in *Nature Climate Change*, Marvel *et al.*[6] showed that these non-CO_2 forcings have distinct effects on temperatures that are not directly equivalent to CO_2. These findings call for what amounts to a downward adjustment to the effective forcing on climate, and thus for an upward revision to observational estimates of climate sensitivity and TCR — another 30% (or so) that is multiplicative with the revision by Richardson *et al.*

The final term, eventually, refers to the time it takes Earth to fully respond to an imposed climate forcing — several thousand years, or more, due to the large heat capacity of the oceans. Thus, observations tell us about a comparatively early phase of warming. Although observation-based studies make the implicit assumption that climate sensitivity estimated today will still apply in the distant future, a recent line of research[7–11] calls this into question based on a robust behaviour of climate models — in the early warming phase, climate sensitivity appears smaller than its true value. This requires yet another upward revision to observation-based estimates (by around 25%, on average) in order to achieve an apples-to-apples comparison with models.

Although each of these independent revisions could stand to be better understood and more fully quantified, so far it seems that their tendencies are robust. In aggregate, the findings indicate that observation-based estimates of climate sensitivity and TCR may be substantially higher than previously reported, aligning them more closely with the range simulated by climate models and raising the spectre of a very warm future (Fig. 1). ❐

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Published online: 27 June 2016

HYDROLOGY

What brings rain to the Sahel?

The Sahel has suffered through severe droughts but recent years have seen increased rainfall. Now research suggests warming of the Mediterranean Sea surface may dictate future rainfall in the region.

Michela Biasutti

Squeezed between the hyper-arid Sahara desert to the north and the lush tropical forests of the Gulf of Guinea and Central Africa, is the Sahel: a ribbon of semi-arid land where summer brings heavy rain but the rest of the year is a prolonged dry season. Normal rains can sustain agriculture and pastoralism, but drought has horrific consequences, as was often the case in the 1970s and 1980s. However, the most recent decades have seen an upswing of rainfall, prompting many to hope that climate change is bringing the onset of another pluvial, and scientists to debate the causes of the recovery. Writing in *Nature Climate Change*, Park, Bader and Matei[1] suggest that increasingly warm temperatures in the Mediterranean Sea have brought anomalous moisture to Africa and have caused the recent trend towards a wetter Sahel. The moistening effect of a warm Mediterranean had been identified before[2,3], but this study suggests that anthropogenic warming of the West Pacific has changed the basic state of the tropical ocean in a way that has left extratropical influences — and the Mediterranean in particular — to dominate Sahel variability now and into the future. The analysis of multi-model ensemble simulations suggests that the degree of warming in the Mediterranean will thus determine the degree of wetting in the Sahel.

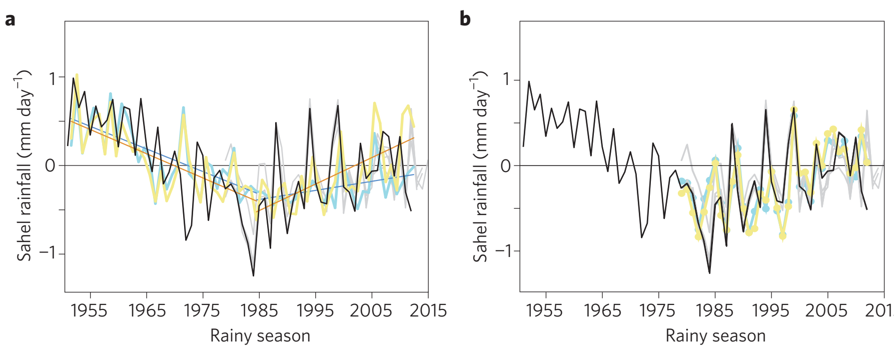

Figure 1 | Inclusion of Mediterranean SST or direct GHG forcing increases the simulated wetting trend in the Sahel, but does not improve the mismatch between models and observations. **a**, Observed Sahel summer rainfall anomalies in several datasets (TS3p2 in black; CHIRPS, TRMM3B42, GPCP and CMAP in grey) compared to AM3 simulations with (yellow) and without (blue) forcing from the Mediterranean. Figure adapted with permission from ref. 1, NPG. **b**, The same observations are compared to the ensemble average of 60 simulations forced by observed SST and observed radiative forcing by atmospheric composition changes (yellow) and 50 simulations by the same models, without the direct radiative forcing (blue). The CAM4, ECHAM5, and LBNL-CAM5-1-1degree simulations were obtained from ref. 16.

The mechanisms of Sahel rainfall variability are many, and not easily separable. It is now accepted that twentieth-century Sahel droughts were paced by variability in the global sea surface temperature (SST)[4,5]. Seminal early work[6] highlighted the connection of the drought with greater warming in the Southern Hemisphere oceans, compared to the Northern, in what might be a reorganization of the entire Hadley circulation[7]. Subsequent studies have parsed the effect of global SST anomalies into regional components, whose path of influence over the Sahel is easier to discern in a mechanistic way. Warming in the tropics — in the Eastern Pacific[8] during an El Niño event and especially, over longer time scales, in the Indian Ocean[4,9] — increases temperatures in the free troposphere across the tropics, which stabilizes the atmosphere and inhibits convection over Africa[10]. The extratropical North Atlantic might influence the Sahel via the Sahara, as anomalously humid and warm air advected from a warm ocean increases regional sea-level pressure gradients and the monsoon flow[11]. Finally, warming in the tropical or subtropical North Atlantic[10,12] or the Mediterranean[1,2] would moisten the monsoon flow and the Harmattan (the northeasterly trade wind from the Sahara), that converge from the west and the northeast into the Sahel — providing more fuel and less inhibition for convection and supporting heavier rainfall. Greenhouse gases (GHGs) can also influence surface temperature and energy fluxes over the continent directly[13], and models uniformly respond to increased atmospheric concentration with a wetting of the Sahel[13]. The issue, however, is that these paths of influence carry different weight in different models[14] and might not add up linearly[5,13].

Park and colleagues suggest that such non-linearity is what has allowed the Mediterranean to become a dominant player in Sahel rainfall variability in recent decades, as the warm West Pacific has saturated the influence of tropical variability, leaving extratropical influence to dominate. But, by the same token, non-linearity complicates the task of stacking the influence of single forcings against each other and determining which one is dominant: a forcing-by-forcing decomposition assumes that the response to a given forcing 'all else being equal' is the same even when all else is not equal. In simulations by Park and colleagues, the precipitation response to tropical and extratropical SSTs do not neatly add up to the response to the global SST, complicating the interpretation of their results.

Moreover, although it is clear that a colder (warmer) Mediterranean consistently makes the simulations drier (wetter) in the Sahel in the early (late) decades (Fig. 1a), including the Mediterranean forcing does not necessarily make the model match the observations more convincingly[1]. Indeed, the simulated wetting of the last decade exceeds observations. A similar problem had marred the specular claim of a previous study[15], namely that the recovery is all due to GHGs and not at all to the SST. Rising concentrations of GHGs during the last decades does indeed produce additional wetting, but it does not substantially alter how well the models match observations (Fig. 1b). Focusing on only one number, the trend, misses important information, including the apparent and worrisome increase in year-to-year variability[12]; focusing on only one aspect of a complex forcing gives rise to contradictory results, by suggesting that a particular mechanism is dominant, when no such signal has yet emerged.

In solving the mystery of Sahel rainfall, we might have to give up the satisfactory simplicity of a game of Cluedo — one culprit, one weapon — for the complex drama of a film noir. But Park and colleagues[1] have shown us that we had overlooked a suspect: the warming of the Mediterranean will likely be playing an important role in the next decades. Their results make our understanding of the possible outcomes for Sahel rainfall more complete. ❐

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Published online: 27 June 2016

VEGETATION PRODUCTIVITY

Humans did it

Observed vegetation change in the Northern Hemisphere can, with a high degree of confidence, be attributed to human-caused global change.

Robert Buitenwerf

During the past three decades, the vegetation over vast areas of the Northern Hemisphere has been changing. That, in short, is the conclusion from a host of studies using satellite measurements. These studies have found changes that include 'greening' trends, increased plant productivity[1] and earlier starts to the growing season[2]. The detected changes are consistent with what might be expected from global change, including climate change, elevated atmospheric CO_2, nitrogen deposition and land cover change. For example, the rapid warming of Arctic regions may enable shrubs to replace herbaceous plants and consequently increase productivity[3]. Hence, not only have studies correlated vegetation change to global change, there are also well-known physiological and ecological mechanisms through which global change might be expected to force the observed vegetation changes. It may come as a surprise then that direct attribution of vegetation change to global change has proved challenging. Writing in *Nature Climate Change*, Mao *et al.*[4] go some way to filling this gap with a cleverly conceived study that combines mechanistic modelling, experiments and observational data.

The difficulty with attributing vegetation change to global change is that the different mechanisms of change are often correlated