Remote sensing using coherently reflected signals of Global Navigation Satellite Systems: Opportunities and Challenges

M. Semmling (1), J. Wickert (2,3), G. Stienne (4), D. Divine (5),
M. Moreno (1), M. Hoque (1), S. Gerland (5), S. Reboul (4)

(1) German Aerospace Center DLR-SO, Neustrelitz, Germany
(2) German Research Centre for Geosciences GFZ, Potsdam, Germany
(3) Technische Universität Berlin, Germany
(4) Université Littoral Côte d'Opale ULCO, Calais, France
(5) Norwegian Polar Institute NPI, Tromsø, Norway

Photo: GEOHALO mission, over Mediterranean Sea

Outline

- Introduction to GNSS Reflectometry
- Opportunity: Altimetric Measurements
- Opportunity: Sea-ice Remote Sensing
- Outlook & Conclusion

DLR

GFZ
Helmholtz Centre
POTSDAM

Introduction to GNSS Reflectometry

GNSS Signals of Opportunity

Global Navigation Satellite Systems [1]

- GPS (31 MEO)
- GLONASS (24 MEO)
- Galileo (24 MEO)
- BeiDou (27 MEO + GEO + IGSO)

Medium Earth Orbit Heights [2]

- GPS: ~ 20,180 km
- GLONASS: ~ 19,130 km
- Galieo: ~ 23,222 km
- BeiDou: ~ 21,500 km

L-band carrier frequencies (GPS)

- L1: 1575.42 MHz
- L2: 1227.60 MHz
- L5: 1176.45 MHz

1 broadcasted orbits, May 2021

2 wikipedia, Sep 2021

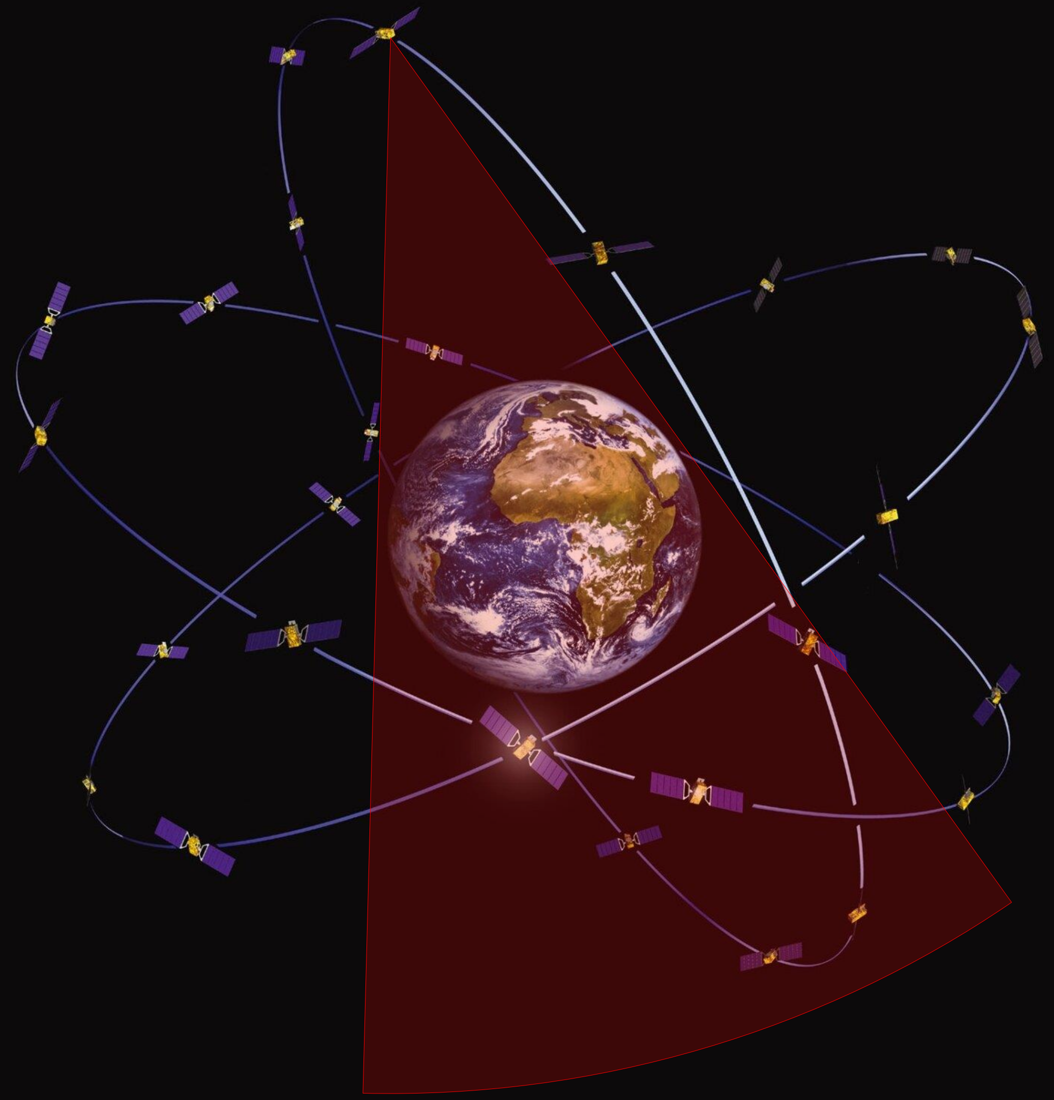


Image: Galileo constellation, ESA

Reflectometry Concept

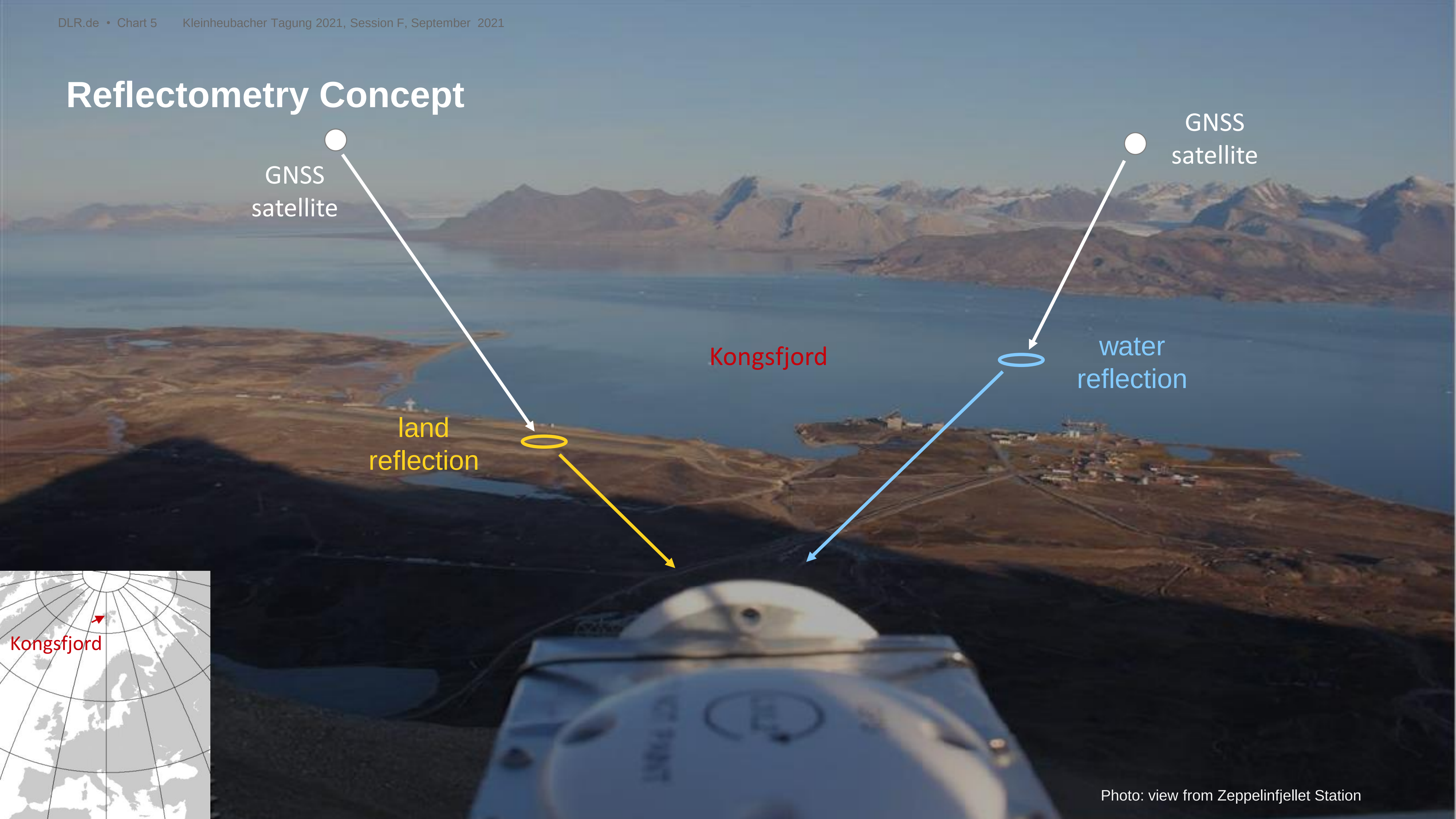


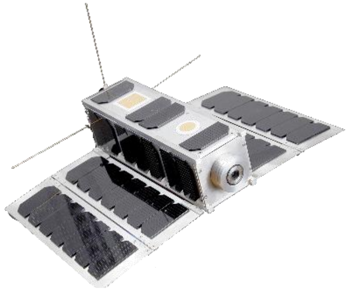
Photo: view from Zeppelinfjellet Station

Reflectometry Concept

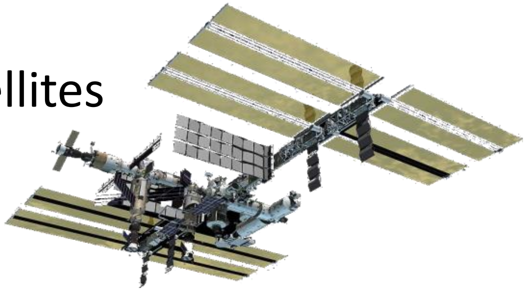
Photo: view from Zeppelinfjellet Station

Observation Scenarios

D: MEO GNSS Satellites



C: LEO Satellites



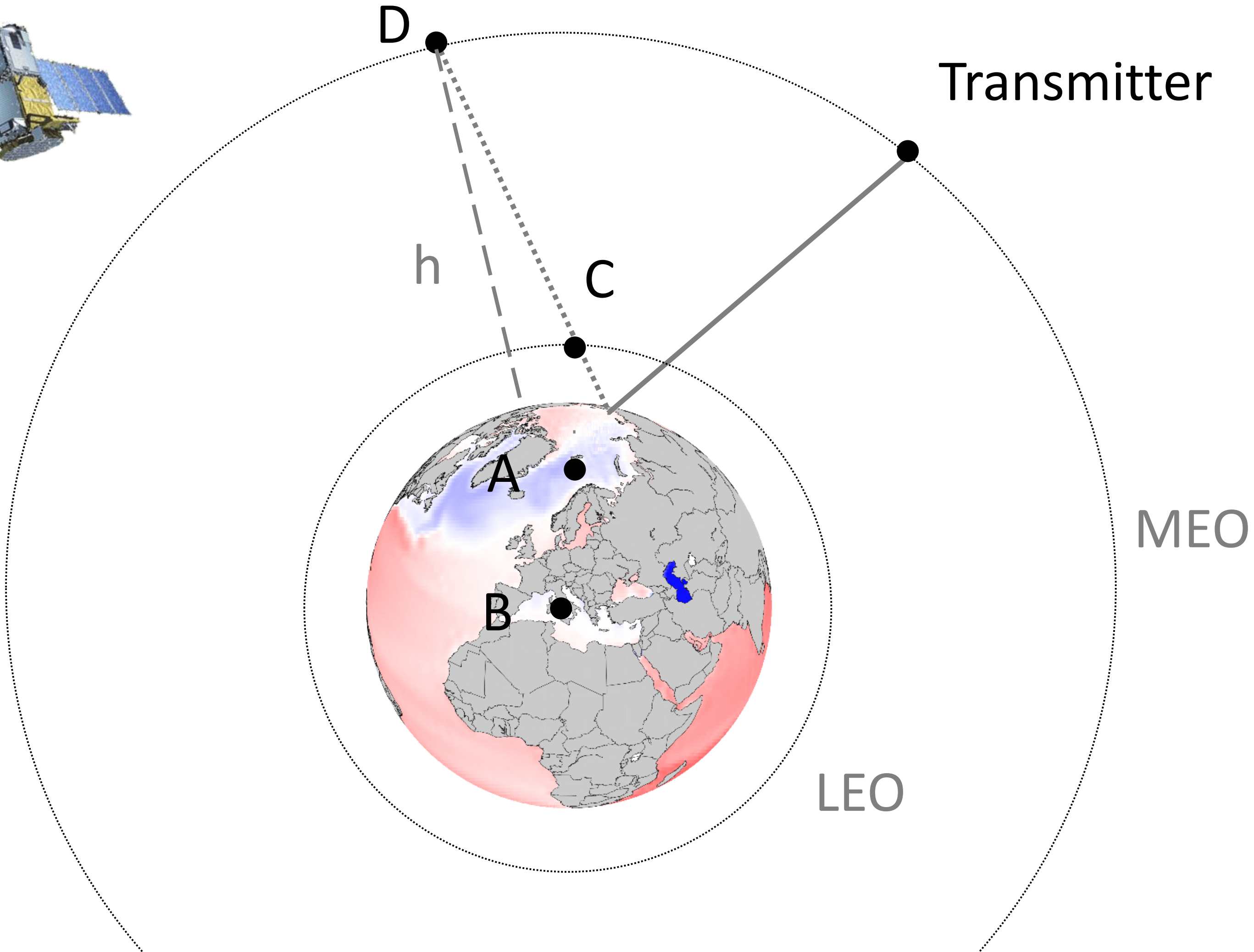
Wickert et al. 2016
Semmling et al. 2016

B: Aircrafts

Semmling et al. 2013, 2014

A: Ships

Semmling et al. 2019, 2021

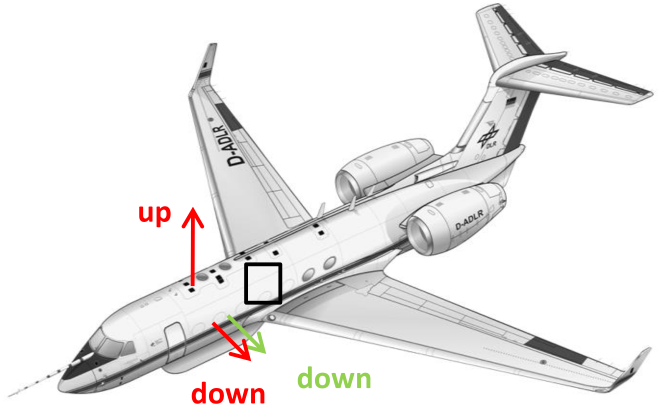


D: Galileo	h ~ 23200 km
C: ISS, PRETTY	h ~ 400 … 650 km
B: Zeppelin NT, HALO	h ~ 700 … 3500 m
A: Lance, Polarstern	h ~ 25 m

Opportunity: Altimetric Measurements

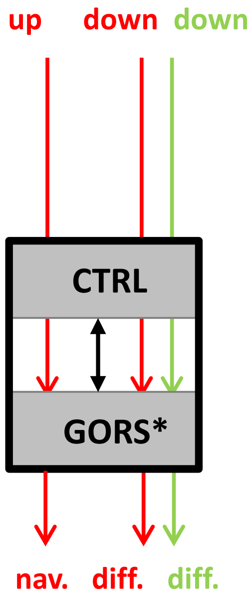
Altimetric Setup

HALO Research Aircraft



Antennas

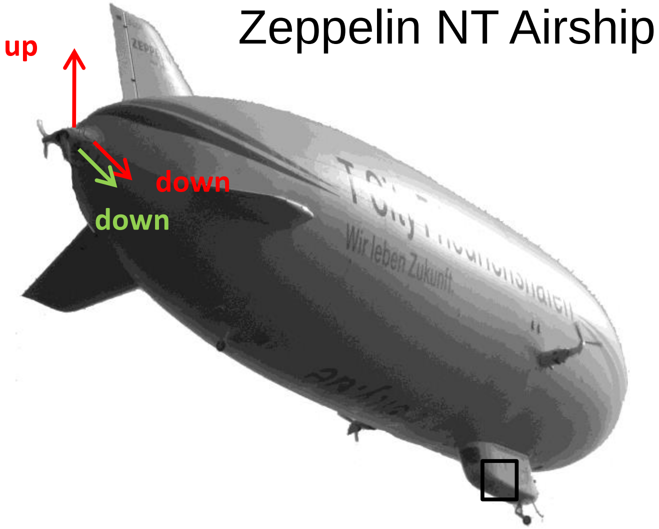
- direct signal tracking
  co-pol. (RHCP) antenna up
- reflected signal acquisition
  co-pol. (RHCP) antenna down
  cross-pol. (LHCP) antenna down



* GORS (GNSS Occultation Reflectometry Scatterometry)

Helm et al. 2007

Zeppelin NT Airship



Receiver

- GORS* unit for real-time navigation data (up signal)
- GORS* unit for differential data (down - up signal)
- control pc for data recording and reflection tracking

Semmling et al. 2013

Aboard Zeppelin NT Airship

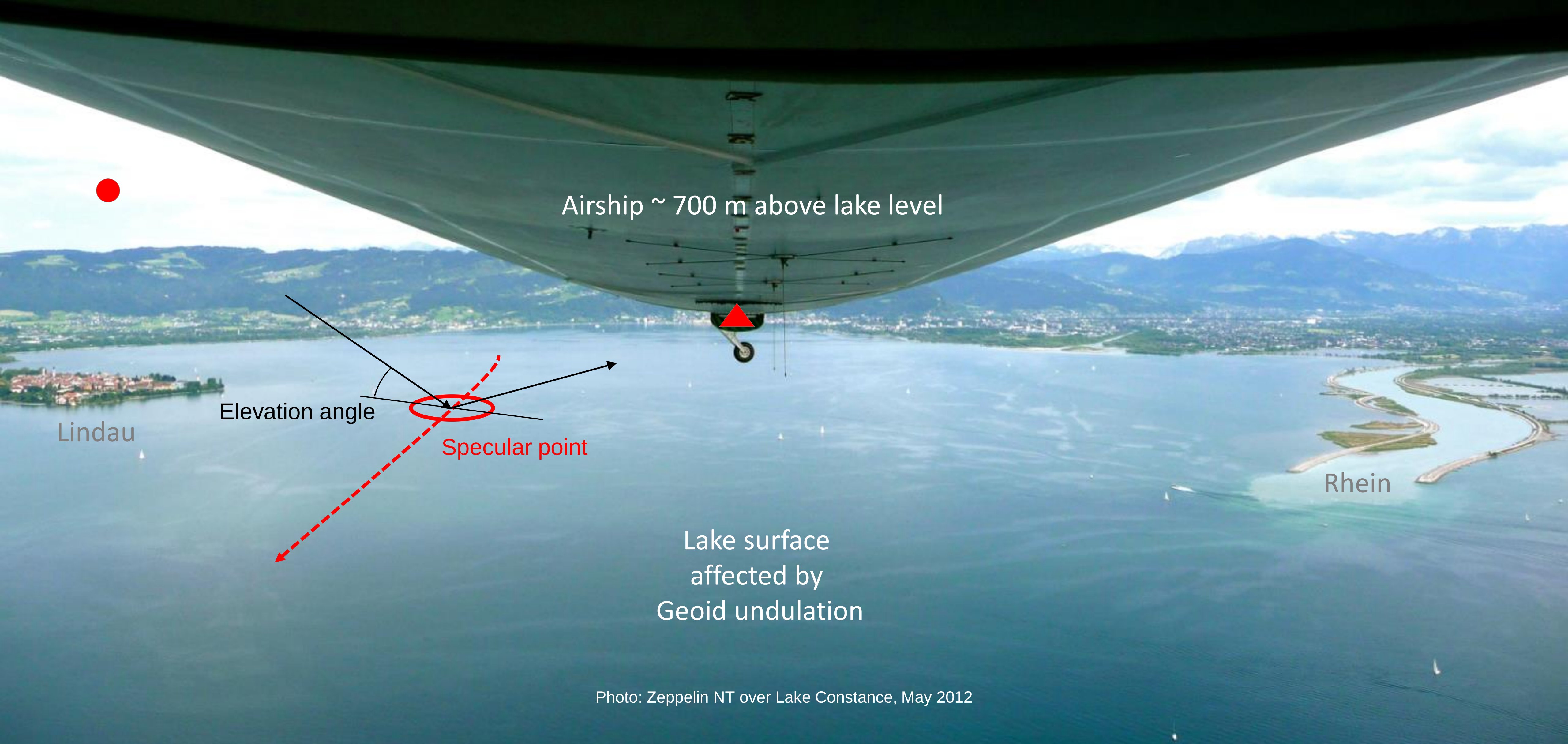
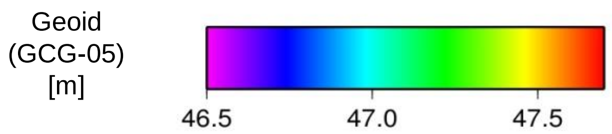
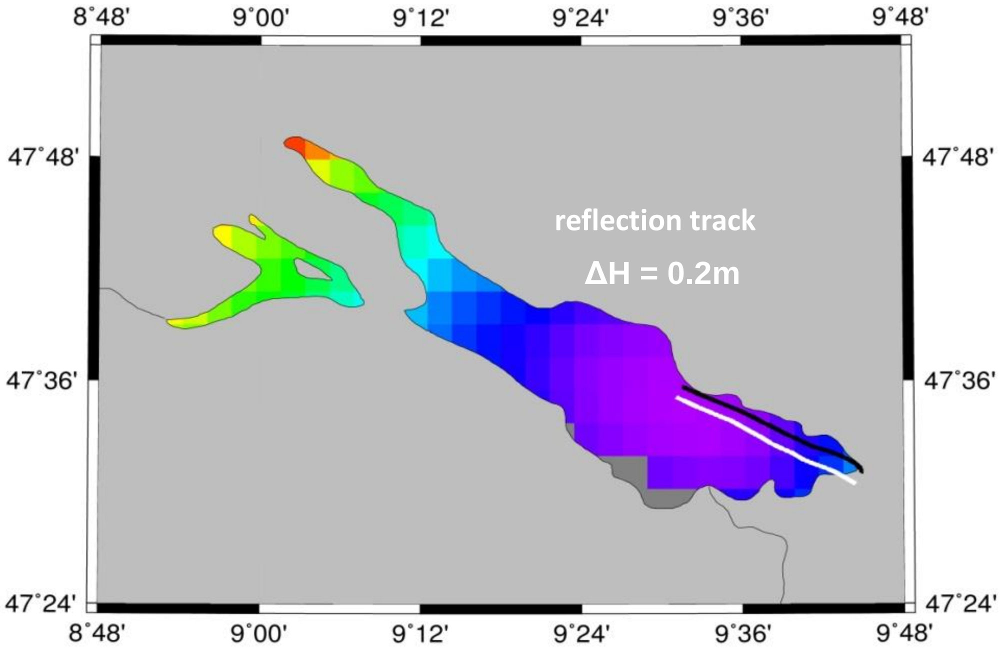


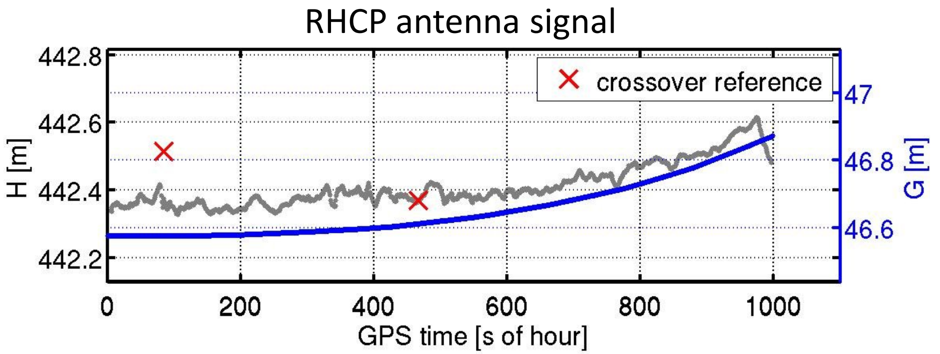
Photo: Zeppelin NT over Lake Constance, May 2012

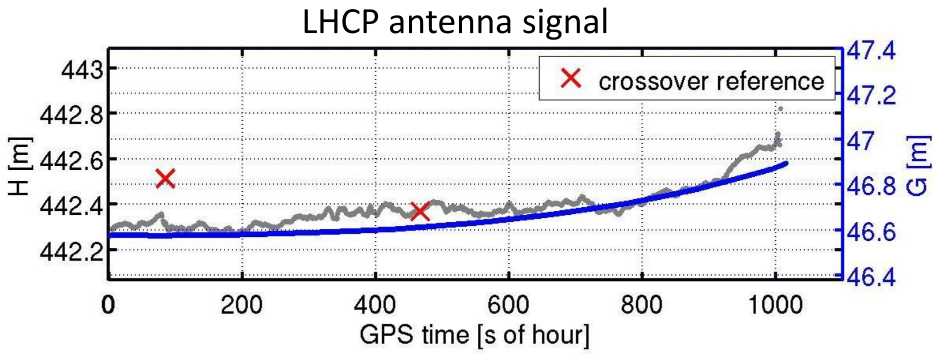
Aboard Zeppelin NT Airship



Liebsch et al. 2006







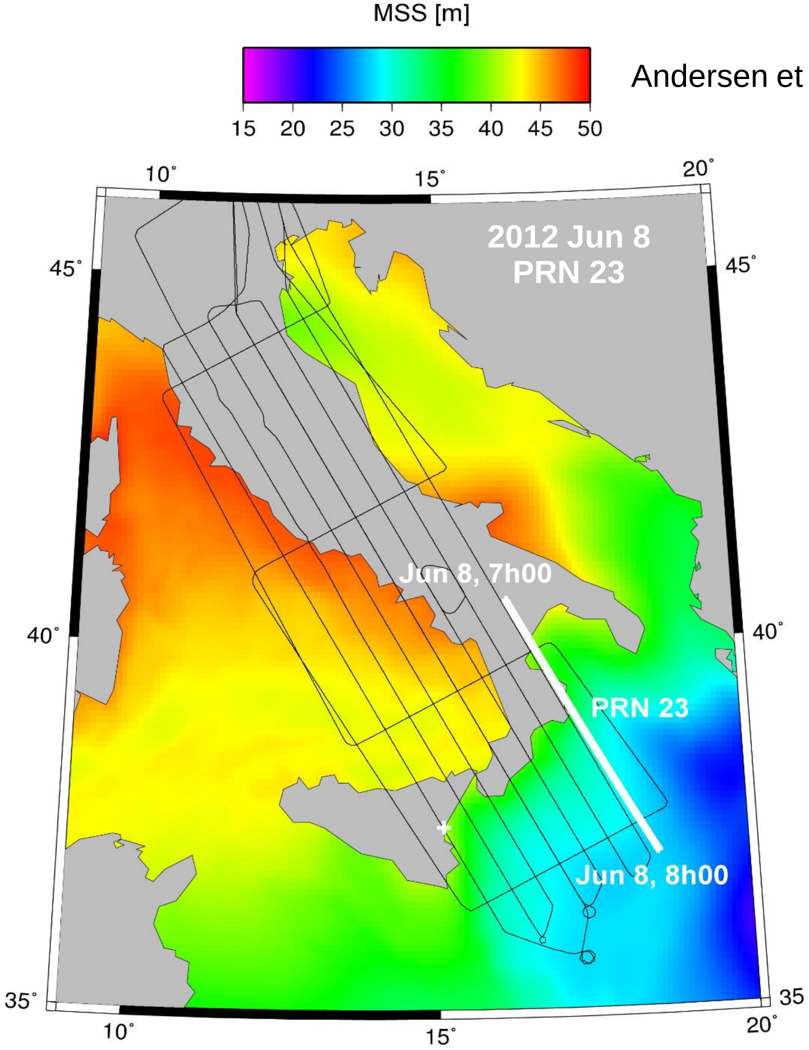
	mean bias	precision
H to G (RHCP)	7 cm	3 cm
H to G (LHCP)	5 cm	4 cm

Semmling et al. 2013, 2014b

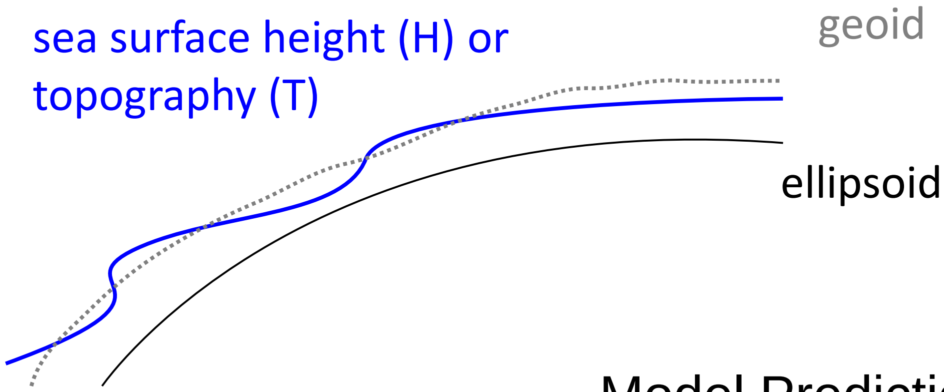
Aboard HALO Research Aircraft

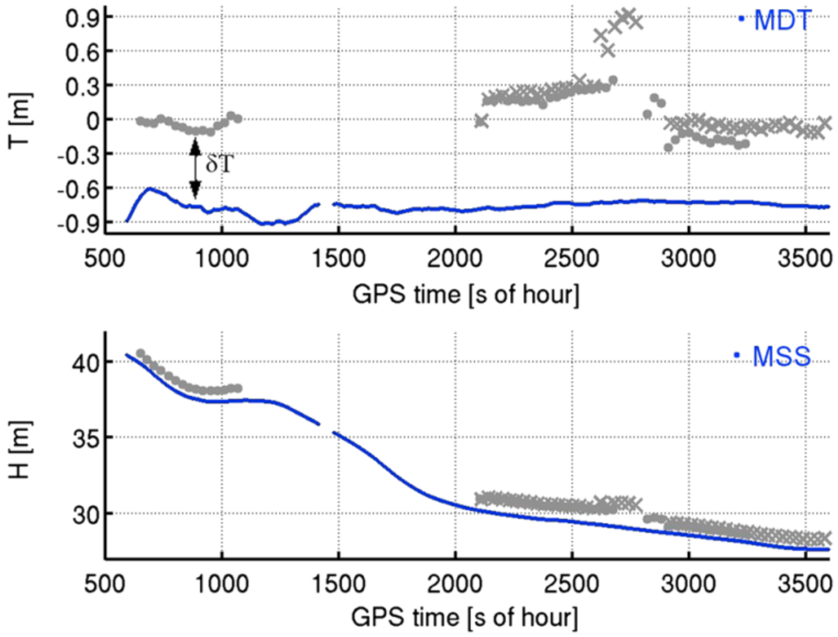
Photo: GEOHALO mission,
over Mediterranean Sea

Aboard HALO Research Aircraft



Andersen et al. 2009





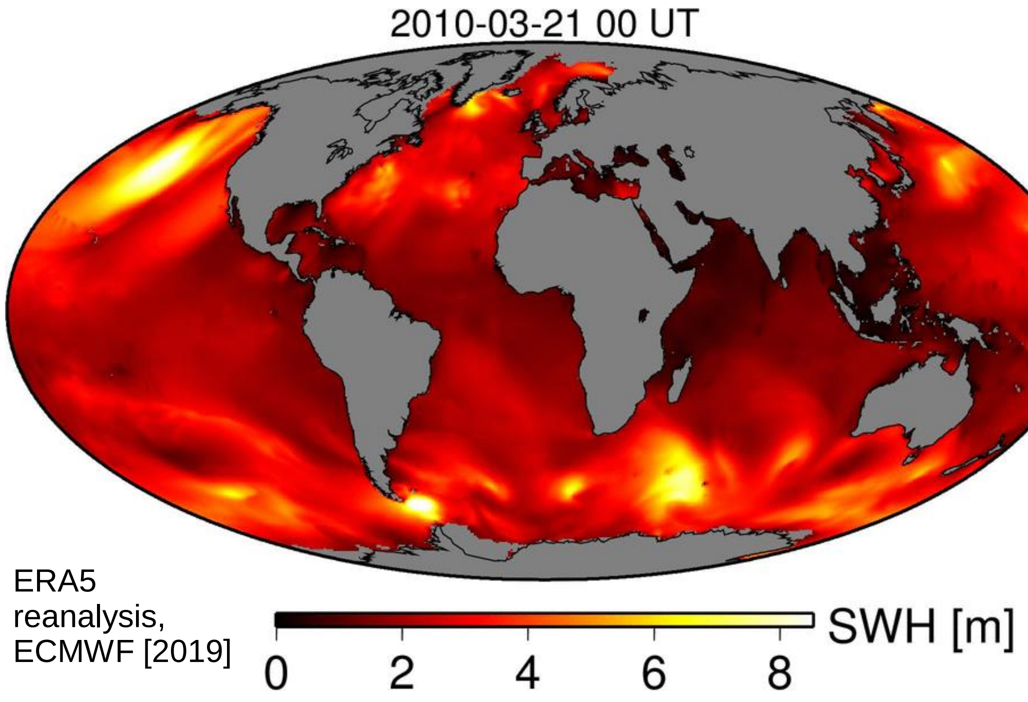
Model Prediction

- Mean Sea Surface (MSS)
- Mean Dynamic Topography (MDT)

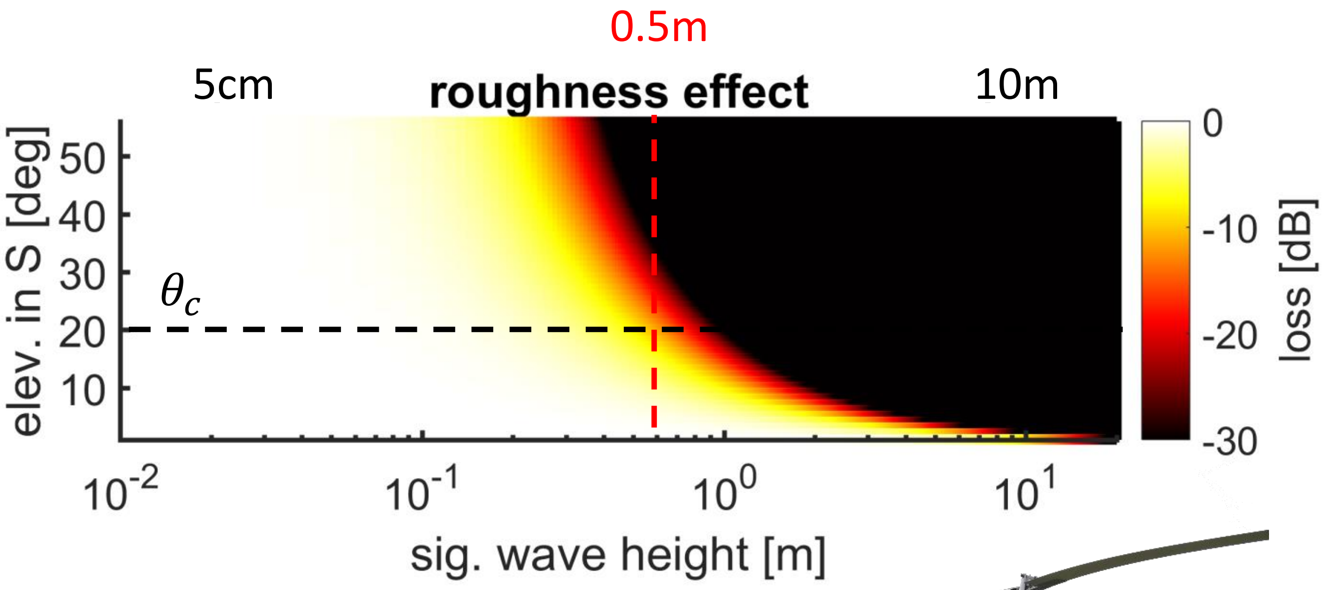
max. range (min. elev.)	# of tracks	mean track length	mean track precision
60 km (3°)	33	53 km	14 cm
39 km (5°)	31	46 km	6 cm
14 km (15°)	16	36 km	5 cm

DLR

Challenge: Sea State



ERA5 reanalysis, ECMWF [2019]



Smooth Ocean Zones

- Significant Wave Height SWH < 0.5 m
- often in Caribbean and Indonesian Sea
- sea-ice affected areas

Sea State Effect

- loss of coherent reflection power
- carrier phase altimetry fails
- sea state retrieval possible (on-going airborne study)

See poster: Moreno et al.

Opportunity: Sea-ice Remote Sensing

Aboard Research Vessel Lance

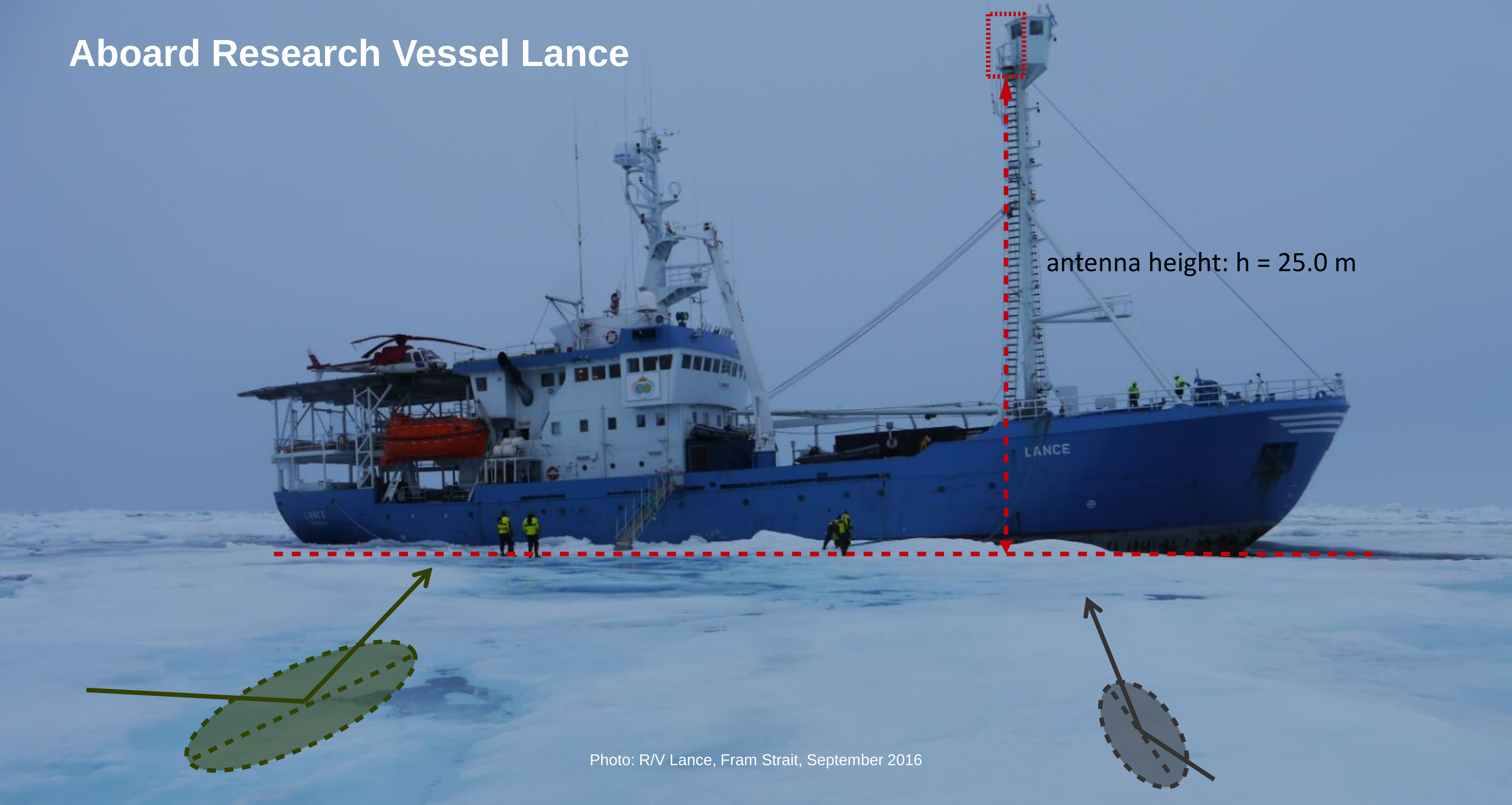
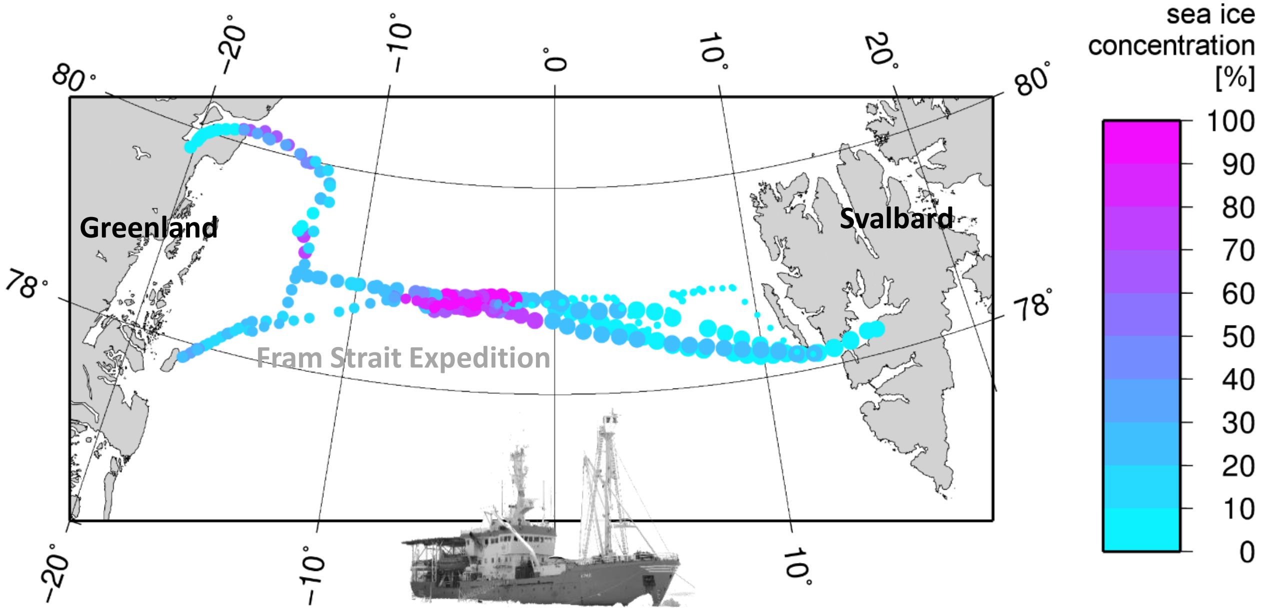
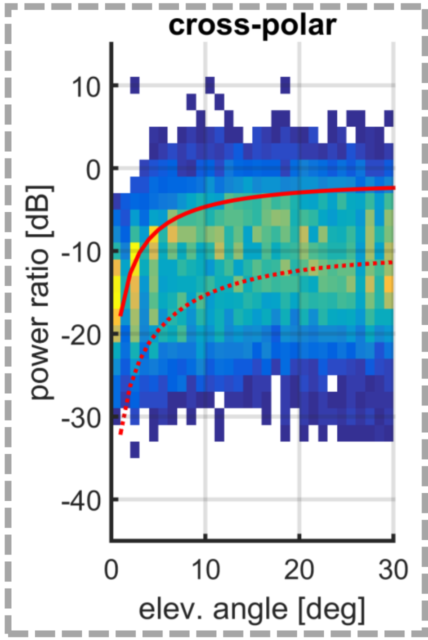
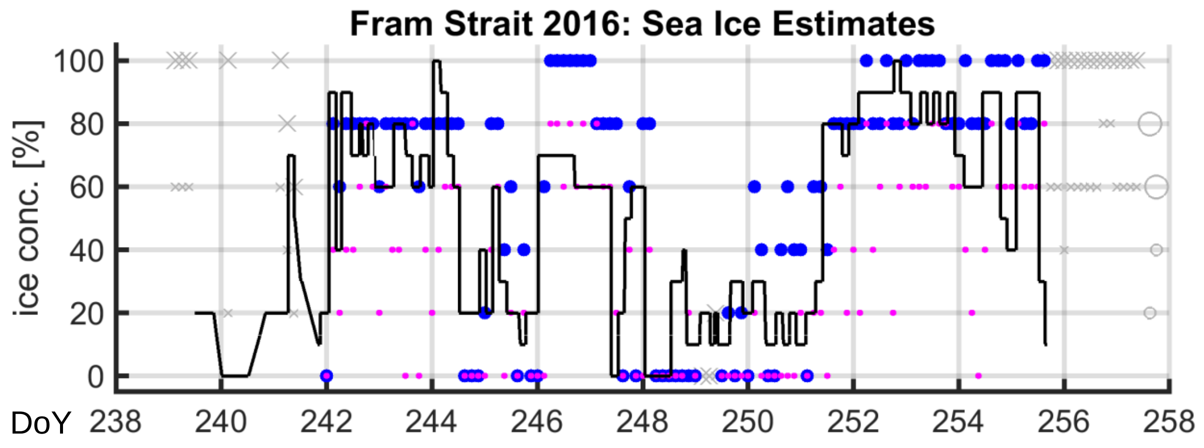


Photo: R/V Lance, Fram Strait, September 2016

Aboard Research Vessel Lance







Further Expedition

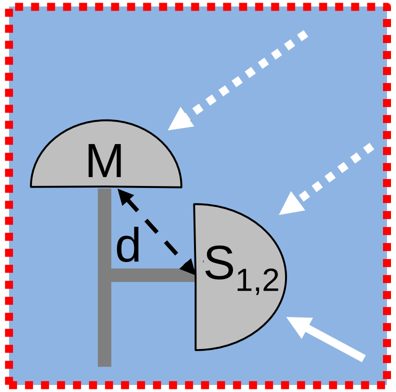
Semmling et al. 2019

Setup & Signal Processing

Antennas	up-look RHCP	side-look RHCP	side-look LHCP
Receiver	Master ch.	Slave ch.	Slave ch.
Data Level 0	I, Q Corr.	I, Q	I, Q
Data Level 1	co-polar ratio	cross-polar ratio	cross-to-co polar ratio
Data Level 2	eff. permittivity		
	sea ice type	sea ice concentr.	

Semmling et al. 2021 (accepted)

Semmling et al. 2019



GORS receiver

Helm et al. 2007

power retrieval

Larson et al. 2008

link separation

Semmling et al. 2013

permittivity model

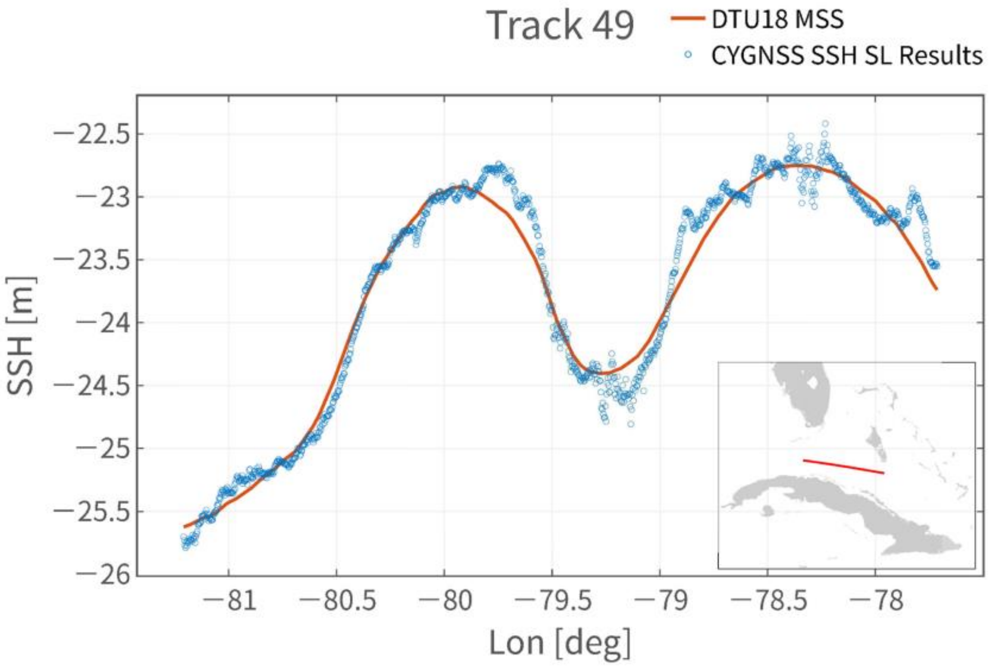
Kaleschke et al. 2010

Outlook & Conclusion

Outlook – Atmosphere

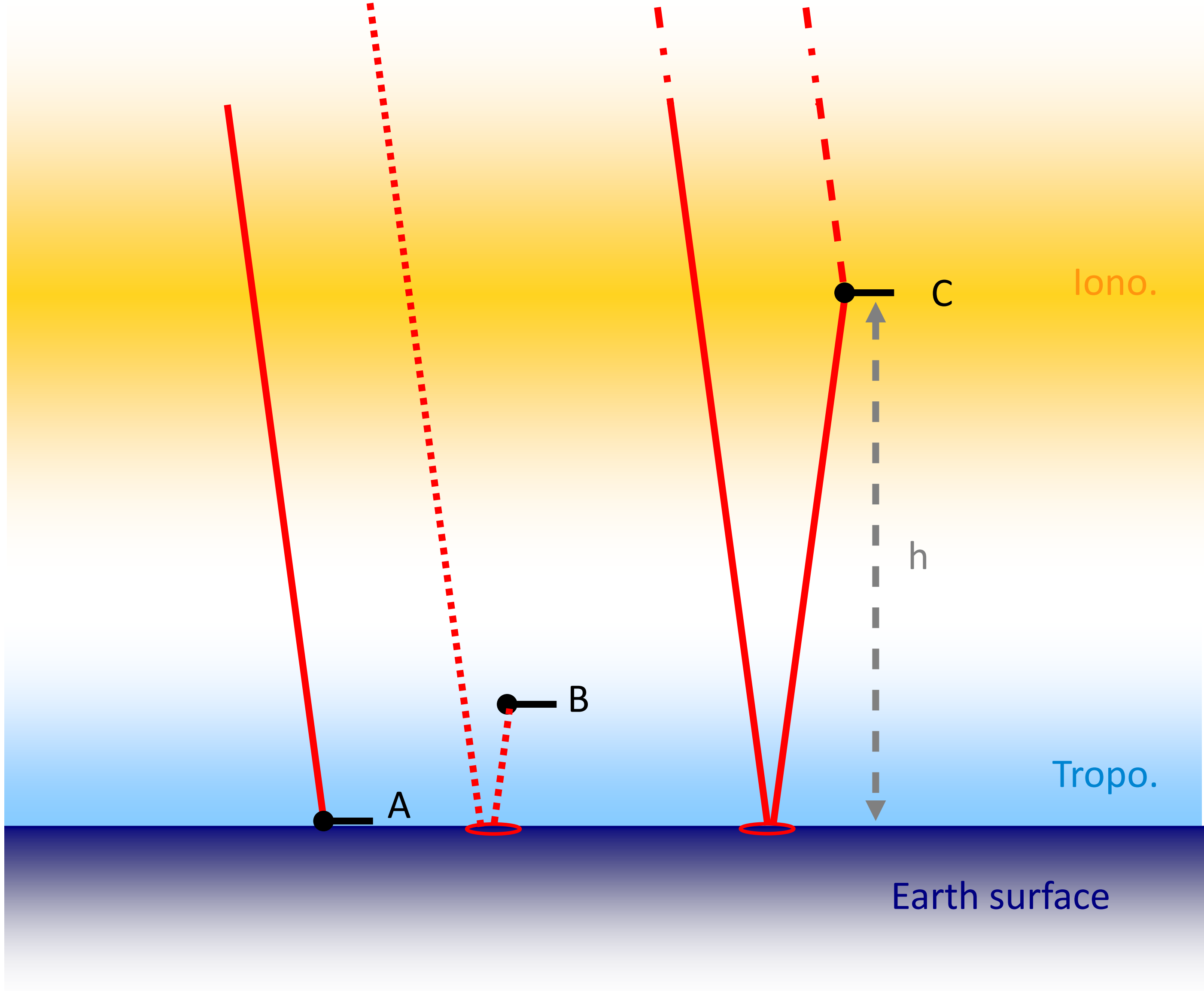
Increasing Biases with Altitude

- Tropospheric refraction
  (signal delay and ray bending)
- Ionospheric refraction
  (group delay/phase advance)



Cardellach et al. 2019

GNSS 19100 … 23200 km

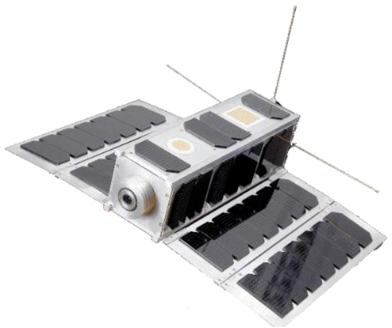


A: R/V Lance, h ~ 25 m

B: HALO, h ~ 3500 m

C: CyGNSS, PRETTY, h ~ 640 km

DLR



Conclusion

Application: Altimetric Measurements

- GNSS reflectometry setup for airborne measurements
- height signatures of water surfaces resolved with centimetre precision
- success rate depends on phase coherent retrieval and sea state

Application: Sea-ice Concentration

- GNSS setup for ship-based measurements
- Sea-ice concentration estimated from power ratio
- additional impact of ice type

Outlook

- General impact of atmospheric variability
- Include satellite data

Thank you for your Attention.

DLR

GFZ Helmholtz Centre POTSDAM

References

Helm et al. 2007: GORS - A GNSS Occultation, Reflectometry and Scatterometry Space Receiver.
ION GNSS

Larson et al. 2008: Using GPS multipath to measure soil moisture fluctuations: initial Results.
GPS Solutions

Kaleschke et al. 2010: A sea-ice thickness retrieval model for 1.4 GHz radiometry and application to airborne measurements over low salinity sea-ice.
The Cryosphere

Semmling et al. 2013: A zeppelin experiment to study airborne altimetry using specular Global Navigation Satellite System reflections.
Radio Science

Semmling et al. 2014a: Sea surface topography retrieved from GNSS reflectometry phase data of the GEOHALO flight mission.
Geophysical Research Letters

Semmling et al. 2014b: Airborne GNSS reflectometry using crossover reference points for carrier phase altimetry.
in Proc. *IEEE IGARSS*

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

Semmling et al. 2019: Sea Ice concentration derived from GNSS reflection measurements in Fram Strait.
IEEE Transaction on Geoscience and Remote Sensing

Semmling et al. 2021 (accepted for publication): Sea-ice permittivity derived from GNSS reflection profiles: Results of the MOSAiC expedition.
IEEE Transaction on Geoscience and Remote Sensing