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Dynamical drivers of Medicane Ianos predictability

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Outline

- Description of regional MetUM simulations
- Simulation of the Medicane and preceding convection
- Features on the flow at upper levels.
    - Role of diabatic processes with the Semi-Geostrophic inversion tool.
    - Baroclinic upper level forced ascent with the Quasi-Geostrophic omega equation.
- Conclusions.

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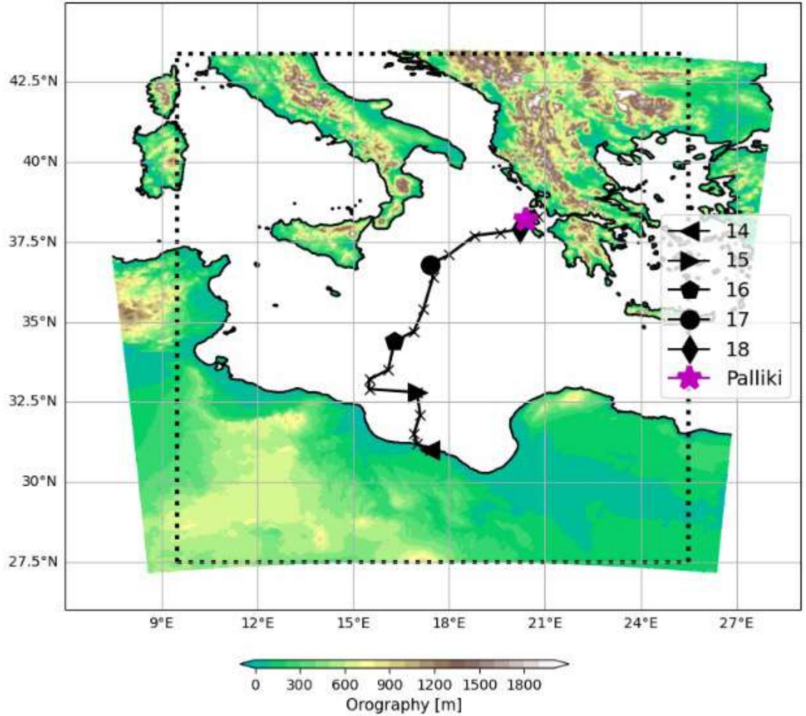
Medicane Ianos model protocol

Exploring the predictability of Medicane Ianos across different initialization times and SST perturbations. *Following Ianos model intercomparison protocol (Florian's talk)*



MetUM Simulations:
2.2km RAL2M, L90 40km top.
Driven by IFS analysis (**IFS-AN**)
Initialized at **00Z 14**, **12Z 14**, **00Z 15**, **12Z 15**, **00Z 16**
Additional simulations: **SST perturbed +2K** and **–2K**

[Left]: Model domain and orography.
Black line Ianos trajectory in IFS-Analysis

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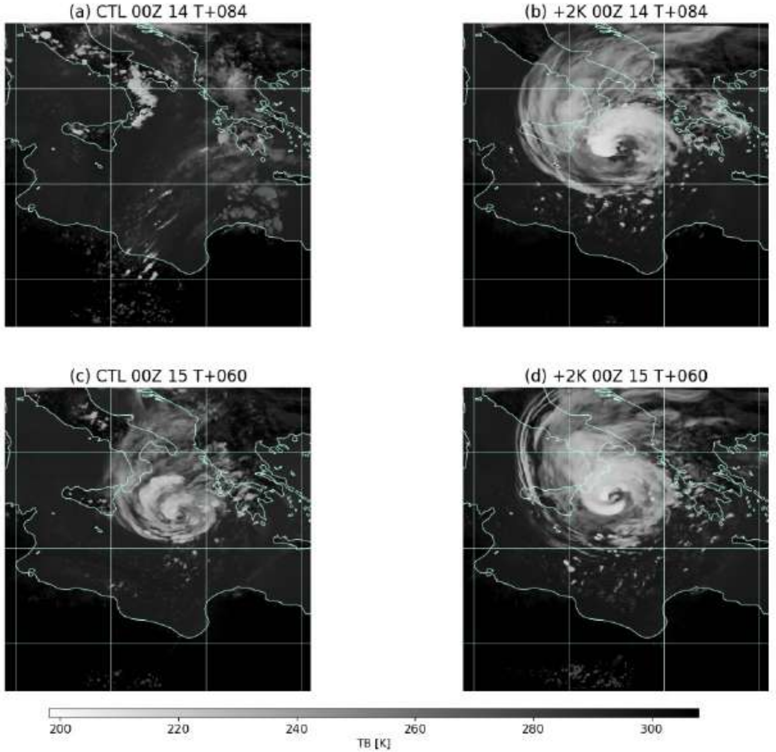
Satellite imagery

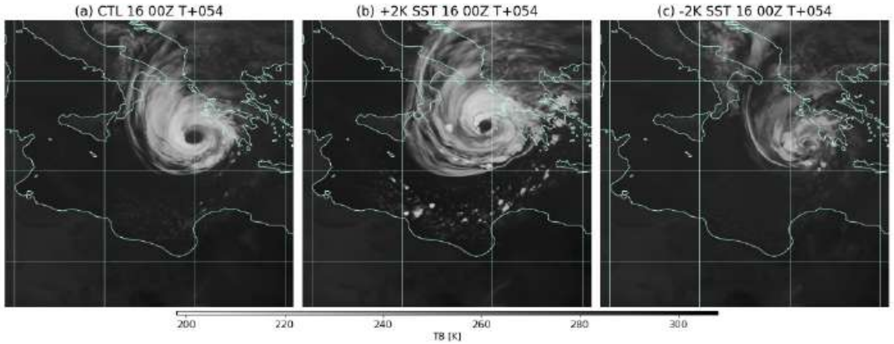
Brightness Temperature (BT) at 10.8μm from Satellite Imagery (RRTOV-based)

Simulations with 2K warmer SSTs predict Ianos one day ahead (right Fig.), but it is quite intense and scary!

Ianos develops a tropical-like cloud-less eye and spiralling branches (left Fig.), Even on the latest simulation with -2K SST

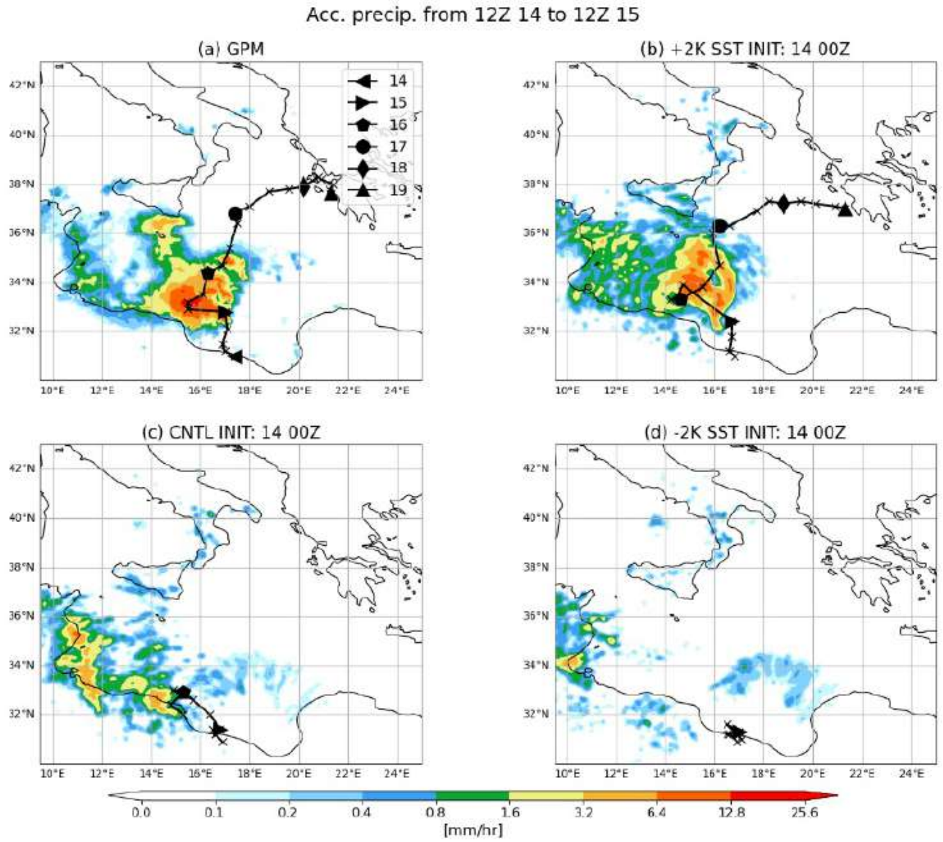


[Top] BT at ***12Z 17 valid time*** for control (left) and +2K SST simulations (right) init. at 00Z 14 (top) and at 00Z 15 (bottom)



[Top] BT at ***06Z 18 valid time*** for (a) control (b) +2K SST (c) -2K SST simulations init. at 00Z 16.

Preceding convective precipitation



Daily acc. "Preceding" precipitation bef. cyclogenesis (12Z 14 to 12Z 16) downstream the cyclone trajectory. In GPM (a) and simulation +2K SST (b).

Misplaced in simulation with control SST (c), and absent in -2K SST (d).

Parallelisms with preconditioning events in cyclone transitions?

[Left]: ***Daily accumulated*** precipitation from ***12Z 14 to 12Z 15***. (a) GPM (b-d) simulations init at 00Z 14. Black line Ianos Trajectory (IFS-An. for GPM)

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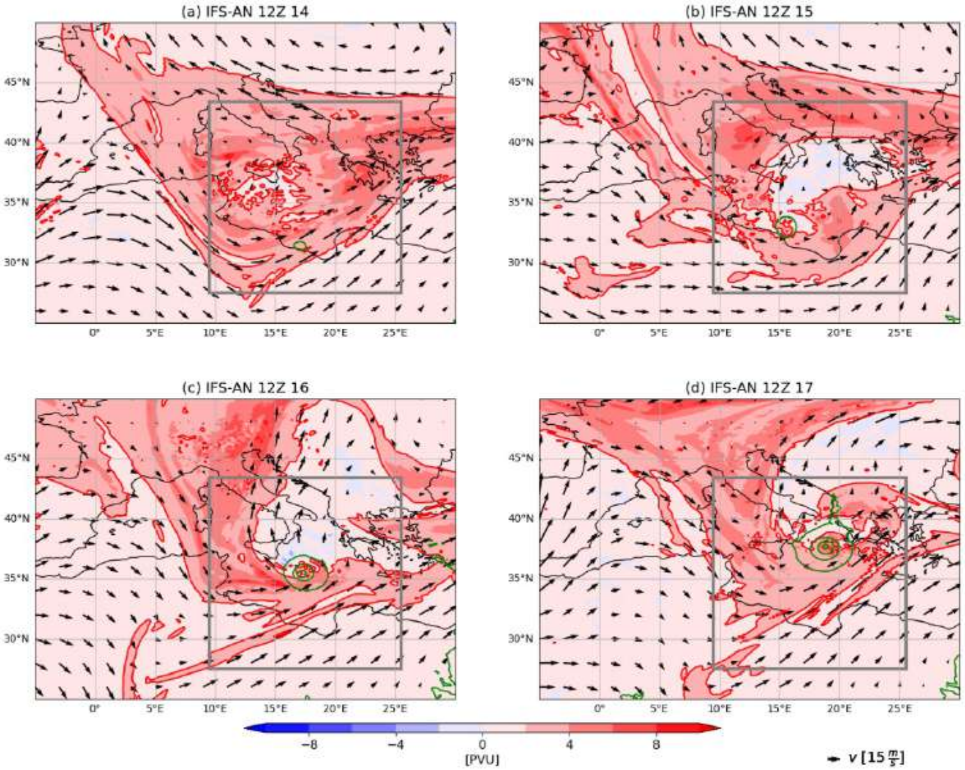
Upper levels: 250-200hPa average



[Top] IFS analysis **MSLP** (green contours) **PV** (coloured) and **horizontal wind** (vectors) in IFS Analysis

At 12Z 14 (a): PV trough with small pockets of tropospheric PV

At 12Z 15 (b): PV pockets coalesce into a low-PV bubble

At 12Z 16 (c): Cyclone intensifies, strong anti-cyclonic southerlies on its western side.

At 12Z 17 (d): The southward PV streamer cyclonically wraps the now tropical-like cyclone. *"Canonical picture of baroclinic instability".*

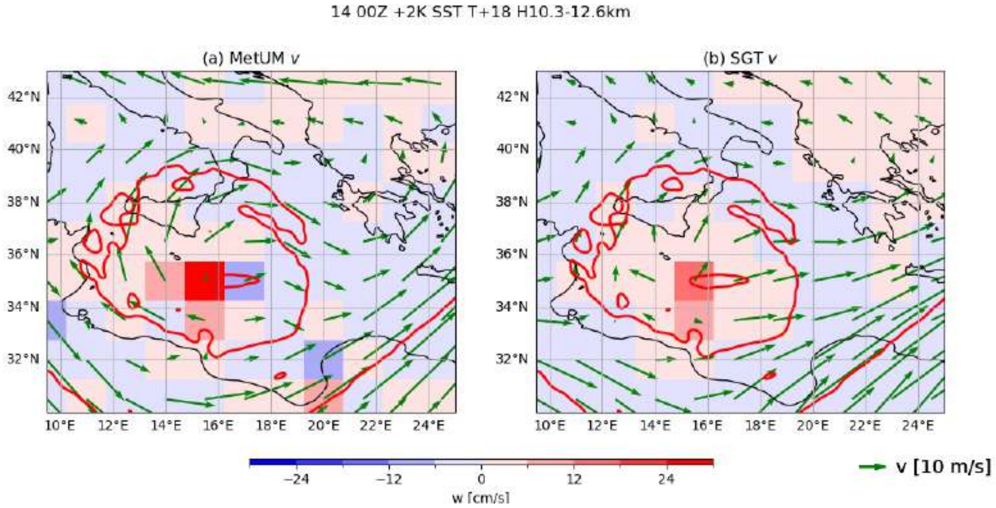
Does the preceding convection create the low-PV bubble?

Does the low-PV bubble create baroclinicity?

Semi-Geostrophic inverted fields

The SG inversion tool derives the Semi-Geostrophic balanced flow from MetUM fields. It also derives the ageostrophic flow to produced by diabatic heating within the model parametrizations (*see extra-slide with maths!*)

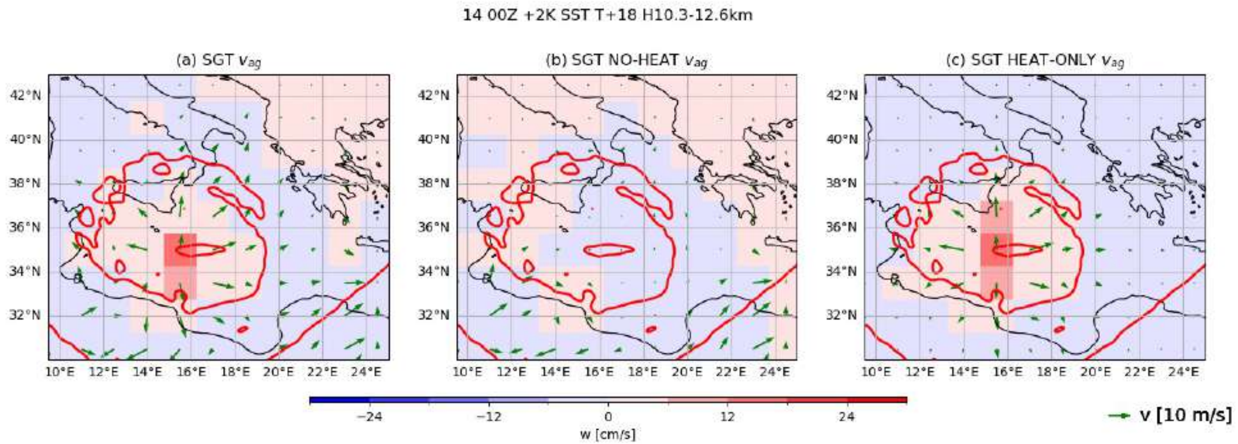
Case study: A strong convective event at T+18 on the +2K SST simulation init. at 00Z 14



The balanced flow from the Semi-Geostrophic inversion tool is equivalent to MetUM (spectrally filtered and regraded). But the SG balanced flow is more divergent than anticyclonic inside the low-PV bubble.

[Top] Upper level **w**, **horizontal wind**, and **PV** at 2PVU for (a) MetUM fields spectrally filtered (0.32 deg.) and re-gridded to 1.5 deg. (b) Winds from SGT inversion tool..

MetUM ageostrophic inverted wind



[Top] **Agestrophic horizontal wind** , **vertical wind** (colour) and MetUM **PV** at 2PVU (red cont.).

(a) Full SG solution.

(b) Without the diabatic forcing.

(c) Only with the diabatic forcing.

The ageostrophic SGT inverted flow inside the low PV bubble is purely divergent and diabatically driven

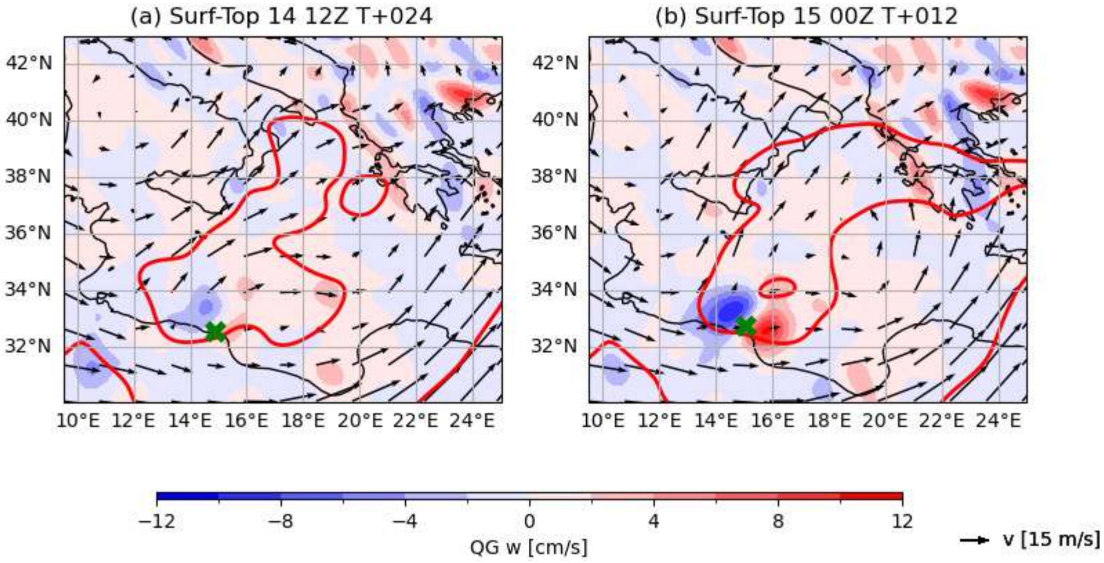
The strong southerlies around the low PV bubble come from the geostrophic adjustment.

Divergent outflow occurs during the preceding precipitation and during Ianos intensification (extra-slide).

Quasi-Geostrophic ω eq.

The QG omega equation determines the baroclinic ascent forced by the differential absolute vorticity advection (1st term) and Laplacian of thermal advection (2nd term).

$$\left(\nabla^2 + \frac{f_0^2}{\sigma}\frac{\partial^2}{\partial p^2}\right)\omega = \frac{f_0}{\sigma}\frac{\partial}{\partial p}\left[v_g \cdot \nabla(\zeta_g + f)\right] + \frac{1}{\sigma}\nabla^2\left[v_g \cdot \nabla\left(-\frac{\partial \phi}{\partial p}\right)\right]$$



[Top] QG inverted **w** and **horiz. wind** forced by all levels.
Control forecast (a) T+24 init at 12Z 14 (b) T+12 init. at 00Z 15.

Integrating the rhs forcing on different levels for ascent at 700hPa:

- Good forecast (T+12 init. at 00Z 15) shows a w dipole around curvature (b), much weaker (a) in the bad forecast (T+24 init. at 12Z 14).

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Conclusions

- Simulations of Medicane Ianos were done at 2.2km resolution for different initialization times + including experiments with +2K and -2K SST
- All simulations with +2K SST, develops Medicane Ianos, but those with control SST only init. at 00Z 15th or later.
- Preceding rainfall event only simulated in simulations with +2K SST.
- A tropospheric low-PV bubble emerges before Ianos cyclogenesis.
- The low-PV bubble is formed by diabatically induced divergent outflow, and the southerlies from the geostrophic adjustment.
- Baroclinic ascent is problably forced by the geostrophic vorticity advection term in the QG ω equation.

Diabatic outflow ➡ ***Low-PV bubble*** ➡ ***Geostrophic vorticity*** ➡ ***Baroclinic ascent*** ➡ ***PV Tower***

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Thanks for your attention!

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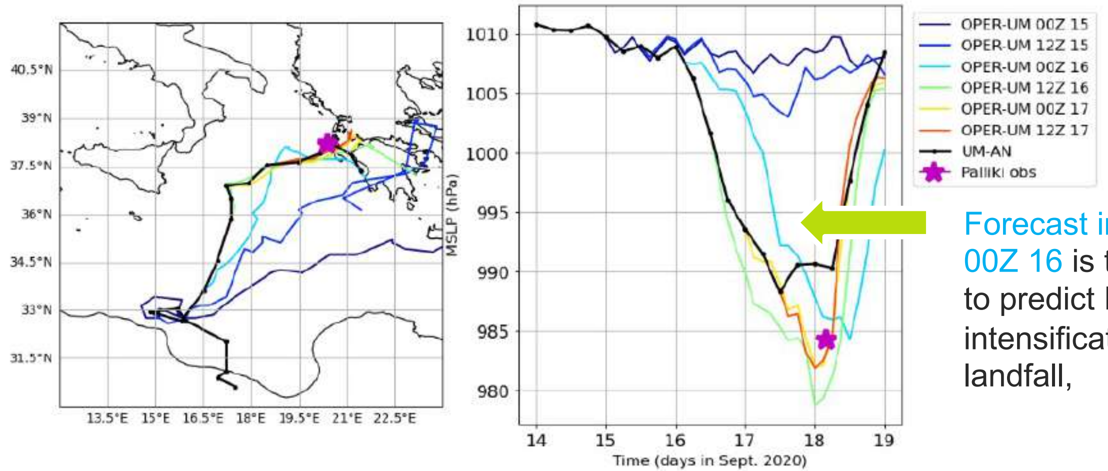
Ianos in the MetOffice Global oper.

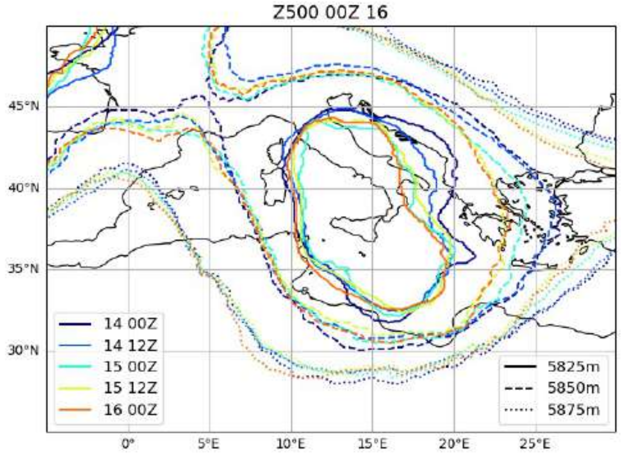
Global model on September 2020: N1280 (12 km), L70

Ianos intensification and landfall are only well predicted two days ahead (left figure). But cut-off low is well simulated at Ianos genesis time (right figure).



Forecast init. at 00Z 16 is the first to predict Ianos intensification and landfall,

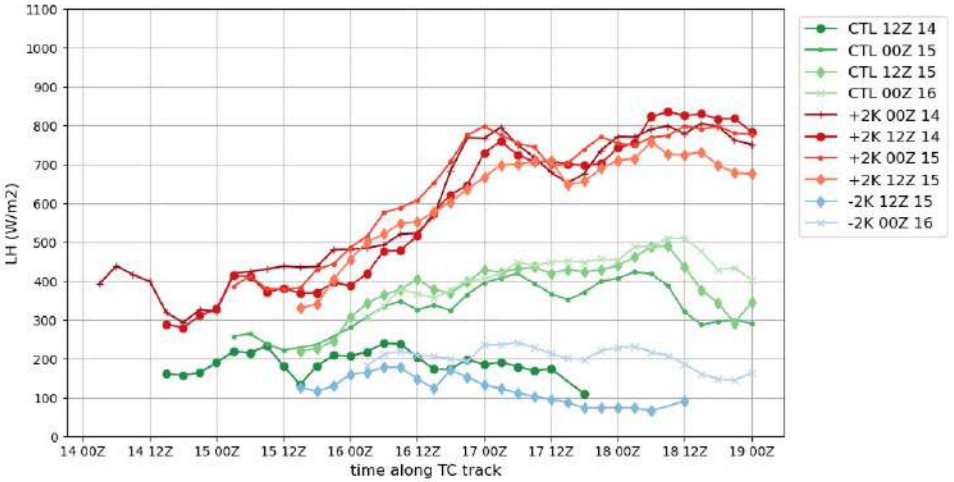
[Top] Track (left) and intensity (right)



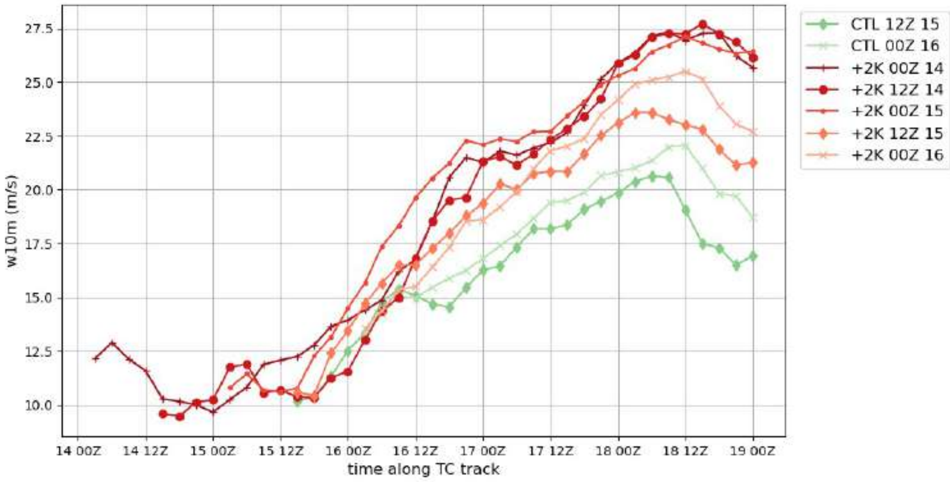
[Top] Geopotential at 500hPa *NOTE: different colours to left Figure!*

Surface Fluxes and 10m winds

- Simulations with +2K SST reach LH above 800 W/m^2 and surface winds peak at 27.5 m/s!
- LH clustered around the same SST experiments during Ianos intensification.
- Simulations with -2K SST show LH below 200 W/m^2 bef. 00Z 16.



[Top]: Timeseries of Latent heat fluxes along the cyclone, averaged over a 3x3 box



[Top]: Same as left but for 10m wind speed

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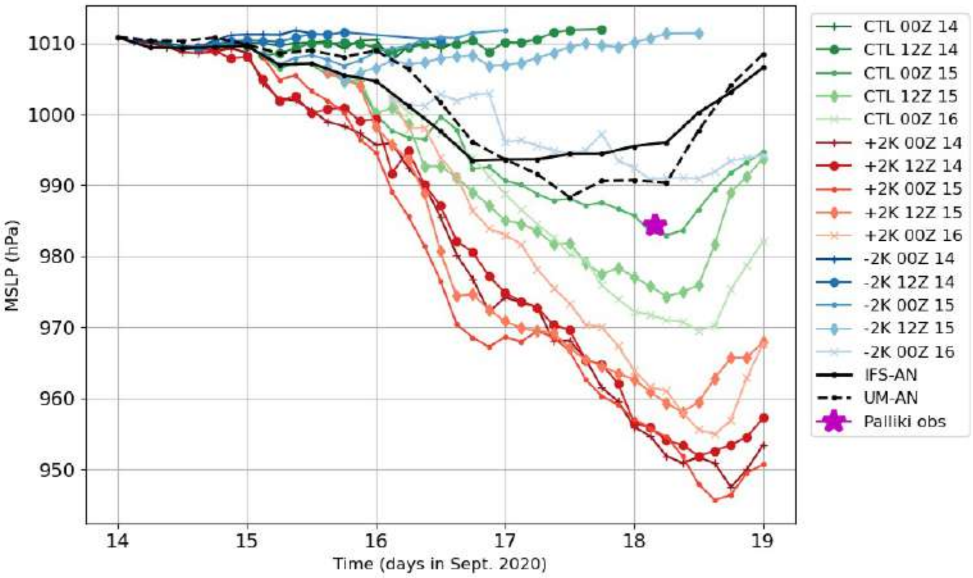
Medicane Ianos intensity



[Top]: MSLP minimum. IFS-Analysis (solid black) UM-AN (dashed black), simulations (green control, red for +2K SST and blue for -2K SST) and observed value at Palliki Station (North Kefalonia, Greece) in purple star.

Ianos weakly intensifies on the 15th, deeper intensification on the 16th. Decays on the 18th.

Analyses (IFS and UM) weaker than obs. at Palliki station (Greece).

Only these simulations develop a Medicane Ianos:

- All +2K SST. But too intense (down to 950hPa!)
- Only Control initialized at and after *00Z 15*. Intensity increases with later init. time
- Last -2K SST (init. *00Z 16*) but weaker

Simulations have a later peak (slower cyclone)

Semi-Geotriptic (SGT) inversion tool

The SGT inverts the MetUM fields into the balanced flow under the hydrostatic and the geostrophic momentum approximations. Accurate on scales larger than the Rossby radius of deformation.
We apply SGT in the upper levels Semi-Geotriptic ~ Semi-Geostrophic.

The SG system is described in the eq. below, where the source terms on the rhs are the linear combination of "geostrophic forcing" and "diabatic and friction forcing". Where *M* are the Momentum sources (ignored here) and S_θ the heat sources. *M=0 here*

$$\mathbf{Q}\begin{bmatrix} u-u_g \\ v-v_g \\ w \end{bmatrix} + \frac{\partial}{\partial t}(\nabla\Phi) = \begin{bmatrix} -f\mathbf{u}_g\cdot\nabla v_g + fM2 \\ f\mathbf{u}_g\cdot\nabla u_g - fM1 \\ -\frac{g}{\theta_0}\mathbf{u}_g\cdot\nabla\theta + \frac{g}{\theta}S_\theta \end{bmatrix}$$

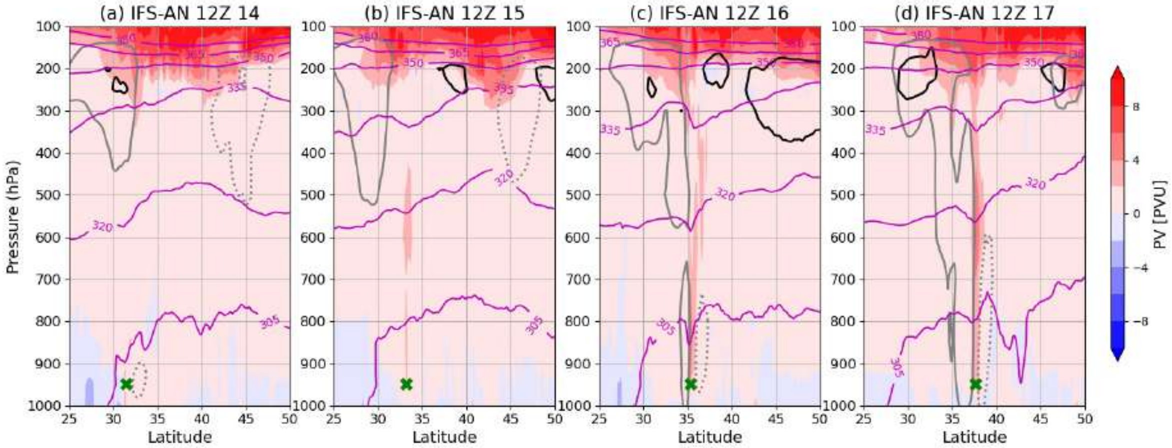
The SGT allows switch on or off any of the two source terms on the rhs: the "geostrophic forcing" or the "diabatic heating".

$$\mathbf{Q} = \begin{bmatrix} f^2 + f\frac{\partial v_g}{\partial x} & f\frac{\partial v_g}{\partial y} & f\frac{\partial v_g}{\partial z} \\ -f\frac{\partial u_g}{\partial x} & f^2 - f\frac{\partial u_g}{\partial y} & -f\frac{\partial u_g}{\partial z} \\ -\frac{g}{\theta_0}\frac{\partial\theta}{\partial x} & -\frac{g}{\theta_0}\frac{\partial\theta}{\partial y} & -\frac{g}{\theta_0}\frac{\partial\theta}{\partial z} \end{bmatrix}$$

MetUM fields are filtered to a 0.32 deg with a spectral cosine transformation and then interpolated to a 1.5x1.5 grid.

Upper levels IFS Analysis (2)

Latitudinal cross sections of PV and winds



[Left]: IFS analysis PV (colours), meridional mean (black contours, solid: +ve, dotted: -ve) **zonal wind** (grey contours solid: +ve, dotted: -ve), **θ** (magenta contours) and green **'x'** showing **Ianos' location**

At 12Z 14 (a): PV trough with westerlies (easterlies) on its southern (northern) side.

At 12Z 15 (b): Tropopause lift above the 350K isentrope inside the PV trough.

At 12Z 16 (c): cyclone produces +ve PV at mid-levels and –ve PV with southerlies aloft. PV intrusion on the southward side.

At 12Z 17 (d): PV tower wrapped by cyclonic winds.

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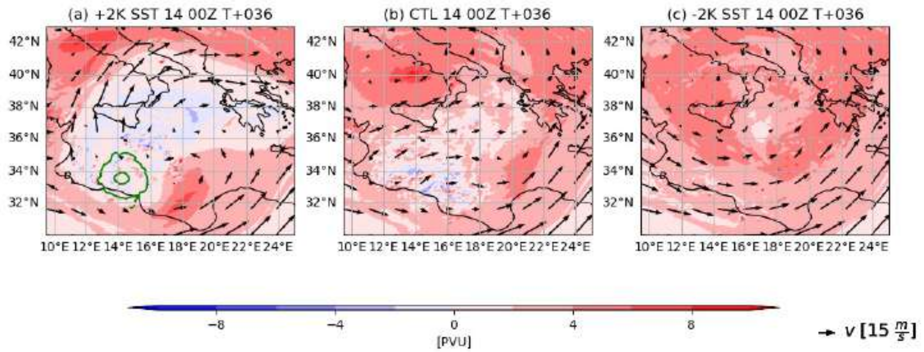
Upper levels MetUM sim.

MetUM simulations at the time of Ianos genesis ***12Z 15*** :

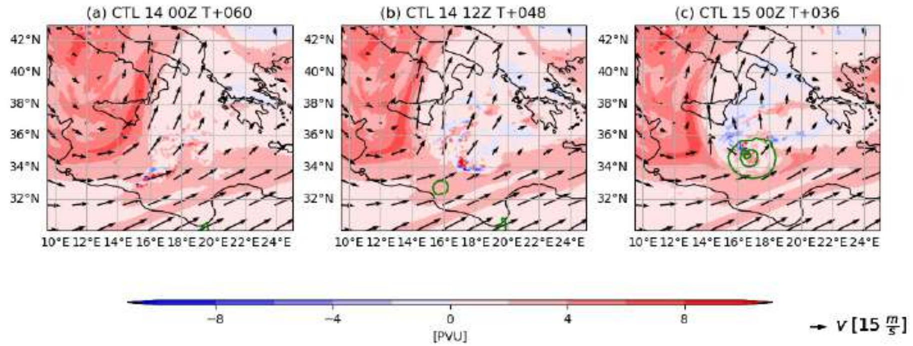


2K Warmer SST: Wider low-PV bubble and strong anticyclonic winds on its west side.

Control SST: Bubble forming but not coalesced yet, weak anticyclonic winds near Libyan coast.

Cooler SST: Marginal low-PV bubble with the PV trough cyclonic wind around it.

Control simulations, one day later at ***12Z 16***, Ianos max. intensification rate

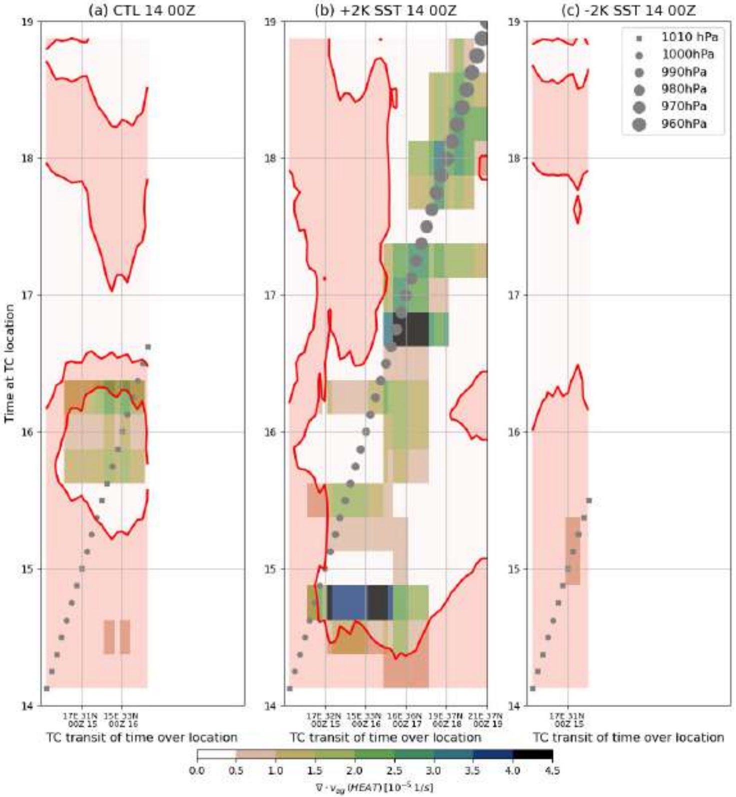


Simulations unable to capture Ianos intensification (a-b) produce a low-PV bubble but ...

- *There is no intensifying cyclone anchored on its southern side, it lags upstream.*
- *The southerly flow doesn’t have an anticyclonic bent like IFS-AN*

Bubble and diabatic outflow Hovmollers

The evolution of the diabatic outflow and low-PV bubble before and after cyclone transit … over all the locations where it travels through.

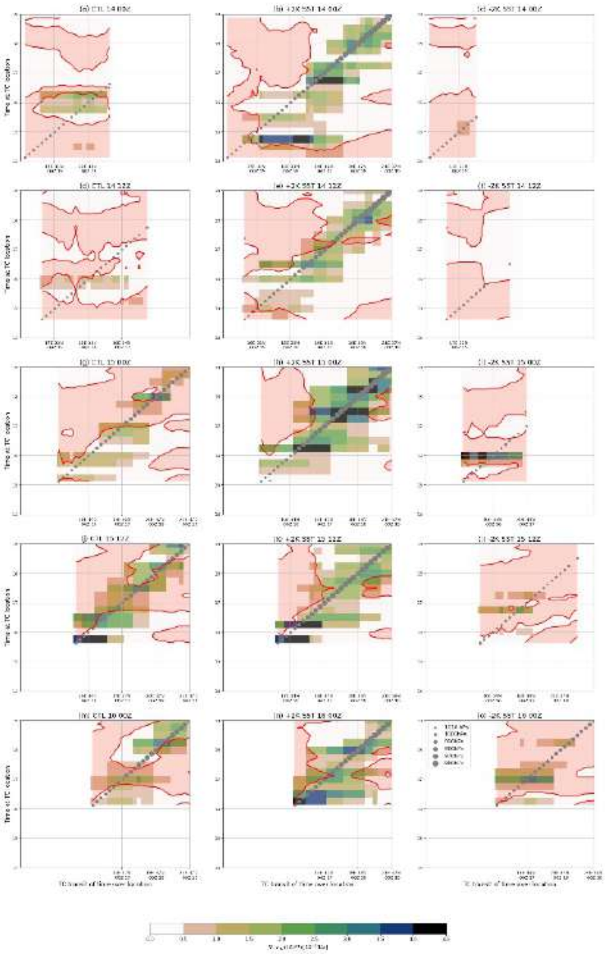


Simulations initialised at 00Z 14:

- **Control SST:**
  - Low-PV bubble and diabatic outflow but late (12Z 15) and not clearly ahead of the cyclone.
  - Weak cyclone dies at 12Z 16 after it lags behind the PV trough
- **+2K SST:**
  - Early emergence of the low-PV bubble and diabatic outflow at 18Z 14 (shown in previous slides)
  - Cyclone intensification once inside the bubble
  - Diabatic outflow along the TC intensification from the 16th
- **-2K SST:**
  - No low-PV bubble nor diabatic divergence.

[Left] Hovmöller of validation time across all TC locations in the simulation for divergence (colour), PV above 2PVU (shaded red) and MSLP intensity (grey dots). Averaged over a 3x3 box.

Hovmollers, all simulations



- **Control SST:**
  - ***Unable to simulate Ianos intensification:*** It moves in and out of the low-PV bubble, isolated and weak diabatic outflow around 00Z 16 (a,d panels).
  - ***Able (after 00Z 15):*** Ianos travels inside the low-PV bubble, diabatic outflow from late 15 onwards (g,j,m).
- **+2K SST:**
  - Stronger Ianos (e) ≠ Stronger diabatic outflow (h)
  - Outflow too strong and "masking" the PV streamer cyclonic wrapping before 00Z 17, unlike in the ones with control SST (g,j)
- **-2K SST:**
  - ***Unable to simulate Ianos intensification:*** Absent or isolated diabatic outflow events (c,f,I,k)
  - ***Able (after 00Z 16):*** Sustained diabatic outflow during the 17th (o) but not strong to produce a low-PV bubble.

[Left] Same Hovmöller figure as previous slides but for simulation with control SST (left column) +2K SST (middle column) and -2K SST (right column), earlier initialisation dates are at the top and later ones at the bottom.

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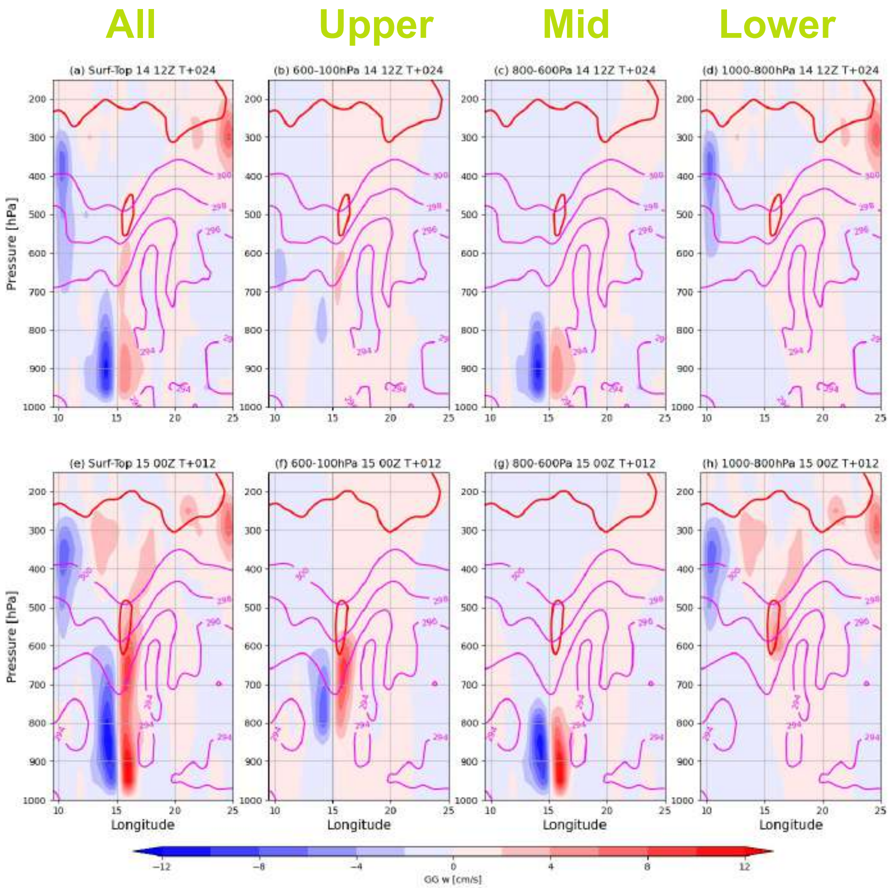
Quasi-Geostrophic (2)



Cross section of the QG w, forced by different levels-sets at 12Z 15 for bad (top) and good (bottom) forecasts:

- Bad forecast triggers low-level ascent forced by the mid-levels (a,c)
- Good forecast ascent extends further up (e) as it is forced by the upper levels (f) besides the mid levels (g)
- Mid-level forcing produces stronger ascent in the low-levels on the good forecast (g)

Ascent triggered by upper levels (geostrophic vorticity advection term), then feedbacks from mid and lower levels.

[Left] Cross section of **QG w**, **θ**, **PV** at 2 PVU. Forced by different levels (columns) for (top) bad forecast at T+24 init at 12Z 14 (bottom) good forecast at T+12 init at 00Z 15.