ESF MedCLIVAR exchange grant 3130 – Report

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ESF MedCLIVAR programme granted me to spend 16 weeks at International Centre for Theoretical Physics (ICTP), Trieste, Italy, hosted by dr. Fred Kucharski. The purpose of the visit was investigation of possible ENSO impacts on European and Mediterranean region in the current and future climate conditions. The stay started on 1 November 2010. During my stay we have been working on two main topics:

1 ENSO impact on Northern Hemisphere atmosphere in a warmer climate, and

2 Delayed winter ENSO impact on spring precipitation in North Atlantic/European region.

The first topic of the investigation involves the study of the changes in the winter atmospheric response to sea surface temperature (SST) anomalies associated with the El Niño–Southern Oscillation (ENSO) in a warmer climate utilizing the two 20–member ensembles made by an atmospheric general circulation model of intermediate complexity developed at ICTP, Trieste, Italy (ICTP AGCM). Warmer climate is simulated by a modification in the radiation parameterization that corresponds to the doubled CO_2 concentration, and SST forcing is represented by the same SST anomalies as in current climate (1855–2002) experiment superimposed on the climatological SST that was obtained from a complex atmosphere–ocean general circulation model forced with the doubled CO_2. SST anomalies in the Niño3.4 region, categorized into five classes, enabled a composite analysis of changes in the Northern Hemisphere tropical/extratropical teleconnections.

The main features of the tropical–extratropical teleconnections are maintained in both experiments; for example, irrespective of the sign of SST anomalies, the amplitude of the atmospheric response is positively correlated with the intensity of ENSO event and the El Niño impact is stronger than that of La Niña of the same intensity. The strongest extratropical signal in the warmer climate, particularly significant for strong warm events, is found over the Pacific/North American region; however, this extratropical teleconnections is reduced in a warmer climate relative to the current climate. Over the North Atlantic/European region, a detectable signal linked to ENSO is found; this model response is significantly strengthened in the experiment with the doubled CO_2 concentration. Such an atmospheric response in a warmer climate is found to be associated with changes in the mean state followed as well as in the jet waveguiding effect and stationary wave activity. The main results of this investigation are presented in the paper "*Winter ENSO teleconnections in a warmer climate*" by Ivana Herceg Bulić, Čedo Branković and Fred Kucharski, which is accepted for publication in Climate Dynamics (Online First, DOI: 10.1007/s00382-010-0987-8).

If we focus more precisely onto European region and particularly to the Mediterranean region, quite important result regarding climate trend and ENSO impact is found. Namely, as depicted in Fig. 1, considerable precipitation change is found for warmer climate conditions associated with doubled CO_2 concentration. Thus, positive winter precipitation anomalies (i.e. wetter conditions) are obtained in the north part of the domain (central and north Europe). Contrary, in the southern part of the domain (particularly Iberian Peninsula and Mediterranean Sea) negative anomalies (i.e. dryer conditions) with maximal values over the eastern Mediterranean are obtained. This implies that precipitation over the easterrn Mediterranean is considerably sensitive to global warming. Furthermore, there is a possibility of enhanced risk of winter floods at the northern part of the domain, while the southern part of the domain, particularly eastern Mediterranean, is associated with possible enhanced risks of droughts.

Such north-south polarisation of precipitation climate trend (Fig.1) is also obtained by some other models with finer resolution as well as for different climate scenarios (e.g. Branković Č, Srnec L, Patarčić M (2010): An assessment of global and regional climate change based on the EH5OM climate model ensemble, Clim Change 98: 21-49, doi: 10.1007/s10584–009–9731–y). This indicates that the warming of SSTs associated with the increased concentration of CO_2 in a future climate would induce similar atmospheric response regardless of the complexity of the model used. In other words, such (an external) change in climate forcing is the dominant factor that clearly overcomes possible modelling differences.

The ENSO impact is investigated by composite analysis that are based on categorisation of years into strong warm (El Niño) and strong cold (La Niña) years. Strong warm (cold) years are defined as those years for which Niño3,4 index is greater (smaller) than $1.5 \cdot std$, where *std* is standard deviation. Niño3,4 index is defined as area-averaged SST anomalies over the Niño3.4 region (the Niño 3.4 region is bounded by 120°W-170°W and 5°S- 5°N). The winter atmospheric response to the winter ENSO forcing is shown in Fig. 2 as precipitation anomalies for the current climate (CTRL, Fig. 2a, b) and warmer climate conditions ($2xCO_2$, Fig. 2c, d). The difference is presented in Fig. 2e, f (statistically significant differences exceeding 95% confidence level are shaded). The Fig. 2 indicates that warm ENSO events have stronger influence on the precipitation than the cold ENSO events in both current and warmer climate conditions. The response does not have the same sign of anomalies over the whole domain. The strongest response is found over the eastern North Atlantic and western part of Iberian Peninsula with wetter (dryer) conditions associated with El Niño (La Niña) events. Thus, the belt with increased (reduced) precipitation associated with warm (cold) ENSO events is stretching from the eastern subtropical Atlantic, across the Iberian Peninsula and southern Europe up to Black Sea. Over the Mediterranean, ENSO impact is the strongest in its eastern part (Greece, Aegean Sea and Crete), particularly for strong warm ENSO events that are associated with dryer than usual conditions. ENSO impact on the considered domain is modified in the warmer climate experiment. Over the eastern North Atlantic the impact is strengthened, but over the southern Europe is weakened. Over the Mediterranean area, the change in ENSO influence shows a weakening of ENSO impact with statistically significant change obtained only for the strong warm ENSO events (Fig. 2e). Comparison of Fig. 1 and Fig. 2 reveales that ENSO has a considerable impact on the eastern Mediterranean area. Its impact is seems to be weaker in warmer climate conditions. Over Iberian Peninsula, El Niño events are associated with more abundant precipitation (according to Fig. 2a) which might diminish to some extent the precipitation reduction associated with warmer climate conditions (Fig. 1), but not considerably since there is found a weaker ENSO impact in climate with warmer conditions. Similarly, over the eastern Mediterranean, where warm ENSO events are associated with reduced winter precipitation, El Niño forcing in warmer climate may cause additional decrease of precipitation, but that reduction is not expected to be significant since El Niño influence on that area is also weaker in warmer climate conditions.

Presented results reveal that ENSO affects Mediterranean region to some extent. Furthermore, that impact is expected to be modified in warmer climate conditions. However, the more detailed study of that impact over relative small area such as Mediterranean region requires a model of higher horizontal resolution than ICTP AGCM has. Therefore, a future study by utilizing outputs of different regional models to create multi-model ensemble is planned (also in collaboration with dr Fred Kucharski, ICTP).

The second topic of my research deals with delayed impact of winter sea-surface temperature (SST) anomalies in tropical Pacific on spring precipitation over the North Atlantic/European (NAE) region. The analysis is based on both measured and modelled data for the period 1901-2002. In an AMIP-type Atmospheric General Circulation Model (AGCM) ensemble, the observed delayed spring precipitation response in Europe to winter ENSO-related SST anomalies is well reproduced. A series of targeted AGCM experiments are performed to further investigate the mechanisms for this delayed influence. Thus, three different SPEEDY experiments were utilized in this study:

1. *CTRL experiment* is the control experiment based on 20-member ensemble of the ICTP AGCM integrations forced by globally prescribed observed monthly SST anomalies. CTRL is the so-called AMIP-type experiments (Gates 1992) whereby atmospheric model is forced with (externally) predefined SSTs and the model reacts to varying SST.

2. *MIX experiment* is based on a 10-member ensemble of integrations performed by using the ICTP AGCM coupled with the passive slab ocean mixed layer in the Atlantic while SST anomalies were prescribed in the tropics. Outside the tropics, SSTs were set to climatological values. Thus, the model integrations in this experiment were forced by the monthly SST anomalies restricted to the tropics, and mixed layer was active during the whole simulation period allowing atmosphere-sea interaction. The mixed layer depth is 50 m.

3. *MIX_winter_ENSO experiment* is 10-member ensemble experiment with the same settings as in the MIX experiment but forced by prescribing time-restricted SST anomalies in tropics. In this experiment, the SST variability was prescribed during the October, November, December, January, February and March of every year (allowing an ENSO development in tropical Pacific during the cold period of year). During the rest of every year, SST anomalies were set to zero (i.e. there were only climatological SST values prescribed), apart from the North Atlantic, where an ocean mixed layer was coupled during the whole year. The purpose of this experiment is to investigate the delayed mixed-layer response and its influence on European climate. Thus, CTRL experiment is based on the ICTP AGCM simulations forced with observed global SSTs, MIX experiment is performed with ICTP AGCM forced with SSTs in tropical Pacific and coupled with mixed ocean slab layer in Northern Atlantic.

It is found that late winter ENSO SST anomalies lead to the well-documented Rossby wave train arching from the Pacific into the Atlantic region. A positive (negative) ENSO event leads to a quasi-barotropic trough (ridge) in the North Atlantic region. The resulting wind and cloud changes cause anomalies in the surface heat fluxes that result in negative (positive) SST anomalies in the central North Atlantic and anomalies of the opposite sign further to the south. The SST anomalies persist into spring and the atmospheric response to these anomalies is an extension of the ENSO-induced trough (ridge) into the

European region, leading to enhanced (reduced) moisture flux and low-level convergence (divergence) and thus positive (negative) precipitation anomalies. Although the signal is overall relatively weak (correlation coefficients of European spring rainfall with winter ENSO SSTs of about 0.3), a proper representation of the outlined mechanism in seasonal forecasting systems may lead to improved seasonal predictions.

Over the Mediterranean region, the delayed ENSO impact is rather weak. Still, mostly increased (decreased) spring precipitation following a winter warm (cold) ENSO event is found at the northern Mediterranean coast (Fig. 3 and Fig. 4). This result is obtained for Climate Research Unit (CRU; Fig. 3) precipitation as well as for modelled precipitation (Fig. 4).

The paper presenting those results is submitted to Climate Dynamics and is under review now. Also, the results will be presented at European Geosciences Union General Assembly 2011as a poster at Session CL2.10 (EGU2011-11817; "*Delayed ENSO impact on spring precipitation over North Atlantic/European region*" by Ivana Herceg Bulić and Fred Kucharski).

A preliminary study revealed possible differences regarding atmospheric response to ENSO forcing over different parts of European region (including Mediterranean region). More detailed spatial investigation of ENSO impact on European region requires model output at finer grid that ICTP AGCM has. Therefore, as an extension of our work, we have also started a more detailed analysis of ENSO impact on European region based on simulations by models with higher horizontal resolution (e.g. MPI_ECHAM5) as well as by regional climate models (e.g. RegCM3 simulations). This investigation will be continued in further collaboration with dr Fred Kucharski (ICTP; Trieste).

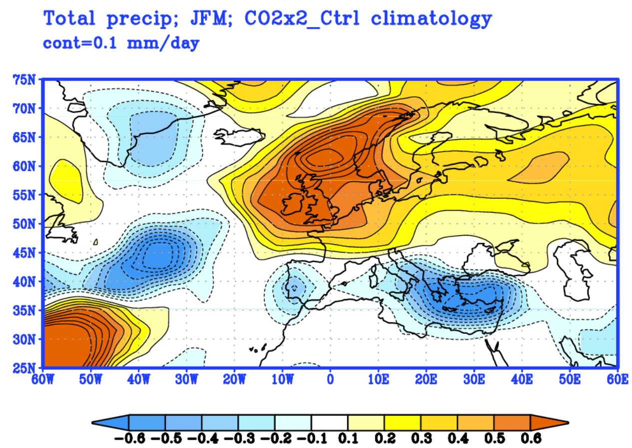

Fig. 1 JFM differences between $CO2\times2$ and CTRL climate for total precipitation. Contours every 0.1 mm/day.

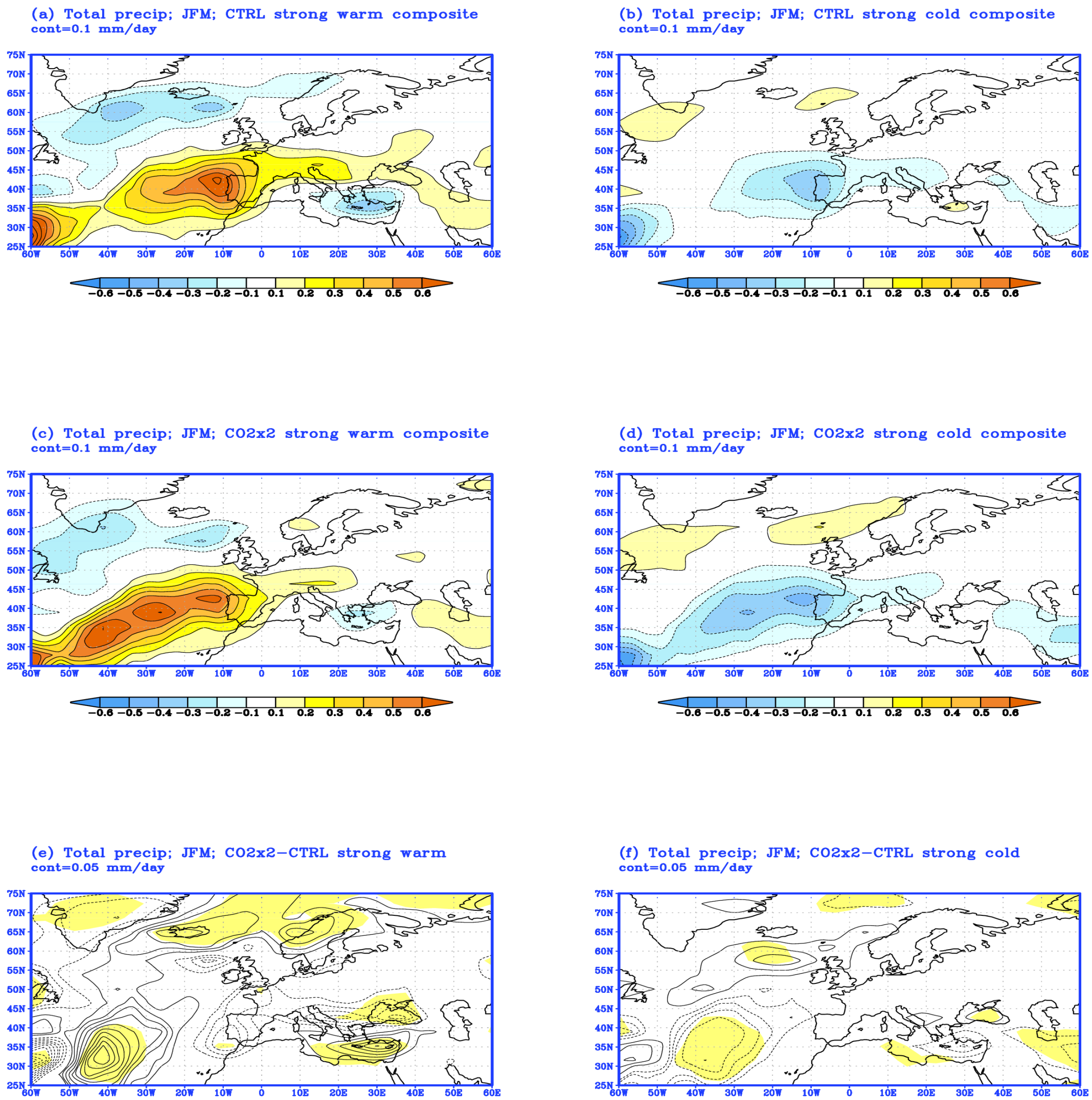

Fig. 2 Total precipitation anomalies in JFM for a) CTRL strong warm composite, b) CTRL strong cold composite, c) CO2×2 strong warm composite, d) CO2×2 strong cold composite. Total precipitation differences between CO2×2 and CTRL in JFM for e) strong warm composite, and f) strong cold composite. Contours in a) to d) 0.1 mm/day dam, in e) and f) 0.05 mm/day. Values exceeding the 95% confidence level of the *t*- statistics are shaded in e) and f).

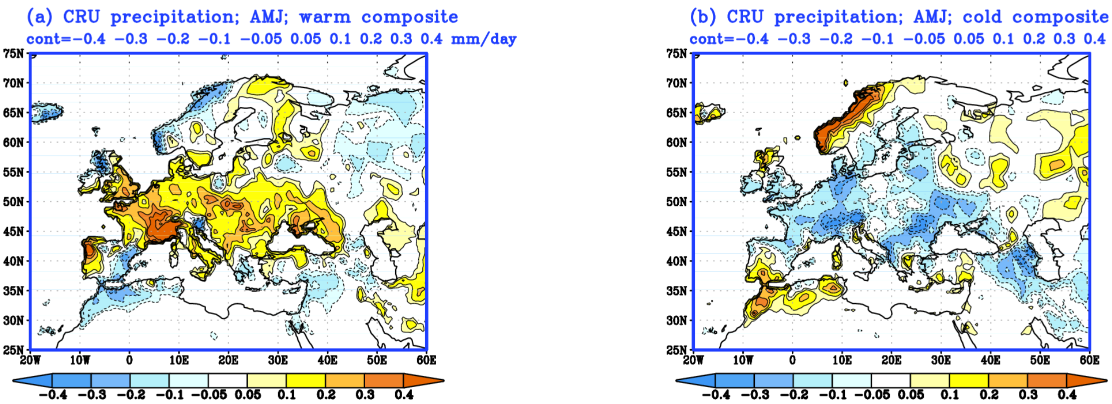

Fig. 3 The spring (AMJ) CRU precipitation composites for: a) warm JFM ENSO events and b) cold JFM ENSO events. Contours every 0.05, 0.1, 0.2, 0.3 and 0.4 mm/day. Negative values are *dashed*.

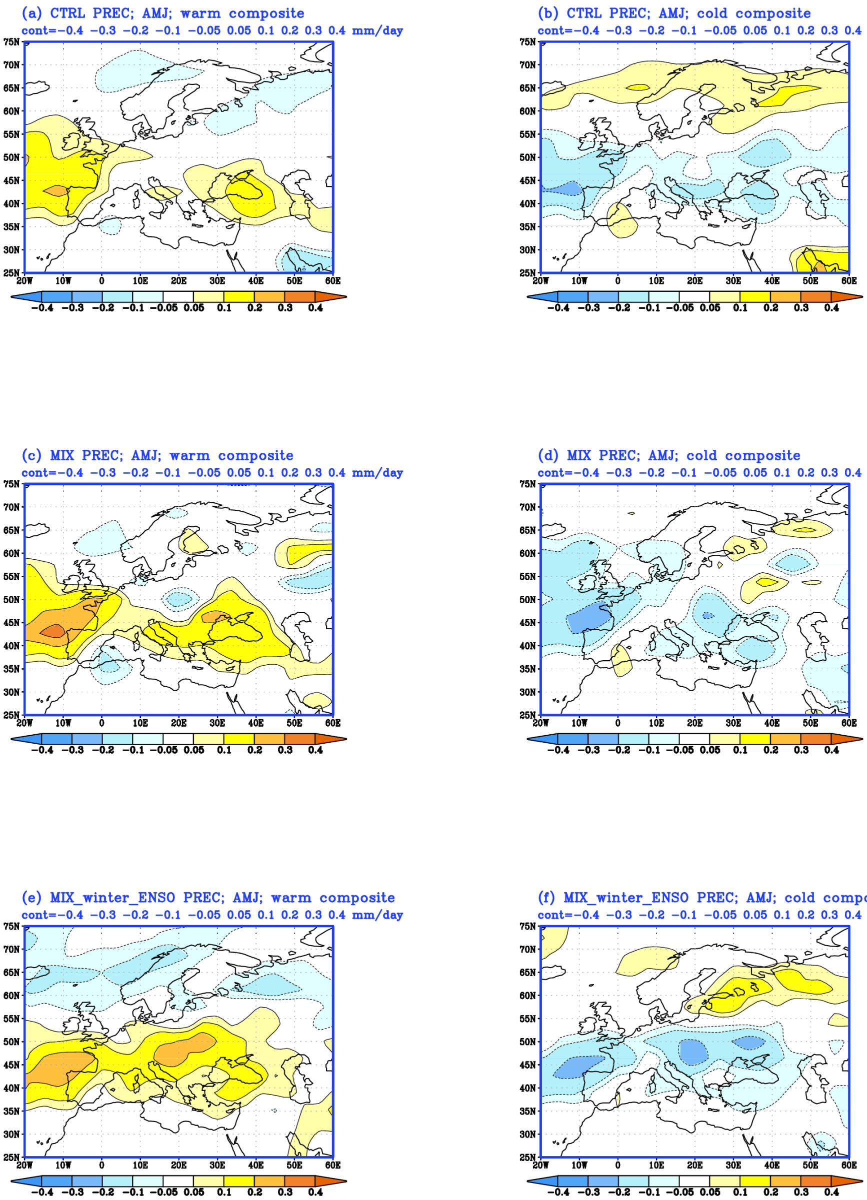

Fig. 4 Warm ENSO composites of spring (AMJ) precipitation anomalies for a) CTRL; c) MIX; d) MIX_winter_ENSO and cold ENSO composites of spring (AMJ) precipitation anomalies for b) CTRL; d)MIX; f) MIX_winter_ENSO experiment. Contours every 0.05, 0.1, 0.2, 0.3 and 0.4 mm/day. Negative values are *dashed*.