On the simulation of S-band backscatter for ocean calibration of the forthcoming NISAR data

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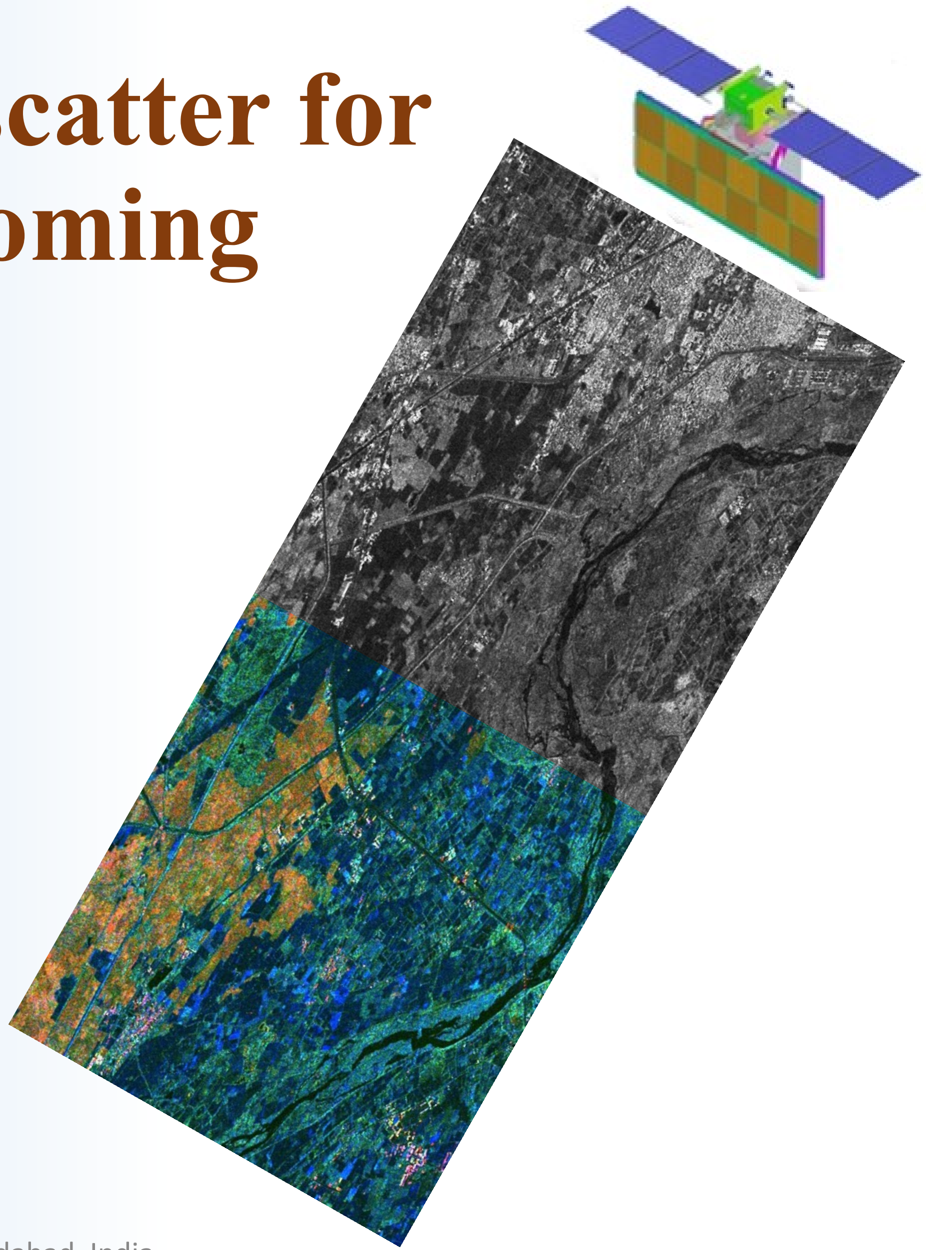


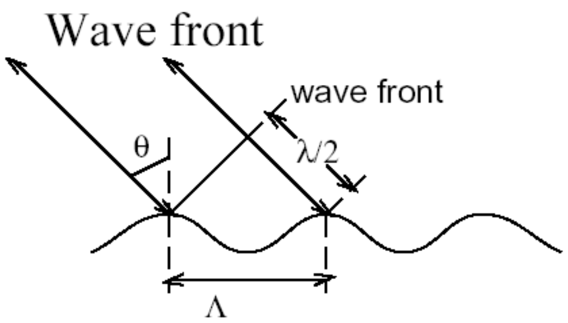
Background

- NISAR is scheduled to be launched in the First quarter of 2025
- NISAR will carry L & S band dual-frequency SARs
- L-band signatures over oceans are already studied using ALOS/PALSAR data
- S-band is novel for ocean applications
- NOVASAR carries S-band SAR, its calibration is still going on
- Hence, an effort is made to develop a pre-launch model function for the S-band (SMOD) using physical approaches
- Such model function will be utilized post-launch to calibrate the NISAR S-band observations over the oceans
- The SMOD will be utilized to retrieve geo-physical parameters (e.g., ocean wind)

Instrument characteristics of S-band NISAR

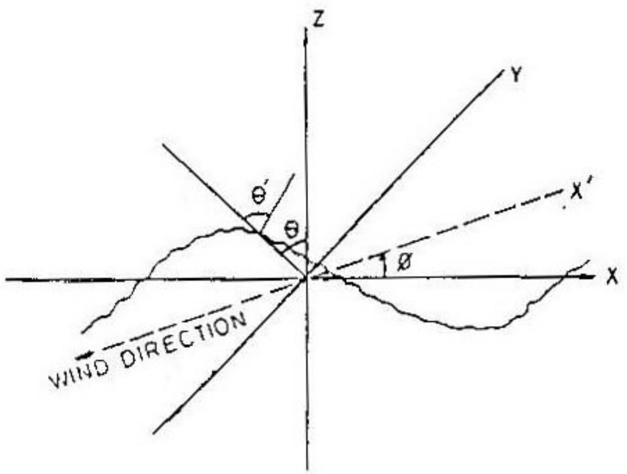
Parameters	S-band
Orbit	747 km with 98° inclination
Repeat Cycle	12 days
Time of Nodal Crossing	6 AM / 6 PM
Frequency	3.2 GHz ± 37.5 MHz
Available Polarimetric Modes	Single Pol (SP): HH or VV Dual Pol (DP): HH/HV or VV/VH Compact Pol (CP): RH/RV Quasi-Quad Pol (QQP): HH/HV and VH/VV
Available Range Bandwidths	10 MHz, 25 MHz, 37.5 MHz, 75 MHz
Swath Width	> 240 Km (except for QQP Mode)
Spatial Resolution	7m (Az); 2m-15m (Slant-Ra)
Incidence Angle Range	33 – 47 deg
Noise Equivalent σ^o	-25 dB (baseline) -20 dB(Threshold)
Ambiguities	< -20dB for all modes except QQP
Pointing control	< 273 arc seconds
Orbit control	< 350 meters
Data and Product Access	Free & Open access

Composite surface model for NRCS



$$\Lambda = \frac{\lambda}{2 \cdot \sin\theta}$$

Bragg Scattering



Two Scale scattering

- Radar return from ocean surface depends on Bragg scattering of the capillary waves
- The return power is also dependent on the interaction of the small scale capillary waves with underlying large scale gravity waves (known as two scale scattering) and physically represented through Modulation Transfer Function (MTF)
- MTF takes care of tilt and hydrodynamic modulation as well as non-linear velocity bunching
- Composite surface model combines Bragg scattering and two scale wave interactions (through surface wave height spectra) to yield a measurement of the Normalized Radar Cross Section (NRCS) in the form of :

$$\sigma 0 = 8\pi k^4 cos^4\theta \, |\alpha_{pp}|^2 [\psi(K_B, \Phi, u_{10}) + \psi(K_B, \pi - \Phi, u_{10})] \quad (1)$$

Where $\boldsymbol{k}$ is the radar wave number, $\boldsymbol{\theta}$ is radar incidence angle, $\boldsymbol{\alpha}$ is scattering coefficient dependent on transmit-receive polarization (***pp***) and incidence angle and $\boldsymbol{\Psi}$ is the directional ocean wave height spectra dependent on the wind speed at 10m height ($\boldsymbol{u_{10}}$), wind direction ($\boldsymbol{\Phi}$) relative to radar antenna and Bragg's wave number ($\boldsymbol{K_B}$).

(Romeiser et al., 1997, JGR – Oceans)

Composite surface model for NRCS (cont.)

In Eqn. (1), the Bragg wave number is given by:

$$K_B = 2k\, Sin\theta \qquad (2)$$

Where $\boldsymbol{k}$ is the radar wave number, $\boldsymbol{\theta}$ is radar incidence angle

Polarization dependent complex scattering coefficients are given by:

$$b_{VV} = \frac{\varepsilon^2(1 + sin^2\theta)}{(\varepsilon cos\theta + \sqrt{\varepsilon})^2} \qquad b_{HH} = \frac{\varepsilon}{(cos\theta + \sqrt{\varepsilon})^2} \qquad (3)$$

Inputs
Frequency
Polarization
Incidence Angle
Azimuth angle
Wind speed
Wind direction

Where $\boldsymbol{\varepsilon}$ is the complex relative dielectric constant dependent on radar frequency, sea surface temperature and salinity.

The wave height is given by:

$$\Psi(k, \phi, u_{10}) = P_L(k, u_{10}) W_H(k) \left(\frac{u_{10}}{u_e}\right)^{\beta(k)} k^{-4} S(k, \phi, u_{10}) \qquad (4)$$

The wave number roll off (using JONSWAP spectra) is given by:

$$P_L = 0.00195 exp\left[-\frac{k_p^2}{k^2} + 0.53 exp\left(-\frac{(\sqrt{k} - \sqrt{k_p})^2}{0.32 k_p}\right)\right]$$ where $k_p = \frac{1}{\sqrt{2}} \frac{g}{u_{10}^2}$ Is the peak wave number. (5)

Composite surface model for NRCS (cont.)

The wind speed exponent in wave height spectrum is given by:

$$\beta = \left[1 - \exp\left(-\frac{k^2}{k_1^2}\right)\right]\exp\left(-\frac{k}{k_2}\right) + \left[1 - \exp\left(-\frac{k}{k_3}\right)\right]\exp\left[-\left(\frac{k - k_4}{k_5}\right)^2\right] \quad (6)$$

The spectra shape parameter is given by:

$$W_H = \frac{\left[1 + \left(\frac{k}{k_6}\right)^{7.2}\right]^{0.5}}{\left[1 + \left(\frac{k}{k_7}\right)^{2.2}\right]\left[1 + \left(\frac{k}{k_8}\right)^{3.2}\right]^2}\exp\left(-\frac{k^2}{k_9^2}\right) \quad (7)$$

Finally, the spreading function is given by:

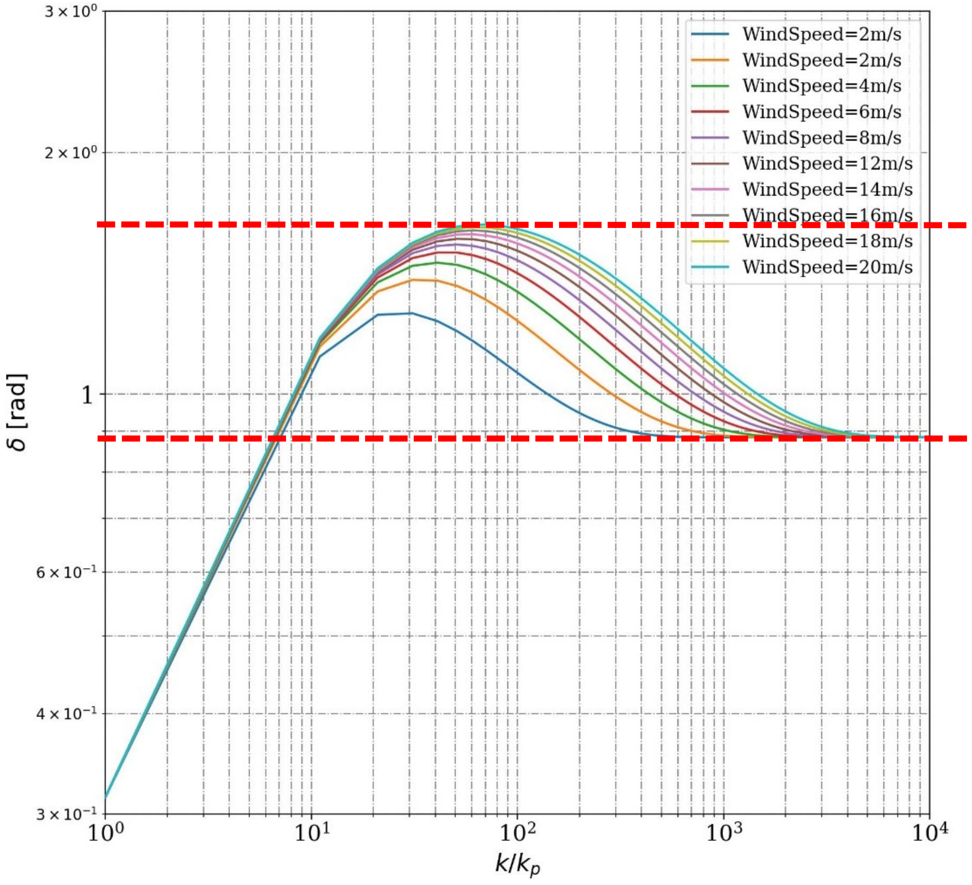
$$S = exp\left(-\frac{\phi^2}{2\delta^2}\right) \quad (8)$$

Where $$\frac{1}{2\delta^2} = 0.14 + 0.5\left[1 - exp\left(-\frac{ku_{10}}{c_1}\right)\right] + 5exp\left[2.5 - 2.6ln\left(\frac{u_{10}}{u_n}\right) - 1.3ln\left(\frac{k}{k_n}\right)\right] \quad (9)$$

All the constant terms like c1, k1,…,k9 are used as per the values given in *Romeiser et al., 1997*.

Verification of the simulation

Simulation of width parameter (Eqn. 9)



As given in the Romeiser et al., 1997

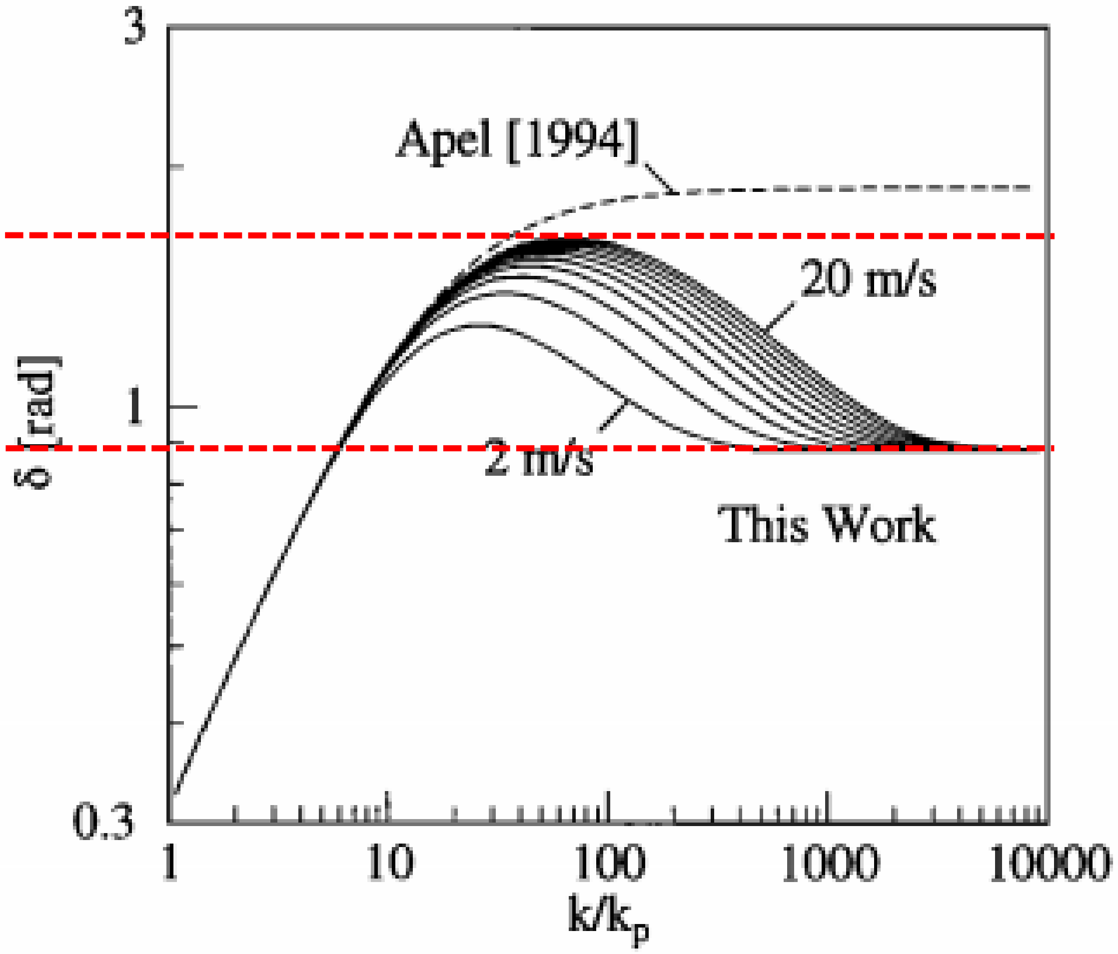
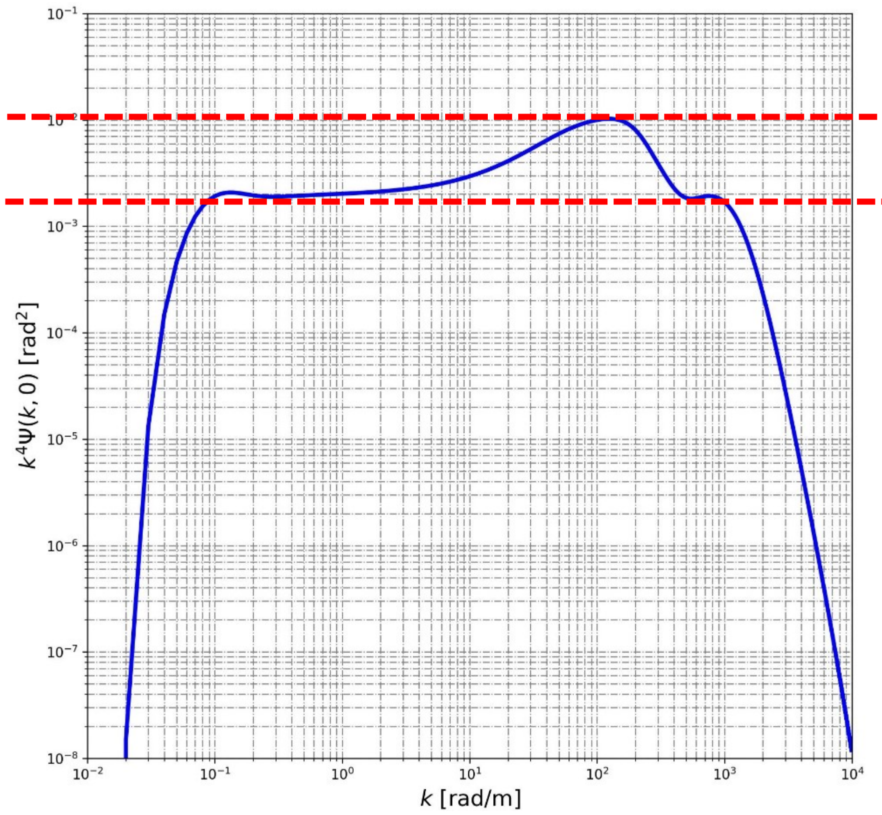


Figure 6. Width parameter δ of the spreading function S as function of k/k_p for wind speeds u_{10} of 2, 4, 6, ..., 20 m/s. The expression by *Apel* [1994] depends on wind speed via k_p only.

Verification of the simulation

Simulation of cross-section of curvature spectra (Eqn. 4)



As given in the Romeiser et al., 1997

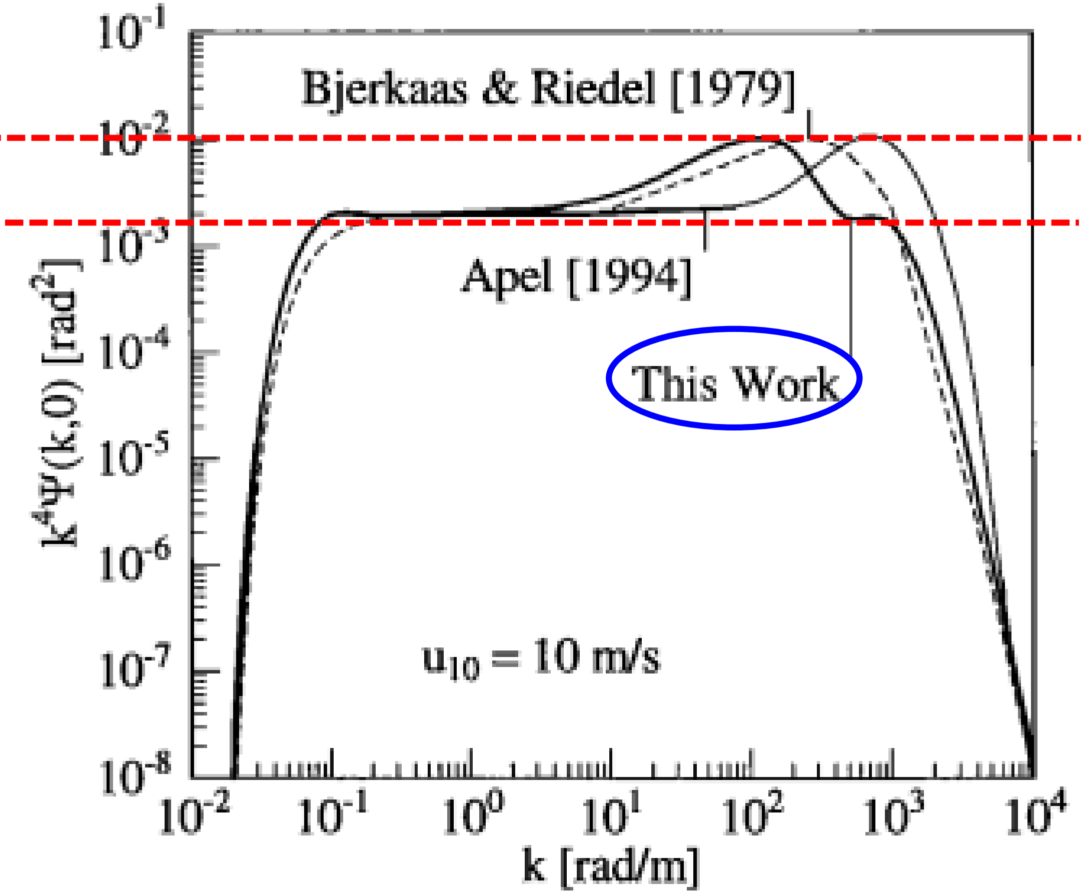
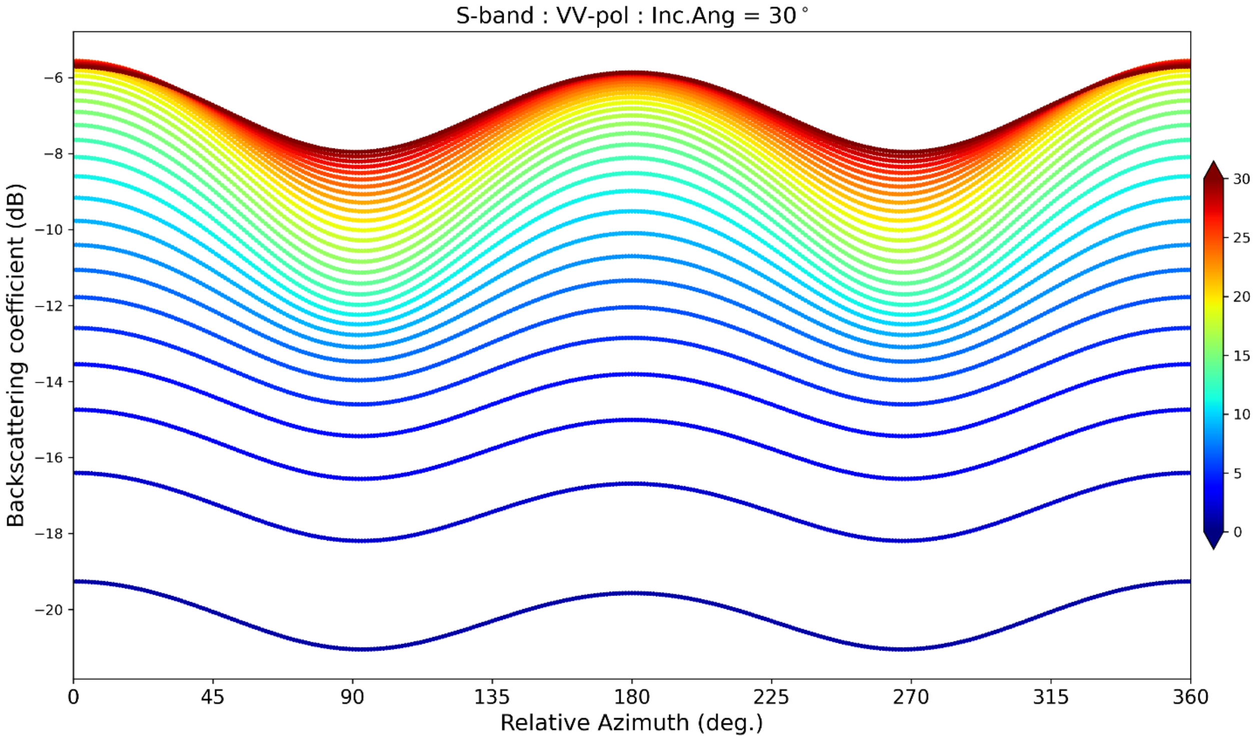
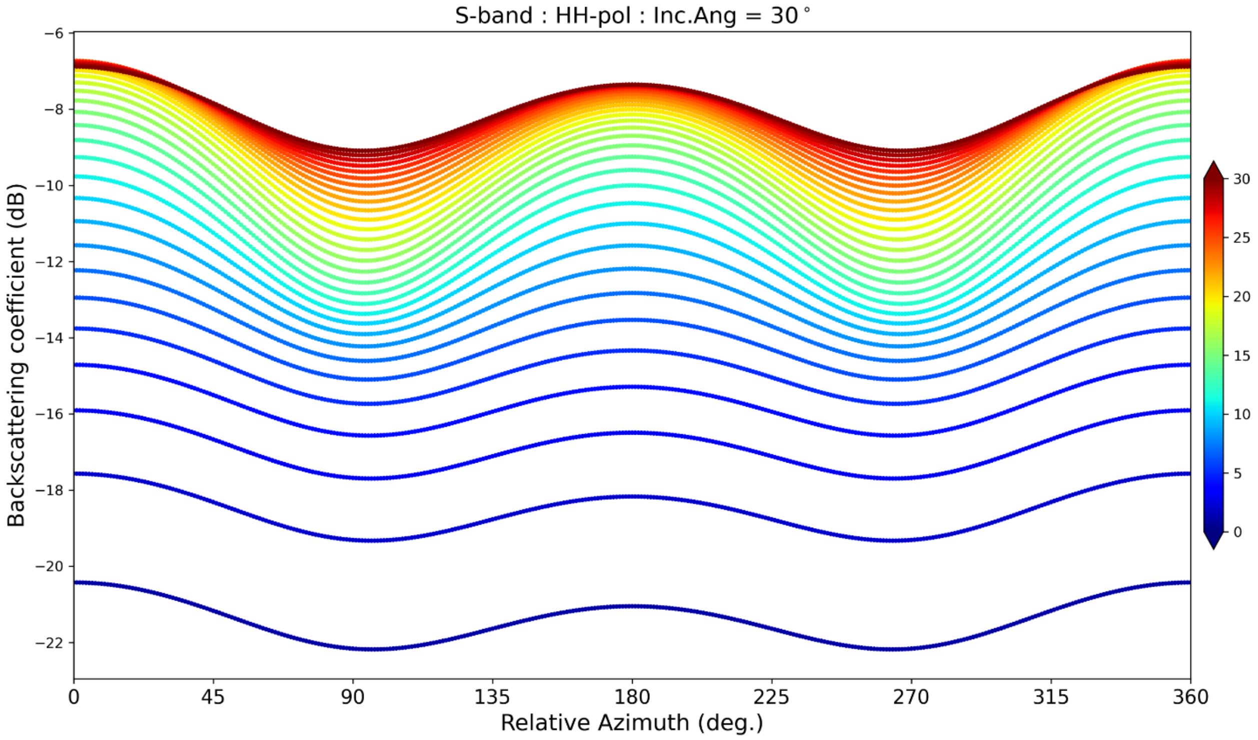


Figure 4. Cross section of curvature spectra $k^4\Psi$ at $\phi = 0$, as proposed by *Bjerkaas and Riedel* [1979] and by *Apel* [1994] and as obtained in this work. The wind speed u_{10} is 10 m/s in this example.

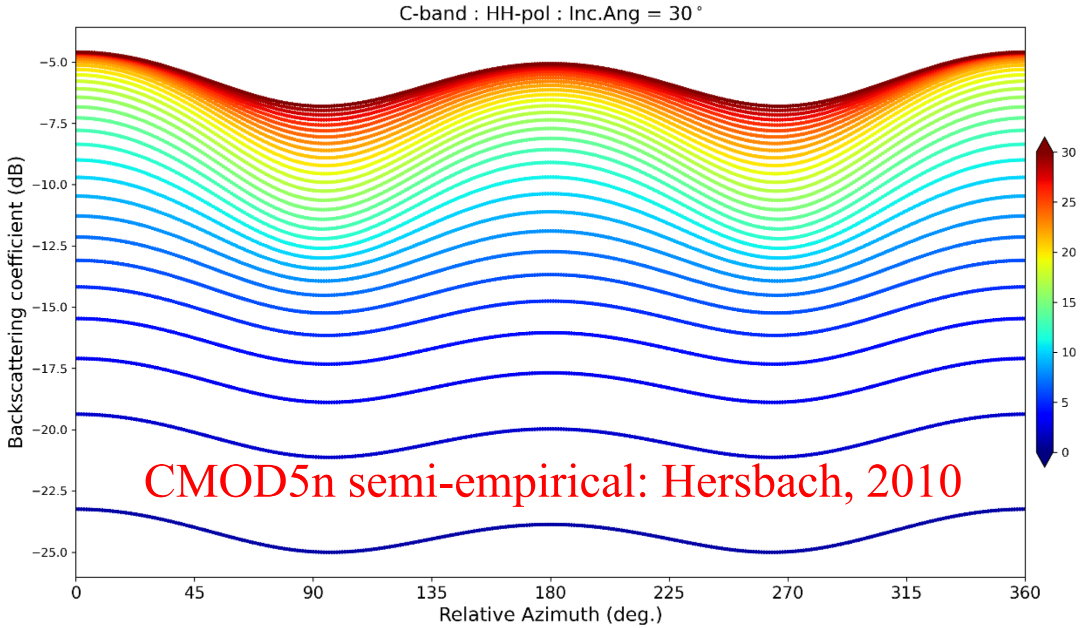
Results of the simulation

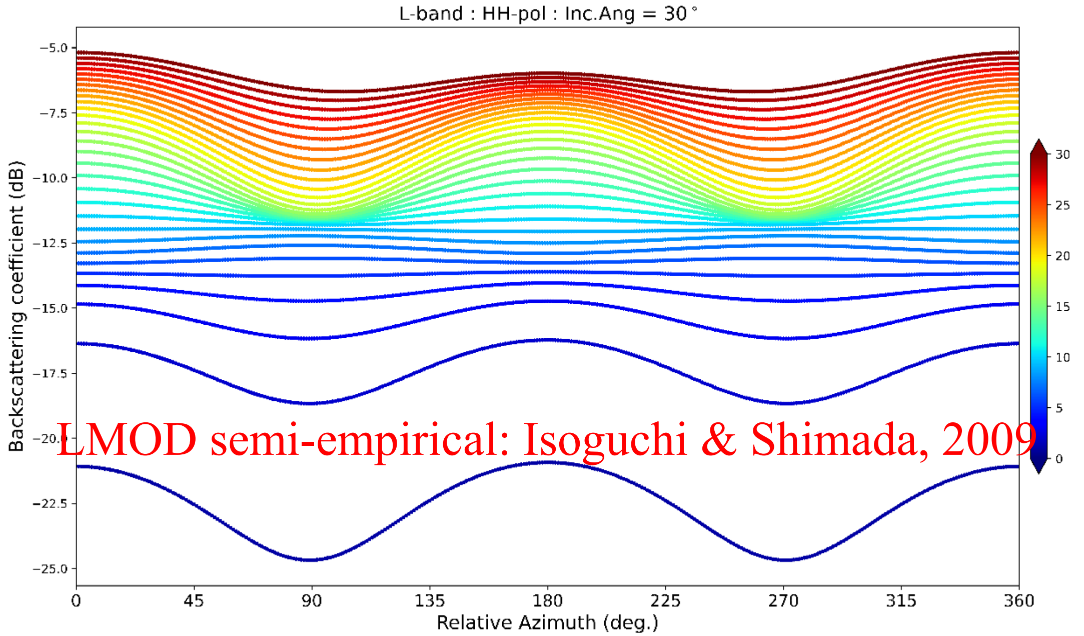
Simulated Normalized Radar Cross Section in S-band

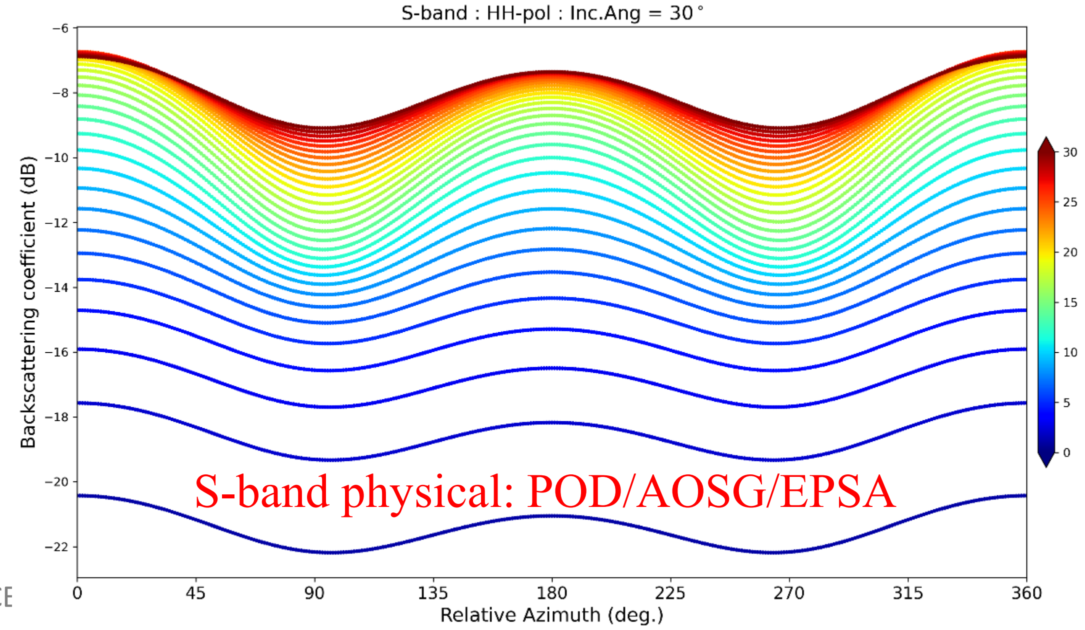




Results of the simulation







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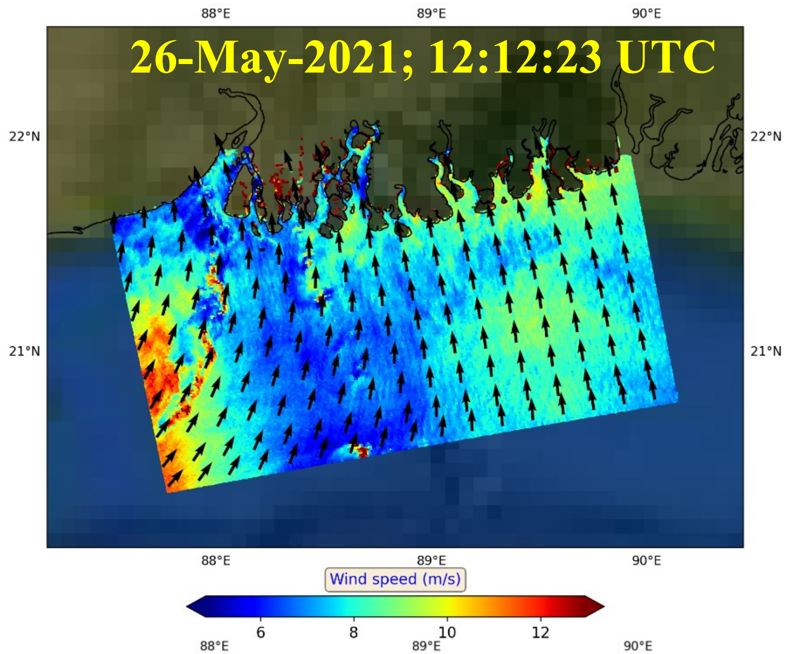
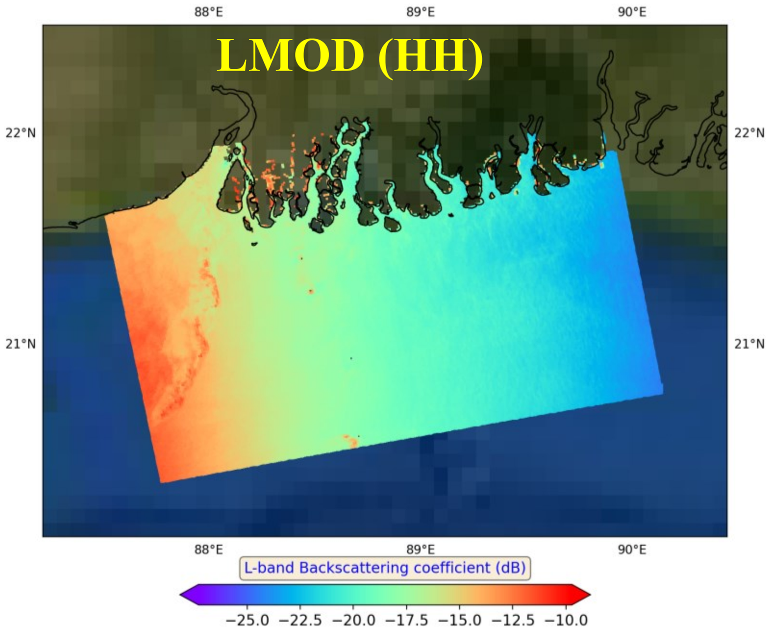
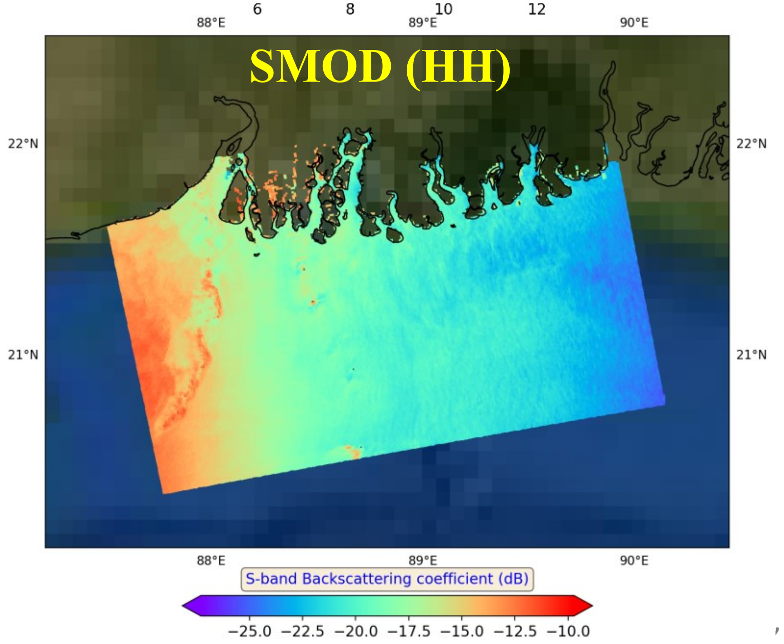
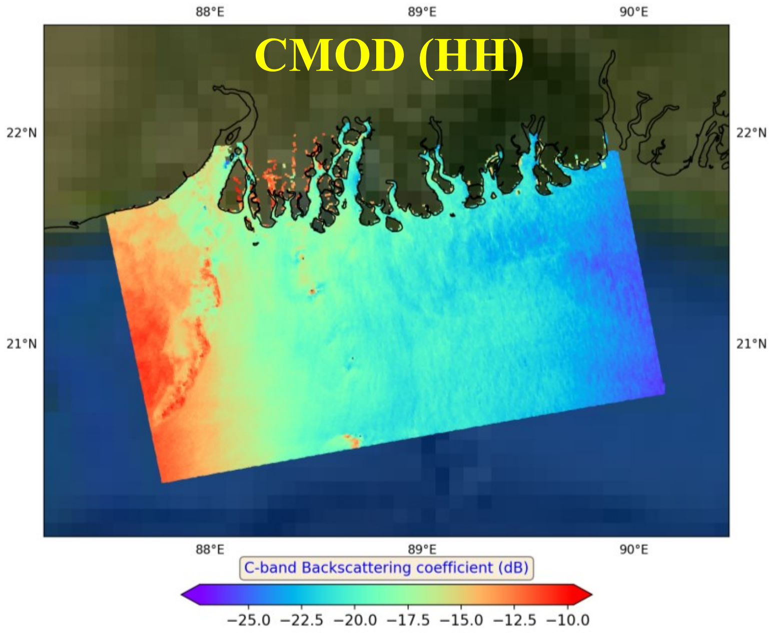
Results of the simulation (Coastal)



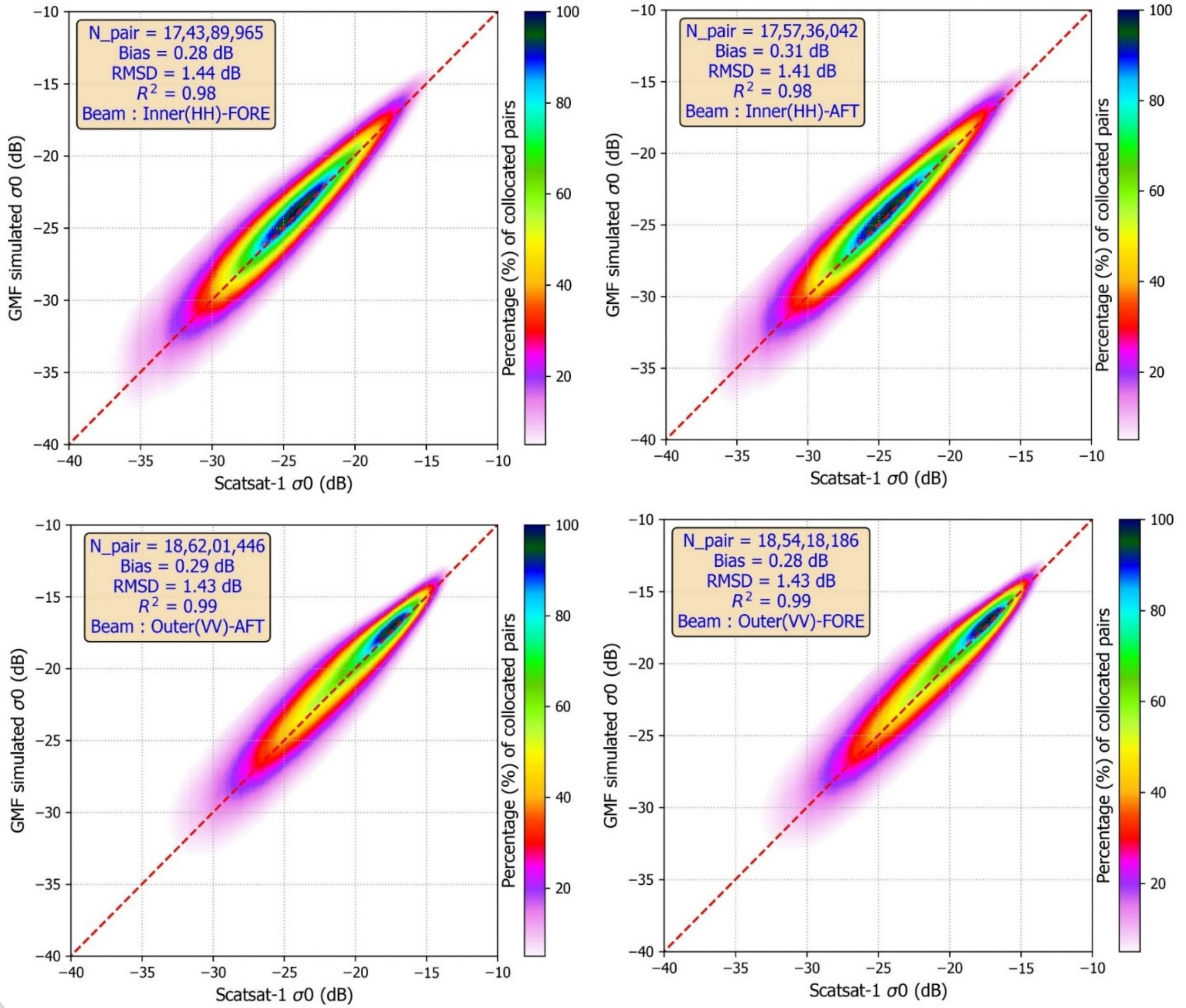


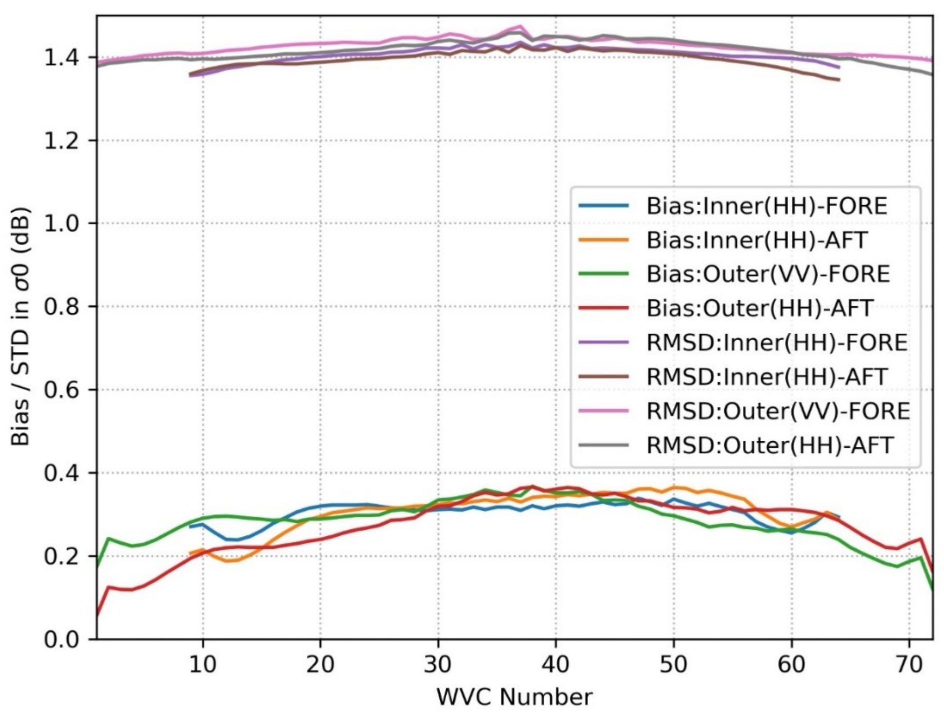




Numerical Ocean Calibration

An example from Ku-band





References:

Verspeek, J., A. Stoffelen, M. Portabella, A. Verhoef, J. Vogelzang (2008), "ASCAT scatterometer ocean calibration", *IEEE Geoscience and Remote Sensing Symposium*, 07-11 July 2008, Boston, USA.

Yun, R., A. Stoffelen, J. Verspeek, and, A. Verhoef. 2012. "NWP Ocean Calibration of Ku-band scatterometers", *IEEE International Geoscience and Remote Sensing Symposium*, pp. 2066 – 2058.

Conclusion & Future scope

- Estimation of S-band model (SMOD) function is carried out using physical based formulation of normalized radar cross section over the oceans
- This preliminary SMOD will help in calibrating the forthcoming NISAR S-band data over the oceans
- At present, a slight saturation in SMOD is observed for the high winds (~ 28 m/s and higher). This may be corrected once the NISAR data becomes available
- The SMOD can be utilized for oceanographic applications requiring absolute backscatter values