PRETTY MISSION PREPARATIONS:
STEPS TO FOSTER GRAZING-ANGLE REFLECTOMETRY

DLR

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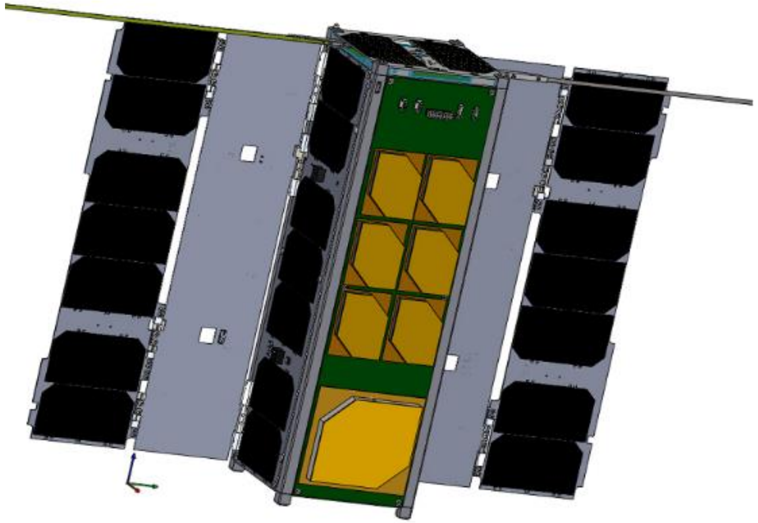


IEEC

GFZ
Helmholtz Centre
POTSDAM

NTNU
Norwegian University of
Science and Technology

Outline

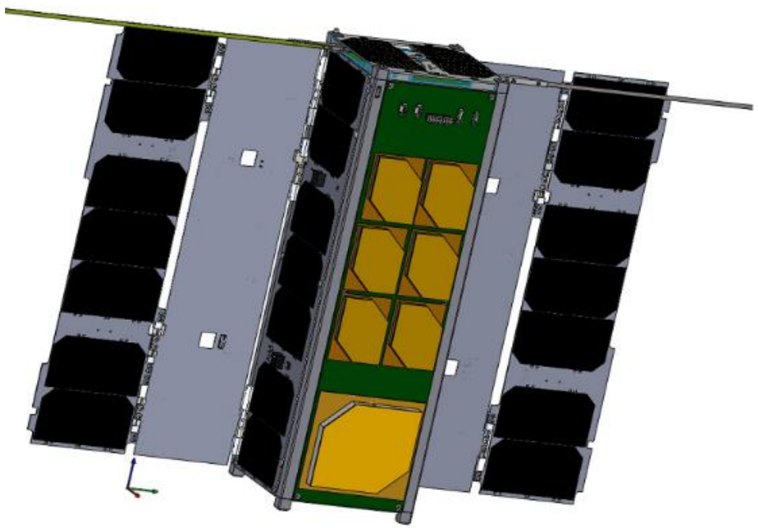
- PRETTY Mission Overview
- Grazing Angle Reflectometry: Preparation Studies
- Preliminary Results over Caribbean
- Preliminary Results over Hudson Bay
- Summary & Outlook

PRETTY Mission Overview

PRETTY Mission Parameters

PRETTY (**P**assive **RE**flec**T**ometry and dosime**T**r**Y**)

- ESA CubeSat mission, developed by an Austrian consortium led by Beyond Gravity Austria
- Size: 30 x 10 x 10 cm³
- Orbit: SSO, altitude 560 km
- GNSS-R antenna: RHCP, limb pointing, 15 dBic
- GNSS-R range of elevations: 5° to 15° elevation
- GNSS-R signal carrier: L5



Fragner et al. 2020

PRETTY Mission Main Payload

Passive **RE**flec**T**ometry and dosime**T**r**Y**

- GNSS-R instrument PACO (PARIS Correlator) for altimetry (interferometric and conventional sampling) at slant and grazing geometries
- Radiation dosimeter (total ionizing dose and single-event effects)

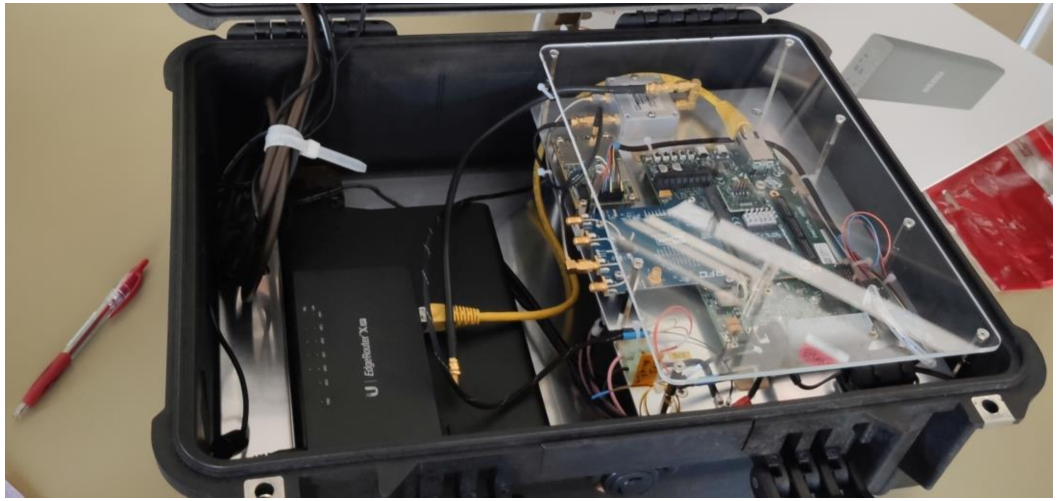
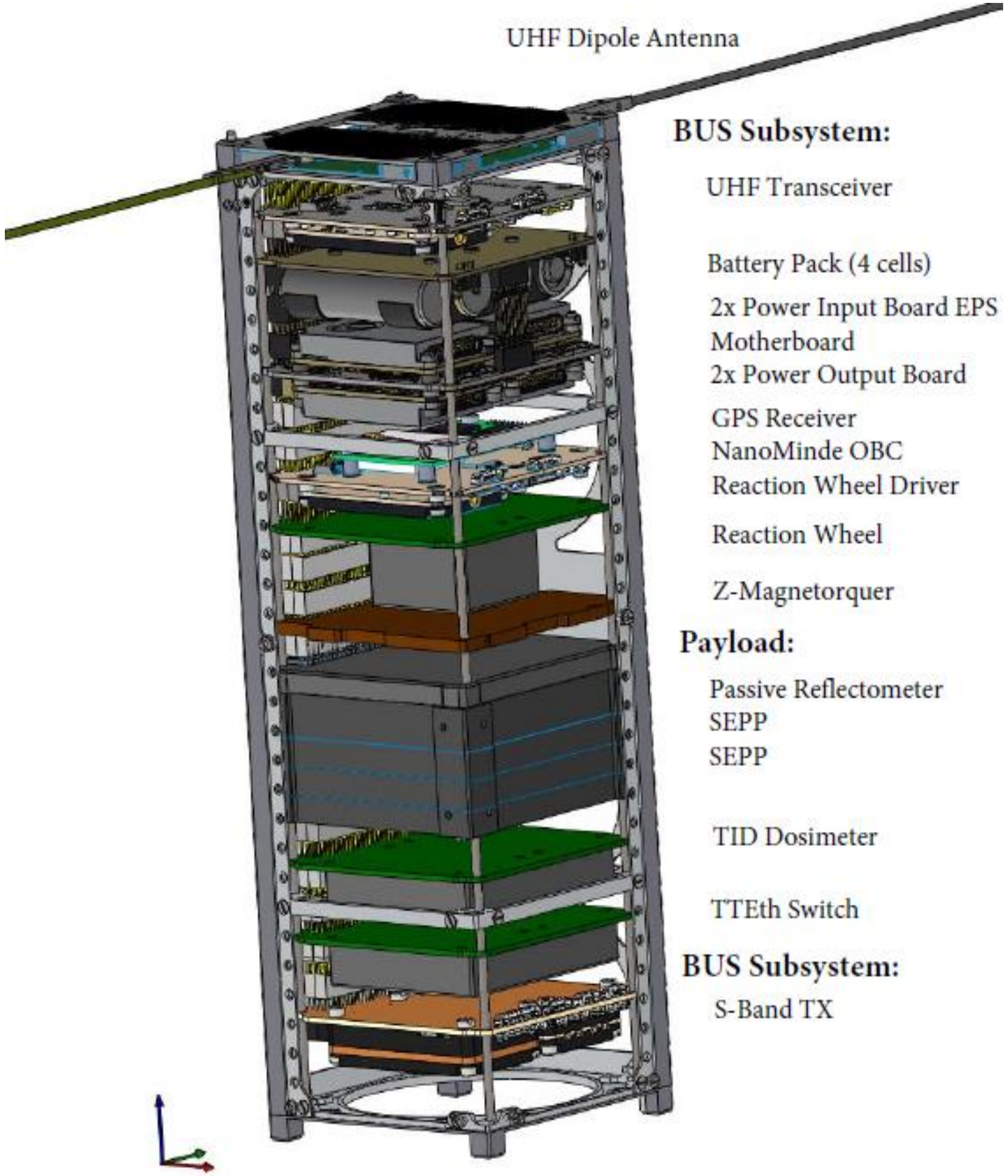


Photo: PACO Receiver unit for ground-based testing

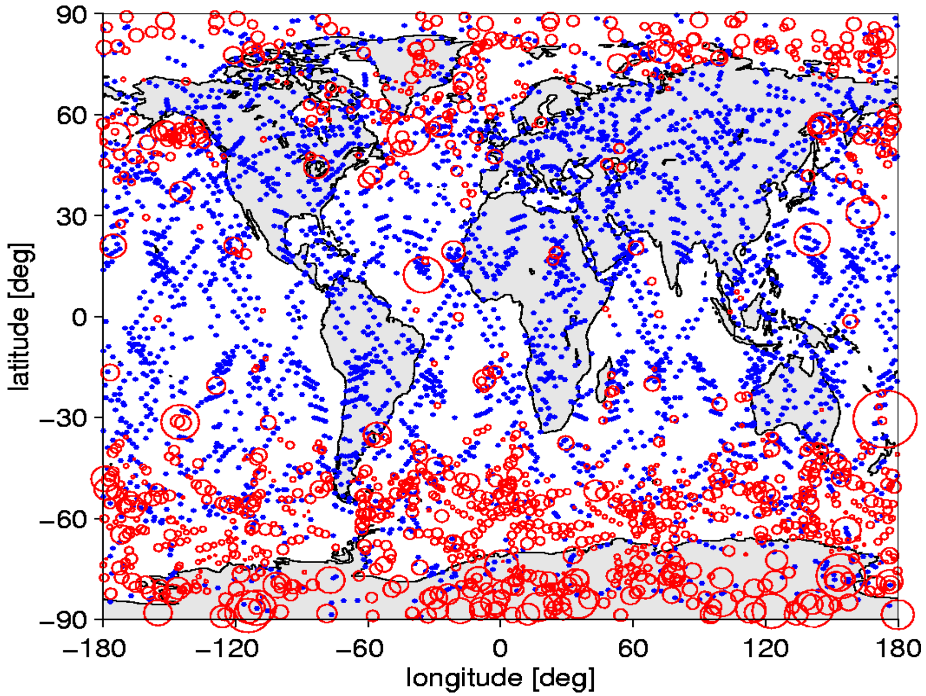


Scheme: PRETTY sat. layout

Dielacher et al. 2019

Objective and Challenges

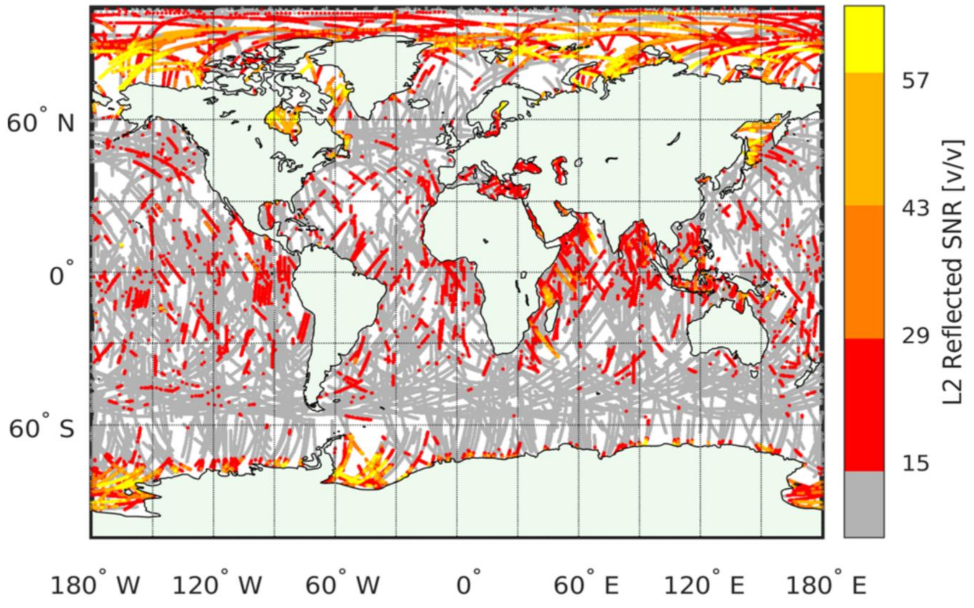
- Obtain complex waveform data in grazing angle Reflectometry
- Retrieve the sea surface height from coherent carrier phase observations
- Disturbances to be considered
  - Irregularities on Earth surface (land, ocean roughness)
  - Irregularities in Earth‘s atmosphere (ionosphere, troposphere)
- Challenges for PRETTY
- Small contract involving
  - NTNU (Norway)
  - GFZ (Germany)
  - DLR-SO (Germany)
  - TUB (Germany)
  - ICE-CSIC/IEEC (Spain)
- to support Beyond Gravity in scientific questions



Radio Occultation events recorded with CHAMP mission (one month)

red with reflection
blue w/o reflection

Beyerle et al. 2002



Reflectometry events recorded by Spire constell. (four months)

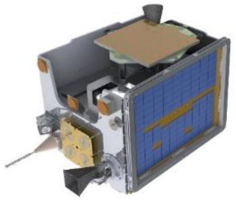
coherent obs. coincide with higher SNR

Roesler et al. 2022

Coherent GNSS-R Measurements

- C: Satellite

  Wickert et al. 2016
  Li et al. 2017
  Cardellach et al. 2019
  Nguyen et al. 2020
  Roesler et al. 2021
  Wang et al. 2022



h: 500 … 640 km

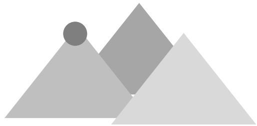
- B: Aircraft

  Semmling et al. 2014
  Moreno et al. 2021

h: 700 … 3500 m

- A: Coastal Setup

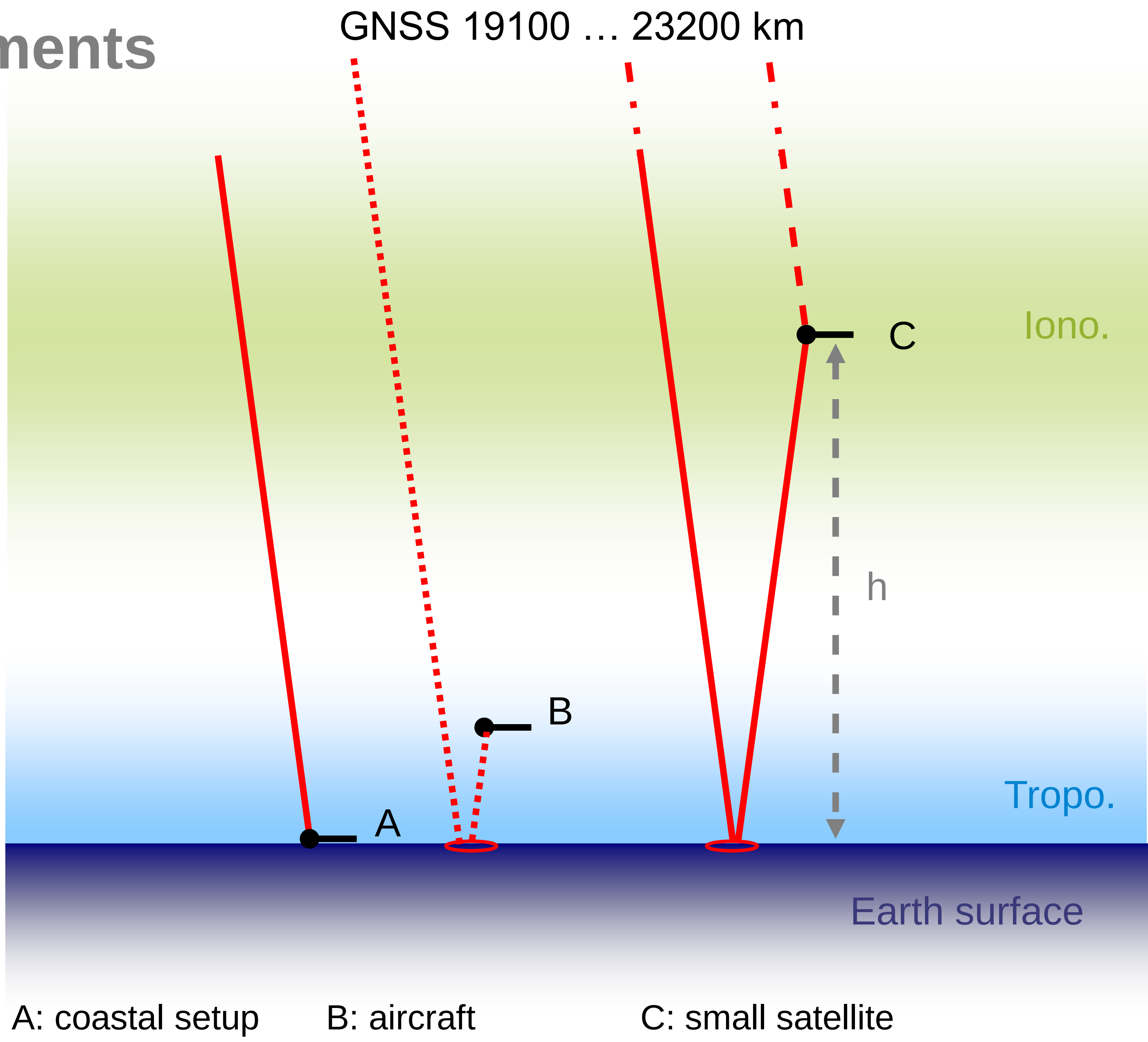
  Anderson 1999
  Fabra et al. 2011
  Semmling et al. 2011



h: 10 … 800 m

- Application

sea surface altimetry
sea-ice altimetry
atmosphere sounding
ionosphere sounding



Grazing Angle Reflectometry: Preparation Studies

Considerable Factors

Sea Surface

- Roughness (Sea State)
- Penetration (e.g. Sea Ice)
- …

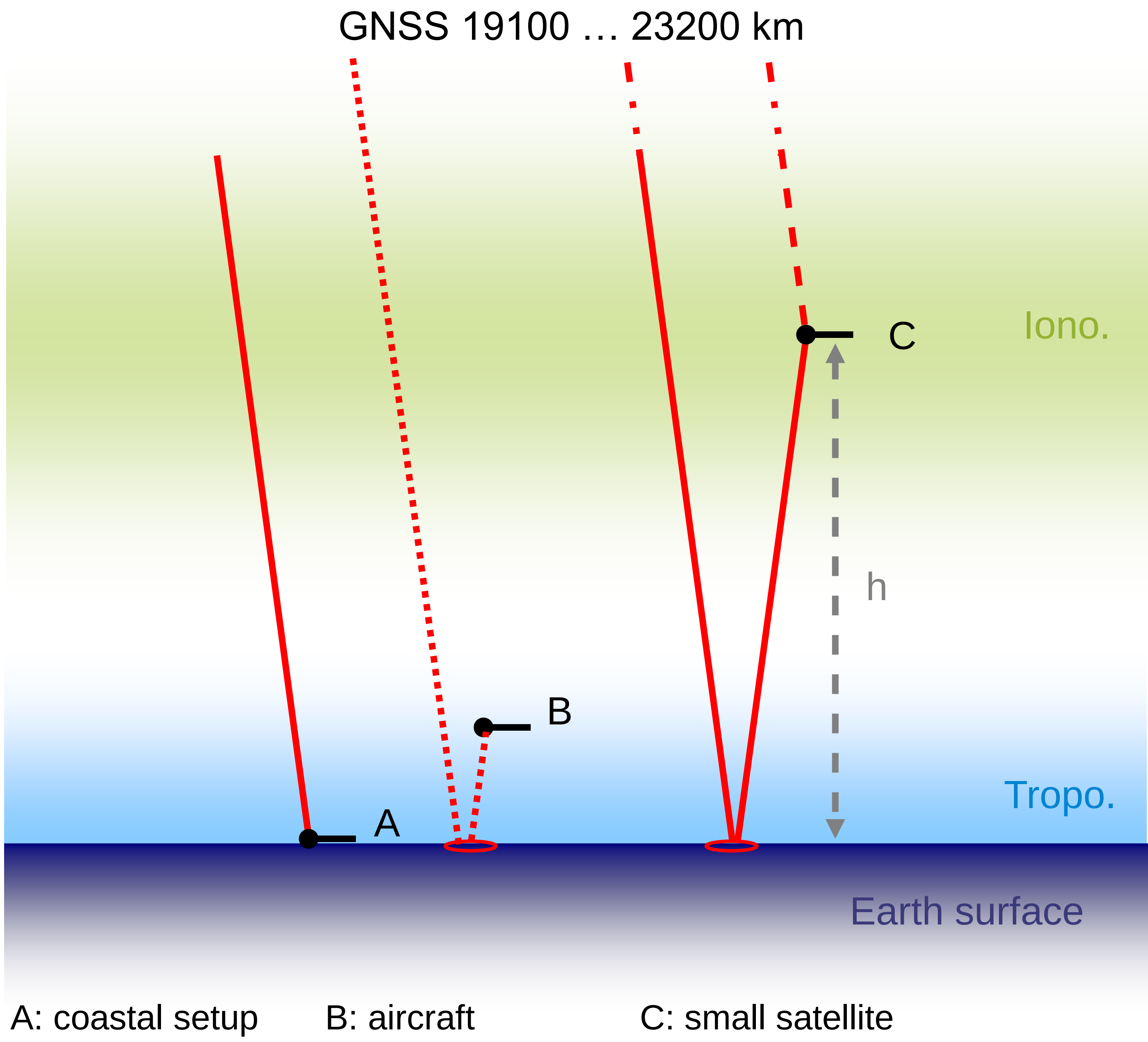
Atmosphere

- Refraction
  (neutral gas and plasma distribution)
- Scintillation
  (Plasma Depletion, Space Weather)
- …

Receiver & Transmitter

- Position & Attitude uncertainty
  (of vessel, aircraft or satellite)
- Antenna & Instrumental parameter
  (e.g. gain pattern)
- …

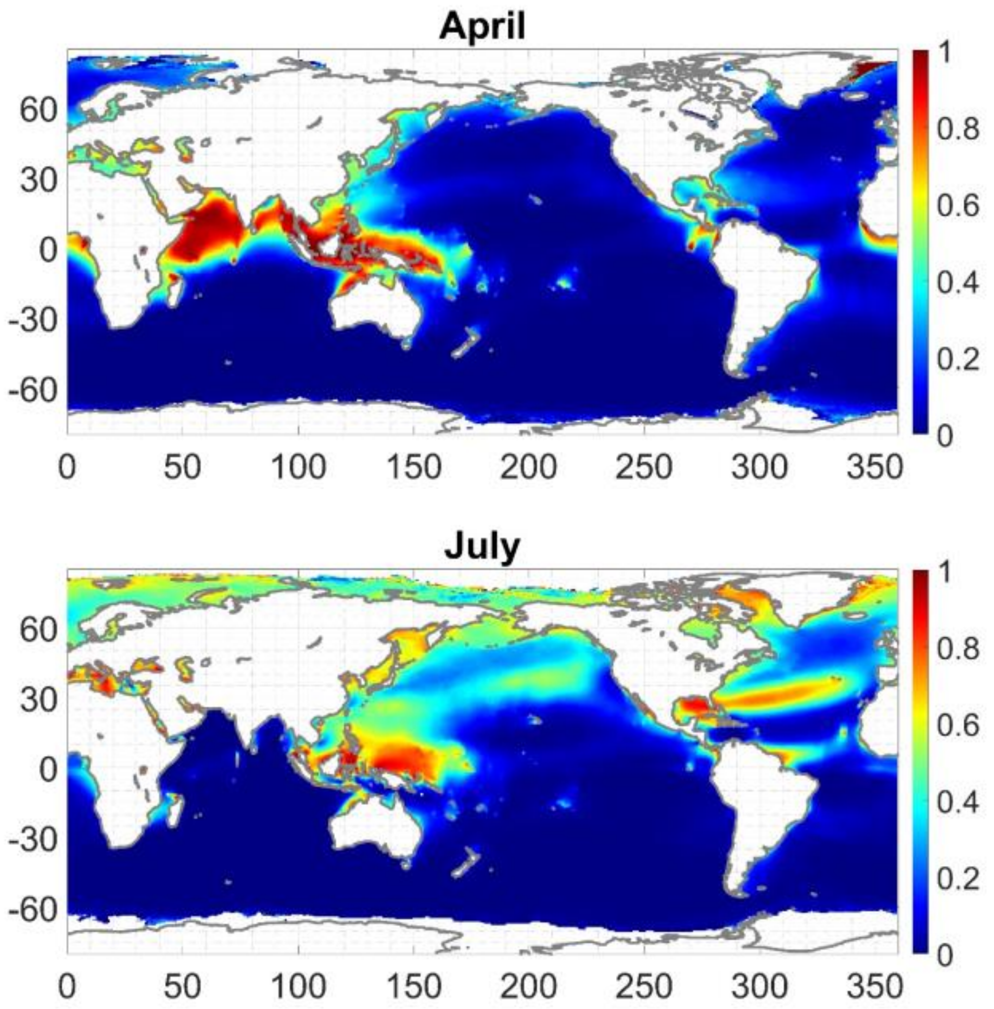
degree of disturbance



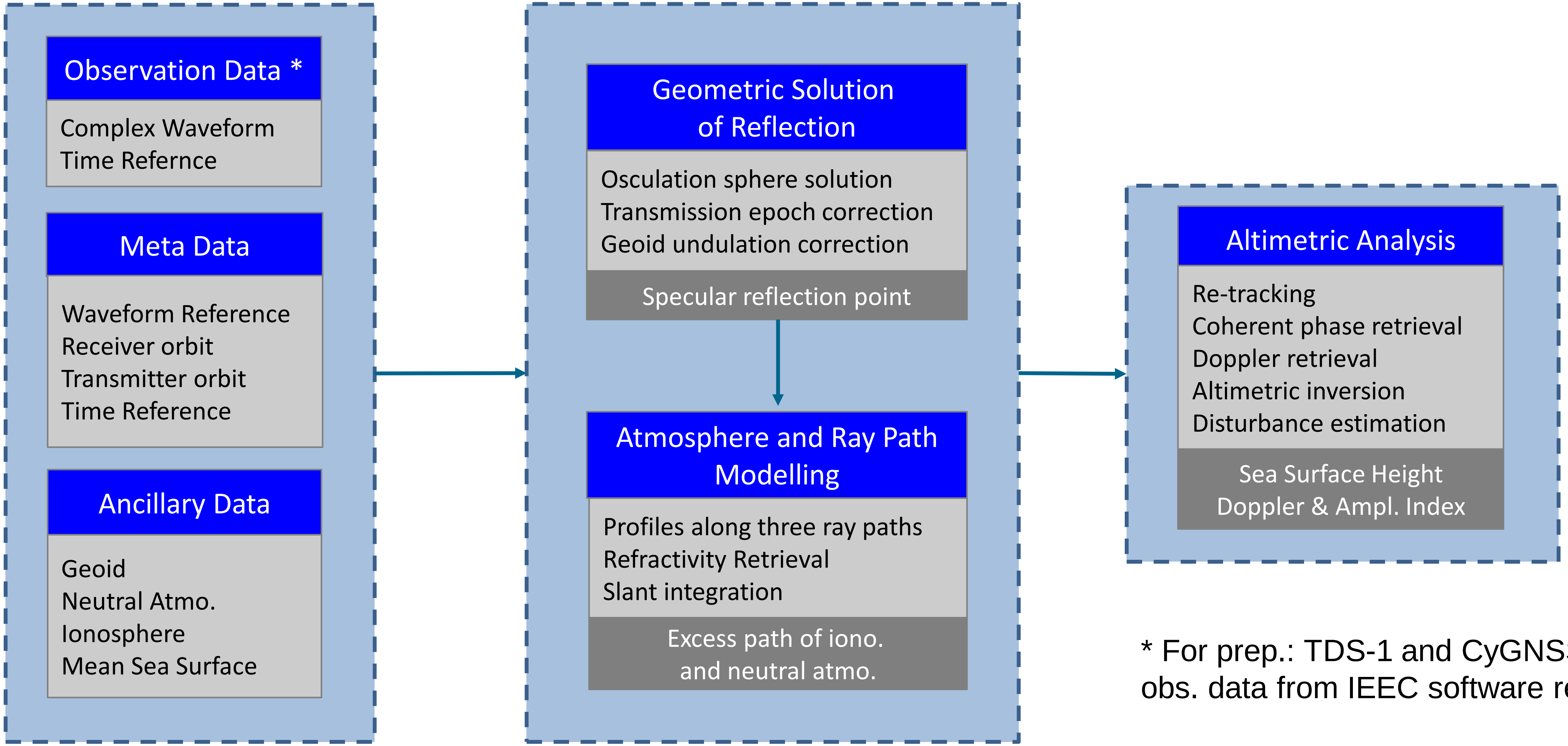
First Step – Target Areas

- **Roughness Disturbance**
  - select targets/periods to maximize scientific outcome in limited duty cycle of PACO instrument

- **Simulation of coherent obs. probability**
  - Priority to areas with high probability of coherent reflections
  - More than three decades (1990 to 2021) analyzed Significant Wave Height (SWH) from the ECMWF ReAnalysis-5 (ERA5).
  - Several scenarios wind-driven waves, combined wind-swell waves and wind speed thresholds considered
  - Threshold set based on Rayleigh criterion
  - Average probability map on global scale for differents month are produced.



Second Step – Algorithm Theoretical Baseline Document



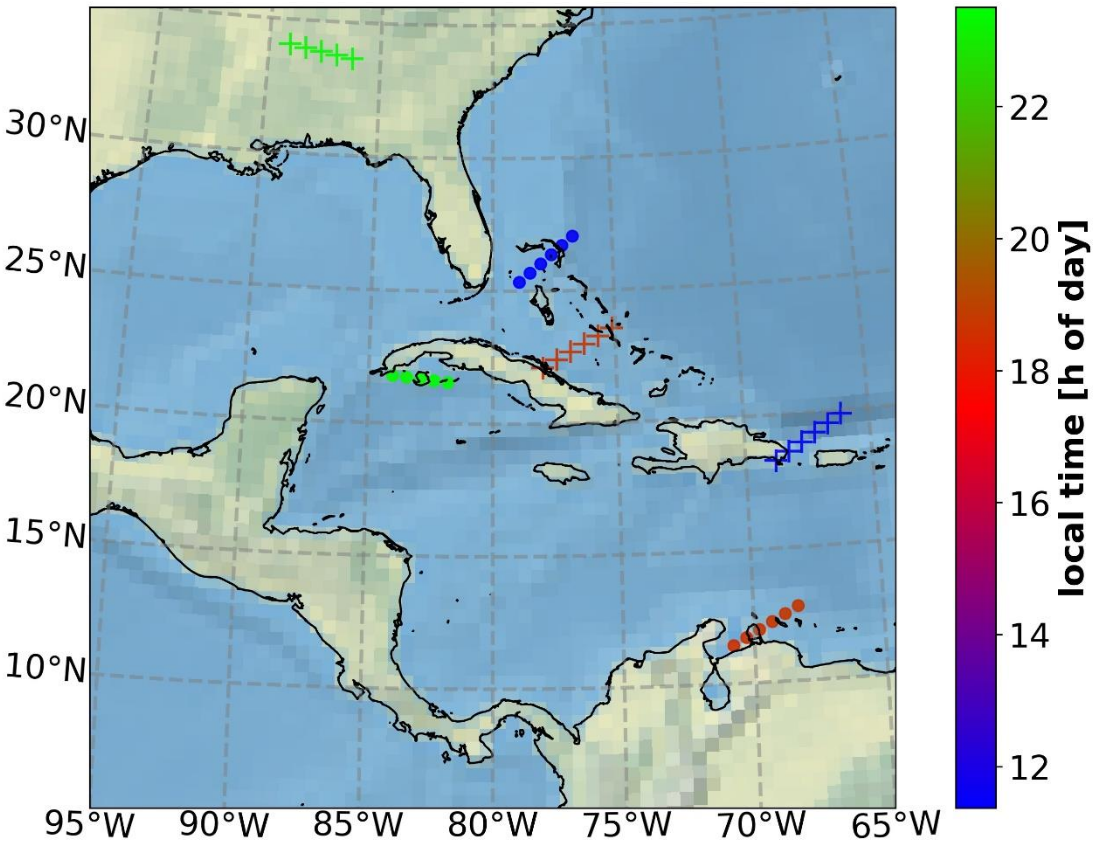
* For prep.: TDS-1 and CyGNSS obs. data from IEEC software receiver

Semmling et al. 2022

Preliminary Results over Caribbean

Reflection Track Reference

Example Events of CyGNSS Mission



+ receiver ground track

• reflection track

Venezuela Event

- GPS PRN 12 by CYG ID 4 on 2017/09/08 23h17 UTC
- local evening (equatorial plasma bubbles?)

Bahamas Event

- GAL PRN 1 by CYG ID 8 on 2017/09/20 16h37 UTC
- local noon

Cuba Event

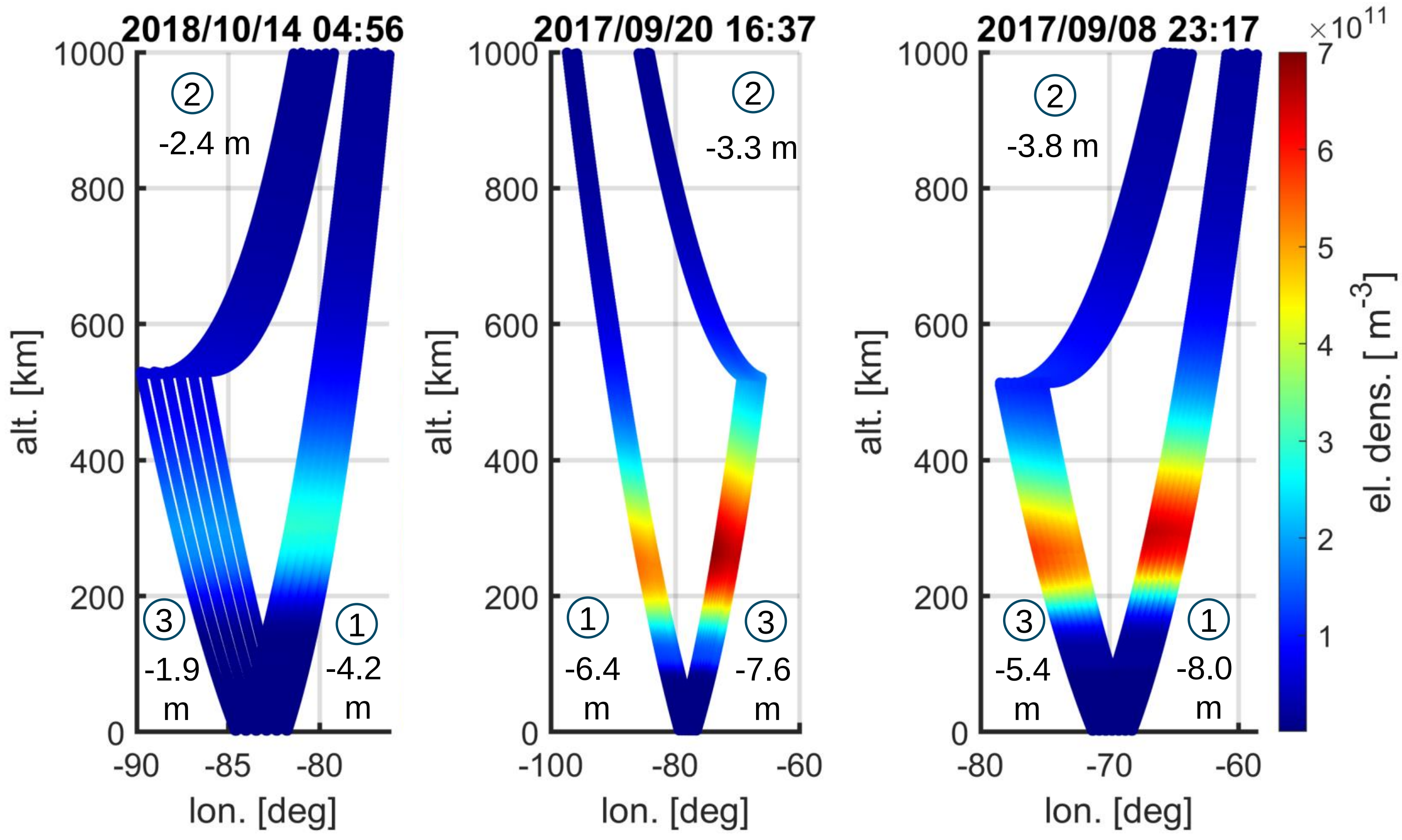
- GAL PRN 5 by CYG ID 5 on 2018/10/14 04h56 UTC
- local night

All three Events

- elev. angle between 13° … 15°

Cardellach et al. 2020

Ionosphere Reference Data



Cuba event
local night

Bahamas event
local noon

Venezuela event
local evening

<u>NEDM model</u>

- global, empirical climatology
- continuous in time and space
- smallest features 2.5° (TEC map based)
- temporal scale (down to semidiurnal)
- provider DLR-SO**
- Ionosphere parameter of interest:

  electron density *ne*

** German Aerospace Center,
Institute for Solar-Terrestrial Physics

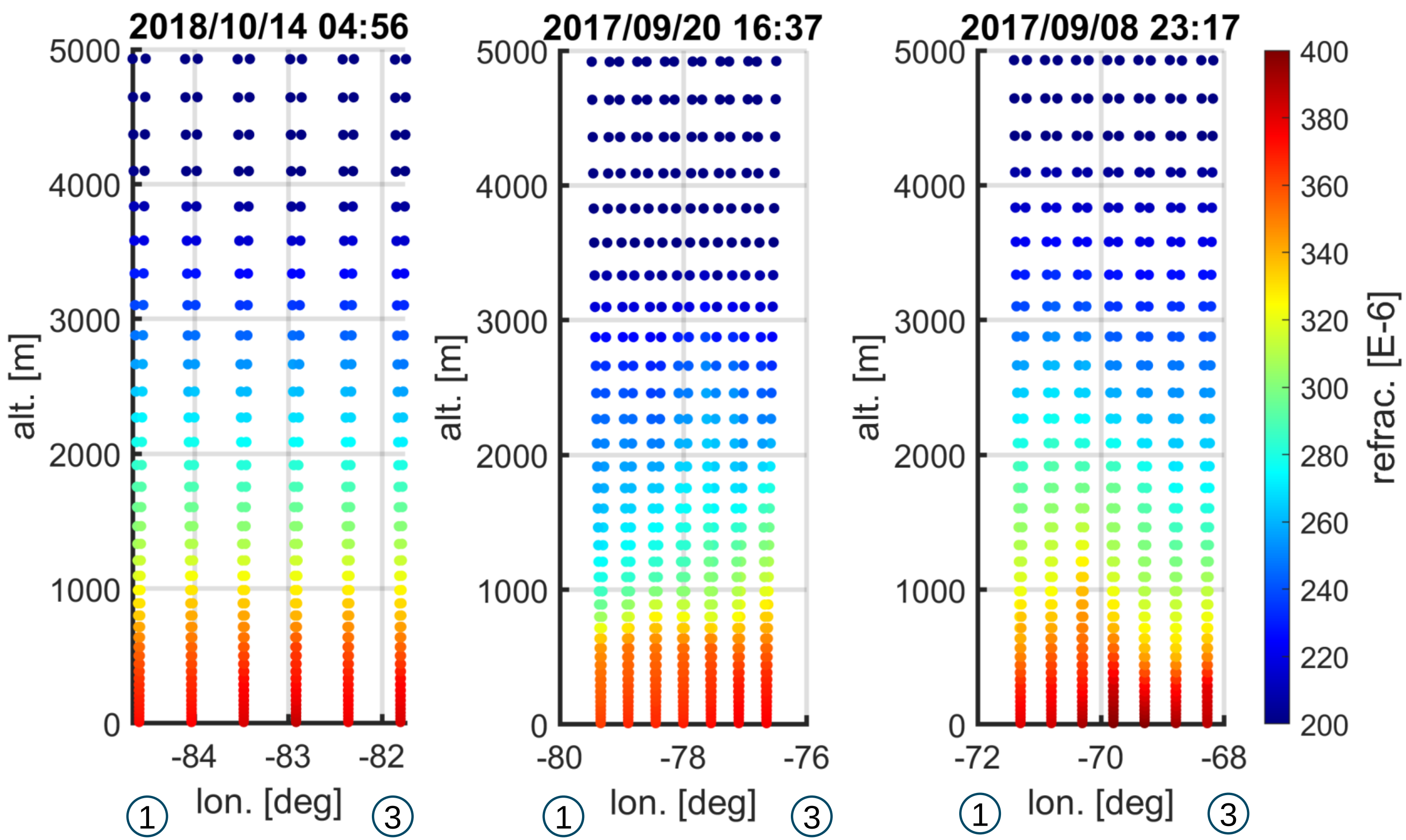
Jakowski & Hoque 2018

① phase excess path xmit to spc (1st ep.)

② phase excess path xmit to rcv (1st ep.)

③ phase excess path spc to rcv (1st ep.)

Neutral Atmosphere Reference Data



①	③	①	③	①	③
12.1 m	12.0 m	9.5 m	9.5 m	11.9 m	11.9 m

Cuba event
local night

Bahamas event
local noon

Venezuela event
local evening

<u>ERA5 model</u>

- global, obs.-driven
- horizontal grid (res.: 30km)
- vertical levels (res.: 10m … ~6km)
- temporal scale (res.: 1h)
- provider ECMWF*
- Meteorological parameter of interest:

  air pressure p
  air temperature T
  specific humidity q

* European Centre of Medium-range Weather Forecast

Hersbach et al. 2020

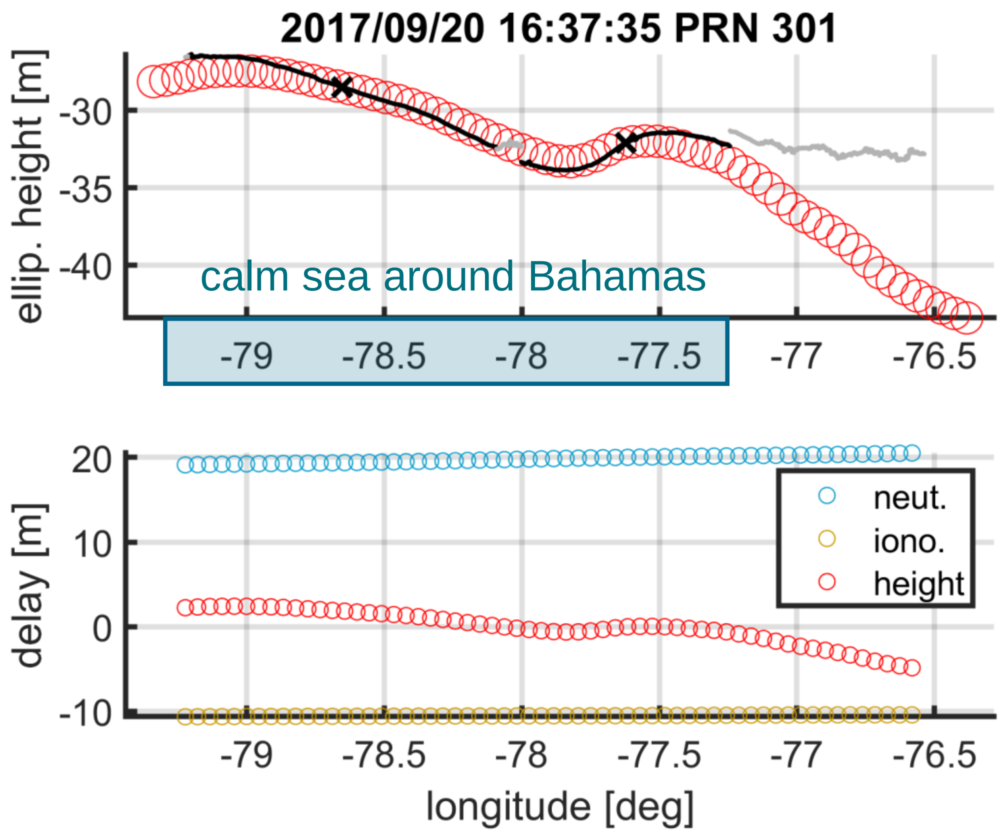
① phase excess path xmit to spc (1st ep.)

③ phase excess path spc to rcv (1st ep.)

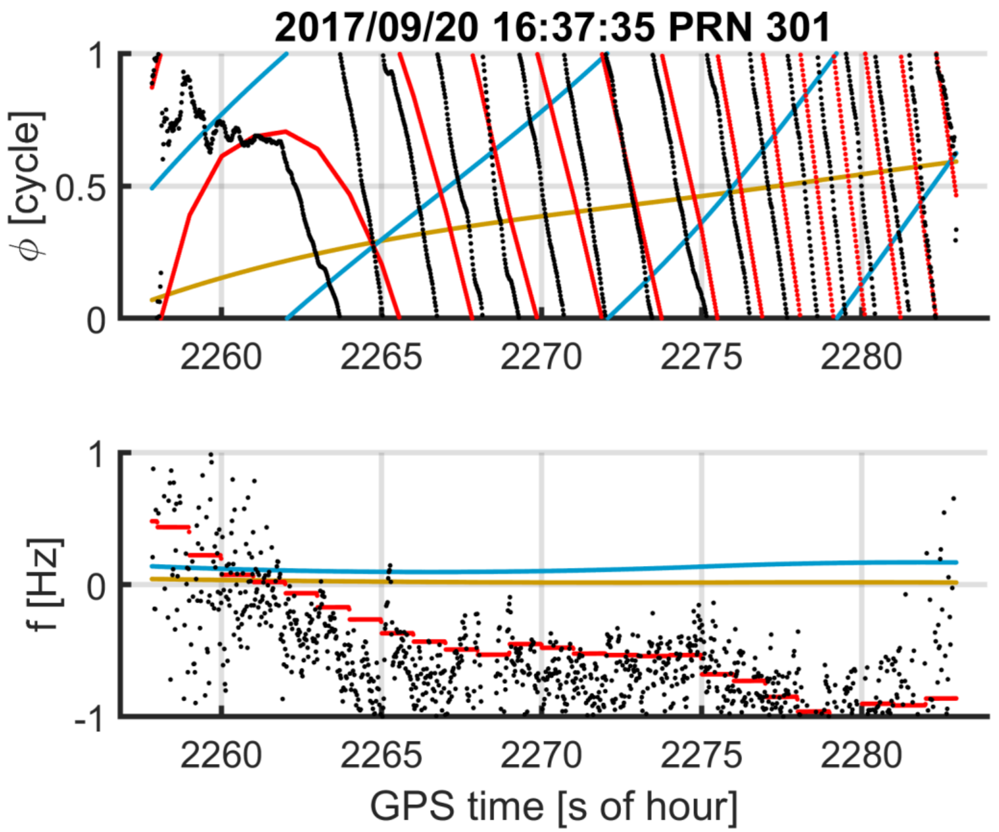
Bahamas Event

DLR

Retrieved Heights and Model corrections



Phase & Doppler of longest coherent track



○ Mean sea surface height from DTU 21

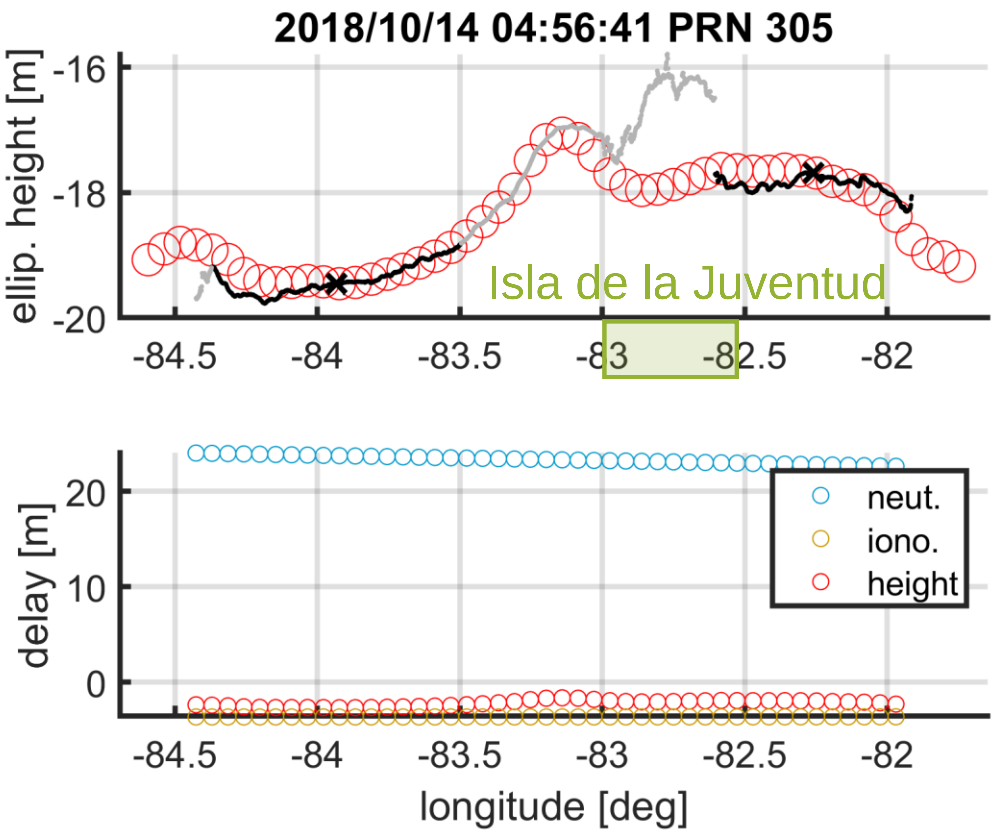
▪ Coherent observation/track   x reference epoch for amb. fix.

▪ Incoherent observation

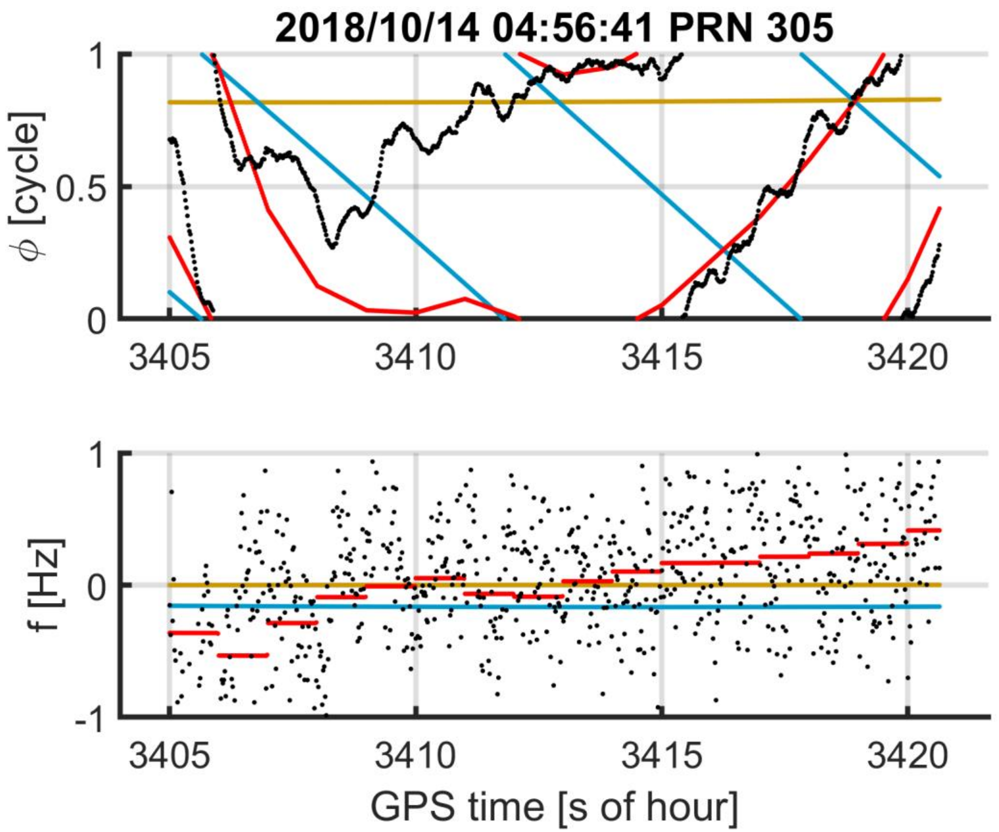
- ➢ long surface dominated track 25 s
- ➢ after surface correction std(f) = 3.49 Hz (50 Hz sampling)

Cuba Event

Retrieved Heights and Model corrections



Phase & Doppler of longest coherent track



○ Mean sea surface height from DTU 21

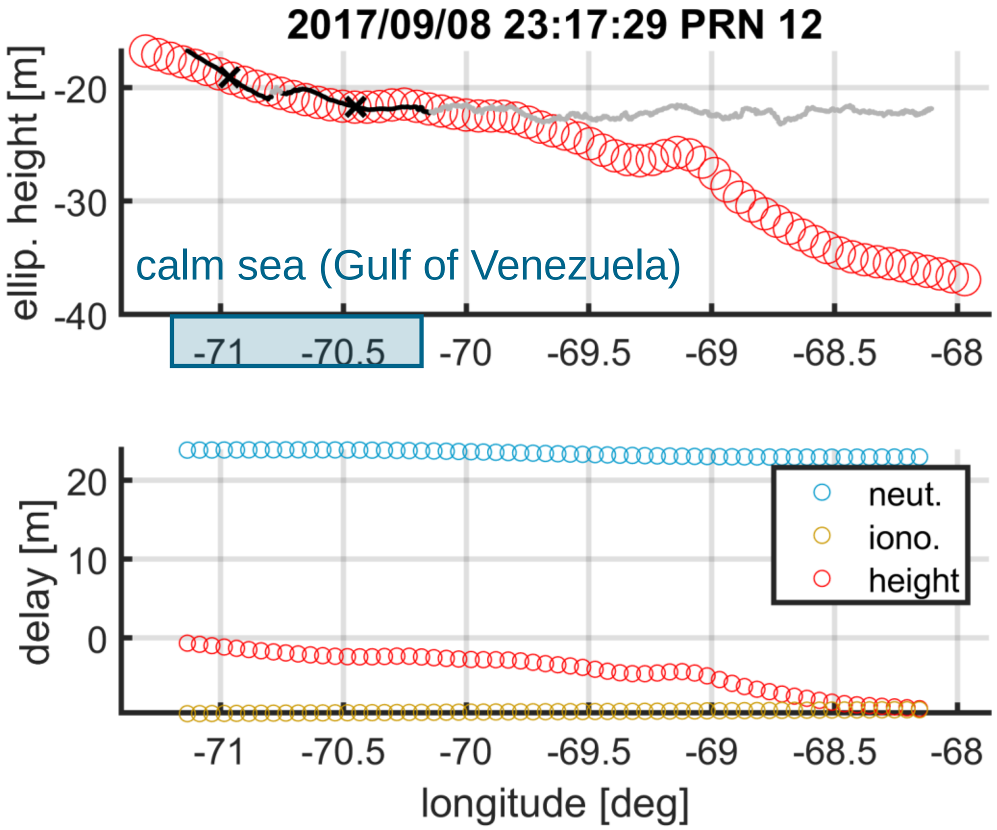
▪ Coherent observation/track x reference epoch for amb. fix.

▪ Incoherent observation

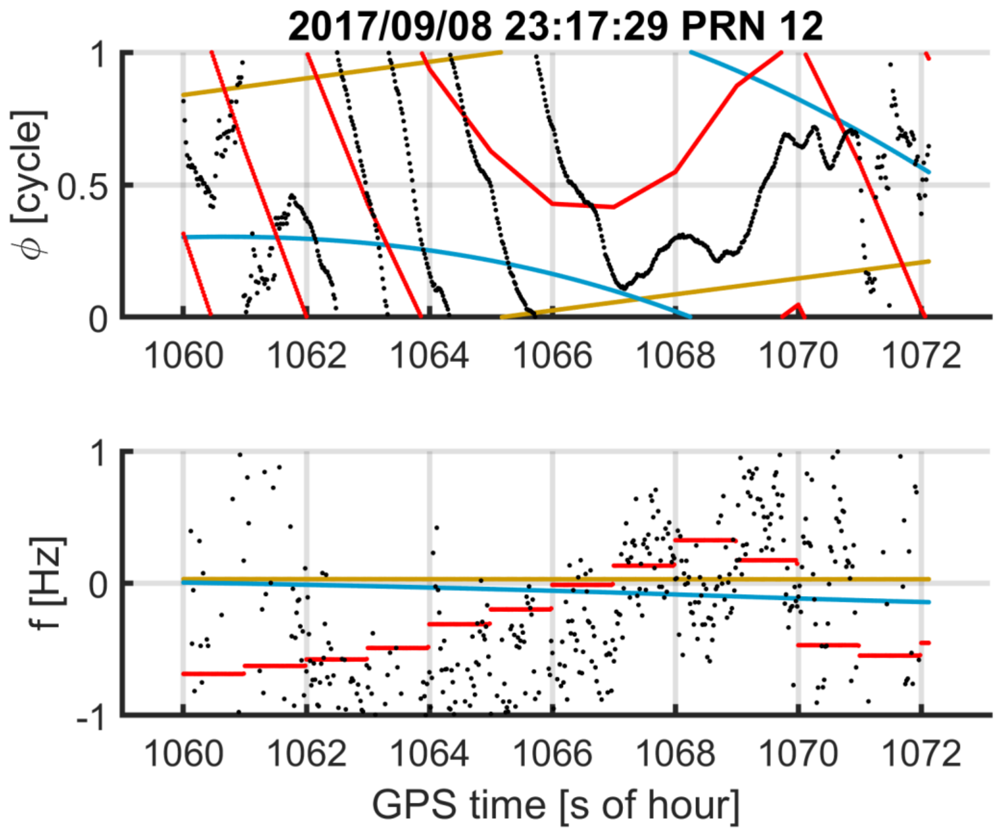
- short surface dominated track 16 s
- after surface correction std(f) = 4.41 Hz (50 Hz sampling)

Venezuela Event

Retrieved Heights and Model corrections



Phase & Doppler of longest coherent track



○ Mean sea surface height from DTU 21

▪ Coherent observation/track x reference epoch for amb. fix.

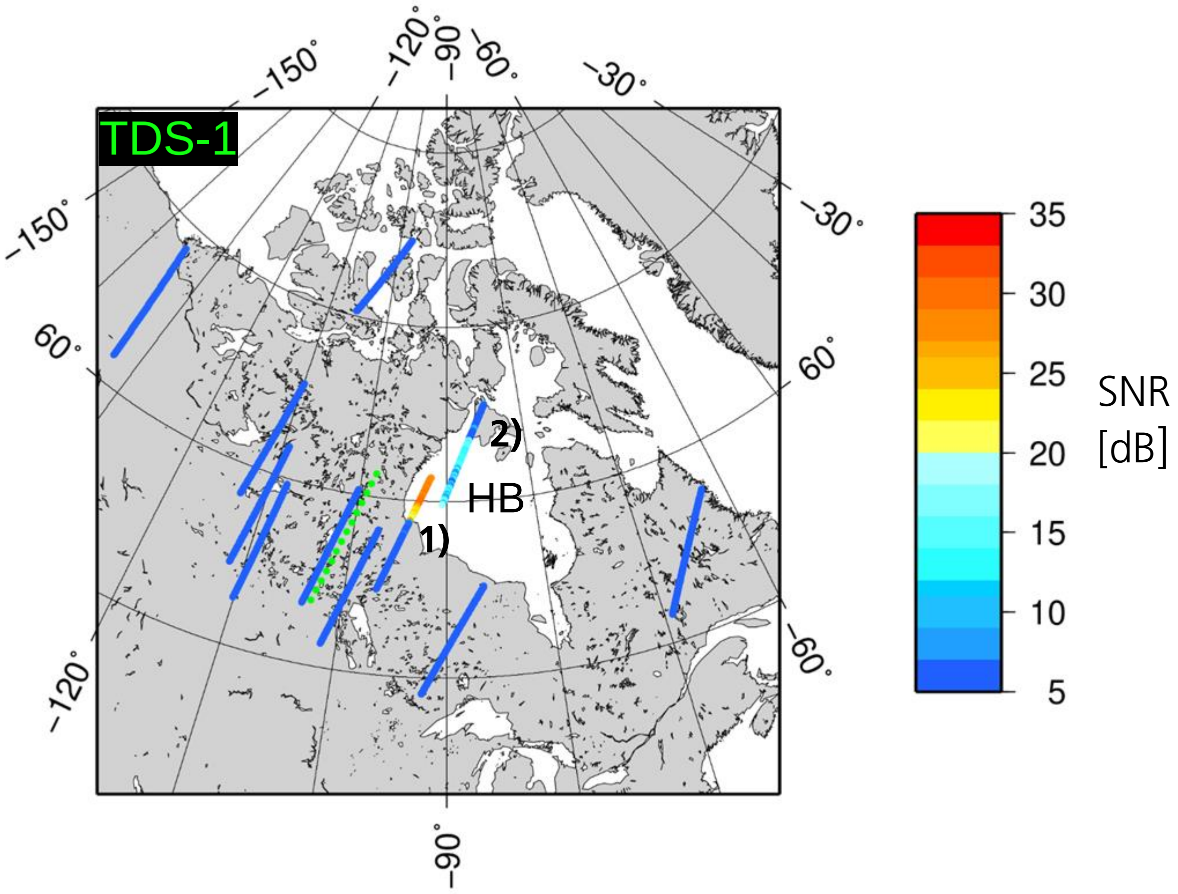
▪ Incoherent observation

- short surface dominated track 12 s
- after surface correction std(f) = 6.96 Hz (50 Hz sampling)

Preliminary Results over Hudson Bay

Reflection Track Reference

Example Events of TechDemoSat Mission



Two sea-ice events over Hudson Bay (HB)
with rather high SNR selected for analysis.

Western HB Event [1)]

- GPS PRN 15 by TDS-1 on 2015/01/18 17h20 UTC
- high elev. angle at spec. point (~ 58°)

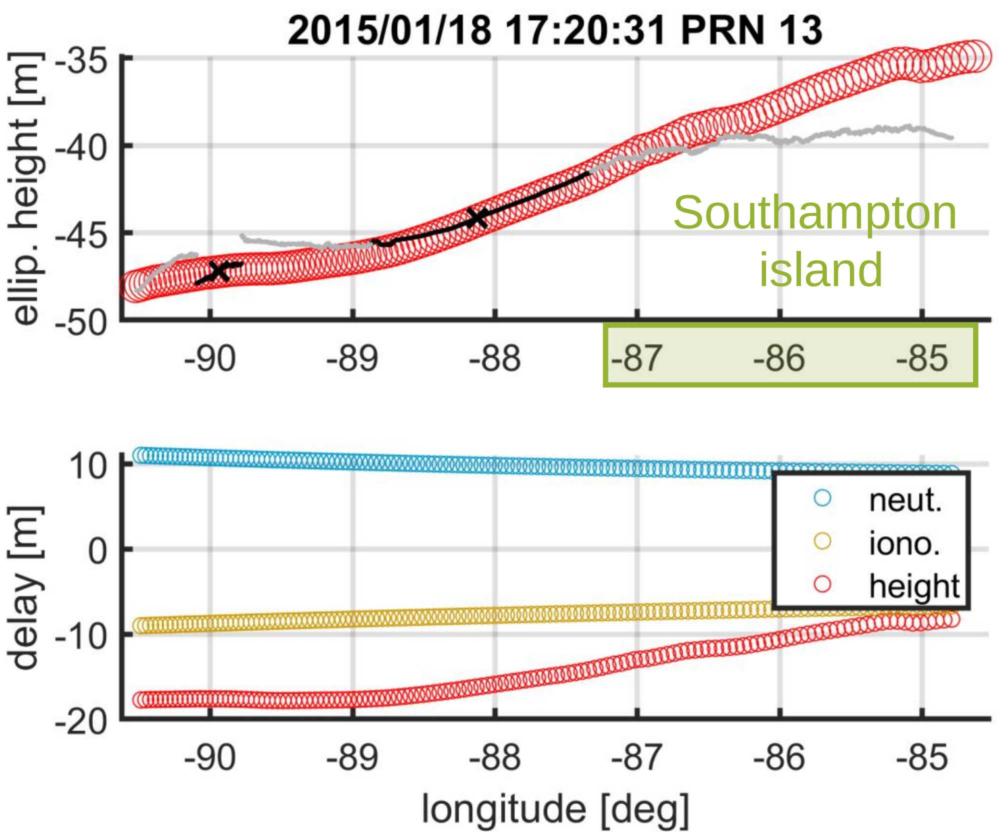
Eastern HB Event [2)]

- GPS PRN 13 by TDS-1 on 2015/01/18 17h20 UTC
- moderate elev. angle at spec. point (~ 30°)

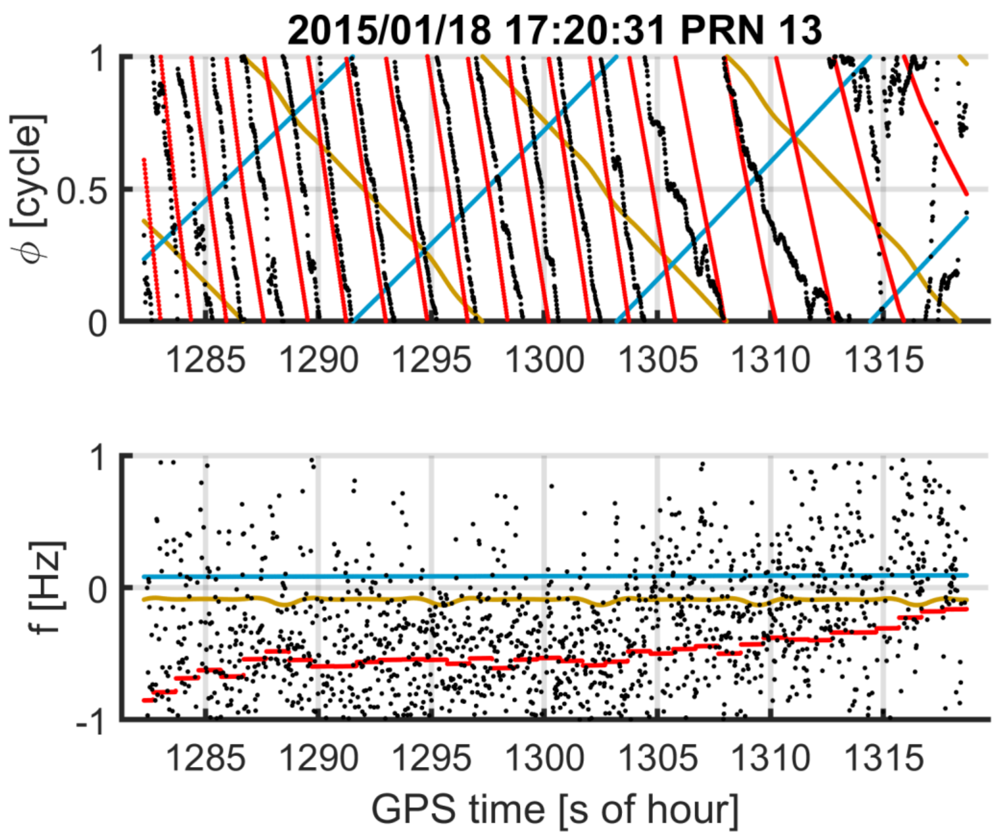
Li et al. 2017

Eastern Hudson Bay Event

Retrieved Heights and Model corrections



Phase & Doppler of longest coherent track



○ Mean sea surface height from DTU 21

▪ Coherent observation/track x reference epoch for amb. fix.

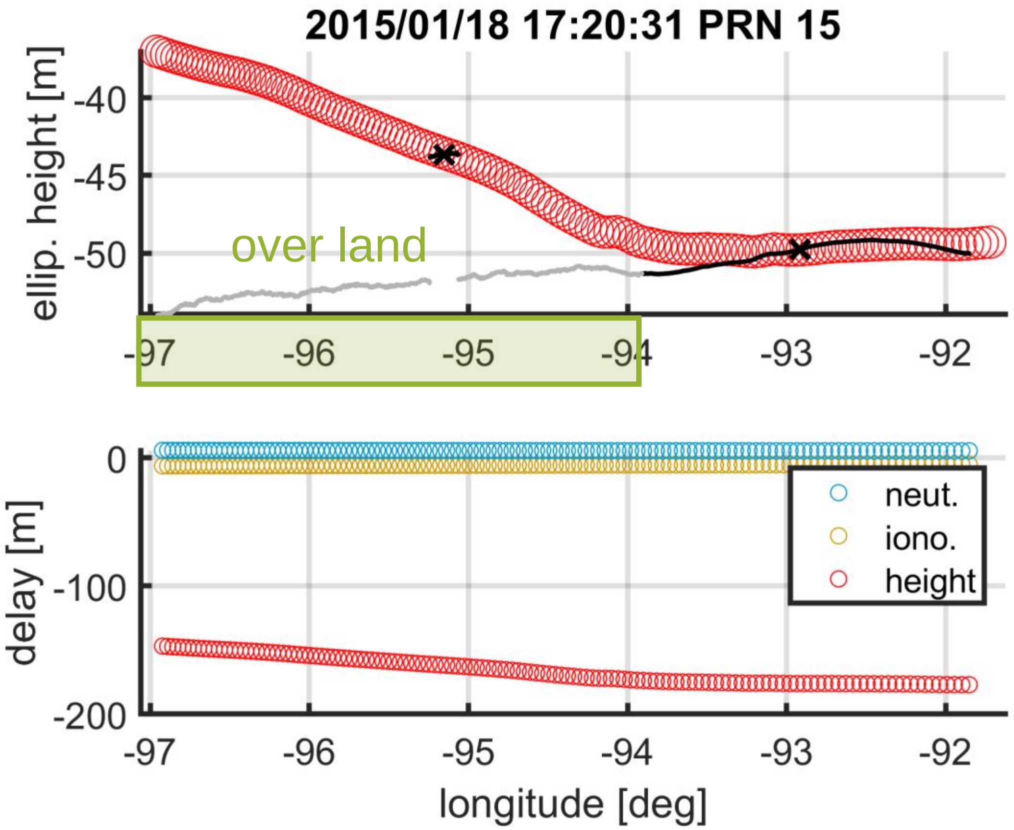
▪ Incoherent observation

- very long surface dominated track 36 s
- after surface correction std(f) = 5.93 Hz (50 Hz sampling)

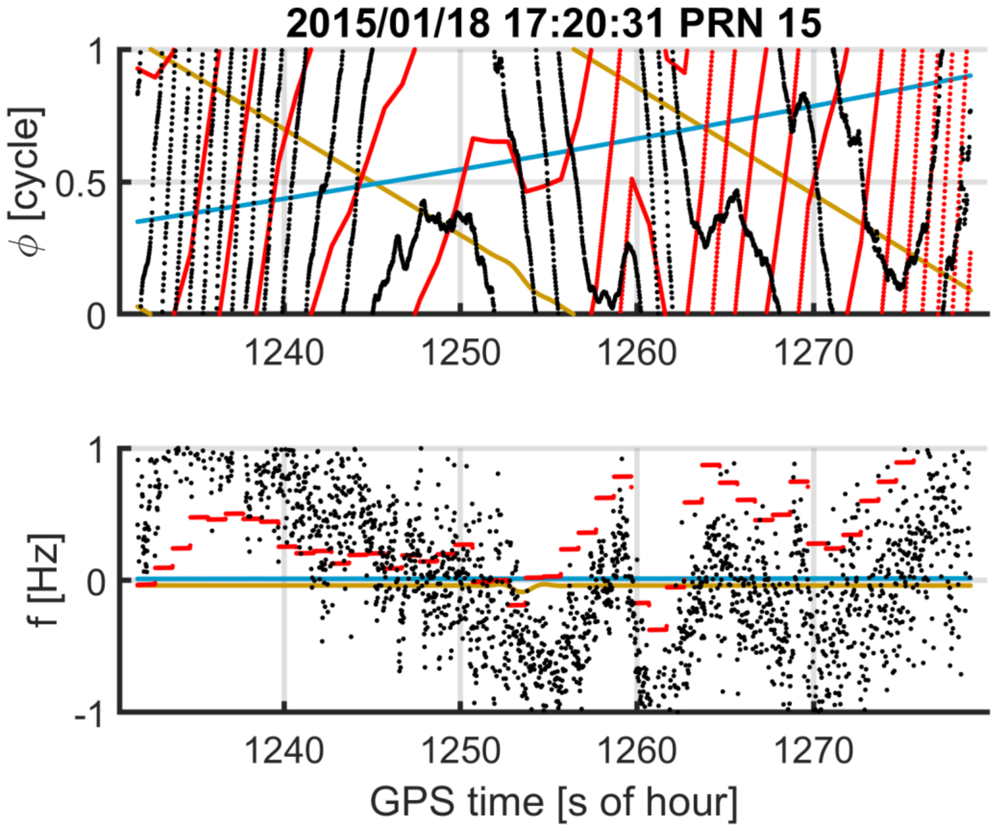
Western Hudson Bay Event

DLR

Retrieved Heights and Model corrections



Phase & Doppler of longest coherent track



○ Mean sea surface height from DTU 21

▪ Coherent observation/track x reference epoch for amb. fix.

▪ Incoherent observation

- ➢ longest surface dominated track (47 s) deviating from surface
- ➢ after surface correction std(f) = 6.96 Hz (50 Hz sampling)

Summary & Conclusion

Summary of analysis after surface correction

	PRN G12	PRN E05	PRN E05	PRN E01	PRN E01	PRN G13	PRN G15
min. Elev. [°]	13	13	13	15	15	30	58
yyyy-mm-dd	2017-09-08	2018-10-14	2018-10-14	2017-09-20	2017-09-20	2015-01-18	2015-01-18
UT [HH:MM]	23:17	04:56	04:57	16:37	16:38	17:21	17:20
LT [HH:MM]	18:35	23:19	23:27	11:21	11:26	11:32	11:13
track length [s]	12	16	12	25	17	36	47
resid. Dopp. [Hz]	0,03	0,05	-0,03	-0,09	0,24	0,05	-0,24
iono. Dopp. [Hz]	0,04	0,00	0,00	0,02	0,02	-0,09	-0,04
neut. Dopp. [Hz]	-0,06	-0,16	-0,18	0,12	0,12	0,09	0,01
Dopp. Std [Hz]	6,96	4,41	4,44	3,49	3,91	5,93	3,89
ampl. Index	0,61	0,36	0,40	0,26	0,33	0,43	0,36
sig. wave hgt. [m]	0,74	0,36	0,36	0,81	0,81	n.n.	n.n.

CyGNSS obs.*
over Caribbean

TDS-1 obs.**
over Hudson Bay

Neutral atmo. correc.: * ERA5, ** Internat. Stand. Atmo.

Conclusion

- PRETTY data will allow to study complex waveform data at grazing elev.
- Algorithms defined for altimetric processing and disturbance analysis
- Grazing geometry may give further insight into atmospheric factors
- Test event of other missions (TDS-1 and CyGNSS) analyzed
- Started looking into Doppler and amplitude dependencies

Acknowledgements

…

This work was partly funded by ESA.

Thank you for your attention

References

- Anderson 1999: Determination of Water Level and Tides Using Interferometric Observations of GPS Signals.
  Journal of Atmospheric and Oceanic Technology
- Fabra et al. 2011: Phase Altimetry with Dual Polarization GNSS-R over Sea Ice.
  IEEE Transaction on Geoscience and Remote Sensing
- Semmling et al. 2011: Detection of Arctic Ocean tides using interferometric GNSS-R signals.
  Geophys. Res. Lett.
- Semmling et al. 2013: A zeppelin experiment to study airborne altimetry using specular Global Navigation Satellite System reflections.
  Radio Science
- Semmling et al. 2014: Sea surface topography retrieved from GNSS reflectometry phase data of the GEOHALO flight mission.
  Geophys. Res. Lett.
- Semmling et al. 2016: A phase-altimetric simulator: studying the sensitivity of Earth-reflected GNSS signals to ocean topography.
  IEEE Transactions on Geoscience and Remote Sensing
- Camps et al. 2016: Ionospheric Effects in GNSS-Reflectometry From Space.
  IEEE Selected Topics in Applied Earth Observations and Remote Sensing
- Wickert et al. 2016: GEROS-ISS: GNSS REflectometry, Radio Occultation and Scatterometry onboard the International Space Station.
  IEEE Selected Topics in Applied Earth Observations and Remote Sensing
- Li et al. 2017: First Space-borne Phase Altimetry over Sea Ice Using TechDemoSat-1 GNSS-R Signals.
  Geophys. Res. Lett.
- Dielacher et al. 2019: The ESA Passive Reflectometry and Dosimetry (PRETTY) Mission
  IEEE International Geoscience and Remote Sensing Symposium (IGARSS)

References

- Fragner, H. et al. 2020: Status of the ESA PRETTY Mission.
  IEEE International Geoscience and Remote Sensing Symposium (IGARSS)
- Cardellach et al. 2020: First precise spaceborne sea surface altimetry with GNSS reflected signals.
  IEEE Selected Topics in Applied Earth Observations and Remote Sensing
- Molina and Camps 2020: First Evidences of Ionospheric Plasma Depletions Observations Using GNSS-R Data from CYGNSS.
  Remote Sens.
- Roesler et al. 2021: Coherent GNSS-Reflections Characterization Over Ocean and Sea Ice Based on Spire Global CubeSat Data.
  IEEE Transaction on Geoscience and Remote Sensing
- Moreno et al. 2022: Airborne Coherent GNSS Reflectometry and Zenith Total Delay Estimation over Coastal Waters.
  Remote Sens.
- Semmling et al. 2022: Algorithm Theoretical Baseline Document PRETTY mission.
  Project report within: Scientific Support for the Nano-Satellite Mission PRETTY
- Yang and Morton 2022: Ionospheric Total Electron Content and Disturbance Observations From Space-Borne Coherent GNSS-R Measurements.
  IEEE Transaction on Geoscience and Remote Sensing