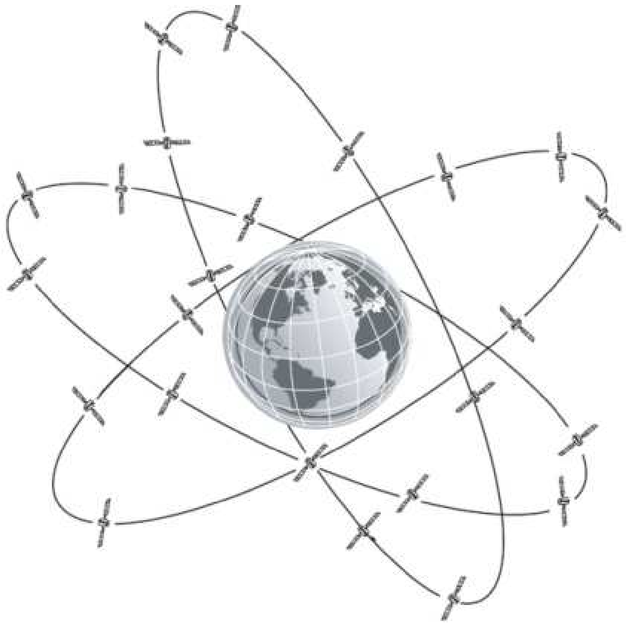
Satellite Positioning
Performances under Ionospheric Scintillations



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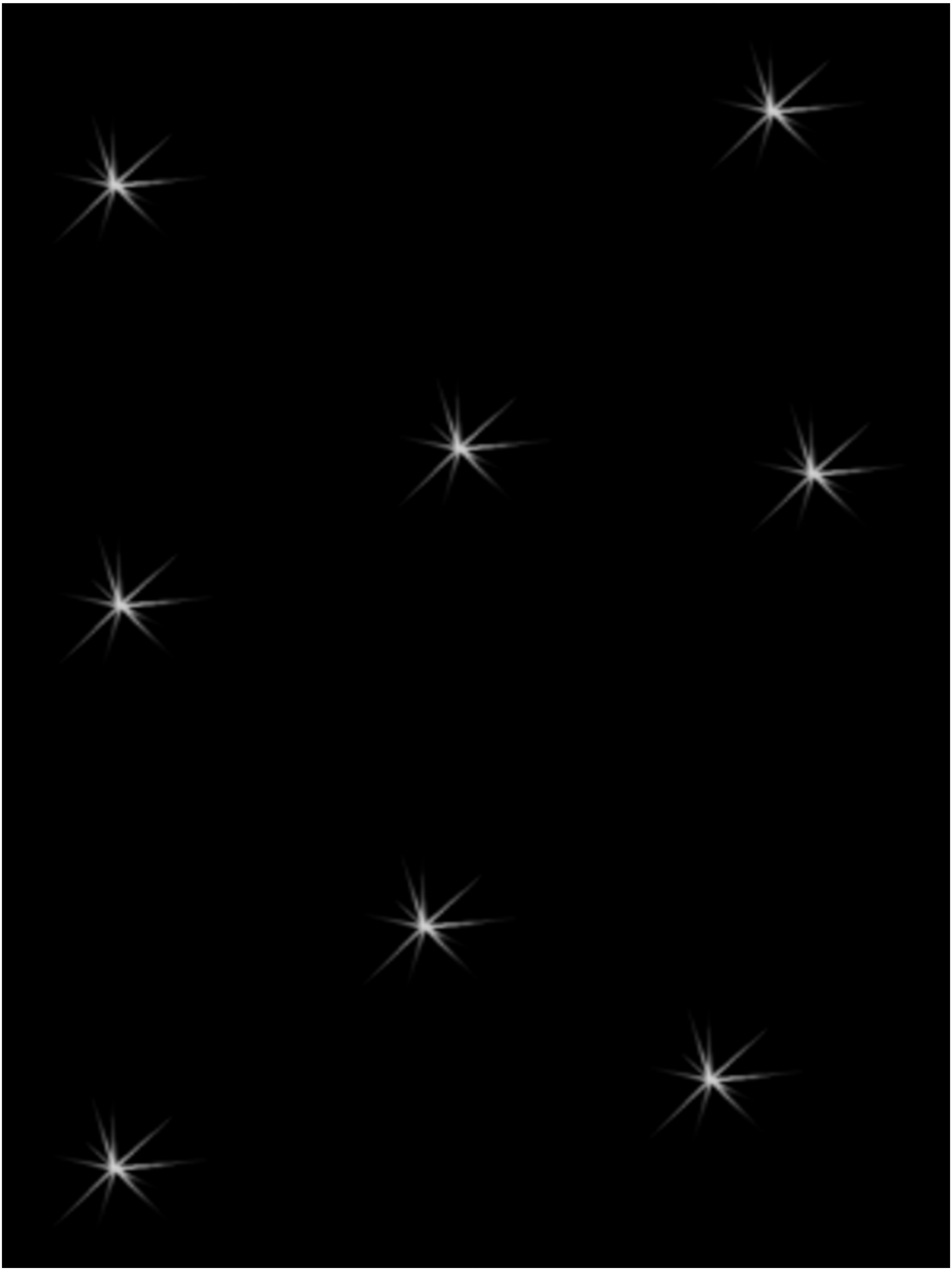
June 11, 2013
Geomatics Unit, ULg



Introduction

Objectives

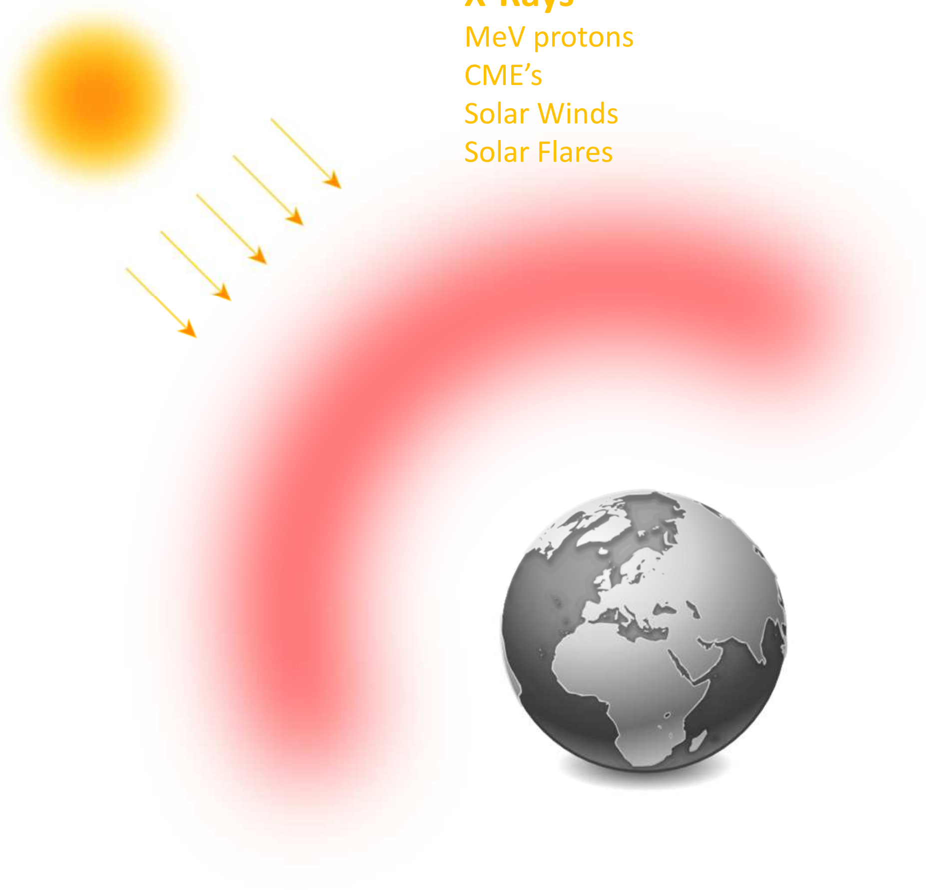
Research

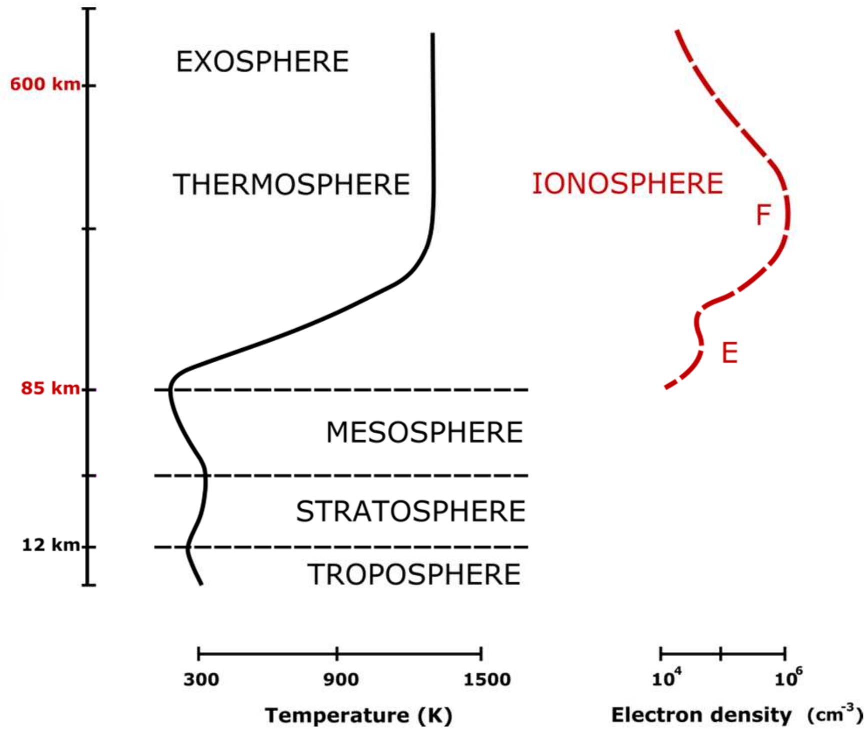
Conclusions

Perspectives

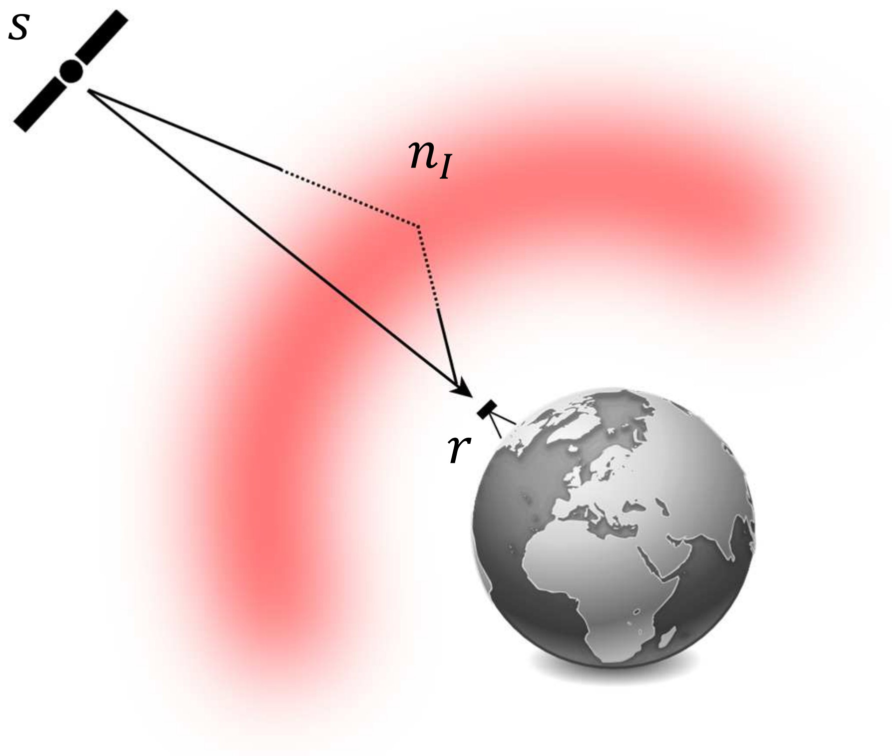
The Ionosphere is Ionized by Solar Radiation

UV
X-Rays
MeV protons
CME's
Solar Winds
Solar Flares





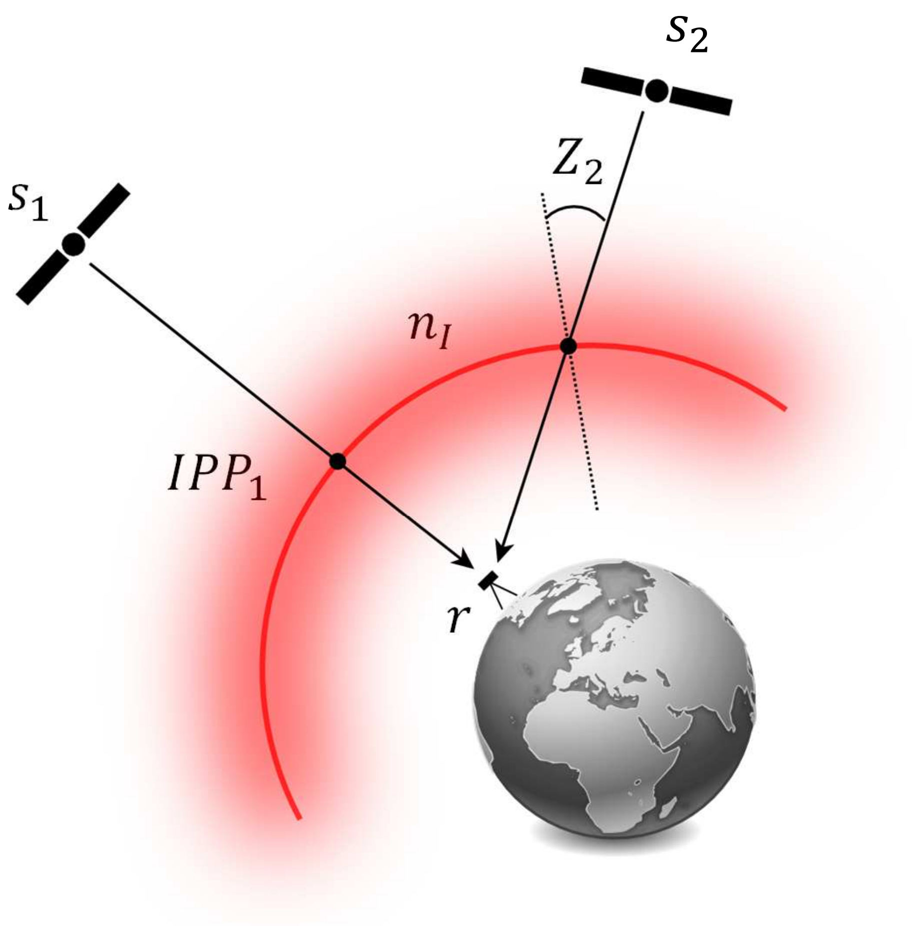
GNSS Signals are refracted by the Ionosphere



$$n_I = \frac{c}{v} \approx 1 \pm \frac{40.3}{f^2} N_e$$

$$I \approx \pm \frac{40.3}{f^2} \int_r^s N_e \, dl = \pm \frac{40.3}{f^2} sTEC$$

GNSS Signals are refracted by the Ionosphere



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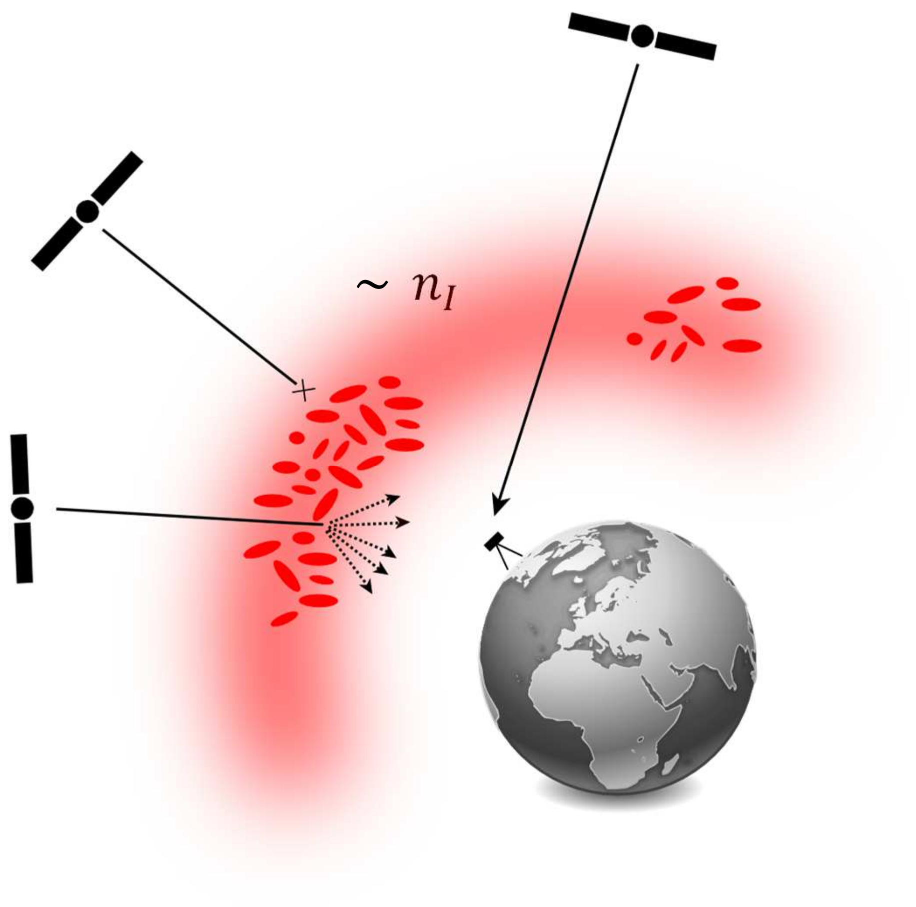
GNSS Signals are diffracted by the Ionosphere



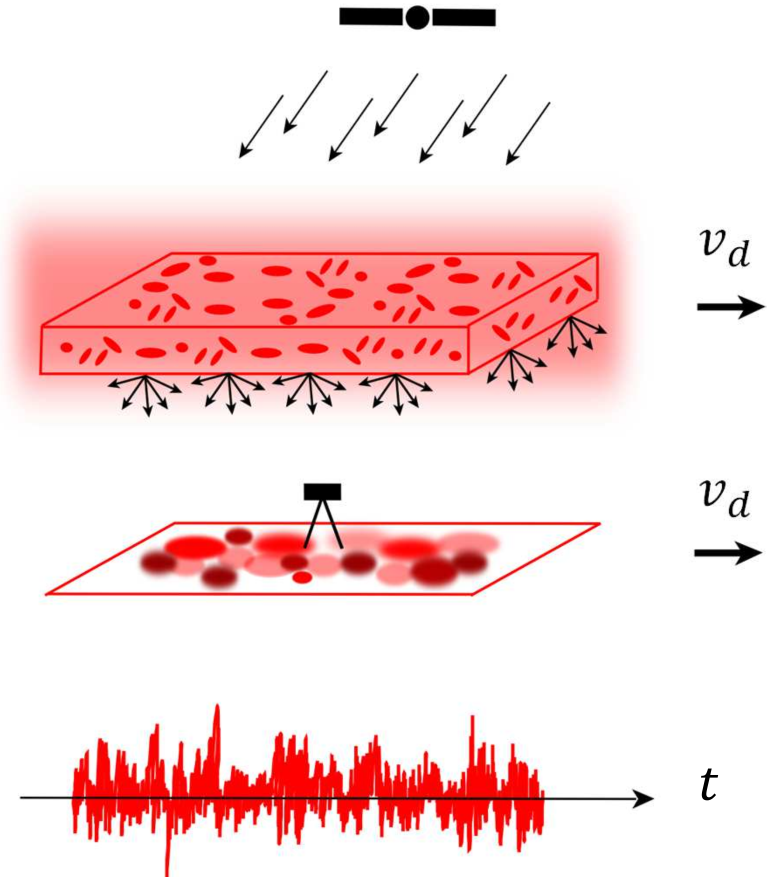
Ionospheric Electron Density
Irregularities

Spatial Variation of the
Refraction Index

Signal Losses
Signal Diffraction

Constructive and Destructive
Signal Interferences

GNSS Signals are diffracted by the Ionosphere

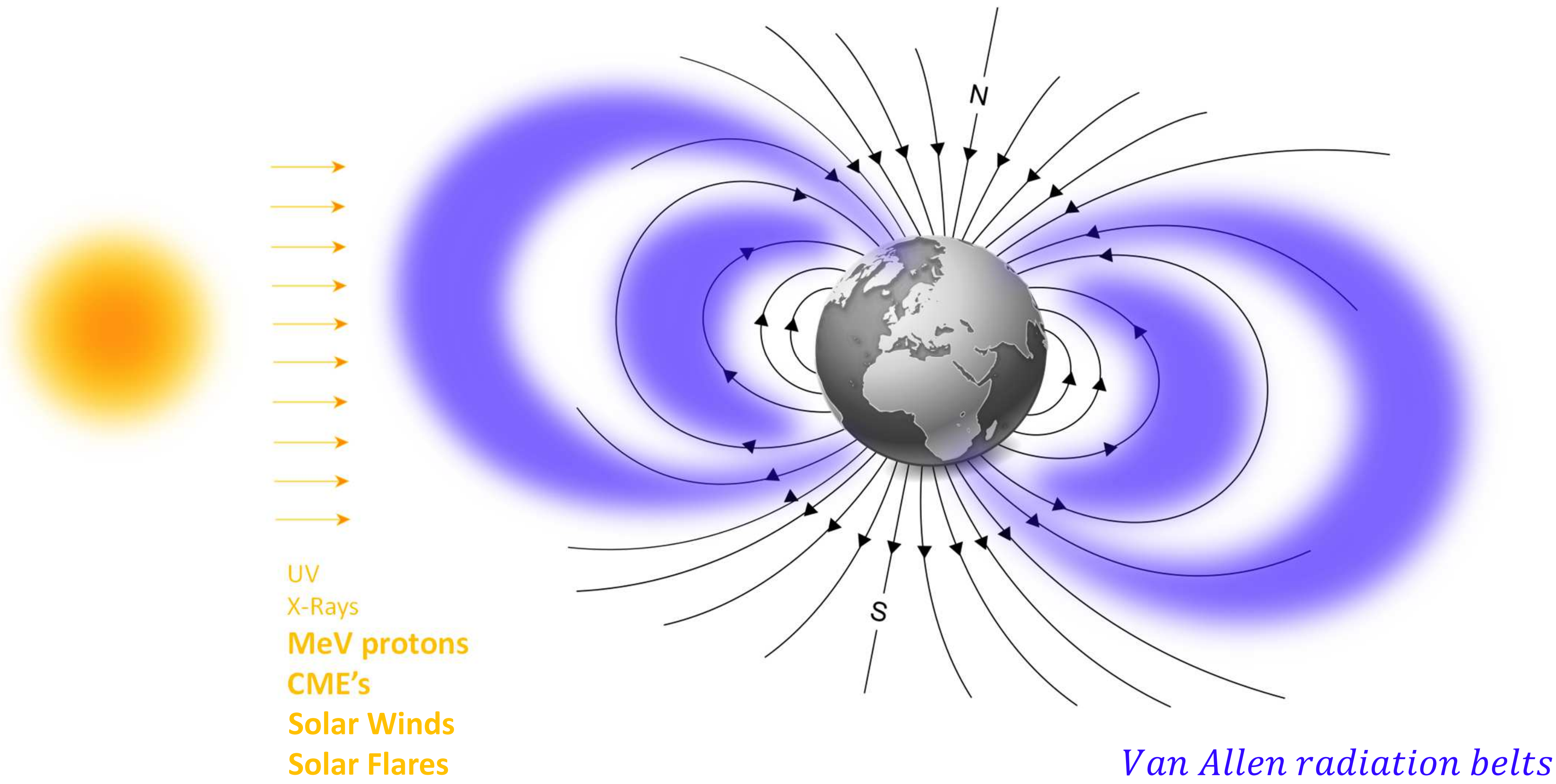


Ionospheric Electron Density

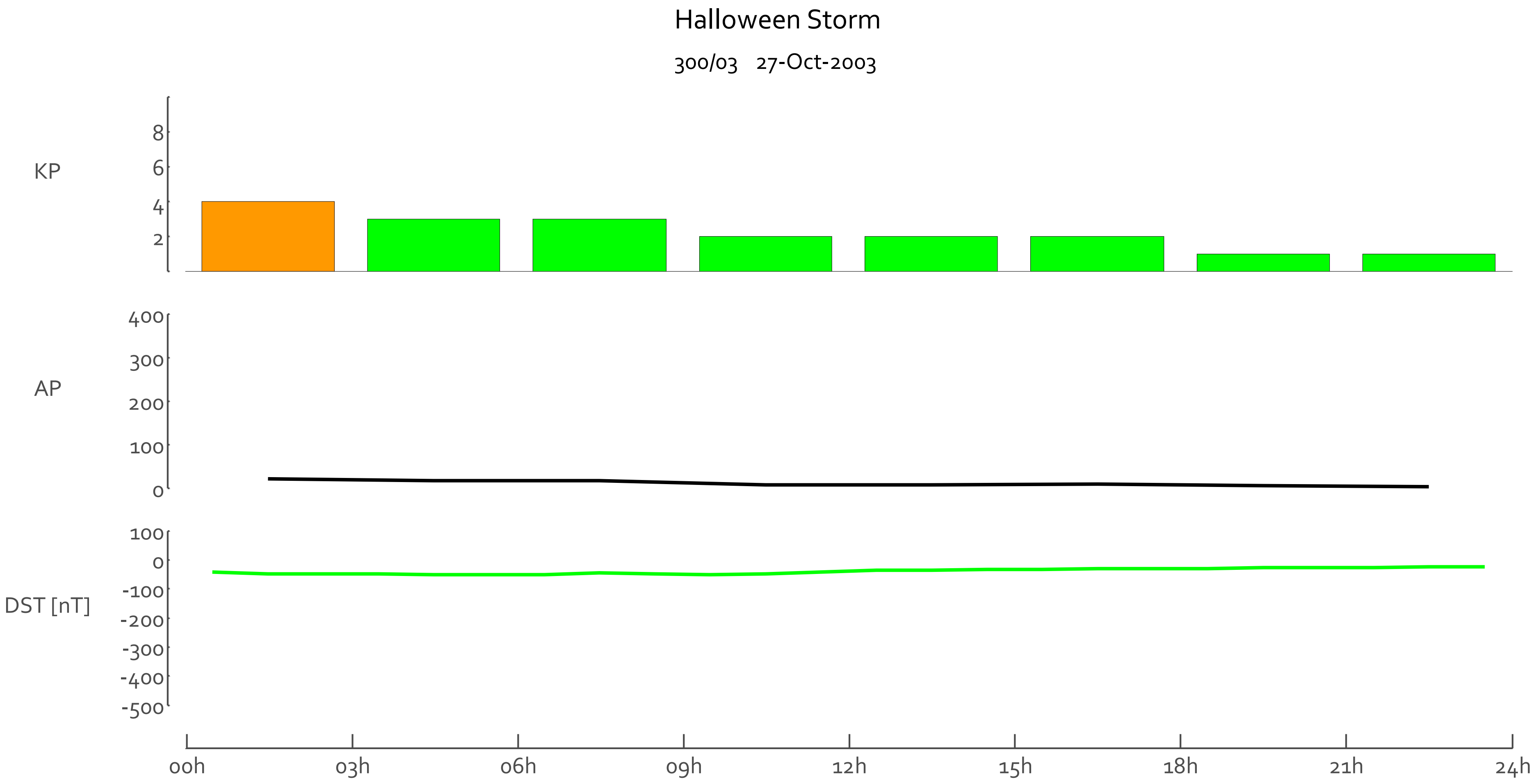
Diffraction Pattern

Received Signal Intensity

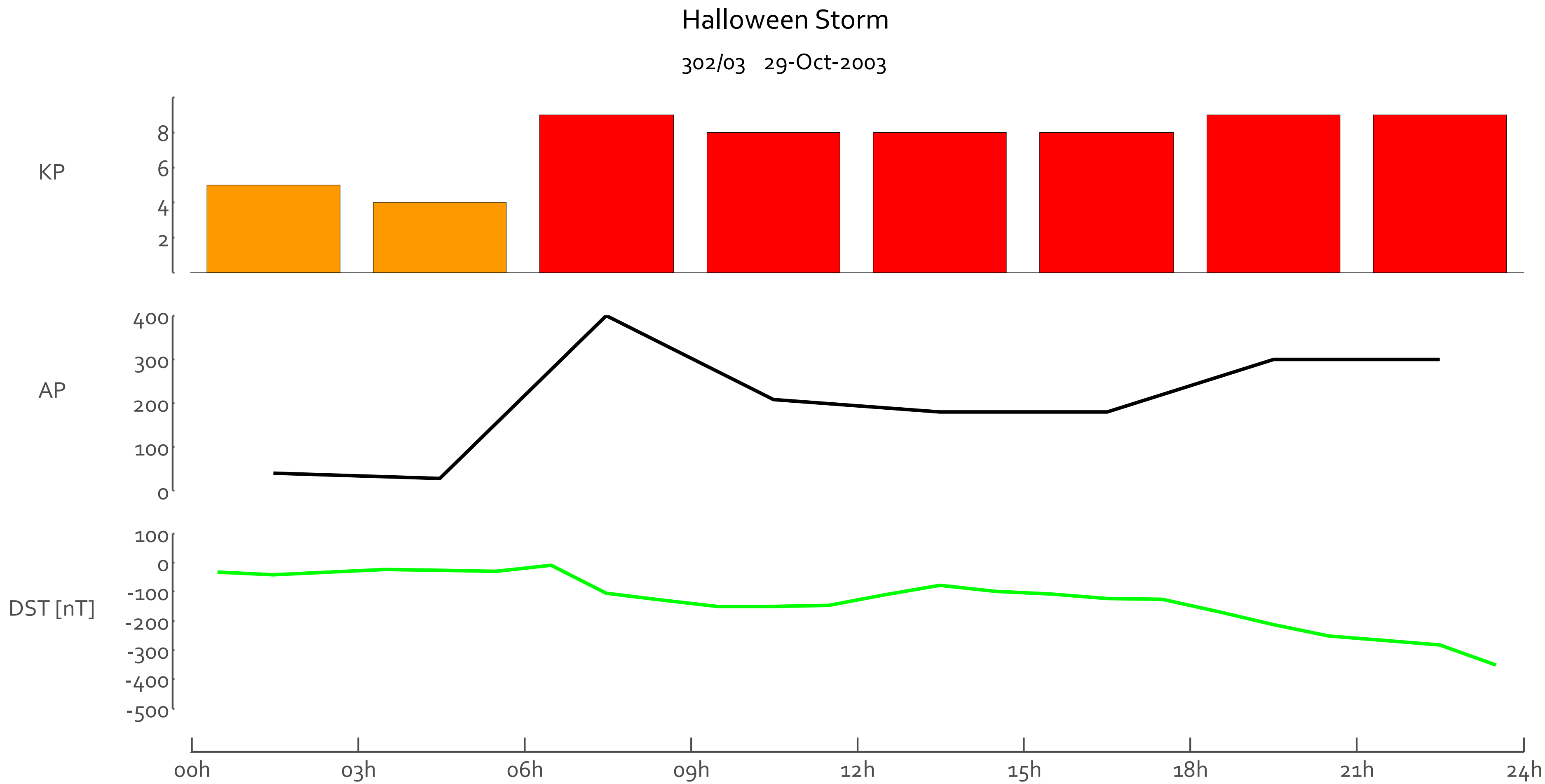
Ionospheric Electron Density Irregularities are involved by Geomagnetic Storms



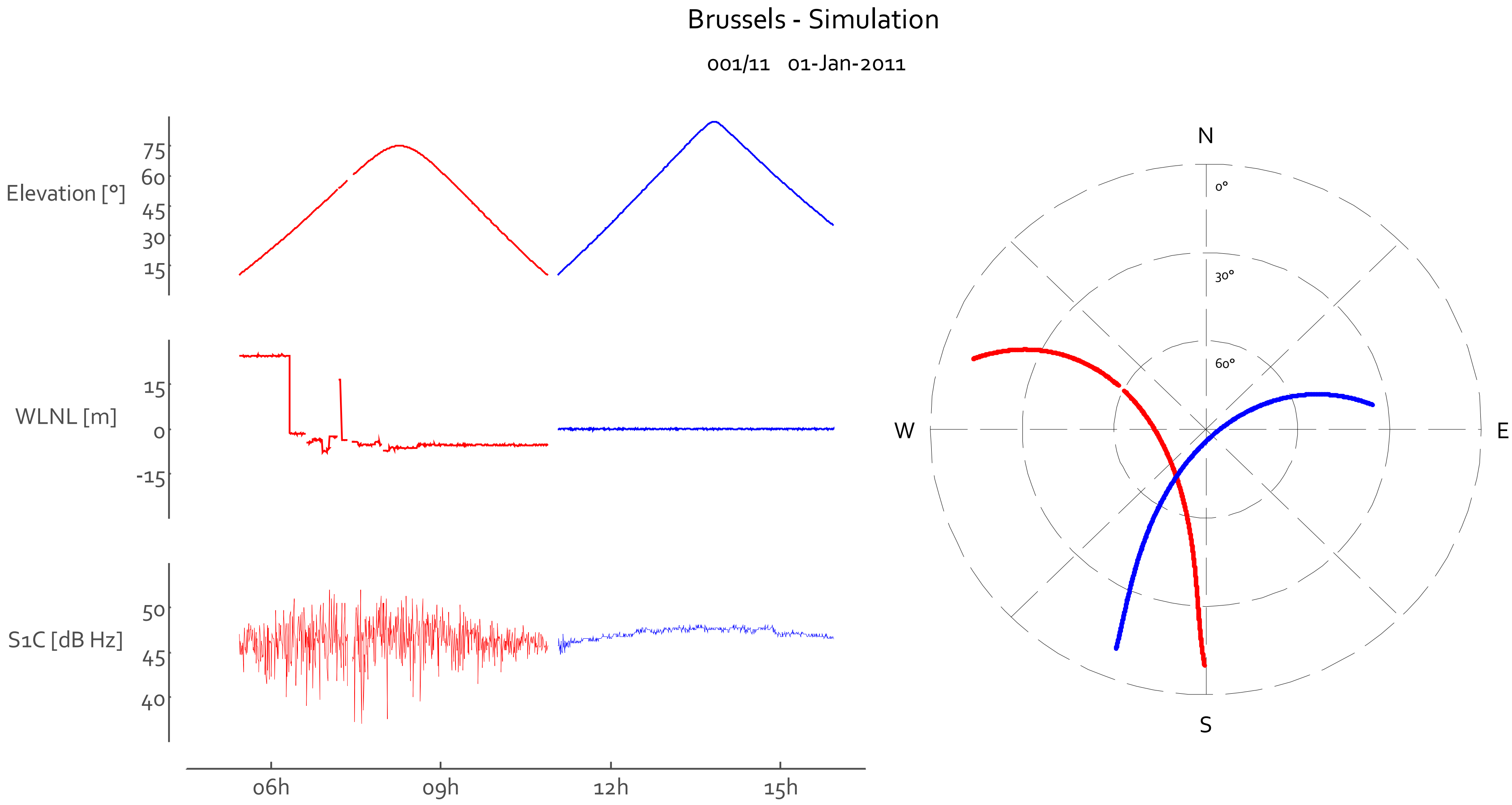
Geomagnetic Storms can be detected by global Geomagnetic Indices



Geomagnetic Storms can be detected by global Geomagnetic Indices

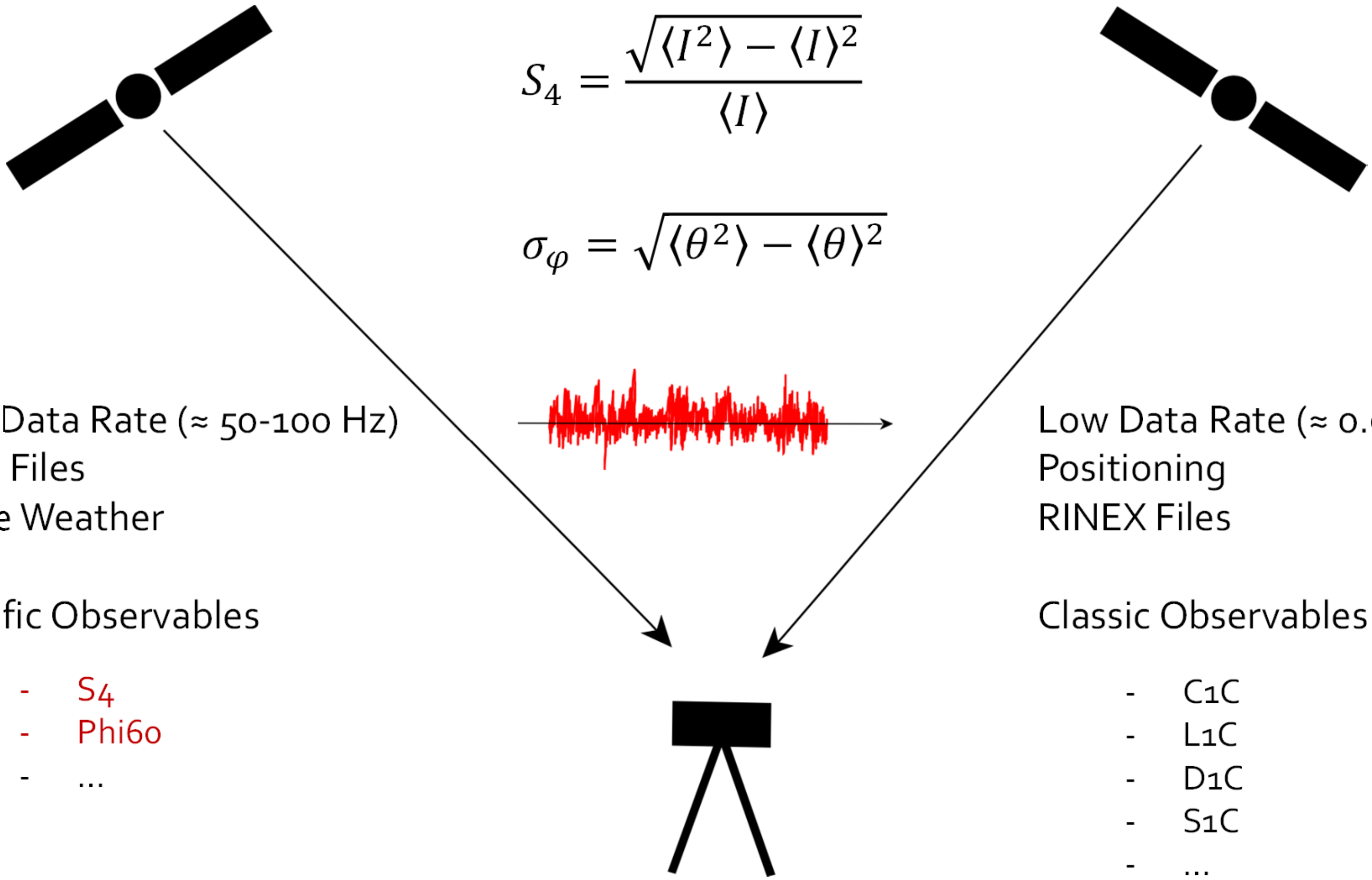


Ionospheric Electron Density Irregularities involve GNSS Signal Phase and Amplitude fluctuations



Ionospheric Scintillation Effects on GNSS Signals are Monitored by Scintillation GNSS Receivers

Ionospheric Scintillation Monitoring Receiver - ISMR



$$S_4 = \frac{\sqrt{\langle I^2 \rangle - \langle I \rangle^2}}{\langle I \rangle}$$

$$\sigma_\varphi = \sqrt{\langle \theta^2 \rangle - \langle \theta \rangle^2}$$

High Data Rate (≈ 50-100 Hz)
ISMR Files
Space Weather

Specific Observables

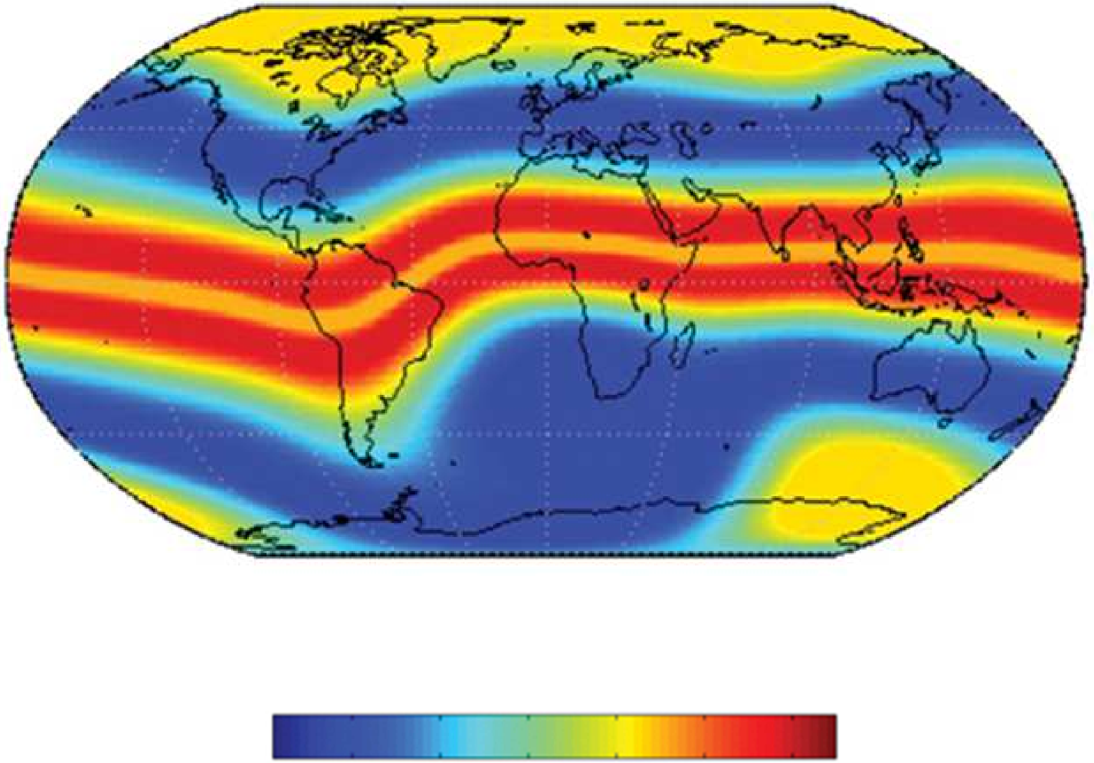
- S4
- Phi60
- ...

Low Data Rate (≈ 0.01 - 1 Hz)
Positioning
RINEX Files

Classic Observables

- C1C
- L1C
- D1C
- S1C
- ...

Ionospheric Scintillations exhibit Spatial and Temporal Characteristics



Operating Frequencies

Geographic Locations

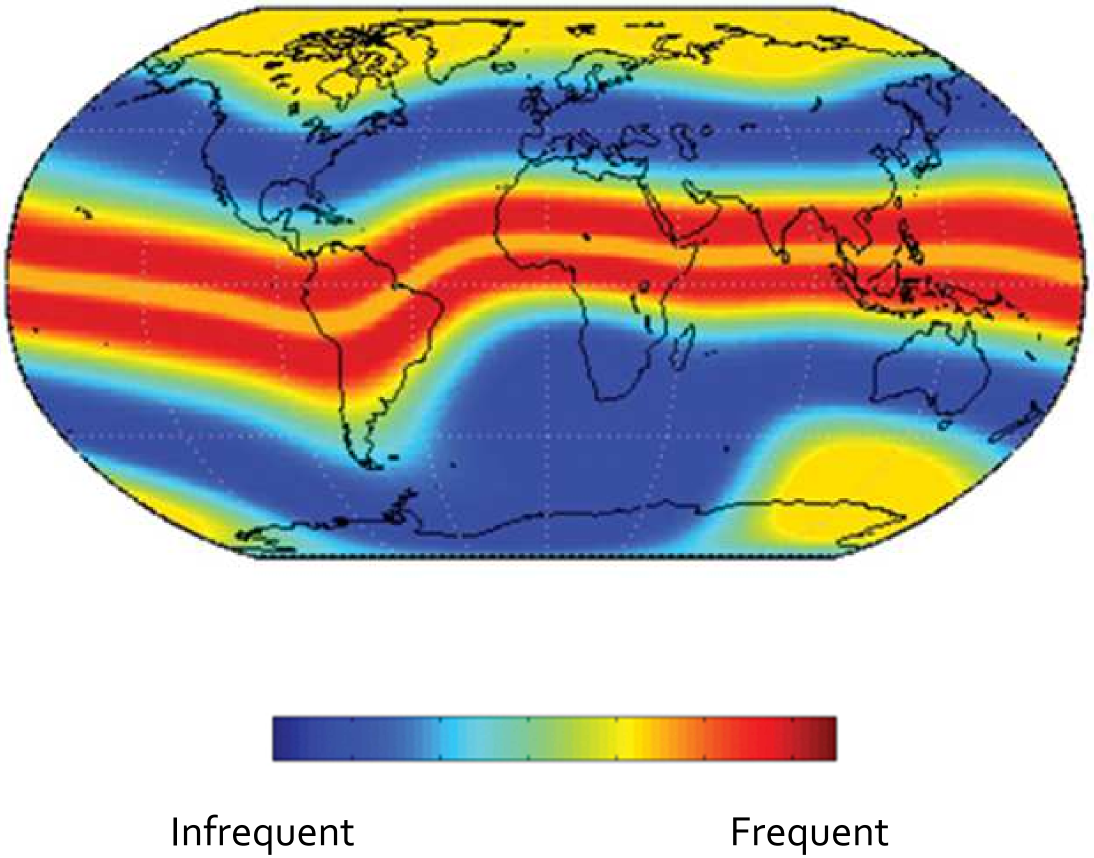
Local Time

Season

Magnetic Activity

Solar Activity

Ionospheric Scintillations exhibit Spatial and Temporal Characteristics



Large Scale Irregularities
≈ 100 km

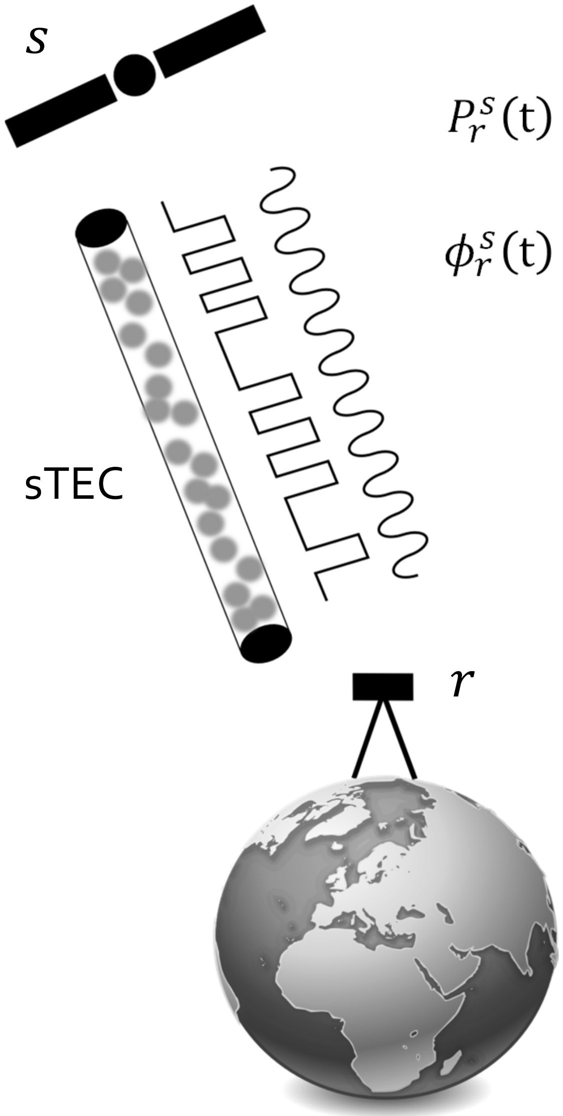
Small Scale Irregularities
≈ 1 – 100 m

Background Plasma Drift Speed
≈ 50-150 ms^{-1}

Duration
≈ minutes/hours

Spatiotemporal Variations of Scintillations Intensity

Satellite Positioning is based on Multilateration



$$P_r^s(\mathrm{t}) = D_r^s + T_r^s + I_{r,k,m}^s + \mathrm{c}\,(\Delta t^s - \Delta t_r) + M_{r,k,m}^s + \varepsilon_{r,k,m}^s$$

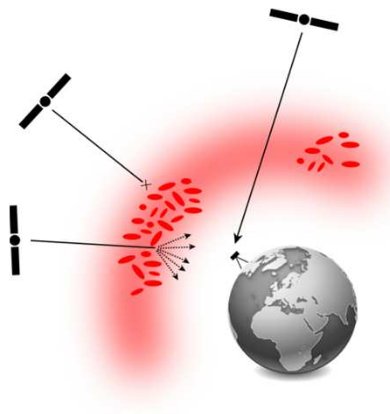
$$\phi_r^s(\mathrm{t}) = D_r^s + T_r^s - I_{r,k,\phi}^s + \mathrm{c}\,(\Delta t^s - \Delta t_r) + \lambda_k N_{r,k}^s + M_{r,k,\phi}^s + \varepsilon_{r,k,\phi}^s$$

$$I_{r,k}^s = \frac{40.3}{f^2} sTEC$$

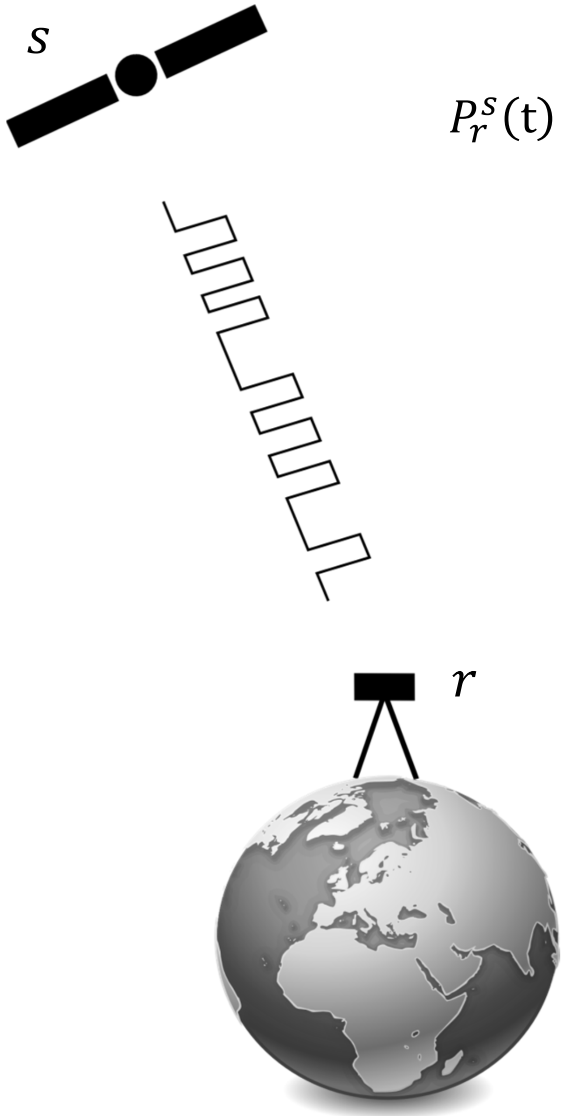
$$D_r^s = \sqrt{(X^s - X_r)^2 + (Y^s - Y_r)^2 + (Z^s - Z_r)^2}$$

$\varepsilon_{r,k,m}^s$ $\varepsilon_{r,k,\phi}^s$

$N_{r,k}^s$



The Standard Point Positioning is an elementary SF Technique



$$P_r^s(\mathrm{t}) = D_r^s + T_r^s + I_{r,k,m}^s + \mathrm{c}\,(\Delta t^s - \Delta t_r) + M_{r,k,m}^s + \varepsilon_{r,k,m}^s$$

$$D_r^s = \sqrt{(X^s - X_r)^2 + (Y^s - Y_r)^2 + (Z^s - Z_r)^2}$$

Pseudorange (code) measurements

Single Frequency

Single Point Single Epoch (SPSE) Technique

Real-Time / Post-Processing

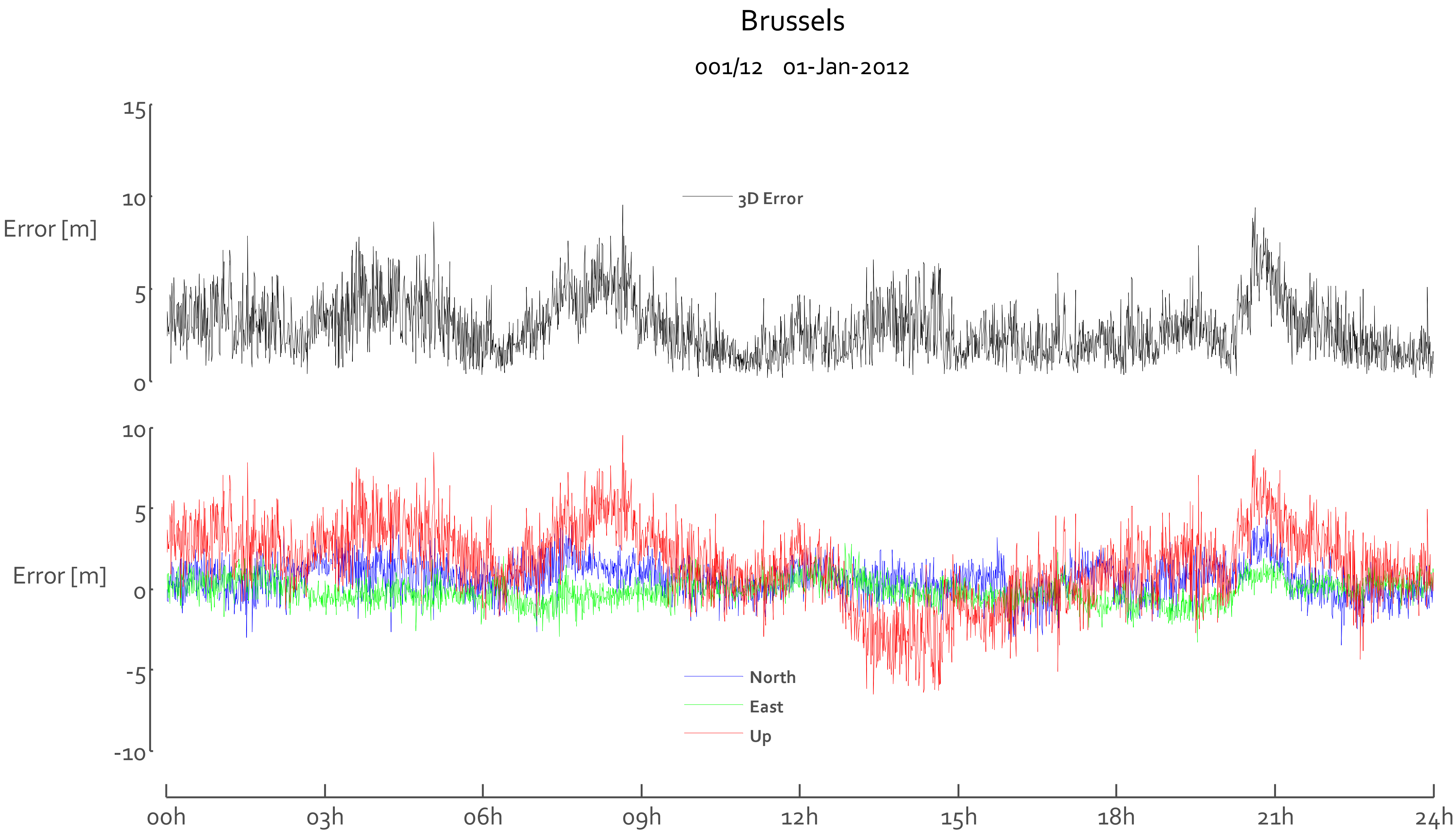
Static / Kinematic

Atmospheric Models (Ionosphere and Troposphere)

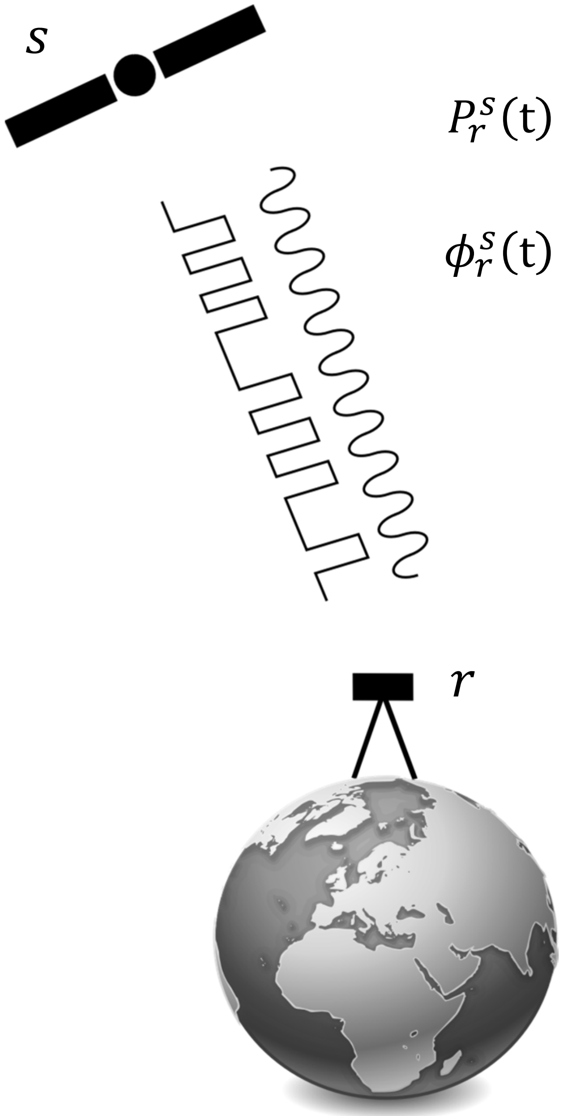
Broadcast Ephemeris

Least Square Adjustement (LSA) to resolve unknowns

The Standard Point Positioning is an elementary SF Technique



The Precise Point Positioning is an advanced DF Technique



$$P_r^s(\mathrm{t}) = D_r^s + T_r^s + I_{r,k,m}^s + \mathrm{c}\,(\Delta t^s - \Delta t_r) + M_{r,k,m}^s + \varepsilon_{r,k,m}^s$$

$$\phi_r^s(\mathrm{t}) = D_r^s + T_r^s - I_{r,k,\phi}^s + \mathrm{c}\,(\Delta t^s - \Delta t_r) + \lambda_k N_{r,k}^s + M_{r,k,\phi}^s + \varepsilon_{r,k,\phi}^s$$

Pseudorange (code) and Carrier-Phase measurements

Ambiguity Resolution Process

Dual Frequency

Real-Time / Post-Processing

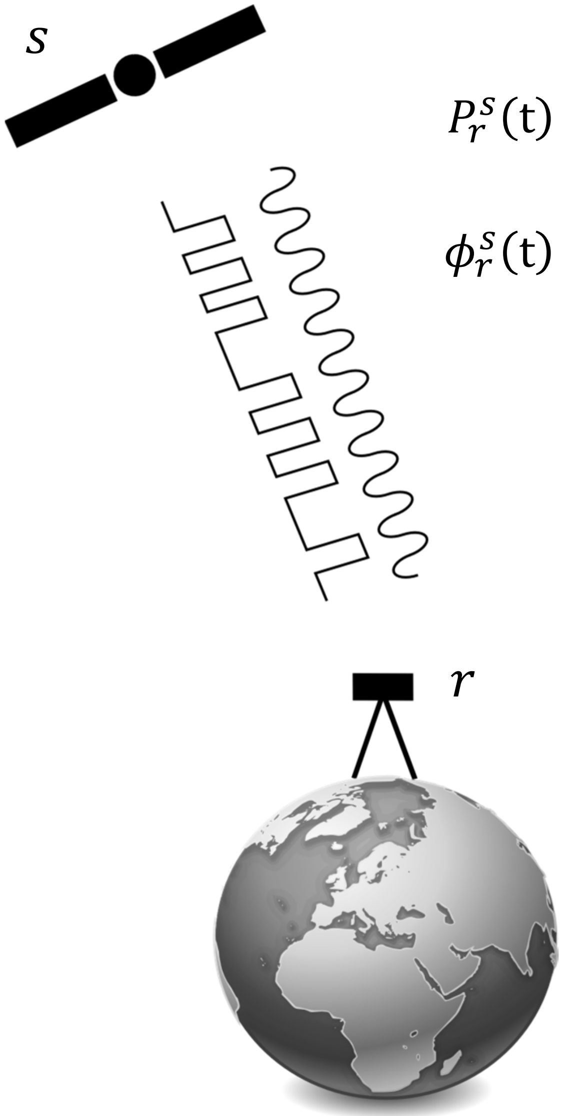
Static / Kinematic

Strategies against atmospheric effects

Precise Products: Ephemeris / Code-Phase Delays / Antenna

Sequential Least Squares Adjustment (Filter)

The Precise Point Positioning is an advanced DF Technique



$$P_r^s(\mathrm{t}) = D_r^s + T_r^s + I_{r,k,m}^s + \mathrm{c}\,(\Delta t^s - \Delta t_r) + M_{r,k,m}^s + \varepsilon_{r,k,m}^s$$

$$\phi_r^s(\mathrm{t}) = D_r^s + T_r^s - I_{r,k,\phi}^s + \mathrm{c}\,(\Delta t^s - \Delta t_r) + \lambda_k N_{r,k}^s + M_{r,k,\phi}^s + \varepsilon_{r,k,\phi}^s$$

Mathematical Model: Ionosphere-Free + Precise Products

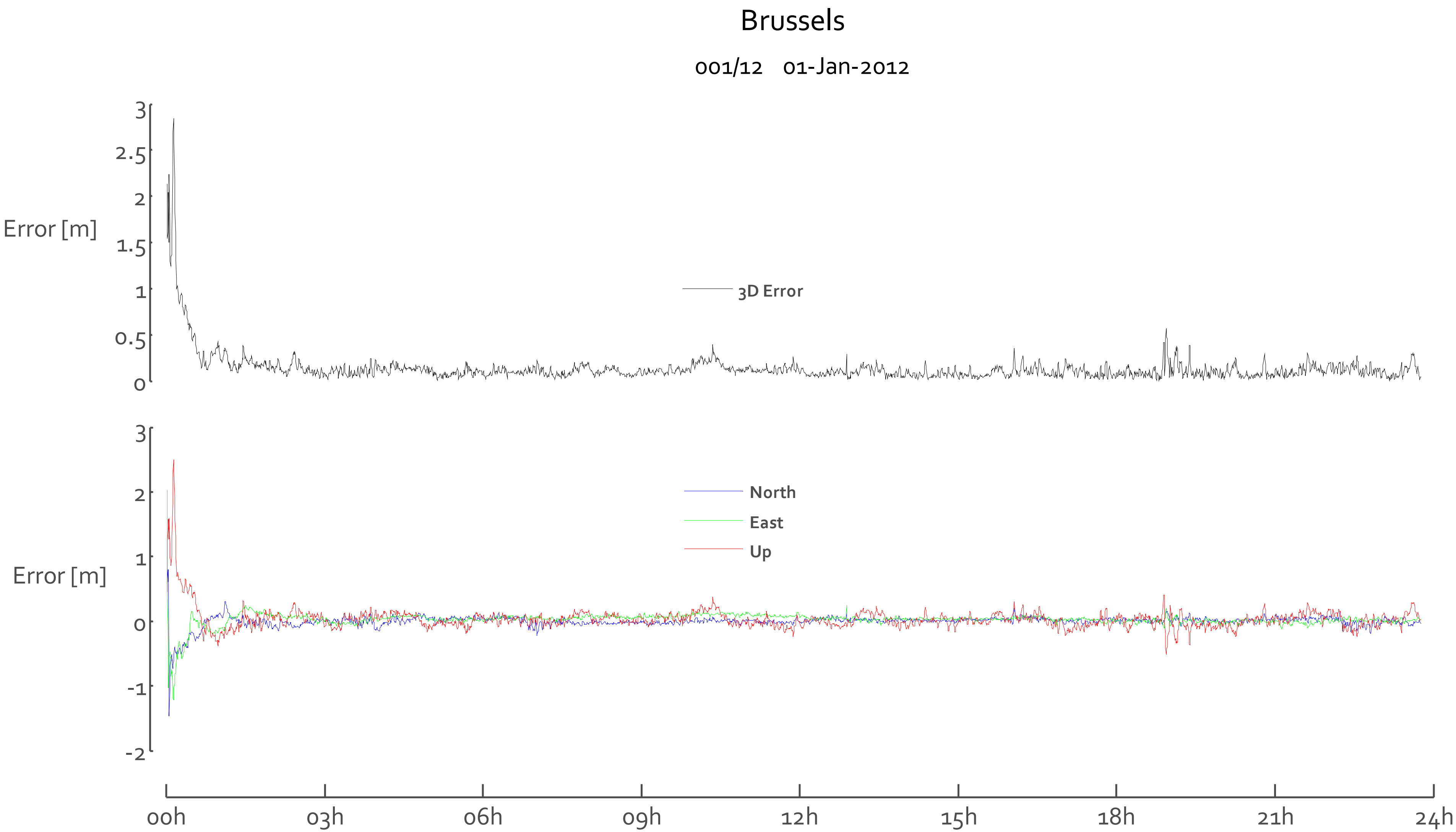
$$P_{r,IF}^s(\mathrm{t}) = D_r^s + T_r^s + \mathrm{c}\,(\Delta t^s - \Delta t_r) + M_{r,IF,m}^s + \varepsilon_{r,IF,m}^s$$

$$\phi_{r,IF}^s(\mathrm{t}) = D_r^s + T_r^s + \mathrm{c}\,(\Delta t^s - \Delta t_r) + \lambda_{IF} N_{r,IF}^s + M_{r,IF,\phi}^s + \varepsilon_{r,IF,\phi}^s$$

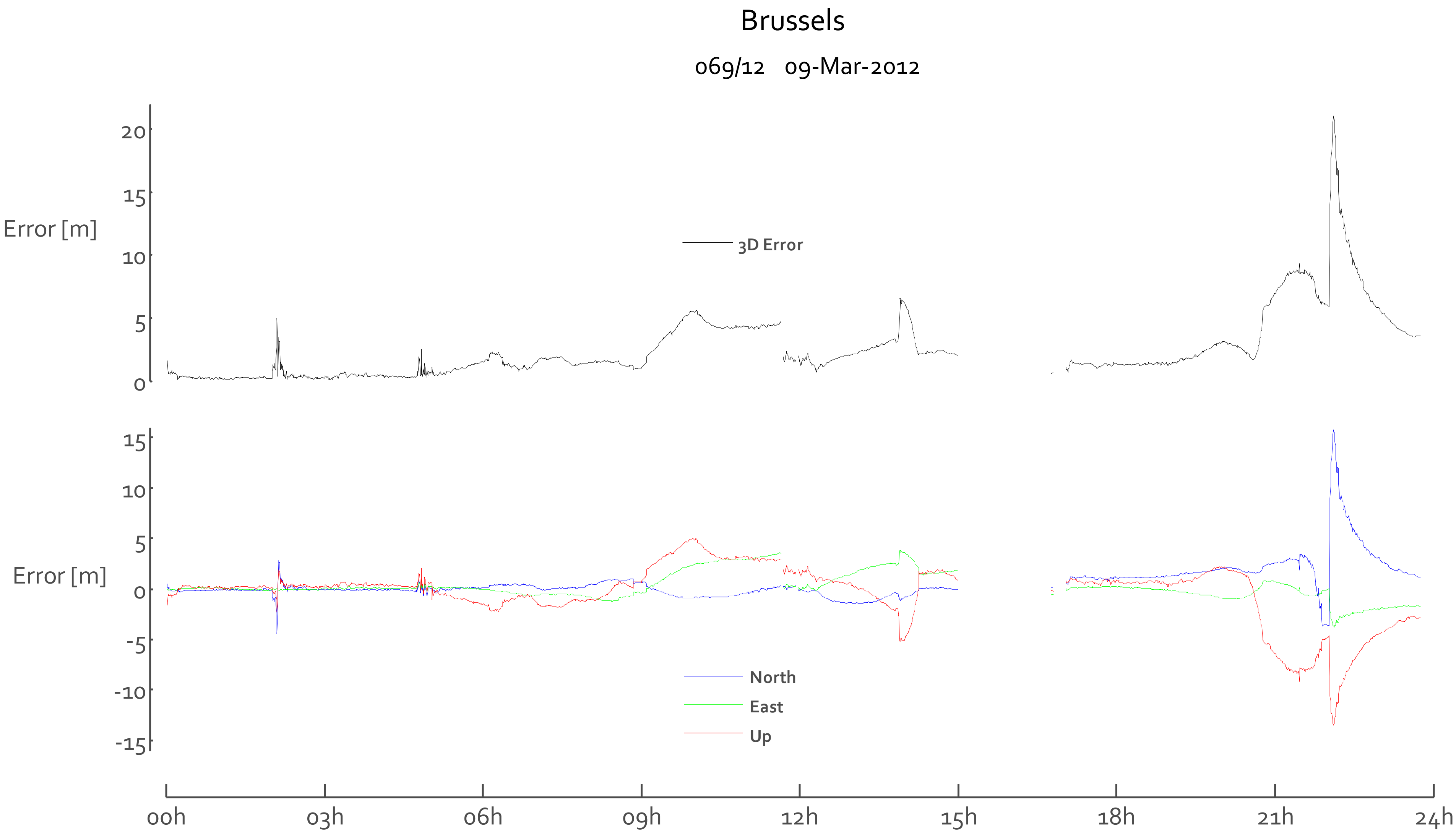
Stochastic Model

Solution: Sequential Least Square Adjustment (Filter)

The Precise Point Positioning is an advanced DF Technique



The Precise Point Positioning is highly sensitive to Ionospheric Scintillations Effects



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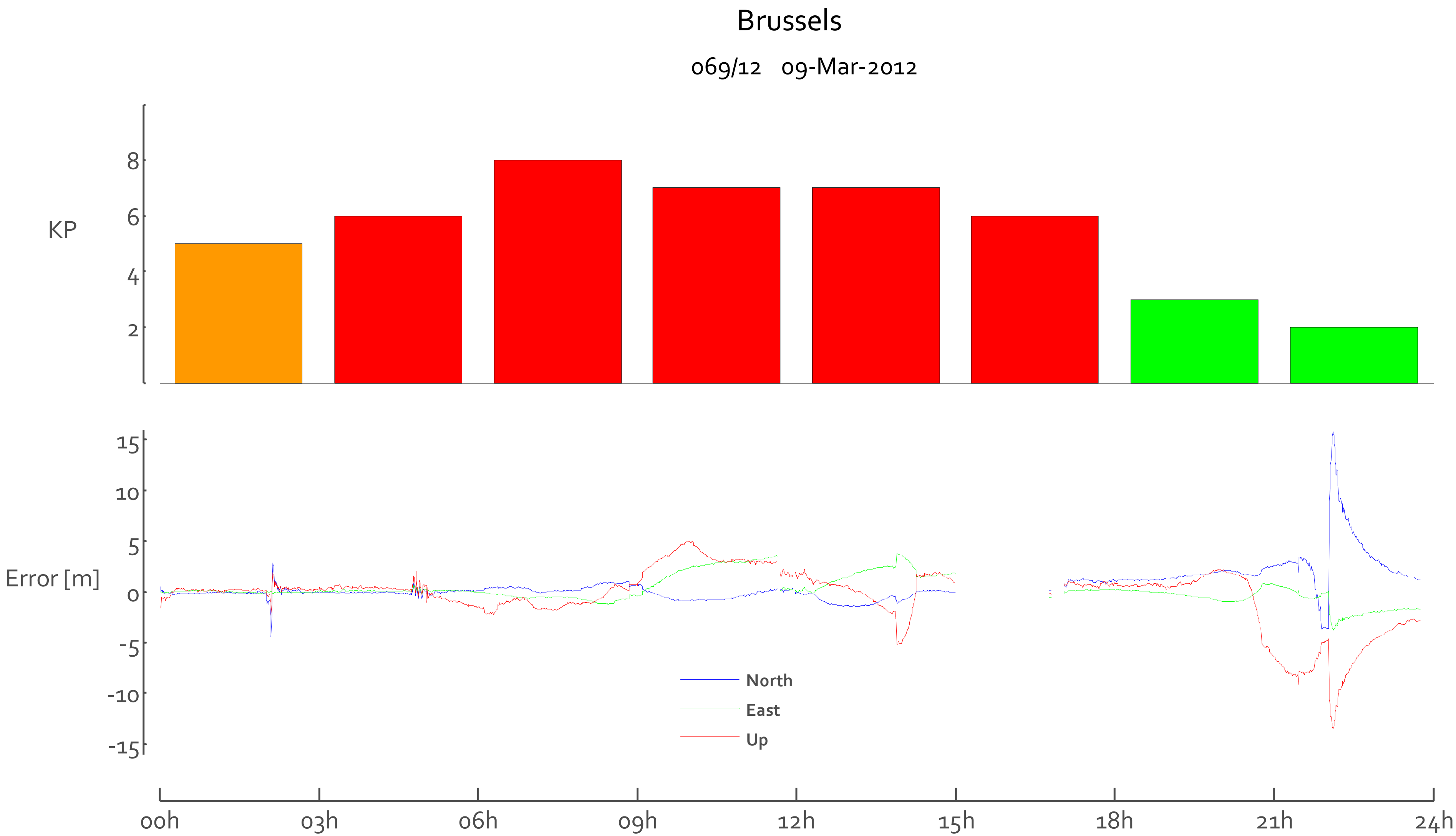

Introduction

Objectives

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Perspectives

The Project aims to develop new Strategies to mitigate the impact of Ionospheric Scintillations on Satellite Positioning

Softwares ➡ *Development of Scintillation Analysis Tools*

Adaptation of existing softwares

Analysis

Stochasticity

Geometry

Preprocessing

The Project aims to develop new Strategies to mitigate the impact of Ionospheric Scintillations on Satellite Positioning

Softwares

Analysis ➡ *Statistical Analysis of Scintillation Effects*

Symptomatic Analysis of Scintillation Effects

Stochasticity

Geometry

Preprocessing

The Project aims to develop new Strategies to mitigate the impact of Ionospheric Scintillations on Satellite Positioning

Softwares

Analysis

Stochasticity ➡

Stochastic Model Improvement

Spatial/Empirical Approach

Correlations Assessment between Observables

Correlations Assessment between Satellites

Validation on SPP and PPP

Validation on different Scintillations Types

- *Equatorial and Polar Scintillations*
- *Weak/Moderate/Intense Scintillations*

Geometry

Preprocessing

The Project aims to develop new Strategies to mitigate the impact of Ionospheric Scintillations on Satellite Positioning

Softwares

Analysis

Stochasticity

Geometry ➡ *Analysis of Geometric Effects of Scintillations*

Preprocessing

The Project aims to develop new Strategies to mitigate the impact of Ionospheric Scintillations on Satellite Positioning

Softwares

Analysis

Stochasticity

Geometry

Preprocessing ➡ *Validation of a Cycle Slips Treatment Method*

Introduction

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Geometry

Preprocessing

gLAB is a SPP and PPP Software for Scientific Purposes

ESA/gAGE (UPC)

GNSS Data Processing Tool

GNSS Data Analysis Tool

Support

Multipurpose

Scientific
Professional
Educational

gLAB can be coupled with a Matlab Environment Programming

Data Downloading

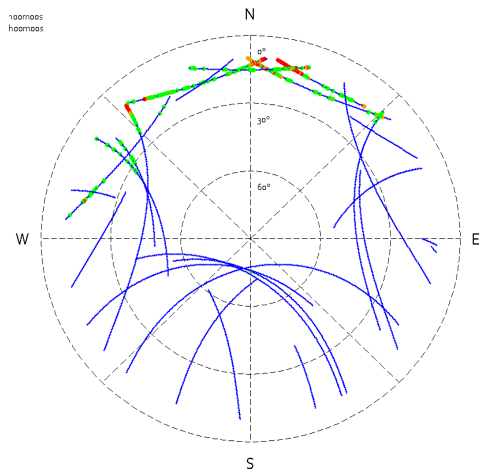
SPP and PPP Processing – Parameters?

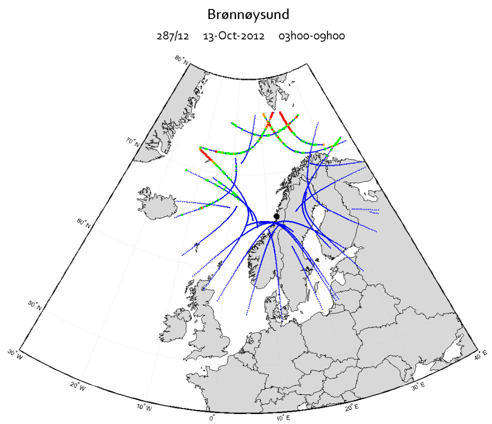
Data Files Reading

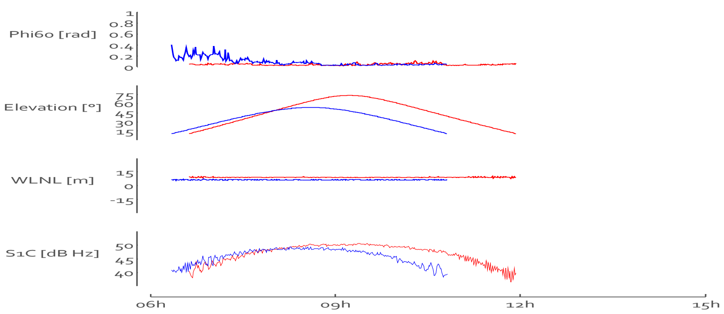
Specific Treatments

Results Visualisations

Graphic Tools: IPP Maps and Skyplots







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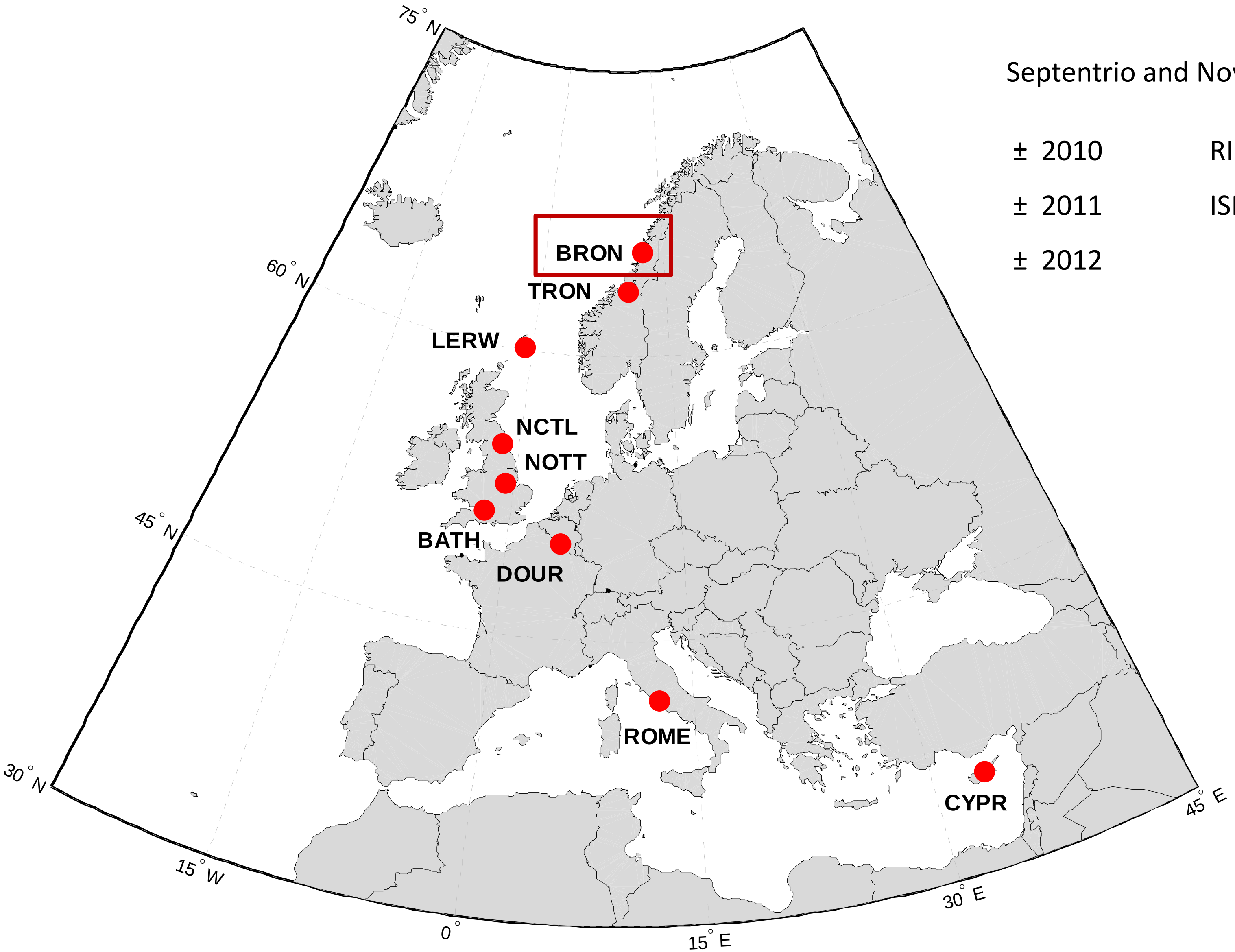
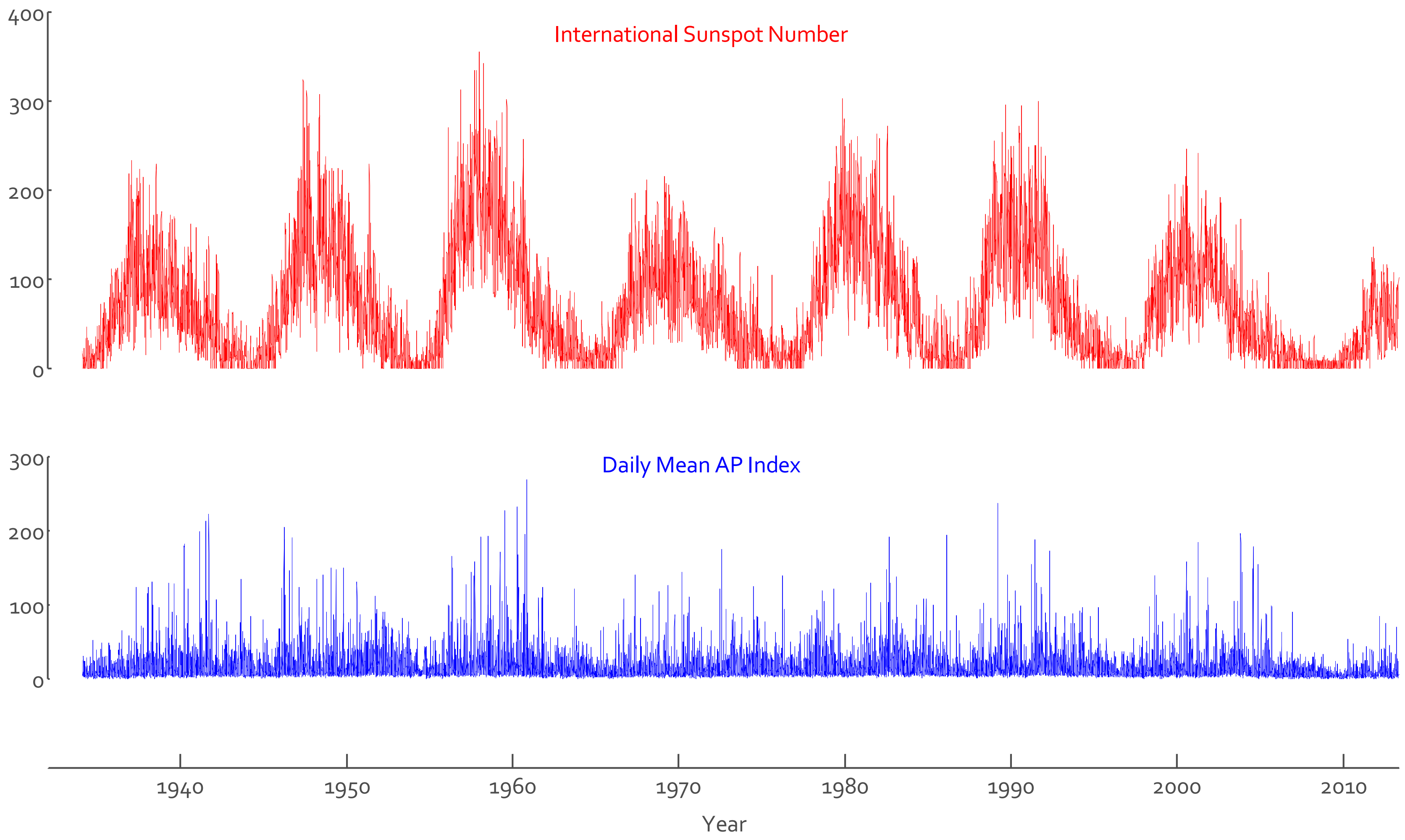
Ionospheric Scintillation Monitoring Receivers (ISMR) Network



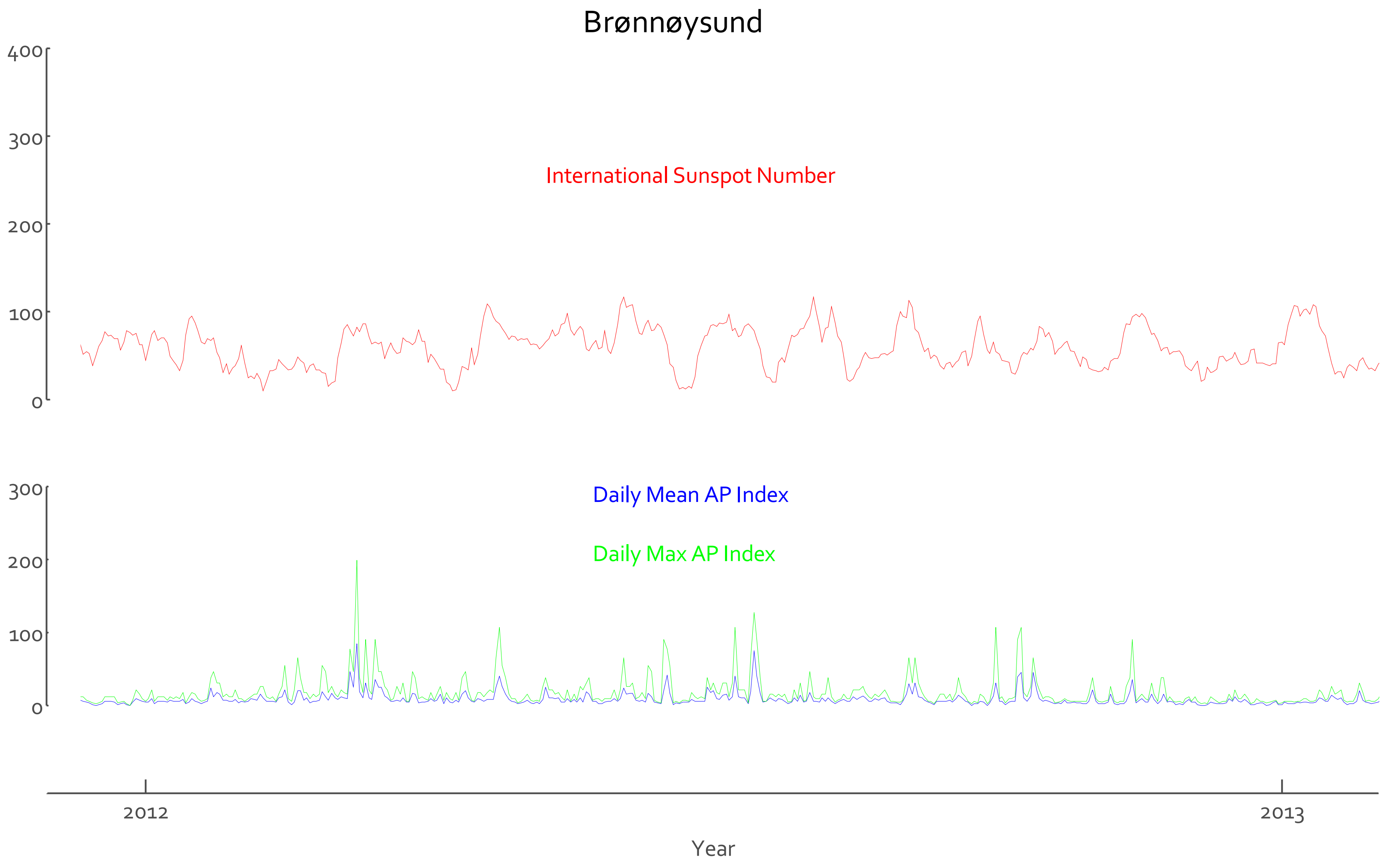
Septentrio and Novatel ISMR

± 2010	RINEX 30”
± 2011	ISMR 60”
± 2012	

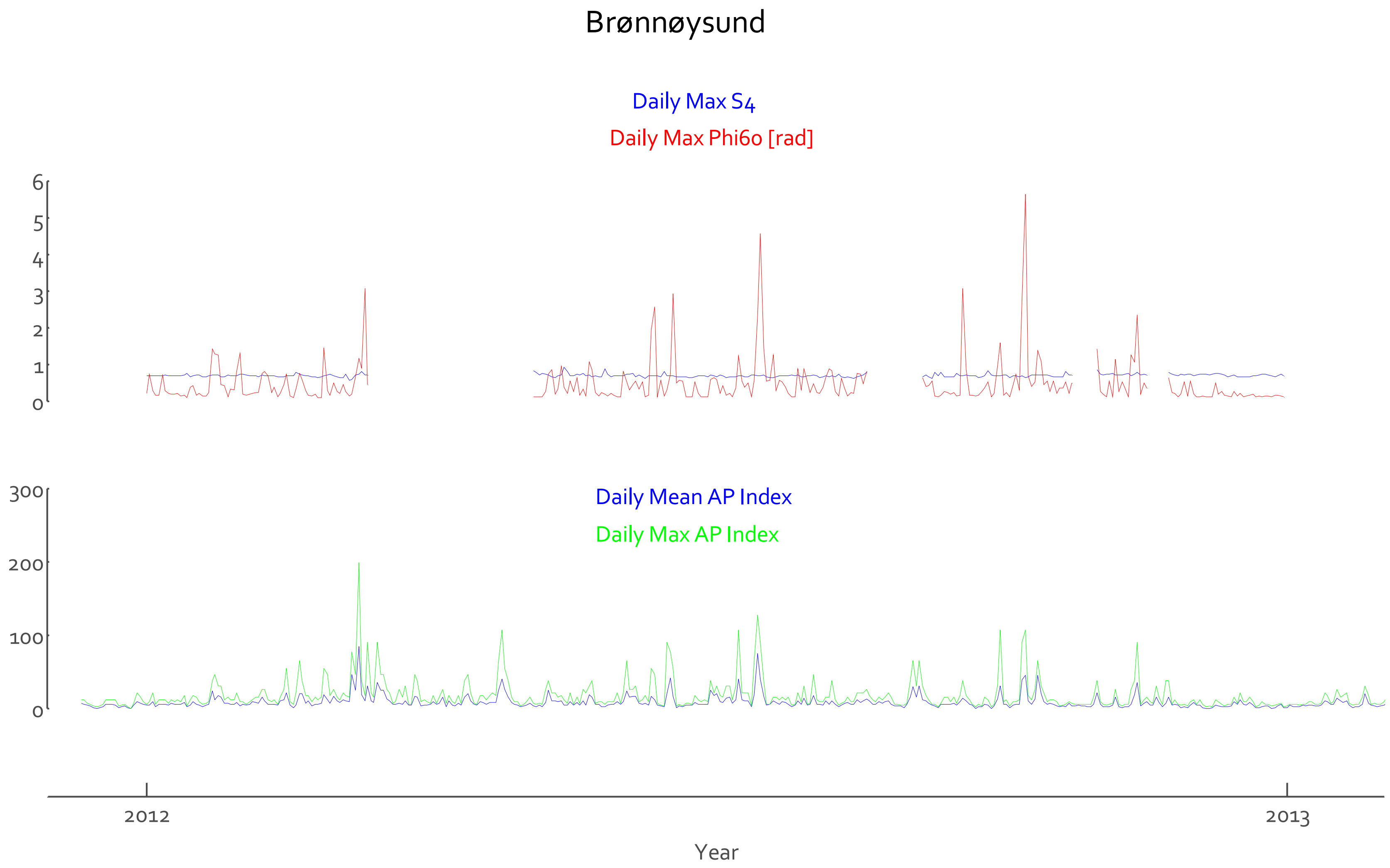
Severe Geomagnetic Storms occur under High Solar Activity



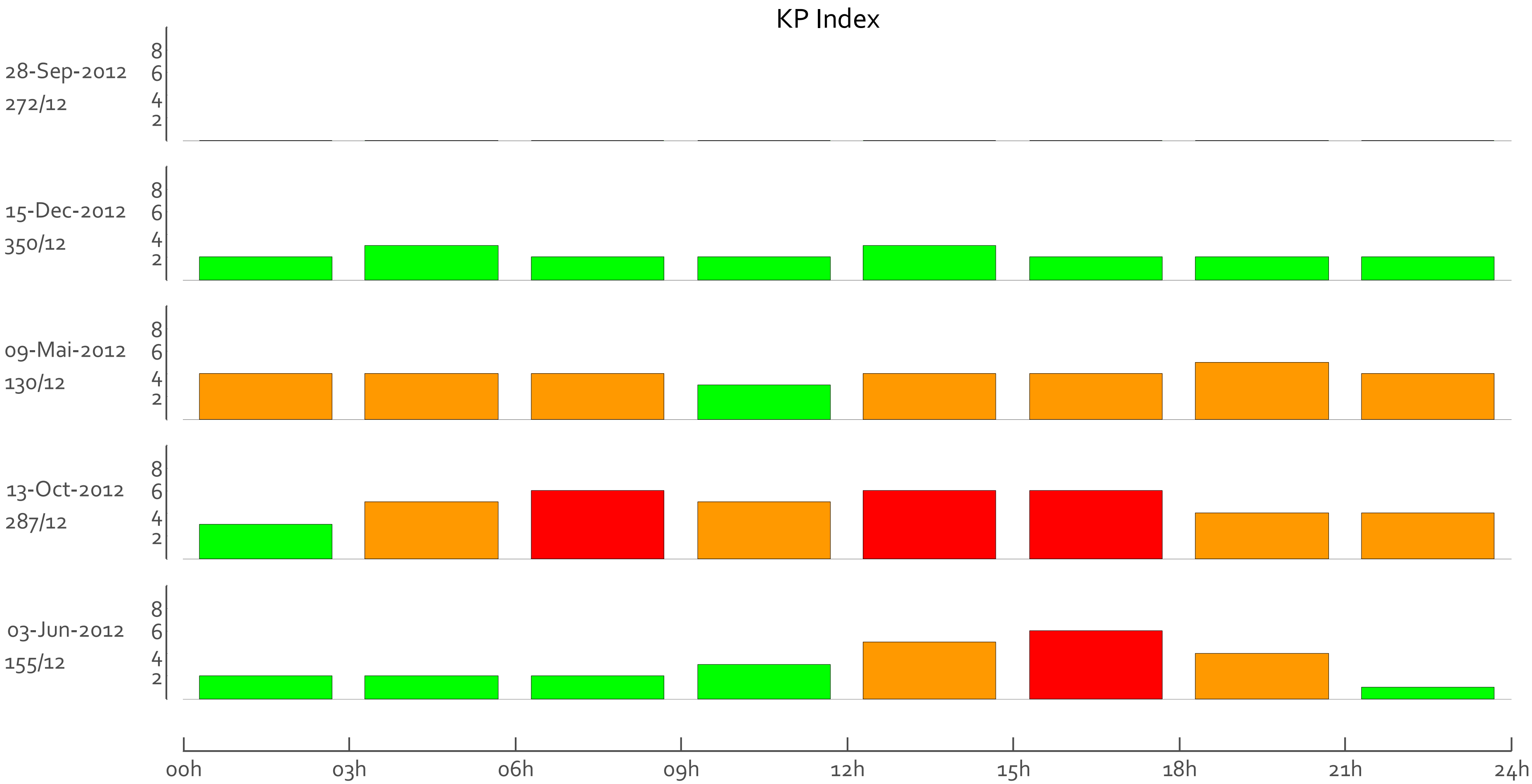
Geomagnetic Storms still occur under Moderate Solar Activity



Ionospheric Scintillations occur under Moderate Solar Activity



The Analysis Strategy is based on the Selection of 5 typical Days



The Analysis Strategy is based on specific Criteria

	Single Station Approach *Low/High Magnetic Activity*
Multi Station Approach *Medium/High Latitude*	*Occurrence: Measurements and Epochs* *Positioning: SPP and PPP* *Geometry: Satellite Number and Dilution of Precision* *Spatial Characteristics* *Cycle Slips* *Noise Measurement*

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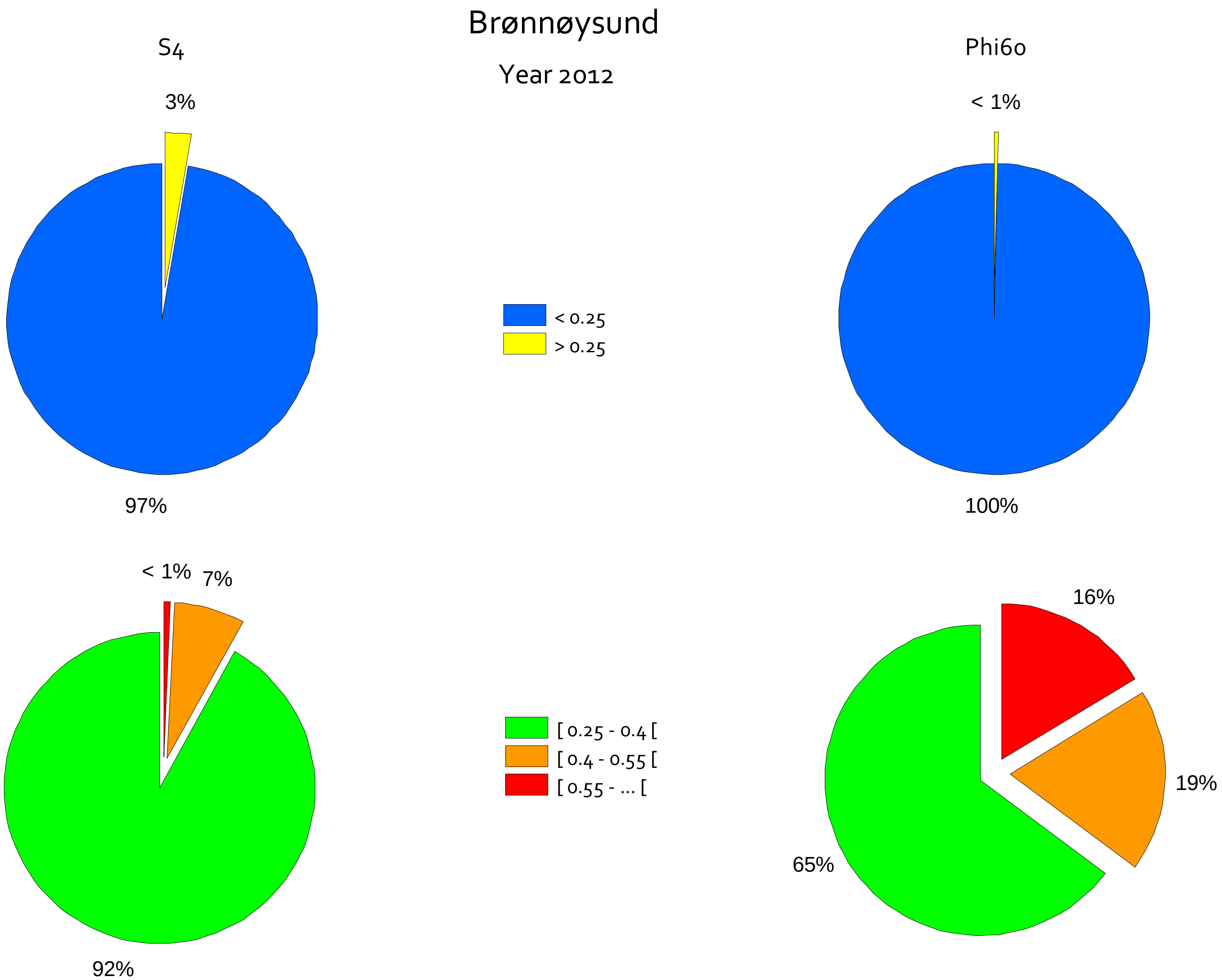
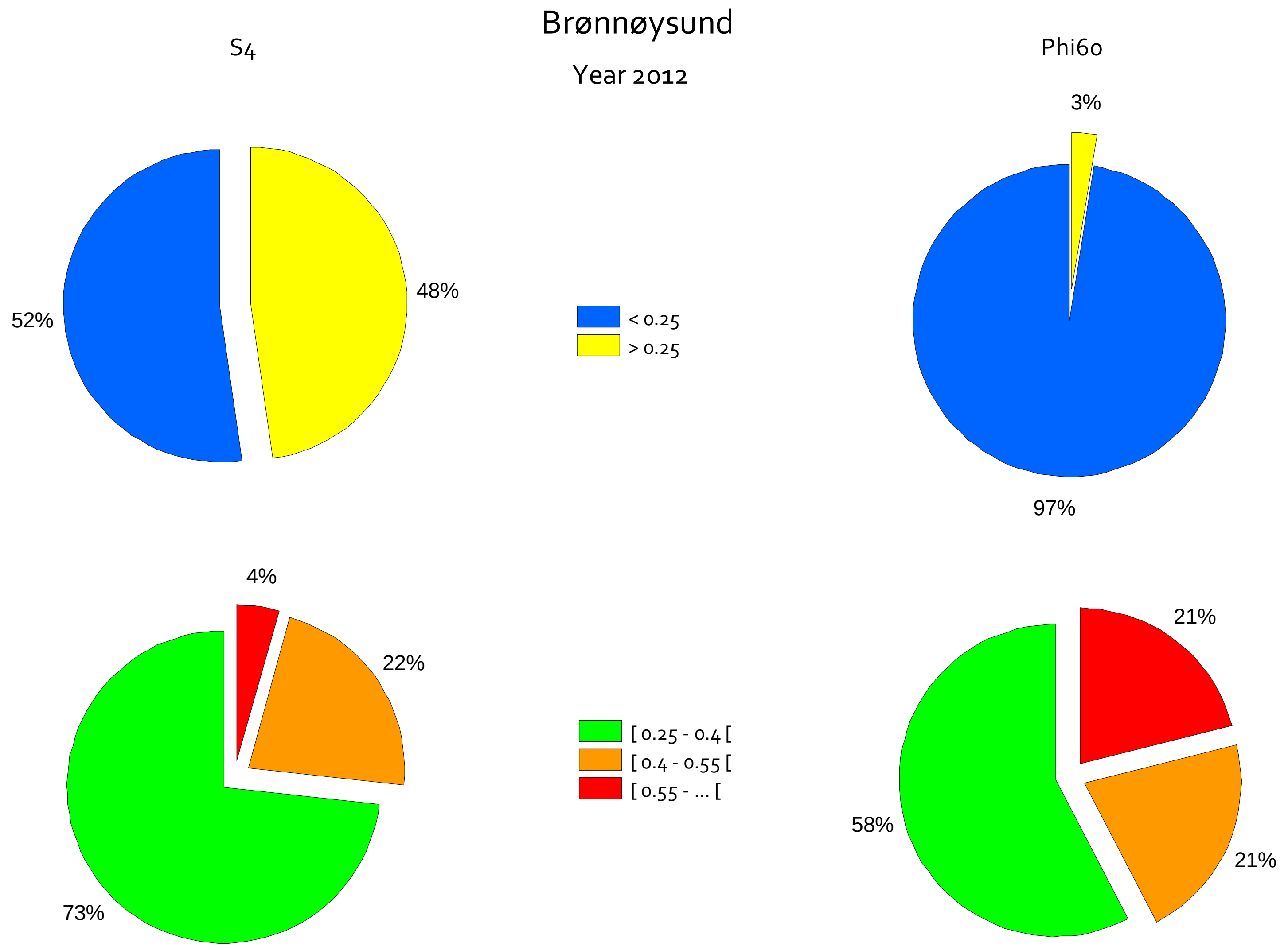
Multi Station Approach *Medium/High Latitude*	*Occurrence: Measurements and Epochs* *Positioning: SPP and PPP* *Geometry: Satellite Number and Dilution of Precision* *Spatial Characteristics* *Cycle Slips* *Noise Measurement*

Ionospheric Scintillations affect a very Small Portion of the Measurements



Ionospheric Scintillations affect a Significant Portion of the Observation Epochs



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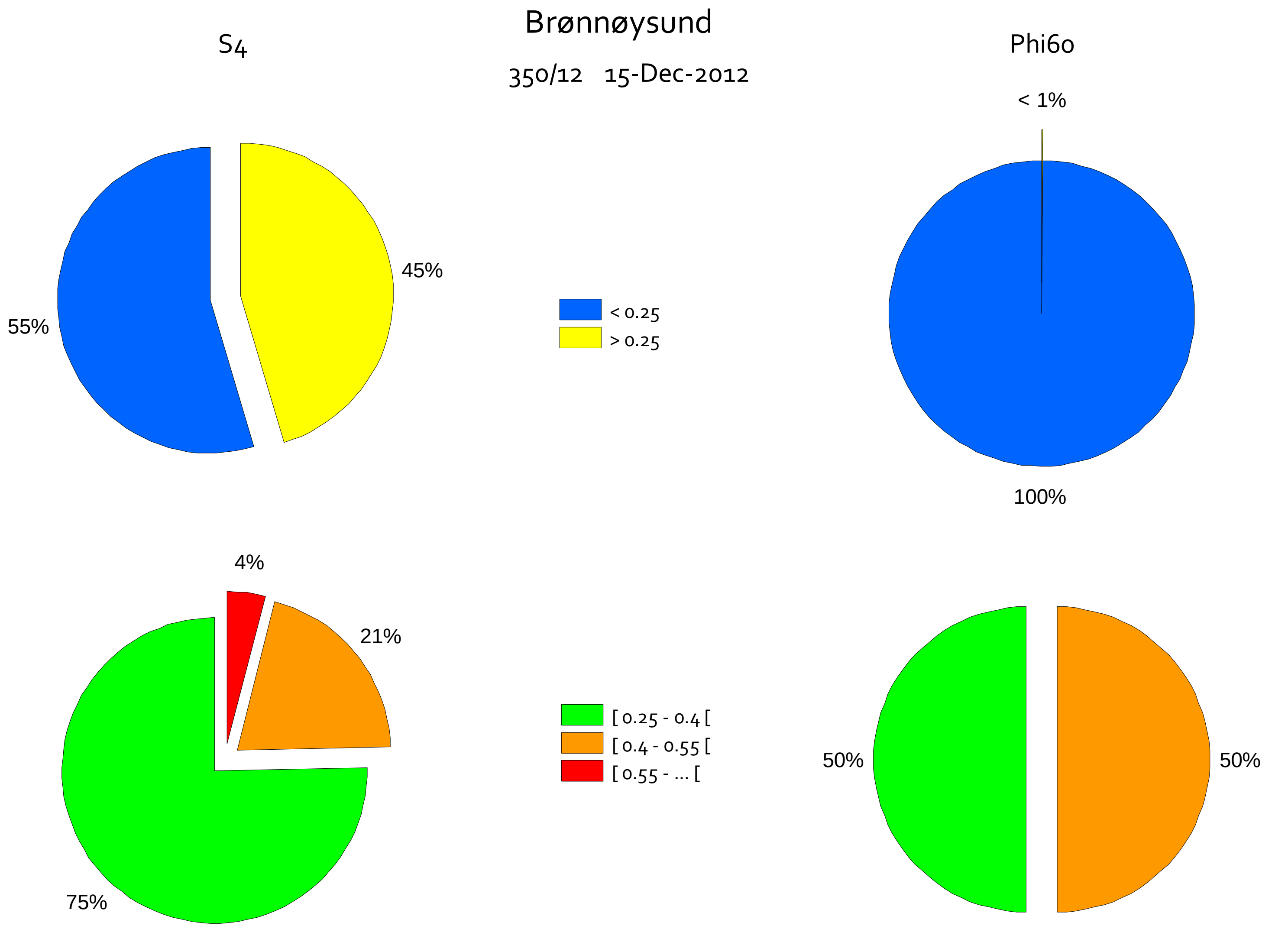
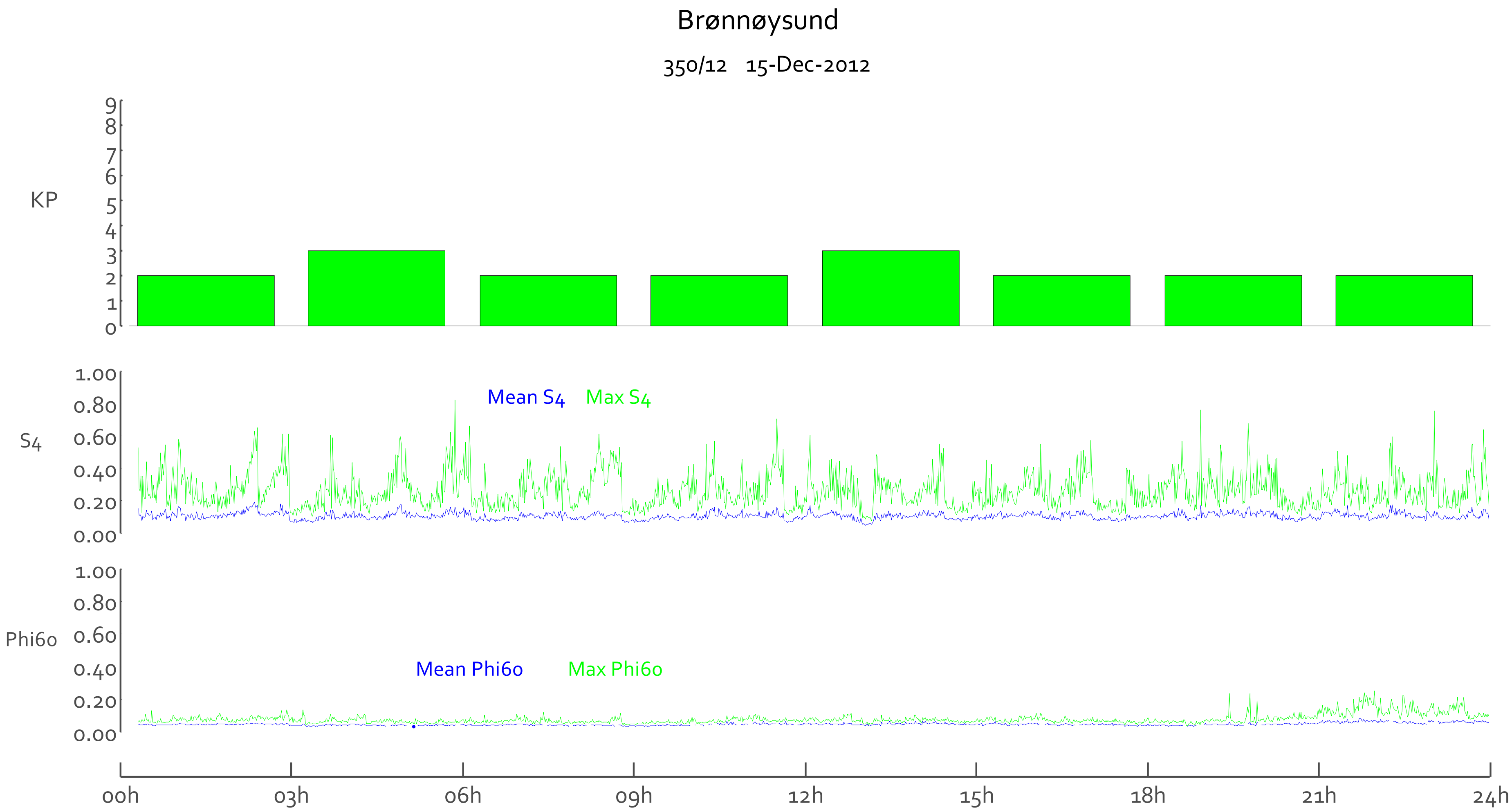


Ionospheric Scintillations affect a Significant Portion of the Observation Epochs



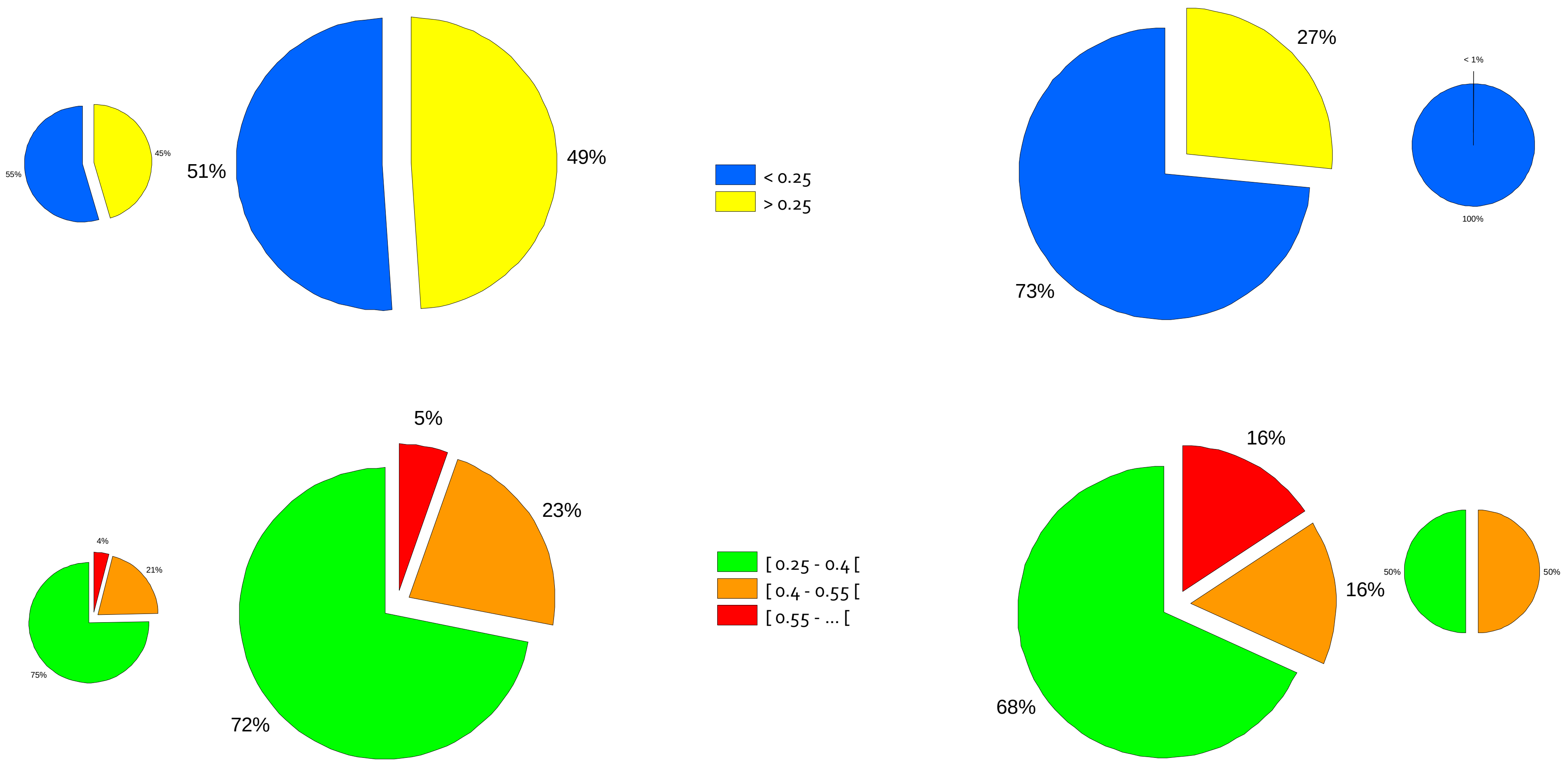
Ionospheric Scintillations affect a Significant Portion of the Observation Epochs

Brønnøysund

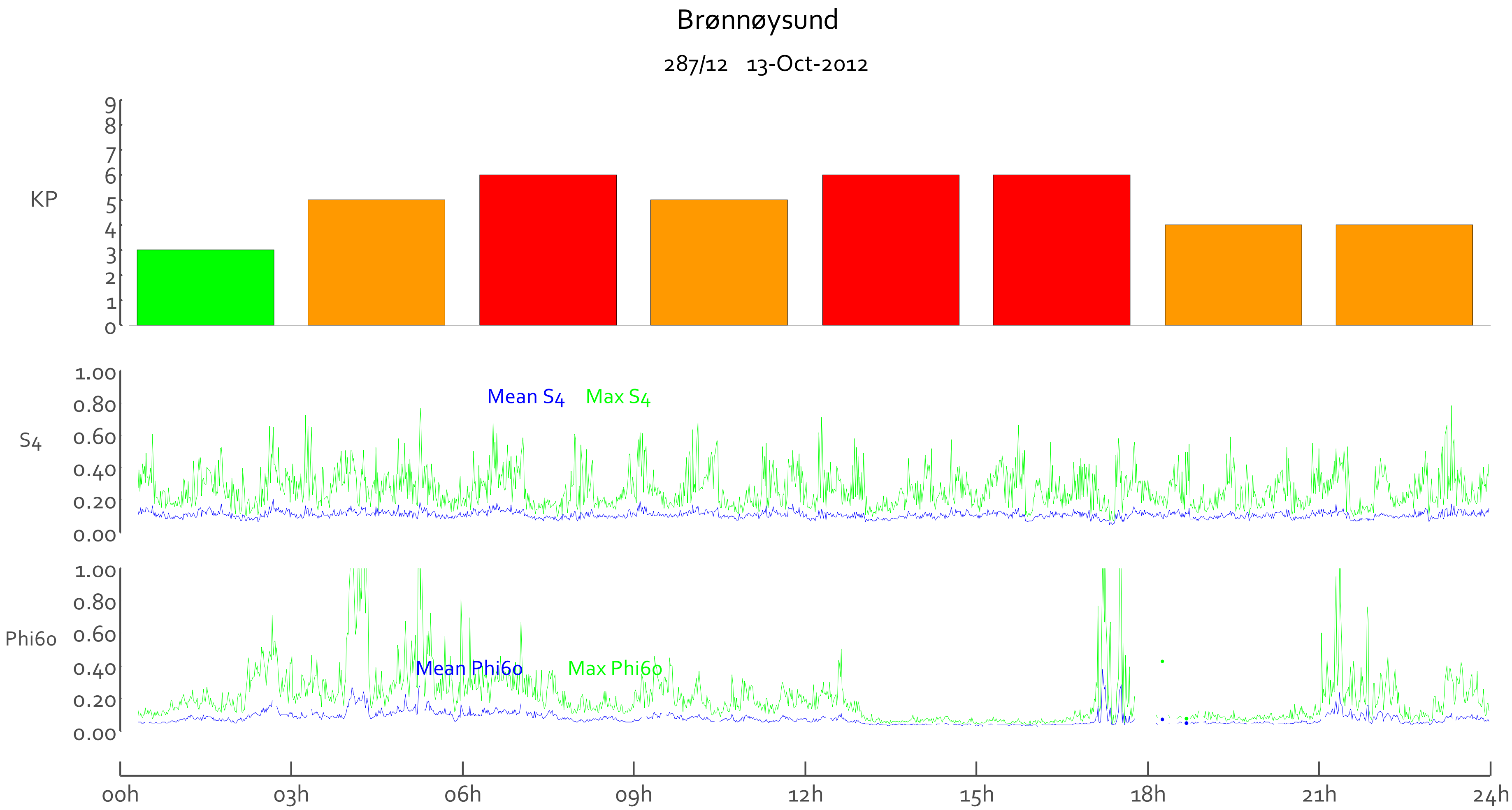
287/12 13-Oct-2012

S4

Phi60



Ionospheric Scintillations affect a Significant Portion of the Observation Epochs



The Analysis Strategy is based on specific Criteria

Single Station Approach

Low/High Magnetic Activity

Multi Station Approach

Medium/High Latitude

Occurrence: Measurements and Epochs

Positioning: SPP and PPP

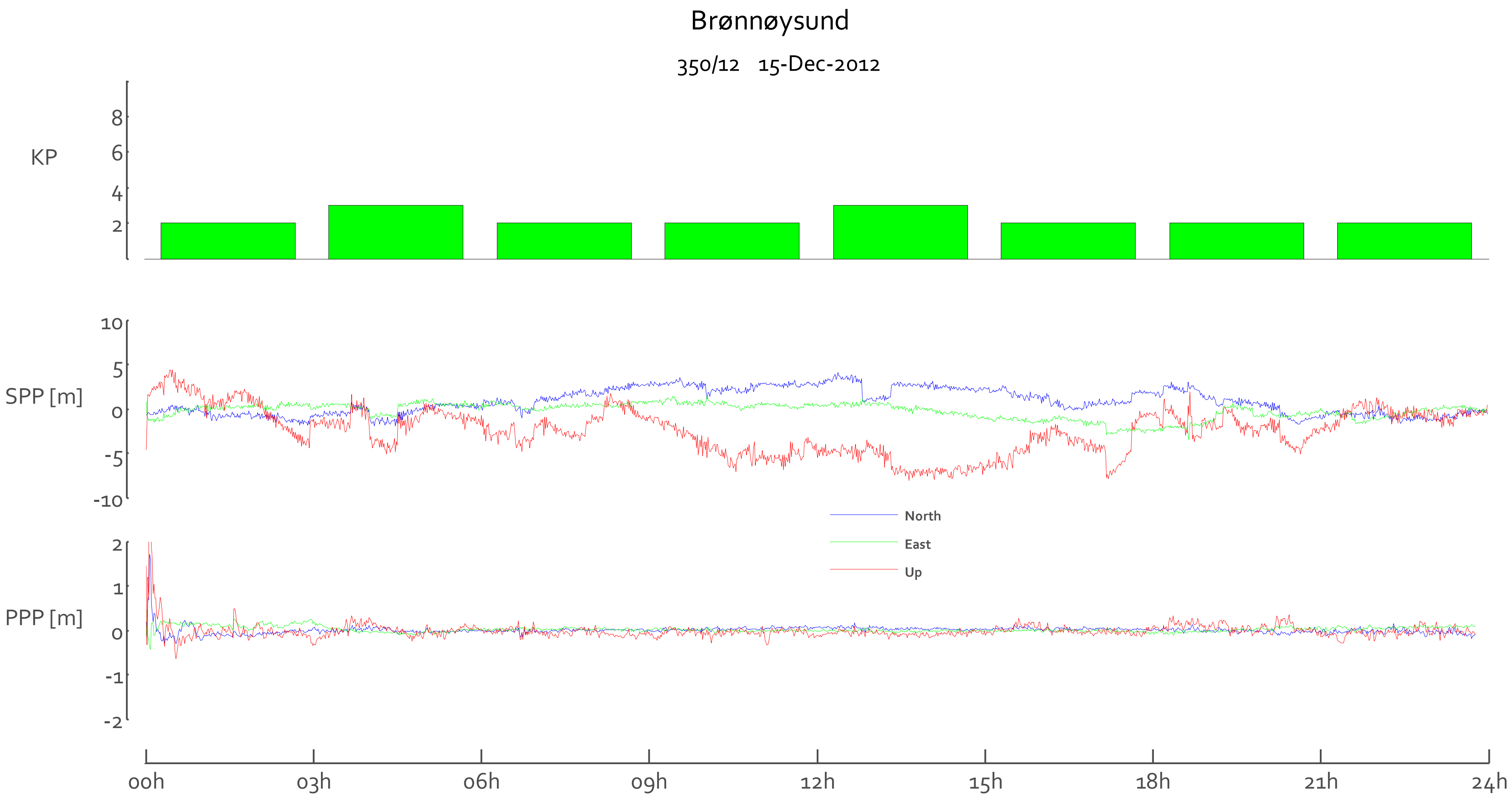
Geometry: Satellite Number and Dilution of Precision

Spatial Characteristics

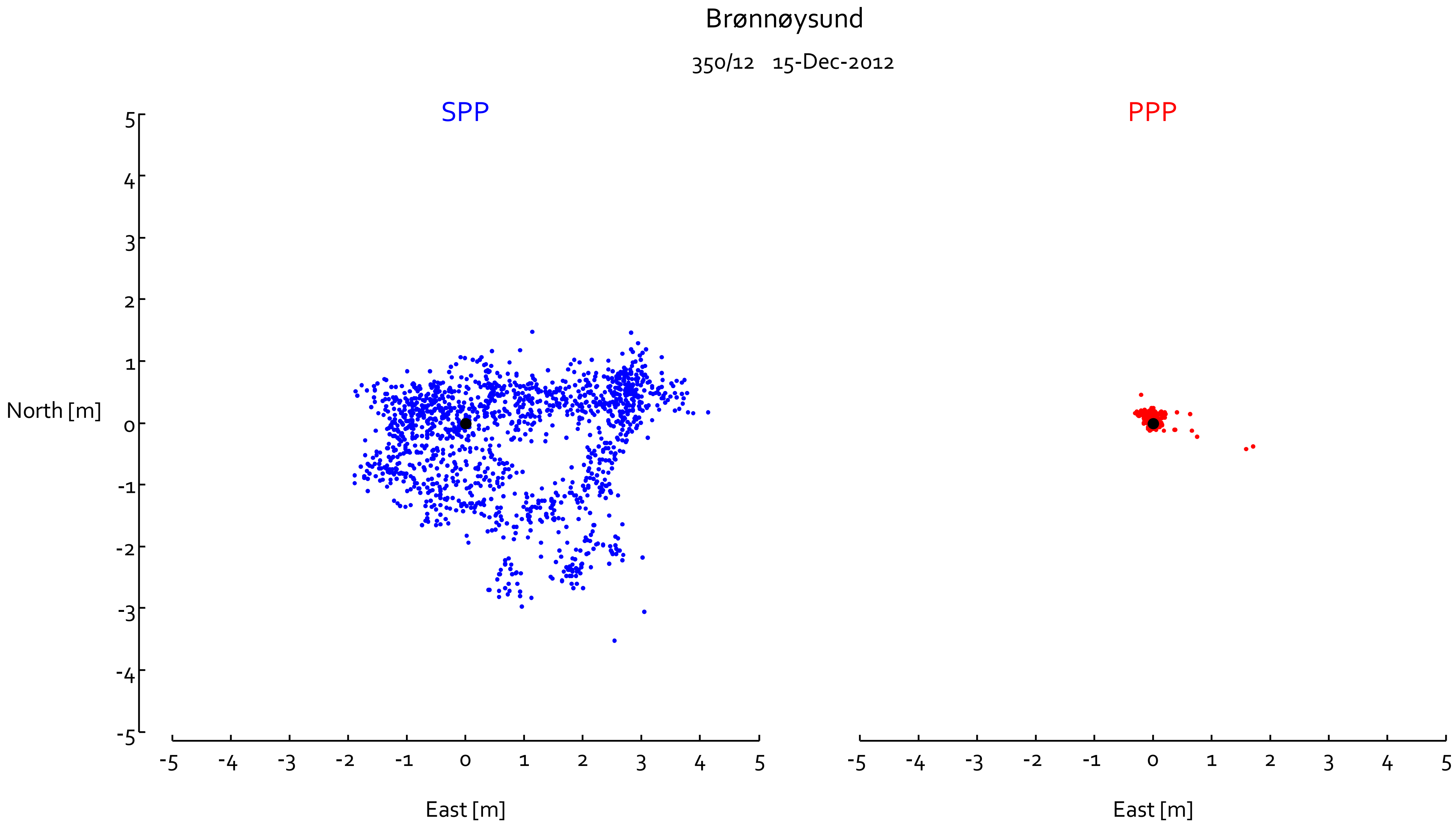
Cycle Slips

Noise Measurement

SPP and PPP Techniques are affected differently by Ionospheric Scintillations Effects



SPP and PPP Techniques are affected differently by Ionospheric Scintillations Effects



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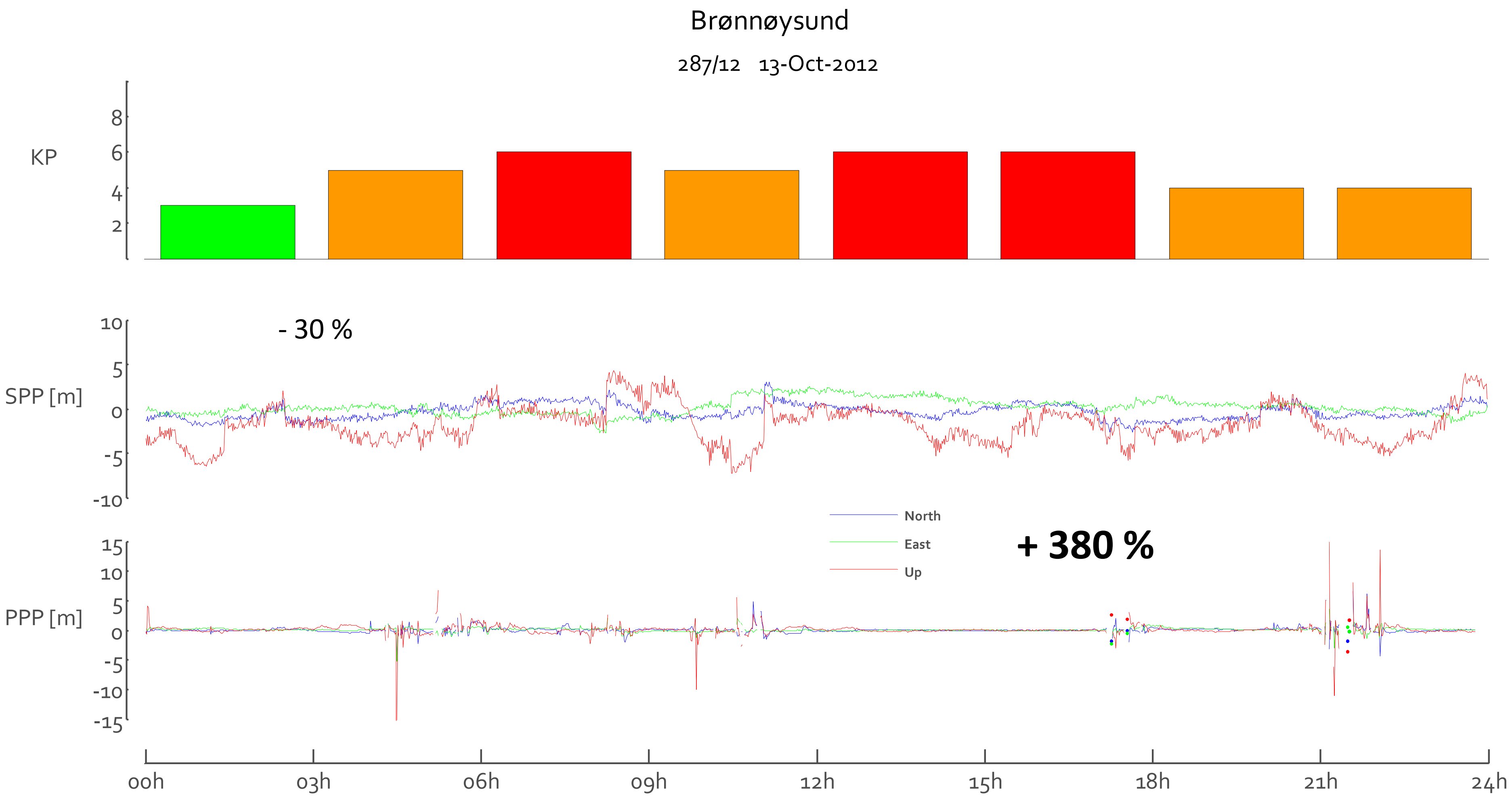

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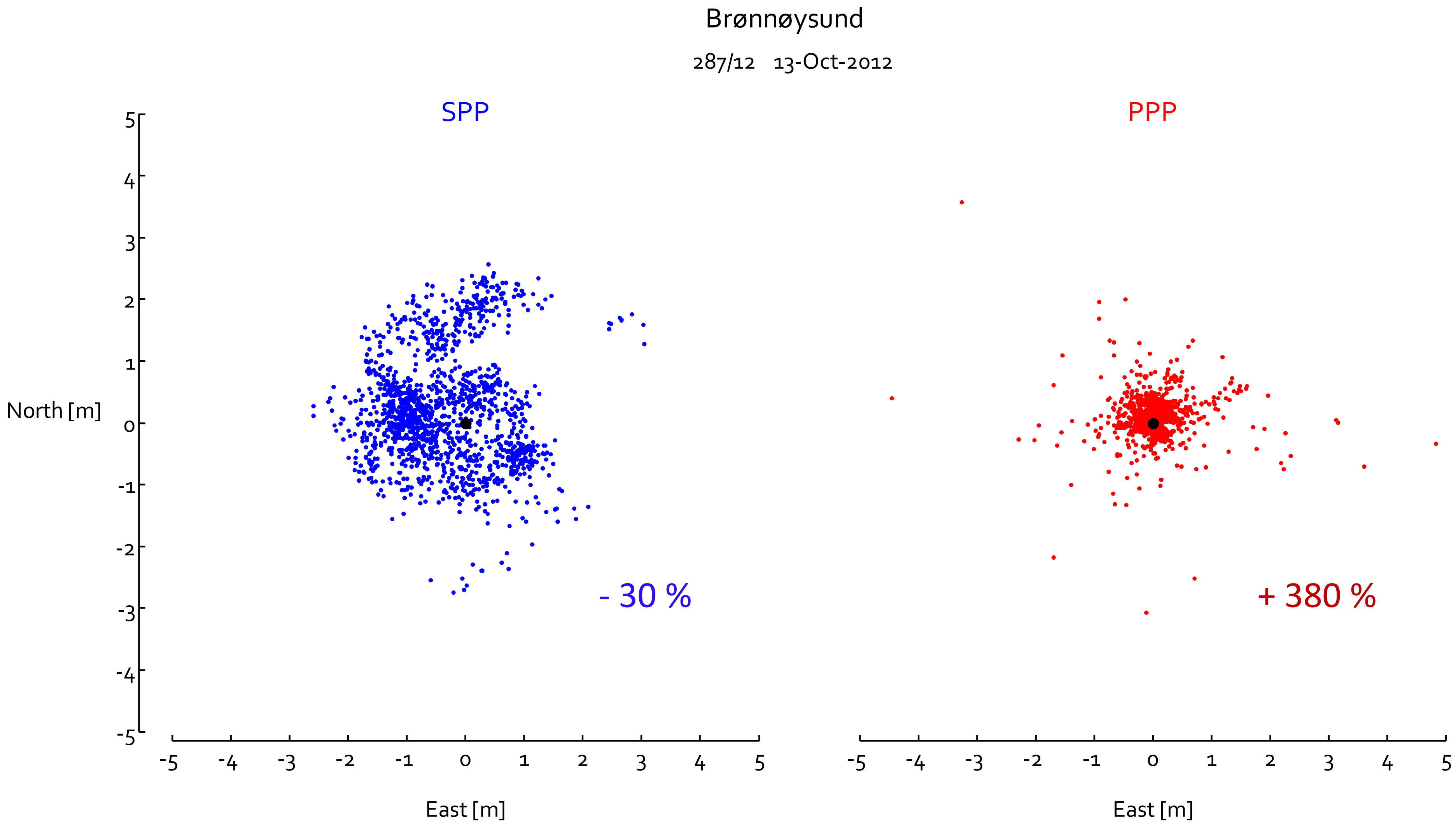

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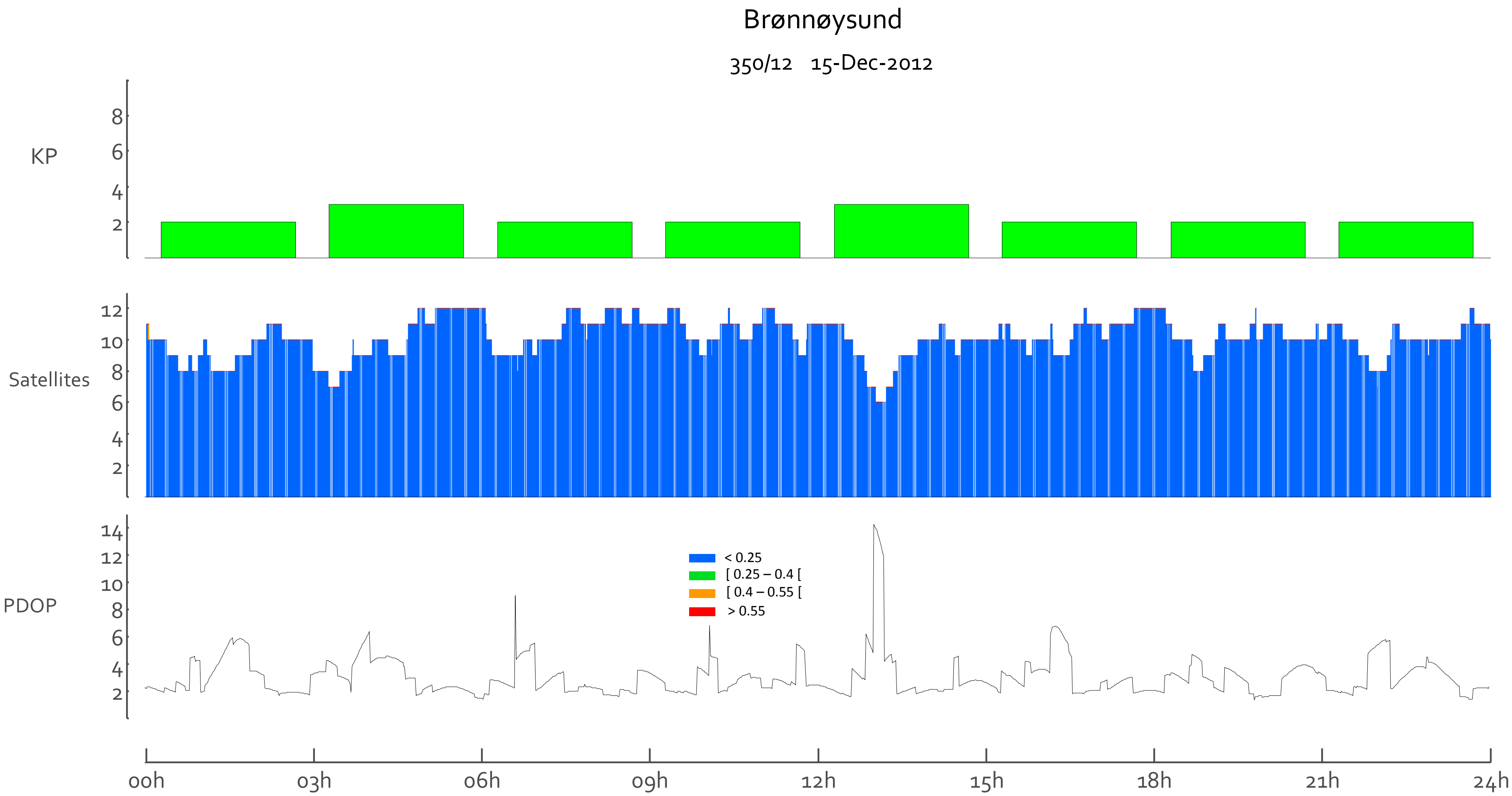
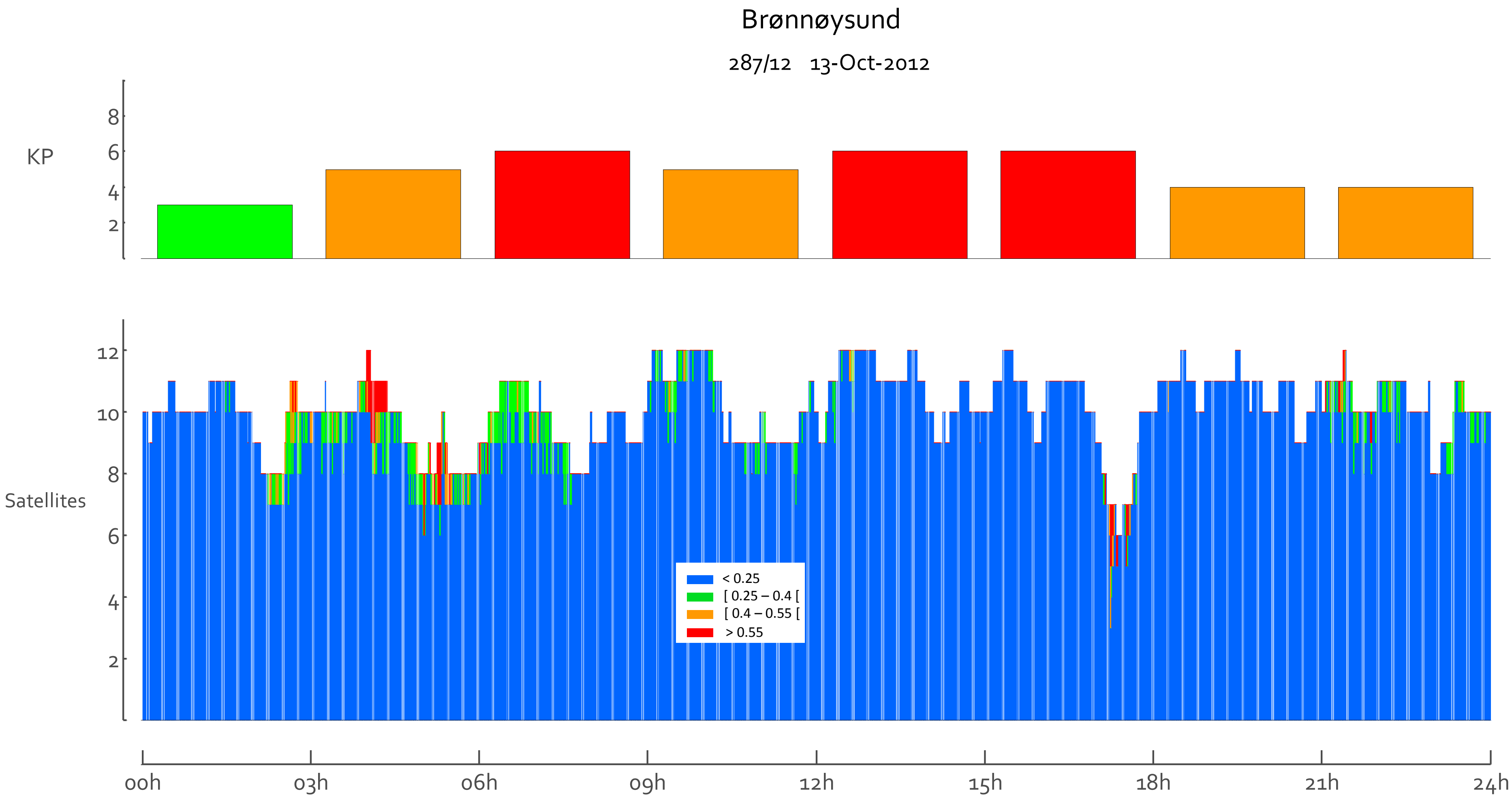
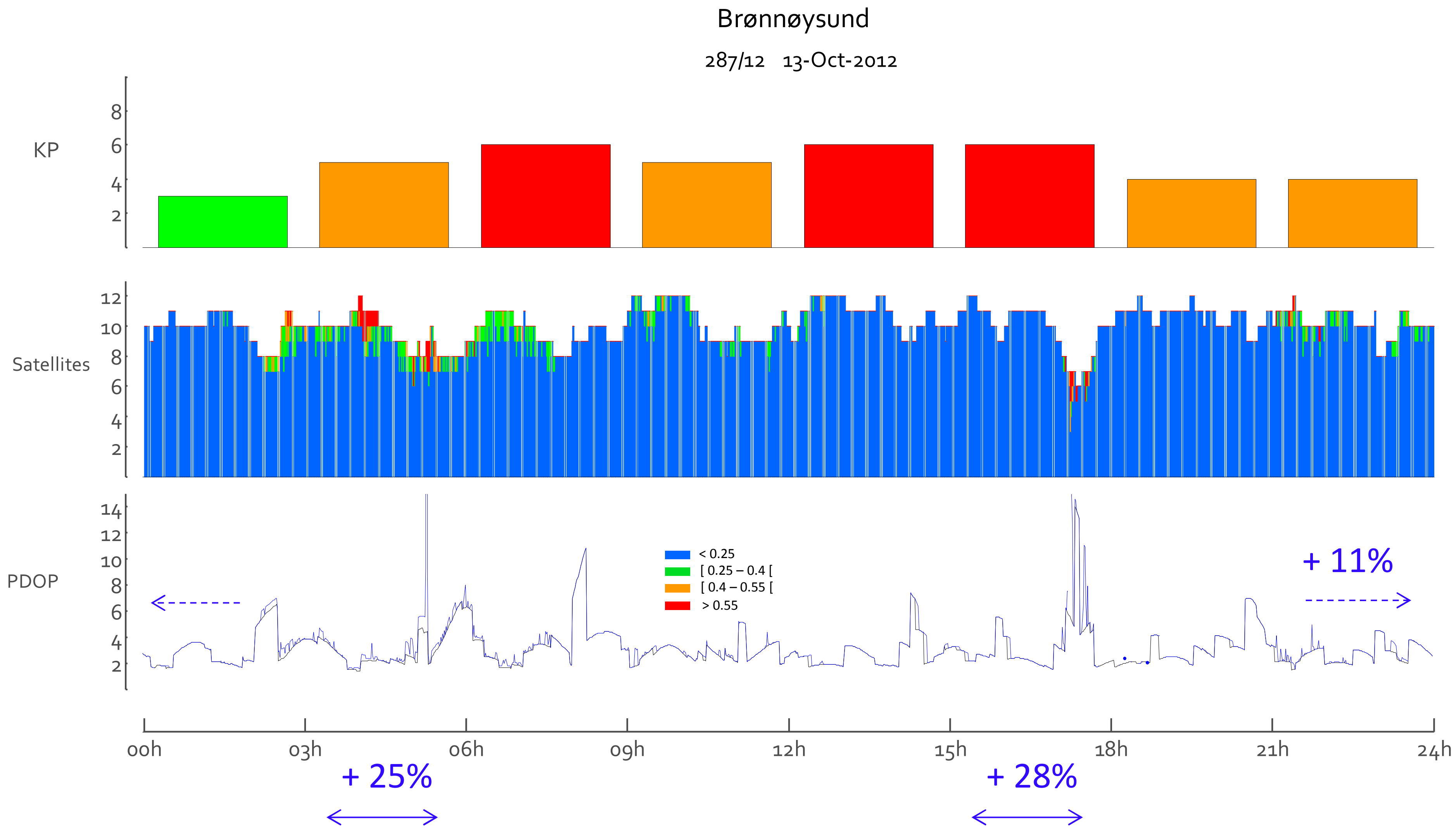
Ionospheric Scintillations Decrease the Satellite Geometry



Ionospheric Scintillations Decrease the Satellite Geometry



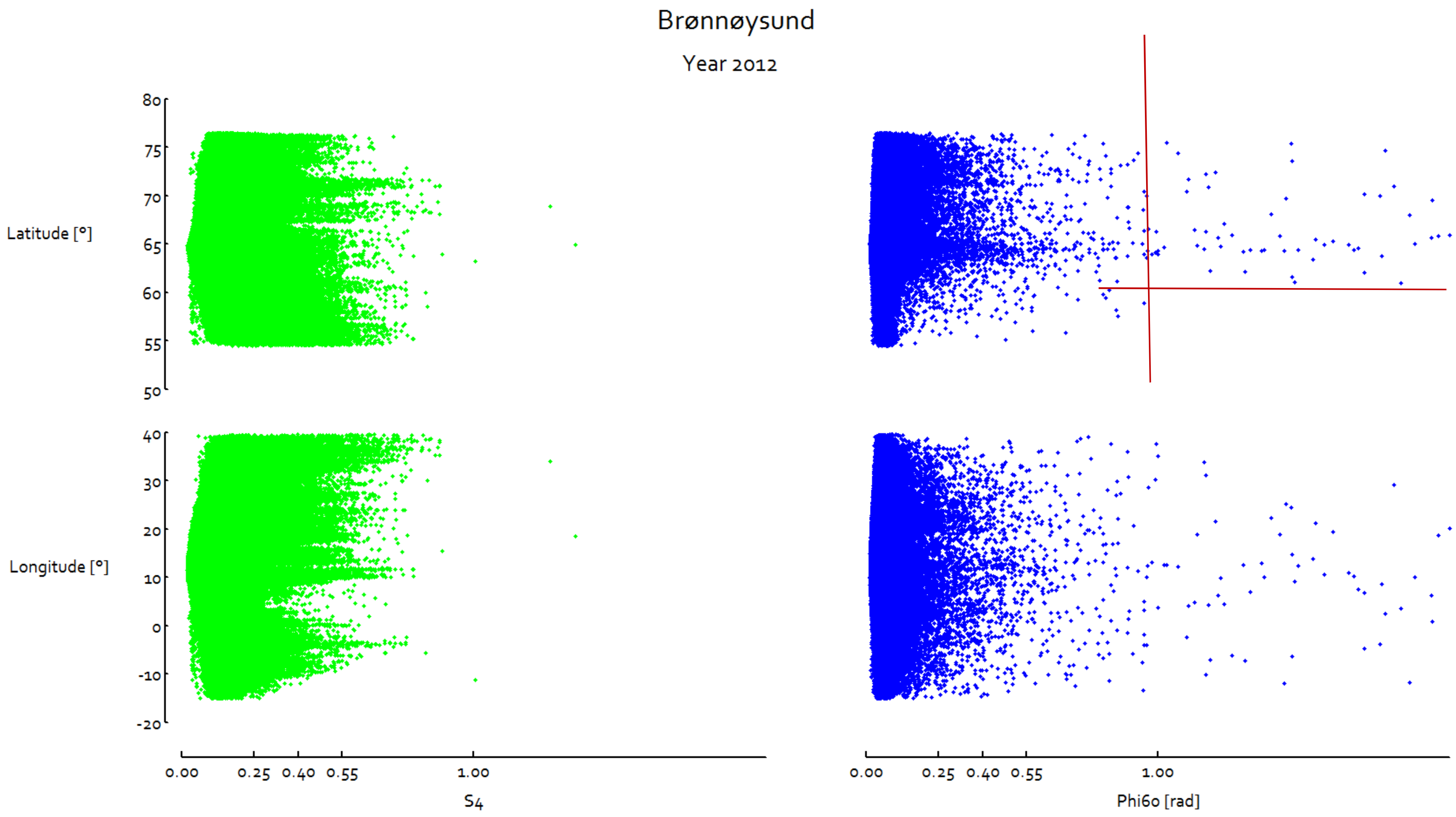
Ionospheric Scintillations Increase the Dilution of Precision



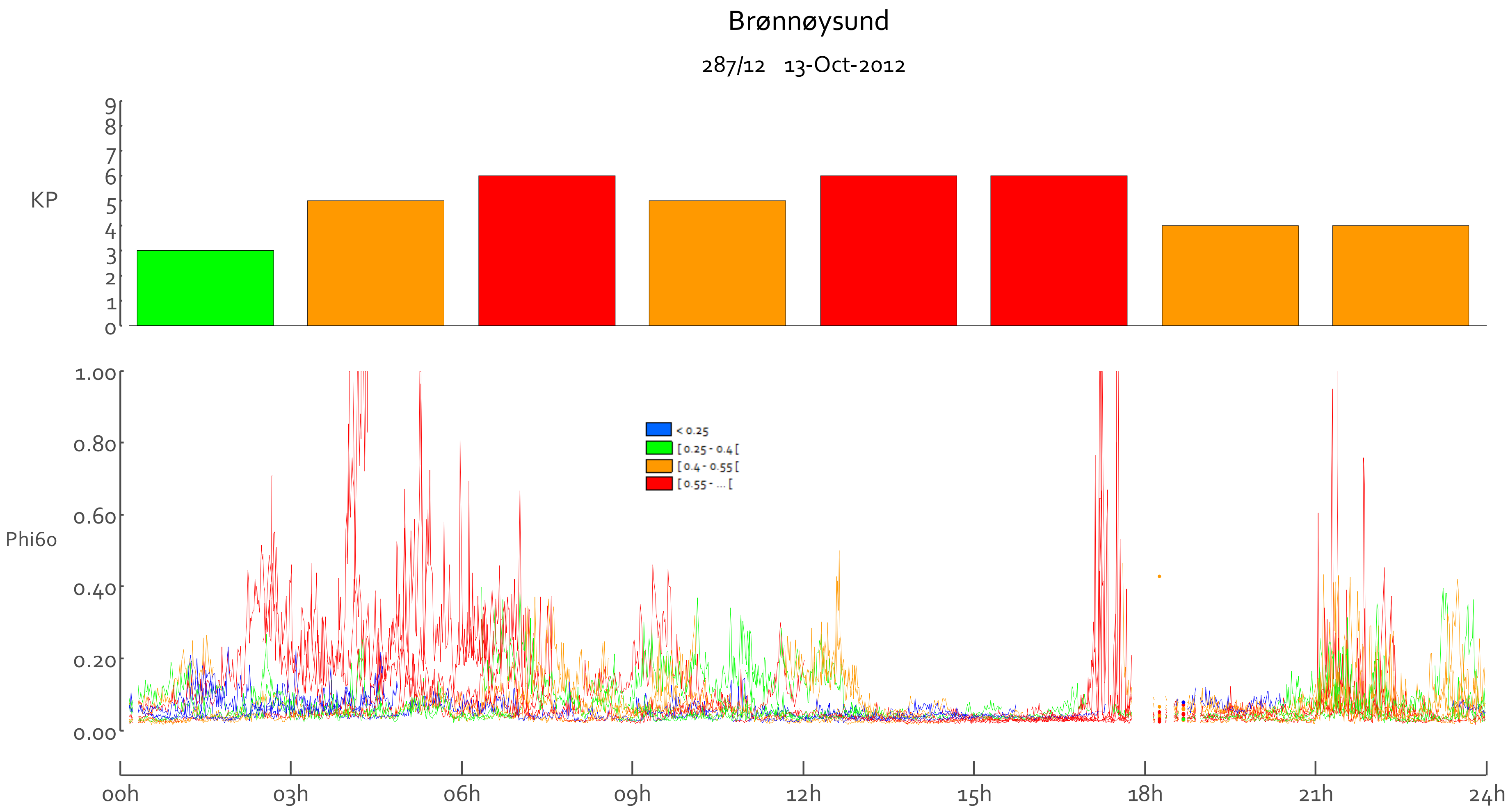
The Analysis Strategy is based on specific Criteria

	Single Station Approach *Low/High Magnetic Activity*
Multi Station Approach *Medium/High Latitude*	*Occurrence: Measurements and Epochs* *Positioning: SPP and PPP* *Geometry: Satellite Number and Dilution of Precision* *Spatial Characteristics* *Cycle Slips* *Noise Measurement*

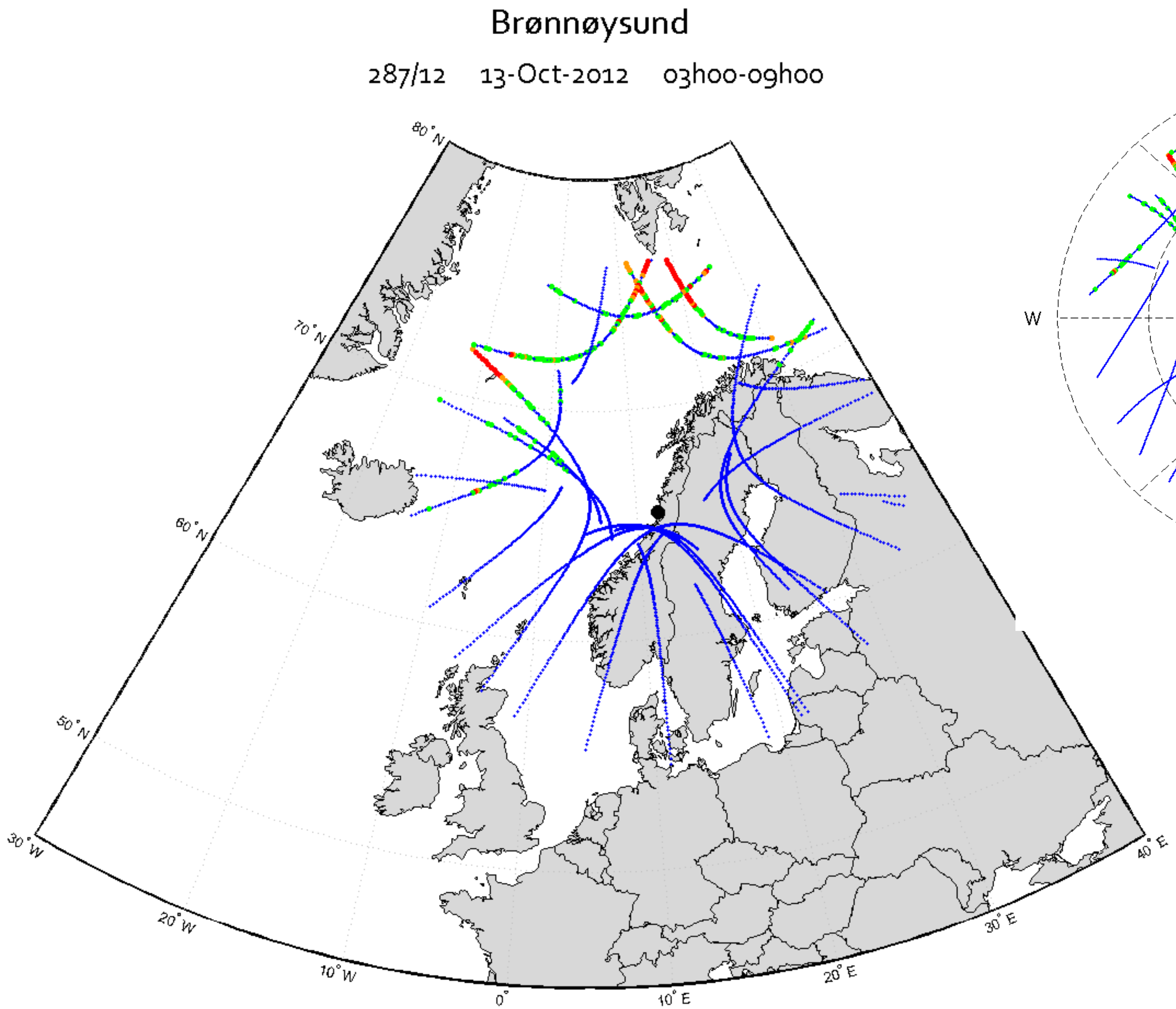
High Phi60 values are frequently observed at High Latitudes

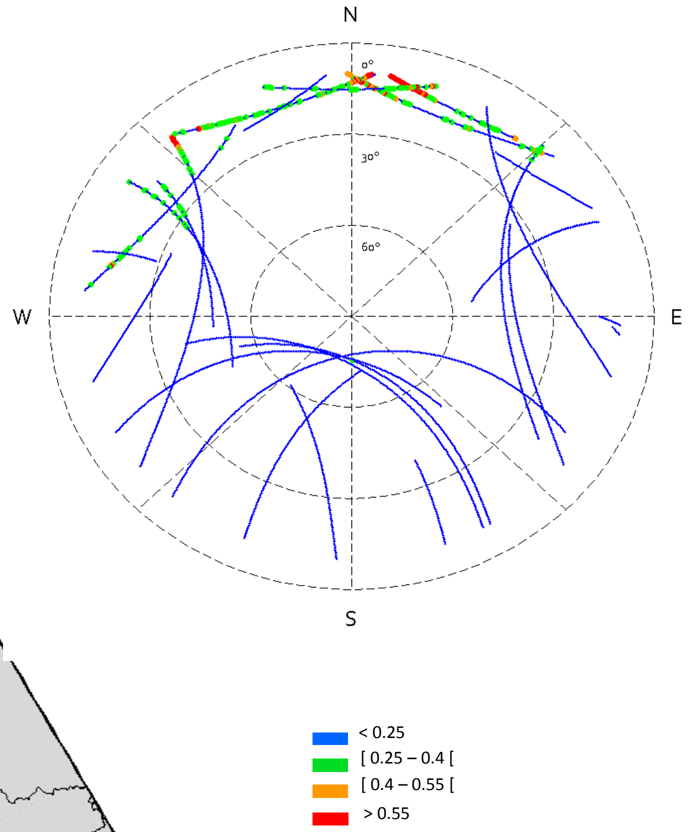


Ionospheric Scintillations: a Spatio-Temporal Phenomenon

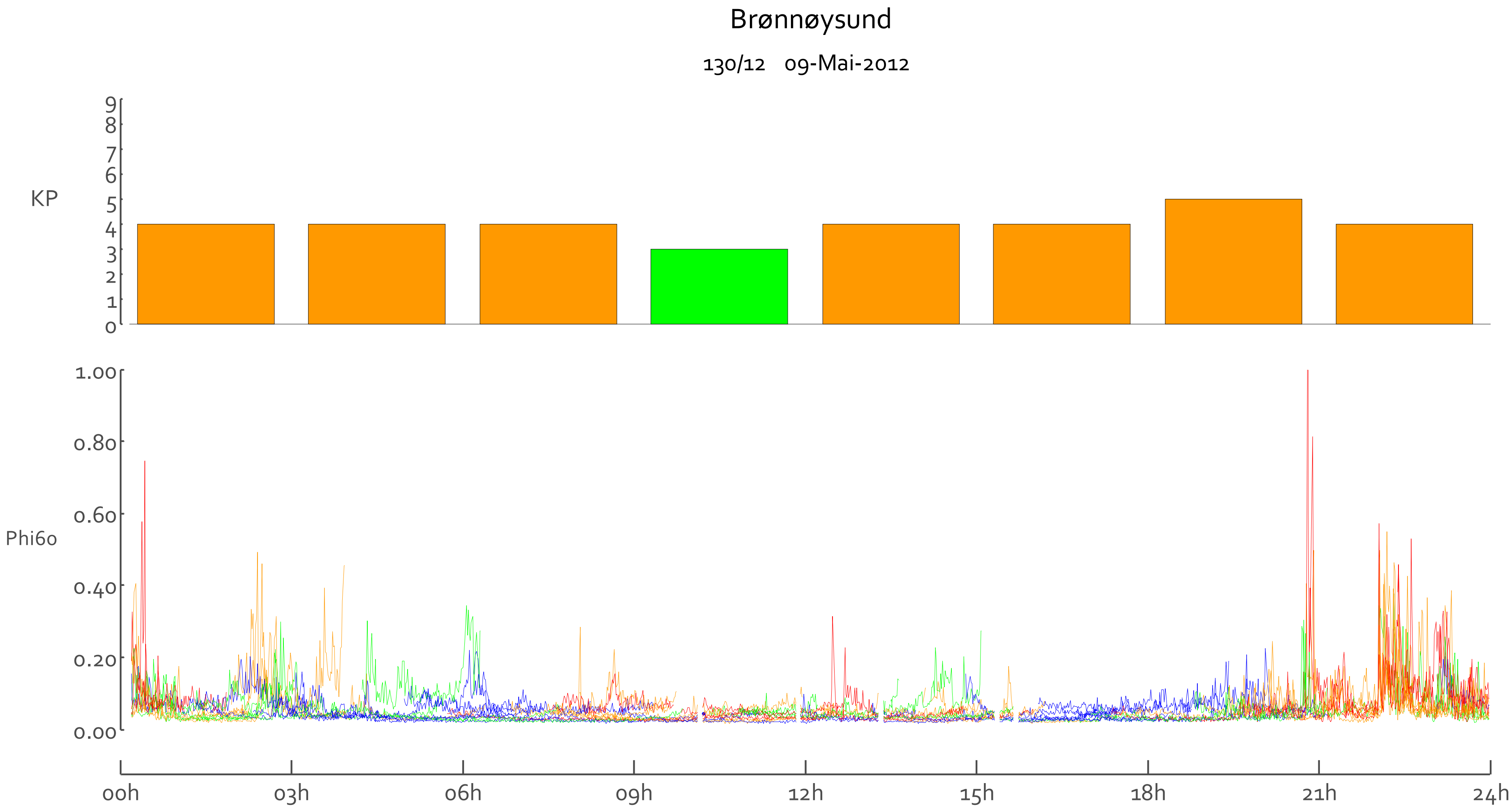


Ionospheric Scintillations: a Spatio-Temporal Phenomenon

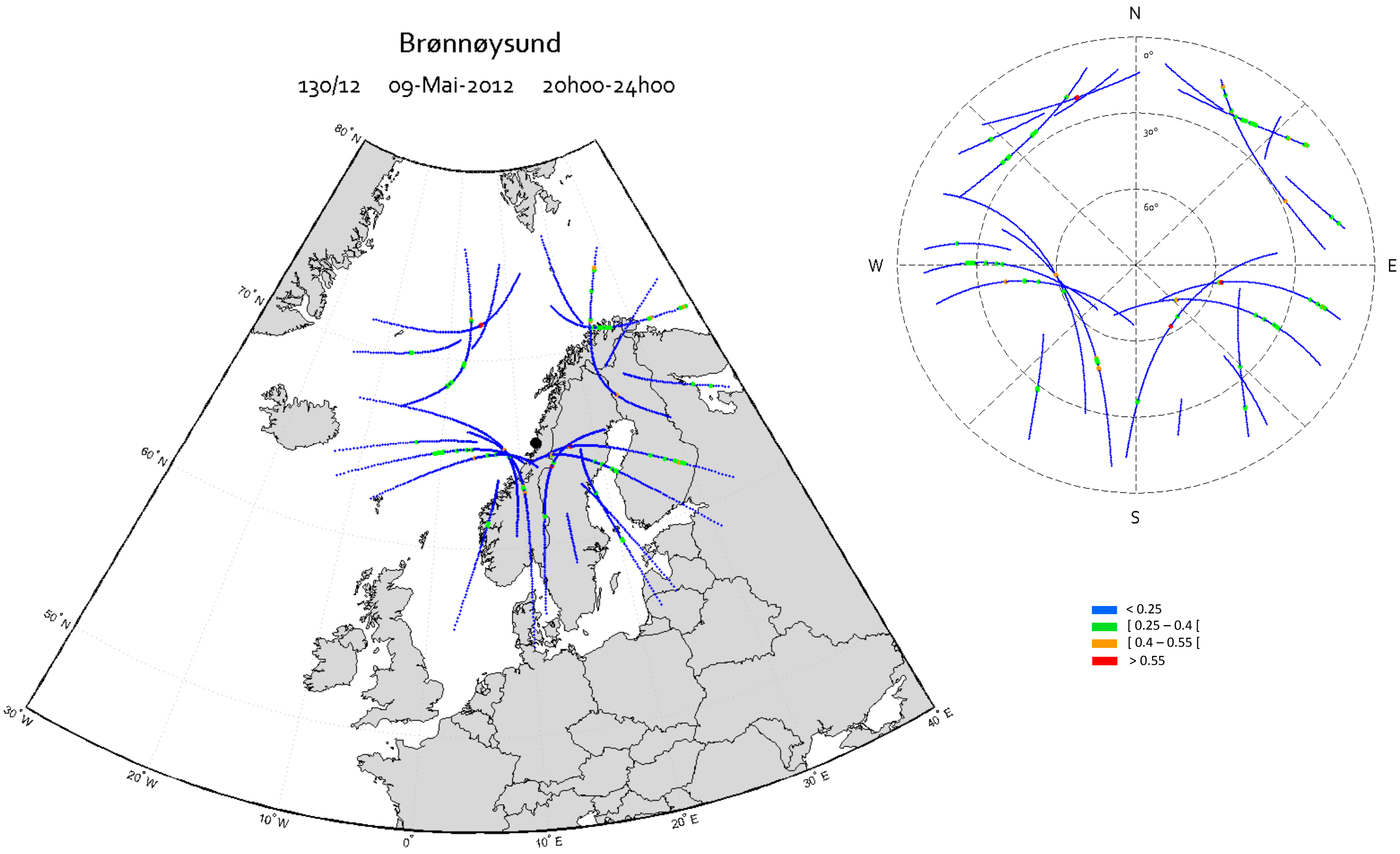




Ionospheric Scintillations: a Spatio-Temporal Phenomenon



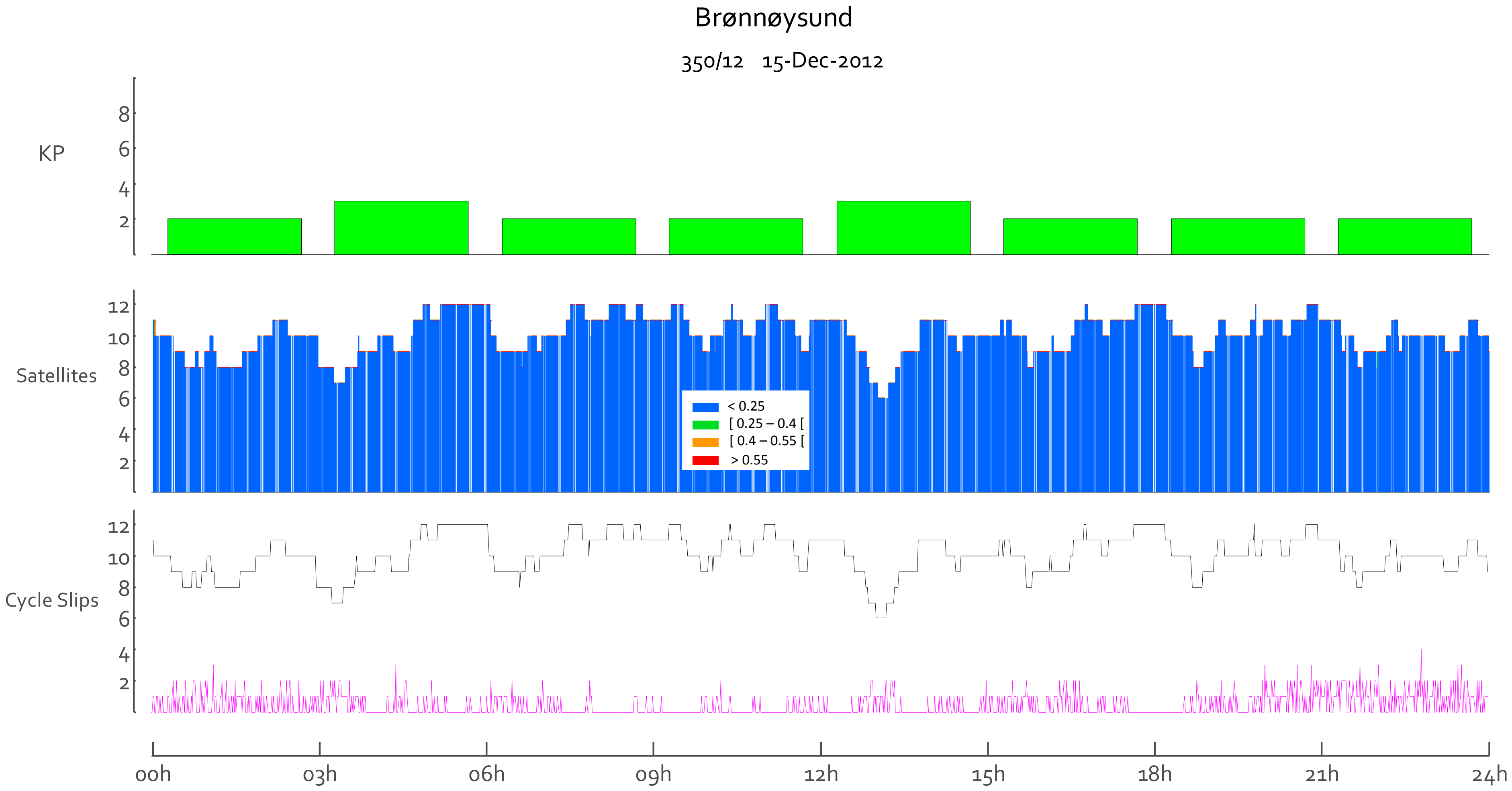
Ionospheric Scintillations: a Spatio-Temporal Phenomenon



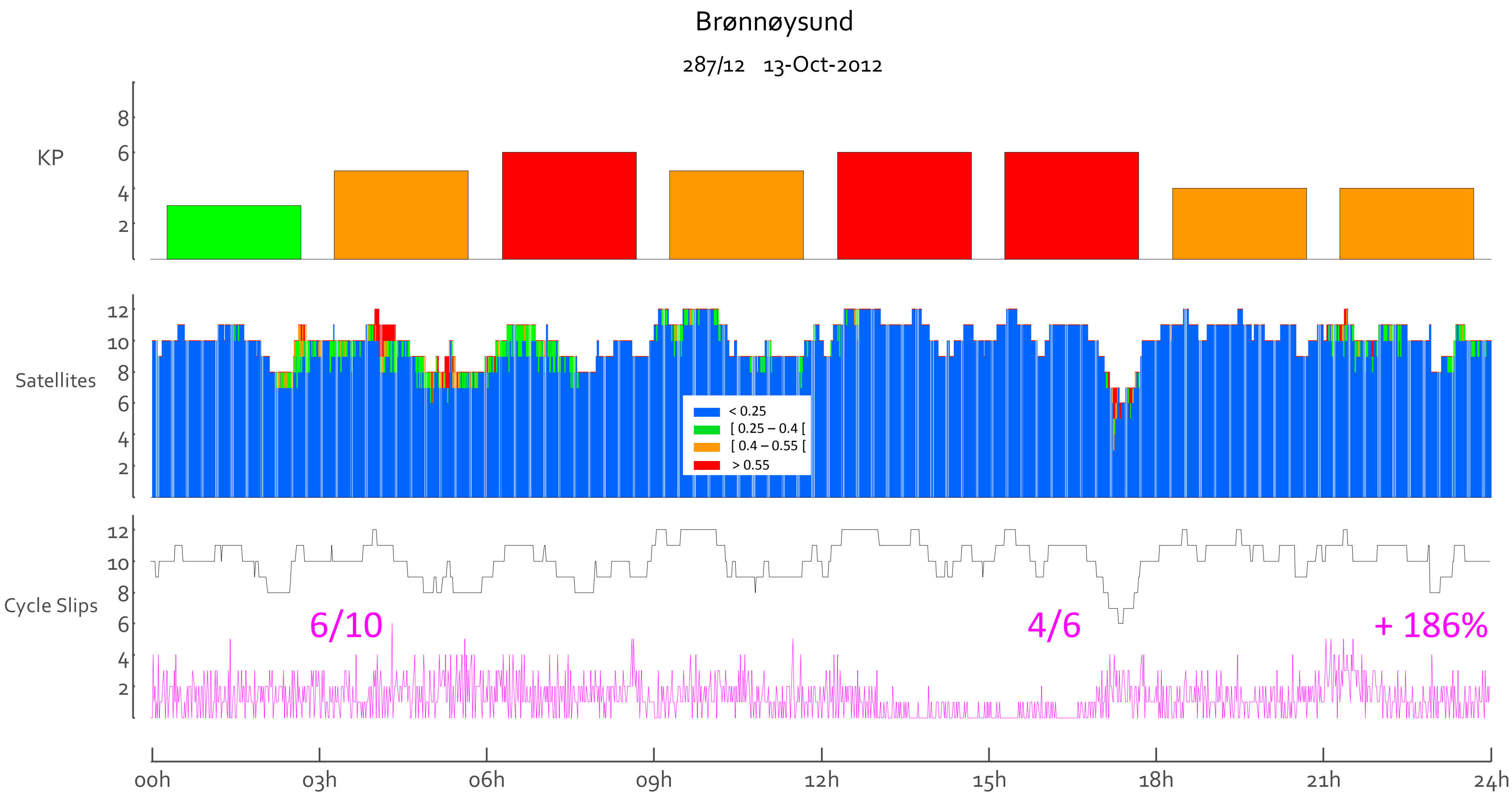
The Analysis Strategy is based on specific Criteria

	Single Station Approach *Low/High Magnetic Activity*
Multi Station Approach *Medium/High Latitude*	*Occurrence: Measurements and Epochs* *Positioning: SPP and PPP* *Geometry: Satellite Number and Dilution of Precision* *Spatial Characteristics* *Cycle Slips* *Noise Measurement*

Ionospheric Scintillations involve Cycle Slips



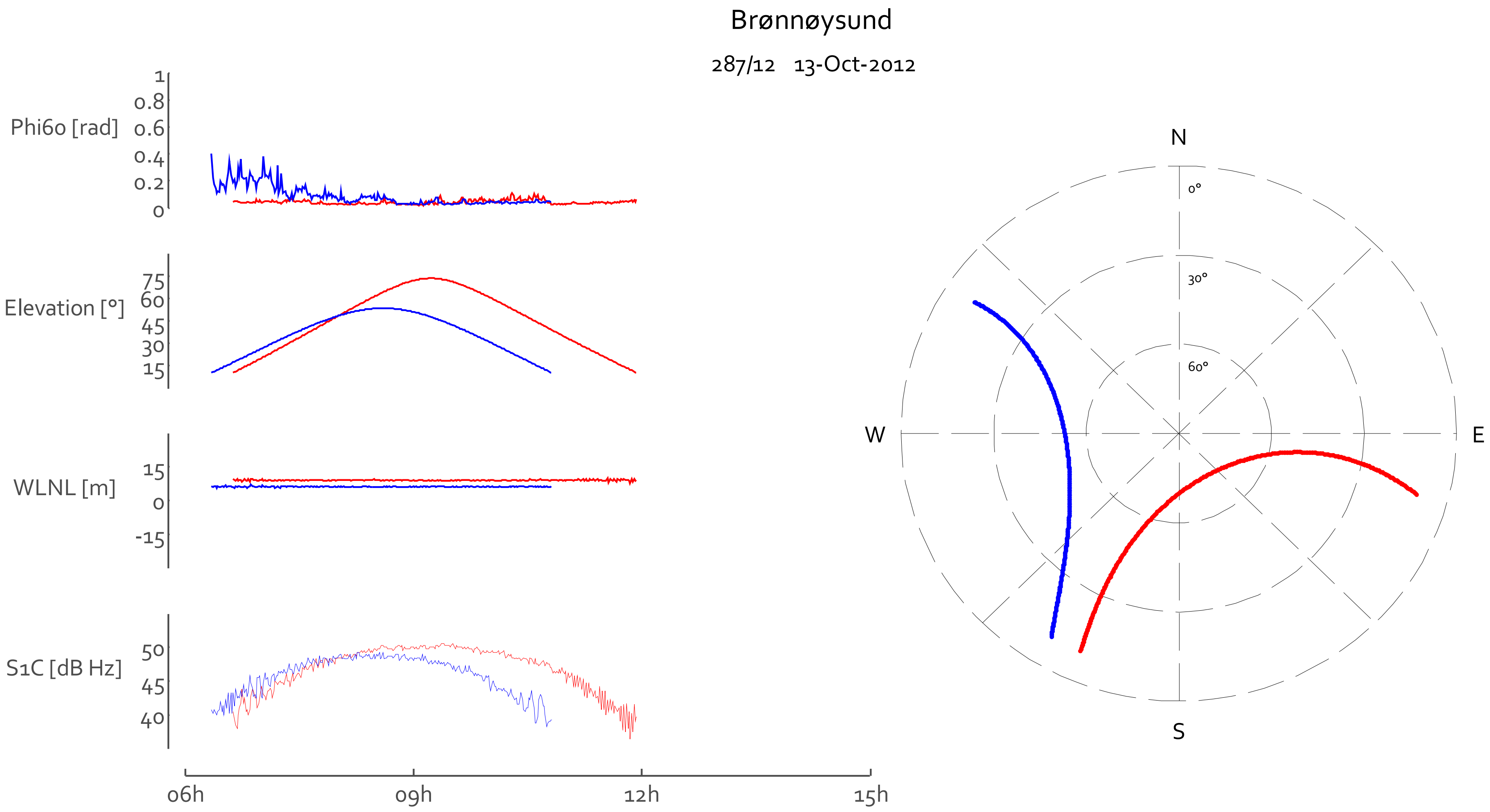
Ionospheric Scintillations involve Cycle Slips



The Analysis Strategy is based on specific Criteria

	Single Station Approach *Low/High Magnetic Activity*
Multi Station Approach *Medium/High Latitude*	*Occurrence: Measurements and Epochs* *Positioning: SPP and PPP* *Geometry: Satellite Number and Dilution of Precision* *Spatial Characteristics* *Cycle Slips* *Noise Measurement*

High Phi60 values do not seem to be correlated with Noise Measurement



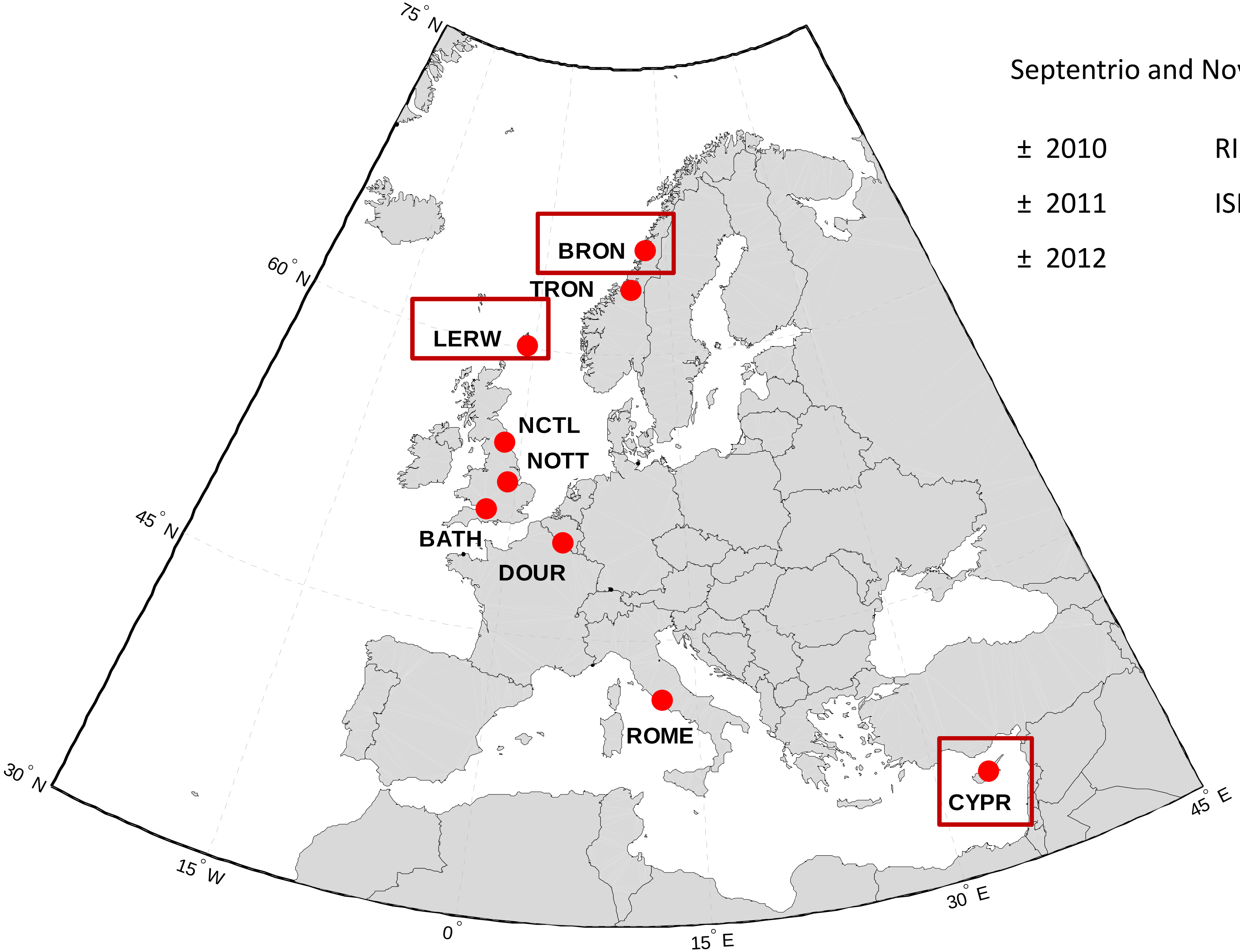
Analysis: Single Station Approach Summarize

	Quiet	Intense
Occurence	*Phi60 / S4*	
Positions	*SPP/PPP*	
Geometry	*Main Scintillations Trouble*	
Cycle Slips	*Cycle Slips Repair*	
Locations	*Spatial Distribution*	
Noise	*Spatial Distribution*	

The Analysis Strategy is based on specific Criteria

	Single Station Approach *Low/High Magnetic Activity*
Multi Station Approach *Medium/High Latitude*	*Occurrence: Measurements and Epochs* *Positioning: SPP and PPP* *Geometry: Satellite Number and Dilution of Precision* *Spatial Characteristics* *Cycle Slips* *Noise Measurement*

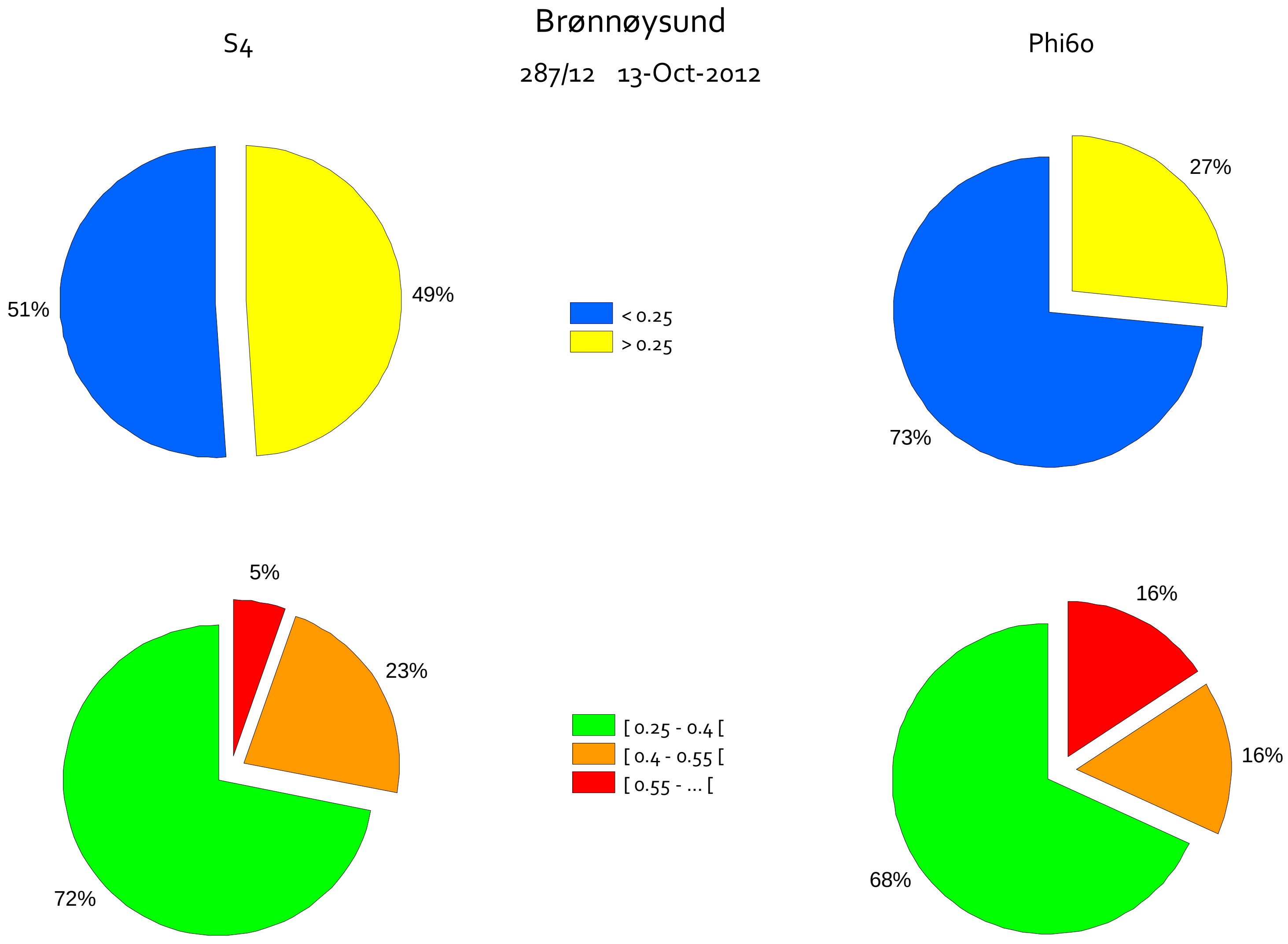
Ionospheric Scintillation Monitoring Receivers (ISMR) Network



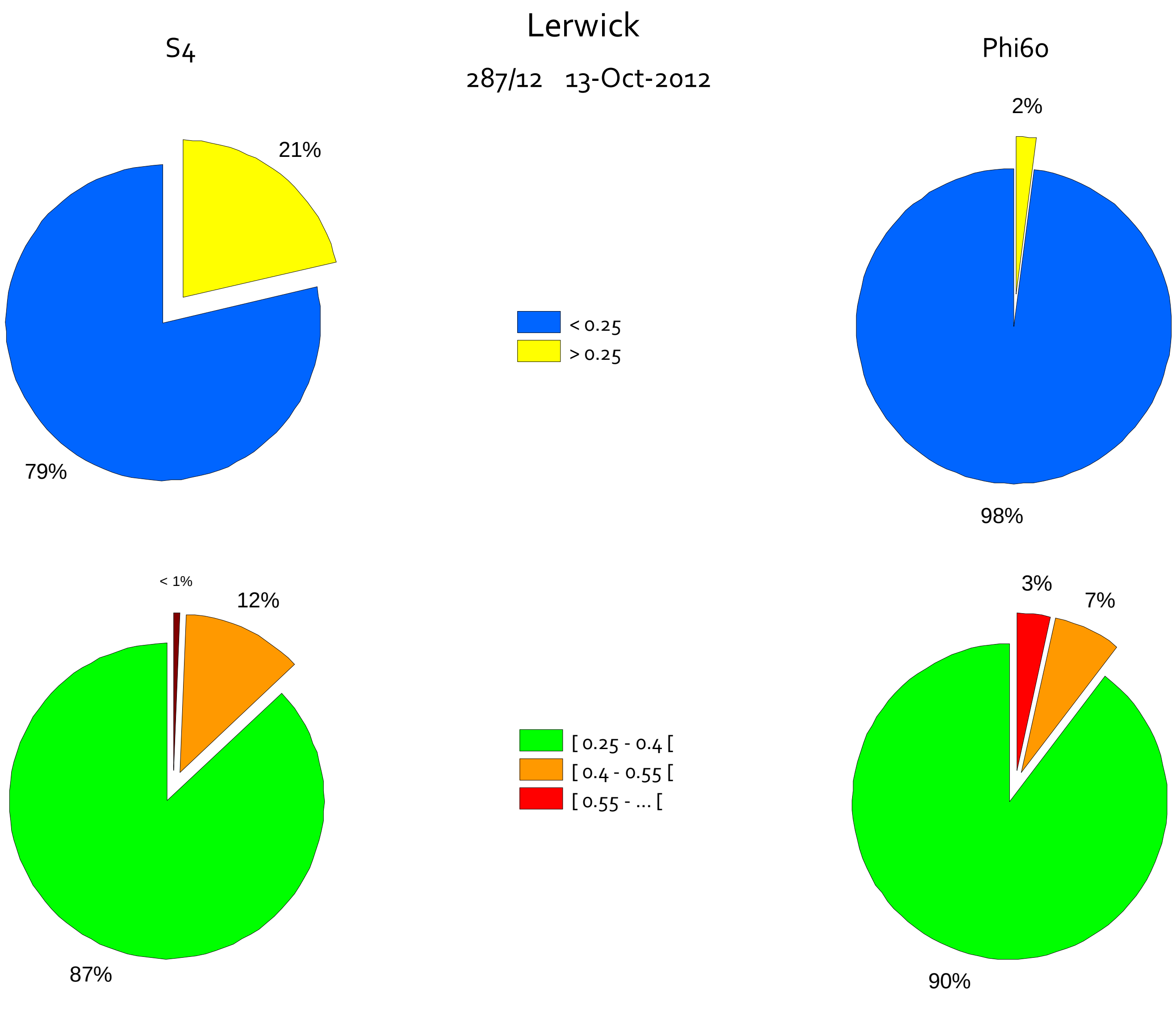
Septentrio and Novatel ISMR

± 2010	RINEX 30”
± 2011	ISMR 60”
± 2012	

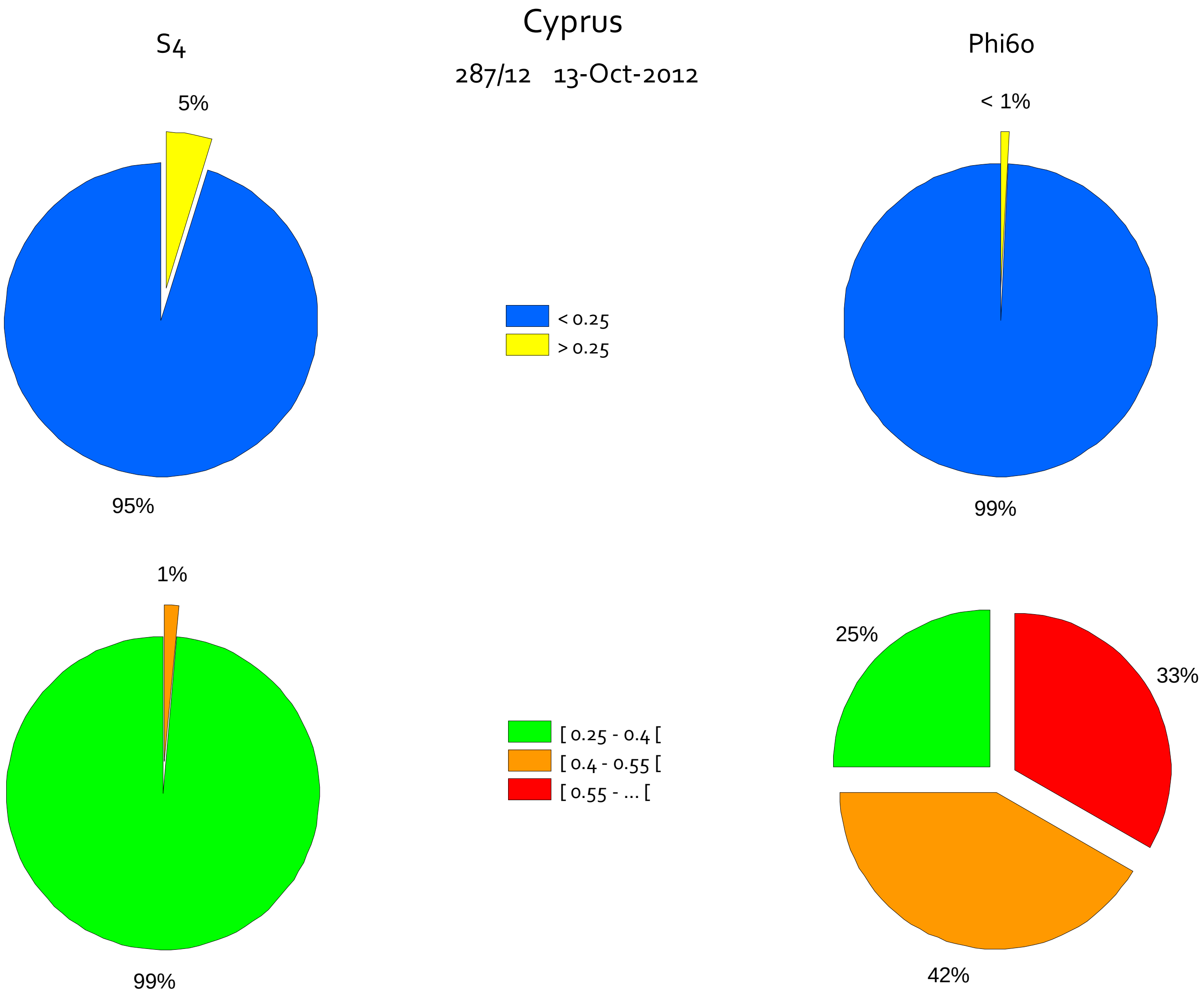
The Occurrence of Ionospheric Scintillations clearly depends on the Geographic Latitude



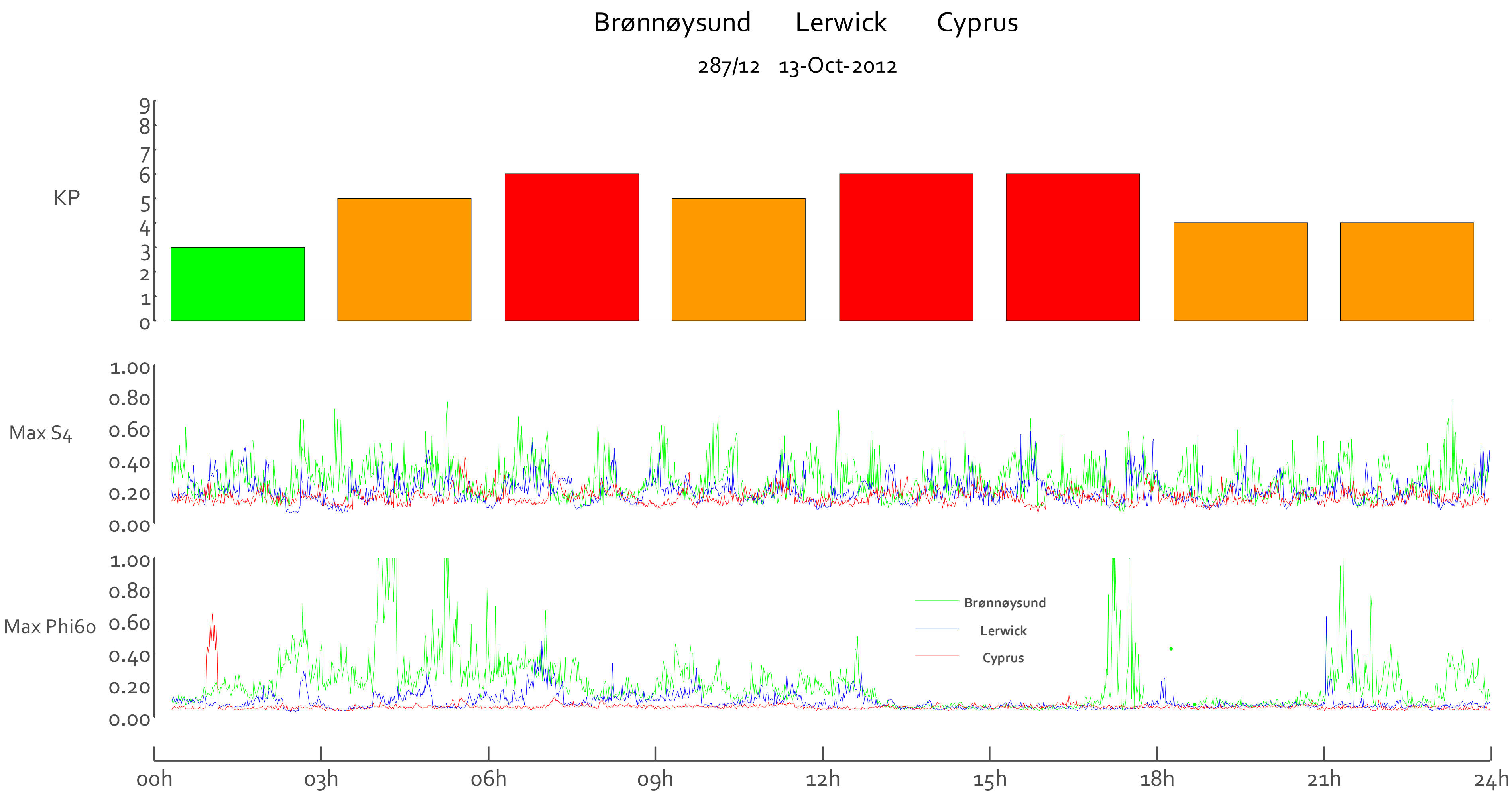
The Occurrence of Ionospheric Scintillations clearly depends on the Geographic Latitude



The Occurrence of Ionospheric Scintillations clearly depends on the Geographic Latitude



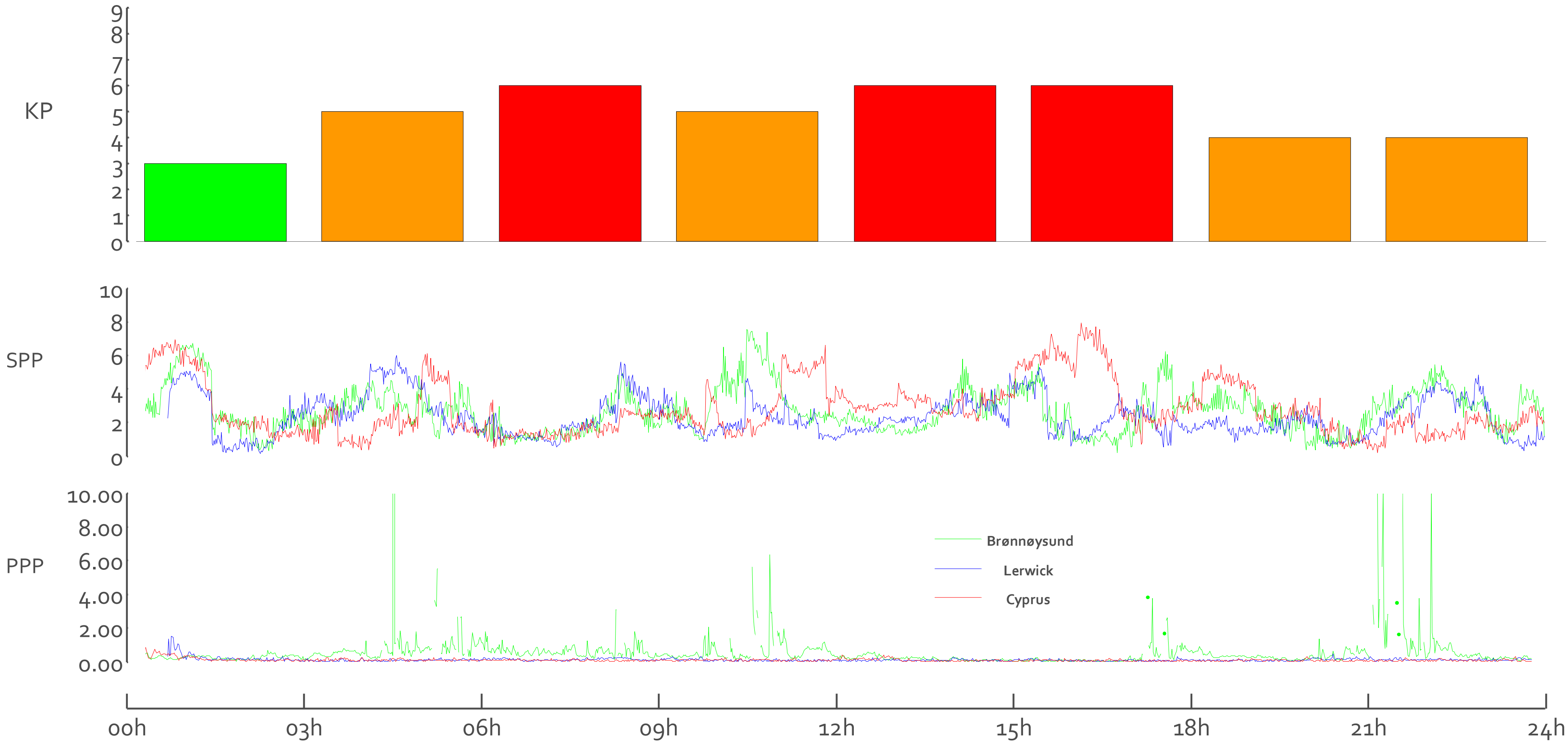
The Occurrence of Ionospheric Scintillations clearly depends on the Geographic Latitude



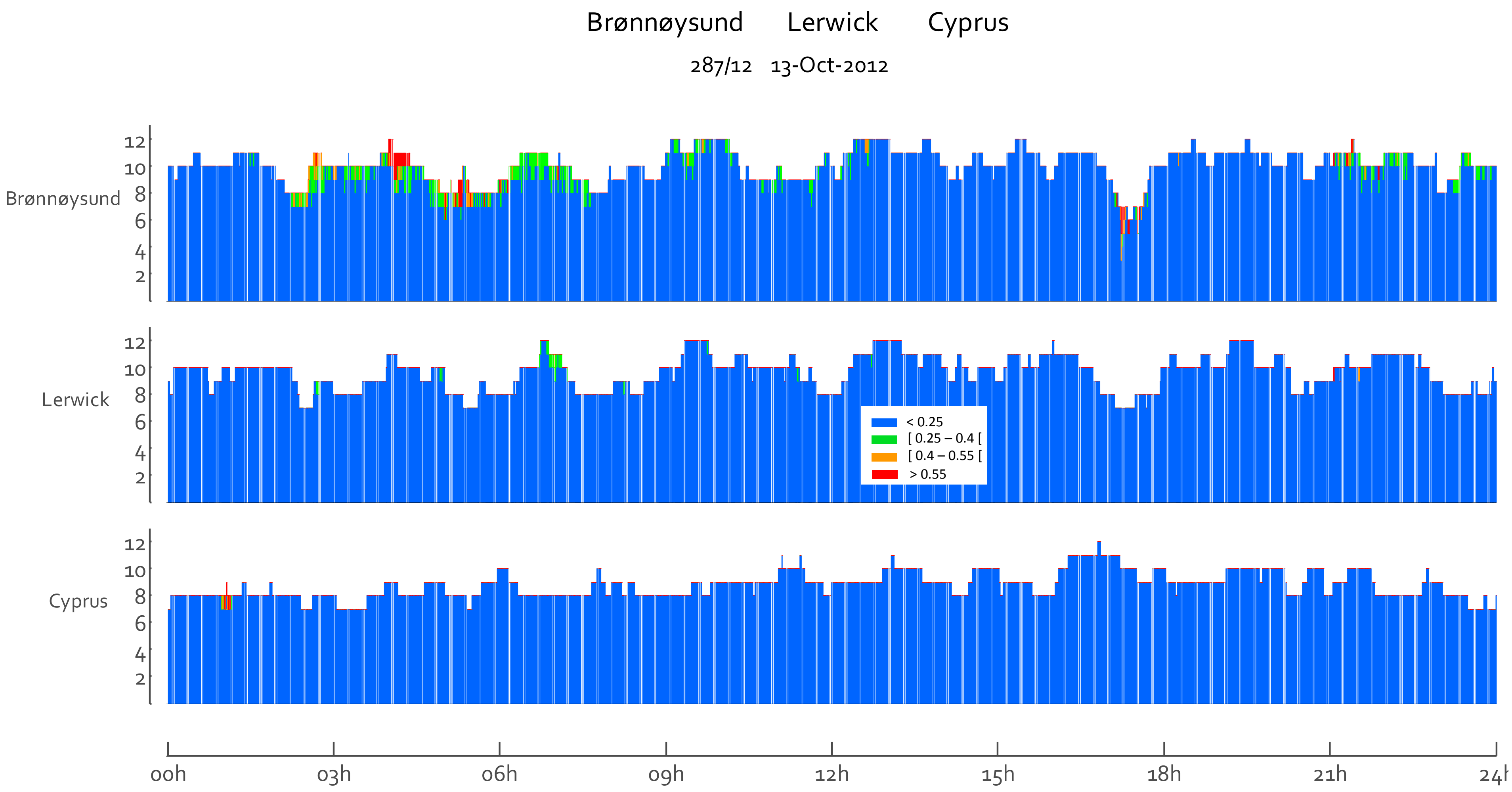
SPP and PPP Techniques are affected differently by Ionospheric Scintillations according to Geographic Latitude

Brønnøysund Lerwick Cyprus

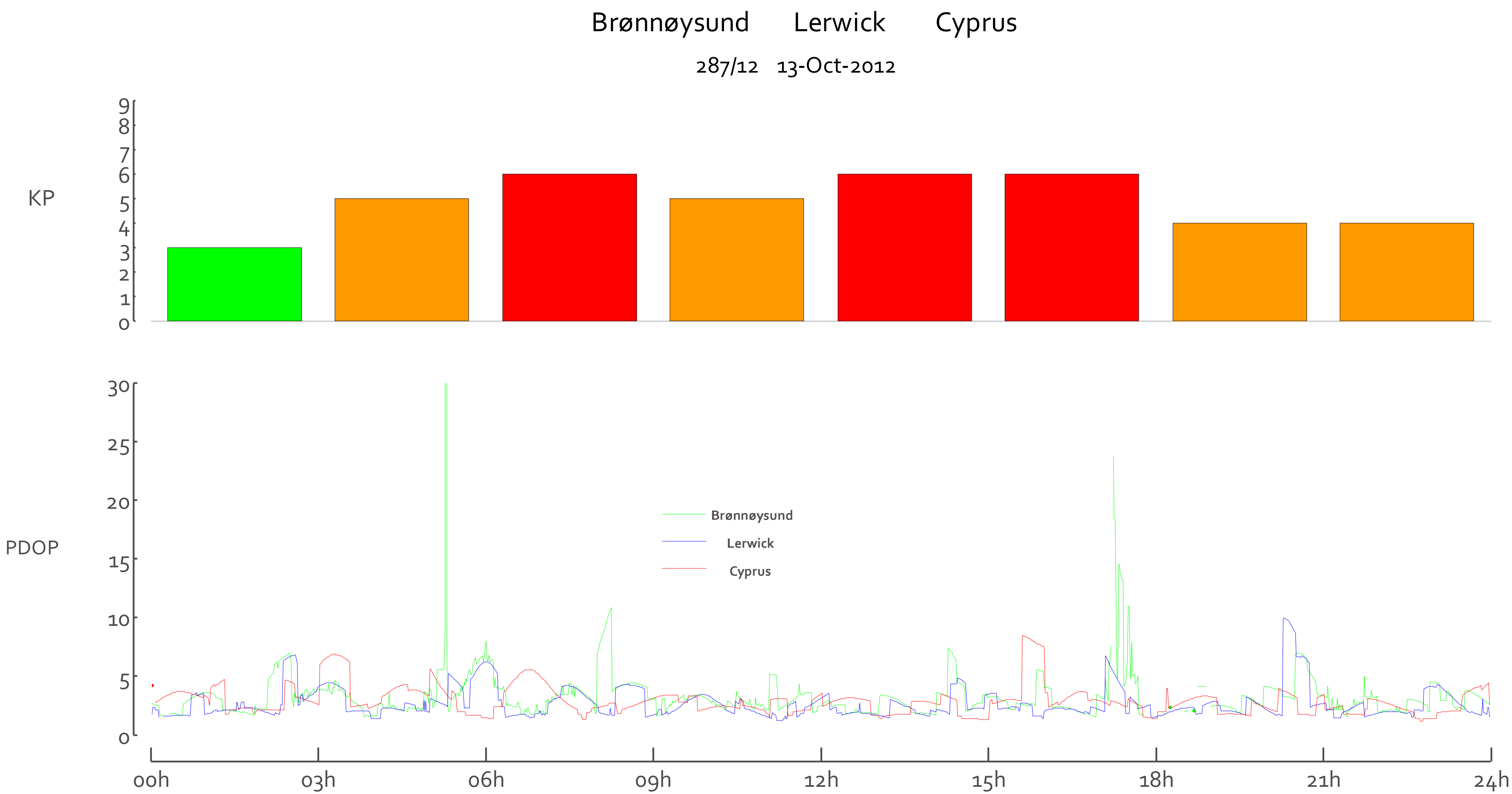
287/12 13-Oct-2012



Satellite Geometry Quality is affected differently by Ionospheric Scintillations according to Geographic Latitude



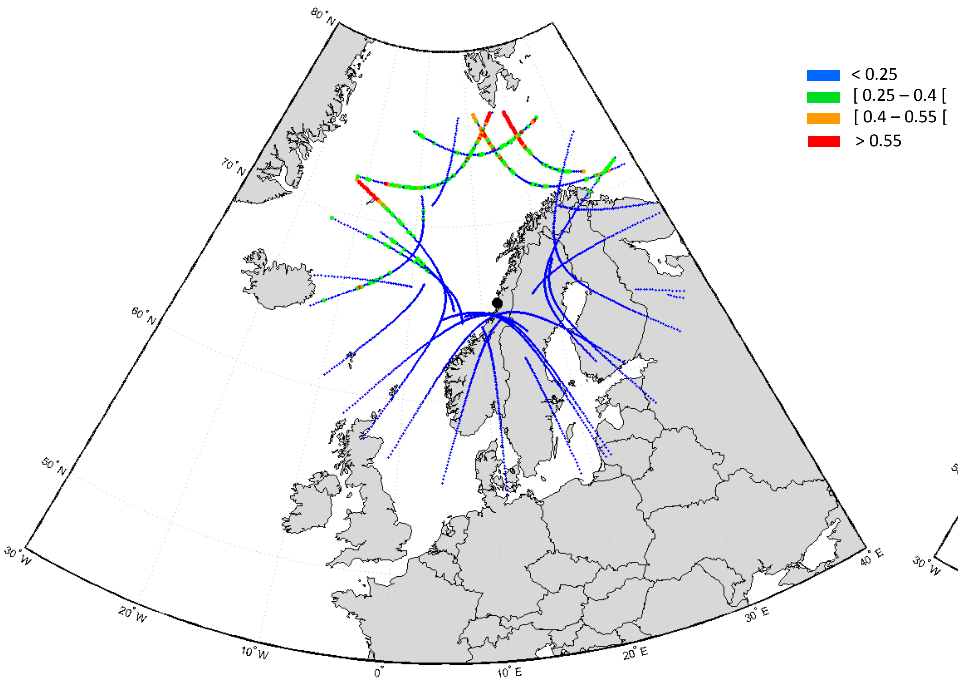
Satellite Geometry Quality is affected differently by Ionospheric Scintillations according to Geographic Latitude



Ionospheric Scintillations concern only High Latitude Ionopheric Pierce Point

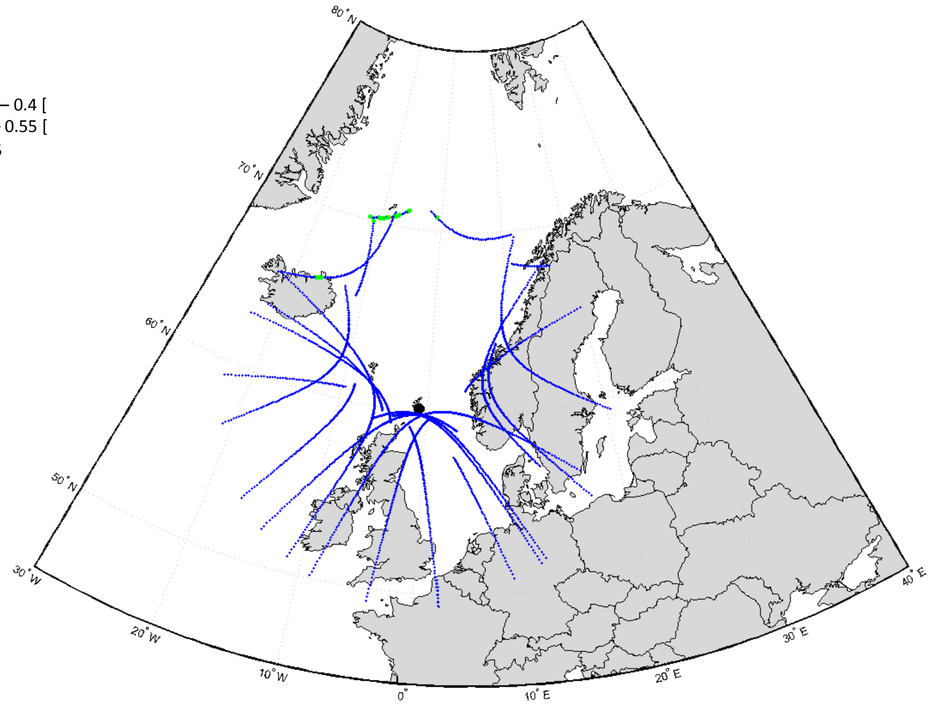
Brønnøysund

287/12 13-Oct-2012 03h00-09h00



Lerwick

287/12 13-Oct-2012 03h00-09h00



Analysis: Multi Station Approach Summarize

	Brønnøysund	Cyprus	Lerwick
Occurence		*Phi60 / S4*	
Positions		*SPP/PPP*	
Geometry		*Main Scintillations Trouble*	
~~Cycle Slips~~		*-*	
Locations		*Spatial Distribution*	
~~Noise~~		*-*	

Introduction

Objectives

Research

Softwares

Analysis

Stochasticity

Geometry

Preprocessing

Conclusions

Perspectives

Satellite Positioning is Resolving a Problem with several unknowns and equations

Mathematic Model

Stochastic Model

Resolution Process

Satellite Positioning is Resolving a Problem with several unknowns and equations

Mathematic Model ➡

$$P_{r,IF}^{s}(\mathrm{t}) = D_r^s + T_r^s + \ \dots$$

$$\phi_{r,IF}^{s}(\mathrm{t}) = D_r^s + T_r^s + \ \dots$$

$$P_{r,IF}^{s}(\mathrm{t}) = D_r^s + T_r^s + \ \dots$$

$$\phi_{r,IF}^{s}(\mathrm{t}) = D_r^s + T_r^s + \ \dots$$

...

Stochastic Model

Resolution Process

Satellite Positioning is Resolving a Problem with several unknowns and equations

Mathematic Model

Stochastic Model

Resolution Process ➡

LSA Adjustment

Kalman Filter

…

Satellite Positioning is Resolving a Problem with several unknowns and equations

Mathematic Model

Stochastic Model ➡

$$\Sigma = \begin{pmatrix} \sigma_1^2 & \sigma_{12} & .. & \sigma_{1n} \\ \sigma_{21} & \sigma_2^2 & .. & \sigma_{2n} \\ .. & .. & ... & ... \\ \sigma_{n1} & \sigma_{n2} & ... & \sigma_n^2 \end{pmatrix}$$

Resolution Process

Satellite Positioning is Resolving a Problem with several unknowns and equations

Mathematic Model

Stochastic Model ➡ $$\Sigma = \begin{pmatrix} 1 & 0 & .. & 0 \\ 0 & 1 & .. & 0 \\ .. & .. & ... & ... \\ 0 & 0 & ... & 1 \end{pmatrix}$$

Resolution Process

Satellite Positioning is Resolving a Problem with several unknowns and equations

Mathematic Model

Stochastic Model ➡

$$\Sigma = \begin{pmatrix} \sigma_1^2 & 0 & .. & 0 \\ 0 & \sigma_2^2 & .. & 0 \\ .. & .. & ... & ... \\ 0 & 0 & ... & \sigma_n^2 \end{pmatrix}$$

Resolution Process

Satellite Positioning is Resolving a Problem with several unknowns and equations

Mathematatic Model

Stochastic Model ➡ $$\Sigma = \begin{pmatrix} \sigma_1^2 & \sigma_{12} & .. & \sigma_{1n} \\ \sigma_{21} & \sigma_2^2 & .. & \sigma_{2n} \\ .. & .. & \cdots & \cdots \\ \sigma_{n1} & \sigma_{n2} & \cdots & \sigma_n^2 \end{pmatrix}$$

Resolution Process

Spatial Approach

Empirical Approach

First Law of Geography…

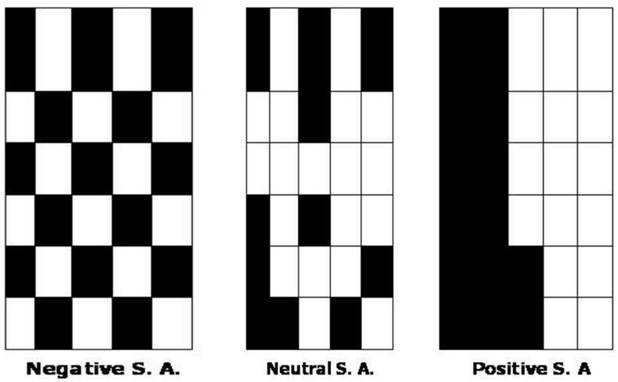
"Everything is related to everything else, but near things are more related than distant things."

Waldo Tobler

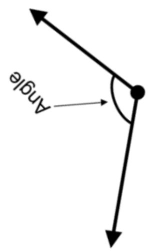
The « Spatial Strategy relies on the fact there exists some Spatial Autocorrelation in Scintillations Observations

1. Spatial Autocorrelation Test

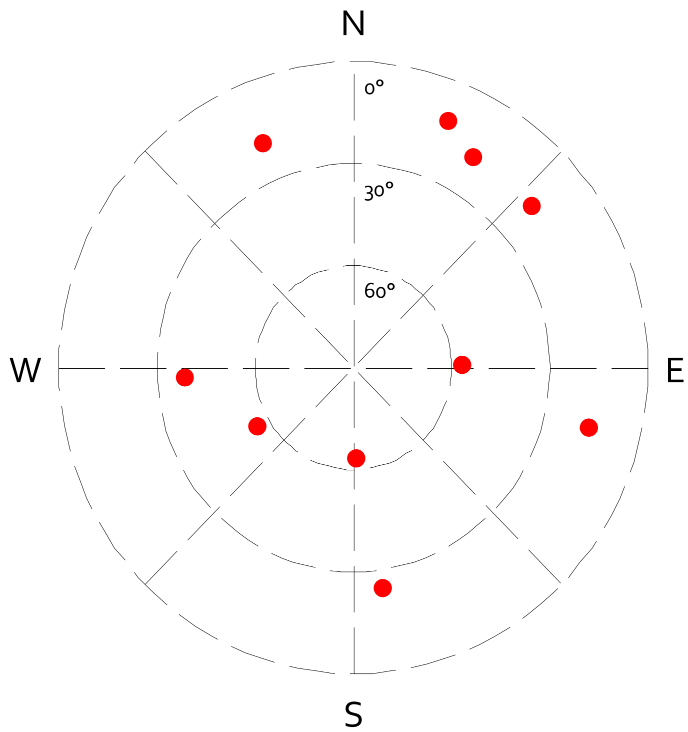
$$I = \frac{N}{\Sigma_i \Sigma_j w_{ij}} \frac{\Sigma_i \Sigma_j w_{ij} (v_i - \bar{v})(v_j - \bar{v})}{\Sigma_i (v_i - \bar{v})^2}$$



$$w_{ij} = \frac{1}{d_{ij}}$$

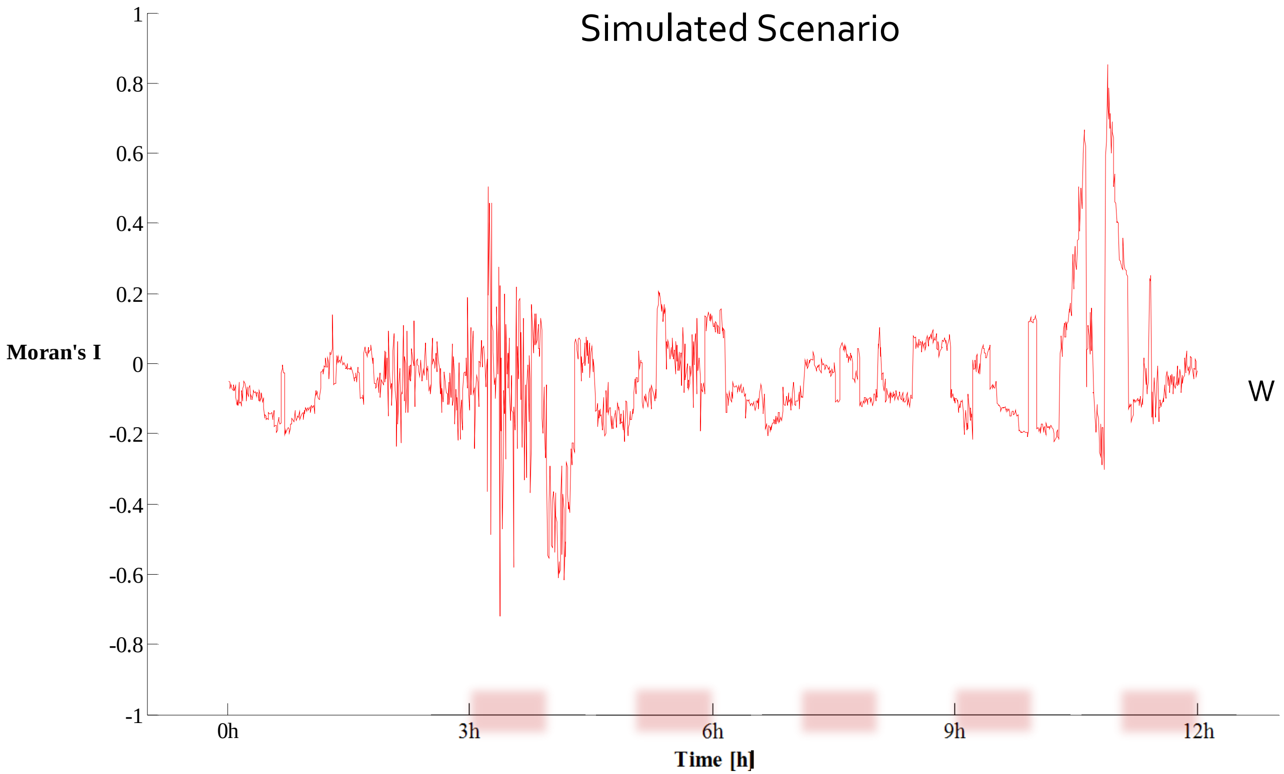


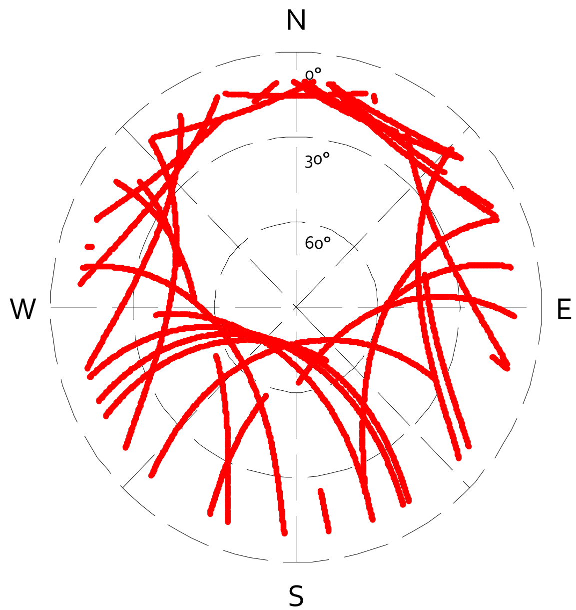
$$v_i = S1C_i$$



The « Spatial Strategy relies on the fact there exists some Spatial Autocorrelation in Scintillations Observations

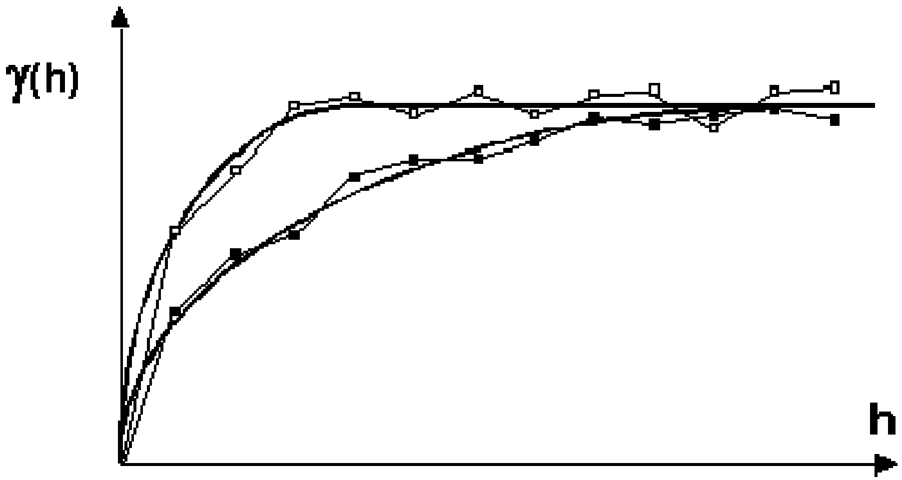
1. Spatial Autocorrelation Test



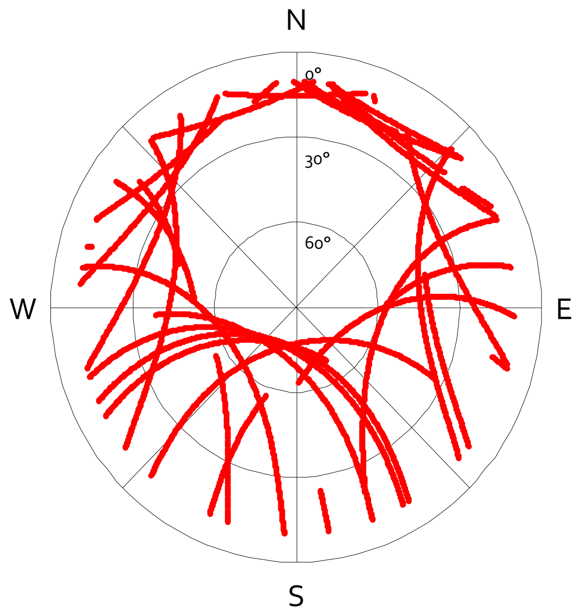


The « Spatial Strategy relies on the fact there exists some Spatial Autocorrelation in Scintillations Observations

1. Spatial Autocorrelation Test
2. Covariance Function

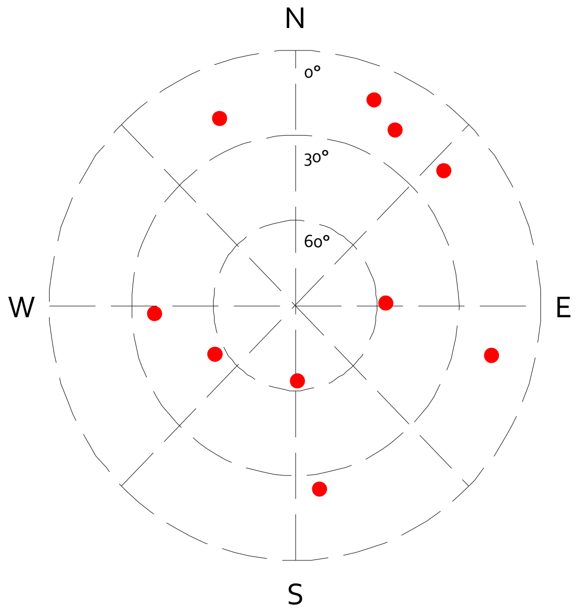


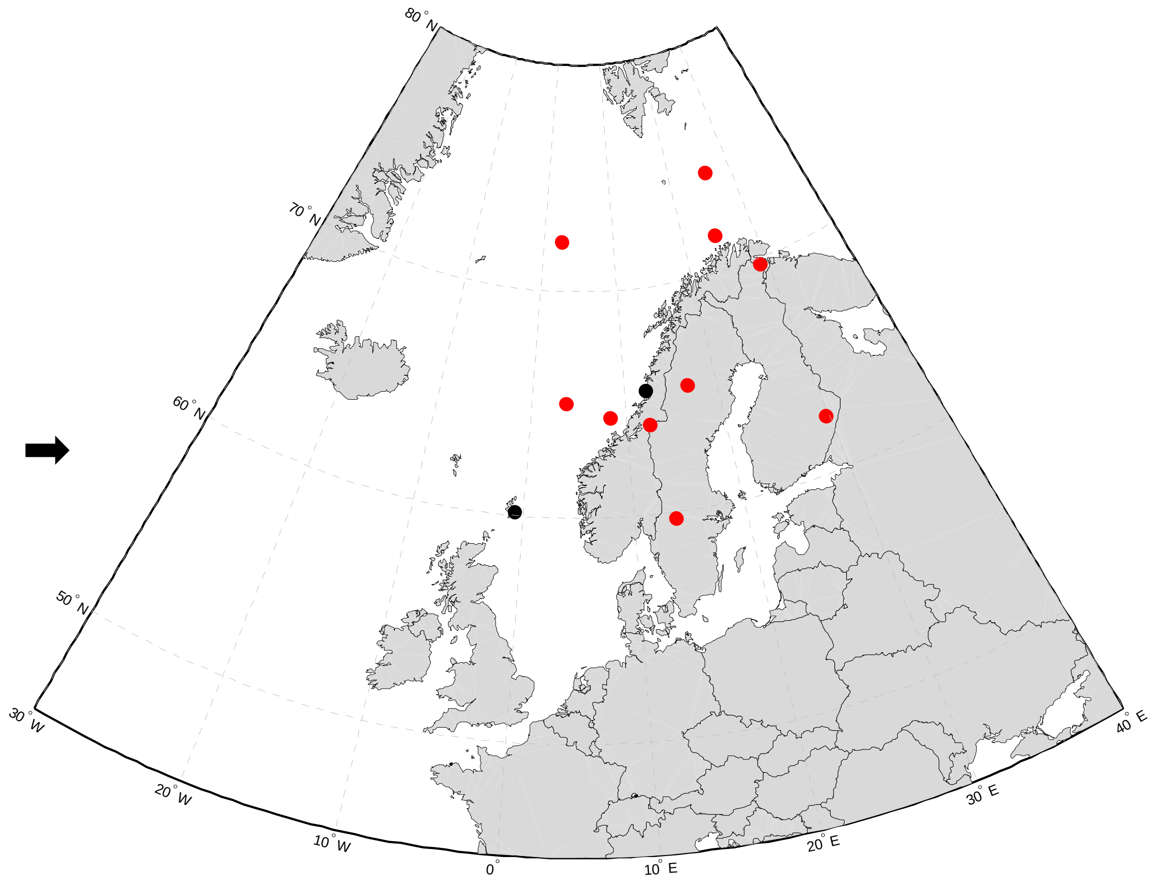
Description of the Spatial Covariance of a random Variable process



The « Spatial Strategy relies on the fact there exists some Spatial Autocorrelation in Scintillations Observations

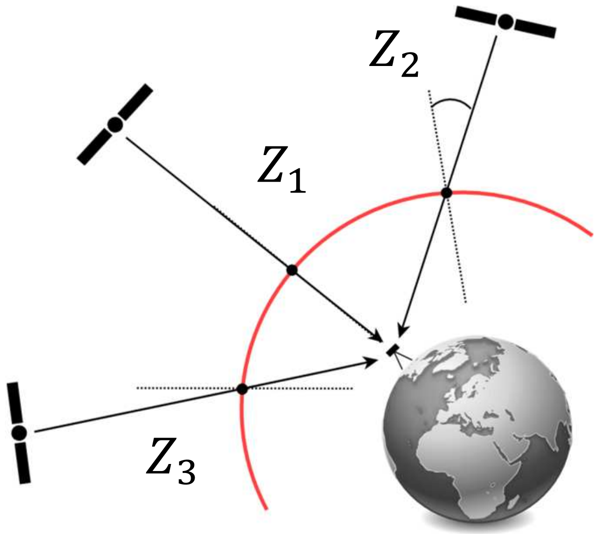
1. Spatial Autocorrelation Test
2. Covariance Function

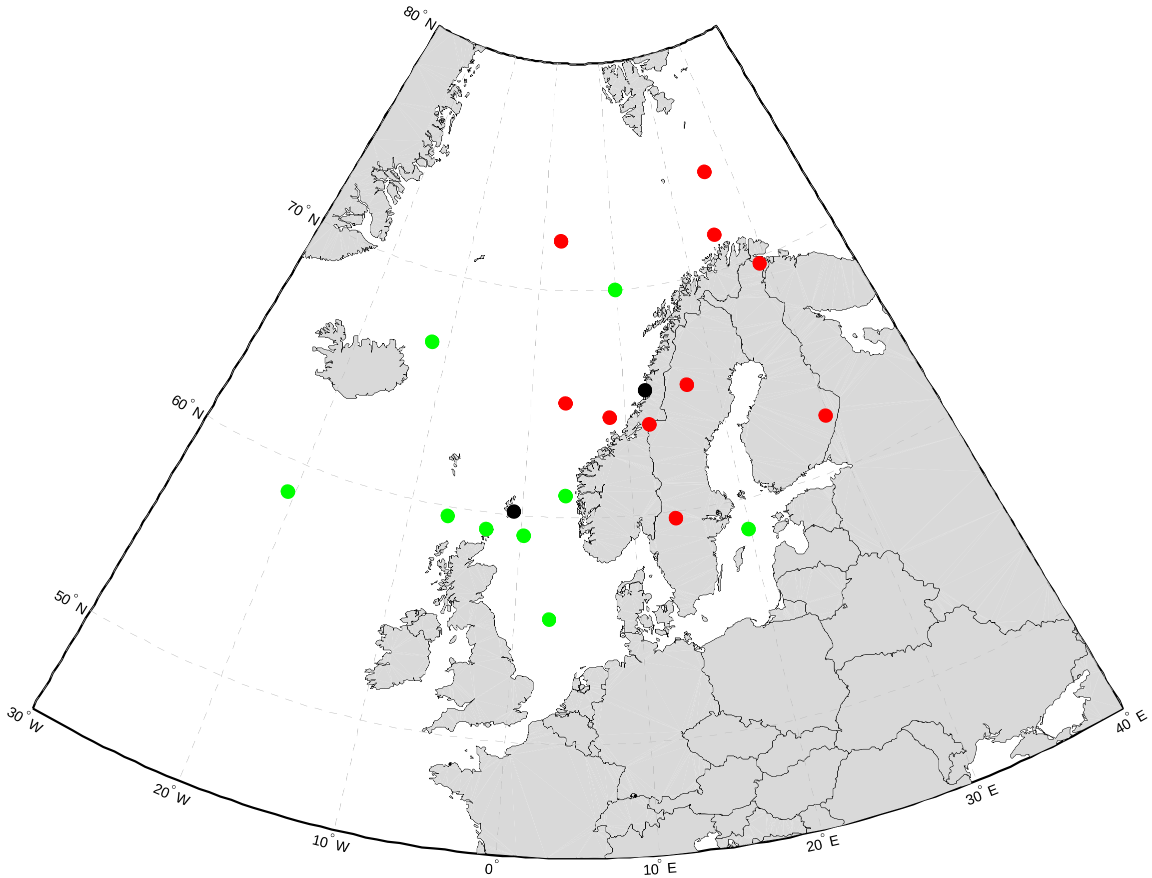




The « Spatial Strategy relies on the fact there exists some Spatial Autocorrelation in Scintillations Observations

1. Spatial Autocorrelation Test
2. Covariance Function



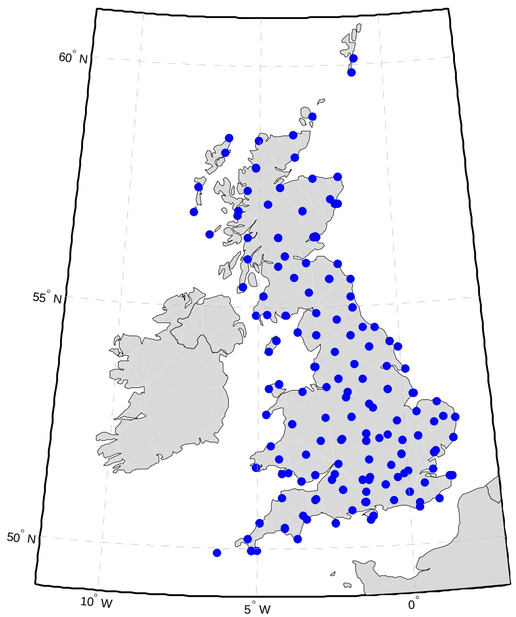


The « Spatial Strategy relies on the fact there exists some Spatial Autocorrelation in Scintillations Observations

1. Spatial Autocorrelation Test
2. Covariance Function
3. RNX vs. ISMR

Variable?
Time Correlation?
Multi-receiver?
Mapping Function?
Scintillation Level?
Time Sampling?
Polar / Equatorial Scintillations?

United Kingdom – Ordnance Survey Network

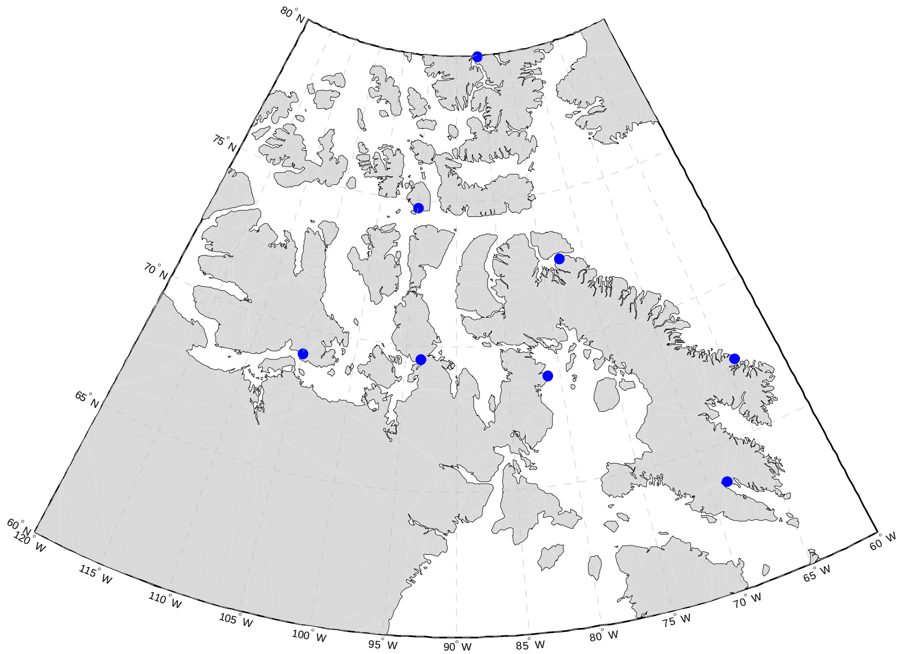


ISMR

RNX

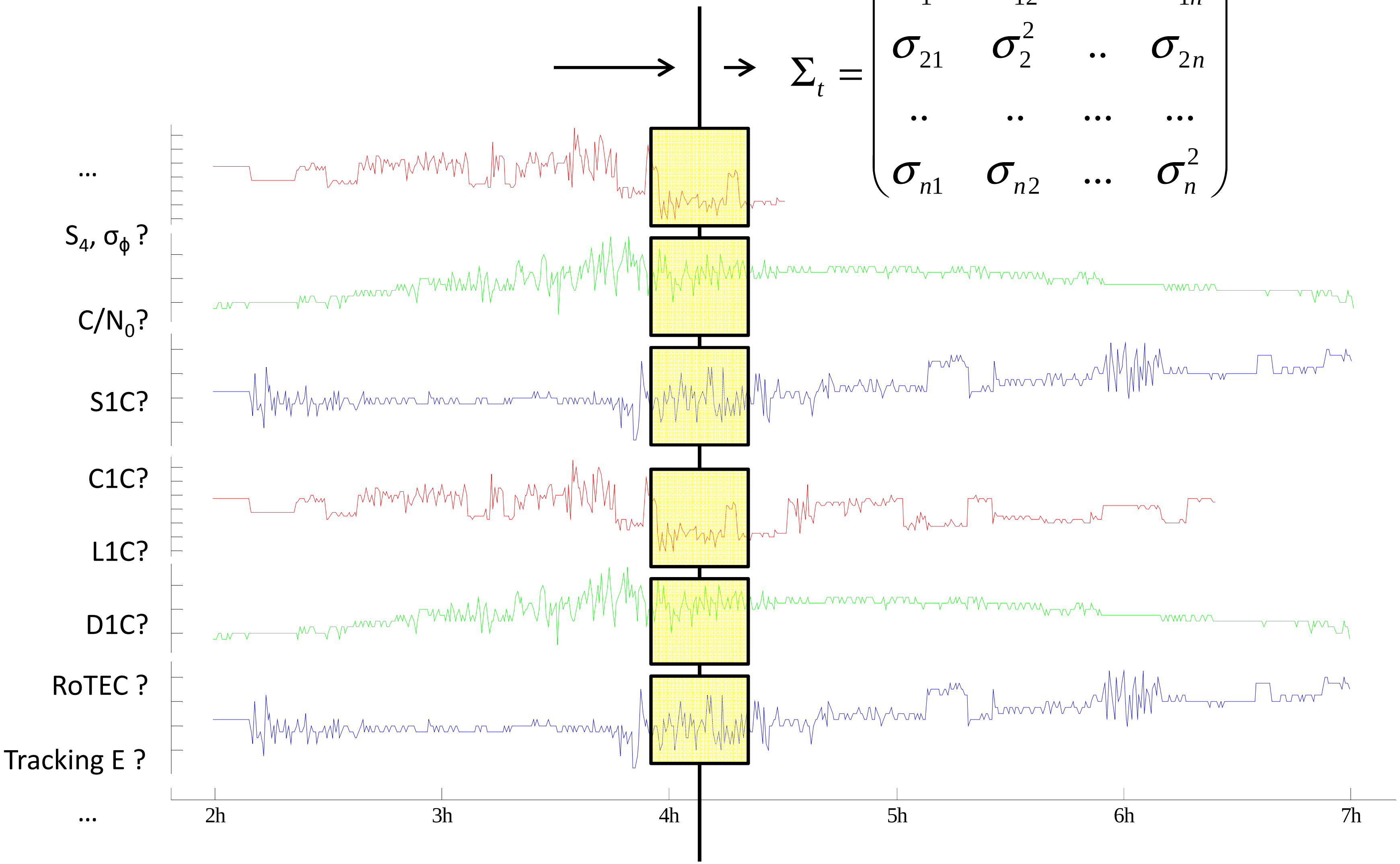
Spatial Density

CHAIN – Canadian High Artic Ionospheric Network



The « Empirical Strategy relies on Observations whatever their Locations

$$\Sigma_t = \begin{pmatrix} \sigma_1^2 & \sigma_{12} & .. & \sigma_{1n} \\ \sigma_{21} & \sigma_2^2 & .. & \sigma_{2n} \\ .. & .. & ... & ... \\ \sigma_{n1} & \sigma_{n2} & ... & \sigma_n^2 \end{pmatrix}$$



Introduction

Objectives

Research

Softwares

Analysis

Stochasticity

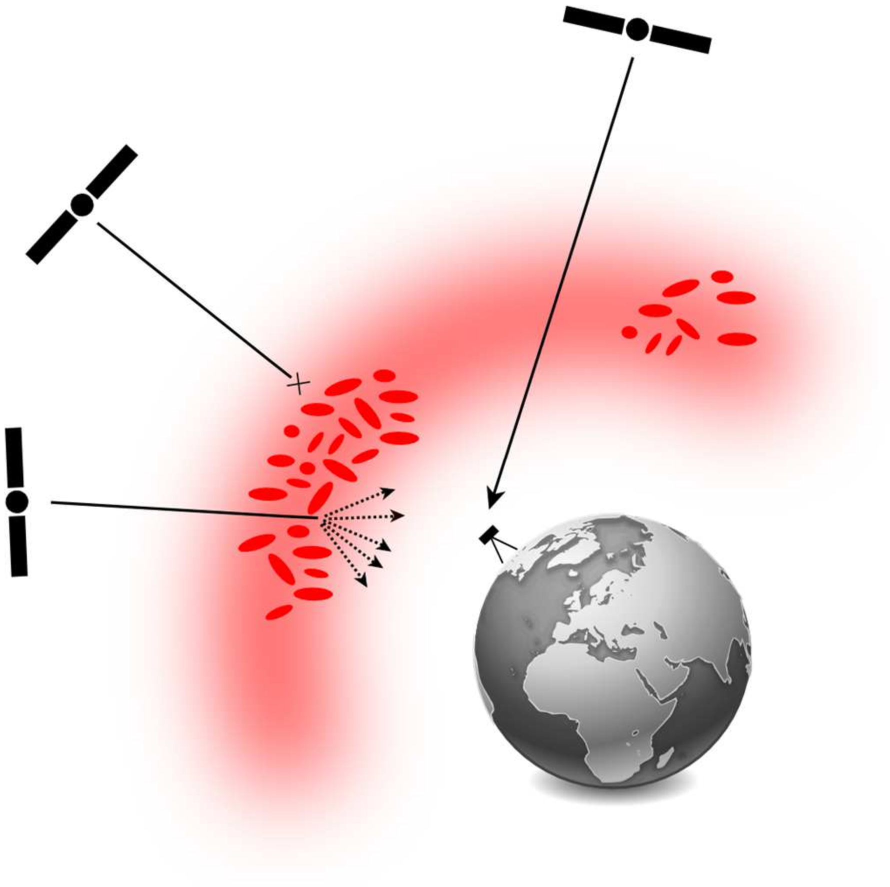
Geometry

Preprocessing

Conclusions

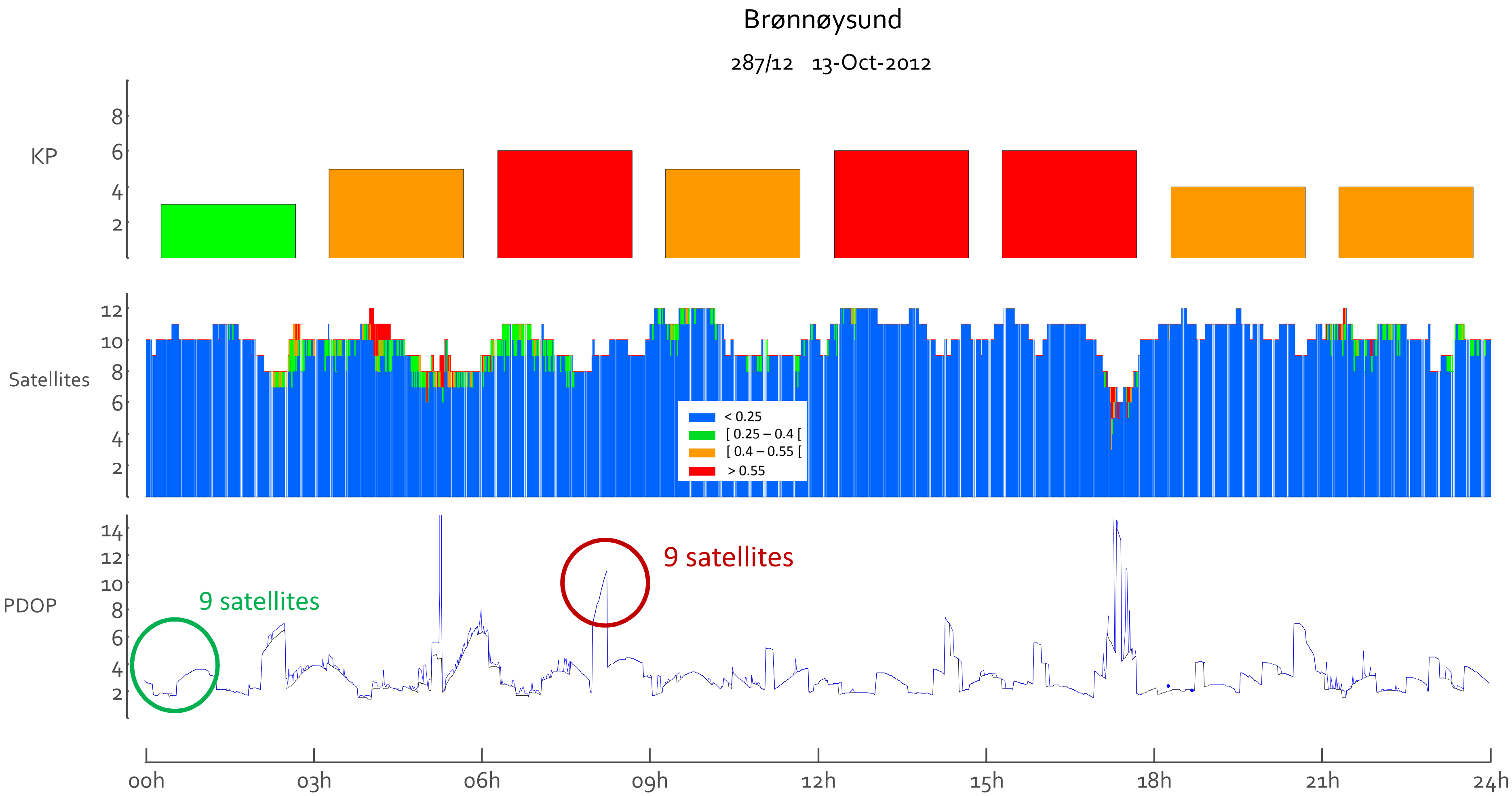
Perspectives

Ionospheric Scintillation involve Satellite Signal Losses

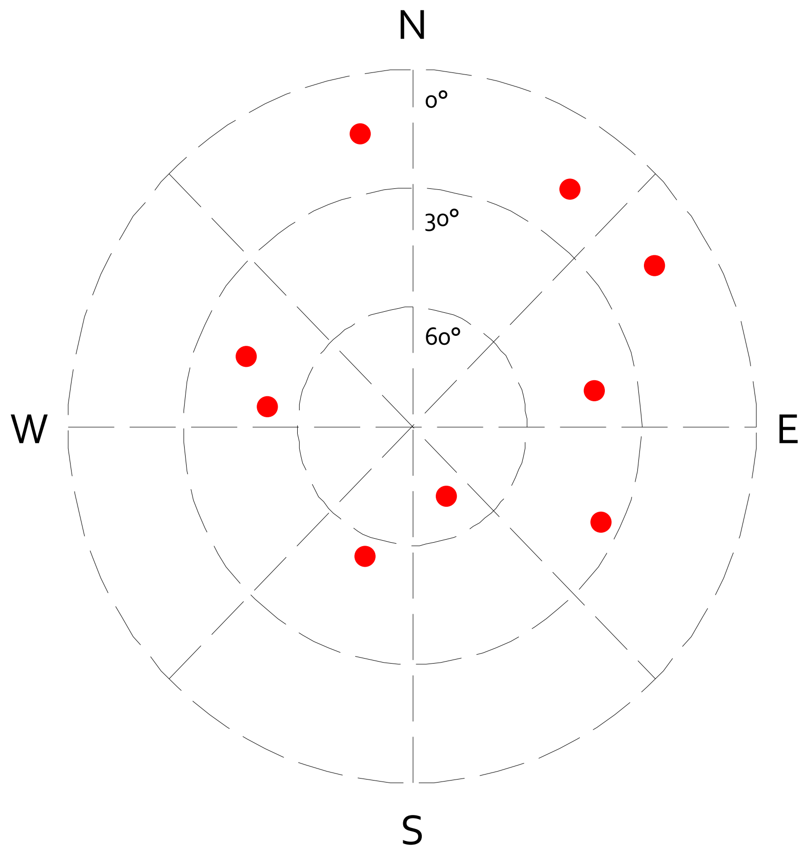


$$\sigma_{POS} = \underline{DOP} \times \sigma_P$$

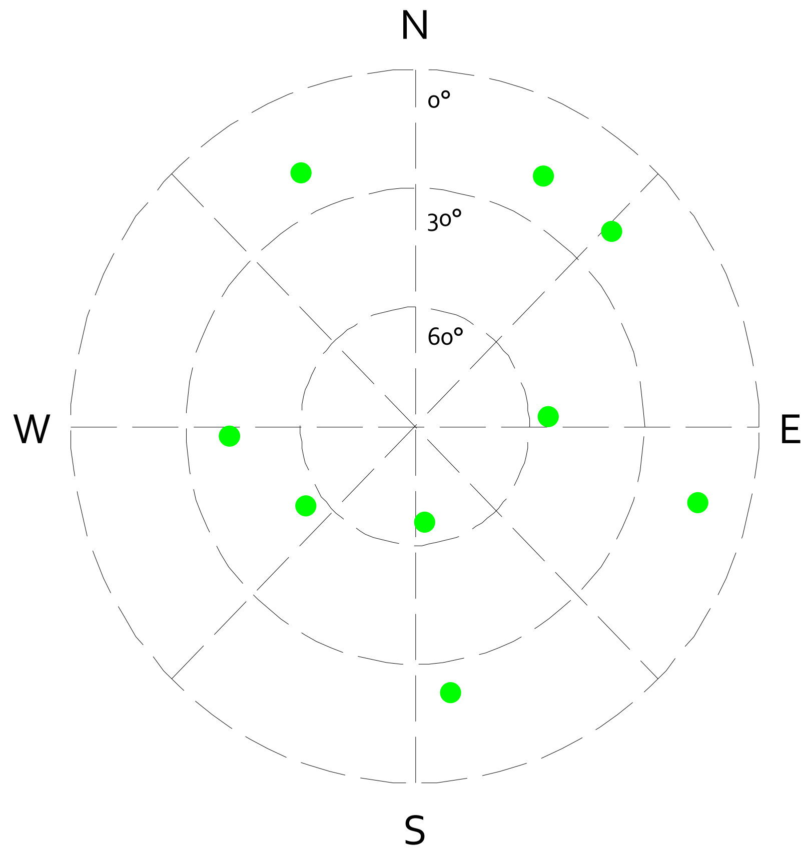
Ionospheric Scintillation increase the Dilution of Precision



The Dilution of Precision depends on the amount and the Spatial Distribution of Tracked Satellites



PDOP = 10.79



PDOP = 2.58

A Conical Satellite Geometry drives the DOP to Infinite Values

$$\underline{x} = -(A^T P A)^{-1} A^T P W$$

$$\sum_{\underline{x}} = (A^T A)^{-1}\sigma_P^2 = N^{-1}\sigma_P^2 = Q_{\underline{x}}\sigma_P^2$$

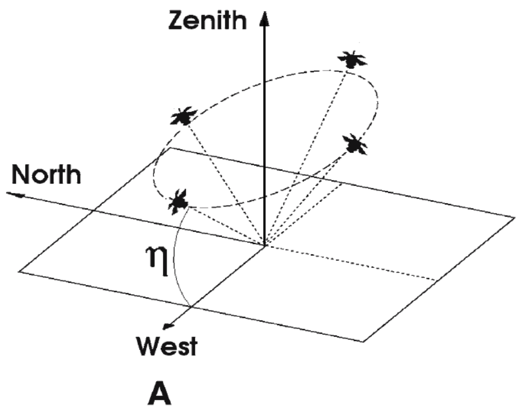
$$\sigma_{POS} = DOP \times \sigma_P$$

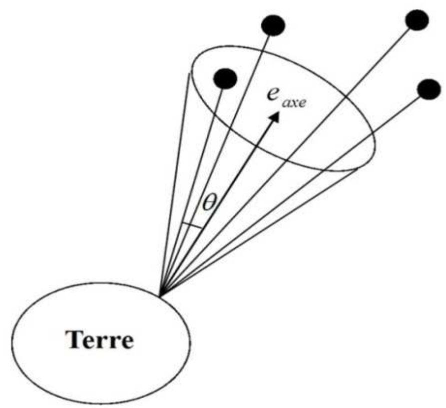
$$Q_{\underline{x}} : \begin{pmatrix} q_{11} & q_{12} & q_{13} & q_{14} \\ q_{12} & q_{22} & q_{23} & q_{24} \\ q_{13} & q_{23} & q_{33} & q_{34} \\ q_{14} & q_{24} & q_{34} & q_{44} \end{pmatrix}$$

$$Q_{\hat{\underline{x}}} = N^{-1} = (A^T A)^{-1}$$

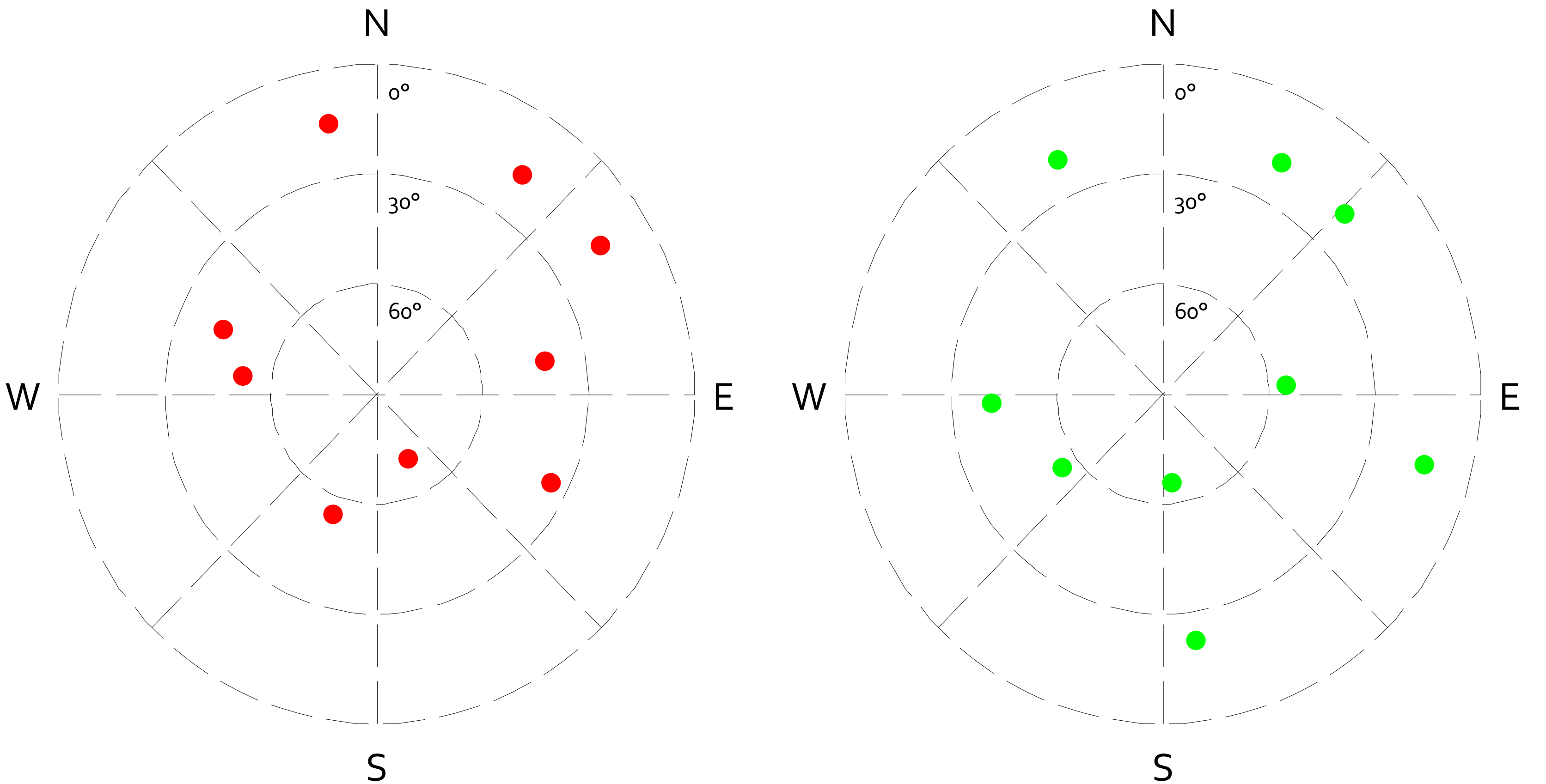
$$A = \begin{bmatrix} -\cos\eta^1 \sin\chi^1 & -\cos\eta^1 \cos\chi^1 & -\sin\eta^1 & 1 \\ -\cos\eta^2 \sin\chi^2 & -\cos\eta^2 \cos\chi^2 & -\sin\eta^2 & 1 \\ \cdots & \cdots & \cdots & \cdots \\ -\cos\eta^n \sin\chi^n & -\cos\eta^n \cos\chi^n & -\sin\eta^n & 1 \end{bmatrix}$$

Any linear dependence?





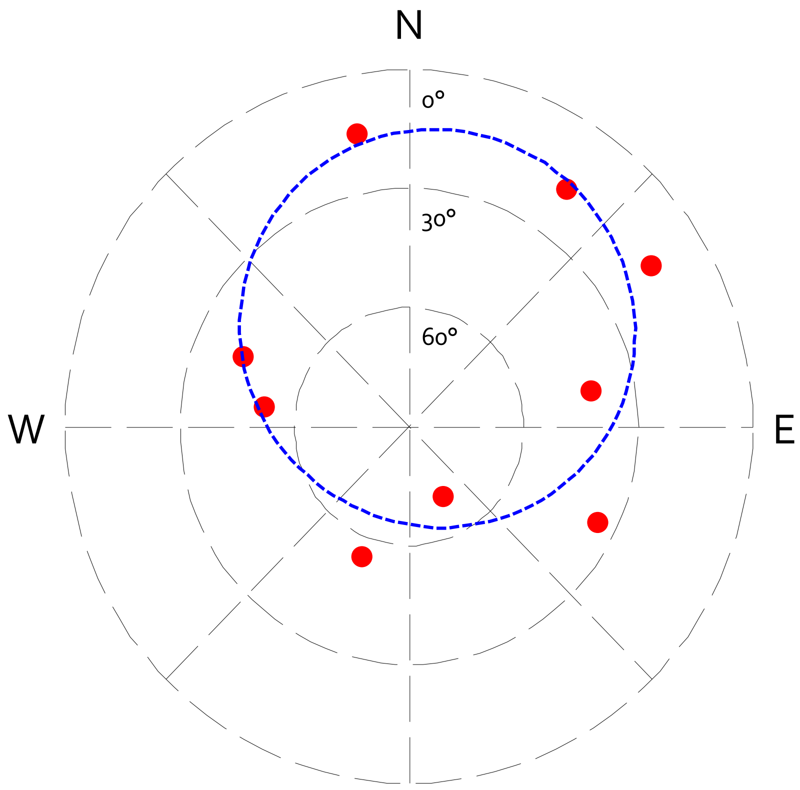
A Conical Satellite Geometry drives the DOP to Infinite Values



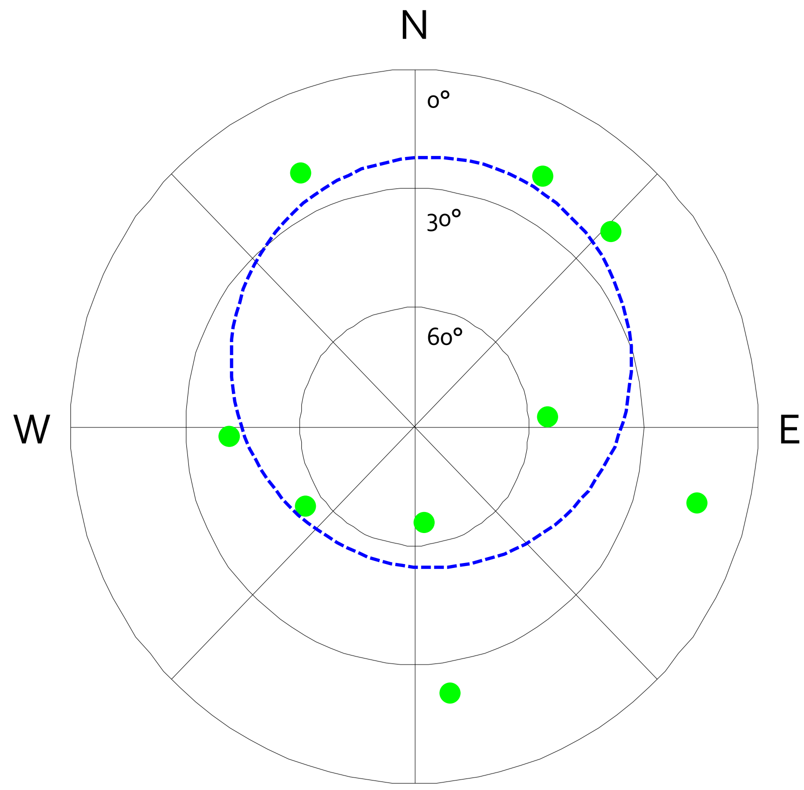
PDOP = 10.79

PDOP = 2.58

A Conical Satellite Geometry drives the DOP to Infinite Values

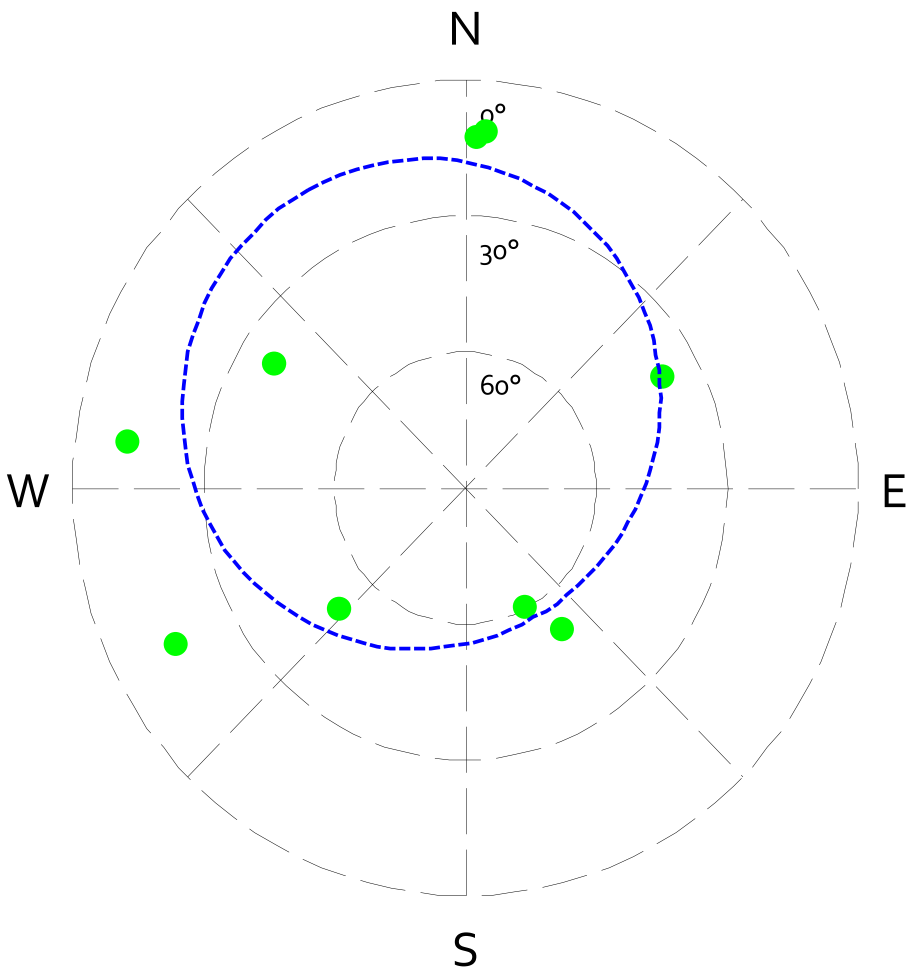


PDOP = 10.79



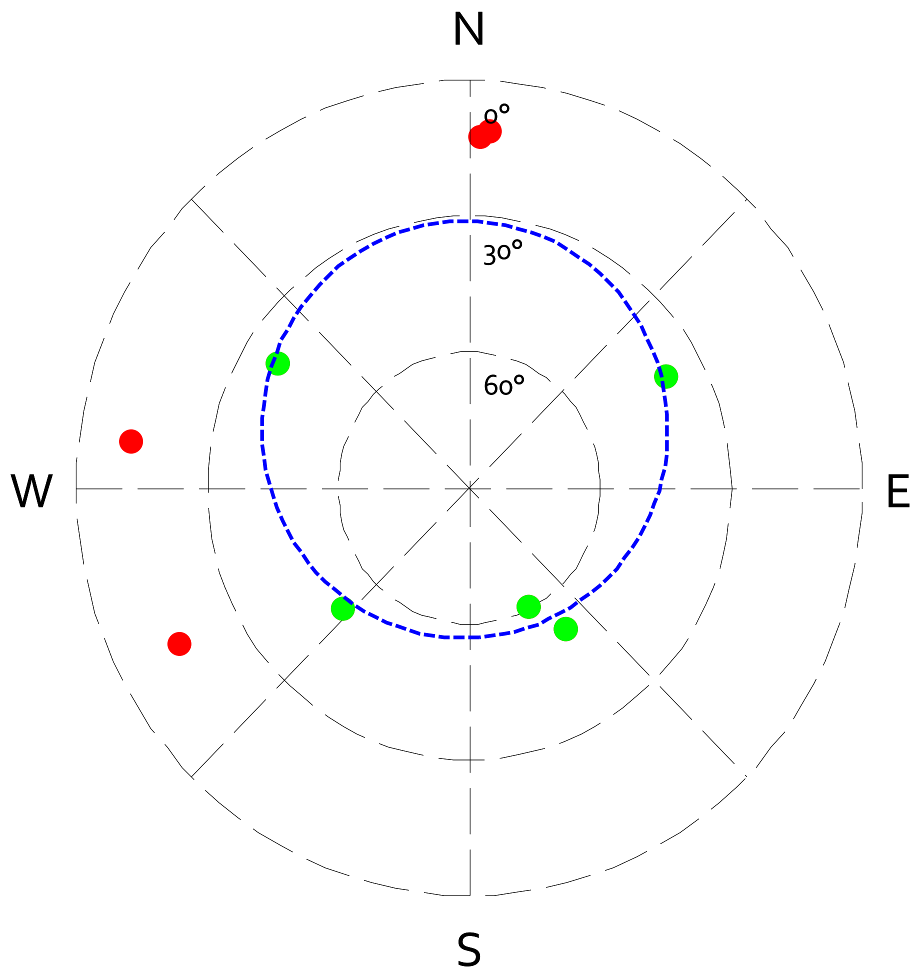
PDOP = 2.58

A Conical Satellite Geometry drives the DOP to Infinite Values



PDOP = 4.39

A Conical Satellite Geometry drives the DOP to Infinite Values



PDOP = 152.05

Introduction

Objectives

Research

Softwares

Analysis

Stochasticity

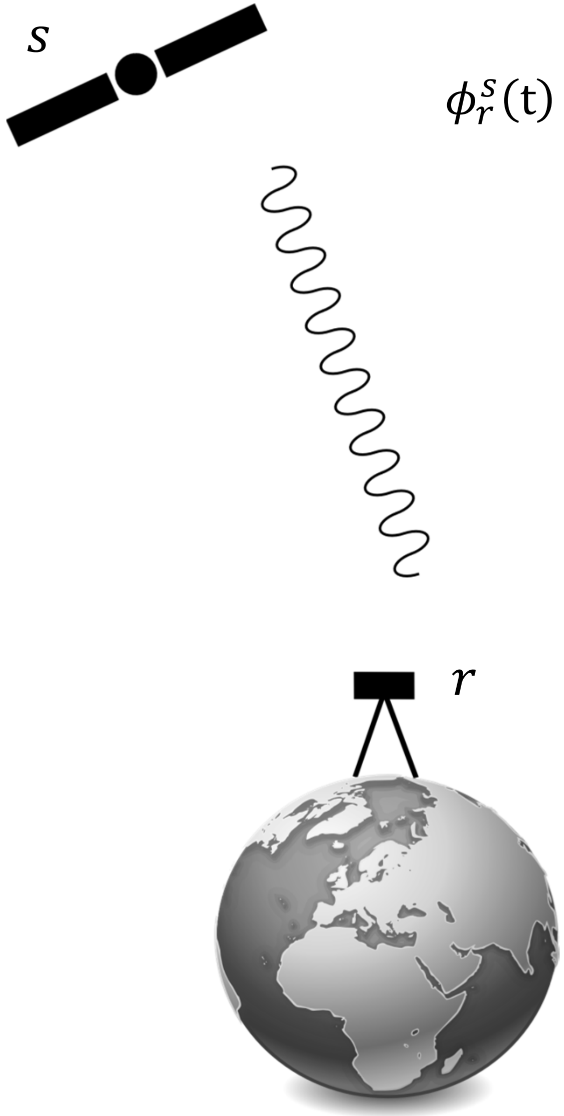
Geometry

Preprocessing

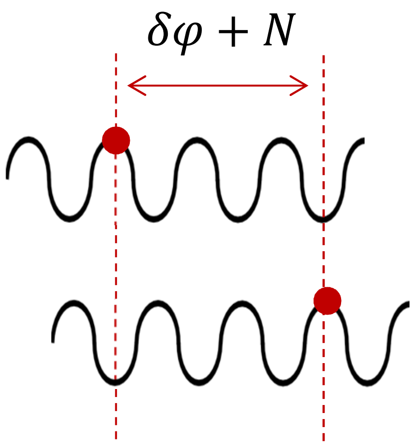
Conclusions

Perspectives

Cycle Slip Detection/Repair is a real need for Precise Positioning Technique

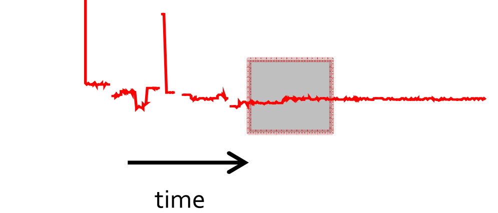


$$\phi_r^s(\mathrm{t}) = D_r^s + T_r^s - I_{r,k,\phi}^s + \mathrm{c}\,(\Delta t^s - \Delta t_r) + \lambda_k N_{r,k}^s + M_{r,k,\phi}^s + \varepsilon_{r,k,\phi}^s$$

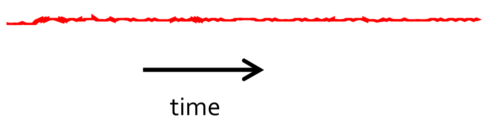


Testing Quantity

Detection Method



Correction Method

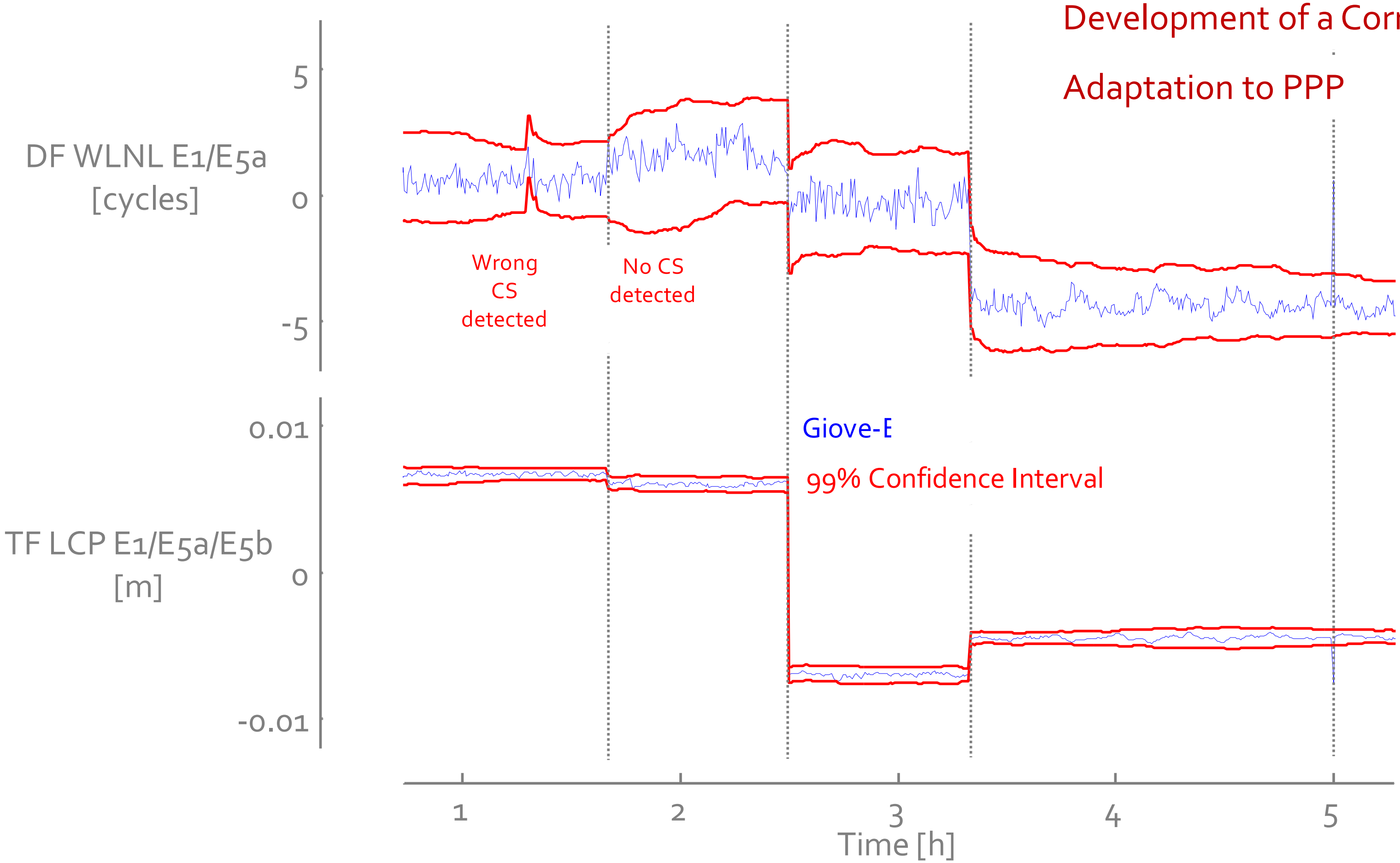


The availability of Three Frequencies makes the CS Detection more efficient

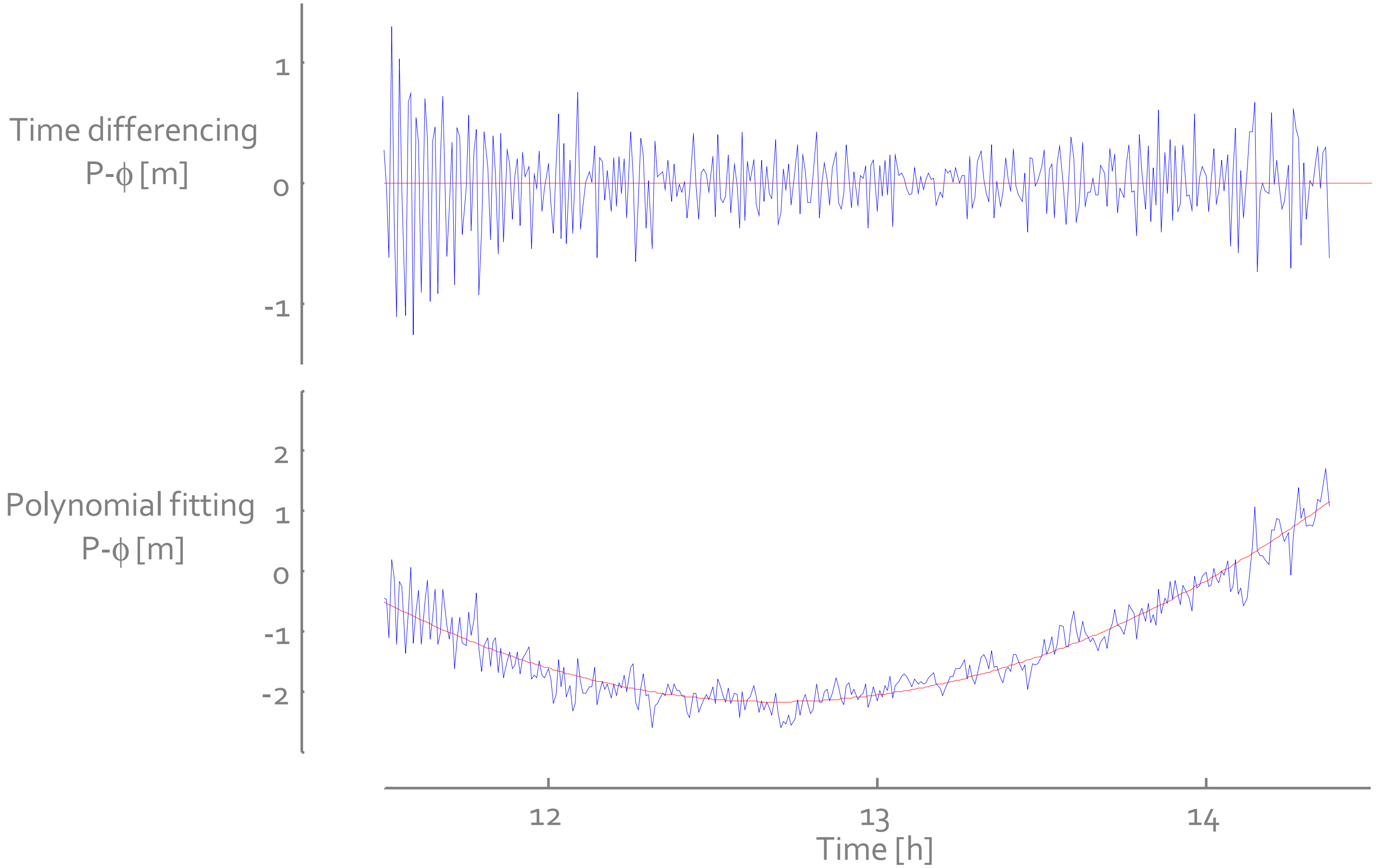
Validation of the Detection under IS

Development of a Correction Method

Adaptation to PPP



Observable Noise Assessment could help to define the Stochastic Model (« Empirical Strategy »)



Softwares

Analysis ➡
- *Symptomatic Analysis for a HL Station*
- *Methodology*
- *Equatorial Scintillations?*

Stochasticity

Geometry

Preprocessing

Softwares

Analysis

Stochasticity ➡ *Spatial / Empirical Strategies*

Geometry

Preprocessing

Softwares

Analysis

Stochasticity

Geometry ➡ *Illustration of Geometric Problems*

Preprocessing

Softwares

Analysis

Stochasticity

Geometry

Preprocessing ➡ *CS Detection Method*

Validation of CS Detection for IS

Development of CS Repair Technique

Introduction

Objectives

Research

Conclusions

Perspectives

Perspectives

FP

100	10	20	40	15	15
	Softwares	**Analysis**	**Stochasticity**	**Preprocessing**	**Geometry**

Introduction

State of the Art

Analysis

Solution

Validation

Conclusions

Softwares

- Versioning
- Python learning
- C learning
- Global Approach
- Global Design
- Adapations
- Stochastic Model
- Preprocessing
- Mathematic Model
- Weigthing Scheme
- Automatisation
- Stoch. Matlab Module
- Matlab routines
- Matlab mapping TB
- Matlab exe
- GIS software

Analysis

- Data Access
- Data Types
- Data Parsing
- Data Network
- Data Documentation
- Data Download
- Data Mapping
- Network Design
- SPP Process
- PPP Process
- SS Analysis
- MS Analysis
- Symptoms

Stochasticity

- Spatial Approach
  ACS Study (Index)
  ACS Study (covar.)
  Corr. Observables
  Index (RNX)
  Spatial Interpolation
  Covariance
  Assesment

- Empirical Approach
  Filter Construction
  Tests

- Validation
  gLAB

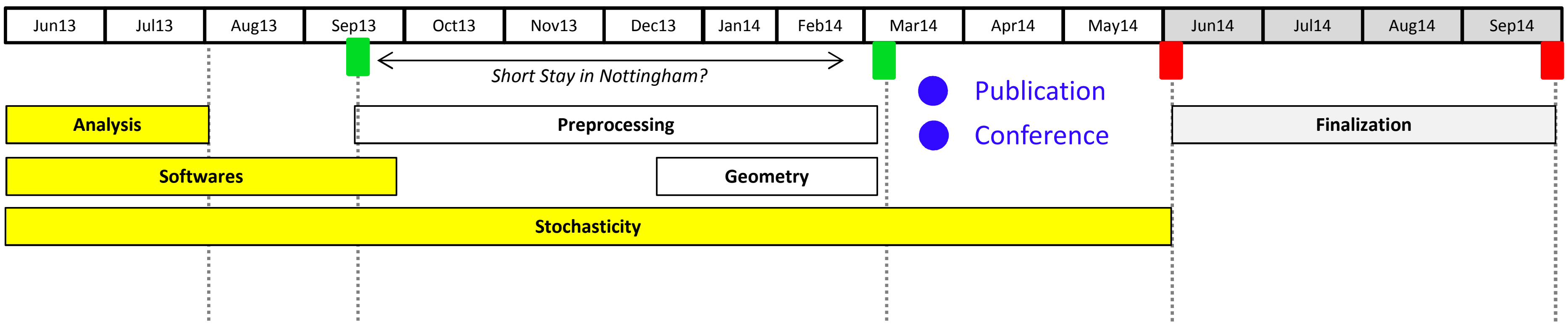
Preprocessing

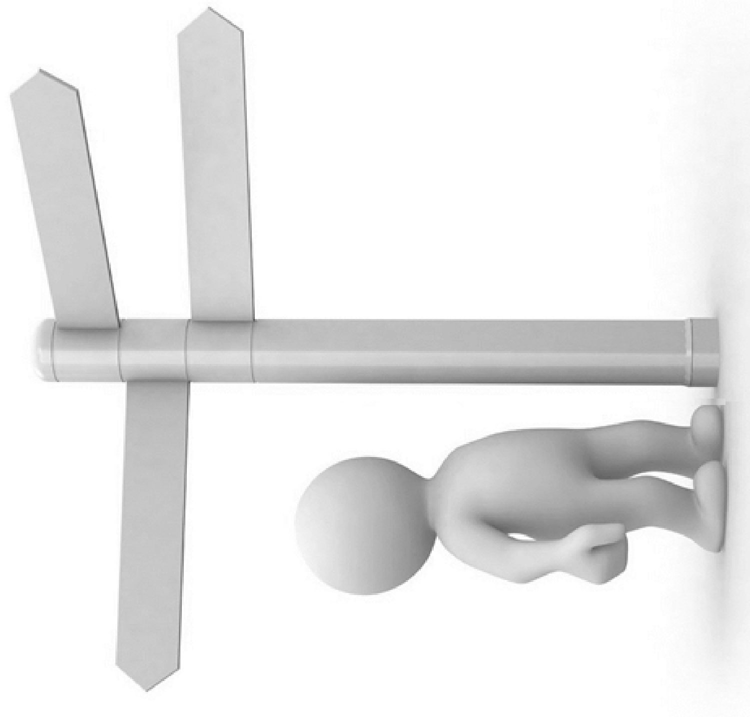
- CS Detection
  TQ DF+TF
  Filter Parameters
  Validation DF+TF

- CS Repair
- Noise Assessment

Geometry

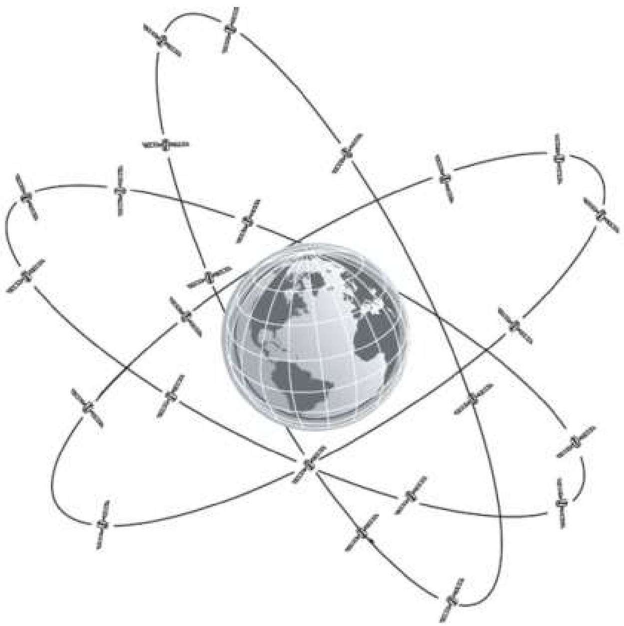
- Conical Theory
- M-GNSS
- Validation?





Satellite Positioning

Performances under Ionospheric Scintillations



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June 11, 2013

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