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SLAINTE: A SAR mission concept for sub-daily microwave remote sensing of vegetation

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Abstract

This paper presents an overview of the Sub-daily Land Atmosphere INTEractions (SLAINTE) mission. SLAINTE comprises a constellation of identical synthetic aperture radars (SAR) with interferometric capability. It aims to bridge a critical observation gap, by providing sub-daily, ≤1 km scale observations related to ecosystem water status, including vegetation water content and surface soil moisture over key regions of scientific, ecological, societal and economic interest. These data will provide unprecedented insight into vegetation water, carbon and health improving our ability to study, understand and model the response of ecosystems to climate change and human impact. This mission concept has been submitted in response to ESA's call for proposals for Earth Explorer 12.

1 Motivation

Changes in sub-daily vegetation water content capture the pulse of the Earth's ecosystems. They reflect the interplay between plant function, evaporation, and soil moisture, and underpin land-atmosphere exchange of water and carbon from leaf to global scales. They reveal how ecosystems respond to biotic and abiotic stress (e.g. changing temperature and vapour pressure deficit, soil moisture, insects, disease) and disturbances (e.g. drought, fire). Observing these processes is critical to understand the resilience of terrestrial ecosystems and their water resources facing increasing climate variability and extremes, and pressures from human land and water use.

As illustrated in (**Figure 1**), current and planned microwave missions provide one snapshot every few days, observing "slow" ecosystem dynamics. They are adequate to observe inter- and intra-annual variations of above ground biomass (AGB), the slow response in water status over weeks and months, and to map (a-posteriori) biomass loss due to deforestation or mortality. However, this is not sufficient to capture the sub-daily, or even daily, dynamics needed to study ecosystem health. SLAINTE aims to fill this critical observation gap by providing sub-daily, ≤ 1 km scale observations related to ecosystem water status, including vegetation water content (VWC) and surface soil moisture (SSM). This allows us to "zoom in" and focus on the fast dynamics associated with water status.

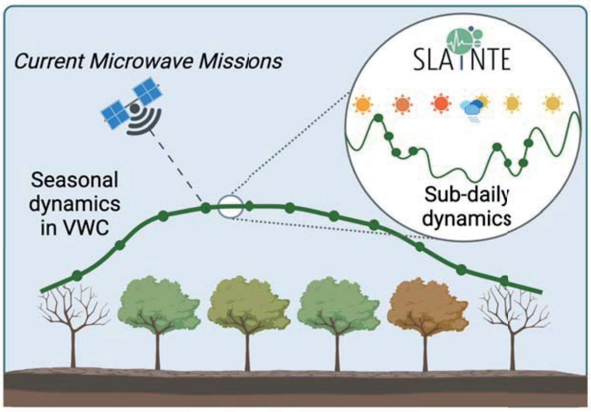

Figure 1 SLAINTE zooming in on sub-daily processes

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2 Objectives

SLAINTE aims to fill major gaps in our ability to study, understand and model vegetation water, carbon and health. SLAINTE will:

1. Enable the estimation of sub-daily evaporation and its components.
2. Unveil sub-daily coupling mechanisms and feedbacks between carbon and water cycles.
3. Quantify the sub-daily stress response of vegetation to abiotic and biotic disturbance.
4. Detect early signs of vegetation health decline, reveal ecosystem resilience to environmental stressors, and support development of early-warning metrics for ecosystem shifts.

By providing sub-daily SAR data, SLAINTE also fills a critical gap in Earth system knowledge where observations of rapid changes in SSM are essential. SLAINTE will enable us to:

5. Quantify agricultural water use for a more sustainable use of water resources, to optimise crop production, and understand the impact of irrigation on local and regional climate.
6. Develop fundamental understanding of how vegetation and soil water status influence time and space scales of predictability of convective storms.
7. Reveal the spatio-temporal evolution of soil moisture at the sub-daily time scale necessary to explain runoff generation processes and infiltration dynamics that drive the triggering and evolution of flash floods, debris flows and landslides.

3 Requirements

At least three acquisitions per day are needed to study the vegetation response to the daily cycle in vapour pressure deficit (VPD), the impact of stomatal regulation and the rate at which vegetation is able to recharge VWC lost during the day. The sub-daily cycle needs to be observed at least once every 3 days to capture plant responses to stress/disturbance, as well as the onset and recovery from such events. Continuous, systematic and consistent observations over the same area are essential to characterise the sub-daily variations in vegetation water content, how these vary inter-annually and seasonally, and in response to stress/disturbance.

Regular, repeated, and consistent observations over selected regions of interest are needed to develop process understanding. To address the vegetation-focused objectives, observations are needed across a range of biomes, particularly in regions that are currently—or projected to become—water-limited (e.g. semi-arid ecosystems, northern Amazonia, most temperate forests), hotspots of vulnerability (e.g. Mediterranean, boreal forests, Amazon arc of deforestation). Observations must overlap with in situ networks (e.g. ICOS, SAPFLUXNET, AmeriFlux) for calibration/validation, but also in data scarce regions of societal and scientific interest. For many regions, study areas of 40 km x 150 km would allow for reconciliation with coarser resolution EO data and characterisation of variability across landscapes. Transects of several hundred km would reveal the impact of regionally important environmental gradients (e.g. the N-S Amazon precipitation gradient). Observations are needed with a spatial resolution $\leq$ 1 km to resolve functional variation within landscapes.

4 Implementation

SLAINTE consists of a LEO constellation of decametric resolution monostatic L-band SARs with high radiometric and interferometric accuracy. The satellites will be displaced in orbit to provide observations separated by six hours. Each spacecraft will fly in a polar 3-day repeat orbit allowing for a revisit shorter than 1.5 days where ascending and descending passes overlap, with a static coverage of about 25% of the globe **Figure 2**. The choice of a LEO constellation enables configuration flexibility, wide coverage, high data quality and capacity of the system. The proposed approach is scalable, where additional satellites can be included to enhance spatial coverage and/or temporal resolution.

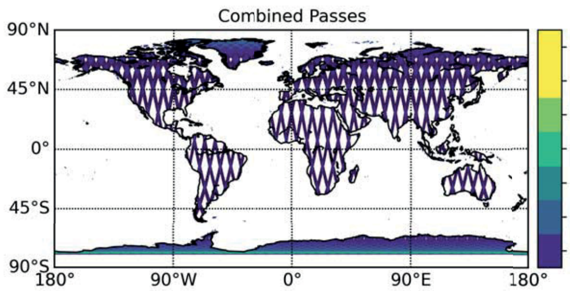

Figure 2 Access of the SLAINTE instruments over a 3-day period

Synthetic Aperture Radar (SAR) allows for use of both radiometric and interferometric information for the estimation of the biogeophysical variables of interest. By ensuring interferometric capability, SLAINTE allows for the exploitation of established and emerging techniques. Several techniques exist to estimate SSM and VOD from SAR radar backscatter (e.g. [1, 2, 3, 4]). In addition, several emerging techniques exploit SAR interferometric phase to generate soil moisture and/or vegetation water content variations (e.g., [5, 6, 7]).

L-band is chosen rather than higher frequencies as it increases the transmissivity, allowing microwaves to penetrate further into the canopy, integrating the effects of the leaves and increasing sensitivity to water dynamics in the branches and trunks of the vegetation (e.g. [8]). Increased transmissivity at lower frequencies improves surface soil moisture retrieval accuracy under vegetation, and increases the sensing depth (0-5cm at L-band) (e.g. [9, 10]). Finally,

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coherence is generally higher at lower frequencies (e.g. [11]), facilitating the use of interferometric techniques and reducing the number of looks required to achieve a given spatial resolution. In addition to retrieval, it is expected that SLAINTE products will be assimilated directly to constrain states and parameters related to water transport within the soil-vegetation-atmosphere continuum.

5 Outlook

SLAINTE will demonstrate how small SAR constellations can complement Sentinel-1 NG and ROSE-L by meeting the growing demand for increased temporal resolution, specifically the emerging need for sub-daily data acquisition. Furthermore, the availability of routine, sub-daily interferometric acquisitions is unprecedented, and offers new opportunities to exploit SAR and InSAR to address the knowledge gaps at fine temporal scales across the geosciences. Finally, while SLAINTE is focused on process understanding, it can also be viewed as a demonstrator for the inclusion of small SAR constellations within the Copernicus programme to allow for operational real-time detection and intervention.

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