Sea ice symposium
UW, Seattle, 12-13 July 2017

Investigating the thermodynamics of sea ice models

The wild competition between negative and positive feedbacks

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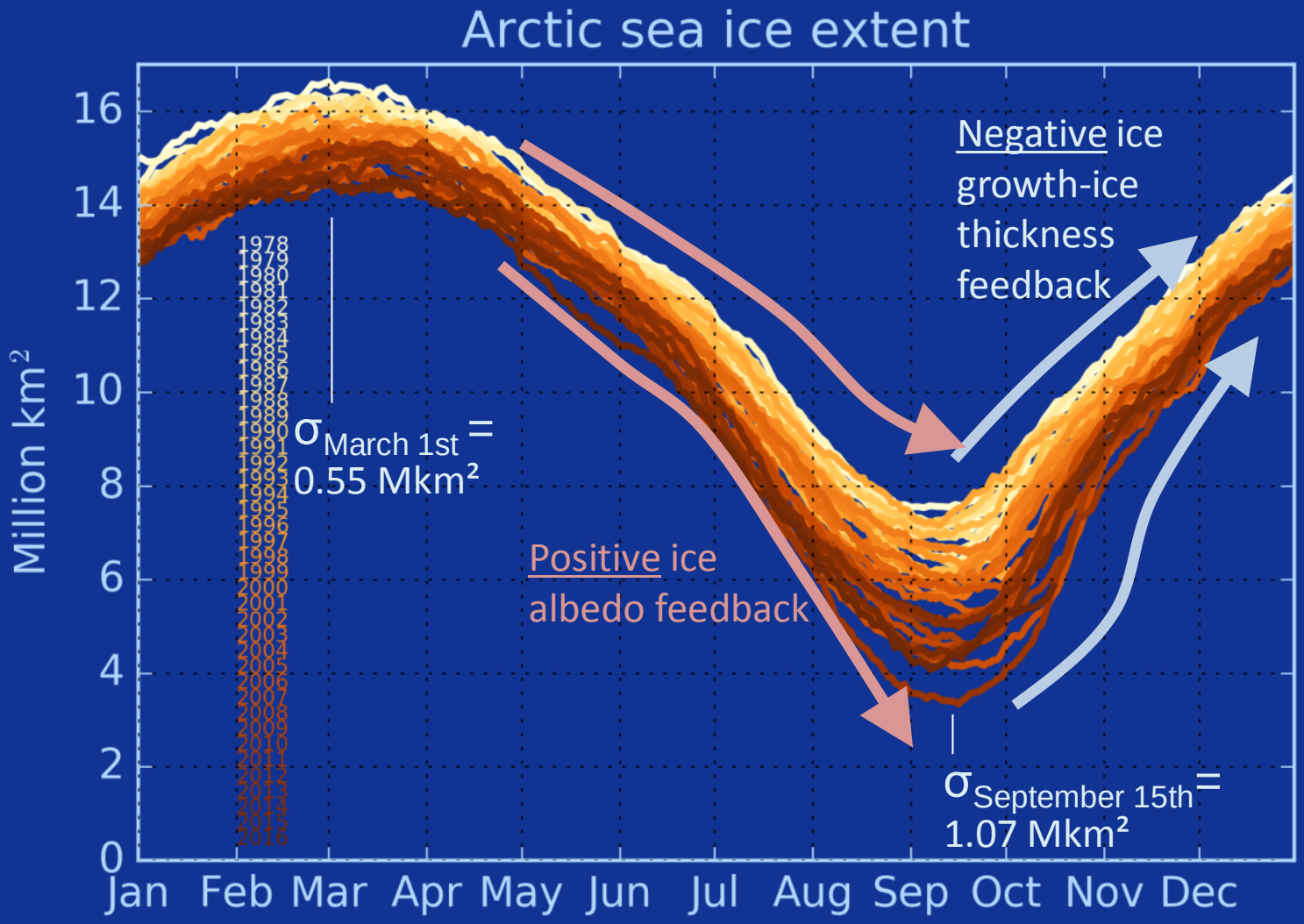
Thanks to M. Vancoppenolle, H. Goosse and many others

Sea ice evolves between two repelling forces



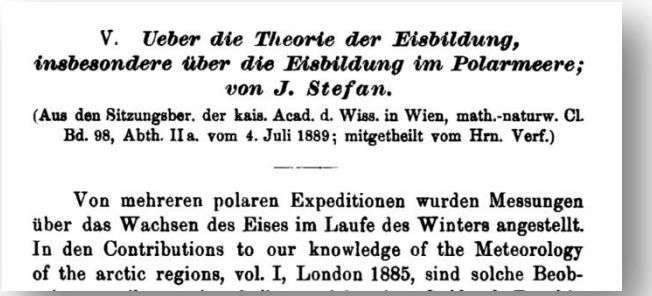
Data: NSIDC sea ice index

1. The negative feedback
2. The positive feedback
3. Synthesis

1. **The negative feedback**
2. The positive feedback
3. Synthesis

The negative ice-growth ice-thickness feedback

Stefan, 1891

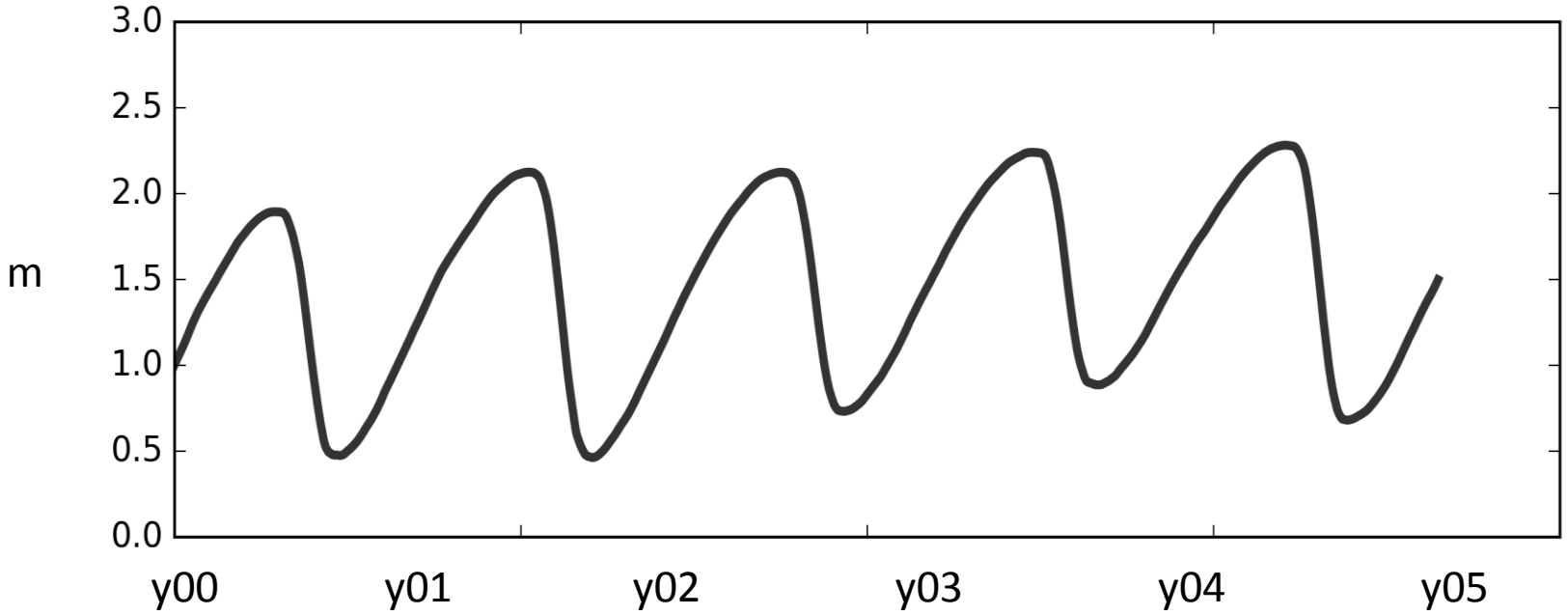


V. *Ueber die Theorie der Eisbildung, insbesondere über die Eisbildung im Polarmeere; von J. Stefan.*

(Aus den Sitzungsber. der kais. Acad. d. Wiss. in Wien, math.-naturw. Cl. Bd. 98, Abth. IIa. vom 4. Juli 1889; mitgetheilt vom Hrn. Verf.)

Von mehreren polaren Expeditionen wurden Messungen über das Wachsen des Eises im Laufe des Winters angestellt. In den Contributions to our knowledge of the Meteorology of the arctic regions, vol. I, London 1885, sind solche Beob-

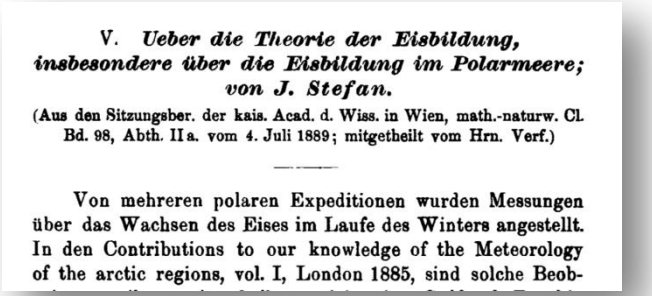
« Thin ice grows faster than thick ice »



This feedback has been known since ages! It is a fundamental property of the ice medium

The negative ice-growth ice-thickness feedback

Stefan, 1891



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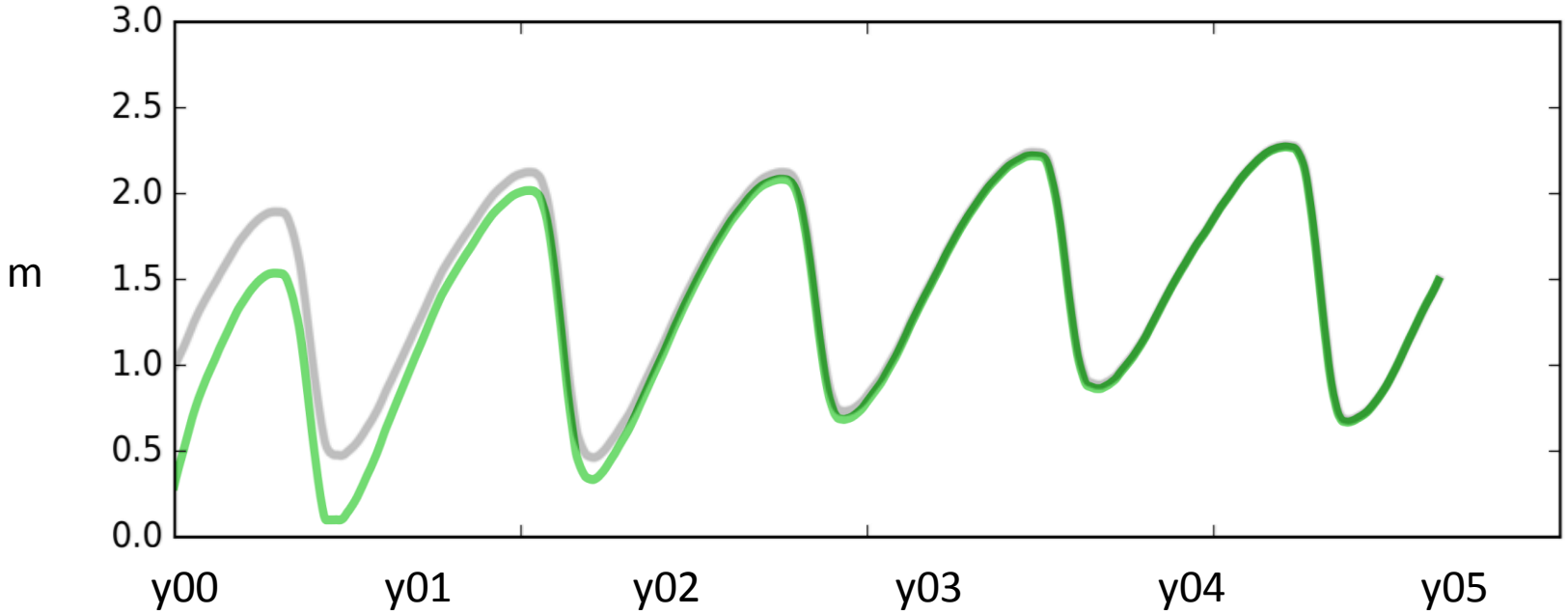

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The negative ice-growth ice-thickness feedback

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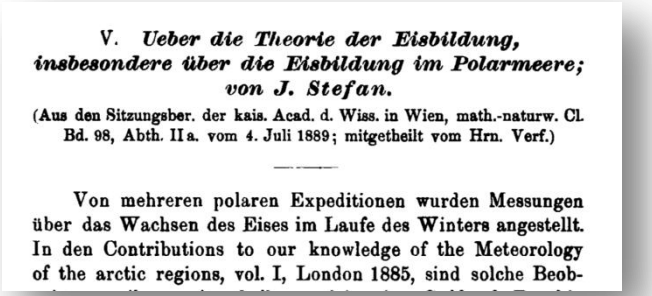

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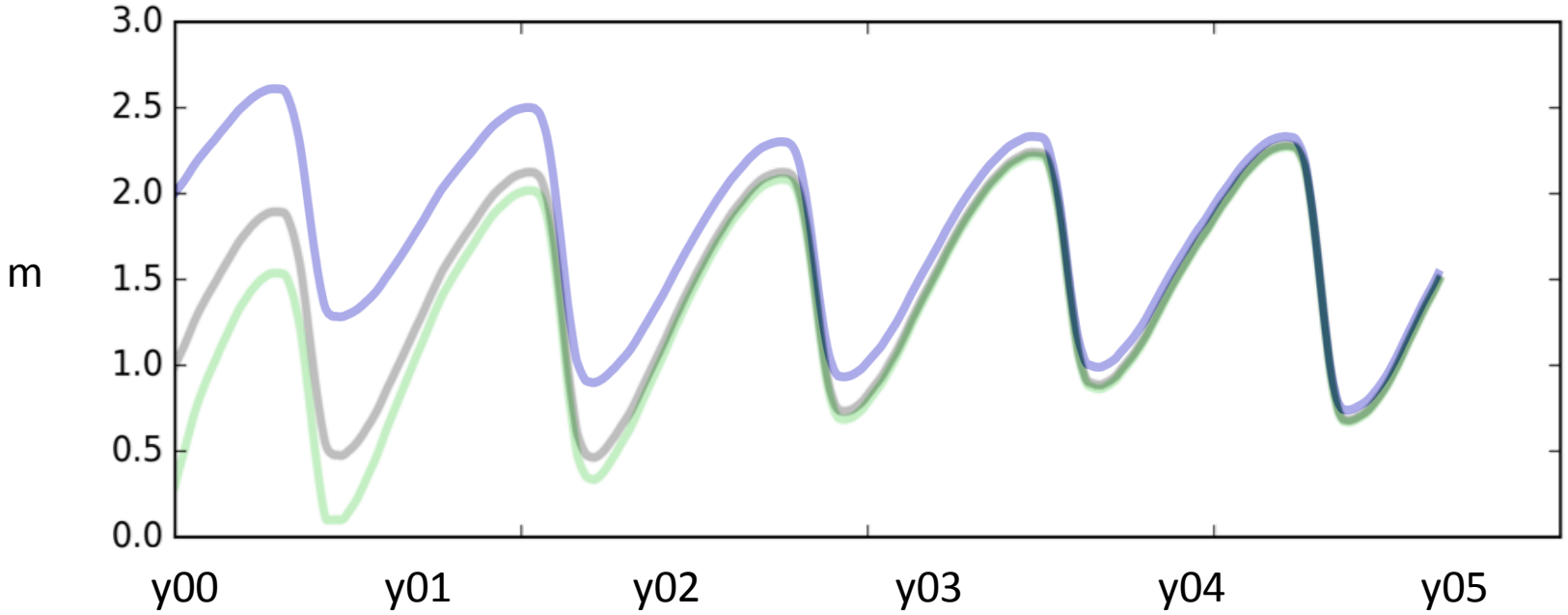
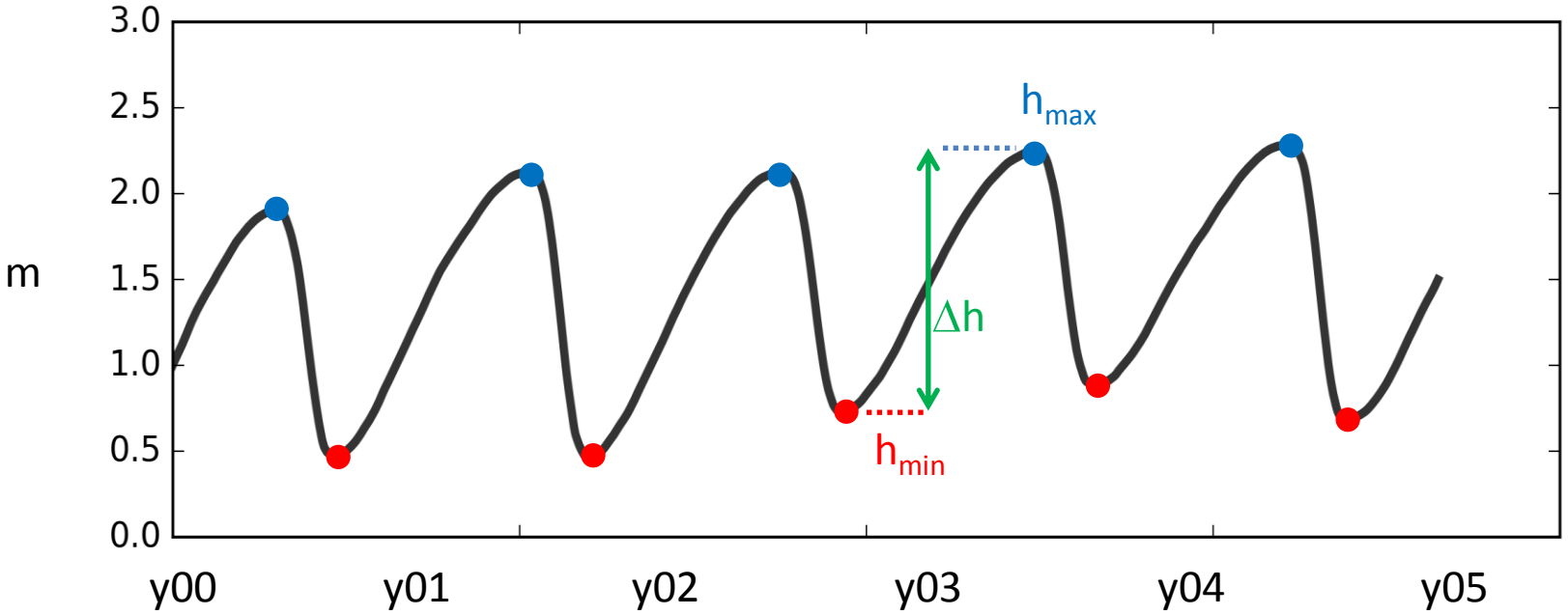


This feedback has been known since ages! It is a fundamental property of the ice medium

Measuring the feedback: methodology

« Thin ice grows faster than thick ice »

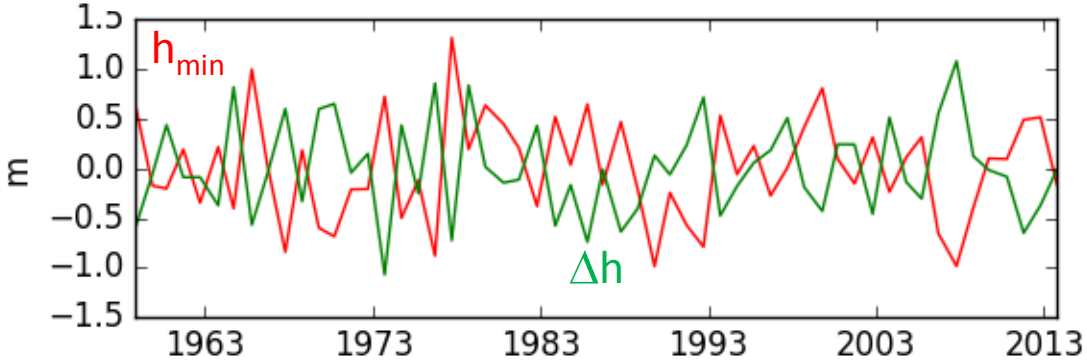


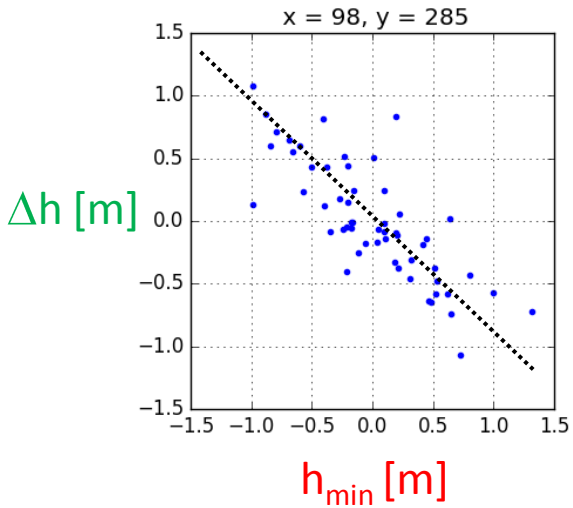
Proposed diagnostic

1. Evaluate h_{min} for each year
2. Evaluate Δh until the next maximum
3. Detrend (3rd order polynomial) h_{min} and Δh to avoid spurious trends
4. Regress (detrended) Δh on h_{min}

Measuring the feedback: example

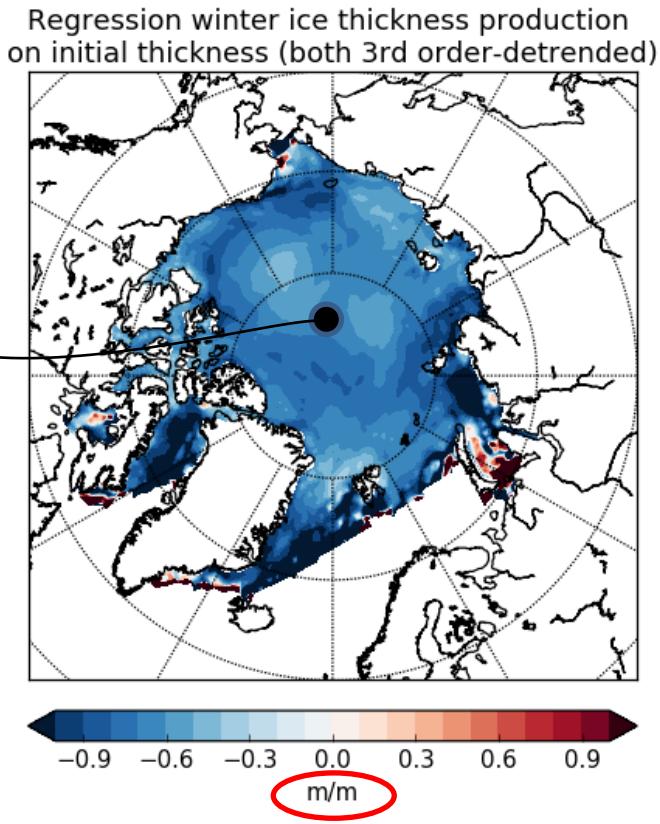
Minimum thickness and thickness produced at (87.5N, 172.5W)





Feedback = regression Δh on h_{min} [m/m]

Ocean-sea ice model (NEMO3.6-LIM3) forced by DFS5.2, 1958-2015



Key science questions:

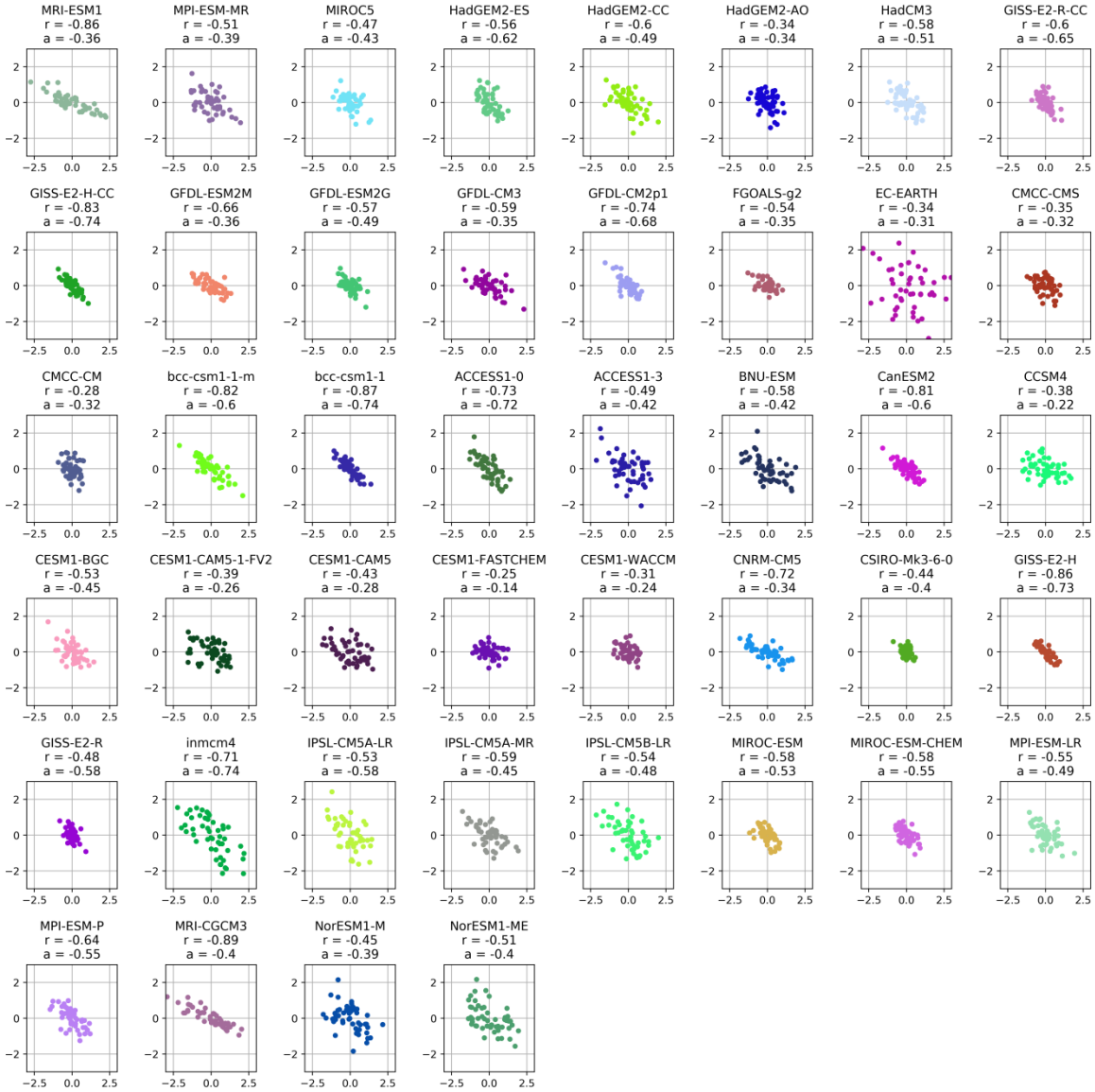
A. Do different models simulate this feedback differently?
B. Does feedback strength vary with the mean state (Bitz & Roe 2005)
C. Does feedback strength affect the sea ice response to radiative forcing?
D. Does feedback strength affect predictability (e.g. persistence)?

Thesis of this talk:

CMIP5 analyses allow to amply address these questions!

- Historical simulations (1861-2004) from N = 44 CMIP5 models; only member 1 considered.
- Sea ice volume north of 80N used instead of thickness (faster processing + not a bad assumption → see later)

All models have the negative feedback, but they all simulate it differently



Legend

Model name

r = … → correlation

a = … → regression (feedback)

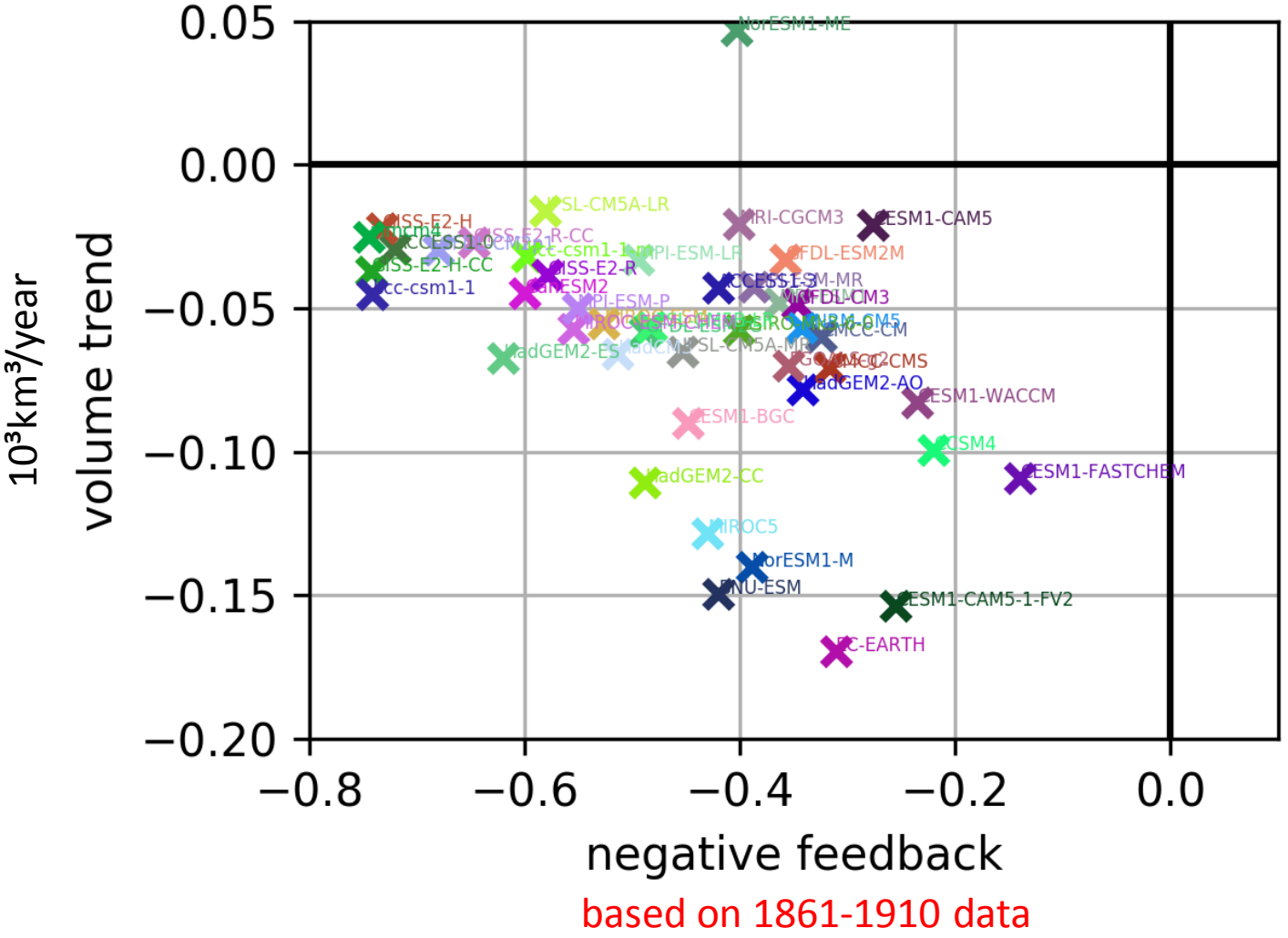
Based on 50 years (1861-1910)

Volume production anomaly

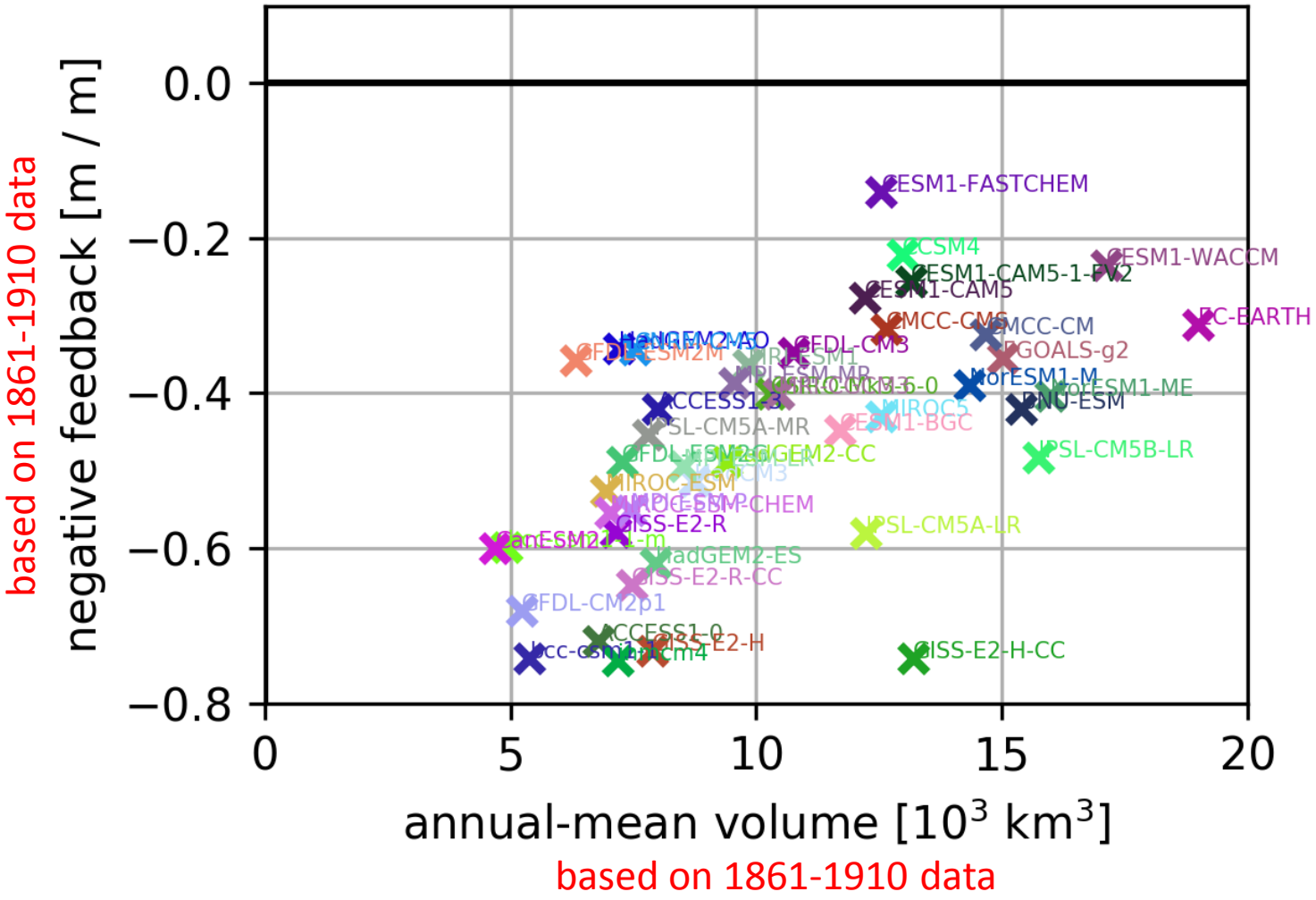
Min volume anomaly

Models with less stabilizing feedback tend to loose sea ice volume faster

Based on 1975-2004 data



The negative feedback is stronger for thinner models



Bitz and Roe (2005 J. Clim) show higher thinning rate for thicker models

Model physics → mean state → feedback strength

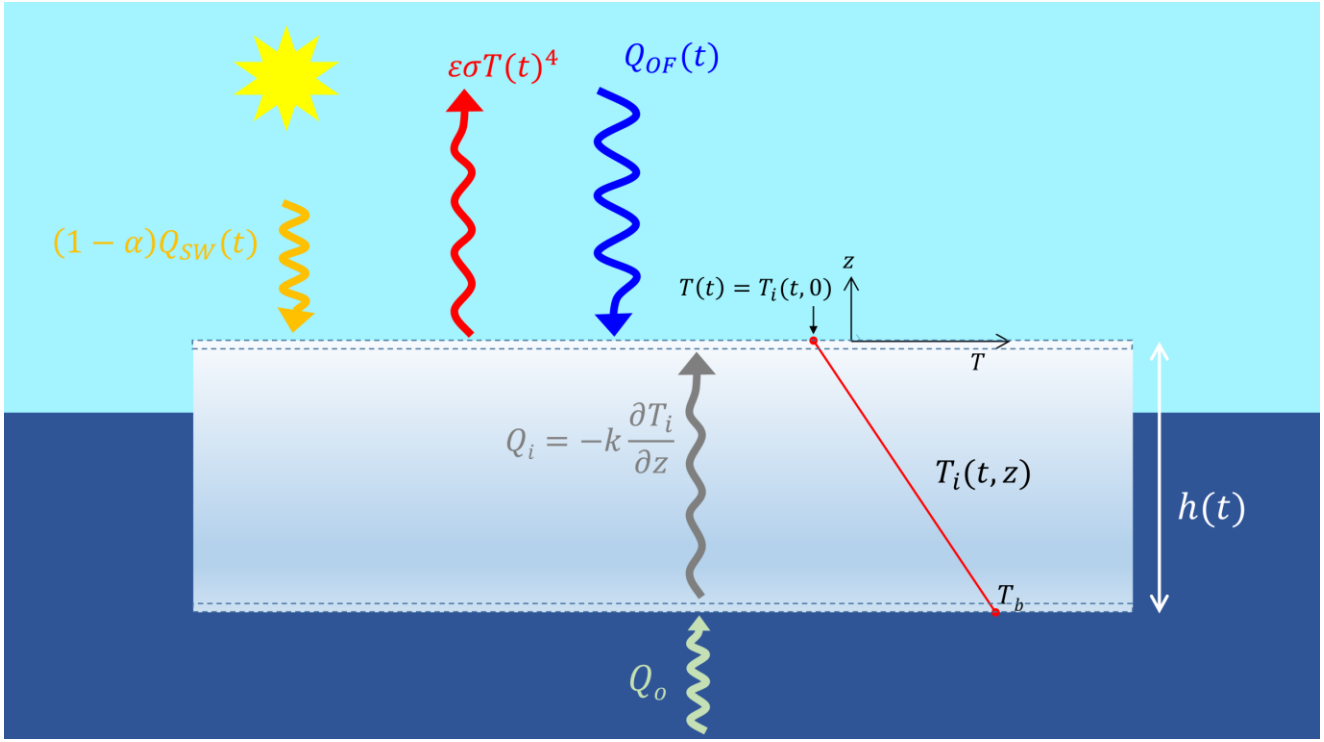
or

Model physics → feedback strength → mean state

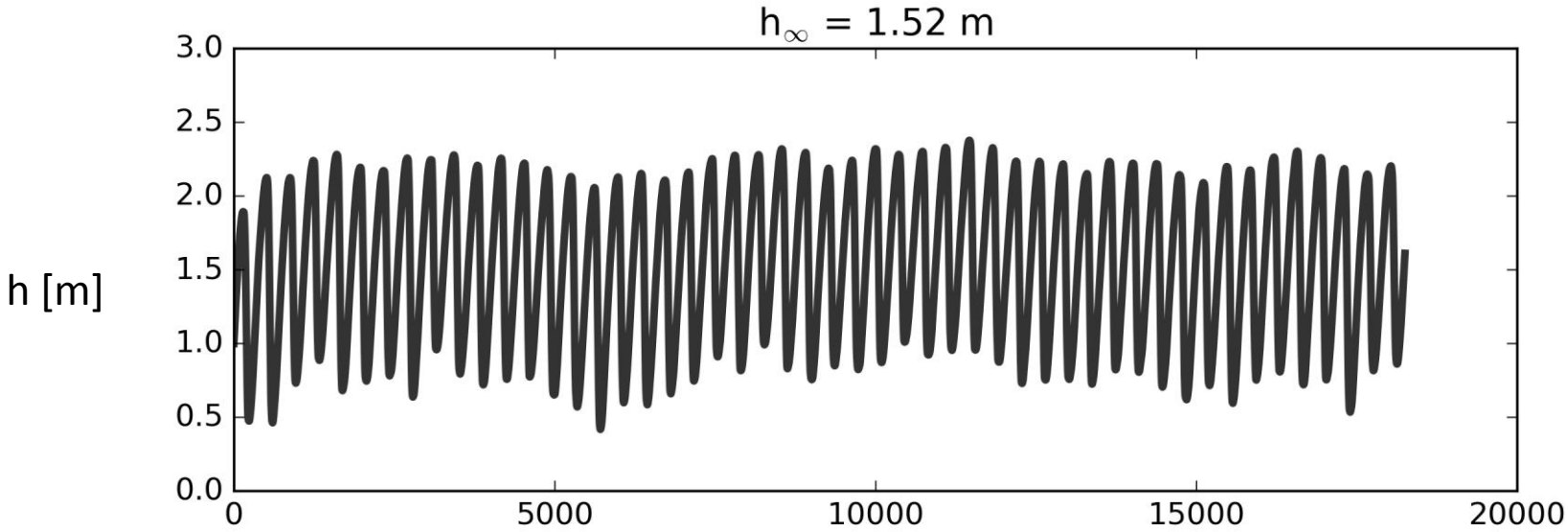
?

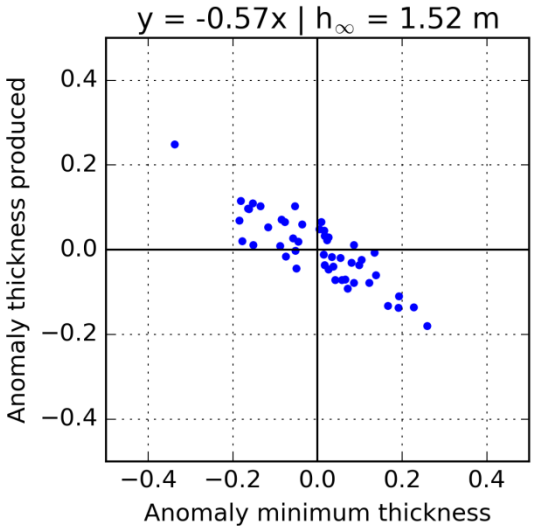
A thermodynamic-only sea ice model

To elucidate this question, let's integrate a thermodynamic-only model by varying its physics (parameters) and hence its mean state, and let's look at the resulting feedback strength

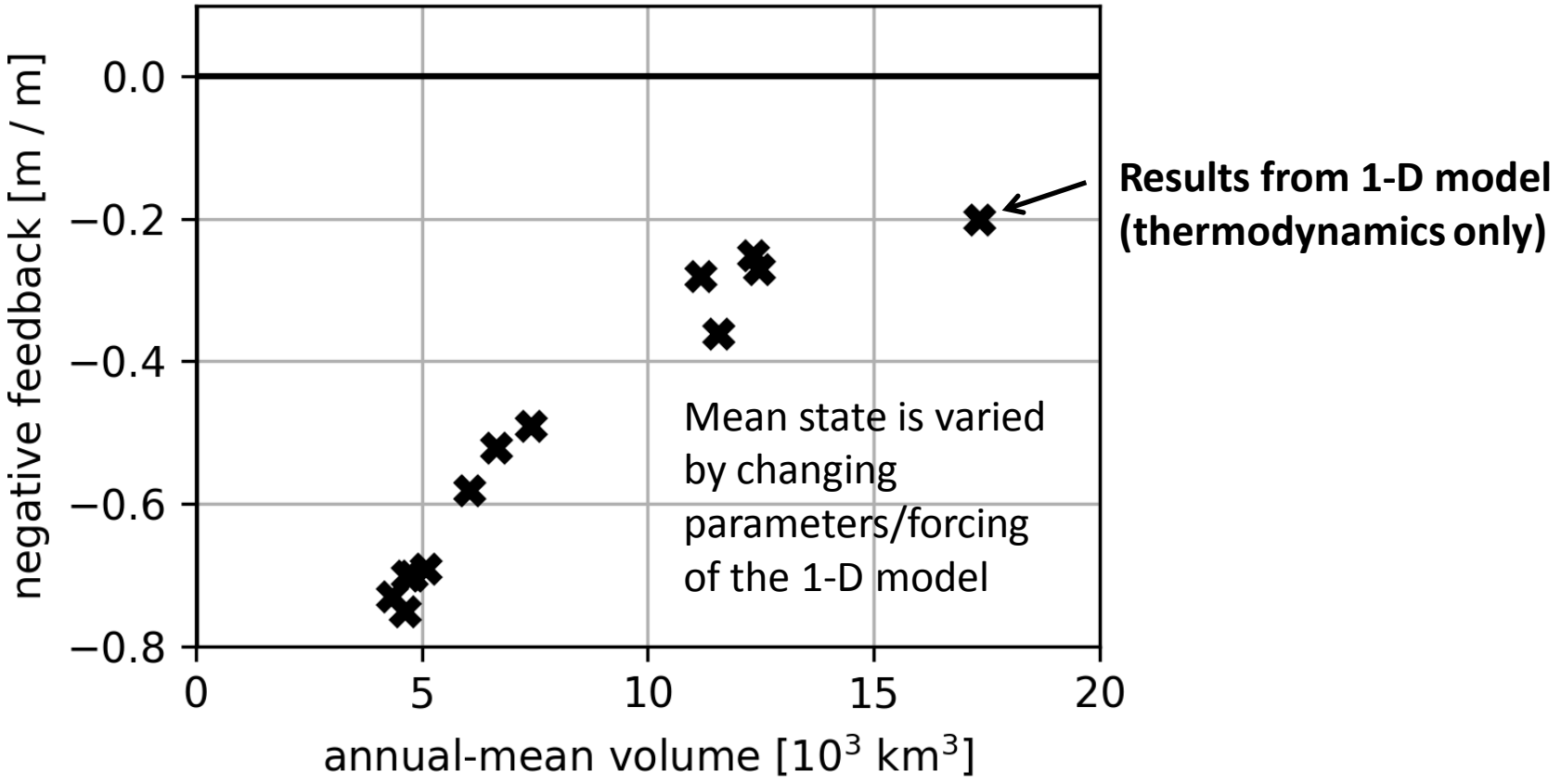


Example

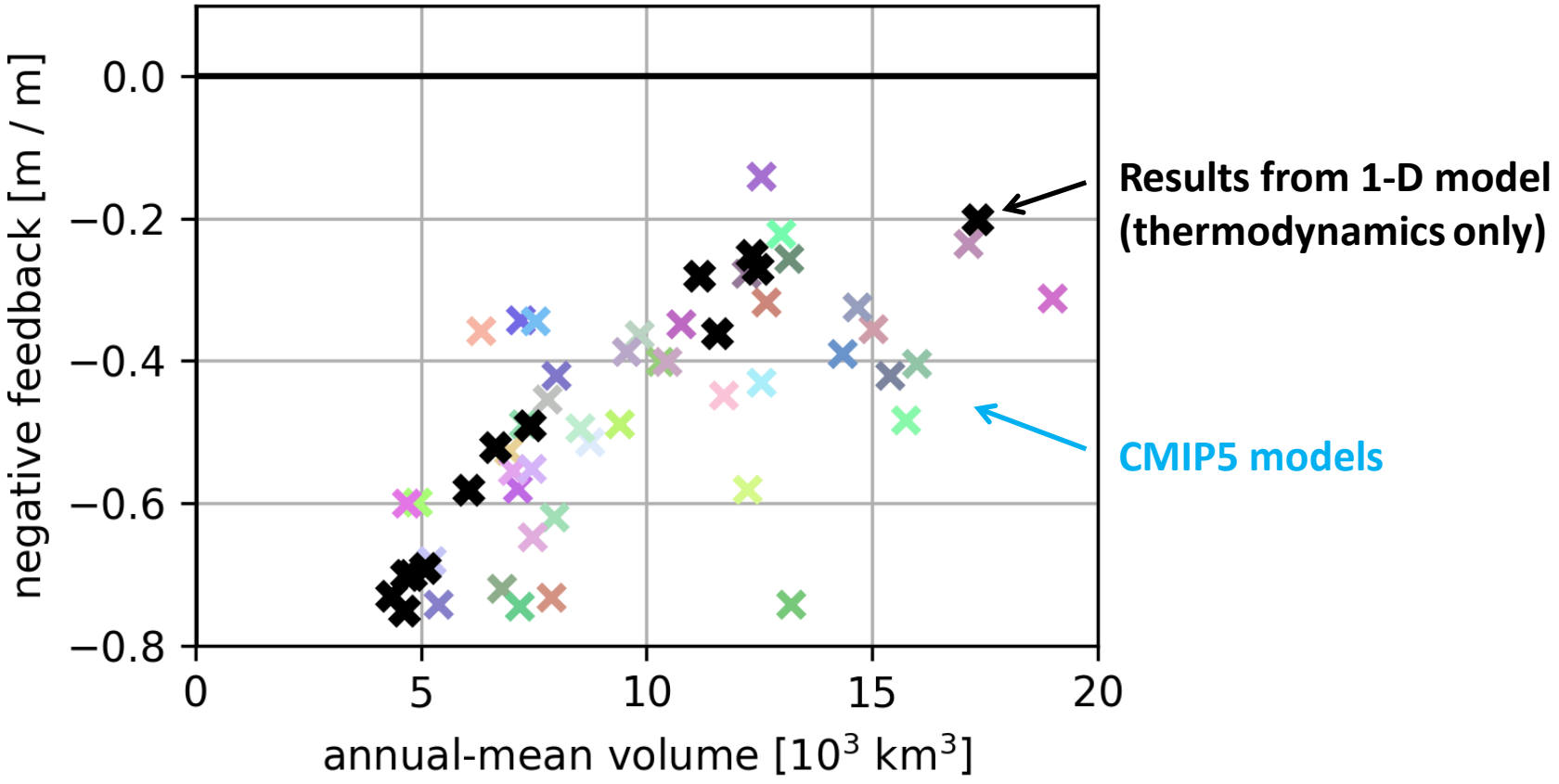

h_∞ = 1.52 m
h [m]
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
5000
10000
15000
20000


y = -0.57x | h_∞ = 1.52 m
Anomaly thickness produced
0.4
0.2
0.0
−0.2
−0.4
−0.4
−0.2
0.0
0.2
0.4
Anomaly minimum thickness

In the 1-D thermodynamic model,
only the mean state matters
(regardless of parameters)



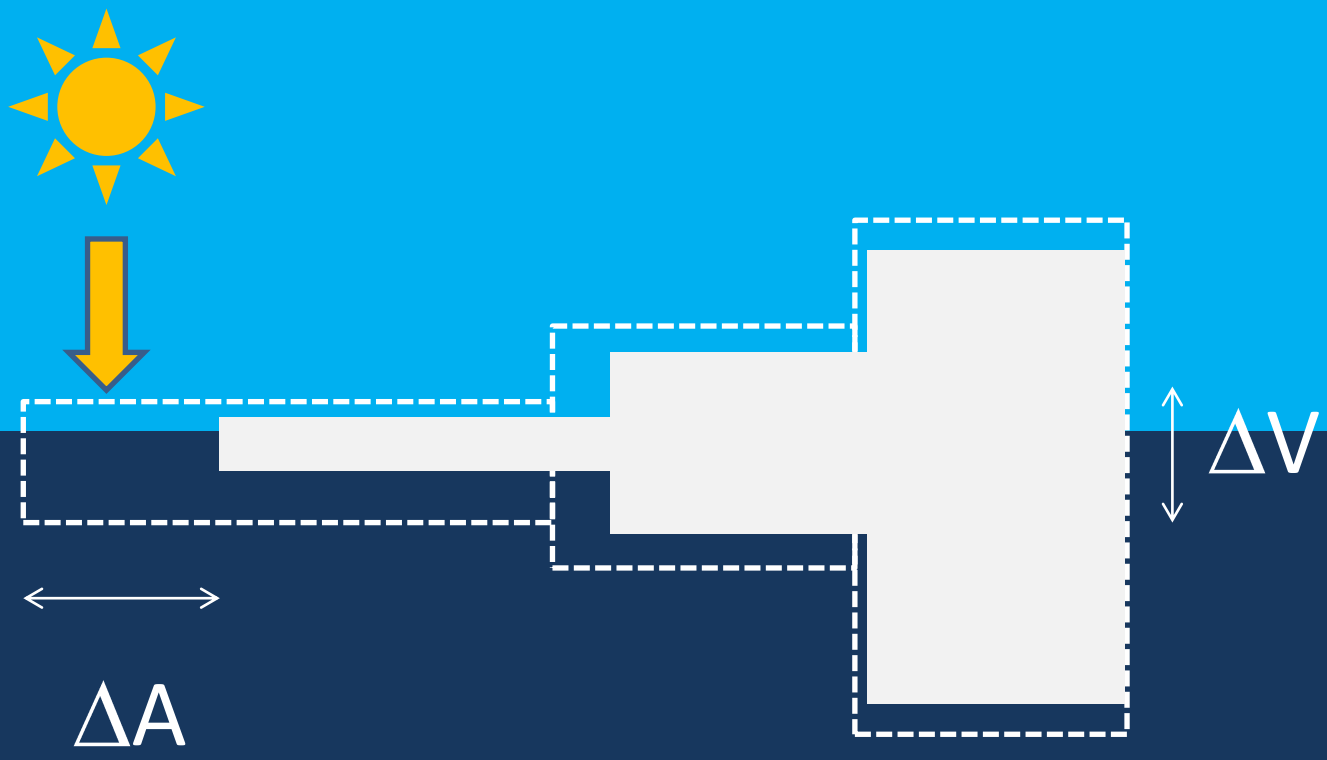
The 1-D and fully coupled models are surprisingly close to each other!



1. The negative feedback
2. **The positive feedback**
3. Synthesis

Measuring the feedback: methodology

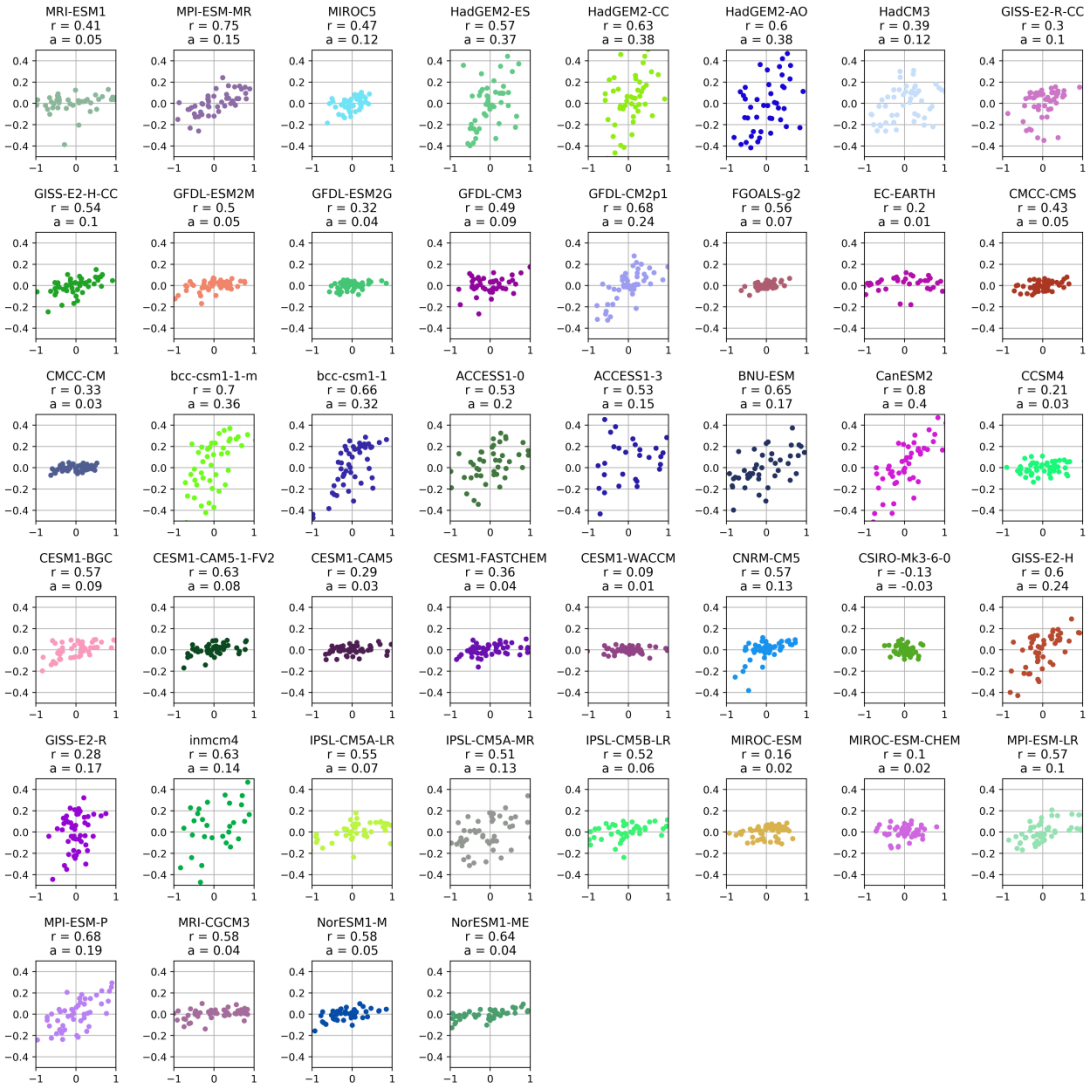
Measuring the feedback: methodology



1. Estimate ΔA and ΔV for each year (June to September)
2. Detrend each term to avoid spurious trends
3. Regress (detrended) ΔA on ΔV
4. Units of feedback: [m^{-1}] or [%/cm]

Similar diagnostic to Holland et al. GRL 2006

All models have the negative feedback, but they all simulate it differently



Legend

Model name

r = … → correlation

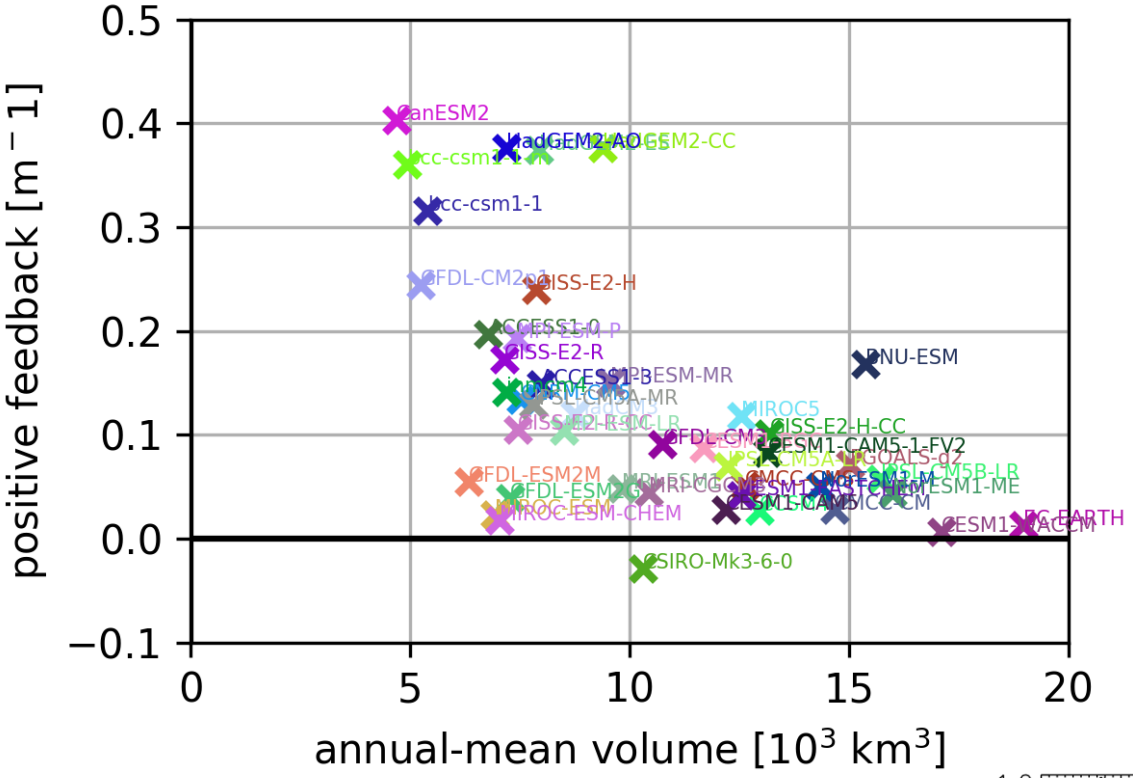
a = … → regression (feedback)

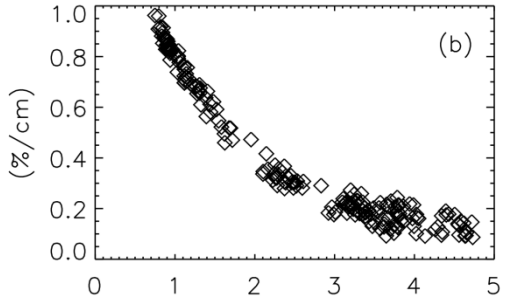
Based on 50 years (1861-1910)

Area loss anomaly

Volume loss anomaly

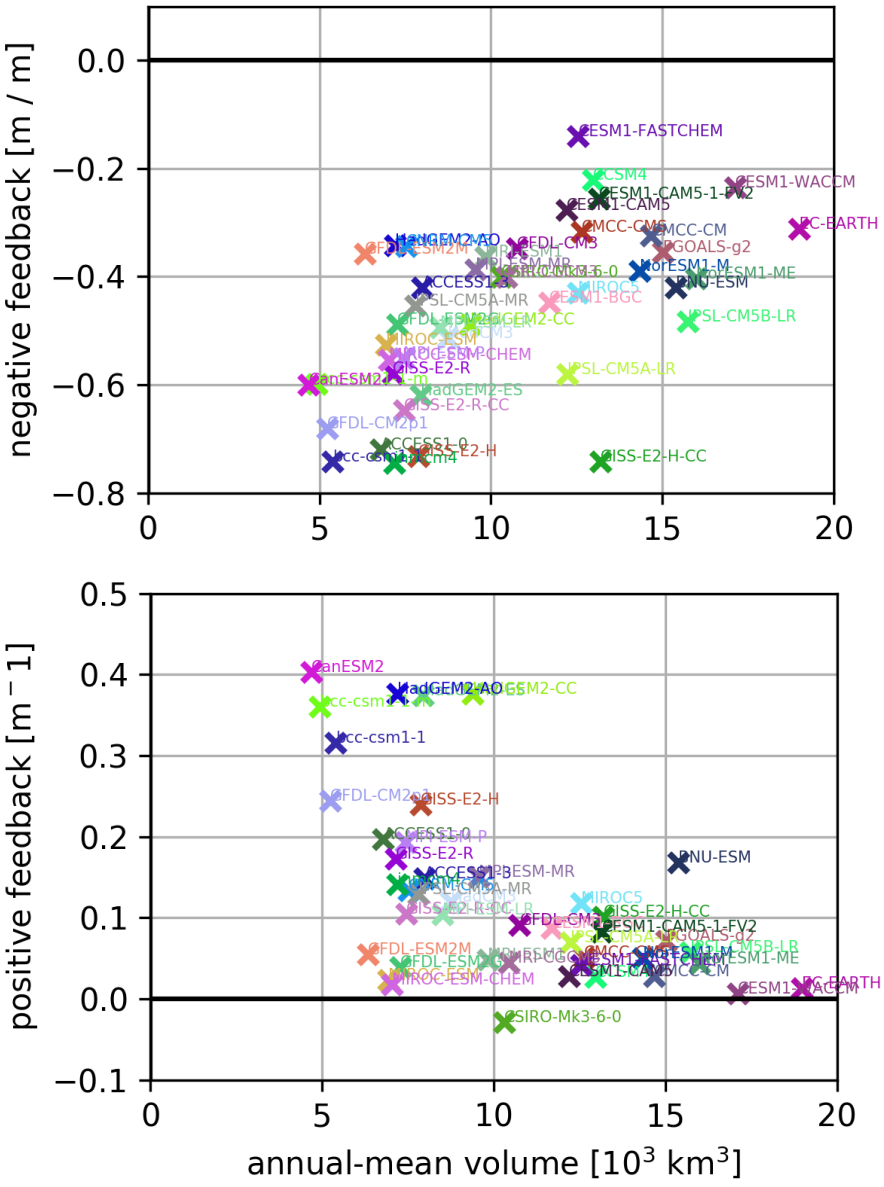
The positive feedback is also mean-state dependent, stronger for thinner ice



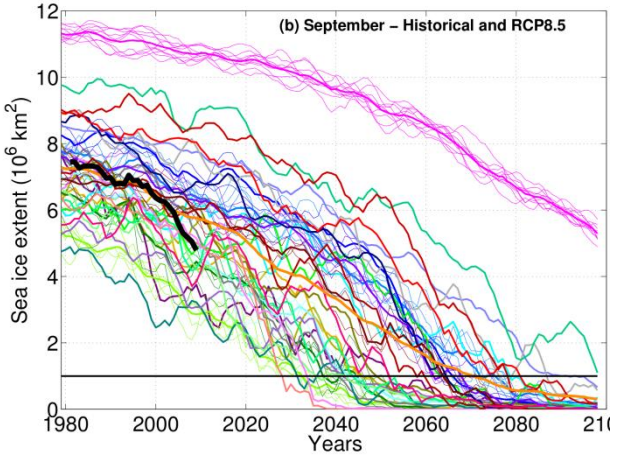


Holland et al., GRL, 2006

1. The negative feedback
2. The positive feedback
3. **Synthesis**

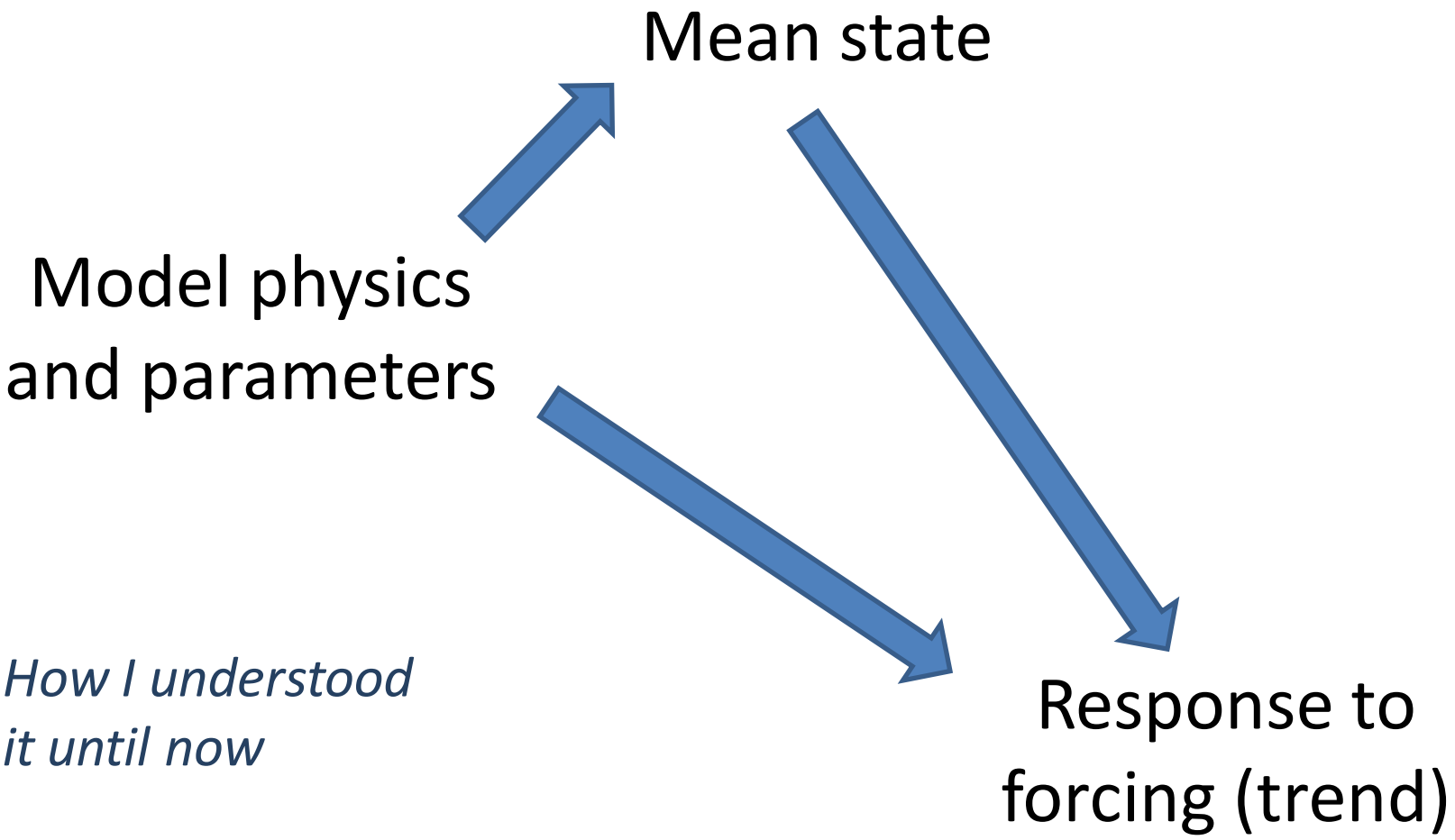


Is the apparently nice clustering of CMIP5 model extent trends masking more fundamental differences?



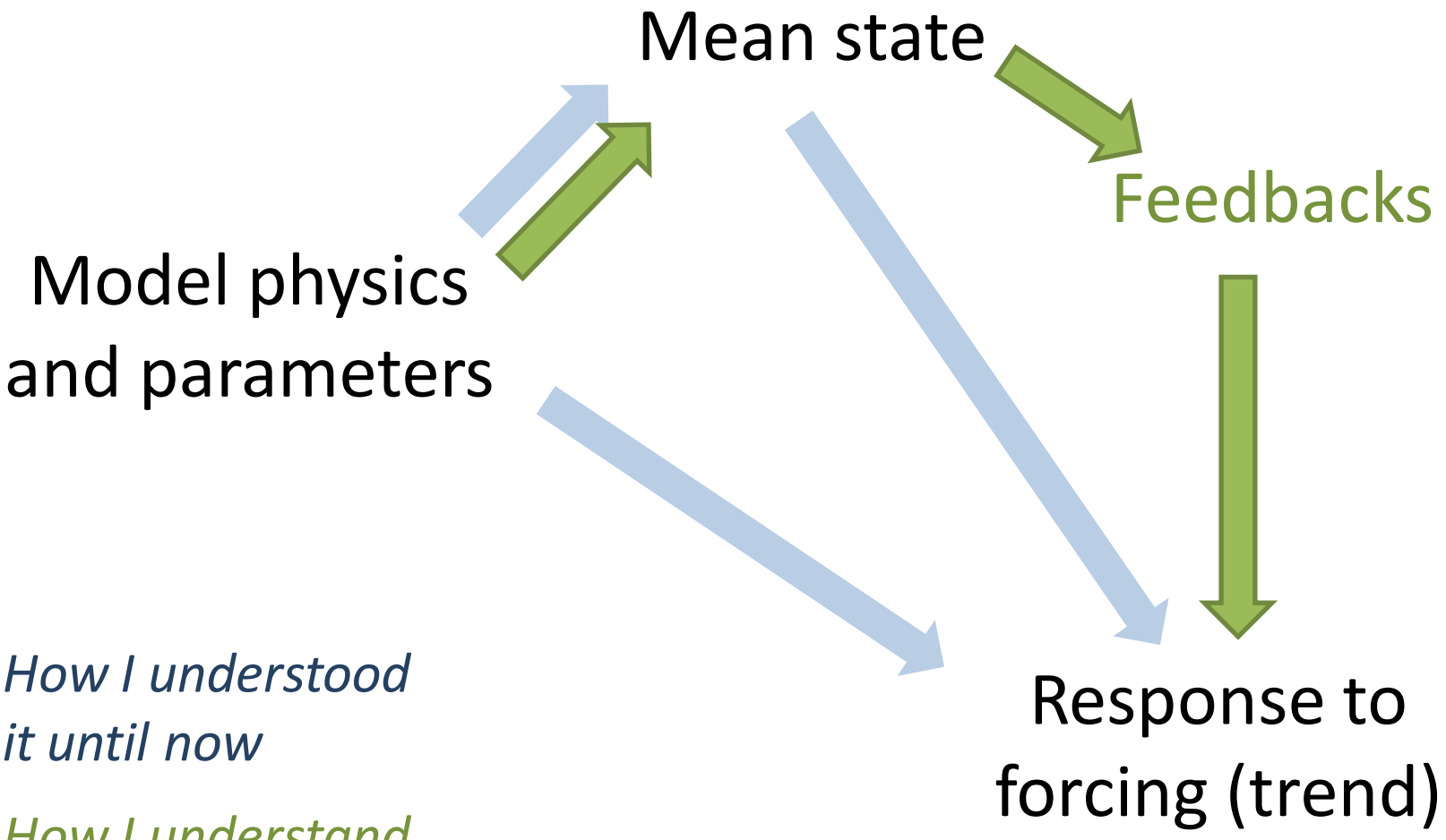
Massonnet et al. The Cryosphere 2012

What drives what?



How I understood it until now

What drives what?



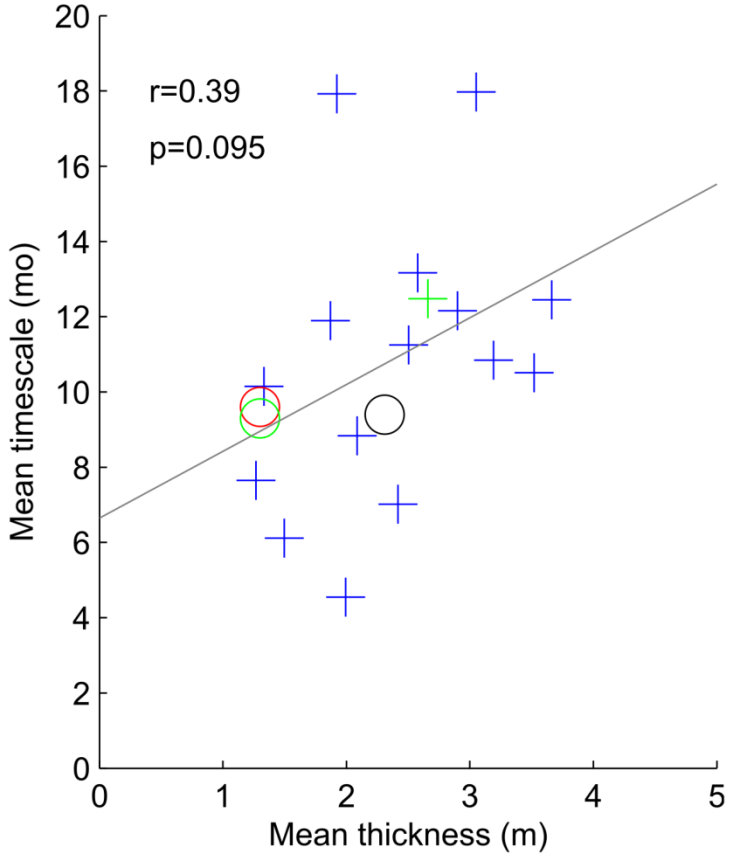
How I understood it until now

How I understand it now

Take home messages

- The feedback analyses proposed
  - Are diagnostic: no additional experiment required
  - Are empirical (no underlying model) and super simple to implement (no extra simulation required)
  - Are based on seasonal relationships
  - Can capture non-linearities
- The two feedbacks are highly mean-state dependent. That's why the mean state is so important for Arctic sea ice.
- The results are in line with Bitz and Roe (2005) and Holland et al. (2006)
- The feedbacks are also key for predictability (see supplementary info).

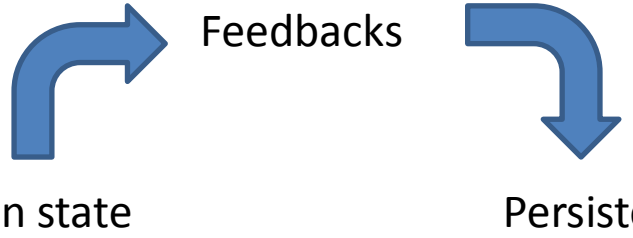
BW2014 suggest that predictability (persistence) is a (weak) function of mean state

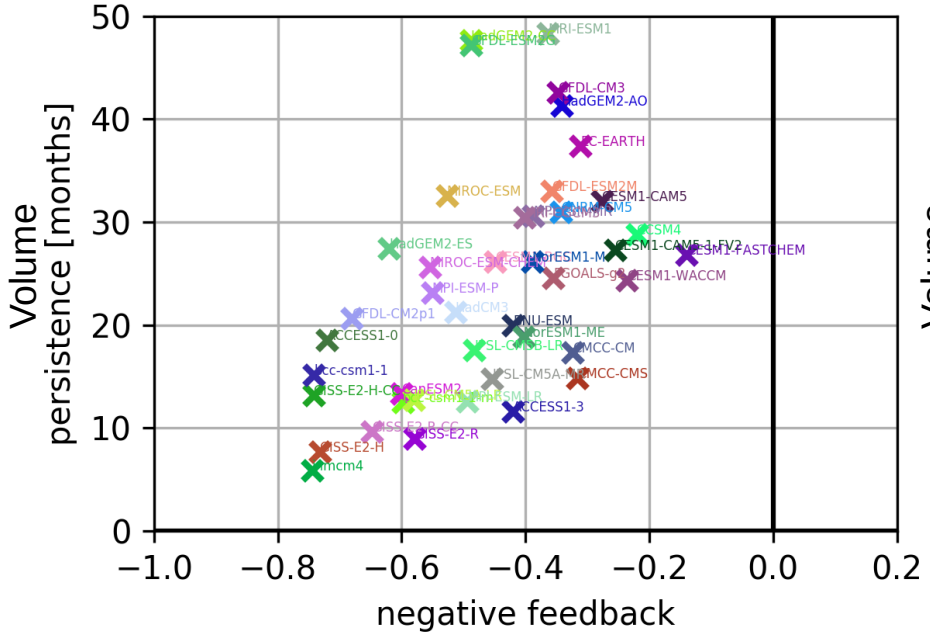


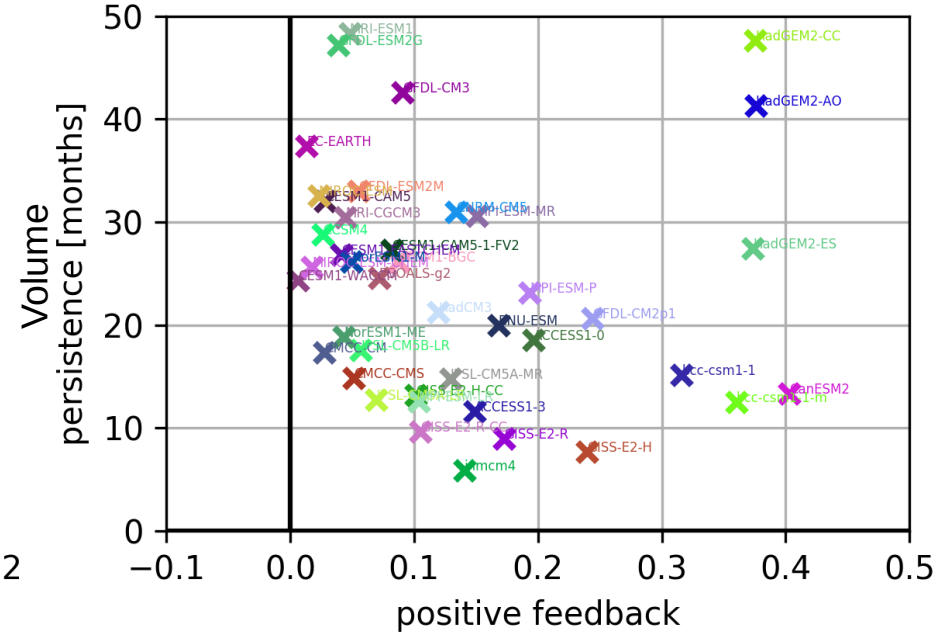
Mean state → Persistence

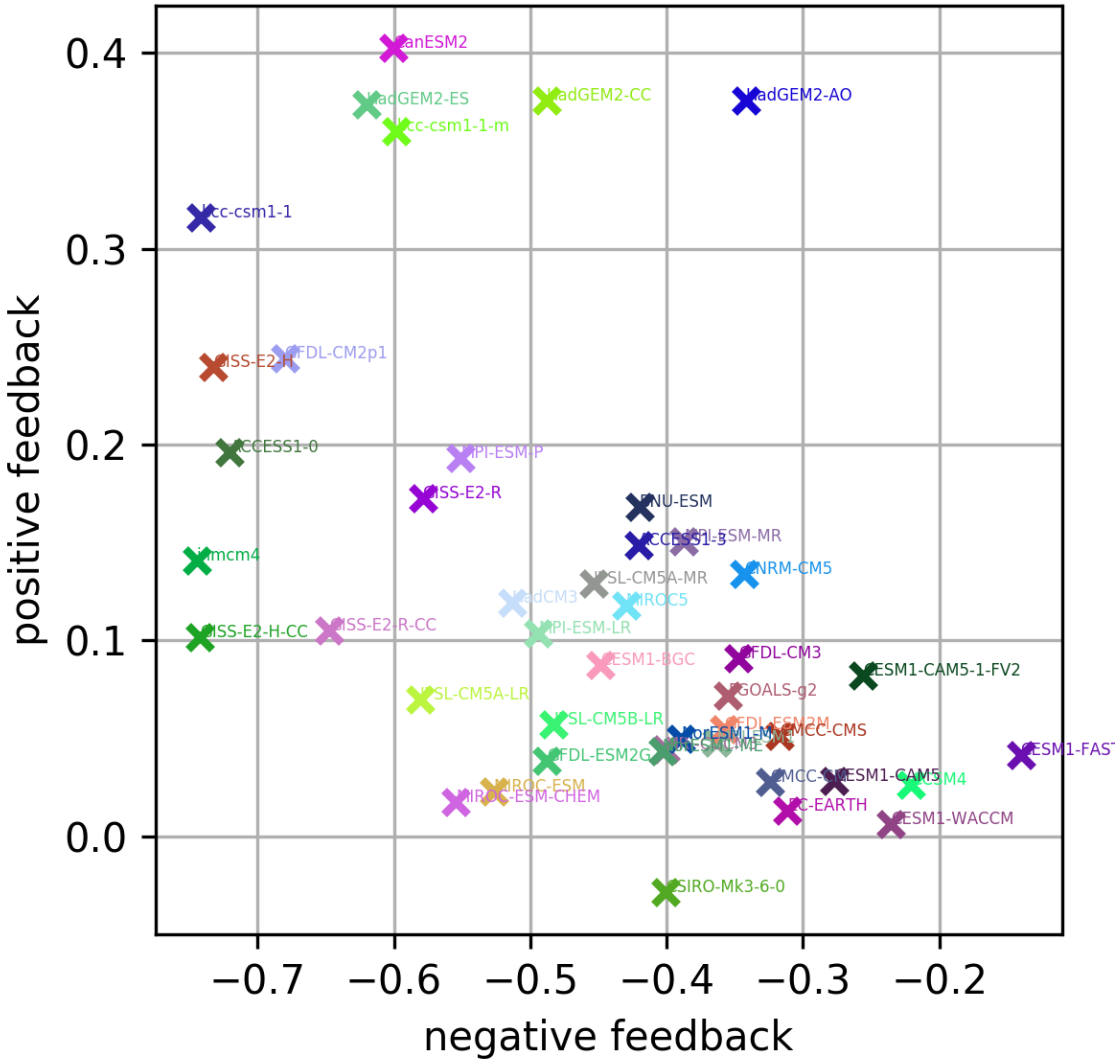
I think this is what is happening

Notice how both feedbacks kill persistence!!








positive feedback
negative feedback
0.4
0.3
0.2
0.1
0.0
−0.7
−0.6
−0.5
−0.4
−0.3
−0.2
anESM2
adGEM2-ES
adGEM2-CC
adGEM2-AO
cc-csm1-1-m
cc-csm1-1
FDL-CM2p1
ISS-E2-H
CCESS1-0
PI-ESM-P
ISS-E2-R
NU-ESM
CCESS1-3
PI-ESM-MR
mcm4
SL-CM5A-MR
NRM-CM5
adCM3
IROC5
ISS-E2-H-CC
ISS-E2-R-CC
PI-ESM-LR
ESM1-BGC
FDL-CM3
ESM1-CAM5-1-FV2
SL-CM5A-LR
GOALS-g2
SL-CM5B-LR
FDL-ESM2M
MCC-CMS
ESM1-FAS
FDL-ESM2G
IROC-ESM
IROC-ESM-CHEM
MCC-CM
ESM1-CAM5
C-EARTH
ESM1-WACCM
SIRO-Mk3-6-0