

Simulation of the sea ice brightness temperature variability at L-band

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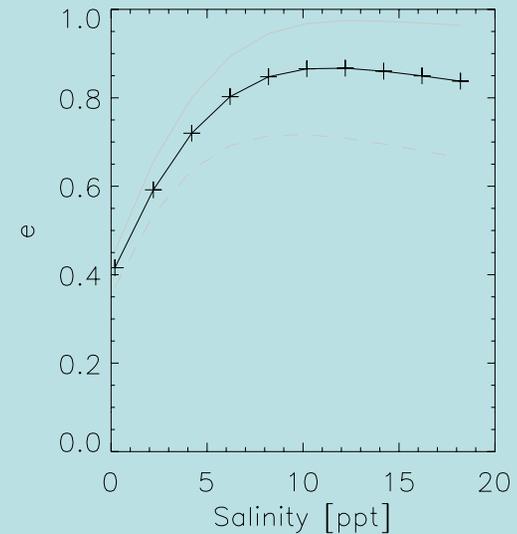
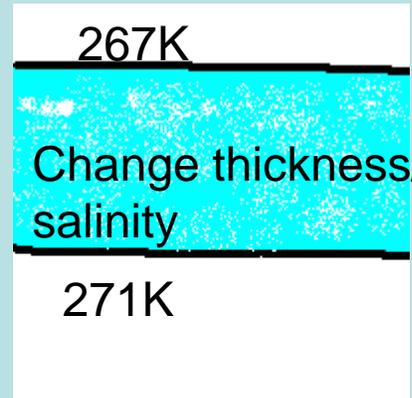
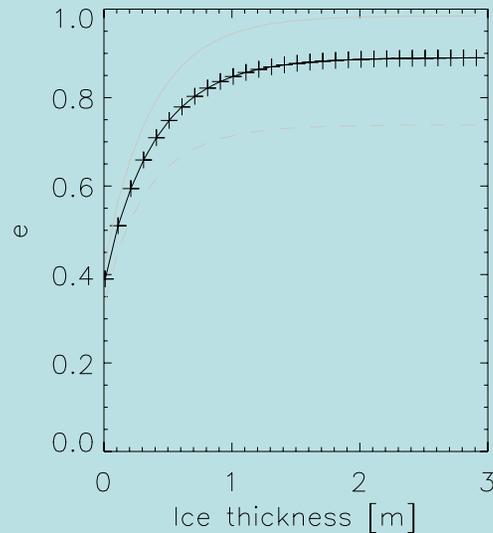
University of Hamburg

Lerici, 18-22. October 2010

SMOS

- The ESA Soil Moisture and Ocean Salinity (SMOS) L-Band radiometer satellite was launched on November 2, 2009 as part of the Earth explorer programme.
- The ESA SMOSICE 1 (2008-2009) and 2 (2010-2012) projects: investigate the possibilities over sea ice.
- My role: to construct a SMOS sea ice signature simulator using a combination of thermodynamic and emission modelling

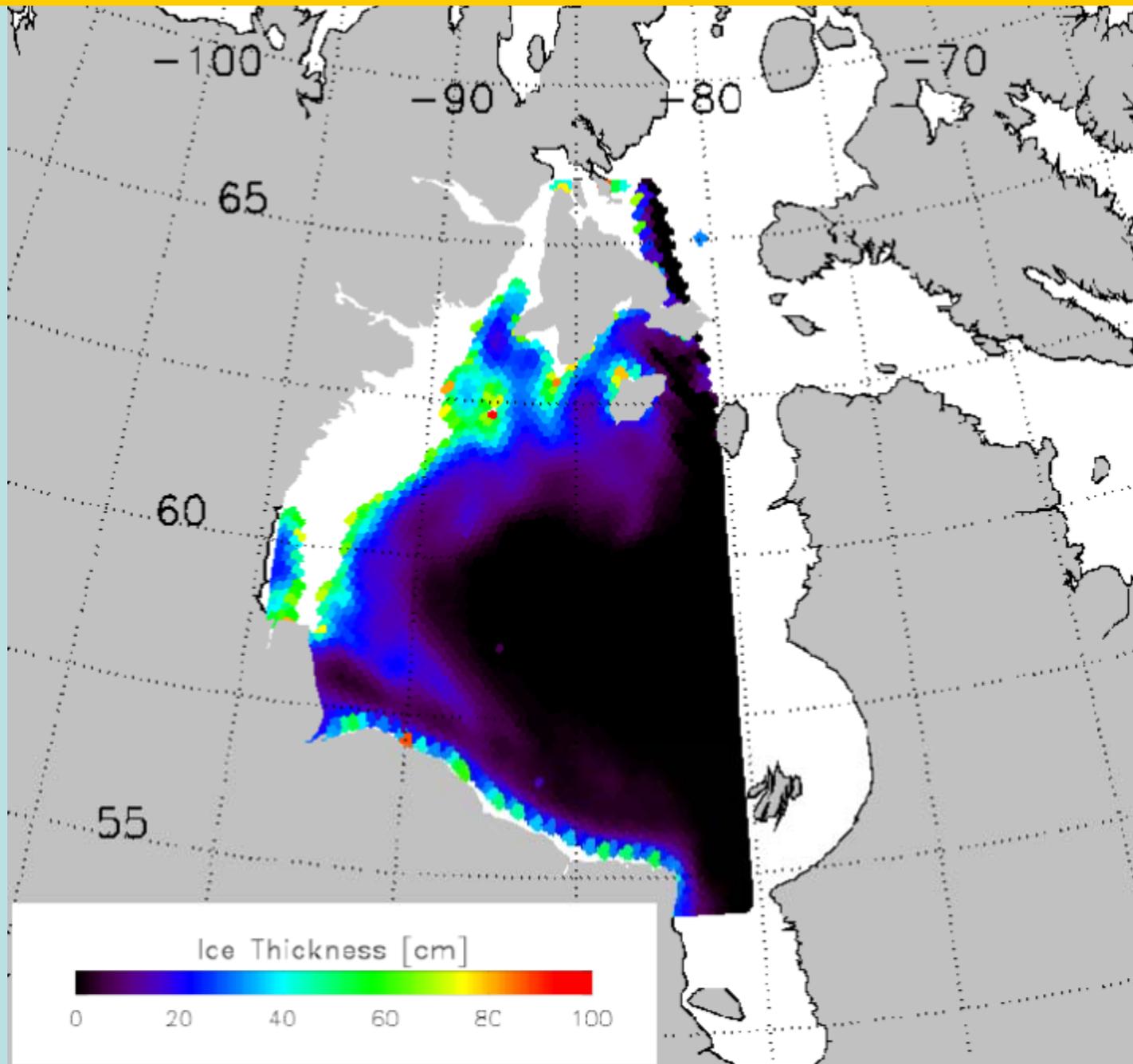
Simulations using a model show that ...



The emissivity as a function of ice thickness. e_{adir} is marked with (+), the e_v and e_h at 54deg are the grey full and dashed line respectively. The salinity is 8ppt and the ice surface temperature is 267K.

The emissivity as a function of bulk salinity. e_{adir} is marked with +, the e_v and e_h at 54deg are the grey full and dashed line respectively. The thickness is 1m and the ice surface temperature is 267K.

Ice thickness?



Thin ice thickness applications

- It is within this thin ice thickness range where non-icebreaker ships can navigate and submarines may find openings all the way to the surface.
- The air-ice-ocean interaction including heat, moisture and salt-flux is orders of magnitude larger for sea ice which is thin than for thick perennial ice.
- This potential new application of SMOS would enable us to map ice thickness in the vast first-year ice areas:
 - In the Arctic the Baffin Bay, Beaufort Sea Bering Strait and over the Siberian Shelves during freeze-up in autumn (Oct. – Dec.).
 - In Antarctica, where most of the ice cover consists of first-year ice, thickness could be mapped during the Austral autumn (Apr. – Jun) and in the large polynyas during winter.

Ice thickness at L-band

- The auxiliary data include sea ice concentration, sea ice temperature and sea ice salinity.
- Ice concentration and temperature can be measured
- Salinity:
 - 1) constraining the salinity by using empirical ice thickness and salinity relationships or
 - 2) solving by thermodynamic modelling using surface temperature and other meteorological data input

Combined thermodynamic and emission modelling

- ECMWF ERA40 meteorological input data
- Detailed profiles: Density, salinity, temperature, snow metamorphosis and layering, ice growth.
- Interface to the emissivity model, a sea ice extension of the microwave emission model for layered snow-packs (Wiesmann & Mätzler, 1999).
- Particularly important at L-band is the salinity profile and the temperature.

The bulk salinity of first-year ice

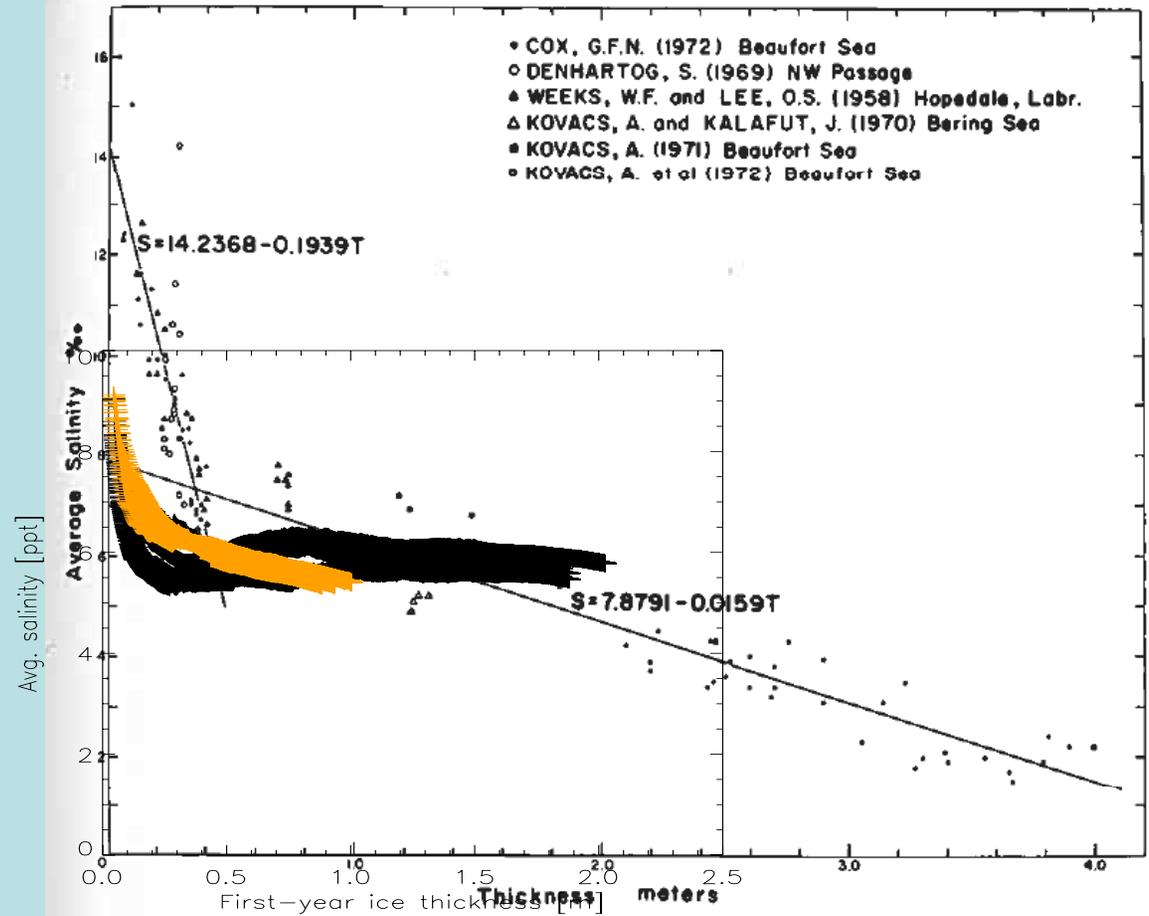
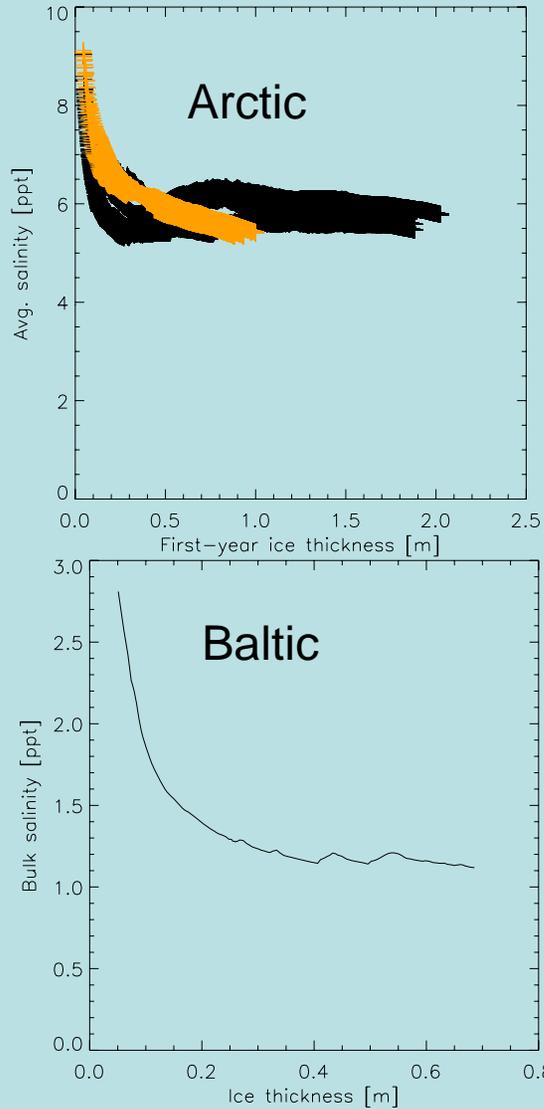
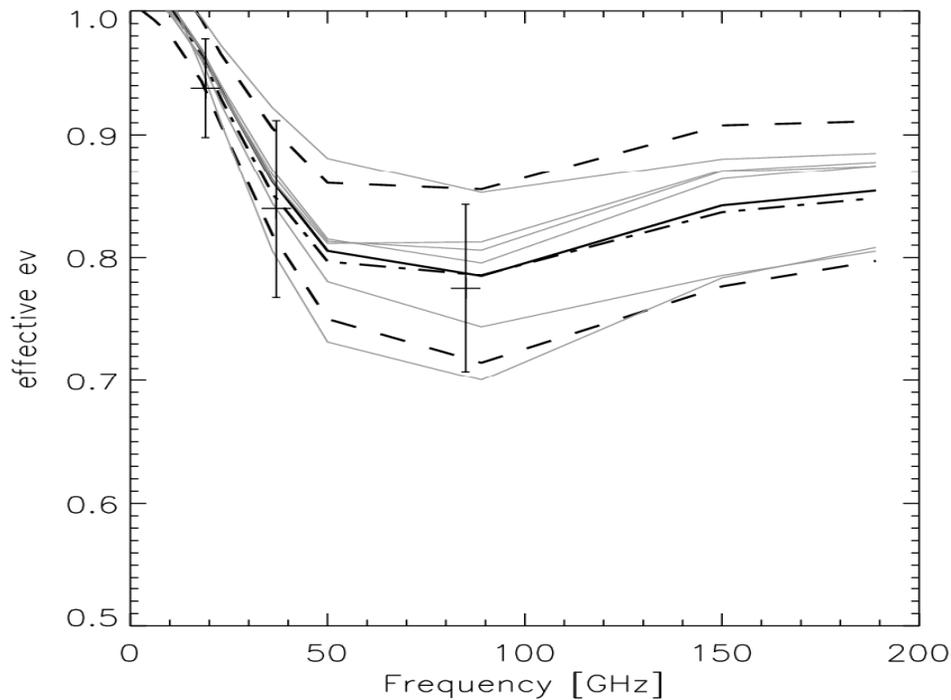


Fig. 64. Average salinity of sea ice as a function of ice thickness for cold sea ice sampled during the growth season (Cox and Weeks, 1974).

Figure 64 from the geophysics of sea ice, 1986, p. 93.

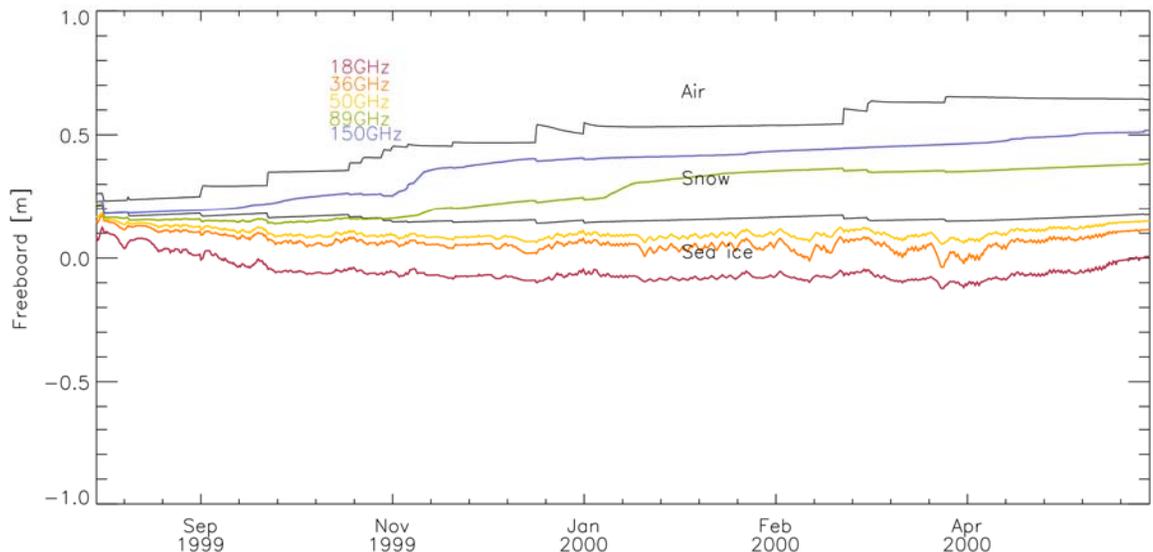


The combined models compares well with measurements at SSM/I frequencies (19-85GHz)

The thermodynamic model has very high vertical resolution

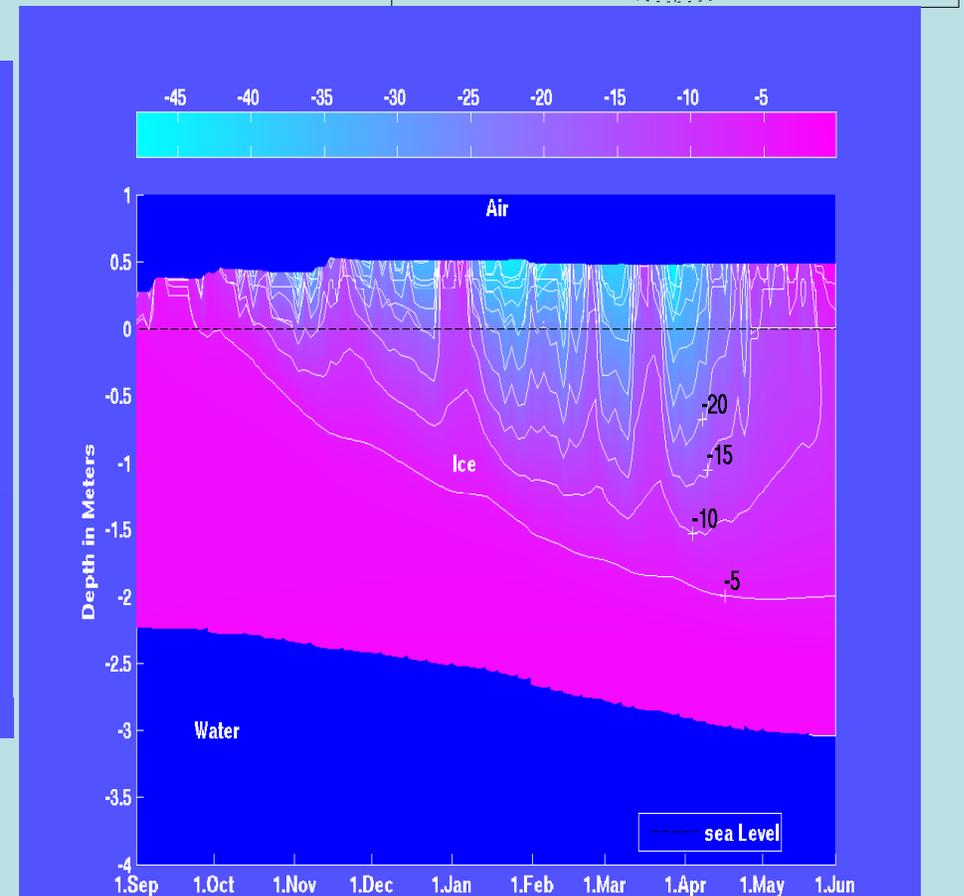
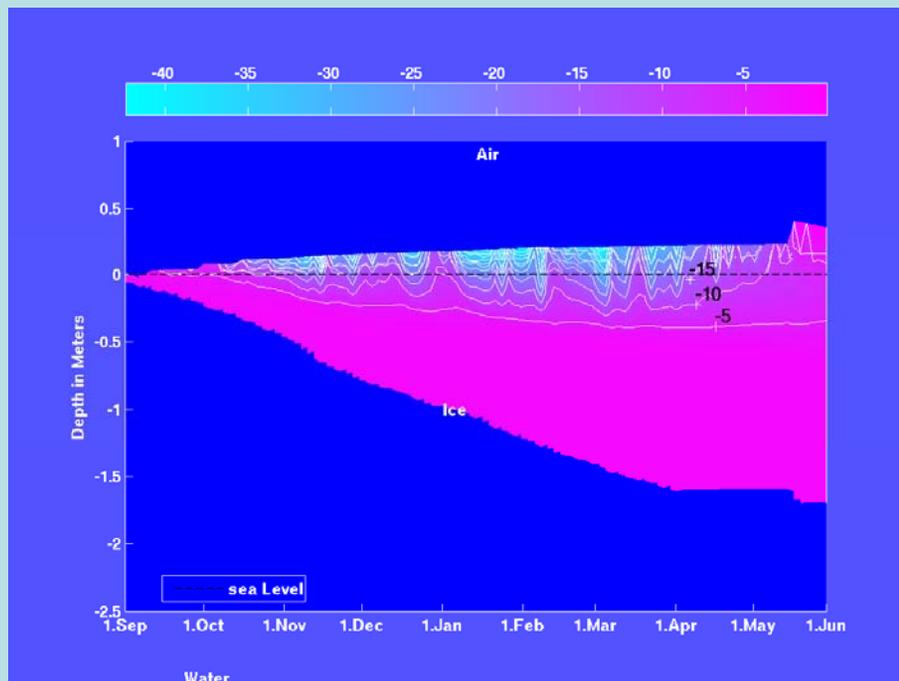
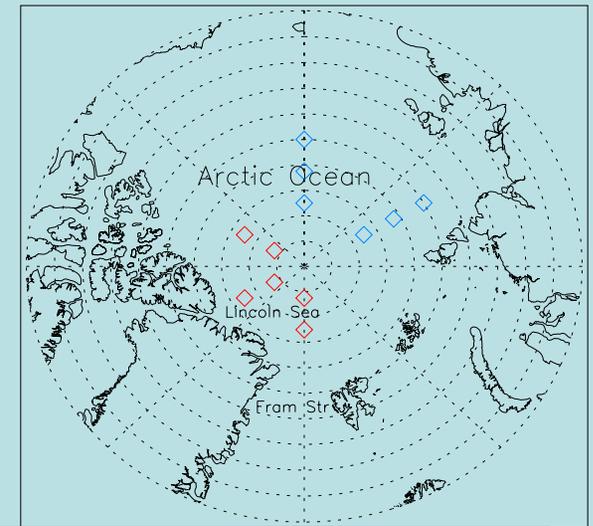
It includes parameters such as temperature, density, salinity, grain size, layering

The initial profile on september 1.



Distributed 1D-model

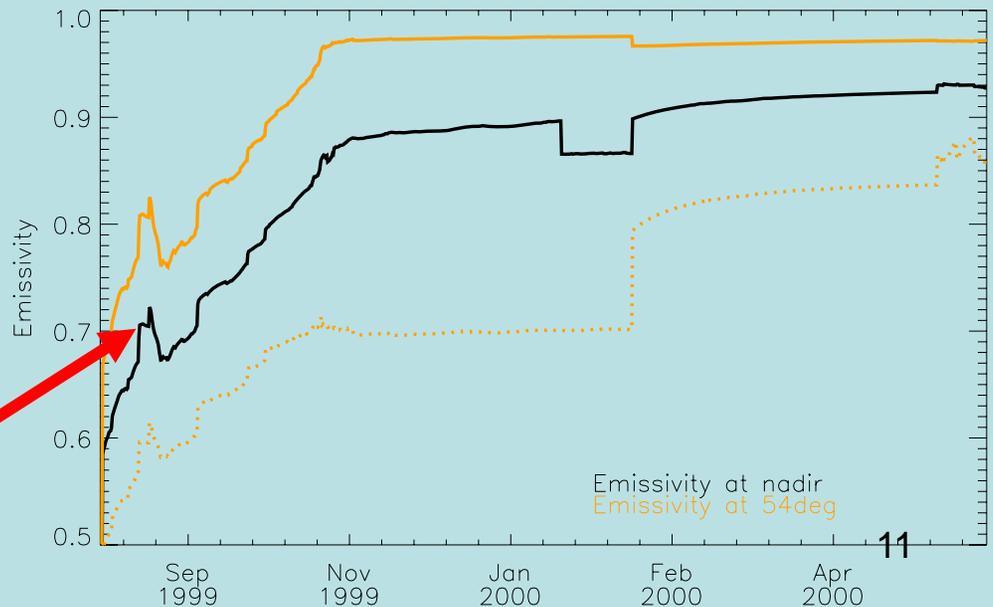
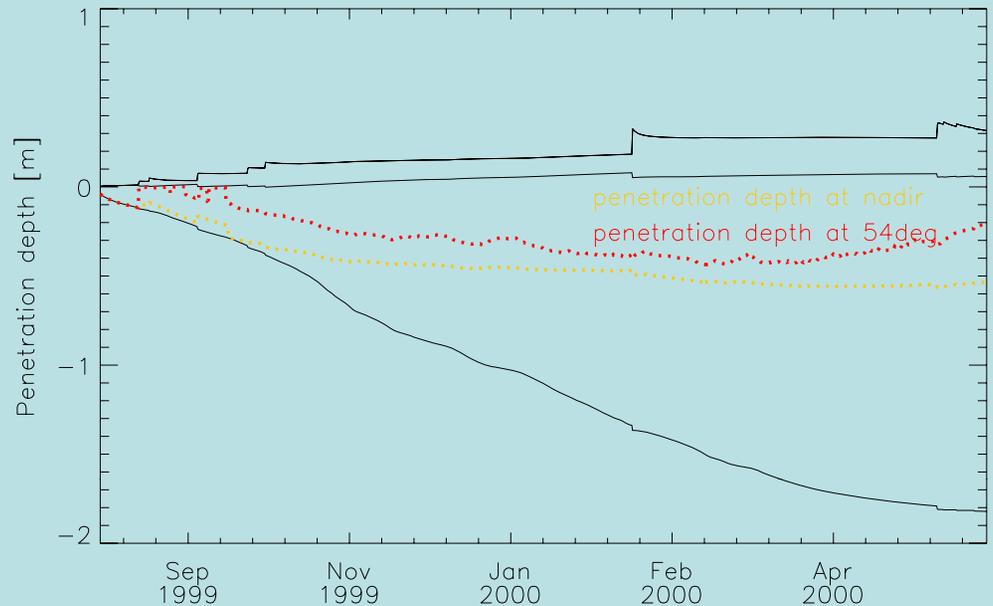
- ECMWF ERA40 meteorological input data
- Detailed profiles: Density, salinity, temperature, snow metamorphosis, ice growth.
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First year ice profiles (85N 120E)

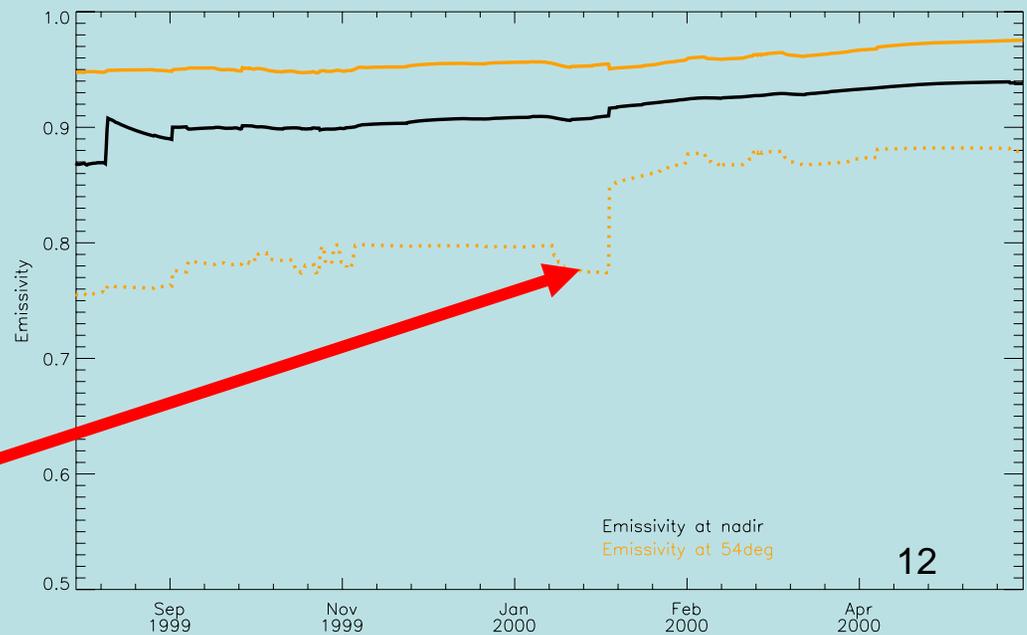
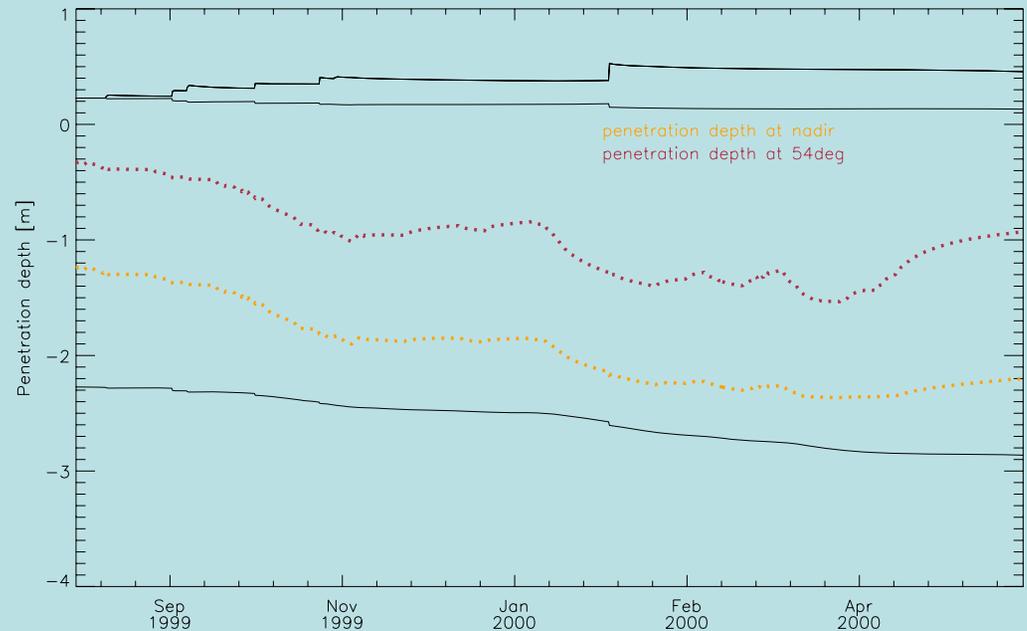
- Simulations begin on Sep. 1 and end on May 31.
- Ice thickness and snow depth are comparable to campaign measurements.
- The h- and the nadir emissivity is sensitive to variations in the surface reflectivity.
- The emissivity is sensitive to ice thickness $< 0.5\text{m}$
- Temporary warming during the early growth increase the emissivity.

Surface warming

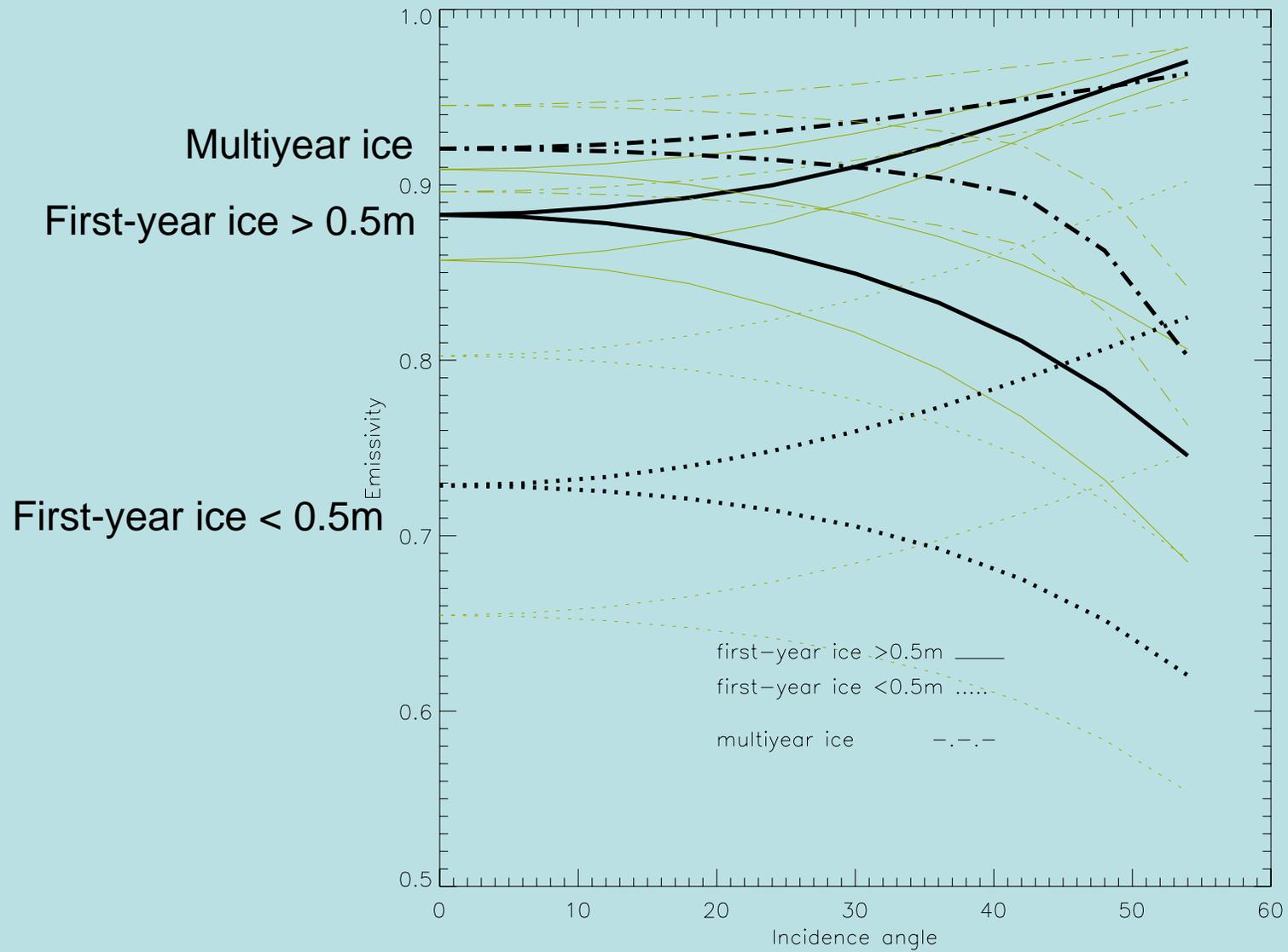


Multiyear ice profile (87.5N 300E)

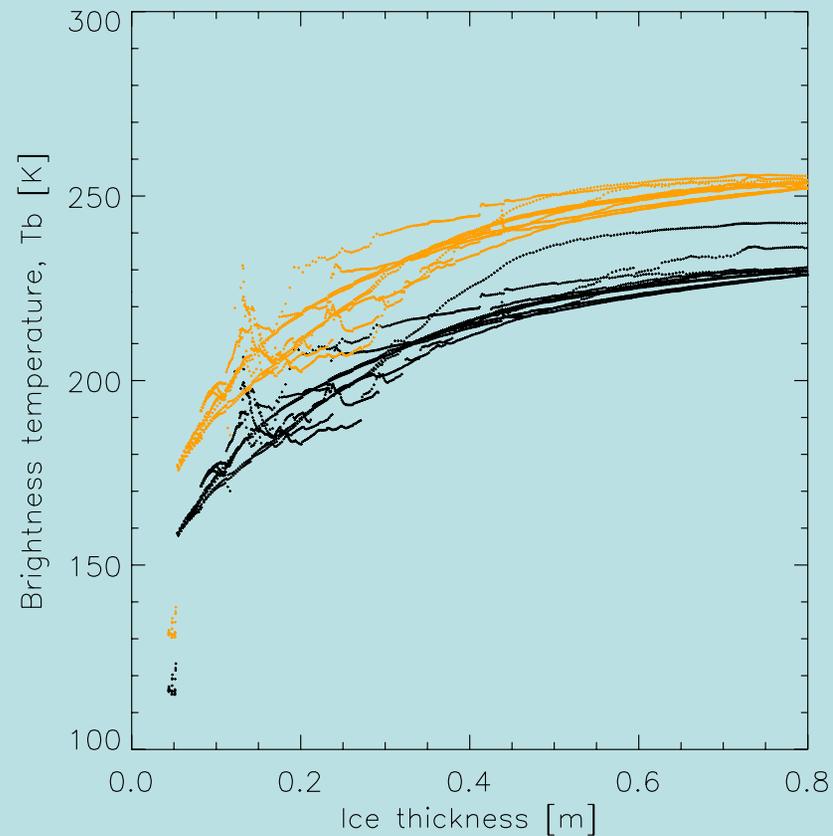
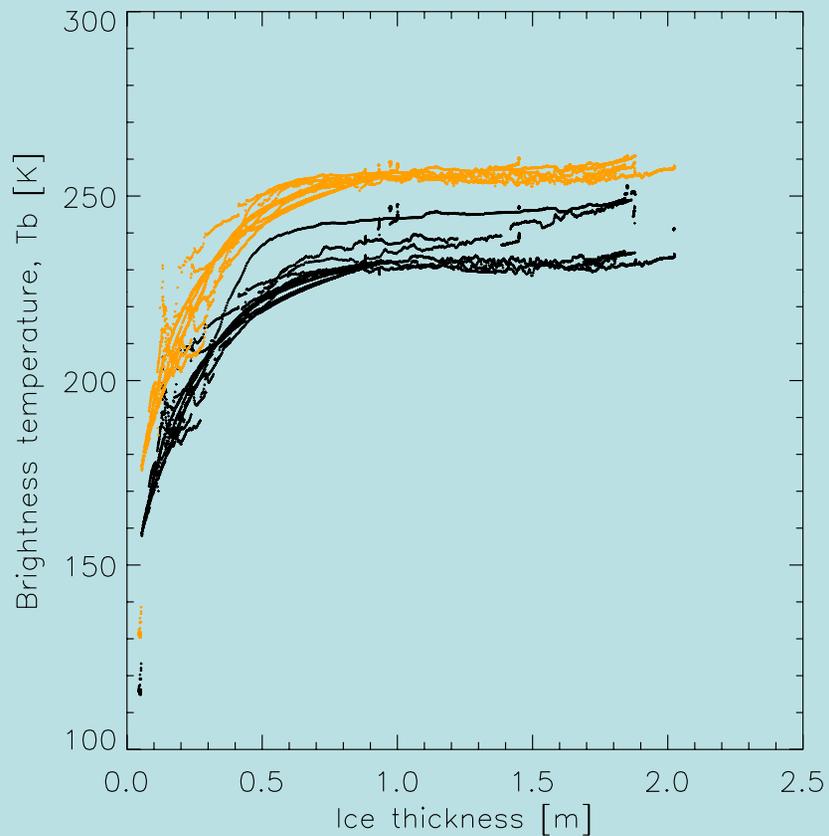
- Simulations begin on Sep. 1 and end on May 31.
- Ice thickness and snow depth are comparable to campaign measurements.
- The h- and the nadir emissivity is sensitive to variations in the surface reflectivity.



The average simulated emissivity for different ice types



The simulated ice thickness vs. brightness temperature



The structural uncertainties

Ulaby et al. 1986

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Microwave Dielectric Properties of Natural Earth Materials

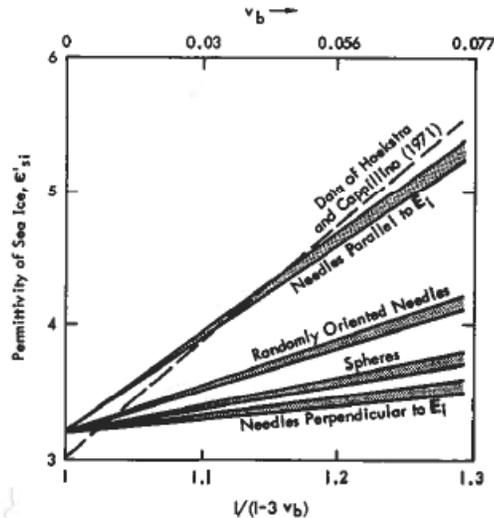


Fig. E.16 Dielectric permittivity of sea ice as a function of brine volume fraction at 9.8 GHz. The theoretical results were obtained by using salinities from 4 ‰ to 8 ‰ and temperatures from -3°C to -16°C (from Hallikainen, 1977).

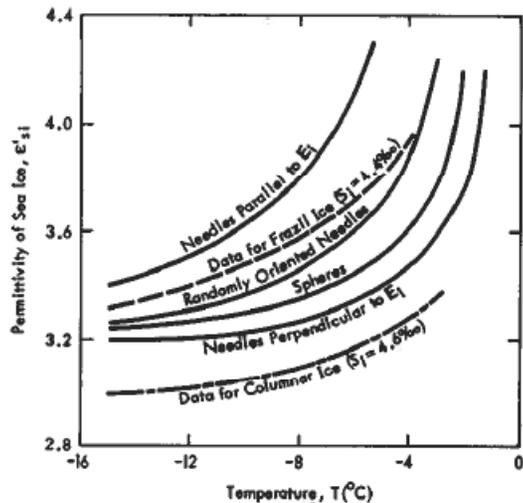


Fig. E.17 Theoretical dielectric constant of sea ice compared to experimental results for frazil ice (density 0.836) and columnar ice (density 0.896) by Vant *et al.* (1974).

E-5 Sea Ice

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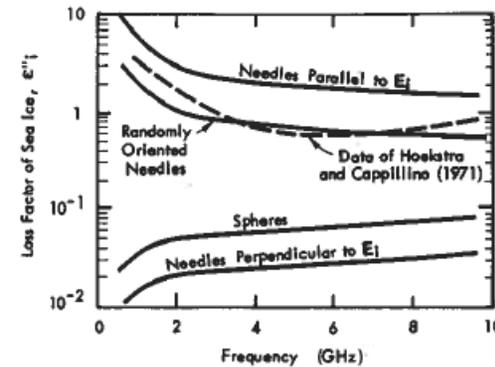


Fig. E.18 Loss factor of sea ice as a function of frequency. The salinity is 8 ‰ and temperature is -10°C (from Hallikainen, 1977).

refractive index of brine, and $n_{air} = 1 - j0$ is the refractive index of air. Because of its linear form, (E.75) can be separated easily into two equations of the same form, one for n_{si}' and the other for n_{si}'' .

For a sea-ice sample with a given salinity S_i and a temperature T , the brine volume fraction v_b can be obtained from Fig. E.14 or from the corresponding expressions given by (E.70). The volume fraction of air pockets is given by

$$v_a = 1 - (\rho_{si} / \rho_i), \quad (E.76)$$

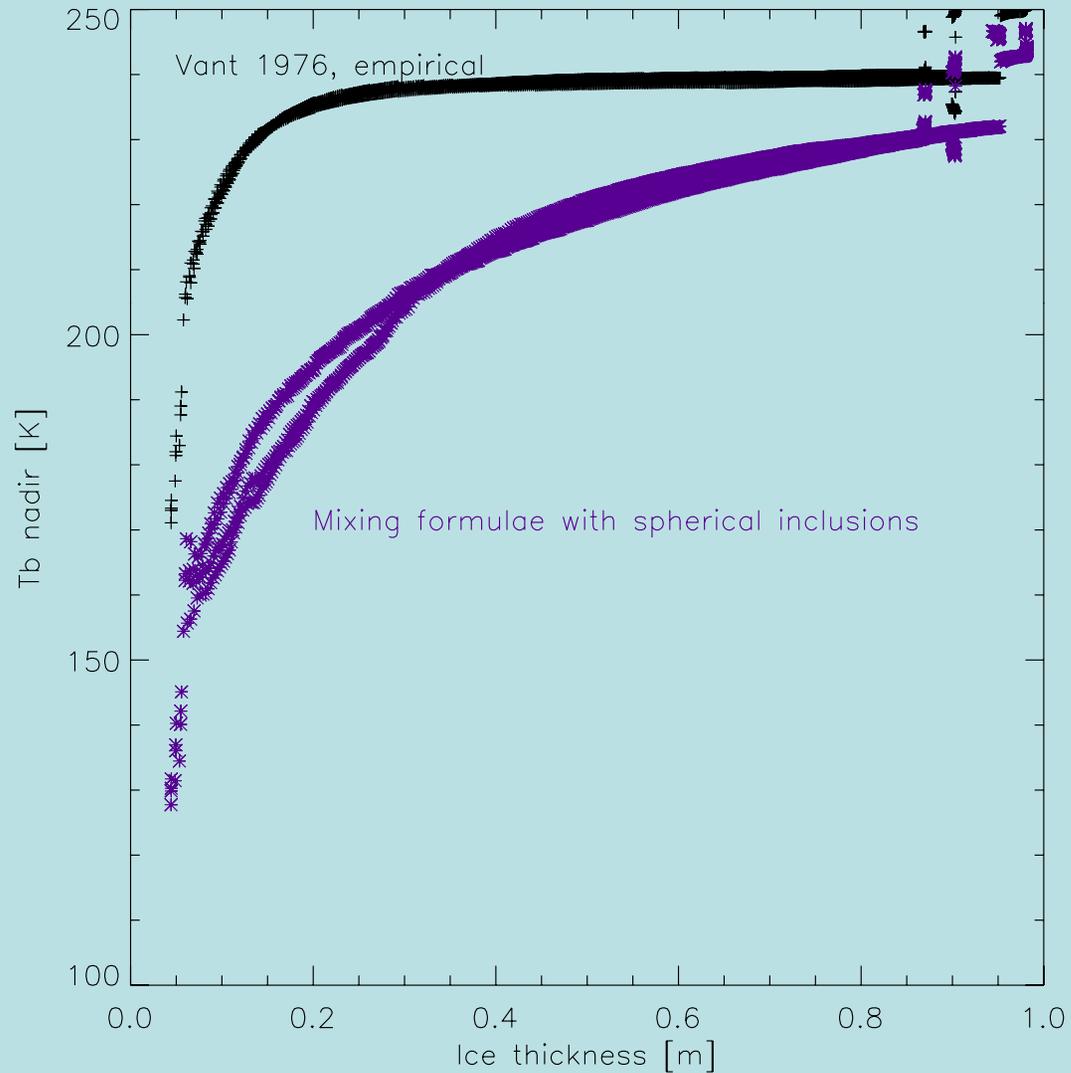
where ρ_{si} is the density of the sea-ice sample and ρ_i is the density of pure ice (0.916 g cm⁻³). For a low-loss material such as pure ice,

$$n_i' \cong \sqrt{\epsilon_i'} = \sqrt{3.15} = 1.78, \quad (E.77)$$

$$n_i'' \cong \frac{\epsilon_i''}{2\sqrt{\epsilon_i'}} = 0.28 \epsilon_i'', \quad (E.78)$$

where ϵ_i' is equal to 3.15 and is temperature-independent (see Section E-3). Gloersen and Larabee (1981) compared calculated values of n_{si}' and n_{si}'' with values measured at 10 GHz. In their calculations, they used the values of $\epsilon_i''(T)$ reported by Cumming (1952), which are given in Fig. E.4, at approx-

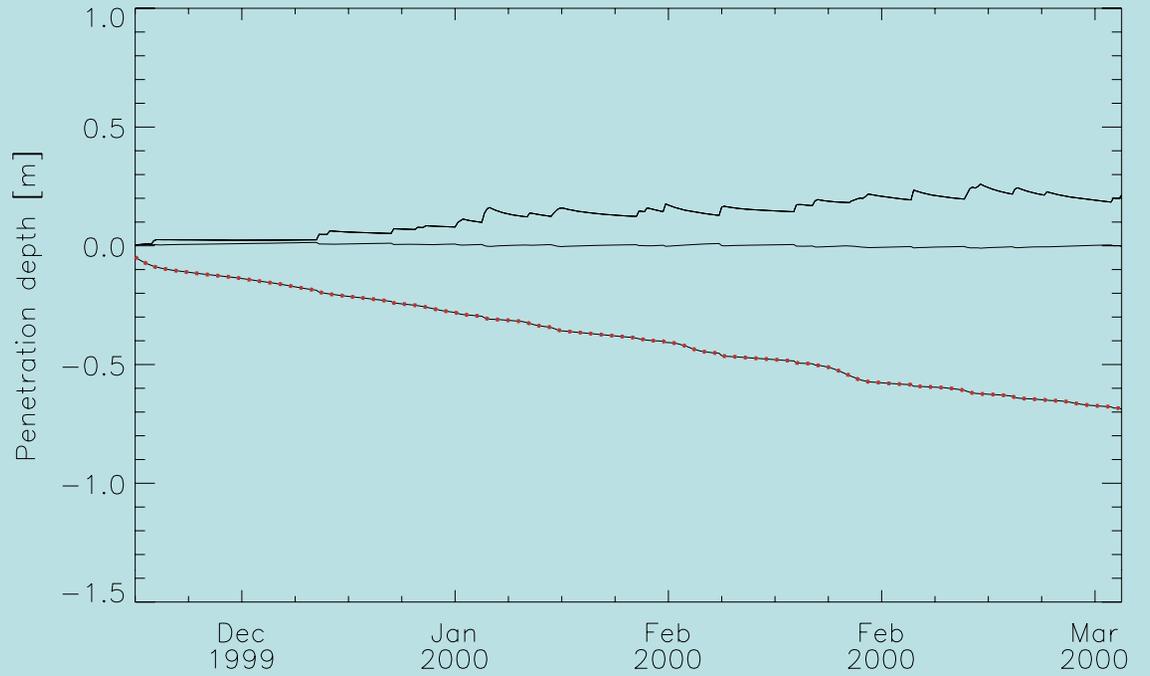
Sea ice permittivity at L-band?



Conclusions

- Penetration in multiyear ice is about 2.5m
- Penetration in first-year ice is about 0.5m
- Penetration in Baltic ice is to the ice-water interface
- Multiyear ice emissivity is greater than first-year ice emissivity because multiyear ice has lower reflectivity ($e=1-r$).
- Surface density (or the reflectivity) is more important for nadir and e_{54h} than e_{54v} .
- **The brightness temperature is a function of ice thickness when the ice is optically thin (thickness < 0.5m). This information would be complimentary to the objectives of CryoSat.**

Baltic 65N 25E near Oulu



The ice is optically thin and the emissivity variability is related to temperature

