September Arctic sea ice minimum predicted by spring melt pond fraction

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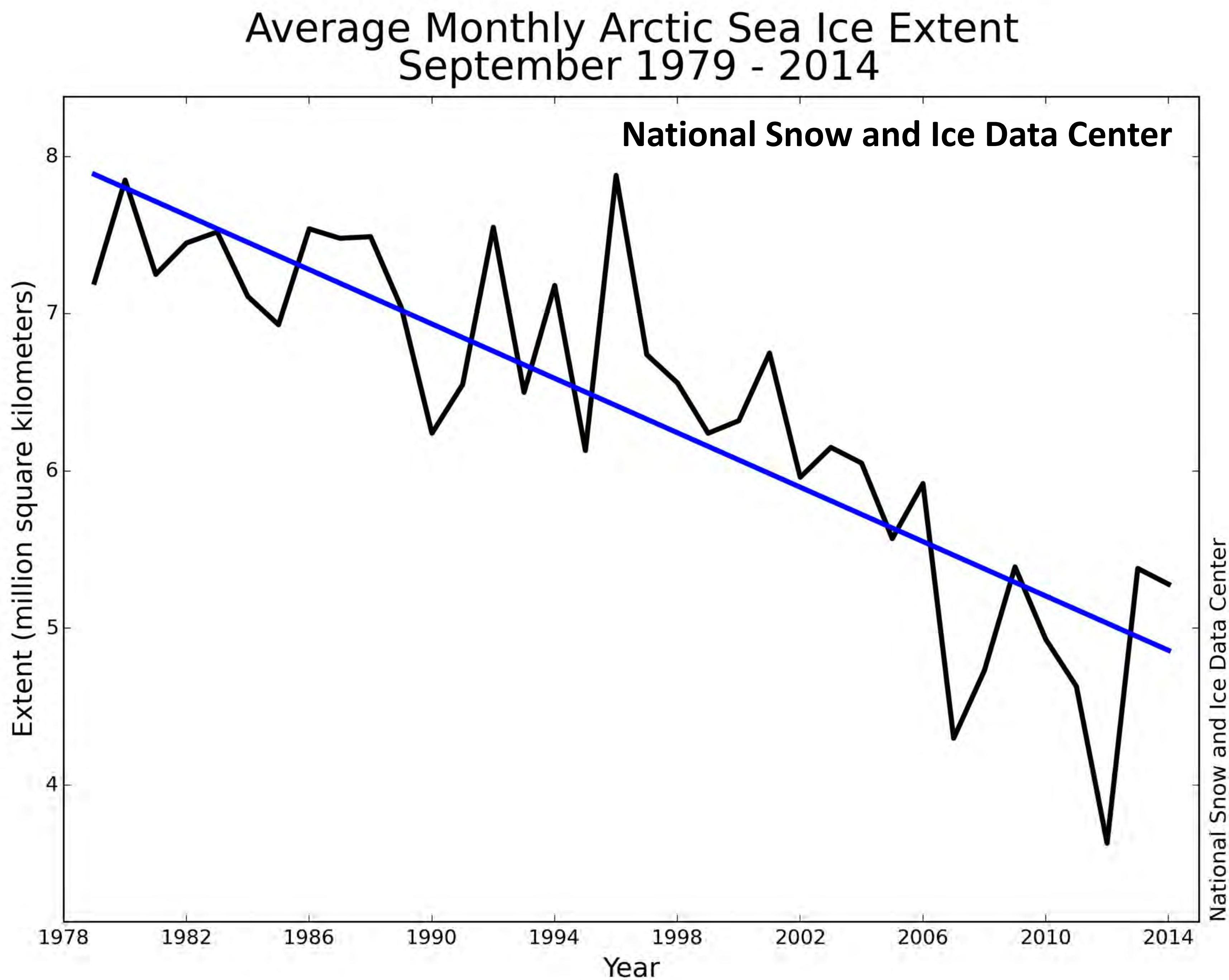
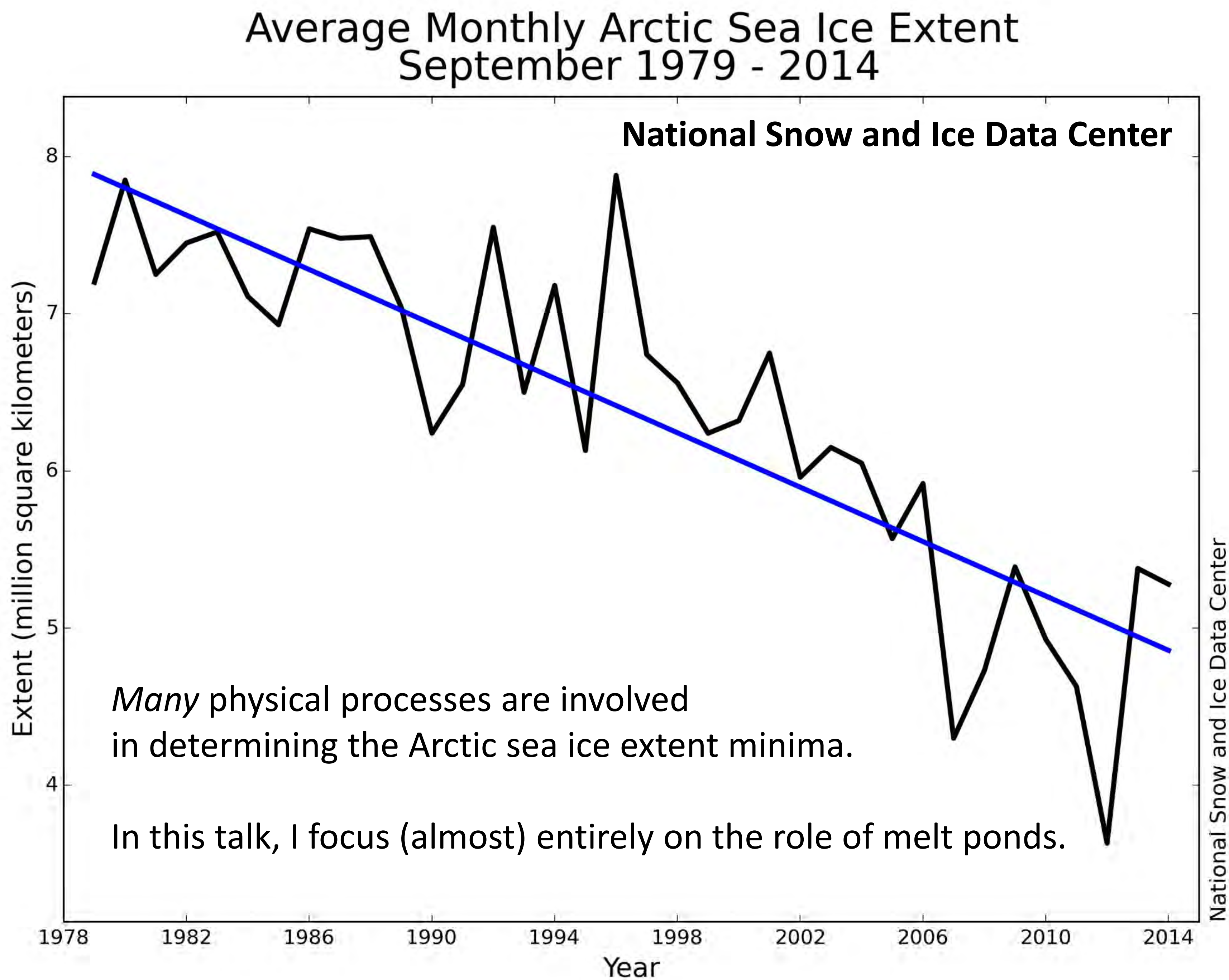
Thanks to Daniela Flocco, Michel Tsamados



Average Monthly Arctic Sea Ice Extent
September 1979 - 2014
National Snow and Ice Data Center
Extent (million square kilometers)
8
7
6
5
4
1978
1982
1986
1990
1994
1998
2002
2006
2010
2014
Year
National Snow and Ice Data Center



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8
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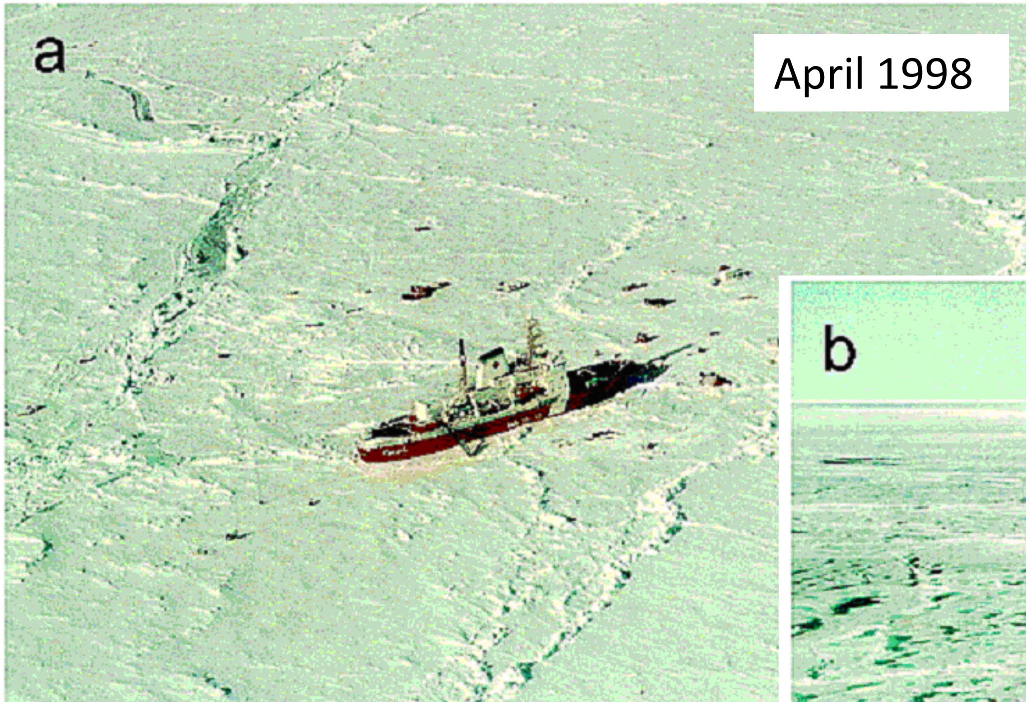
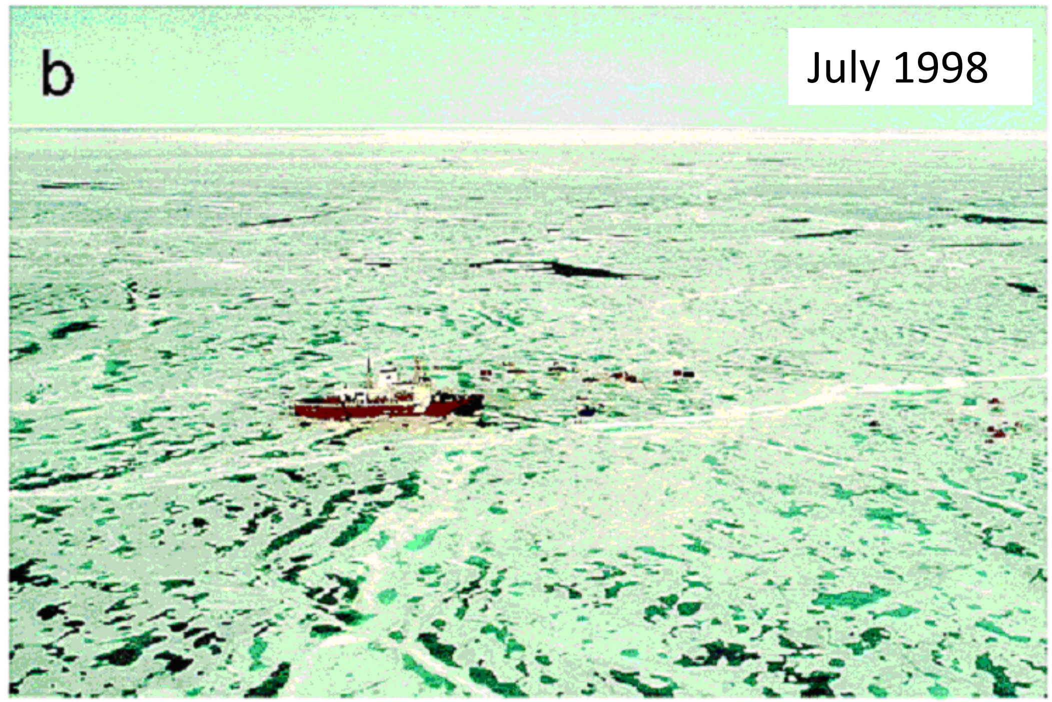
Many physical processes are involved
in determining the Arctic sea ice extent minima.
In this talk, I focus (almost) entirely on the role of melt ponds.

SHEBA field experiment

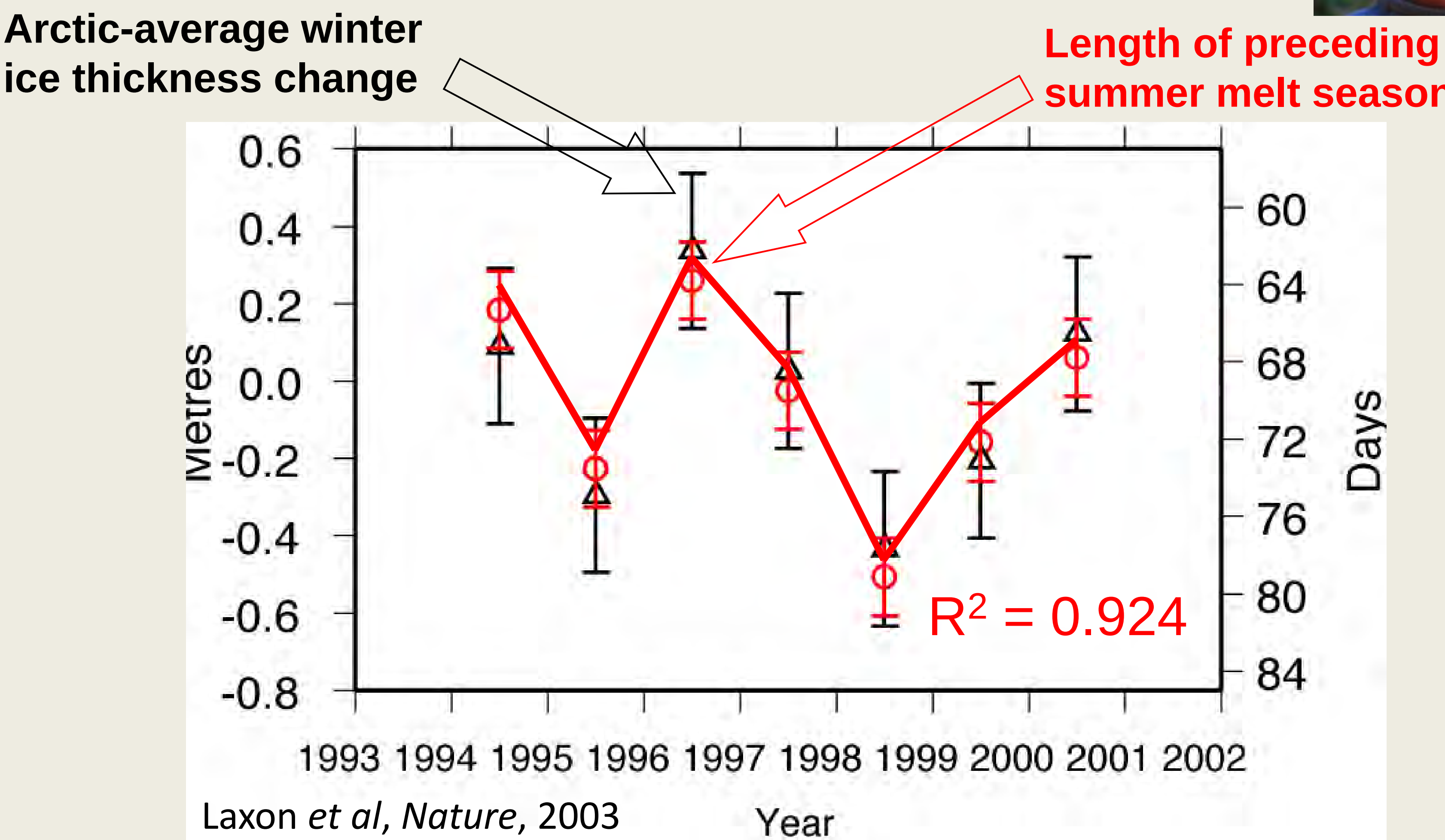




Ice Station SHEBA. Canadian Coast Guard icebreaker *Des Groseilliers*.

"The story of summer [surface] melting of the Arctic ice cover is the story of melt ponds" Don Perovich, lead scientist of the SHEBA field experiment.

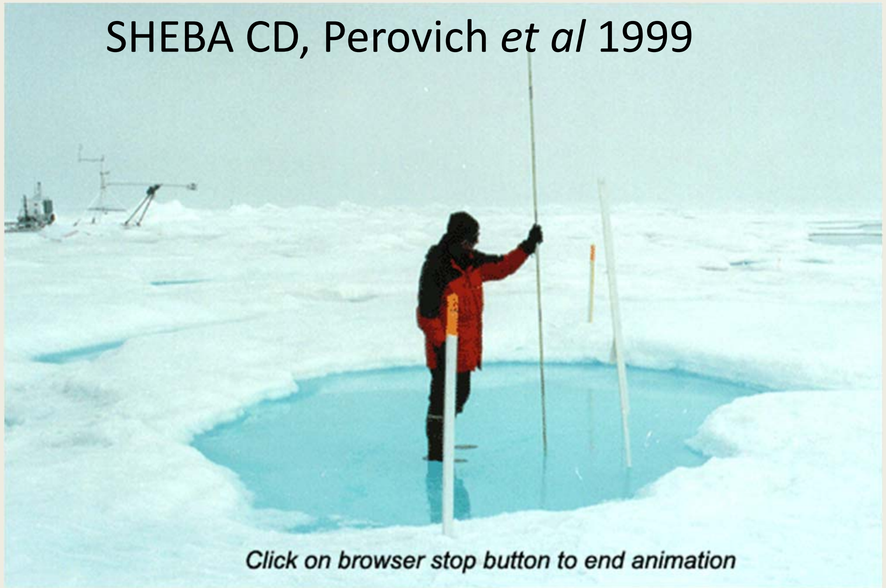
Importance of summer melt processes to sea ice mass balance



Laxon *et al*, *Nature*, 2003

Using ERS satellite data, strong correlation found between ice thickness and length of previous melt season.

Melt ponds



- Surface snow and ice melts due to absorbed solar, short wave radiation and accumulates in ponds. Ponds are typically 1-100m wide and 0.1-1.5m deep.
- 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)
- Deeper ponds have a lower albedo, which saturates at about 1.5m depth.
- Ponded ice melt rate is 2—3 times greater than bare ice and melt ponds contribute to the albedo feedback mechanism.
- **Melt ponds are not (yet) explicitly represented in Global Climate Models.**

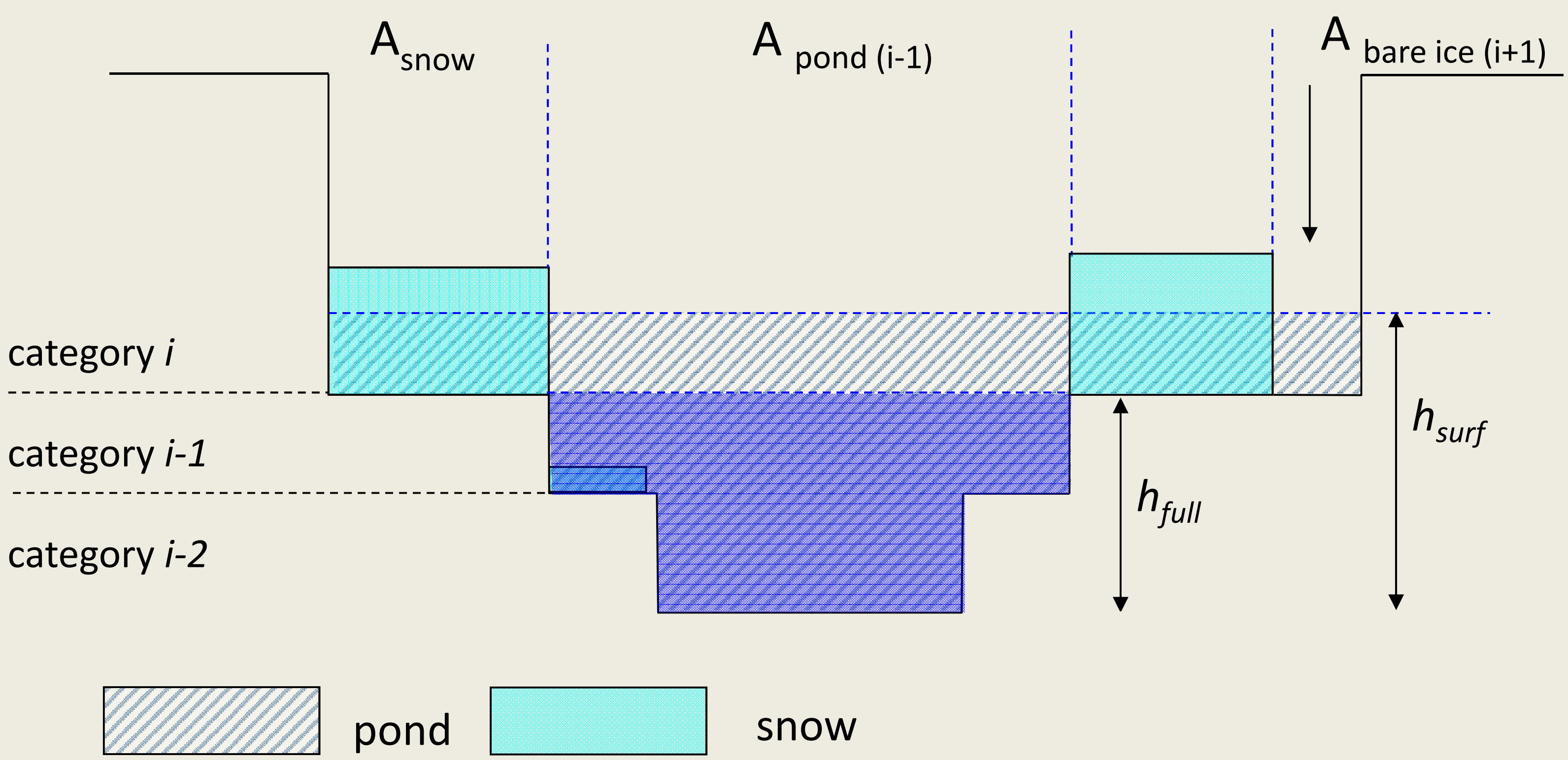
Climate model melt ponds

[Flocco and Feltham, 2007]

Main difficulty with including melt ponds into a climate model is lack of surface topography.

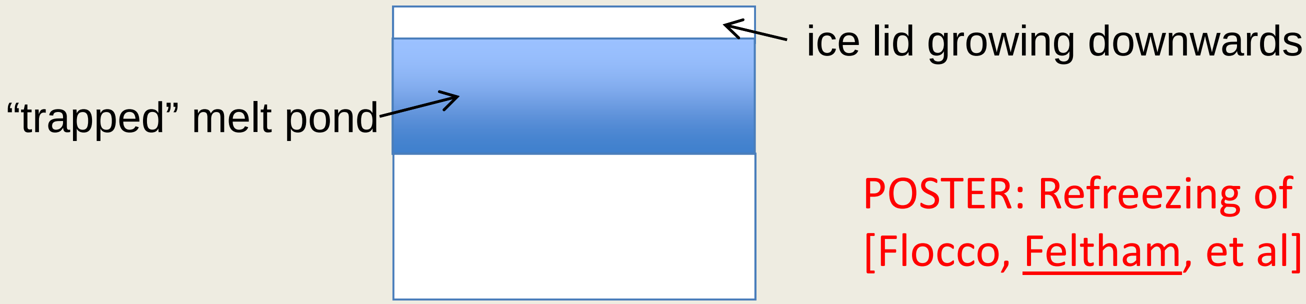
As a partial fix, we introduced a surface height *α(h)* distribution, which gives the relative area of ice of a given surface height.

We let melt water fill up the surface, which determines the pond area and depth.



Melt pond parameterisation features

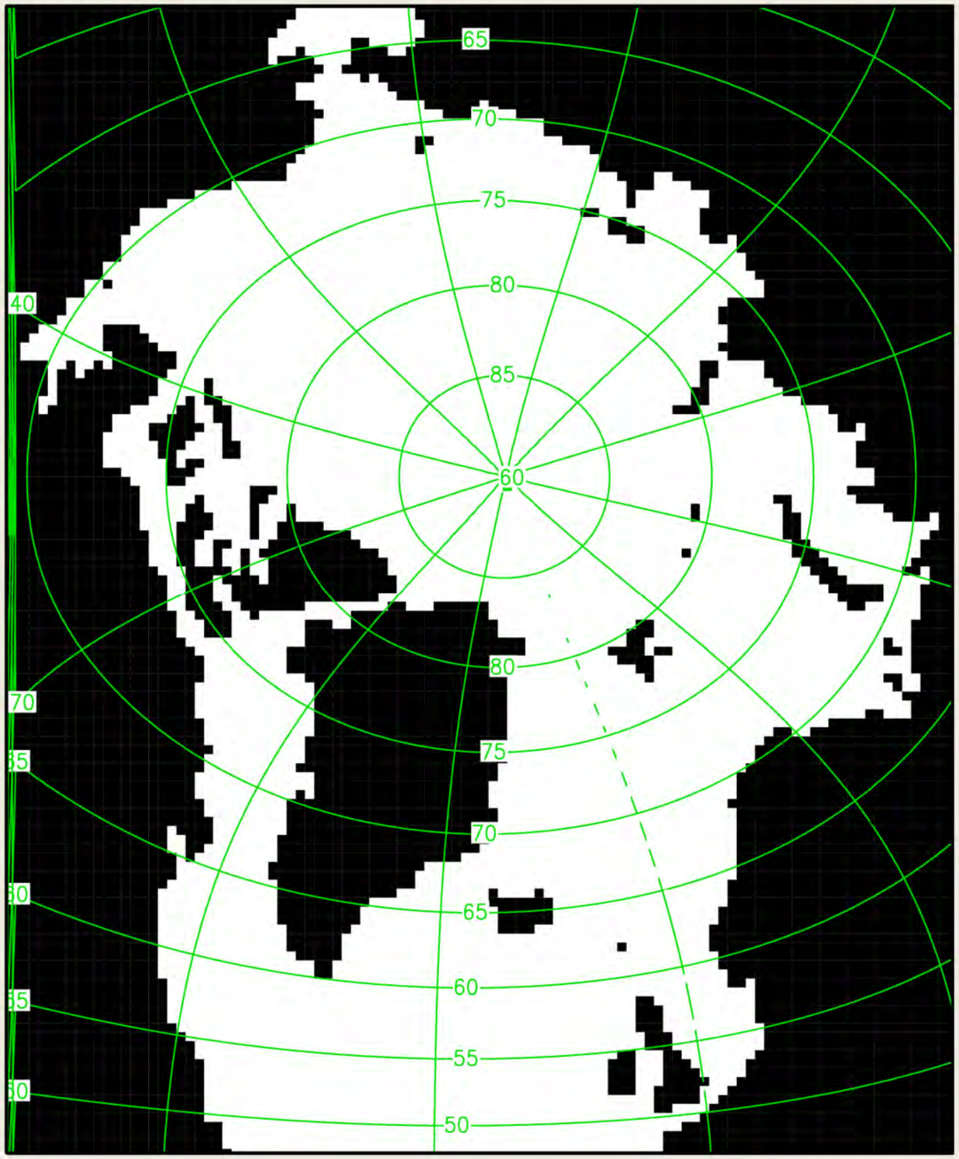
- Pond volume collects on ice of lowest height.
- Hydrostatic balance is maintained throughout.
- Vertical drainage is by Darcy's law with a variable permeability.
- Melt water is lost during ridging.
- Melt water is transported as a tracer on each thickness class.
- During refreezing, a pond lid forms that grows/melts at each time step.



POSTER: Refreezing of melt ponds [Flocco, Feltham, et al]

Our melt pond model has now been incorporated into a climate sea ice model (CICE) and is being included in climate models.

CPOM sea ice simulation with our pond scheme

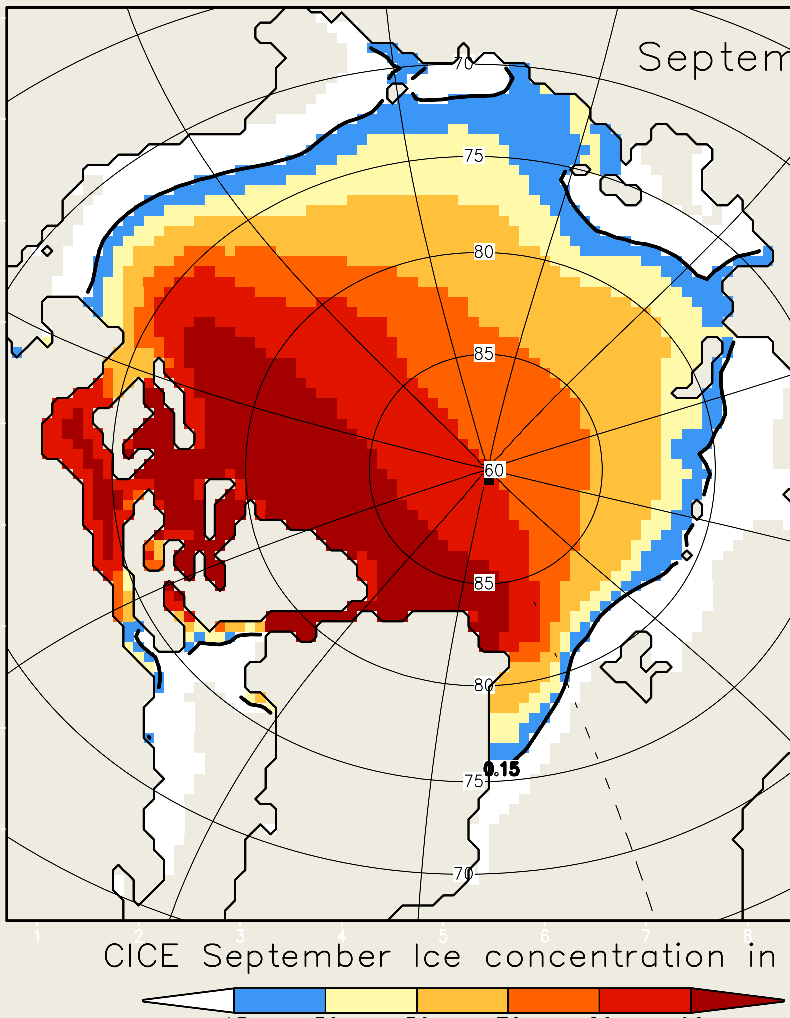


- Based on the CICE model used by the Met Office
- Stand-alone (1979-2013)
- Arctic domain (40 km)
- Atmosphere:
  - T2m, q2m (6-hourly)
  - u10m, v10m (6-hourly)
  - QLW, QSW (daily)
  - PRECIP, SNOW (monthly)

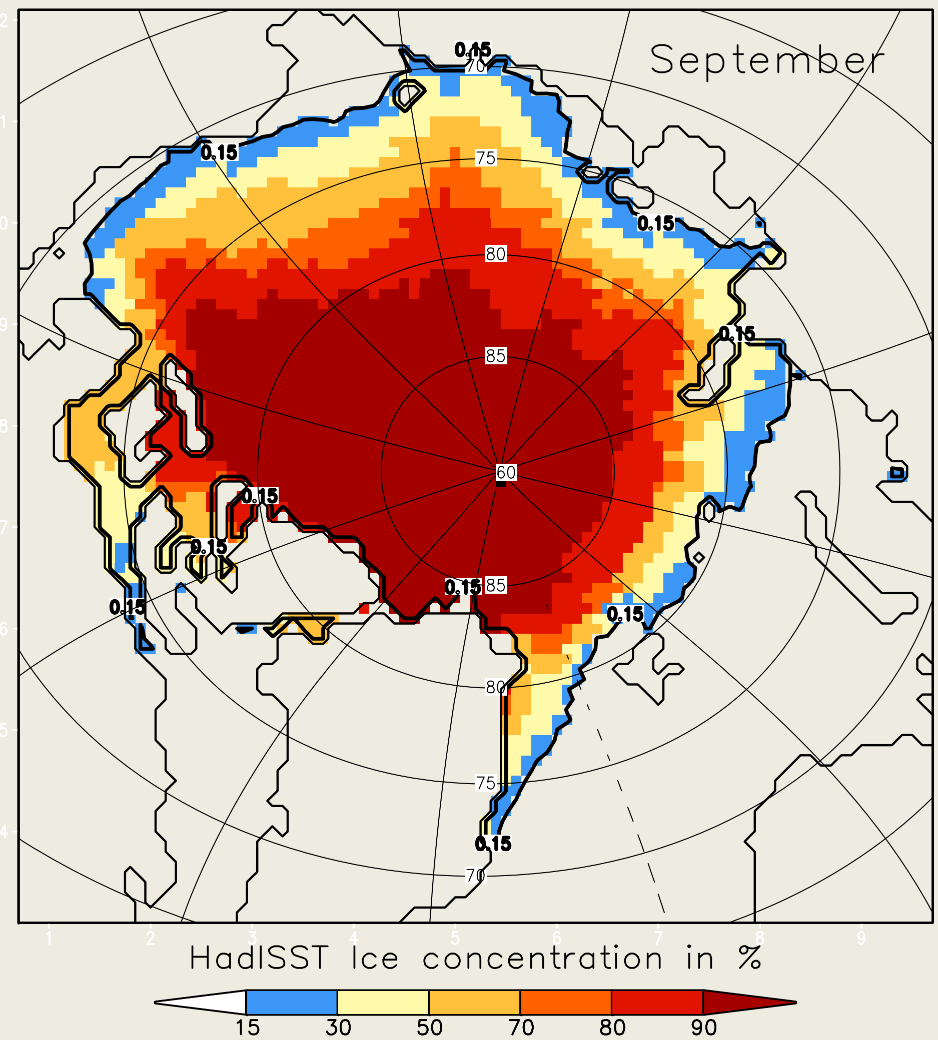
  (**NCEP2**, **ERA-Interim**, **DRAKKAR DFS5**)
- Ocean:
  - Mixed-layer ocean (20 m)
  - SO1m, TO1m (clim. monthly means)
  - SO prescribed, TO prognostic, 20d restoring

  (Reading Ocean-Reanalysis)

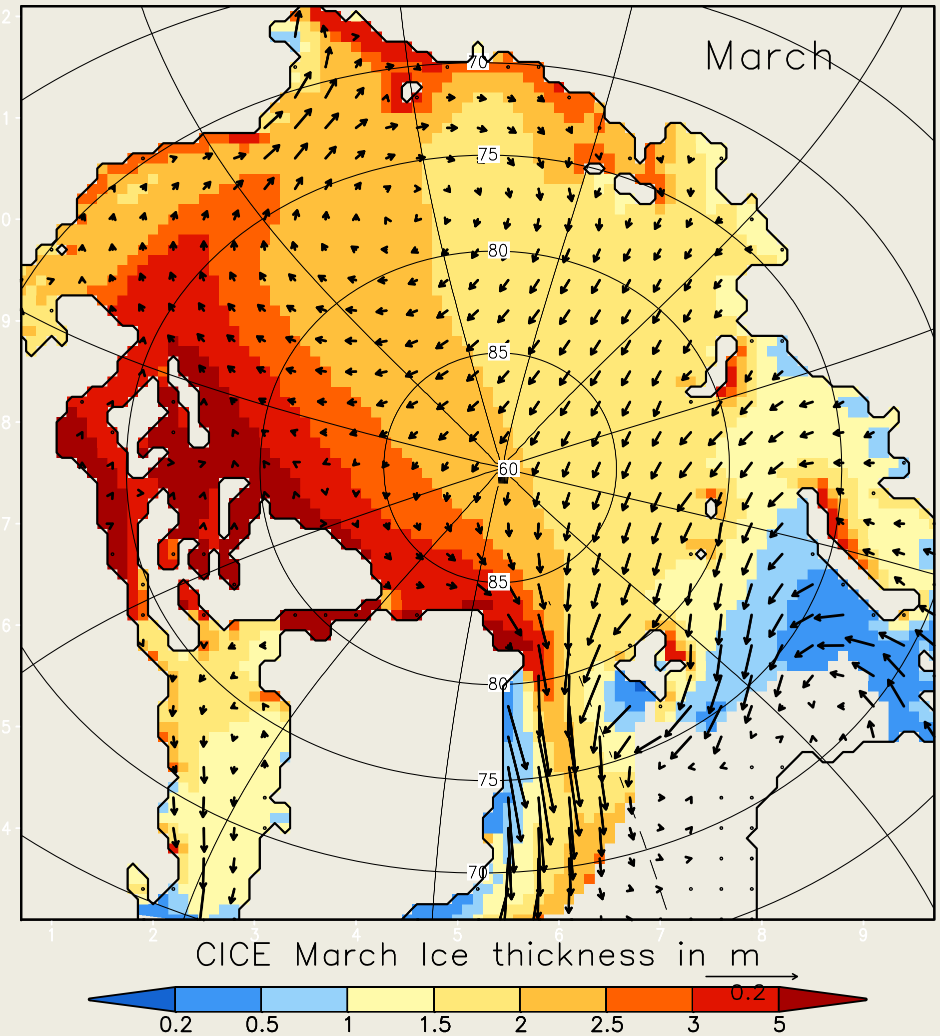
Climatology 1979-2012 September Ice Concentration

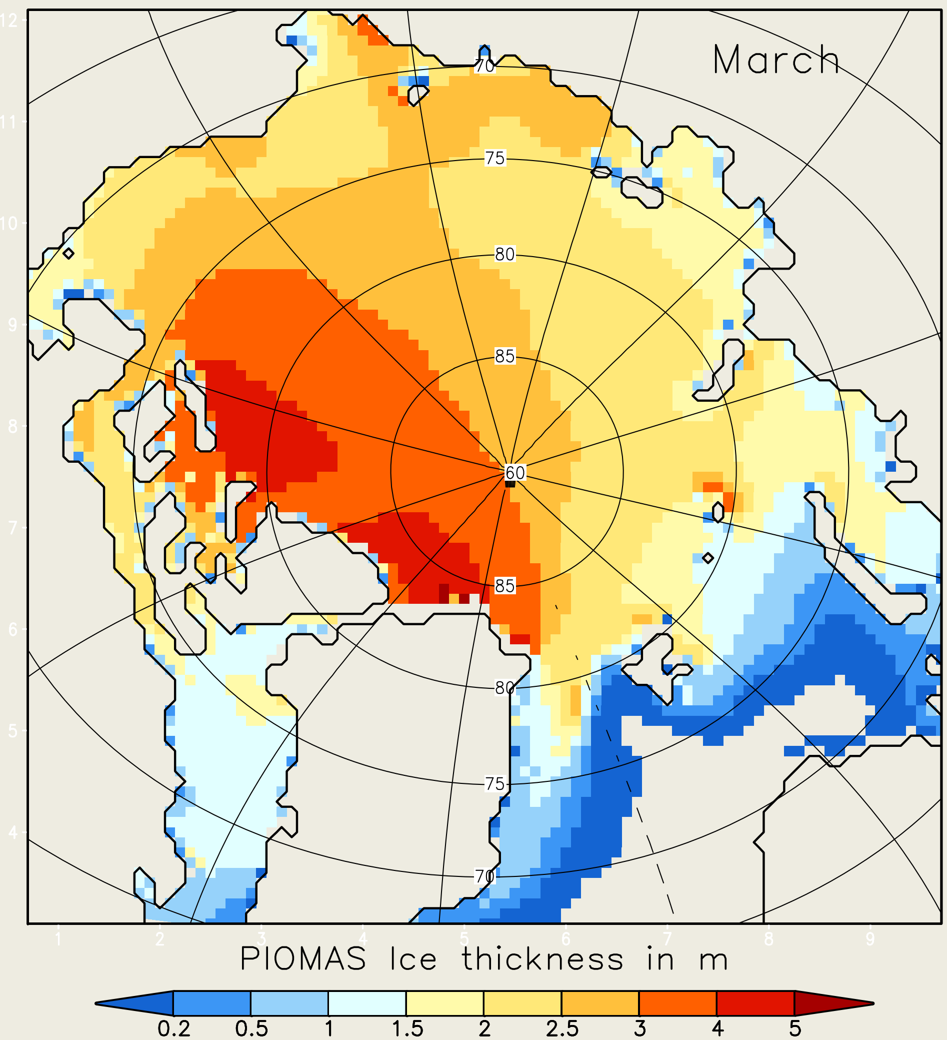


Hadley Centre Sea Ice and Sea Surface Temperature data set (HadISST)



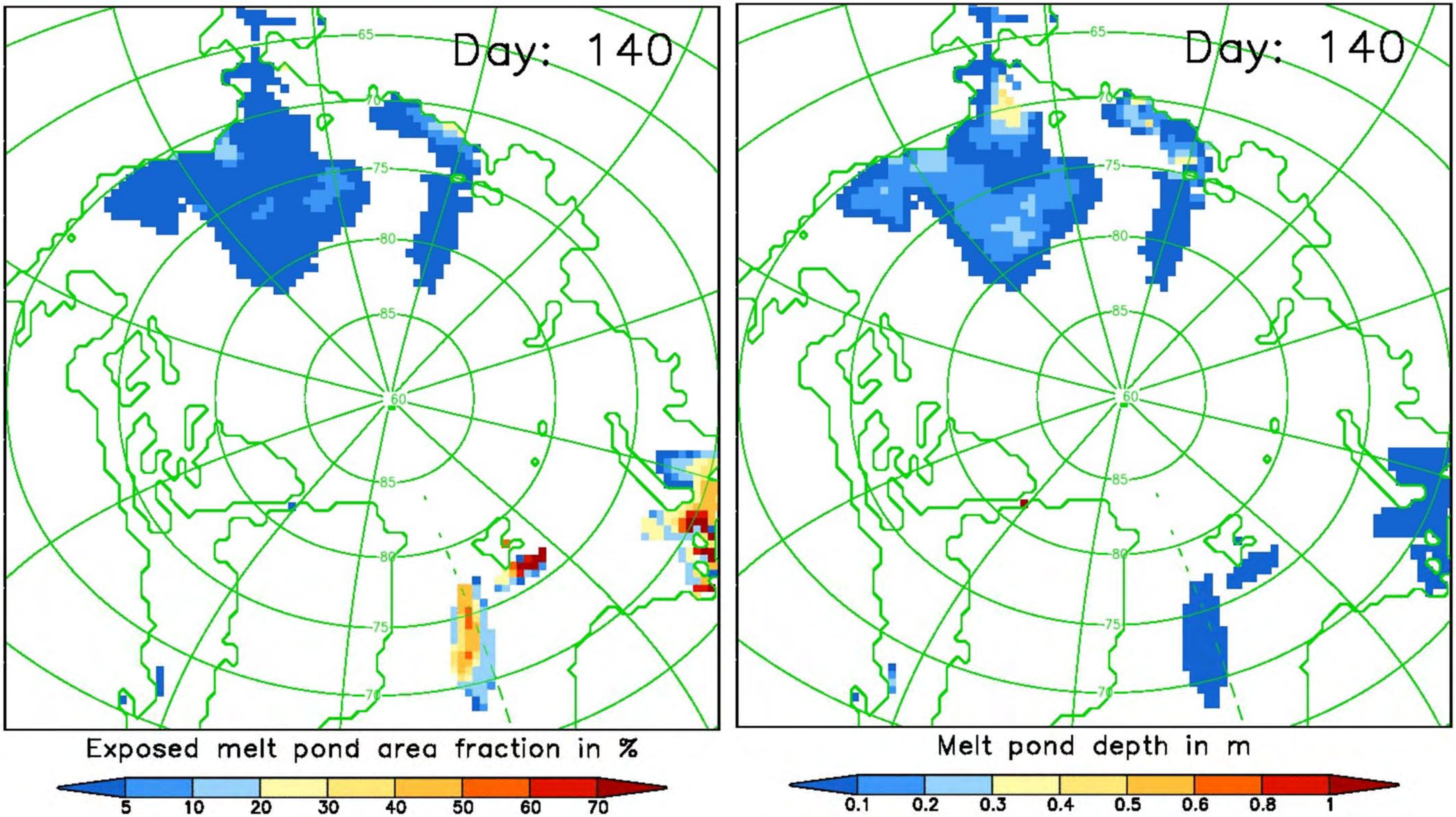
Climatology 1979-2012
March Ice Thickness

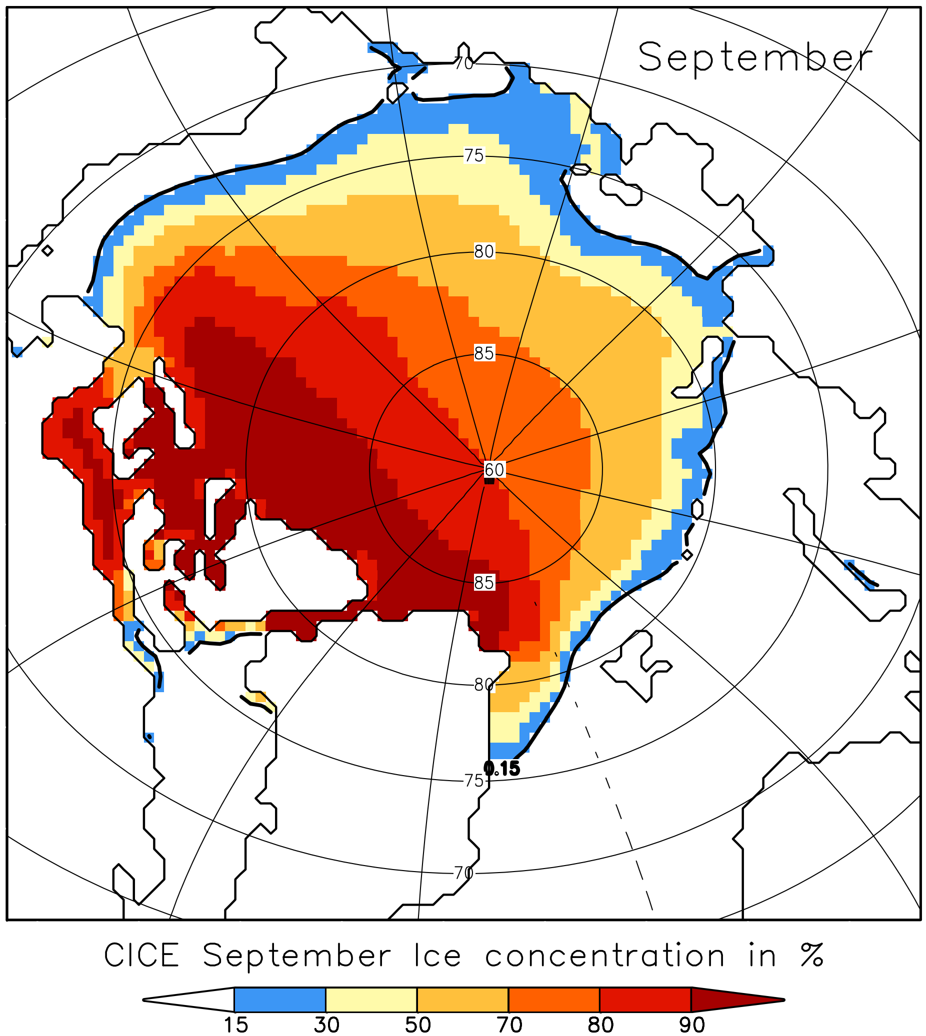




PIOMAS (Pan-Arctic Ice-Ocean Modeling and Assimilation System) Data Sets – from the Retrospective Investigation [c.f. CryoSat2, Laxon et al 2013]

Melt pond area and depth
20th May (Day 140) – 18th August (Day 230) 2012

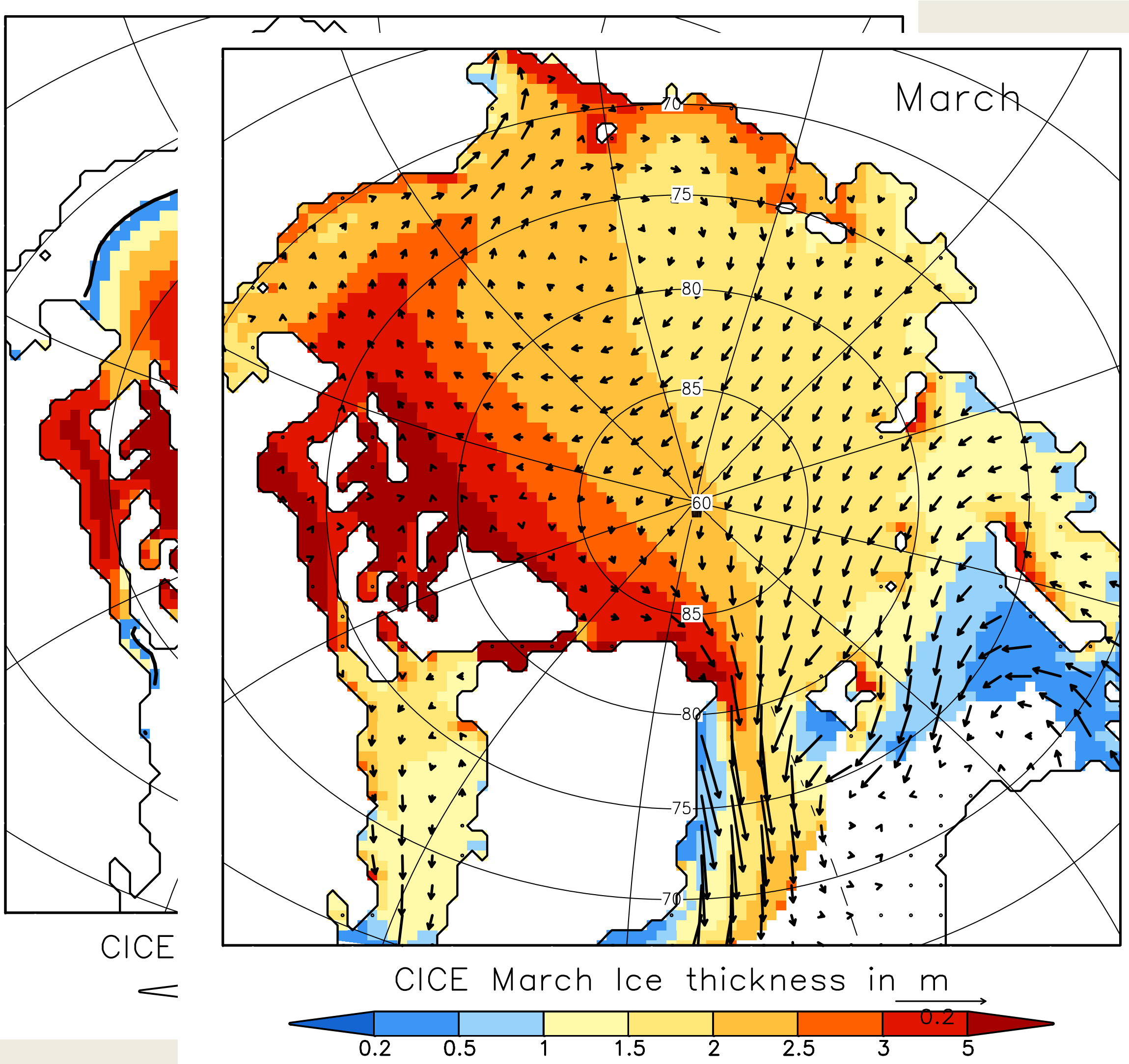




Climatology 1979-2012 September Ice Concentration

Stand-alone, i.e. forced, sea ice model including our pond scheme.

Climatological sea ice concentration and thickness are reasonable compared with observations (HadISST and PIOMAS).



Climatology 1979-2012 March Ice Thickness

Stand-alone, i.e. forced, sea ice model including our pond scheme.

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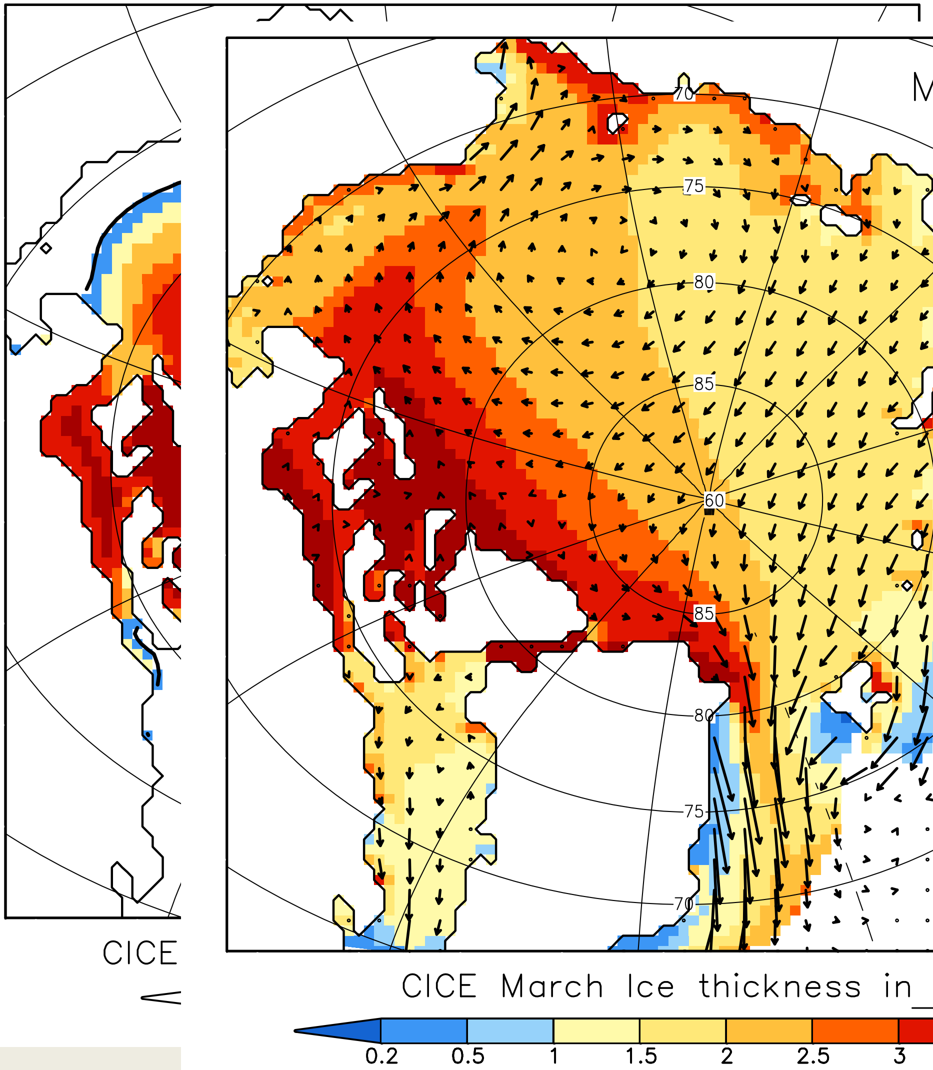
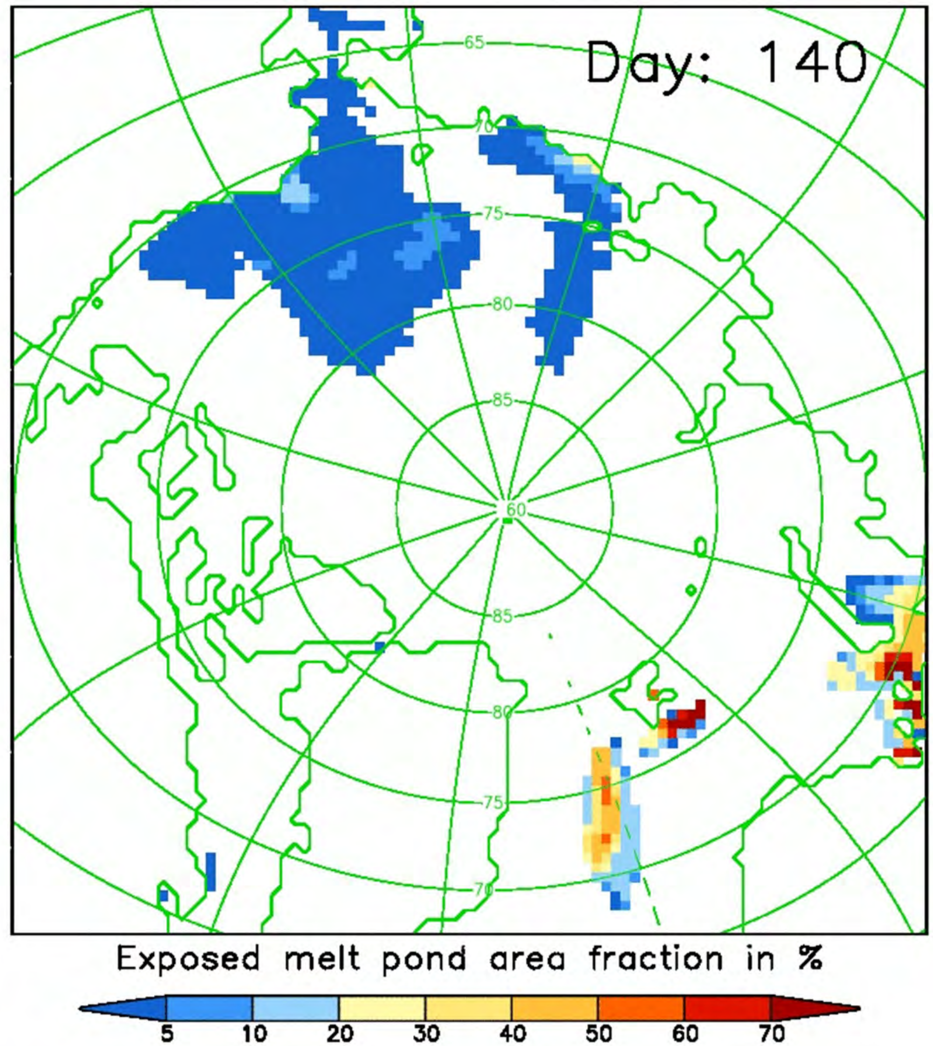
Melt pond area, summer 2012

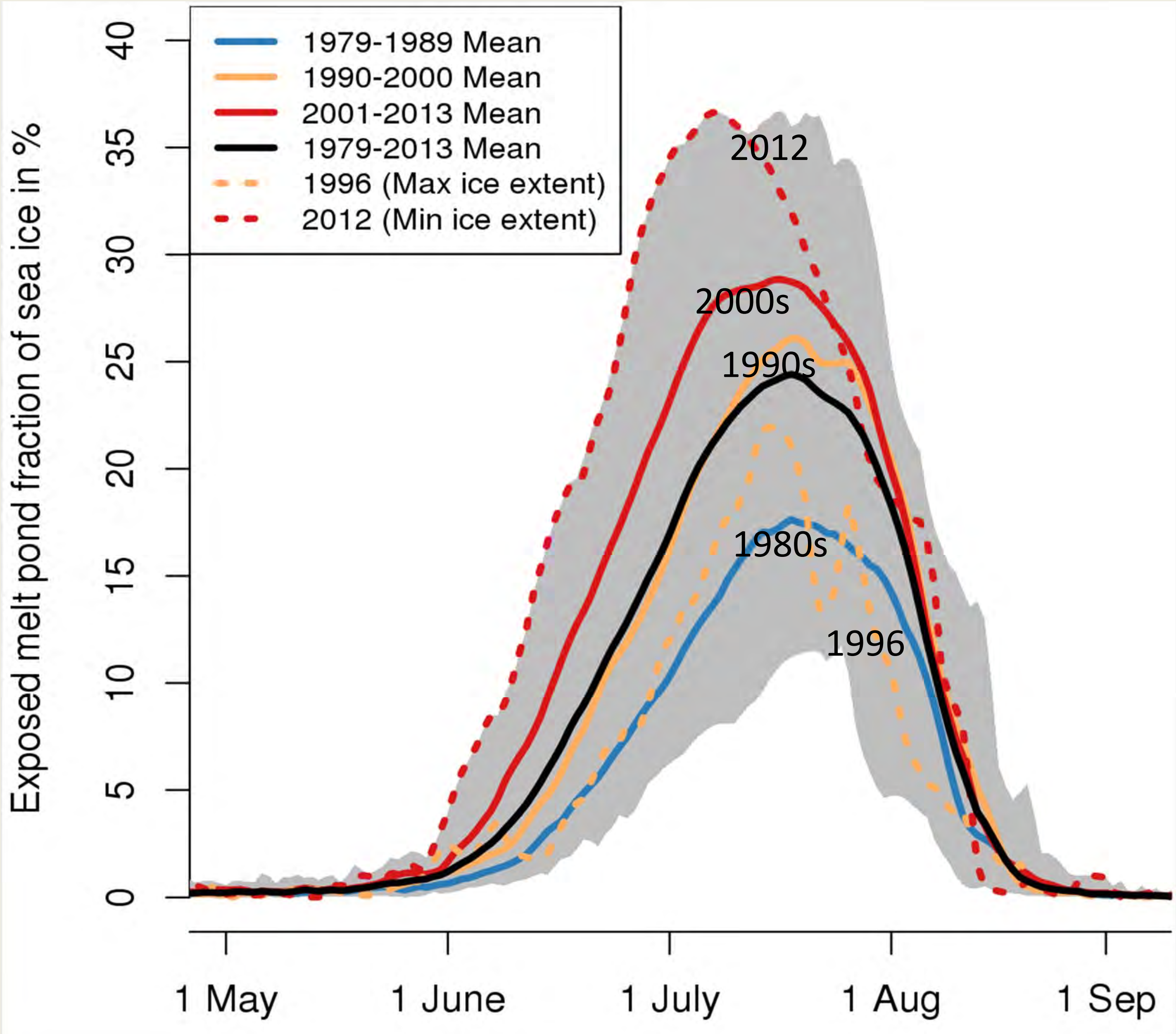




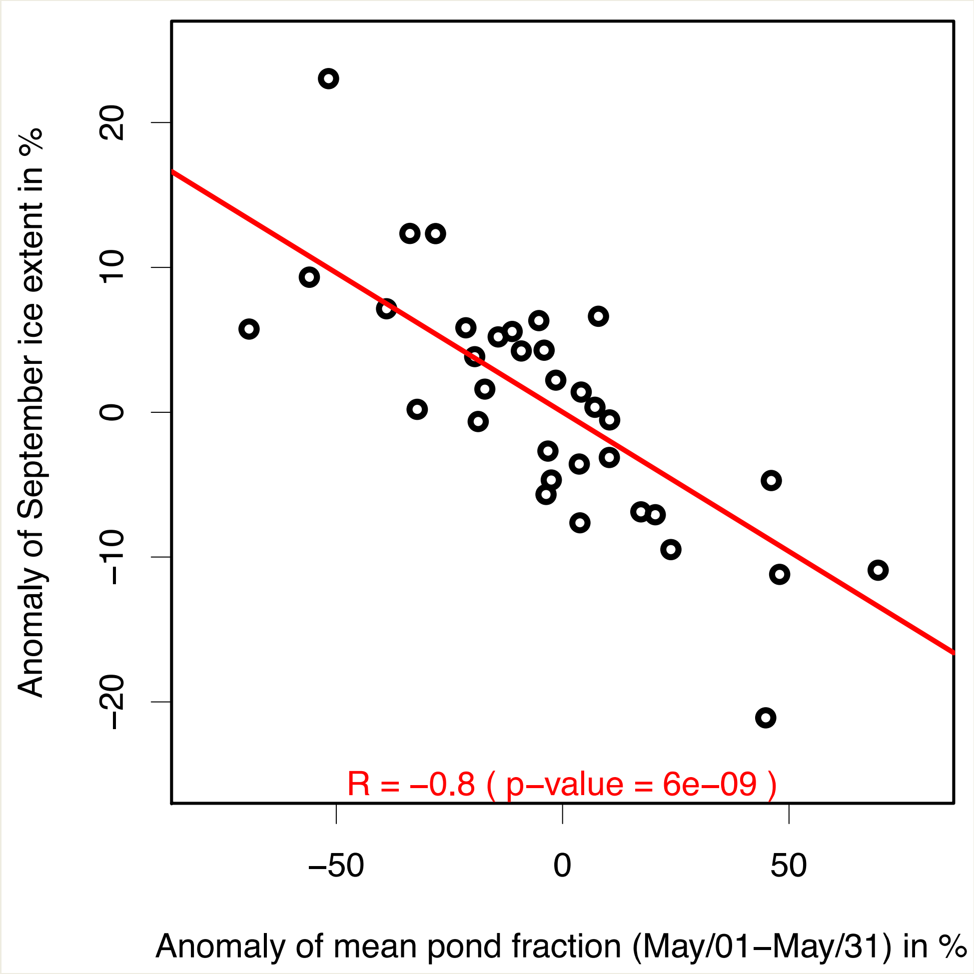
Stand-alone, i.e. forced, sea ice r

Climatological sea ice concentrat
compared with observations (Ha

Seasonal evolution of melt ponds



Correlation of September sea ice minima with pond fraction in May

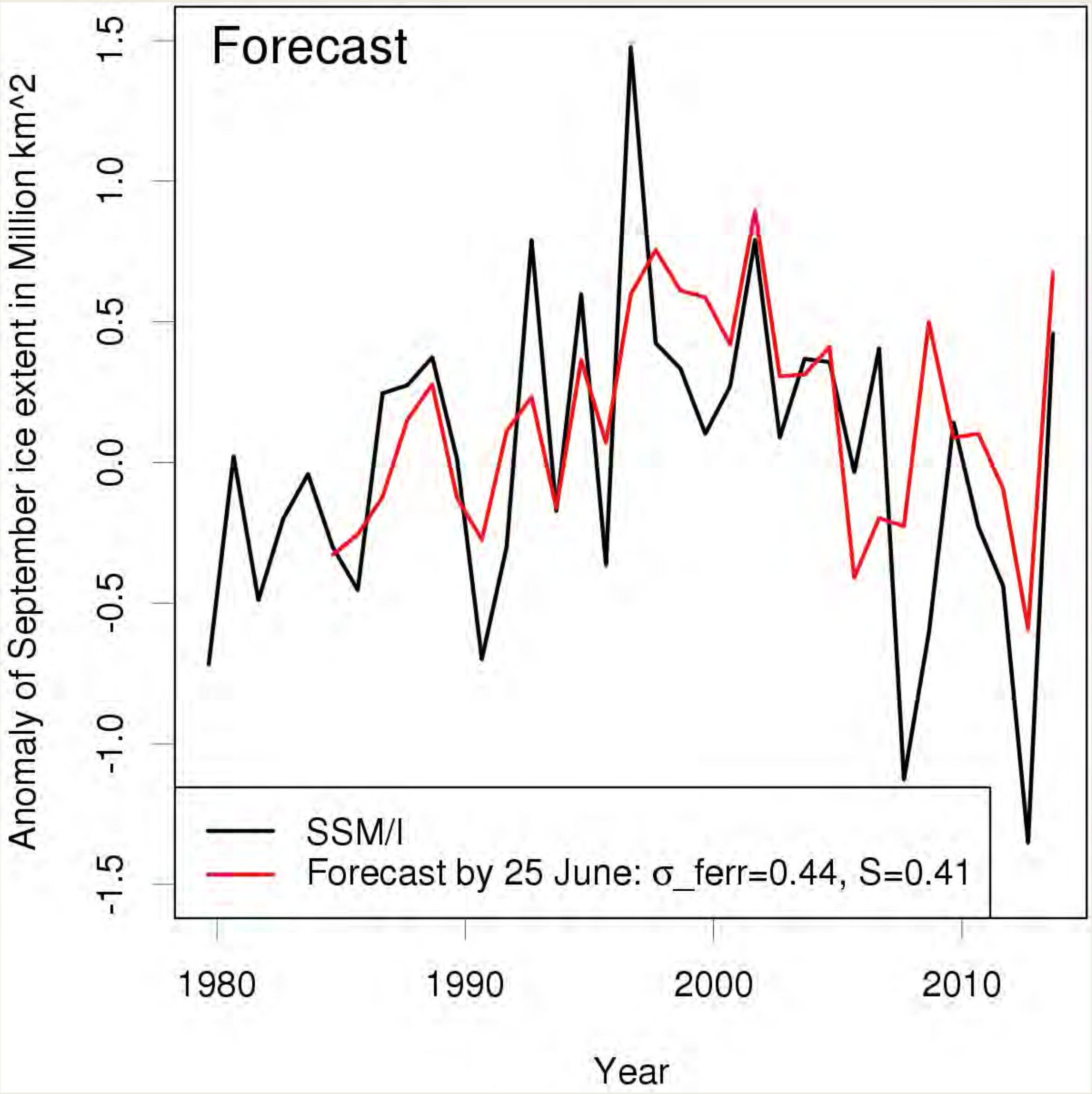


Anomaly-anomaly plot of **detrended** ice extent vs pond fraction

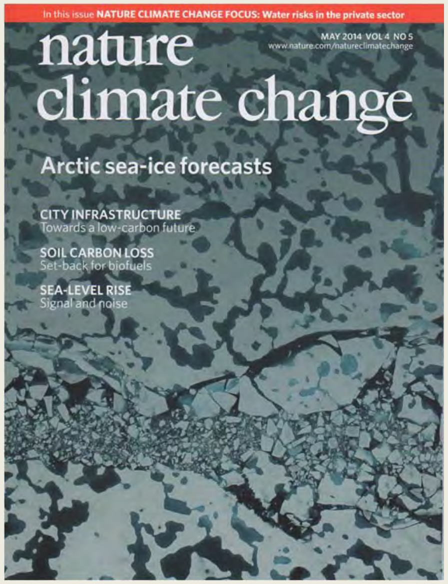
We found a strong, negative correlation between the **model** early season pond fraction and the late season **observed** September sea ice extent minima.

This is a correlation between **anomalies**, e.g. an unusually high pond coverage is correlated with an unusually low ice extent.

For the first time it is possible to make **skilful forecasts** of September sea ice minima more than 2 months in advance, using melt pond cover.

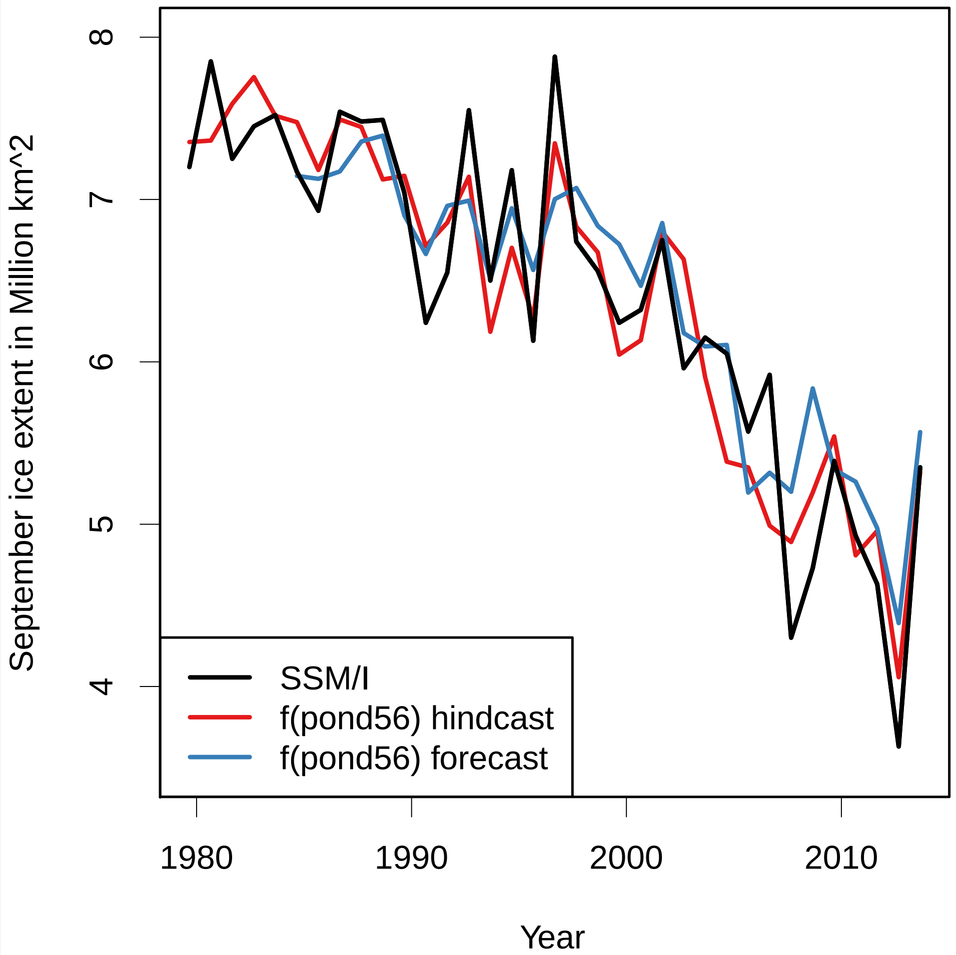


Maximum skill in late June but noteworthy skill in late May.



Schroeder, Feltham, Flocco, and Tsamados [2014]

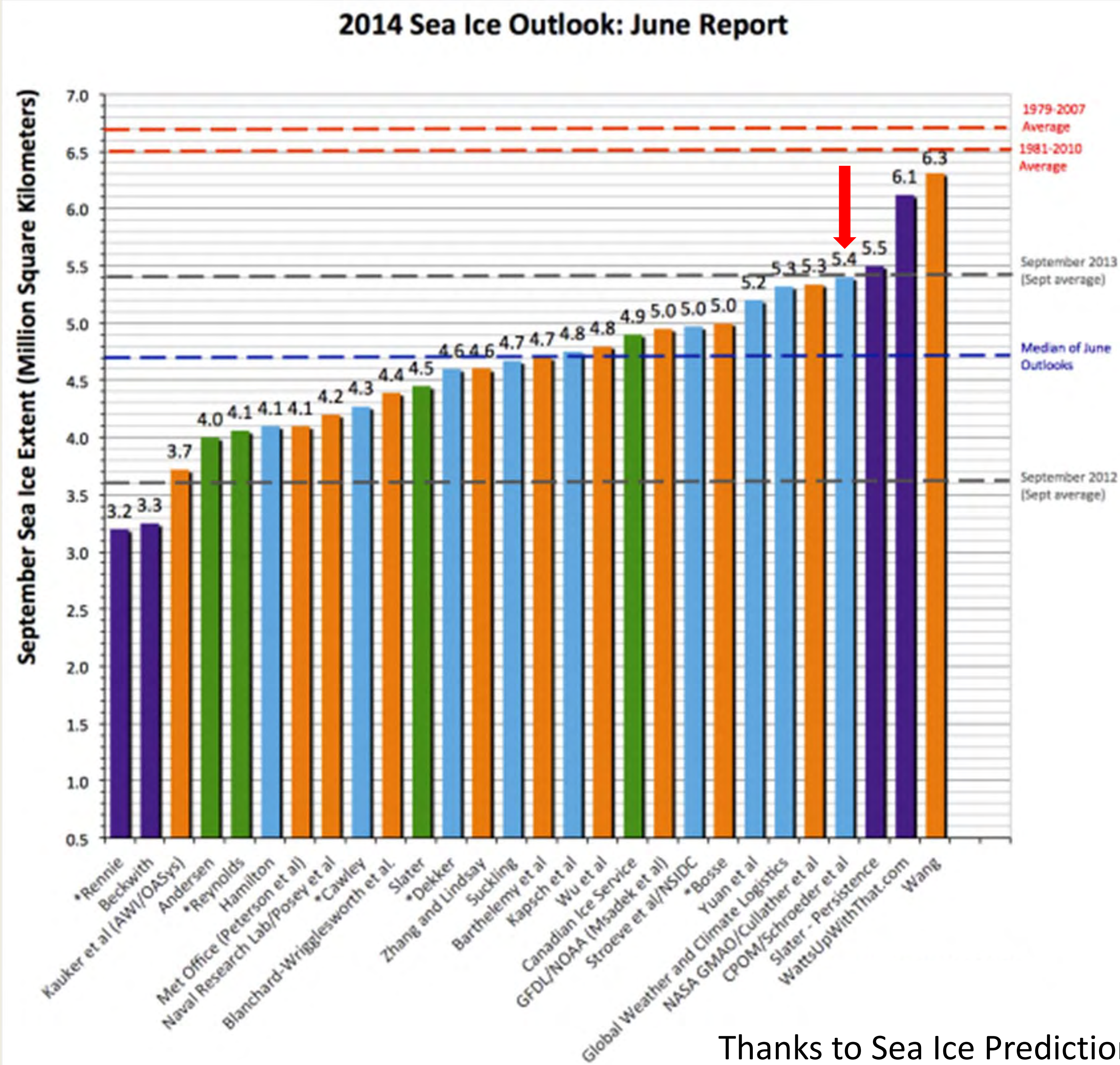
Our melt pond technique made an **accurate** prediction of sea ice minima for September 2013



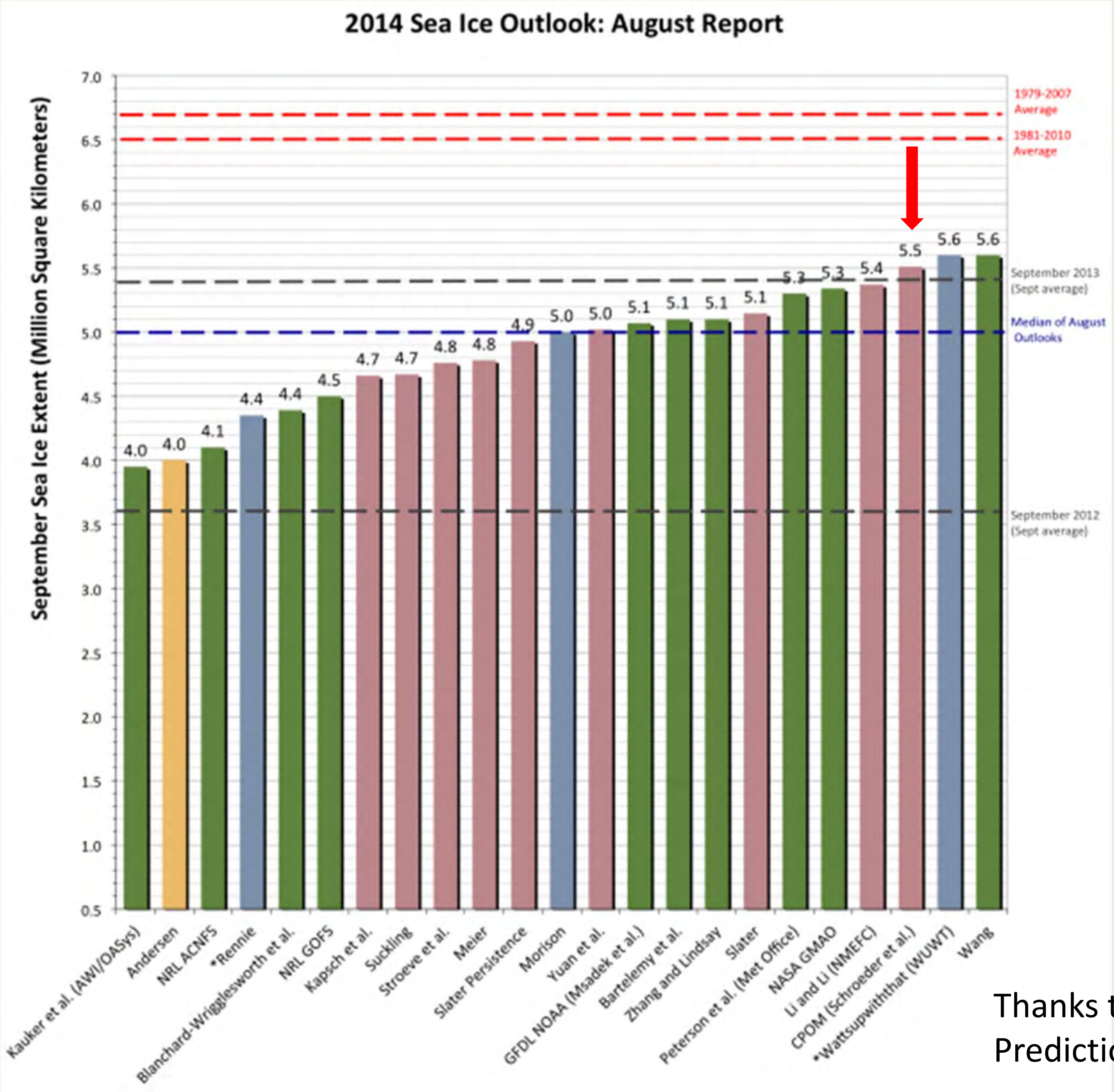
2013 forecast:
5.6 +/- 0.4
Million km^2

SSMI:
5.4
Million km^2

We believe the success of using melt ponds to predict ice extent is due to it incorporating two important factors: the thin ice fraction (upon which ponds collect) and the integrated surface melt. These factors strongly influence the ice extent.



Thanks to Sea Ice Prediction Network



Thanks to Sea Ice Prediction Network

Concluding remarks

- On 16 June, we predicted the 2014 sea ice minimum to be 5.4 M km^2 +/- 0.5 M km^2. The actual value was 5.28 M km^2. So... pretty good! But we were also lucky.

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- *Strong correlation found between pond fraction in spring and September sea ice (R=-0.80 for de-trended time-series), physically explained by the albedo feedback mechanism.*
- *We can forecast September ice extent with an error of about 0.44 M km^2 and a skill value of S = 0.41.*

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- *We can forecast September ice extent with an error of about 0.44 M km^2 and a skill value of S = 0.41.*
- A physically realistic melt pond model has been incorporated into a climate sea ice model.
- Including physically-realistic melt ponds promises to improve GCMs for seasonal sea ice forecasts and climate predictions.

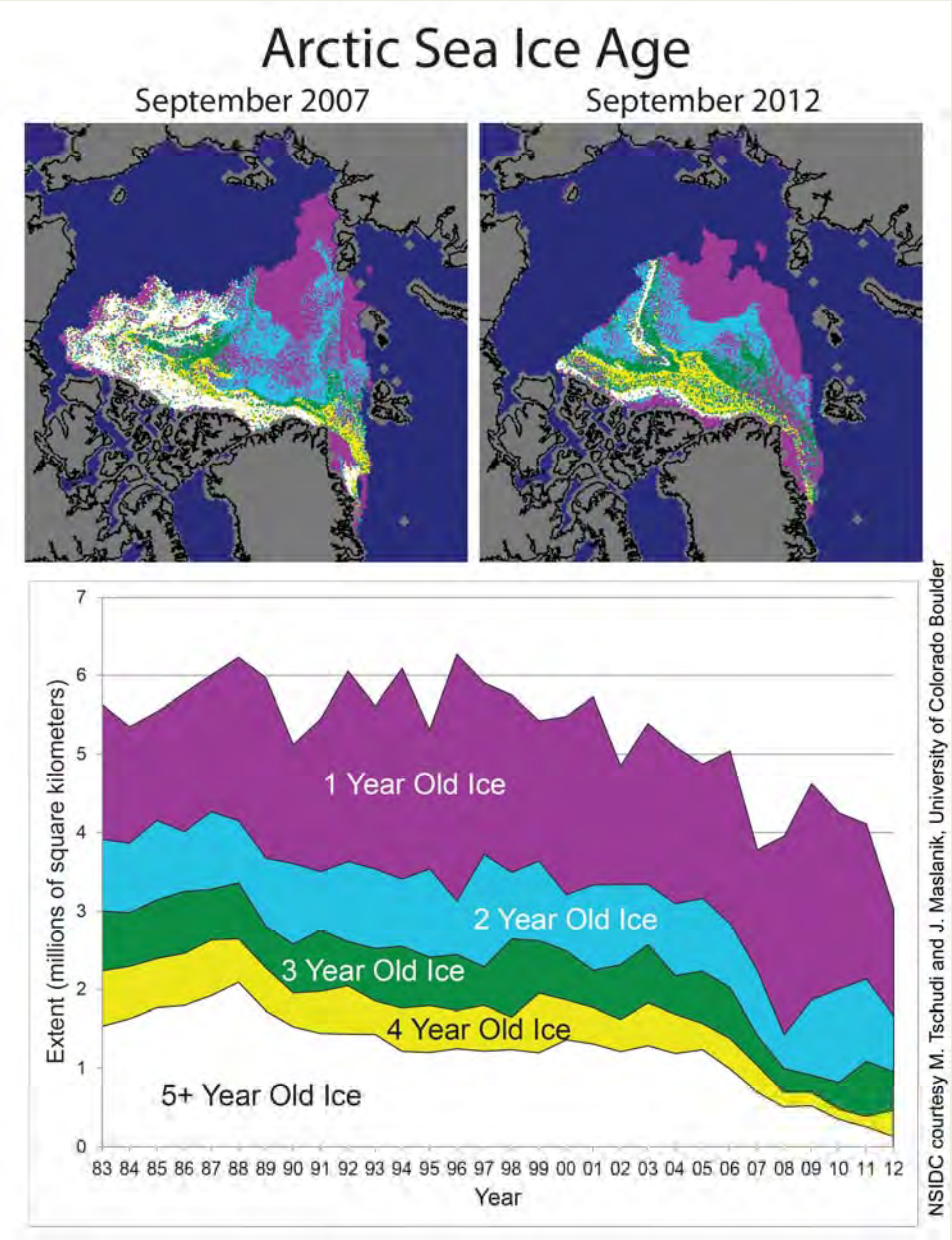

Questions?

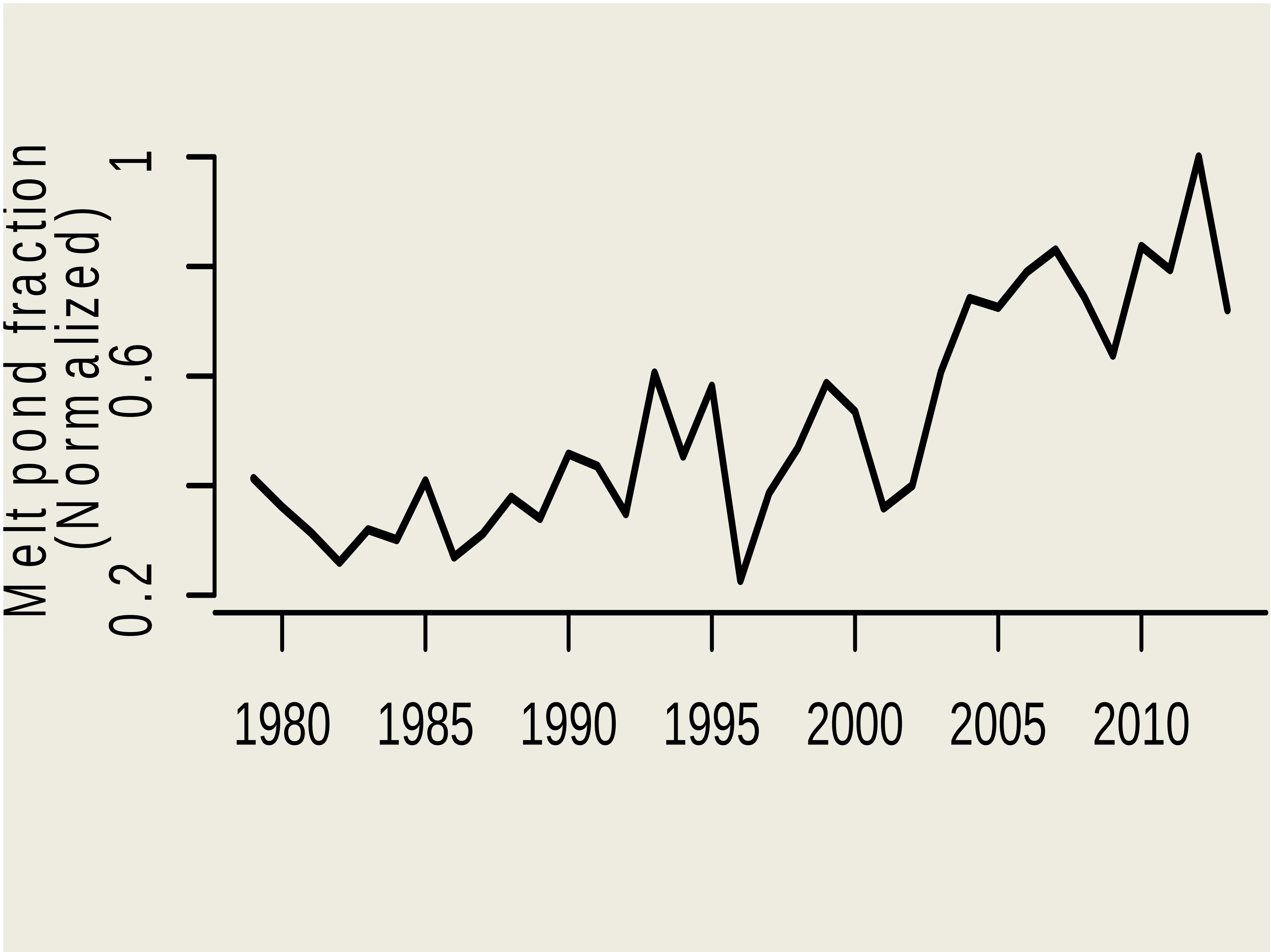
Addendum: melt ponds in a changing climate

- Younger ice is flatter than older ice.
- The fraction of younger ice is increasing.
- Contribution of melt ponds to albedo feedback is **stronger** on flatter ice, because of greater pond area, and leads to **greater** total ablation.

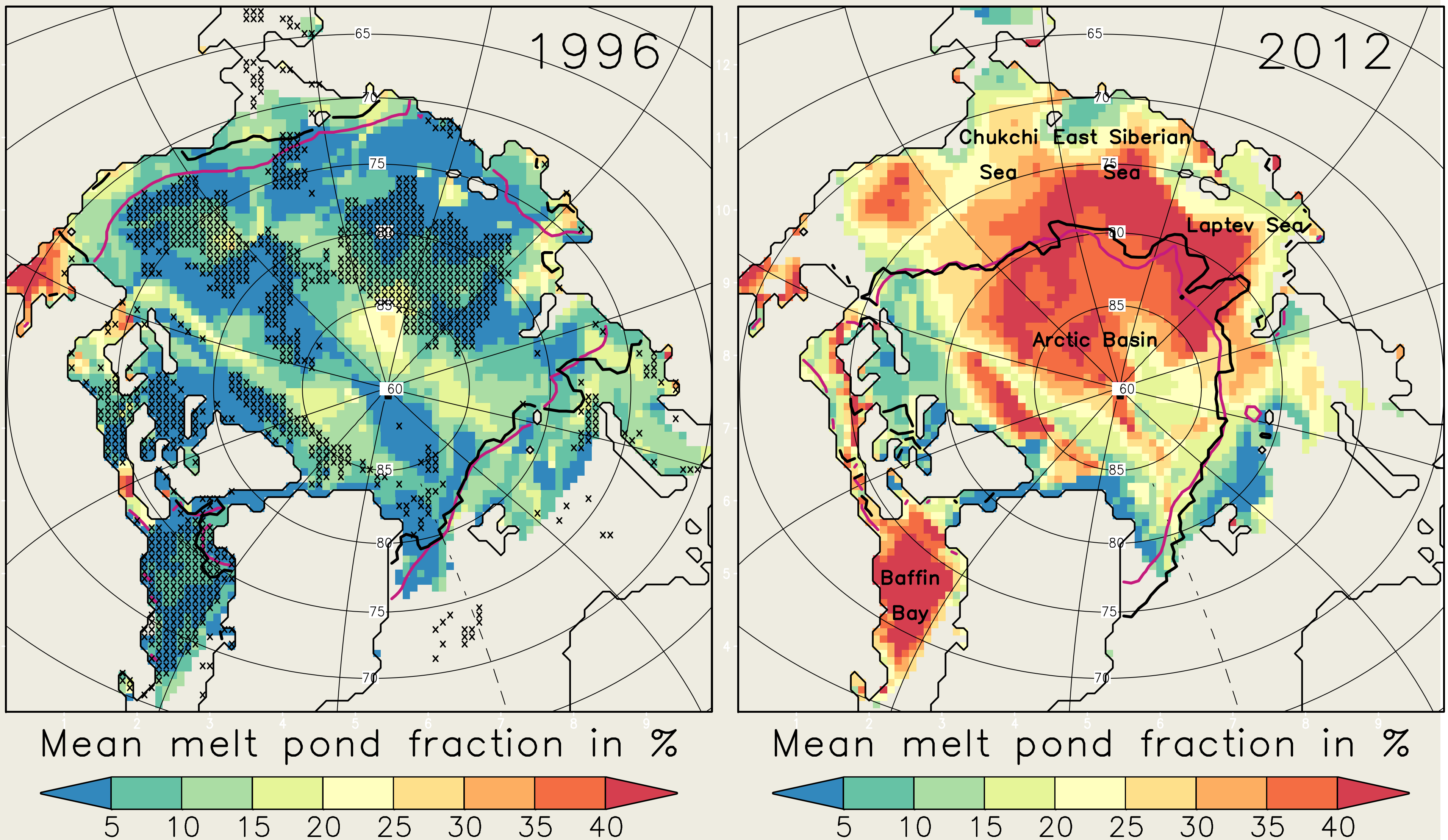
→ Even with **no change** in radiative forcing, atmospheric or oceanic conditions, the change in sea ice topography alone will result in **greater sea ice melt**.

- Accurate melt pond models must account for changing sea ice conditions. Melt ponds will become increasingly important.

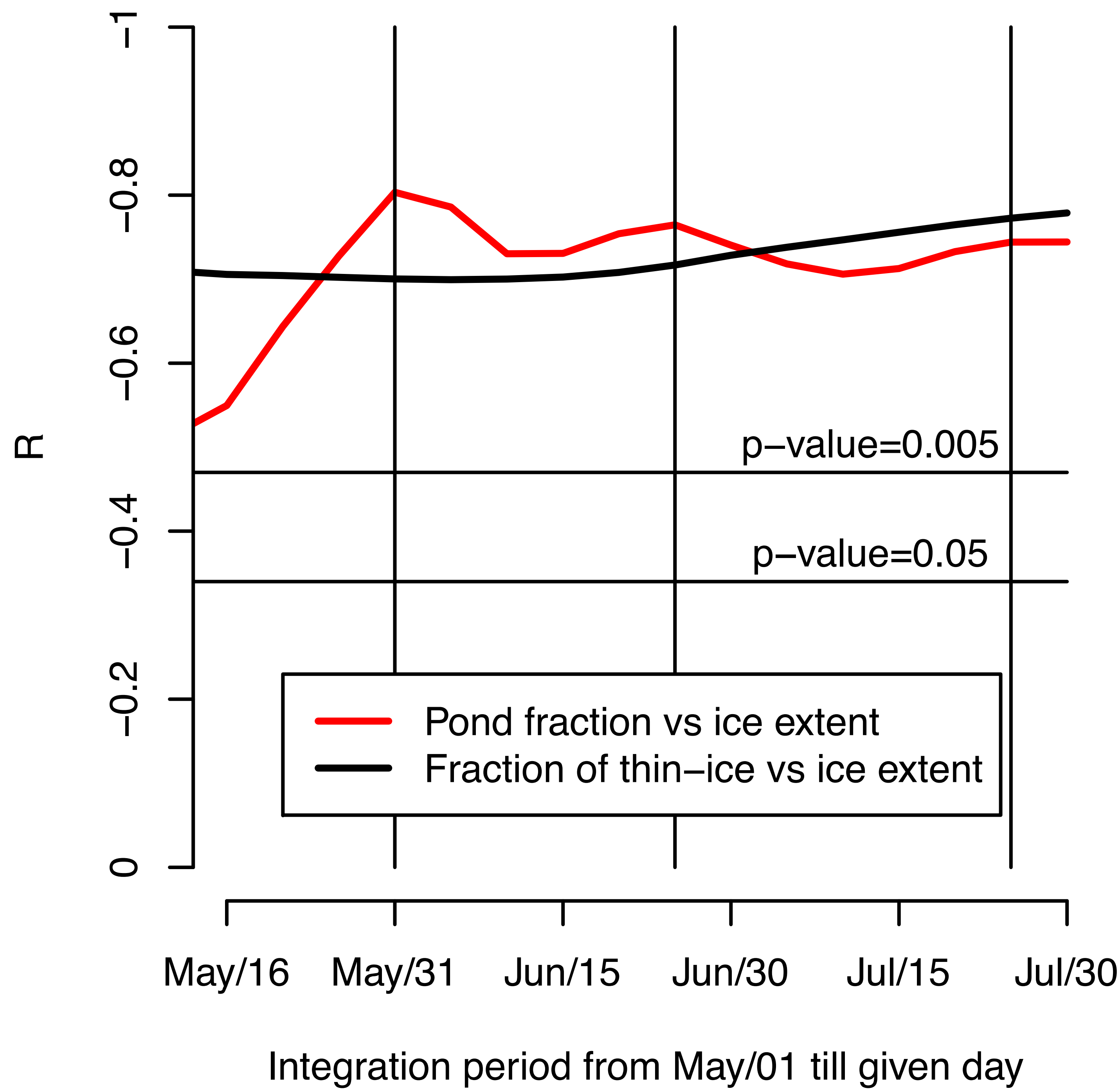




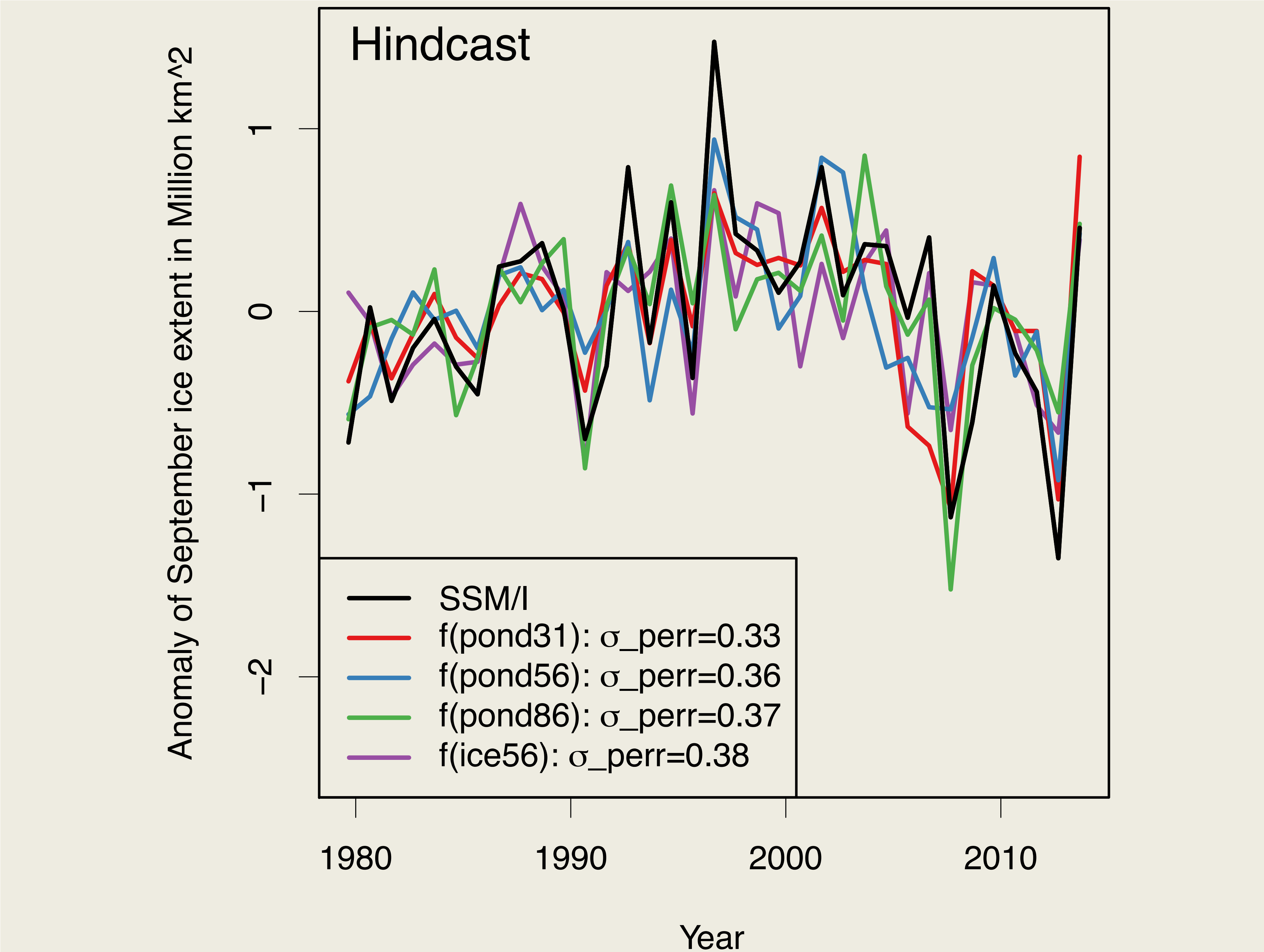
Melt pond fraction
(Normalized)
0.2
0.6
1
1980
1985
1990
1995
2000
2005
2010



1996
2012
Chukchi Sea
East Siberian Sea
Laptev Sea
Arctic Basin
Baffin Bay
Mean melt pond fraction in %
5 10 15 20 25 30 35 40
Mean melt pond fraction in %
5 10 15 20 25 30 35 40



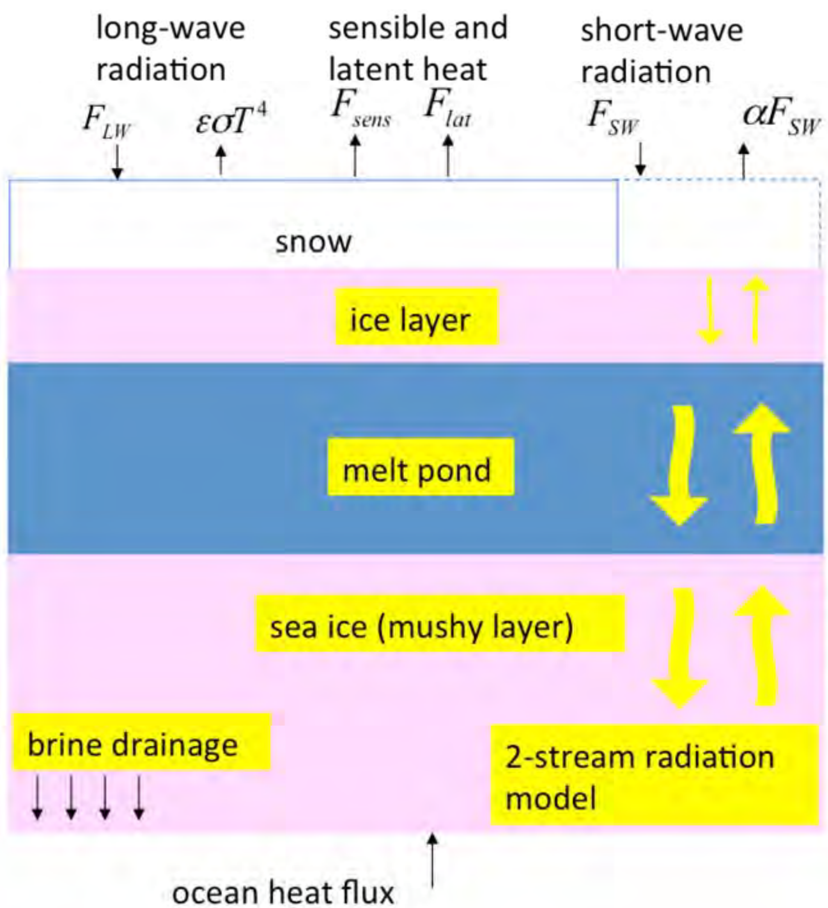
-1
-0.8
-0.6
-0.4
-0.2
0
R
p−value=0.005
p−value=0.05
Pond fraction vs ice extent
Fraction of thin−ice vs ice extent
May/16
May/31
Jun/15
Jun/30
Jul/15
Jul/30
Integration period from May/01 till given day


Hindcast
Anomaly of September ice extent in Million km^2
1
0
−1
−2
1980
1990
2000
2010
Year
SSM/I
f(pond31): σ_perr=0.33
f(pond56): σ_perr=0.36
f(pond86): σ_perr=0.37
f(ice56): σ_perr=0.38

Process models have been developed

One-dimensional melt pond-sea ice model

Taylor and Feltham [2004]



- 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
- Sensitivity studies performed

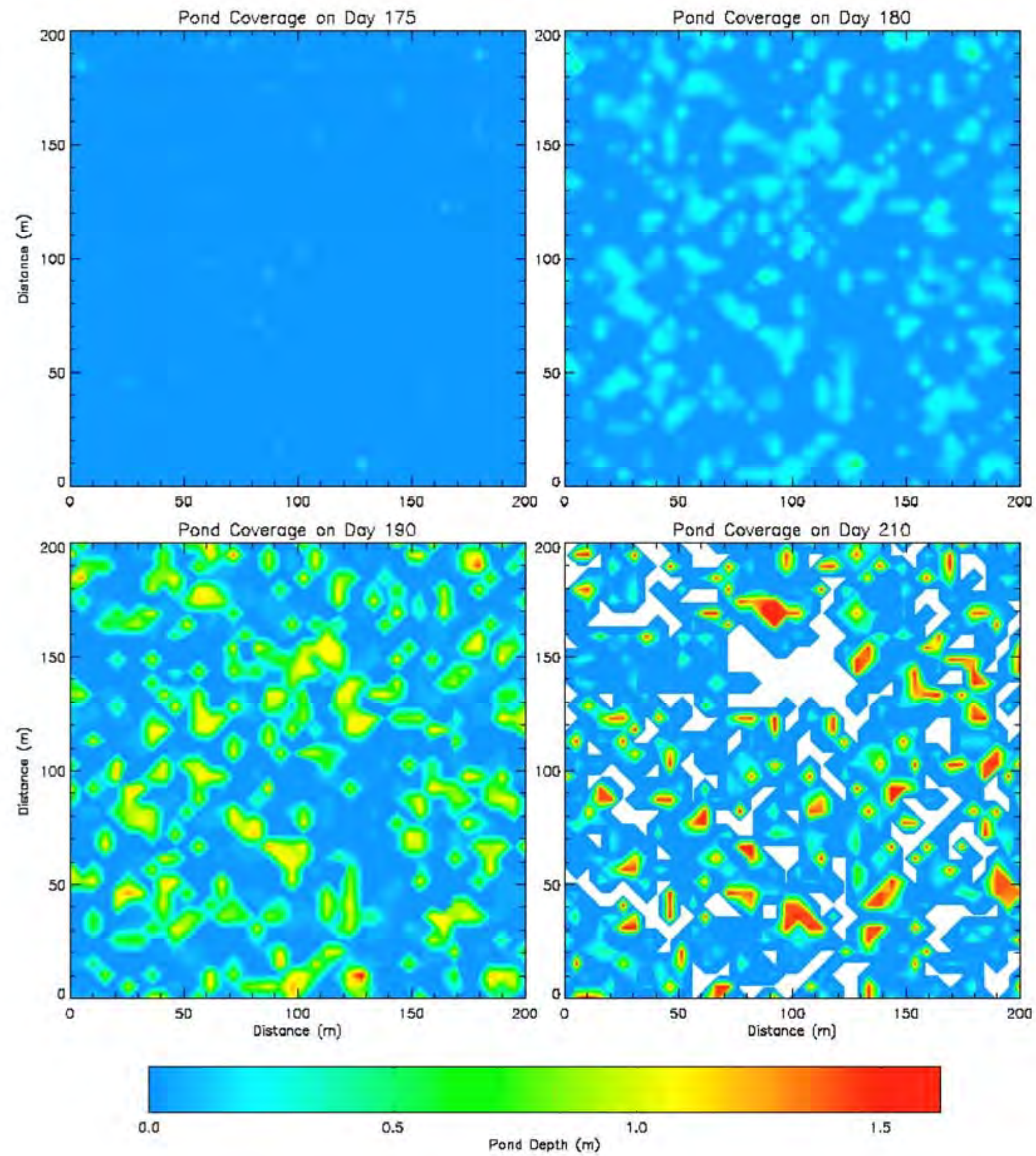
Process models have been developed

Cellular model of horizontal pond cover

Scott and Feltham [2010]

$$\bar{h}_{ice} = 1.7\text{m}$$
$$\sigma_{ice} = 0.2\text{m}$$
$$a_{ice} = 10\text{m}$$
$$\bar{h}_{snow} = 0.3\text{m}$$
$$\sigma_{snow} = 0.15\text{m}$$
$$a_{snow} = 20\text{m}$$

White regions have melted through completely.



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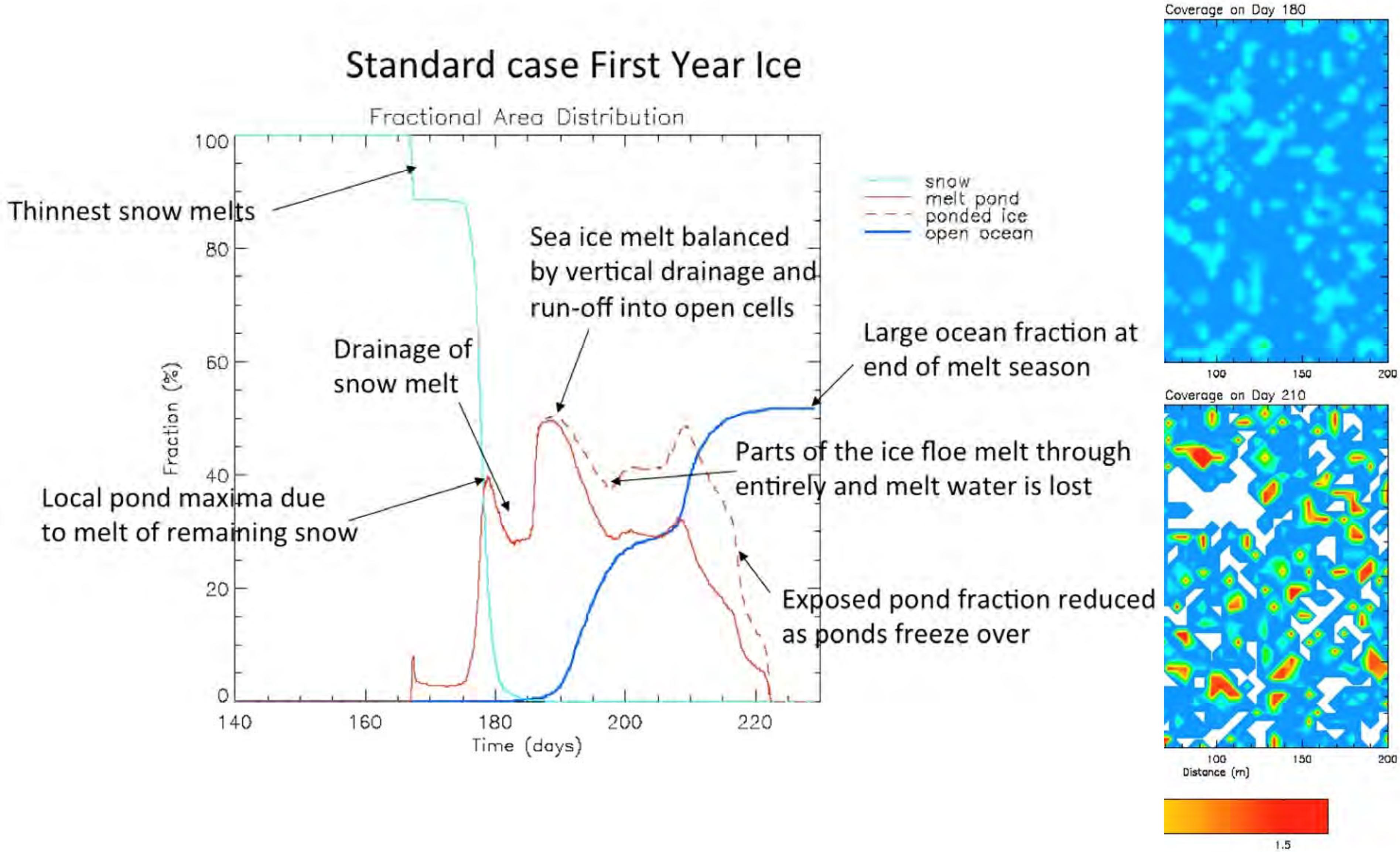

Melt pond area and depth
30th May (Day 150) – 18th August (Day 230) 2007