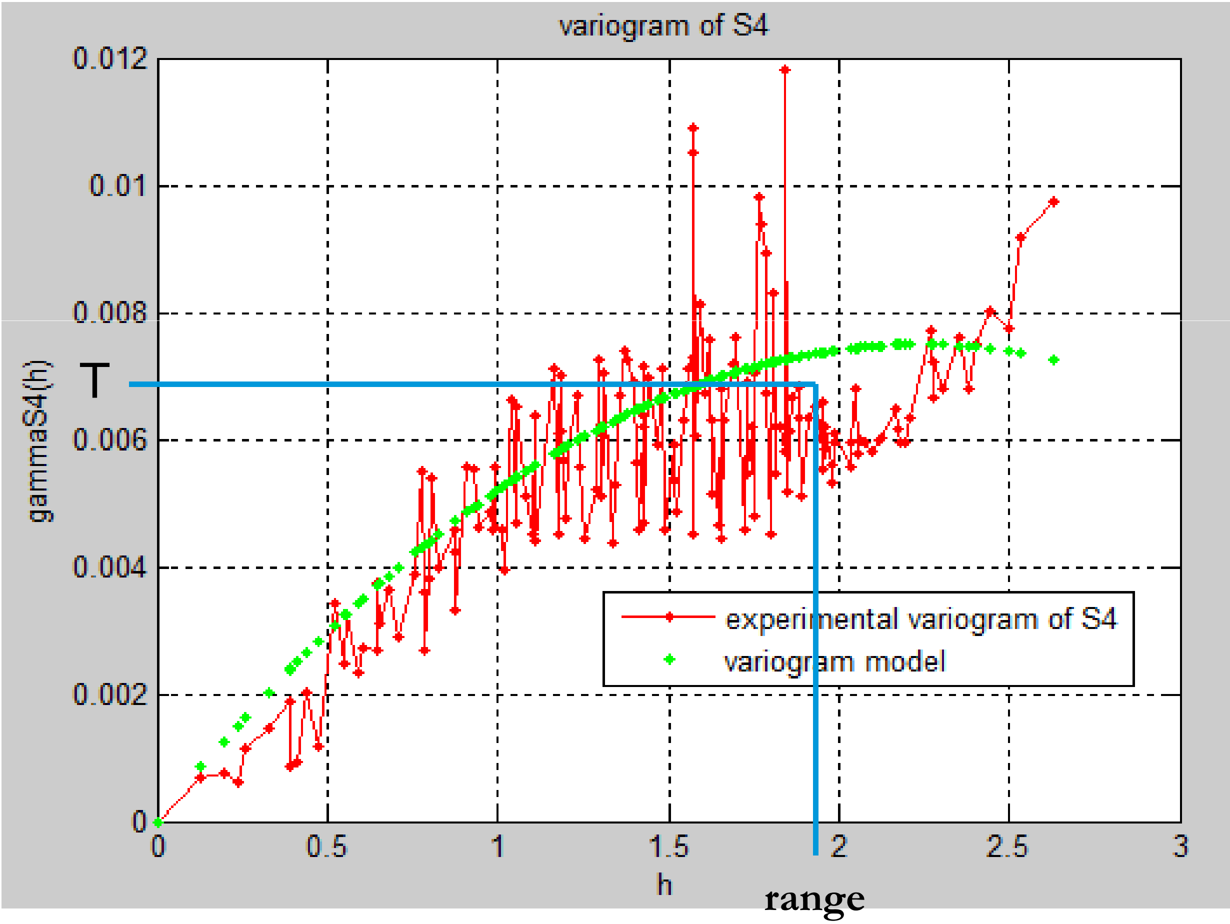
S4 variogram



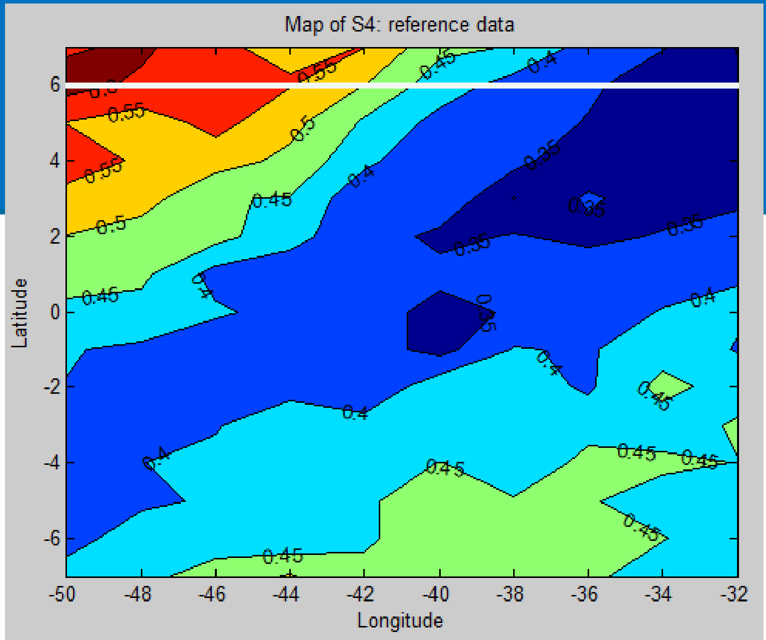
σ_{φ} variogram

Covariance Function

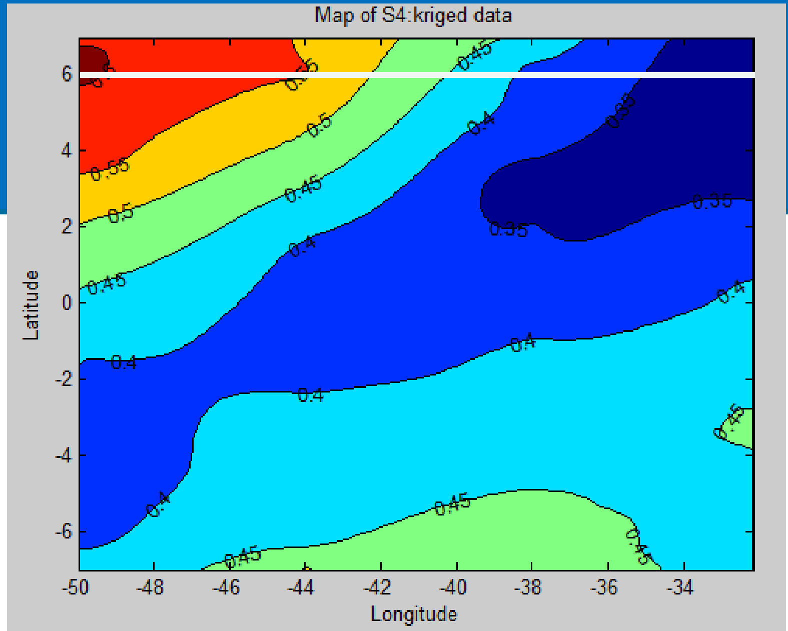
$$C(h) = T - \gamma(h) \quad \text{with} \quad T = 7.410^{-4}$$



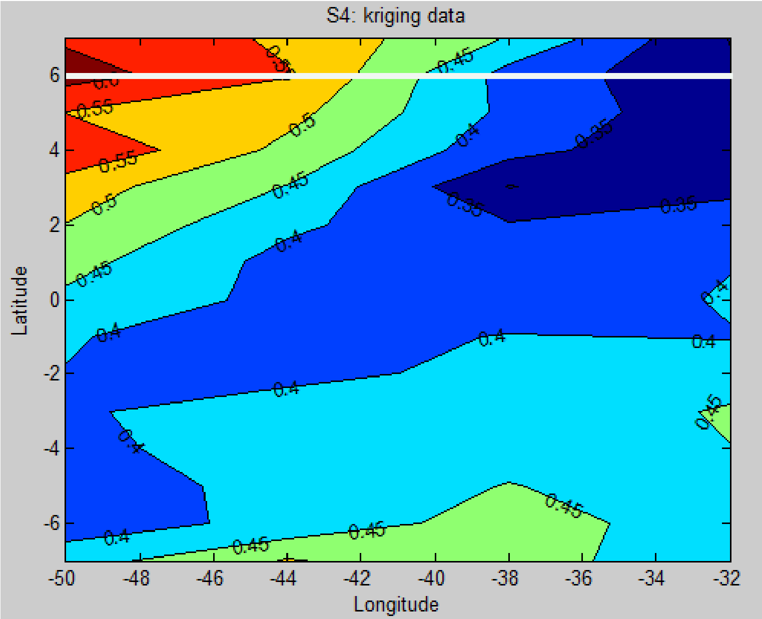
Results of S4 data kriging



Reference data

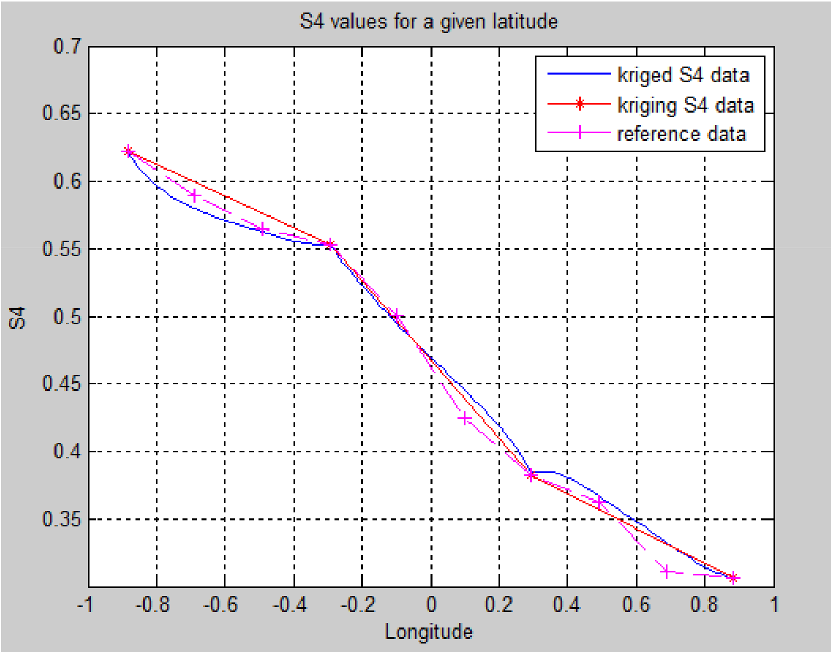


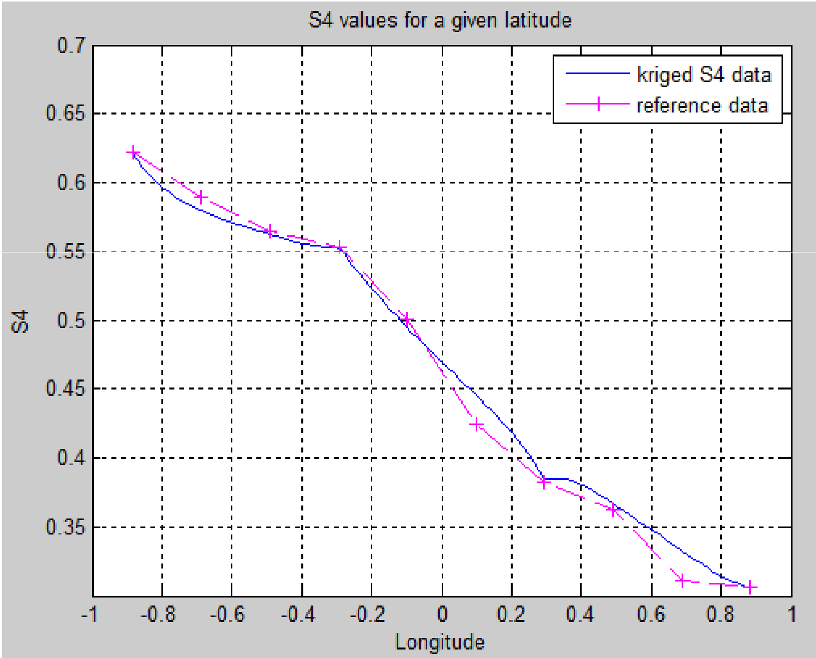
Kriged data



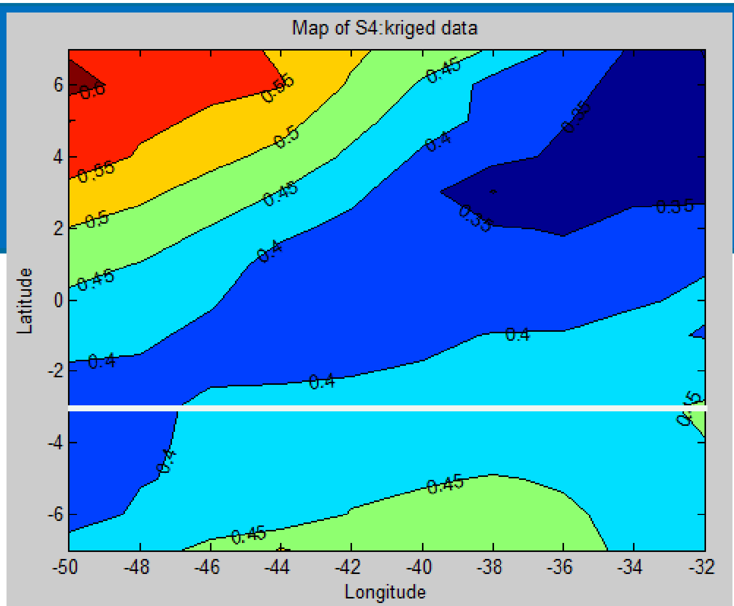
Kriging data

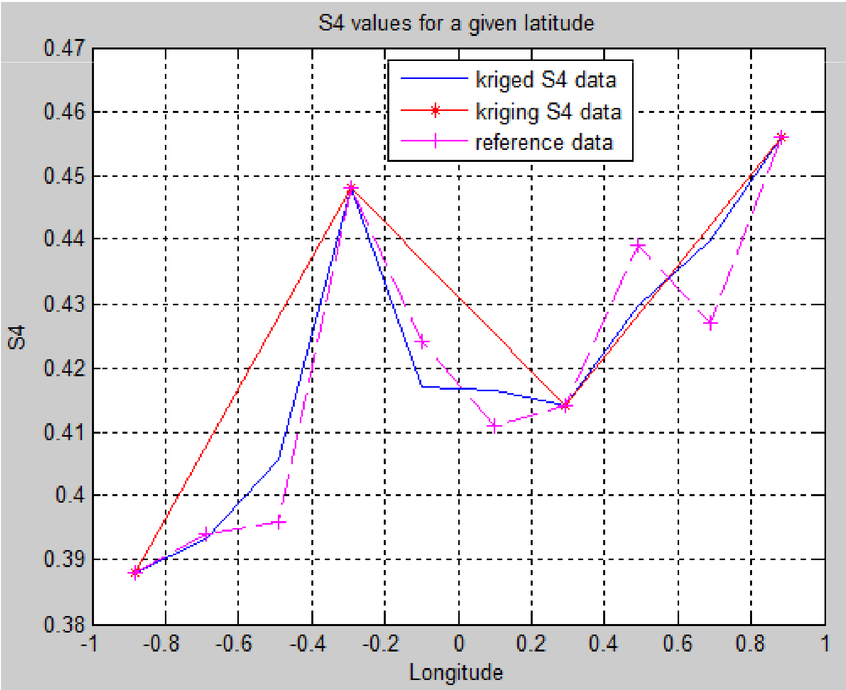
Cut at Latitude 6°

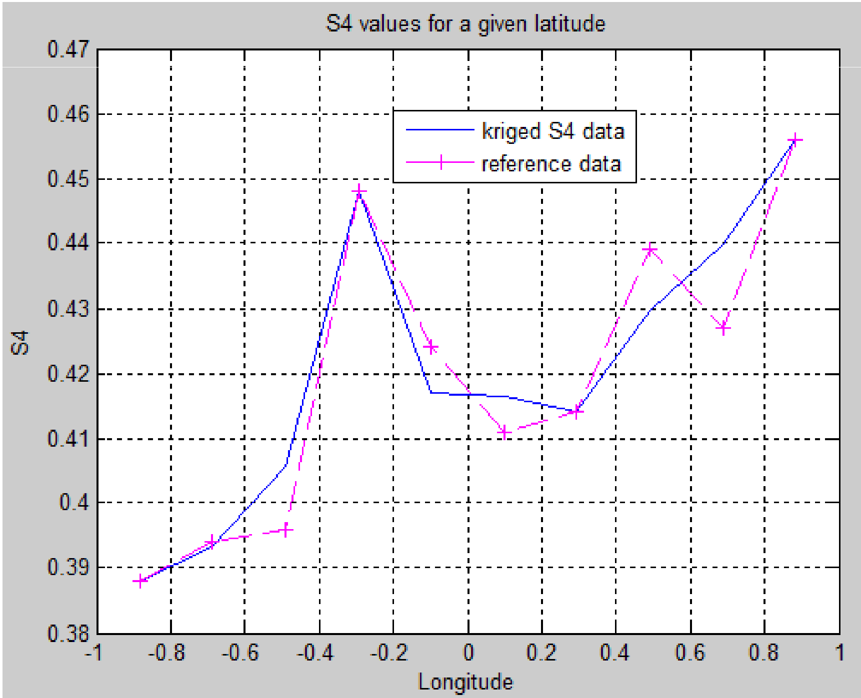




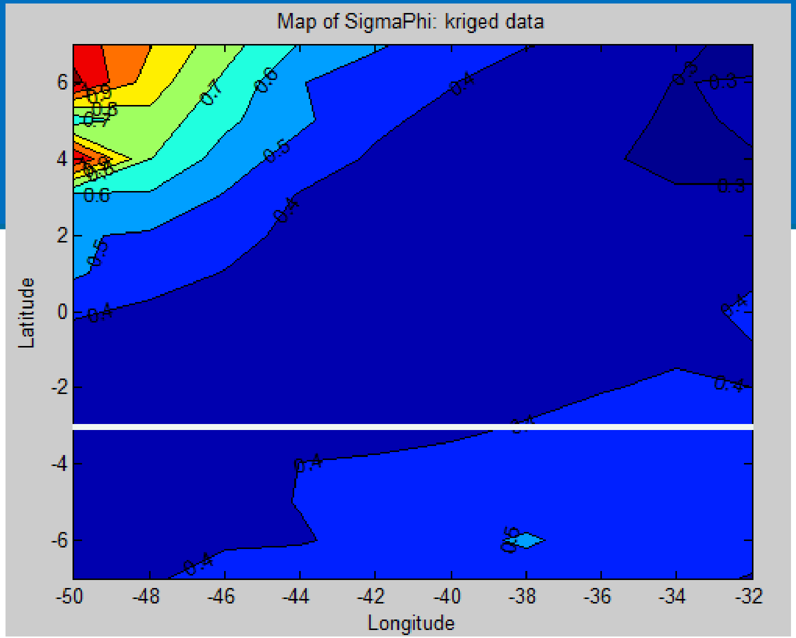
Cut at Latitude - 3°

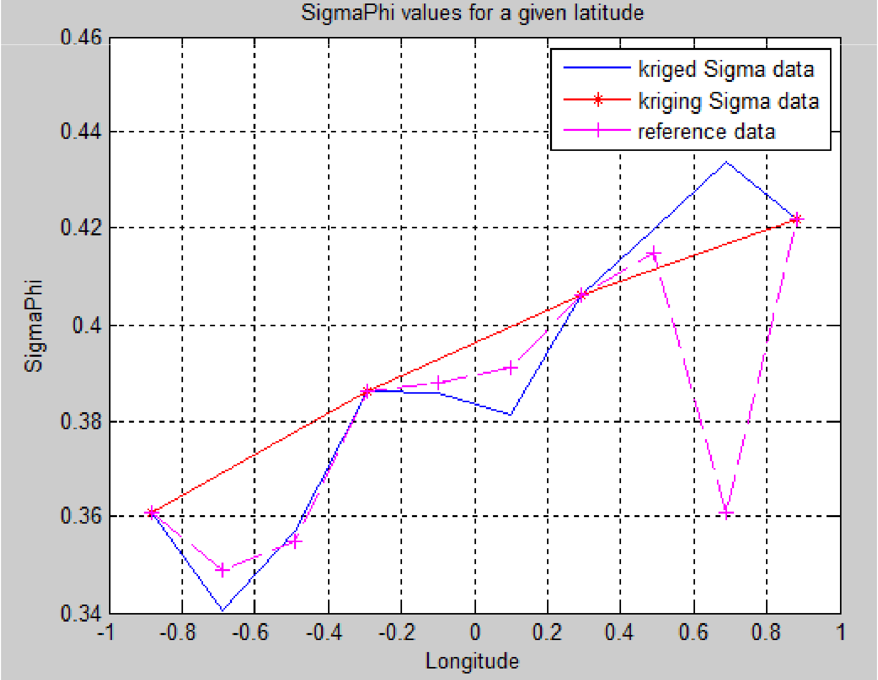


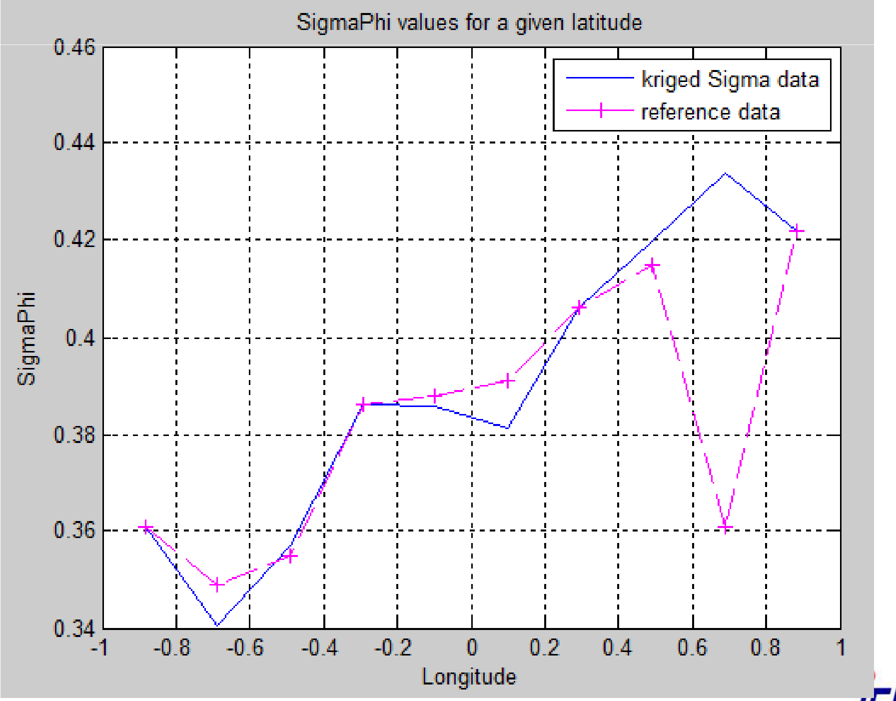




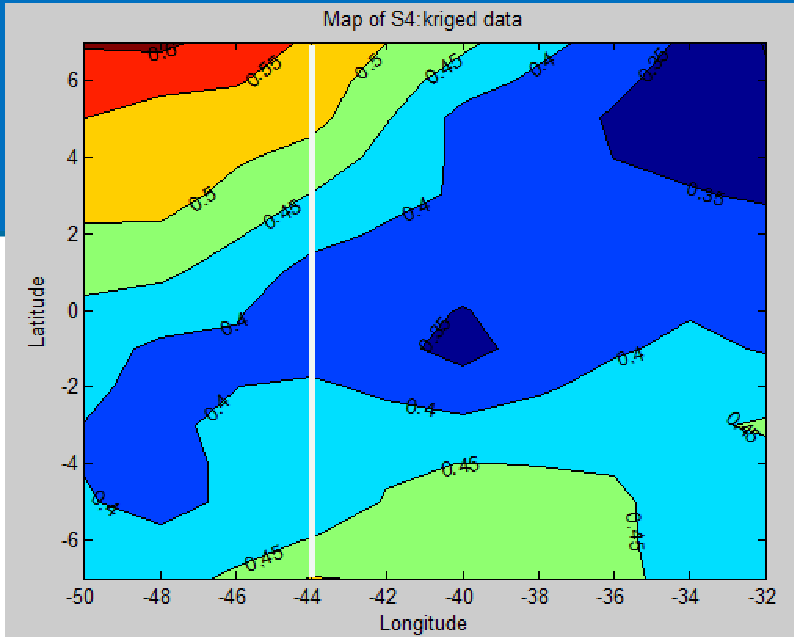
Cut at Latitude – 3°

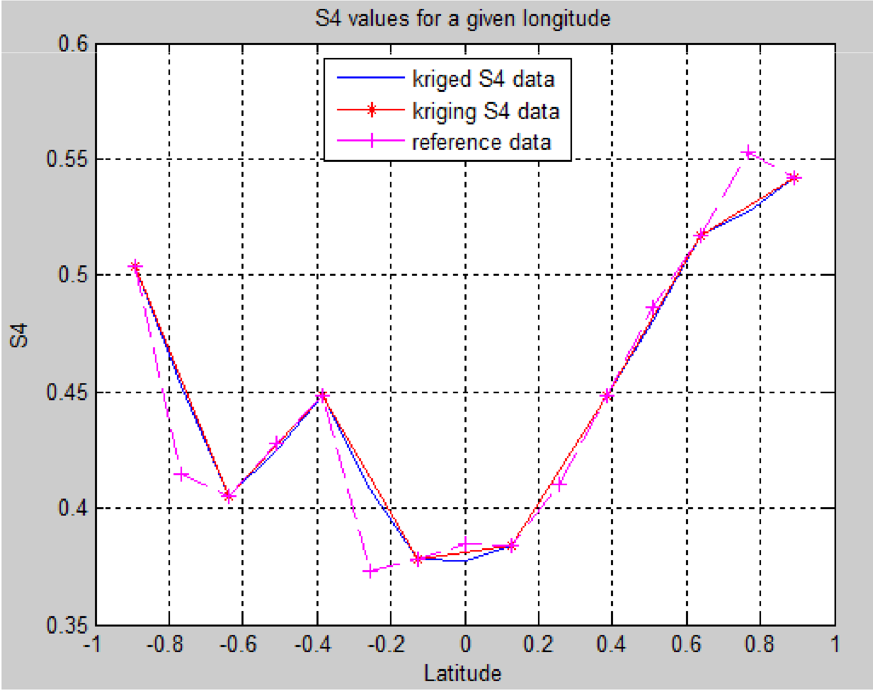


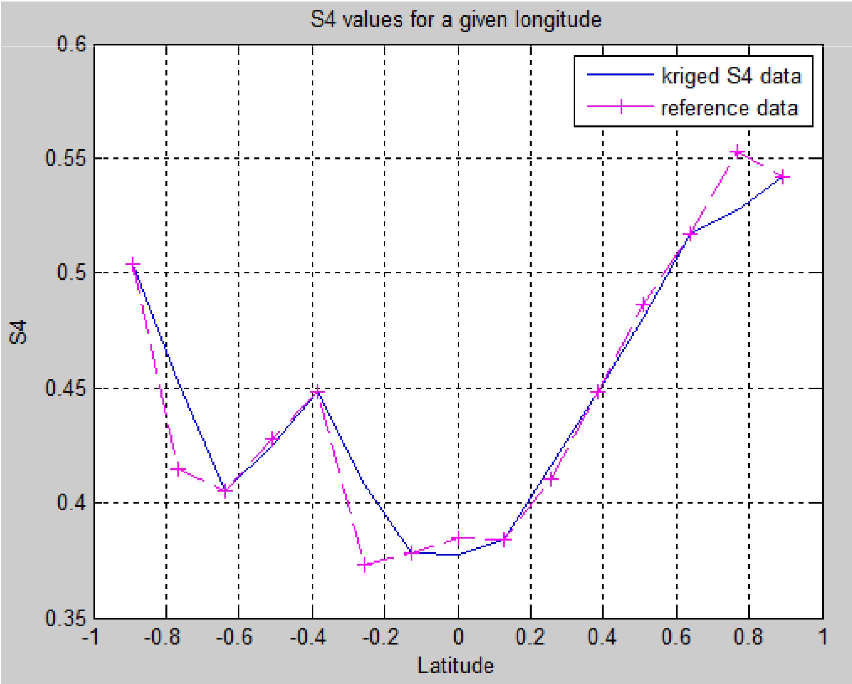




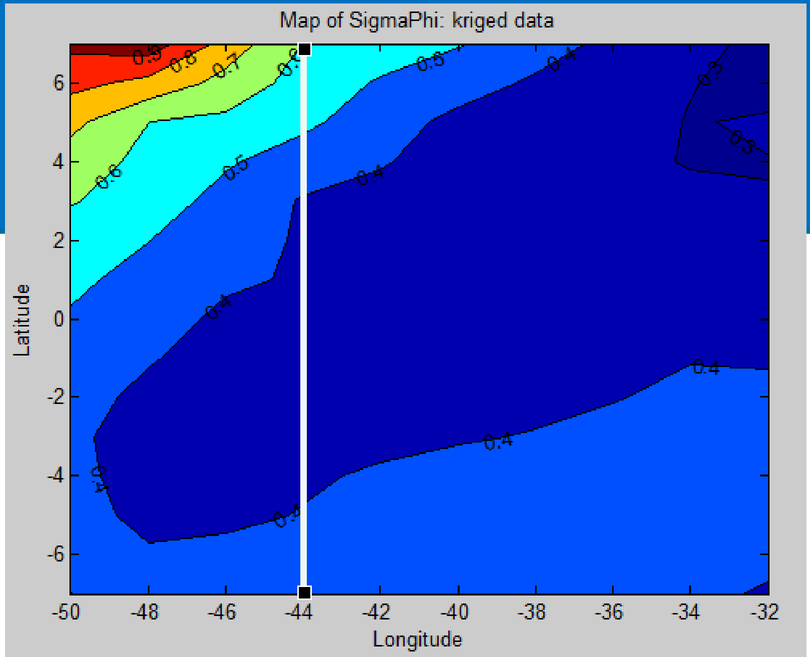
Cut at Longitude - 44°

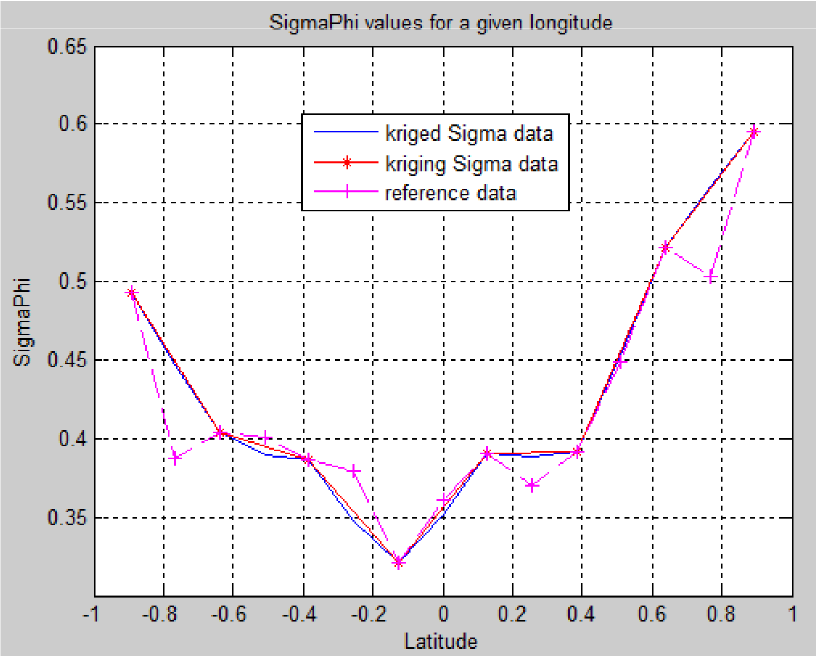


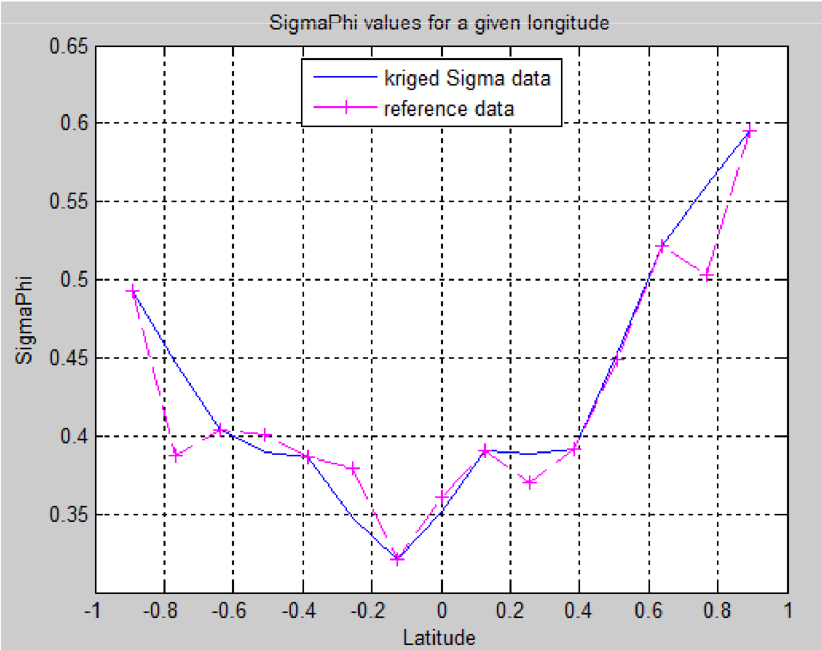




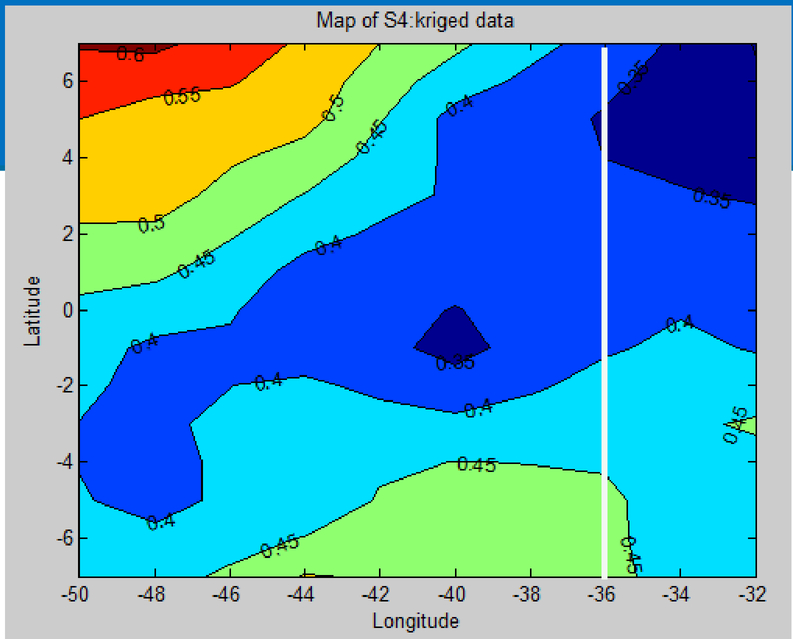
Cut at Longitude - 44°

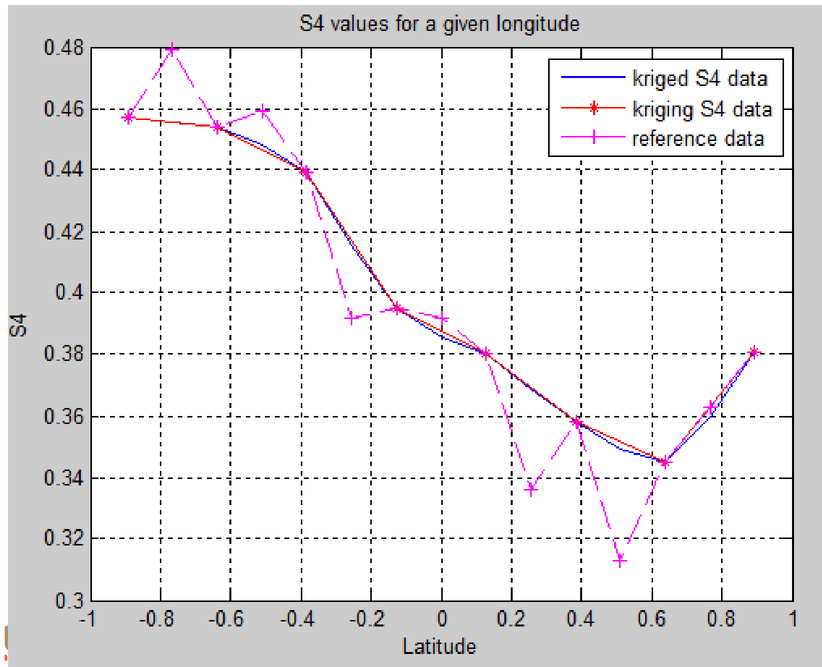


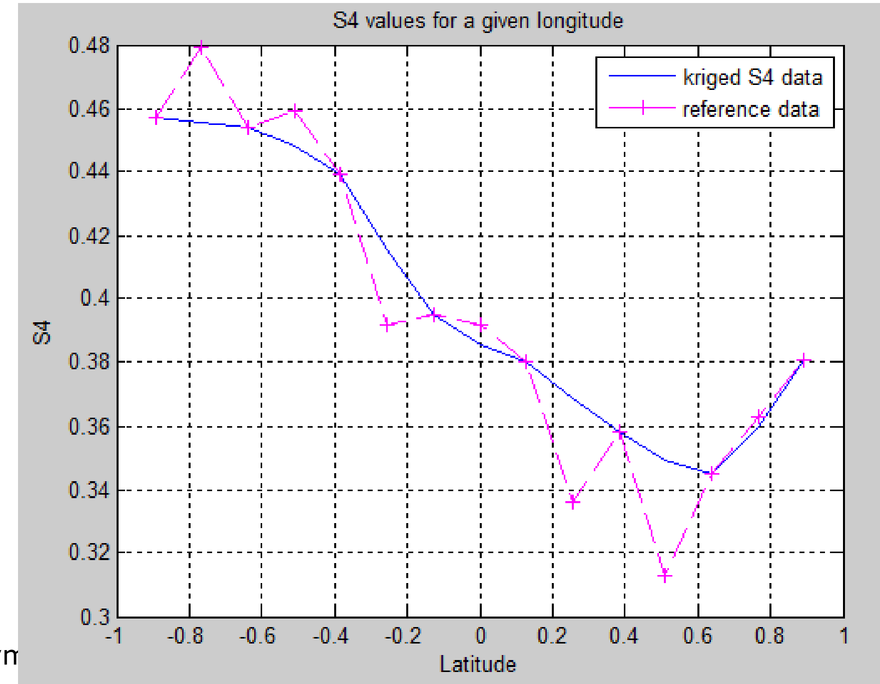




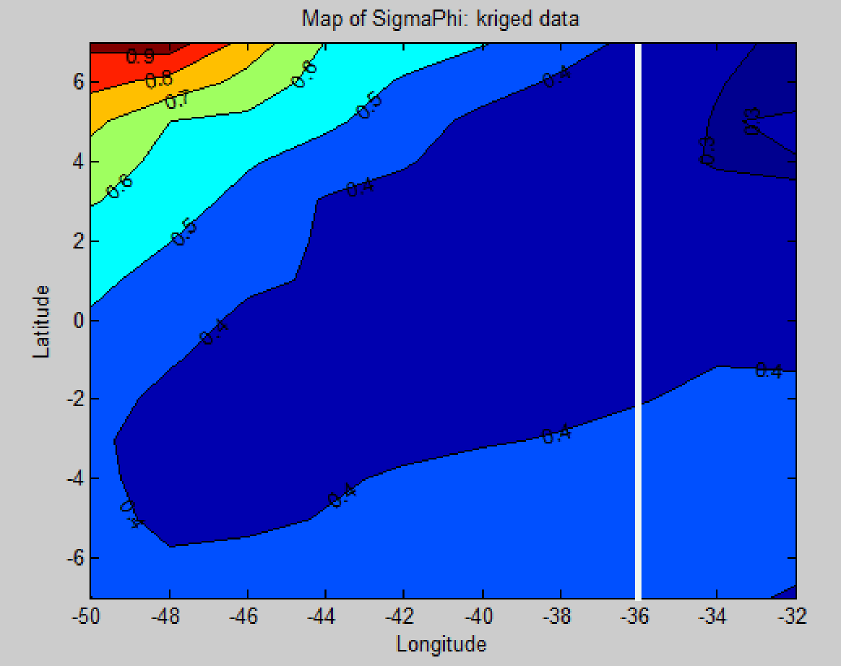
Cut at Longitude - 36°



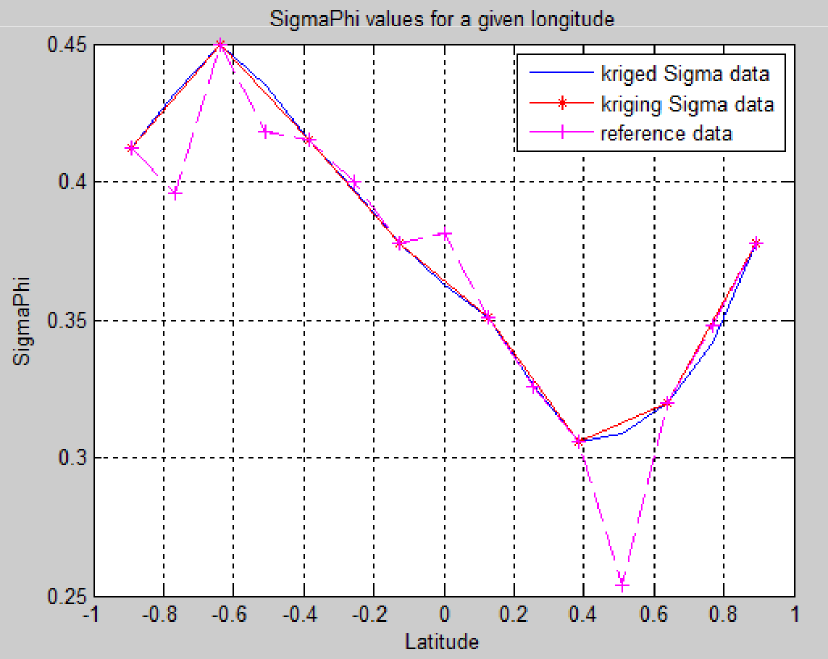


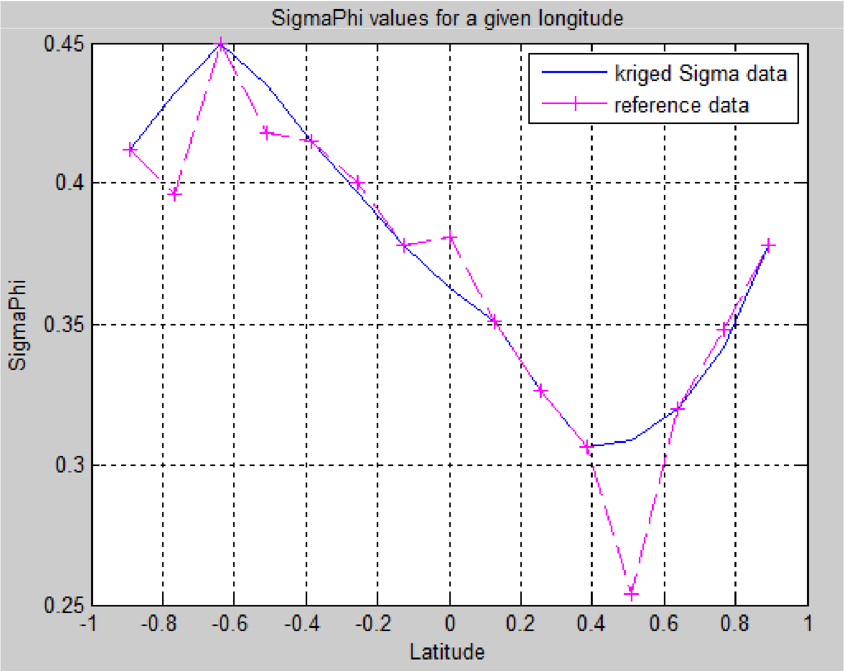


Cut at Longitude - 36°

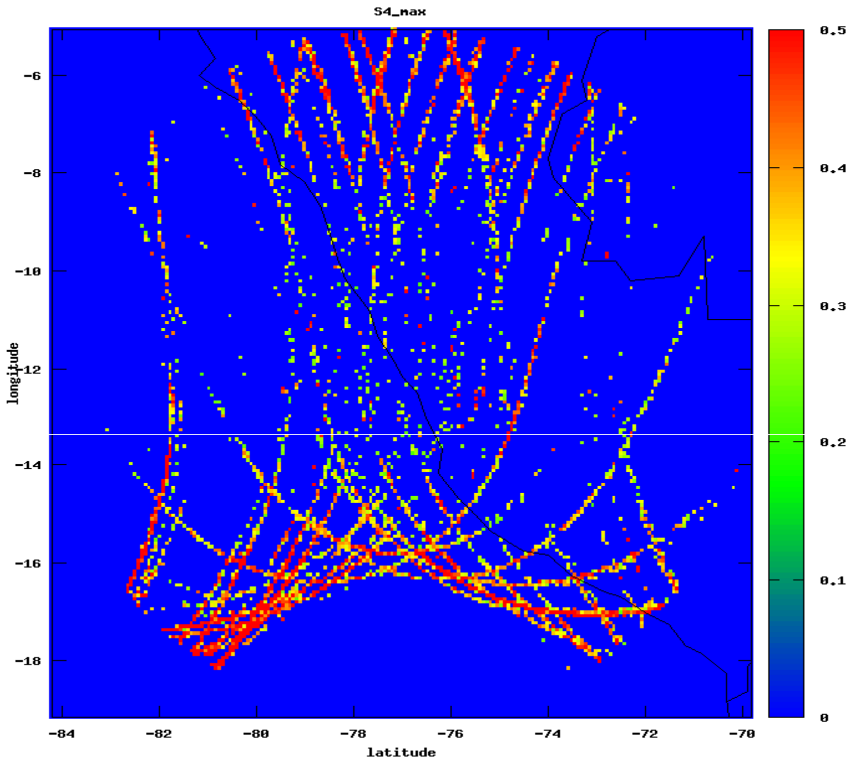


Coupe de SigmaPhi pour une longitude de -36°

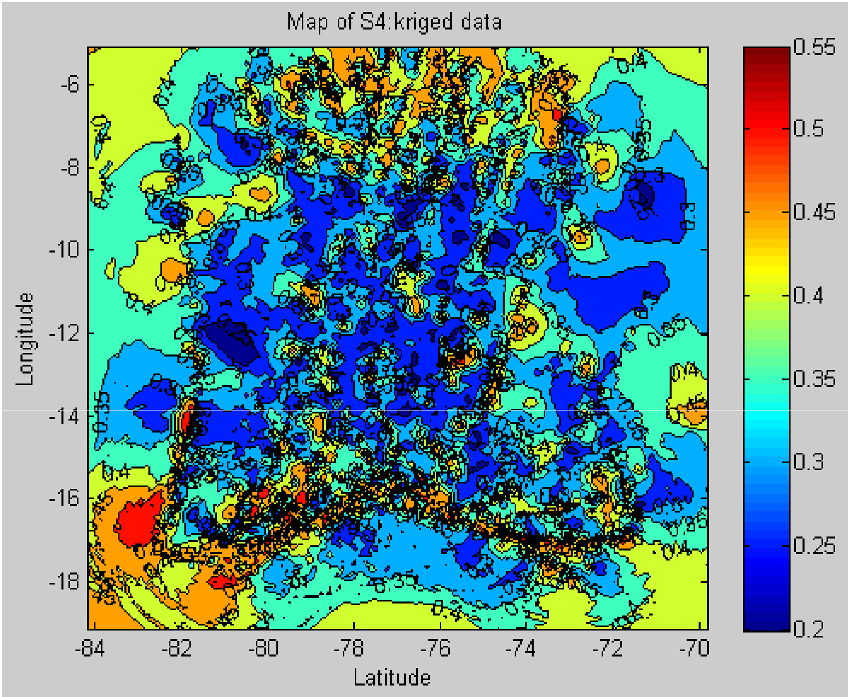




Kriging Over a Whole Year



Lima 2012
Dip Lat. 0°65



The covariance function used was deduced from GISM calculations

Conclusion

Analysis of scintillations using the IGS network

(Comparison to 50 Hz data)

Improve the calculation of the variogram

(Time as an additionnal factor)

Produce the error maps

Thank you