Case studies of 4D-Var assimilation of potential vorticity observations derived from image processing

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Abstract

This work is related to the assimilation of pseudo-observations of potential vorticity (PV) to improve the forecast of strong impact cyclogenesis. Whereas information may be visible to forecasters, direct assimilation of water vapour (WV) or ozone (O3) channels bring few information on the initial fieds of potential vorticity (PV) such that the use of pseudo-observations is considered.

A satellite image-processing technique has been developed for the identification and tracking of upper-tropospheric dry intrusions that are known to be related to mid-latitude cyclogenesis. Persistent warm radiance features are detected on the WV 6.2μm channel of MSG geostationnary images. (Michel and Bouttier, 2006). These features have been shown to be correlated with positive anomalies of PV, and their brightness temperature and PV behaviours are linked along time. Satellite and model trajectories are compared to build diagnosis of displacement and amplitude errors. This algorithm is used as a basis for the generation of pseudo-observations of potential vorticity (PV) in the ARPEGE 4D-Var assimilation scheme, in which we assimilate PV tendencies based on the warming of the radiances. Several cases studies illustrates the impact, limited by the fact that few observations enter the DA scheme and that pseudo-observations may be biased by the background.

Some alternative ideas are being considered, for example using ozone absorption channels. A first study show high correlation between Aura Microwave Limb sounder O3 data and PV. A logarithmic regression is used to specify PV pseudo-observations between 215 and 100 hPa. Experiments will carry on with Aura UV OMI and in case of positive results GOME2 onboard Metop-A (monitoring of partial O3 columns vs vertical averaged PV, assimilation studies) as UV sounders allow to estimate O_3 and therefore hopefully PV in the upper troposphere (lower sensitivity to clouds)

Tracking of dry intrusions on MSG WV 6.2μm channel

A multi-level thresholding technique for warm features

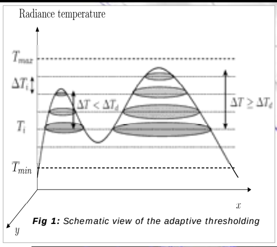

Fig 1: Schematic view of the adaptive thresholding

- Method based on iterative thresholdings to detect relative maxima of radiance temperature (Fig 1).
- Connected cells are selected if they are deep enough (temperature criterion) and large enough (surface criterion).
- Cells are tracked along time using a motion estimation from cross-correlation between images

The warm feature detection algorithm, adapted from Morel and Sénési (2002), allows detection and tracking of dry intrusions on WV images. Several additional criterions are used to filter dynamical features (Michel and Bouttier, 2006) including time persistence, warming of radiances and proximity a jet-streak (being deduced from NWP short range forecast)

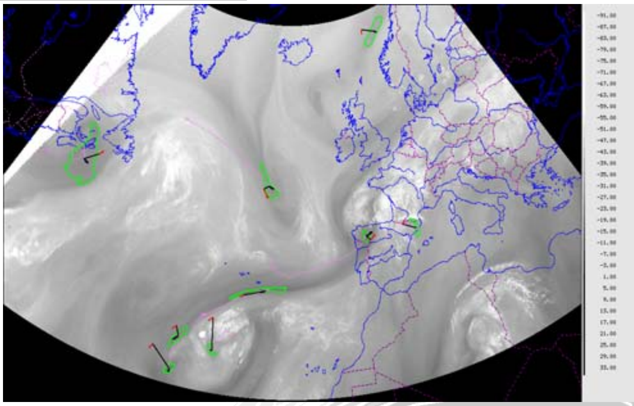

Fig 2: The tracking algorithm (green=detected cells, magenta=trajectories) on 2006100212 (shortly before a strong storm)

O_3 and relationship with PV: another way of specifying pseudo-observations?

Real-time high quality O_3 soundings in the troposphere lower stratosphere will soon be available from MetOp (IASI, GOME2). Potential for using a statistical correlation model between O_3 partial columns and PV average on a vertical layer have been shown in case studies (Jang etal., 2003 for TOMS measurements).

As a very first step we consider EOS Microwave Limb Sounder (MLS) onboard satellite Aura to study correlation between O_3 and PV in the lower stratosphere. A fair logarithmic correlation (r=0.9) is found on levels 215, 147 and 100 hPa (figure 3). Using this statistical model to simulate pseudo-observations for the next ten days (figure 4) shows that the residual have a slightly non-Gaussian distribution with over-occurrence of high departures, but remains unbiased.

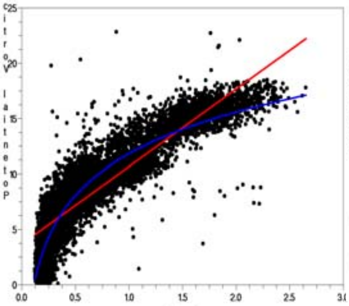

Fig 3: The relationship between MLS O_3 and PV from ARPEGE background (observations every 165 km, 12h, for 10 days)

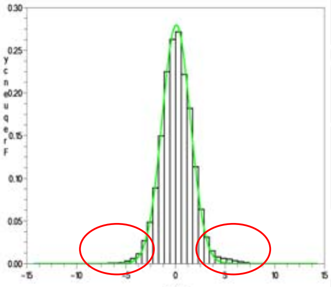

Fig 4: Statistics for pseudo-observations of PV minus PV from the background for the next ten days and Gaussian law with μ=0.04 PVU, σ=1.4 PVU

4D-Var assimilation of PV pseudo-observations from the imagery: methodology, results on case studies

The PV observation operator

A PV operator, its tangent-linear and its adjoint versions based on a simplified form of Ertel PV have been implemented into the ARPEGE assimilation scheme (Guérin *et al.*, 2006).

$$Q = -g\zeta_a \frac{\partial\theta}{\partial p} - g\frac{fp}{R}\left(\frac{p_0}{p}\right)^{R/c_p}\left\{\left(\frac{\partial U}{\partial p}\right)^2 + \left(\frac{\partial V}{\partial p}\right)^2\right\},$$

Generating pseudo-observations

Height assigment problem: the background is used to locate among the vertical the PV anomaly or the tropopause height associated with the cells tracked on the imagery.

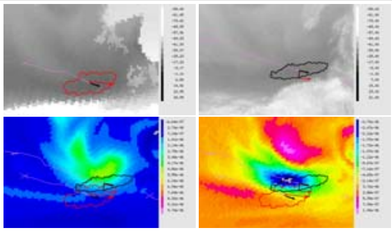

Fig. 5 : Up: Tracking of dry intrusions (20060520 00UTC) on 6.2 μm WV channel for model (left) and satellite (right). Bottom: PV of the background field at 350 hPa (left) and PV dipolar increment associated with the assimilation of pseudo-observations (right) that correct the displacement error.

Correcting displacement error:

pseudo-observations are build that intend to correct the vortex location (Fig 5) if the displacement error is large enough compared to the lengthscale of 4D-Var structure functions. Problems occur if the PV maximum is not sampled so that observations are produced at this latter location rather than at the cell's location.

Correcting amplitude error: a simple model is used to link linearly the variation of radiance ΔT_{BB} and the variation of the tropopause (1.5 PVU) pressure level $\Delta P_T = -\Gamma \cdot \Delta T_{BB}$ with Γ=6.5 hPa·K⁻¹.

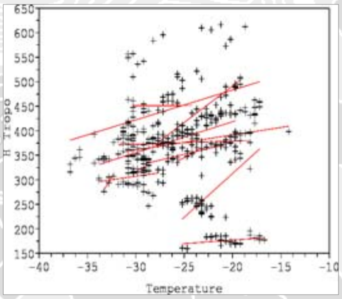

Fig 6: Linear regressions along the trajectories of the cells between their temperatures and their mean 1.5 PVU level.

As shown on the figure 6, there is however little correlation between absolute values of tropopause height and radiances which is a strong limitation to the careful specification of PV pseudo-observations (e.g. we will introduce biases from the background).

The validity of the conceptual model (e.g. variations of T_{BB} and of height of tropopause) is tested by comparing PV profiles and radiances along trajectories of cells.

We found necessary to discard the cases of tropopause foliations, and to limitate the observations on the vertical levels around the tropopause.

The PV departure is based on the estimate of the tropopause pressure level ΔP_T and vertical advection of the PV of background.

Case studies on one-cycle assimilation experiments

Several strategies to build pseudo-observations have been tested on 16 case studies of cyclogenesis.

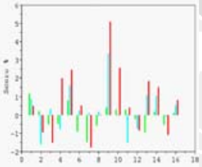

Fig 6: Impact in terms of MSLP scores for EXP 4, forecast ranges 24,48 and 72h.

EXP	amplitude correction	Displacement of structures
1	6h window	×
2	Full trajectory	×
3	6h window	Ø
4	Full trajectory	Ø

Results show that trying to displace PV anomalies often yields poor results (both because of the smoothing effect of analysis on PV structures and because of spatial correlations), EXP 1-2. EXP 3 has overall neutral impact. EXP 4 show small improvements (figure 8).

References

Guérin et.al, 2006: 4D-Var analysis of pseudo potential vorticity observations. *Quart. J. Roy. Meteor. Soc.*, 132, 2257-2276

Michel and Bouttier, 2006: Automated tracking of dry intrusions on satellite water vapour imagery and model output. *Quart. J. Roy. Meteor. Soc.*, 132, 1283-1298

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