Characterization of Ka- and Ku-Band Sea Surface Backscatter for GPM Radar Applications

Simone Tanelli , Stephen L. Durden and Eastwood Im ,
Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA, USA
E-mail: simone.tanelli@jpl.nasa.gov ; Tel: +1-818-354-0195; Fax: +1-818-393-6440

Several Single- and Dual-Frequency Radar algorithms for TRMM and GPM use the sea surface as a reference target of known backscattering characteristics in order to constrain their retrieval algorithms with an estimate of the total Path Integrated Attenuation (PIA).

While the characteristics of the normalized sea surface cross section σ^0 at Ku-band are well-understood and widely published, the existing experimental data concerning σ^0 at Ka-band are scarce and results are inconsistent. The Ku/Ka band σ^0 measurements collected by APR-2 constitute a unique source of information to address this issue for the following reasons:

- Ku- and Ka- measurements are simultaneous and collocated.
- Very high range resolution obtained through pulse compression allows to minimize the range-sampling error.
- Measurements are obtained in the ±25˚ cross-track scanning mode, with pointing knowledge better than 1˚.

APR-2 measurements of σ^0 during the Wakasa Bay Experiment enabled the following findings:

a) the measured σ^0 at Ka-band at around 10˚ incidence angle appears to be close to that at Ku-band σ^0

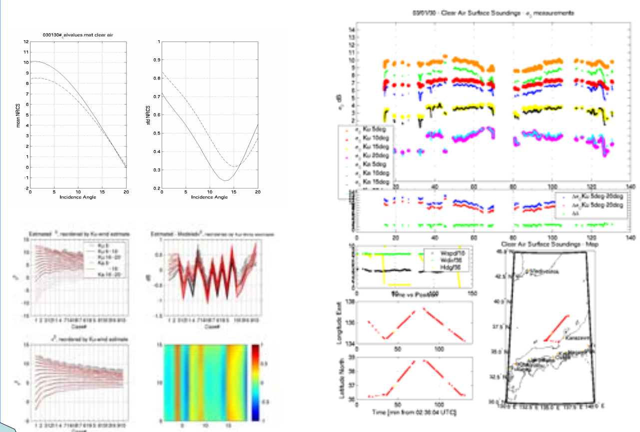
b) Ka-band exhibits a non-negligible difference in wind dependence with respect to Ku-band for moderate to high winds.

A second point of interest with regards to the implementation and use of any Surface Referenced Algorithm is that of the impact of Non-Uniform Beam Filling. GPM footprint is >4 km, which is larger than the typical scale of convective cells, hence NUBF is expected to occur in some scenarios. APR-2 high resolution measurements have been used to assess the relationship between the apparent PIA ($\Delta\sigma^0$) at the GPM resolution and the fine-scale pdf of PIA within the GPM footprint. Results shown here are for Ka-band.

ACKNOWLEDGEMENT

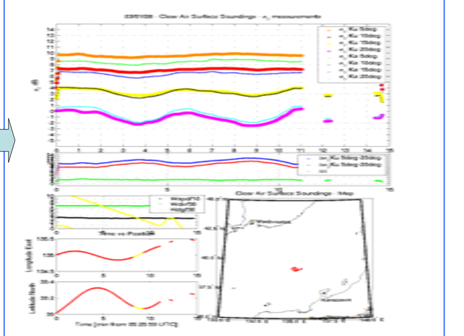
The research described in this paper was performed at the Jet Propulsion Laboratory, California Institute of Technology, for the PMM, TRMM, AMSR-E, and NIP Programs under contract with the National Aeronautics and Space Administration.

Ka-band Wind Speed Dependence



Ka-band Wind Azimuth Dependence

Observed during a 10 minute bank (360° degree turn with constant 10° roll angle)



Dual-Frequency Clear Air Observations of Sea Surface

Ku-band was externally calibrated by matching σ_0 of sea surface to the existing databases. σ_0 at 10° incidence angle, from different days and wind conditions, is in good agreement (±1 dB) with TRMM/PR and AAFE/RADSCAT predicts.

Ka-band calibration relative to Ku-band is estimated to have a (±1 dB) uncertainty relative to Ku-band.

The measured $\sigma_0(10°,w,Ka)$ is ~1.1 dB below $\sigma_0(10°,w,Ku)$; however, 2-way clear air attenuation estimates vary between 0.3 and 0.9 dB at Ka band, reducing the gap to less than a dB wich could be due to the smaller Fresnel coefficient. Overall this dataset is in agreement with the findings of Vandemark et al. (2004) and extends them to off-nadir incidence angles. In agreement with Vandemark et al. (2004), this analysis indicates that the previous experimental data of sea surface $\sigma_0(\theta,w,Ka)$ presented in Masuko et al. (1996) could have been affected by a large calibration error (>5dB).

Wind dependence of $\sigma_0(\theta,w,Ka)$ is qualitatively consistent with results obtained from a two-scale e.m. model (Durden et al. 1985), showing that $\sigma_0(\theta,w,Ka)$ behaviour is analogous to $\sigma_0(\theta,w,Ku)$: the 'wind invariant' region is confirmed around 10 ° incidence angle and the response to wind azimuth is consistent with that of $\sigma_0(\theta,w,Ka)$. The observed drop-off with θ is in general smaller than $\sigma_0(\theta,w,Ku)$ drop-off (by ~0.5 and ~3 dB if calculated between θ=5° and θ=15° for low and high winds, respectively), this is consistent with the assumption that the same surface appears 'rougher' at higher frequency. (Tanelli et al. 2005) Preliminary results confirm also the SST dependence at Ka band predicted by the two-scale model (~0.3dB decrease for 10°C drop in SST), however a targeted calibration mission is needed to provide better evidence.

Vandemark D., et al., Ocean Wave Slope Observations Using Radar Backscatter and Laser Altimeters, *J. Phys. Oce.*, **34**, 2825-2842, 2004

Masuko H., et al., Measurement of Microwave Backscattering Signatures of the Ocean Surface Using X Band and Ka Band Airborne Scatterometers, *J. Geophys. Res.*, **91**, 13065-13083, 1996

Durden S.L., and J.F.Vesecky, A Physical Radar Cross-Section Model for a Wind-Driven Sea with Swell, *IEEE J. Oce. Eng.*, **OE-10**, 445-451, 1985

S. Tanelli, S.L.Durden and E. Im, Simultaneous Radar Observations of Sea Surface at Ku- and Ka-band by APR-2, *Geosc. and Rem. Sens. Letters*, accepted for publication, 2005

σ^0 vs Squared Incidence Angle

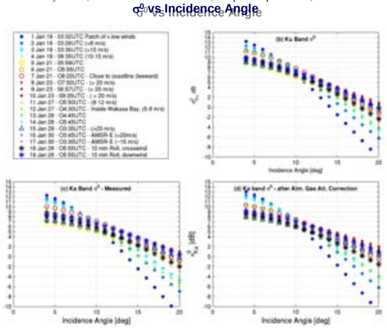
$$\sigma^0_f(\theta) = \frac{\rho_f}{mss_f}\frac{1}{\cos^4(\theta)}e^{-\left[\frac{\tan^2(\theta)}{mss_f}\right]}$$

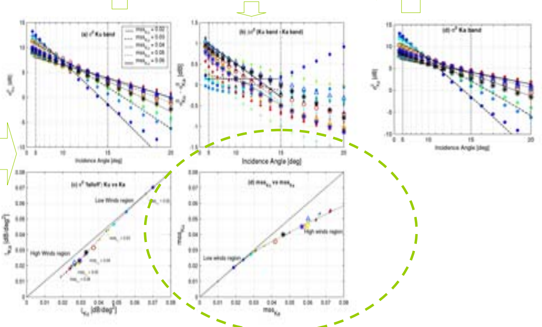
$$mss_f = \int_0^{k_f} |\mathbf{k}|^2 S(\mathbf{k})\, d\mathbf{k} = \langle s_f^2 \rangle$$

$$k_{Ku} \approx 90 \text{ rad m}^{-1}; \quad k_{Ka} \approx 250 \text{ rad m}^{-1};$$

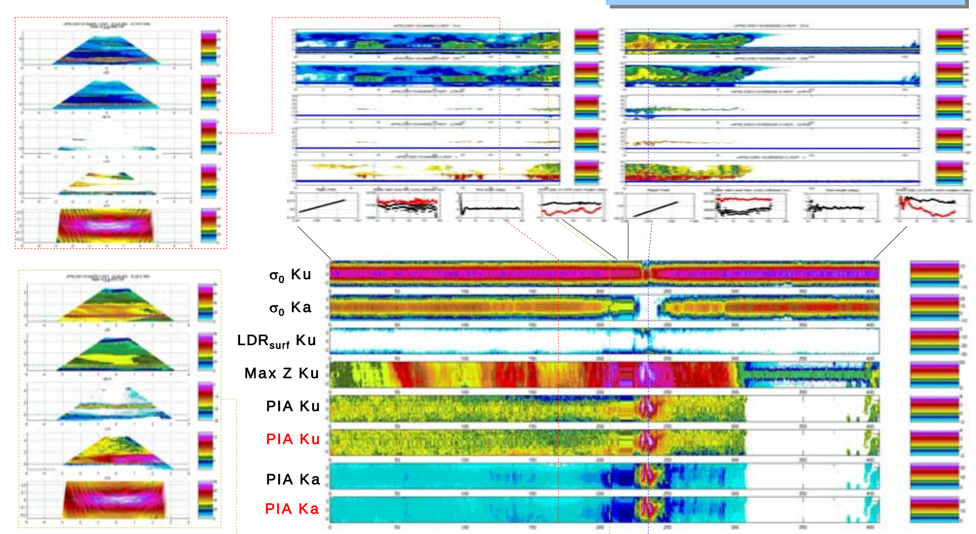
Δ

σ^0 vs Incidence Angle



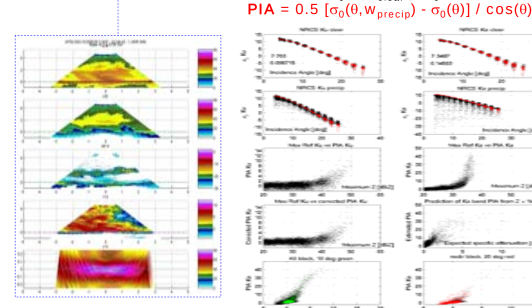


Dual-Frequency PIA measurements

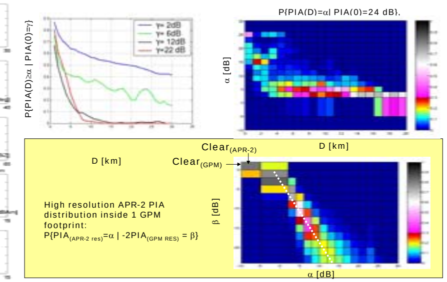


$$\text{PIA} = 0.5\,[\sigma_0(\theta,w_{clear}) - \sigma_0(\theta)] / \cos(\theta)$$

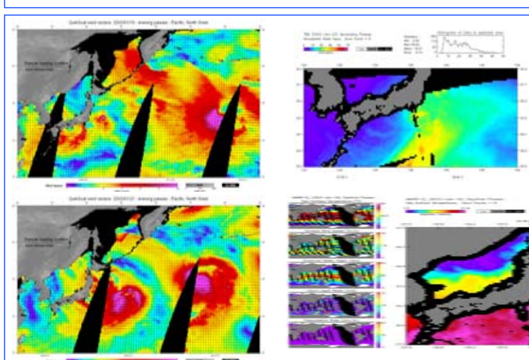
$$\text{PIA} = 0.5\,[\sigma_0(\theta,w_{precip}) - \sigma_0(\theta)] / \cos(\theta)$$



PDF of Dual-Frequency PIA at GPM and sub-GPM scales



Ancillary Data



Surface Winds were estimated from Quikscat, AMSR-E, TMI and SSM/I data products. Columnar water vapor and SST was estimated from TMI, AMSR-E and SSM/I data products. Temperature profiles were estimated from APR-2 measurements of freezing level altitude.

The QuikScat, TRMM/TMI, and AMSR-E data shown in this panel are produced by Remote Sensing Systems and sponsored by the NASA Ocean Vector Winds Science Team. Data are available at www.remss.com.