Development of Assimilation Setups Suited for NWC

Carlos Geijo Guerrero, NWP Meteorologist, AEMET

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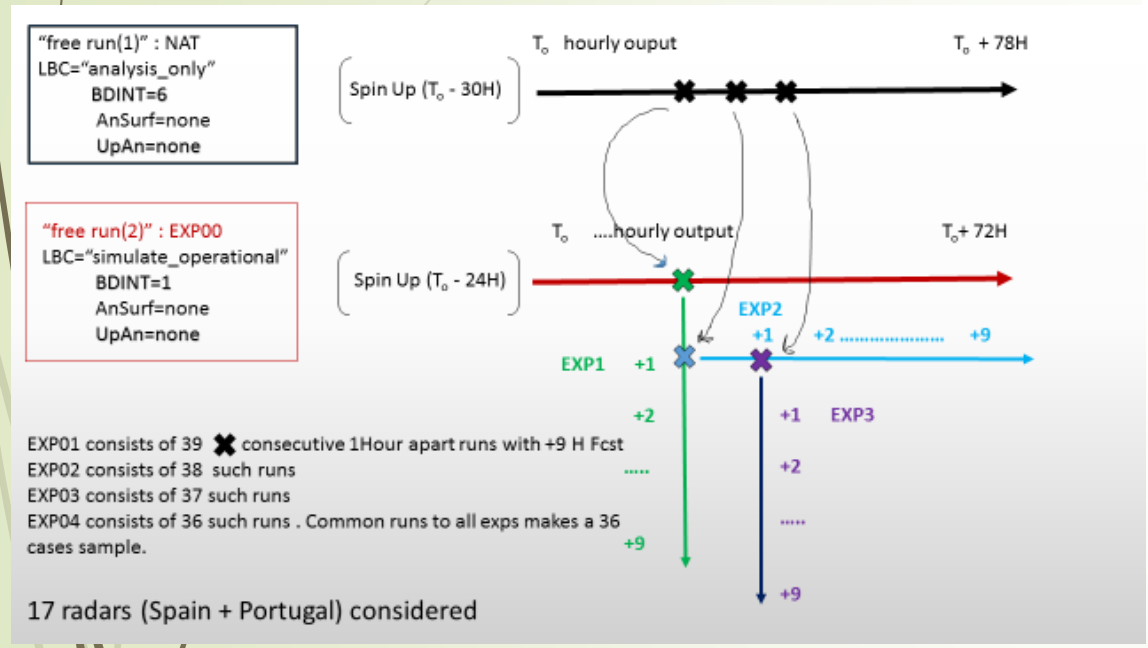
WP2021 (Prospective and R&D Activities) , WP DA5 " *[…] how data assimilation configurations may need to be adapted in order to optimally function in the now-casting range […] Aspects to be considered [..] rapid cycling strategies and high-frequency observations, choice of initialization methods […]* "

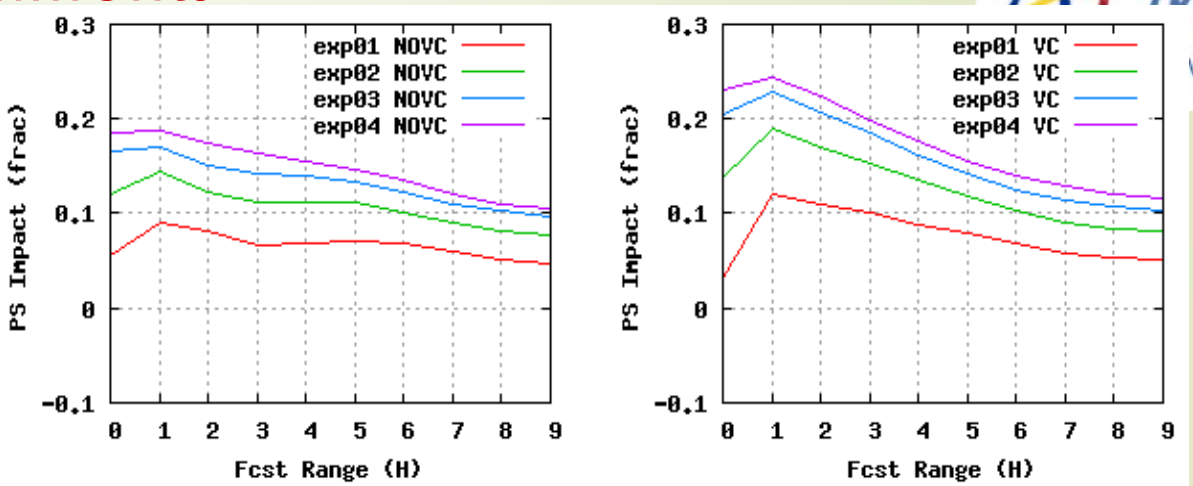
Assimilation of Radar Wind Data using Model Fields – Radar Image matching Methods (FA)

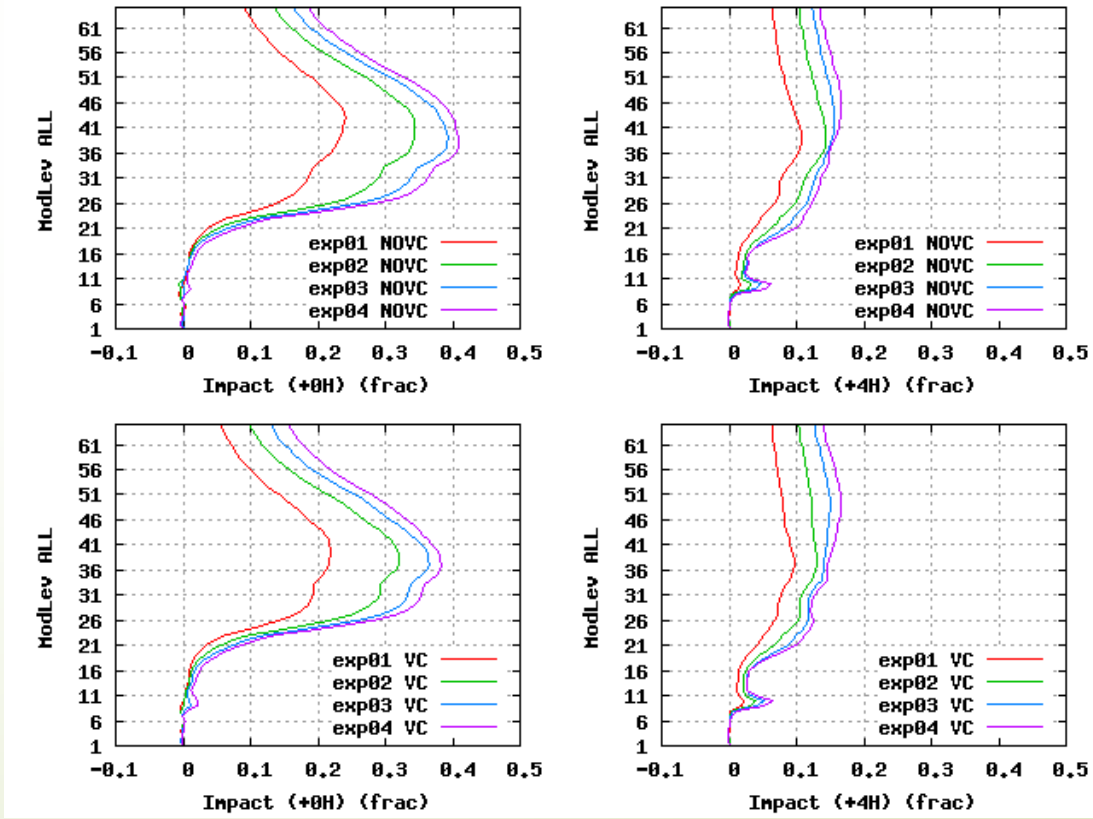
Initialization of NH Dynamics with variational Techniques (VC)

Developments to enable sub-hourly Cycling / DA (*in progress*)

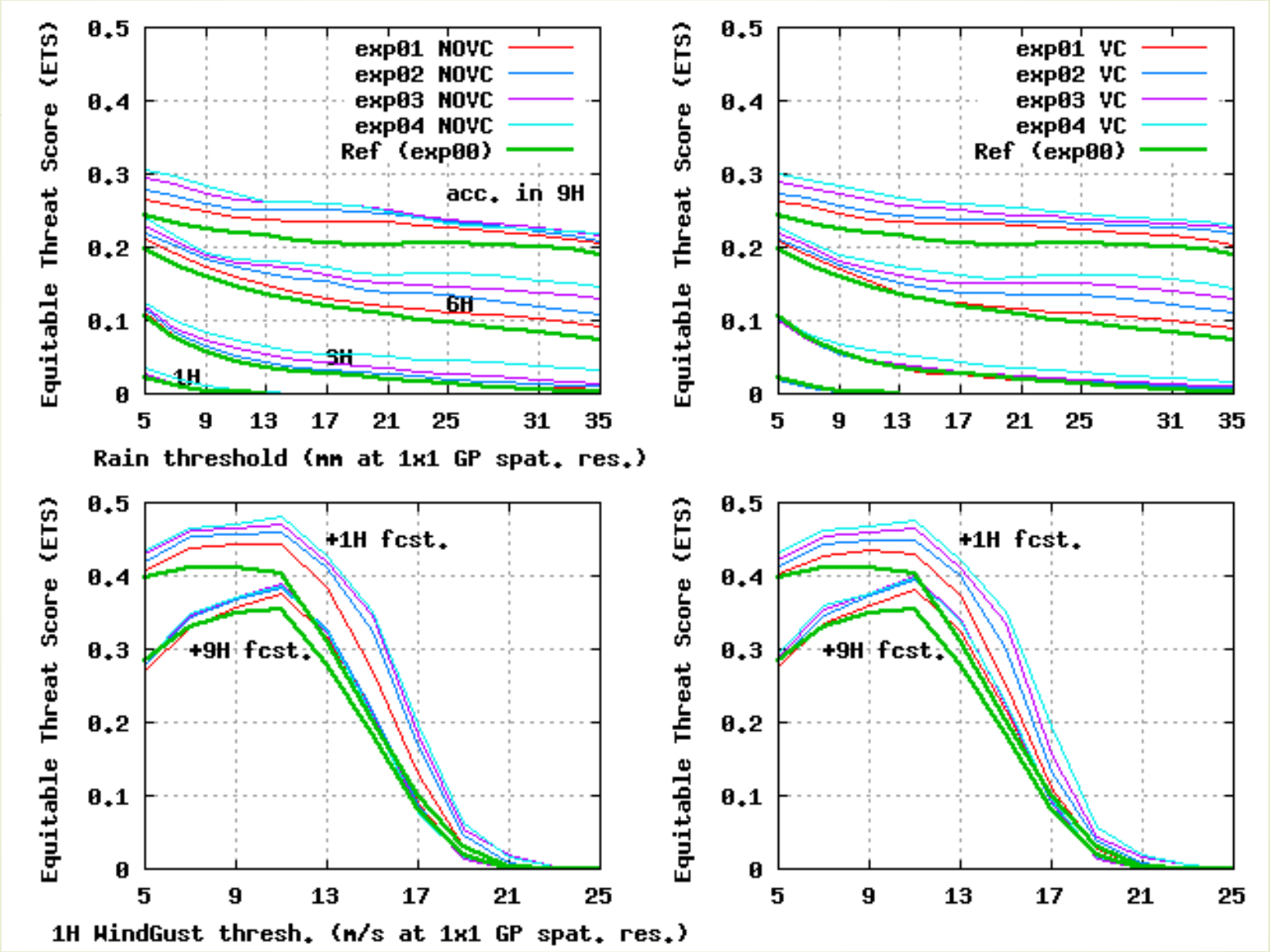
Validation in cy40 with DA twin experiments



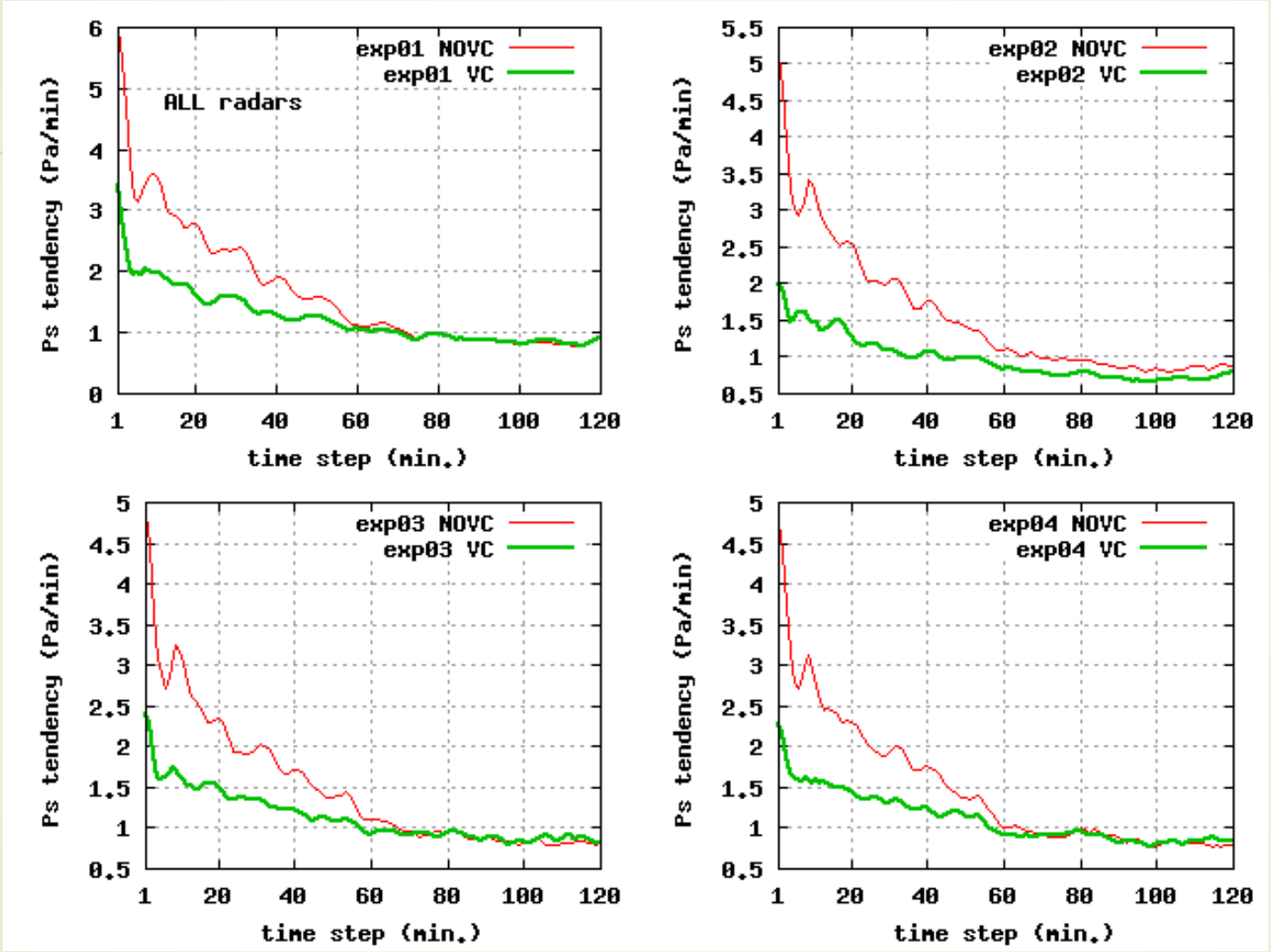




Validation in cy40 with DA twin experiments



Validation in cy40 with DA twin experiments



Validation in cy40 with DA twin experiments

Validation with radar synthetic data passed successfully.

FA improves impact scores clearly. Scope of this development limited by all the specifics to radar data (geometry of scans, kind of observations, …). Adaptation to other data types (e.g. satellite winds, MODE-S, …) requires important development investments.

VC effectively filters noise generated by insertions of observations in the initial conditions. Impact evaluation limited by the hourly setup of the validation experiments.

VC can be effective in several interesting scenarios: **(1)** Sub-hourly DA. **(2)** Coupling to the nesting model (e.g. spectral nudging)**. (3)** In 4D-Var, to dump noise during the re-linearization with the full resolution trajectory (surrogate to J_c)

Implementation in Cy43 ongoing. It should incorporate the possibility to carry out new validation experiments, ideally **including options (1), (2) and (3) mentioned above.**

The VC algorithm (1/6)

The VC algorithm arises from the search of an algorithm to solve the SI of the ALADIN-NH dynamics using Green's functions (*Geijo, ALADIN-HIRLAM ASM 2015, Helsingor*, also *ALADIN-HIRLAM Newsletter #5, August 2015*)

The VC algorithm is an example of the connection between **inverse of covariance operators** and **self-adjoint differencial operators of definite norm** (Guillet et al. , 2019)

Both conditions (self-adjointness and definite norm) are trivially satisfied by the VC operator as this operator is of the form K^+K ; $K = \partial^2 + \partial - \lambda = L - \lambda$

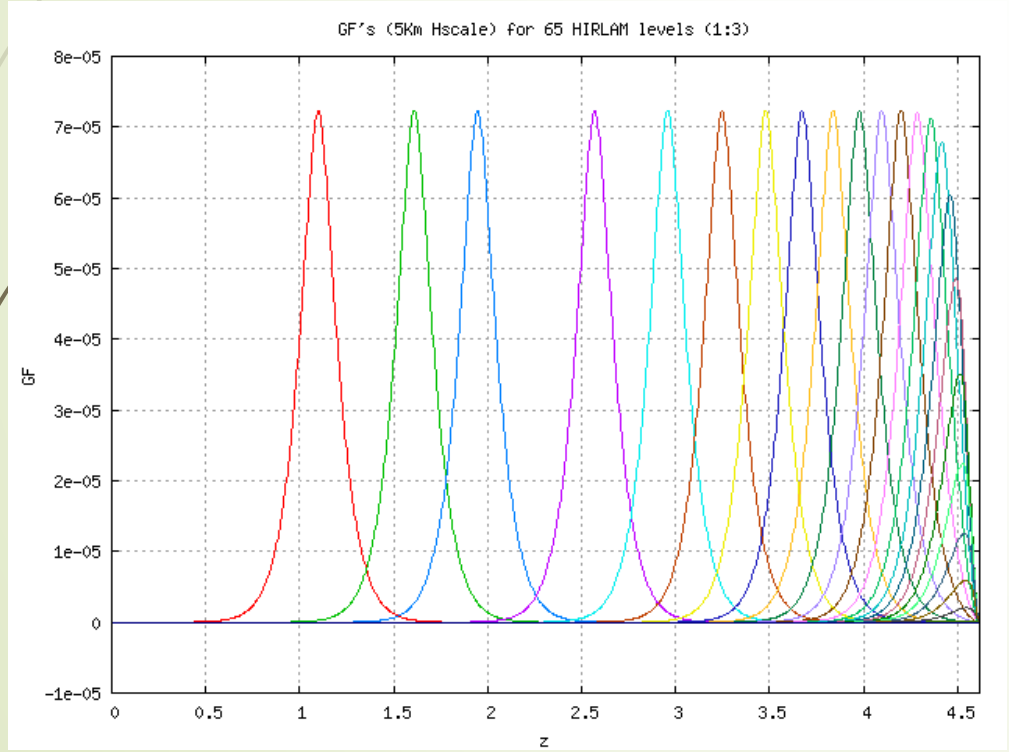
The symmetry condition follows from the symmetry property of the Green's function of such an operator. The positive definite condition follows from the simple observation that $(u, K^+K\,u) = (Ku, Ku) > 0$ when $Ku = 0\ iff\ u = 0$, i.e. K has empty kernel. This is so in the VC algorithm because with the imposed boundary conditions $u(bottom) = u(top) = \partial u(bottom) = \partial(top) = 0$, and λ>0 , λ cannot be in the spectrum of L

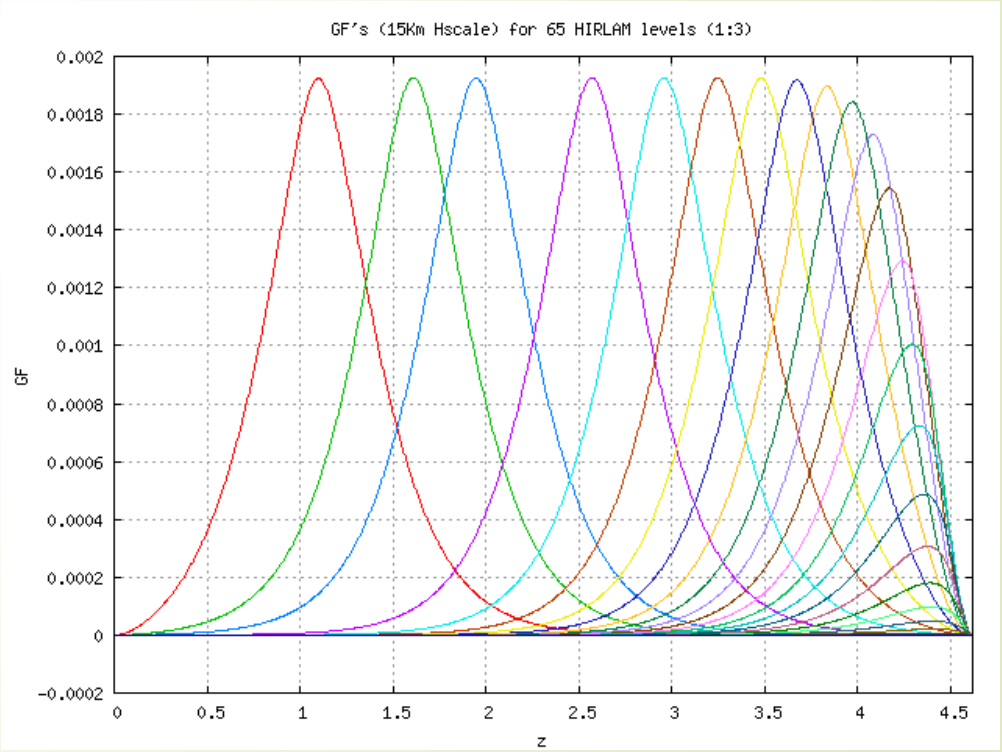
The Green's function for the VC algorithm is therefore a genuine covariance operator

The VC algorithm (2/6)

The VC covariance is ***not*** constrained to be **homogeneous** in the vertical coordinate and ***has*** **compact support**

The VC covariance does ***not*** **arise from any specific covariance function** model, it has been **derived from the *properties of the ALADIN-NH dynamics alone***





The VC algorithm (3/6)

Following the correspondence between inverse covariance operators and differential operators, it is possible to relax the constraints of homogeneity and isotropy in 2D/3D space (VC covariance is just 1D).

Guillet et al 2019, apply this correspondence to **model R^{-1} with unstructured spatial distributions of observations**.

Also the technique of **Gaussian Integrals** (*Geijo ALADIN-HIRLAM ASM 2019, Madrid* also *ALADIN-HIRLAM Newsletter #13 August 2019*) originates from this correspondence, and permits giving considerable **flow dependency to the covariance of random fields**.

In this last case, the (Gaussian) PDF is modified by introducing derivatives (approximated by a suitable discretization scheme) of the random field

$$e^{-\frac{1}{2}\Delta^T B^{-1}\Delta} \quad \rightarrow \quad e^{-\frac{1}{2}\left(\Delta^T B^{-1}\Delta + \mu(\partial_j\Delta)^T M_{ji}\partial_i\Delta\right)}$$

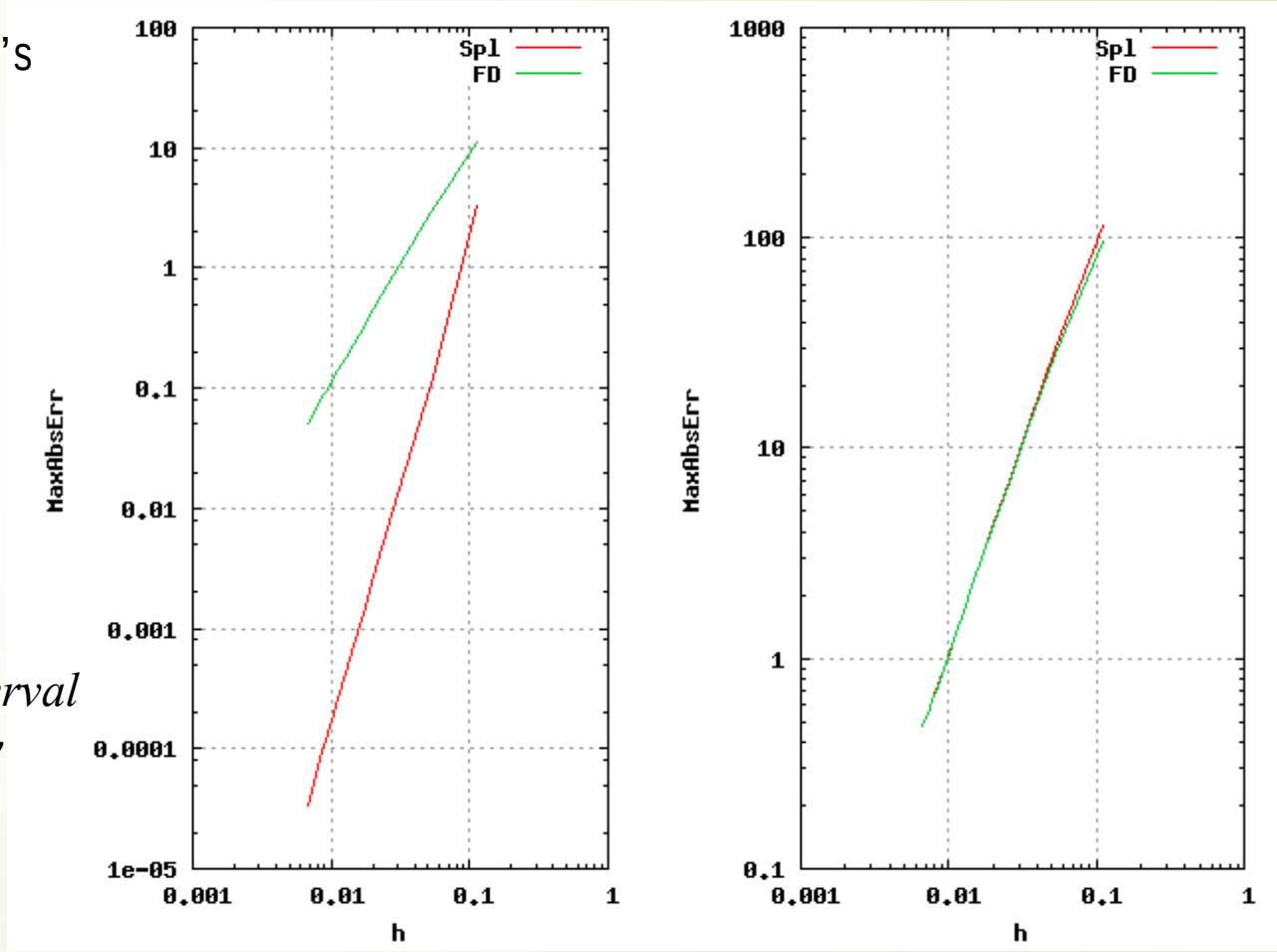
with $\mu > 0$ and $M_{ij} = M_{ij}(x)$ is symmetric and positive. The elements of the covariance (not those of its inverse !) are then calculated by a perturbation series akin to the pseudo-time step employed by Guillet at al.

The VC algorithm (4/6)

The algorithm for solving SI ALADIN-NH with Green's Functions utilizes a splines-based discretization which is more accurate in the calculation of derivatives than the Finite Differences algorithm

$$\max\left|f^k(x) - Spl^k(x)\right| = O\left(h^{4-k}\right)\ ;\ \mathrm{k} = 0,1,2$$

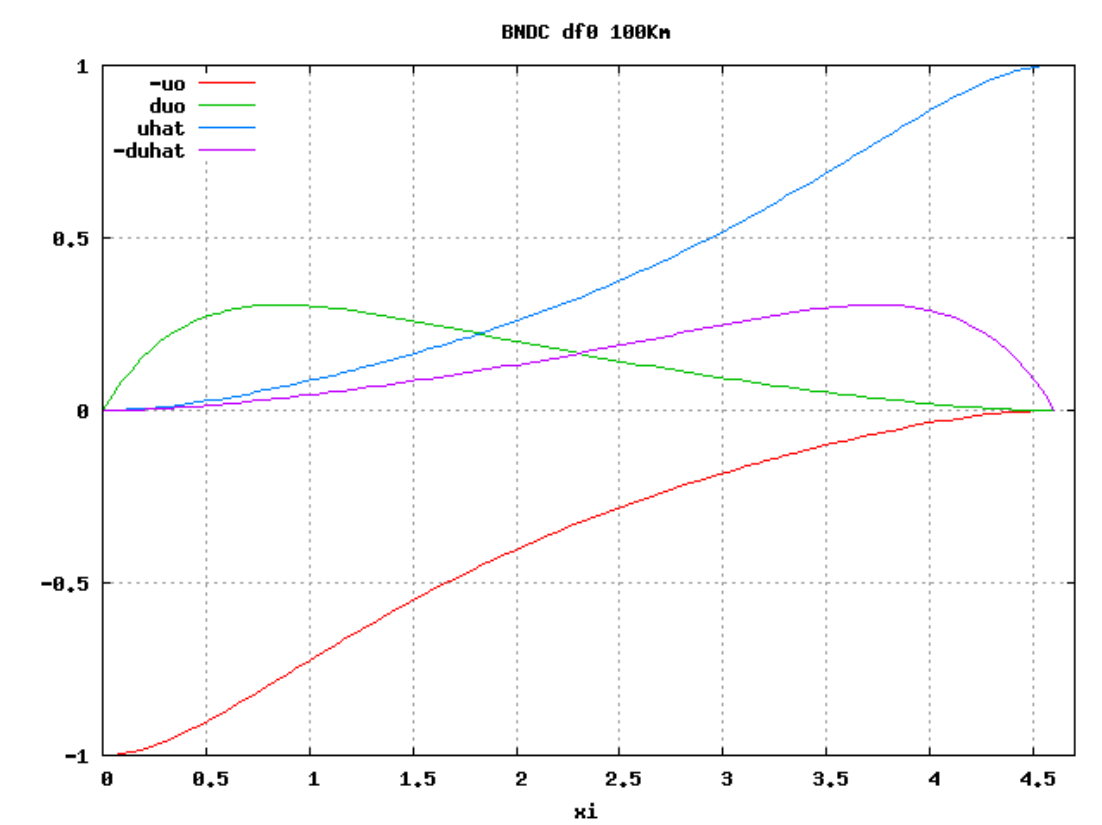
Max Abs Error (Eq above) for the first derivative (left) and second derivative (right) for the function sin(6πx) in the interval [0,1] calculated with the Spline algorithm (red lines) and by Finite Differences (green line). The x-axis corresponds to discretizations from 10 points up to 150 points.

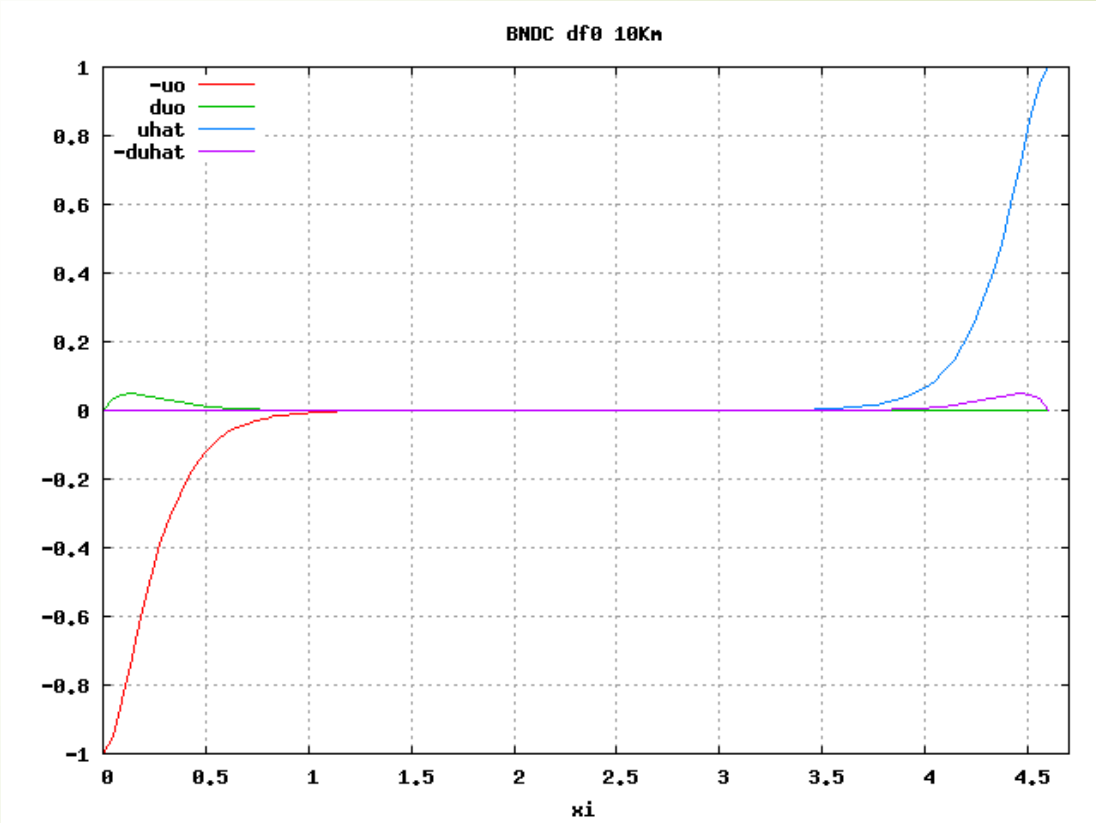


The VC algorithm (5/6)

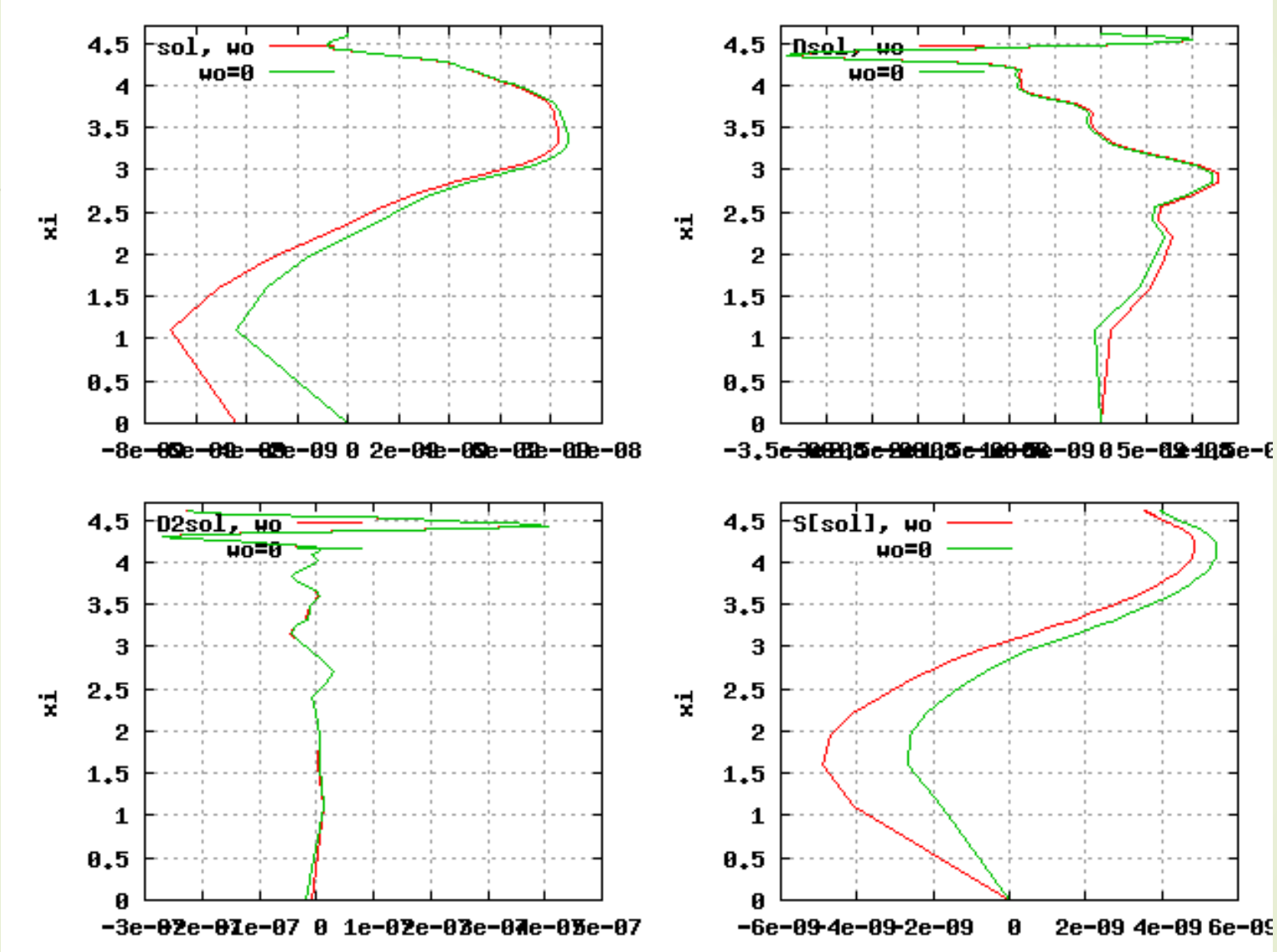
This algorithm allows to include in a natural way non-homogeneous boundary conditions (coupling to vertical BC, spectral nudging , weights for LSMIX)

Current kernels used for LSMIX are ad-hoc. These ones are derived in an objective way





The VC algorithm (6/6)



DA at sub-hourly cycling

- Sub-hourly cycling is clearly of interest to NWP-NWC
- ***Which should be the main lines for the design and development of such capacity ?***
  - One possibility is simply increasing the frequency of the current schedule i.e. NCONFs **(701 +)** 2 + 131 (3D-Var) (+ Overlapping Windows)
  - Another possibility is continuous 4D-Var.
  - Developments with NCONF=1 as baseline. (precursors: VC, Spectral Nudging, IAU, Cloud & Aerosol DA, Latent Heat Nudging, ... *what else ??*)
- Initialization (presumably very) important. Connection DA-Dynamics and DA-Physics.
- DA-EPS connection

➢ Development of DA Setups Suitable for NWC

- DA-NWC prototype for assimilation of Doppler Radar Winds with FA+VC has been implemented and successfully validated in Cy40
- Implementation of this software in Cy43 is in progress and within schedule (RWP2021)
- New validation will be carried out *only* when sub-hourly capacity has been implemented (Cy43 or posterior)
- The Variational Constraints (VC) algorithm offers a number of possibilities in nudging and nesting that will be validated
- The VC kernels are genuine covariances and constitute an example of the connection between differential operators and inverse of covariance operators
- DA at sub-hourly frequencies implies several important different aspects that require effective coordination across experts in different areas

THANK YOU FOR THE ATTENTION !