Constrained scales in ocean forecasting

Constrained by present observations: > 58 km e-folding scale Gaussian filter

Considering internal ocean instabilities (not tides, …)

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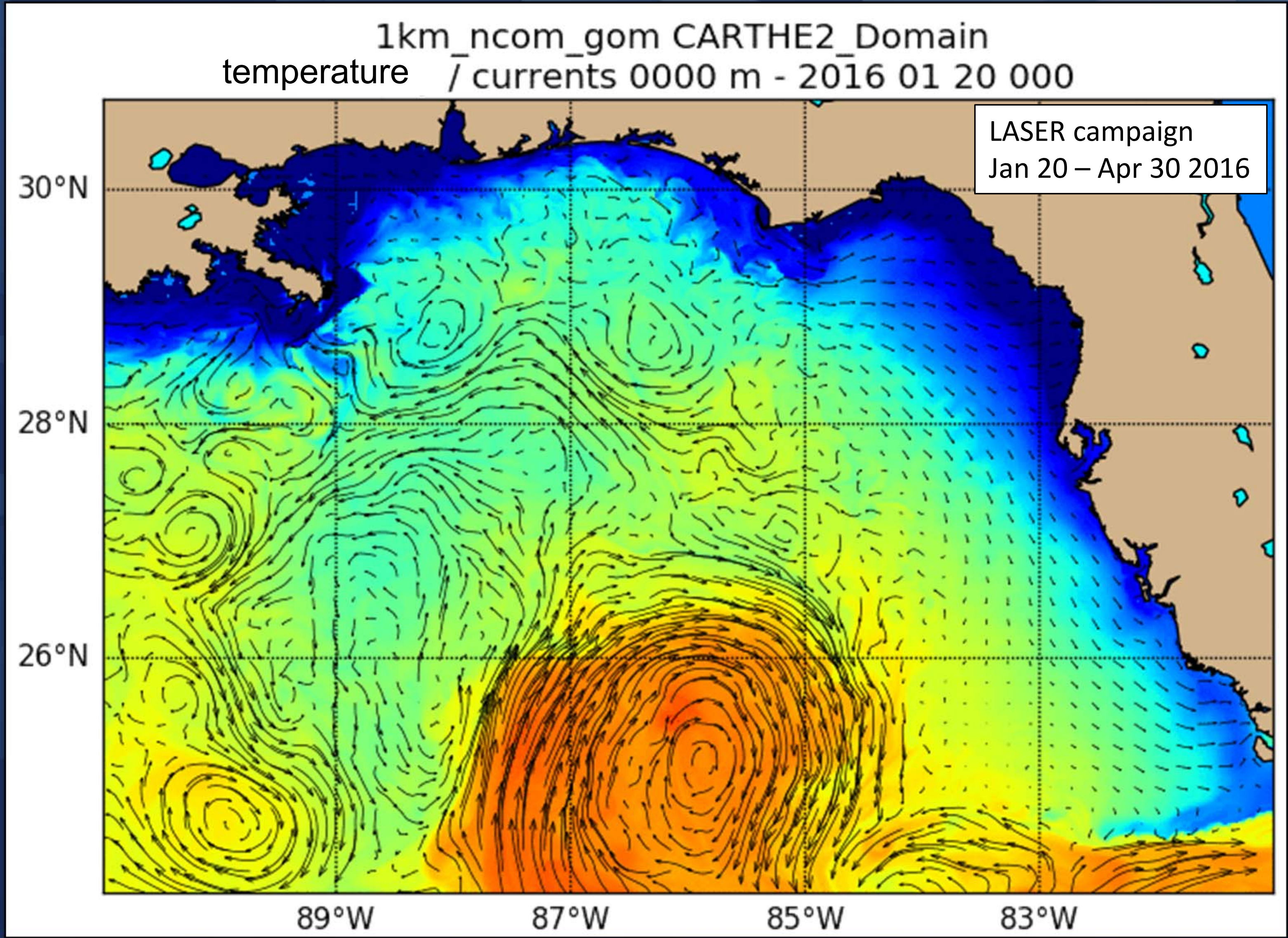
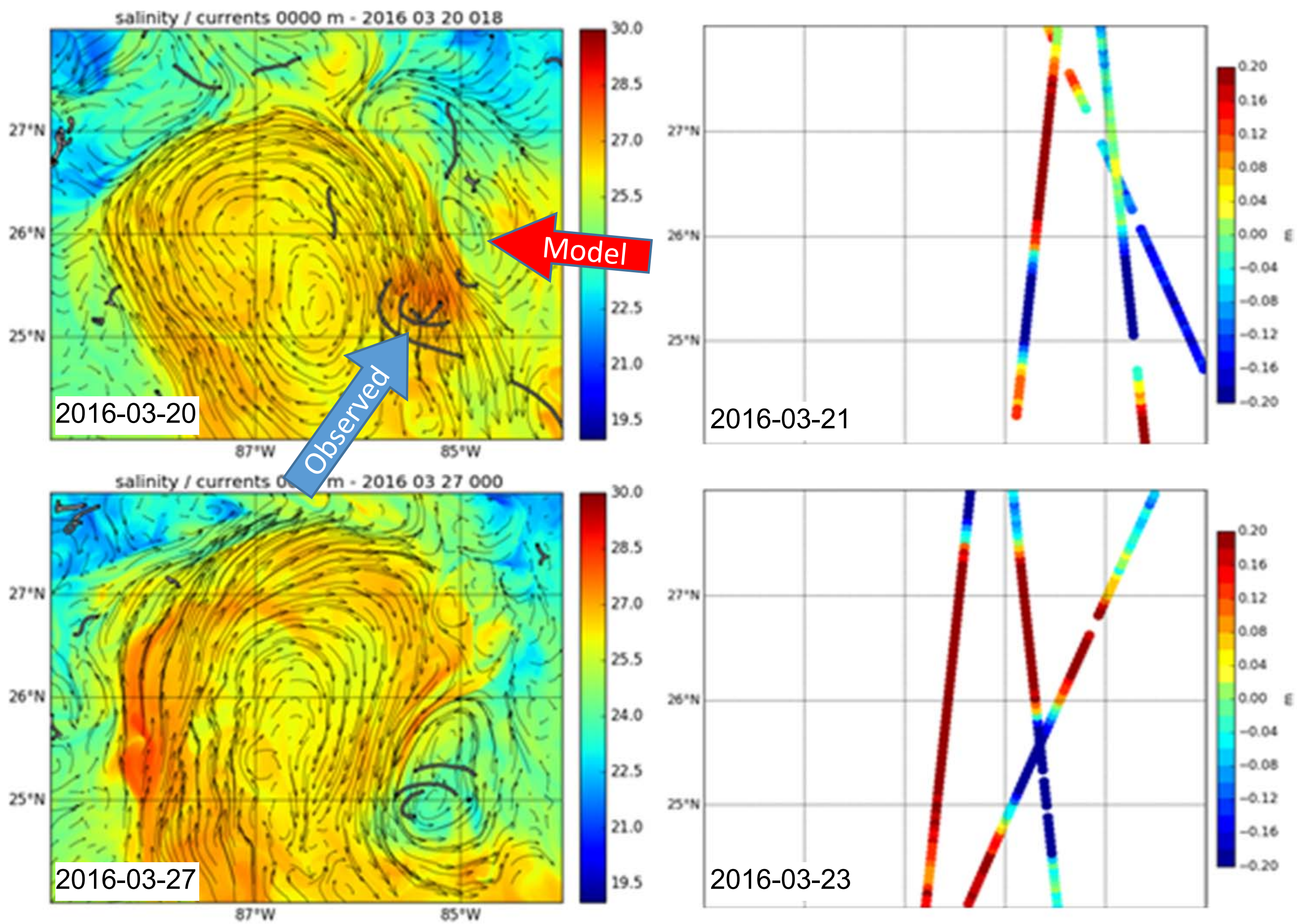


A feature not sufficiently constrained

The positioning of 200 km features is often incorrect because of sparse data

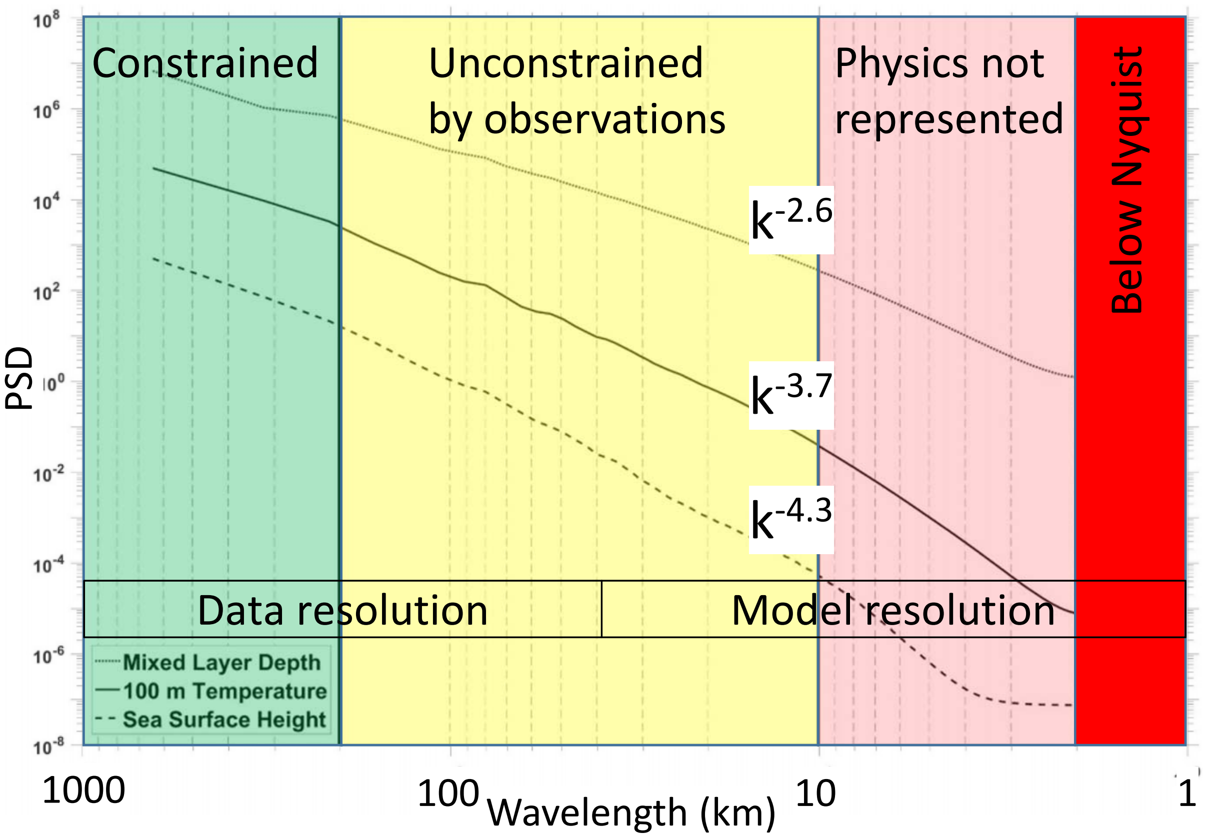


Data resolution is the limiting factor in predicting smaller scales

Over a 7 day period, only 2 days have data on the misplaced feature

The data shifts the eddy position in the model solution, but on average it is debatable if the model has skill in predicting this feature

Definition of constrained and unconstrained



Data resolution is the limiting factor in predicting smaller scales

	Representing in models
Beyond Nyquist frequency	Features at these scales are not represented in model results. There is no method for a numerical model to represent the errors in the forecast.
Physics not represented at this resolution	
Unconstrained	Model errors are greater than variability
Constrained	Model errors are less than variability

1 km resolution model

$$\frac{\mathrm{var}\langle \varepsilon_\lambda \rangle}{\mathrm{var}\langle nature_\lambda \rangle} \rightarrow \begin{cases} <1 & \text{Constrained} \\ >1 & \text{Unconstrained} \end{cases}$$

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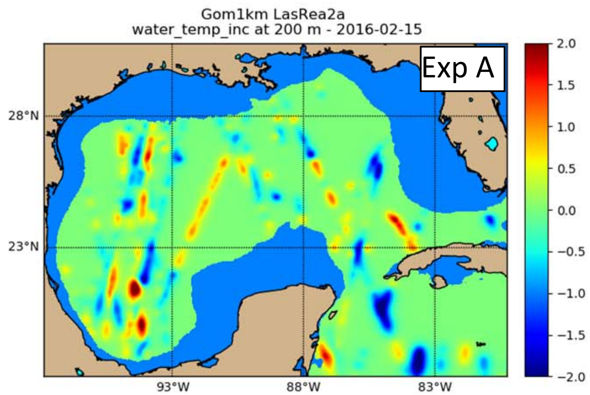
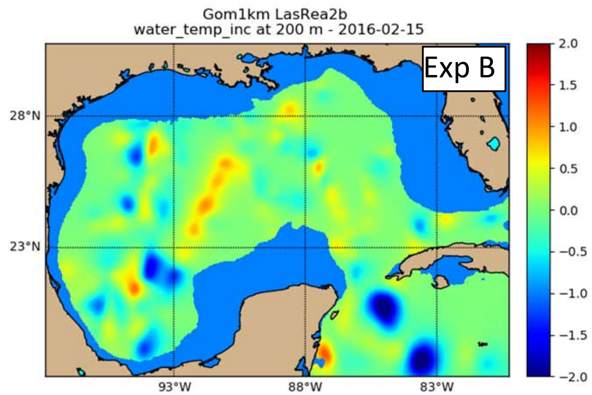
Assimilation scales

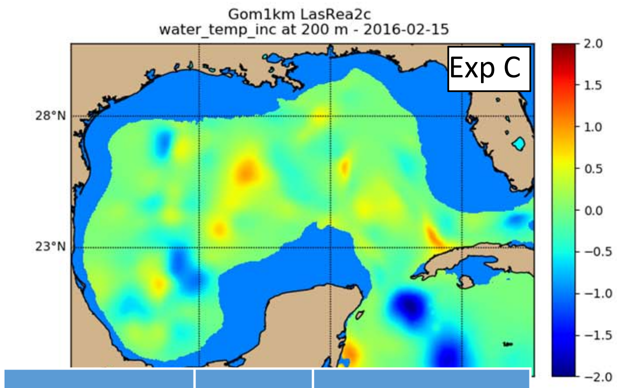
Observations must affect fields away from point locations

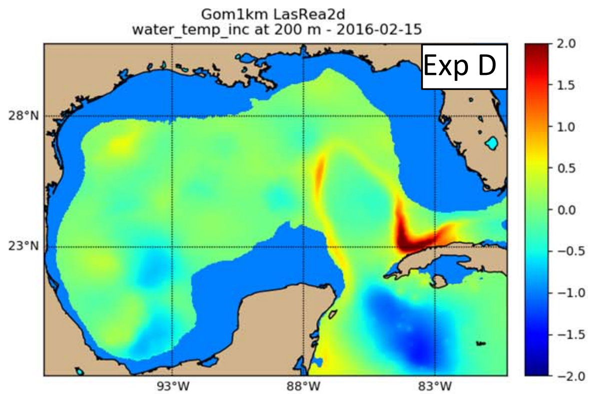
Described by background error covariance, which is separated into standard deviations, horizontal correlation, flow dependent correlation and vertical correlation $B(x,y,z,v,x',y',z',v') = S(v)C_H(x,y,x',y')C_{FD}(x,y,x',y')C_V(z,z')S(v')$

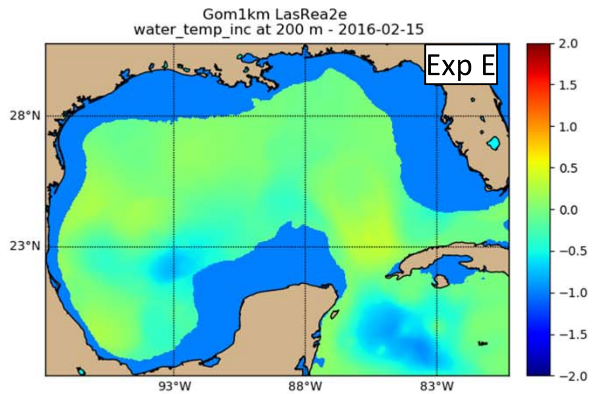
Horizontal correlation is a Second Order AutoRegressive with decorrelation scale related to local Rossby radius of deformation and an adjustment scale that define L: $C_H(x,y,x',y') = \left(1+\frac{r}{L}\right)\exp(-\frac{r}{L})$







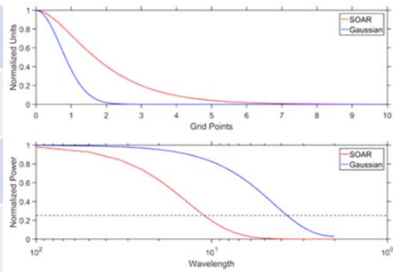




Experiment	rscl	Mean L (km)
A	0.4	9
B	1.2	23
C	2.0	36
D	4.4	78
E	6.5	114

SOAR

Gaussian



F(SOAR)

F(Gaussian)

We do not have 2D fields from drifters

Drifters:

Drifter distribution is continuously changing

We cannot difference from model and make PSD of errors

Error estimation:

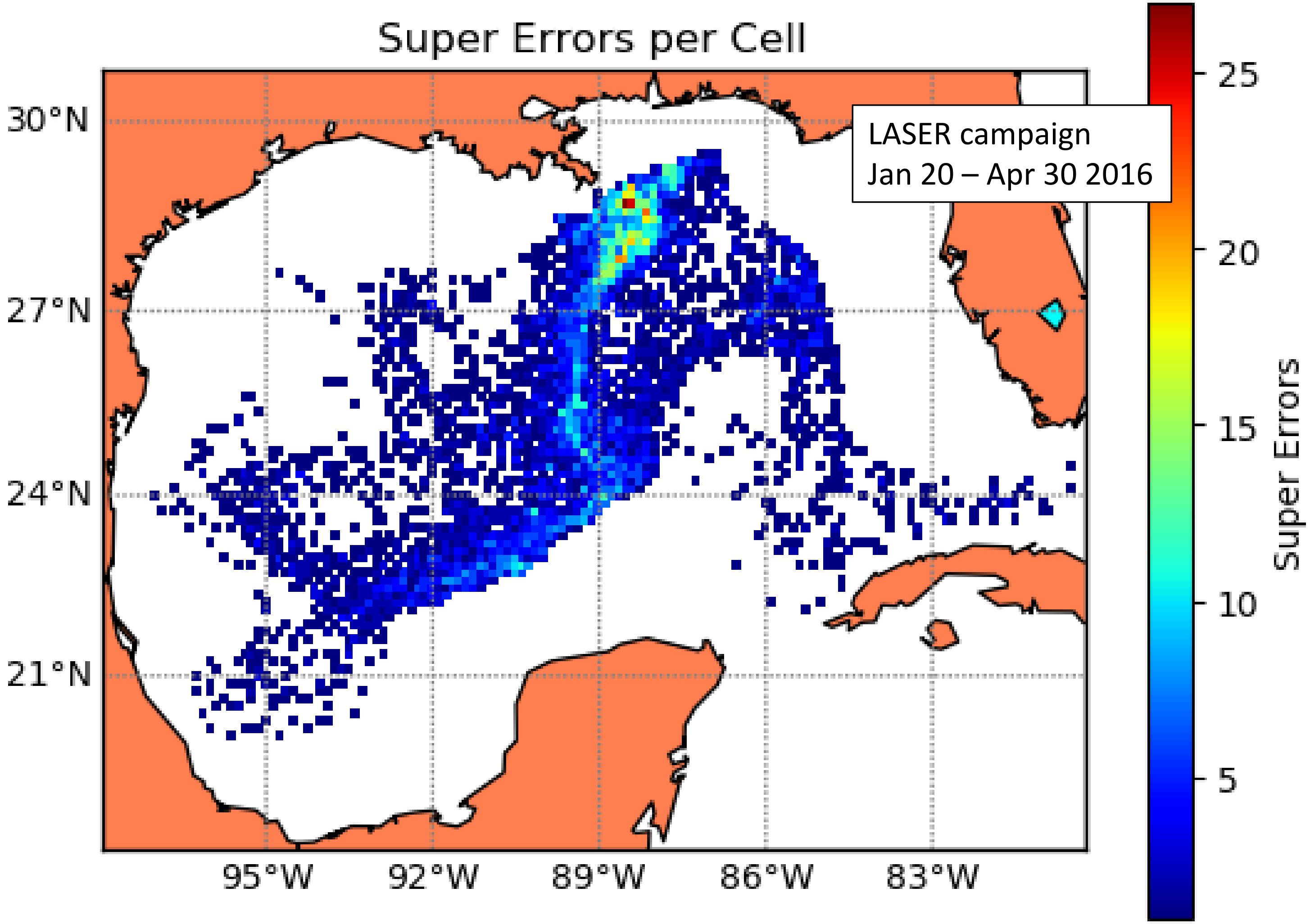
Initialize particles in model at 00Z at observed locations on every day

Integrate one inertial period to minimize effects of errors due to winds

Error is difference in end position converted to km / day

Use only depths greater than 300 m

Construct super-errors



How do we determine what is constrained?

Assume that the length scale separating constrained and unconstrained L_c

Separate true velocity based on the length scale L_c: $u = u_c + u_u$

Separate model velocity in a similar manner: $u' = u'_c + u'_u$

Assume constrained and unconstrained velocities are uncorrelated

The variance of the difference in true and model velocity is: $\mathrm{Var}(u - u') = \langle (u_c - u'_c)^2 + (u_u - u'_u)^2 \rangle$

Assume model unconstrained is realistic so $\mathrm{Var}(u_u) = \mathrm{Var}(u'_u)$

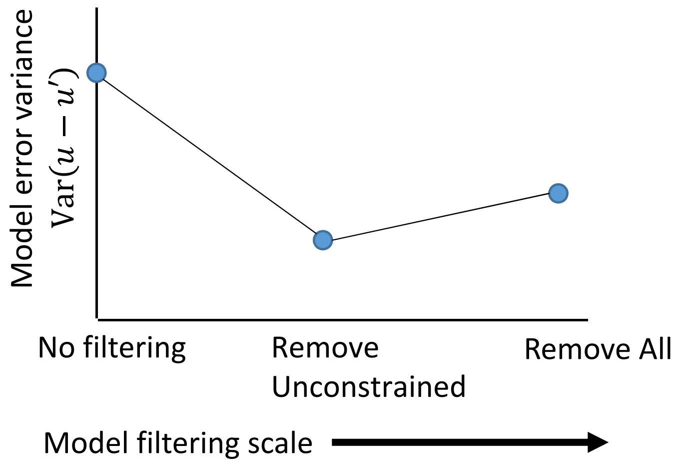
If the variance of the error in the constrained velocity is ε_c^2, $\mathrm{Var}(u - u') = \varepsilon_c^2 + 2\mathrm{Var}(u_u)$

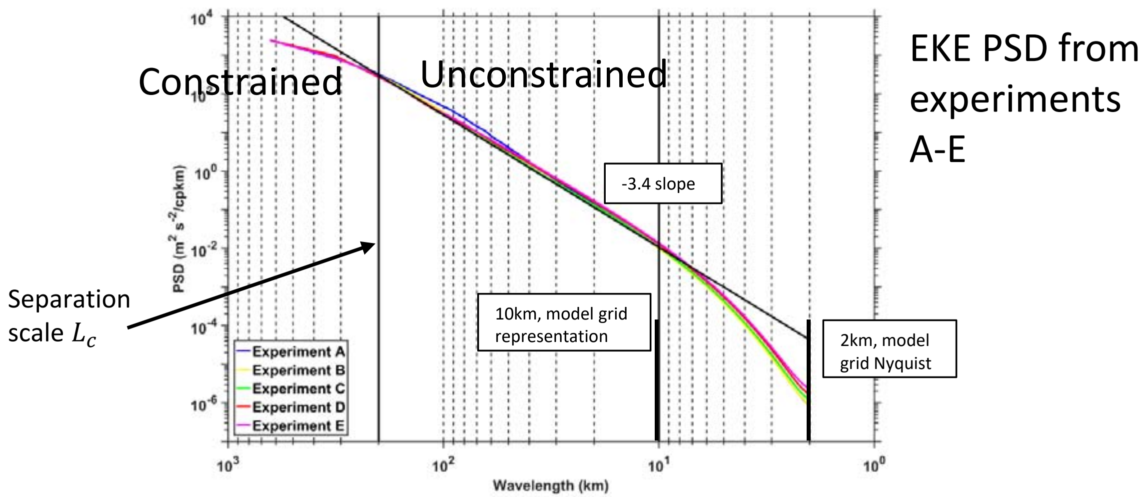
If we filter the unconstrained velocity from the model, then $\mathrm{Var}(u - u'_c) = \varepsilon_c^2 + \mathrm{Var}(u_u) < \mathrm{Var}(u - u')$

If we filter away all the model velocity, then $\mathrm{Var}(u - 0) = \mathrm{Var}(u_c) + \mathrm{Var}(u_u)$

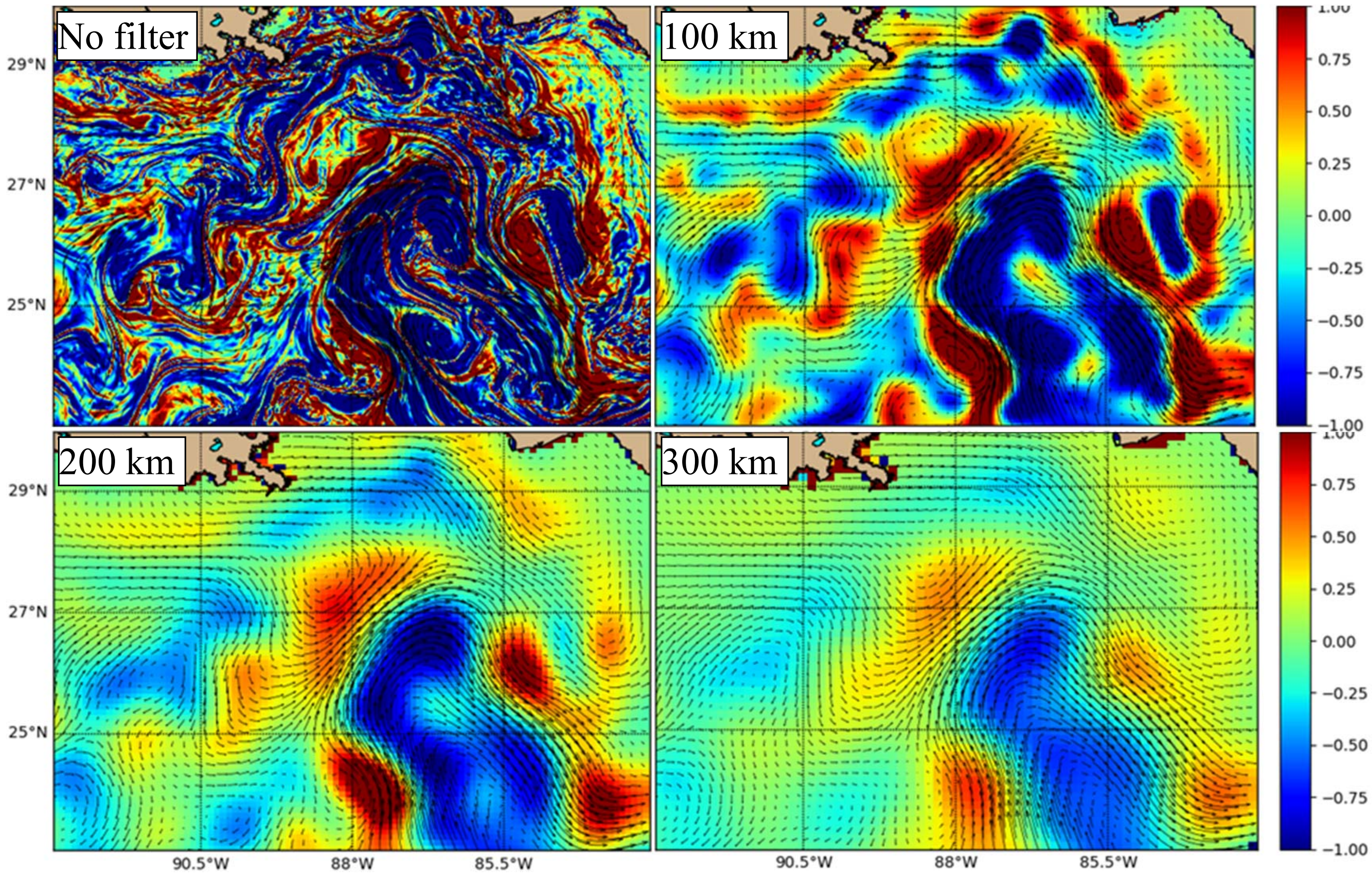
By definition, skill in the constrained field implies $\varepsilon_c^2 < \mathrm{Var}(u_c)$

Therefore $\mathrm{Var}(u - u'_c) < \mathrm{Var}(u - 0)$





Separating scales by filtering



Relative vorticity from filtered velocity fields

Filter each experiment with a Gaussian kernel with e-folding scale: $F(r) = \exp\left(-r^2/f_l^2\right)$ With scale from 20 to 300 km in 20 km increments

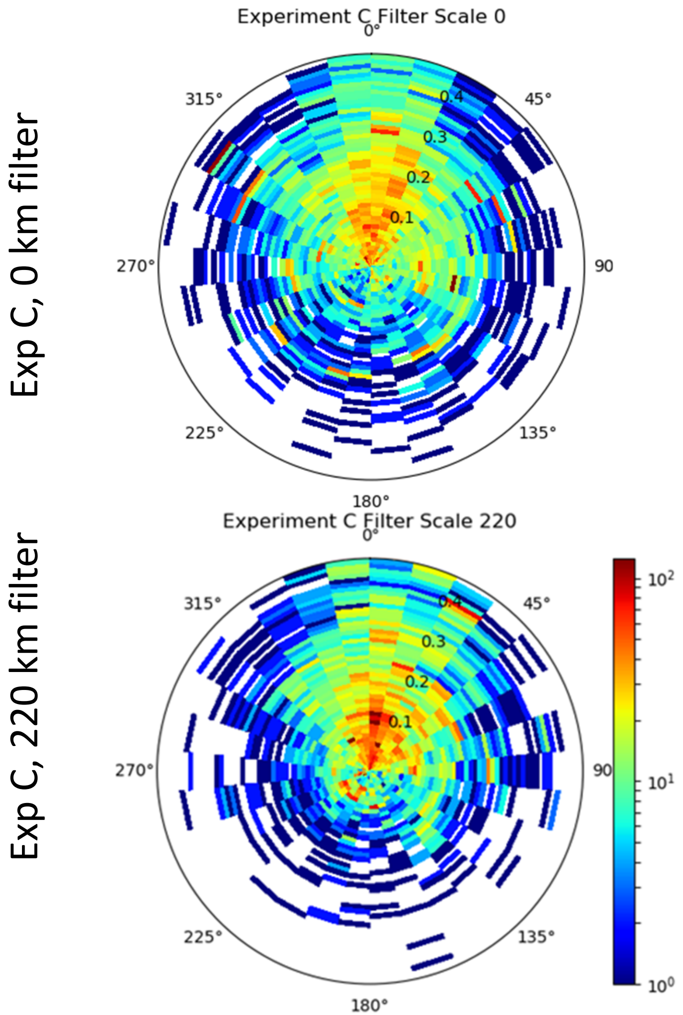
Experiment C filtering examples Vorticity / f

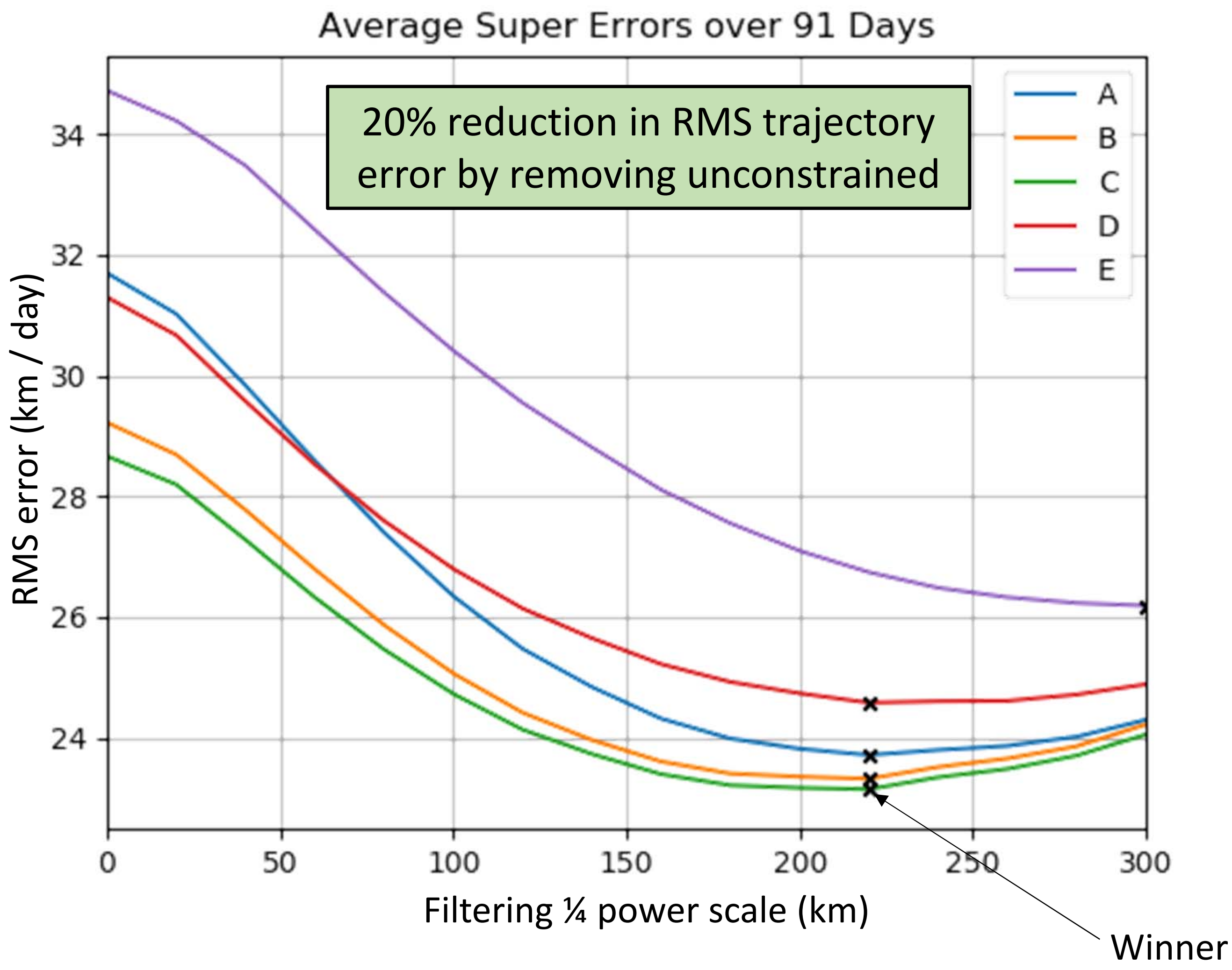
Spoiler: Experiment C does best

Spoiler: 220 km does best

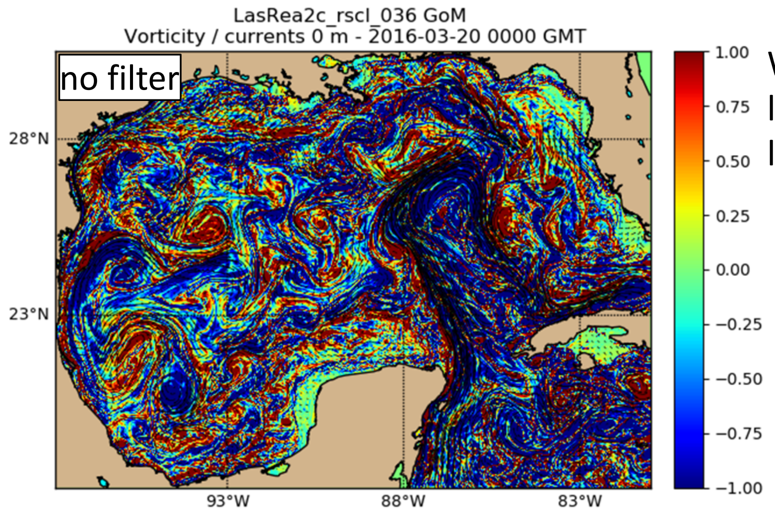
Results

Velocity error histogram (not super-errors)

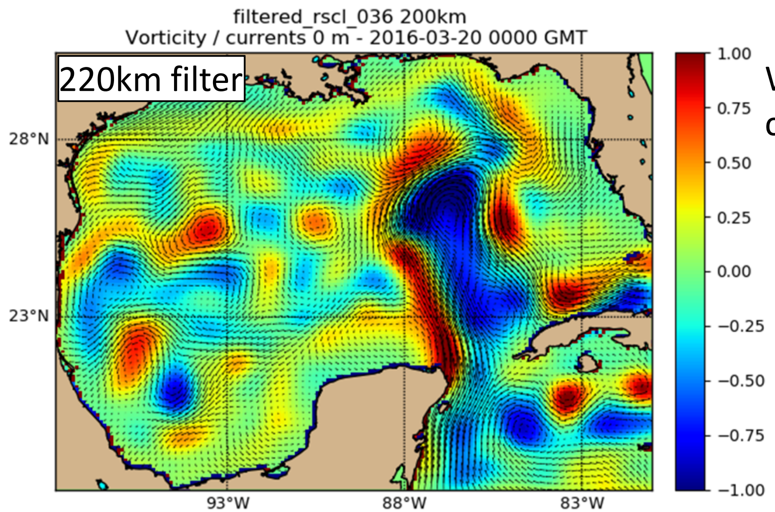




What is constrained (what we can predict)



What the ocean looks like (if it looks like a model)



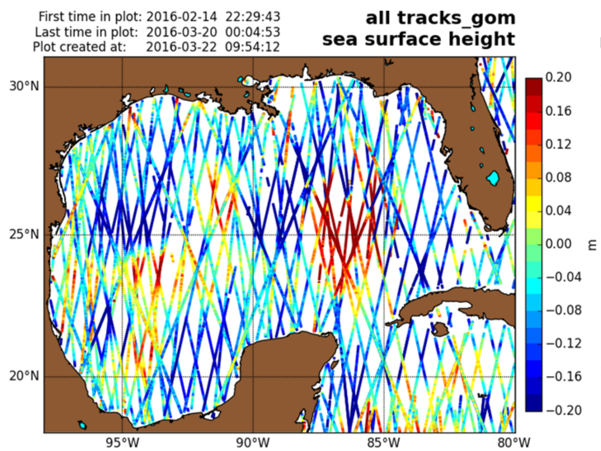
What we can predict

Consistent with prior work using only model and Observation System Simulation Experiments (OSSEs)

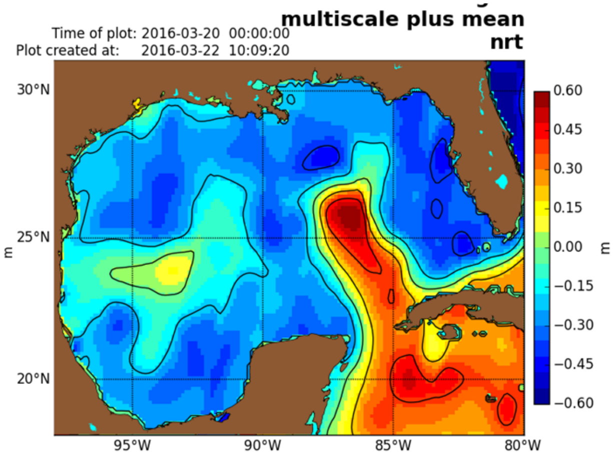
J. M. D'Addezio, S. Smith, G. Jacobs, R. Helber, C. Rowley, I. Souopgui, and M. Carrier: **Quantifying Wavelengths Constrained by Simulated SWOT Observations in a Submesoscale Resolving Ocean Analysis/Forecasting System**, accepted 2019, Ocean Modeling.

Observations are limiting more than fraternal twin issues in OSSEs

SSH anomaly 31 day composite



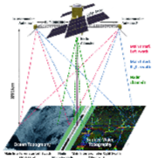
Interpolated SSHA plus mean

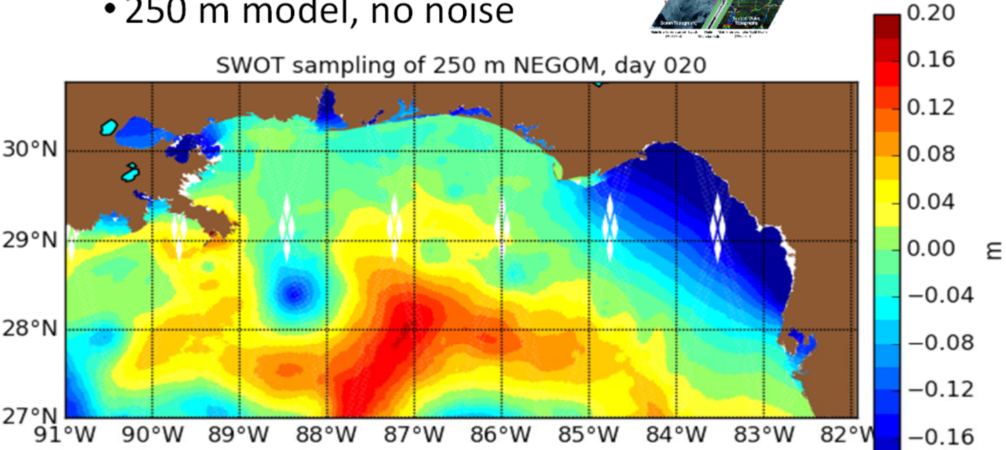


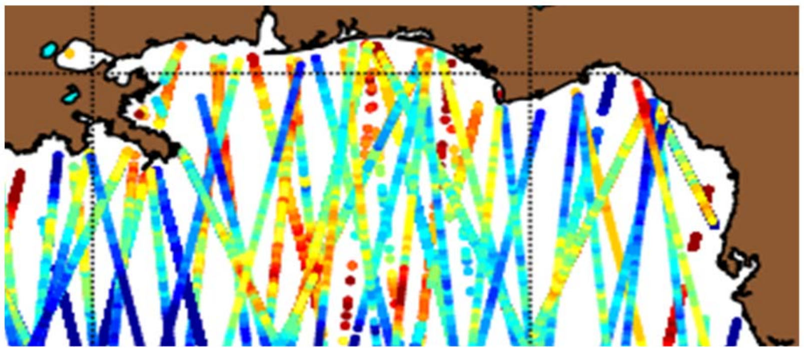
Compared to how we typically interpolate altimeter SSH

Future capability

- SWOT-sampled
- 21 day composite
- 250 m model, no noise







- Jason-2, AltiKa, CryoSat-2
- 35 day composite
- Observed values

SWOT reduces constrained scales by 50 km in SSH

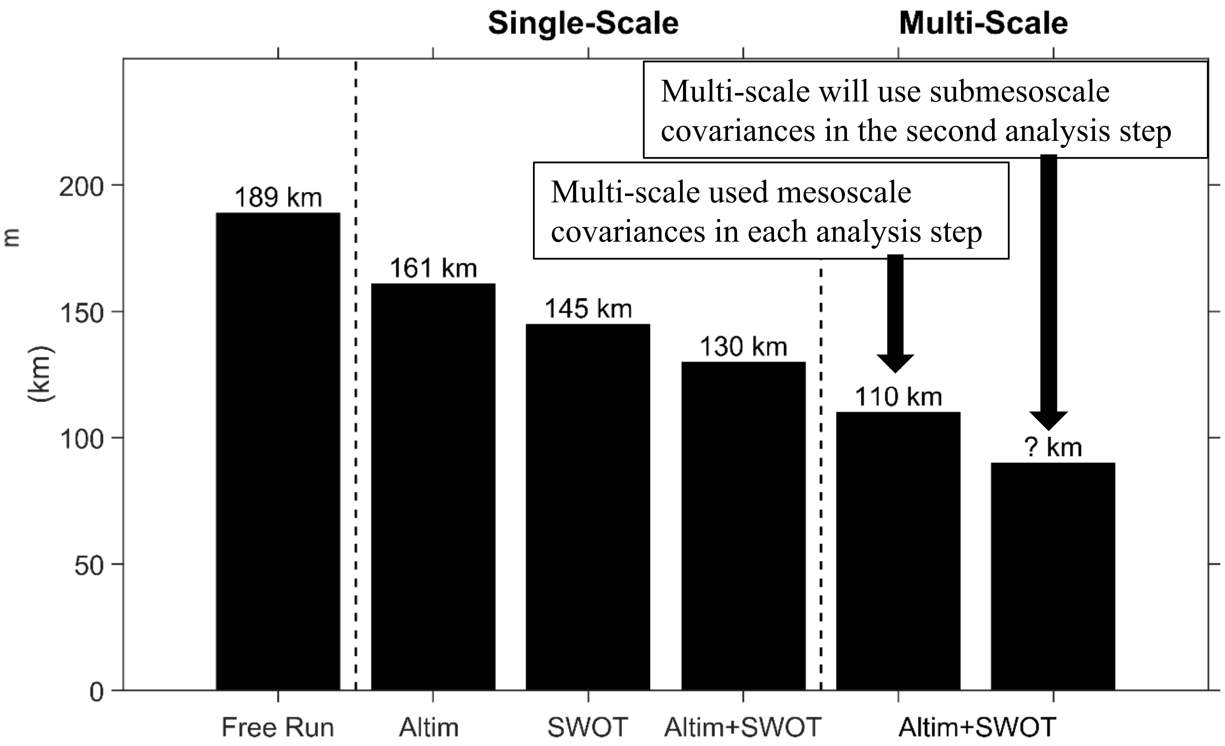
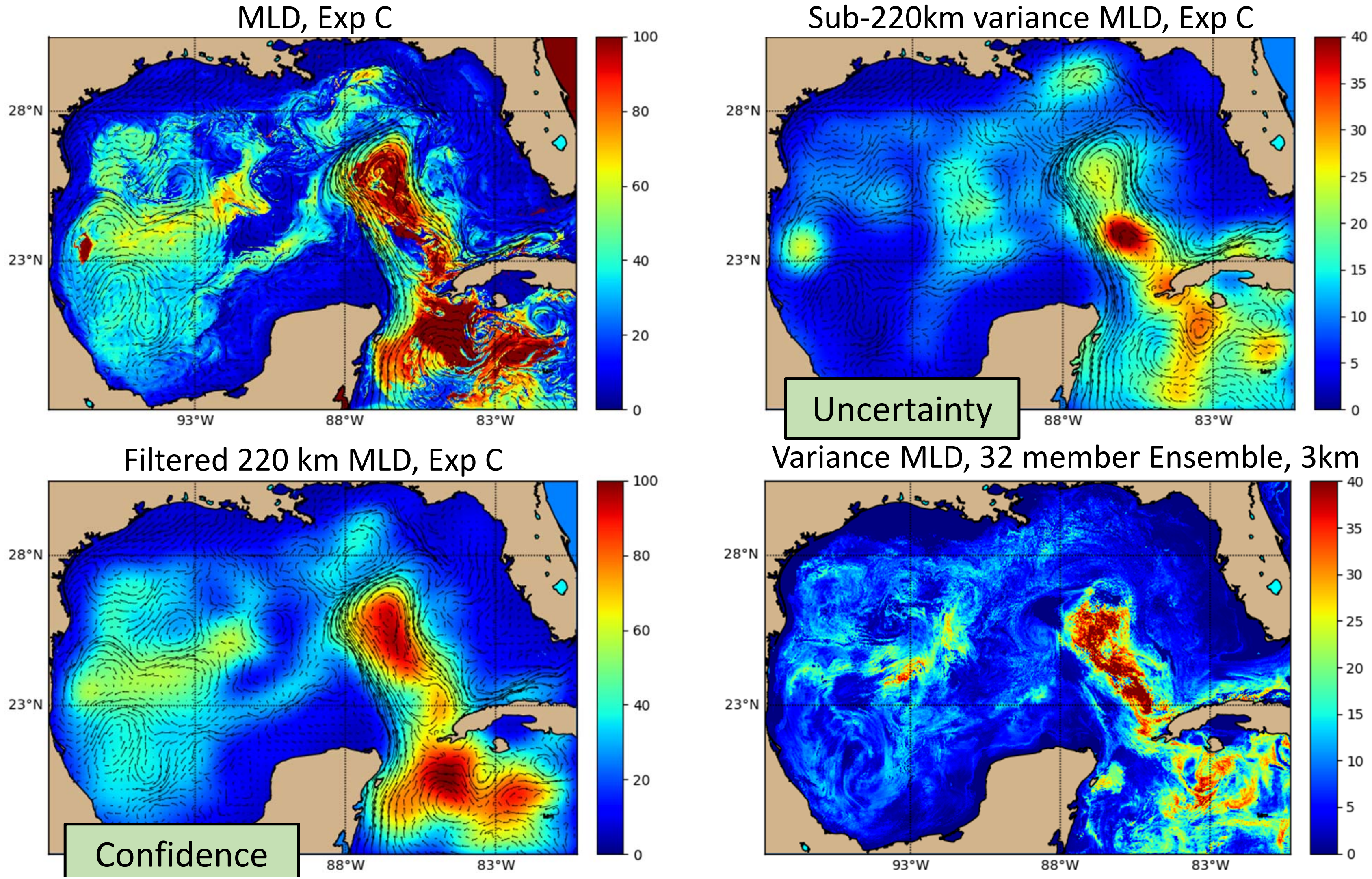


Figure 4. Minimum constrained wavelength when examining 100 m temperature (ºC). Each experiment assimilated different observation types and single- and multi-scale assimilation schemes are compared. Results were obtained using an Observing System Simulation Experiment (OSSE) in the western Pacific.

What part of uncertainty is the small scale? And the terrible implications…



Unconstrained spatial variance

- captures a sizeable portion of the uncertainty
- does not capture uncertainty at constrained scales

Ensembles

- Typically not sufficient resolution to capture the small scale unconstrained variability

These are both important contributors to the uncertainty

2016-03-20

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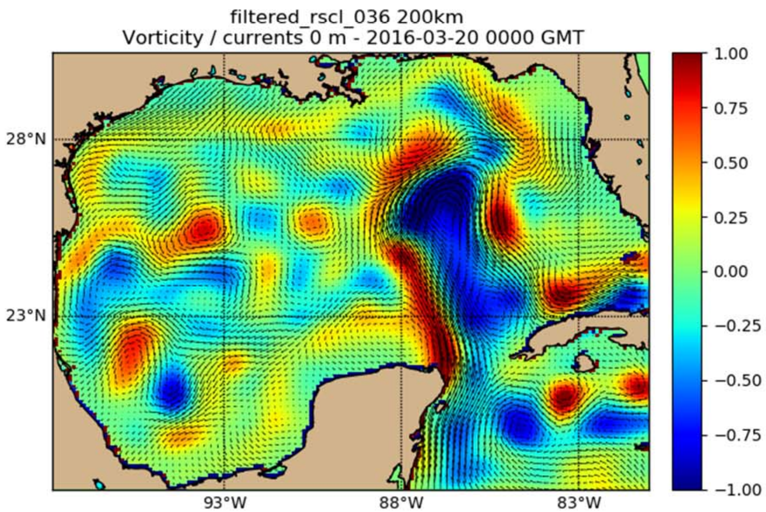
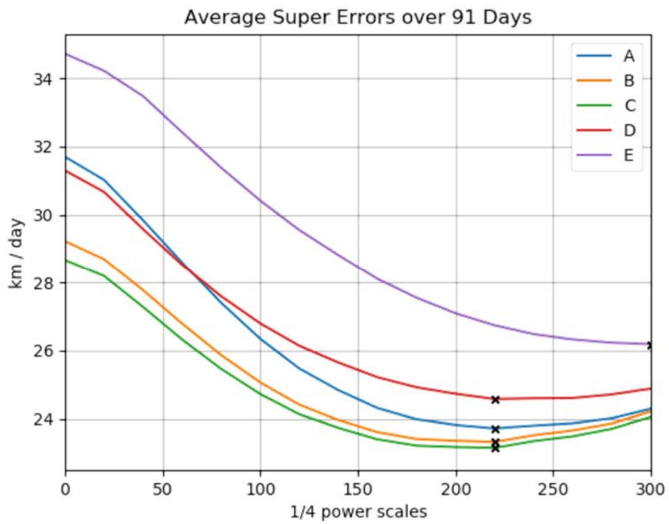
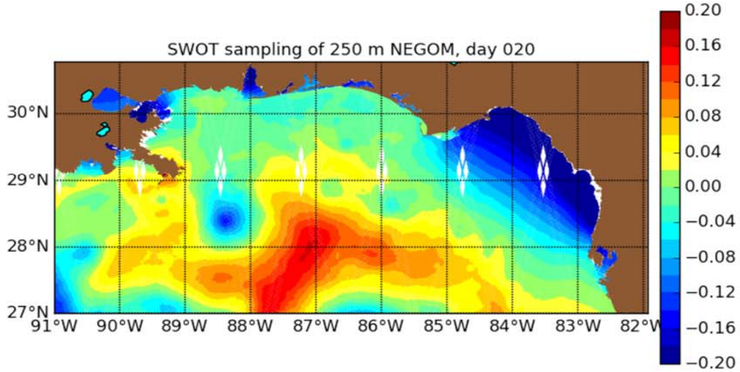
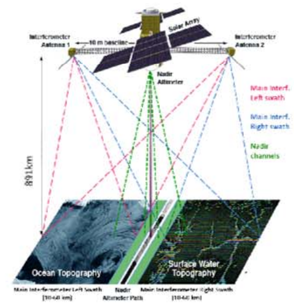
Conclusions

- With LASER observations, we quantify predictable scales (220 km scales)
- Errors increase when correcting scales smaller than observations resolve
- 20% improvement in trajectory forecasts by removing unconstrained features (in 1 km prediction system)
- We know separation of multiscale analyses for the future
- We add small scale variance to ensembles
- We must forecast unconstrained variance
- Observation density dictates a fundamental limit to prediction









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Constrained by present observations: > 58 km e-folding scale Gaussian filter

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