Step by step to PaRIS – Airborne Carrier Phase Altimetry using reflected GPS signals

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Photo: Estuary baltic sea, Finnland 2007

Overview

GPS Sea Ice - Introduction

- Geometry
- Altimetry

Tropospheric Bias

- Model
- Observation
- Results

Ionospheric Bias

- Model
- Observation
- Results

Summary & Outlook

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GPS Sea Ice - Introduction

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Geometry

Receiver

- coast high above the ocean
- Earth fixed position

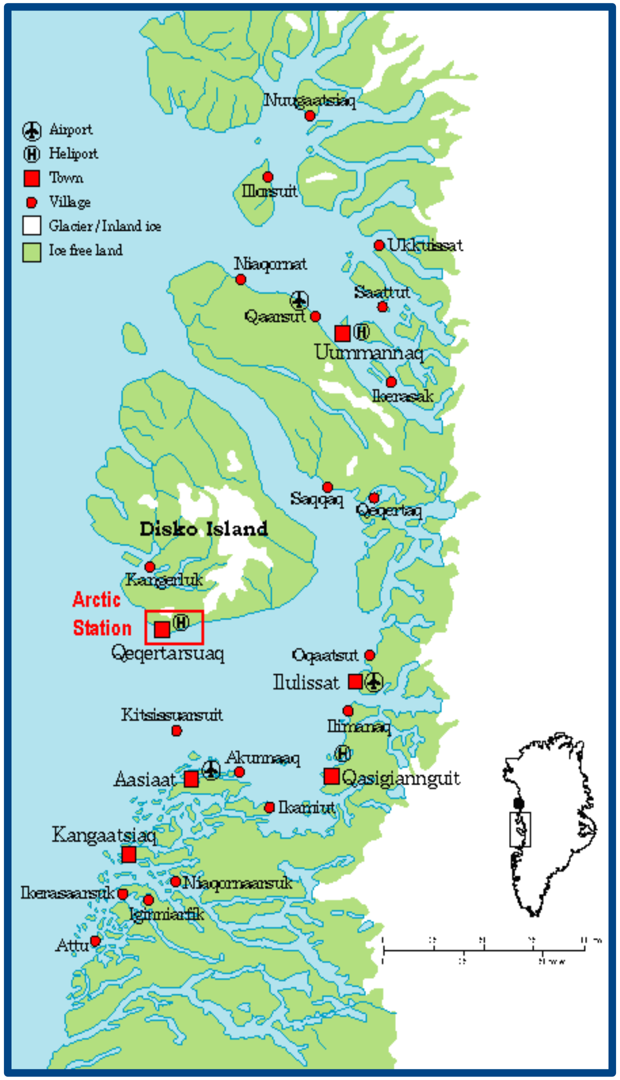
Transmitter

- at low elevation
- rising and setting

Reflection Track

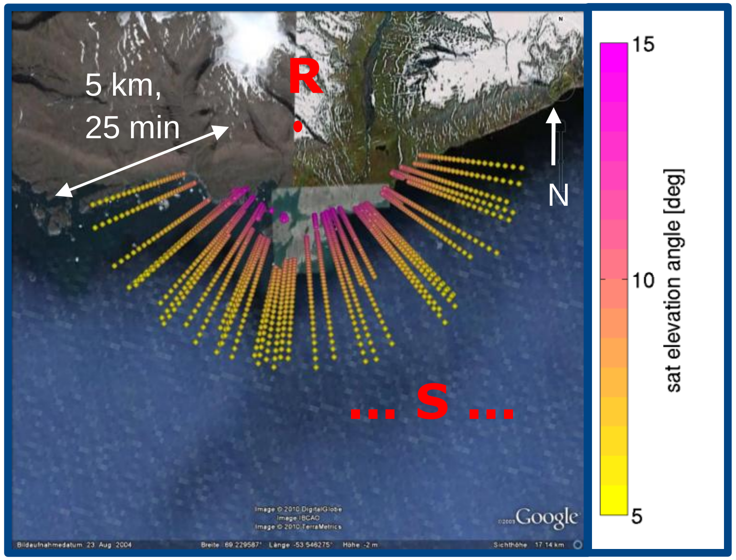
- specular points
- on the ocean surface

Geometry



Reflection Tracks

- fan-shaped area
- low satellite elevation angle



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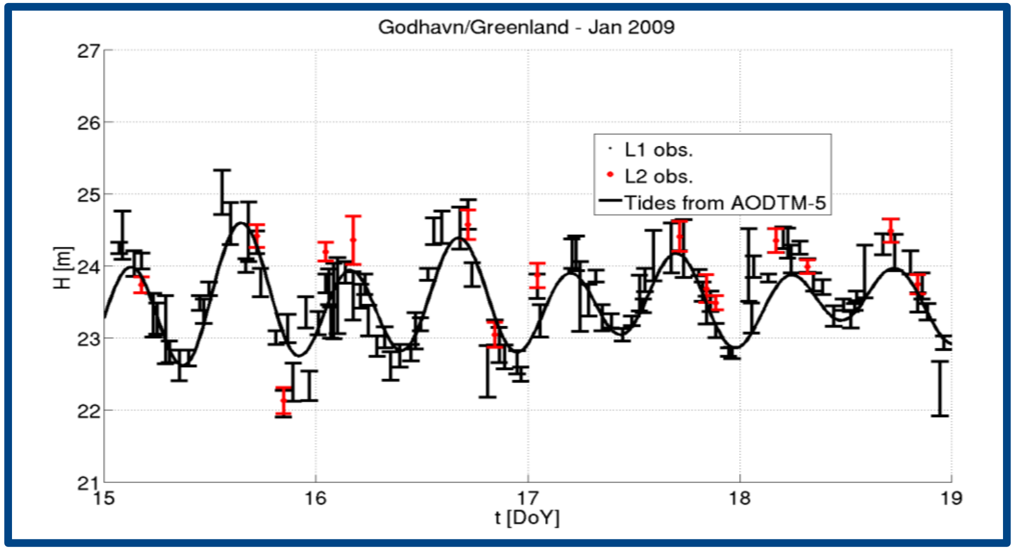
Altimetry



M. Semmling et al.,
"Detection of Arctic Ocean Tides using GNSS-R"
in prep.

Altimetry

- residual phase method
- specular ocean heights
- serveral days
- semi-diurnal tides
- restriction due to refraction

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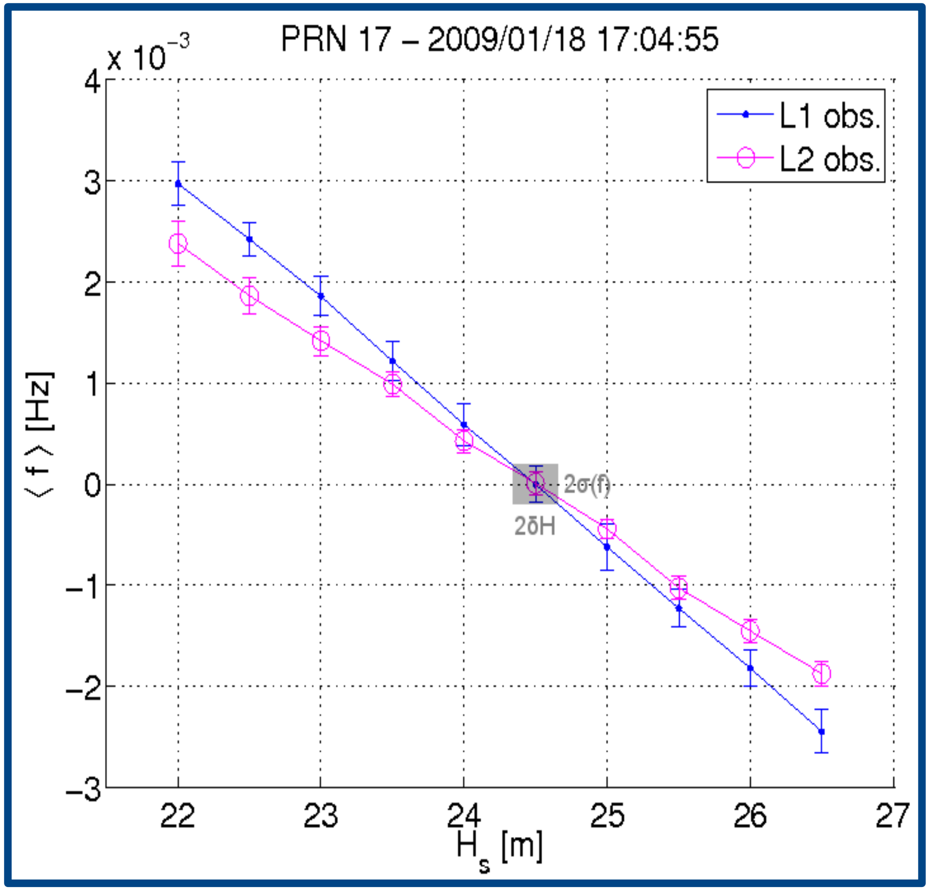
Geometry



Ionospheric Delay

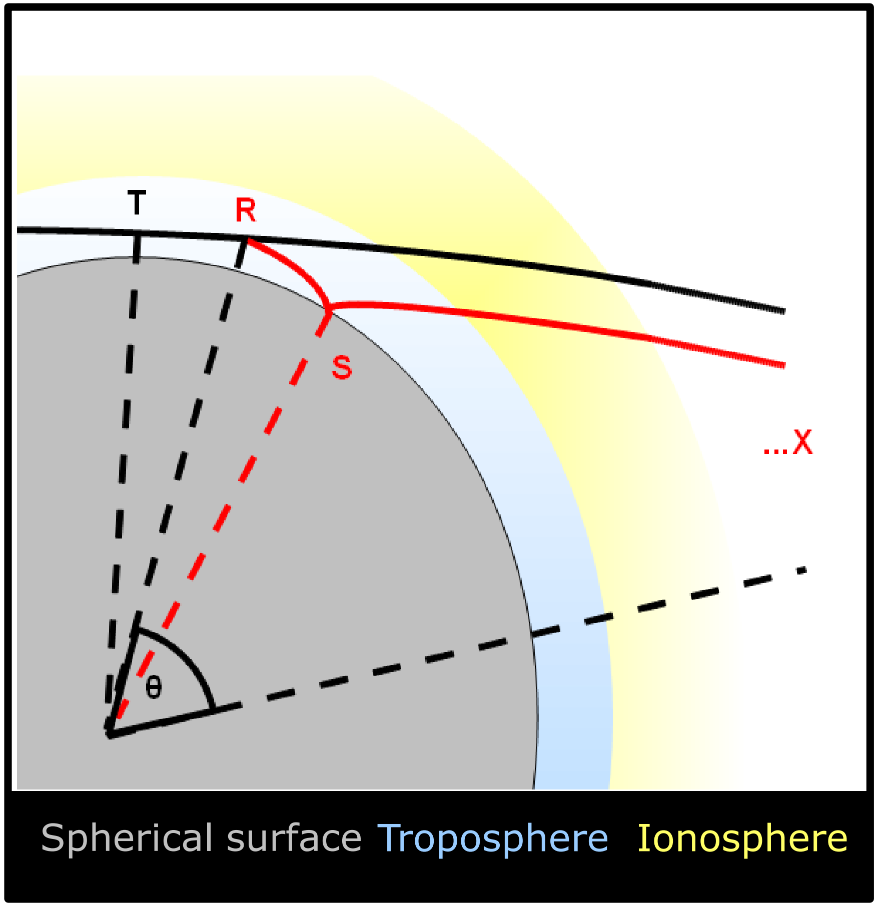
- dispersive refraction
- highly variable density of free electrons

Tropospheric Delay

- non dispersive refraction
- N_2, O_2, CO_2 const.
- highly variable H_2O content

Ray Tracing of Signal Path

Geometry



Ionospheric Delay

- dispersive refraction
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Tropospheric Delay

- non dispersive refraction
- N_2, O_2, CO_2 const.
- highly variable H_2O content

Ray Tracing of Signal Path

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Troposphere

Model

$$
\begin{aligned}
N &= k_1 \frac{p-e}{T} + k_2 \frac{e}{T} + k_3 \frac{e}{T^2} \\
N_w &= k_2 \frac{e}{T} + k_3 \frac{e}{T^2}
\end{aligned}
$$

$$
\begin{aligned}
k_1 &= 0.7760 \, \frac{\mathrm{K}}{\mathrm{Pa}} \\
k_2 &= 0.704 \, \frac{\mathrm{K}}{\mathrm{Pa}} \\
k_3 &= 3.739 \, 10^3 \, \frac{\mathrm{K}^2}{\mathrm{Pa}}
\end{aligned}
$$

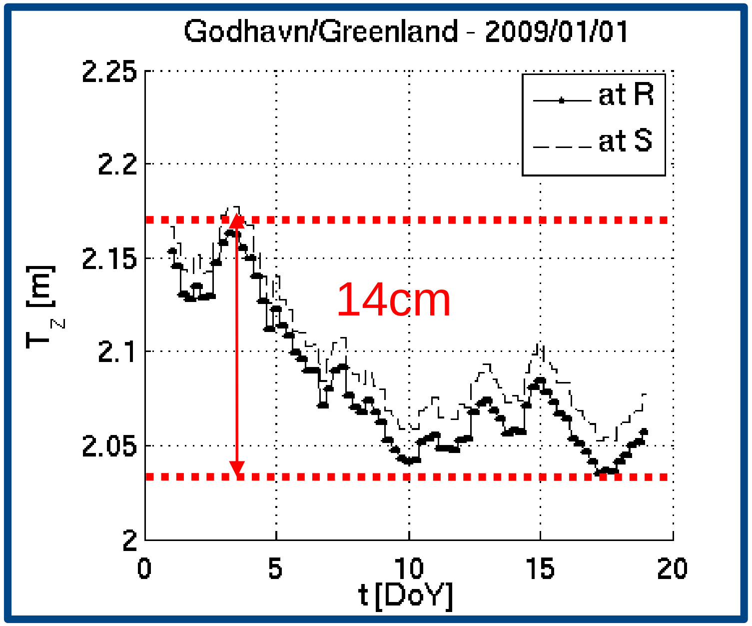
M. Bevis et al., 1994
“GPS meteorology: Mapping zenith delays onto precipitable water.”

Neutral Atmosphere

- total refractivity N
- wet refractivity N_w

Model

$$T_z = \int_R^X N(z) 10^{-6} dz$$



Total Zenith Delay

- prediction ECMWF
- at receiver
- at surface

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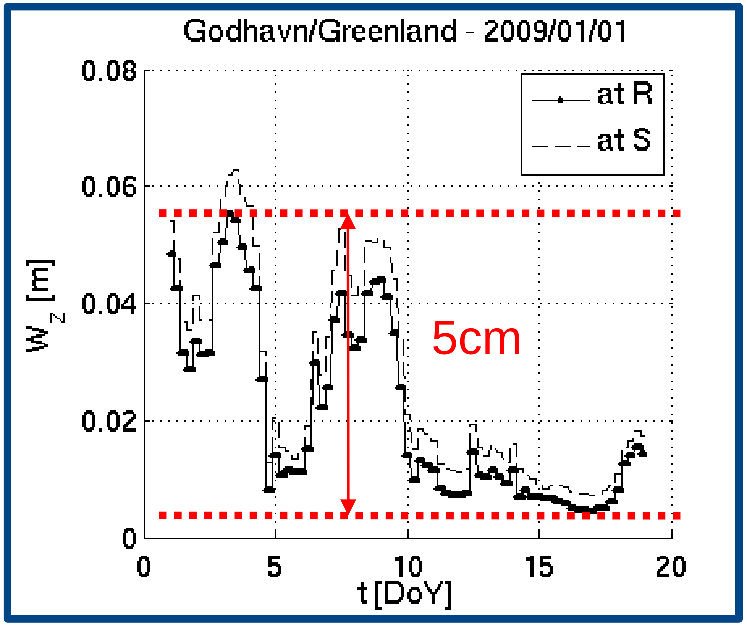
Model

$$W_z = \int_{\mathrm{R}}^{\mathrm{X}} N_w(z) 10^{-6} dz$$

Wet Zenith Delay

- prediction ECMWF
- at receiver
- at surface



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Observation

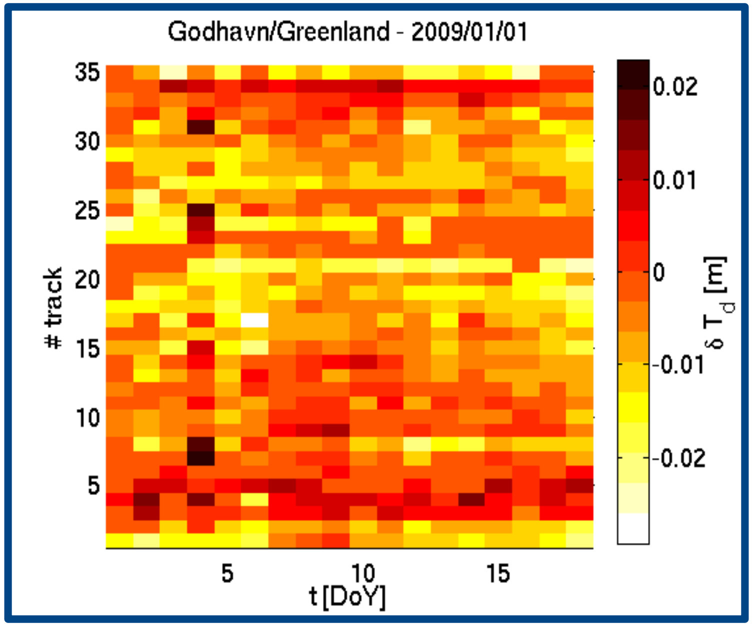
Slant Delay

- direct signal
- model T_d
- observation T

$$T_d = L_d - |\mathrm{XR}|$$
$$\delta T_d = T_d - T$$

Error

- nearly anisotrop
- almost symmetric
- δT/T < 1%



M. Bender et al., 2009
"Estimates of the information provided by GPS slant data observed in Germany."

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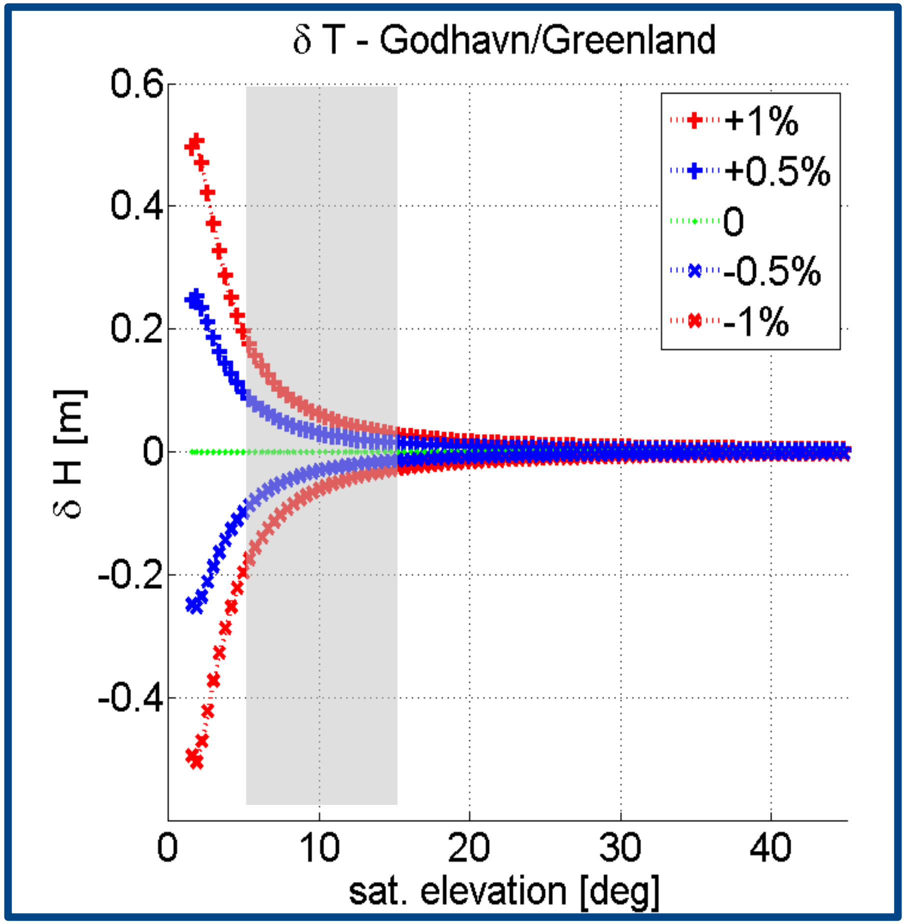
Results

$$
\begin{aligned}
f(H,T) &= 0 \\
\tilde{f}(\tilde{H},T+\delta T) &= 0 \\
\delta H &= \tilde{H} - H
\end{aligned}
$$



Altimetric Bias

- over estimate
- under estimate
- symmetric
- <20cm

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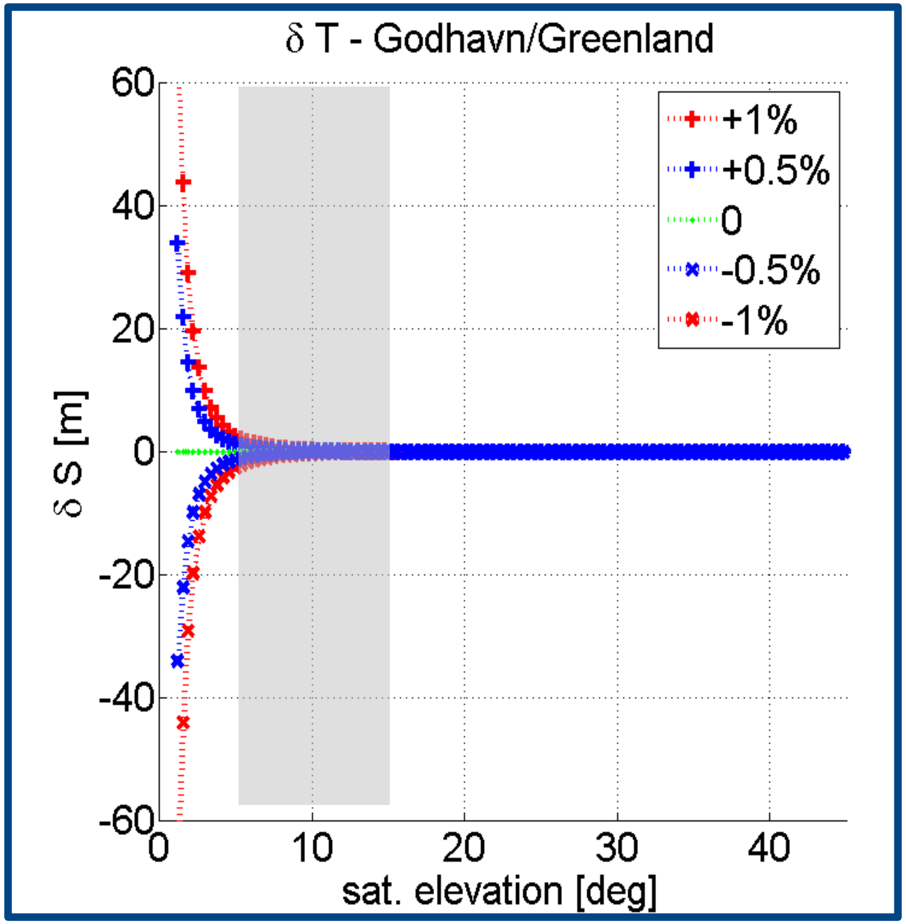
Results

$$f(\mathrm{s}, T) = 0$$
$$\tilde{f}(\tilde{\mathrm{s}}, T + \delta T) = 0$$
$$\delta S = \overline{\tilde{\mathrm{s}}\mathrm{s}_t}$$



Tangent Shift

- over estimate
- under estimate
- symmetric
- ~1m

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Ionosphere

Model

$$\eta(z) = \eta_0 \exp\left[\frac{1}{2}\left(1 - \frac{z - z_0}{\Delta z}\right) - e^{-\frac{z-z_0}{\Delta z}}\right]$$

$$\eta_0 = 3\,\mathrm{E}^{12}\,\mathrm{m}^{-3}$$
$$z_0 = 300\,\mathrm{km}$$
$$\Delta z = 60\,\mathrm{km}$$

F-Layer

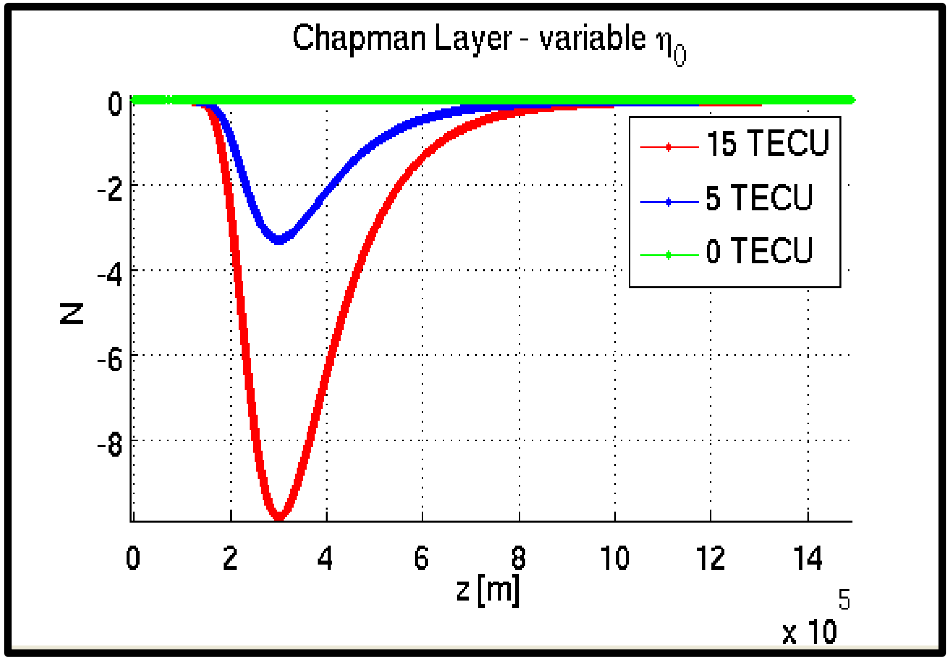
- electron density η
- peak density η_0
- peak height z_0
- peak width Δz

S. Chapman, 1931
"Absorption and dissociative or ionising effects of monochromatic radiation in an atmosphere on a rotating earth."

$$N = -\frac{A}{f^2}\eta$$

Model

$$TECV = \int_{R}^{X} \eta(z)dz$$



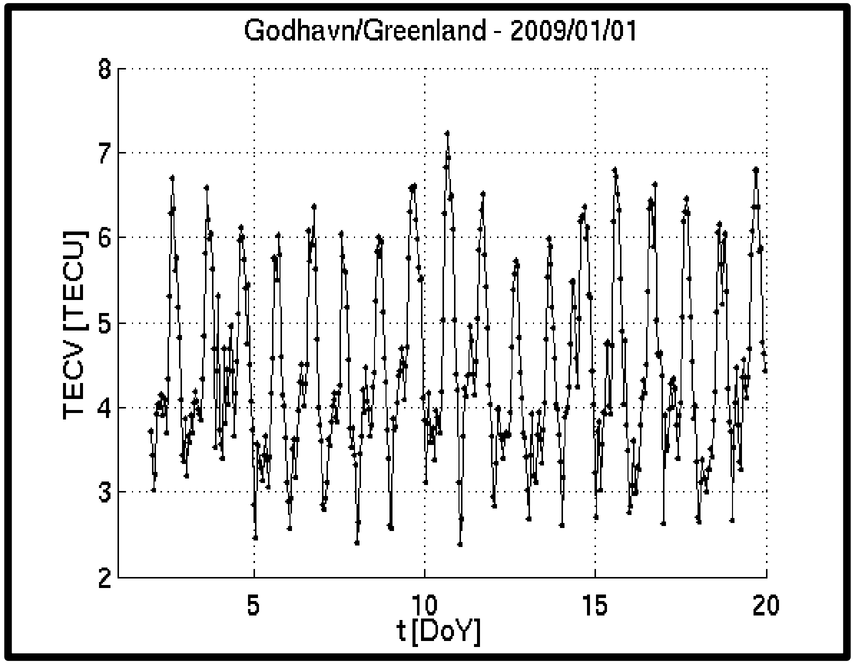
Total Electron Content

- vertical TEC
- scale η_0

Observation

Vertical TEC

- direct signal
- mapped



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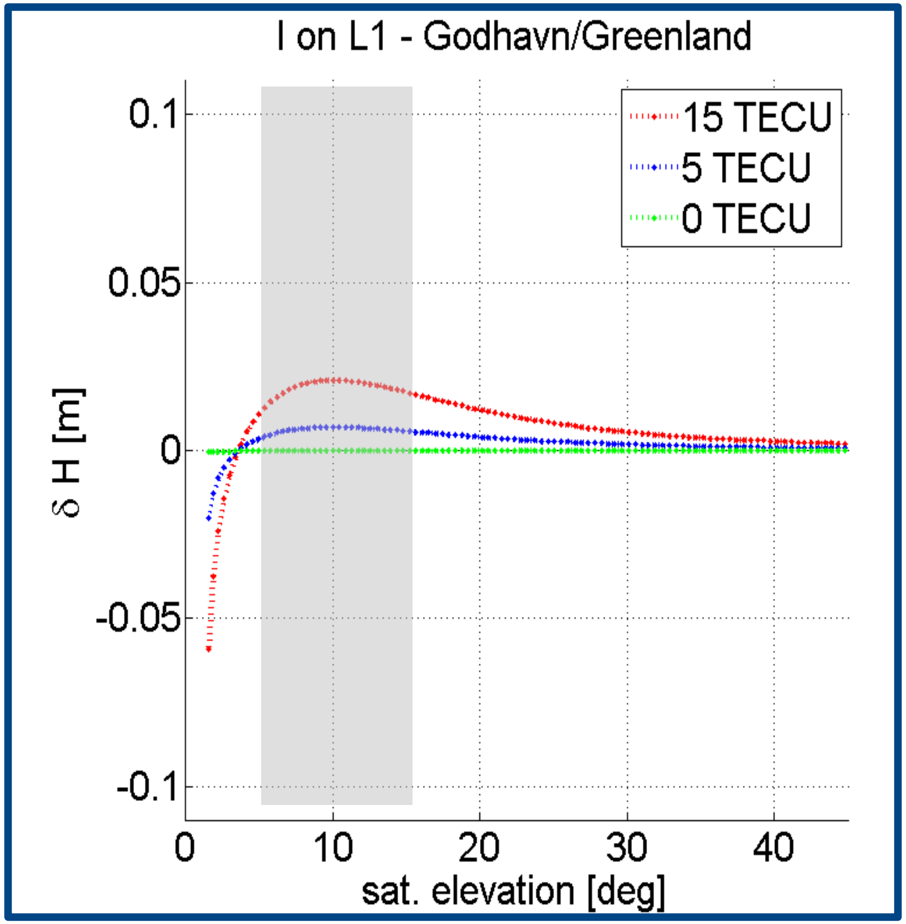
Results

$$f(H) = 0$$
$$\tilde{f}(\tilde{H}, I_{L1}) = 0$$
$$\delta H = \tilde{H} - H$$



Altimetric Bias

- different TECV
- slant elevations
- L1
- ~1cm

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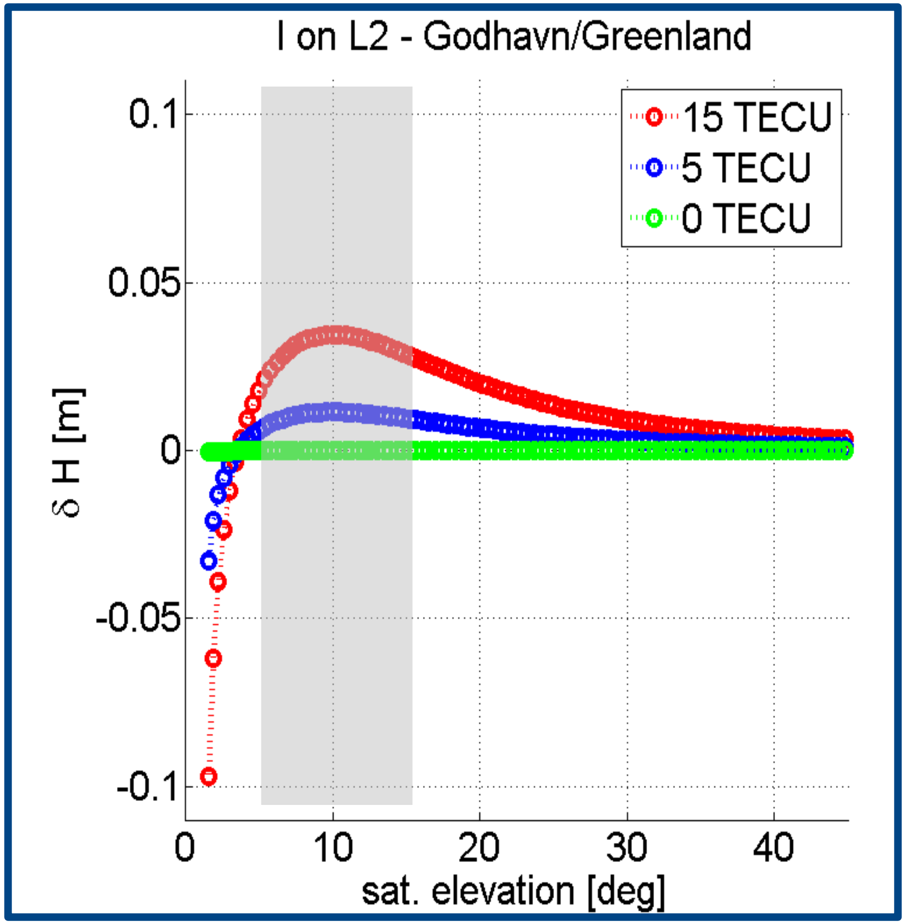
Results

$$f(H) = 0$$
$$\tilde{f}(\tilde{H}, I_{L1}) = 0$$
$$\delta H = \tilde{H} - H$$



Altimetric Bias

- different TECV
- slant elevations
- L2 larger
- ~1cm

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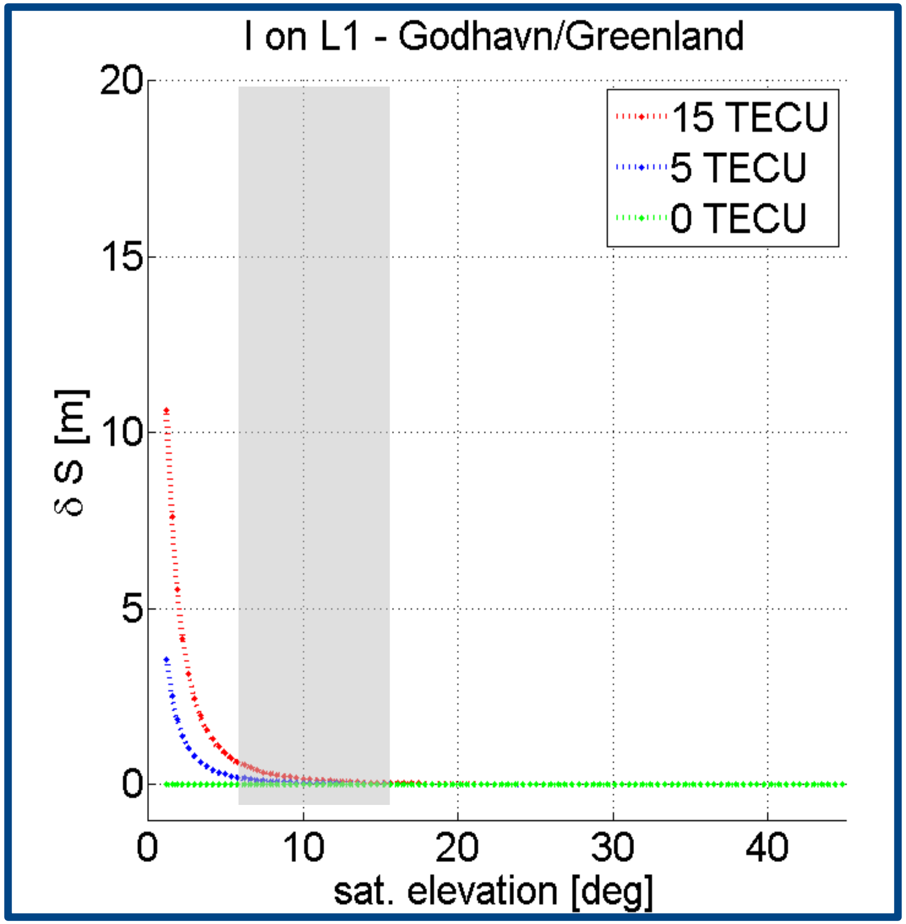
Results

$$
\begin{aligned}
f(\mathrm{s}) &= 0 \\
\tilde{f}(\tilde{\mathrm{s}}, I_{L1}) &= 0 \\
\delta S &= \overline{\tilde{\mathrm{s}}\mathrm{s}_t}
\end{aligned}
$$



Tangent Shift

- different TECV
- grazing elevations
- L1
- <1m

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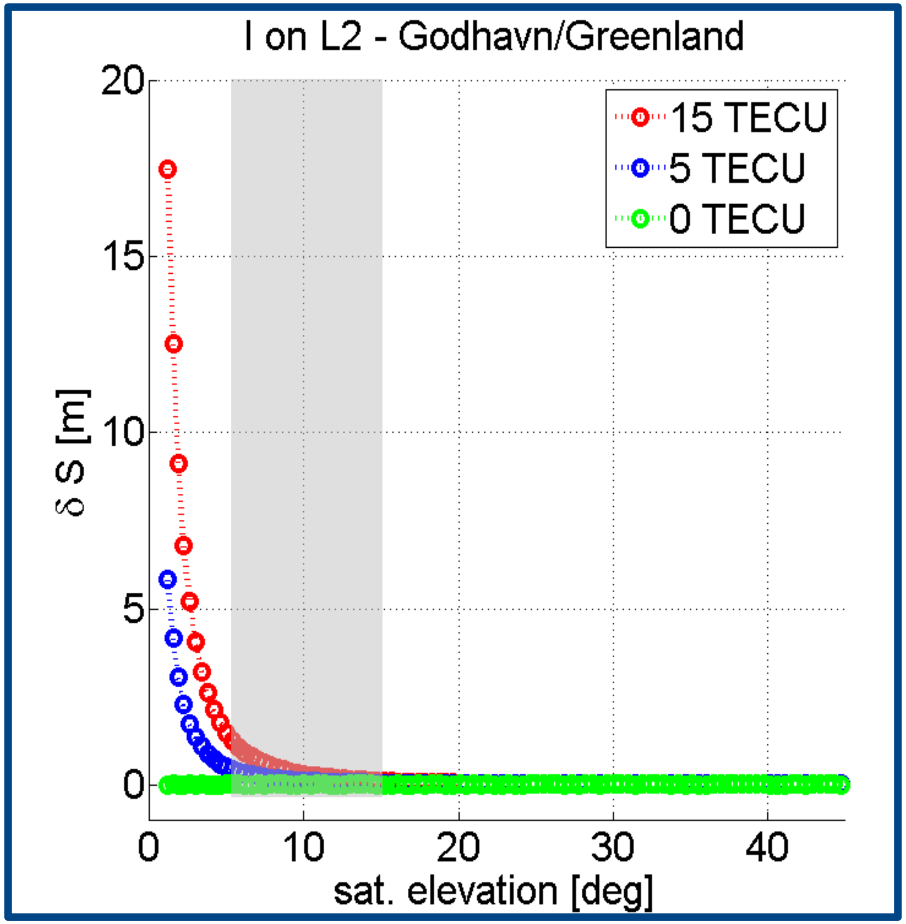
Results

$$
\begin{aligned}
f(\mathrm{s}) &= 0 \\
\tilde{f}(\tilde{\mathrm{s}}, I_{L2}) &= 0 \\
\delta S &= \overline{\tilde{\mathrm{s}}\mathrm{s}_t}
\end{aligned}
$$



Tangent Shift

- different TECV
- grazing elevations
- L2 larger
- <2m

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Summary

Groundbased Experiment

- specular ocean height
- in remote sensing
- restricted by refraction

Airborne Proof of Concept

- less refraction
- few observations
- changes specular aircraft height

Next step to PaRIS

- new flight campaign
- longer observations
- measure geoid undulations

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Outlook

Thanks to all colleagues.

Thank you, for your attention!