THE FINE RESOLUTION EXPLORER FOR SALINITY, CARBON AND HYDROLOGY (FRESCH): A SATELLITE MISSION TO STUDY OCEAN-LAND-ICE INTERFACES

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ABSTRACT

The Fine Resolution Explorer for Salinity, Carbon and Hydrology (FRESCH) is presented. The science case and the mission objectives are discussed before presenting the mission concept. FRESCH is an L-band antenna array operated in beamforming mode providing data at a spatial resolution of 10-15 km to study the biogeochemical and physical phenomena taking place at the interfaces of ocean, land and ice. FRESCH has been submitted to the European Space Agency Earth Explorer 12 program.

Index Terms— L-band, Satellite mission, Beamforming

1. INTRODUCTION

Understanding the Earth system requires to study the processes taking place at the interfaces of different components (atmosphere, ocean, cryosphere, land, etc.). In particular, monitoring the dynamic evolution of the coastal ocean at its interfaces with the land, the atmosphere and the cryosphere (Figure 1), is key for understanding the present and future climate of the Earth, the impact of human-induced environmental perturbations and their effect on the marine ecosystems and the society. A deeper understanding of the energy and biogeochemical cycles at the interfaces requires a proper representation of (sub)mesoscale processes that are ubiquitous in the entire ocean and occur at spatial scales of 1 to 100 km and temporal scales of days to months [1]. They include the formation and dissipation of meanders and eddies, filaments near frontal zones often characterized by intense biological activity and they affect the transport of water, heat, salt, nutrients, oxygen, and pollutants over long distances.

shows a comparison of surface currents from model simulations at different resolutions (2.5, 8, 25 and 100 km). The simulations with resolutions of 25 km or finer show complex eddy systems and resulting meanders in the Antarctic Circumpolar Current [2]. In the 100-km simulation, these complex structures can be hardly detected. SMOS and SMAP can resolve mesoscale processes up to a scale of 40-80 km. A comparison of the different model output in Figure 2 clearly shows that a spatial resolution finer than 25 km already represents a quantum leap in our understanding of how the ocean works.

The sea surface salinity (SSS) can be used to trace transport phenomena associated with (sub)mesoscale dynamics including freshwater discharges from land and ice sheets, atmospheric precipitation/evaporation and sea ice growth and melting [3], [4]. In combination with other variables (e.g. sea surface temperature and ocean color), SSS enables the identification of water masses that carry various carbon contents or other compounds in the ocean and across interfaces, via e.g. river outflows, and influence the air-sea gas exchange [5], [6]. This information can be used to estimate the sea surface partial pressure of CO2 (pCO2), which will provide much-needed new constraints for closing the global carbon cycle and to monitor the fate of anthropogenic CO2 in the ocean.

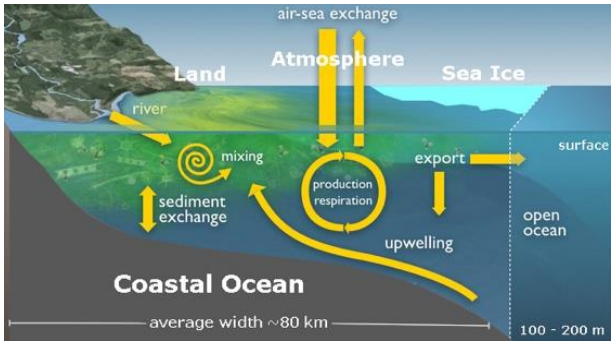

Figure 1: Schematic of the coastal ocean showing processes at the ice-ocean-land interface that are crucial for understanding our environment and its changes (from NOAA Panel Marine Environmental Laboratory).

2. MISSION OBJECTIVES

The lack of satellite sensors to observe SSS at high spatial resolution required to study interface regions (1-10 km) has not yet allowed comprehensive studies in interface regions showing SSS variability on spatial scales of 1-10 km as frequently identified in shipboard observation or by using autonomous instruments or in the regions of the world's largest river plumes [7]. Therefore, the primary goal of the Fine Resolution Explorer for Salinity, Carbon and Hydrology (FRESCH) mission is to produce SSS and pCO2 maps with a spatial resolution of ~10 km at temporal scales of 1-3 days and with an accuracy of 0.4 pss and <12 microatm, respectively. The objectives of the mission are: *(i)* Understanding the spatial and temporal variability of the processes taking place at the ocean's interface with land, ice and the atmosphere in coastal regions, *(ii)* Resolving (sub)mesoscale circulation patterns in the global ocean, and *(iii)* Estimating pCO2 in the surface ocean

In addition to SSS and pCO2, FRESCH will also provide estimates of soil moisture, vegetation water content and soil freeze-thaw state over land, sea ice thickness, stability and melting of ice sheets in polar regions. FRESCH will deliver data on four Essential Climate Variables (ECVs: SSS, sea ice, soil moisture and biomass) and data related to another four ECVs (dissolved inorganic carbon, evaporation from land, fires and permafrost surface temperature). Thanks to these variables, FRESCH will address a number of secondary mission objectives, which in turn will help to better understand the variability of the primary mission objectives (SSS and pCO2). The secondary mission objectives are: *(i)* Reducing uncertainties in the terrestrial carbon and water cycle to better understand fluxes in the land-ocean interface regions, *(ii)* Improving estimates of the shrinking cryosphere in support of better understanding of the ice-ocean interfaces, *(iii)* Monitoring of extreme events, hazards and operational applications.

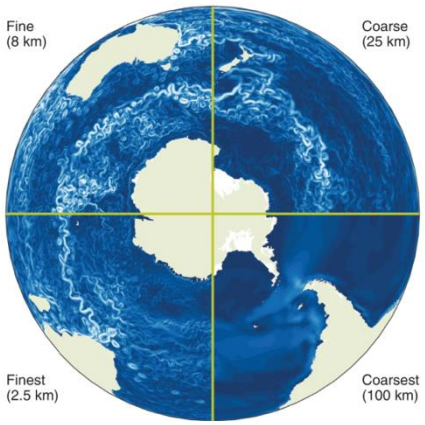

Figure 1: Representation of the surface ocean currents at different resolutions for the Southern Ocean [2]. The 2.5 km simulation comes from the NextGEMS project. The lower resolution simulations come from the CMIP6 project.

3. TECHNICAL CONCEPT

FRESCH is a multi-polarization, multi-incidence angle, L-band imaging radiometer composed of an array of 171 antennas distributed along a cross with four ~8.5 m orthogonal arms. Figure 3 shows an overall view of the FRESCH instrument.

3.1. FRESCH geometry and measurement technique

The FRESCH antenna array will operate as a beamforming phased array. This technique is currently used for telecommunications with a small number of beams digitally formed in/from specific directions (not for imaging). More recently, some instruments for radio astronomy are starting to use beamforming phased arrays as some pathfinders of the Square Kilometer Array [8]. FRESCH will be the first Earth observation satellite using this technique. Beam forming shows several advantages with respect to aperture synthesis such as a more robust image reconstruction with less sensitivity to disparities in the antenna patterns [9]. FRESCH will also introduce several innovations: *(i)* a large number of beams have to be created, which implies that new cutting edge signal processing techniques must be used, and *(ii)* in contrast to beamforming arrays used for telecommunications and radio astronomy, the FRESCH antenna array is sparse with few elementary antennas at some specific positions. This implies that an additional deconvolution step is needed [9].

Figure 4 shows the FRESCH field of view including the positions of the Earth and sky aliases. FRESCH will have a reduced alias with respect to L-band interferometers such as SMOS [10] thanks to a new patented approach in which the positions of the antennas in the fourth arm are chosen in a

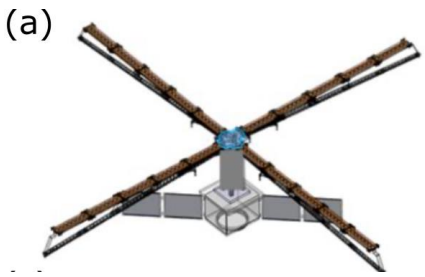

Figure 3: Overall view of FRESCH

specific way to provide non-redundant spatial frequencies densifying the frequency coverage [11].

Figure 5 shows the sampled incidence angles as a function of the distance to the swath center and the overflight duration time at different dwell lines. With an integration time of 3.6 sec (time to see a footprint with a ground incidence angle variation of 2°), the number of brightness temperature samples along the trace is 167/3.6~44 (in the field of view free from Earth aliases). In other words, a given footprint is seen 44 times. Interestingly, another advantage of the proposed Cartesian geometry is that this number of samples is almost constant across the swath (in contrast to SMOS-like hexagonal geometries).

3.2. Radiometric accuracy

The radiometric accuracy of FRESCH over the ocean in a single snapshot is 1.1 K. With an imaging instrument, a given point on the Earth surface will be observed by FRESCH in many different snapshots at different incidence angles. To estimate the effective radiometric accuracy of multi incidence angle retrievals, one can take into account that the first Stokes parameter (the addition of the brightness temperatures at two orthogonal polarizations) is weakly dependent on the incidence angle from 0º to 60º. In this case, all the measurements along a dwell line can be averaged. On average there will be around 44 acquisitions in a dwell line (Sect 3.2.1). Taking into account the ~44 acquisitions for one footprint, the accuracy increases from 1.3 K to 0.17 K (~0.34 pss for 0.5 K/pss), fitting the value of the salinity specification of 0.4 pss. Additional temporal and spatial aggregation, when a specific application allows it, could further increase the accuracy. The single snapshot accuracy of FRESCH will be better than that of SMOS (1.1 K vs ~2 K) but those are at the native spatial resolution of each instrument. That means that when compared at the same spatial resolution of 45 km, the accuracy of FRESCH SSS maps will be an additional factor of ~2.5 better (~1.1/2.5 = 0.44 K, instead of ~2 K).

3.3. FRESCH functional architecture

Figure 6 illustrates the proposed functional architecture for the instrument. The 171 antennas collect the signals simultaneously at H and V polarizations. To do so, two receiver chains are connected to each of the antennas. The signals are digitized and transmitted to the instrument control unit, located in the central hub, where different beams are formed and the RFI filtering is done. The scientific data are then transmitted to the platform to be transmitted to the ground.

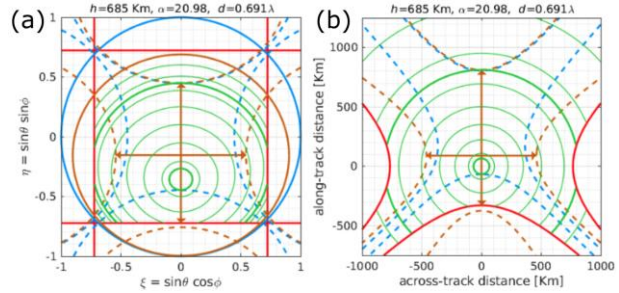

Figure 4: Examples of synthesized fields of view (red) at direction cosines level in the reference frame of the instrument (a) and at ground level (b) for an elevations/spacings of h=685 km and d=0.691λ (right), when the platform is tilted from nadir. Brown and blue circles are the Earth and sky views. Brown and blue dashed lines are the positions of the aliased images of the Earth and the sky, respectively.

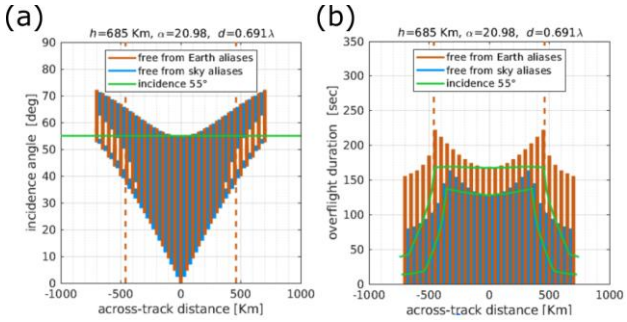

Figure 5. Distributions of the incidence angles (left) and of the overflight times (right) for various dwell lines in the synthesized fields of view for an elevation of h = 685 Km (right) and a tilt of 20.98º.

The FRESCH architecture is based on a common Local Oscillator (LO) signal distributed to all the antennas. The same rationale is applied to the sampling clock signal generation. This will avoid phase jumps such as those that have been observed between different LO units of instruments such as SMOS, that lead to high phase error change between antennas not sharing the same LO unit. The approach used by FRESCH will provide the stringent phase stability needed for scientific applications.

The receivers' parameters (gain and noise figure) are calibrated (CAS in Figure 6) using the two-points method with a common noise source ON (hot temperature) and OFF

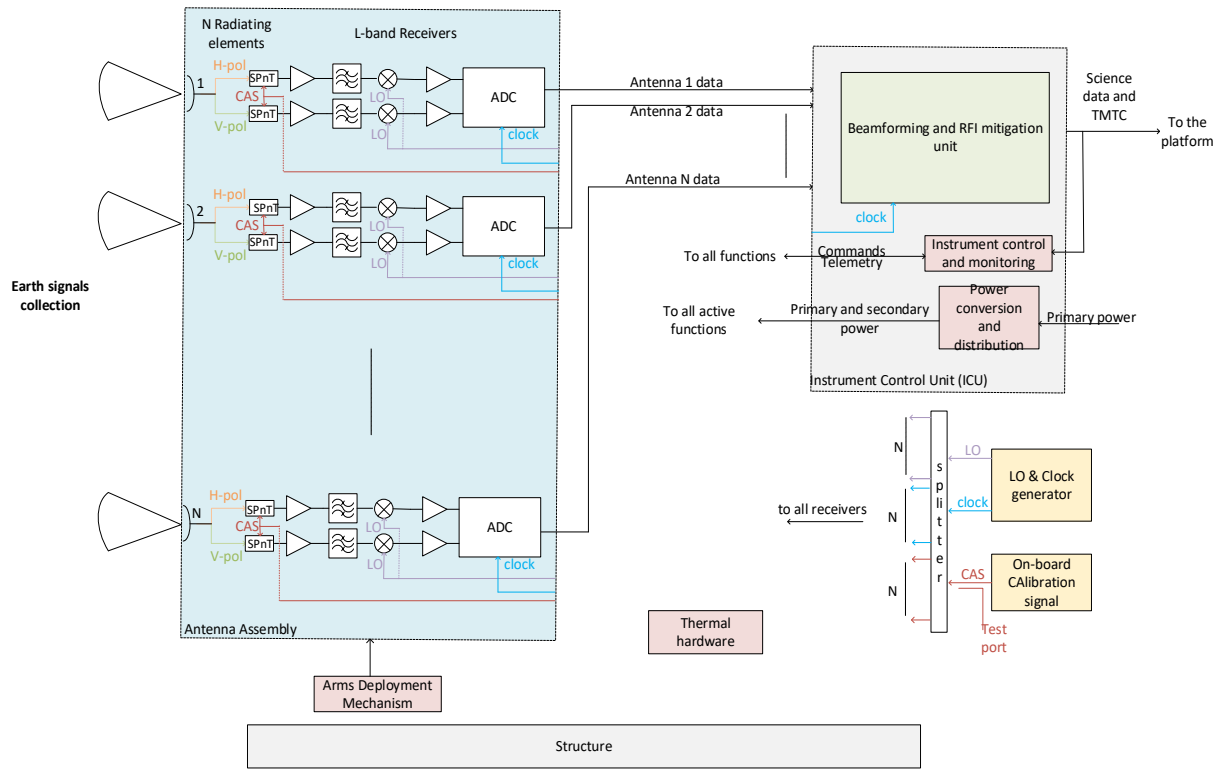

Figure 6: FRESCH functional architecture

(ambient temperature). The temperature of the parts not included in the internal calibration loop (mainly the antennas and switches) will be monitored in order to estimate the impact of their losses. Regular external calibrations with the cold sky are planned to correct the CAS noise estimation. The amplitude and phase of each path need to be known thanks to an initial calibration on ground saved in a LUT (lookup table). This calibration will be updated periodically in flight with the CW generator to compensate for any drift.

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