### An adaptive optimal interpolation based on analog forecasting: application to SSH in the Gulf of Mexico

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#### The 3DA Team



- 2 groups (Brest & Grenoble, France)
- 2 skills (applied mathematics & oceanography)



# Methodology: **Analog forecast** + Data Assimilation (AnDA)

Analog forecast: construct an approximate dynamical model at each time step.





## Methodology: Analog forecast + Data Assimilation (AnDA)

More details can be found in [Lguensat et al., 2017, Tandeo et al., 2015]

- Use ensemble Kalman filter(EnKF) to calculate the state analysis;
- Use analog forecast (AF) for state forecast;

 Use ensemble Kalman smoother (EnKS) for reprocessing the data.

$$X_{1}^{f} \xrightarrow{\text{EnKF}} X_{1}^{a} \xrightarrow{\text{AF}} X_{2}^{f} \xrightarrow{\text{CNKF}} X_{T}^{a} \xrightarrow{\text{EnKF}} X_{T}^{a}$$

$$X_{1}^{s} \xleftarrow{\text{EnKS}} \xrightarrow{\text{EnKS}} X_{T-1}^{s} \xleftarrow{\text{EnKS}} X_{T}^{s}$$



Numerical Experiments: OSSE and real data application

EXP 1: Comparison of AnDA and optimal interpolation using simulated sea-surface height data.

- comparison of AnDA and a well-tuned simple version of optimal interpolation algorithm (OI).
- Details can be found in: [Zhen et al., 2020]

EXP 2: Comparison of AnDA results and SSH reprocessed data.

 comparison of AnDA and an operational optimal interpolation algorithm (DUACS).



#### EXP 1: OSSE at Gulf of Mexico



- ▶ Dataset ⇒ OCCIPUT simulation (50 members, 20 years, 0.25°, daily, more details in [Bessières et al., 2017])
- Catalog ⇒ the time series of the first 100 EoFs of OCCIPUT dataset (49 members, 19 years);
- Truth  $\Rightarrow$  OCCIPUT(1 member, 1 year).
- ► Obs ⇒ simulated along-track obs (without error) of SSH from altimeters in 2004.
- ► Two different OI ⇒ optimal interpolation with well-tuned spatial/temporal correlation scale and a conventional OI ([Le Traon et al., 1998])



### EXP 1 (OSSE): SSH time series





#### EXP 1 (OSSE): SSH temporal spectrum



 $\Rightarrow$  AnDA has a better energy cascade (energy does not collapse on small scales like OI)



### EXP 1 (OSSE): SSH mapping errors





- Absolute error and estimated std are well correlated in AnDA
- Estimated std is observation-dependent in Ols
- Estimated std is flow-dependent in AnDA



#### **EXP 1: Conclusions**

- AnDA avoids tuning of spatial and temporal correlations.
- AnDA captures rapid fluctuations.
- AnDA provides better estimates of error maps.
- $\Rightarrow$  These three properties are due to the use of analogs.



# EXP 2: comparison of DUACS and AnDA using real SSH/SST

- ► Dataset ⇒ DUACS-two-satellites reprocessed SSH data and REMSS reprocessed SST data (1998-2018, 0.25°, daily).
- ► Observations ⇒ the satellite altimetry data used to create DUACS-two-satellites product, and the REMSS reprocessed SST data (from 01/06/2015 to 31/05/2016).
- ► Truth (reference) ⇒ the satellite altimetry data that were not used to create the DUACS two-satellites product (from 01/06/2015 to 31/05/2016).
- Catalog (AnDA(SSH)-2sats) ⇒ 100 EoFs of SSH<sub>DUACS2sats</sub> (1998-2018).
- Catalog (AnDA(SSH+SST)-2sats-2sats) ⇒ 150 EoFs of (SSH<sub>DUACS2sats</sub>, SST<sub>REMSS</sub>/4) (1998-2018).
- Catalog (AnDA(SSH+SST)-2sats-allsats) ⇒ 150 EoFs of (SSH<sub>DUACSallsats</sub>, SST<sub>REMSS</sub>/4) (1998-2018).



#### EXP 2: why do we consider SST?





#### EXP 2: Patchwise implementation of AnDA



- AnDA is implemented independently for each patch.
- Solutions for each patch are merged to get a complete SSH map.



# EXP 2: why don't we use OCCIPUT simulation as the catalog?



- Discrepancy between the attractors of OCCIPUT simulation and DUACS reprocessed data.
- AnDA would not be reliable if the observation and the catalog lie on different attractors.



#### EXP 2: numerical results

### **Truth (reference)** $\Rightarrow$ satellite altimetry observations that were not used to create DUACS-2sats.

RMSE(cm)	DUACS-2sats	AnDA(SSH)-2sats	AnDA(SSH+SST)-2sats-2sats	${\sf AnDA(SSH+SST)-2 sats-all sats}$
2015.6-2015.11	4.301	4.522	4.260	3.416
2015.12-2016.5 2015.6-2016.5	4.134	4.296	4.103	3.182 3.320



- AnDA(SSH+SST) slightly improves DUACS reanalysis in most of the locations and time.
- Both AnDA(SSH+SST) and DUACS are better than AnDA(SSH)
- Better catalog  $\Rightarrow$  better results for AnDA.



#### EXP 2: numerical results



- Minor differences between the geostrophic velocities of AnDA DUACS.
- AnDA reduces the estimated std.
- AnDA interpolates SST at the same time.



#### **EXP 2: Conclusions**

#### Take home message:

- AnDA is a multivariate interpolator (both SSH and SST).
- AnDA results are improved using microwave SST.

#### Work in progress:

- Comparison of AnDA and DUACS when all satellite altimetry data are assimilated. Need measurement from an independent source for validation.
- Optimization of the data assimilation scheme (estimation of observation error covariance).
- Re-construct the whole SSH/SST time series using AnDA and use this new time series as the new catalog.



#### Thank you! Any question?





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