Large case benchmark: NATL025 NEMO configuration

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Model description

NATL025 configuration of the NEMO model:

- domain: $20°$S - $80°$N, $98°$W - $23°$E
- horizontal resolution: $\frac{1}{4}^{\circ}$
- vertical levels: 46 levels between ~ 3 m and 6000 m in depth
- time integration: a leap frog scheme with time step 2400 s
- ERAinterim atmospheric forcing
- Initial conditions: Levitus climatology for T and S, 0 for ssh, u, v, w
- spin up time: 16 years (January 1989 - January 2005)

Observation

Observation for assimilation

- Sea surface height: Jason-1 track, observation error 5 cm
- Sea surface temperature: composed AVHRR, error map (standard deviation of analysed sst)
- Temperature profile: ARGO, observation error 0.3°

Observation for validation

- Sea surface height: Envisat track
- Sea surface temperature: Mercator reanalysis
- Salinity profile: ARGO

Observation localization

- Observation weight function:

$$w = exp(-\frac{r^2}{d^2})$$

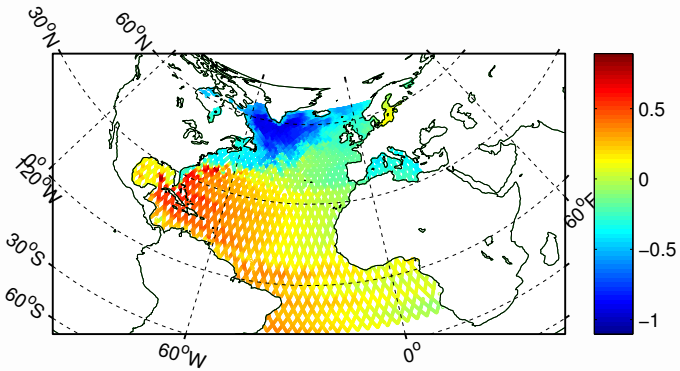
(d: correlation length, r: distance from the considered water column)

- autocorrelation length of model variables:
  - ssh: 200 km
  - sst: 400 km
- Localization length-scale: 300 km
- Maximum correlation length: 3000 km

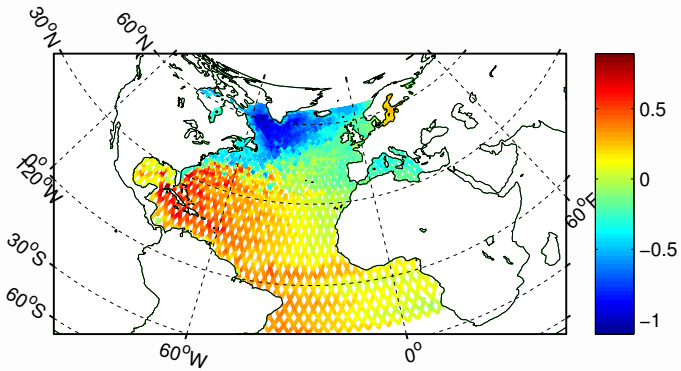
Ensemble generation

- 60 members
- perturbation in forcing variables: u, v, t, radlw, radsw (related to SST)
- Fourier decomposition of the forcing variables vector (Barth et al. 2011)
- Monthly variability taken into account
- ensemble validation: ensemble spread / RMS misfit of the model prediction and observations at the end of the ensemble spin-up

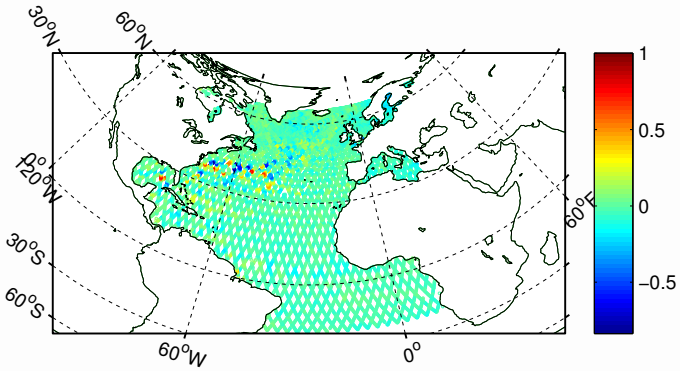
Ensemble validation: SSH



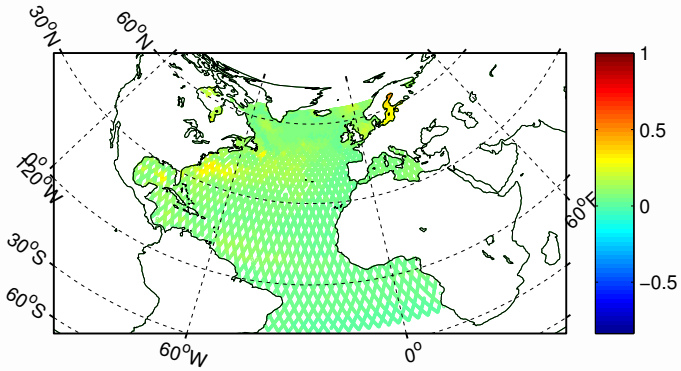
model



observation

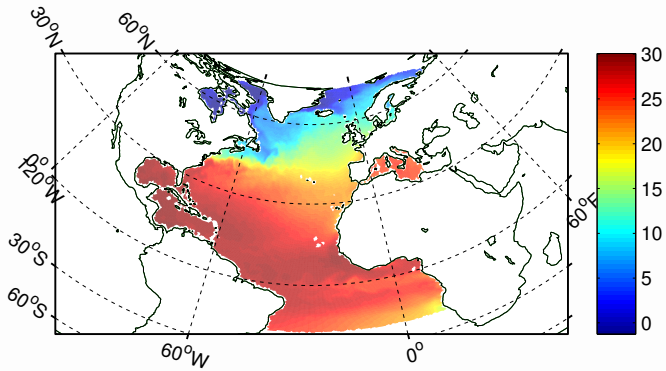


model - observation

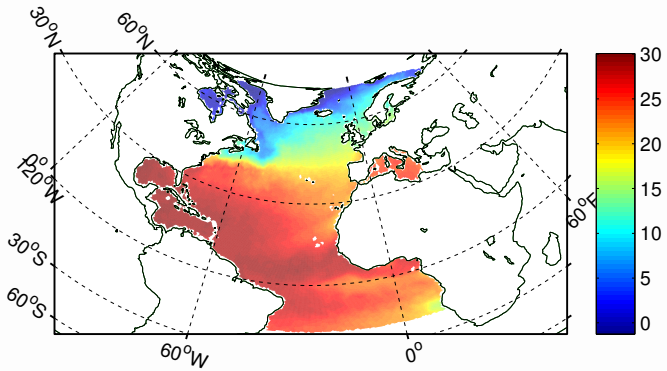


ensemble spread

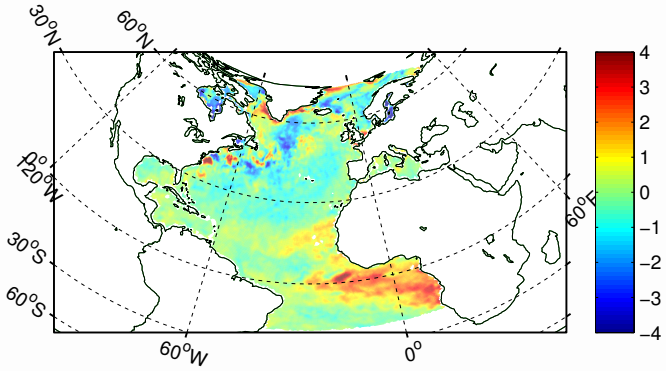
Ensemble validation: SST



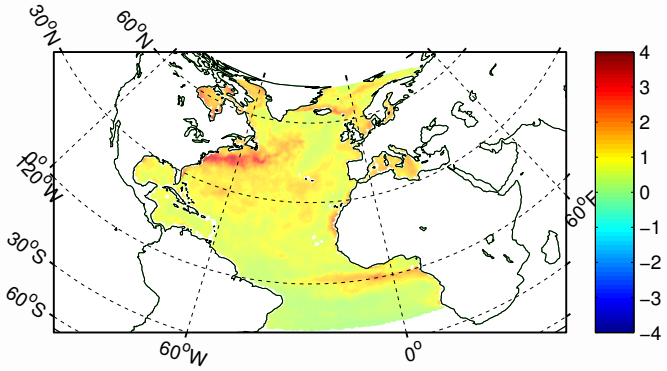
model



observation

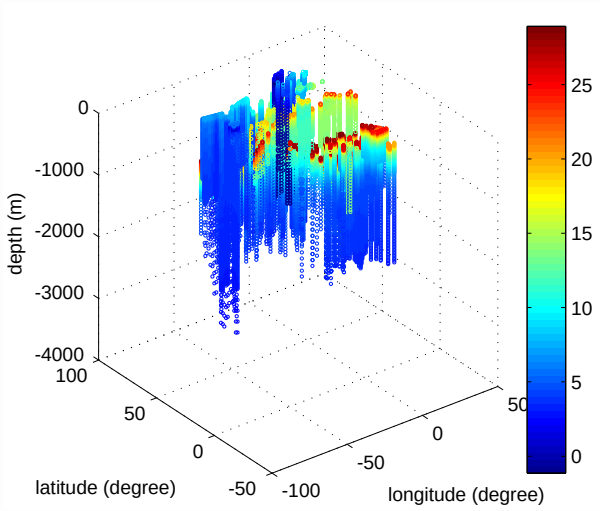


model - observations

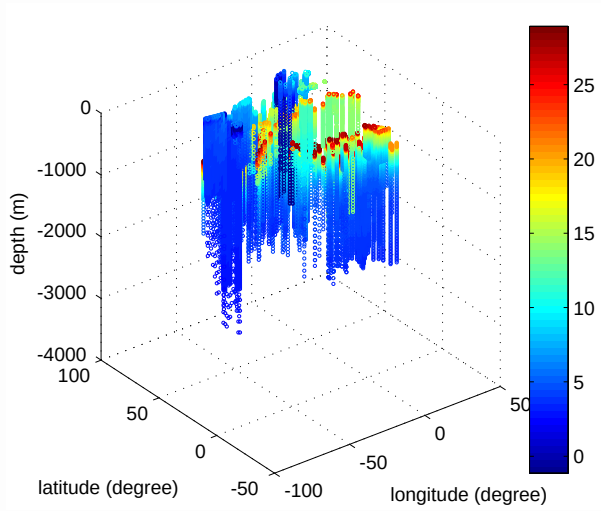


ensemble spread

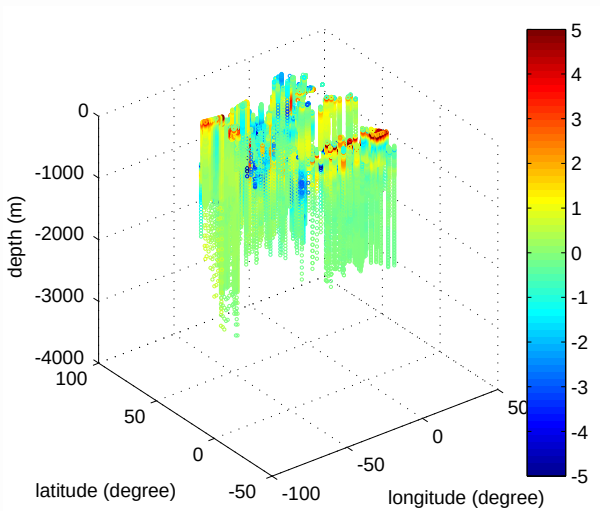
Ensemble validation: temperature profile



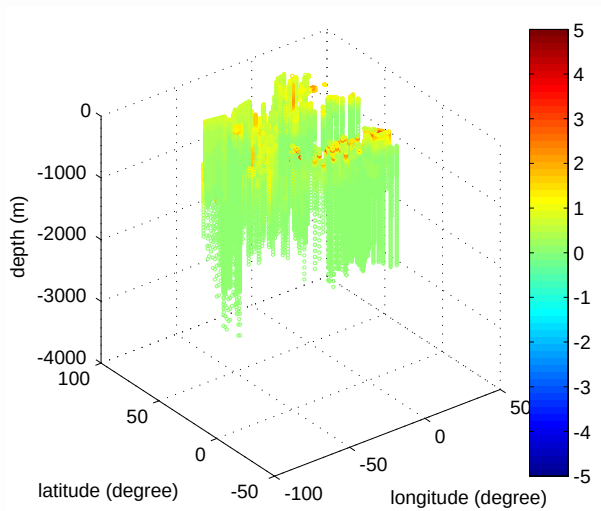
model



observation



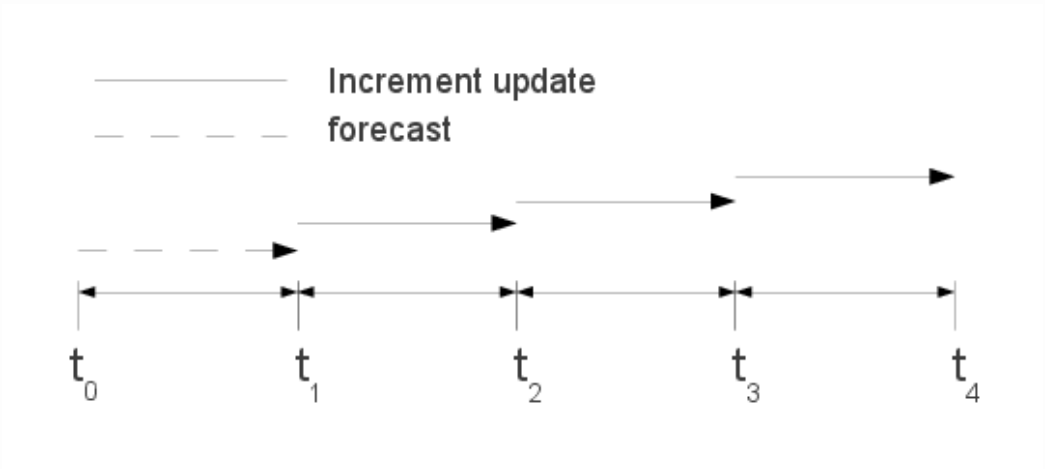
model - observation



ensemble spread

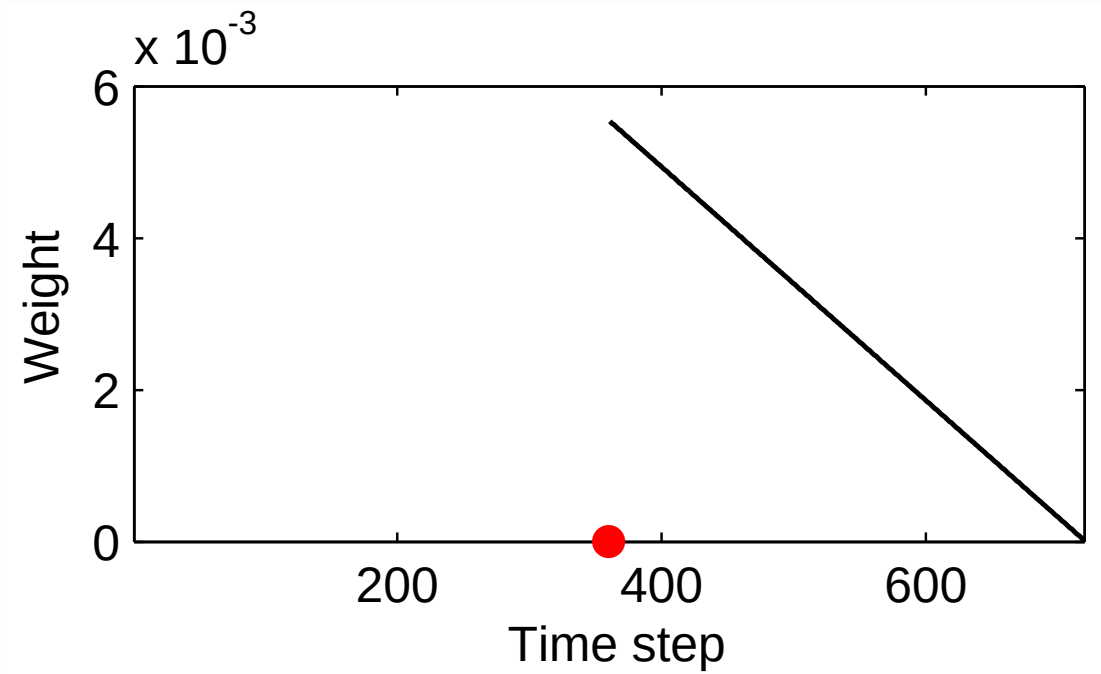
Assimilation setting

- Timing parameters:
  - analysis frequency: 10 days
  - duration: one year with ensemble spin-up of 6 months
- Assimilation tool: Ocean Assimilation Kit (OAK)
- Assimilation method: square root analysis scheme of EnKF
- Assimilation scheme: IAU 0 (Incremental Analysis Update)



Assimilation setting

Increment weighting in accord with observation decorrelation time scale: linearly decreasing function



red point: analysis time step

State vector

- Model state vector:
  - SSH
  - temperature
  - salinity
- Incremental Analysis Update:
  - temperature (ΔT)
  - salinity (ΔS)

Validation metrics

Metrics definition

1. Deterministic validation:
   - Criterion: distance between the observation and the ensemble mean
   - Scores: RMS of ensemble mean, ensemble mean/spread | observation (value + error) plot
2. Probabilistic validation:
   - Criterion: reliability and resolution of the ensemble distribution
   - Scores: Continuous Ranked Probability Score (CRPS), Reduced Centered Random Variable (RCRV)

Diagnosed variables

- Thermohaline variables: SST, temperature, salinity, SSH
- Horizontal velocity: zonal and meridional velocities

Probabilistic validation: CRPS

CRPS: measures both reliability and resolution

- Decomposition (Hersbach 2000):

$$\text{CRPS} = \text{CRPS-Reli} + \text{CRPS}_{\text{pot}} \quad (1)$$

$$\text{CRPS}_{\text{pot}} = \text{CRPS-Uncert} - \text{CRPS-Reso} \quad (2)$$

- Interpretation:
  - CRPS, CRPS-Reli and CRPS_{pot} negatively oriented
  - CRPS-Reli = 0 for a perfectly reliable system
  - CRPS_{pot} reaches its minimum for a perfectly deterministic system
  - large CRPS-Uncert corresponds to a broad distribution of the verification sample
  - The smaller CRPS_{pot} is than CRPS-Uncert, the more informative the ensemble system is

Probabilistic validation: RCRV

RCRV: measures the reliability

$$\text{RCRV} = \frac{y_o - \overline{x}}{\sqrt{\sigma_o^2 + \sigma^2}} \tag{3}$$

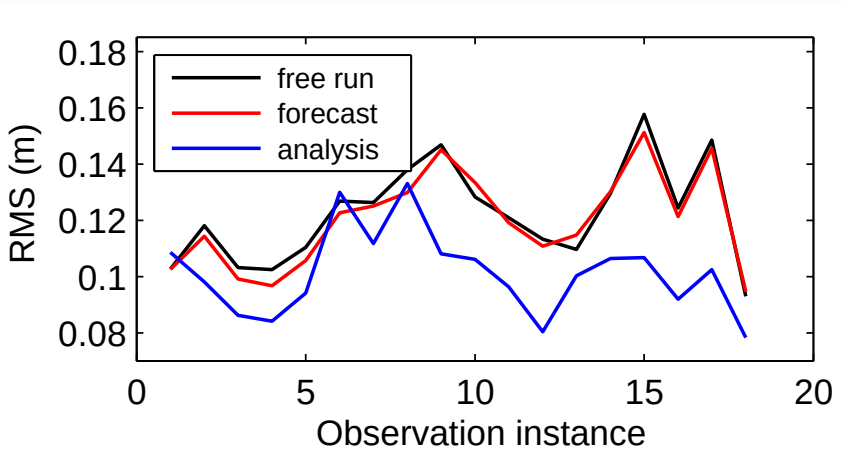
y_o: observation, σ_o: observation error, $\overline{x}$: ensemble mean, σ: ensemble spread

- RCRV-bias: average of RCRV, weighted bias between the ensemble and the observation
- RCRV-dispersion: standard deviation of RCRV, an indicator of systematic over and under dispersion of the ensemble
- For a perfectly reliable system, RCRV-bias =0, RCRV-dispersion = 1
- A negative (positive) value of RCRV-bias $\leftrightarrow$ a positive (negative) bias
- A value of RCRV-dispersion significantly larger (smaller) than 1 $\leftrightarrow$ under-dispersion (over-dispersion) of the system

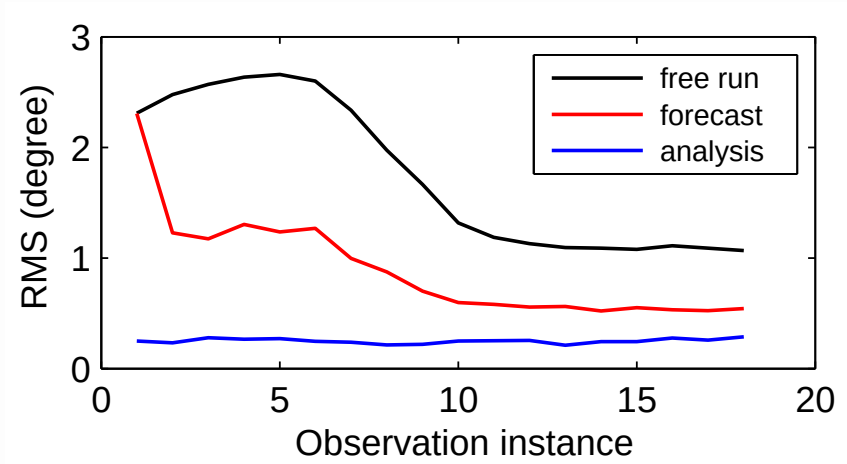
Deterministic validation

RMS of ensemble means

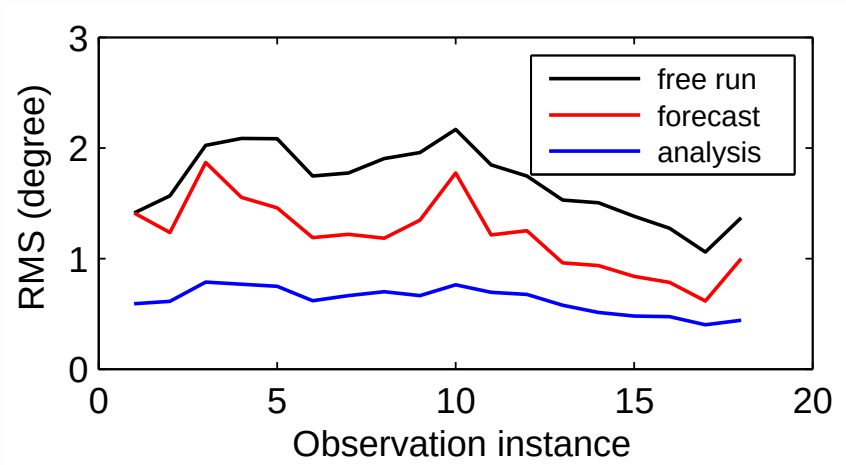
SSH



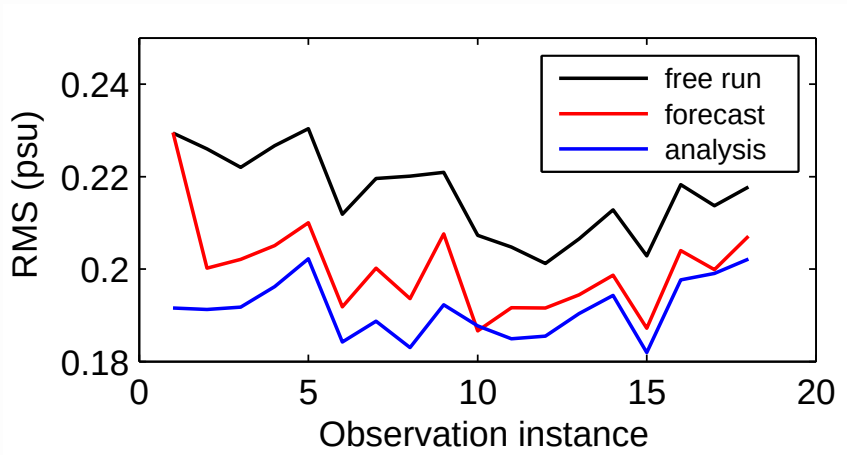
SST



temperature

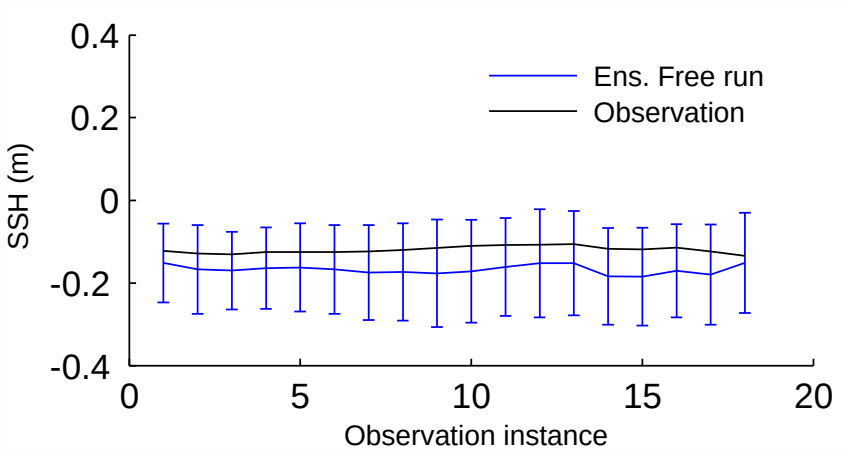


salinity

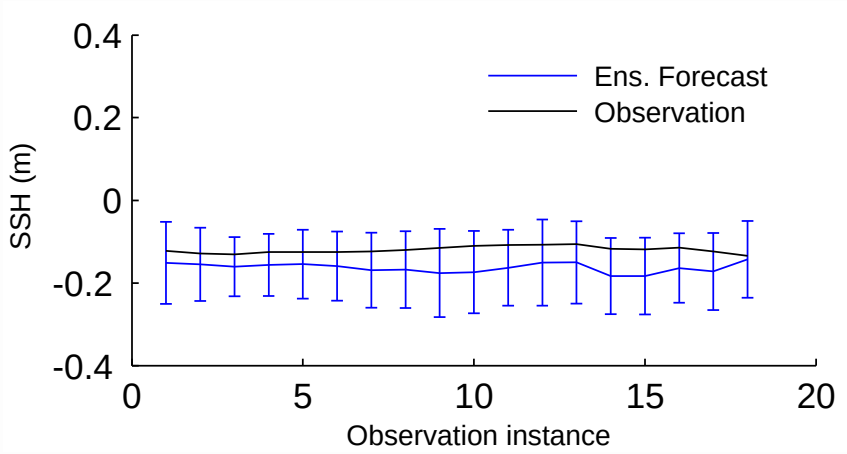


SSH: ensemble | observation

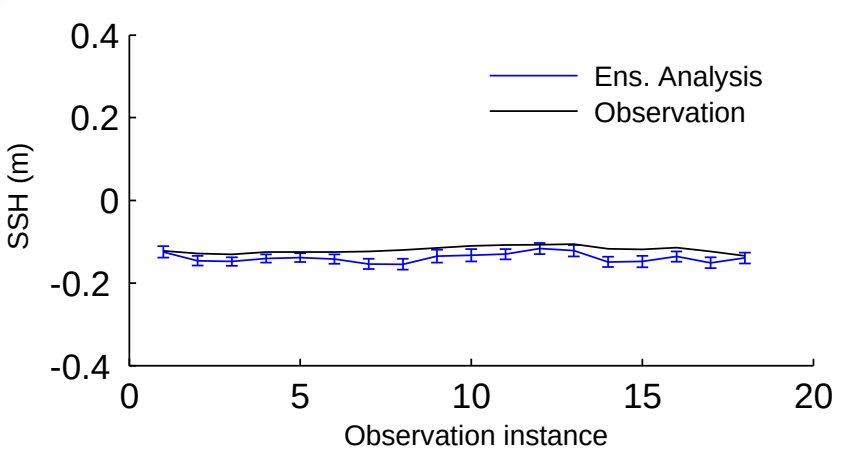
free run



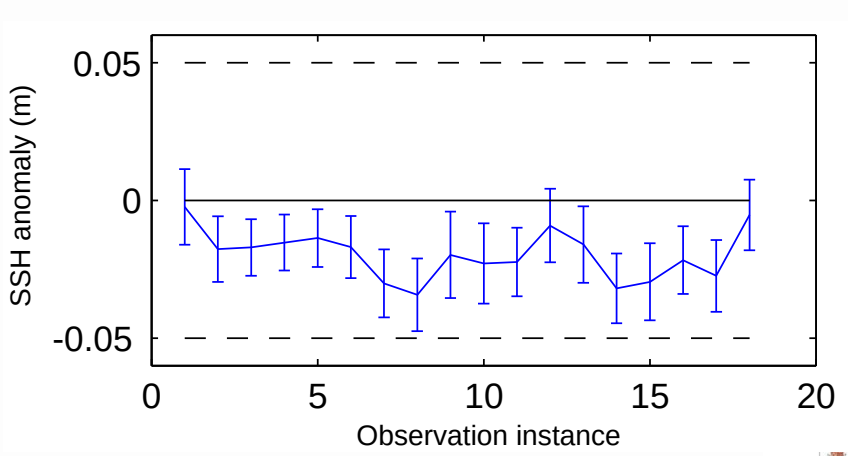
forecast



analysis



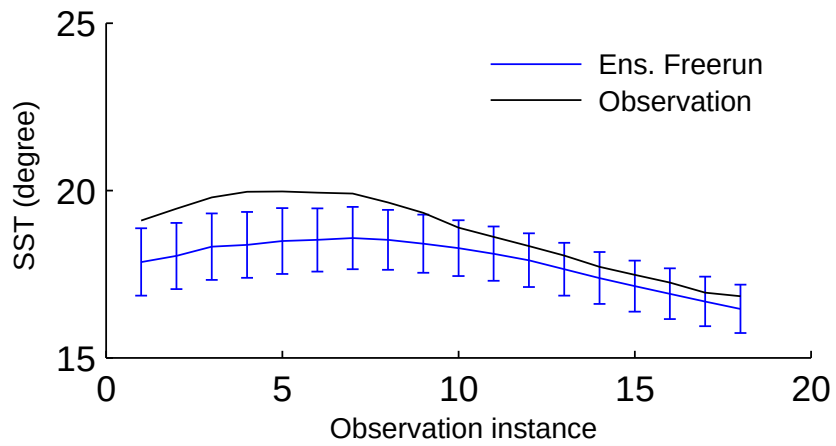
anomaly (analysis - observation)



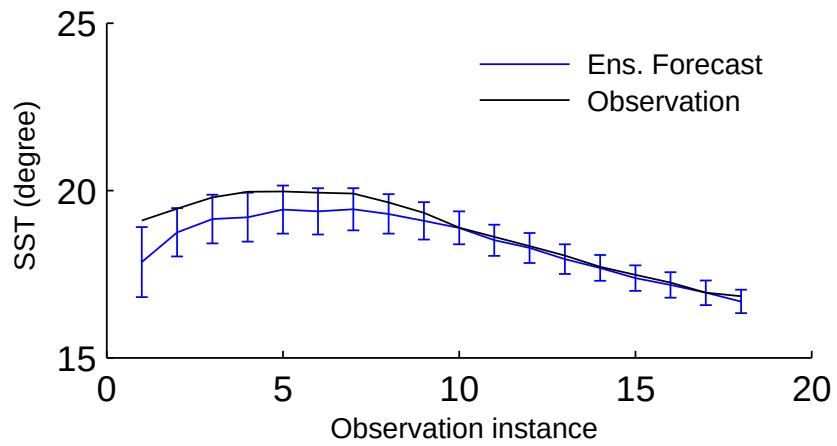
error bar: ensemble spread, dashed line in (d): observation error

SST: ensemble | observation

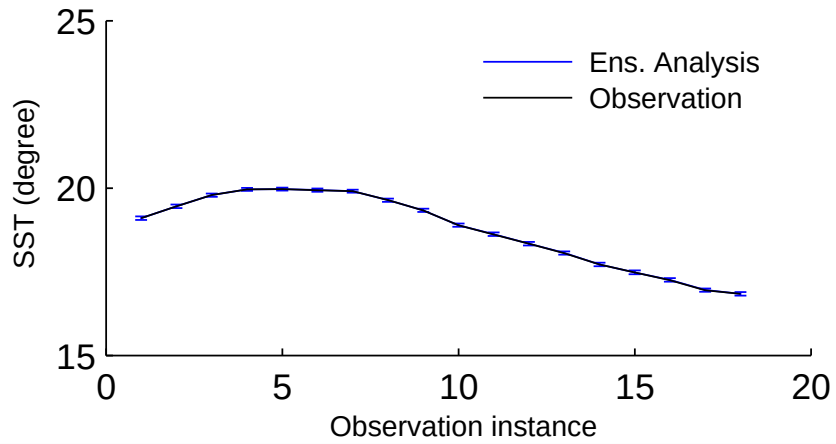
free run



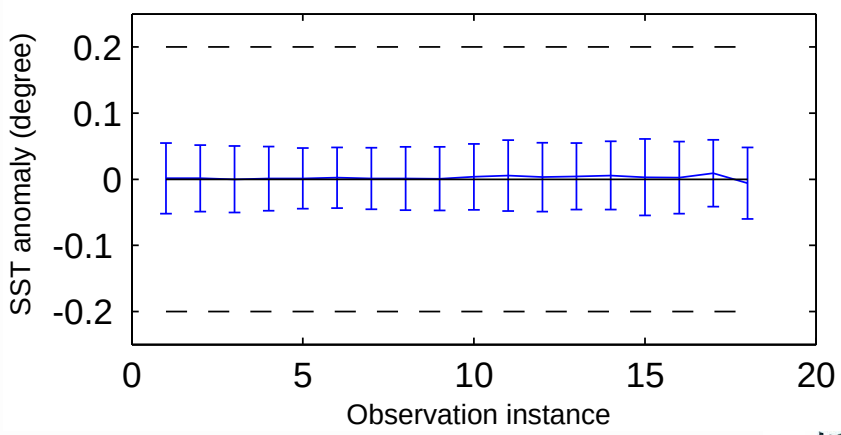
forecast



analysis

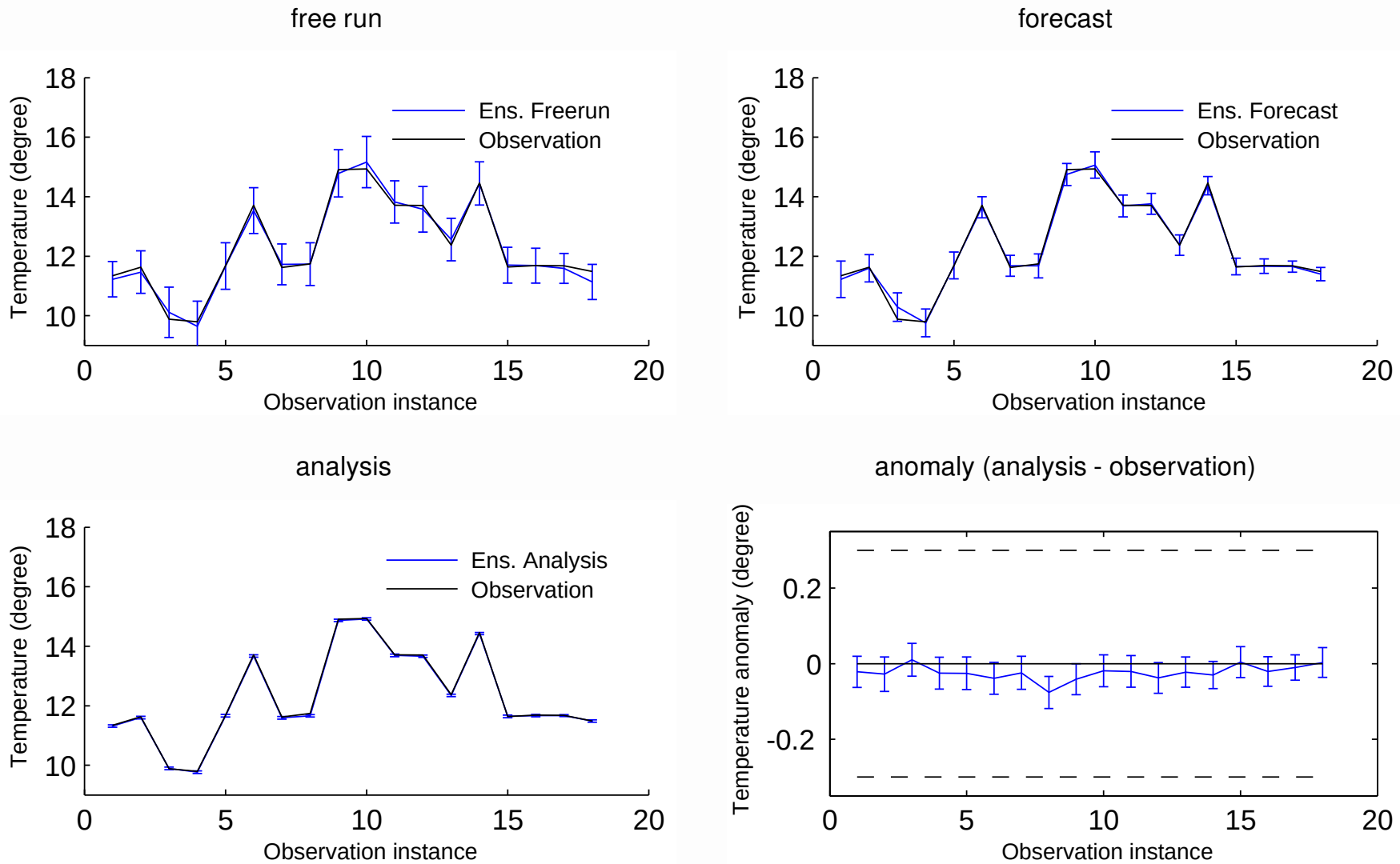


anomaly (analysis - observation)



error bar: ensemble spread, dashed line in (d): observation error

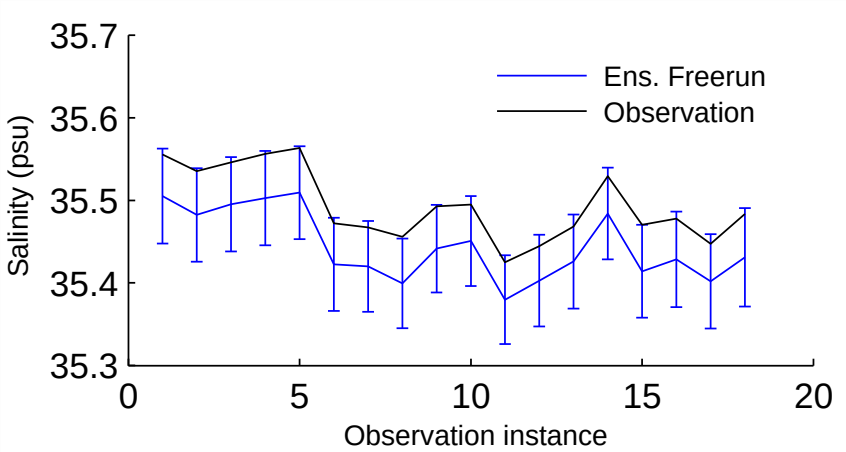
Temperature: ensemble | observation



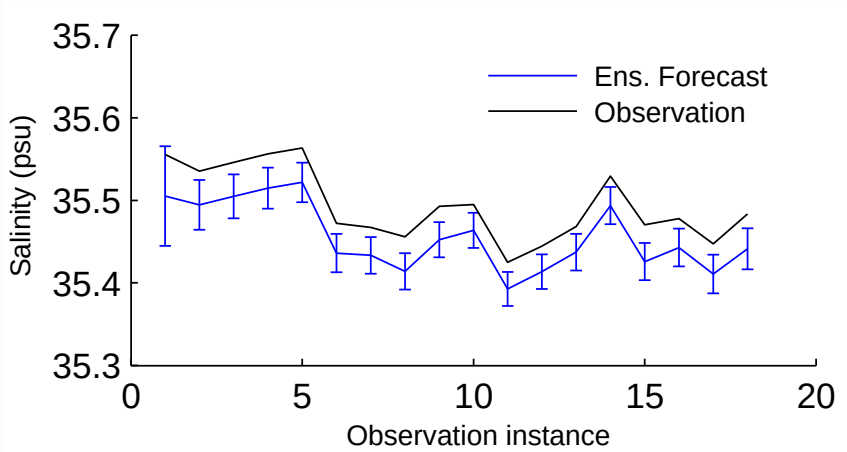
error bar: ensemble spread, dashed line in (d): observation error

Salinity: ensemble | observation

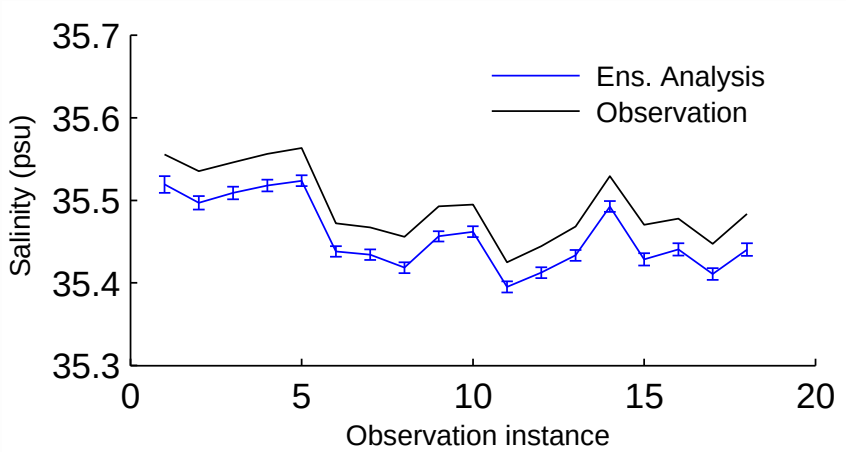
free run



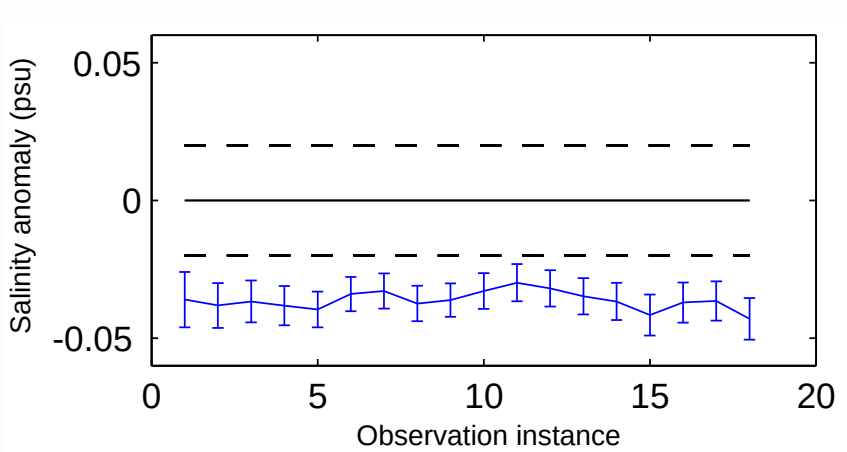
forecast



analysis



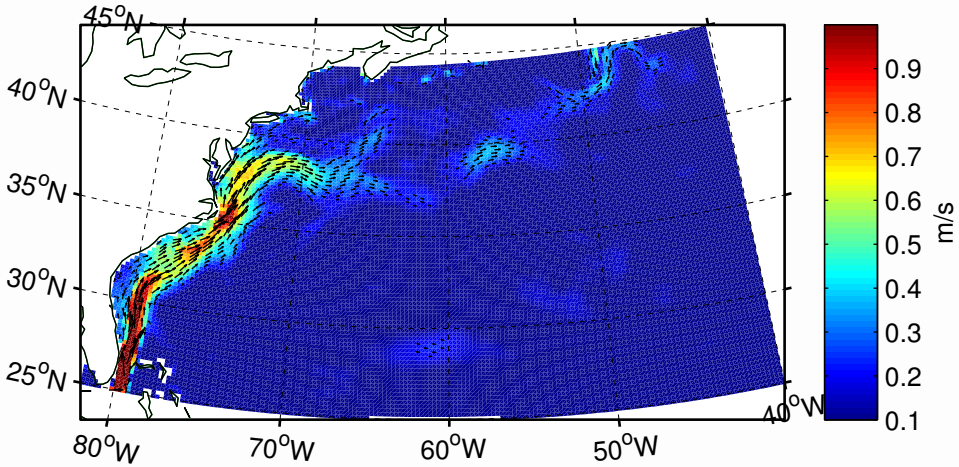
anomaly (analysis - observation)



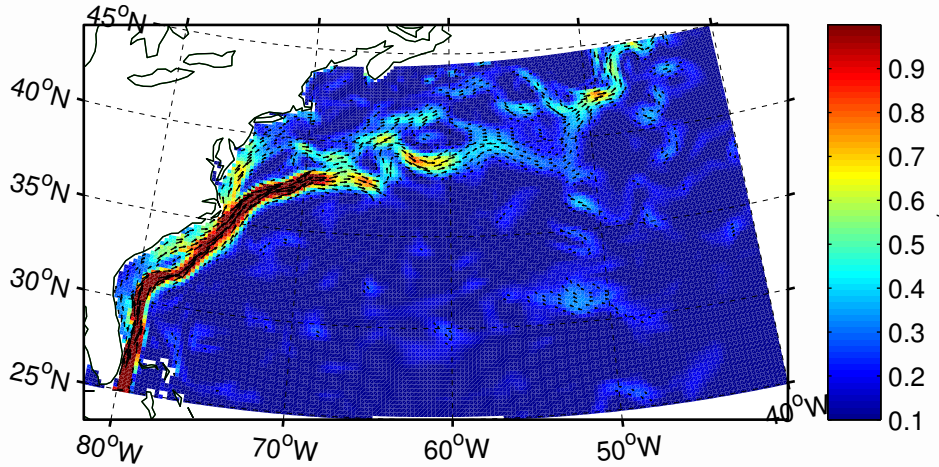
error bar: ensemble spread, dashed line in (d): observation error

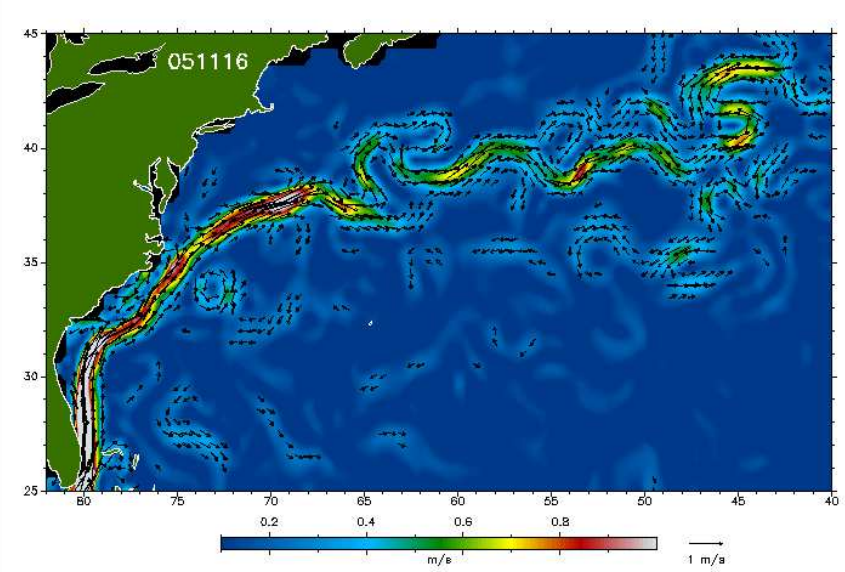
Horizontal velocity at surface:

Free run



Assimilation

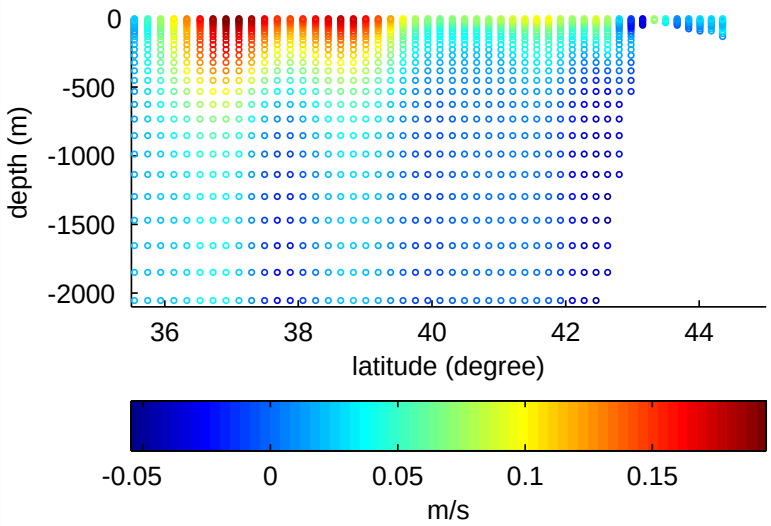


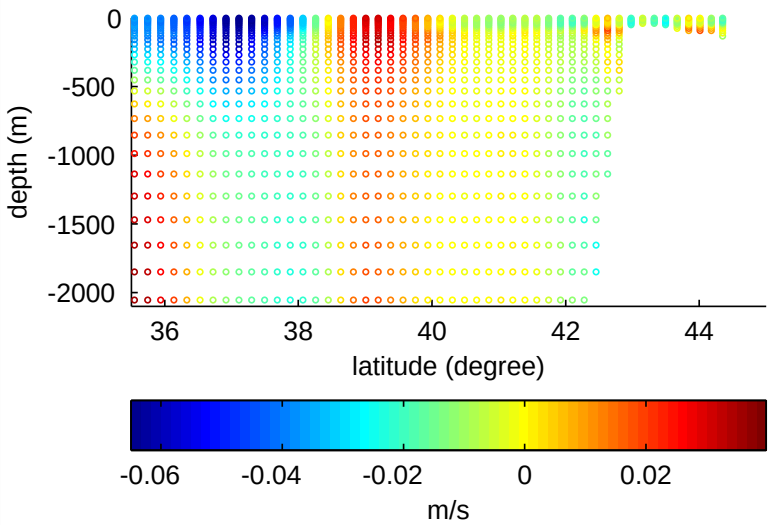


Gulf Stream velocity field generated from 4 altimetric satellite data (DEOS)

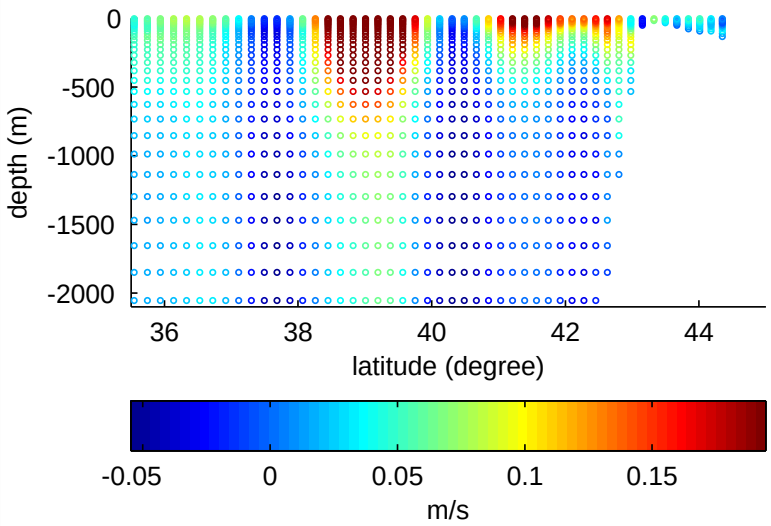
Meridional section in the Gulf Stream region (61.5° W):

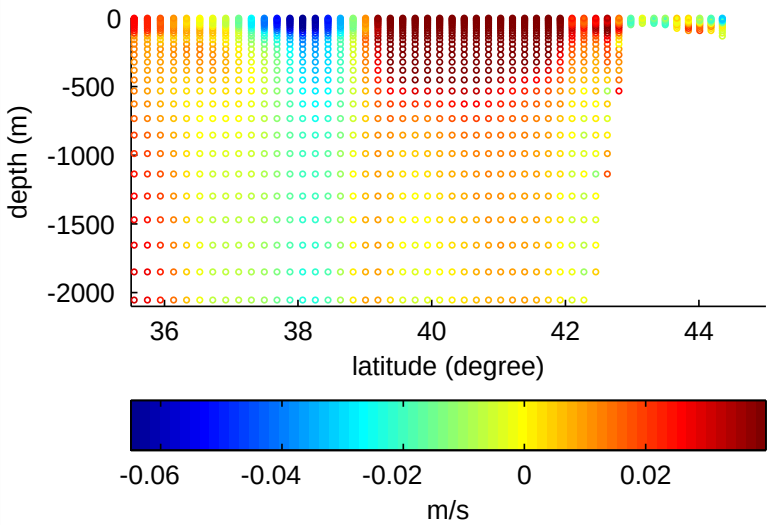
Free run





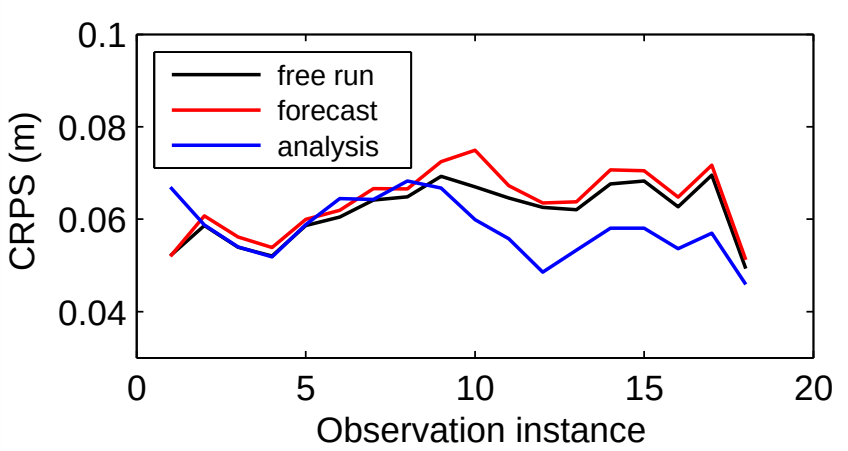
Assimilation

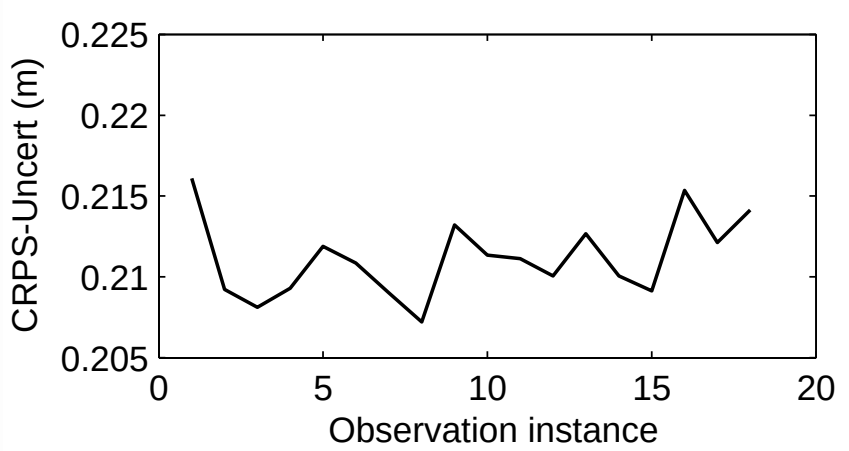


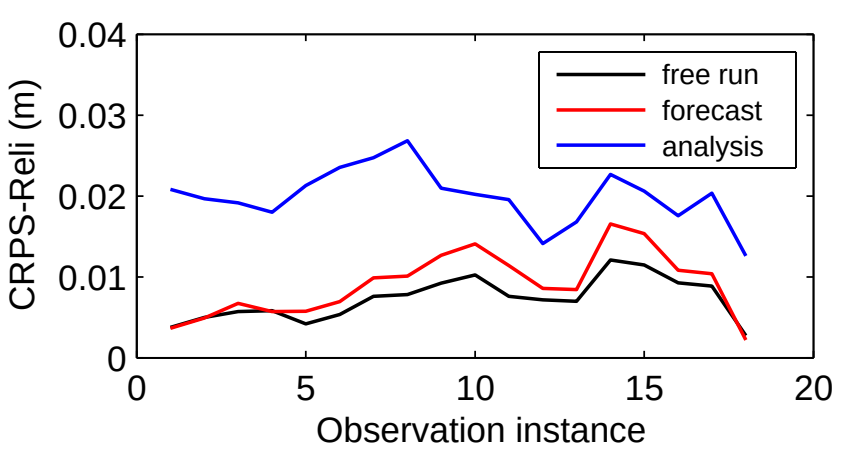


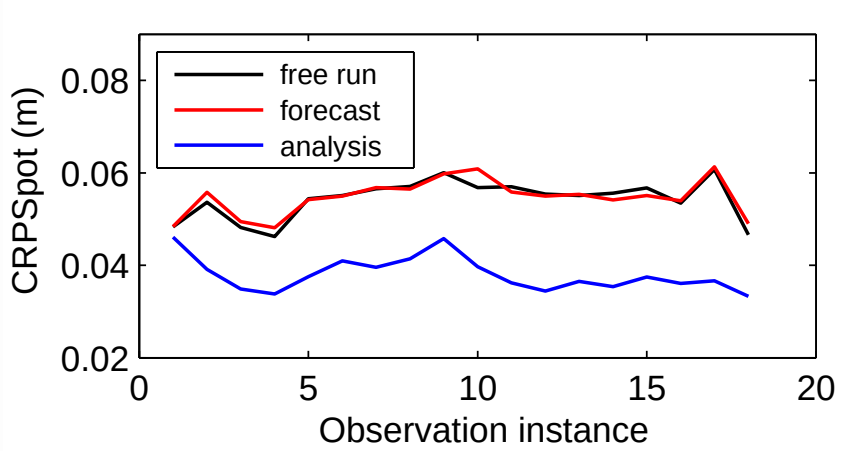
Probabilistic validation

SSH: CRPS

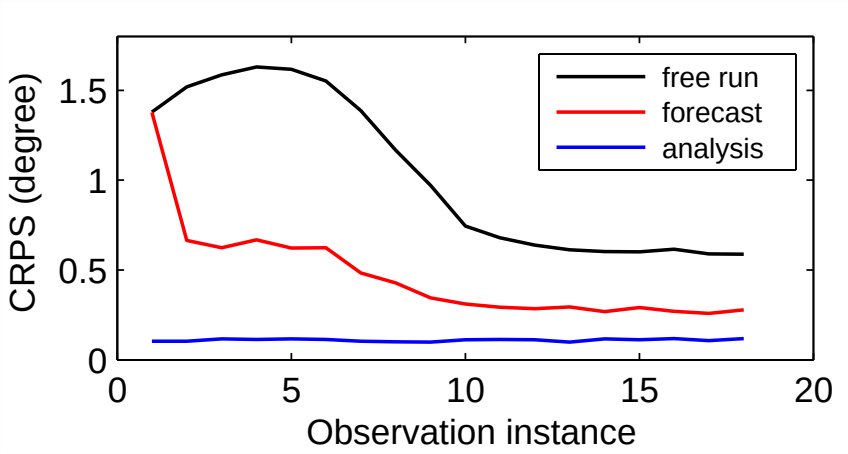

CRPS (m)
Observation instance
free run
forecast
analysis

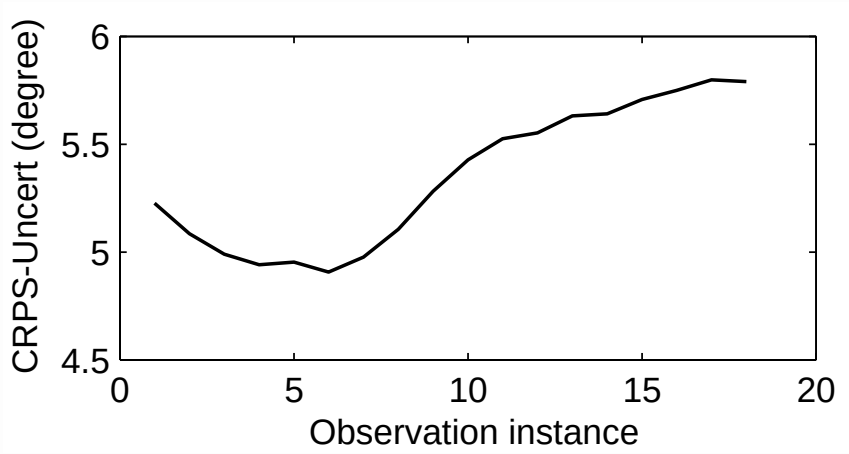

CRPS-Uncert (m)
Observation instance

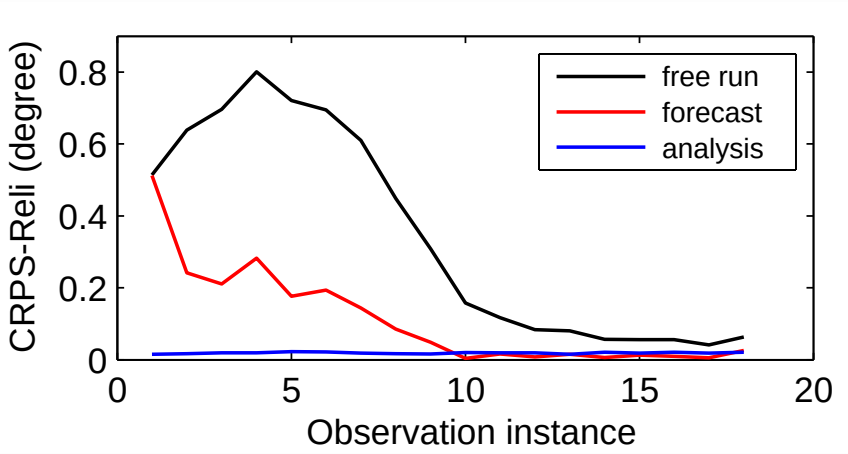

CRPS-Reli (m)
Observation instance
free run
forecast
analysis

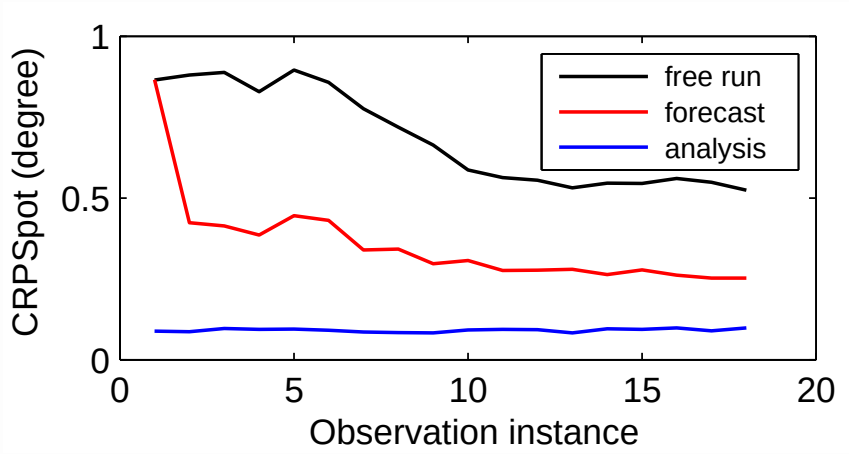

CRPSpot (m)
Observation instance
free run
forecast
analysis

SST: CRPS

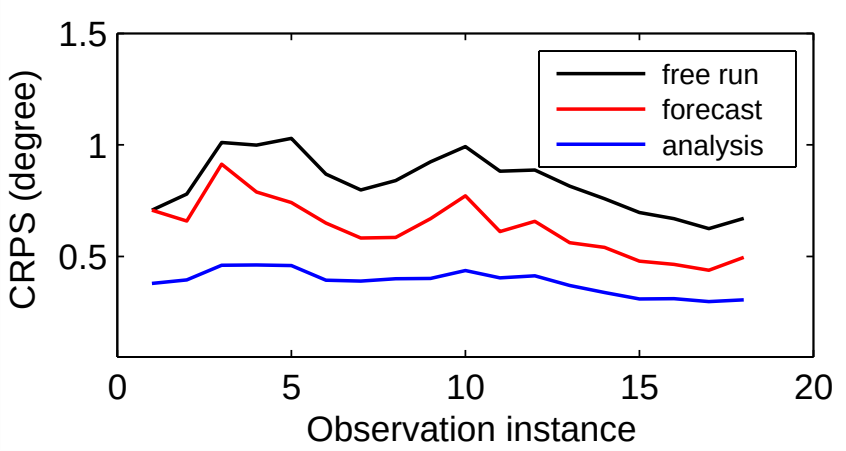

CRPS (degree)
Observation instance
free run
forecast
analysis

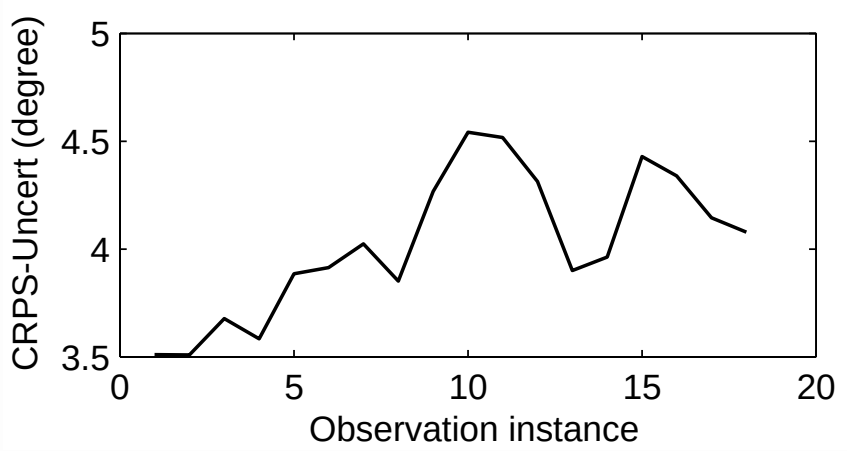

CRPS-Uncert (degree)
Observation instance

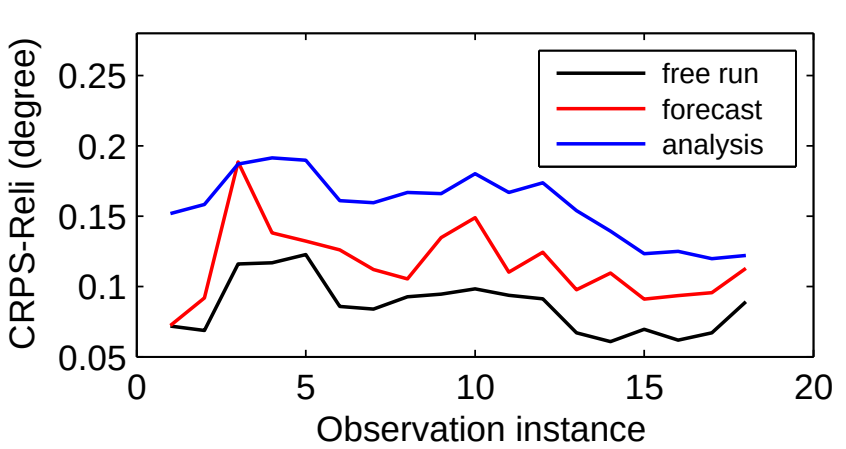

CRPS-Reli (degree)
Observation instance
free run
forecast
analysis

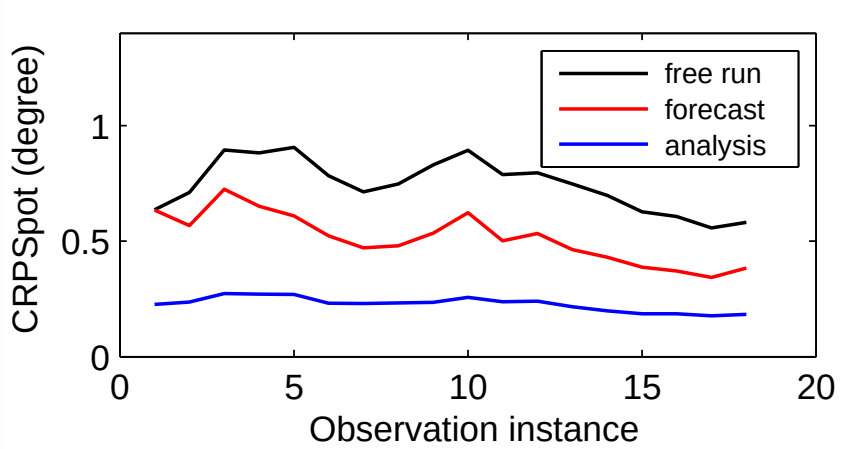

CRPSpot (degree)
Observation instance
free run
forecast
analysis

Temperature: CRPS

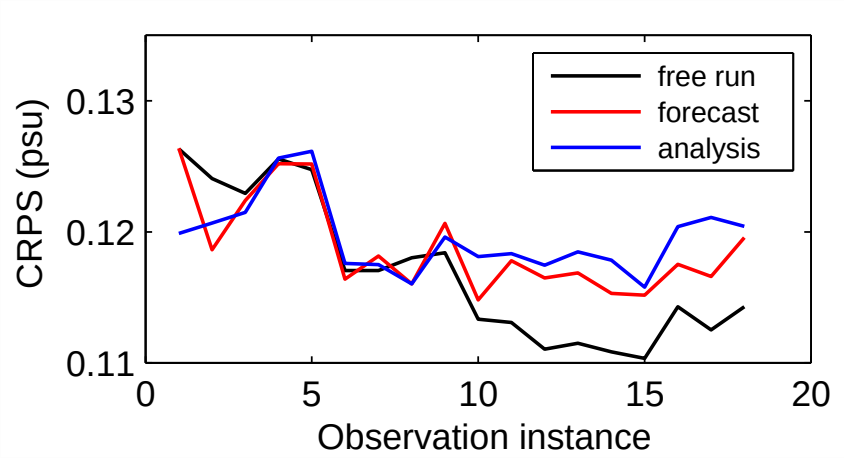


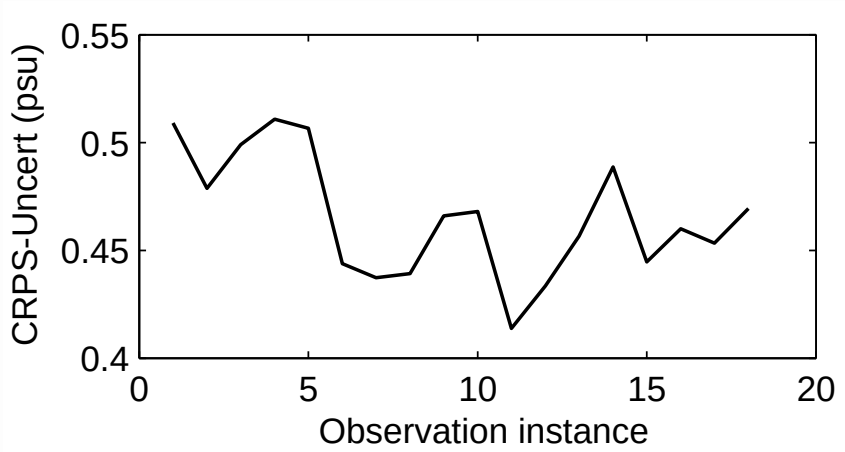


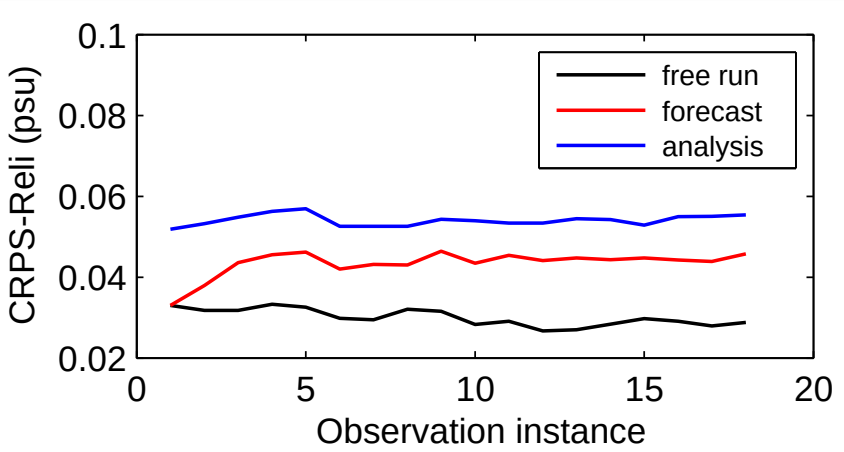


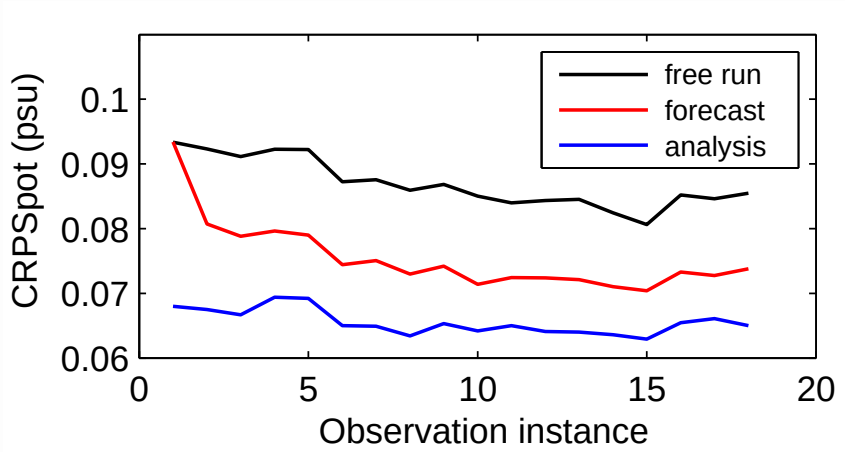


Salinity: CRPS



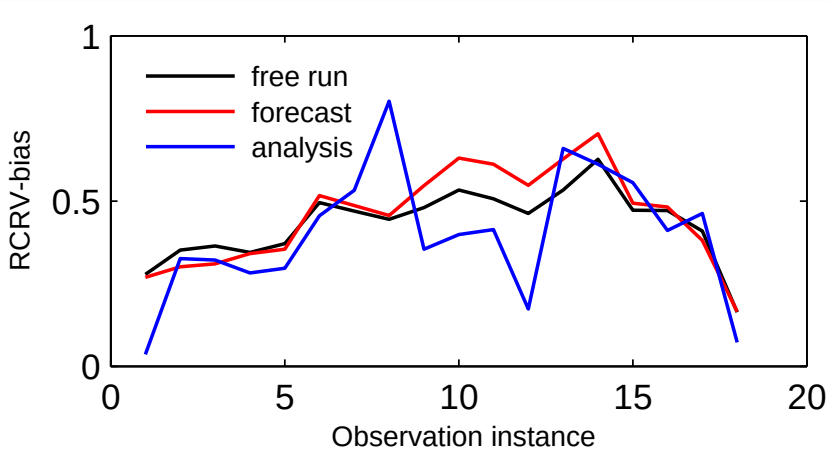




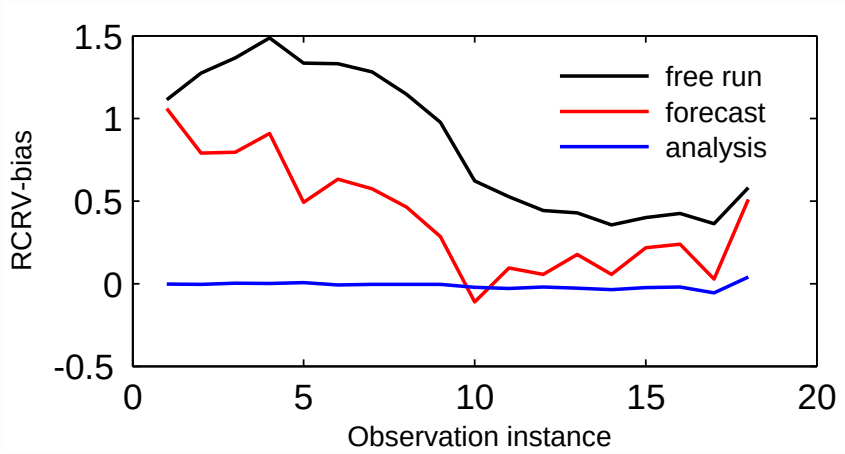


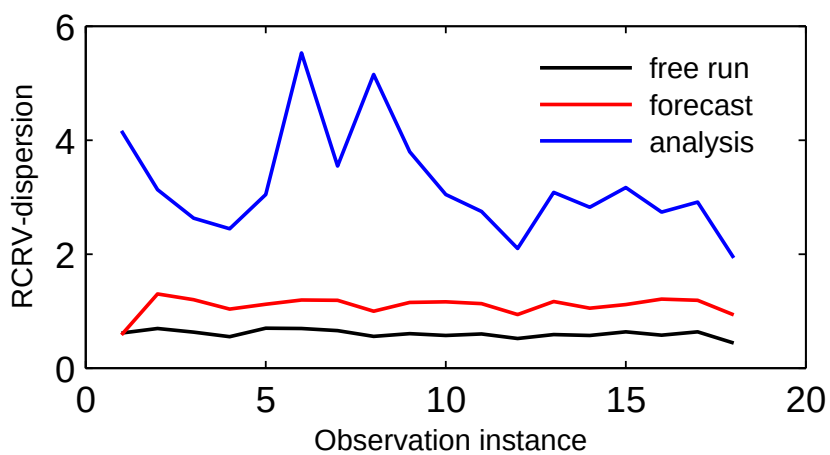
RCRV: SSH, SST

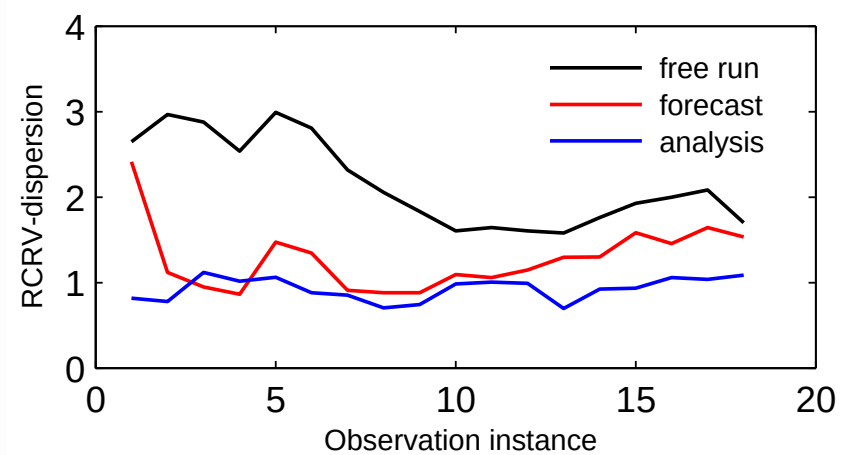
SSH



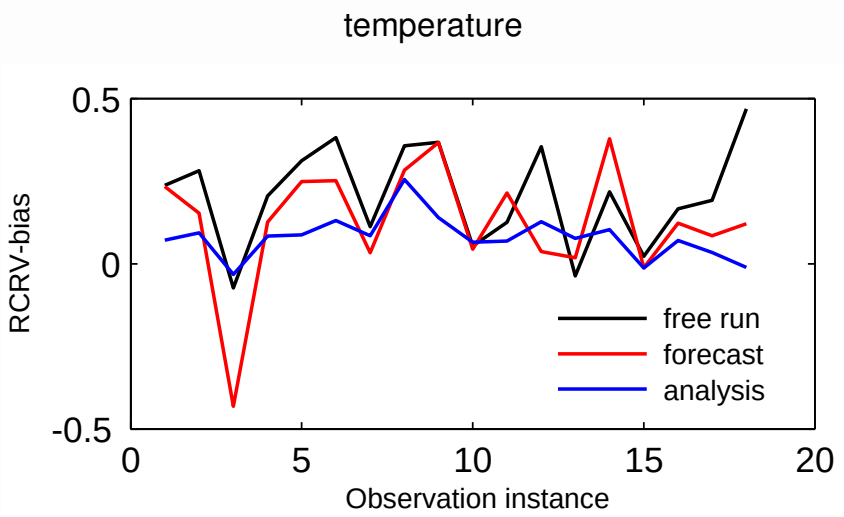
SST

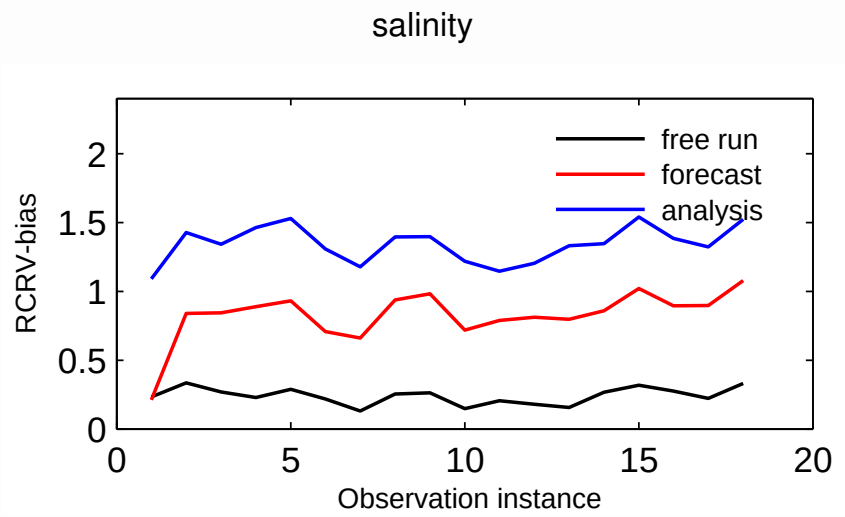


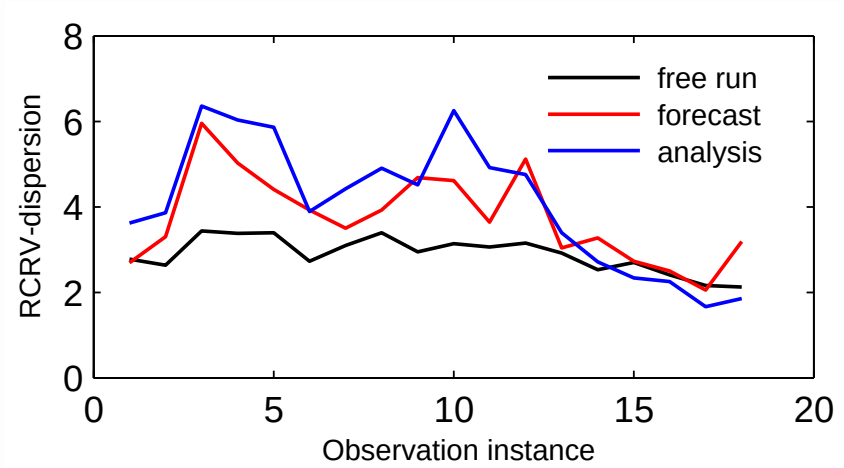


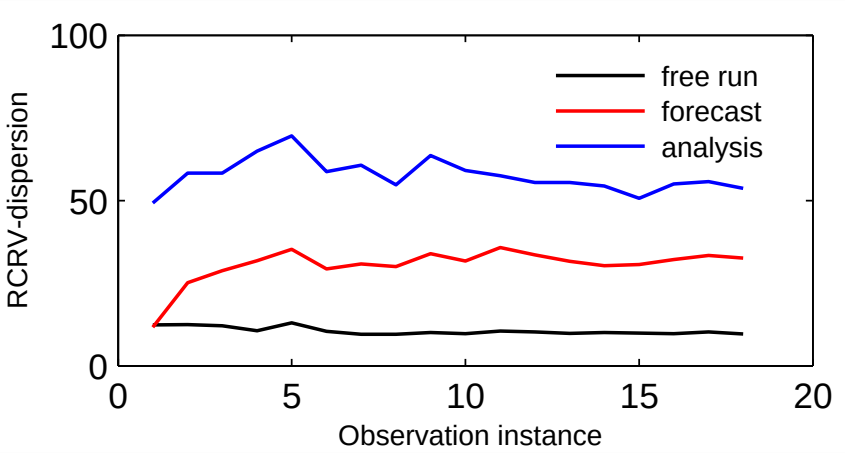


RCRV: temperature, salinity









Summary

Joint analysis of deterministic validation and probabilistic validation:

-	Deterministic metrics		Probabilistic metrics				
Variable	RMS	Ensemble/Observation Plot	CRPS	CRPS-Reli	CRPS-Reso	RCRV-bias	RCRV-disp
SST	~ 0	$y_o \in [\overline{x} \pm \sigma], x \in [y_o \pm \sigma_o]$	~ 0	~ 0	~ 0	~ 0	~ 0
T	$\downarrow$	$y_o \in [\overline{x} \pm \sigma], x \in [y_o \pm \sigma_o]$	$\downarrow$	$\uparrow$	$\downarrow$	$\downarrow$	$\uparrow$
SSH	$\downarrow$	$y_o \notin [\overline{x} \pm \sigma], x \in [y_o \pm \sigma_o]$	$\downarrow$	$\uparrow$	$\downarrow$	$\rightarrow$	$\uparrow$
S	$\downarrow$	$y_o \notin [\overline{x} \pm \sigma], x \notin [y_o \pm \sigma_o]$	$\uparrow$	$\uparrow$	$\downarrow$	$\uparrow$	$\uparrow$

$\sim$: closeness. $\uparrow$: increase, $\downarrow$: decrease, $\rightarrow$: no change.

Conclusions

- In reliable system, CRPS and RMS have similar behaviors. The resolution component of CRPS dominates the reliability component and RMS has significance on the resolution.
- The ensemble mean/spread | observations plot can be connected directly to CRPS and RCRV.
- The fact that the observation lies outside the ensemble spread interval is a sign of lack of reliability.
- In reliable system, the fact that the ensemble always lies within the observation error interval is a sign of resolution.
- The ensemble mean/spread | observations plots give qualitative information on the ensemble bias and dispersion, while RCRV score gives quantitative information.
- For unassimilated variables whose ensemble is probably subject to low reliability and ensemble spread underestimation, it seems important to use the probabilistic scores for validation.

Acknowledgments

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