Predictability and prediction of Atlantic circulation and climate

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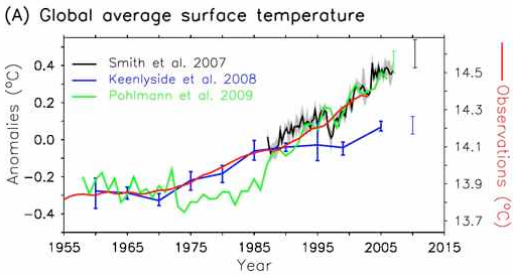
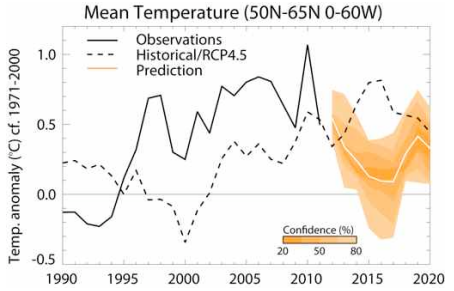
Overview

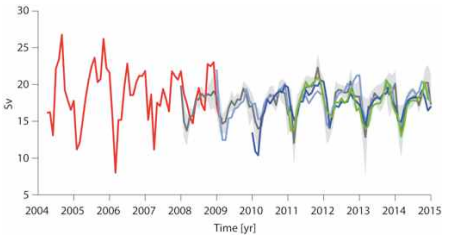
1. Background



2. Predictions of surface temperature in the Atlantic region
   - Dependence on ocean state estimate
   - The coming decade – CMIP5 results



3. Predictions of the Atlantic Meridional Overturning Circulation (AMOC)



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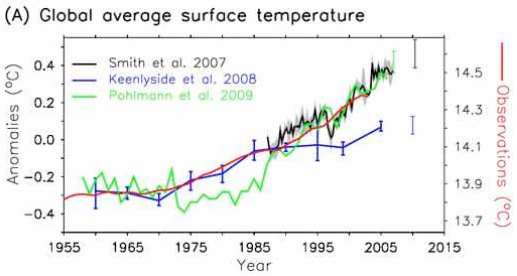

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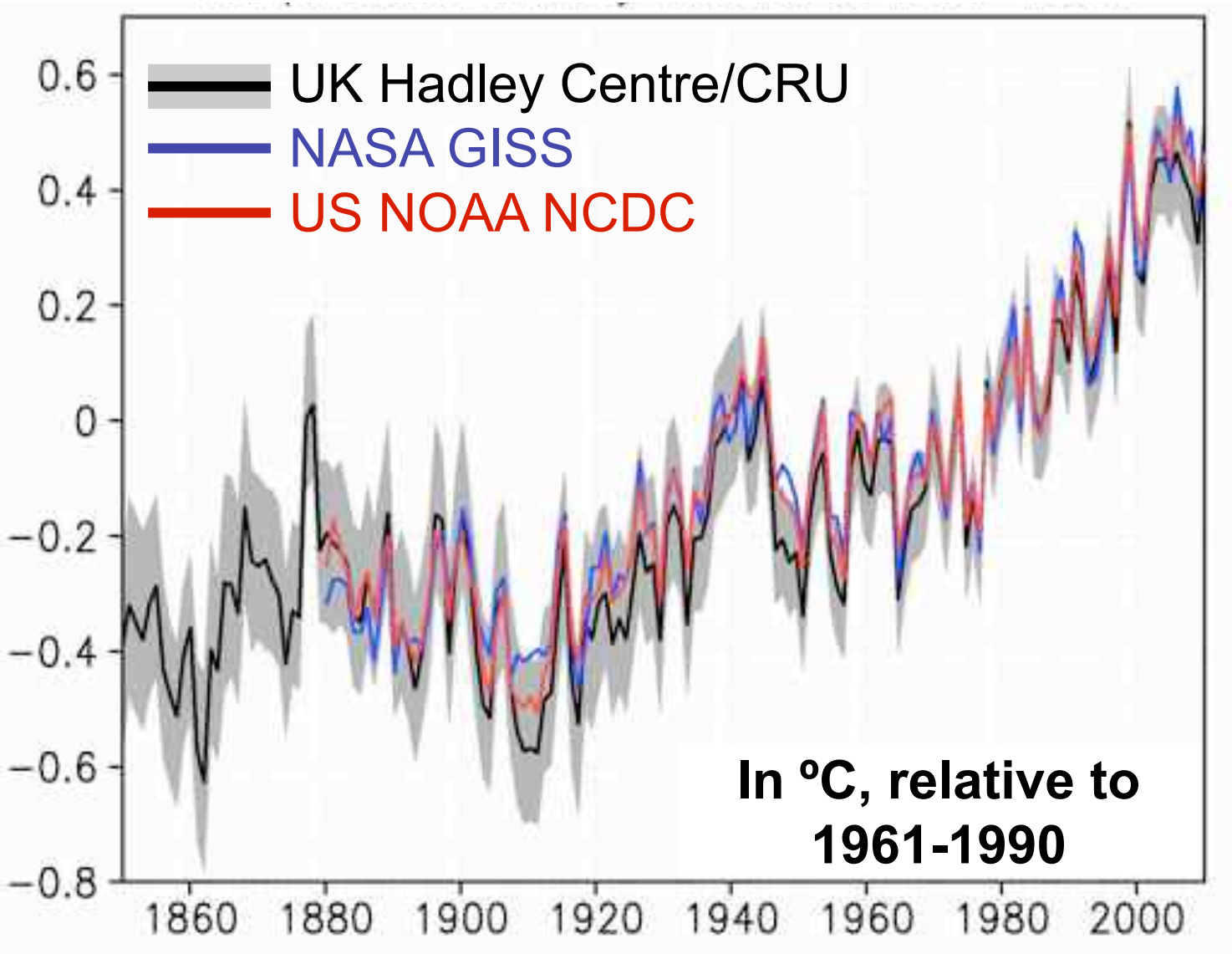
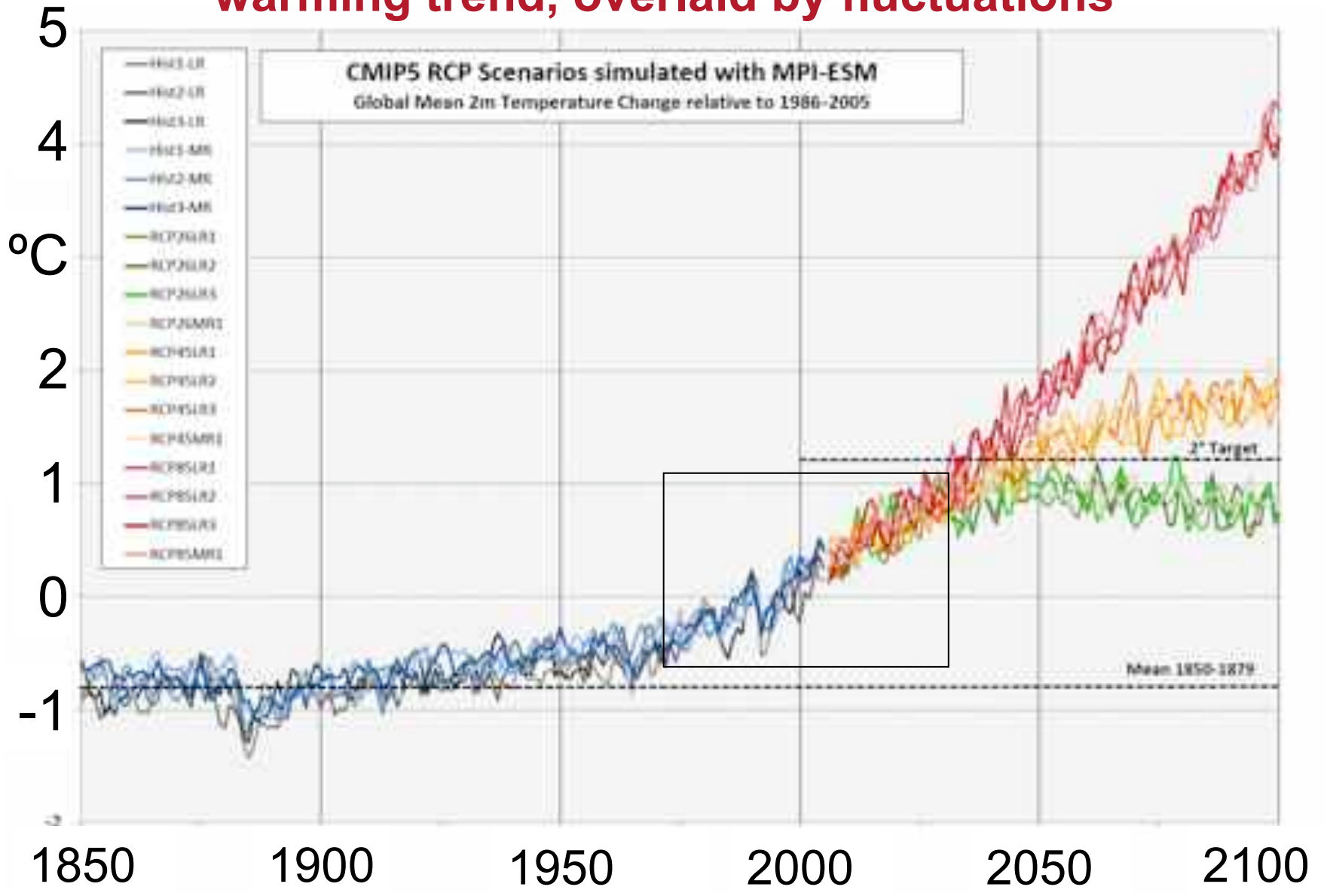
Observed global-mean surface temperature shows long-term warming trend, overlaid by fluctuations

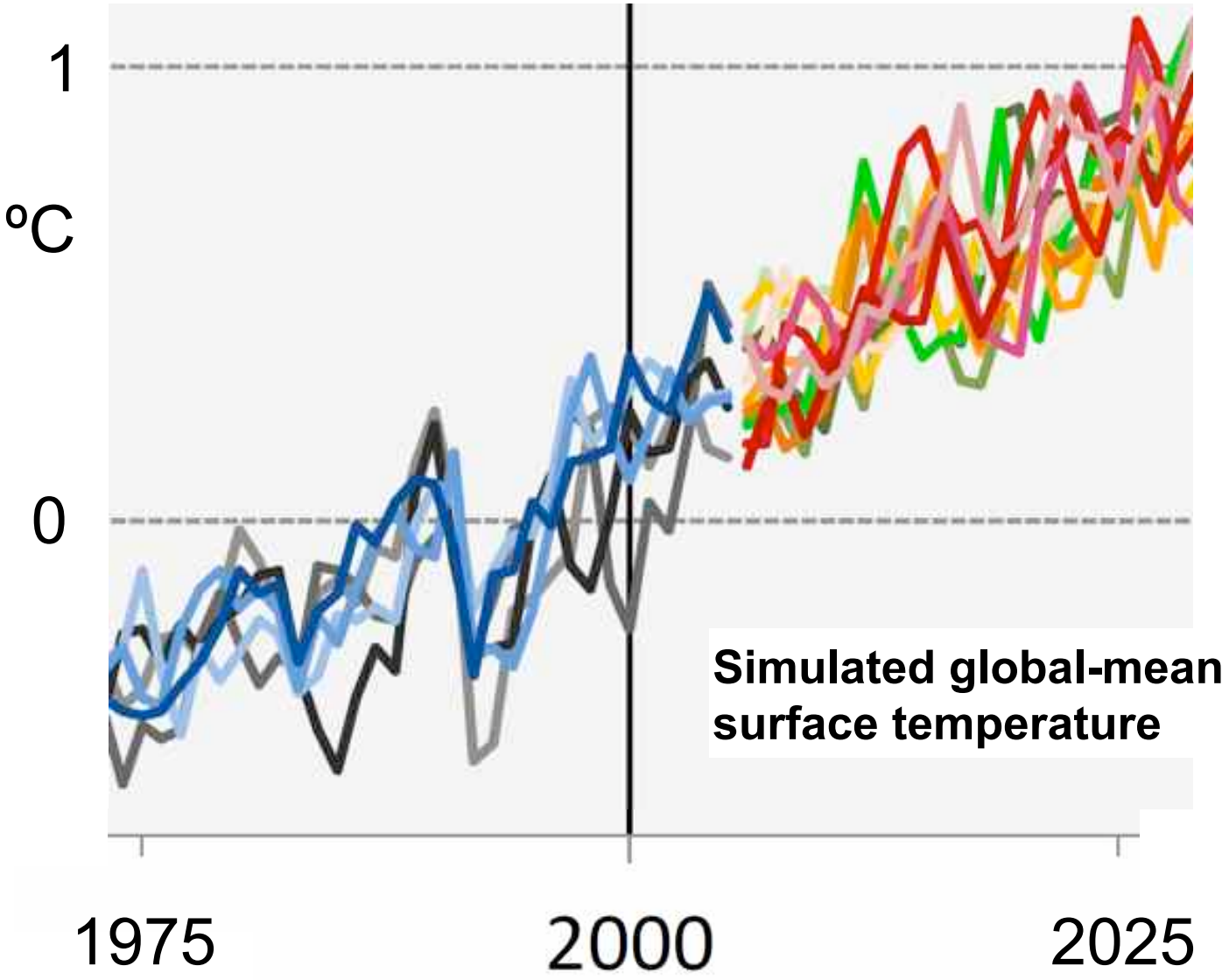


WMO et al. (2010)

Simulated global-mean surface temperature shows long-term warming trend, overlaid by fluctuations



The shorter the period, the more important the fluctuations

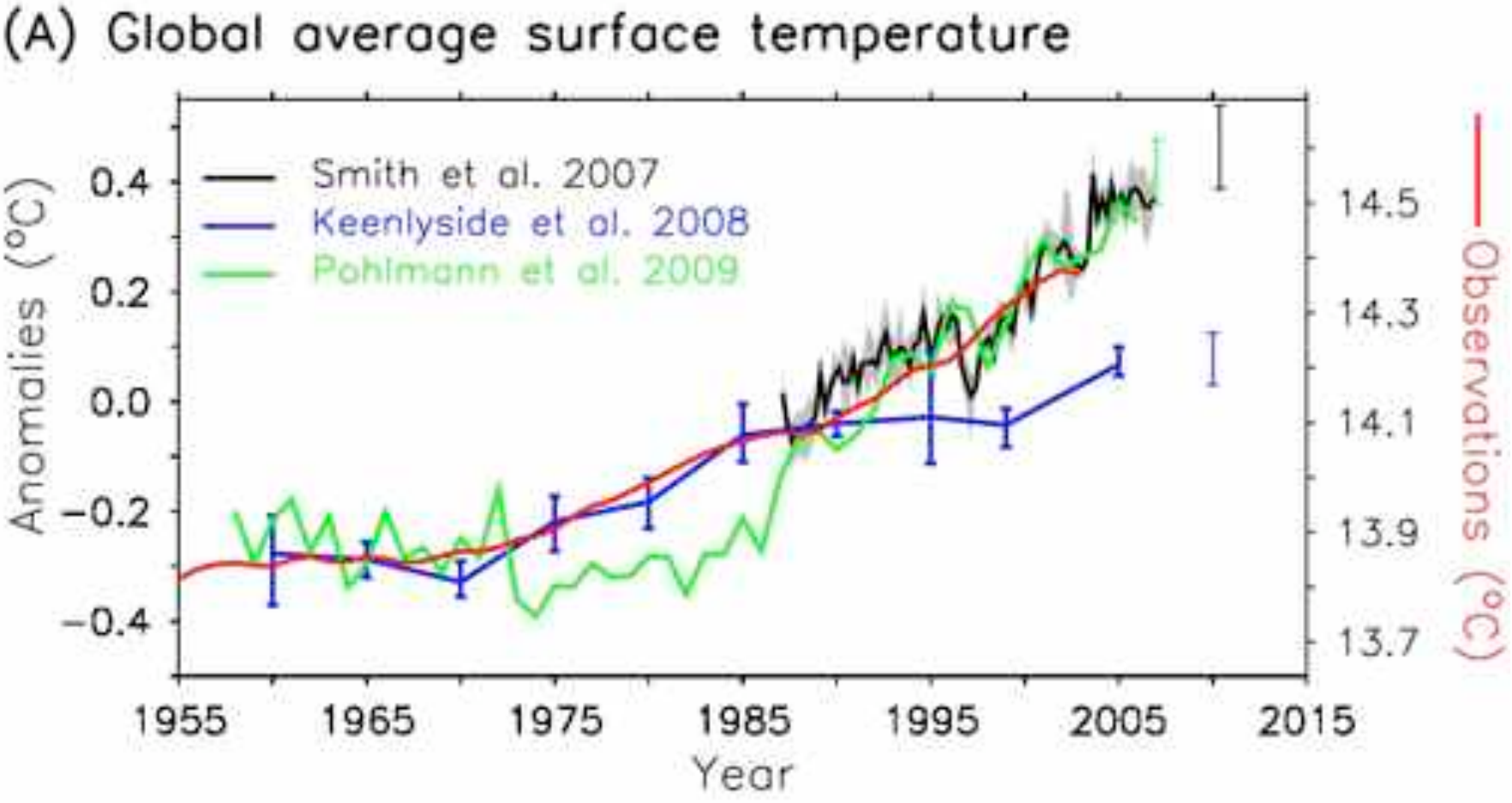


Climate predictions are fundamentally different from climate projections

- **Climate projection:**
  - *One* **potential** future evolution of climate
  - Contingent on emissions or concentration scenarios
  - Initial state and climate variability not considered essential

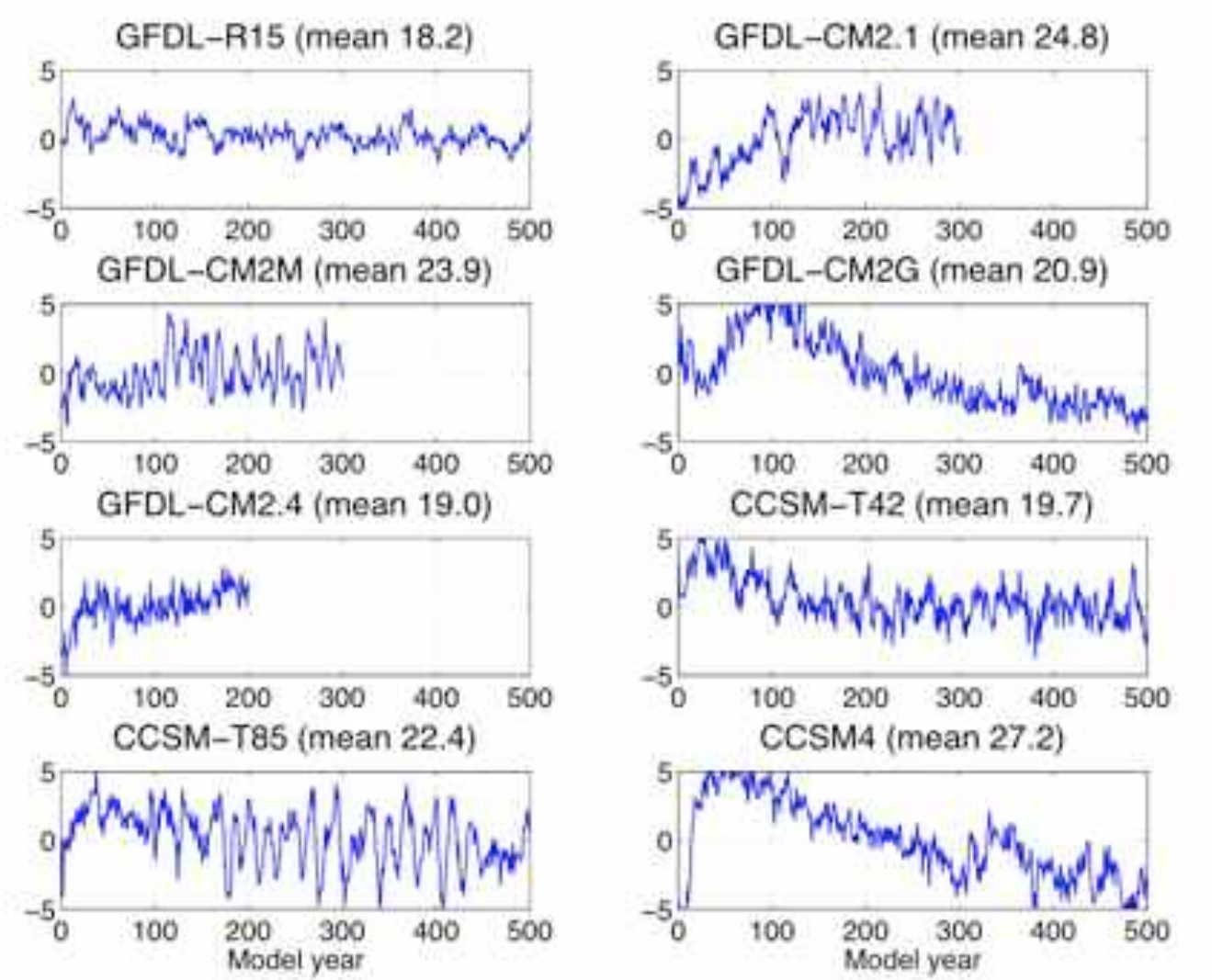
- **Climate prediction:**
  - An estimate of the **actual** future evolution of climate
  - Predicts anthropogenic change **and natural fluctuations**
  - Initial state based on observations of slow climate components (ocean, others) – **Initialisation**
  - Retrospective predictions (hindcasts) allow us to assess prediction skill

Disagreement among prediction results are substantially influenced by initialisation procedures



- SAT predictions from the first three decadal prediction papers
- Keenlyside and Pohlmann used (almost) the same model

Decadal climate variability not at all robust across models



MOC variability in different versions of GFDL and NCAR climate models

We here address two open questions:

1. Effect of two different ocean initialisation strategies on the forecast skill of a decadal climate prediction system (Matei et al., submitted)

2. Robustness of our results as we move from previous model generation (used in Matei et al., submitted) to the model used in CMIP5
   - Work in progress (Müller et al., in preparation)

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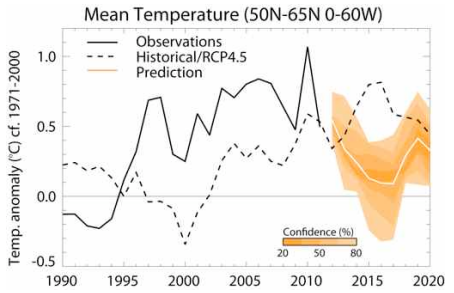


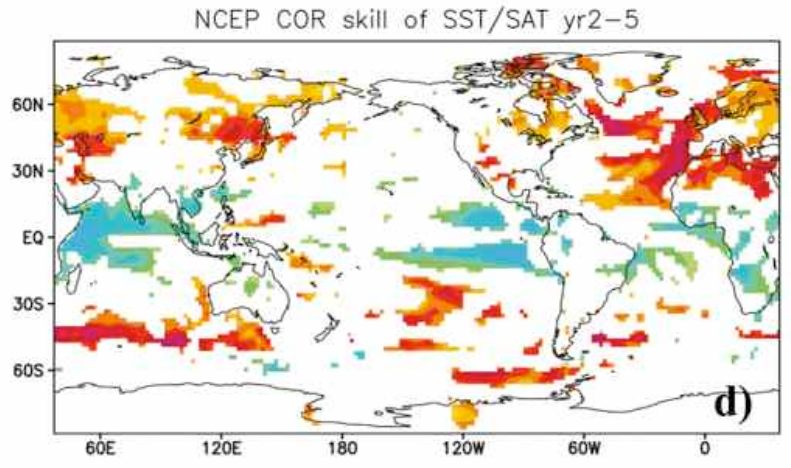
3. Predictions of the Atlantic Meridional Overturning Circulation (AMOC)

We use two different ocean state estimates from which to start (initialise) our coupled climate model ECHAM5/MPIOM

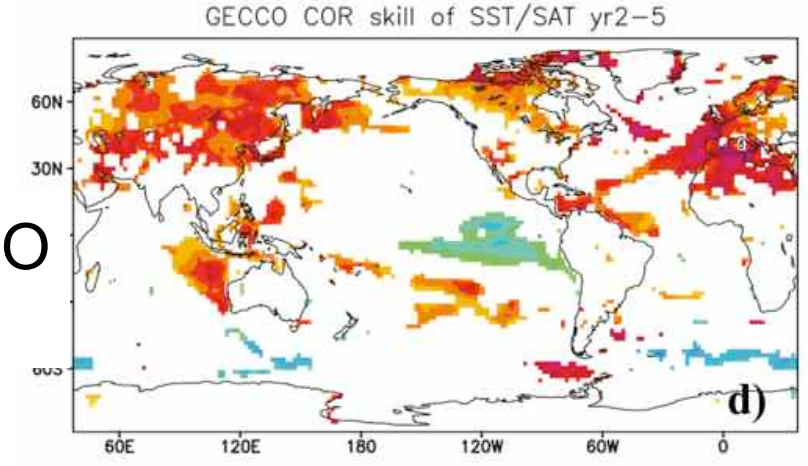
- State estimate 1:
  - Run the uncoupled ocean component of our climate model over the period 1948-2007, driven at the surface by observed atmosphere from NCEP-NCAR reanalysis
- State estimate 2 (used in Pohlmann et al., 2009):
  - Use ocean reanalysis from GECCO (Köhl & Stammer, 2008a,b), in which ocean model is fitted to all available data ("4D-Var")
- In either case, then:
  - Identify the temporal anomalies of temperature and salinity in the state estimate, for each time and over full depth of the ocean
  - Insert anomalies into the coupled model in an "assimilation run"
  - Start coupled model on every 1 January, 1949-2007, of the assimilation run; run coupled model for 10 years ("hindcast")
  - Assess quality of the hindcasts against observations

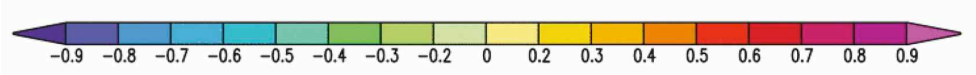
Largely onsistent hindcast quality for the two initialisations

NCEP init.



GECCO init.



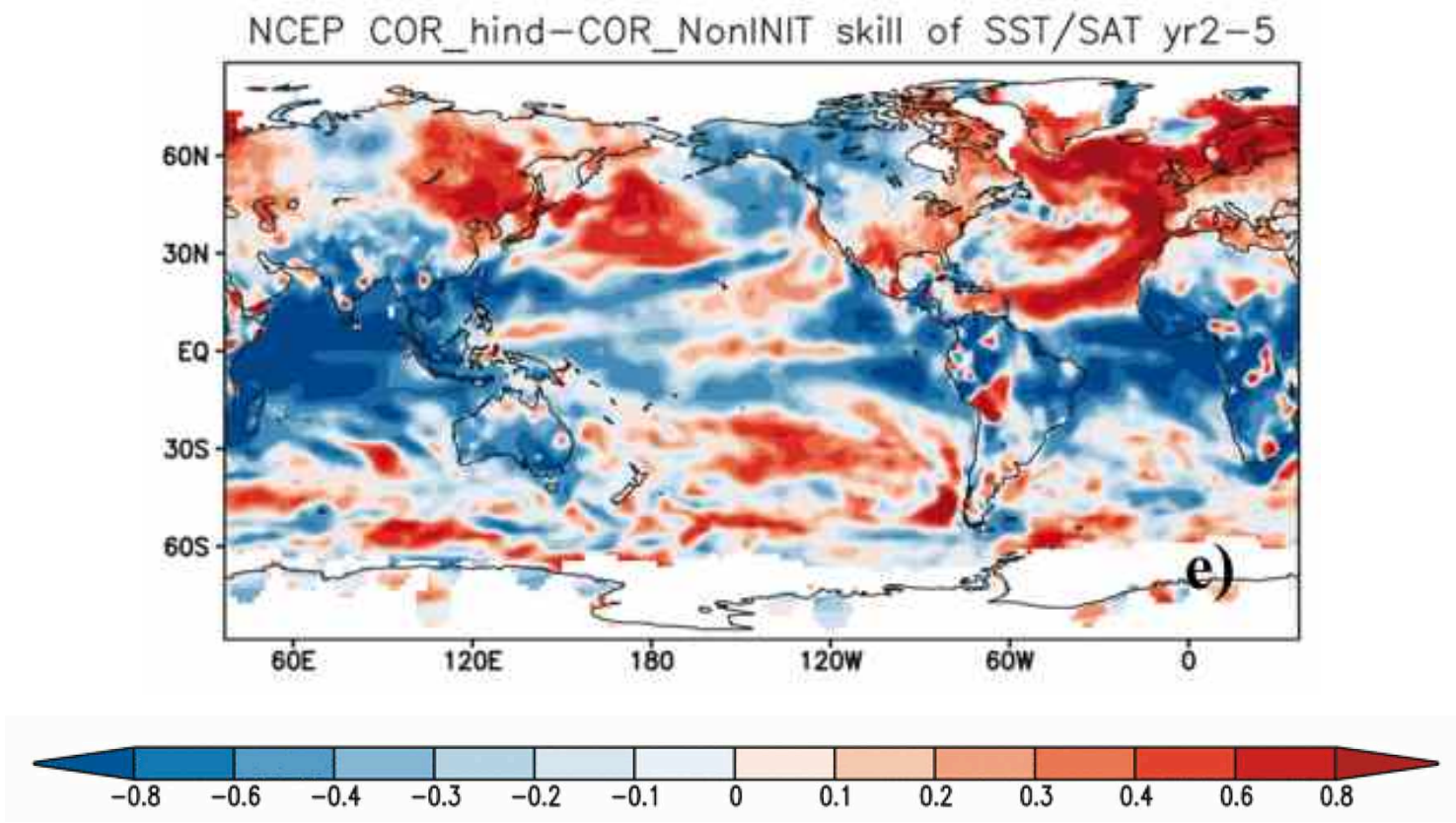


Surface temperature, averaged over hindcast years 2-5

COR skill: Pointwise correlation with observations

Skill is high if the sign of an anomaly is correctly predicted at the correct time

Benefit of initialisation as compared to uninitialised simulation: deterioration of hindcast skill in the tropics; robust improvement especially in North Atlantic sector

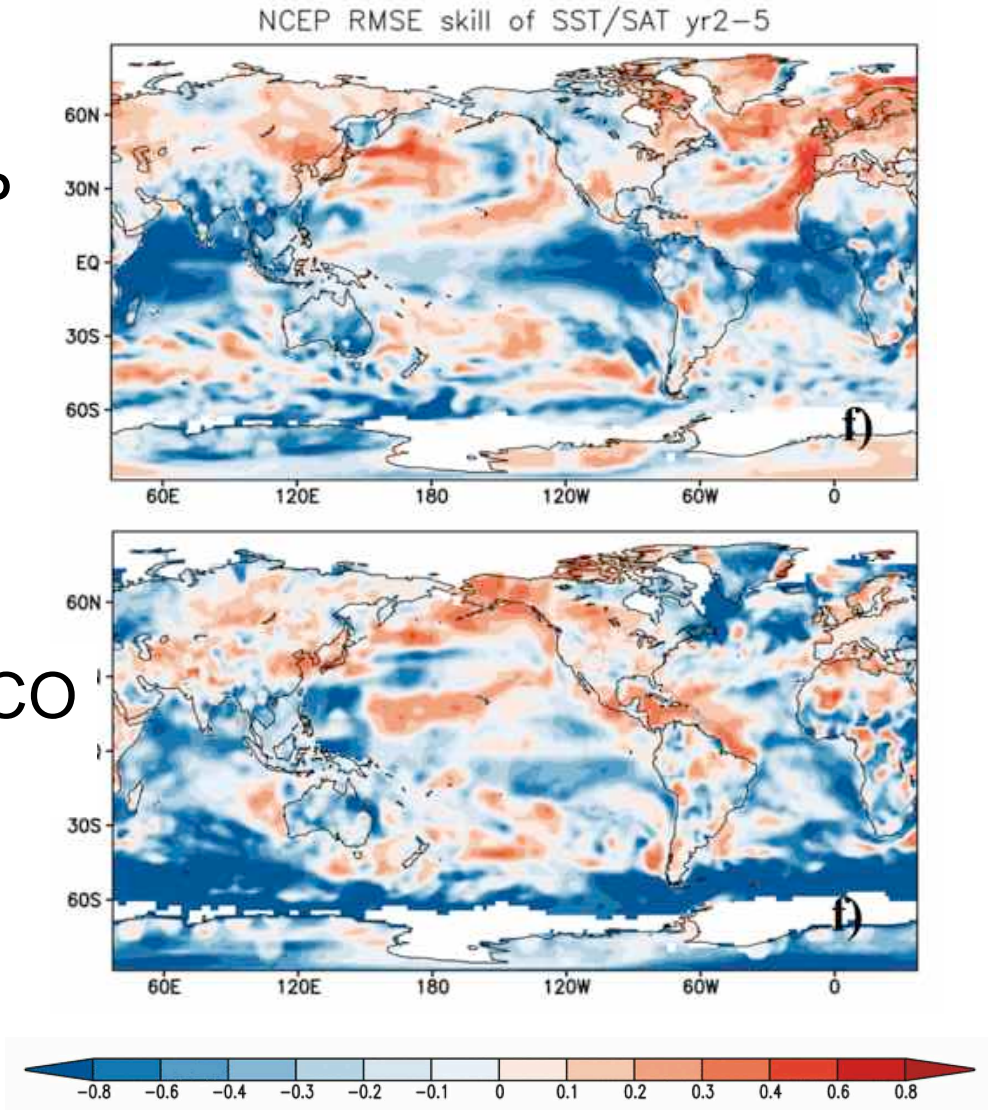


Surface temperature, hindcast years 2-5, NCEP initialisation
Hindcast skill: COR skill, hindcast minus uninitialised model

Alternative skill measure: NCEP initialisation better than GECCO initialisation over North Atlantic

NCEP init.

GECCO init.



Surface temperature, averaged over hindcast years 2-5

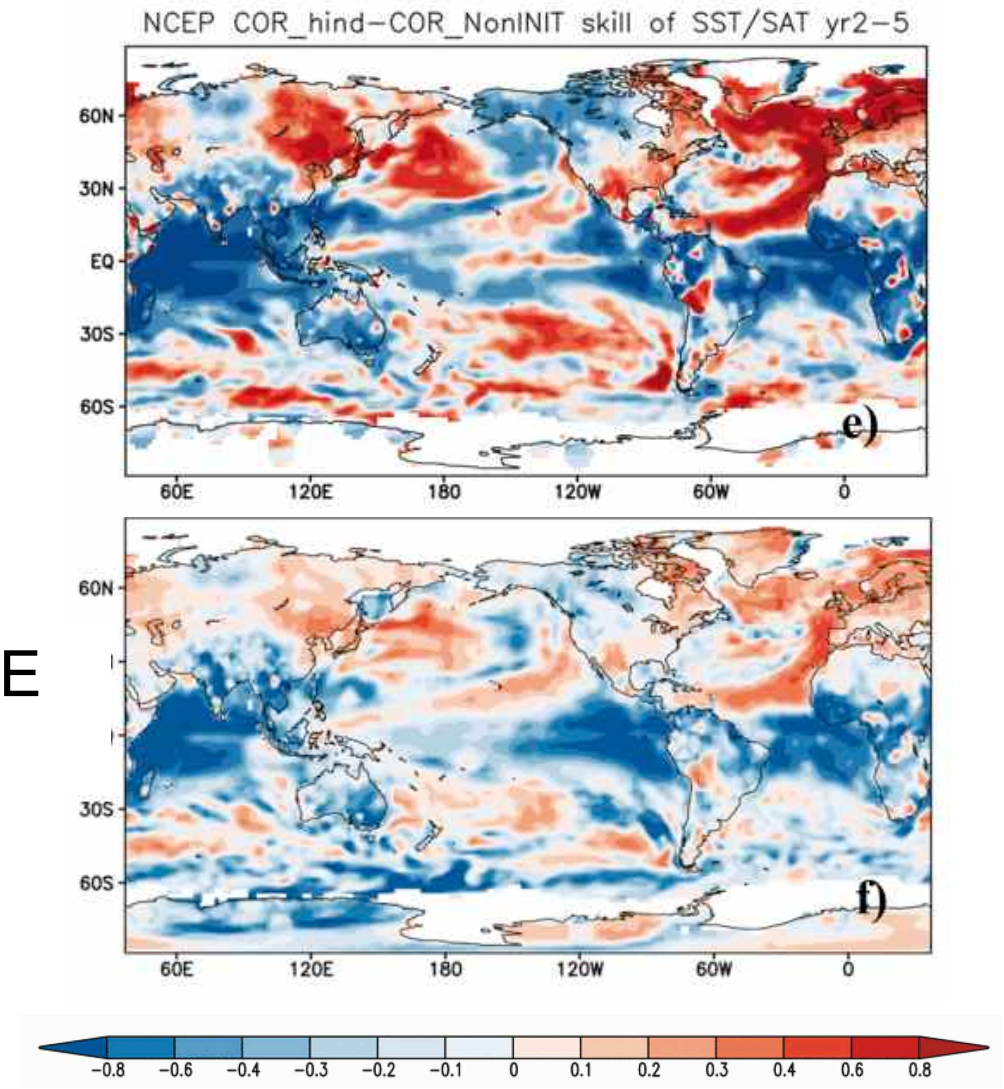
Normalised reduction in mean error magnitude (RMSE), compared to uninitialised model

GECCO reanalysis overestimates 1975-2005 North Atlantic temperature trend

NCEP initialisation: compared to uninitialised run, gain or loss in skill is consistent for both skill measures

COR skill

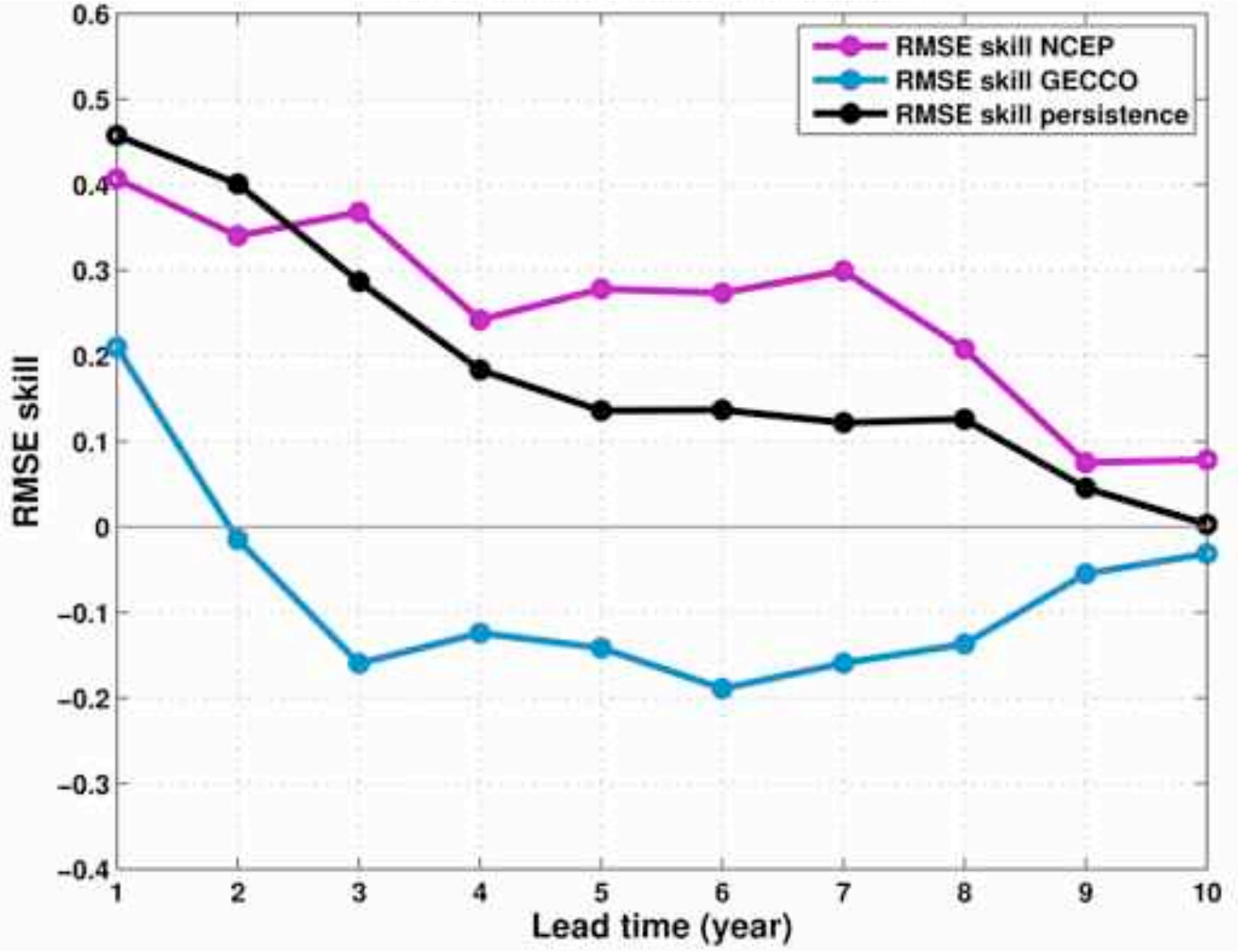
RMSE skill



Surface temperature, averaged over hindcast years 2-5

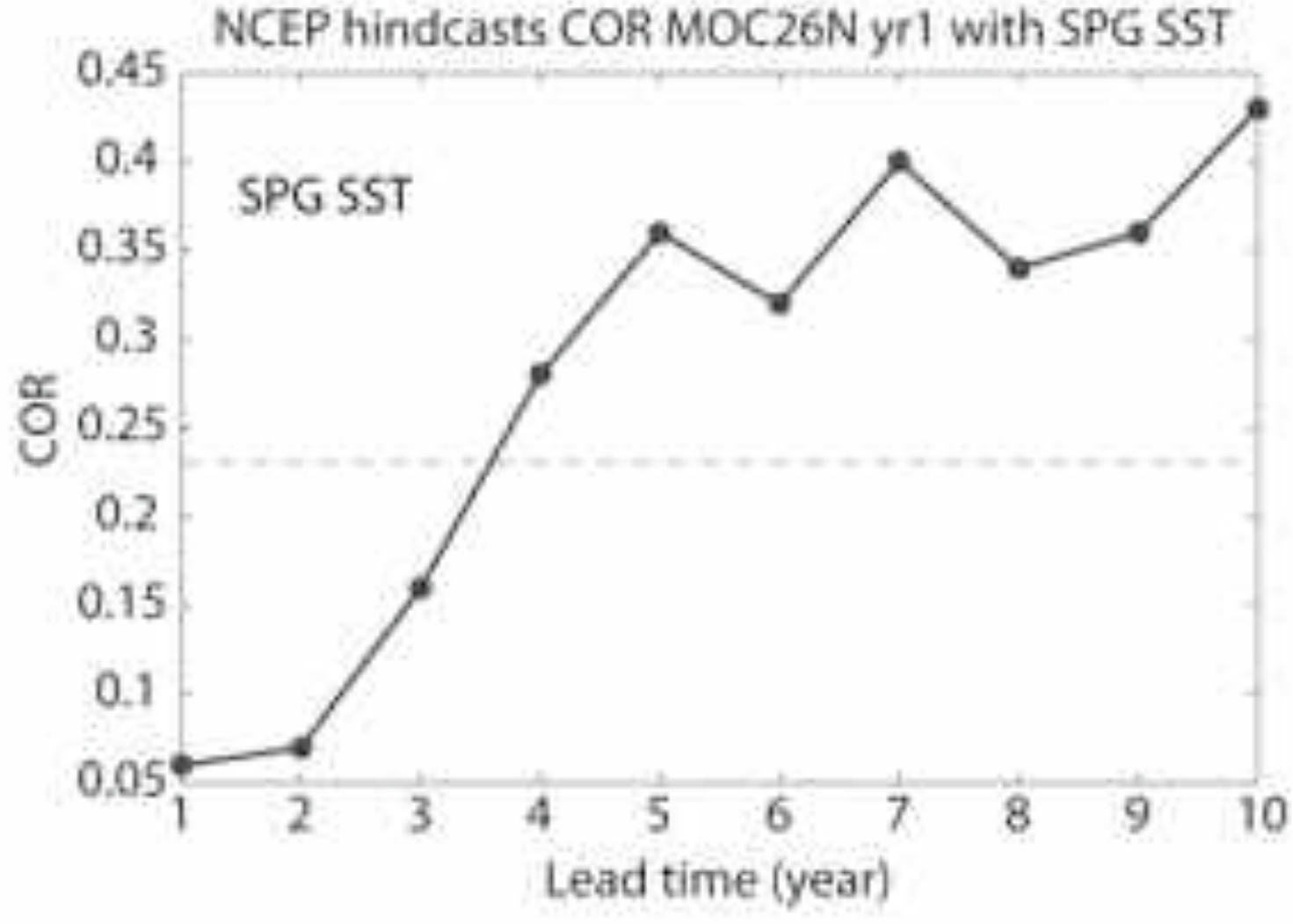
Robust skill improvement over North Atlantic and Europe

North Atlantic SST: NCEP initialisation better than persistence after year 3; RMSE skill increases for years 5-7



Matei et al. (submitted, 2012)

Possible cause for long-term skill: correlation between AMOC and subpolar-gyre surface temperature?



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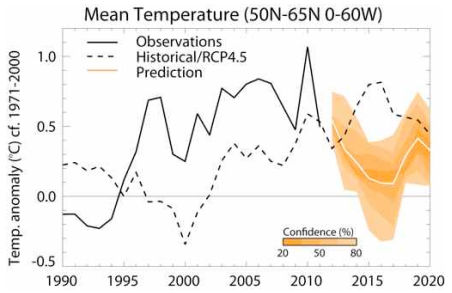
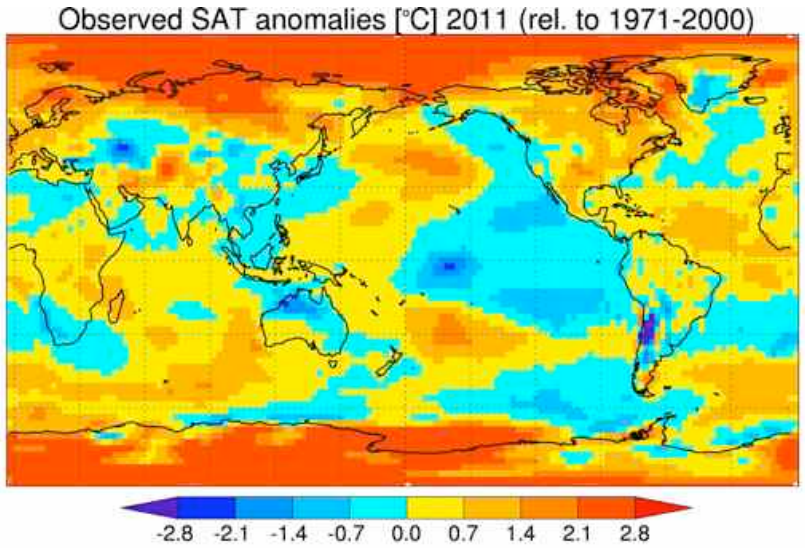
   - New model version, NCEP initialisation

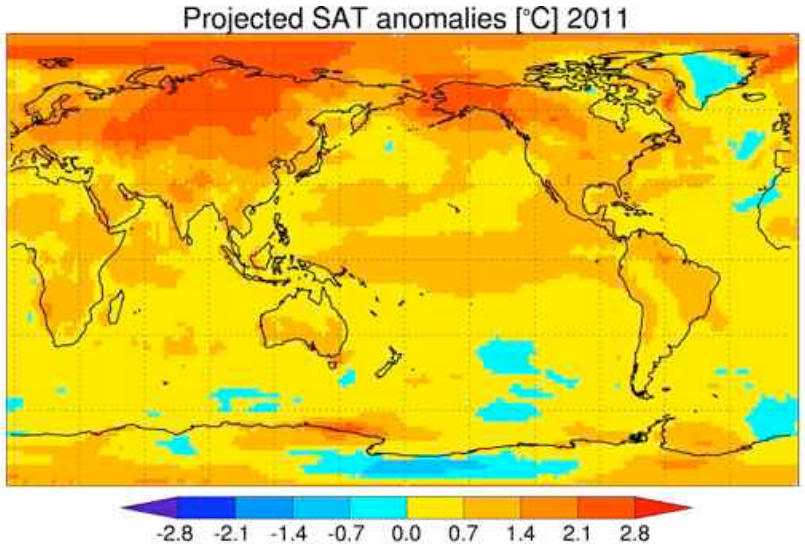


3. Predictions of the Atlantic Meridional Overturning Circulation (AMOC)

Uninitialised model reproduces observed pattern of 2011 surface temperature anomaly only poorly

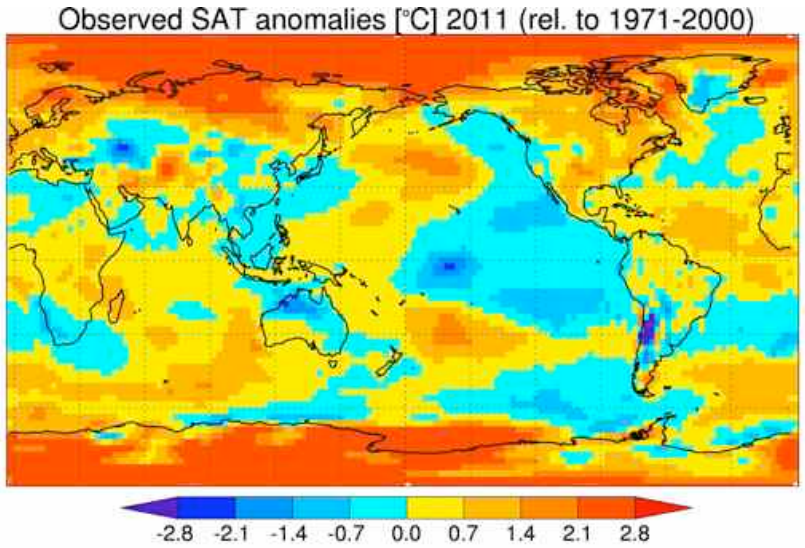


Observed

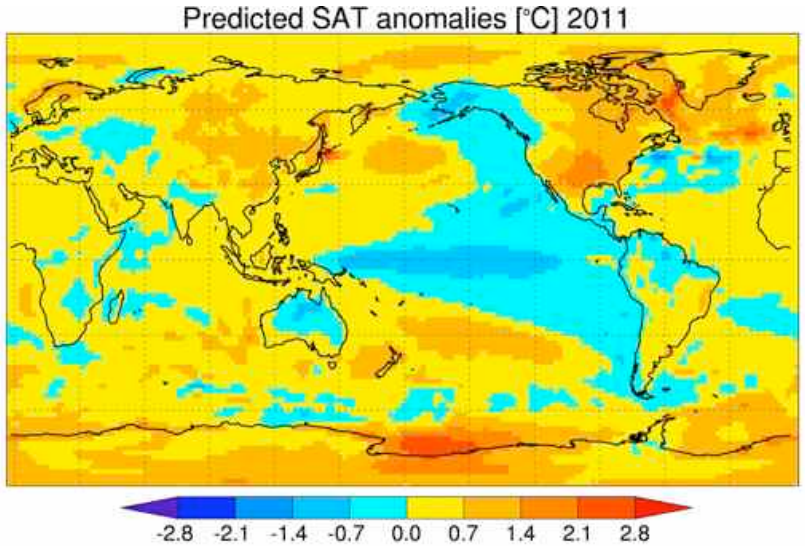


Uninitialised model

First year of initialised prediction: good match with observed 2011 surface temperature anomaly pattern

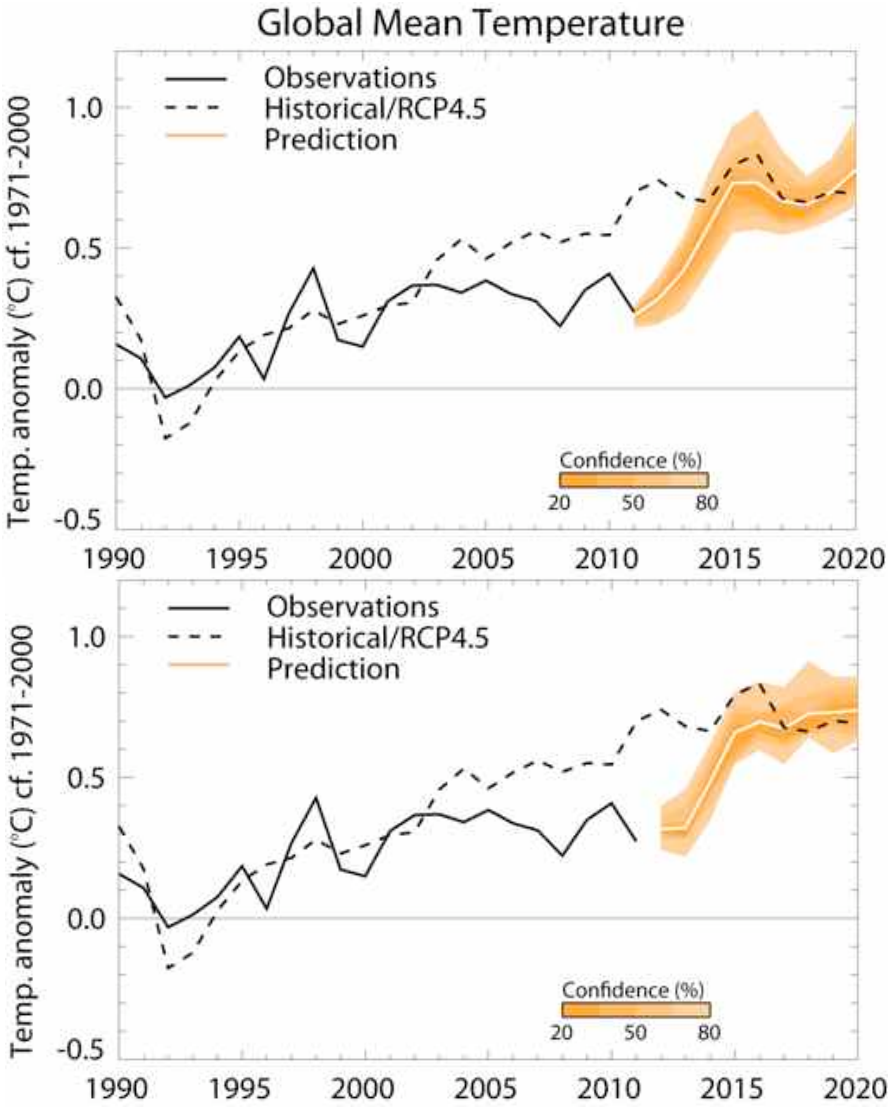


Observed



Initialised on
1 Jan. 2011

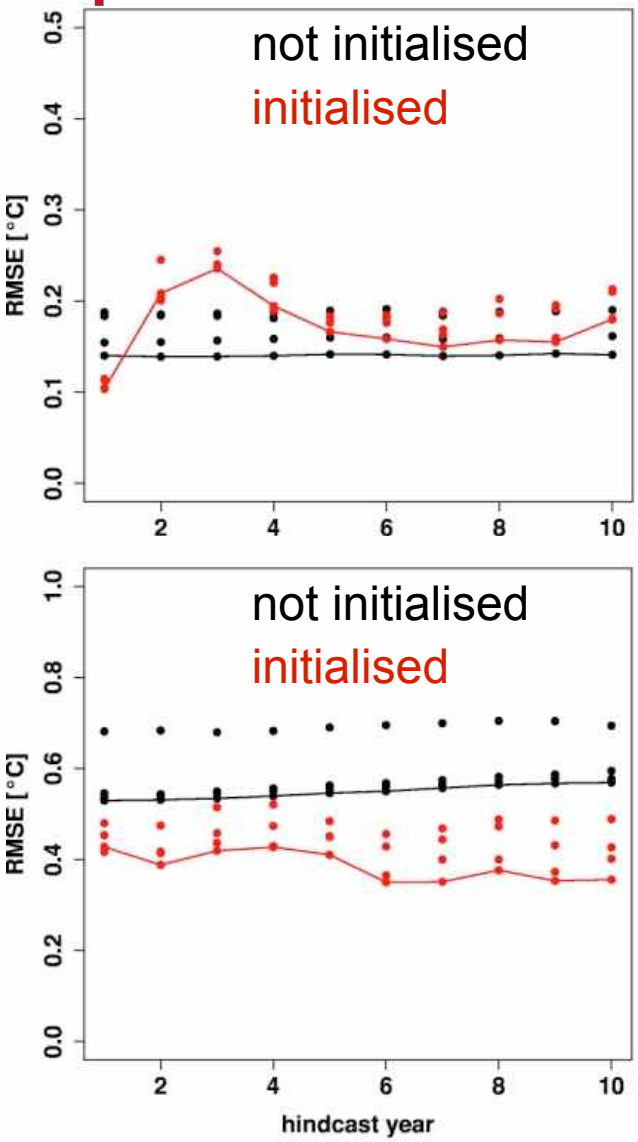
However: we have little confidence in our predictions of global mean surface temperature for the coming decade



Initialised on 1 Jan. 2011

Initialised on 1 Jan. 2012

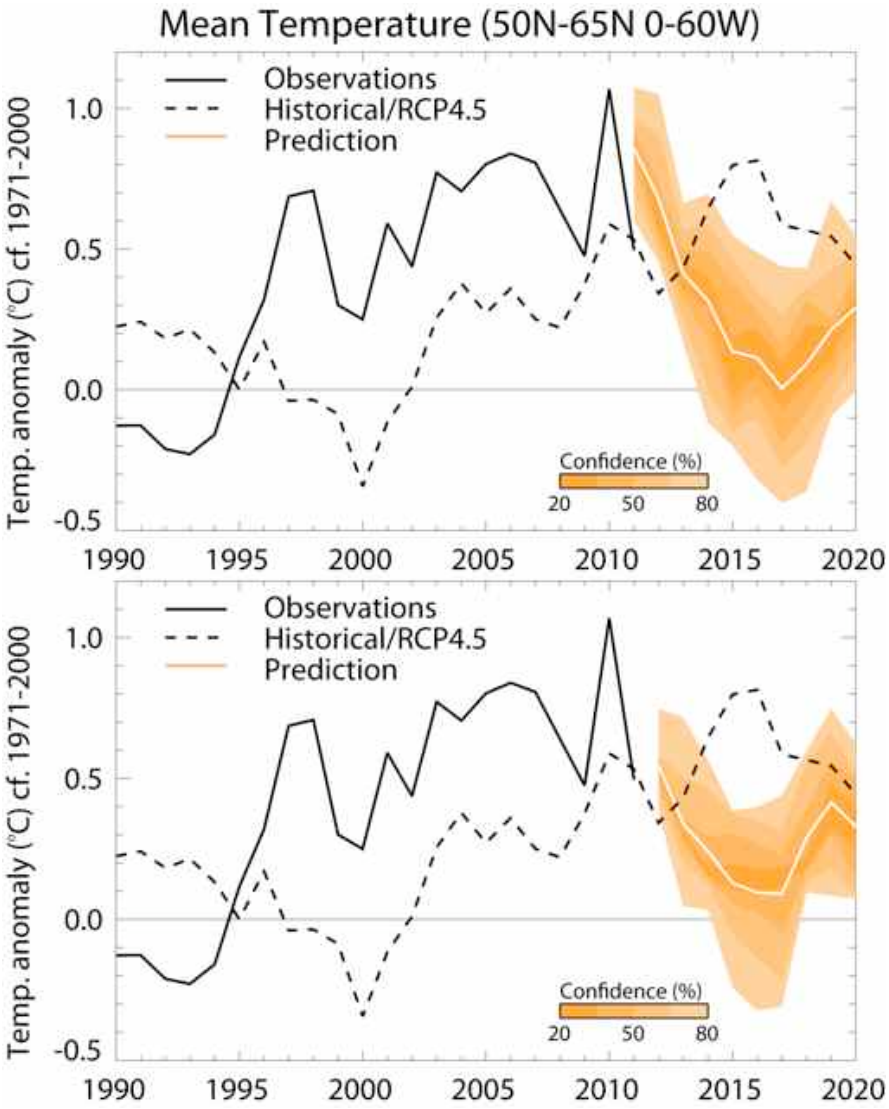
Surface temperature in North Atlantic sector: clear improvement of hindcast skill through initialisation



RMS error in global mean surface temperature

RMS error in North Atlantic surface temperature

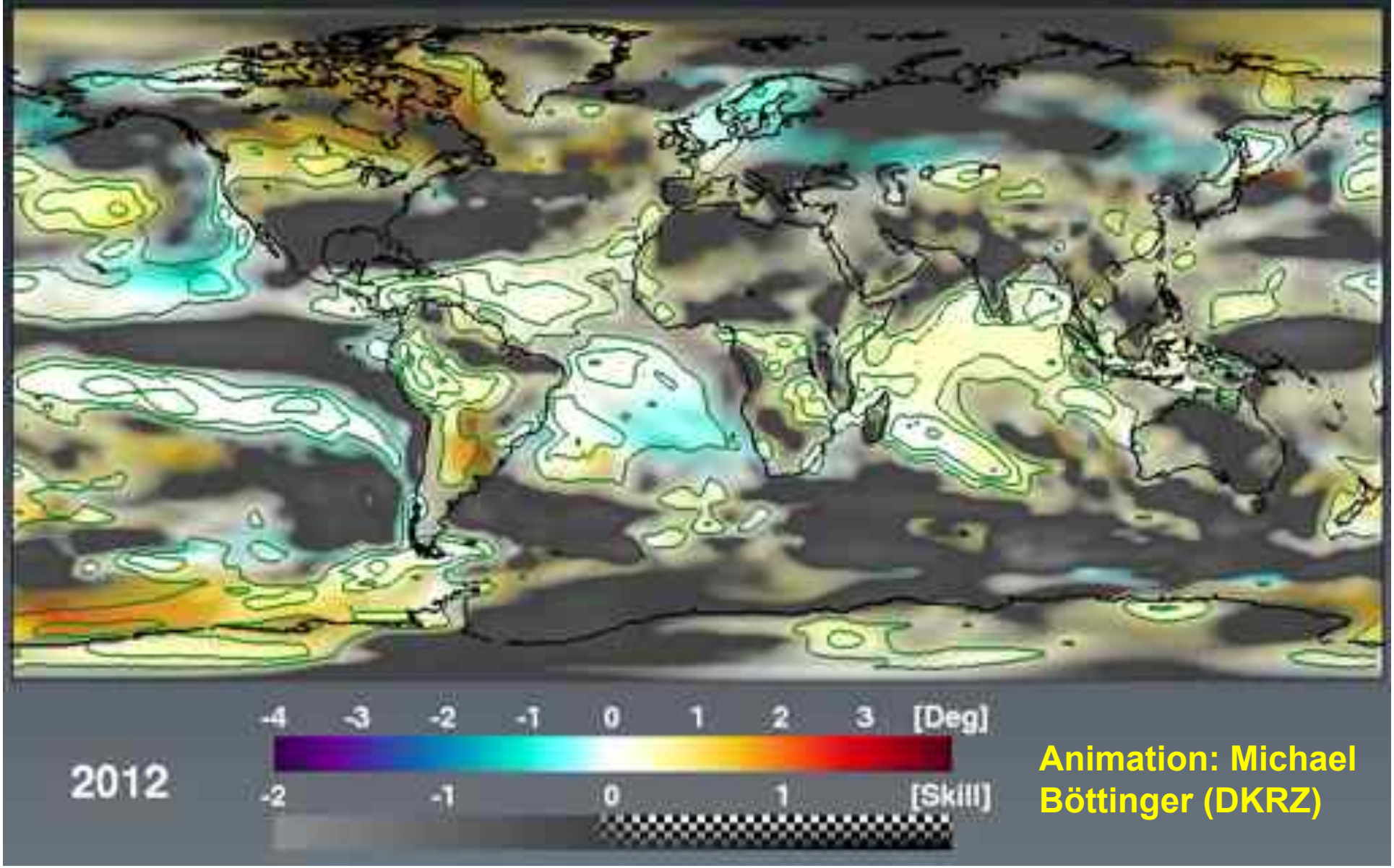
North Atlantic sector: robust prediction of surface temperature reduction during this decade



Initialised on 1 Jan. 2011

Initialised on 1 Jan. 2012

Colours: temperature anomaly relative to 1971-2000
Contour lines: RMSE reduction through initialisation



Animation: Michael Böttinger (DKRZ)

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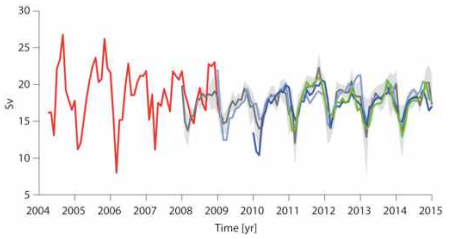
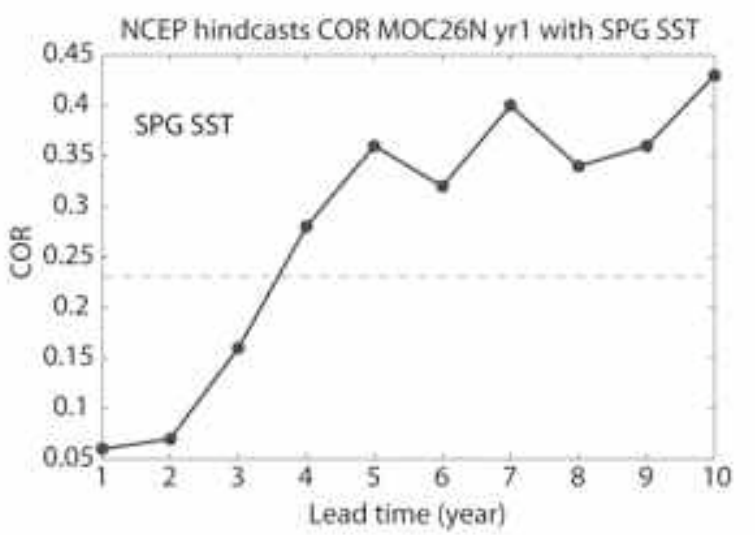
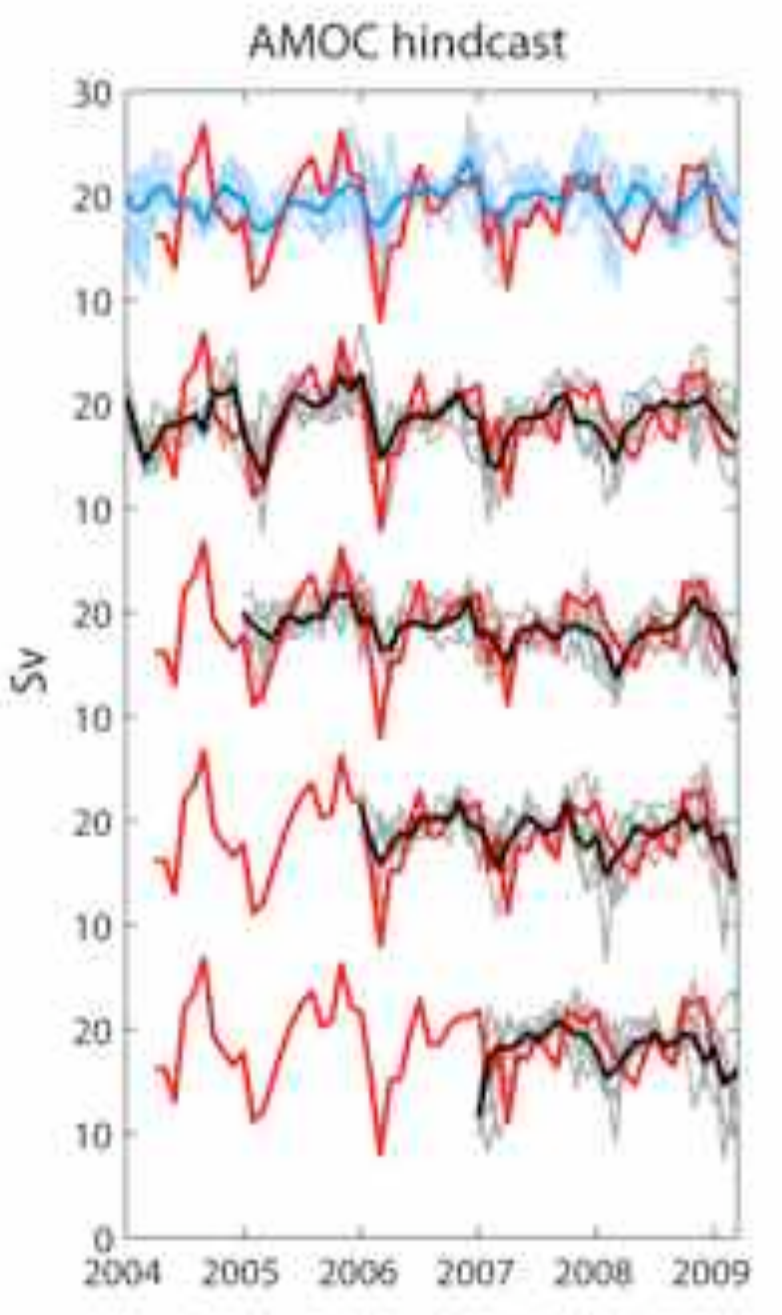


Climate prediction and AMOC

- Matei et al. (submitted) argues that multiyear hindcast skill for Atlantic SST and European SAT arises from
  - Ocean heat content during years 2-5
  - AMOC during years 6-10



- Important to understand why skill arises, both for scientific reasons and to improve skill
- Is there skill in predicting AMOC?



Observations and hindcasts of the MOC at 26.5°N

Climate model initialised from NCEP-forced ocean model

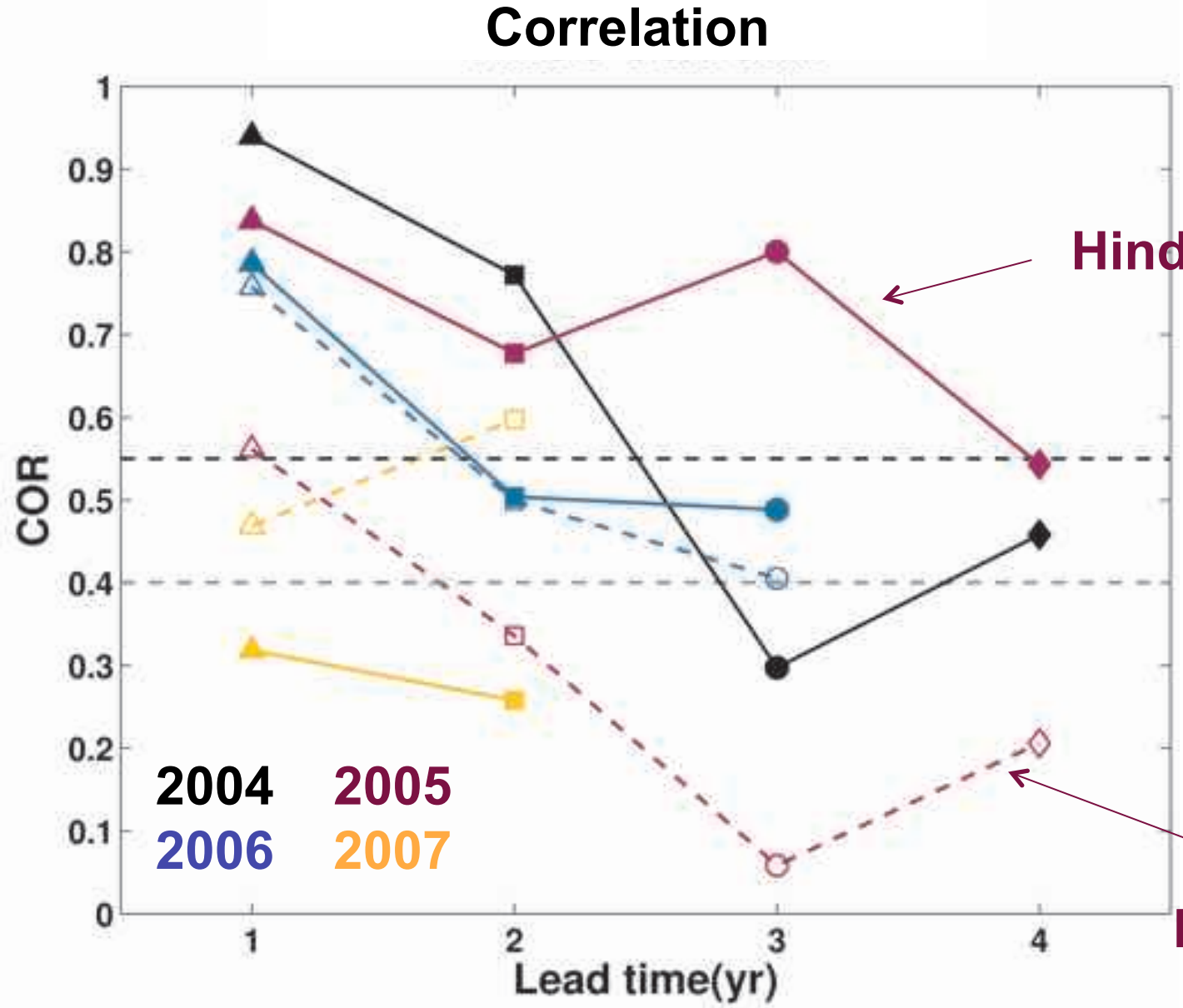
20C simulation ("free" model)

RAPID observations

Individual hindcasts

Ensemble-mean hindcasts

Significant hindcast skill for MOC at 26.5°N (2004-2008)



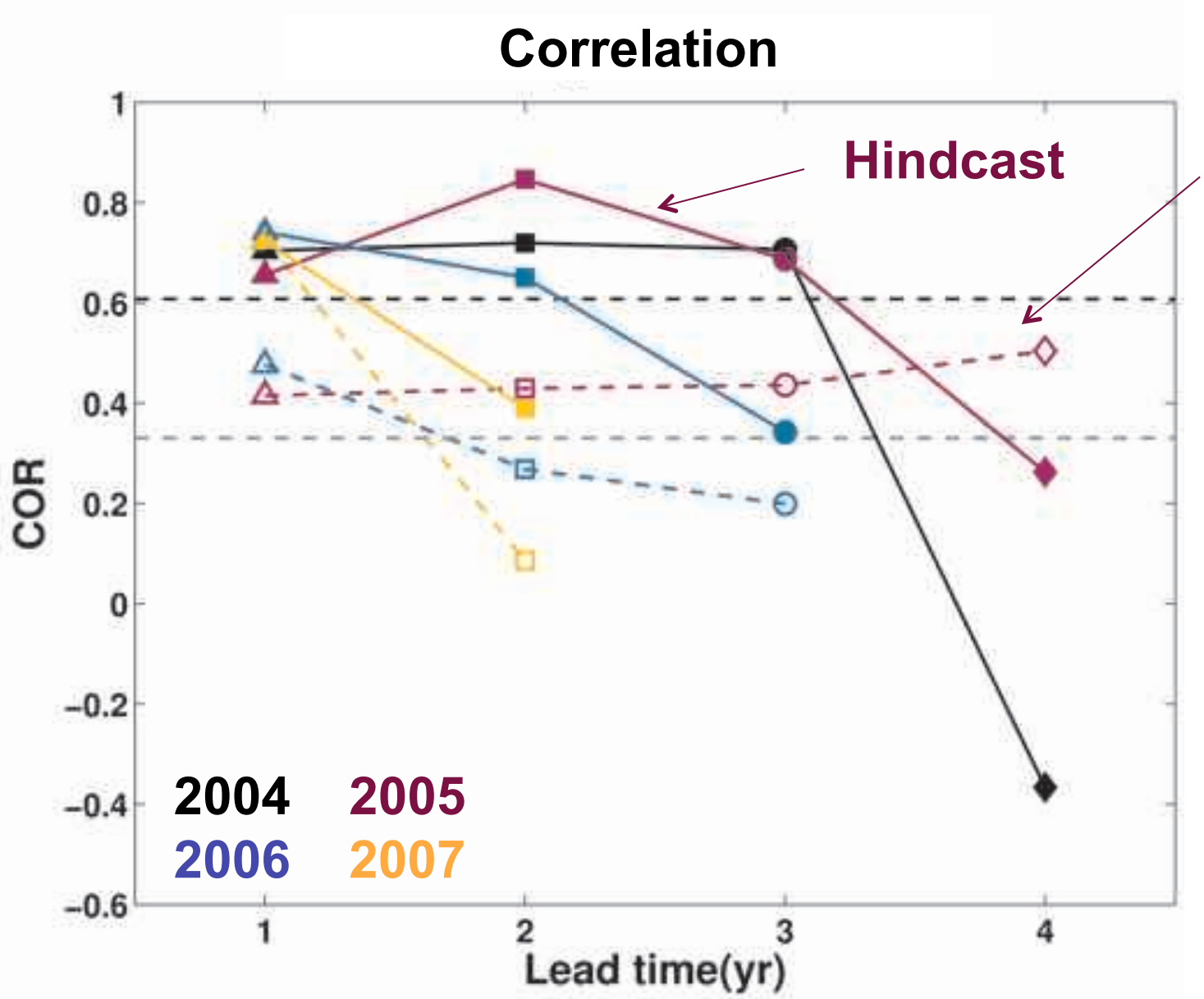
Hindcast

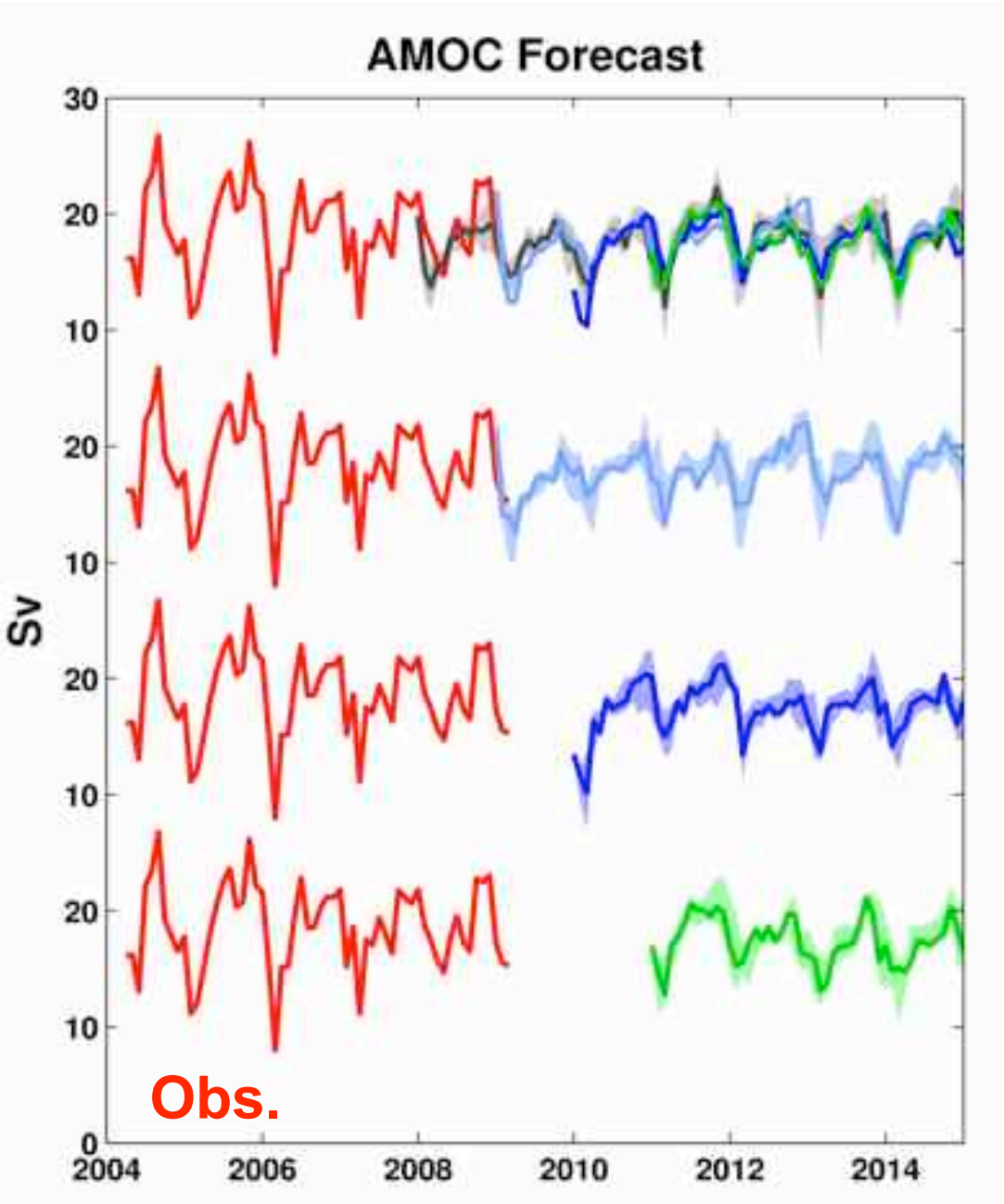
10% sign.

"Free" model

Persistence (repeat of previous year)

Skill arises through zonal density difference $\Delta\rho_u$



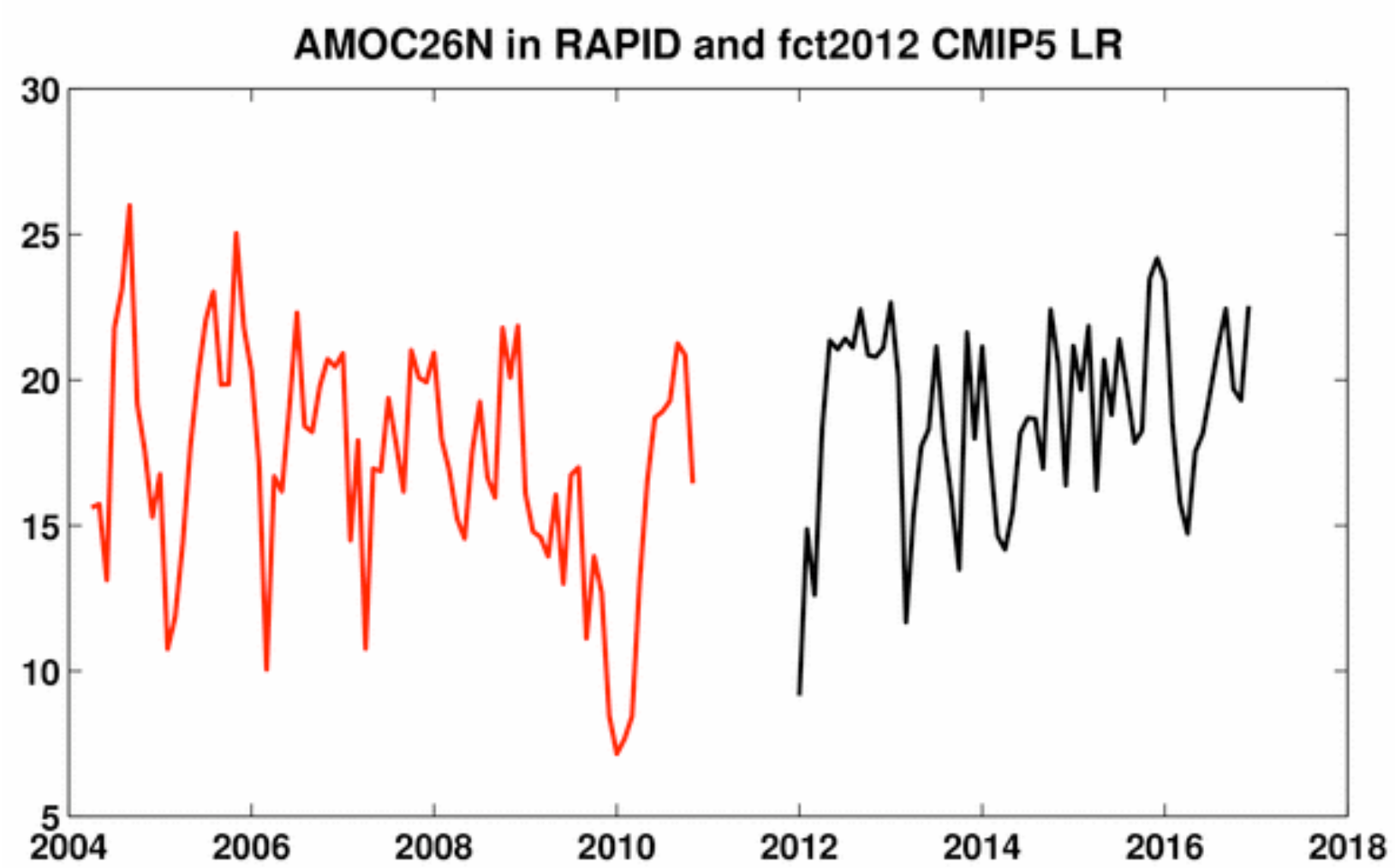


Initialisation on 1 Jan 2010 predicts:

- March 2010 AMOC minimum is caused by extreme negative NAO
- minimum is short-lived

Forecasts initialised
2008, 2009, 2010, 2011

Forecast from Jan 2012 “confirms” AMOC recovery



Conclusions

- Forcing an ocean model with the observed atmosphere is a simple yet effective way to produce an ocean state estimate for initialising climate predictions
  - Caveat: substantial weaknesses in tropics
- Robust forecast skill for surface temperature in North Atlantic regions, including Europe
  - Across model versions, initialisation procedure, and skill measure
  - We predict cooling of NA SST during the coming decade
- Indications that this skill is related to Atlantic Meridional Overturning Circulation (AMOC)
- Skill in multiyear prediction of AMOC at 26.5 ºN
  - Our prediction: observed 2009 and 2010 weakening is short-lived

Thank you for your attention!