FINNISH METEOROLOGICAL INSTITUTE

# Monitoring of soil freeze and thaw processes by L-band radiometry: implications for monitoring of methane stocks in Northern latitudes

ECMWF/ESA workshop on using low frequency passive microwave measurements in research and operational applications

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# Contents

1. SMOS based soil freeze/thaw product
   - Developed in FMI in co-operation with GAMMA remote sensing
   - Funded by European Space Agency (ESA) and Finnish national programs

2. First results on using F/T product for climate research
   - Relation between the soil freezing and methane emissions from wetlands
   - Work performed in FMI by T. Aalto, V. Kangasaho and A.Tsuruta

3. Way forward
   - From demonstrator product to operational product
   - Using F/T data as priori for CH4 inversion model

# Background and motivation

- Half of the Earth's land masses are affected by soil freezing
- Soil freezing has an effect on
  - surface energy balance, water flows, and exchange rates of carbon with the atmosphere
  - photosynthetic activity of plants and microbial activity within soils

- *With satellite observations it is possible to provide global and continuously updated information on soil state*

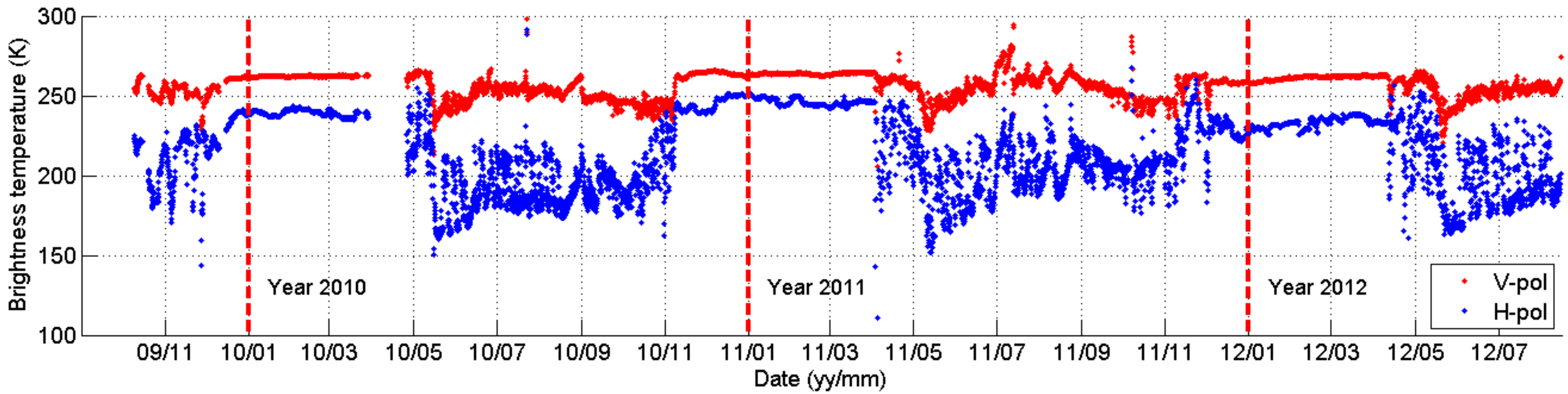
- Objective: to get direct measurements of the top surface layer => requires measurements at low microwave frequencies

# SMOS – Soil Moisture and Ocean Salinity

- ESA satellite mission, launched on November 2009.
- Passive microwave radiometer – operating at L-band (1.4 GHz, corresponding to a wavelength of 21 cm)
- Good global coverage – Earth covered in 3 days, high latitudes almost every day
- Moderate spatial resolution about 40 – 50 km

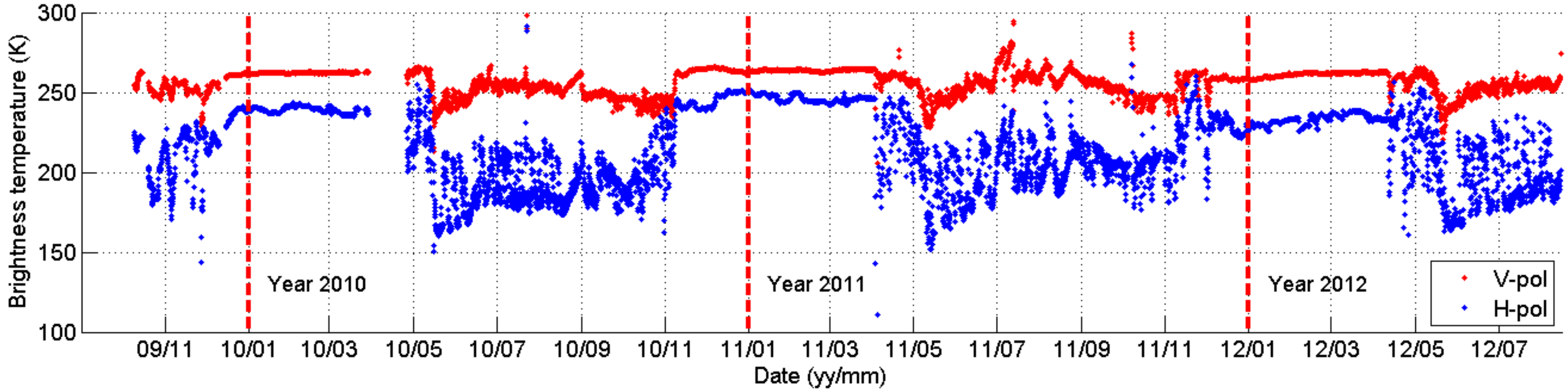
# Measurement basics

- Radiometer measures the emitted radiation of the target - the emitted power is mainly dependent on the permittivity of the target
- At L-band the permittivity difference between the free liquid water and bare soil is very large
  - As the soil freezes, the unbound water molecules decrease resulting to stronger emission
  - However, challenging on dry and rocky environment



# Measurement basics

- Relatively long wavelength enables gathering information beneath the soil surface (effective layer thickness about 10-20 cm)
- Also less affected by the vegetation and snow layer (compared to higher frequency instruments)
- However, limited spatial resolution



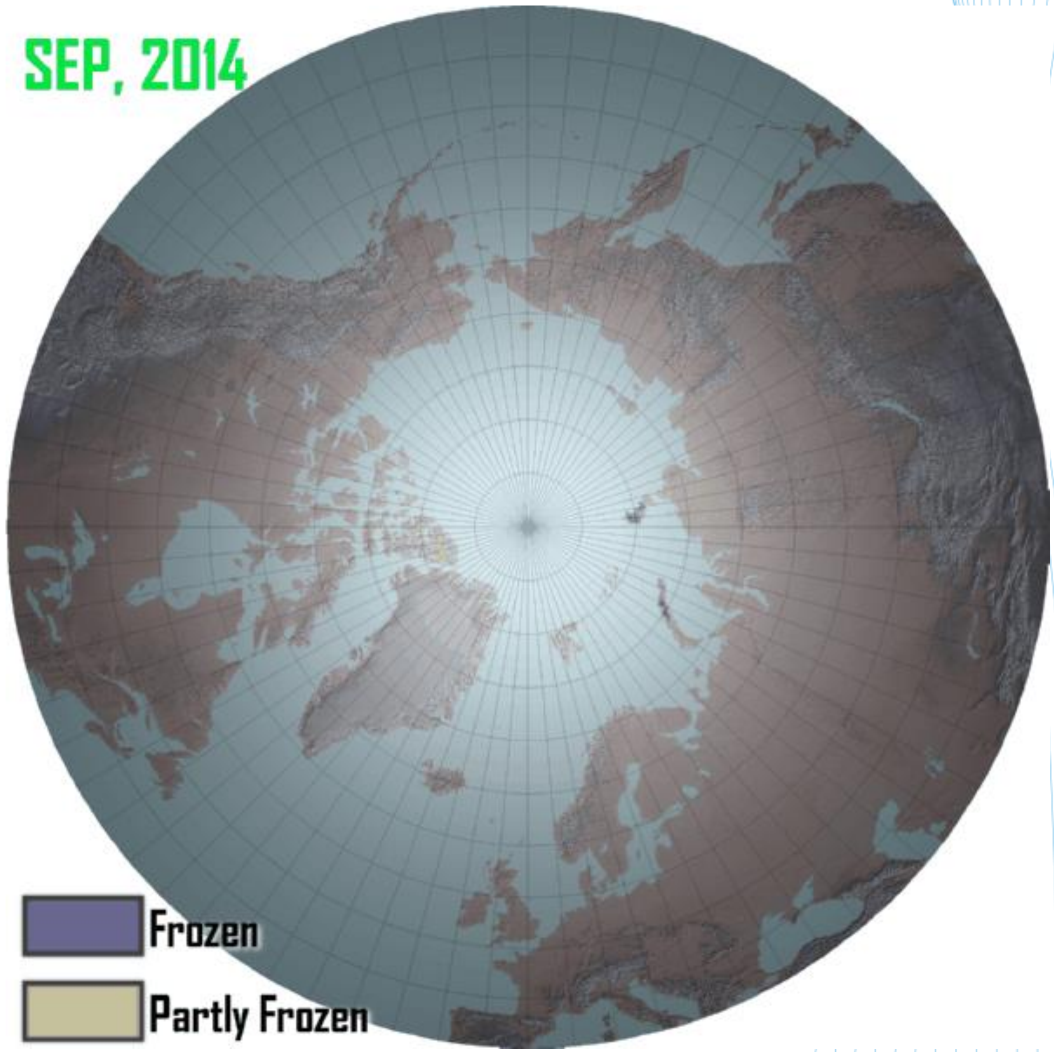
# Freeze/Thaw algorithm shortly

- *Based on threshold detection approach*

- Empirically defined reference signatures for frozen and thawed states (pixel-wise)
- Soil state is categorized based on predefined thresholds to three categories: “frozen, “partially frozen”, or “thaw”
- Obvious errors are removed using ancillary data:
  - ECMWF 2m air temperature (re-analysis)
  - Daily snow cover data

# F/T Product

- Coverage: Northern Hemisphere
- Spatial resolution: 25x25km (EASE grid)
- Three levels: ”frozen”, ”partially frozen”, ”thaw”
- Current dataset time period: 2010 - 2017 => operational product under development



# Product validation

- Challenging validation
  - *In situ* observations: huge spatial scale difference, data only from discrete locations and depths
  - Global models

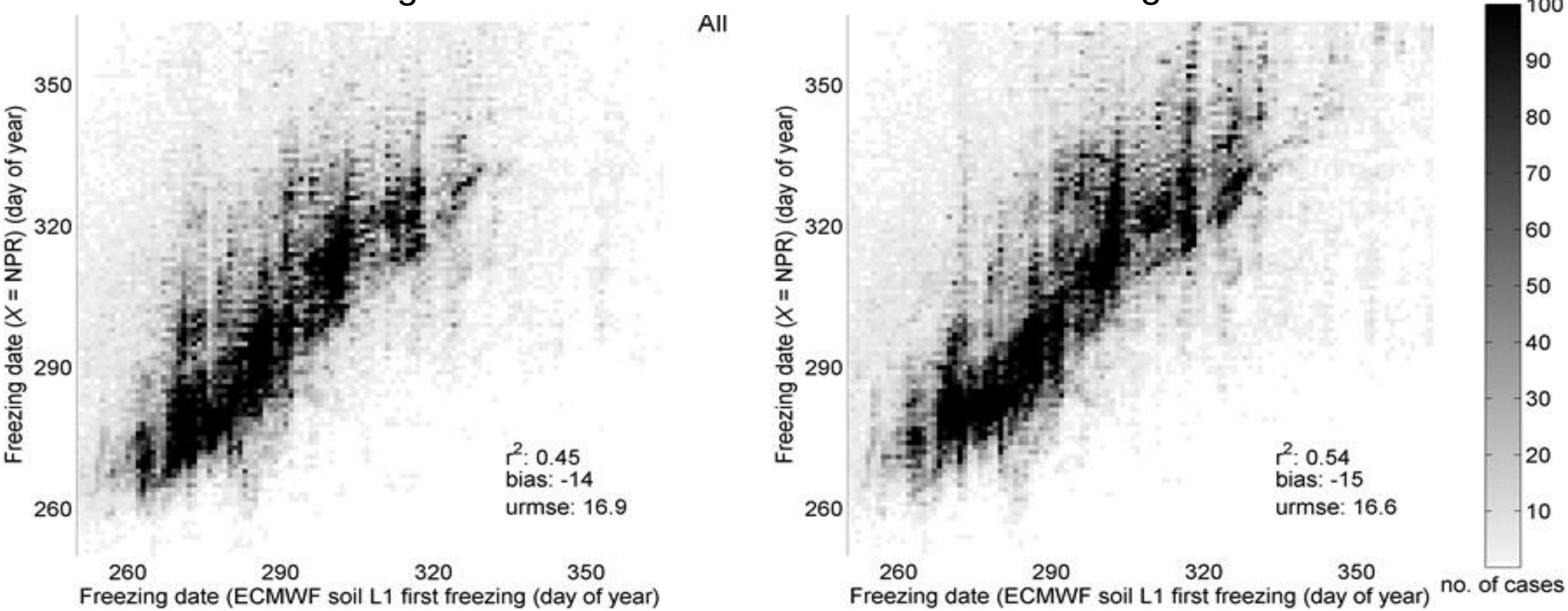
- Global comparison data: ECMWF re-analysis data (soil temperature, 0-7 cm)

- *In situ* data from various locations in Finland, Siberia, Canada and Alaska (soil temperature at 5 cm depth)

# Global comparison with model data

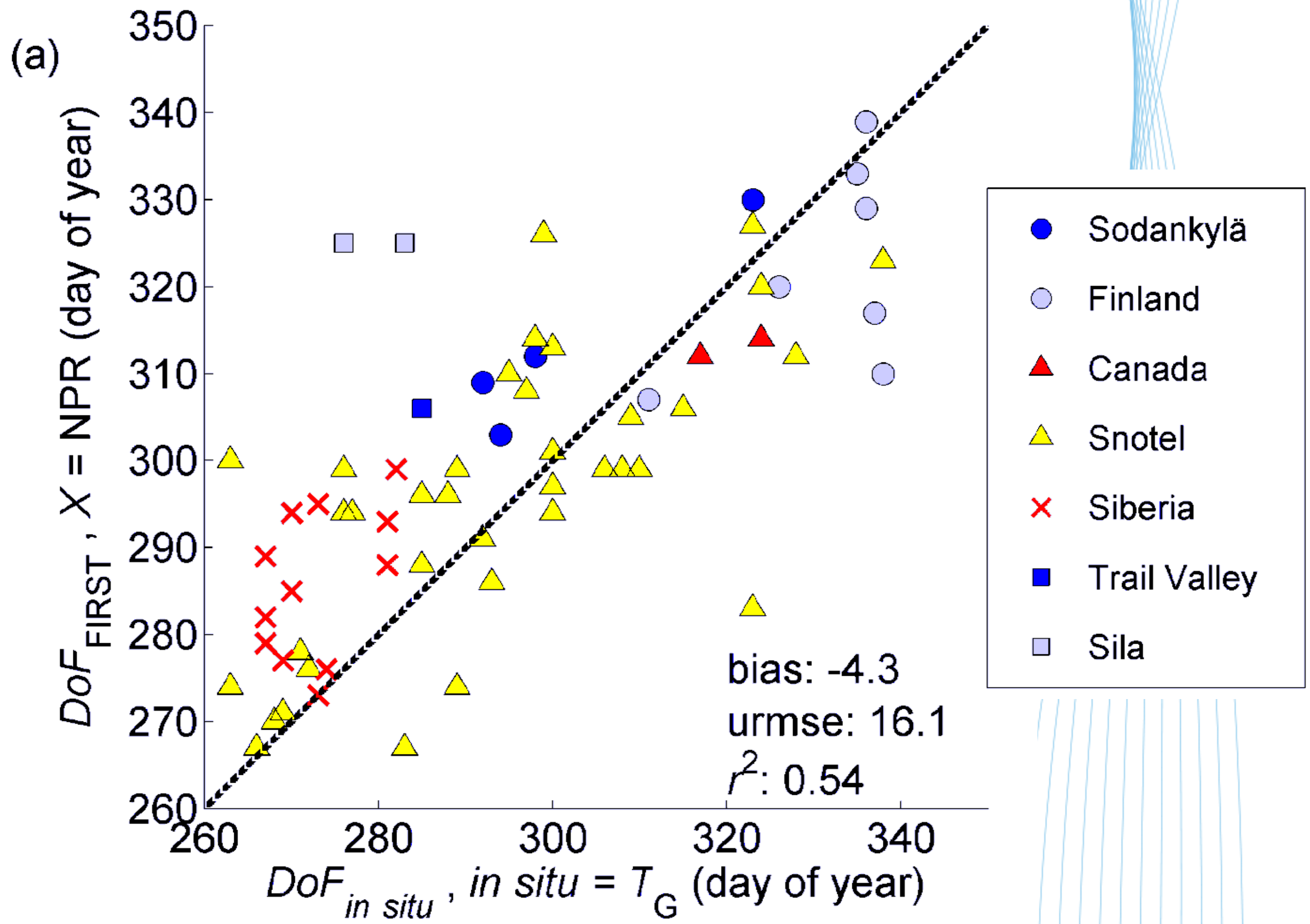
- F/T product vs ECMWF soil temperature data (0-7 cm)
- Day of freezing compared

ascending orbits | descending orbits



# SMOS FT vs *in situ* data – day of freezing

- Day of freezing compared (2010 – 2015)
- *In situ* data: soil temperature at depth of 5 cm



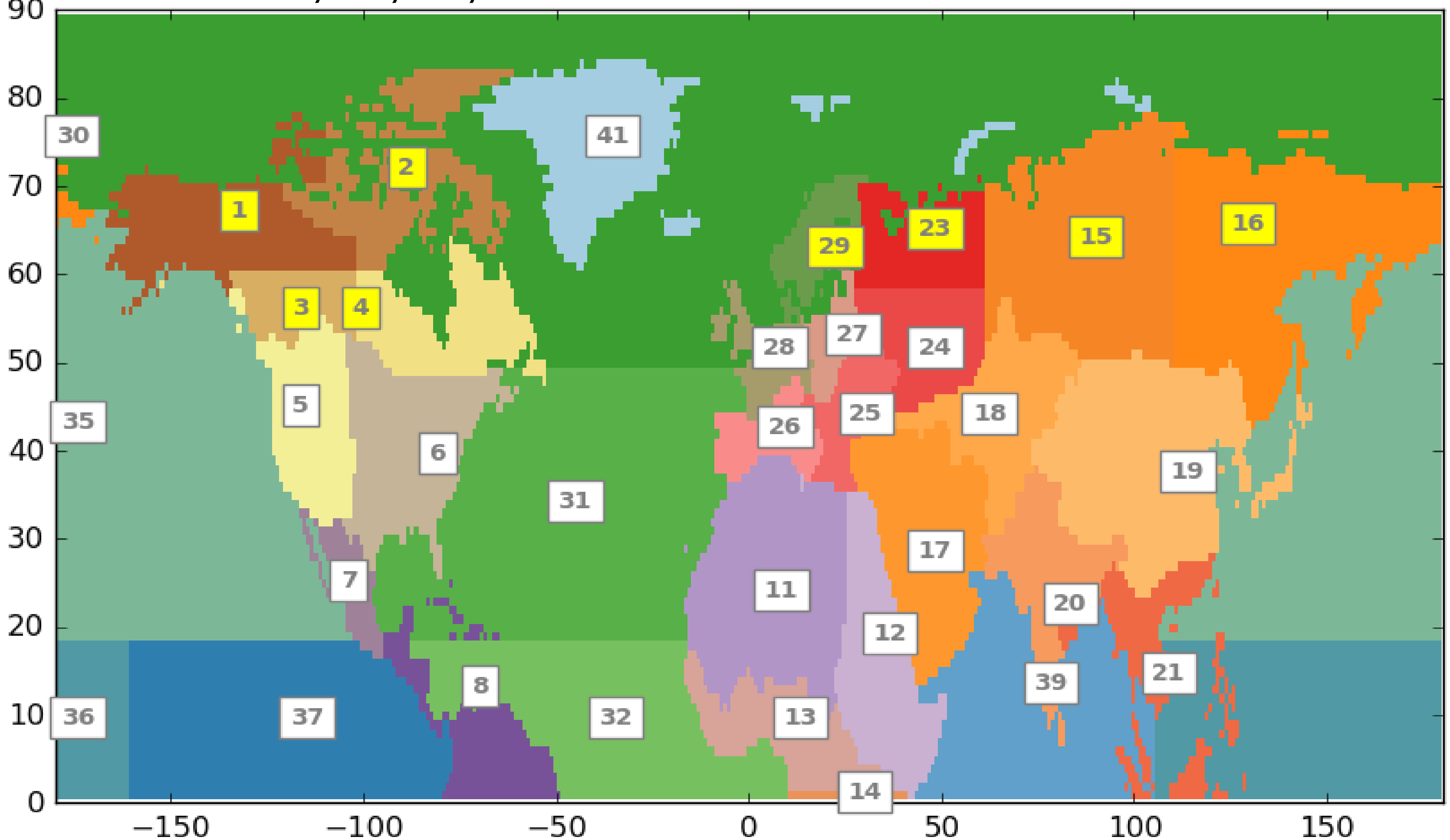
# Case study: Methane budgets in northern latitudes during soil freezing period

- Work done by T. Aalto et al.
- Objective: Study the methane emissions during the soil freezing period

- CarbonTracker Europe – CH4 (CTE–CH4) inversion model for estimating methane fluxes
- SMOS F/T data for soil freezing and thawing
- Freezing period: Start: frozen soil cover exceeds 1% in studied region and temperature is below 275.15 K. End: frozen soil cover exceeds 80%
- ERA-Interim for meteorological data

# Areas for research

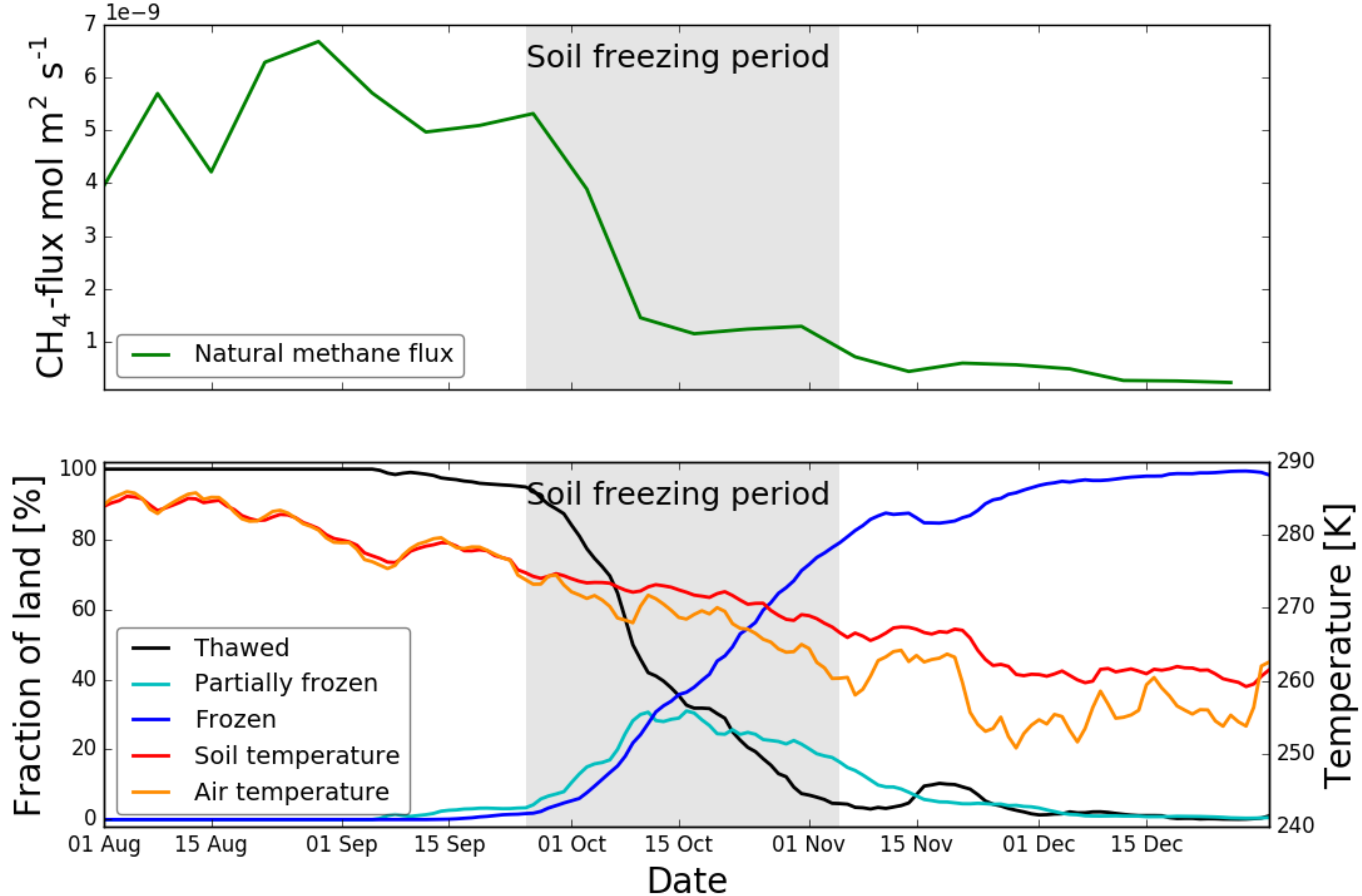
- North-America 1-4
- Eurasia 15,16,23,29



# Results

- Modelled $CH_4$ emission (above) and defined soil freezing period (shaded) for area 1 (2014)
- Methane emissions tend to approach zero when soil is finally frozen

Modelled $CH_4$ emission



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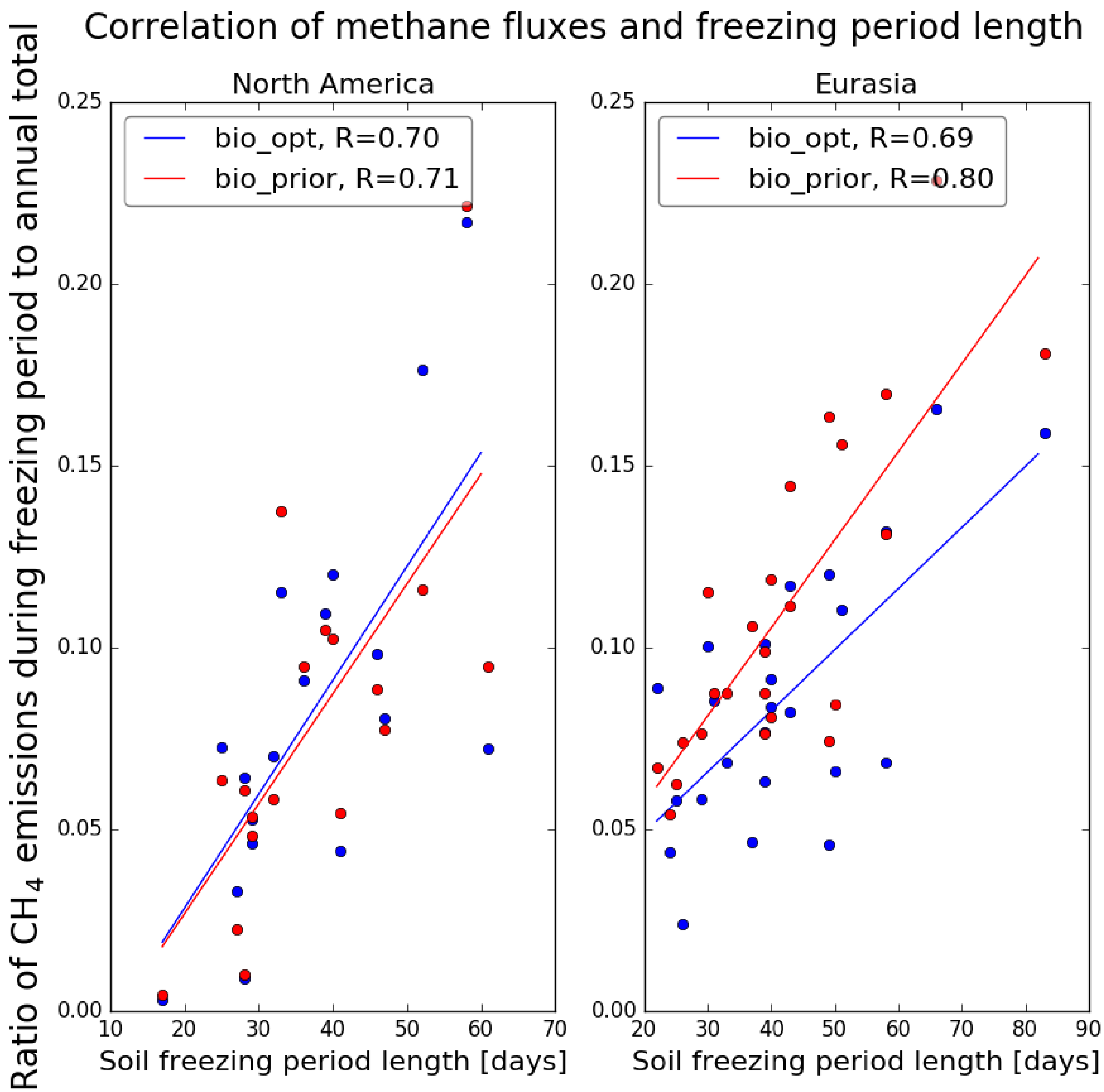
# Results

- Length of freezing period (transition from thawed to frozen), detected from SMOS, correlates with freezing period CH4 emissions



# Way forward – operational product

- F/T product currently covers a time period from June 2010 onwards
- An operational product is under development – Estimated to be available in early 2018
- Product will be further developed to better take into account
  - Dry snow cover during freezing period (Schwank et al., 2015; Lemmetyinen et al., 2016)
  - Melting snow during spring period.
  - Pixel heterogeneity - land classification and vegetation cover as well as soil type
  - Improved use of SMOS multi-angular observations
- Comparison studies to other F/T products: SMAP, ESDR-FT, ASCAT F/T flag

# Way forward – using F/T data with CH4 inversion models

- Study idea: investigate Northern Hemisphere methane sources
- Atmospheric inversion model Carbon Tracker Europe (CTE),
  - Developed in NOAA/ESRL and University of Wageningen for carbon dioxide)
  - Further developed by Finnish Meteorological Institute for methane flux estimations.
  - The CTE-CH4 model assimilates atmospheric CH4 concentration observations, (in situ sites and/or CH4 column retrievals)
- Soil F/T data will be utilised in building the prior estimates for the biospheric fluxes
  - An additional constraint to the prior wetland emissions retrieved from ecosystem model.

# CryoRad

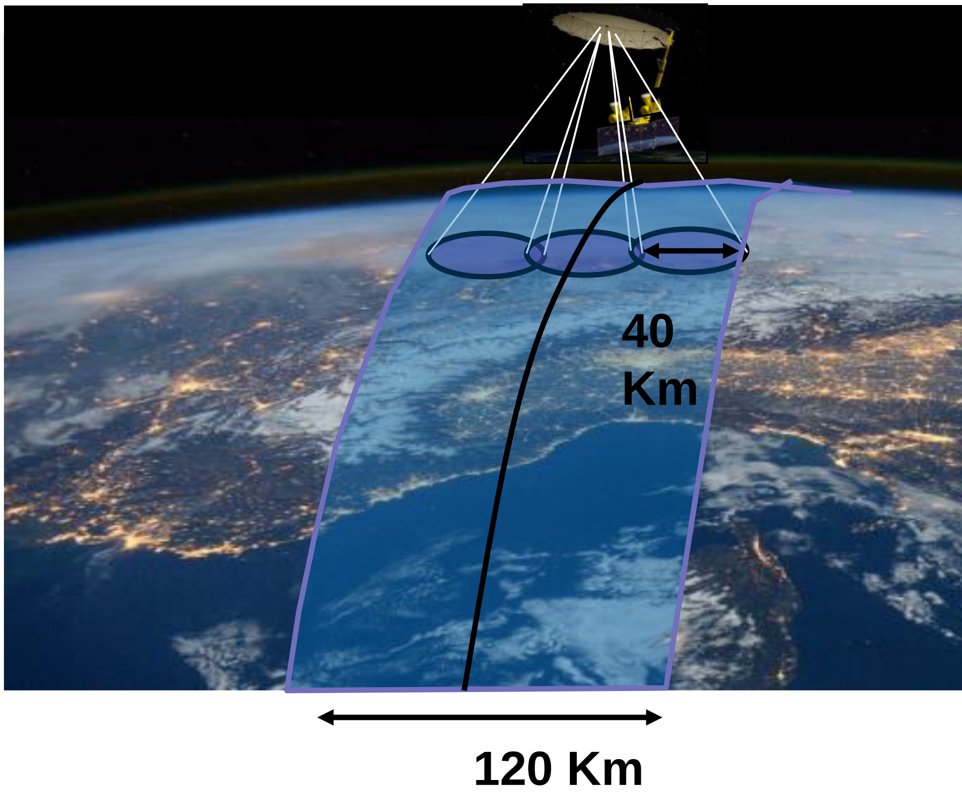
## *A Low frequency wideband radiometer mission for the study of the cryosphere*

***Giovanni Macelloni***, *Marco Brogioni, Francesco Montomoli, Marion Leduc-Leballeur, Giacomo De Carolis, Francesca De Santis, Silvio Varchetta, Lars Kaleschke, Joel Johnson, Kenneth Jezek*

IFAC ifac THE OHIO STATE UNIVERSITY Universität Hamburg DER FORSCHUNG I DER LEHRE I DER BILDUNG ThalesAlenia Space A Thales / Finmeccanica Company

# CryoRad: A Low frequency wideband radiometer mission for the study of the cryosphere

Develop a space mission concept for the monitoring of cryosphere processes with an innovative payload: **a multi-channel microwave radiometer observing in the range 400 MHz – 2 GHz.**




**<u>Main parameters to be investigated</u> :**

- **-sea ice thickness in the range 0-2 m**
- **-sea surface salinity**
- **-soil freeze /thaw state**
- **-ice sheet temperature 0-4000 m**
- **-ice sheet aquifers (water )**
- **-ice shelves stability**

**The concept will be proposed for EE10 and is in Decadal Survey**

# Conclusions

- Soil F/T algorithm based on SMOS satellite observations has been developed
- F/T algorithm performs well; the estimation of soil freezing agrees well with *in situ* observations and ECMWF data

➢ **Passive L-band observations are extremely useful for observations of soil freeze/thaw transitions**.

- Current L-band missions: SMOS (2010=>) and SMAP (2015=>)
    - Continuation ??

Thank you for your attention!

*Rautiainen, K., Parkkinen, T., Lemmetyinen, J., Schwank, M., Wiesmann, A., Ikonen. J., Derksen, C., Davydov, S., Davydova, A., Boike, J., Langer, M., Drusch, M., Pulliainen, J., (2016) SMOS prototype algorithm for detecting autumn soil freezing, Remote Sensing of Environment, 180, pp.346–360.*