A 20-year MODIS-based snow cover dataset for Svalbard and its link to phenological timing and sea ice variability

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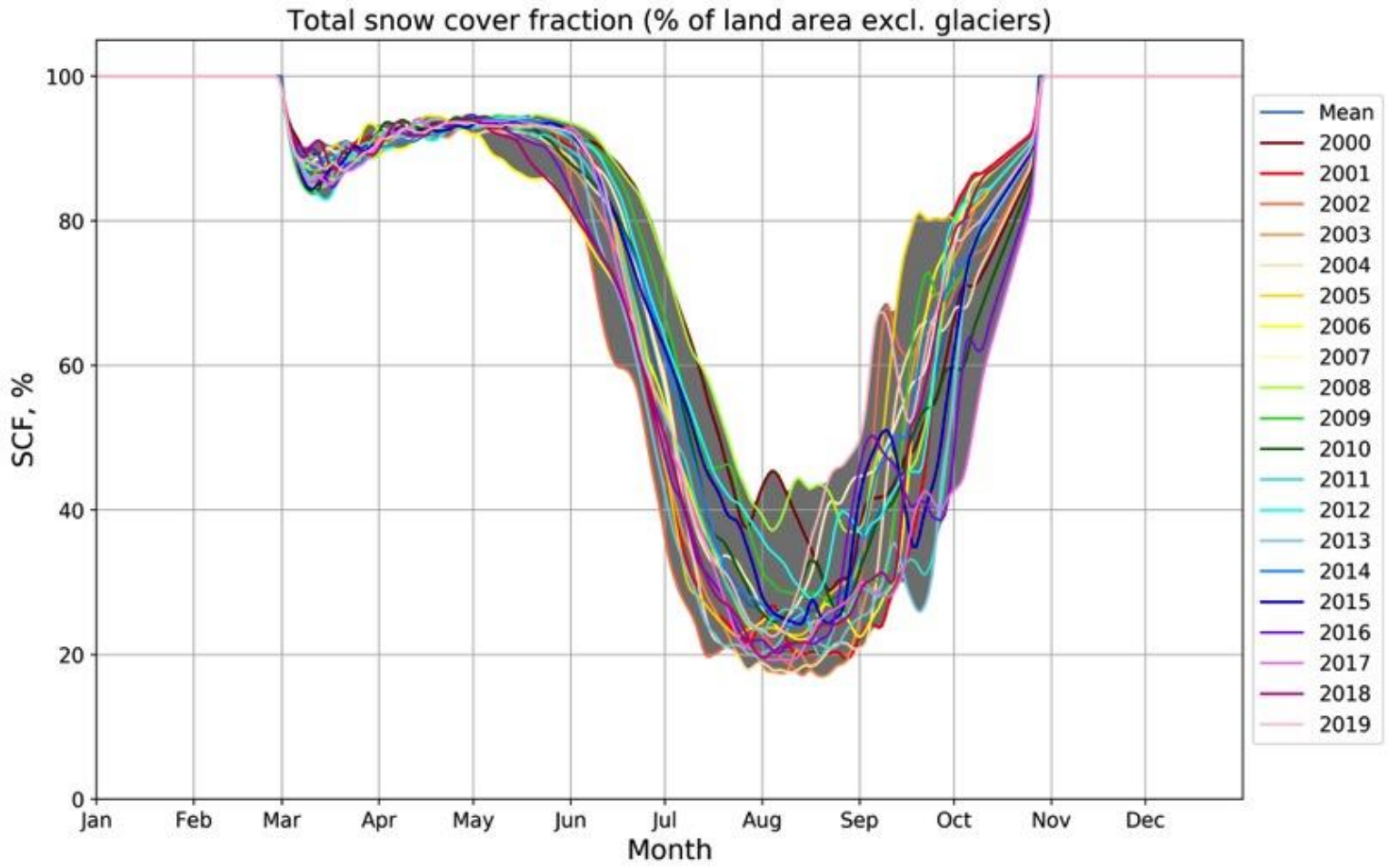
Background for study

- Initiated by work to prepare 20-year snow cover fraction dataset for Svalbard based on Moderate Resolution Imaging Scatterometer (MODIS) Terra data -> contribution to SIOS database
- Snow cover is in continual state of transition due to influence of meteorological factors -> sensitive to long term changes in climate
- Snowmelt on Svalbard has been earlier linked to sea ice variations
- Impacts on vegetation growth which follows snowmelt
- Can we utilise existing SIOS datasets (sea ice concentration, growing season onset) to study and quanitify the relationships with snow cover (changes)? -> test concept of Cryosphere Virtual Lab, www.cvl.eo.esa.int)

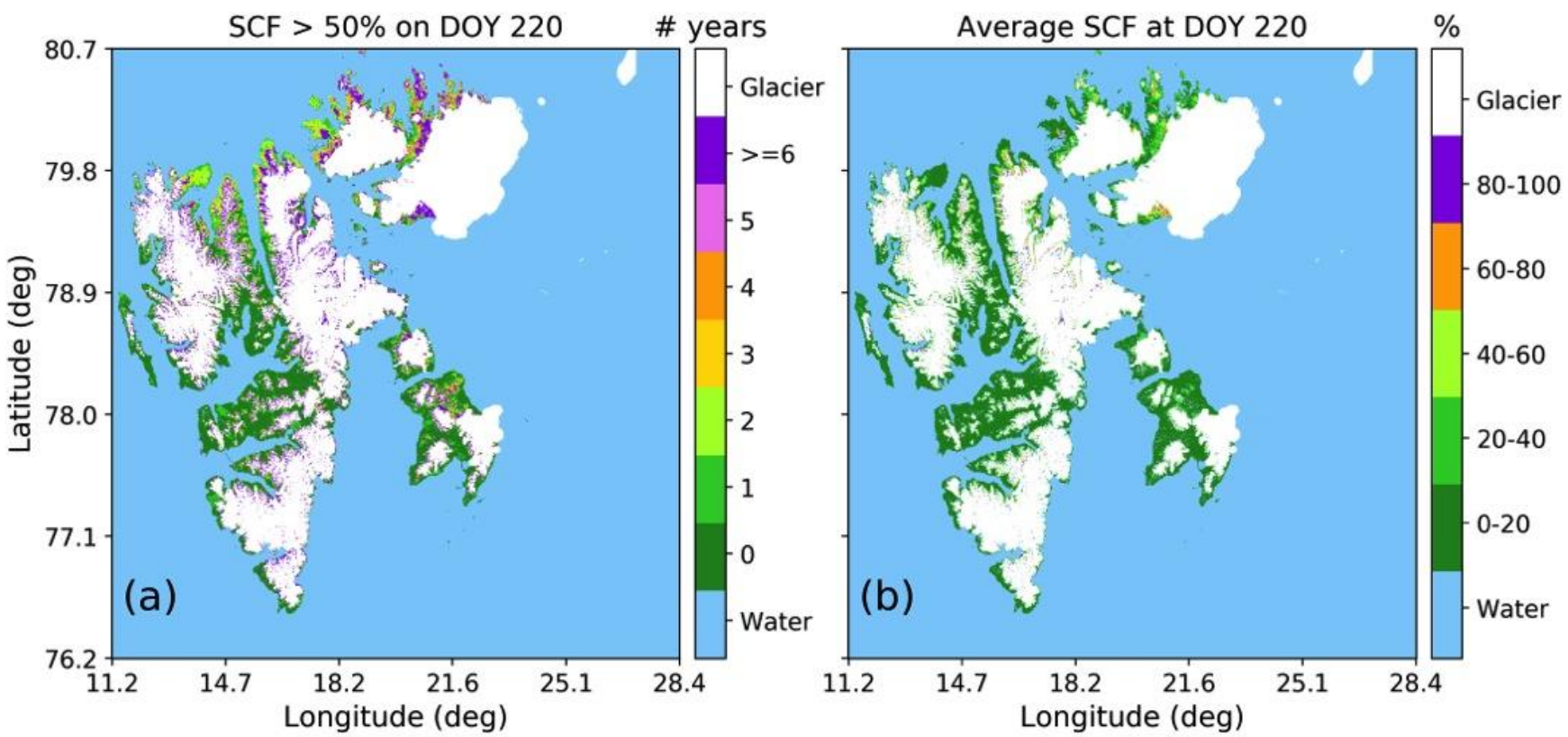
Snow cover dataset

- Snow cover fraction (SCF) product earlier developed for Northern Scandinavia using MODIS Terra data -> optical images at 500 m resolution
- Normalised Difference Snow Index (NDSI) derived from difference between visible and IR bands divided by the sum of the two bands
- SCF related to NDSI by: *SCF = 0.06 + (1.21 x NDSI)*
- At Arctic latitudes SCF cannot be estimated during the polar night (darkness) or under periods of cloud cover (often)
- Method uses interpolation between cloud-free pixels to produce daily SCF maps for an entire year

Land-averaged annual variation in SCF 2000-2019

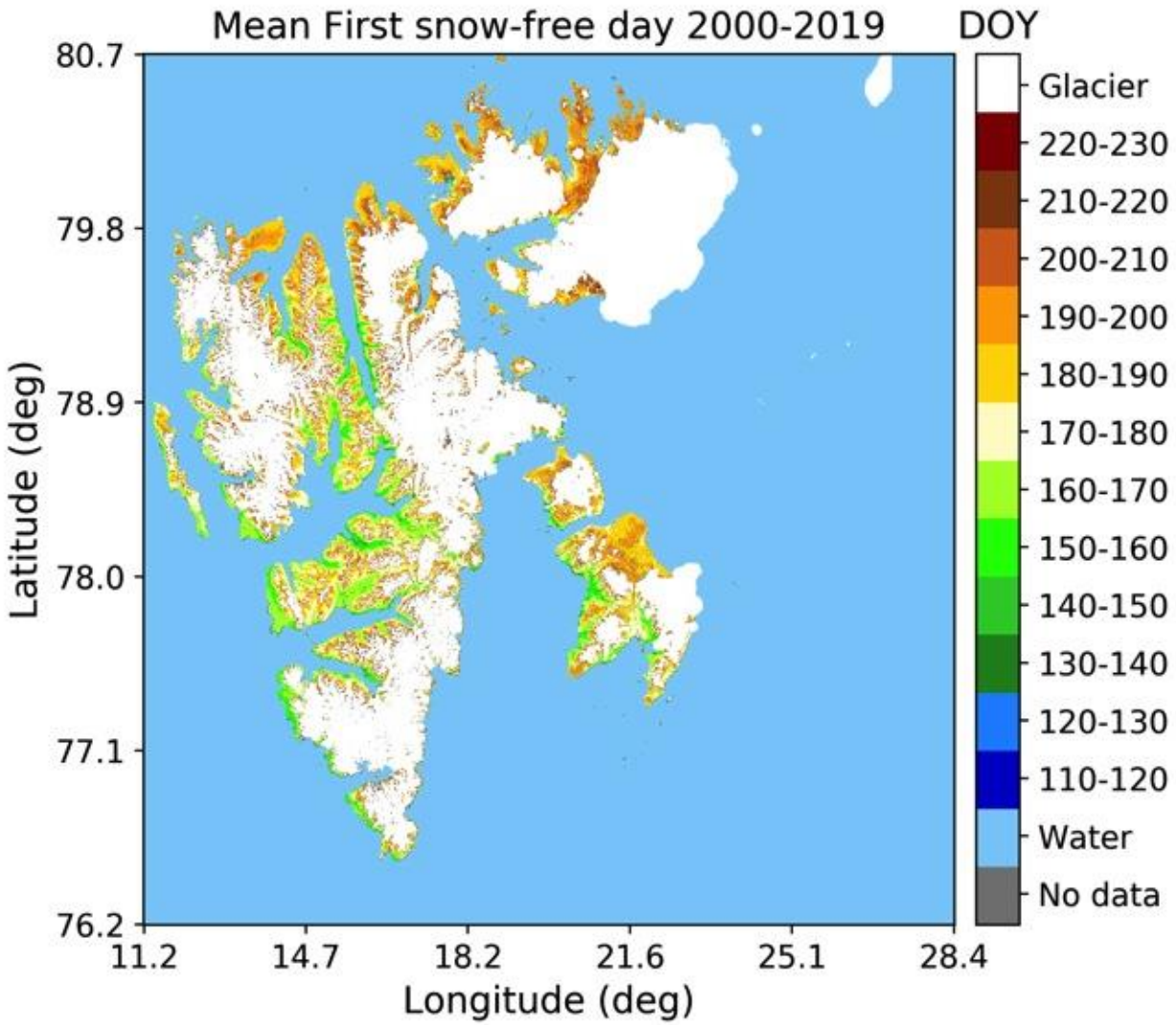


- SCF forced to be 100% over entire Svalbard during the polar night
- Greatest variation between years at minimum SCF
- Average date of minimum SCF is August 8th (DOY 220)



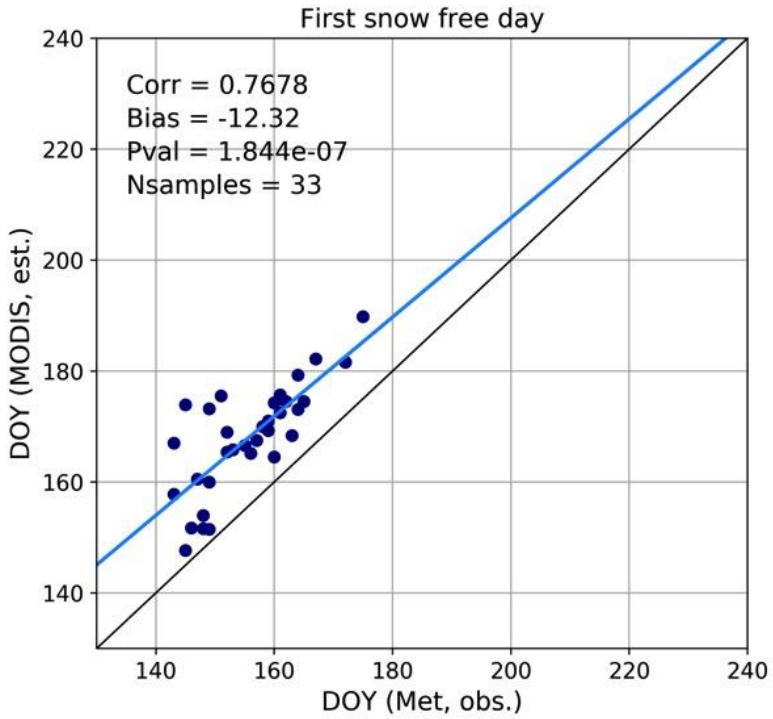
- Minimum land-averaged SCF never falls to < 20% due to areas in north with high minimum SCF
- For August 8th (DOY 220) there were areas at the northern end of the archipelago with SCF > 50% for >5 years of the 20-year period

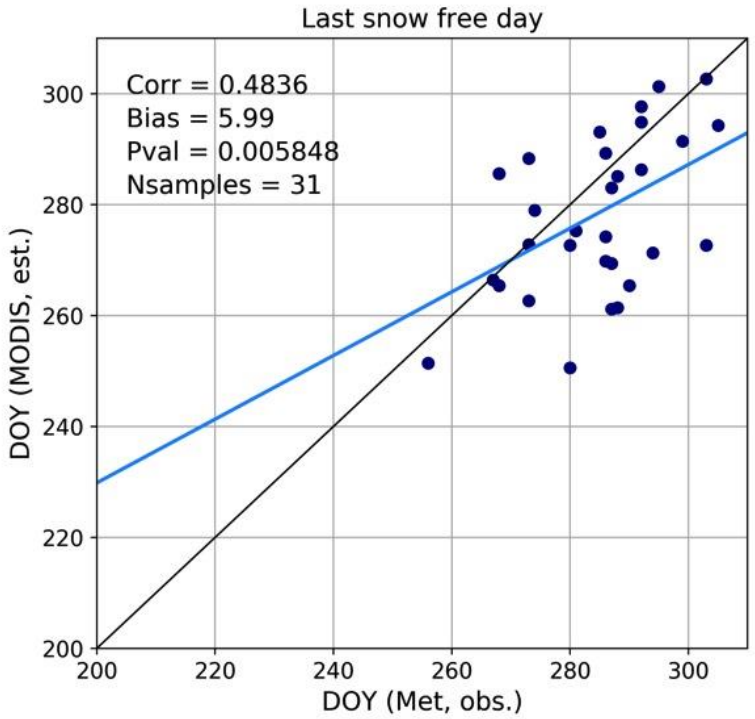
Timing of snow disappearance and onset



- Detect snow disappearance (first snow-free day) and onset (last snow-free day) as DOY when SCF crosses 50%
- Later snow disappearance in the north, east on Edgeøya and in mountainous areas, earlier snow disappearance in valleys, southern, central and western Svalbard

Validation with in-situ snow depth measurements

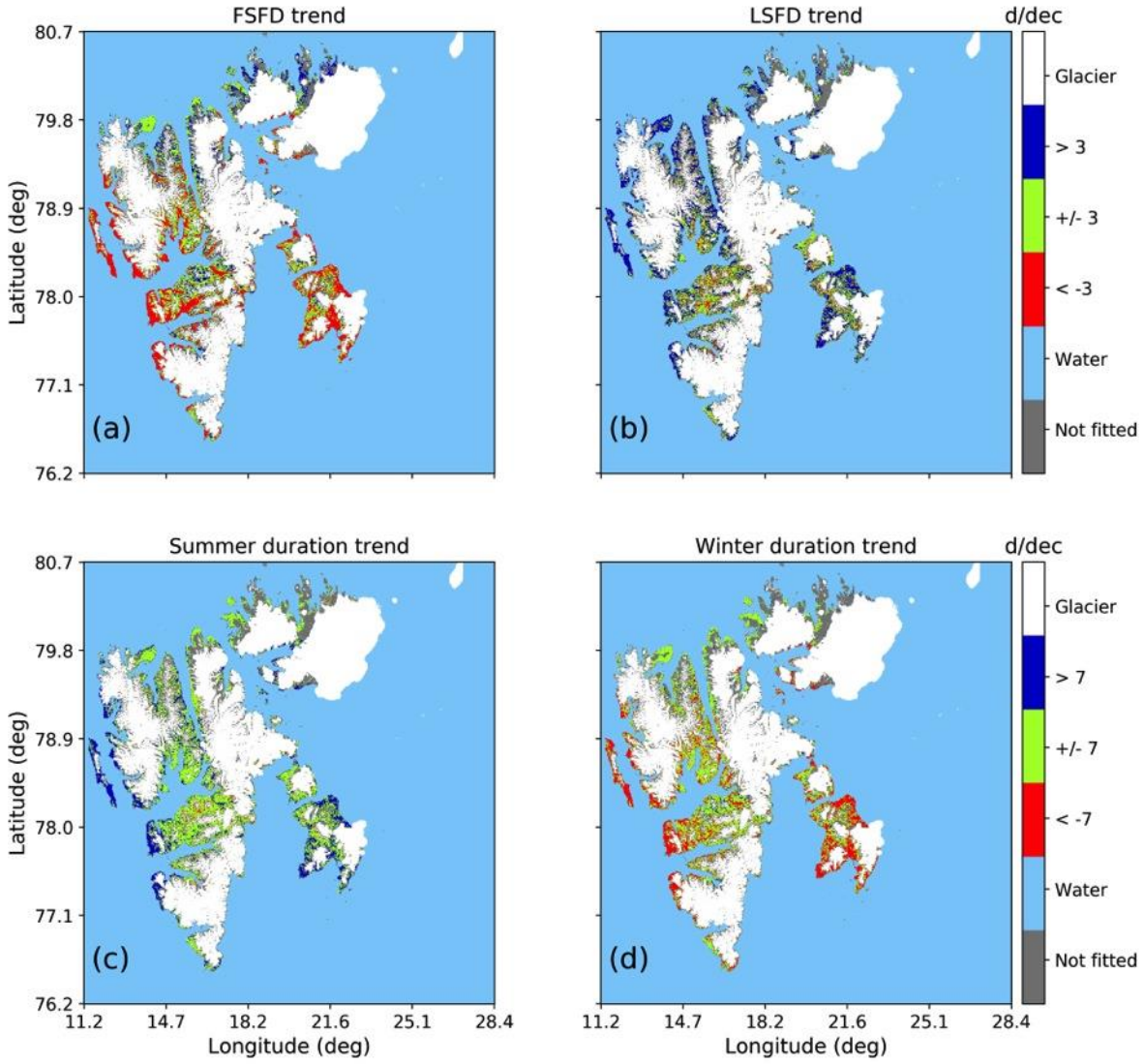




- Snow depth measurements from Hornsund, Svea, Platåberget, Longyearbyen, Adventdalen, Ny Ålesund
- Defined meteorological FSFD as SD < 2cm for 5 or more consecutive days
- Strong correlation between FSFD from snow depth nmeasurements (6 sites) and MODIS (500m grid) estimates, but MODIS is on average 12 days later w.r.t meteorological data

Trends 2000-2019

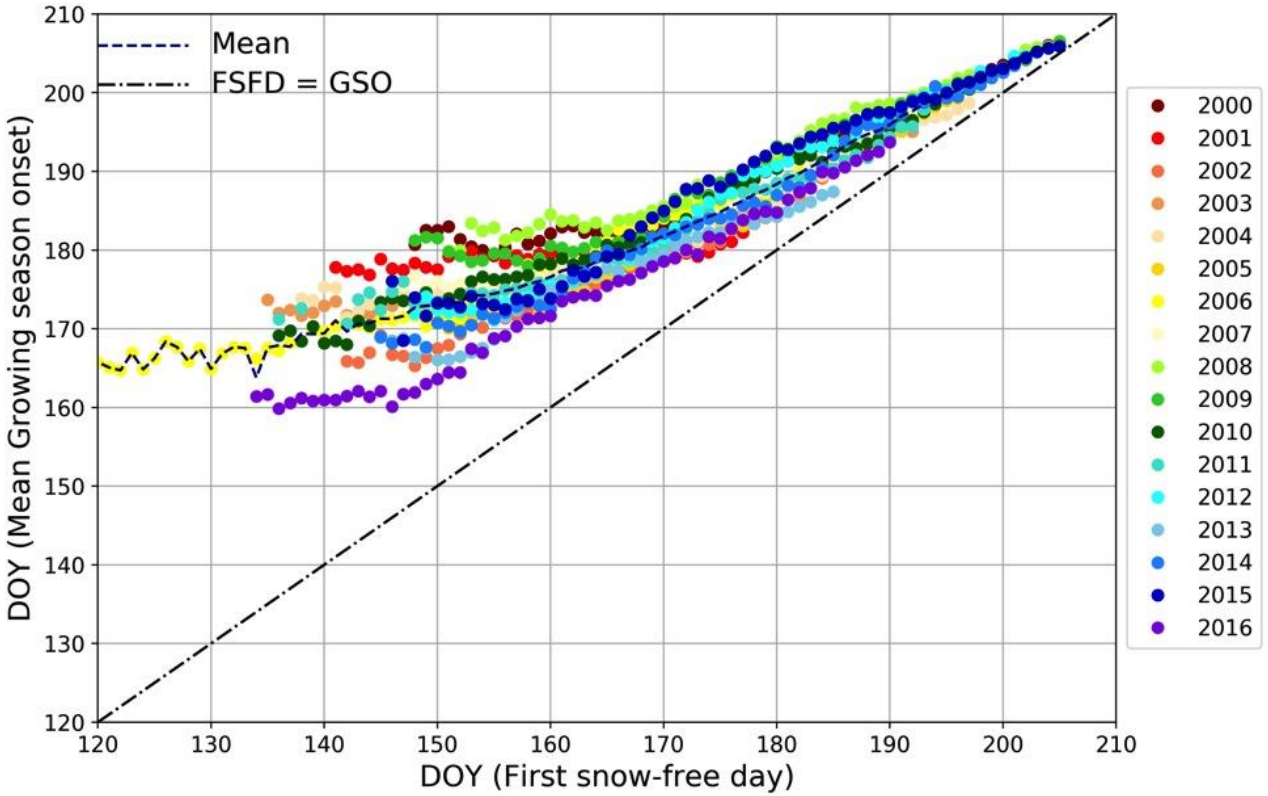
- FSFD becoming earlier across eastern, southern, central and western parts of the archipelago and later in the north (mainly Nordaustlandet)
- LSFD becoming later over most parts of the archipelago, earlier in some parts of Nordenskiold Land
- Length of summer >7 days longer per decade & length of winter >7 days shorter per decade in the west and east
- Trends of ±7 days change per decade in length of summer & winter in the central and northern parts of Svalbard

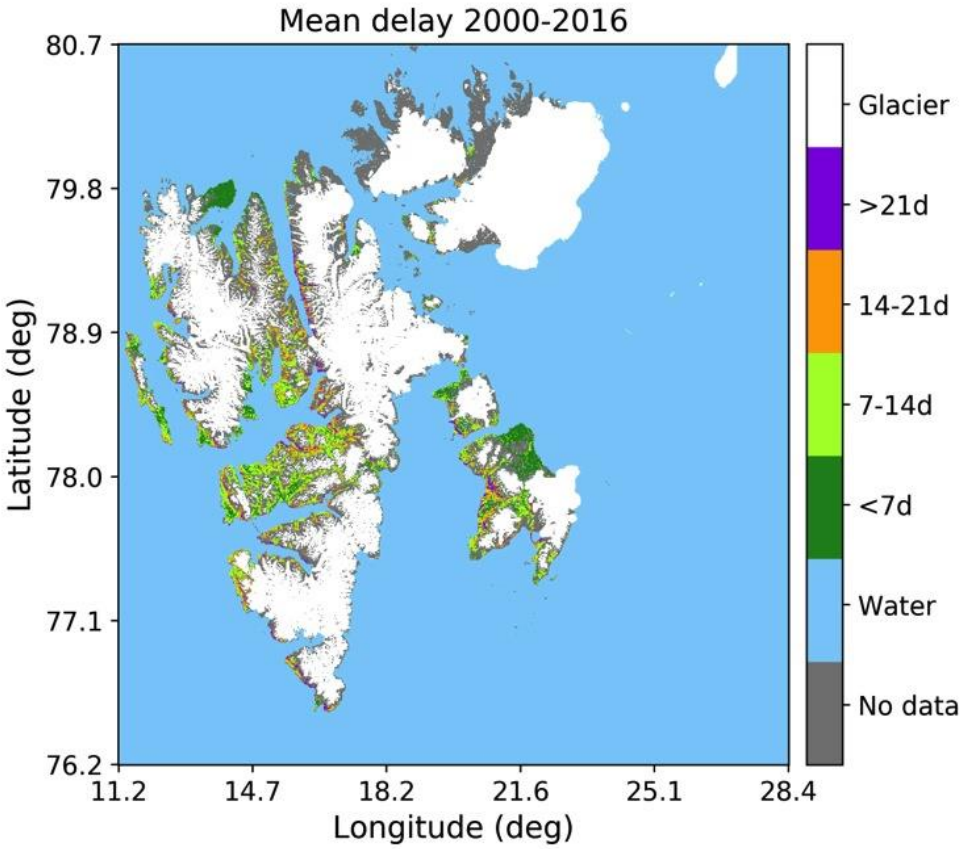


Timing of snow disappearance and influence on growing season onset

- GSO dataset for Svalbard will be part of the SIOS database -> based on NDVI measurements also using MODIS dataset
- Onset of the growing season follows timing of snow disappearance
- How long is the length of time from snow disappearance to GSO estimated using optical remote sensing?
- How does the ”delay” vary across the archipelago?
- What is the relation to mean daily air temperature during the period between snow disappearance and GSO?

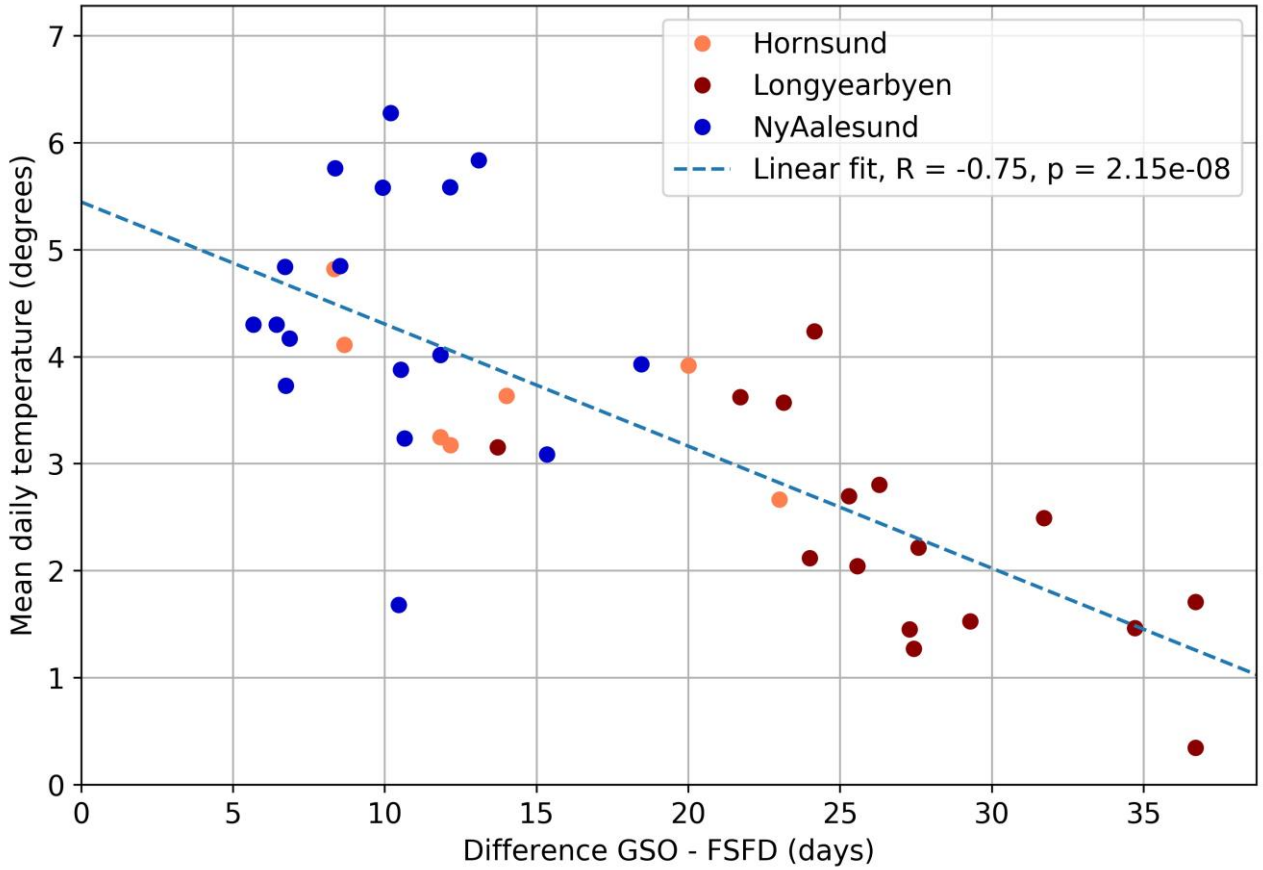
Snow disappearance and growing season onset





- For early snowmelt (DOY 160) eg. valleys, central/southern areas, there is a longer period of time (10-25 days) to growing season onset
- For late snowmelt (DOY 190) eg. mountainous areas, northern areas, the length of time to GSO is shorter (5-10 days)

Effect of temperature on the length of time from snow disappearance and growing season onset

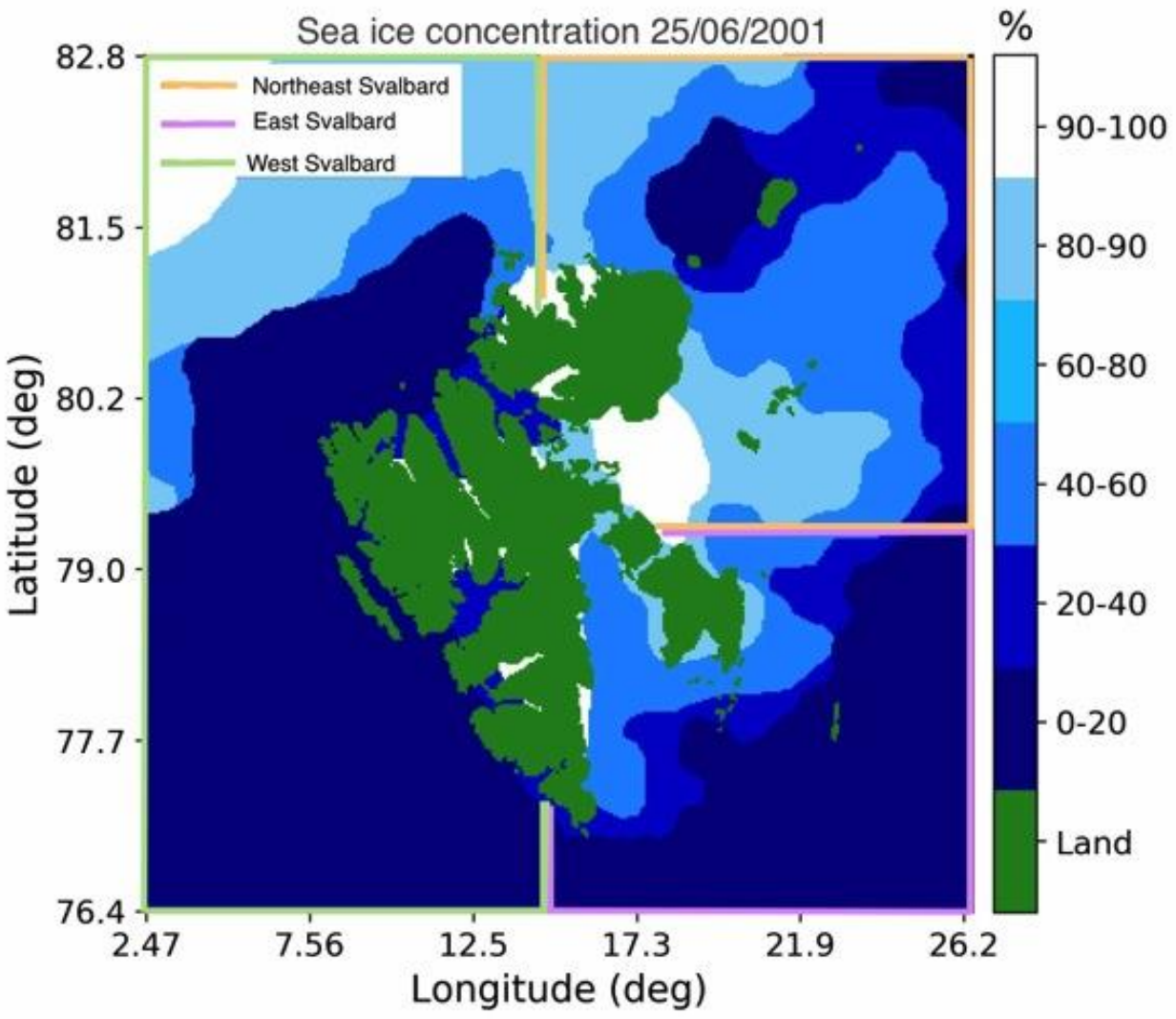


- 3 sites selected -> spread latitudinally
- Averaged the FSFD in a 3 x 3 pixel box around each site
- Initially thought that sum of thawing degree days (TDD) would be constant – not observed
- Significant and strong negative correlation between mean daily temperature (averaged over the period between FSFD and GSO) and the length of the delay

Influence of sea ice variability on snow disappearance

- Sea ice decline has been linked to increased heat and moisture fluxes as area of open water is increased -> may increase autumn/wintertime snowfalls
- Proximity to sea ice also known to influence air temperatures regionally due to advection of cold air onto land
- Earlier studies using scatteromoeters have identified coincidence between sea ice presence north of Svalbard and timing of snowmelt, but not demonstrated quantitatively
- Can we utilise database of sea ice concentration to study the link between timing of snow disappearance estimated using MODIS and sea ice variability around Svalbard?

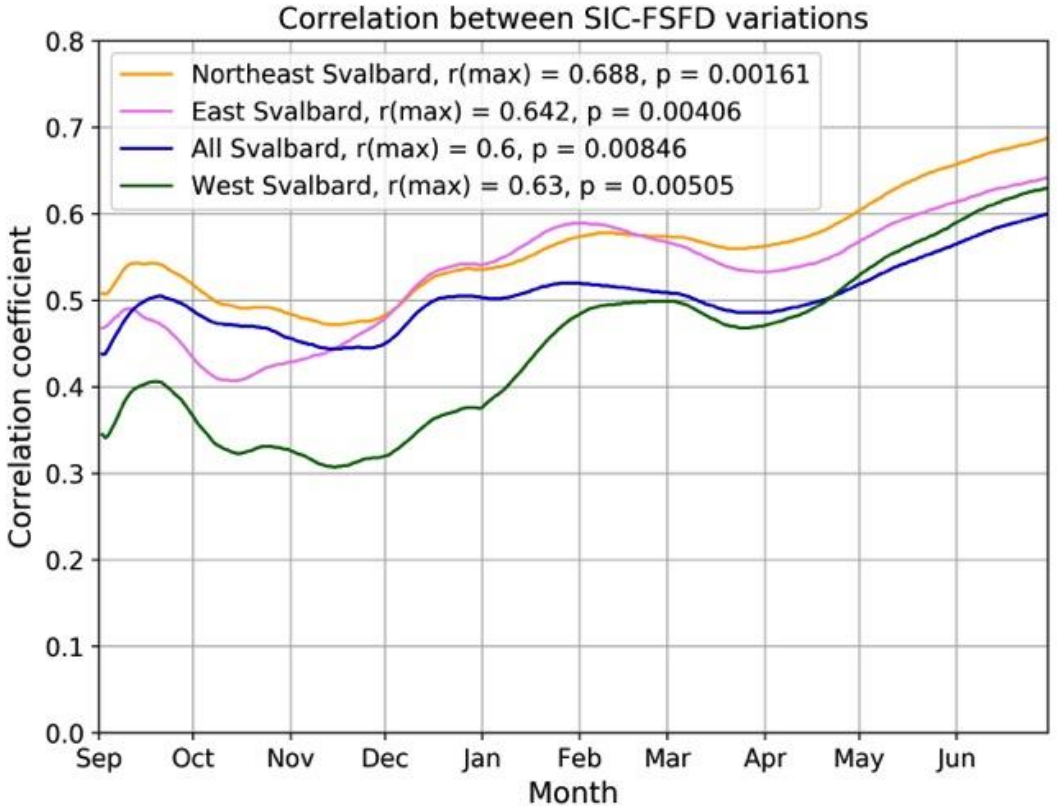
Influence of sea ice variability on FSFD

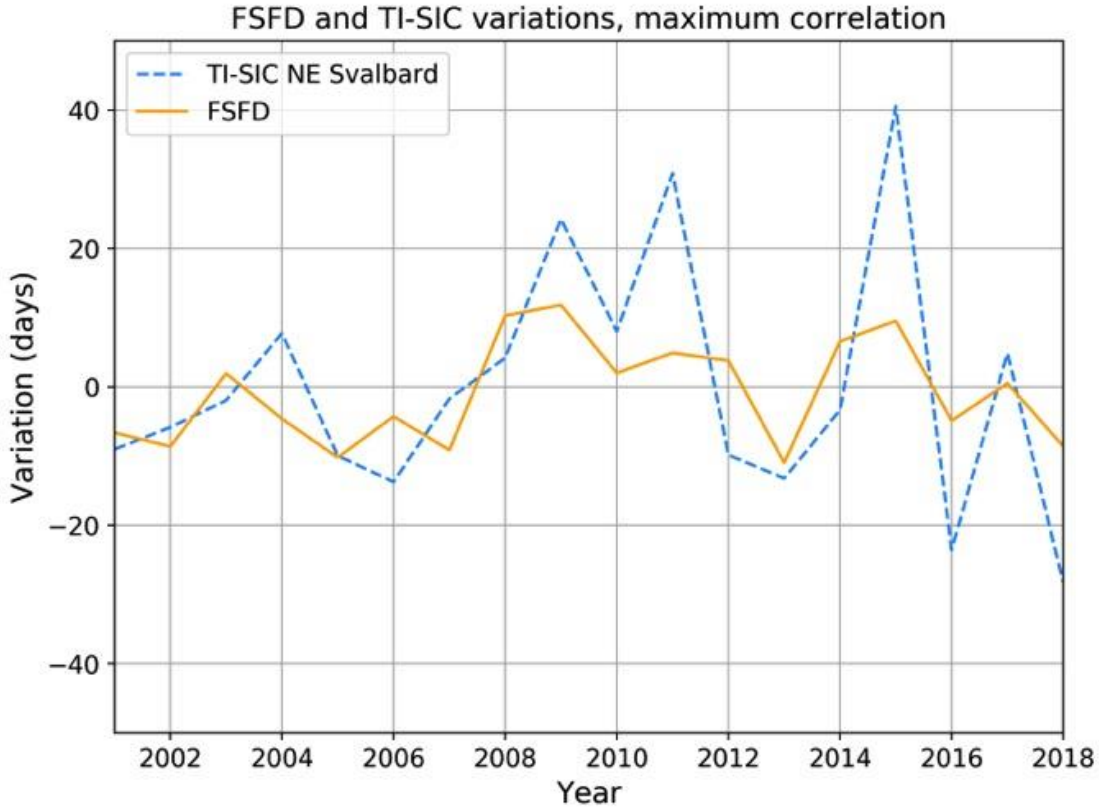


- Study four sea regions around Svalbard where sea ice present
- Correlate detrended time series of time-integrated SIC with FSFD averaged over 4 areas (Nordenskioldland, Nordaustlandet, Edgeøya, entire Svalbard)

Correlation with sea ice concentration

- Strength of correlation increases beyond April (maximum SIC) -> years of lower/greater than average SIC better distinguished i.e. Lower than average SIC = earlier than average FSFD, greater than average SIC = later than average FSFD
- Strongest correlations between FSFD on Nordaustlandet and TI-SIC in NE of Svalbard





Conclusions

- Produced maps of SCF for entire Svalbard archipelago for 2000-2019
- Derived and mapped estimates of FSFD and LSFD
  - Trend toward earlier FSFD and later LSFD over majority of Svalbard -> longer summer, shorter winter; exception is Nordaustlandet -> trend toward later FSFD& LSFD, link to precipitation trends?
- Quantified relationship between start of phenological growing season and FSFD
  - For early snow disappearance, time to GSO is longer (10-25 days), for later snow disappearance, time to GSO is shorter (ca. 5-10 days) -> link to mean temperature
  - For all of Svalbard, the average length of time between FSFD and GSO is 12.4 days
- Correlation between sea ice variability and timing of snow disappearance on land
  - Strongest correlations between sea ice variability NE of Svalbard and variations in FSFD on Nordaustlandet -> regulation of air temperature due to proximity to sea ice

Further work

- Improve and validate SCF algorithm/model by combining datasets from other sensors (SESS/Infranor2 proposal)
  - Sentinel-2: higher spatial resolution
  - AVHRR: longer time series
  - Snowpack modelling