EGU 2013, Vienna, April 8-12

On the Impact of Nonlinearity on Ensemble Smoothing

Lars Nerger

Alfred Wegener Institute for Polar and Marine Research
Bremerhaven, Germany

Svenja Schulte and Angelika Bunse-Gerstner

University of Bremen, Germany

www.data-assimilation.net

Smoothers

Filters (e.g. Ensemble Kalman filter)

- Estimate using observations until analysis time

Smoothers perform retrospective analysis

- Use future observations for estimation in the past

- Example applications:
  - Reanalysis
  - Parameter estimation

Ensemble smoothing

- Smoothing is very simple (ensemble matrix $\mathbf{X}^f_{k|k-1}$) (see e.g. Evensen, 2003)

  Filter: $\mathbf{X}^a_{k|k} = \mathbf{X}^f_{k|k-1}\mathbf{G}_k$

  Smoother: $\mathbf{X}^a_{k-1|k} = \mathbf{X}^a_{k-1|k-1}\mathbf{G}_k$

- Optimal for linear systems:
  - ➜ Forecast of smoothed state = analysis at later time
  - ➜ Each additional lag reduces error
- Not valid for nonlinear systems!

➜ What is the effect of the nonlinearity?

➜ Do ensembles just decorrelate? (see e.g. Cosme et al. 2010)

Numerical study with Lorenz-96

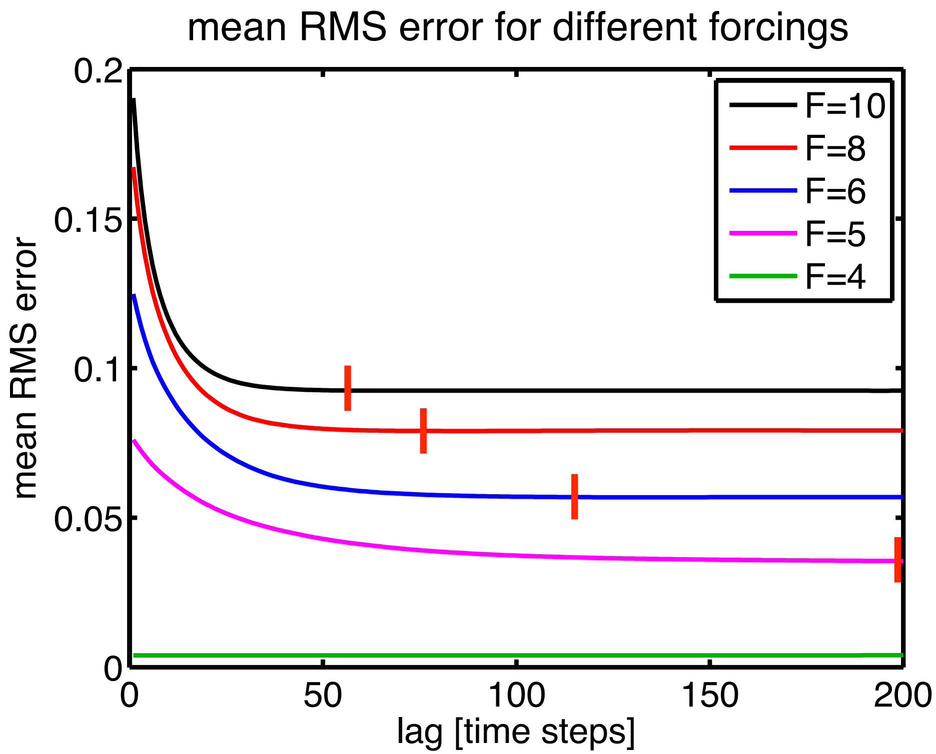
- Cheap and small model (state dimension 40)
- Local and global filters possible
- Nonlinearity controlled by forcing parameter *F*
  - Up to *F*=4: periodic waves; perturbations damped
  - *F*>4: non-periodic
- Nonlinearity of assimilation also influenced by forecast length

- Experiments over 20,000 time steps
- Tune covariance inflation for minimal RMS errors
- Implemented in open source assimilation software PDAF (*http://pdaf.awi.de*)

Effect for forcing – optimal lag

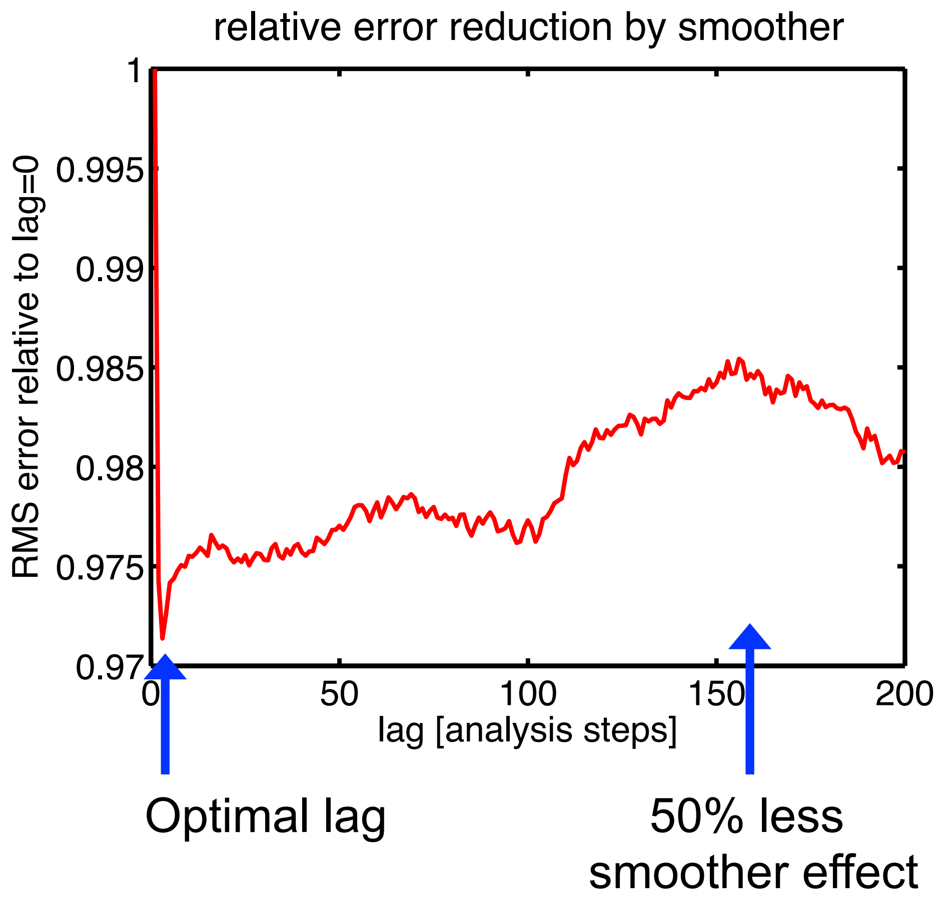
- Assimilate at each time step
- Ensemble size N=34
- Global ESTKF
  (Nerger et al., MWR 2012)

- Up to *F*=4
  - very small RMS errors
- *F*>4
  - Strong growth in RMS
  - Clear impact of smoother
  - Optimal lag:
    minimal RMS error (red lines)

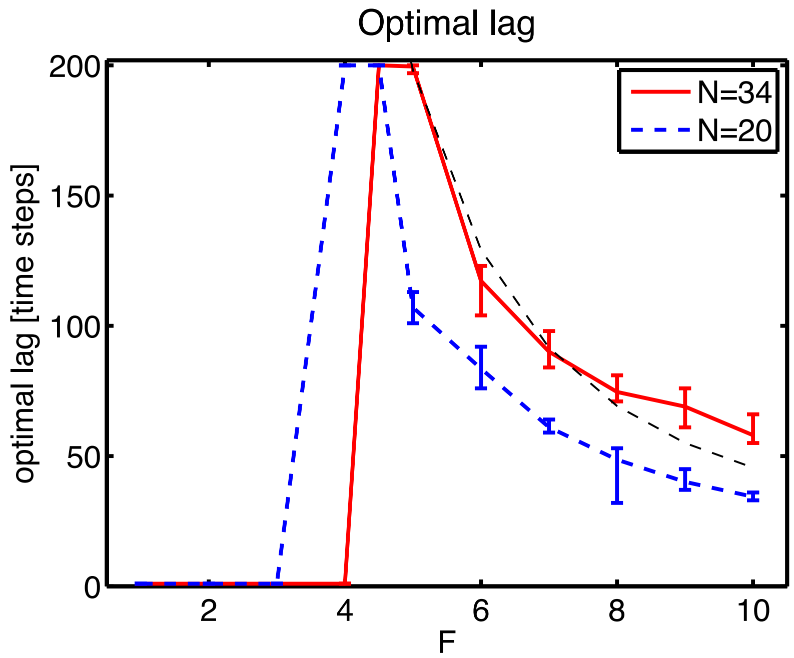


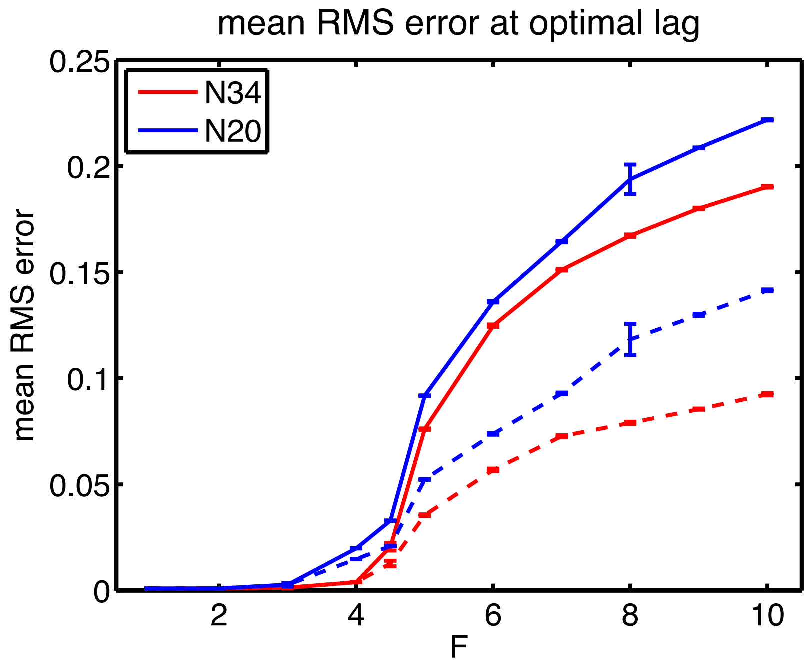
Stronger nonlinearity

- *F*=7
- Forecast length: 9 steps
- Clear error-minimum at 2 analysis steps
  - ➜ the optimal lag
- Error increase beyond optimal lag (here 50%!)
  - ➜ spurious correlations



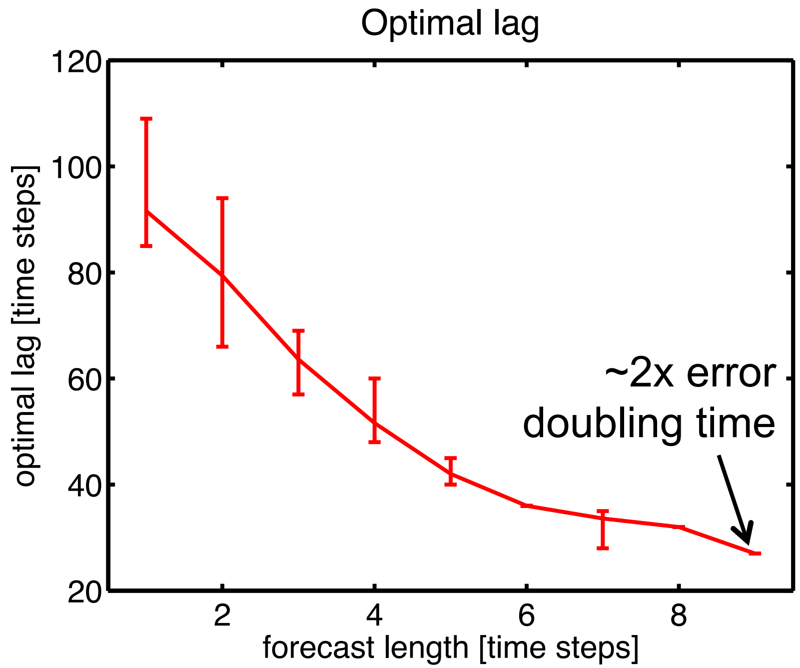
Impact of smoothing

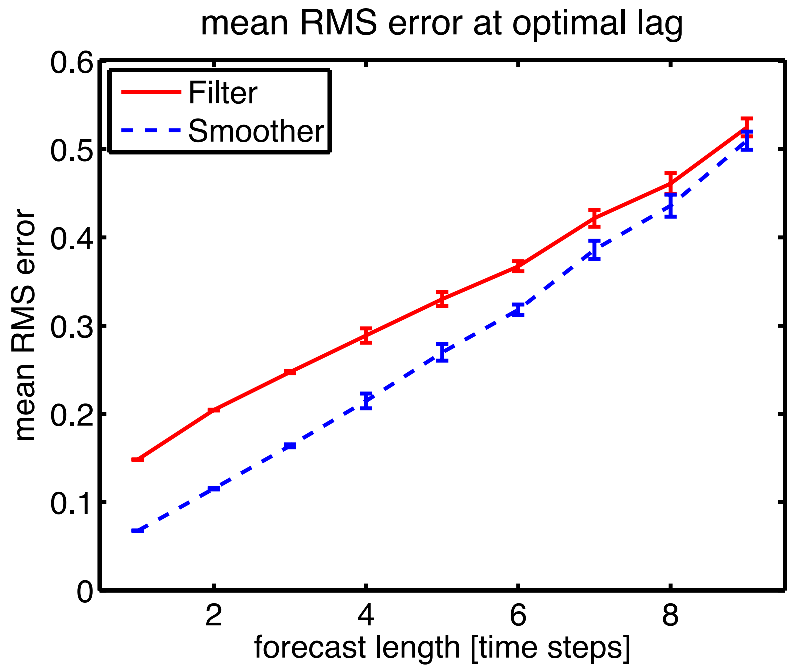




- Optimal lag (minimal RMS error)
  - Behavior similar to error-doubling time
- RMS error at optimal lag
  - Smoother reduces error by 50% for all F>4
- Effect of sampling errors visible with smaller ensemble

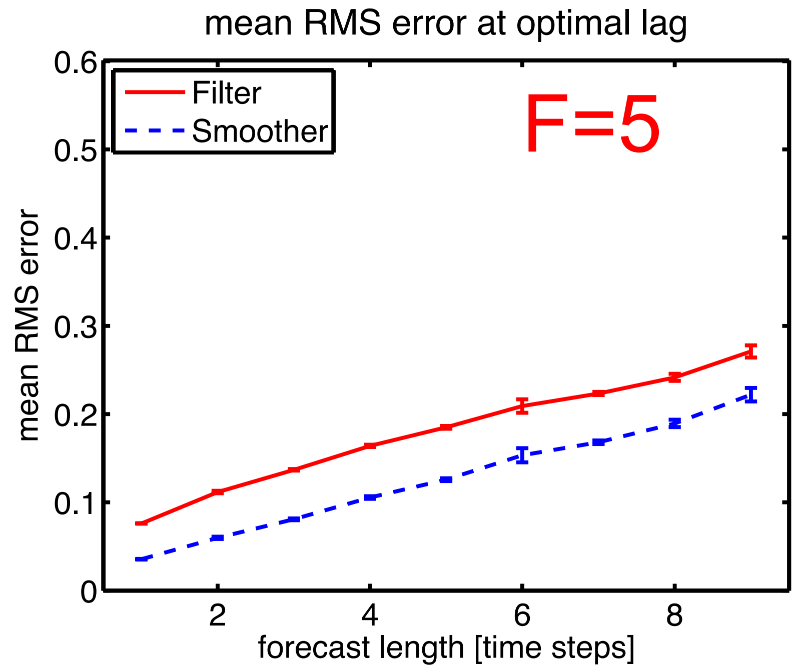
Vary forecast length (F=7)

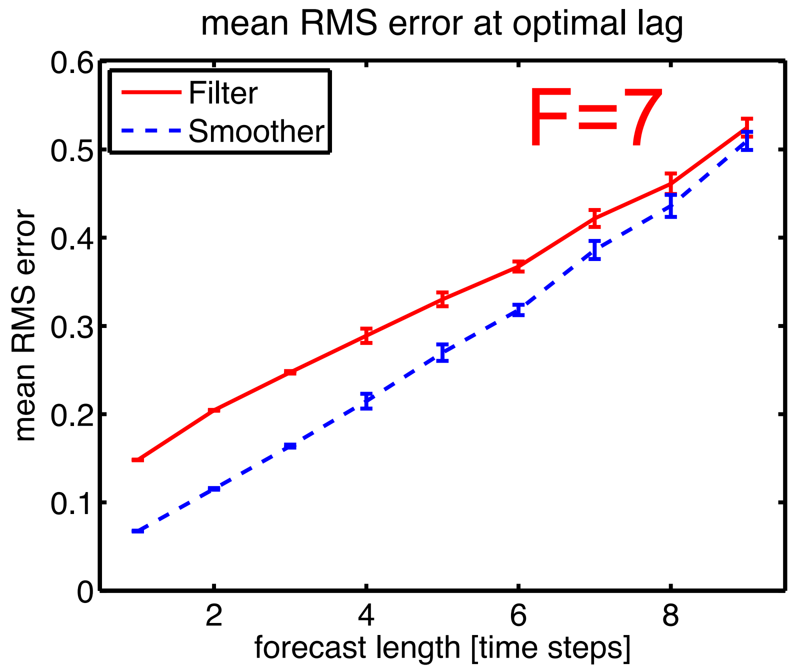




- Forecast length = time steps over which nonlinearity acts on ensemble
- Longer forecasts:
  - ➜ Optimal lag shrinks
  - ➜ RMS errors grow for filter and smoother
  - ➜ Improvement by smoother shrinks (depends on forcing strength)

Vary forecast length (F=7)





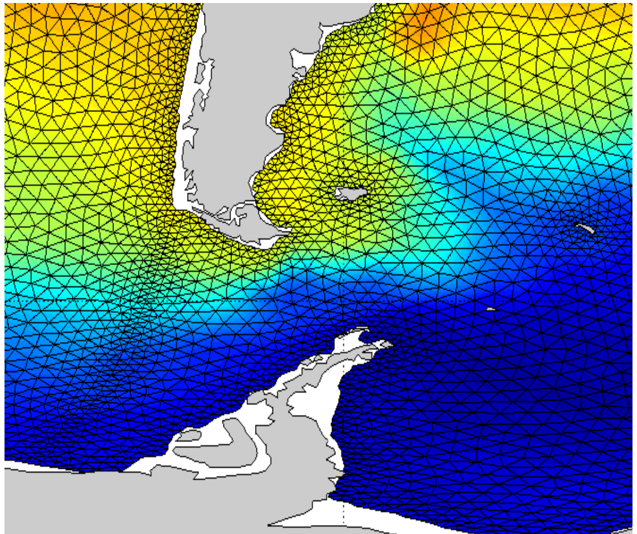
- Forecast length = time steps over which nonlinearity acts on ensemble
- Longer forecasts:
  - ➜ Optimal lag shrinks
  - ➜ RMS errors grow for filter and smoother
  - ➜ Improvement by smoother shrinks (depends on forcing strength)

Smoothing with global ocean model

FESOM (Finite Element Sea-ice Ocean model, Danilov et al. 2004)

Global configuration

- 1.3° resolution, 40 levels
- Horizontal refinement at equator
- State vector size 10^7
- Weak nonlinearity

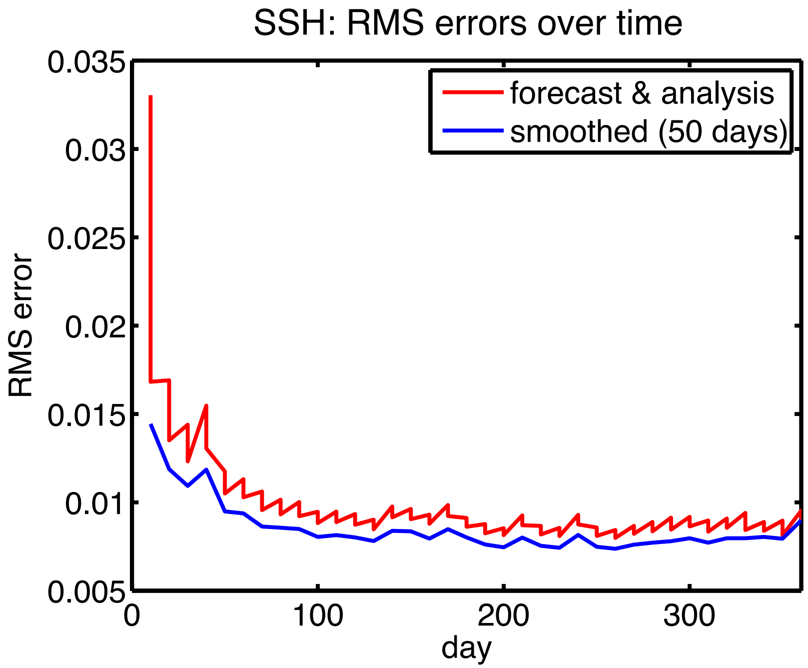


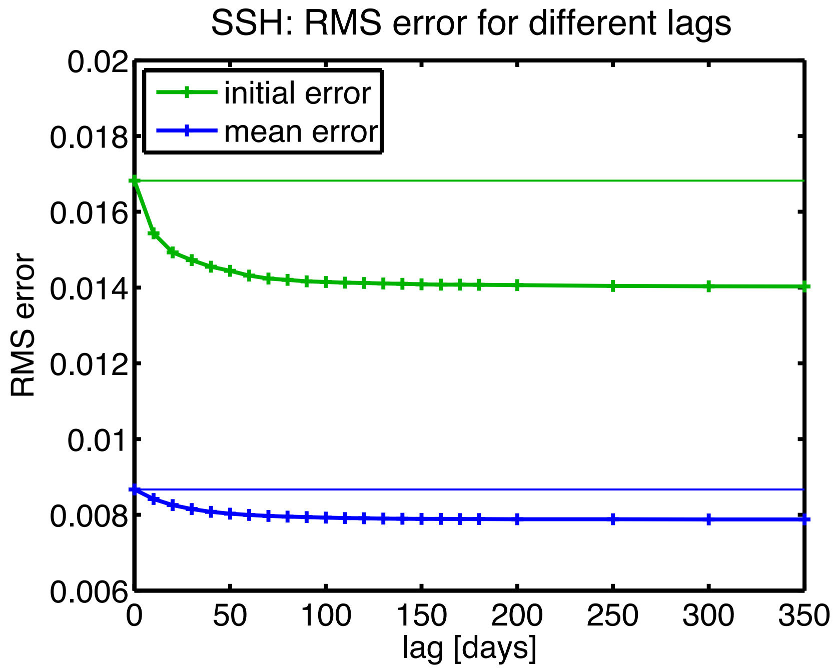
Drake passage

Twin experiments with sea surface height data

- Ensemble size 32
- Assimilate each 10th day over 1 year
- ESTKF with smoother extension and localization
  (Using PDAF environment as for Lorenz-96)
- Inflation tuned for optimal performance (ρ=0.9)

Effect of smoothing on global model





Typical behavior

- RMSe reduced by smoother

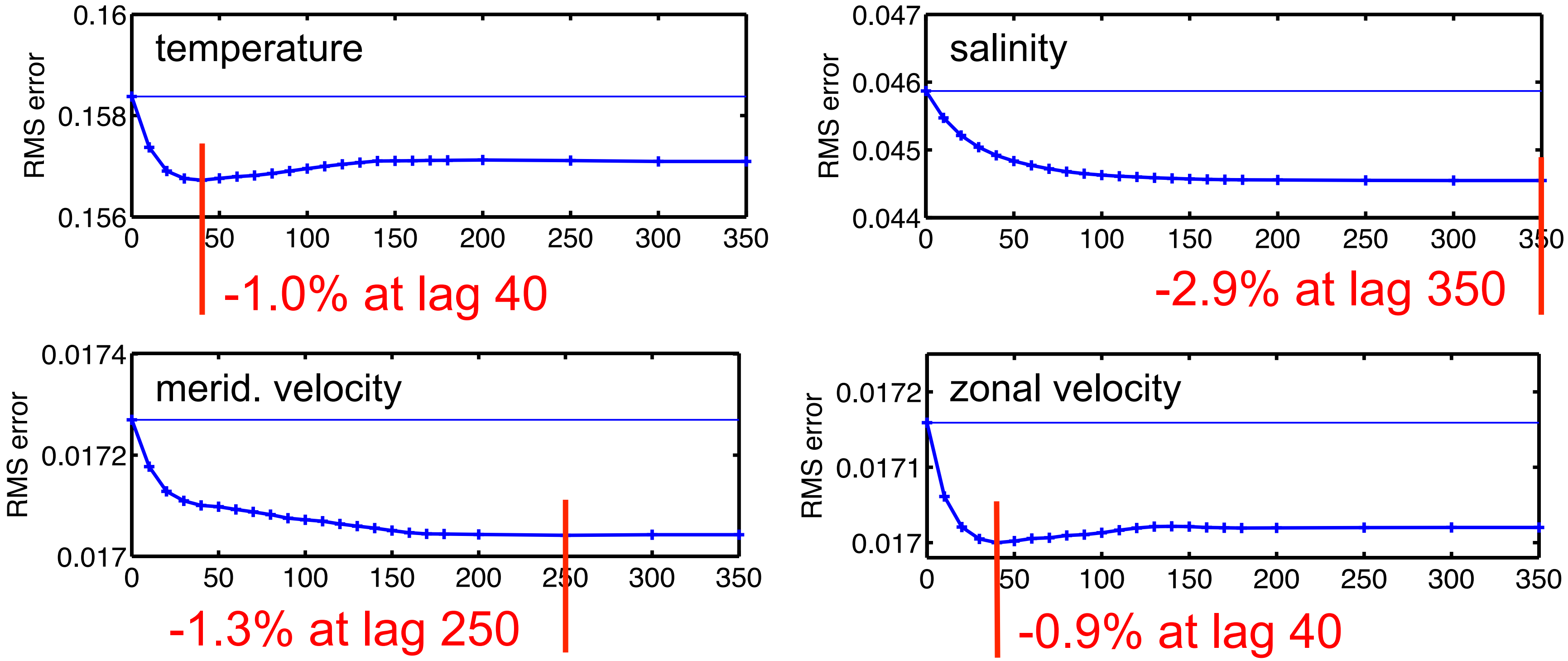
Error reductions:

~15% at initial time

~8% over the year

- Large impact of each lag up to 60 days
- Further reduction over full experiment (optimal lag = 350 days)

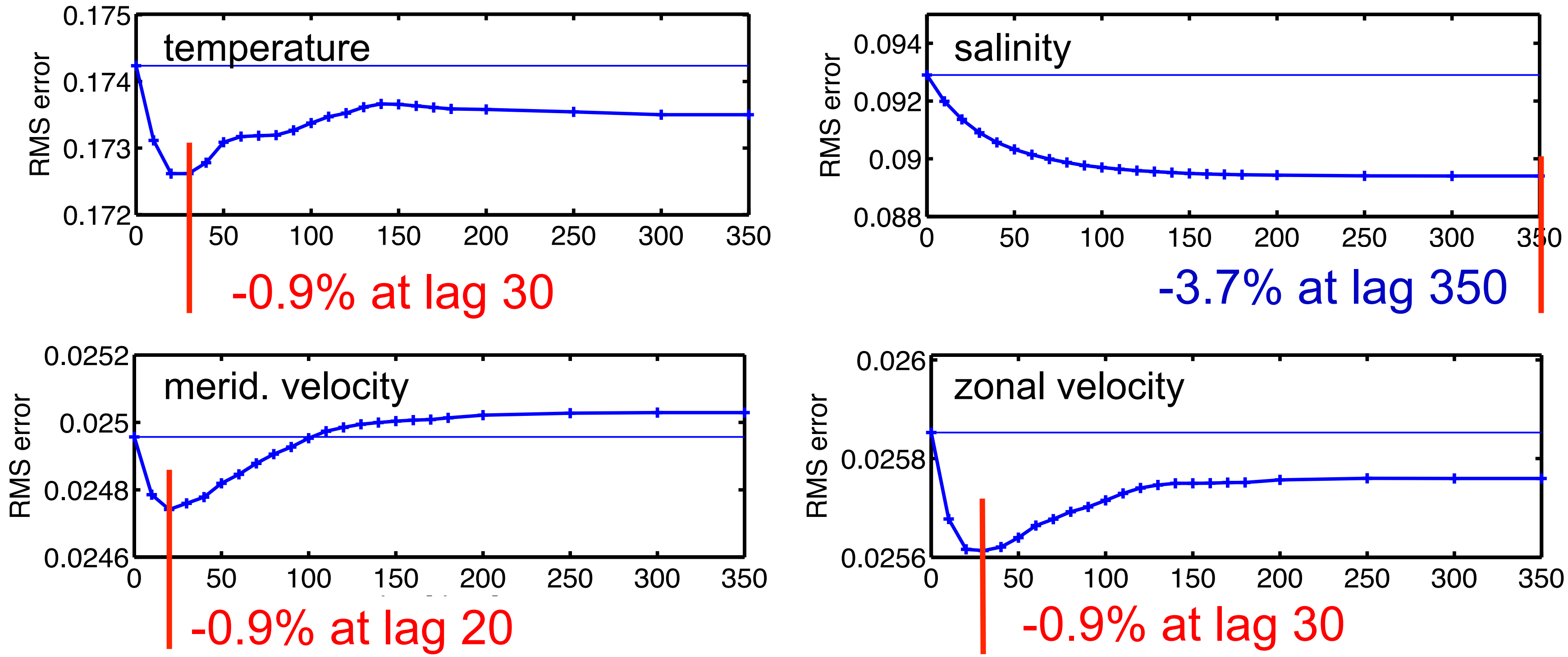
Multivariate effect of smoothing – 3D fields



3D fields:

- Multivariate impact smaller & specific for each field
- Optimal lag specific for field
- Optimal lag smaller than for SSH

Multivariate effect of smoothing – surface fields



Ocean surface:

- Relative smoother impact not larger than for full 3D
- Deterioration for meridional velocity at long lags

➜ What is the optimal lag for multivariate assimilation?

Conclusion

- Multivariate assimilation:
  - ➜ Lag specific for field
  - ➜ Choose overall optimal lag or separate lags
  - ➜ Best filter configuration also good for smoother

- Nonlinearity:
  - ➜ Introduces spurious correlations in smoother
  - ➜ Error increase beyond optimal lag
  - ➜ Optimal lag: few times error doubling time

Thank you!

Web-Resources

SANGOMA www.data-assimilation.net

PDAF Parallel Data Assimilation Framework pdaf.awi.de