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Quantifying uncertainty in coupled forecasts

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In collaboration with many people from the Navy ESPC effort

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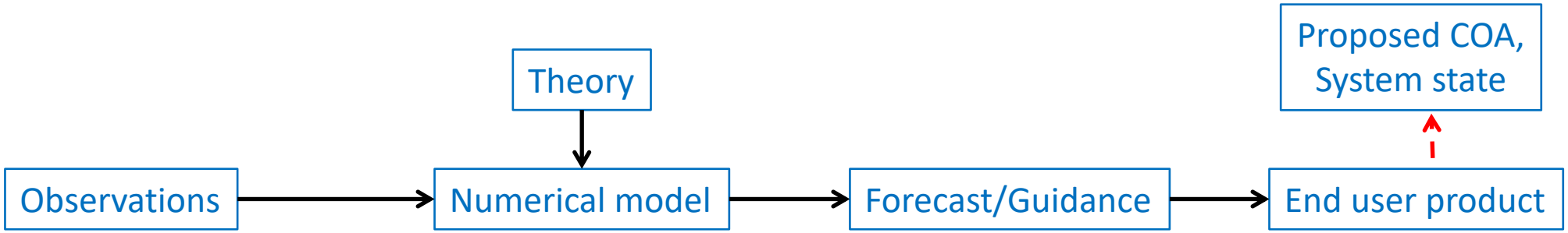
Overview

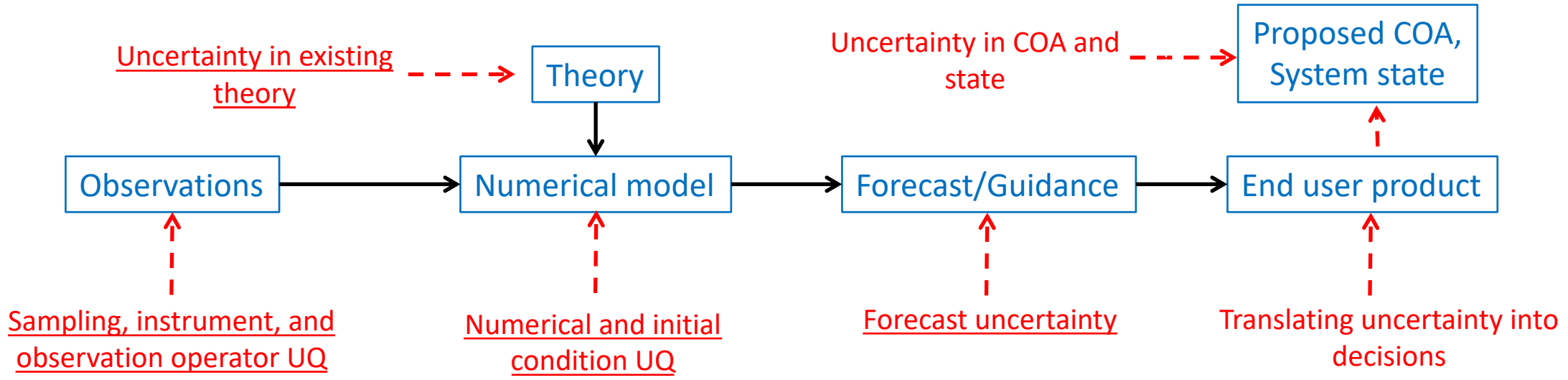
- UQ and the Navy decision chain.
- Focus on forecast UQ.
- Example of Navy Earth System Prediction Capability:
  - System description,
  - Uncertainty in Initial conditions,
  - Uncertainty in the model forecast.

Uncertainty quantification chain



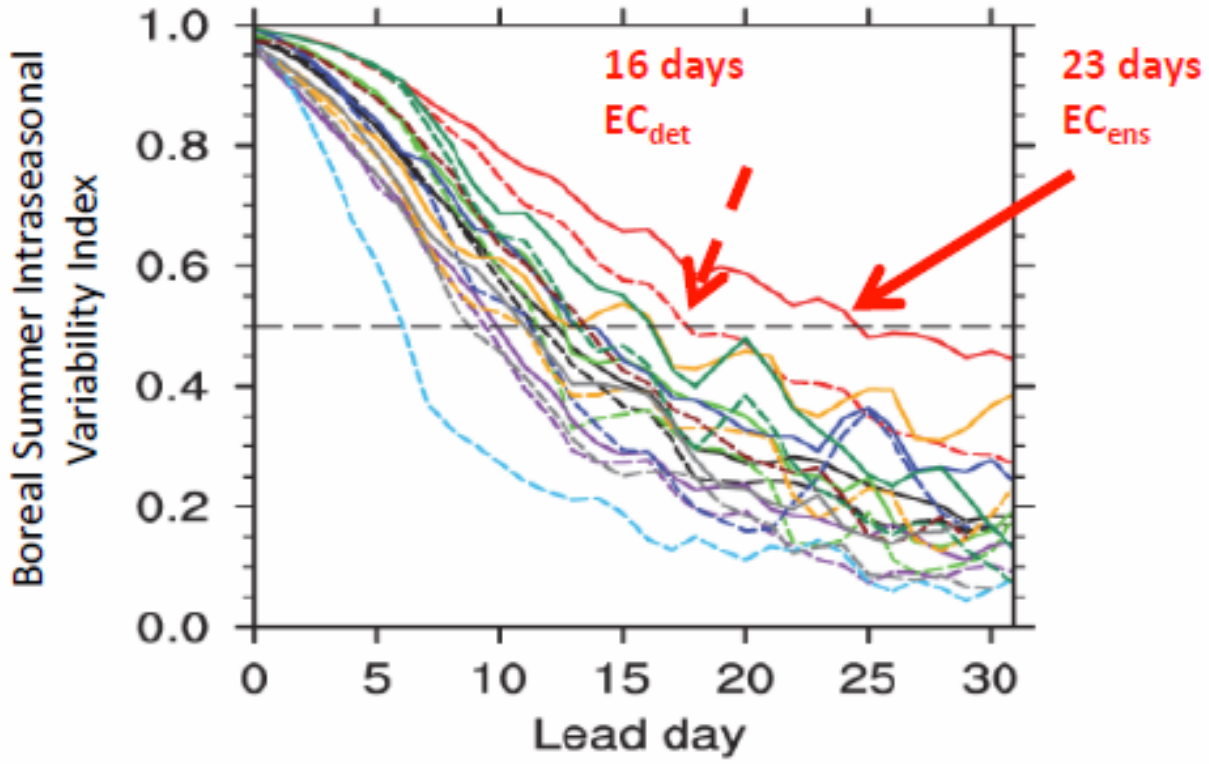
- Typical NAVY decision pipeline starts with observations (events) and ends with a Courses of Action (COA).

Uncertainty quantification chain



- Typical NAVY decision pipeline starts with observations (events) and end in COA (Courses of Action).
- Uncertainty enters Navy pipelines in multiple ways.
- I will talk about “traditional” UQ in the forecast system.

Model forecast and ensembles



- Multi-model ensemble mean outperforms each individual ensemble member and the high-res model from ECMWF
  - Ensemble mean verifies better because it is smoother than either the high-res or individual forecasts
  - Ensemble mean is a better predictor for propagation of the distribution with a non-linear model

From Jie et.al. (2017)

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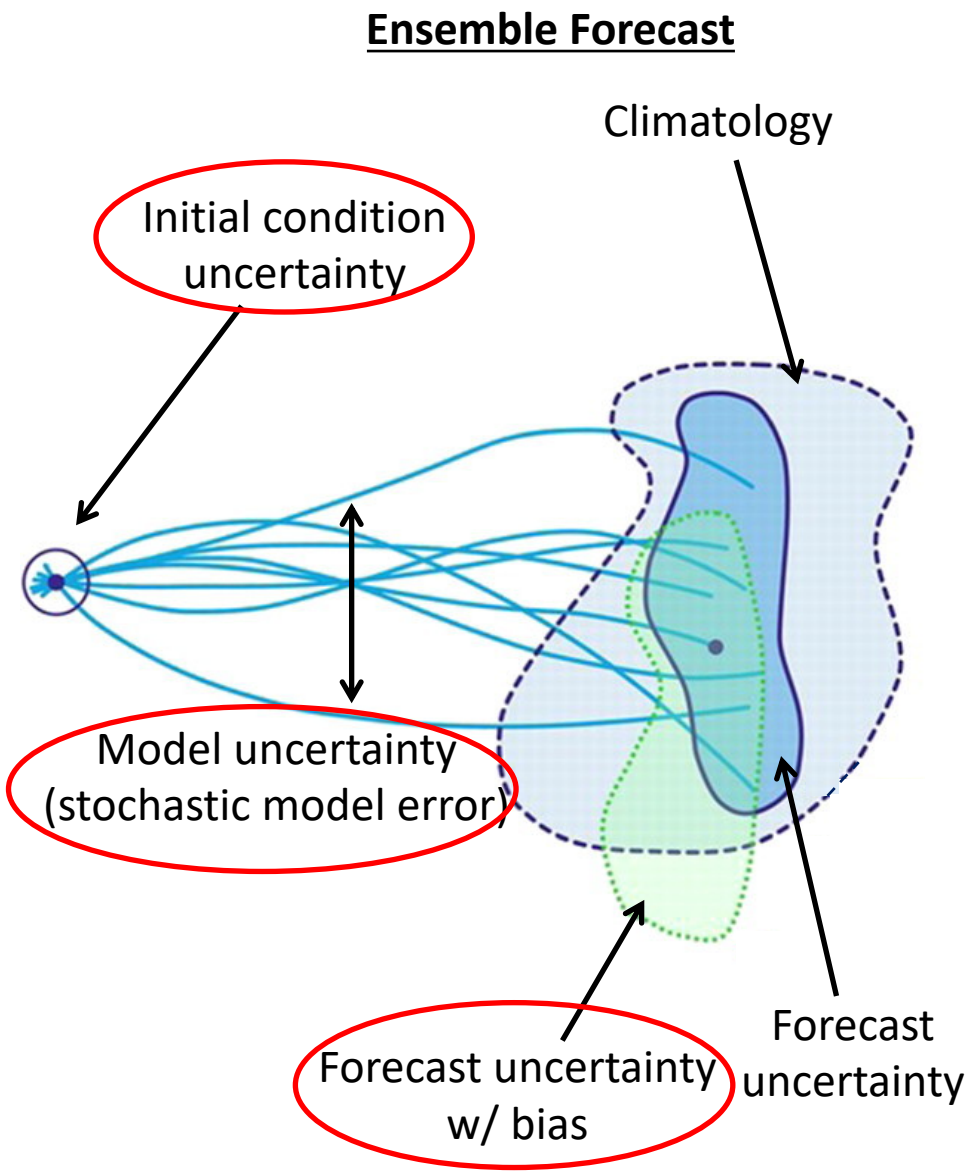
Primer on ensemble forecasting



From Slingo and Palmer (2011)

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Navy ESPC configuration

The Initial Operational Capability (IOC) is scheduled for the end of FY19, with Final Operational Capability (FOC) at the end of FY22. Both a high resolution deterministic and lower resolution probabilistic ensemble will be run.

Horizontal and vertical resolution at IOC

Forecast	Time Scale, Frequency	Atmosphere NAVGEM	Ocean HYCOM	Ice CICE	Waves WW3[1]	Land-Surface NAVGEM-LSM	Aerosol
Deterministic short term	0-16 days, daily	T681L80 (19 km) 60 levels	1/25° (4.5 km)[2] 41 layers	1/25° (4.5 km)	1/8° (14 km)	Module within NAVGEM	Module within NAVGEM
Probabilistic long term	0-45 days, weekly[3] 16 members	T359L60 (37 km) 60 levels	1/12° (9 km)[2] 41 layers	1/12° (9 km)	1/4° (28 km)	Module within NAVGEM	Module within NAVGEM

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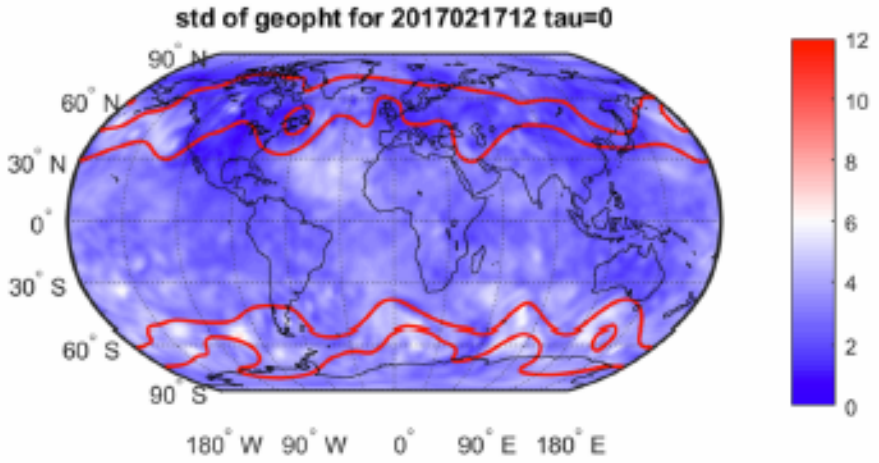
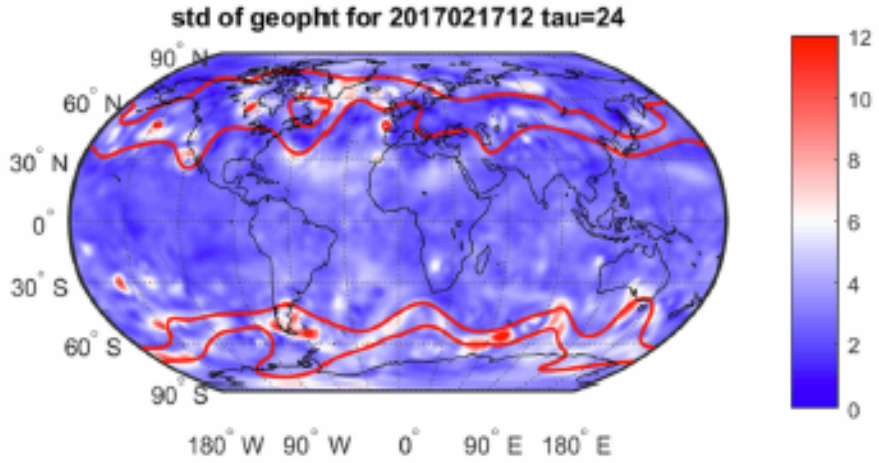
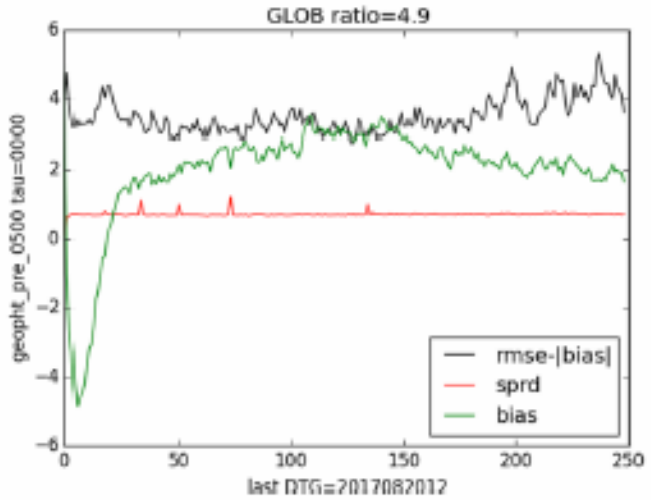
Design of Navy-ESPC ensemble system

- Ensemble of data assimilations
  - 16 replicate data assimilation systems a executed in parallel,
  - 15 members assimilate randomly-perturbed observations, and
  - 1 control member with un-perturbed observations.
- Benefits:
  - Easy to implement,
  - Good foundation for all further system developments.
- Known issues:
  - Ignores model error,
  - Overconfidence in highly observed areas (e.g. atmosphere),
  - Can be significantly under spread at initial time.

Uncertainty in initial conditions: atmosphere



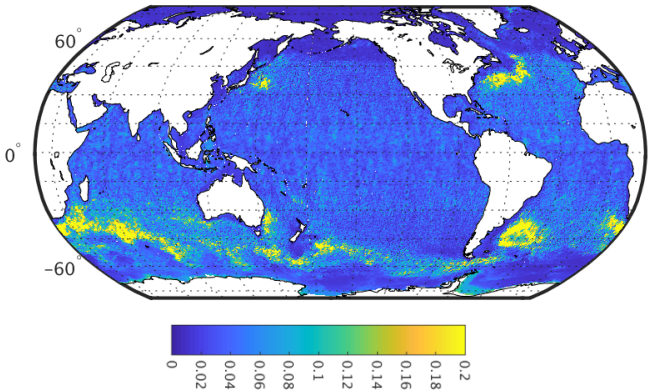




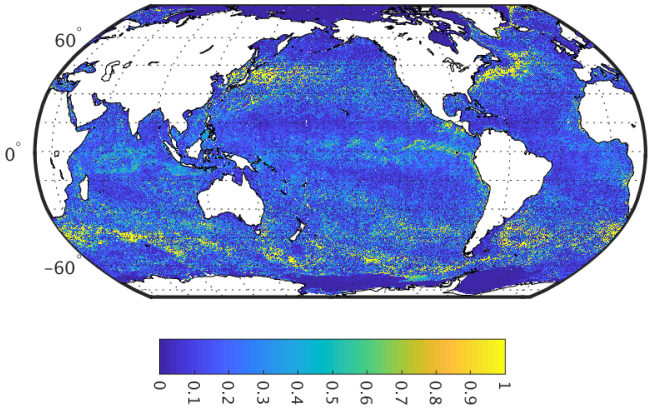
- (left) We have realistic patterns of spread in the atmosphere (higher spread around the storm track).
- (above) As expected, the absolute magnitude of spread is too low (factor of 3-7)
- Work is currently underway to calibrate the spread using experience of UKMO (Bowler et.al. 2016):
  - Relaxation to prior perturbations
  - Analysis correction additive inflation

Uncertainty in initial conditions: ocean

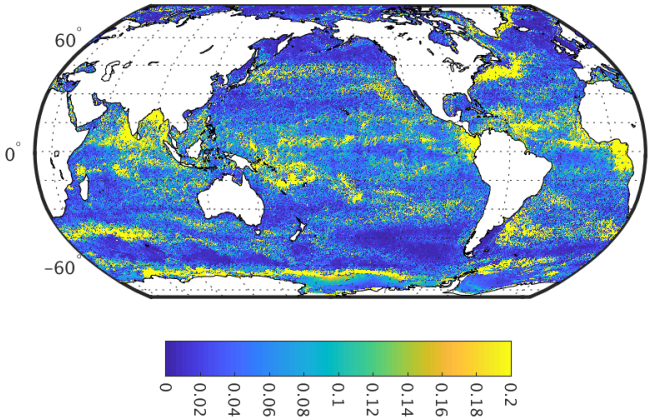
Standard deviation SSH (m)



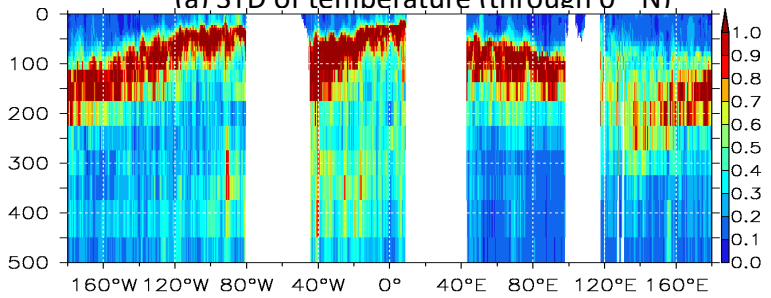
Standard deviation SST (K)



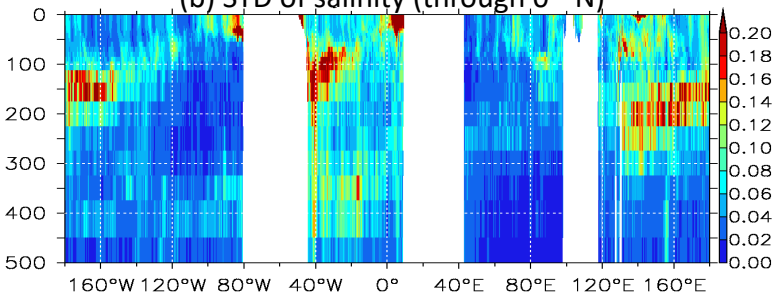
Standard deviation SSS (psu)



(a) STD of temperature (through 0 ° N)



(b) STD of salinity (through 0 ° N)

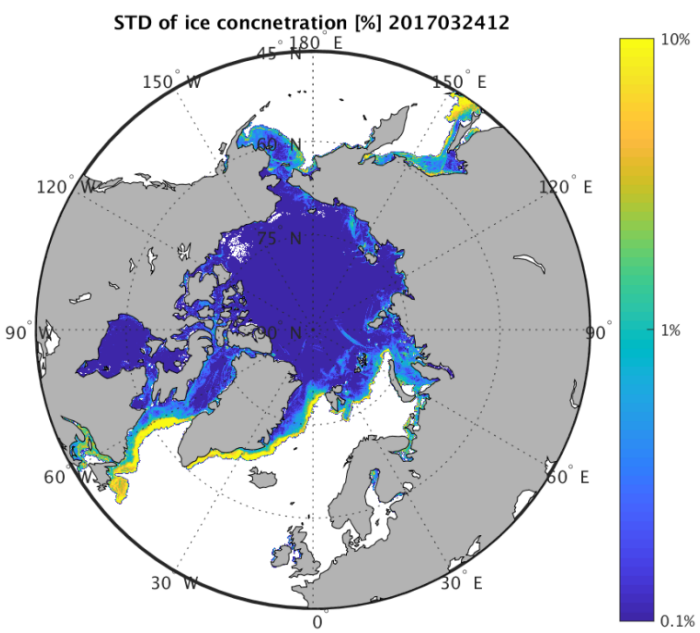


E. Pacific O. Atlantic O. Indian O. W. Pacific O.

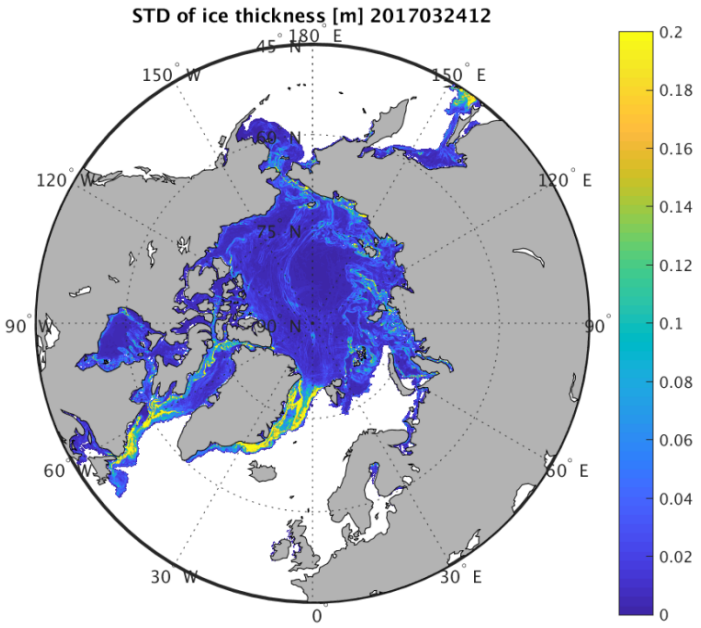
- Large IC uncertainties in:
  - location of boundary currents;
  - Impact of Tropical precipitation;
  - Tropical instability waves.
  - Location of the thermocline;
  - Location of ice edge.

Uncertainty in initial conditions: ice (winter)

STD ice conc. (20170324)



STD ice thickness (20170324)

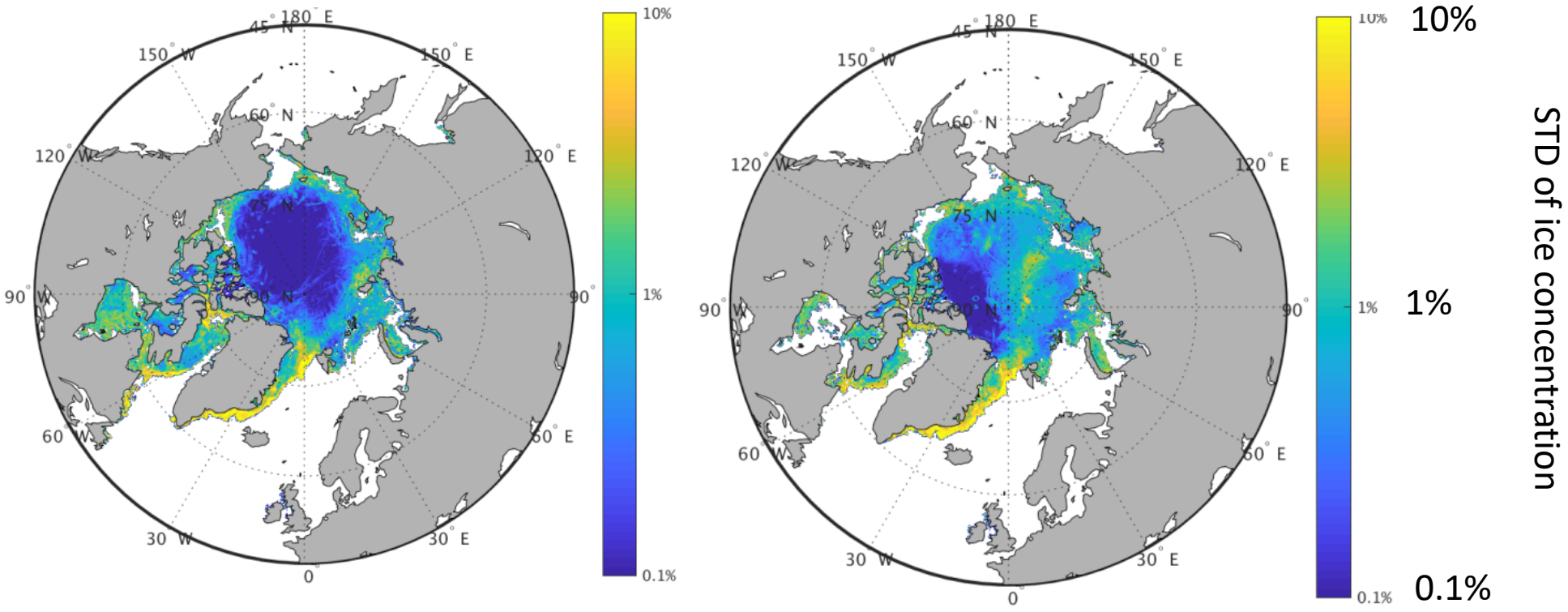


- Ice concentration:
  - Large along the Atlantic ice edge.
  - Low along the Pacific ice edge.
  - Very low in the middle of the winter ice pack.
- Ice thickness:
  - Very high along the Atlantic ice export path.
  - High along the ice linear kinematic features.

Uncertainty in initial conditions: ice (summer)

Before Arctic cyclone
(2017/06/16)

Before Arctic cyclone
(2017/07/07)



- Impact of Arctic storms is very pronounced in the Arctic interior.
- Minor immediate impact of storm on the ice edge.

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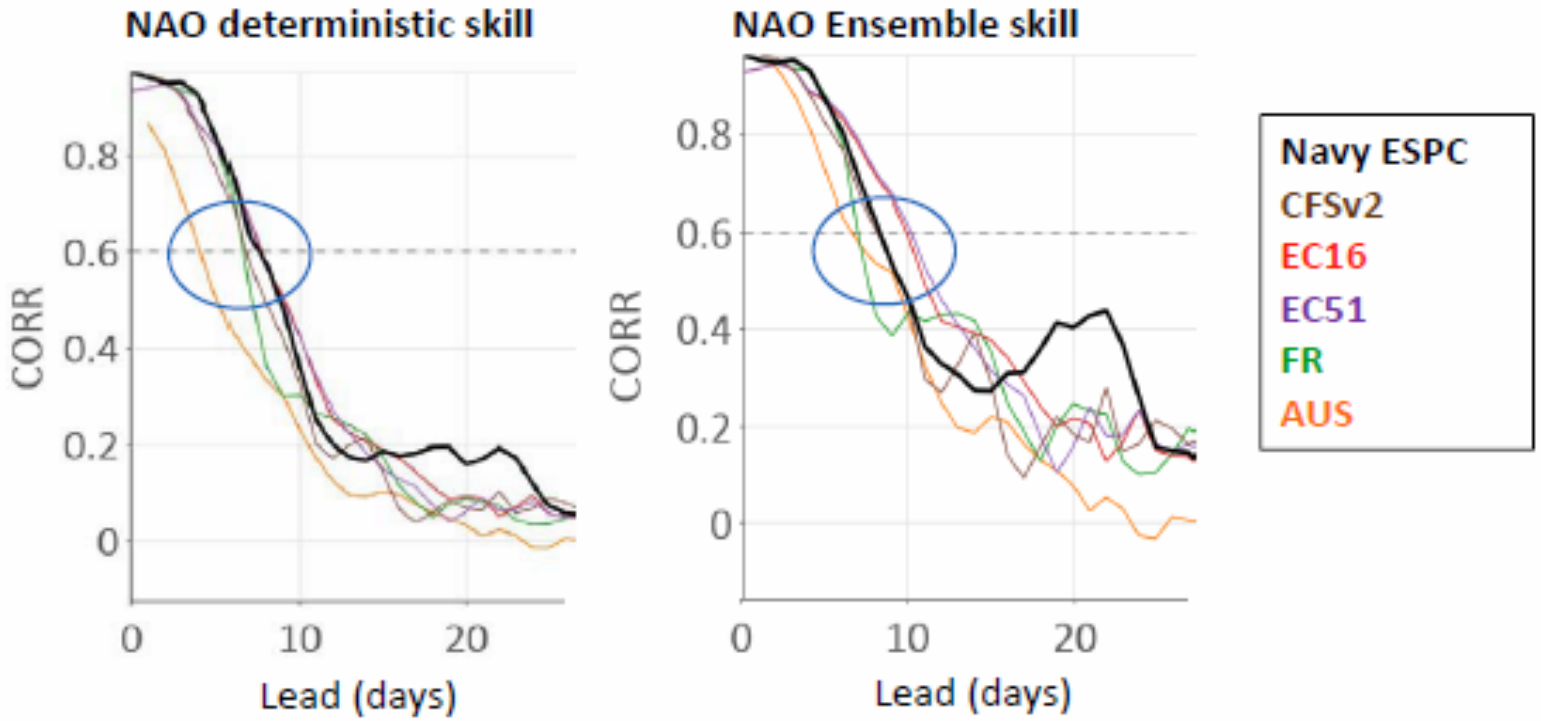
Forecast skill for the atmosphere



- In deterministic mode, skill of most credible models is similar.
- However, best forecast systems (i.e. EC) gains the competitive edge through careful ensemble design.

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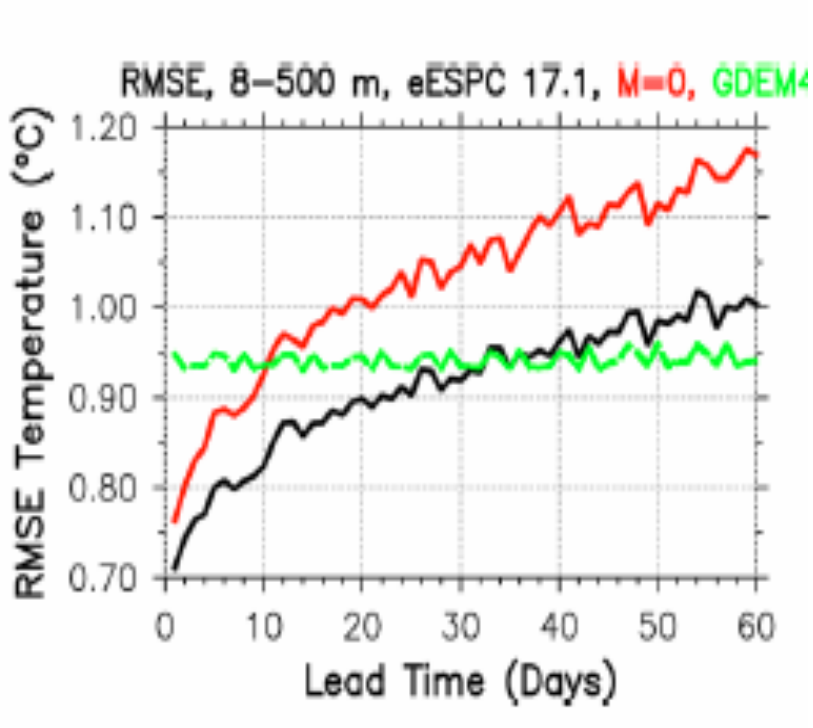
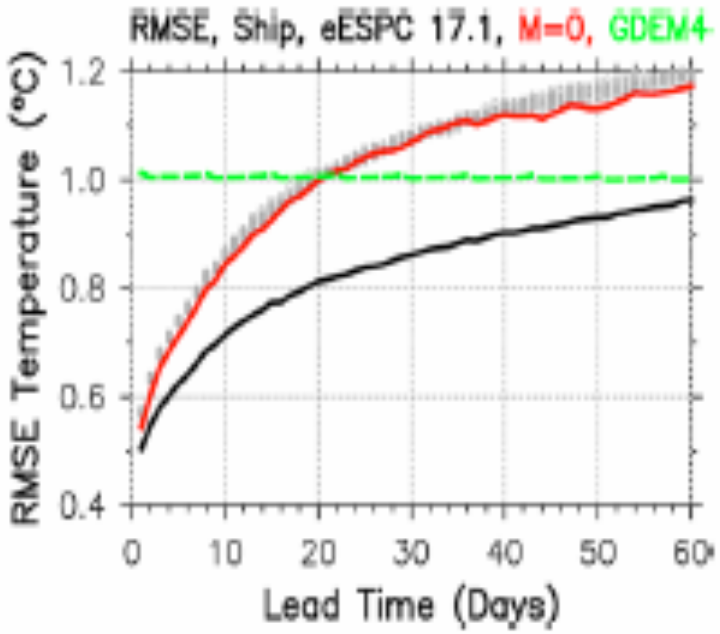
Forecast skill for the ocean

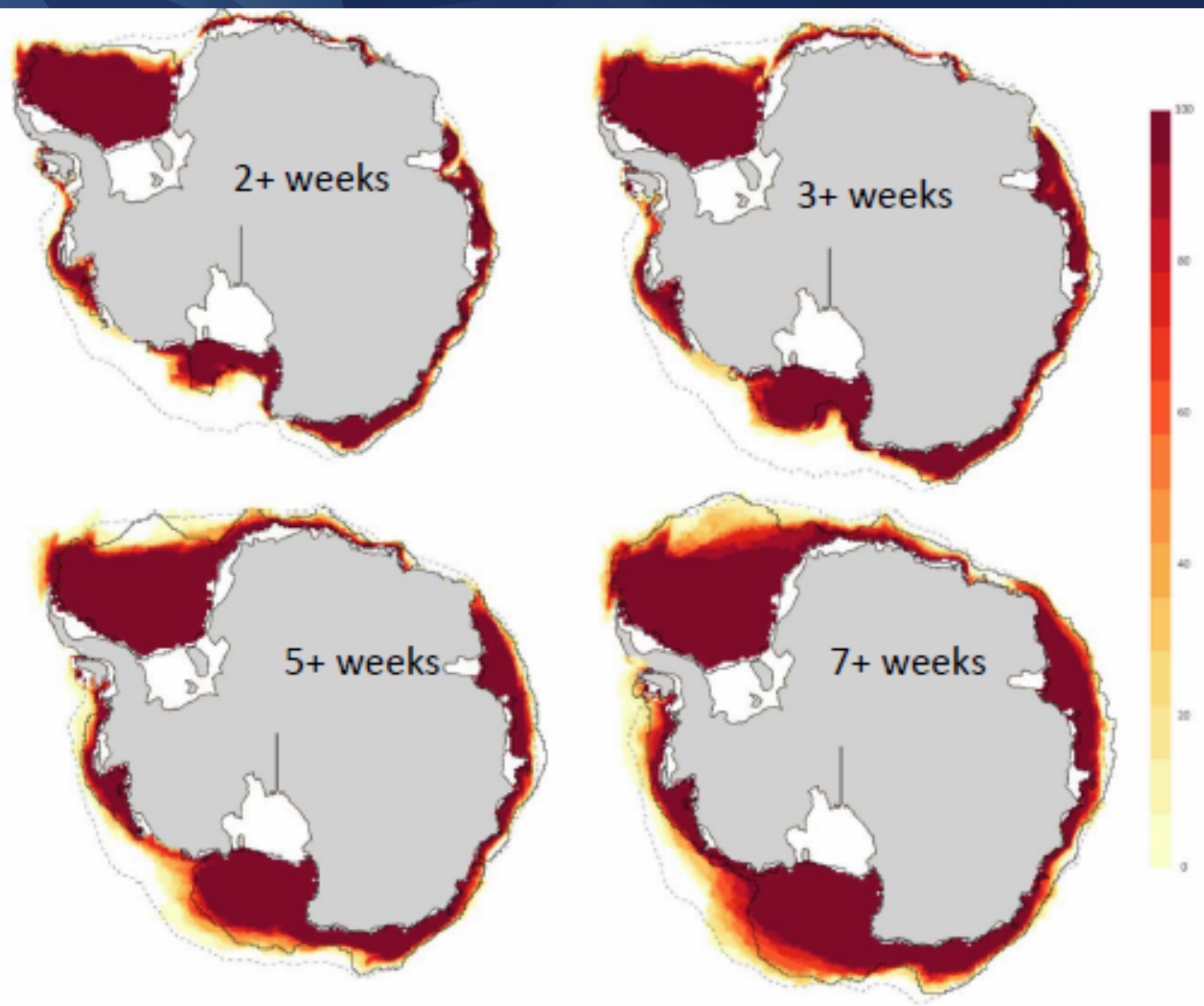




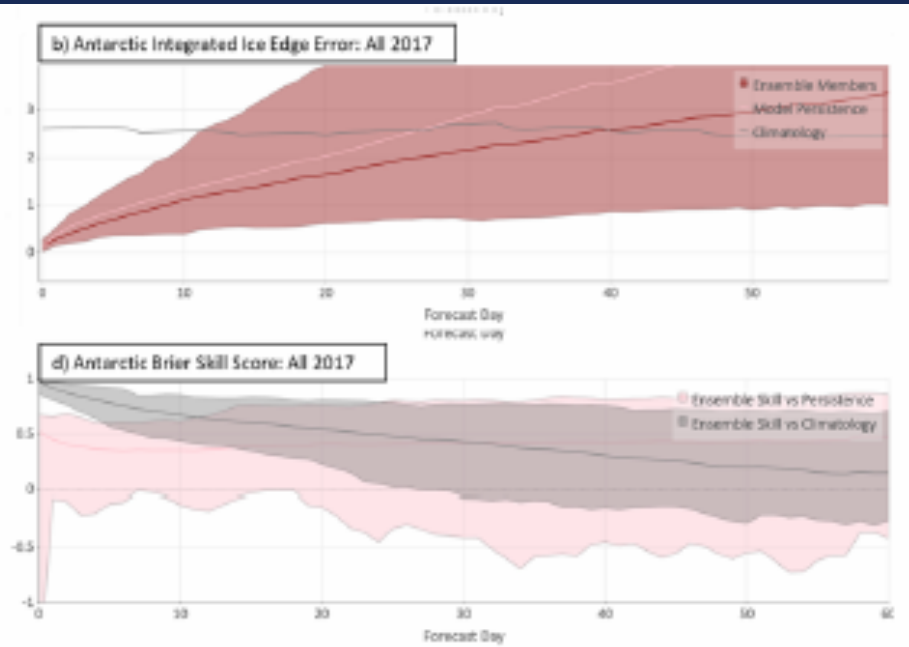
Ens. Mean
Deterministic
Climatology

- Ocean ensembles triple (!!!) the predictive skill of the deterministic system
- Ensemble impact exceeds impact of increased resolution.

Forecast skill: ice



Color: % of 15 Members in Agreement Black: NSIDC, Gray Dash: Clim. Time | Forecast Day: 2017-04-28 51



Skill>50 days

- (top) Ice forecasts appear to be skillful at > 50 days compared to 30 year cliamtology
- (right) Probabilistic forecasts (shaded color) adds significant information

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End

- Navy-ESPC ensemble and S2S system
  - Passed the initial development, undergoing evaluation and operational transition.
- Initial results show:
  - UQ (ensemble forecast) adds significant skill to the forecast in all fluids.
  - Atmosphere is under spread but better spread in the ocean and ice.
- Final operating capability development has commenced
  - Addresses under-spread of atmospheric variables.