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Advances in supraglacial lake detection and characterization on the Nansen Ice Shelf from active microwave and visible light satellite remote sensing

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The evolution of cryospheric components (snow cover, ice, and meltwater) plays a fundamental role in regulating energy exchanges between the atmosphere and ice shelves and represents a key indicator of climate change impacts in remote polar regions. Within the framework of the HOLISTIC (Holistic Overview of the supraglacial Lake–Ice–Snow Timing and Climate causality) project, funded by the Italian National Antarctic Research Program, we present an advanced multi-sensor assessment of supraglacial lake (SGL) dynamics over the Nansen Ice Shelf (Victoria Land, Antarctica).

We adopted a synergistic remote sensing approach, aimed at integrating active microwave observations from satellite SAR and radar altimetry missions with optical imagery. This multi-frequency and multi-platform strategy investigates the possibility of detection, mapping and temporal monitoring of SGL position and extent and spatial distribution under all-weather conditions and across different spatial and temporal scales. HH-polarized SAR data proved effective in identifying surface meltwater signatures and characterizing seasonal lake evolution, despite polarization limitations, while optical data provided complementary constraints on lake morphology and surface hydrology during cloud-free periods. The seasonal melt and refreezing processes of SGL units were further investigated by leveraging the combined revisit time of operational sensors such as Sentinel-2 and Landsat, together with dedicated tasking missions like PRISMA, providing a more comprehensive understanding of lake dynamics over time.

A dedicated processing chain for Sentinel-3 altimetry L1A individual echoes was implemented using the PISA algorithm (Abileah and Vignudelli, 2021, https://doi.org/10.1016/j.rse.2021.112580). This allowed the retrieval of localized elevation anomalies associated with bright targets, mountainous targets and supraglacial water bodies, and the characterization of surface roughness changes presumably linked to melt and drainage processes, as well as to changes in snow density and surface slope.

The combined analysis highlights the strong coupling between snowpack evolution, surface energy feedback, and the formation and drainage of SGLs, providing new insights into ice-shelf surface hydrology and its seasonal to interannual variability. The results represent a step forward in quantifying SGL properties using active microwave and passive/active optical techniques and offer a valuable testbed for existing and future altimetry missions, such as NASA's ICESat-2 and ESA's CRISTAL missions, aimed at directly retrieving snow depth. The capabilities of high-resolution satellite-born SAR sensors are also expected to benefit from this study, in detecting and monitoring snowpack changes, particularly those resulting from surface snow melt and the formation of supraglacial lakes. Supraglacial lakes emerge as particularly suitable targets for assessing visible light as well as Ka-, Ku- and C-band scattering contributions and for advancing the understanding of snow–ice–water interactions in polar environments.