# Regional climate simulations using the HPC ARIS infrastructure

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# What is climate?

▶   Following the World Meteorological Organization (WMO) 30 years is the classical period for performing the statistics used to define climate.

▶ Climate in a particular region must contain an analysis of **mean** conditions, probability of **extremes** and **frequencies**.

▶ While weather captures the atmosphere's short-term behavior, climate sums up its long-term behavior.

▶ Climate depends on components of the Earth system:

atmosphere, hydrosphere, biosphere, cryosphere, lithosphere

and anthropogenic activities.
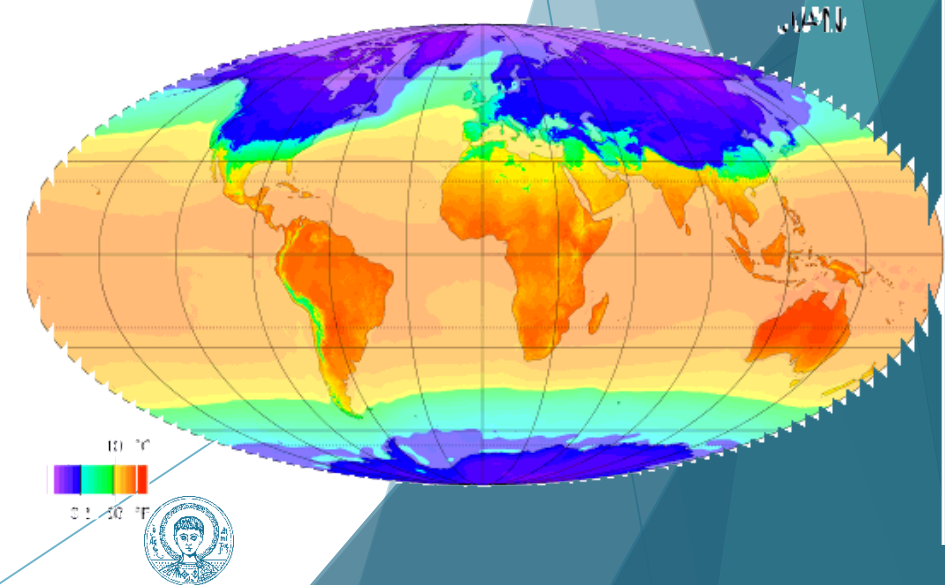
# Why is climate important?

- Climate and climate change is important because it affects:
  - food production
  - water availability
  - wildlife
  - human health
  - infrastructure
  - economic gains/losses

- Changes in atmospheric composition (e.g. increase of greenhouse gases due to anthropogenic activity) affect the risks from some **extreme events**, such as heat waves and heavy rainfall, and the **risks** are set to rise further in the future.

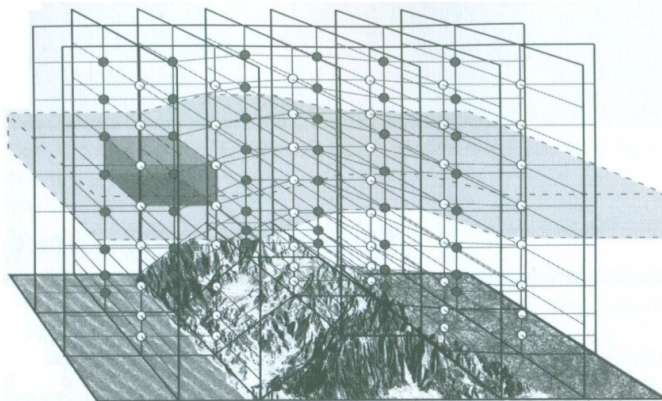- It is these kind of extreme events that often have the largest **climate impacts.**

# Where can we find information on climate change and impacts?

▶ The **Intergovernmental Panel on Climate Change (IPCC)** is the leading international body for the assessment of climate change. It was established by the United Nations Environment Programme UNEP and the World Meteorological Organization WMO in 1988.

▶ IPCC, with the **Assessment Reports**, provides the world with a clear scientific view on the current state of knowledge in **climate change** and its potential environmental and **socio-economic impacts**. www.ipcc.ch

# How do we estimate future climate changes?

- Climate changes can be projected using **climate models**, which are mathematical representations of the climate system.

- Climate models are principally based on laws of physics. The prognostic equations derived from these laws are so complex that they must be solved numerically, in the grid points of a 3-D grid.

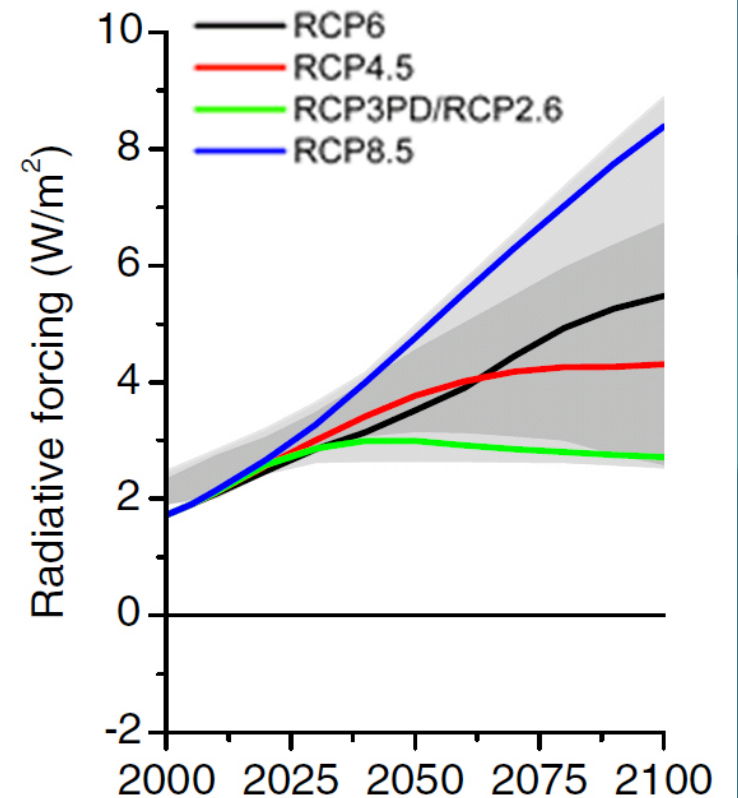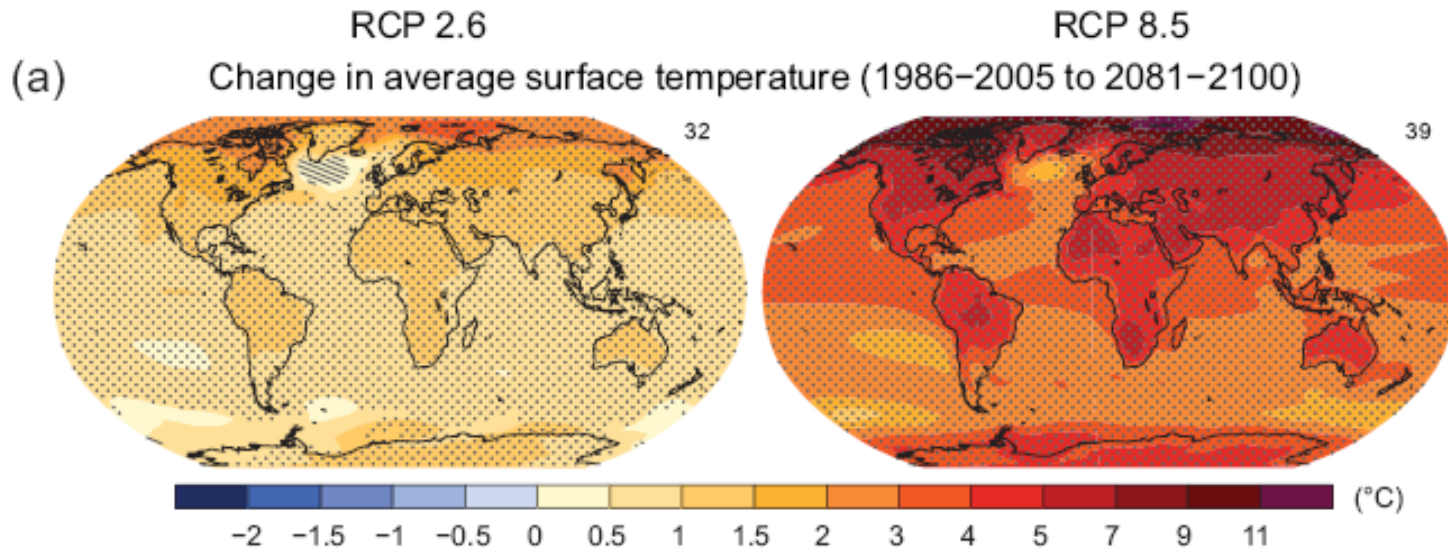- Programming codes of climate models are among the most complex examples of scientific software.

$$\frac{\partial w}{\partial t} = -u\frac{\partial w}{\partial x} - v\frac{\partial w}{\partial y} - w\frac{\partial w}{\partial z} - a\frac{\partial p}{\partial z} + (2\Omega cos\varphi)u + F_z - g$$

$$\frac{\partial T}{\partial t} = \frac{1}{C_p}\frac{dq}{dt} + \frac{a}{C_p}\frac{\partial p}{\partial t} - u\frac{\partial T}{\partial x} - v\frac{\partial T}{\partial y} - w\frac{\partial T}{\partial z}$$

# What kind of simulations we perform with a climate model?

▶ **Historical simulations** refer to simulations of past climate.

▶ **Future climate projections** are simulations based on tentative emissions scenarios.



(a)

RCP 2.6                                    RCP 8.5

Change in average surface temperature (1986–2005 to 2081–2100)

32                                          39

$(\degree C)$

-2  -1.5  -1  -0.5  0  0.5  1  1.5  2  3  4  5  7  9  11



— RCP6
— RCP4.5
— RCP3PD/RCP2.6
— RCP8.5

Radiative forcing $(W/m^2)$

10
8
6
4
2
0
-2

2000  2025  2050  2075  2100

# Why computational infrastructure is important for climate modeling?

- Computational time of a climate simulations is:

**Computational time** = (operation per equation) x (number of equations per grid box) x (number of grid boxes) x (number of time steps per simulations)

- Increasing spatial resolution by a factor of 2, the number of grid cells increase by a factor of $2^3$ =8 and with the doubled number of time steps, the computational time of the run increases by a factor of $2^4$ = 16.
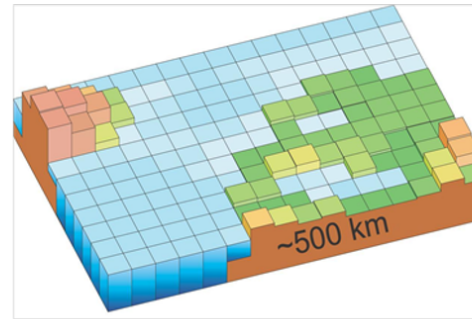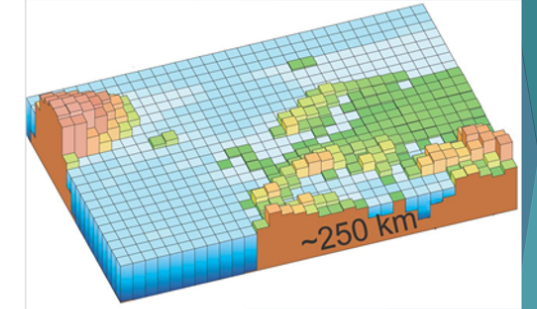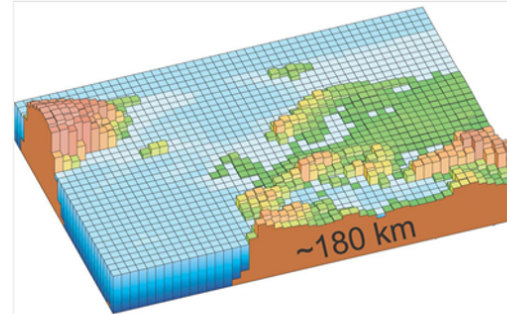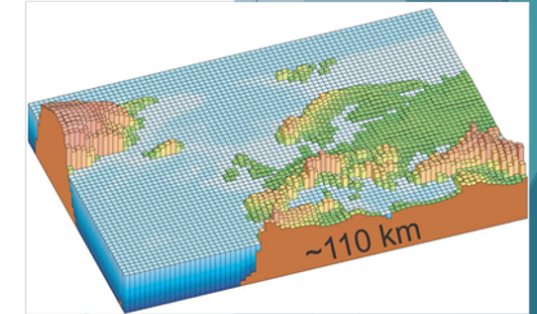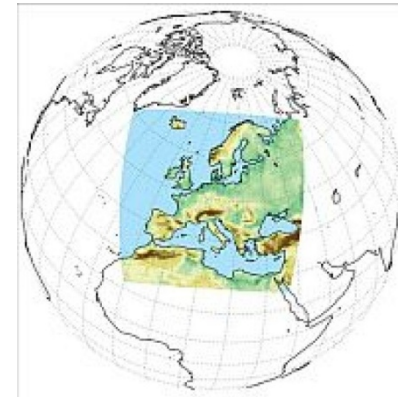
# AUTH-MC-WRF regional climate simulations

▶ The group of regional climate modeling in AUTH-MC uses the WRF regional climate model to simulation present and future climate.

▶ The simulations follow the international protocol of the **CORDEX** initiative, operating under the auspices of the **World Climate Research Project**.

▶ EURO-CORDEX is the application of the CORDEX initiative over the European domain.

▶ www.cordex.org

▶ http://euro-cordex.net/

WCRP
CORDEX
Coordinated Regional Climate Downscaling Experiment

# Climate applications in HPC-ARIS

- AUTH-MC-WRF climate simulations have been awarded with the following computational resources:

  - 1st production call: pr001020, 2015, REGINA (165,000 core hours)

  Regional climate simulations over Europe

  - 2nd production call: pr002046, 2016, VERGINA (1,400,000 core hours)

  Very high resolution regional climate simulations over Europe

  - 3rd production call: pr003005, 2017, CORERATE (1,900,0000 core hours)

  Convective permitting regional climate simulations

  - Preparatory/Development projects: pa006006, 2016, (100,000 core hours)

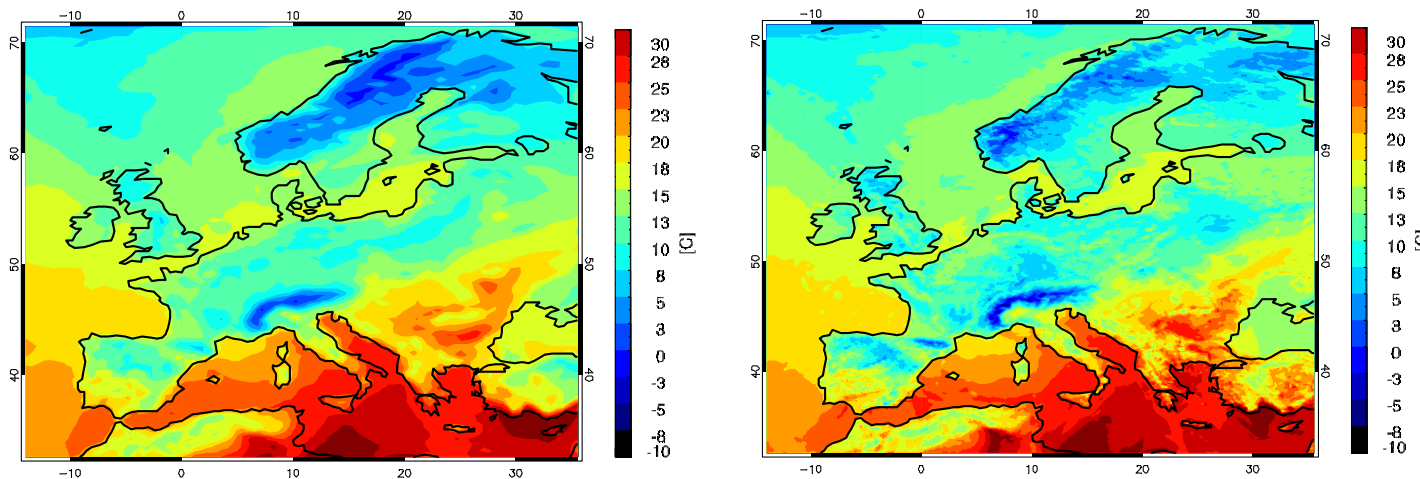  Impact of aerosol on atmospheric radiation and clouds (PI V. Pavlidis)

# REGINA

- Climate model: AUTH-MC-WRF coupled to NASA_GISS_E2 global climate model
- Spatial resolution: 50 Km (Europe)
- Simulations:  historical (1970-2004) ; projection (2005-2100) under RCP8.5
- Project: EURO-CORDEX historical/projection simulation



**Temperature Trend**
**South Europe**

Trend:0.32 °C/decade
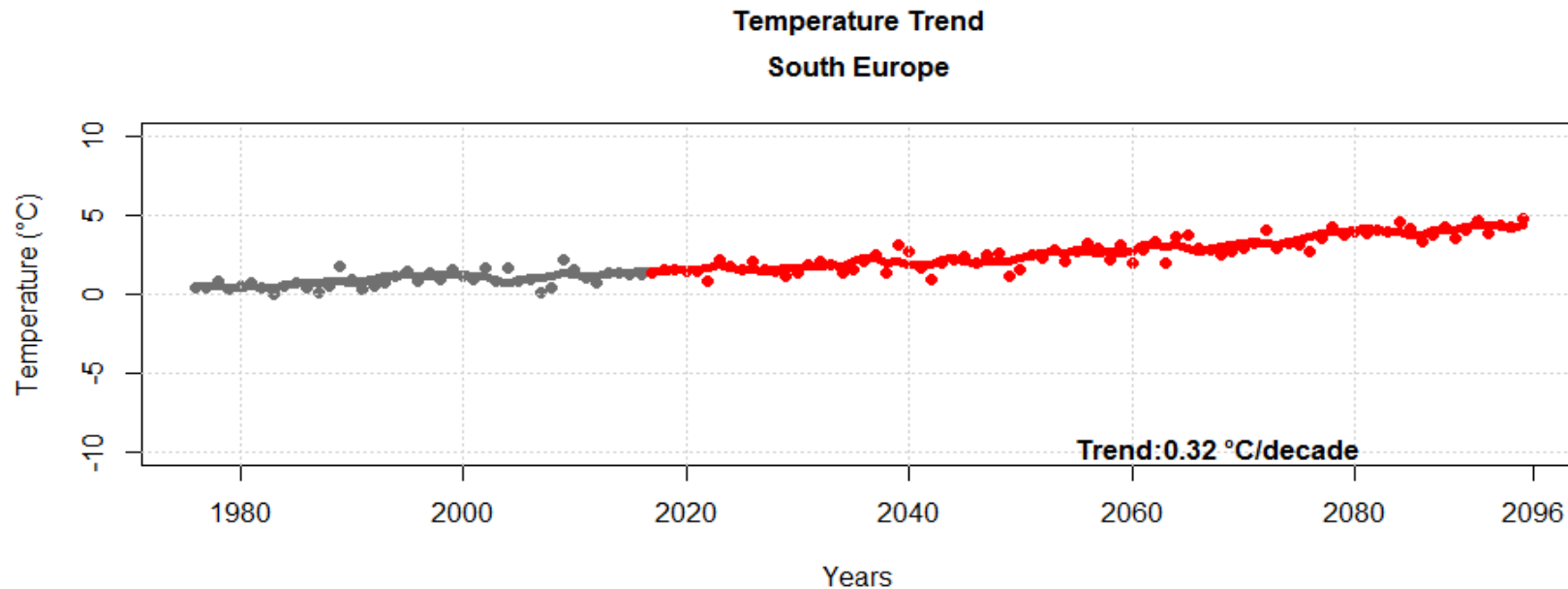
Μεταβολή της μέσης θερμοκρασίας σε σχέση με το διάστημα αναφοράς 1976-2005 πάνω από τη Νότια Ευρώπη, Σοφιάδης Ι.  (2017)

# VERGINA

- Climate model: AUTH-MC-WRF forced by ERA-interim reanalysis

- Spatial resolution: 50 Km - 12 Km (Europe)

- Simulations: hindcast (1990-2008)

- Project: EURO-CORDEX hindcast simulation



The improvement in a spatial resolution by a number of 4 over the European domain (downscaling from 50 to 12 Km), increased the demand in computational resources by a factor of 36 (regarding the increase in time execution in seconds).

H Average near surface temperature (1990-2008) with 50 Km resolution (left) and 12 Km resolution (right)

# COPERATE – ongoing project

- Climate model: AUTH-MC-WRF forced by ERA-interim reanalysis

- Spatial resolution: 50 Km - 12 Km  (Europe) – 4 Km (Alps)

- Simulations:  hindcast (2000-2015)

- Project: EURO-CORDEX, FPS on Convective Permitting simulations
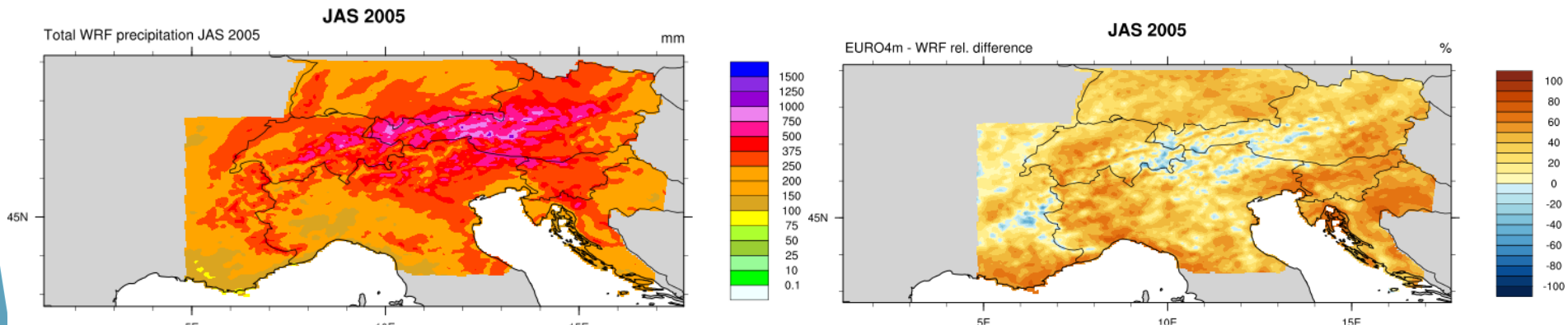


Precipitation over the Alps regions for the time period JAS 2005 (left) and bias (right)

# Publication of scientific results

- MSc thesis:

    - Γκότοβου Ιωάννα, Μελέτη επίδρασης οριακών συνθηκών σε περιοχικές κλιματικές προσομοιώσεις και αξιολόγηση με δορυφορικά δεδομένα, Τομέας Μετεωρολογίας Κλιματολογίας, ΑΠΘ (03/2017)

    - Σοφιάδης Ιωάννης, Μελέτη της κλιματικής αλλαγής πάνω από την Ευρώπη για τον 21ο αιώνα με χρήση περιοχικής κλιματικής προσομοίωσης οδηγούμενης από το σενάριο RCP8.5, Τομέας Μετεωρολογίας Κλιματολογίας, ΑΠΘ (11/2017)

- Peer review journals/ Conference proceedings:

    - Katragkou E., .. S. Kartsios, V. Pavlidis...  et al., AUTH Regional Climate Model Contributions to EURO-CORDEX, Chapter in  Karacostas, Theodore, Bais, Alkiviadis, Nastos, Panagiotis T., eds., Springer International Publishing, 2017

    - Coppola, .. S. Kartsios, E. Katragkou … et al., A first-of-its-kind multi-model convection permitting ensemble for investigating convective phenomena over Europe and the Mediterranean, submitted in Climate Dynamics