RADAR ALTIMETRY BACKSCATTERING SIGNATURES AT KA, KU, C AND S BANDS OVER LAND

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ABSTRACT

Satellite radar altimetry, initially designed for studying ocean surface topography, demonstrated a strong potential for the continuous monitoring of ice sheets and land surfaces over the last 25 years. If radar altimetry is mostly used for its capacity to determine surface height, the backscattering coefficients provide information on the surface properties.

Spatio-temporal variations of radar altimetry backscattering over land were related to the nature of the surface and its changes against time. This study presents the results of an along-track analysis of radar altimetry echoes over land at S, C, Ku and Ka bands using data from Jason-2, ERS-2, ENVISAT and SARAL on their nominal orbit. Temporal average and deviations are presented at global scale.

1. INTRODUCTION

Spaceborne radar sensors provide global observation of continental surfaces at different frequencies, resolution, incidence angles and polarizations. Backscattering coefficients (σ0) from radar scatterometers and Synthetic Aperture Radar (SAR) images are commonly used to monitor the dynamics of key variables characterizing the continental surfaces, such as vegetation density or surface soil moisture (SSM)[1-3]. Spatial and temporal variations of radar altimeter (RA) backscattering coefficients (σ0) were related to the dynamics of surface properties over land and ice sheets [4,5]. Over land, RA backscattering coefficients at C-band were used to detect flood in Siberia[6]. Signatures of soil roughness and SSM changes in the deserts were identified at Ku band using ERS-1 and Topex/Poseidon data[7,8]. Backscattering coefficients from Topex/Poseidon were found to be decreasing as vegetation increase in Sahel[9]. A comprehensive comparison of radar signatures acquired over West Africa (between 0° and 25°N and 5°W - 25°E) at both C- and Ku- bands using nadir-looking altimeters (35-day orbital period ENVISAT RA-2 over 2003-2010 and 10-day orbital period Jason-2 over mid-2008-2012) that covers the major bioclimatic zones, soil and vegetation types encountered in this region was performed[10]. A recent study also demonstrated the capability to retrieve SSM from ENVISAT RA-2 backscattering coefficients over Sahelian savannahs in the Gourma region of Mali[11]. Preliminary results using the first of SARAL measurements at Ka-band showed the potential of Kauf for detecting SSM changes and water even under forest canopy[12].

In this study, we present global maps of along-track average backscattering coefficients and associated standard deviation at S, C, Ku and Ka bands using data from Jason-2, ERS-2, ENVISAT and SARAL on their nominal orbit over land. Then, we relate the resulting maps to the nature of the surface and its temporal evolution.

2. RADAR ALTIMETRY BACKSCATTERING

Over ocean-like surfaces, the altimeter echo can be described as the sum of the reflections from elementary surface facets distributed around the mean surface ordered by their arrival time or range[13]. This radar altimetry echo (or waveform W) results from the convolution of the impulse response shape (I) with the antenna pattern function (Ant) and the point distribution function (pdf):

\[ W = I \otimes \text{pdf} \otimes \text{Ant} \]  

(1)

Over land and ice sheets, the electromagnetic (EM) waves emitted by the altimeter are likely to penetrate most of the underneath surfaces. The resulting radar response can be composed of surface and volume echoes. Over ice sheets, it is the sum of surface and snowpack layers echoes. Over land, the resulting waveform can be the sum of echoes from the canopy, ground layers and possibly snow layers depending on
3. ALTIMETRY DATASETS

3.1. ERS-2

European Remote Sensing-2 (ERS-2) was launched in 1995 by ESA as ERS-1 follow-on mission. It was designed to study the Earth environment. The satellite carries, among other instruments, a radar altimeter (RA) operating at Ku-band (13.8 GHz) developed for measuring height over ocean, land and ice caps. ERS-2 orbits at an average altitude of 790 km, with an inclination of 98.54°, on a sun-synchronous orbit with a 35-day repeat cycle. It provides observations of the Earth surface (ocean, land, and ice caps) from 82.4° latitude north to 82.4° latitude south. This orbit was formerly used by ERS-1 mission, with an equatorial ground-track spacing of about 85 km. ERS-2 data are available from 17 May 1995 to 9 August 2010. After 22 June 2003, the dataset coverage is limited to ground station visibility.

3.2. ENVISAT

Environment Satellite (ENVISAT) mission was launched on March 1st 2002 by ESA. It carried 10 instruments including the advanced radar altimeter (RA-2). It was based on the heritage of sensor on-board the ERS-1 and 2 satellites. RA-2 was a nadir-looking pulse-limited radar altimeter operating at two frequencies at Ku- (13.575 GHz), as ERS-1 and 2, and S- (3.2 GHz) bands. Its goal was to collect radar altimetry over ocean, land and ice caps[14]. ENVISAT remained on its nominal orbit until October 2010 and its mission ended 8 April 2012. Its initial orbital characteristics are the same as for ERS-2 (see 3.1).

3.3. SARAL

SARAL is a CNES-ISRO joint-mission that was launched on 25 February 2013. Its payload is composed of the AltiKa radar altimeter and bi-frequency radiometer, and a double system for precise orbit determination [15]: DORIS instrument and a Laser Retroflector Array (LRA). SARAL flights on the same nominal orbit than ENVISAT (see above). AltiKa radar altimeter is a mono-frequency altimeter and the first one to operate at Ka-band (35.75 GHz).

3.4. Jason-2

Jason-2 mission was launched on 20 June 2008 as cooperation between CNES, EUMETSAT, NASA and NOAA. Its payload is mostly composed of the Poseidon-3 radar altimeter from CNES, the Advanced Microwave Radiometer (AMR) from JPL/NASA, and a triple system for precise orbit determination: the DORIS instrument from CNES, a GNSS receiver and a Laser Retroflector Array (LRA) from NASA. Jason-2 orbits at an altitude of 1336 km, with an inclination of 66°, on a 10-day repeat cycle, providing observations of the Earth surface (oceans and lands) from 66° latitude North to 66° latitude South, with an equatorial ground-track spacing of about 315 km. This orbit was formerly used by Topex/Poseidon, and Jason-1. Poseidon-3 radar altimeter is a two-frequency altimeter, operating at Ku- (13.575 GHz) and C- (5.3 GHz) bands[16].

3.5. Altimetry backscattering coefficients

Altimetry data used in this study are the backscattering coefficients estimated using the Ice-1[17] and the Ice-2[5] retracking algorithms from the ERS-2 GDRs from Centre de Topographie des Océans et de l’Hydrosphère that were recently made available after the reprocessing of ERS-2 Waveform Altimeter Products (WAP)[18], the ENVISAT Geophysical Data Records (GDRs) v2.1 and the SARAL GDRs T patch 2. Backscattering coefficients estimated using Ice-1 retracking algorithms are present in the GDRs D. Backscattering coefficients derived from these retracking algorithms are commonly used for characterizing land and ice sheets surface properties[5,6,10-12]. The ones used in this study are the high frequency measurements (i.e., 20 Hz for ERS-2 and Jason-2, 18Hz for ENVISAT and 40 Hz for SARAL) These datasets were made available by Centre de Topographie des Océans et de l’Hydrosphère (CTOH : http://ctoh.legos.obs-mip.fr/).

4. METHODS

Along-track altimetry data were first sorted using an average track defined using the mean location of altimetry data for each mission during its nominal orbit (Fig. 1). This mean track is defined by four parameters: the mean longitude and latitude of each cell composing the mean track, and its size given by its dimensions along (δ_Along-track) and cross track (δ_Cross-track). If δ_Cross-track is chosen arbitrarily (equals two kilometers in this study as this distance corresponds to the maximum cross-track variations along the orbit of ERS-2 and ENVISAT missions), δ_Along-track is given by[19,20]:

$$\delta_{Along-track} = V_{sat} \delta_{sat}$$ (3)

where $V_{sat}$ is the velocity of the satellite along the orbit equals to 7.45 km.s⁻¹ and δ is chosen equals to 1 second, that mean that every cell contains, each cycle a maximum of 18 measurements for ENVISAT, 20
In each cell, every cycle, the mean backscattering coefficient and the associated standard deviation were computed as follows:

$$\left\langle \sigma_0 \right\rangle_{dB} = 10 \log_{10}\left(\frac{\sigma_0 / 10}{10}\right)$$  \hspace{1cm} (4)$$

And

$$\text{std}\left(\sigma_0\right)_{dB} = 10 \log_{10}\left(1 + \left(\frac{\text{std}\left(\sigma_0 / 10\right)}{10}\right)\right)$$  \hspace{1cm} (5)$$

where $<\sigma_0>_{dB}$ and $\text{std}(\sigma_0)_{dB}$ stand for the average of $\sigma_0$ in dB and its associated standard deviation in dB, respectively. As the backscattering coefficients of the different altimetry missions are provided in dB in the GDRs, they were first converted into their natural values as expressed in (4) and (5).

Using the mean backscattering value per cycle, average backscattering coefficients and associated standard deviations were computed for the whole observation periods of ERS-2 at Ku-band (cycles 1–85 from May 1995 to July 2003), ENVISAT at Ku- (cycles 6–94 from June 2002 to October 2010) and S-bands (cycles 6–64 from June 2002 to January 2008 when RA-2 altimeter onboard ENVISAT stopped operating correctly at S-band), Jason-2 at Ku- and C-bands (cycles 1 to 259 from August 2008 to February 2016), and SARAL at Ka-band (cycles 1-25 from March 2013 to August 2015) using (4) and (5) over land.

5. RESULTS

In the followings, only results obtained Ice-1 backscattering coefficients, retracking applied on all the missions will be presented. Similar results are found using Ice-2 retracking algorithm.

5.1. Mean backscattering over land

Radar altimetry backscattering values averaged over the whole period of availability of the different altimetry missions considered in this study (ERS-2, ENVISAT, SARAL, and Jason-2) range between 0 and 25 dB at Ku-band (Figs. 2a, c and d for ERS-2, ENVISAT and Jason-2 respectively), between 0 and 30 dB at S- and C-bands (Figs. 2e and f for ENVISAT and Jason-2 respectively), and between -5 and 25 dB at Ka-band (Fig. 2b for SARAL). Altimetry backscattering is low (< 5 dB at Ku-band, < 7 dB at S- and C-bands, and < 2.5 dB at Ka-band) over mountainous regions (Himalaya, Andes, Rocky Mountains) as the power returned to the altimeter decreases with the angle of incidence[4,5], and lower at Ka than at S-band as the antenna aperture increases (2). Largest values, that can reach 20 dB at Ku- and Ka-bands and 25 dB at S- and C-bands are found over flat areas such as deserts and large river basins with extensive wetlands, as well as in large irrigated zone where specular returns occur. Due to the lower footprint size at Ka-band than at lower frequencies, these regions can be very clearly identified (Fig. 2b). For example, this is clearly visible in large regions of the Sahara, in Arabian, Gobi and Australian deserts, along the Ganges, and especially in the Ganges-Brahmaputra-Meghna delta, the Plata or the Ob’, a large peri-arctic river. Along the Ganges and in the Mekong basins, the large backscattering values are also due to the inundated rice paddies. Similar patterns were found at Ku and C bands using Topex/Poseidon data[4]. Oyer rivers with extensive floodplains covered with forest, as in the Amazon Basin, the mean backscattering coefficient is low due to the presence of the forest once averaged on 7 km along the track, especially at low frequencies as C and S-bands (Fig. 2e and f for ENVISAT and Jason-2). At high latitudes, in peri-arctic basins, covered with snow from fall to spring, the backscattering is increasing while the frequency is decreasing (from Ka to S) as previously observed[21,22].
5.2. Variability of backscattering over land

Along with the averaged values of backscattering, standard deviations were computed. Results obtained using Ice-1 re-tracking algorithm are presented in Fig. 3. Std values reached up to 3 dB at Ku-band (Figs. 3a, c and d for ERS-2, ENVISAT and Jason-2 respectively), 2.5 dB at S- and C-bands (Figs. 3e and f for ENVISAT and Jason-2 respectively), and 3 dB at Ka-band (Fig. 2b for SARAL). As the footprint size increases against the frequency, the surface appears smoother at lower frequency. As a consequence, the deviation increases with the frequency. Low std values (< 1 dB for all bands) are found over flat areas such as deserts (Sahara, Kalahari, Arabian, Gobi and Australian deserts), inner seas as the Caspian Sea, high plateaus such as Bolivian, Colorado, Mongolia and Siberian plateaus. On the contrary, high variability is found in some large extensive floodplains with important changes of hydric state such as along La Plata River, Mamoré floodplain at the Bolivian/Brazilian border, some flat regions covered in snow during winter in northern Eurasia and Canada. These high variations in backscattering are related to seasonal changes in roughness and dielectric constant values of the soil.
5.3. Difference in backscattering over land

Differences of radar altimetry backscattering were computed for bi-frequency missions (i.e., ENVISAT and Jason-2). Average and standard deviation of the differences of backscattering S–Ku for ENVISAT and C–Ku for Jason-2 were estimated over the whole period of availability of the two altimetry missions. They are presented in Fig. 4. Over land, differences in backscattering range from a few decibels to more than 10 dB. High values of the differences (>8 dB) are found in arid and desert regions: Sahara, Takla Makan (China), Gobi desert, Central Asia deserts and some mountainous areas as the south of the Andes and of the Rocky Mountains. Lower values of the difference C–Ku (< 5 dB) correspond to dense tropical rain forests of Africa, South America and South East Asia and forest of temperate regions. These regions are characterized by the smallest values of standard deviation (< 1.2 dB). S–Ku averaged values are generally lower than C–Ku ones (Figs. 4a and b), but their standard deviation is higher (Figs. 4c and d).
6. CONCLUSION

The altimeter backscattered responses at Ka-, Ku-, C- and S-bands and the C-Ku and S-Ku differences exhibit a wide range of spatial and temporal variations over land surfaces. The backscattered energy by each surface can be related to its soil roughness and soil dielectric constant and their variations against time. This study points out the interest of using nadir-pointing radar observations for the monitoring of land and ice sheets surfaces and their temporal evolution. If the use of radar altimetry for the monitoring of land surfaces currently suffers from its low spatial and temporal resolutions, the launch of the Surface Water and Ocean Topography (SWOT) mission in 2020 will permit to overcome the limitations. Using the SAR interferometry technique at near nadir incidences, SWOT will provide backscattering coefficients in a swath of ~120 km with a spatial resolution of 100 m over land.

7. REFERENCES


