Estimation of Sea Ice Concentration and Soil Moisture
A GNSS Reflectometry Concept

M. Semmling [1, 2], G. Stienne [2], S. Gontharet [3]
S. Gerland [4], S. Reboul [2], J. Wickert [1]

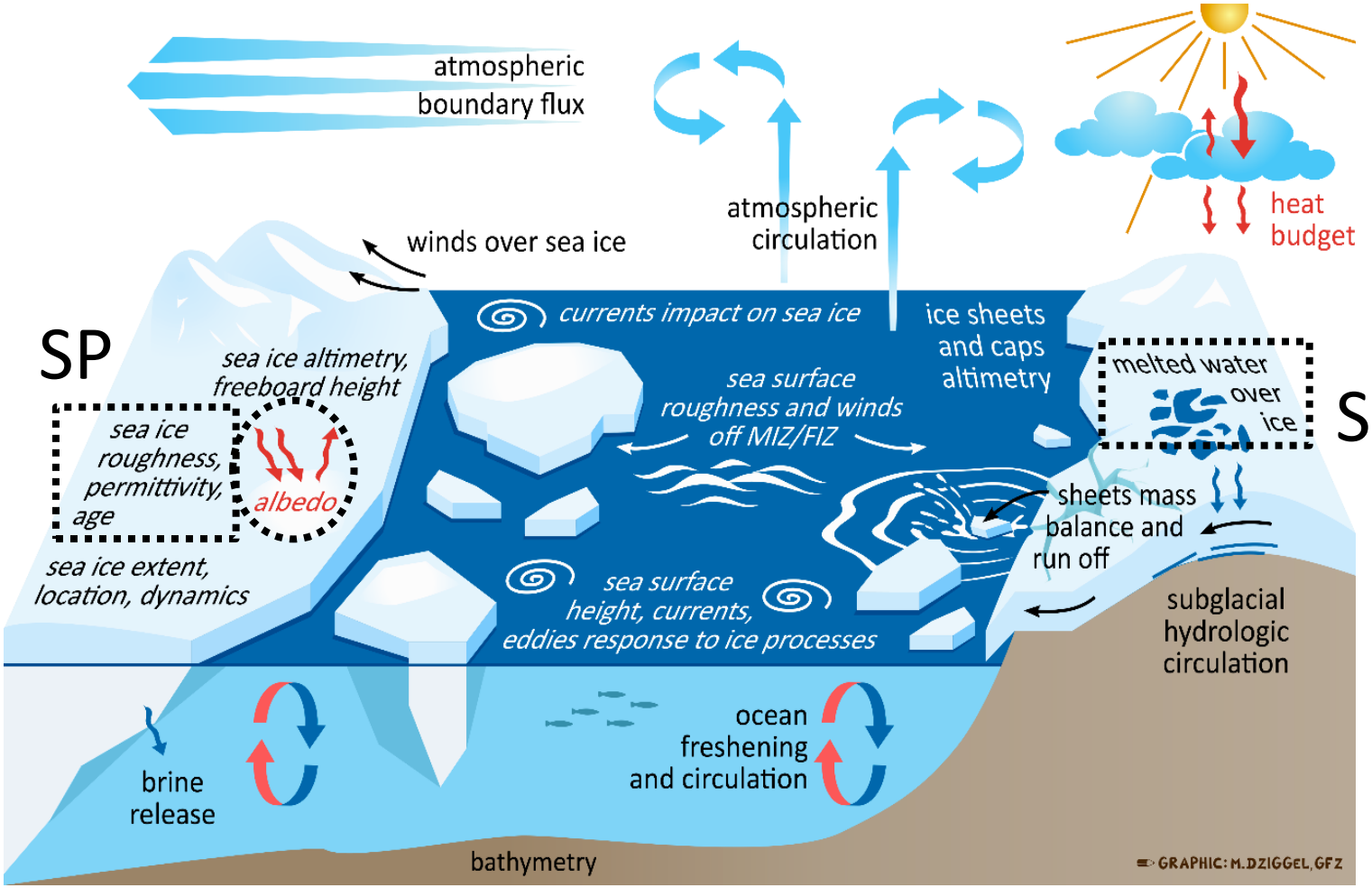
[1] German Research Centre for Geosciences GFZ, Potsdam, Germany
[2] Lab. d'Informatique, Signal et Image de la Côte d'Opale LISIC, Calais, France
[3] Lab. d'Océanologie et de Géosciences, Wimereux, France
[4] Norwegian Polar Institute NPI, Tromsø, Norway

GNSS+R Workshop
Bevevento May 2019

Photo: Ny-Alesund and Kongsfjorden, Svalbard Apr 2018

Motivation

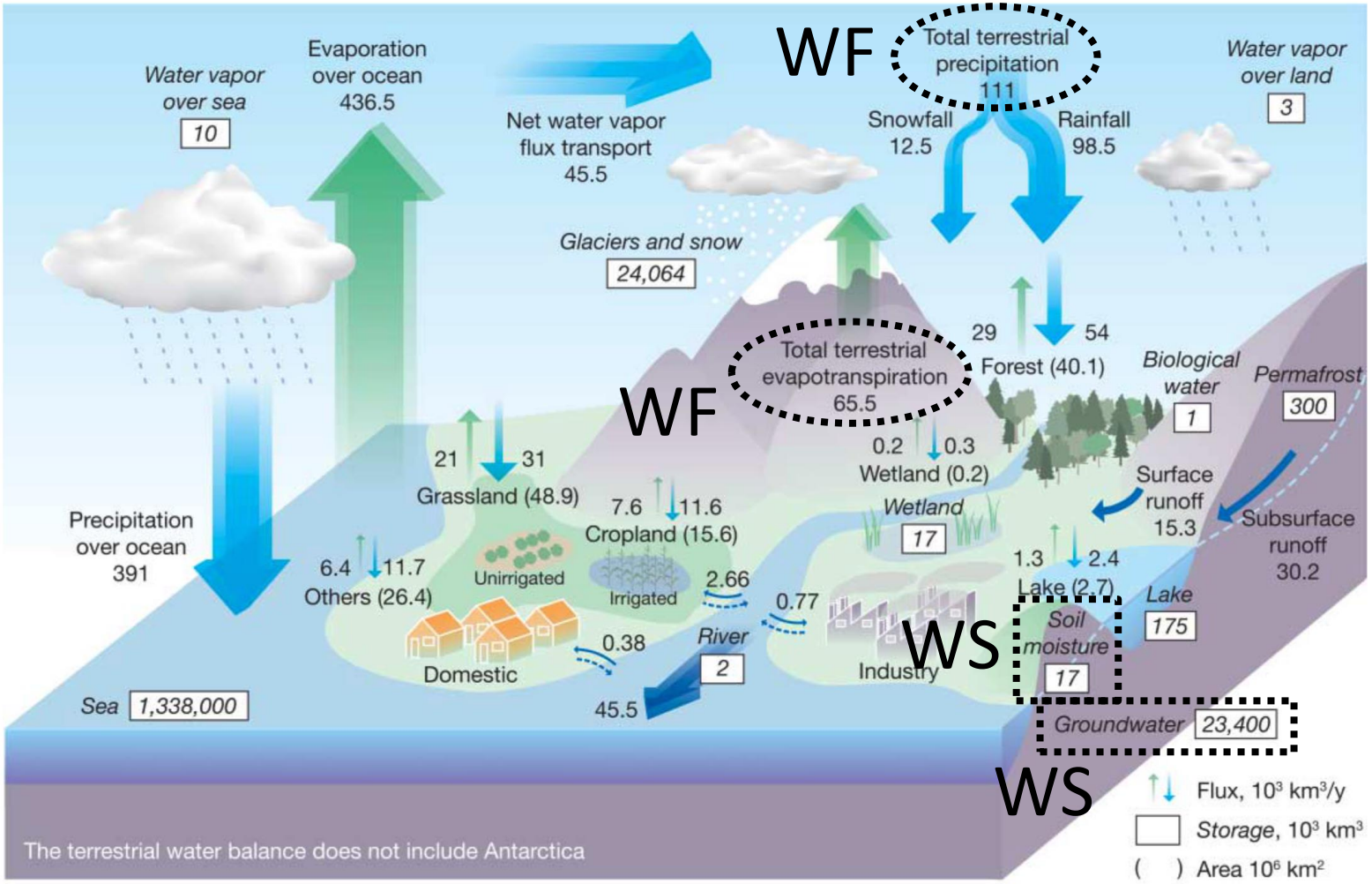
Earth Surface and Radiation Budget



surface properties (SP)

Figure: Cardellach et al. 2018

Soil Moisture and Water Cycle



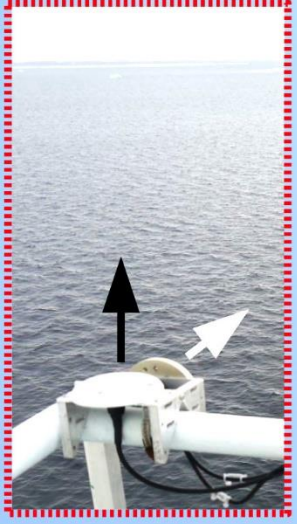
water flux (WF)

water storage (WS)

Figure: Oki & Kanae 2006

Sea Ice Concentration

Experiment



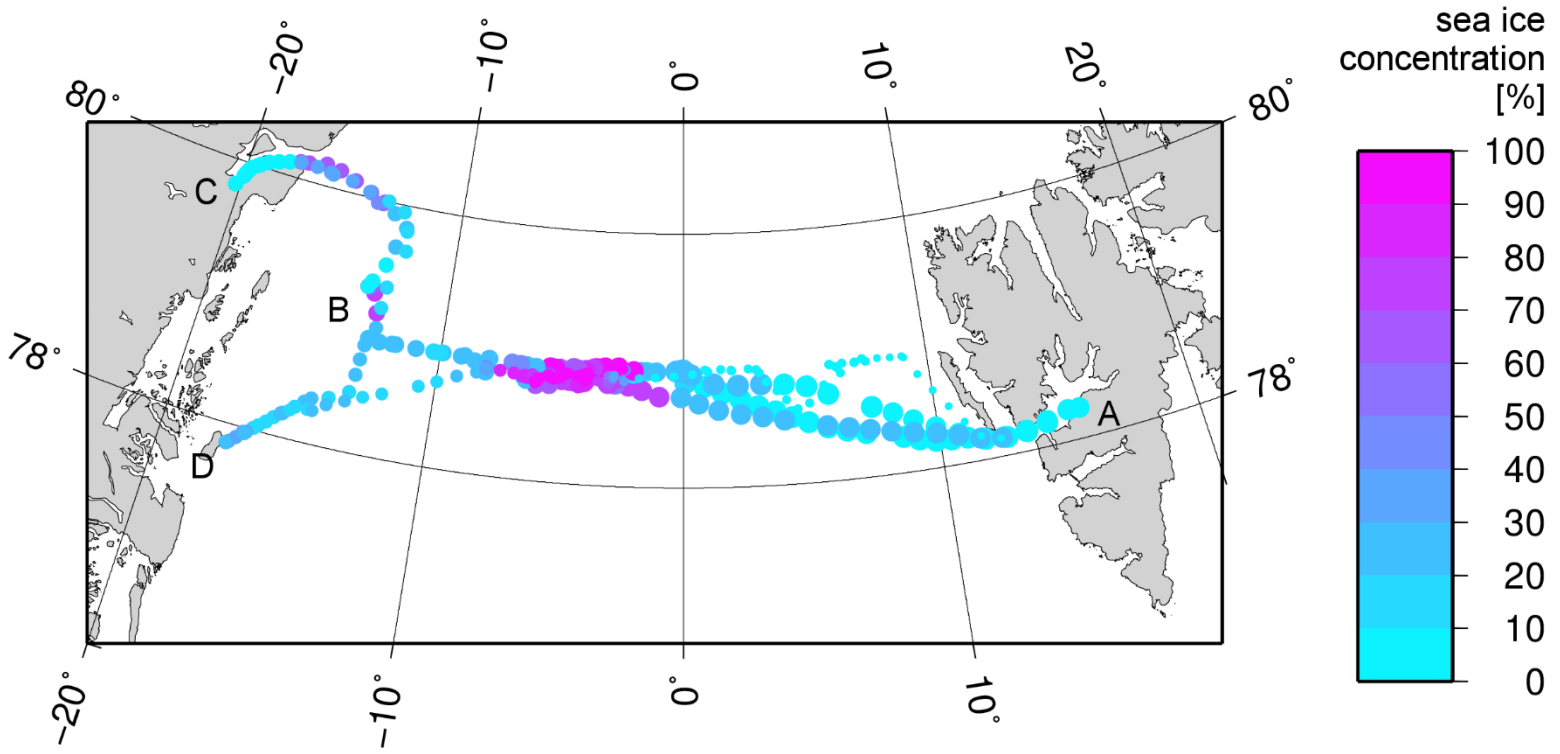
h

θ

Setup cf.: Semmling et al. 2013, 2014; Peraza et al. 2017

Photo: R/V Lance at sea ice station, Fram Strait, Sept. 2016

Fram Strait Cruise

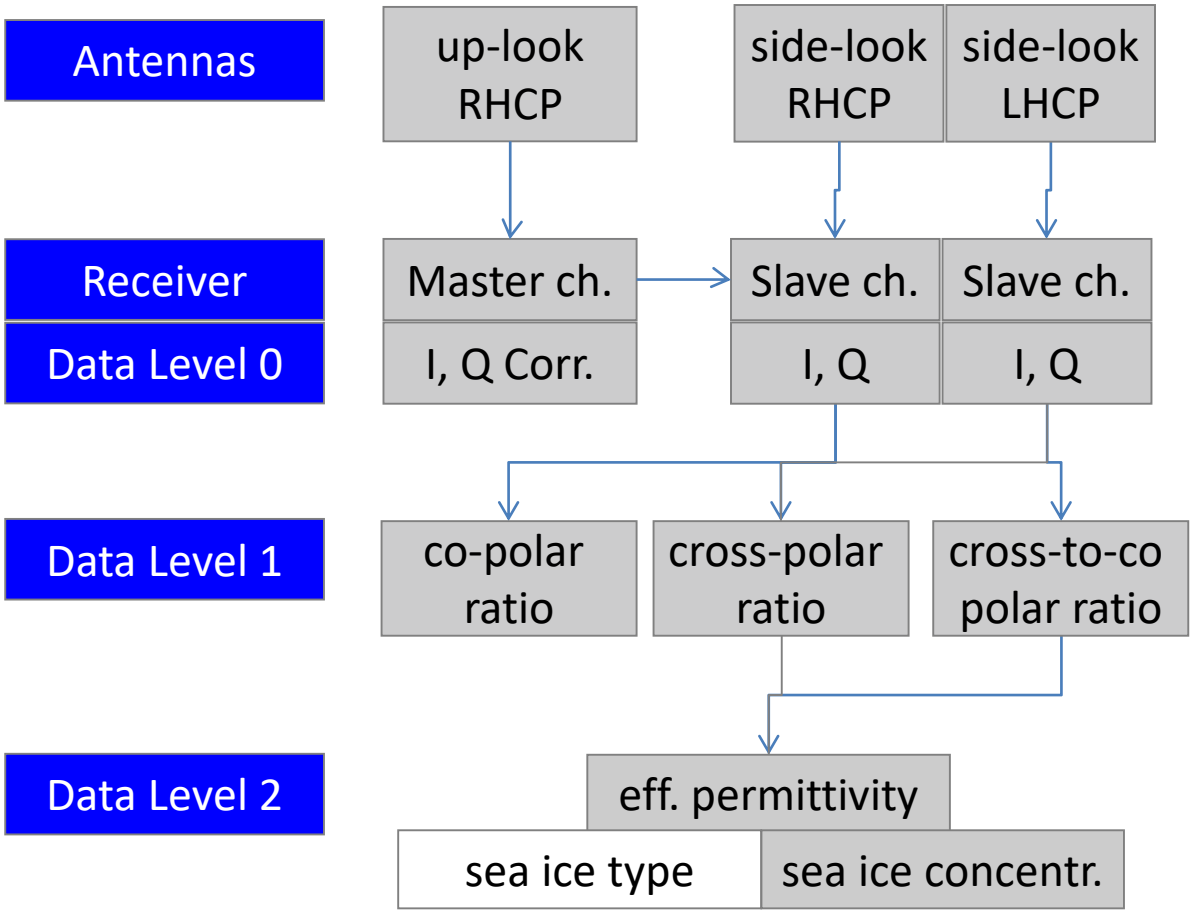


B: stations at fast ice ← 8 days — **A**: start Longyearbyen, Svalbard (25/08/2016)

5 days

C/D: stations at Greenland coast → 7 days — **A**: end Longyearbyen, Svalbard (13/09/2016)

Data Processing



GORS receiver

Helm et al. 2008

power retrieval

Larson et al. 2008

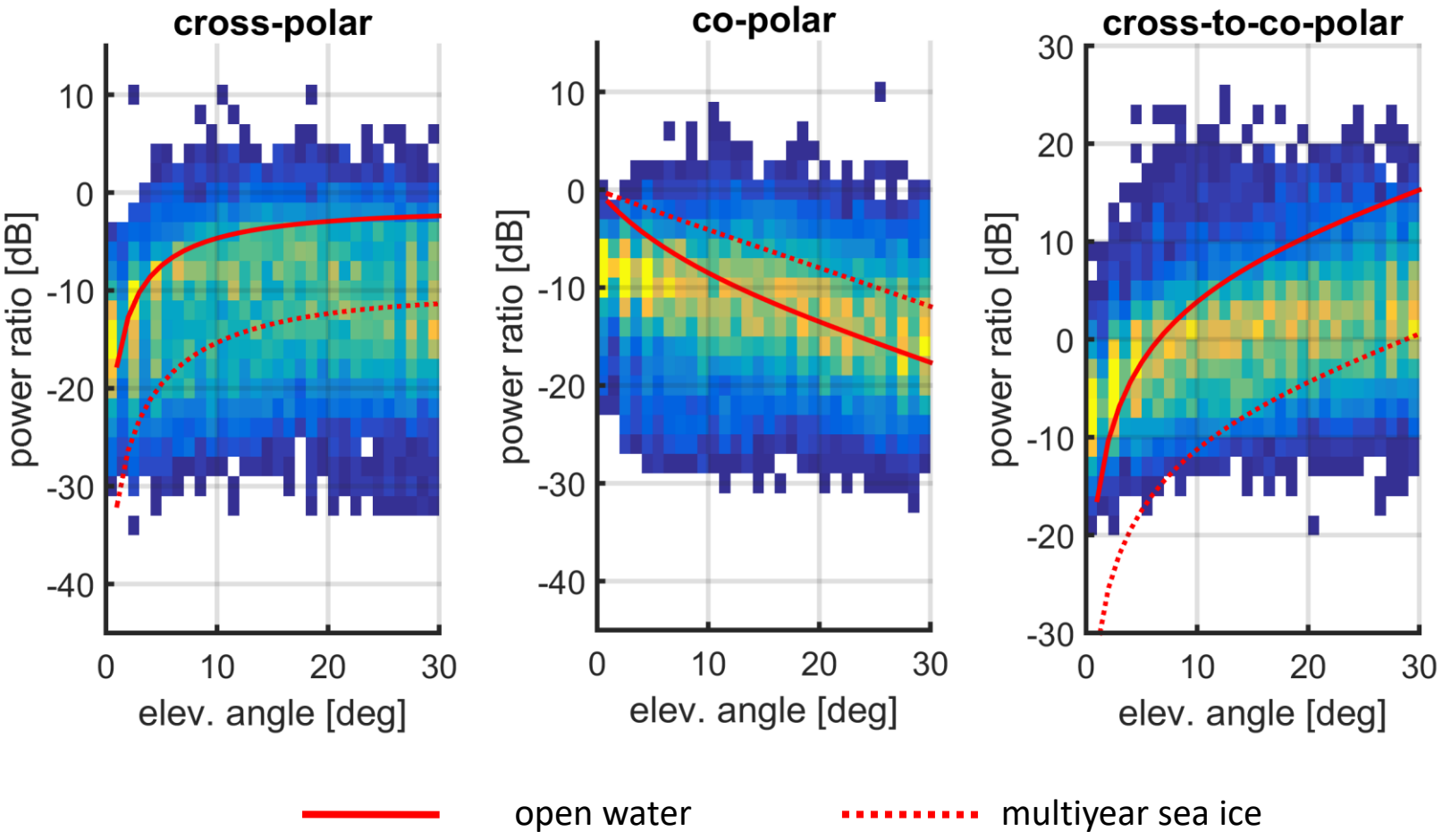
link separation

Semmling et al. 2013

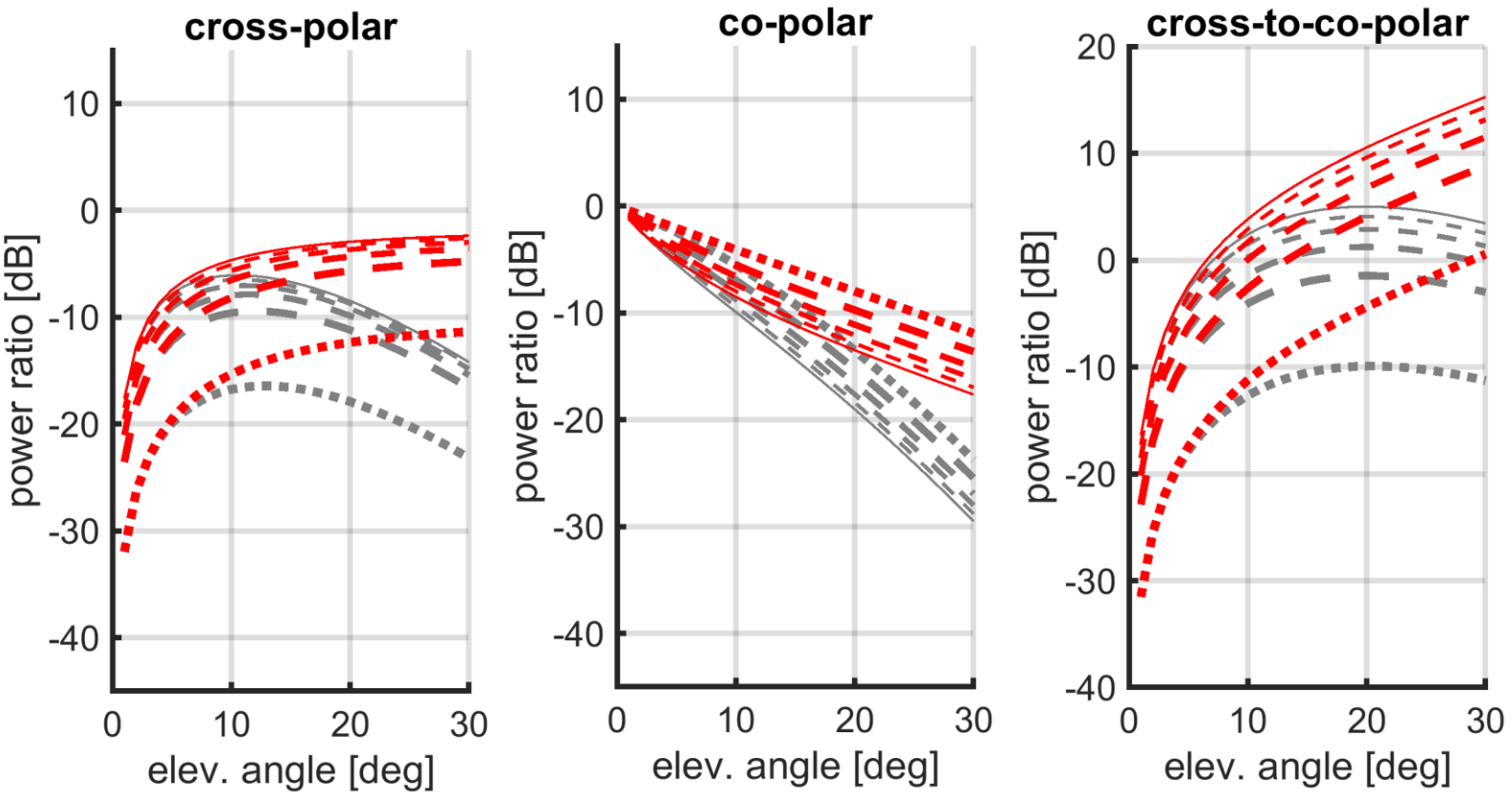
permittivity model

Kaleschke et al. 2010

Data Level 1

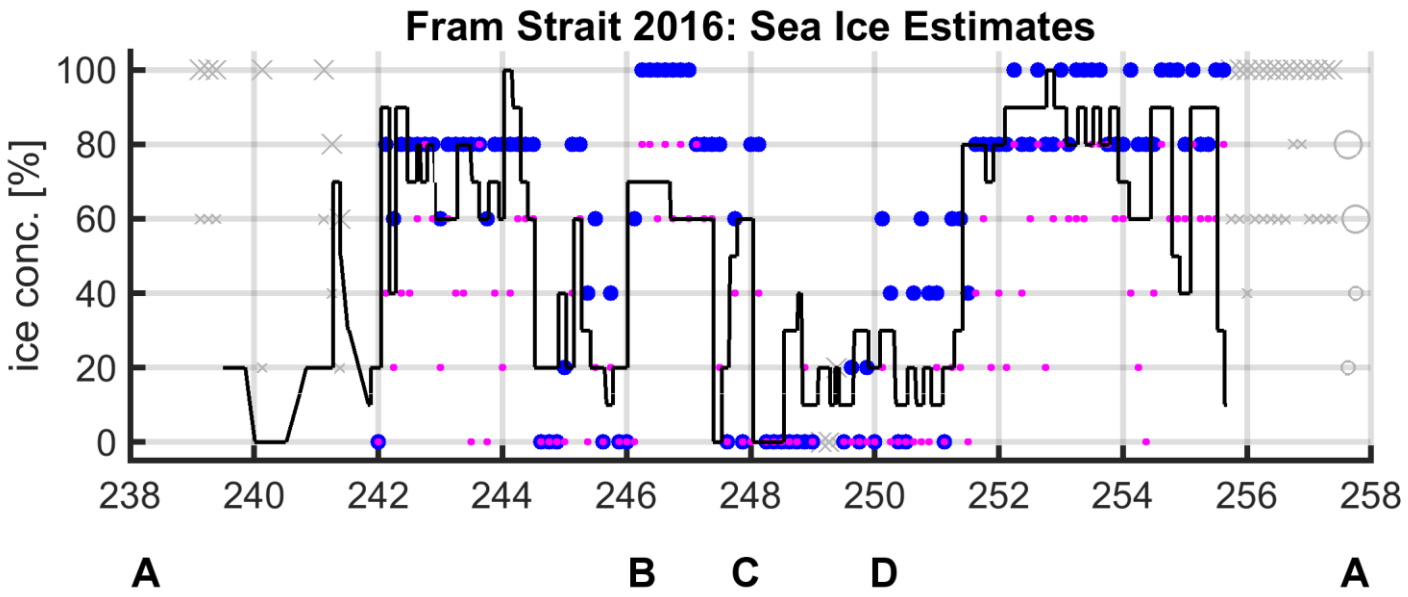

cross-polar
co-polar
cross-to-co-polar
power ratio [dB]
elev. angle [deg]
open water
multiyear sea ice

Data Level 1



open-water 20 % sea ice 40 % sea ice 60 % sea ice 80 % sea ice 100 % sea ice

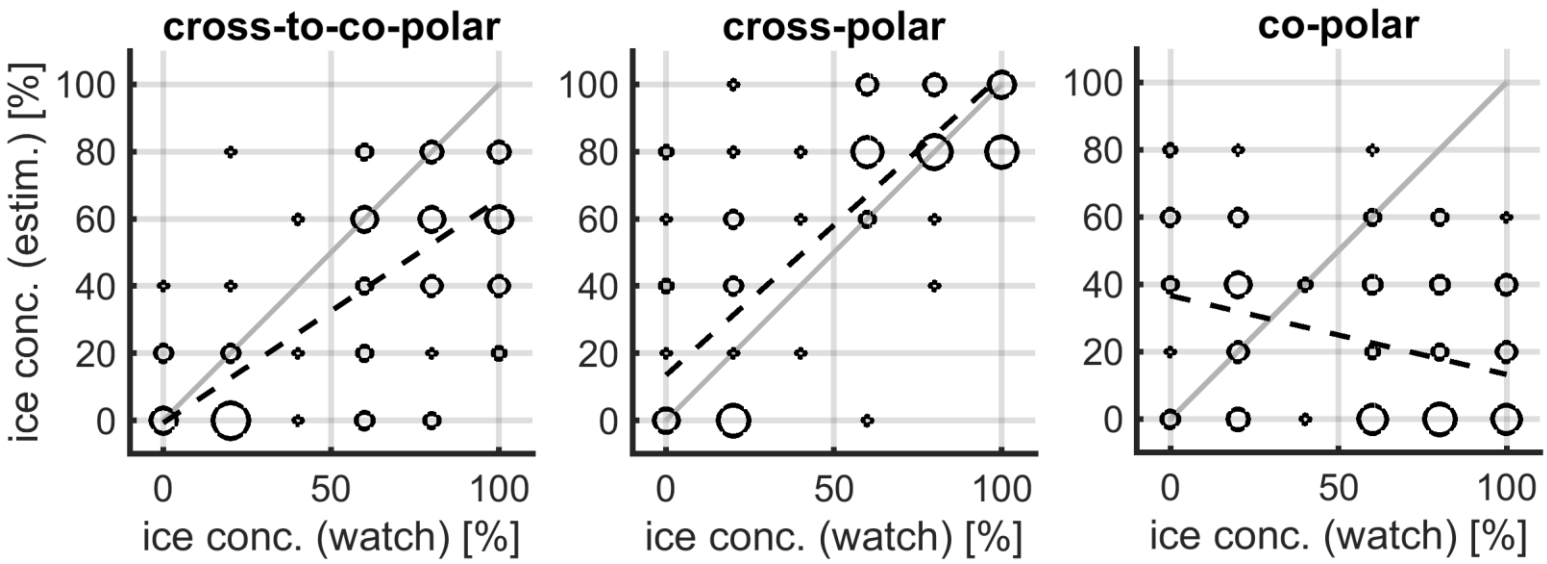
Data Level 2



- cross-polar ratio
- cross-to-co-polar ratio
- in-situ reference
- x high sea state (increased noise)
- o land reflection

Semmling et al. 2019
(under review)

Data Level 2



corr. coef.	0.67	0.75	-0.28
RMSE [%]	31	25	53
rough. est. [cm]	10	10	5

Soil Moisture Content

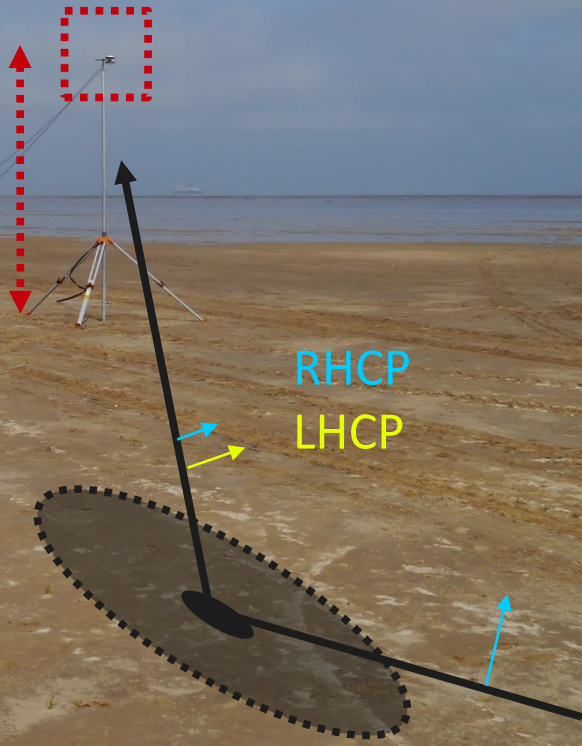
Experiment

direct signal

reflected signal

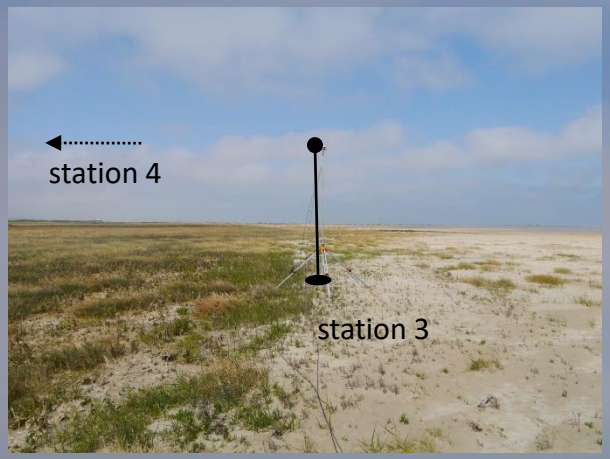
Inside box:

- delay line and signal combiner
- front-end bit grabber (Syntony) software solution



Setup cf.: Kucwaj et al. 2017

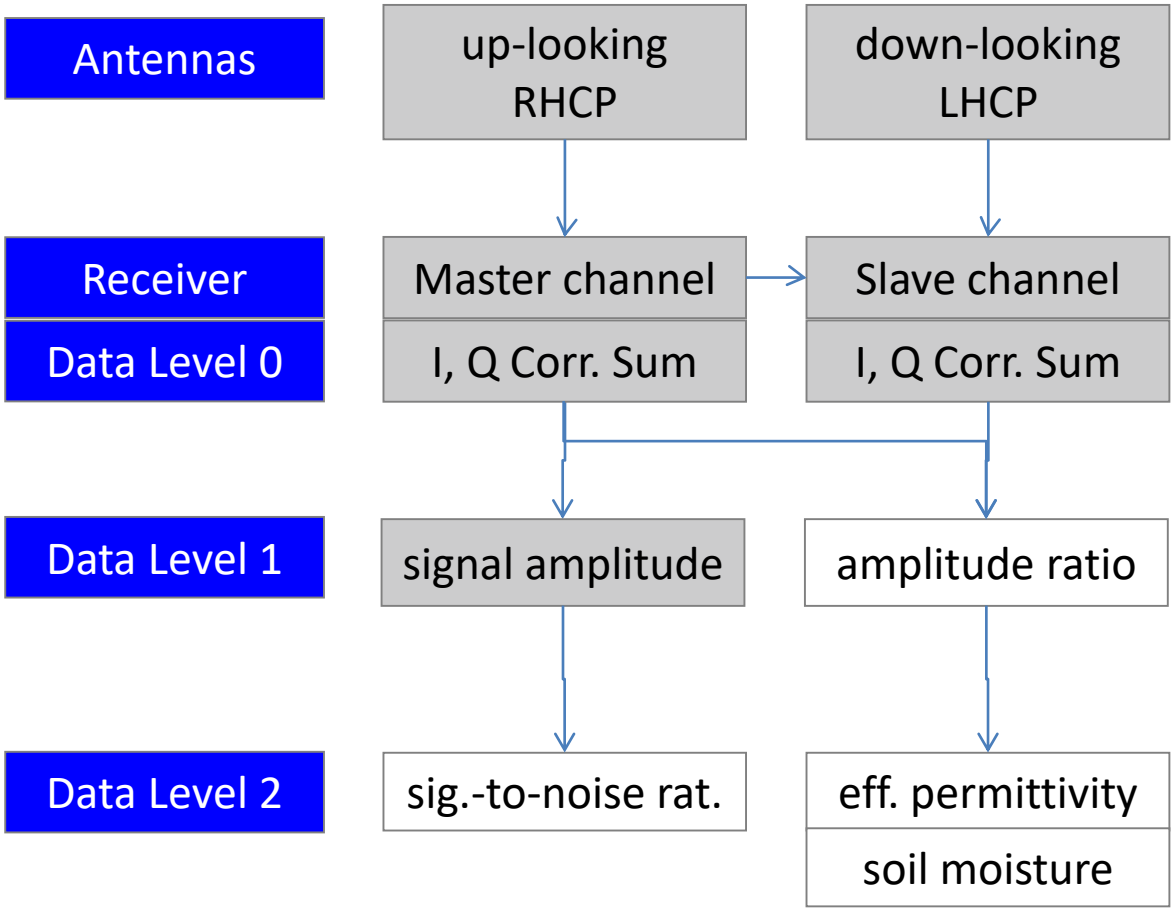
Experiment



station 1

station 2

Experiment



coherent tracking

Kucwaj et al. 2017

amplitude estimator

Reboul et al. in prep.

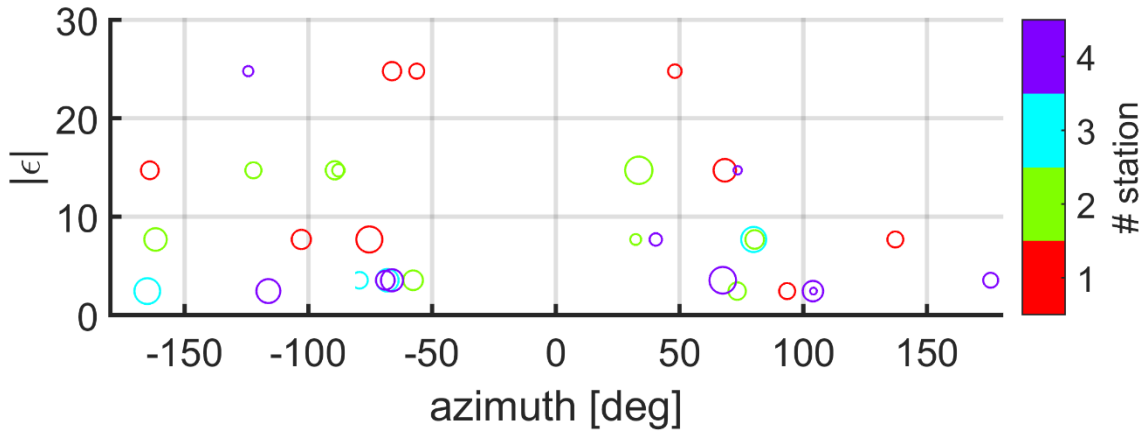
multipath separation

Semmling et al. 2013

permittivity model

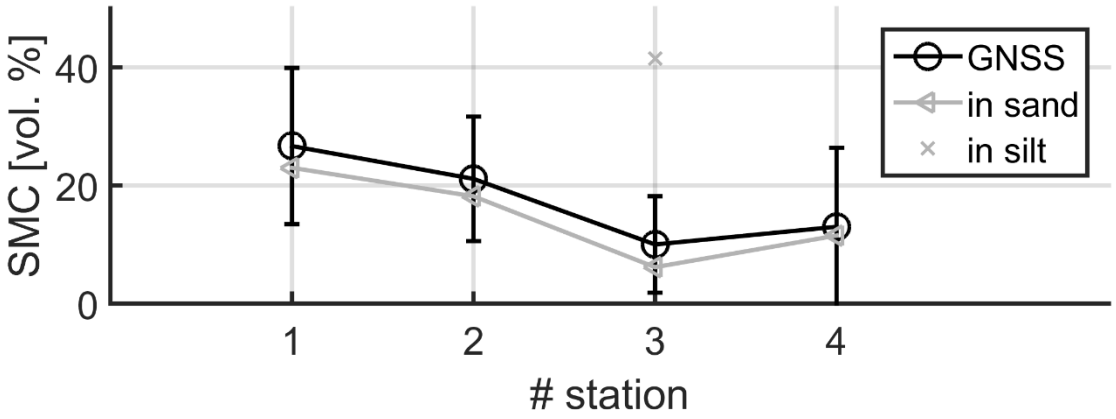
Vall-llossera et al. 2005

Preliminary Results



permitt. retrieval:

- 12 mn mean
- significant variation with azim.
- elev. dependence indic. (marker size)



related soil moisture:

- station mean
- agree with in-situ sand samples (corr. 0.99)
- differ from in-situ silt sample

Summary & Conclusion

Sea Ice Concentration

- shipborne GNSS reflectometry demonstrated
- coherent reflection data up to 30 deg elev.
- data processing (3 levels) up to sea ice concentration
- time series for 20 days in Fram Strait
- agreement with in-situ observations (corr. 0.75 and 0.67)
- extend coherent model to sub-surface reflections

Soil Moisture Content

- ground-based setup well-defined soil reflection scene
- coherent reflection data up to 60 deg elev.
- data processing (3 levels) up to soil moisture content
- 4-station retrievals mainly for sand
- agreement with in-situ sand measurements
- ambiguity of soil type (sand or silt)

Acknowledgements

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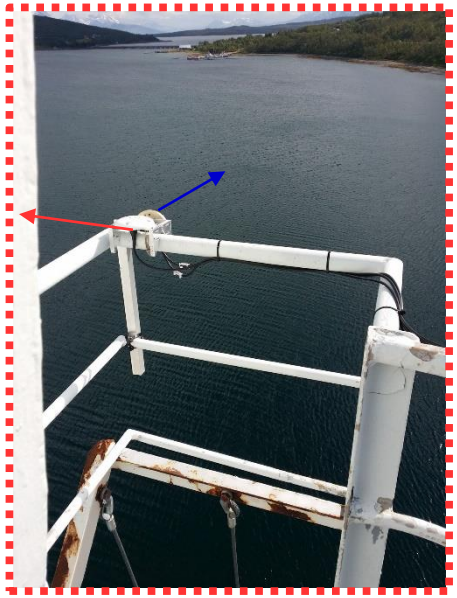
Thank you for your attention.

Photo: Ny-Alesund and Kongsfjorden, Svalbard Apr 2018

References

- Vall-llossera et al. 2005: L-Band Dielectric Properties of Different Soil Types Collected during the MOUSE 2004 Field Experiment.
  IEEE Int. Geoscience and Remote Sensing Symp.
- Oki & Kanae 2006: Global Hydrological Cycles andWorld Water Resources.
  Science.
- 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. 2014: Sea surface topography retrieved from GNSS reflectometry phase data of the GEOHALO flight mission.
  Geophysical Research Letters.
- Kucwaj et al. 2017: Circular Regression Applied to GNSS-R Phase Altimetry.
  Remote Sens.
- Peraza et al. 2017: Analysis of Grazing GNSS Reflections Observed at the Zeppelin Mountain Station, Spitsbergen.
  Radio Science.
- Cardellach et al. 2018: GNSS Transpolar Earth Reflectometry exploriNg System (G-TERN): Mission Concept.
  IEEE Access
- Semmling et al. 2019: Sea Ice concentration derived from GNSS reflection measurements in Fram Strait.
  IEEE Trans. Geosci. Remote Sens. (under review)

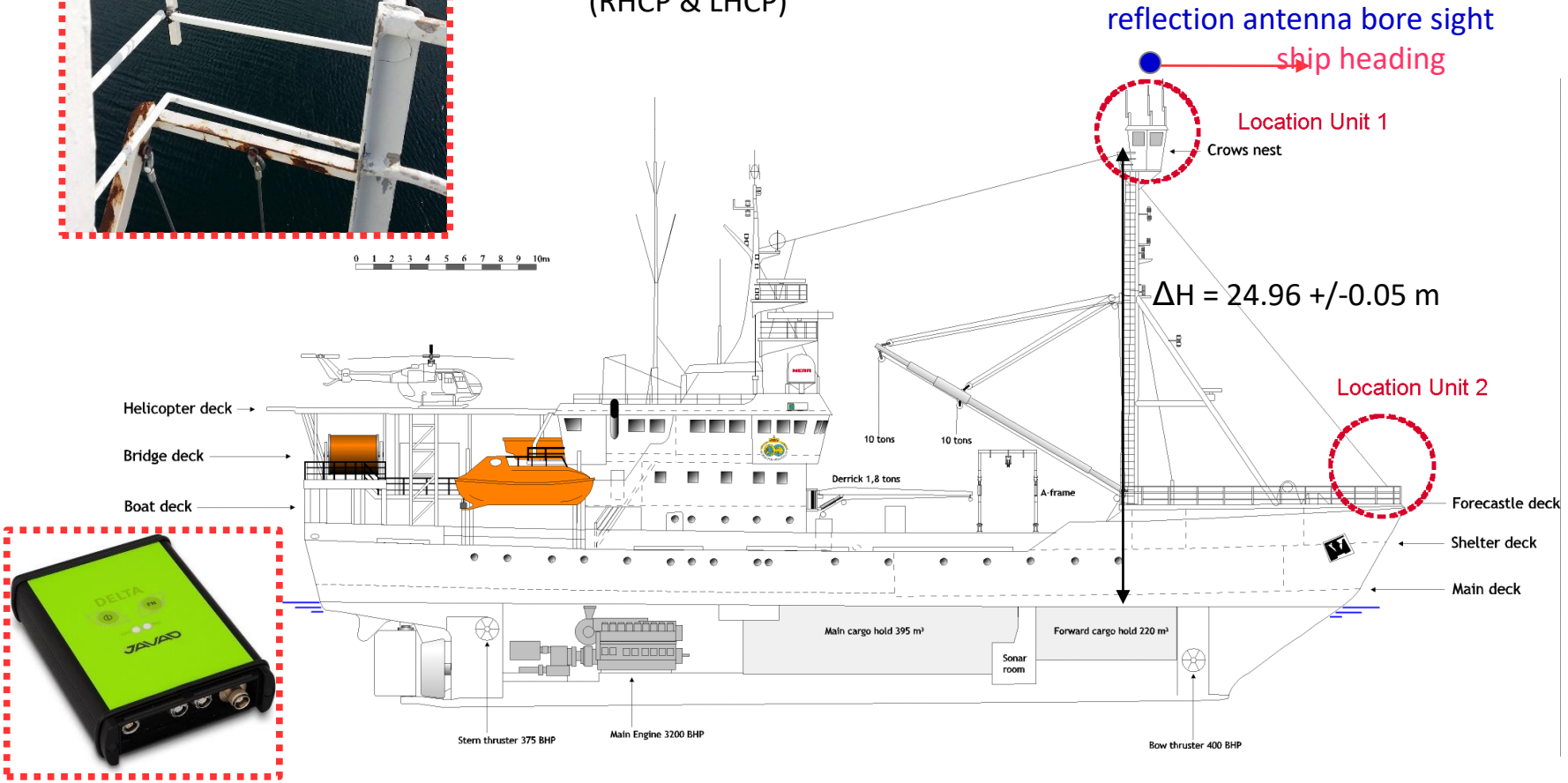
Hardware Setup



three antenna links

- up-looking for direct signal
- two starboard-looking for reflection (RHCP & LHCP)

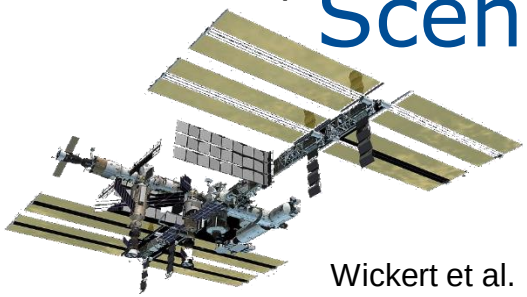
cf. Semmling et al. 2013



Altimetric Scenarios

Scenarios

D: Internat. Space Station

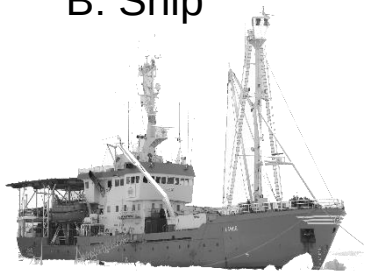


Wickert et al. 2016

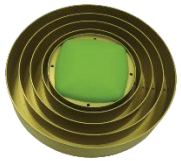
C: Aircrafts

Semmling et al. 2014

B: Ship



A: Ground Stations

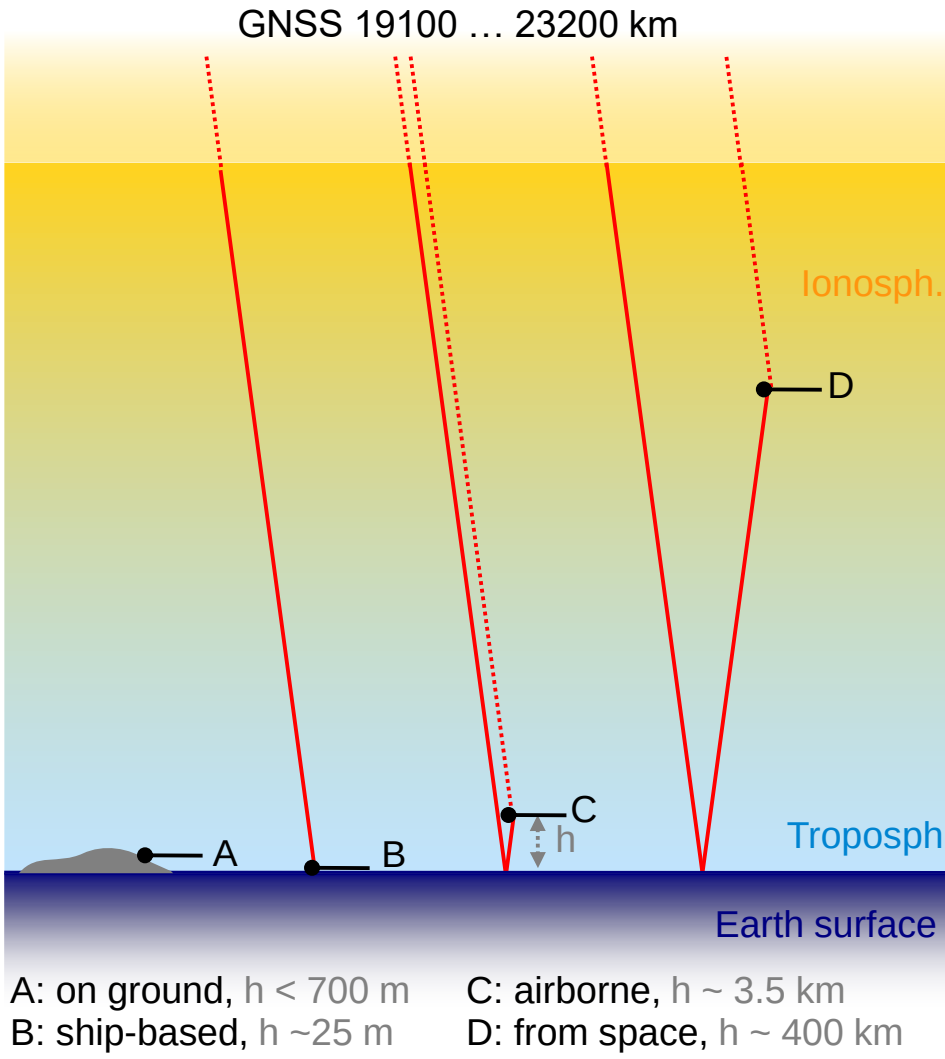


Vey et al. 2015

Peraza et al. 2017

Properties of Earth Surface

- height, penetration depth (phase)
- roughness and reflectivity (amplitude)

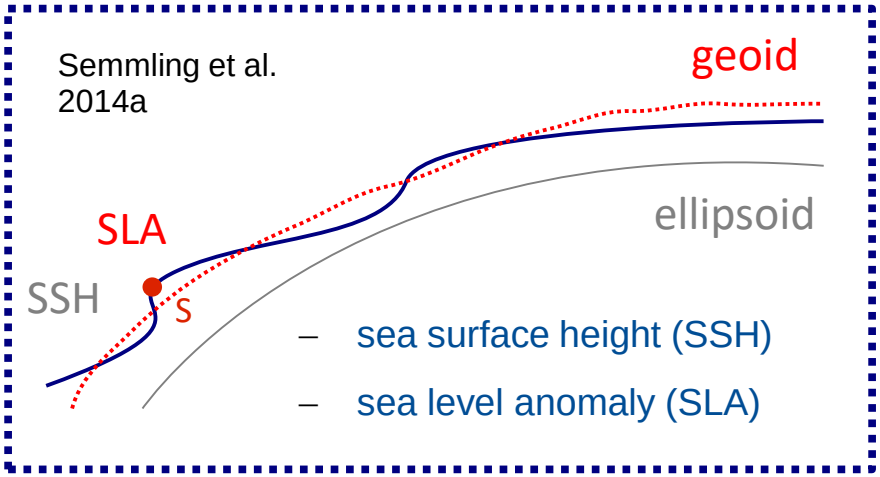


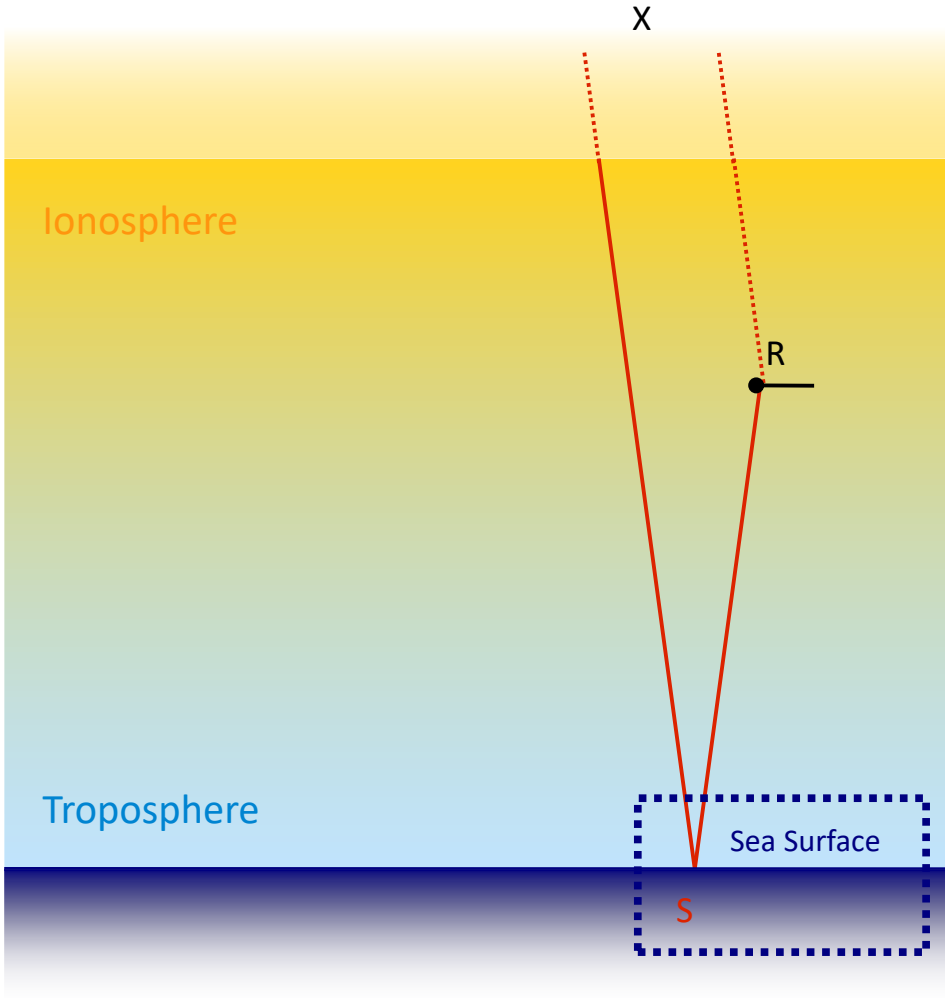
A: on ground, h < 700 m
B: ship-based, h ~25 m
C: airborne, h ~ 3.5 km
D: from space, h ~ 400 km

Altimetric Concept

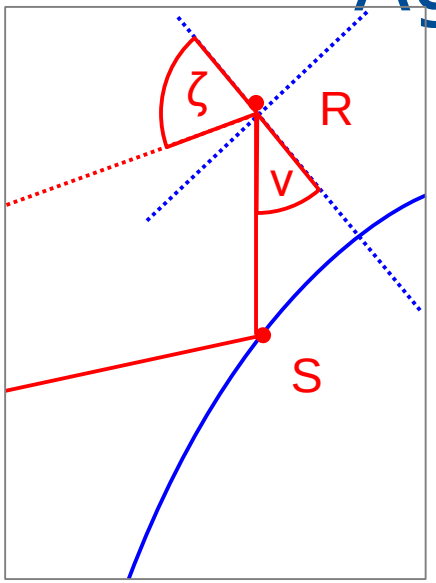
Model Contributions

- geometric path
- ionospheric excess path
- tropospheric excess path
- **SLA** residual



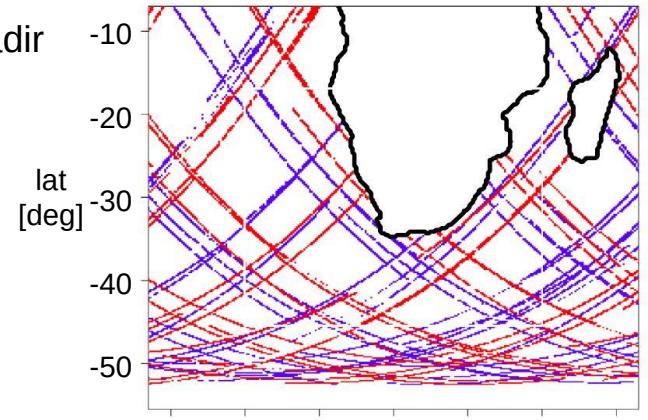


Agulhas Scenario

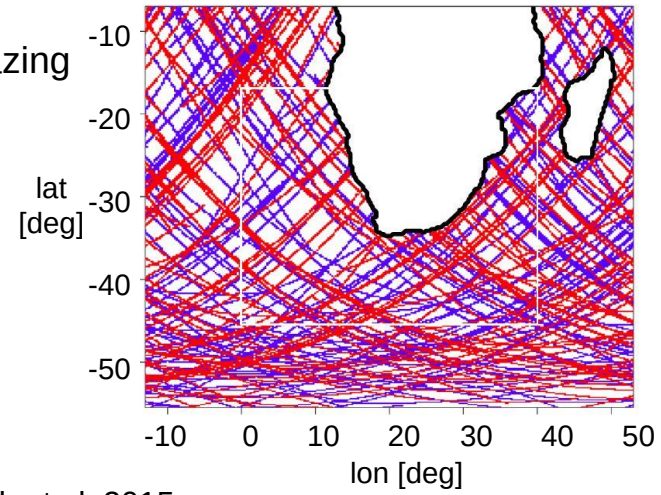


two day ocean coverage

near nadir
v < 41°



near nadir & grazing
v < 67°



Saynisch et al. 2015

Sea Level Anomalies

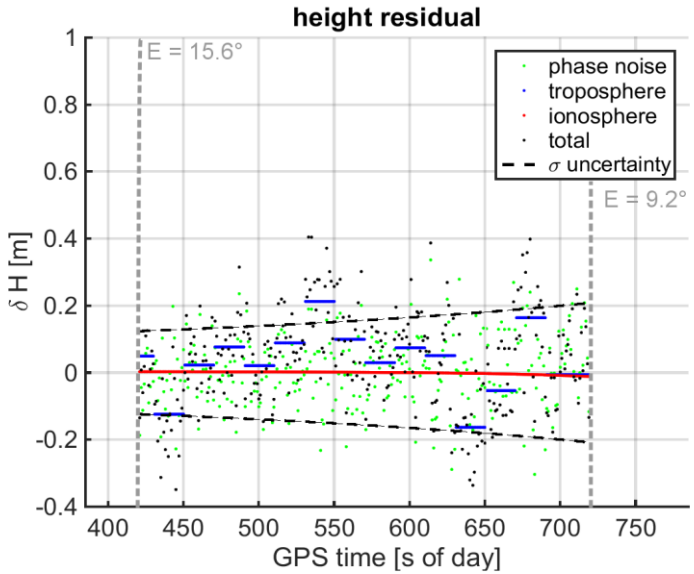
- simulated for assimilation in ocean model
- near nadir obs. leave considerable gaps
- coverage improved by additional grazing obs.

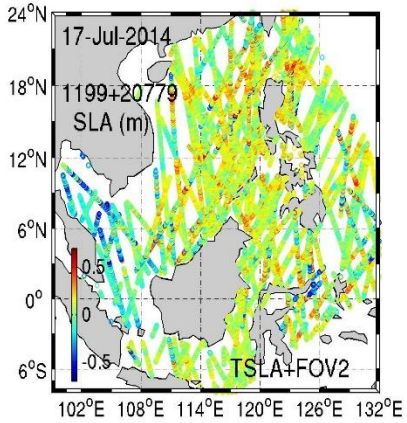
South China Sea Scenario

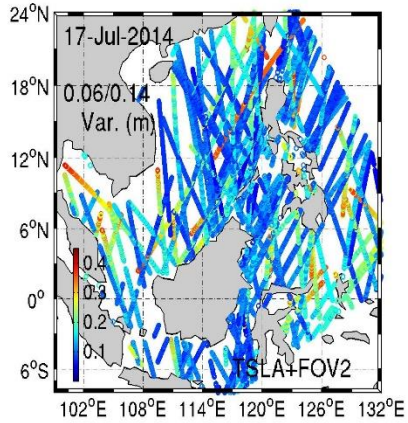
Sea Level Anomalies

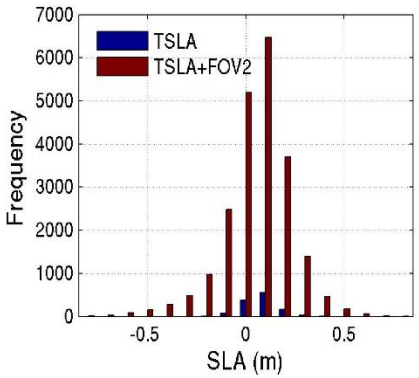
- simulated for typhoon detection
- assuming grazing observations (FOV2)
- ionosphere and troposphere correction
- total RMS error in dm range
- number traditional observations (TSLA) significantly exceeded

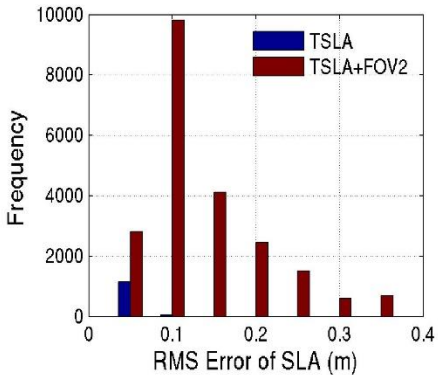
Xie et al. 2018



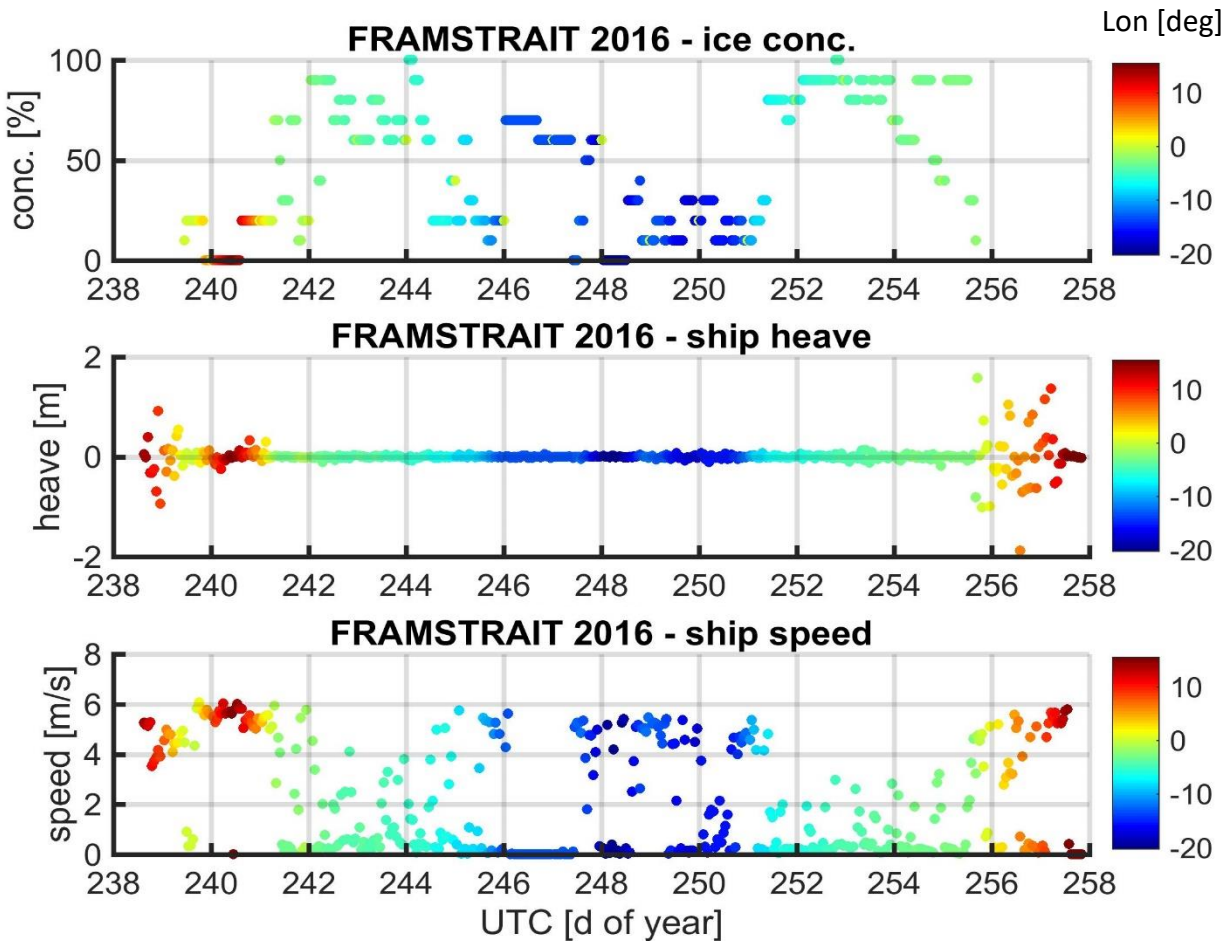








Fram Strait Cruise



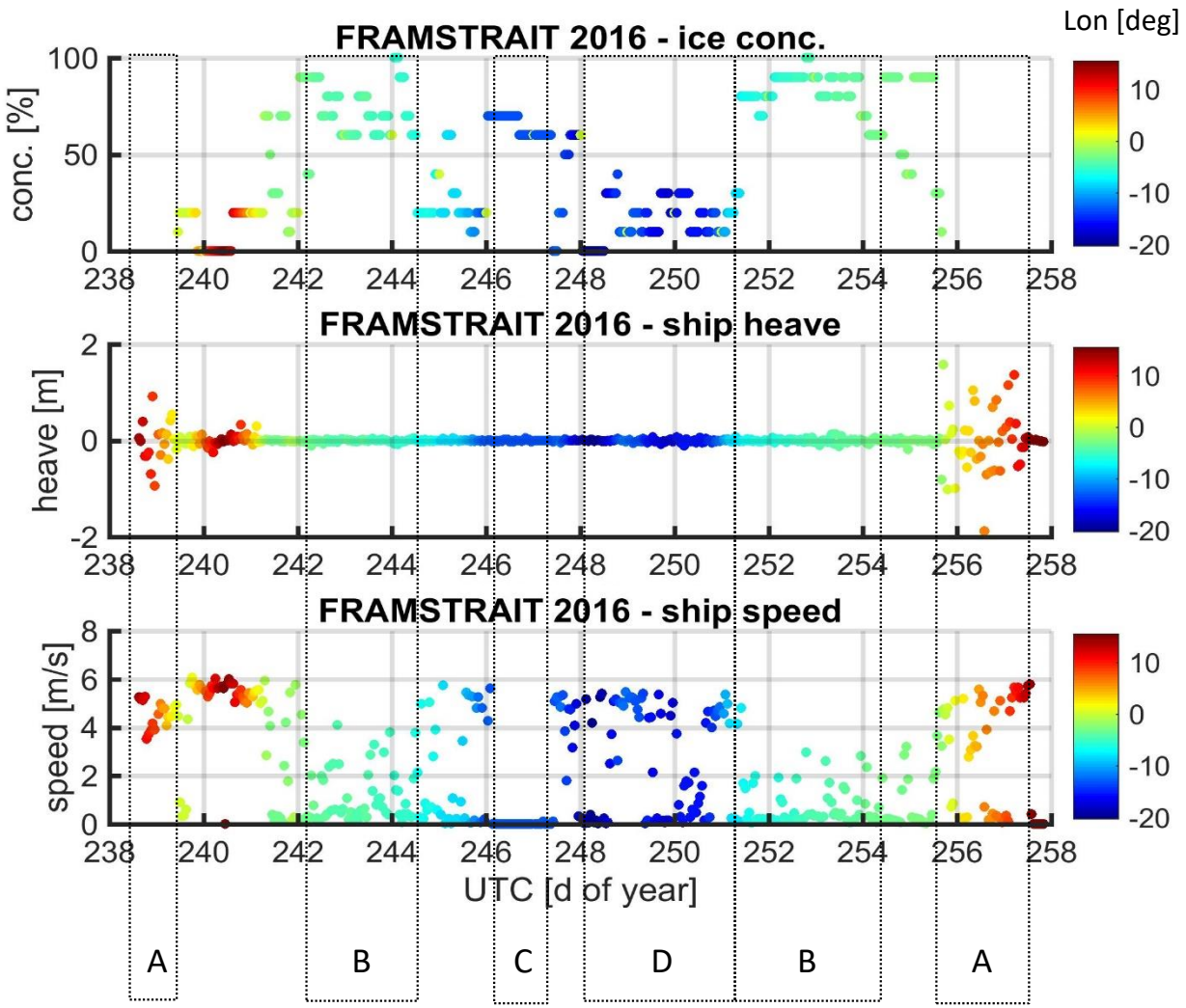
A: rough sea
- heave > 0.5 m

B: close drift ice
- conc. > 50 %

C: fast ice
- conc. > 50 %
- speed = 0

D: open drift ice
- heave < 0.5 m
- conc. < 50 %

Sea Ice Scenarios



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Height Estimates