Capability of a 3D-Variational mesoscale assimilation scheme ALADIN to simulate a cyclone in the southwest Indian Ocean

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1. Introduction

Over the last years, the global models have realized great progress concerning the trajectory forecasts but their representation of the cyclone itself remains very poor due to rough horizontal resolutions, including the initial state. Improvements in cyclone track and intensity predictions are expected with a better simulation of the cyclone structure. This can probably be achieved with a mesoscale model. In a global model, the background errors statistics are not well suited for the cyclone prediction. The correlation functions are not sharp enough. We expect them to be sharper in a limited area model in a tropical zone.

These arguments encourage to test the impact of a mesoscale assimilation/prediction suite on the cyclone predictions. The 3D-Var ALADIN has naturally made up our test software.

2. ALADIN-Réunion characteristics

2.1. The coupling model

The coupling model is ARPEGE-Tropiques, a global model with a uniform resolution about 55km. The analysis uses a 4D-Var algorithm at 187km resolution. The calculation grid is linear.

The vertical is described by 41 levels from 17 meters to 1 hPa.

The binary file name is *cy28t2_tropique-op1.09.*

The domain

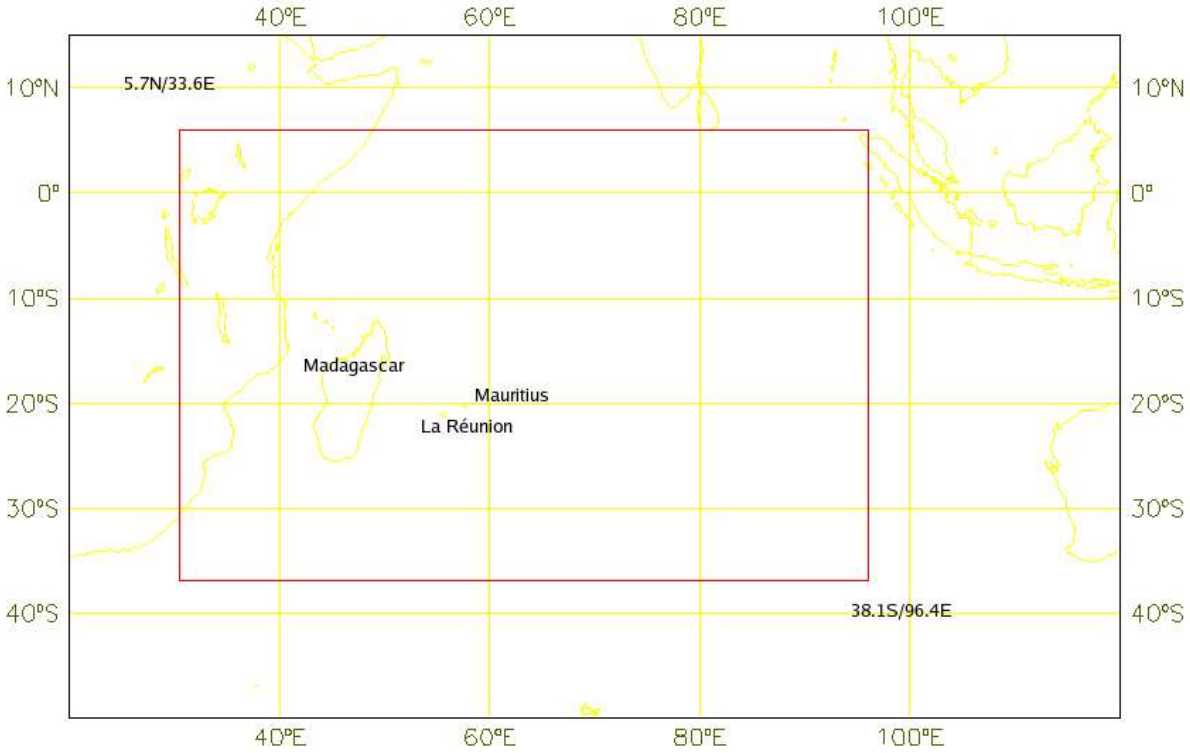

Fig.1: The ALADIN-Réunion domain (Coupling and Inner zones) is represented by the red rectangle.

The horizontal resolution is 21,6 km in both latitude and longitude. The domain covers the entire RSMC (Regional Specialized Meteorological Center) area for cyclones analysis and prediction for which Météo-France La Réunion has international duties for cyclone monitoring.

The entire calculation grid corresponds to 270 points in latitude and 360 in longitude. 36 points in longitude and 27 in latitude are used for the extension zone necessary to get a biperiodic

domain ; 8 points define the coupling zone both in latitude and longitude ; the remaining points constitute the inner area. The projection is the Mercator one. The vertical resolution is the same as ARPEGE-Tropiques.

The calculations grid is quadratic but it is planned to use a linear one in a near future.

2.2. Background errors correlations

They have been computed with the Lagged-NMC method over the first quarter 2004 corresponding to warm season meteorological conditions. They should then better fit our cyclonic prediction aim. A rapid scan of these matrices showed that they contain some specific structures probably linked to the characteristics of the domain.

2.3. The assimilation algorithm

The 3D-Var ALADIN available on OLIVE has been used with a 6 hours window.

The assimilation is made at the same resolution as the forecast model. The observations file is a simple extraction from the ARPEGE-Tropiques' one over our area.

3. Experiment description

3.1. The case study : the cyclone BENTO

The forecasters have issued regular warnings on Bento between 20th and 30th of November 2004. Bento intensified very suddenly on the 22th. On the 23rd, it was an intense tropical cyclone which is rare at this period (fig 3). It moved slowly to the south at 10 km/h mean speed (fig 2).

ARPEGE-Tropiques forecasts were disappointing, particularly at the beginning of the cyclone life (fig 4).

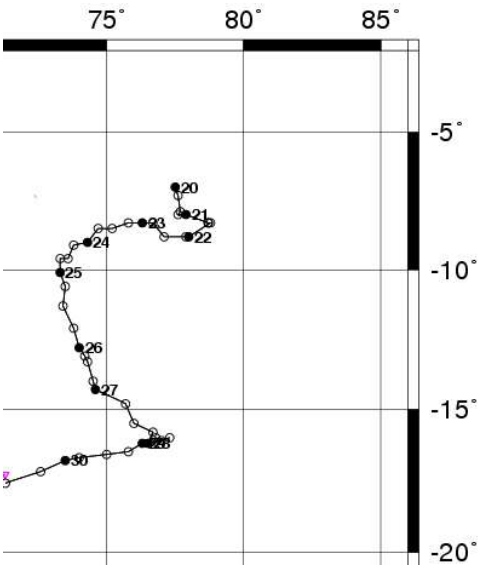

Fig.2: Observed BENTO track.

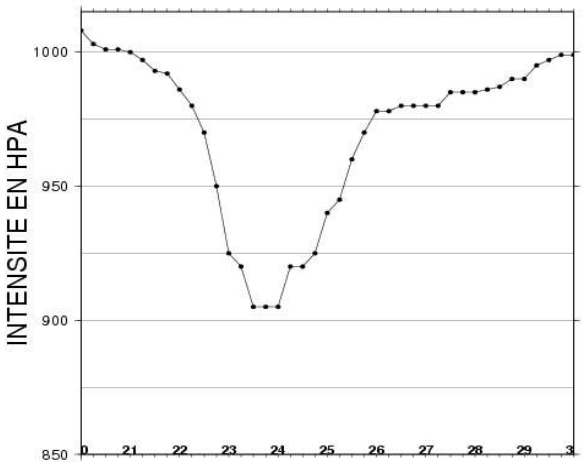

Fig.3: Observed BENTO intensity.

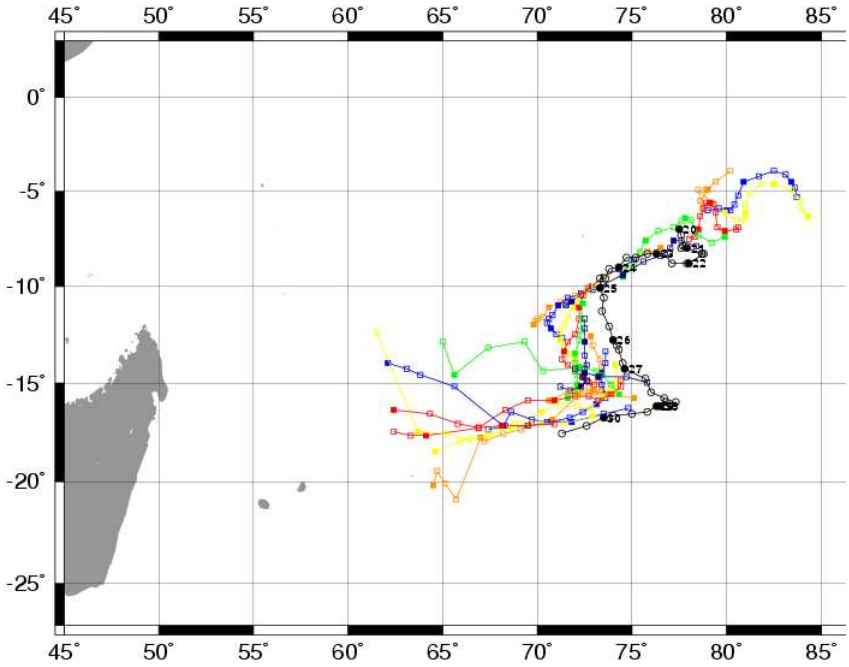

Fig.4: ARPEGE-Tropiques 3-days forecasts every 12 hours on 00 and 12 UTC basis. The observed track is black.

4. ALADIN configuration

The run cycle is *al28t3_main.03*. The assimilation of observations types 8 (cyclone bogus) and 9 (QuikScat scatterometer winds) has been activated as in ARPEGE-Tropiques. To take into account QuikScat winds, a new binary has been built which is used only for the observations screening. The forecast model has run on the 00h UTC basis up to 2 days.

The assimilation period extends from November the 19th at 06h UTC till the 30th at 00h UTC. It began one day before the first warning related to the system.

5. Results

5.1. Assimilation

5.1.1 Assimilated observations

More conventional observations and SATOB winds are assimilated by the ARPEGE-Tropiques 4D-Var. The reason is intrinsic to the assimilation algorithm that takes into account the temporal dimension. Several measures at the same place but at different times are used by the 4D-Var when just one, associated to the time at the center of the assimilation window, is used in the 3D-Var. More aircrafts data are assimilated by ALADIN-Réunion ; it has been noticed afterwards that their thinning was looser than the ARPEGE-Tropiques' one. No difference appears for other observation types.

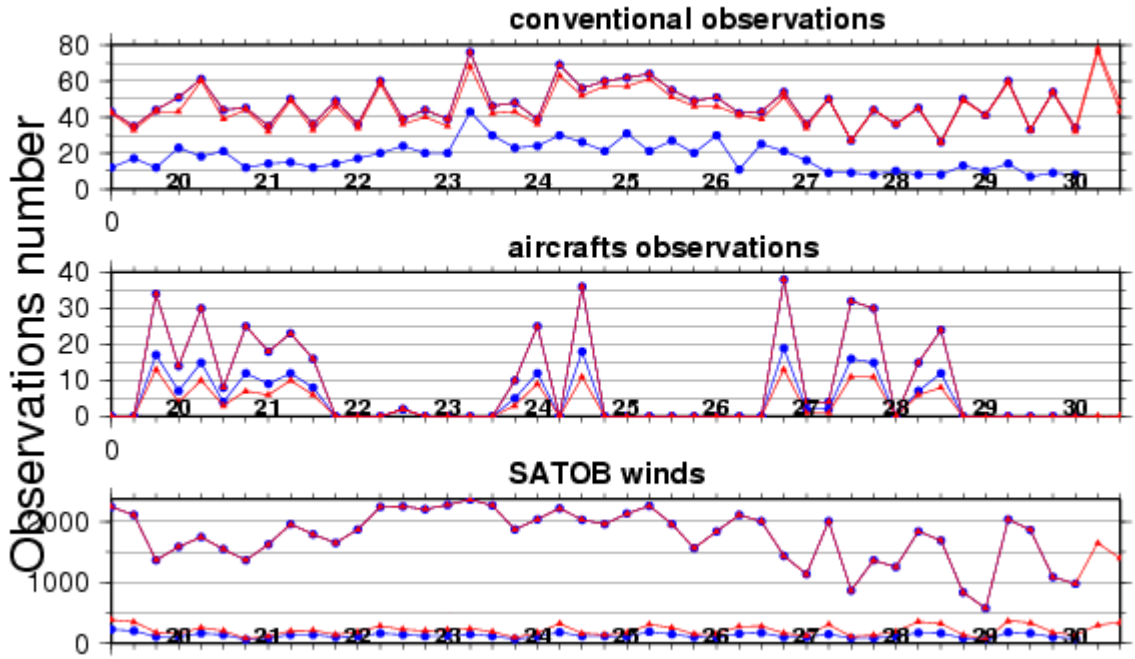

Fig.5: Available and assimilated observations in a 8 degrees side square centered on Bento. Red triangles stand for ARPEGE-Tropiques and blue circles for ALADIN-Réunion. Conventional observations gather observations types 1 (synop, ship,...) and 4 (buoys).

5.1.2 Bento track and intensity analysis

On average, the cyclone forecast position (fig,6) is better with ALADIN-Réunion than ARPEGE-Tropiques but the sample is very weak (10 forecasts). In both models the cyclone position is analysed at the same position. The interesting feature is the decrease of the position error slope with range obtained in ALADIN-Réunion. In the following paragraphs, the focus will be made on the cyclone structure.

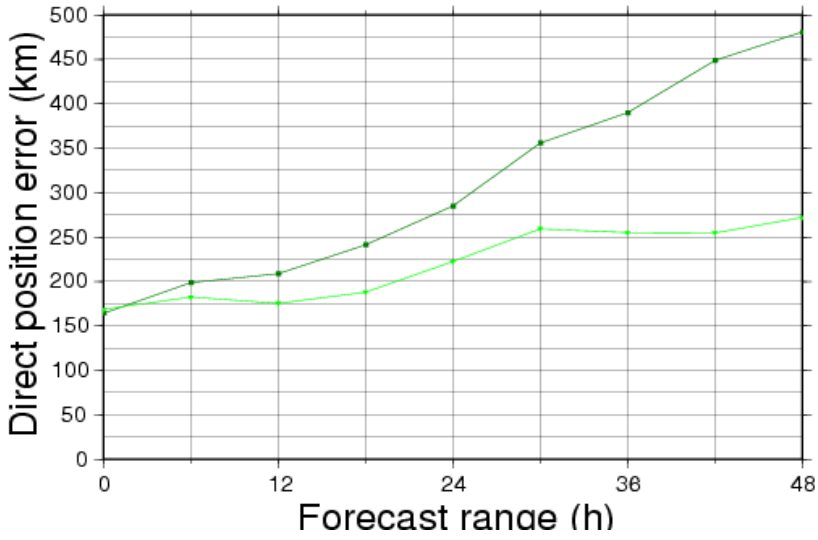

Fig.6: Evolution of direct cyclone position error with range for ARPEGE-Tropiques (dark green) and ALADIN-Réunion (light green) over the entire experiment period.

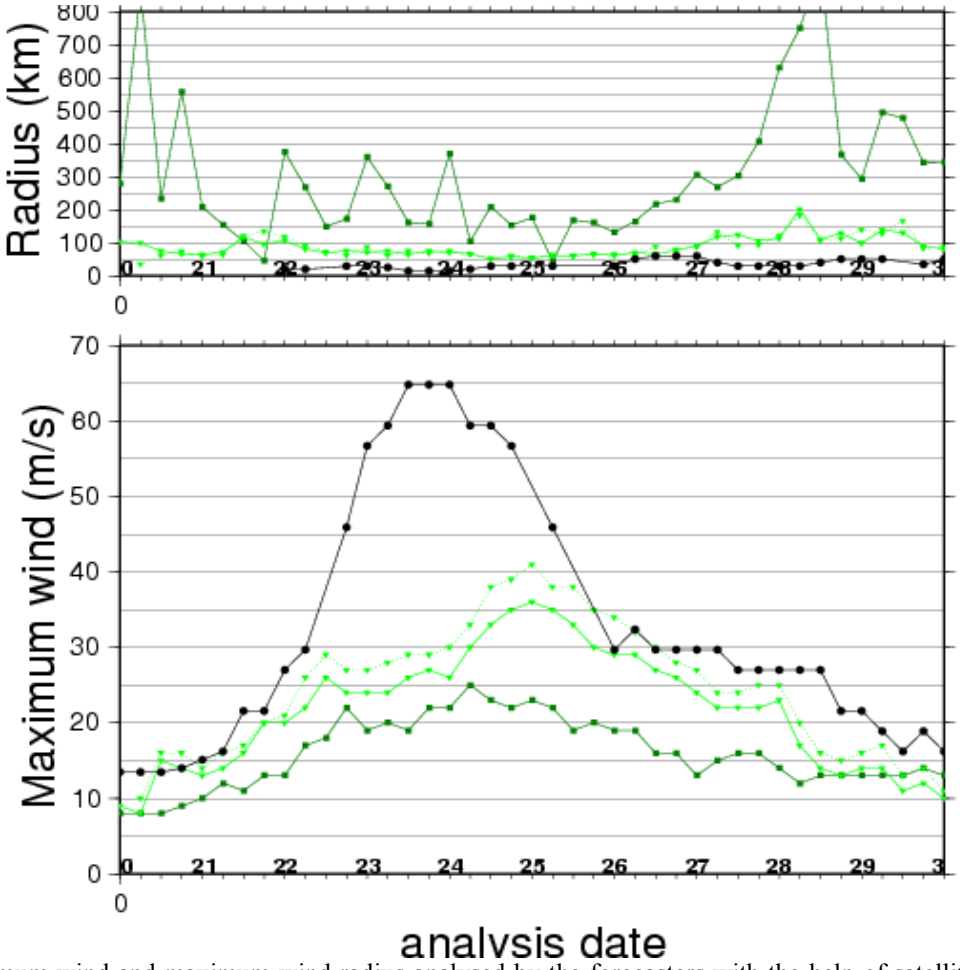

Fig.7: Maximum wind and maximum wind radius analysed by the forecasters with the help of satellite pictures (black) and analysed by ARPEGE-Tropiques (dark green) and ALADIN-Réunion (light green) over the entire experiment period. Dashed lines represent the maximum wind in the guess used for the corresponding analysis.

On figure 7, the maximum wind radius analysed by ALADIN-Réunion is far closer from the reality than ARPEGE-Tropiques' one. The analysed maximum wind is 10m/s stronger and better with ALADIN-Réunion.

In both models, the analysis weakens the intensity of the cyclone present in the guess. This can be explained by two reasons :

- the cyclone position error in the guess is on average 200 km ; there is a contradiction between the guess and the observations in the cyclone area ;
- almost no observations are assimilated in the cyclone core, except the mean sea level pressure bogus because most of satellite observations are contaminated by the rain or are not reliable in strong winds conditions.

5.2. A problem detected with scores

Mean forecast differences between ALADIN-Réunion and ARPEGE-Tropiques show a stratified structure (fig 8). Associated to scores in which the ECMWF analysis is taken as a reference (not shown here), it can be said that the heating in the lower layers by ALADIN-Réunion is not correct ; neither is the cooling around 850 hPa ; the heating at 500 hPa is exaggerated even if ARPEGE-Tropiques seems too cool and the cooling at 300 hPa emphasizes a cold bias existing in ARPEGE-Tropiques.

The heating in lower layers is propagated in the assimilation cycle by the guess and the analysis can not correct it. This points out a problem in the temperature forecast. A default in the

convection or turbulence scheme is suspected. This problem does not hinder though from studying the cyclonic structures both models produce.

The run model cycle is experimental and afterwards two 6 hours forecasts have been run with *al28t2_op1.05* and *al28t3_op1.02* cycles : they both fix the problem.

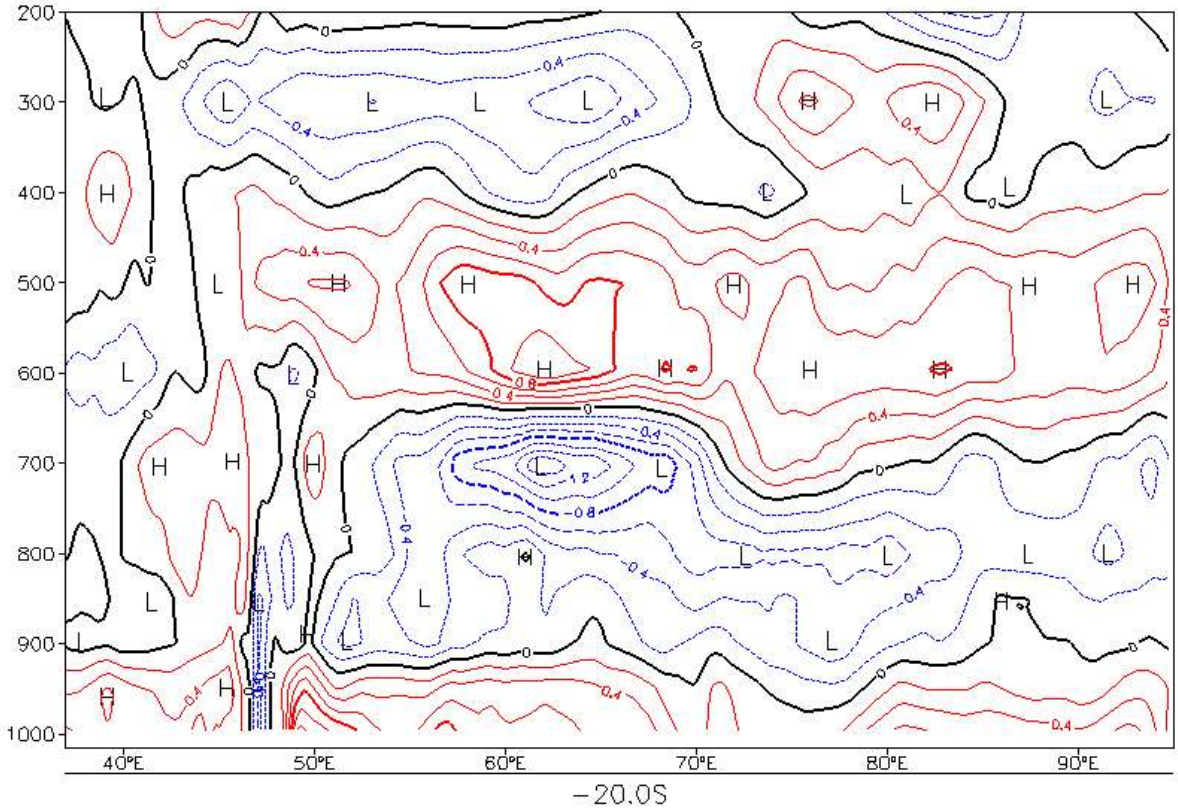

Fig.8: Vertical cross section at 20°S of ALADIN-Réunion and ARPEGE-Tropiques 24 hours temperature forecasts mean differences (K) from 20th to 30th of November runs.

5.3. Forecasted cyclone structure based on the 24th at 00h UTC

In the following we focussed on the cyclone structure simulated by both models because it tells a lot about the capability of the model.

We have chosen the forecast based on the 24th of November at 00h UTC analysis. At this date in reality the cyclone is weakening but both models analyse quite an intense cyclone (984 hPa for ALADIN-Réunion and 991 for ARPEGE-Tropiques) and deepen it during the forecast.

5.3.1 A few fields after a 36h forecast

The ALADIN precipitations field is more realistic (fig 9) :

- precipitations are more intense and more concentrated around the eye ;
- the ring of heavy precipitations linked to the eyewall is more apparent with ALADIN.

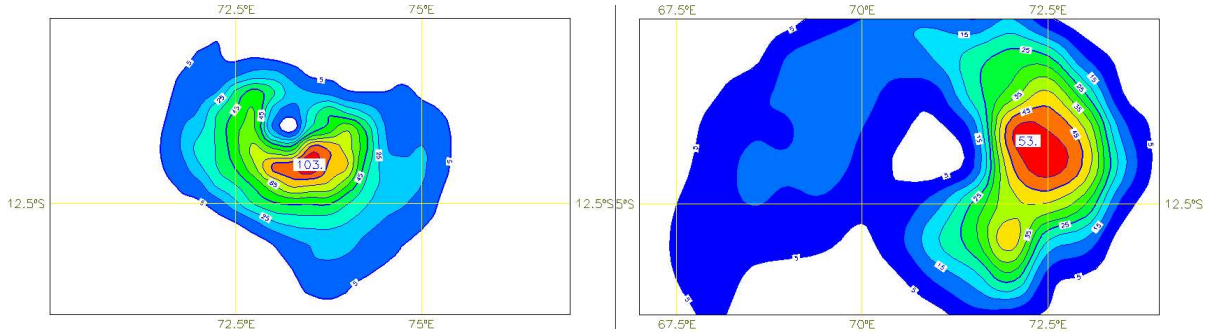

Fig.9: Cumul of precipitations between 33h and 36h forecast ranges in mm, for ALADIN-Réunion on the left and ARPEGE-Tropiques on the right. Base date : 24th of November, 00hUTC.

A characteristic of tropical cyclones is the presence of a warm core, the maximum of which is located in the 250-300 hPa layer. In this layer the horizontal extension of the warm anomaly (compared to the cyclone environment) is the biggest. The figure 10 shows a nice anomaly for ALADIN. In ARPEGE-Tropiques, the warm anomaly appears too large and strangely sheared. The wind force cross-section (fig 11) of ALADIN is also in good agreement with litterature : on either side of the calm zone corresponding to the eye, the wind is very strong in the lower layers and decays above 700 hPa and away from the eye. The tilted structure simulated by ARPEGE-Tropiques is suspicious.

The maximum wind (50 m/s) in ALADIN is quite reasonable. The maximum wind radius simulated by ALADIN (50 km) is a bit high but not very far from the estimated reality (30 km).

Another characteristic of tropical cyclones is the weak subsidence in the eye. This can not be seen in a cross-section of simulated vertical velocity (fig 12), even in ALADIN that simulated however quite a nice structure in temperature and wind. This is perhaps due to the diagnostic nature of the vertical velocity parameter. The large scale compensating subsidence is much weaker in ALADIN than ARPEGE-Tropiques.

It is not shown here but the troposphere is not moist enough in the analysed cyclone core. However, during the forecast, the model is able to humidify the cyclone core. This point needs further investigation.

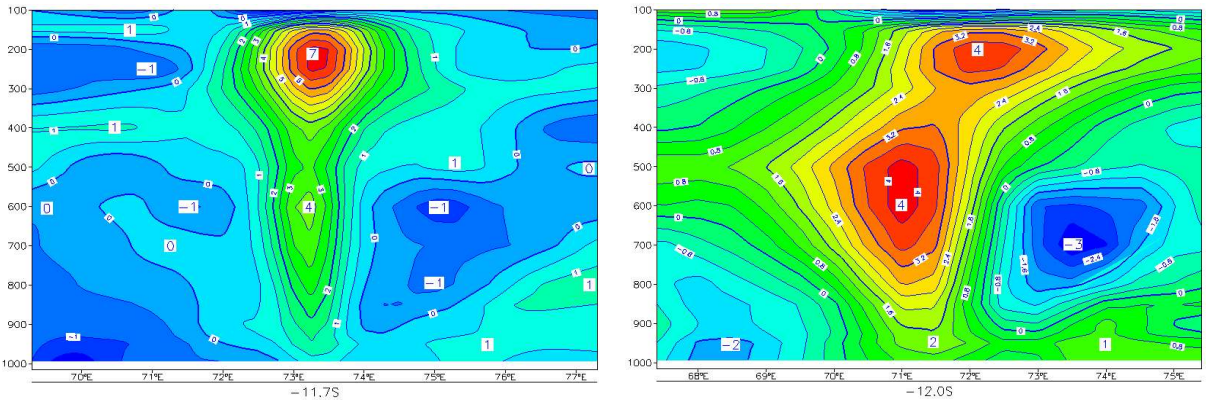

Fig.10: West-East vertical cross-section of the temperature anomaly (local temperature-environment temperature in K) West-East at the simulated cyclone center (ALADIN in the left panel, ARPEGE-Tropiques in the right one). Base date : 24th of November, 00hUTC.

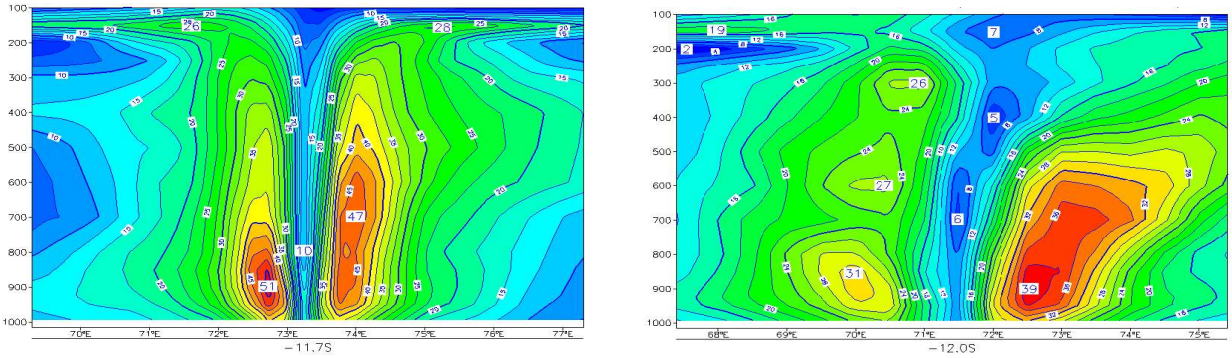

Fig.11: West-East vertical cross-section of the wind force (in m/s) at the simulated cyclone center (ALADIN in the left panel, ARPEGE-Tropiques in the right one). Base date : 24th of November, 00hUTC.

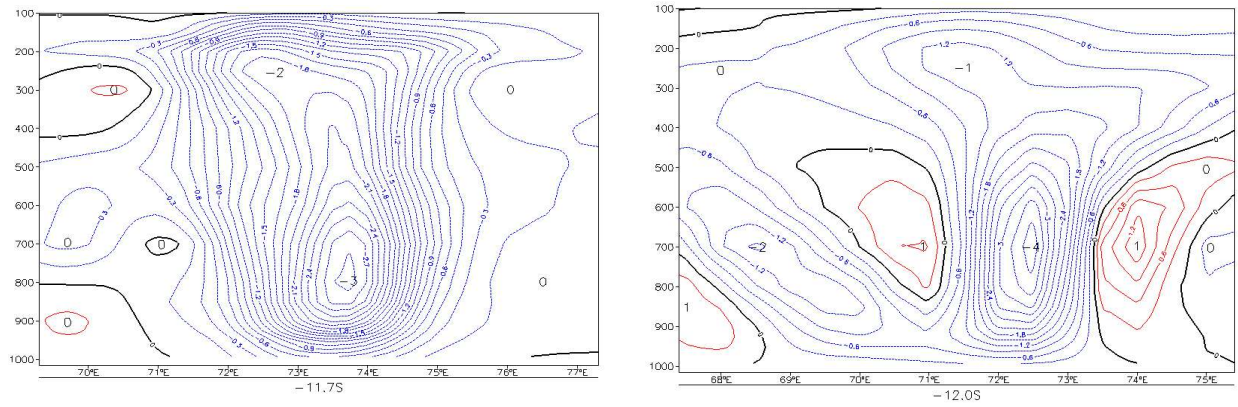

Fig.12: West-East vertical cross-section of the vertical velocity (in Pa/s) at the simulated cyclone center (ALADIN in the left panel, ARPEGE-Tropiques in the right one). Base date : 24th of November, 00hUTC.

5.3.2 Rainy bands in a 12h forecast

The precipitations location around the cyclone center is more realistic in ALADIN (fig 13). A nice rainy band associated to lower levels convergence can be seen in ALADIN. ALADIN simulates a cyclone structure in better agreement with theory than ARPEGE-Tropiques. The chosen date (24th of November) is favorable in the sense that both models deepen the cyclone during the forecast.

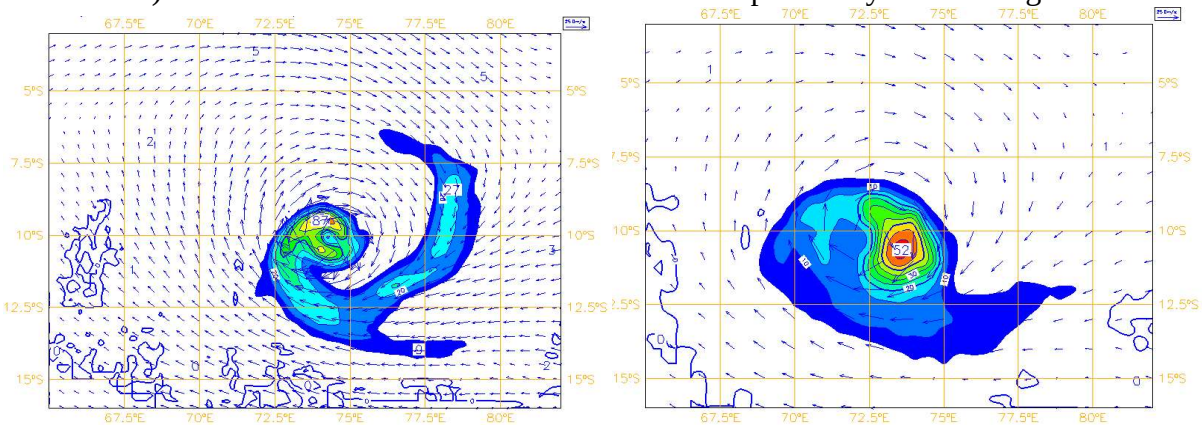

Fig.13: Cumul of precipitations between 9h and 12h forecast ranges in mm superimposed to 850 hPa wind for ALADIN-Réunion in the left panel and ARPEGE-Tropiques in the right one. Base date : 24th of November, 00hUTC.

6. Conclusions and prospects

These experiment results are encouraging in regard to the pertinence of a 3D-Var ALADIN over the southwest Indian ocean for cyclonic prediction. The much better resolution both in analysis and forecast has been translated into a better simulated cyclonic structure.

Several ways are now worth being investigated :

- -in the experiment the observations set is the same for the limited area model as for the global model. Satellite data are used in Numerical Weather Prediction models at a spatial resolution allowing a description of large scale patterns and of the cyclone environment, which is crucial to forecast quality. But the cyclone description remains schematic and needs substantial improvement. In a near future the area under investigation will be the assimilation of satellite data at optimal spatial resolution. More sophisticated refinements will probably be necessary in the assimilation since high density observations are correlated.
- -we plan to use an ensemble technique to estimate the background error covariances. This produces sharper correlation functions which should be beneficial in tropical cyclones cases.
- -the ALADIN model is able to simulate more intense cyclones with a correct structure. The initial position is still approximative (around 150 km error) but the error increase with forecast range appears weaker than ARPEGE's one. A more sophisticated bogussing (wind vertical profiles in the cyclone core) than the only bogussing of the mean sea level pressure at the center could probably give better results.
- -too few observations are assimilated in the cyclone core : because the conventional observations network is sparse over oceans and because the majority of satellite measurements are contaminated by the rain or can not estimate strong winds. The challenge for next years is to assimilate satellite observations contaminated by the rain which will give a lot of information on the cyclone core.

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