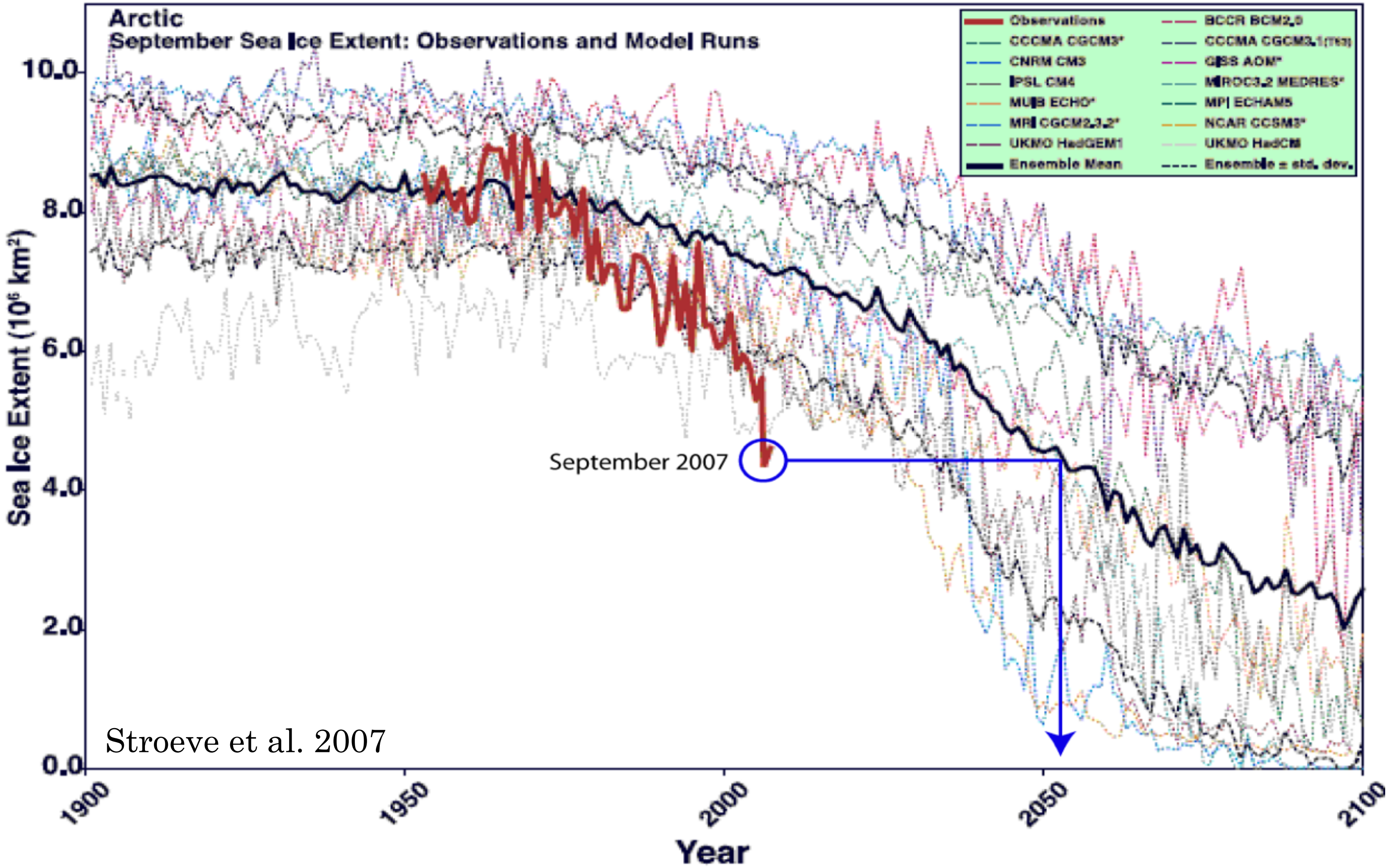
INCORPORATION OF A PHYSICALLY-BASED MELT POND SCHEME INTO CICE

Daniela Flocco
Centre for Polar Observation and Modelling
University College London

OUTLINE

- Why study melt ponds
- Melt pond formation, evolution and refreezing
- Melt pond modeling results

MODELS VS OBSERVATIONS



AN OUTLINE

Global warming

AN OUTLINE

Global warming

The polar regions

AN OUTLINE

Global warming

The polar regions

Melt ponds

ALBEDO

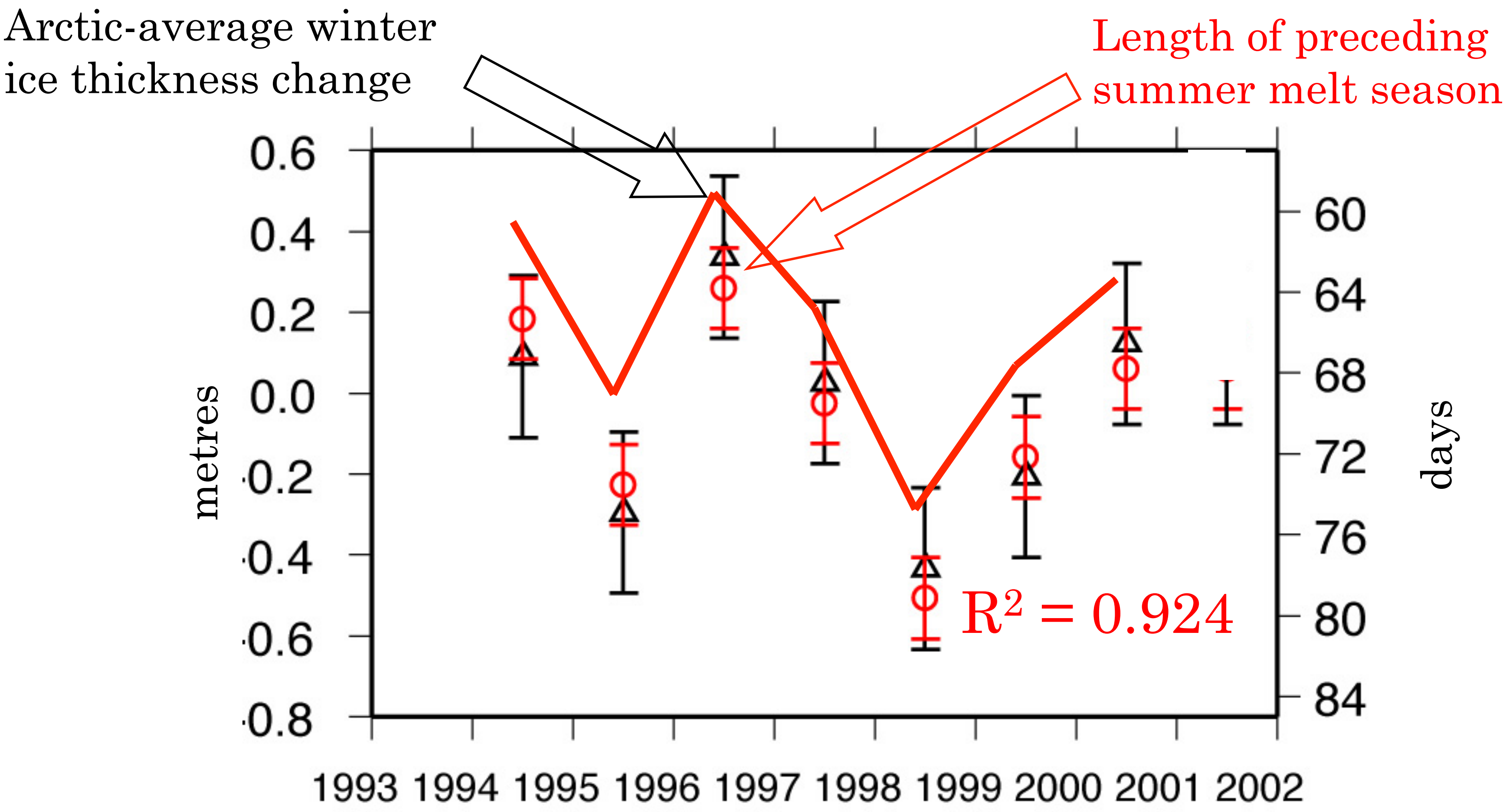



ICE ALBEDO FEEDBACK

- Global warming is intensified in polar regions due to the albedo feedback mechanism [IPCC, 2007]: since ice and snow is highly reflective compared to other surface types, a reduction in the ice or snow coverage due to melting results in enhanced absorption of solar radiation, which leads to further melt and local warming ($\alpha_{snow} = 0.8$, $\alpha_{ocean} = 0.1$, $\alpha_{grass} = 0.3$).

- Satellite observations show that a decrease in successive years of winter ice thickness is correlated with the length of the intervening melt season, with an R^2 of 0.98 (Laxon et al, 2004). As a result of the albedo feedback mechanism, Arctic sea ice is a sensitive indicator of climate change.

SEA ICE MASS BALANCE



Using ERS satellite data, strong correlation found between ice thickness and length of previous melt season (Laxon *et al*, *Nature*, 2003)

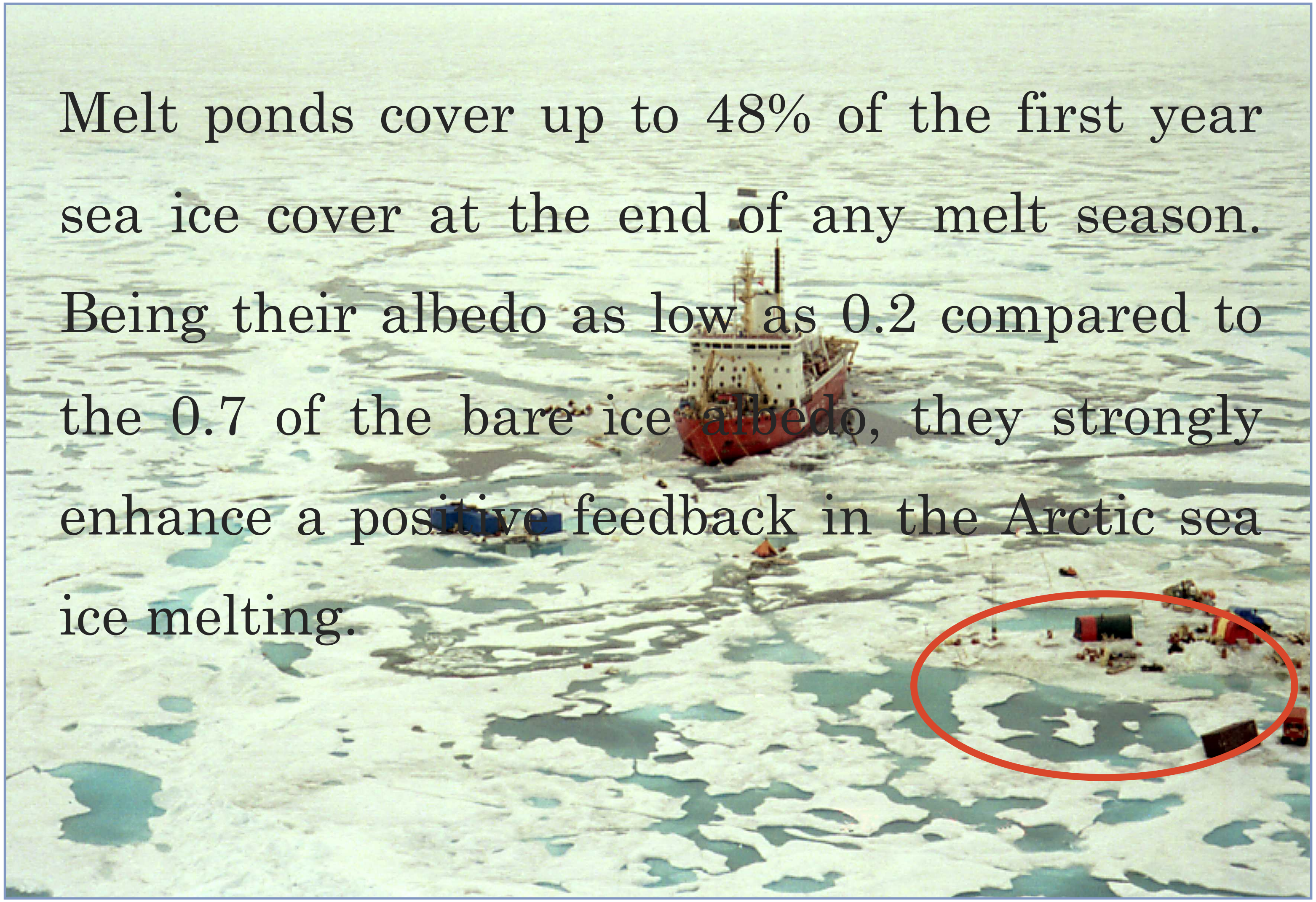
MELT PONDS FORMATION

- Melt ponds form on Arctic sea ice during summer (rarely seen in Antarctic)
- In spring from snow and ice melt due to absorbed solar, short wave radiation
- Pond coverage ranges from 5—50%
- Albedo of pond-covered ice (0.15—0.45) < albedo of bare sea ice or snow covered ice (0.52—0.87)
- Ponded ice melt rate is 2—3 times greater than bare ice

MELT PONDS: CONSIDERATIONS

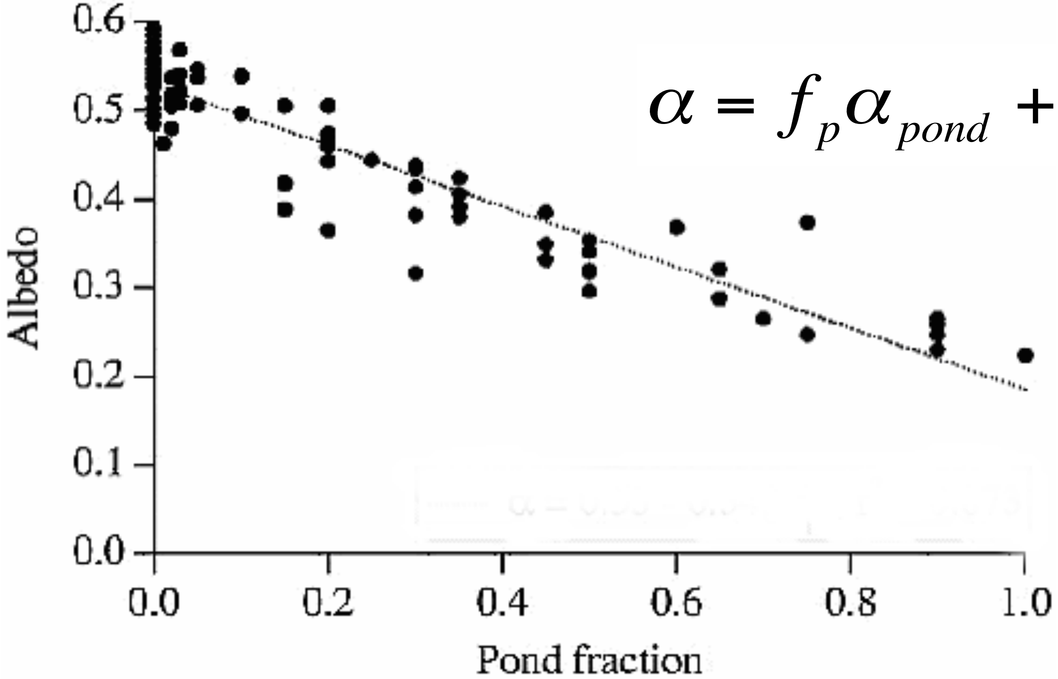
- Surface melting is enhanced by the presence of ponds
- Melt pond area is greater on thin ice than on thick ice

MELT PONDS



Melt ponds cover up to 48% of the first year sea ice cover at the end of any melt season. Being their albedo as low as 0.2 compared to the 0.7 of the bare ice albedo, they strongly enhance a positive feedback in the Arctic sea ice melting.

MELT PONDS AND SEA ICE ALBEDO



$$\alpha = f_p \alpha_{pond} + \left(1 - f_p\right)\alpha_{ice}$$

Albedo α as a function of pond areal fraction *fp* for first-year sea ice at Barrow on 4 June 2001 (Eicken et al 2004)

In terms of the heat budget of the Arctic, a change in mean albedo of 0.1 (e.g. a change in f_p of 20%) is equivalent to a change in sea ice extent of 10%.

Uncertainty in model albedos is much greater than this!

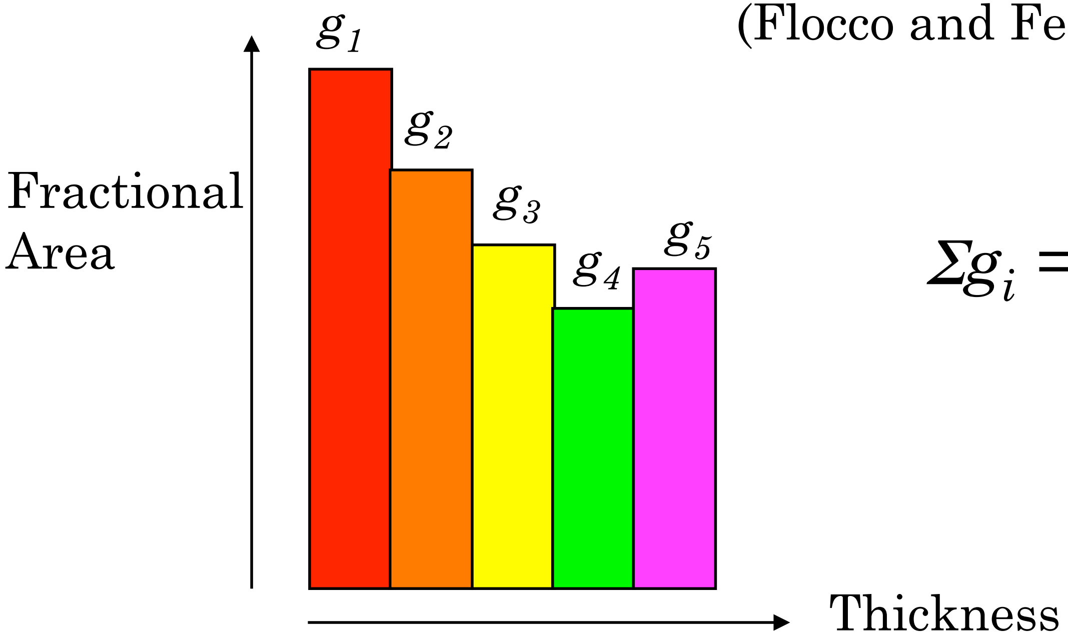
GCM-COMPATIBLE MELT POND MODEL

Requirements of constructing a melt pond model for use in existing GCMs places strong constraints on the form the model can take.

Main difficulty is that GCMs do not determine the sea ice topography.

Modern GCMs contain a thickness distribution function *g(h)*.

(Flocco and Feltham, JGR, 2007)



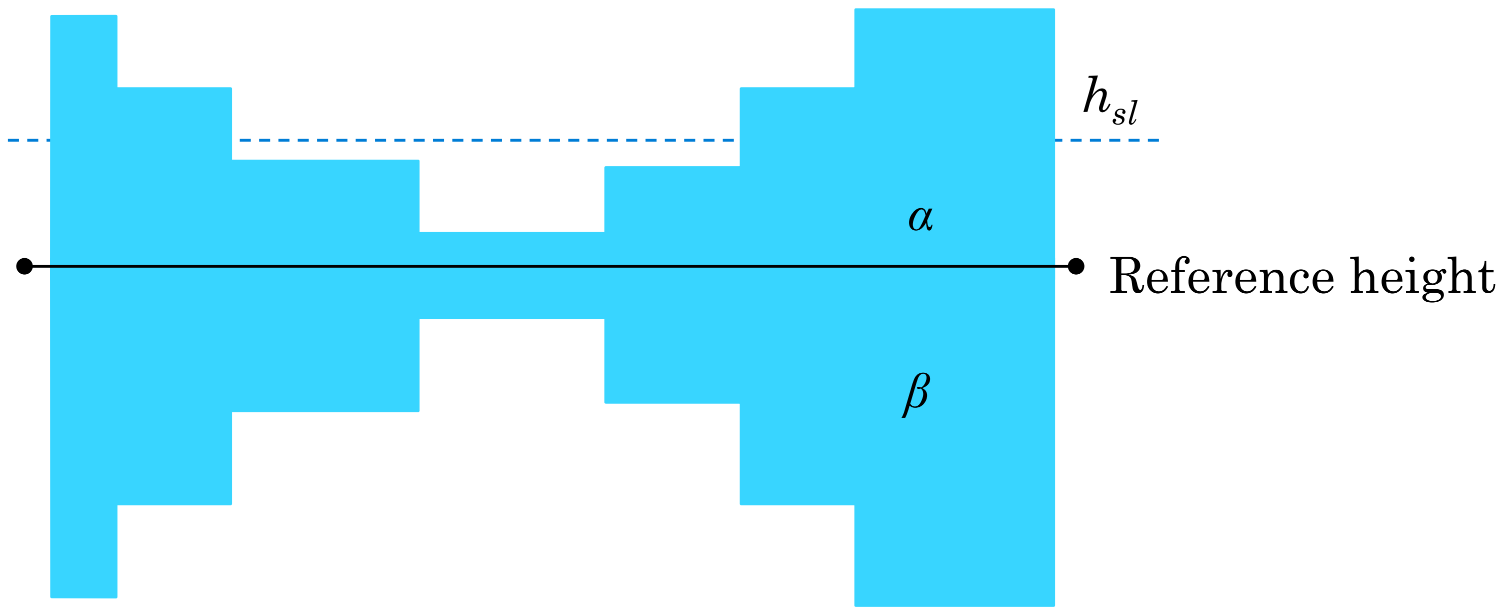
$$\Sigma g_i = 1$$

HEIGHT AND DEPTH DISTRIBUTION FUNCTION

To redistribute surface water, we need information about the surface height.

We introduce surface height $\alpha(h)$ and basal depth $\beta(h)$ distributions, which give the relative area of ice of a given surface height or basal depth.

We derive $\alpha(h)$ and $\beta(h)$ from the thickness distribution $g(h)$.



NOTE: $\alpha(h)$ and $\beta(h)$ **do not** describe the topography.

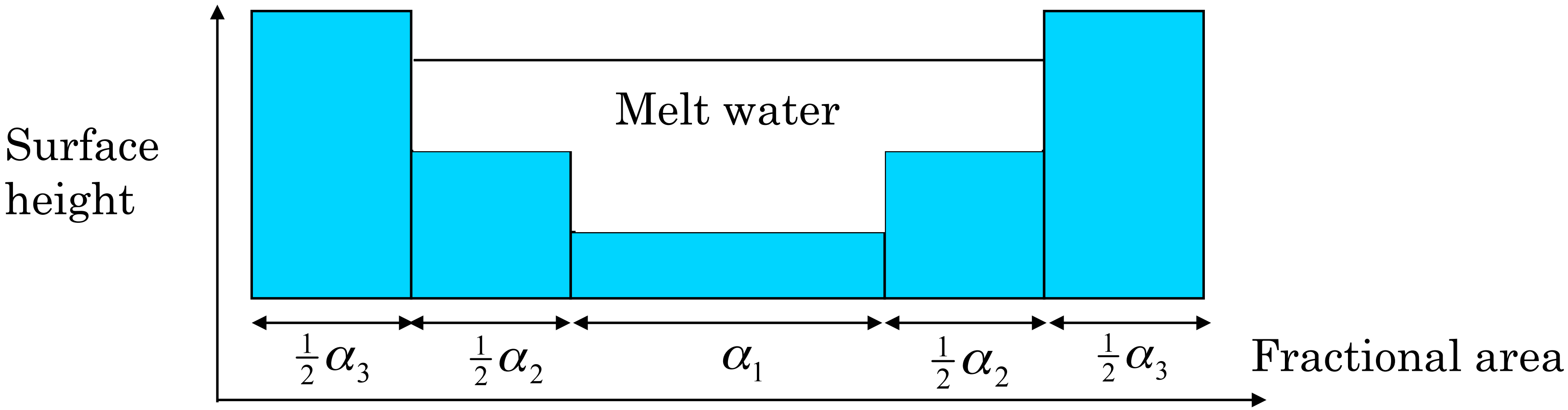
HORIZONTAL REDISTRIBUTION OF MELTWATER

- ASSUMPTION: Any point on the ice cover is surrounded by ice of all surface heights, with the relative fraction of ice of given height given by the surface height distribution *g(h)*.

  Given the presence of ice of all surface heights, surface melt water will tend to collect on ice of the lowest surface height.

- ASSUMPTION: Melt water is transported laterally to the lowest surface height within one timestep of a GCM model.

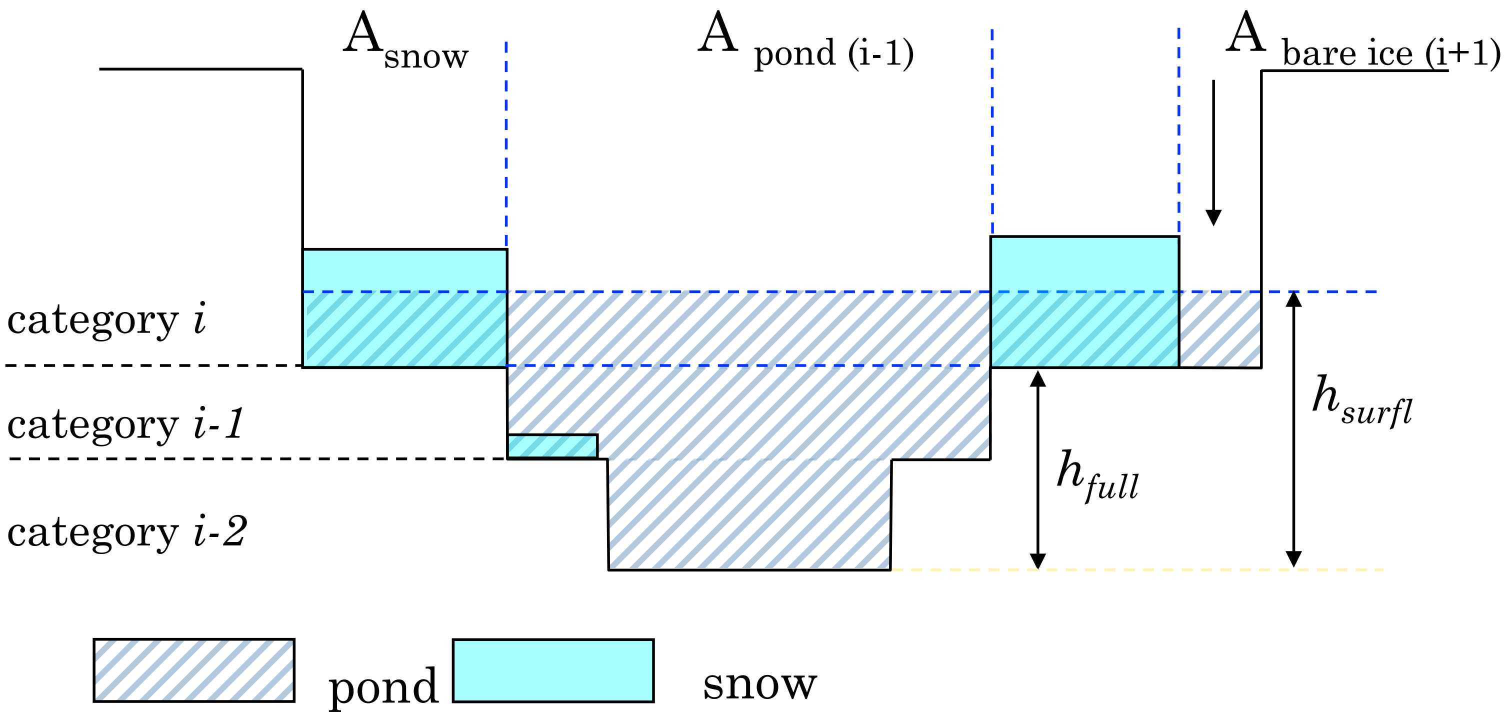
  Surface meltwater "fills up" the surface, covering ice of lowest height first.



MELT POND MODEL STRUCTURE

- Initialize surface and basal distribution α and β, and snow distribution
- Evolution of the ice distribution and calculation of the volume of water from snow and ice melting
- Calculate the melt pond covered area and pond depth
- Enhance the snow and ice melting rate depending on pond presence
- Drainage of melt water

MELT POND THEORY

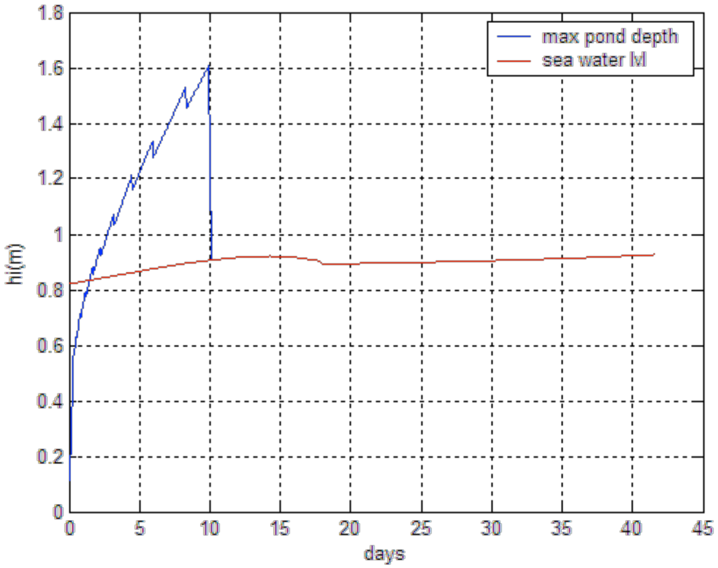


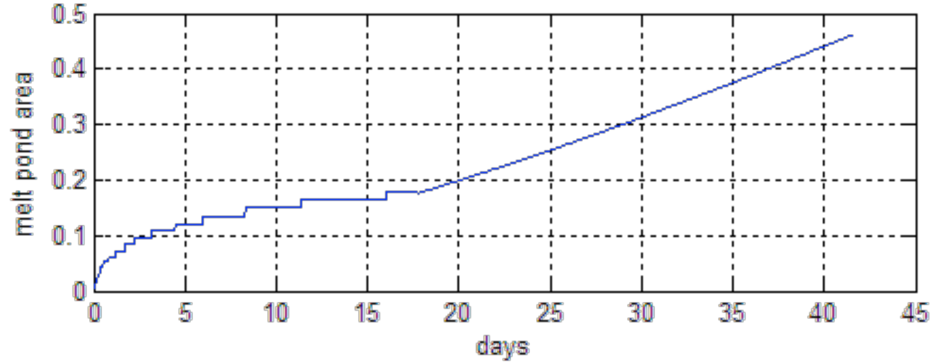
$$h_{surf} = \frac{Total\ Volume - Volume(h_{full})}{0.6 \cdot Area\ of\ Snow + Area\ of\ Bare\ Ice + \sum_{n=1}^{i} \alpha_n} + h_{full}$$

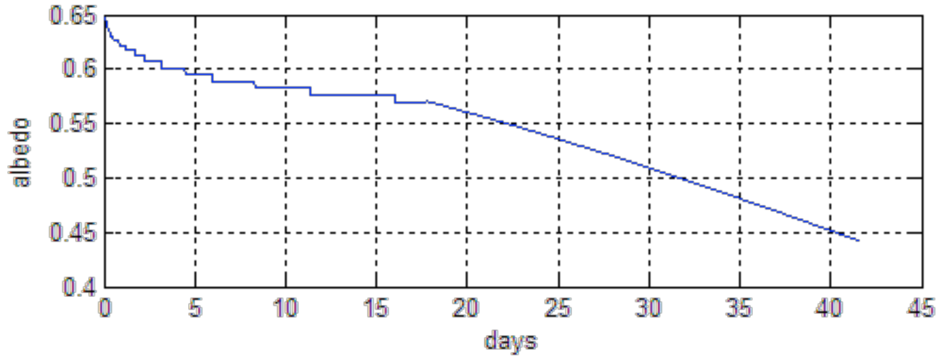
Flocco and Feltham (JGR, 2007)

STANDALONE MODEL RESULTS

Melt ponds cover about 45% of the floe area after one month

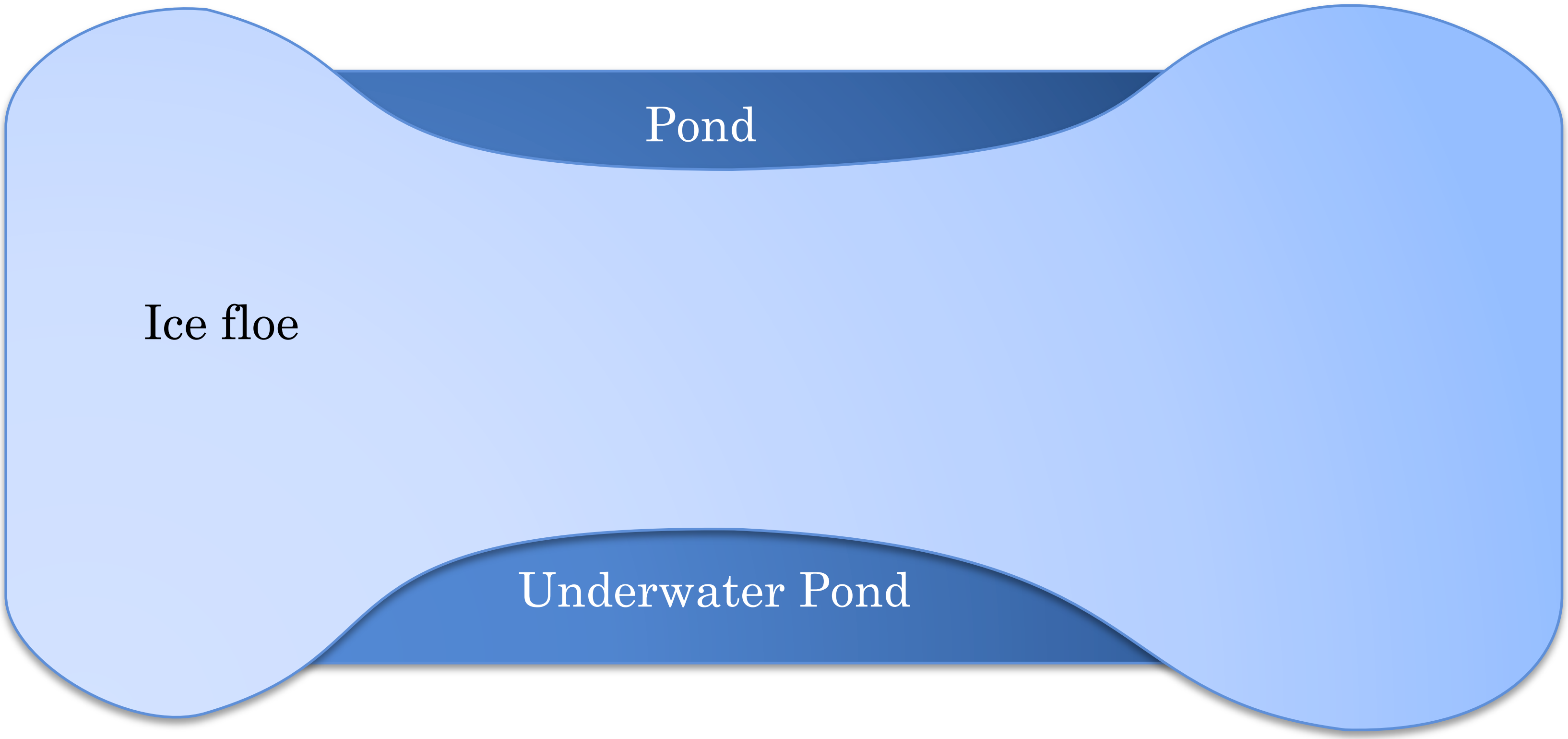




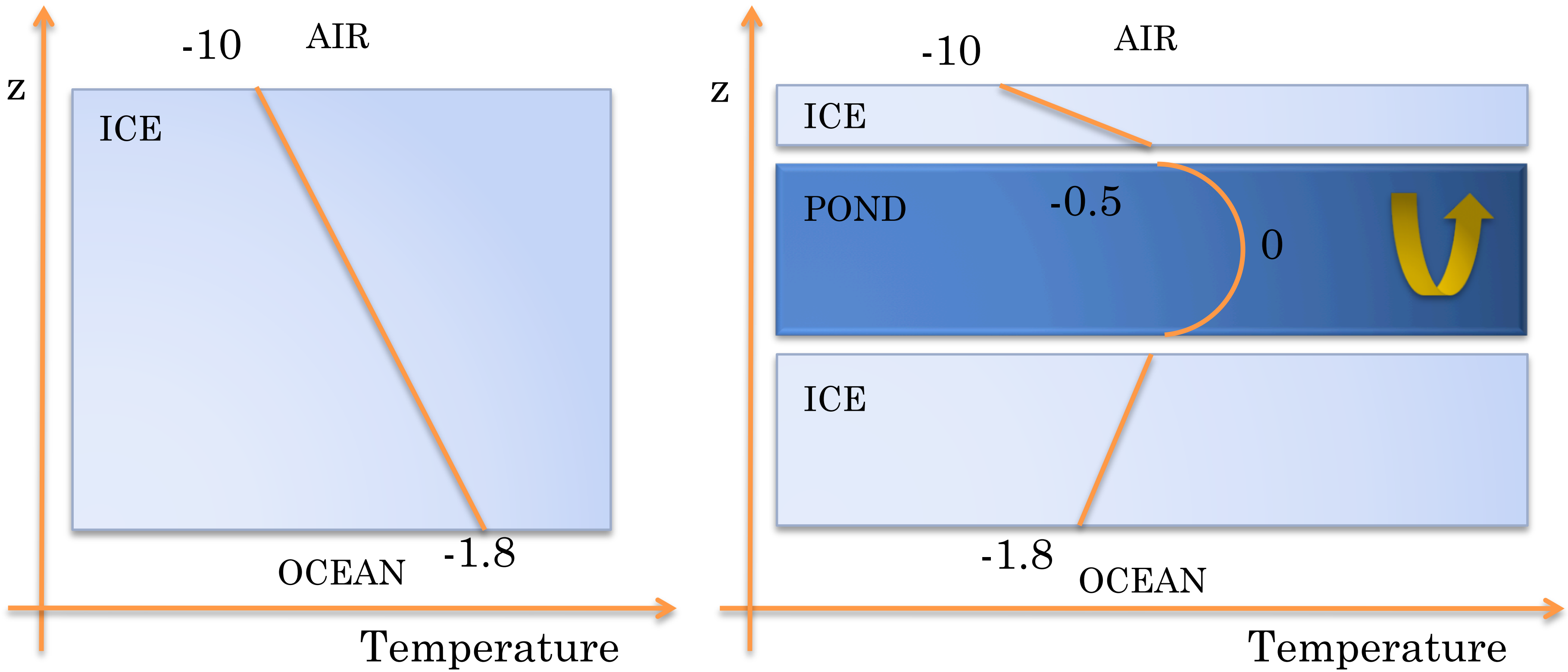


The albedo value decreases from 0.65 to 0.52 in one month

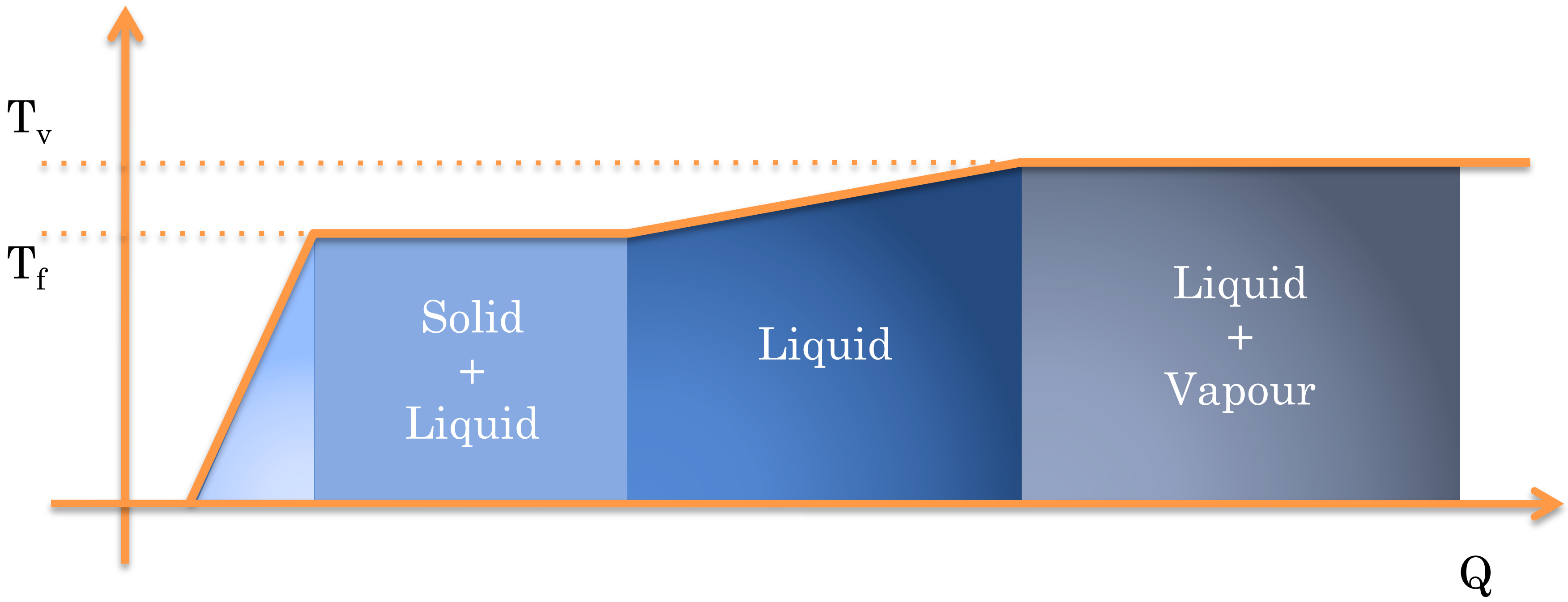
UNDERWATER PONDS



TEMPERATURE PROFILES



LATENT HEAT



PONDS REFREEZING

- Melt ponds freeze in September
- Underwater ponds are insulated by an ice layer and take up to 2-3 months to freeze completely

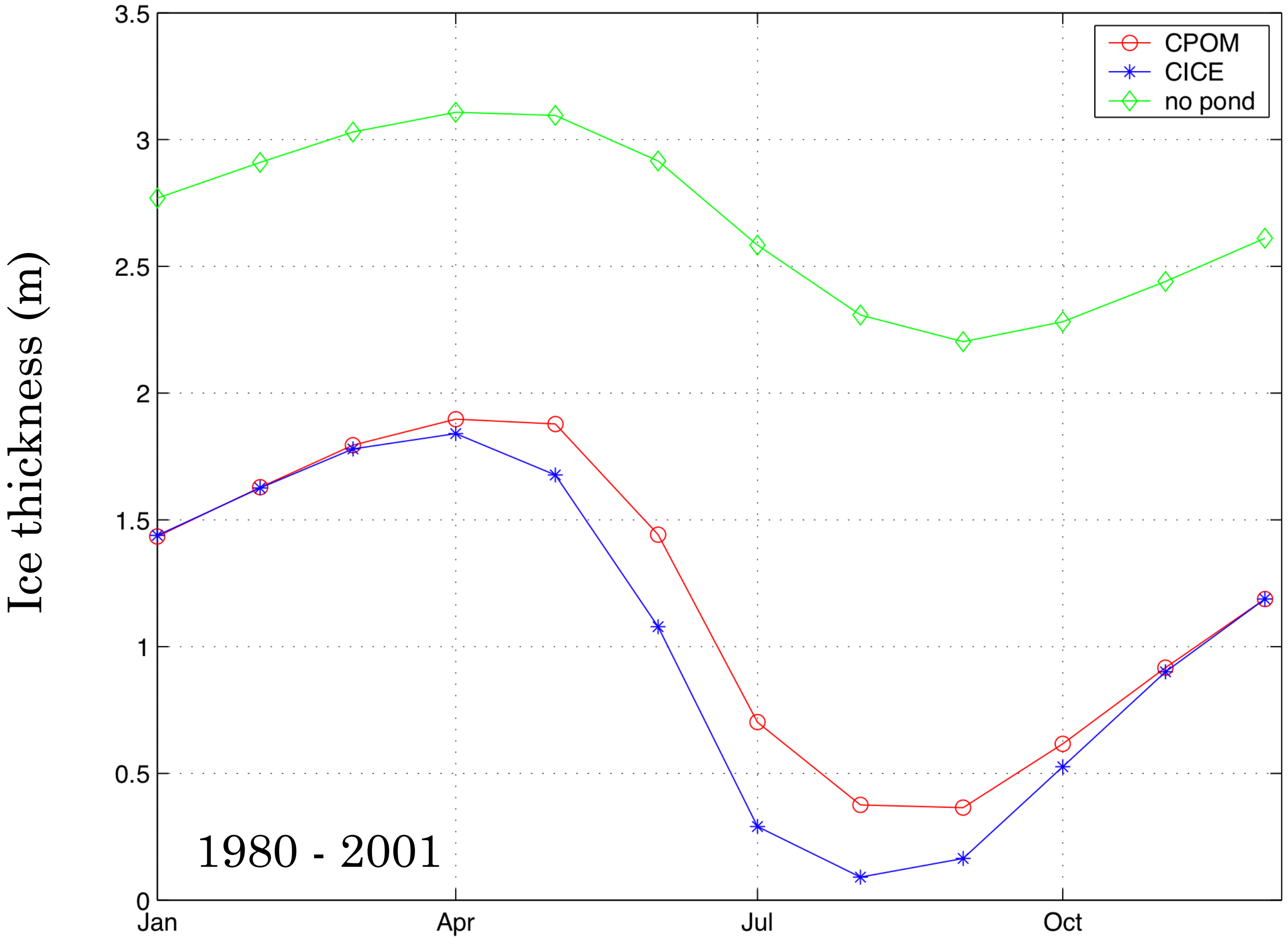
REFREEZING: STEFAN CONDITION

The thickening of the floating ice layer over the pond (H_{ui}) is only dependent on the temperature gradient difference between the two sides of the ice layer

$$\rho_s L \phi \frac{\partial H_{ui}}{\partial t} = k_m \frac{\partial T_{ice}}{\partial z} - k_l \frac{\partial T_p}{\partial z}$$

L_s = volumetric latent heat of fusion of pure ice (3.01×10^8 J m^{-3}),
Φ = solid fraction of sea ice,
K_m = thermal conductivity of sea ice (2 W m^{-1} K^{-1})
T_{ice} = temperature within the ice layer
K_l = thermal conductivity of the pond (0.5 W m^{-1} K^{-1})
T_p = temperature within the pond

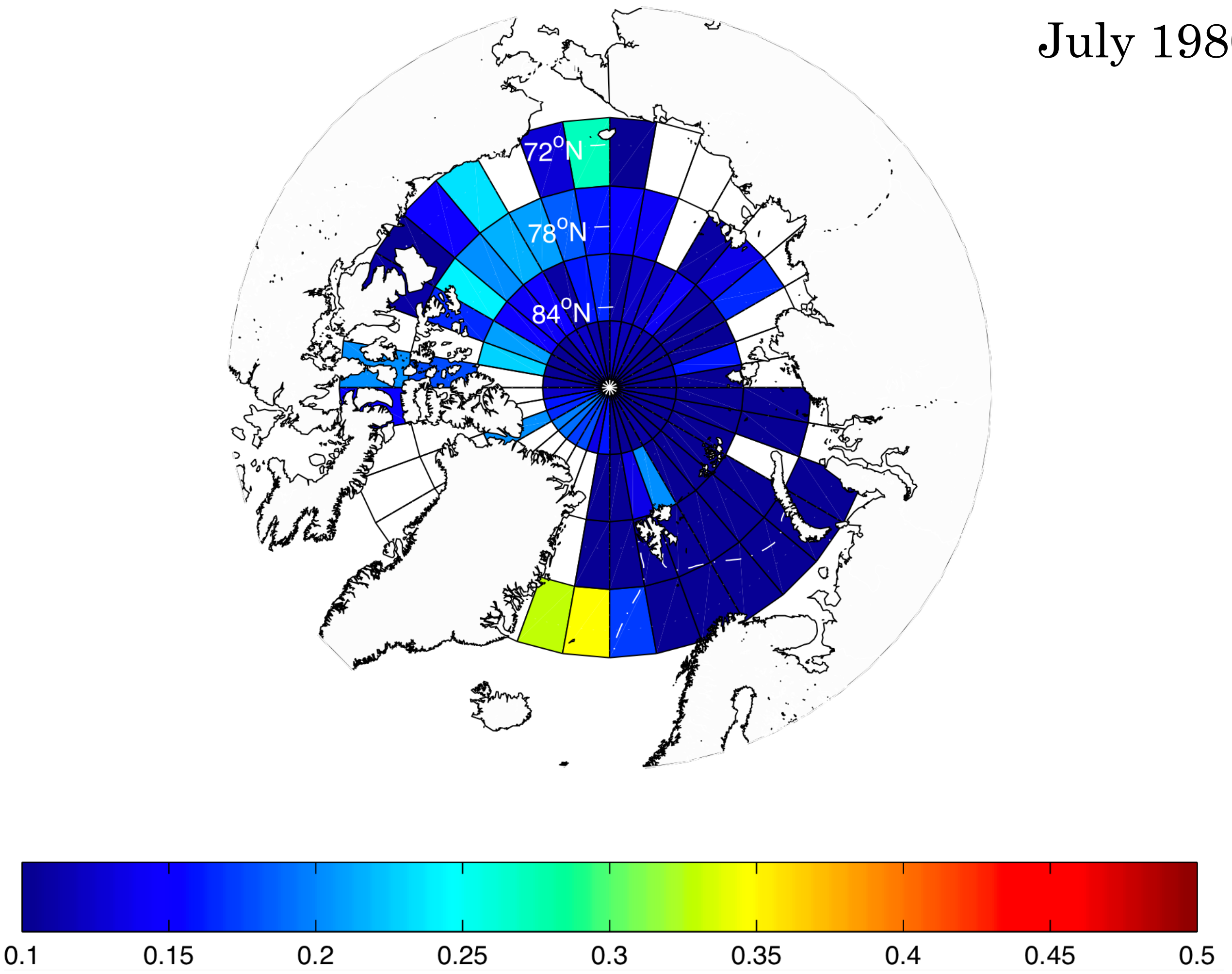
CICE RESULTS: ICE THICKNESS COMPARISON



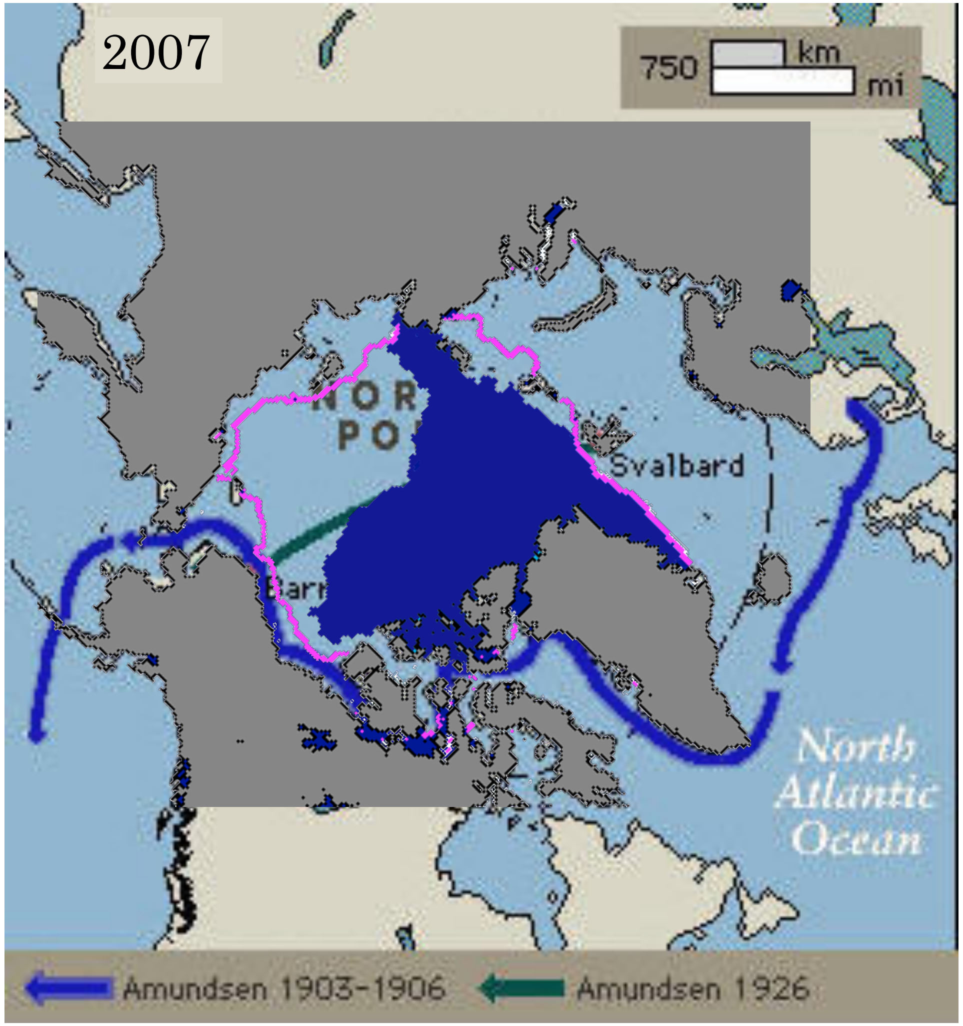
Flocco Feltham and Turner (JGR, *in press*)

POND AREA

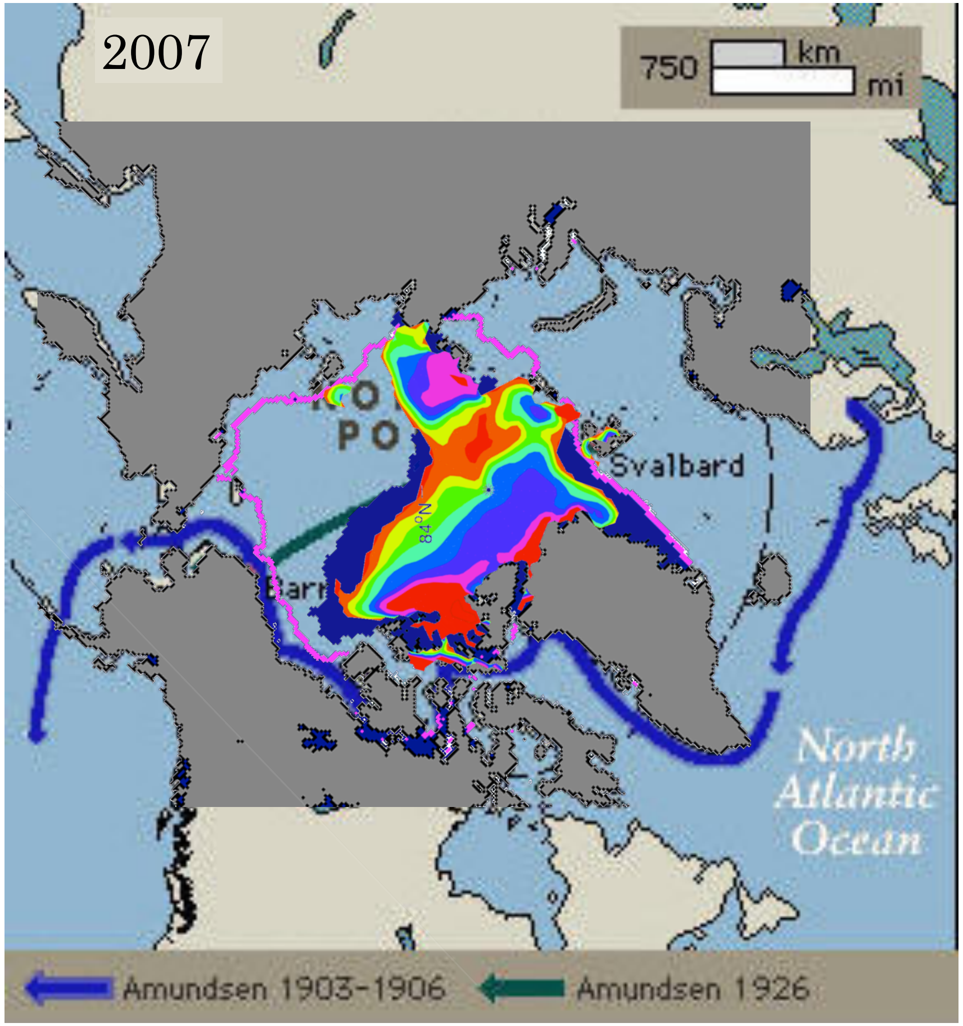
July 1980 - 2001



North west passage or Anián Strait…



North west passage or Anián Strait…



CONCLUSIONS

- We study melt ponds to quantify their importance for the increased melting rate due to global warming
- Global Circulation Models are sensitive to the presence of a melt pond routine
- We can run a model that describes well the sea ice extension in September 2007

Thank you