Dealing with Uncertainties of Future Climate: The Special Challenge of Semi-Arid Regions

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Abstract

Semi-arid regions face a range of threats from climate change, including droughts, flash flooding, soil degradation and erosion, desertification and water scarcity. For example, climate change is expected to decrease runoff and increase water resources stresses around the Mediterranean basin. However, precipitation scenarios are notoriously difficult to produce for such areas because of the high variability and intermittence of rainfall in space and time. The task may be further exacerbated by complex orography and sparse observational networks. Nonetheless, tools and techniques are urgently needed to support regional climate change assessments, especially for developing countries in semi-arid and arid regions. This paper reviews the latest techniques for constructing regional rainfall scenarios in semi-arid areas such as the Mediterranean basin, North Africa and parts of the Middle East. Projections made from different climate models and downscaling techniques typically show large variations at river basin scales. Hence, there is increasing emphasis on indentifying "low regret" adaptation solutions – those that make good sense regardless of the future climate scenario. Examples include seasonal forecasting to improve preparedness for drought, or a return to traditional water harvesting techniques. Other approaches such, as sensitivity analysis, help identify "tipping points" or limits to adaptation. However, efforts to characterise supply-side uncertainties must ultimately be balanced by initiatives to reduce water demand and hence minimise long-term vulnerability.

Key words: Climate change, dryland, scenario, downscaling, uncertainty, precipitation

1. Introduction

It is widely accepted that the inhabitants of drylands are amongst some of the most vulnerable to climate change anywhere (UNDP, 2007). Furthermore, many arid and semi-arid regions (in both the developed and developing world) are experiencing rapid urban population growth through a combination of migration and high fertility rates, placing even greater demands on local water resources. At the same time the very character of these precipitation regimes presents major technical challenges for accurate monitoring of water resources and modelling future impacts (regardless of the level of investment of observing networks). Water management in drylands is generally problematic because of:

- High variability of rainfall in time due to the seasonal migration of monsoon rains, or strength of major circulation patterns such as the El Nino Southern Oscillation (ENSO) or North Atlantic Oscillation (NAO)
- High variability of rainfall in space depending on the proximity to water bodies, and the interplay of moisture-laden airflows with complex, high-elevation terrain (as in Figure 1)
- Significant fractions of the annual rainfall total being delivered in very short periods of time by extreme events such as local convective storms, or cyclones
- Abrupt changes in rainfall regimes over decadal time-scales linked to a combination of ocean temperature changes, regional land-surface feedbacks, and anthropogenic greenhouse gas emissions, as in the case of the Sahel drying since the late 1960s
- Sparse and/or decaying land-based networks for meteorological, surface and groundwater monitoring
- Limited monitoring and reporting of direct and indirect impacts of the changing climatology on socio-economic and environmental systems.

Figure 1. *The Hadramawt, Yemen in the late 1920s.*

Not surprisingly, the above represent significant factors that are confounding development of climate change projections, attendant impact assessment and adaptation options appraisal. This paper outlines two main strategies that have been applied to date: the so-called “top down” scenario-led approaches and the vulnerability based "bottom up" methods. It is contested that the former may have limited applicability across the Middle East and North Africa (MENA) region, and that more attention should be focused on "low regret" adaptation measures that yield societal benefits NOW, and are robust, regardless of the climate outcome. These points are illustrated using two case studies taken from opposite ends of the MENA region and extremes of the methodological spectrum.

2. The case studies: Morocco and Yemen

Even without climate change, many drylands are already facing a water crisis. This is certainly the case for both Morocco and Yemen. Both have high population growth rates (when compared, for example, with Spain); high water scarcity (as defined by the widely cited World Health Organisation definition of <1000 m3/yr/per capita); high-dependence on rain-fed agriculture; and low levels of access to clean water supplies in rural areas (Table 1).

Table 1. *Country snapshots. Source: United Nations Statistic Division.*

Index	Morocco	Yemen	Spain
Population (1000)	31,478	20,975	43,064
Growth rate (%)	1.5	3.1	1.1
Water per capita (m^3/yr)	921	195	2578
GDP agriculture (%)	16	13	3
Rural water access (%)	56	65	100

As noted above, long-term, systematic records of precipitation and temperature are very scarce in the MENA region. Data are often tied to specific projects such as irrigation schemes, or to short-lived monitoring campaigns. Available data suggest that even by global standards, the MENA region has experienced rapid warming (especially in summer). There have also been reported declines in the number of cold nights. Observed rises in annual mean temperatures for the Mediterranean basin and North Africa as a whole fall within the range expected by the IPCC climate models given past emissions of greenhouse gases (Figure 2).

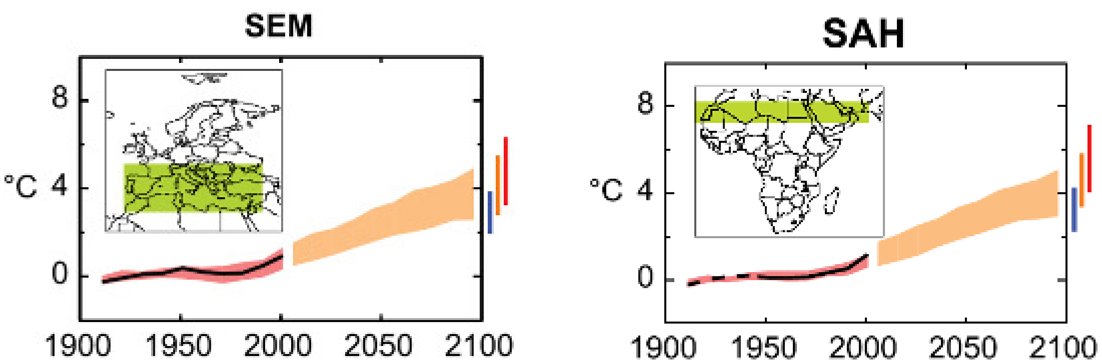

Figure 2. *Temperature anomalies with respect to 1901-1950 for the Mediterranean basin (SEM) and the Sahara (SAH) land regions for 1906-2005 (black line) and the Intergovernmental Panel on Climate Change (IPCC) climate model ensemble (red*

envelope) under known forcing; and projected to 2100 under A1B (orange), B1 (blue) and A2 (red) emission scenarios. Source: Christensen et al. (2007).

Observations and climate reconstructions show that over multiple decades and century timescales the NAO has been the dominant influence on large scale patterns of winter precipitation, river flow and surface temperature across the Middle and Near East. Winter rainfall over Southern Europe and North Africa has declined since the 1970s partly as a consequence of a strongly positive phase in the NAO since that time. In Yemen, summer monsoon rains are affected by variations in the northward migration of the Inter Tropical Convergence Zone (ITCZ). In common, with the Sahel, Yemen has witnessed a decline in monsoon rainfall since the late 1960s.

Morocco's annual and seasonal rainfall totals are highly variable: the coefficient of variation for annual totals ranges between 25% close to the Atlantic to over 100% in the Sahara. Nationally, spring rainfall has declined by over 40%, and the maximum dry-spell length has increased by 15 days since the 1960s. Annual maximum wet-day totals have increased in the northwest but the trend is not significant

Unfortunately, there are insufficient data for long-term trend analysis, even of annual totals, for much of the rest of the MENA region (see the grey areas in Figure 3). Nonetheless, several notable high-intensity precipitation events and attendant societal impacts have been reported (e.g., Algeria in 2001, Morocco in 2002, Tunisia in 2003, Oman in 2007) but, again, observing networks are too sparse and records to short for formal trend detection in extremes.

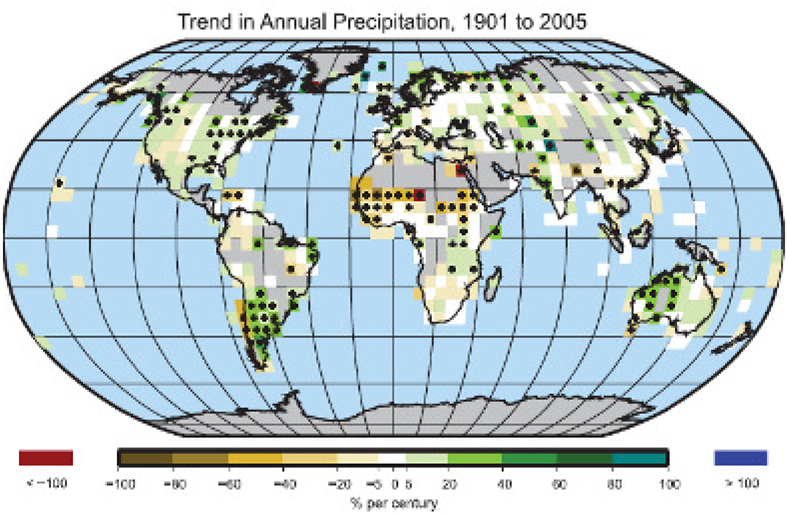

***Figure 3.** Trend of annual land precipitation amounts for 1901 to 2005 (% per century) using the Global Historical Climate Network (GHCN) precipitation data set. The percentage is based on the means for the 1961 to 1990 period. Areas in grey have insufficient data to produce reliable trends. The minimum number of years required to calculate a trend value is 66 for 1901 to 2005. An annual value is complete for a given year if all 12 monthly percentage anomaly values are present. Note the different colour bars and units in each plot. Trends significant at the 5% level are indicated by black + marks. Source: Trenberth et al. (2007).*

3. Global climate model (GCM) projections and uncertainty

According to the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (FAR), Africa is expected to experience more rapid warming than the global average during the 21st century, with the drier subtropics warming more than the moist tropics. The largest temperature changes in North Africa are projected to occur in summer. Annual rainfall is expected to decrease over Mediterranean Africa and the northern Sahara. The annual number of precipitation days is very likely to decrease and the risk of summer drought is likely to increase around the Mediterranean basin. This is widely regarded as a robust scenario that is applicable to Morocco. However, there is no such consensus amongst the 21 climate models about the sign of the projected changes in winter, summer or annual rainfall for Yemen (see Figure 4).

This large uncertainty is presumably related to poorly characterised precipitation processes for East Africa and the Middle East within the present generation of climate models. Even under observed climate conditions, regional climate models (RCMs) such as RegCM3 are known to over-estimate rainfall totals in areas of high elevation (see for example, Pal et al. 2007). Presumably, these limitations might be reducible in time through improved monitoring and understanding of fundamental climate controls leading to further model development and refinement. However, for the time being the "uncertainty mask" (i.e., blank areas) shown in Figure 4 provides a useful basis for judging where scenario-led adaptation strategies might be justifiable, and where the uncertainty is simply too great to meaningfully assist decision-makers.

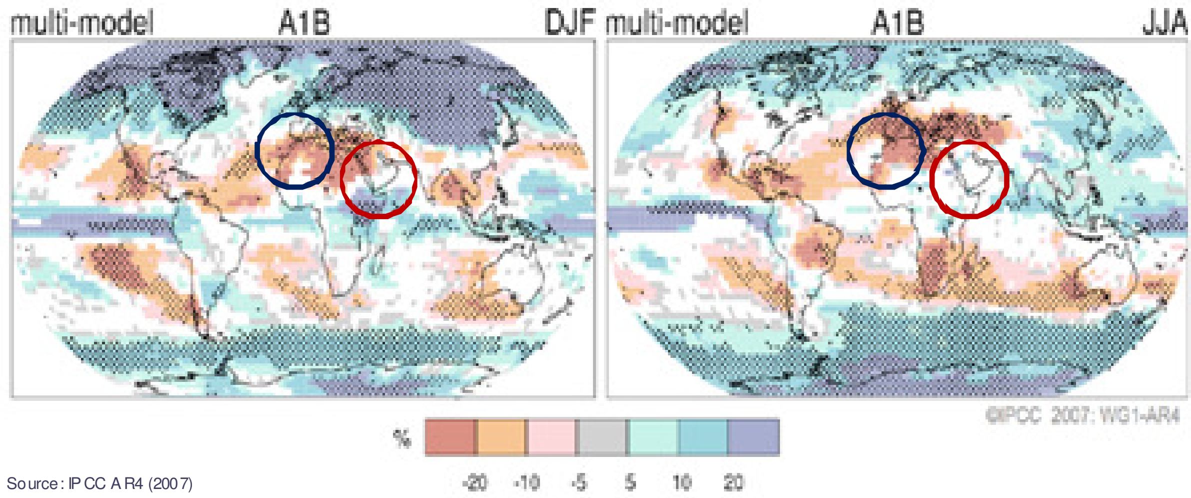

Figure 4. *Changes (%) in precipitation for 2090-2099 compared with 1980-1990 based on multi-model average projections under the SRES A1B scenario. White areas show where the model consensus about the sign of the change is less than 66%; stippled areas where 90% of models agree about the sign. The case study regions centred on Morocco (blue circle) and Yemen (red circle) are also shown. Adapted from IPCC SPM (2007).*

4. Top down scenario-led impacts assessment

Downscaling techniques are widely employed to improve the spatial (and sometimes temporal) resolution of GCM output under present and future climate conditions. This involves deriving physically-sensible empirical relationships between local variable(s) of interest (such as daily precipitation) and large-scale atmospheric predictors (such as sea level pressure, humidity, etc) (Figure 5). For a recent review and a critique of hydrological applications see respectively Fowler et al. (2007) and Fowler and Wilby (2007).

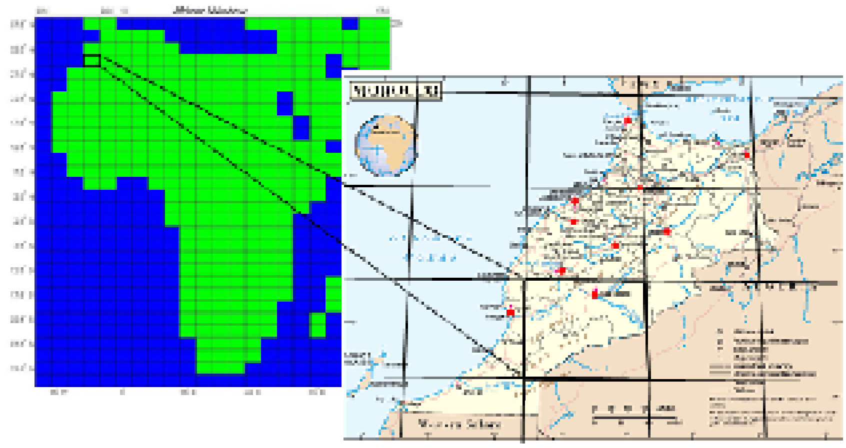

Figure 5. *Location of meteorological stations (red dots) used for downscaling shown in relation to the overlying grid cells of HadCM3. Source: Wilby and DMN (2007).*

As evidenced by illustrative results produced by the Statistical DownScaling Model (SDSM) (Wilby et al., 2002) for Casablanca, credible representations can be made of daily temperature and rainfall totals at local scales given *observed* large-scale weather patterns (Figure 6). Indeed, the World Bank has been piloting a web-based climate scenarios portal for the MENA region (see: http://go.worldbank.org/NT4CG9W6K0). With further development, the tool could weight scenarios originating from different climate models and downscaling techniques, as well as provide "point-and-click" access to ensembles of daily temperature and precipitation series at individual meteorological stations across the region.

The ability to access multiple climate experiments is important because downscaled scenarios for the *future* are dependent on the choice of GCM used to supply the predictor variables and on the downscaling method itself (Figure 7). Where there is consensus amongst the GCMs about the regional climate change downscaled scenarios may convey a consistent outlook, as in the expectation of drier conditions for Morocco. These scenarios can then inform quantitative assessments of climate impacts on agricultural and water sectors, and help frame uncertainties arising from emissions, natural climate variability, regional climate and impacts modelling. However, where there is no such consensus, the downscaled scenarios might yield unhelpfully wide uncertainty in local rainfall scenarios, as in the case of Yemen (not shown).

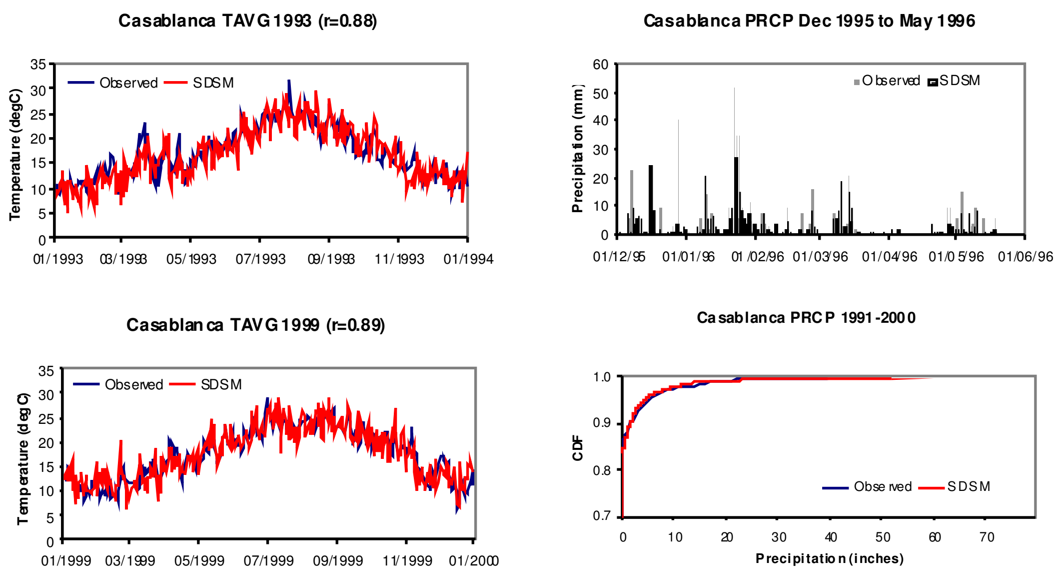

Figure 6. *A comparison of observed and statistically downscaled mean daily temperatures (TAVG) and daily precipitation amounts at Casablanca, Morocco. Source: Wilby and DMN (2007).*

5. Bottom up vulnerability assessment and low regret options

The "blank areas" on maps of projected rainfall (Figure 4) cover large parts of Africa, south Asia and Latin America – perversely those very regions where integration of climate risk information in adaptation planning is of highest priority. Although the anthropogenic climate change signal is detectable and growing, it is expected to remain a relatively small component (when compared with large climate variability of drylands) for the next few decades. Hence, whilst the sustainability of Millennium Development Goals (MDGs) could be undermined by climate change in the long-term, risk exposure will be greatest where human and environmental systems are already marginal (such as some rain-fed agricultural regions, or coastal zones subject to frequent flooding). In these cases, even modest changes in the mean climate or to extremes could be sufficient to cross a threshold or tipping point. Furthermore, even modest changes in meteorological conditions could be amplified by non-linear responses in water supply systems.

Given the large uncertainty in regional rainfall scenarios coupled with the already high vulnerability of populations, it makes sense to identify robust strategies that perform well (though not necessarily optimally) over a wide range of conditions faced NOW and potentially in the future. It is unlikely that "no regret" adaptation measures can be identified as there is often an opportunity cost or trade-off associated with most interventions. Instead, "low regret" measures should meet present needs as well as keeping open or maximising options for adaptation in the future. For example, protecting water sources from contamination or salinization is a sound strategy under any climate context. Likewise, long-term monitoring of environmental quality is a necessary for establishing sustainable resource use and for benchmarking changing conditions or the outcome of management decisions. Other types of low regret measure are listed in Table 2.

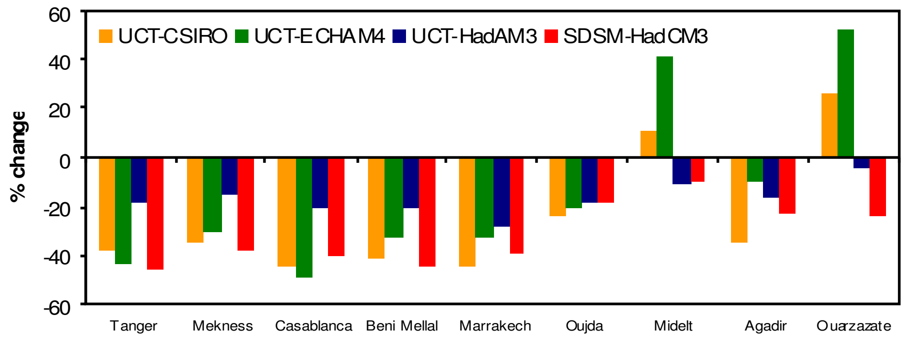

Figure 7. *Changes (%) in annual precipitation totals projected by different downscaling methods (UCT, SDSM) and GCM boundary forcing (ECHAM4, CSIRO, HadAM3, HadCM3) under A2 emissions by the 2080s. Source: Wilby and DMN (2007).*

Table 2. *Examples of "low regret" adaptation measures for water management.*

Scientific and climate risk information
• Support meteorological data rescue and digitization • Monitoring baseline and environmental change (indicators) • Improve surface and groundwater resource models • Improve scientific understanding of regional climate controls • Develop real-time, seasonal and decadal forecasting capability
Water management practices
• Improve water governance and methods of allocation • Undertake source protection from pollution and salinization • Facilitate agricultural (and urban) drainage water re-use • Undertake asset management and maintenance (leakage control) • Improve water efficiency (domestic, agricultural, industrial sectors) • Develop faster growing and/or more drought resistant crop cultivars • Employ traditional water harvesting and storage techniques

Adapting better to *present* climate variability is regarded by some as the first step towards addressing the greater development and scientific challenges posed by climate change (Washington et al., 2006). To this end, there is growing interest in seasonal forecasting as a means of increasing preparedness of society to climate extremes, especially in the agricultural and water sectors. For example, seasonal climate forecasts combined with real-time monitoring can help plan agricultural activities (such as crop planting, fertilizer and pesticide application, irrigation scheduling, etc.), wildfire, rangeland, reservoir and hydro-power management, or provide alerts for extreme events, disease control, and civil construction. However, seasonal forecasts are known to be most effective when credible, disseminated in user-accessible formats, and targeted at appropriate scales.

There must of course be a useful level of predictive skill for the region(s) and seasons of interest. For example, evaluation of the Met Office seasonal forecasts for Africa suggests that skilful outlooks of monsoon rainfall are currently possible for Yemen, with two or three months lead time (Figure 8).

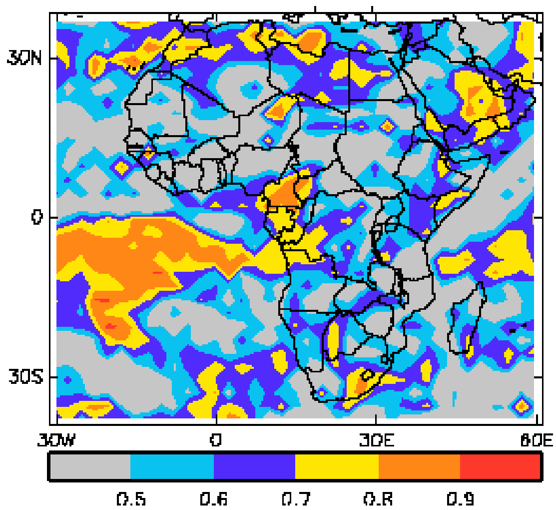

Figure 8. *The Relative Operating Characteristic (ROC) score (defined as the ratio of the hit rate to the corresponding false-alarm rate) for forecasts issued in March of below average rainfall in April-May-June. Regions of greatest forecast skill are shown in colours other than grey. Source: Met Office.*
(http://www.metoffice.gov.uk/research/seasonal/)

One of the most advanced seasonal forecasting systems developed to date provides outlooks for the drought-prone State of Ceará in northeast Brazil. By global standards, rainfall and river flow anomalies in this region have high predictability with lead times of several months. Skill is greater under El Niño precursor conditions than La Niña implying greater utility and/or potential benefits to decision-makers concerned with managing drought. Even so, forecast signals are relatively weak compared with model uncertainty and inter-annual variability, so forecasts must be expressed in probabilistic terms.

Each year the Ceará State Foundation for Meteorology and Water Resources (FUNCEME), in partnership with the National Institute for Space Research (INPE) issues forecasts for the rainy season following an established format. The process begins in November with a review of Tropical sea surface temperature (SST) anomalies. These are carried forward as boundary conditions for climate model forecasts of rainfall anomalies in January-February-March. Developments of the SST fields along with forecasts from several dynamical models are then reviewed at a December/January workshop attended by a panel of experts and users. The forecasts are published at the end of the workshop. FUNCEME then continues to monitor ocean and atmosphere conditions and releases forecasts to end-users via a public-domain web-site (http://www.funceme.br).

Seasonal climate forecasting is expected to become more skilful as further data on ocean conditions become available through global arrays such as the Argo floats. These instruments provide data on sea surface (and deep-ocean) temperatures and salinity that can improve the boundary conditions used to initiate forecasts. The same data can also help detect changes in large-scale climate forcing (such as the ocean cooling) which may herald abrupt changes in regional precipitation regimes.

6. Concluding remarks

Water scarcity is already a major concern for dryland communities. For example, recent estimates suggest that Yemen's annual water overdraft is presently 40% greater than the sustainable resource. Rising demand and reduced water supply under climate change, combined with increased frequency of hydrological extremes, are expected to multiply present risks to livelihoods and biodiversity across the MENA region. Unfortunately, the precipitation regimes of drylands are characterised by high variability in space and time, and their understanding hindered by sparse observational records, and by decaying monitoring networks.

In view of these physical and scientific challenges it is hardly surprising that uncertainty surrounds climate model projections of rainfall for much of the region. This in turn brings into question the "predict and provide" strategies that are typically advocated for climate adaptation. Instead, the blanks on the map should be challenging scientific and policy communities to consider how best to support robust decision making in the face of deep uncertainty and socio-economic tipping points. There are already many low regret options open to national and international governments, not least of which is to commit to long-term environmental monitoring and data sharing. These are prerequisites to filling knowledge gaps, detecting changes in natural systems, building better climate models, driving seasonal weather predictions, and adapting management within a broader human development context. Such measures would accrue societal benefits regardless of the longer-term climate outlook.

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