Automatic estimation of seasonal sea ice thickness with MODIS data

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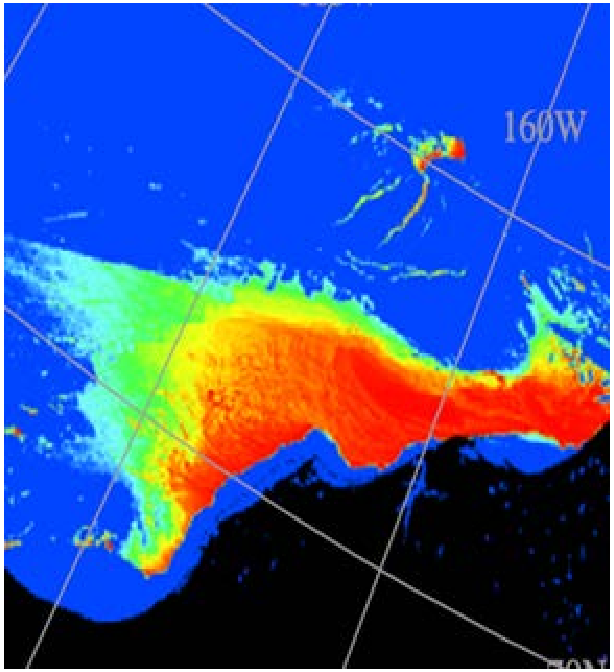
Why thin ice thickness?

- Sea ice is an important component in the climate system
- Sensitive indicator of climate change
- Areas of thin ice important for ship navigation
- Useful in numerical weather forecasting

Basic idea

- Heat from the water beneath thin sea ice penetrates the ice
- Heat flux through the ice is assumed inversely proportional to the ice thickness
- If the surface temperature and atmospheric conditions are known, the ice thickness can be estimated



Thermal radiation penetrates sea ice as observed with NOAA AVHRR. Chukchi Sea, northern Alaskan coast

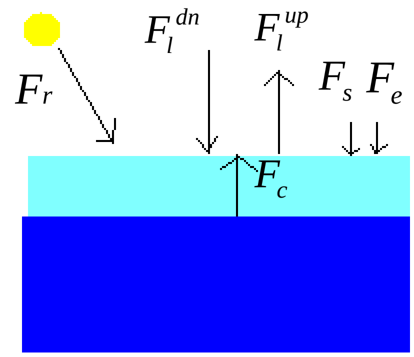
The ice thickness model

- Model by Yu & Rothrock (1996)
- Can model the heat flux on the ice surface as

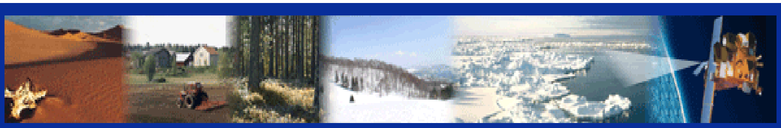
$$F_{total} = F_r - F_l^{up} + F_l^{dn} + F_s + F_e + F_c$$

- Thermal equilibrium: $F_{total} = 0$
- Night images: $F_r = 0$
- First approximation: $F_s = F_e = 0$

$$F_l^{dn} - F_l^{up} + F_c = 0$$



F_r: solar radiation heat flux
F_l^{up}: upwelling longwave heat flux
F_l^{dn}: downwelling longwave heat flux
F_s: turbulent sensible heat flux
F_e: latent heat flux
F_c: conductive heat flux

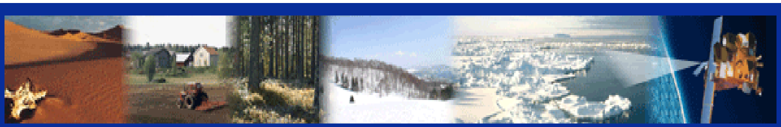


The ice thickness model

$$F_c = \frac{k_i k_s (T_f - T_s)}{k_s H + k_i h}$$

T_f: freezing temperature of sea water
T_s: surface temperature of ice/snow
T_a: air temperature
h: snow thickness
H: ice thickness
ε: emissivity

- Assume empirical models for snow thickness, h(H), thermal conductivity of sea ice, k_i (S), and sea ice salinity, S(H) (Yu & Rothrock, 1996)
- Thermal radiation: $F_l^{up} = \varepsilon_i \sigma T_s^4 \quad F_l^{dn} = \varepsilon_a \sigma T_a^4$
- Given values for T_s and T_a we can solve for ice thickness, H



Daytime images

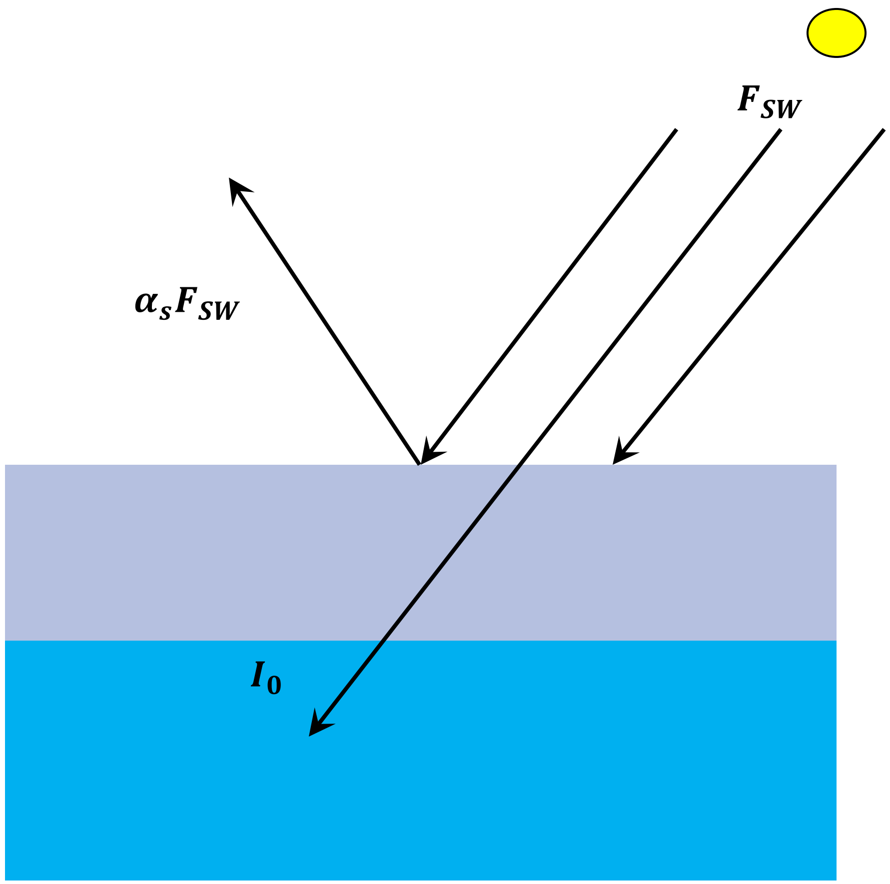
- To study Arctic areas in summer season
- All bands available – better cloud masking
- Need to describe heat flux from solar radiation

Solar radiation flux

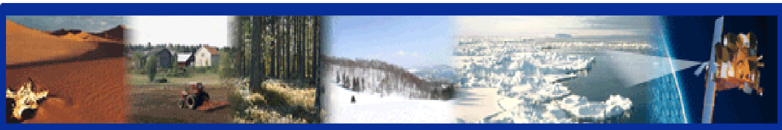
$$F_r = (1 - \alpha_S)F_{SW} - I_0$$

$$I_0 = i_0(1 - \alpha_S)F_{SW}$$

Use parametrizations for shortwave flux, F_{SW} (Zillman, 1972), albedo, α_s and transmittance, i_0 (Grenfell,1979).



$$F_r + F_l^{dn} - F_l^{up} + F_c = 0$$

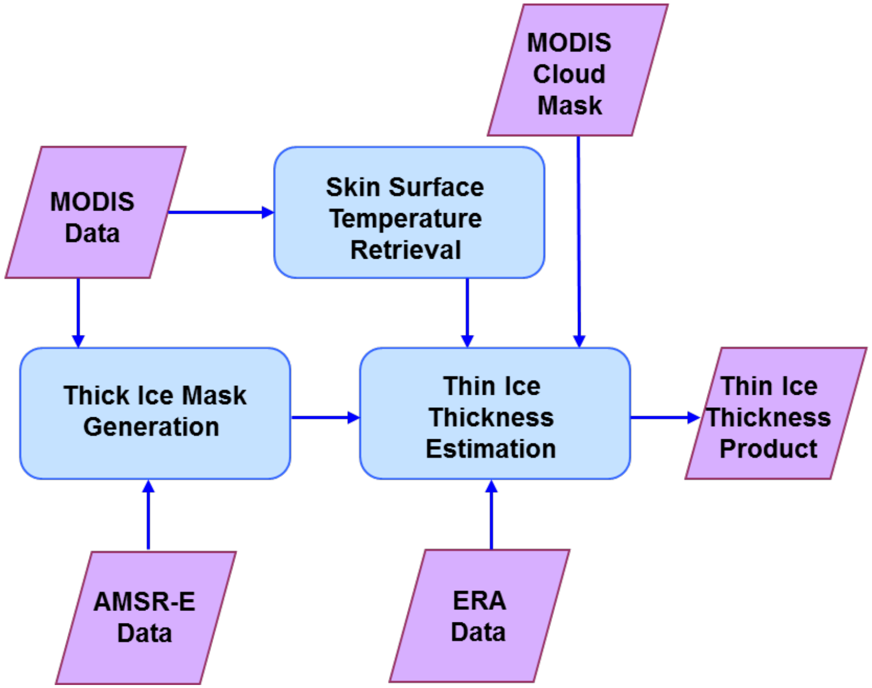


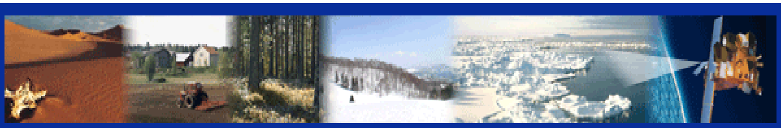
Approach and processing chain

- Get T_s (via Key's algorithm) from thermal MODIS bands of Aqua
- T_a from re-analysed ERA 2m air temperature data
- Estimate ice thickness, H, for every pixel in MODIS image
- Use Aqua AMSR-E microwave images to exclude areas with thick ice:

$$\frac{T_{89GHz}}{T_{19GHz}} > 1$$

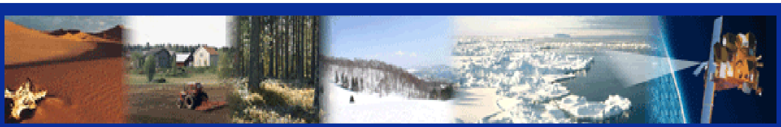
- Mask out land
- Use official MODIS cloud mask





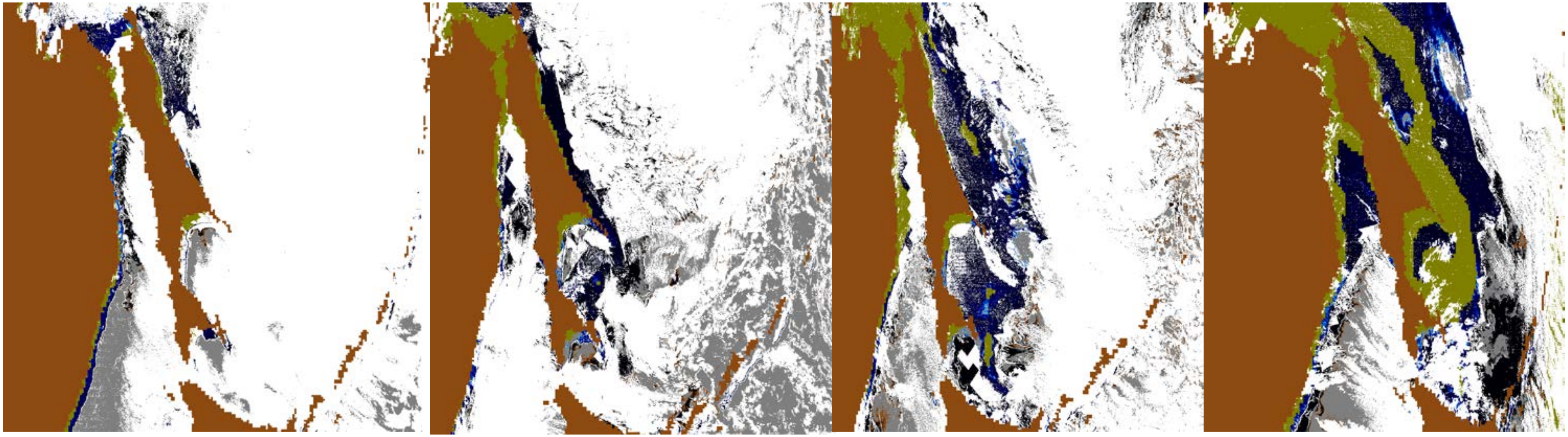
Area for testing

Sea of Okhotsk, December 15, 2008 – March 1, 2009



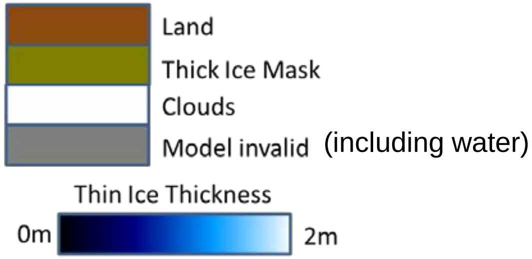
Preliminary results: Night Images

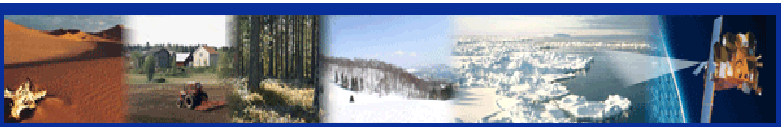
Sakhalin Island (in Sea of Okhotsk)



December 18, 2008 **January 12, 2009** **February 6, 2009** **February 25, 2009**

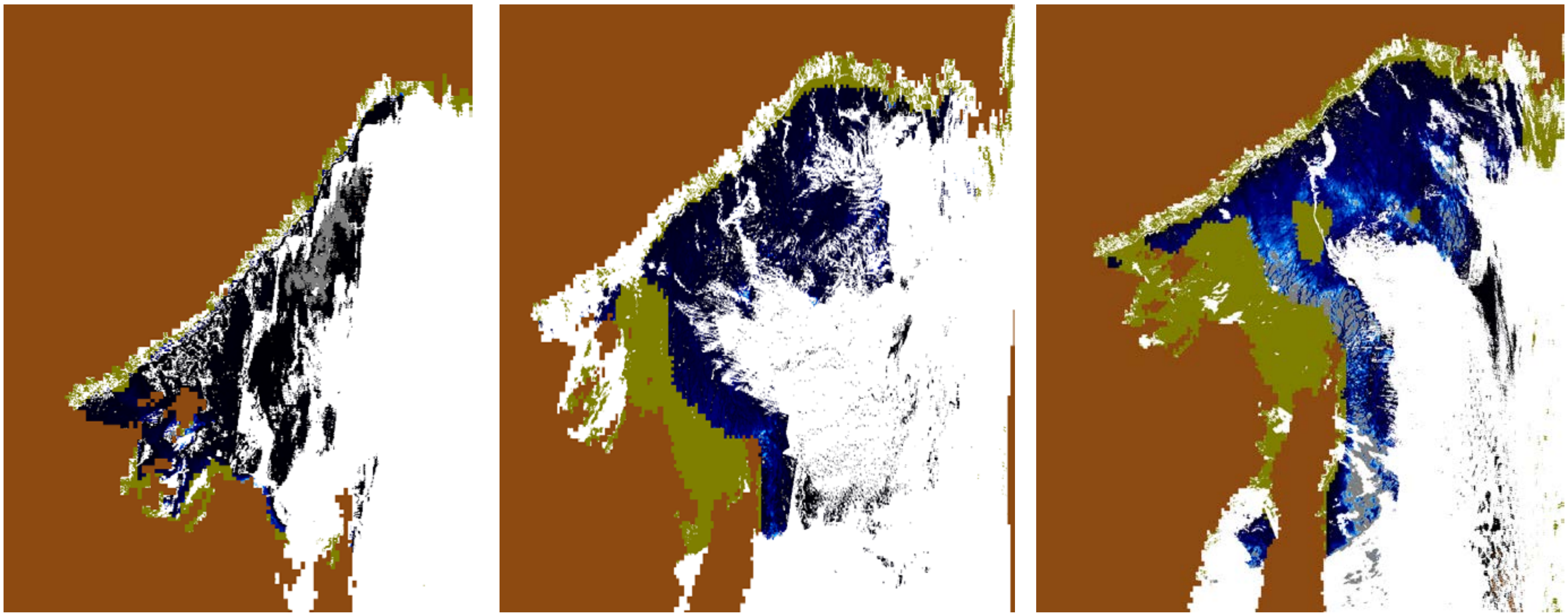
- Shows ice growth through the winter
- Poor cloud masking



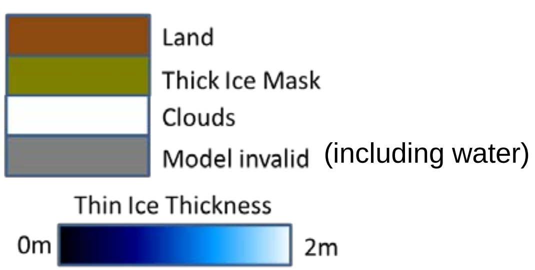


Preliminary results: Day Images

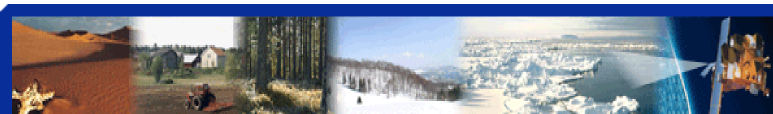
Sea of Okhotsk



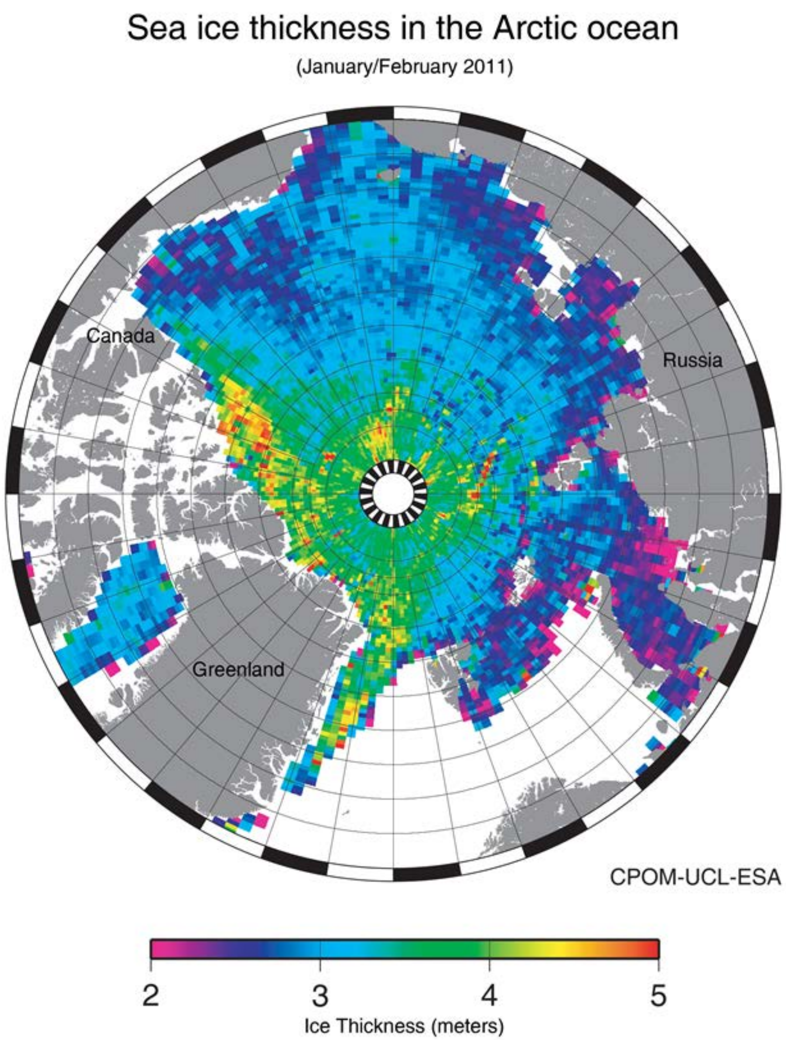
January 2, 2009 **January 15, 2009** **January 22, 2009**



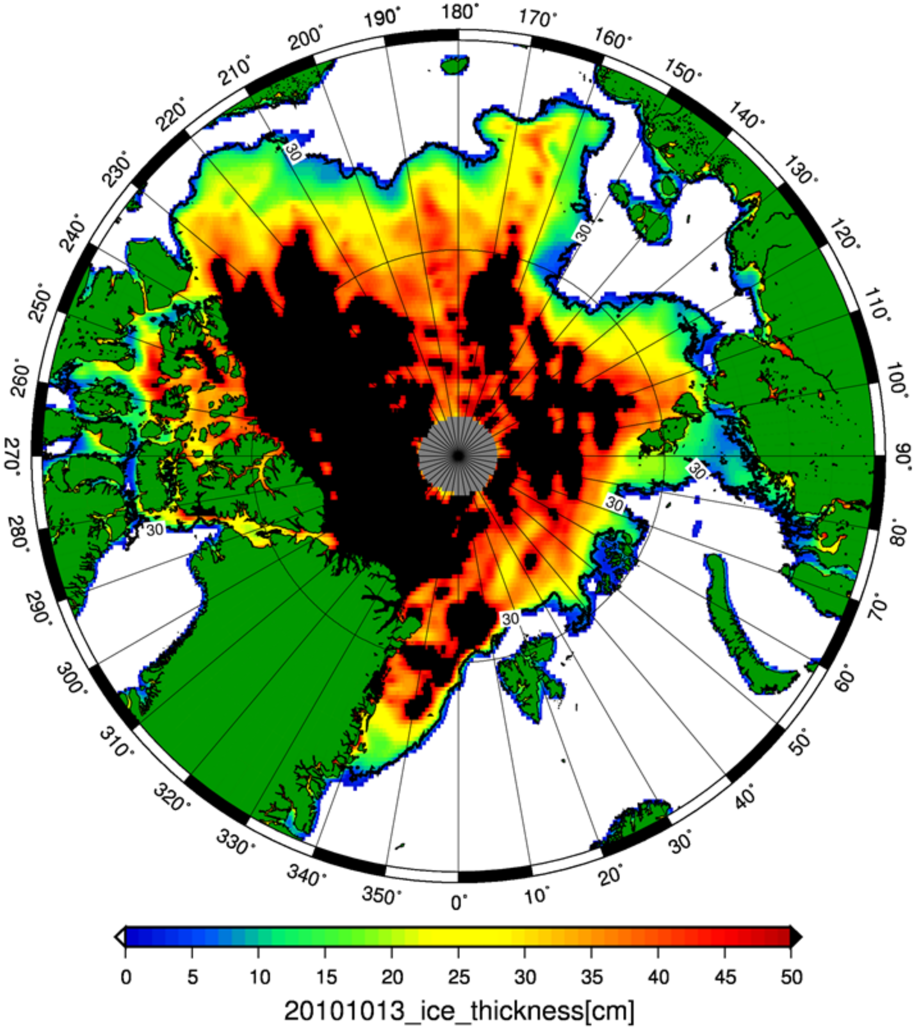
- Shows ice growth in Sea of Okhotsk
- Improved cloud masking
- Algorithm breaks down when ice gets too thick



CryoSat sea ice thickness



SMOS sea ice thickness

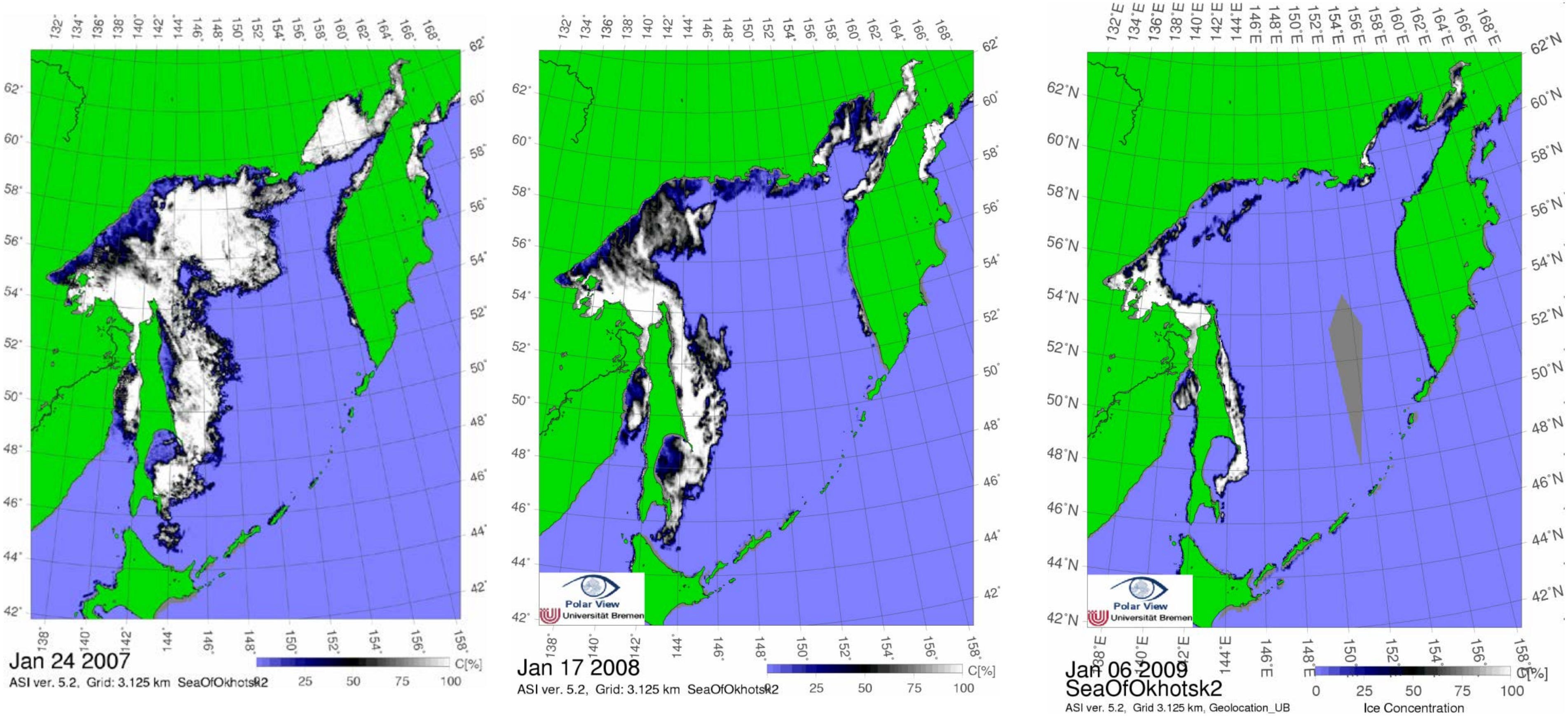


- **All data of Oct 13, 2010**
- **RFI filtered out**
- **Overall plausible**

To validate:

- **Thin ice: thickness**
- **Thick ice**
- **Open Water (excluded here)**

AMSR-E, SSM/I sea ice concentration



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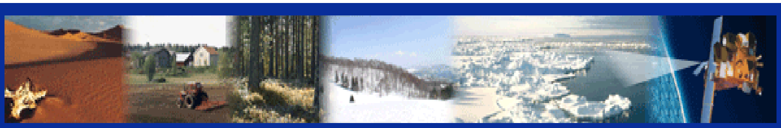
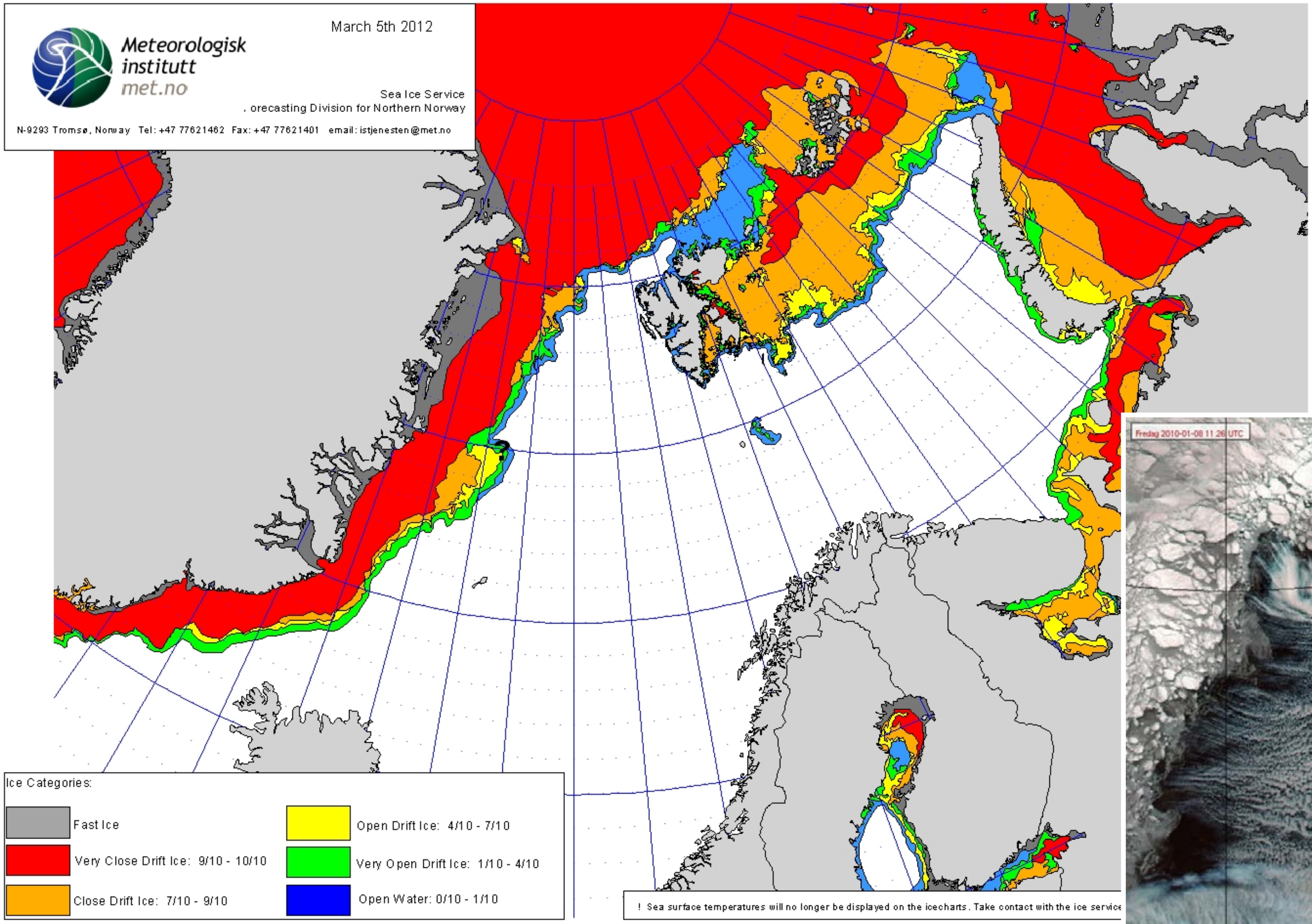
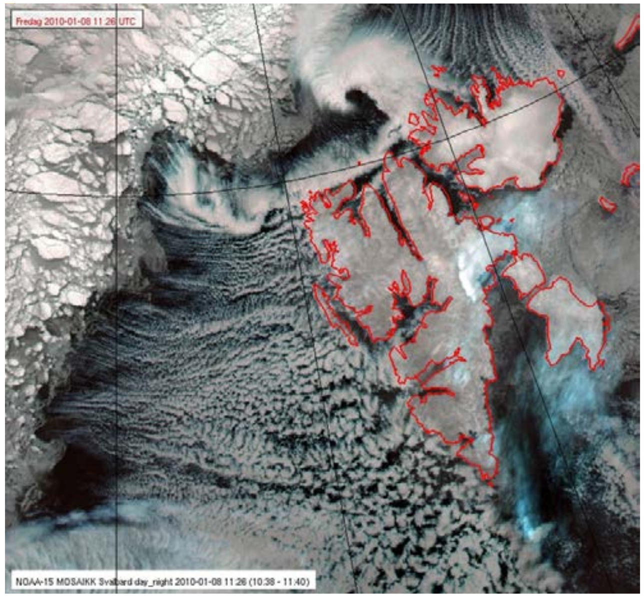
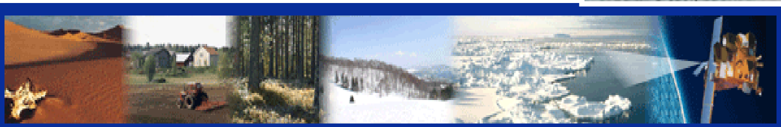


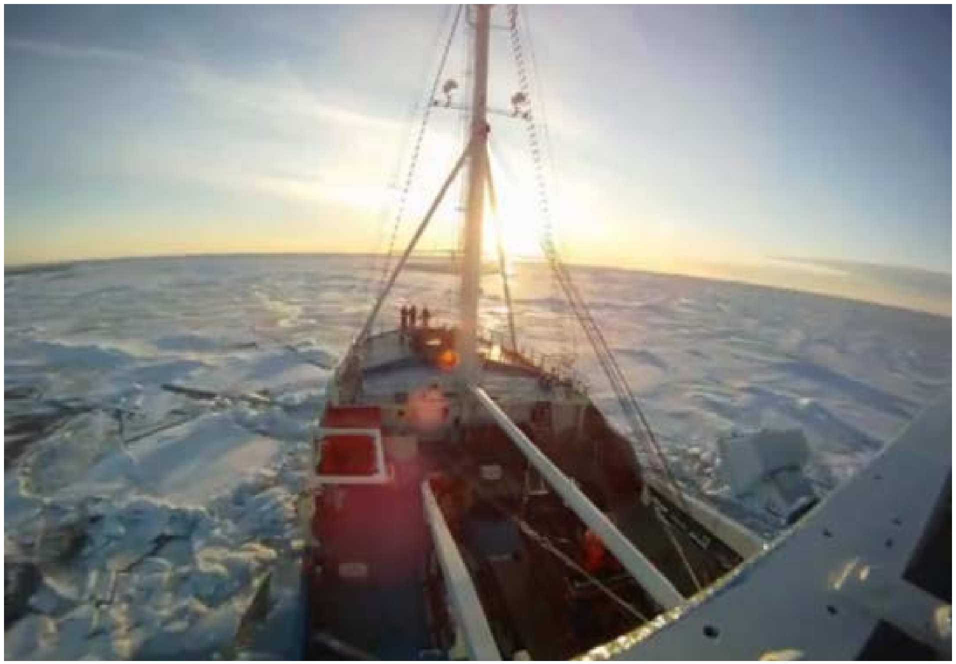
Sea ice charts from METNO



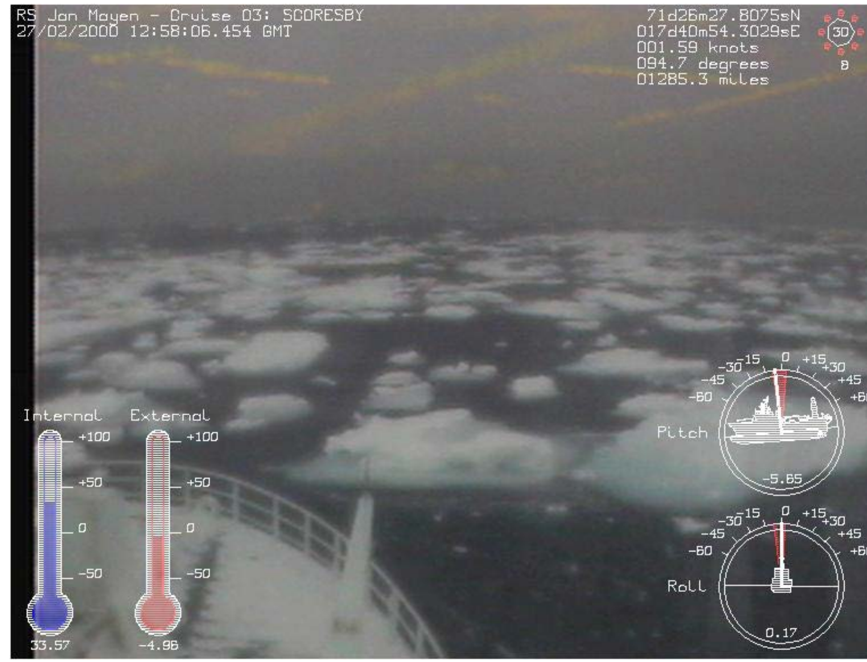




NPI Lance and ice cam



Lance 20 August 2012



Ice Cam sea ice camera system

Synchronises all observation parameters into one database:

- **Image**
- **Latitude and longitude**
- **Time stamp**
- **Pitch and roll**
- **Meteorological readings**

Overall conclusions and way forward

Overall conclusions:

- Automatic production of high resolution sea ice thickness maps (~1 km)
- Has applications in ship navigation, NWF, climate studies and studies of microwave ice products
- May be adapted to inland lake ice thickness monitoring
- Results so far look plausible, but there has been a lack of validation data in general

Way forward:

- Much to be gained by improved modelling of heat fluxes
- Improved cloud masking
- Validation based on new datasets available