http://www.meteo.unican.es

Introduction:

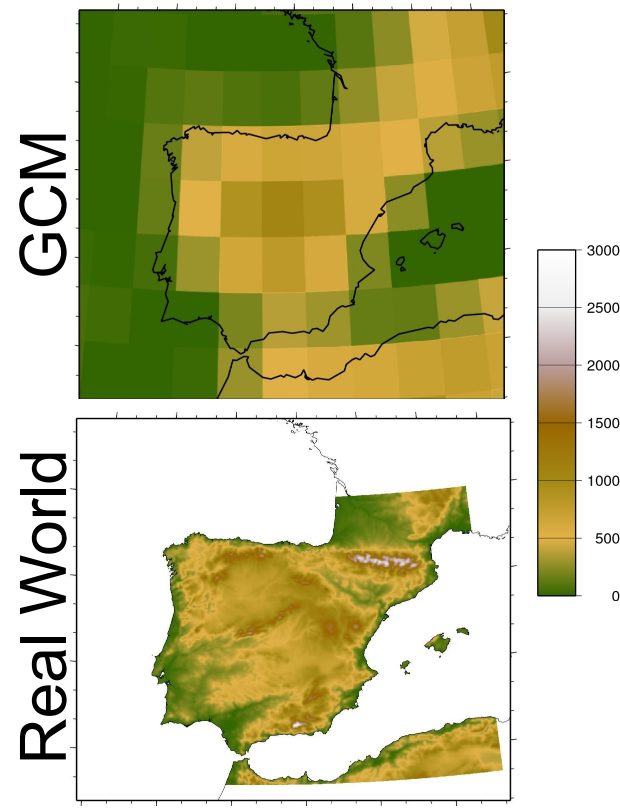
Global and regional climate change scenarios

José Manuel Gutiérrez

gutierjm@unican.es

Instituto de Física de Cantabria
CSIC – Univ. de Cantabria
Grupo de Meteorología de Santander

UNIVERSIDAD DE CANTABRIA
CSIC
Dpto. Matemática Aplicada y Ciencias de la Computación
IFCA
Instituto de Física de Cantabria



Contenidos

- ***Introduction to Global Climate Modeling***
  - ***Multi-model and multi-scenario ensembles***
  - ***From AR4 to AR5***
- ***Introduction to Downscaling***
  - ***Dynamical vs Statistical approaches***
- ***Validation of GCMs for Downscaling***
  - ***Distributional similarity measures.***

Climate Change: IPCC (AR4)

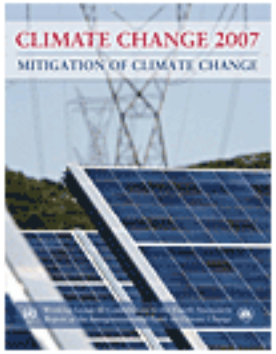
The **Intergovernmental Panel on Climate Change (IPCC)** was established in **1988** by the United Nations Environment Programme (UNEP) and the WMO to provide the world with a clear scientific view on the current state of knowledge in climate change:

WG1. The Physical Science Basis.
WG2. Impacts, Adaptation and Vulnerability.
WG3. Mitigation of Climate Change.

IPCC have published four assessment reports (http://www.ipcc.ch), the last one (**AR4**) in 2007 (the next one, **AR5**, will be ready in 2013).

Working Group I Report
"The Physical Science Basis"

Working Group II Report
"Impacts, Adaptation and Vulnerability"

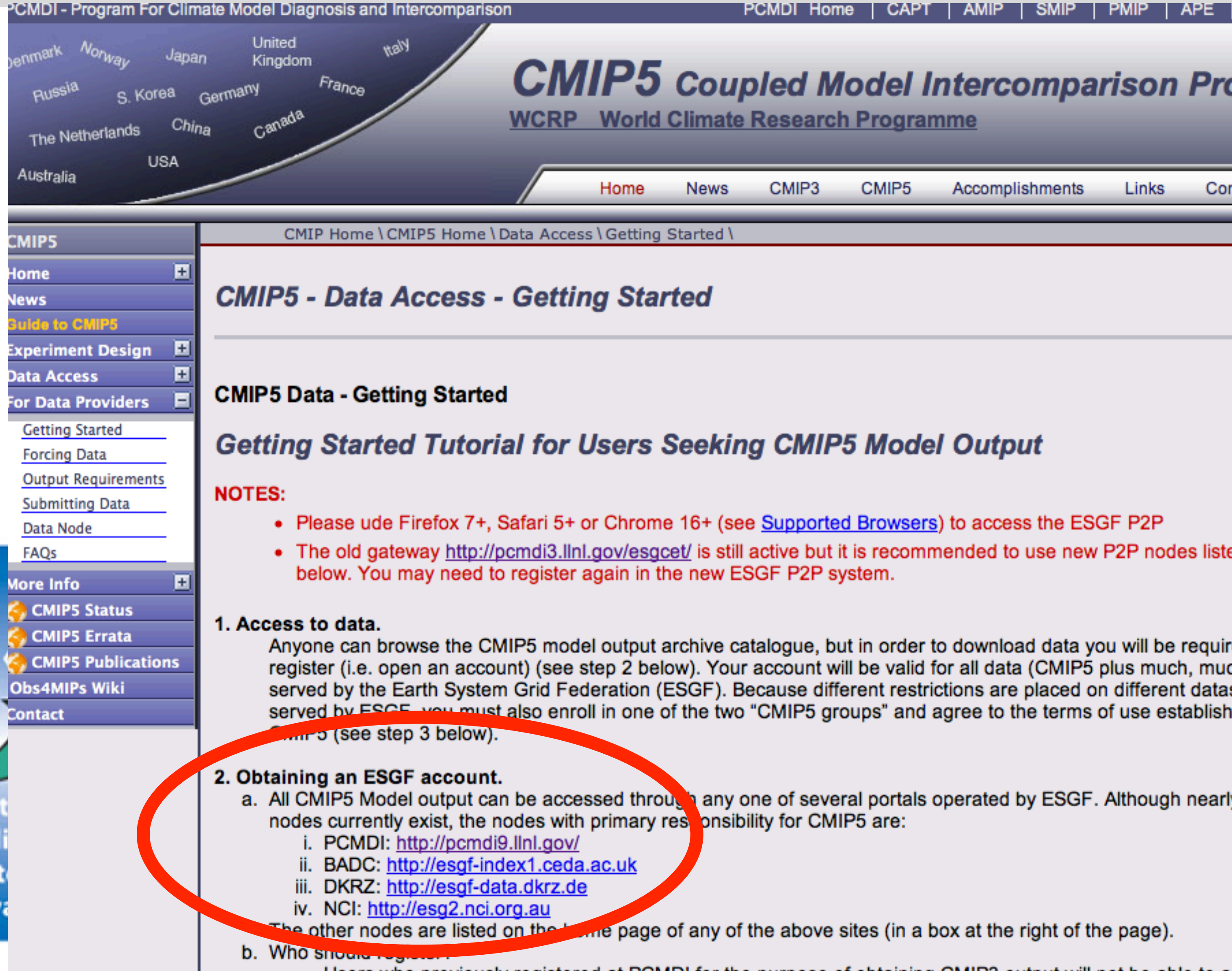


Working Group III Report
"Mitigation of Climate Change"

Santander Meteorology Group

A multidisciplinary approach for weather & climate

From AR4 to AR5



PCMDI - Program For Climate Model Diagnosis and Intercomparison | PCMDI Home | CAPT | AMIP | SMIP | PMIP | APE

Denmark Norway Japan United Kingdom Italy Russia S. Korea Germany France The Netherlands China Canada Australia USA

CMIP5 Coupled Model Intercomparison Pro

WCRP World Climate Research Programme

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CMIP5
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CMIP5 - Data Access - Getting Started

CMIP5 Data - Getting Started

Getting Started Tutorial for Users Seeking CMIP5 Model Output

NOTES:

- Please ude Firefox 7+, Safari 5+ or Chrome 16+ (see Supported Browsers) to access the ESGF P2P
- The old gateway http://pcmdi3.llnl.gov/esgcet/ is still active but it is recommended to use new P2P nodes liste below. You may need to register again in the new ESGF P2P system.

1. Access to data.
Anyone can browse the CMIP5 model output archive catalogue, but in order to download data you will be requir register (i.e. open an account) (see step 2 below). Your account will be valid for all data (CMIP5 plus much, muc served by the Earth System Grid Federation (ESGF). Because different restrictions are placed on different data served by ESGF, you must also enroll in one of the two "CMIP5 groups" and agree to the terms of use establish CMIP5 (see step 3 below).

2. Obtaining an ESGF account.

a. All CMIP5 Model output can be accessed through any one of several portals operated by ESGF. Although nearl nodes currently exist, the nodes with primary responsibility for CMIP5 are:
   i. PCMDI: http://pcmdi9.llnl.gov/
   ii. BADC: http://esgf-index1.ceda.ac.uk
   iii. DKRZ: http://esgf-data.dkrz.de
   iv. NCI: http://esg2.nci.org.au

The other nodes are listed on the home page of any of the above sites (in a box at the right of the page).

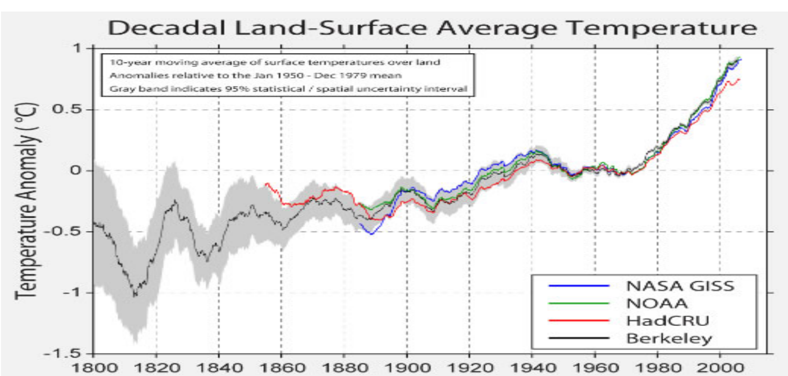
b. Who should register?

Evidences: Observation

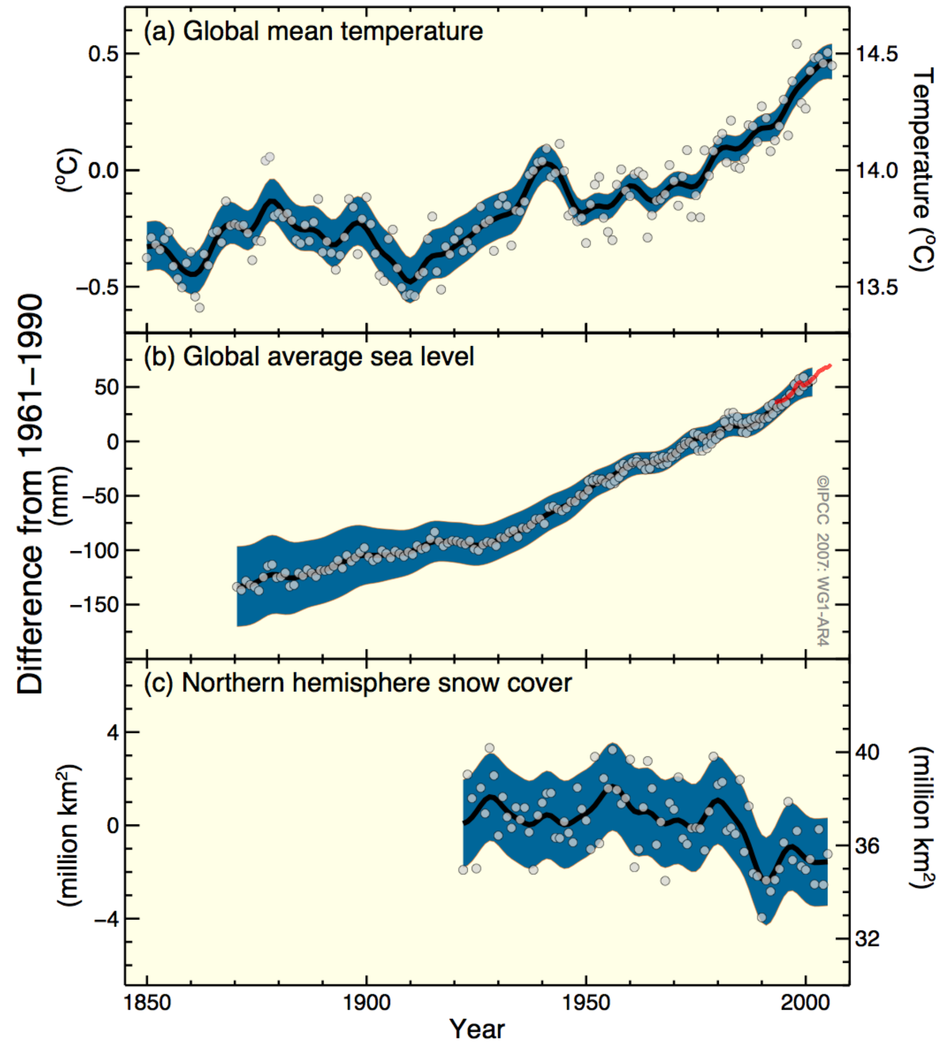
Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level. **(AR4-IPCC, 2007)**

BERKELEY EARTH SURFACE TEMPERATURE

berkeleyearth.org

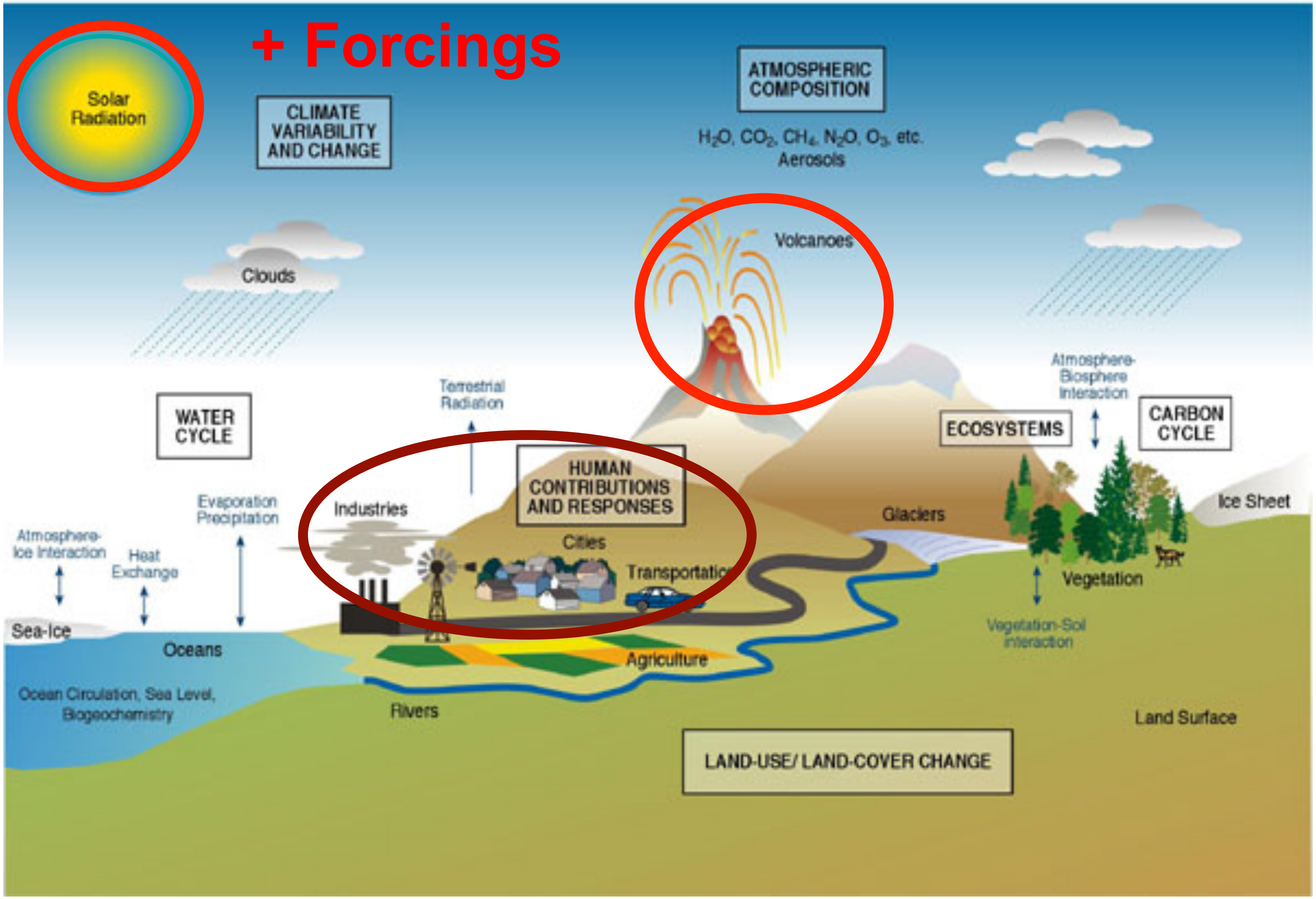


Changes in Temperature, Sea Level and Northern Hemisphere Snow Cover



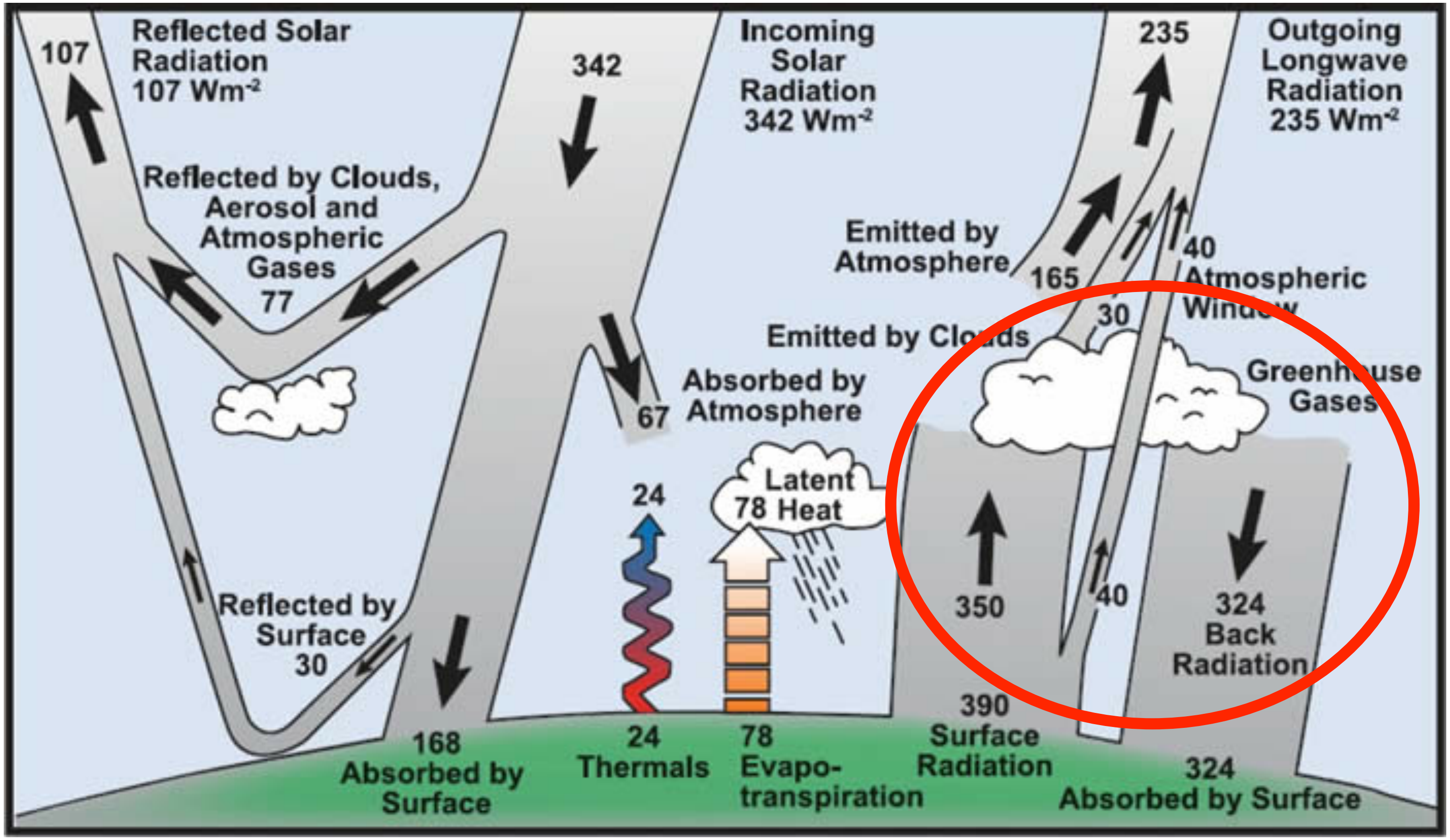
The Climatic Sytem

Atmosphere + Hydrosphere + Cryosphere + Lithosphere + Biosphere



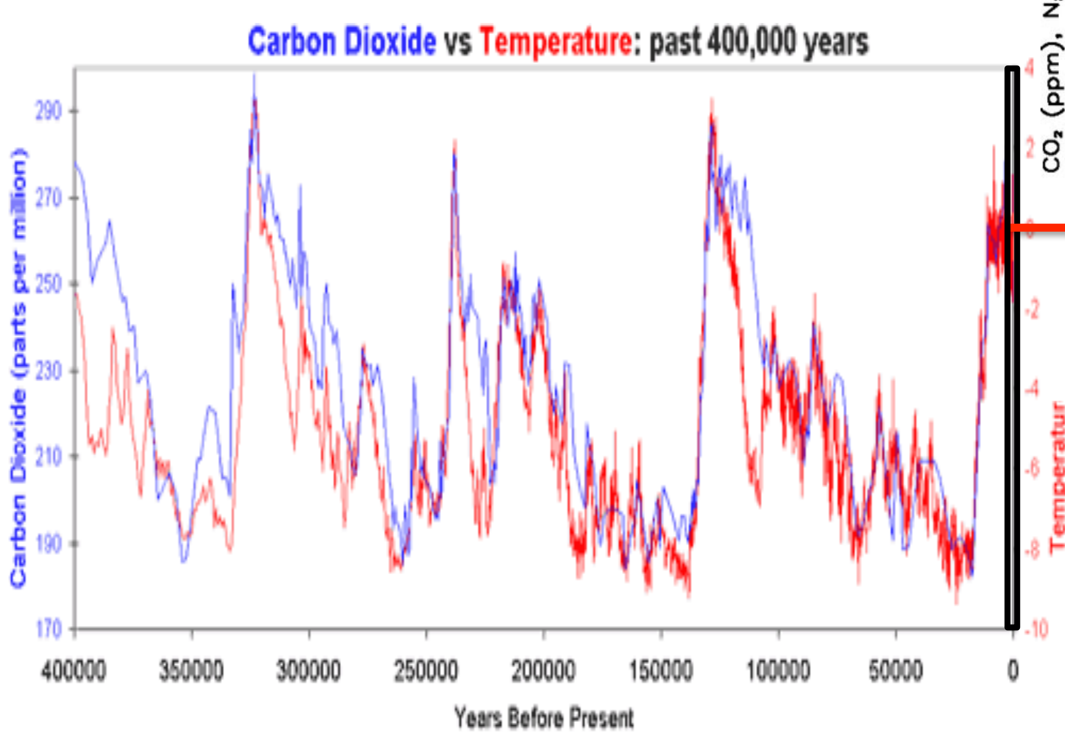
Greenhouse Gases

Half the solar radiation is absorbed by the Earth's surface and is latter emitted as infrared radiation which passes through the atmosphere, but most is absorbed back by greenhouse gases (CO_2, CH_4, etc.), with a warming effect.

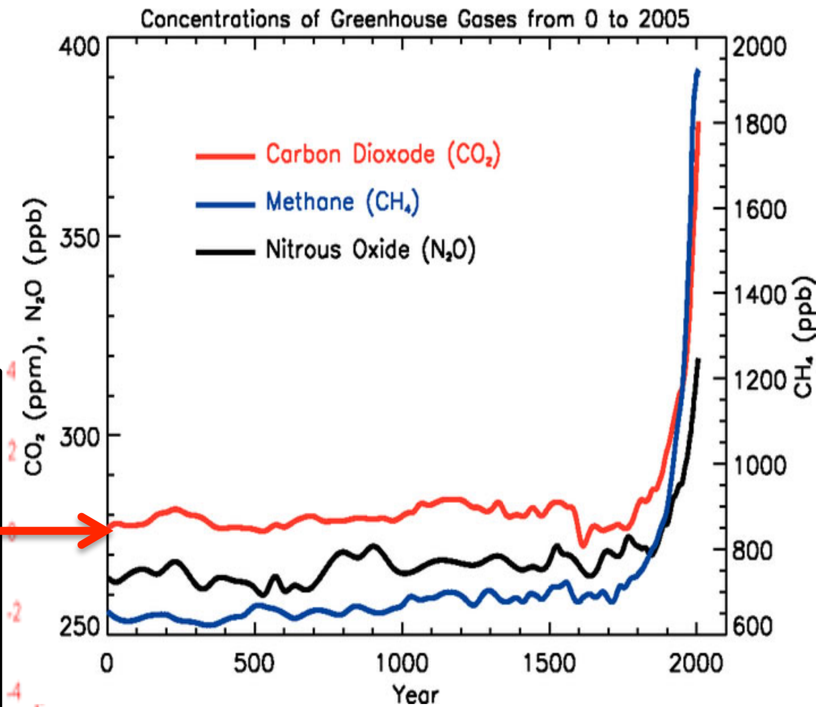


Variability of CO_2 concentration

The variations of the Earth's orbit around the Sun determines the climate variations at a geological timescale (alternation between glaciation and interglacial periods).



CO_2 levels varied between 180 and 300 parts per milion during the 400,000 years.



Antrophogenic/Global climate change

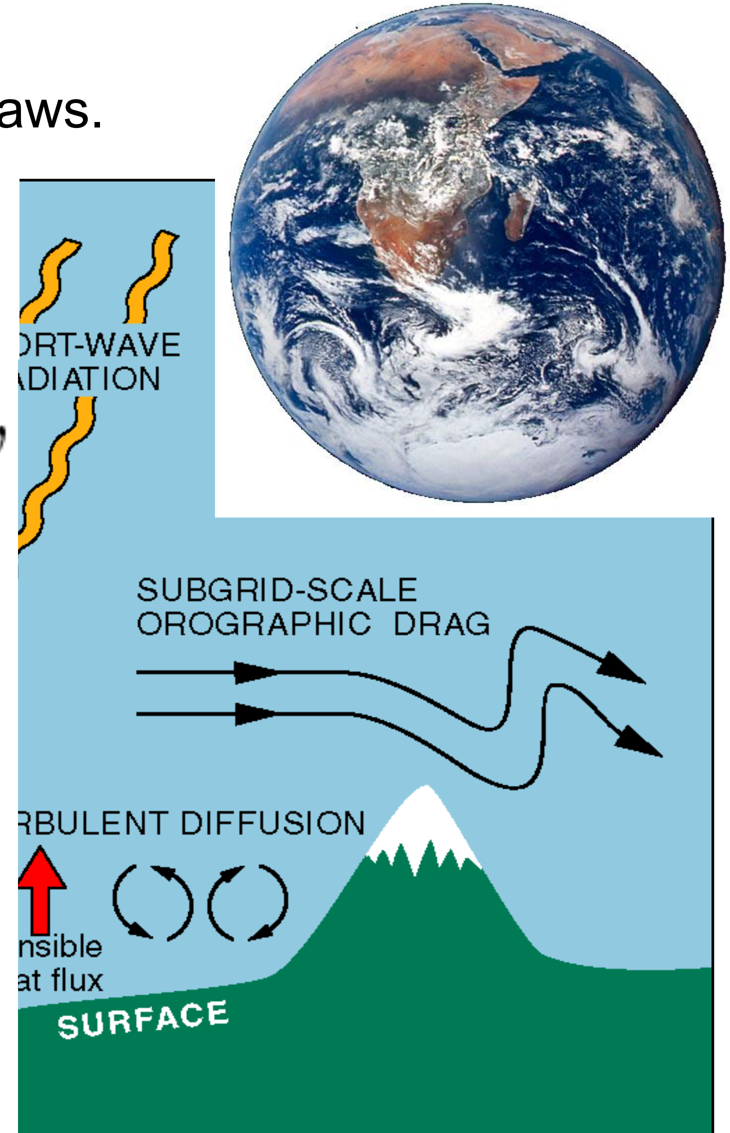
John Tyndall discovered that greenhouse gases block infrared radiation. Arrhenius estimated that doubling the CO_2 concentration, the temperature will increase 5°C.

The synoptic dymamics (global scale) of the atmosphere is governed by well-known physic laws.

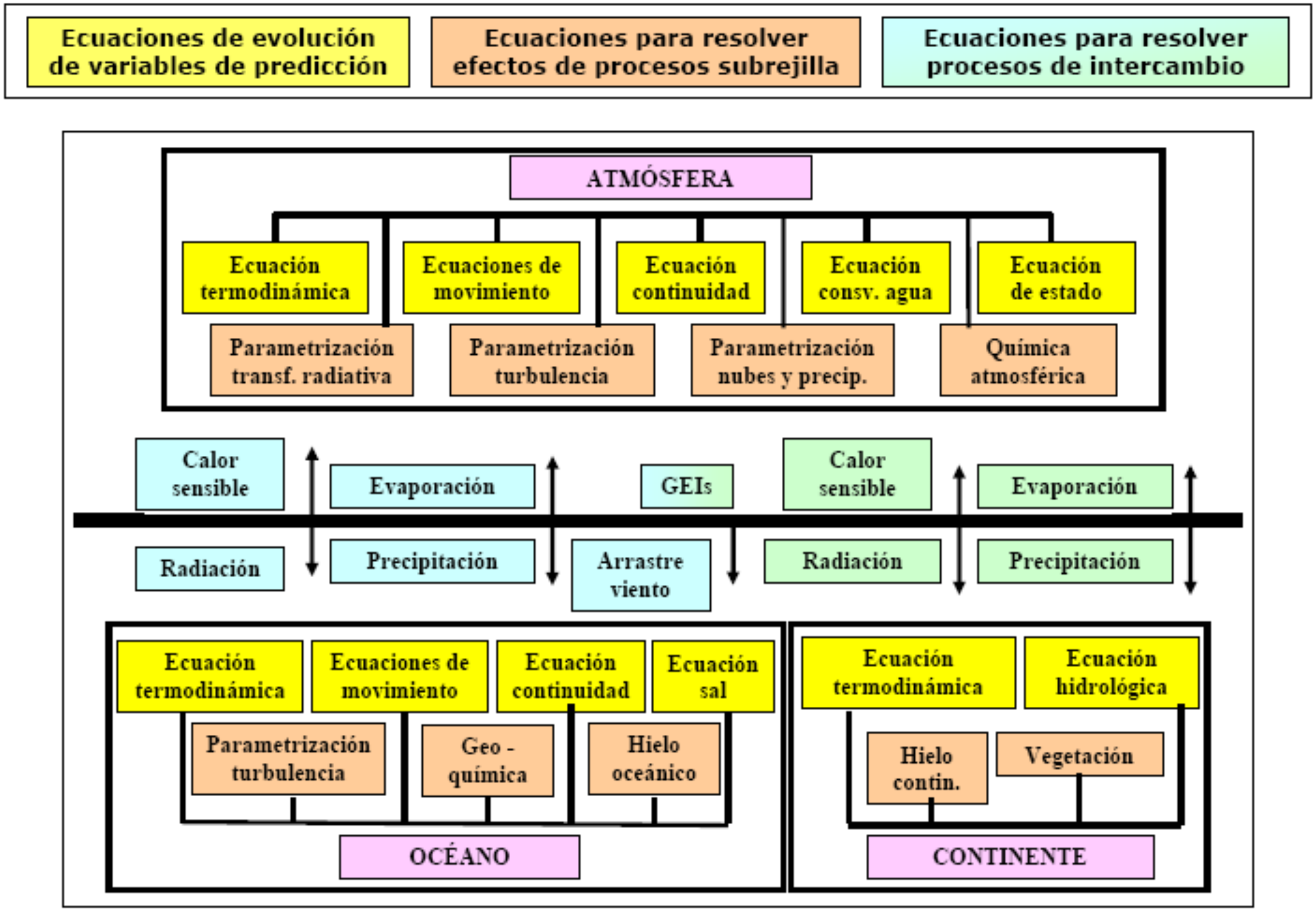
Conservación de energía, masa, momento, vapor de agua, ecuación de estado de gases.

$$
\begin{aligned}
\frac{d\boldsymbol{v}}{dt} &= -\alpha\boldsymbol{\nabla}p - \boldsymbol{\nabla}\phi + \boldsymbol{F} - 2\boldsymbol{\Omega}\times\boldsymbol{v} \\
\frac{\partial\rho}{\partial t} &= -\boldsymbol{\nabla}\cdot(\rho\,\boldsymbol{v}) \\
p\,\alpha &= R\,T \\
Q &= C_p\frac{dT}{dt} - \alpha\frac{dp}{dt} \\
\frac{\partial\rho\,q}{\partial t} &= -\boldsymbol{\nabla}\cdot(\rho\,\boldsymbol{v}\,q) + \rho\,(E - C)
\end{aligned}
$$

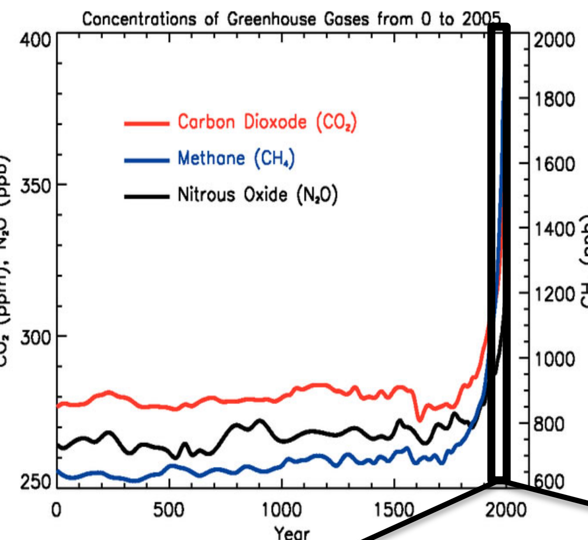
$\mathbf{v} = (u, v, w)$, T, p, $\rho = 1/\alpha$ y q

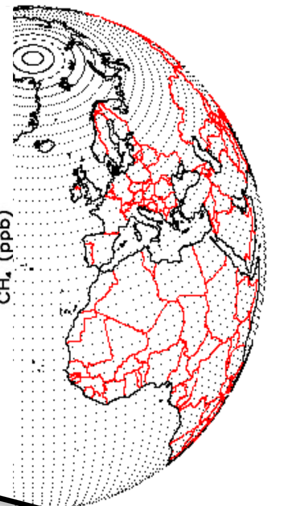


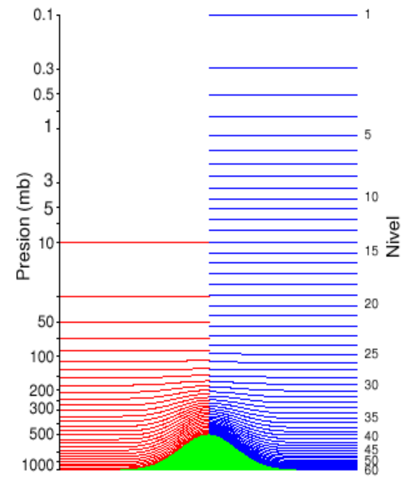
ECUACIONES DE LOS MODELOS CLIMÁTICOS GLOBALES



Numerical modeling... Historical period



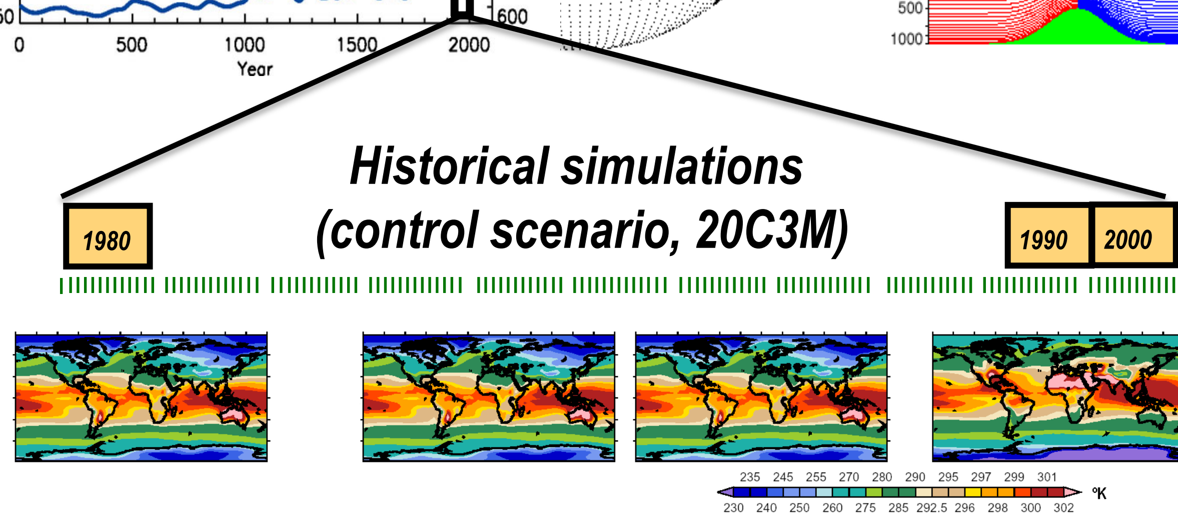




Ecuaciones de conservación y estado

$$\begin{cases} \frac{d\boldsymbol{v}}{dt} = -\alpha\boldsymbol{\nabla}p - \boldsymbol{\nabla}\phi + \boldsymbol{F} - 2\boldsymbol{\Omega}\times\boldsymbol{v} \\ \frac{\partial\rho}{\partial t} = -\boldsymbol{\nabla}\cdot(\rho\,\boldsymbol{v}) \\ p\,\alpha = RT \\ Q = C_p\frac{dT}{dt} - \alpha\frac{dp}{dt} \\ \frac{\partial\rho\,q}{\partial t} = -\boldsymbol{\nabla}\cdot(\rho\,\boldsymbol{v}\,q) + \rho\,(E-C) \end{cases}$$

$\boldsymbol{v} = (u, v, w)$, T, p, $\rho = 1/\alpha$ y q

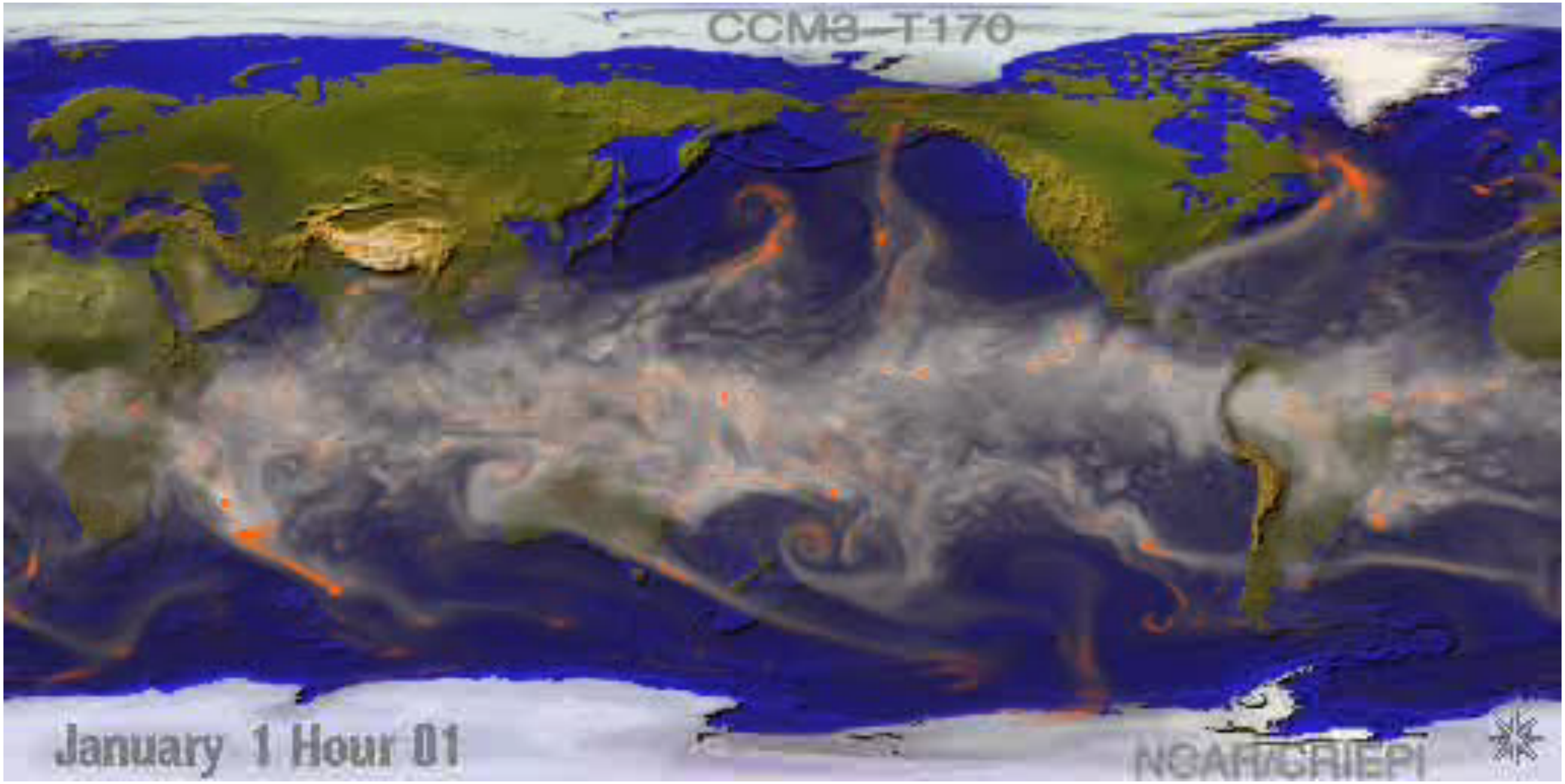


Different initial conditions allow testing the internal variability of the model.

According to WMO, the climatology is defined by a 30 years period, suitable to estimate statistics such as the mean, var, trend, etc.

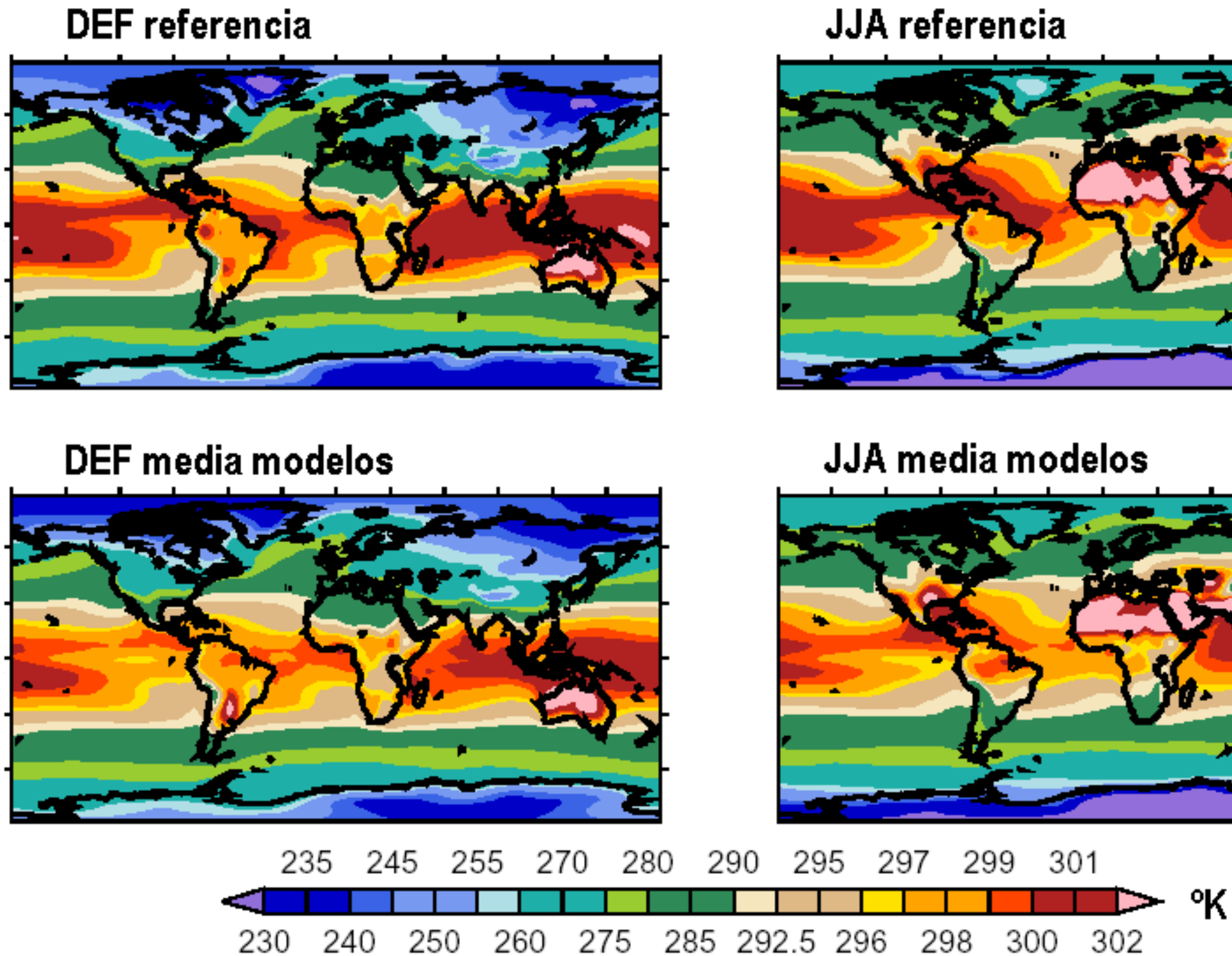
In some cases, 20 years or a decade are also considered.

Global Climate Models, GCMs (CCM3)



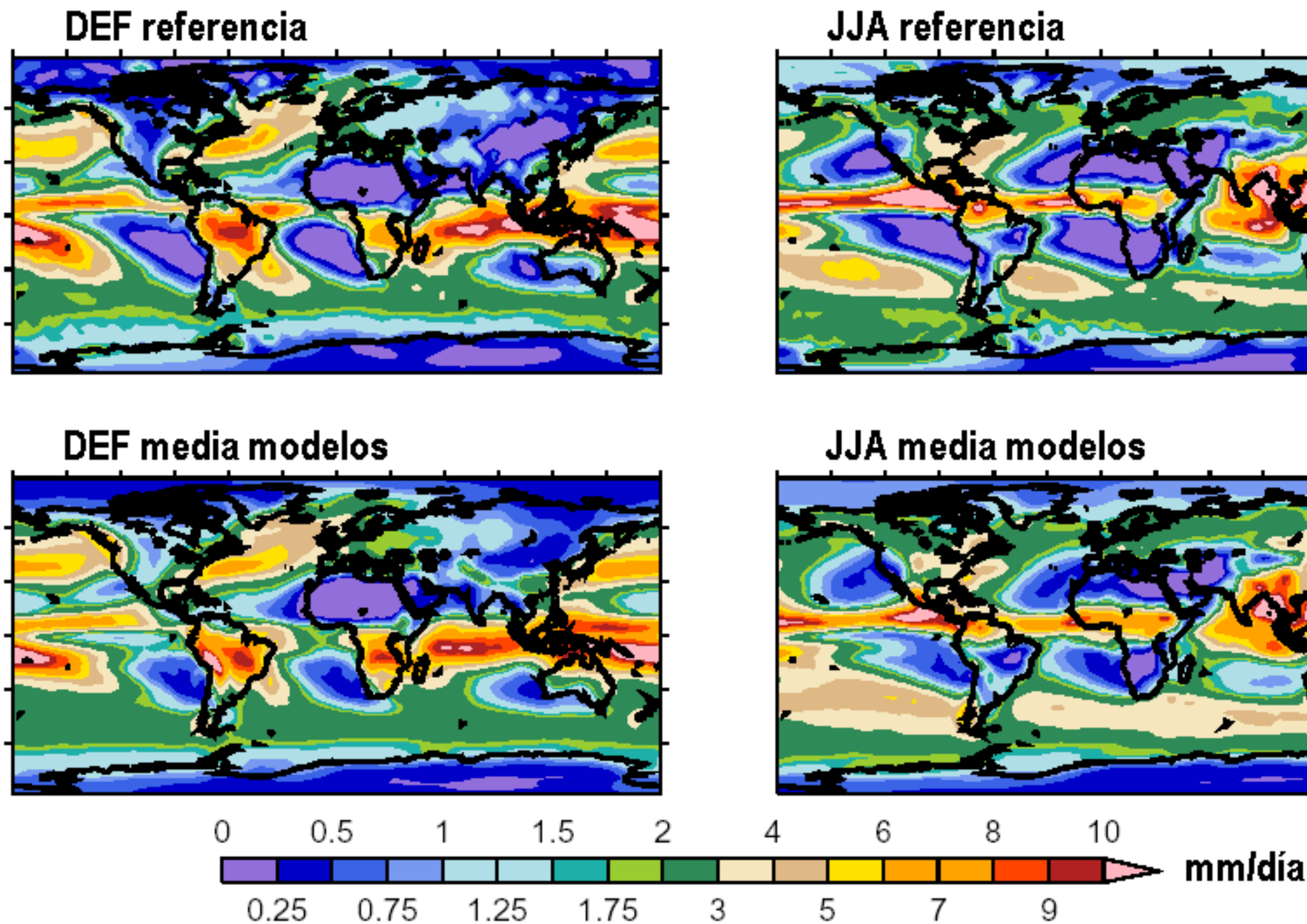
Validation: Temperature

www-pcmdi.llnl.gov/ipcc/about-ipcc.php

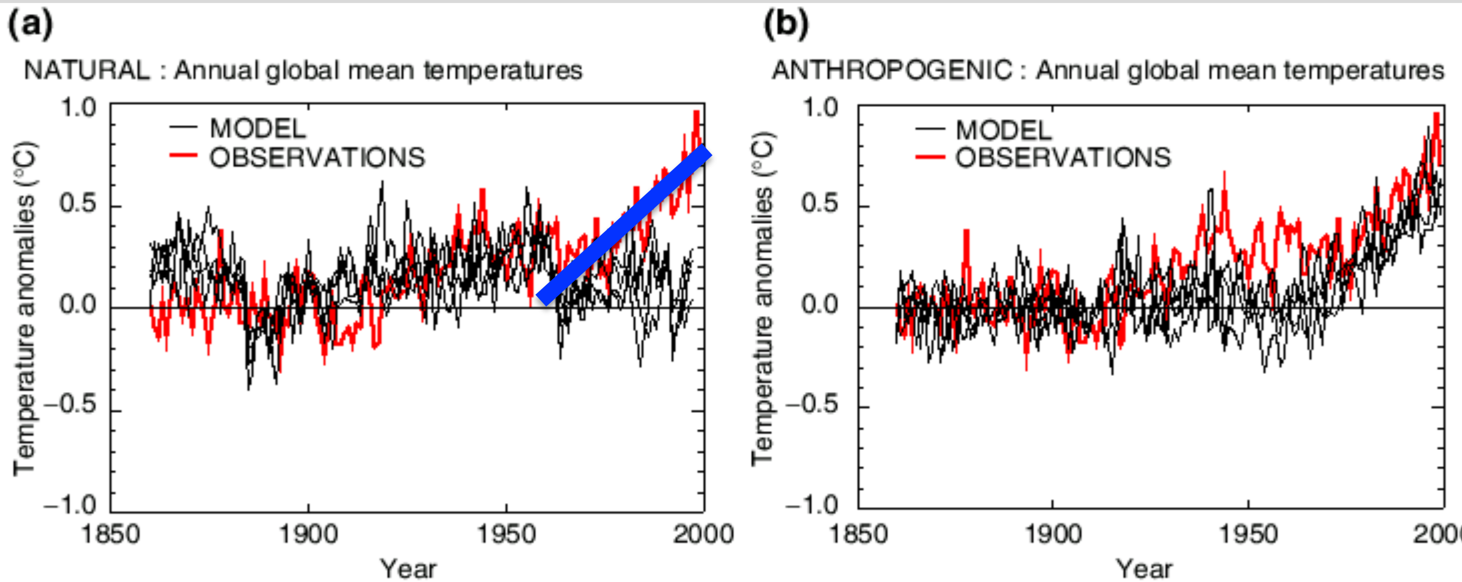


Validation: Precipitation

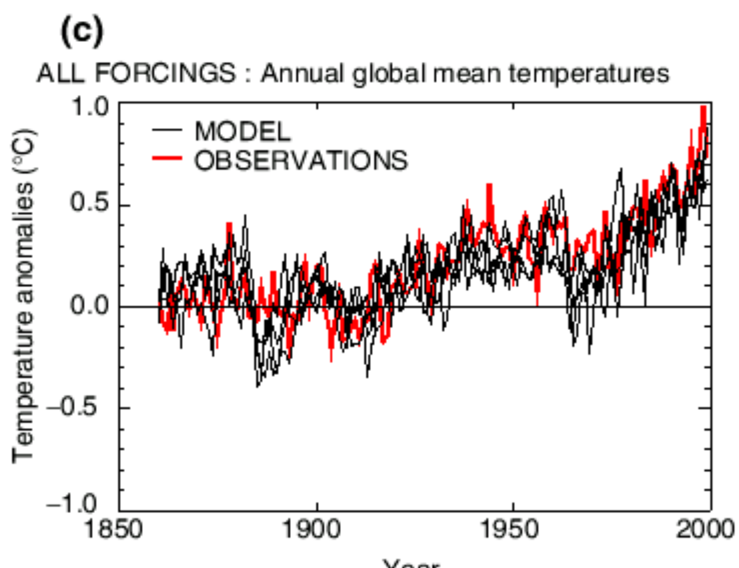
www-pcmdi.llnl.gov/ipcc/about-ipcc.php



PROBLEMS: Attribution

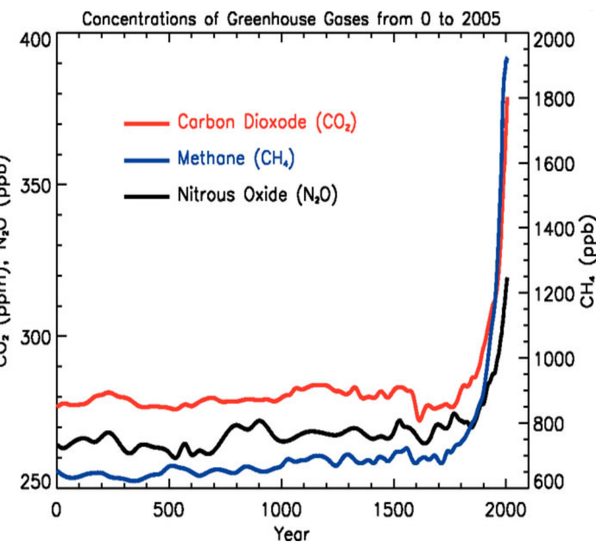


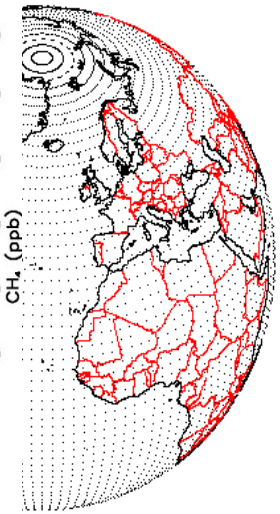
Anomalías de la temperatura superficial media global, relativas al promedio de 1880-1920, de los registros instrumentales, comparadas con conjuntos de cuatro simulaciones realizadas con un modelo acoplado océano-atmósfera .

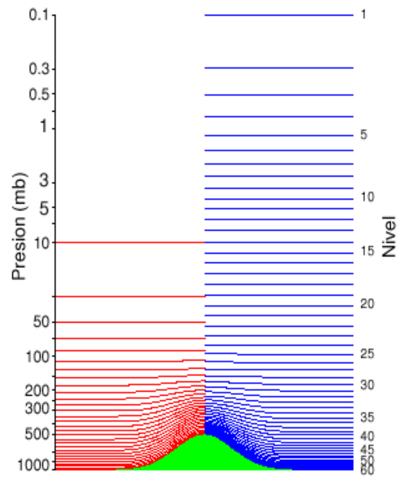


(a) forzamientos solar y volcánico solamente; **(b)** antropogénicos, incluyendo gases invernadero, ozono estratosférico y troposférico, y efectos indirectos de aerosoles sulfato; y **(c)** todos los forzamientos, tanto naturales como antropogénicos.

Numerical modeling... Future Projections







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$\boldsymbol{v} = (u, v, w)$, T, p, $\rho = 1/\alpha$ y q

Control

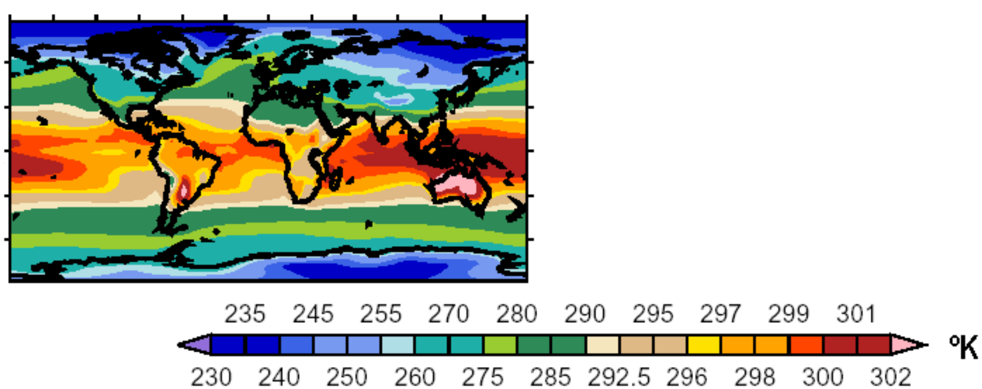
Scenario (e.g. 20C3M scenario)

1980	1990	2000

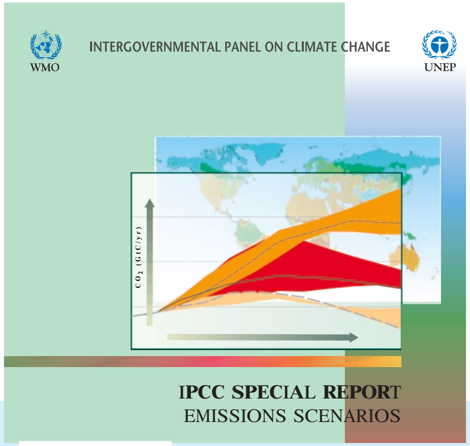
Future ???

Need for scenarios

2010	2020	2030	2040	2050	2060	2070	2080	2090

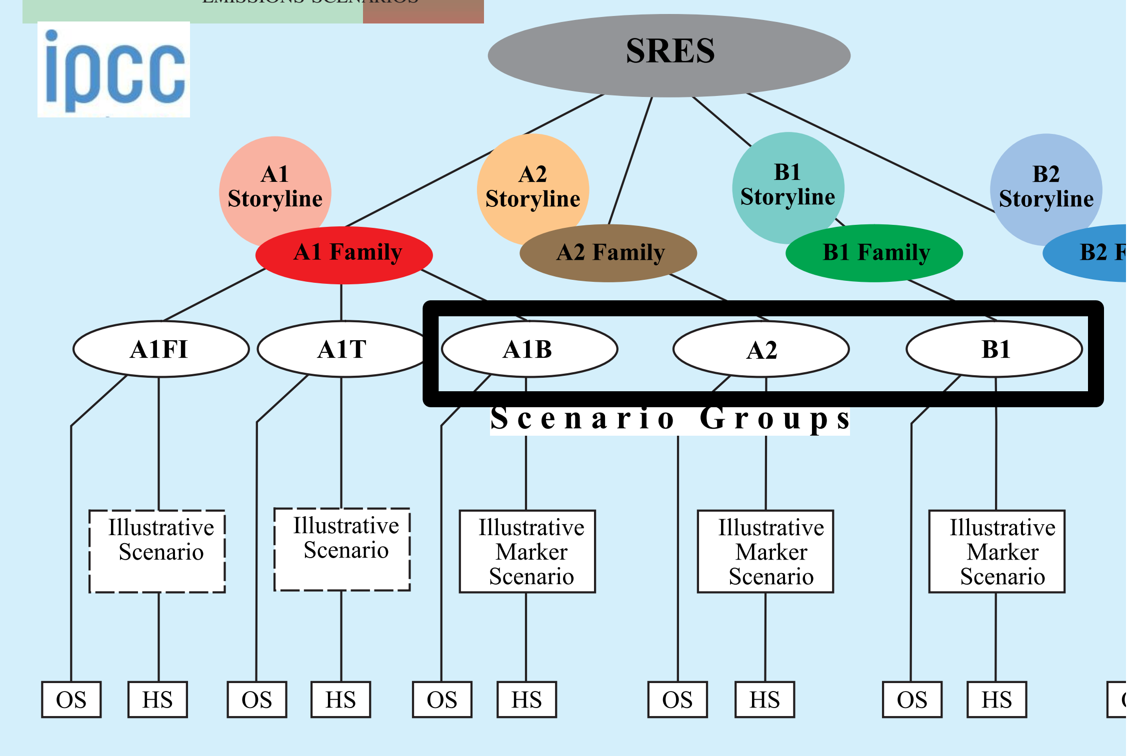


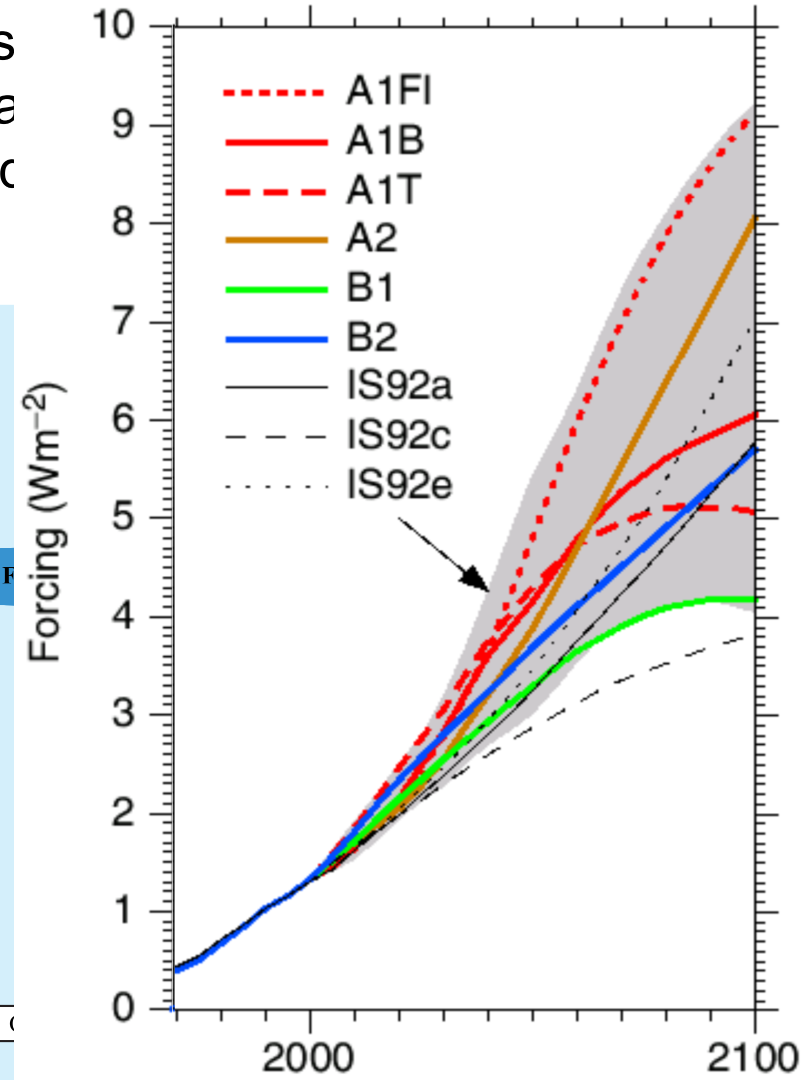
Forcings: SRES Emission Scenarios



http://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf

Special Report on Emis
scenarios (2000) are ba
gross world product anc





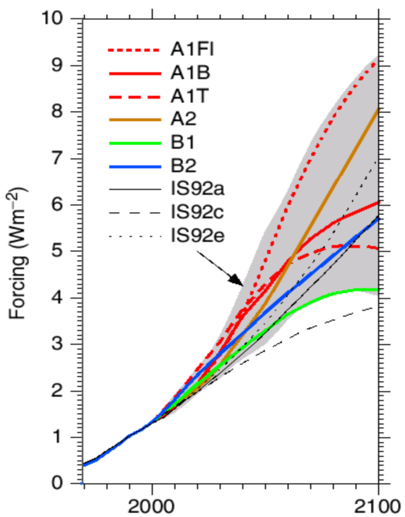
SRES Emission Scenarios

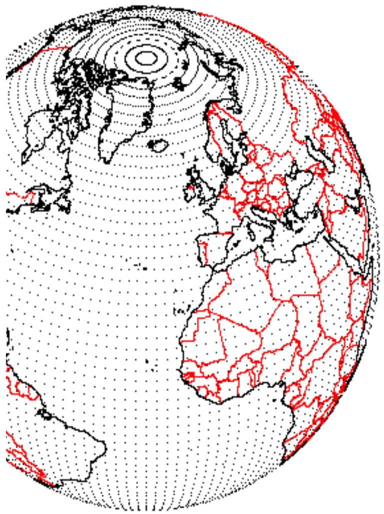
Family		A1			A2	B1	B2
Scenario group	**1990**	**A1FI**	**A1B**	**A1T**	**A2**	**B1**	**B2**
Population (billion)	5.3						
2020		**7.6** (7.4-7.6)	**7.4** (7.4-7.6)	**7.6** (7.4-7.6)	**8.2**	**7.6** (7.4-7.6)	**7.6**
2050		**8.7**	**8.7**	**8.7**	**11.3**	**8.7** (8.6-8.7)	**9.3**
2100		**7.1** (7.0-7.1)	**7.1** (7.0-7.1)	**7.0**	**15.1**	**7.0** (6.9-7.1)	**10.4**

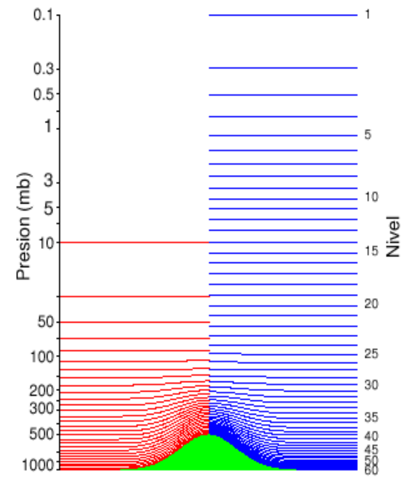
Family		A1			A2	B1	B2
Scenario group	**1990**	**A1FI**	**A1B**	**A1T**	**A2**	**B1**	**B2**
Final energy intensity (10^6J/US$)[a]	16.7						
2020		**9.4** (8.5-9.4)	**9.4** (8.1-12.0)	**8.7** (7.6-8.7)	**12.1** (9.3-12.4)	**8.8** (6.7-11.6)	**8.5** (8.5-11.8)
2050		**6.3** (5.4-6.3)	**5.5** (4.4-7.2)	**4.8** (4.2-4.8)	**9.5** (7.0-9.5)	**4.5** (3.5-6.0)	**6.0** (6.0-8.1)
2100		**3.0** (2.6-3.2)	**3.3** (1.6-3.3)	**2.3** (1.8-2.3)	**5.9** (4.4-7.3)	**1.4** (1.4-2.7)	**4.0** (3.7-4.6)

Family		A1			A2	B1	B2
Scenario group	**1990**	**A1FI**	**A1B**	**A1T**	**A2**	**B1**	**B2**
Carbon dioxide, fossil fuels (GtC/yr)	6.0						
2020		**11.2** (10.7-14.3)	**12.1** (8.7-14.7)	**10.0** (8.4-10.0)	**11.0** (7.9-11.3)	**10.0** (7.8-13.2)	**9.0** (8.5-11.5)
2050		**23.1** (20.6-26.8)	**16.0** (12.7-25.7)	**12.3** (10.8-12.3)	**16.5** (10.5-18.2)	**11.7** (8.5-17.5)	**11.2** (11.2-16.4)
2100		**30.3** (27.7-36.8)	**13.1** (12.9-18.4)	**4.3** (4.3-9.1)	**28.9** (17.6-33.4)	**5.2** (3.3-13.2)	**13.8** (9.3-23.1)

ipcc







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\end{cases}
$$

$\boldsymbol{v} = (u, v, w)$, T, p, $\rho = 1/\alpha$ y q

Control

Scenario (20C3M)

1980	1990	2000

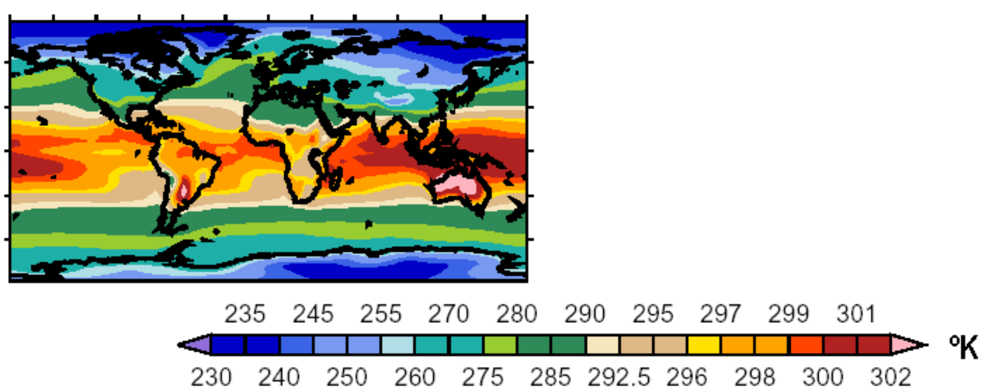
Future

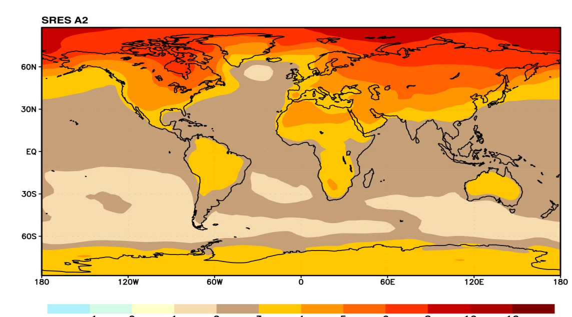
B1, A1B, A2 scenarios

2010	2020	2030	2040	2050	2060	2070	2080	2090

"delta" method

Warming signal

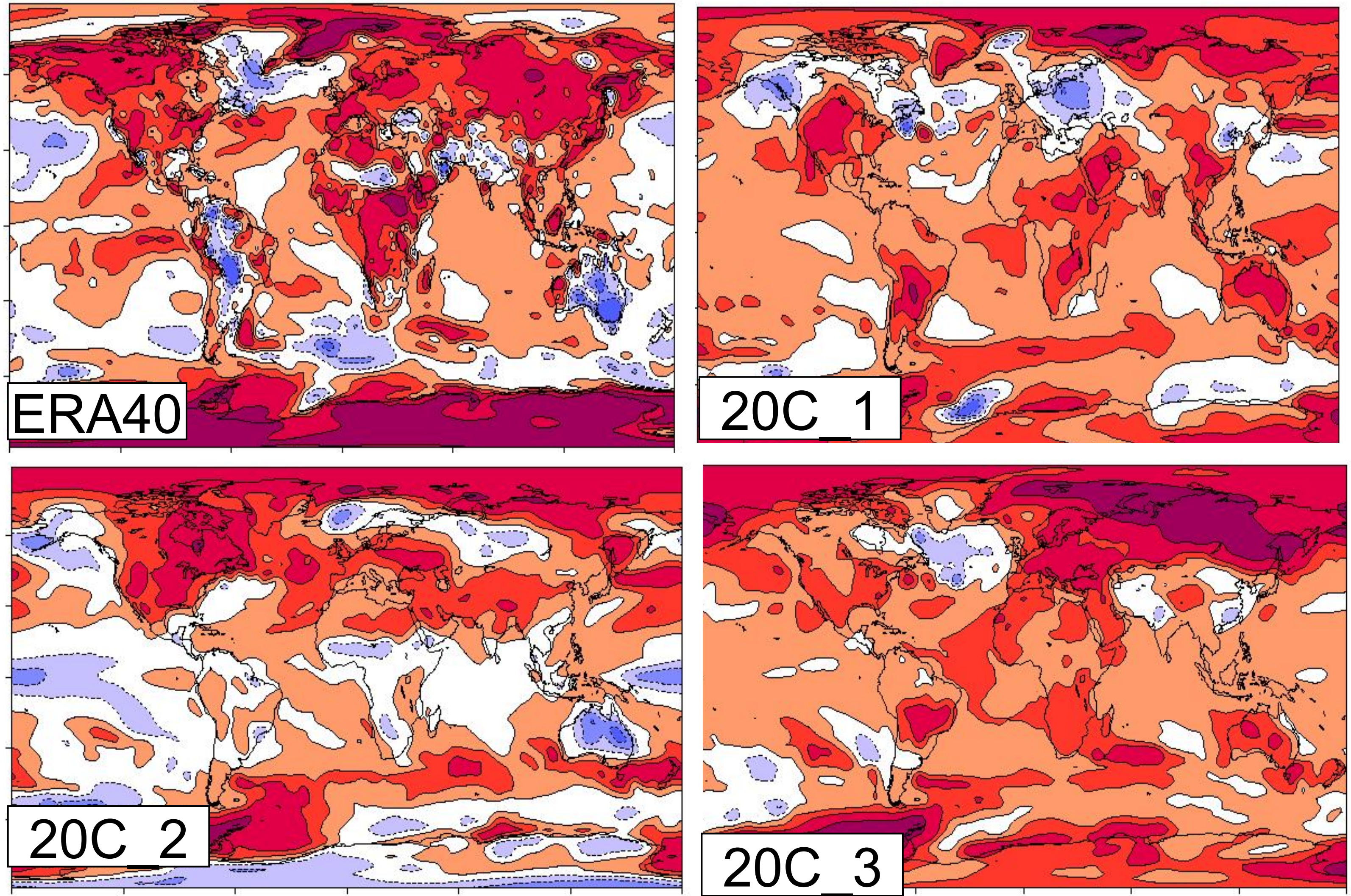




Internal variability

Max-Planck-Institut für Meteorologie
Max Planck Institute for Meteorology

Annual change in sfc air temperature change (1986-2000) - (1961-1990)



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- ***Validation of GCMs for Downscaling***
  - ***Distributional similarity measures***

GCMs in CMIP3 (IPCC-AR4)

THE WCRP CMIP3 MULTIMODEL DATASET

BY GERALD A. MEEHL, CURT COVEY, THOMAS DELWORTH, MOJIB LATIF, BRYANT MCAVANEY, JOHN F. B. MITCHELL, RONALD J. STOUFFER, AND KARL E. TAYLOR

SEPTEMBER 2007 BAMS | 1383
AMERICAN METEOROLOGICAL SOCIETY
DOI:10.1175/BAMS-88-9-1383

Performance metrics for climate models

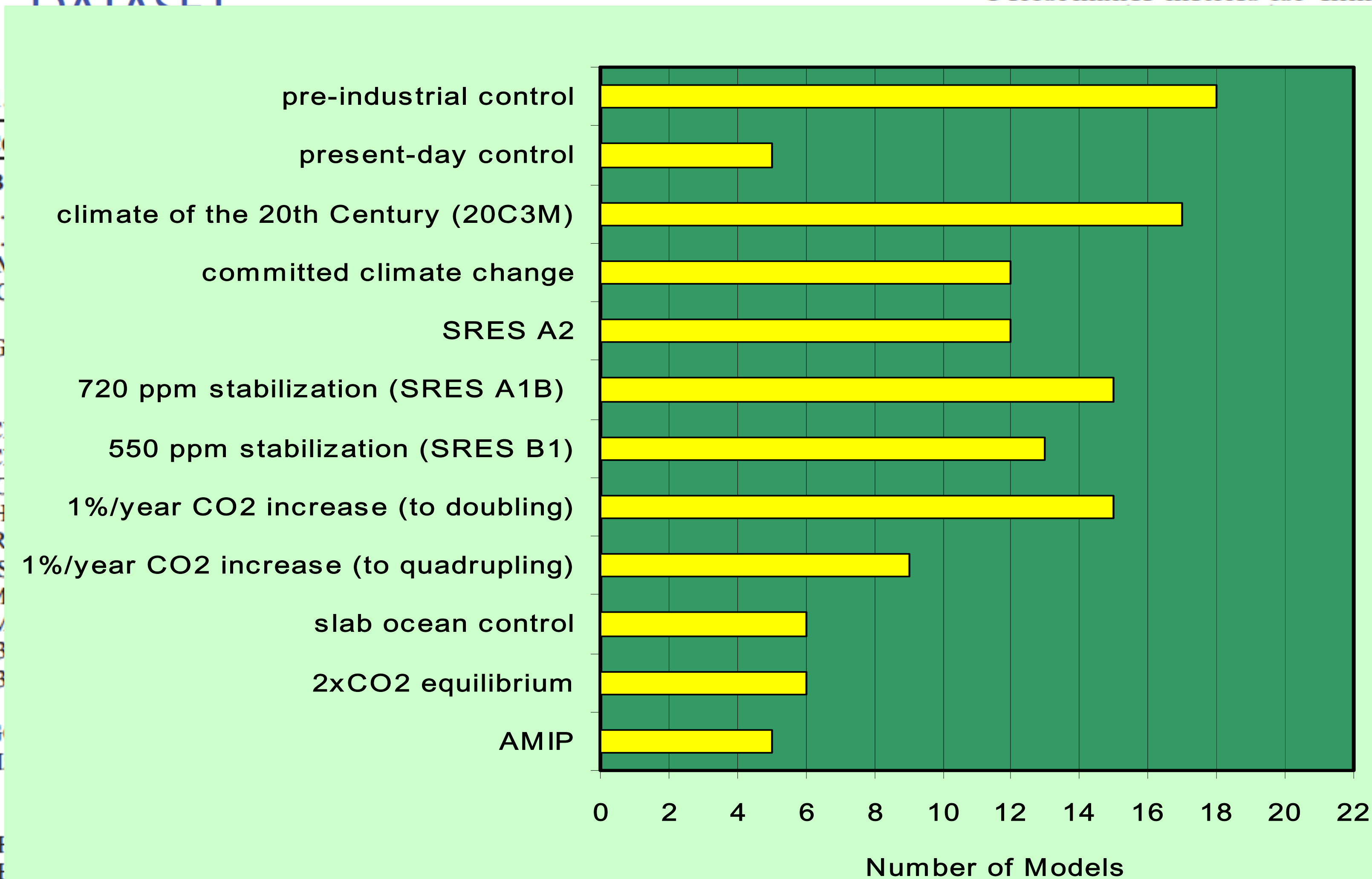
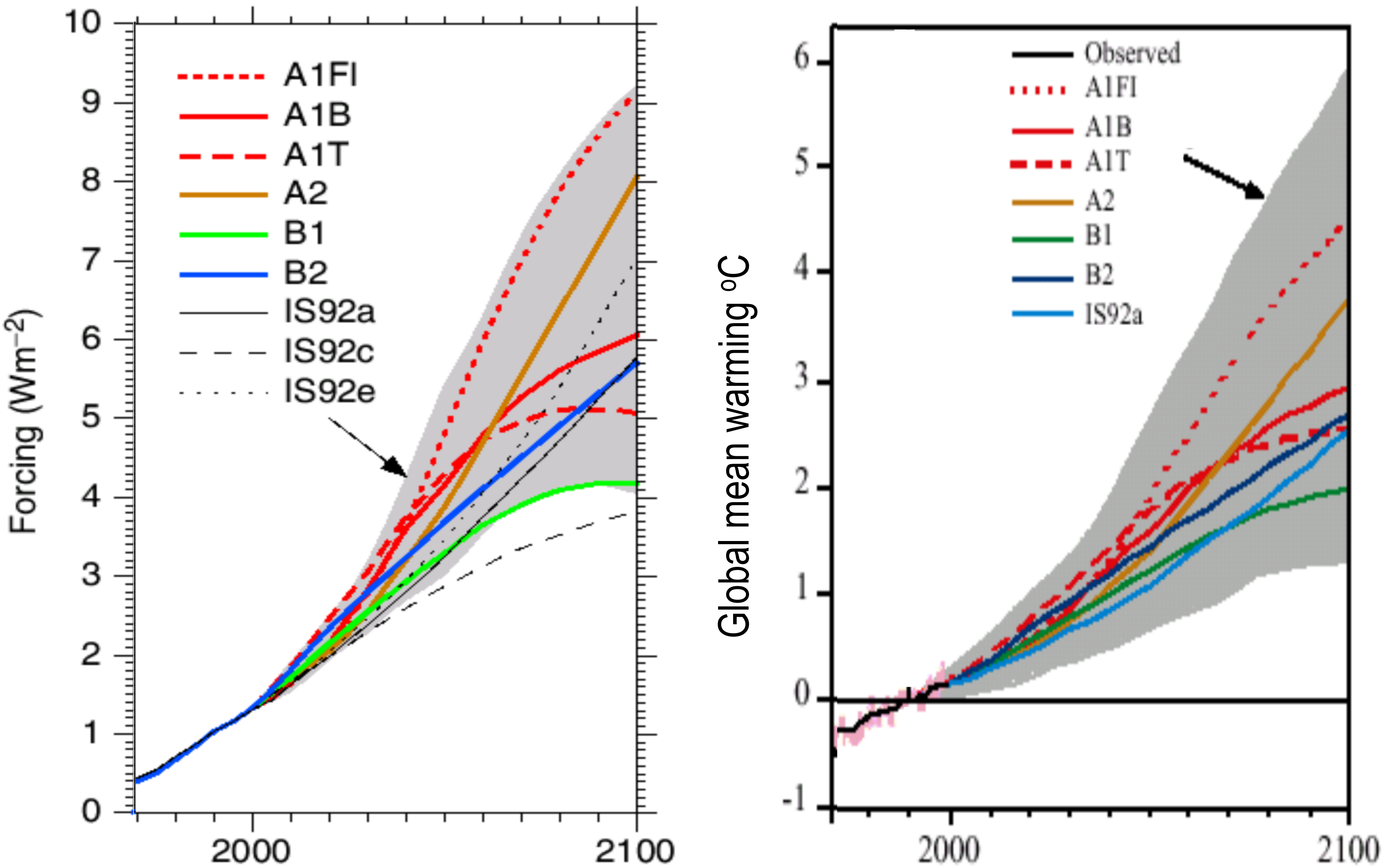


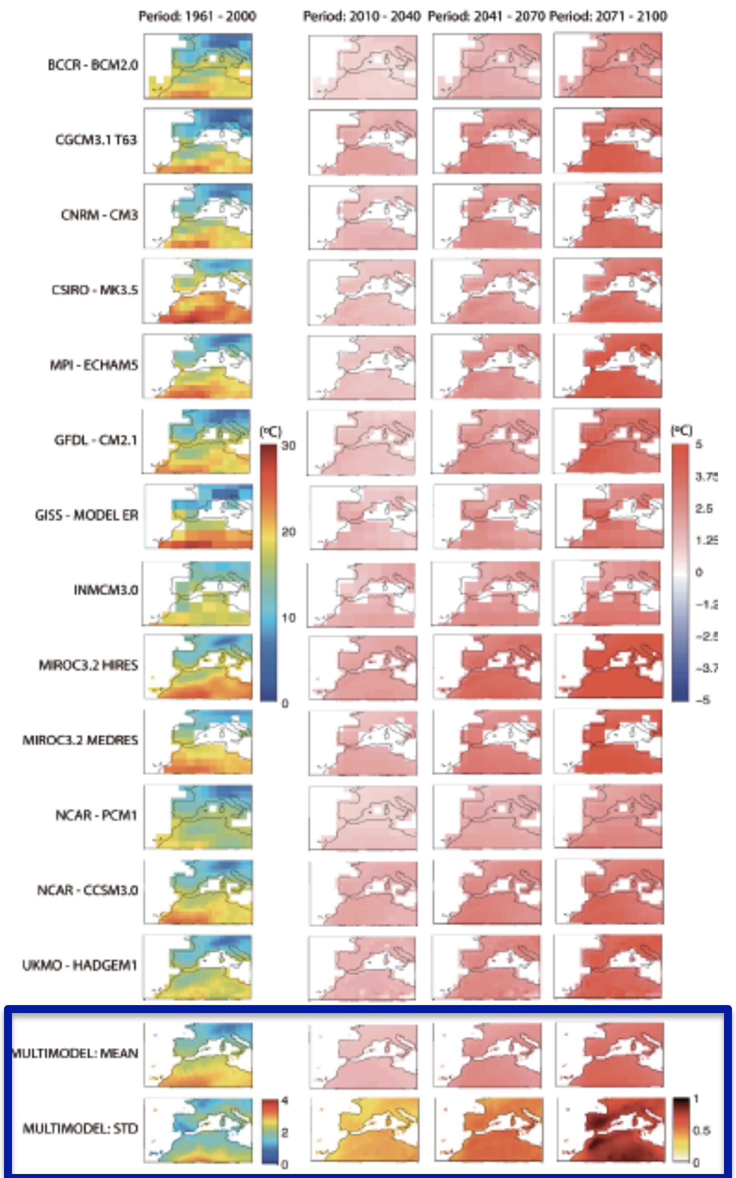
Table 1

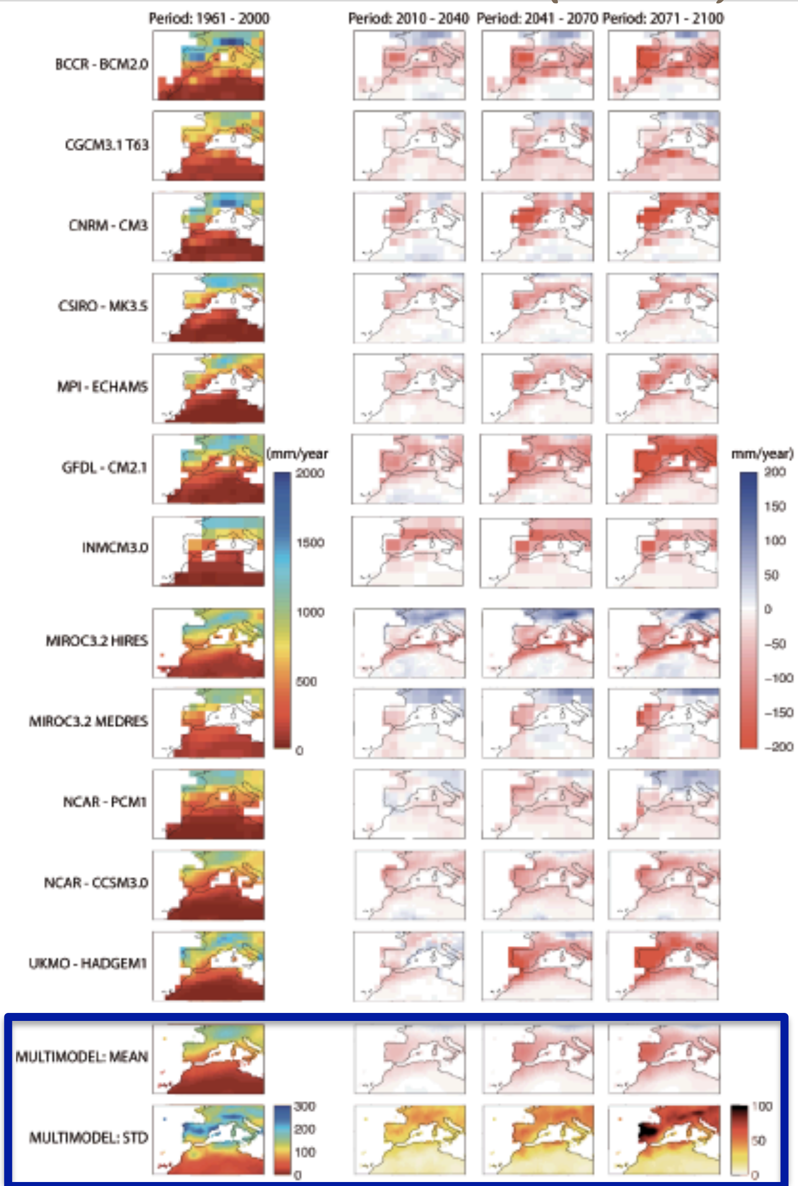
IPC	…re Resolution
BCCR-B	3 L31
CGCM3.	7 L31
CGCM3.	3 L31
CSIRO-M	3 L18
CNRM-C	2 L45
ECHO-G	0 L19
GFDL-C	5 L24
GFDL-C	5 L24
GISS-AC	60 L12
GISS-EH	46 L17
GISS-ER	46 L17
FGOALS	60 L26
INM-CM	45 L21
IPSL-CM	72 L19
MIROC3	2 L20
MIROC3	6 L56
MRI-CG	2 L30
ECHAM	3 L32
CCSM3	5 L26
PCM	2 L18
UKMO-H	72 L19
UKMO-H	6 L38

UNCERTAINTY: Emission Scenarios

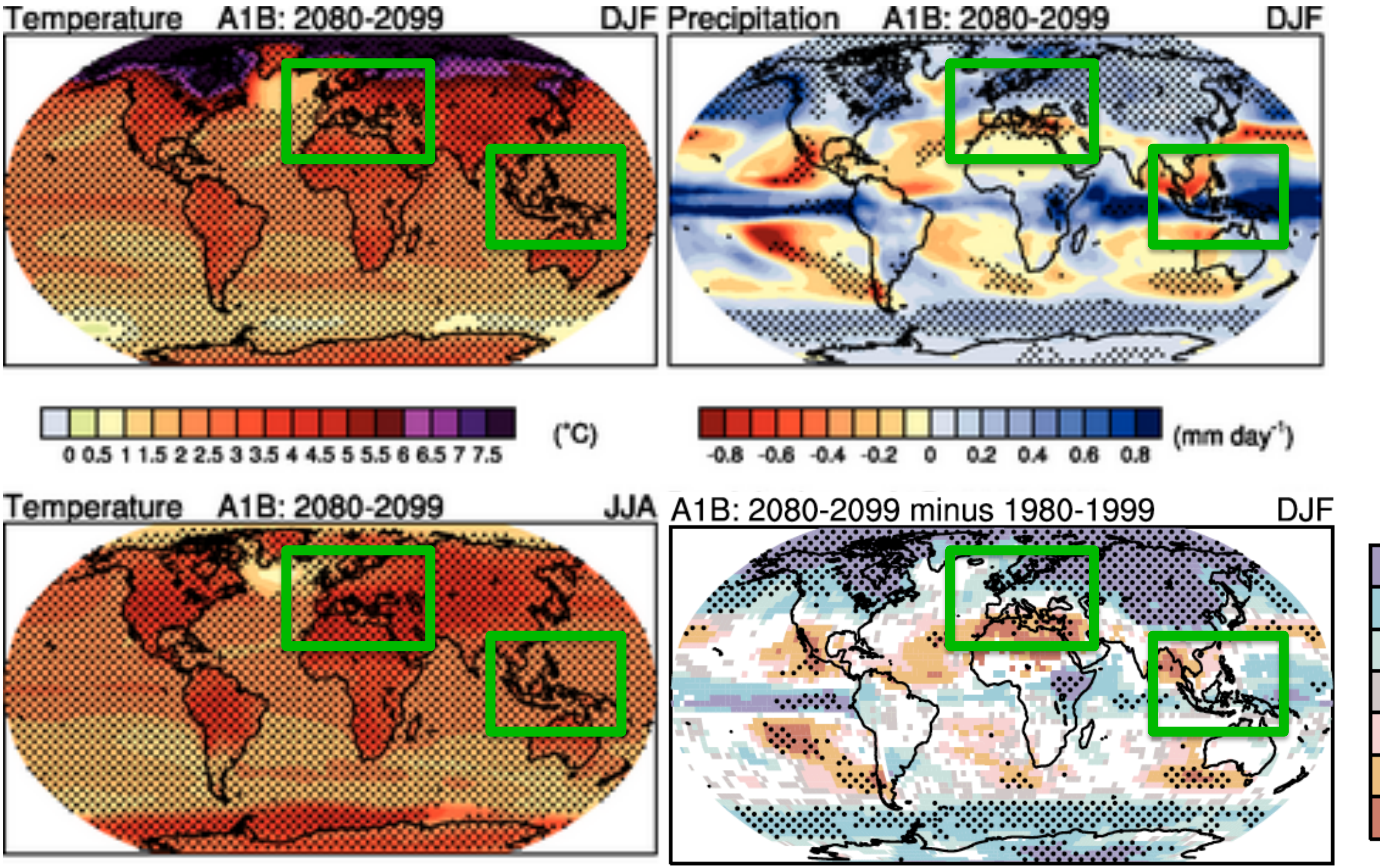


Scenarios IPCC-AR4 A1B (2007)

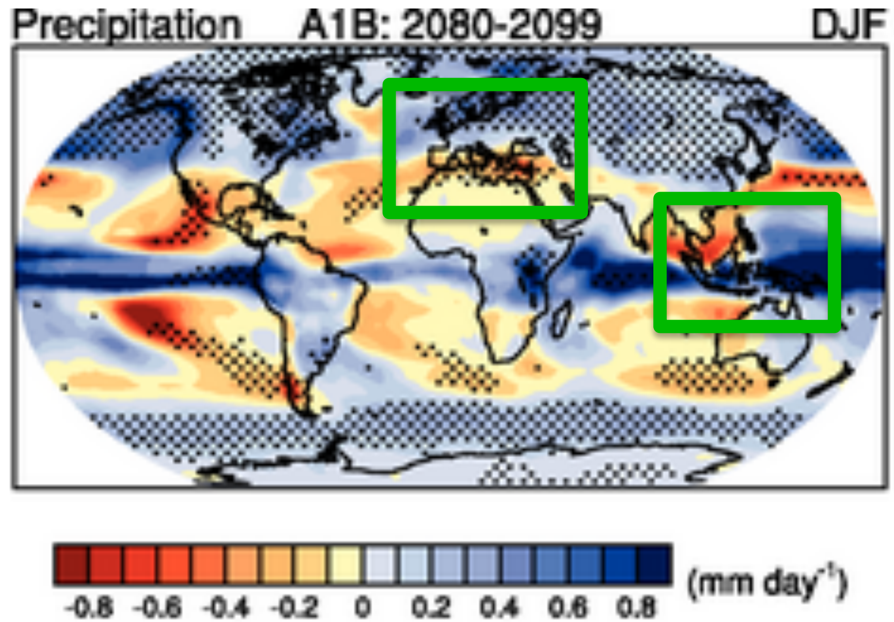


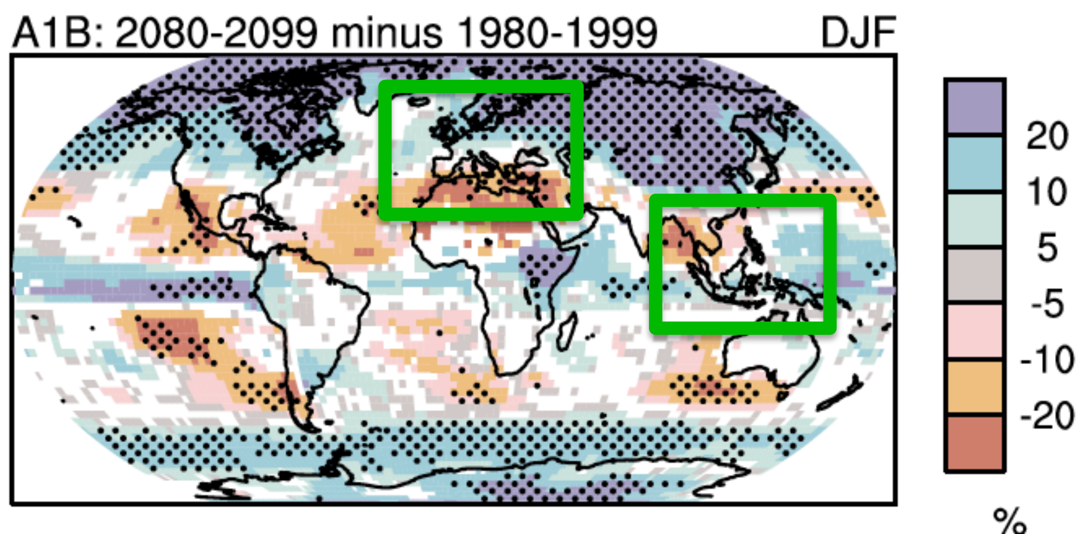


Muti-Model Uncertainty: GCM Selection



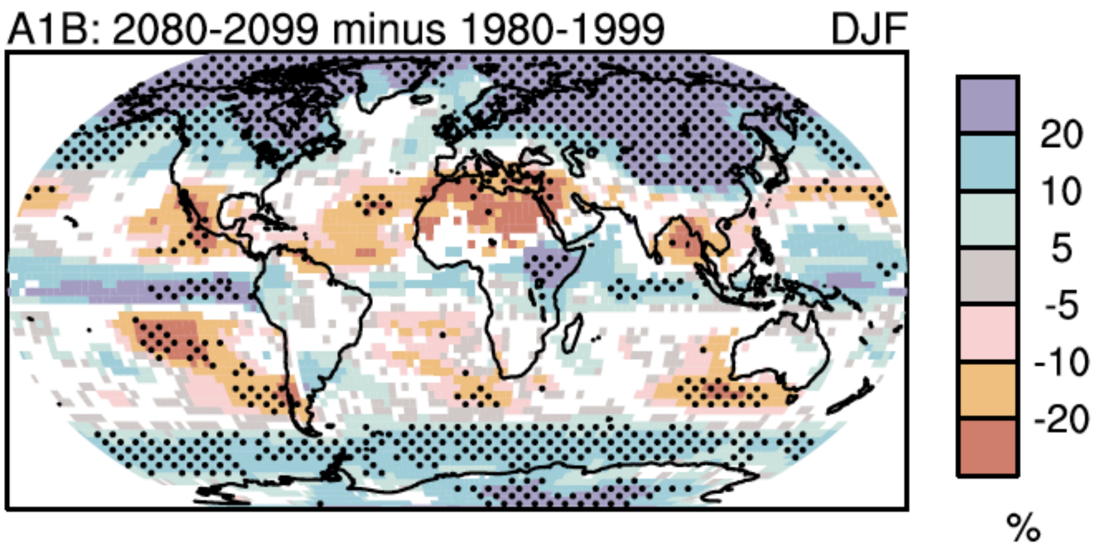
Mapping Model Agreement





[7] SPM.7 represented by colors the value of the multi-model averages and by stippling the areas where at least 90% of the models agreed on the sign of the change. When less than 66% of the models agreed in sign the map was left white, to indicate lack of agreement and therefore lack of any robust information about the direction of future change.

Mapping Model Agreement



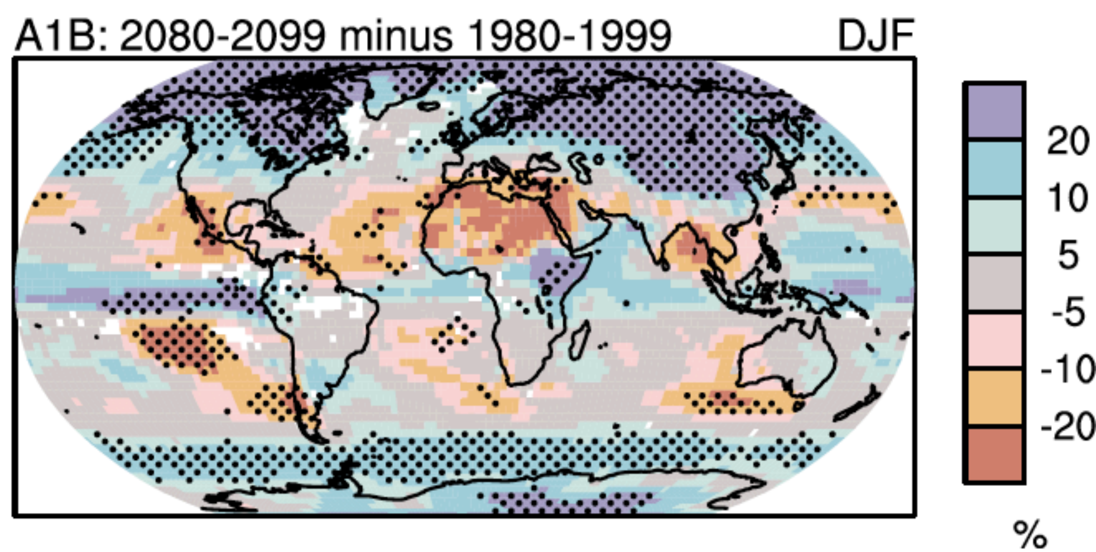
[7] SPM.7 represented by colors the value of the multi-model averages and by stippling the areas where at least 90% of the models agreed on the sign of the change. When less than 66% of the models agreed in sign the map was left white, to indicate lack of agreement and therefore lack of any robust information about the direction of future change.

GEOPHYSICAL RESEARCH LETTERS, VOL. 38, L23701, doi:10.1029/2011GL049863, 2011

Mapping model agreement on future climate projections

Claudia Tebaldi,[1] Julie M. Arblaster,[2,3] and Reto Knutti[4]

[8] Our method explicitly considers statistical significance in the choice of coloring or not, and stippling or not. Differently from SPM.7, therefore, we distinguish the case where models do not agree in sign but are still within the boundaries of natural variability - in which case we argue that information is available, and we still use colors to represent the multimodel mean – from the case where models do not agree and simulate a significant change – in which case we argue that we truly have conflicting information, originating from the different models different responses to forcings – and we leave the corresponding areas white.



Dealing with multi-model projections

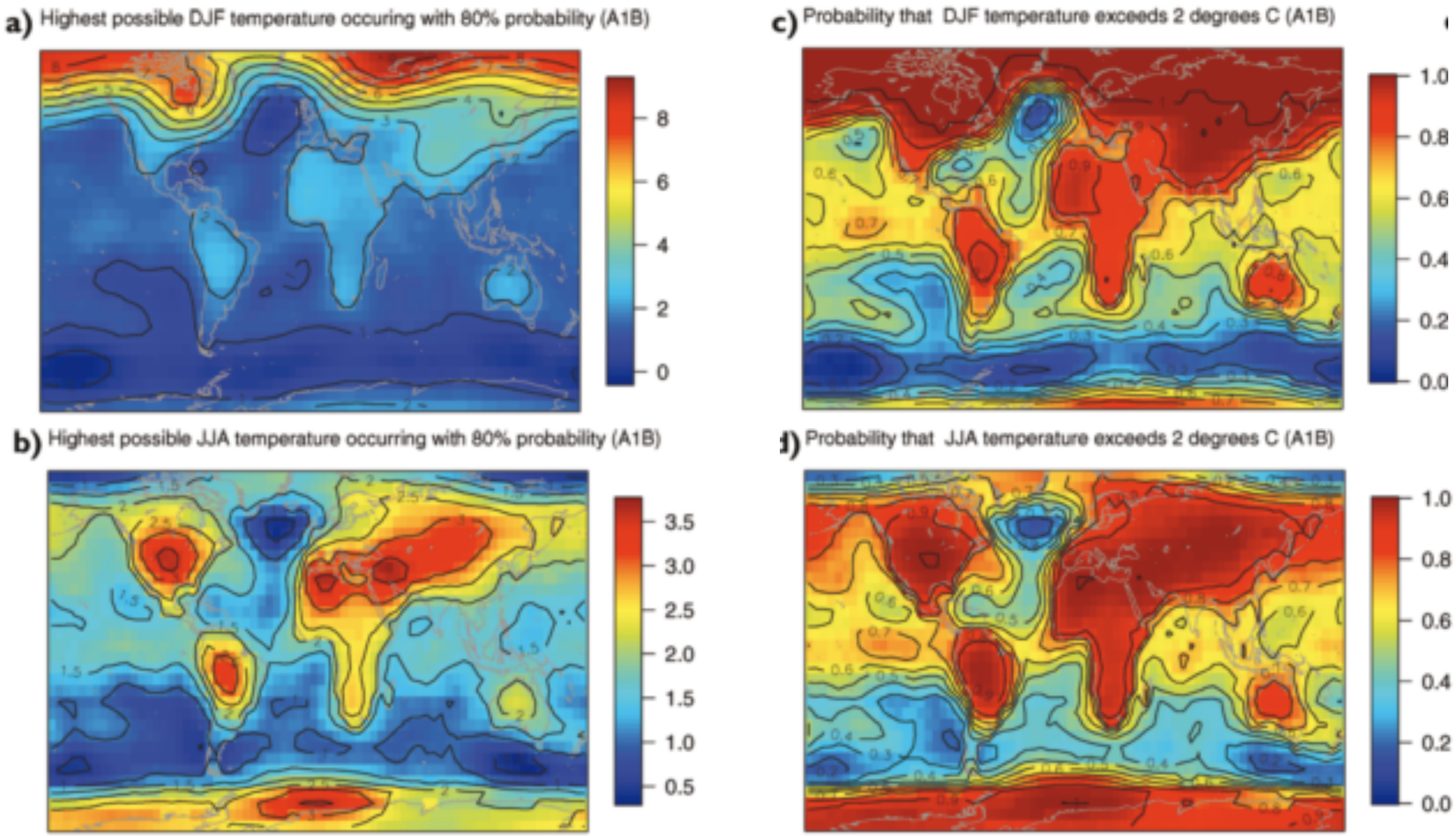


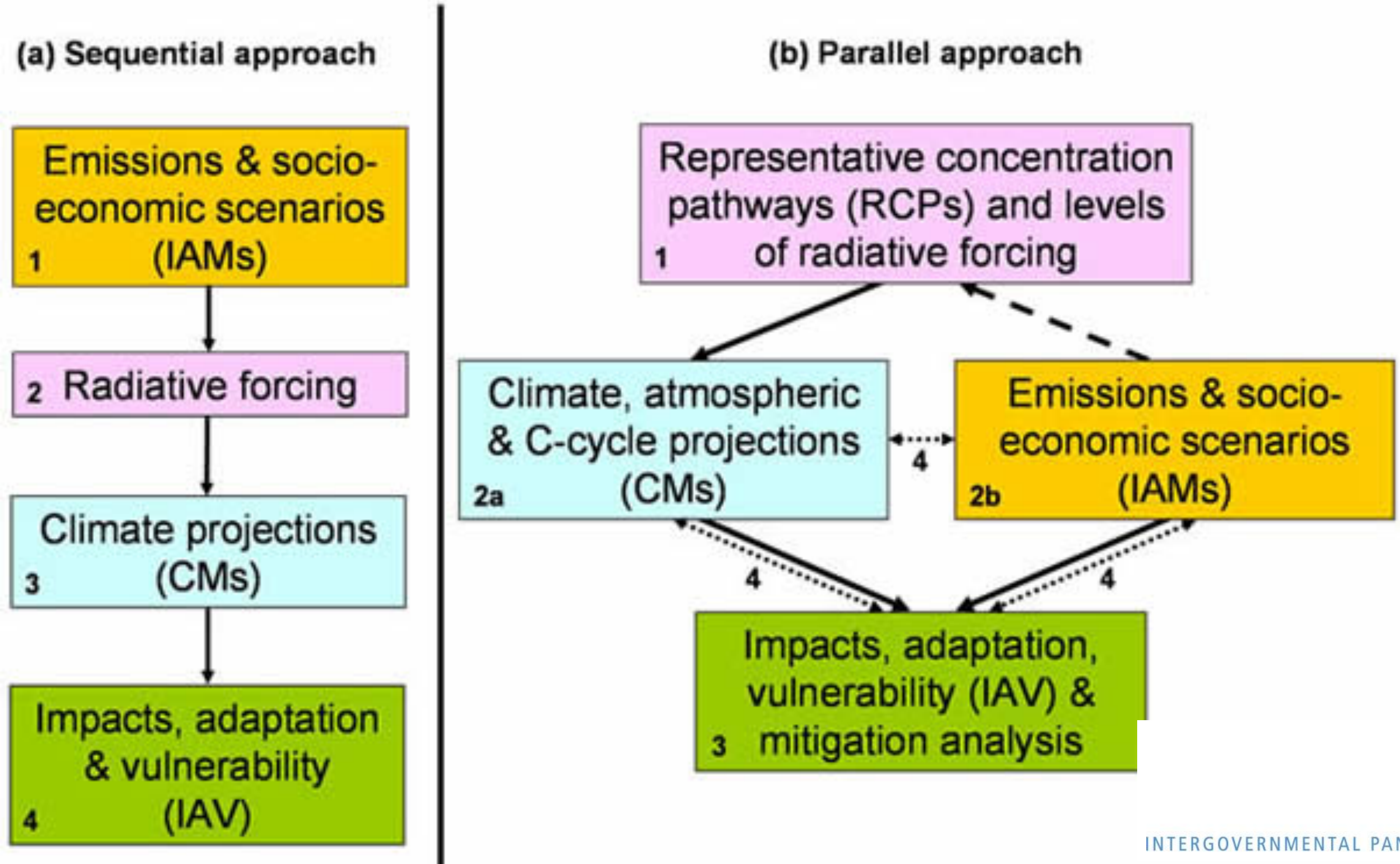
Fig. 8. Probabilistic climate change results from 21 AOGCMs, 2080–99 compared to 1980–99, for the A1B scenario, converted to a common 5° lat–lon grid: (a) DJF and (b) JJA values of temperature increase with an 80% chance of occurrence by the end of the twenty-first century. Also shown are contours of probabilities of the occurrence of at least a 2°C warming for (c) DJF and (d) JJA (Furrer et al. 2007a).

- ***Introduction to Global Climate Modeling***
  - ***Multi-model and multi-scenario ensembles***
  - ***From AR4 to AR5***
- ***Introduction to Downscaling***
  - ***Dynamical vs Statistical approaches***
- ***Validation of GCMs for Downscaling***
  - ***Distributional similarity measures***

RCP Emission Scenarios… From AR4 to AR5

The new scenarios take alternative futures in global greenhouse gas and aerosol concentrations as their starting point. These RCPs are used:

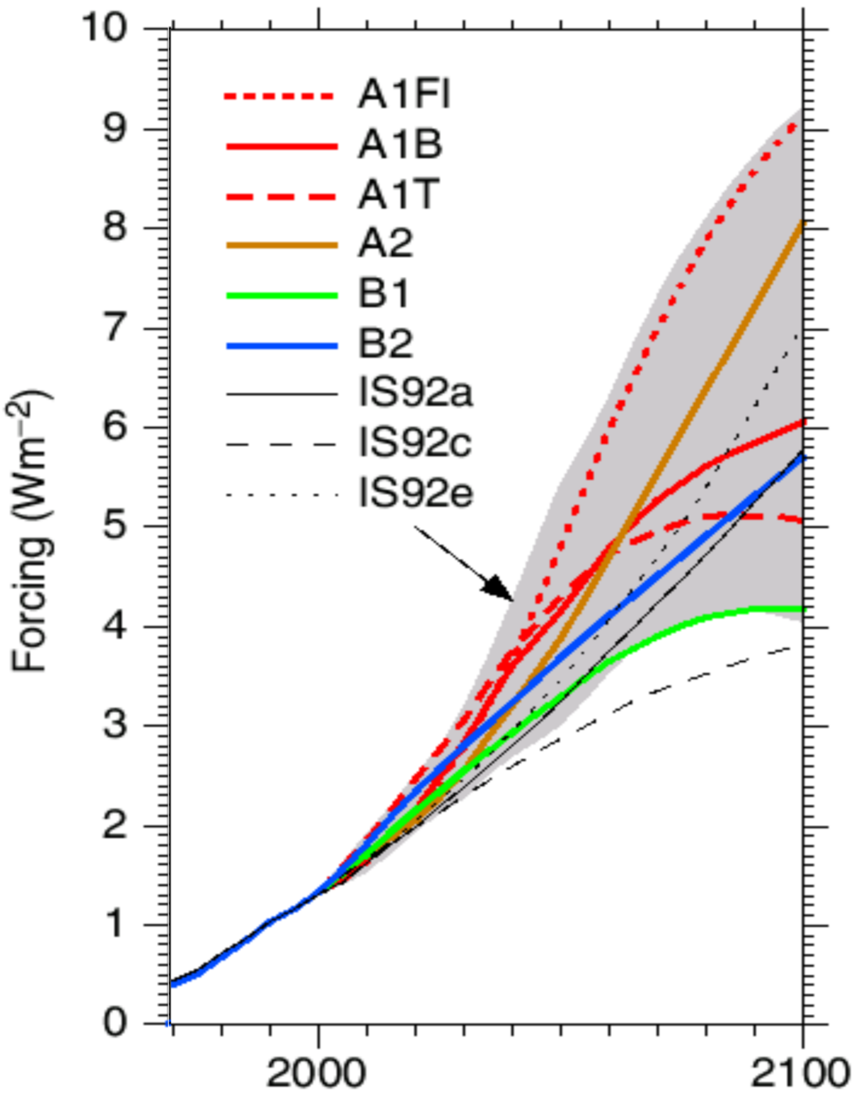
- by Earth System Models (ESMs): physical and biogeochemical resp.
- by Integrated Assessment Models (IAMs): socio-economic conditions

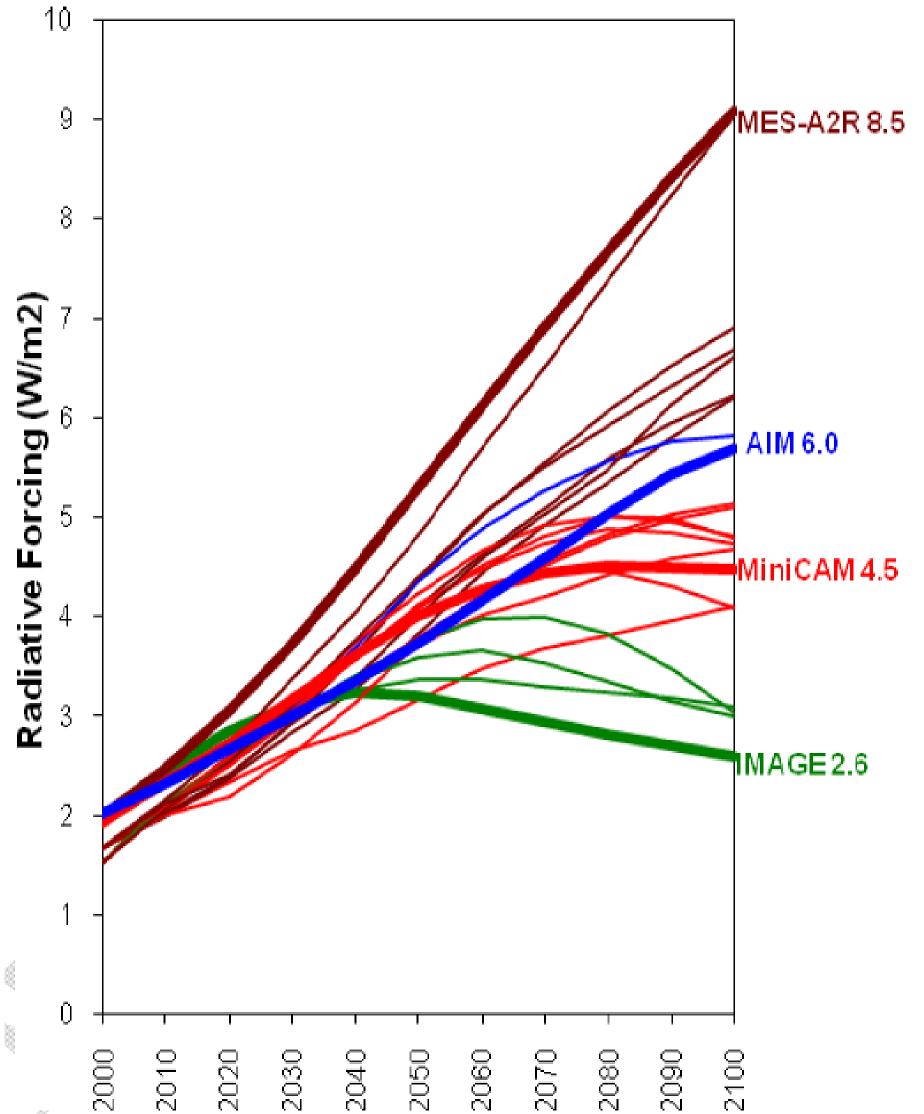


Four Representative Concentration Pathways (RCPs)

Name	Radiative forcing	Concentration	Pathway	Model providing RCP	Reference
RCP8.5	>8.5 W/m^2 in 2100	>1370 CO_2-eq in 2100	Rising	MESSAGE	Rao & Riahi (2006), Riahi et al. (2007)
RCP6.0	~6 W/m^2 at stabilisation after 2100	~850 CO_2-eq (at stabilisation after 2100)	Stabilisation without overshoot	AIM	Fujino et al. (2006), Hijioka et al. (2008)
RCP4.5	~4.5 W/m^2 at stabilisation after 2100	~650 CO_2-eq (at stabilisation after 2100)	Stabilisation without overshoot	MiniCAM	Smith & Wigley (2006), Clarke et al. (2007)
RCP3.0	Peak at ~3 W/m^2 before 2100 and then decline	Peak at ~490 CO_2-eq before 2100 and then decline	Peak and decline	IMAGE	van Vuuren et al. (2006, 2007)

SRES vs. RCP Emission Scenarios



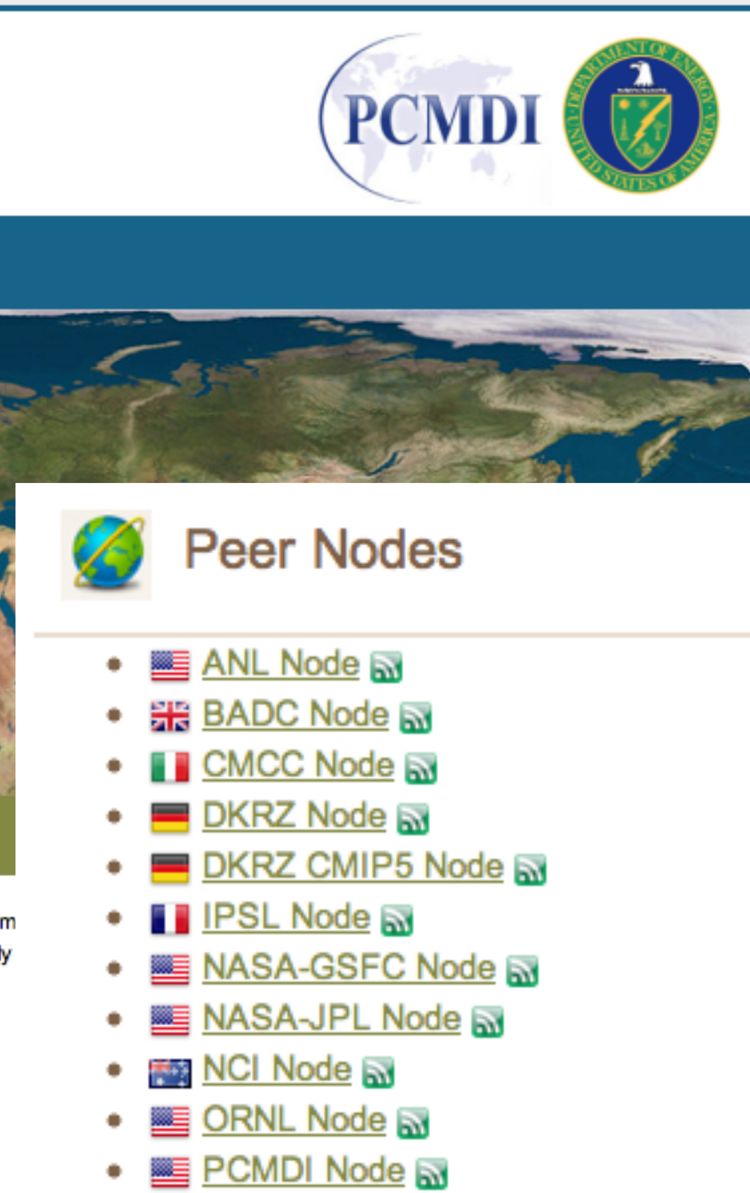


CMIP5 Earth System Models considered in this study

Model	Hor. Resolution	Reference
CanESM2	$2.8 * 2.8°$	Chylek et al (2011)
CNRM-CM5	$1.4 * 1.4°$	Voldoire et al (2011)
HadGEM2-ES	$1.875 * 1.25°$	Collins et al (2011)
IPSL-CM5-MR	$1.5 * 1.27°$	Dufresne et al (submitted)
MIROC-ESM	$2.8 * 2.8°$	Watanabe et al (2011)
MPI-ESM-LR	$1.8 * 1.8°$	Raddatz et al (2007); Jungclaus et al (2010)
NorESM1-M	$1.5 * 1.9°$	Kirkevag et al (2008); Seland et al (2008)

Table 2 Variables considered in this study.

Code	Name	Height	Unit
Z	Geopotential	500hPa	$m^2 s^{-2}$
T	Temperature	2m, 850hPa	K
Q	Specific humidity	850hPa	$kg\,kg^{-1}$
U	U-wind	850hPa	$m\,s^{-1}$
V	V-wind	850hPa	$m\,s^{-1}$
SLP	Sea-level pressure	mean sea-level	Pa



CERTIFICATES

http://pcmdi9.llnl.gov/esgf-web-fe/

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Current Selections

- (x) text:Earth System Model

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- Time Frequency

Earth System Model [Search]

Examples: *temperature*, *"surface temperature"*, *climate AND project:CMIP5 AND variable:hus*.
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< 1 2 3 … 5897 5898 > displaying 1 to 10 of 58975 search results

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Results | Data Cart

project=CMIP5, model=BNU-ESM, College of Global Change and Earth System Science, Beijing Normal University, experiment=AMIP, time_frequency=day, modeling realm=landIce, ensemble=r1i1p1, version=20120504

Data Node: esg.bnu.edu.cn

Version: 20120504

Description: BNU-ESM model output prepared for CMIP5 AMIP

Further options: Add To Cart, Model Metadata

Earth System Grid Federation

Santander Meteorology Group

ESGF.org

http://esgf.org/

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ESGF

Earth System Grid Feder

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- design
- releases
- installation
- sub-projects
- developer info
- mailing lists
- bugs
- blog
- wiki
- committee
- acknowledgments

Earth System Grid F

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enabling world wide acc

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observational data. ESG
international effort led by
Administration (NASA),
and international laborat
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- *Integrate and inter by NASA, NOAA,*
- *Create software ir*

ESGF P2P is a compon

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ESGF_Wiki: Cmip5Status/ CMIP5NodeStatus

RecentChanges | FindPage | HelpContents | CMIP5NodeStatus

Edit (Text) | Info | Attachments | More Actions:

Status of the CMIP5 nodes

Last Update: *Mon Nov 5 17:36:46 UTC 2012* (UTC) - (Build: 8415) - Download results

Status	Response time	Node
✔	0.41	http://albedo2.dkrz.de/thredds/catalog.html
✔	0.47	http://bcccsm.cma.gov.cn/thredds/catalog.html
✔	0.41	http://bmbf-ipcc-ar5.dkrz.de/thredds/catalog.html
✔	0.55	http://cmip-dn1.badc.rl.ac.uk/thredds/catalog.html
✔	0.42	http://cmip3.dkrz.de/thredds/catalog.html
✔	0.40	http://cmip5.fio.org.cn/thredds/catalog.html
✔	0.15	http://dapp2p.cccma.ec.gc.ca/thredds/catalog.html
✔	0.33	http://dias-esg-nd.tkl.iis.u-tokyo.ac.jp/thredds/catalog.html
✖	<timeout>	http://ec2-23-21-209-87.compute-1.amazonaws.com/thredds/catalog.html
✔	1.26	http://esg.bnu.edu.cn/thredds/catalog.html

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- ***Validation of GCMs for Downscaling***
  - ***Distributional similarity measures***

Problema: Resolución Inapropiada

THE WCRP CMIP3 MULTIMODEL DATASET

A New Era in Climate Change Research

BY GERALD A. MEEHL, CURT COVEY, THOMAS DELWORTH, MOJIB LATIF, BRYANT MCAVANEY, JOHN F. B. MITCHELL, RONALD J. STOUFFER, AND KARL E. TAYLOR

SEPTEMBER 2007 BAMS | 1383
AMERICAN METEOROLOGICAL SOCIETY
DOI:10.1175/BAMS-88-9-1383

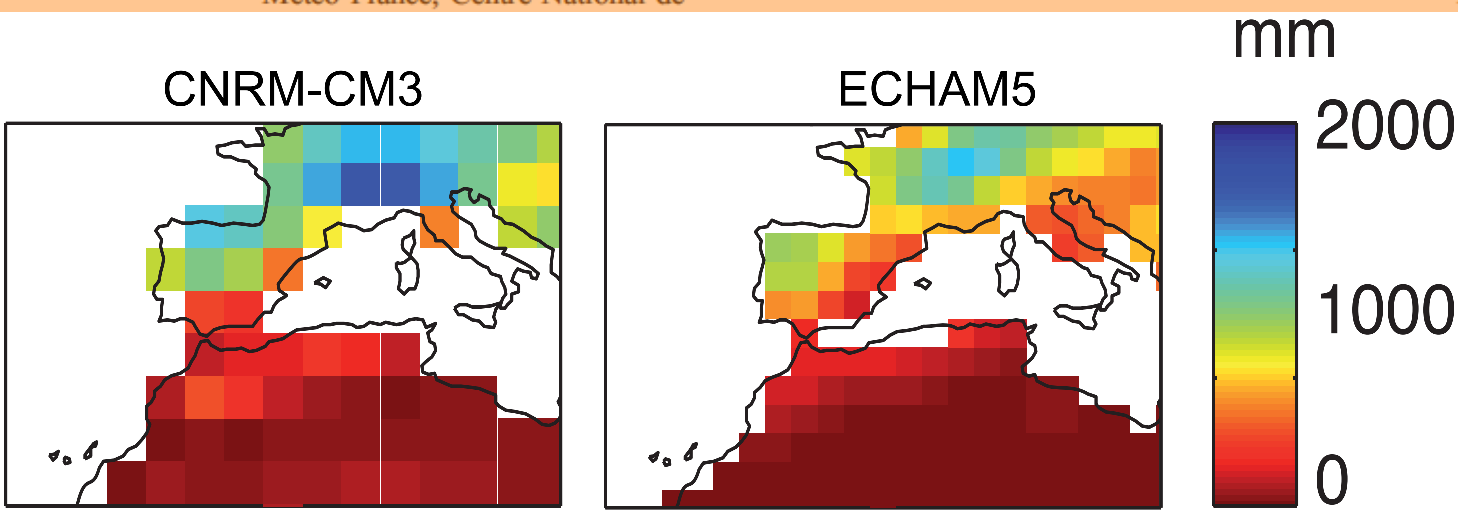
Performance metrics for climate models

P. J. Gleckler,[1] K. E. Taylor,[1] and C. Doutriaux[1]

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 113

Table 1. Model Identification, Originating Group, and Atmospheric Resolution

IPCC I.D.	Center and Location	Atmosphere Resolution
BCCR-BCM2.0	Bjerknes Centre for Climate Research (Norway)	T63 L31
CGCM3.1(T47)	Canadian Centre for Climate Modelling and Analysis (Canada)	T47 L31
CGCM3.1(T63)		T63 L31
CSIRO-Mk3.0	CSIRO Atmospheric Research (Australia)	T63 L18
CNRM-CM3	Météo-France, Centre National de	T42 L45
ECHAM5/MPI-OM	Max Planck Institute for Meteorology (Germany)	T63 L32
CCSM3	National Center for Atmospheric Research (USA)	T85 L26
PCM		T42 L18
UKMO-HadCM3	Hadley Centre for Climate Prediction and Research,	96 × 72 L19
UKMO-HadGEM1	Met Office (UK)	N96 L38

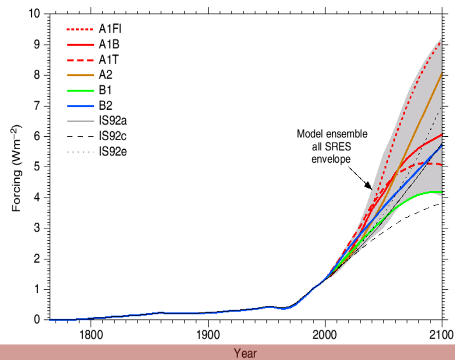


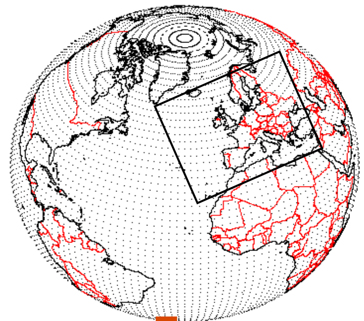
Santander Meteorology Group

A multidisciplinary approach for weather & climate

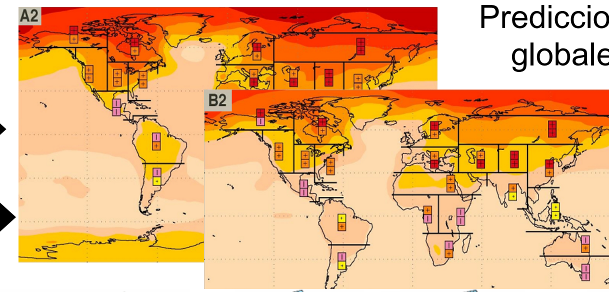
Dynamical Downscaling: Regional Climate Models (RCMs)

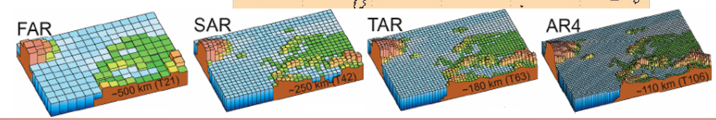
Escenarios de emisión





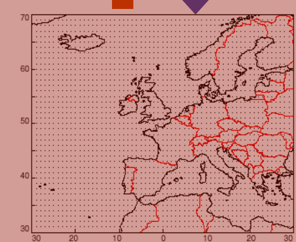
Predicciones globales

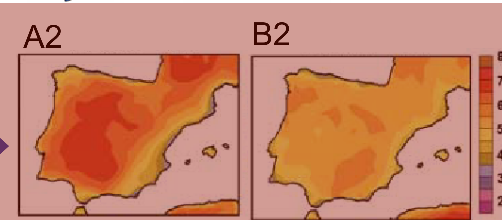




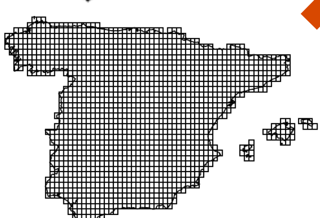
RCM

Downscaling Dinámico:
basado en Modelos
Regionales del Clima (RCMs)





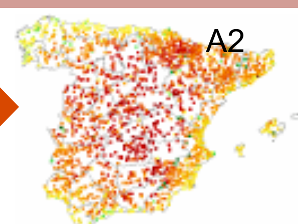
Registros históricos

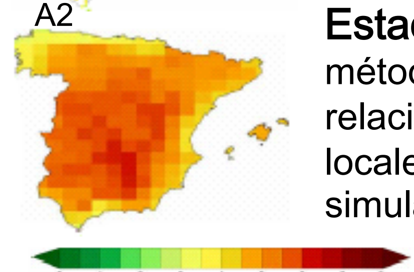


Rejilla interpolada (**20 km**)

$$\mathbf{Y} = f\,(\mathbf{X};\theta)$$

Los parámetros de los modelos son ajustados con los datos observados y simulados en clima presente.





Downscaling Estadístico: basado en métodos estadísticos que relacionan las ocurrencias locales con las simulaciones globales.

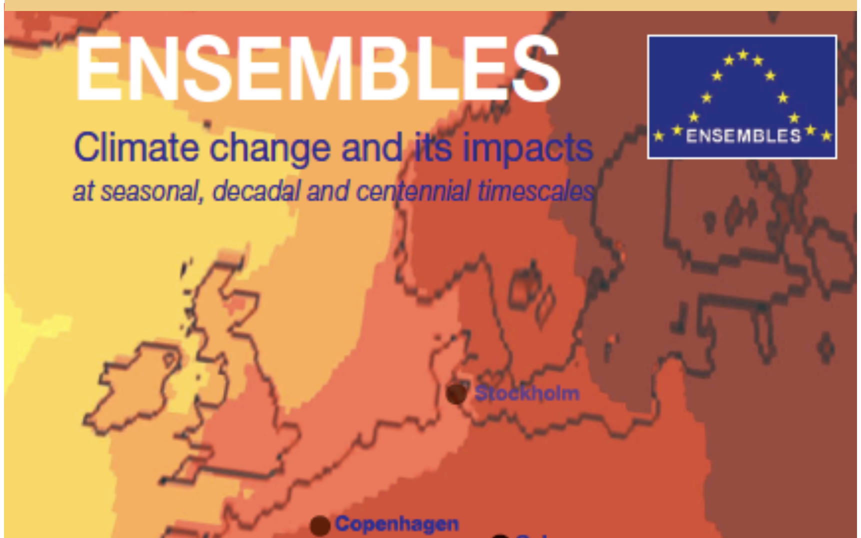
http://ensembles-eu.metoffice.com

ENSEMBLES Project (2004-2009)

ENSEMBLES

Develop an ensemble prediction system for climate change and linking the outputs to a range of applications.

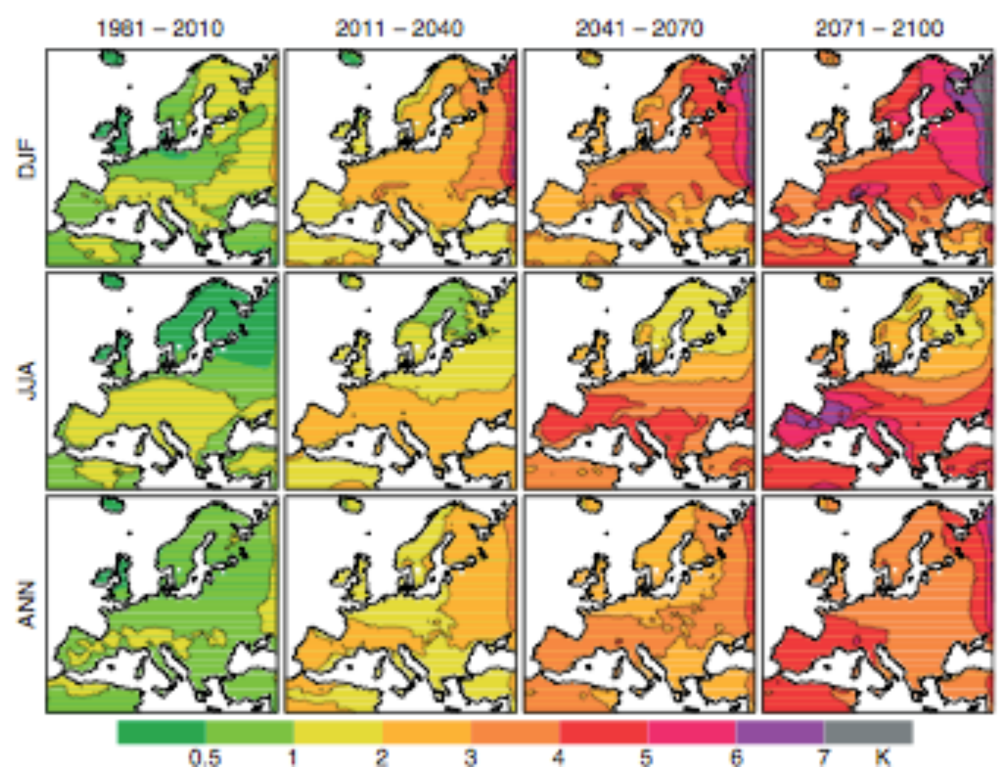
- **RCM simulations.**
- **Statistical Downscaling (SD).**
- **Gridded observations: E-OBS**



Advanced Review

State-of-the-art with regional climate models

Markku Rummukainen*



Dynamical Downscaling: Methodology

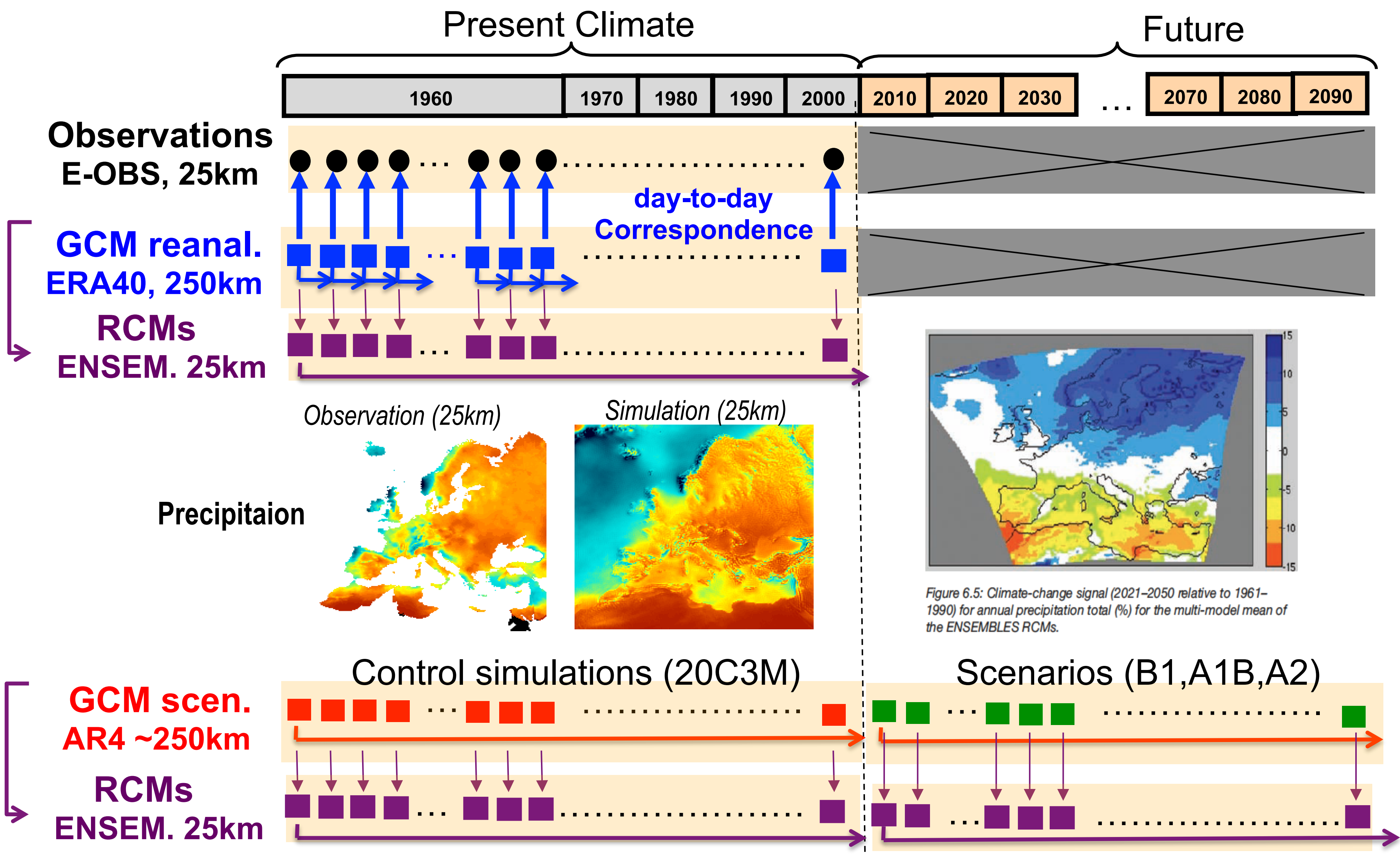


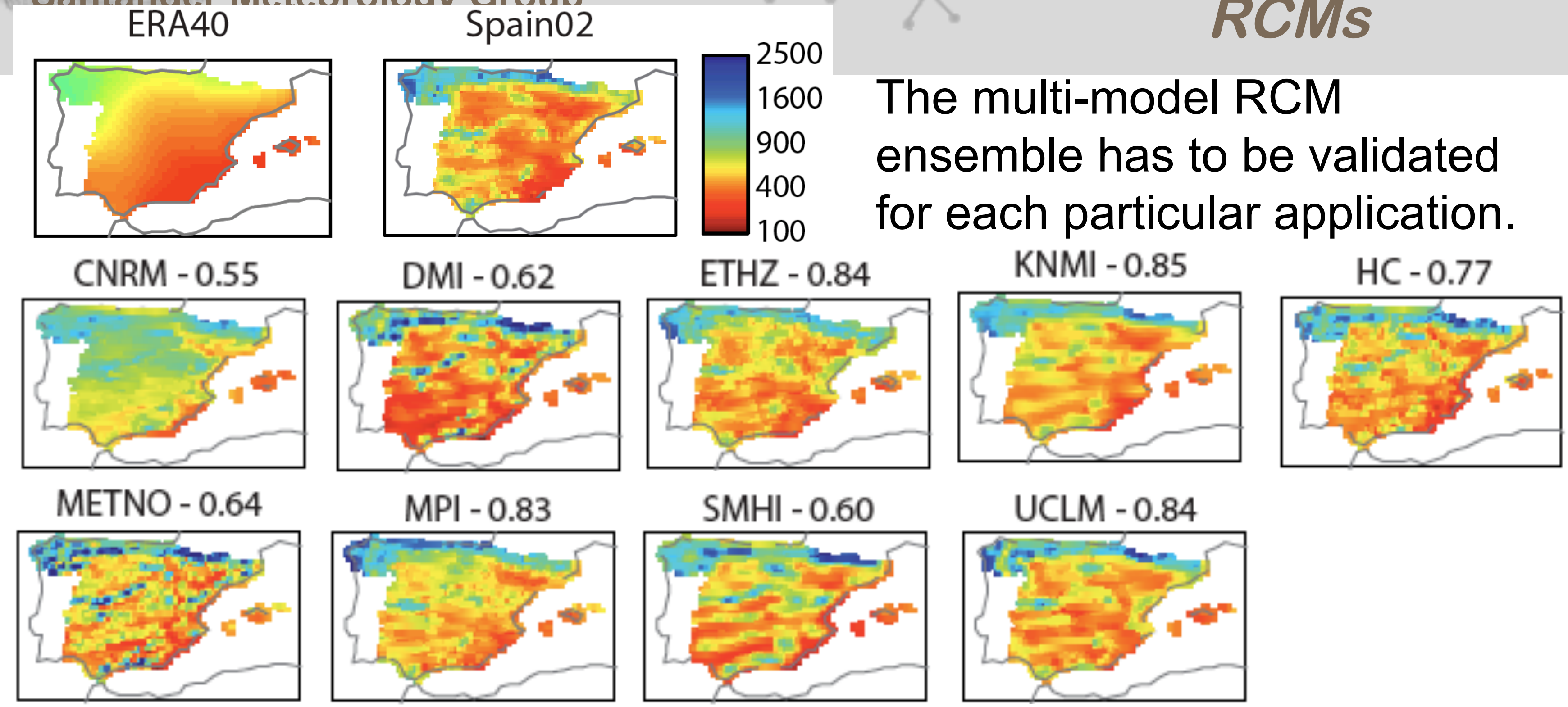
Figure 6.5: Climate-change signal (2021–2050 relative to 1961–1990) for annual precipitation total (%) for the multi-model mean of the ENSEMBLES RCMs.

Variables	Description	Units
tas	2-meter temperature	K
tasmax	Daily maximum 2-m temperature	K
tasmin	Daily minimum 2-m temperature	K
uas	10-meter U-wind	m/s
vas	10-meter V-wind	m/s
wss	10-meter wind speed	m/s
huss	2-meter specific humidity	Kg/kg
hurs	2-meter relative humidity	%
tdps	2-meter dew point temperature	K
psl	Mean sea level pressure	Pa
pr	Precipitation	Mm
prc	Convective precipitation	Mm
prls	Large-scale precipitation	Mm
evspsbl	Evaporation	Mm
evspsblpot	Potential Evapotranspiration	Mm
rss	Net SW surface radiation	W/m^2
rls	Net LW surface radiation	W/m^2
rst	Top net SW	W/m^2
rsds	Downward SW surface radiation	W/m^2
rlds	Downward LW surface radiation	W/m^2
rsdt	Top downward SW radiation	W/m^2

RCMs provide a **large number of physically consistent variables**.

However, they exhibit large biases which need to be calibrated for impact studies. This callibration process **assumes stationarity**.

Validation of reanalysis-driven RCMs



The multi-model RCM ensemble has to be validated for each particular application.

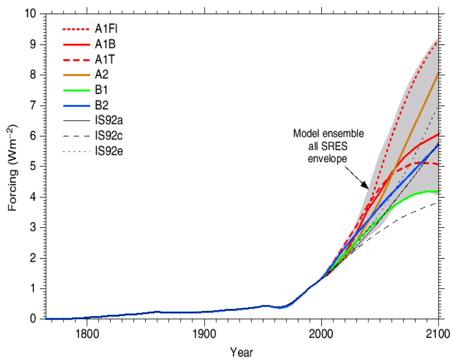
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, D21117, doi:10.1029/2010JD013936, 2010

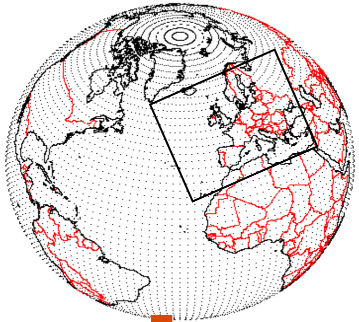
Evaluation of the mean and extreme precipitation regimes from the ENSEMBLES regional climate multimodel simulations over Spain

S. Herrera,[1] L. Fita,[2] J. Fernández,[2] and J. M. Gutiérrez[1]

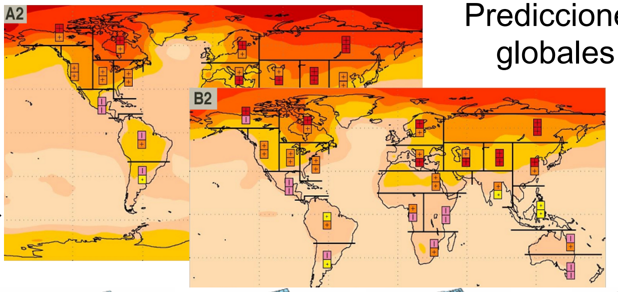
Statistical Downscaling

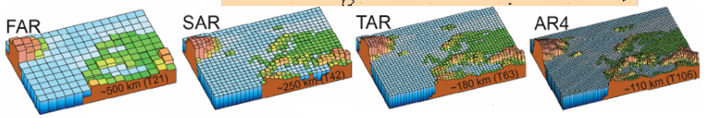
Escenarios de emisión



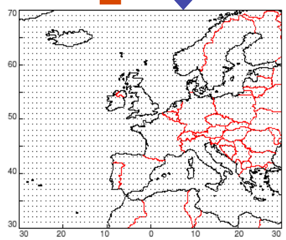


Predicciones globales

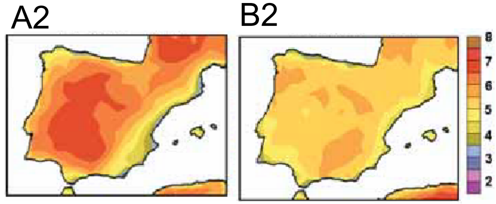




RCM



Downscaling Dinámico: basado en Modelos Regionales del Clima (RCMs)

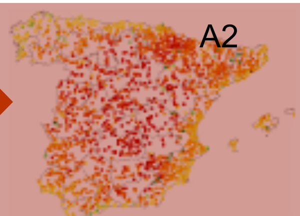


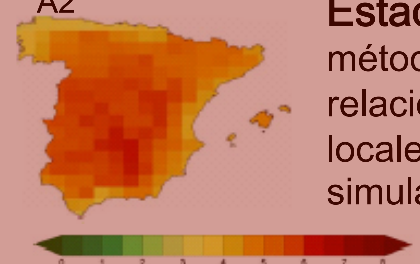
Registros históricos

Rejilla interpolada (**20 km**)

$$\mathbf{Y} = f\,(\mathbf{X};\theta)$$

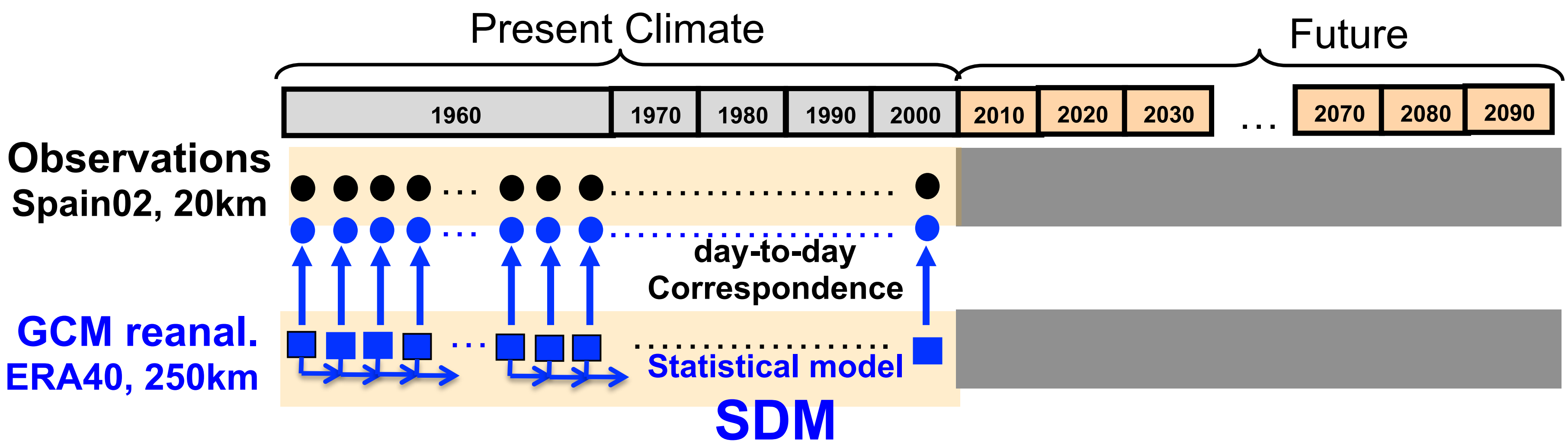
Los parámetros de los modelos son ajustados con los datos observados y simulados en clima presente.



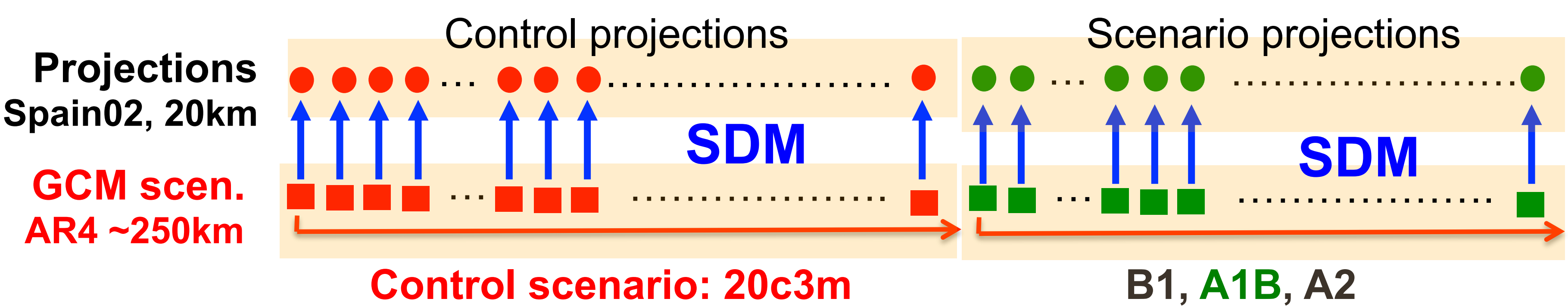


Downscaling Estadístico: basado en métodos estadísticos que relacionan las ocurrencias locales con las simulaciones globales.

Statistical Downscaling: Perfect Prog.



- **PROBLEM 1: Choosing consistent predictors:**
- **PROBLEM 2: Stationarity/robustness: SDM SDM**



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wss	10-meter wind speed	m/s
huss	2-meter specific humidity	Kg/kg
hurs	2-meter relative humidity	%
tdps	2-meter dew point temperature	K
psl	Mean sea level pressure	Pa
pr	Precipitation	Mm
prc	Convective precipitation	Mm
prls	Large-scale precipitation	Mm
evspsbl	Evaporation	Mm
evspsblpot	Potential Evapotranspiration	Mm
rss	Net SW surface radiation	W/m^2
rls	Net LW surface radiation	W/m^2
rst	Top net SW	W/m^2
rsds	Downward SW surface radiation	W/m^2
rlds	Downward LW surface radiation	W/m^2
rsdt	Top downward SW radiation	W/m^2

RCMs provide a **large number of physically consistent variables**.

However, they exhibit large biases which need to be calibrated for impact studies. This callibration process **assumes stationarity**.

SDM require historical records of the variables under study.

SDM has some theoretical limitations: non-stationarity?

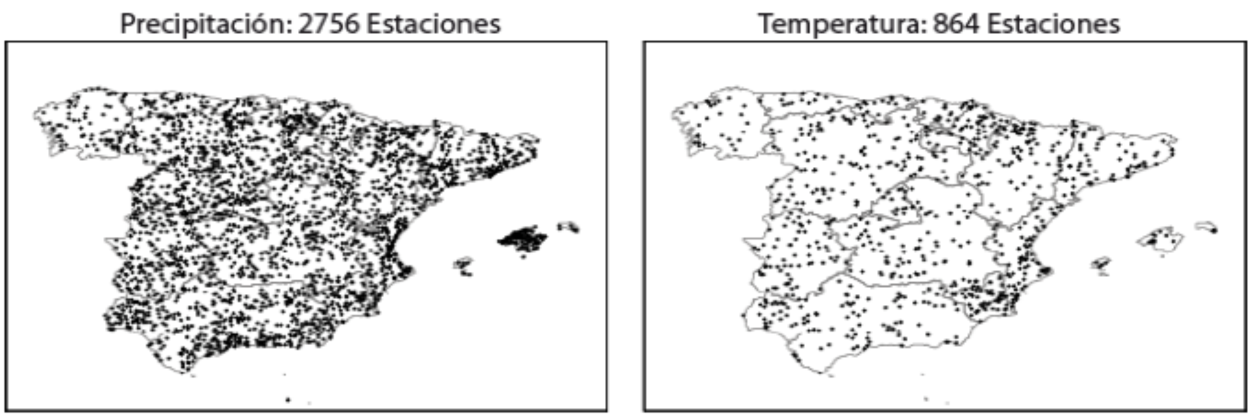
Freely-available observations in Iberia (Spain02)

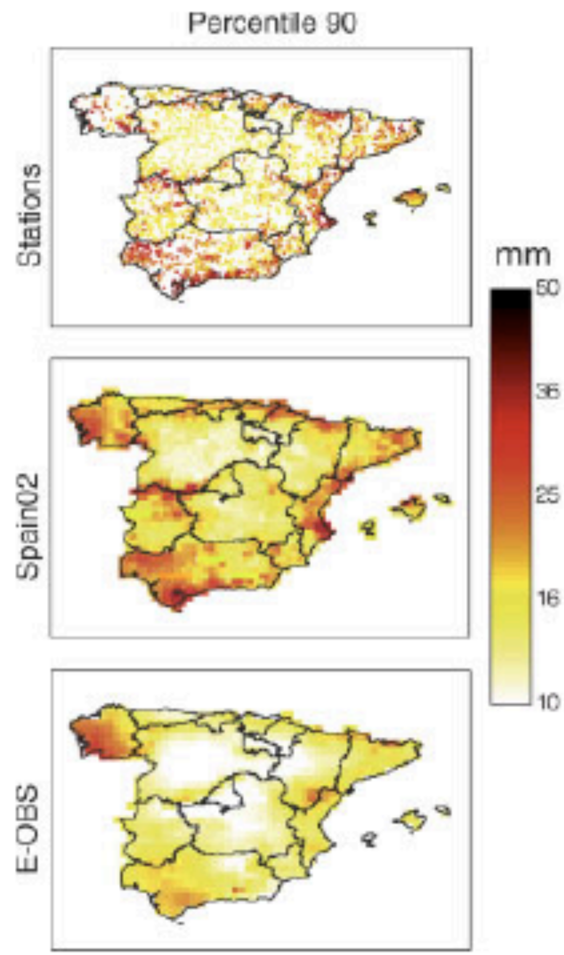
INTERNATIONAL JOURNAL OF CLIMATOLOGY
Int. J. Climatol. (2010)
Published online in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/joc.2256

RMetS
Royal Meteorological Society

Development and analysis of a 50-year high-resolution daily gridded precipitation dataset over Spain (Spain02)

S. Herrera,[a]* J. M. Gutiérrez,[a] R. Ancell,[b] M. R. Pons,[b] M. D. Frías[c] and J. Fernández[c]
[a] *Instituto de Física de Cantabria, CSIC-University of Cantabria, Avenida de los Castros s/n, Santander, Spain*
[b] *Agencia Estatal de Meteorología (AEMET), Santander, Spain*
[c] *Department of Applied Mathematics and Computer Science, Universidad de Cantabria, Santander, Spain*

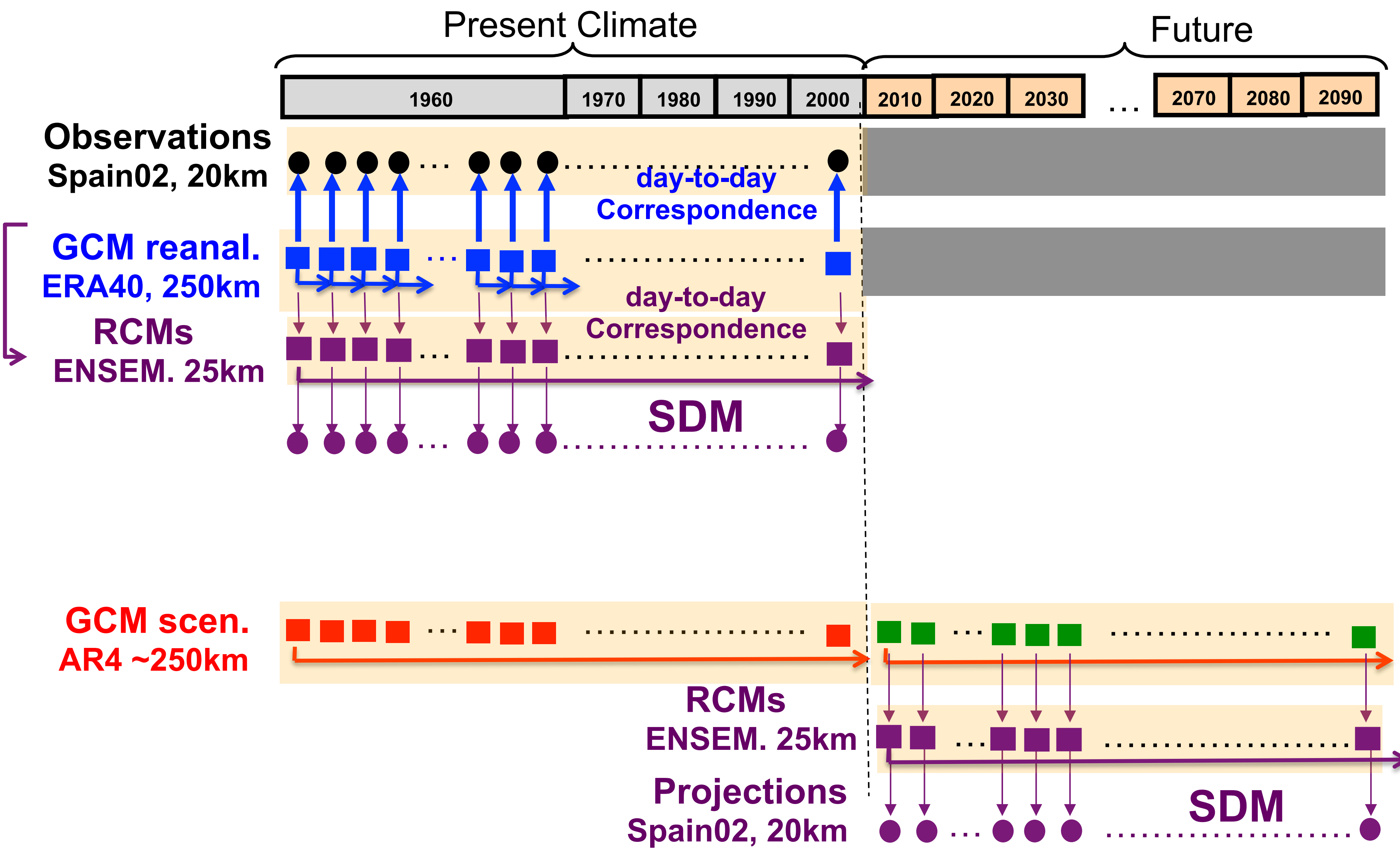




Precipitation, min. and max. temperatures

Freely available at:
http://www.meteo.unican.es/datasets/spain02

Combined Downscaling Approaches



Geography Compass 5/6 (2011): 275–300, 10.1111/j.1749-8198.2011.00425.x

Climate Scenario Development and Applications for Local/Regional Climate Change Impact Assessments: An Overview for the Non-Climate Scientist

Part I: Scenario Development Using Downscaling Methods

Julie A. Winkler[1]*, Galina S. Guentchev[2], Perdinan[1], Pang-Ning Tan[3], Sharon Zhong[1], Malgorzata Liszewska[4], Zubin Abraham[3], Tadeusz Niedźwiedź[5] and Zbigniew Ustrnul[6]
[1]Department of Geography, Michigan State University
[2]UCAR CLIVAR Postdocs Applying Climate Expertise (PACE) Program
[3]Department of Computer Science and Engineering, Michigan State University
[4]Interdisciplinary Centre for Mathematical and Computational Modelling, University of Warsaw
[5]Department of Climatology, University of Silesia
[6]Department of Climatology, Jagiellonian University

Part II: Considerations When Using Climate Change Scenarios

Julie A. Winkler[1]*, Galina S. Guentchev[2], Malgorzata Liszewska[3], Perdinan[1] and Pang-Ning Tan[4]
[1]Department of Geography, Michigan State University
[2]UCAR CLIVAR Postdocs Applying Climate Expertise (PACE) Program
[3]Interdisciplinary Centre for Mathematical and Computational Modelling, University of Warsaw
[4]Department of Computer Science and Engineering, Michigan State University

- ***Introduction to Global Climate Modeling***
  - ***Multi-model and multi-scenario ensembles***
  - ***From AR4 to AR5***
- ***Introduction to Downscaling***
  - ***Dynamical vs Statistical approaches***
- ***Validation of GCMs for Downscaling***
  - ***Distributional similarity measures.***

GCMs in CMIP3 (IPCC-AR4)

THE WCRP CMIP3 MULTIMODEL DATASET

A New Era in Climate Change Research

BY GERALD A. MEEHL, CURT COVEY, THOMAS DELWORTH, MOJIB LATIF, BRYANT MCAVANEY, JOHN F. B. MITCHELL, RONALD J. STOUFFER, AND KARL E. TAYLOR

SEPTEMBER 2007 BAMS | 1383
AMERICAN METEOROLOGICAL SOCIETY
DOI:10.1175/BAMS-88-9-1383

Performance metrics for climate models

P. J. Gleckler,[1] K. E. Taylor,[1] and C. Doutriaux[1]

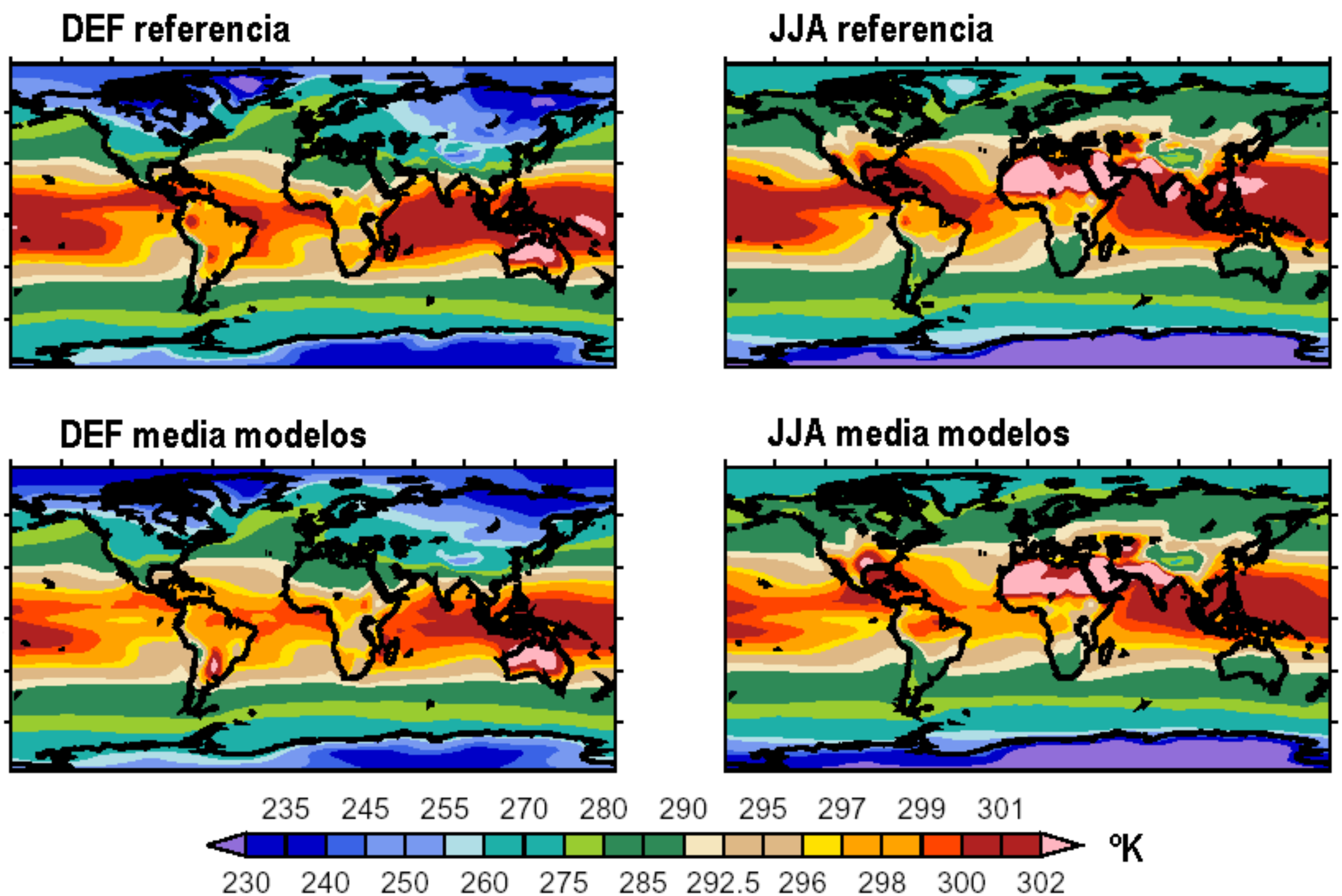
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 113

Table 1. Model Identification, Originating Group, and Atmospheric Resolution

IPCC I.D.	Center and Location	Atmosphere Resolution
BCCR-BCM2.0	Bjerknes Centre for Climate Research (Norway)	T63 L31
CGCM3.1(T47)	Canadian Centre for Climate Modelling and Analysis (Canada)	T47 L31
CGCM3.1(T63)		T63 L31
CSIRO-Mk3.0	CSIRO Atmospheric Research (Australia)	T63 L18
CNRM-CM3	Météo-France, Centre National de Recherches Météorologiques (France)	T42 L45
ECHO-G	Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA, and Model and Data group (Germany and Korea)	T30 L19
GFDL-CM2.0	US Dept. of Commerce, NOAA Geophysical Fluid Dynamics Laboratory (USA)	N45 L24
GFDL-CM2.1		N45 L24
GISS-AOM	NASA/Goddard Institute for Space Studies (USA)	90 × 60 L12
GISS-EH		72 × 46 L17
GISS-ER		72 × 46 L17
FGOALS-g1.0	LASG/Institute of Atmospheric Physics (China)	128 × 60 L26
INM-CM3.0	Institute for Numerical Mathematics (Russia)	72 × 45 L21
IPSL-CM4	Institut Pierre Simon Laplace (France)	96 × 72 L19
MIROC3.2(medres)	Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC) (Japan)	T42 L20
MIROC3.2(hires)		T106 L56
MRI-CGCM2.3.2	Meteorological Research Institute (Japan)	T42 L30
ECHAM5/MPI-OM	Max Planck Institute for Meteorology (Germany)	T63 L32
CCSM3	National Center for Atmospheric Research (USA)	T85 L26
PCM		T42 L18
UKMO-HadCM3	Hadley Centre for Climate Prediction and Research, Met Office (UK)	96 × 72 L19
UKMO-HadGEM1		N96 L38

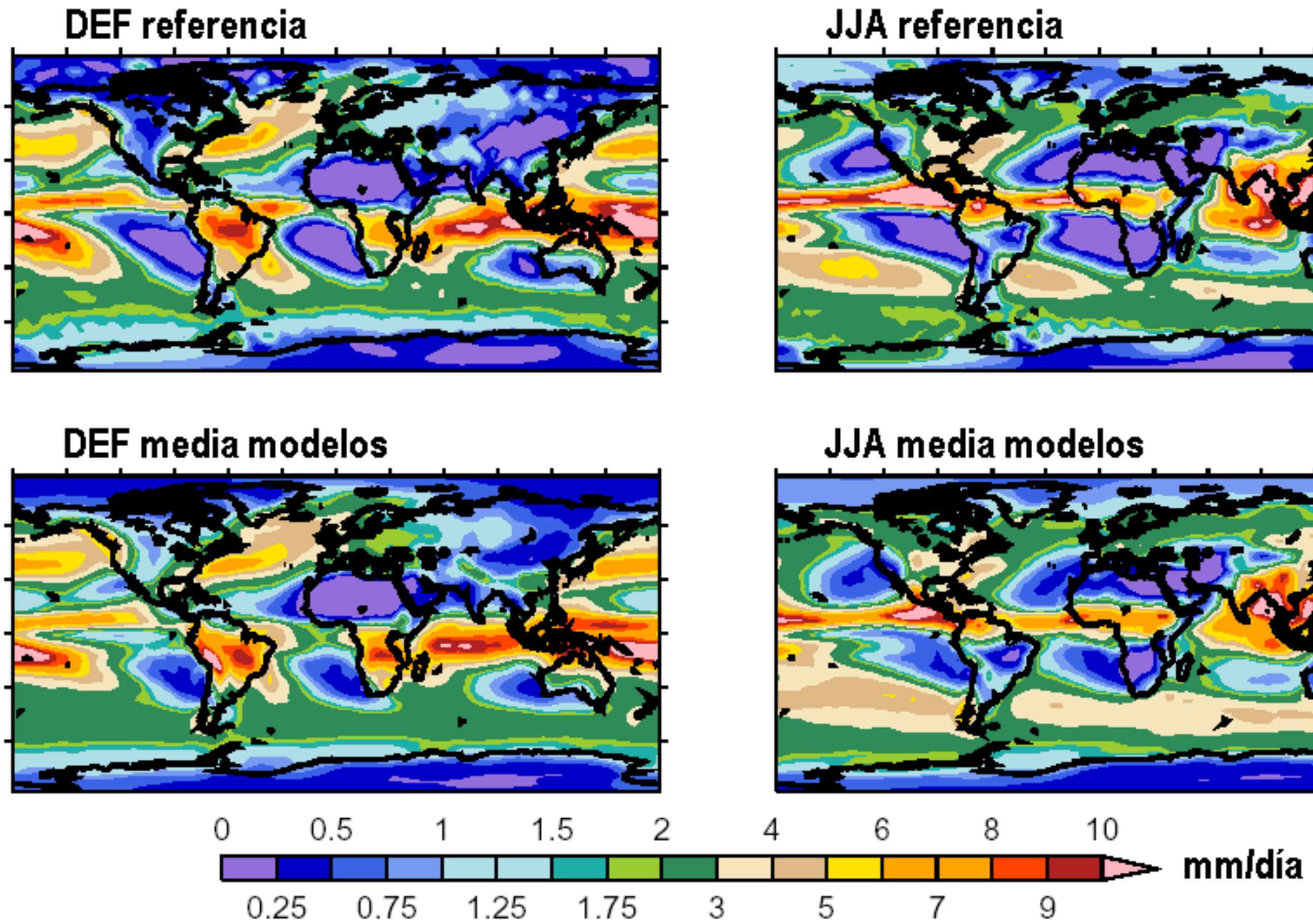
Validación: Temperature

CMIP3. *www-pcmdi.llnl.gov*



Validación: Precipitation

CMIP3. ***www-pcmdi.llnl.gov***



Brands S, Gutiérrez J, Herrera S, Cofiño A (2012) On the use of reanalysis data for downscaling. J Clim DOI {10.1175/JCLI-D-11-00251.1}

Atmospheric Reanalyses Comparison Table

Name	Source	Time Range	Assimilation	Model Resolution	Model Output Resolution	Publicly Available Dataset Resolution
Arctic System Reanalysis (ASR)	Polar Met Group	2000-2010	WRF-Var	10-20km	10-30km	10-30km
ECMWF Interim Reanalysis (ERA Interim)	ECMWF	1989-present	4D-VAR	T255L60	125 km	1.5x1.5 / 0.7x0.7
ECMWF 40 year Reanalysis (ERA-40)	ECMWF	1958-2001	3D-VAR	T159L60	80 km	2.5x2.5 / 1.125x1.125
Japanese Reanalysis (JRA-25)	Japan Meteorological Agency	1979-2004	3D-VAR	T106L40	1.125x1.125/2.5x2.5	1.125x1.125/2.5x2.5
NASA MERRA	NASA	1979-2010	3D-VAR	1/2x1/2 deg	1/2x1/2 deg	1/2x1/2 deg
NCEP Climate Forecast System Reanalysis (CFSR)	NCEP	1979-?	3D-VAR	T382 L64	.5x.5 and 2.5x2.5	.5x.5 and 2.5x2.5
NCEP/DOE Reanalysis AMIP-II (R2)	NCEP/DOE	1979-present	3D-VAR	T62 L28	2.5x2.5	2.5x2.5
NCEP/NCAR Reanalysis I (R1)	NCEP/NCAR	1948-present	3D-VAR	T62 L28	2.5x2.5 and 2x2 gaussian	2.5x2.5 and 2x2 gaussian
NCEP North American Regional Reanalysis (NARR)	NCEP	1979-present	RDAS	32km	32km	32km
NOAA-CIRES 20th Century Reanalysis (20CR)	NOAA/ESRL PSD	1871-2008	Ensemble Kalman Filter	T62 L28	2x2	2x2

Comparing Reanalysis Data

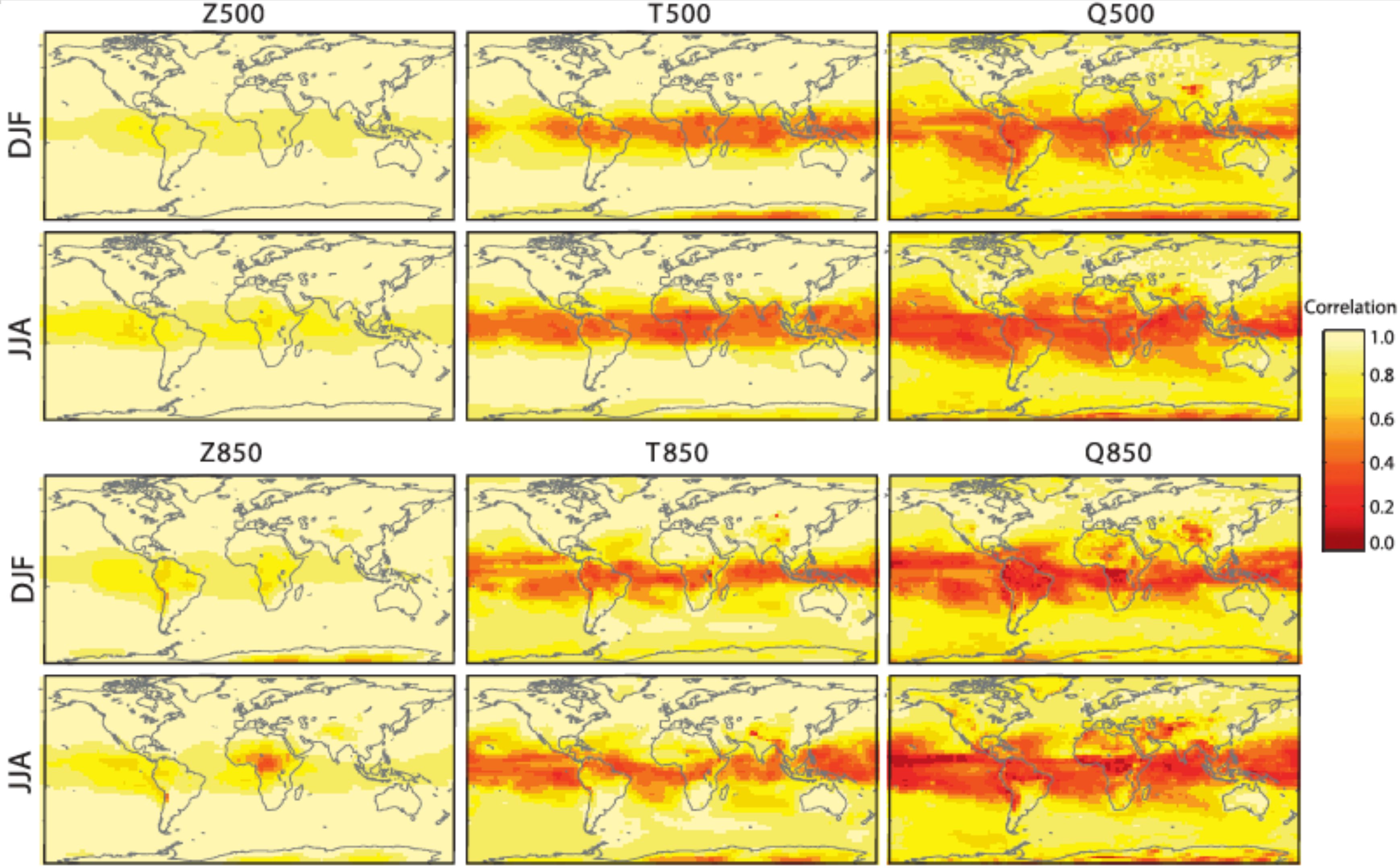
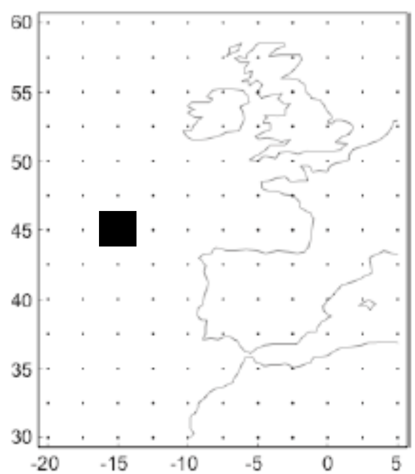


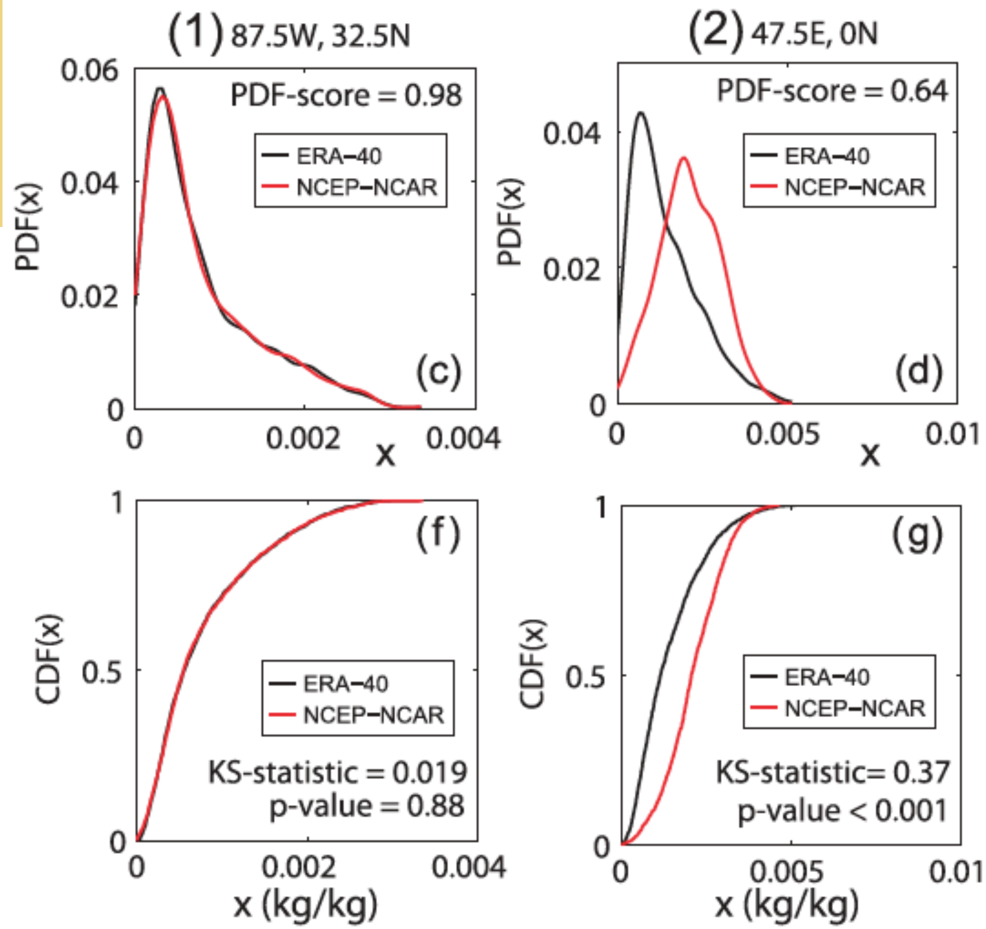
FIG. 5. Maps of consistency for the day-to-day sequence of the daily time series of ERA-40 and NCEP–NCAR Z, T, and Q at (top) 500 and (bottom) 850 hPa, as revealed by the Pearson correlation coefficient. Color darkening from yellow to black indicates increasing dissimilarity.

Comparing the distributional similarity (at a daily grid-box basis) between ERA40 and NCEP for typical predictors using both the classical Kolmogorov-Smirnov (KS) test and the more recent PDF-score.

$$\text{PDF-score} = \sum_{i=1}^{N} \min\{f(m_i), g(m_i)\}.$$

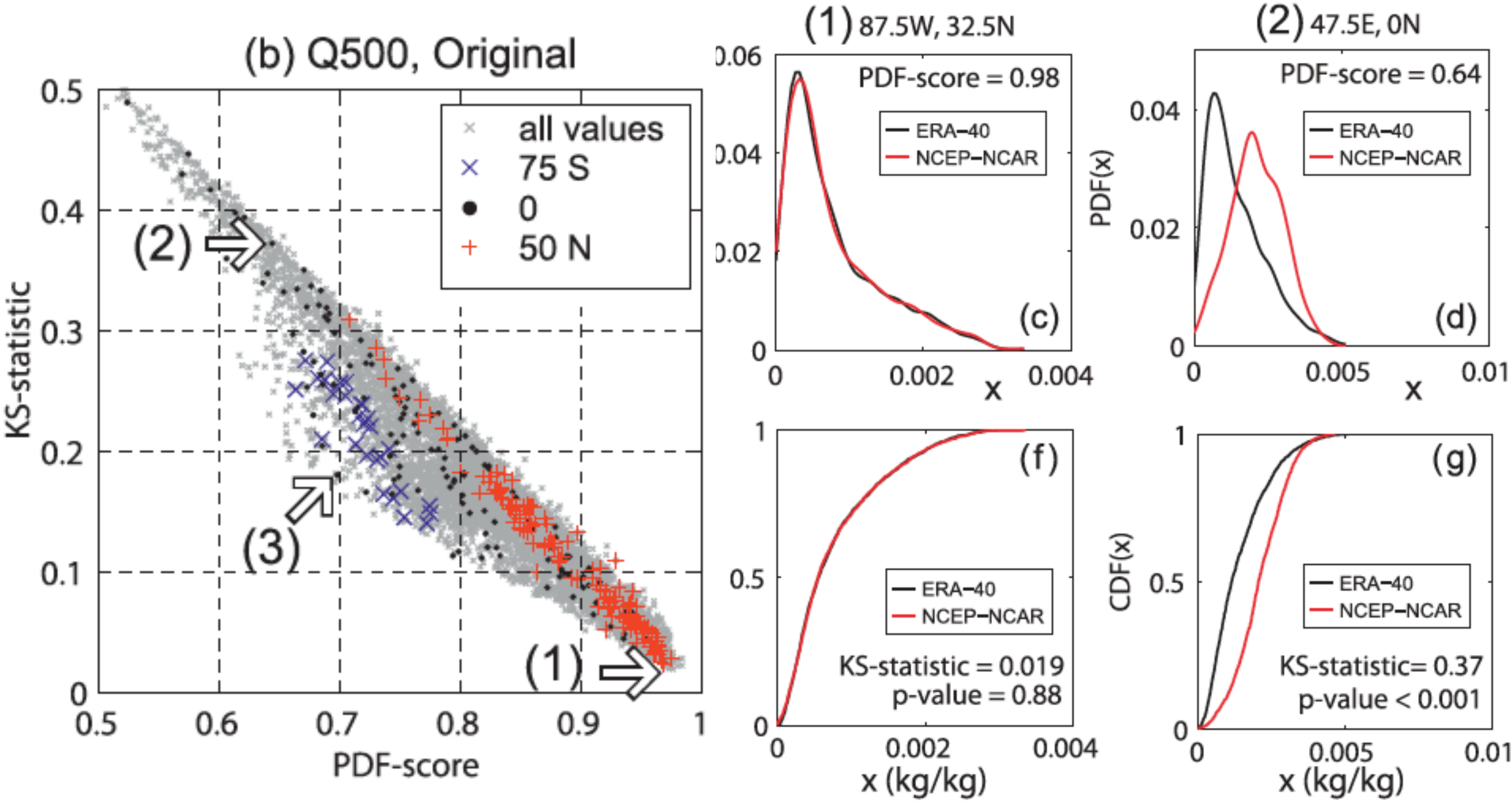
$$\text{KS-statistic} = \max_{i=1}^{2n} |F(z_i) - G(z_i)|,$$





KS-test was found to be more appropriate. They both provide similar results.

Assessing GCM Data: Reanalysis



ERA40 vs. NCEP

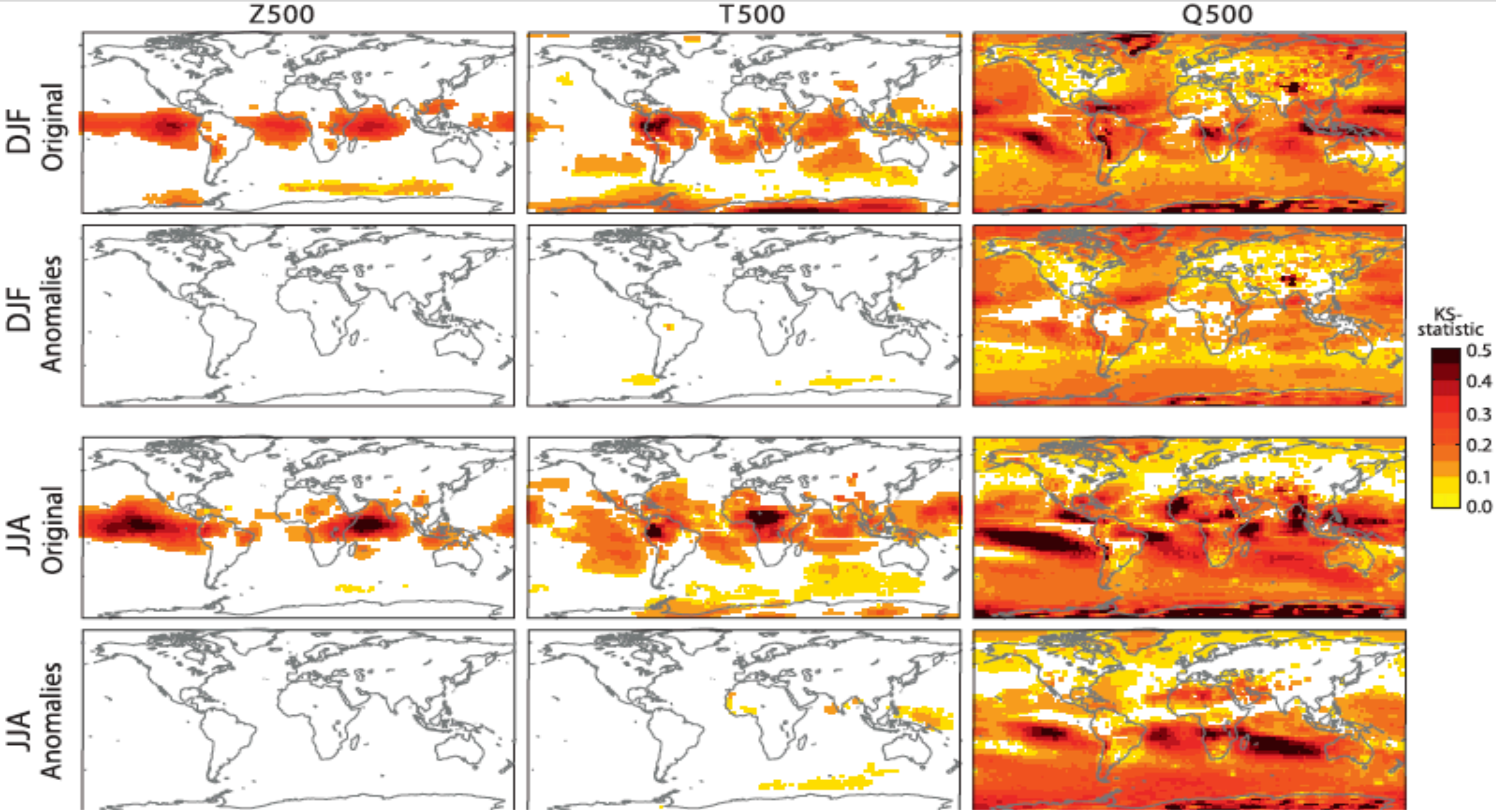


FIG. 3. Maps of distributional similarity for the daily time series of ERA-40 and NCEP–NCAR Z, T, and Q at (top) 500 and (bottom) 850 hPa, as revealed by the KS statistic. Color darkening from yellow to black indicates increasing dissimilarity. If the H_0 values of equal distributions cannot be rejected at a test level of 5%, the grid box is whitened and the distributional similarity is assumed to be optimal. Results are presented for both the original and anomaly data.

ERA40 vs. NCEP

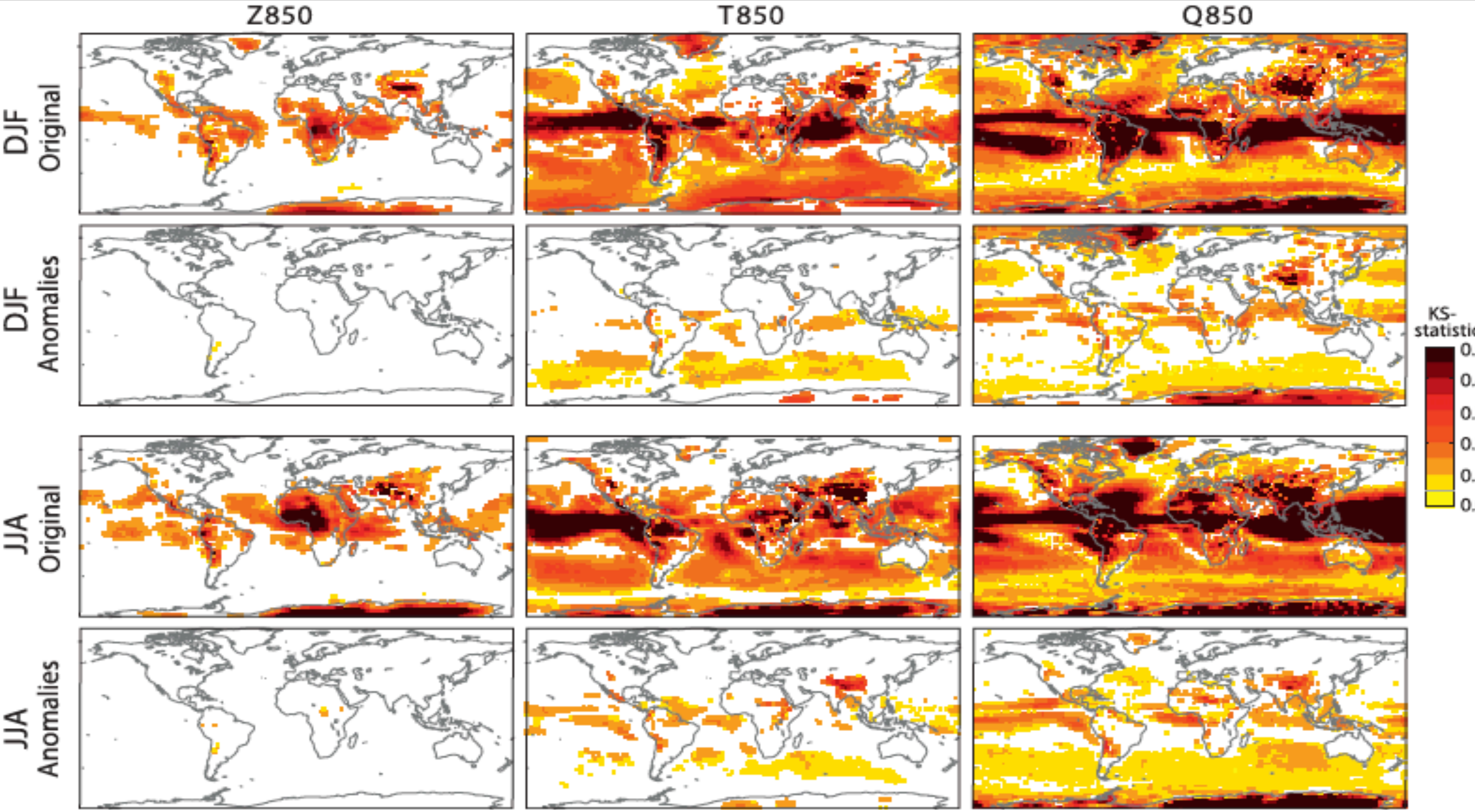


FIG. 3. Maps of distributional similarity for the daily time series of ERA-40 and NCEP–NCAR *Z*, *T*, and *Q* at (top) 500 and (bottom) 850 hPa, as revealed by the KS statistic. Color darkening from yellow to black indicates increasing dissimilarity. If the H_0 values of equal distributions cannot be rejected at a test level of 5%, the grid box is whitened and the distributional similarity is assumed to be optimal. Results are presented for both the original and anomaly data.

Assessing GCM Data: CMIP3 + ENSEMBLES

Typical downscaling predictors:

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CLIMATE RESEARCH
Clim Res
Published August 30

Contribution to CR Special 27 'Climate change in the NW Iberian Peninsula'

OPEN ACCESS

Validation of the ENSEMBLES global climate models over southwestern Europe using probability density functions, from a downscaling perspective

S. Brands*, S. Herrera, D. San-Martín, J. M. Gutiérrez

Instituto de Física de Cantabria (CSIC – Universidad de Cantabria), 39005 Santander, Spain

MSLP
2T

U,V
Z
T
Q, R
500,850mb

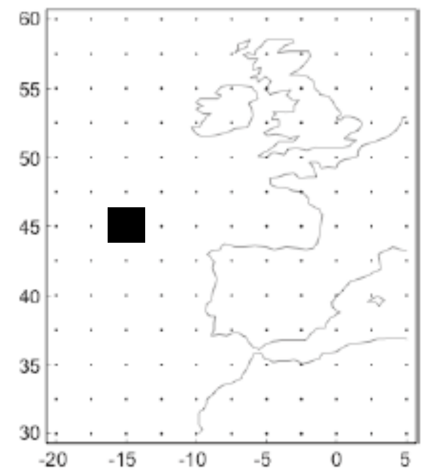
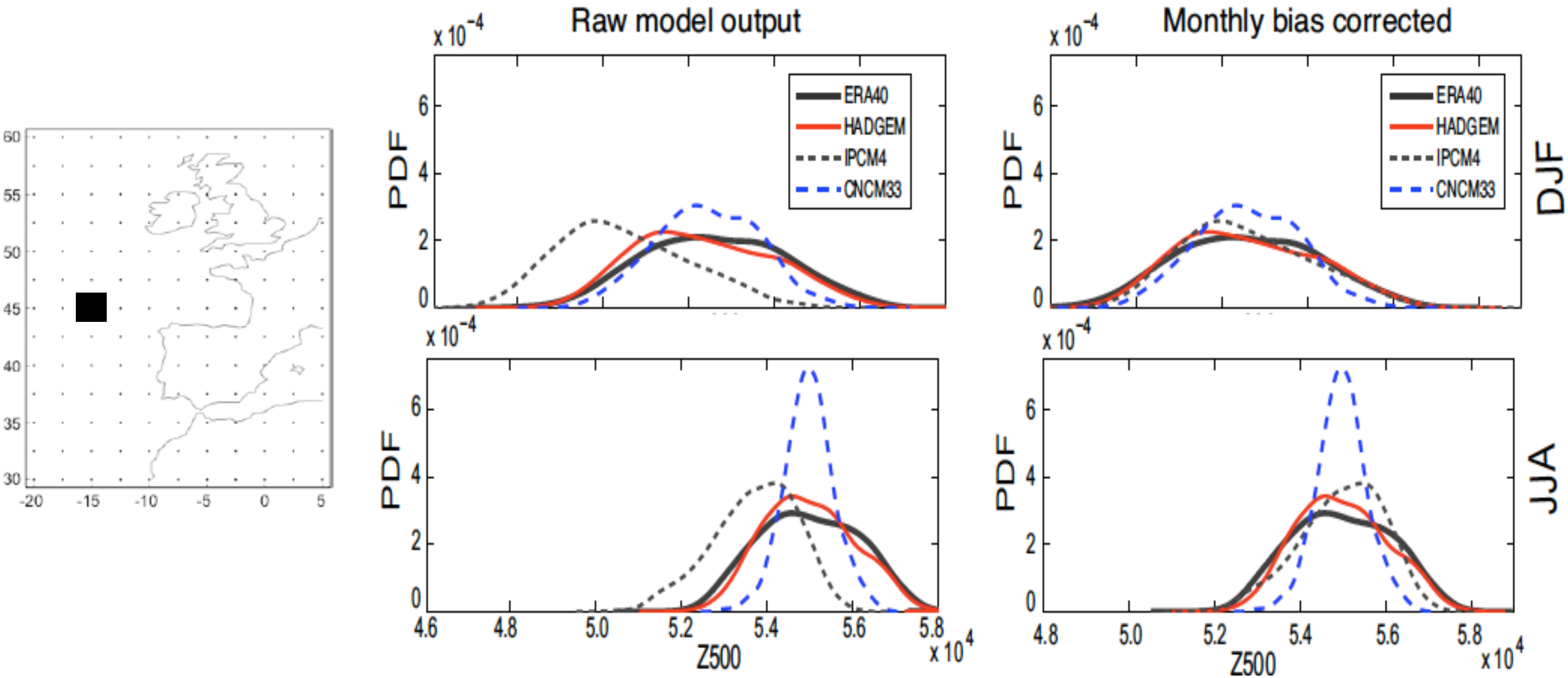


Table 2. Overview of the global climate models (GCMs) used in the present study, taken from the 2 streams of the ENSEMBLES project. Stream 1: model versions from the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC-AR4); Stream 2: new versions developed within the ENSEMBLES project

GCM name	Acronym	Stream	Institution	Source
BCCR-BCM2	BCM2	1	Bjerknes Centre for Climate Research, Norway	Drange (2006)
CNRM-CM3	CNCM3	1	Centre National de Recherches Météorologiques, France	Royer (2006)
ECHO-G	EGMAM	1	Freie Universität Berlin, Germany	Niehörster (2008)
IPSL-CM4	IPCM4	1	Institut Pierre Simon Laplace, France	Dufresne (2007)
METO-HC-HadGEM	HADGEM	1	Met Office Hadley Centre, UK	Johns (2008)
MPI-ECHAM5	MPEH5	1	Max Planck Institute for Meteorology, Germany	Roeckner (2007)
CNRM-CM33	CNCM33	2	Centre National de Recherches Météorologiques, France	Royer (2008)
ECHO-G2	EGMAM2	2	Freie Universität Berlin, Germany	Huebener & Koerper (2008)
IPSL-CM4v2	IPCM4V2	2	Institut Pierre Simon Laplace, France	Dufresne (2009)
METO-HC-HadCM3C	HADCM3C	2	Met Office Hadley Centre, UK	Johns (2009a)
METO-HC-HadGEM2	HADGEM2	2	Met Office Hadley Centre, UK	Johns (2009b)
MPI-ECHAM5C	MPEH5C	2	Max Planck Institute for Meteorology, Germany	Roeckner (2008)

Since the SD methods are trained with reanalysis data and later applied to GCM data, the predictors should at least satisfy that they have “similar” distributions for both reanalysis and GCMs.



- Tests for distributions (e.g. **KS-test**) or similarity scores (**PDF-score**).

Climate Dynamics manuscript No.
(will be inserted by the editor)

How well do CMIP5 Earth System Models simulate present climate conditions in Europe and Africa?

A performance comparison for the downscaling community

S. Brands · S. Herrera · J. Fernández ·
J.M. Gutiérrez

Received: date / Accepted: date

Abstract This study provides a comprehensive evaluation of seven Earth System Models (ESMs) from the Coupled Model Intercomparison Project Phase 5 in present climate conditions from a downscaling perspective, taking into account the requirements of both statistical and dynamical approaches. ECMWF's ERA-

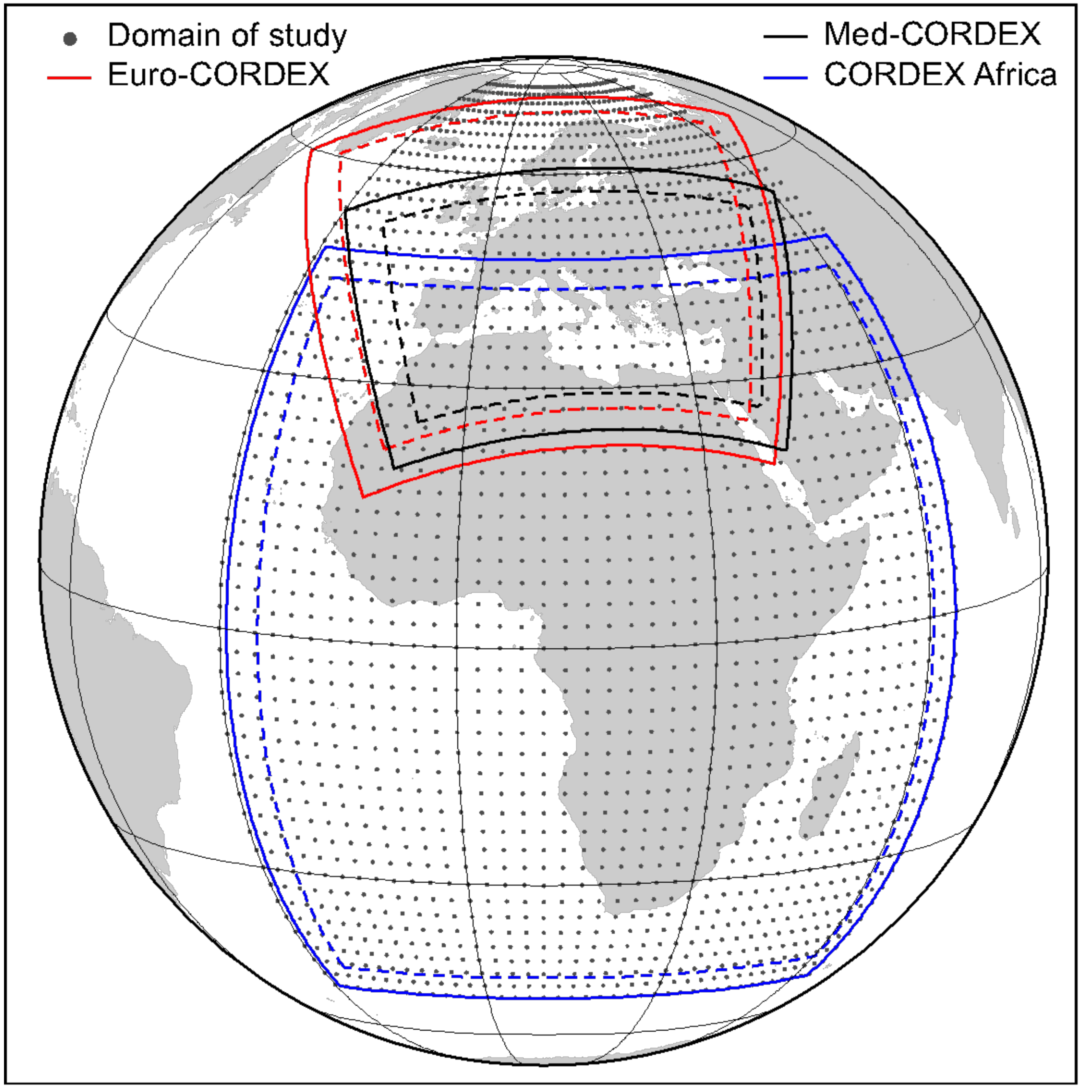
CMIP5 Earth System Models considered in this study

Model	Hor. Resolution	Reference
CanESM2	$2.8 * 2.8°$	Chylek et al (2011)
CNRM-CM5	$1.4 * 1.4°$	Voldoire et al (2011)
HadGEM2-ES	$1.875 * 1.25°$	Collins et al (2011)
IPSL-CM5-MR	$1.5 * 1.27°$	Dufresne et al (submitted)
MIROC-ESM	$2.8 * 2.8°$	Watanabe et al (2011)
MPI-ESM-LR	$1.8 * 1.8°$	Raddatz et al (2007); Jungclaus et al (2010)
NorESM1-M	$1.5 * 1.9°$	Kirkevag et al (2008); Seland et al (2008)

Table 2 Variables considered in this study.

Code	Name	Height	Unit
Z	Geopotential	500hPa	$m^2 s^{-2}$
T	Temperature	2m, 850hPa	K
Q	Specific humidity	850hPa	$kg\,kg^{-1}$
U	U-wind	850hPa	$m\,s^{-1}$
V	V-wind	850hPa	$m\,s^{-1}$
SLP	Sea-level pressure	mean sea-level	Pa

EuroAfrica Domains



For statistical downscaling:

Grid-box scale validation for a large domain covering the western Old World

For dynamical downscaling:

Validation along the lateral boundaries used in:

->EURO-Cordex
->MED-Cordex
->Cordex Africa

vs

JRA-25 → Reference for validation: **ERA-Interim** ← CMIP5 Earth System Models (ESMs)

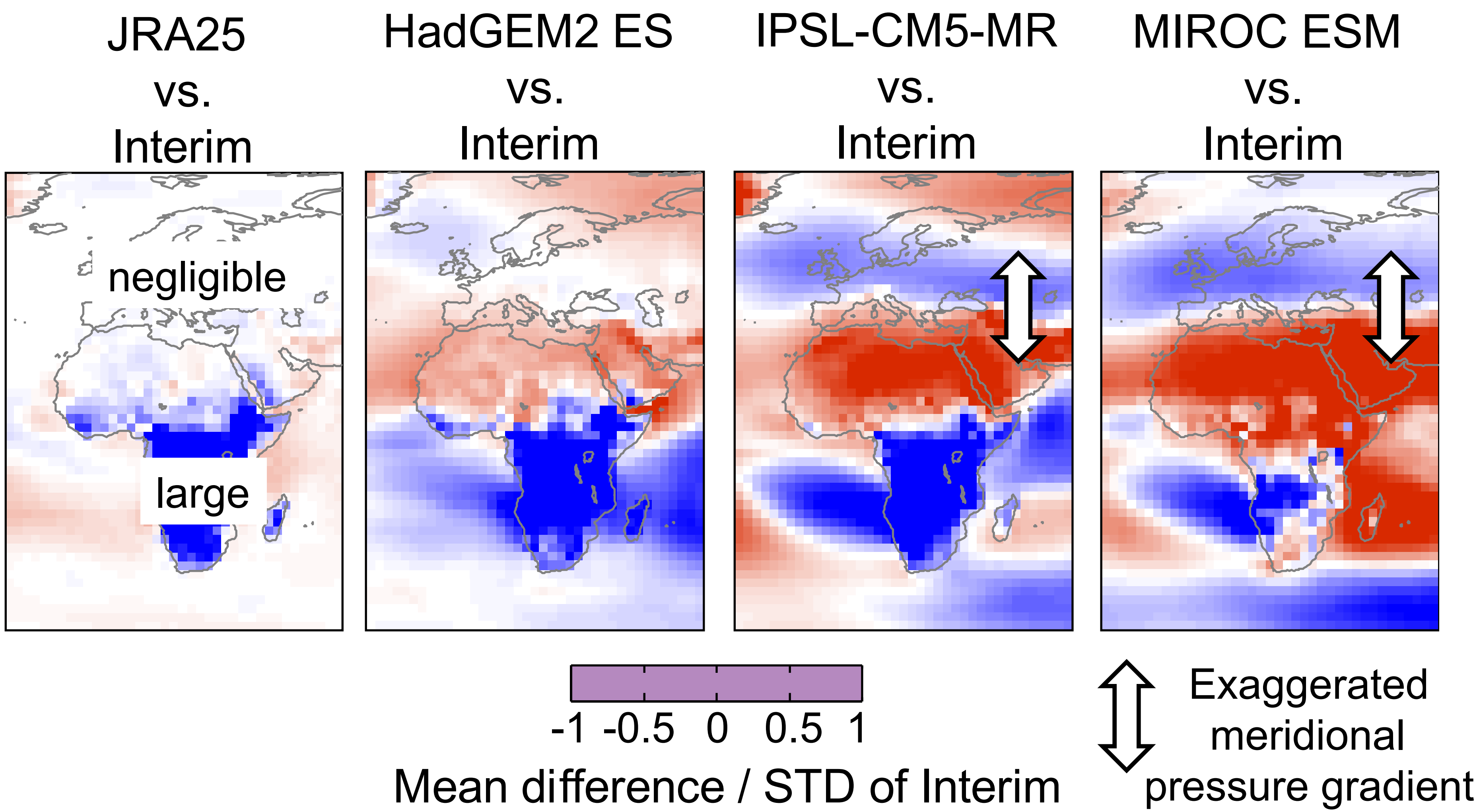
=
Observational uncertainty

<

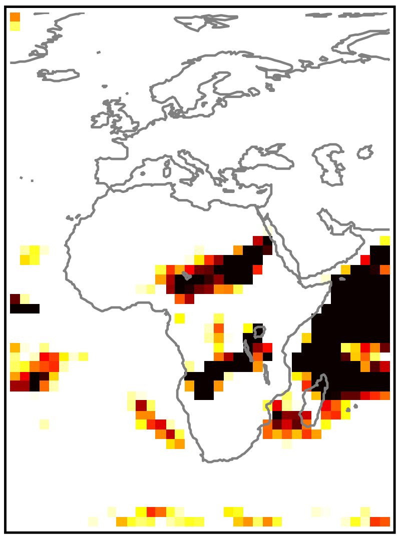
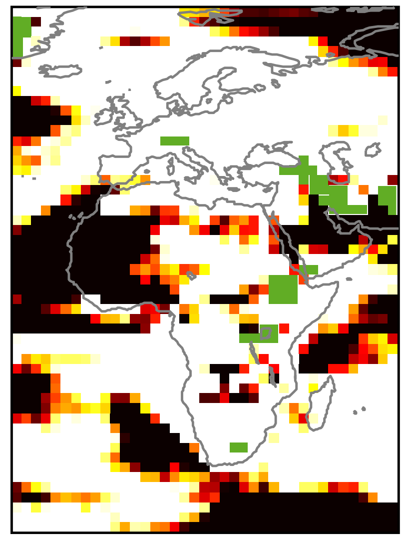
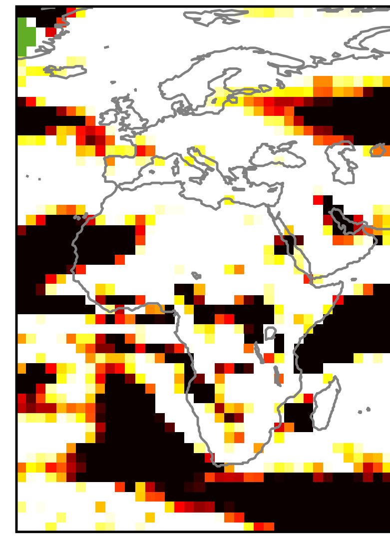
=
GCM/ESM error

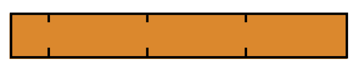
?

Bias/std for SLP in DJF



KS test (Q850)
Zero-mean data

JRA25 vs. Interim	HadGEM2 ES vs. Interim	IPSL-CM5-MR vs. Interim	MIROC ESM vs. Interim
	Variable not available at ESG Portals		



P-value of the KS-statistic (log scale)

Green boxes indicate lack of data at ESG portals!

Median of the absolute bias/std values along the lateral boundaries of 3 CORDEX-domains for SLP in all seasons