Glaciology

State-of-the-art and challenges:. Recent decades have seen the first dedicated satellite Earth observation missions with specific objectives related to ice sheets and glaciers, such as ICESat and CryoSat-II providing ice elevation changes and GRACE providing total ice mass changes. Other satellite EO missions as e.g. RADARSAT, ERS and ENVISAT have provided ice velocity maps enabling studies of ice-dynamics. The new Copernicus programme (European Commission/European Space Agency) will vastly improve our capability for monitoring the environment in the Arctic. *In situ* observational networks are comparatively sparse in the Arctic and play an important role in providing ground-truth for the satellite products (see Figure 1). Two networks of automatic weather stations are in operation on the Greenland ice sheet; the US Greenland Climate Network (GC-Net) and the Danish Programme for Monitoring of the Greenland Ice Sheet (PROMICE), whereas the GNET installation of differential GPSs measure crustal movement due to load changes along the perimeter of the Greenland ice sheet and GLISN acquires seismological measurements. The NASA projects Operation IceBridge (OIB) and Oceans Melting Greenland (OMG) are currently leading the airborne monitoring of the Arctic ice masses and neighbouring waters, supplemented by European missions such as CryoVex and PROMICE.

A major challenge regarding the Arctic ice sheets and glaciers is the difficulty of obtaining high quality in-situ observations in the extremely harsh environment. Logistical difficulties often mean that it is not possible to revisit instruments more than once every few years, ensuring that robustness takes precedence over other factors. Lack of links and integration between the current monitoring efforts, which will be required for producing new and enhanced climate services needed for the increasingly accessible Arctic region.

Progress beyond state of the art

- Integrate ESA Sentinel/Copernicus data with in situ observations and climate modelling to deduce sub-annual mass loss estimates from the Greenland ice sheet at sub-basin scale.
- Develop guidelines and tools for using GNET GPS data for monitoring mass changes in the coming years. Combine with methods for using GRACE data and compare results of both methods.
- Upgrade positioning of ice sheet weather stations to WMO-standard data to enable use in weather forecasting and for validation of ice velocity maps from the ESA Sentinel-1 mission.

- Introduce observation of snow water equivalent (SWE) at ice sheet weather stations to improve performance of ice sheet meltwater runoff models and regional climate models.
- Improve methods for ice volume estimation and calculation of the ice discharge of Arctic ice masses.
- Upgrade albedo measurements from weather stations on snow/ice to allow calibration of satellite albedo products and regional climate models.