Bjerknes Centre for Climate Research

Seasonal-to-decadal prediction with the Norwegian Climate Prediction Model

COUNILLON F., BETHKE I., KEENLYSIDE N., WANG Y. , BENTSEN M., BERTINO L., ZHENG F.

UNIVERSITY OF BERGEN
uniResearch
NERSC Nansen Center, Bergen
HAVFORSKNINGSINSTITUTTET INSTITUTE OF MARINE RESEARCH

NorCPM

Norwegian Climate Prediction Model

NorCPM = NorESM + ocean data assimilation (EnKF)

Objectives:

- Long term reanalysis
- Seasonal-to-decadal prediction
- Regional focus into the Nordic Seas

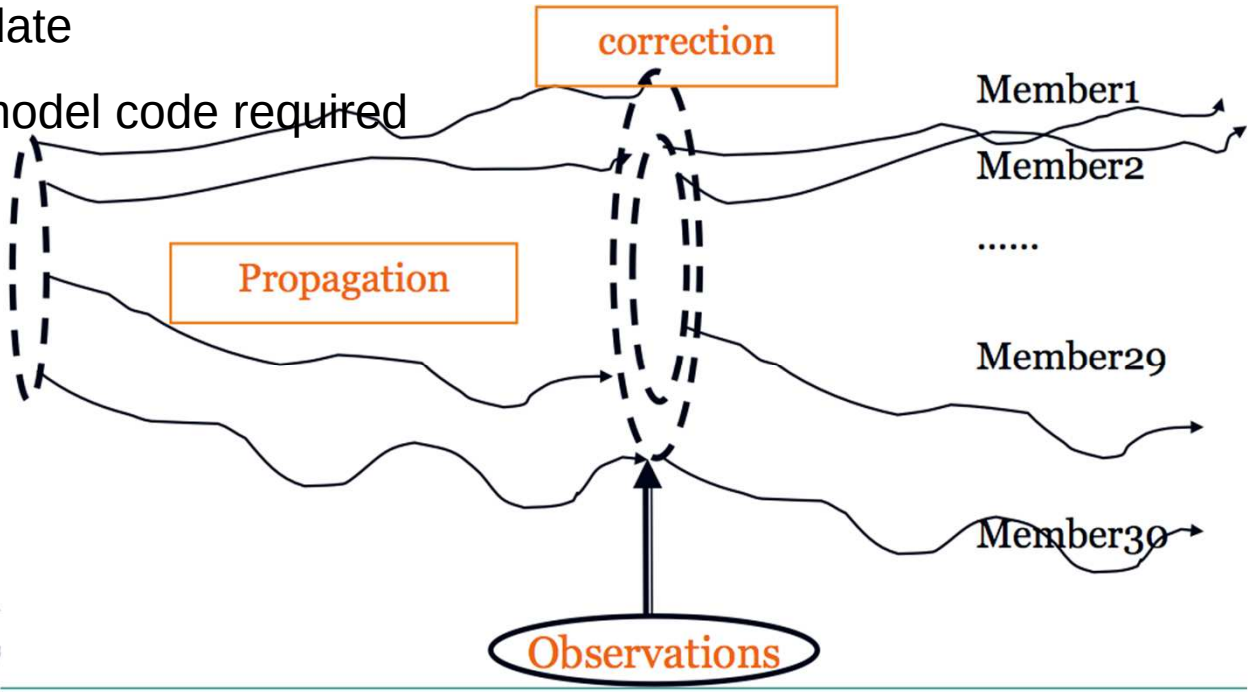
Outlines:

- Twin-experiment:
  - Assimilate monthly SST
  - A numerically efficient version of NorESM (T31, 3.6º for ocean)
- Test with real observation
  - Assimilate monthly SST (1980-2006)
  - 2º ocean tripolar grid + atmophere F19

Ensemble Kalman Filter (EnKF)

Sequential Monte-Carlo method with **propagation** and **correction** step

- Forecast = Ensemble mean, Forecast uncertainty = ensemble std deviation
- Ensemble covariance used to update the **full water column** from the obs (e.g., SST)
  - **More information extracted** from sparse observations
  - Consistency in the update
  - No knowledge of the model code required



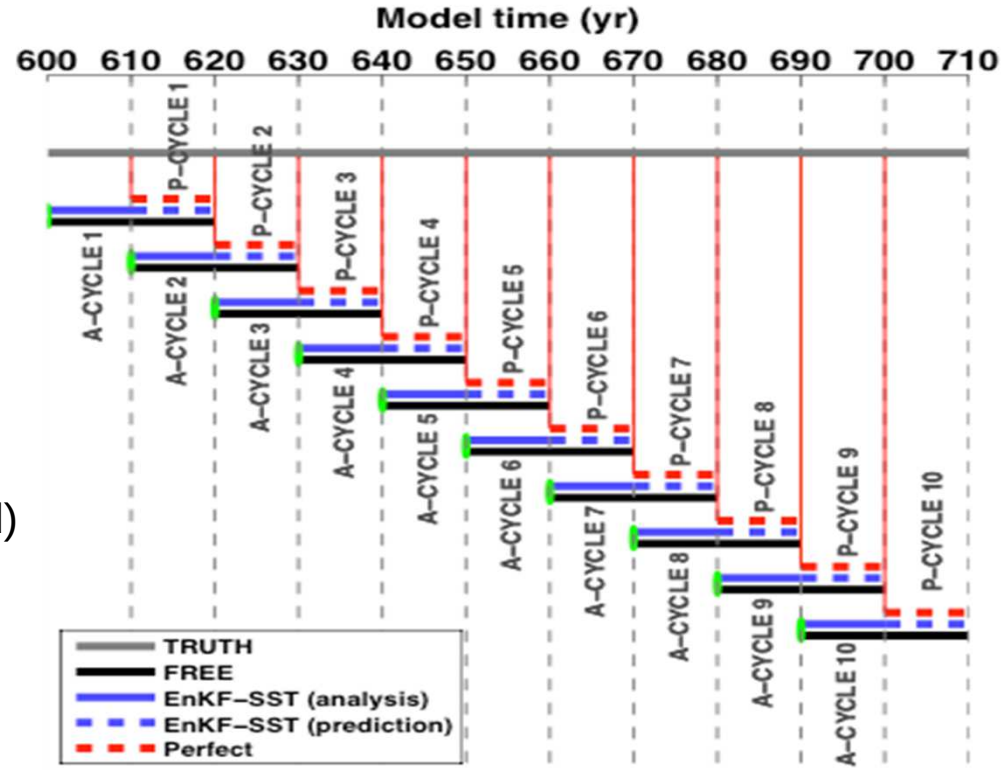
Twin prediction experiment

Truth (synthetic observations)
- covers 110 years with fixed pre-industrial forcing

EnKF-SST (initialized, assimilation runs)
- 10 assimilation/prediction cycles
- 30 members

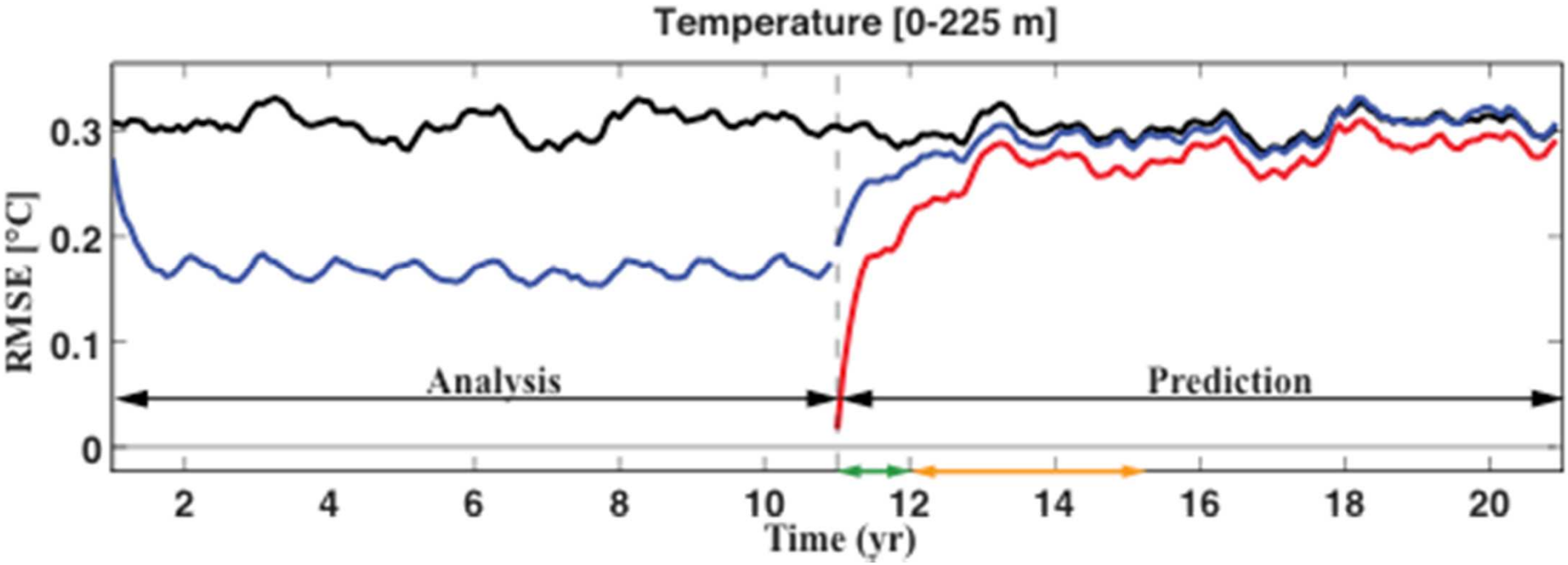
Free (no-assimilation, **lower benchmark**)
- Same initial ensemble (30 members)

Perfect (**upper benchmark**)
- 10 prediction cycles (30 members)
- Initial conditions for TRUTH (ice,atm,ocn,lnd) + small pert. SST



Global skill assessment: Upper ocean temperature

RMSE calculated over the full model domain (averaged over the 10 prediction cycles)



For all model variables at 1-year lead average; 2-5 lead year average

- Analyze reduction of RMSE in **EnKF-SST** relative to **Free**
- Compare the improvements relative to **Perfect**

Global skill assessment

	$\mathrm{RMSE}_{\mathrm{FREE}}$		$\mathrm{RRMSE}_{\mathrm{EnKF}}(\%)$	
Prediction year	$\overline{1\,\mathrm{Y}}$	$\overline{2\text{-}5\,\mathrm{Y}}$	$\overline{1\,\mathrm{Y}}$	$\overline{2\text{-}5\,\mathrm{Y}}$
T2M (°C)	0.55	0.37	7	4
Precip (mm/day)	0.48	0.26	11	5
icec (%)	0.8	0.6	4	5
sst (° C)	0.3	0.2	21	8
sss (psu)	0.1	0.09	15	4
T[0 225](°C)	0.21	0.19	22	5
S[0 225](psu)	0.05	0.05	18	6
T[225 500](°C)	0.16	0.16	11	4
S[225 500](psu)	0.03	0.03	11	7
T[500 1050](°C)	0.12	0.12	3	0
S[500 1050](psu)	0.02	0.02	5	4

Global skill assessment

	$\mathrm{RMSE}_{\mathrm{FREE}}$		$\mathrm{RRMSE}_{\mathrm{EnKF}}(\%)$	
Prediction year	$\overline{1\,\mathrm{Y}}$	$\overline{2\text{-}5\,\mathrm{Y}}$	$\overline{1\,\mathrm{Y}}$	$\overline{2\text{-}5\,\mathrm{Y}}$
T2M (°C)	0.55	0.37	7	4
Precip (mm/day)	0.48	0.26	11	5
icec (%)	0.8	0.6	4	5
sst (° C)	0.3	0.2	21	8
sss (psu)	0.1	0.09	15	4
T[0 225](°C)	0.21	0.19	22	5
S[0 225](psu)	0.05	0.05	18	6
T[225 500](°C)	0.16	0.16	11	4
S[225 500](psu)	0.03	0.03	11	7
T[500 1050](°C)	0.12	0.12	3	0
S[500 1050](psu)	0.02	0.02	5	4

EnKF-SST reduces RMSE compare to **Free**:

- Improvement gets smaller with depths for T and S
- Improvements for atmospheric variables and ice concentration

Global skill assessment

	$\mathrm{RMSE}_{\mathrm{FREE}}$		$\mathrm{RRMSE}_{\mathrm{EnKF}}(\%)$	
Prediction year	$\overline{1\,\mathrm{Y}}$	$\overline{2\text{-}5\,\mathrm{Y}}$	$\overline{1\,\mathrm{Y}}$	$\overline{2\text{-}5\,\mathrm{Y}}$
T2M (°C)	0.55	0.37	7	4
Precip (mm/day)	0.48	0.26	11	5
icec (%)	0.8	0.6	4	5
sst (° C)	0.3	0.2	21	8
sss (psu)	0.1	0.09	15	4
T[0 225](°C)	0.21	0.19	22	5
S[0 225](psu)	0.05	0.05	18	6
T[225 500](°C)	0.16	0.16	11	4
S[225 500](psu)	0.03	0.03	11	7
T[500 1050](°C)	0.12	0.12	3	0
S[500 1050](psu)	0.02	0.02	5	4

EnKF-SST reduces RMSE compare to **Free**:

- Improvement gets smaller with depths for T and S
- Improvements for atmospheric variables and ice concentration

Global skill assessment: Ocean state summary

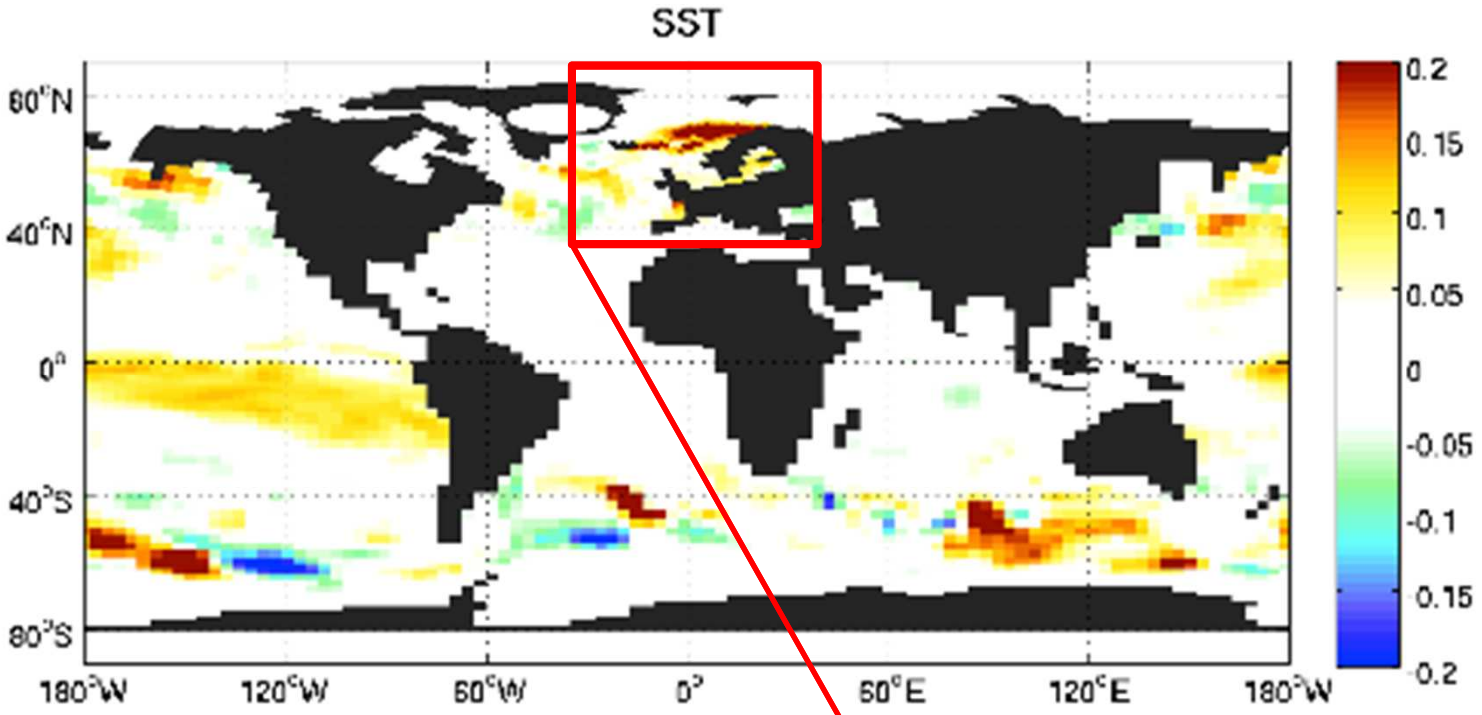
	$\mathrm{RRMSE}_{\mathrm{EnKF}}(\%)$		$\mathrm{RRMSE}_{\mathrm{PERFECT}}(\%)$	
Prediction year	$\overline{1\,\mathrm{Y}}$	$\overline{2\text{-}5\,\mathrm{Y}}$	$\overline{1\,\mathrm{Y}}$	$\overline{2\text{-}5\,\mathrm{Y}}$
T2M (°C)	7	4	13	7
Precip (mm/day)	11	5	19	10
icec (%)	4	5	29	19
sst (°C)	21	8	39	18
sss (psu)	15	4	56	30
T[0 225](°C)	22	5	54	25
S[0 225](psu)	18	6	73	45
T[225 500](°C)	11	4	74	51
S[225 500](psu)	11	7	84	66
T[500 1050](°C)	3	0	85	72
S[500 1050](psu)	5	4	92	84

Moderate improvement of **EnKF-SST** compare to **Perfect**

➔SST is not sufficient to initialize the full system

Spatial distribution of the benefits
2—5 lead year

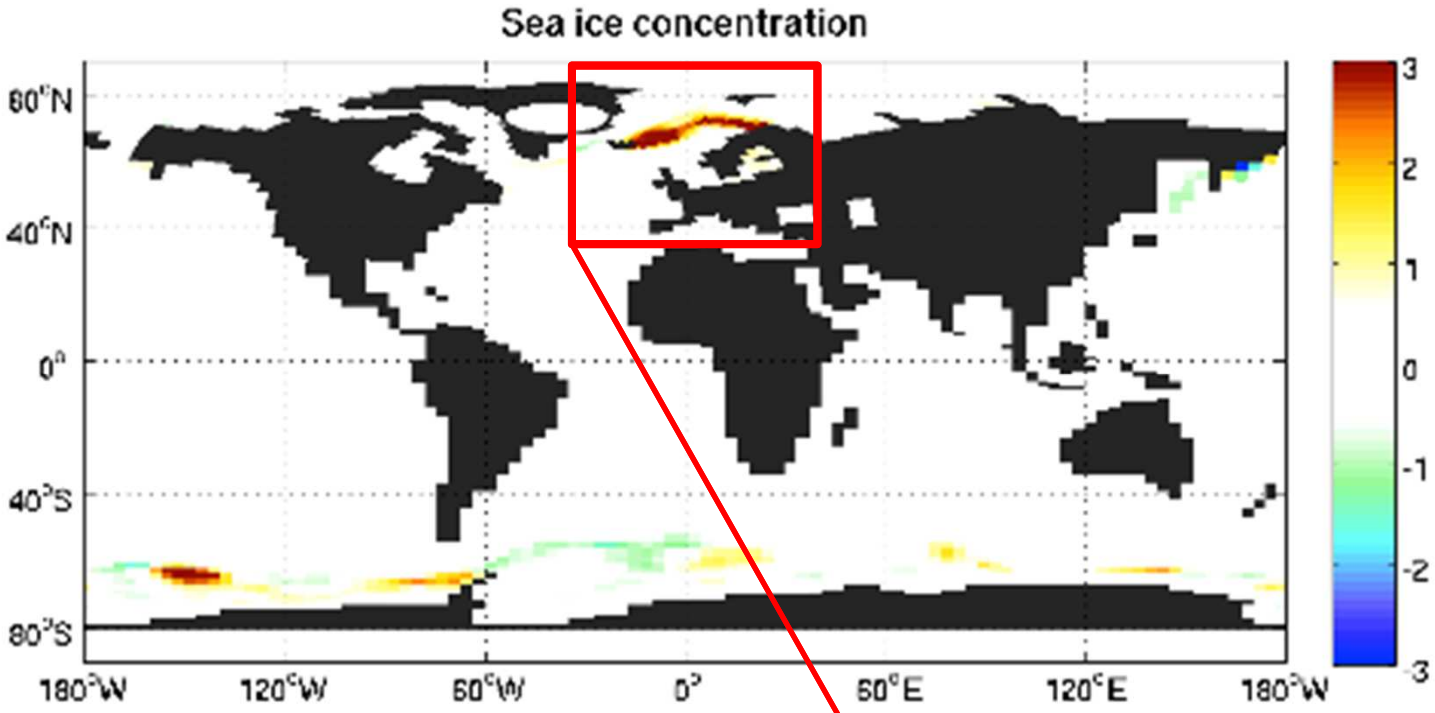
$RMSE_{Free}$ - $RMSE_{EnKF}$ averaged over 10 cycles (red means improvement)



Nordic Seas stands out

Spatial distribution of the benefits
2—5 lead year

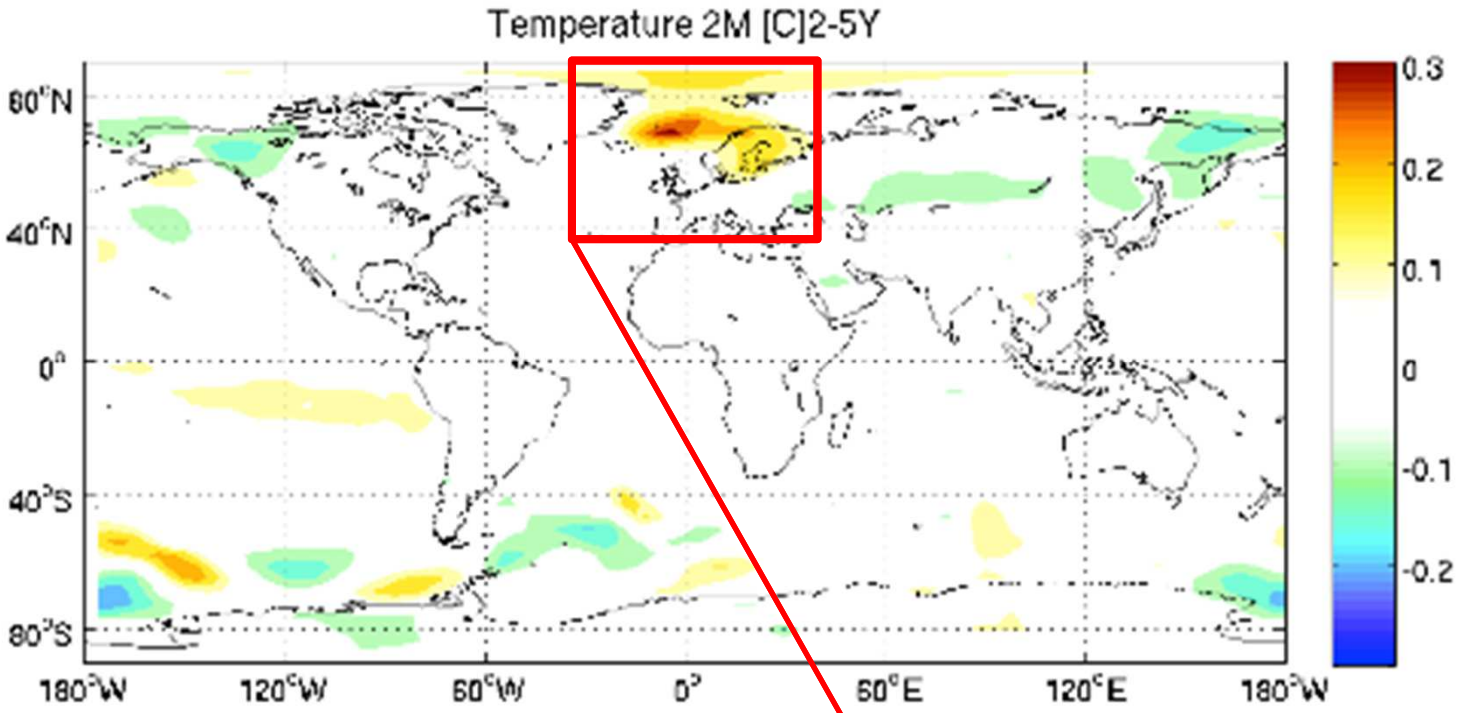
$RMSE_{Free}$ - $RMSE_{EnKF}$ averaged over 10 cycles (Red means improvement)



Nordic Seas stands out

Spatial distribution of the benefits
2—5 lead year

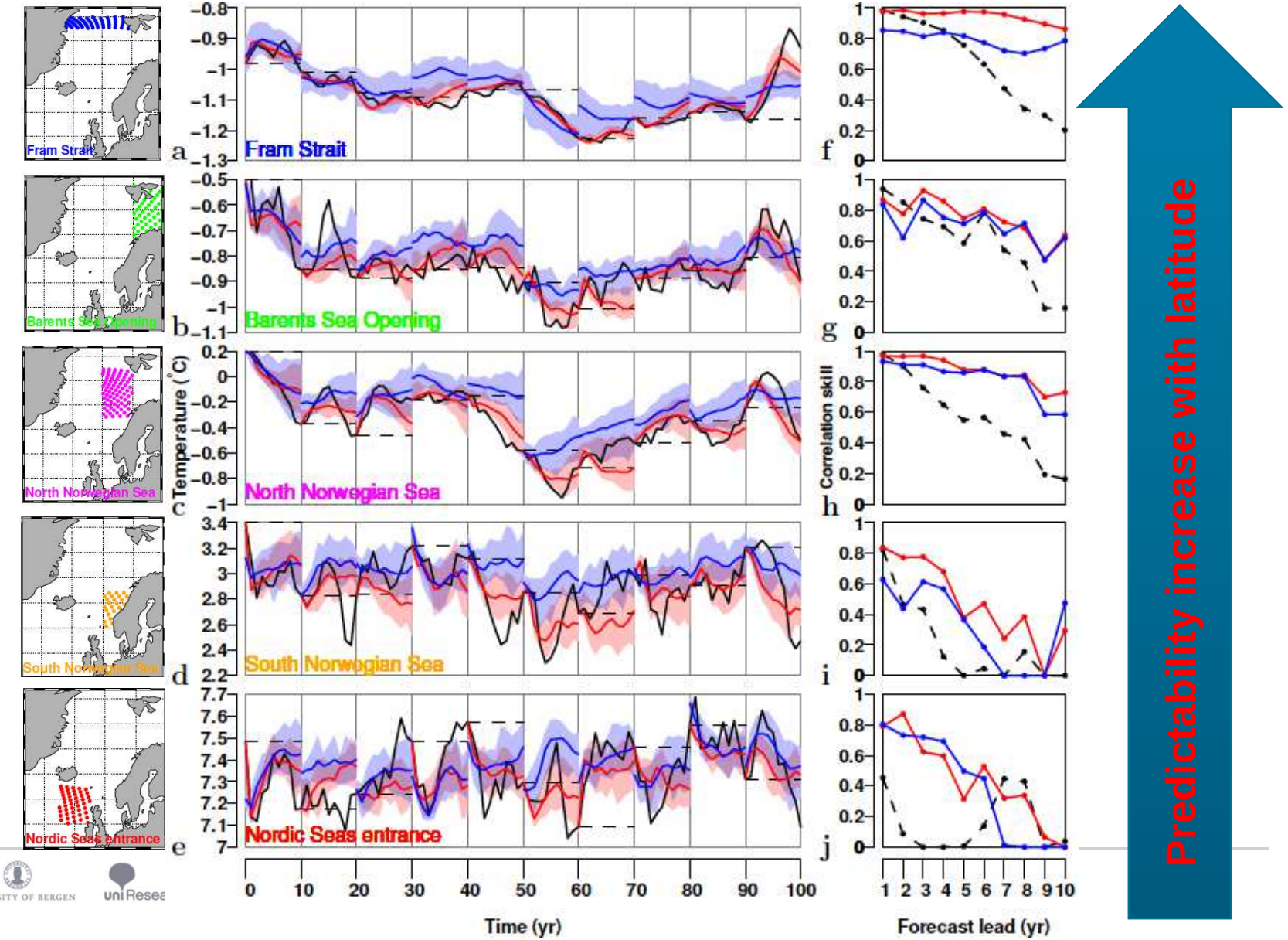
$RMSE_{Free}$ - $RMSE_{EnKF}$ averaged over 10 cycles (Red means improvement)



Nordic Seas stands out

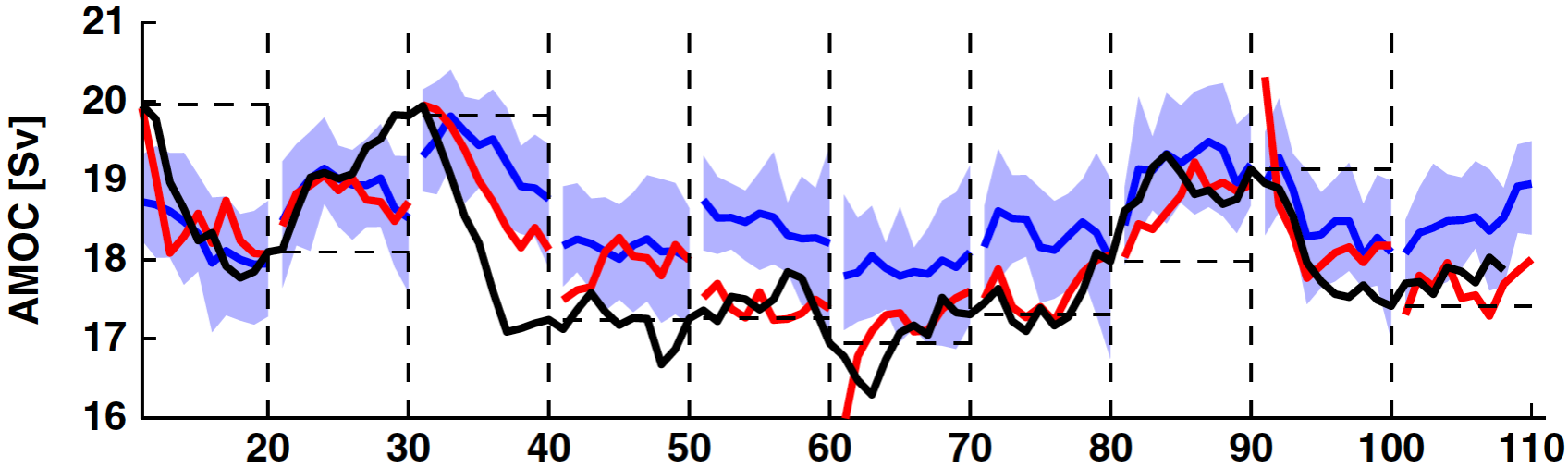
Nordic Seas heat content (0—300m)

Predictability 1—10 lead-year

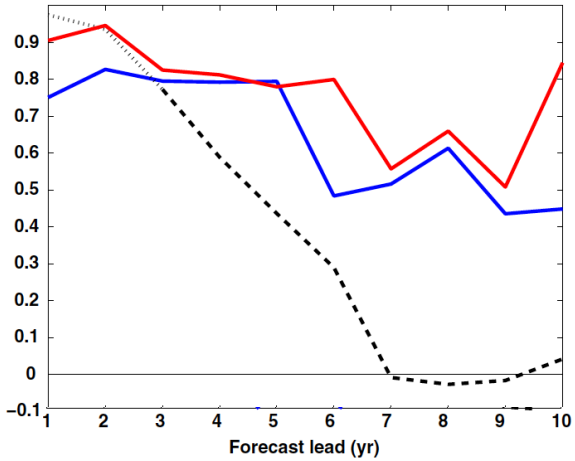


AMOC at 48°N

5 year running mean index



- EnKF-SST beats persistence
- Predictability up to 10 year close to perfect
- Lower skill when AMOC departs from its climatology



Twin experiment summary

Conclusion:

•EnKF-SST reduces RMSE for all variables (T,S, icec, T2M, precip) up to few years

•Prediction in the North Atlantic stand out: skill for Nordic Seas upper ocean heat content up to 10 years almost comparable to **Perfect**

•Skills for AMOC and SPG but seems beneficial to use a longer analysis cycle

But:

•Drift at intermediate depth T & S → hard to use a longer analysis period >10-year ?

•Improvements are moderate compare to Perfect

→More observations should be assimilated

F. Counillon, I. Bethke, N. Keenlyside, M. Bentsen, L. Bertino, F. Zheng, Seasonal-to-decadal prediction with the Ensemble Kalman Filter and the Norwegian Earth System Model: a twin experiment, Tellus A, 2014

NorCPM

A first test with real observation

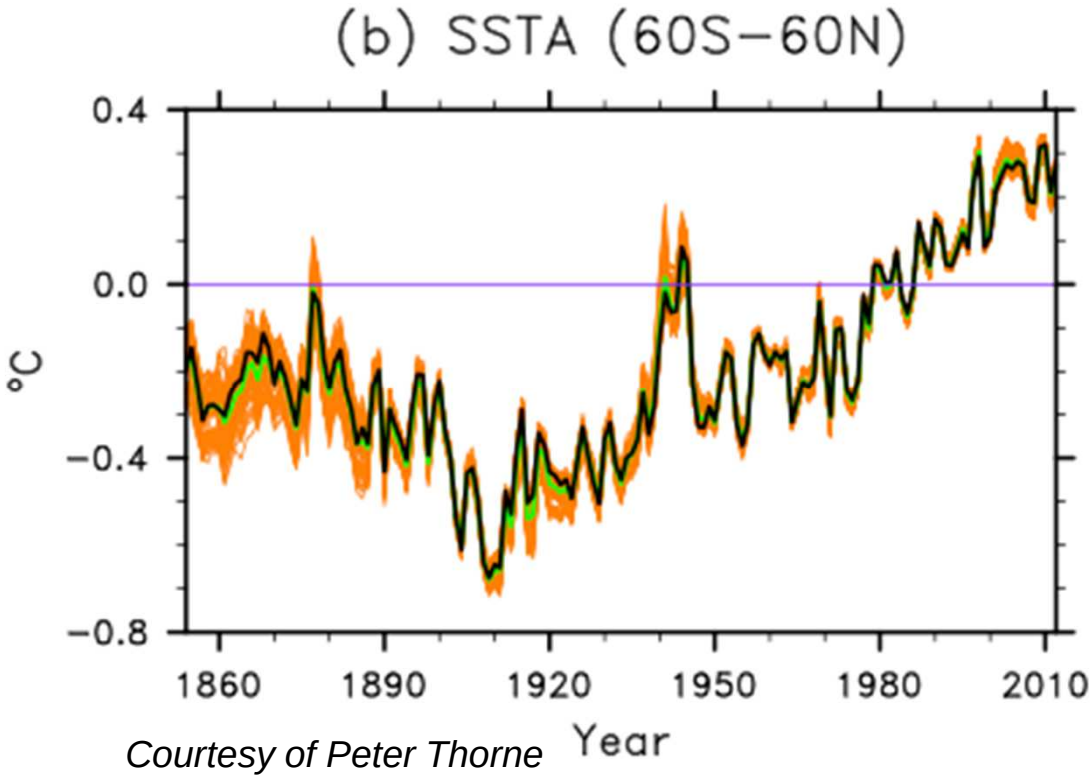
- Analysis for the period 1980-2005 (cover the SPG shift)
  - 5 predictions: 1990, 1992, 1994, 1995, 1996

- Uses 2º ocean tripolar grid + atmophere F19 of NorESM
- Assimilate monthly SST anomaly wrt period **(**~~1980-1999~~**)**

- Observation HadISST2 SST (1850-2007)

- Validate the system against:
  - SPG index
  - Nordic Sea Altantic layer water properties

SST Observation (HadISST2)

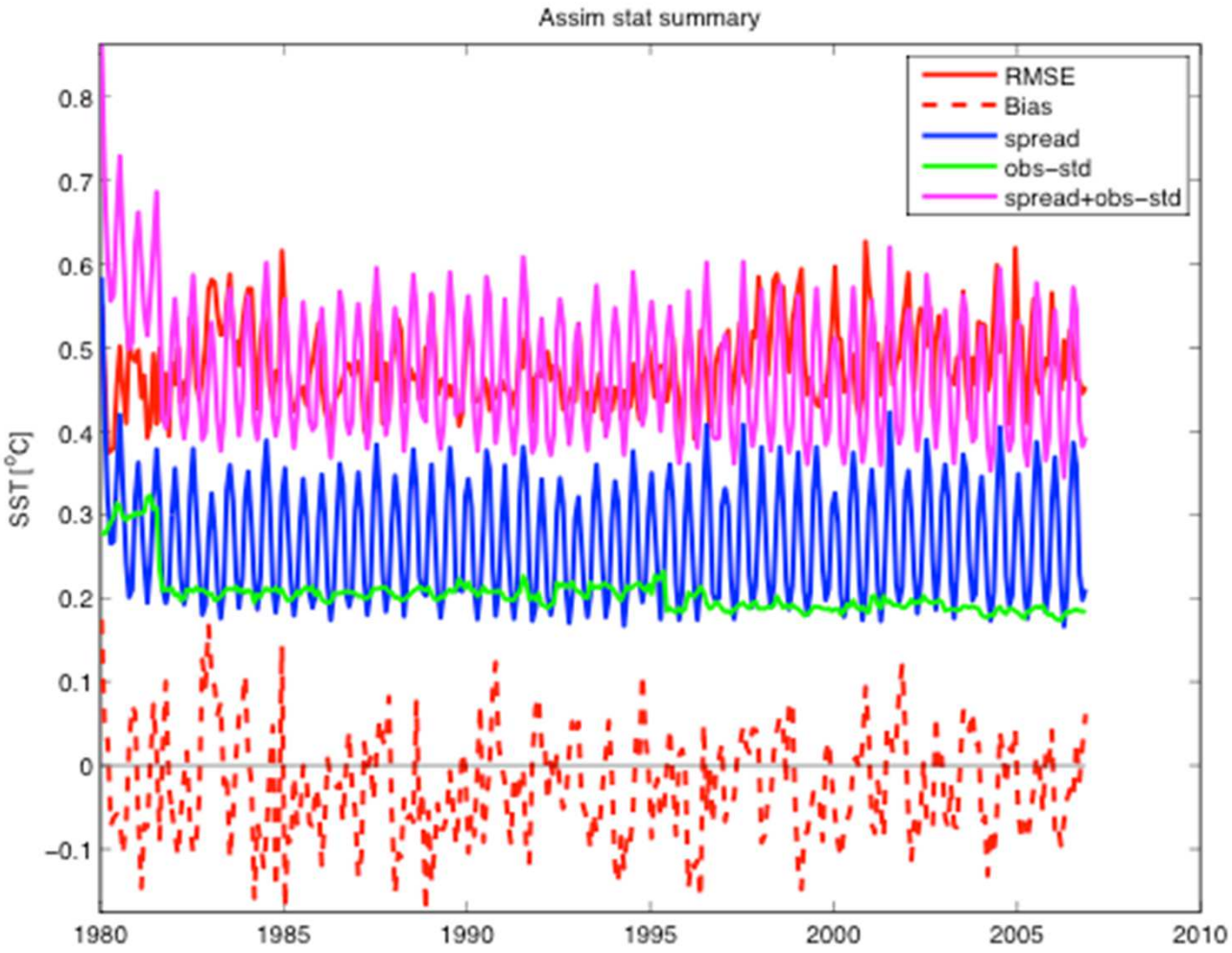


Courtesy of Peter Thorne

- Available from 1850-2007
- 1º resolution
- Obs error varies space & time

Assimilate ensemble mean
Ensemble spread =obs error

Assimilation statistics

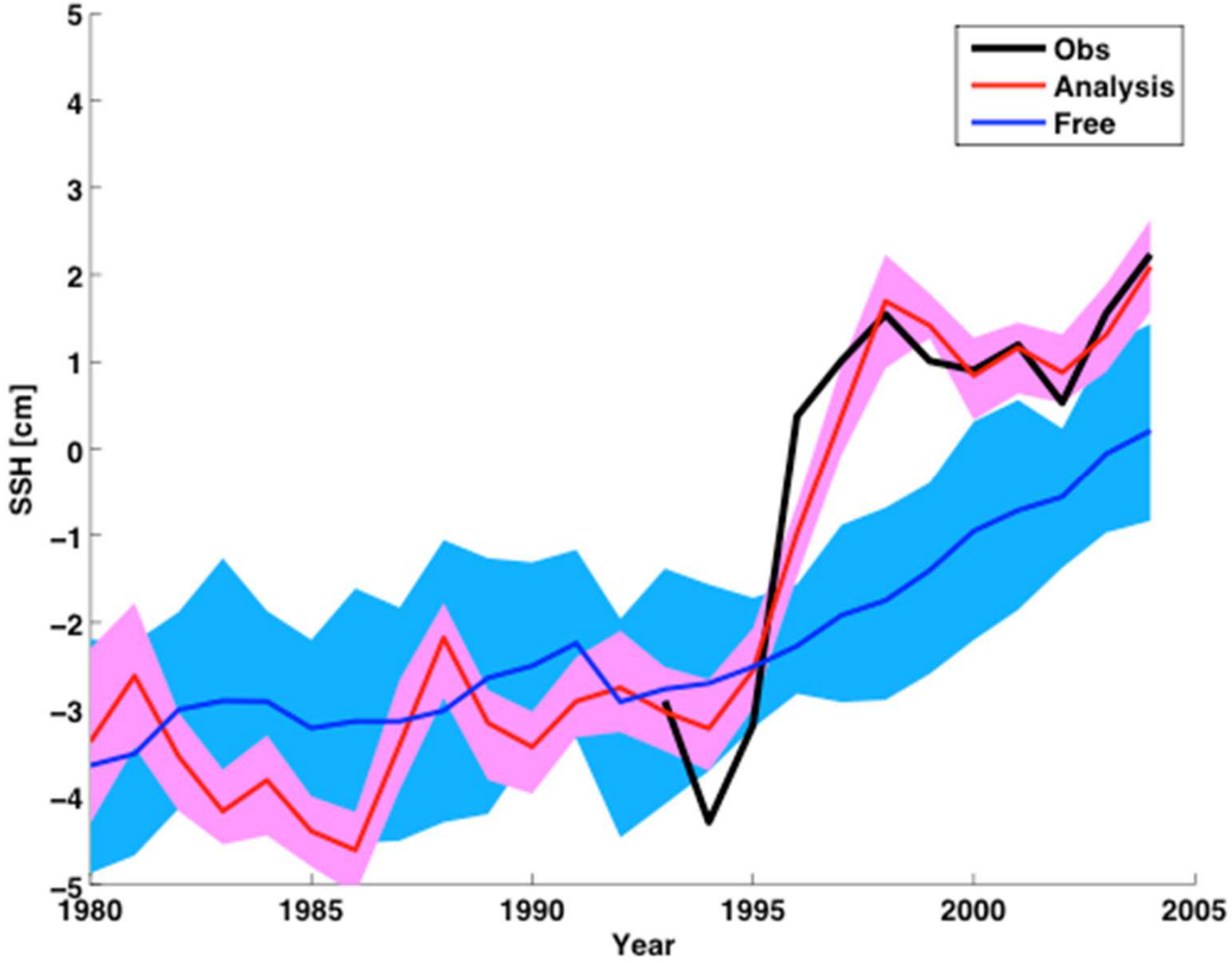


System stable for SST:

- Stable RMSE
- No spread collapse
- Good reliability

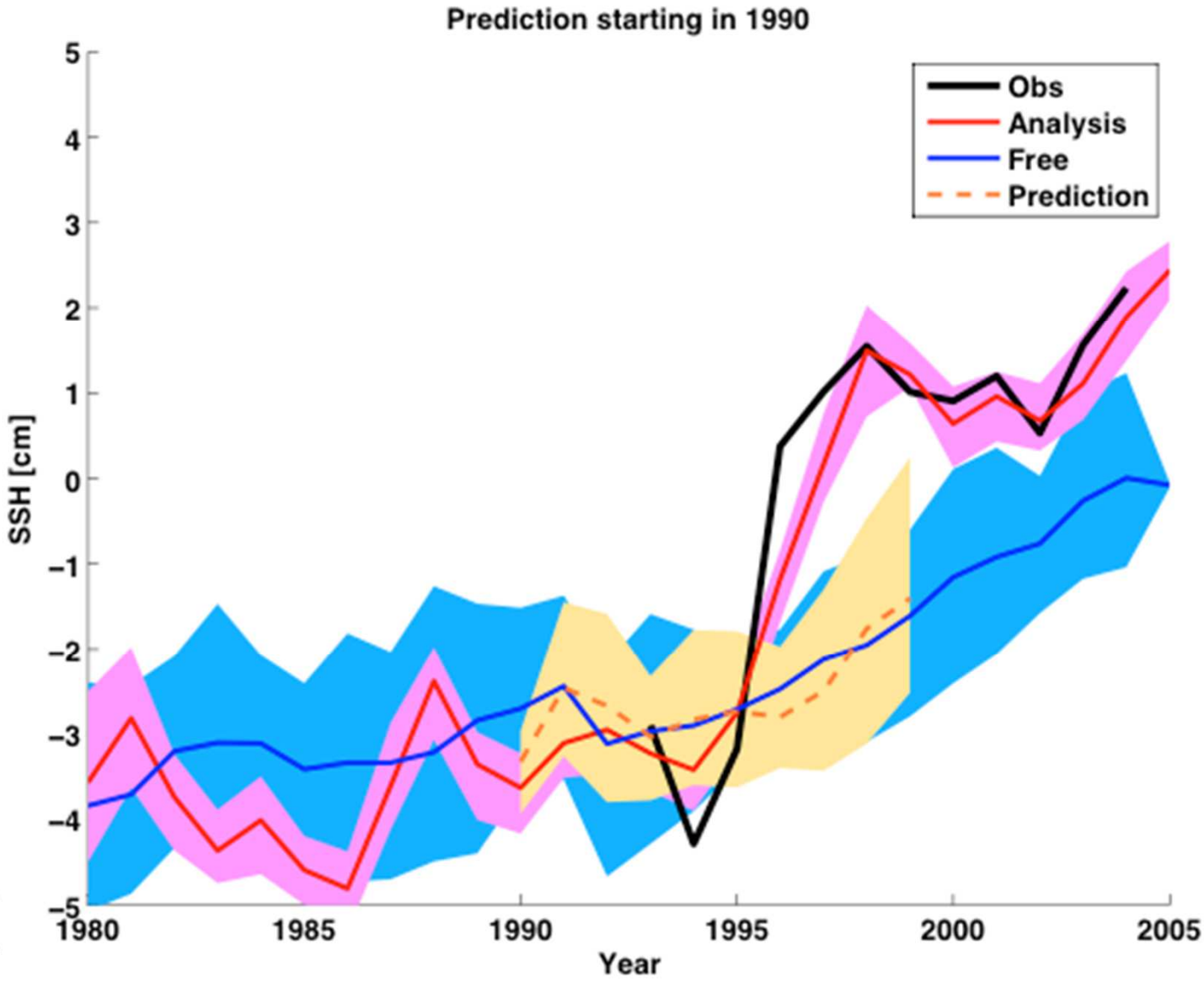
Bjerknes Centre for Climate Research

SPG index



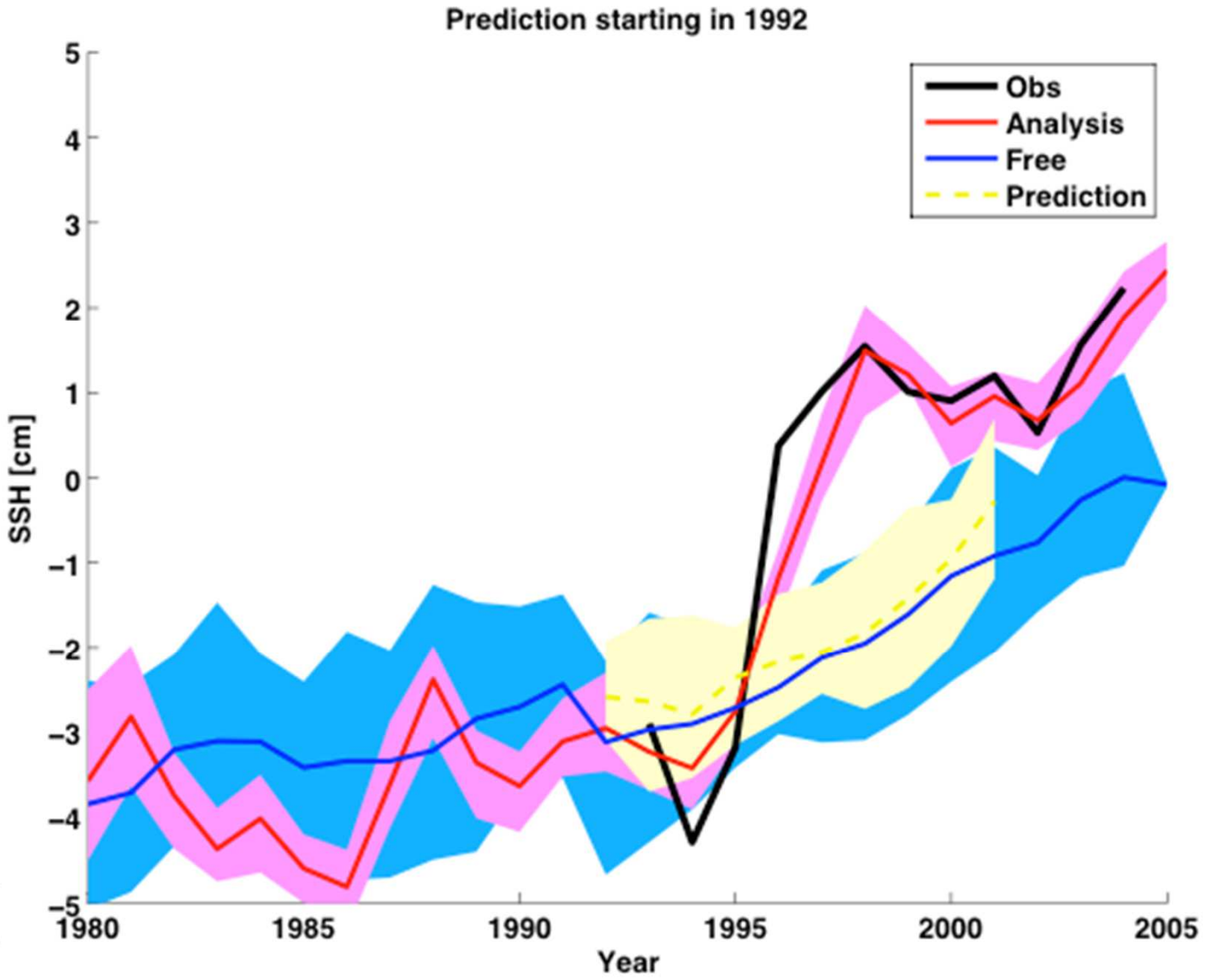
Bjerknes Centre for Climate Research

SPG index Prediction



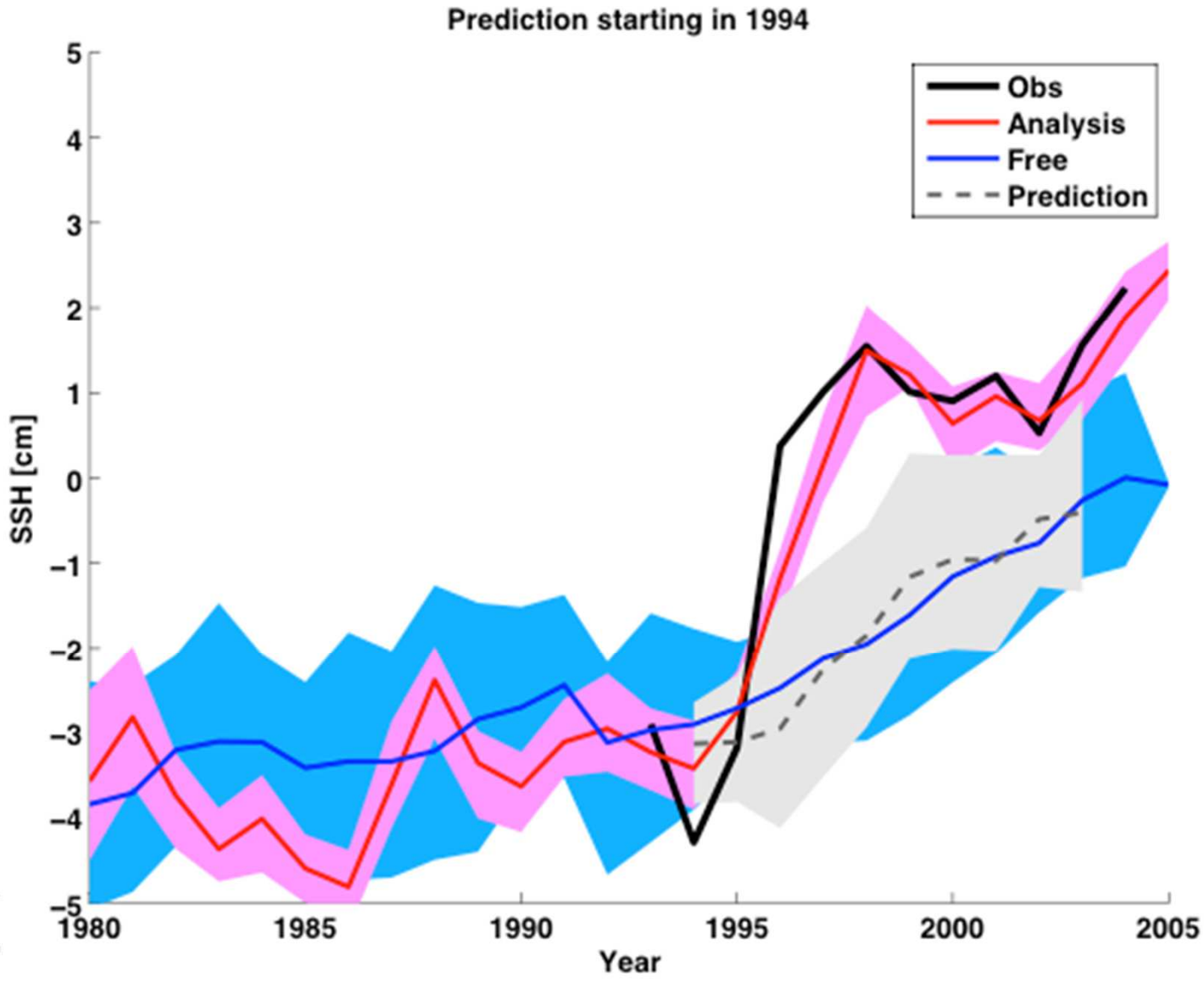
Bjerknes Centre for Climate Research

SPG index
Prediction



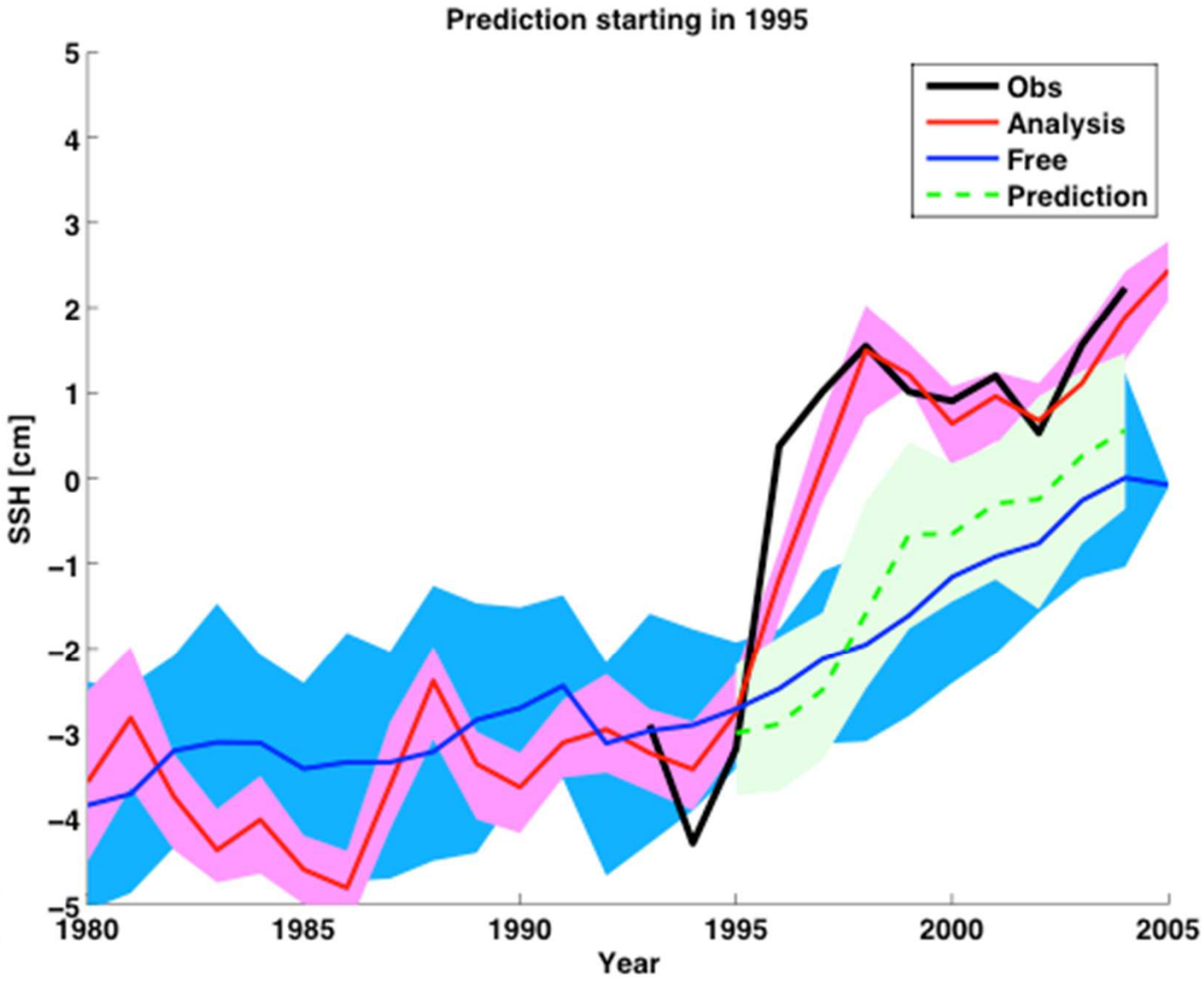
Bjerknes Centre for Climate Research

SPG index
Prediction



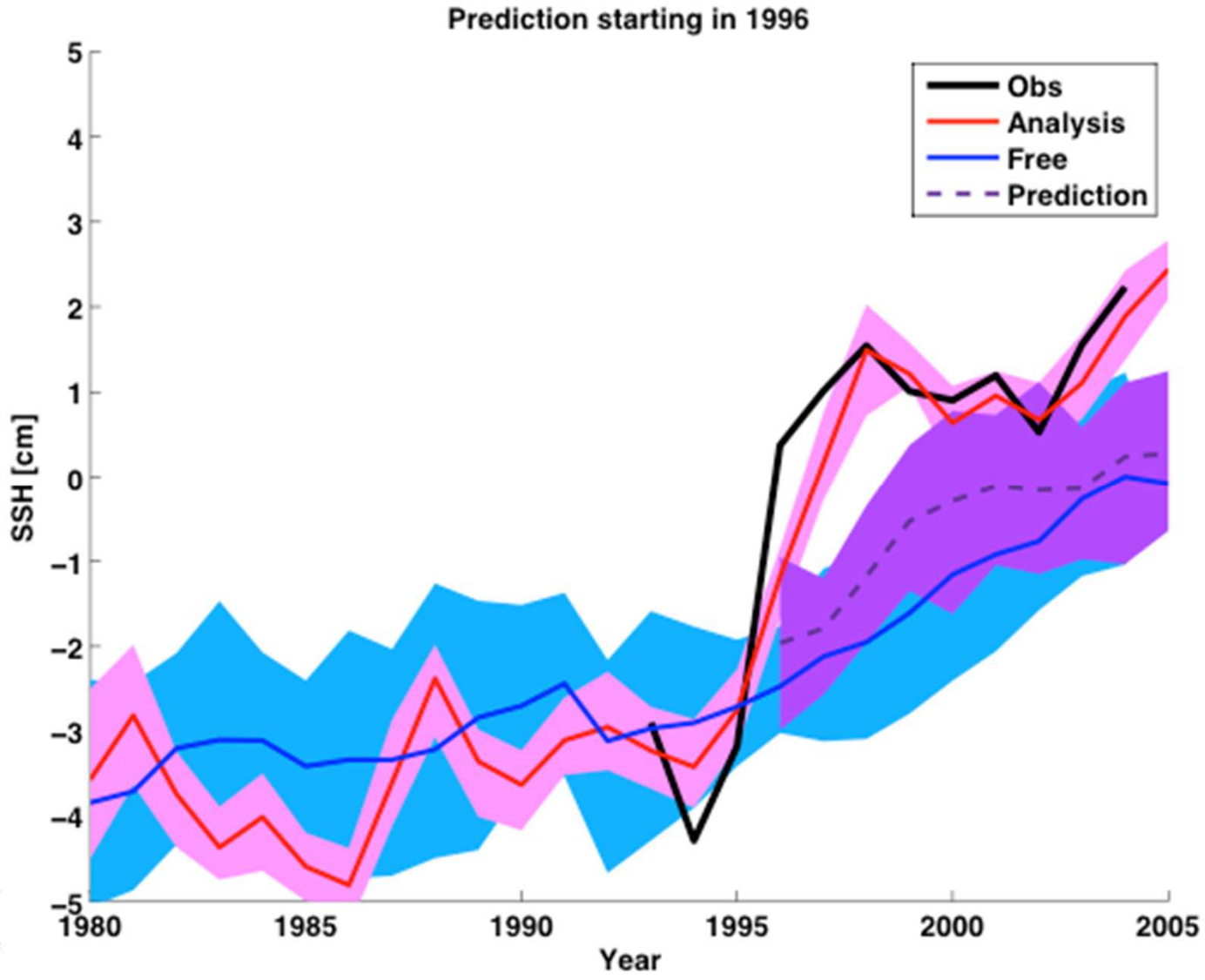
Bjerknes Centre for Climate Research

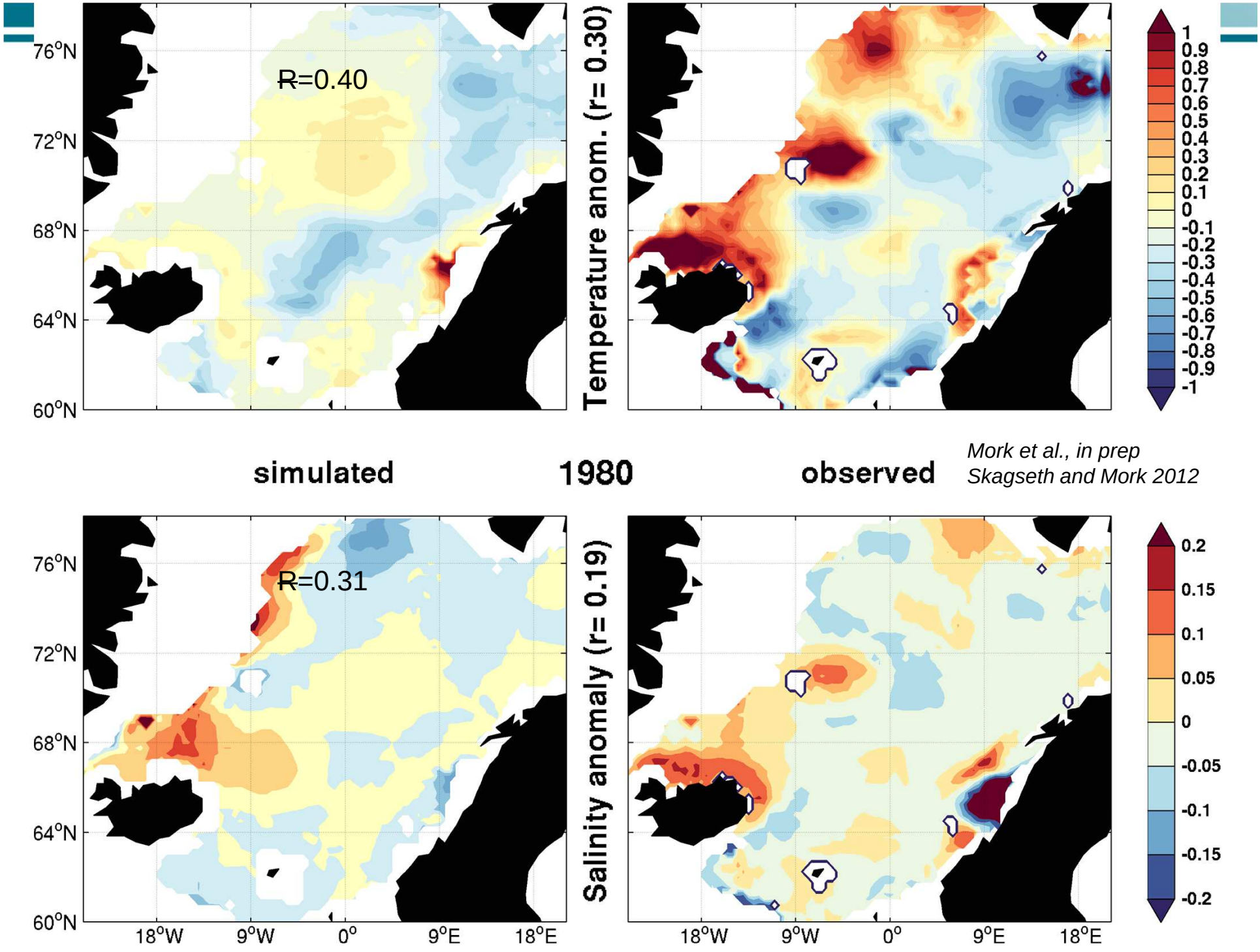
SPG index
Prediction



Bjerknes Centre for Climate Research

SPG index
Prediction




R=0.40
Temperature anom. (r= 0.30)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
76°N
72°N
68°N
64°N
60°N
simulated
1980
observed
Mork et al., in prep
Skagseth and Mork 2012
R=0.31
Salinity anomaly (r= 0.19)
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
18°W
9°W
0°
9°E
18°E

Conclusion

Primary test with real SST observations for 1980-2006 completed

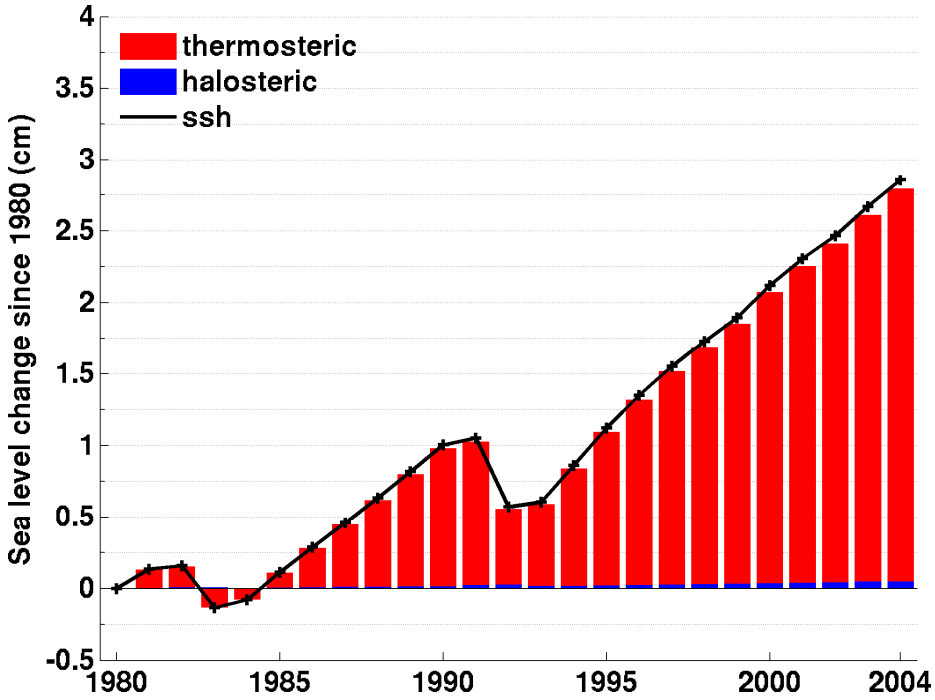
- Good match with SPG index, Nordic Sea Atlantic layer water property
- Poor skill in prediction mode (SPG and Nordic Sea Atlantic Layer)
  - A bit unclear if this is caused by:
    - Assimilation imbalance ?
    - Poor model skill ?

Assimilation in a lagrangian vertical coordinate system found to cause a small drift

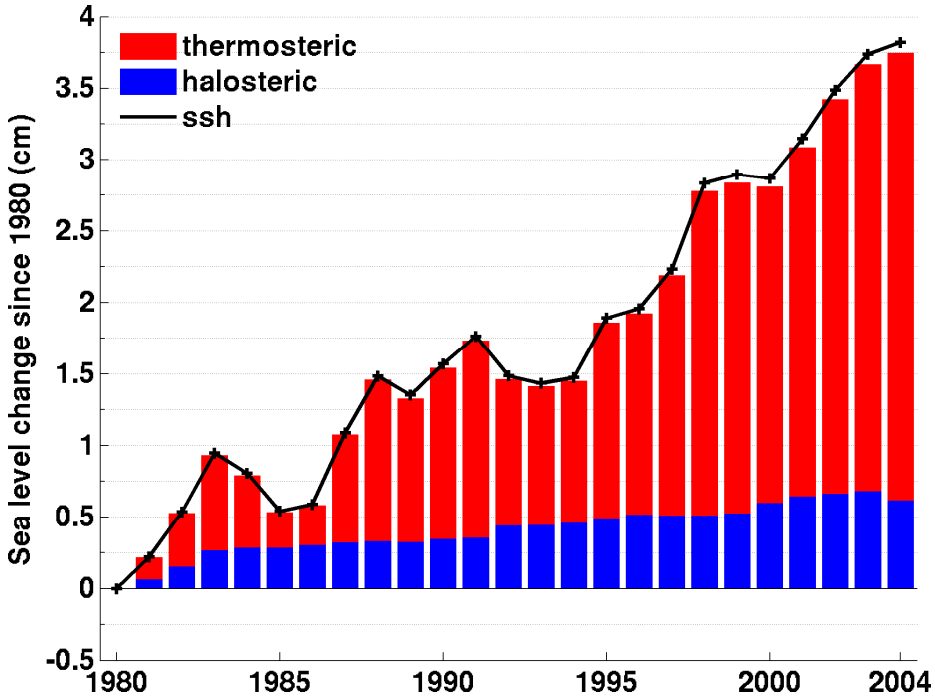
➔investigating assimilation drift using a idealized 1-column model seems to have identified a configuration that suppress DA drift

Global mean SSH

Free run

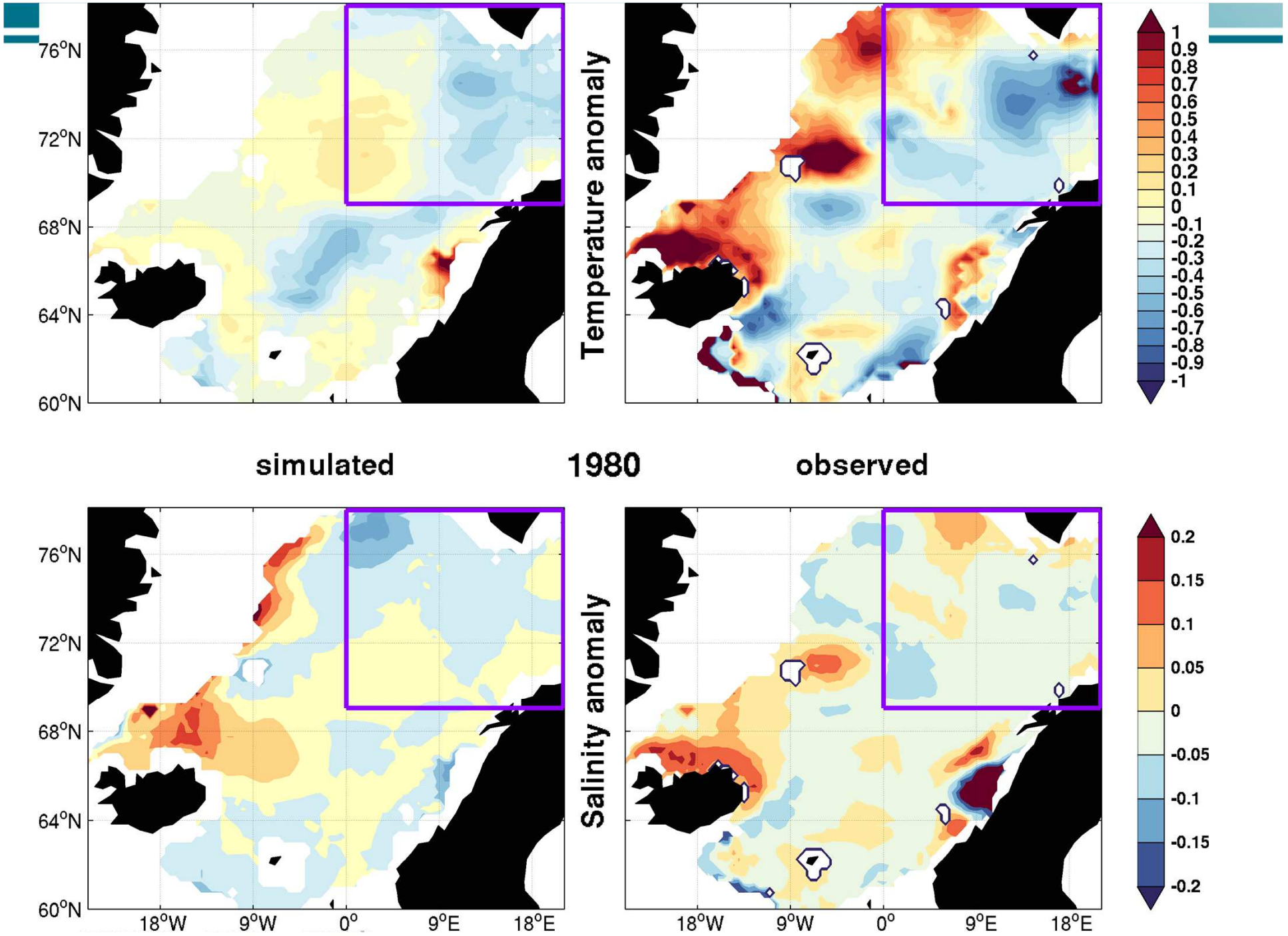


Analysis

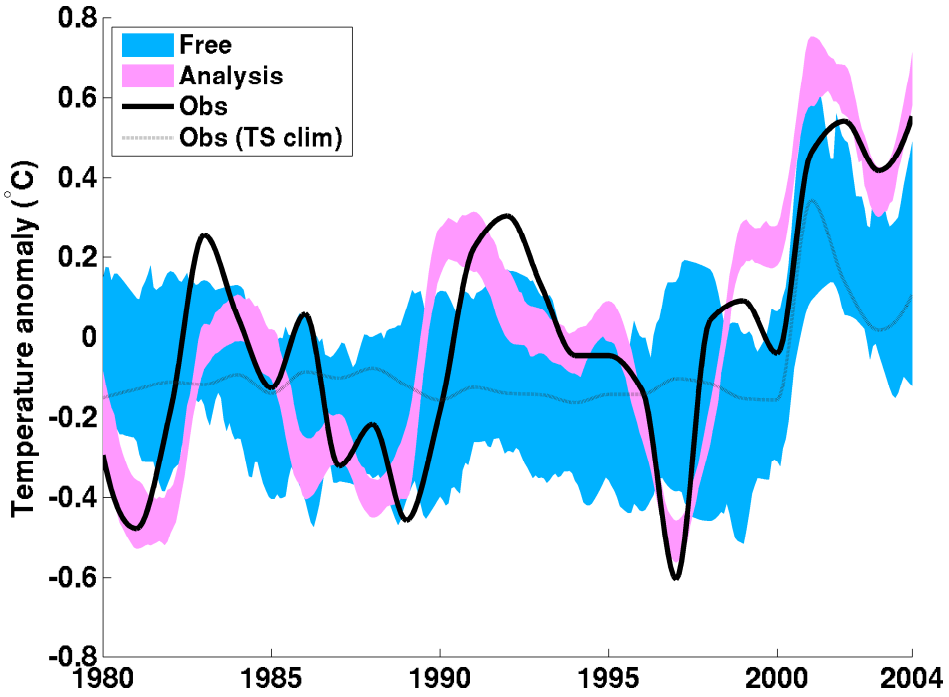


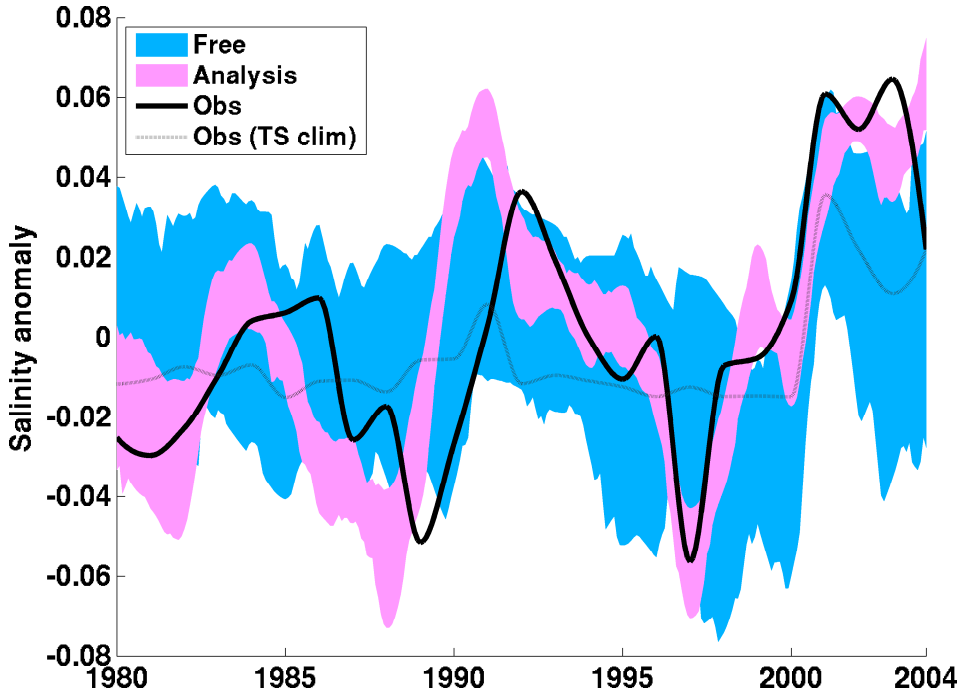
Assimilation creates a increase MSSH drift

response to a drift in temperature and salinity caused by assimilation


76°N
72°N
68°N
64°N
60°N
18°W
9°W
0°
9°E
18°E
Temperature anomaly
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
simulated
1980
observed
Salinity anomaly
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2

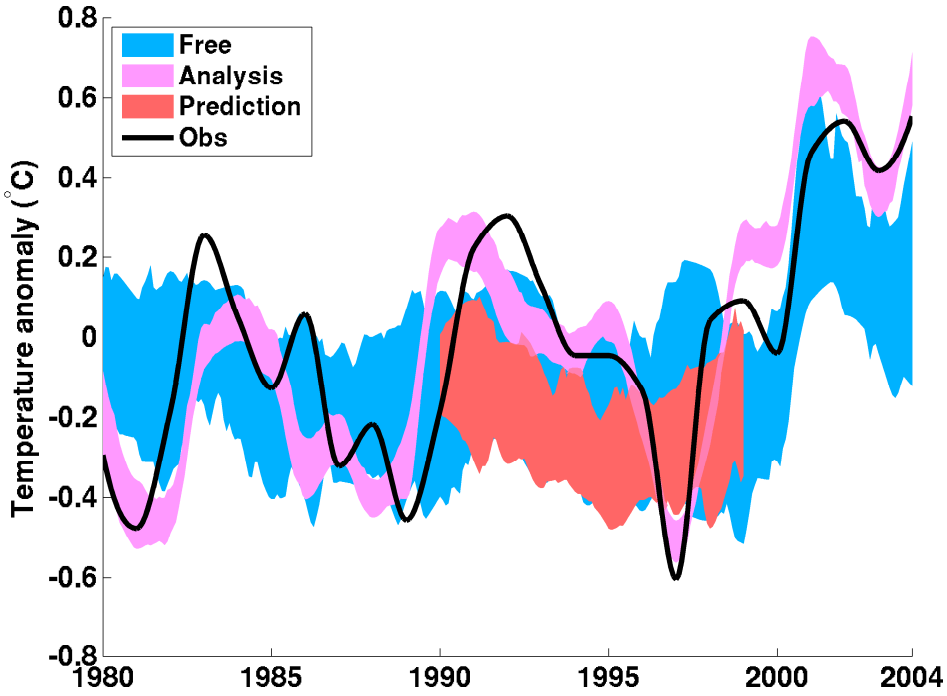
Nordic Sea Atlantic Layer

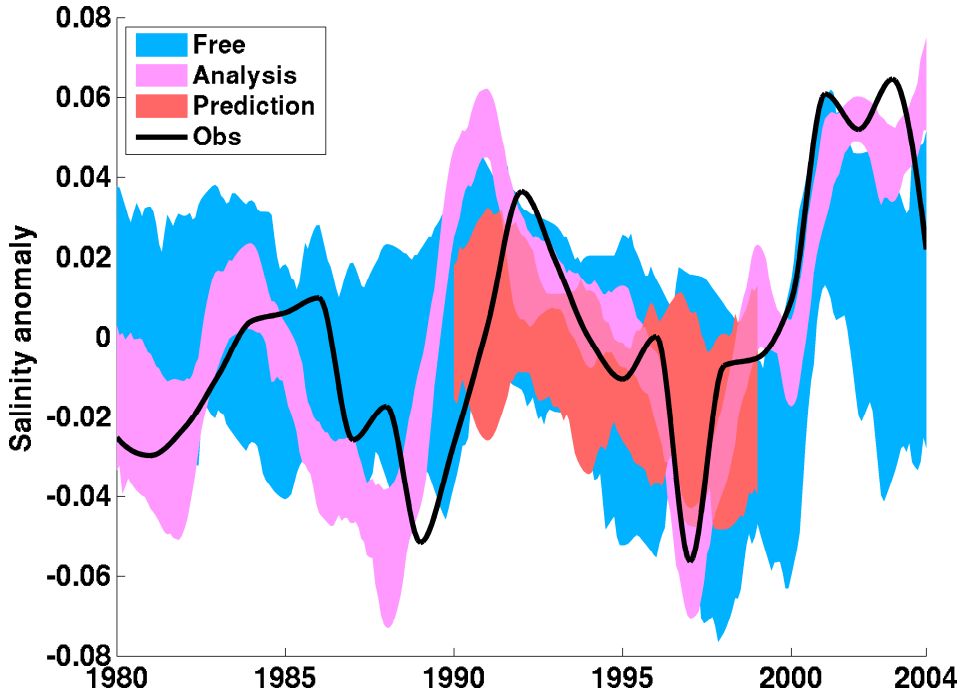




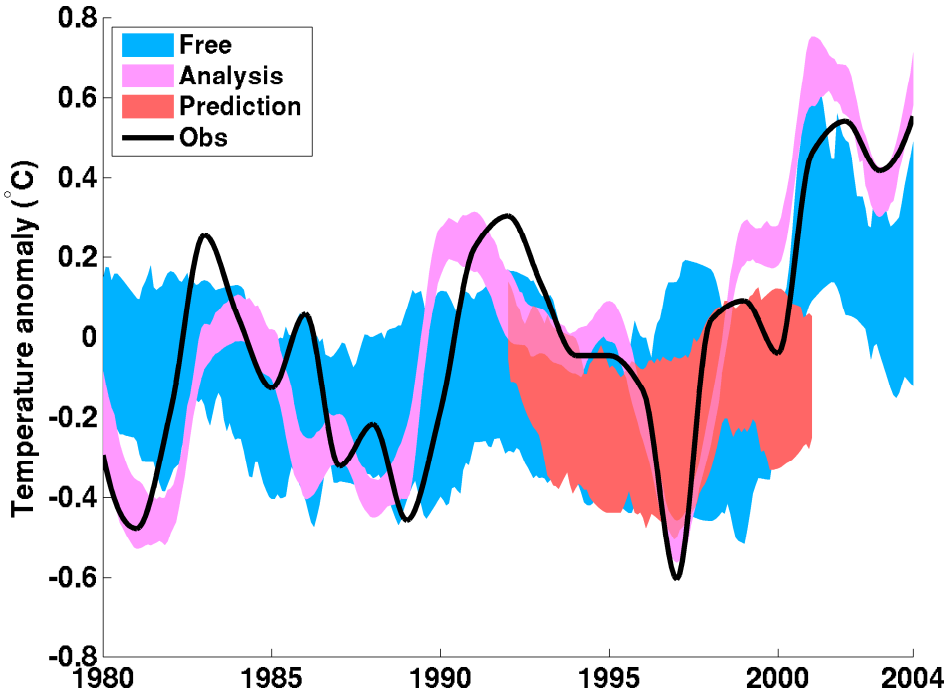
Nordic Sea Atlantic Layer

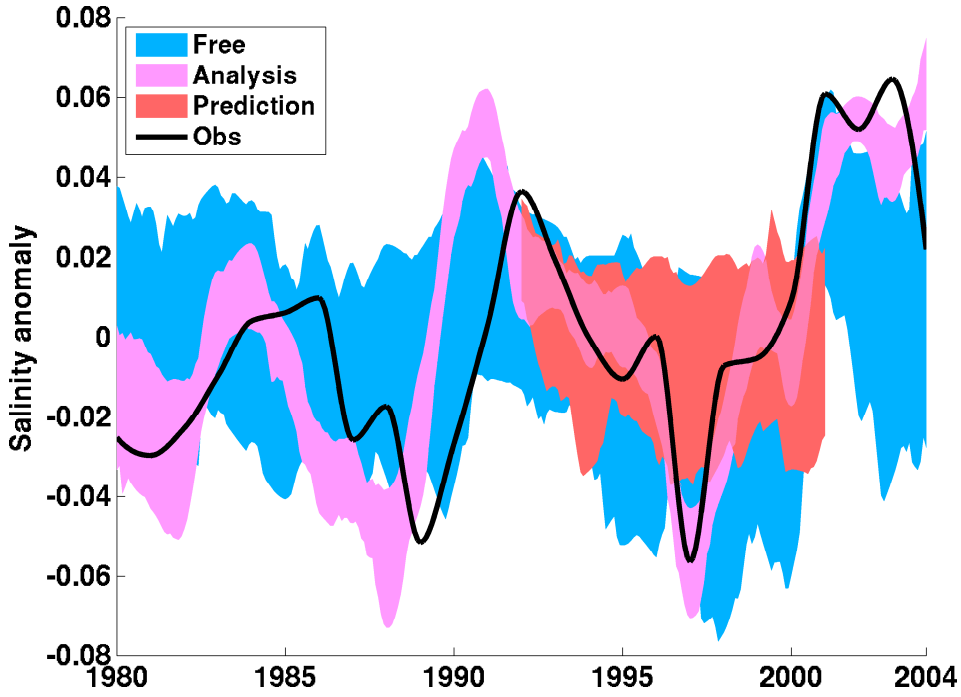
1990 Prediction



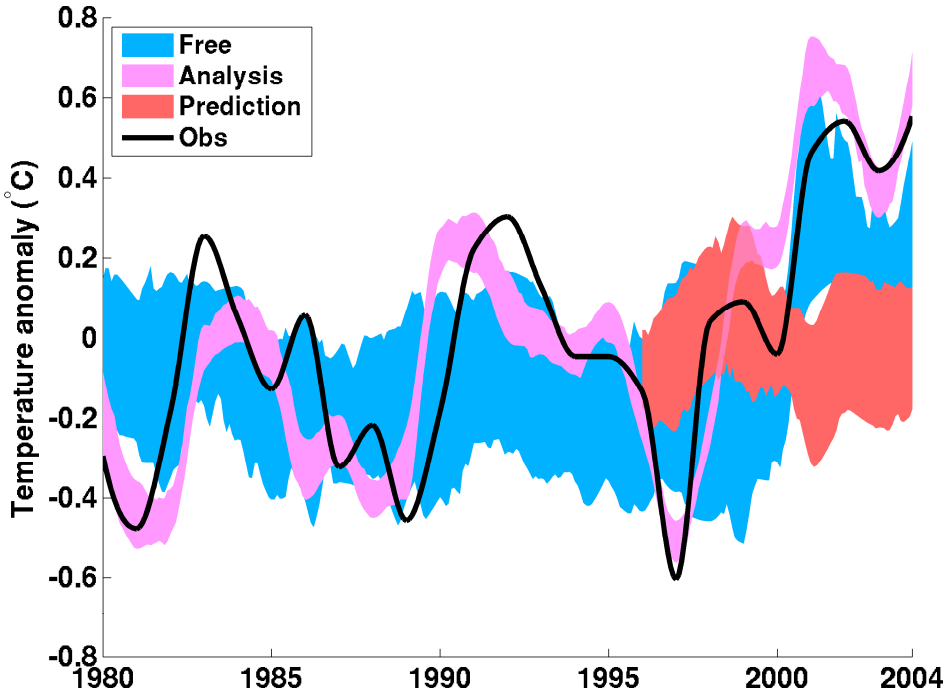


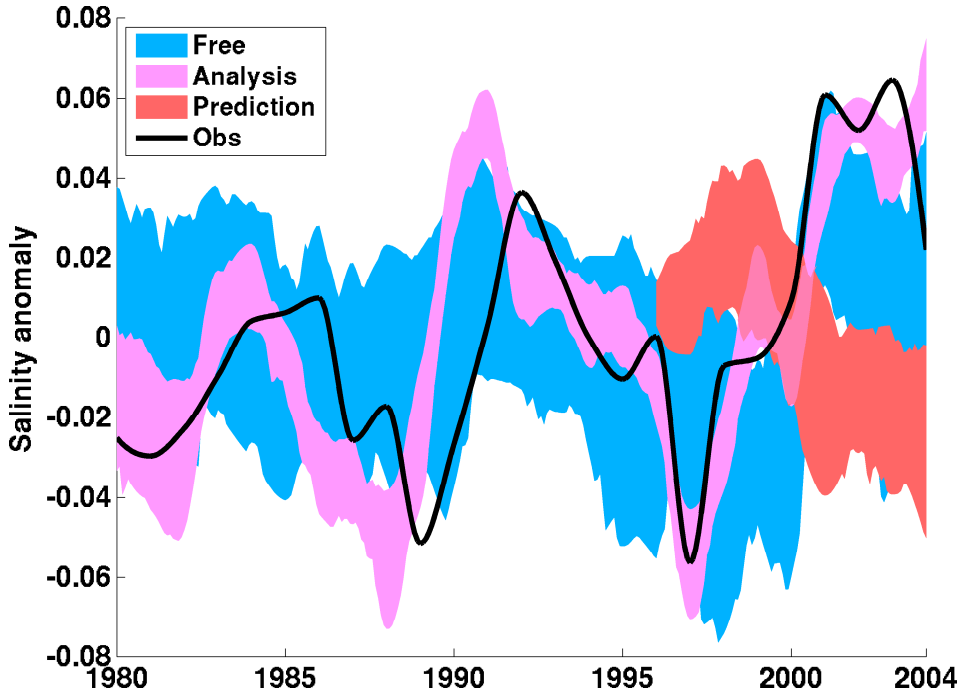
Nordic Sea Atlantic Layer 1992 Prediction



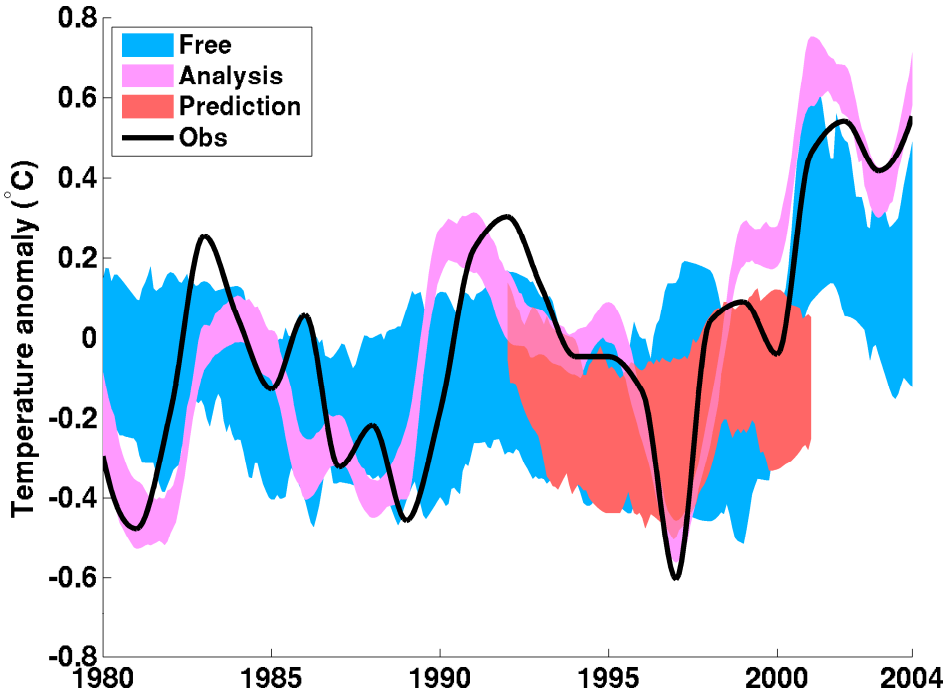


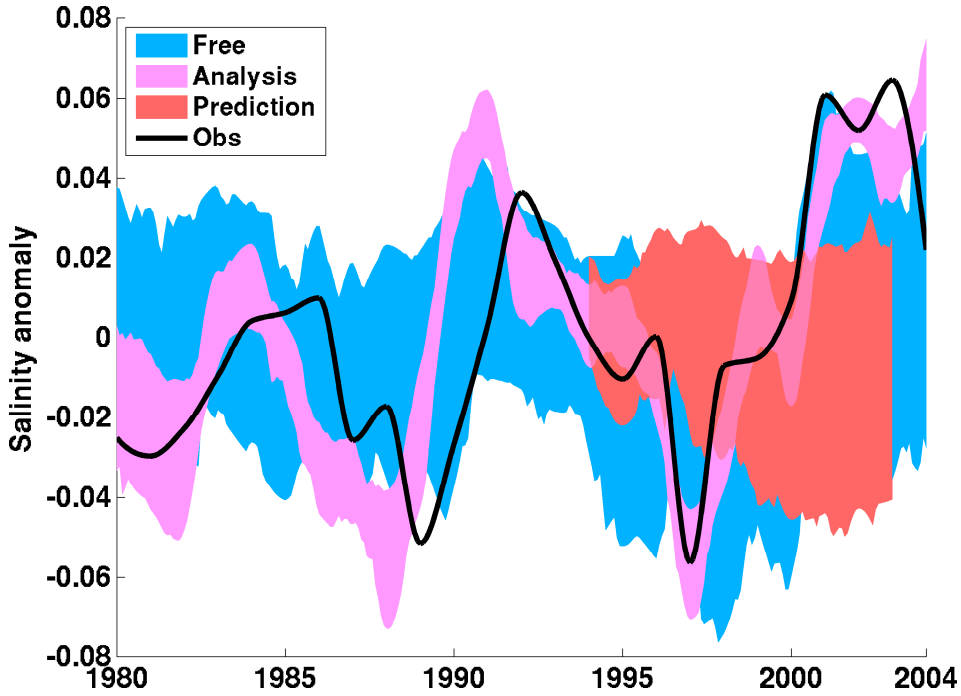
Nordic Sea Atlantic Layer 1994 Prediction





Nordic Sea Atlantic Layer 1996 Prediction





Assimilation drift

Calculate the model drift (steric) over the period 1980-2005

	Global T	Global S	Global SSH
FREE			2.6
ASSIM			3.5
OBS			2.86 +-0.8

Drift caused by assimilation in a lagrangian vertical coordinate system

➔investigating assimilation drift using a idealized 1-column model

Identified model state vector which would suppress model drift