Inhomogeneous Background Error Modeling and Estimation over Antarctica with WRF-Var/AMPS

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AMPS is a version of WRF regional model adapted to the polar physics of Antarctica. Data assimilation is performed for the two nested 45 km and 15 km resolution domains.
Variational assimilation minimizes a cost function:

\[ J(v) = \frac{1}{2} v^T B^{-1} v + (d - Hv)^T R^{-1} (d - Hv) \]

where the background error covariance matrix \( B \) is usually too large (\( \sim 10^{12} \)) to be either stored or estimated. \( B \) is modeled through a sequence of operators (Control Variable Transform) describing the average covariances of background errors. In WRFVAR, the formulation is the sequence of four transforms:

\[ v = B^{1/2} \chi = U_p U_v U_{ih} S \chi \]

- \( U_p \) describes locally-averaged physical balances of errors between variables \( \rightarrow \) use of grid-point statistical regressions,
- \( U_v \) describes domain-averaged vertical autocorrelations \( \rightarrow \) use of Empirical Orthogonal Functions
- \( U_{ih} \) describes locally-averaged horizontal autocorrelations \( \rightarrow \) use of inhomogeneous recursive filters,
- \( S \) describes locally-averaged variances.
Data assimilation and Background Error

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The balance $U_p$ aims to represent the cross-correlations between errors that are linked with atmospheric dynamics

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\begin{pmatrix}
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Ps \\
rh
\end{pmatrix} =
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The balance represents geostrophic coupling between wind and mass fields, surface friction effects, and tracer-like relationships.

This matrices are computed from local or domain-averaged regressions.

**Latitude-binning**

A new latitude-binning accounts for the special AMPS stereographic polar projection, and allows to represent large scale inhomogeneities in the balance.
Inhomogeneous Background Error Modeling: Balance

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The $\chi - \psi$ balance

Figure: Cross-covariances $\chi - \psi$ at 60 S
The $\chi - \psi$ balance

**Figure:** Cross-covariances $\chi - \psi$ at 30 S

Decrease of $\chi - \psi$ balance at the equator is well known and linked with decrease of geostrophy.

**Figure:** Cross-covariances $\chi - \psi$ at 60 S

**Figure:** Cross-covariances $\chi - \psi$ at 90 S

Decrease of $\chi - \psi$ balance may be explained by topography effects over the Antarctic plateau.
The $t - \psi$ balance

**Figure:** Cross-covariances $t - \psi$ at 60 S

**Figure:** Cross-covariances $t - \psi$ at 90 S

Temperature inversion through radiative cooling in clear sky conditions?
Outline

1. Introduction
2. The Physical Transform
3. Horizontal Correlations
4. Variances
5. Summary
Recursive filters are a fast $\mathcal{O}(N)$ grid smoothing technique that can be applied to correlation modeling.

Inhomogeneous recursive filters have two main advantages:

- Representation of the spatial variations of background error length scales
- Use of large grids featuring high map projection factors.

**Figure:** Inhomogeneous recursive filters over AMPS domain with a map factor.
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**Figure**: Inhomogeneous recursive filters over AMPS domain with a map factor.
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Figure: Inhomogeneous recursive filters over AMPS domain with a map factor
Lengthscales estimates

A new economical estimate of lengthscales is performed through the computation of the ratio of variance a field over the variance of the Laplacian:

\[ L = \left( 8 \frac{V(\psi)}{V(\xi)} \right)^{1/4} \]

Lengthscales geographical variations

For balanced variables, geostrophic scaling may be written

\[ \Delta L = \frac{N}{f_0} \Delta Z \]

\( \Delta Z, 1/f_0 \downarrow \) going poleward such that one expects \( \Delta L \downarrow \) going poleward. Data density and topography effects may be important as well.
Grid-Point Lengthscales

Figure: $\psi$ local lengthscale (km)

Figure: $Ps_u$ local lengthscale (km)
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Grid-Point Variances

Figure: $\psi$ local variance rescaling factor

Figure: $t_u$ local variance rescaling factor
Background error modeling

A newly developed formulation of $\mathbf{B}$ in WRFVAR allows main climatological inhomogeneities to be represented for the balance, lengthscales and variances parts.

Antarctic Background error

♣ Application to the Antarctic region with WRFVAR/AMPS shows strong similarities with mid-latitude estimates. However interesting differences can be pointed out, and related to special properties of this region (strong topography, boundary layer, sea/ice).
♣ Local variances are higher in storm tracks ($\psi$, $rh$, $Ps_u$) or in contrary over the plateau ($t_u$), or more complicated ($\chi_u$)
♣ Local lengthscales estimates show ’geostrophic’ inhomogeneity for $\psi$ and $rh$, as well as local inhomogeneity for $\chi_u$, $t_u$, $Ps_u$ (featuring a local maximum over the plateau).
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