Surface reflectivity over Hudson Bay retrieved from TDS-1 mission data

BERLIN 2020 INTERGEO
13. – 15. OKTOBER
WISSEN UND HANDELN FÜR DIE ERDE

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14th October 2020

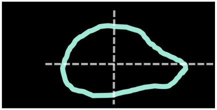
Why observing sea ice?

Creative Common

Types of sea ice variables

Sea Ice Extent

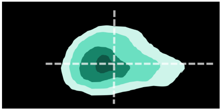
Area of seawater covered by any amount of ice (>15%)



[SIE]

Sea Ice Concentration

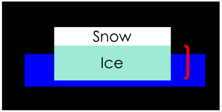
Fraction (%) of seawater covered by ice



[SIC]

Sea Ice Thickness

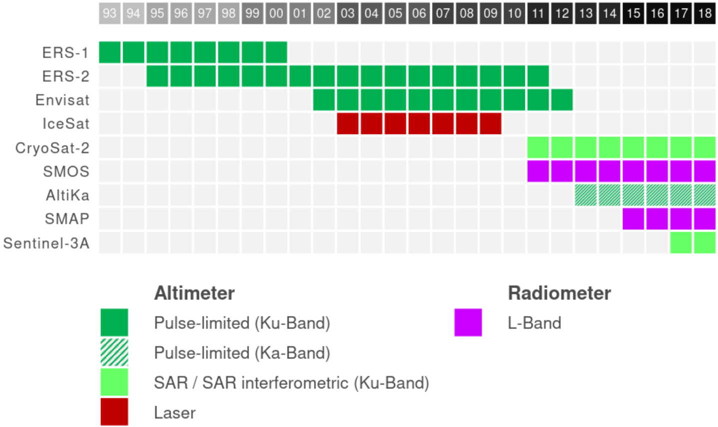
Depth between ice-sea interface and snow layer



[SIT]

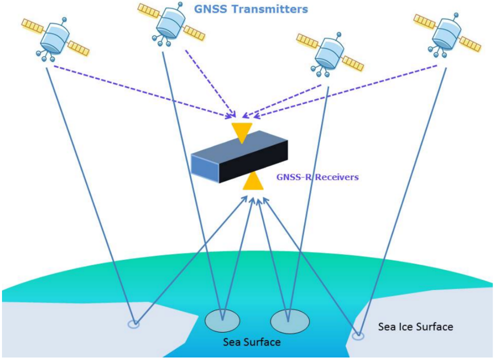
uci.edu

Previous Missions for Retrieval of Sea Ice Thickness

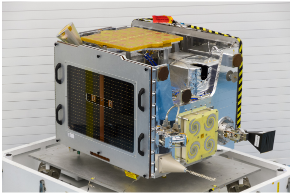


Hendricks et al. 2018

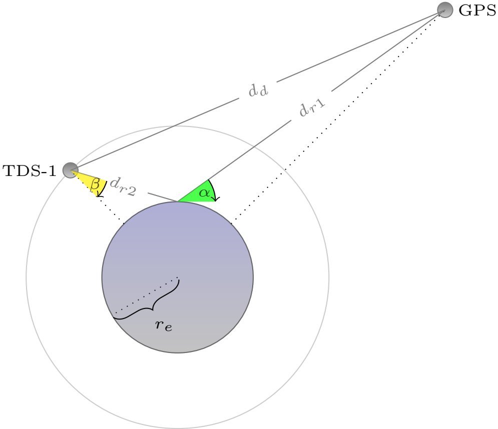
What about reflected power P_R of GNSS (Garrison et al. 1997)?



GFZ/Y. Zhu

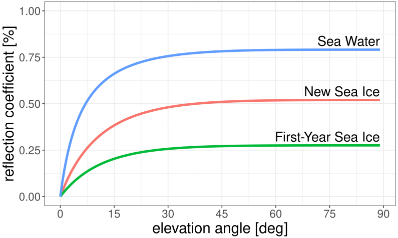


TechDemoSat-1 (SSTL)

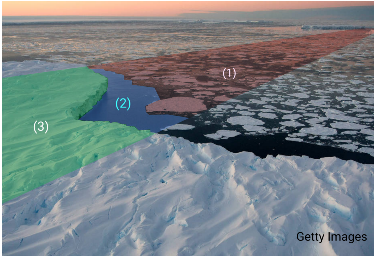


reflection geometry: direct and reflected signal path

Reflectivity of GNSS on **smooth surfaces** depends on **angle** θ and **relative permittivity** e_r:



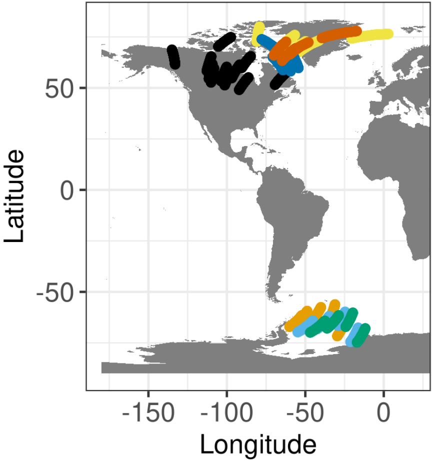
Fresnel coefficients indicate expected amount of reflection (for left-handed polarization)



fictive swath shows areas of (1) relatively low, (2) high and (3) low reflectivity

Our data

- 7 reflection slots
- 37 reflection tracks
- Arctic and Antarctica
- Acquisition time ca. 120s each
- Data product provided by the Institut d'Estudis Espacials de Catalunya



GPS signal analysis

The received power P_r at the input of LNA for direct and reflected signal path is composed of:

$$P_{\mathrm{r,di}} = P_{\mathrm{s}} + G_{\mathrm{t}} - L_{\mathrm{pl,di}} + G_{\mathrm{r,zenith}} + e_{\mathrm{di}}$$
$$P_{\mathrm{r,re}} = P_{\mathrm{s}} + G_{\mathrm{t}} - L_{\mathrm{pl,re}} + G_{\mathrm{r,nadir}} - \mathbf{L_{su}} + e_{\mathrm{re}}$$

where:

P_{r} = received power (dBW)
P_{s} = transmitted power (dBW)
G_{t} = transmitting antenna gain (dB)
L_{pl} = Free Space Path loss (dB)
G_r = receiver antenna gain (dB)
$\mathbf{L_{su}}$ = surface reflection loss (dB)
e = further unmodelled error sources (dB)

So what do we want to do?

- to derive geophysical parameters from surface reflection loss $\mathbf{L_{su}}$
- to cancel the effect of varying antenna gain and Free Space Path Loss
- to keep further unmodelled error sources e as small as possible

Free Space Path Loss

FSPL in dB

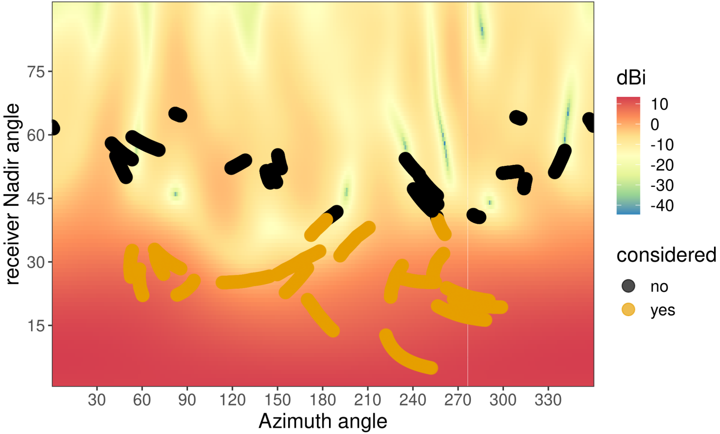
$$FSPL = 20 \cdot \log_{10}\left(\frac{4\pi df}{c}\right)$$

where:

$$\begin{aligned} d &= \text{distance between receiver and antenna} \\ f &= \text{used frequency (e.g. 1575.42 MHz for L1 GPS)} \\ c &= \text{speed of light (vacuum)} \end{aligned}$$

Receiver antenna gain pattern

Nadir antenna shows inhomogeneous gain pattern:



Signal correction

In Decibel

$$P^c_{\mathrm{r,di}} = P_{\mathrm{s}} + G_{\mathrm{t}} - L_{\mathrm{pl,di}} + L_{\mathrm{pl,di}} + G_{\mathrm{r,zenith}} - G_{\mathrm{r,zenith}} + e_{\mathrm{di}}$$
$$P^c_{\mathrm{r,re}} = P_{\mathrm{s}} + G_{\mathrm{t}} - L_{\mathrm{pl,re}} + L_{\mathrm{pl,re}} + G_{\mathrm{r,nadir}} - G_{\mathrm{r,nadir}} - \mathbf{L_{su}} + e_{\mathrm{re}}$$

after removing G_{r} and FSPL:

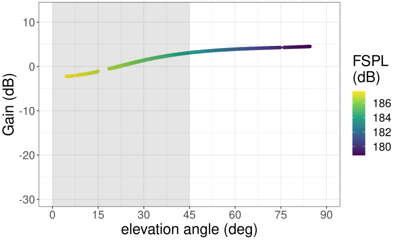
$$P^c_{\mathrm{r,di}} = P_{\mathrm{s}} + G_{\mathrm{t}} + e_{\mathrm{di}}$$
$$P^c_{\mathrm{r,re}} = P_{\mathrm{s}} + G_{\mathrm{t}} - \mathbf{L_{su}} + e_{\mathrm{re}}$$

Next: corrected power ratio between direct and reflected signal

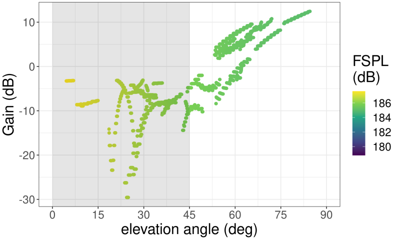
$$P^c_{\mathrm{re/di}} = P^c_{\mathrm{r,re}} - P^c_{\mathrm{r,di}}$$

Path Loss and Antenna gain

Gain and FSPL tracks for



...Zenith antenna

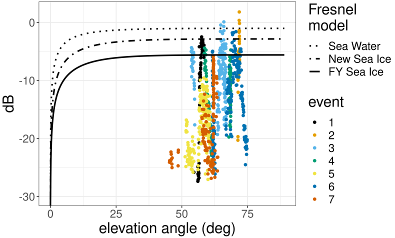


...Nadir antenna

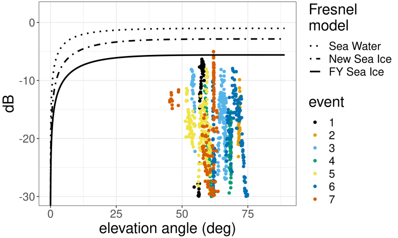
Cross-polar power ratio (Semmling et al. 2019)

Difference between corrected reflected and direct power, in dB:

$$P^c_{\mathrm{re/di}} = P^c_{\mathrm{r,re}} - P^c_{\mathrm{r,di}}$$



uncorrected reflectivity $P_{\mathrm{re/di}}$



corrected reflectivity $P^c_{\mathrm{re/di}}$

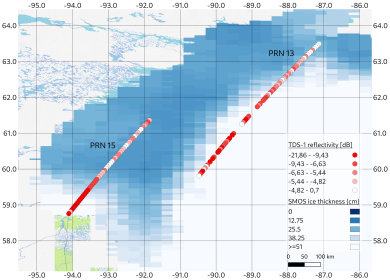
Results

Hudson Bay

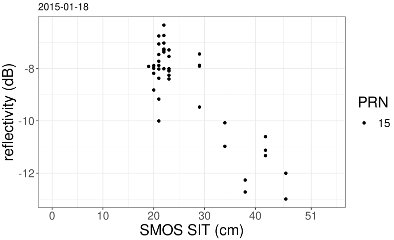
- Eastern Canada
- covered by First-Year Sea Ice for 5 to 10 months
- complex melting behavior

swiftmaps.com

Comparison with SMOS over Hudson Bay



reflectivity values with underlying SMOS Sea Ice Thickness



Correlation plot of PRN 15, after angle and SNR filter was applied

Discussion: Further error terms

- Uncertainties of the calculated antenna gains, also affected by unreliable attitude estimation
- Atmospheric loss L_{atm} of GPS is dominated by oxygen attenuation. It varies from 0.035 dB at zenith to 0.38 dB at 5° elevation (Spilker Jr 1996)
- Ionospheric attenuation should be taken into account
- more rough scattering than expected

Conclusion and Outlook

Conclusion

- Gain and Path Loss has a certain influence on the derived reflectivity
- TDS-1 data over Hudson Bay has retrieved sea ice reflectivity from GNSS reflections and differences to water reflection
- The comparison with ancillary SMOS data shows expected reciprocal relation between reflectivity and sea ice thickness

What remains to be solved:

- Estimation of the influence of surface roughness
- Calculation of Sea Ice Thickness from reflectivity values

Garrison, J. and S. Katzberg (Apr. 1997). "Detection of ocean reflected GPS signals: theory and experiment". In: *Proceedings IEEE SOUTHEASTCON '97. 'Engineering the New Century'*. IEEE, pp. 290–294.

Hendricks, S. et al. (2018). "Merged sea-ice thickness product from complementary L-band and altimetry information". In:

Kwok, R. (2018). "Arctic sea ice thickness, volume, and multiyear ice coverage: losses and coupled variability (1958–2018)". In: *Environmental Research Letters* 13.10, p. 105005.

Semmling, M. et al. (2019). "Sea-Ice Concentration Derived From GNSS Reflection Measurements in Fram Strait". In: *IEEE Transactions on Geoscience and Remote Sensing*.

Spilker Jr, J. J. (1996). "Tropospheric effects on GPS". In: *Global Positioning System: Theory and Applications, Volume I*. American Institute of Aeronautics and Astronautics. Chap. 13, pp. 517–546.

References II

Tian-Kunze, X. et al. (2014). “SMOS-derived thin sea ice thickness: algorithm baseline, product specifications and initial verification”. In: *The Cryosphere* 8, pp. 997–1018.

Thanks for your attention!