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Guassianized 2dVar assimilation of ice concentration into CICE model

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ABSTRACT

Results of numerical experiments assimilating SSMI/IMS data into the HYCOM-driven CICE model are presented. To remove inconsistency between the Gaussian assumptions underlying the 2dVar algorithm and non-Gaussian nature of ice concentration (IC) errors, IC innovations are gaussianized prior to the analysis. The inverse (degaussianization) transform is computed at the analysis step and exploits similarity between the PDFs of IC innovations and increments. Gaussianization uncertainties are taken into account by an additional 2dVar algorithm optimizing the estimate of the background error variance with respect to the innovations obtained after the analysis. Numerical experiments with 2dVar assimilation of SSMI/IMS observations acquired in September-December 2015 in the Beaufort Sea demonstrate 5-10% improvement of the 24-hour forecast skill compared to the operational runs executed without gaussianization. An additional set of experiments was conducted to assess the impact of anisotropic IC covariance generated by the background ice velocity field. The respective forecast skill improvements were 1-2% in the gaussianized mode and 4-6% without gaussianization.

METHODOLOGY

1. Univariate gaussianization & degaussianization:

$$\mathcal{G}(\delta\mathbf{d}) = \mathcal{P}_g{}^{-1}\mathcal{P}_d(\delta\mathbf{d})$$

$$\mathcal{P}_g(\delta d) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\delta d}\exp(-x^2/2)dx = \frac{1}{2}\left(1+\mathrm{erf}\frac{\delta d}{\sqrt{2}}\right)$$

$$\mathcal{G}^{-1}(\delta\mathbf{x}) = \mathcal{P}_d{}^{-1}\left[\frac{1}{2}(1+\mathrm{erf}\frac{\delta\mathbf{x}}{\sqrt{2}})\right]$$

2. Inhomogeneous/anisotropic correlation model:

$$\mathbf{Cx} = \mathbf{N}\exp\left[-\frac{1}{2}\nabla^{\mathsf{T}}\mathbf{D}(\boldsymbol{x})\nabla\right]\mathbf{x}$$

$$\mathbf{D} = \hat{\mathbf{D}}^{\mathsf{T}}\hat{\mathbf{D}}: \qquad \hat{\mathbf{D}}(\boldsymbol{x}) = r\begin{bmatrix}\sqrt{\lambda(\boldsymbol{x})} & 0\\ 0 & 1\end{bmatrix}\begin{bmatrix}\cos\theta(\boldsymbol{x}) & \sin\theta(\boldsymbol{x})\\ -\sin\theta(\boldsymbol{x}) & \cos\theta(\boldsymbol{x})\end{bmatrix}$$

$$\nabla^{\mathsf{T}}\mathbf{D}\nabla = (\tilde{\mathbf{D}}\nabla)^{\mathsf{T}}(\tilde{\mathbf{D}}\nabla)$$

3. 2dVar:

$$\delta\mathbf{x} = \mathbf{VC}\hat{\mathbf{H}}^{\mathsf{T}}(\hat{\mathbf{H}}\mathbf{C}\hat{\mathbf{H}}^{\mathsf{T}}+\mathbf{I})^{-1}\mathbf{R}^{-1}\delta\mathbf{d} \qquad \hat{\mathbf{H}} = \mathbf{VHR}^{-1}$$

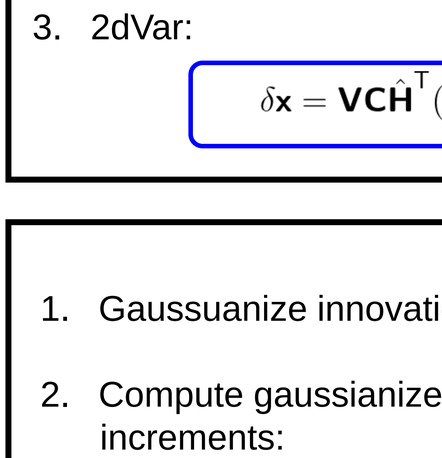
ALGORITHM

1. Gaussuanize innovations: $\delta\mathbf{d}_\star = \mathcal{G}(\mathbf{R}^{-1}\delta\mathbf{d})$ $\qquad \hat{\mathbf{H}} \to \mathbf{H}$
2. Compute gaussianized increments: $\delta\mathbf{x}_\star = \mathbf{CH}^{\mathsf{T}}(\mathbf{HCH}^{\mathsf{T}}+\mathbf{I})^{-1}\delta\mathbf{d}_\star$
3. Degaussianize the increments: $\delta\mathbf{x}' = \mathcal{G}^{-1}(\delta\mathbf{x}_\star)$
4. Correct for degaussianization errors: $\mathbf{v} \to \mathbf{v}+\delta\mathbf{v}$

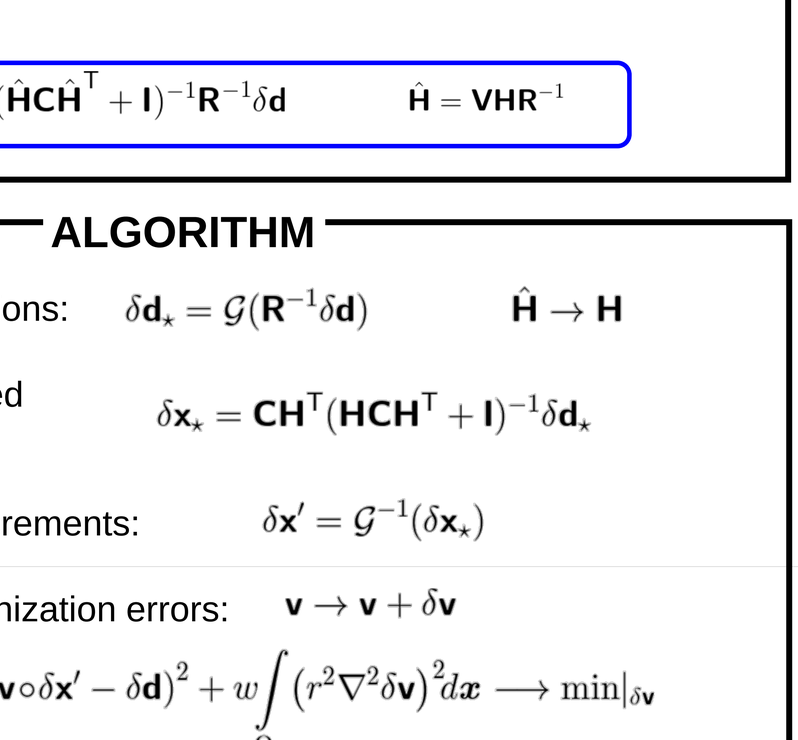
$$\delta\mathbf{v}: \quad J = \sum_\Omega\left(\mathbf{H}\,\delta\mathbf{v}\circ\delta\mathbf{x}' - \delta\mathbf{d}\right)^2 + w\int_\Omega\left(r^2\nabla^2\delta\mathbf{v}\right)^2 d\boldsymbol{x} \longrightarrow \min|_{\delta\mathbf{v}}$$

5. Compute corrected increments: $\delta\mathbf{x} = (\mathbf{V}+\delta\mathbf{V})\delta\mathbf{x}'$

EXPERIMENT SETTING



CICE at 2 km driven by:
NAVGEM 1.2 forcing
and GOFS 3.1
(1/12° HYCOM/NCODA)
Assimilation period:
9/2/2015-12/31/2015



Forecast skill assessment: $s^n(a|r) = 1 - \dfrac{(\mathbf{Hx}_a^n - \mathbf{d}^n)^{\mathsf{T}}(\mathbf{Hx}_a^n - \mathbf{d}^n)}{(\mathbf{Hx}_r^n - \mathbf{d}^n)^{\mathsf{T}}(\mathbf{Hx}_r^n - \mathbf{d}^n)}$

IMPACT OF GAUSSIANIZATION

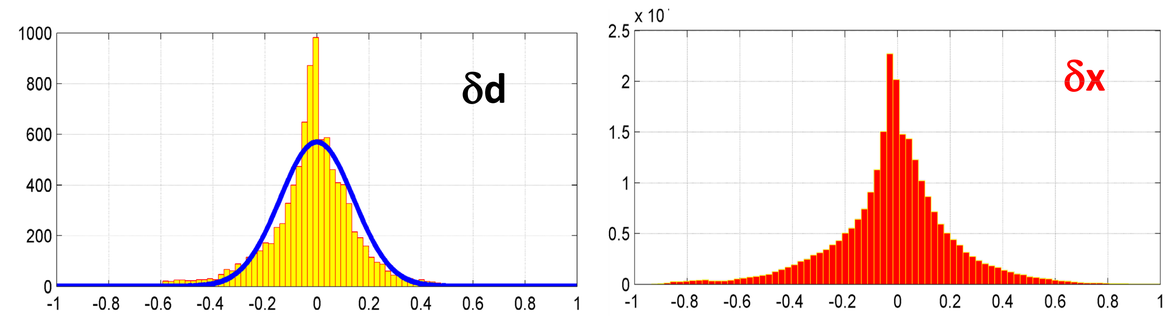


Fig. 1 PDFs of operational innovations and increments

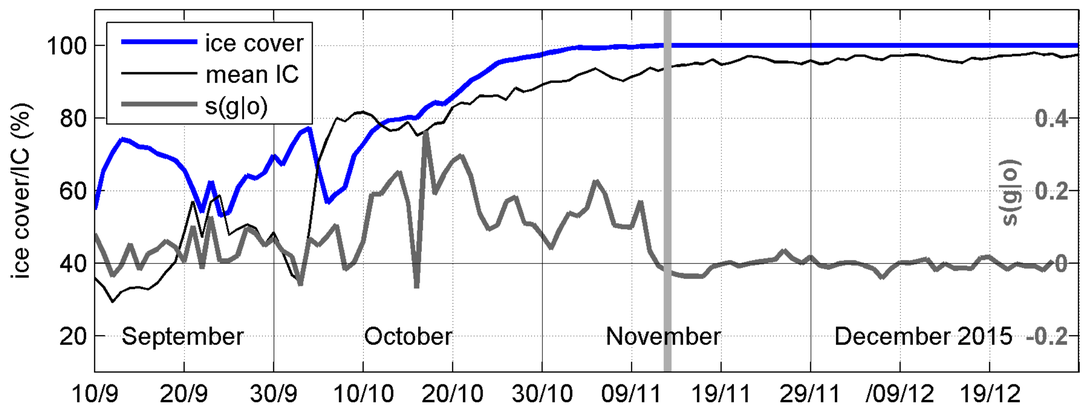


Fig. 2 Improvement of the forecast skill wrt operational run (gray); ice cover Percentage (blue) and mean ice concentration (black).

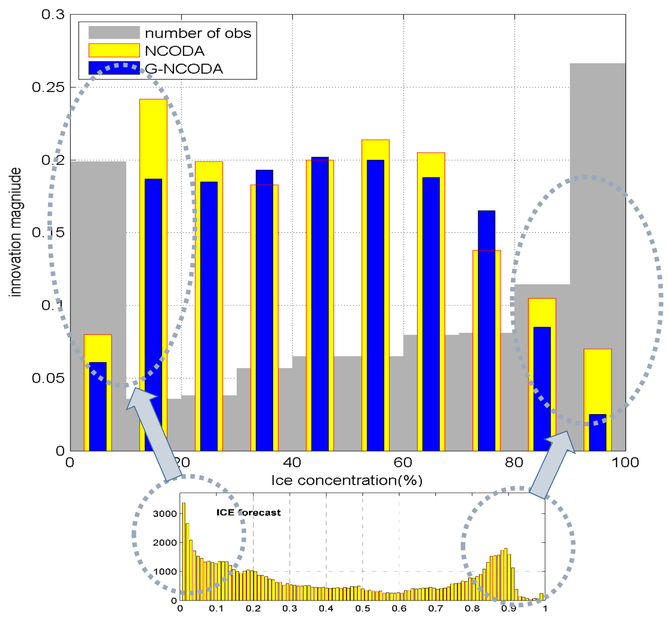
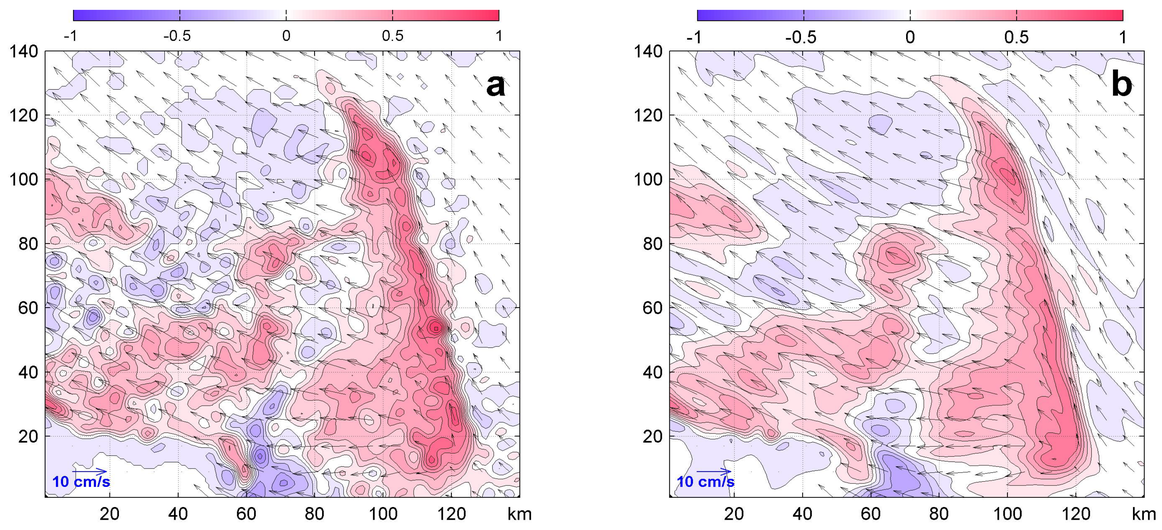
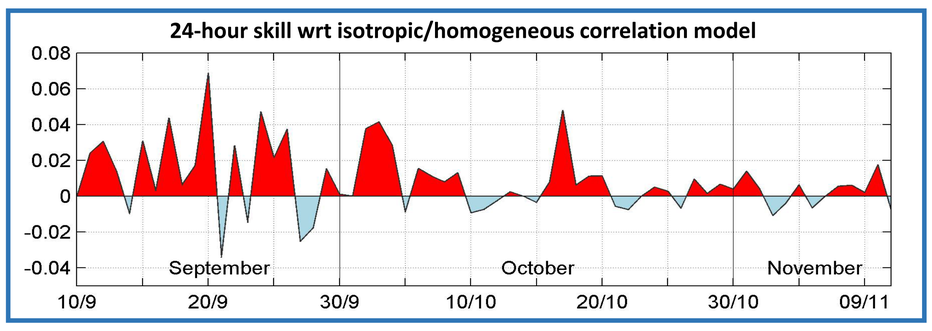
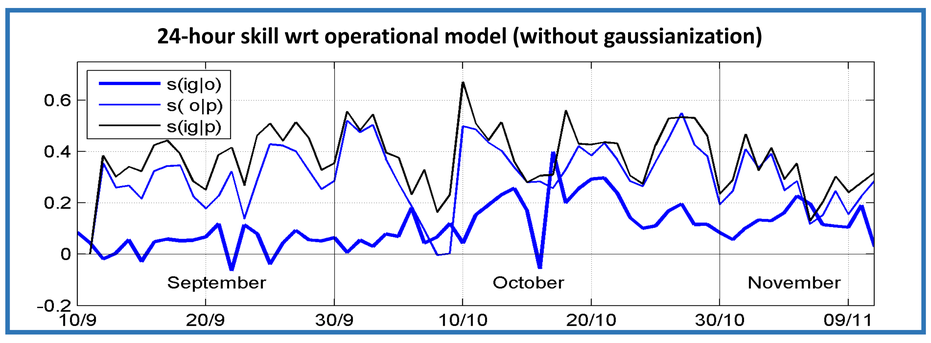


Fig. 3 Distribution of the space and time averaged innovation magnitudes over ten ice concentration cathegories for the operational run (yellow bars) and for the gaussianized run (blue bars). Grey bars show relative numbers of the respective observation points.

IMPACT OF VELOCITY–DRIVEN CORRELATION MODEL







SUMMARY

1. Gaussianization methodology has been developed, featuring a) single gaussianization transform in the data and model spaces and b) correction for the degaussianization errors via adjustment of the forecast error variances.
2. Gaussianization improves IC 24-hour forecast skill by 5-9% during the freezing period
3. Inhomogeneous (ocean velocity driven) correlation model provides 1-2% improvement in the gaussianized mode and 5-7% improvement without gaussianization.