A NEW 4D VARIATIONAL ASSIMILATION OF MULTIPLE SPACEBORNE DATASETS FOR REGIONAL WATER AND ENERGY BUDGETS. AN APPLICATION TO THE BRET HURRICANE.

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1. INTRODUCTION

For some years many spaceborne instruments were launched in order to bring new and more information on cloud systems over oceanic surfaces. To process these new data, new methods, in particular methods of data assimilation allowing the processing and merging of these new various kinds of data are needed. In this context MANDOPAS4D, 4D variational data assimilation technical to retrieve 4D fields such as wind, specific humidity and related quantities (pressure, temperature, vorticity potential, apparent heat source, apparent moisture sink, evaporation rate, condensation rate), has been developed. The present work illustrates this method on a real data set devoted to the study of the hurricane Bret. This hurricane was located over the Gulf of Mexico from the 18th to the 23rd of August 1999.

The first objective of this MANDOPAS4D application deals with the estimate of the energetic impact of this hurricane. The knowledge of the space-time evolution of diabatic heating distributions and thus latent heat is crucial for storm diagnostics and forecasting applications (Olson, 1999). Indeed the energy needed for the working of hurricane is essentially supplied under this form (Burlaud 2003, Le Vourc'h, 2001), this method allows to access to the temporal evolution of moisture and wind, and consequently to the latent heat release and heating. This is illustrated in the present case during the intensification phase of Bret hurricane on the 21st. The evolution of the apparent moisture sink (Q), the apparent heat source and the heating latent profiles show an increase of the latent heat, of the humidification of the troposphere with a maximum near 3km and thus a heating of the troposphere..

The second objective deals with the improvement of the description of the large scale environment in particular humidity fields used in the mesoscale modelling of these hurricanes. Indeed, various studies have shown the need of a better initial humidity field (Chong 1990; Nuissier 2005) to simulate accurately vortex tracks, structure and intensity.

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Currently, the need to use all available sources of data in the numerical prediction of hurricanes has been recognized. Many techniques were proposed (for instance Kurihara, 1993: Zou and Xiao, 2000). Atmospheric data with a great resolution (dropsonde, radar …) have a large potential but up to now have not been assimilated. In this context MANDOPAS4D can help as shown by the present application.

The present paper is organized as follows. Section 2 is devoted to a brief description of the Bret hurricane. Section 3 recalls the MANDOPAS4D principle and describes the used dataset. Section 4 gives some illustrations of results obtained by the analysis. Energy budgets are discussed in section 5. Finally conclusions are presented in section 6.

2. THE BRET HURRICANE: 18-25 AUGUST 1999

Bret, forms as a tropical depression over the Bay of Campeche on 18 August, and appears as one among 5 hurricanes that attained category 4 on the Saffir-Simpson hurricane scale (Simpson, 1974). On 19 august, the disturbance becomes the tropical storm Bret (Nuissier, 2005, Burlaud 2003, Lawrence, 2001) and reaches category 4 at 19h the 21st August. The slow moving of Bret allows it to intensify rapidly. Bret moves North-Westward and hits Texas coast between Brownsville and Corpus Christi at midnight. Bret weakens by the time of landfall and dissipates on the 25th.

3. MANDOPAS 4D

MANDOPAS 4D is an assimilation method that allows the retrieval of 4D (spatial and temporal) field of any thermodynamic or dynamic quantity. This method is based on the assumption that these fields can be expressed under an analytical form (orthonormal functions basis). No first guess provided by a meteorological model are used in the present application. The searched fields are derived only from observations using a few equations of the fluids mechanism (which don't depend on any parametrisation) as model/constraints. The objective

is to be as close as possible to observations. Thus the scale resolved by the analysis depends only on the spatial and temporal density of the observations.
Two kinds of observations are considered for the present BRET application:, airborne/ground based data and satellite data.

Two planes (WP3s Orions and NOAA Gulfstream IV-SP) supply information on specific humidity and horizontal wind through dropsonding over the ocean. Radiosoundings performed on the coast provide the same information over the continent.

Information supplied by sensor on satellite is first Integrated Water Vapour. Two imagers provide such a product, **TMI** (Tropical Rainfall Measuring Mission's Microwave imager) and **SSMI** (Special Sensor Microwave Imager). Satellite supply also information on horizontal wind and surface wind from the geostationary satellite GOES-8/9 and QuikSCAT respectively.

4. 4D THERMODYNAMICAL FIELDS

Humidity and wind fields are presently the two main quantities considered in this work. The retrieval is performed over the Gulf of Mexico (domain of 1500 km x 1500 km x 12 km). The mean spatial density of observations leads to an order of development used in the MANDOPAS analysis which resolved scale greater than 160km. Mesocale structures of the hurricane environment are thus considered.

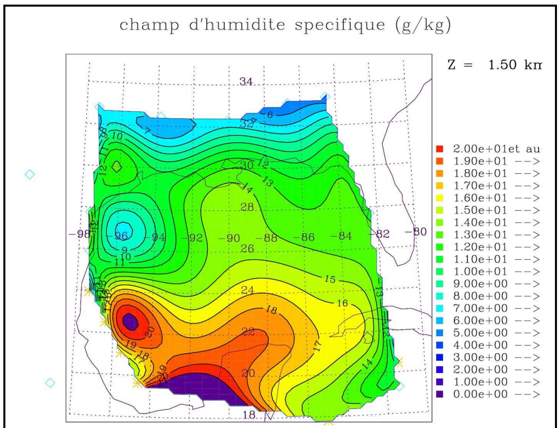

Figure 1 : Horizontal cross-section of specific humidity field at 24h UTC at 1,5km

Figure 1 shows an example of horizontal cross-section extracted at 1.5 km altitude and 24h from the retrieved 4D analytical form of the specific humidity field.. It reveals the existence, at low levels, of a tongue of strong specific humidity south of the location of the hurricane. The analysis of the temporal evolution of this field (not shown) show that the observed meridian gradient of humidity is reinforced with time and the Gulf of Mexico is moistened during the night on the 21 August. The small area (96W-27N) of weak specific humidity (less than 8g/kg) is associated with the hurricane. Air coming from the continent appears drier than the one above the ocean. This evolution of humidity field appears correlated with the life cycle of the hurricane. The studied period corresponds to the growing phase of the hurricane. Thud the increasing available humidity that feeds the hurricane allows it to intensify

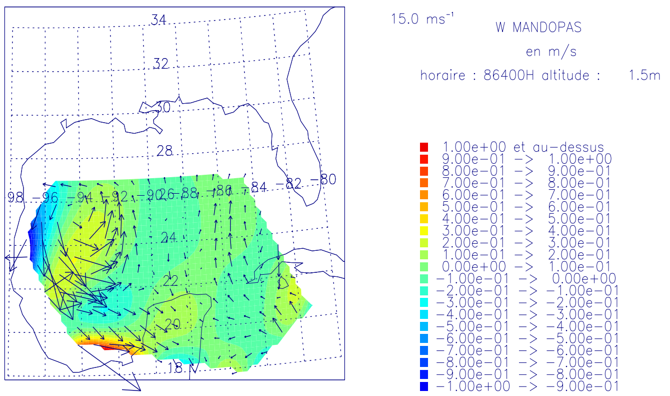

Figure 2: horizontal cross-section of the wind field at 24h and 1,5km. In background is plotted the vertical wind field (m/s).

Figure 2 shows an example of horizontal cross-section extracted at 1.5 km altitude and 24h from the retrieved 4D analytical form of the wind field, with in background, contours of vertical velocity. The location of the hurricane is traced by the observed cyclonic circulation. This cyclonic circulation appears associated with subsiding motions on the eastern side and ascending motions on the western side of this circulation. This cyclonic circulation is surmounted by an anti-cyclonic one at higher altitude (not shown).

From this last 4D wind field, 4D pressure and temperature fields have been diagnosed using the retrieval method proposed by Protat et al. (1998). This method is based on the momentum equations expressed using the non-dimensional pressure (Exner function Π) and the virtual temperature.

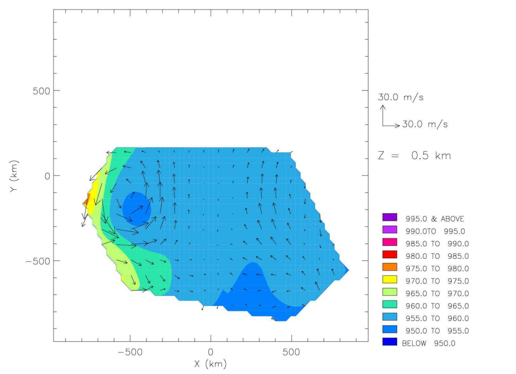

Figure 3: horizontal cross section of pressure

Figure 3 shows an example of horizontal cross-section of the pressure field at 0.5km and 22h. The location of the hurricane corresponds to the pressure low.

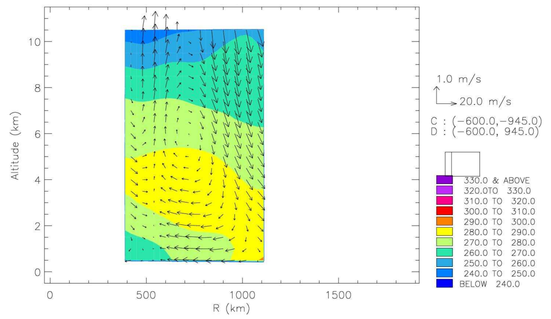

Figure 4: Vertical cross section of the temperature

Figure 4 gives a vertical cross-section of the retrieved temperature field at y=15km. It reveals a maximum at 4km altitude, the 0°C isotherm being around 5km altitude in the environment surroundings the hurricane.

4. HUMIDITY AND ENERGY BUDGETS

The humidity and wind fields retrieved in the section 3 allow the estimate of energy and humidity budgets crucial to understand the hurricane working. The heat budget is useful to quantify the net warming/cooling of the environment and to identify the respective role of diabatic processes. Two approaches are generally used to access to water and heat budgets:

- one uses the apparent heat source and apparent moisture sink developed by Yanai (Yanai, 1973),
- another one is based on the parameterisation of the equation of water mass conservation, (Houze, 1993)

Apparent heat source Q_1 and moisture sink Q_2 are frequently used to evaluate the importance and the impact of convection and associated diabatic processes.

Q_1 for a large scale system is due to radiance (Q_R), relaxation of latent heat (Q_H) and convergence of eddy transport. It can be expressed in two ways:

$$\begin{cases} Q_1 = \overline{\Pi}\,\overline{S(\theta)} - \dfrac{\overline{\Pi}}{\overline{\rho}}\overline{\vec{\nabla}(\rho\vec{V}'\theta')} - \dfrac{\overline{\Pi}}{\overline{\rho}}\overline{D_\theta} \\ Q_1 = \overline{\Pi}\left(\dfrac{\partial\overline{\theta}}{\partial t} + \overline{(\vec{V}.\vec{\nabla})\theta}\right) \end{cases} \quad (1)$$

where Π is the Exner function, θ the potential temperature , $\overline{D_\theta}$ the sub-grid diffusion. This last term is generally neglected except in boundary layer (Lafore, Relsperger and Jaubert, 1988).

A negative value of Q1 indicates a cooling induced by evaporation processes.

Q_2 measures the apparent sink moisture due to condensation and eddy turbulence flux. The expression of Q_2 derives from the conservation of water. It is written:

$$\begin{cases} Q_2 = -\dfrac{L}{C_p}\left(\dfrac{\partial\overline{q}}{\partial t} + \overline{(\vec{V}.\vec{\nabla})q}\right) \\ Q_2 = \dfrac{L}{\overline{\rho}C_p}\overline{D}_{Q_2} + \dfrac{L}{\overline{\rho}C_p}\overline{\vec{\nabla}.(\rho\vec{V}'q')} - \dfrac{L}{C_p}\overline{S(q)} \end{cases}$$

(2)

where L is:

- the latent heat of sublimation below the 0°c isotherm with $L = L_s = 2.83*10^6\,J.K.kg^{-1}$;
- the latent heat of vaporisation above the 0°C isotherm with $L = L_V = 2.5*10^6\,J.K.kg^{-1}$.

$\overline{D}_{Q_2}$ is the sub-grid diffusion generally neglected, the second term in the second equation is the turbulent transport eddy, and the last term (S(q)) the humidity source.

A negative value of Q2 means that there is a sink of moisture resulting from condensation/deposition processes.

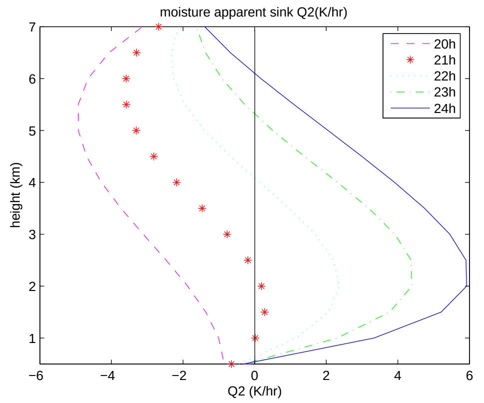

Figure 5: temporal evolution of Q2 profile

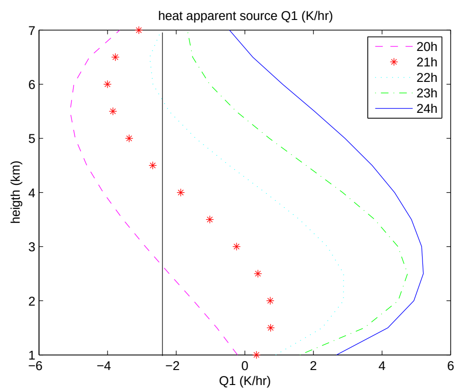

Figure 6: temporal evolution of Q1 profile

Figure 5 shows that during the intensification phase the time evolution of the Q2 profile indicates a moistening throughout all the atmosphere (sink of humidity) A detailed analysis of the various terms involved in this time evolution (not shown) put in evidence the importance of the condensation and the contribution of the horizontal eddy convergence fluxes in low levels.. The shape of the Q1 profiles (see figure 6) appears similar to Q2's shape with a peak near 3 km. The latent heat dominates the heat apparent source during all the phases of intensification. The eddy convergent fluxes occur mainly in the low level. That explains the similar Q1 and Q2 profiles.

5. CONCLUSIONS

The present application aimed at evaluating the capabilities and the robustness of the MANDOPAS. It allowed drawing two main conclusions:

- The analysis succeeds to access to 4D humidity and wind field at the synoptic scale, i.e to describe the environment of the hurricane in the Gulf of Mexico;
- Using these humidity and wind fields, it is possible to estimate water and energy budgets.

Other diagnostics could be performed thanks to the present retrieval of 4D fields of humidity, wind, pressure and temperature such as potential vorticity and processes involved in its production, energetic conversion, etc…. As an example latent heat release can be evaluated. It has been recognized for a long time that the latent heat flux from the ocean is the primary energy source for tropical storm (Chen, 2003). The latent heat flux over the land is one order of magnitude smaller than that over the ocean and this implies that the hurricane will decay rapidly upon making landfall. If we assume that the latent heat can be expressed by:

$$Q_H = -\frac{L}{Cp}(e-c) \ , \quad (3)$$

the profile of QH can be also derived from the 4D humidity and wind fields using the water continuity equation .

Figure 7 shows an example of temporal evolution of the vertical profile of latent heat during the phase of intensification from 20h till 24h. It reveals a production of latent heat throughout all the troposphere, with a peak close to 3km altitude at 24h.

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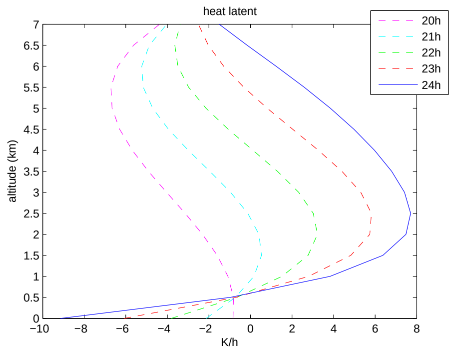

Figure 7: Time evolution of the profiles of the latent heat

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