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"Towards Improved Monsoon Simulations"
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The South Asian monsoon and the Mediterranean: A multi-model analysis

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Thanks to:
A. Alessandri (ENEA, Italy), H. Annamalai (IPRC, US), S. Masina (CMCC), A. Navarra (CMCC)

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TALK IS ABOUT:

Teleconnection between the South Asian region and the Mediterranean

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Teleconnection between the South Asian region and the Mediterranean

OUTLINE:

Background (monsoon-desert: what is it? and how does it work?)

Summer mean state (CMIP5 models' performance)

Interannual variability (observations & simulations)

Climate projections

Conclusions & Perspectives

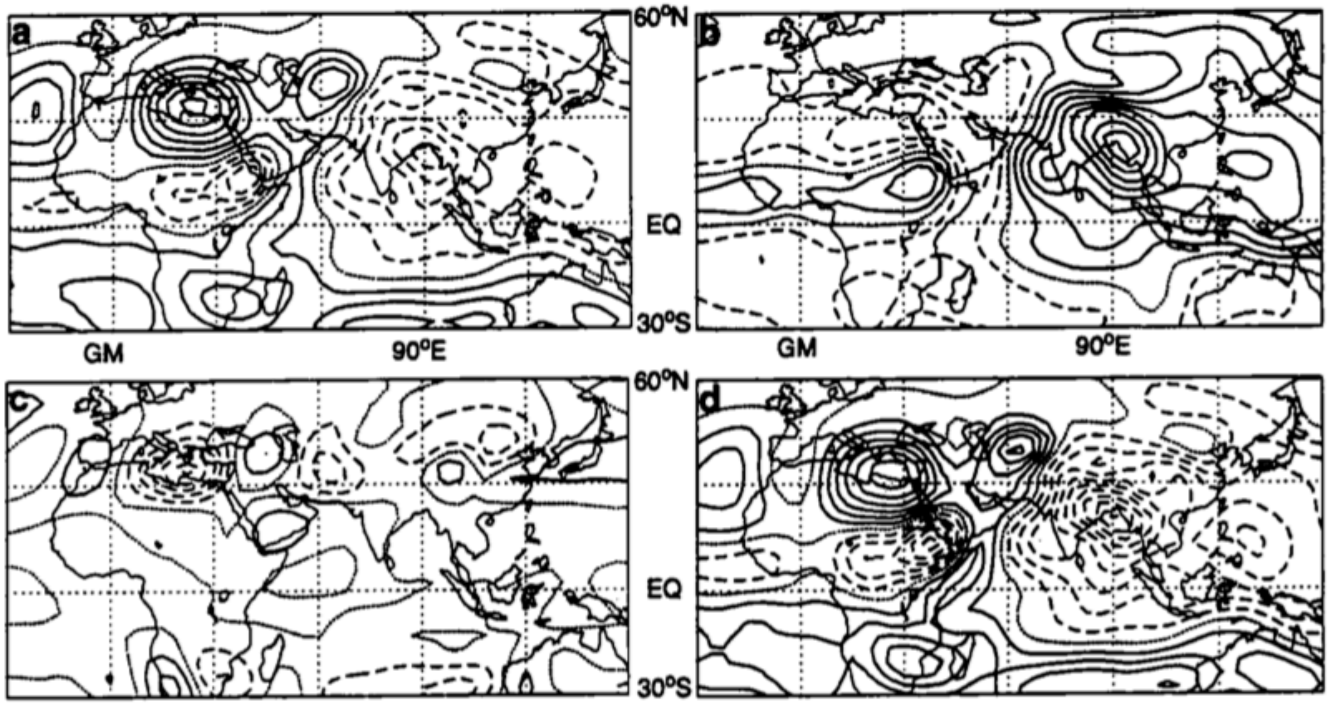
Monsoon-desert mechanism (Rodwell and Hoskins, 1996; 2001)

descent over the Mediterranean region is a consequence of the interaction between westward propagating Rossby waves (generated by diabatic heating over the Asian monsoon sector) and mean westerly flow north of it

ω

diabatic heating

477 hPa



horizontal advection

vertical advection

Thermodynamic energy equation:

$$\frac{Q}{c_p} = v \cdot \nabla_p T + \left(\frac{p}{p_0}\right)^k \omega \frac{\partial \theta}{\partial p}$$

horizontal temperature advection to balance temperature equation in mid-latitudes

LOCAL DIABATIC ENHANCEMENT (contributes to strengthen the descent)

Method of analysis for summer mean state (3-steps approach):

Step 1 – statistical analysis to evaluate CMIP5 models' performance (comparison with atmospheric re-analysis & precipitation data)

Step 2 – idealized experiments with linear atmosphere model to investigate the sensitivity to spatial and vertical distribution of diabatic heating over Asia

Step 3 – moist static energy (MSE) budget analysis to quantify relative role of temperature, moisture and radiative fluxes

Step 1 – statistical analysis to evaluate CMIP5 models' performance (comparison with atmospheric re-analysis & precipitation data)

18 CGCMs & ESM

Historical experiment (20th century) 1901-2005

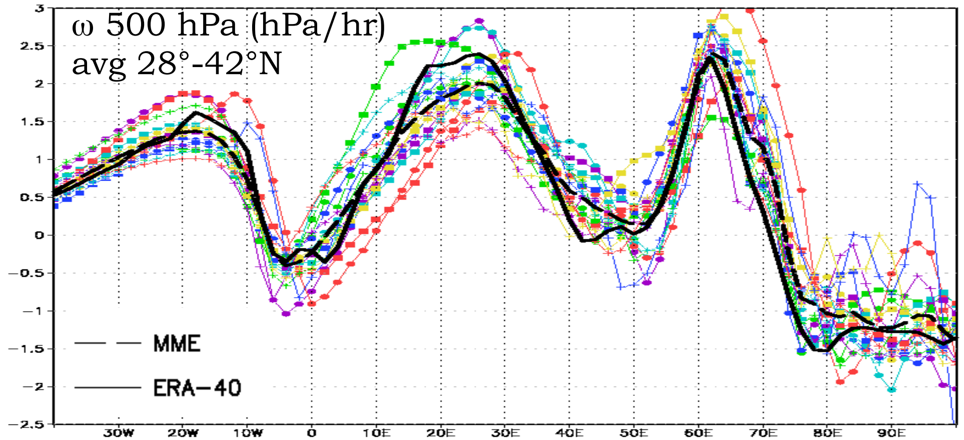
Observational data:

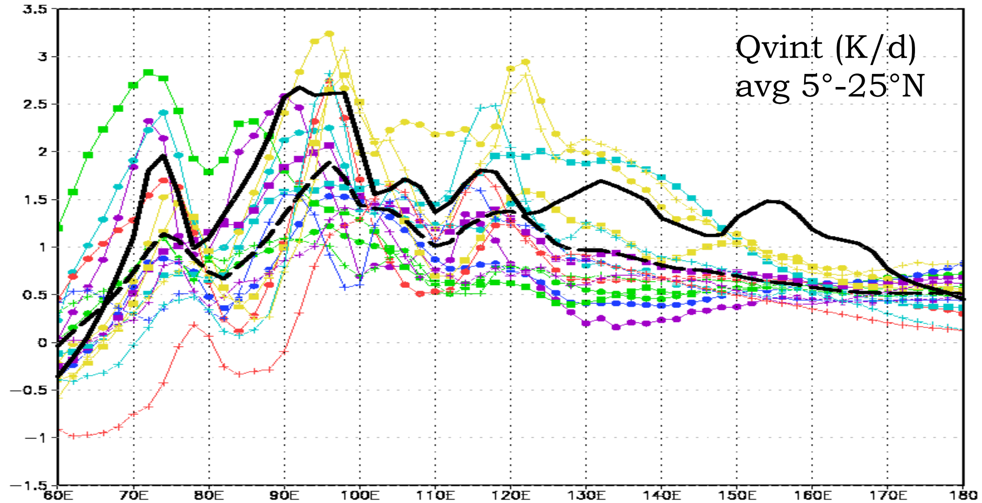
ERA40 1958-2001 (omega, temperature, wind) – Uppala et al. (2005)

GPCP 1979-2009 (precipitation) – Adler et al. (2003)

Model name	Institute/Country	Resolution	Ens size
CCSM4	NCAR/US	2.5°x2°	5
NorESM1-M	NCC/Eu	2.5°x1.895°	3
MIROC5	MIROC/Jpn	1.4°x1.4°	3
MPI-ESM-LR	MPI-M/Eu	1.875°x1.85°	3
CMCC-CMS	CMCC/Eu	1.875°x1.85°	1
FGOALS-g2	LASG-CESS/China	2.8125°x3.06°	1
MIROC-ESM	MIROC/Jpn	2.8125°x2.8125°	1
FGOALS-s2	LASG-IAP/China	2.8125°x1.67°	1
GFDL-CM3	NOAA-GFDL/US	2.5°x2°	5
GFDL-ESM2G	NOAA-GFDL/US	2.5°x1.5°	3
bcc-csm1-1	BCC/China	2.8125°x2.8125°	1
HadCM3	MOHC/UK	3.75°x2.5°	10
CESM1-CAM5	NCAR/US	1.25°x0.9425°	1
IPSL-CM5A-MR	IPSL/Eu	2.5°x1.27°	1
inmcm4	INM/Russia	2.0°x1.5°	1
HadGEM2-AO	MOHC/UK	1.875°x1.25°	1
CSIRO-Mk3-6-0	CSIRO-OCCCE/Au	1.875°x1.875°	10
ACCESS1-3	CSIRO-BOM/Au	1.875°x1.25°	1

Descent in east Med & diabatic heating over South Asia (JJA)





- subsidence: spread among models mostly in terms of intensity (from 1 to 3 hPa/hr);

- diabatic heating: spread among models mostly in terms of location of max heating;

Cherchi et al. (2014)

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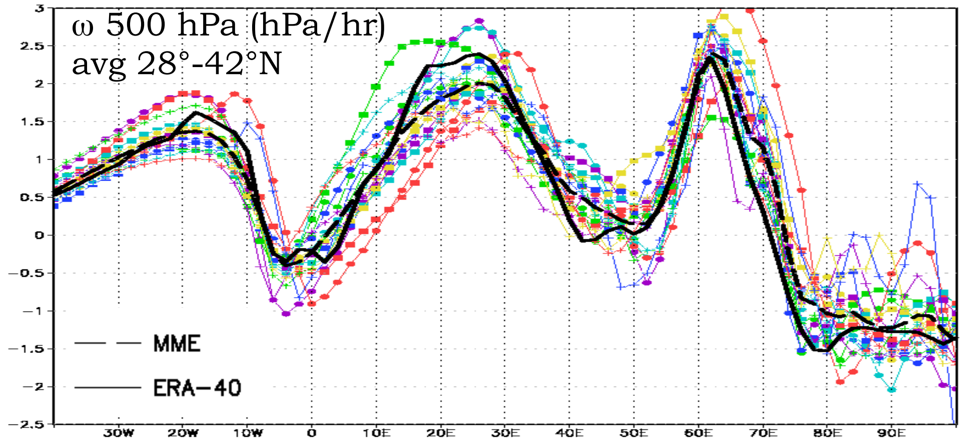
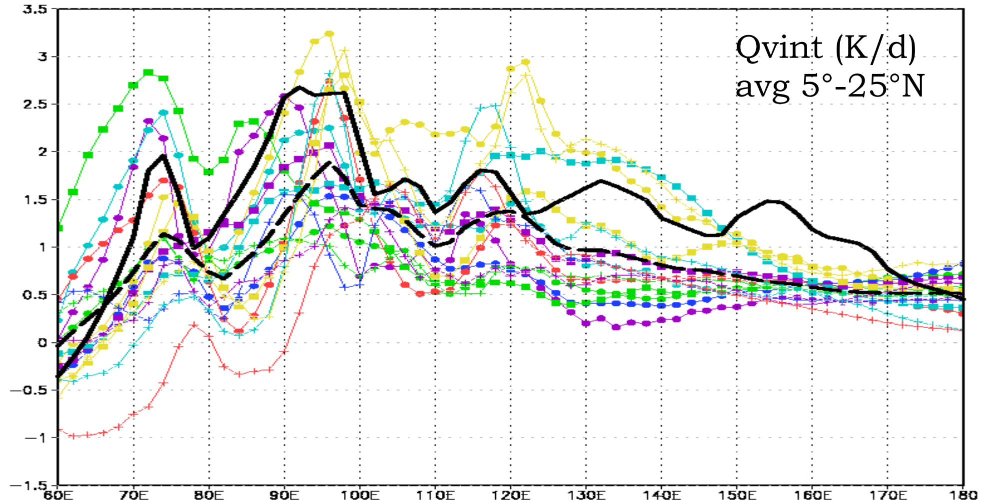
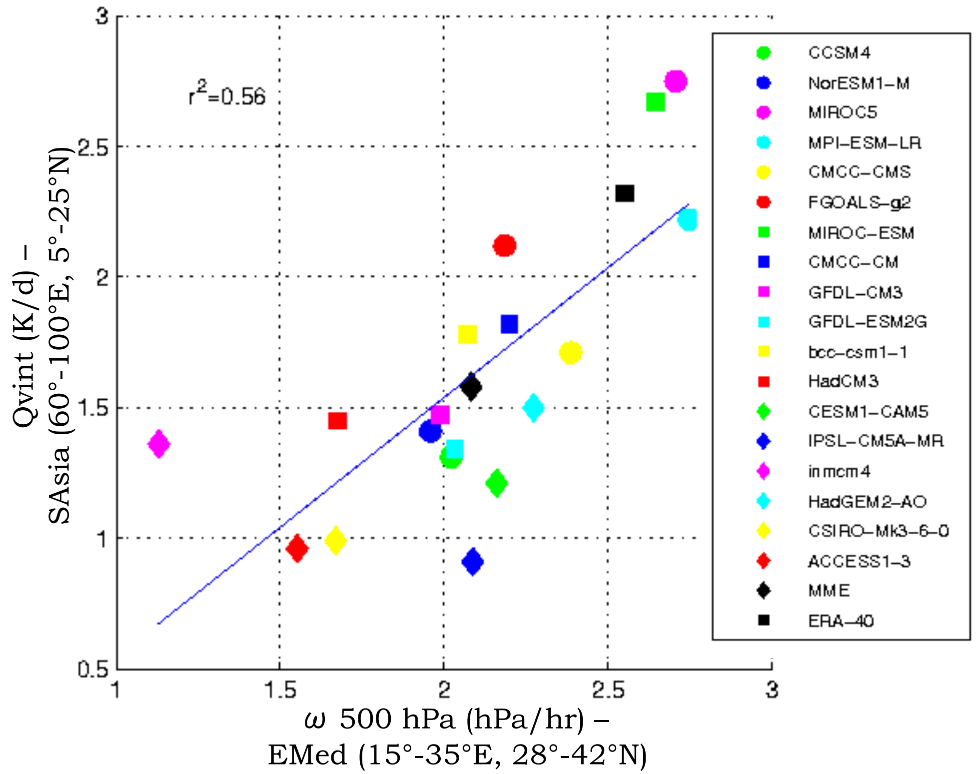






- subsidence: spread among models mostly in terms of intensity (from 1 to 3 hPa/hr);
- diabatic heating: spread among models mostly in terms of location of max heating;

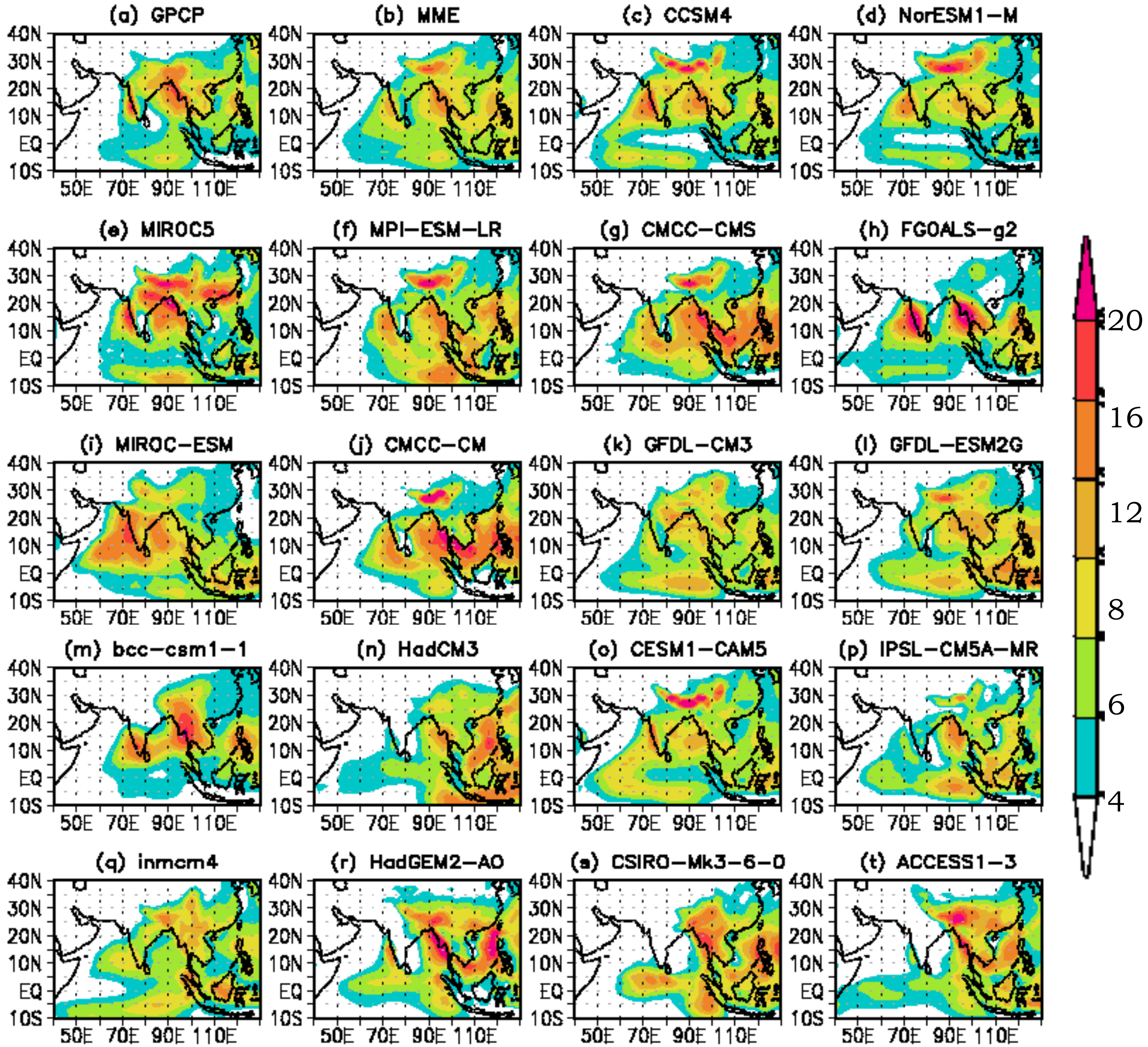
despite the variety of location and intensity of the diabatic heating over Asia, the response in terms of subsidence in the Mediterranean region is coherent and realistic in space

Cherchi et al. (2014)

South Asian monsoon precipitation (JJA mean, mm/d): CMIP5 models' performance

For each model, the details in the spatial patterns and intensity of monsoon precipitation may differ from observations (top-left panel)

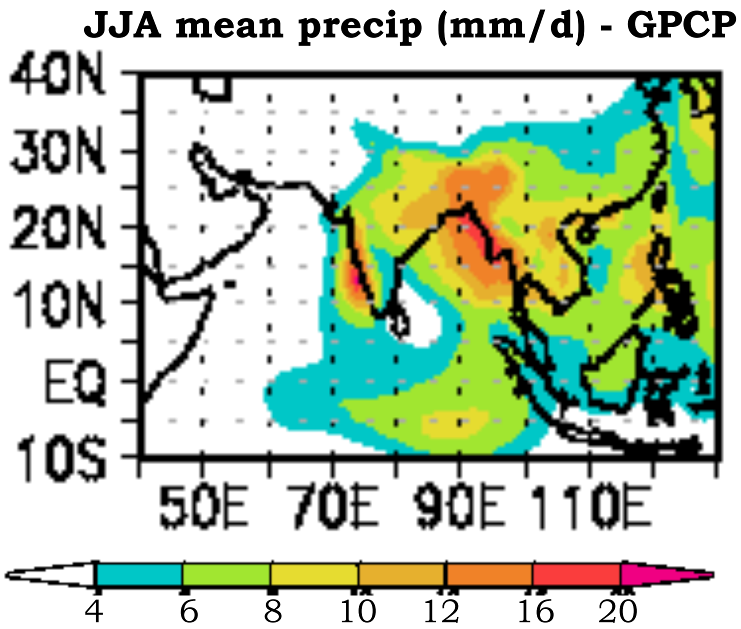
CMIP5 improved vs CMIP3, but still basic aspects are challenging (Sperber et al., 2013)



Cherchi et al. (2014)

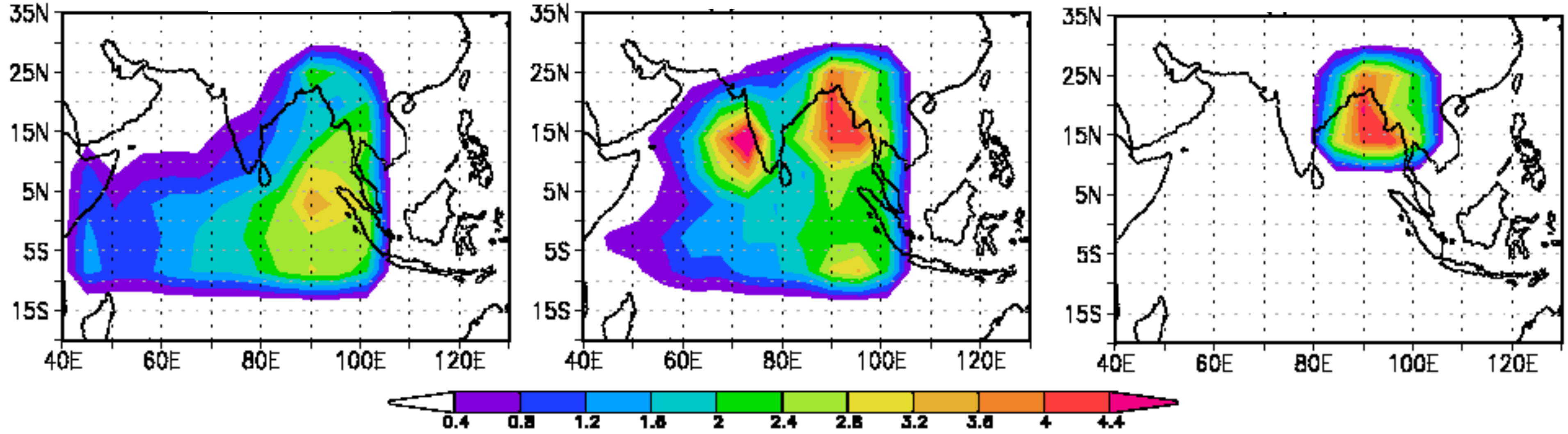
Step 2 – idealized experiments

LBM experiments inspired by horizontal shape of simulated diabatic heating

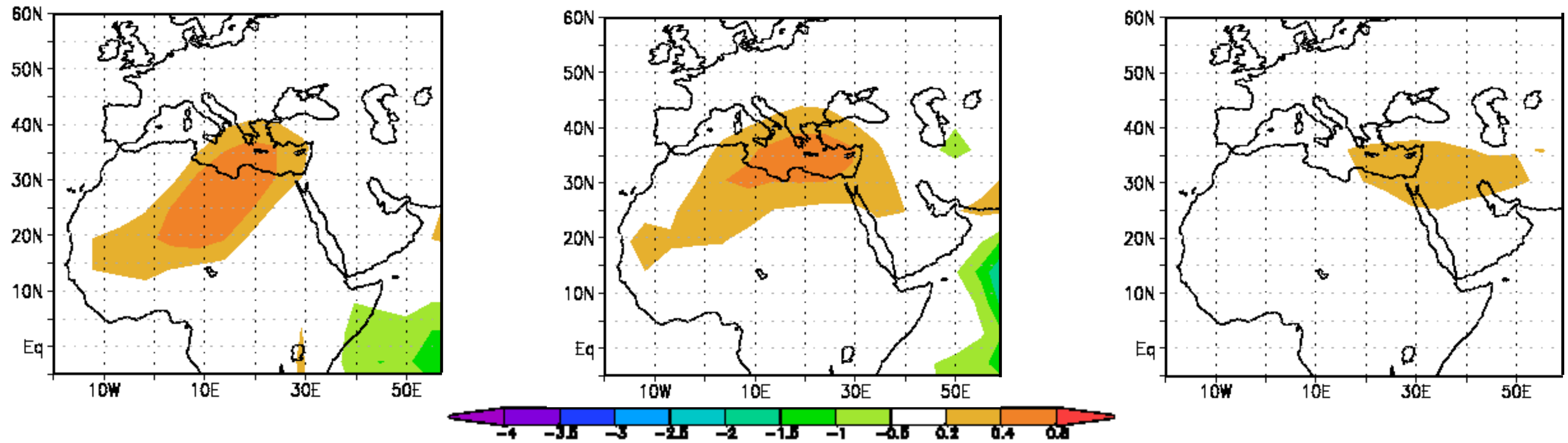


We noticed:
- some models having maxima in eastern equatorial Indian Ocean;
- most of the models are deficient in the Bay of Bengal;
- some of the model have excess of precipitation in the west (toward Arabian Sea)

Heating forcing (°C/d) applied



Response ω at 500 mb (day 21)



- descent anomalies over eastern Mediterranean for all solutions but with different intensity
- the “location” of maximum descent is realistic for the heating imposed over the AS/BoB

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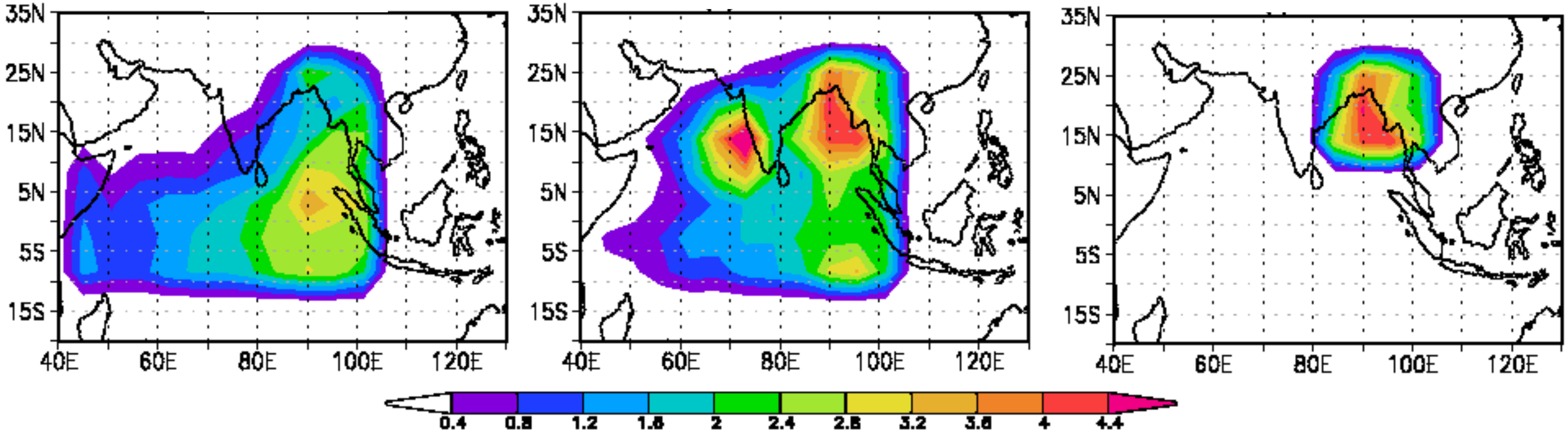
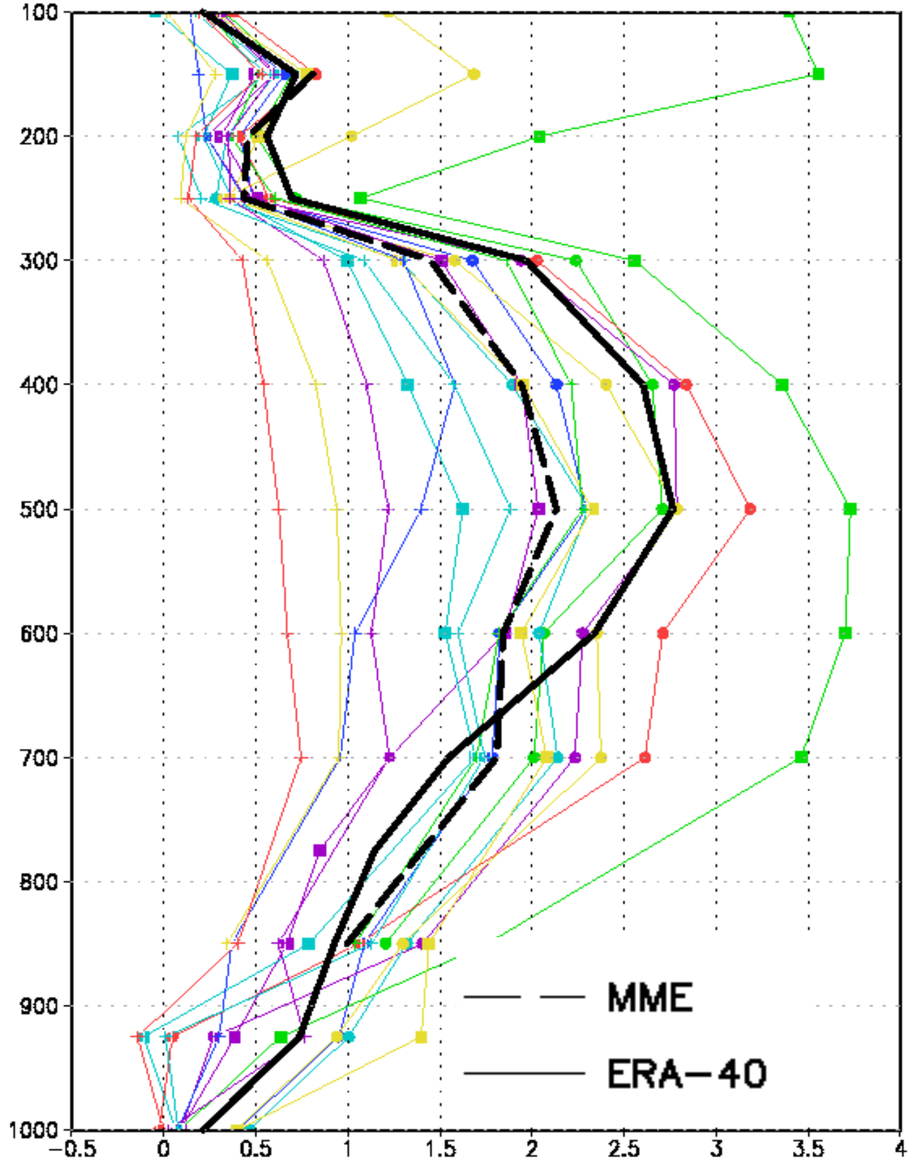


Step 2 – idealized experiments

LBM experiments inspired by vertical shape of simulated diabatic heating



Vertical profiles of JJA mean diabatic heating (°C/d) averaged over South Asia:

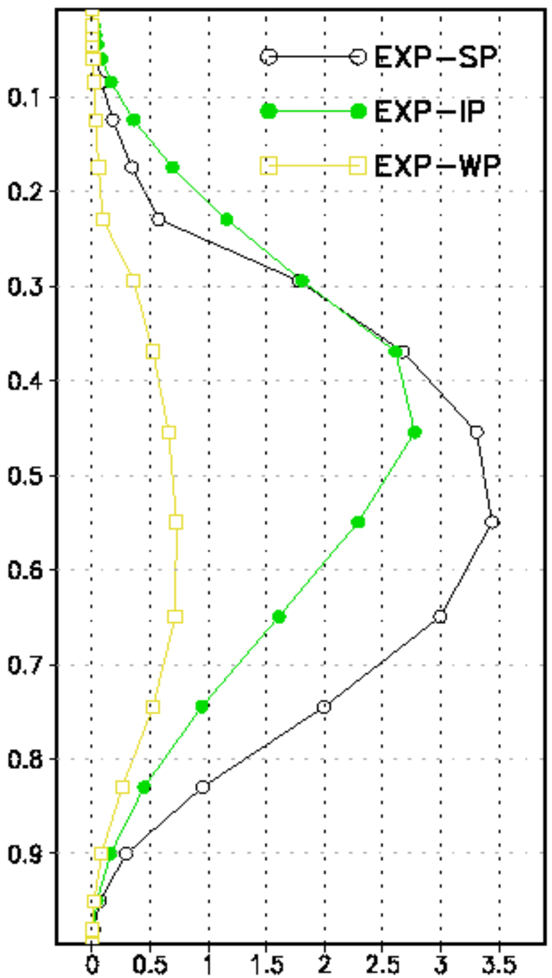
• lower troposphere: simulated Q is higher than in the reanalysis (see MME)

• in the layer 700-300 hPa simulated Q is lower than in reanalysis (see MME)

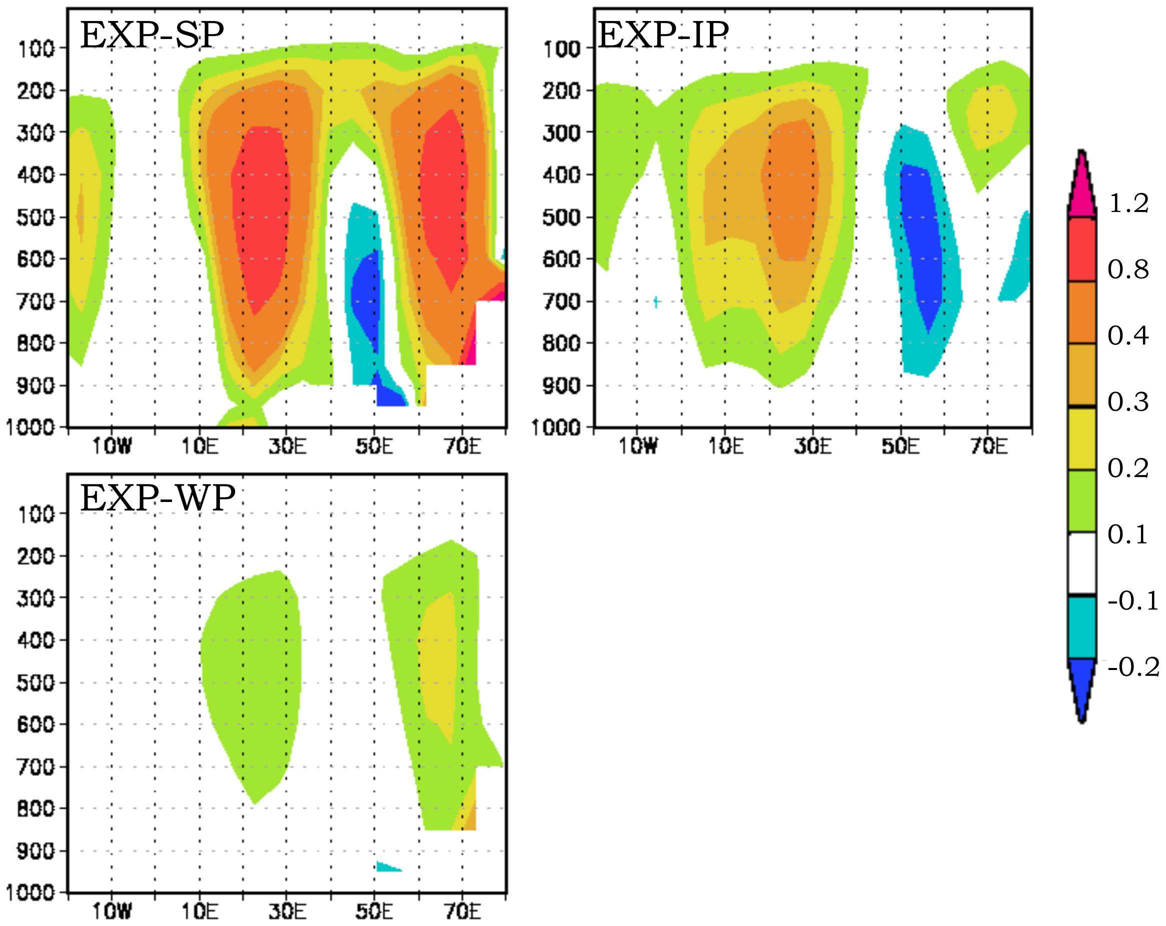
Most climate models produce too much convective and too little stratiform precipitation (Dai, 2006)

LBM experiments (sensitivity to heating vertical profile)

Vertical profiles of heating forcing (°C/d) applied



Response ω (hPa/h) (day 21) avg 28-42N

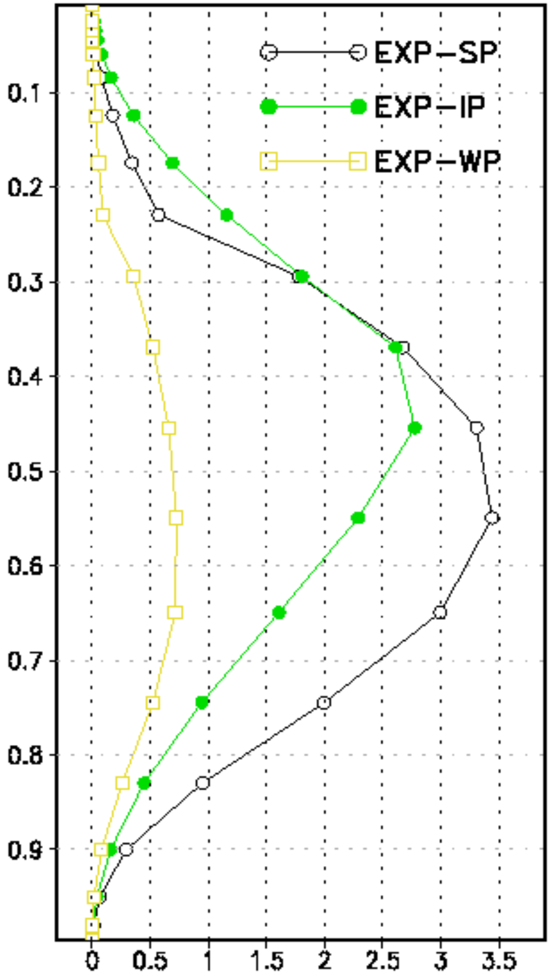


- descent intensity over Mediterranean proportional to the vertical gradient in Q
- EXP-SP: the western Asia descent weakens once that over Mediterranean intensify (westward propagating Rossby waves)
- EXP-WP: forced Rossby wave is weak and largely confined to western Asia

Shortcoming: coarse horizontal resolution in LBM could compromise effect of orography.

LBM experiments (sensitivity to heating vertical profile)

Vertical profiles of heating forcing (°C/d) applied



Step 3: Moist static energy (MSE) budget - to quantify relative role of temperature, moisture and radiative fluxes

$$\langle \frac{\partial m}{\partial t} \rangle = -\langle \mathbf{v} \cdot \nabla (c_p T) \rangle - \langle \mathbf{v} \cdot \nabla (Lq) \rangle - \langle \omega \frac{\partial m}{\partial p} \rangle + F_{rad} + LH + SH$$

horizontal advection of dry enthalpy

vertical advection of MSE

radiative fluxes

Annamalai (2010)
Chen and Bordoni (2014)

$$m = c_p T + gz + Lq$$

Horizontal temperature advection (T_{adv}) and net radiative flux (F_{rad}) are the dominant terms of the MSE budget

Cherchi et al. (2014)

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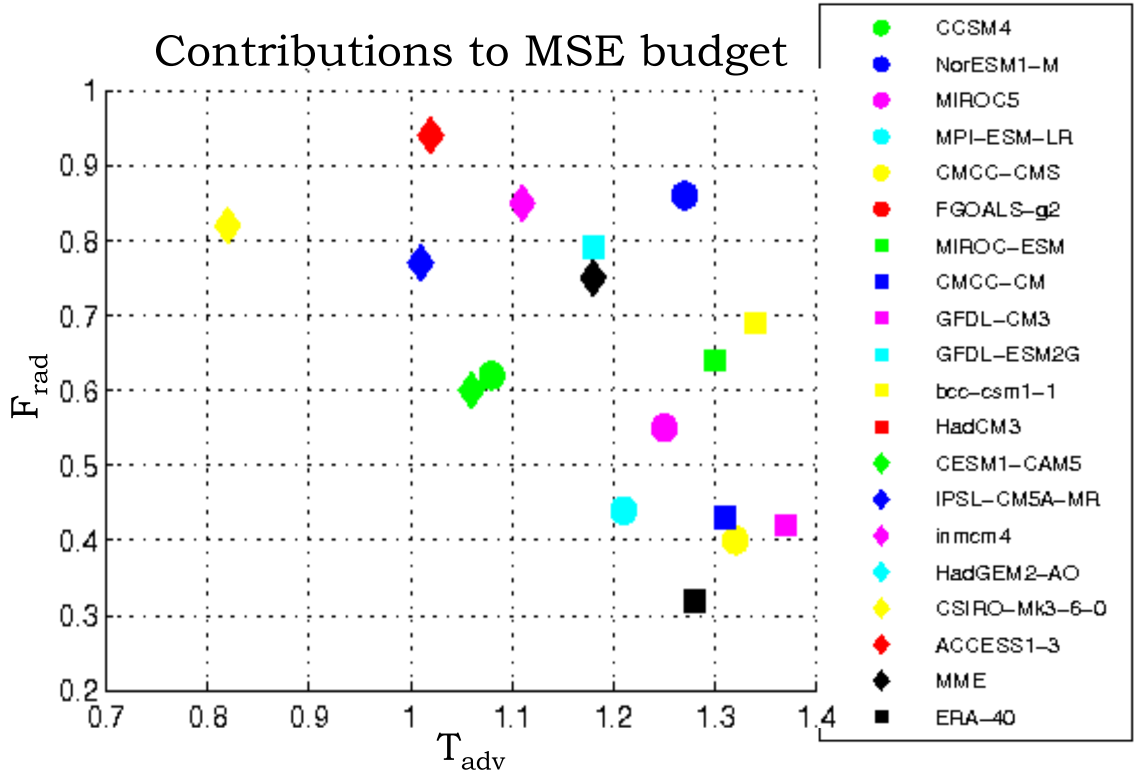
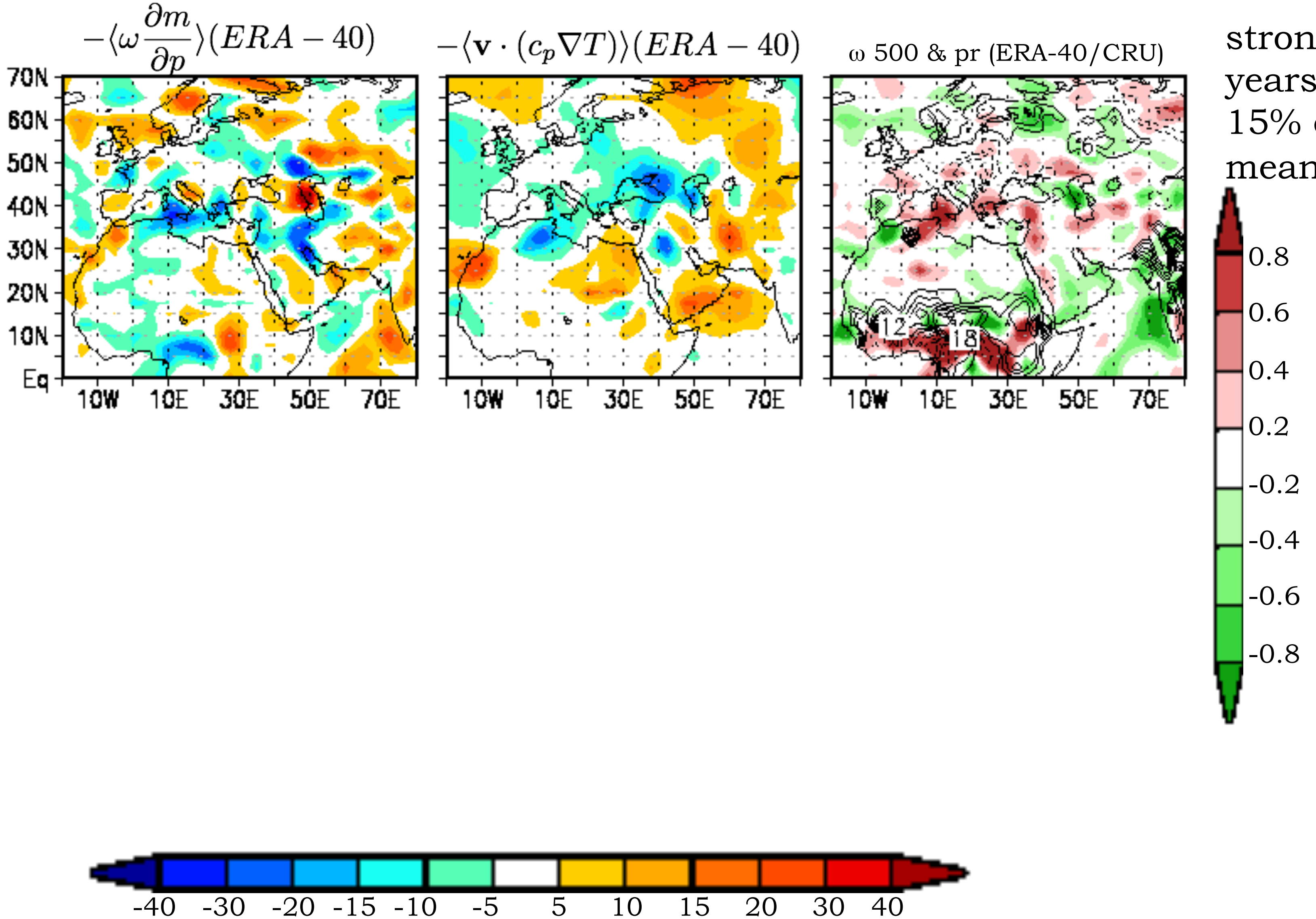


If contribution in ERA-40 corresponds to "true" value, most CMIP5 models underestimate the contribution of T_{adv} while they overestimate that of F_{rad} in their respective budgets

Cherchi et al. (2014)

Monsoon-desert mechanism at interannual timescale – MSE budget



strong monsoon years (exceeding 15% of summer mean rainfall)

- Mediterranean sector experiences drier and stronger descent conditions during years of severe strong monsoon over south Asia
- MSE divergence over Mediterranean is largely balanced by T_{adv} term

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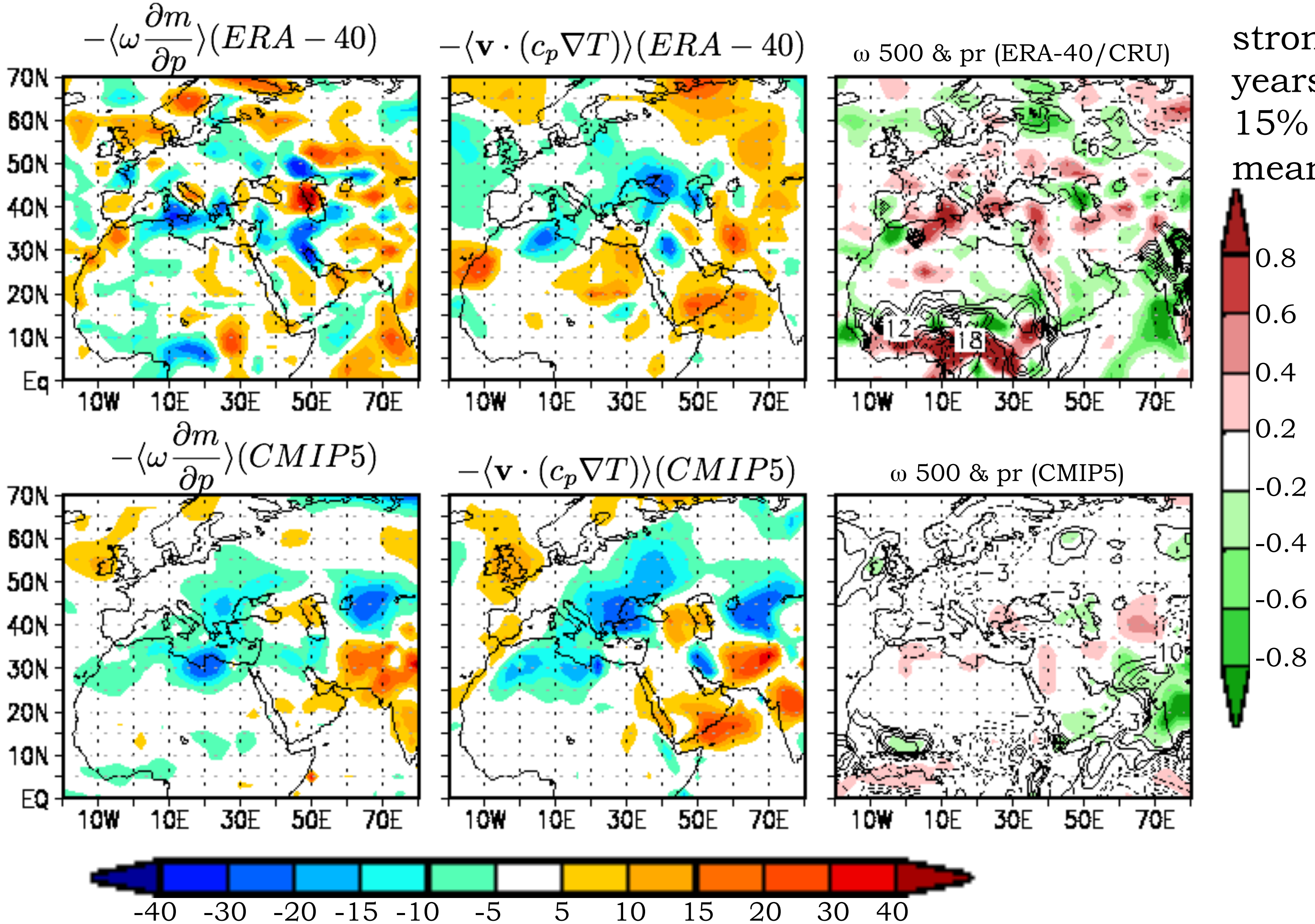

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CMIP5 = MIROC5, CCSM4 and NorESM1-M

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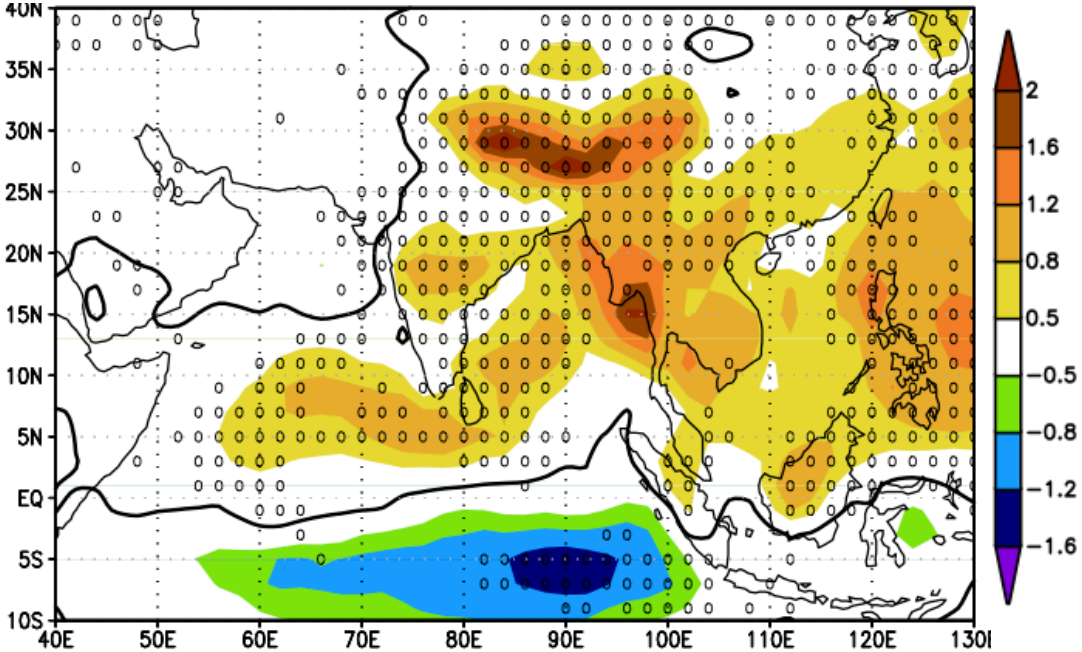
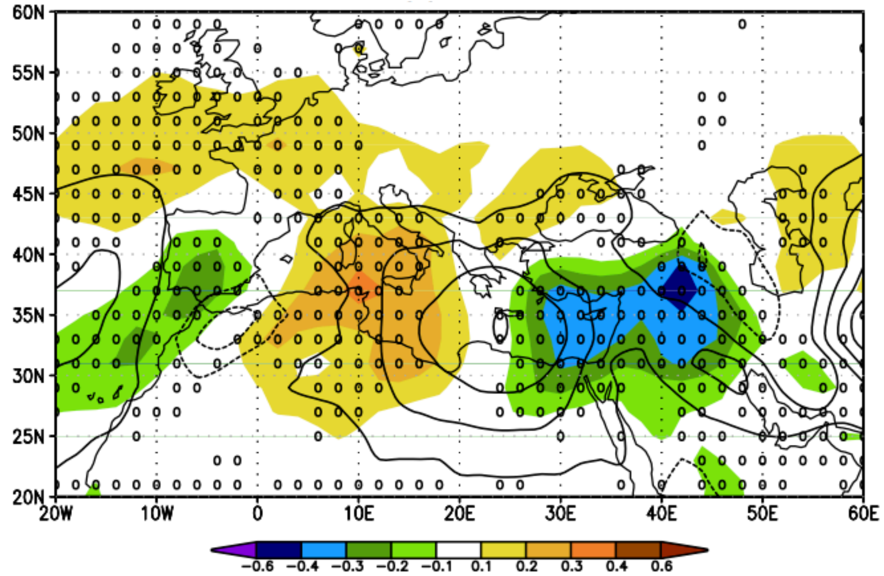
Cherchi et al. (2014)

21st CENTURY PROJECTIONS
21C (RCP4.5 2069-2098 JJA) minus 20C (1980-2004 JJA)

precipitation (mm/d)



ω at 500 hPa (hPa/hr)



maxima of increase in regions most favorable for excitation of atmospheric westward Rossby waves (RH96)

westward shift of subsidence - decrease (increase) in the eastern (central) part of the Mediterranean

can we explain the projected changes in the eastern Mediterranean, at least in part, as consequence of the monsoon-desert mechanism?

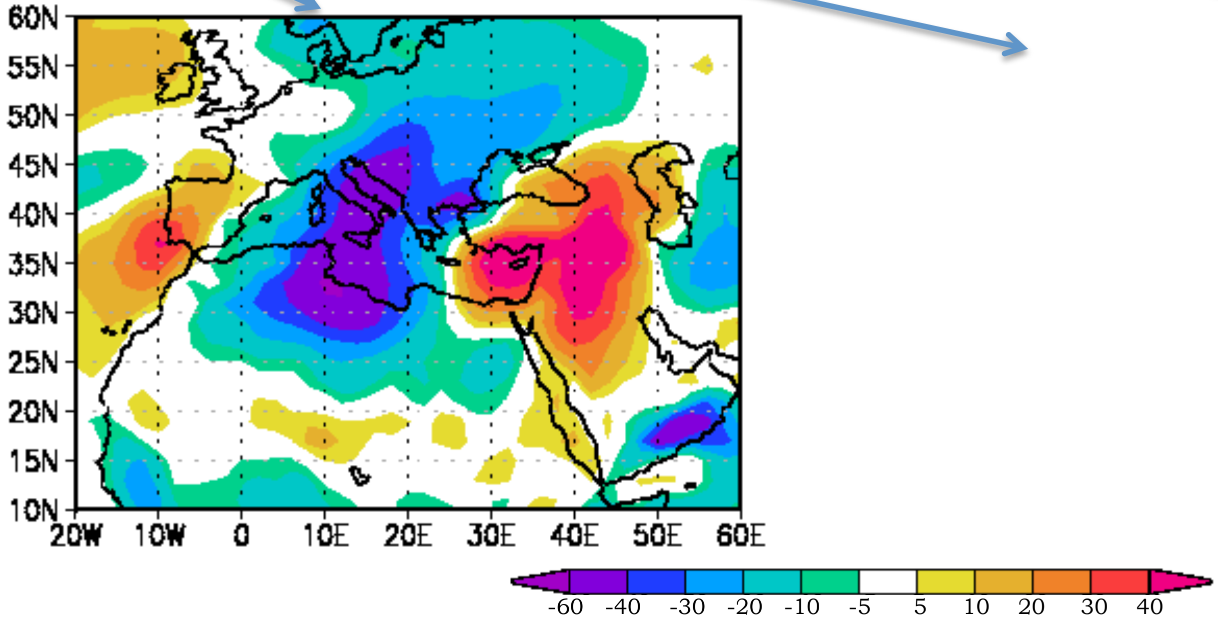
Cherchi et al. (2016)

Desert-descent region (21st century projections): horizontal temperature advection & its decomposition (JJA)

horizontal temperature advection change dominates MSE divergence change and it has dipole in the projected pattern (as omega at 500 hPa)

$$\langle \mathbf{v} \cdot \nabla T \rangle' = \langle \mathbf{v}' \cdot \nabla T^c \rangle + \langle \mathbf{v}^c \cdot \nabla T' \rangle + \langle \mathbf{v}' \cdot \nabla T' \rangle$$

' 21C minus 20C
c 20C



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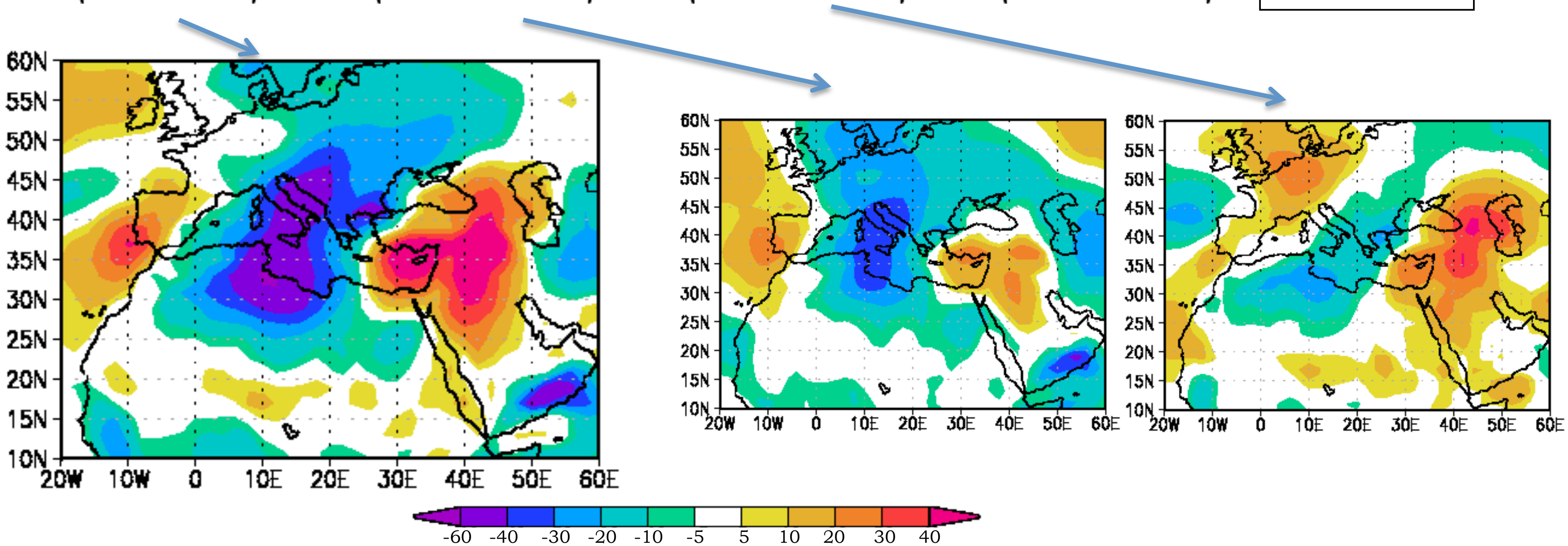

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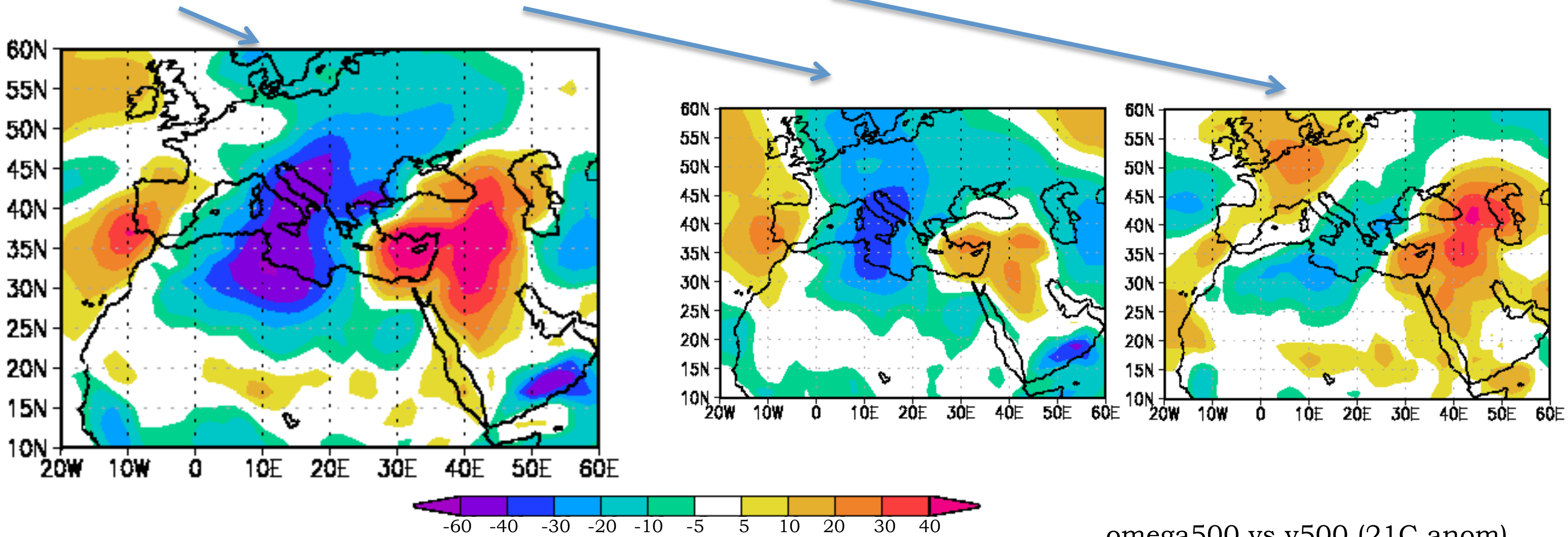
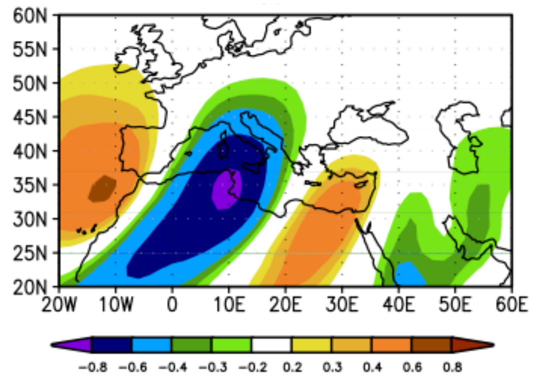


Projected changes in the circulation: "etesian" winds intensify & temperature increase maximize on the east

omega500 vs v500 (21C anom)



Cherchi et al. (2016)

SUMMARY

a quasi-linear relationship exists between the intensities of Q and descent over eastern Mediterranean, despite a large diversity in the precise location of simulated monsoon rainfall and associated Q

the combined Q pattern over the Arabian Sea-Bay of Bengal regions exerts the largest descent over eastern Mediterranean

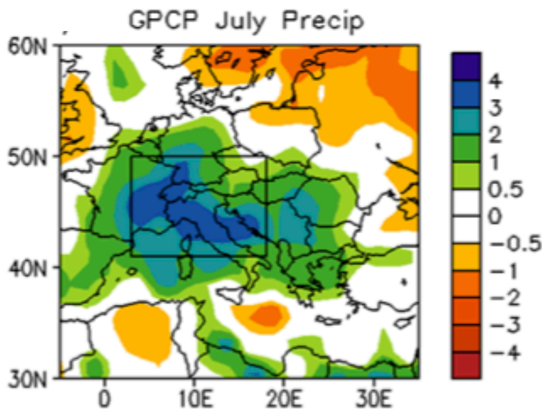
the models tend to underestimate the contribution due to adiabatic descent and to overestimate the contribution from radiative cooling (this suggests that local diabatic enhancement in the models may play a more important role in determining the intensity of the descent)

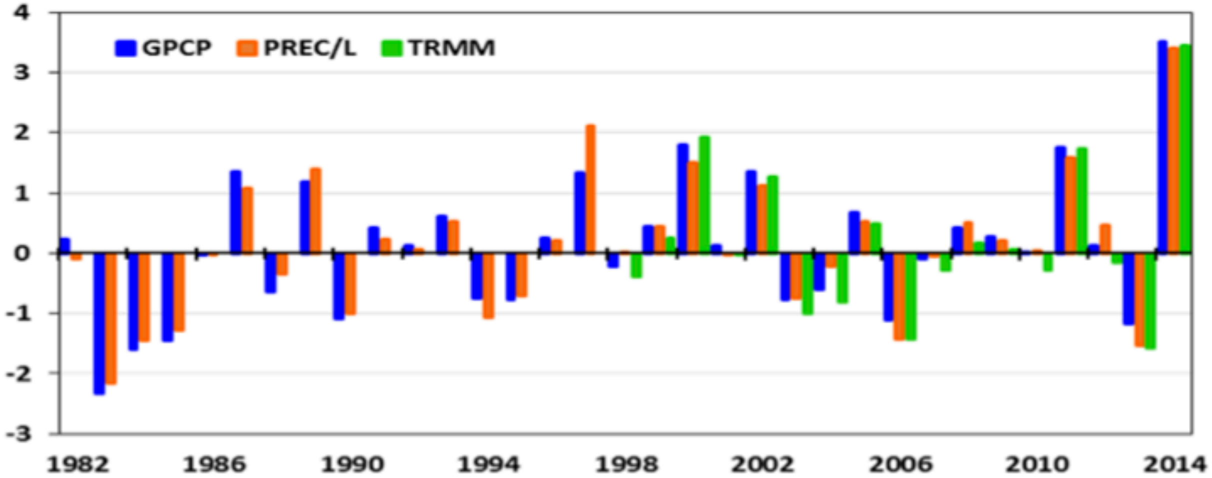
the same physical processes are at work at interannual timescales

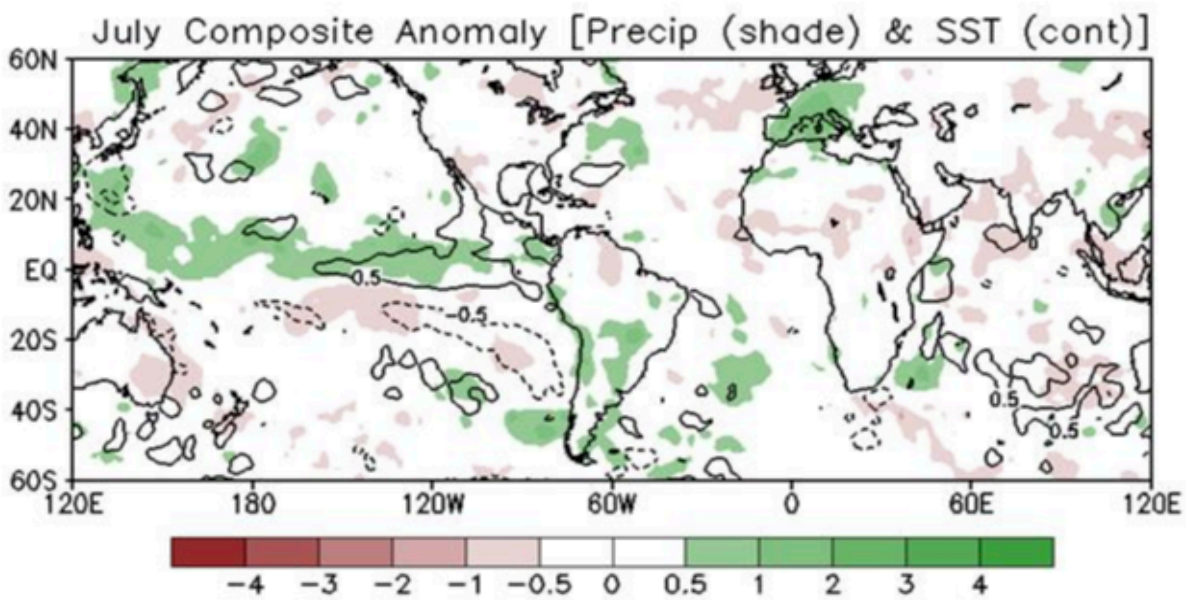
our diagnostics identify few models (i.e. CCSM4, MIROC5, CMCC-CMS, GFDL-CM3, MPI-ESM-LR, CMCC-CM and CESM1-CAM5) that capture the “monsoon-desert mechanism” for correct reasons (results from statistical measures and budget diagnostics converge in their identification)

in climate projections we can relate the changes in subsidence with the changes in the precipitation pattern over South Asia (at least where we have the max in subsidence increase)

The unusual wet summer (July) of 2014 in South Europe







Ratna et al. (under review)

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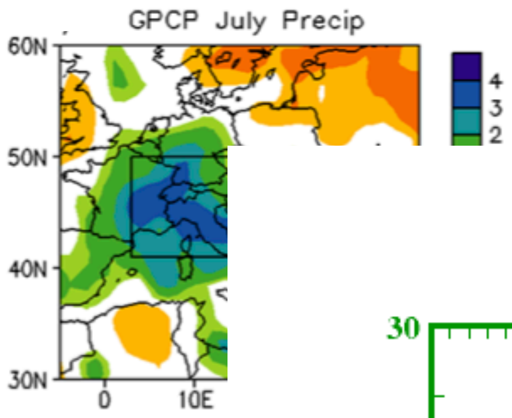

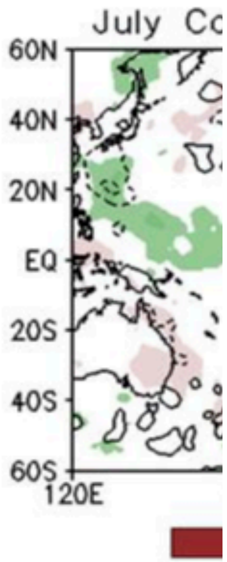

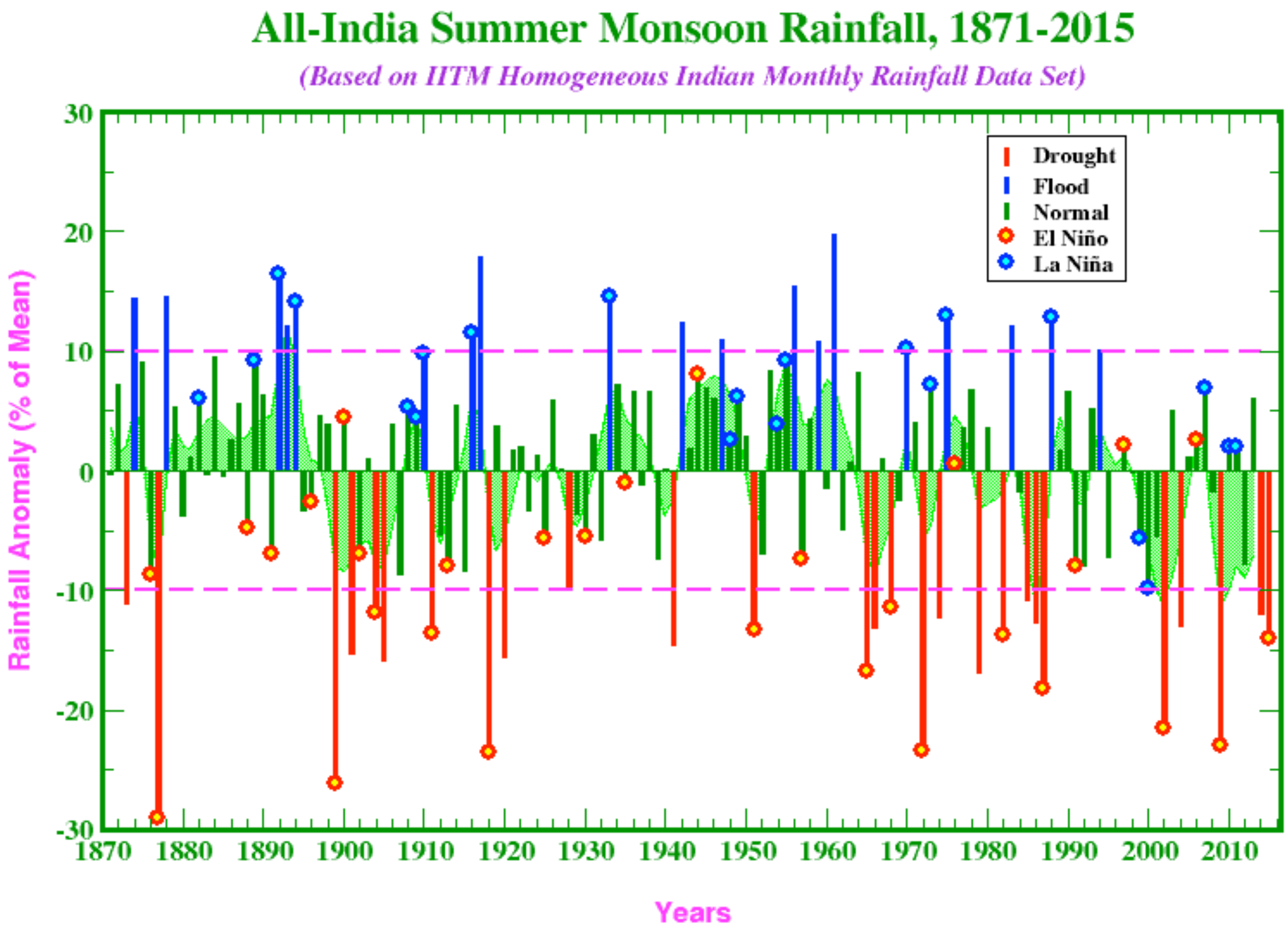

PERSPECTIVES

chances of predictability over Europe (?)

role of monsoon onset

analysis of recent trends (shortcomings of model and projections)

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References:

Cherchi A, Annamalai H, Masina S, Navarra A (2014) South Asian summer monsoon and the eastern Mediterranean climate: the monsoon-desert mechanism in CMIP5 simulations. J. Climate, 27(18), 6877-6903 doi:10.1175/JCLI-D-13-00530.1.

Cherchi A, Annamalai H, Masina S, Navarra A, Alessandri A (2016) 21st century projected summer mean climate in the Mediterranean interpreted through the monsoon-desert mechanism. Climate Dynamics

Ratna SB, Ratnam JV, Behera SK, Cherchi A, Wang W, Yamagata T (2016) The unusual wet summer (July) of 2014 in South Europe. Clim Dyn (under review)

THANK YOU