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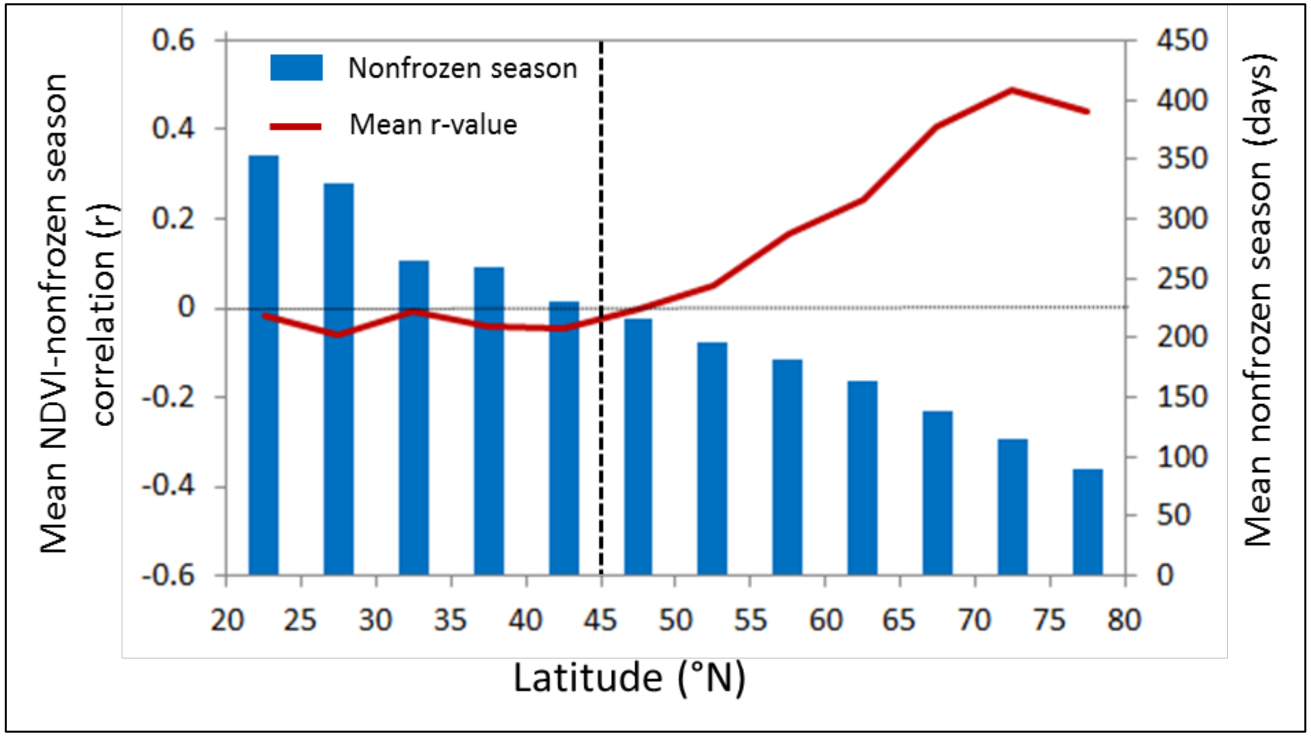
Soil frost from microwave data

Kimmo Rautiainen, Jouni Pulliainen, Juha Lemmetyinen, Jaakko Ikonen, Mika Aurela

Why landscape freeze/thaw?



Latitudinal variation in mean correlations (r) between annual non-frozen season variations and summer (JJA) NDVI growth anomalies defined over a 9-year record (2000-2008) (after Kim et al. 2012, Fig 5b).

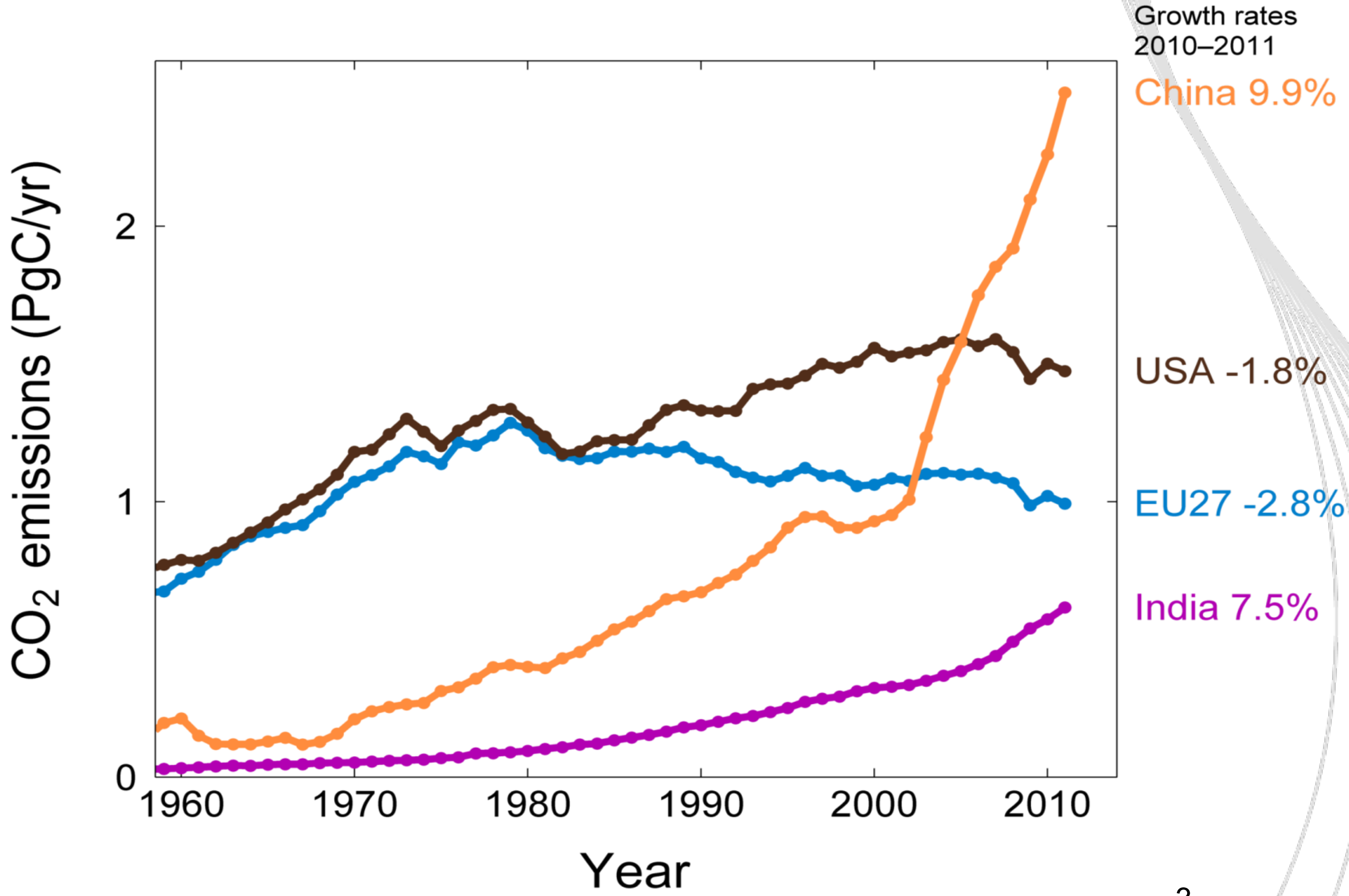
- Ecosystem function and geochemical cycling
- Hydrological processes/flood forecasting
- Soil state inputs to radiometer and radar algorithms for other land surface variables (i.e. for terrestrial snow)
- Land surface initialization (data assimilation and numerical weather prediction)

Slide courtesy of Youngwook Kim, John Kimball (Montana State University)

Motivation: CO2 emissions are growing

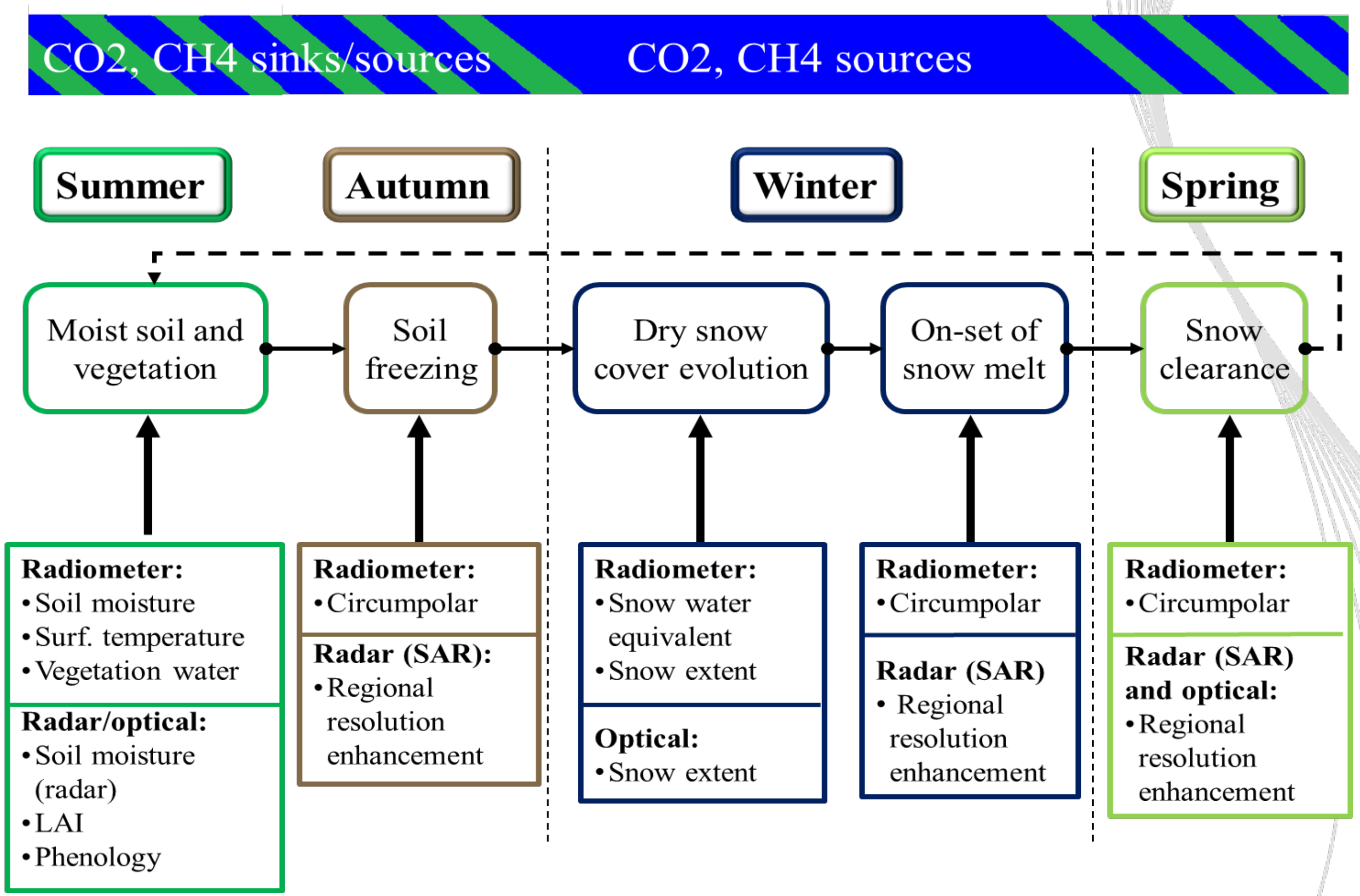
Additionally, natural (ecosystem) sinks and sources are changing due to climate change

Top four emitters in 2011 covered 62% of global emissions
China (28%),
United States (16%),
EU27 (11%),
India (7%)



Integrated view on the land cryosphere: snow and soil processes

- Soil and vegetation processes in addition to snow cover
- Full seasonal view on phenomena relevant to carbon exchange and annual balance at the high latitudes



FMI Sodankylä satellite CAL-VAL program:

Among key topics: Development of satellite data retrieval algorithms to map ***snow*** and ***soil state characteristics***, and their relation to ***carbon cycle (CO2 and CH4 fluxes)***

ESA SMOS

Sodankylä soil process CAL/VAL program: L-band reference radiometer for SMOS and SMAP

ELBARA-II reference radiometer for SMOS

- L-band (1.4GHz), dual polarization
- Manufactured by Gamma RS AG (Switzerland)
- Currently on lease from ESA
- Development of satellite applications
- Detection soil freeze/thaw status for the monitoring of annual carbon cycle
- Collected time series:
  - ***Mineral soil site***: 2009-2012
  - ***Organic soil (wetland) site***: 2012 ->

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ELBARA-II observations vs soil freezing

- Three-year period of forest opening observations – mineral soil with thin organic layer

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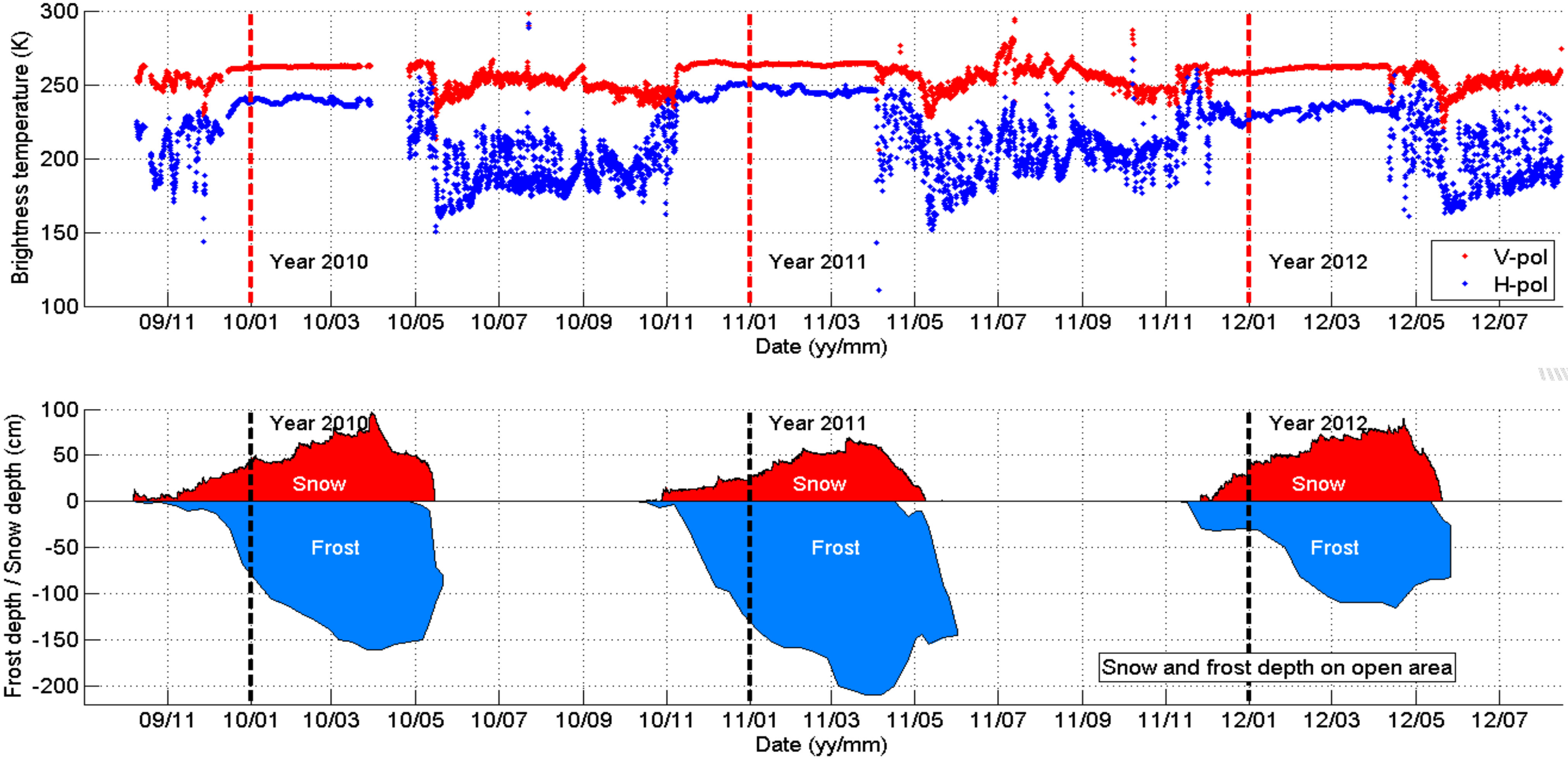
Three-winter time-series: ELBARA-II and frost/snow



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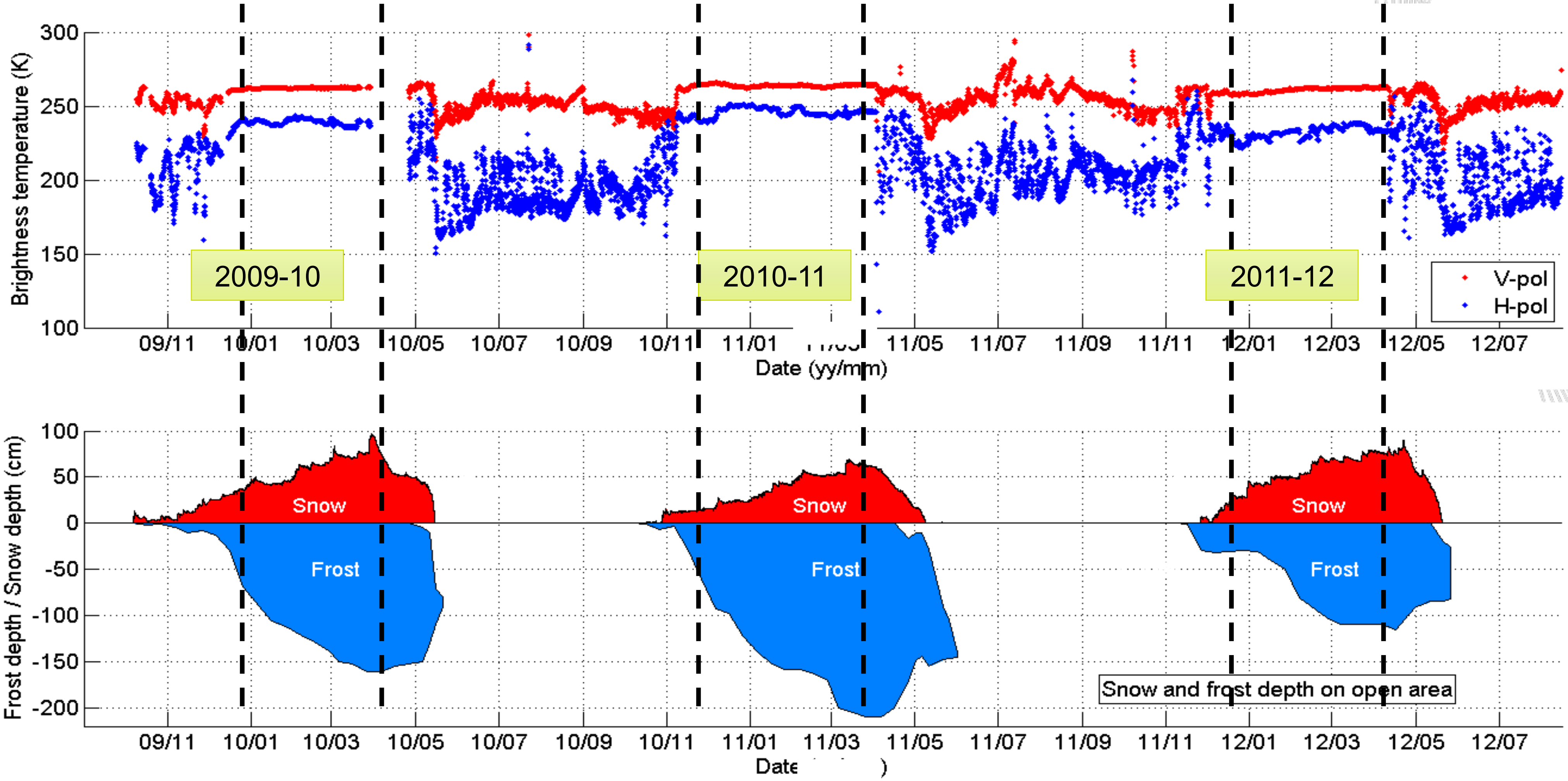
Winter period: saturated T_b signal (especially for V-pol), winter average increased from summer, decreased polarization difference



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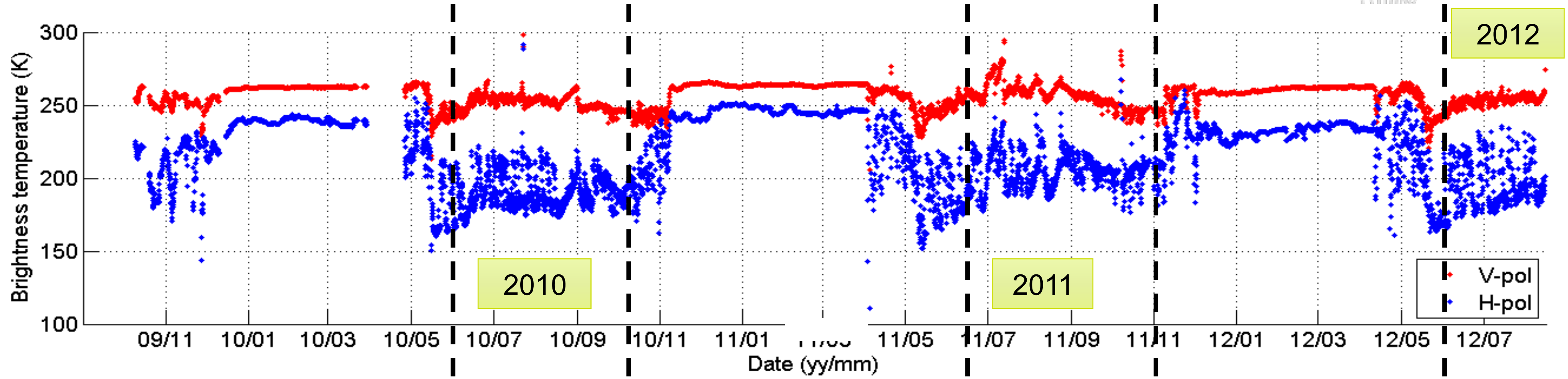
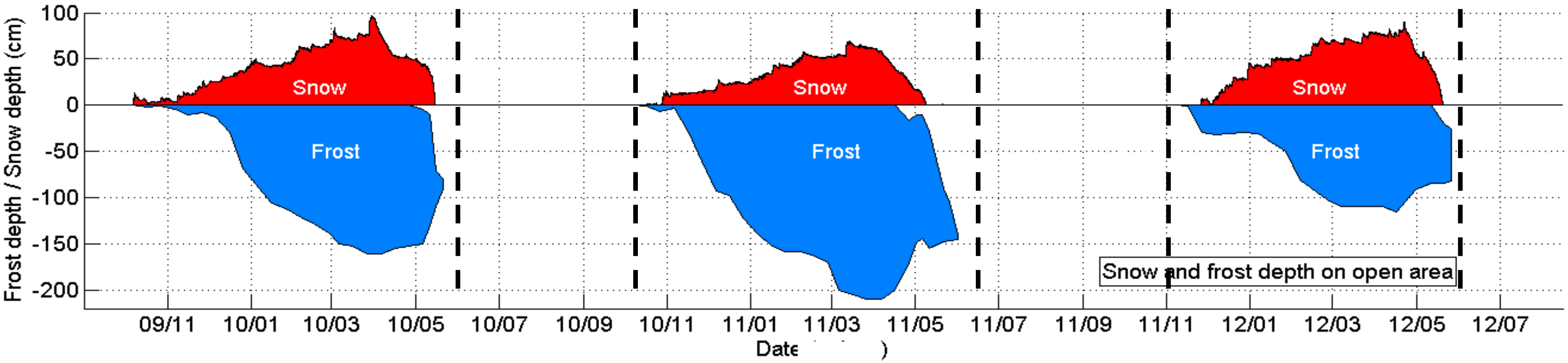
Summer period: higher variability in the signal, larger polarization difference





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Summary on ELBARA-II results

- Soil freezing has following clear effects to ELBARA-II signal:
  1. Increased and saturated observed brightness temperature
  2. Decrease in polarization difference ($T_{b,Vpol} – T_{b,Hpol}$)

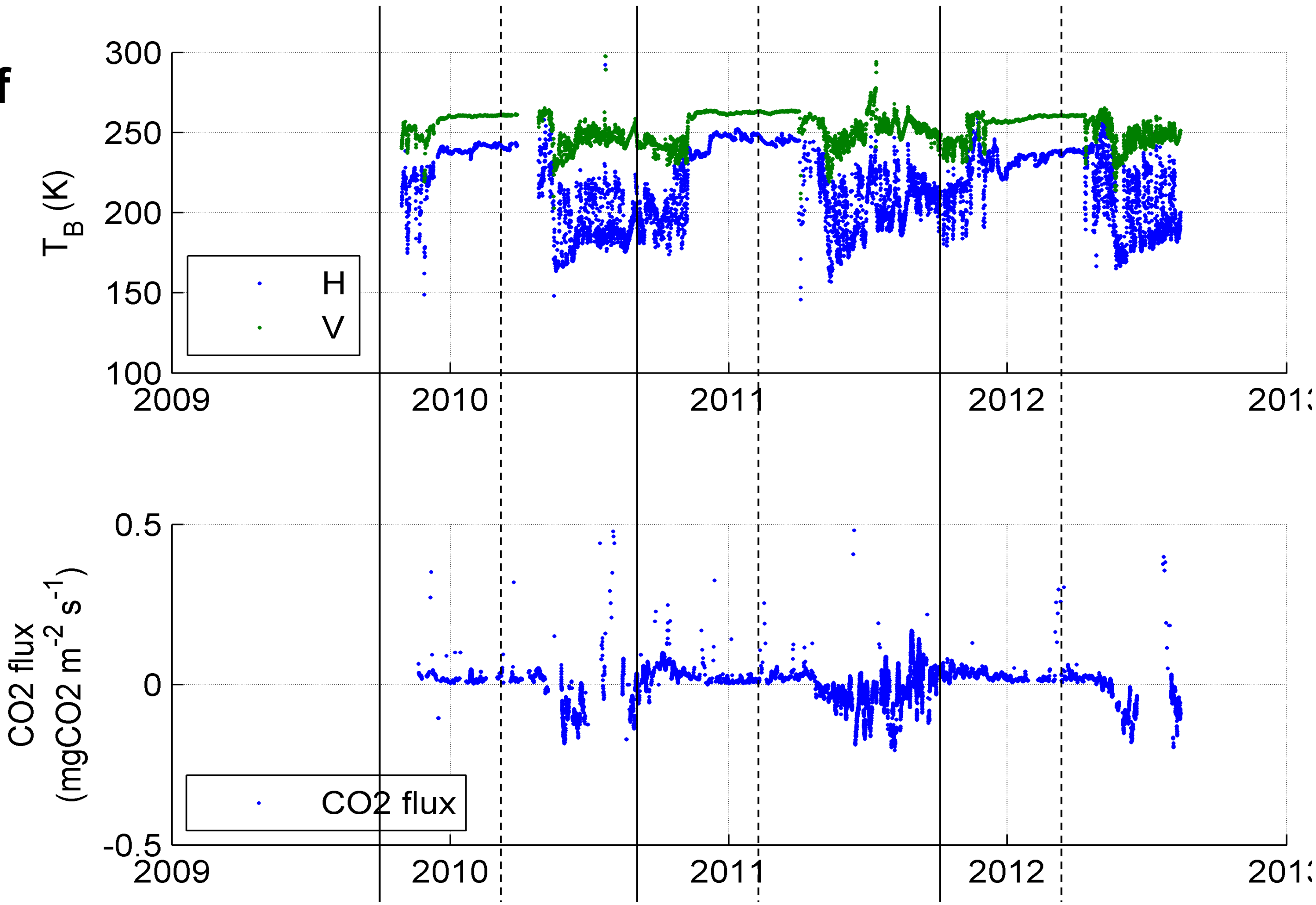
- Algorithm based on the change detection of the “Frost Factor” parameter calculated as:
  - **(T_{VPol} - T_{HPol}) (T_{ref} -T_{HPol}), where T_{ref} = 270K**
  - **Polarization difference enhanced with H-pol brightness temperature**

- Rautiainen, K., Lemmetyinen, J., Schwank, M., Kontu, A., Ménard, C.B., Mätzler, C., Drusch, M., Wiesmann, A., Ikonen, J., Pulliainen, J. “Detection of soil freezing from L-band passive microwave observations,” Remote Sensing of Environment, Vol. 147, pp. 206-218, May 2014

CO2 flux in forest and its relation to L-band brightness temperature

Three-year time series of ELBARA-II in forest opening (top) and concurrent CO2 net flux (below)

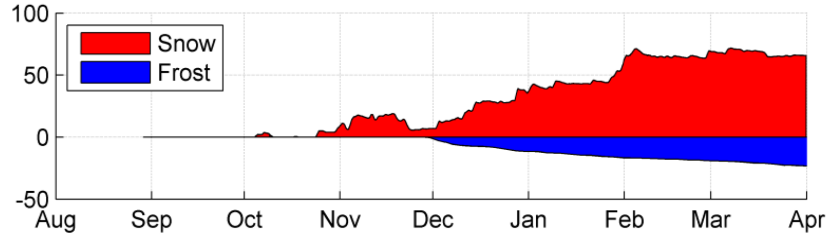
- **After snow melt-off a CO2 sink** due to photosynthesis
- During autumn a clear **CO2 source before soil freezing** (weak source during winter)



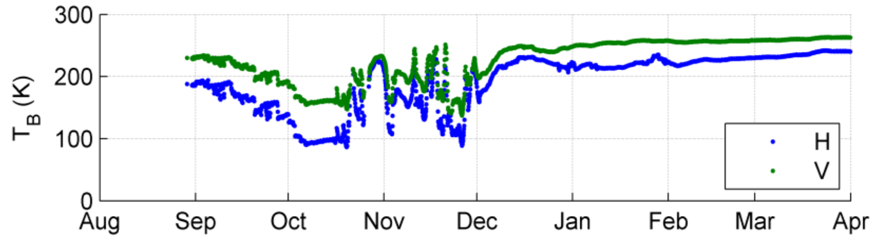
Link of soil freezing with carbon exchange – wetland

Since 2013, ELBARA-II installed at wetland (peatbog) site

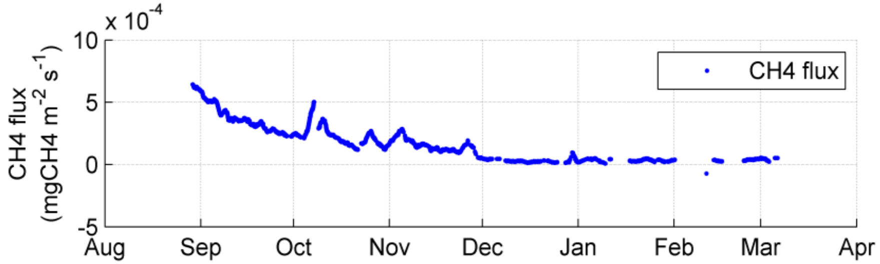
Measured snow depth and soil frost depth



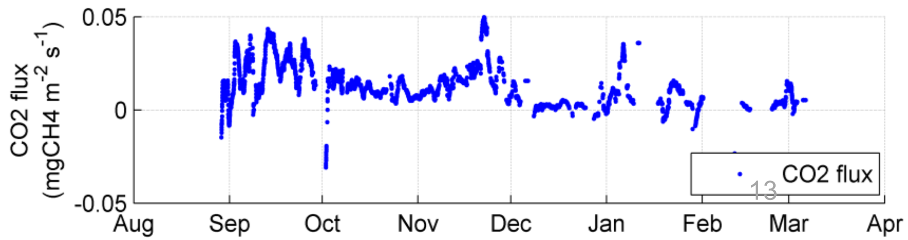
ELBARA-II brightness temperature



CH4 flux



CO2 flux



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Spaceborne

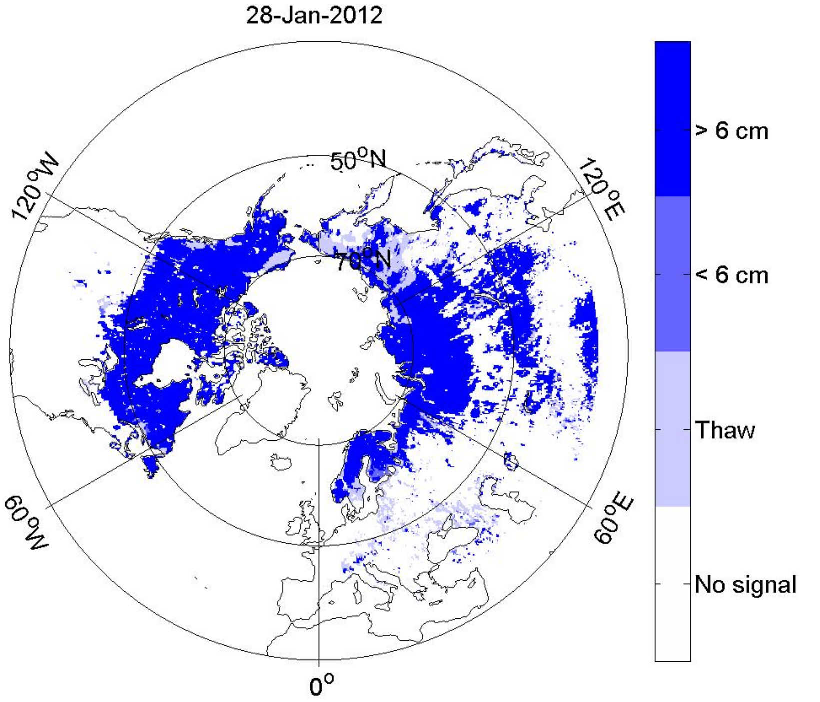
Prototype retrieval algorithm for space-borne L-band observations have been successfully demonstrated

Discrimination into thawed, frozen and partially frozen states

SMOS – ESA's Soil Moisture and Ocean Salinity –mission

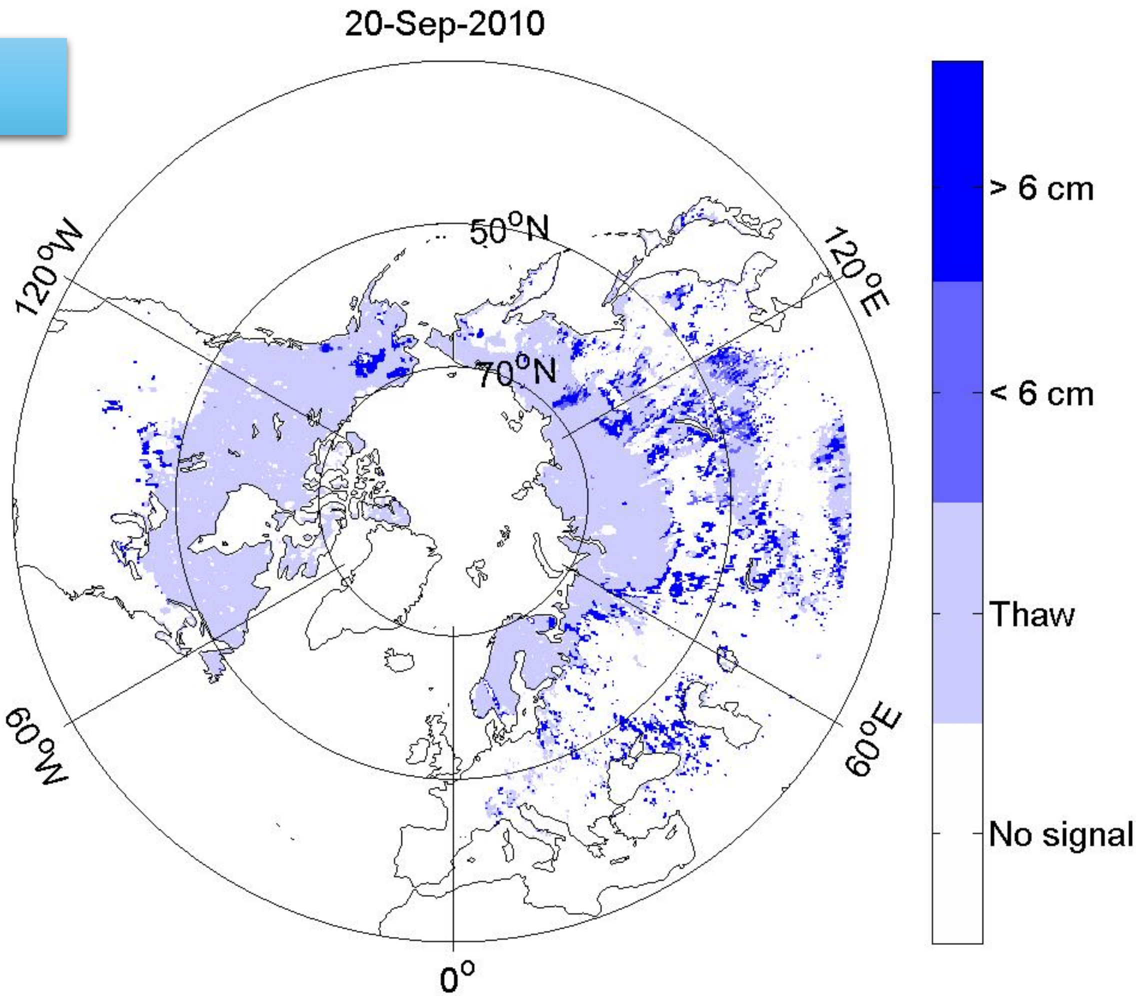
Coverage: whole Northern Hemisphere

Methodology also applicable to NASA SMAP



Frost maps for Northern Hemisphere

20-Sep-2010



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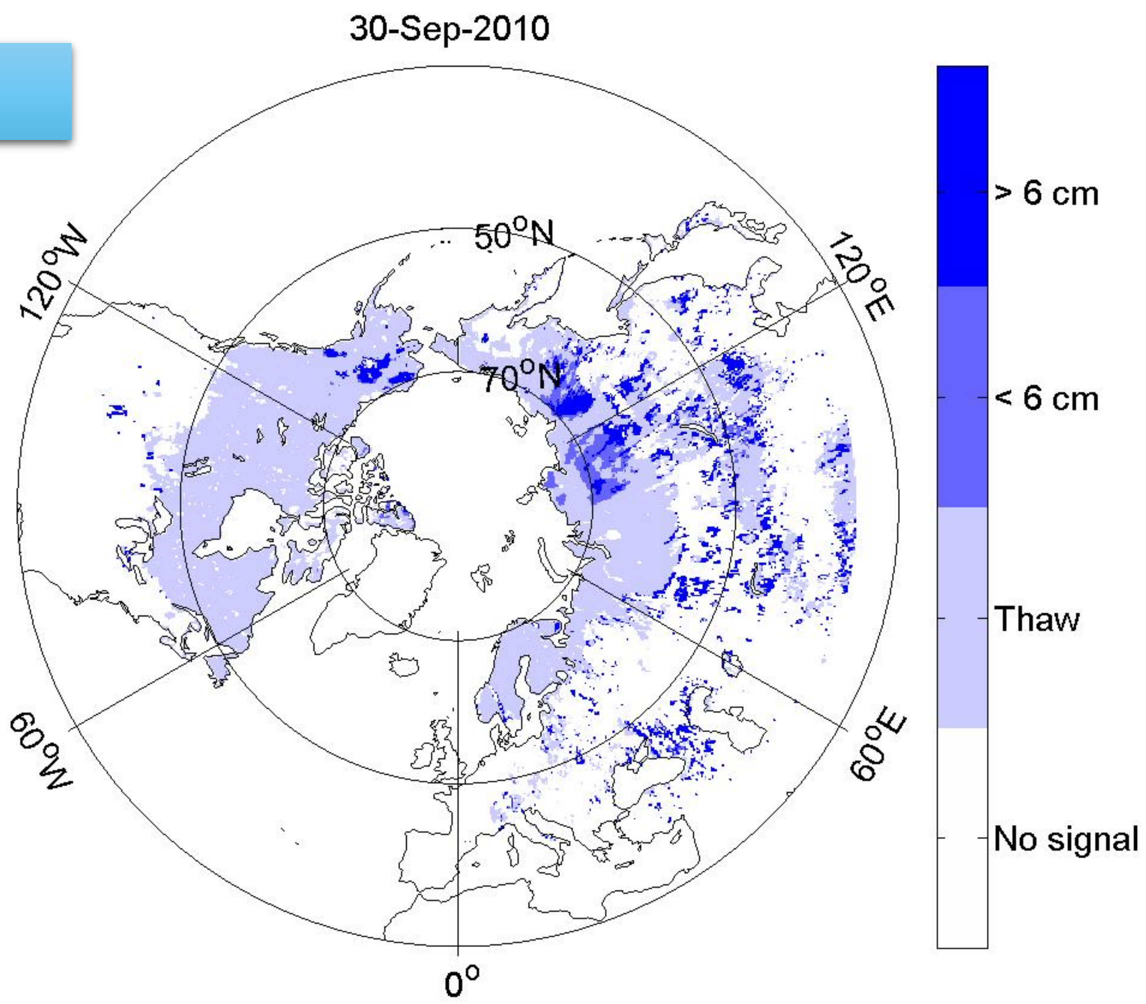
Frost maps for Northern Hemisphere

30-Sep-2010



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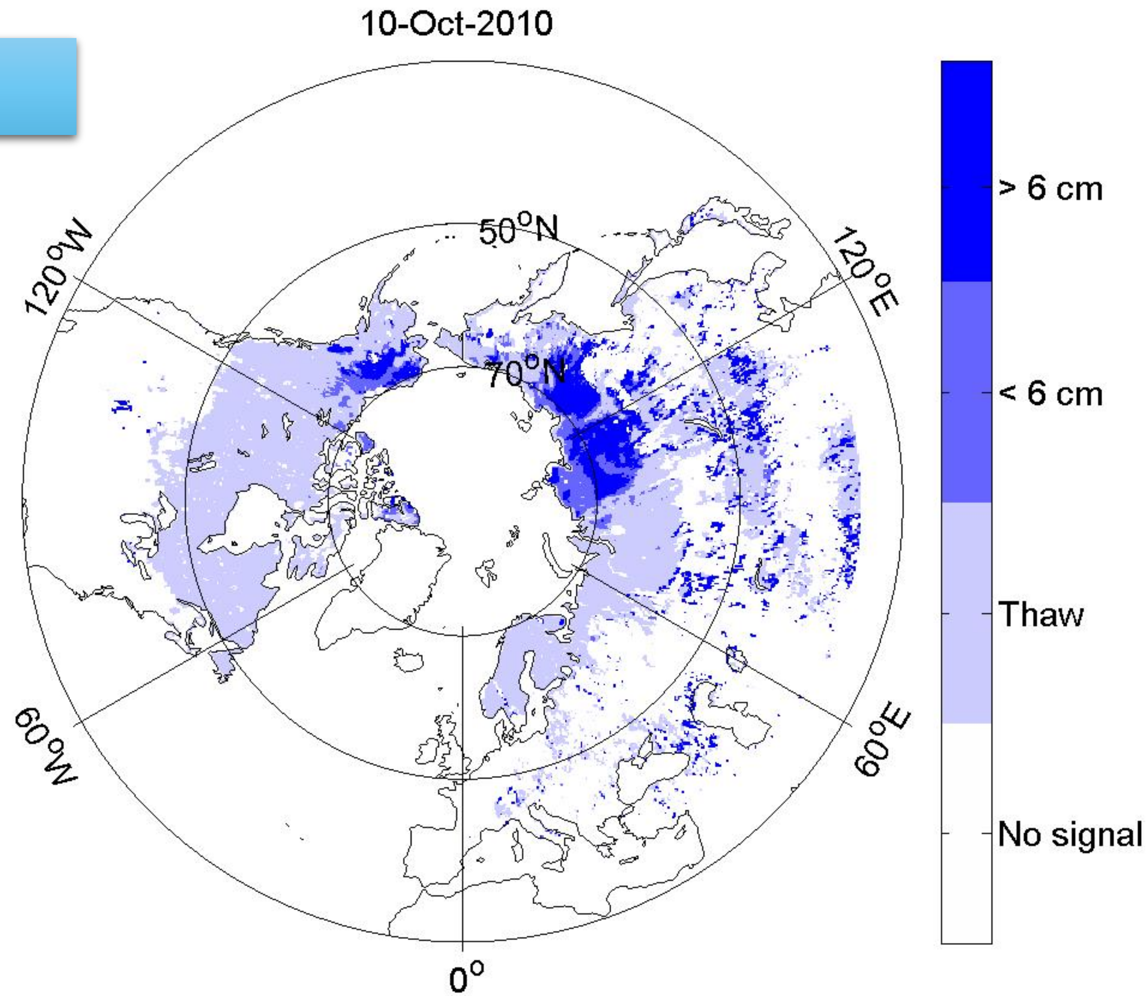
Frost maps for Northern Hemisphere

10-Oct-2010



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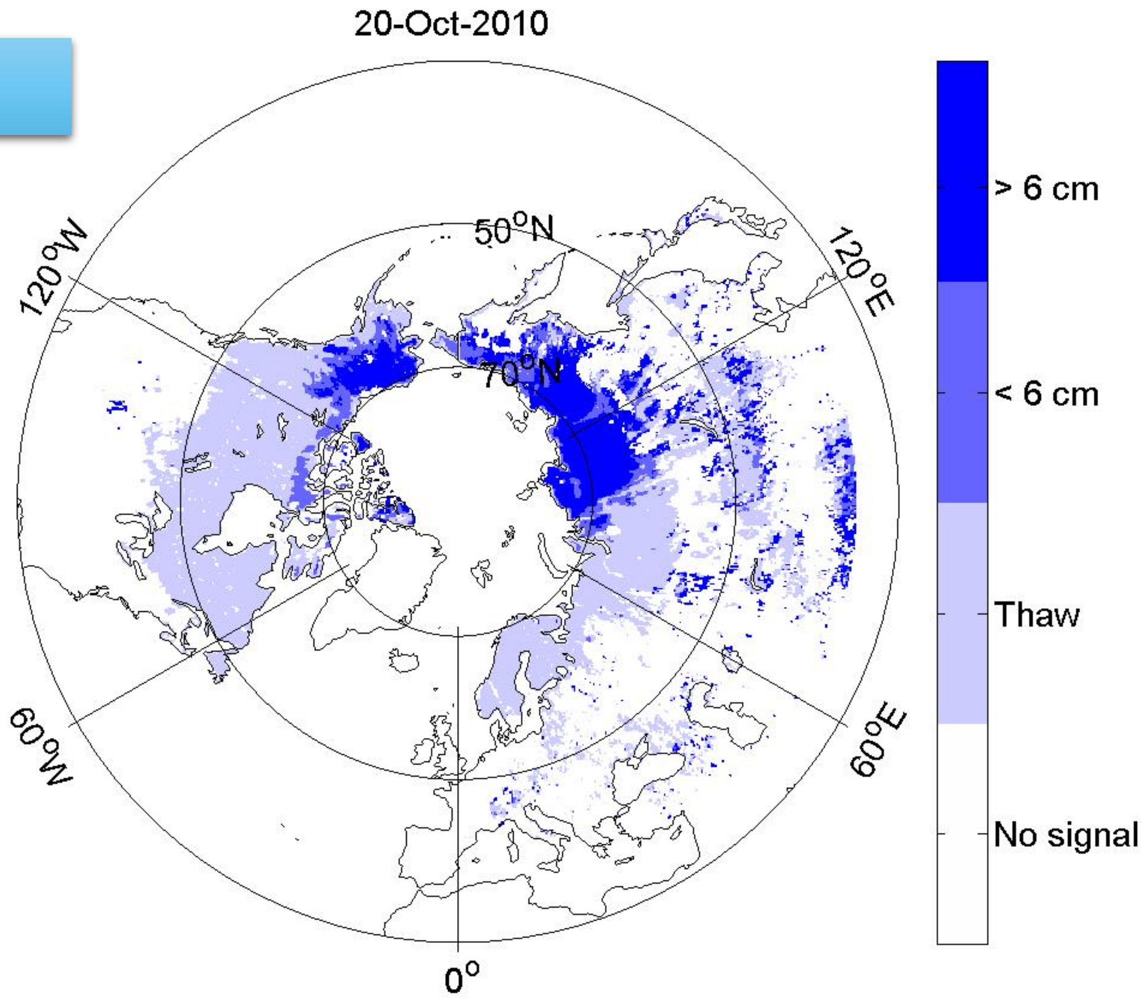
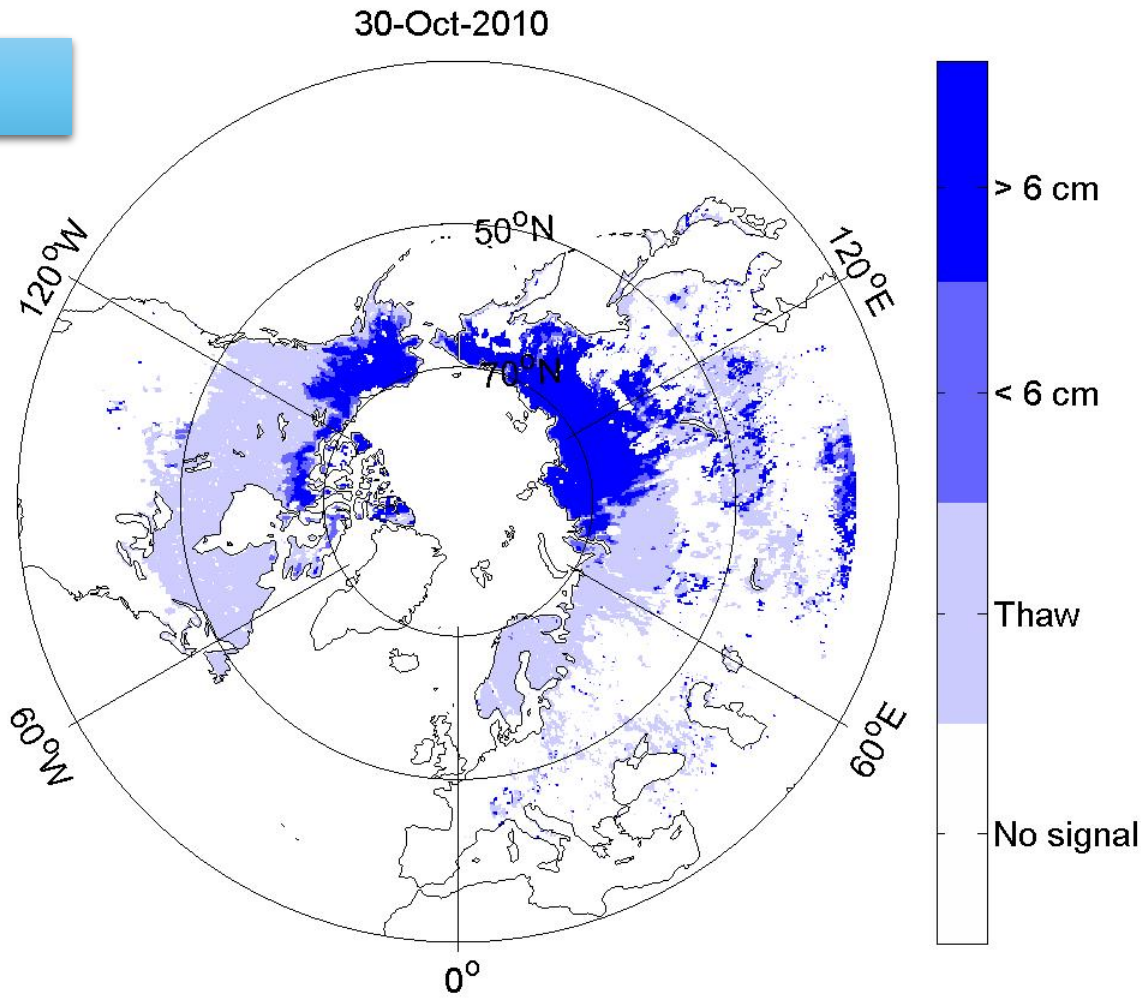
Frost maps for Northern Hemisphere

20-Oct-2010



Frost maps for Northern Hemisphere

30-Oct-2010



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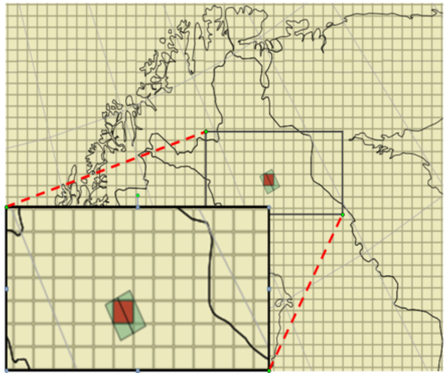
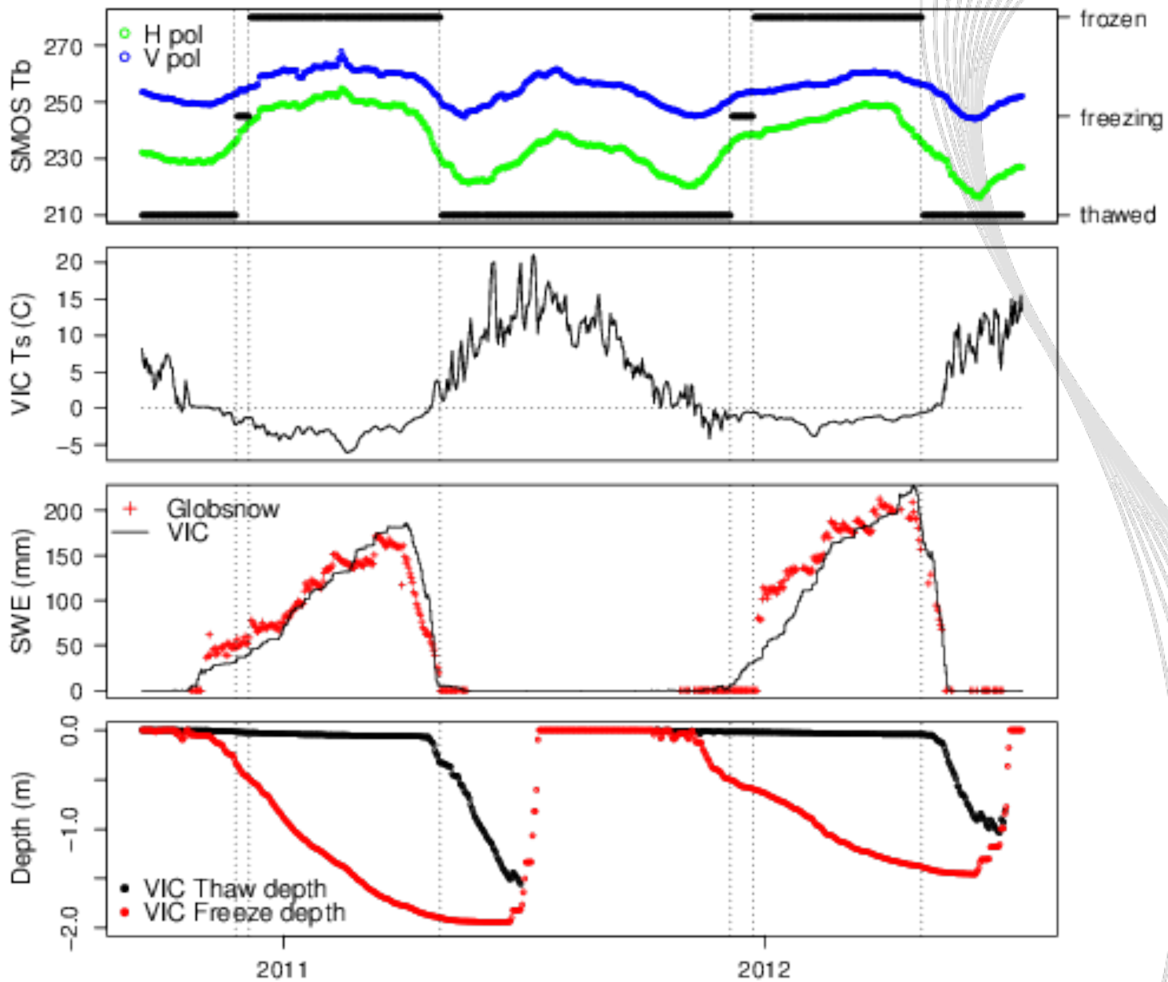
Potential for assimilation with LSMs



Location of the VIC distributed model domain (0.4 degrees) in reference to SMOS pixels in EASE grid projection



Top to bottom:

1. SMOS Tb and soil states estimates from SMOS data: Frozen, Freezing and Thawed
2. VIC soil temperatures (C)
3. VIC and GlobSnow SWE (mm)
4. VIC thawing and freezing depths.

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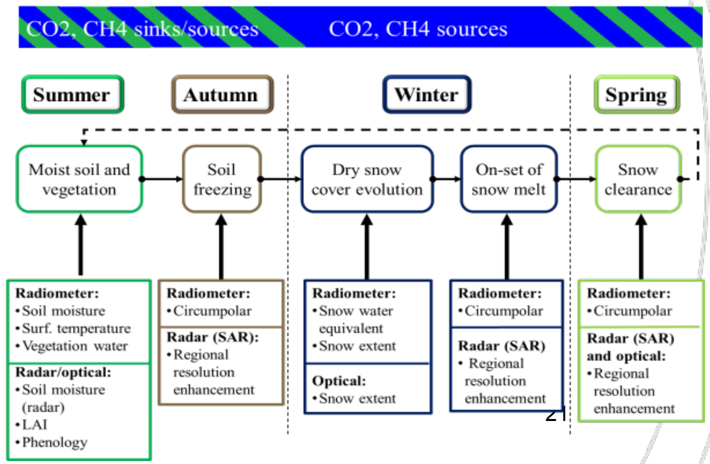
Way forward: Combined products to monitor the seasonal cycle of carbon exchange related phenomena

- Relevant microwave and optical satellite instruments/missions
  - SSMI/I, AMSR-E (2), SMOS, Envisat ASAR, TerraSAR-X, MODIS, AATSR, MERIS, Sentinel 1, Radarsat-1/2, Chinese FY-series …
  - Future missions: Sentinels 2 and 3, NASA SMAP
- Combination of snow, soil and vegetation products
  - Monitoring of all carbon relevant processes of the land cryosphere
- Combined use with *in situ* data and assimilation with models
  - Proxy indicators (developed with *in situ* data)
  - Use with LSM




Thank You for Your Attention!