Heat fluxes over sea ice

FROM A SEA ICE MODELING PERSPECTIVE

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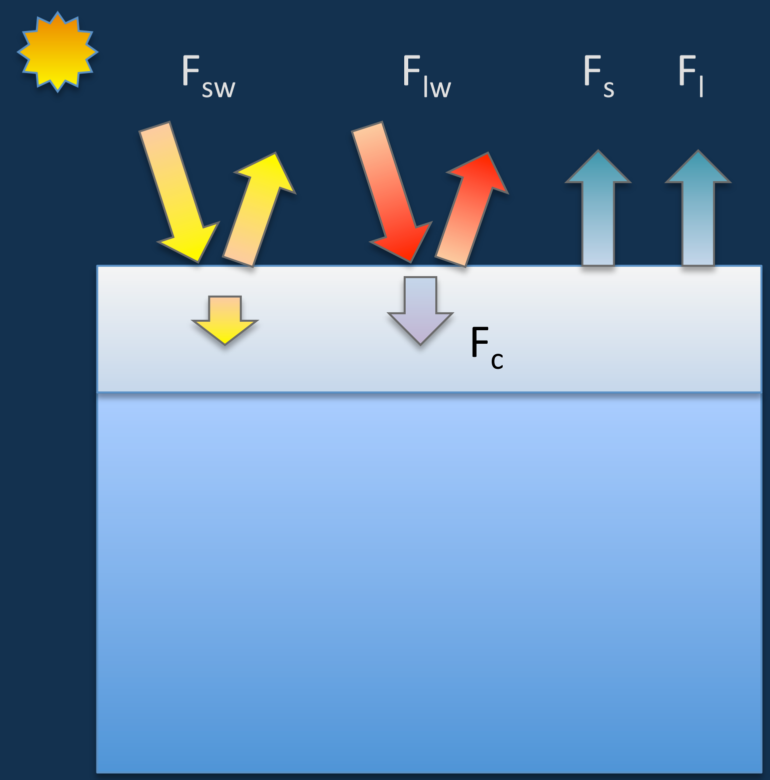
1. INTRO

Why energy fluxes over sea ice are important?

- Sea ice affects climate
  - Insulation effect
  - Ice-albedo feedback
  - Ocean circulation
- Sea ice is changing
- Energy fluxes over sea ice are central
  - Sea ice mass balance ($dh/dt = F/L \Rightarrow 1\ W/m^2 = 10\ cm/yr$)
  - Sea ice model development
  - Climate projections

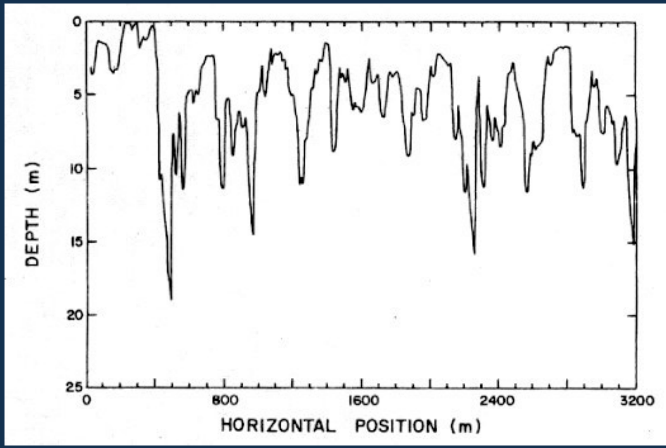
Heat budget over sea ice

- $F_{sw}+F_{lw}+F_s+F_l=F_c+F_m$
  - F_{sw}= net shortwave flux
  - F_{lw}= net longwave flux
  - F_s & F_l sensible and latent heat fluxes (turbulent)
  - F_c = conduction flux through the snow/ice
  - F_m=heat sink associated to ice melt

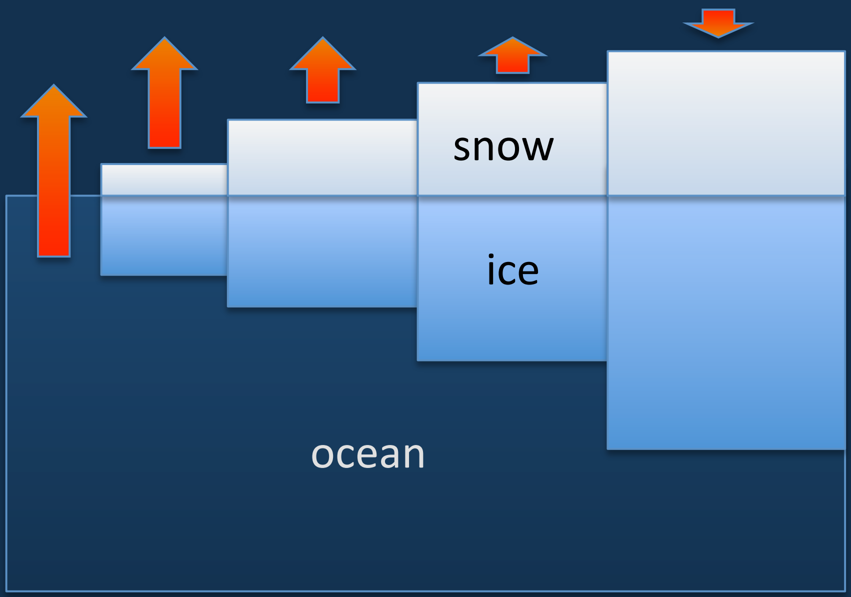


Regional heat flux over polar oceans

- Open water
- Ice thickness distribution
- Conduction heat flux, albedo, surface temperature depend on ice /snow thickness



A submarine sounding of sea ice draft in the Arctic (Thorndike et al., 1975)



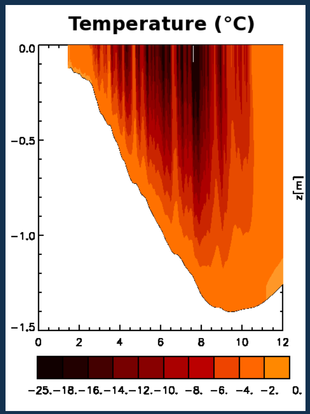
Sea ice mass balance and energy budget are strongly inter-dependent

2. SEA ICE AND MODELS

Sea ice models

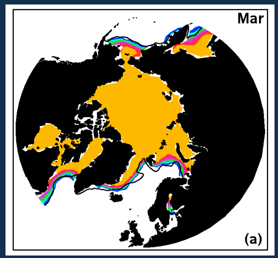
1D / process models
development – process studies

- Sea ice thermodynamics
- Fluxes from field obs.
- No feedbacks
- Highly sensitive
- Easy tuning to match observations



3D Hindcasts
validation

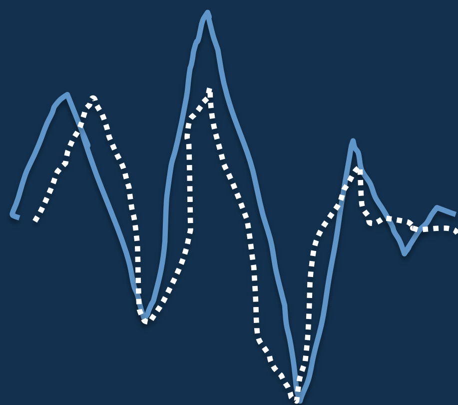
- Sea ice physics
(thermodynamics, dynamics and thickness redistribution)
- Ocean dynamics
- Atmospheric fluxes from reanalyses
- Ice-ocean feedbacks
- Less sensitive
- Tuning not too hard
- Reasonable agreement with observations



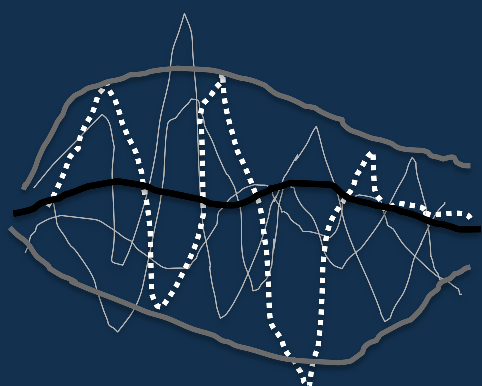
Climate simulations
projections

- Sea ice physics
- Ocean dynamics
- Atmospheric circulation
- Fluxes interactive
- Atmosphere-ice-ocean feedbacks
- Hard tuning
- Agreement with observations for some of them
- Climate variability (ensembles)

Some basics on sea ice simulation with models

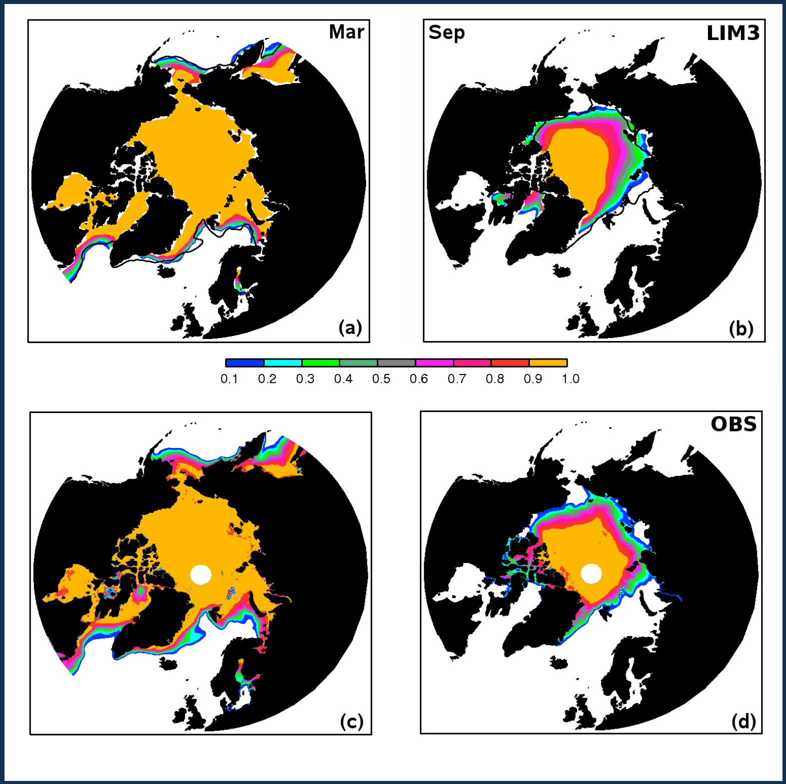


- Hindcasts
  - Are not (highly) sensitive to initial conditions
  - Do not have (high levels of) internal variability
  - Comparable to time series of observations
  - Miss atmospheric feedbacks
- Climate simulations
  - Sensitive to initial conditions
  - Have internal variability
  - Need to run ensembles
  - Not directly comparable to time series of obs (long-term means required)
  - Have all feedbacks (in principle)



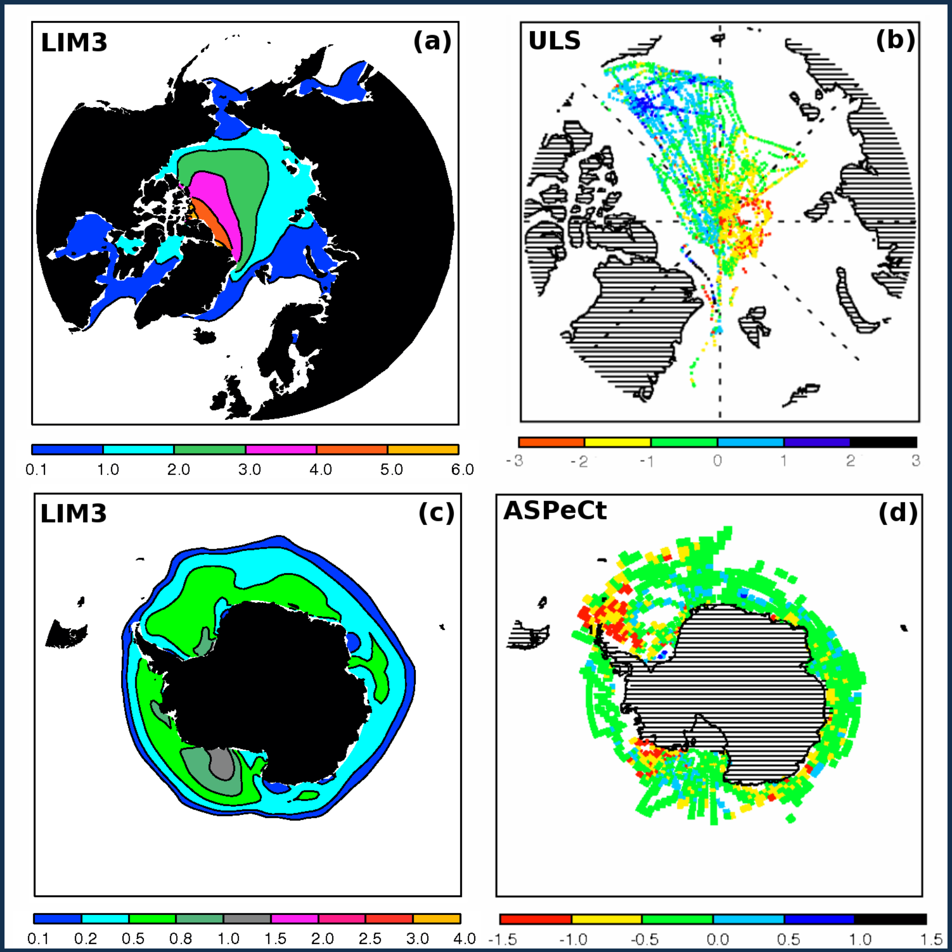
1979-2006 ice concentration in a hindcast with NEMO-LIM3

1950-2008 daily atmospheric forcing
+ large-scale ice-ocean model



Vancoppenolle et al., 2009

1976-2001 ice thickness
in a hindcast with NEMO-LIM3



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Sea ice mass balance in 3D hindcasts: Summary

Comparison to observations of a sea ice hindcast run with an ice-ocean model (NEMO-LIM) forced by daily atmospheric reanalyses and climatologies
(1979-2006)

Diagnostic	Arctic	Antarctic
Model - obs. relative bias on summer ice area (%)	- 21	- 71
Model - obs. relative bias on winter ice area (%)	- 0.9	14
Model - obs. relative bias on ice thickness (%)	-17	-44
Correlation between model and obs. ice area variability	0.74	0.65

Obs of ice area from satellites (Comiso et al., 2008)
Arctic thickness data from submarines (Rothrock et al., 2008)
Antarctic thickness from visual data (Worby et al., 2008)

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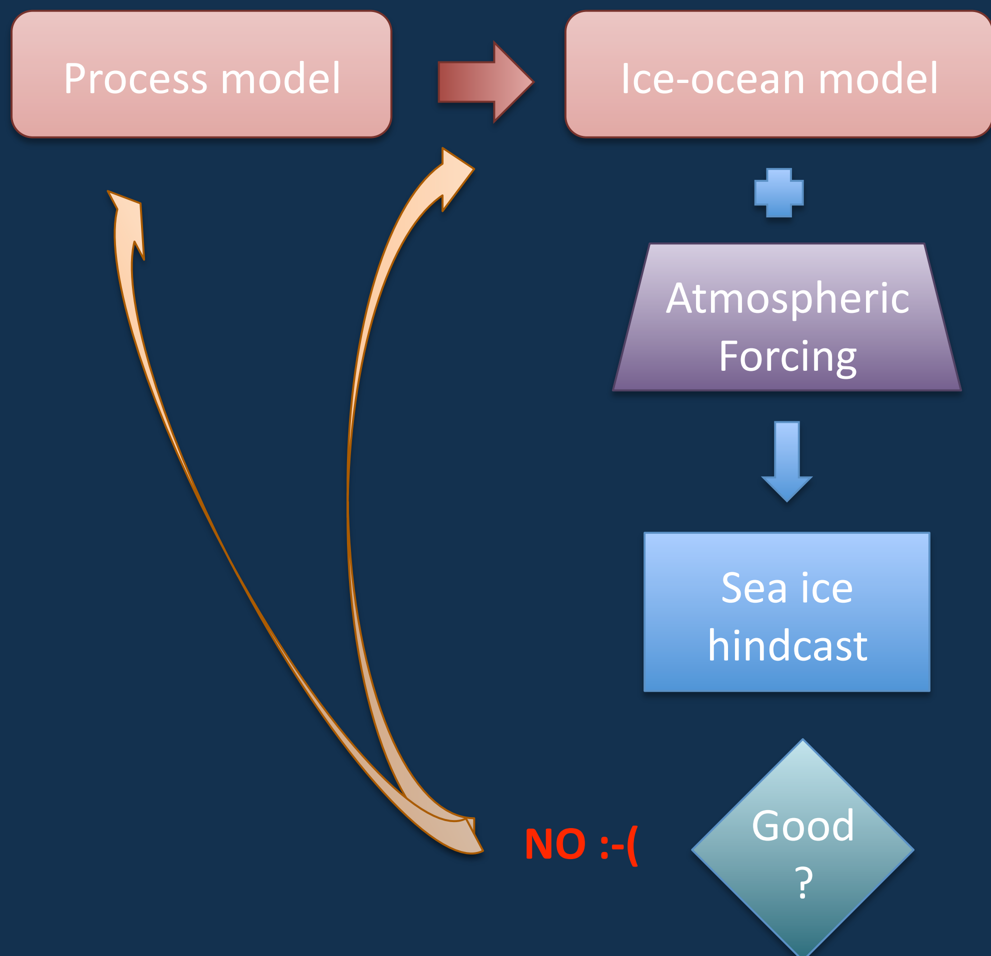
Improvement of models



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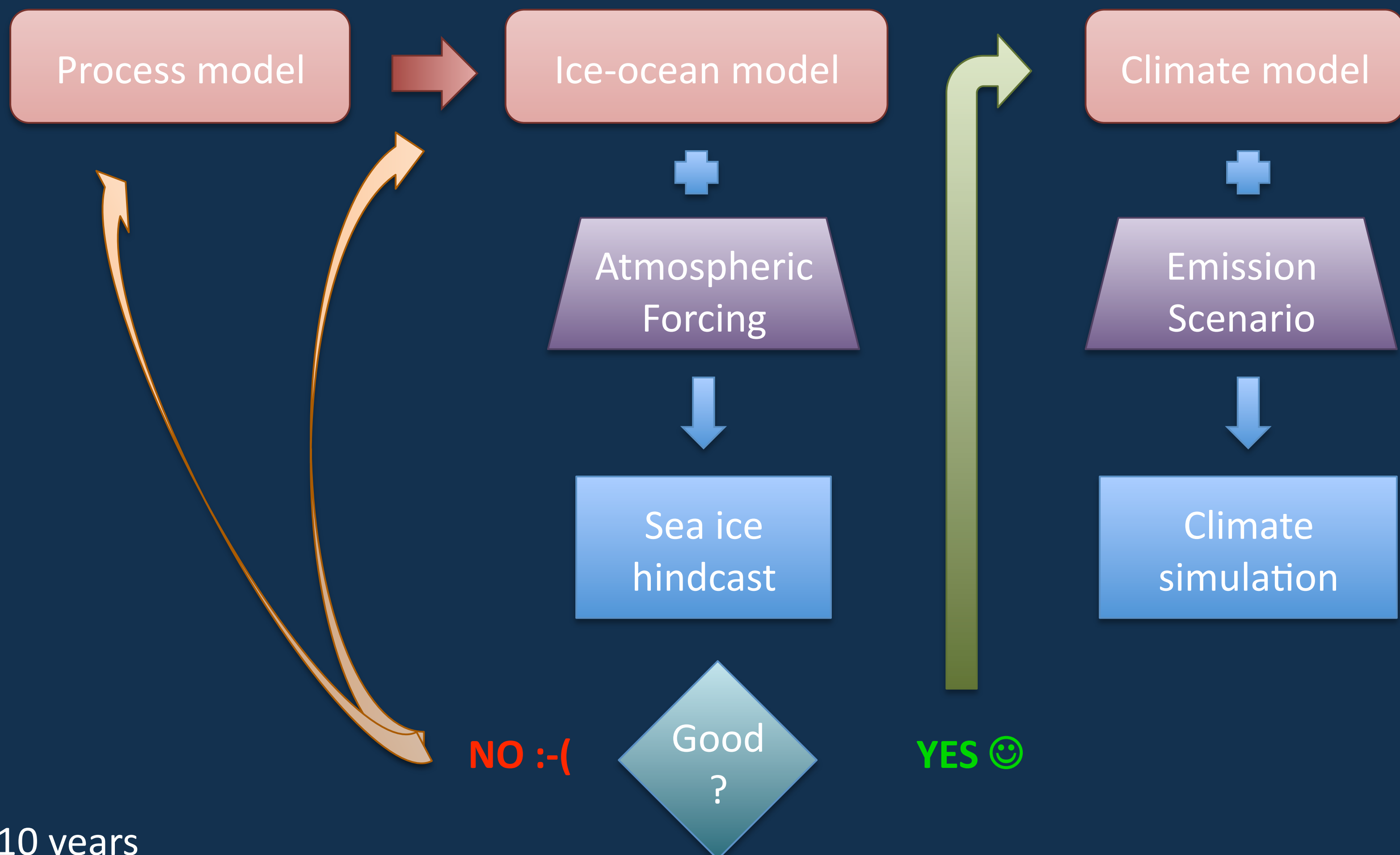

T = 5-10 years

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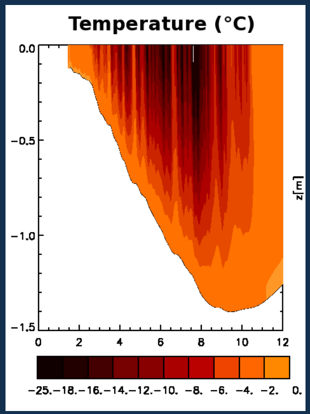

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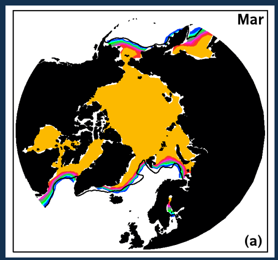

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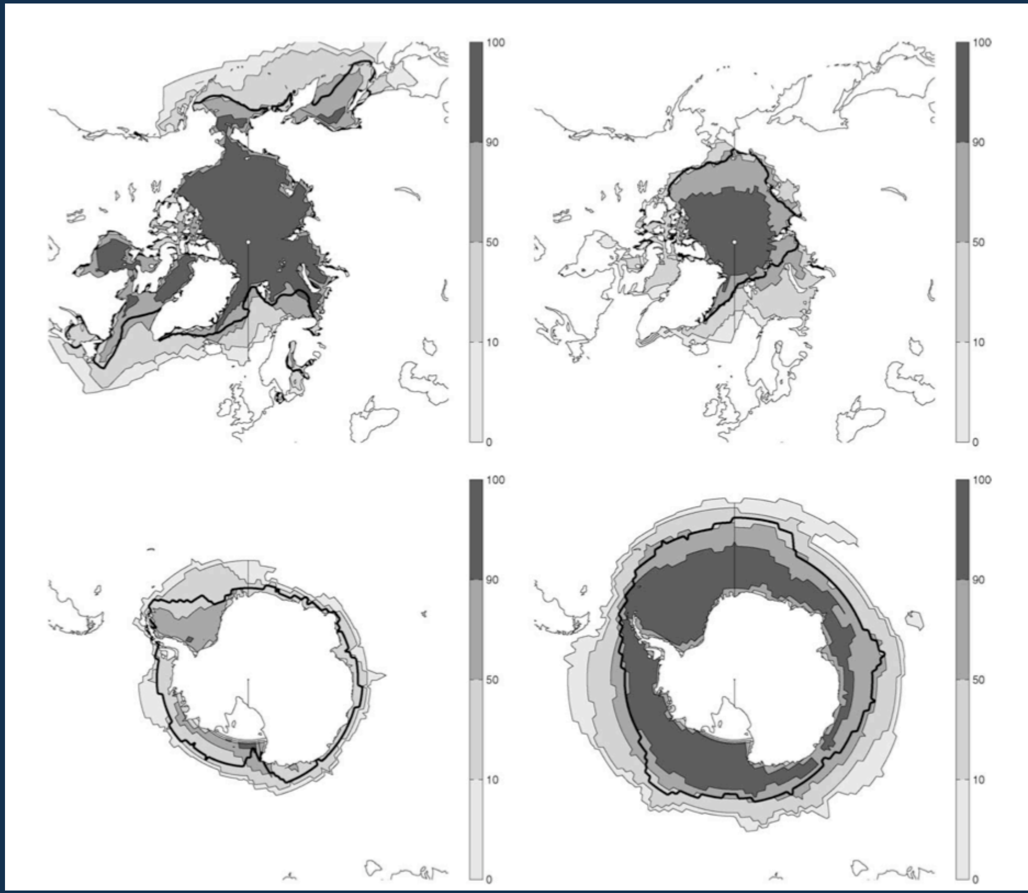
Sea ice mass balance in climate simulations

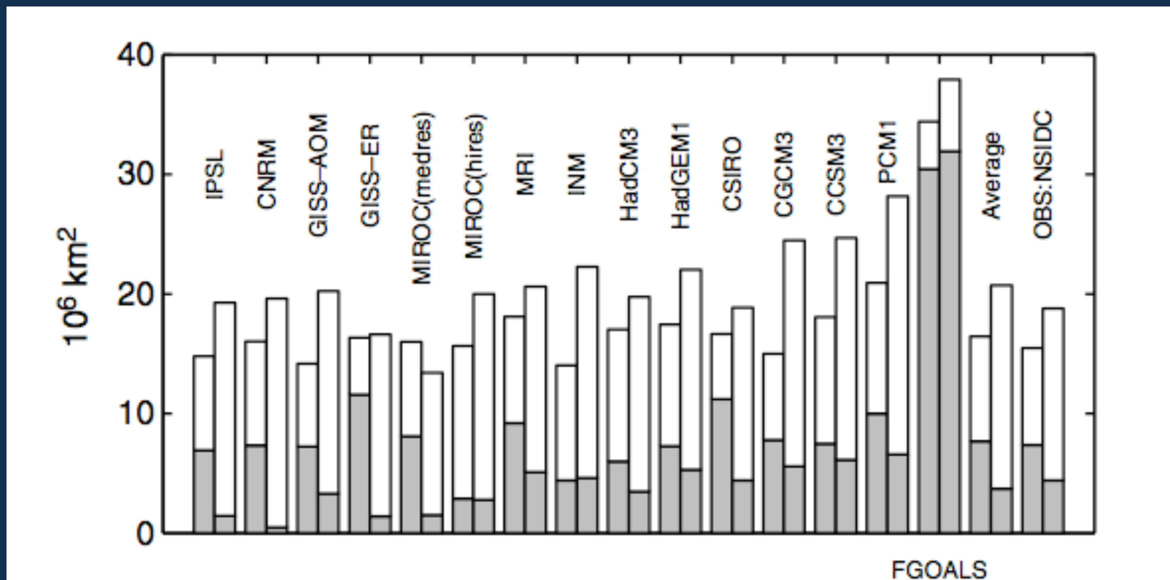
March September



% of IPCC models that have sea ice in a given grid cell

Arzel et al., 2006

Sea ice mass balance in climate simulations

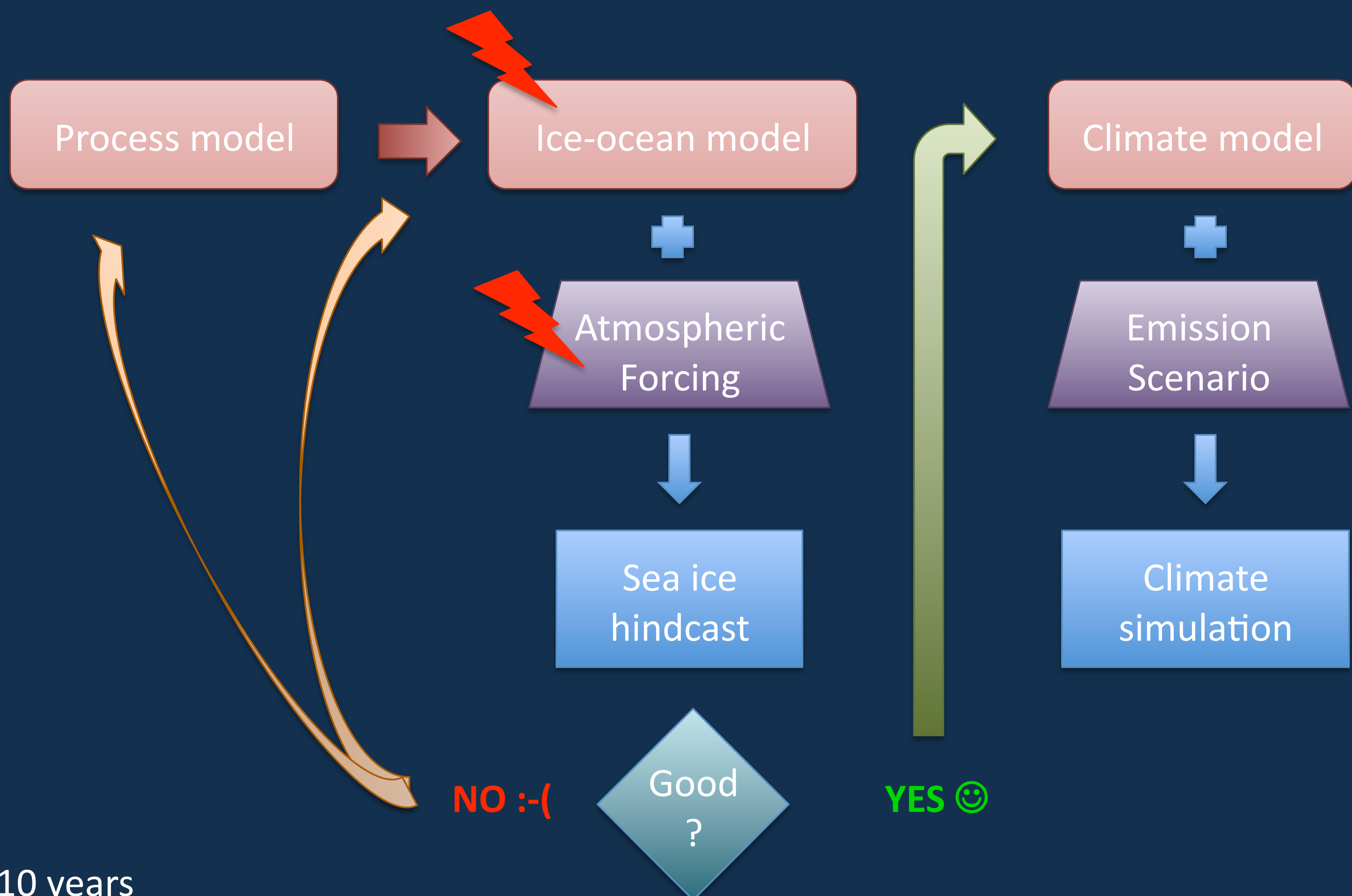


Ice extent statistics of IPCC runs
Left bar = Arctic / Right bar = Antarctic
Grey = minimum extent / White = maximum extent

Mean model ok
Large scatter
Particularly over SH
Models with more physics are not necessary better

Arzel et al., 2006

Errors we have control on



T = 5-10 years

Errors in sea ice simulations

- Errors come from the model or forcing
- Errors from the forcing in hindcasts can bias models and favor larger error in climate simulations
- Particularly large errors in the Southern Hemisphere

3. FLUX STRATEGIES IN SEA ICE HINDCASTS AND ASSOCIATED ERRORS

5 min left ?

Fluxes strategies in sea ice models

SW fluxes

- Atmospheric reanalyses
- Equation of *Zillman* (1972)
  - Fsw = Fsw (solar angle, humidity, cloud fraction)
- Equation of *Shine* (1984)
  - Fsw = Fsw (solar angle, humidity, cloud fraction, cloud optical depth)
- …

LW fluxes

- Atmospheric reanalyses
- Equations of *Berliand and Berliand* (1952) and *Efimova* (1961)
- Flw = Flw (temperature, humidity, cloud fraction)
- …

Turbulent fluxes

- Bulk aerodynamic formulae

Arctic Antarctic

Russian polar drift stations
(*Lindsay*, 1998)

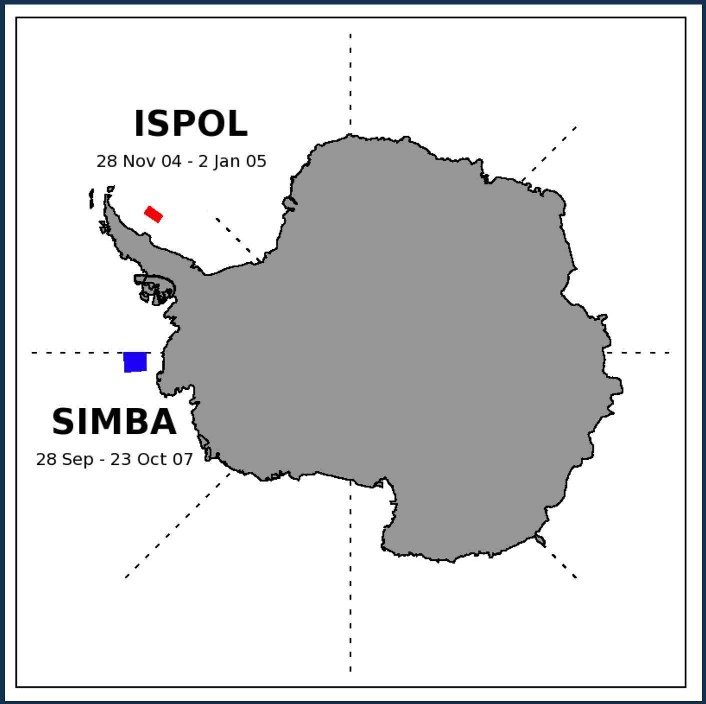
- 6228 / 4403 days of data
- SW – *Shine* (1984) best if cloud optical depth is tuned month by month
  Bias: - 0.4 W/m^2 7.2 W/m^2
  RMS: 31.7 W/m^2 25.5 W/m^2
- LW – *Efimova* (1961) best
  Bias: -1.5 W/m^2 7.3 W/m^2
  RMS: 11.9 W/m^2 10.9 W/m^2

Barrow radiation observatory
(*Walsh et al.*, 2009)

- 4 seasons of data
- Huge scatter in cloud fraction among the different reanalysis products NCEP/NCAR
- Large biases in radiation fluxes, esp. in NCEP/NCAR
  - SW: + 43 W/m^2 + 76.9 W/m^2
  - LW: - 21 W/m^2 - 32.5 W/m^2

Errors in fluxes – Antarctic (1)

Radiation data from 2 drift stations (1 month) in the Antarctic:
ISPOL (*Hellmer et al.*, 2008) and SIMBA (*Ackley et al.*, 2007)



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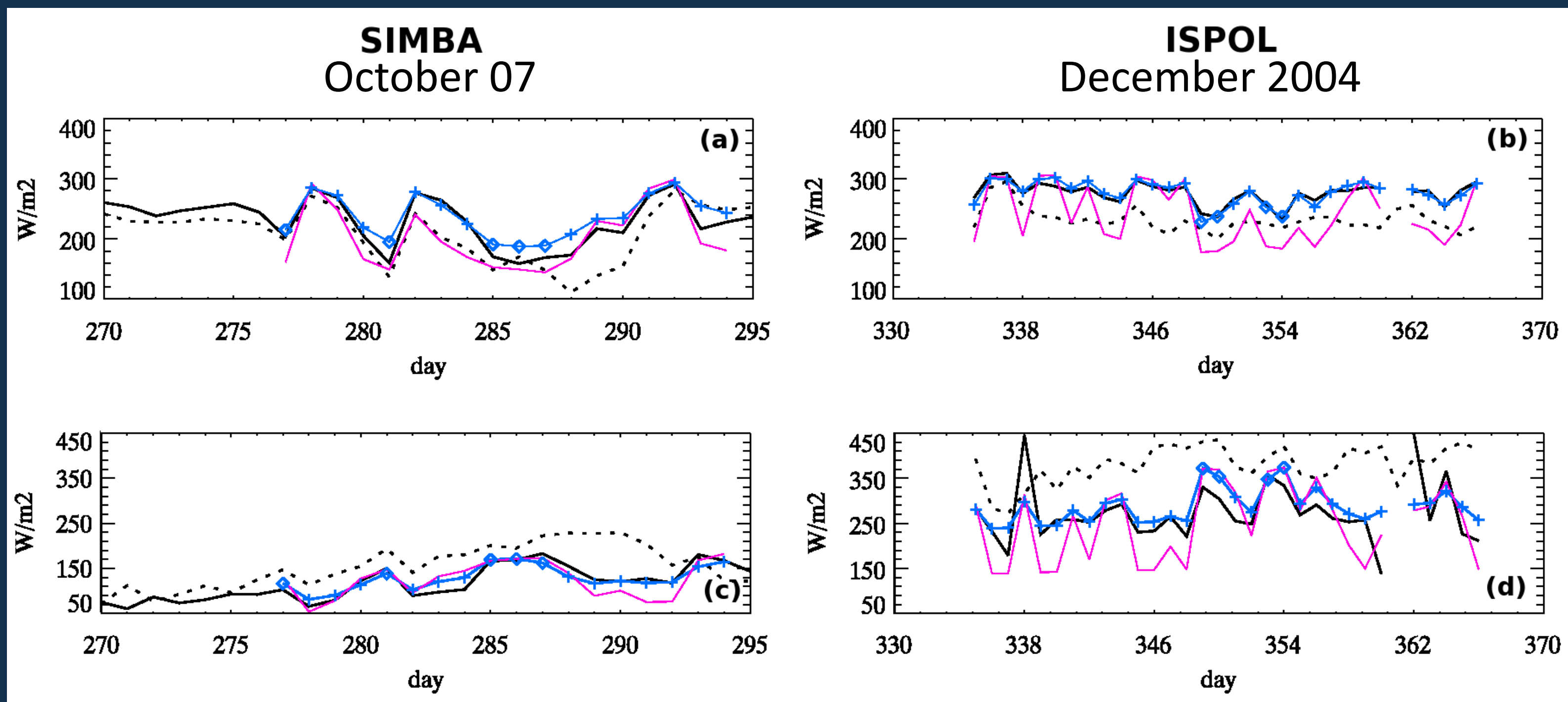
Errors in fluxes – Antarctic (2)

Time series of daily radiation fluxes

LW

SW



Obs

NCEP/NCAR reanalysis

SW: *Shine* (1984) / **LW**: *Efimova* (1961)

SW: *Zillman* (1972) / **LW**: *Berliand and Berliand* (1952)

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Errors in fluxes – Antarctic (3)

ID	Comput. meth.	q	c	τ	Bias	RMSE	c.c.
			SIMBA				
1	NCEP	n.a.	n.a.	n.a.	42.8	50.1	0.63
2	*Shine* (1984)	TOWER	VISUAL	16.297	0.0005	12.4	0.92
3	*Shine* (1984)	TOWER	VISUAL	CLIM (5.6)	16.6	19.9	0.92
4	*Shine* (1984)	NCEP	NCEP	CLIM (5.6)	33.3	35.5	0.61
5	*Shine* (1984)	CLIM (1.8)	CLIM (0.66)	CLIM (5.6)	28.32	34.5	0.55
6	*Zillman* (1972)	TOWER	VISUAL	n.a.	-3.92	18.5	0.79
7	*Zillman* (1972)	NCEP	NCEP	n.a.	18.1	33.7	0.57
8	*Zillman* (1972)	CLIM (1.8)	CLIM (0.66)	n.a.	21.8	30.7	0.58

- Formula fed by reanalysis data are in principle better than direct reanalysis
- However, error in the reanalysis values of cloud and humidity imply errors in computed value
- Smallest bias obtained when combining formula, reanalyses and climatologies

Vancoppenolle et al., 2010

Summary & conclusions

- Energy fluxes are key for understanding the sea ice mass balance
- Model tuning for validation in hindcast simulations is dependent on energy fluxes
- Errors in model calibration can be amplified in climate simulations
- Further developments in model physics depend on the quality of the fluxes

Summary & conclusions (2)

- Radiation fluxes from reanalyses should not be used
- Radiation fluxes formulations are quite good in principle
- However, errors in cloud fraction, optical depth and humidity from data induce biases in prescribed fluxes
- More data ???

Thxs & Refs

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Deep Sea Research (II), **2010***, in revision.*