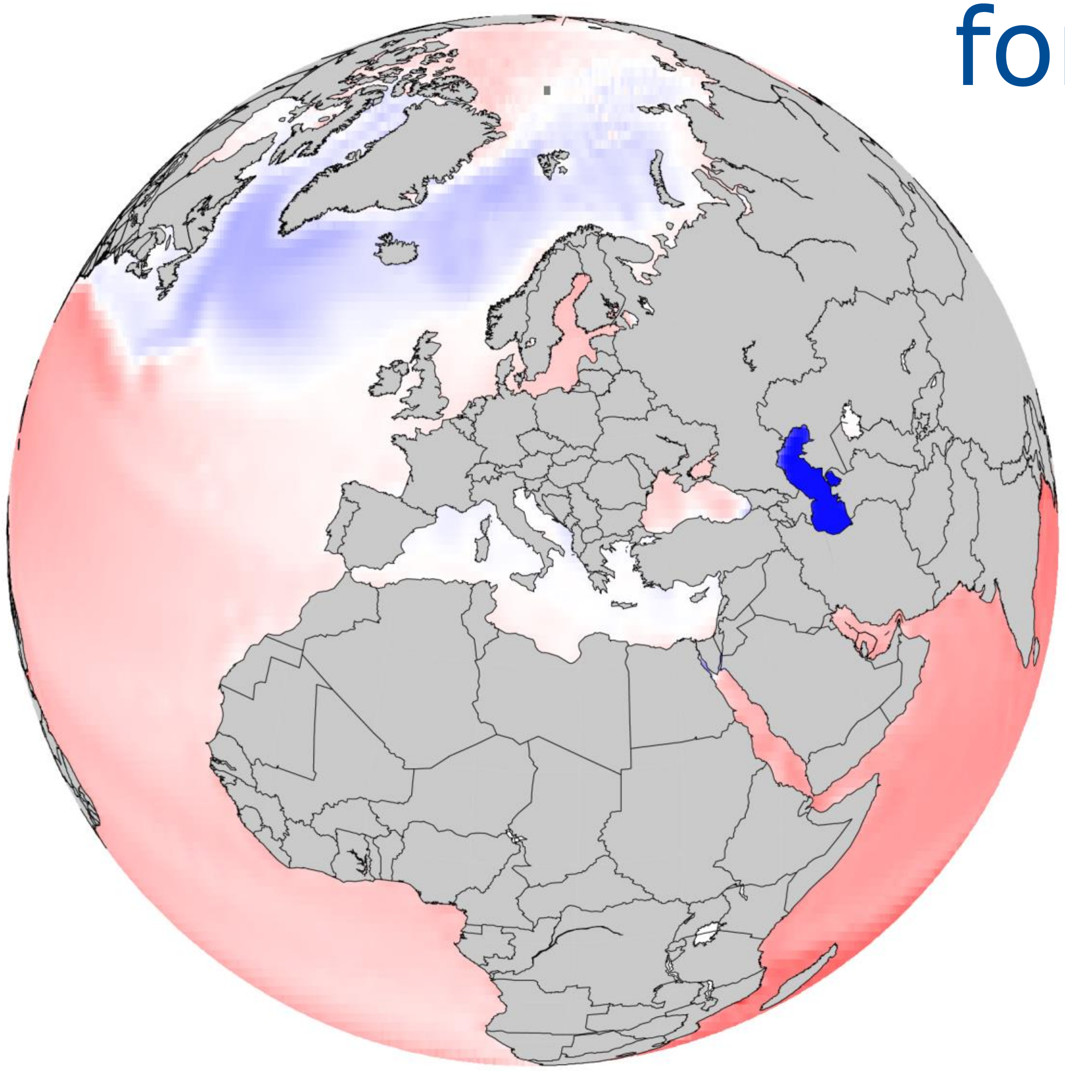
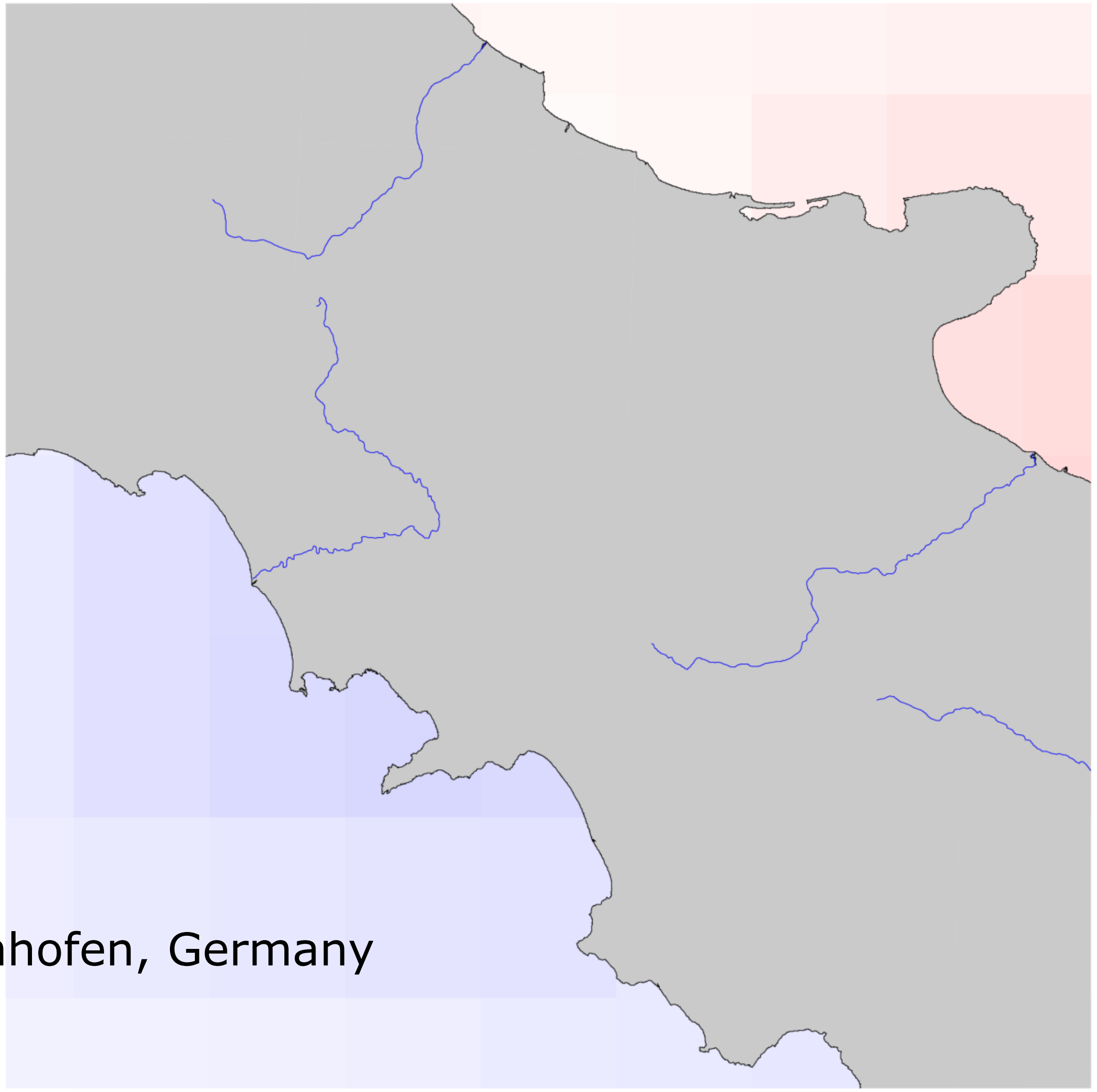
Kepler observing Earth – A reflectometry concept for ocean altimetry



K. Balidakis [1]
M. Semmling [1]
F. Zus [1]
M. Asgarimehr [1]
G. Michalak [1]
G. Beyerle [1]
J. Wickert [1,2]
H. Schuh [1,2]

[1] German Research Centre for Geosciences GFZ, Potsdam & Oberpfaffenhofen, Germany
[2] Technische Universität Berlin, Germany



Background

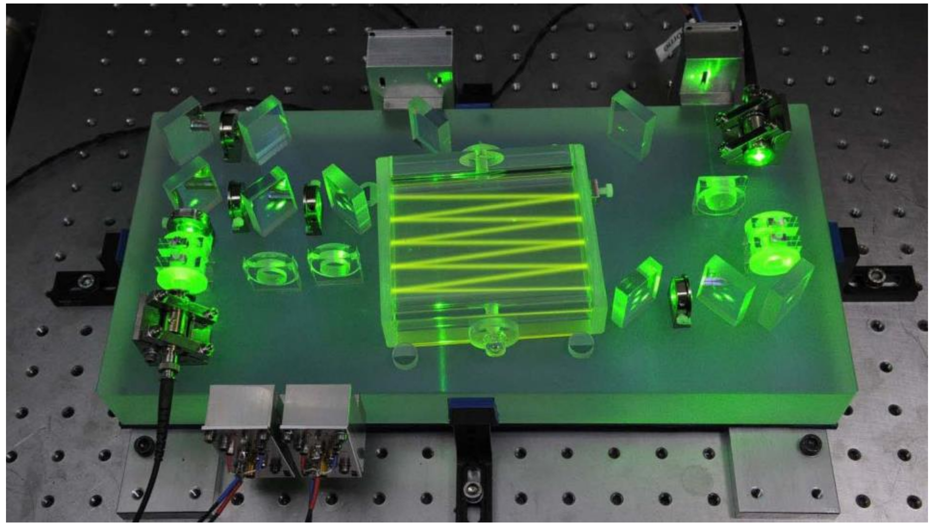
ADVANTAGE Project

Overall Objective

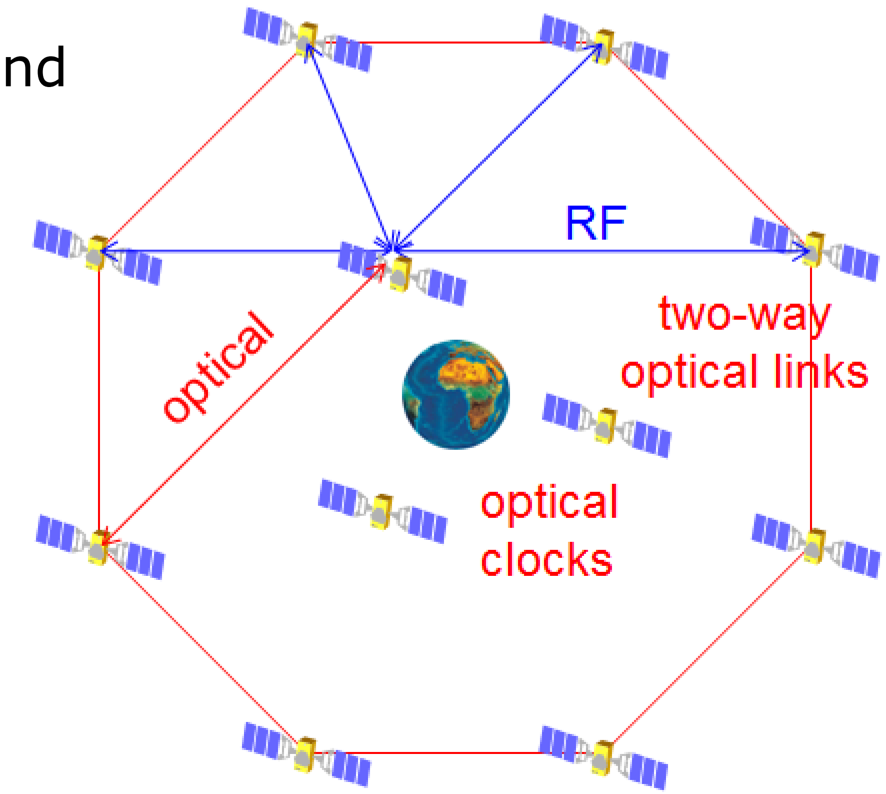
Establish an architecture for a future GNSS (Kepler) that exploits the technological advances and developments in optical frequency references and inter-satellite links

Particular Objective

Investigate whether bi-static reflectometry within a future GNSS (Kepler) is feasible.

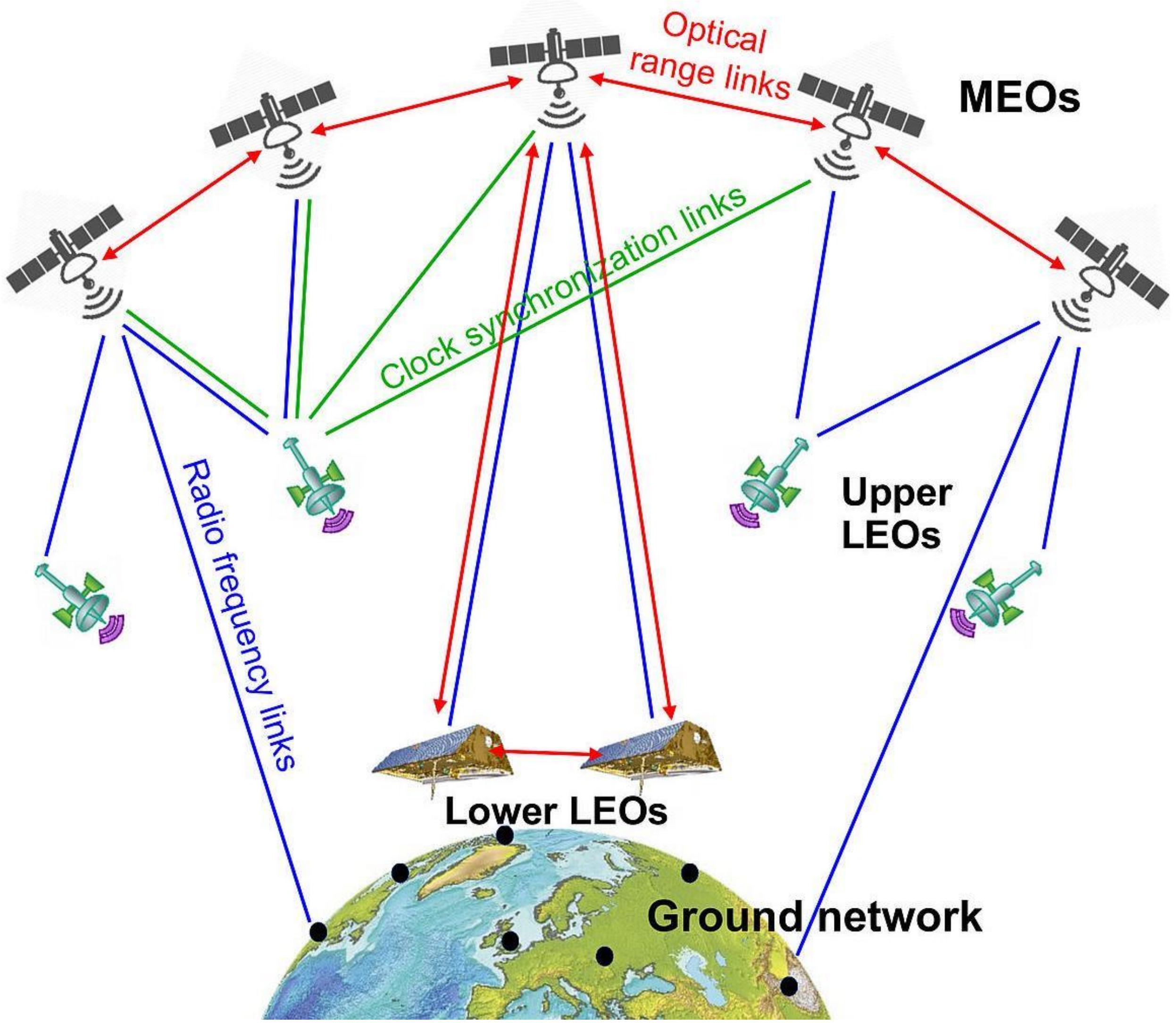


Setup for optical frequency reference (Döringshoff et al. 2014)



Scheme of Kepler GNSS indicating links between satellites (Günther 2018)

ADVANTAGE Project



System Satellites (current status)

- 24 MEOs in 3 orbit planes
  - Galileo-like
  - positioning/navigation
- 4-6 upper LEOs in perpendicular polar planes
  - linking MEO planes

Linked Infrastructure

- optical frequency references and inter-satellite links
- 1-2 lower LEOs in 1 plane
  - GRACE-like
- ground network

Scenarios for Simulation

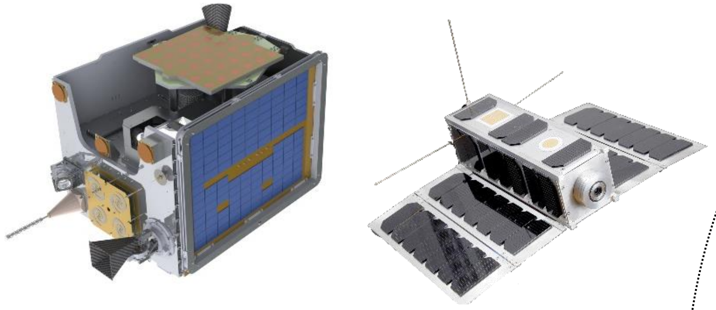
Reflectometry Scenarios

D: MEO GNSS Satellites

C: LEO Satellites

Wickert et al. 2016

Semmling et al. 2016



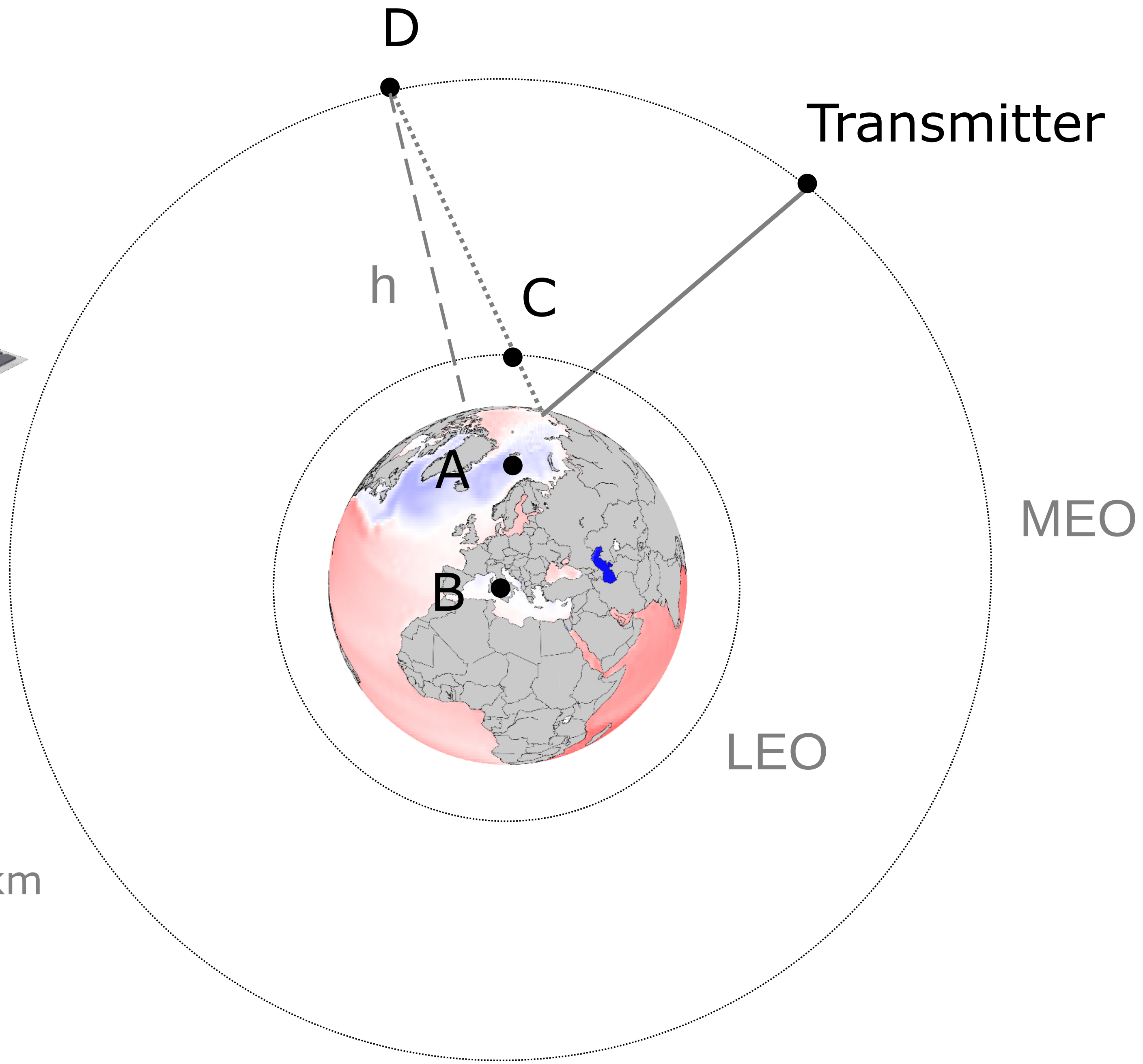
B: Aircrafts

Semmling et al. 2014

A: Ships

Semmling et al. under review

D: Kepler, h ~ 23200 km
C: TDS-1, h ~ 640 km
B: HALO, h ~ 3500 m
A: R/V Lance, h ~ 25 m



GFZ Helmholtz Centre Potsdam

HELMHOLTZ

Reflectometry Scenarios

ADVANTAGE for GNSS-R

- expected POD accuracy for system satellite < 1cm
- benefit to realize coherent reflection altimetry
- Can we receive coherently reflected signals on LEO and MEO satellites?

Scenario C: MEO-R-LEO

Scenario D: MEO-R-MEO

Reflectometry Model

Model aspects studied so far:

- signal power loss (coherent reflection)
  - path loss of signals received on LEO or MEO
  - roughness loss induced by ocean wave spectrum
- possible links (direct signal & coherent reflection)
  - limits set by the transmitter

Further crucial aspects:

- footprint and signal integration time
- receiver hardware on MEO
- data downlink from MEO

Reflectometry Model

Received power (direct signal)

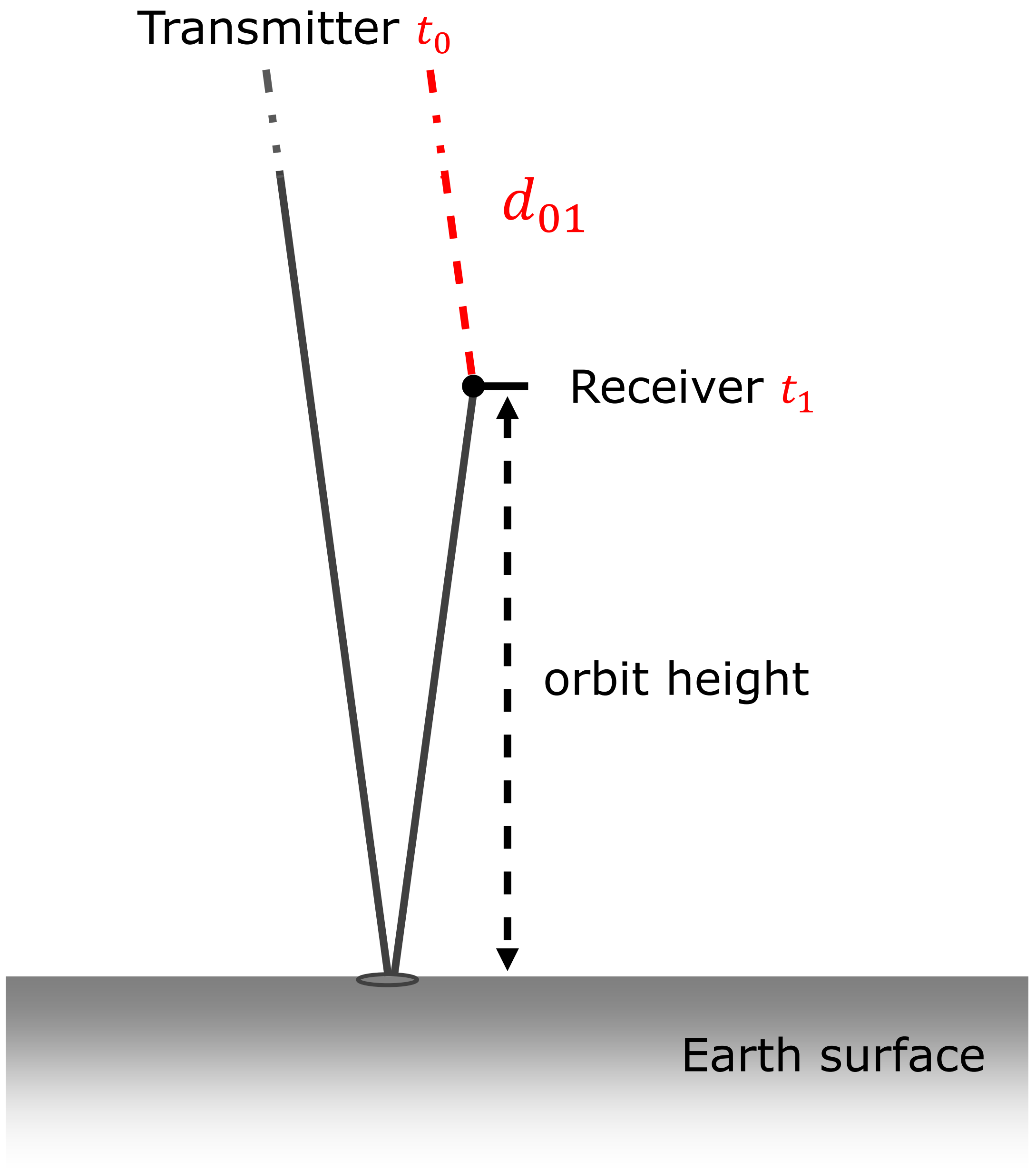
$$P_1[\mathrm{dBW}] = P_0[\mathrm{dBW}] - L_{01}[\mathrm{dB}] \ldots$$

$$L_{01}[\mathrm{dB}] = 10\log\left\{\frac{\lambda^2}{(4\pi)^2}\frac{1}{(d_{01})^2}\right\}$$

path effect
direct signal

$$\left(\ldots + G_T + G_R - L_{pol} - L_{atm}\right)$$

further terms



Steigenberger et al. [2017]

Reflectometry Model

Received power (coherent reflection)

$$P_2[\mathrm{dBW}] = P_0[\mathrm{dBW}] - L_{02}[\mathrm{dB}] - L_r[\mathrm{dB}] \ldots$$

$$L_{02}[\mathrm{dB}] = 10\log\left\{\frac{\lambda^2}{(4\pi)^2}\frac{1}{(d_{01}+d_{12})^2}\right\}$$

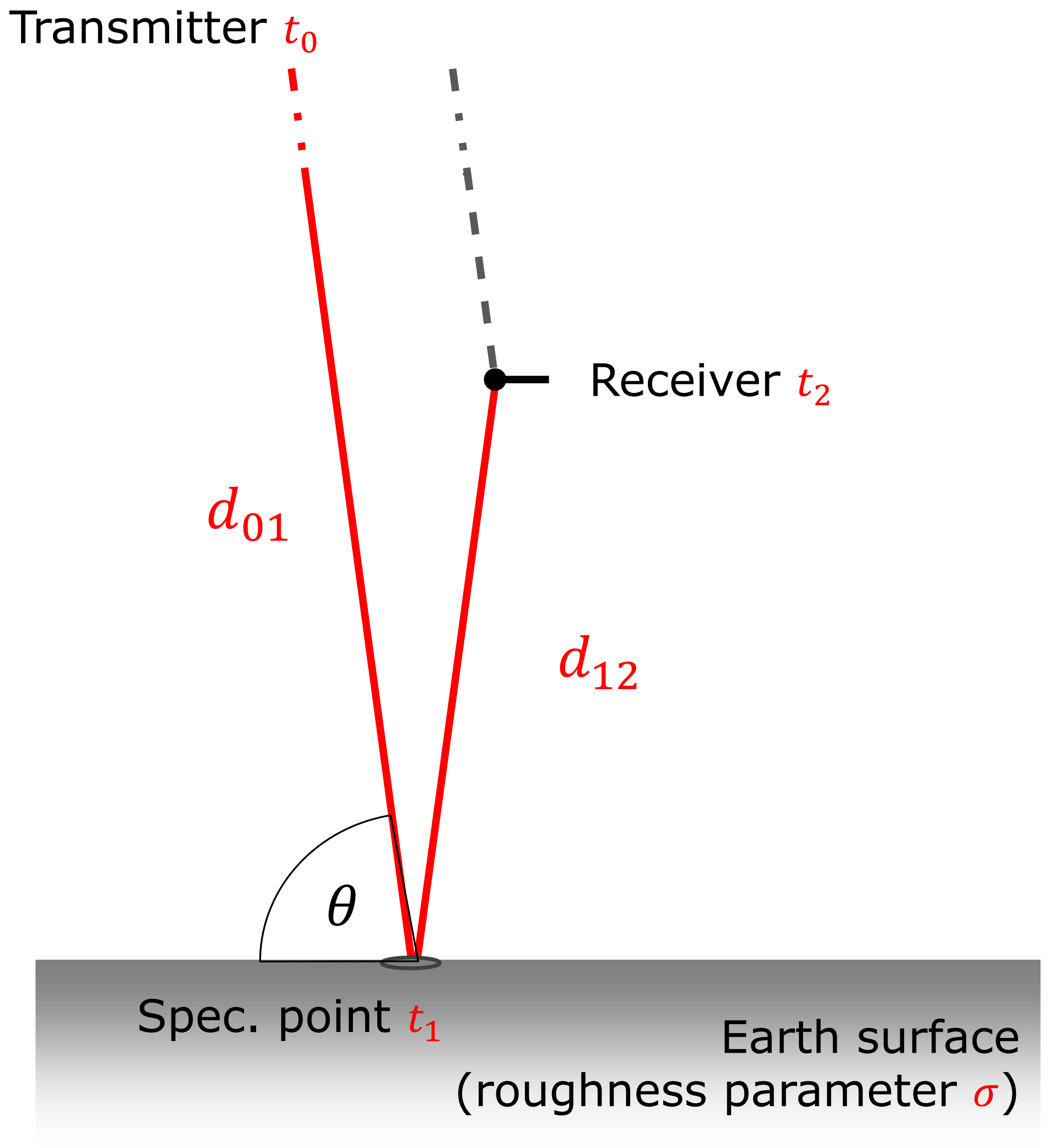
path effect
coherent reflection

$$L_r[\mathrm{dB}] = 10\log\left\{|\Gamma(\theta)|^2 e^{-k^2\sigma^2\sin^2\theta}\right\}$$

reflection & roughness effect

$$\left(\ldots + G_T + G_R - L_{pol} - L_{atm}\right)$$

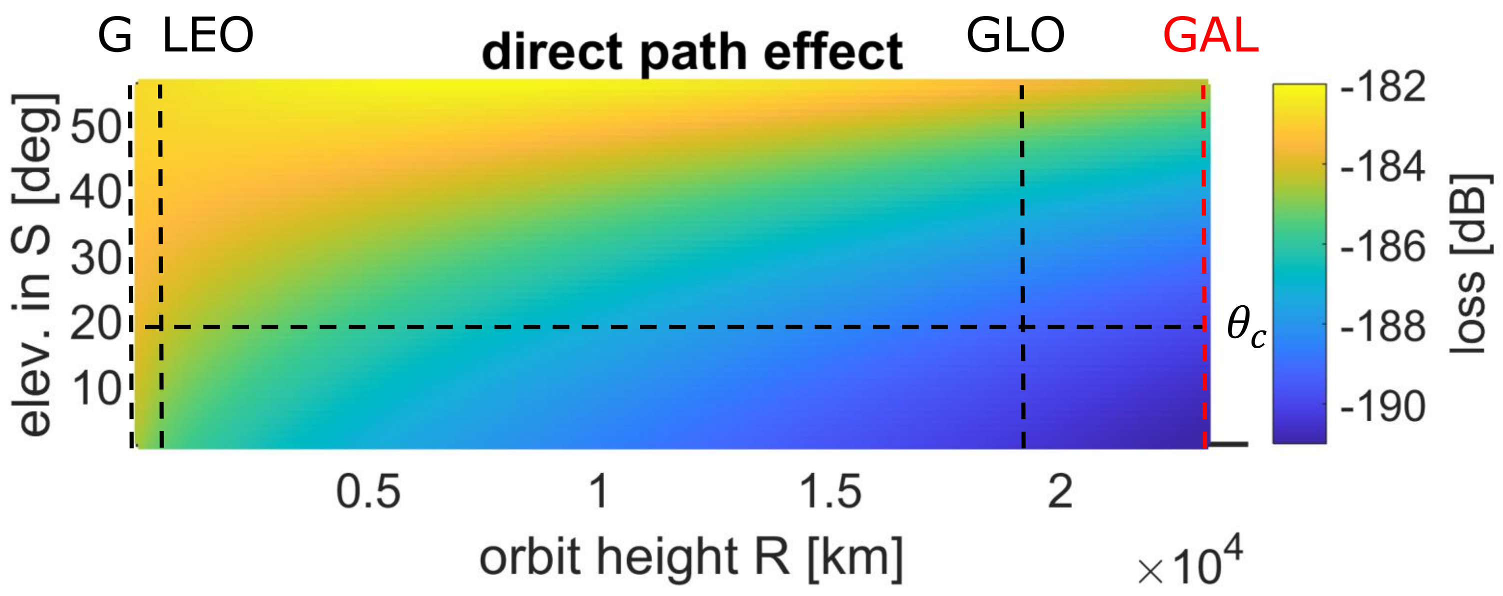
further terms



Nievinski & Larson [2014]; Carreno-Luengo et al. [2019]

Simulation Results
-
Signal Power Loss

Path Loss L_{01}

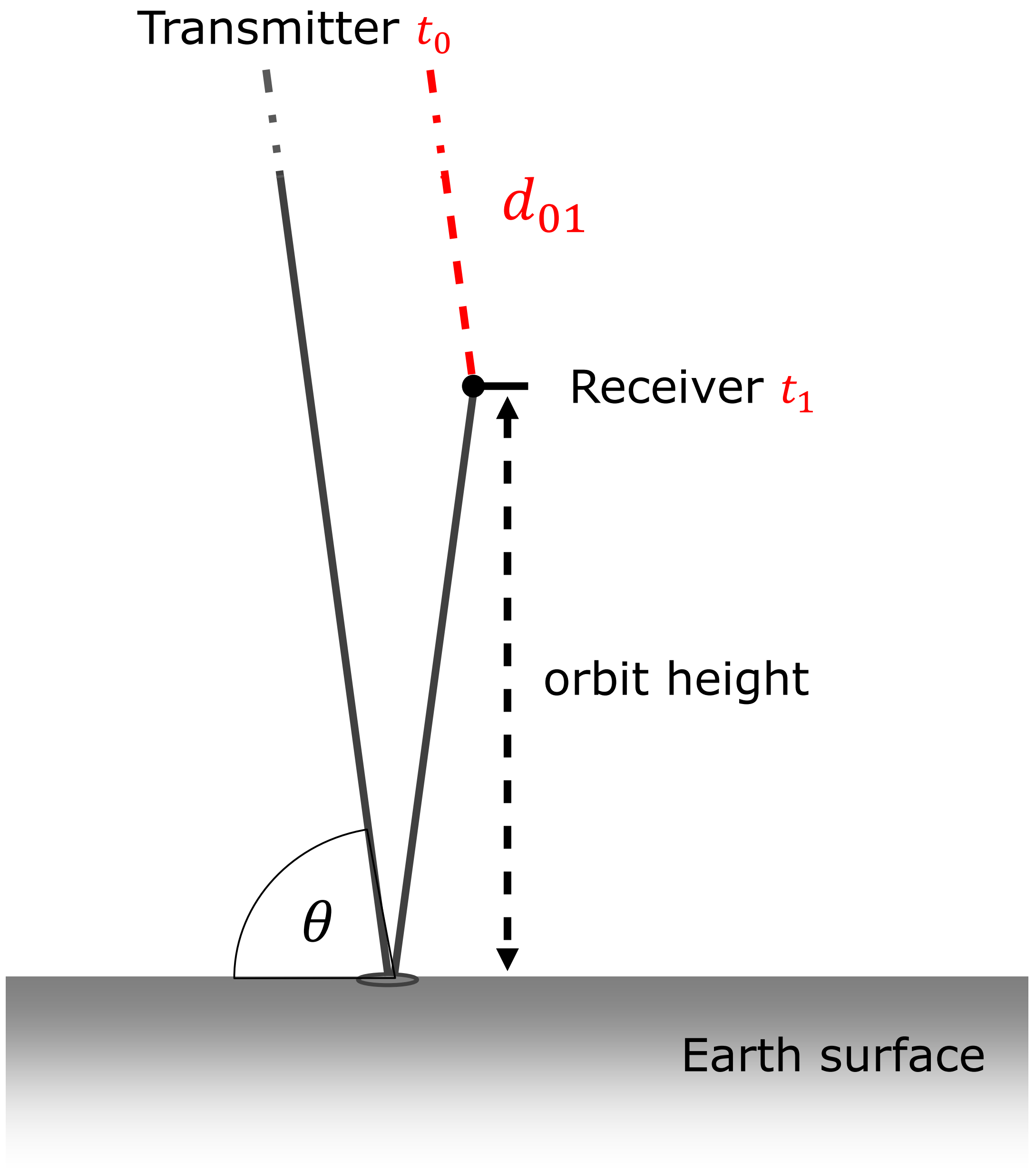


G: $L_{01} = L_G = -183.7\text{dB}$

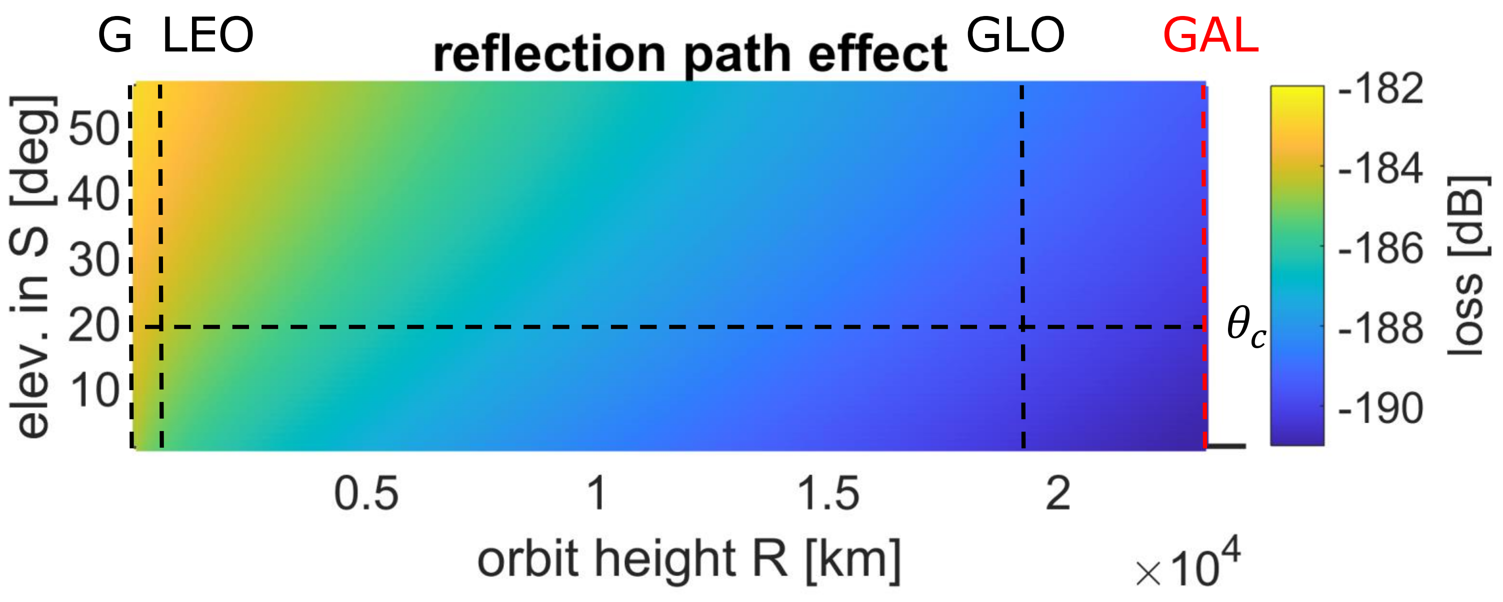
LEO: $L_{01} = L_G - 0.4\text{dB}$

GLO: $L_{01} = L_G - 5.3\text{dB}$

GAL: $L_{01} = L_G - 6.1\text{dB}$



Path Loss L_{02}

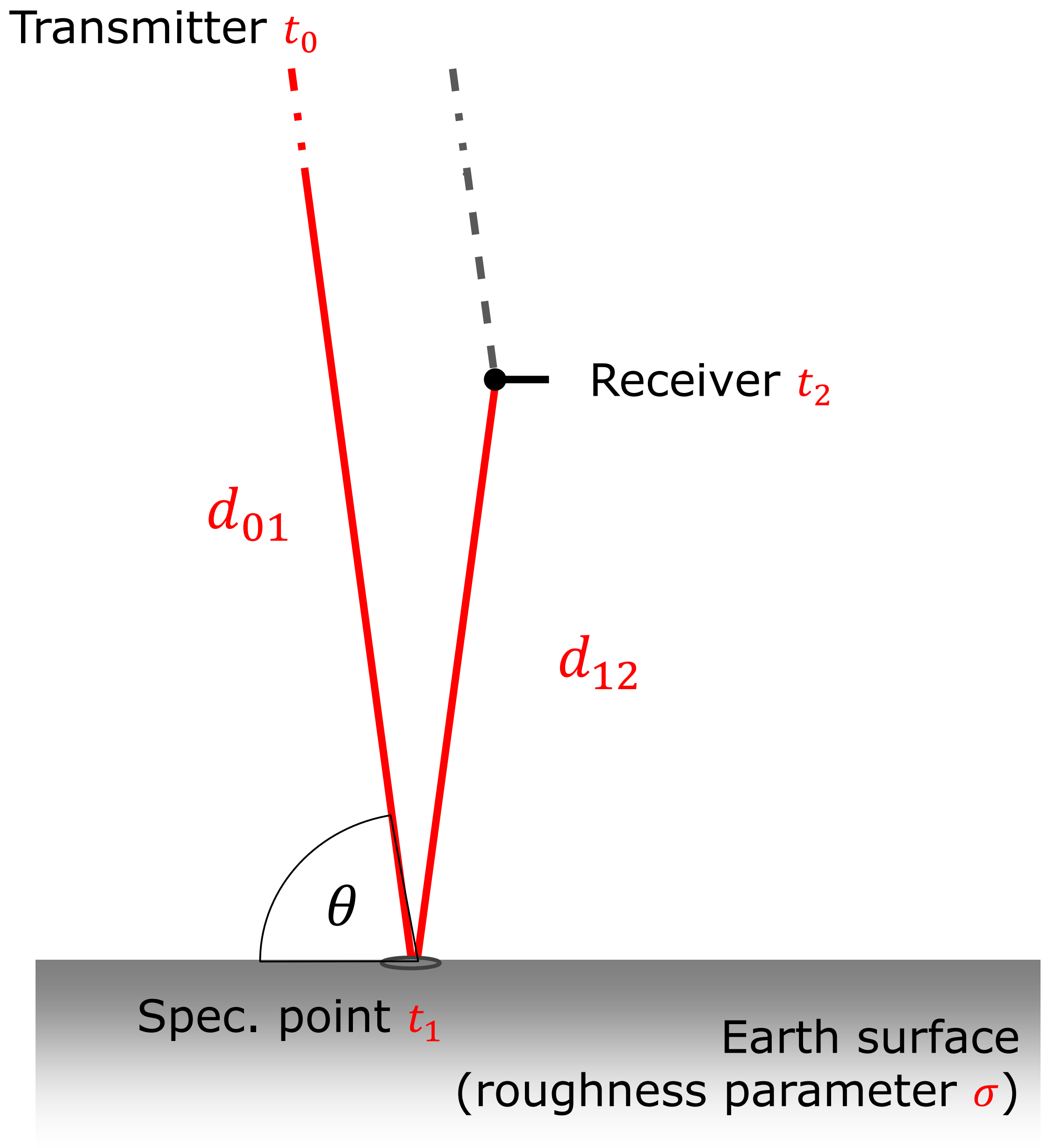


G: $L_{02} = L_G = -183.7\text{dB}$

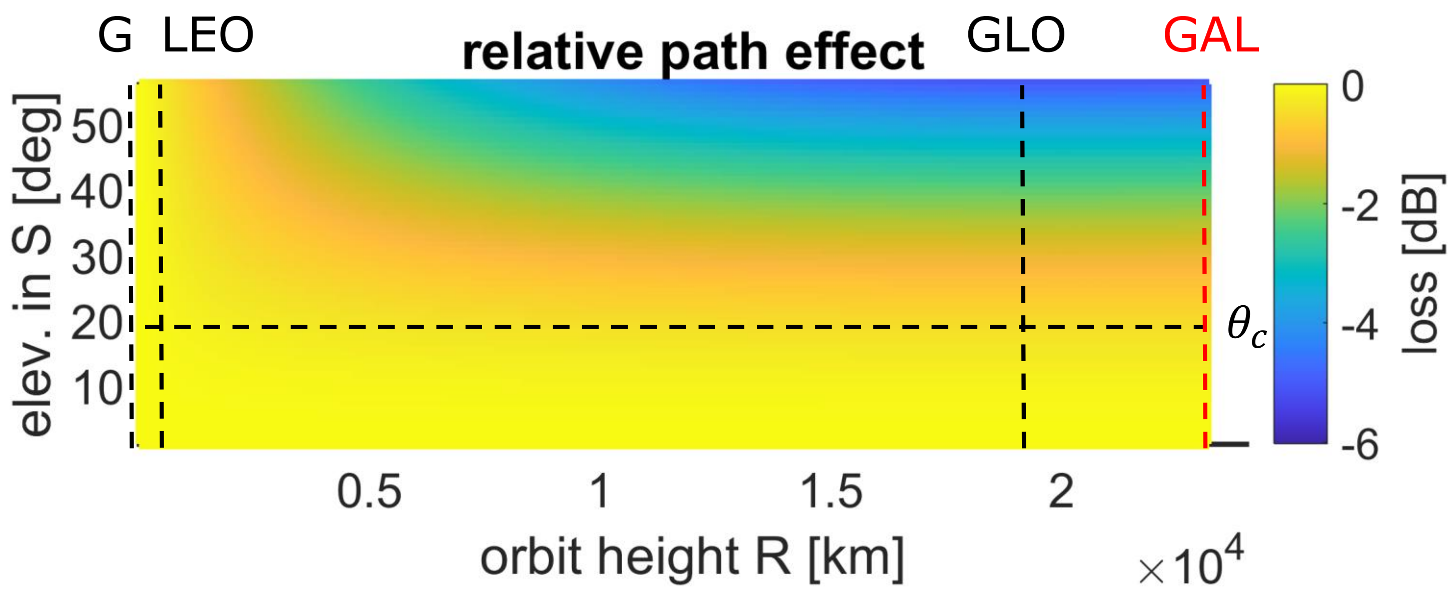
LEO: $L_{02} = L_G - 0.5\text{dB}$

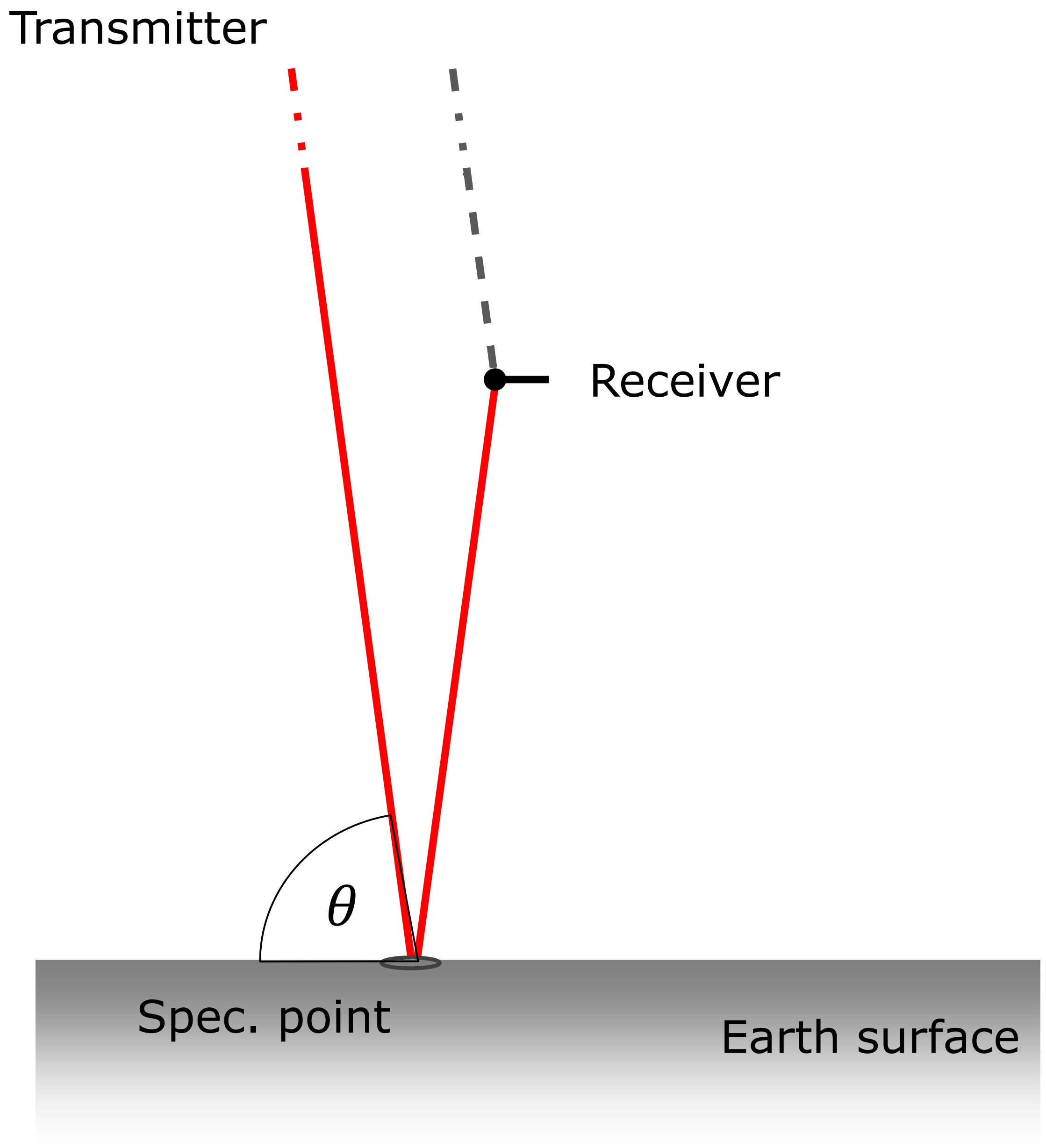
GLO: $L_{02} = L_G - 5.9\text{dB}$

GAL: $L_{02} = L_G - 6.7\text{dB}$



Path Loss L_{02}-L_{01}





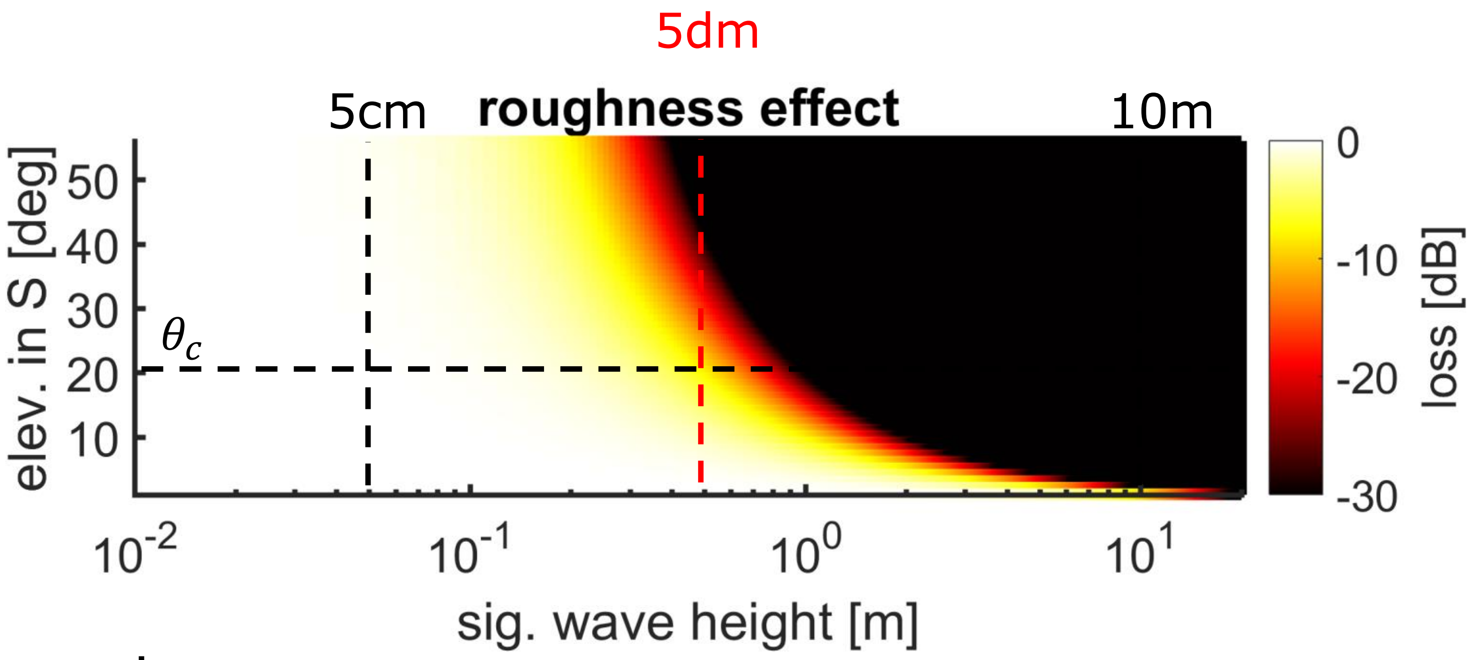
G: $L_{02} - L_{01} = L_G = 0\text{dB}$

LEO: $L_{02} - L_{01} = L_G - 0.1\text{dB}$

GLO: $L_{02} - L_{01} = L_G - 0.6\text{dB}$

GAL: $L_{02} - L_{01} = L_G - 0.6\text{dB}$

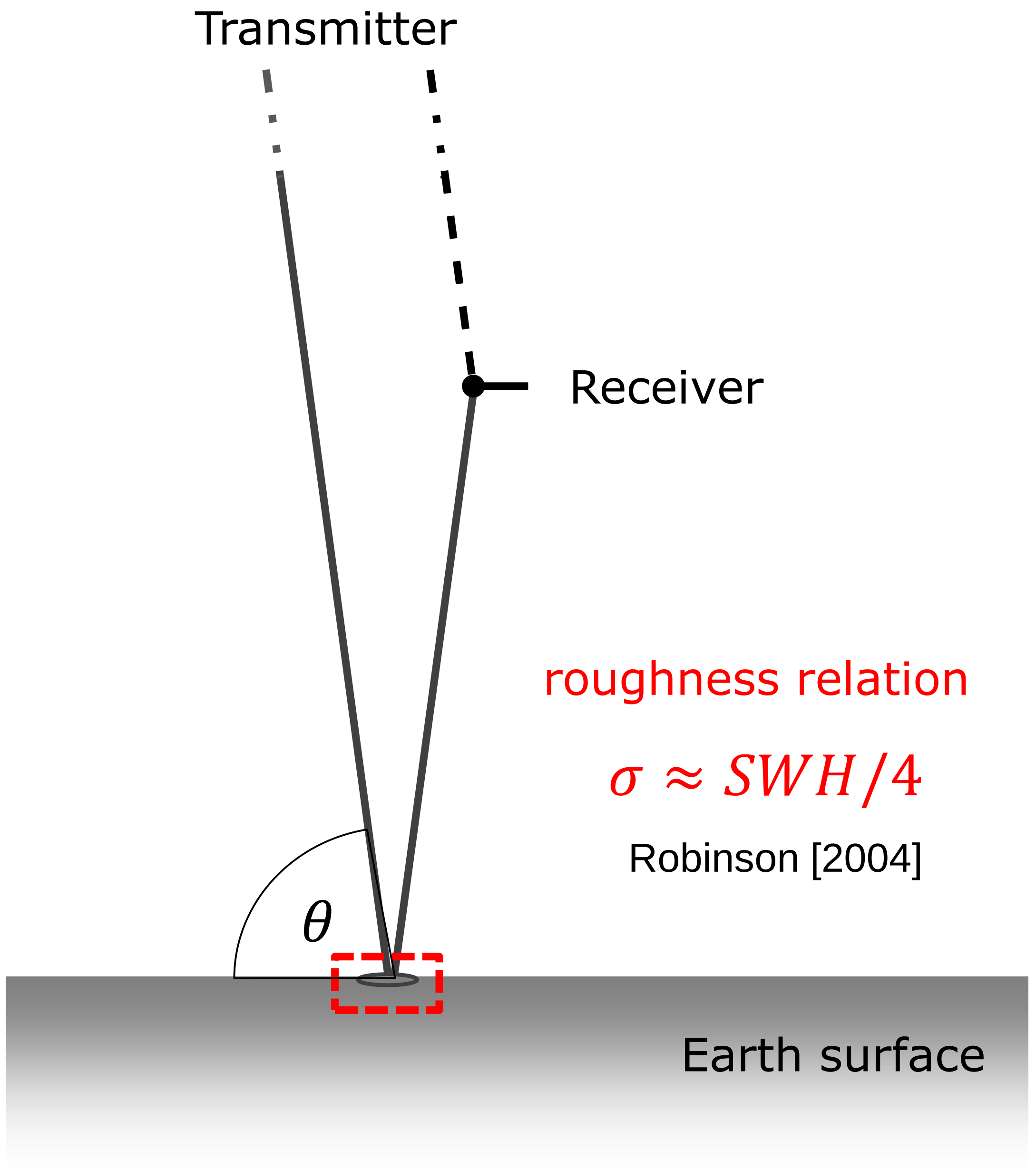
Roughness Loss L_σ



5cm: $L_\sigma = -0.1\text{dB}$

5dm: $L_\sigma = -8.7\text{dB}$

10m: $L_\sigma \prec -100\text{dB}$



roughness relation

$\sigma \approx SWH/4$

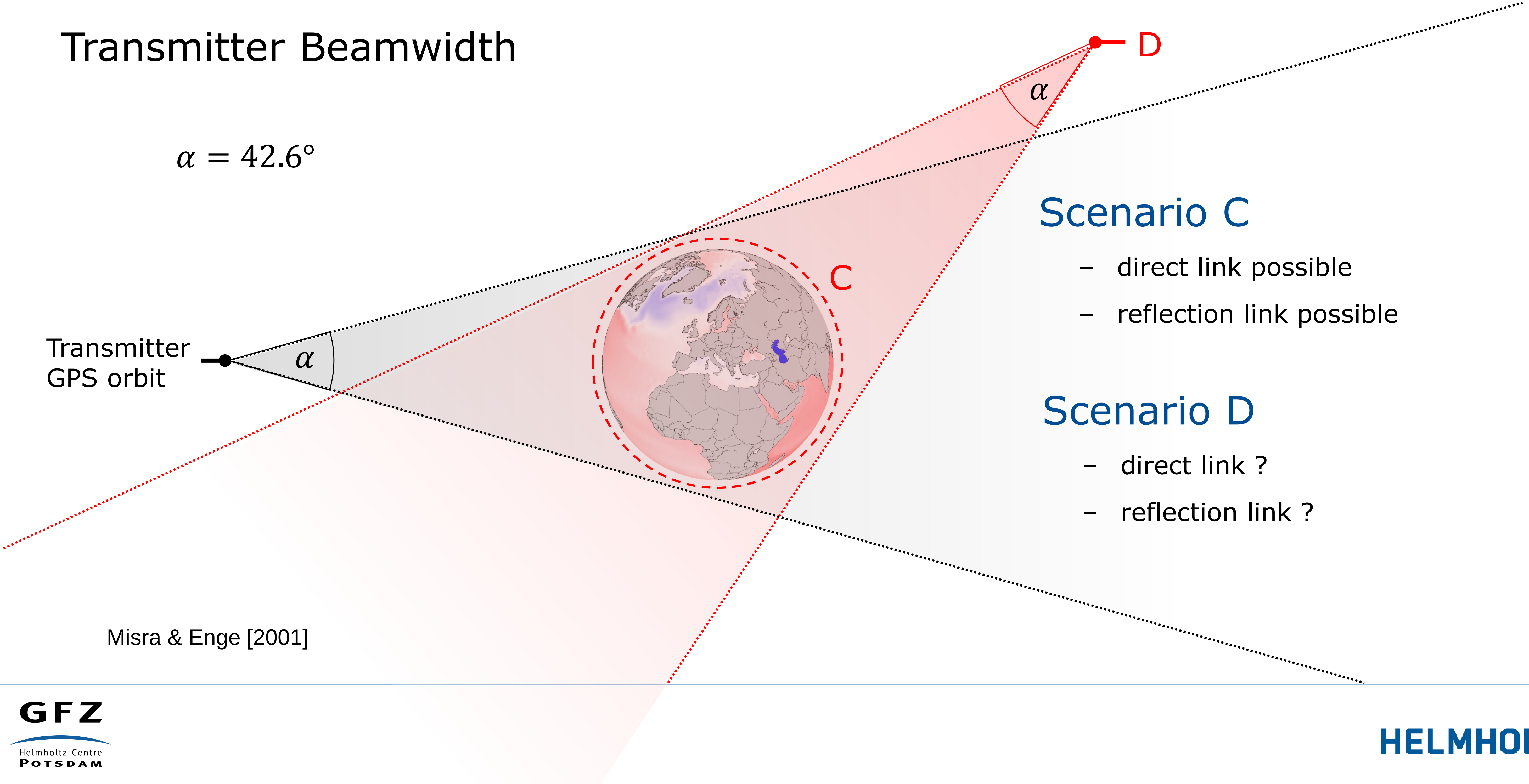
Robinson [2004]

Simulation Results
-
Link Geometry & Ocean Coverage

Link Geometry

Transmitter Beamwidth

$\alpha = 42.6°$



Scenario C

- direct link possible
- reflection link possible

Scenario D

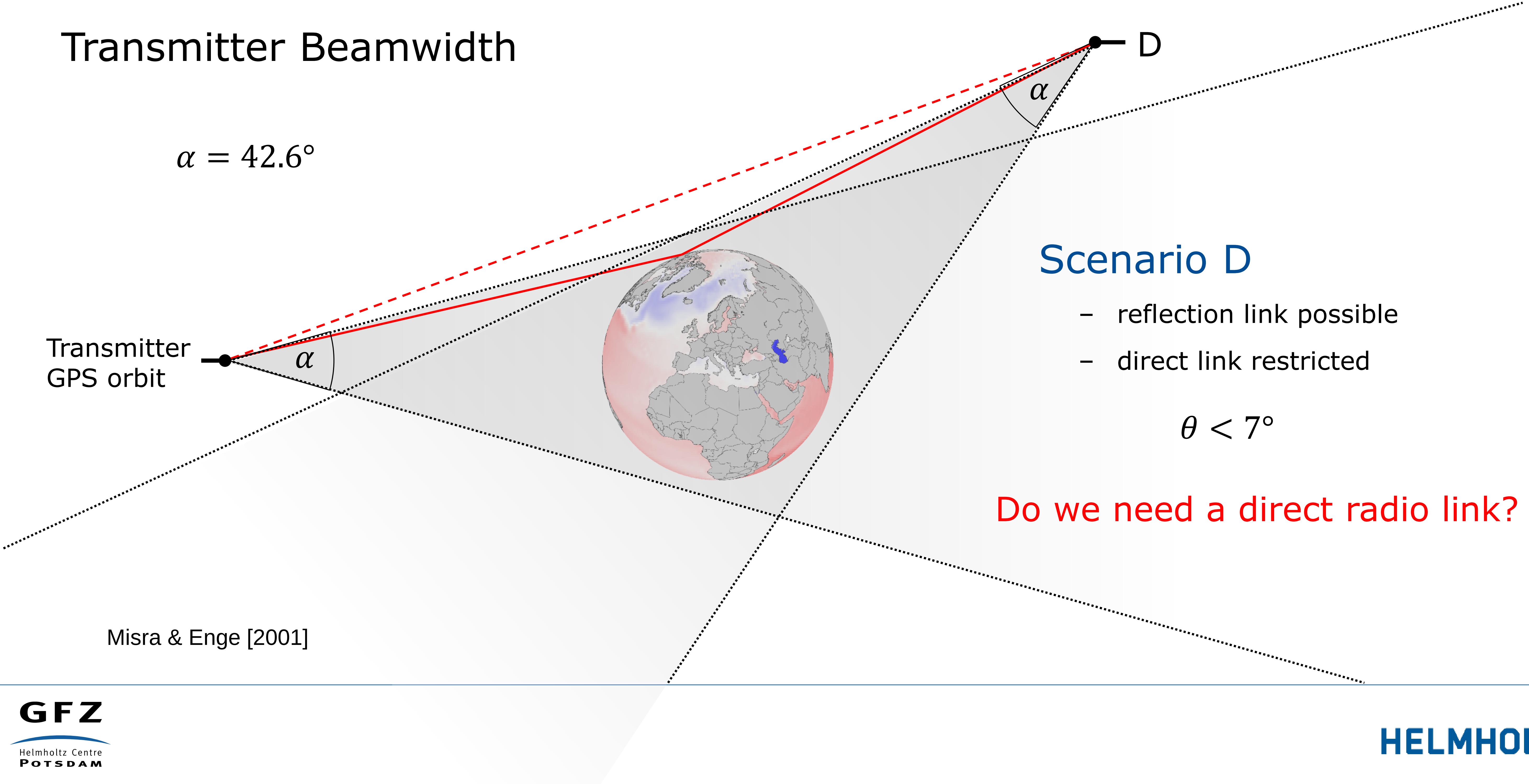
- direct link ?
- reflection link ?

Misra & Enge [2001]

Link Geometry

Transmitter Beamwidth

$\alpha = 42.6°$



Scenario D

- reflection link possible
- direct link restricted

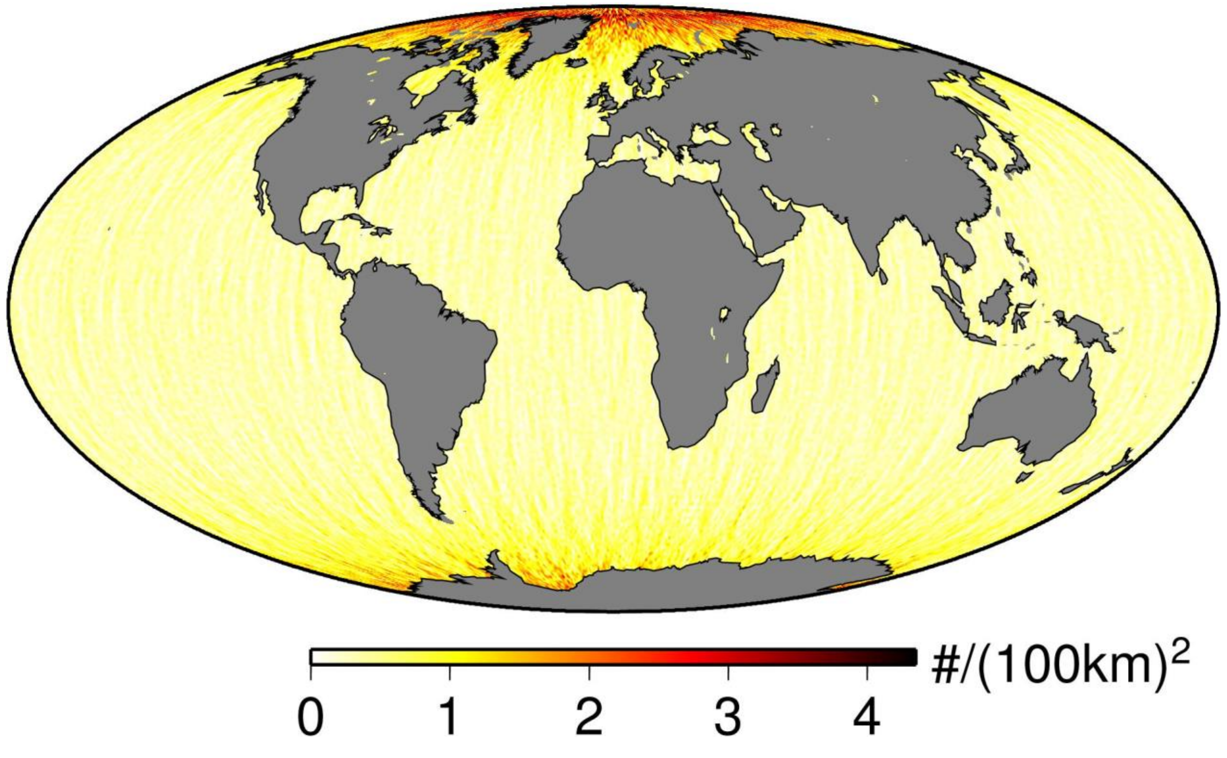
$\theta < 7°$

Do we need a direct radio link?

Misra & Enge [2001]

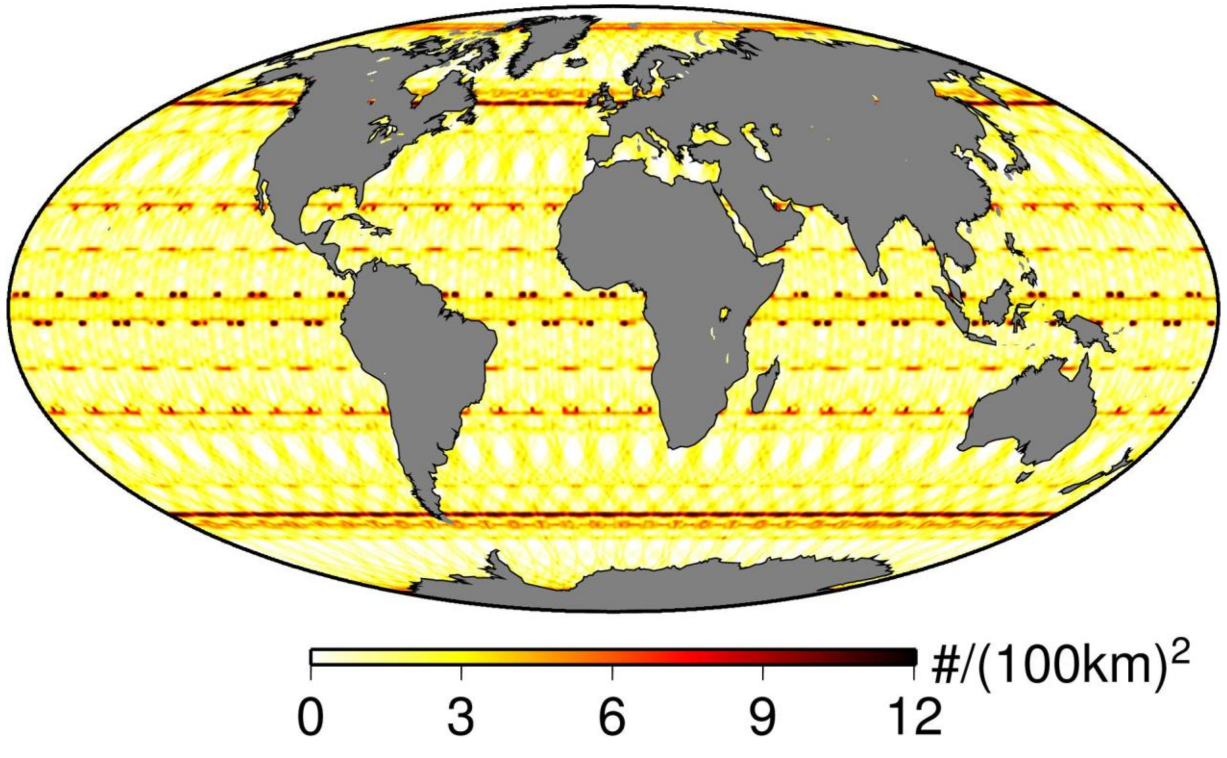
Ocean Coverage

1-day cover – scenario C



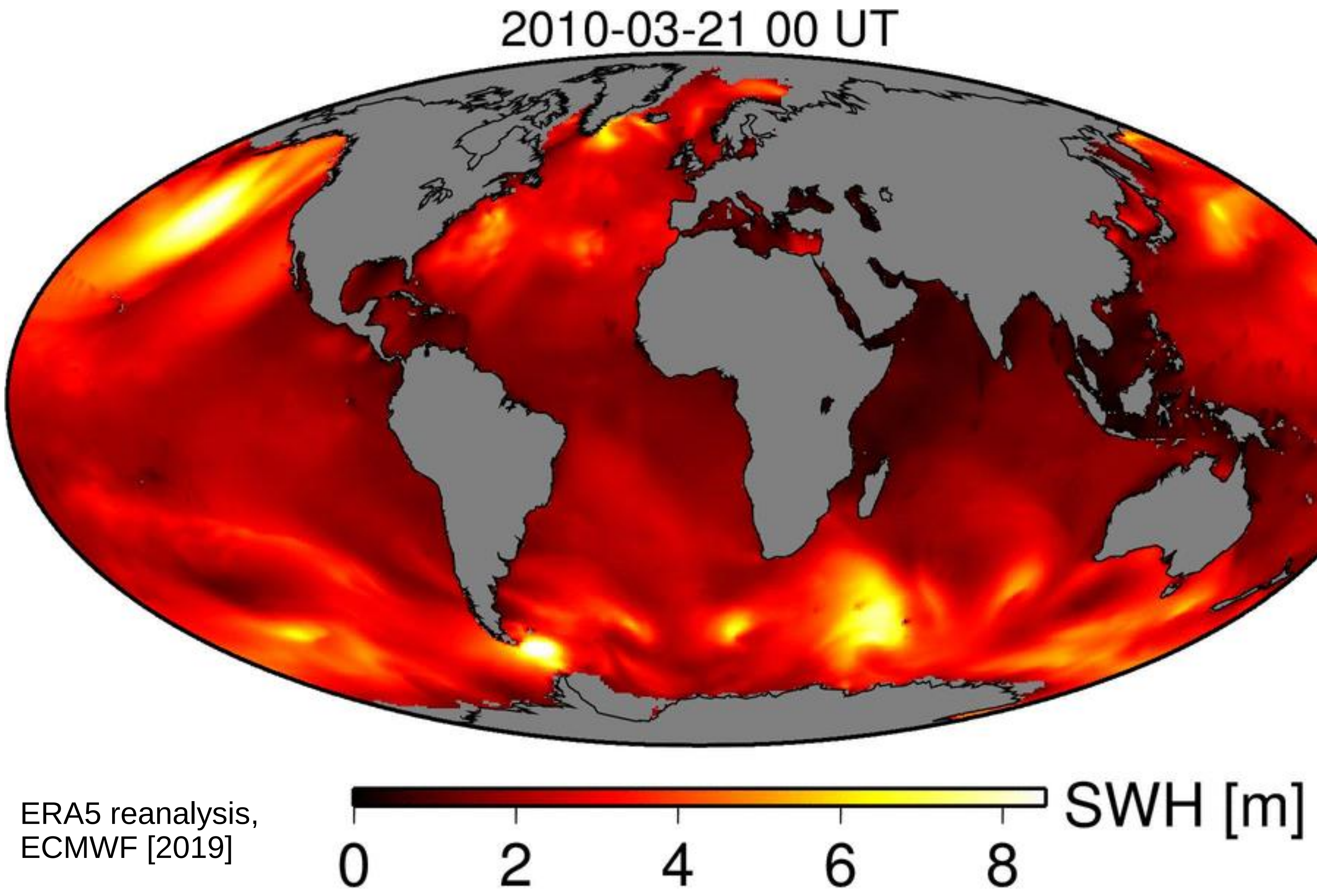
- 24 MEO transmitter, 4 LEO receiver (polar orbit)
- random pattern with up to 4 daily revisits (polar)
- dense mesh

1-day cover – scenario D



- 24 MEO satellites each transmitting and receiving
- distinct pattern with up to 12 daily revisits
- hot spots and gaps

Ocean Coverage



ERA5 reanalysis,
ECMWF [2019]

Global Ocean Roughness

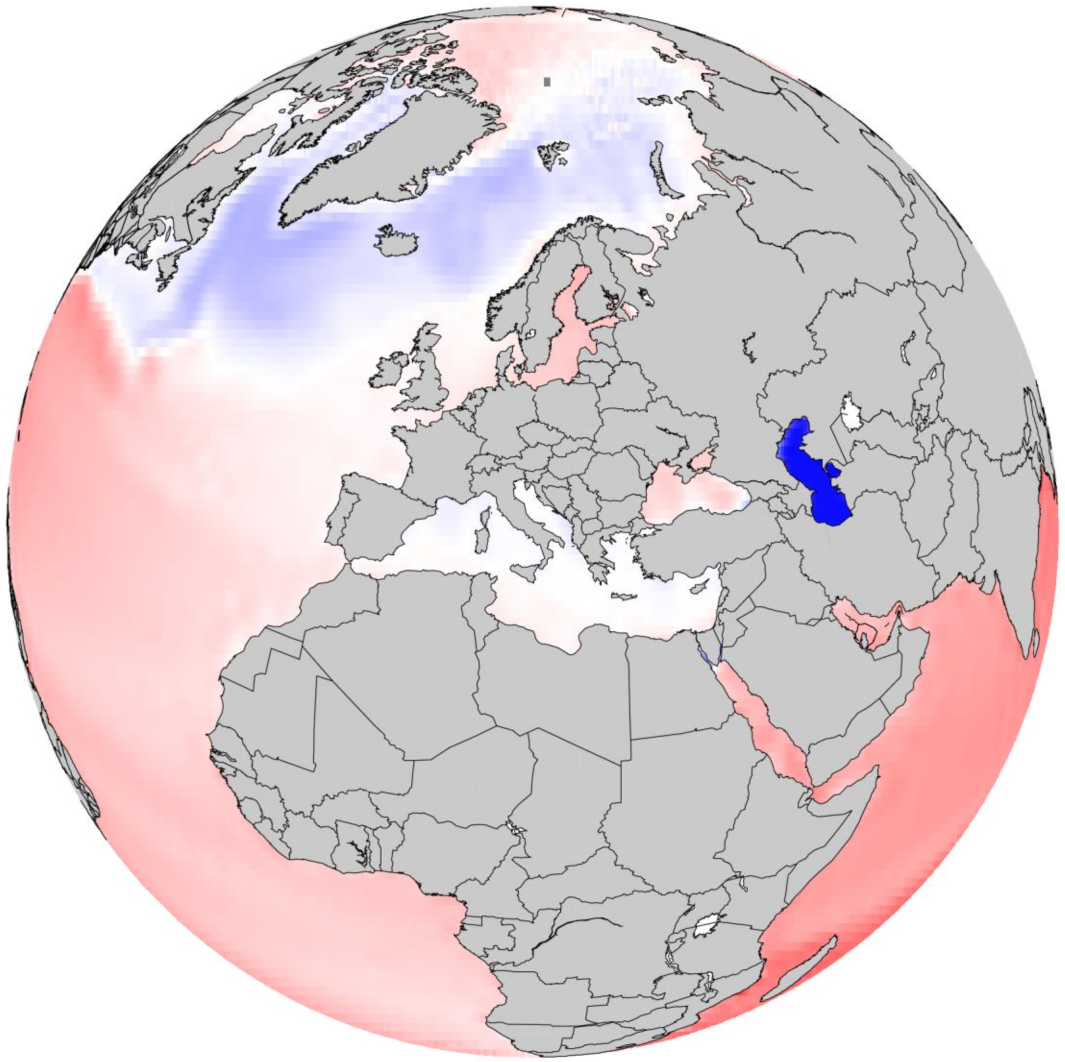
- significant wave height (SWH)
- 10 days in northern spring
- global model with hourly resolution
- wind waves and swell considered

Smooth Ocean Zones

- SWH < 0.5m
- only few on global oceans e.g. around Indonesian islands
- sea ice covered areas

Summary & Outlook

Summary



Signal Power Loss

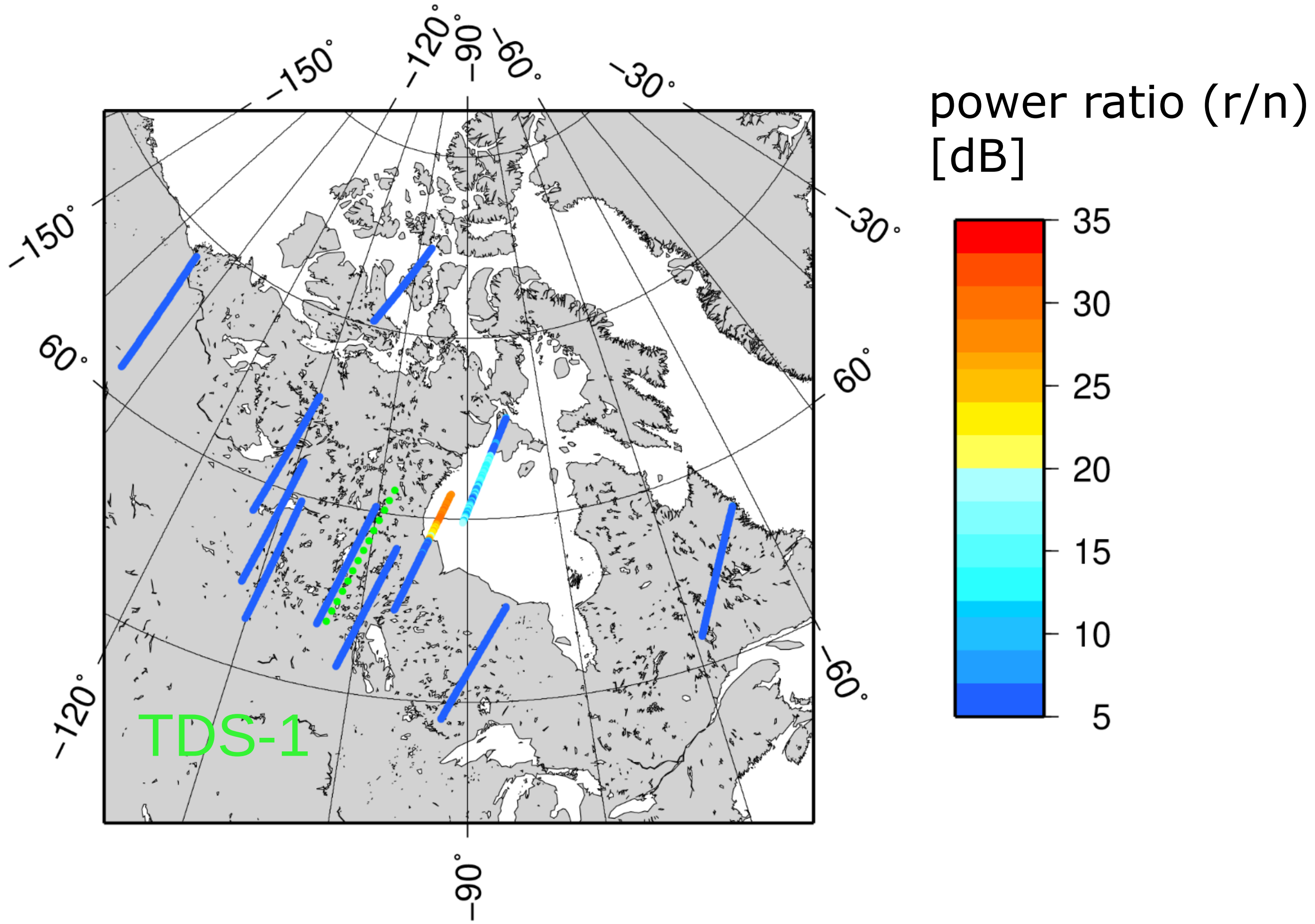
- coherent scenarios MEO-R-LEO (C) and MEO-R-MEO (D)
- C: path loss little above ground ref. (< 0.5dB)
- D: path loss bit more above ground ref. (< 6.7dB)
- **path losses can be compensated** by antenna gain
- **roughness loss critical** for sign. wave heights > 0.5m

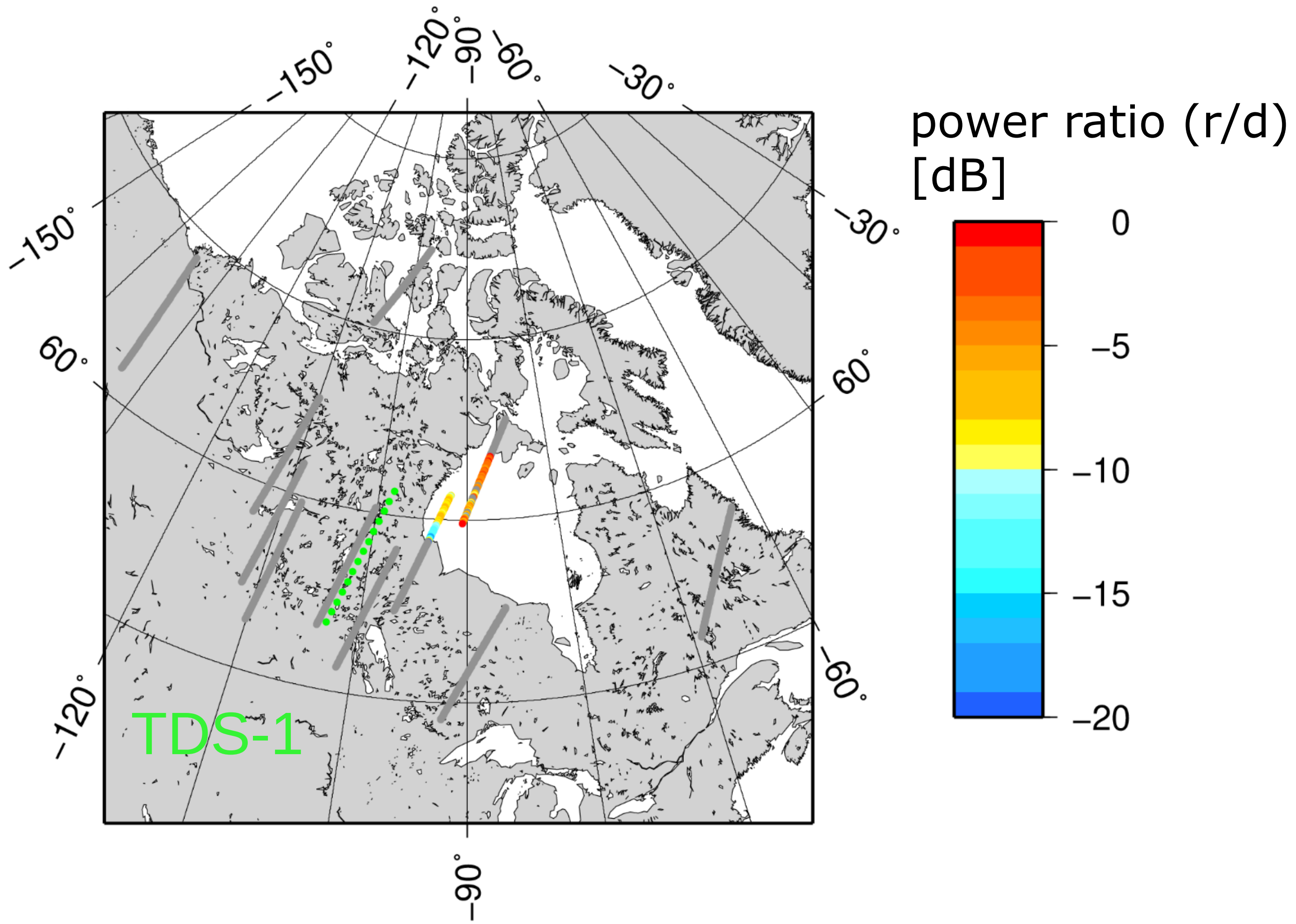
Link Geometry & Ocean Coverage

- unrestricted link geometry scenario C
- **direct link restricted** for scenario D
- **is direct radio link necessary?** optical link instead
- scenarios C and D differ pattern of ocean cover
- only few areas with uncritical wave heights over oceans
- coherent reflections expected over sea ice

Outlook

MEO-R-LEO sea ice events over Hudson bay





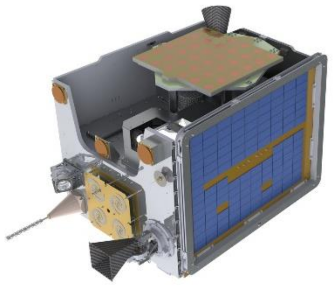
Thanks for your attention!

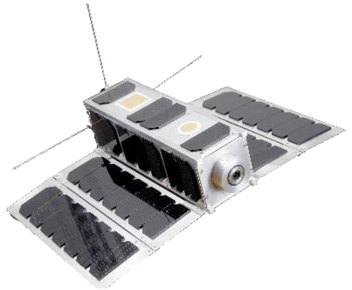
References

- Misra & Enge [2001]: Global Positioning System - Signals, Measurements, and Performance. Ganga-Jamuna Press, Lincoln, Massachusetts
- Robinson [2004]: Measuring the Oceans from Space: The principles and methods of satellite oceanography. *Springer* Praxis
- Nievinski & Larson [2014]: Forward modeling of GPS multipath for near-surface reflectometry and positioning applications. *GPS Solutions*
- Semmling et al. [2014]: Sea surface topography retrieved from GNSS reflectometry phase data of the GEOHALO flight mission. *Geophysical Research Letters*
- Semmling et al. [2016]: A Phase-Altimetric Simulator: Studying the Sensitivity of Earth-Reflected GNSS Signals to Ocean Topography. *IEEE TGRS*
- Wickert et al. [2016]: GEROS-ISS: GNSS REflectometry, Radio Occultation and Scatterometry onboard the International Space Station. *IEEE Select. Top. Appl. Earth Obs. Remote Sens.*
- Döringshoff et al. [2017]: A flight-like absolute optical frequency reference based on iodine for laser systems at 1064 nm. *Applied Physics B*
- Steigenberger et al. [2017]: GNSS satellite transmit power and its impact on orbit determination. *J Geod*
- Günther [2018]: Kepler Satellite Navigation without Clocks and Ground Infrastructure. *Proceedings of ION GNSS+ 2018*
- Carreno-Luengo et al. [2019]: Sensitivity of CyGNSS Bistatic Reflectivity and SMAP Microwave Radiometry Brightness Temperature to Geophysical Parameters Over Land Surfaces. *IEEE JSTAR*

Reflectometry Scenarios

C: LEO Satellites





Semmling et al. 2016

D: MEO GNSS Satellites

B: Aircrafts

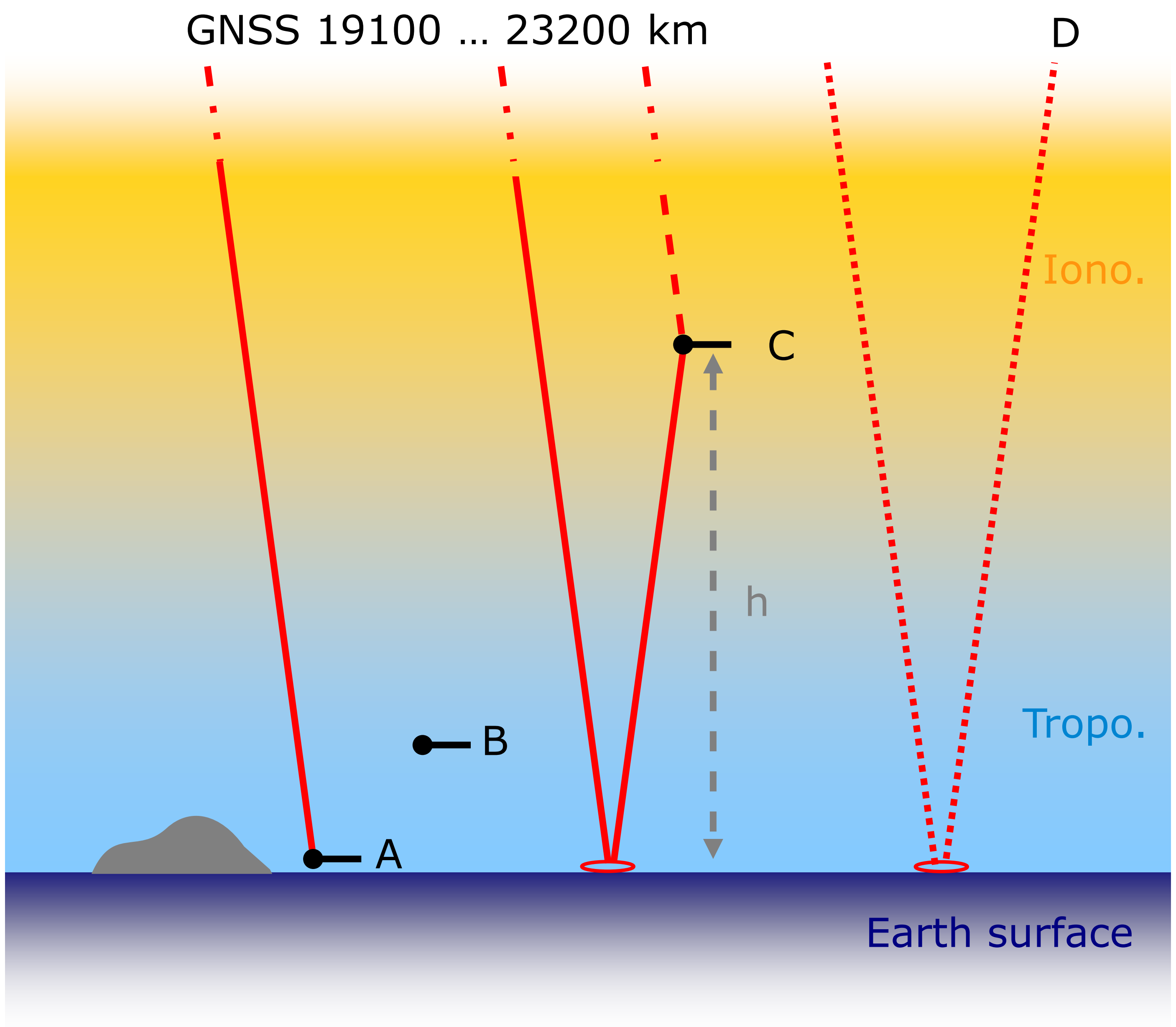
Semmling et al. 2014

A: Ships

Semmling et al. under review

ADVANTAGE for GNSS-R

- expected POD accuracy for system satellite < 1cm
- benefit to realize coherent reflection altimetry
- Can we receive coherently reflected signals on LEO and MEO satellites?
- scenario C: MEO-surface-LEO
- scenario D: MEO-surface-MEO



A: R/V Lance, h ~ 25 m
B: HALO, h ~ 3500 m

C: TDS-1, h ~ 640 km
D: Kepler, h ~ 23200 km