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## Complex Wavelets for representations of 3D structure functions

The purpose of this work is to improve the representation of background error covariances in a the 3d-Var assimilation of a limited area model (LAM). In particular, we want to include local variations in variance, heterogeneity and anisotropy of the structure functions. In 3 dimensions, the model should be able to represent locally tilted structure functions.

Due to the very large size of the background state vector (around $10^7$), it is not possible to represent the full background error covariance matrix $\mathrm{B}$. (Many 3d-Var schemes actually implement $\mathrm{B}^{-1/2}$.)

By diagonalising a 2D covariance matrix in *grid point space*, we would get a perfect representation of local variances but no covariances at all. On the other hand, a diagonalisation in *Fourier space* yields the mean variance and structure function at every location.

A kind of intermediate solution is to diagonalise $\mathrm{B}$ in a *wavelet basis* . In [1] a hybrid method was used that combines an orthogonal basis of Meyer wavelets with further diagonalizations in grid point and Fourier space. This showed a much improved representation of correlation length, but only limited anisotropy. We are now researching a new approach using **Dual Tree Complex Wavelets** [2].

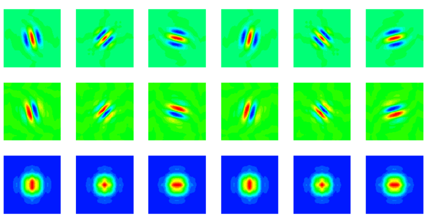

**Figure 1: Complex wavelets. row 1: real part; row 2: imaginary part; row 3: modulus**

## 3D structure functions

Compared to orthogonal 2D wavelet transforms as used in [1], these functions have several advantages:

- **Directional resolution**: the functions have 6 different orientations at intervals of approximately $30^o$.
- **Near shift invariance**: The 4-fold redundancy results in a wavelet decomposition that has much less artefacts. It also implies that local variations are better captured.

In Figure 2 a vertical profile is shown for a chosen location. While the wavelet diagonalisation obviously eliminates many details, some salient features are retained. Most notably, the vertical profiles are tilted.

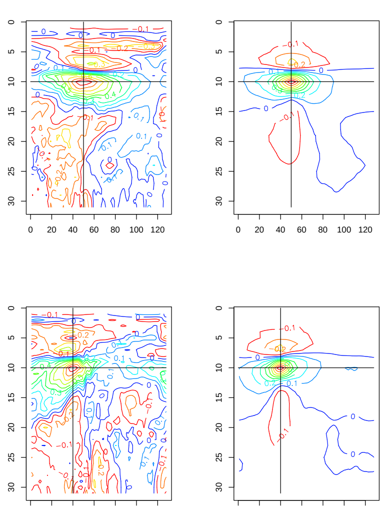

**Figure 2: Zonal and meridional cross sections of correlation functions from original data and from complex wavelet diagonalisation.**

## Neural Networks for Model Output Statistics

We are currently researching the use of artificial neural networks for Model Output Statistics (MOS) of temperature forecasts. Figure 3 shows the improvements in monthly RMSE scores of a simple linear model (LM) and a neural network.

Both (experimental) MOS systems were trained on 3 years of forecasts of the ALADIN model (cycle 15) and tested on a fourth year.

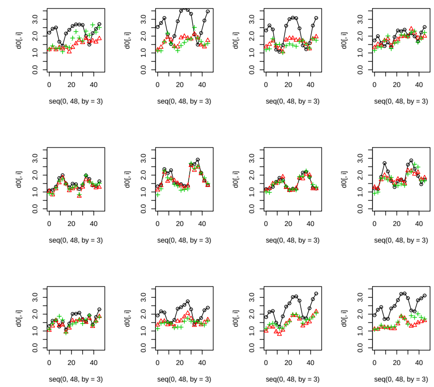

**Figure 3: Monthly RMSE for plain forecasts (black), a simple linear MOS (green) and a neural network (red).**

## New approaches to deep convection parametrisation and its binding to a microphysical scheme

It has been a long practice in operational NWP models to separate the saturation processes between a 'resolved' part (i.e. which can be considered homogeneous when seen at the scale of the grid box), associated to stratiform or frontal events and a 'subgrid' part, linked to deep convection. For the 'resolved' part, statistical considerations may address the smaller scale inhomogeneities; this is the starting point of most microphysical packages. However, at all resolutions with grid boxes greater than 2 or 3 km, the effects of deep convective systems cannot be represented satisfactorily without a dedicated scheme. Then, combining the output of this scheme – condensation, precipitation, cloudiness – with the main microphysical scheme is not straightforward. Keeping a separate convective scheme, directly producing its own precipitation, which should be added to the one of the resolved scheme poses several problems, and induces mesh size and time step dependencies.

The problem is especially acute for the resolutions between 7 km and 2 km, where the convective clouds are partly resolved, partly subgrid. This is now often referred to as a 'grey zone' of resolutions, which 'should be avoided'.

Still, being able to handle the grey-zone resolutions is very desirable, because:

- They may be interesting in many circumstances.
- Jumping over this grey zone is very expensive.
- The parametrisation effort increases our understanding of the natural phenomena.

Moreover, having a scheme which results are not dependent of the resolution thanks to a smooth combination of resolved and subgrid parts represents a considerable advance. The present version of our scheme (details to be published soon) uses a modified version of the microphysical scheme developed by Lopez [4], with prognostic variables for cloud ice and liquid water, but not for the precipitating species. Various enhancements were brought to this scheme, as modelling the Bergeron effect, and a better representation of the phase changes of the condensates.

A new method has been developed for combining the subgrid and resolved contributions of cloud condensation and precipitation. The convective updraught routine is an extension of the one described in [3]. It includes prognostic variables for the updraught velocity and mesh fraction, and now it detrains condensates instead of producing precipitation fluxes.

We also use a proposition of J.M. Piriou (PhD-thesis 2005) to calculate the contribution of the updraught to the model fields. The convective scheme is completely integrated with the microphysical routines; an external downdraught is applied at the end, driven by the cooling accompanying the total precipitation.

This new version of the integrated scheme yielded significantly better predictions than the operational Aladin model for various convective events. Tests at different resolutions also show a good independence of the forecast precipitation amounts to the model grid-box length and to the time step.

Figure 4 shows an episode of very intense showers over Belgium on Saturday 10 September 2005. The model fields are the 1-hour-accumulated precipitation at 19:00 and 20:00 utc, the mean-sea-level pressure (hPa), the 2m-temperature ($^o$C). On the composite radar images (here at 19:00 and 20:00 utc), several cells show very few motion for several hours. The operational model (above) missed the strong convective events (this model uses a diagnostic convection scheme and a diagnostic representation of cloud water). On the contrary, our new integrated scheme (below) shows very realistic pictures of the situation. Also the total accumulated precipitation between 12:00 and 24:00 utc is very patchy, with amounts up to 80mm, in quite good agreement with the synoptic stations which measured amounts between 50 and 100mm.

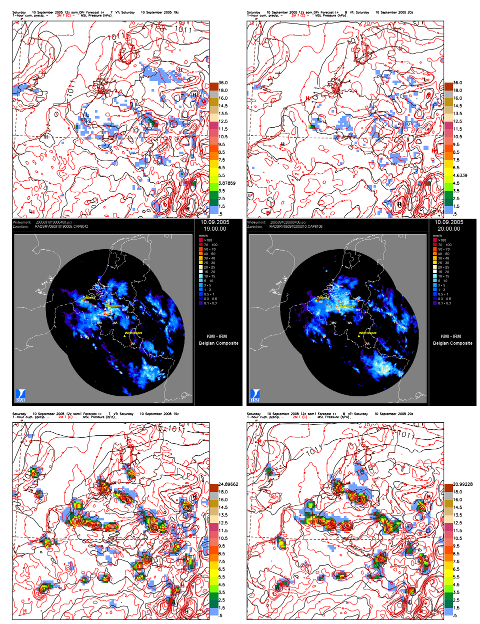

**Figure 4: Top: operational Aladin 29. Centre: composite radar images. Below: new integrated scheme for convection and microphysics (see text).**

## Other Research Subjects

Other research in the ALADIN group currently includes:

- physics/dynamics interfacing
- externalisation of surface scheme

## References

[1] Deckmyn, A. and L. Berre, 2005: Wavelet Approach to Representing Background Error Covariances in a Limited Area Model, *Mon. Weath. Rev.* **133** (2005), pp 1279–1294.

[2] Kingsbury, N., 2001: Complex Wavelet analysis for shift invariant analysis and filtering of signals, *Applied and Computational Harmonic Analysis* **10**, 234–253.

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[4] Lopez, Ph., 2002: Implementation and validation of a new prognostic large-scale cloud and precipitation scheme for climate and data assimilation purposes, *Q. J. R. Meteorol. Soc.* **128**, 229–258.