DUAL-POLARIZATION SPACEBORNE GNSS-R
FROM THE SMAP MISSION: AN STUDY OVER LAND AND CRYOSPHERE

by


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I INTRODUCTION

- Global Navigation Satellite Systems Reflectometry (GNSS-R) experiment: SMAP L-band radar receiver (orbit SSO, inclination ~ 98 °, height ~ 685 km)
- Raw data download and on-ground processing
- Antenna beam over specular reflection point
- Antenna pattern constant: Solar panels and spacecraft structure do not disturb radar data
- Study: First study GNSS-R scattering properties over land and cryosphere using linear polarization antenna from Low Earth Orbit (LEO)
- Motivation: Exploration GNSS-R capabilities for soil moisture determination, biomass monitoring and cryosphere studies
II GNSS REFLECTOMETRY EXPERIMENT ON-BOARD THE SMAP MISSION

- ~ 14 rev/min rotating 6-m-aperture reflector antenna: 1000-km wide swath
- High antenna gain (~ 36 dB) at H and V POL, elevation angle $\theta_e$ ~ 55°
- GPS code: L2C (1227.6 MHz)
- Coherent integration time $T_{coh} = 5$ ms, incoherent averaging $N_{inc} = 5$
III METHODOLOGY

- Waveforms (WFs) central Doppler

- Quantitative Analysis:  
  a) Signal-to-Noise Ratio (SNR)
  b) Leading (LE) & Trailing (TE) edges
  c) Polarimetric Ratio (PR): \[ PR = \frac{\sigma_H}{\sigma_V} = \frac{\langle |V_H^{\text{ref}}|^2 \rangle}{\langle |V_V^{\text{ref}}|^2 \rangle} \]

- Incoherent Scattering:
  \[ \sigma_{\text{qp}}^{\text{inc}} = (|a_0| kl/2)^2 e^{-q^2\sigma^2} \sum_{n=1}^{\infty} \frac{(q^2\sigma^2)^n}{n! n} e^{-\frac{(q^2+q^2)\sigma^2}{4n}} \]

  \[ a_{0,v} = 2R_v(\theta_{\text{inc}})\cos\theta_{\text{inc}} \]
  \[ R_v = \frac{\varepsilon_r\sqrt{1 - \sin^2(\theta_{\text{inc}})} - \sqrt{\varepsilon_r - \sin^2(\theta_{\text{inc}})}}{\varepsilon_r\sqrt{1 - \sin^2(\theta_{\text{inc}})} + \sqrt{\varepsilon_r - \sin^2(\theta_{\text{inc}})}} \]

  \[ a_{0,h} = -2R_h(\theta_{\text{inc}})\cos\theta_{\text{inc}} \]
  \[ R_h = \frac{\sqrt{1 - \sin^2(\theta_{\text{inc}})} - \sqrt{\varepsilon_r - \sin^2(\theta_{\text{inc}})}}{\sqrt{1 - \sin^2(\theta_{\text{inc}})} + \sqrt{\varepsilon_r - \sin^2(\theta_{\text{inc}})}} \]

- Coherent Scattering: \[ PR = \frac{R_H}{R_V} = \frac{|R_H|^2 e^{-(2\pi k \cos \theta_{\text{inc}})^2}}{|R_V|^2 e^{-(2\pi k \cos \theta_{\text{inc}})^2}} \]

PR: “Independent surface roughness”
III METHODOLOGY

- Averaged WFs associated RMS each lag
- H and V-Pol data for different terrain types

Surprising results: large WFs’ spreading Greenland & high SNR over Sahara Desert
IV GLOBAL SCALE

- 1 year averaged values: 0.1° latitude/longitude grid with 1° spatial averaging
- ~35,000 observations/month, ~25 ± 4 measurements per pixel
- High SNR: a) bare regions high SM (Pampas, Great Lakes, Northern India, Yakutia Region) and b) Sahara Desert
- Signal depolarization after scattering over dense vegetation and rough topography
IV GLOBAL SCALE

- SNR from ~15 dB to ~30 dB: Amazon river and riparian forests
- High power peaks: Effect coherent scattering
- Power peaks higher than those over Greenland: Effect specular reflection over calm water
IV GLOBAL SCALE

- Reflectometry and Radiometry lose sensitivity as surface roughness and AGB increase
- PR roughly independent surface roughness
- ↑ Soil Moisture: ↑ Reflectivity vs. ↓ Emissivity
- PR and Soil Moisture (SM) Pearson correlation factor $r \sim -0.6$
- SMAP data set ($\theta_e \sim 55^\circ$) useful sensitivity analysis dielectric constant changes
IV GLOBAL SCALE

- Trailing (TE) & leading (LE) edges widths: sensitivity different surfaces types, showing dissymmetric shape (TE > LE)
- Similar spreading H-Pol & V-Pol: Similar antenna gain & rate change radar cross-section with positioning vector
- Rough topography, TE&LE: lower probability facet could forward scatter signal in a specular way
- Biomass, TE&LE: high attenuation affects away nominal specular point
- Lower WFs’ spreading does not mean higher signal coherence
IV GLOBAL SCALE

- Differentiated scattering properties over specific target areas
- Heterogeneous areas
- Differentiated mean values and fluctuations (topography, biomass, rivers)
- Differentiating from boreal to tropical forests
- Higher WFs’ spreading winter over Greenland
V REGIONAL SCALE: ARID DESERTS AND CONGOLIAN RAINFORESTS

- Significant seasonal variations (SNR, PR, leading & trailing edges) assessed using SWI (METOP-ASCAT) and NDVI (MODIS)
- Effect of ABG (350 tons/ha) tropical forests: Low SNR, PR and WFs’ spreading
- Higher variability SNR Sahara & Kalahari Deserts (surface, subsurface-dry conditions): Higher SNR values low values Soil Moisture
- Large WFs’ spreading over deserts (~ 2 m penetration depth for 0% SM L Band): Effects winds on “sand seas“ (dunes)?
- TE width similar [9, 15] & [15, 30], different NDVI values: Canopy height key parameter (see tropical rainforests)

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V REGIONAL SCALE: ARID DESERTS AND CONGOLIAN RAINFORESTS

- Zoom selected target areas: North & South hemispheres
- Changes SWI and NDVI correlated SNR_H & trailing edge; anti-correlated PR:
  a) Larger soil scattering coefficient (larger SWI) increases SNR
  b) Larger NDVI attenuates H-Pol more than V-Pol signals
- PR more sensitive SWI changes over regions with lower AGB: Effect signal depolarization

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V REGIONAL SCALE: ARID DESERTS AND BOREAL FORESTS

- Areas with separated SWI and AGB effects
- WFs’ sensitivity to different levels canopy height
- Boreal forests: Lower SNR (higher signal attenuation) and PR < 0 dB (depolarization GNSS signals)
- Gobi Desert:  
  a) Higher PR ~ 5 dB, evidence low SWI
  b) Larger trailing edge (TE) width, little vegetation
- Northern Siberia: PR higher sensitivity to SWI fluctuations (summer-SWI to winter-snow), bare soil
V REGIONAL SCALE: ARID DESERTS AND BOREAL FORESTS

- WFs similar trend summer & winter
- NDVI not associated with SWI
- Effect AGB
- Lower SNR and TE width values winter: Effect of snow
- Smaller region around SP contributes to WFs
V REGIONAL SCALE: LAKES REGION AND ICE CAP

- GNSS-R applications extended to study of snow and ice: ~ 100s m penetration depth at L-band over dry ice (volume scattering and scattering at different layers)
- Larger Greenland WFs’ spreading winter (dry ice): Subsurface effects (higher WFs’ peak and TE width)
- Extended regions of Greenland affected by melting. Inner ice cap:
  a) Peak values of SNR ~ [18, 22] dB, PR ~ [3, 5] dB, TE width ~ [500, 600] m
  b) WFs parameters takes alternatively low and high values (are we seeing melting effects?)
- North America: Effect of SWI fluctuations from Summer to Winter
VI CONCLUSIONS

• PR and SM by SMAP radiometer Pearson linear correlation factor $r \sim -0.6$

• $\text{SNR}_H$ levels: $\text{SNR}_{H,\text{Sahara}} \sim 18 \text{ dB}, \text{SNR}_{H,\text{Greenland}} \sim 17 \text{ dB}, \text{SNR}_{H,\text{Boreal Forests}} \sim 13 \text{ dB}, \text{SNR}_{H,\text{Tropical Forests}} \sim 12 \text{ dB}$

• WFs’ parameters sensitivity seasonal fluctuations over regions seasonal changes SWI and NDVI

• Trailing and leading edges widths sensitivity to different levels AGB up $\sim 350 \text{ ton/ha}$

• AGB shows a more pronounced effect on GNSS-R signatures than NDVI

• GNSS signals depolarized upon scattering over high levels AGB and and/or rough topography

• Large WFs’ spreading over Greenland suggest possibility cryosphere monitoring using GNSS-R sensors from space
THANK YOU FOR YOUR ATTENTION

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