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Mediterranean climate future: an insightful look into the Basin's precipitation response to greenhouse gas forcing

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Abstract

In a new investigation of model projections of greenhouse gas warming impact on the Mediterranean, Zappa *et al* (2015 *Environ. Res. Lett.* **10** 104012) find that the decline in basin-wide precipitation scales linearly with the strength of the 850 hPa zonal wind over North Africa. This result supports previous findings that climate change will affect the Mediterranean primarily through changing the regional atmospheric circulation. The results of this study may guide improvements of climate models to better simulate the impact of greenhouse gas warming in this critical world region.

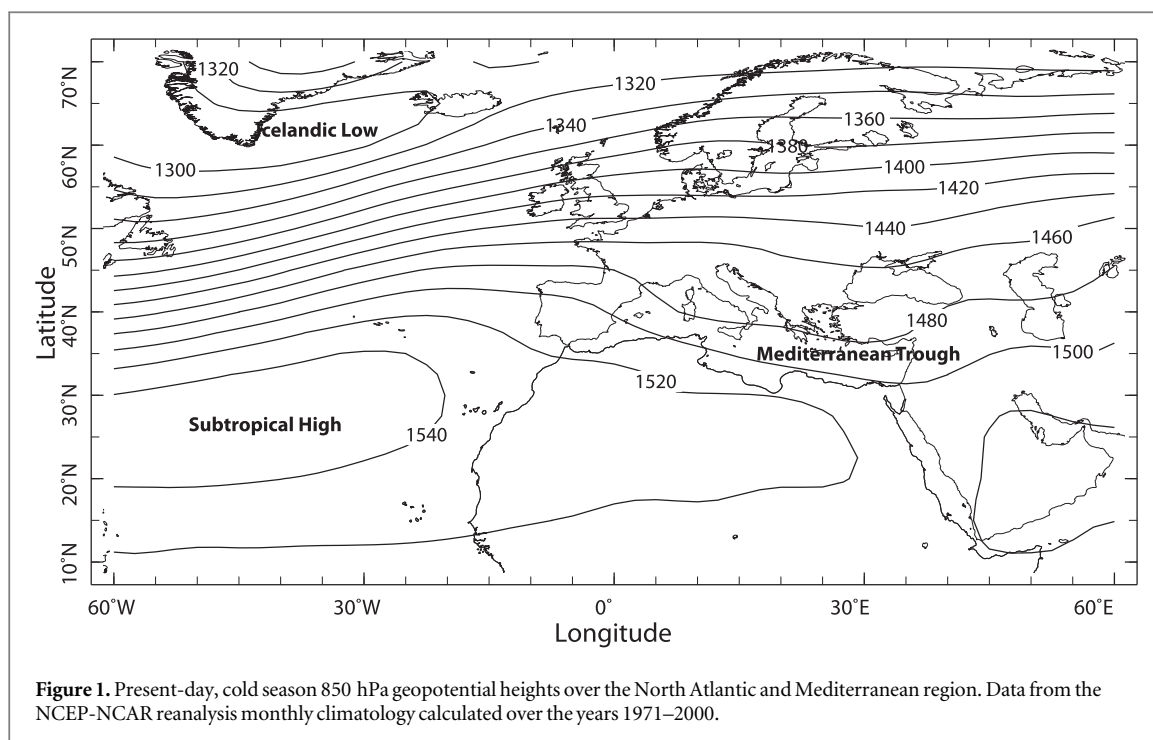
The Mediterranean Sea marks the boundary between the desert belt of North Africa and Arabia and the temperate climate zone of Eurasia. The Mediterranean has for millennia provided a pathway for commerce and a source of food but above all, a source of moisture that fed the seasonal rains over the surrounding land areas. These rains, which prevail between October and May and the mild temperatures encouraged human settlement in the region and enabled early development of agriculture. It is primarily the climate factor that spurred the emergence of the flourishing Mediterranean civilizations that have continued to enchant us to the present day. That said, large and significant fluctuations in water availability as well as droughts and related food scarcity have been a characteristic signature of Mediterranean climate and shaped the history of its people (e.g., Roberts *et al* 2011, Mercuri *et al* 2011). Today, the increase in anthropogenic greenhouse gas concentration threatens to strain the inhabitants of Mediterranean countries further through a gradual, persistent decrease in rainfall (Mariotti *et al* 2008; Hoerling *et al* 2012). In fact, it is plausible that greenhouse gas drying has already affected the weaker countries in the region contributing to social instability, conflict and open war (Kelly *et al* 2015).

As Zappa *et al* (2015a) describe in their letter, climate models of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2013) unanimously agree on the sign of the

forced Mediterranean drying trend, albeit with a large degree of uncertainty regarding its rate. It is the search for quantifying and understanding the IPCC model uncertainty that motivates the present study.

The increase in atmospheric greenhouse gas concentration impacts climate in two distinct ways: by forcing a rise in global surface and air temperatures, greenhouse gases contribute directly to an increase in the moisture carrying capacity of the air. As a result, world regions into which moisture tends to converge, that is where precipitation surpasses evaporation, are expected to see an increase in rainfall while regions from where the atmospheric flow acts to diverge moisture will face increased moisture deficits (Held and Soden 2006). This first effect of greenhouse warming is generally referred to as the 'thermodynamic effect'. Consistently with this effect, the atmosphere immediately above the Mediterranean Sea, which is a source of moisture for the surrounding land areas, is projected to see an increase of evaporation and therefore an already observed increase in sea surface salinity (Mariotti *et al* 2008).

But what about the surrounding land regions? The primary facilitators of the transfer of moisture from sea to land in the Basin are the wintertime Mediterranean cyclones (Seager *et al* 2014, Zappa *et al* 2015b). Changes in the activity of these storms are governed by a different effect of greenhouse gas warming referred to as the 'dynamic effect', which is related to a change in the permanent and transient atmospheric



circulation systems. Such is the case, for example, when the eastward migrating cyclones divert from their present-day course because of climate change or if their frequency is reduced or increased. As a group, the models used to project the impact of greenhouse gas warming in the recent IPCC assessment (referred to as the Coupled Model Intercomparison Project 5 or CMIP5 models) agree markedly on the reductions in cyclonic activity over the Mediterranean Basin (Stocker *et al* 2013, see chapter 12, figure 20, Zappa *et al* 2015b).

Here Zappa *et al* (2015a) demonstrate that the dynamic effect of greenhouse gas warming dominates the Mediterranean's hydroclimatic future. They uncover the importance of this effect by looking at the relationship between the seasonal mean basin-wide precipitation and the average zonal (west-east) 850 hPa wind over North Africa. Pooled over all historical CMIP5 simulations, year-by-year, the Mediterranean wet season departure of precipitation from its climatological mean is linearly related to a similarly calculated departure of the 850 hPa wind. A similar linear relationship is also exhibited by observations. Moreover, the climate-change precipitation departure scales with the wind in the same way that year-by-year variability does. This simple relationship thus opens the way to compare the models' precipitation sensitivity to greenhouse gas forcing to what can be deduced from observations. This comparison shows that the excluding one case, the models might be less sensitive to climate change than what is expected from observations.

The novelty of what Zappa *et al* (2015a) find, is that rather than painstakingly calculating each model's reduction in Mediterranean cyclone activity (a

method that involves detecting and tracking cyclones in 6 h weather maps) it is enough to measure the strength of the seasonal mean 850 hPa zonal wind over North Africa to determine the seasonal precipitation response. The intensity of the seasonal mean wind over the southern Mediterranean countries constitutes a simple measure of the intensity of the seasonally averaged, atmospheric circulation over the Basin. Presently, the Mediterranean resides under a weak pressure trough from Europe, which together with a high pressure belt over North Africa and the Sahara Desert drives a mean westerly flow (see figure 1). We might view subtropical high-pressure belt over North Africa as an expression of the sinking branch of the Hadley Cell, which with greenhouse warming was found to expand poleward (Lu *et al* 2007). Over the Mediterranean this poleward spreading is particularly robust for reasons that are so far not well understood. This is associated with the weakening of the Mediterranean trough, with the suppression of Mediterranean cyclone activity and therefore with a reduction in rainfall. This explains the success of the metric used by Zappa *et al* (2015a) though not its remarkable linearity and general applicability.

More work is needed to understand why the Mediterranean climate displays such coherent dynamical response to greenhouse gas warming. Such understanding will help determine why different models display different sensitivity to the forcing and why their sensitivity tends to be weaker than suggested by observations. All this may help improve the models and their projections over the Basin and possibly elsewhere. From Zappa *et al* (2015a, and see also Kelley *et al* 2012) it appears that within the Mediterranean Basin, the response is largest over the far western and eastern ends

of the Basin, over the Iberian Peninsula and the Atlas Mountains and over the Middle East, respectively. Why that is so is also important to understand as it has clear political and global security implications. Overall, this study paves the way for improving our ability to assess the pattern and strength of future regional climate change.

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