

Modelling of the Mediterranean climate system and climate projections



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BACKGROUND & MOTIVATION

Outcomes of the work performed in the framework of the CIRCE EU Project



CHANGING CLIMATE, ADAPTING WORLD
CIRCE Climate Change and Impact Research: the Mediterranean Environment

CIRCE
Climate Change and Impact Research:
The Mediterranean Environment



Circe



EVALUATING THE EHT G IMPACTS OF CLIMATE E CHANGE IN THE EHT MEDITERRANEAN REGION



health



tourism



energy demand



human migration



III SFM
MFW

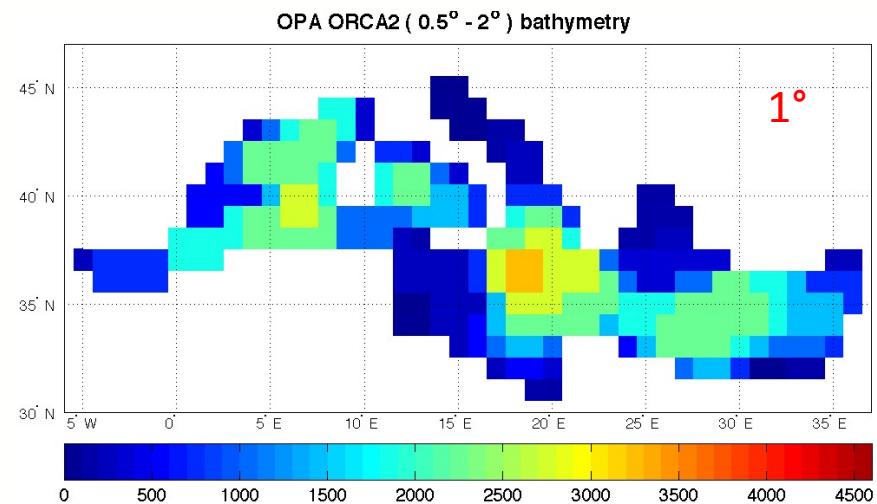
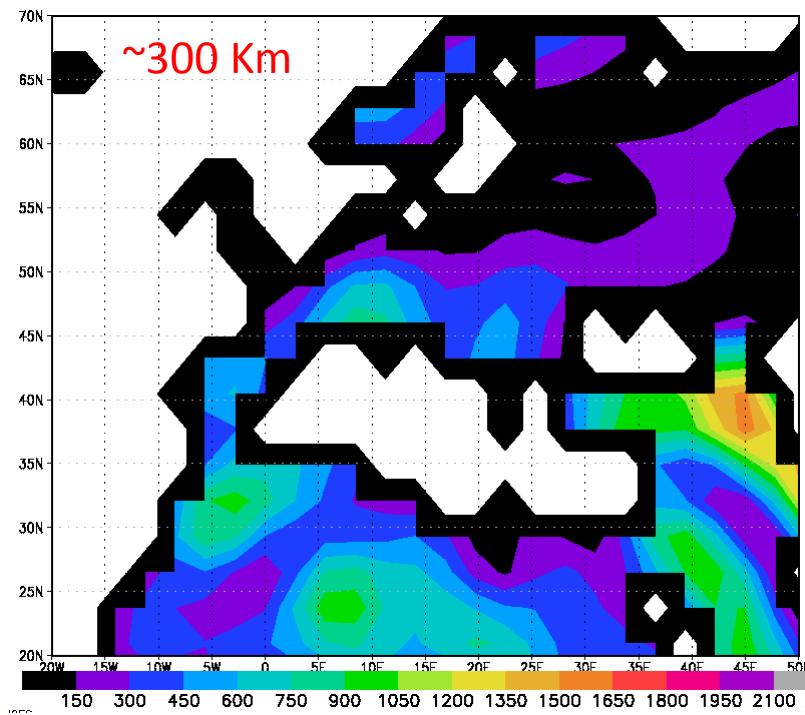
17-21 mars
march

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BACKGROUND & MOTIVATION

State of the art (CMIP3) coupled models are inadequate to resolve the dynamical features of the Euro-Mediterranean region

Orography, Land-Sea mask and Mediterranean Sea bathymetry in many CMIP3 model



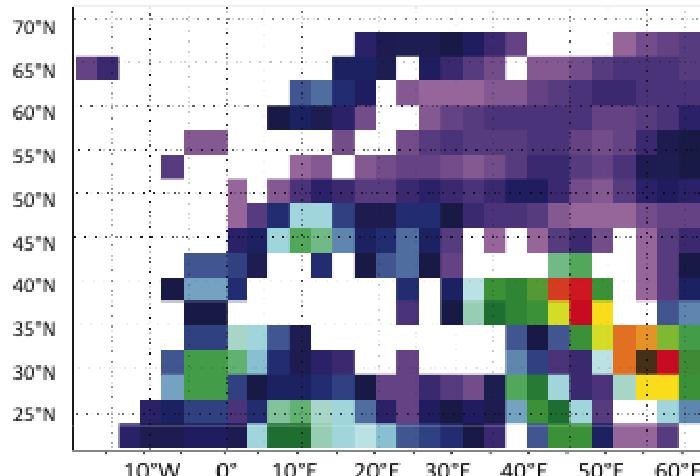
High-resolution atmospheric regional models (e.g. ENSEMBLES) do not include air-sea feedbacks, thus no coherence between SST, surface fluxes and atmospheric column (e.g. Sanchez-Gomez et al. 2011)

BACKGROUND & MOTIVATION

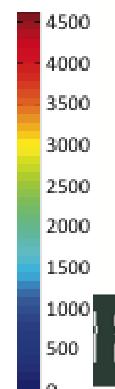
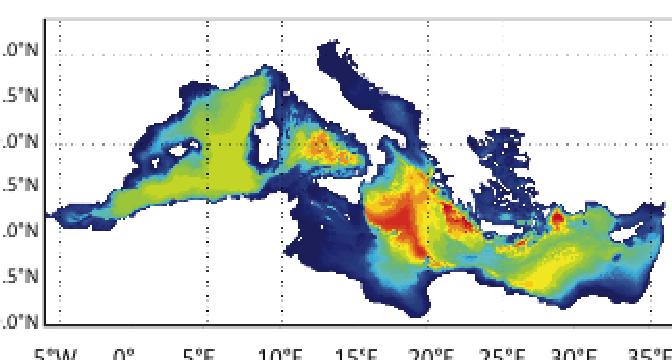
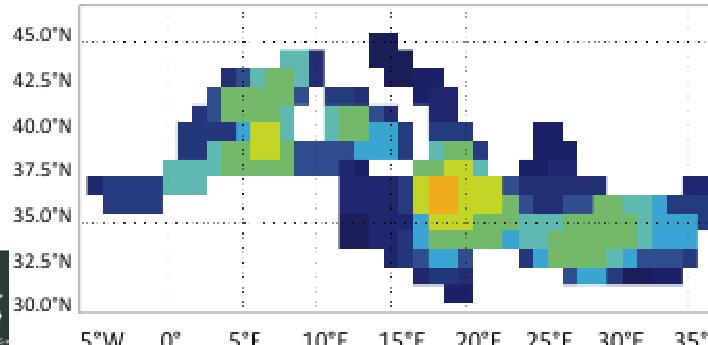
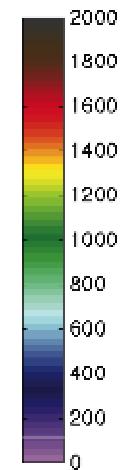
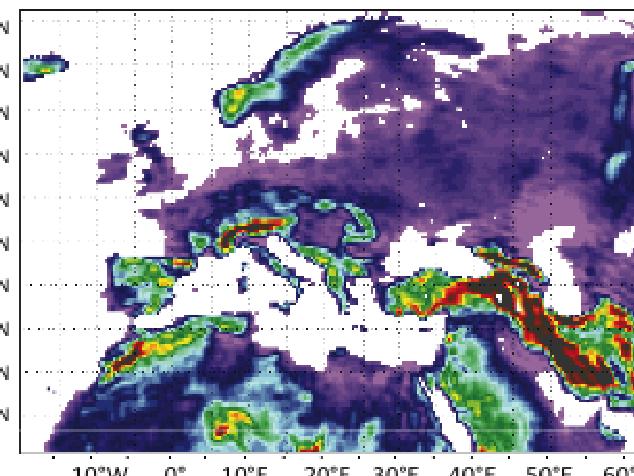
Need to perform new and more advanced climate simulations specific for the Mediterranean Region

1. Better resolved small-scale feature of the basin (orography land-sea contrast)

CMIP3

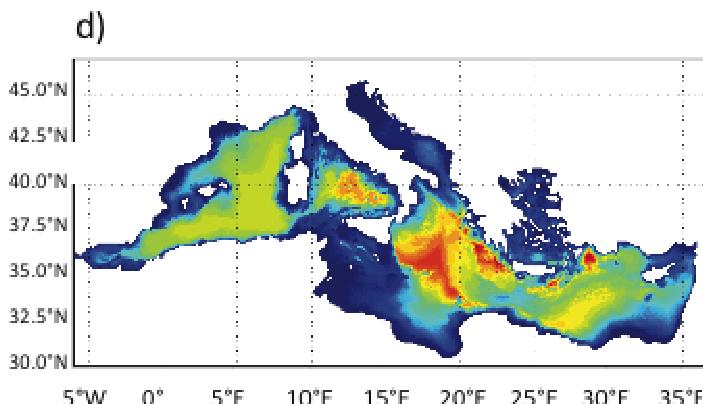
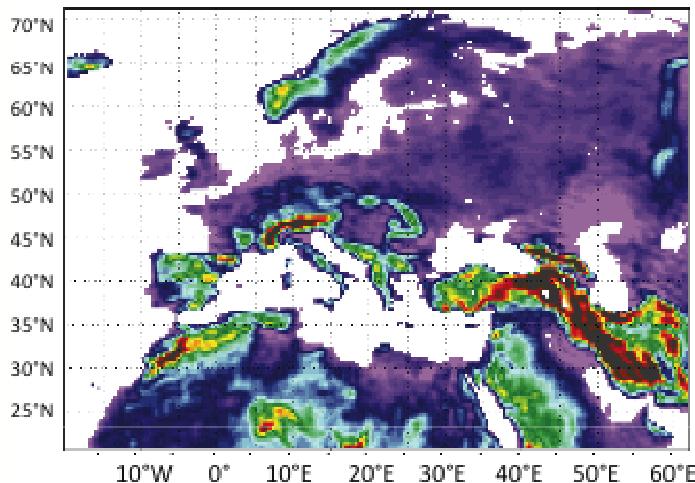


CIRCE



BACKGROUND & MOTIVATION

Need to perform new and more advanced climate simulations specific for the Mediterranean Region



2. Improved representation of the air-sea feedbacks

- Improve the representation of the small-scale processes and features of the observed climate
- Improve the surface fluxes over the Mediterranean Sea
- Improve the representation of the Mediterranean-Atlantic interaction (Gibraltar)

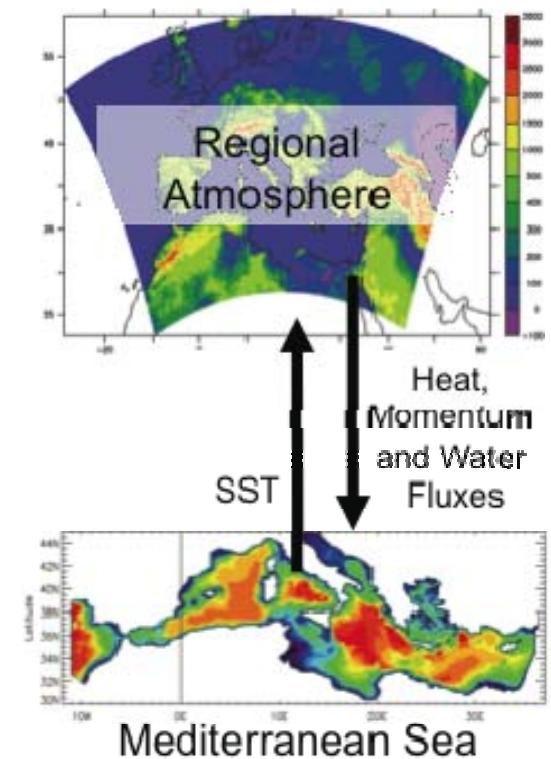
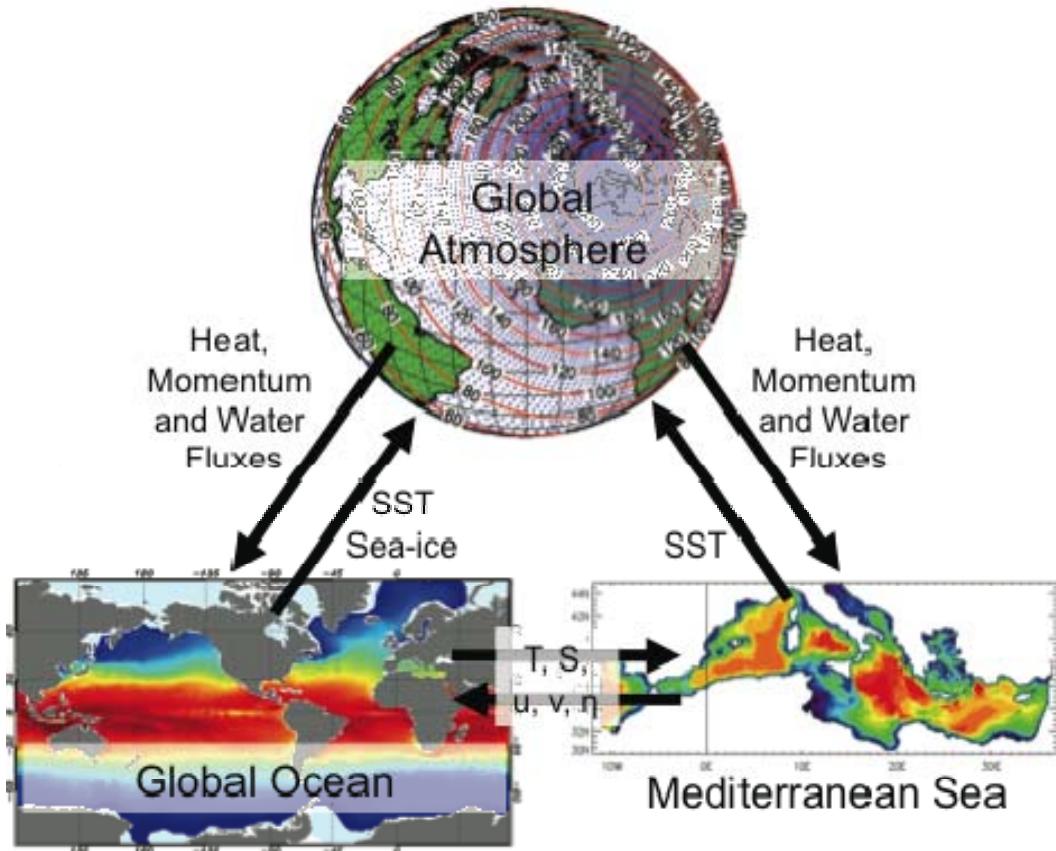


APPROACH & METHODS

The CIRCE models

In order to reach these objectives two modelling approaches:

1. Global models with a well-resolved and interactive Mediterranean Sea
2. Regional coupled models



APPROACH & METHODS

The CIRCE models

Model	Atmosphere component	Global Ocean Component	Med. Sea Component	Gibraltar and lateral Boundary Conditions	Rivers and Black Sea
CMCC (INGV) Scoccimarro et al. 2011	ECHAM5 80km L31	OPA8.2- ORCA2 ~2°x2°(0.5°) L31	NEMO-MFS 1/16° L71 Oddo et al 2009	Fluxes exchanged between global ocean and Med Sea. Med. outflow distributed over upper 300m in global ocean grid point near Gibraltar	TRIP river scheme (Nile runoff corrected to observations after 1968). Black Sea input from the E-P-R flux (Oki and Sud 1998)
LMD (IPSL) Zou et al. 2010	LMDZ glob + LMDZ reg 300km L19 + 30km L19	OPA9- ORCA2 ~2°x2°(0.5°) L31	NEMO-MED 1/8° L43 Beuvier et al. 2010	Tracer profile and fluxes exchanged using Cross-Land Advection parametrization and buffer zone	Climatological river discharge (Ludwig et al. 2009)
CNRM (MF-CNRM) Somot et al. 2008	ARPEGE-Climate T159 L31 Stretched model: 50km in Med. Area	OPA9- ORCA2 ~2°x2°(0.5°) L31	NEMO-MED 1/8° L43 Beuvier et al. 2010	Tracer profile and fluxes exchanged using Cross-Land Advection parametrization and buffer zone.	Climatological river discharge (Ludwig et al. 2009)
PROTHEUS (ENEA) Artale et al. 2010	REG-CM3 30km L19	/	MIT-gcm 1/8° L42 Sannino et al. 2009	Atlantic buffer zone. Lateral boundaries from ECHAM5/MPI-OM (Giorgetta et al. 2006)	IRIS river scheme. Instantaneous runoff to the river mouth. . Black Sea input from the E-P-R bias corrected.
MPI (MPI-HH) Elizalde 2011	REMO 25km L31	/	MPI-OM 9km L29 Elizalde et al. 2010	Atlantic buffer zone. Lateral boundaries from CMCC (Scoccimarro et al.	Interactive hydrological model and Black Sea model (Hagemann and

APPROACH & METHODS

The CIRCE simulations

- **Initial conditions:** ocean mean state obtained from Levitus or MedAtlas-II
- **Spin-up:** long integration performed with the observed 1950s (permanent) conditions (radiative forcing)
- **Integration 1951-2000:** radiative forcing (GHGs and aerosol) prescribed according to observations (CMIP3)
- **projection 2001-2050:** radiative forcing (GHGs and aerosol) prescribed according to the **A1B AR4-SRES** (CMIP3)



APPROACH & METHODS

Data for validation and comparison:

- **Observations and analyses of the Mediterranean Sea**

(e.g. SST Adani et al. 2011, Surface Fluxes Pettenuzzo et al. 2010 , Sanchez-Gomez et al. 2011, in situ measurements Be'thoux 1979; Bunker et al. 1982; McDonald et al. 1994)

- **CRU precipitation and T2m temperature (land)**

- **CMIP3 simulations**

CMIP3 model name	Centre	Atmospheric resolution	Oceanic resolution	
BCCR-BCM2.0	BCCR (Norway)	2.81° x 2.81°	L31	1.5°x(1.5° - 0.5°)
CNRM-CM3	CNRM (France)	2.81° x 2.81°	L45	2°x(1.5° - 0.5°)
CSIRO-Mk3.5	CSIRO (Australia)	1.88° x 1.88°	L18	1.88° x 0.84°
GFDL-CM2.1	GFDL (USA)	2.5° x 2°	L24	1°x(1° - 0.33°)
FGOALS-g1.0	IAP (China)	2.81° x 2.81°	L26	1°x(1° - 0.33°)
IPSL-CM4	IPSL (France)	3.75° x 2.5°	L19	2°x(1.5° - 0.5°)
MIROC3.2(hires),	FRCGC (Japan)	1.1° x 1.1°	L56	0.28° x 0.19°
ECHAM5/MPI-OM	MPI (Germany)	1.88° x 1.88°	L31	1.5° x 1.5°
CCSM3	NCAR (USA)	1.4° x 1.4°	L26	1°x(1.1° - 0.27°)
HADCM3	Hadley Centre (UK)	3.75° x 2.5°	L38	1.25° x 1.25°

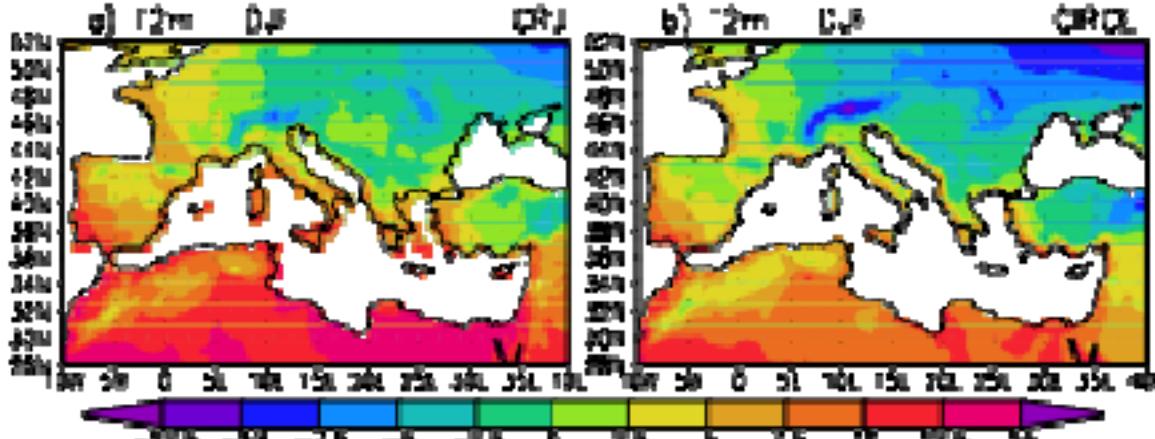


RESULTS: PRESENT CLIMATE (1961-1990)

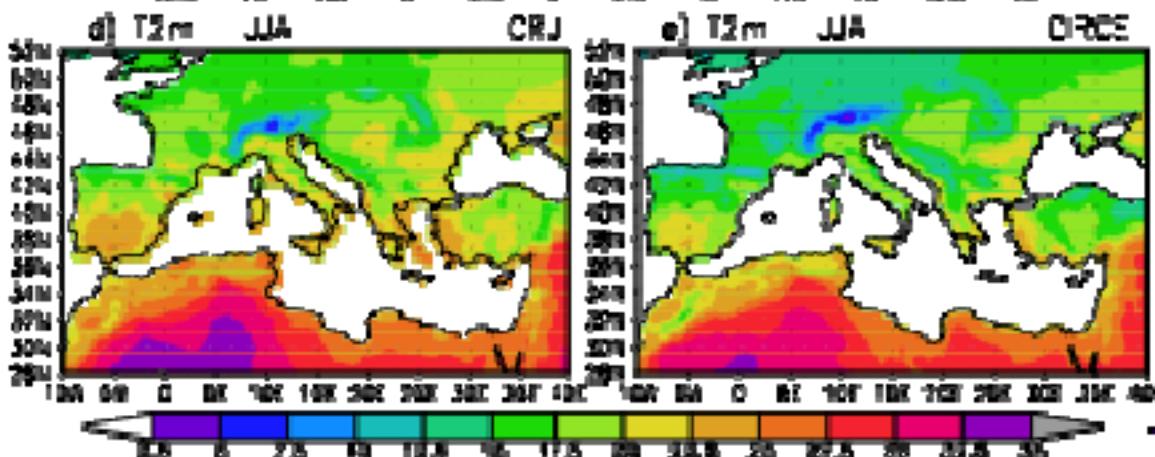
Systematic error in the CIRCE simulations

Near-surface Temperature

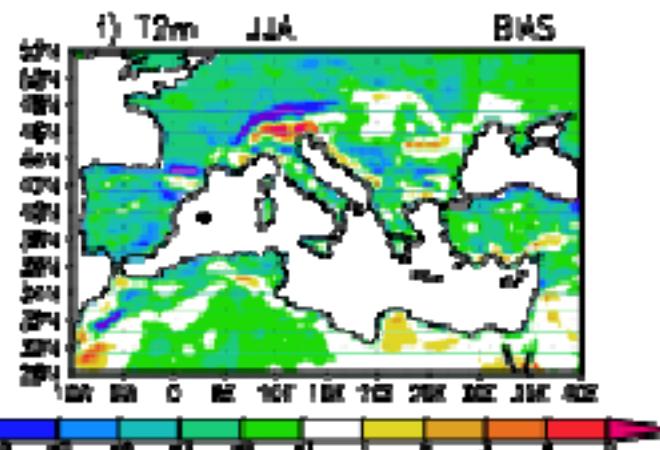
OBSERVATIONS



CIRCE MULTI-MODEL MEAN



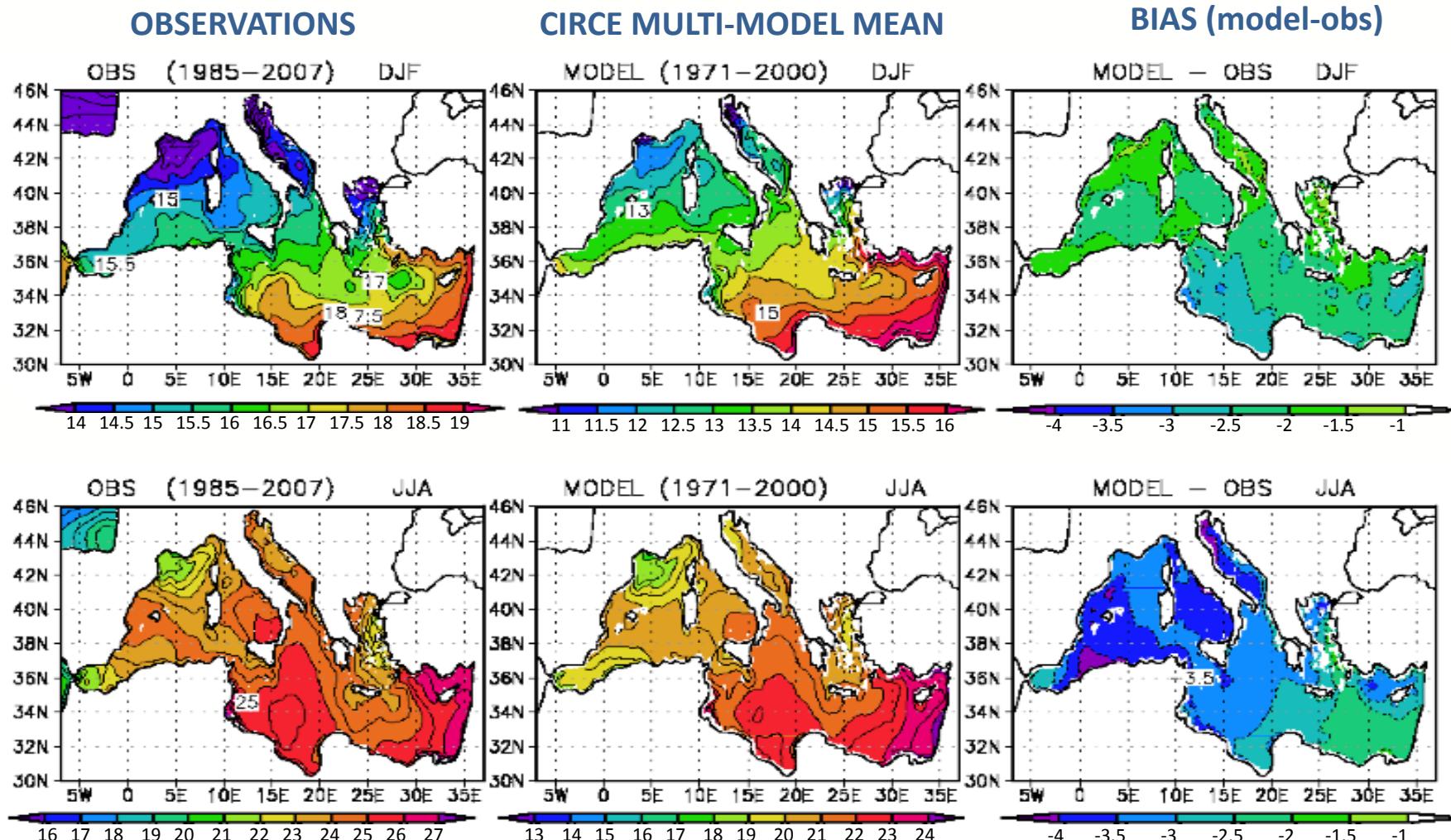
BIAS (model-obs)



RESULTS: PRESENT CLIMATE (1961-1990)

Systematic error in the CIRCE simulations

Sea-surface Temperature

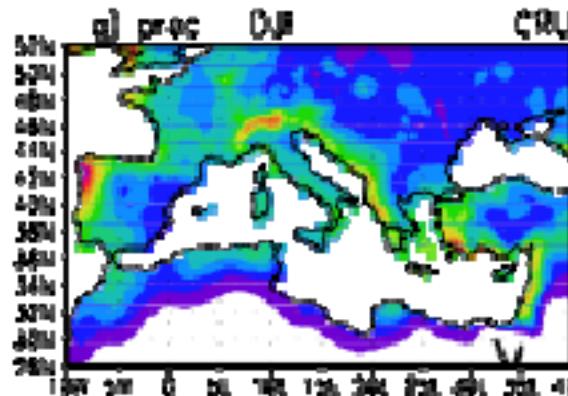


RESULTS: PRESENT CLIMATE (1961-1990)

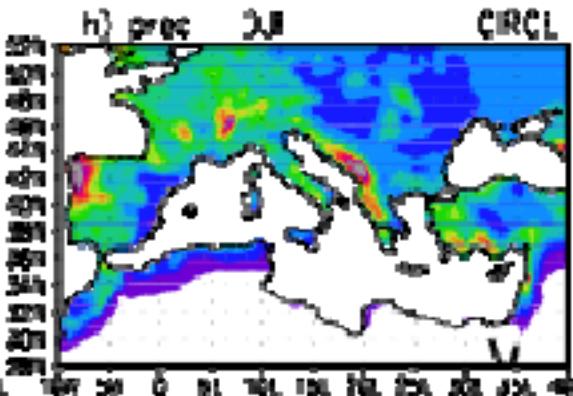
Systematic error in the CIRCE simulations

Precipitation

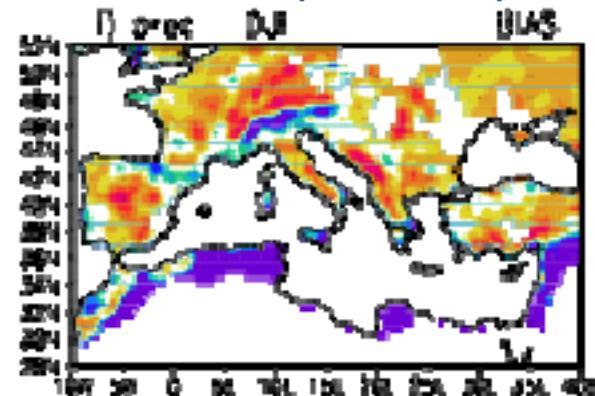
OBSERVATIONS



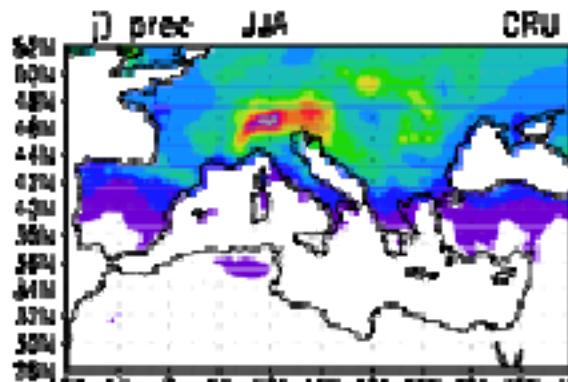
CIRCE MULTI-MODEL MEAN



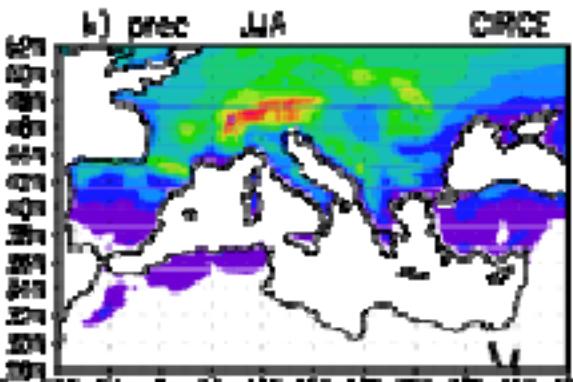
BIAS (model-obs)



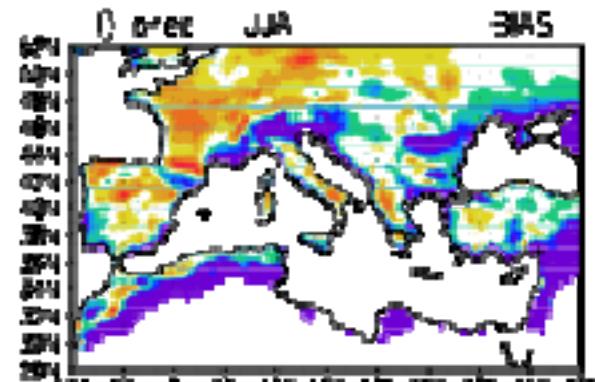
d) prec JJA CRU



e) prec JJA CIRCE



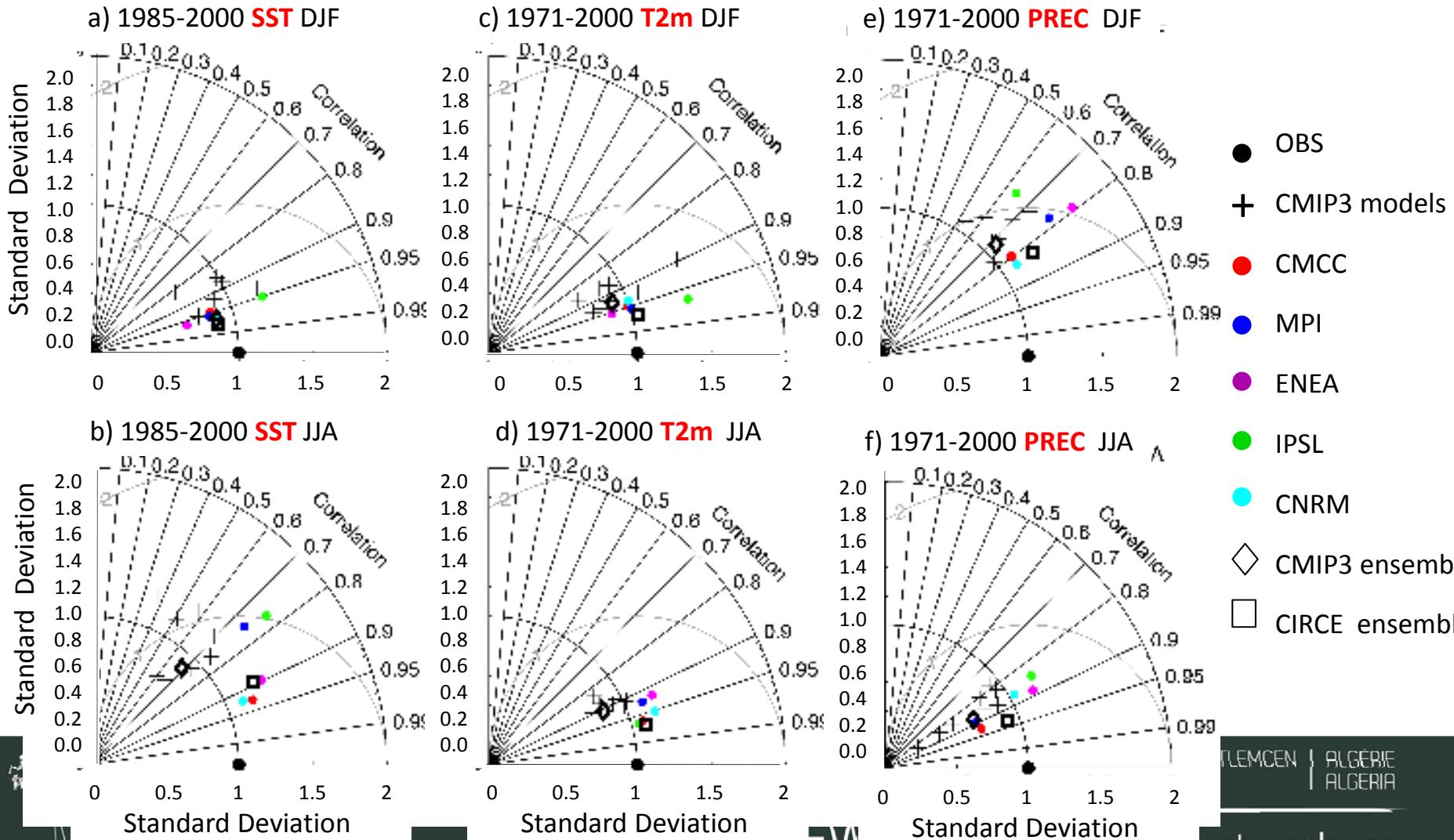
f) prec JJA BIAS



RESULTS: PRESENT CLIMATE

CMIP3 vs CIRCE simulations

Taylor diagrams of the SST, T2m and PREC seasonal means

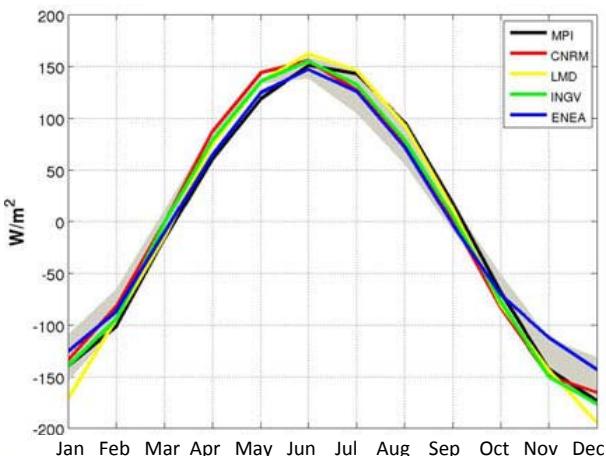


RESULTS: PRESENT CLIMATE (1961-1990)

Mediterranean Sea Heat Budget in the CIRCE simulations

mean seasonal cycle

Surface Heat Budget



shading = observational data sets

	HB	SW	LW	SH	LH	G
OBS1	-7	178	-79	-14	-92	-
OBS2	-1 ± 8	187 ± 3	-84 ± 1	-14 ± 2	-90 ± 7	-
OBS3	-	-	-	-	-	3-10
CIRCE ENS MEAN	-3.8 ± 2.2	182.0 ± 1.7	-82.3 ± 0.5	-13.6 ± 0.7	-89.9 ± 1.3	1.78 ± 1.6
ENEA	-1.7 ± 1.7	192.7 ± 1.8	-80.2 ± 0.9	-16.3 ± 0.6	-97.9 ± 0.9	-6.3 ± 0.9
CMCC	-4.7 ± 1.7	172.4 ± 0.7	-81.6 ± 0.5	-11.5 ± 0.6	-84.0 ± 1.2	4.4 ± 2.5
MPI	-4.0 ± 2.1	150.0 ± 0.9	-66.3 ± 0.4	-9.1 ± 0.5	-78.4 ± 1.5	4.0 ± 1.1
CNRM	-2.2 ± 2.8	190.7 ± 1.0	-87.5 ± 0.3	-12.6 ± 1.0	-92.7 ± 1.6	2.3 ± 1.3
LMDglo	-6.4 ± 2.5	204.4 ± 0.9	-95.8 ± 0.6	-18.6 ± 1.0	-96.4 ± 1.3	4.5 ± 2.2

OBS1 from Pettenuzzo et al. (2010) - 1958–2001

OBS2 from Sanchez-Gomez et al. (2011)

OBS3 from in situ measurements (Be'thoux 1979; Bunker et al. 1982; McDonald et al. 1994)

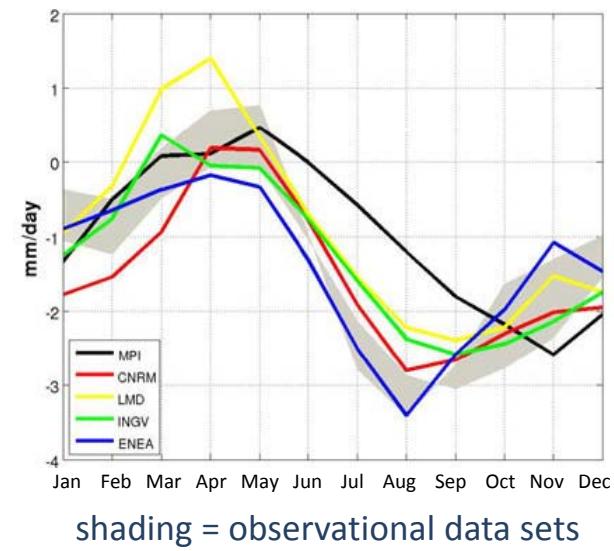
modified from Dubois et al. 2012

RESULTS: PRESENT CLIMATE (1961-1990)

Mediterranean Sea Water Budget in the CIRCE simulations

mean seasonal cycle

Water Budget



mean value (\pm std) mm/day

	WB	P	E	R	B	G
OBS1	-	1.4	3.2	-	-	-
OBS2	-1.7	0.7	3.1	0.4	0.3	-
OBS3	-	-	-	0.28	-	1.3-3.2
CIRCE ENS MEAN	-1.2 ± 0.2	1.0 ± 0.1	3.1 ± 0.1	0.4 ± 0.1	0.5 ± 0.1	1.3 ± 1.3
ENEA	-1.5 ± 0.3	1.1 ± 0.1	3.4 ± 0.1	0.4 ± 0.1	0.4 ± 0.1	1.5 ± 1.2
CMCC	-1.4 ± 0.2	0.9 ± 0.1	2.9 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	1.3 ± 3.3
MPI	-0.9 ± 0.2	1.0 ± 0.1	2.7 ± 0.1	0.3 ± 0.1	0.5 ± 0.1	0.4 ± 0.6
CNRM	-1.5 ± 0.2	1.2 ± 0.1	3.2 ± 0.1	0.3 ± 0.1	0.2 ± 0.1	1.5 ± 0.7
LMDglo	-0.5 ± 0.2	1.0 ± 0.1	3.3 ± 0.1	0.6 ± 0.1	1.2 ± 0.1	1.8 ± 0.9

OBS1 from Pettenuzzo et al. (2010) - 1958–2001

OBS2 from Sanchez-Gomez et al. (2011)

OBS3 from Struglia et al. (2004) and from in situ measurements (Garcia Lafuente et al. 2007; Soto-Navarro et al. 2010)

modified from Dubois et al. 2012

RESULTS: PRESENT CLIMATE

Summary I:

When compared with the CMIP3 simulations the CIRCE models show **some (small) improvement** in reproducing the seasonal means of T2m, SST and precipitation

However, the CIRCE simulations still show **significant systematic errors**

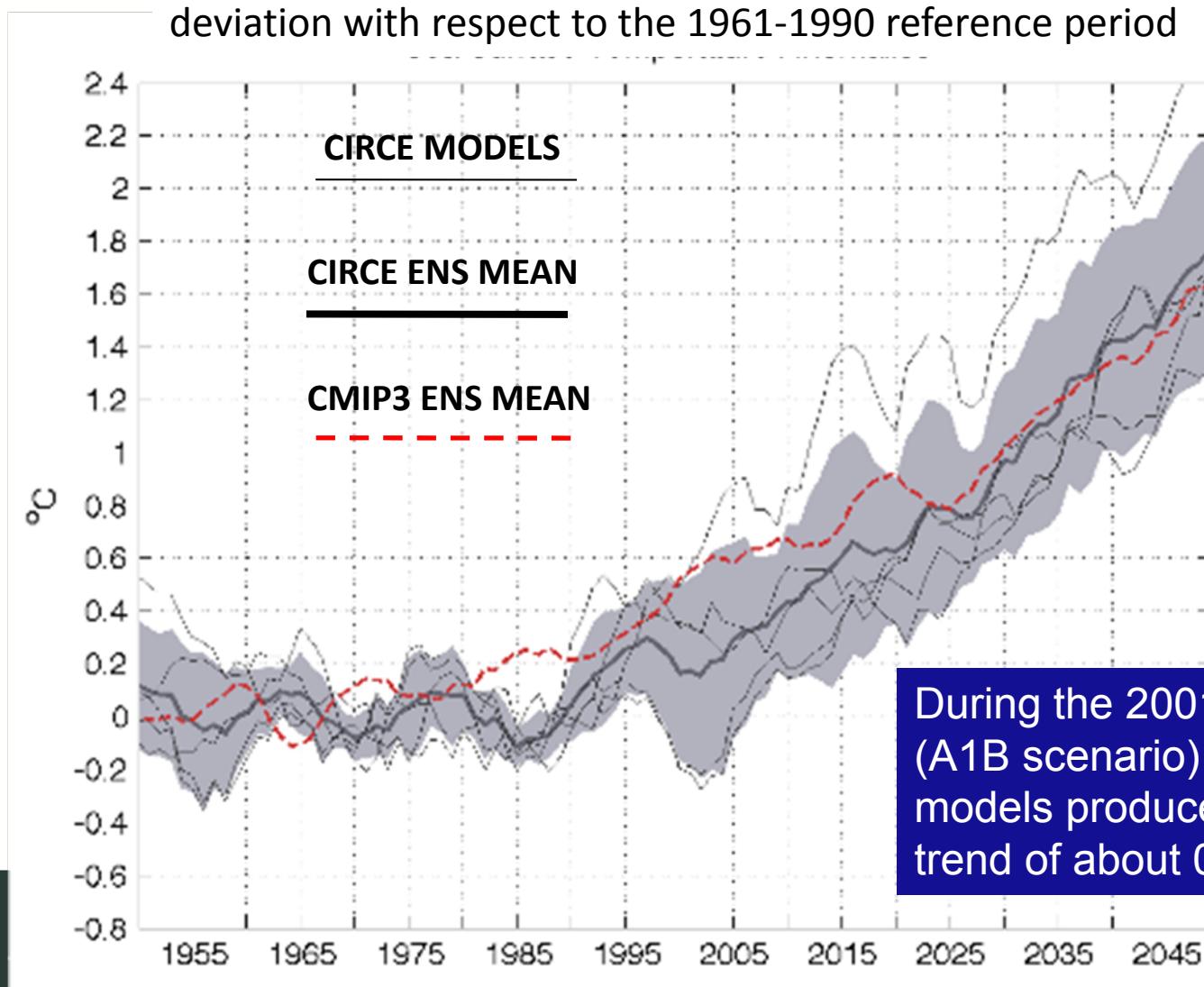
But the CIRCE models provide **reasonably good estimates of the Mediterranean Heat and Water surface budget**

In contrast with most of the ENSEMBLES models, **the total surface heat budget in all of the CIRCE simulations is negative**, with values in good agreement with observations, satisfying the heat closure budget controlled by the heat transport through Gibraltar, also consistent with the observational results.



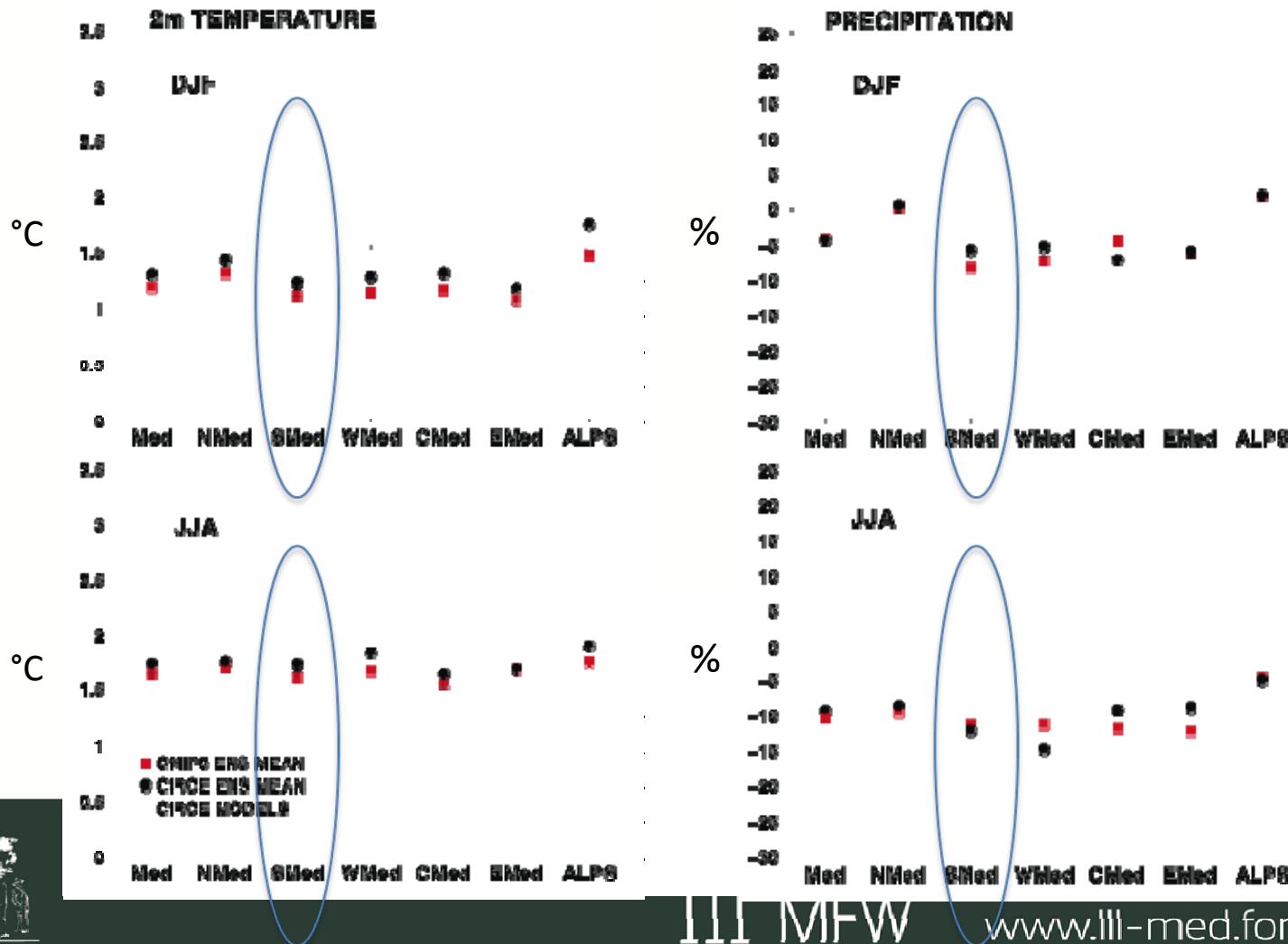
RESULTS: Climate Change Projections

Evolution of the Mediterranean Sea Surface Temperature anomalies



RESULTS: Climate Change Projections

Land T2m and Precipitation changes (2021-2050)-(1961-1990)
in the Mediterranean region and 6 sub-regions (Giorgi and Lionello 2008)

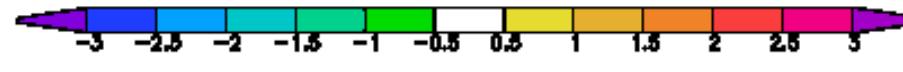
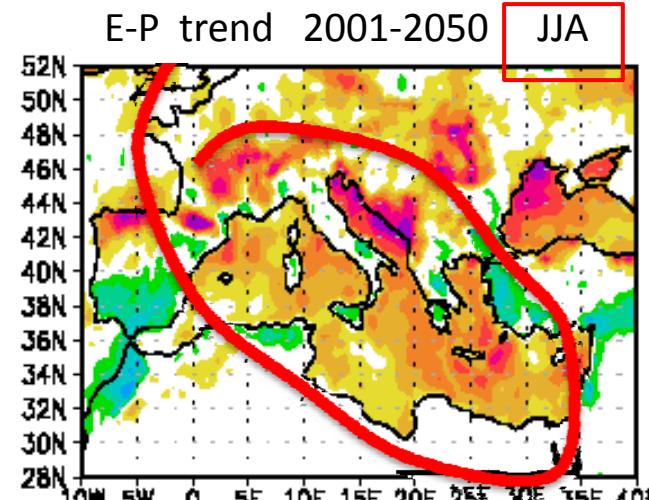
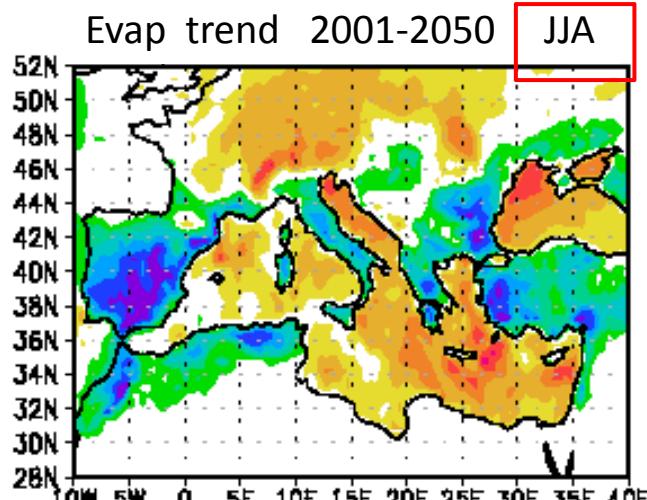
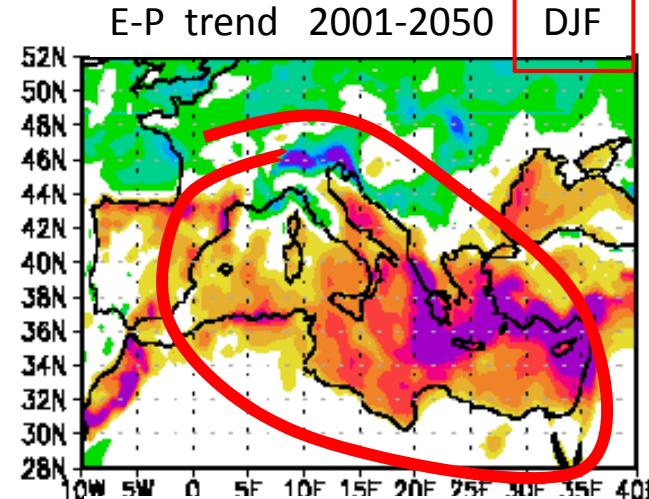
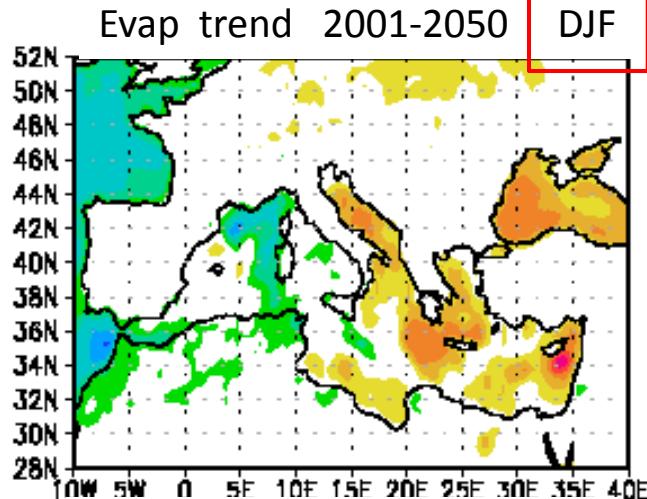


RESULTS: Climate Change Projections

Evaporation and E-P trends 2001-

2050

$\frac{\text{mm/day}}{\text{year}} * 100$



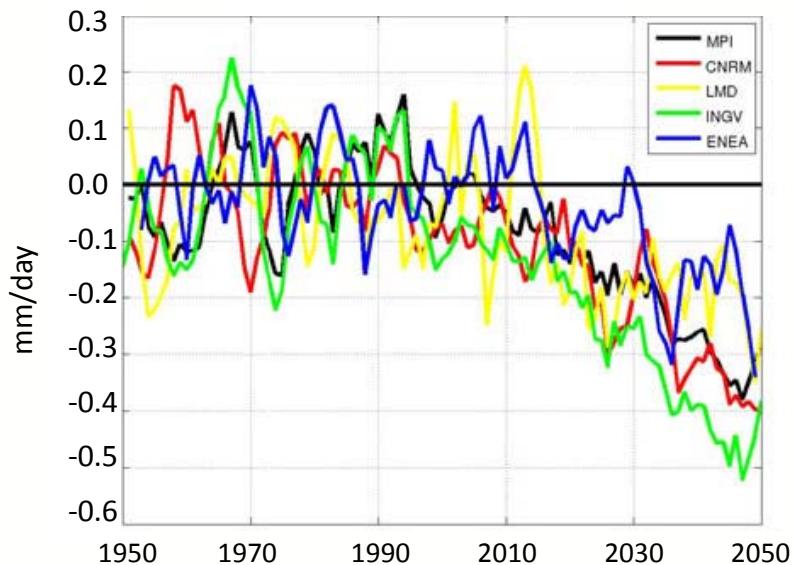
RESULTS: Climate Change Projections

Evolution of the Mediterranean Sea surface Water Budget (E-P-R)

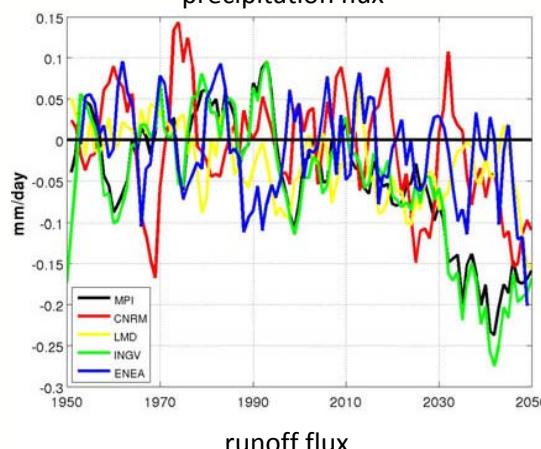
deviation with respect to the 1961-1990 reference period

projected surface water budget decreases ($\approx -0.07 \text{ mm/day per decade}$) → **MORE EVAPORATIVE**

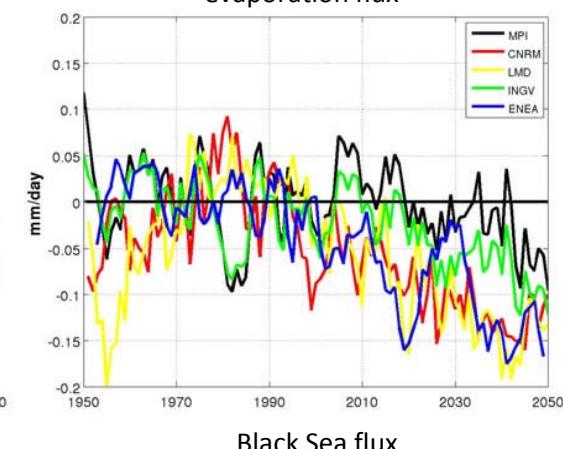
surface water flux



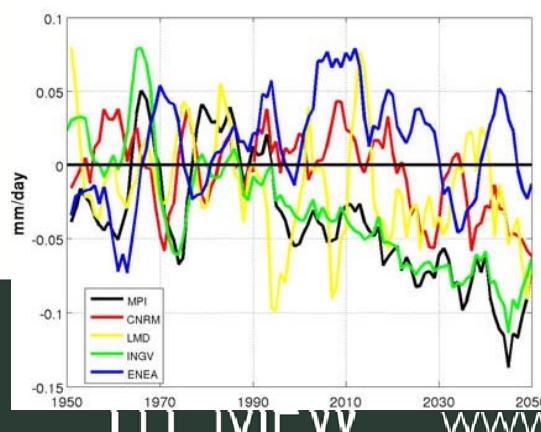
precipitation flux



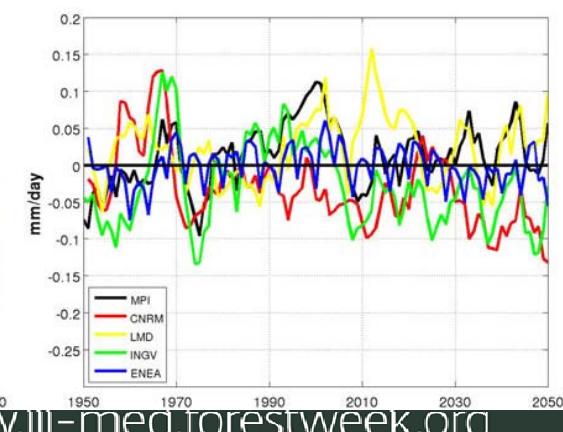
evaporation flux



runoff flux



Black Sea flux

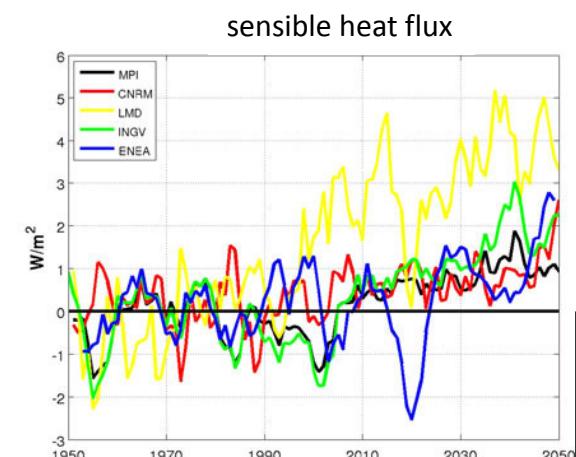
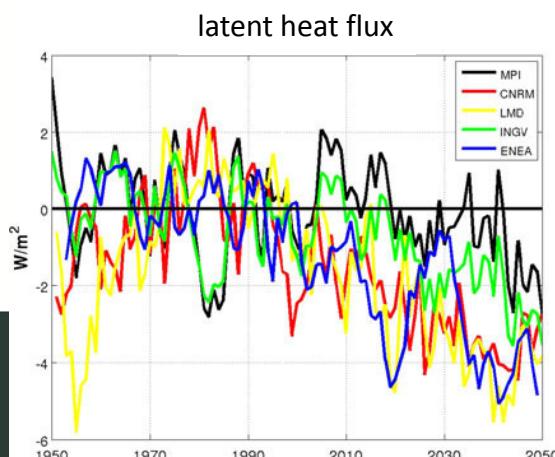
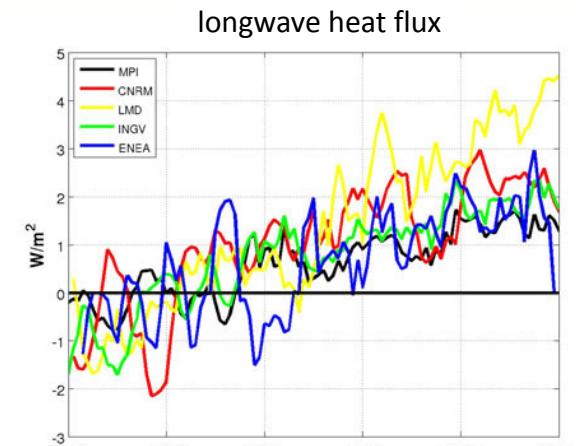
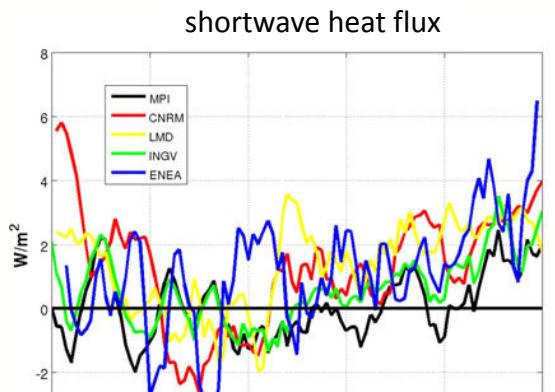
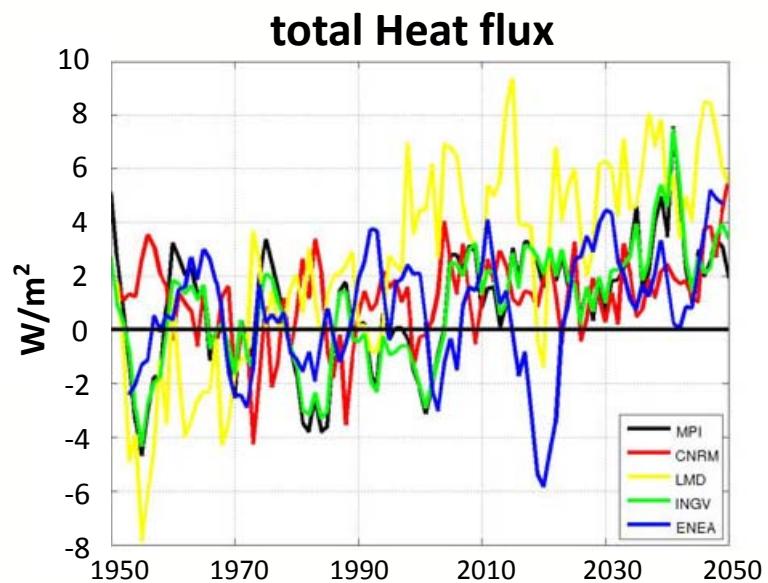


RESULTS: Climate Change Projections

Evolution of the Mediterranean Sea surface Heat Budget

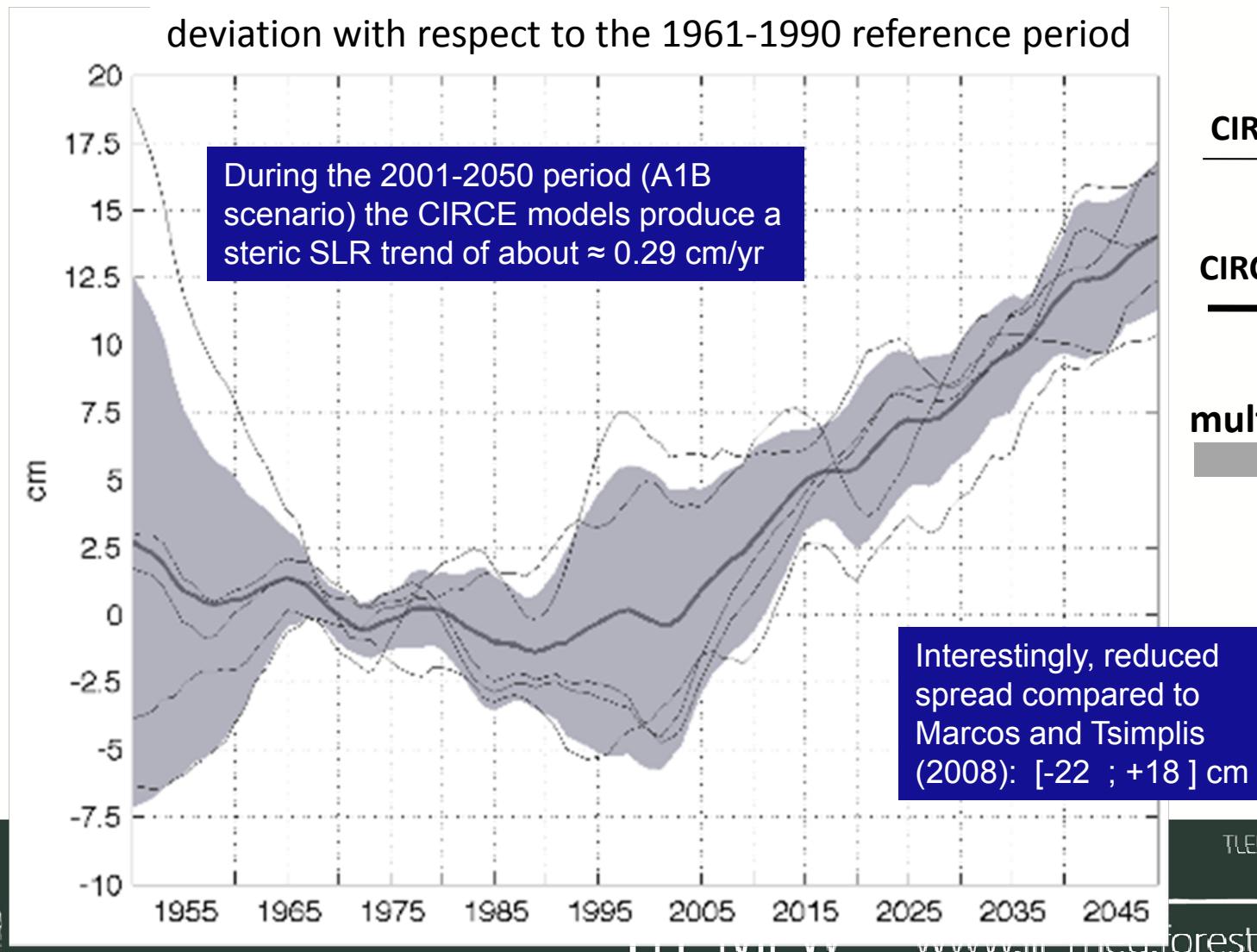
deviation with respect to the 1961-1990 reference period

projected surface heat flux increases ($\approx 0.6 \text{ W/m}^2$ per decade) → less surface heat loss



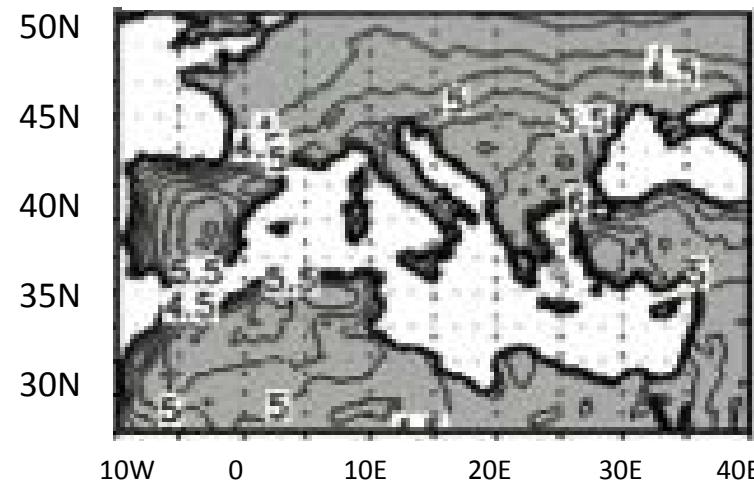
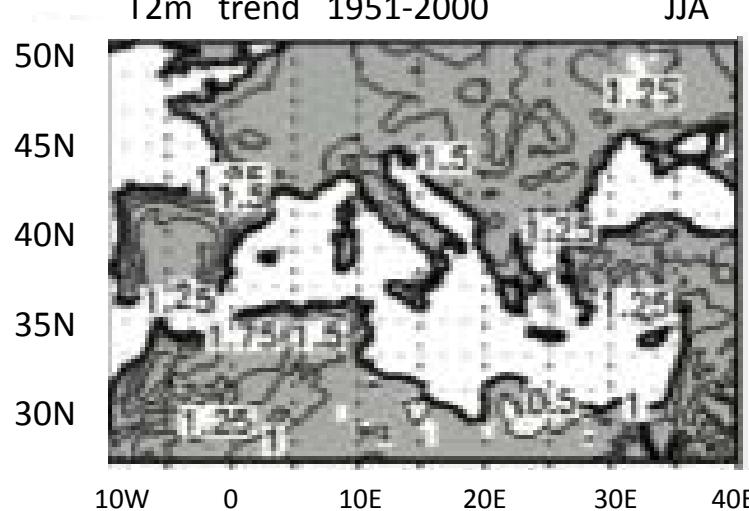
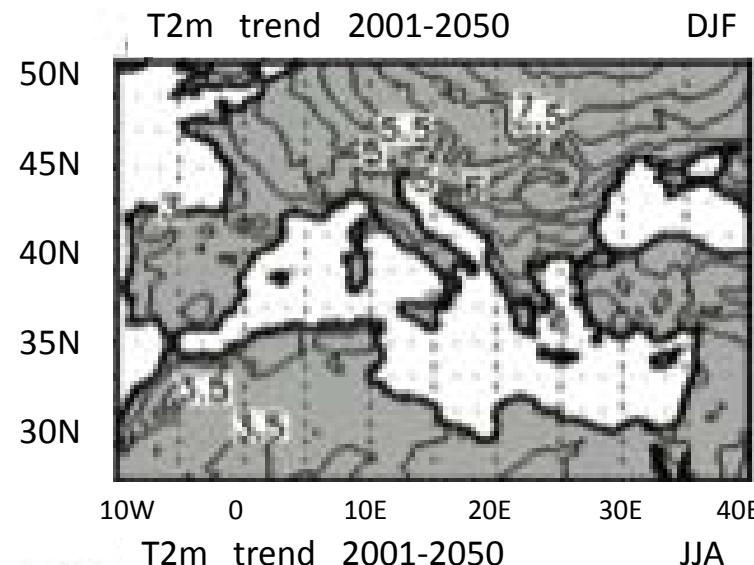
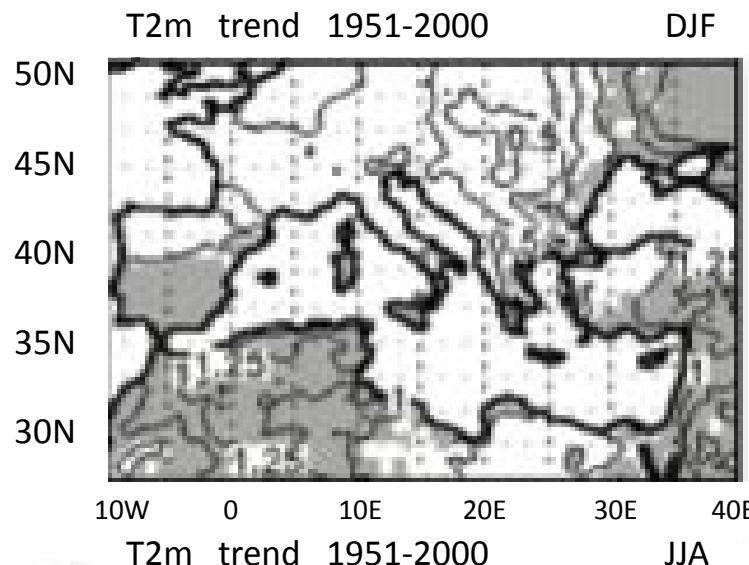
RESULTS: Climate Change Projections

SEA LEVEL CHANGE due to the STERIC EFFECT computed from the CIRCE models



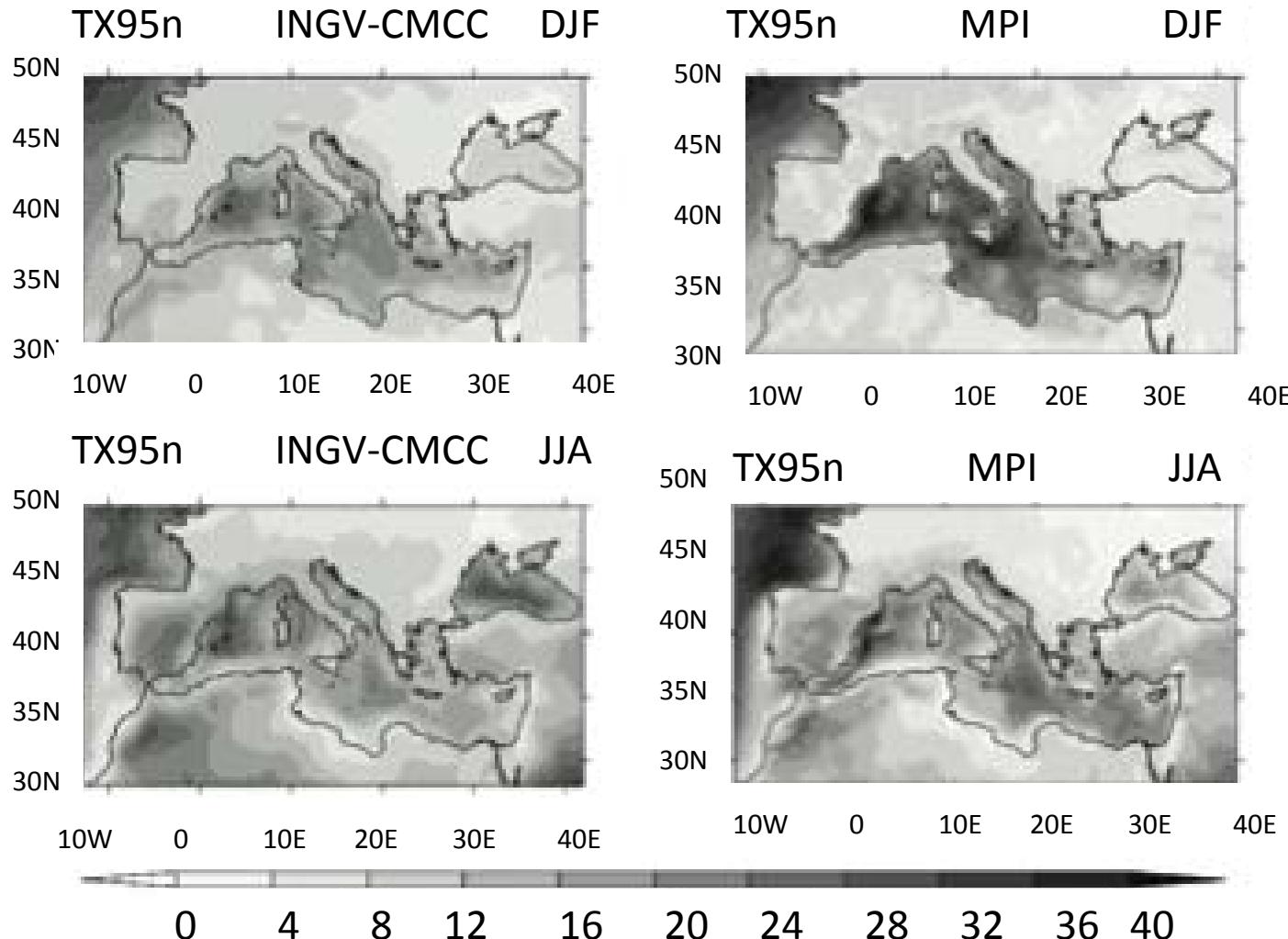
RESULTS: Climate Change Projections

T2m trends ($^{\circ}\text{C}/\text{decade}$) ensemble mean



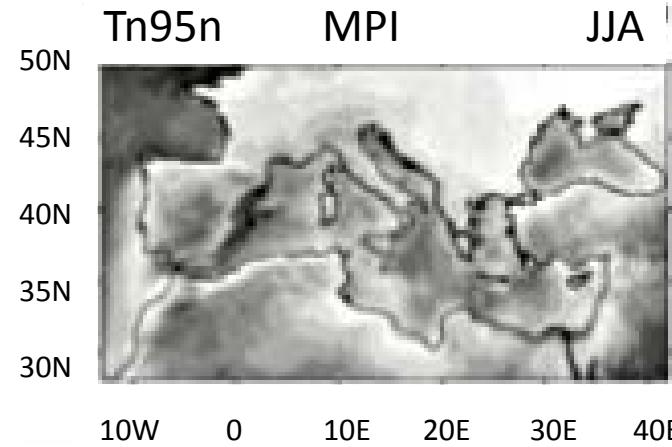
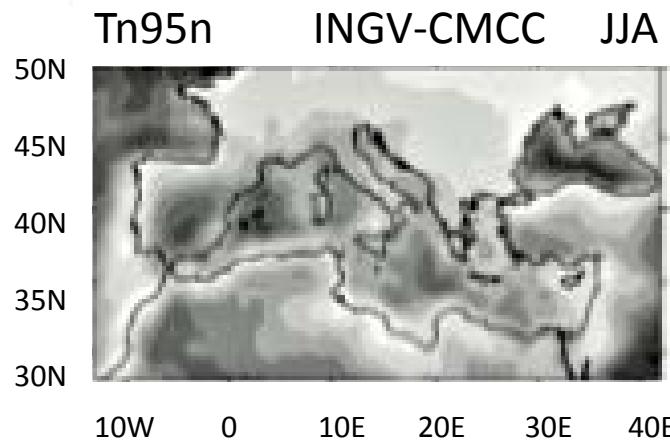
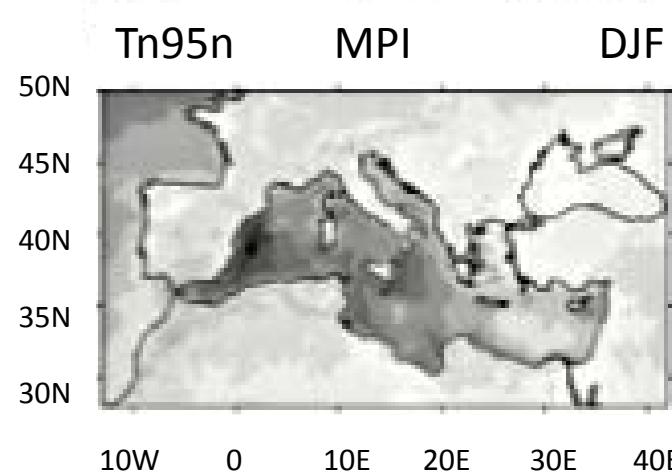
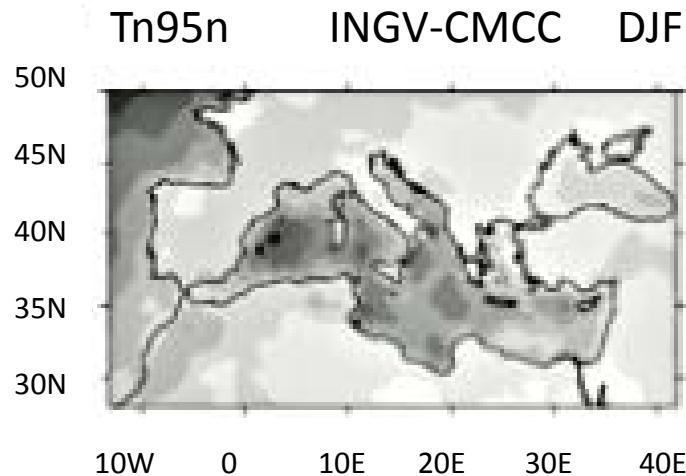
RESULTS: Climate Change Projections

Tx95n (2021-2050) – (1961-1990) number of hot days



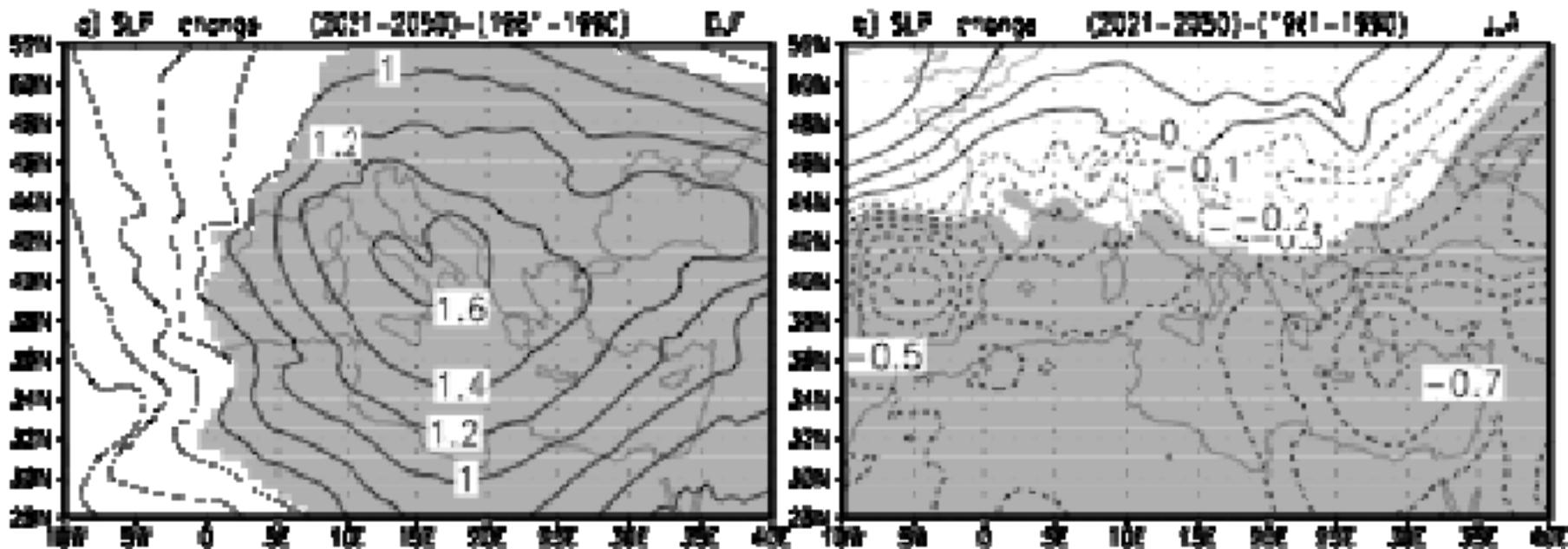
RESULTS: Climate Change Projections

Tn95n (2021-2050) – (1961-1990) number of hot nights



RESULTS: Climate Change Projections

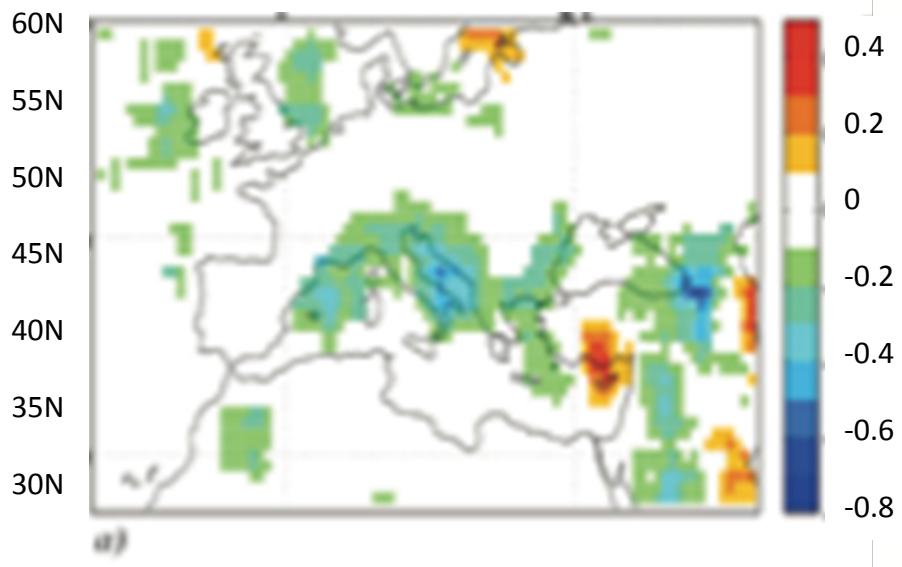
SLP (2021-2050) – (1961-1990) ensemble mean



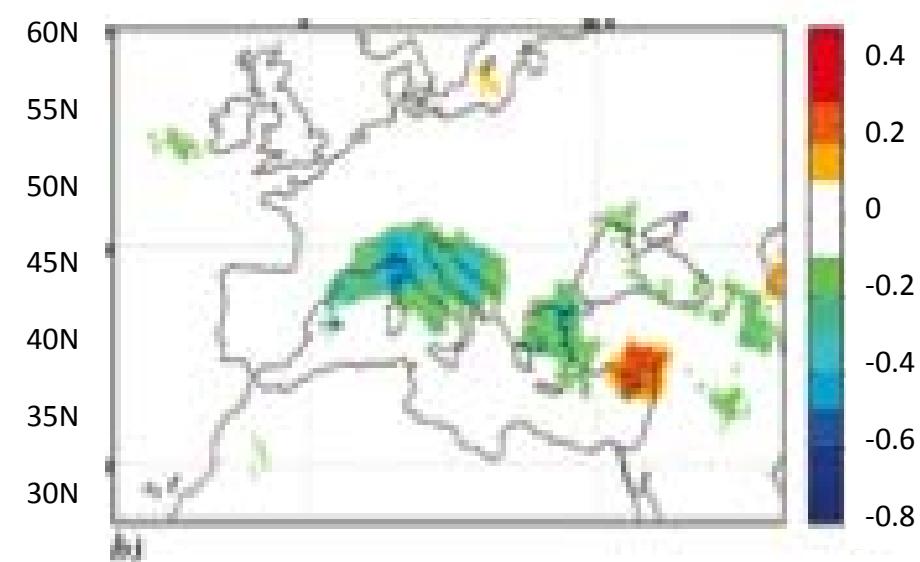
RESULTS: Climate Change Projections

Cyclones minimum density (2021-2050) – (1961-1990)

CMCC-CM



MPI



RESULTS: Climate Change Projections

Summary II:

The CIRCE projections indicate that remarkable changes in the Mediterranean region climate might occur already in the early few decades of the scenario

A substantial **warming** ($\approx 1.5^{\circ}\text{C}$ in winter and $\approx 2^{\circ}\text{C}$ in summer) and a significant **decrease of precipitation** ($\approx -5/-10\%$) might affect the region in the 2021-2050 period compared to the reference period (1961-1990), in an A1B emission scenario.

The Mediterranean Sea **surface net heat loss decreases** (-0.6 W/m^2) in the projected period, leading to a weaker cooling of the basin by the atmosphere

The projected **surface water budget decreases** ($\approx -0.07 \text{ mm/day}$), leading the Mediterranean Sea to loose more water through its surface than in the past.

The CIRCE projections show a 2021-2050 mean **steric sea-level rise** that ranges between **+7 and +12 cm**, with respect to the period of reference.



CONCLUSIONS

The climate change projections obtained from the CIRCE models are overall consistent with the findings obtained in ENSEMBLES and CMIP3, **suggesting that these findings are robust to substantial changes in the the models** used to produce the scenario simulations.

The CIRCE results show also a **non-negligible spread**, which is, most likely due to differences in the models physics and in the experimental set up (e.g., global vs limited area models).

Also, it is likely that the introduction of **the air-sea coupling in the CIRCE models contributes to the spread** of the responses, although a size of five ensemble members does not allow testing it in a statistical sense.

Despite some improvements, the CIRCE models still **have large systematic errors**. Therefore, to increase the reliability of the climate change projections, further efforts are required to reduce the biases (e.g., clouds, albedo, hydrology ...)

The **CIRCE simulations represent the first attempt** to address the climate change in the Mediterranean area using models with a realistic the Mediterranean Sea and with a multi-model approach. This seminal effort is continued in new international programmes such as, for example, HyMeX and Med-CORDEX

