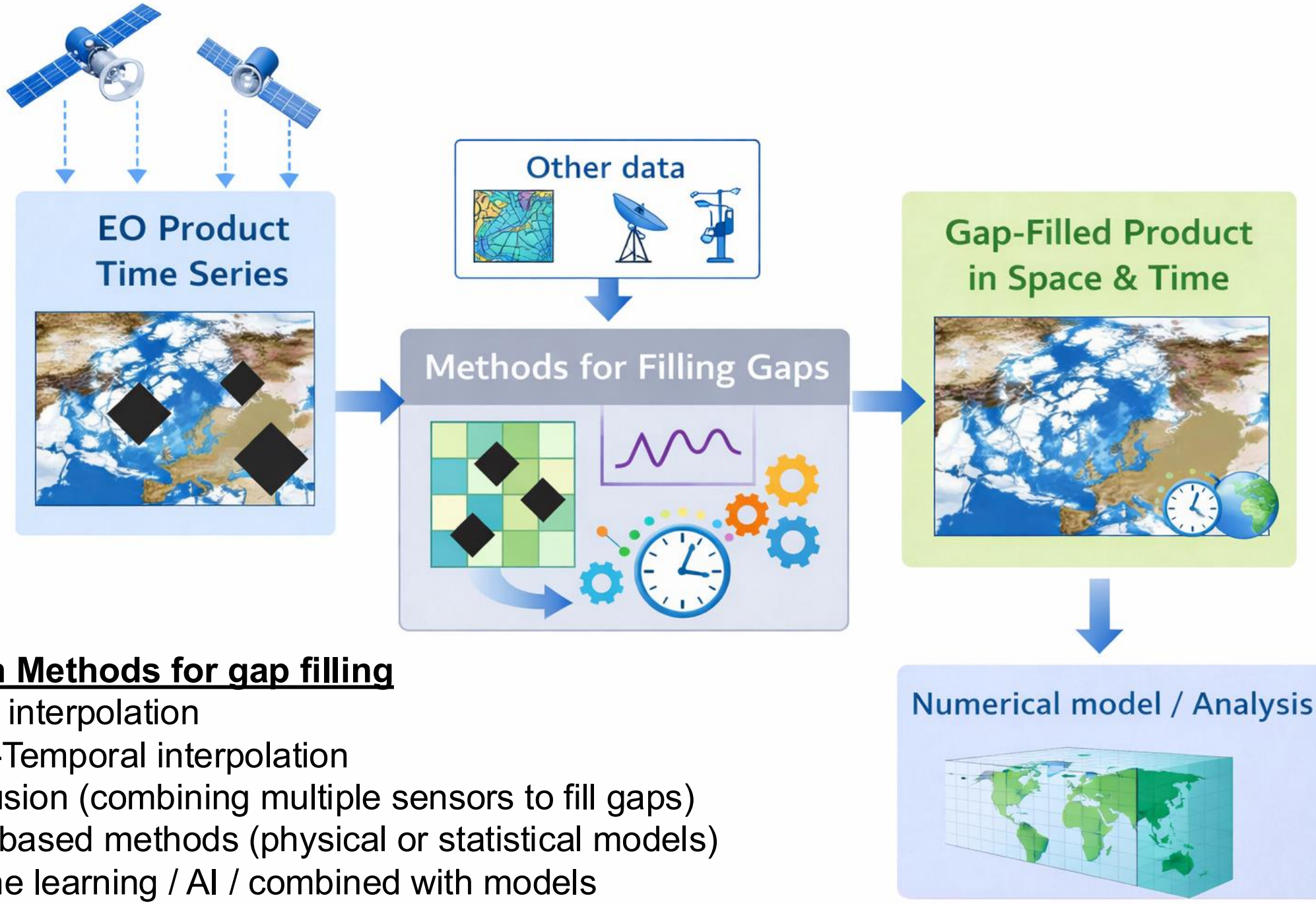
Filling Gaps in Time Series of EO Products

towards continuous, consistent datasets for analysis, long-term monitoring and input to models

Thomas Nagler / ENVEO

CCI Colocation Meeting || Harwell || 24-26 March 2026



Common Methods for gap filling

- Spatial interpolation
- Spatio-Temporal interpolation
- Data fusion (combining multiple sensors to fill gaps)
- Model-based methods (physical or statistical models)
- Machine learning / AI / combined with models

Gaps in AOD CDR due to missing satellite acquisitions

AOD record gap filling

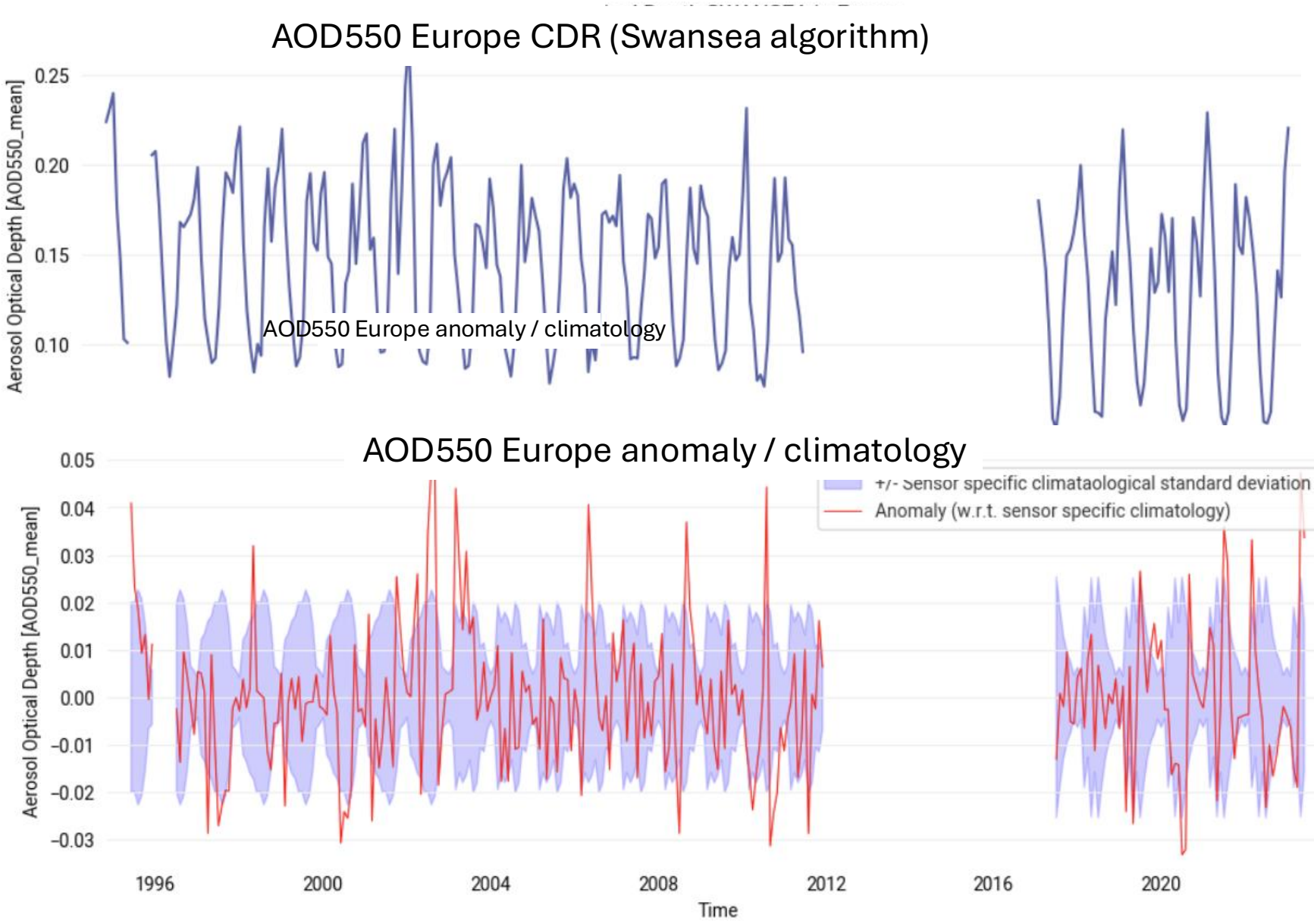
Dual view sensor line

- ERS-2 / ATSR-2 (1995 – 2003)
- ENVISAT / AATSR (2002 – 2012)
- SENTINEL-3 / SLSTR (2017 -)
- Gap: 2012 – 2016

Develop methodology

- Can we use MODIS?
  - nadir only, but wider swath
- How can we combine the different data?
  - anomalies + climatology
  - MODIS anomaly + SLSTR climatology

courtesy Thomas Popp / DLR

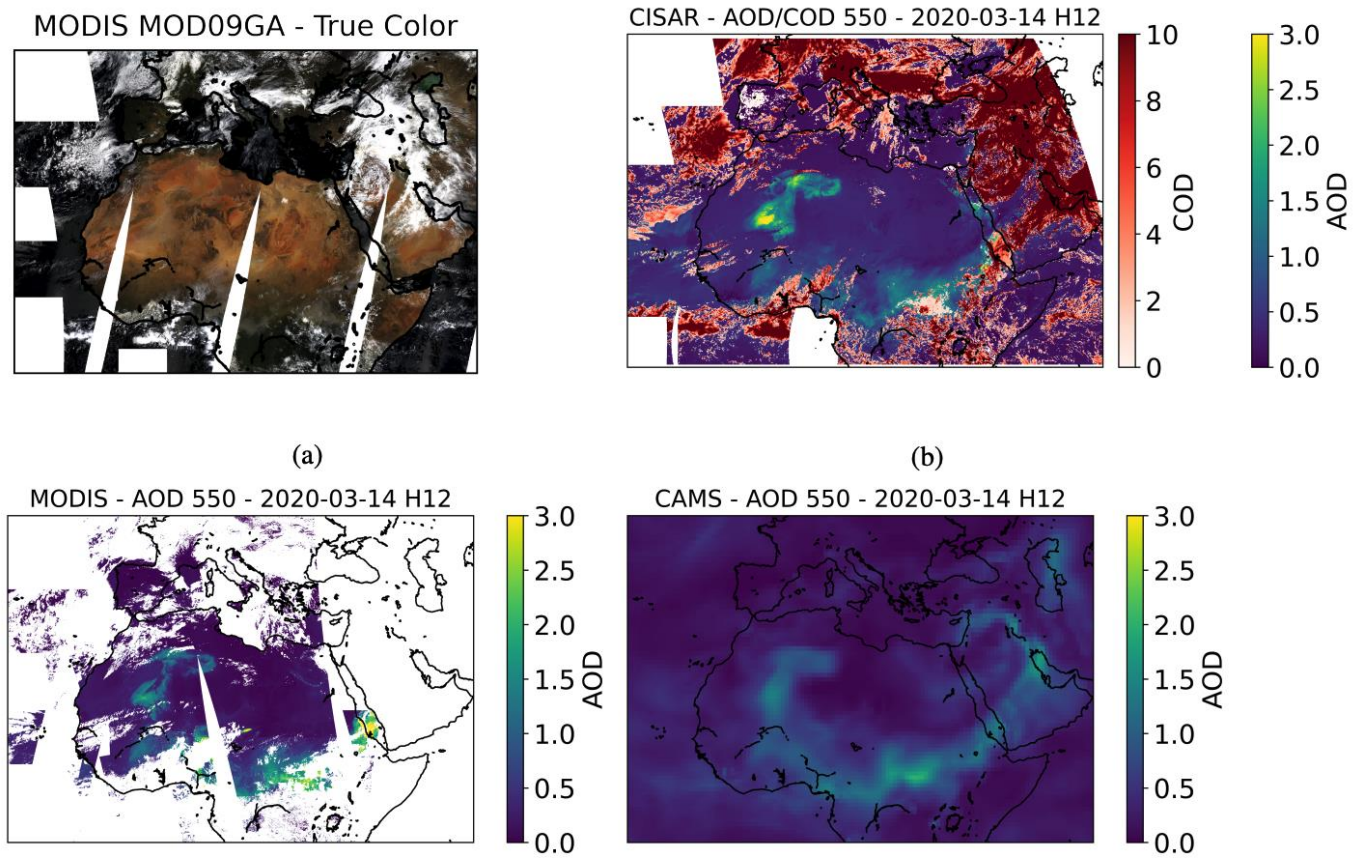


Lost pixels in Aerosol-cloud Retrieval Algorithms

Aerosol retrieval is limited to cloud-free conditions and a few kms away from clouds.

About 20% of pixels worldwide are excluded by both aerosol and cloud retrieval algorithms (Schwarz et al., 2017).

The CISAR algorithm extends aerosol retrieval near clouds, increasing spatial coverage while maintaining accuracy.



Products over over the processed common area between MSG1 and MSG4: true color image obtained from the MODIS MOD09GA product (a); SEVIRI/CISAR combined AOD/COD retrieval (b), MODIS/MAIAC MCD19A2 product (c) and CAMS dataset (d).

Courtesy Marta Luffarelli

Filling gaps in CCI Soil Moisture Products

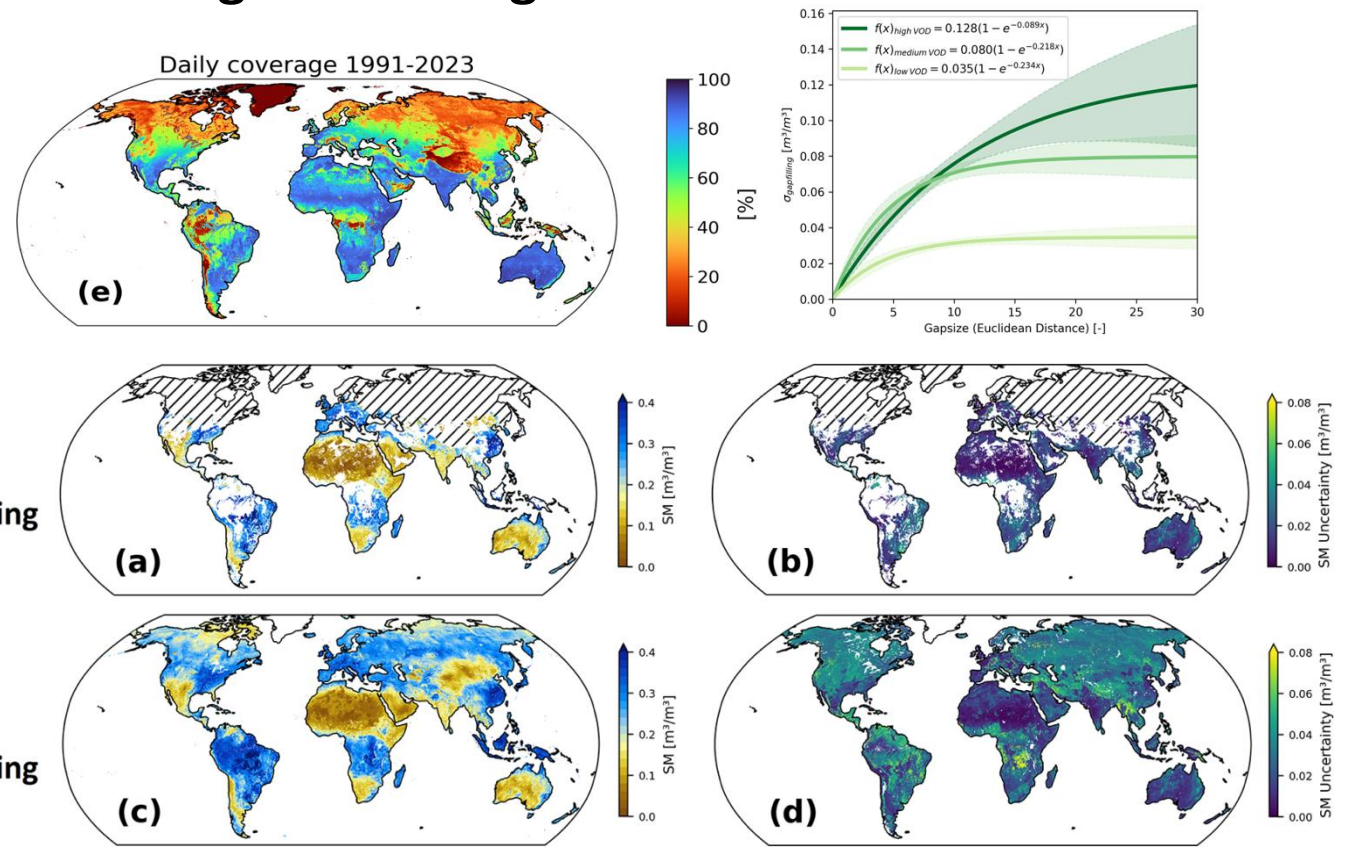
To fill gaps:

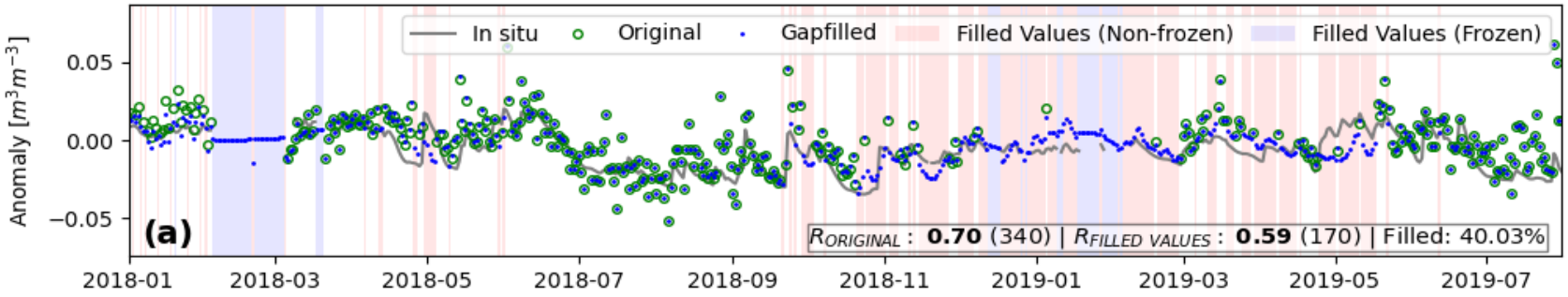
- DCT-PLS statistical method + linear interpolation to fill seasonal gaps
- No ancillary information
- Preservation of original measurements
- Uncertainty related to gap size and vegetation density

Courtesy Wouters Dorigo

Original coverage

uncertainty model



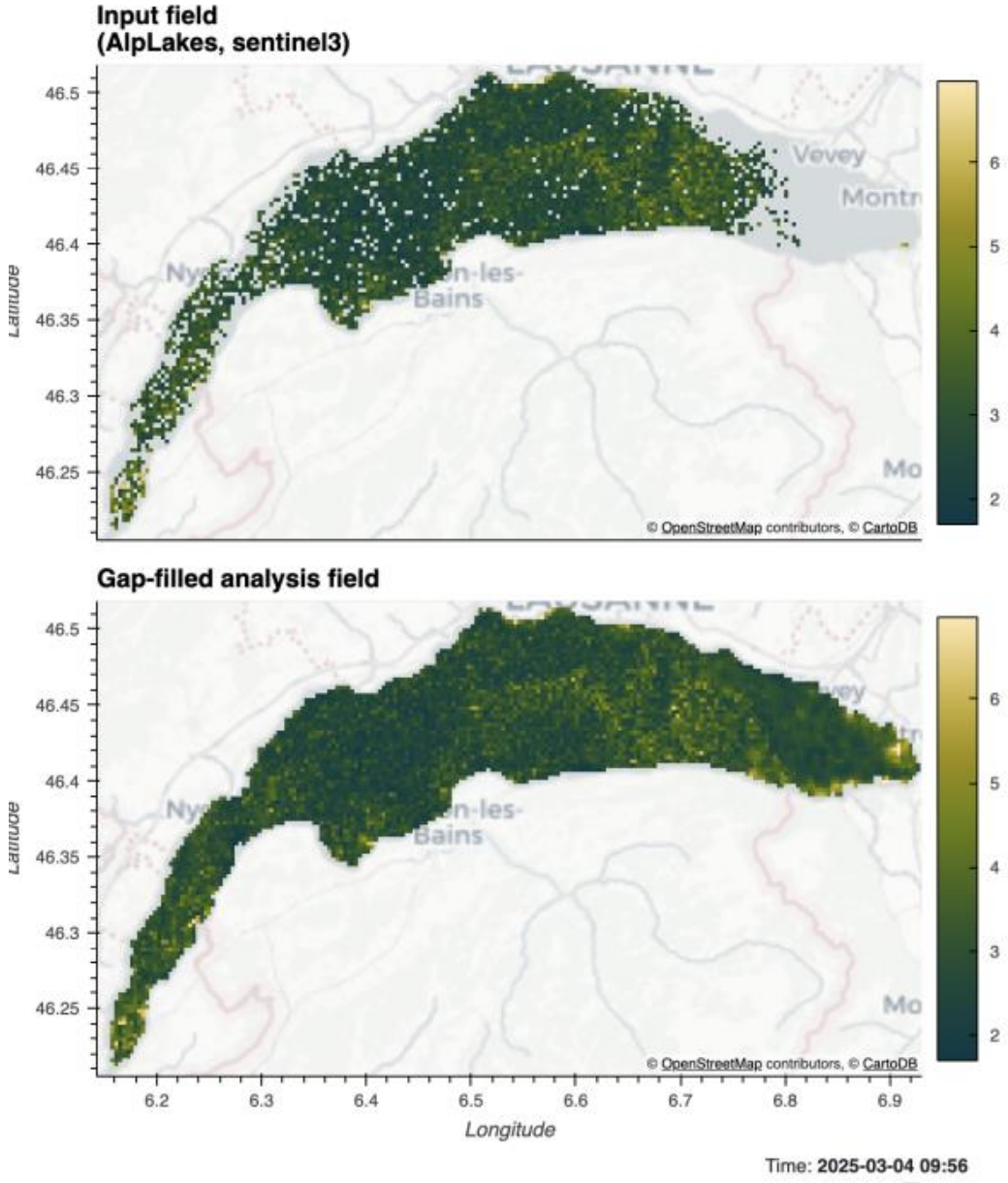


Gaps in daily Sentinel-3 Chlorophyll-A Products

Sentinel-3 OLCI data Gaps due to clouds and pixels where retrieval method fails

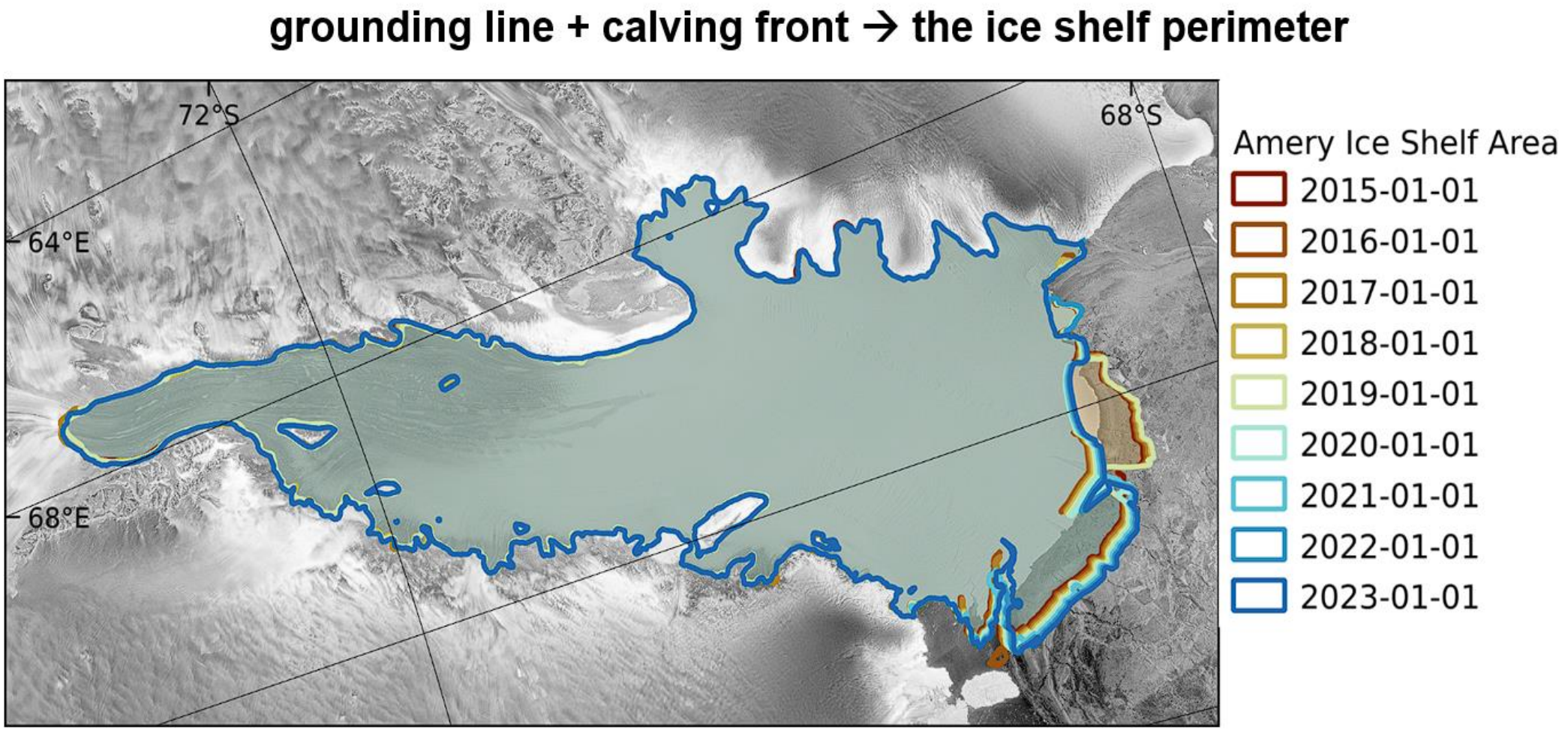
DIVAnd gapfilling method for lake chlorophyll-a products:

- Clear water periods and small gaps are filled
- Algal blooms can still not be filled



Courtesy Daniel Odermatt

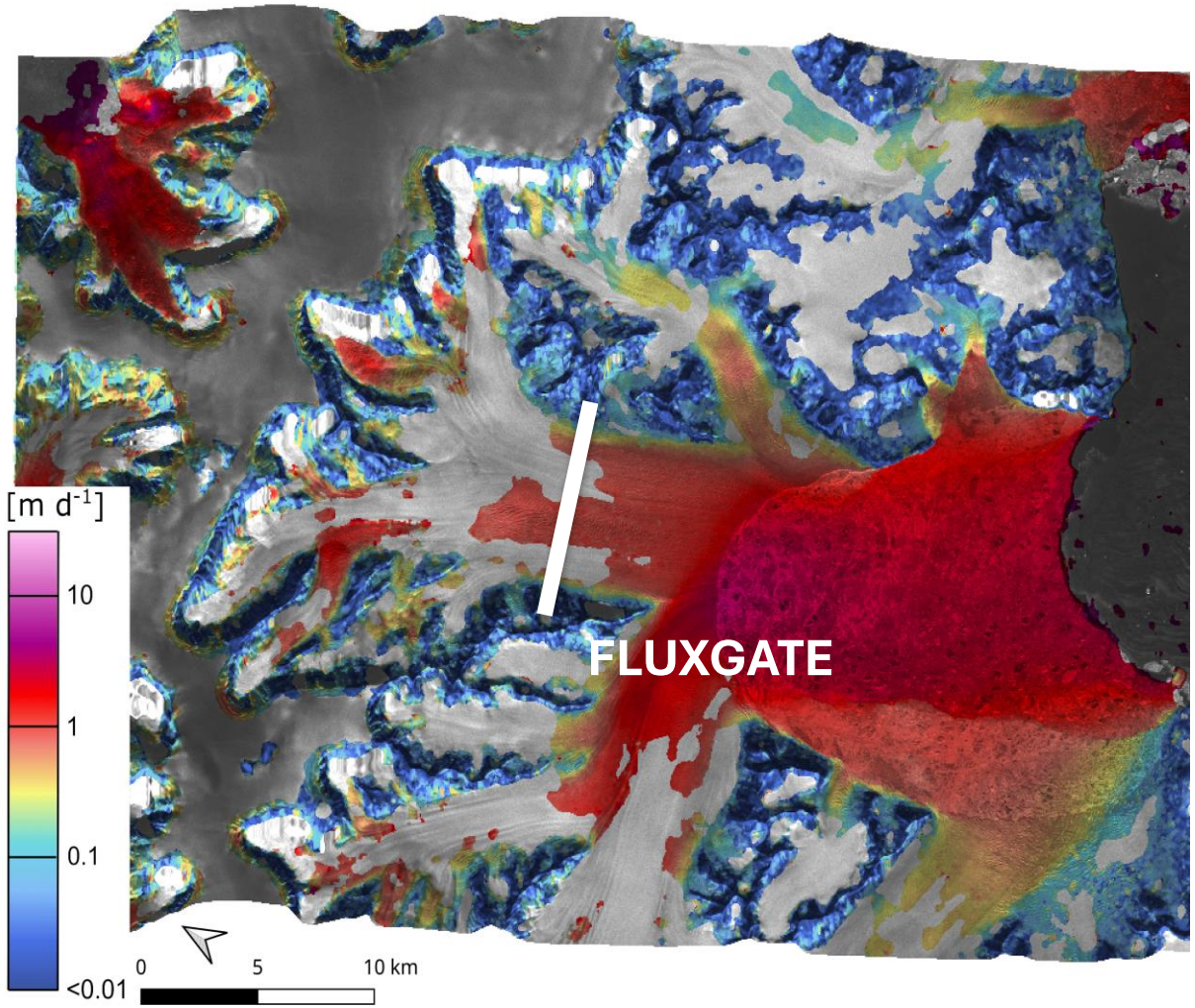
Gapless Grounding Line for Ice Shelf Perimeter



Courtesy Dana Floricioiu / DLR

Gaps in Ice Velocity Products affect Ice Discharge calculation

Ice discharge across a flux gate is calculated by integrating the product of ice velocity and ice thickness along the gate.



Filling gaps of Ice velocity across flux gate

1) Spatial interpolation:

- Gaps ≤ 5 sample points -> linearly interpolation
- Gaps >5 sample points -> mass flux is set to None for the gate (% valid velocity data recorded)

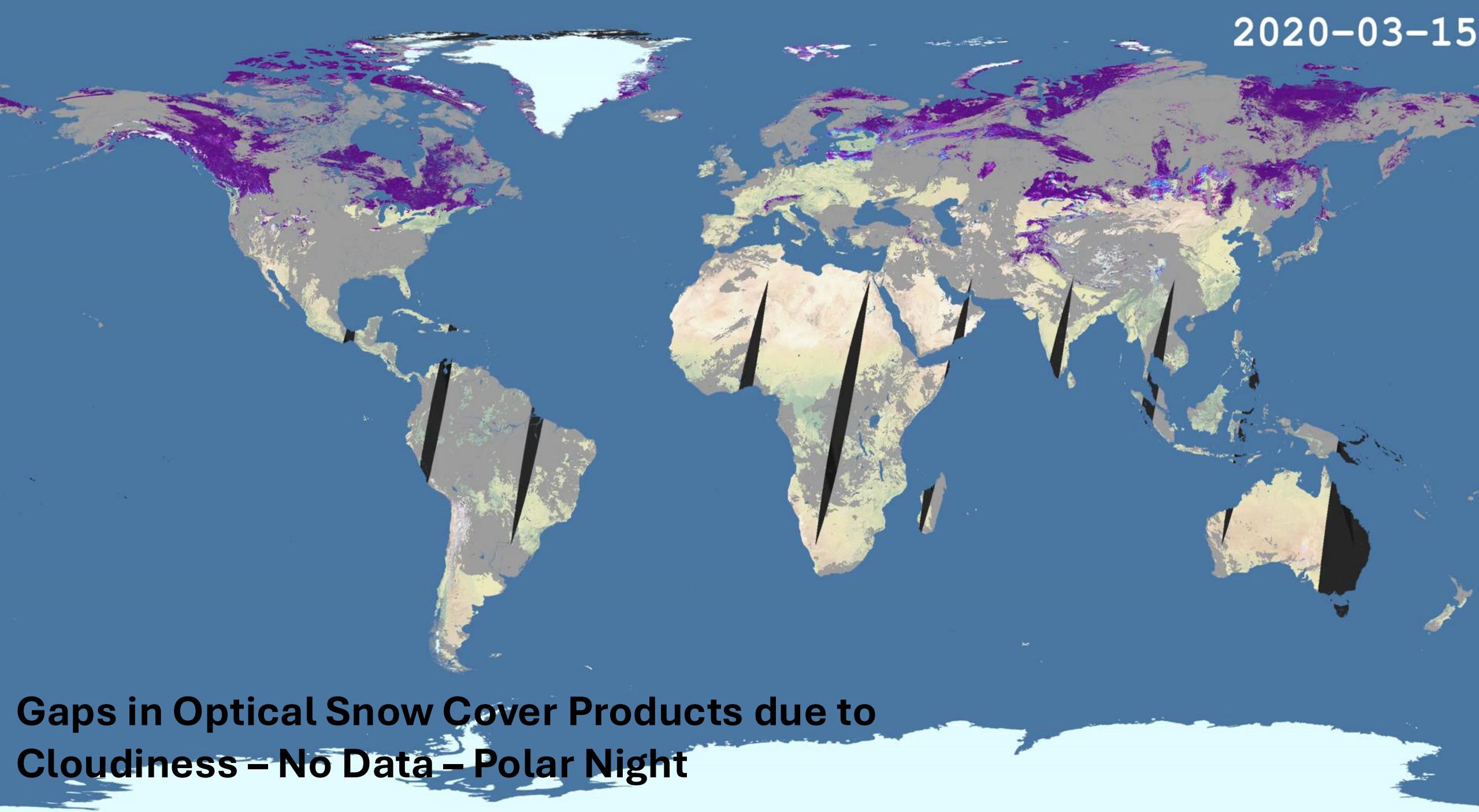
2) Temporal Interpolation

- Gaps after spatial interpolation -> linear temporal interpolation for missing data points
- For missing data points at the beginning/end of time series use temporally nearest neighbor

Filling gaps of Ice thickness across flux gate

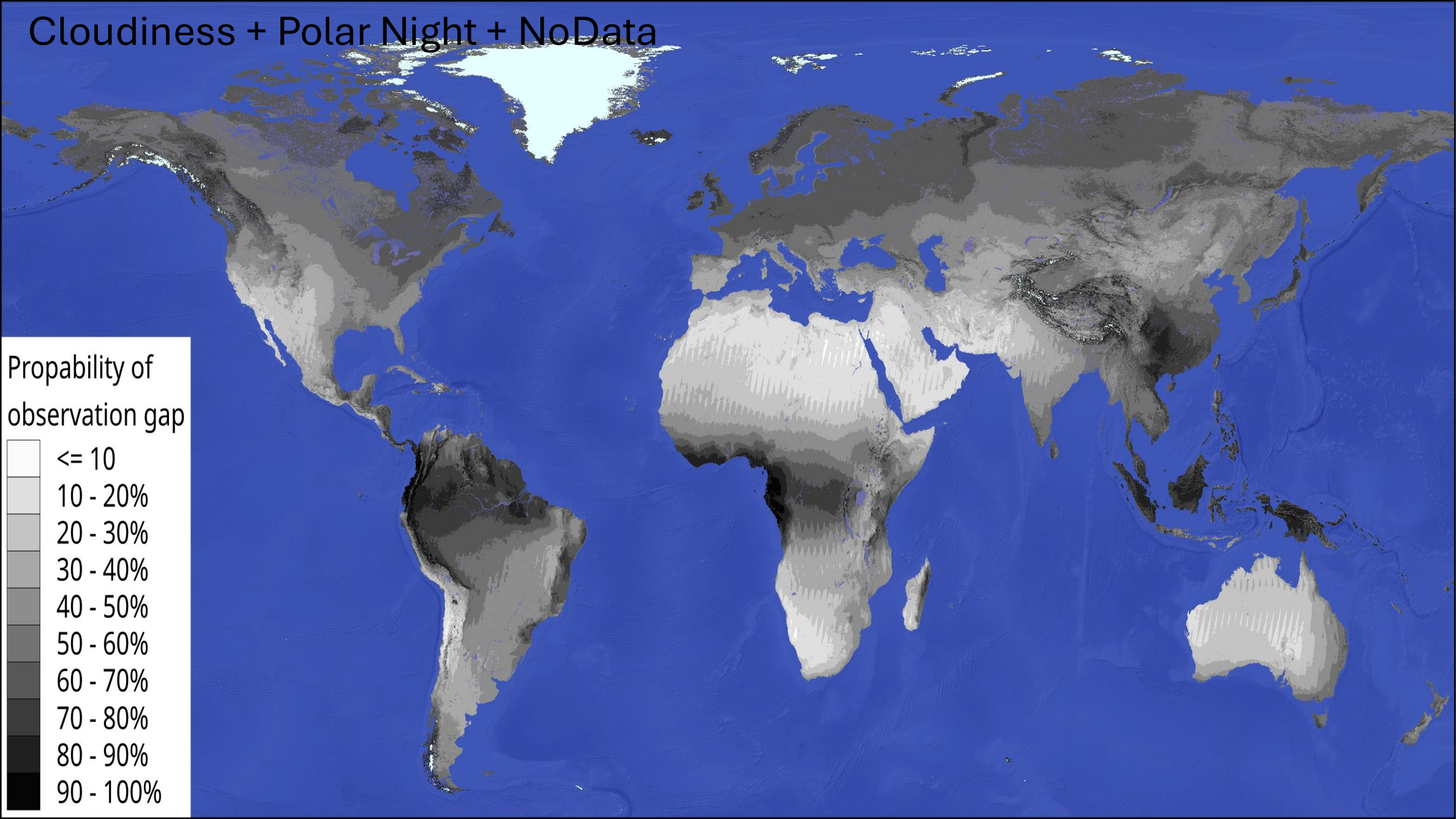
- Select nearest neighbor in 7x7 window
- If no data mass flux is set to None for the gate
- Same procedure is applied for the error of the ice thickness

Courtesy ENVEO

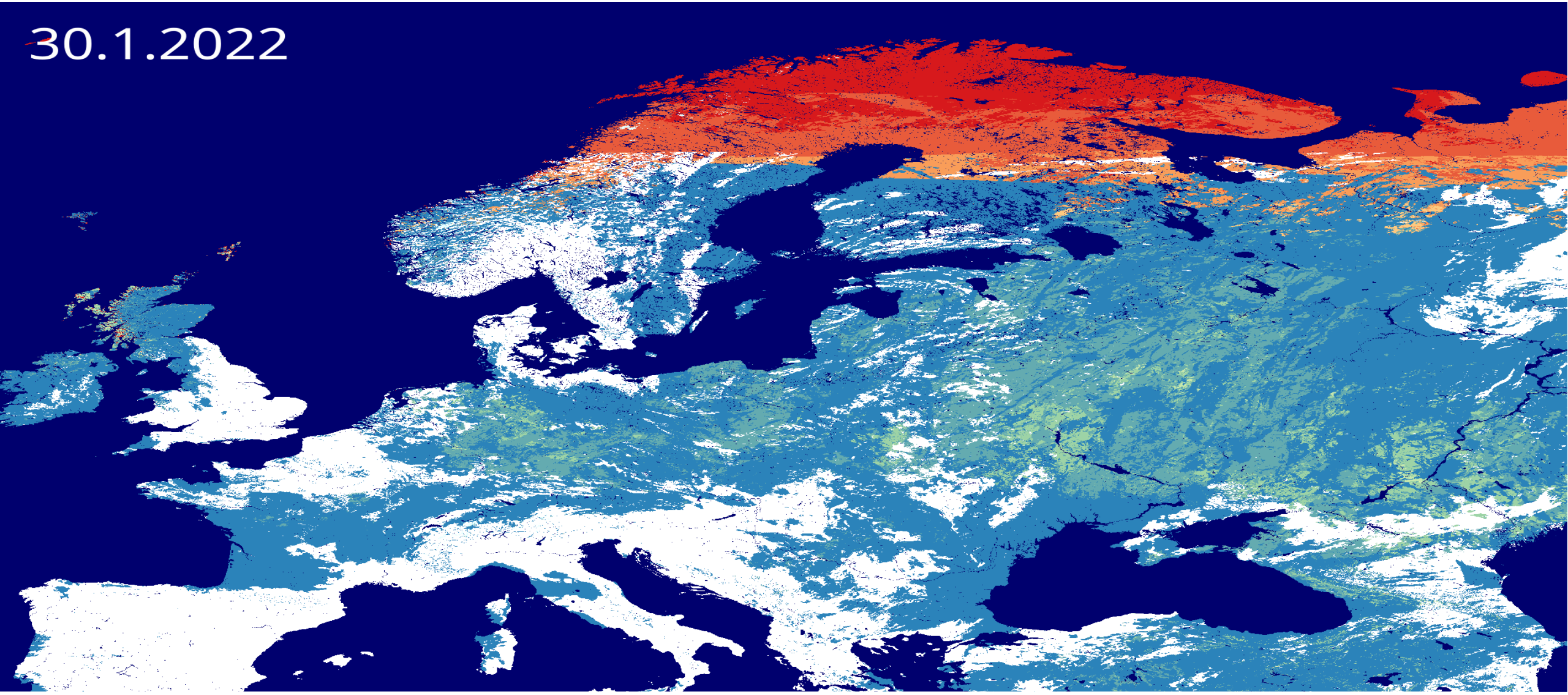


Gaps in Optical Snow Cover Products due to Cloudiness – No Data – Polar Night

Cloudiness + Polar Night + NoData

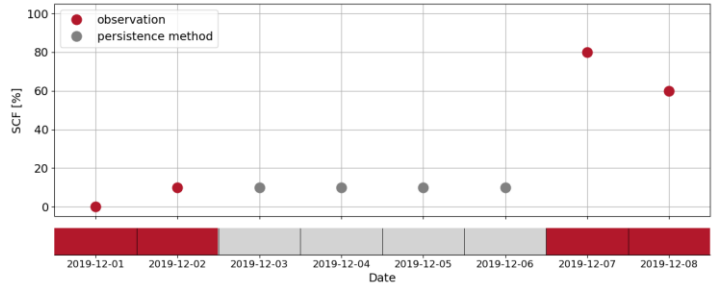


Duration of continuous observation gaps - an Example

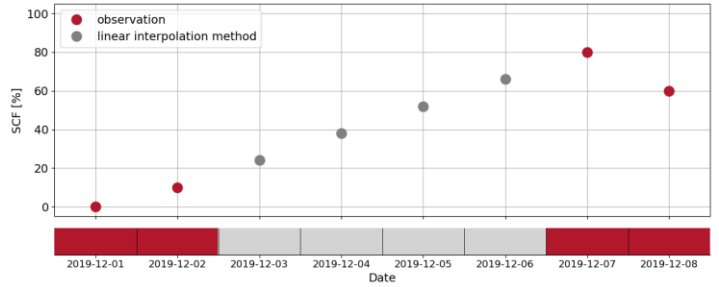


Some methods for filling gaps in Snow CDRs

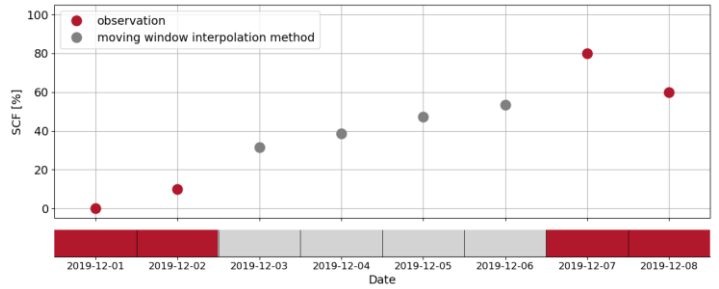
Persistence method:
SCF value remains constant until next observation



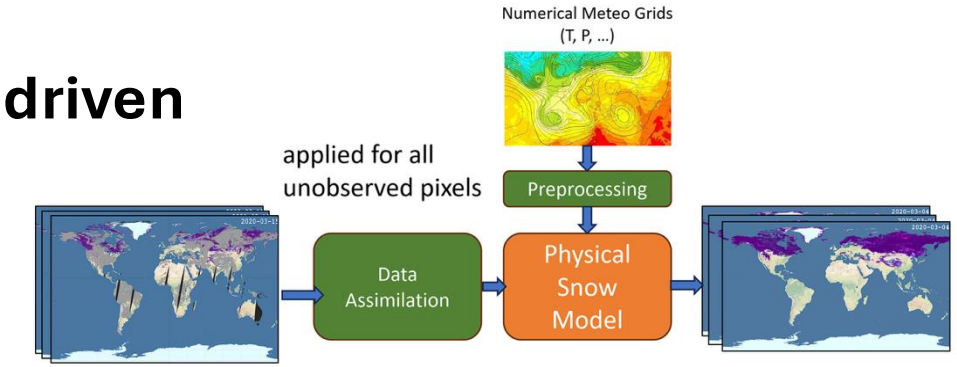
Linear interpolations method:
Linear interpolation between two SCF observations



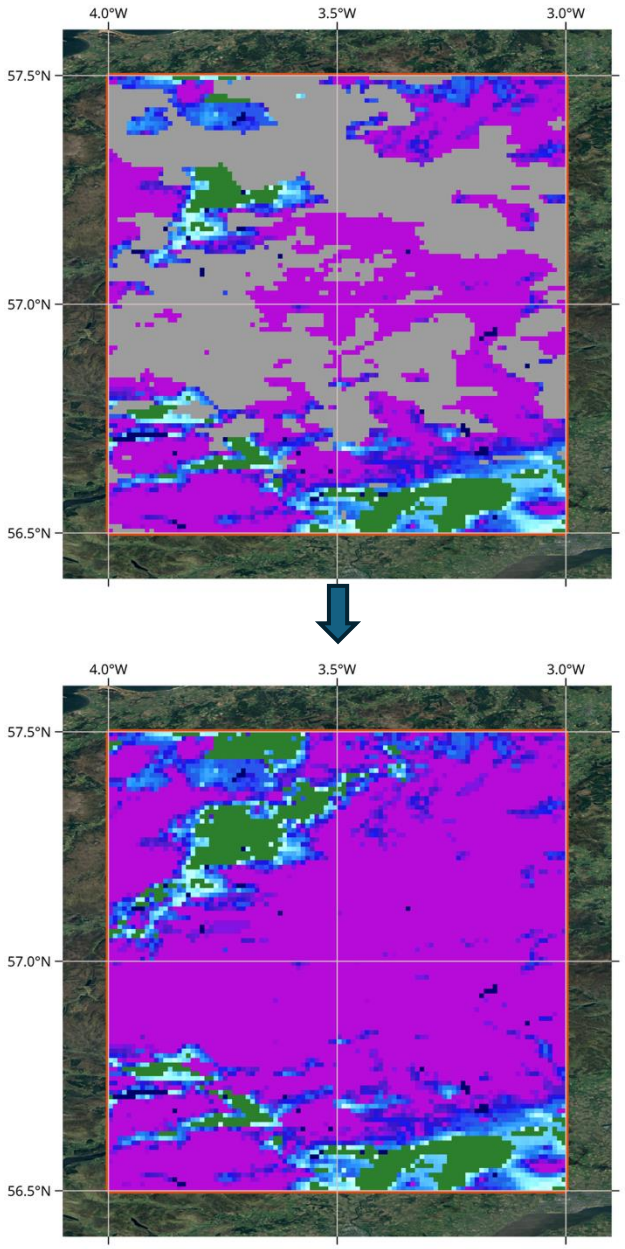
Moving window interpolation method:
First gaps are filled by linear interpolation and then replaced by the average of all observations within ±3 days around that date

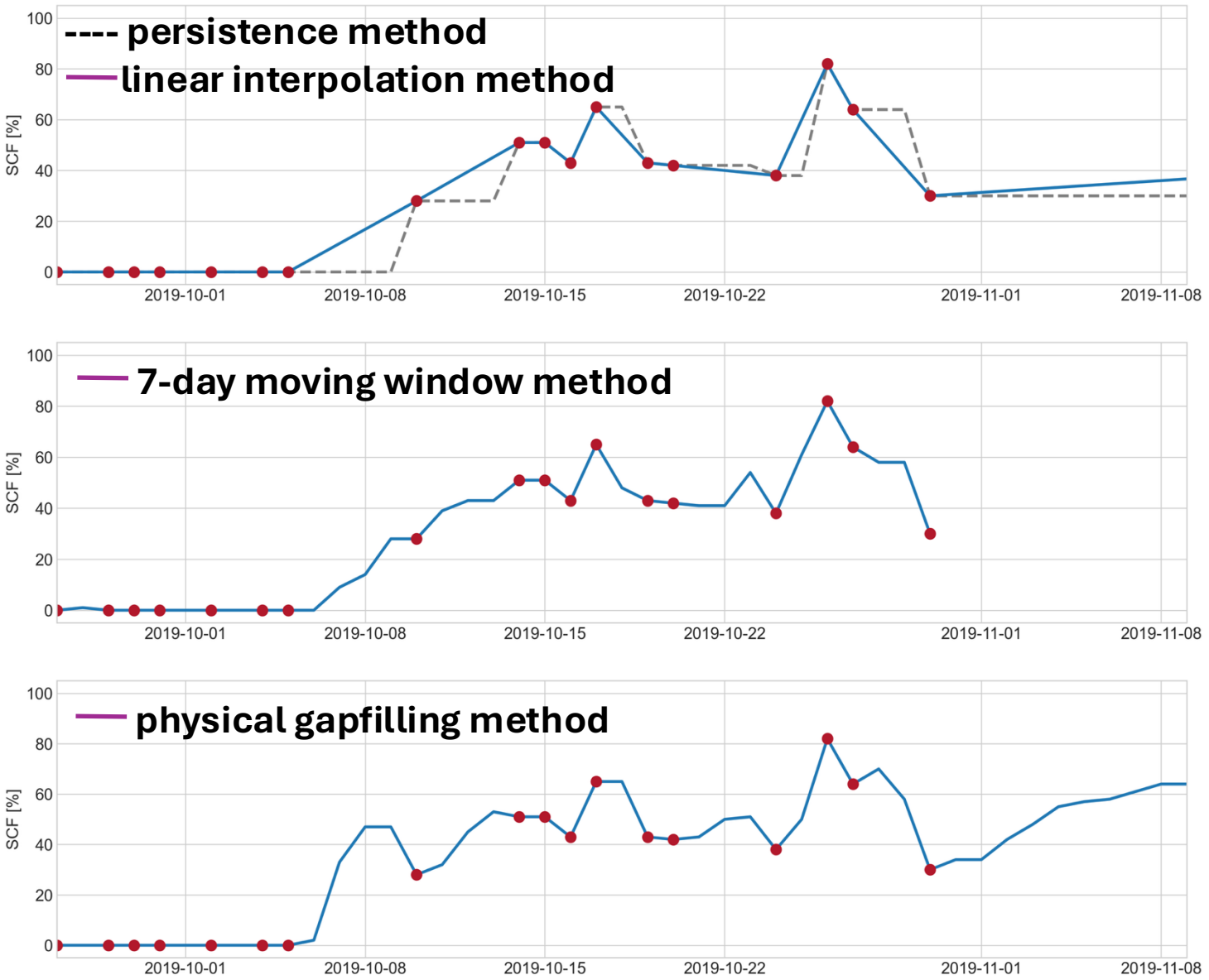


Assimilation of last observation with physical model driven by numerical weather models

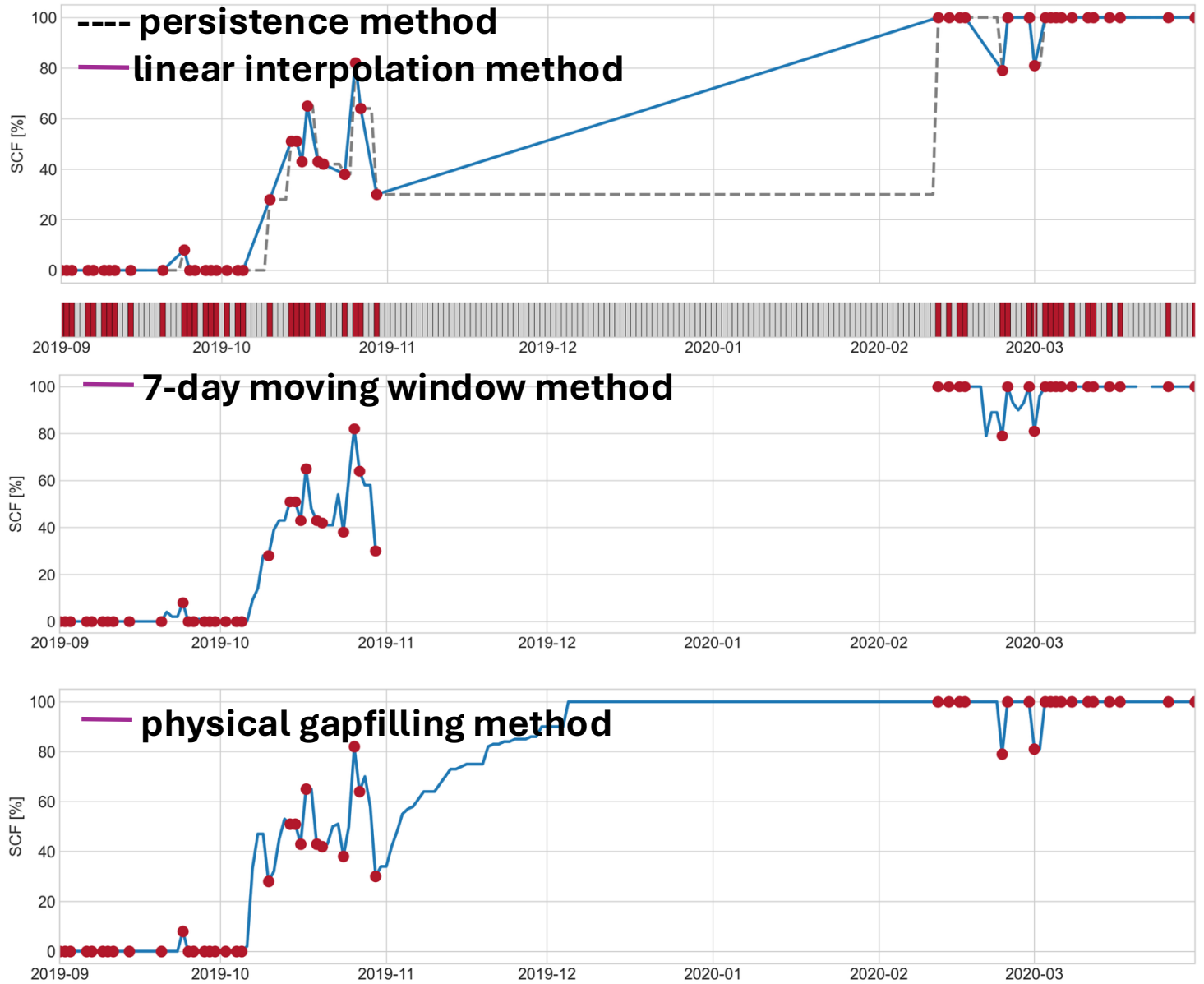


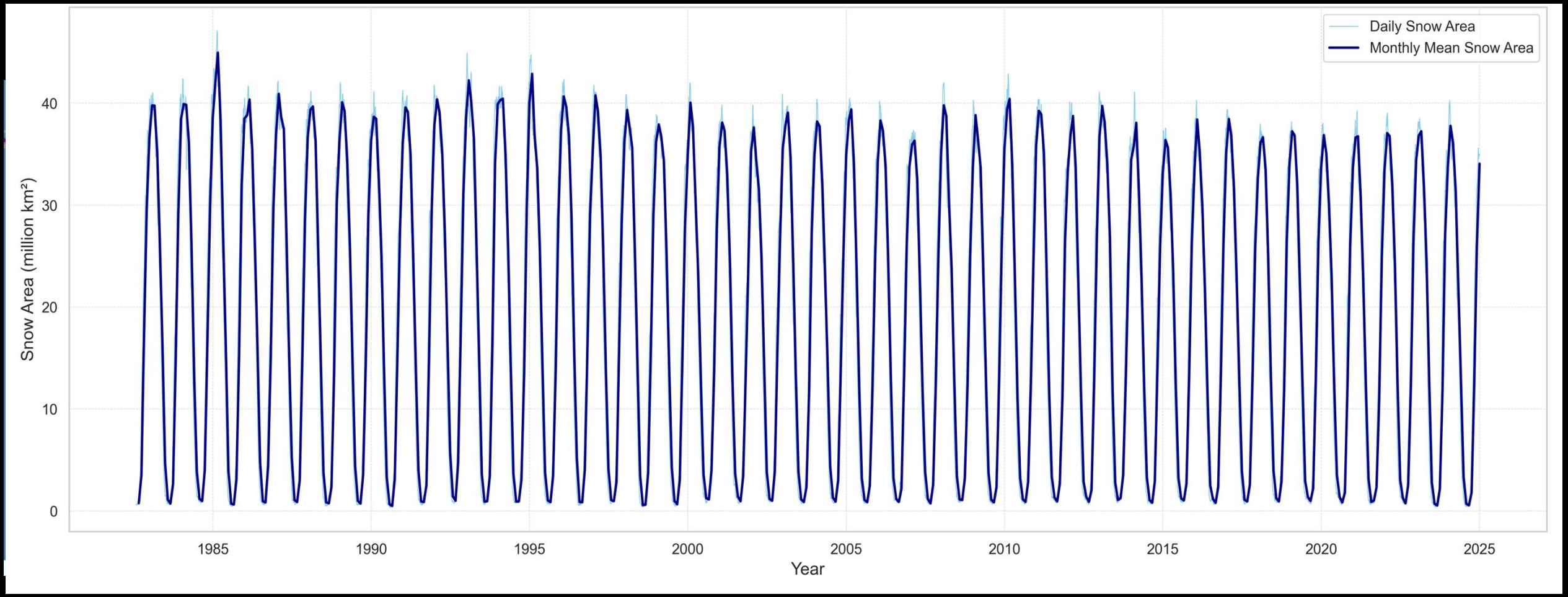
Filling short term gaps in snow extent products





Example Long duration gap - Polar night gap > 3 months




Daily Snow Area
Monthly Mean Snow Area
Snow Area (million km²)
0
10
20
30
40
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year

Summary

- Gaps affect most CDRs, although their causes may differ.
- The suitable gap-filling method depend on the ECV product. Their selection is influenced by the availability of auxiliary datasets as well as computational costs.
- Uncertainty estimates for gap-filled regions are essential, though their derivation can be challenging.
- Validation of gap filled regions is required. One approach is to introduce artificial gaps and compare the reconstructed data with the original observations.