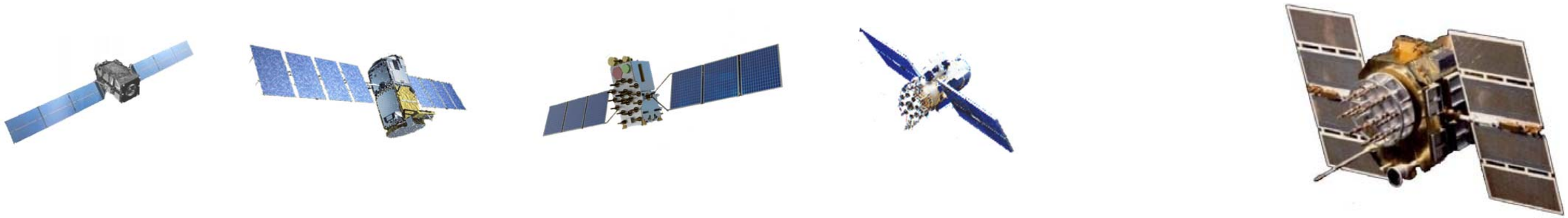
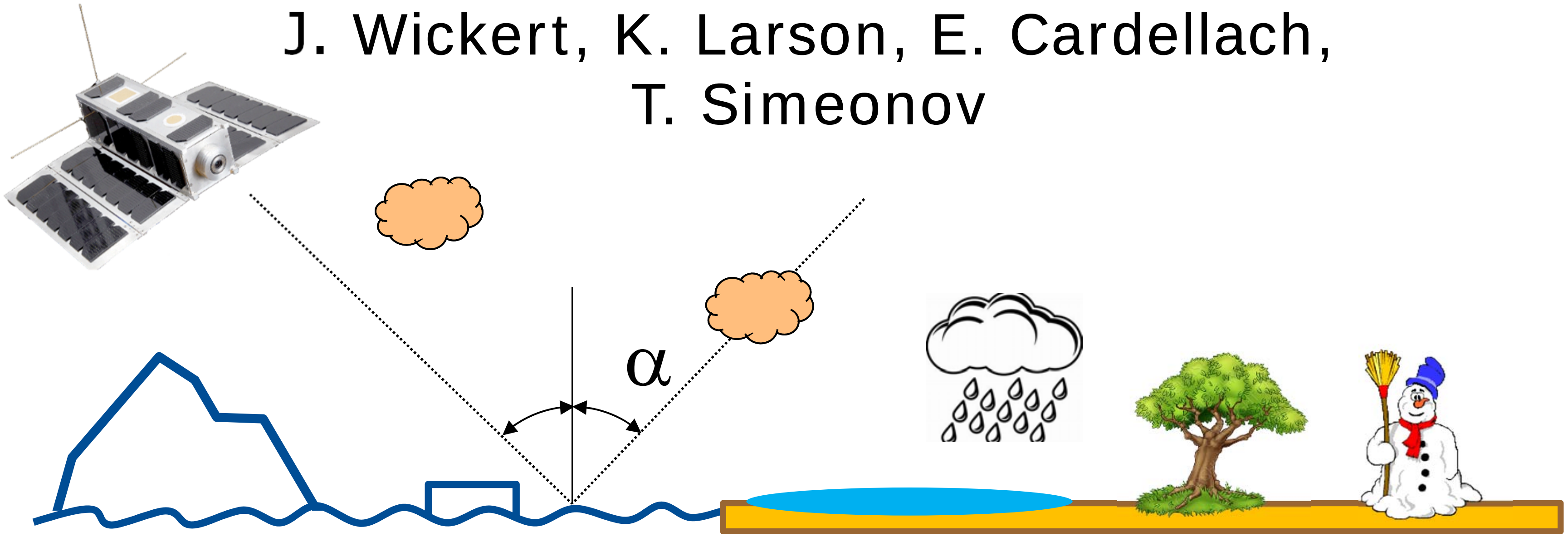


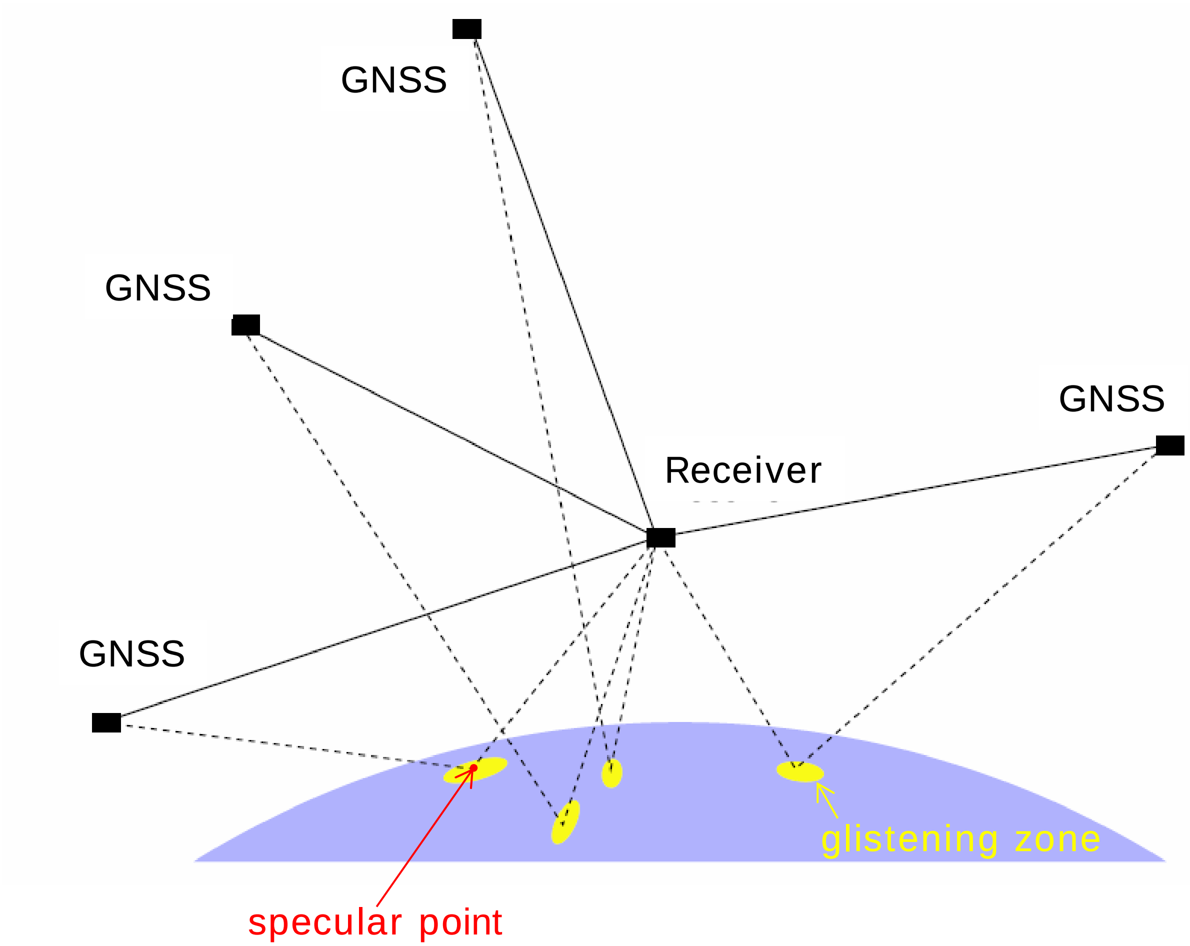
GNSS-Reflectometry for Earth Observation: History, Results and Prospects

J. Wickert, K. Larson, E. Cardellach,
T. Simeonov



What do we speak about?

GNSS Reflectometry



*Multistatic radar
(Transmitter/Receiver at different locations, receiving of „echos“ from reflecting objects, several parallel)

*Transmitters (~100): GPS, GLONASS, Galileo, Beidou, QZSS, microwaves L-Band

*Receivers: satellites, aircrafts, ground stations etc.

*Reflections over oceans, land, ice, snow

*Specular points, Glistening zones

*High rain transmissivity

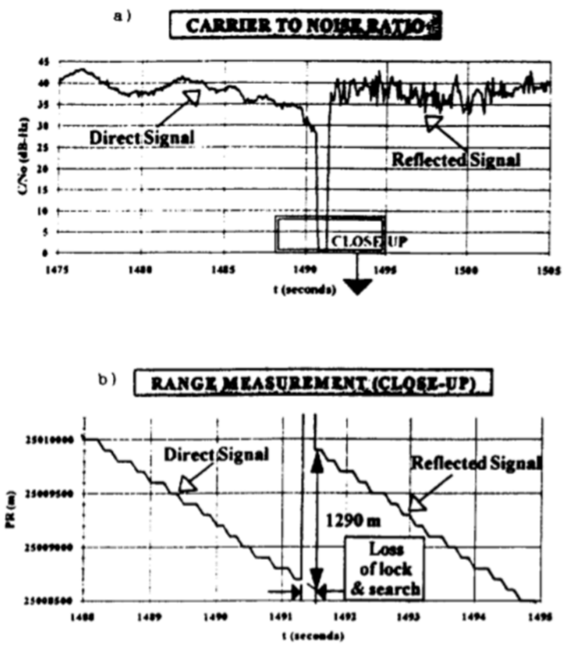
*High degree of synergy with GNSS-RO for satellite based application

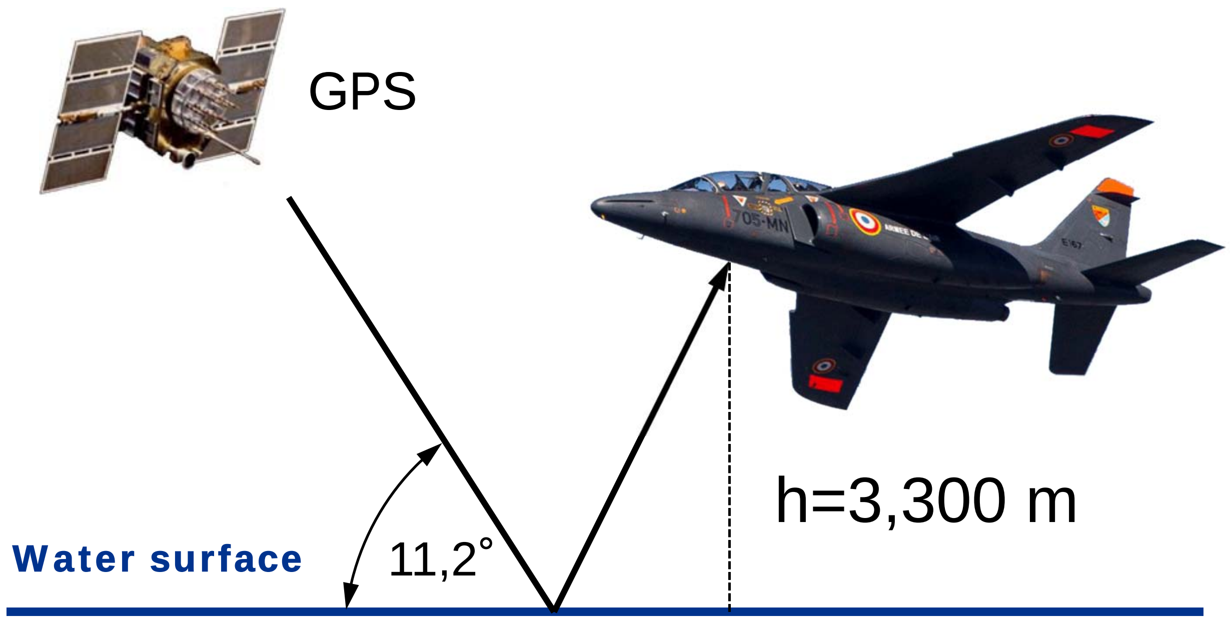
Some history

GNSS-R History I

1988 Hall and Cordey: proposed concept of Multistatic scatterometry using GPS

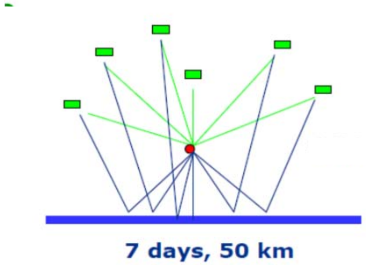
1991 Incident with french Alpha-Jet aircraft over the Atlantic ocean testing GPS receiver did show that reflected signals could be tracked (Aubert et al., 1994)





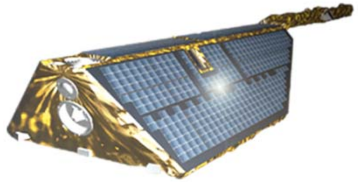
GNSS-R History II: Satellites (selection)

PARIS
(Martin-Neira 1993)



SHUTTLE
(Lowe et al., 2001)

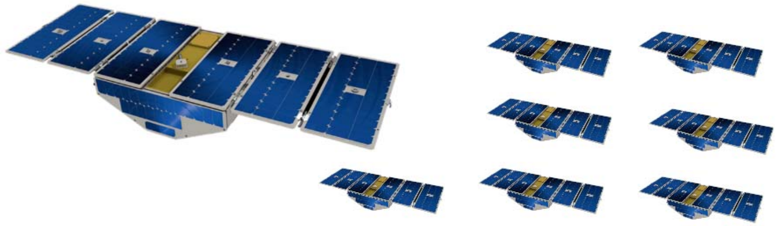
CHAMP
(Beyerle et al., 2002,
Cardellach et al., 2004)



UK-DMC
(Gleason et al., 2005)

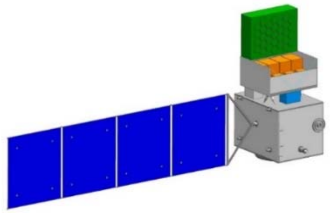
TDS-1
(Unwin et al., 2016)

CYGNSS
(Ruf et al., 2018)



GEROS-ISS
(Wickert et al., 2016)

G-TERN
(Cardellach et al., 2018)



PRETTY
(Fragner et al., 2017)

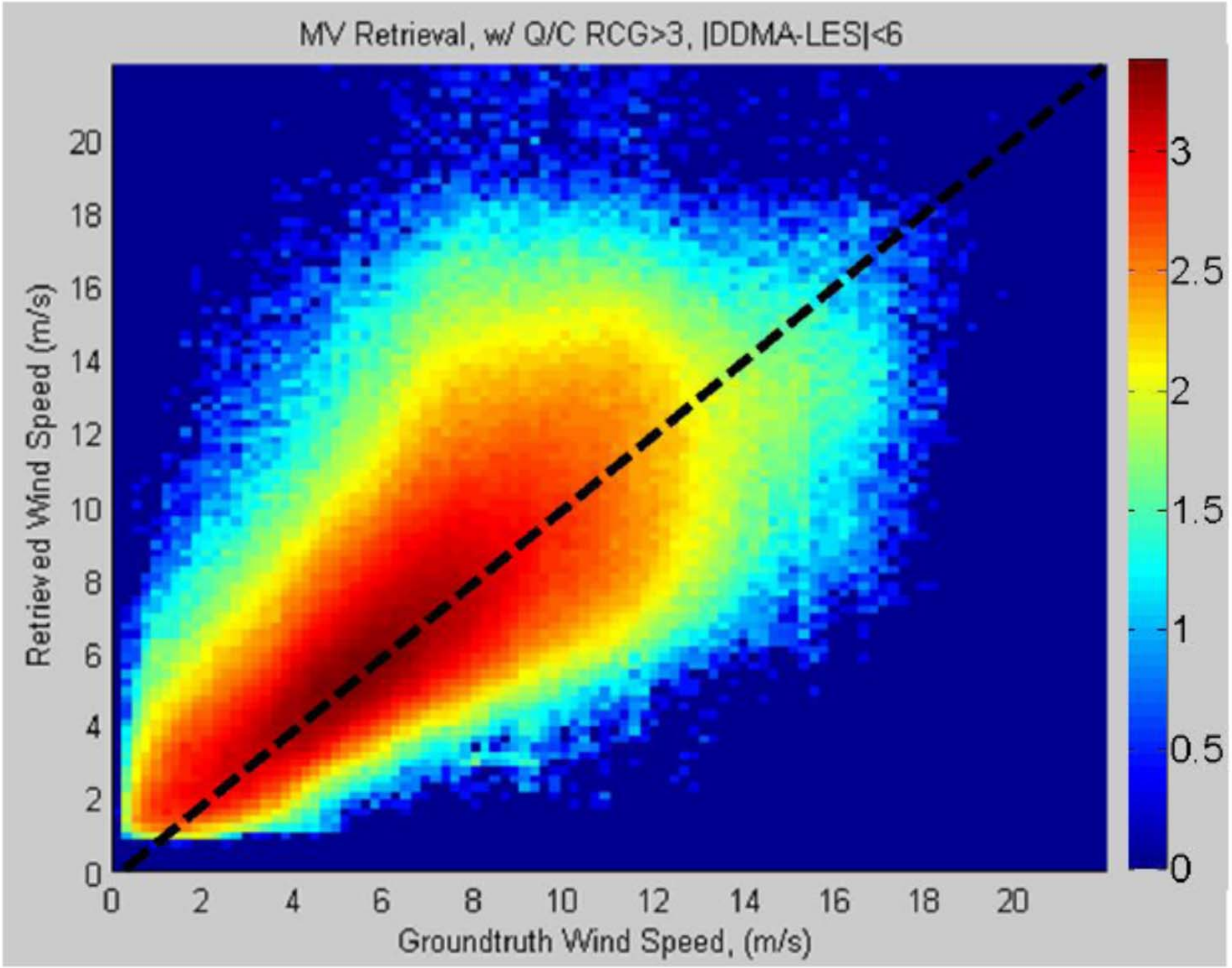
GNSS-R History III: CYGNSS wind speeds

Groundtruth: ECMWF

30.9 M matchups

1.96 m/s RMS (incl. error in ECMWF & interpolation)

Block IIR IIR-M (IIF Excluded)

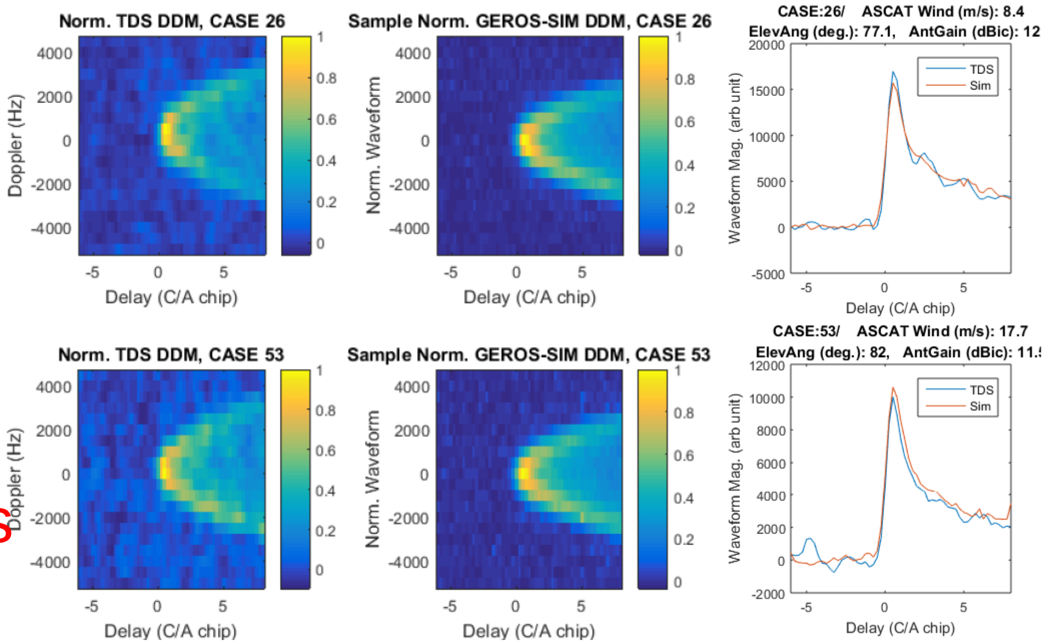


Ruf et al., IEEE, 2018, wind speed < 20 m/s

GNSS-R History IV: **GEROS-SIM**ulator: Altimetry

Wind
8.4 m/s

Wind
17.7 m/s



GEROS-SIM tested with real TDS-1 data and compared with simulated GEROS interferometric approach

Different wind speeds assumed

Integration time:	Along-track resolution:	Across-track resolution:	Precision figure:
L5 with 'clean' ionospheric correction			
1 second	7.5 km	4 km	11.3 cm
14 seconds	100 km	4 km	3.0 cm

precision
3.0 cm

Estimated precision is well within Mission requirement

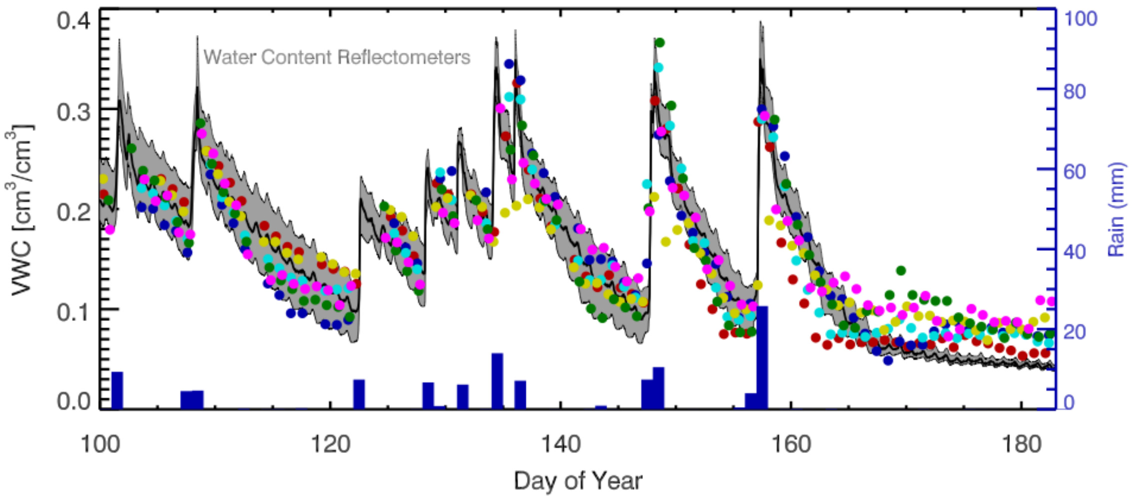
Wickert et al., 2016

GNSS-R history V: Geodetic Receivers and Zenith-pointing Antennas

2008-2010 Initial demonstrations of soil moisture, snow depth, vegetation water content measurements (Larson, Small, Braun, Zavorotny).

2013 First sea level measurements (Larson, Löfgren, Haas).

2017-present Deployments of GNSS units to Antarctica, Greenland, and Alaska for reflectometry.



Selected principles

Specular and diffuse reflection

Visible light at sunset: (water is quite calm inside the red ellipse)

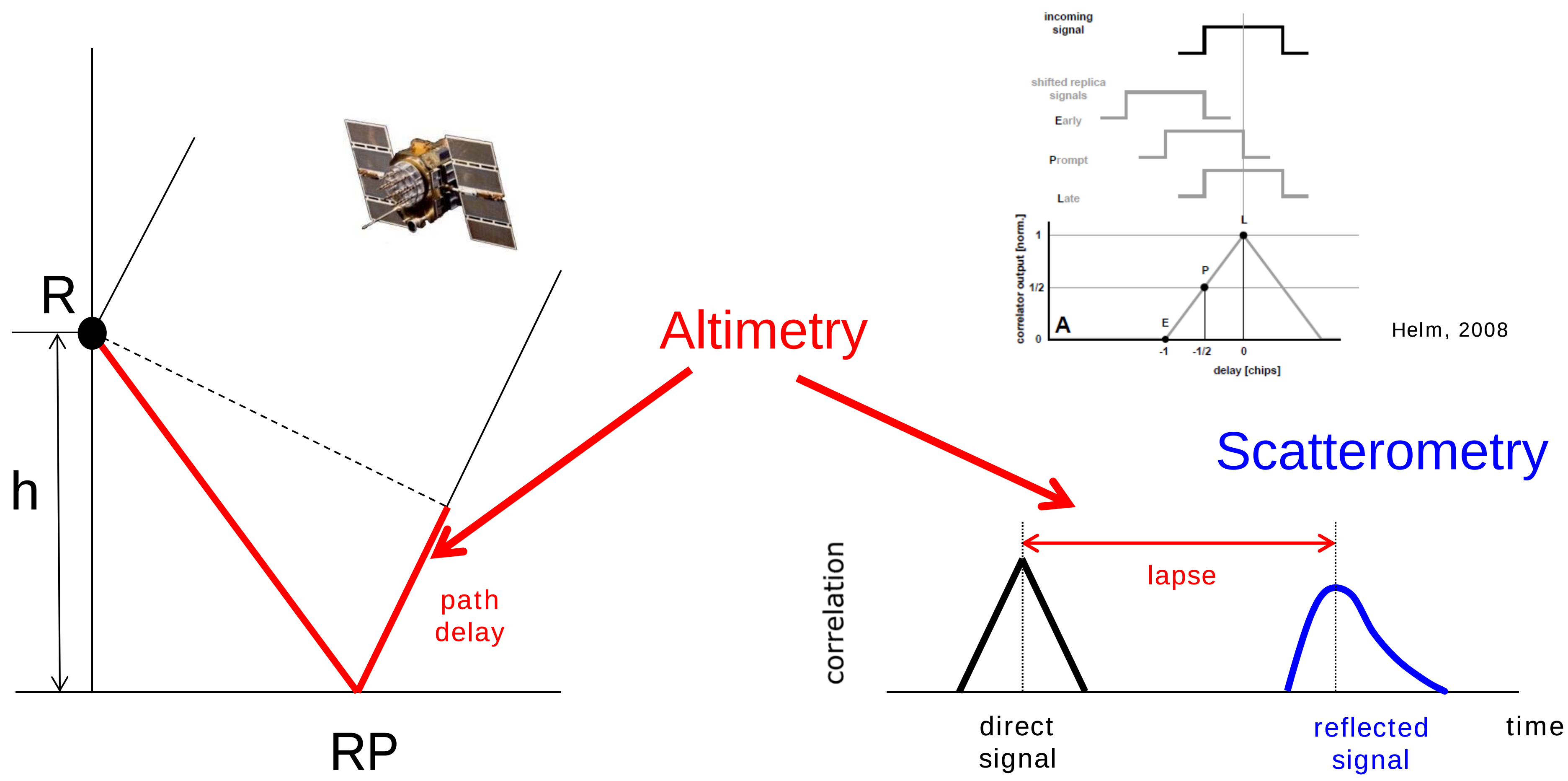
Glistening zone turns to be a specular point

(From Chapron and Ruffini, Photo taken at Le Conquet, Brittany)

GNSS-Reflectometry (Altimetry/Scatterometry)

Path delay (lapse)

Correlation and waveform



Applications, results and prospects

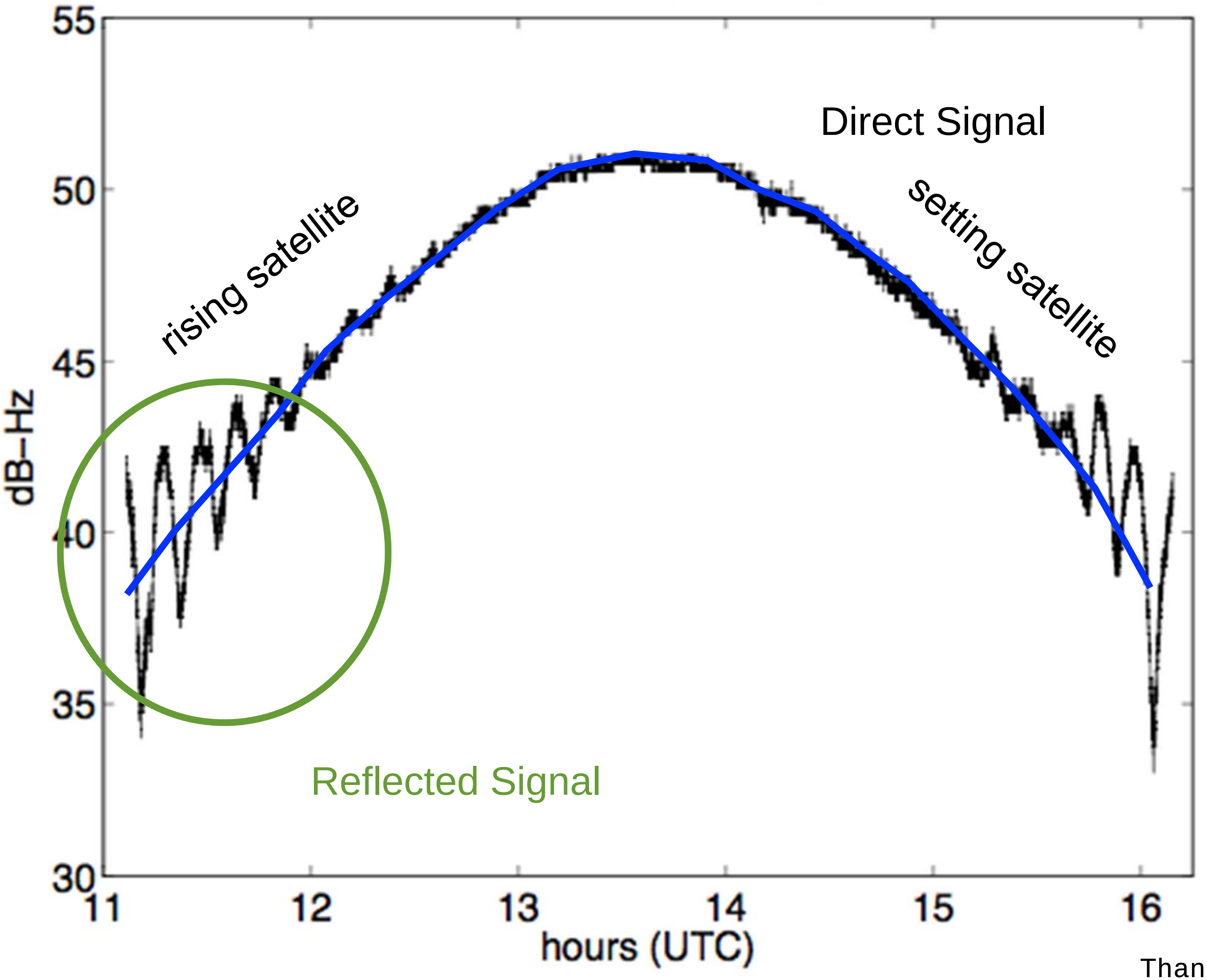
Applications of GNSS Reflectometry

- Weather: wind direction/velocity, specific humidity, precipitation?
- Climate: sea level, sea ice coverage, ice shelf altitude, salinity
- Ionosphere and Space Weather: electron density
- Disasters: tsunami early warning, flood monitoring
- Land surfaces: soil moisture, biomass, snow cover and depth, humidity content of snow
- Infrastructure: ship detection

Wickert et al., EU-project report GfG², 2012

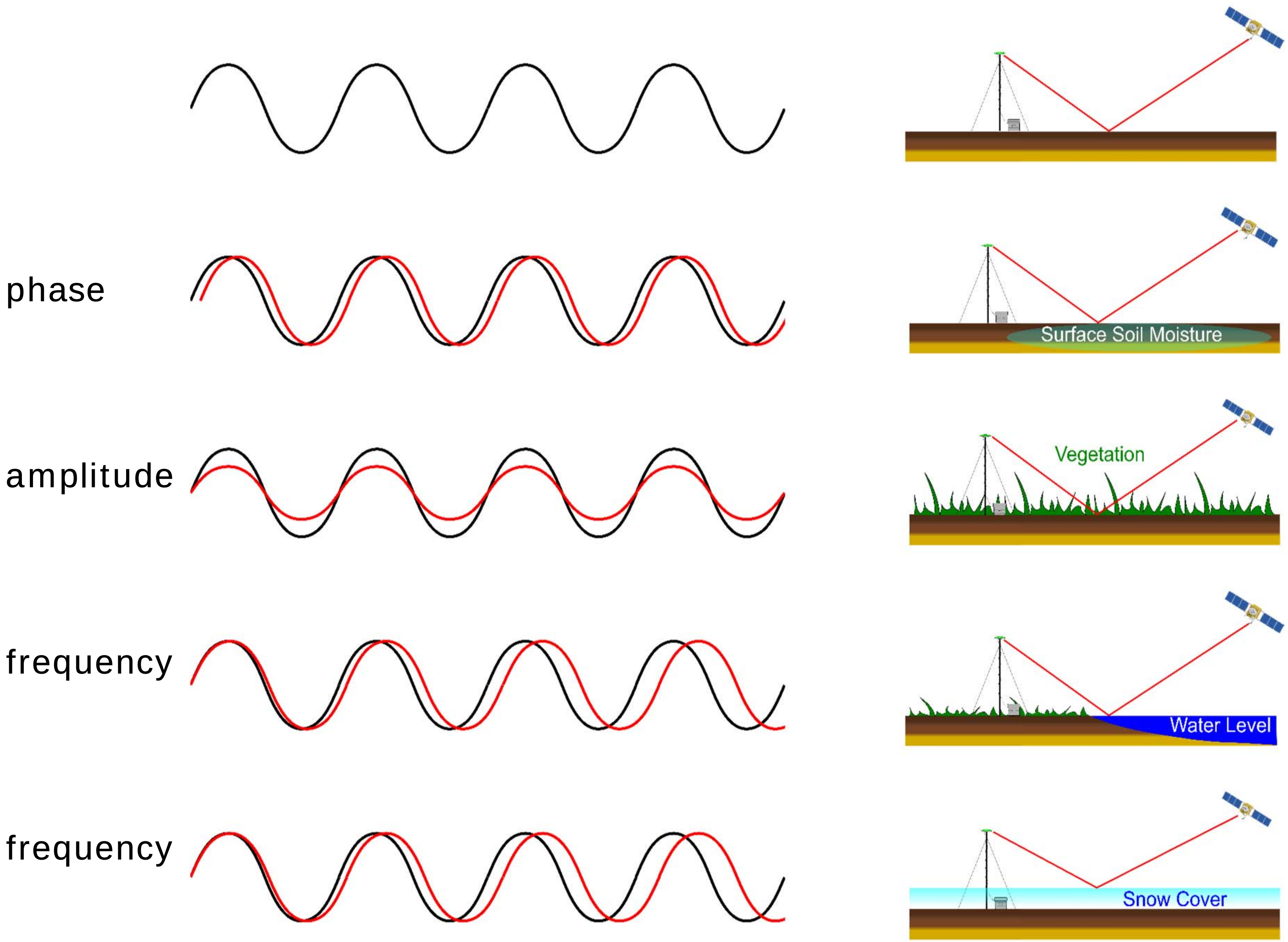
E.g., land surface monitoring with geodetic receivers

How does it work?: GNSS SNR Data

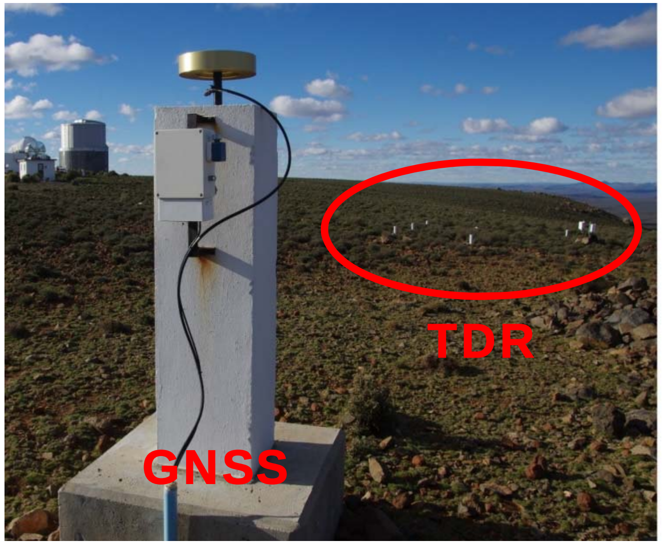


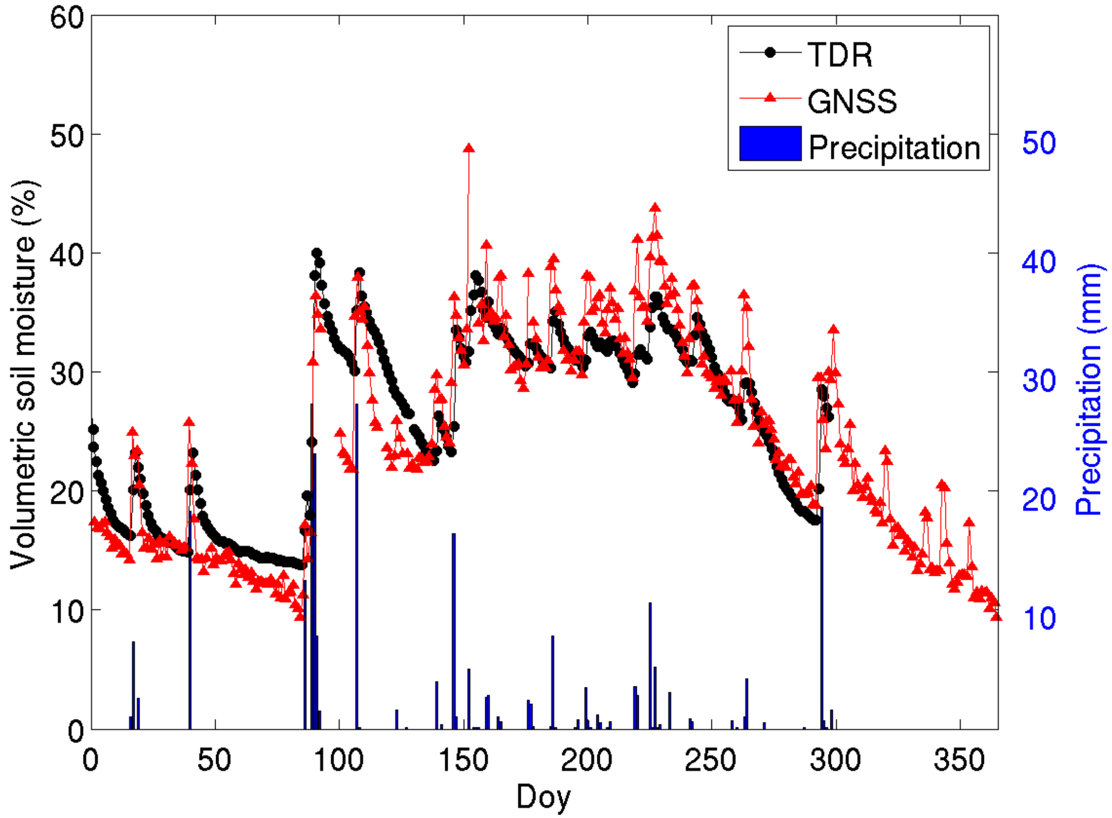
Thanks: K. Larson

Multipath patterns can be exploited for Remote Sensing



Soil moisture at Sutherland, South Africa





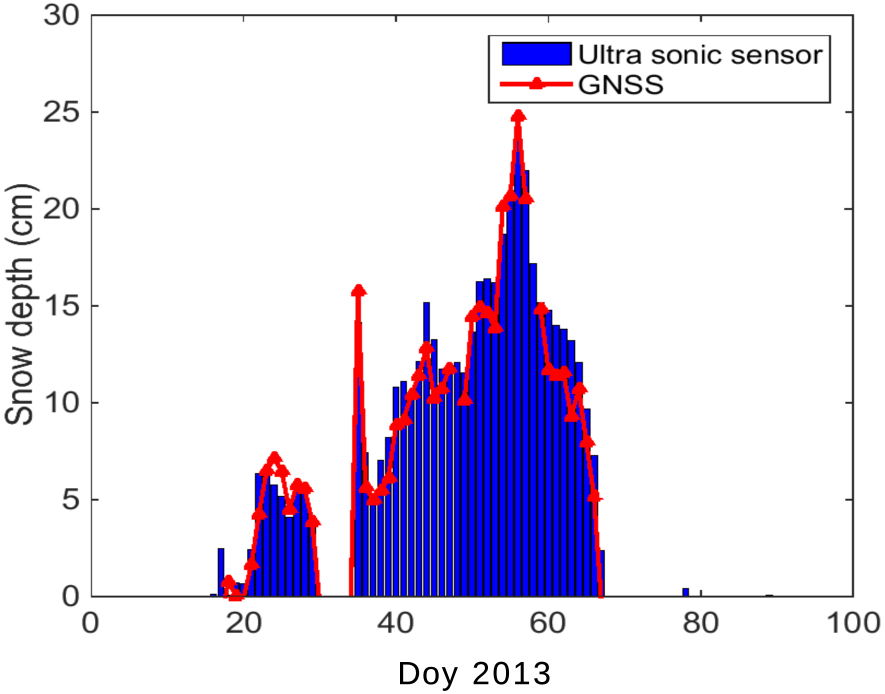
Very good representation of precipitation events and evapotranspiration

Vey et al., 2016

Snow depth in Bavaria, Germany

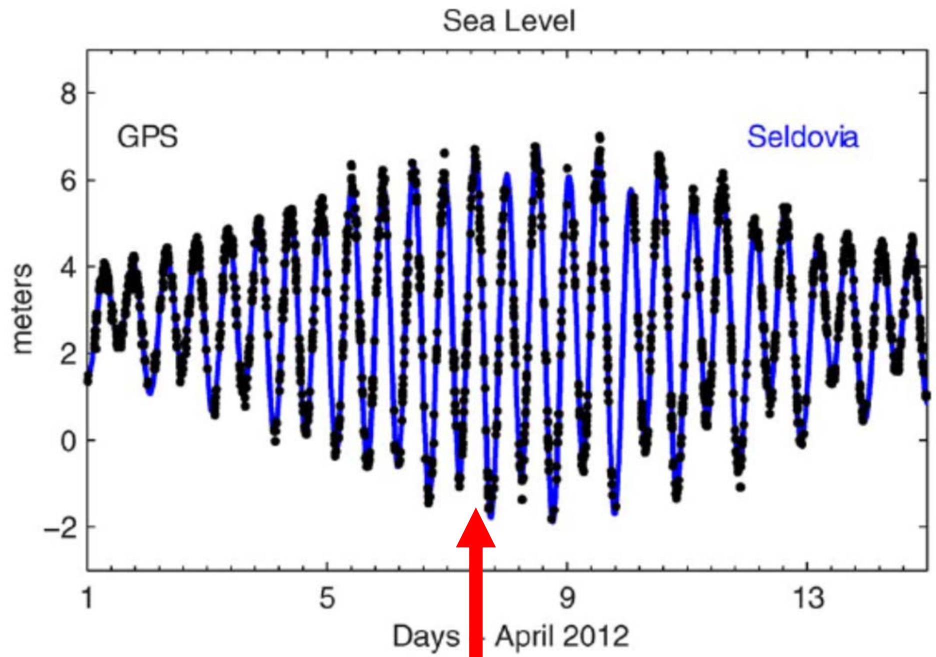
Methodic study at Wettzell

GNSS derived snow depths correspond very well to in-situ observations by an ultra sonic sensor (RMSE 1.7 cm)



Vey et al., 2016

„Accidental“ Tide Gauge“ near Kachemark Bay, Alaska

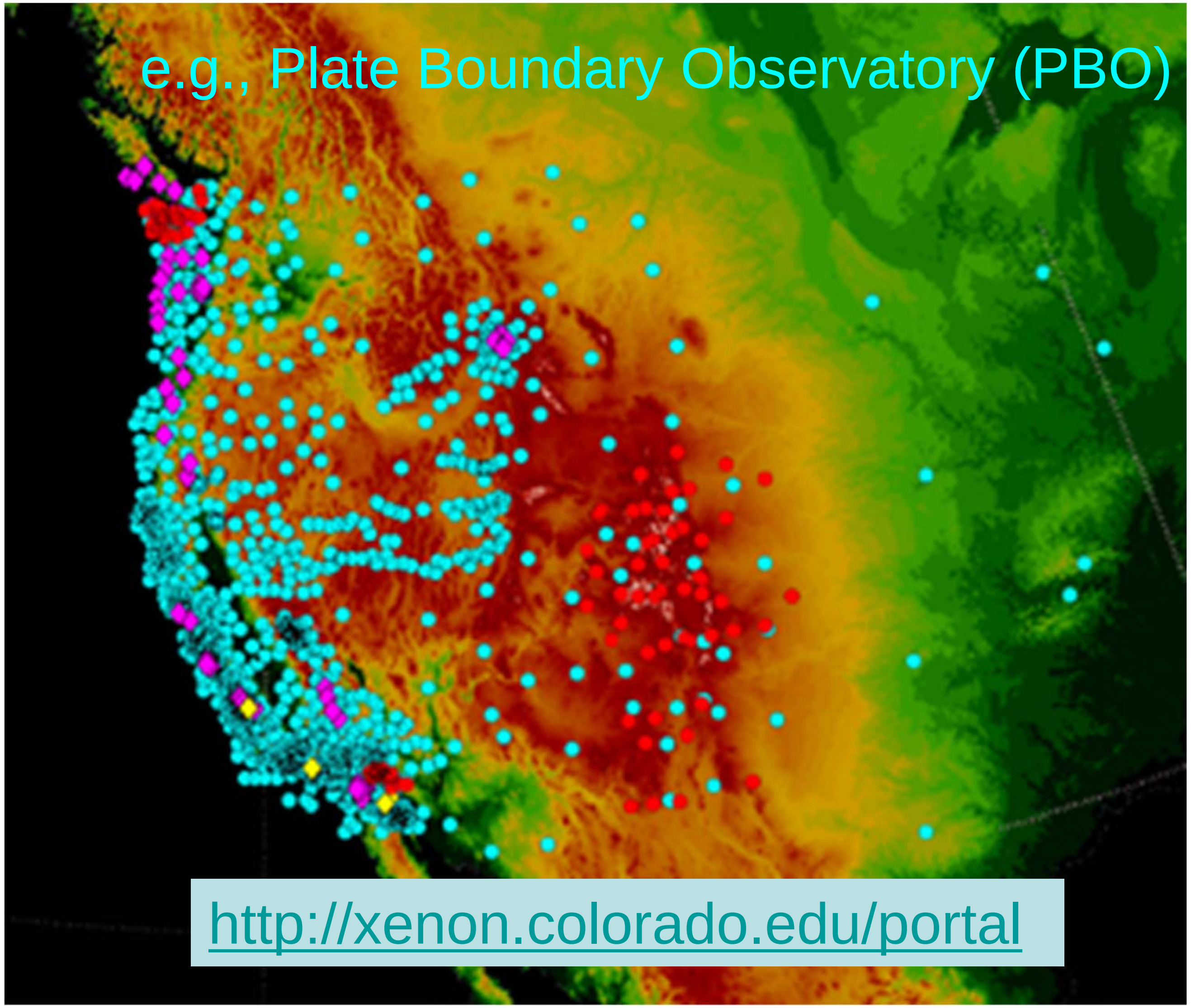


GPS site installed to measure crustal deformation

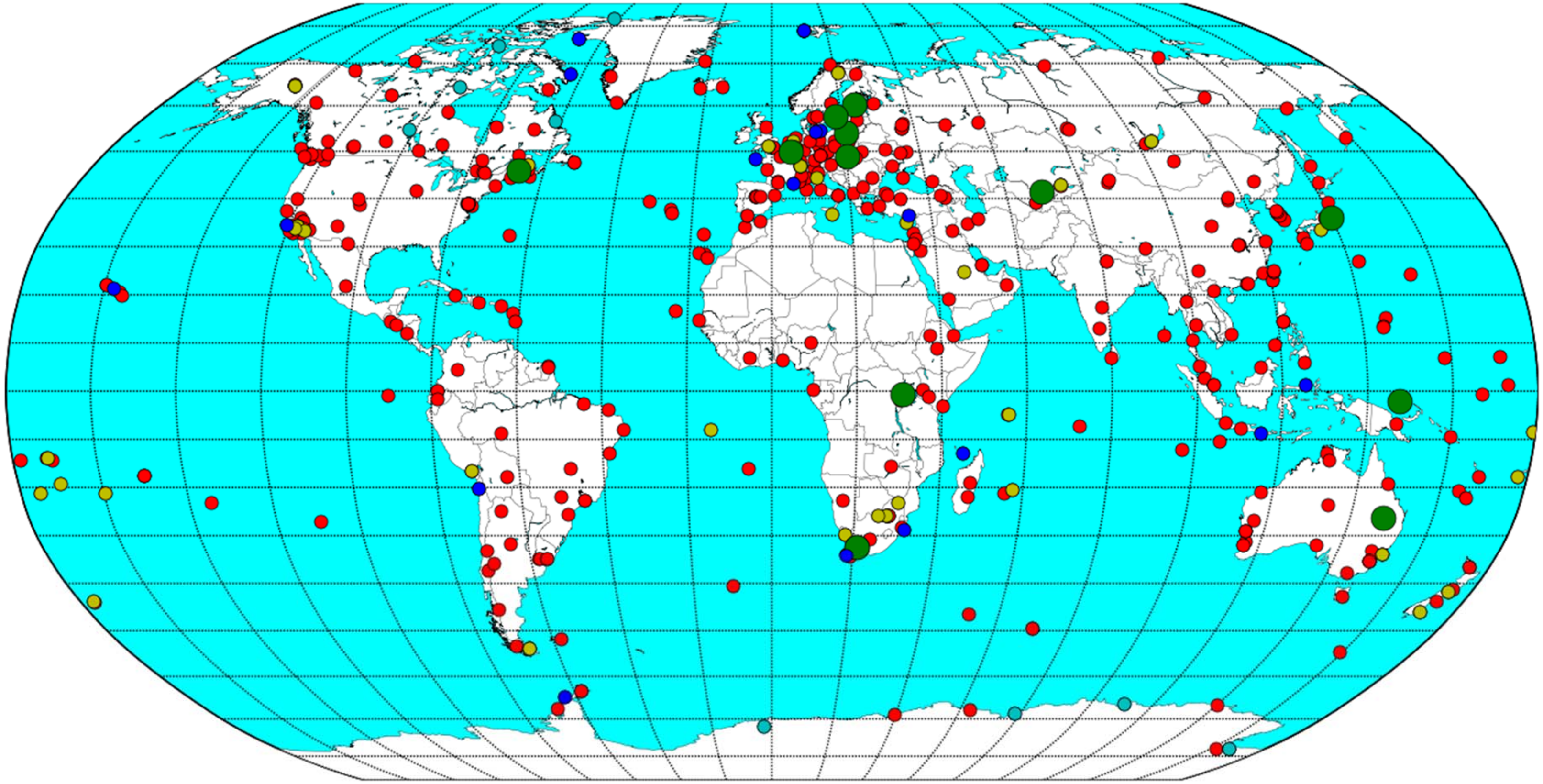
9 meters tides amplitude

Larson et al., 2013

Operational usage of existing ground networks



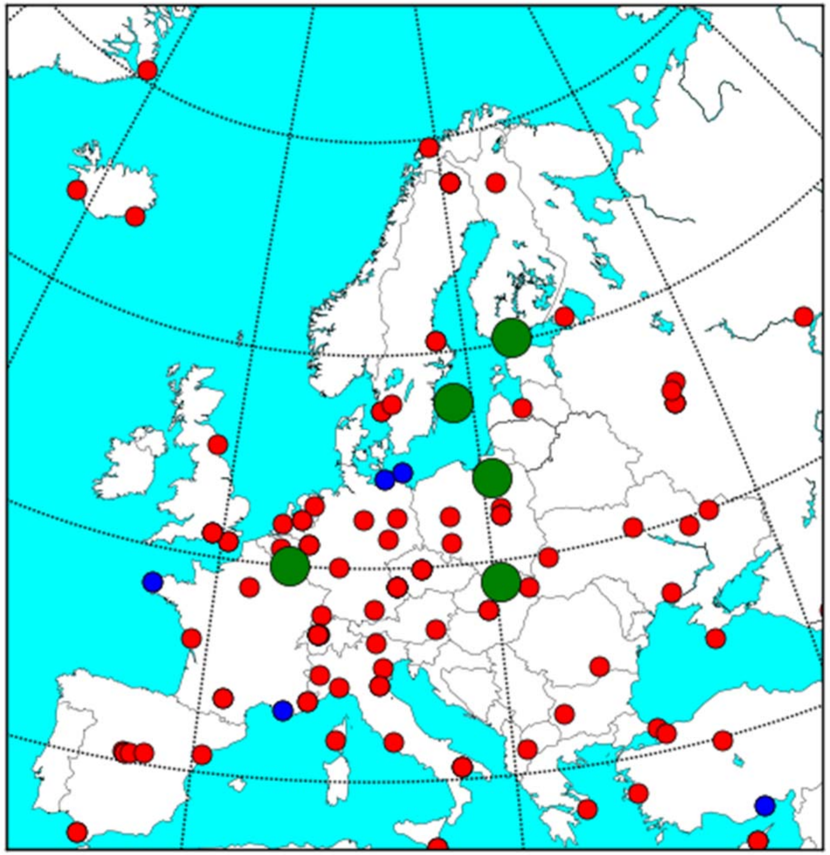
Is the IGS network such potential GNSS-Reflectometry network?

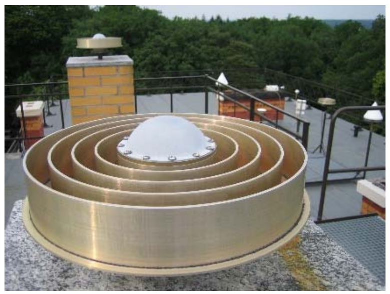


www.igs.org (Sept. 2018)

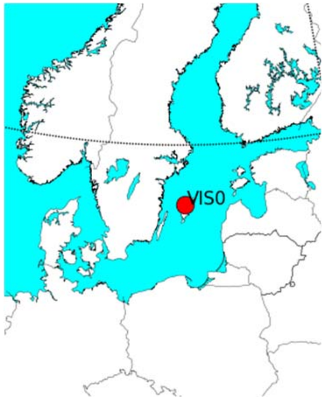
IGS network for GNSS reflectometry

- 506 stations:
- 441: not suitable
- 14: soil moisture
- 10: snow height only
- 19: water level
- 22: quite likely (tbc)

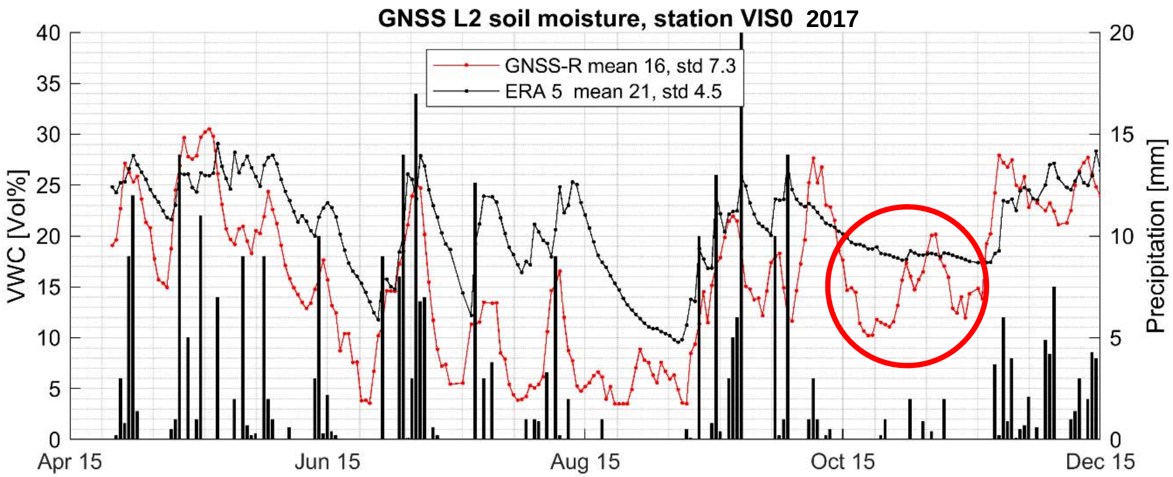




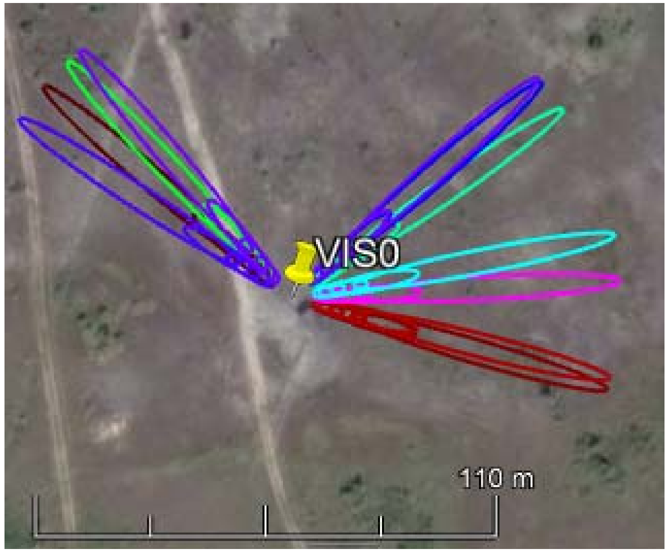
IGS station VIS0: Visby, Sweden VIS0



- Antenna height 3.5m
- Established in 1993
- SNR data since 2004



ERA5 is best available reanalysis,
but cannot cover all precipitation events



Conclusions and outlook

- GNSS-Reflectometry (GNSS-R) has high potential to be (and is already in part) a versatile and cost effective complement of existing Earth Observing Systems.
- GNSS-R is at the moment in transition from research to operational mode. Several ground and satellite systems are already operational or in planning.
- There are numerous different ways to apply GNSS-R, the focus was set here to geodetic receivers, applied within IGS.
- Sometimes it is easy to take aspects of GNSS-R into consideration, when installing new ground station, we kindly ask to do this in future. Additional geophysical information in the vicinity of the station can be provided.
- Should we think on a Working Group or a similar forum on GNSS-Reflectometry within IGS? It could cover also the interests of the related GNSS-R Earth Observation Community.

非常感谢