Medicanes as subtropical cyclones: the December 2005 case from the perspective of atmospheric water budget

3D water budget WRF implementation

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the new **FF-Water budget**

1. budget terms from internal model integration
2. keep terms at the native grid

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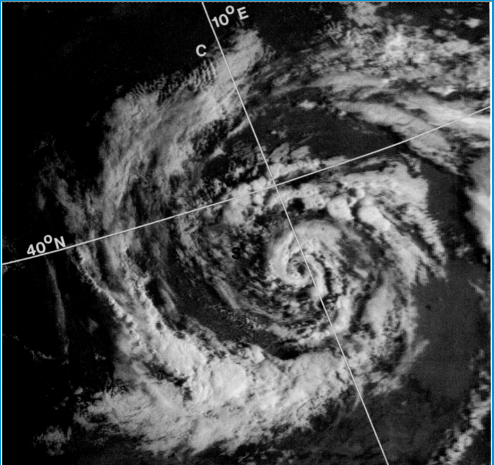

From *[Rasmussen & Zick, Tellus, 1987]*, NOAA-7 image 1983/09/28

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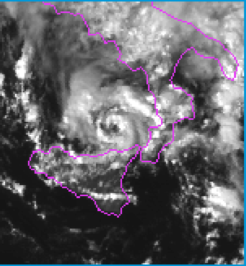

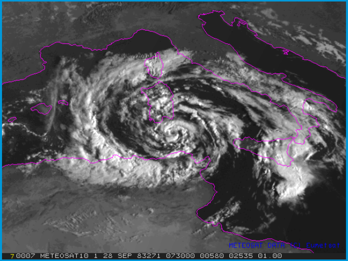

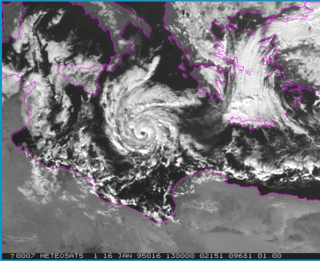

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- More details:
  `http://meteorologia.uib.eu/medicanes/`

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case description

- Medicane product from strong convection on Tunisian coast

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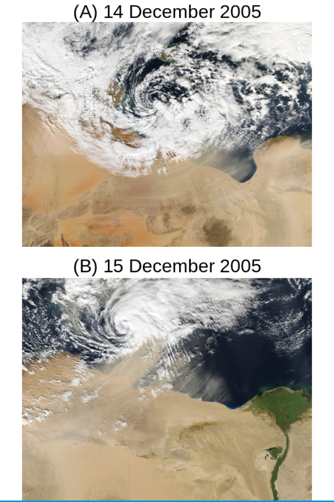

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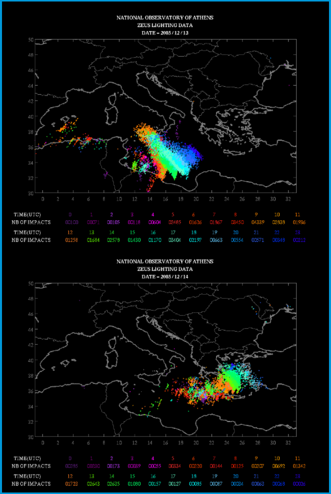

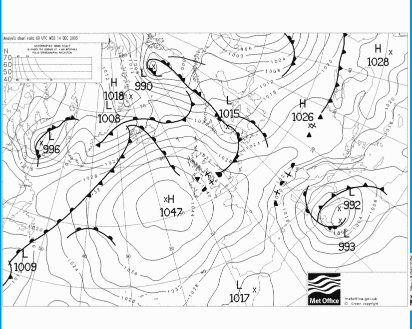

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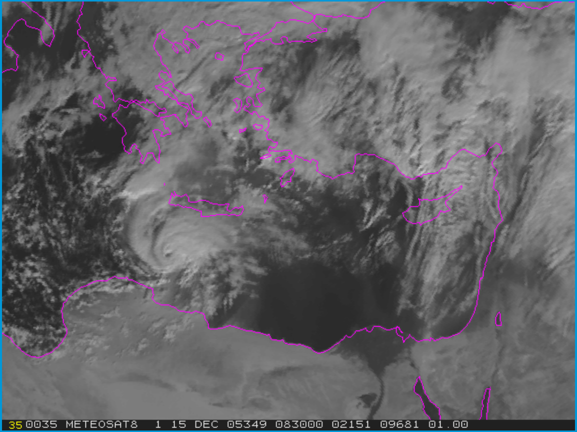

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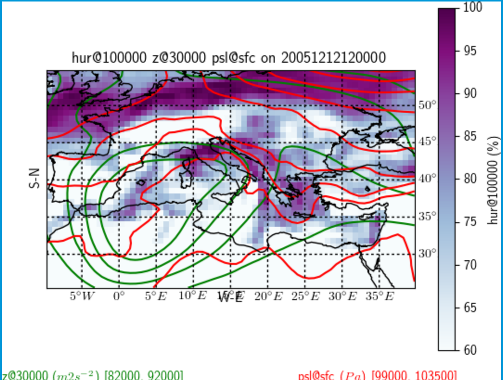
Dec. 12^{12} Upper-level through above Atlas (ERA-I)



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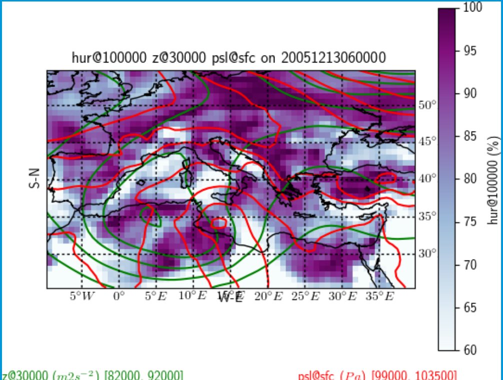
Dec. 13^{06} Formation sfc. disturb. in high humidity (ERA-I)



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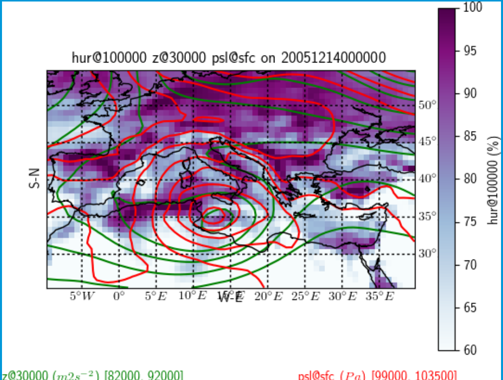
Dec. 14^{00} Deepening & interaction with through (ERA-I)



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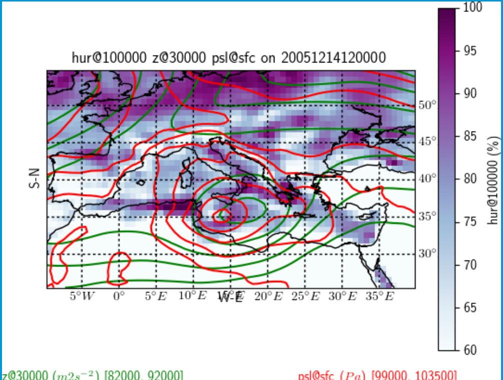
Dec. 14[12] Upper-level through overpass medicane (ERA-I)



The medicane of december 2005
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- Medicane product from strong convection on Tunisian coast
- Three clear phases: strong convection, visible eye, weakening
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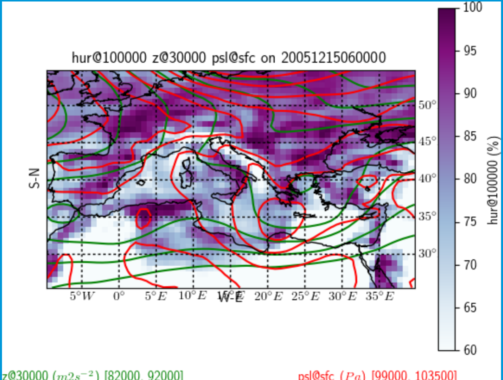
Dec. 15^{06} Weakening of both disturbances (ERA-I)



WRF's configuration & simulated medicane

WRF v3.6.1. with FF
modifications included

WRF's configuration & simulated medicane

WRF v3.6.1. with FF modifications included

- Two nested domains (10, 3.3 km)
- From Dec. 12th to 16th (30s, 10s time-step)
- 40 vert. levels, $p_{top} = 50hPa$
- ERA-I grid-nudging d01, no cloud scheme in d02
- mp: *WSM5*, sw: *Dudhia*, lw: *RRTMG*, pbl: *YSU*, cu:*KF* (after *[Miglietta et al., 2015, Atmos. Res.]*)

WRF's configuration & simulated medicane

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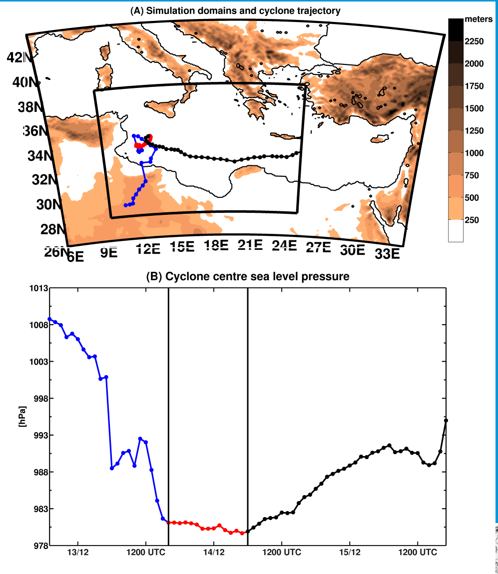
- Trajectory similar to the observed one *[Fita et al., 2007, NHESS]* , *[Claud et al., 2010, NHESS]*
- 3-phases medicane evolution



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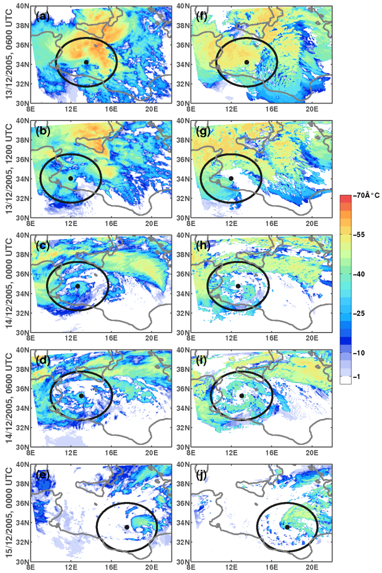
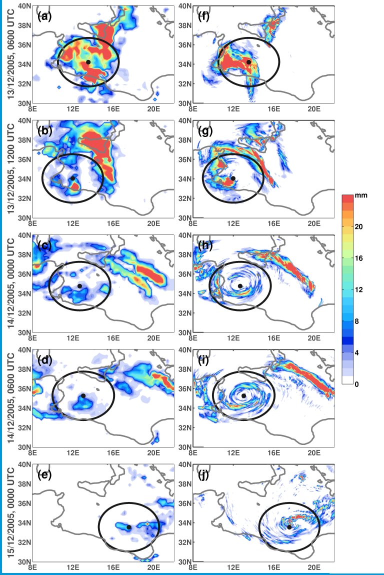
- Similar cloud structure (from SEVIRI, 10.8 μm, left col.)
- Simulation of an eye-like structure



WRF's configuration & simulated medicane

WRF v3.6.1. with FF modifications included

- Similar precipitation patterns (from TRMM estimations, *[Huffman et al., 2007,]* , *[Romilly and Gebremichael, 2011,]* left col.)
- Heavy rain at center and front. Underestimation on Dec. 13th



Warm core symmetry structure in Hart diagrams *[Hart, 2003, MWR]*

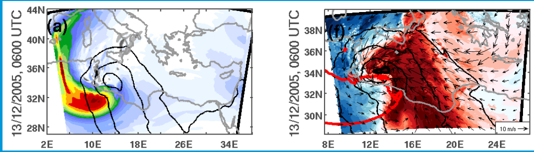
Simulation analysis
Hart diagram

Warm core symmetry structure in Hart diagrams *[Hart, 2003, MWR]*
4-areas diagram which provides cyclone characteristics along track (adapted for Mediterranean *[Chaboureau et al., 2012, QJRMS]* radius: 250 km):

- core thermal properties: cold/warm. Thermal wind within lower $-V_T^L$ $(900-600\ hPa)$ and upper $-V_T^U$ $(600-300\ hPa)$ levels.
- symmetry. Geopotential thickness between right and left side within lower troposphere B $(900-600\ hPa)$

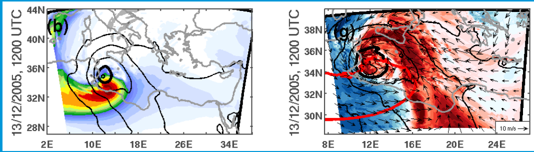
Warm core symmetry structure in Hart diagrams *[Hart, 2003, MWR]*

Phase I: transition cold core → warm cold (blue)



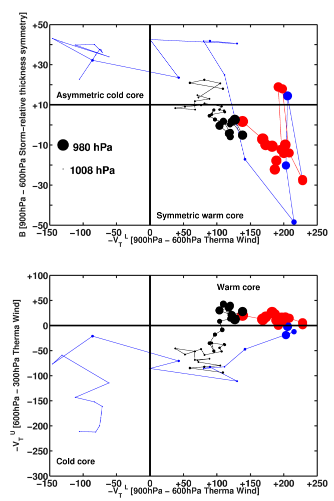
d01: PV_{300} streamer SW of cyclone center

d02: Cold (blue θ_e@850), warm (red) air mixing



d01: PV Approach to cyclone's center

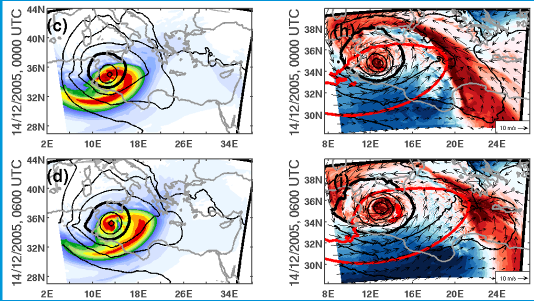
d02: S-N Front formation (16°E) with heavy rain



Simulation analysis
Hart diagram

Warm core symmetry structure in Hart diagrams *[Hart, 2003, MWR]*

Phase II: symmetric warm core (red)



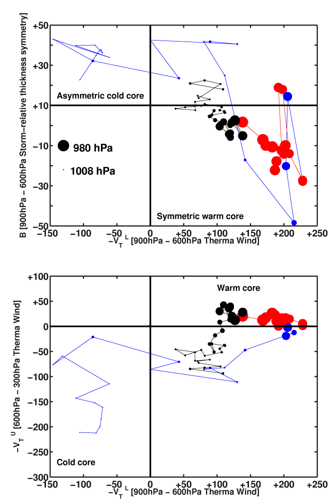
d01: PV_{300} wrapped aloft cyclone center

d01: diabatic re-inforcement of PV

d02: Cold front away from center

d02: T-bone occluded fronts *[Shapiro and Keyser, 1990,]*

d02: Wrapping of warm air at center



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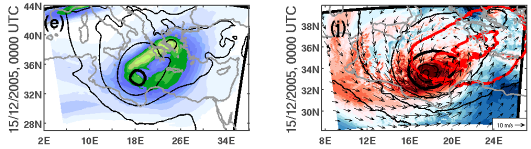
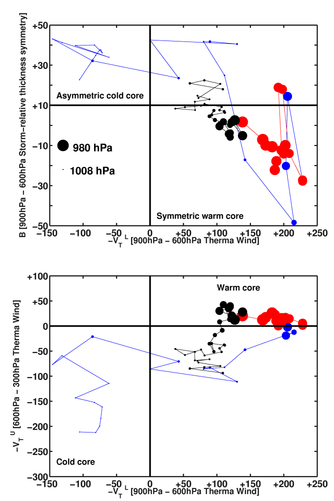
Warm core symmetry structure in Hart diagrams *[Hart, 2003, MWR]*

Phase III: weakening and movement (black)



d01: PV_{300} as cut-off, NE center

d02: No associated precipitation



Processes analysis of pressure surface tendency *[Fink et al., 2012, GRL]*

Simulation analysis
$\partial_t \mathcal{P}_{sfc}$ budget

Processes analysis of pressure surface tendency *[Fink et al., 2012, GRL]*
Decomposition of surface tendency equation:

$$\frac{\partial \mathcal{P}_{sfc}}{\partial t} = \rho_{sfc}\frac{\partial \phi_{100\ \ hPa}}{\partial t} + \ \rho_{sfc} R_d \frac{\int_{sfc}^{100\ \ hPa} \partial T_v}{\partial t} dln(\mathcal{P}) + g(\mathcal{E} - \mathcal{P}) + RES_{PTE}$$

- Dp $= \frac{\partial \mathcal{P}_{sfc}}{\partial t}$ surface pressure rate exchange
- Dϕ $= \rho_{sfc}\frac{\partial \phi_{100hPa}}{\partial t}$ changes to geopotential height up to 100 hPa
- ITT $= \rho_{sfc} R_d \frac{\int_{sfc}^{100hPa} \partial T_v}{\partial t} dln(\mathcal{P})$, changes to vertically integrated virtual temperature T_v
- EP $= g(E - P)$ changes to atmospheric water mass (E, evaporation; P, precipitation)
- RES_{PTE}: residual

Simulation analysis
$\partial_t \mathcal{P}_{sfc}$ budget

Processes analysis of pressure surface tendency *[Fink et al., 2012, GRL]*
Further decomposition of T_v term:

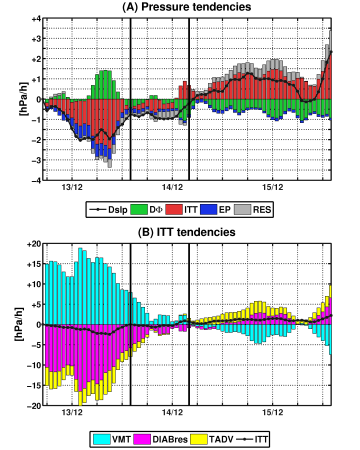
$$ITT = \rho_{sfc} R_d \int_{sfc}^{100\ hPa} -\vec{V}_h \vec{\nabla}_p T_v dln\mathcal{P} +$$
$$\rho_{sfc} R_d \int_{sfc}^{100\ hPa} \left(\frac{R_d T_v}{C_p \mathcal{P}} - \frac{\partial T_v}{\partial \mathcal{P}} \right) \omega dln\mathcal{P} + \ DIAB + \ RES_{ITT}$$

- TADV$= \rho_{sfc} R_d \int_{sfc}^{100\ hPa} -\vec{V}_h \vec{\nabla}_p T_v dln\mathcal{P}$, horizontal advection of T_V
- VMT $= \rho_{sfc} R_d \int_{sfc}^{100\ hPa} \left(\frac{R_d T_v}{C_p \mathcal{P}} - \frac{\partial T_v}{\partial \mathcal{P}} \right) \omega dln\mathcal{P}$, T_v changes due to vertical movements
- DIAB $= \rho_{sfc} R_d \int_{sfc}^{100\ hPa} \frac{T_v Q}{C_p T} d \ln p$, diabatic processes
- RES_{ITT}, residual

Processes analysis of pressure surface tendency *[Fink et al., 2012, GRL]*

$$\mathrm{Dp} = \mathrm{D}\phi + (\mathrm{TADV} + \mathrm{VMT} + \mathit{DIAB} + \mathit{RES}_{ITT}) + \mathrm{EP} + \mathit{RES}_{PTE}$$

- **Phase I:** Diabatic processes: loss of water on the column (EP), air advection (TADV), diffluent side of PV streamer between Dec. 13^{5-11} ($\mathrm{D}\phi > 0.$)
- **Phase II:** Low but negative values of terms (except, VMT)
- **Phase III:** Dominance of ITT: diabatic cooling and cold advection compensates PV interaction ($\mathrm{D}\phi$)



$\partial_t \mathcal{P}_{sfc}$ Conclusions

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- Medicane exhibits three clear phases:
    - **I: Formation** Strong convection, heavy precipitation, interaction uppper PV disturbance. cold core
    - **II Maturation:** Wrapping PV cut-off, T-bone frontal structures. warm core
    - **III Dissipation:** Weakening, end PV interaction, cold dry air advection

$\partial_t \mathcal{P}_{sfc}$ **Conclusions**

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  - **II Maturation:** Wrapping PV cut-off, T-bone frontal structures. warm core
  - **III Dissipation:** Weakening, end PV interaction, cold dry air advection
- $\partial_t \mathcal{P}_{sfc}$ analysis corroborates phases and system-environment interactions. Role of diabatic processes during formation. Dissipation due to diabatic cooling and cold-dry air advections

FF: Fita-Flaounas grid Water Budget
3D-on fly water budget

- Water budget terms on native 3D-grid at each integration model time-step

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- Decomposition from *[Jiang et al., 2008, Wea. Forecasting]* , *[Huang et al., 2013, JAS]*

$$\frac{\partial q_C}{\partial t} = -\vec{v}_h \vec{\nabla} q_C - w\frac{\partial q_C}{\partial z} + MP_C$$

$$\begin{array}{l} \text{TEND} = \frac{\partial q_C}{\partial t}\text{, water tendency} \\ \text{HFC} = -\vec{v}_h \vec{\nabla} q_C\text{, horizontal advection} \\ \text{VFC} = w\frac{\partial q_C}{\partial z}\text{, vertical advection} \\ \text{MP} = \text{SI} + \text{SO}\text{, microphysics sinks (SI) and sources (SO)} \end{array}$$

- One equation for each water specie C: vapour (v), liquid (l), rain (r), snow (s), ice (i). Species grouped as *[Huang et al., 2013, JAS]* :

  cloud, $q_c = q_l + q_i$

  precipitation, $q_p = q_r + q_s$

FF: Fita-Flaounas grid Water Budget
3D-on fly water budget

- Water budget terms on native 3D-grid at each integration model time-step
- Accumulate vertically integrated terms (mms^{-1})
- Instantaneous values at 3D grid points ($kgkg^{-1}s^{-1}$)
- Water budget consistency of terms:
  - Species advection terms directly from WRF dynamics
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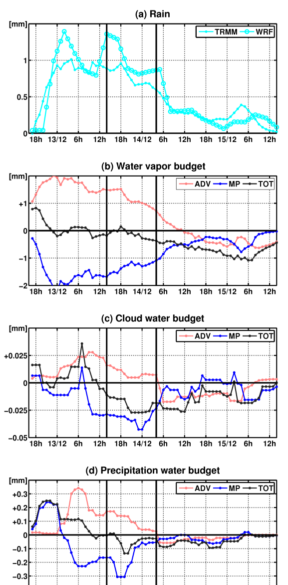
- $TEND_{\chi} = HFC_{\chi} + VFC_{\chi} + (SI_{\chi} + SO_{\chi}), \chi = [v, c, p]$

FF
Vertically integrated results (avg. rad 500 km)



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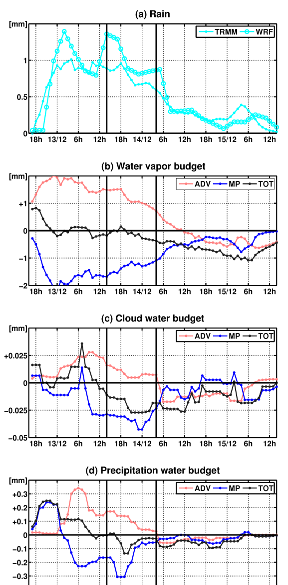

- Agreement btw. observed (TRMM) & simulated precipitation
- By definition, $\int_{sfc}^{p_{top}} ADVz_{\chi} dz \equiv 0$

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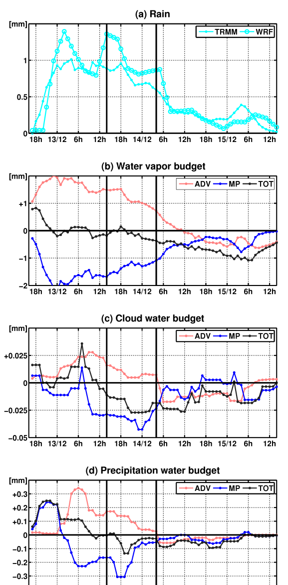

Phase I:

- equilibrium ($TOT_v \simeq 0$, black), between advection (ADV_v, red) and microphysics (MP_v, blue)
- cloud maximum (TOT_c) coincident at difluent side of PV.
- heavy precipitation fueled by MP_p and then by ADV_p

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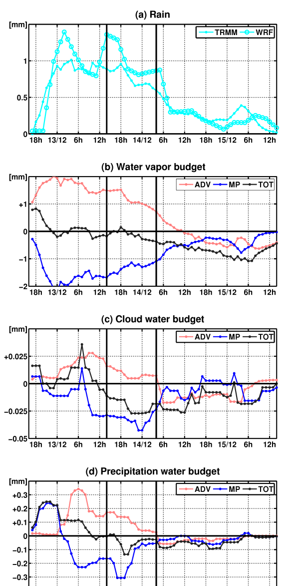
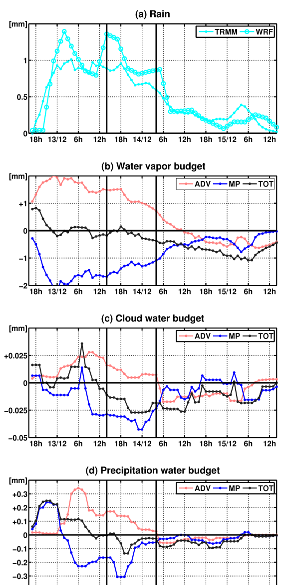
Vertically integrated results (avg. rad 500 km)



Phase II:

- still equilibrium ($TOT_v \simeq 0$), with decrease of ADV_v and MP_v
- strong cloud decrease ($TOT_c < 0.$) by microphysic processes ($MP_c < 0.$)
- strong phase interchange on Dec. 13^{18}
- **Deepest** medicane stages (Dec. 14^{6}) on decays of: precipitation, MP_v, MP_c, all cloud terms. Change of sign of cloud advection ($ADV_c < 0.$)

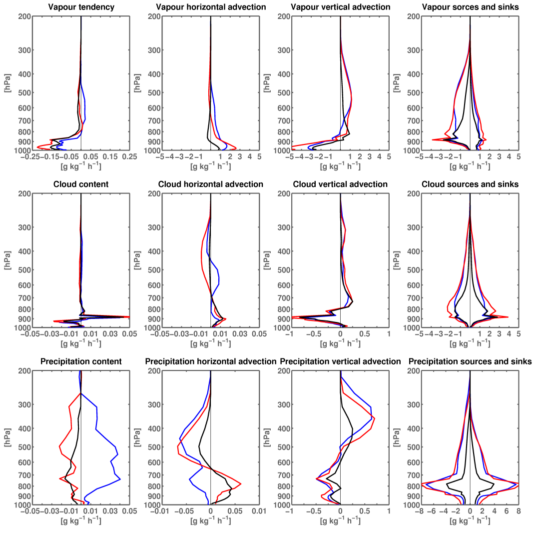
FF
Vertically integrated results (avg. rad 500 km)



Phase III:

- Advection of water vapor (ADV_v, red) stops compensating loss by microphysics (MP_v) and increases vapour loss by dry advections ($ADV_v < 0.$)
- Advection of dry air ($ADV_c < 0.$) dominates over weak microphisics production ($MP_c \geq 0.$) of clouds
- No precipitation terms at this phase ($TOT_p \simeq ADV_p \simeq MP_p \simeq 0.$)

FF
Instantaneous vertical values (avg. rad 500 km)



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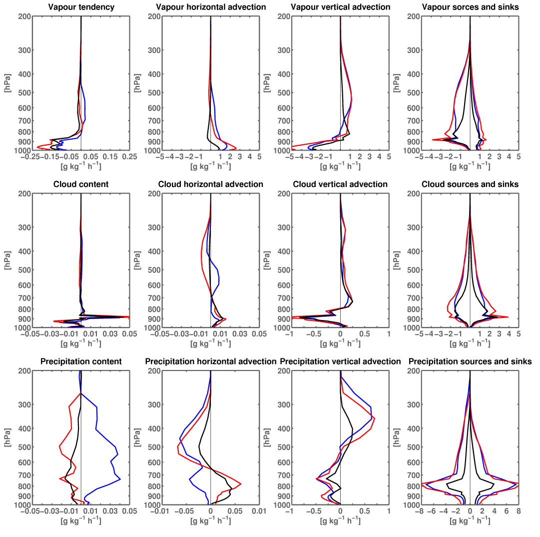

Phase I:

q_v Convection:

$$TOT_v, ADVz_v \begin{cases} < 0 \; 1000 - 800 \; hPa \\ > 0 \; 800 - 500 \; hPa \end{cases}$$

Mid. atmos. $TOT_v > 0$, also due to $ADVh_v > 0$ compensated by $MP_v < 0$.

Mid. atmos. $ADVh_c > 0$

Overall column precipitation:

$TOT_p > 0$,

divergence $ADVh_p < 0$,

upper atmos. vert. adv. $ADVz_p^{p<500} > 0$.

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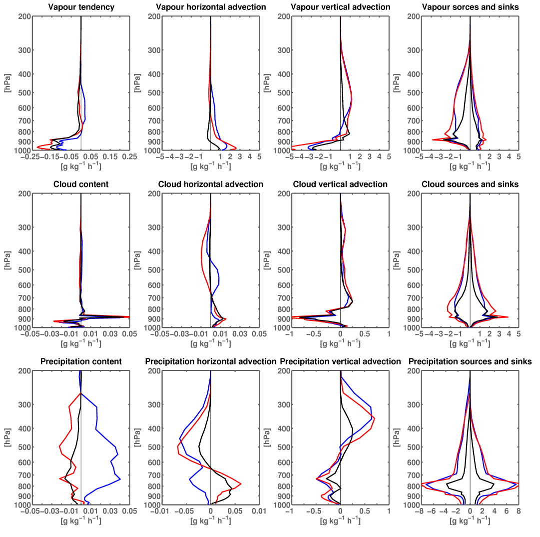
Instantaneous vertical values (avg. rad 500 km)



Phase II:

Strong winds ($ADVh_v >> 0$), compensated by:

$ADVz_v << 0$, $MP_v^{p>950} << 0$

Cloud regime changes $ADVh_c^{p<700} < 0$

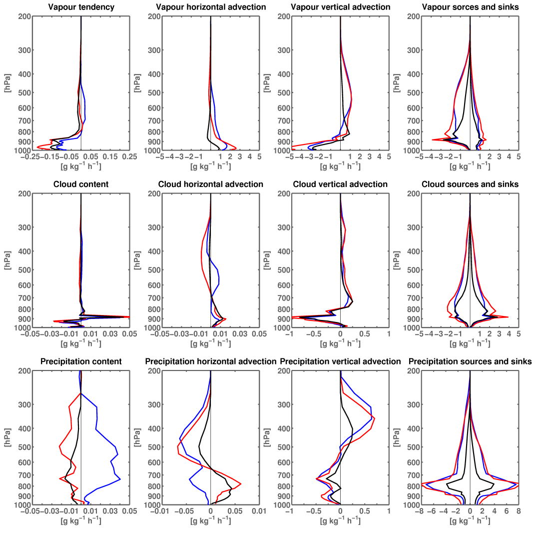
Low water vapour to cloud formation:

$MP_v^{p>950} \rightarrow MP_c^{p>950}$

Precip. regime changes $TOT_p|_I > 0 \rightarrow |_{II} < 0$ &

Low lev. $ADVh_p > 0$

FF
Instantaneous vertical values (avg. rad 500 km)



Phase III:
Weakening from phase II or nullifying of all the terms

Conclusions

- FF-water budget new deep insight of the moist processes in atmospheric processes:
    - Equilibrium between moist advection and microphysics processes
    - Fueling of heavy precipitation from microphysics and/or horizontal advections
    - Mature state without high terms
    - Advection of vapour and clouds responsible for dissipation
    - Absence of precipitation terms during dissipation
    - Clear signature of strong convection at initial stages
    - Compensation of strong horizontal advection by vertical adv. and microphysics processes at mature stage
    - Vertical regime changes of terms along medicane evolution

Conclusions

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  - Vertical regime changes of terms along medicane evolution
- FF promises new valuable insights, but more reflexion is needed to maximize its outcomes.

Further work

- Concrete role of surface fluxes in the budget

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- Concrete role of surface fluxes in the budget
- Perform a climatology on extreme cyclone cases with FF
- Obtain a full budget including energy and PV... (not too soon)
- Some open questions
  - Did we probe the existence of a **tropical transition** for this case?
  - A case without **strong convection** on its mature state?
  - **Frontal occlusion** as another strengthening mechanism?

… y ya en el CIMA

- Desarrollo de modelos: colaboraciones con el IPSL, Francia:
  - Acoplamiento **DYNAMICO** - **ORCHIDEE**
  - Acoplamiento físicas de **WRF** a **DYNAMICO**
  - Desarrollo de una versión de área limitada del **DYNAMICO**
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- **DYNAMICO**: `http://forge.ipsl.jussieu.fr/dynamico`

  - Nueva din. atmos. en icosahedro
  - Formul. Hamiltoniana
  - Integración temporal Runge-Kutta
  - Usable en atmósferas planetárias
  - Atmósfera profunda y todo Coriolis
  - Altamente escalable (20,000 procs)

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- **MORCE**: https://sourcesup.renater.fr/wiki/morcemed
  - WRF: modelo atmosférico

    http://www.mmm.ucar.edu/wrf/users/
  - ORCHIDEE: modelo de suelo, ríos incorporados

    https://forge.ipsl.jussieu.fr/orchidee/wiki/DevelopmentActivities
  - NEMO: modelo oceánico

    http://www.nemo-ocean.eu/
  - Chimère: modelo química troposférica

    http://www.lmd.polytechnique.fr/chimere/
  - OASIS: acoplador de modelos

    https://verc.enes.org/models/software-tools/oasis

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- **WRFmeas**: Desarrollo módulos para WRF 'observaciones sintéticas' (aplicado en Argentina para la campaña **RELAMPAGO**)

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Gracias por su atención !!