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

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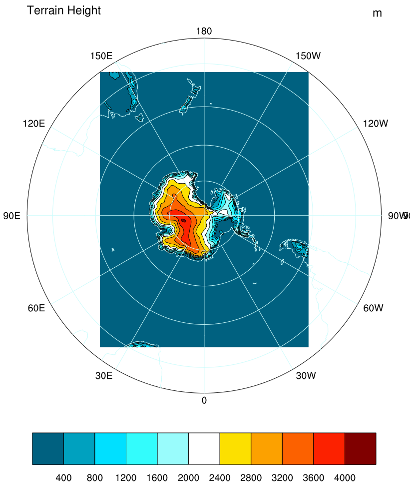
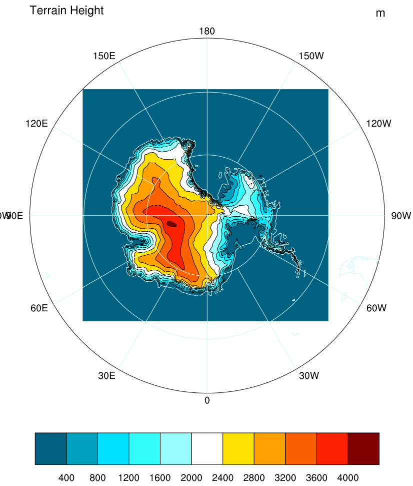
Numerical Weather Prediction over Antarctica with WRF/AMPS

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:

$$J(\mathbf{v}) = \frac{1}{2}\mathbf{v}^{\mathrm{T}}\mathbf{B}^{-1}\mathbf{v} + (\mathbf{d} - \mathbf{H}\mathbf{v})^{\mathrm{T}}\mathbf{R}^{-1}(\mathbf{d} - \mathbf{H}\mathbf{v})$$

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:

$$\mathbf{v} = \mathbf{B}^{1/2}\chi = \mathbf{U}_p\mathbf{U}_v\mathbf{U}_{\mathrm{ih}}\mathbf{S}\chi$$

- $\mathbf{U}_p$ describes locally-averaged physical balances of errors between variables $\longrightarrow$ use of grid-point statistical regressions,
- $\mathbf{U}_v$ describes domain-averaged vertical autocorrelations $\longrightarrow$ use of Empirical Orthogonal Functions
- $\mathbf{U}_{\mathrm{ih}}$ describes locally-averaged horizontal autocorrelations $\longrightarrow$ use of inhomogeneous recursive filters,
- **S** describes locally-averaged variances.

Data assimilation and Background Error

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Outline

The balance $\mathbf{U}_p$ aims to represent the cross-correlations between errors that are linked with atmospheric dynamics

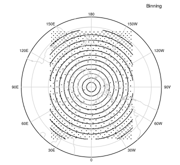
$$\begin{pmatrix} \psi \\ \chi \\ t \\ Ps \\ rh \end{pmatrix} = \begin{pmatrix} \mathbf{I} & 0 & 0 & 0 & 0 \\ \mathbf{M} & \mathbf{I} & 0 & 0 & 0 \\ \mathbf{N} & \mathbf{P} & \mathbf{I} & 0 & 0 \\ \mathbf{Q} & \mathbf{R} & \mathbf{S} & \mathbf{I} & 0 \\ 0 & 0 & 0 & 0 & \mathbf{I} \end{pmatrix} \begin{pmatrix} \psi \\ \chi_u \\ t_u \\ Ps_u \\ rh \end{pmatrix}$$

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.



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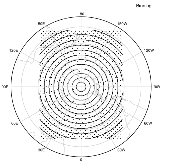

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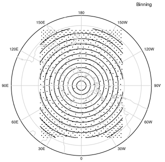

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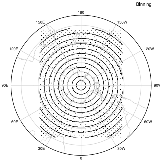

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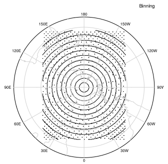


The $\chi - \psi$ balance

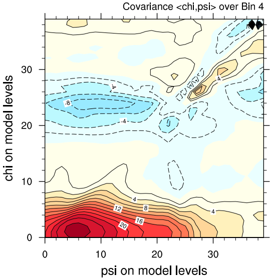
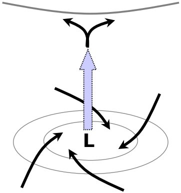


Figure: Cross-covariances $\chi - \psi$ at 60 S



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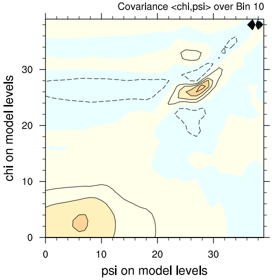
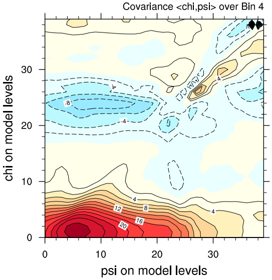


Figure: Cross-covariances $\chi - \psi$ at 30 S



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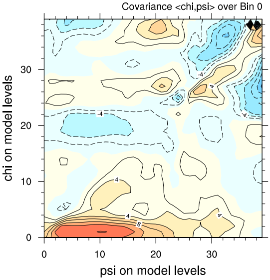
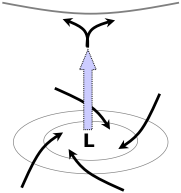


Figure: Cross-covariances $\chi - \psi$ at 90 S

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



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

The $t - \psi$ balance

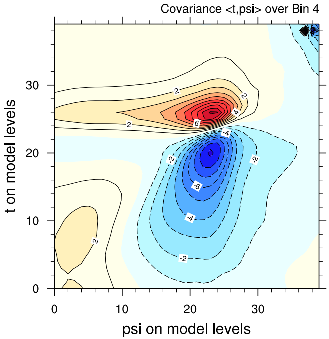


Figure: Cross-covariances $t - \psi$ at 60 S

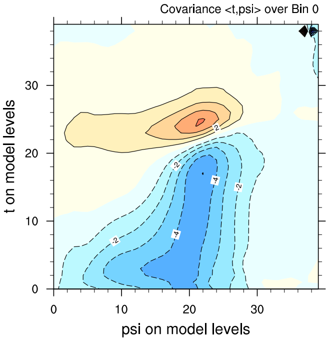
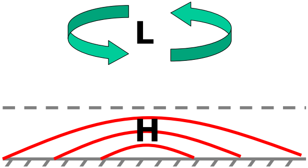


Figure: Cross-covariances $t - \psi$ at 90 S



Temperature inversion through radiative cooling in clear sky conditions ?

Inhomogeneous Background Error Modeling: Horizontal correlations

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 lengthscales
- Use of large grids featuring high map projection factors.

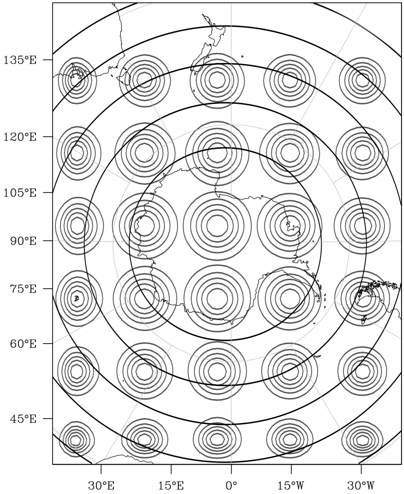


Figure: Inhomogeneous recursive filters over AMPS domain with a map factor

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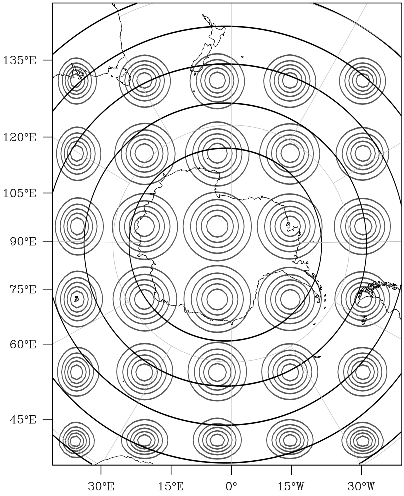

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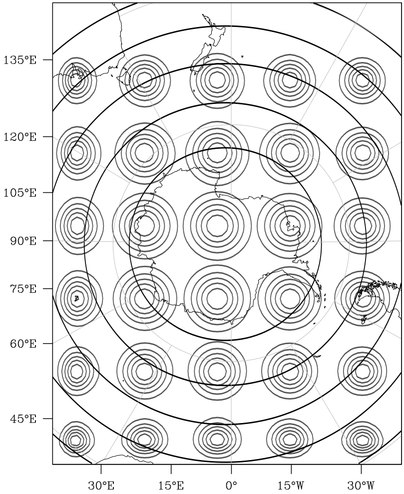

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Grid-Point Lengthscales

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

$$\Delta L = \frac{N}{f_0}\Delta Z$$

$\Delta Z, 1/f_0 \searrow$ going poleward such that one expects $\Delta L \searrow$ going poleward. Data density and topography effects may be important as well.

Grid-Point Lengthscales

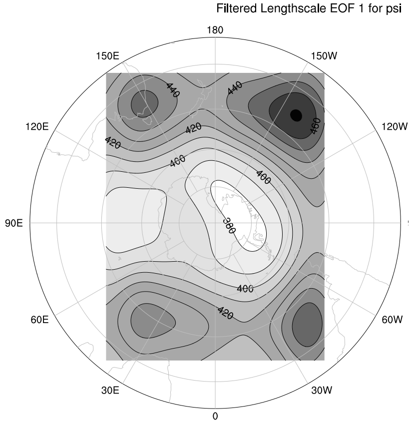

Figure: ψ local lengthscale (km)

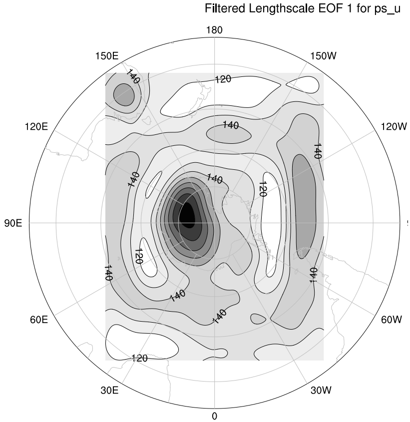

Figure: Ps_u local lengthscale (km)

Outline

Grid-Point Variances

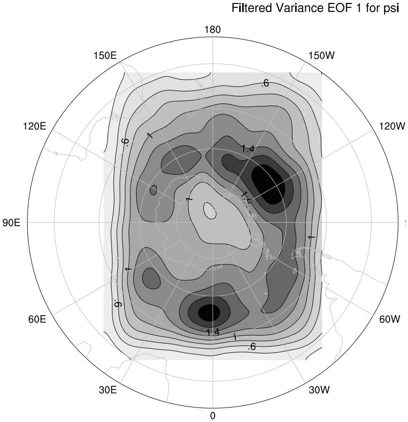

Figure: ψ local variance rescaling factor

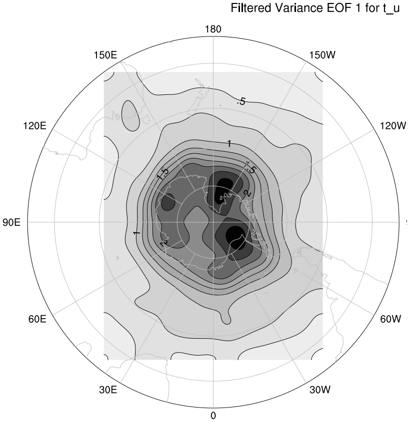

Figure: t_u local variance rescaling factor

Summary

Background error modeling

A newly developed formulation of **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 (ψ, rh, Ps_u) or in contrary over the plateau (t_u), or more complicated (χ_u)
♣ Local lengthscale estimates show 'geostrophic' inhomogeneity for ψ and rh, as well as *local* inhomogeneity for χ_u, t_u, Ps_u (featuring a local maximum over the plateau).

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