Lagrangian Data Assimilation of VORCORE Antarctic Balloons in the GEOS-5 Data Assimilation System

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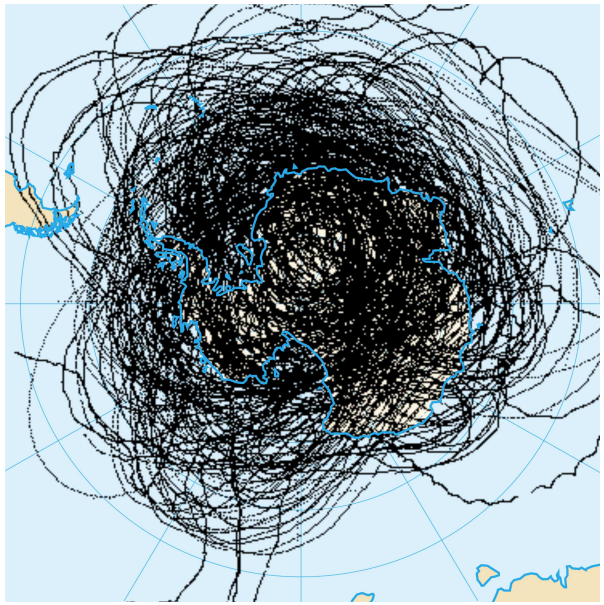
METEO FRANCE
Toujours un temps d'avance

NASA

The VORCORE Campaign

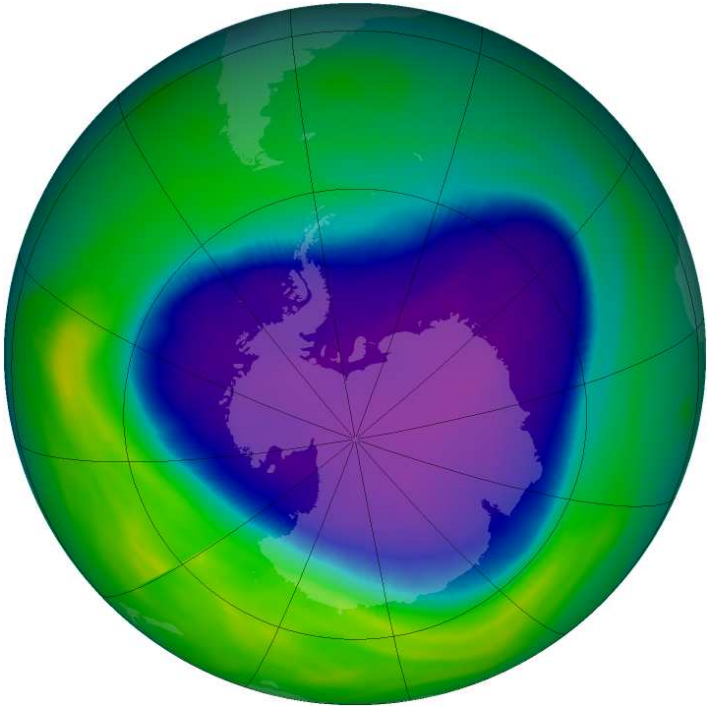
- 27 long duration balloons launched between August and October 2005;
- GPS recording of their position (every 15 minutes)
- Quasi-Lagrangian tracers of the flow

Source: `http://www.lmd.ens.fr/`



VORCORE balloons trajectories

The Antarctica Polar Vortex



Ozone Total Column measured by the Aura satellite October 1st 2005.

Source:
`http://ozonewatch.gsfc.nasa.gov/`

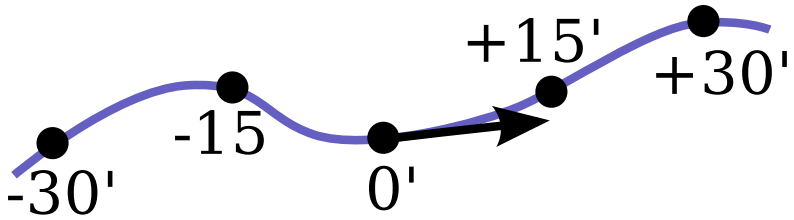
Geographical domain

- The Antarctic Area (between 40S and 90S);
- Lower Stratosphere (between 50 and 70hPa);

Period

- Winter / austral spring 2005 (Polar vortex and ozone hole).

Derived winds *Vs.* Positions



Conventional method : Interpolate winds along the balloon trajectory

Why use another method ?

- The wind calculated is only an approximation;
- The successive positions contain an integrated information (which is lost using interpolated winds);

The aim of this study is to assimilate directly positions in order to extract the maximum information.

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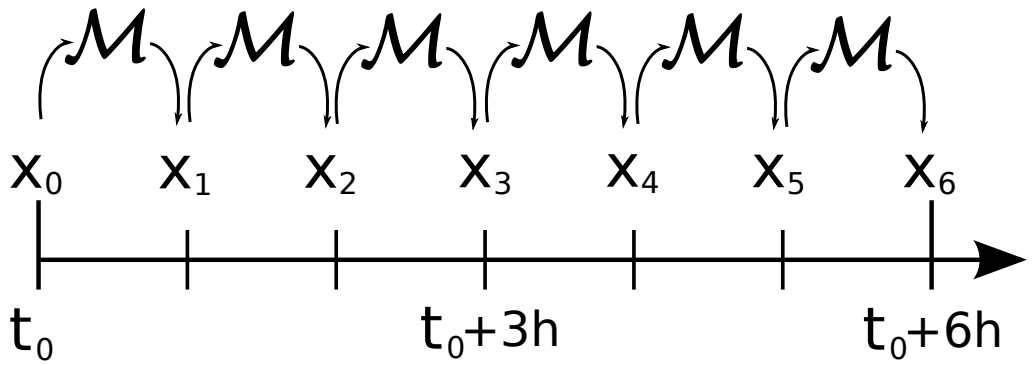
4D-var GEOS-5 Data Assimilation System

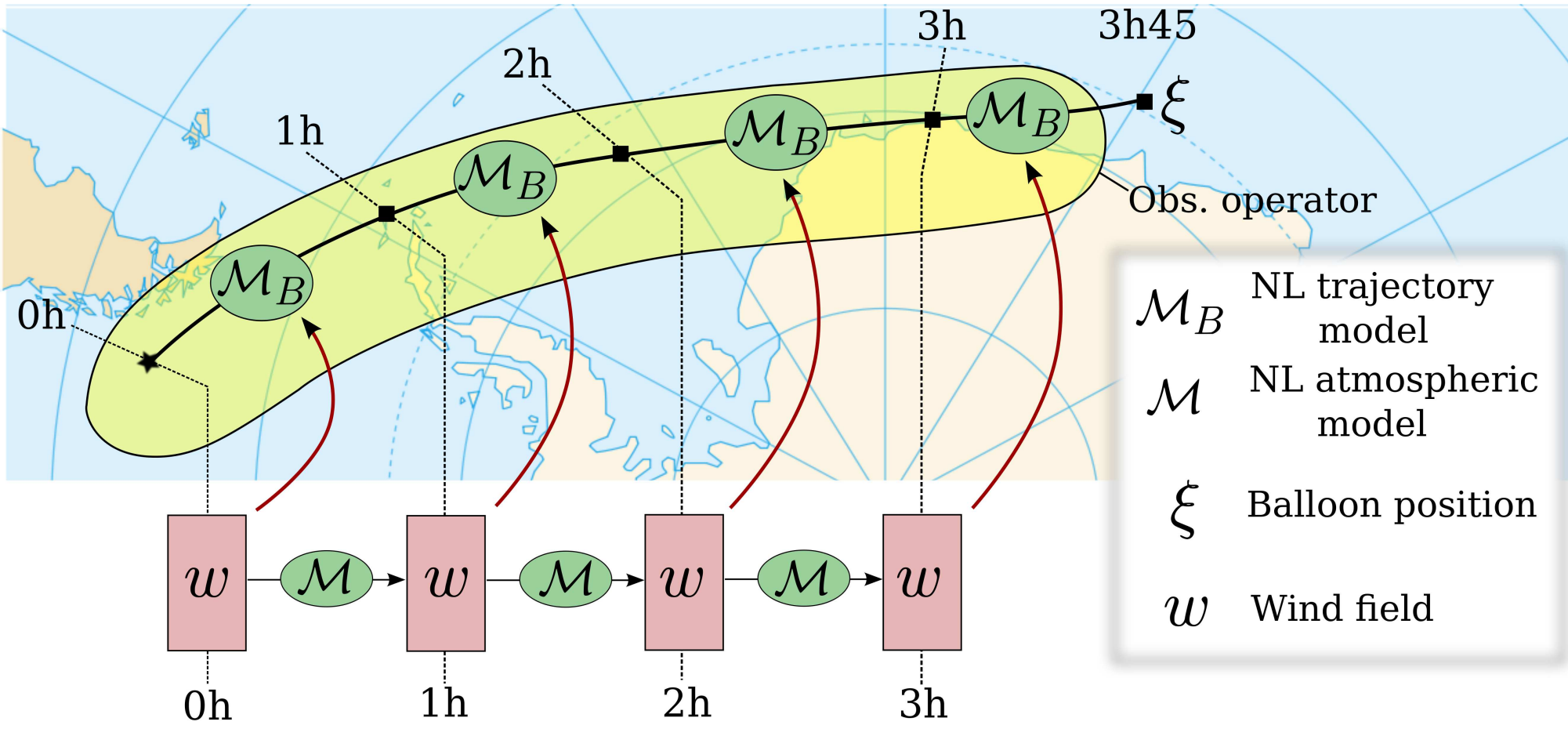
- Analysis done using the GSI software (based on the 4Dvar incremental formulation)
- + GEOS-5 Atmospheric Global Circulation Model ($\mathcal{M}$)



- We need a model equivalent of the observation to calculate the innovations: $d_i = y_i^o - \mathcal{H}[\mathcal{M}_{i,0}(x_0^b)]$;
- To minimize the cost function we use the linearized (**H**) and adjoint ($\mathbf{H}^T$) of the obervation operator (along with the linearized (**M**) and adjoint ($\mathbf{M}^T$) of the GEOS-5 AGCM).

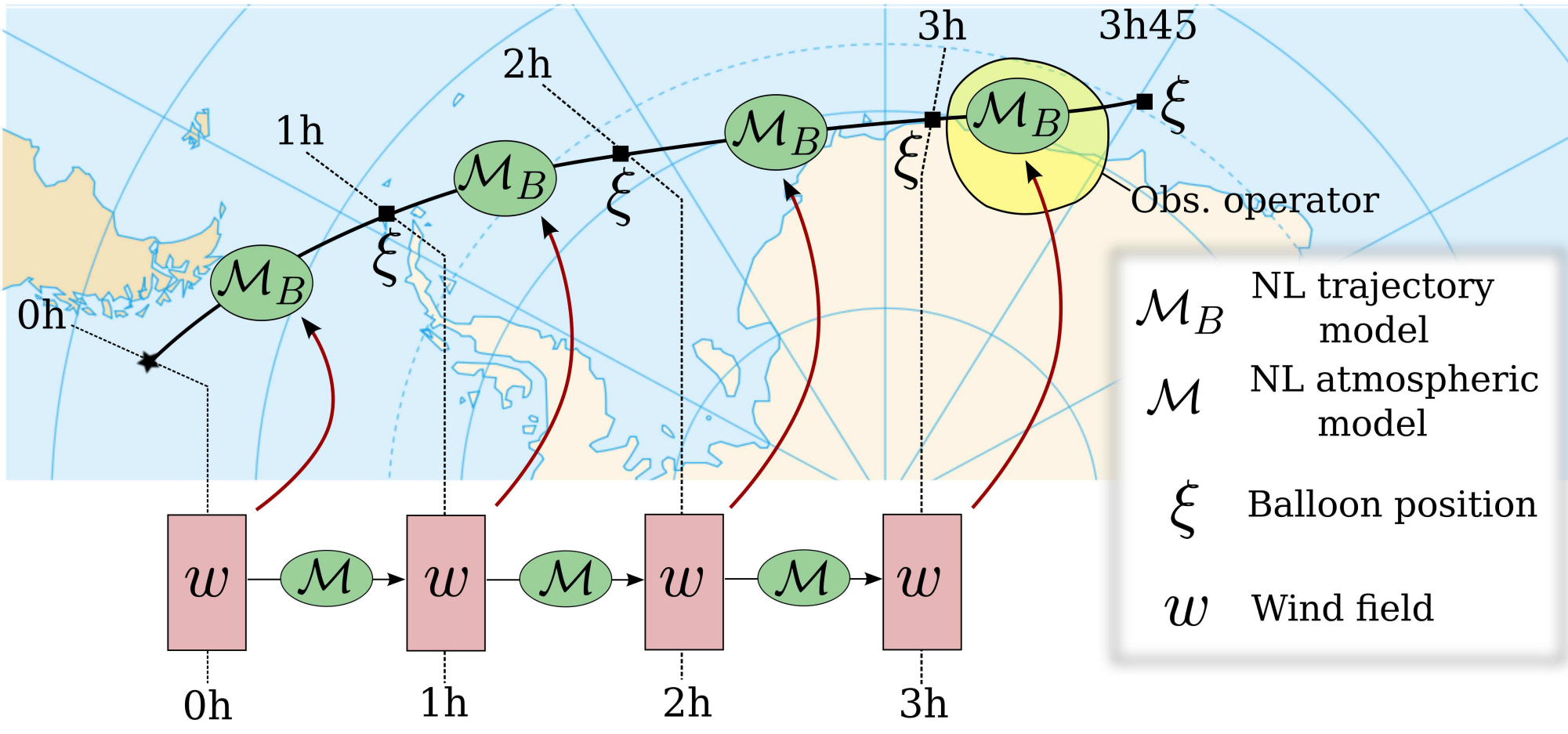
Computation of the innovations

$$d_i = y_i^o - \mathcal{H}[\mathcal{M}_{i,0}(x_0^b)]$$



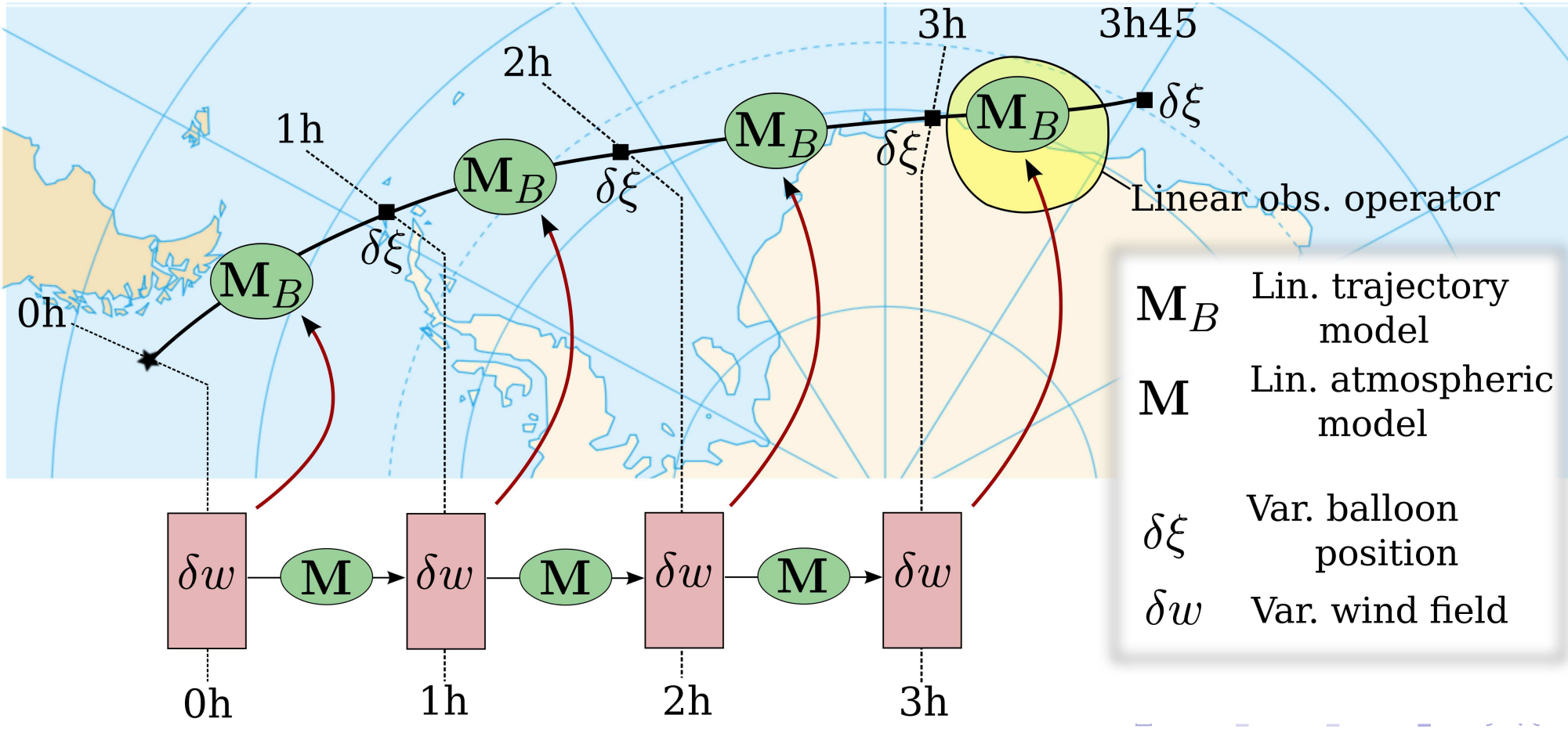
Computation of the innovations (practical way)

$$d_i = y_i^o - \mathcal{H}[\mathcal{M}_{i,0}(x_0^b)]$$



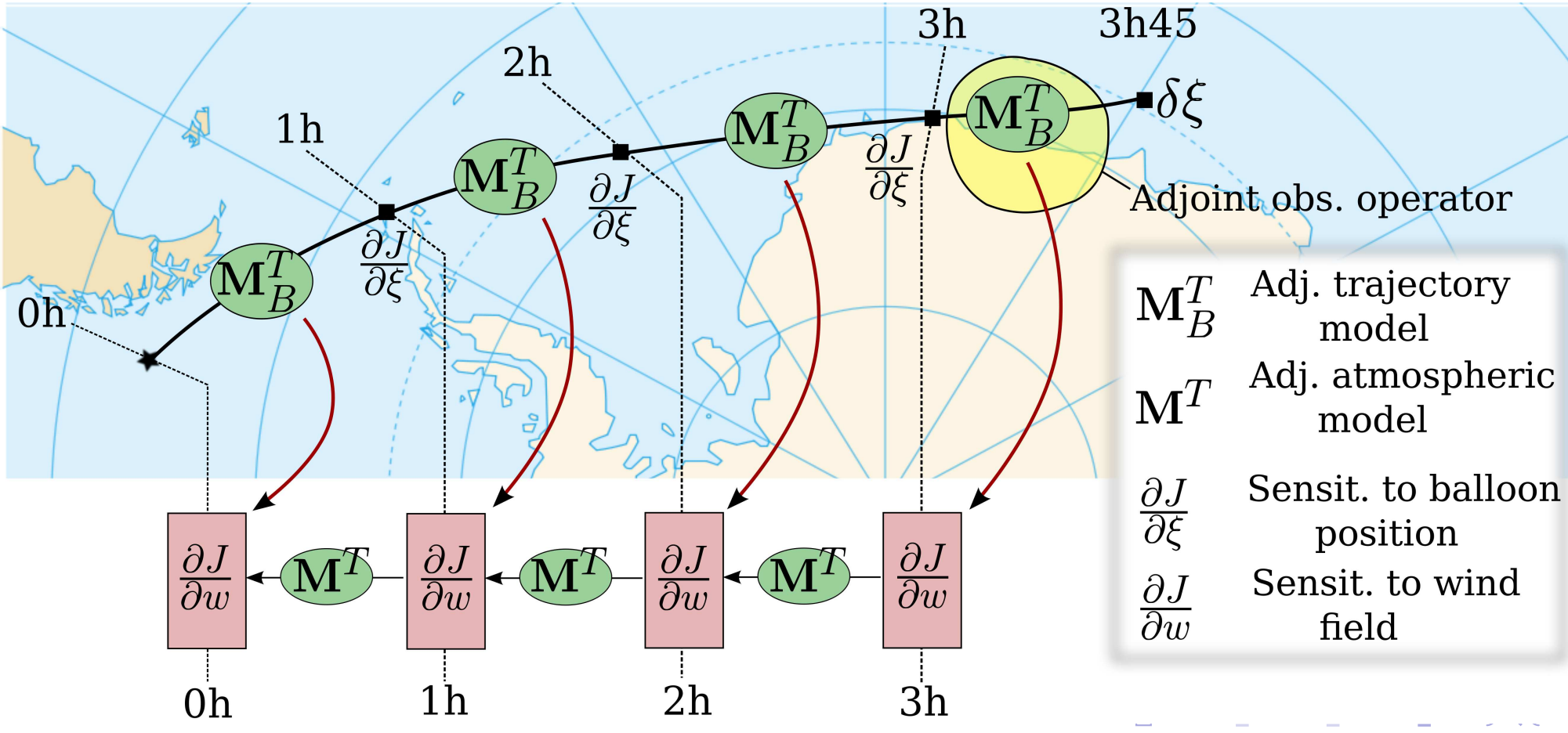
Computation of the gradient: linear integration

$$\frac{\partial J}{\partial x_0} = \mathbf{B}^{-1}\delta x_0 + \sum_{i=0}^{n} \mathbf{M}_{i,0}^T \mathbf{H}_i^T \mathbf{R}_i^{-1}(\mathbf{H}_i \mathbf{M}_{i,0}\delta x_0 - d_i)$$



Computation of the gradient: adjoint integration

$$\frac{\partial J}{\partial x_0} = \mathbf{B}^{-1}\delta x_0 + \sum_{i=0}^{n} \mathbf{M}_{i,0}^T \mathbf{H}_i^T \mathbf{R}_i^{-1}(\mathbf{H}_i \mathbf{M}_{i,0}\delta x_0 - d_i)$$



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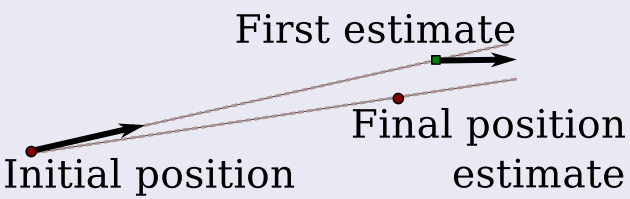
Non-linear model hypotheses

- Vertical movement: Balloon considered to flight on an isobar surface
- Horizontal movement: Driven by the wind

Algorithm



- 3D interpolation of the wind
- Computation of the displacement using a Runge Kutta 2^{nd} order method
- Displacement transformed to a lat/lon variation

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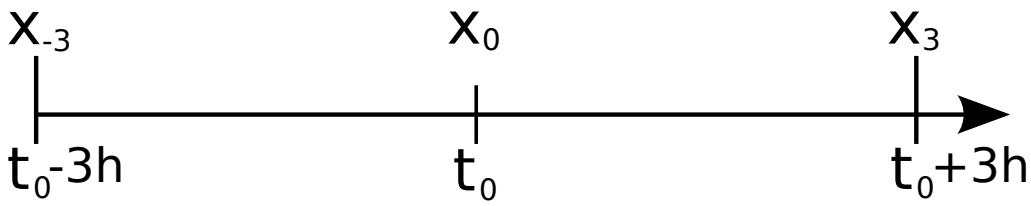
3D-var GEOS-5 Data Assimilation System

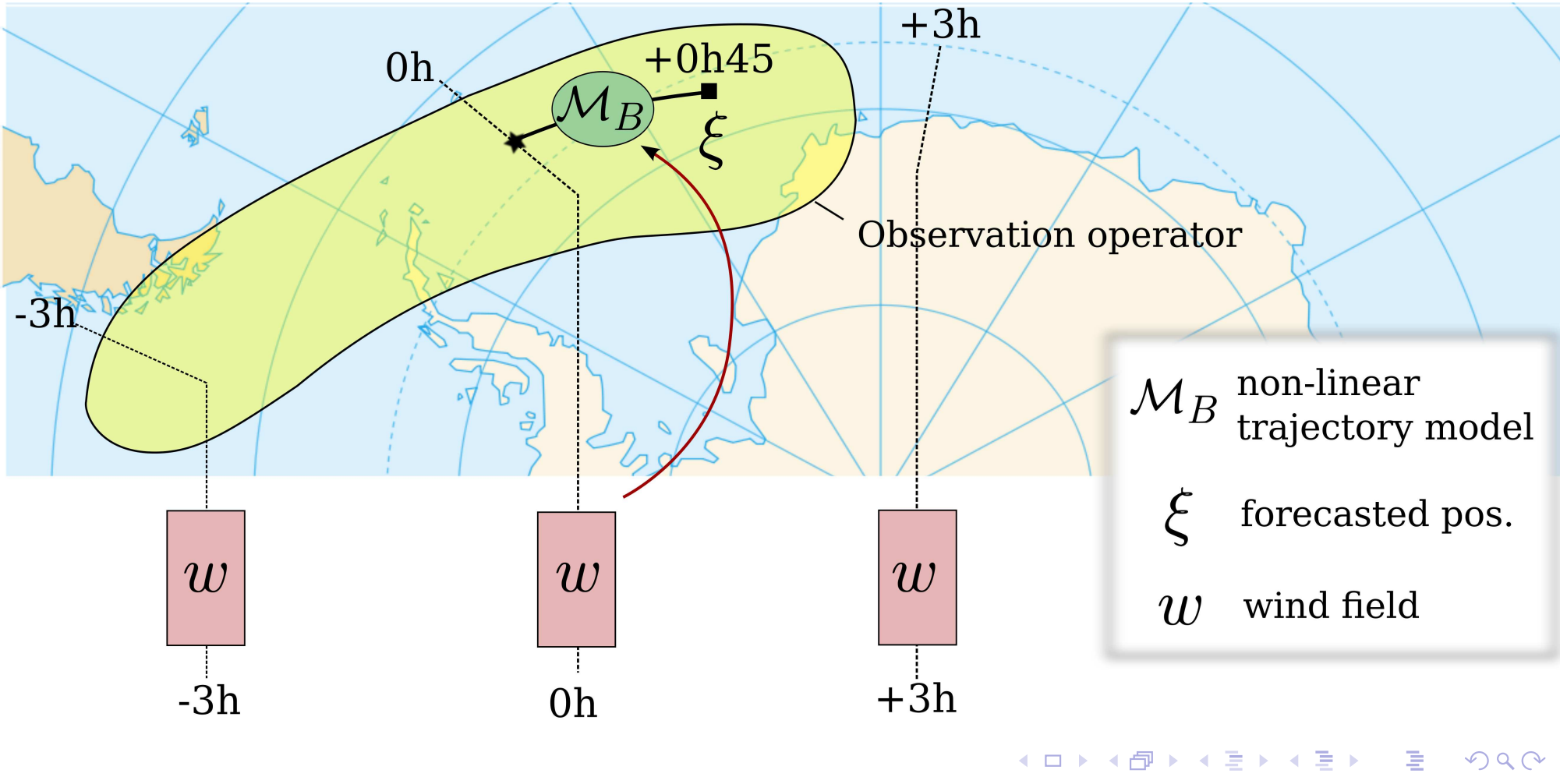
- Analysis done using the GSI software (based on the 3Dvar incremental formulation)
- GEOS-5 Atmospheric Global Circulation Model used to cycle



- Calculation of the innovations using an observation operator : $d = y^o - \mathcal{H}(x^b)$
- Linearized (**H**) and Adjoint ($\mathbf{H}^T$) of this observation operator used to perform the cost function minimization

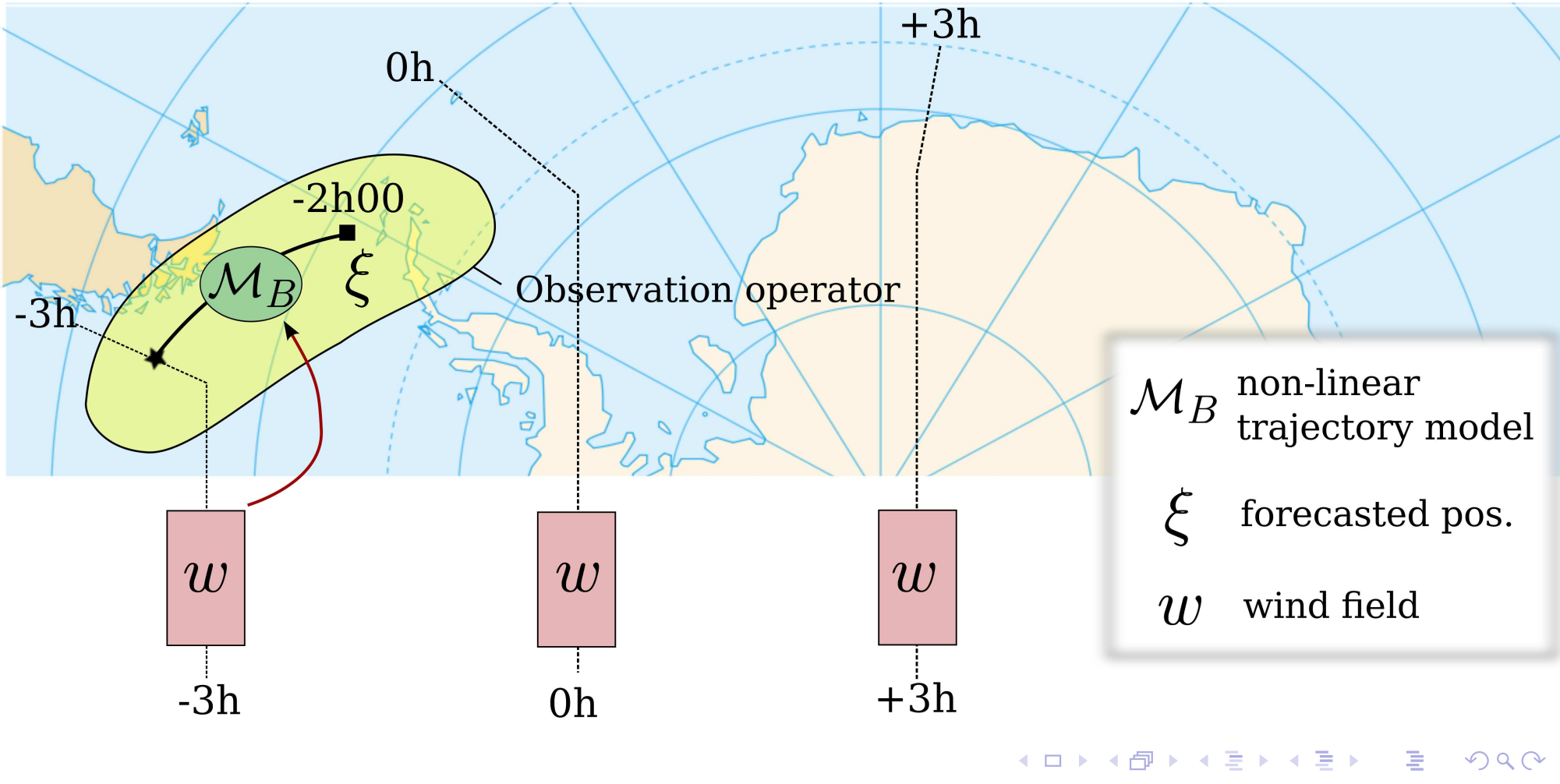
Computation of the innovations

$$d = y^o - \mathcal{H}(x^b)$$



Computation of the innovations

$$d = y^o - \mathcal{H}(x^b)$$



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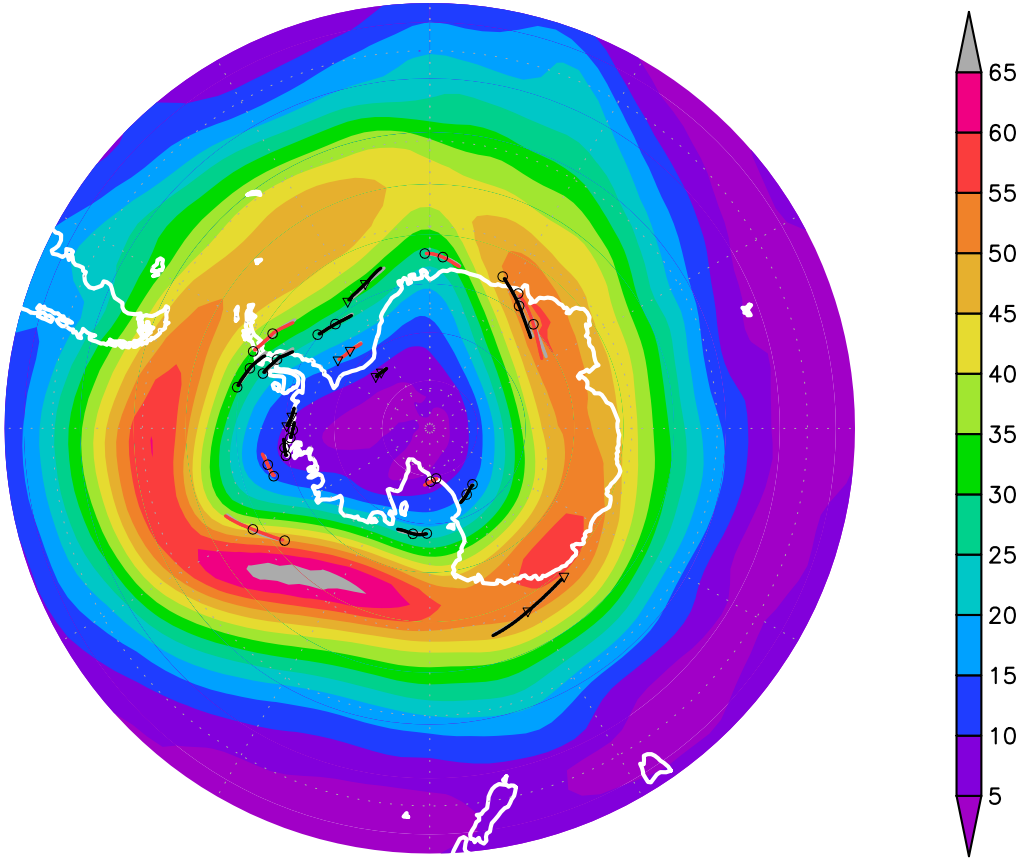
Validation methodology

- Several assimilation experiments (see table below) from November 1st to December 15th 2005
- Some VORCORE data were not assimilated to provide a control sample

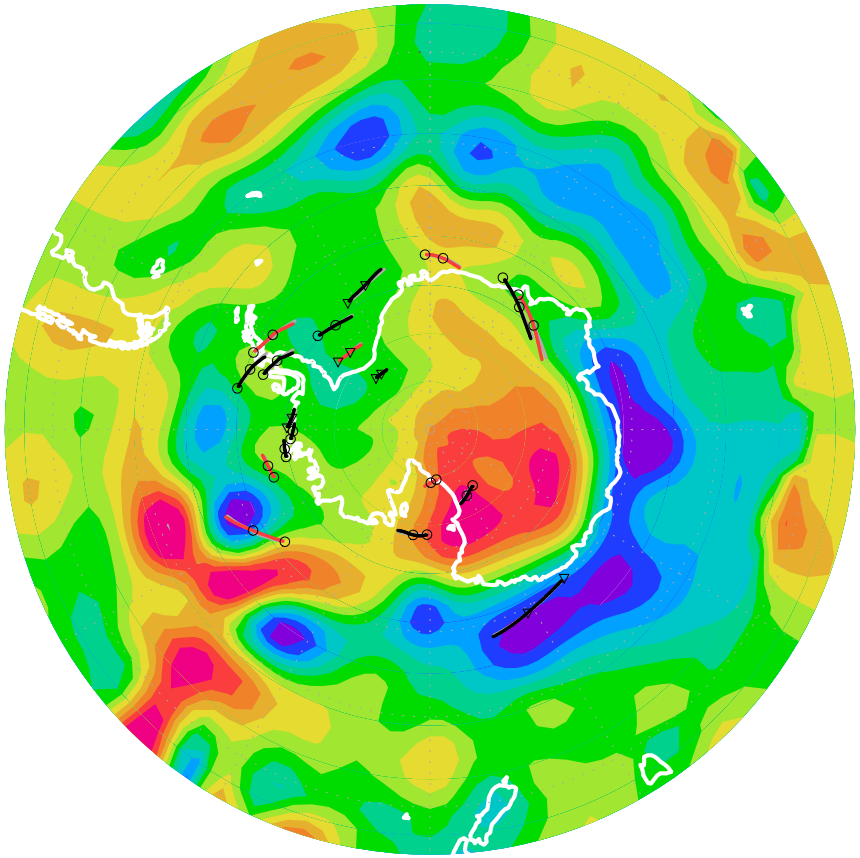
Experiment Name	Conventional + Sat. data	VORCORE derived winds	VORCORE positions
REF	X		
BAL15m	X		Every 15min
WIND15m	X	Every 15min	
BAL180m	X		Every 180min
WIND180m	X	Every 180min	

1st Nov. 2005, 00h UTC: Wind speed

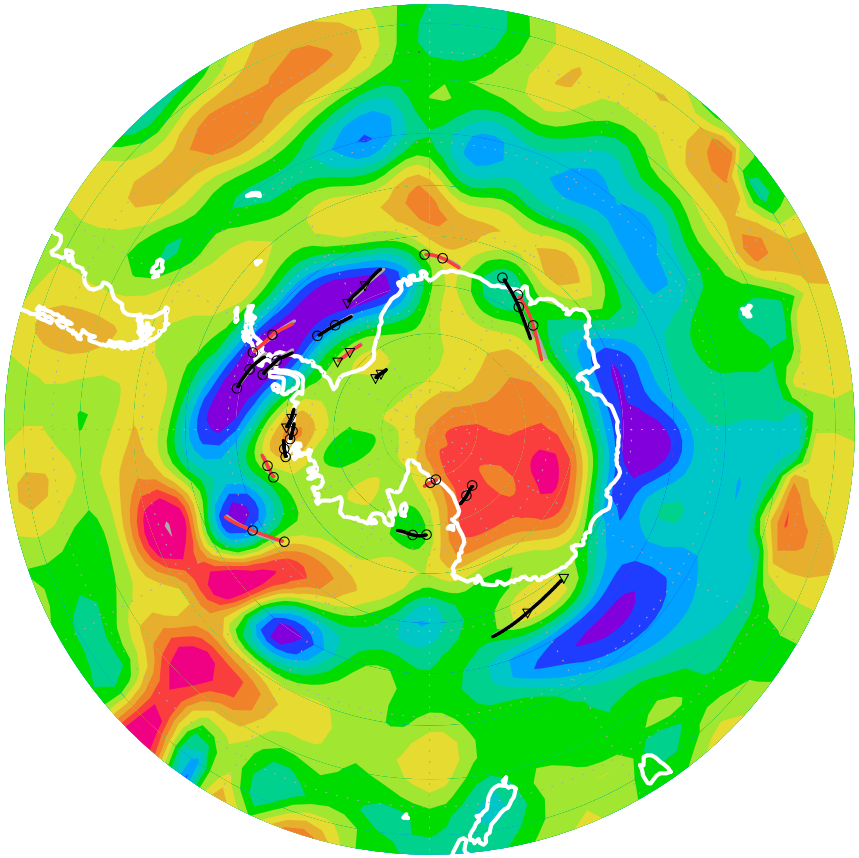


Background field
Wind speed at 50hPa ($m.s^{-1}$)

1st Nov. 2005, 00h UTC: Reference *Vs.* BAL15m

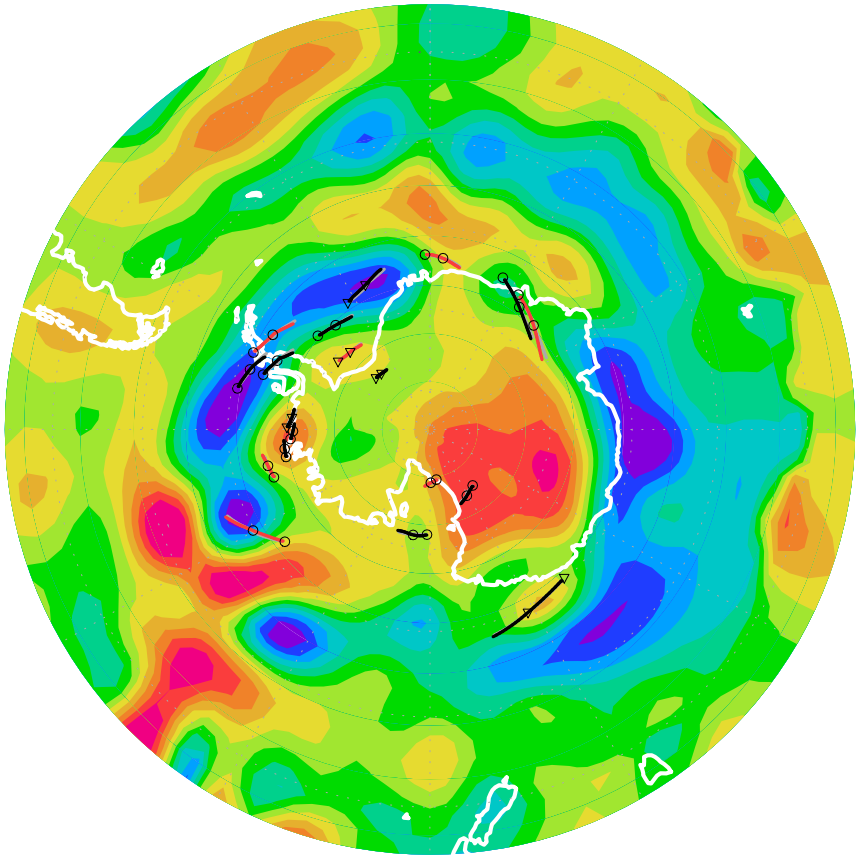


REF - Reference
Increment on wind speed at 50hPa ($m.s^{-1}$)

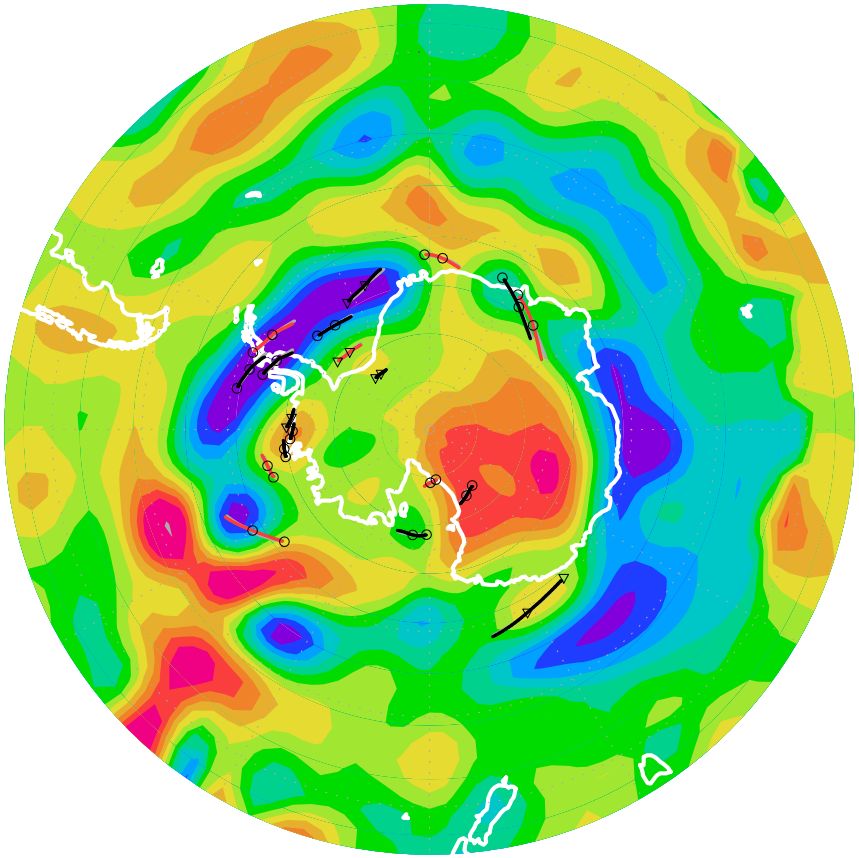


BAL15m - 15 min positions assimilation
Increment on wind speed at 50hPa ($m.s^{-1}$)

1st Nov. 2005, 00h UTC: WIND15m *Vs.* BAL15m

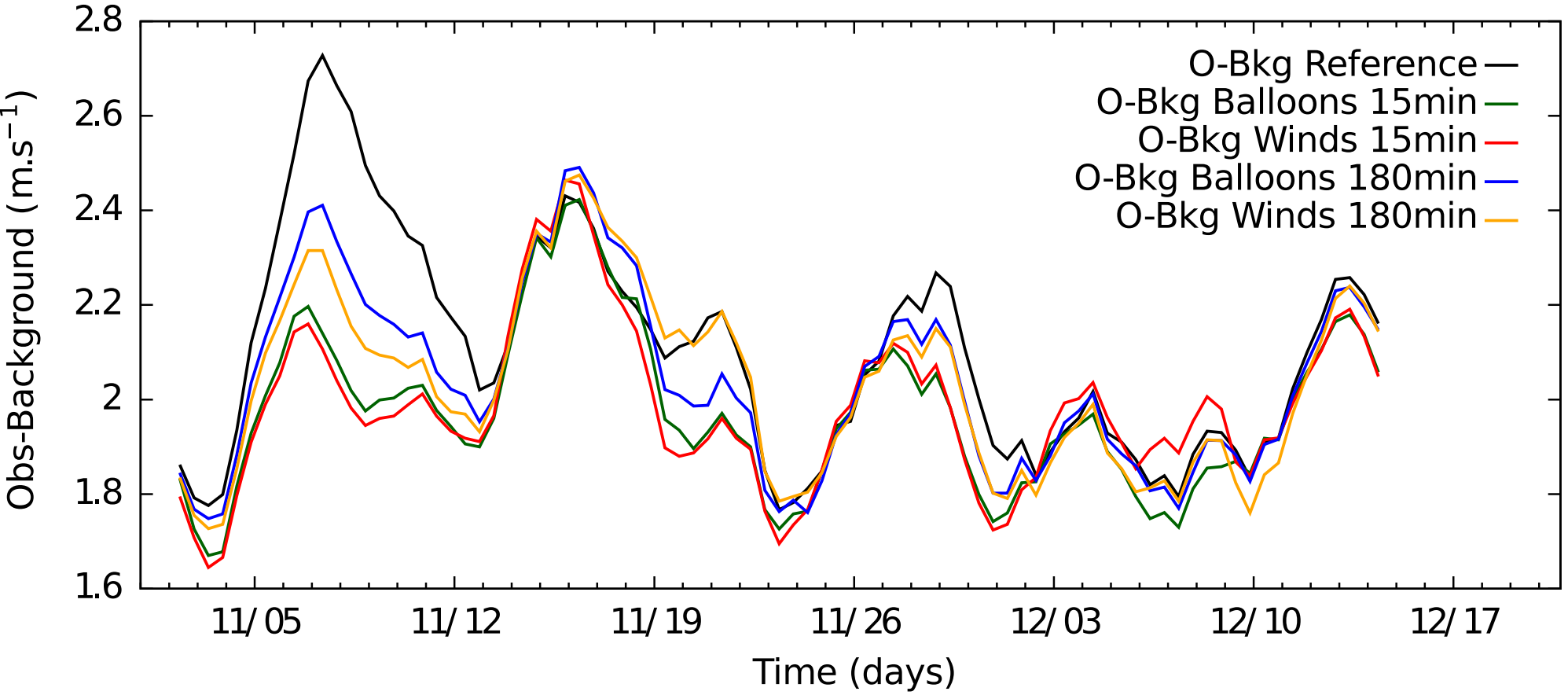


WIND15m - 15 min derived winds assim.
Increment on wind speed at 50hPa ($m.s^{-1}$)



BAL15m - 15 min positions assimilation
Increment on wind speed at 50hPa ($m.s^{-1}$)

Temporal evolution of the Observation-Background difference



Evolution of the absolute observation-background difference on the wind speed for the non-assimilated balloons (3 days moving mean).

Overall results on wind speed : Observation-Background

Experiment name	Mean	Standard deviation	Sample size
REF	2.11	1.64	26180
BAL15m	1.97	1.54	26180
WIND15m	1.98	1.54	26156
BAL180m	2.04	1.58	26180
WIND180m	2.03	1.57	16180

Statistics on the absolute observation-background differences on the wind speed for the non-assimilated balloons ($m.s^{-1}$)

Conclusion and prospects

To do list...

- Carry out an evaluation in 4Dvar
- Study the sensitivity to measurement error
- Study the effect of representativeness error correlations
- Use *posteriori* diagnoses to obtain a better estimate of the observation error

Prospects

- Apply this method to other field campaigns
- Use Lagrangian Assimilation for other types of position observations (e.g. successive positions of clouds used for MODIS winds)