Development of ROMS/EnKF forecasting system for GBR

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Outline

The EnKF

ROMS/EnKF system for GBR
- System settings
- Biases
- Fields
- Single observation experiments
- SST bias correction

The EnKF

DA: the minimisation problem

$$\{\mathbf{x}_i^a\}_{i=1}^k = \arg \min_{\{\mathbf{x}_i\}_{i=1}^k} \mathcal{L}(\mathbf{x}_1, \ldots, \mathbf{x}_k),$$

$$\begin{aligned}\mathcal{L}(\mathbf{x}_1, \ldots, \mathbf{x}_k) = &(\mathbf{x}_1 - \mathbf{x}_1^f)^{\mathrm{T}} (\mathbf{P}_1^f)^{-1} (\mathbf{x}_1 - \mathbf{x}_1^f) \\ &+ \sum_{i=1}^{k} [\mathbf{y}_i - \mathcal{H}_i(\mathbf{x}_i)]^{\mathrm{T}} (\mathbf{R}_i)^{-1} [\mathbf{y}_i - \mathcal{H}_i(\mathbf{x}_i)] \\ &+ \sum_{i=2}^{k} [\mathbf{x}_i - \mathcal{M}_i(\mathbf{x}_{i-1})]^{\mathrm{T}} (\mathbf{Q}_i)^{-1} [\mathbf{x}_i - \mathcal{M}_i(\mathbf{x}_{i-1})] .\end{aligned}$$

(i = cycle number)

The EnKF

- Based on a recursive solution in the linear case ("Kalman Filter")
- State of the DA system $\text{SDAS}_i = \{\mathbf{x}_i, \mathbf{P}_i\}$
- The EnKF carries the SDAS by an ensemble of model states: $\text{SDAS}_i = \{\mathbf{E}_i\}$

The EnKF (2)

Cost(EnKF) = Cost(model propagation) $\times$ ensemble size

Main features:

- simple
- for propagation – needs forward model only
- long-term behaviour needs to be managed

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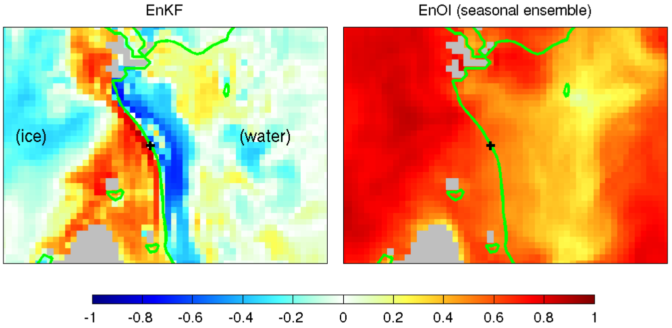
Example of dynamic covariance

Correlation of ICEC at location "+" with SSS



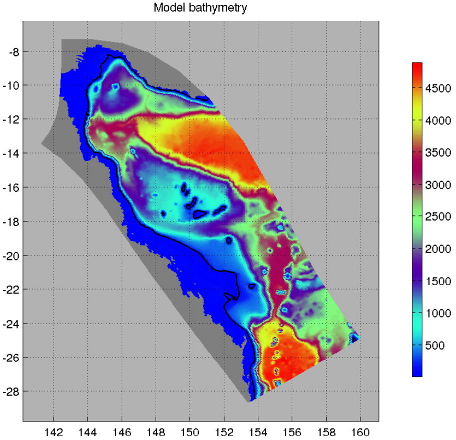
GBR ROMS/EnKF system

- Our first ocean forecasting experience with ROMS
- One of the most challenging regions around Australia for the EnKF
- ... and for a model with vertical σ coordinates

GBR ROMS/EnKF system: the domain

Some domain characteristics

- Includes both shelf and deep ocean
- Has long ocean boundary
- Has quite a bit of internal variability: not as chaotic as the EAC region, and not as forcing-driven as the Gulf of Carpentaria
- Enough of internal variability to generate ensemble spread and propagate it on shelf
- Rugged terrain, steep shelf break



Implications for the system design

Compared to the Tasman Sea system:

- Good atmospheric and boundary forcing is critical
- Forcing perturbation is necessary for the best performance

System settings

- EnKF with 96 members (EnKF-C code)
- 3-day cycle ($\sim 40\,\mathrm{m}/1, 1152$ CPUs, $541 \times 197 \times 30$ grid, $600\,\mathrm{s}$ time step)
- Assimilating SLA, SST, T, S (SSS) obs.
- Assimilating SLA and SST asynchronously with 1-day binning
- Using night time SST observations only
- Using instantaneous fields for T/S
- Using de-tided daily average zeta for SLA (propagating extra 1/2 day)
- DEnKF scheme, moderated with ALPHA = 0.8

$$\mathbf{A}^f = \left(\mathbf{I} - \frac{\alpha}{2}\mathbf{KH}\right)\mathbf{A}^a$$

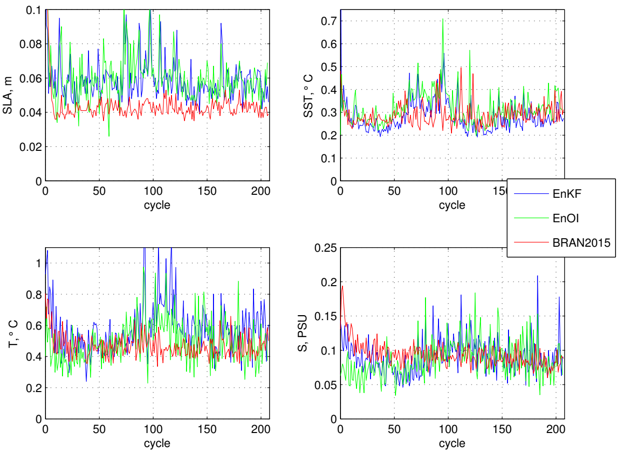
- Inflation 5%, capped
- $R_{loc} = 150\,\mathrm{km}$ for SLA/SST, $400\,\mathrm{km}$ for T/S
- R-factor = 1.5 for SLA, 16 for SST, 7 for T/S, 3 for SSS
- SST bias correction: RANDOMISE 0.96 0.3
- Forcing perturbation: TAIR 0.03; UV 0.05 SWRAD 0.05 RIVER 0.2

Performance

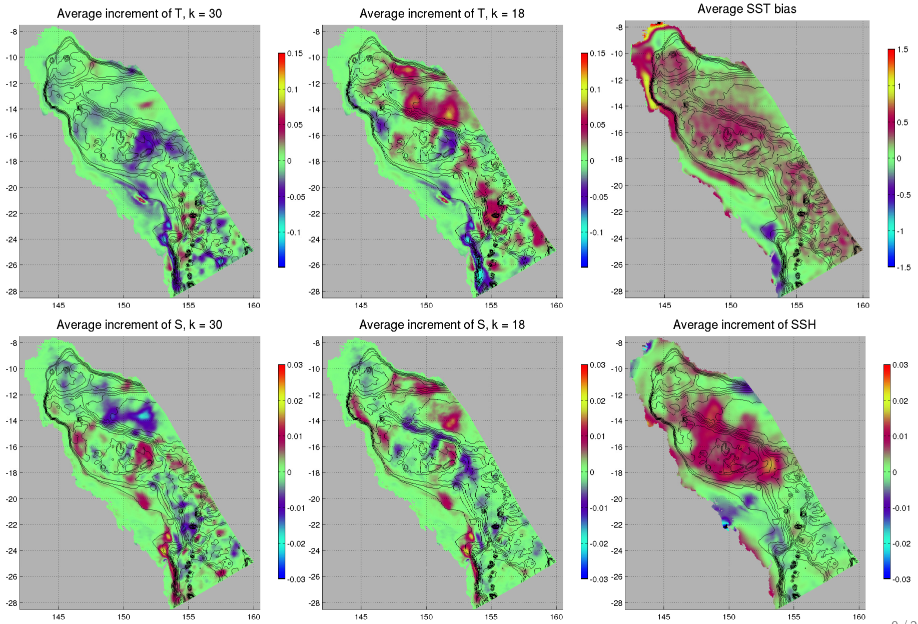
Innovation statistics for July 2013 - December 2014

	SLA	SST	T	S	SSS
EnKF	5.83	0.279	0.575	0.0896	0.213
EnOI	5.96	0.321	0.510	0.0885	0.207
BRAN2015*	4.18	0.274	0.438	0.0805	-

*0.1° model, ERA-interim forcing, stats for domain 135E-165E, 25S-5S



Biases


Average increment of T, k = 30
Average increment of T, k = 18
Average SST bias
Average increment of S, k = 30
Average increment of S, k = 18
Average increment of SSH
0.15 0.1 0.05 0 -0.05 -0.1
1.5 1 0.5 0 -0.5 -1 -1.5
0.03 0.02 0.01 0 -0.01 -0.02 -0.03
-8 -10 -12 -14 -16 -18 -20 -22 -24 -26 -28
145 150 155 160

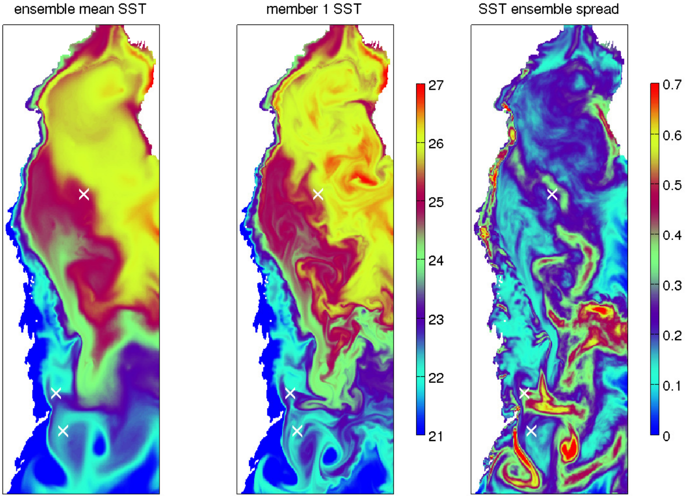
A bit more stats

Innovation statistics for July 2013 - December 2014

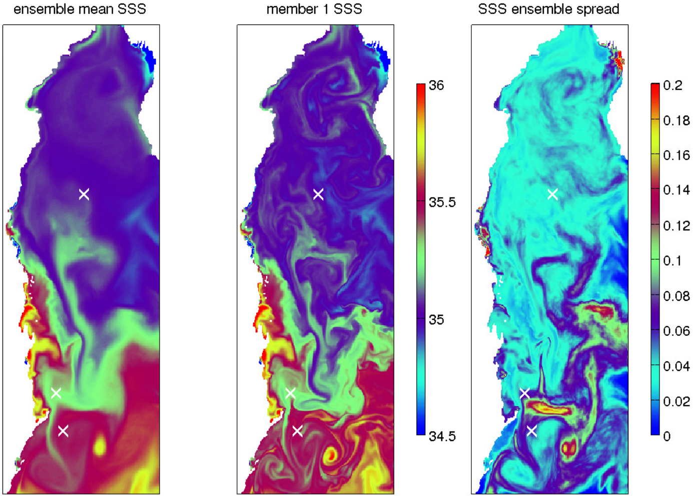
	SLA	SST	T	S	SSS
MAD	5.83	0.279	0.575	0.0896	0.215
Bias	0.82	0.020	-0.203	-0.0132	0.0806
Persistence MAD	5.87	0.307	0.569	0.0891	0.219

- SST looks good
- Biases for all fields but SST are quite substantial
- The model is consistently too warm
- The model is too fresh at surface

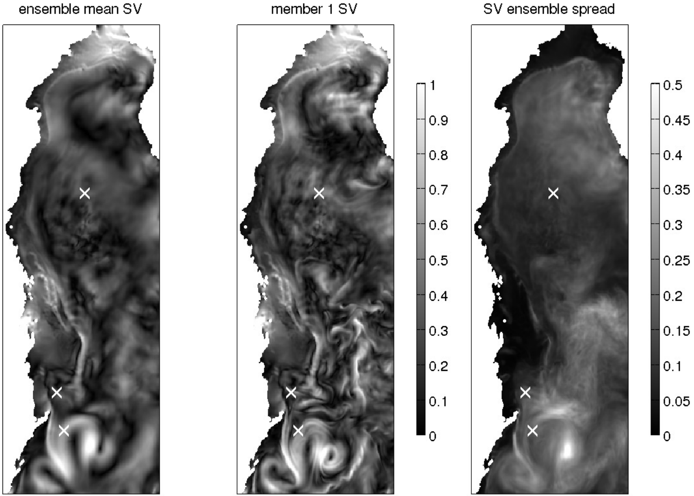
SST on 14-07-2007



SSS on 14-07-2007

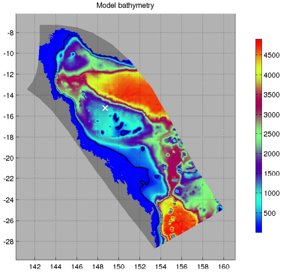


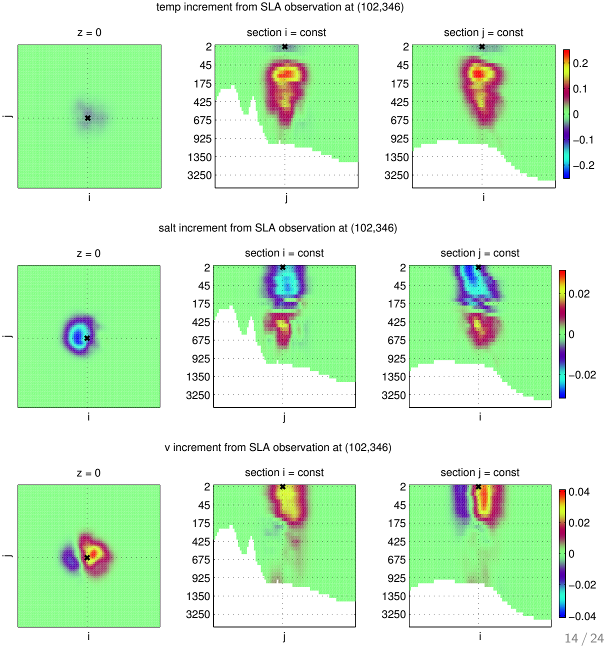
Surface velocity on 14-07-2007



Single observation experiments

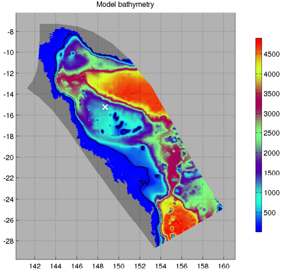
Single SLA observation
run enkf-27 on 14-07-2007
innovation = 5 cm
error STD = 3 cm
at (i, j) = (102, 346)

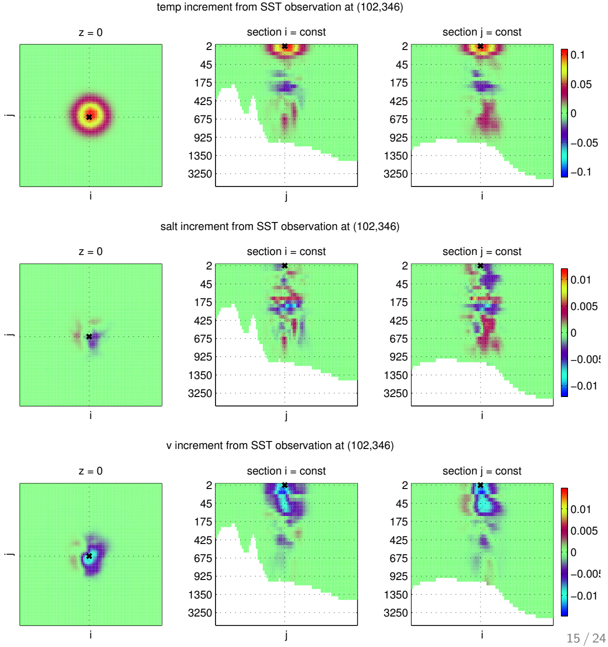




Single observation experiments (2)

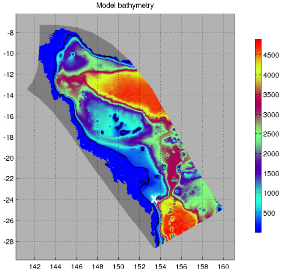
Single SST observation
run enkf-27 on 14-07-2007
innovation = 1°
error STD = 0.5°
at (i, j) = (102, 346)

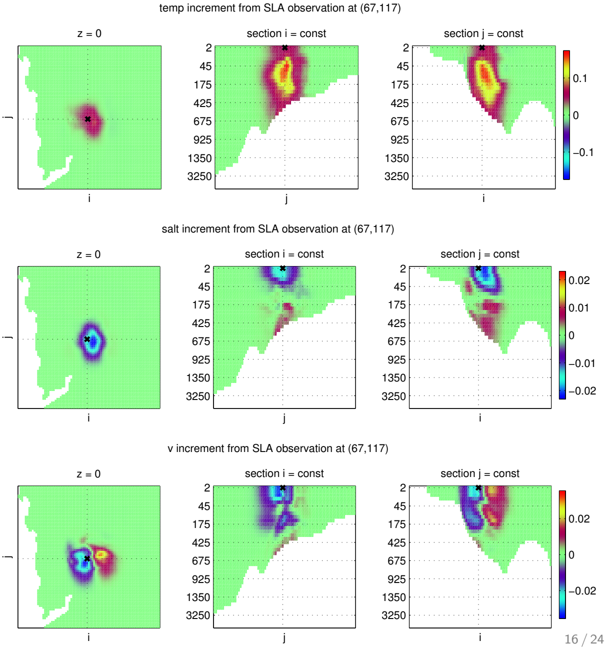




Single observation experiments (3)

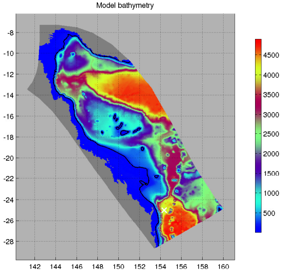
Single SLA observation
run enkf-27 on 14-07-2007
innovation = 5 cm
error STD = 3 cm
at (i, j) = (67, 117)

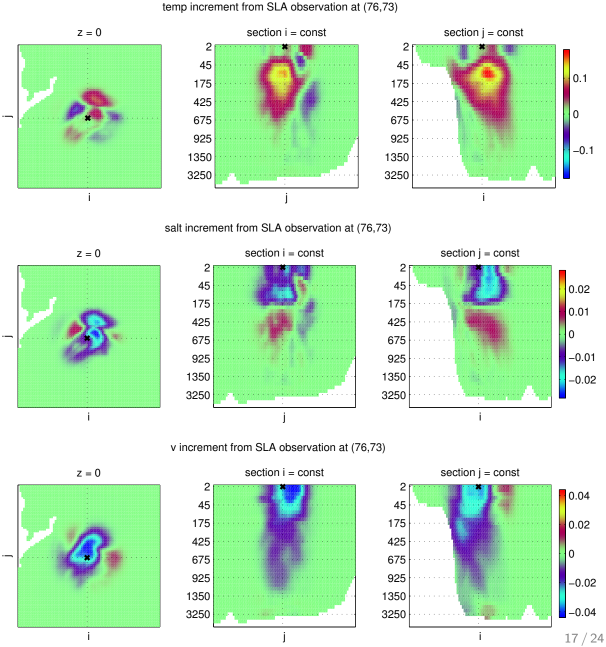




Single observation experiments (4)

Single SLA observation
run enkf-27 on 14-07-2007
innovation = 5 cm
error STD = 3 cm
at (i, j) = (76, 73)

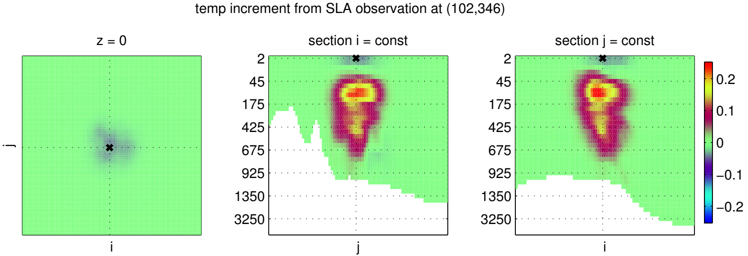




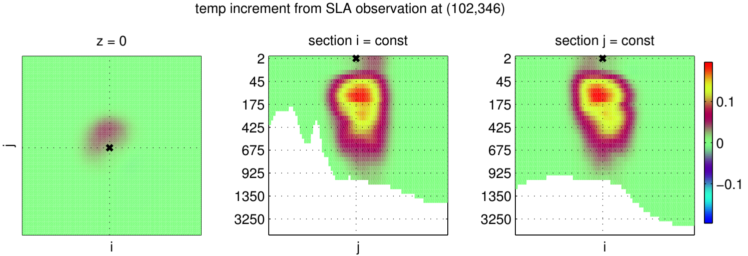
Single observation experiments: EnKF vs. EnOI

SLA $\rightarrow$ T

EnKF



EnOI

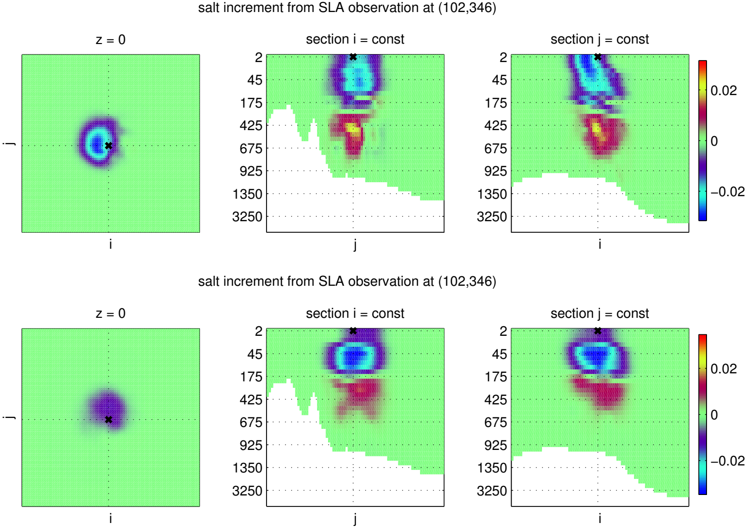


Single observation experiments: EnKF vs. EnOI (2)

SLA → S

EnKF

EnOI

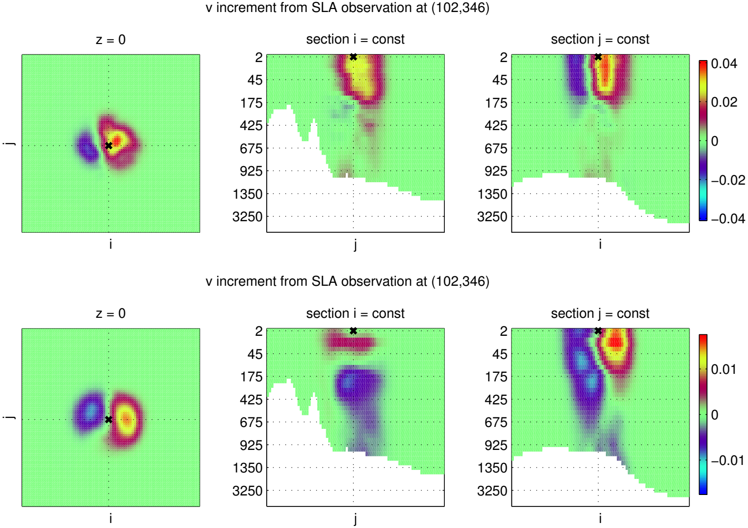


Single observation experiments: EnKF vs. EnOI (3)

SLA $\rightarrow$ V

EnKF

EnOI



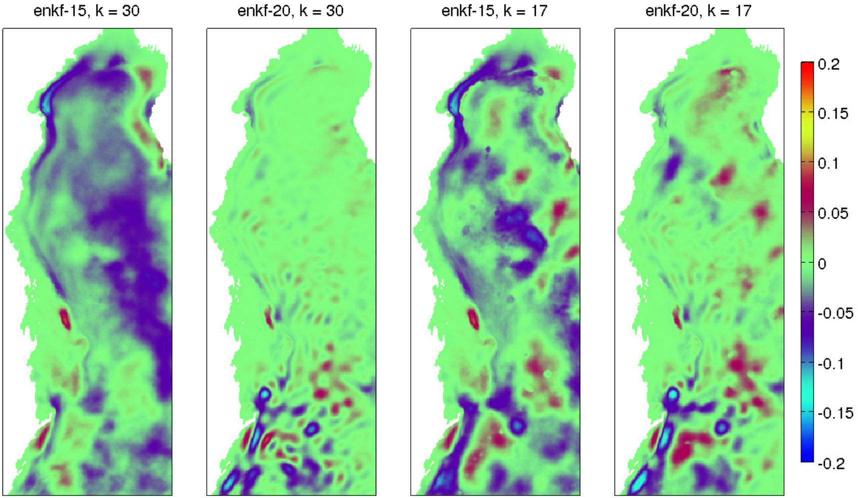
Effect of SST bias correction

Comparison of run enkf-15 (w/o SSTB correction) and enkf-20 (with SSTB correction); Jan 2006 – Feb 2009

	SLA	SST	T	S
enkf-15 MAD	5.78	0.303	0.672	0.145
enkf-20 MAD	5.64	0.291	0.538	0.131
enkf-15 bias	-0.001	-0.088	0.148	-0.055
enkf-20 bias	-0.006	-0.006	-0.134	0.038

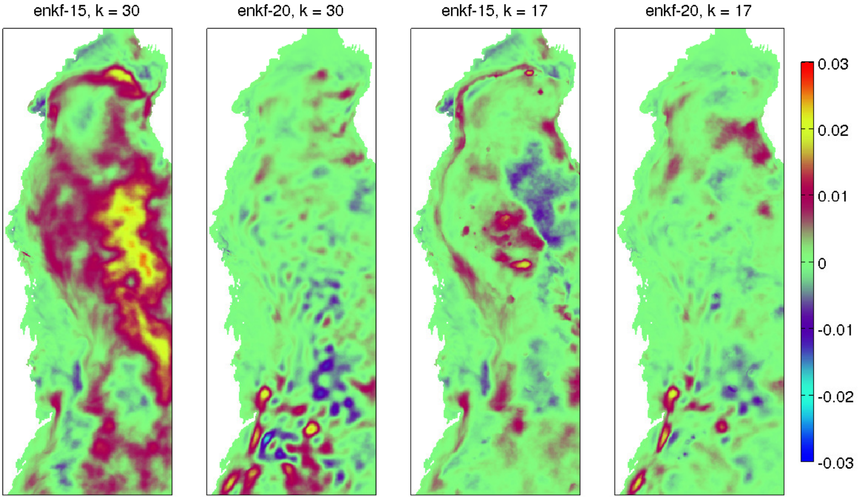
Effect of SST bias correction (2)

Mean T increments for runs enkf-15 and enkf-20



Effect of SST bias correction (3)

Mean S increments for runs enkf-15 and enkf-20



Conclusions

- EnKF forecasting system for GBR region has been developed based on a 4-km ROMS model with CFSR forcing and BRAN BC, and EnKF-C code (https://github.com/sakov/enkf-c)
- The system involves SST bias correction and (simplistic) forcing perturbation
- The system is quite robust and relatively inexpensive to run, doing a 3-day cycle in about 40 minutes on 1,152 CPUs
- The performance is rather good on SST, and OK on SLA, subsurface T and S (loosing on those to BRAN2015)

On ROMS

- ROMS internal de-tiding works well
- Looses on SSH (zeta) to MOM

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