Norwegian
Meteorological Institute
met.no

Developments towards assimilation of surface sensitive AMSU-A observations over sea ice in HIRLAM

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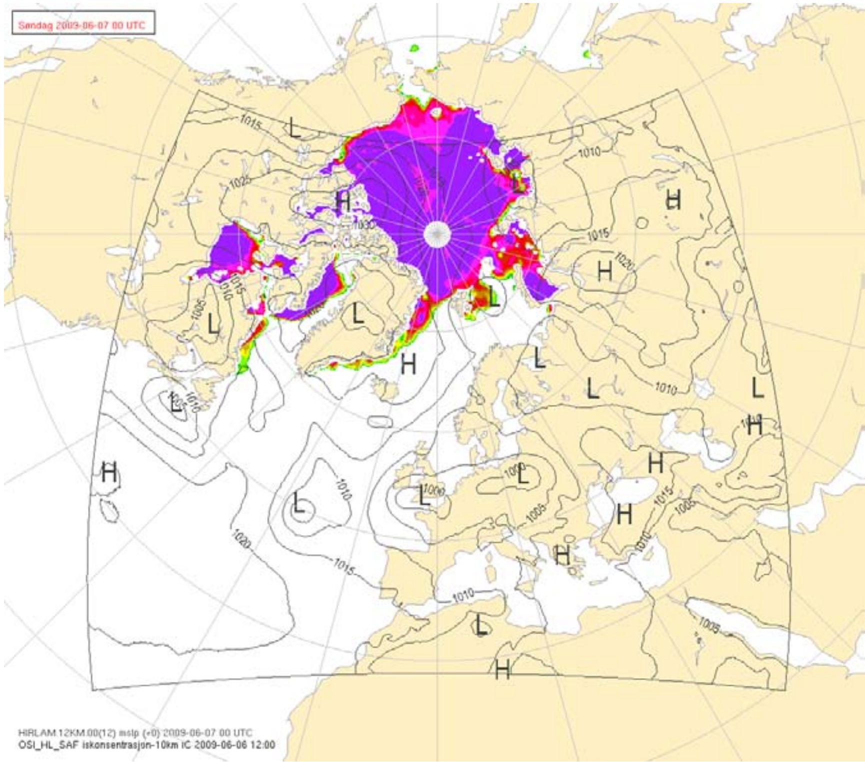
with thanks to
Rasmus Tonboe (DMI), Mariken Homleid (met.no)

Met.no NWP models and development

- Met.no national forecasting responsibility includes North-Atlantic and Arctic areas
- Main regional model is HIRLAM 12 km, large domain
  - Forecasting over snow and ice covered areas
  - Utilize remote sensing over Arctic sea ice

Two classes of problems connected to surface

- The boundary layer physics over snow and sea ice
- The surface contribution to sounding channels over Arctic sea ice



Motivation for better use of AMSU over sea ice:

The Arctic NWP observing system:

Tropospheric profile observations necessary for NWP assimilation

Over the Arctic NWP observation system is basically constituted of *ATOVS*, *AIRS/IASI and MODIS winds* (and a few *radiosondes* and *aircraft* observations)

Met.no NWP code framework:

- Presently HIRLAM (9 countries)
- Towards HARMONIE (larger European consortium)
- (Met.no also runs non-hydrostatic UM at high resolution over Norway, but without assimilation)

Operational assimilation system at met.no:

- HIRLAM 3D-Var, 6 hours cycling
- (4D-Var under testing, not yet operatonal)
- Conventional observations + AMSU + scatterometer being used
- (More observation types under implementation and testing in Met.no test version of HARMONIE)

Projects/programmes:

DAMOCLES (EU integrated FP6 project):

- Large IPY-related project (50 partners within sea ice, ocean, atmosphere, biology, social science …)
- Some NWP activity at met.no: Develop a method for assimilating surface-affected AMSU-A channels

EUMETSAT O&SI-SAF (Sat. Application Facility):

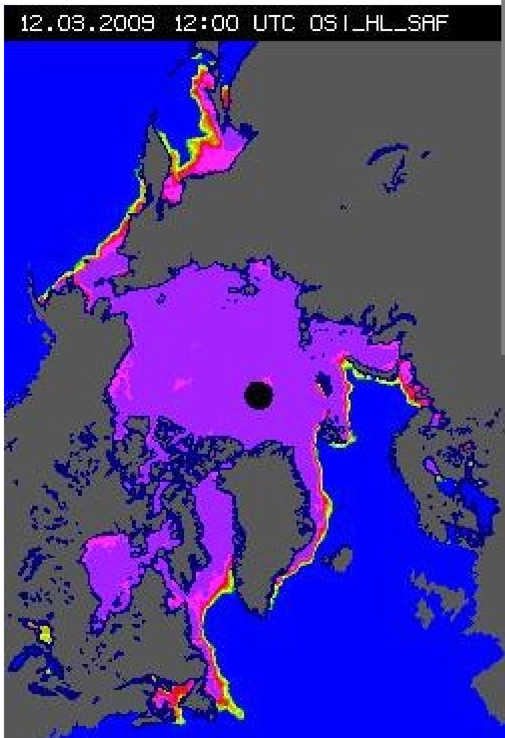
- Extend sea ice products towards emissivity products useful in NWP

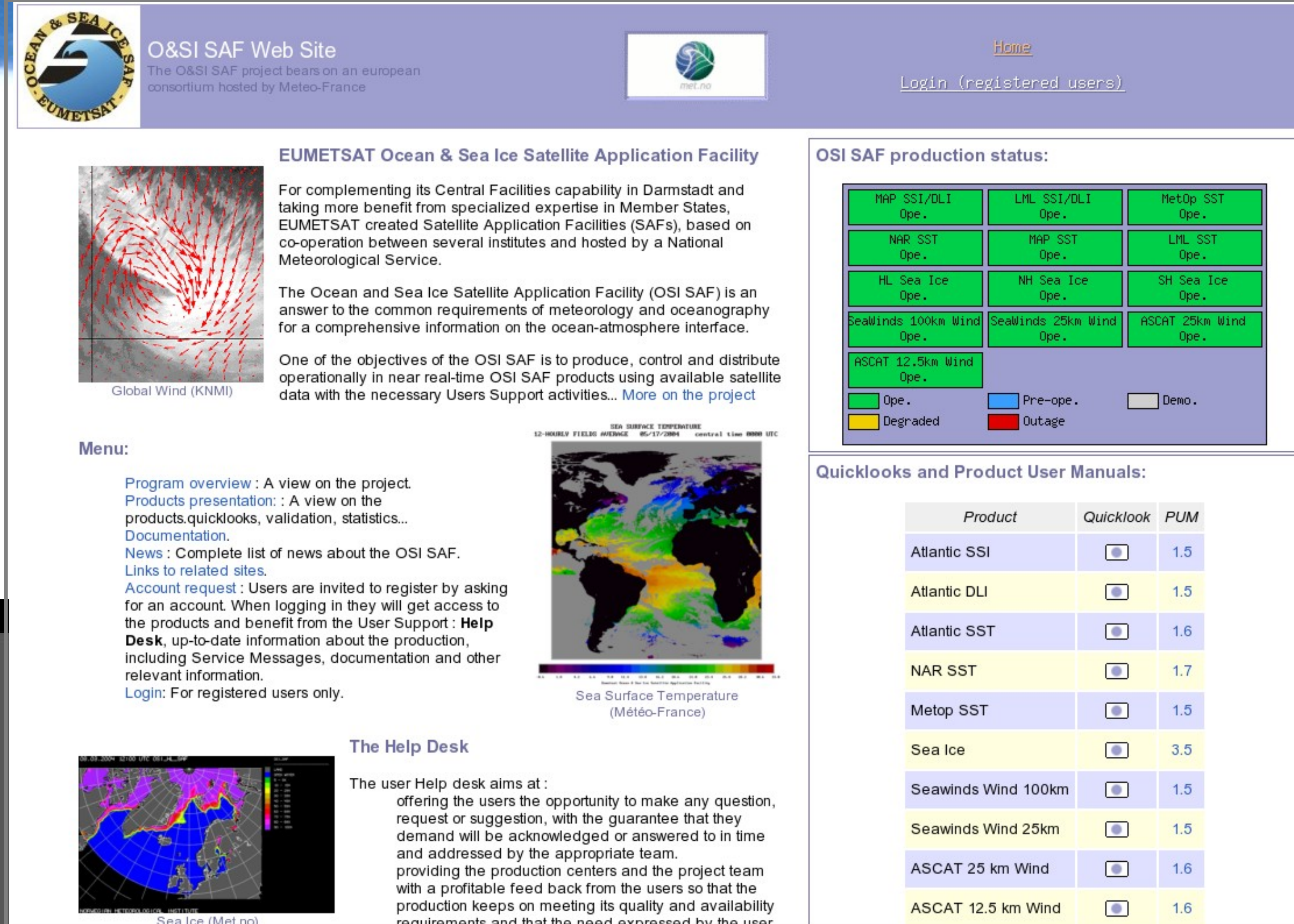
O&SI SAF
Sea Ice Conc.:

- daily
- hemispheric
- polar stereographic
- 10 km

Based on

- SSM/I



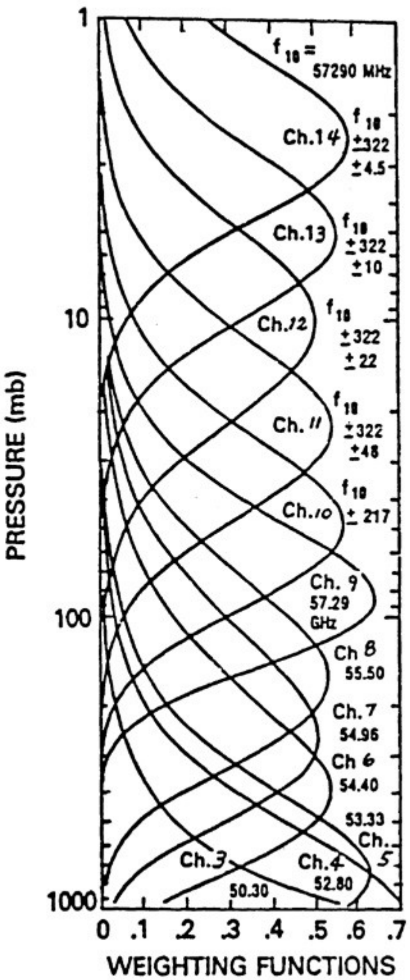


For more information see:
http://www.osi-saf.org/
http://saf.met.no/

Towards exploiting surface affected microwave radiances over sea ice

- Pre-DAMOCLES impact studies with upper AMSU channels over sea ice:
  - Positive impact of adding AMSU-A on EWGLAM verification, but impact highly situation dependent
- At present surface-affected AMSU-A observations are unexploited

AMSU-A channels



We simulate observations from NWP fields using radiative transfer model RTTOV-8 (“B”) and compares against the real observations (“O”)

When using fixed emissivity and NWP surface temperatures, typical O-B rms magnitudes over sea ice are:

Ch 3 ~5K

Ch 4 ~3K

Ch 5 ~2K

Ch 6-9 <~ 0.5K

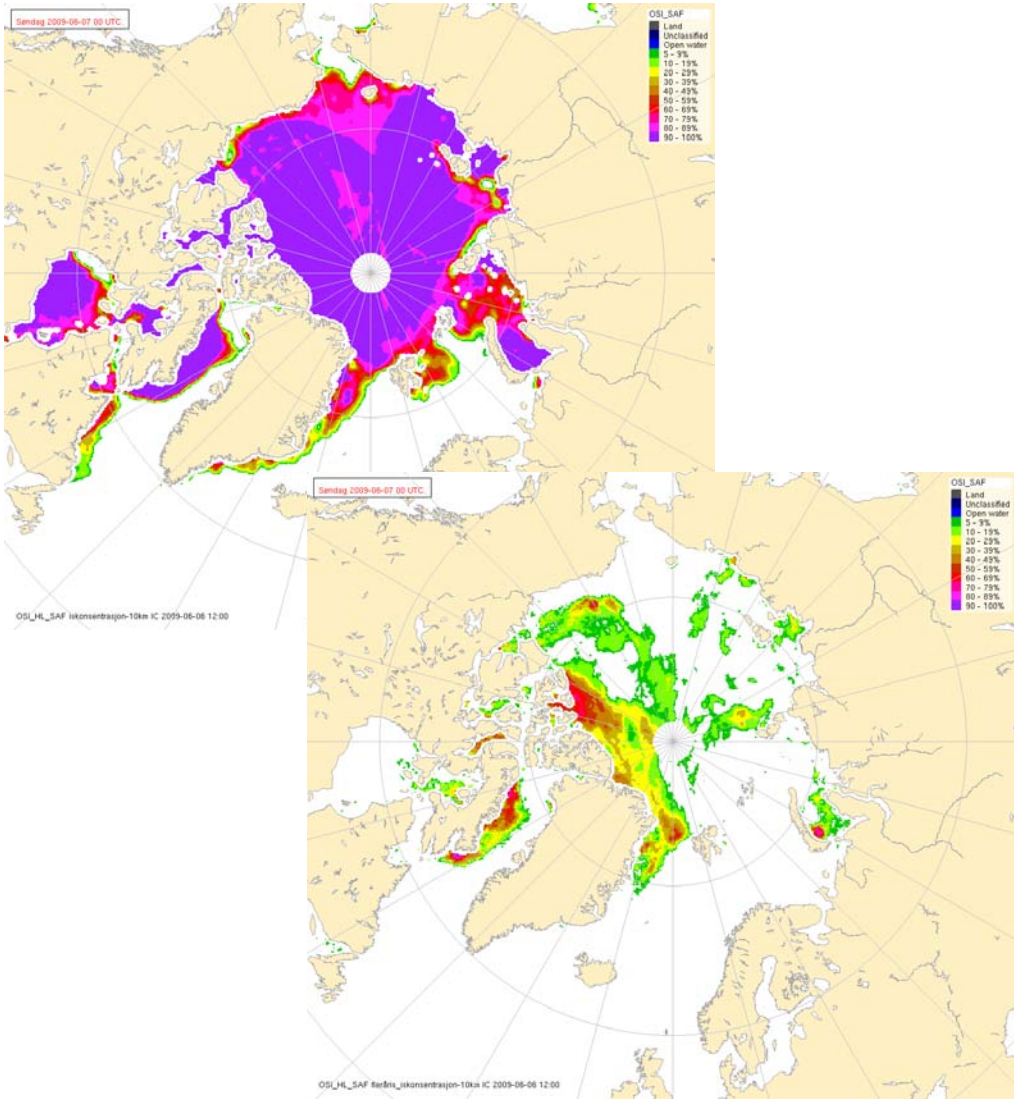
Previously ch 6-10 has been used over sea ice.

Can we improve the use of ch 6-7 and add lower peaking channels?

Two main issues

1. Improved surface/sub-surface emission modeling to input emissivity and emitting temperature to RTTOV
2. Handling surface property uncertaincies and correlations in variational assimilation scheme:
   - should some surface properties be added to the control vector?

A first approach to emissivity



- If we can handle areas with near 100% ice coverage, we still cover a large area (disregards marginal ice zone)
- Use OSISAF concentration chart to find near-100% ice covered area
- In this area multi-year sea ice from OSISAF was used as predictor for sounding ch emissivity

Emissivities (earlier work)

Use OSI SAF FY and MY ice concentrations with typical values (Toudal) of AMSU emissivities for these surfaces:

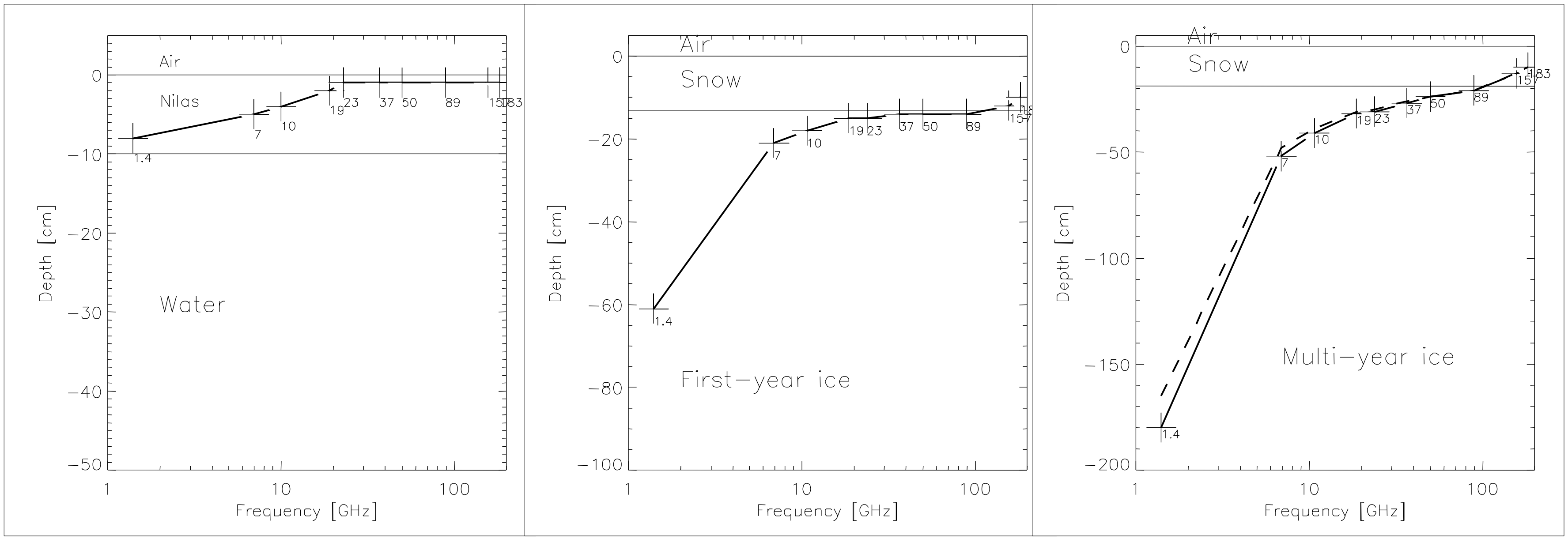
$$\varepsilon = c_W \varepsilon_W + c_F \varepsilon_F + c_M \varepsilon_M,$$

$$c_W + c_F + c_M = 1.$$

AMSU-A channel	First year ice	Multi year ice
1	0.971	0.874
2	0.970	0.829
3	0.928	0.796
4	0.928	0.796
5	0.928	0.796
6	0.928	0.796
7	0.928	0.796
8	0.928	0.796
9	0.928	0.796
10	0.928	0.796
11	0.928	0.796
12	0.928	0.796
13	0.928	0.796
14	0.928	0.796
15	0.913	0.744

- Could be further improved by adding yearly variations, incidence angle dependence, …

Improving the handling of emitting temperature (figures from R.Tonboe)



Variations in penetration depth, increasing temperature with ice depth:

- *The colder, the more misrepresentative is the surface temperature for the emitting layer*
- Surface temperature dependence now tested in radiative transfer calculations with HIRLAM data colocated with AMSU-A

Scatter in O-B can be further reduced by introducing surface temperature dependence

TABLE I
PENETRATION DEPTHS IN CENTIMETERS FOR DIFFERENT SURFACE TYPES AT −10 °C INTERPOLATED FROM [22]

ν [GHz]	Dry snow	Multi-Year ice	First-year ice
23.8	143.35	7.76	1.52
31.4	129.91	7.32	1.45
50.3	96.47	6.23	1.28
89.0	28	4	0.94
150	13	2	0.75

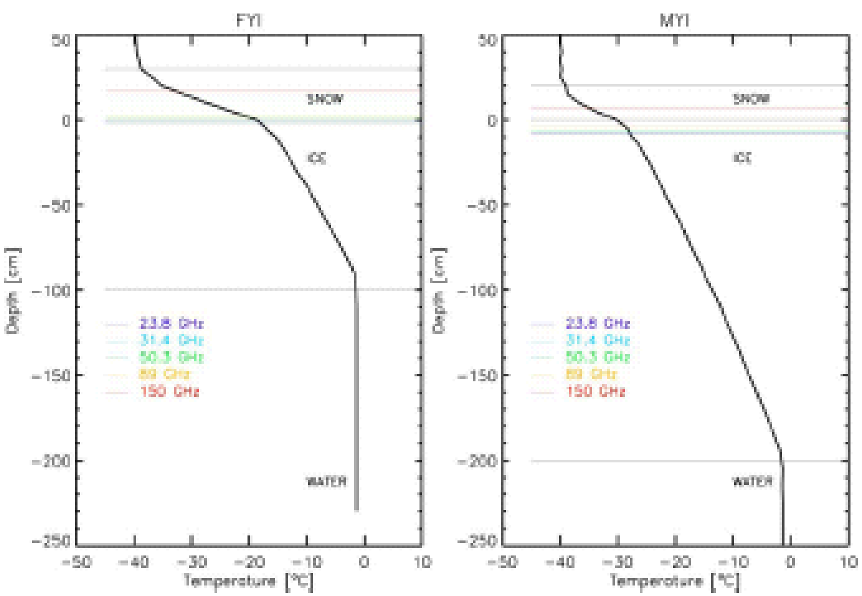


Fig. 1. Examples of temperature profiles of snow and ice and penetration depths assumed for different frequencies for (left) the FYI and (right) the MYI.

Physical basis described by Mathew et al, 2008

Leads to empirical expression:

$$T_{emitting} = aT_{2m} + b$$

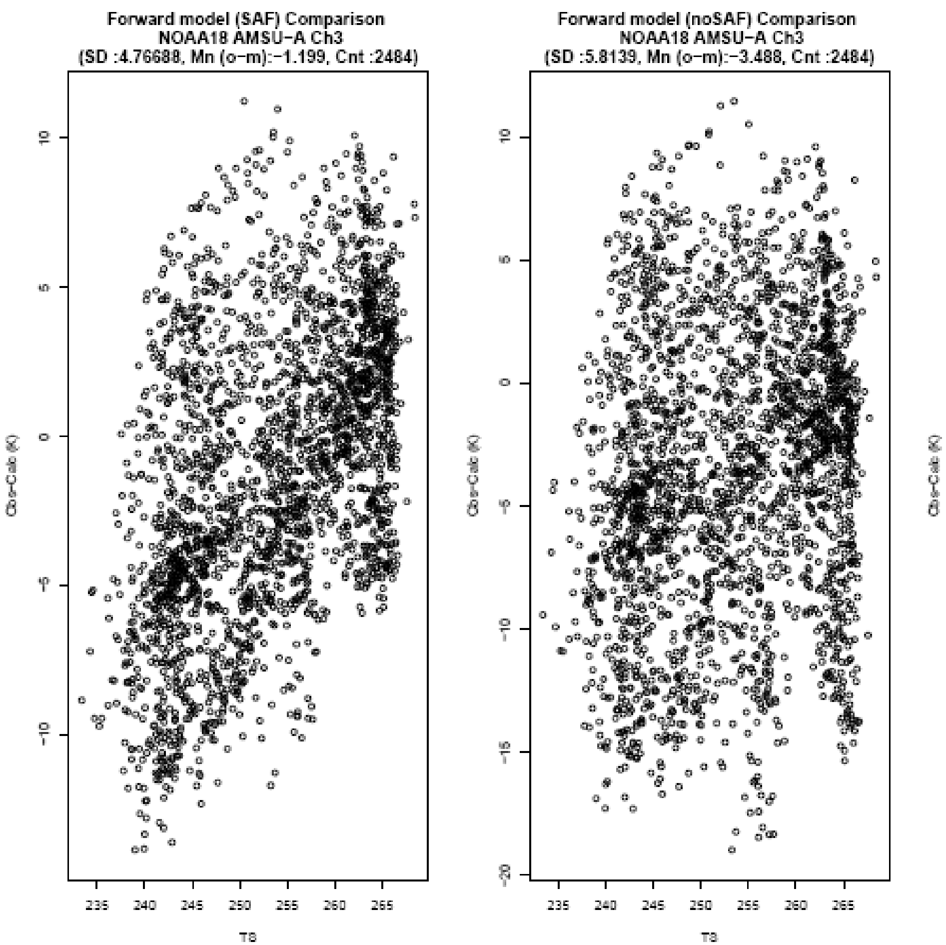
Can this be dealt with through the bias correction?

Linear dependence of observed brightness temperature on T_s

But:

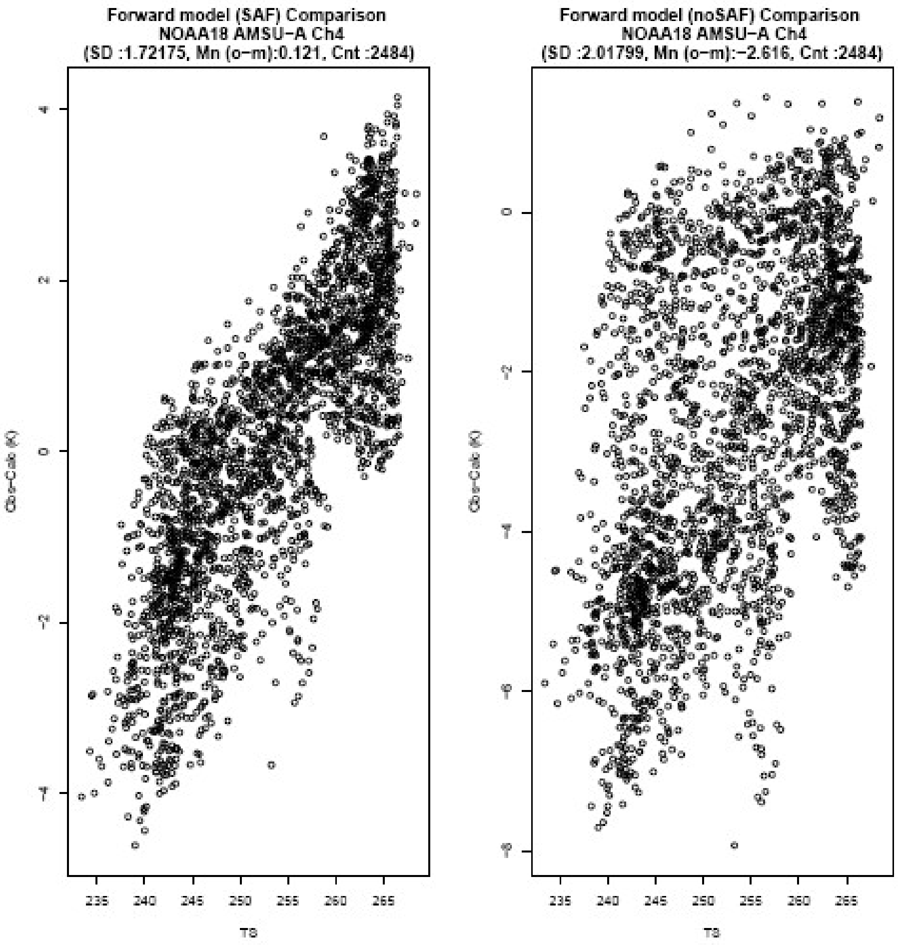
- slope is of T_b vs T_s dependent on ice characteristics such as type
- need to simultaneously include e.g. multi-year ice fraction dependence

Example: O-B statistics *ch 3* using RTTOV-8 over sea ice



- Right panel: RTTOV with constant sea ice emissivity
- Left panel: With OSISAF multiyear sea ice as emissivity predictor

Example: O-B statistics *ch 4* using RTTOV-8 over sea ice



Right panel: With RTTOV default sea ice emissivity

Left panel: With OSISAF multiyear sea ice as emissivity predictor

Variational assimilation allows a first guess of surface temperature and emissivity as a "soft" constraint

HIRLAM 3D- and 4D-Var:

Analysis is found by minimizing cost function:

$$J(x) = \tfrac{1}{2}\,(x-x_b)^T\,\mathbf{B}^{-1}\,(x-x_b) + \tfrac{1}{2}\,(y-H(x))^T\,\mathbf{O}^{-1}\,(y-H(x))$$

Emissivities and ice surface temperature can be added to the control variable x, including a first guess x_b and corresponding error covariance matrix.

Ongoing work:

HIRVDA: Presently one single skin temperature for all AMSU channels can be put into control variable

- Emissivity and skin temperature for each channel into control variable?

- Will probably leave too much freedom

- Need to constrain

How to constrain the surface description further?

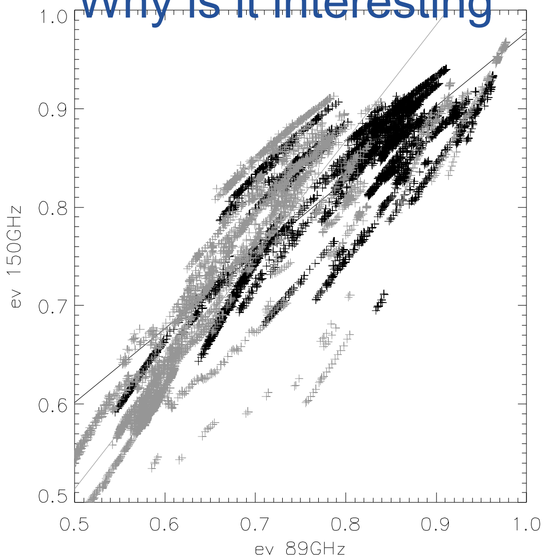
- Subsistence in time of emissivity
  ⇒ With emissivity in control variable – use output from analysis to update dynamic emissivity maps to feed back as first guess
  ⇒ Replace or complement maps of MY ice fraction
- Model emissivity correlations between channels
  ⇒ Karbou et al (2006) tries retrieved emissivity at 23.8 GHz as emissivity for all channels. More advanced methods possible.
- Common skin temperature for all channels in control variable
  ⇒ Then model varying penetration depth according to Mathew et al (2008) relation

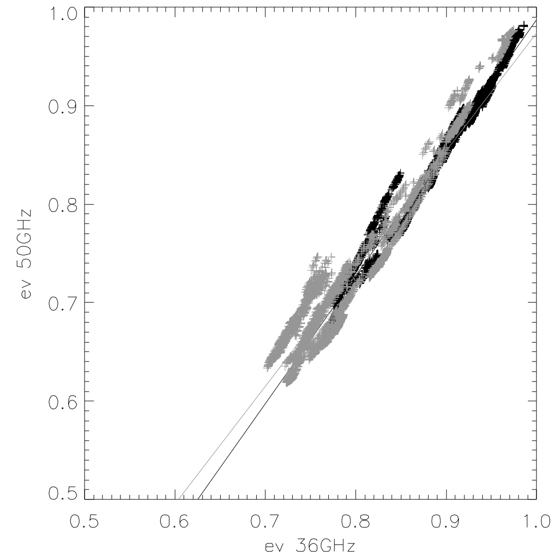
Channel correlations: Emissivity proxy/predictor (some figures from R. Tonboe, DMI)

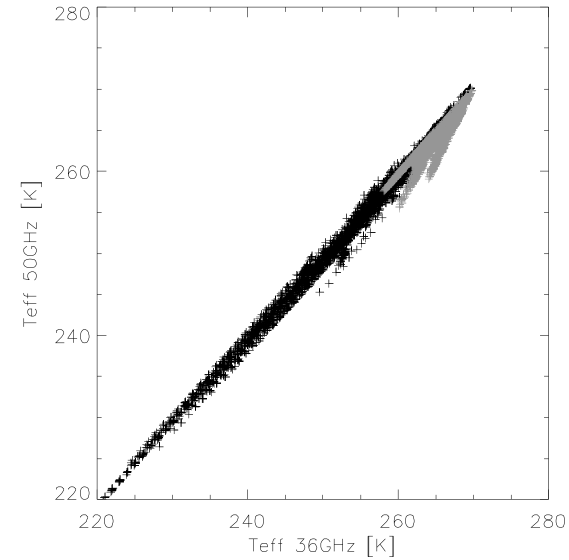
- Based on microwave emission model MEMLS also including a sea ice component
- Coupled with a sea ice thermodynamic model driven by ECMWF reanalysis data

Channel correlations (window/ sounding)

Why is it interesting







The 89GHz channel contains much independent information.

The emissivity at 89GHz is relatively poorly correlated to the emissivity at 150GHz (or the lower frequencies at eg. 50GHz).

The correlation between the emissivity at the window 36 and the sounding channel 50GHz is high

The correlation between the effective temperature at the window 36 and the sounding channel 50GHz is also high

The problem is only that neither the emissivity nor the effective temperature are measurable on large scales.

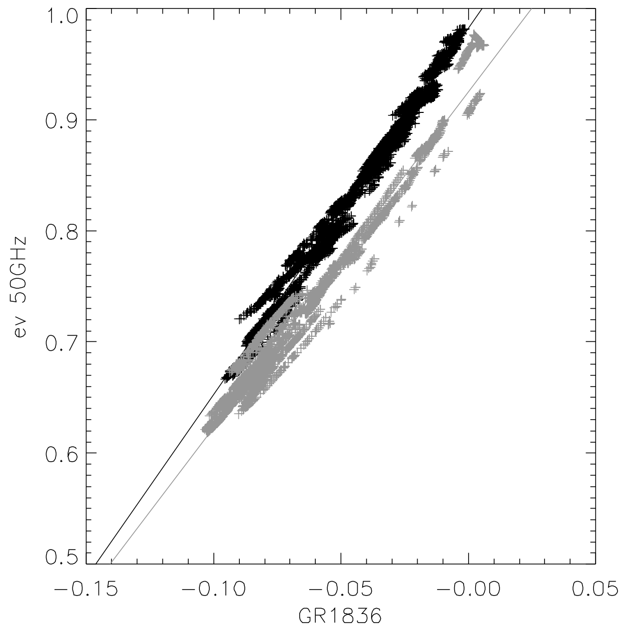
Proxies for emissivity?

A relationship between GR1836 and the emissivity at 50GHz?

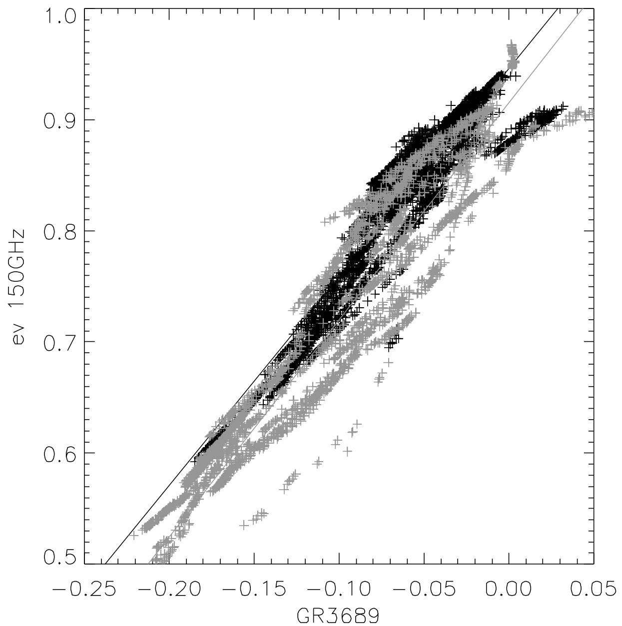
The snow scattering intensity which is reflected in GR1836 is important for the emissivity.

A relationship between GR3689 and the emissivity at 150GHz?

The processes affecting the GR3689 are generally deeper than the ev150 which is mostly affected by the snow surface layer.



$$ev50 = 3.29(GR18/36) + 0.98$$



$$ev150 = 1.88(GR36/89) + 0.95$$

Final remarks

- Work in progress – implementation to be completed and assimilation impact tested next year: Parallel assimilation experiments with and without surface affected observations

- EUMETSAT OSISAF has ambitions for aiding the NWP community with sea ice emissivity products operationally

- Ultimate solution (?): Use advanced surface model to help model emissivity (snow and ice depths, transformations by meteorological forcings – integrated with the sea ice surface scheme of NWP model?)