Effects of ocean-atmosphere coupling in regional climate models on the simulation of medicanes: present climate representation and future projections

Miguel Angel Gaertner, Juan Jesús González-Alemán,
Jesús Gutiérrez, Alba de la Vara

University of Castilla-La Mancha (Toledo, Spain)

Instituto de Ciencias Ambientales de Castilla-La Mancha

UCLM
CAMPUS DE EXCELENCIA INTERNACIONAL
Universidad de Castilla-La Mancha

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Motivation: uncertainties about future evolution of medicanes

- Main results of existing projections of future changes of medicanes:

    * Frequency decrease

    * Increase in the intensity of most intense medicanes

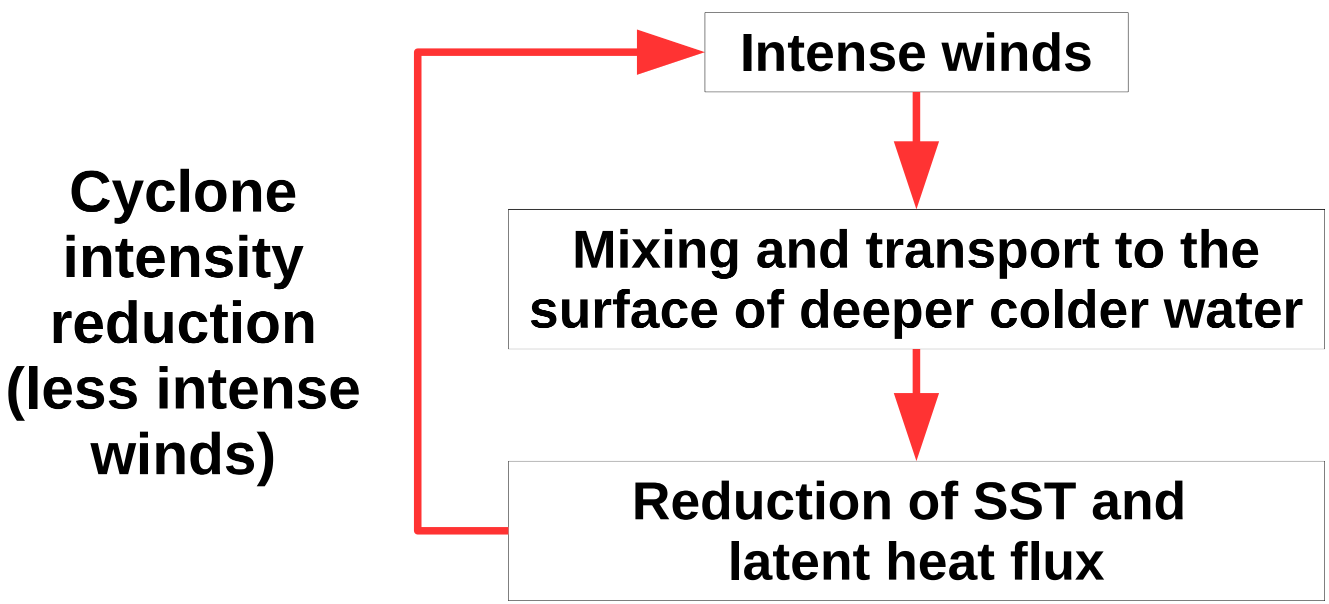
- Most existing projections have been done without ocean coupling

- Open question: could the simulated future increase in medicane intensity depend on the coupling?

Motivation: uncertainties about future evolution of medicanes

- **Air-sea exchanges are particularly important for these cyclones**

Initial hypothesis:
Ocean-atmosphere coupling could reduce the intensity of medicanes through a negative feedback



Previous studies of air-sea impact on cyclones: overall Mediterranean cyclones

* Flaounas et al. (2016): weak impact of air-sea coupling on climatology and intensity of overall Mediterranean cyclones

- Reason: most cyclones are driven by large scale baroclinicity; air-sea fluxes only of secondary importance

* Sanna et al. (2013): effect of eddy-permitting Mediterranean Sea circulation model on atmospheric cyclones and precipitation (comparison of high/low resolution of marine module)

- Strong positive effect on SST and precipitation

- Significant effect on cyclogenesis (improving in some areas) consistent with importance of small-scale structure of air–sea interaction

Previous studies of air-sea impact on medicanes

* Akhtar et al. (2014):

- Coupling effect on medicanes significant for atmospheric model grid spacings of the order of 10 km, but rather weak for coarser grids

- Atmospheric high resolution coupling: improves tracks and spatial structure of medicanes

Data for the study

- Simulations:
  - Pairs of uncoupled and coupled runs from Med-CORDEX
  - Evaluation runs (nested in ERA-Interim reanalysis)
  - RCP8.5 scenarios (ongoing work)

Simulation of observed medicanes: evaluation runs

- No coincidence on a case-by-case basis between climate simulations and observations: statistical evaluation of climate simulations

- Intensity is generally underestimated in simulations

- Spatial distribution is well reproduced

Reference:

Gaertner, M.A. et al. (2016): Simulation of medicanes over the Mediterranean Sea in a regional climate model ensemble: impact of ocean-atmosphere coupling and increased resolution. Climate Dynamics, doi: 10.1007/s00382-016-3456-1

Impact of ocean-atmosphere coupling on the simulation of medicanes (evaluation runs)

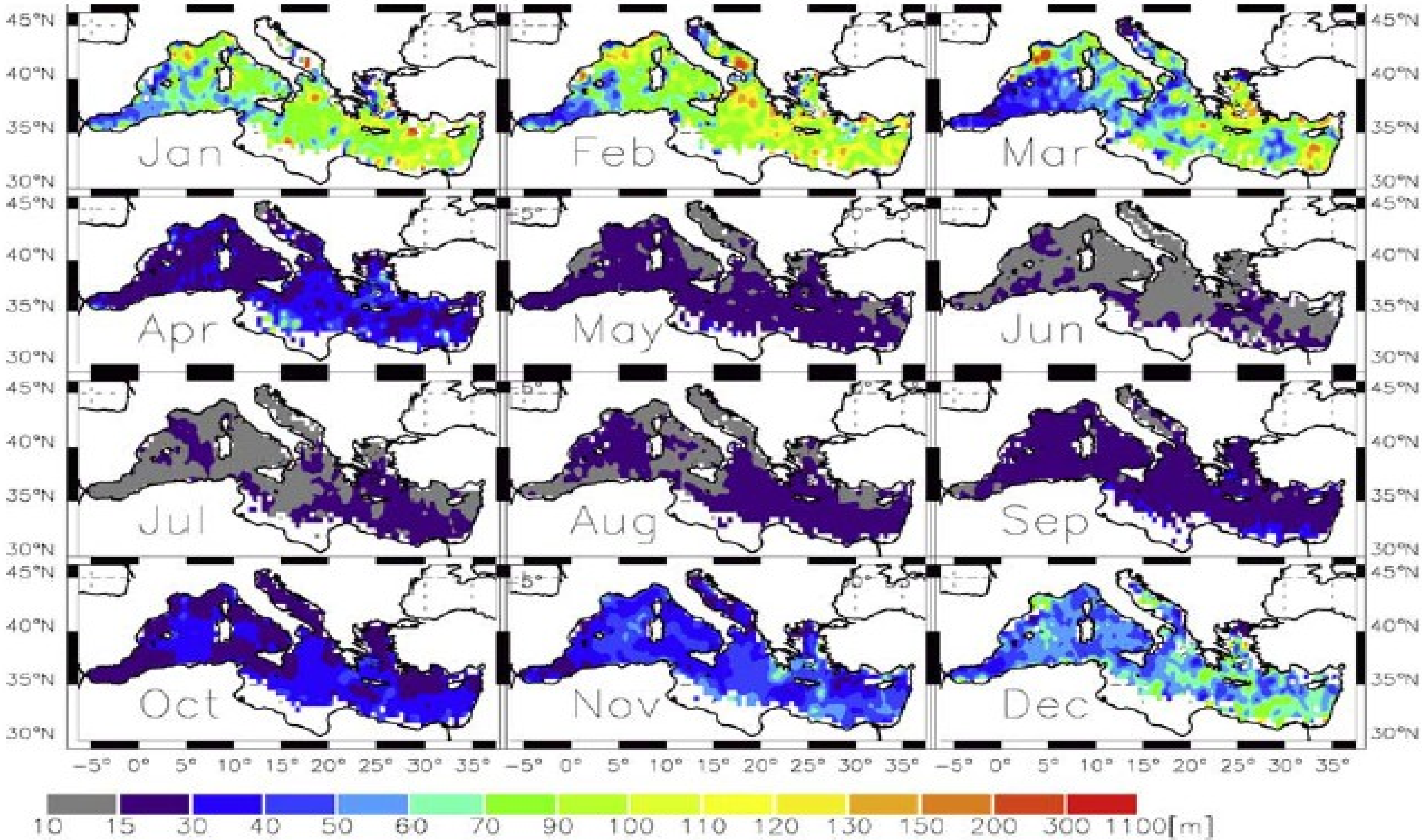
- Clear impact: seasonal shift of medicanes from autumn to winter in coupled simulations

- Positive change in coupled simulations: winter maximum as observed, instead of autumn maximum

- Shift follows seasonal increase of Mediterrean Sea mixed layer depth: ¿relationship between deeper mixed layers and more frequent medicanes in coupled runs?

Negative intensity feedback depends on oceanic mixed layer depth

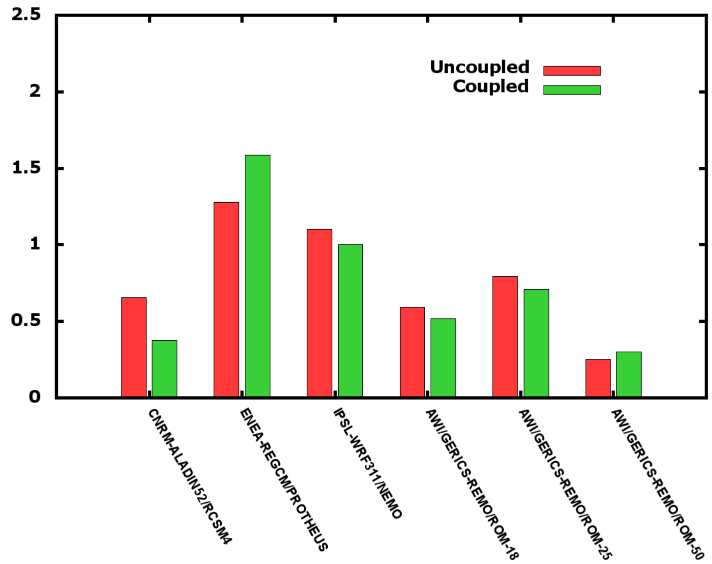
- **Shallow mixed layers** (typical in summer in the Med. Sea) **favour the negative feedback**
- **Deep mixed layers** (typical in winter in the Med. Sea) **limit the negative feedback**



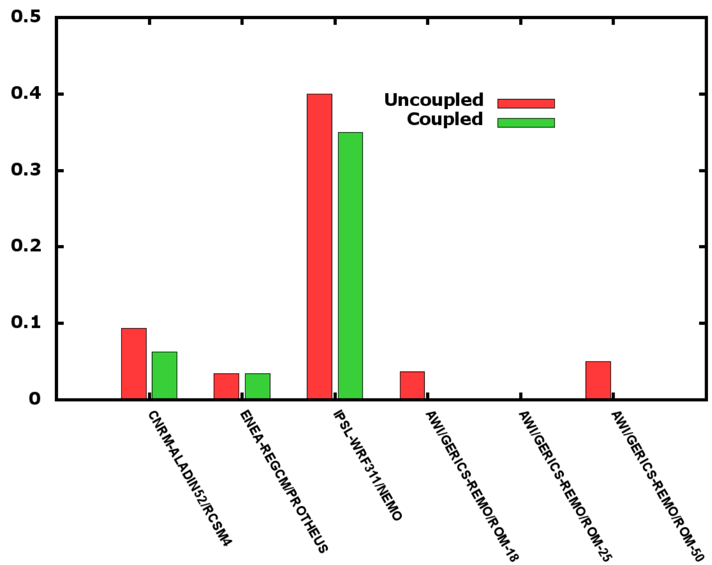
Annual cycle of Mediterranean mixed layer depth (d'Ortenzio et al., 2005)

Impact of ocean-atmosphere coupling on the simulation of medicanes (evaluation runs)

Frequency of medicanes (number per year)



Frequency of high-intensity medicanes (max. wind above 25 m/s)



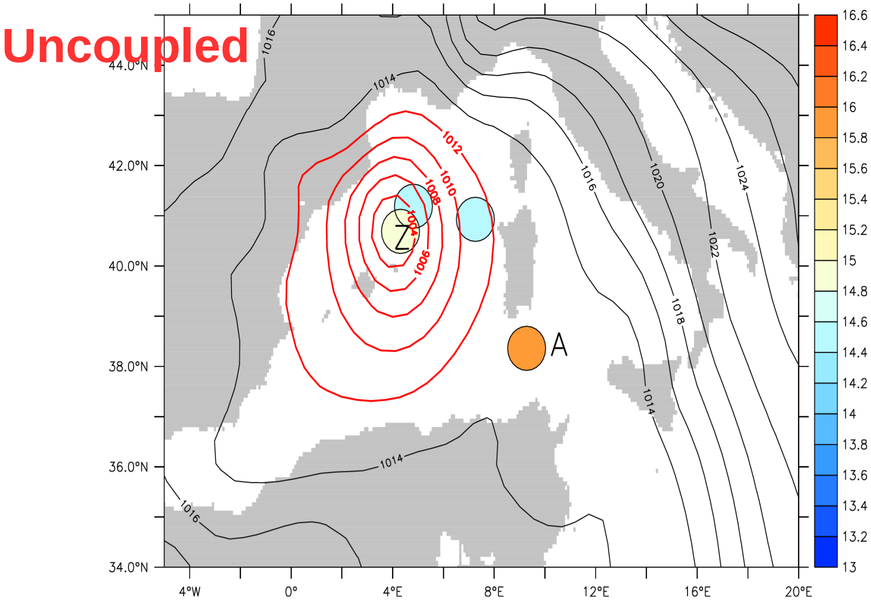
Pairs of uncoupled/coupled runs

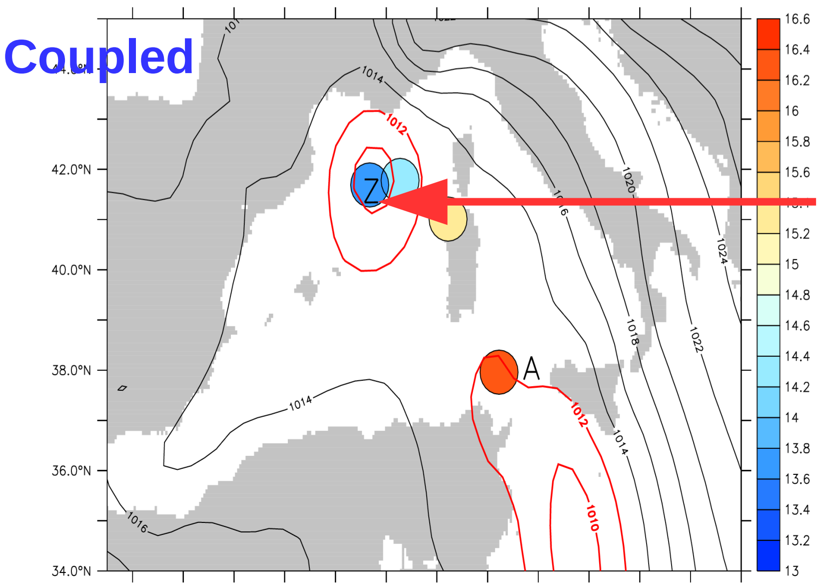
No clear aggregate impact of coupling of frequency and intensity of medicanes (slight decrease of high-intensity medicanes)

Aggregate values might be hiding different types of air-sea interactions: What happens in specific cases?

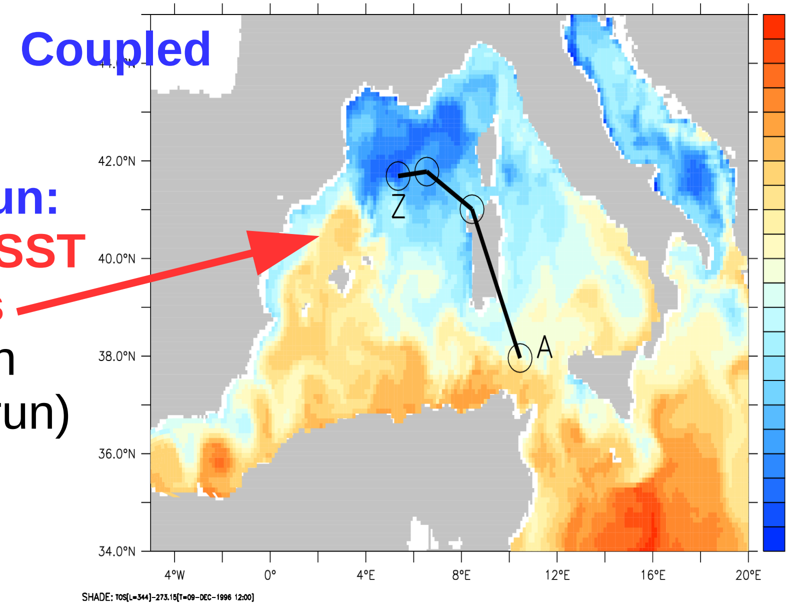
Specific case: intensity reduction in coupled simulation (evaluation run)

SLP at maximum intensity and SST under cyclone track

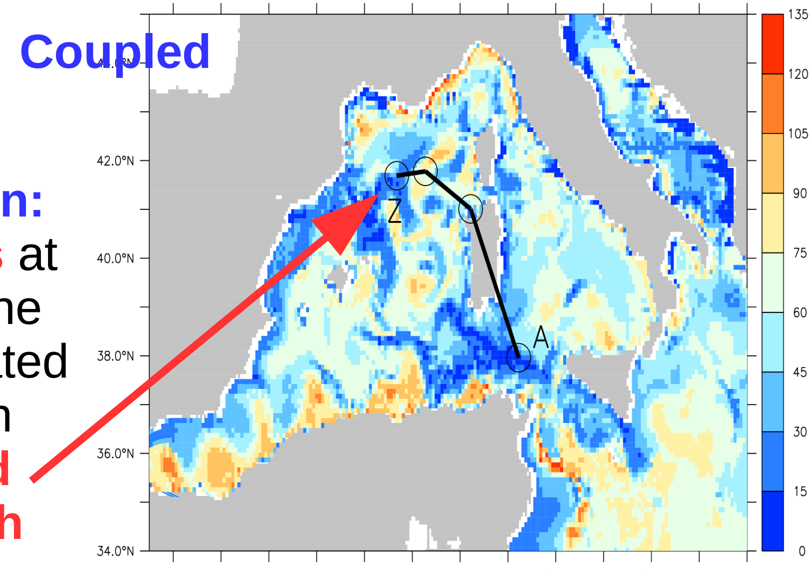




SST and cyclone track



Coupled run:
Mesoscale SST features
(absent in uncoupled run)



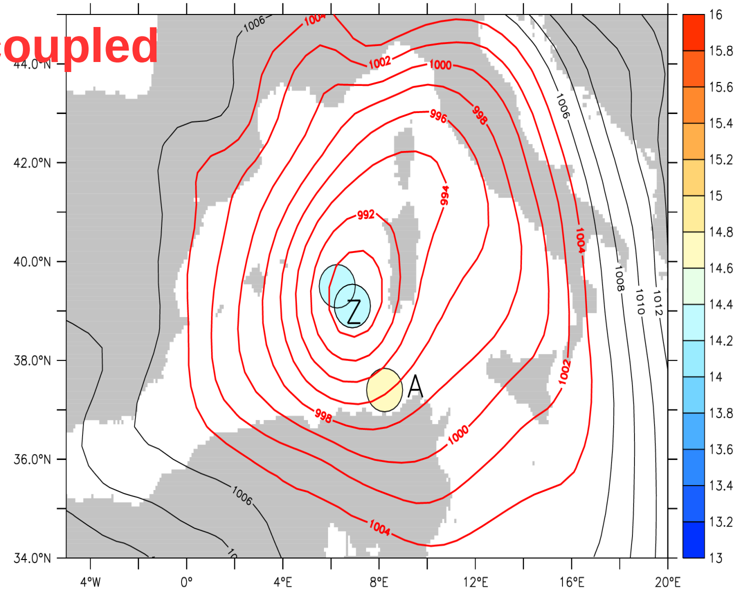
Mixed layer depth and cyclone track

Coupled run:
Lower SSTs at the end of the track associated to area with **low mixed layer depth**

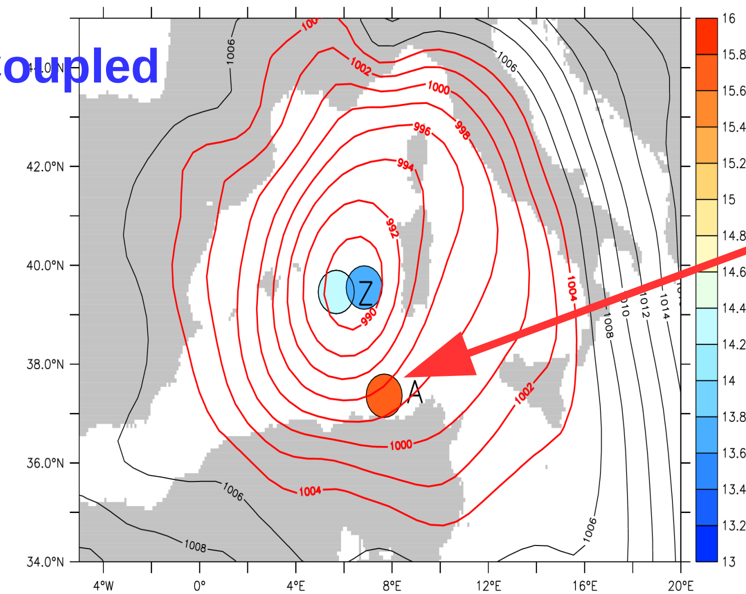
Specific case: intensity increase in coupled simulation (evaluation run)

SLP at maximum intensity and SST under cyclone track

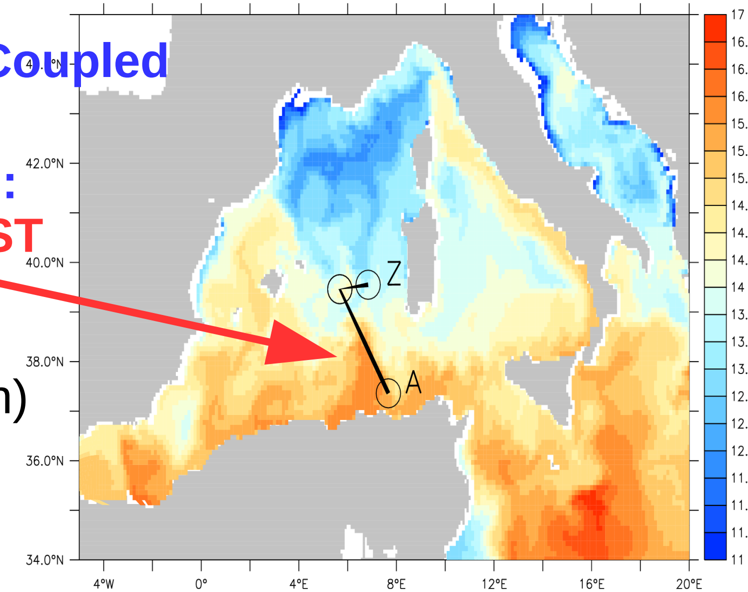
Uncoupled



Coupled

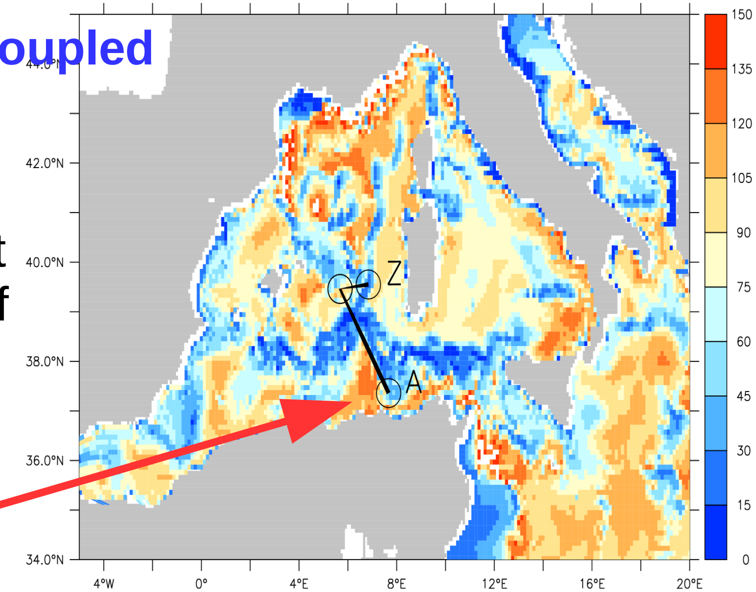


Coupled



Coupled run:
Mesoscale SST features
(absent in uncoupled run)

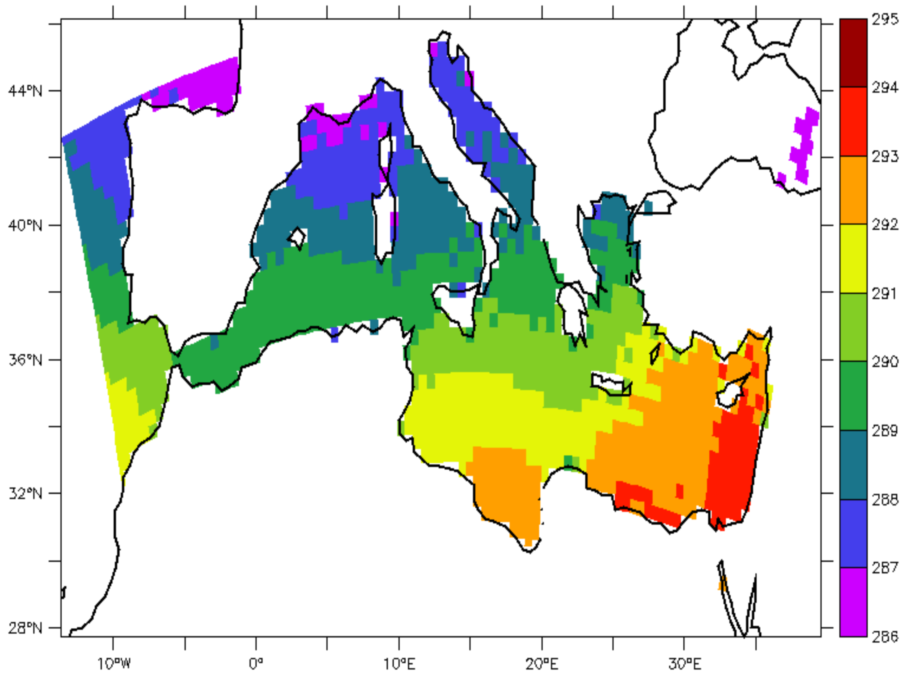
Coupled



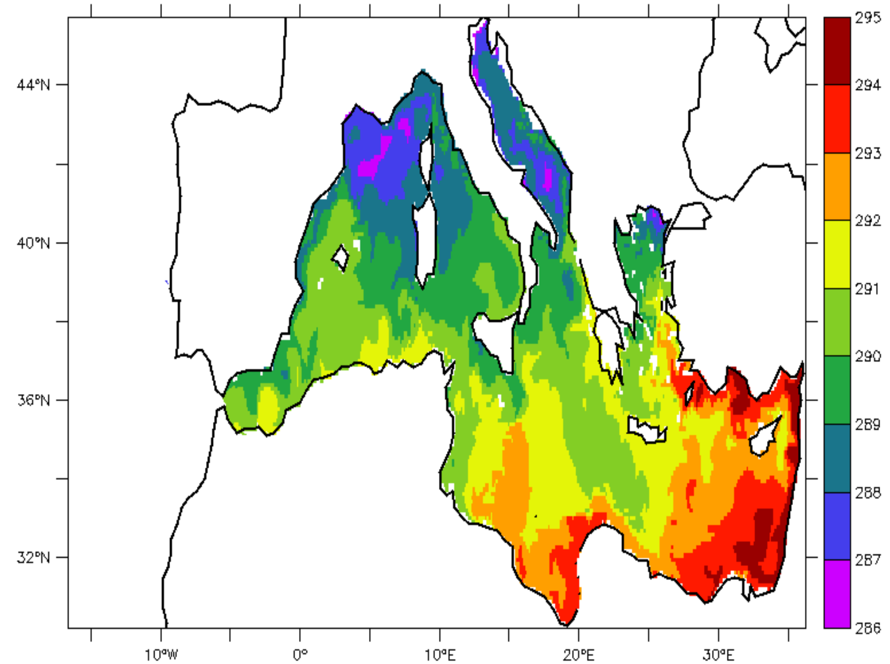
Coupled run:
Higher SSTs at the beginning of the track, associated to area with **high mixed layer depth**

A possible explanation for the simulated impact of ocean-atmosphere coupling on medicanes

Example of SST differences between uncoupled and coupled runs



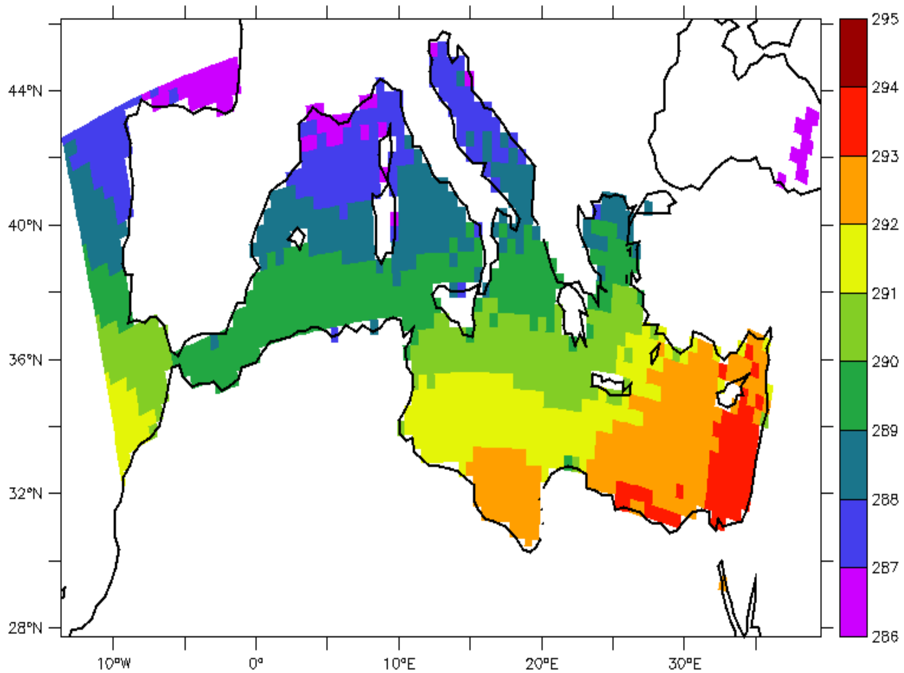
SST distribution for uncoupled RCM



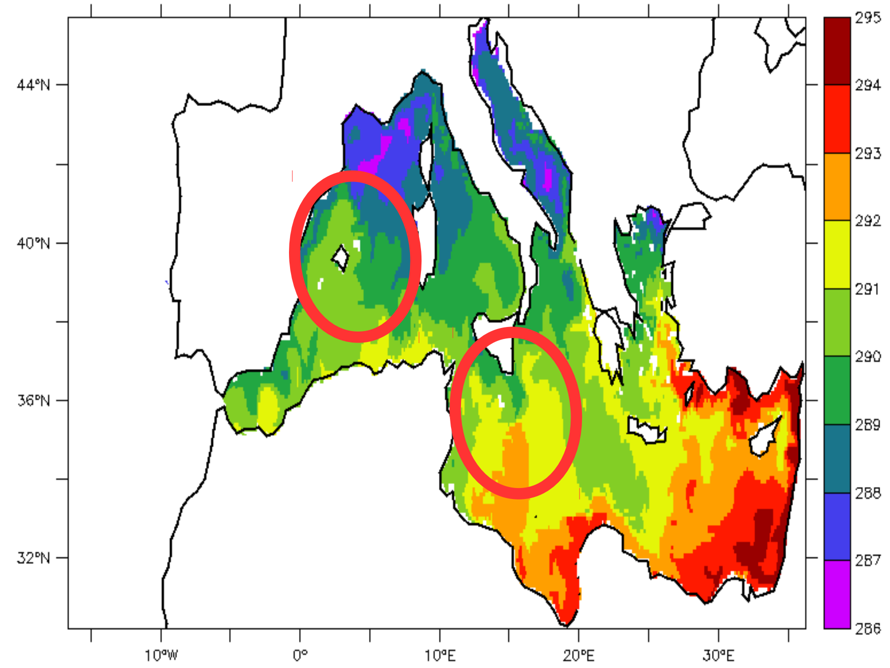
SST distribution for coupled RCM

A possible explanation for the simulated impact of ocean-atmosphere coupling on medicanes

Are pre-existing mesoscale oceanic structures in coupled runs important for the medicane development?



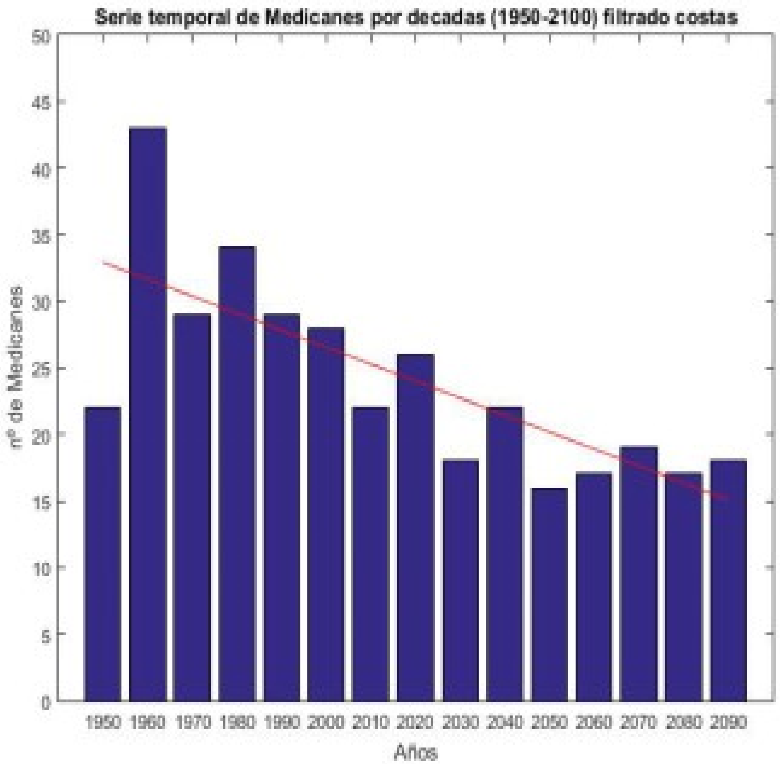
SST distribution for uncoupled RCM



SST distribution for coupled RCM

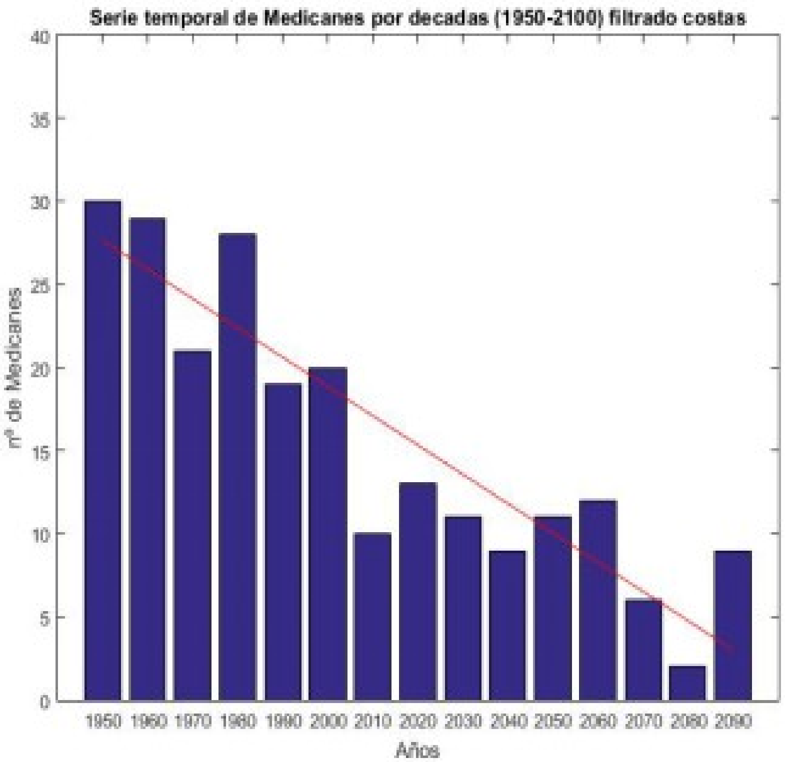
Future medicane projections (ongoing work)

Uncoupled model



Frequency per decade (1950-2099)

Coupled model

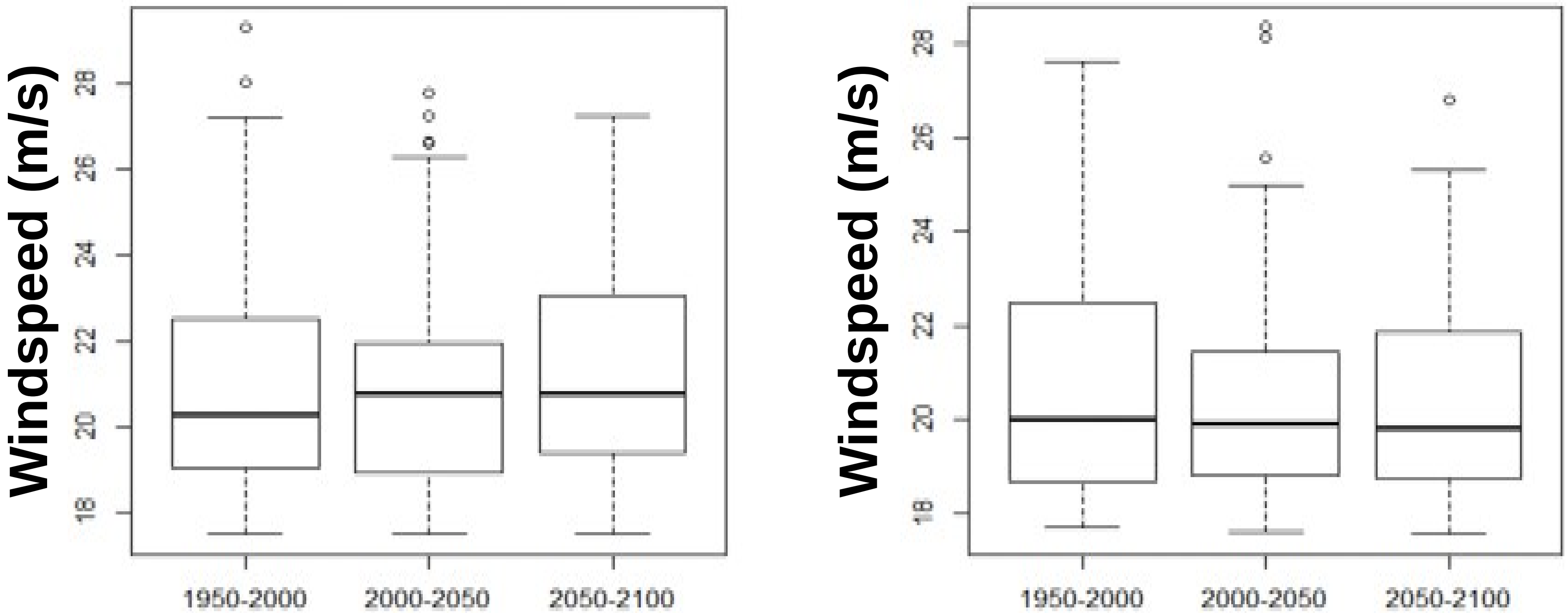


Frequency per decade (1950-2099)

Future medicane projections (ongoing work)

Uncoupled model **Coupled model**

Cyclone intensity (maximum windspeed)
Periods of 50 years (1950-2099)

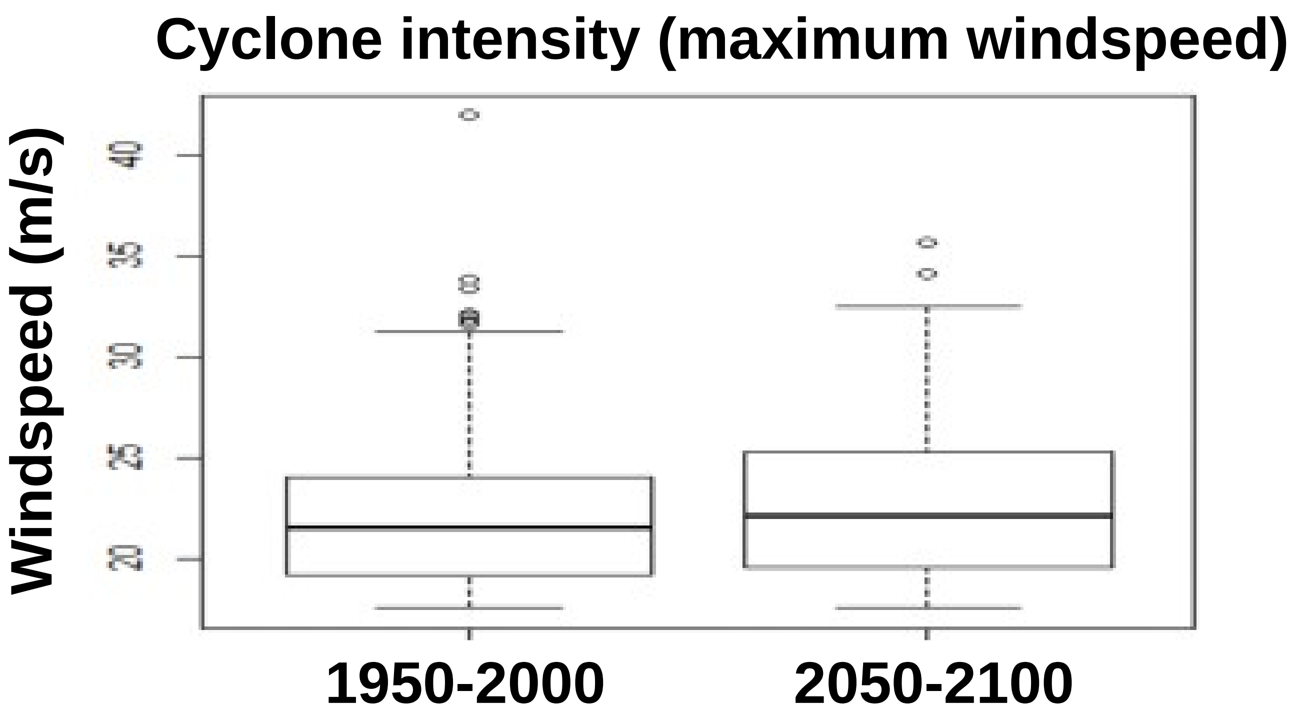


No change of 95th intensity percentile

Future decrease of 95th intensity percentile

Future medicane projections (ongoing work)

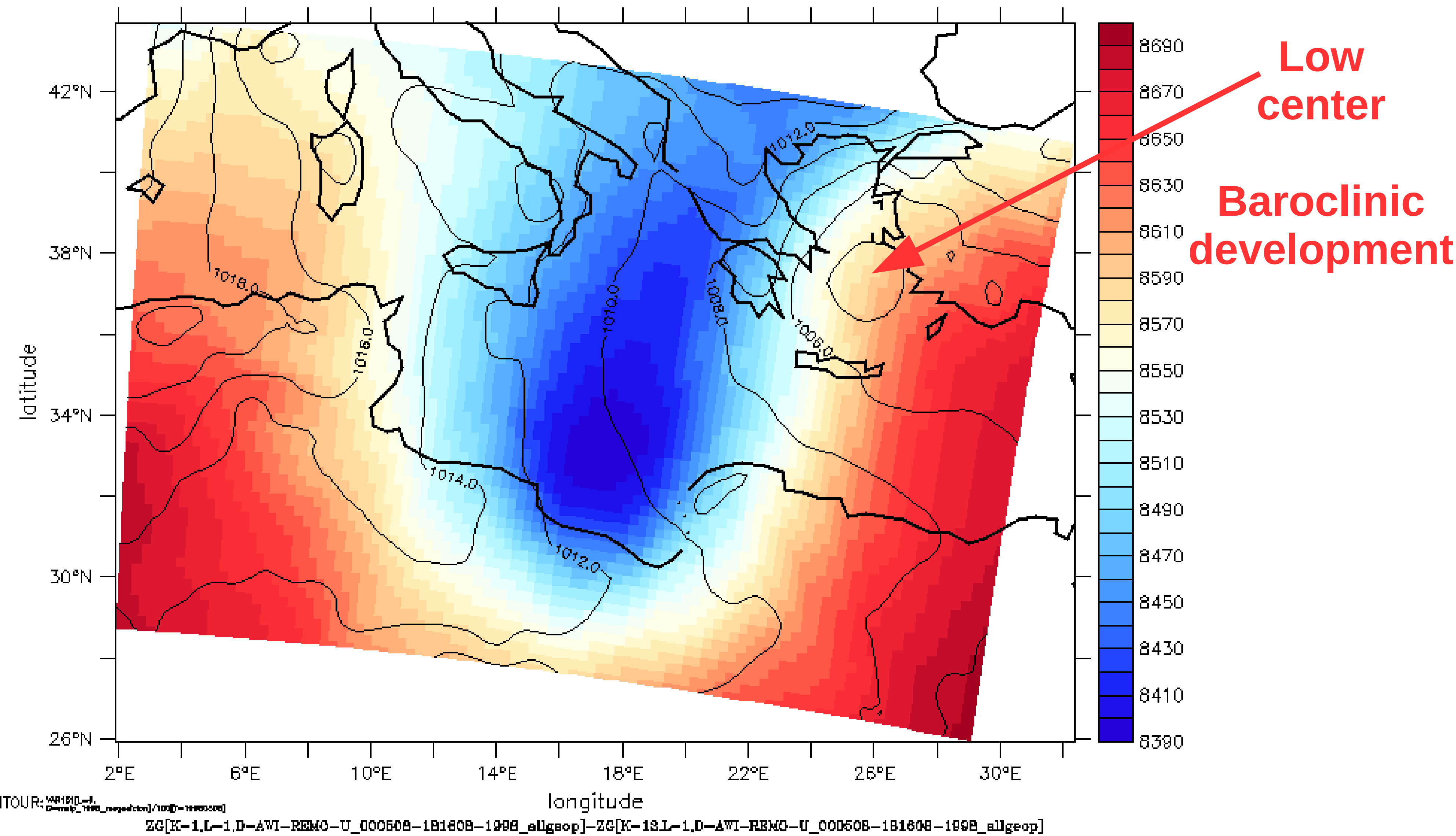
Model with good representation of intensity
Only coupled simulation available



Good simulation of past climate intensity

Future increase of 95th intensity percentile

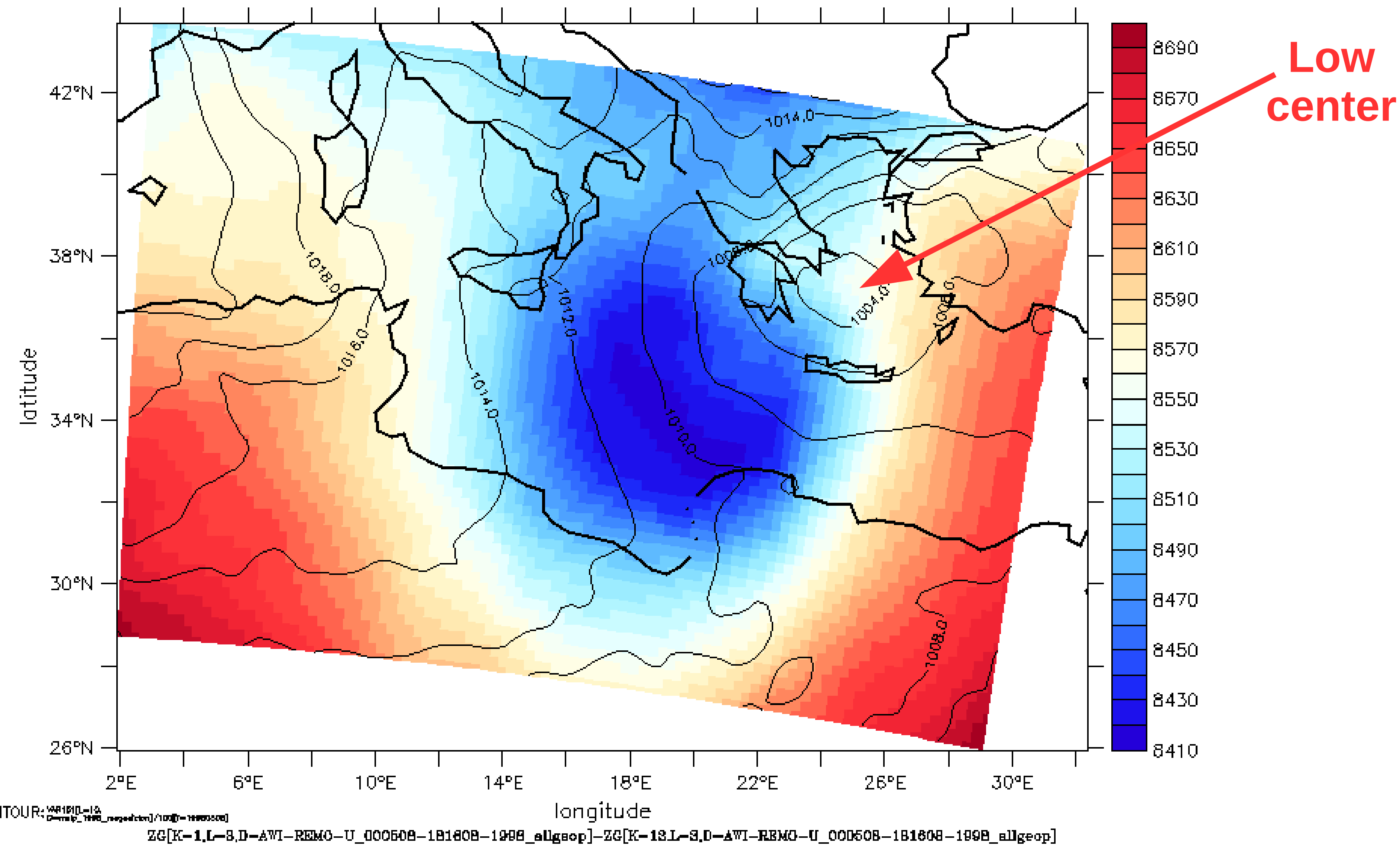
Important added value of coupling



Uncoupled RCM past climate simulation: 5th August

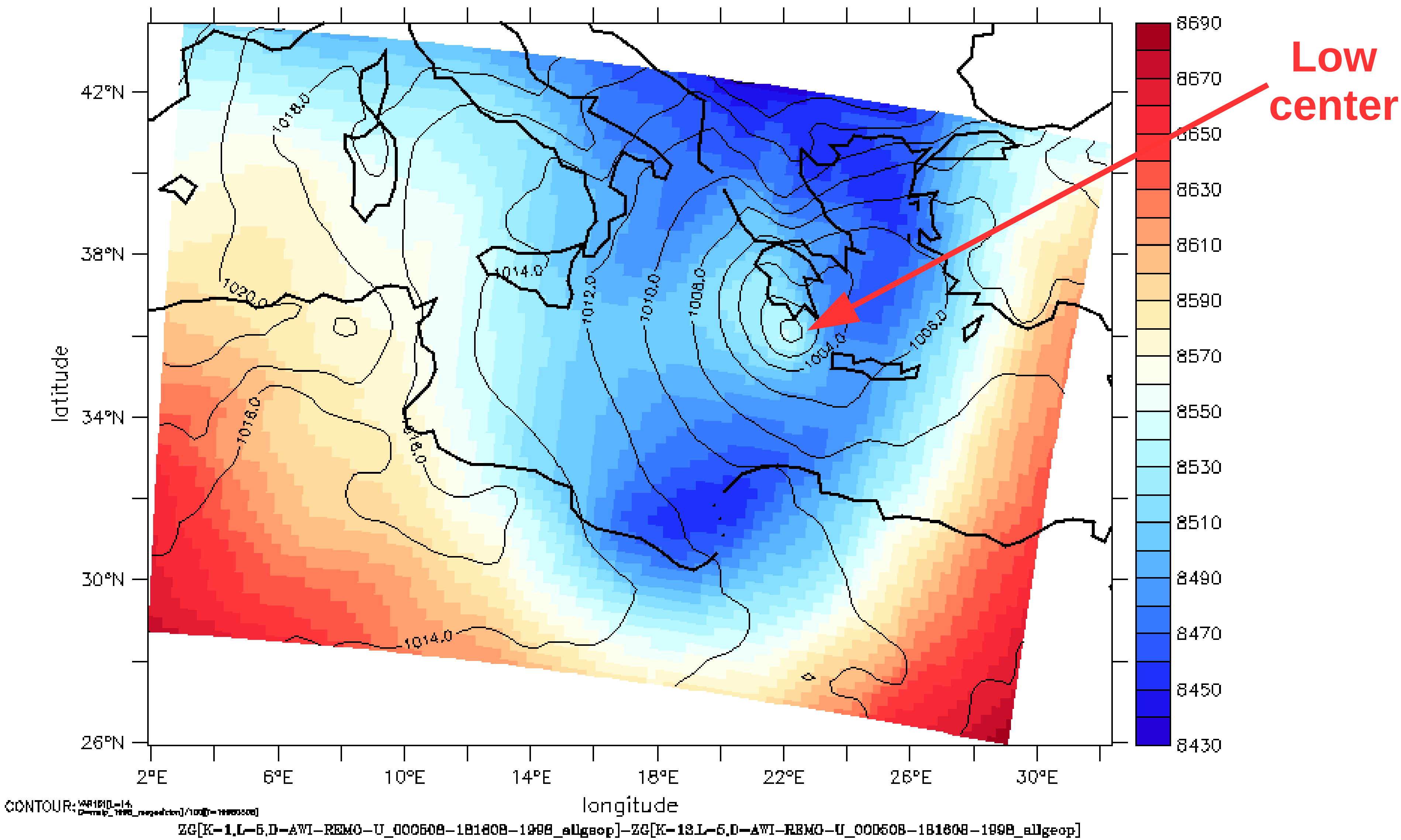
Contours: SLP (hPa); Coloured shading: 900-300 hPa geopotential thickness

Important added value of coupling



Uncoupled RCM past climate simulation: 6th August
Contours: SLP (hPa); Coloured shading: 900-300 hPa geopotential difference

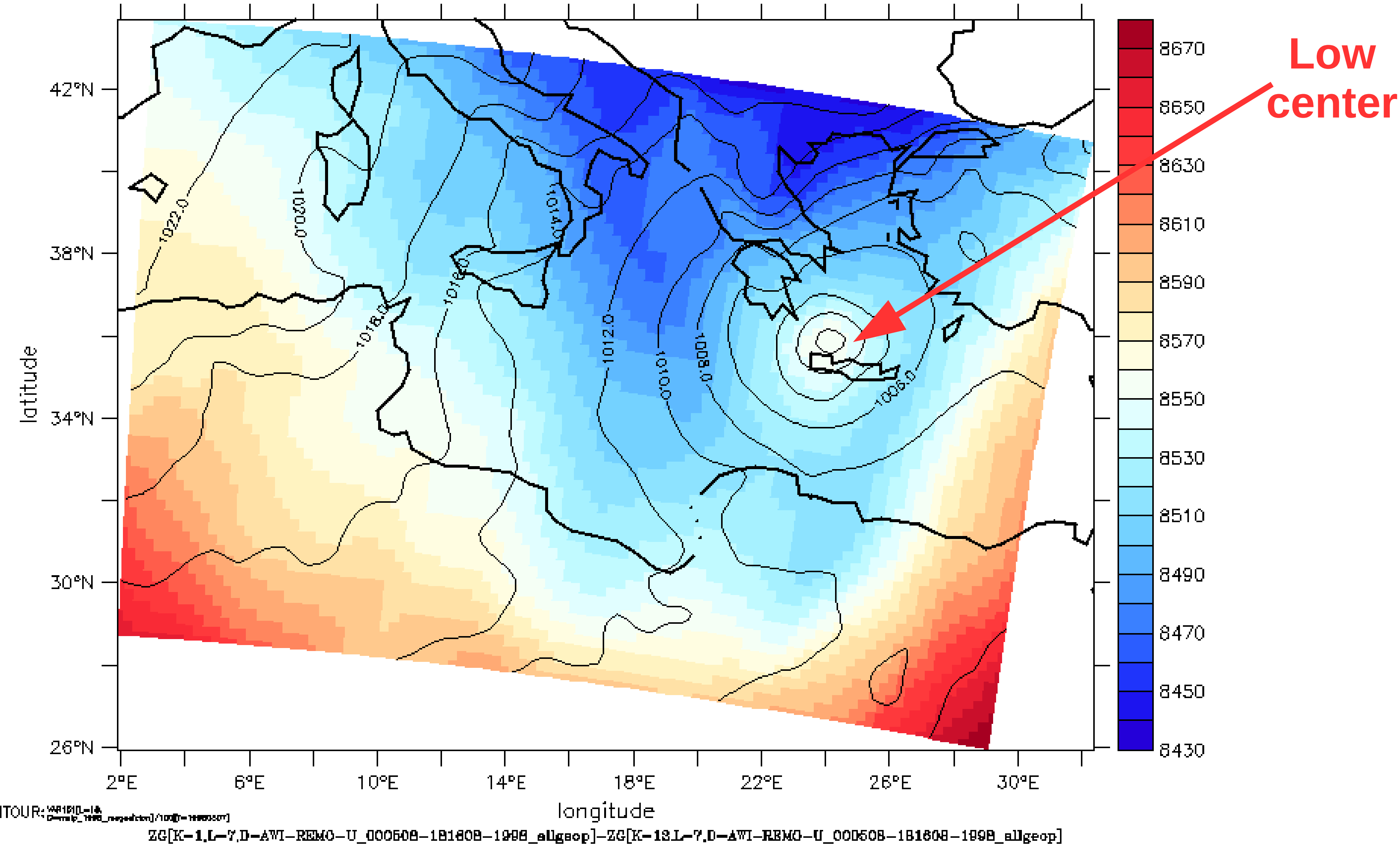
Important added value of coupling



Uncoupled RCM past climate simulation: 6th August

Contours: SLP (hPa); Coloured shading: 900-300 hPa geopotential difference

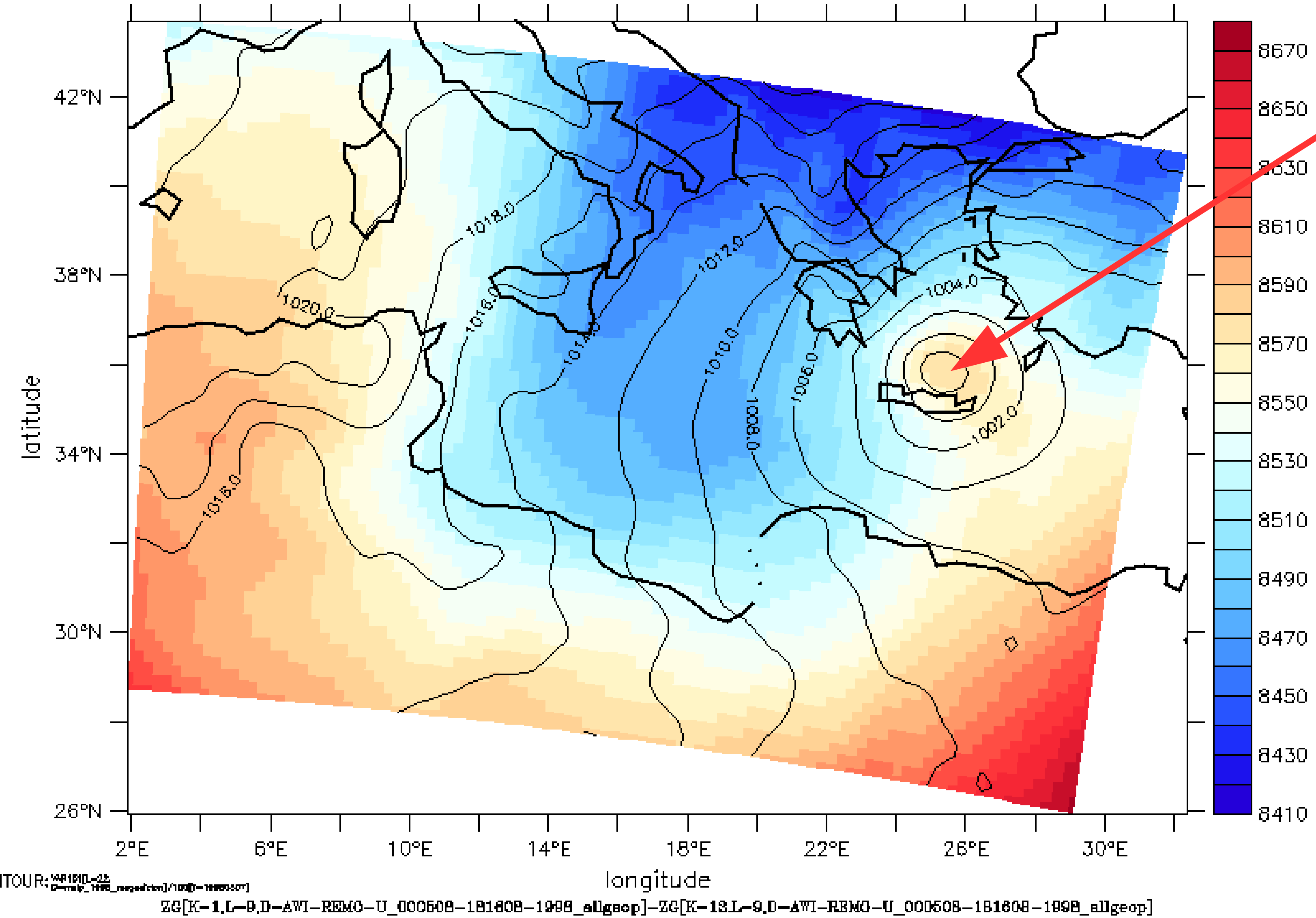
Important added value of coupling



Uncoupled RCM past climate simulation: 7th August

Contours: SLP (hPa); Coloured shading: 900-300 hPa geopotential difference

Important added value of coupling



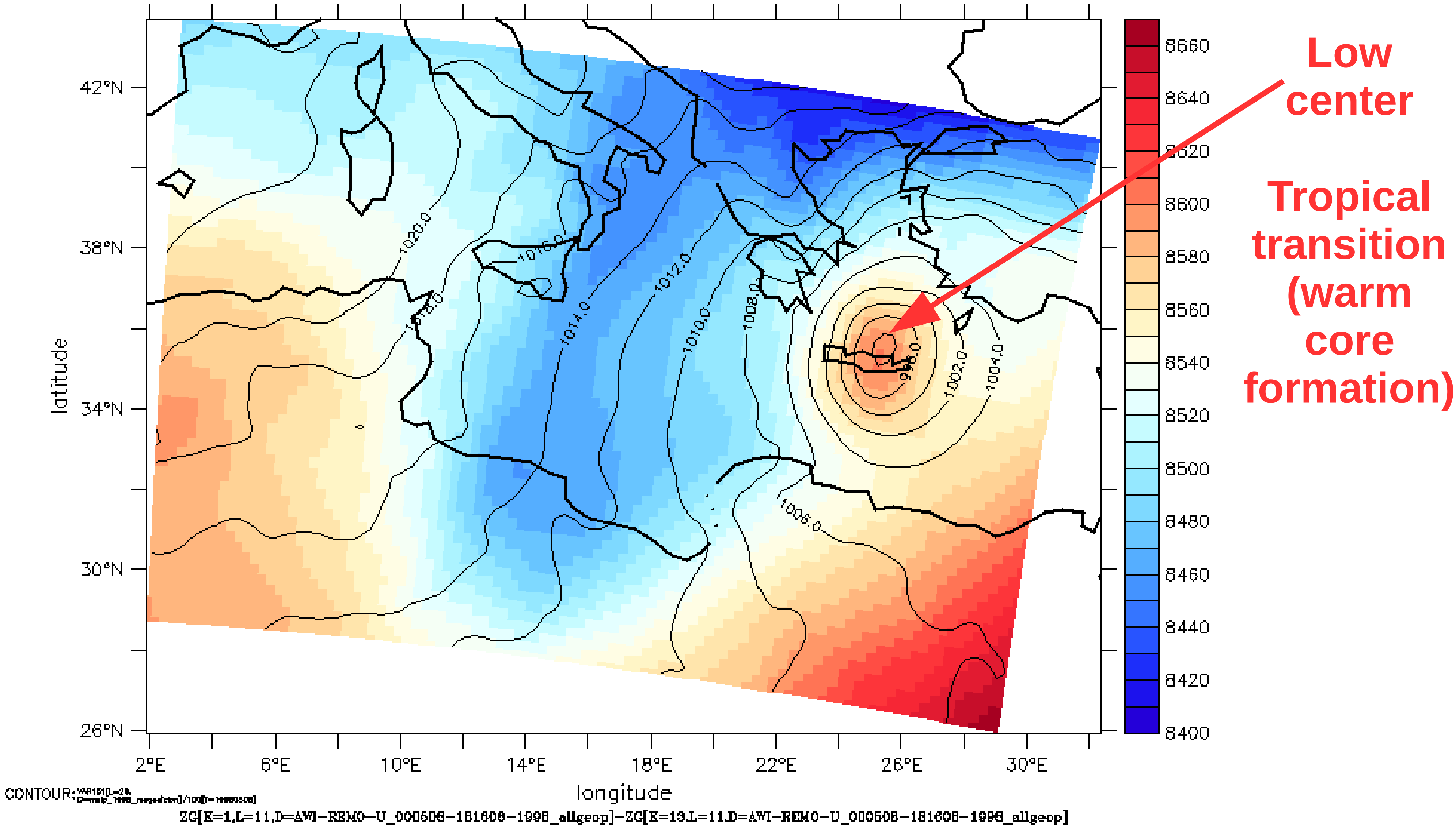
Low center

Tropical transition (warm core formation)

Uncoupled RCM past climate simulation: 7th August

Contours: SLP (hPa); Coloured shading: 900-300 hPa geopotential difference

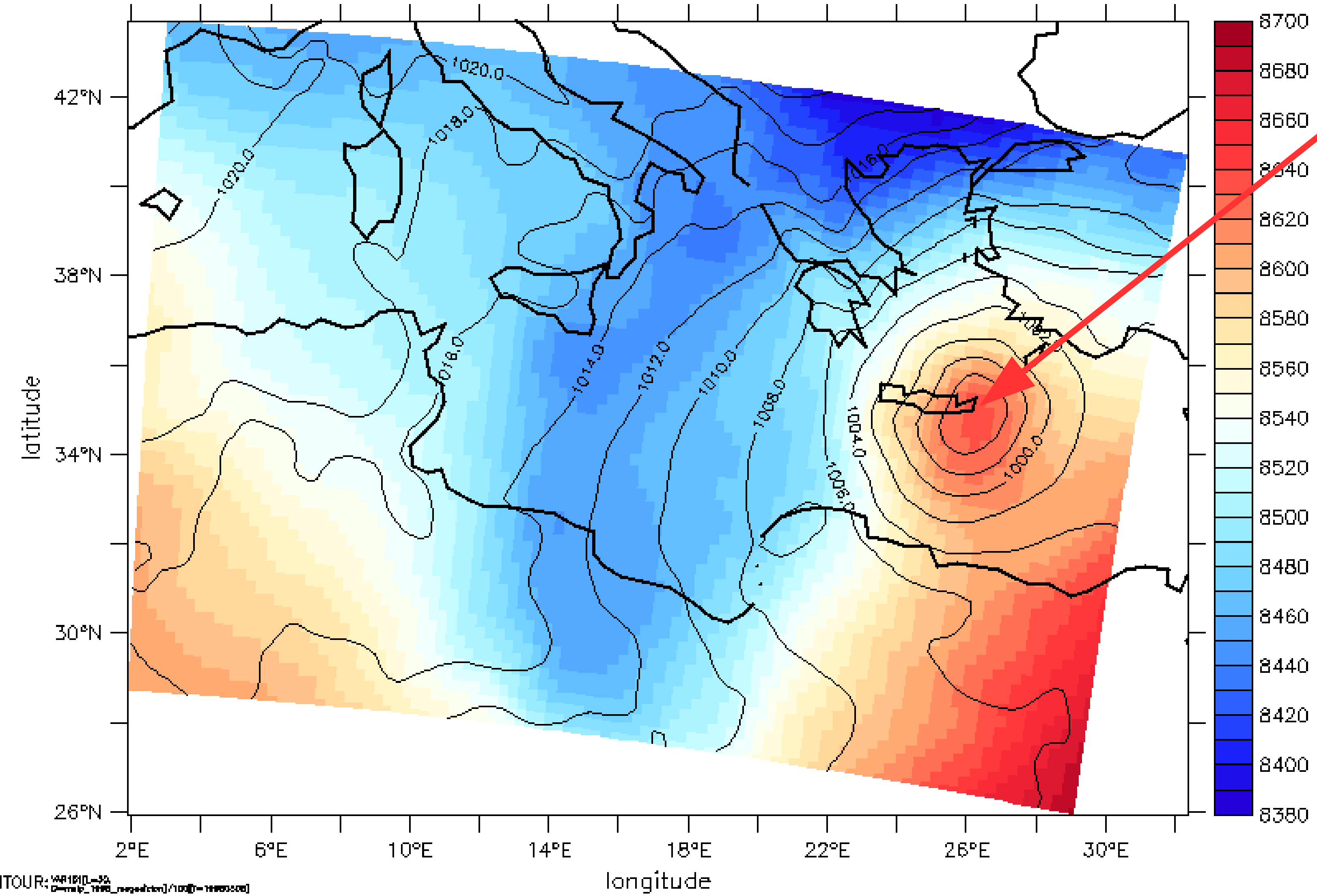
Important added value of coupling



Uncoupled RCM past climate simulation: 8th August

Contours: SLP (hPa); Coloured shading: 900-300 hPa geopotential difference

Important added value of coupling



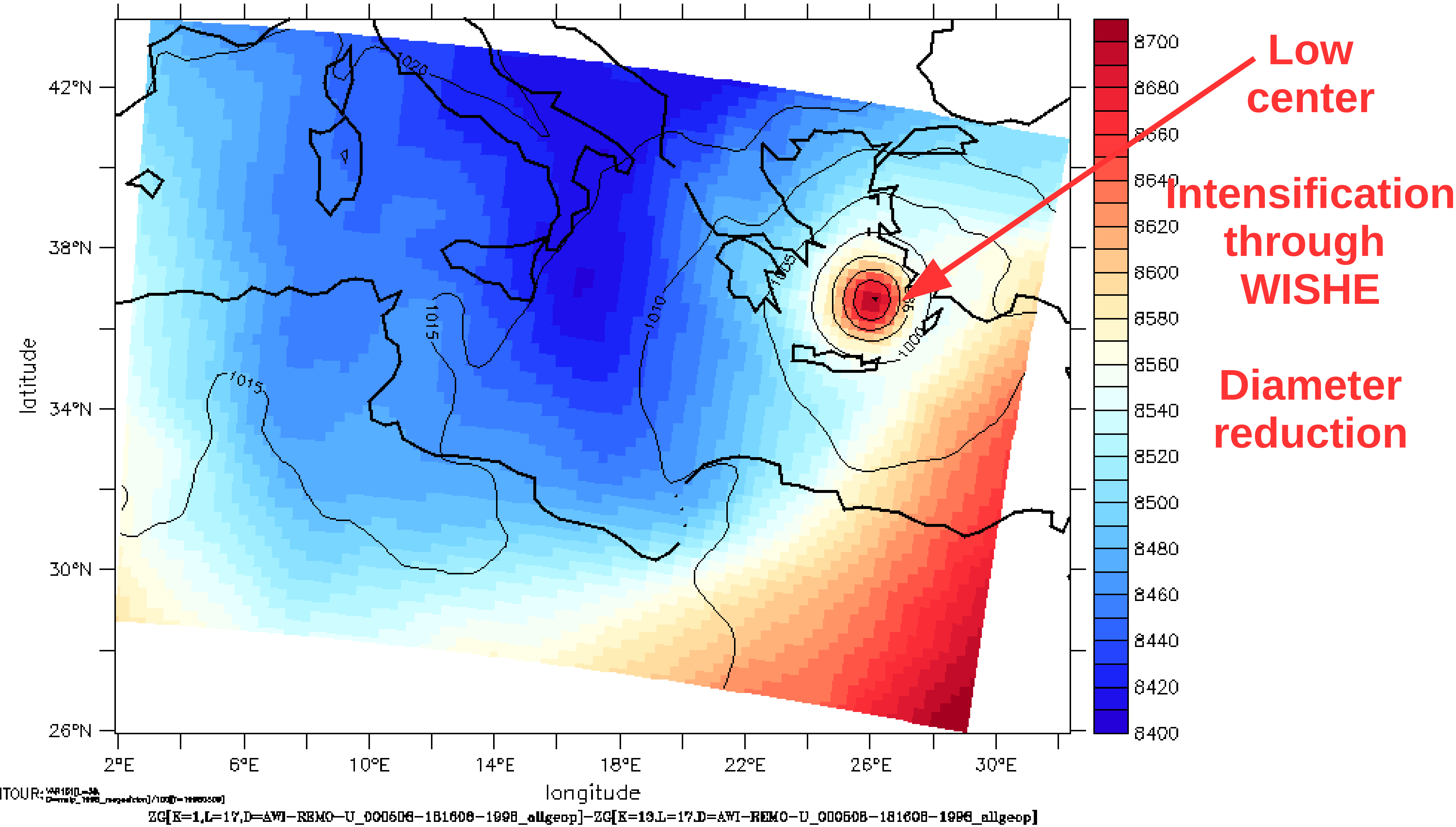
Low center

Tropical transition (warm core formation)

Uncoupled RCM past climate simulation: 8th August

Contours: SLP (hPa); Coloured shading: 900-300 hPa geopotential difference

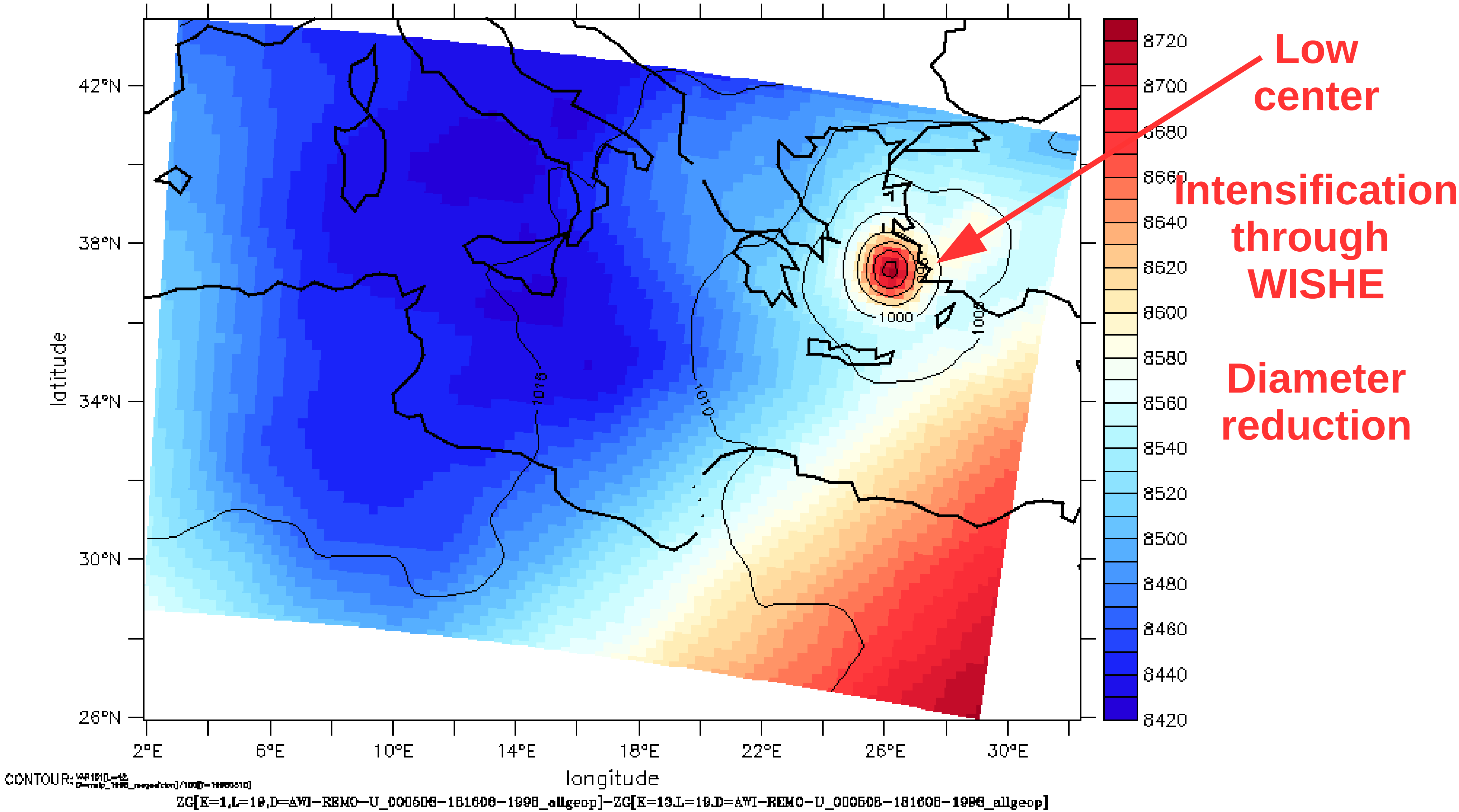
Important added value of coupling



Uncoupled RCM past climate simulation: 9th August

Contours: SLP (hPa); Coloured shading: 900-300 hPa geopotential difference

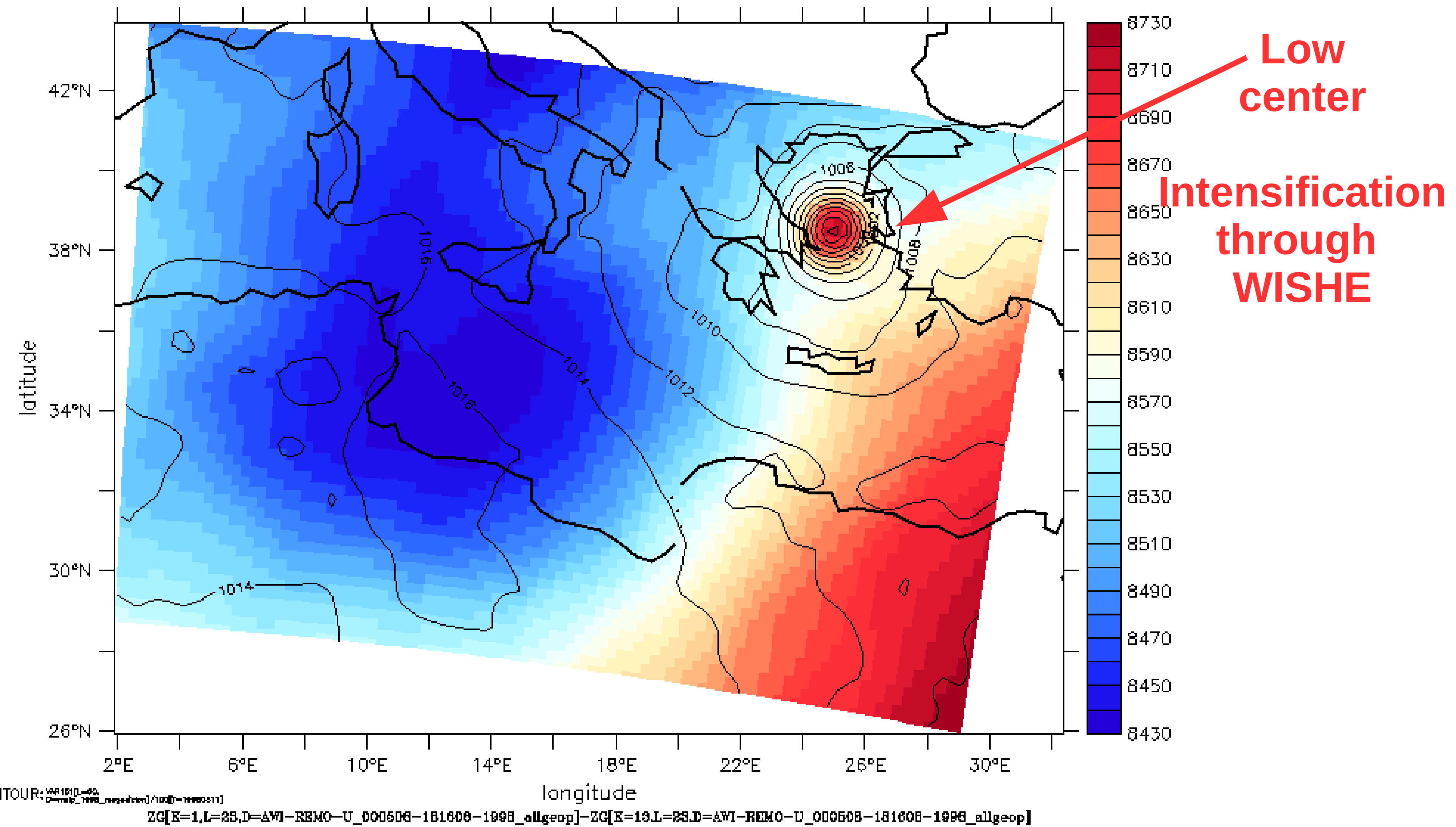
Important added value of coupling



Uncoupled RCM past climate simulation: 10th August

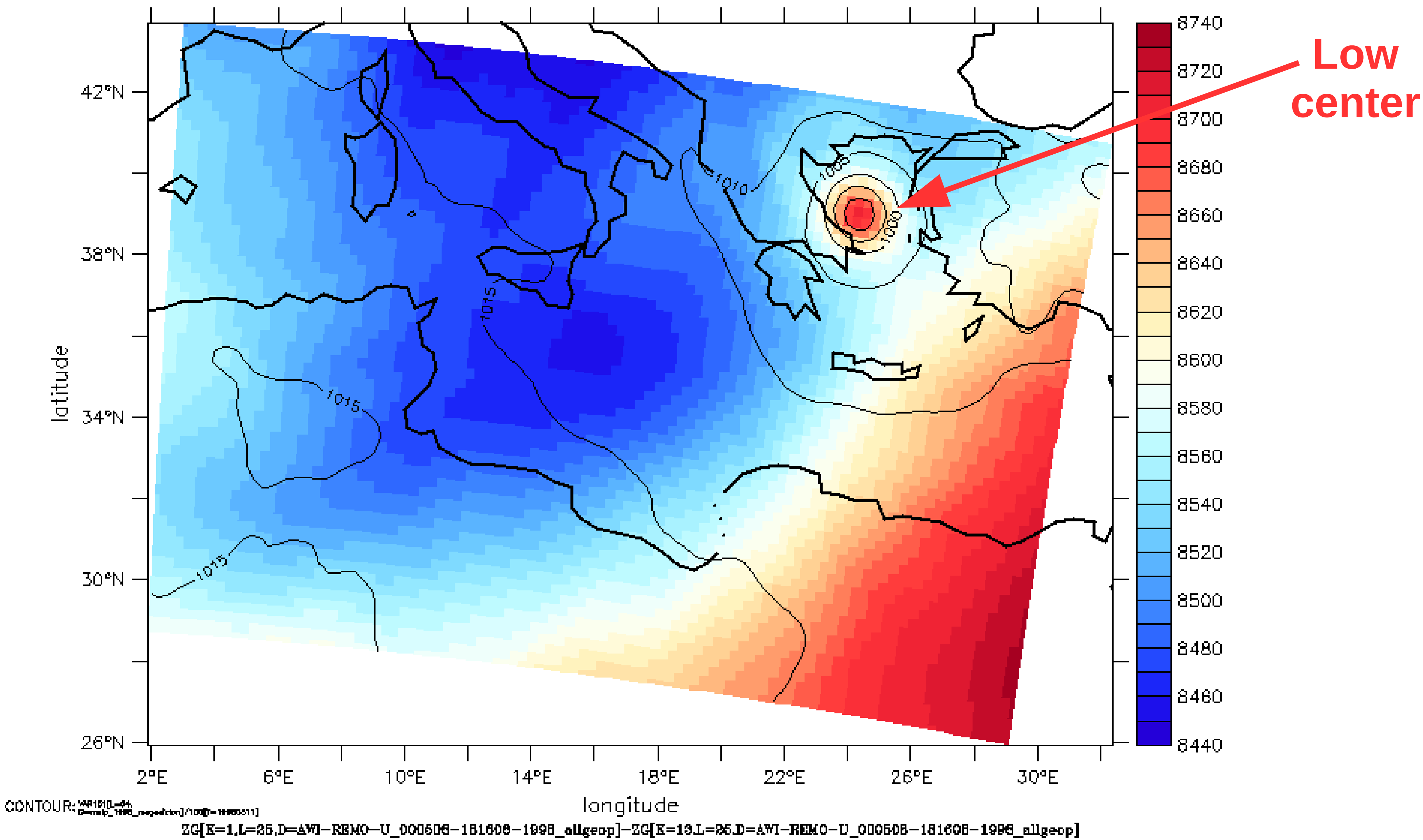
Contours: SLP (hPa); Coloured shading: 900-300 hPa geopotential difference

Important added value of coupling



Uncoupled RCM past climate simulation: 11th August
Contours: SLP (hPa); Coloured shading: 900-300 hPa geopotential difference

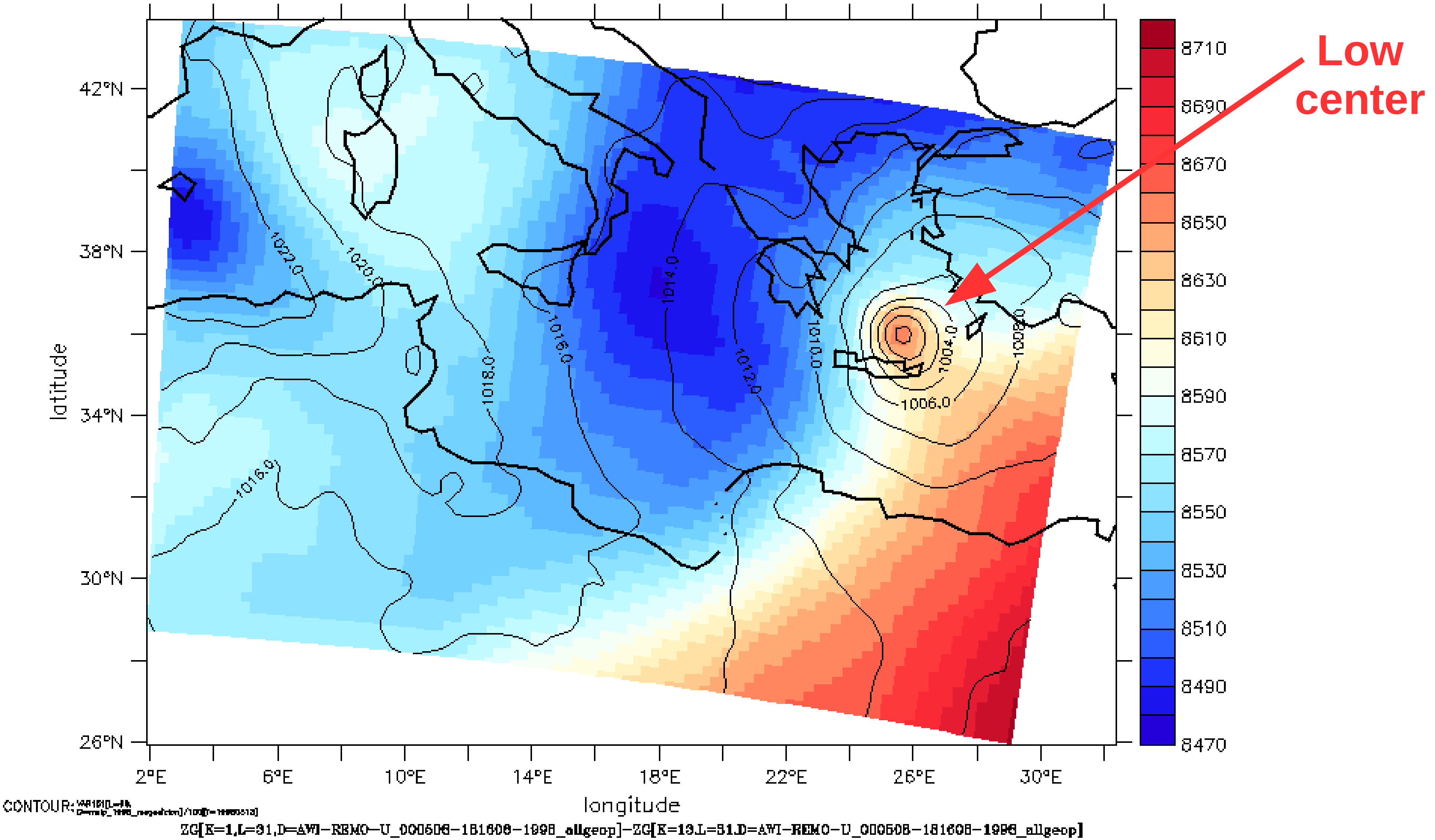
Important added value of coupling



Uncoupled RCM past climate simulation: 12th August

Contours: SLP (hPa); Coloured shading: 900-300 hPa geopotential difference

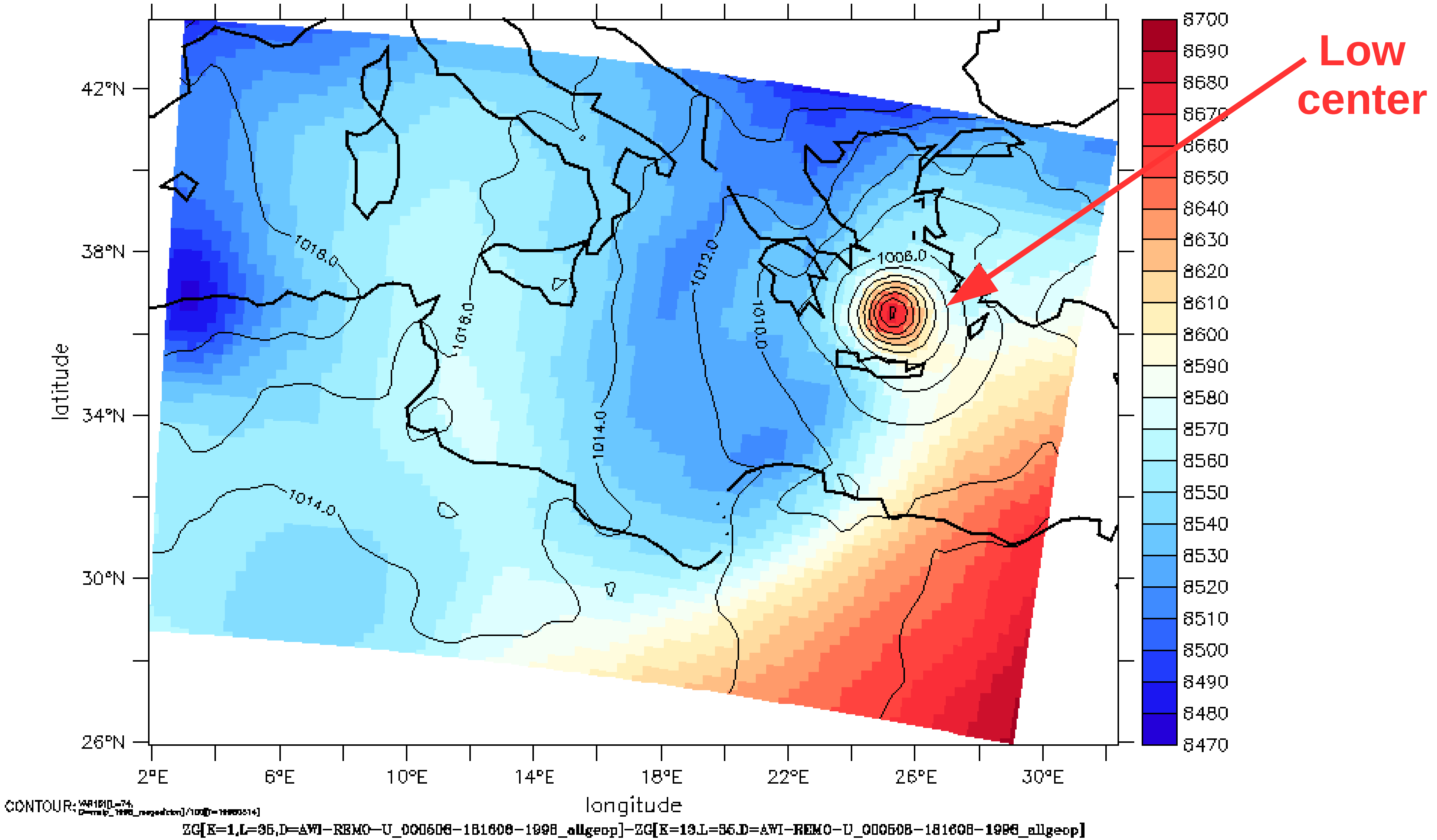
Important added value of coupling



Uncoupled RCM past climate simulation: 13th August

Contours: SLP (hPa); Coloured shading: 900-300 hPa geopotential difference

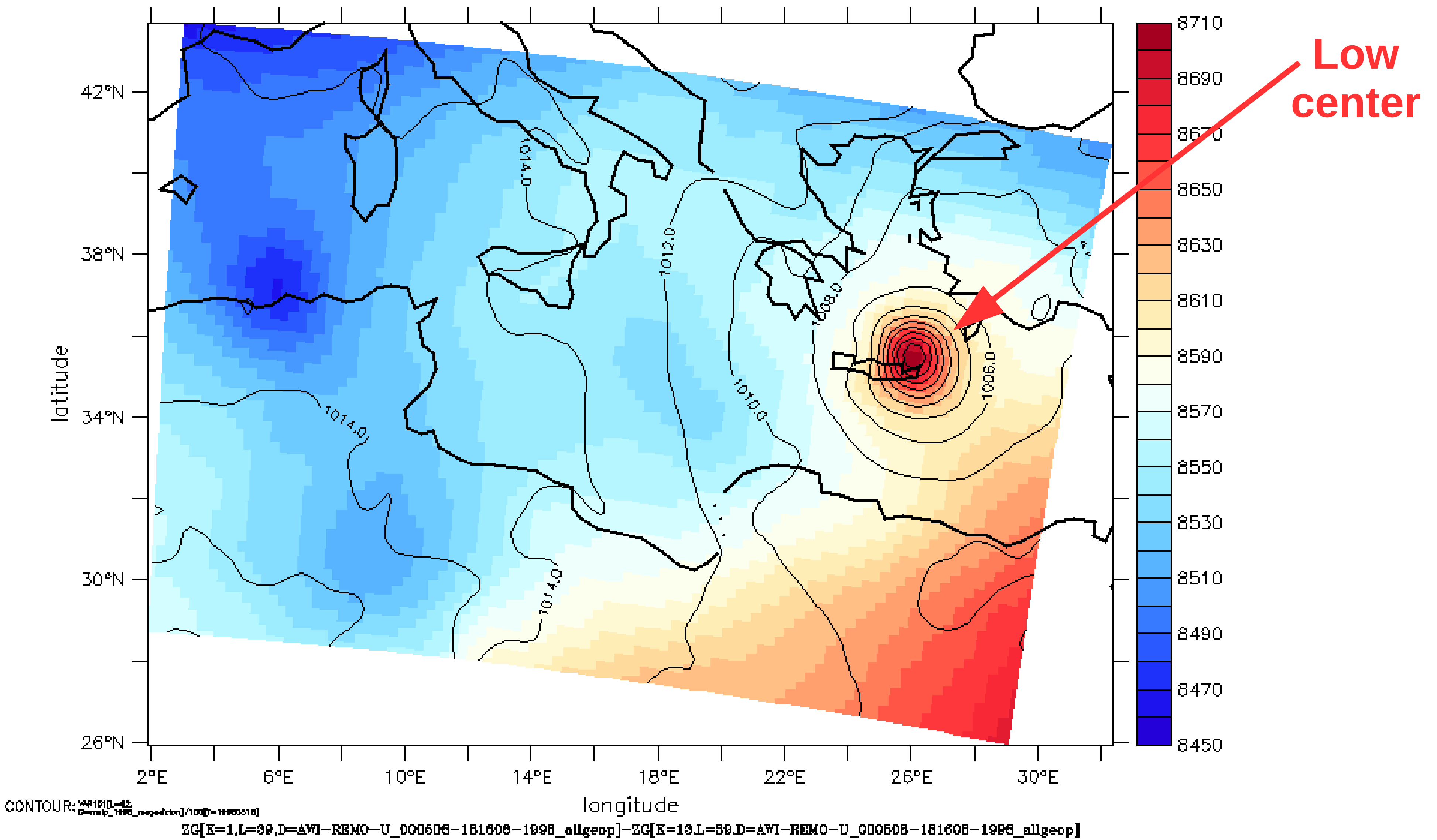
Important added value of coupling



Uncoupled RCM past climate simulation: 14th August

Contours: SLP (hPa); Coloured shading: 900-300 hPa geopotential difference

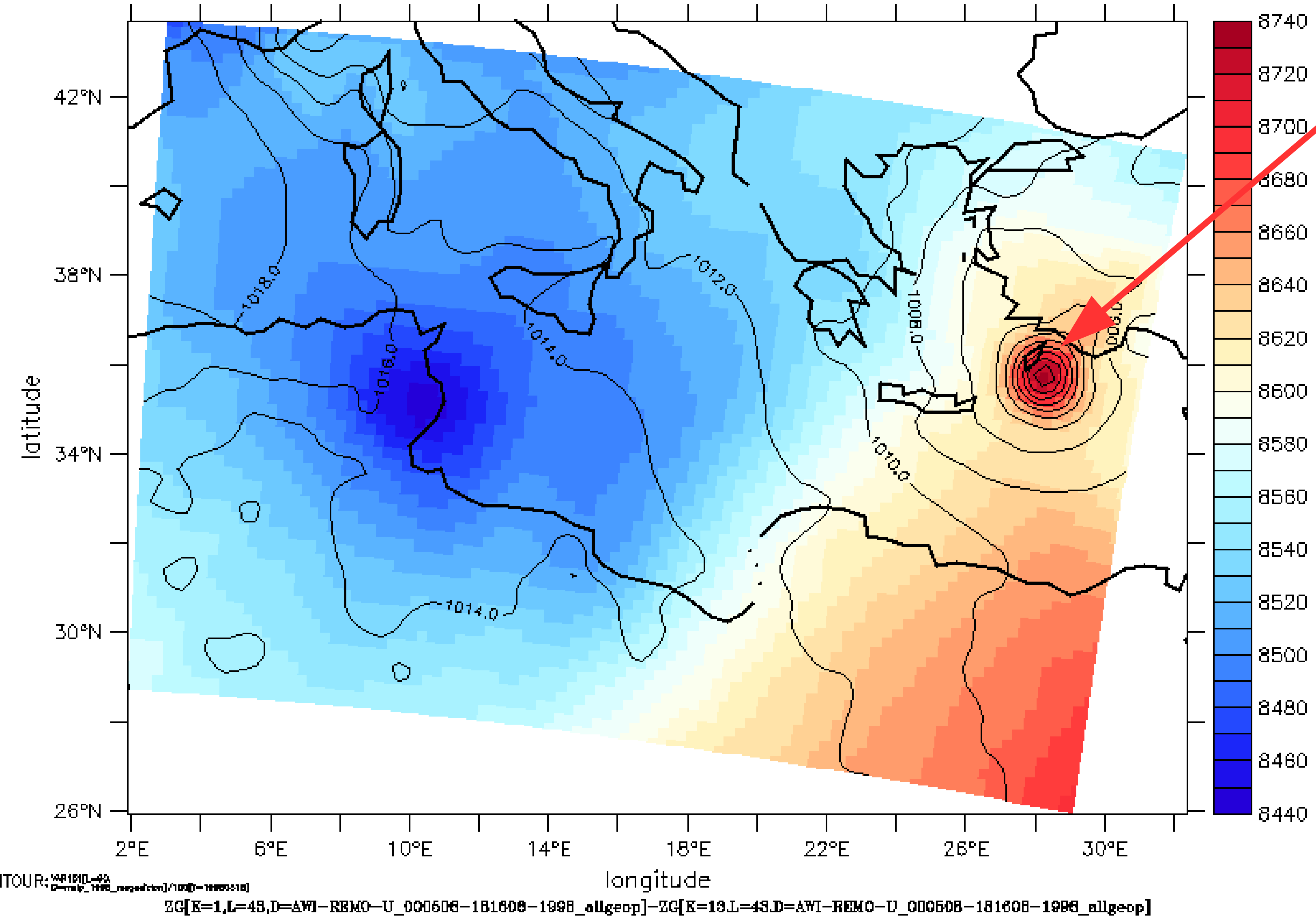
Important added value of coupling



Uncoupled RCM past climate simulation: 15th August

Contours: SLP (hPa); Coloured shading: 900-300 hPa geopotential difference

Important added value of coupling



Low center

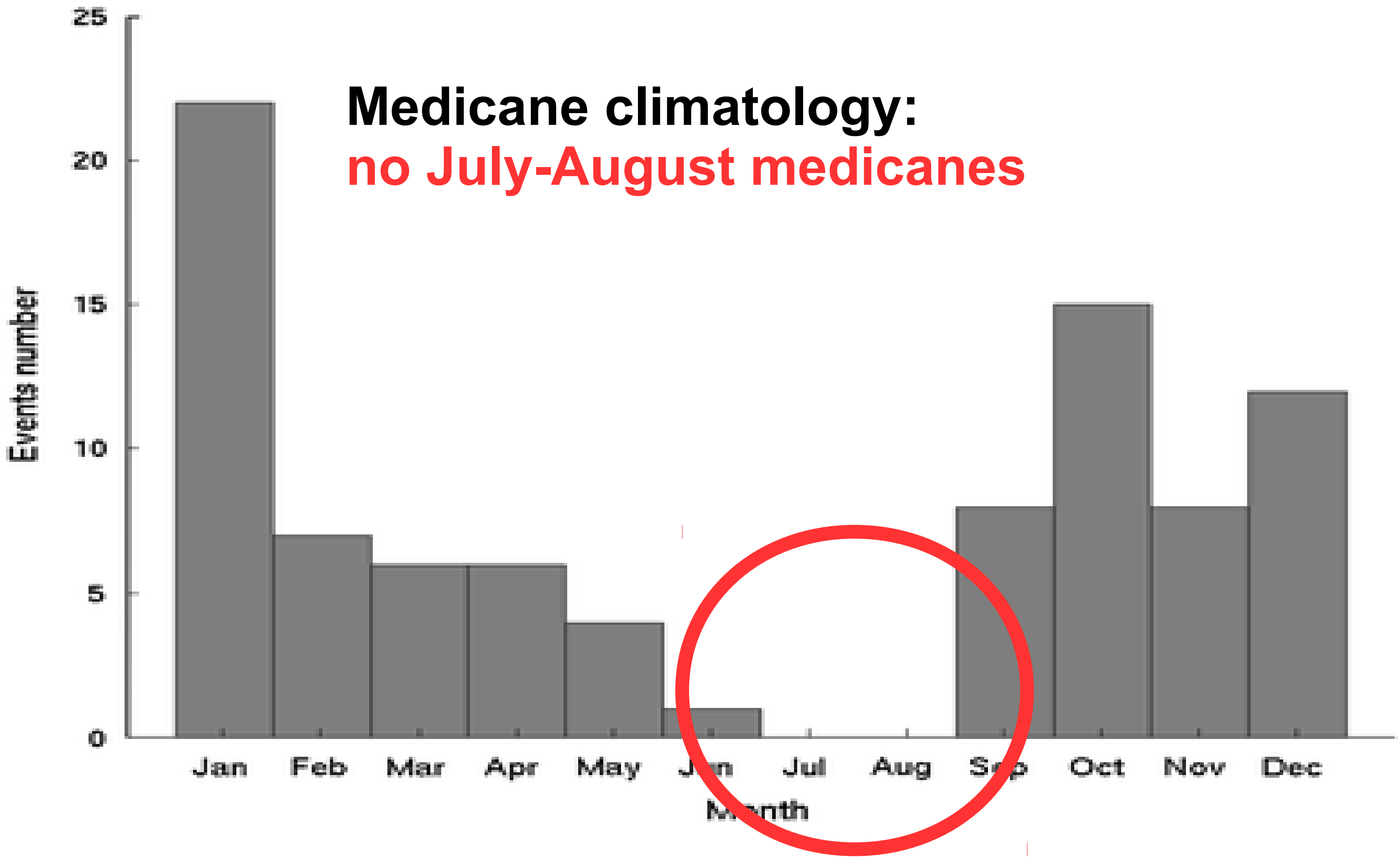
Deep warm core during more than a week

Uncoupled RCM past climate simulation: 16th August

Contours: SLP (hPa); Coloured shading: 900-300 hPa geopotential difference

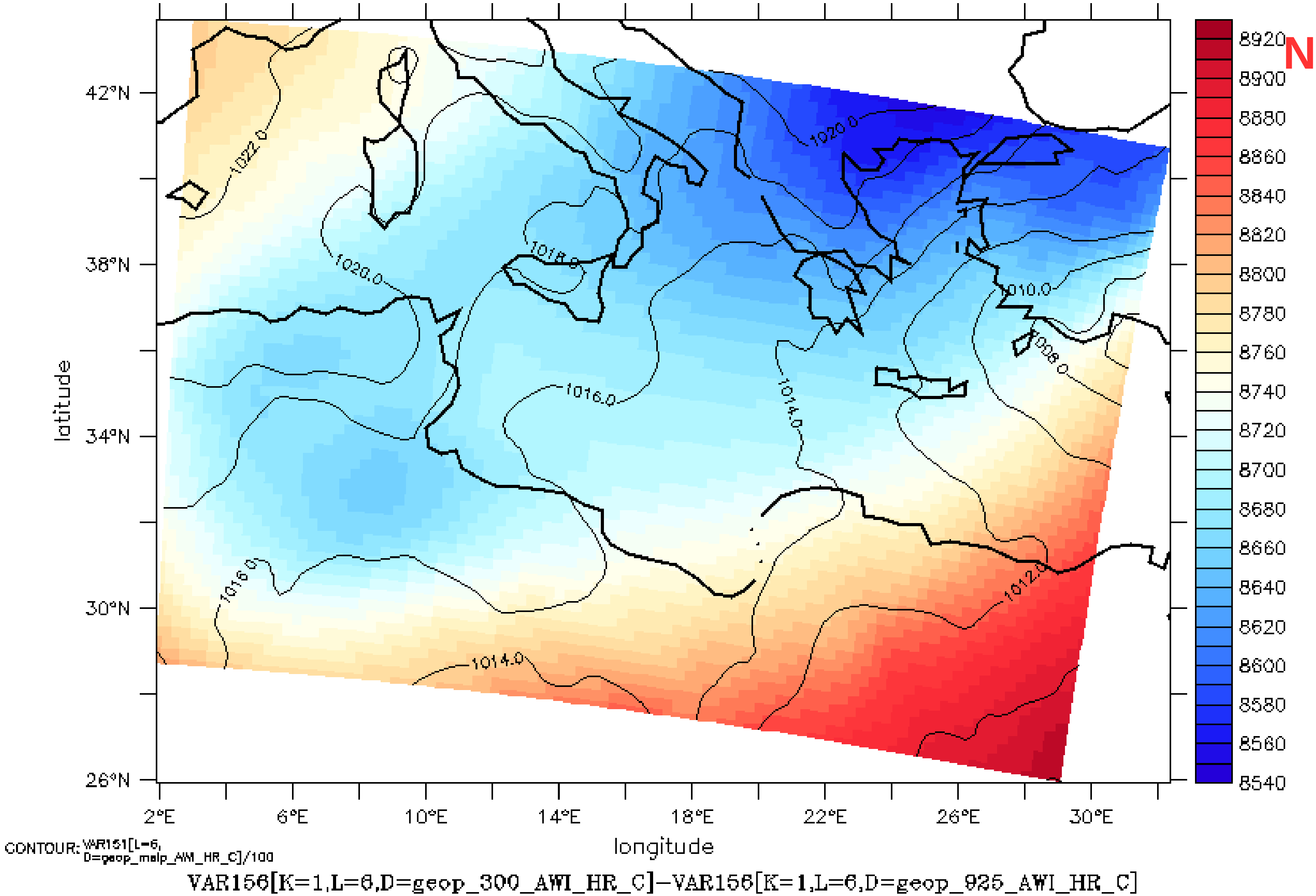
Important added value of coupling

- This remarkable development of a very strong August medicane is problematic: it is not realistic



Cavicchia et al. (2014), Figure 3:
Number of medicanes per months (total number in period 1948-2011)

Important added value of coupling

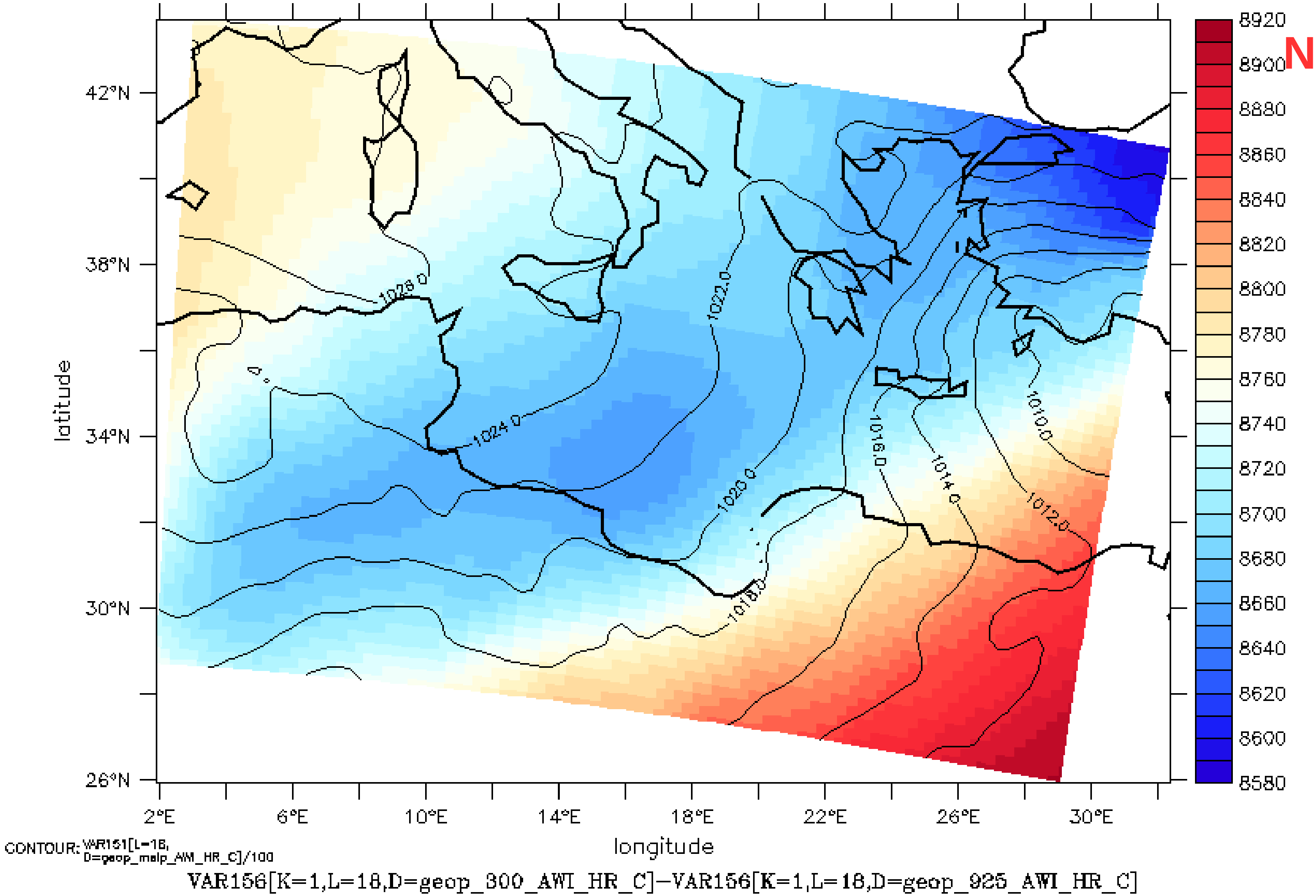


No low center develops in coupled run

Coupled RCM past climate simulation: 5th August

Contours: SLP (hPa); Coloured shading: 925-300 hPa geopotential difference

Important added value of coupling

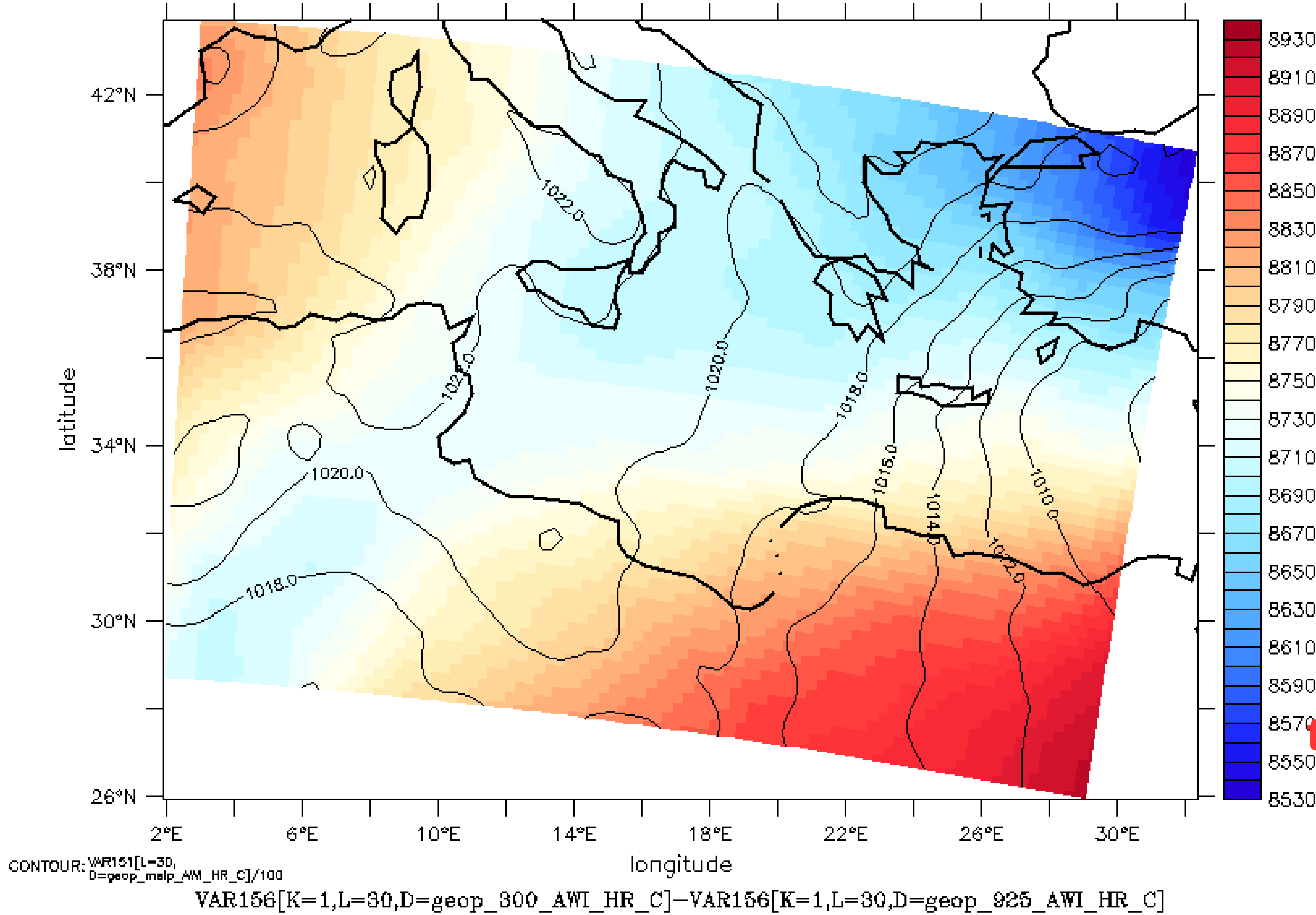


No low center develops in coupled run

Coupled RCM past climate simulation: 6th August

Contours: SLP (hPa); Coloured shading: 925-300 hPa geopotential difference

Important added value of coupling



No low center develops in coupled run

At this moment, a warm core cyclone had already developed in the uncoupled run

Coupled RCM past climate simulation: 8th August

Contours: SLP (hPa); Coloured shading: 925-300 hPa geopotential difference

The coupled run avoids the development of the unrealistic August medicane

Several possible reasons for this individual case:

- Very shallow mixed layer: strong negative feedback if cyclone forms and intensifies

- Lower SSTs in coupled run

- Internal variability (Sánchez-Gómez, 2016)

Why are cases like this important in climate studies?

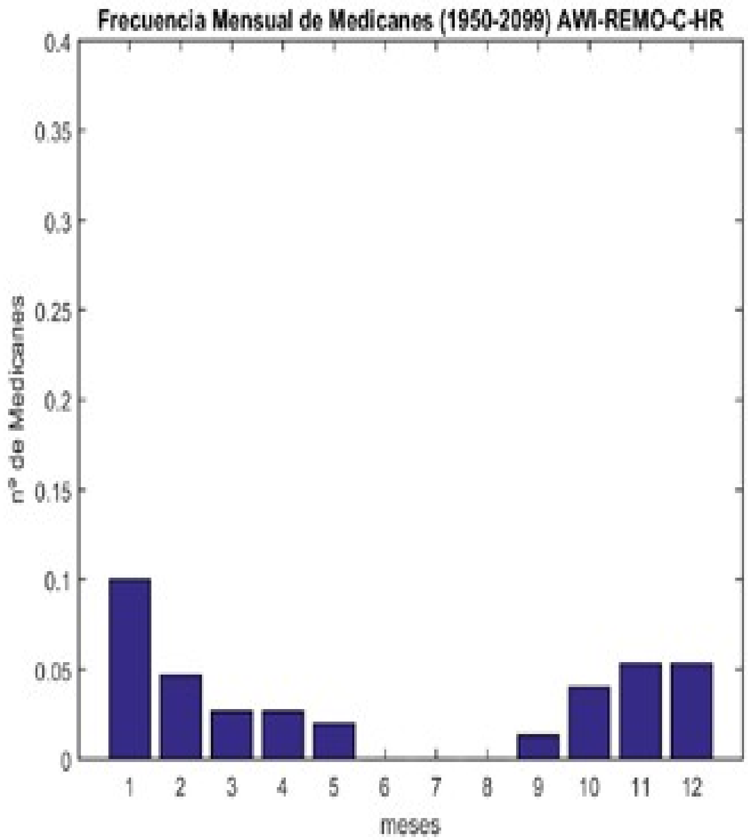
- High-end extremes cause the largest negative impacts

- The presence of unrealistic strong summer medicanes in uncoupled climate change simulations could distort future intensity tendencies

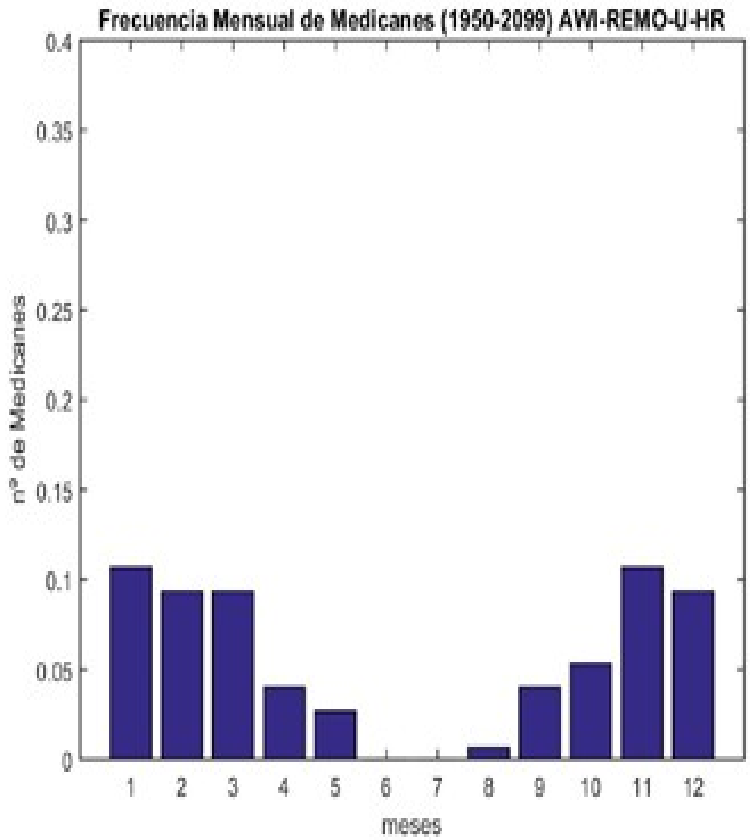
Why does the coupled run avoid the development of such an unrealistic medicane?

- Despite other possible explanations in this particular case, there is a clear overall seasonal change in the coupled run, suggesting an influence of mixed layer depth

Coupled run



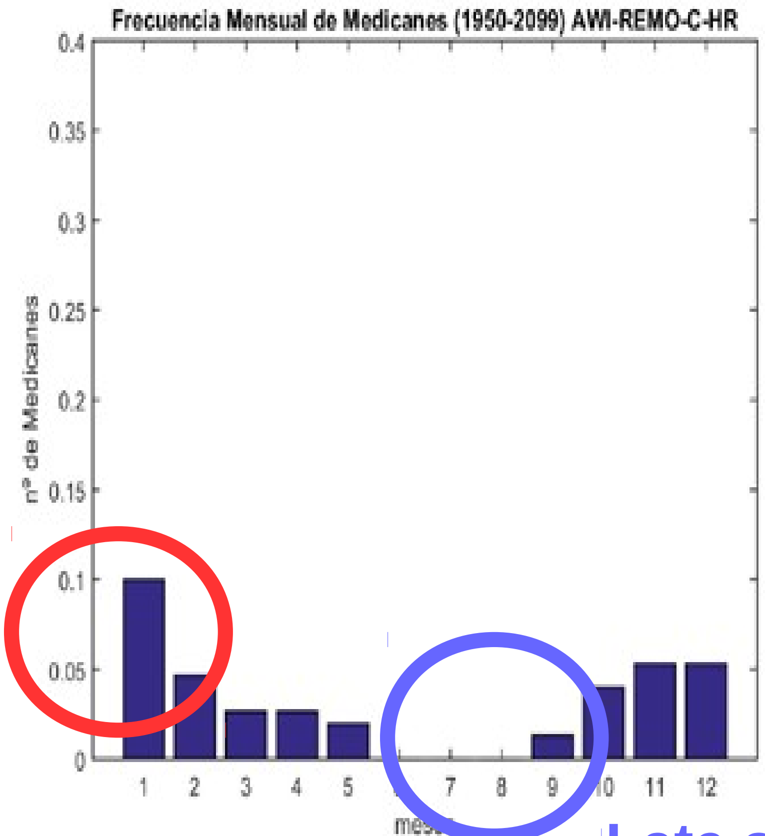
Uncoupled run



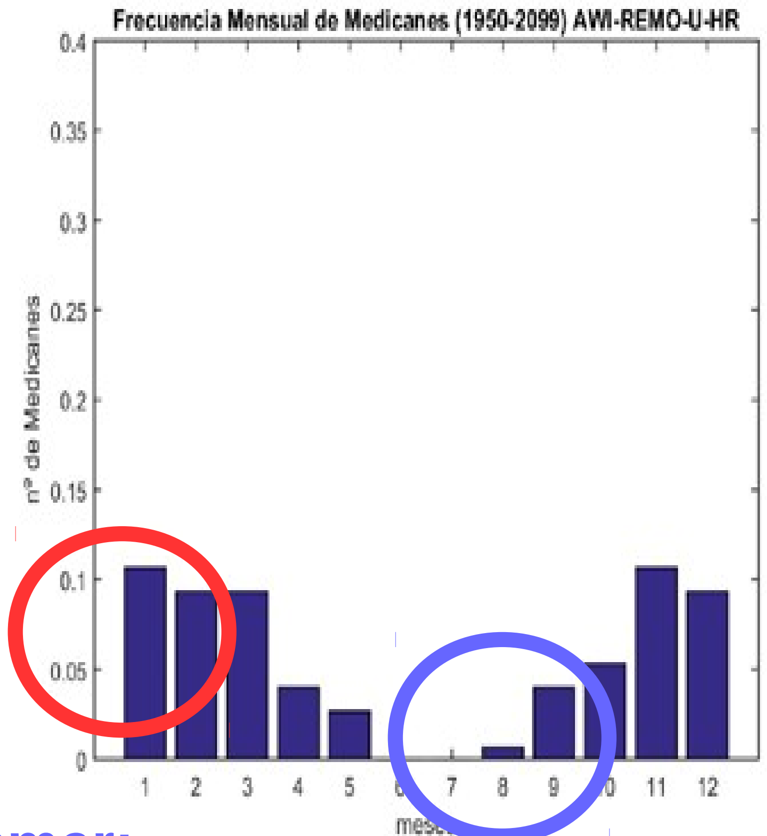
Why does the coupled run avoid the development of such an unrealistic medicane?

- Despite other possible explanations in this particular case, there is a clear seasonal change in the coupled run, suggesting an influence of mixed layer depth

Coupled run



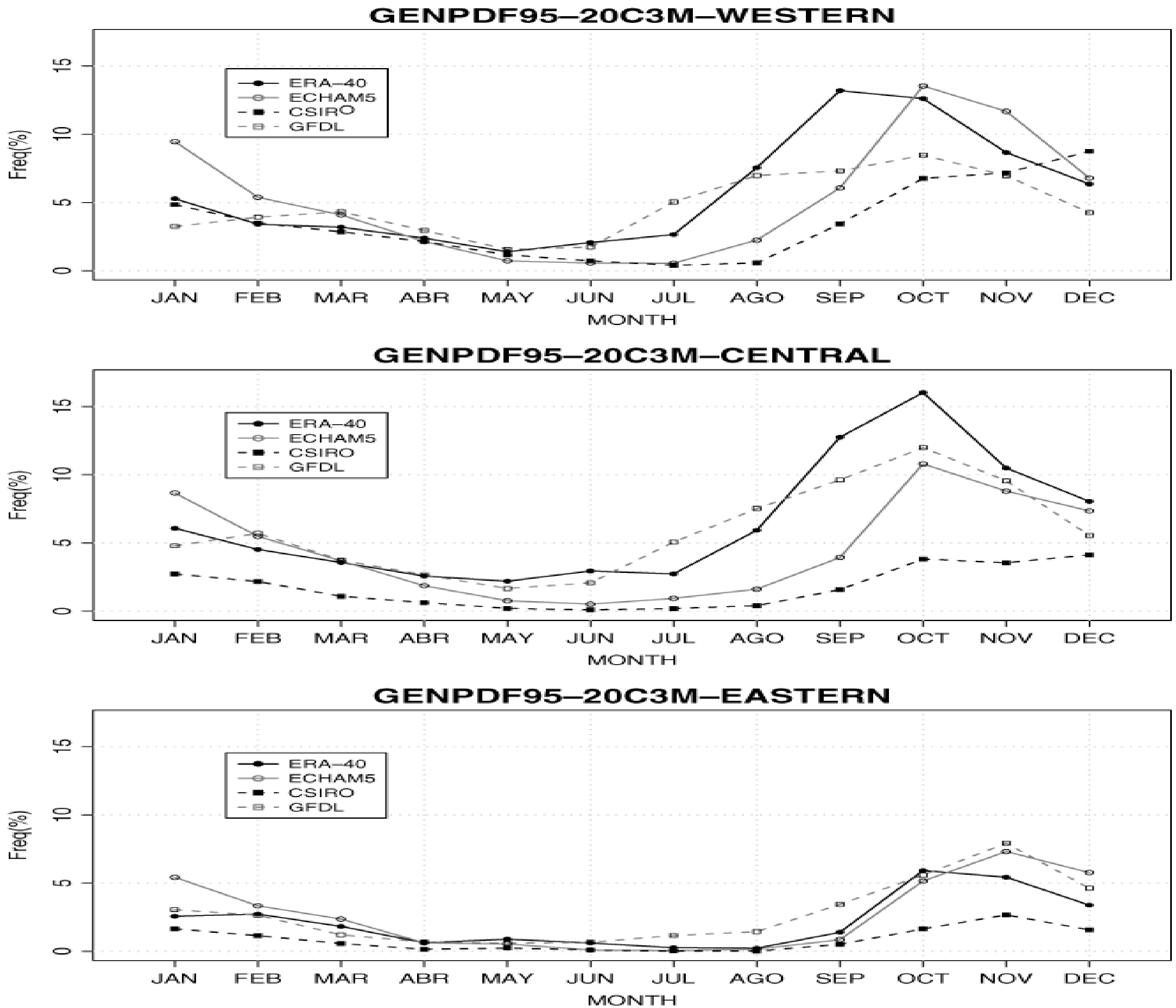
Uncoupled run



January: almost no change

Late summer: clear frequency decrease

Genesis potential (tropical cyclones) applied to medicane environments – past climate



Tous et al. (2012), fig. 8: Monthly mean frequency of days with high values of genesis potential (ERA-40 and 3 GCMs)

Genesis potential:

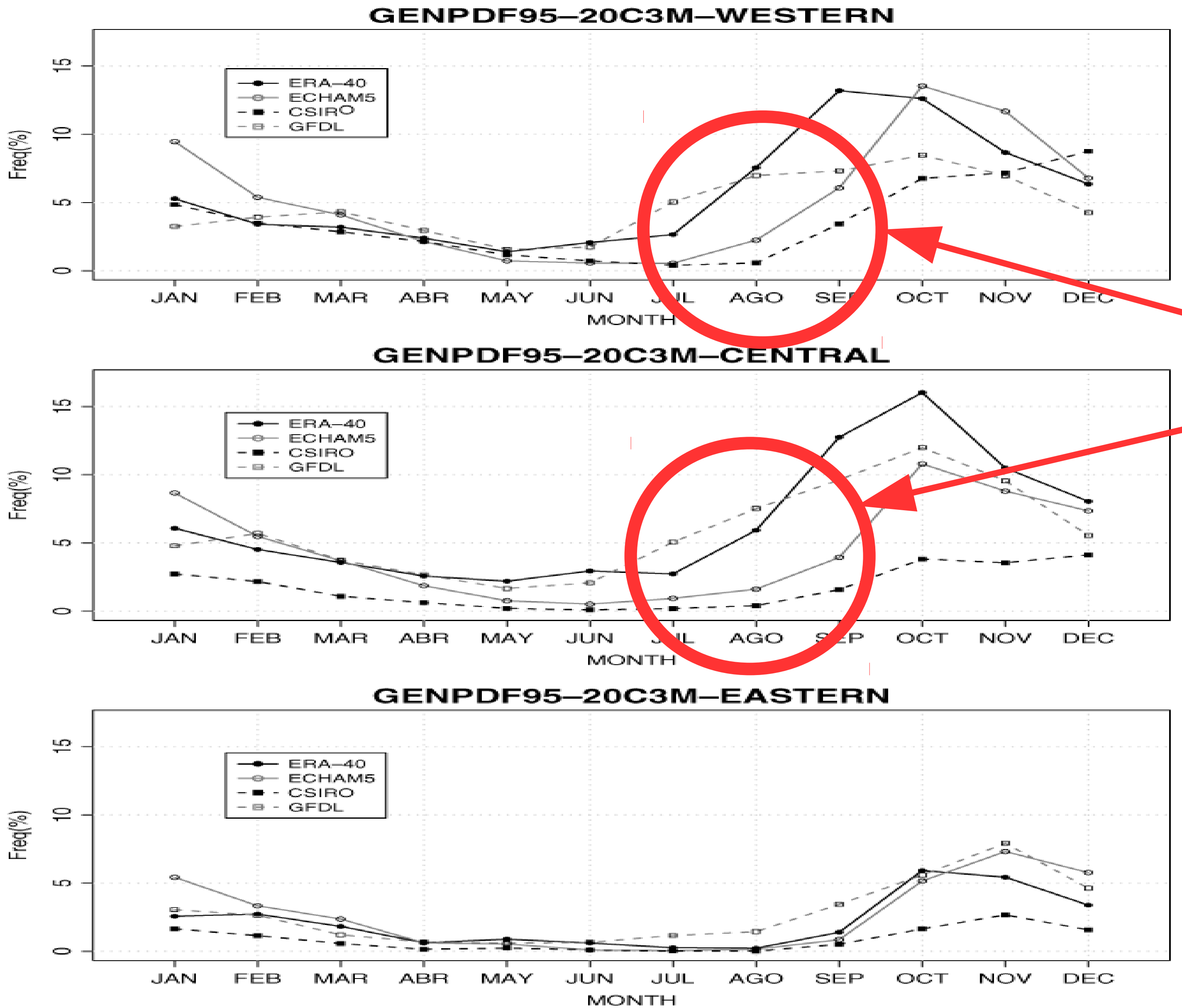
850 hPa vorticity

600 hPa relative humidity

Vertical wind shear

Potential intensity (SST, high altitude temperature)

Genesis potential (tropical cyclones) applied to medicane environments – past climate



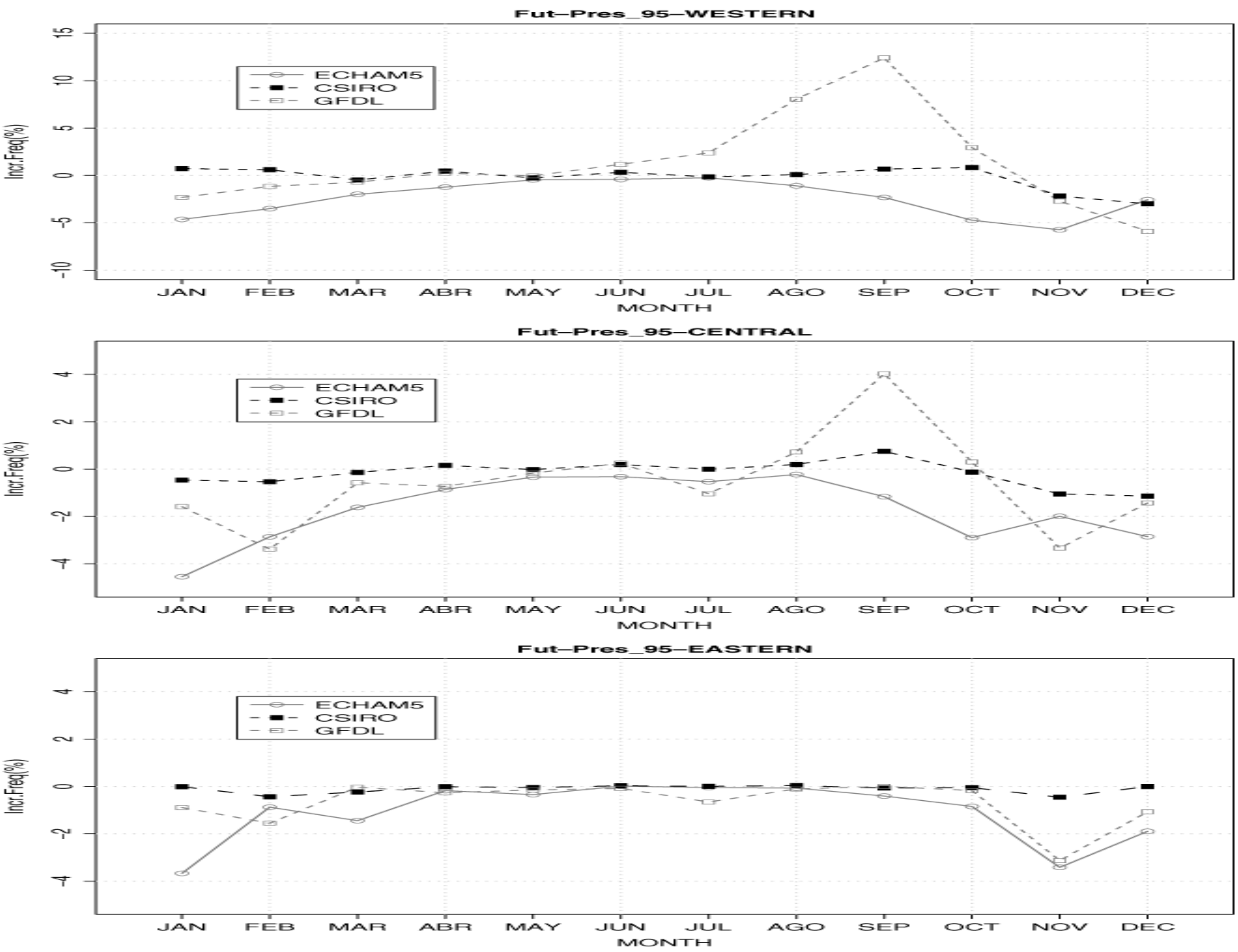
Genesis potential:

ERA-40 data show high values in August (well reproduced in GFDL model)

Uncoupled runs driven by such environmental fields could simulate August medicanes

Tous et al. (2012), fig. 8: Monthly mean frequency of days with high values of genesis potential (ERA-40 and 3 GCMs)

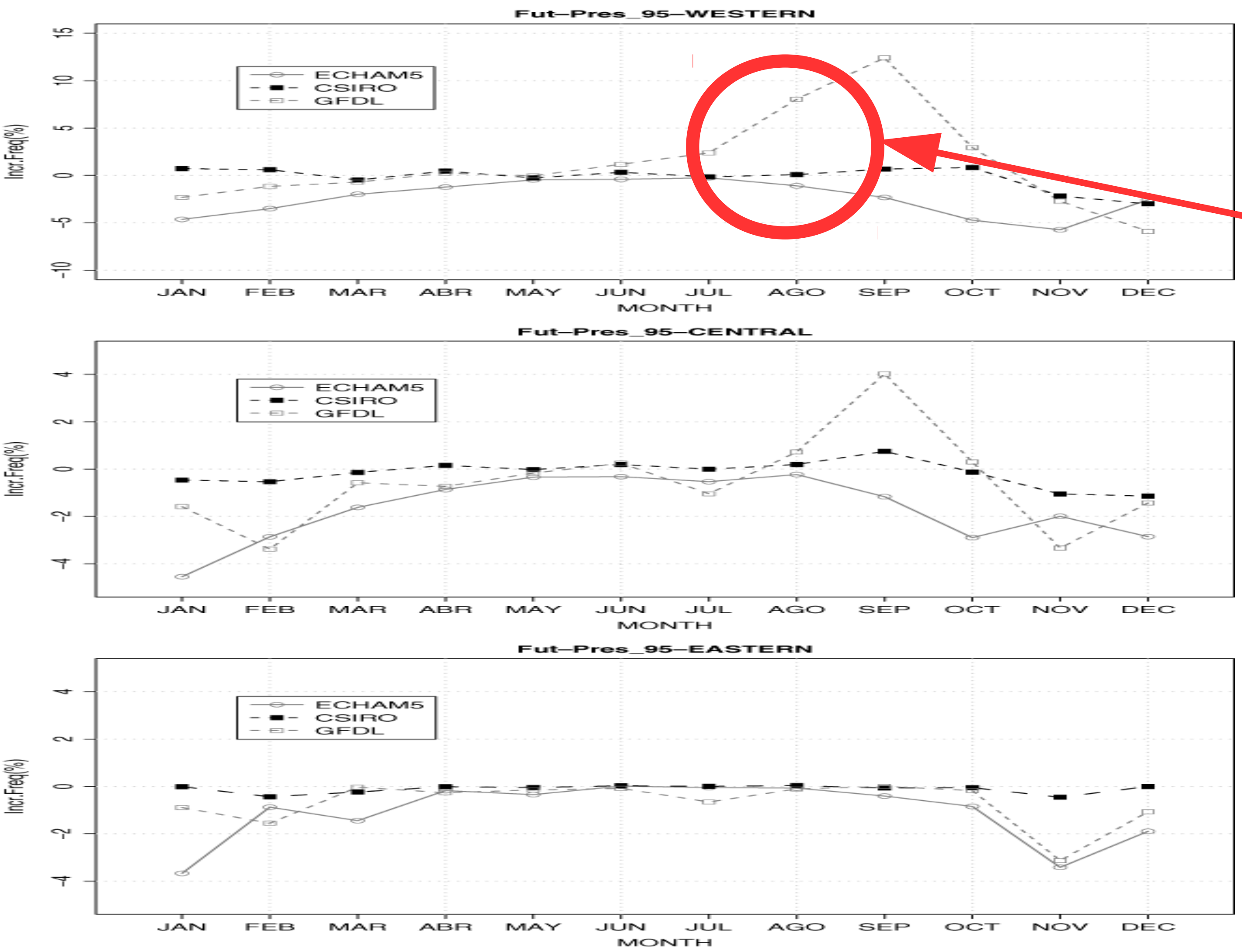
Genesis potential (tropical cyclones) applied to medicane environments – future climate



Future change in genesis potential

Tous et al. (2012), fig. 9: Future change of monthly mean frequency of days with high values of genesis potential (ERA-40 and 3 GCMs)

Genesis potential (tropical cyclones) applied to medicane environments – future climate



GFDL increases genesis potential in August for future climate for part of the Mediterranean

Uncoupled runs driven by such environmental fields could simulate more frequent August medicanes

Tous et al. (2012), fig. 9: Future change of monthly mean frequency of days with high values of genesis potential (3 GCMs)

Concluding remarks

IMPORTANT EFFECT OF AIR-SEA COUPLING ON MEDICANES:

- **Seasonal shift of medicanes from autumn to winter in coupled runs: possibly related to annual cycle of mixed layer depth**

ADDED VALUE OF COUPLING:

- **Realistic restriction on medicane seasonality (no August medicanes)**

- **Avoids the simulation of very intense and long-lasting medicanes over waters with high SST but very shallow mixed layer**

Concluding remarks

IMPACT OF COUPLING ON INTENSITY PROJECTIONS:

- **Uncertain (ongoing work)**
- **Coupled model with good present climate reproduction of intensity shows future intensity increase**

Concluding remarks

POSSIBLE FUTURE IMPROVEMENTS IN THE SIMULATION OF MEDICANES WITH MEDCORDEX-2 RUNS:

- **Higher spatial resolution coupled simulations**
- **Better representation of marine mesoscale features**
- **Higher frequency air-sea coupling**