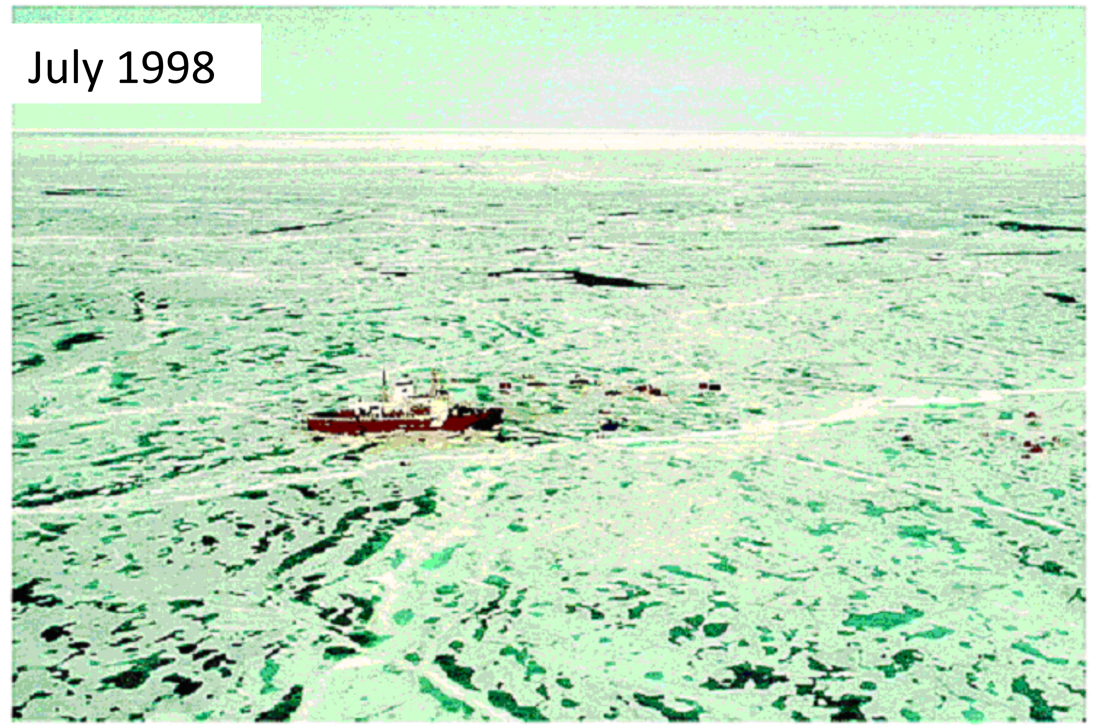
Putting the physics into sea ice parameterisations: a case study (melt ponds)

April 1998

Ice Station SHEBA. Canadian Coast Guard icebreaker *Des Groseilliers*.



July 1998

Danny Feltham
Centre for Polar Observation and Modelling,
University College London,
UK

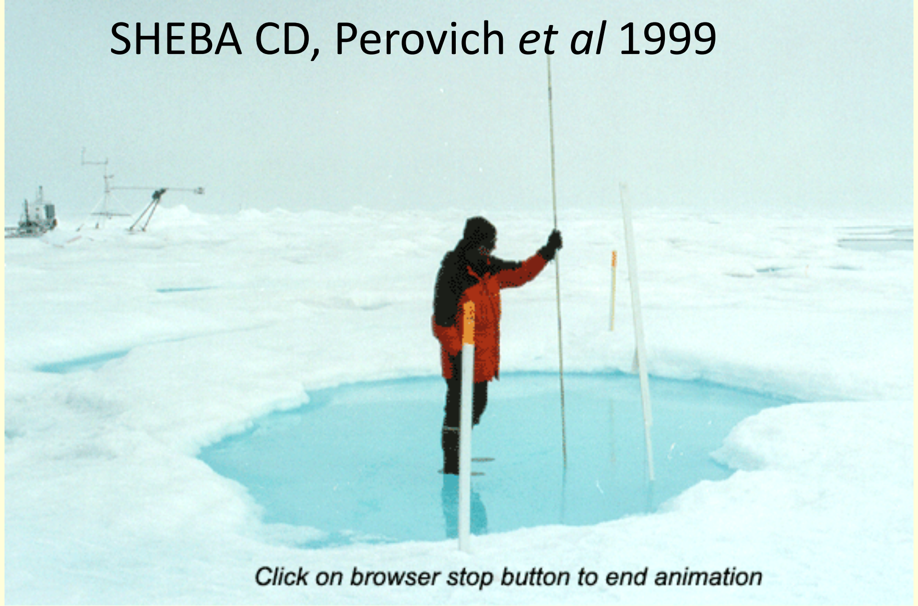
National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

cpom

Melt ponds

http://sheba.apl.washington.edu/

SHEBA August 14, 1998



SHEBA CD, Perovich *et al* 1999

Click on browser stop button to end animation

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

Attaining a theoretical understanding of melt ponds

Understanding achieved through experiment and observation:

- Field experiments, e.g. using tracers, especially SHEBA
- Satellite and aircraft observation

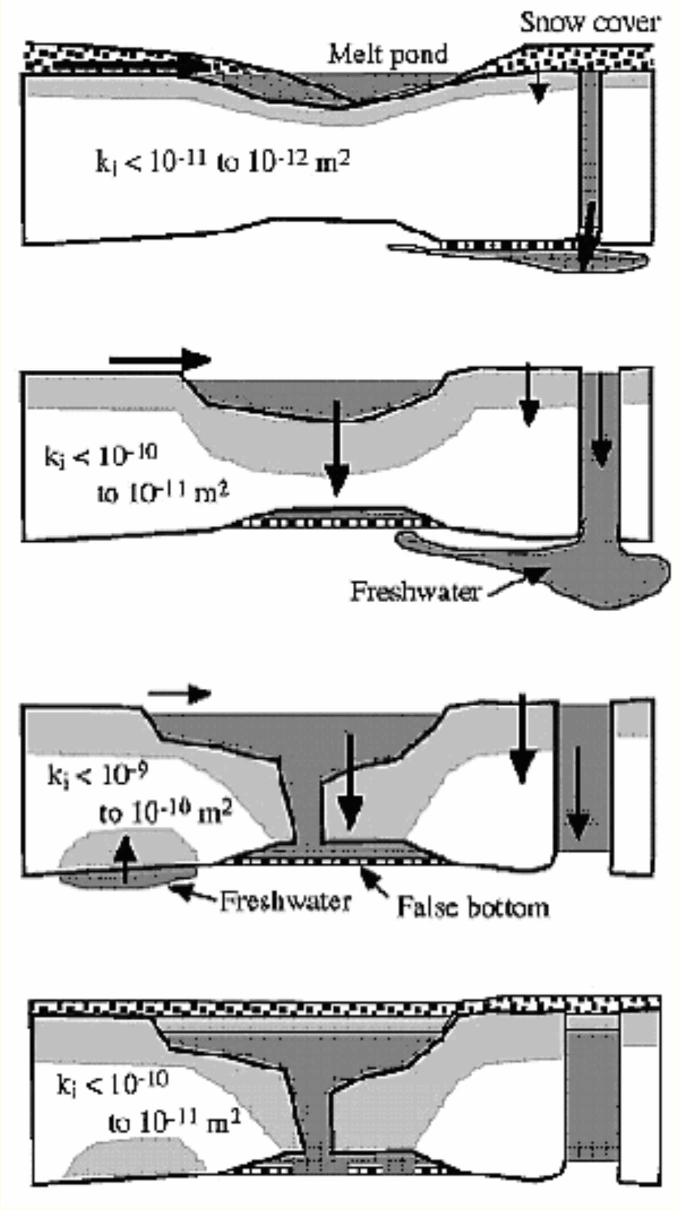
and through modelling/theory:

- 1D, vertical modelling of an individual melt pond (Taylor and Feltham, 2004)
- 2D horizontal modelling of melt pond area evolution (Luthje et al 2006, Scott and Feltham submitted)

The observations and modelling have been used to create a parameterisation for a GCM (Flocco and Feltham, 2007 and Flocco et al, submitted)

Lifecycle of melt pond

Eicken et al, 2002



Stage I: Snow melt; lateral melt water transport dominate vertical drainage; drainage in flaws; some underwater ice formation

(late May – 20 June)

Stage II: Lateral and vertical melt water transport; reduction of hydraulic head (height of pond above sea level); flaws enlarged; "false bottom"

(20 June – 20 July)

Stage III: Lateral and vertical melt water transport; flaws enlarged to point of floe disintegration

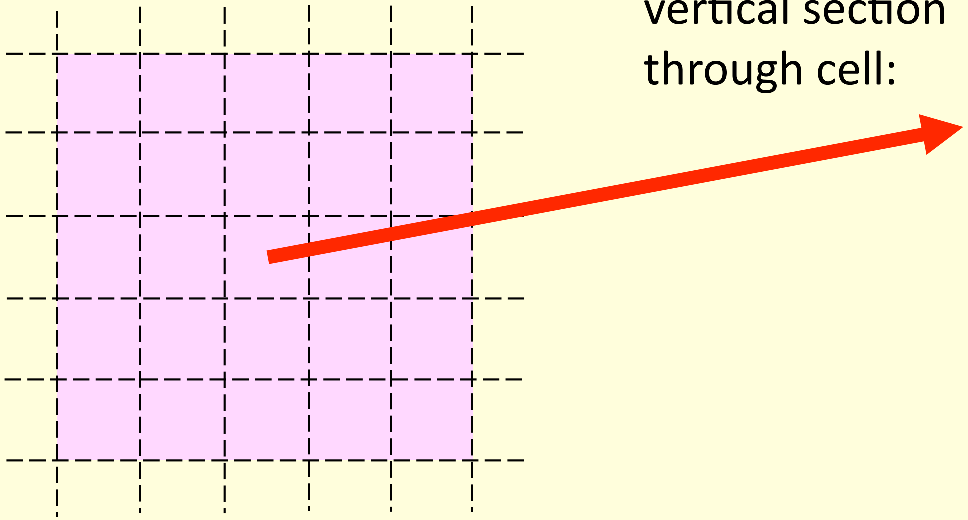
(20 July – 10 Aug)

Stage IV: Ponds freeze over; snow fall; bottom melting may continue

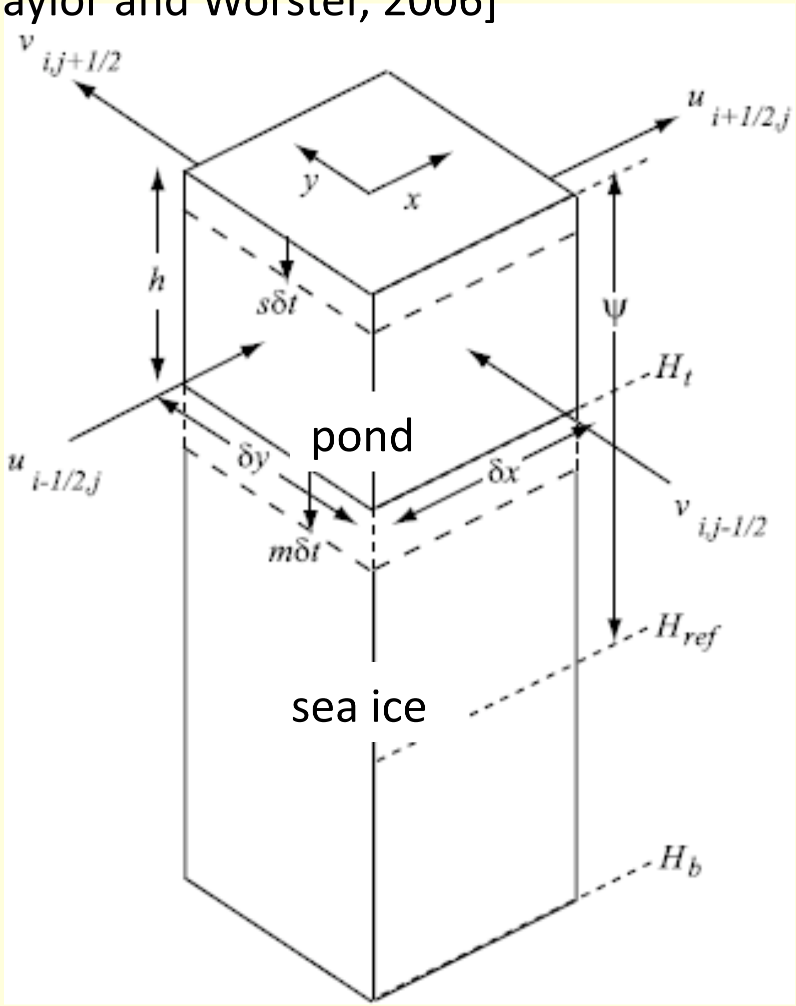
A model of horizontal melt pond evolution 1/4

[Scott and Feltham, submitted; cf Luthje, Feltham, Taylor and Worster, 2006]

Bird's eye view of sea ice:



vertical section through cell:



- The sea ice cover is split into equal squares cells like a checker board with variables
- In time Δt :

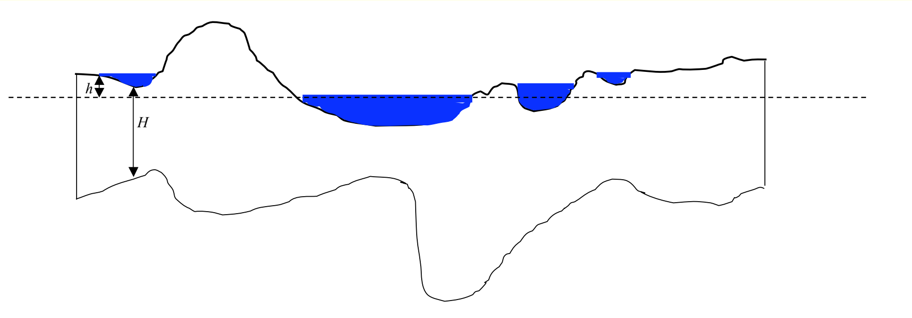
  1) the sea ice in a square melts at a rate *m* calculated from a 1D melt pond/sea ice model;

  2) melt water drains out of the bottom of the cell at a seepage rate *s* calculated from hydraulic head and Darcy's law;

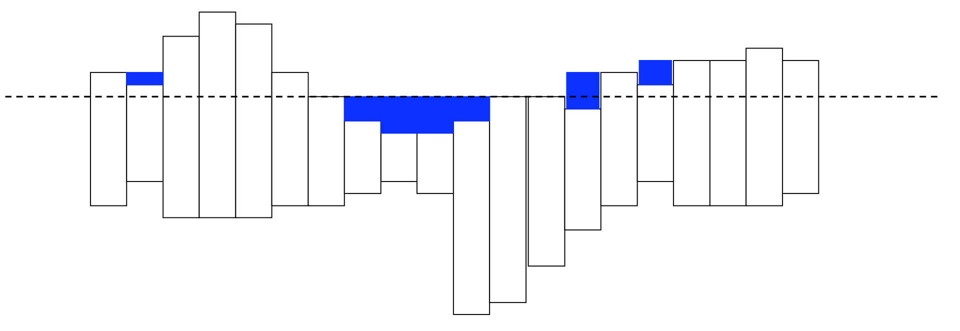
  3) melt water is transported to/from adjacent cells according to Darcy's law and with the horizontal pressure gradient determined from the topography.

Melt water transport 2/4

Profile of sea-ice floe



Profile of sea-ice floe as represented by cellular model



- Sea level calculated by assuming entire floe is in hydrostatic equilibrium
- Drainage rate calculated using Darcy's Law:

$$\mathbf{u} = -\Pi_h \frac{g\rho}{\mu} \nabla h$$

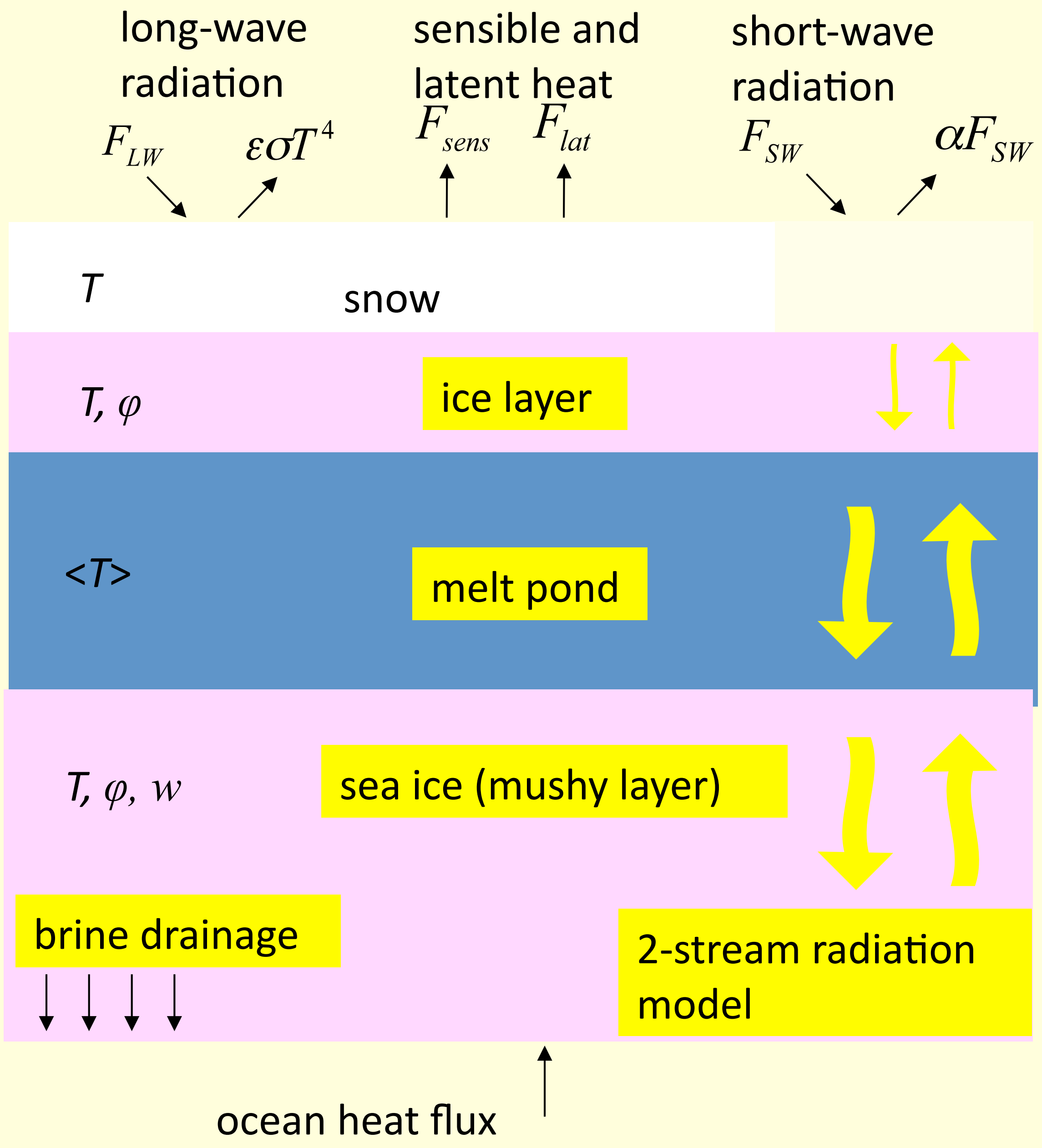
Horizontal transport

$$w = -\Pi_v \frac{g\rho}{\mu} \frac{\Delta h}{H}$$

Vertical seepage, Δh is pond height above sea level

One-dimensional melt pond-sea ice model 3/4

(Taylor and Feltham, JGR, 2004)



- Each grid cell calls the 1D melt pond-sea ice model
- Local heat balance equations in each phase coupled to 2-stream radiative model that allows albedo to be calculated
- Multiple phase combinations, e.g. snow on ice, pond on ice
- Model forced using SHEBA data

Ice and snow topography generated statistically 4/4

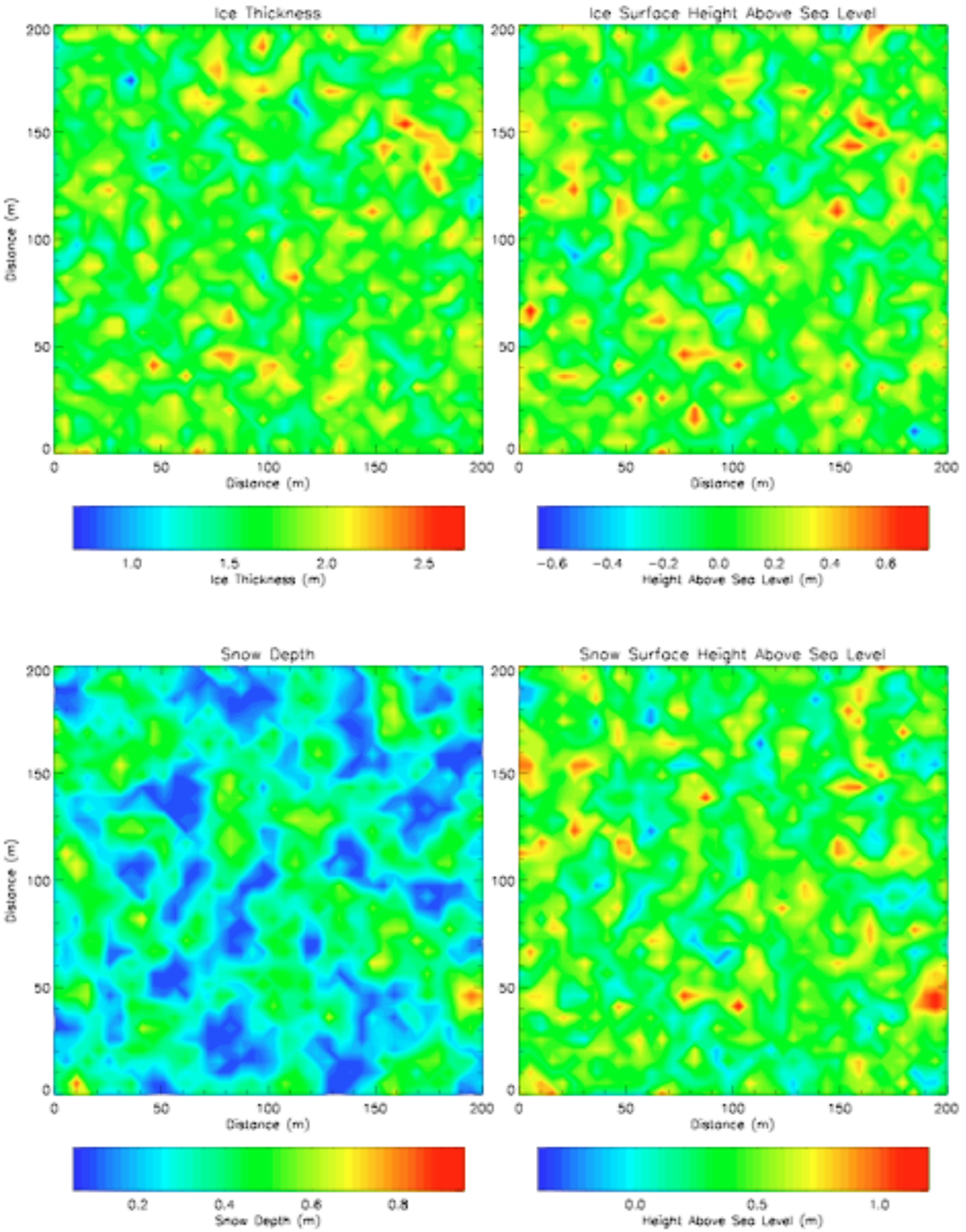
Model is composed of cells 5mx5m.

Represent a section of a 200mx200m sea ice floe.

Edge effects are not modelled (periodic).

Statistical models of ice and snow topography generated using **r-project**.

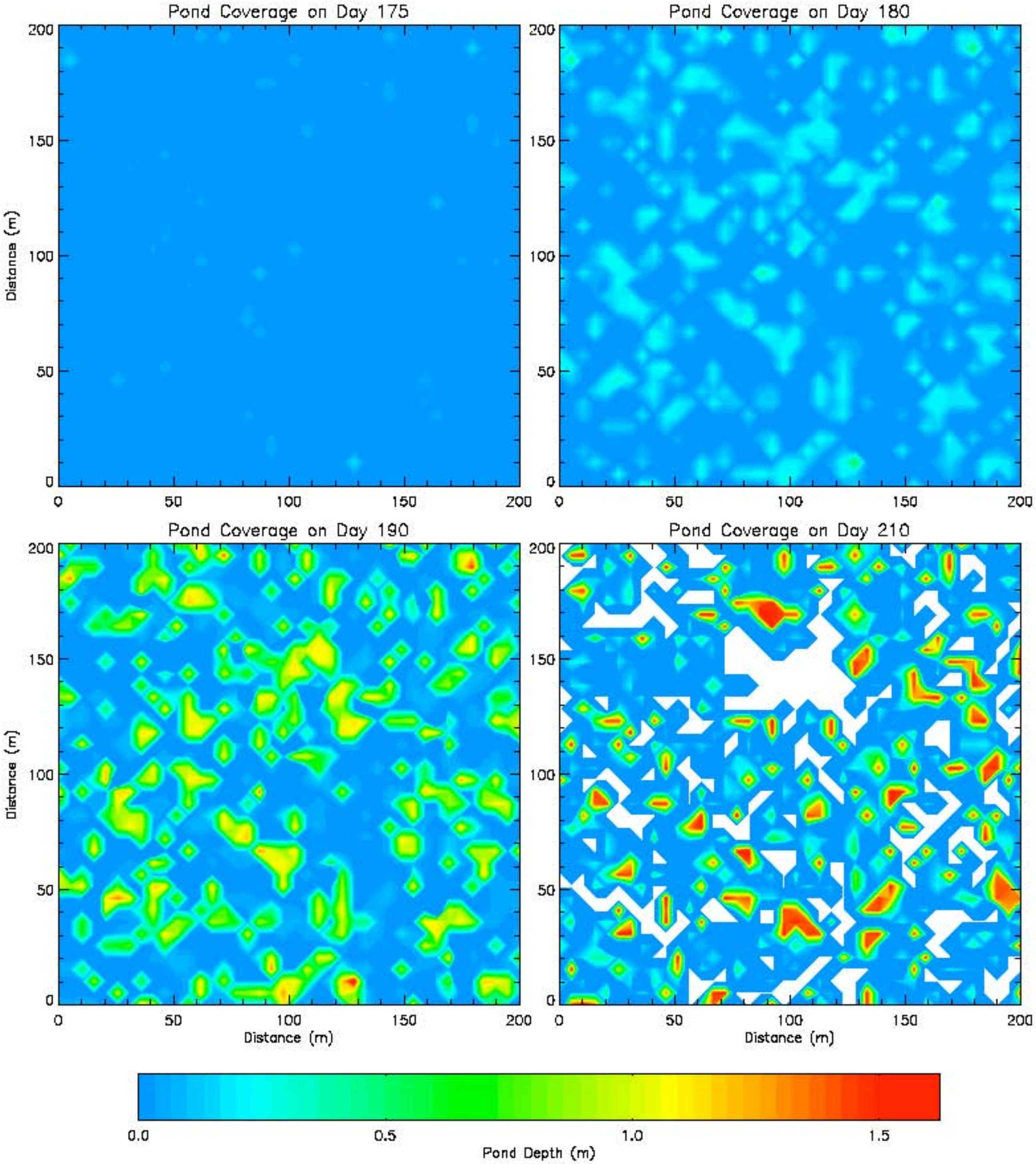
Data for ice and snow thickness mean and variance comes from the **SHEBA EM Ice Thickness** data.



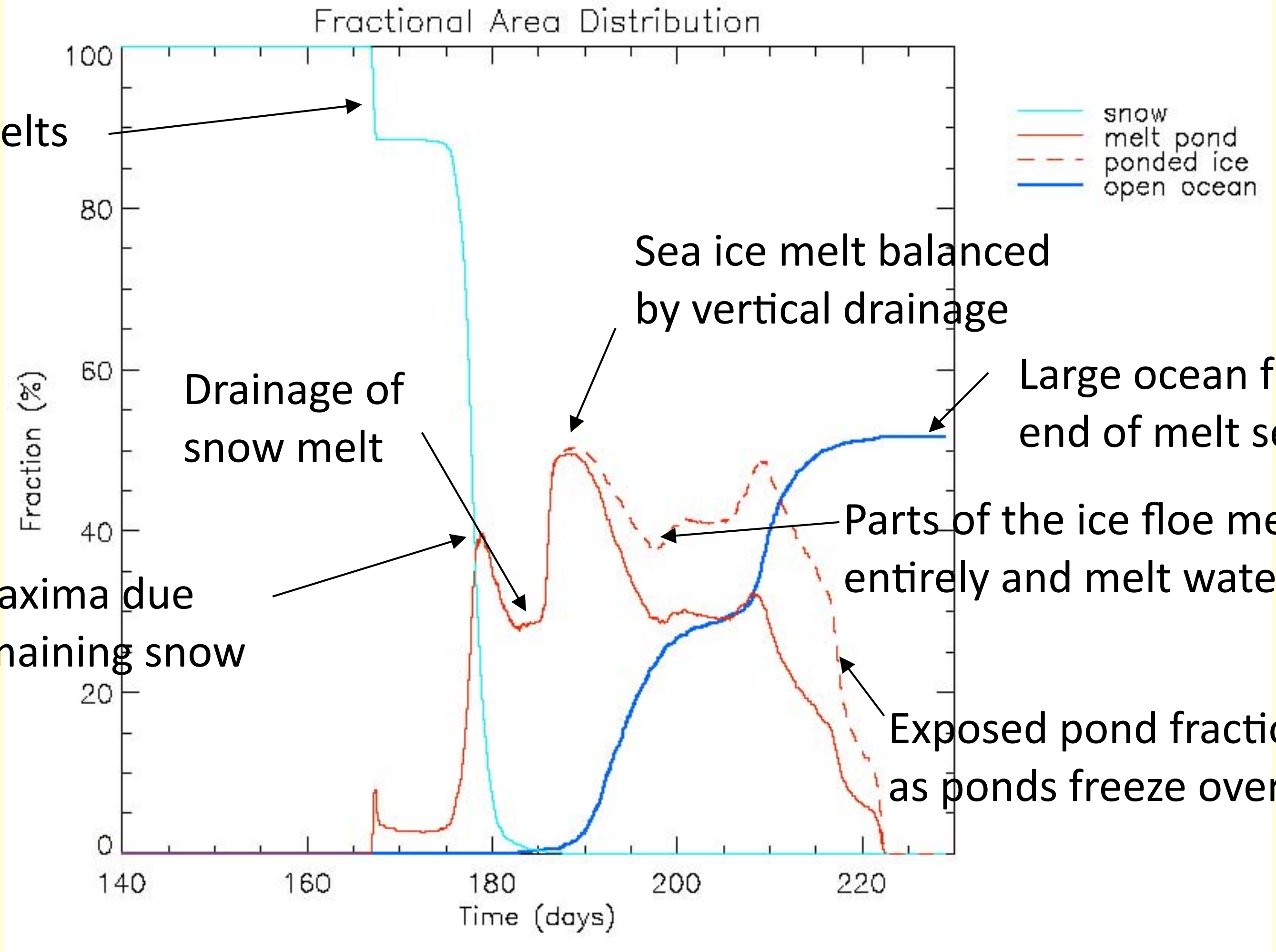
Results 1/2

Simulation of pond evolution during melt season on FYI

White regions have melted through completely



Standard case First Year Ice 2/2



Thinnest snow melts

Sea ice melt balanced by vertical drainage

Large ocean fraction at end of melt season

Drainage of snow melt

Parts of the ice floe melt through entirely and melt water is lost

Local pond maxima due to melt of remaining snow

Exposed pond fraction reduced as ponds freeze over

Initial topography:
Mean ice thickness is 1.7 m, standard deviation in ice thickness is 0.2 m,
mean snow thickness is 0.3 m and standard deviation in snow thickness is 0.15 m.

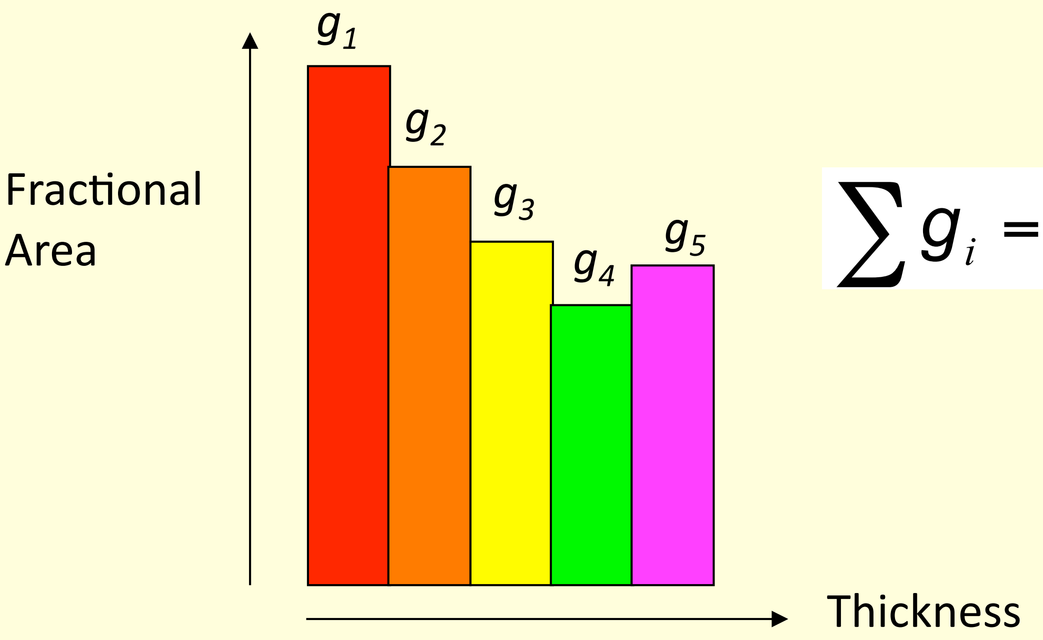
GCM-compatible melt pond model

(Flocco and Feltham, JGR, 2007)

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).*



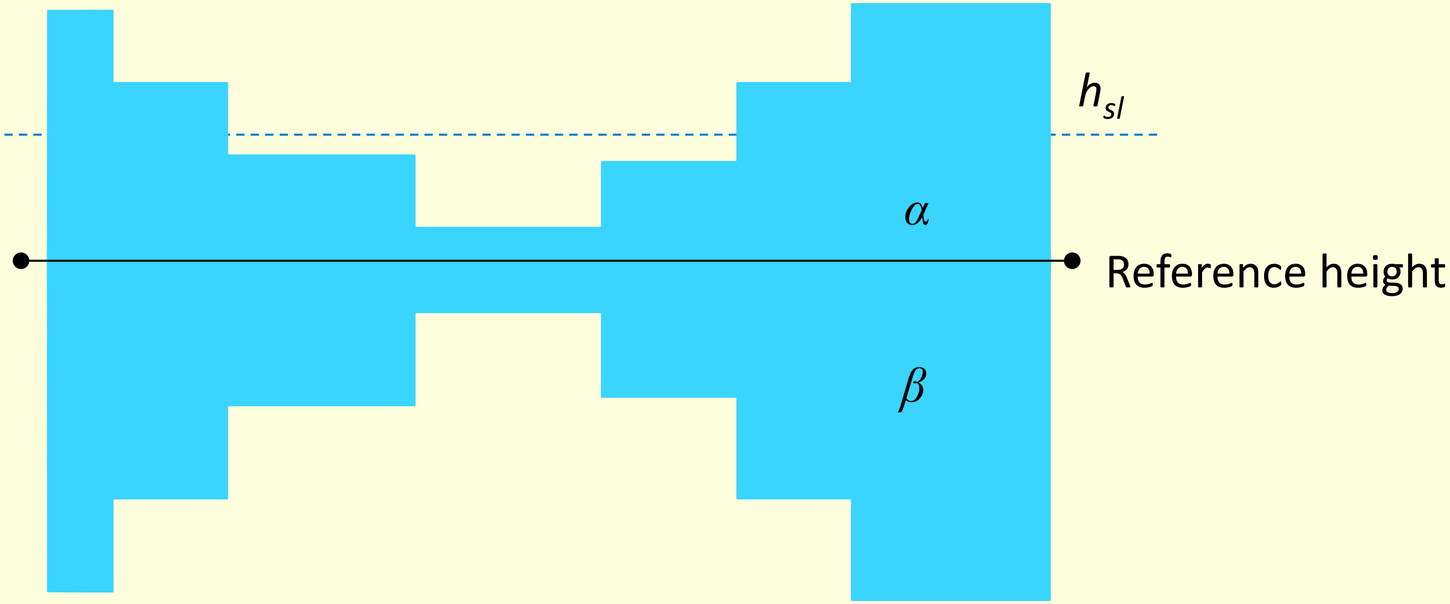
$$\sum g_i = 1$$

Height and depth distribution functions

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

We introduce surface height α*(h)* and basal depth β*(h)* distributions,
which give the relative area of ice of a given surface height or basal depth.

We derive α*(h)* and β*(h)* from the thickness distribution *g(h)*.



NOTE: α*(h)* and β*(h)* **do not** describe the topography.

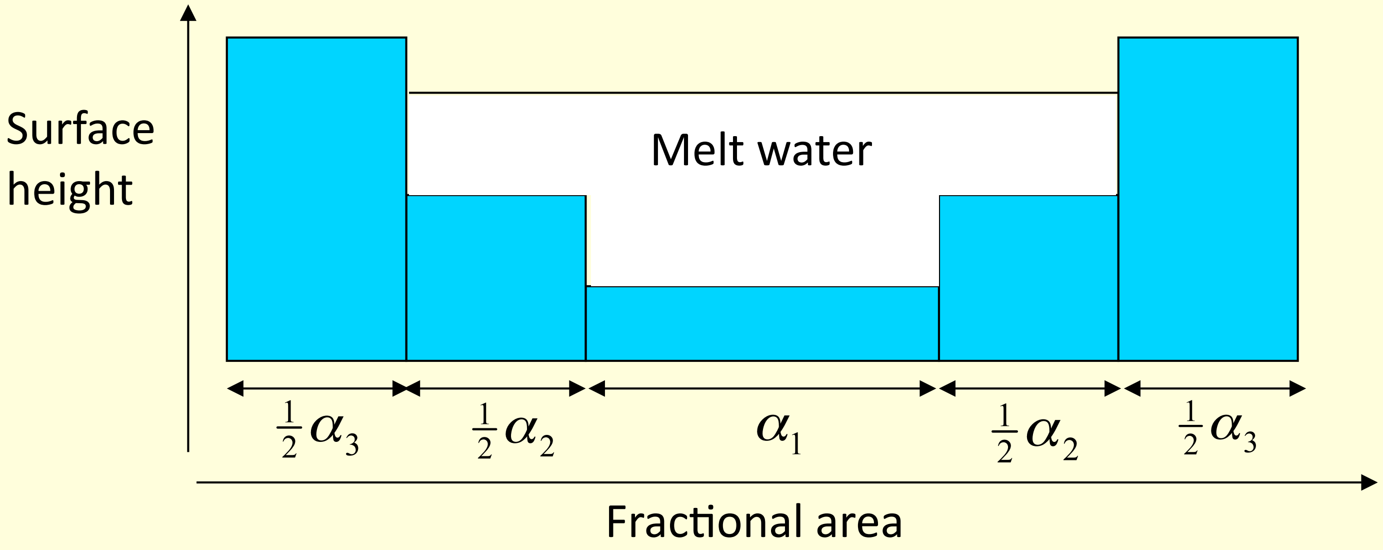
Horizontal redistribution of meltwater

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 α*(h)*.

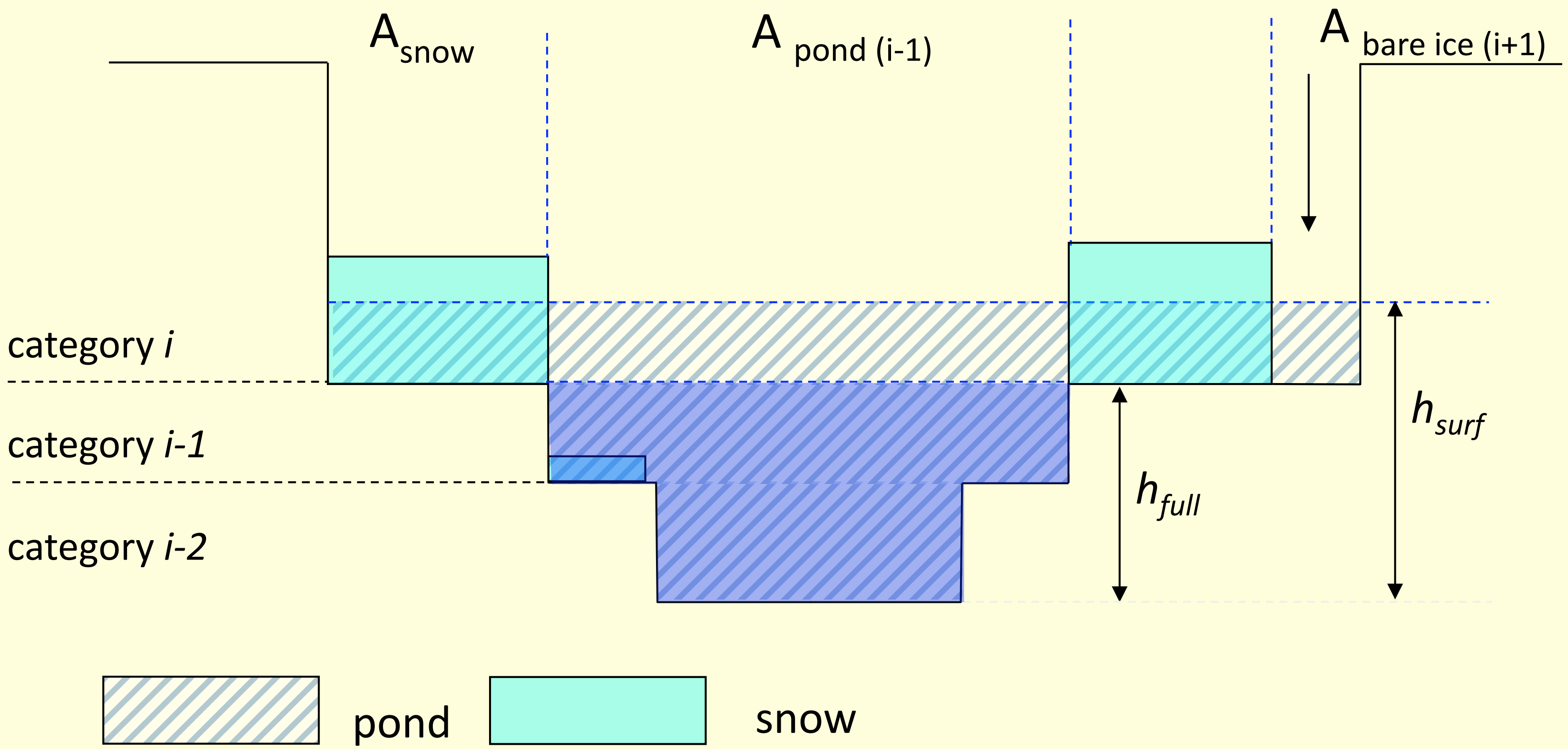
➔ Given the presence of ice of all surface heights, surface melt water will tend to collect on ice of the lowest surface height.

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.



Calculation of pond depth



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

Vertical drainage

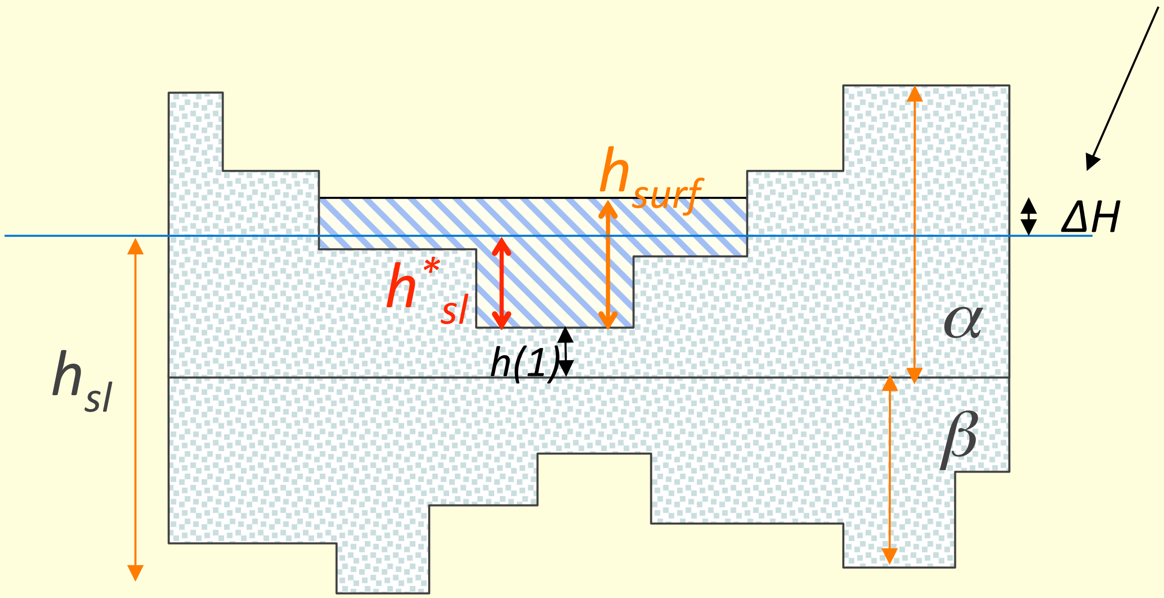
Melt water percolates vertically through the porous ice cover according to Darcy's law

$$w = -\frac{\Pi_{\mathrm{v}}}{\mu}\rho_{\mathrm{ocean}}\, g\,\frac{\Delta H}{H}$$

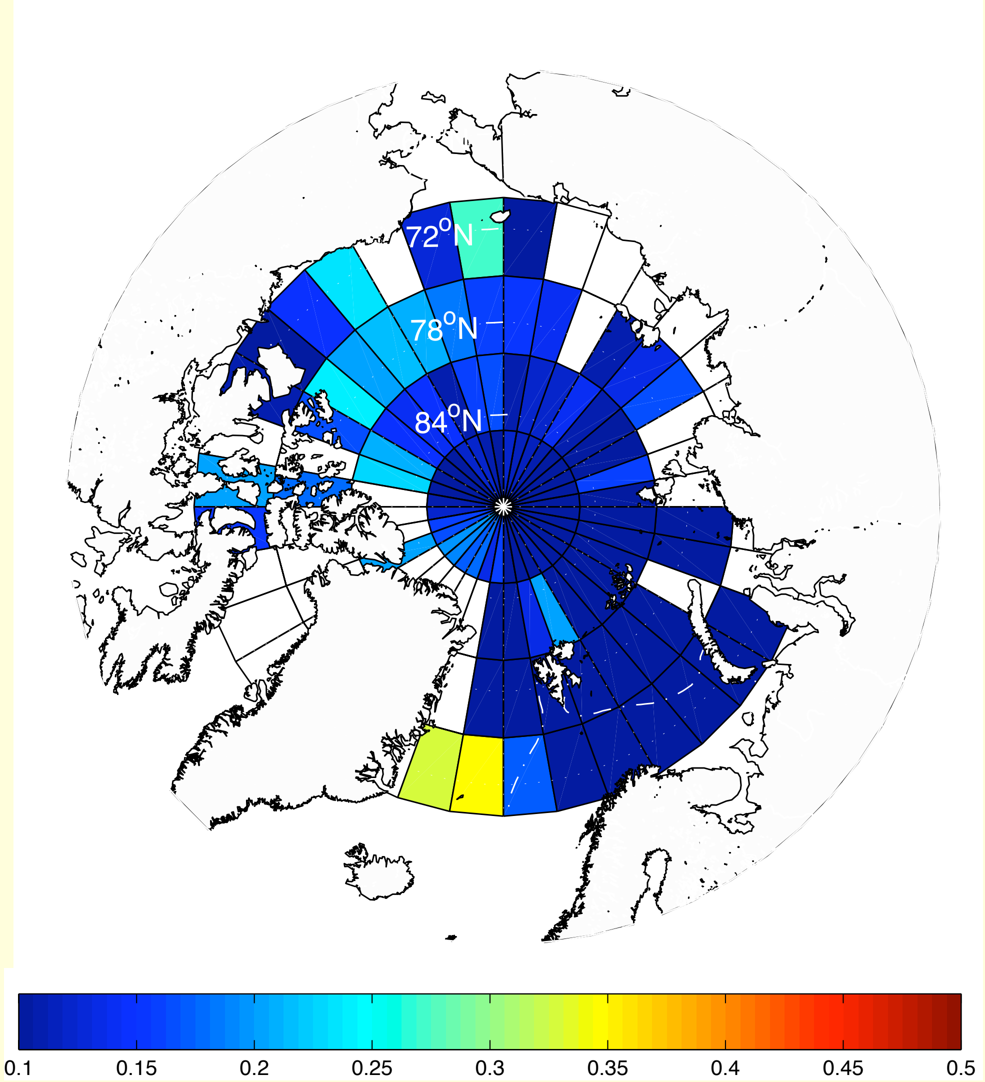
Vertical mass flux

Permeability

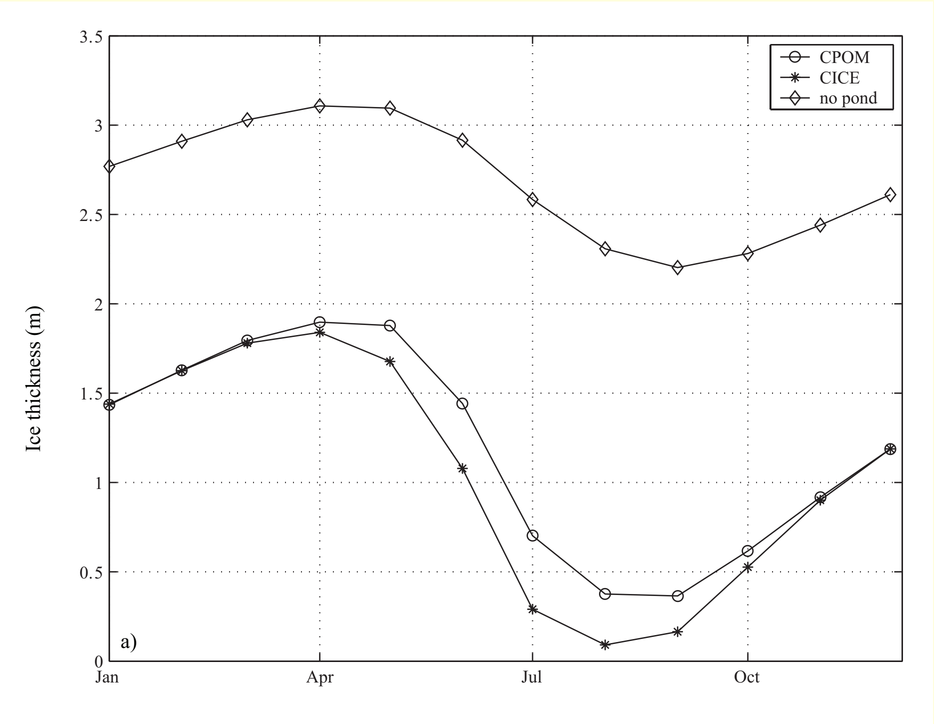
Height of pond surface above sea level



Sample output from CICE + melt pond routine 2009



Average July pond fraction 1980-2001



Model climatology basin-average ice thickness over 1980-2001

Flocco, Feltham and Turner, submitted

Further work

Process model experiments shows strong sensitivity of sea ice melt to uncertainty in:

- Optical (scattering) properties of pond-covered ice as brine fraction increases
- Permeability of ice as brine fraction increases
- Initial ice (not snow) topography

GCM modelling would benefit from:

- inclusion of melt ponds, with a greater number of thickness classes to resolve thin, pond-covered ice
- Separate treatment of pond-covered ice
- Simulations show including ponds gives a dramatic decrease in ice thickness and extent to unrealistic values

  ➔ other processes have been tuned to compensate for the lack of ponds?

Parameterisation – some requirements

- Parameterisation must transfer to the grid-scale the *essential* aspects of the sub-grid scale, *non-resolvable* processes.
- Parameterisation should *predict* how the sub-grid scale process will respond under altered forcing conditions.

  I.e. the parameterisation should be based on a *theoretical* description (and *understanding*), of the process.
- Parameterisation should be computationally practical and not contain arbitrary parameters that have a huge impact.

Parameterisation issues

- *Scalability*

  Is the process being resolved scale-invariant? I.e. does the same theoretical description apply at sub-grid and supra-grid scales, e.g. turbulence vs. sea ice mechanics

- *Continuity*

  If the sub-grid (or grid) scale approaches the *element* size, continuity may be compromised

  element=lead, floe, melt pond etc

Closely connected to this is the assumption of *isotropy*, e.g. of active leads