GNSS Ocean Reflected Signals

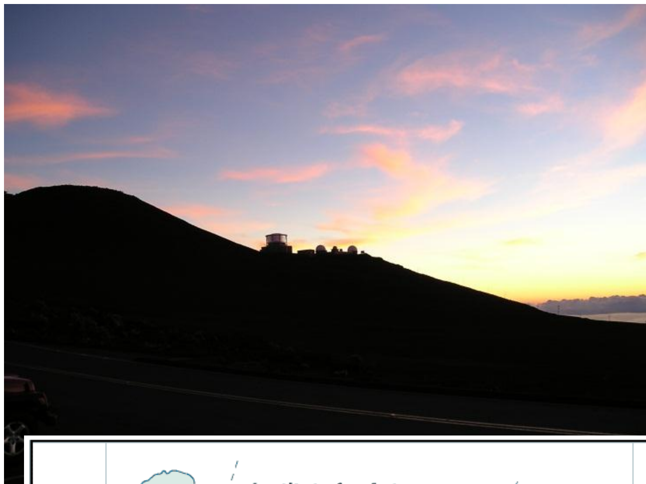
Per Høeg

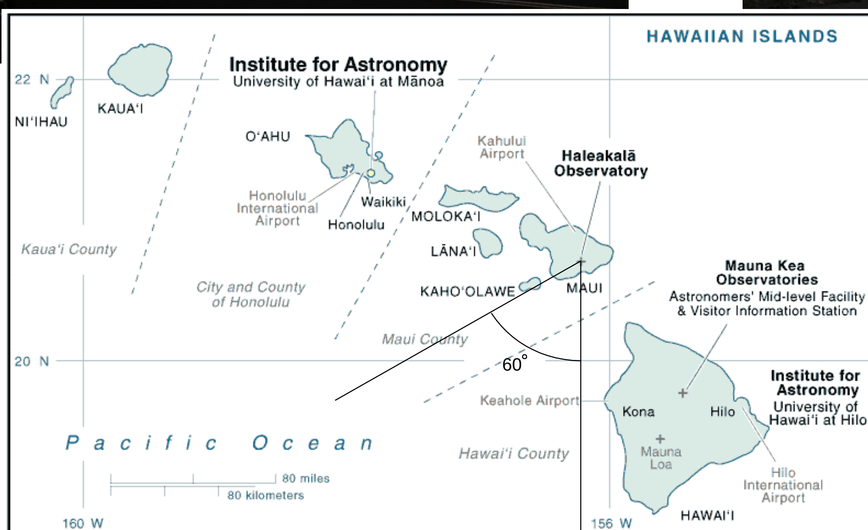
DTU Space
Technical University of Denmark

Content

- Experimental setup
- Instrument
- Measurements and observations
- Spectral characteristics, analysis and retrieval method

Experiment



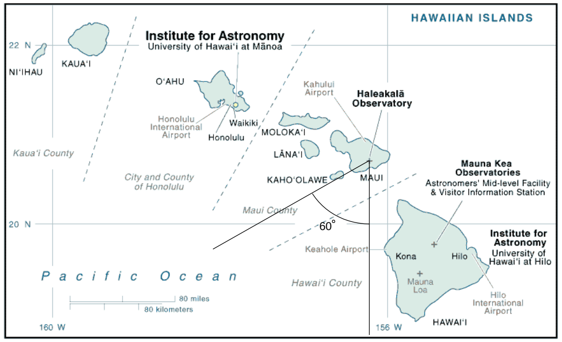


Altitude: **> 3000 meters**

Year: **2004**

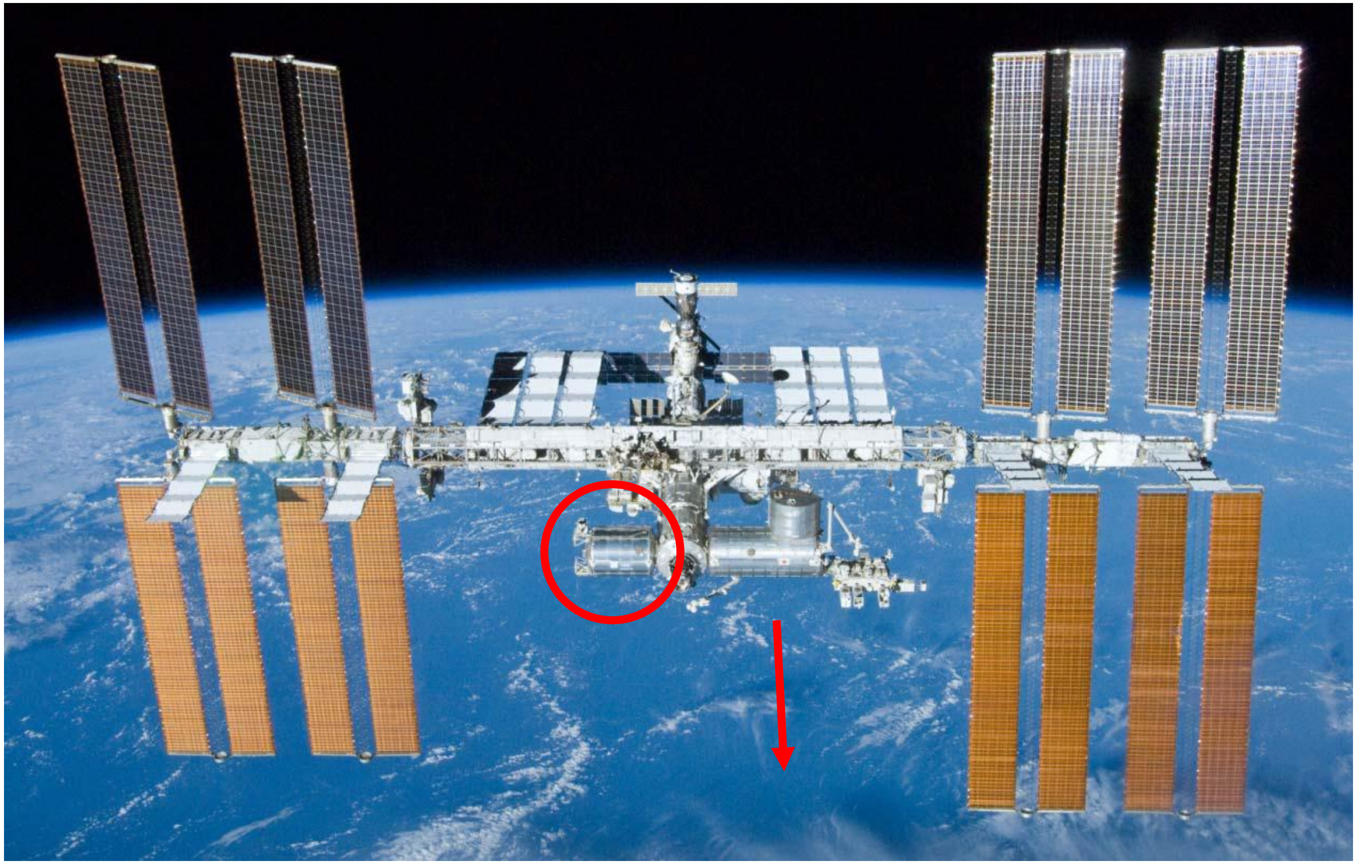
GNSS Ocean Reflected Signals

- GNSS ocean reflected signals describe the height and the roughness of the ocean
- The characteristics of the reflected signal depend on the scattering properties of the sea surface and the footprint of the reflection zone
- The footprint size and shape in turn depends on the signal incidence angle and the relative velocities of transmitter and receiver
- Scattering properties of the sea surface (the roughness parameter) relates to the ocean wave characteristics

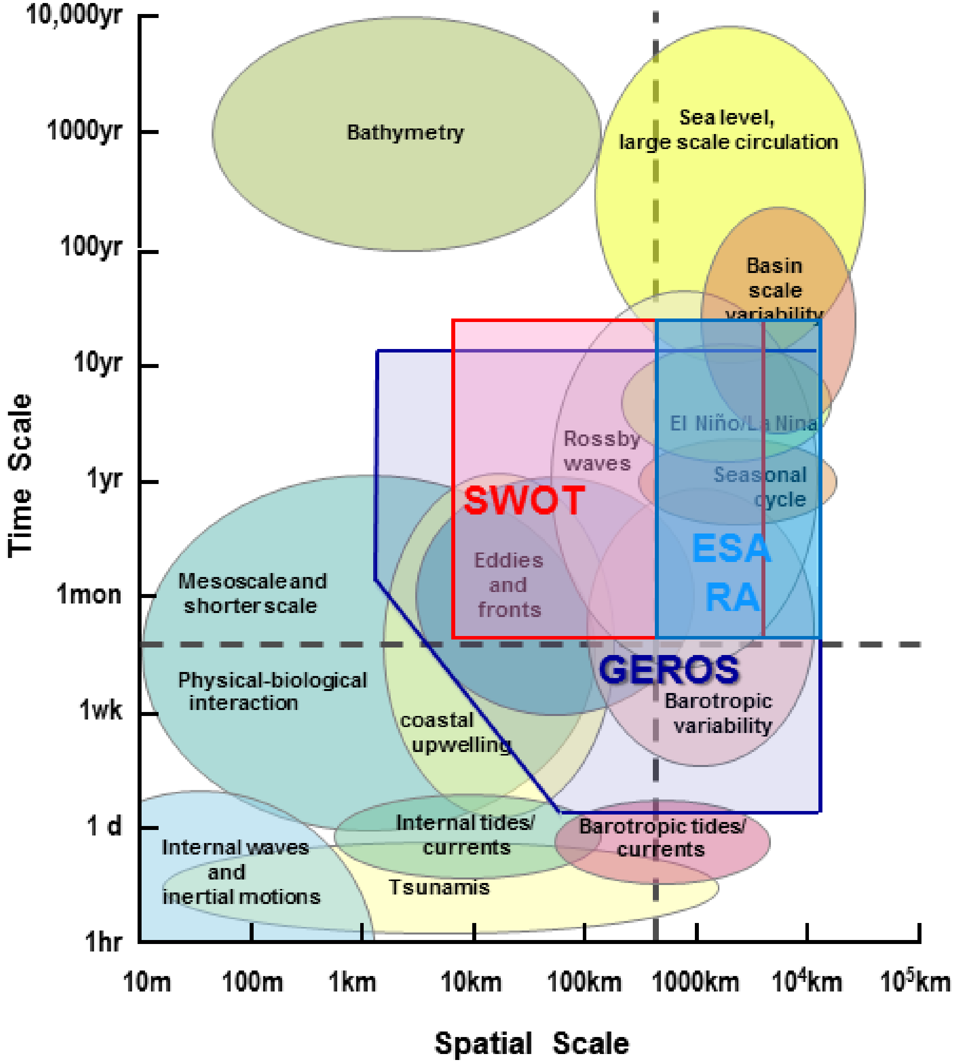


Motivation

- Studies of Sea Surface Height Processes
- GEROS on the ISS Columbus Module



Ocean Sea Surface Height Processes

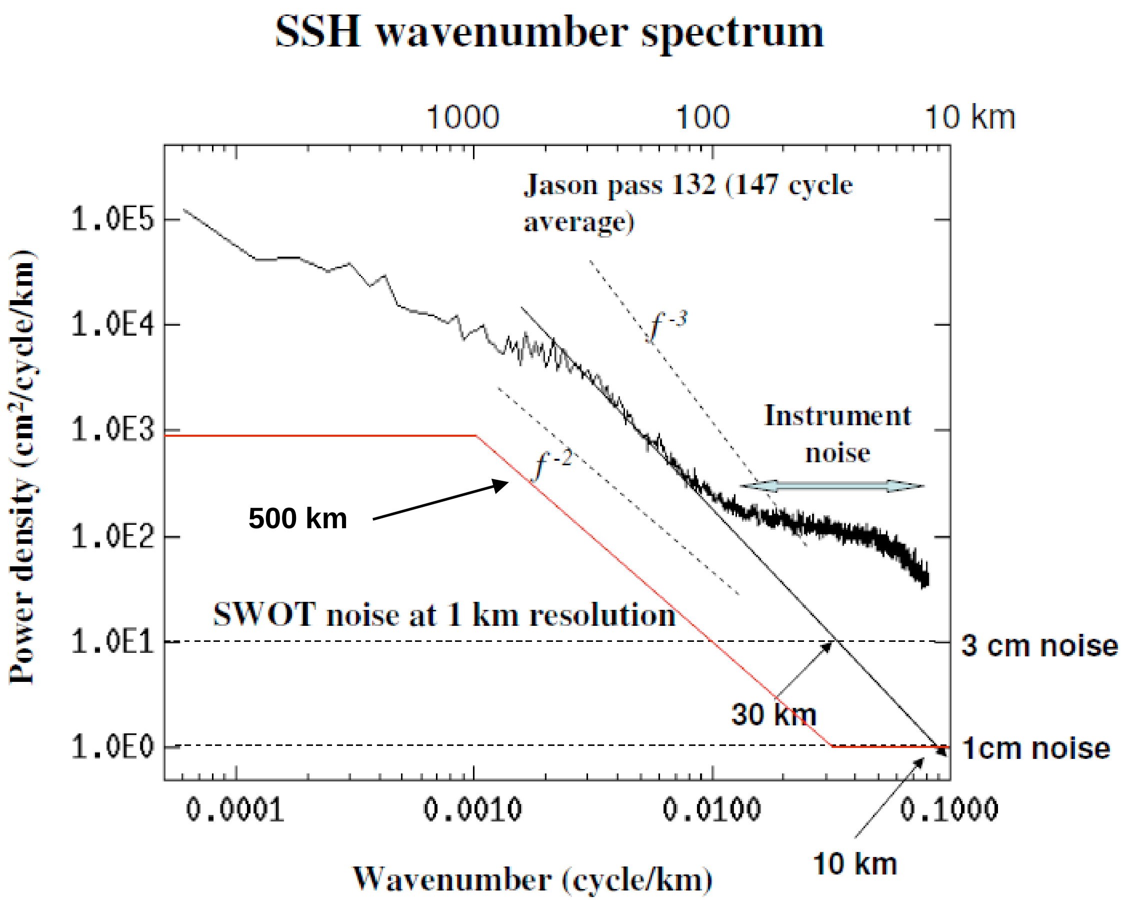


Oceanic observations carry signals of a wide range of related processes.

The observed fingerprints of these processes have temporal time scales from 1 hour to thousands of years and spatial scales from ten to tens thousands of kilometres.

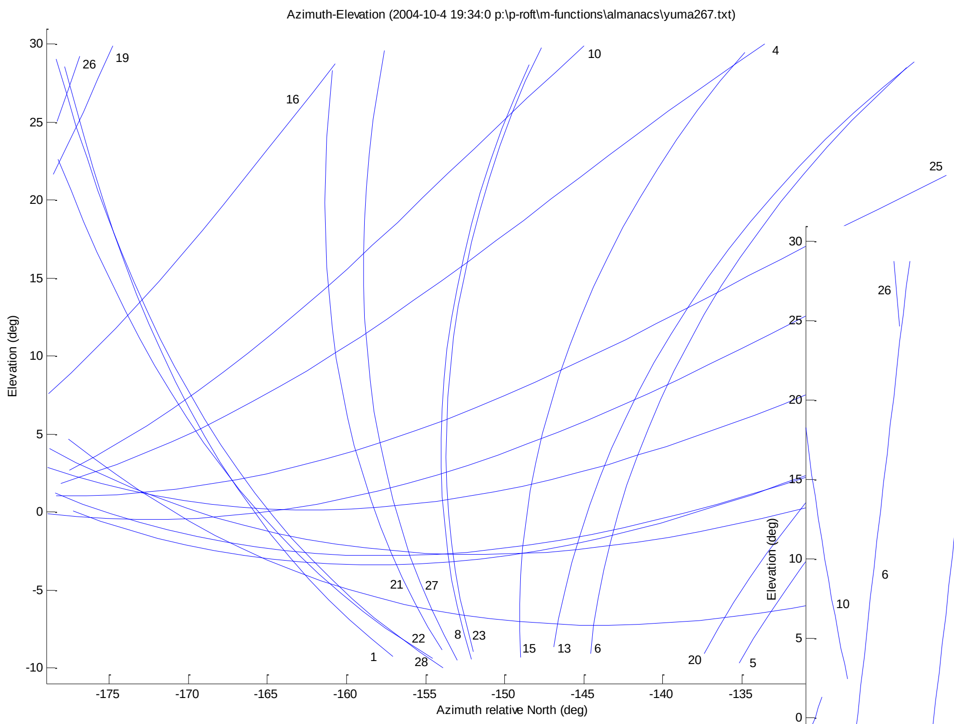
The figure illustrates the spatial and temporal scales for these processes and indicates phenomena, which can be investigated with GEROS-ISS data complementary to and distinct from the planned NASA SWOT mission and ESA and NASA radar altimetry missions (Revised from Zuffada et al., 2005).

Power Spectrum of Sea Surface Heights (SSH)

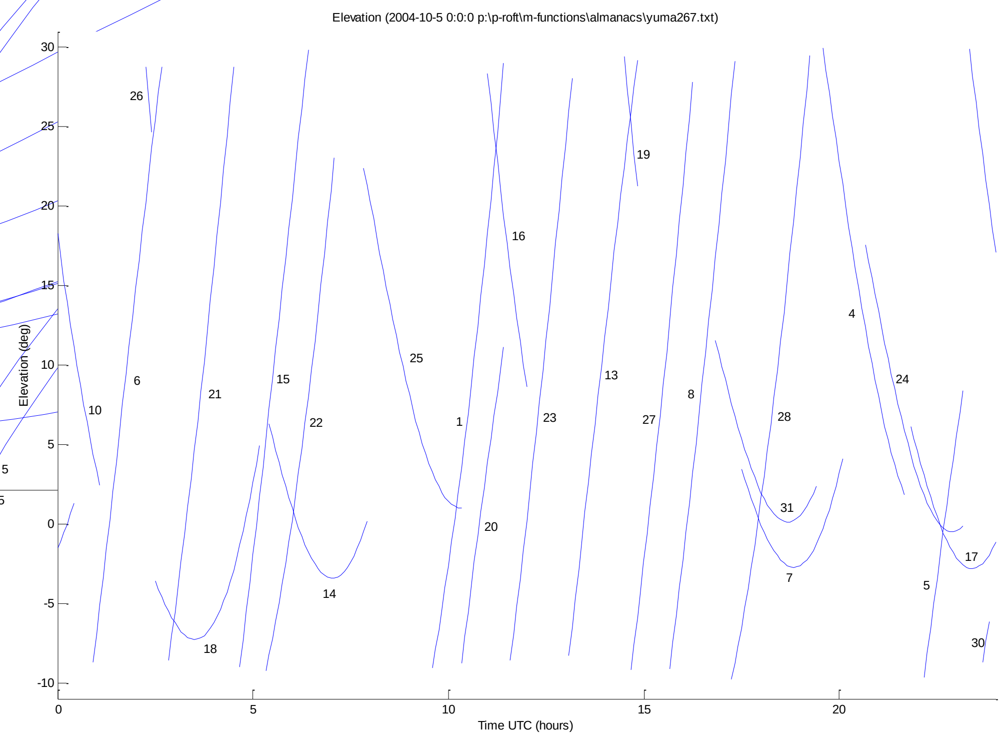


The black SSH power spectrum is for reference based on Jason altimeter observations (pass 132).
The red curve gives the error spectrum of the NASA SWOT mission. The solid black line is the expected spectral continuation.
The intersection of the spectral signal with the noise floor at 10km determines the resolving capabilities
for the SWOT instrument (JPL, NASA, 2009).

Experiment

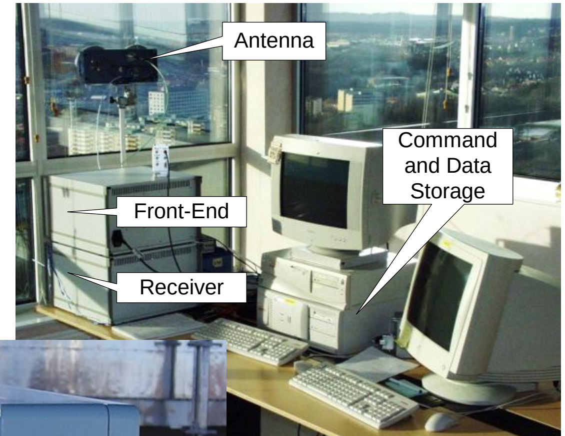


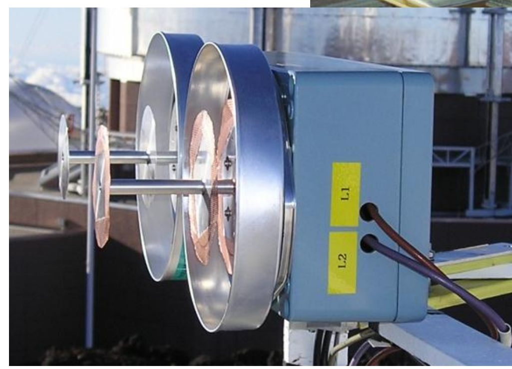
Azimuth (deg)

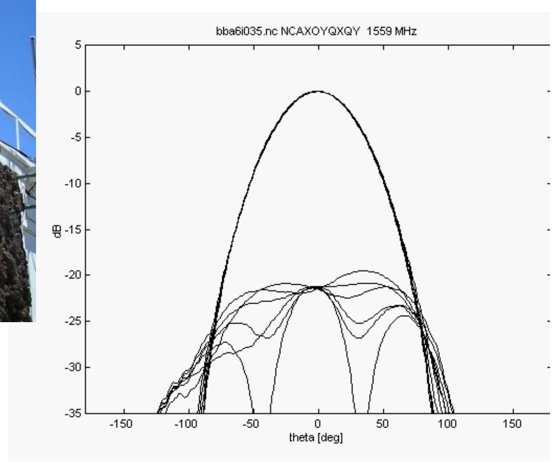


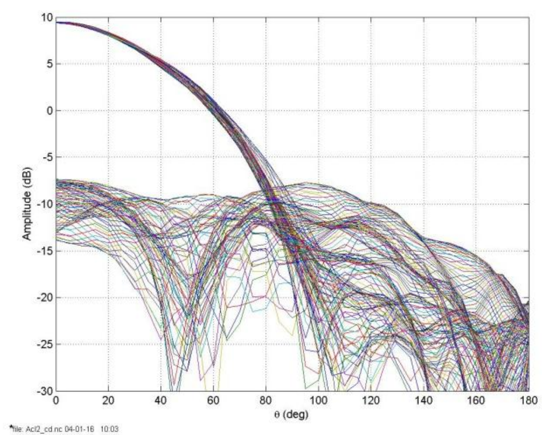
Time of day (hours)

Experiment

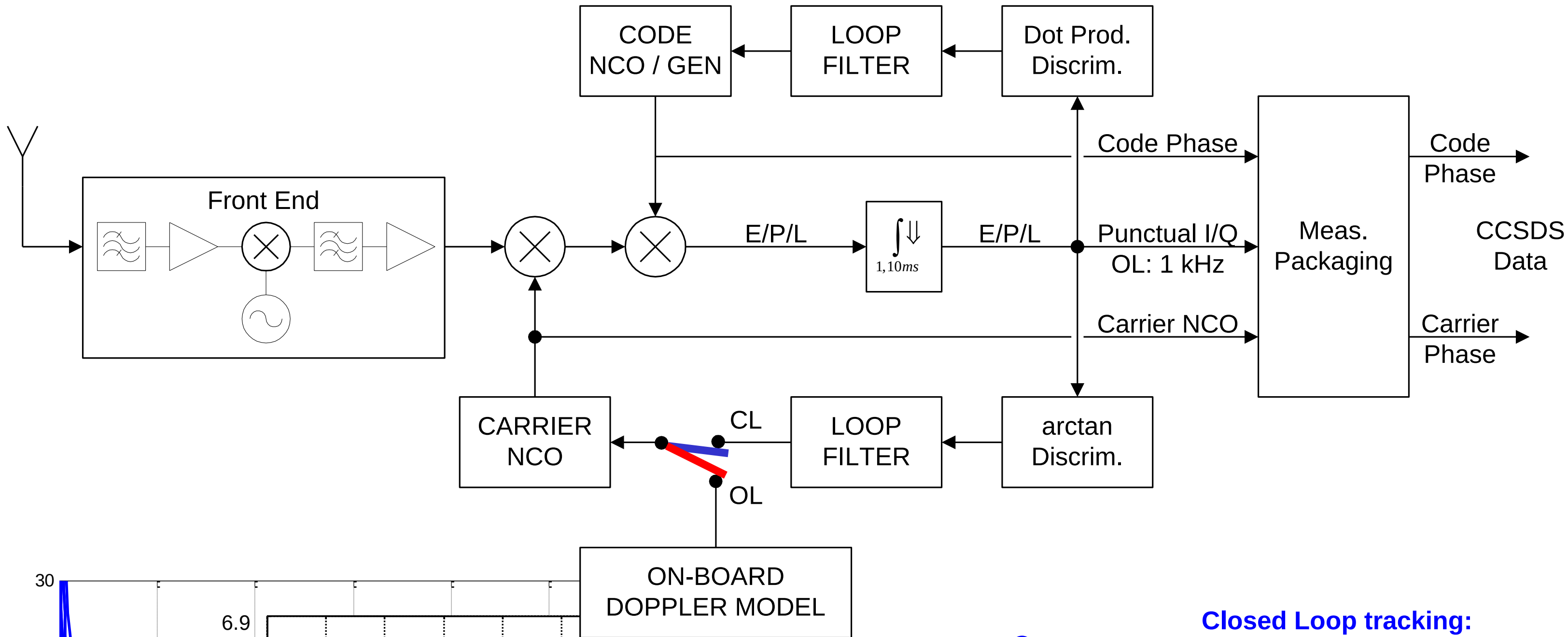

Antenna
Front-End
Receiver
Command and Data Storage

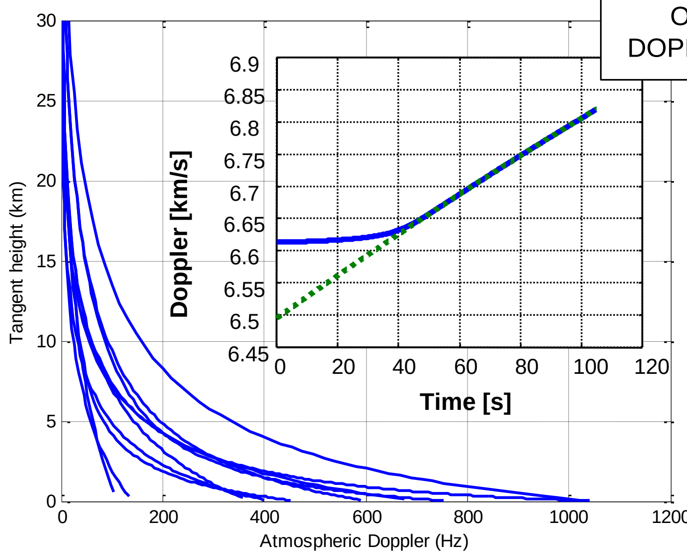


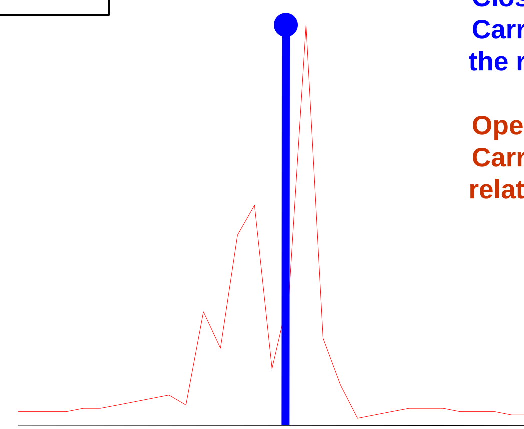

bba6i035.nc NCAXOYQXQY 1559 MHz
dB
theta [deg]
5
0
-5
-10
-15
-20
-25
-30
-35
-150
-100
-50
0
50
100
150


Amplitude (dB)
θ (deg)
10
5
0
-5
-10
-15
-20
-25
-30
0
20
40
60
80
100
120
140
160
180

Instrument





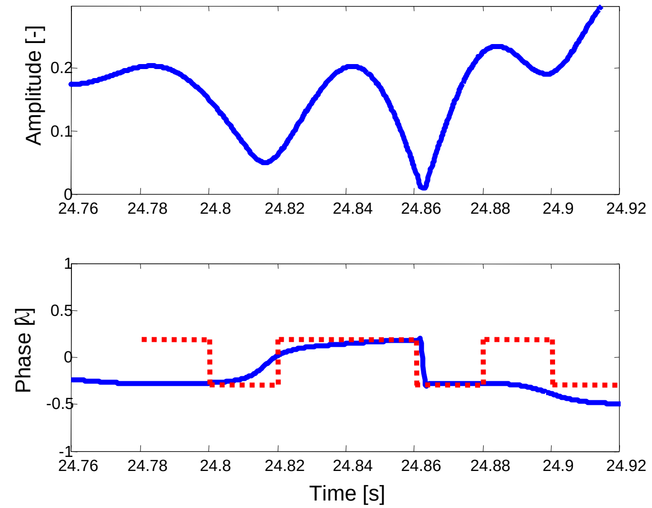


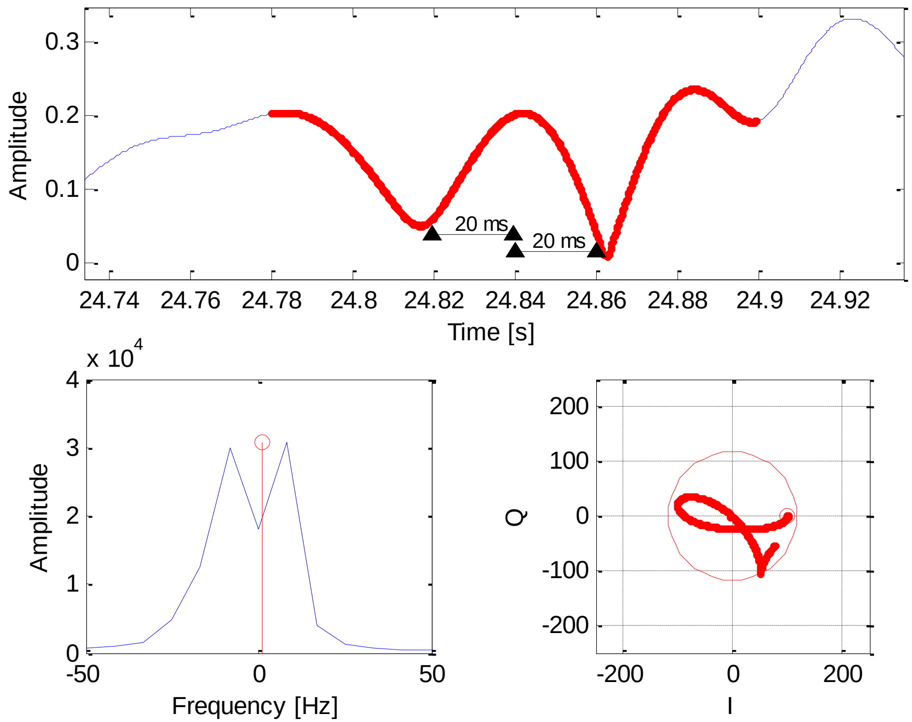
Closed Loop tracking:
Carrier Phase is phase locked to the received signal.

Open Loop tracking (raw mode):
Carrier Phase is measured relative on-board Doppler model

Instrument

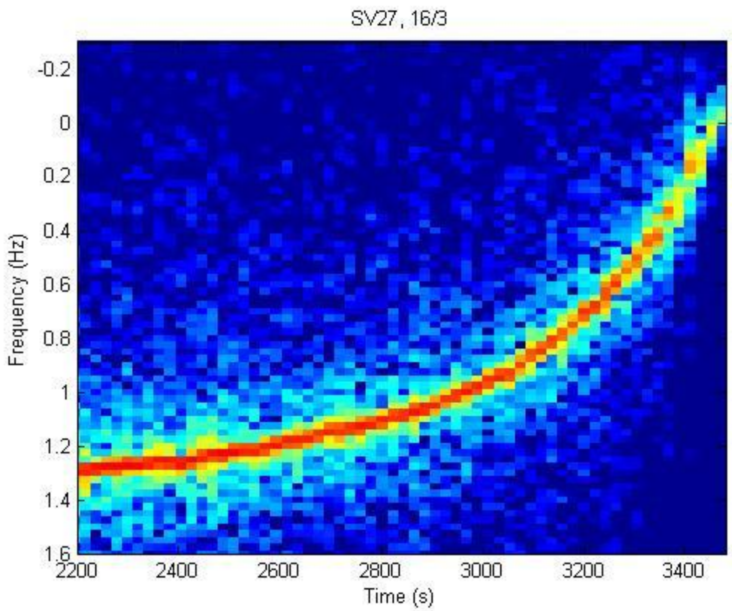
(Navigation Data De-modulation)

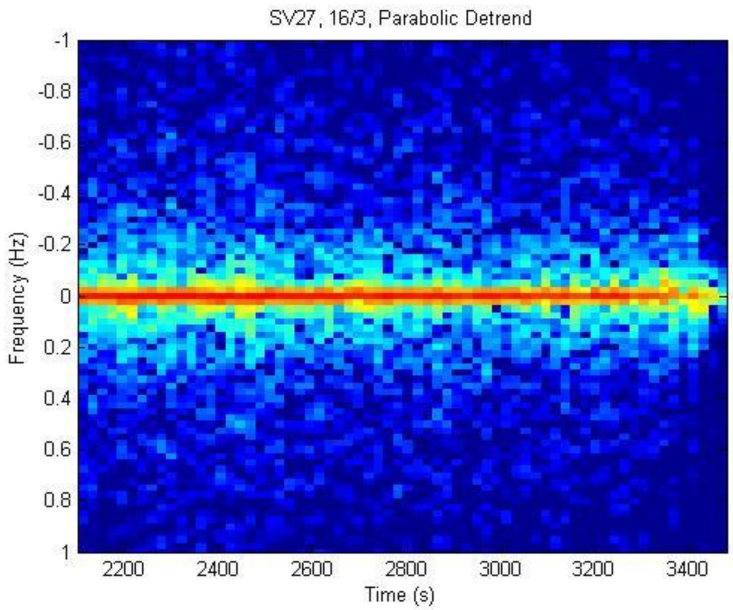




Measurements

(De-trended Power Spectra)

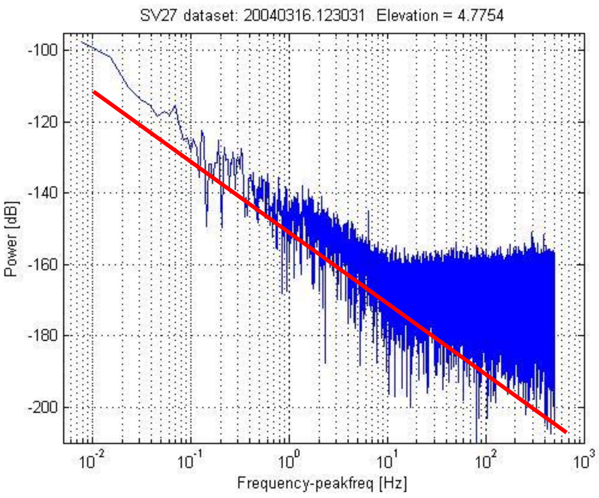


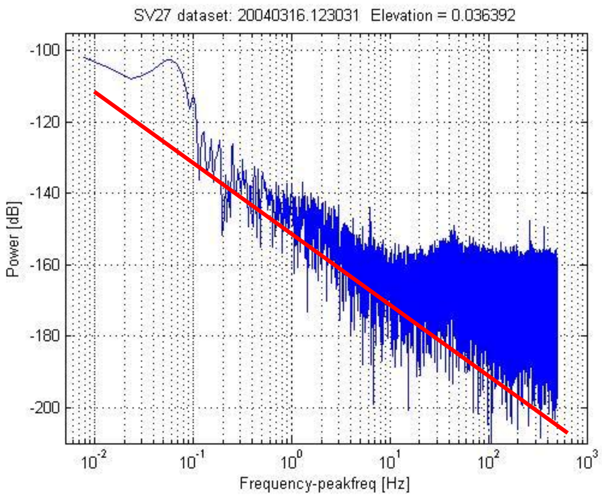


Background signal frequency drift are removed using a least squares fit parabola to the main phase.

Measurements

(Power Spectra at Different Elevation Angles)





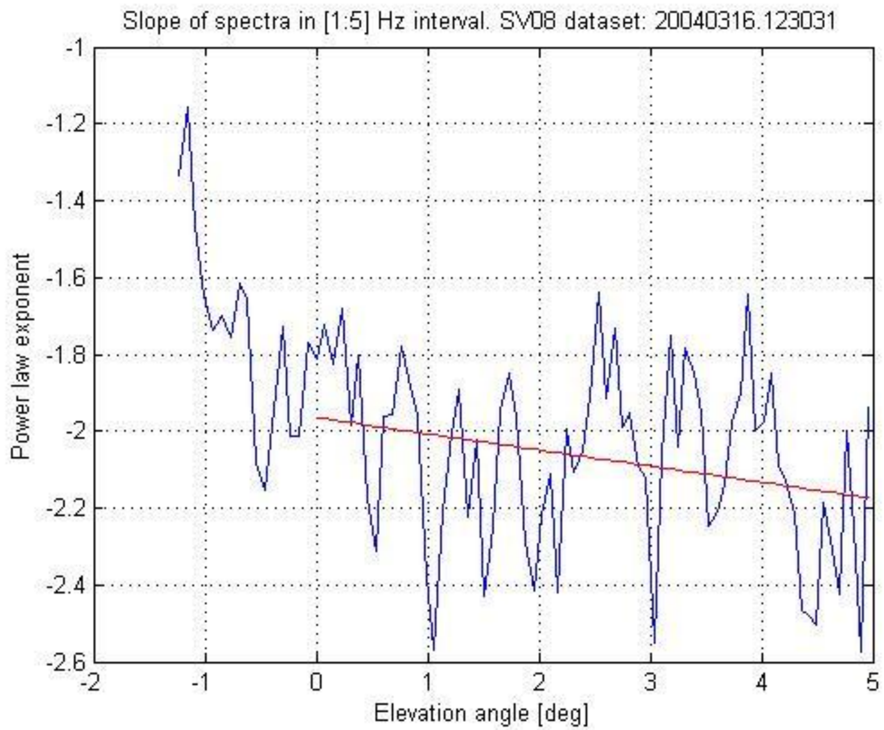
Power spectra as function of frequency difference ($f-f_0$) from the main signal peak f_0.

Clock related spectral slope of f^{-2}.

No clock correction has been applied.

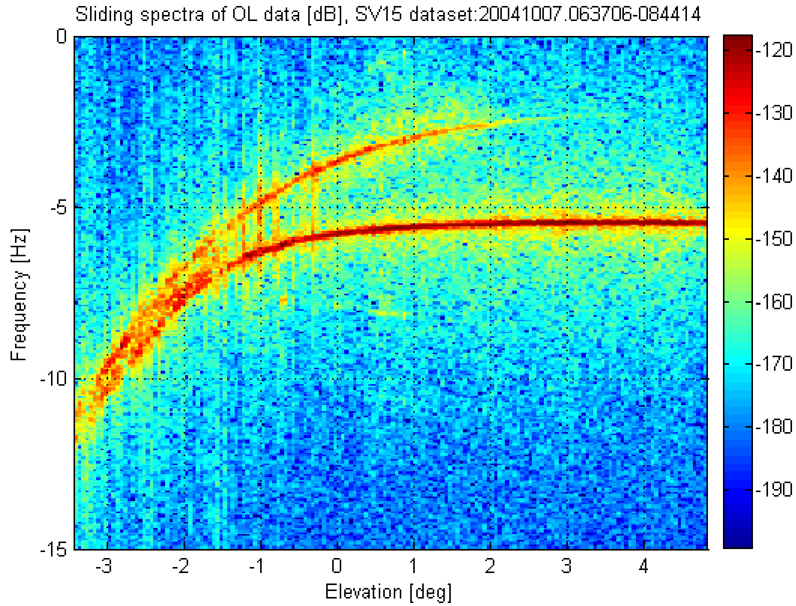
Measurements

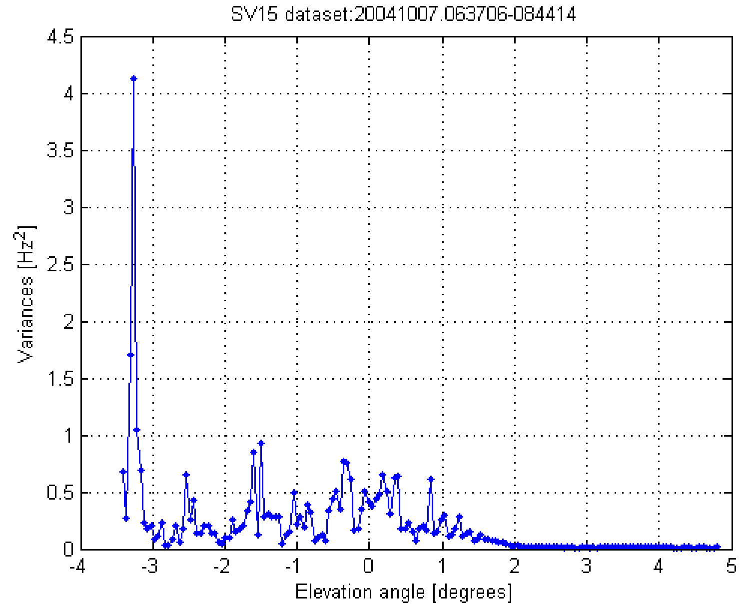
(Trend Analysis)

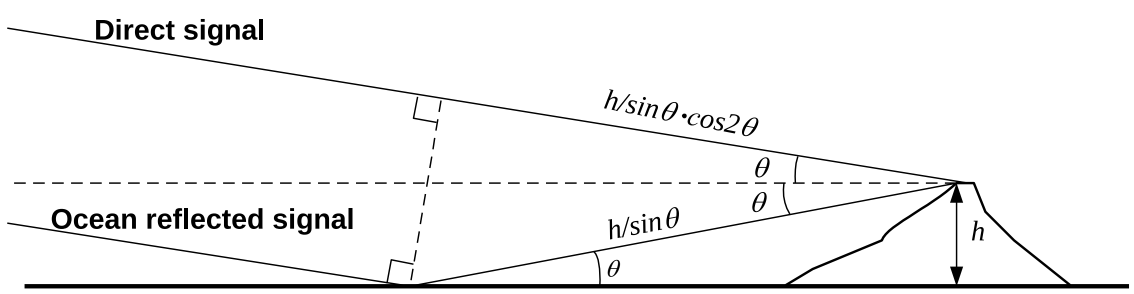


Variation of the slope in the frequency region 1 - 5 Hz of the power spectrum, as function of elevation angle.
The red straight line is the linear least squares fit to the curve in the elevation angle interval, 0-5 degrees.

Spectral Analysis

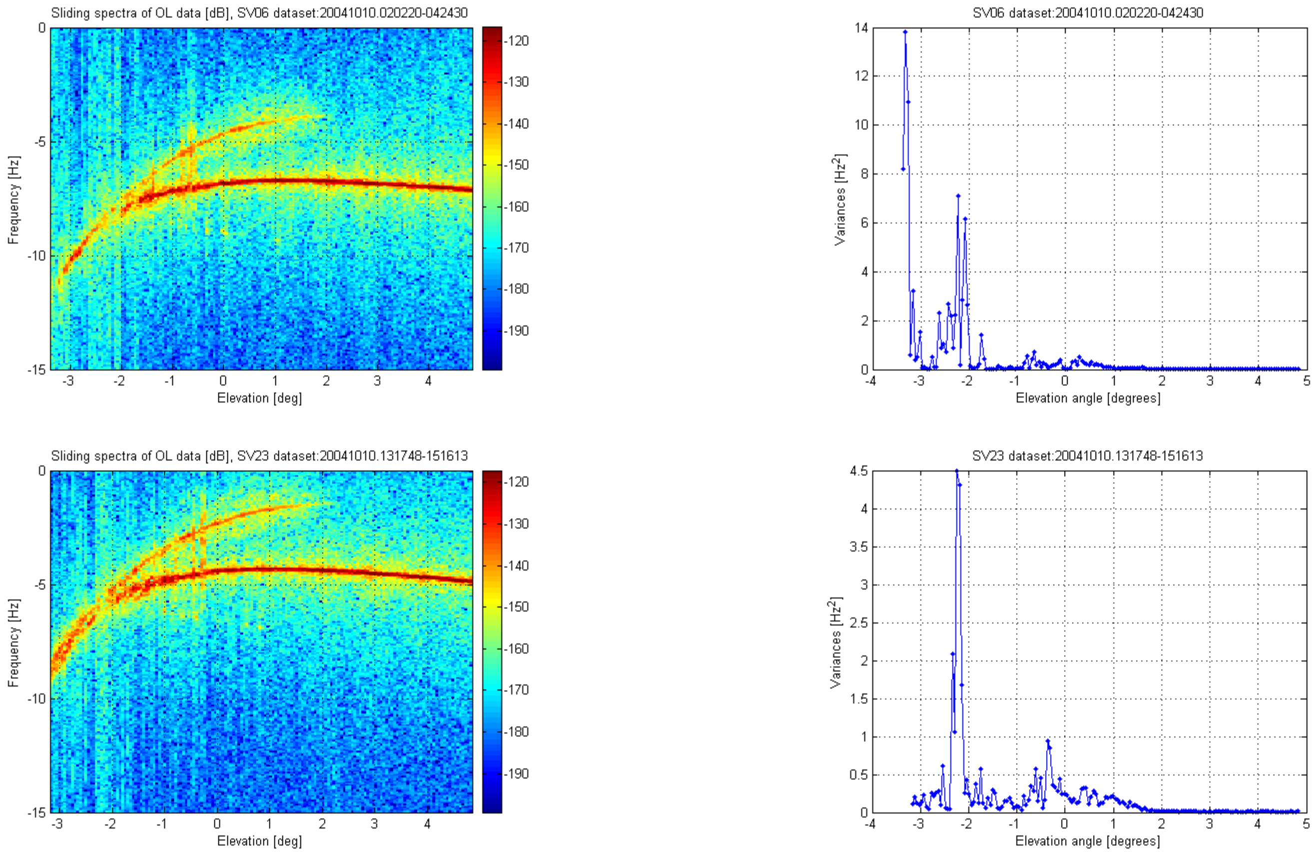




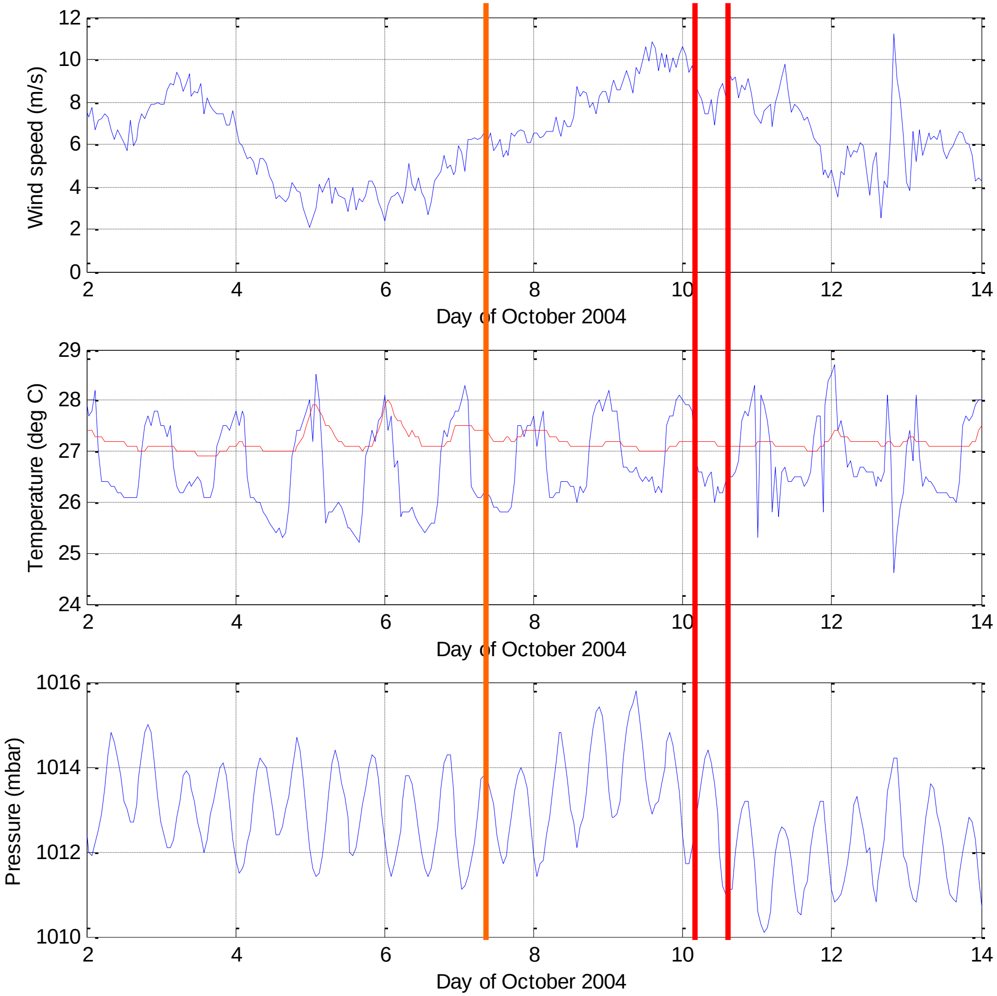


Path length difference: $h / \sin\theta \; (1 - \cos 2\theta)$

Spectral Analysis



Meteorological Conditions



Particle Filtering Method

The State Model

Tracking the position of a reflection point can be viewed as estimation of the state of the dynamical system based on sets of measurements.

We assume that the state (parameterized by its position, height and velocity) is a first-order Markov process of the form (time-varying stochastic process):

$$\theta_k = F_k \theta_{k-1} + G_k W_{k-1}$$

θ_K **is the reflection point state vector at the time *k***

W_k **is the unknown system noise input**

$$\theta_k = \begin{bmatrix} \vec{p}_k \\ \vec{v}_k \end{bmatrix}$$

Here, the state vector consists of the 3-dimensional position and velocity vectors

The discrete time matrices:

$$F_k = \begin{bmatrix} I_M & t \cdot I_M \\ O_M & I_M \end{bmatrix} \quad and \quad G_k = \begin{bmatrix} \frac{t^2}{2} \cdot I_M \\ t \cdot I_M \end{bmatrix}$$

Particle Filtering Method

The Observation Model

The system has *M* received signals and a single GNSS transmitter.

The time-variant *m*^th^ received signal in the *k*^th^ snapshot is given as:

$$y_{m,k}(t) = x_{m,k}(t) + z_{m,k}(t) + \omega_{m,k}(t)$$

The signal component:

$$x_{m,k}(t) = \alpha_{m,k}(t)\, u(t - \tau_{m,k}(t))\, e^{(j2\pi f_c \tau_{m,k}(t))}$$

$\omega_{m,k}(t)$ **is the complex zero-mean Gaussian noise process with spectral height** σ_ω^2

$\alpha_{m,k}(t)$ **denotes the complex amplitude of the wave propagation path**

f_c **carrier frequency,** $u(t)$ **the transmitted signal**

$\tau_{m,k}(t)$ **the delay of the signal received from the m^{th} received signal at time *t* in the k^{th} observation window**

Particle Filtering Method

The Particle Filtering Algorithm

A sequential Bayesian estimation method is used to estimate recursively

the conditional probability density function $p_y\left\langle \theta_{1:k} \middle| y_{1:k} \right\rangle$

$$y_{1;k} = \left[y_1, y_{2,} \cdots, y_k \right] \quad \text{and} \quad \theta_{1;k} = \left[\theta_1, \theta_{2,} \cdots, \theta_k \right]$$

denote respectively, a sequence of observations and state vectors, from the *1st* to the *kth* measurement cycle

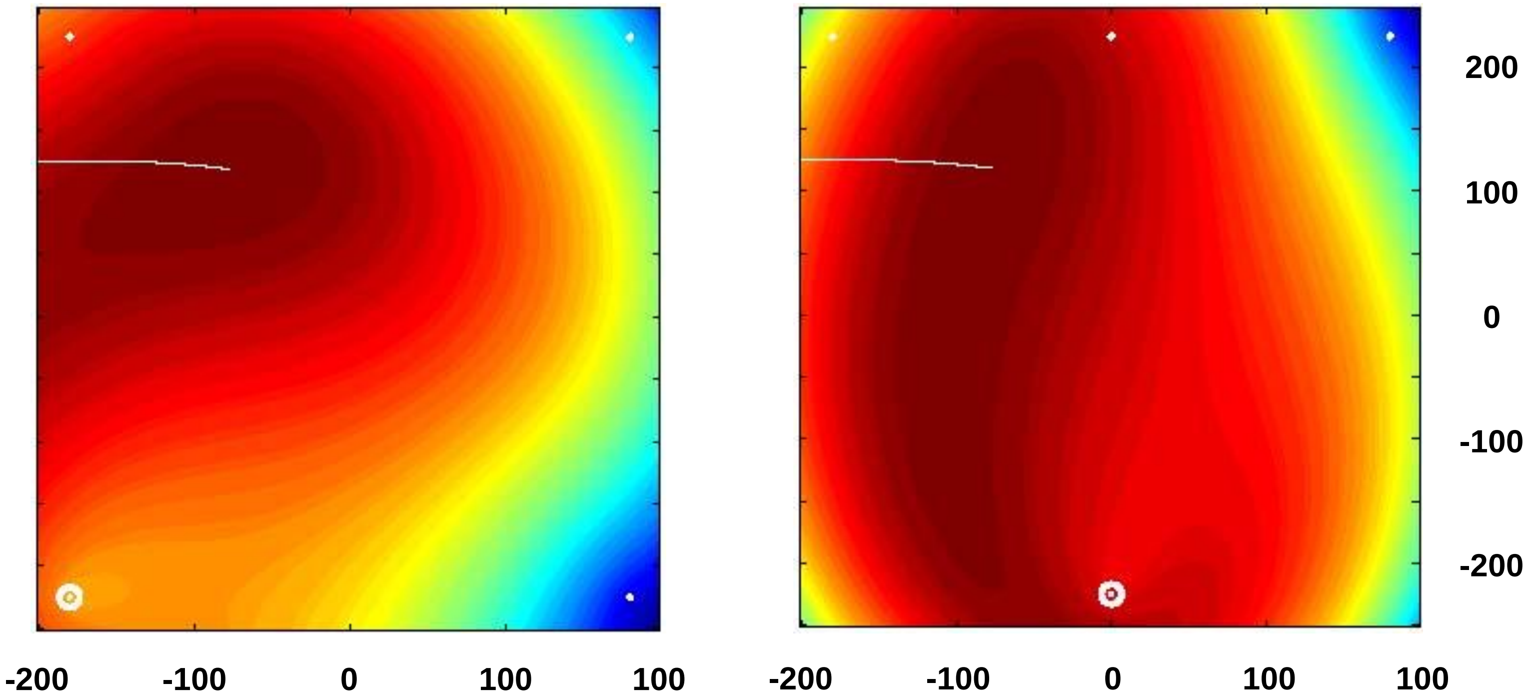
The proposed particle filter technique makes use of a fixed number of particles, where each particle is associated with a state vector

$$\Omega_k^i = \begin{bmatrix} p_k^i \\ v_k^i \\ \omega_k^i \\ \alpha_k^i \end{bmatrix}$$

Steps for each new observation:

1) **Predict the states of particles and calculate the weights**
2) **Re-sampling**
3) **Estimate the power density function**

Sea Surface Reflection Zone



Horizontal probability density functions at the reflection location (in meters)

Conclusions

- The spectral variances are driven by the atmospheric physical conditions, sea surface roughness and wind dynamics.
- Spectral noise characteristics follows a power distribution related to the clock noise and the receiver amplitude estimation.
- Estimated spectral variances link directly to the turbulence structure function constant of the measured atmosphere region.

Thank you !