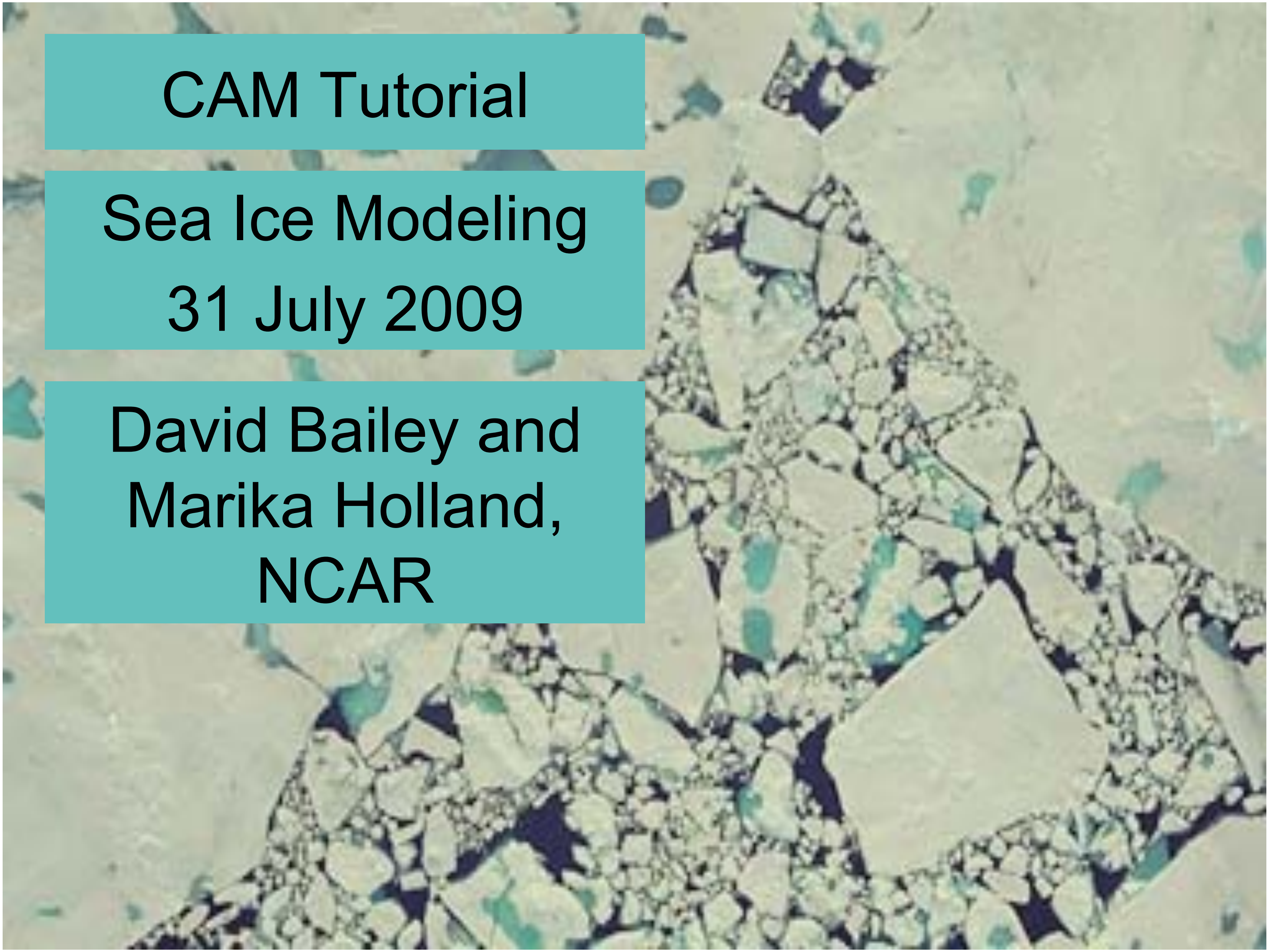


CAM Tutorial

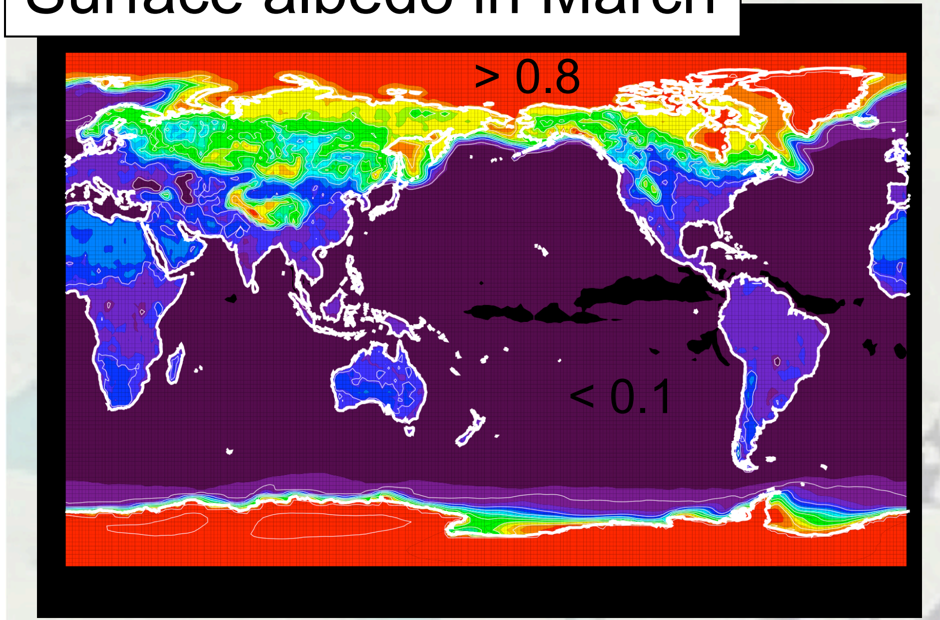
Sea Ice Modeling

31 July 2009

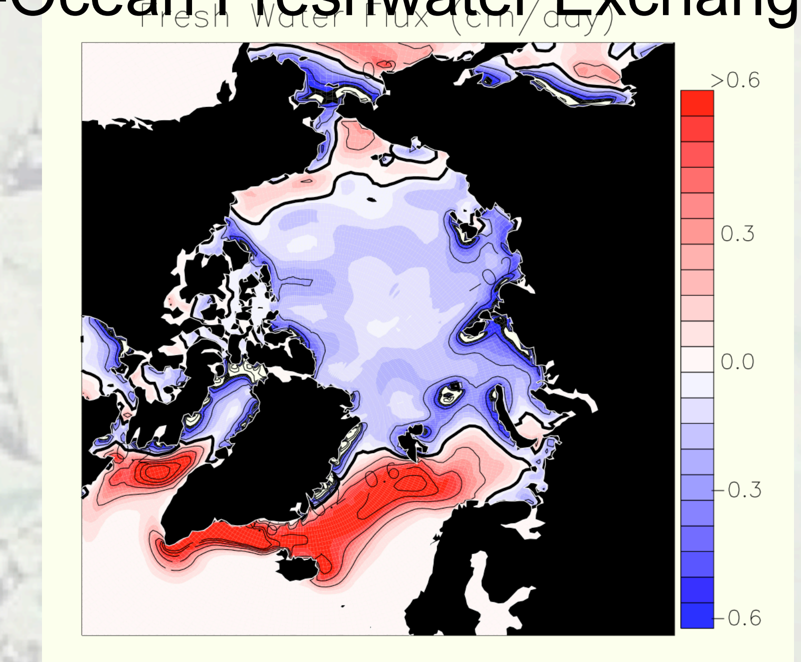
David Bailey and
Marika Holland,
NCAR

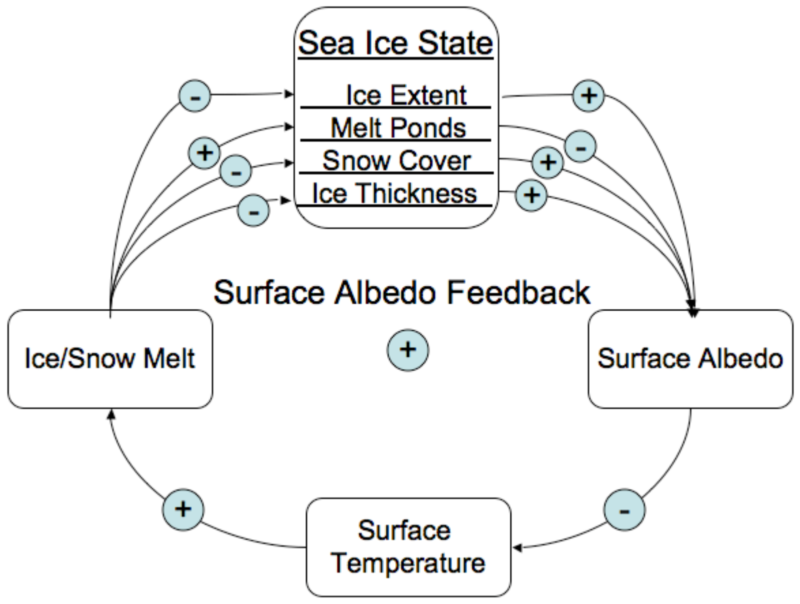
Sea ice influences in the climate system

Surface albedo in March



Ice-Ocean Freshwater Exchange





Sea Ice State

Ice Extent

Melt Ponds

Snow Cover

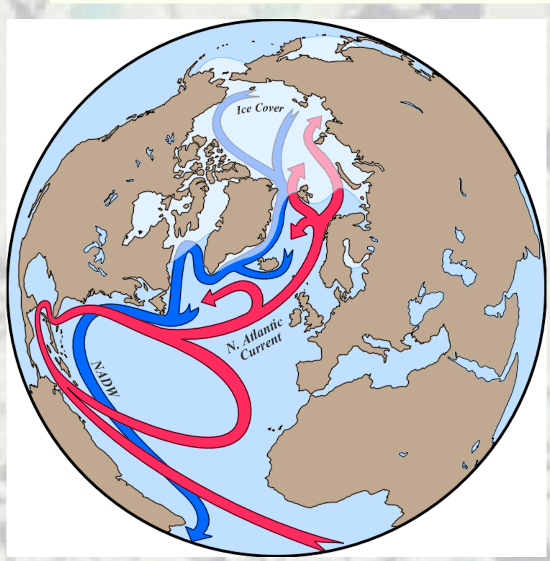
Ice Thickness

Surface Albedo Feedback

Ice/Snow Melt

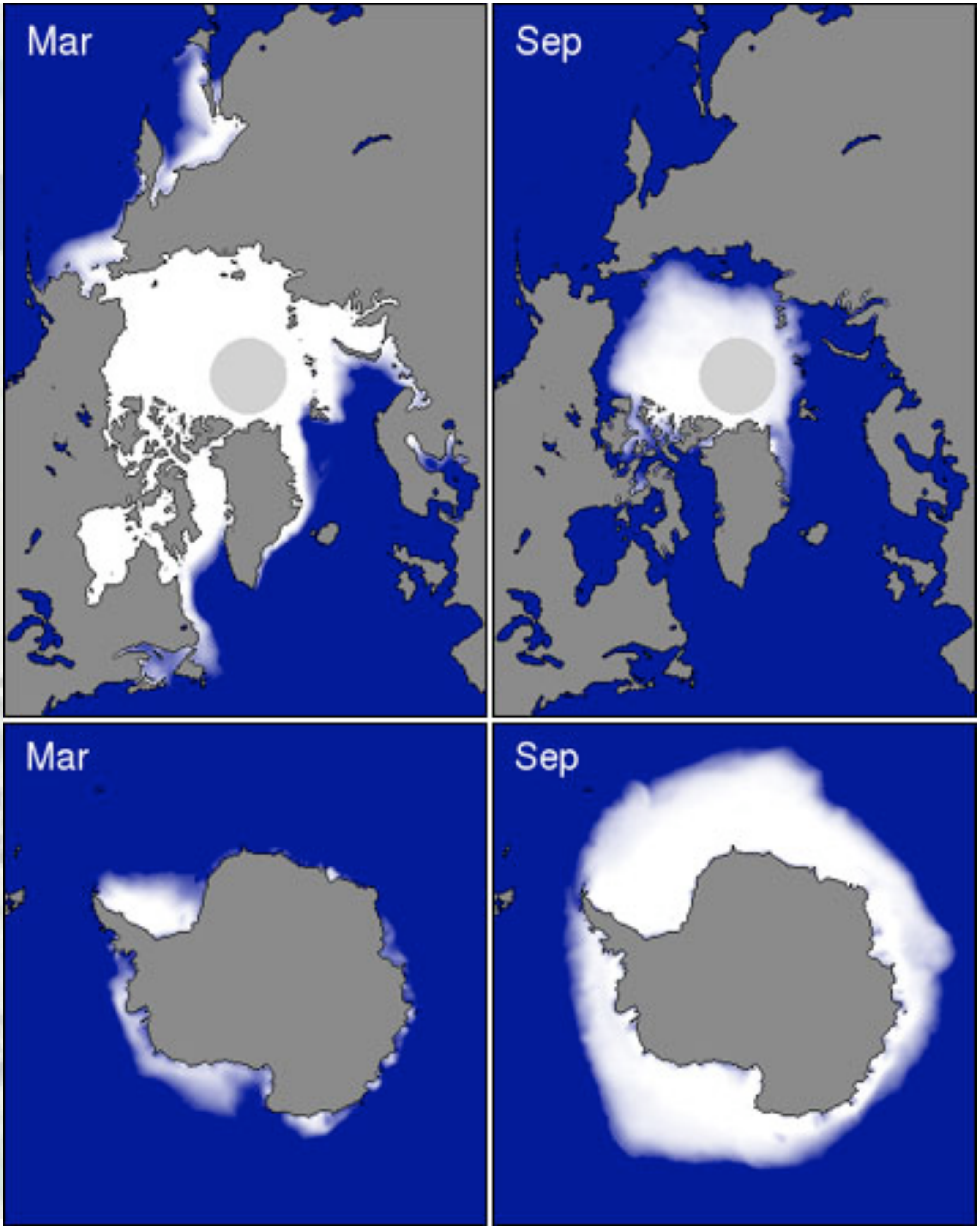
Surface Albedo

Surface Temperature

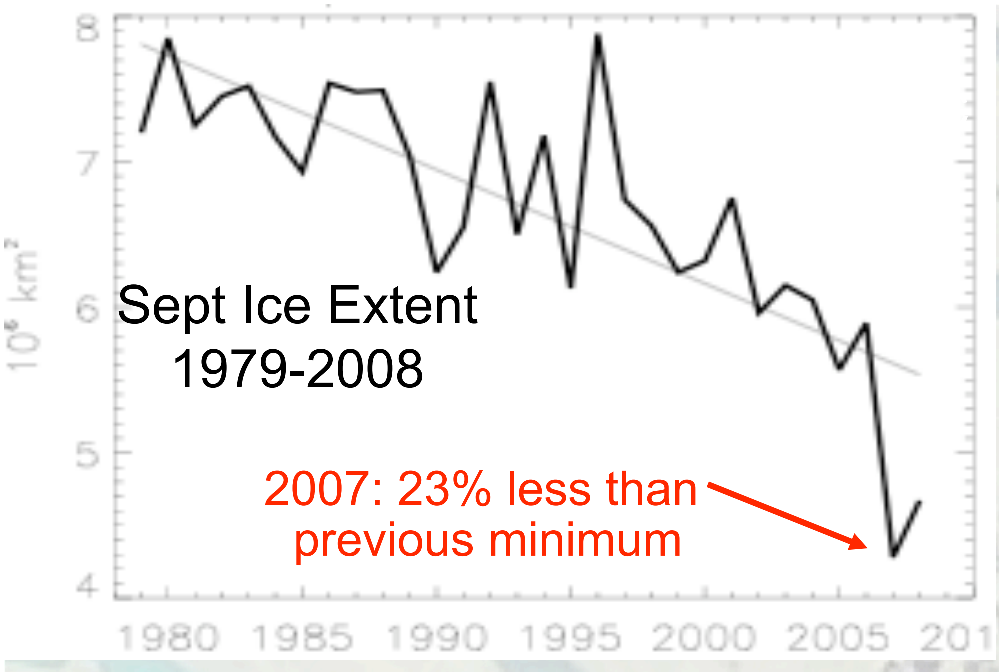


Contrasting the Hemispheres

- •Arctic Ocean surrounded by land (thicker ice).
- •Southern Ocean unbounded (free drift).
- •Larger seasonal cycle in south.
- • Winter extent set by ocean in south and land/ ocean in north.



Arctic summer sea ice



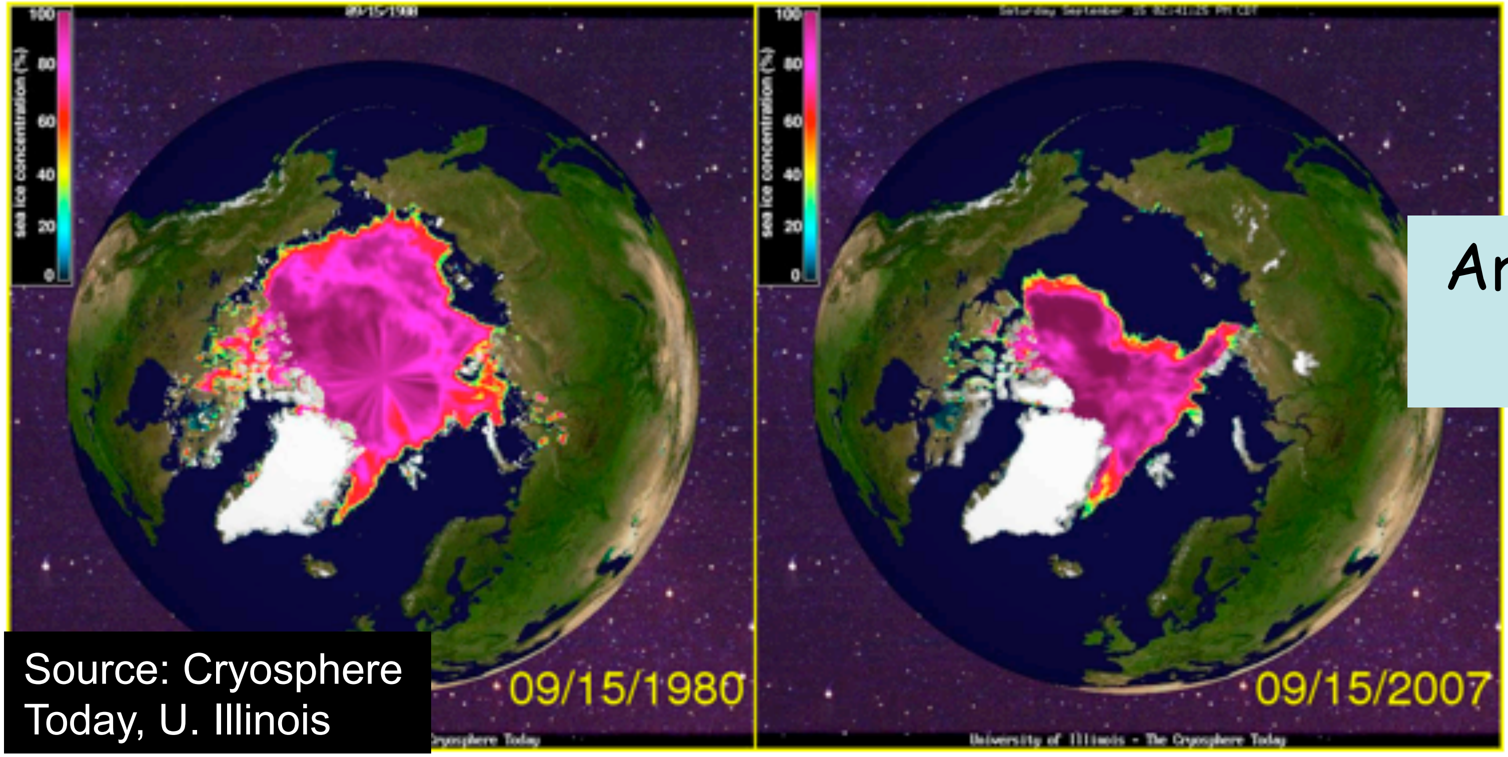
Sept Ice Extent
1979-2008

2007: 23% less than
previous minimum

The New York Times

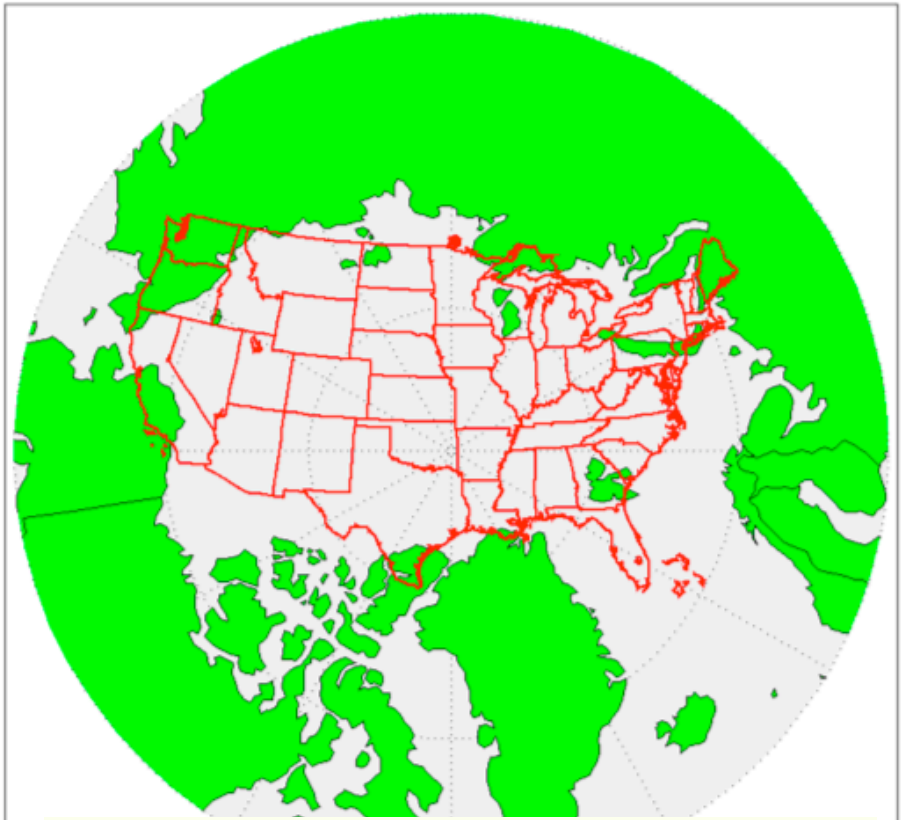
Arctic Melt Unnerves the Experts

l Oceanic and Atmospheric Administration



Source: Cryosphere
Today, U. Illinois

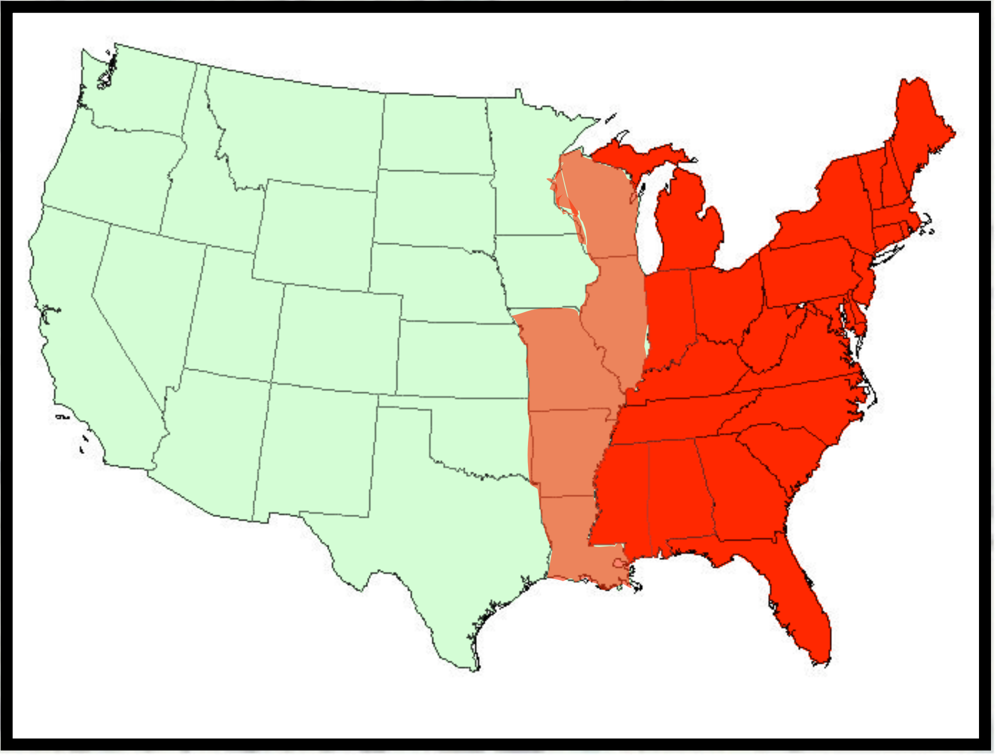
Loss of the summer Arctic ice cover in context



(courtesy of Harry Stern, U. Washington)

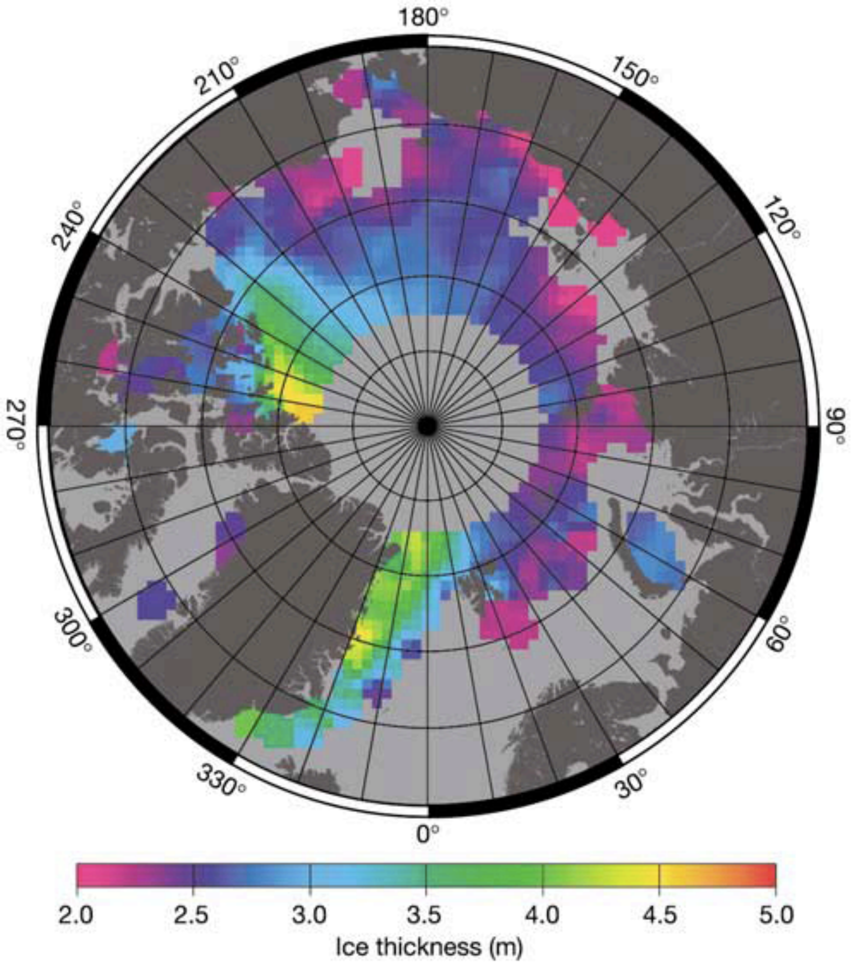
From 1980 to 2005: summer ice loss equal to 24 states; most of the US east of the Mississippi

To 2007: 5 additional states



We really need thickness data!

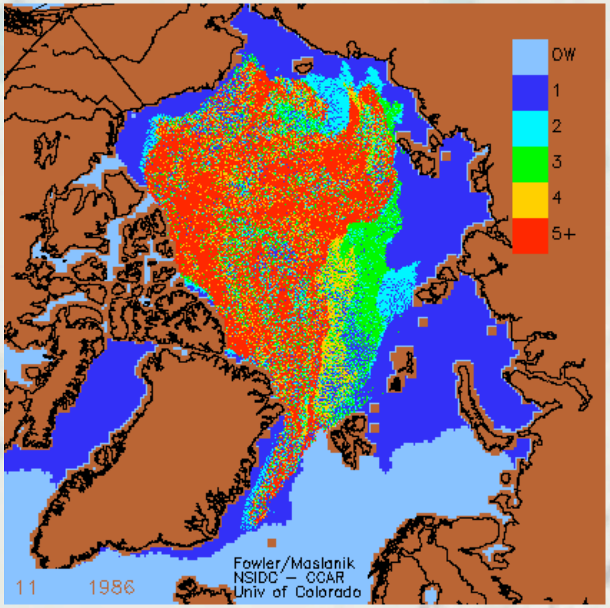
Bourke and Garrett 1987



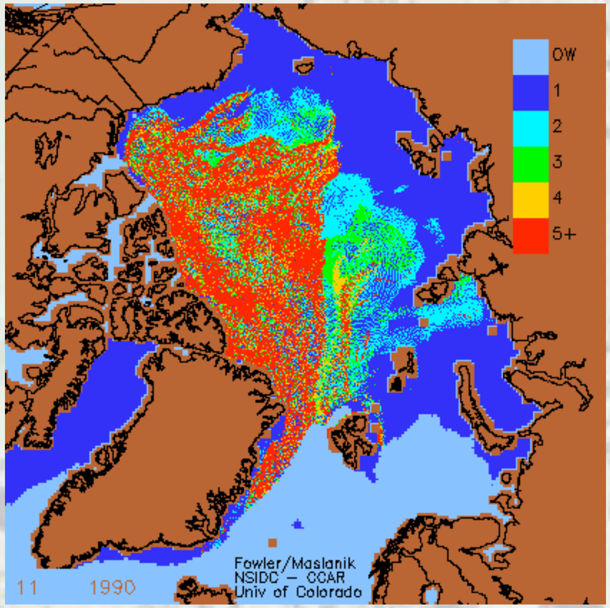
Laxon et al. 2003

Transition Towards Younger, Thinner Ice

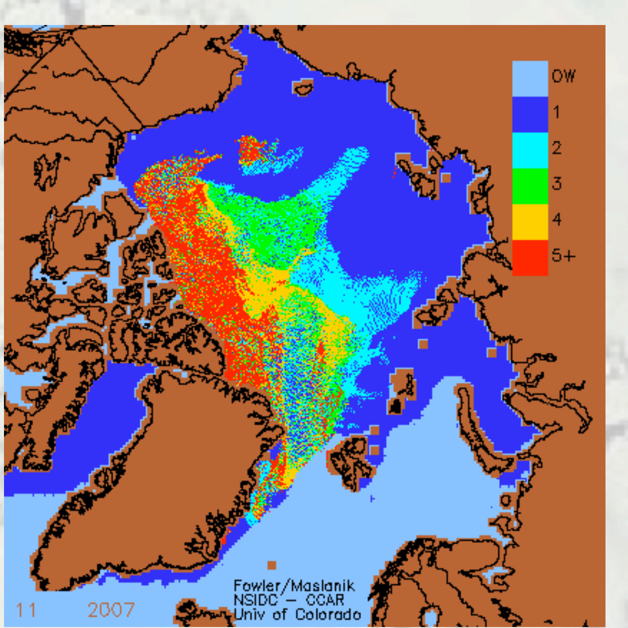
- Ice age tracking algorithm from C. Fowler and J. Maslanik
- By 2007 ice >5 years is only 10% of the perennial ice pack.
- Younger ice is generally thinner ice
- Consistent with ULS data; hindcast model experiments



Spring 1986



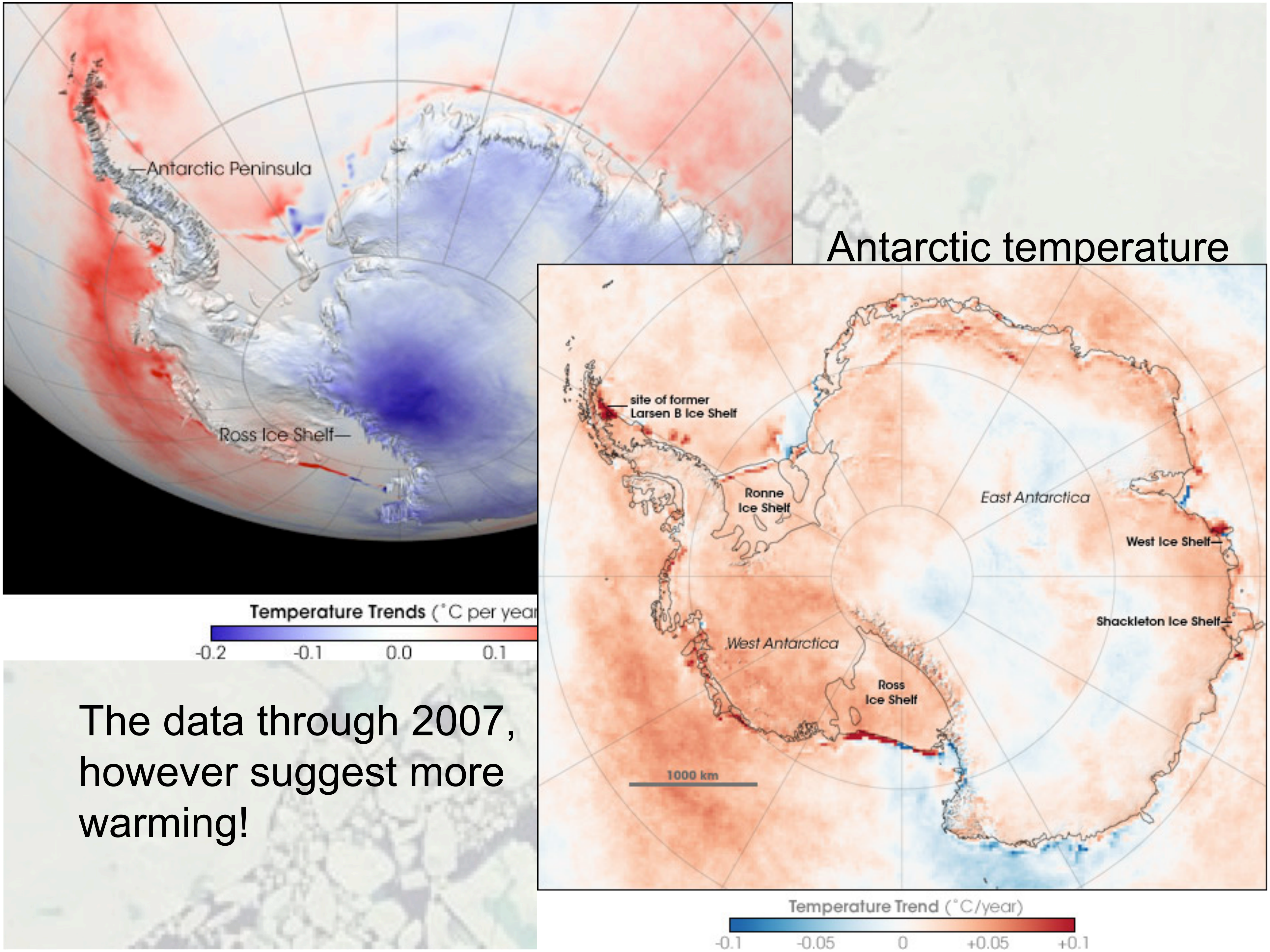
Spring 1990



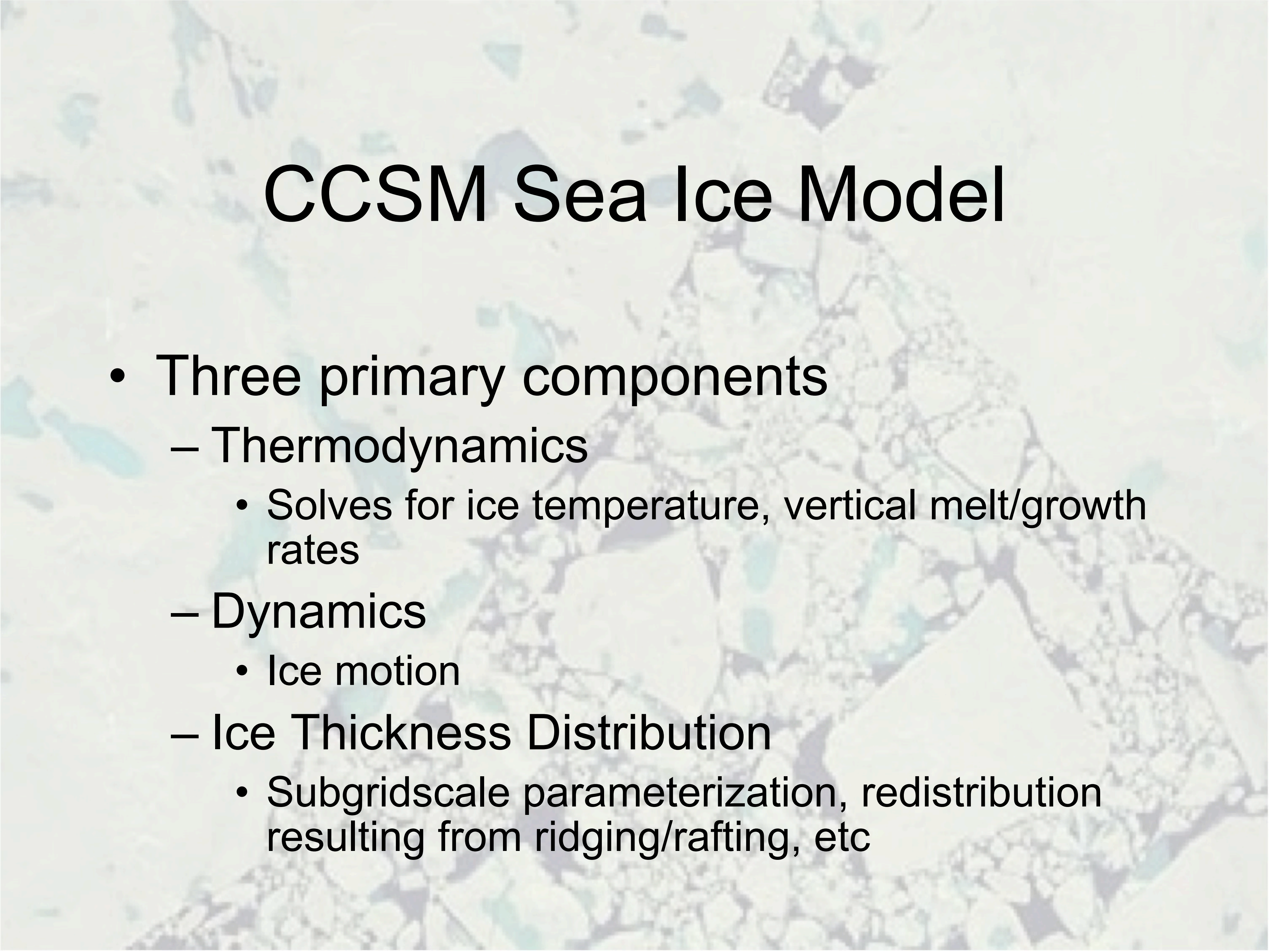
Spring 2007

Maslanik et al., 2007

Antarctic temperature



The data through 2007, however suggest more warming!



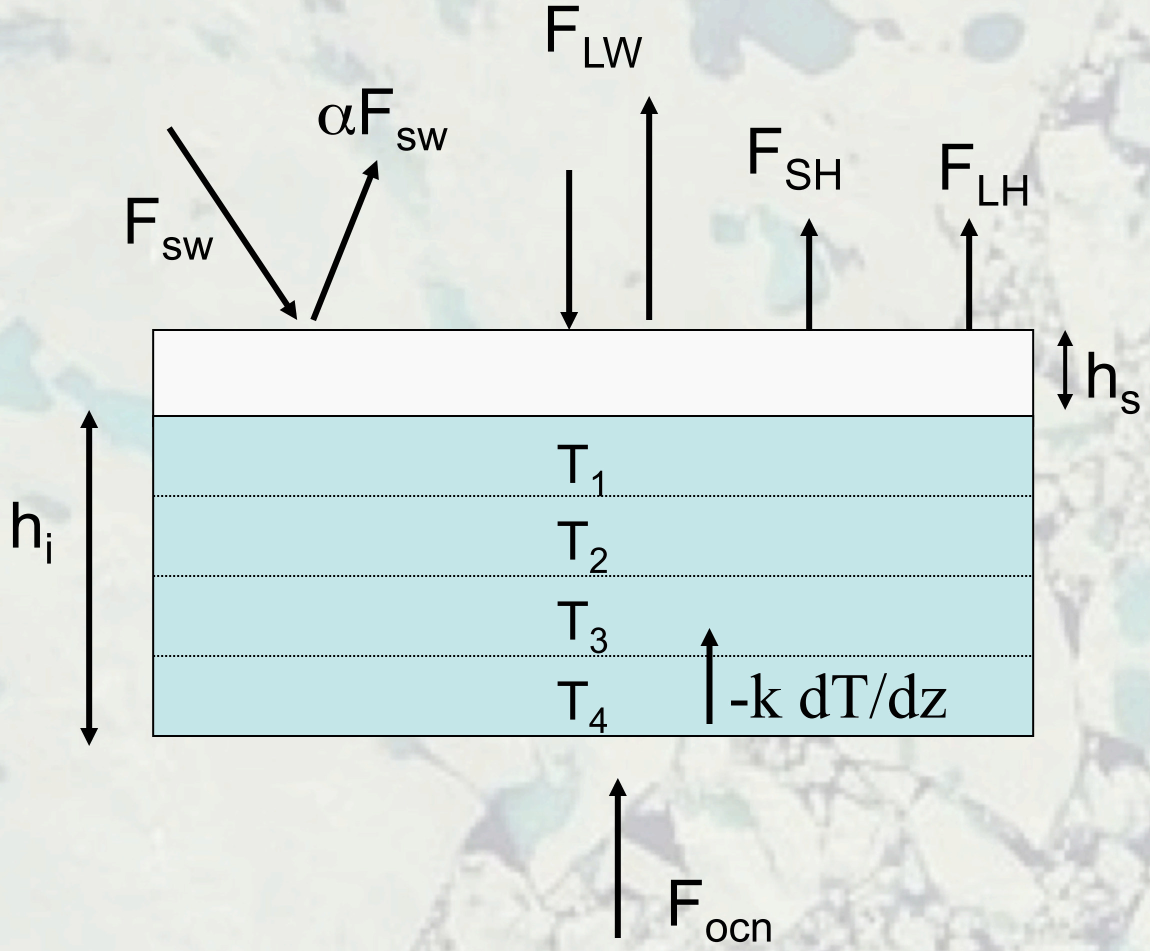
CCSM Sea Ice Model

- Three primary components
  - – Thermodynamics
    - Solves for ice temperature, vertical melt/growth rates
  - – Dynamics
    - Ice motion
  - – Ice Thickness Distribution
    - Subgridscale parameterization, redistribution resulting from ridging/rafting, etc

CCSM Sea Ice Model (2)

- Physical Processes (included above)
  - Radiative transfer in ice and snow.
  - Ridging / Rafting.
  - Snow-ice formation.

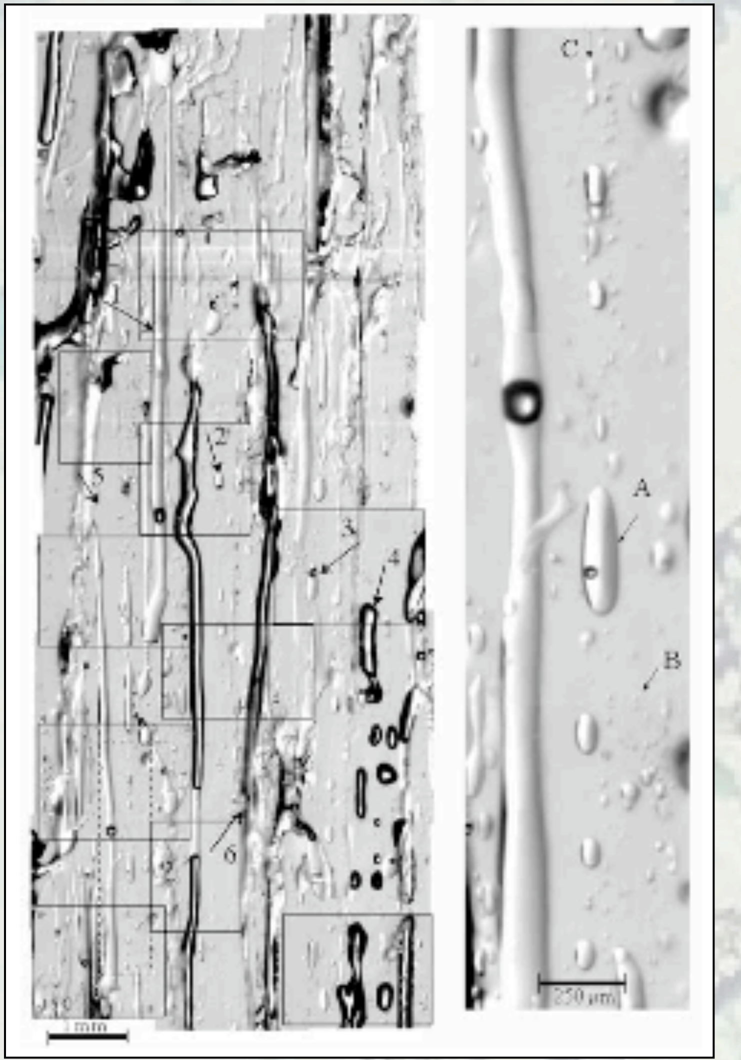
Sea ice thermodynamics



- Simulate vertical heat transfer (conduction, SW absorption)
- Balance of fluxes at ice surface (ice-atm exchange, conduction, ice melt)
- Balance of fluxes at ice base (ice-ocn exchange, conduction, ice melt/growth)

Vertical heat transfer

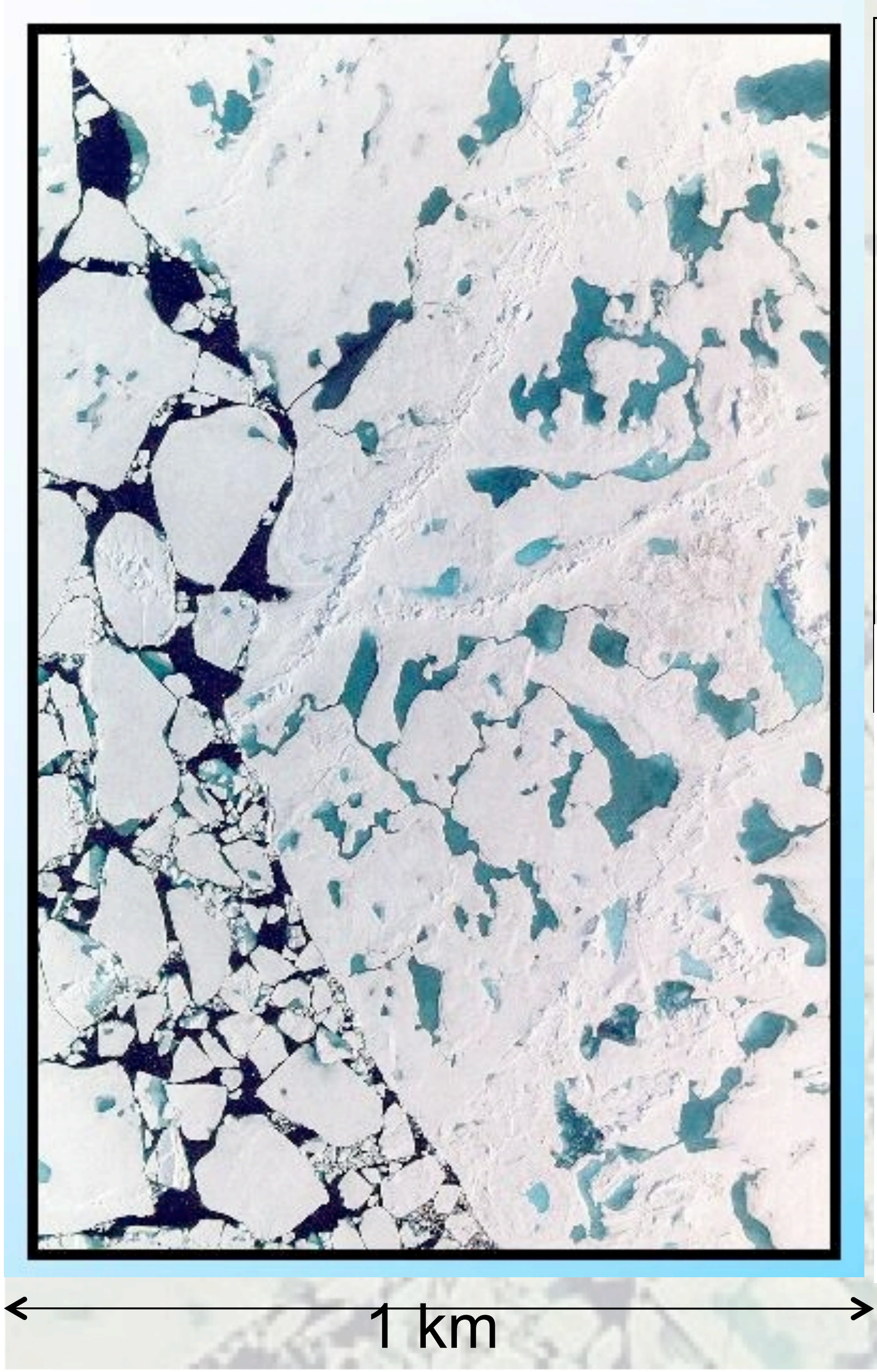
$$\rho c \frac{\partial T}{\partial t} = \frac{\partial}{\partial z} k \frac{\partial T}{\partial z} + Q_{SW}$$



(from Light, Maykut, Grenfell, 2003)

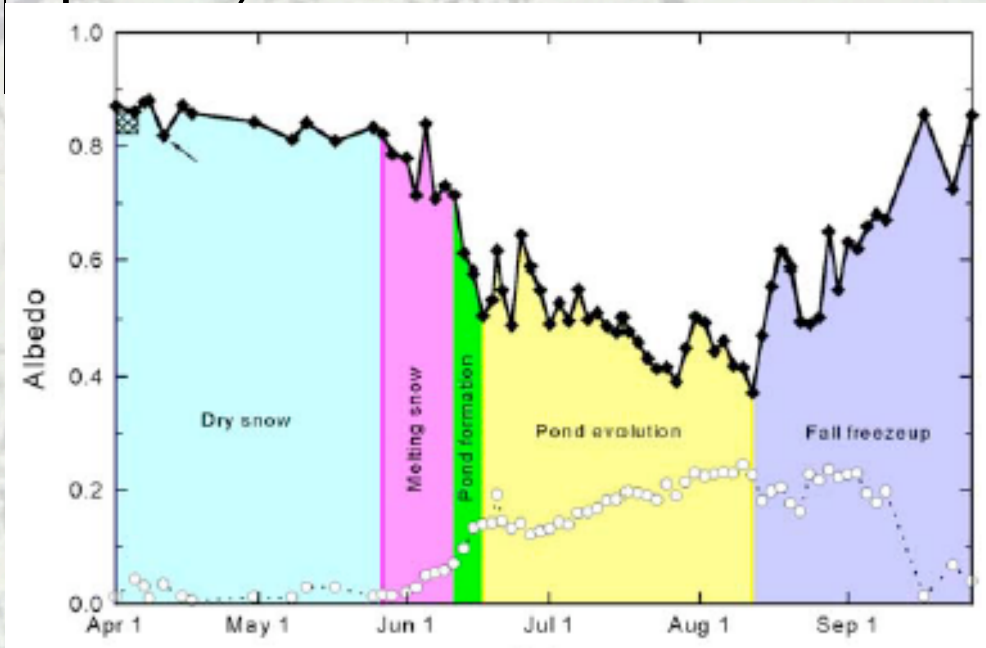
- Assume brine pockets are in thermal equilibrium with ice
- Heat capacity and conductivity are functions of T/S of ice
- Assume constant salinity profile
- Assume non-varying density
- Assume pockets/channels are brine filled
- $Q_{SW} = -\frac{d}{dz} I_{SW} e^{-\kappa z}$ where $I_{SW} = i_0(1-\alpha)F_{SW}$

(Maykut and Untersteiner, 1971; Bitz and Lipscomb, 1999; others)

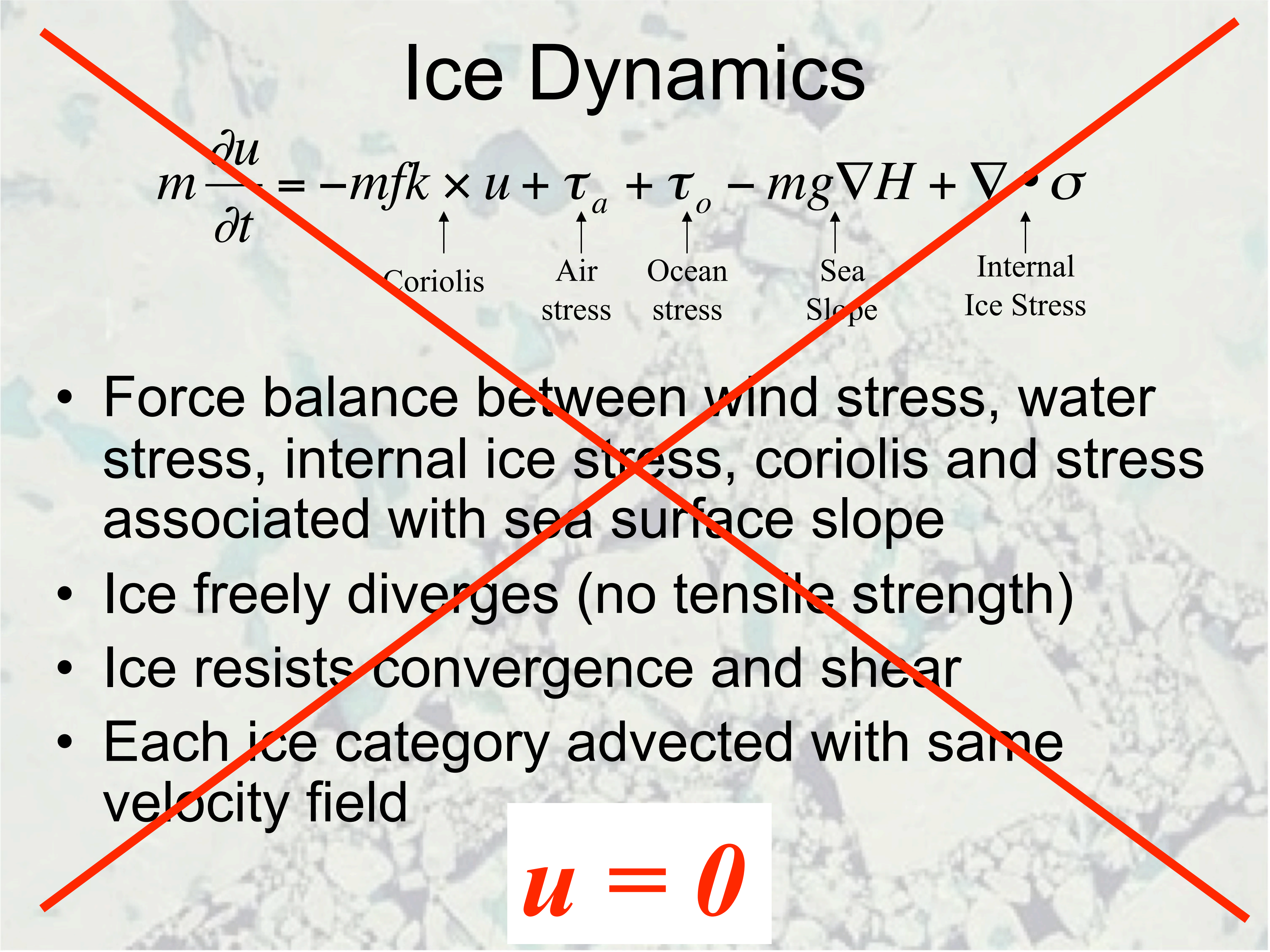


Albedo

- Melt ponds are prevalent on sea ice.
- Influence surface albedo and ice mass budget.
- Parameterized albedo depends on surface state (snow, temp, h_i, ponds).



Albedo Evolution During SHEBA
(Perovich et al. 2002)



~~Ice Dynamics~~

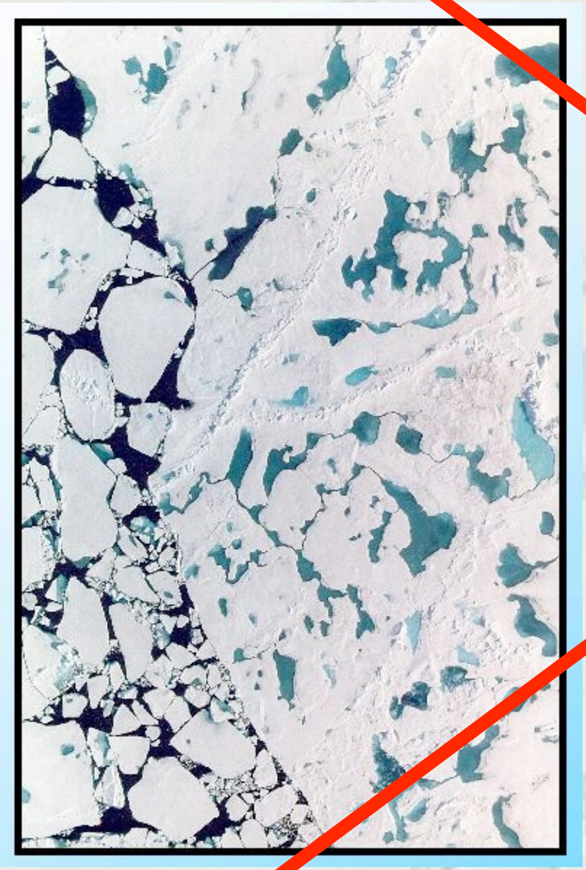
$$m\frac{\partial u}{\partial t} = \underset{\substack{\uparrow\\ \text{Coriolis}}}{-mfk \times u} + \underset{\substack{\uparrow\\ \text{Air}\\ \text{stress}}}{\tau_a} + \underset{\substack{\uparrow\\ \text{Ocean}\\ \text{stress}}}{\tau_o} - \underset{\substack{\uparrow\\ \text{Sea}\\ \text{Slope}}}{mg\nabla H} + \underset{\substack{\uparrow\\ \text{Internal}\\ \text{Ice Stress}}}{\nabla \bullet \sigma}$$

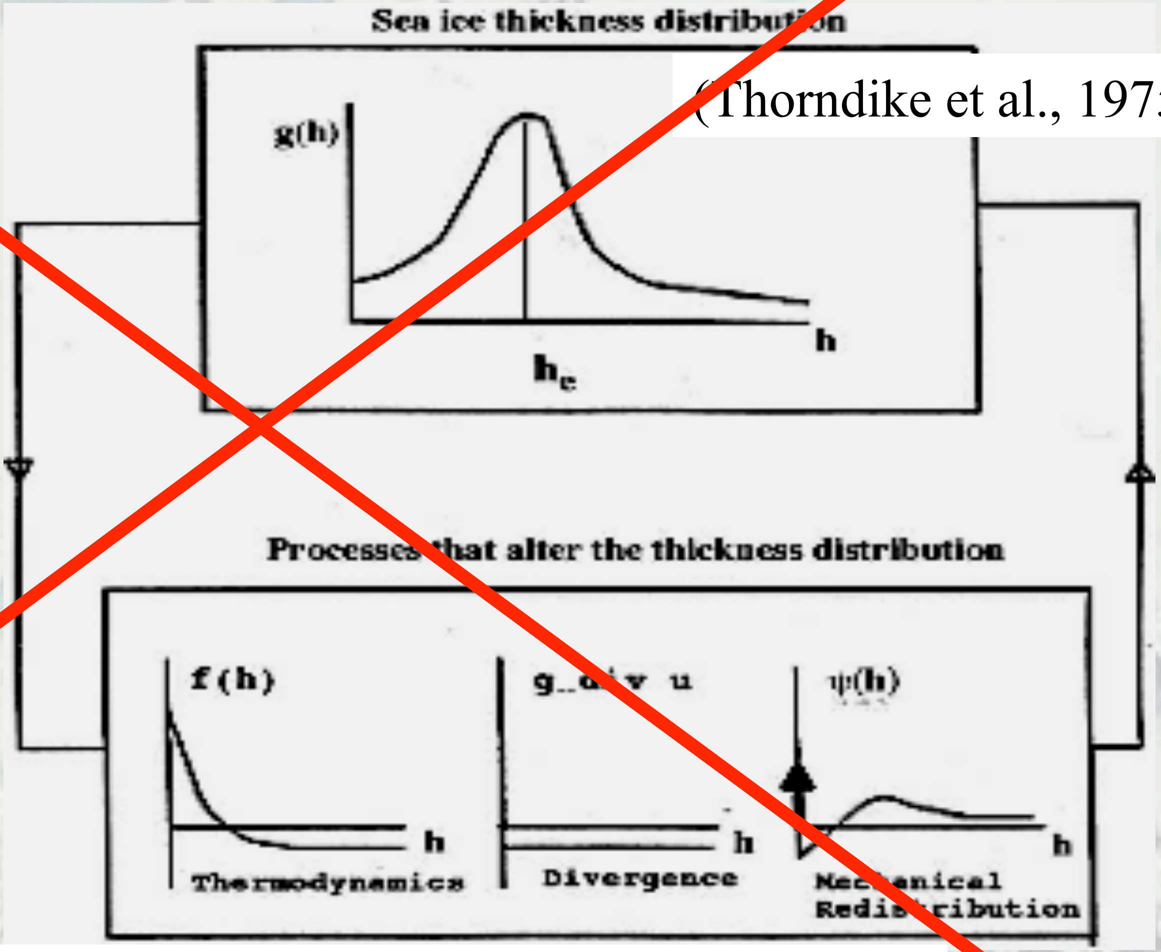
- ~~Force balance between wind stress, water stress, internal ice stress, coriolis and stress associated with sea surface slope~~
- ~~Ice freely diverges (no tensile strength)~~
- ~~Ice resists convergence and shear~~
- ~~Each ice category advected with same velocity field~~

$$\boldsymbol{u = 0}$$

Ice Thickness Distribution

$$\frac{\partial g}{\partial t} = -\frac{\partial}{\partial h}(fg) + L(g) - \nabla \bullet (\vec{v}g) + \Psi(h,g,\vec{v})$$



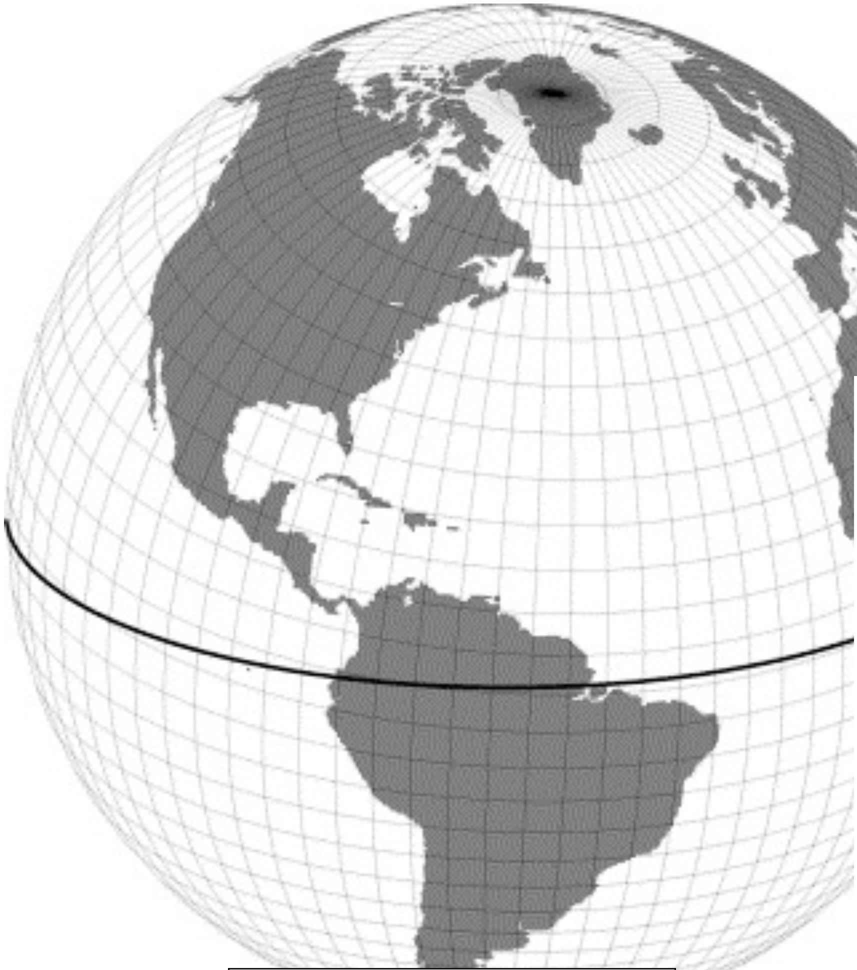


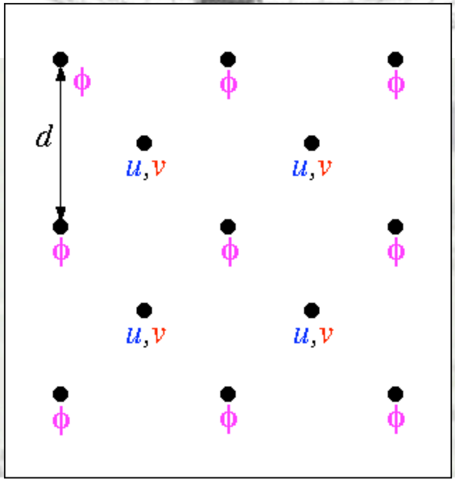
(Thorndike et al., 1975)

Evolution … ce, and

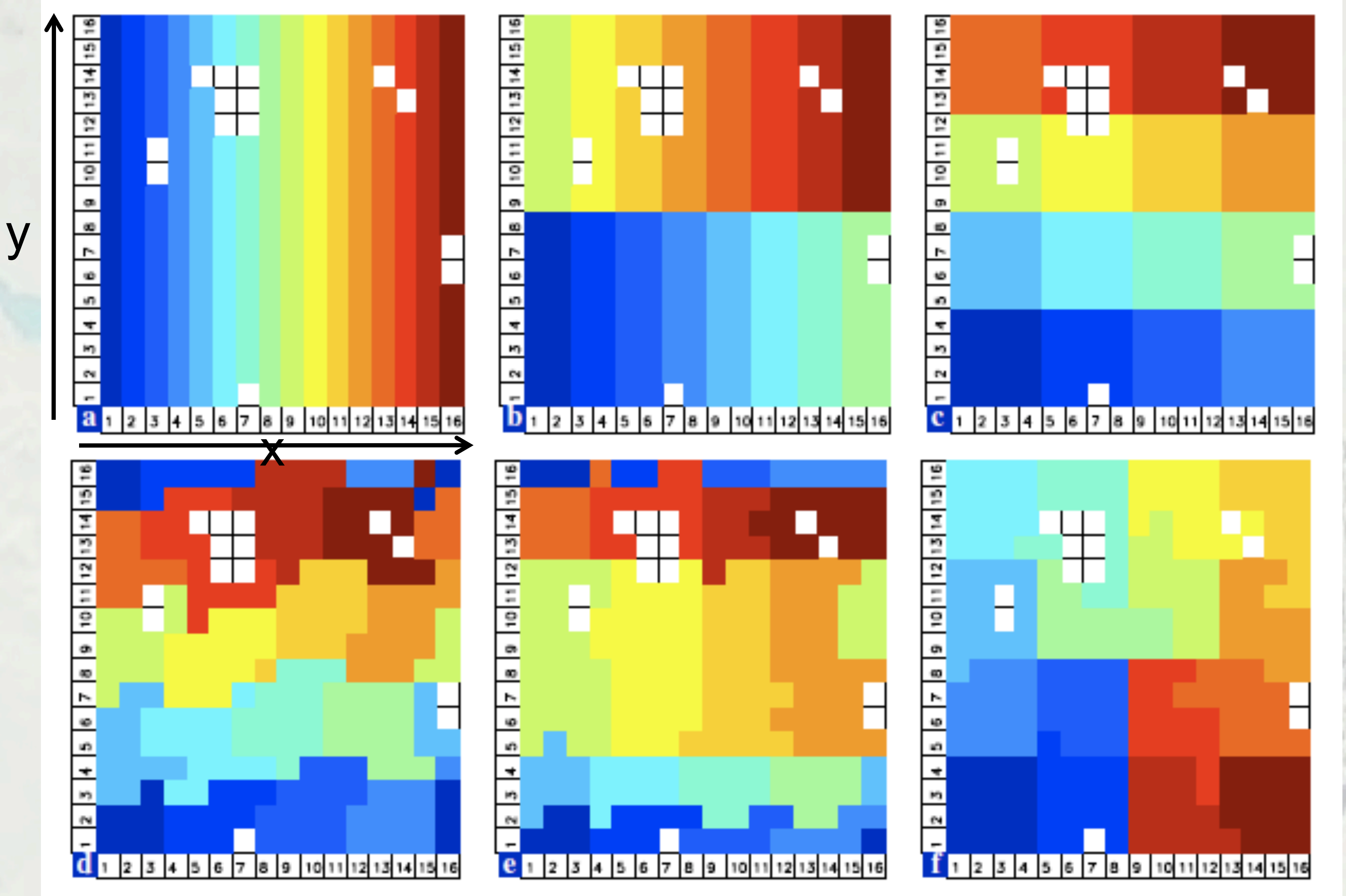
g = obs, h = 2 or 1

CICE model is discretized on an Arakawa B-grid using a dipole or tripole grid.





Computational Decomposition



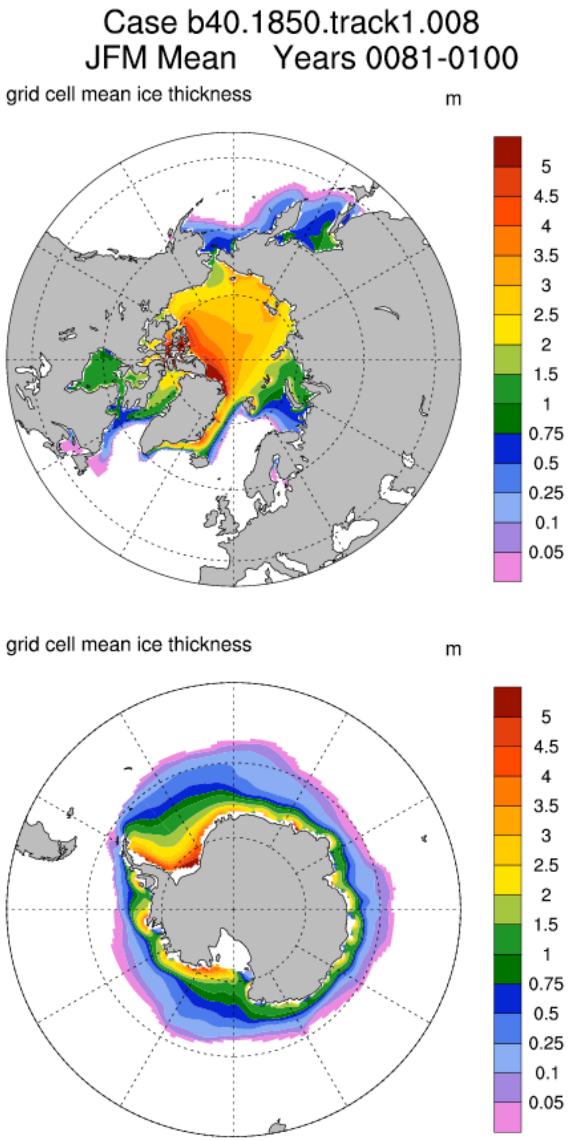
Coupling with Atmosphere

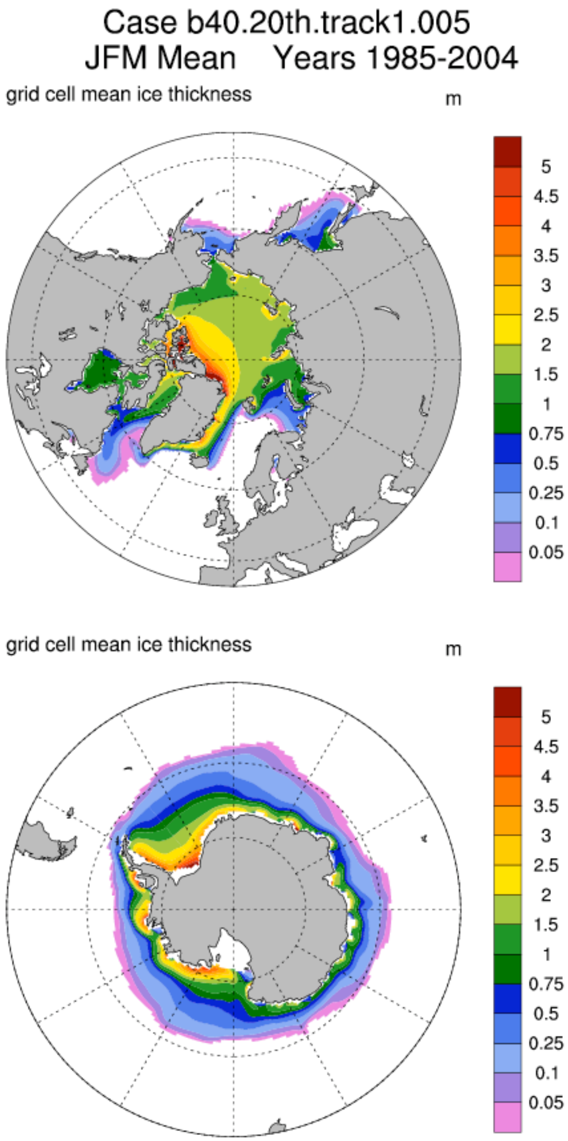
- Sea ice receives temperature, density, humidity, incoming radiation fields, rain, and snow.
- Sea ice returns grid cell aggregate ice fraction and thickness, surface temperature, albedo, surface stresses, turbulent heat fluxes, and upward radiative fluxes.

CCSM4 Sea Ice Component

- Community Ice CodE (CICE) 4.0 Base Code
- Delta-Eddington Radiative Transfer in sea ice and snow. (Briegleb and Light)
- Melt Pond Parameterization. (Bailey and Holland)
- Arbitrary Number of Tracers (for example – age, melt ponds, aerosols).
- Simple (linear) snow aging.
- Aerosol cycling and deposition on sea ice / snow.

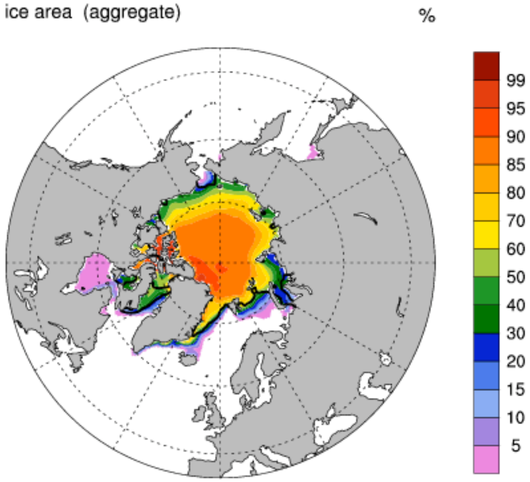
1850 control and 20th Century Runs

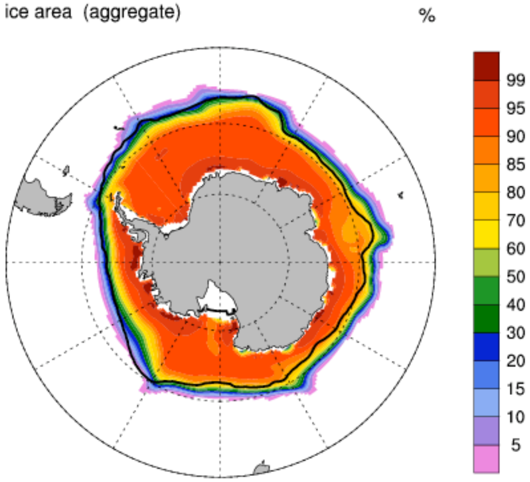

Case b40.1850.track1.008
JFM Mean Years 0081-0100


Case b40.20th.track1.005
JFM Mean Years 1985-2004

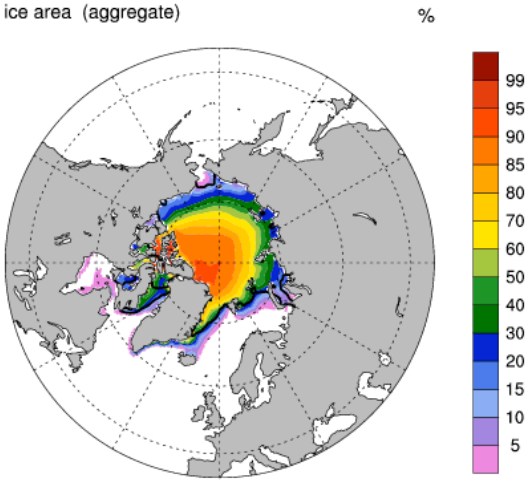
1850 control and 20th Century Runs (2)

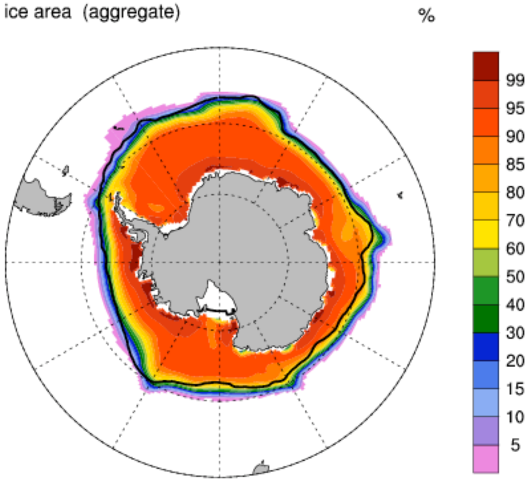
Case b40.1850.track1.008
JAS Mean Years 0081-0100

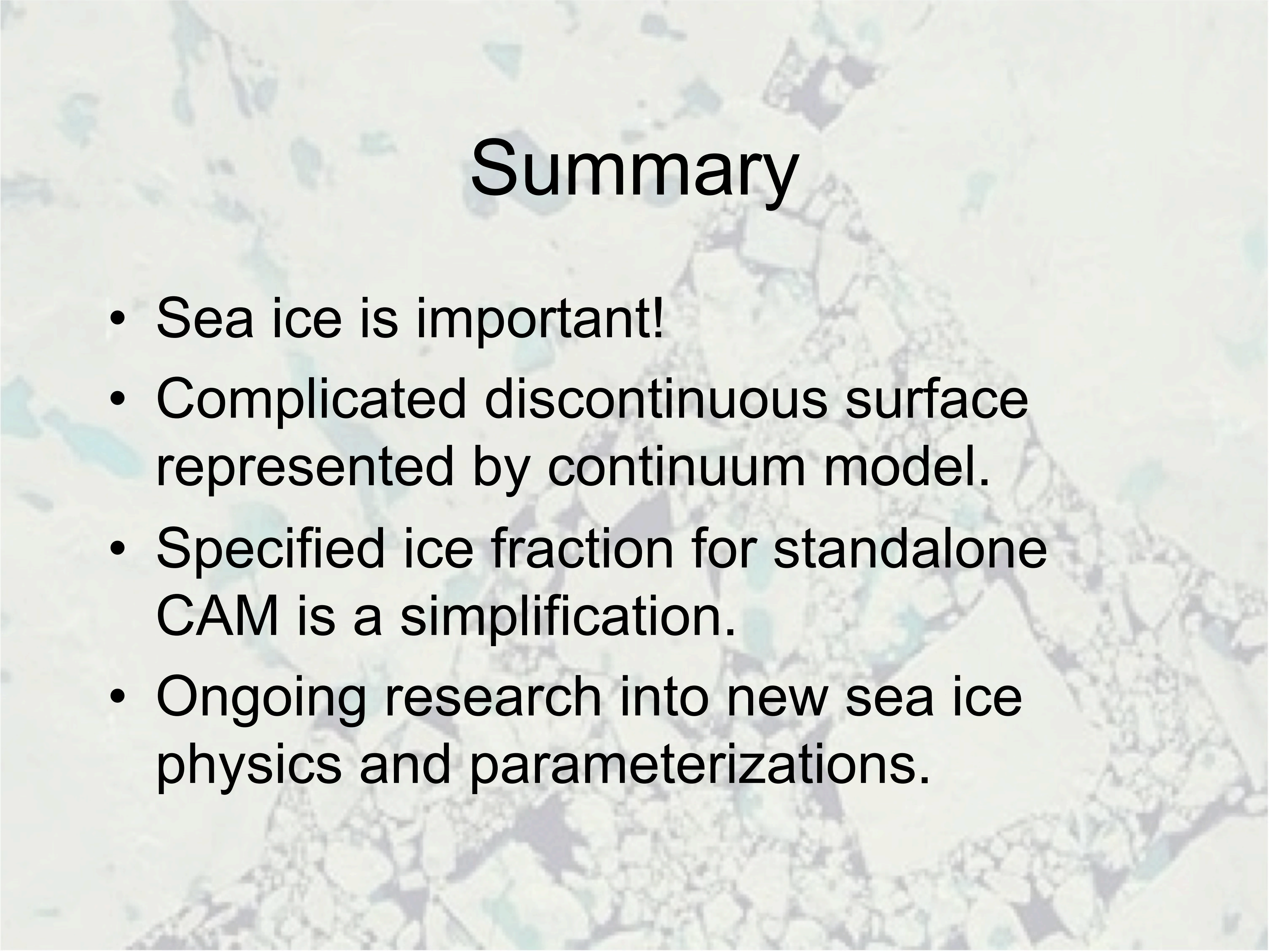




Case b40.20th.track1.005
JAS Mean Years 1985-2004







Summary

- Sea ice is important!
- Complicated discontinuous surface represented by continuum model.
- Specified ice fraction for standalone CAM is a simplification.
- Ongoing research into new sea ice physics and parameterizations.