# Development Pathway of an Alpine Lee Cyclone: Dependence on Model Resolution

Ron McTaggart-Cowan[1], Thomas J. Galarneau[2] Jr., Lance F. Bosart[2] and Jason A. Milbrandt[1]

[1] Environment Canada, Montreal, QC, Canada
[2] State University of New York at Albany, Albany, NY, USA

# Outline

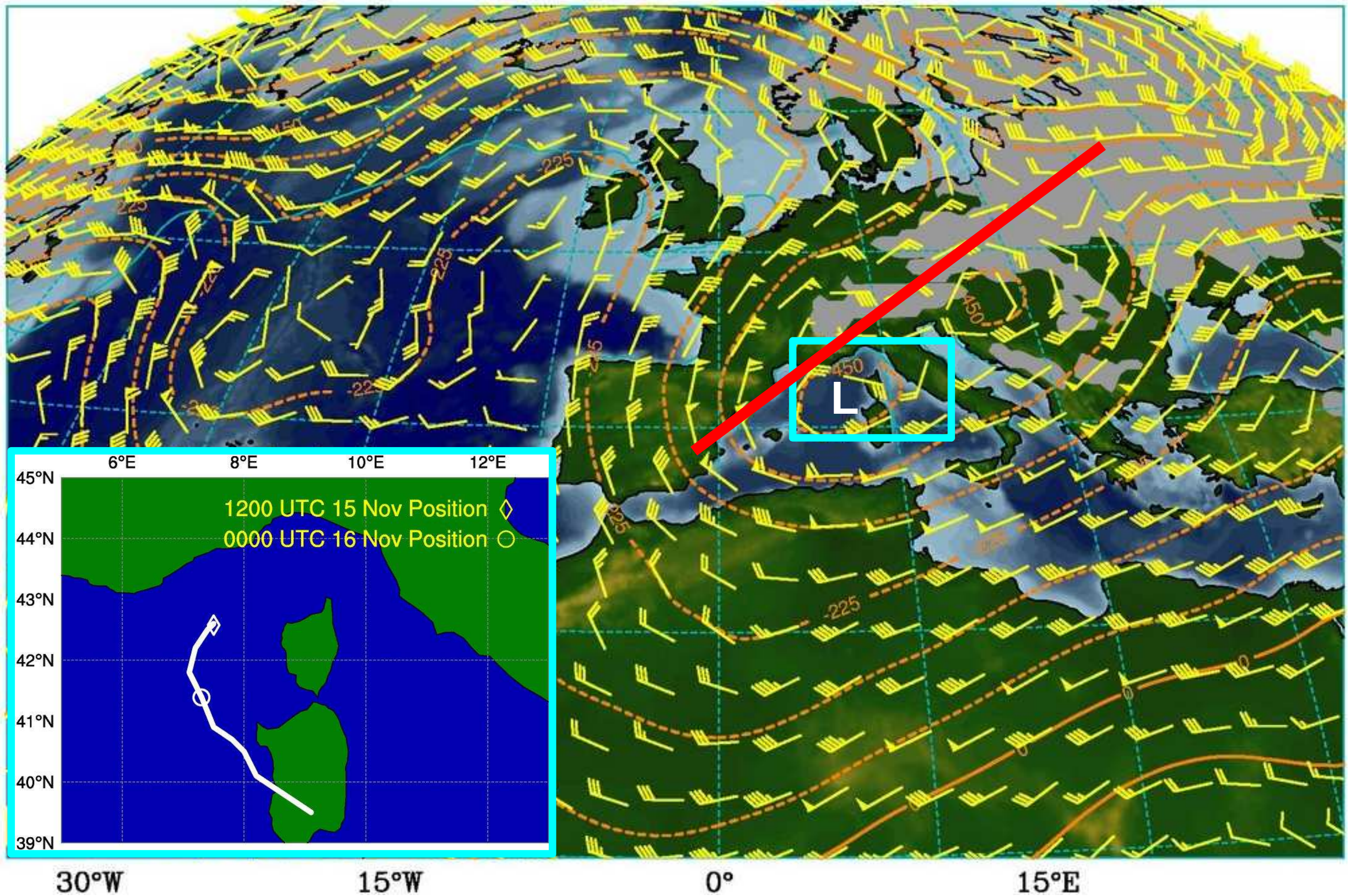
- Development of the 15 Nov 2007 Alpine lee cyclone during MAP D-PHASE
  - Tropical transition (TT) of the vortex
  - Sensitivity to orographic modification
- Effects of model grid spacing in the operational triply-nested system (33 km, 15 km, 2.5 km)
  - Evolution of storm structure
  - Modifications to development energetics

Insufficient resolution of the Alpine barrier leads to a baroclinic mode of development without TT: the right answer (a cyclone), but for the wrong reason. The convection-permitting resolution is required to correctly predict TT and a moist-diabatic mode of development.

# Synoptic Setup

- Strong northerly flow across the Alps on 15 November during trough / front passage and embedded coherent tropopause disturbance (CTD)

GFS Analysis valid 0000 UTC 16 11 2007

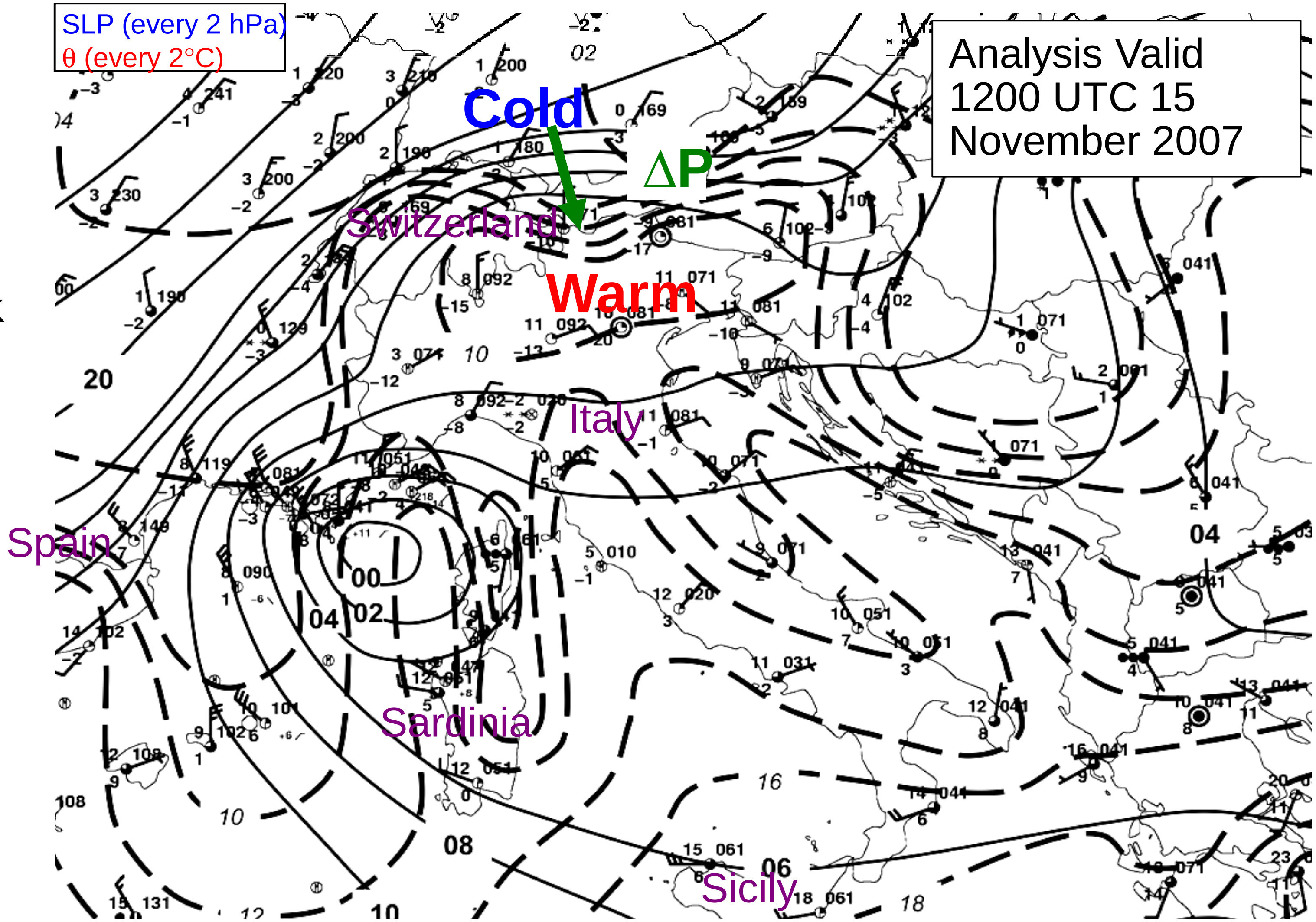



Streamfunction and nondivergent wind at 500 hPa computed from the 0.5° GFS final analysis. Extent of snow cover is shown by grey shading. Short, long and pennant wind barbs represent wind speeds of 5, 10 and 50 kt, respectively as for the remainder of the presentation. A solid red line indicates the trough axis. Inset shows the track of the cyclone from 1200 UTC 15 November to 1500 UTC 16 November 2007.

# Vortex Initiation

- Orographic blocking of cold air leads to a large cross-Alpine pressure gradient

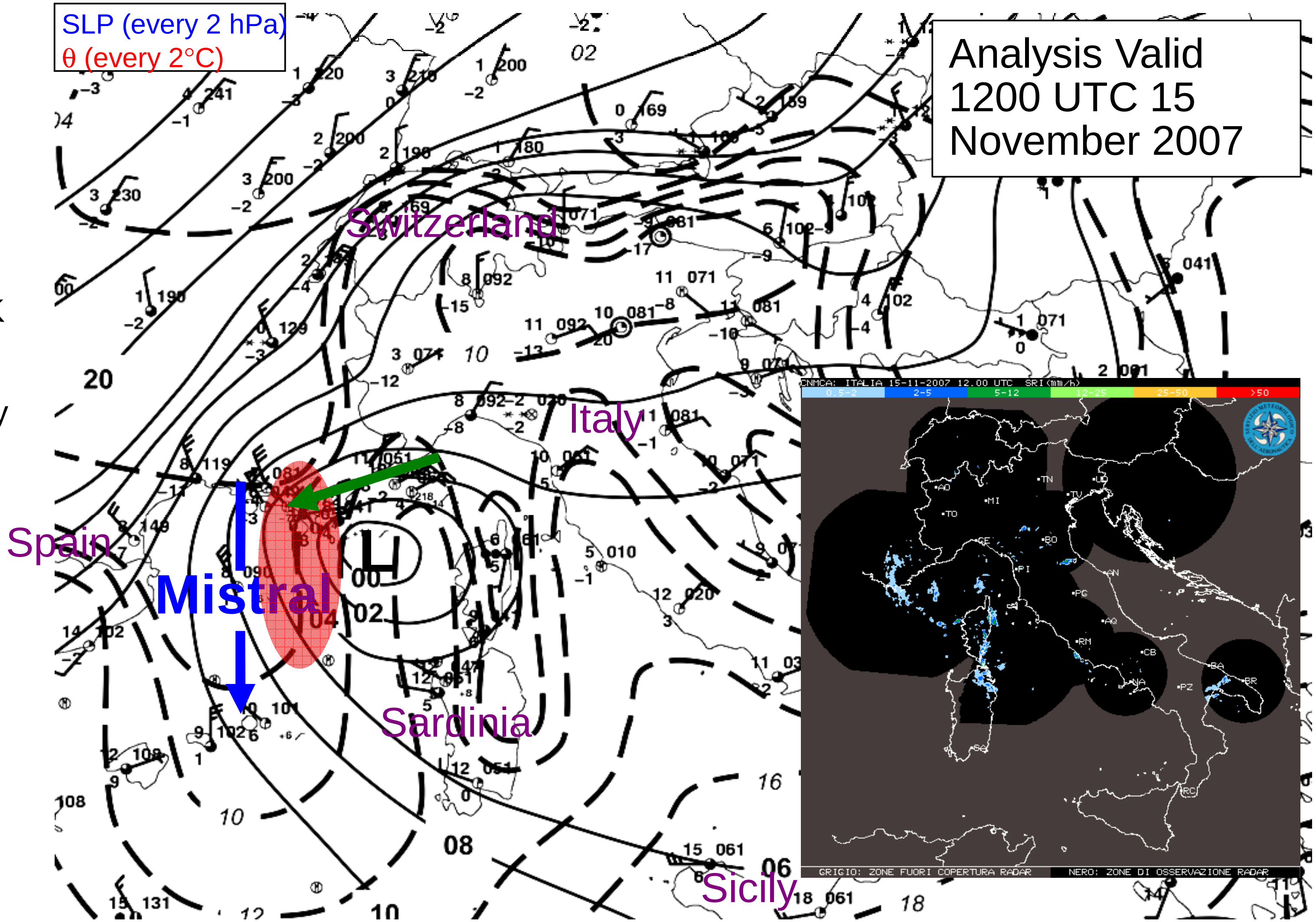
Analysis of surface observational data for 1200 UTC 15 November. Isobars at 2 hPa intervals are plotted with solid lines, and surface potential temperatures at 2 K intervals are plotted with dashed lines.



# Vortex Initiation

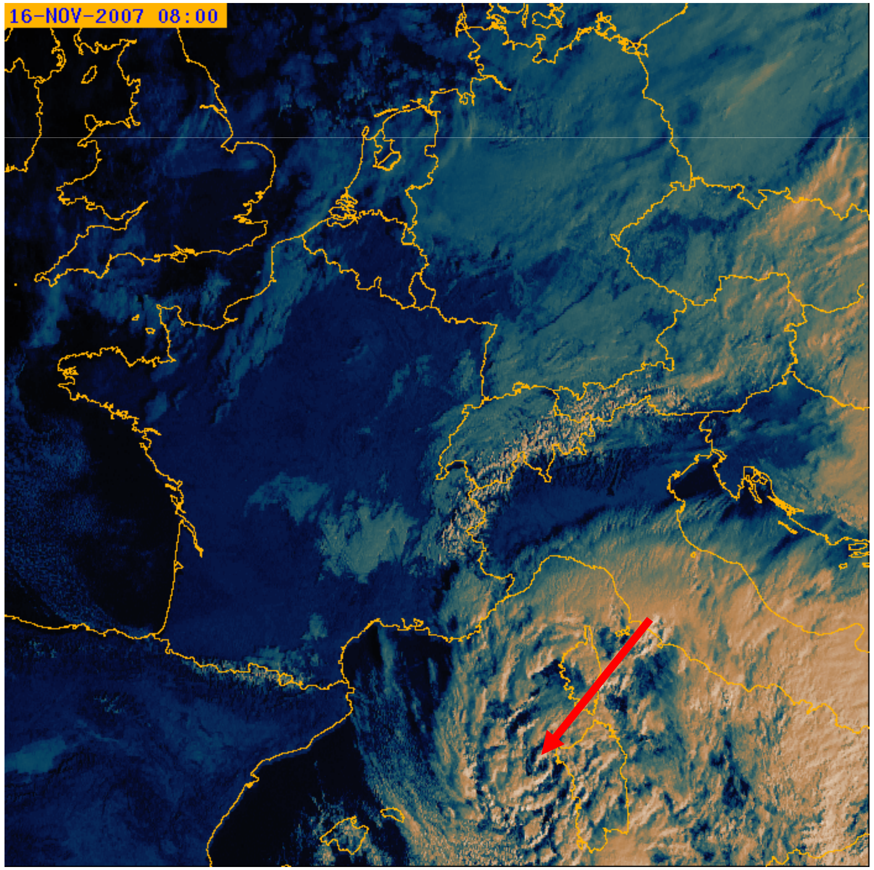
- A subsynoptic-scale vortex develops on cyclonic shear side of Mistrals in strong confluent frontogenesis

Analysis of surface observational data for 1200 UTC 15 November. Isobars at 2 hPa intervals are plotted with solid lines, and surface potential temperatures at 2 K intervals are plotted with dashed lines. The Italian radar composite (provided by ARPA-SIM) for this time is shown in the inset.

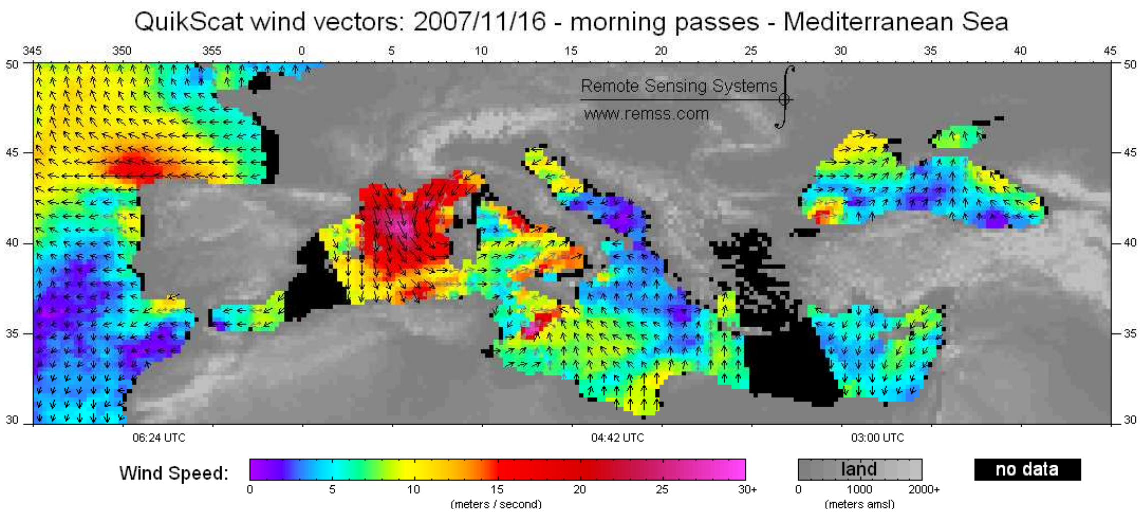


# Storm Intensification

MeteoSat visible satellite image for 0800 UTC 16 November 2007.



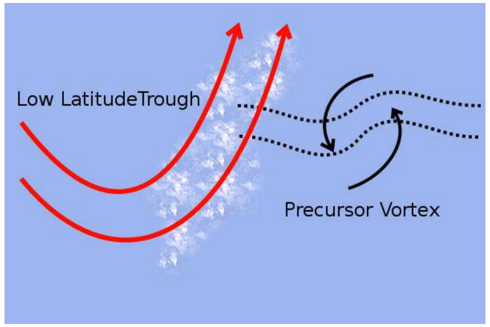

- Cyclone undergoes TT to develop an axisymmetric warm core structure as the remnant front progresses eastward



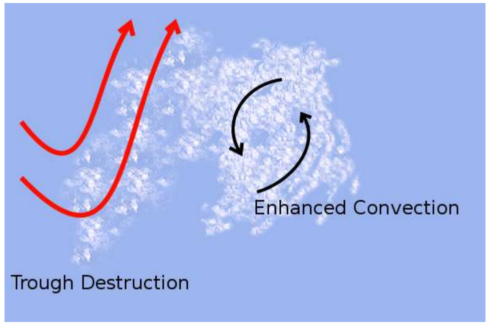

- Cyclone sustains high tropical storm-force surface winds of (30 $ms^{-1}$) by 0000 UTC 16 November

# Tropical Transition

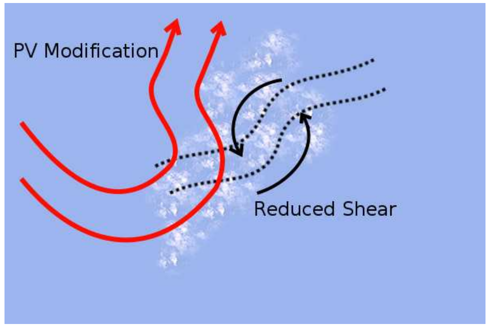
- An initially-baroclinic vortex transitions to a tropical cyclone-like barotropic vortex with an axisymmetric structure and an upright warm core (Davis and Bosart 2004)



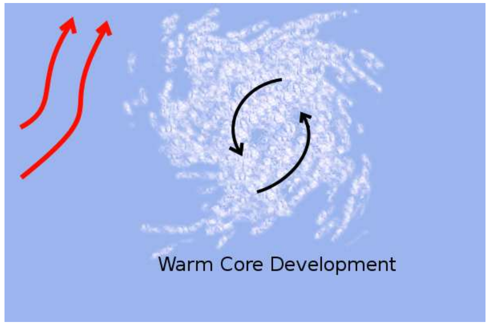

A weak (<10 ms$^{-1}$) vortex interacts with an approaching upper-level trough. In this case, the vortex is an incipient lee cyclone




Shear is reduced over the vortex as the trough strength decreases. In this case, deep shear is reduced to <10 ms$^{-1}$.




Quasigeostrophic forcing for ascent and destabilization enhance convection in the near-surface vortex. Upper-level PV is destroyed, causing the erosion of the trough. In this case, vertical momentum transport by convection enhances trough modification.




The vortex takes on an axisymmetric structure and persistent convection creates a warm core anomaly. In this case TT is completed soon after 0000 UTC 16 November.

# Eddy APE Energetics

- Eddy-APE ($A_E$) describes the locally-available energy contained in baroclinic perturbations:

$$A_E = \int_{p_b}^{p_t} \frac{\overline{[T'^2]}}{2\overline{\sigma}} dp$$

- The physical source/sink terms of $A_E$ yield information about the energy sources of the disturbance:

$$\frac{\partial A_E}{\partial t} = C_A - C_E + G_E$$

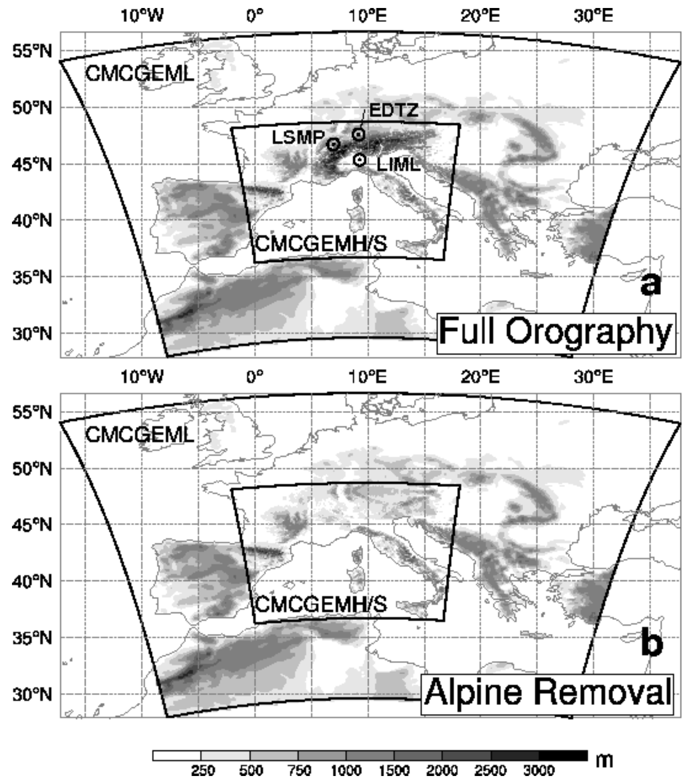
  - $C_A$: Conversion from basic-state APE to $A_E$
  - $C_E$: Conversion from $A_E$ to eddy kinetic energy
  - $G_E$: Diabatic generation of $A_E$ (primarily convective in this case)

# Eddy APE Energetics

- The ratio of $G_E$ (diabatic generation) to $C_A$ (basic state transfer to $A_E$) describes the diabatic nature of the vortex (Parker and Thorpe 1995; Moore and Montgomery 2004, 2005)
- Diabatic-dominated cyclones have R-values that approach or exceed unity, while those whose primary energy source is baroclinic have a much lower R.
- All $A_E$ diagnostics are computed for the free troposphere (850 hPa – 250 hPa in this case) at all points above terrain and within a storm-centered 8$^o$ latitude box).
- Non-physical residual terms (including boundary fluxs) remain small.

# Sensitivity Tests

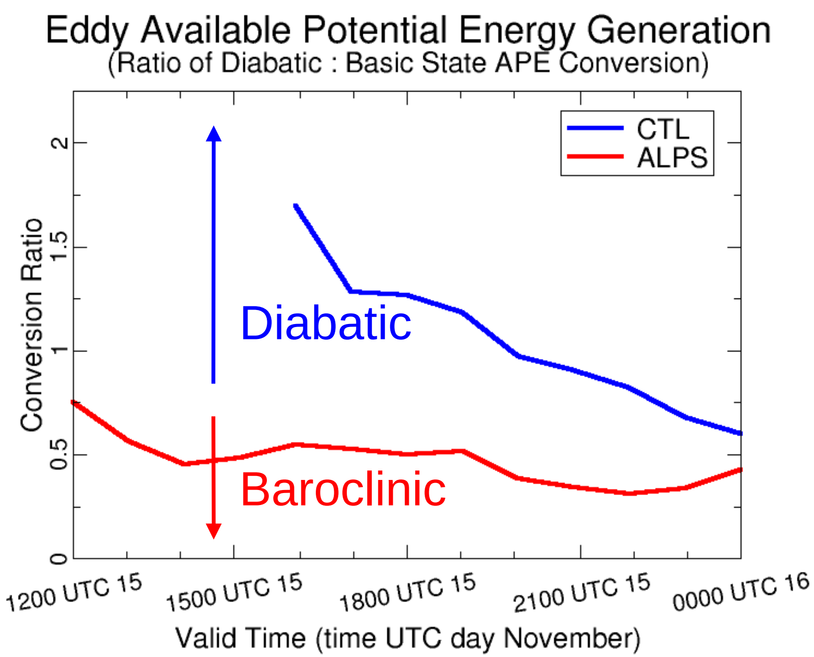
- All simulations use a triply-nested configuration of the GEM model (33 km Global, 15 km CMCGEML, 2.5 km CMCGEMH) used during the MAP D-PHASE project
- A series of attribution tests involving orographic modification shows that the development pathway of the cyclone is modulated by the Alpine barrier.
- Reduced blocking in the ALPS (removed) simulation results in strengthened cold flow over the western Mediterranean and a baroclinically-domainated development (no TT).




Domains used during MAP D-PHASE and for CTL (a) and ALPS (b) sensitivity tests. Orography is shaded as indicated on the greyscale bar.

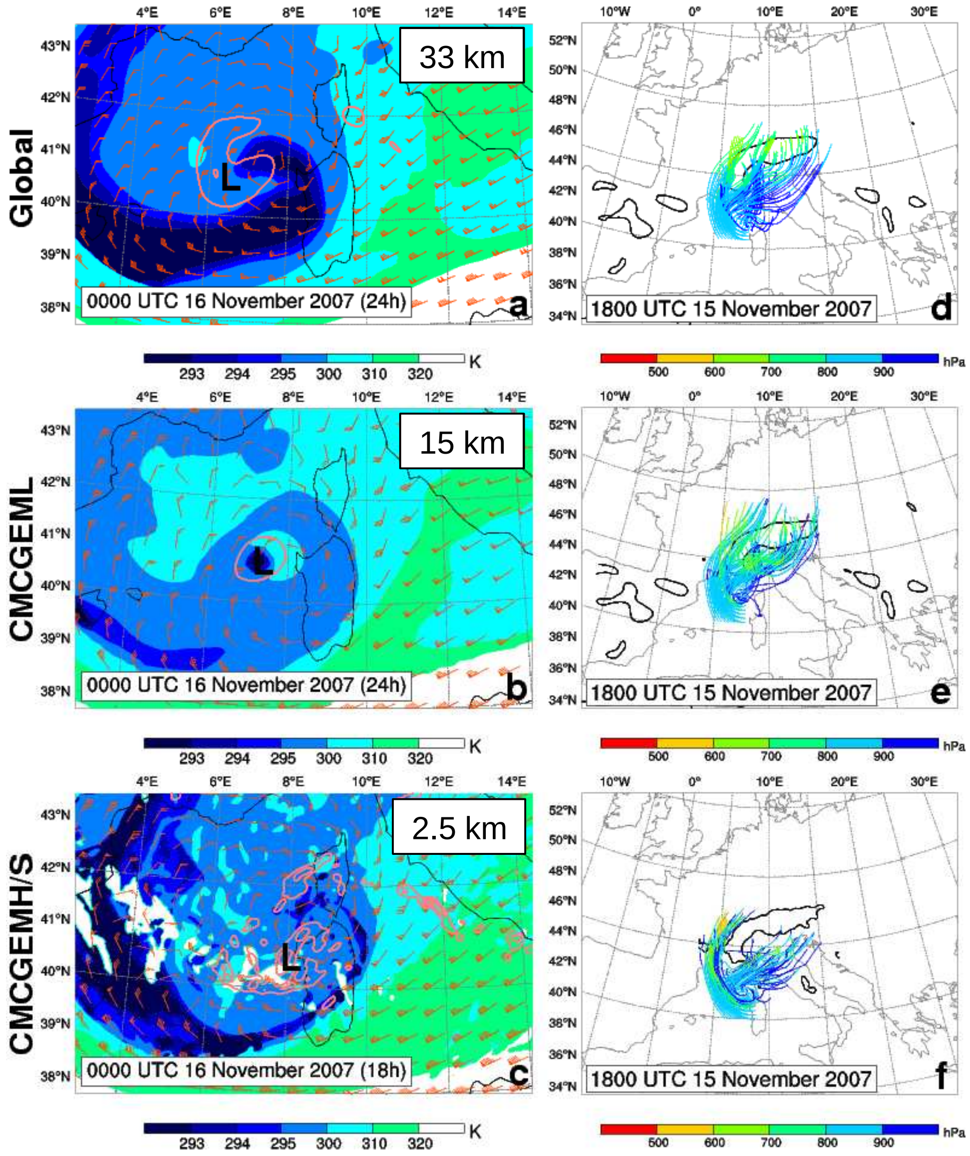
# Sensitivity Tests

- All simulations use a triply-nested configuration of the GEM model (33 km Global, 15 km CMCGEML, 2.5 km CMCGEMH) used during the MAP D-PHASE project
- A series of attribution tests involving orographic modification shows that the development pathway of the cyclone is modulated by the Alpine barrier.
- Reduced blocking in the ALPS (removed) simulation results in strengthened cold flow over the western Mediterranean and a baroclinically-domainated development (no TT).




Evolution of R on the CMCGEMH domain.

# Flow Structure

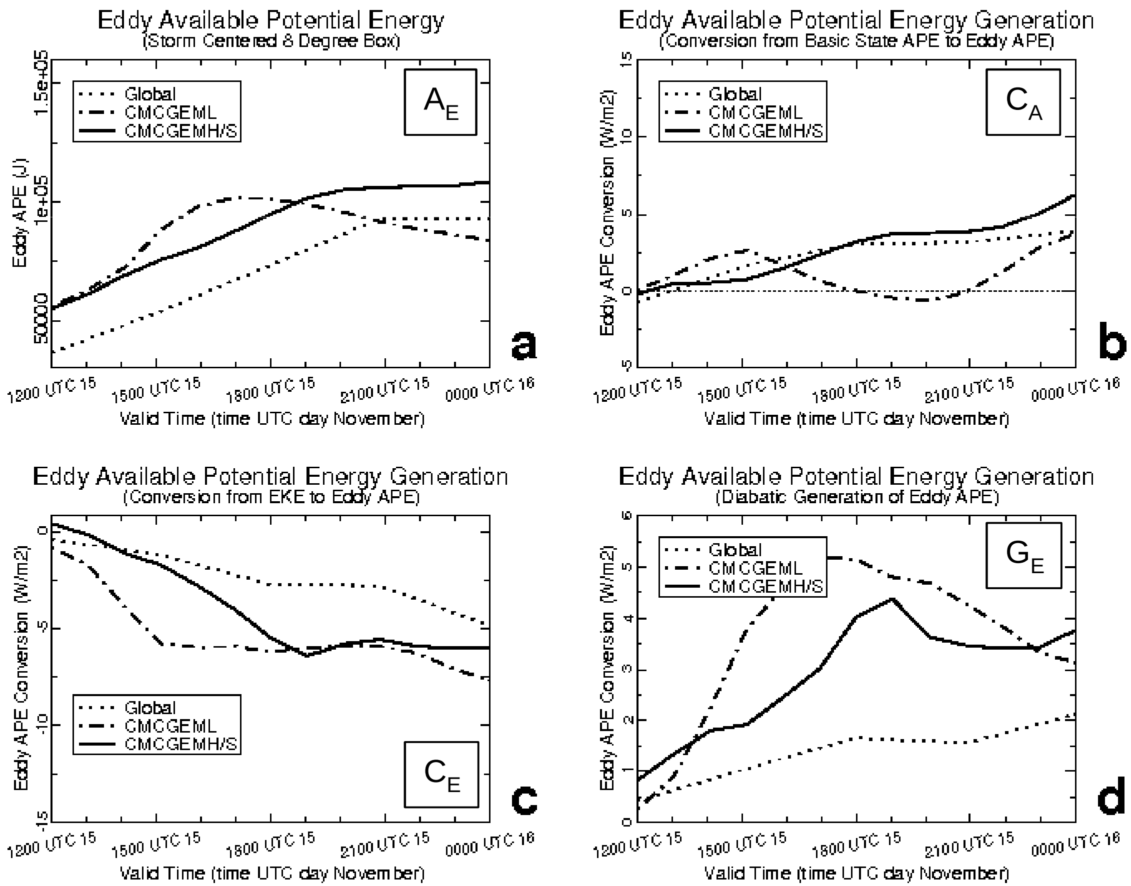



Dynamic tropopause potential temperature (K, coloured), winds and lower-level vorticity (left column), and back-trajectories from the lower-level centre with parcel pressure coloured (right column).

- A Genoa cyclone develops at all resolutions.
- The formation of a PV hook ("treble-clef") structure in Global suggests a frontal seclusion.
- Both CMCGEML and CMCGEMH show erosion of the PV streamer by persistent convection.
- Flow splitting becomes progressively stronger as the barrier is better resolved.

# Differences in $A_E$ Sources

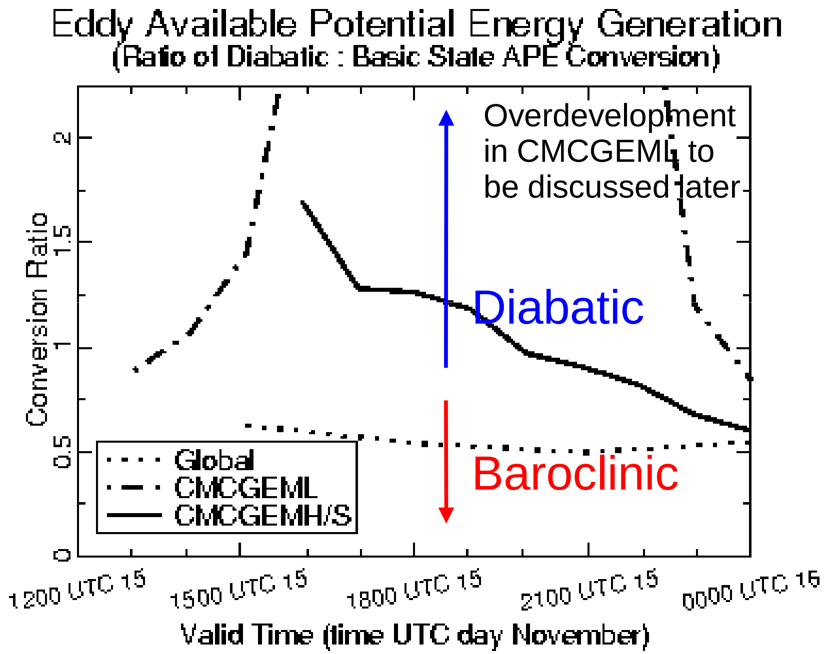
- Rate of $A_E$ development in Global and CMCGEMH is similar, but CMCGEML shows early over-intensification (a and d).
- Reduced $C_E$ in Global is a direct result of reduced $A_E$ at lower resolution (c).
- Diabatic generation ($G_E$) is much stronger in CMCGEML and CMCGEMH than in Global (d).




Evolution of $A_E$ (a) and physical terms of the $A_E$ tendency equation from 1200 UTC 15 to 0000 UTC 16 November for Global (33 km), CMCGEML (15 km) and CMCGEMH (2.5 km).

# Differences in $A_E$ Sources

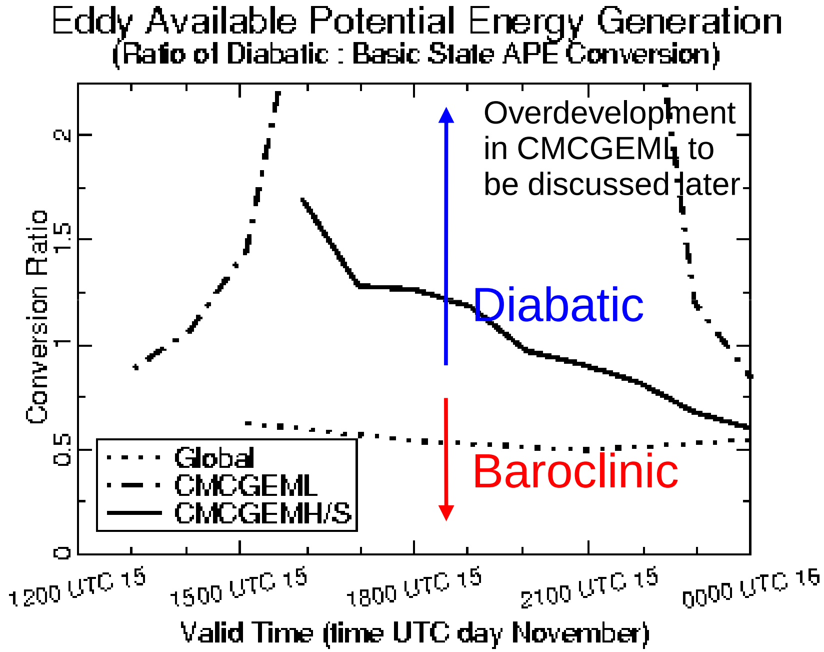
- Since $C_E$ remains similar in all integrations, larger $G_E$ leads to increased R in CMCGEML and CMCGEMH.



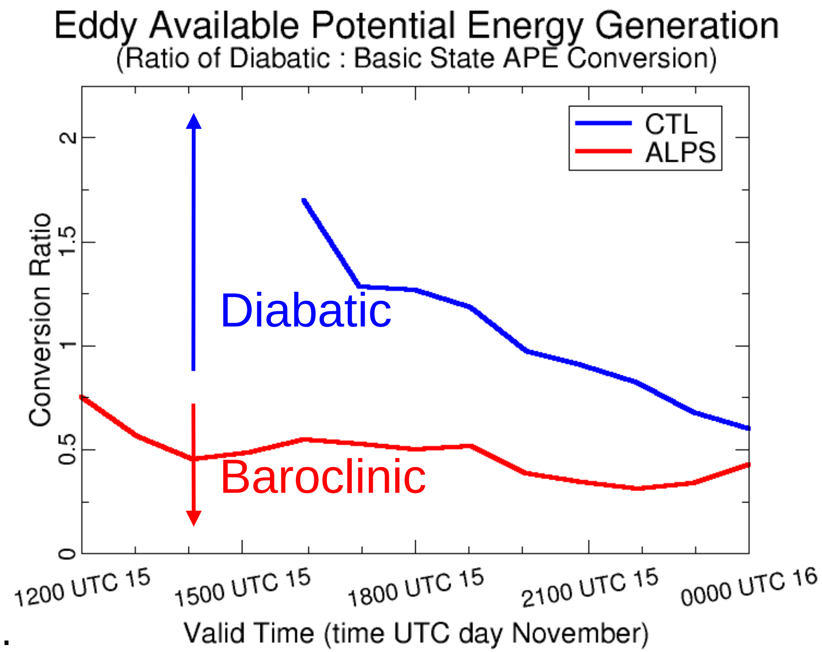

Evolution of R in the triply-nested domains.

# Differences in $A_E$ Sources

- Since $C_E$ remains similar in all integrations, larger $G_E$ leads to increased R in CMCGEML and CMCGEMH.
- The baroclinically-dominated lifecycle in Global is similar to that of the Alpine removal test, indicating that insufficient resolution of the Alpine block modifies the development pathway.



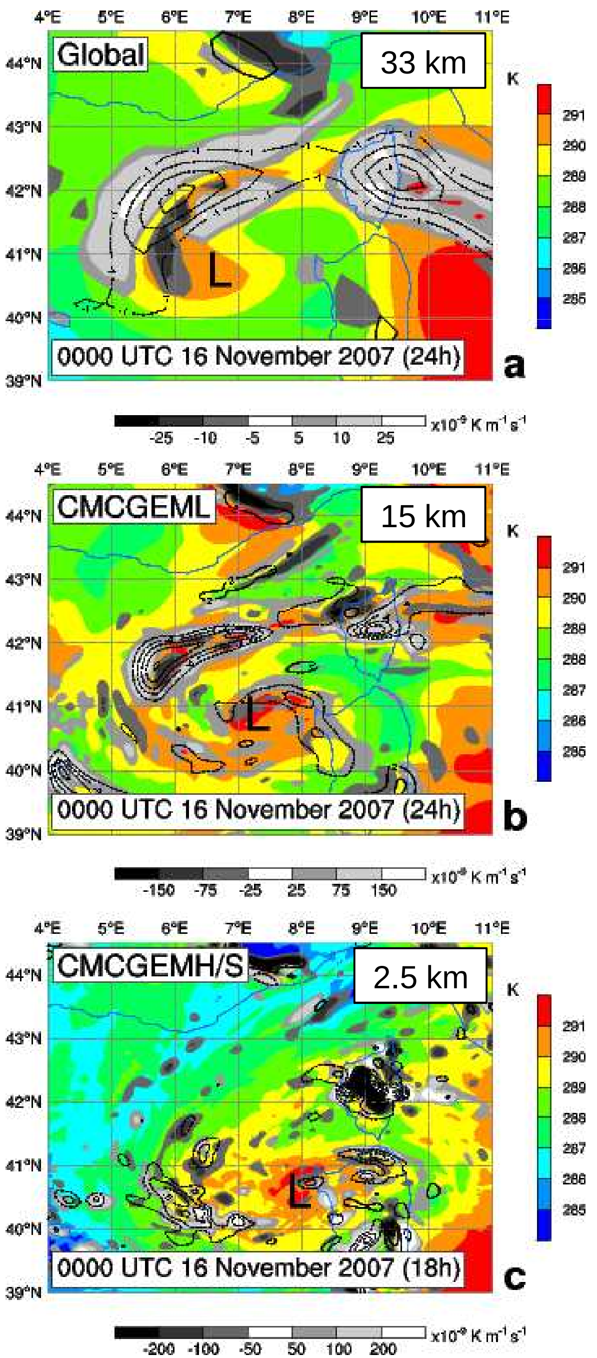
Evolution of R in the triply-nested domains.




These differences in the cyclone's energy source (baroclinic at low resolution and diabatic at higher resolution) must be reflected in the thermal structure of the system.

Evolution of R on the CMCGEMH domain (as shown earlier).

# Development Pathway

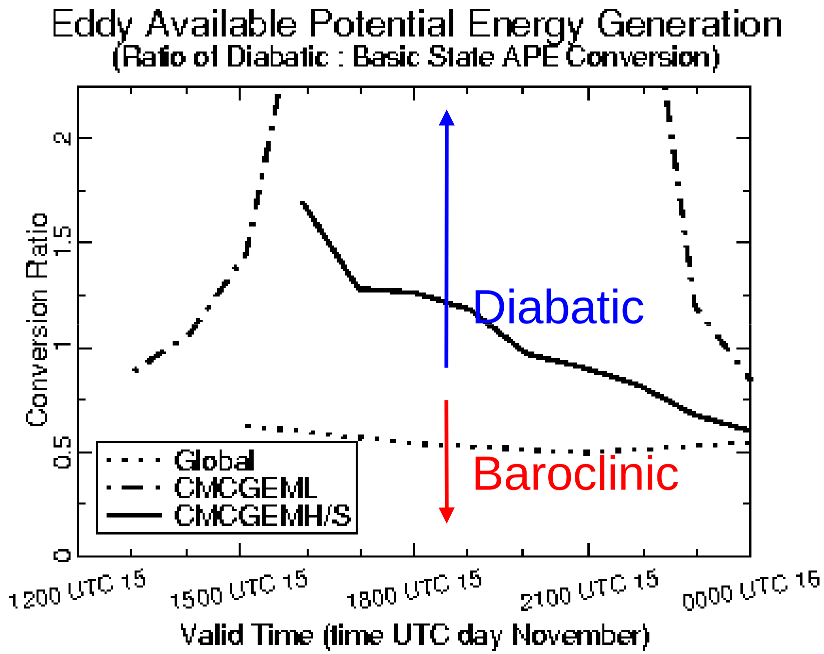



- Ascent and frontogenesis in Global (a) are focused along the bent-back warm front, indicative of a frontal seclusion (Posselt and Martin 2004).
- Frontogenesis in CMCGEML (b) is focused along a remnant warm front, but moist convective ascent near the centre leads to the formation of a warm core (hybrid storm).
- Bent-back frontal structure is absent in CMCGEMH (c), and all ascent is focused in the convective cells that fuel warm-core development.

Potential temperature (K, coloured), frontogenesis ($Km^{-1}s^{-1}$, grey-shaded) and vertical motion ($Pas^{-1}$, with dashed negative for upwards motion) at 700 hPa.

# Overdevelopment in CMCGEML

- The diabatic mode of development appears to be too dominant in CMCGEML: large $G_E$ values and extremely large R values.
- Inactivity of Kain-Fritsch parameterized convection (CPS) leads to excessive instability over the Mediterranean, which is only released once gridscale saturation is achieved.




Evolution of R in the triply-nested domains (as shown earlier).

- Domain-averaged precip is 15% larger in CMCGEML than in CMCGEMH; can be reduced by changing CPS triggering.

Evaluation of development pathway may help with parameter optimization for planning future domain configurations.

# Summary

- An Alpine lee cyclone forms over the Gulf of Genoa ahead of a strong trough with an embedded CTD on 15 November 2007.
- Persistent convection over the warm Mediterranean waters erodes upper level PV, reduces vertical shear, and leads to the development of a diabatically-generated warm core: a tropical transition (TT) development pathway.
- The grid spacing of Global (33 km) is insufficient to adequately resolve the Alpine barrier, resulting in the development of a frontal seclusion without TT – similar to high resolution tests without the barrier.
- CMCGEML (15 km) develops a hybrid vortex, suggesting that it is close to being capable of resolving the storm dynamics; however, it is diagnosed to have insufficient CPS activity resulting in overdeveloped instability.

# Conclusions

- The strong dependance of development pathway on model resolution may explain some of the conflicting results from Alpine orography modification sensitivity tests over the last couple of decades: different flavours of cyclogenesis will likely have different sensitivities to the presence/absence of the barrier.

The low resolution model is capable of simulating the initiation of the lee cyclone, but insufficient resolution of the barrier results in a baroclinic mode of development: the right answer (a cyclone), but for the wrong reason.

Only the convection-permitting model configuration resulted in robust TT that effectively tapped the diabatic energy source to follow a “Mediterranean Hurricane” development pathway.