ΠΟΛΥΤΕΧΝΕΙΟ ΚΡΗΤΗΣ
TECHNICAL UNIVERSITY OF CRETE

AXA Research Fund

LEVERHULME Centre for Wildfires, Environment and Society

CLIMPACT

Climate Change and its Impacts: Tools used for Simulation and Prediction

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Twin Digital and Green Transition to a Resilient Economy, Chania, 23 March 2022

Laboratory of Atmospheric Environment and Climate Change

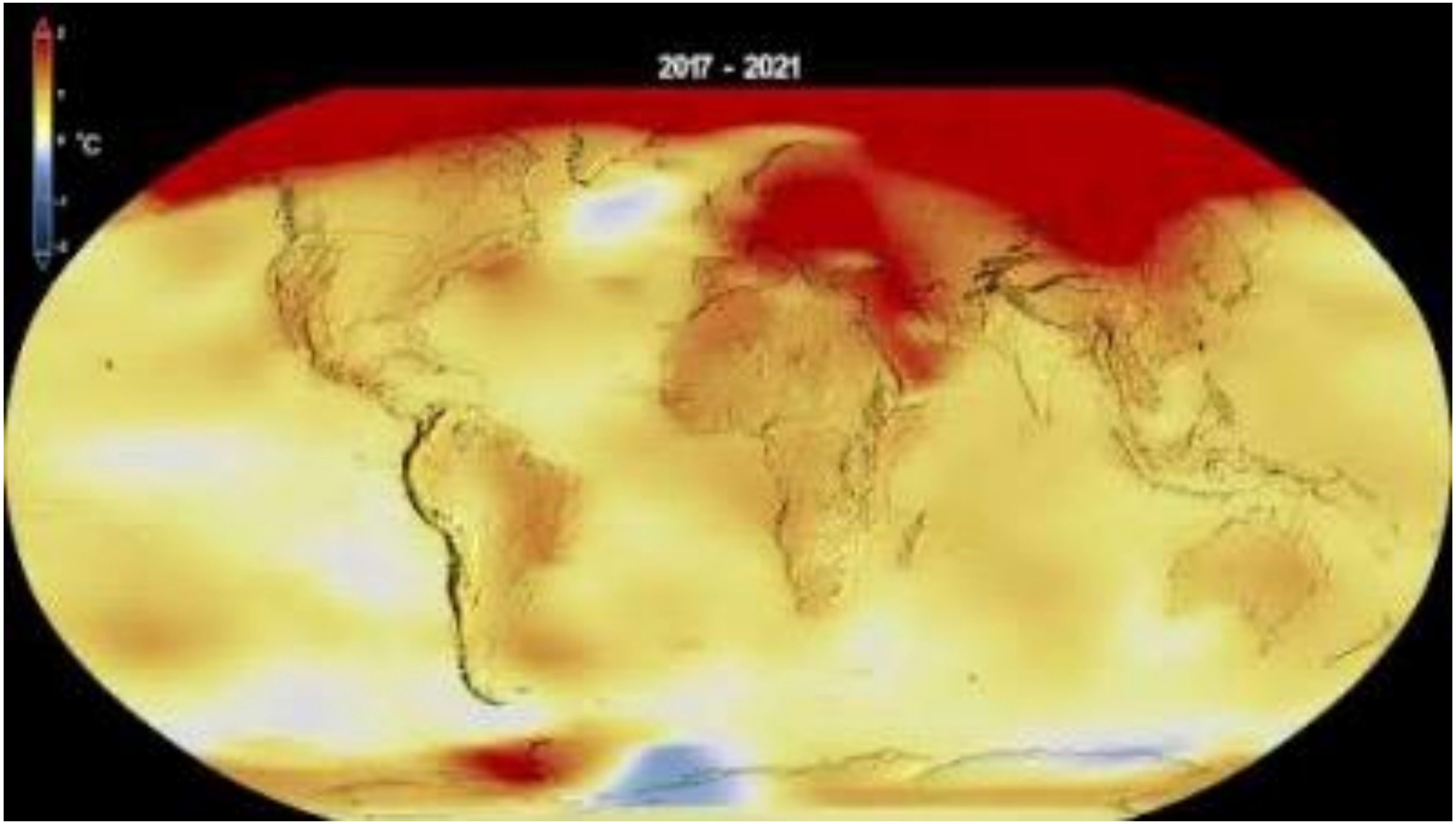
Technical University of Crete

climate.tuc
ATMOSPHERIC ENVIRONMENT & CLIMATE CHANGE LAB

What we work on:

- **Modelling** of the climate and the atmospheric environment.
- Influence of **anthropogenic and natural** factors on climate change and air quality.
- **Wildfires**, atmospheric composition και and climate change.
- Analysis of **satellite measurements** for understanding the above.
- Using **machine learning** to study climate change problems.

Climate change is a problem that is getting more and more severe in the past few decades



Important climate change impacts: Forest fires

INDEPENDENT

Environment

Greenland hit by largest wildfire on record, scientists report

CNN

California fire explodes in size, is now largest in state history

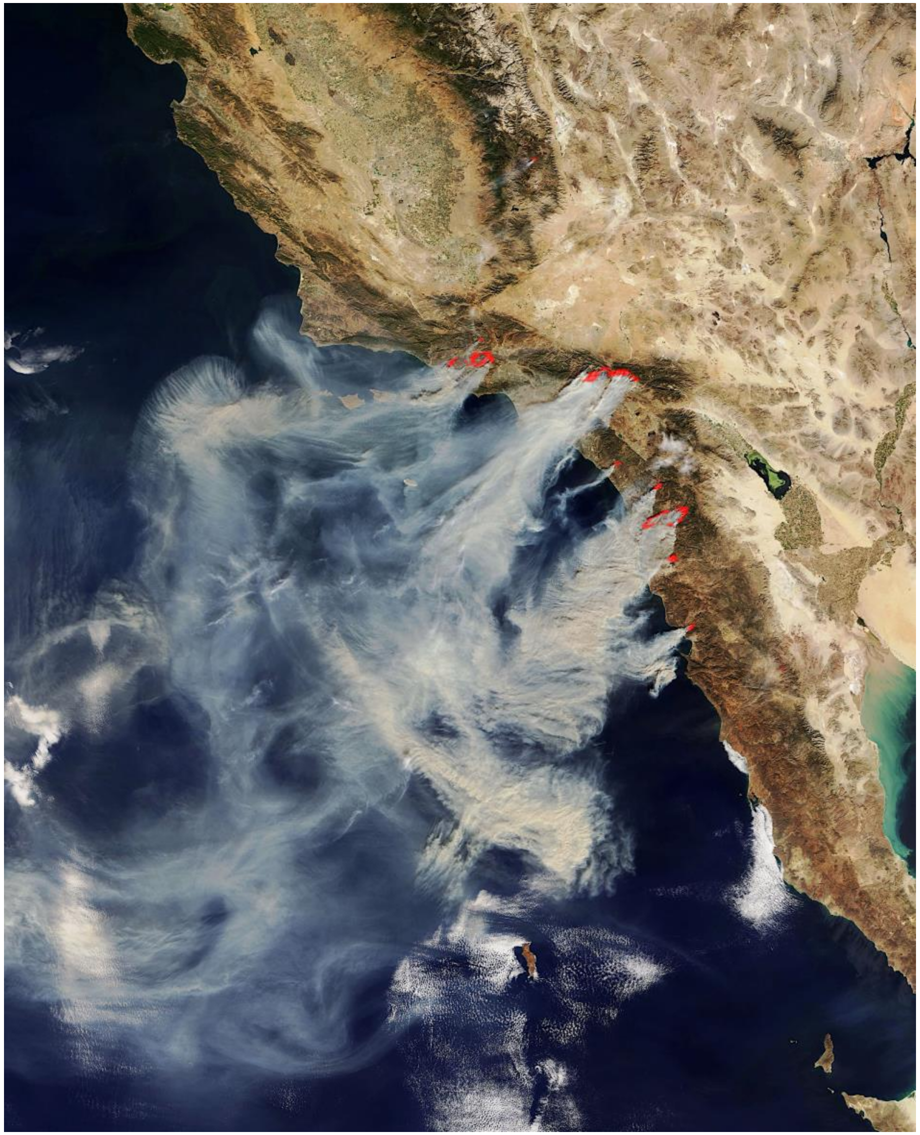
The Guardian UK edition

Firefighters from seven counties fight Greater Manchester moor fires

BBC NEWS

Greece wildfires: Dozens dead in Attica region

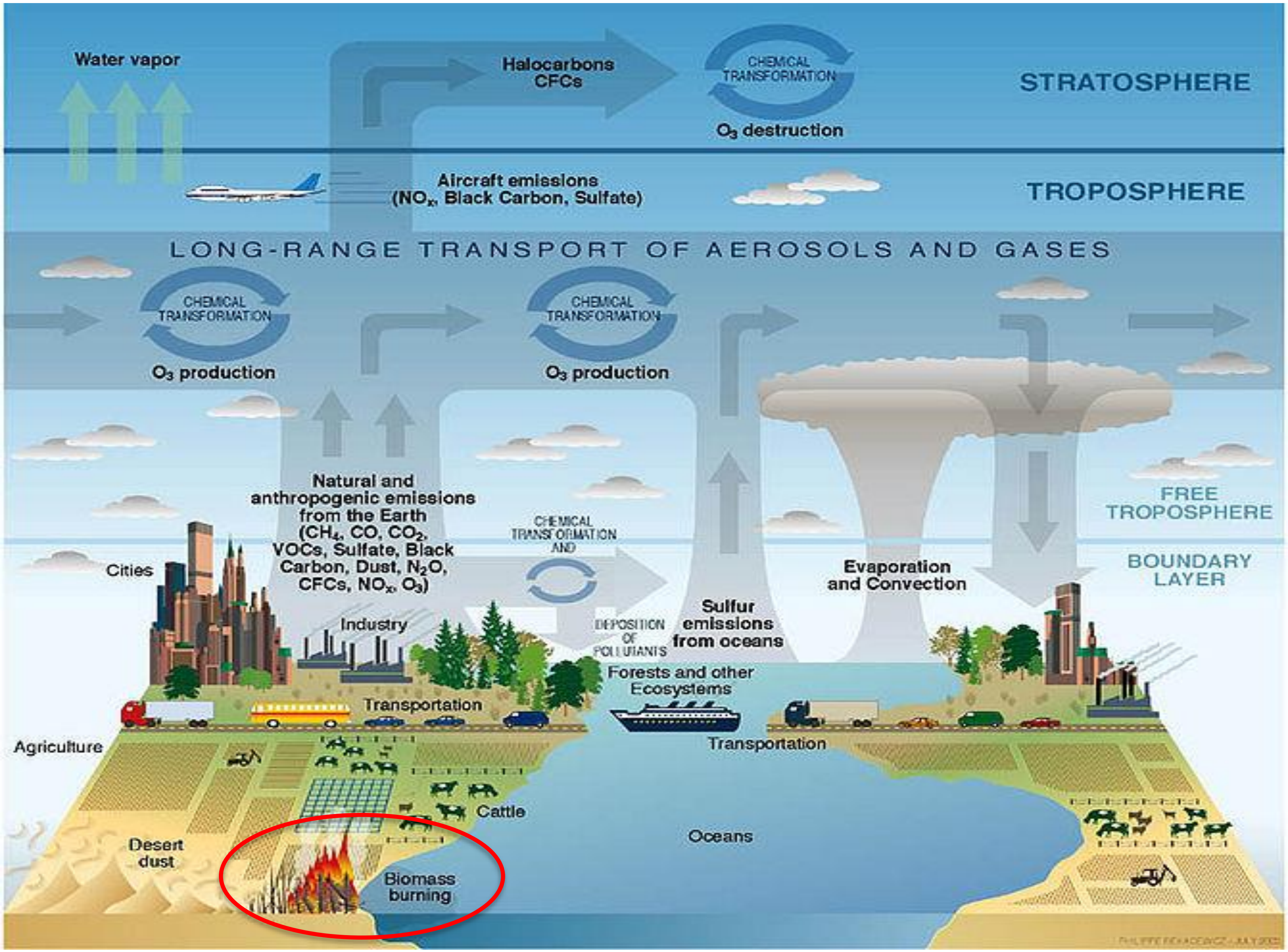
Fires also cause major air pollution events



Source: NASA

Also see the following animation on fire-generated aerosols from NASA: https://www.youtube.com/watch?v=oRsY_UviBPE

In the Earth system, lots of things interact (complexity)

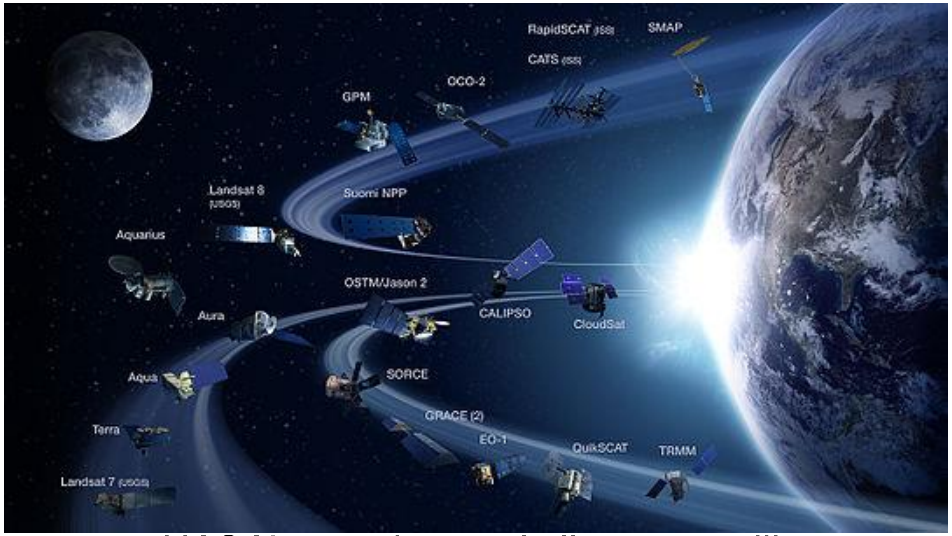


Source: US Climate Change Science Program.

So, how do we simulate all these things?

(Image by: Harunobu Toribatake)

Recent advances that revolutionised climate change research



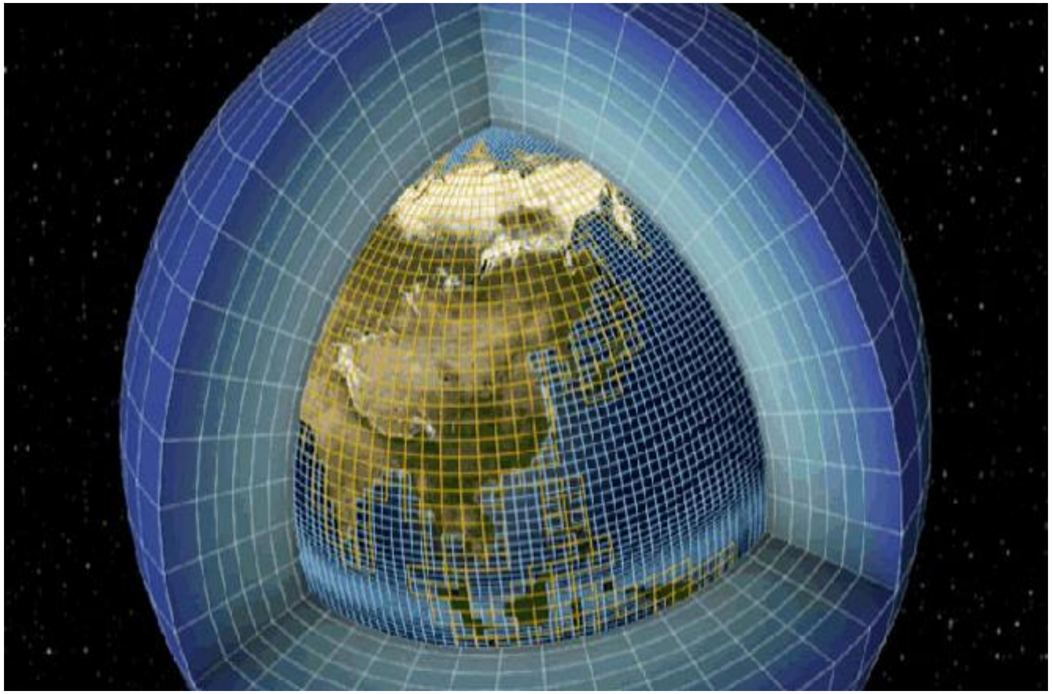
NASA's weather and climate satellites

NASA's Discover supercomputer

Models have advanced massively in the last 2-3 decades, with higher and higher *resolution* and more and more *processes* included (increasing computational power has been crucial).

Satellite observations of atmospheric constituents have produced a wealth of data that helps us *constrain our models* in a way that we could not have done before.

Our main tool: Global atmospheric (climate) modelling



www.sciencemuseum.org.uk

• Global models have 3D domain with finite number of gridboxes. Typical global models: horizontal resolution of ~100km, vertical of ~1km -> total of ~10^6 gridboxes. **Differential equations then solved for *all* gridboxes**.

How we (should) use models

Improve model, characterize its error

Define problem of interest and its scale → **Design model; make assumptions to simplify equations** → **Design observational system to test model** → **Evaluate model with observations**

Design model; make assumptions to simplify equations → **Apply model: test hypotheses, predictions**

http://acmg.seas.harvard.edu/education/

Need to be in constant dialogue.

Processes simulated in an atmospheric model

Gas processes

- Emission
- Photochemistry
- Heterogeneous chemistry
- Aerosol nucleation
- Condensation/evaporation
- Dissolution/evaporation
- Dry deposition
- Washout

Aerosol processes

- Emission
- Nucleation
- Aerosol–aerosol coagulation
- Aerosol–hydrometeor coagulation
- Condensation/evaporation
- Dissolution/evaporation
- Equilibrium chemistry
- Aqueous chemistry
- Heterogeneous chemistry
- Dry deposition/sedimentation
- Rainout/washout

Cloud processes

- Condensation/ice deposition
- Homogeneous, contact freezing
- Melting/evaporation/sublimation
- Hydrometeor–hydrometeor coag.
- Aerosol–hydrometeor coagulation
- Gas dissolution/aqueous chemistry
- Precipitation, rainout, washout
- Lightning

Radiative processes

- Solar and infrared radiation
- Gas, aerosol, cloud absorption
- Gas, aerosol, cloud scattering
- Heating rates
- Actinic fluxes
- Visibility
- Albedo

Meteorological processes

- Air temperature
- Air density
- Air pressure
- Wind speed and direction
- Turbulence
- Water vapor

Transport processes

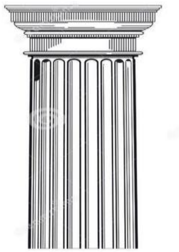
- Emission
- Gas, aerosol, cloud transport in air
- Gas, aerosol transport in clouds
- Dry deposition/sedimentation
- Rainout/washout

Surface processes

- Soil, water, sea ice, snow, road, roof, vegetation temperatures
- Surface energy, moisture fluxes
- Ocean dynamics

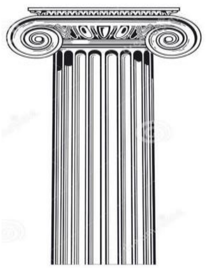
Jacobson (2005)

The three pillars of an atmospheric model



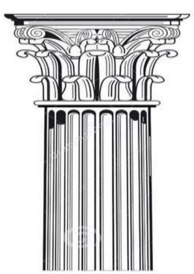
Conservation of mass

$$\frac{\partial n}{\partial t} = -\nabla \cdot (n\mathbf{U}) + D\nabla^2 n + P - L$$



Conservation of energy

$$\frac{\partial E}{\partial t} = -\nabla \cdot (\mathbf{U}E) + r_A \frac{q_V}{T_V}\frac{dQ}{dt}$$



Conservation of momentum

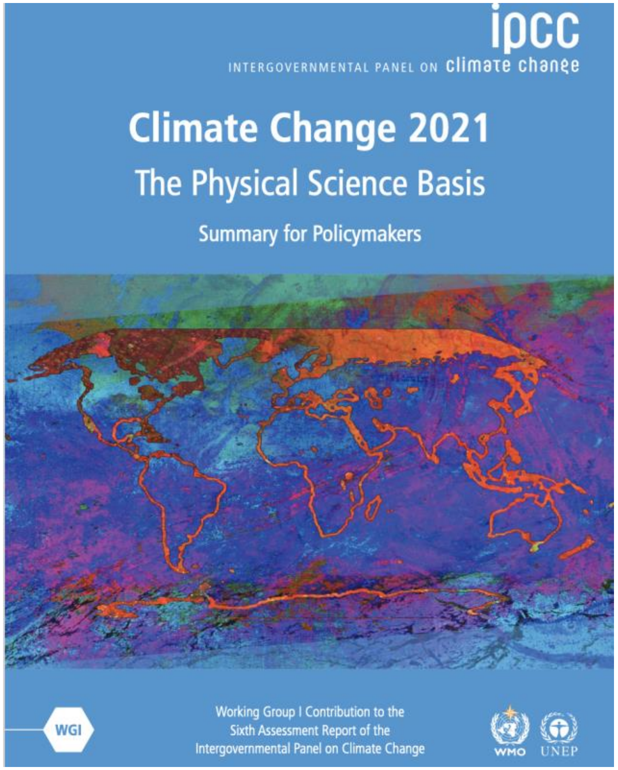
$$\frac{\partial \mathbf{U}}{\partial t} = -(\mathbf{U} \cdot \nabla)\mathbf{U} + v\nabla^2\mathbf{U} - \frac{\nabla p}{r_A} + g$$

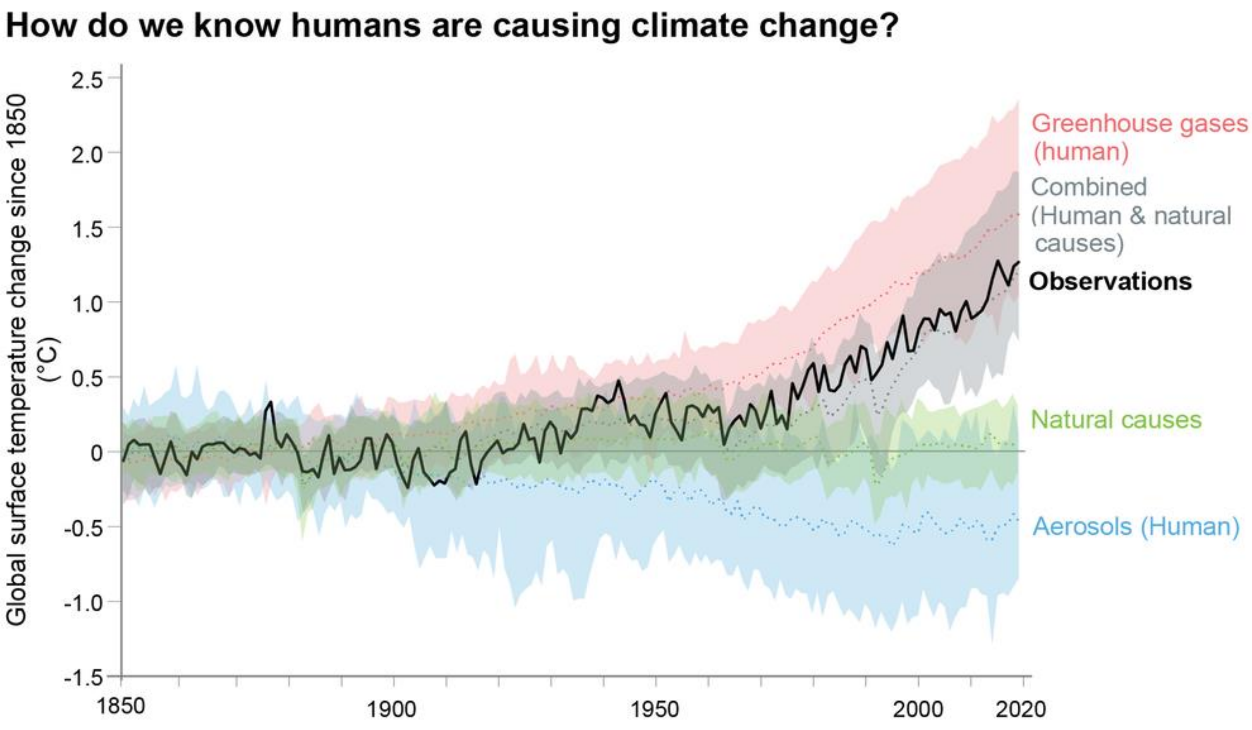
These equations “talk” each other in a chemistry-climate model.

What we can study with these models?

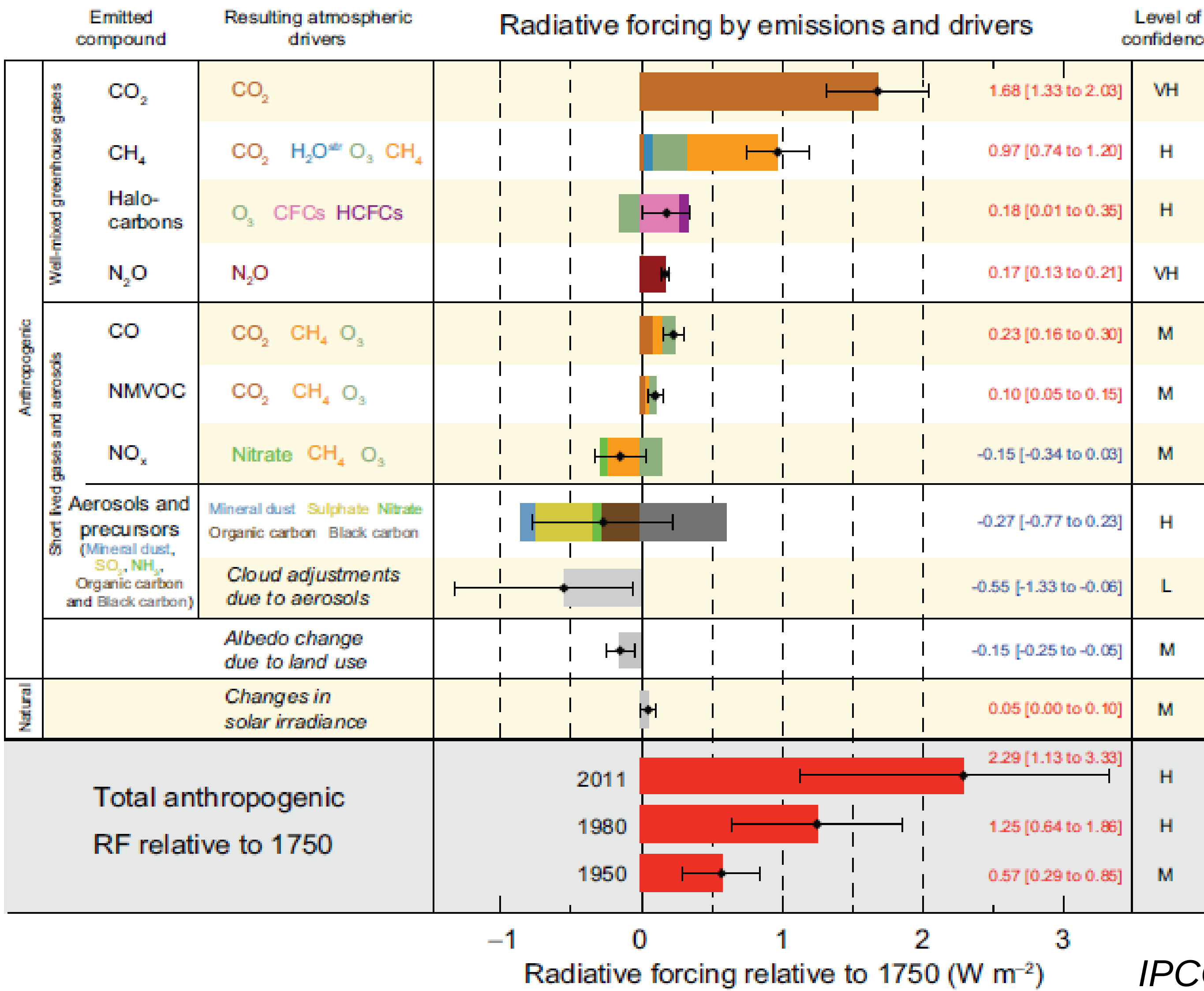
(Image by: Michael D. Brown)

Past/current climate change and its causes (attribution)



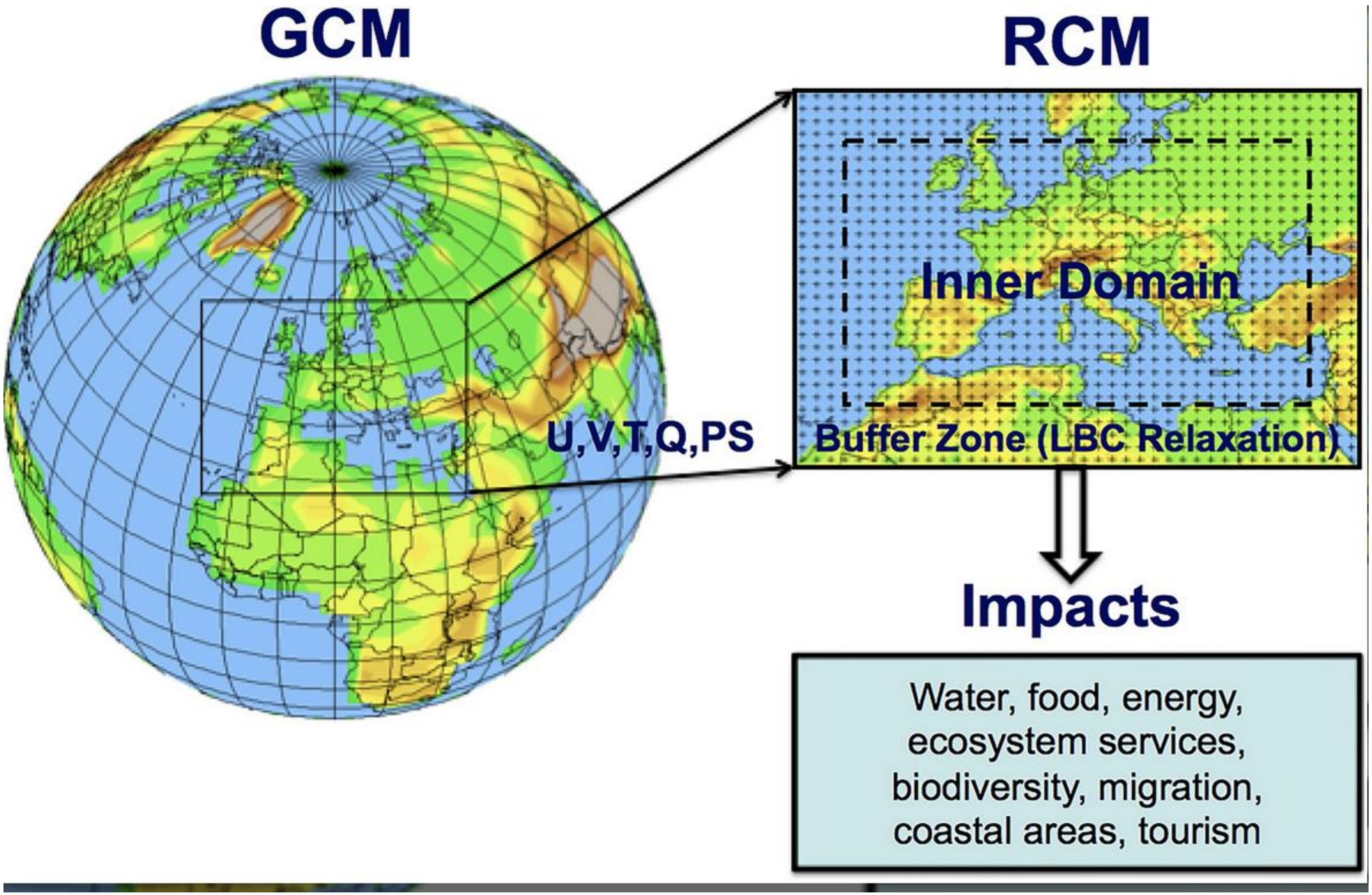


Influences of different gases and aerosols



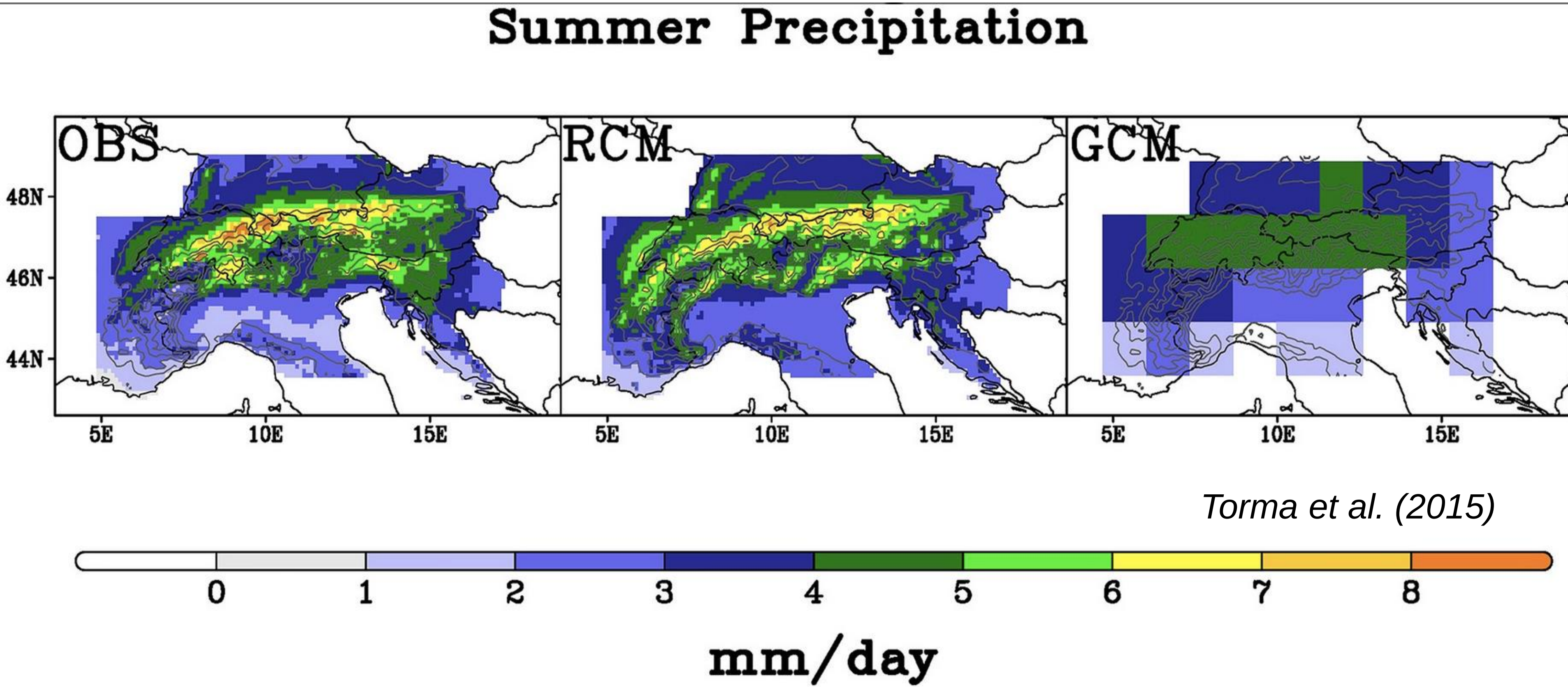
IPCC AR5 (2013)

High resolution forecasts of climate change



Giorgi (2019, JGR, https://doi.org/10.1029/2018JD030094)

Example of performance improvement when moving from global (GCM) to regional (RCM) model

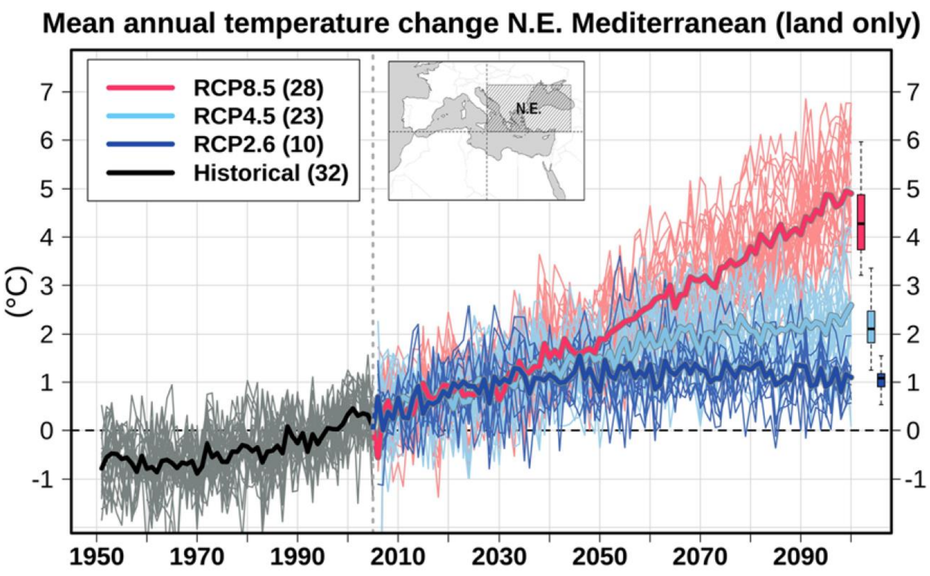


Torma et al. (2015)

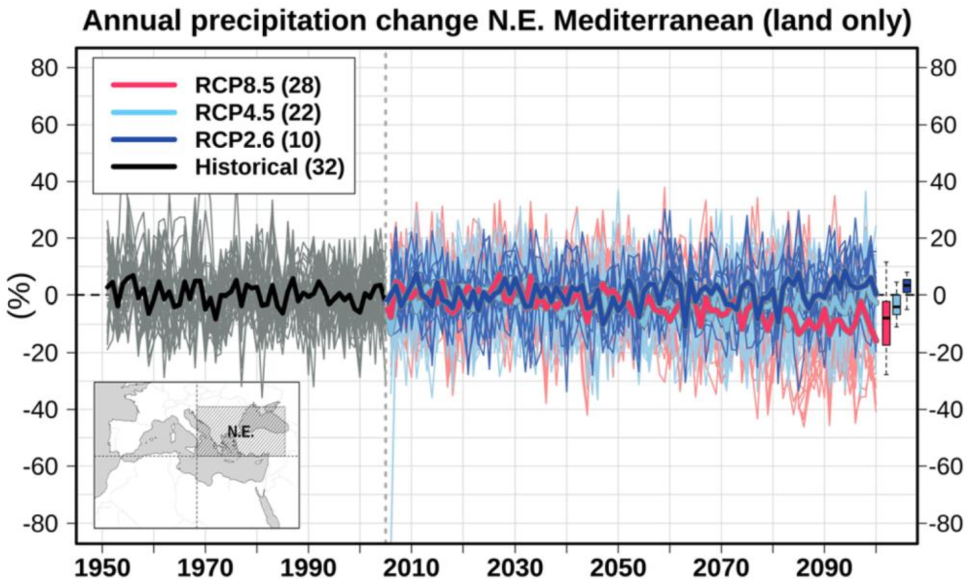
- Fine features ‘smeared’ in GCM.

Example of future climate forecast for the Eastern Mediterranean

Temperature



Rainfall

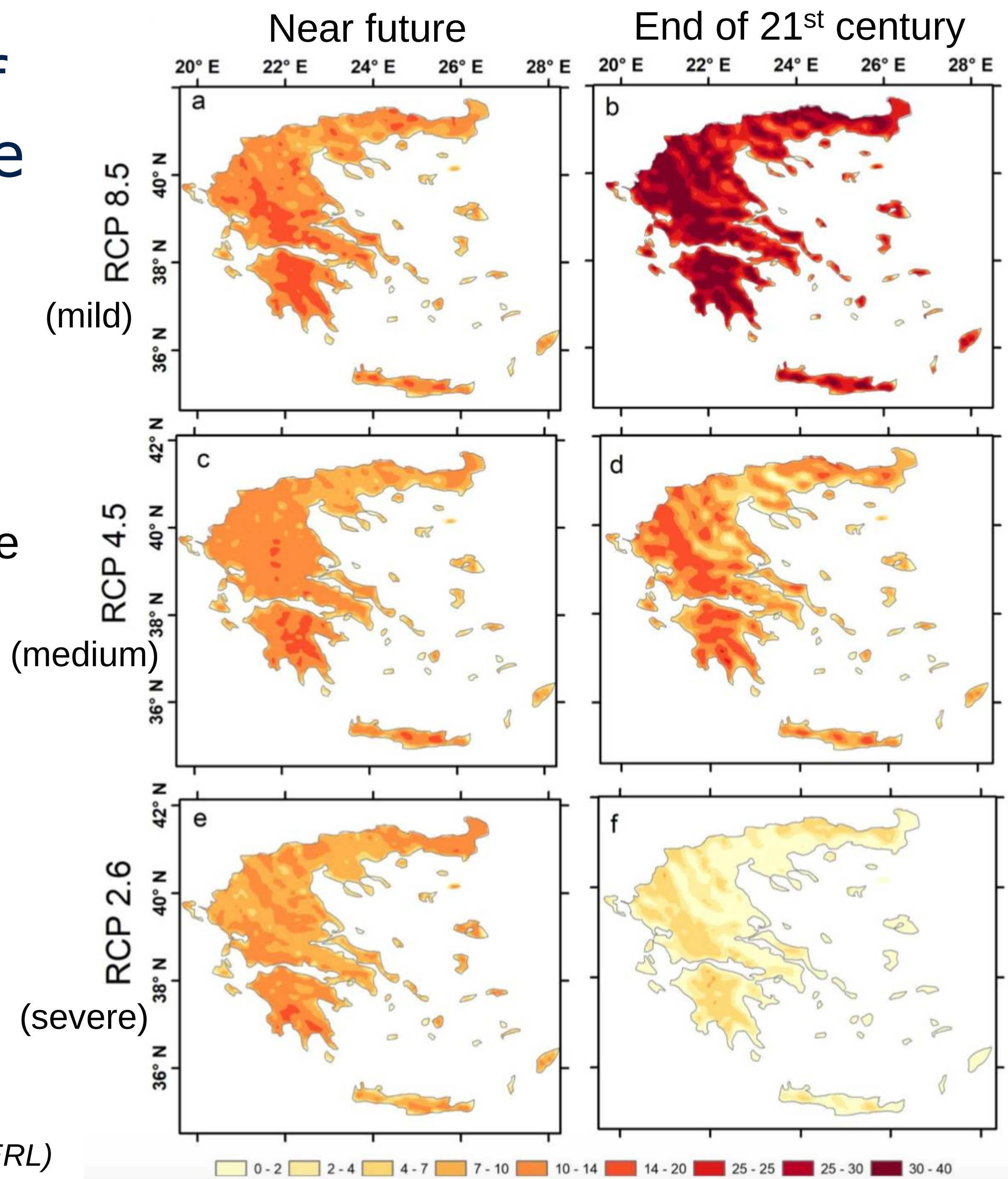


(Zittis et al.)

- We are located at a climate change **“hot spot”.**

Predictions of Future Wildfire Danger over Greece

- Drastic changes, especially in most severe climate change scenario.
- Currently studying air quality implications of such changes.



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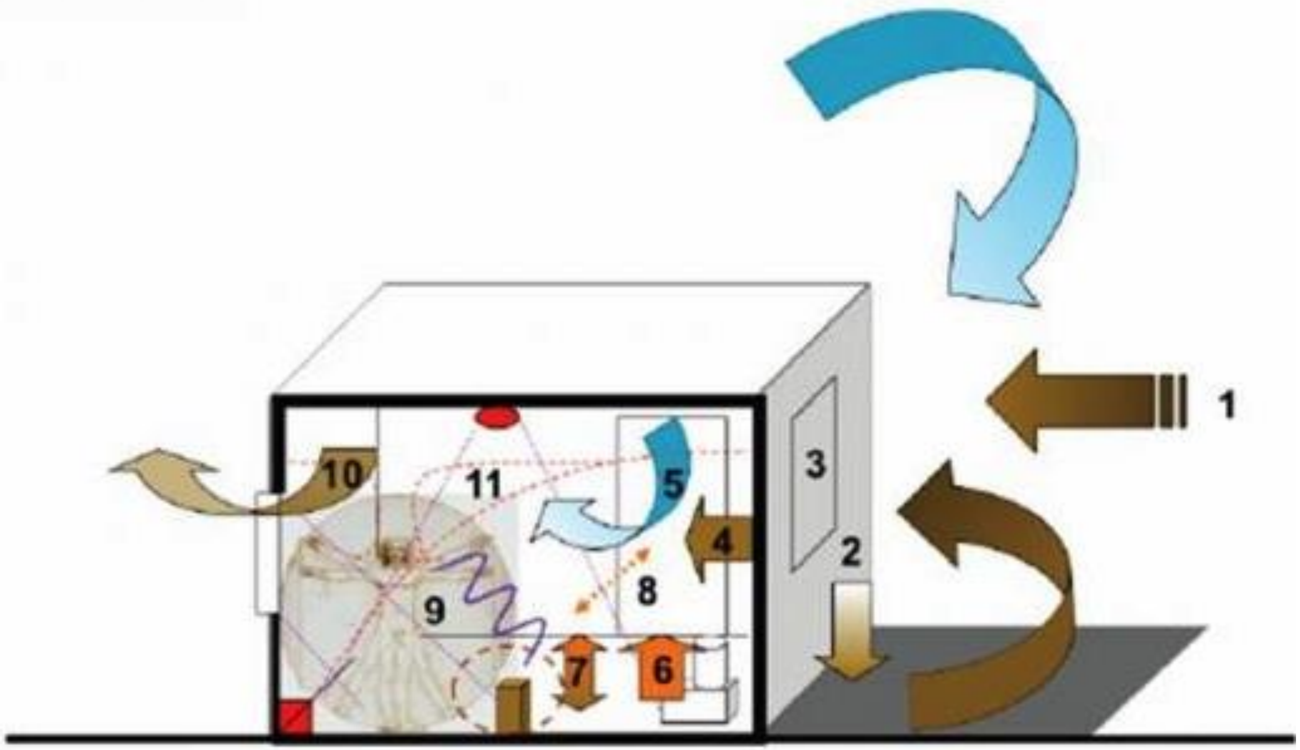
Rovithakis et al. (ERL)

Even indoor air pollution models!



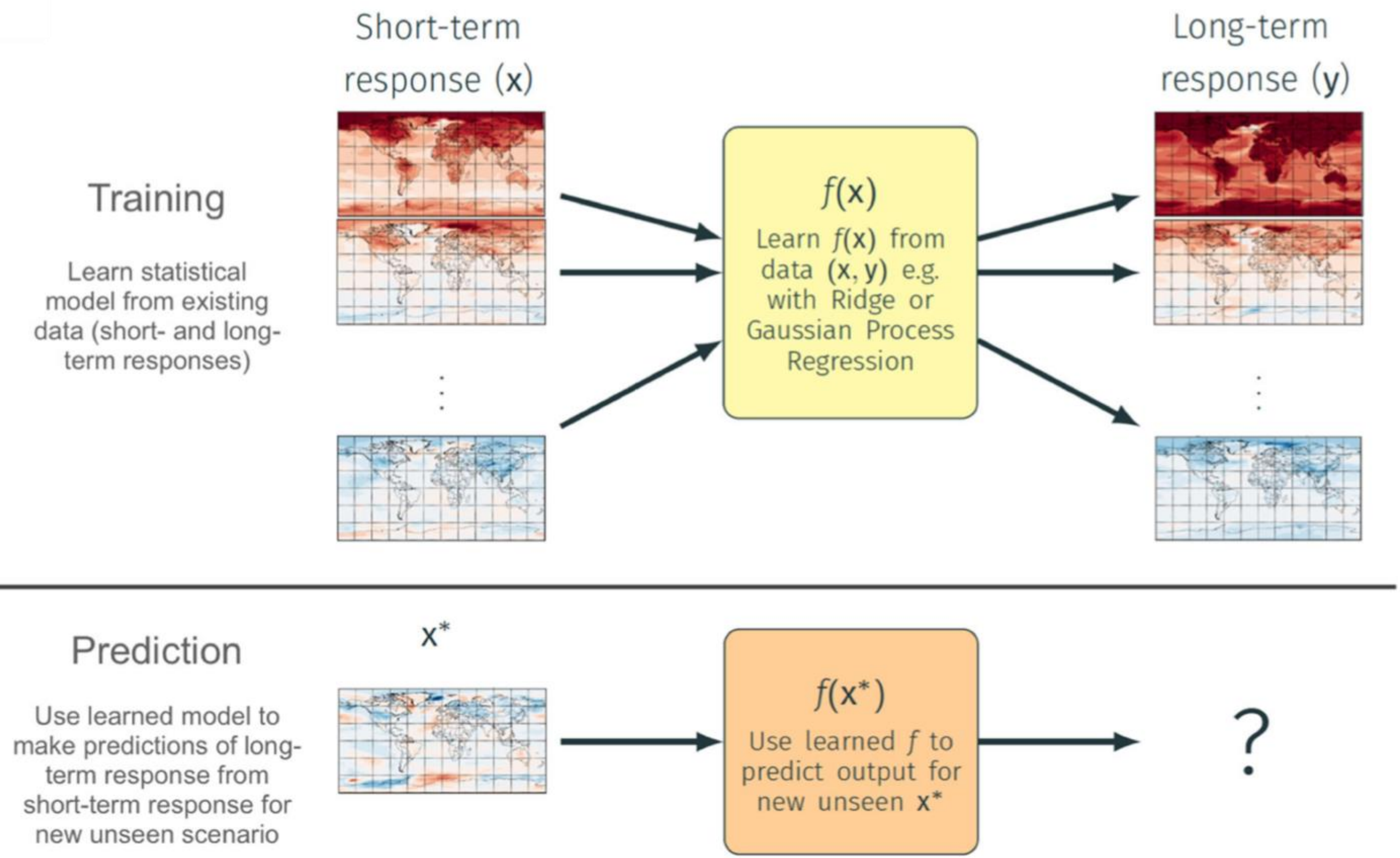
1. Levels of outdoor-PM and its distributions
2. Penetration loss of outdoor-PM concentrations
3. Building characteristics
4. Outdoor-PM indoors gain through natural ventilation and infiltration
5. Outdoor clean air through natural ventilation
6. Levels of indoor-PM from indoor sources
7. Deposition loss and re-suspension of PM
8. Indoor-PM concentrations loss and gain through other rooms and/or indoor passageways
9. Human/animal presence and activity
10. Indoor-PM loss through natural ventilation and exfiltration
11. Interaction of and between pollutants (i.e. formation, phase change, coagulation)

- In many ways similar to what we saw earlier.
- Atmospheric models share several of their principles/characteristics, from the (very) local to the global scale.

Where are these models heading?

(Image by: Aleutie)

Applications of machine learning for climate prediction

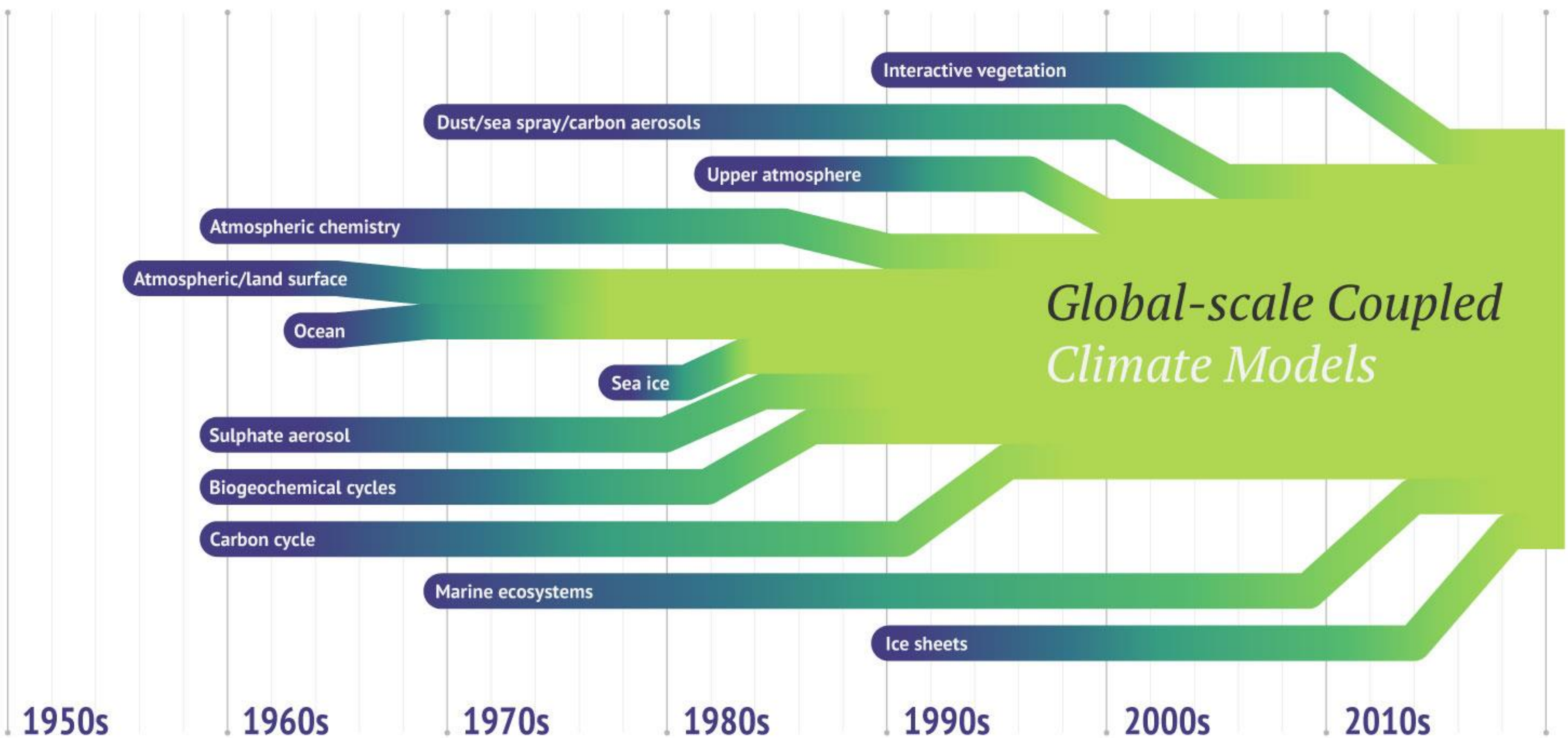


Mansfield et al. et al. (2020)

The evolution from separate to 'coupled' modelling systems

Climate models

For decades scientists have been using mathematical models to help us learn more about the Earth's climate. Known as climate models, they are driven by the fundamental physics of the atmosphere and oceans, and the cycling of chemicals between living things and their environment. Over time they have increased in complexity, as separate components have merged to form coupled systems.



Note: There were some very simplified models before the dates mentioned.

CarbonBrief
CLEAR ON CLIMATE

The future: towards a **digital twin** of our Earth