Climate change projections for Cyprus

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Workshop on climate change adaptation in Cyprus

Nicosia, 2-3 November 2011

The Cyprus Institute

EEWRC

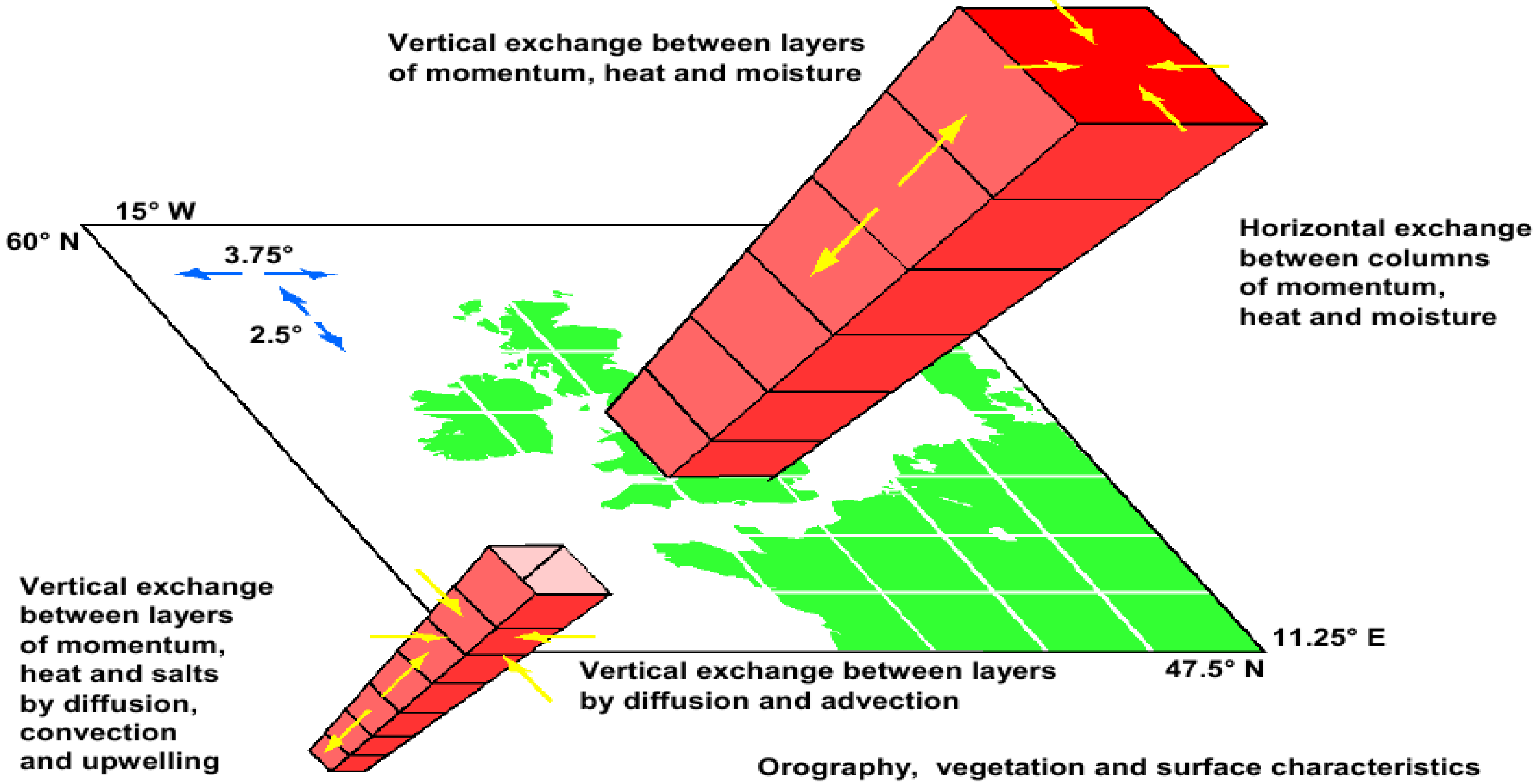
Outline

- Climate Change Modelling
  - IPCC CO_2-driven climate projections
  - Dynamical downscaling of global climate
- PRECIS projections for Cyprus up to 2099
  - Annual time-series for Nicosia
  - Statistical distributions
  - Map projections
- ENSEMBLES projections for Cyprus up to 2026-2050
  - 6-RCM projections for 3 locations
  - Indices of extremes
- Use of RCM projections for impact studies
  - Spatial issues
  - Temporal issues
- Other atmospheric effects
  - Air pollution
  - UV radiation

IPCC Global Circulation Models

Met Office
Hadley Centre

Modelling Global Climate



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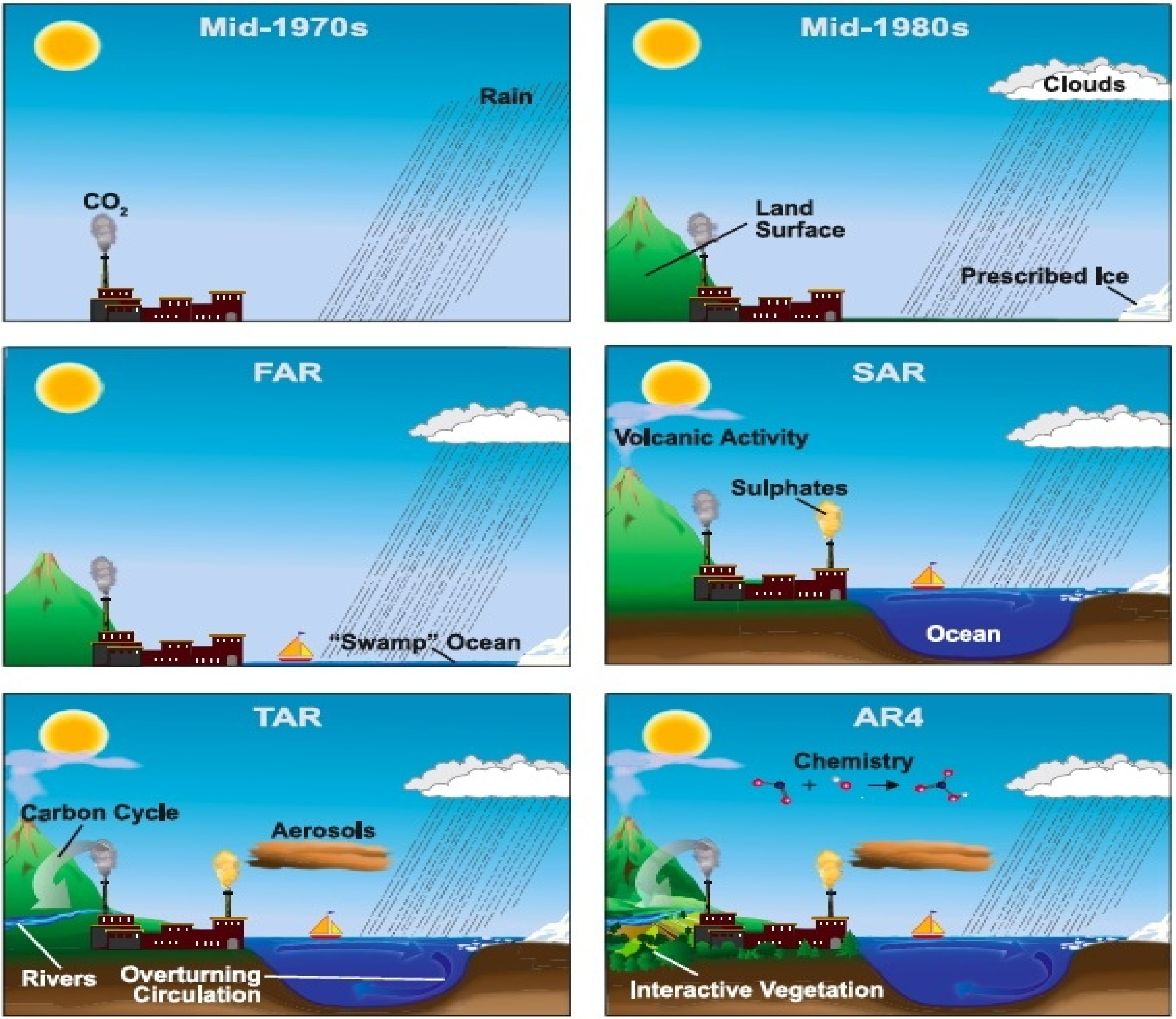
IPCC Global Circulation Models



Improvements in the representation of:

Aerosols

Land surface

Sea ice

More to be done in:

Clouds

Chemistry

Attribution/uncertainties

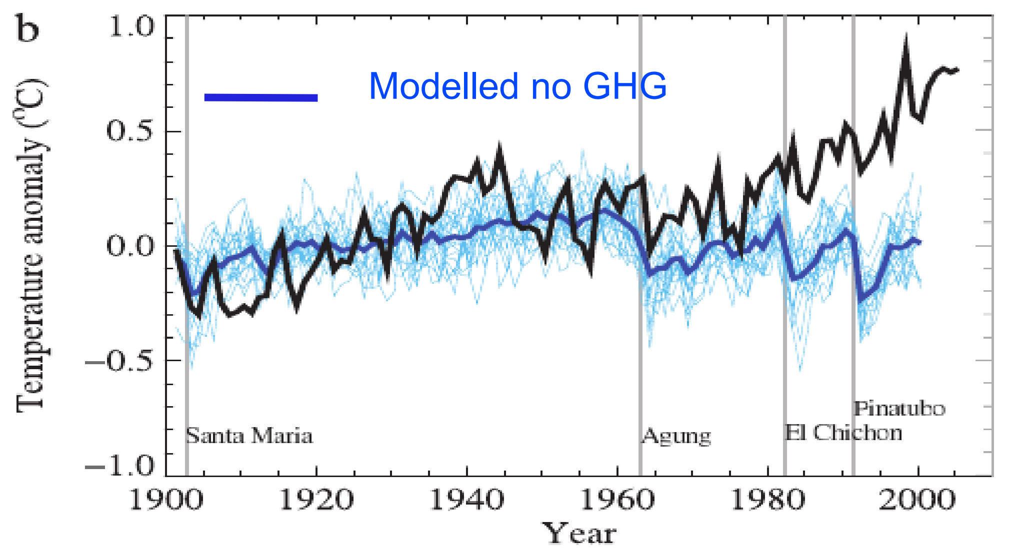
IPCC models:

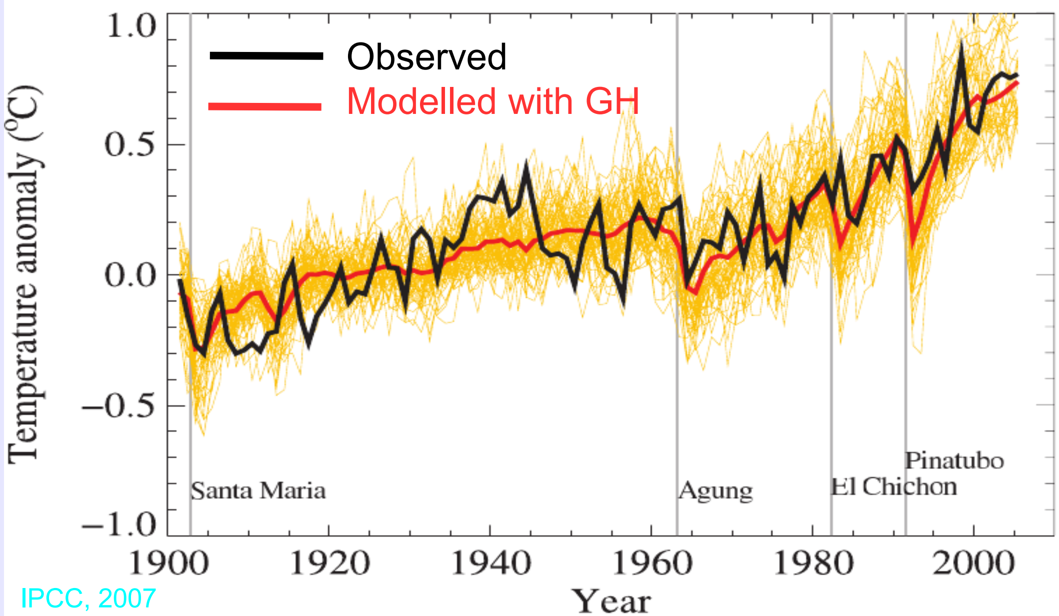
- (blue line) can't reproduce the observed warming without GHG forcing

- (red line) seem to capture well the observed warming (trend and I.A.V.) of late 20th century

- (red line) catch the direction but miss a similar magnitude warming during 1900-1940

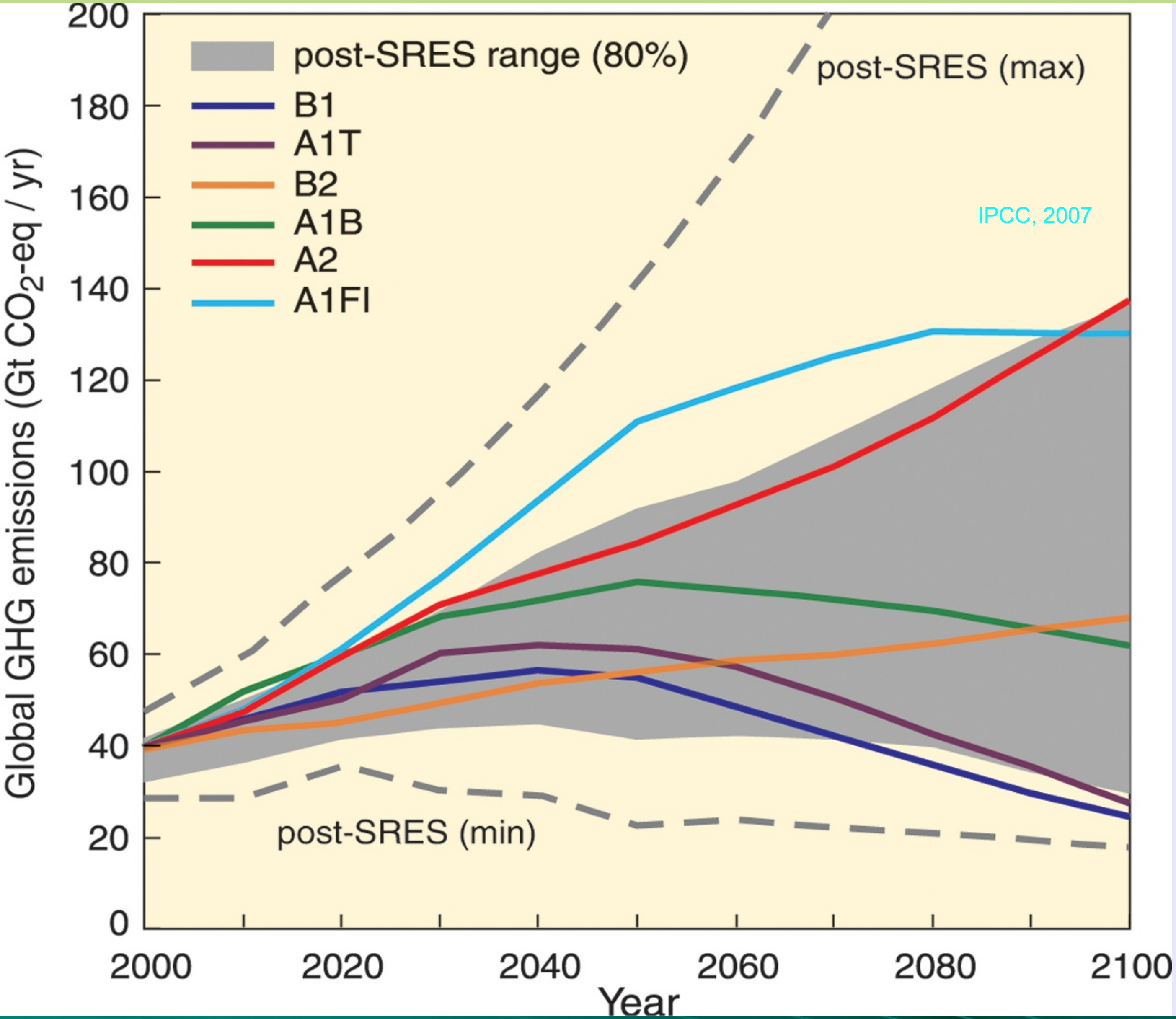
- (orange lines) exhibit a range of 0.3°-0.4°C, a measure of model fidelity?





IPCC, 2007

CO_2-driven projections



Emission scenarios

A1B (moderate):

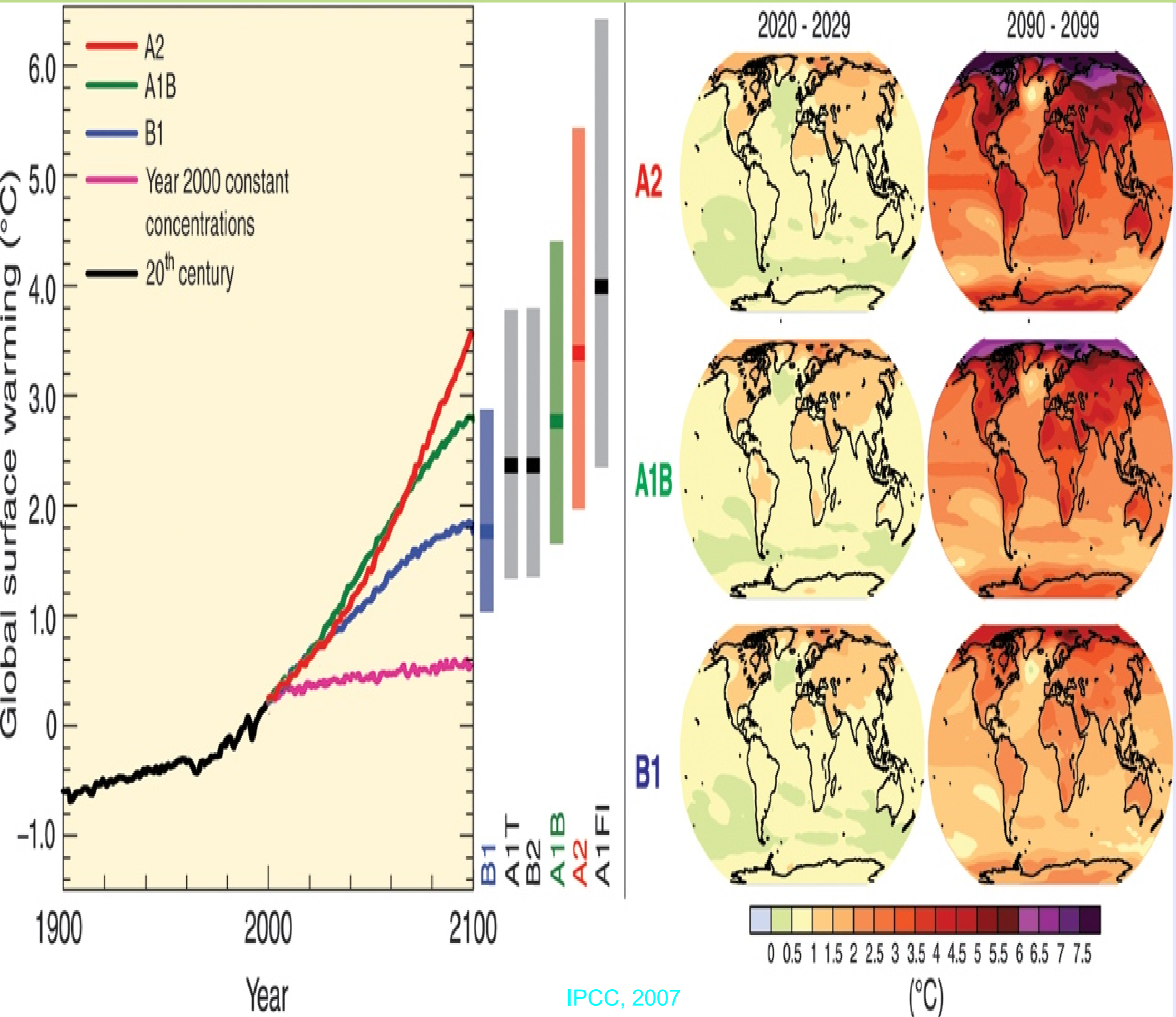
Rapid economic growth

Population increase until mid-century

Introduction of new technologies

Balanced use of fossil fuels and renewables

CO_2-driven projections



IPCC, 2007

Global temperature

Warming lag in the system

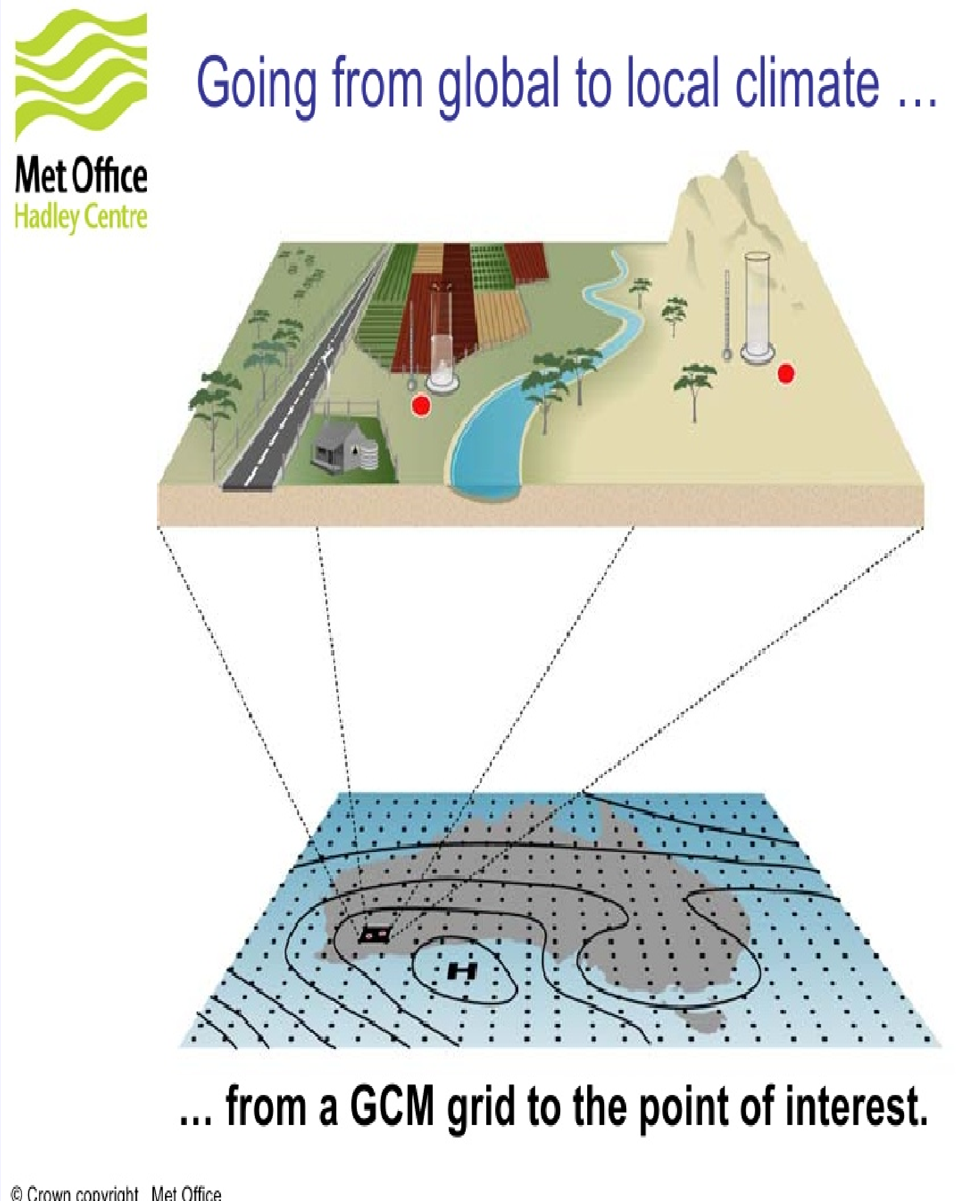
Scenarios diverge after 2040

A1B warms up to 3^{o}C by 2100

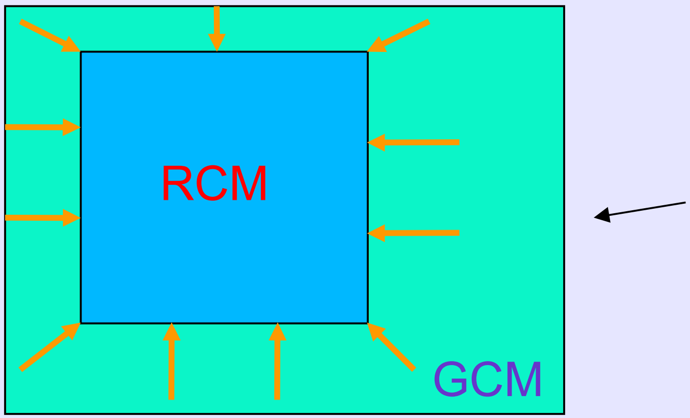
Need for regionalisation

Fine-scale information derived from global model output:

- Reveals smaller scale climatic features resulting from the interaction between global climate and local geographical details
- Provides country-level detail to impact assessments of vulnerability and adaptation to climate change

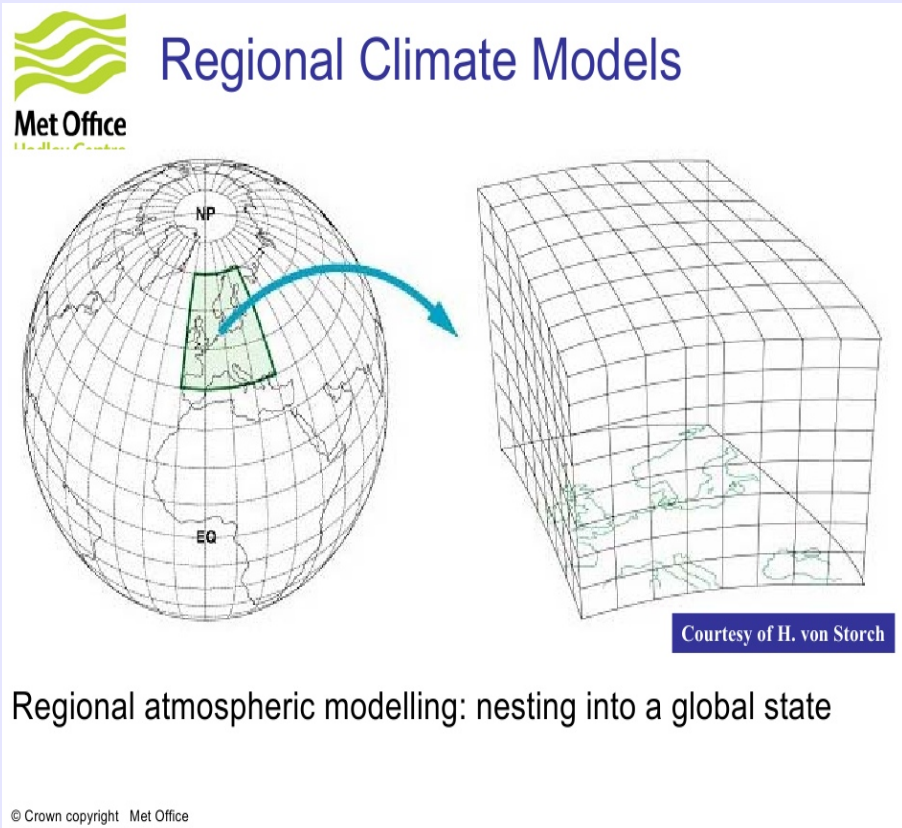


Dynamical downscaling: Definition



High-resolution limited-area (Regional) Climate Model (**RCM**) forced at its boundaries by a Global large-scale Climate Model (GCM) output

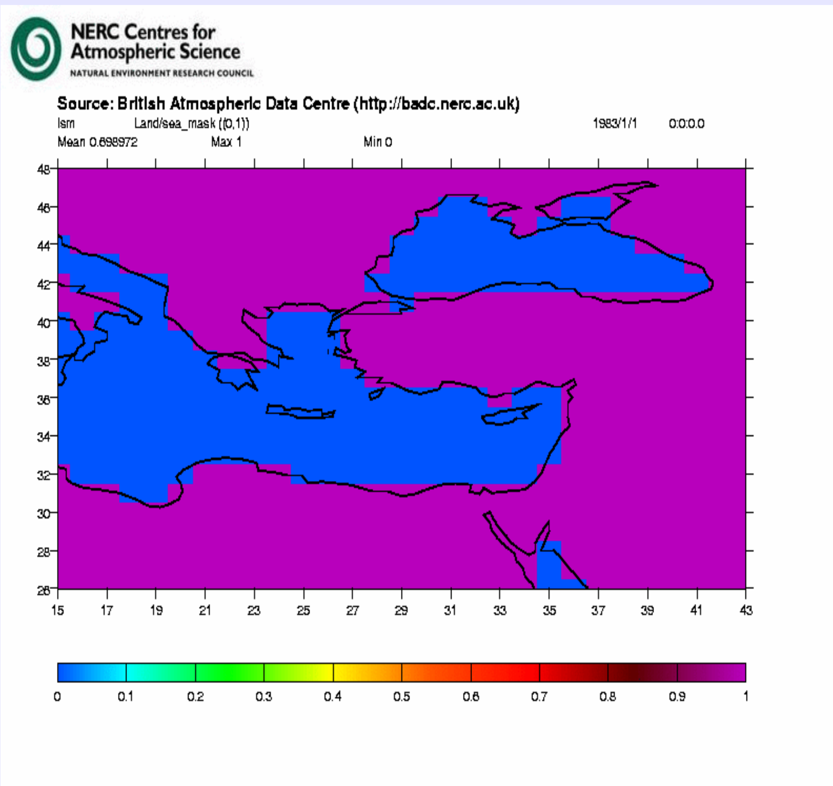
- **"Magnification" of global climate model projections**
- Not arithmetic "interpolation" of global scale but **a physically consistent regional climate simulation** that generates meteorologically coherent small-scale features (Jones et al., 1995; Giorgi and Mearns, J. Geophys. Res, 1999)



Dynamical downscaling: resolution

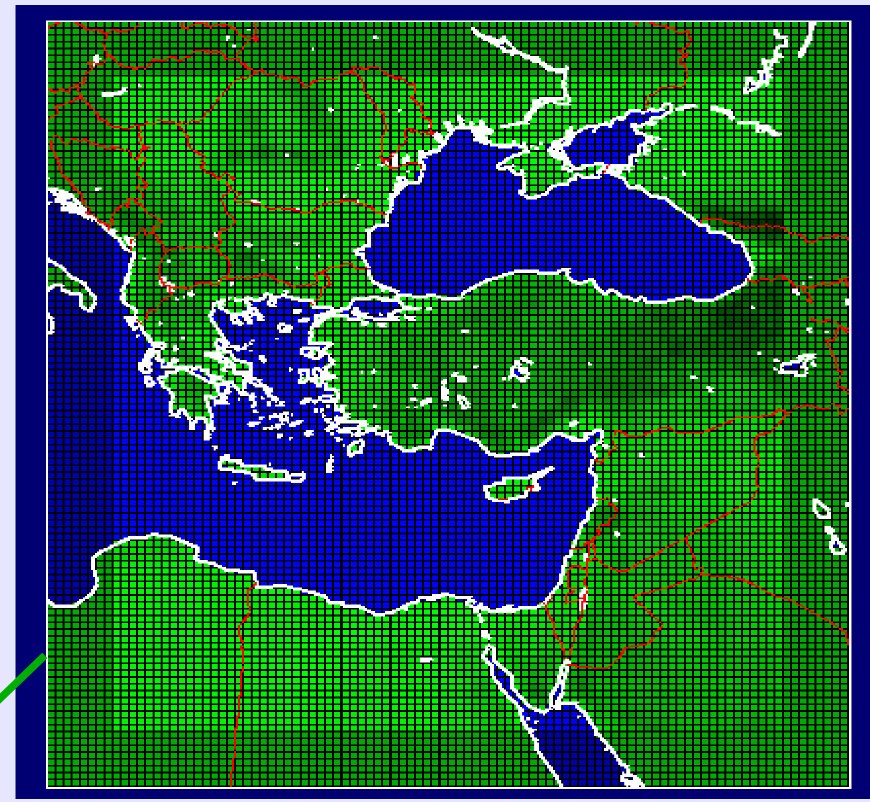
global-scale model (GCM)

~ 150 km



regional-scale model (RCM)

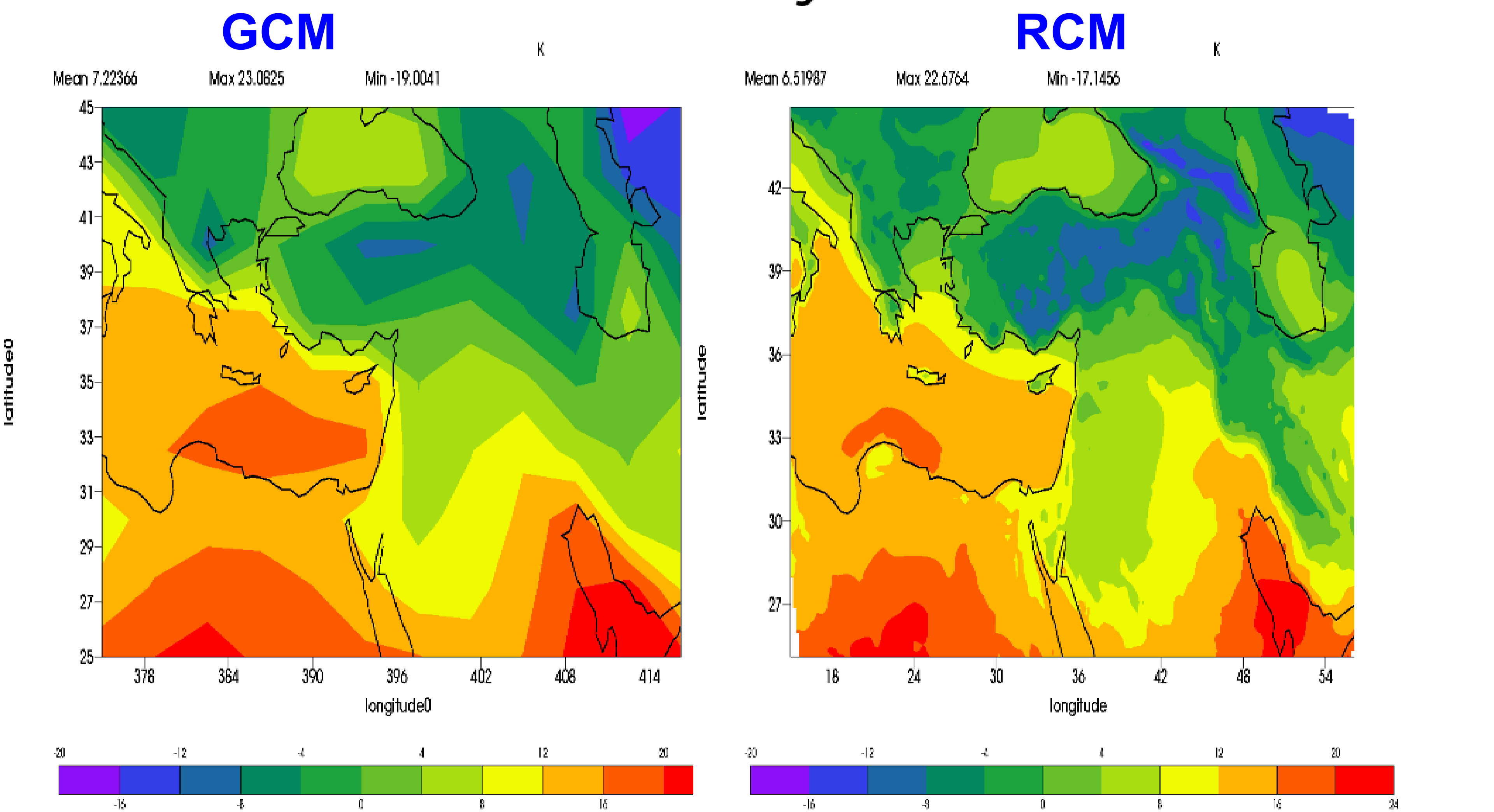
25 km



Better representation of coastlines and islands

Dynamical downscaling: detail

20 January 1990



Dynamical downscaling: limitations

- Horizontal resolution:

- State-of-the-art RCM grid-box dimensions (~15-25 km) cannot explicitly resolve clouds and local orography

- Non-atmospheric components:

Less detailed treatment of other processes and related feedbacks, e.g.

prescribed SSTs, surface and sub-surface modelling and interactions with air

Dynamical downscaling: Uncertainties

- Issues related to downscaling, like application of boundary forcing, domain size, physical parametrisation consistency between and “father” and nested models = **RCM uncertainty**

- GCMs (that provide the boundary conditions for the RCMs) contain uncertainties related to the mathematical formulation of the earth’s climate system and the parametrisations of the sub-grid processes

= **GCM uncertainty**

- Green-house gas (GHG) concentrations that radiatively force the GCM projections result from emission scenarios based on “storylines” of economic, population and technological development

= **Emissions uncertainty**

The PRECIS RCM

www.precis.org.uk (Jones et al., 2004)

PRECIS stands for "Providing REgional Climates for Impacts Studies."

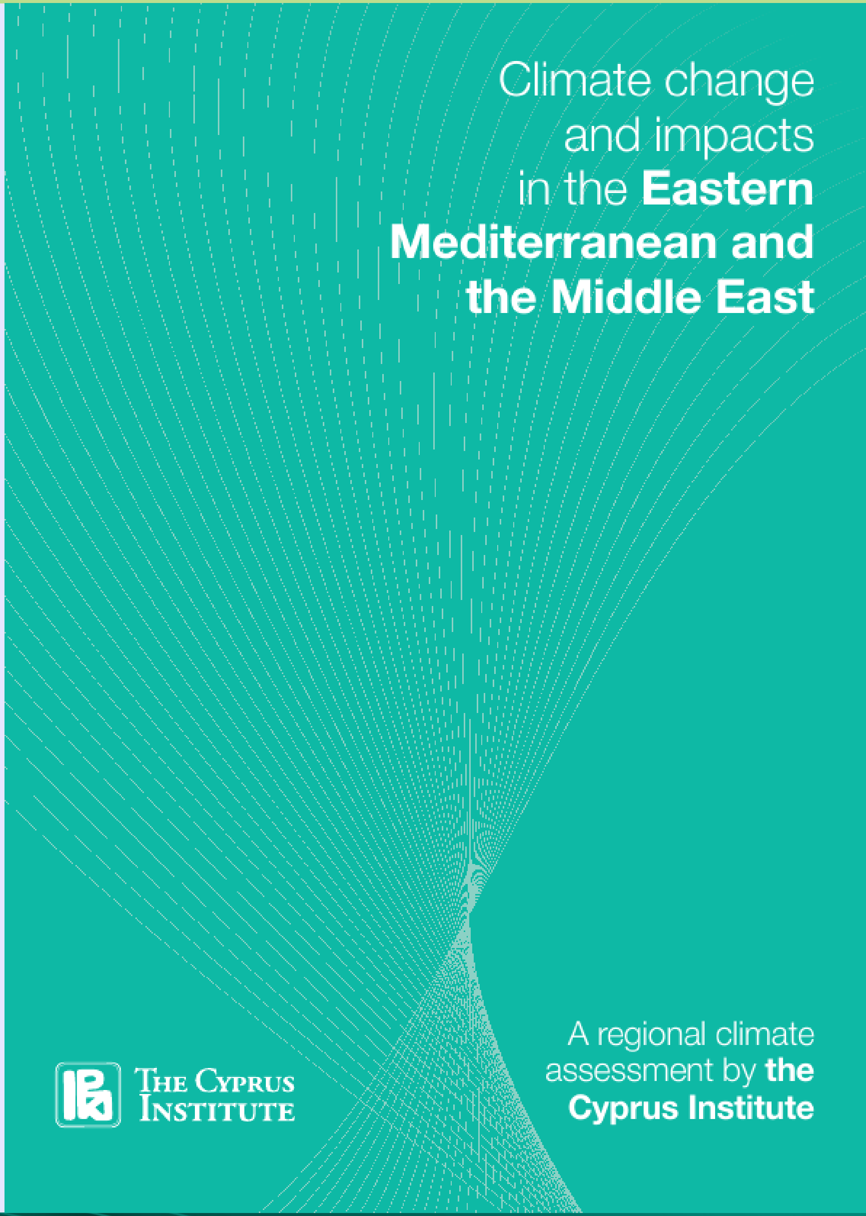
Developed at the Hadley Centre at the UK Met Office, PRECIS is a regional climate modelling system that can be applied to any area of the globe to generate detailed climate change projections.

These scenarios can be used in impact, vulnerability and adaptation studies, and to aid in the preparation of National Communications, as required under Articles 4.1 and 4.8 of the United Nations Framework Convention on Climate Change (UNFCCC).

PRECIS CIMME simulation

- Climate Change Impacts in the Eastern Mediterranean - Middle East
- Funded by CyI
- International collaboration
- Cyprus, neighbouring countries and beyond
- Relevant impact sectors
- Led by Prof. Jos Lelieveld

http://www.cyi.ac.cy/climatechangemetastudy



PRECIS CIMME simulation

- Climate Assessment (Climate data collection, Climate projections- dynamical downscaling)
- Energy (Electricity demand, wind potential)
- Water (Regional water balances, weather modification)
- Air Quality (natural/anthropogenic effects)
- Health (Heat related mortality)

Changing number of dry days/year by mid-century

Summary

The Eastern Mediterranean and the Middle East (EMME) is made up of two dozen countries with over 400 million inhabitants spread over an area with a 2,000 km radius. After years of intense industrialisation, rapid population growth and extensive land conversion, the EMME has now become a global climate change 'hot spot'.

Predicted climate changes

To understand the implications of EMME's shifting weather patterns, researchers have projected climate change for the 21st Century, using a regional climate model based on an intermediate emission scenario, and predicted impacts on the environment. The research suggests substantial regional climate changes, with significantly dryer and warmer conditions.

Increasing temperatures

There is expected to be a continual and gradual warming of temperatures, with highest rates in the north of the EMME. The mean temperature rise will be about 1-3°C in the next three decades, 3-5°C by mid-century and 3.5-7°C by the end of the century. This is increasing at about 0.37±0.9°C per decade, which suggests that the region is likely to warm at a much faster rate than the global mean rate of 2.8°C by the end of the century.

In addition, there are likely to be extremely high summer temperatures.

Decreasing rain

The precipitation throughout the EMME region is expected to decline. In the north a decrease of 10-50% during the 21st Century is expected, with rainfall primarily decreasing in spring and summer. In the south, precipitation may actually increase due to the expanding influence from the humid tropics, though this is modest in absolute terms.

Impacts of the expected changes

The predicted warming and drying of the EMME region will have major consequences for both humans and natural ecosystems, especially from the increased heat stress and reduced rainfall.

Impacts on air quality

Air quality is expected to decline in the EMME. In the north, increasing dryness will lead to escalating vegetation fires and resulting pollution emissions. The EMME has several megacities in which air quality is already seriously degraded and ozone levels are expected to continue to increase. As a result, air quality control measures are considered to be critical.

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Impacts on human health

There is compelling evidence that the maximum daytime temperatures in the EMME are increasing especially rapidly, which will lead to extended heat waves with major consequences for city dwellers. In addition, vector-borne parasitic and viral diseases are expected to increase in prevalence. Although increasing temperatures promote the spreading of vector organisms, hosts and infectious diseases, it will be necessary to consider climate change in combination with other influences.

Impacts on land ecosystems and agriculture

The EMME has a high biodiversity due to its large gradients in topography and soil fertility, and the varied climate. The predicted drying and warming of the EMME has the potential to dramatically alter the balance of species in the region. Projections suggest that the milder winters in the north will be associated with a lengthening of the growing season, which could positively influence agriculture. However, this will likely be overshadowed by the increasing number of hot days and the decreasing soil moisture.

Impacts on marine ecosystems

The marine ecosystems of the Mediterranean Sea are already affected by climate-driven and other human-induced changes. There is expected to be a warming of water temperature, increasing salt content and resulting in water mass stabilisation and an expected sea level rise of about 1.3-2.5 cm per decade. The marine biodiversity will be affected by decreased nutrient availability, marine ecosystems becoming more 'tropical' and the invasion of alien species.

Impacts on freshwater resources

Parts of the EMME, especially in the Middle East, are already notorious for fresh water scarcity. The predicted decreasing rainfall will result in a river discharge decrease of 10-30% by the end of the 21st Century and a significant reduction in the availability of freshwater for the EMME, with important social and economic implications, especially in agricultural areas. The region will need to invest in desalination and improved water-use efficiencies.

Impacts on energy demand

Fossil fuels dominate the energy supply in the EMME and this use is growing at one of the highest rates in the world. During the warm season the demand for air conditioning is expected to increase significantly. This energy demand will grow in parallel with water deficits, which additionally places pressure on energy production. Alternative sources of energy and improved energy efficiencies are therefore critical for the EMME region.

Extended heat waves will have major consequences for city dwellers

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PRECIS projections for Cyprus

PRECIS CIMME simulation

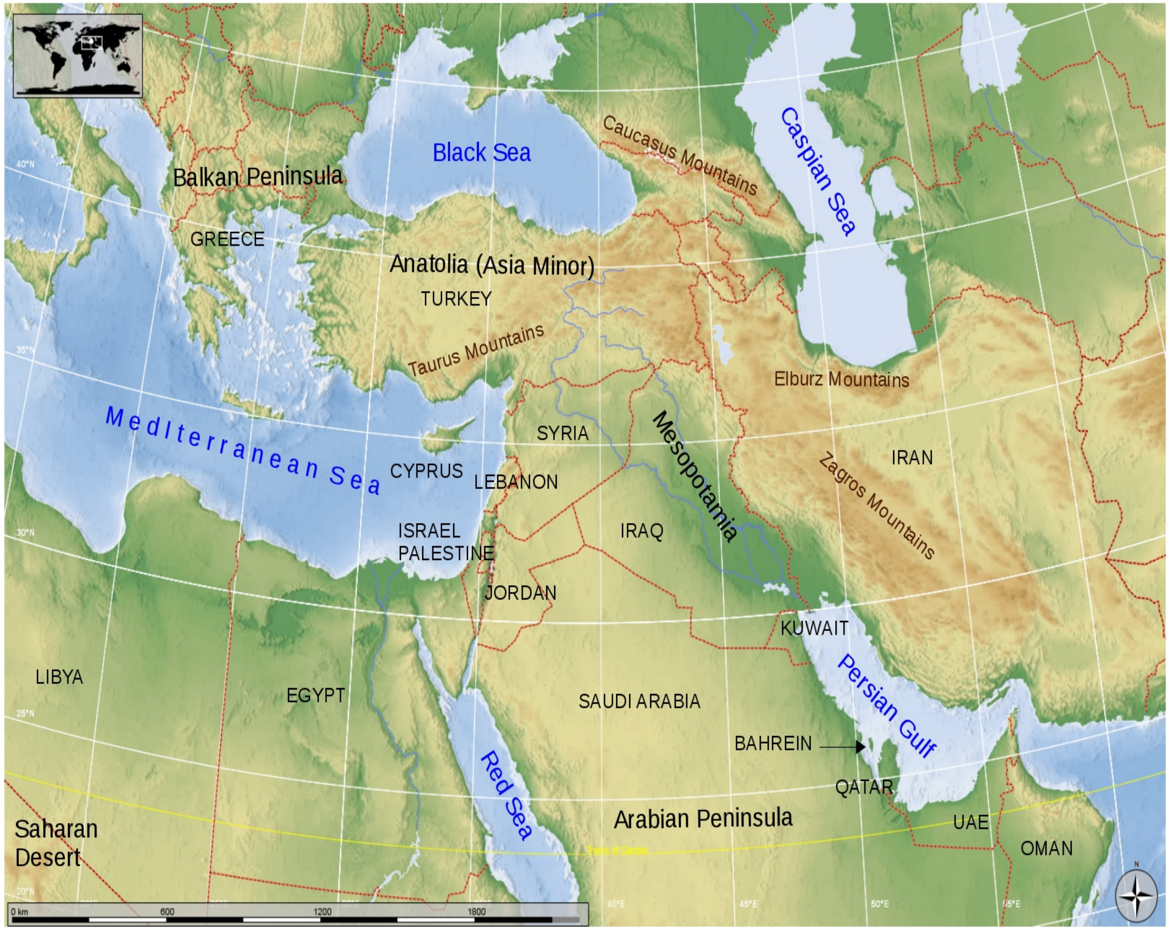
Eastern Mediterranean and Middle East (EMME):

Variable topography (land alternating with major water bodies)

Steep orography (from deserts to mountains several Km high)

Atmospheric circulation crossroad (influenced by North Atlantic and South Asia flows)

Diverse climate with remarkable gradients:

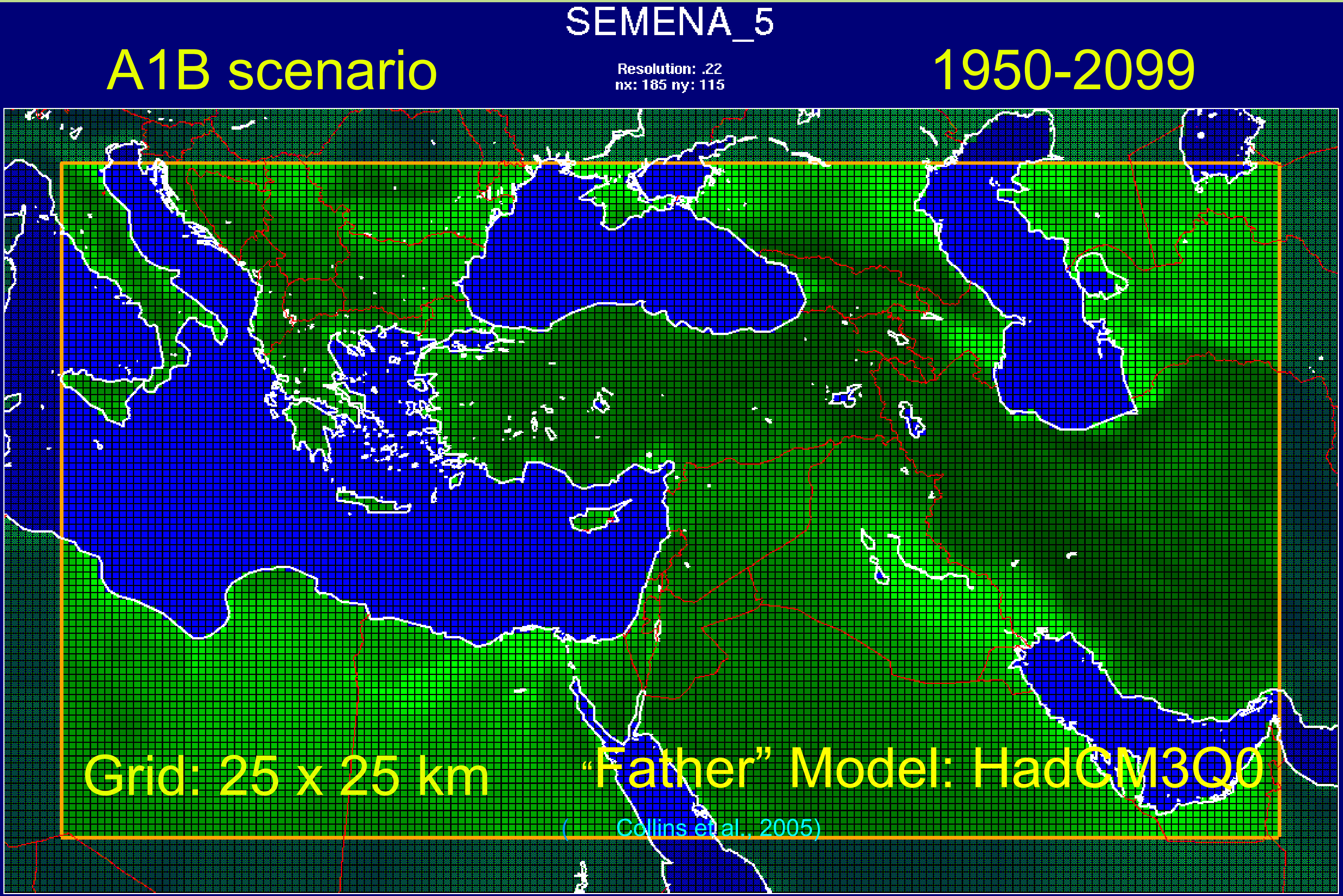


Summer Temperature (July average Tmax) ranges from 27°C (Belgrade) to 47°C (Kuwait City)

Annual Precipitation (total) is only 14mm in Cairo while in Tirana is around 1400mm

PRECIS projections for Cyprus

PRECIS CIMME simulation



PRECIS projections for EMME

Already utilised regionally

- Impact Assessment of Climate Change

http://www.moe.gov.lb/Climatechange/snc.html

REPUBLIC OF LEBANON MINISTRY OF ENVIRONMENT

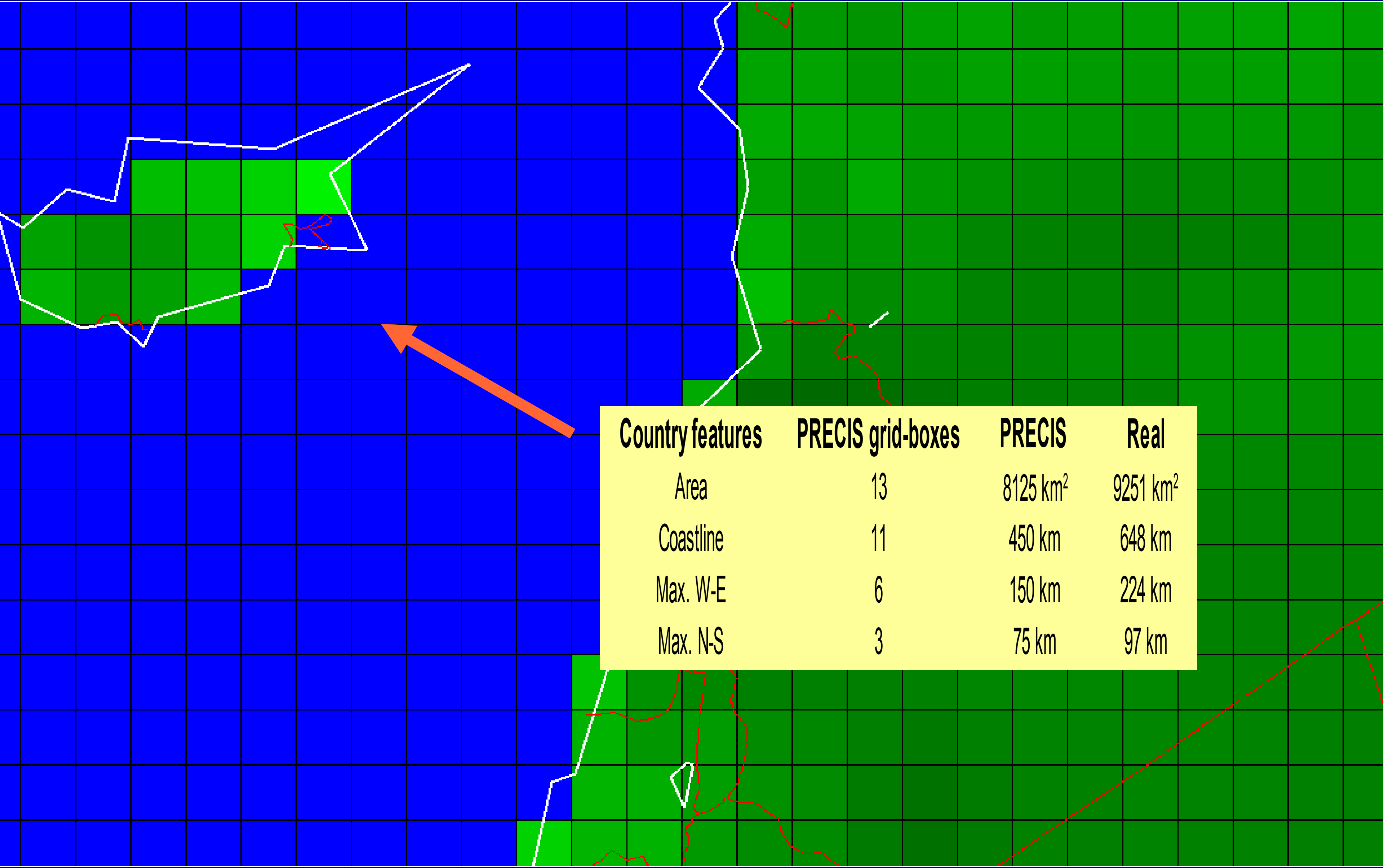
gef

UN DP

plus ELARD (Lebanon), Atlantis/CyI (Cyprus)

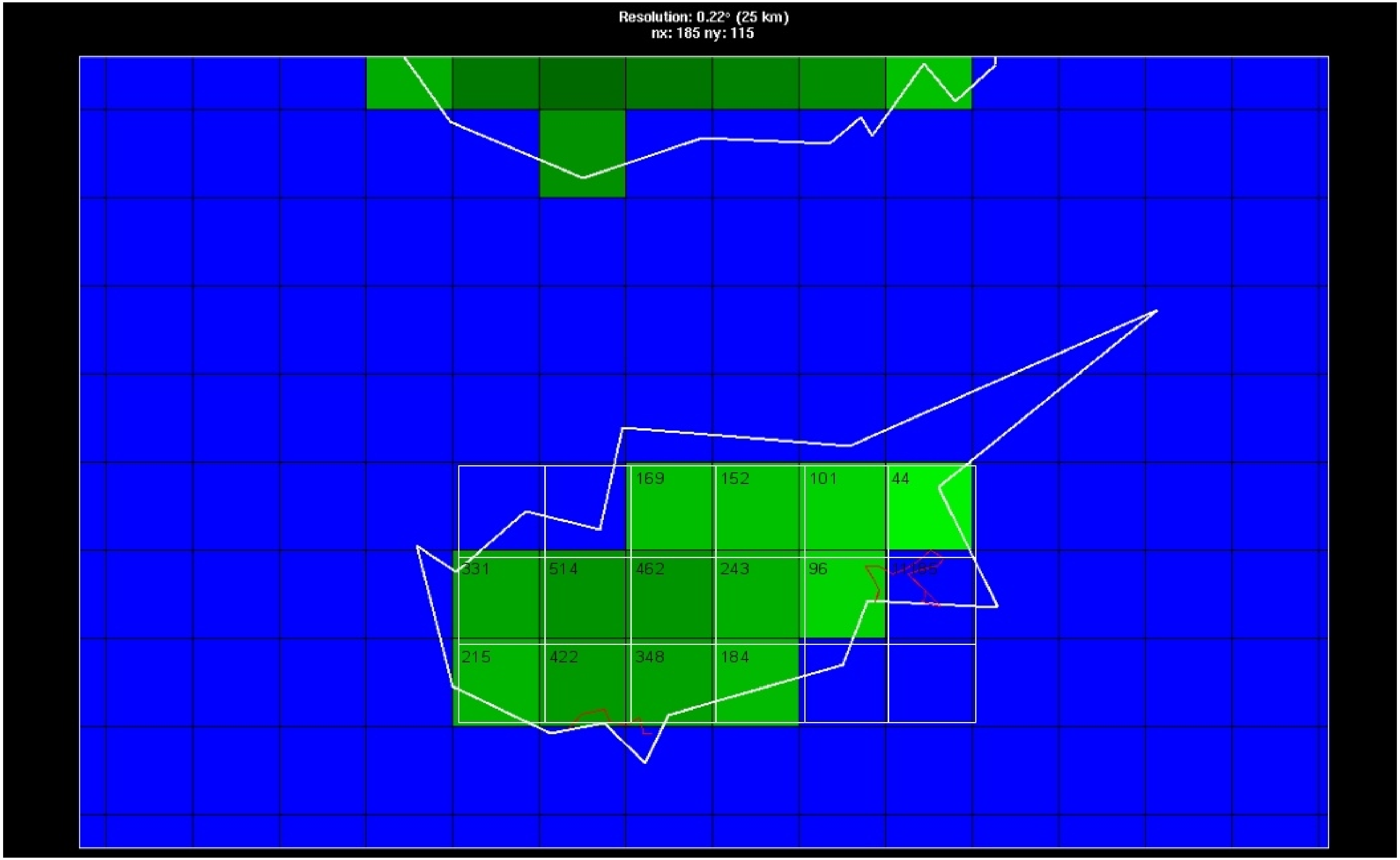
LEBANON'S
SECOND NATIONAL COMMUNICATION
TO THE UNFCCC

PRECIS topography



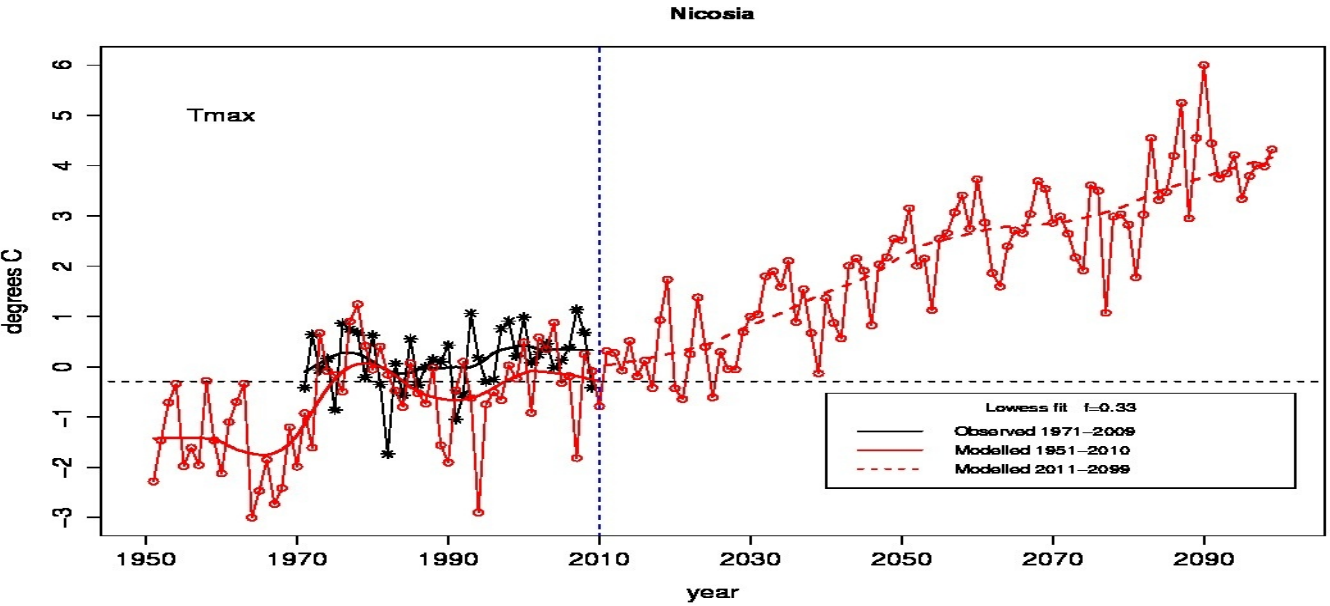
Country features	PRECIS grid-boxes	PRECIS	Real
Area	13	8125 km^2	9251 km^2
Coastline	11	450 km	648 km
Max. W-E	6	150 km	224 km
Max. N-S	3	75 km	97 km

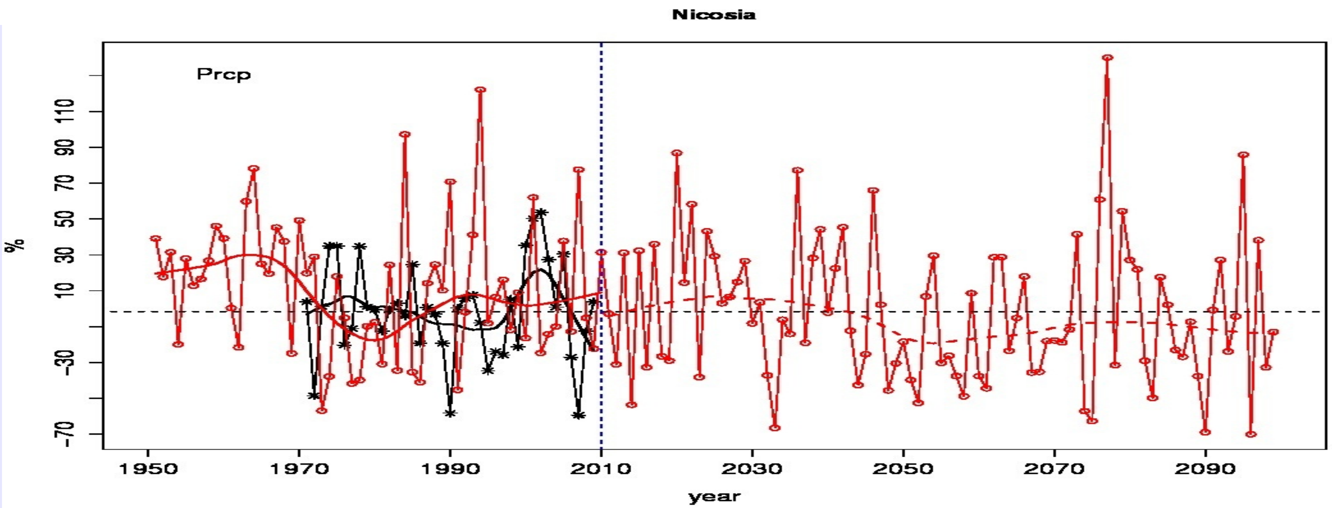
PRECIS gridbox elevation



PRECIS projections for Cyprus

Long-term evolution



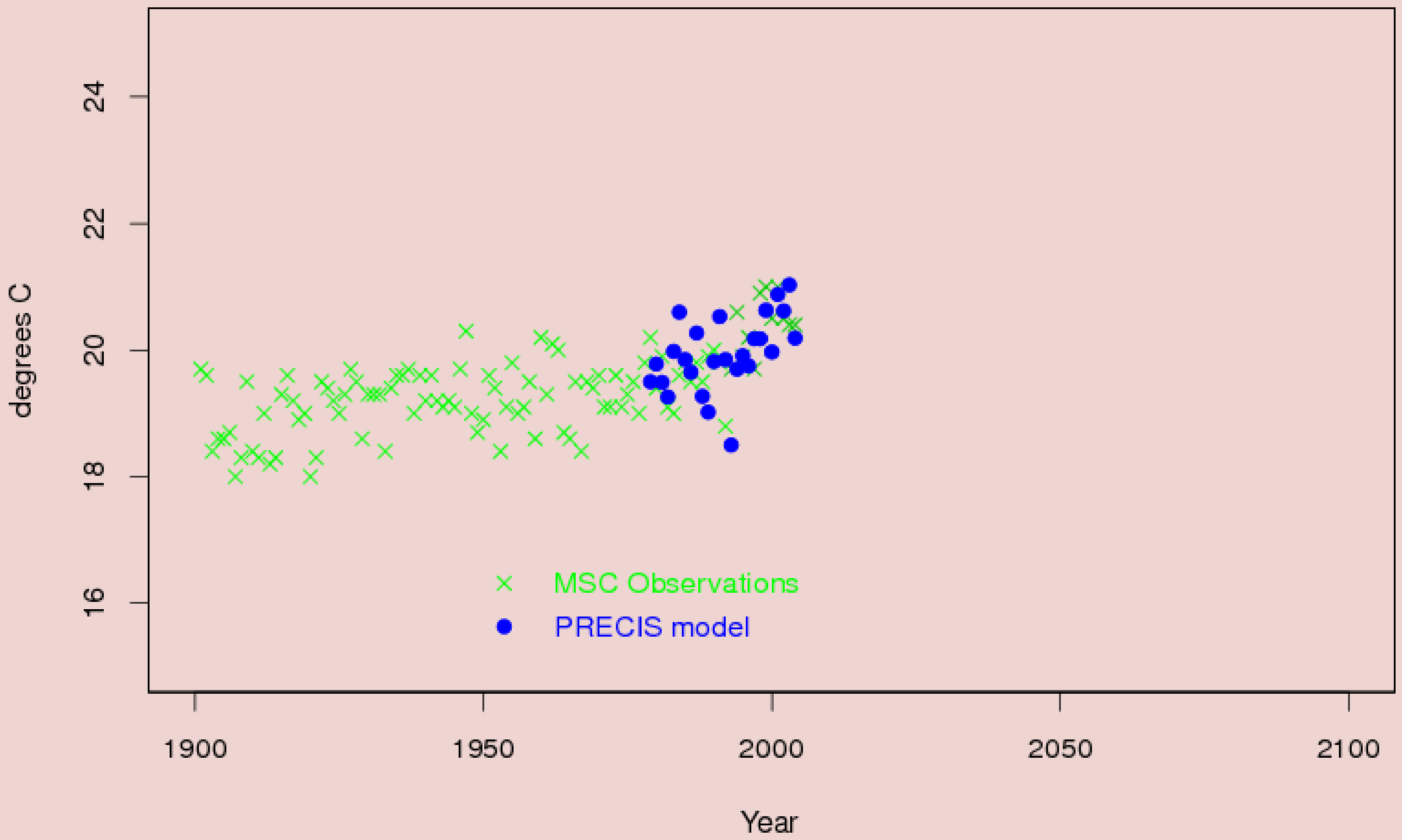


- Year-to-year anomalies of annual mean time-series
- Lowess fit smooths inter-annual variability and reveals long-term tendency
- 1970-2010:
- Temperature no clear upward trend both in model and observations
- Precipitation much more variable, model fails to capture recent drying
- 21St century
- Almost linear temperature increase with large inter-annual variability
- Overall drying after 2050, cyclic behaviour?

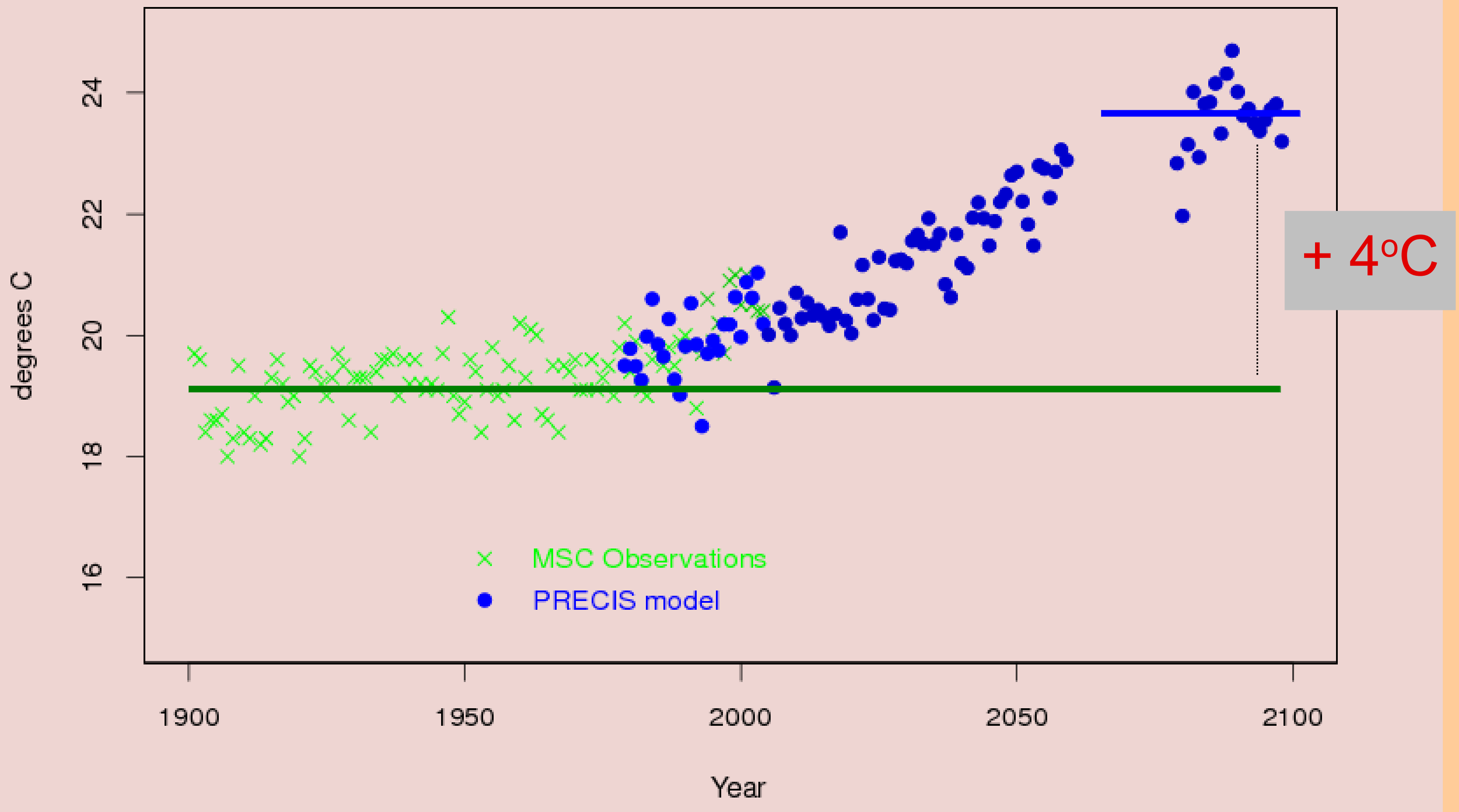
Annual Temperature Nicosia

Annual Temperature Nicosia

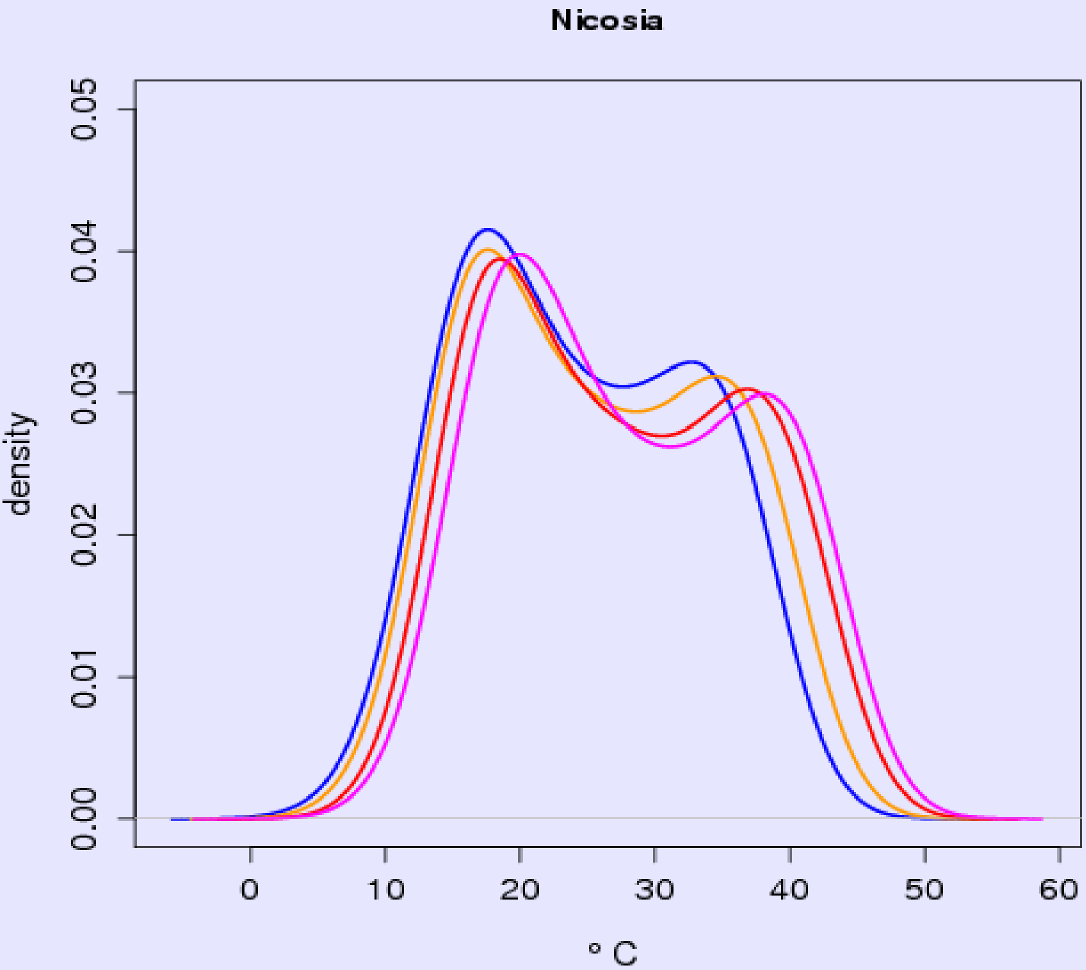
Annual Temperature Nicosia



Annual Temperature   Nicosia



Temperature distribution



- Temperature statistical distribution change

- Bimodal distributions represent the cold (mild) and the warm season.

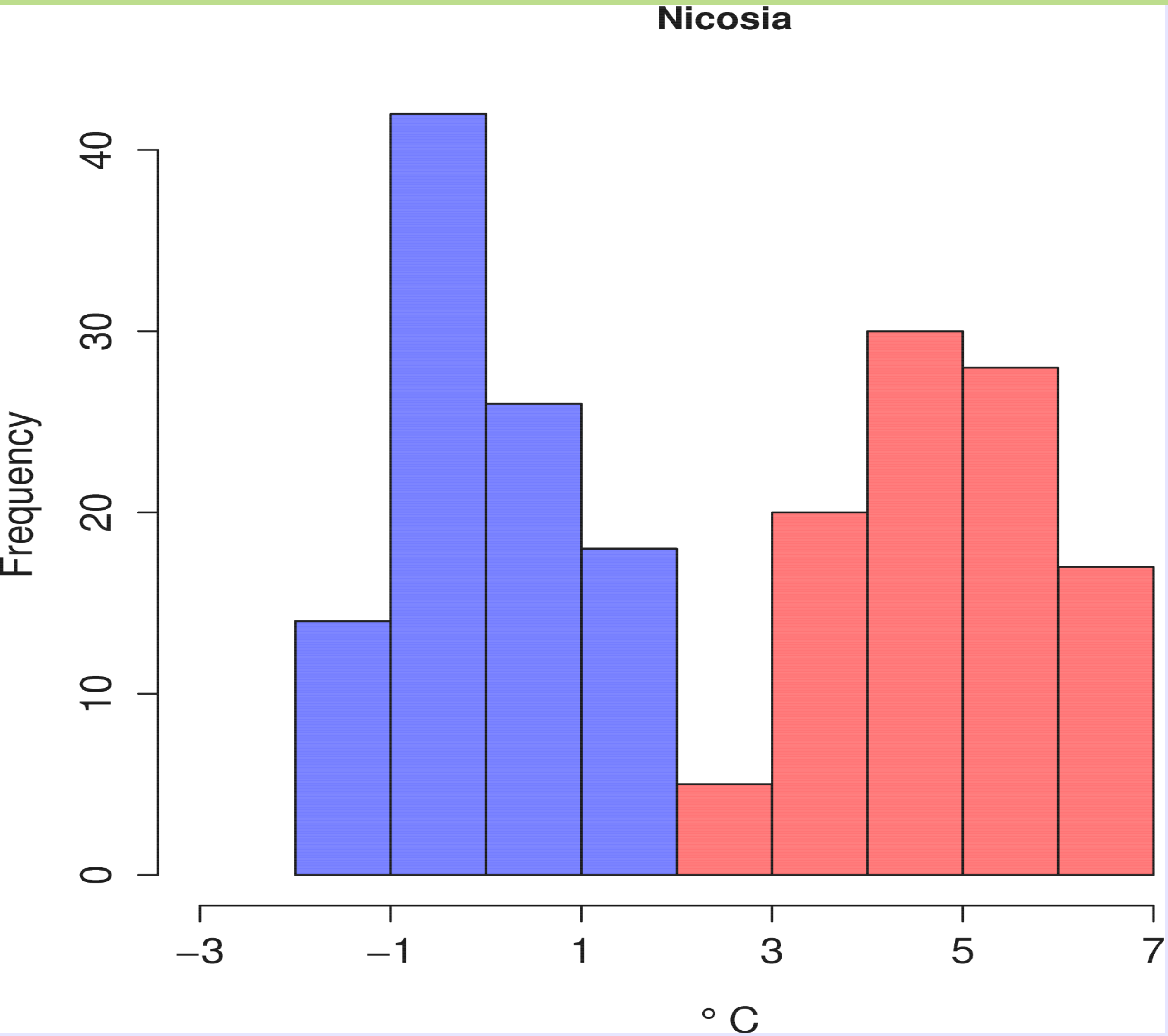
- The first mode is higher, indicative of cool and mild conditions during late autumn, winter and early spring.

- A gradual shift of the density curves to the right occurs, being most pronounced for the second mode and the peak heights decrease slightly.

- The changing tails of the distributions demonstrate the importance of increasing hot extremes, up to 5-6°C by the end-of-century (the cold extremes on the left-hand tail are getting warmer by 2-4 degrees).

(Lelieveld et al., 2011)

Summer frequency



- Summer temperature statistical distribution change

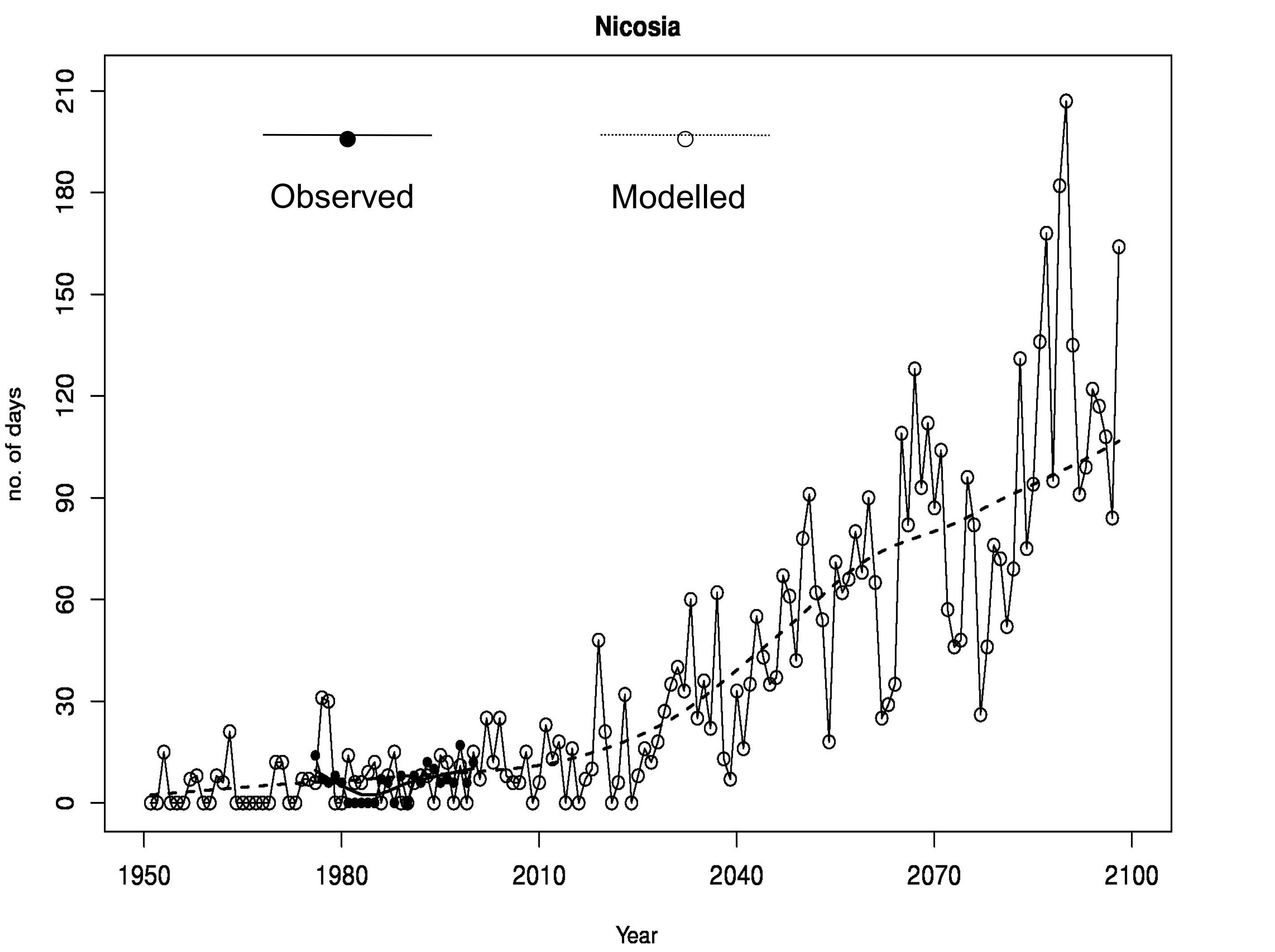
- Occurrence of (1°C interval) temperature anomalies from the mean maximum temperatures (TX) in summer (June-August) during the control period 1961-1990 and the end-of-century (both relative to the control period).

- The 2070-2099 and 1961-1990 histograms suggest that the coldest summers at the end-of-century may be warmer than the hottest ones in the recent past.

(Lelieveld et al., 2011)

PRECIS projections for Cyprus

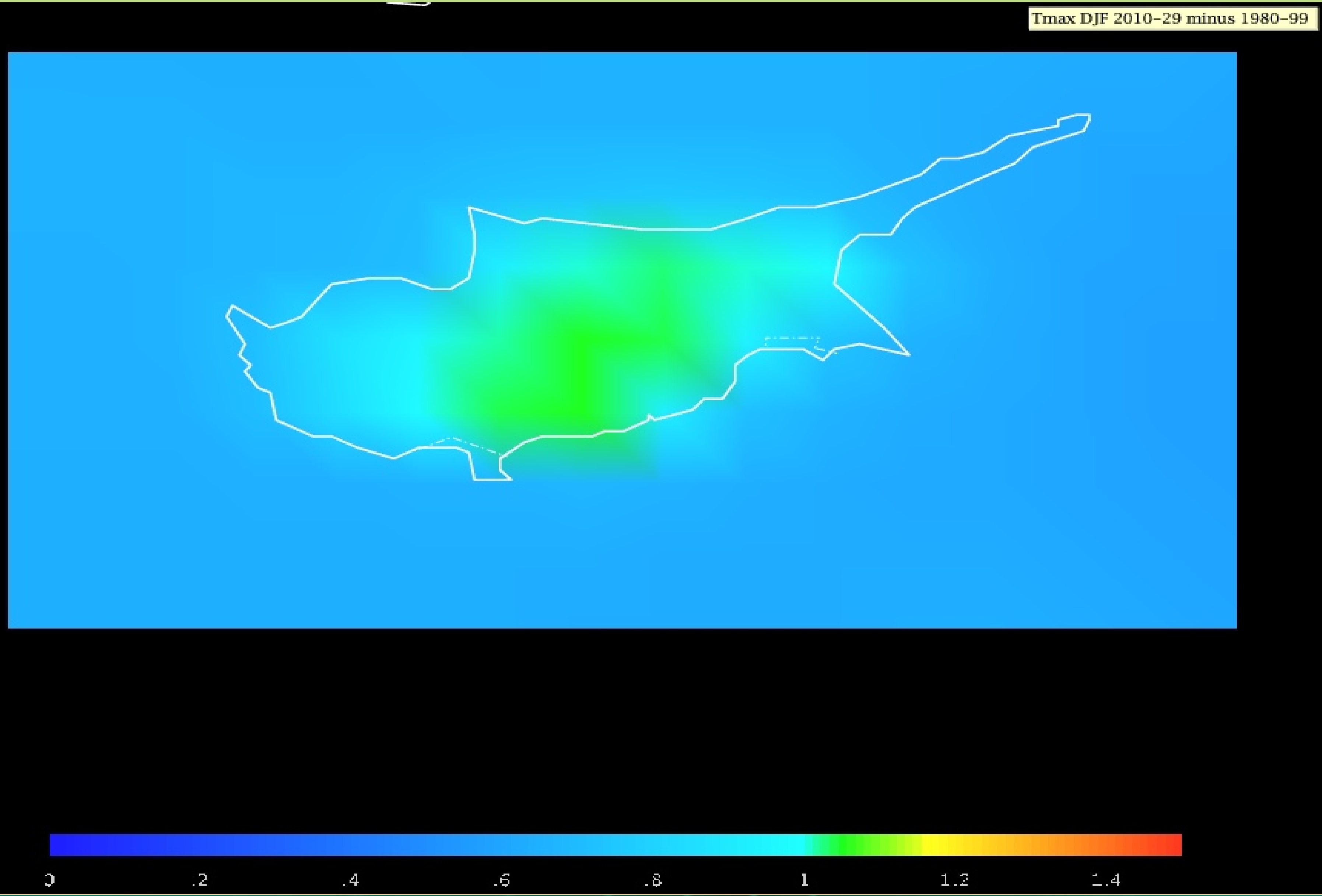
Heatwave duration



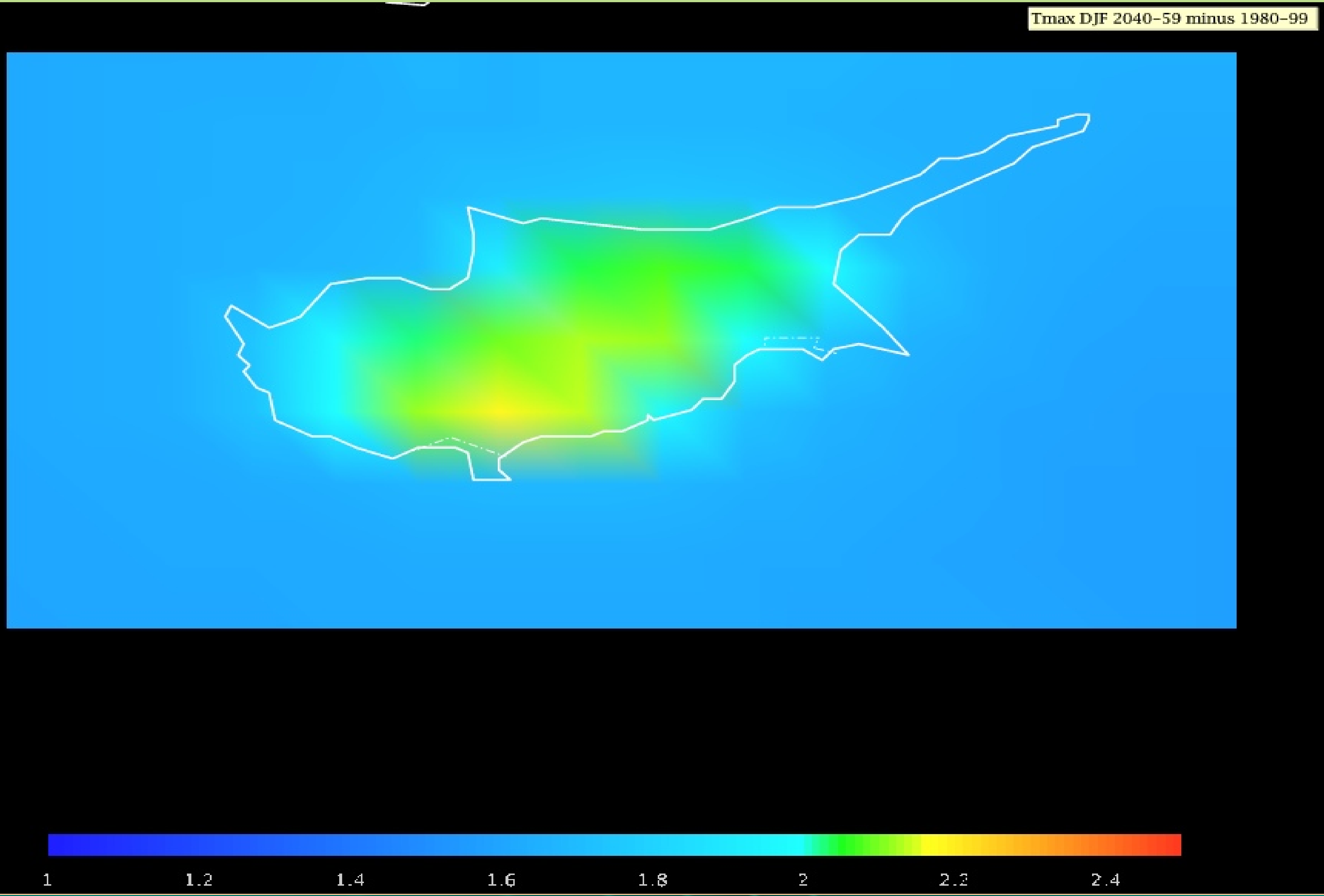
- Heatwave duration A1B scenario
- Defined as a spell of at least six consecutive days with maximum temperatures exceeding the local 90th percentile of the reference period.
- Model agrees well with observed duration and year-to-year variation during 20th century
- Exponentially longer projected duration in the 21st century
- Increase by a factor of 4-10 by mid and 7-10 by end of 21st century
- Increase in inter-annual variability adds to the severity of heat extremes

(Lelieveld et al., 2011)

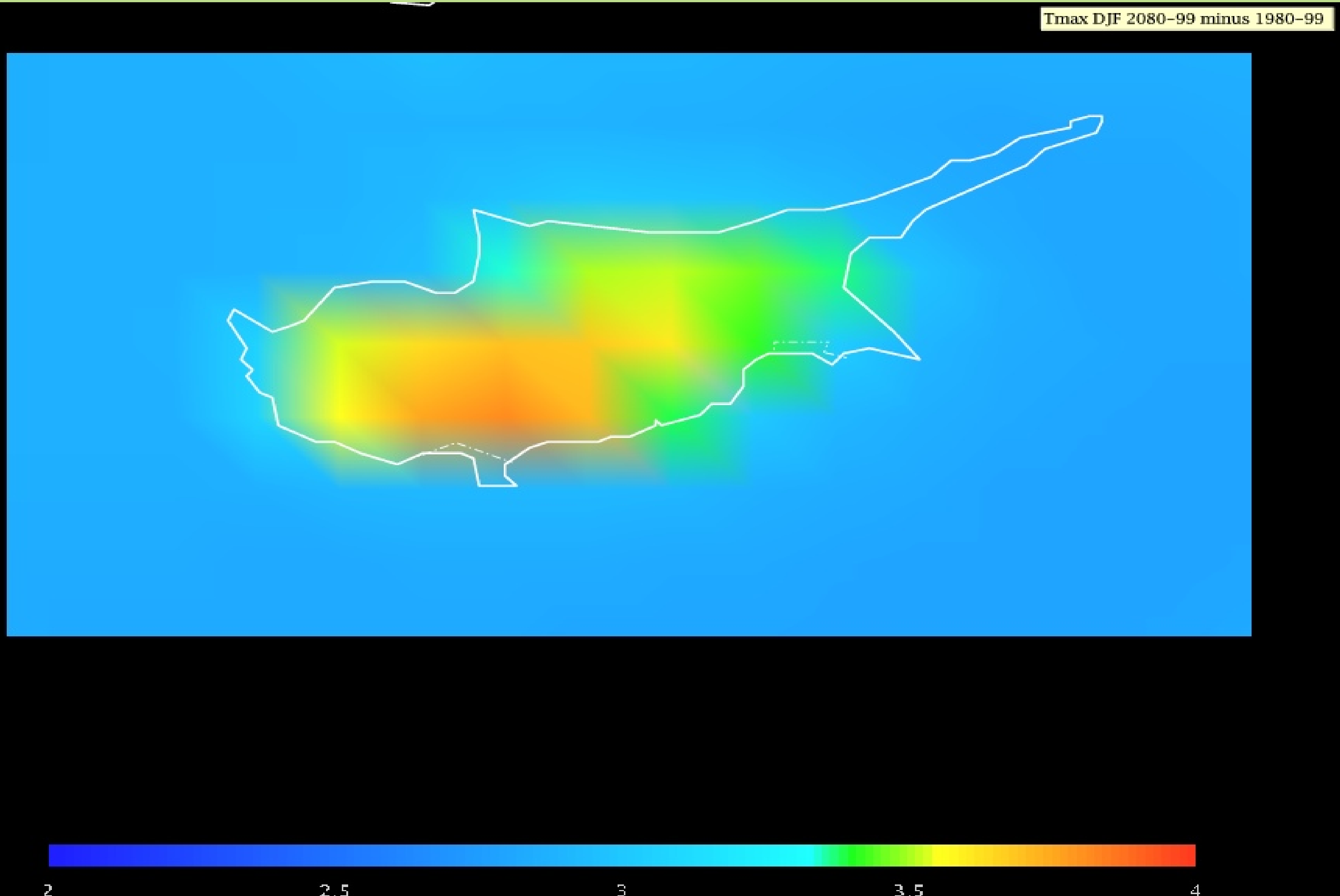
ΔTmax DJF 2010-2029



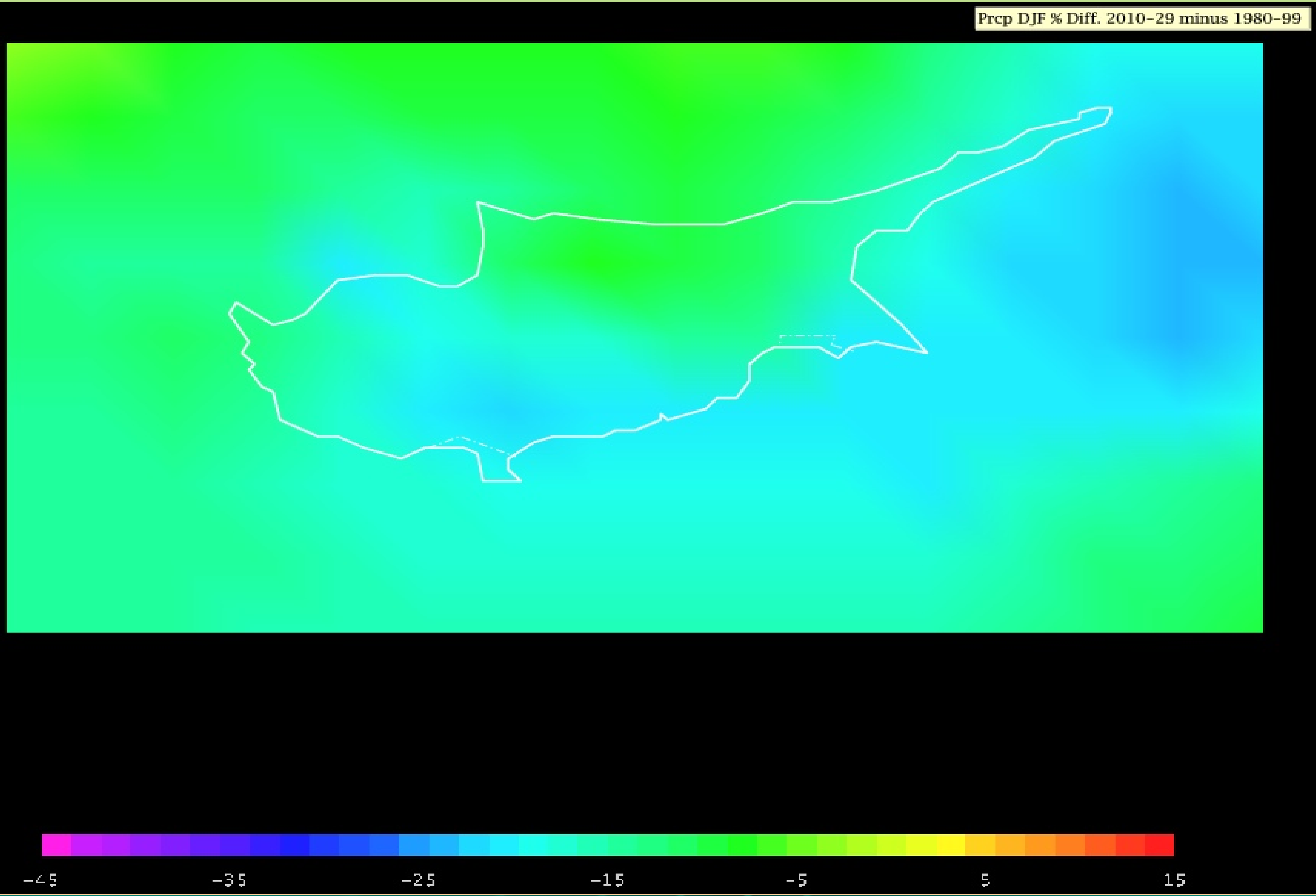
ΔTmax DJF 2040-2059



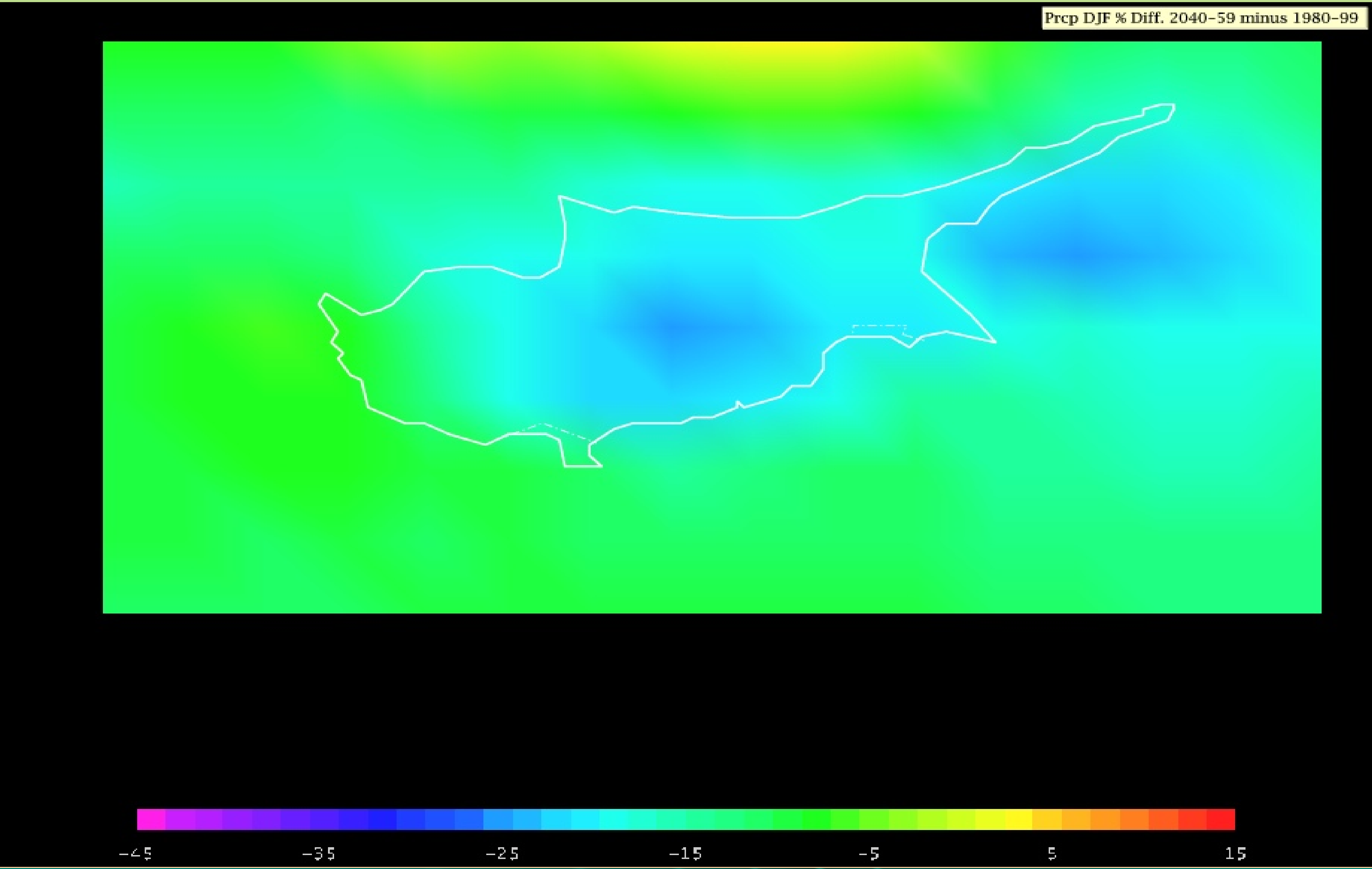
ΔTmax DJF 2080-2099



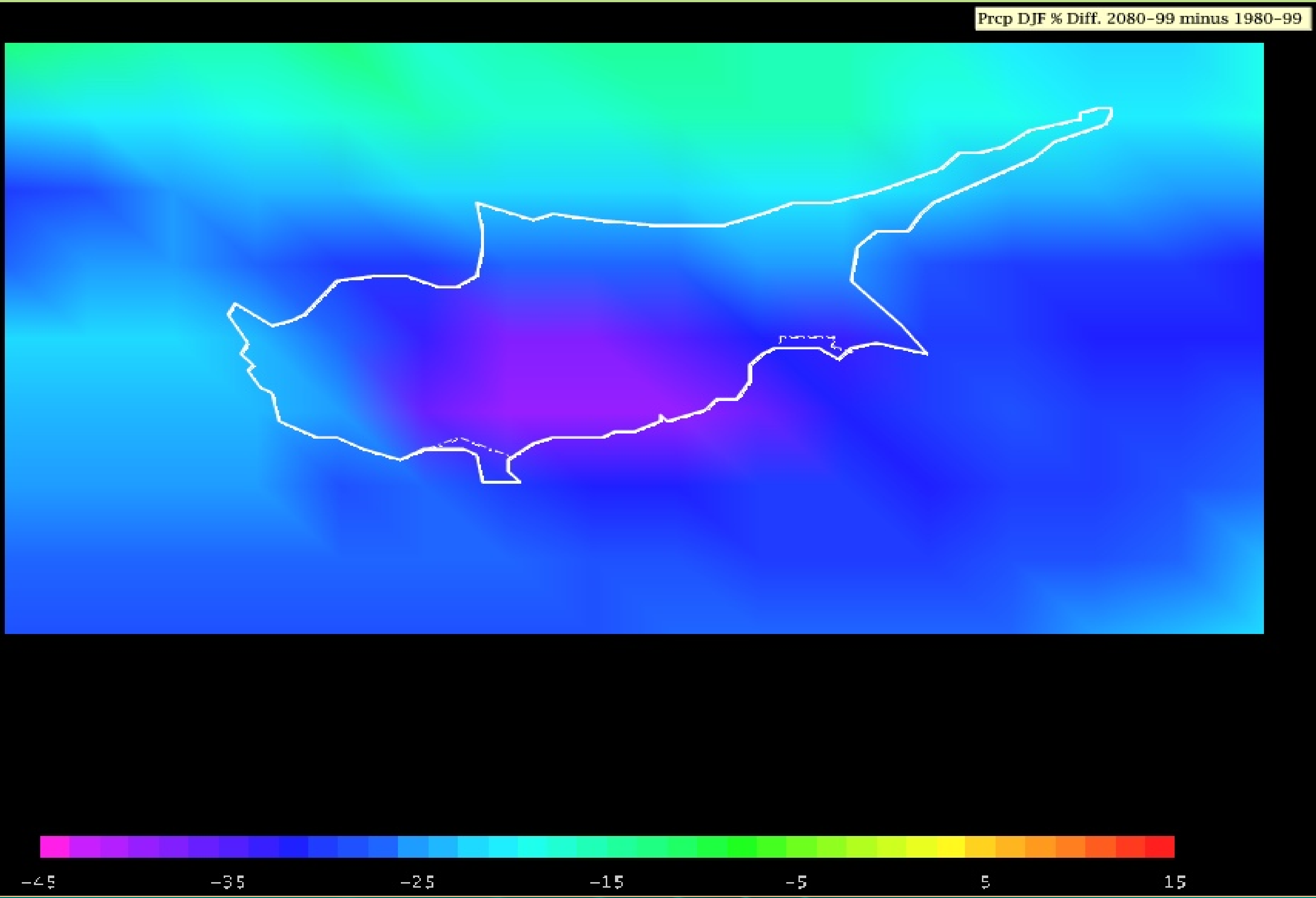
Δprcp %   DJF 2010-2029



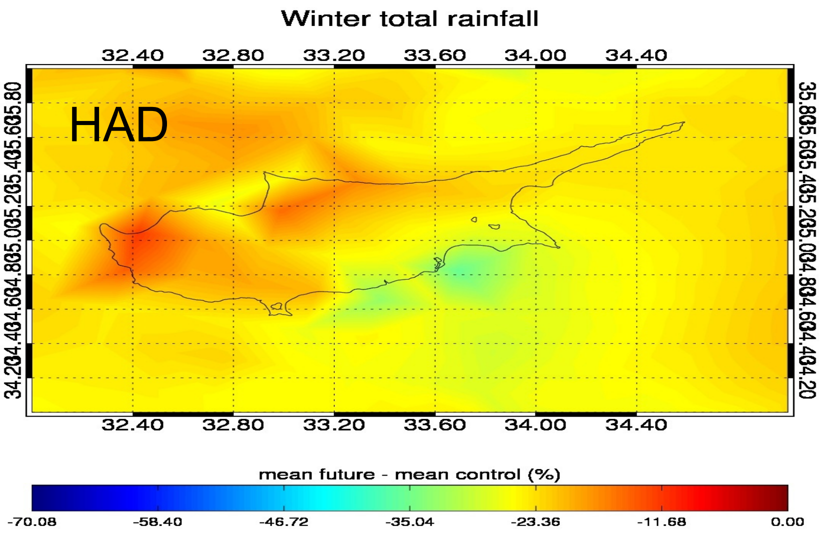
Δprcp % DJF 2040-2059

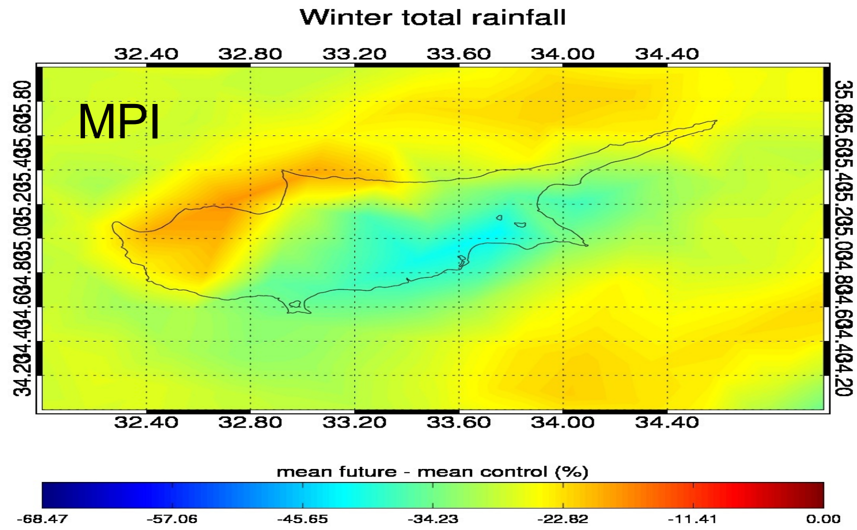


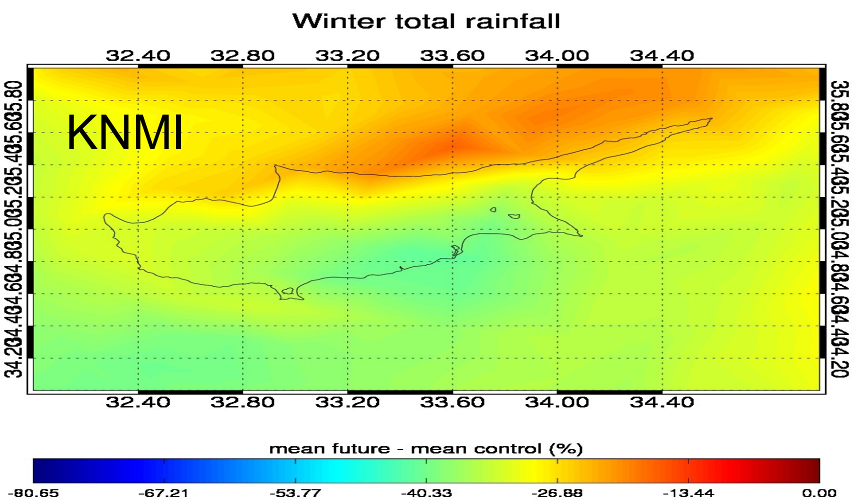
Δprcp % DJF 2080-2099



Δprcp % DJF 2070-2099



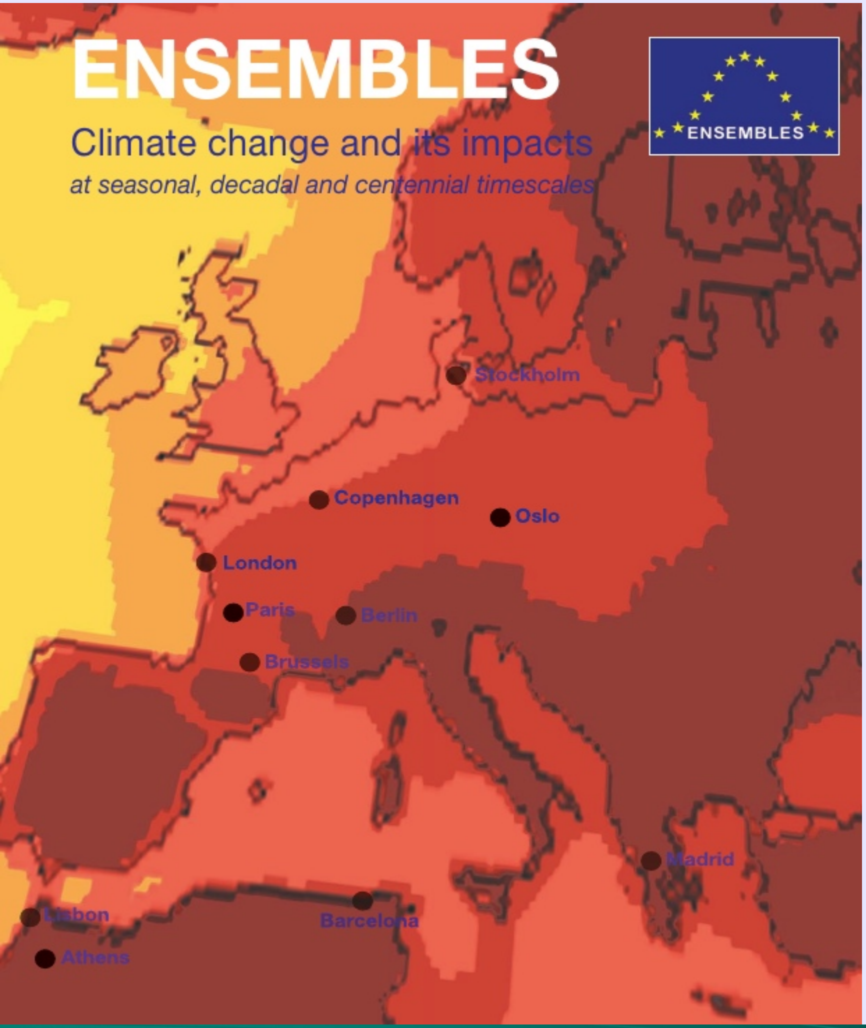


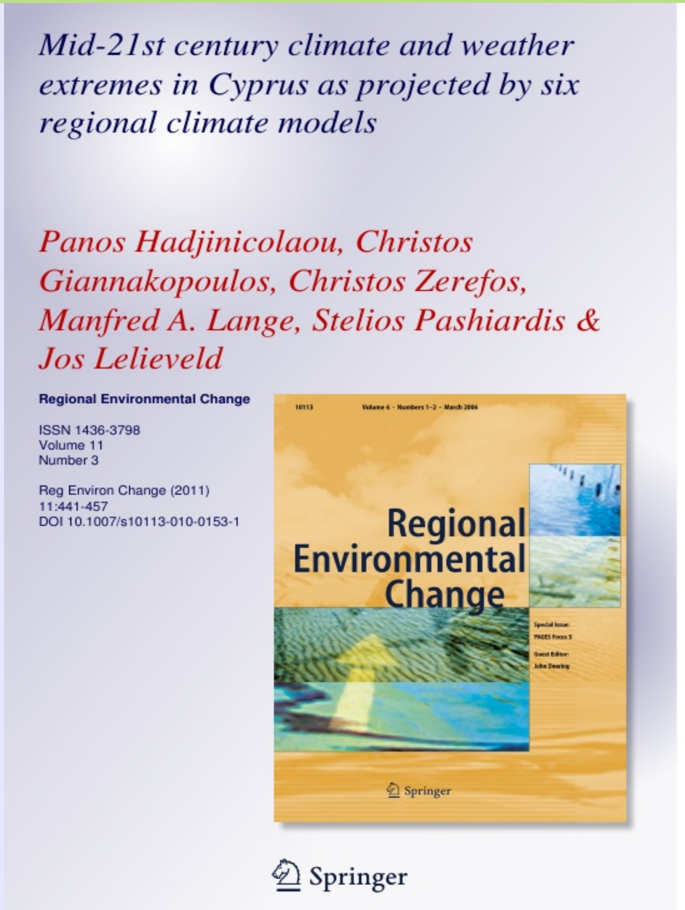


Different RCMs give diverse spatial distribution of projected drying

Projections from ENSEMBLES

Several RCMs simulated climate driven by the A1B scenario over a European domain




Mid-21st century climate and weather extremes in Cyprus as projected by six regional climate models

Panos Hadjinicolaou, Christos Giannakopoulos, Christos Zerefos, Manfred A. Lange, Stelios Pashiardis & Jos Lelieveld

Regional Environmental Change

ISSN 1436-3798
Volume 11
Number 3

Reg Environ Change (2011)
11:441-457
DOI 10.1007/s10113-010-0153-1

Springer

With the collaboration of the National Observatory of Athens extracted multi-model projection for locations in Cyprus

Analysed changes in mean and extreme climate in Cyprus by mid-21st century

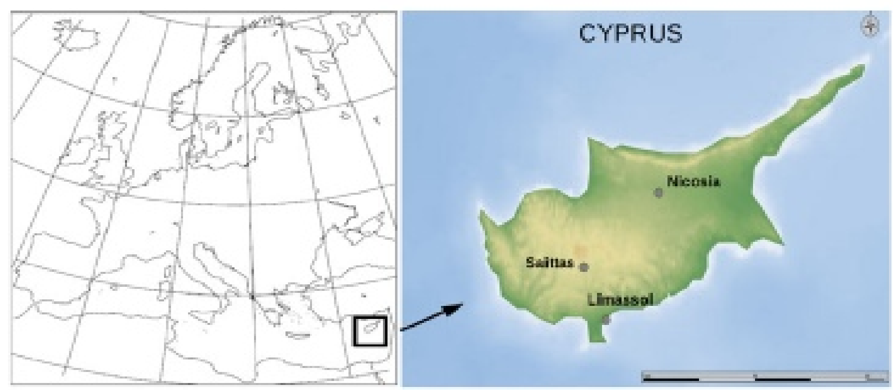
ENSEMBLES projections for Cyprus

Projections from ENSEMBLES

Acronym	RCM	Parent GCM	Institute	Country	Contact
CNR	Aladin	ARPEGE	CNRM	France	M. Déqué
ETH	CLM	HadCM3Q0	ETHZ	Switzerland	C. Schär
HAD	HadRM3Q0	HadCM3Q0	Hadley Centre	UK	E. Buonomo
KNM	RACMO2	ECHAM5-r3	KNMI	Netherlands	E. van Meijgaard
MNO	HIRHAM	ARPEGE	METNO	Norway	J.E. Haugen
MPI	REMO	ECHAM5-r3	MPI	Germany	D. Jacob

- 6 RCMs driven by 3 GCMs
- 25 x 25 km resolution
- Daily output for the periods 1976–2000 and 2026–2050 was extracted from all six RCMs
- Best performing gridbox (among several neighbouring) was used according to comparison with observations

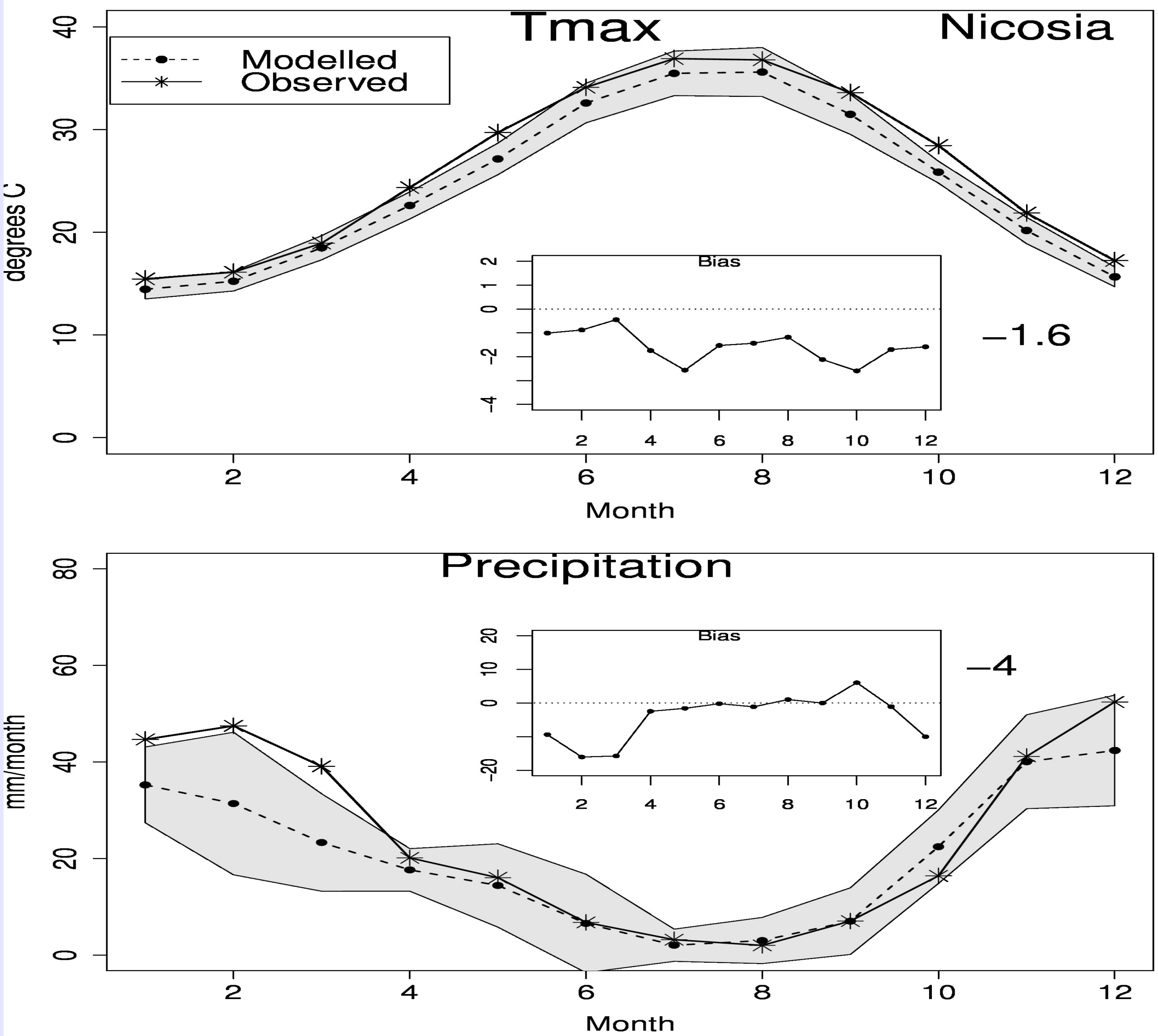
Daily time-series of Tmax, Tmin, Prcp provided by the Meteorological Service of Cyprus (MSC) for the stations of Nicosia, Limassol and Saittas.



Station	Lat (deg)	Lon (deg)	Height (m) Observed	Height (m) Model ave.
Nicosia	35.16	33.35	160	260
Limassol	34.66	33.02	31	160
Saittas	34.86	32.91	641	805

Locations representative of the island's climate and topographical features: inland (Nicosia), coastal (Limassol) to mountainous (Saittas)

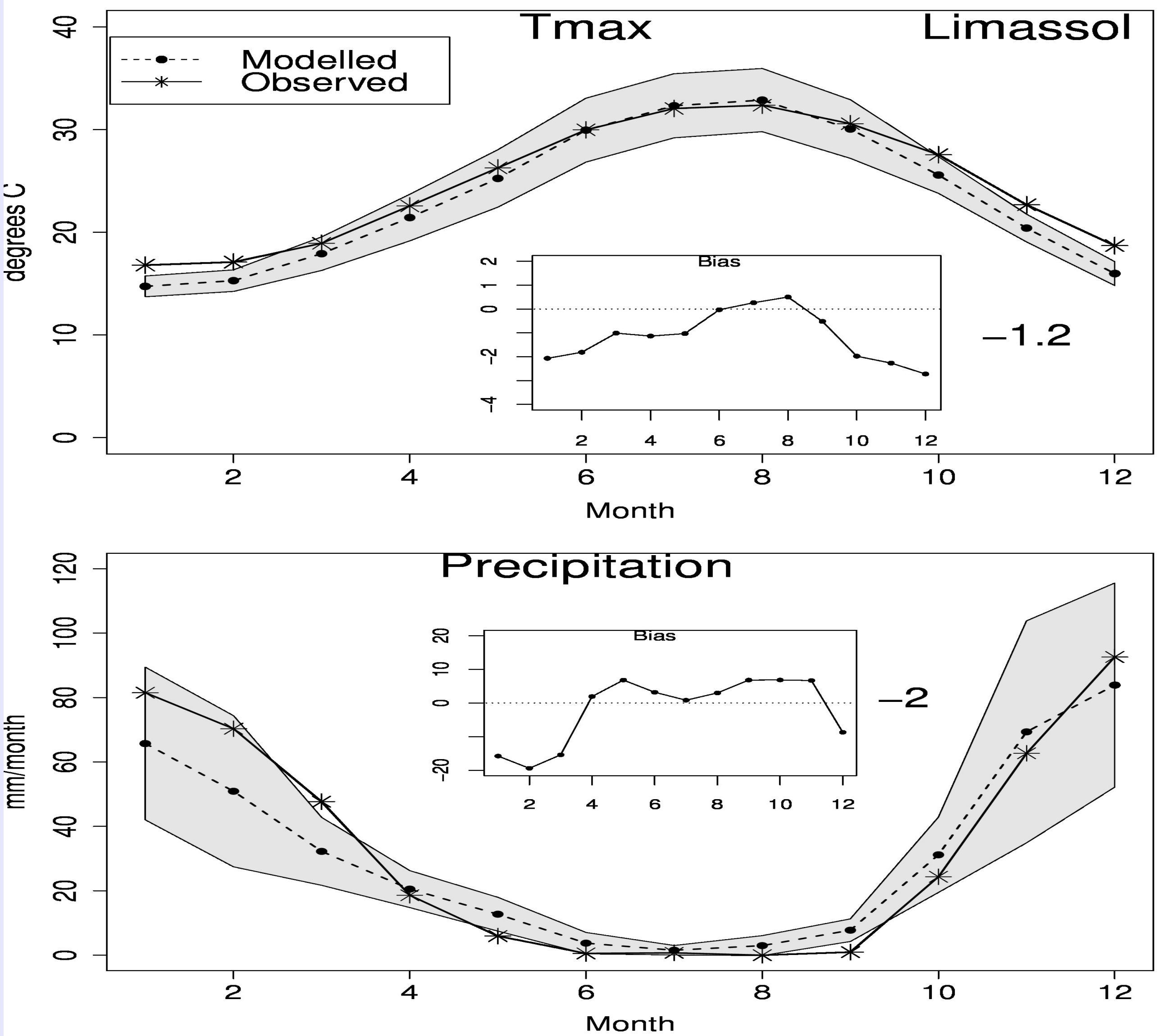
Model evaluation: climatology



- Multi-model average improves comparison with observations (contrast with one-model evaluation)

- Observations fall within the 6-model range (1σ)

Model evaluation: climatology



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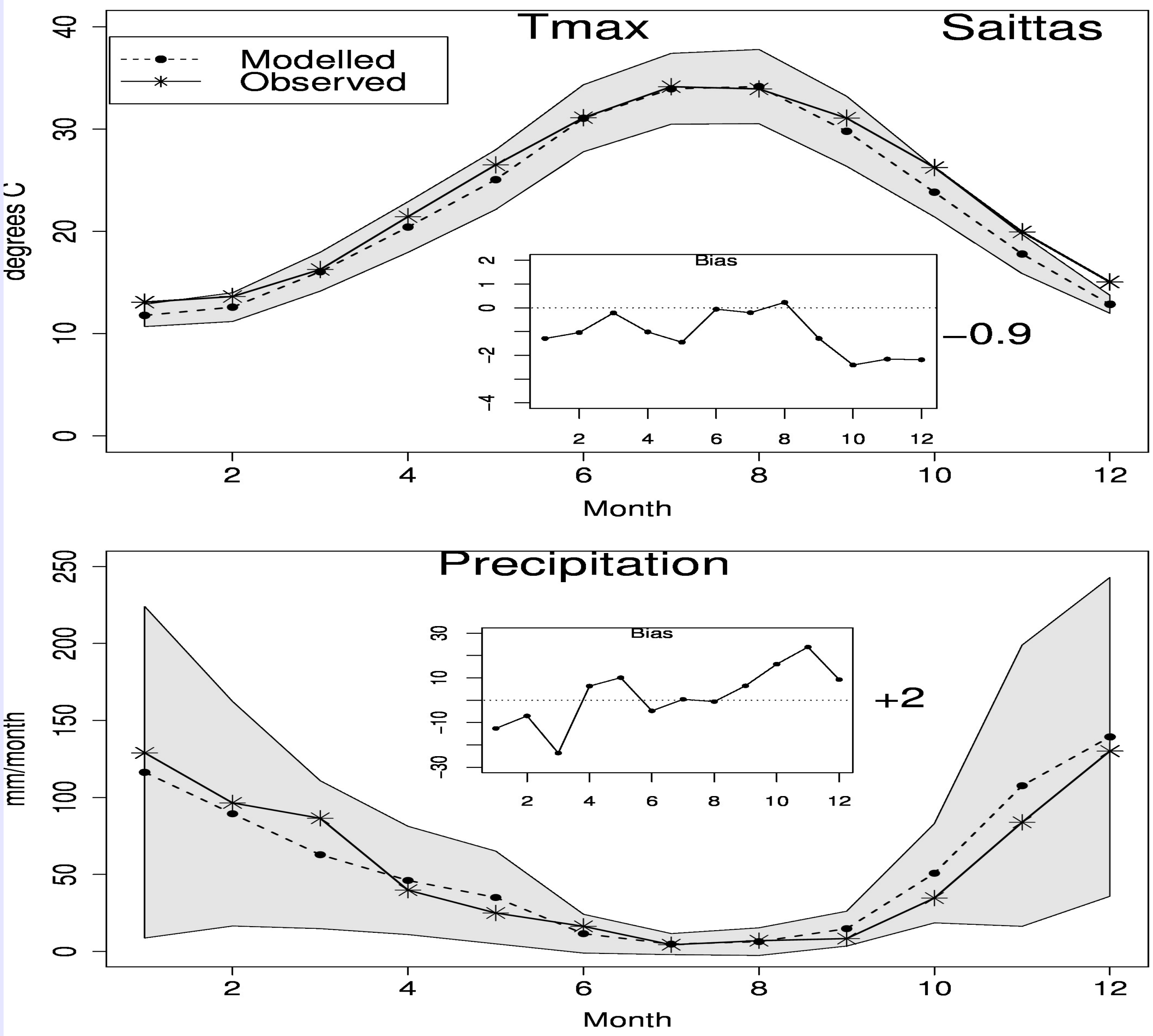
ENSEMBLES projections for Cyprus

Model evaluation: climatology



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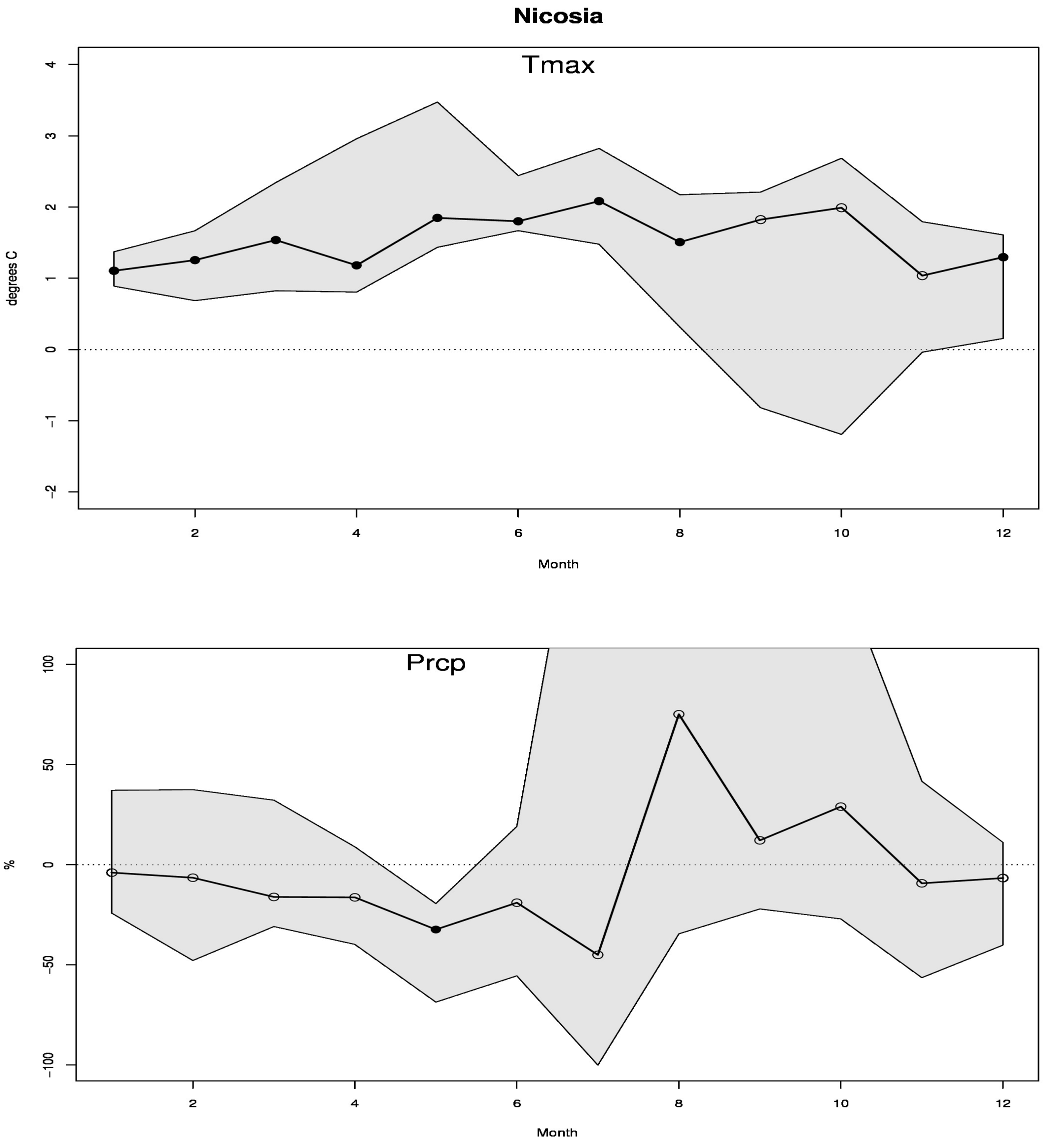
ENSEMBLES projections for Cyprus

Projections 2026-2050 Nicosia



Multi-model average offers a range of projected warming (95% confidence levels)

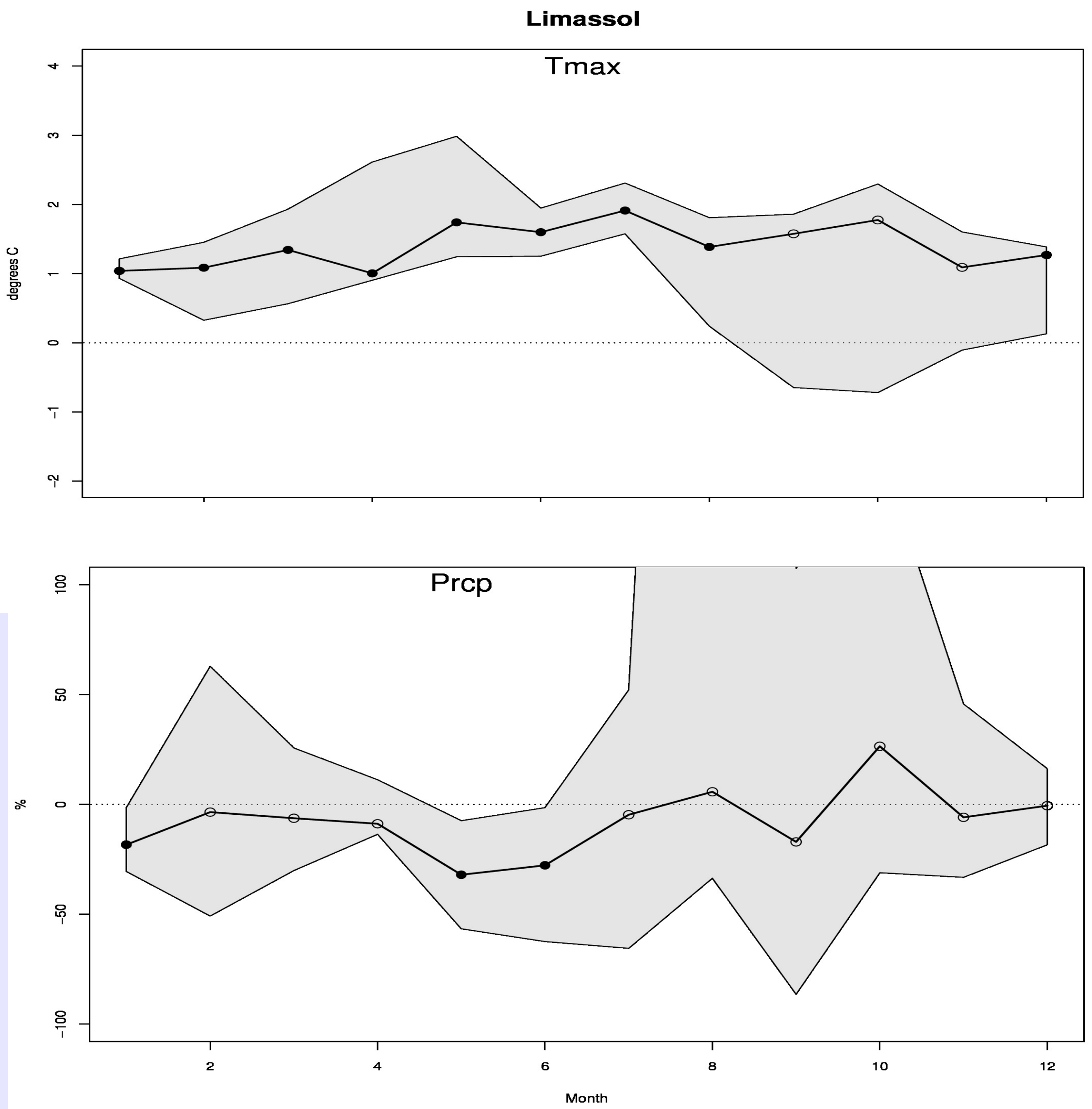
Statistical significance derived from the 6-model sample

Projected warming larger from May to October

Projected drying not statistically significant

ENSEMBLES projections for Cyprus

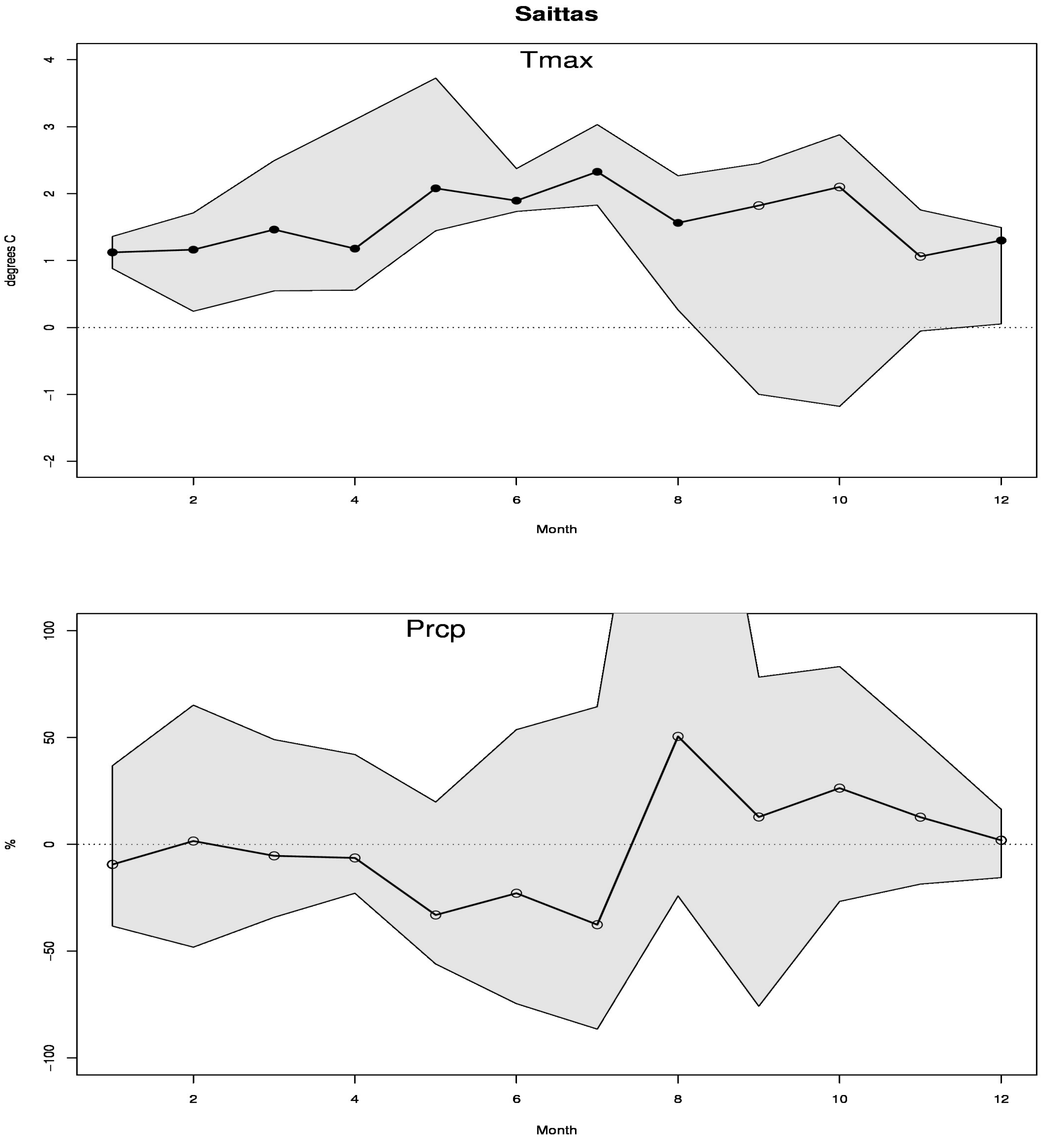
Projections 2026-2050 Limassol



- Multi-model average offers a range of projected warming (95% confidence levels)
- Statistical significance derived from the 6-model sample
- Projected warming larger from May to October (slightly smaller than Nicosia)
- Projected drying not statistically significant (except Jan., May, Jun.)

ENSEMBLES projections for Cyprus

Projections 2026-2050 Saittas



- Multi-model average offers a range of projected warming (95% confidence levels)
- Statistical significance derived from the 6-model sample
- Projected warming larger from May to October (similar to Nicosia)
- Projected drying not statistically significant, autumn increase

ENSEMBLES projections for Cyprus

Indices of extremes   Nicosia

Index	Name	UNITS	MSC 1976-2000	ENS 1976-2000	ENS 2026-2050	Δ ENS
SU38	Summer days	Days	24.3	18.3	35.3	17.0
TR23	Tropical nights	Days	24.3	36.3	70.6	34.3
TXx	Max Tmax	ºC	41.8	40.4	42.4	1.9
TNx	Max Tmin	ºC	26.2	26.8	28.9	2.1
CDD	Consecutive dry days	Days	119.2	111.6	101.7	-9.9
CWD	Consecutive wet days	Days	4.6	5.5	5.1	-0.4
R17	Heavy precipitation days	Days	3.6	1.5	1.5	0.0
RX5	Max 5-day precipitation	mm	57.8	46.8	46.5	-0.3

MSC: Meteorological Service Cyprus   ENS: ENSEMBLES models

ENSEMBLES projections for Cyprus

Indices of extremes   Saittas

Index	Name	UNITS	MSC 1976-2000	ENS 1976-2000	ENS 2026-2050	Δ ENS
SU36	Summer days	Days	16.9	27.9	42.5	14.5
TR23	Tropical nights	Days	16.1	30.6	62.3	31.7
TXx	Max Tmax	ºC	38.9	40.0	42.1	2.0
TNx	Max Tmin	ºC	24.1	24.3	26.7	2.4
CDD	Consecutive dry days	Days	79.9	77.7	78.4	0.7
CWD	Consecutive wet days	Days	6.7	8.3	8.0	-0.3
R33	Heavy precipitation days	Days	3.3	3.2	2.9	-0.3
RX5	Max 5-day precipitation	mm	120.3	95.7	101.2	5.5

MSC: Meteorological Service Cyprus   ENS: ENSEMBLES models

Spatial issues

- Current state-of-the-art 15-25 km RCM horizontal resolution not refined enough to provide locally realistic climate output

- RCM gridbox elevation not high enough to represent real mountainous climatic conditions

- Further downscaling from the RCM scale to the local scale (< 10km) can be obtained with empirical/statistical methods

- Need for long-term, homogeneous and spatially dense observational data

Temporal issues

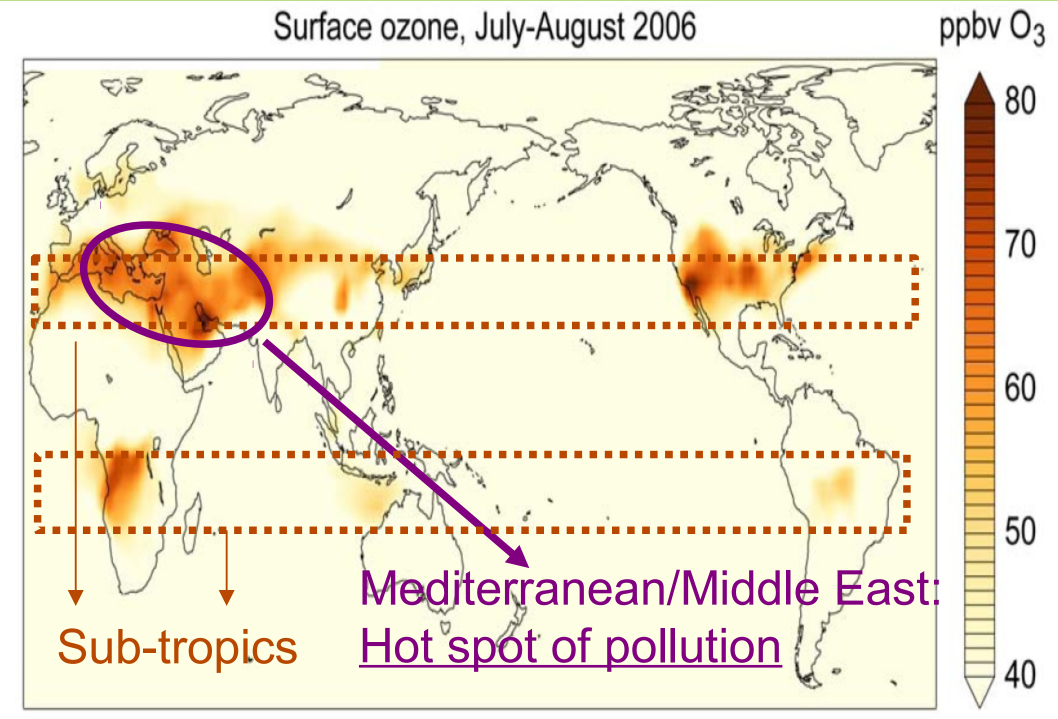
- Long-term (centennial) RCM simulations restrict standard temporal output frequency of climate variables to daily

- Good enough for analysing climatic extremes (heatwaves, intense rainfall)

- Hourly output is useful for studies of sub-daily events (e.g. flash floods, diurnal cycle) but not always feasible due to vast data storage

- Continuous, inter-annual time-series allow studies over different periods in the 21st century

Air pollution ("bad" ozone)



Ground-level Ozone

EU health protection limit = 57 ppbv

Permitted exceedances:
25 days averaged over 3 years

Summer average > 60 ppbv

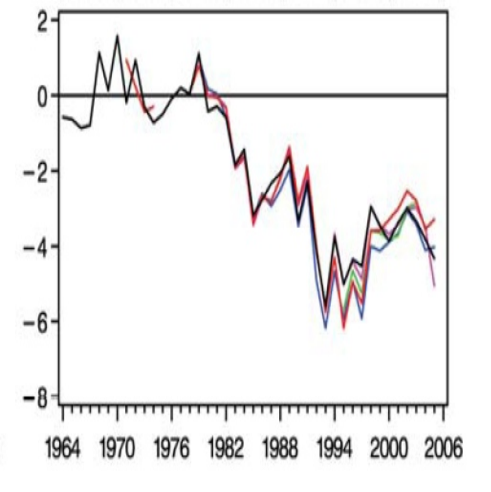
EMAC model, Lelieveld et al., *Atm. Chem. Phys.*, 2009

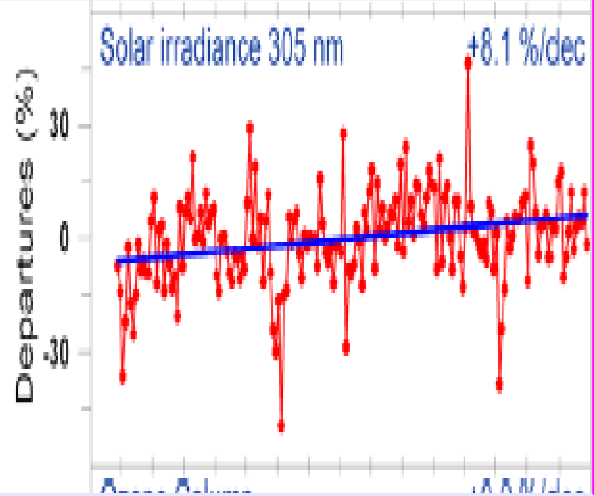
Atmospheric stability, dryness =>

lack of pollutant removal by convective mixing and precipitation

These dry and stagnant conditions are likely to increase under climate change that could deteriorate further the regional air quality (which might be also further affected by the positive ozone-temperature correlation)

UV radiation ("good ozone)





Stratospheric Ozone Depletion:

- caused by human activities
- enhanced UV radiation
- Climate change affects ozone through:
- stratospheric circulation
- stratospheric temperatures

Climate change can amplify several damaging effects of solar UV-B radiation on human health (Andrady et al., Photochem. Photobiol. Sci., 8, 2009)

- For the same UV dose, each 1°C increase in temperature would result in estimated increases in the incidences of certain skin cancers of 3%-6%,

- High temperatures and humidity, as experienced in the tropics, may increase the deleterious effects of UV-B radiation on human health, including suppression of immunity to infectious diseases and skin cancers

Epilogue

If:

1) the assumed radiative effect of CO_2 on the atmosphere is correct and

2) the concentrations of CO_2 and other GHGs continue to rise in the current rates, then:

by the end of this century global temperature will reach levels much higher than the ones human civilisation has been accustomed to in the last millennia

Conclusions

For Cyprus, regional climate models project, that by 2026-2050:

- Average temperature will increase by 1-2^{o}C
- Temperatures will rise more in the summer than in the winter
- Summer days will be 15 days more and tropical nights will increase by 30 days
- Annual precipitation will decrease by 10%
- (autumn increase, winter/spring reductions)
- Dry periods and rainfall intensity will not change
- Air quality could deteriorate

Acknowledgements

- Projects: FP7-ERC-C8, CyI-CIMME, FP7-CIRCE,
- PRECIS software/support: PRECIS Team, Hadley Centre, UK Met. Office
- Data: FP7 ENSEMBLES, ECAD, Cyprus Meteorological Service
- RclimDex: X. Zhang, Environment Canada, CCI/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices
- Graphics/Statistics: R-Project, UNIDATA, UCAR

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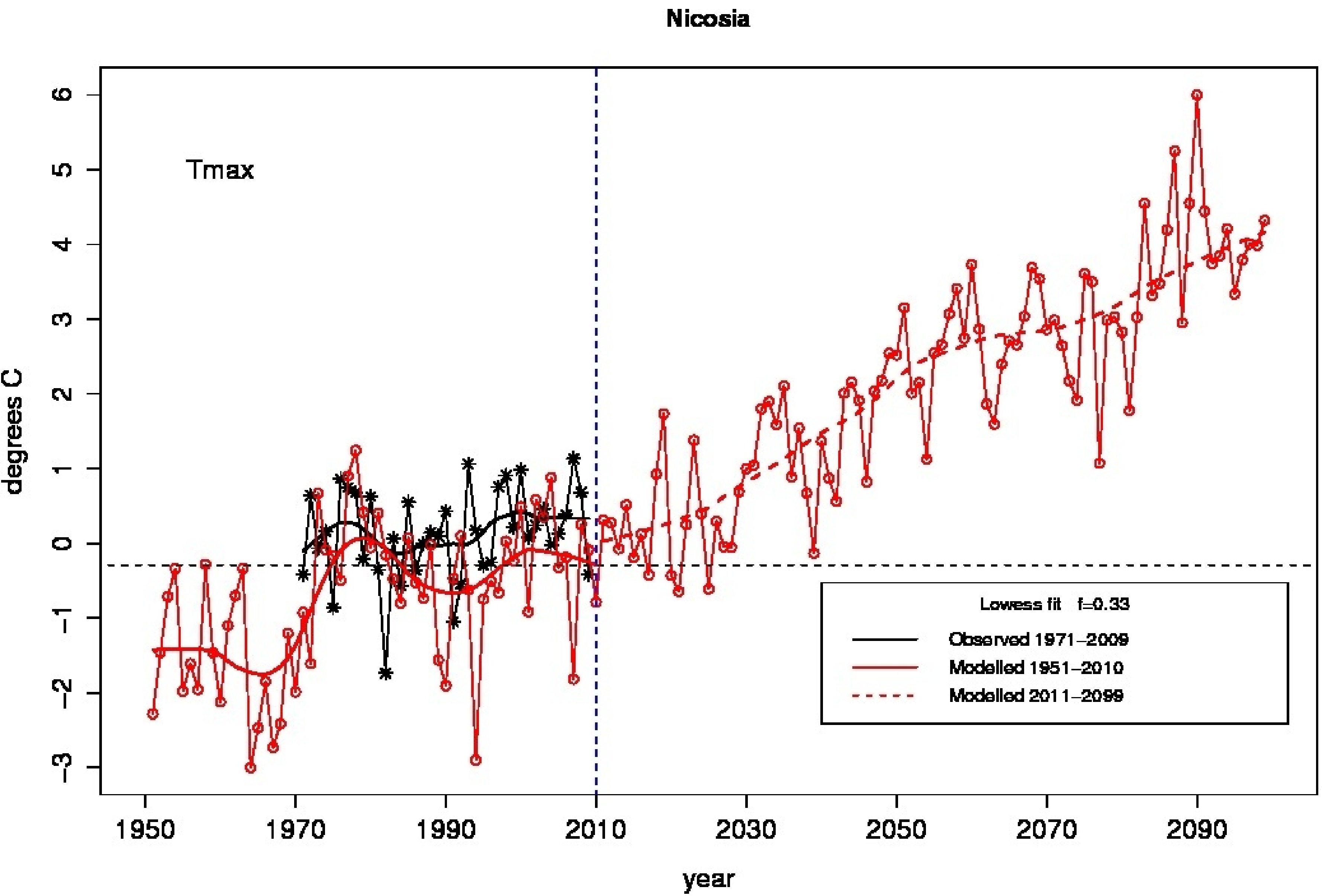
Nicosia
Tmax
degrees C
year
1950
1970
1990
2010
2030
2050
2070
2090
6
5
4
3
2
1
0
−1
−2
−3
Lowess fit f=0.33
Observed 1971–2009
Modelled 1951–2010
Modelled 2011–2099