Observation Operators for sea ice thickness to L-band brightness temperatures

F. Richter, M. Drusch, L. Kaleschke, N. Maass, X. Tian-Kunze, G. Heygster, S. Mecklenburg, T. Casal, and many others

ESA, ESTEC

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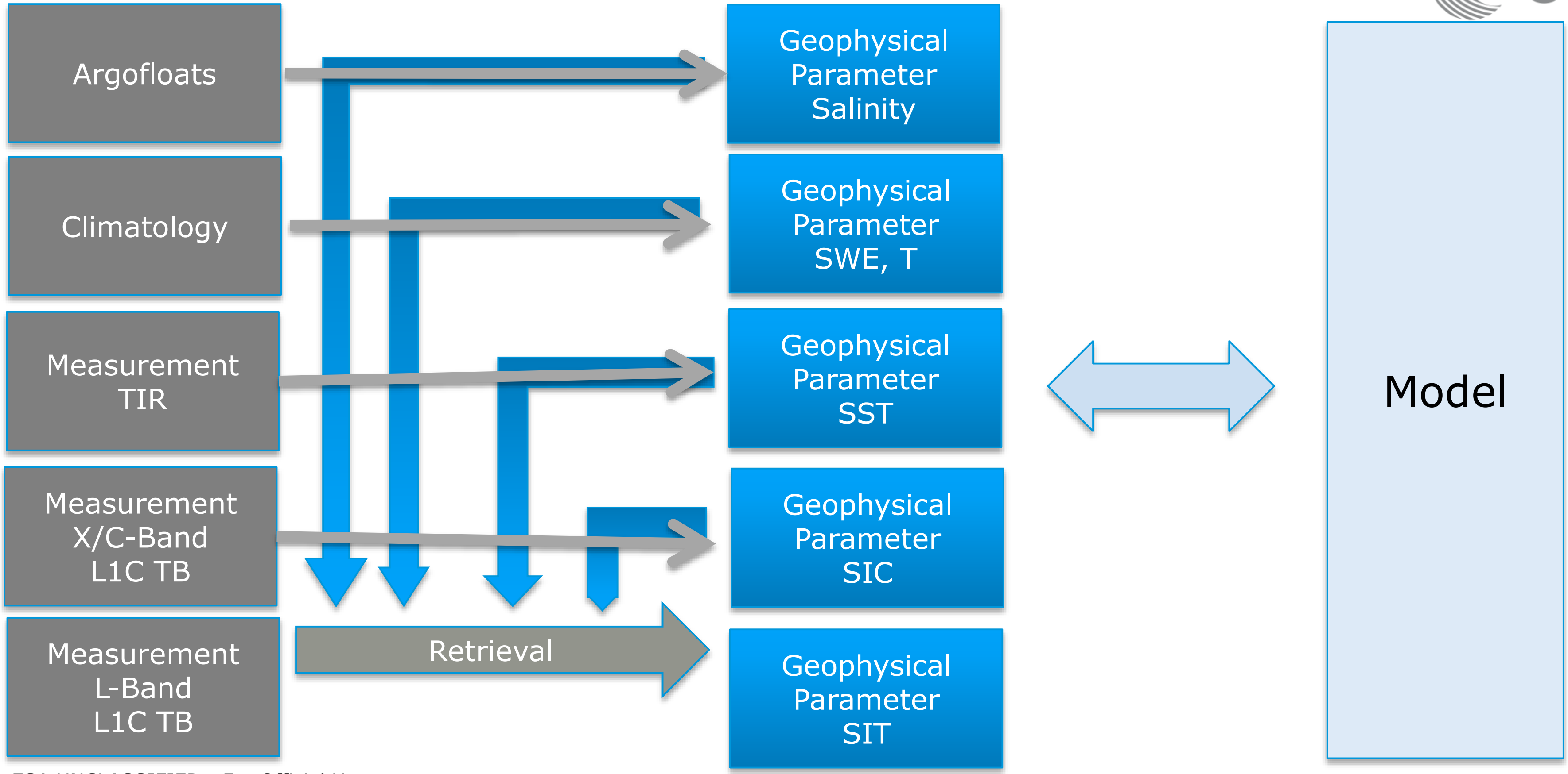
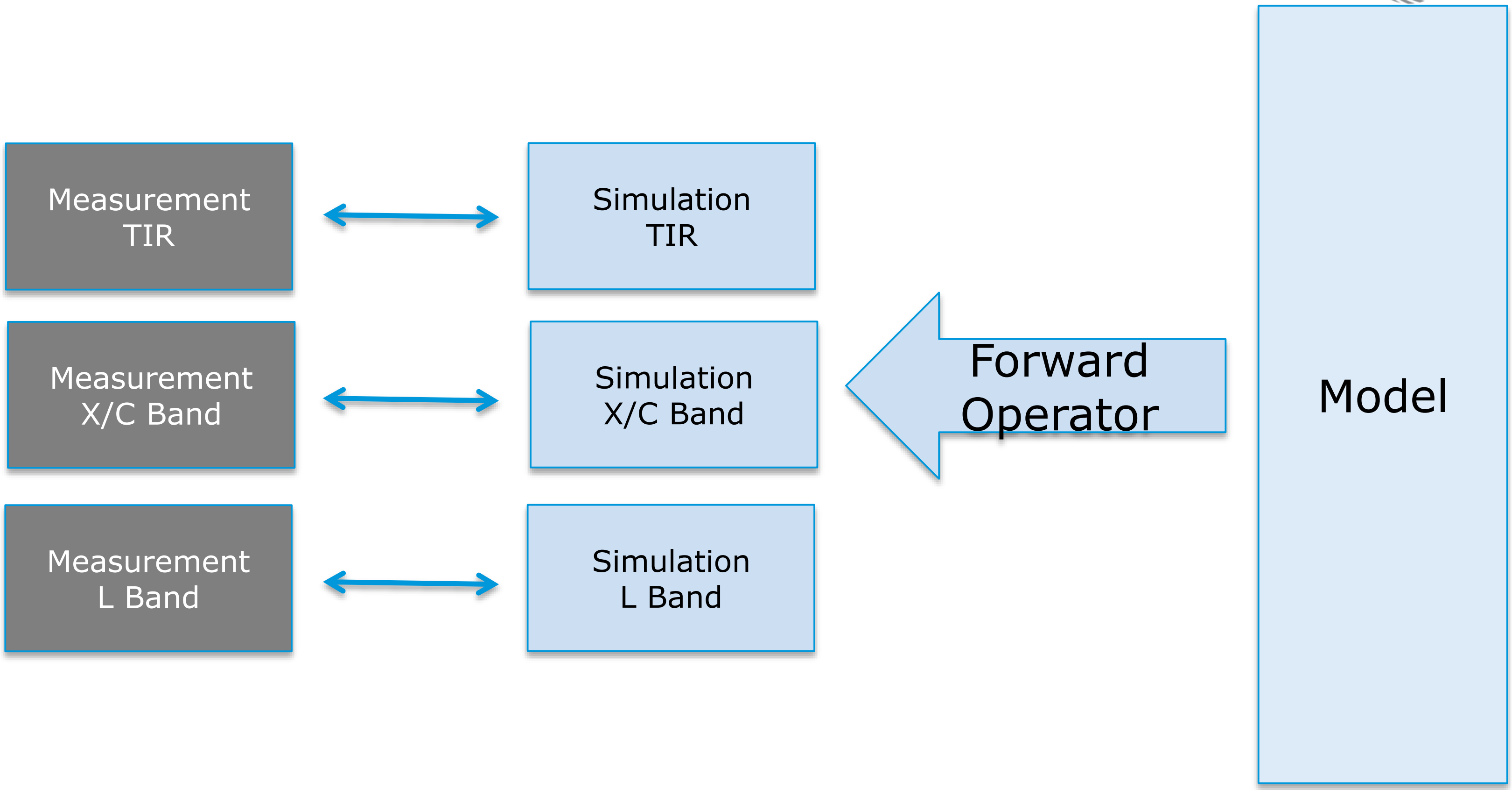
Motivation I



Motivation II



Summary I

- **Geophysical products are needed.**
- Assimilating L1 (measurements) or L2/3/4 (derived geophys. parameters):
  - ➢ The physics of the problem remain the same.
  - ➢ We have to quantify the same errors.
  - ➢ The same expertise / resources are needed.

Observation Error:

- Instrument
- Processor L0 to L1
- (Retrieval algorithm)
- (Aux Data Sets)

Representativity mismatch:

- Spatial support
- Vertical support
- Temporal sampling
- …

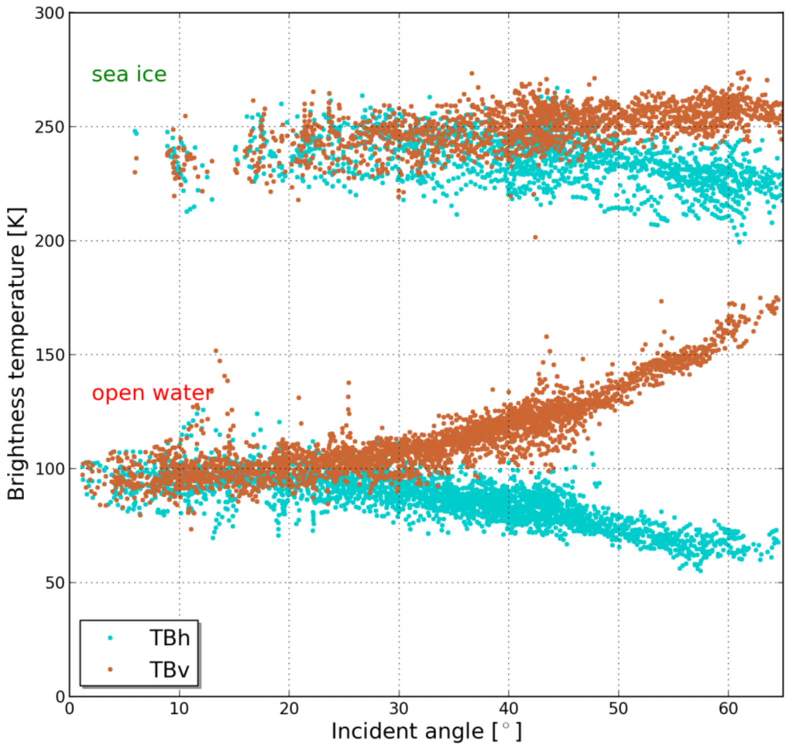
Model Error:

- Initial conditions
- Model physics
- Boundary conditions
- (Observation Operator)

Benefits of assimilating measurements (= L1b/c)

- Consistent input data to the observation operator; better knowledge of uncertainties and error correlations in aux data fields.
- Better knowledge of observation errors with full traceability to instrument errors;
- Observation errors between different instruments remain uncorrelated;
- Possibility to correct biases consistently against a common reference;
- Better control on the representativity error;
- Observations are used only once;
- Information about sensitivities (Jacobians);
- Consistent QC in observation space;
- Consistent use of "independent" in-situ data;
- Full potential to support the design of future observation systems;
- ...

SMOS observations



THE MISSION

Launch - 2 November 2009

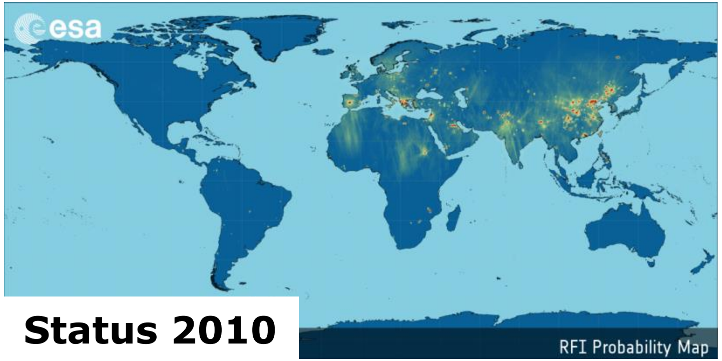
Orbit - ~ altitude of 758 km; inclination of 98.44°; low-Earth orbit, polar, sun-synchronous, quasi-circular, dusk-dawn (6am/6pm), 23-day repeat cycle, 3-day sub-cycle

THE PAYLOAD

MIRAS, the Microwave Imaging Radiometer using Aperture Synthesis instrument, is a passive microwave 2-D interferometric radiometer measuring in L-Band (1.4GHz, 21cm); 69 antennas are equally distributed over the 3 arms and the central structure.

SMOS – Current Status

- ✓ After ~ 8 years in orbit SMOS is in **excellent technical conditions.**
- ✓ **Guaranteed mission operations until 2019/2021** (current funding horizon), pending extension review in 2018 – no technical limits to operate mission beyond 2019
- ✓ **Platform and instrument in good health**
- ✓ **High data availability ~99%**
- ✓ Data products up to level 2 generated continuously, including data products (L1 brightness temp, L2 soil moisture) in near-real time (NRT).
- ✓ **RFI contamination worldwide much reduced** (but still present in middle East and Asia): ~75% of known sources do not operate anymore in the protected band.



Status 2010

Status 2017

SMOS Data Products over land, ocean and sea ice

Operational/ Near-Real-Time (NRT) / Latency < 3 hours

- ✓ Light: Level 1 brightness temperature (land only, N256 Gaussian grid, angular binning, BUFR)
- ✓ Level 2 soil moisture based on Neural Network (NETCDF)

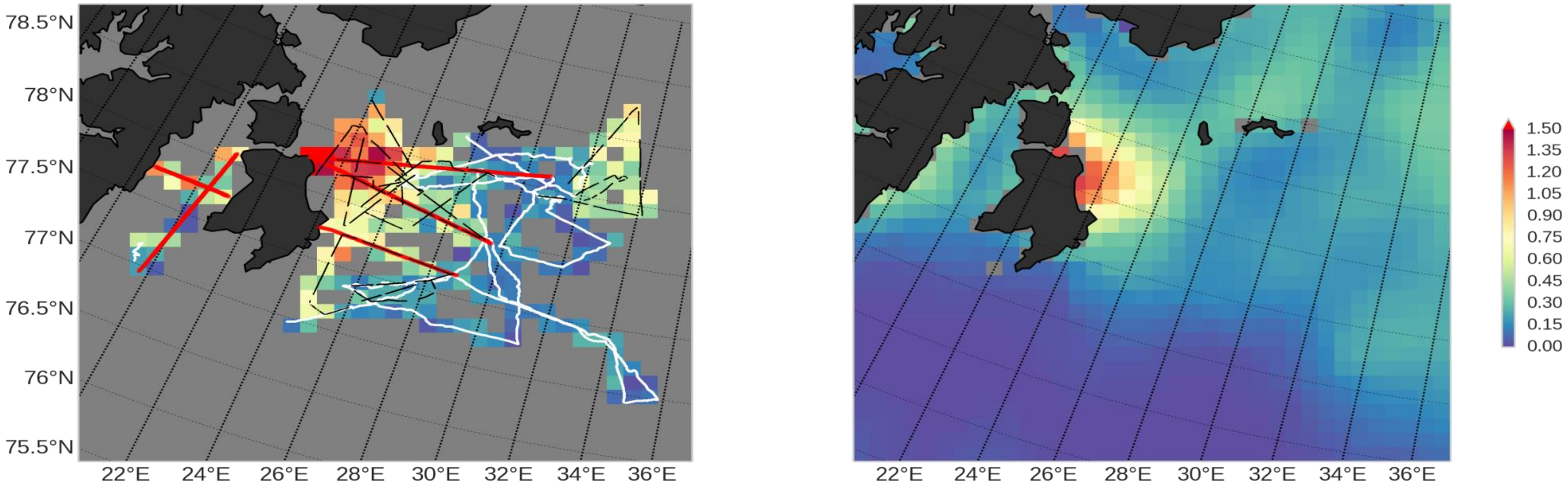
Science and composite products / Latency > 3 hours

- ✓ Level 1 brightness temperature
- ✓ Level 2 soil moisture, vegetation optical depth, sea surface salinity
- ✓ Level 3 brightness temperature, soil moisture, vegetation optical depth, sea surface salinity
- ✓ Level 4 fine-scale soil moisture **(1 km)**
- ✓ Level 4 Root Zone Soil Moisture
- ✓ Level 4 sea surface salinity (merged with in-situ)
- ✓ Sea surface salinity in Arctic and Mediterranean Sea **(25km)**
- ✓ Agricultural drought index **(25 km)**
- ✓ Freeze and thaw **(25 km)**
- ✓ Severe wind speed
- ✓ Sea ice thickness: SMOS based and SMOS+CryoSat

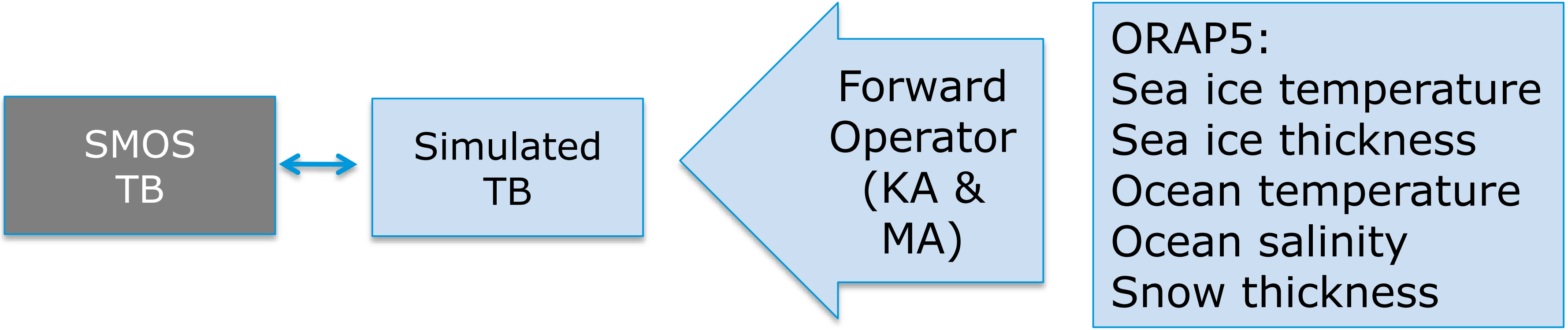
Spatial resolution 35-50km, sampling 15 km grid – unless otherwise stated

Format: L1 NRT = BUFR, L1/L2 = EEF/NETCDF, L3/L4 = NETCDF

SMOS based sea ice thickness – Validation experiment, March 2014

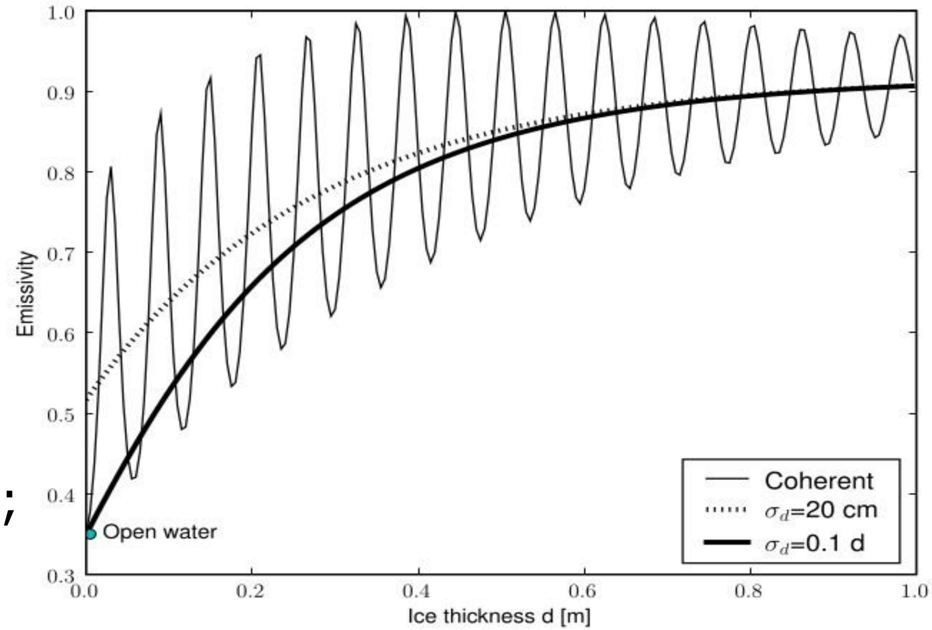


Experimental Set-up



Radiative Transfer I – Kaleschke & Tian-Kunze

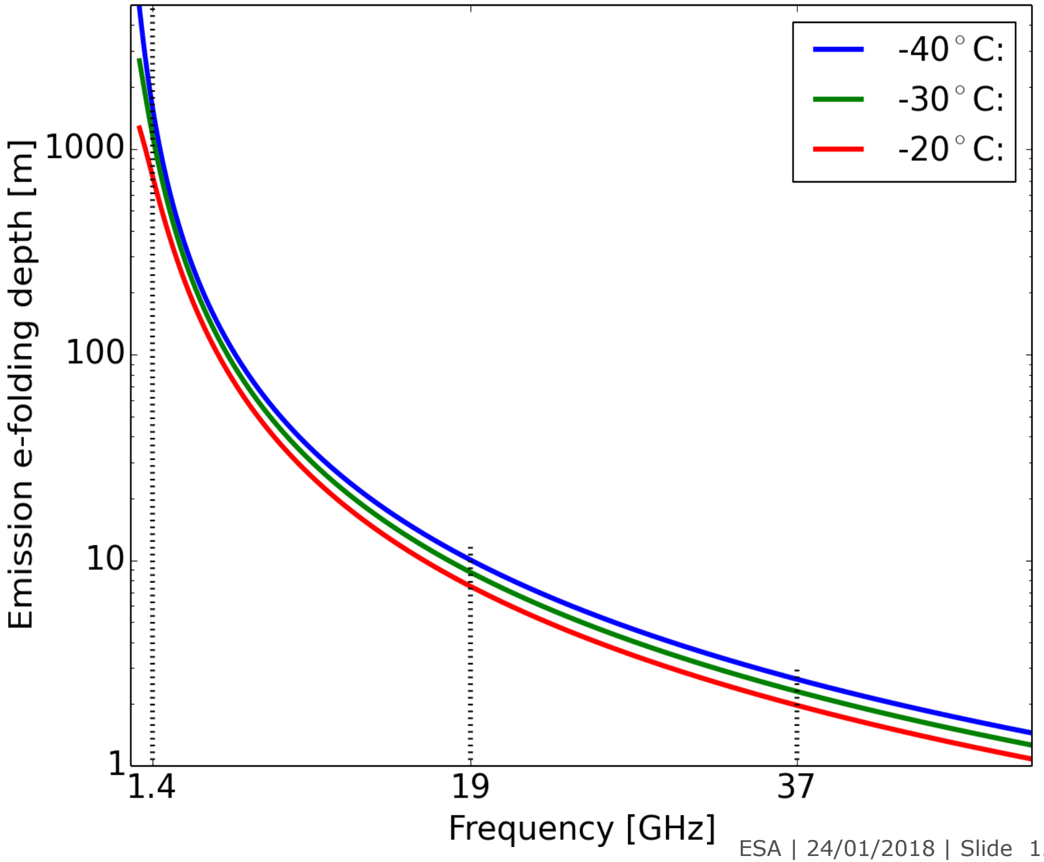
- Menashi et al. (1993) derived emissivity for dielectric slab with thickness variability
- Converges to open water for d → 0
- Used in operational SMOS sea ice thickness retrieval
- Permittivity parameterized as function of relative brine volume Vb Vant et al. (1978); Kaleschke et al. (2010)
- Thermal effect of snow layer is considered



Advantage of L-band radiometry for the cryosphere

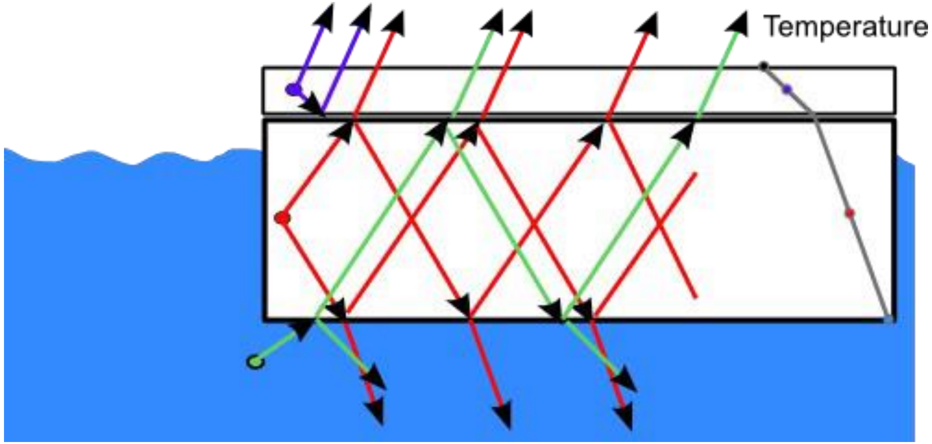
Ice is a very low-loss medium with a minimum of absorption at 1 GHz

- Absorption/emission increases with increasing temperatures and concentration of impurities (e.g. salt ions in sea ice)
- SMOS measures the emission from very deep ice sheet layers
- Retrieval of cryospheric parameters

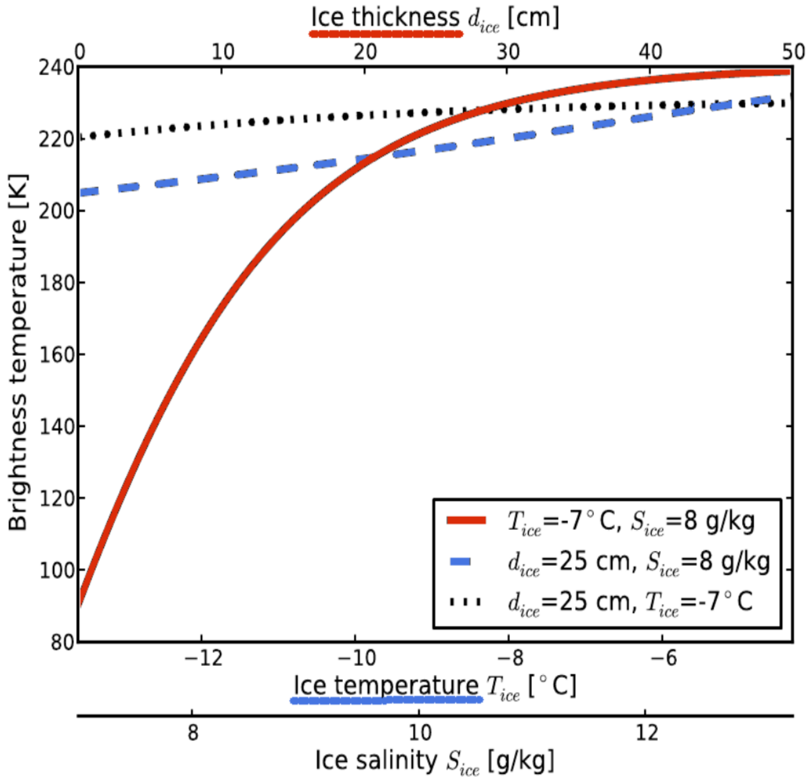


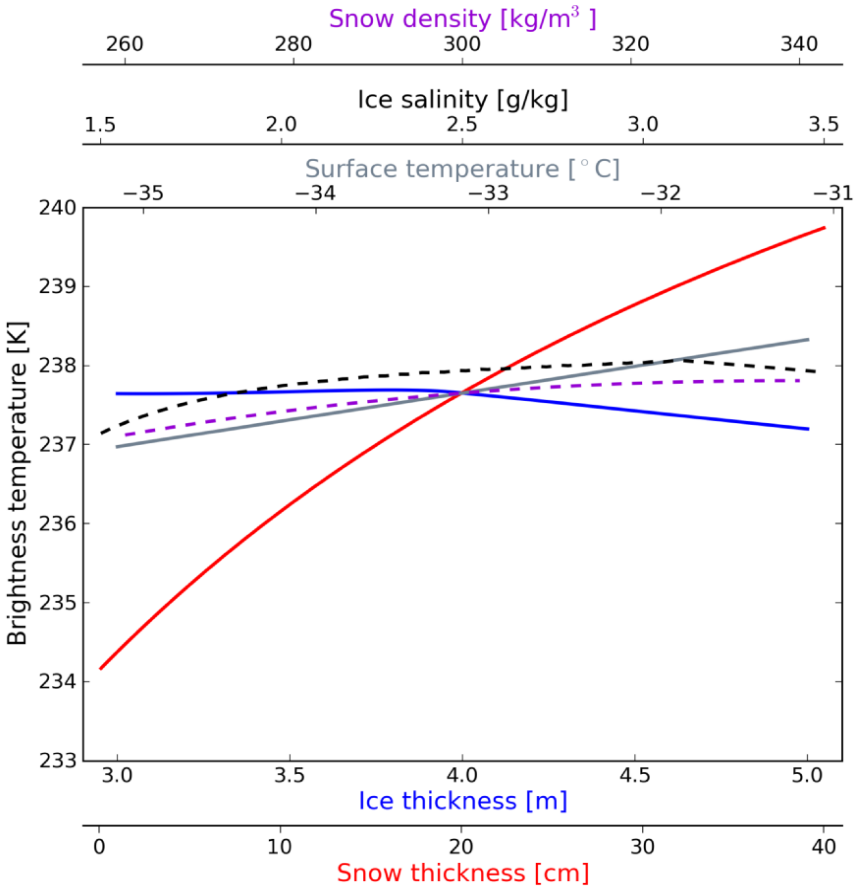
Radiative Transfer II - Maass

- Radiation model for layered media after Burke et al. (1979)
- Modified to account for multiple reflection (by Nina Maa.)
- Same results as MEMLS 2-stream model version by Mike Schwank



TB model sensitivities at 1.4 GHz





Kaleschke, L., X. Tian-Kunze, N. Maaß, M. Mäkynen, and M. Drusch (2012), Sea ice thickness retrieval from SMOS brightness temperatures during the Arctic freeze-up period, Geophys. Res. Lett., doi:10.1029/2012GL050916

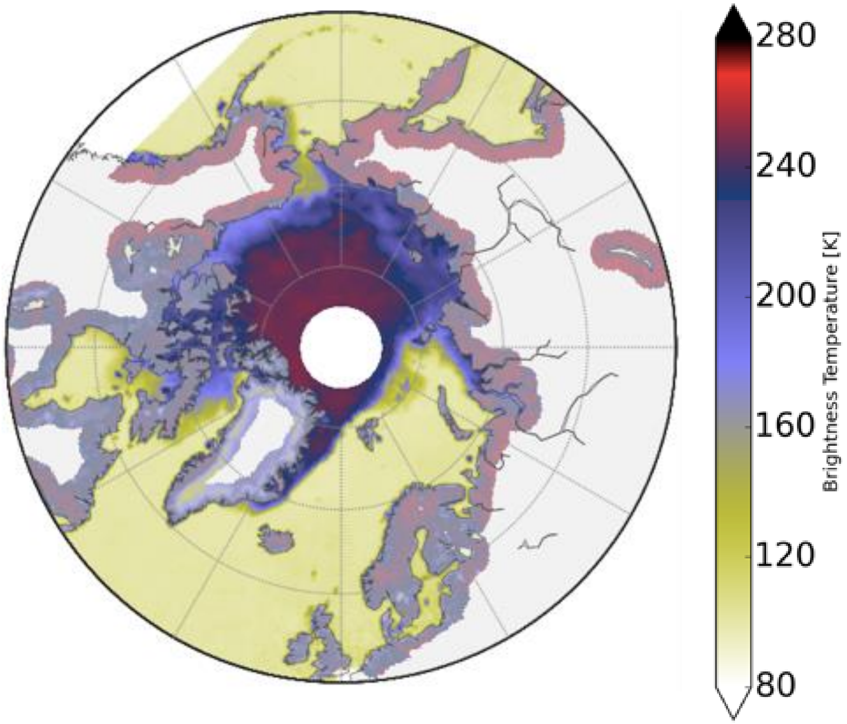
Maaß, N., Kaleschke, L., Tian-Kunze, X., and Drusch, M.: Snow thickness retrieval over thick Arctic sea ice using SMOS satellite data, The Cryosphere, 7, 1971-1989, doi:10.5194/tc-7-1971-2013, 2013.

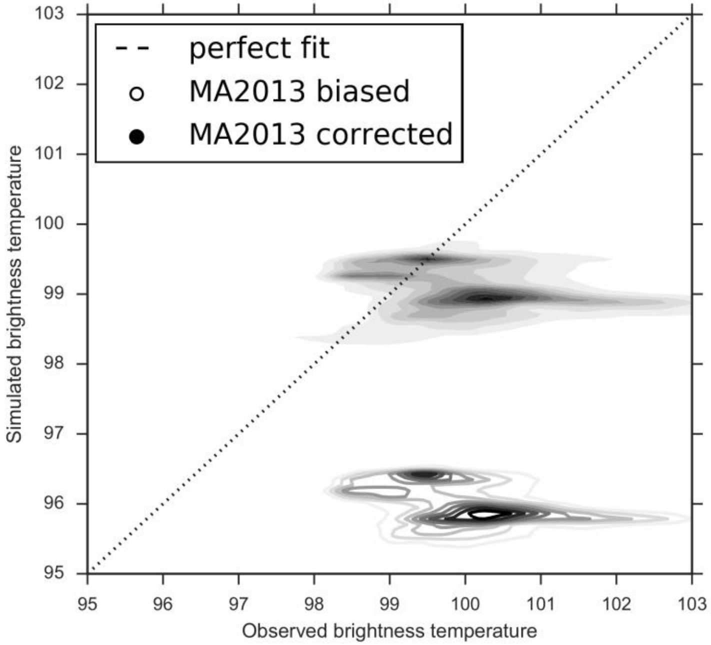
ORAP

- ORAP5 (Ocean ReAnalysis Pilot 5)
- Global ocean reanalysis product by ECMWF
- NEMO v.3.4 ocean model with ORCA **1/4° horizontal resolution**
- uses **dynamic-thermodynamic** sea ice model LIM2
- already assimilated: subsurface temperature, salinity, **sea ice concentration**, sea level anomalies
- Atmospheric surface forcing: ERA-Interim

TB Open Water correction

SMOS TB November 20112

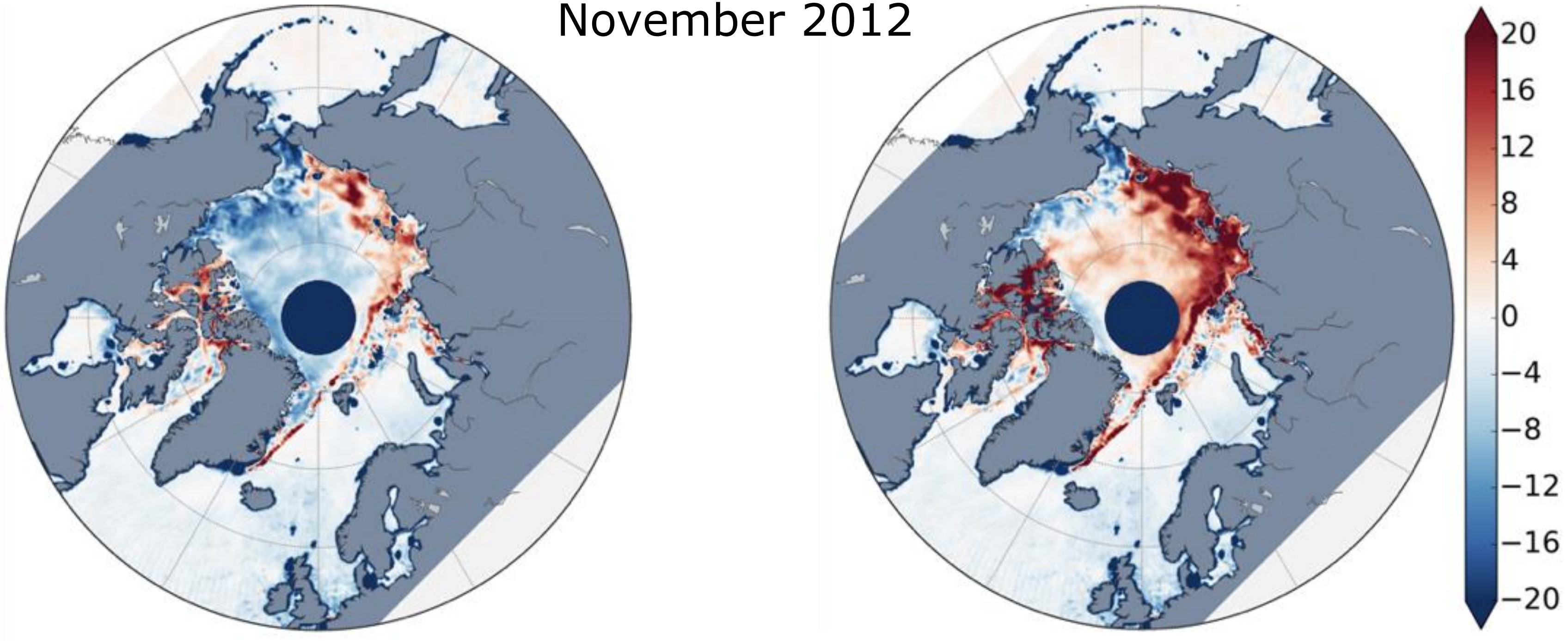




Modeled water TBs are corrected by ~3.1 K.

TB Model - Observation

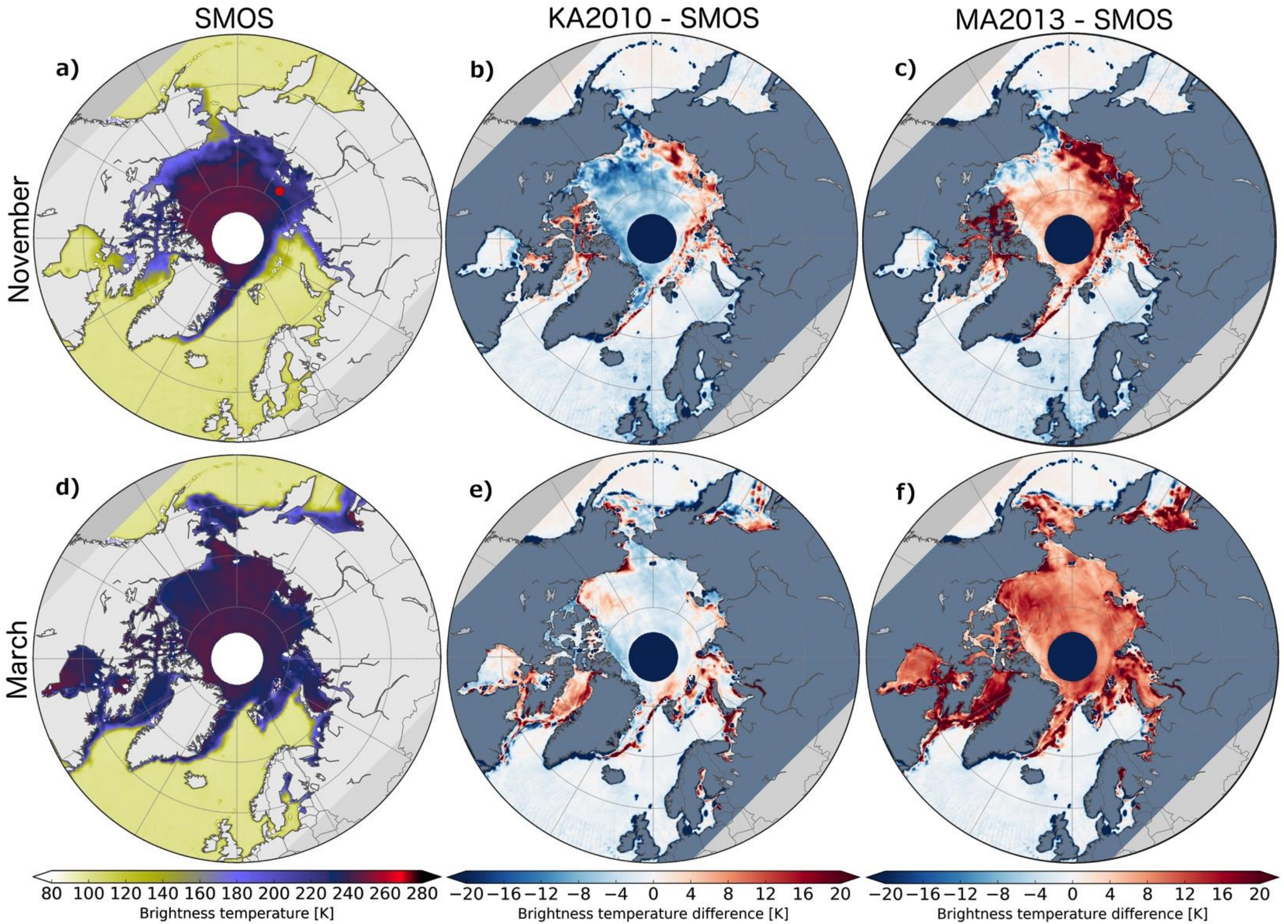
November 2012



STD_{KA} = 13.5 K

STD_{Maass} = 15.3 K

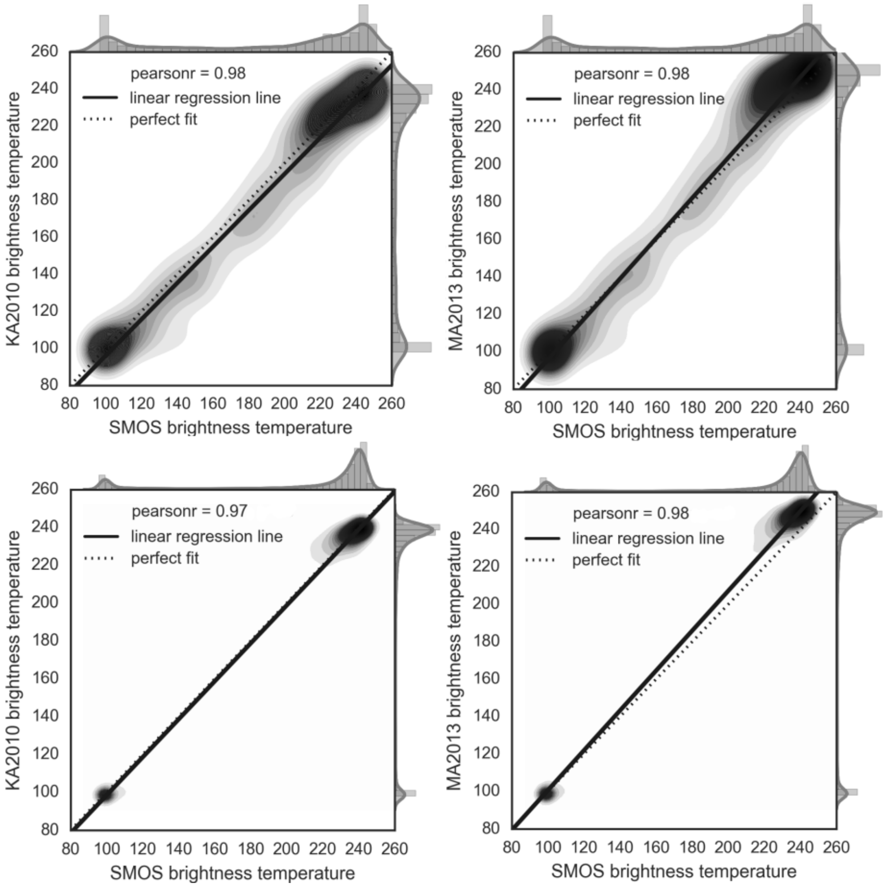
TB Model - Observation



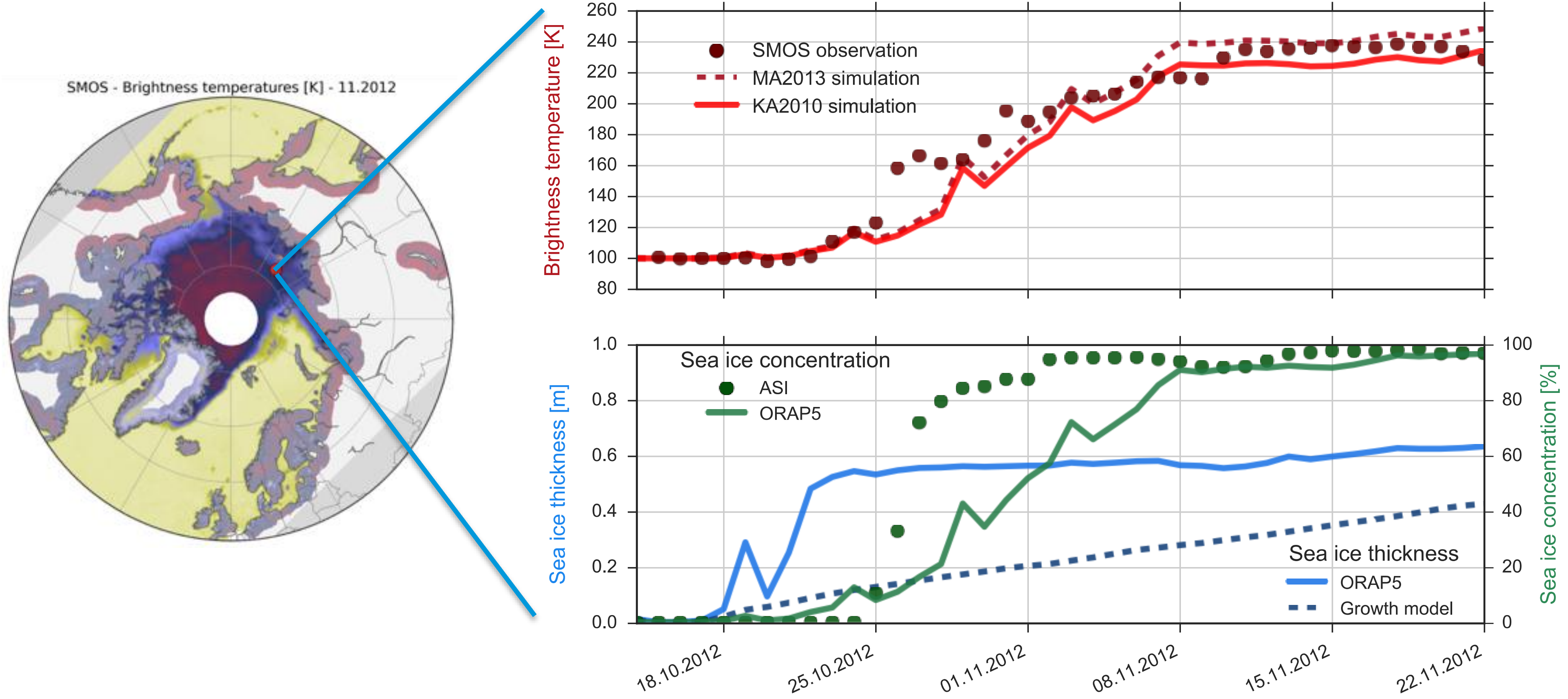
Observed vs Modelled TB

November 2012

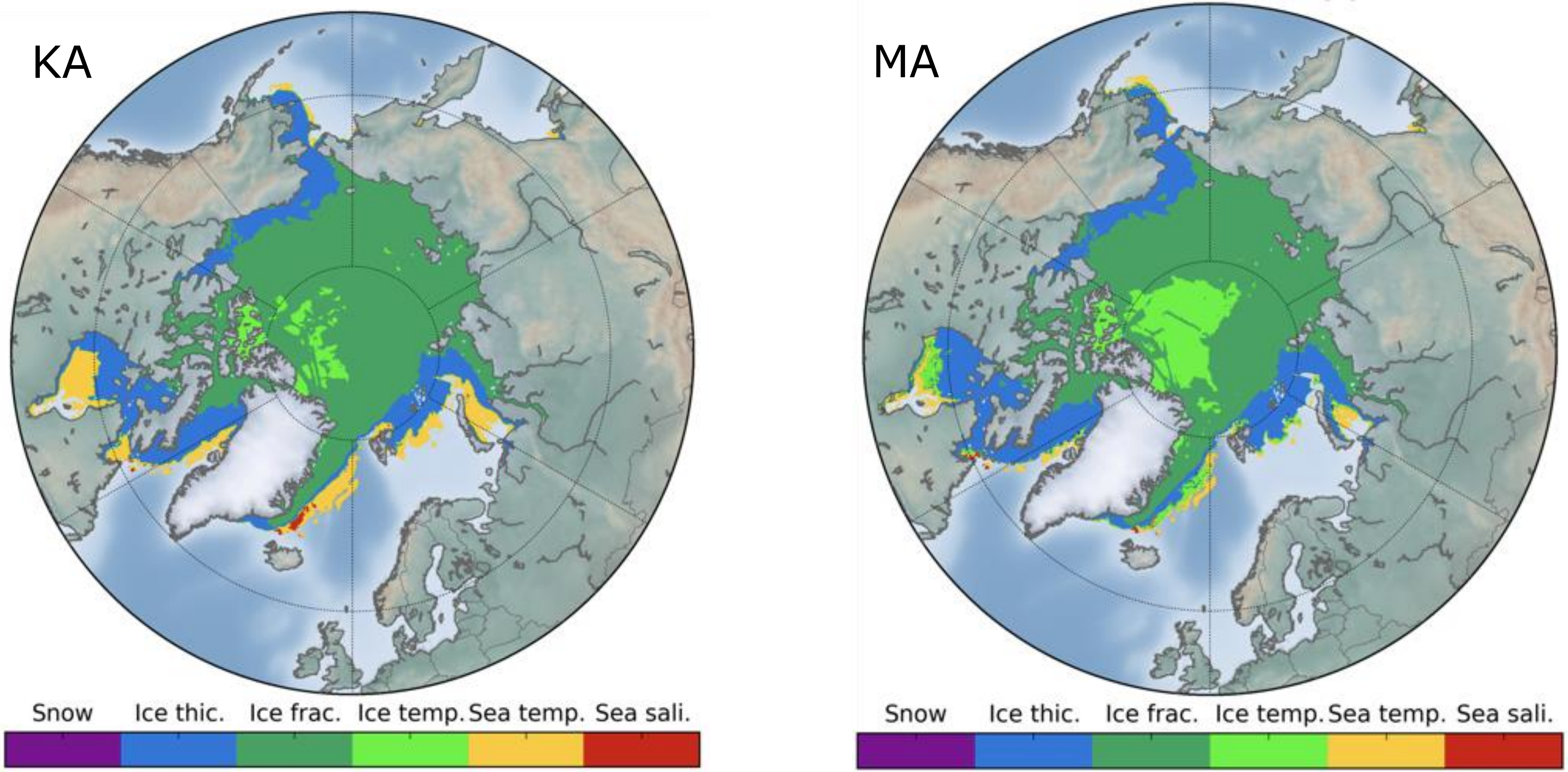
March 2013



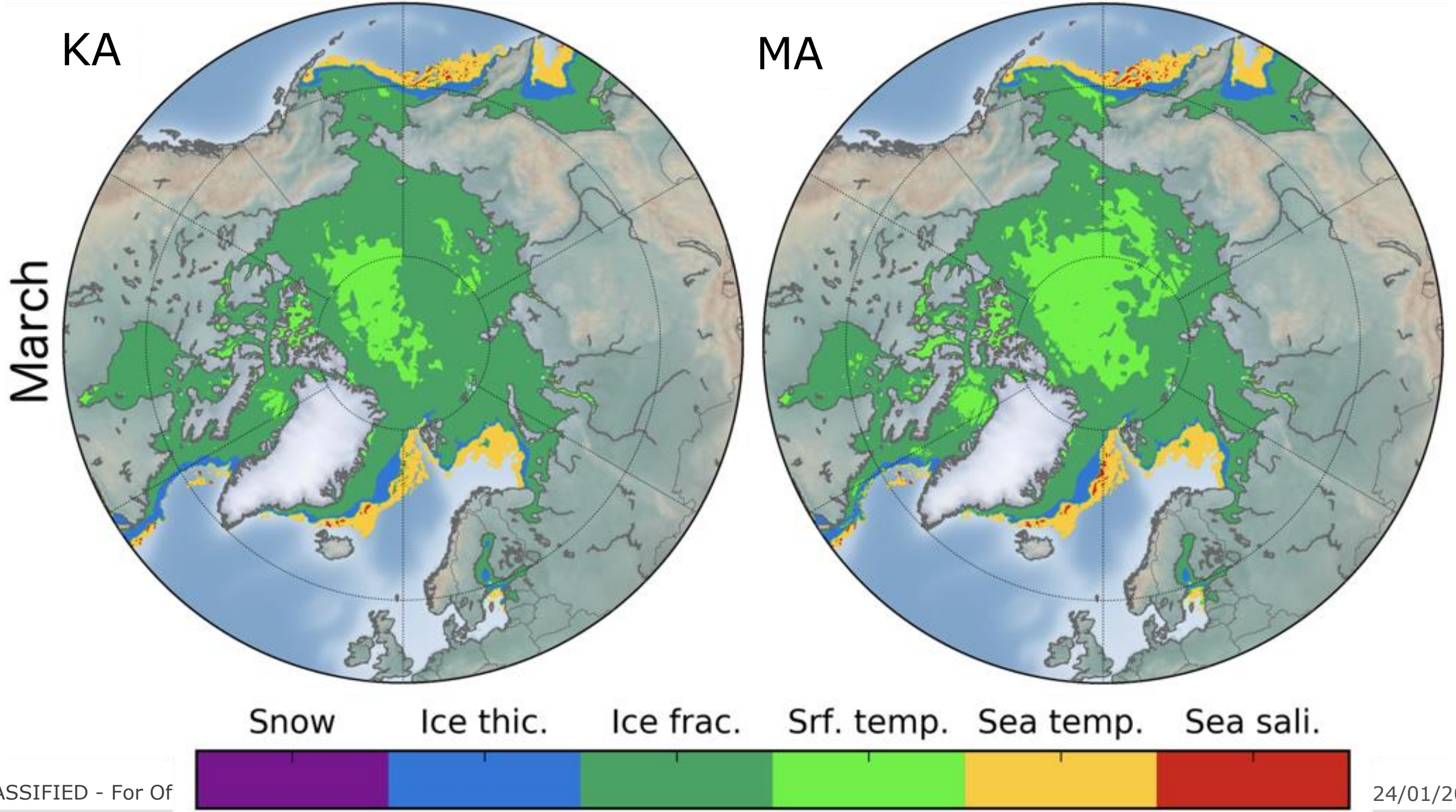
Time series in the Laptev Sea



Dominant Jacobians - November



Dominant Jacobians - March



Summary II

- An open water bias correction of ~ 3.1 K is needed.
- Both radiative transfer models provide TB estimates that match the observations.
- For the marginal ice zone the simpler model seems to be sufficient to generate realistic representation of variability.
- L-band measurements shall be assimilated together with higher frequency measurements to constrain sea ice fraction and thickness simultaneously with uncorrelated errors.
- The direct assimilation of measurements is:
  - ✓ highly complementary to the assimilation of geophysical parameters;
  - ✓ can help designing future observation systems;
  - ✓ can lead to substantial spin-offs in model and DA development .

ISSI Sea Ice Virtual Mission Working Group

Focus on

- Defining a strategy towards a **community sea-ice emission model** that can facilitate an improved and consistent exploitation of existing capabilities and support the definition of future EO missions, and
- Outlining a **model verification strategy** including laboratory measurements and campaigns.

Status

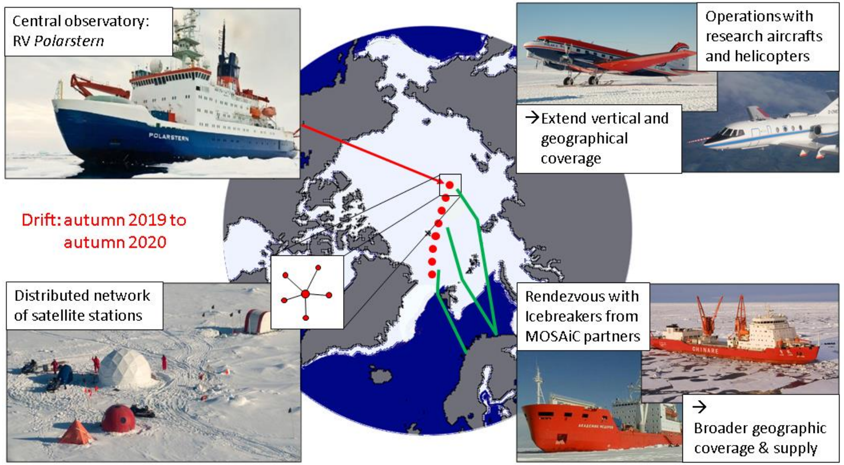
- Two meetings so far (September 2016, May 2017), next meeting planned for May 2018

Feedback from recent meeting: discussion focussed on

  - Snow microwave radiative transfer model (SMRT) was selected as starting point for community sea ice model – discussion on work needed to include a sea ice layer.
  - Inputs to MOSAIC campaign, objectives and instrumentation relevant for emissivity model evaluation.

MOSAIC - Multidisciplinary drifting Observatory for the Study of Arctic Climate

- ❑ First year-round expedition into the central Arctic exploring the Arctic climate system starting in 2019.
- ❑ Total **budget** exceeding 60 Million €
- ❑ **International consortium** under the umbrella of the International Arctic Science Committee (IASC)



ESA contribution:

- ❑ Radiometer on board RV Polarstern, funding EMIRAD/DTU or ELBARA3
- ❑ BALAMIS/Spain: new radiometers featuring flat antenna array; operated from small vehicles including drones; could be operated from a sledge; multi frequency?
- ❑ 2 months berth on board RV Polarstern