CoRe-H_2O – A Dual Frequency SAR Mission for Hydrology and Climate Research

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***Abstract*— Taking into account the needs for improved, spatially detailed observations of snow and ice in climate research, hydrology, and glaciology, the satellite mission COld REgions Hydrology High-resolution Observatory, CoRe-H_2O, was proposed to ESA. As payload a co- and cross-polarized Ku-band (17.2 GHz) and X-band (9.6 GHz) SAR was selected, because of its sensitivity to dry snow, thin sea ice, and the metamorphic state of snow, firn and ice on glaciers and ice caps. A cost-effective ScanSAR scheme with parabolic reflectors (each with multiple beams) is proposed fulfilling the requirements for swath width, spatial resolution and radiometry. The mission has been selected by ESA for further scientific and technical studies in the frame of the Earth Explorer Satellite Programme.**

Keywords: SAR; Ku-band; X-band; snow; ice.

I. INTRODUCTION

Snow and ice are very sensitive to changes in temperature and precipitation, and interact with other climate variables through complex feedbacks. They play also an important role in biogeochemical cycles, particularly in the supply of water and nutrients to terrestrial and aquatic ecosystems. Moreover, snow and glacier melt is a basic resource of water for many densely populated areas of the world, the abundance of which is seriously threatened by climate change. Therefore accurate inventories of the snow and ice masses and their dynamics, as well as improved parameterizations and modeling of water and energy exchange processes, are necessary to advance the understanding of climate change and its impact on the environment.

The lack of spatially distributed information of the snow accumulation on land surfaces, glaciers and sea ice has been recognized by the climate research, meteorological and hydrological communities. In its Cryosphere Theme Report [1] the Integrated Global Observing Strategy (IGOS) Partnership recommends the development and implementation of satellite systems for spatially distributed measurements of snow water equivalent (SWE) and other properties of the snow cover. In order to close essential gaps in cryosphere observations, the satellite mission COld REgions Hydrology High-resolution Observatory, CoRe-H_2O, was proposed to ESA in response to the 2005 Call for Earth Explorer Core Missions.

II. OBSERVATION REQUIREMENTS

Main mission objectives of CoRe-H_2O are spatially detailed observations of snow, ice, and water cycle characteristics required for understanding and modeling land surface, atmosphere and ocean processes in cold environment. The observational requirements address the needs for a wide range of topics in cryospheric monitoring and research, including

- Improved modeling and prediction of water balance and streamflow for snow covered and glacierized basin
- Assessing effects of climate change on water supply from snow cover and glaciers
- Monitoring surface water extent in high latitudes and its relation to climate variability
- Improving parameterization of snow and ice processes in numerical weather prediction and climate models
- Studying mass balance of glaciers and ice caps
- Performing process studies for lake and river ice
- Contributing to the understanding of sea ice kinematics and dynamics in marginal ice zones

- Improving estimates of sea ice surface heat fluxes and mass balance and their variability by retrieving properties of snow cover on the ice.

The mission objectives lead to a set of observational requirements for seasonal snow cover, glaciers and ice sheets, fresh-water ice, sea ice, and surface water. For snow cover the main parameters required are snow extent, water equivalent, and depth; for glaciers these are diagenetic facies and winter snow accumulation; for sea ice snow depth, ice type, and motion (with emphasis on new sea ice).

The mission concept foresees two different temporal observation phases. A 3-day repeat cycle with limited area coverage is aimed at observing effects of meteorological forcing on snow and ice, particularly addressing cryosphere-atmosphere exchange and the parameterization of snow and ice processes in hydrological models and numerical weather forecasting models. The second phase is aimed at near complete observation of the global cryosphere with about 15 day repeat cycle. Emphasis of this mission phase is on climate research applications and on validation of hydrological models and coupled land-atmosphere models.

III. Measurement Concept

The retrieval of the snow parameters will be based on backscatter measurements at X-band (9.6 GHz) and Ku-band (17.2 GHz) frequencies with comparatively high spatial resolution. Ku-band is more sensitive to shallow snow, with a typical one-way penetration depth d_p of 3-4 m for dry seasonal snow [2]. X-band provides greater penetration for deeper snow, especially for older, coarse-grained snow, with d_p of the order of 10 m. Co- and cross-polarized channels are important for separating surface and volume scattering contributions. Spaceborne scatterometry and airborne SAR have demonstrated the high information content of X- and Ku-band frequencies for observations of snow, sea ice, ice sheets and glaciers [3], [4], [5], [6]. The mission objectives can be achieved by a sensor with swath width of about 100 km, which enables the implementation of the mission within the given budgetary constraints.

The present baseline version for SWE retrieval from dual frequency (9.6 and 17 GHz), dual polarized (VV and VH) backscatter applies a second order radiative transfer model [7]. This combination of frequency and polarization enables separation of volume and surface scattering contributions and determination of grain size effects. The total backscatter signal of dry snow over ground at polarization pq is composed of the following contributions

$$\sigma^{t}_{pq} = \sigma^{as}_{pq} + \sigma^{v}_{pq} + \sigma^{gv}_{pq} + \sigma^{g}_{pq} \qquad (1)$$

where the first term on the right hand side, scattering at the air/snow interface, is a small contribution for dry snow. The second and third term are the snow volume scattering term and ground surface/volume interaction term, respectively. The last term represents backscatter at the ground surface after transmission through the snowpack. The importance of each scattering component depends on sensor frequency and polarization, observation geometry, and snow/ice properties. Validated numerical simulations, as shown in Fig.1, are an important tool for understanding and predicting snow-radar response and for establishing algorithms for retrieval of snow physical properties.

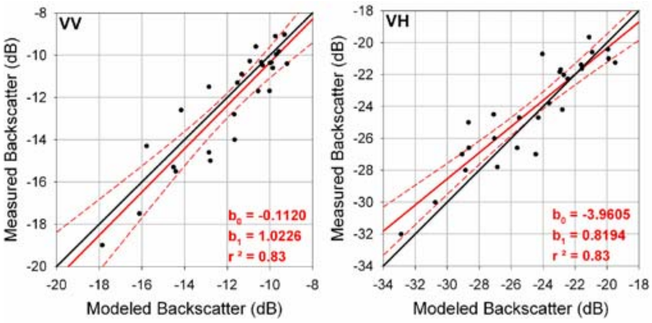

Figure 1. Comparison of backscatter measurements at X- and Ku-band, VV and VH polarizations, to backscatter modeled by second-order radiative transfer model, for a wide range of incidence angles and snow characteristics.

An essential step in the SWE retrieval is isolating the volume scattering contribution which can be determined from the depolarisation factor for both frequencies. Grain size effects need to be corrected, which is possible by estimating the scattering albedo from the optical thickness ratio of the two frequencies. The residual optical thickness is applied to retrieve SWE.

Fig. 2 shows an example of the capability for retrieval of SWE with coarse resolution Ku-band (13.4 GHz) backscatter data over the western United States. A simple decomposition technique, based on radiative transfer, has been used to retrieve SWE from QuikSCAT. This is compared to observations in and near the scatterometer footprints through a single season at four sites. The dual frequency approach will enable accurate decomposition of backscatter contributions over a wide range of different snow and ice properties.

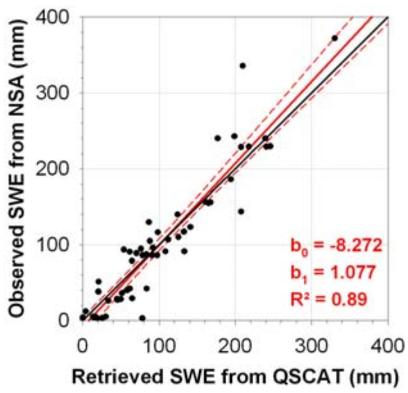

Figure 2. Comparison of observed SWE from NOAA National Snow Service Analysis (NSA) with SWE from QuikSCAT Ku-band data using a radiative transfer model function for several sites in the western U. S.

IV. Technical Concept

A technical concept for the CoRe-H_2O mission, including the satellite and payload elements, has been identified to meet the mission/science requirements and the mission cost cap. The current technical concept employs SAR systems at X-band and Ku-band, operating on two separate spacecrafts. Preliminary technical design concepts were developed for ESA by EADS Astrium GmbH and EADS Astrium Ltd [8]. Alternate technical concepts will be studied within an upcoming technical study. In particular, the feasibility of accommodating both SARs on one spacecraft will be investigated. This will require modification of the antenna design, but it is expected that the basic concept (parabolic reflectors) will be maintained.

Some details on instrument design parameters are listed in Table 1. The major drivers for the instrument design are the required swath width and the instrument radiometric sensitivity driven by cross-polarized measurements for snow and ice. To meet these requirements a cost effective solution is proposed, based on passive reflector antennas with array-feed designs to provide multi-beam capability for ScanSAR operation. The ScanSAR operation requires a set of antenna elevation beams operating in a repeated sequence at adjacent incidence angles.

TABLE I. INSTRUMENT DESIGN PARAMETERS – BASELINE VERSION

Parameter	**X-Band SAR**	**Ku-Band SAR**
Frequency	9.6 GHz	17.2 GHz
Polarization	VV, VH	VV, VH
Incidence Angle	30-40 deg.	30-40 deg.
Antenna (el x az)	2.2 m x 4.4 m	1.2 m x 3.2 m
Antenna Directivity	46 dB	49 dB
Antenna Beamwidth	1.5 x 0.5 deg.	0.9 x 0.3 deg.
Antenna Footprint (el)	24 km	16 km
Nr. of ScanSAR Beams	4	6
Swath Width	≥ 100 km	≥ 100 km
Peak Transm. Power	3 kW	4 kW
Chirp Bandwidth	10 MHz	10 MHz
NESZ	< -25dB	< -25dB
ScanSAR resolution single look (el x az)	25 m x 8 m	25 m x 10 m

For the Ku-band radar, an innovative antenna design using an array of 3 parabolic reflectors of 1.2 m x 1.1 m size is proposed, fed by dual-polarized array feeds [8]. Sequential switching of neighbouring horns produces the required ScanSAR beams to provide a total swath of about 100 km. Each reflector is illuminated by a separate feed system.

For the X-band radar, an offset parabolic reflector is proposed with about 4.4 m x 2 m main axes, illuminated by a linear feed array with 9 dual polarized feed horns. For ScanSAR operation, overlapping antenna elevation beams are achieved by sequential switching groups of 3 neighboring horns. Multiple ScanSAR beams, each providing about 24 km sub-swath, will be combined to obtain a total swath width of ~ 100 km. The total required RF peak power is about 3 kW.

Other antenna design options will be investigated which allow the sharing of one antenna for both frequencies and hence the operation of the dual-frequency SAR on one spacecraft, to find a cost and performance optimized solution.

V. CONCLUSION

CoRe-H_2O is a cost-efficient and innovative solution for obtaining cryospheric data for climatology, meteorology, hydrology, and glaciology. The dual frequency Ku- and X-band SAR offers the possibility to observe snow and ice physical properties that are not well observable at lower radar frequencies. The spatial resolution and sampling intervals of the two mission phases will enable accurate repeat observations of snow cover properties over lowlands and mountain areas, to generate snow cover products for distributed hydrological models, to study surface/atmosphere interaction processes on glaciers and ice caps, and to observe the dynamics of sea ice formation and transport in polynyas and leads. The CoRe-H_2O mission will open up new opportunities for studying important cryospheric processes not observable in such detail by other missions, thus complementing long term observations from operational satellites.

For mission preparation the activities on high frequency radar retrieval methods for snow and ice have been intensified, both on the experimental and theoretical side. Field campaigns on Ku-and X-band backscatter signatures of snow were carried out in the Alps and in the western United States in winter 2006/07, and further campaigns are planned for the upcoming winter. A technical study on further advancing the mission concept has recently been launched by ESA.

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