Use of the MM5 Adjoint Modeling System

Victor Homar Santaner

victor.homar@noaa.gov

NRC PostDoc at the National Severe Storms Laboratory in colaboration with Dr. David Stensrud

What is the adjoint of a nonlinear model?

It goes backward in time

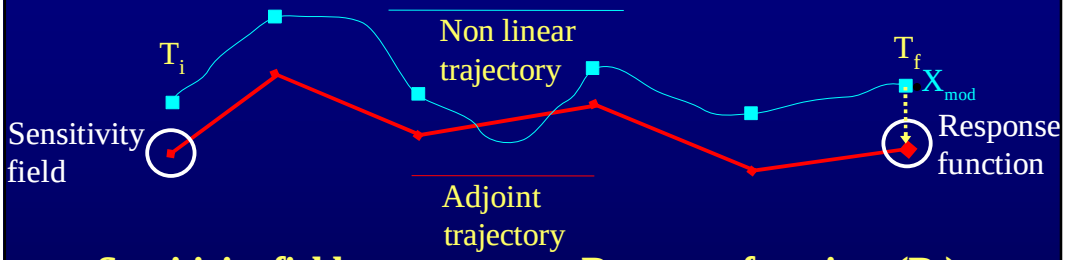
- The Adjoint is a linear operator which follows a nonlinear model solution backwards in time.

It computes sensitivity fields

- The Adjoint is the linearized and transposed version of the nonlinear model.

How does it work?

Schematic view:



Sensitivity fields

- Units of:

$$\frac{[R_f]}{[\text{Init. Cond.}]}$$

- It shows the sensitivity of R_f to the model initial fields

Response functions (R_f)

- Model error: X_{obs} -X_{mod}
- Particular feature of interest
  - Cyclone's central pressure
  - Jet stream location and intensity
  - Temperature at a certain point
  - ...
- Any differentiable function of X_{mod}

Algebraic view and Singular Vectors?

Three models play a role in the MM5 Adjoint System:

- $x(t_f) = F\ x(t_0)$ Nonlinear Forward
- $x(t_f) = L\ x(t_0)$ Tangent Linear Forward
- $x(t_0) = A\ x(t_f)$ Adjoint Backward (with A; <x;Ly>=<Ax;y>)

Considering L as a linear operator, its maximum-growth modes, under a certain E norm are:

$$\frac{\|X_t\|}{\|X_0\|} = \frac{(X_t;X_t)_E}{(X_0;X_0)_E} = \frac{(LX_0;LX_0)_E}{(X_0;X_0)_E} = \frac{< X_0;EE^{-1}L^*ELX_0 >}{< X_0;EX_0 >} = \frac{\sigma < X_0;EX_0 >}{< X_0;EX_0 >} = \sigma$$

where $(E^{-1}L^*EL)X_0 = \sigma X_0$ is the eigenproblem to solve

Singular vector calculation reduces to an eigenvector problem.

Simulation configuration

Domain limitations:

- 2 big (~10Gb) files stores the nonlinear basic state (Whole grid every time step)
- No nesting capability
- High resolutions uncoherent with simplified physics

Typical configuration:

- Grid: 71x71x23 with Dx = 60 km and Dt = 120 s.
- IC and BC from the standard MM5 preprocessing package
- Available parameterizations:
  - Cumulus Convection: Kuo, Grell
  - Explicit moisture: Dudhia
  - PBL: High resolution Blackadar
  - Radiation: Cloud-radiation scheme

Computational notes

Source code and documentation available at:

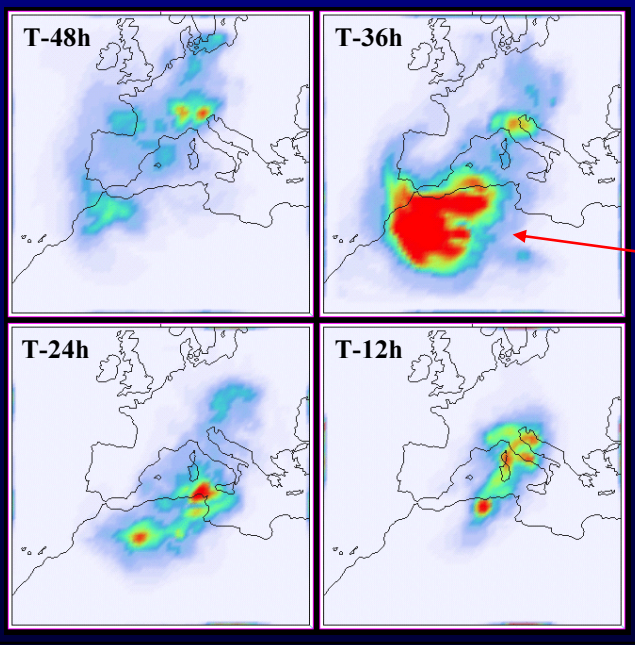
ftp://ftp.ucar.edu/mesouser/MM5_ADJ/

Computer details:

- Systems supported: SGI, DEC, Linux
- Code is NOT parallelised
- Some benchmarks on a Xenon 2.4 GHz running PGF77 Linux with 71X71x23 (60 km, 120 s):
  - 24 h Sensitivity run (Fwd and Adj modules) ~ 2.5 h
  - 24 h First 10 Singular Vectors (Fwd and 100x Tgl and Adj modules) ~ 275 h (11.5 days)

Example: Superstorm 10 and 11 November 2001

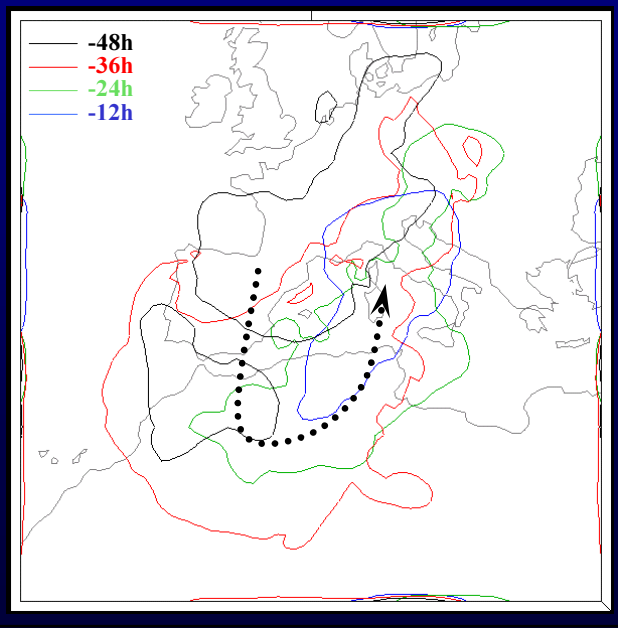
Averaged sensitivity field to a wind maximum over the Balearics:



Close to a critical time?

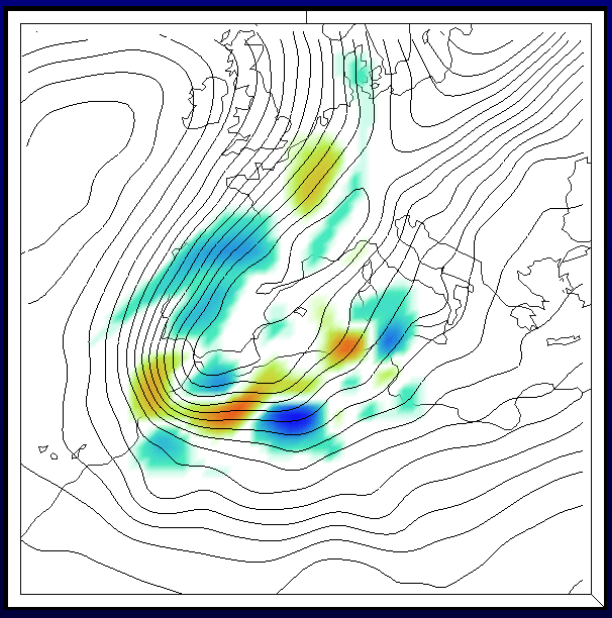
Example: Superstorm 10 and 11 November 2001

Sensitivity progression backwards:



Example: Superstorm 10 and 11 November 2001

H at 500 T-30:

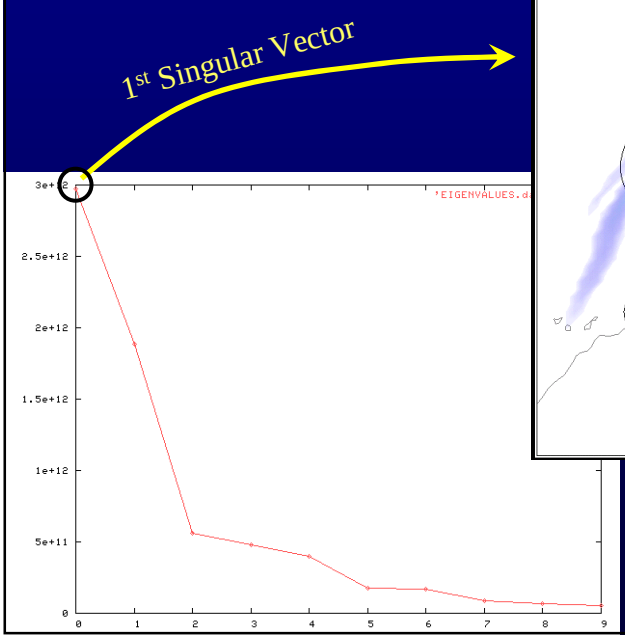


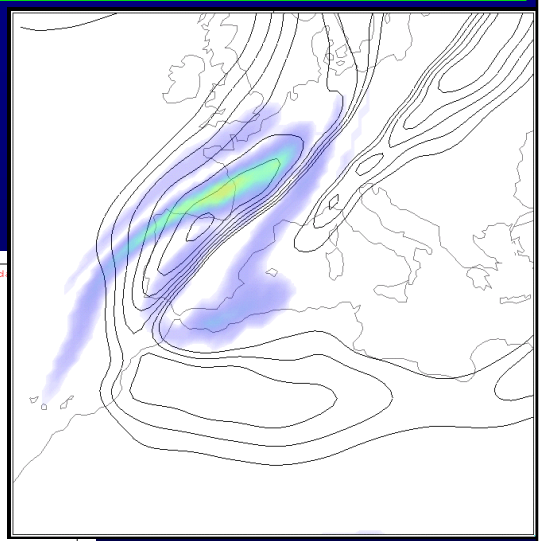
RED (BLUE): An increase (decrease) of H into the IC will produce an increase to the response function.

Interpretation:
The response function (Wind speed over the Balearics at 00UTC 11 Nov) shows high sensitivity to the precise shape of the mid-levels trough, and particularly to the details regarding the embedded secondary waves.

Example: Superstorm 10 and 11 November 2001

Singular vectors results:





Wind speed component of the 1st SV (colored) over the IC Wind field (isolines).

• All results shown are preliminar and under study

• Contributions to the Spanish MM5 Network would include:

- ➢ Distribution of the code developed to compute SV using the standard Adj MM5 distribution
- ➢ Support on the installation and run of the standard Adjoint system modules
- ➢ General support (when possible)

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Red Ibérica de MM5

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