Bjerknes Centre for Climate Research

Data assimilation of sea ice – investigating key strategies in an Earth system model with a multi-category sea ice model

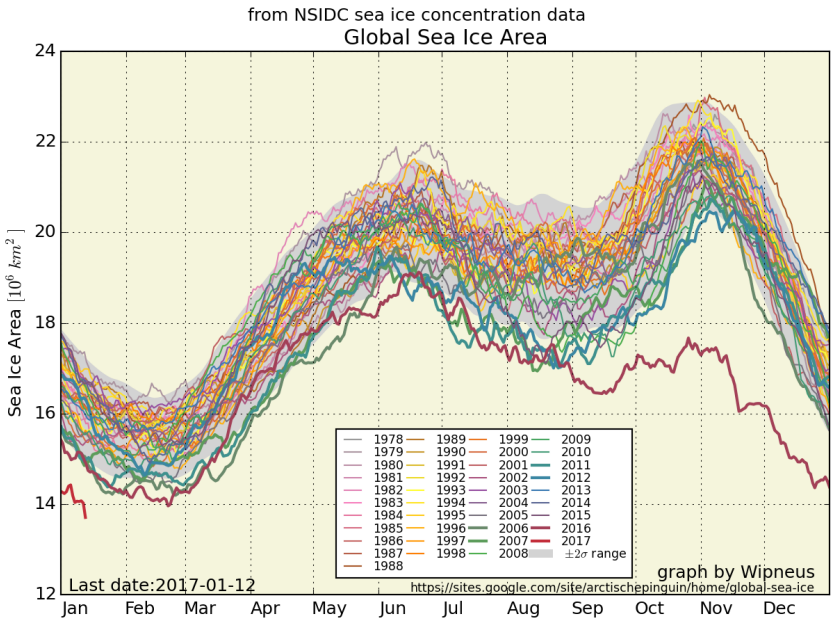
Madlen Kimmritz, *Francois Counillon, Cecilia Bitz, Francois Massonnet, Ingo Bethke, Yongqi Gao*

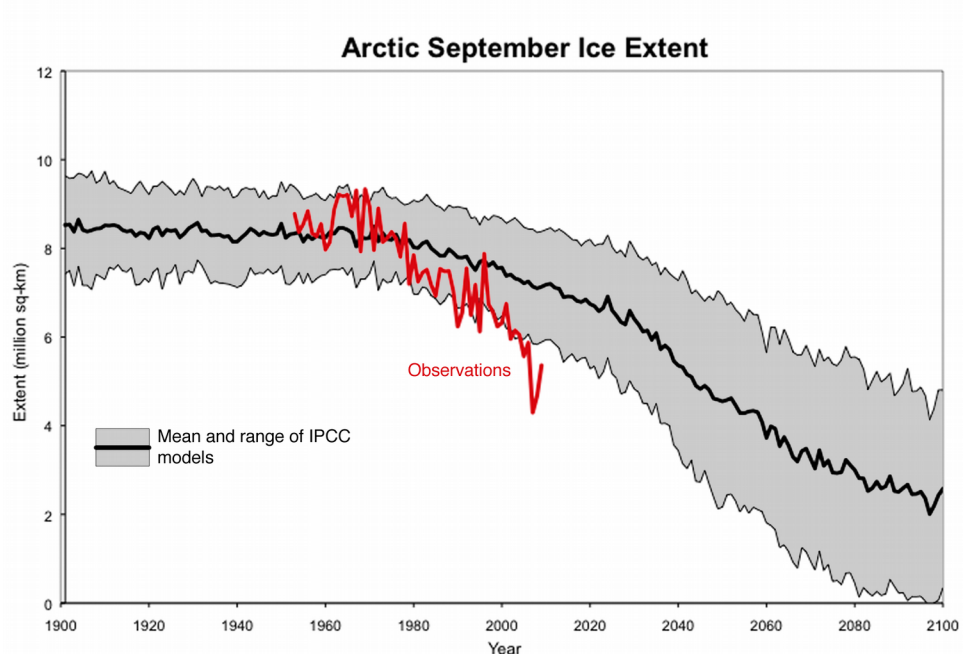
8th Annual Meeting of the GODAE OceanView Science Team, Bergen, Norway, November 9th 2017

Motivation

Data assimilation of sea ice

- Provides improved coupled reanalysis of the climate
- Enhances prediction skill on seasonal-to-decadal time scale
- Allows testing climate sensitivity to changes in sea ice

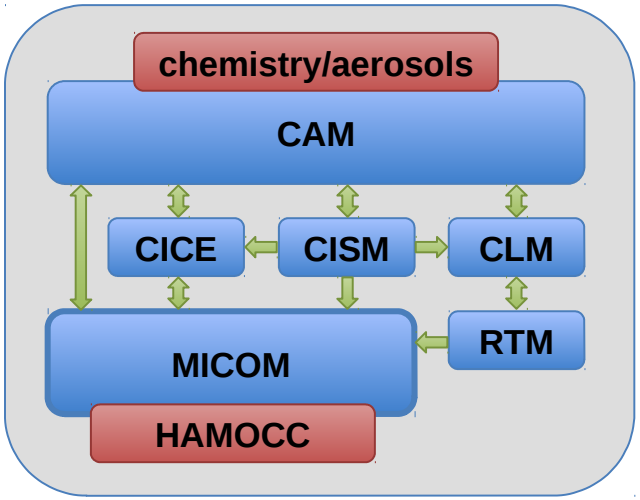




Setup

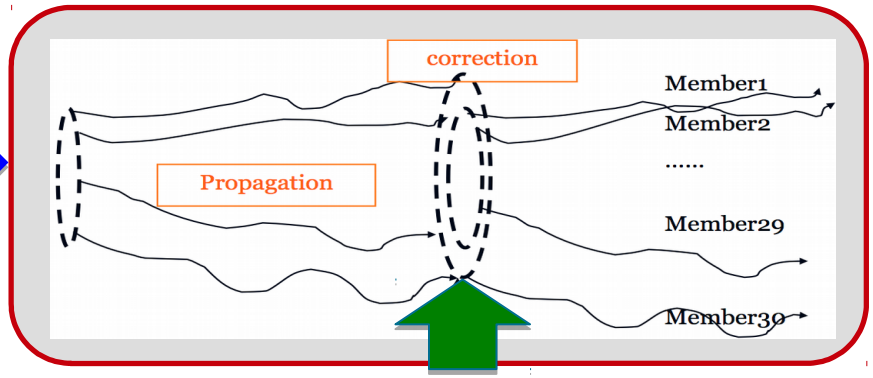
The Norwegian Climate Prediction Model (NorCPM)

Norwegian Earth System model

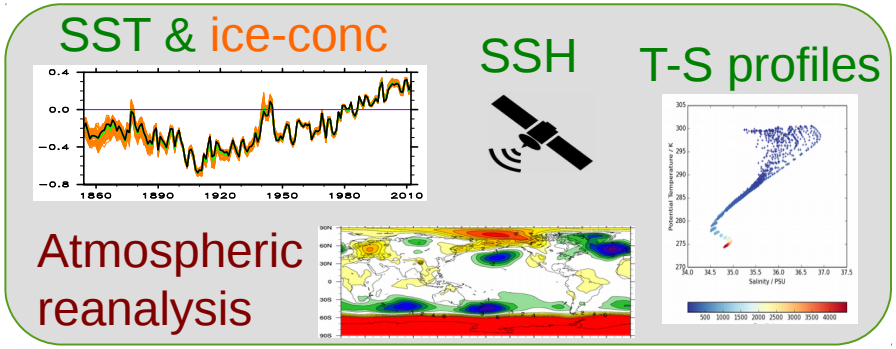


Ensemble

Data assimilation (EnKF)

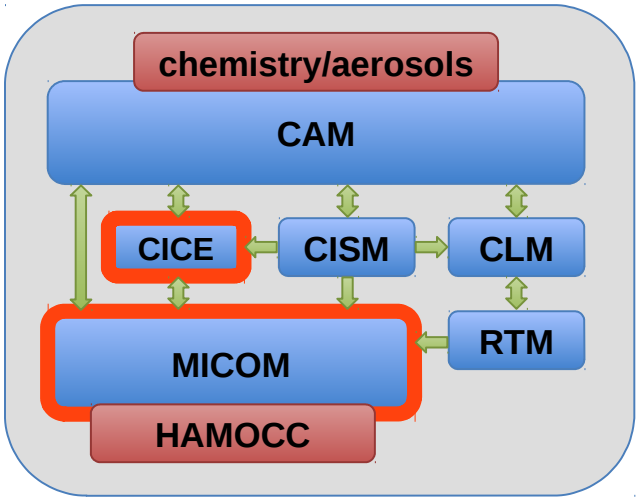


Observations



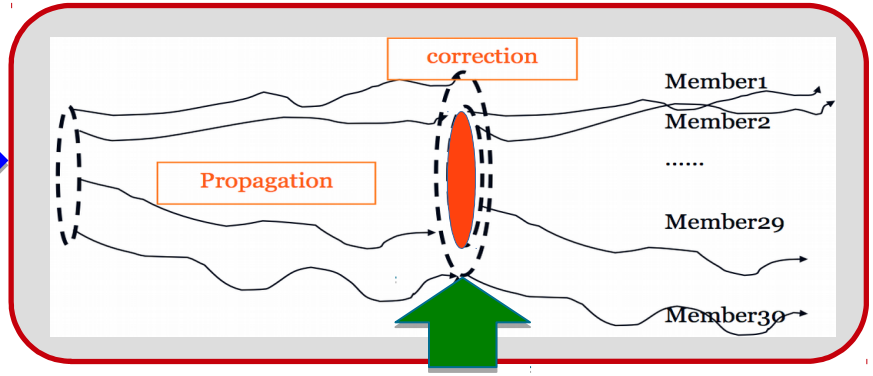
The Norwegian Climate Prediction Model (NorCPM)

Norwegian Earth System model



Ensemble

Data assimilation (EnKF)

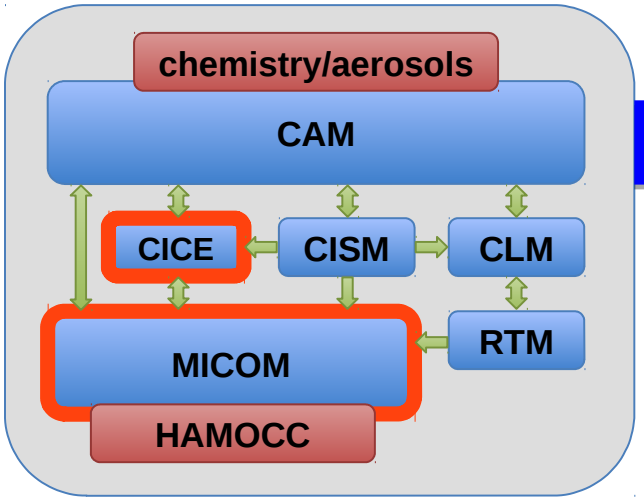


Observations

ice-concenctration

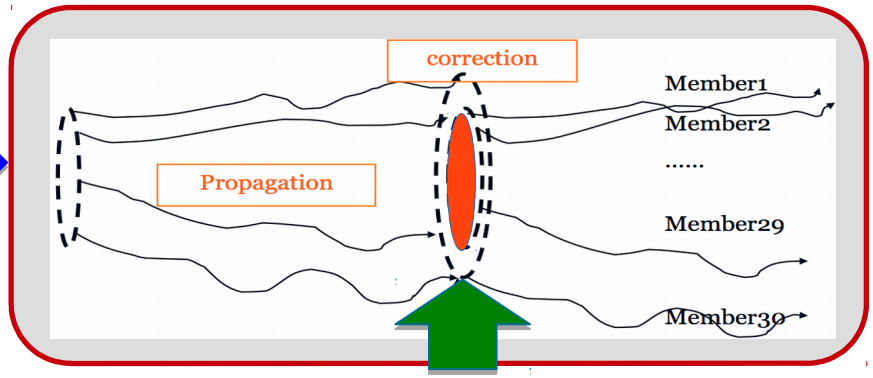
The Norwegian Climate Prediction Model (NorCPM)

Norwegian Earth System model



Ensemble

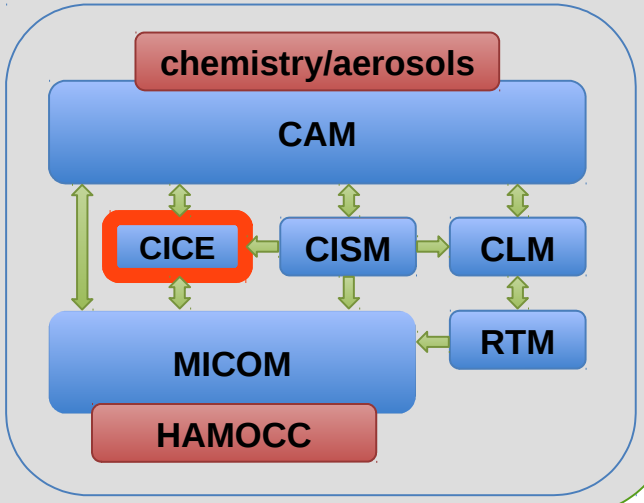
Data assimilation (EnKF)



Observations

Synthetic observations ice-conc

→ unperturbed
→ from different time than model run (>100yrs)
→ monthly assimilation
→ preindustrial



Twin experiment

→ **know the "truth" (ALL variables);**
→ **can study assimilation problem without model bias**

(Kimmritz et al. (under review))

Assimilation:
The sea ice component

Multicategory sea ice model

Simplified Example with 3 categories:

Model:
Each grid cell is divided into
3 ice thickness categories

Observations:
Only one sea ice
concentration „per cell“

Thick ice category:

- Concentration = 5 %
- Temperature =-15°C
- Thickness = 5 m

Medium category:

- Concentration = 15 %
- Temperature = -7°C
- Thickness = 2 m

Thin ice category:

- Concentration = 50 %
- Temperature = -2°C
- Thickness =0.4 m
-

Total (model) concentration 70 % to be compared with observation

Multicategory sea ice model

Simplified Example with 3 categories:

Model:
Each grid cell is divided into
3 ice thickness categories

Observations:
Only one sea ice
concentration „per cell“

Thick ice category:

- Concentration = 5 %
- Temperature =-15°C
- Thickness = 5 m

Medium category:

- Concentration = 15 %
- Temperature = -7°C
- Thickness = 2 m

Thin ice category:

- Concentration = 50 %
- Temperature = -2°C
- Thickness =0.4 m
-

Total (model) concentration 70 % to be compared with observation

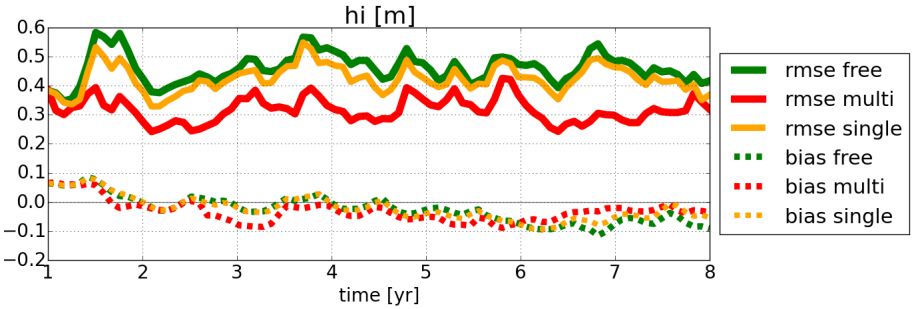
How should we update the individual category with DA:

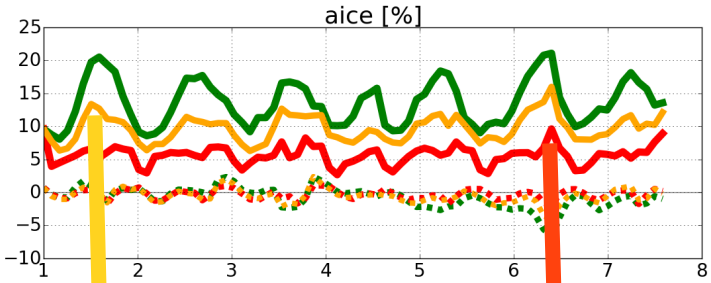
Update each category individually from the innovation

Update the sum and uniformly stretch each individual category

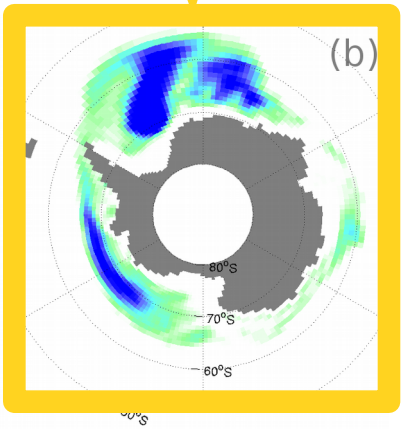
Multicategory sea ice model

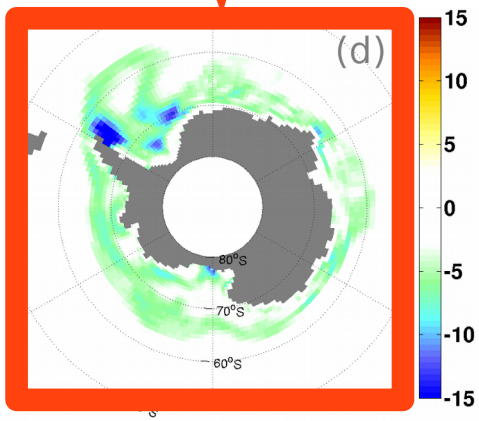
Space averaged rmse‘s and biases
For free (green), single category (yellow) and multi category (red)





Assimilating in **multicategory** sea ice model clearly **outperforms single category** with stretching

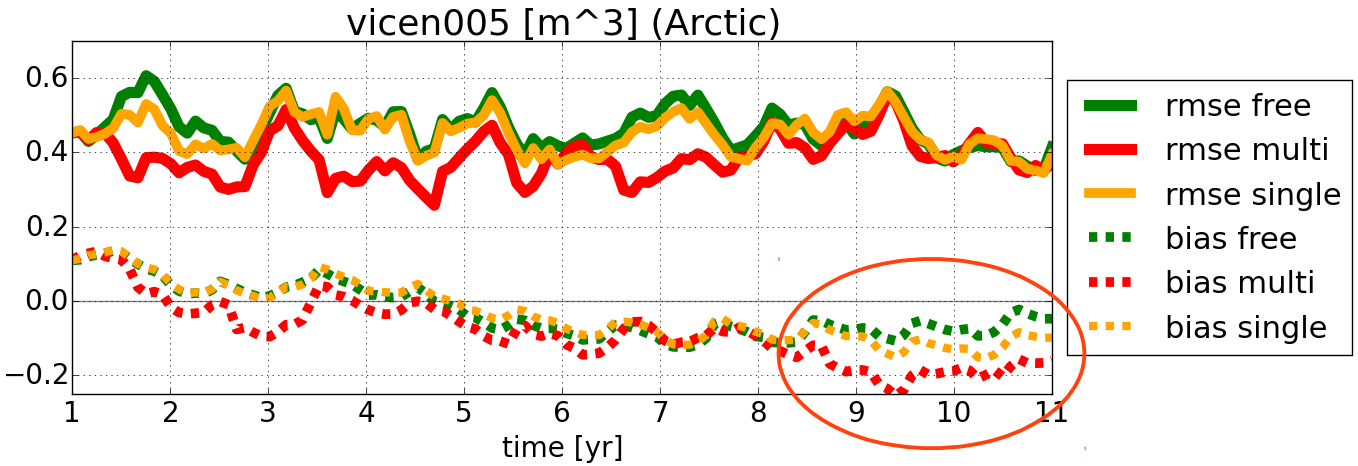




improved rmse(single) over rmse(free)

improved rmse(multi) over rmse(single)

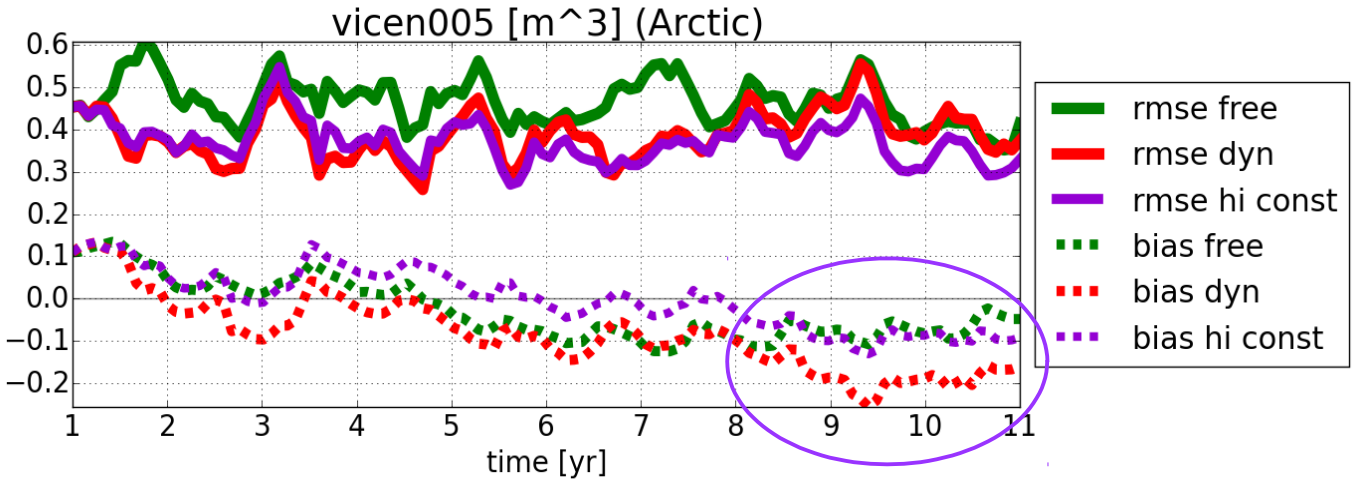
degradation of the bias in thickest ice



	dynamic
state vector (EnKF)	aicen(1:5), vicen(1:5)
postproc. vicen(1:5)	cut due to hicen(1:5)

We create unphysical values that need to be postprocessed!

preserving ice thickness



	dynamic	hi constant
state vector (EnKF)	aicen(1:5), vicen(1:5)	aicen(1:5)
postproc. vicen(1:5)	cut due to hicen(1:5)	scale s.th. hicen(1:5) preserved

Preserving ice thickness

- **removes** the **bias degradation in thick ice**
- **no degradation of performance in total thickness**

Summary

multicategory sea ice component:

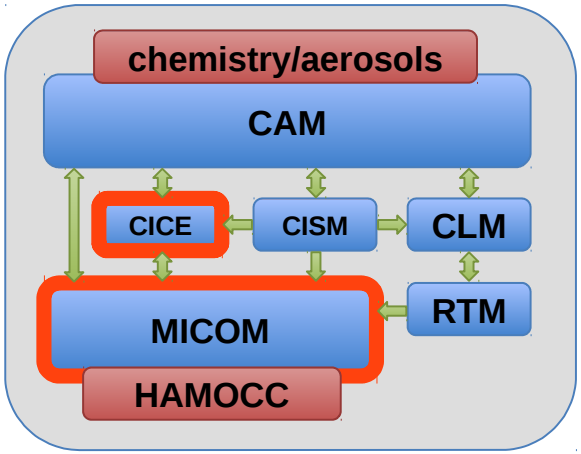
→ Update dynamically in *all* ice thickness classes instead of the aggregated variables (+ stretching)!

→ Choose state vector and postprocessing wisely!

Assimilation:
Coupling with other model components

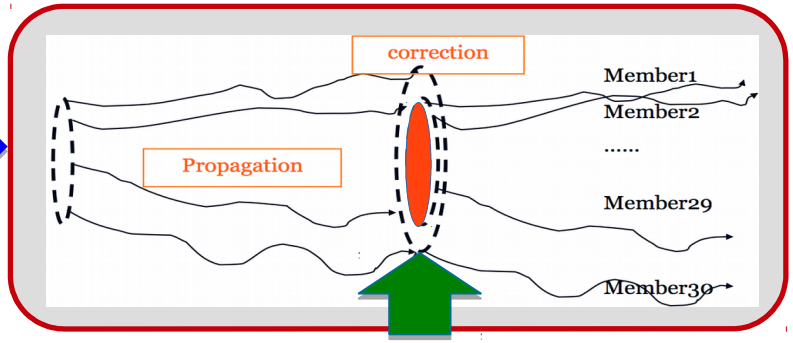
The Norwegian Climate Prediction Model (NorCPM)

Norwegian Earth System model



Ensemble

Data assimilation (EnKF)

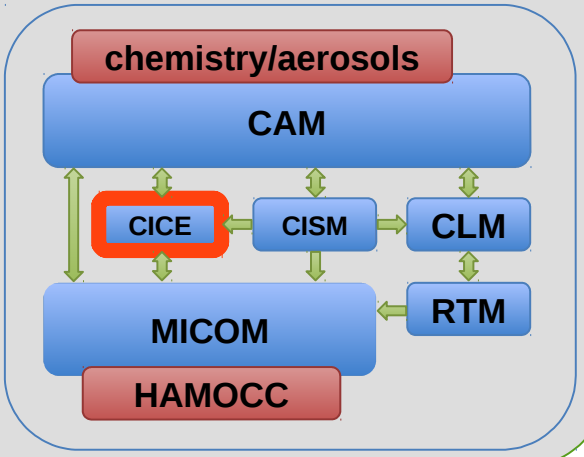


Observations

Synthetic observations ice-conc

→ from different time than model run (>100yrs)

→ monthly assimilation

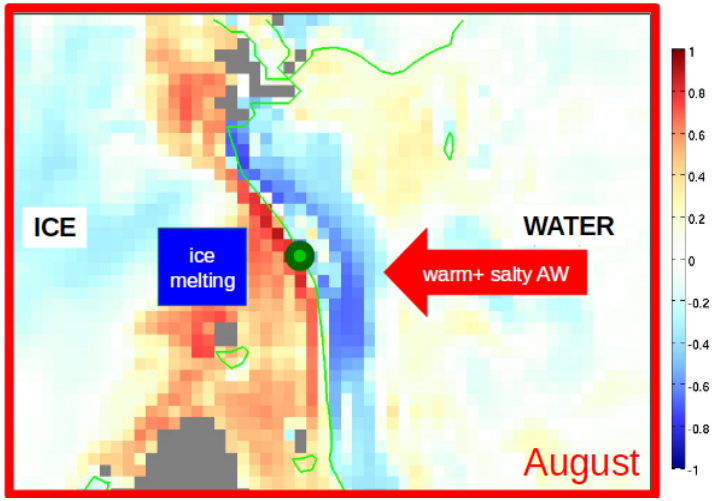


→ modelling scales of ice and ocean are similar

→ **ocean surface and ice are strongly correlated**

Constraining sea ice: a coupled problem

Correlation between ice concentration at dot and SSS



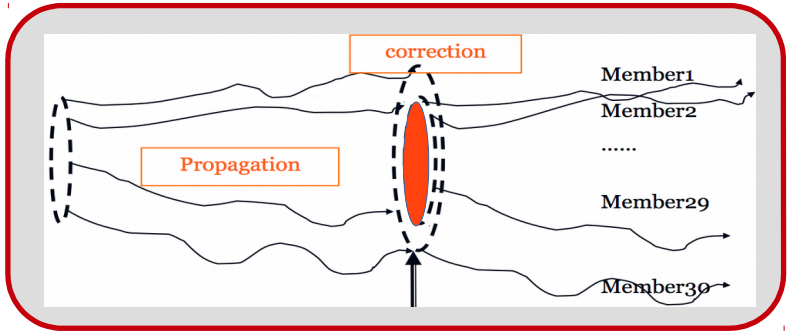
Sakov et al. 2012

EnKF handles flow dependent and strongly anisotropic cross covariances between ocean and sea ice

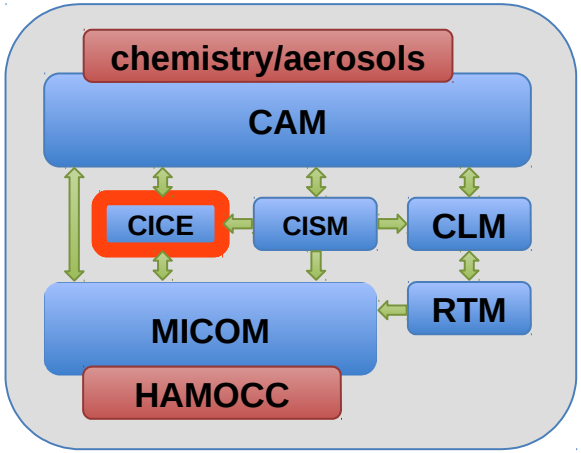
Lisæter et al. 03, Sakov et al.12, Massonnet et al. 14

Coupled update: ocean and ice
Crucial for preserving the ocean Stratification?

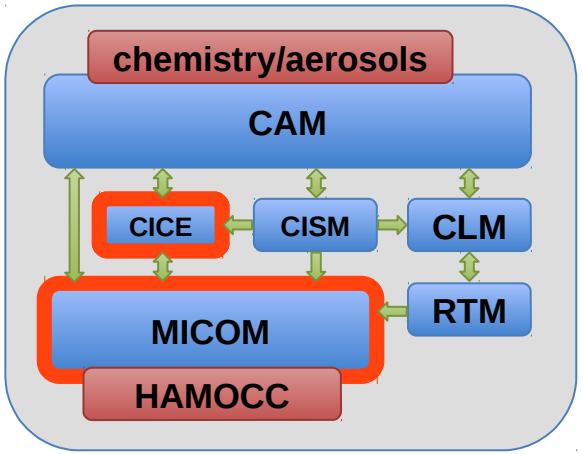
Constraining sea ice: a coupled problem



Weakly coupled



Strongly coupled

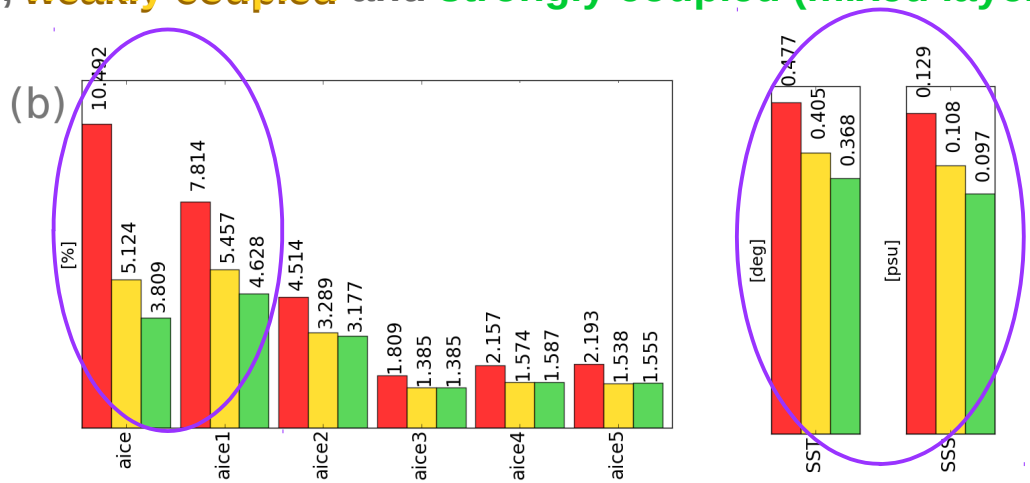


No update of ocean state during assimilation!

Dynamical update of ocean state in mixed layer (temperature,salinity) during assimilation!

Constraining sea ice: a coupled problem

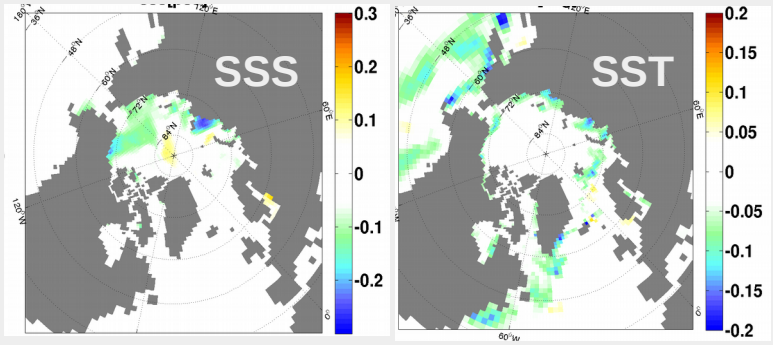
Space&time averaged rmse's in the Southern Ocean for free, weakly coupled and strongly coupled (mixed layer)



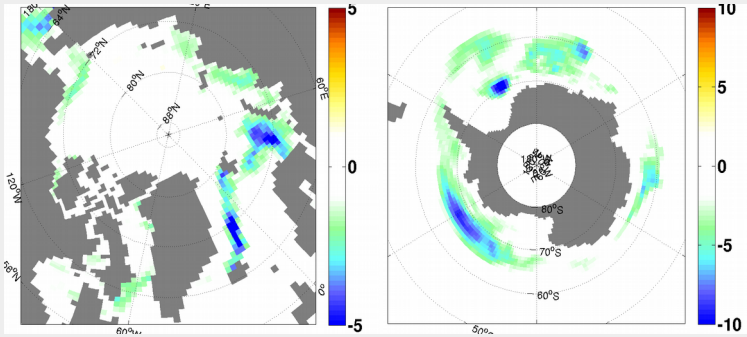
improvement of strong in thinnest ice category and in ocean surface states

Time averaged rmse's: differences between strongly and weakly coupled

OCEAN SURFACE

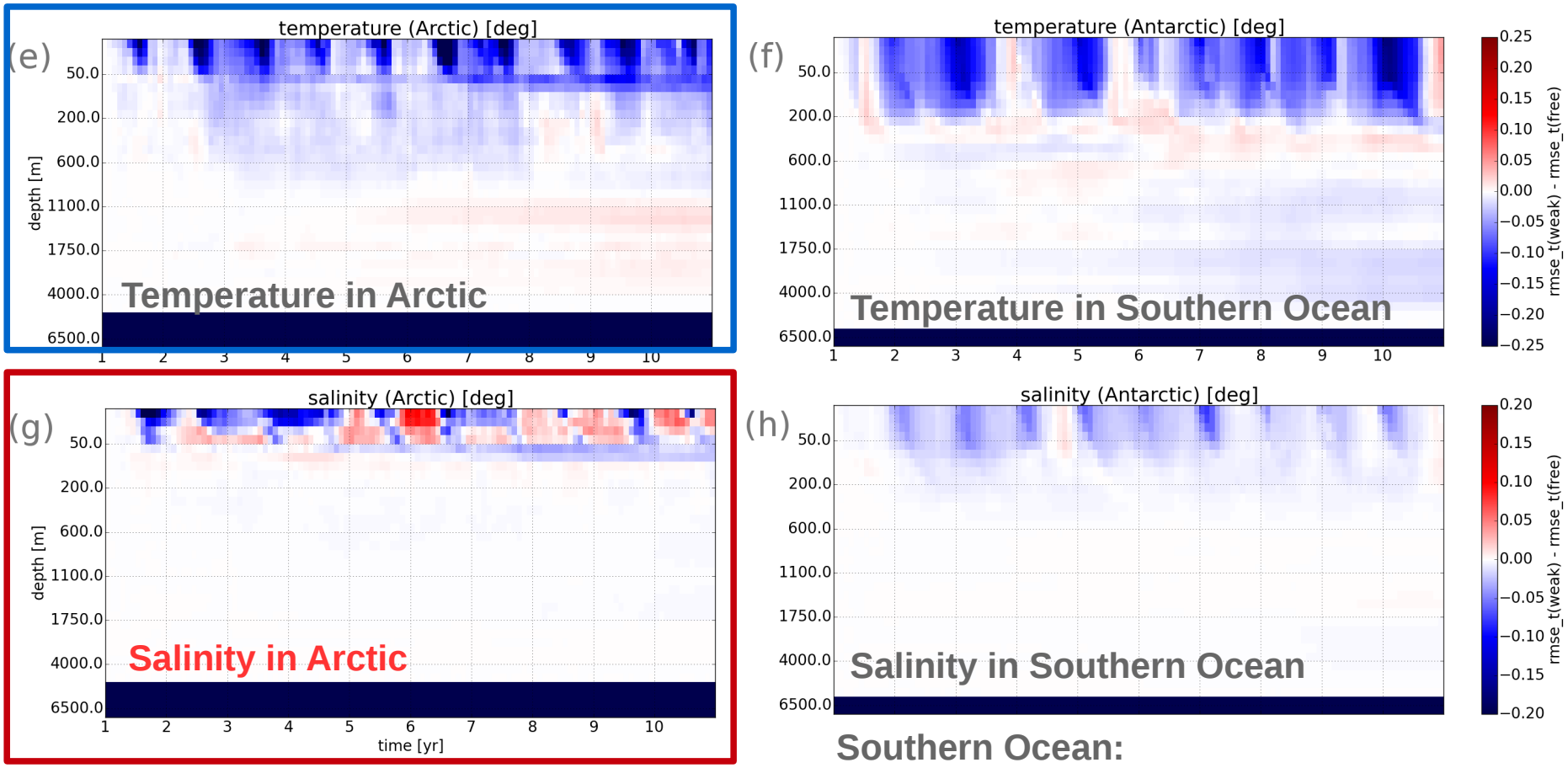


ICE CONCENTRATION



Constraining sea ice: a coupled problem

Space averaged rmse's: Differences between **weakly coupled** and **free**



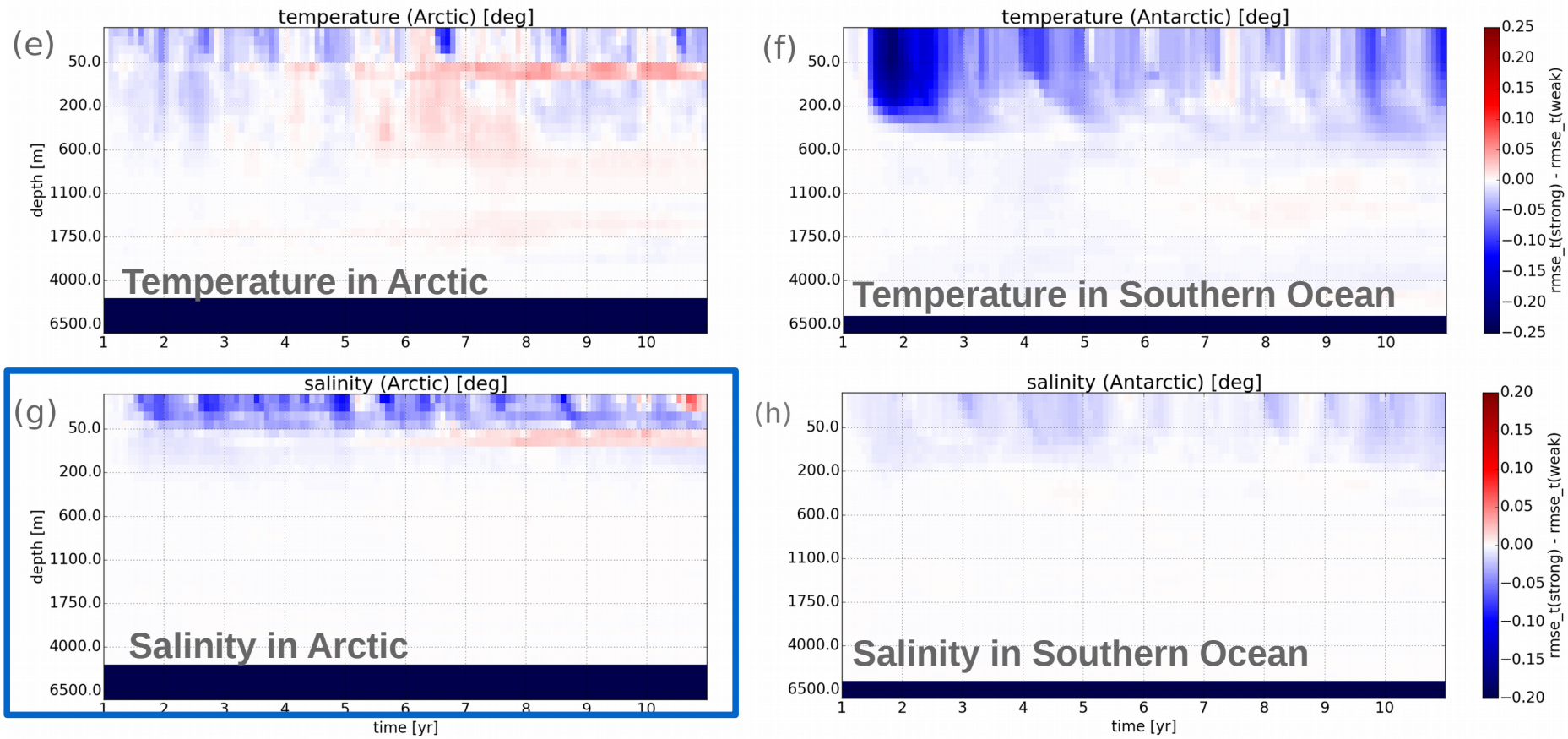
Arctic ocean:
weakly coupled already beneficial for temperature, but not for salinity

Southern Ocean:
→ mostly temperature determined
→ only updating ice is widely beneficial

Constraining sea ice: a coupled problem

Space averaged rmse's: Differences between

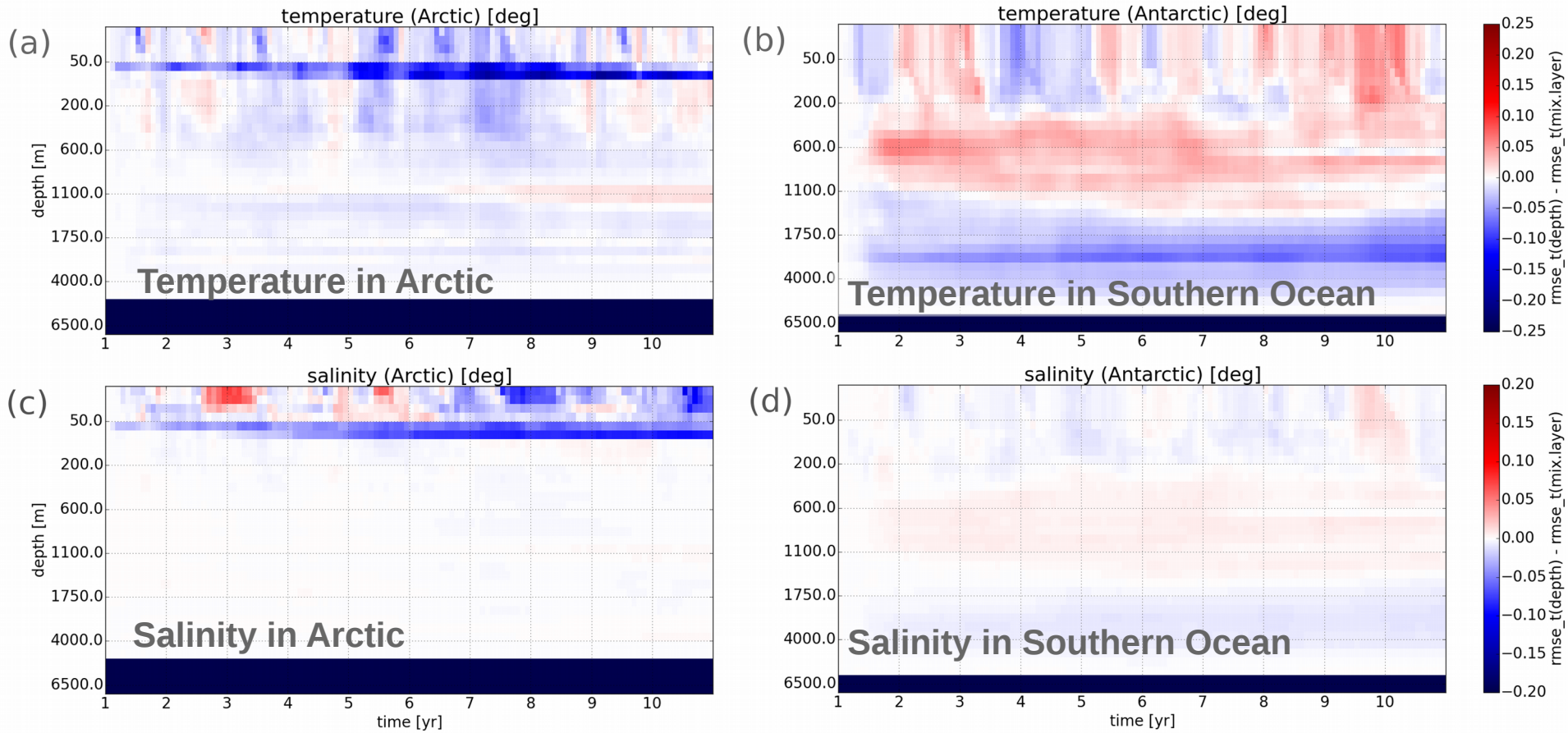
strongly coupled and weakly coupled



Southern Ocean:
- **improves in all locations**
- **compensates degradations in weakly coupled**

Constraining sea ice: a coupled problem
Updating down to the ocean bottom?

Space averaged rmse's: Differences between entire depth and mixed layer

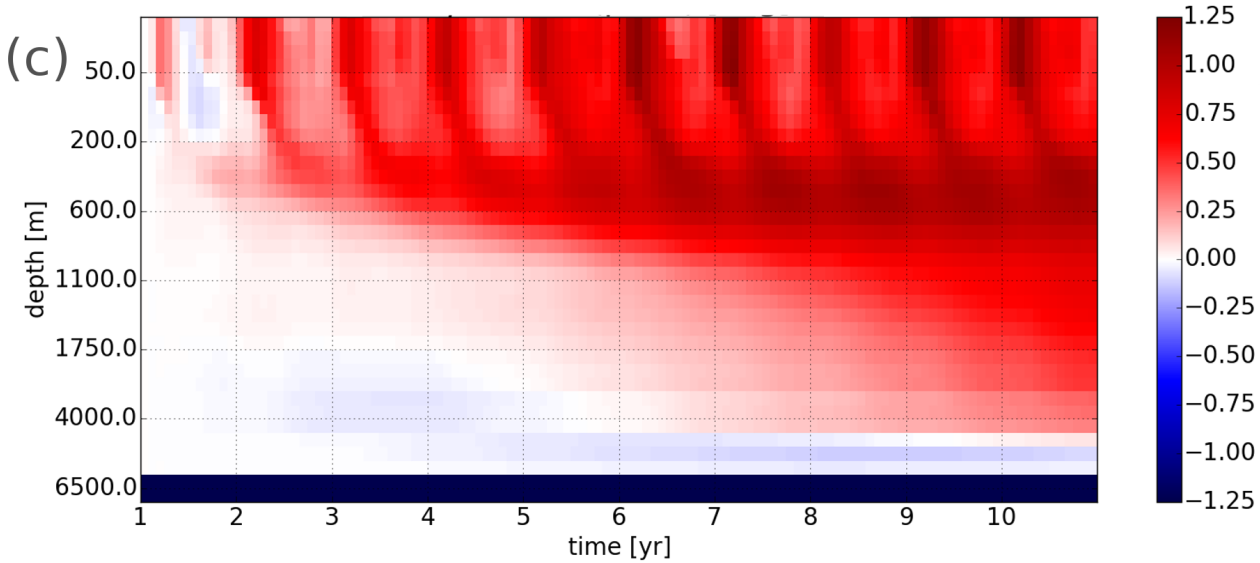


Constraining sea ice: a coupled problem
Is it sufficient to *crudely (statically)* adapt the ocean?

Where is ice, assure T = -1.8degC
Where is no ice, assure T > -1.8degC

Keep salinity untouched

Spatially averaged RMSE(temperature):
Differences between coupled and free



Summary
inter-component coupling:

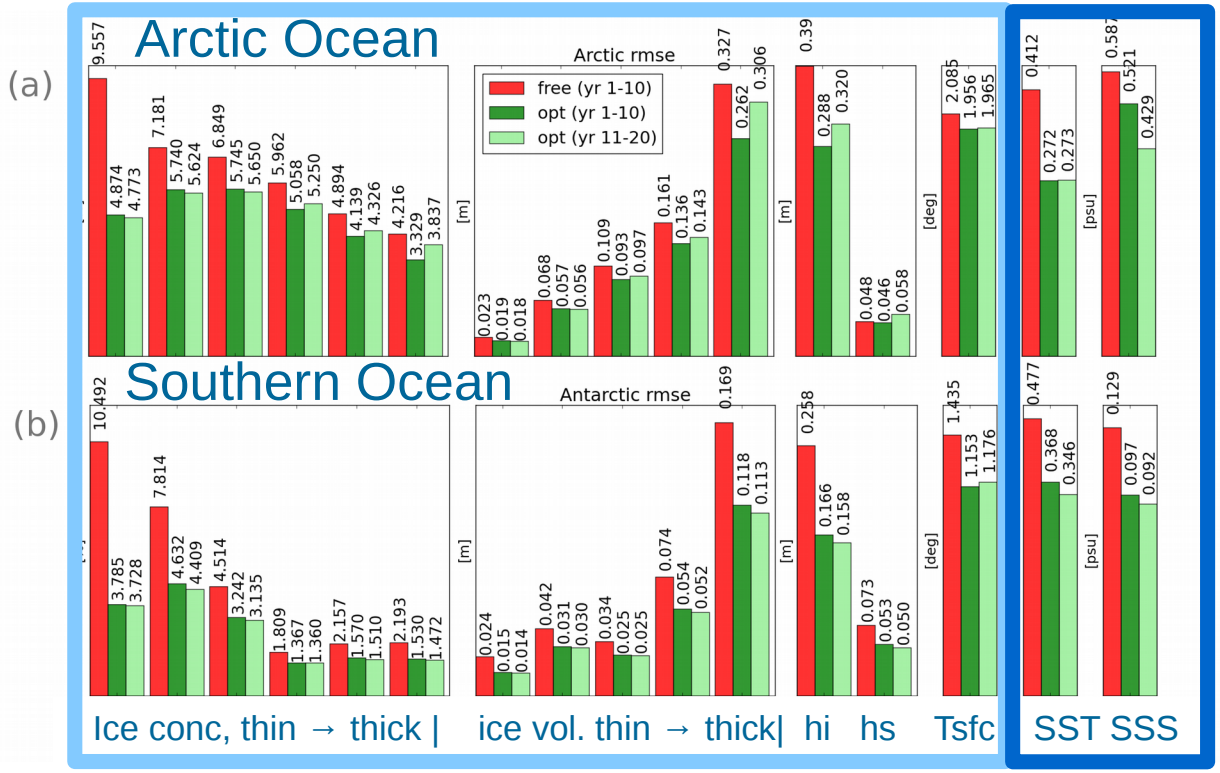
→ only updating ice component (ocean adjusts itself)
- beneficial – even for ocean temperature
- not well captured salinity in upper Arctic ocean

→ dynamically updating ice and ocean component
→ improved thin ice states
(instant feedback from ocean surface)
and improved ocean state
(particularly Arctic salinity and temperature in S.O.)
→ updating below the mixed layer:
might give slightly negative effect (in S.O.)

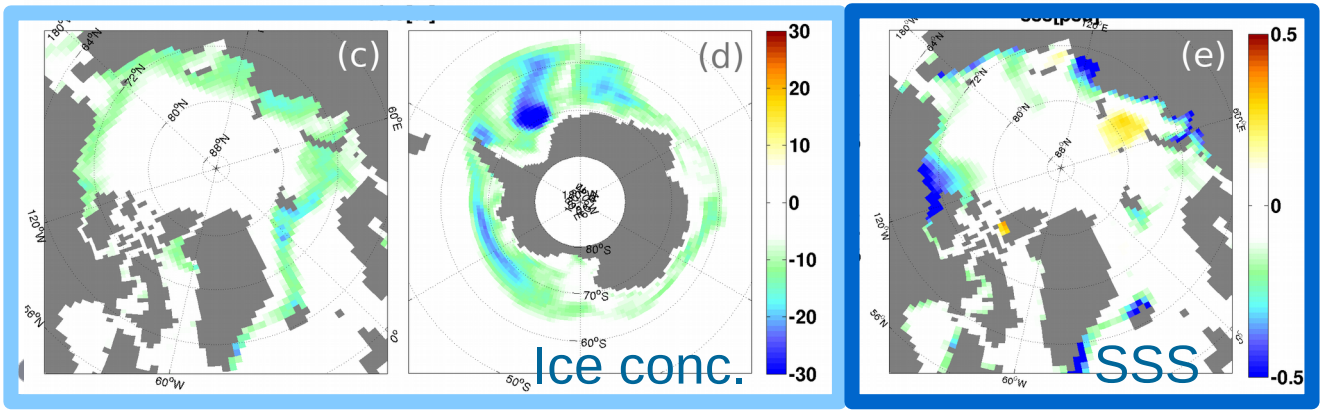
→ *Prescribing* the ocean surface according to ice state is non trivial!

What do we gain by assimilating sea ice?

Time and space averaged RMSE



Time averaged RMSEs: differences between assimilated and free



Conclusions

Conclusions

Much of **sea ice variability** can be **constrained just with** aggregated **ice concentration** (reliable!)

Multicategory is beneficial over single category assimilation

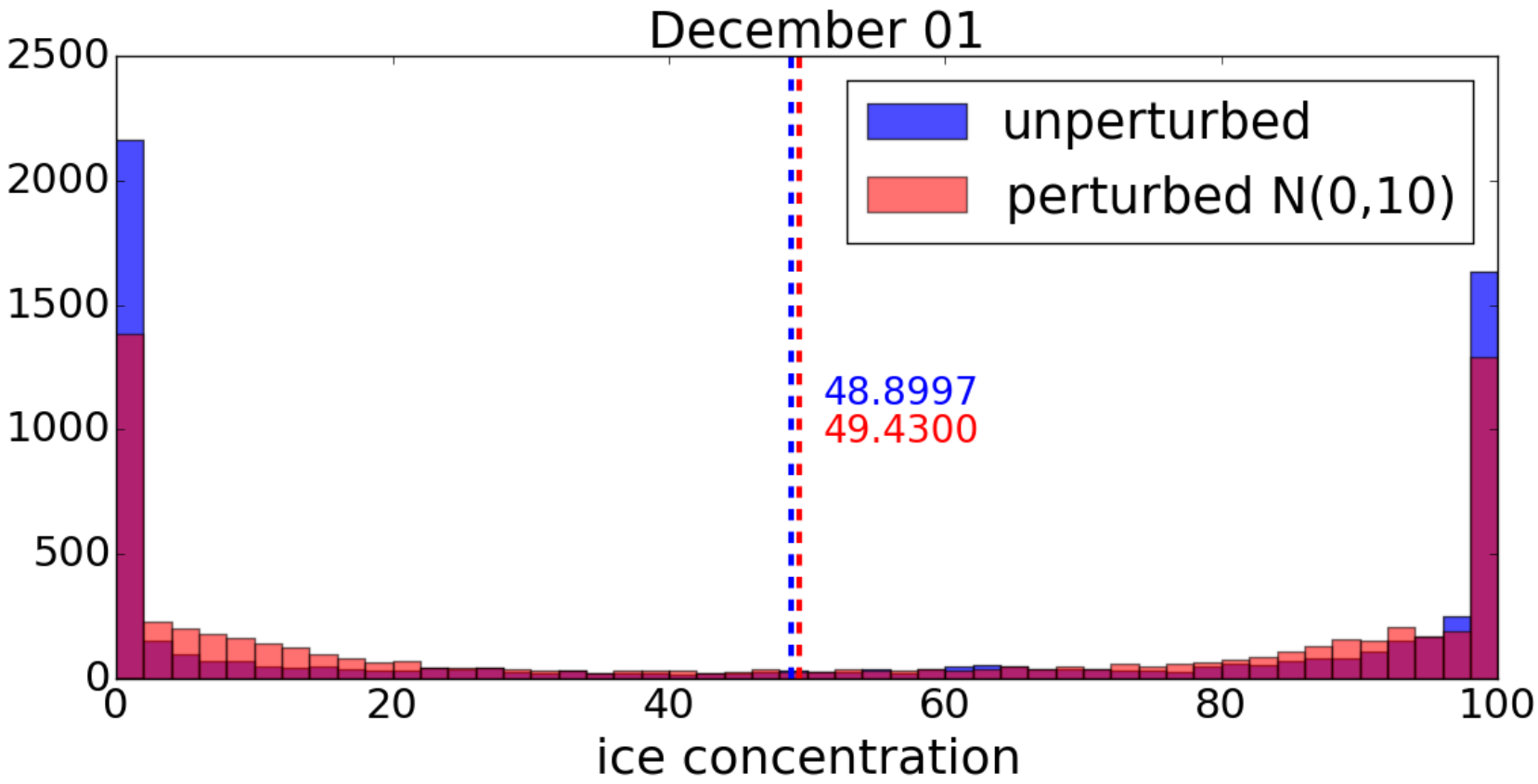
Strongly coupled assimilation with **prescribed** cross-covariance is not trivial!

Strongly coupled outeperforms weakly coupled for **thin ice**

Recipe: **minimize „critical“ postprocessing**

Assimilation **into deep ocean** only has a **minor impact,** but is not suggestable for real observations

Appendix



→ **sea ice concentration: nonGaussian distributed**
→ **perturbation of observations and postprocessing changes mean**
→ **introduction of bias**
→ **not clear assessment of assimilation techniques**

Multicategory sea ice model

	single-category	multi-category
aicen(1:5)	**sum** → EnKF	EnKF
vicen(1:5)	**sum** → EnKF	EnKF

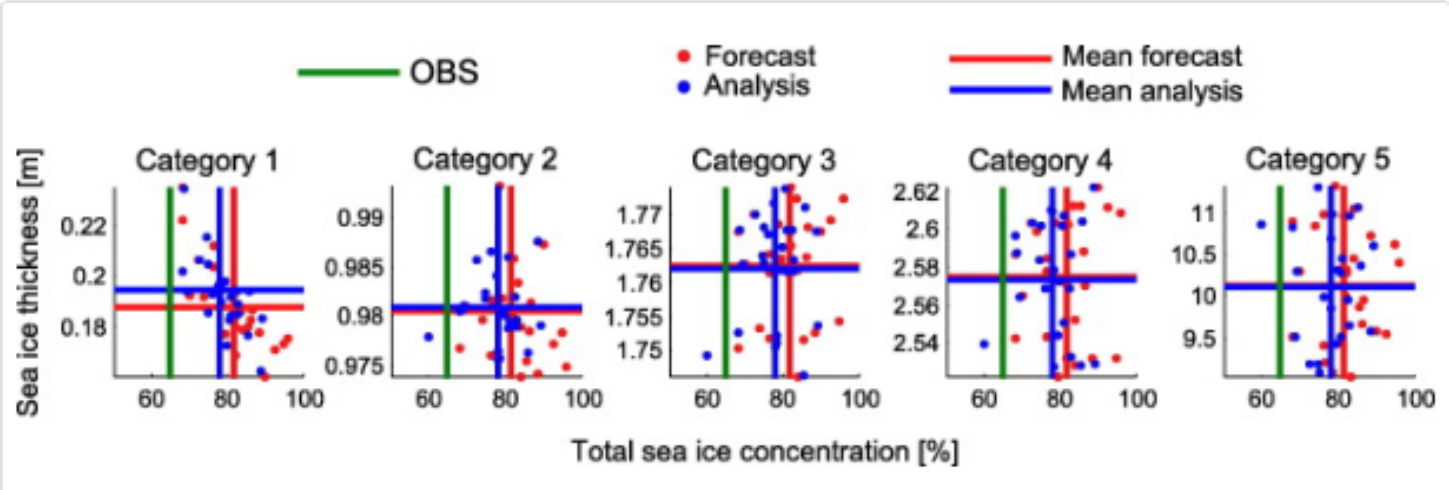
Temperature, salinity in mixed layer: EnKF

Post processing for ice:

- Basic adjustment (dependent on aice>0, thickness categories)
- Scaling of ice/snow energy and snow thickness
- due to changes in vicen(1:5) and aicen(1:5)

- Sea ice state

Using LIM3

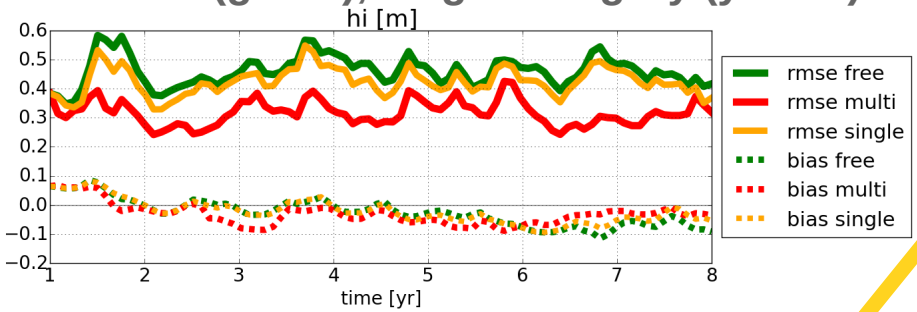


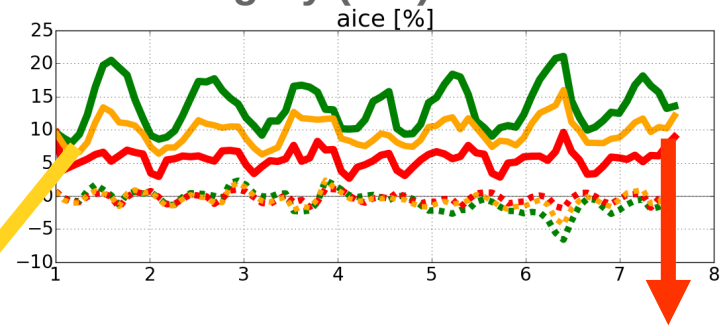
Massonnet et al. 2015

Beneficial: use correlations for each category

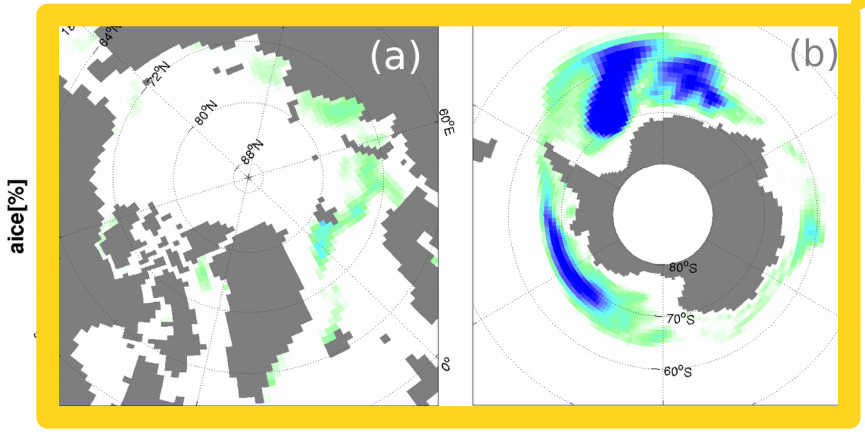
Multicategory sea ice model

Space averaged rmse‘s and biases
For free (green), single category (yellow) and multi category (red)

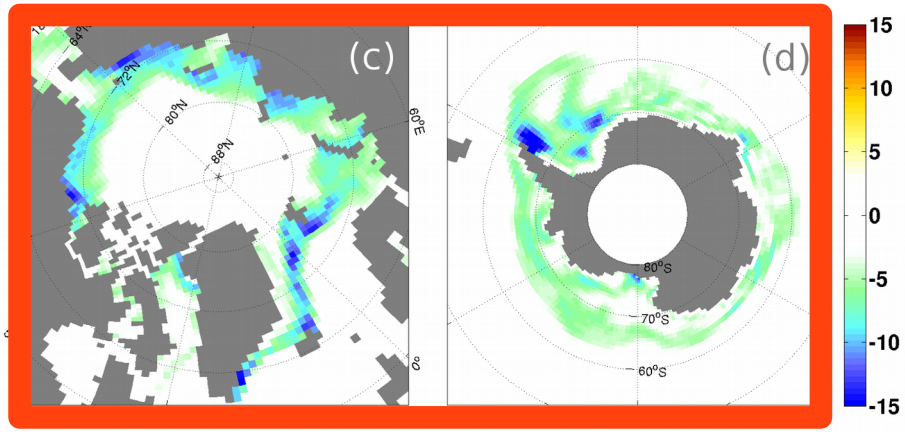




Time averaged rmse‘s: single - free



Time averaged rmse‘s: multi - single

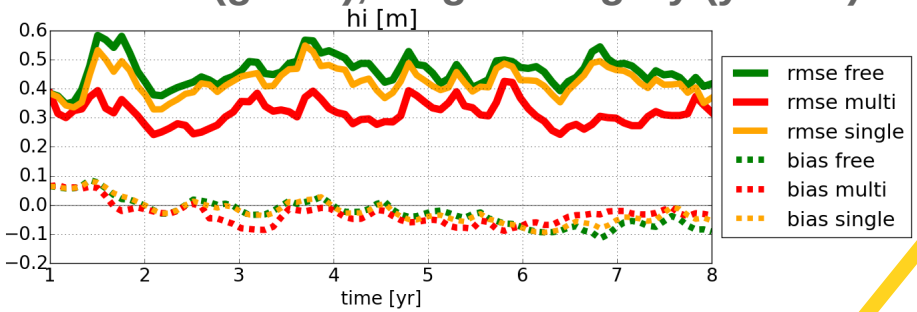


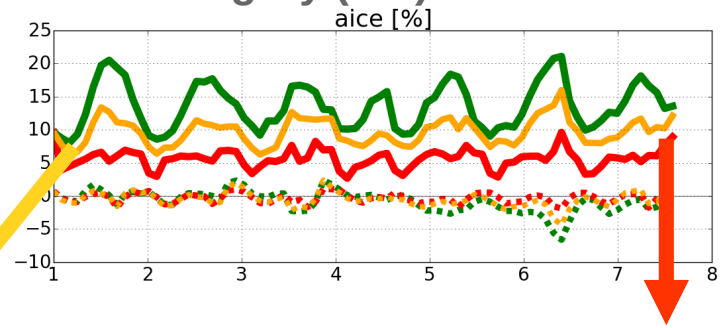
singlecategory states in EnKF
→ improvement mostly in thin ice

multicategory states in EnKF
→ improvement in every single category
→ *largest for thick ice categories*

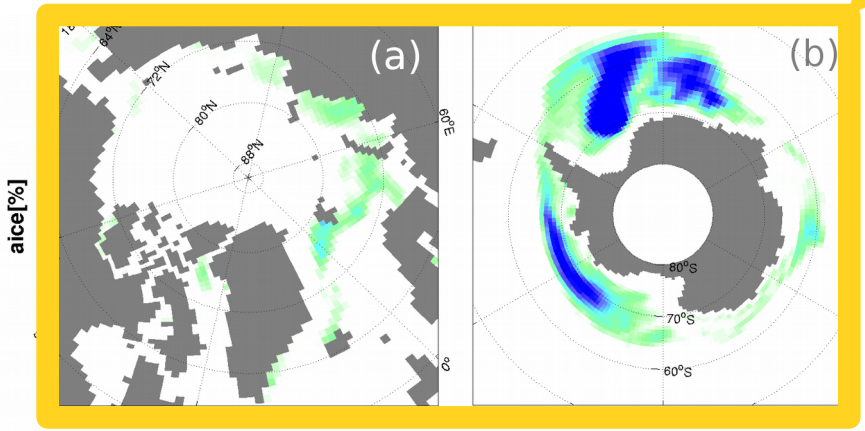
Multicategory sea ice model

Space averaged rmse‘s and biases
For free (green), single category (yellow) and multi category (red)

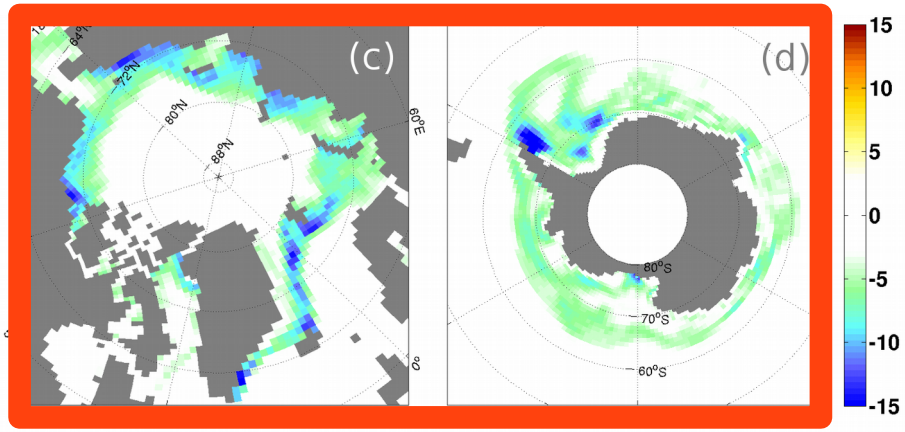




Time averaged rmse‘s: single - free



Time averaged rmse‘s: multi - single



singlecategory states in EnKF
→ improvement mostly in thin ice

multicategory states in EnKF
→ improvement in every single category
→ *largest for thick ice categories*

Assimilating in **multicategory** sea ice model clearly **outperforms single category** with stretching

Twin experiment

coupled covariance

aicen(1:5) vicen(1:5)	• weak EnKF	prescribed EnKF	strong EnKF
temp in mixed layer saln in mixed layer	no update	diagnosed Temp = -1.8, if ice Temp > -1.8+eps, if no ice	EnKF

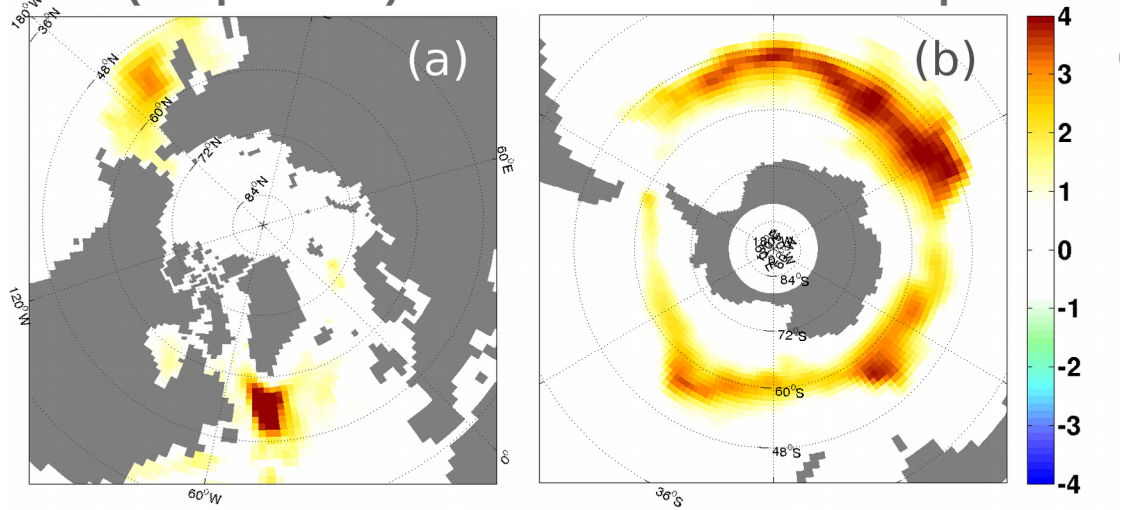
Constraining sea ice: a coupled problem
Is it sufficient to *crudely* adapt the ocean?

Time averaged RMSE(temperature): Differences between coupled and free

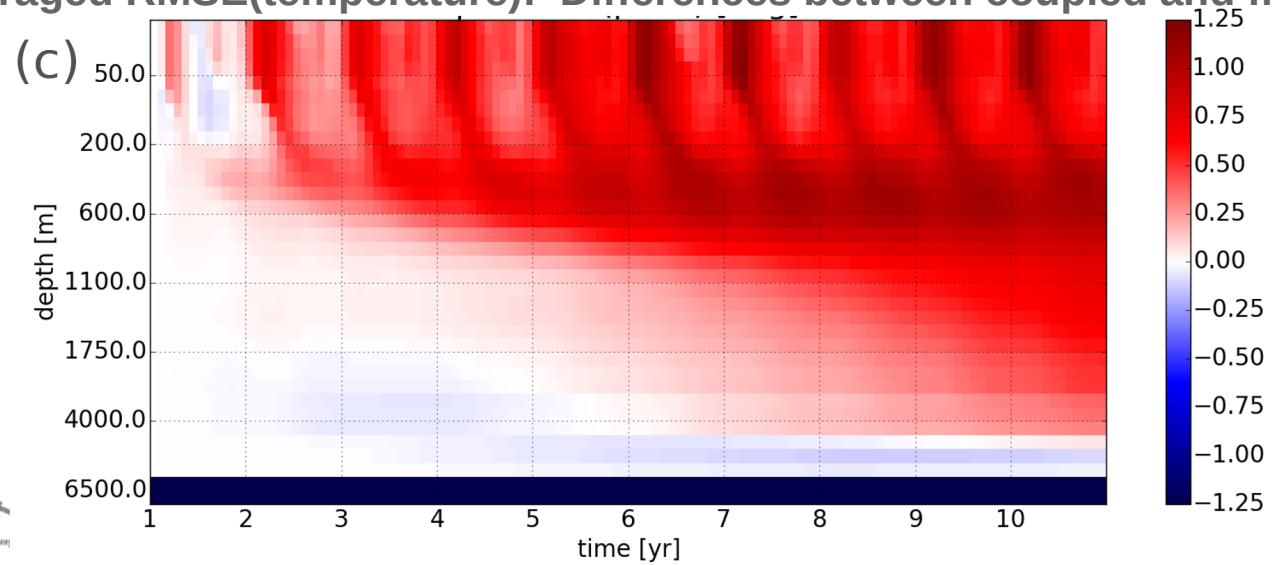
Where is ice, assure T=-1.8degC

Where is no ice, assure T > -1.8degC

Keep salinity untouched

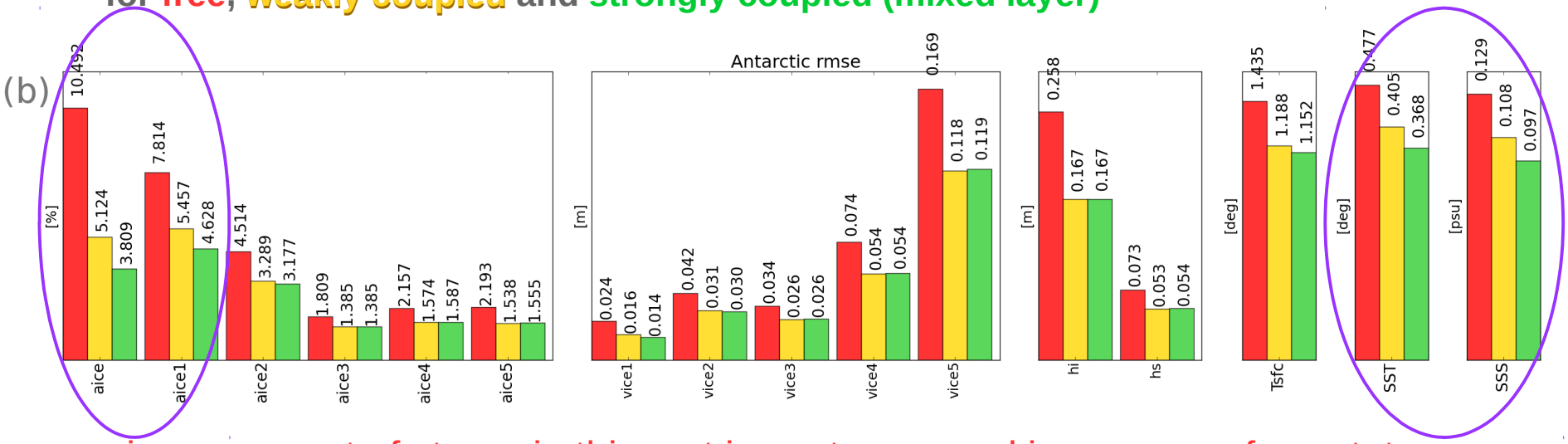


Spatially averaged RMSE(temperature): Differences between coupled and free



Constraining sea ice: a coupled problem

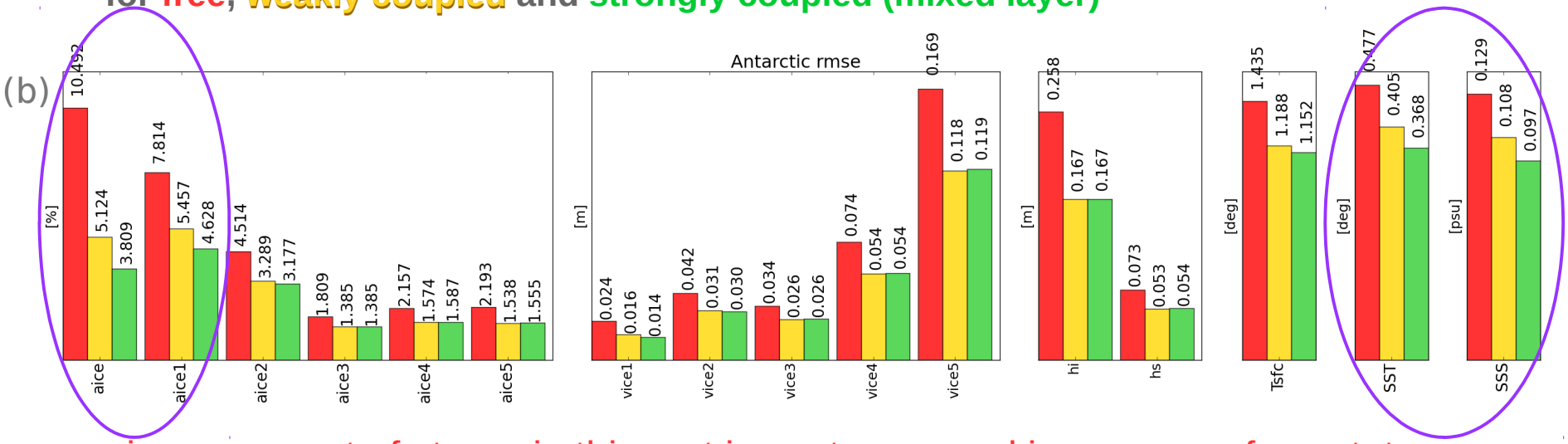
Space&time averaged rmse's in the Southern Ocean for free, weakly coupled and strongly coupled (mixed layer)



improvement of strong in thinnest ice category and in ocean surface states

Constraining sea ice: a coupled problem

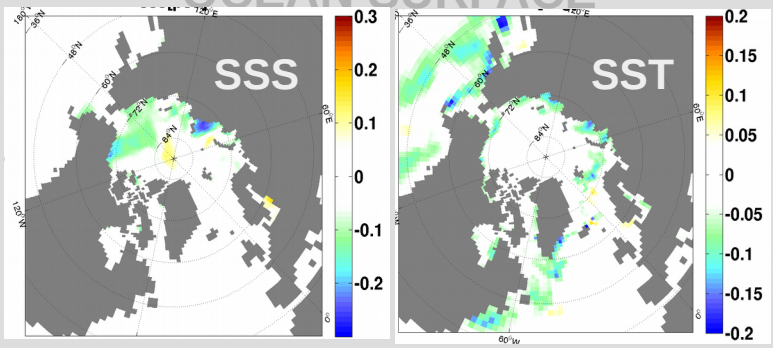
Space&time averaged rmse's in the Southern Ocean for free, weakly coupled and strongly coupled (mixed layer)



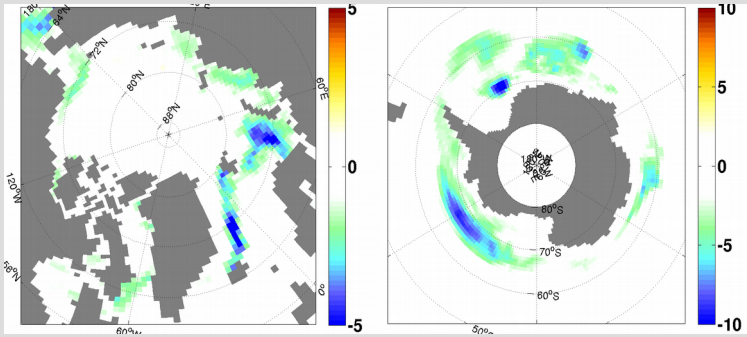
improvement of strong in thinnest ice category and in ocean surface states

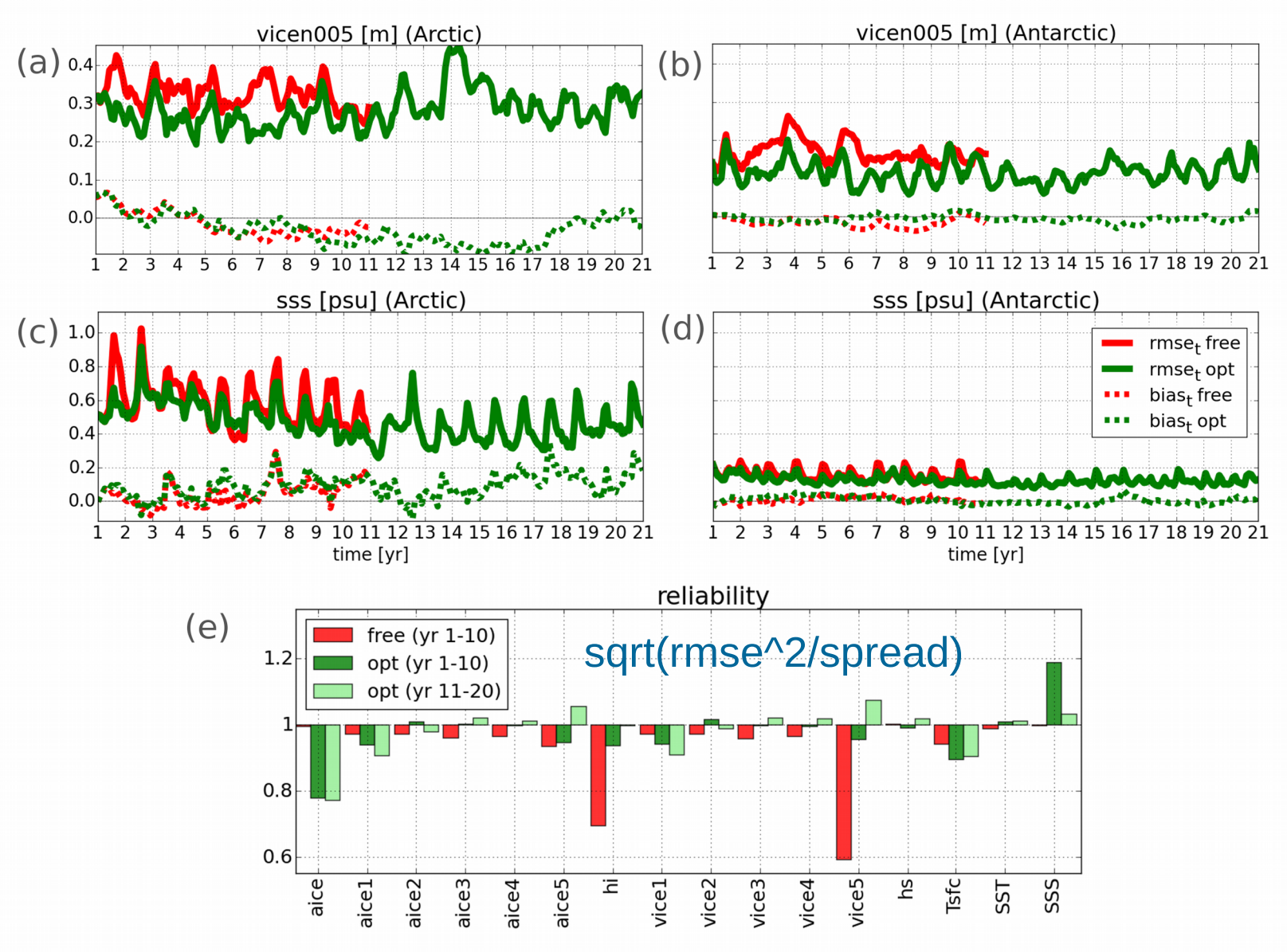
Time averaged rmse's: differences between strongly and weakly coupled

OCEAN SURFACE

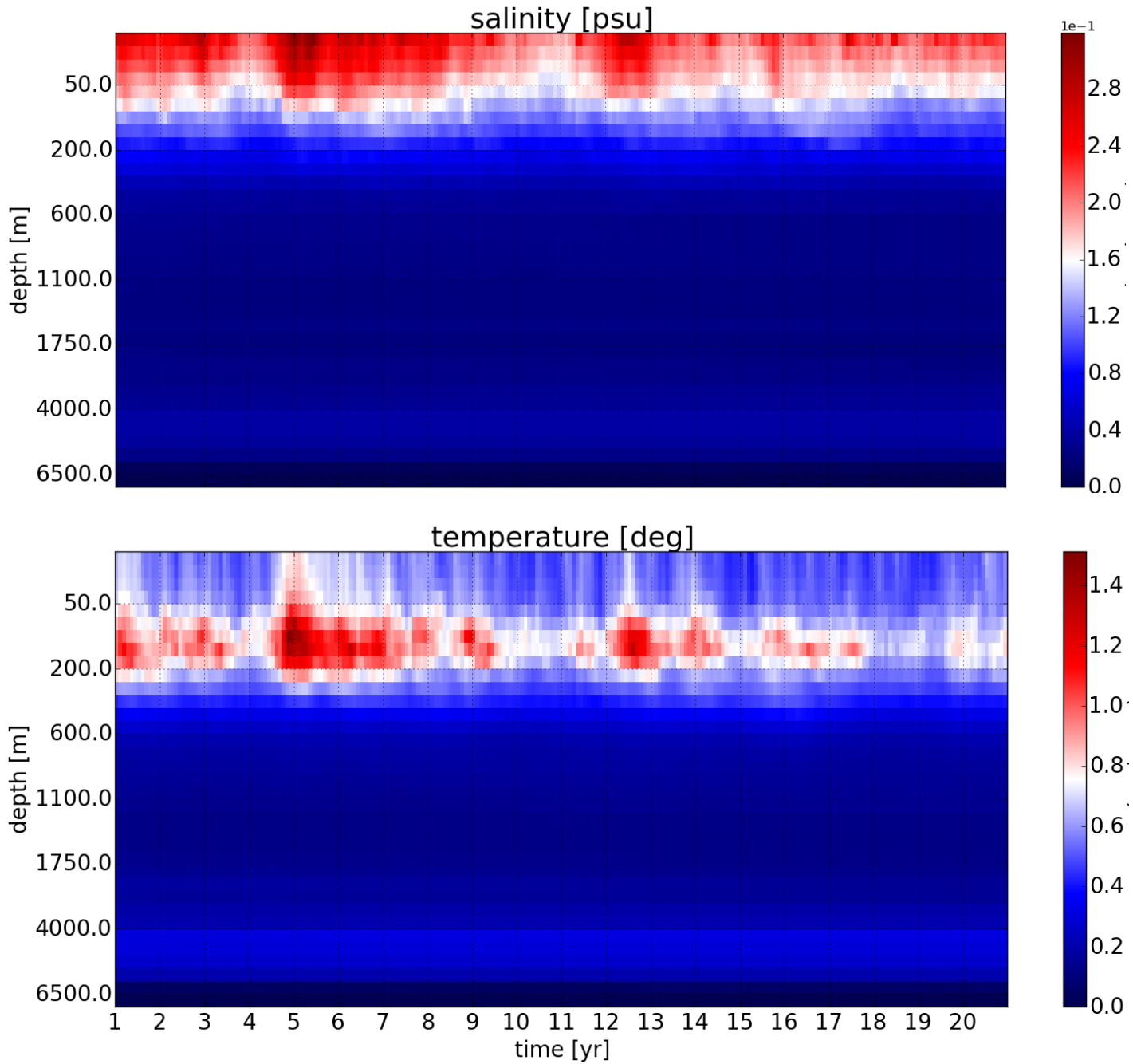


ICE CONCENTRATION




(a)
vicen005 [m] (Arctic)
(b)
vicen005 [m] (Antarctic)
(c)
sss [psu] (Arctic)
(d)
sss [psu] (Antarctic)
time [yr]
time [yr]
rmse$_t$ free
rmse$_t$ opt
bias$_t$ free
bias$_t$ opt
(e)
reliability
free (yr 1-10)
opt (yr 1-10)
opt (yr 11-20)
sqrt(rmse^2/spread)
aice
aice1
aice2
aice3
aice4
aice5
hi
vice1
vice2
vice3
vice4
vice5
hs
Tsfc
SST
SSS

RMSE


salinity [psu]
depth [m]
50.0
200.0
600.0
1100.0
1750.0
4000.0
6500.0
1e−1
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0.0
temperature [deg]
depth [m]
50.0
200.0
600.0
1100.0
1750.0
4000.0
6500.0
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
time [yr]