# A Need for Actionable Climate Projections Across the Global South

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***Inconsistent climate projections for much of the Global South from six generations of IPCC assessments, have compounded the many challenges it faces in adapting to climate change. Here, we propose using emerging technologies and strengthening international collaborations to address these challenges.***

The Global South[1], which hosts the majority of the world's population, is unequivocally more vulnerable to climate change than the Global North due to widespread poverty, income inequality, and its heavy dependence on climate-sensitive sectors. In contrast, the affluent North, which is mostly comprised of high-income countries[1], is better poised to face climate change, particularly in implementing mitigation and adaptation policies[2]. Climate risks are exacerbated for the Global South because climate projections that inform adaptation policies are found to be inconsistent over many of its most vulnerable regions (see the Box1), a major pitfall in effective policymaking[3]. Therefore, it is imperative to provide actionable climate projections for the Global South, though doing so is a challenge.

**Inconsistency in climate projections**

The majority of countries in the Global South, in the absence of their own national or regional climate assessments, mainly draw guidance from the periodic assessments carried out by the Inter-governmental Panel on Climate Change (IPCC). But the distillation of these assessments to the national or regional scale is plagued with uncertainties because for some regions, the projections made by the IPCC are inconsistent, and at times contradictory (Fig. 1). For instance, the six generations of IPCC assessments are wildly inconsistent for precipitation and temperature in South Asia and undermine effective policymaking. Similar inconsistencies in climate projections are also observed for other regions of the Global South. Considering this uncertainty, the current guidance provided by the IPCC is effectively unactionable in many regions.

The issue of inconsistent regional projections needs to be addressed by a concerted effort on the part of the climate modeling community, policymakers, and governments. Here, we present suggestions to improve future projections, making them more accurate and better constrained to be useful for national level climate policies. These ideas and suggestions that are motivated by inconsistencies seen in South Asia can be easily extended and generalized to help ramp up climate adaptation efforts across the Global South, considering the existence of analogous socio-economic structure and climate risks for many of its countries.

**Kilometer-scale modeling**

Parameterized physical processes are a major source of disagreement in climate projections[7]. This issue can be alleviated by using the Kilometer-scale (k-scale) modeling approach as doing so would explicitly capture previously unresolved processes and eliminate the need for many existing parameterizations[4,5]. K-scale modeling is expected to improve the representation of complex topographies and other surface properties, mesoscale processes and associated feedbacks, and moist convection and gravity wave drag[5]. K-scale modeling efforts are already underway in affluent countries, and some countries, like the UK, have started using "convection permitting models" to project climate at regional scales[6]. As k-scale modeling needs huge infrastructural advances and a quantum leap in computational resources[5], lower income countries from the Global South are not able to adopt such models. This issue may be addressed with a collective global effort that explicitly includes the needs of the Global South and by an increased cooperation between less affluent countries in building their own modeling capacities together. Both options demand unprecedented cooperation to strengthen scientific and technological capabilities, develop a cluster of regional climate modeling centers and shared exascale computing infrastructures[7]. Dedicated data output facilities equipped with state-of-the-art technology such as Artificial Intelligence and Machine Learning (ML) must be built to evaluate and deliver the projections of k-scale modeling in a timely, well-informed, and consistent manner. The Destination Earth[8] of European Commission is a concerted effort on the part of EU countries to assist those that cannot individually afford setting-up such ambitious facilities. Similarly, countries from the Global South can coordinate their discrete and loosely coordinated efforts, mobilize their resources, and expand their network of expertise and capacity building beyond the spheres of academic projects to build one or a constellation of climate modeling centers. This can be done perhaps at least at a continental scale through multi-governmental engagements fostering cooperation rather than competition and thus enhancing collective capabilities[1,7].

**Region specific model customization**

On a parallel track, an effort should be made by the nations from the Global South to bolster regional climate modeling and projection efforts, which can enhance the reliability of country scale future projections. India is currently pursuing such an initiative at IIT Delhi for the customization of a global model for high resolution treatment of the Indian region, with promising early results. The outputs from this effort can be downscaled to finer resolutions, and subsequently bias corrected using local observations with some of the advanced post processing techniques tailored for end-to-end sectoral climate change assessments[9]. Unlike k-scale modeling approach, an interim solution like this does not require substantial investment in computing infrastructure and can be immediately extended for other regions in Global South.

**Machine and deep learning approaches**

The parameterization of sub-grid scale processes which is a major source of uncertainty can be improved by adopting machine and deep learning approaches. Leveraging the power of convection resolving models and observations (where sufficient observations are available), with the help of deep learning and its integration in GCMs, to prognostically simulate sub-grid scale processes could improve convective parameterization in next generation models[10]. The interconnected non-linear nodes of a deep learning network allow learning from statistical covariates approximating non-linear relationships effectively which rather are oversimplified in traditional parameterization. This can sufficiently improve representation of the tropical convection and vegetation in Earth System Models[10,11]. These emerging techniques should be implemented in parallel by existing and proposed climate modelling centers based in the Global South to deliver a computationally inexpensive and short-term solution for reducing the uncertainties in climate projections.

**Constrained climate projections using observations**

In recent decades, the increasing availability of quality observations along with an emergence of innovative statistical methods such as emergent constraints (ECs) have facilitated new ways of model evaluation with the goal of providing more policy relevant future projections[12]. For example, evaluation through process based emergent constraints for narrowing uncertainty which are usually done at a global scale, can be used to constrain regional scale projections too[13]. Moreover, the direct diagnosis of patterns of forced change from observations, as a constraint on models, could reduce uncertainty. These observations can be preferably of variables that do not exhibit substantial internal variability such as ocean heat content and sea level rise[14]. In addition, instead of using the typical approach of model democracy, which gives equal weightage to all models for generating multi-model ensemble (MME) mean, models can be ranked based on their performance. Higher weights can be assigned to better performing models for a region before generating the MME in simulating a certain climatic feature over that region[15]. These weighting techniques could be driven by ML methods to capture the non-linearity instead of simple linear regressions[11]. Both approaches could work more efficiently for region-specific evaluation of climate simulations, across the Global South, facilitating the detection of new ECs in regional processes and assignment of weights based on regional scale performance of models, thus reducing uncertainty in climate projections.

**Regional climate assessments**

A comprehensive and periodic assessment focusing primarily on countries and regions of the Global South would also prove to be beneficial for attentive evaluation of climate change and its regional impacts. Although some of the countries, such as India, have already realized the need for periodic national assessments, the intermittent and irregular nature of these reports poses a challenge for policymakers. For instance, the first assessment report[16] for India was released in 2010 utilizing the CMIP3 and PRECIS (Providing Regional Climates for Impact Studies) model data. The next assessment report[17] was released in 2020 after a long decade based on the next generation of climate models of CMIP5 and CMIP6. Considering the rapid change of climate and the concurrent rapid advancements of technological capabilities, ten years is a long period to reissue assessments. Moreover, these assessments are not yet mandated and regulated by law, which exempts the concerned government agencies from being accountable. So, more frequent climate assessments not only keep the political liability in check but also minimize damages arising out of date policies and associated course corrections. An example can be drawn from the Fourth National Climate Assessment (2017-2018)[18] in the USA, which is a part of a comprehensive effort to assess the climate and make useful projections every four years at ultra-high resolution guiding the nation's climate policies.

## Concluding remarks

In summary, these proposed approaches provide initial steps through which climate modelers can help to address a major challenge – informing societies and policymakers in the Global South of the uniquely momentous challenge they face in dealing with climate change, with limited resources and high vulnerability. Given the similarities amongst nations across the Global South, there is an opportunity to leverage shared insights. Along the way, lessons will be learned, and an optimal approach can be assessed and refined with the goal of guiding these nations through the challenges they are bound to encounter in the coming decades as climate change and its impacts intensify. The relevance of IPCC for national and regional climate policies can be improved if it increases its focus on publishing integrated information for targeted problems required by policy makers and governments rather than on more general climate change topics. Doing so would entail structural and procedural reforms in IPCC; a detail discussion is beyond the scope this paper. Meanwhile, until these suggestions bear fruits for the Global South, its countries should constantly increase the adaptive capacity through conducting detailed hyperlocal (district or sub-district level) climate risk assessments and making use of new financial innovations such as extra-regional risk pooling by strongly advocating for a Global Resilience Reserve Fund[19].

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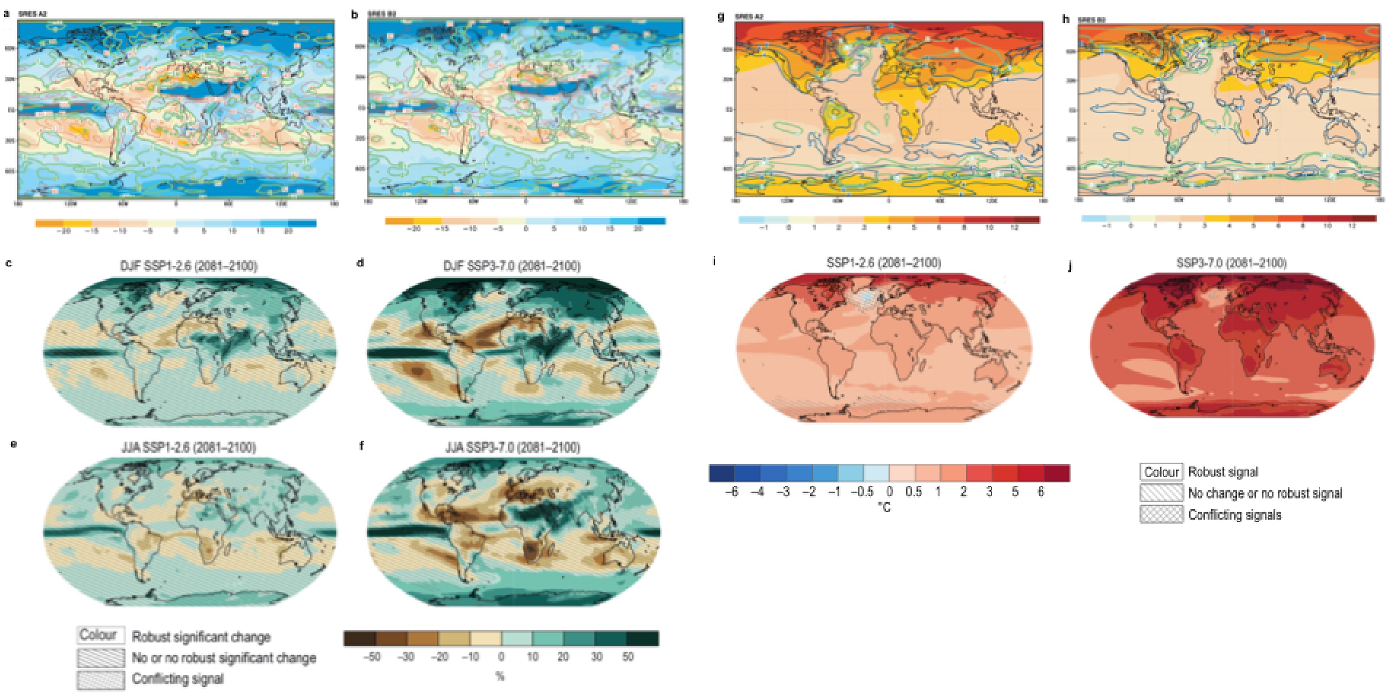


**Fig. 1 | Spatial distribution of projected changes in precipitation and surface air temperature**. **a,b,** Projected changes of annual mean precipitation from the Third Assessment Report[20] (TAR) for the period 2071-2100 relative to baseline period 1961-1990 for SRES A2 **(a)** and SRES B2 (**b)** emission scenarios. **c-f**, Projected changes of seasonal mean precipitation from Sixth Assessment Report[21] (AR6) for the period 2081-2100 relative to baseline period 1995-2014 for the two scenarios SSP1-2.6 (**c,e**) and SSP3-7.0 (**d,f**) and two seasons DJF (**c,d**) and JJA (**e,f**). **g,h,** Same as (**a,b**) but for surface air temperature. **i,j,** Projected changes of annual mean surface air temperature from AR6 for the period 2081-2100 relative to baseline period 1995-2014 for SSP1-2.6 (**i**) and SSP3-7.0 (**j**) emission scenarios. The figures are adapted from IPCC reports as – **a**, from Fig. 9.11 (d) of page no. 550, TAR[20]; **b**, from Fig. 9.11 (e) of page no. 551, TAR[20];

(**c**,**d**,**e**,**f**) from Fig. 4.24 of page no. 602, AR6[21]; **g**, from Fig. 9.10 (d) of page no. 547, TAR[20]; **h**, from Fig. 9.10 (e) of page no. 548, TAR[20]; (**i**,**j**) from Fig. 4.19 of page no. 595, AR6[21].

**Box1:**

## Inconsistency in climate projections for South Asia from six IPCC assessments

We assess and discuss the lack of consistency in projections for South Asia across six generations of IPCC assessments. It focuses on the projections of annual temperature and precipitation (also seasonal mean whenever available) in South Asia, the two time-mean climatic parameters that play influential roles in informing policy.

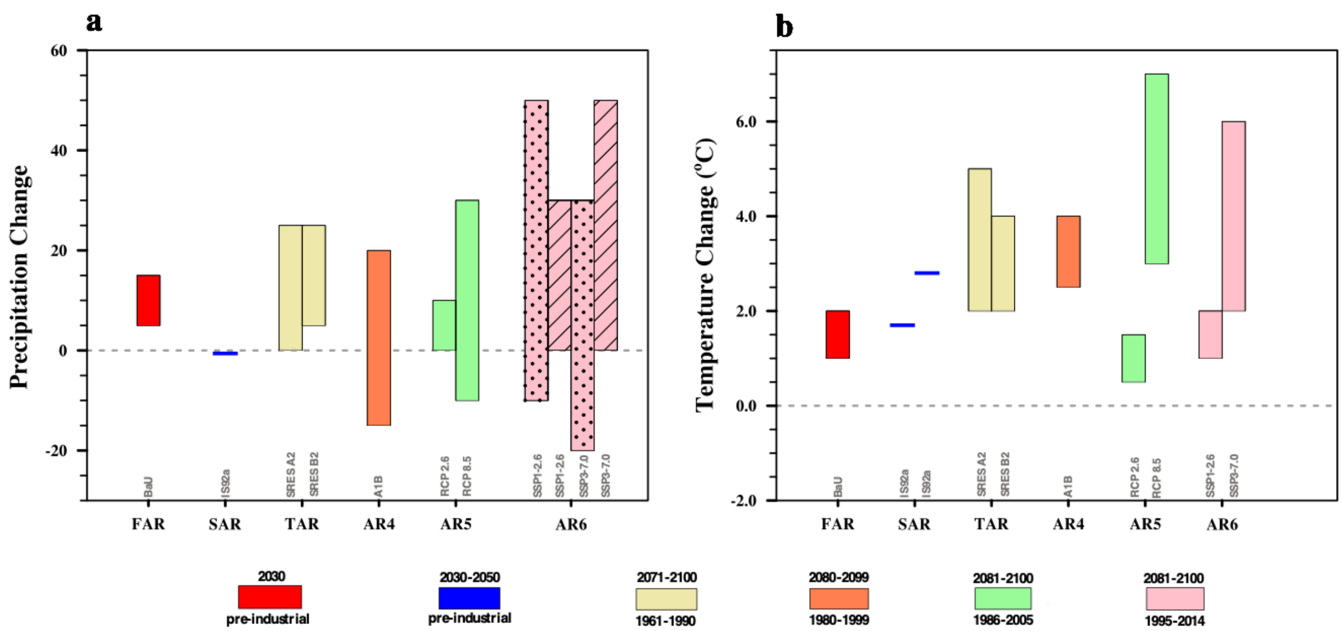


**Fig. 2 | Projected changes in precipitation and surface air temperature for South Asia**. **a**, Projected precipitation changes from the six IPCC reports for different emission scenarios — First Assessment Report[22] (FAR) for BaU, Second Assessment Report[23] (SAR) for IS92a, TAR for SRES A2 and B2, Fourth Assessment Report[24] (AR4) for A1B, Fifth Assessment Report[25] (AR5) for RCP2.6 and RCP8.5, and AR6 for SSP1-2.6 and SSP3-7.0. Projections are shown for annual mean precipitation from all the reports except for FAR (summer), SAR (summer), and AR6 (winter – stippled and summer – hatched) for which seasonal precipitation projections are presented. The precipitation projections are presented in terms of percentage change in the projected period (mentioned above the labels) w.r.t. the base period (mentioned below the labels) except for SAR for which it is only available in absolute scale (mm day$^{-1}$). **b**, Same as (**a**) but for surface air temperature with some differences for FAR, SAR and AR6. Projections are shown for annual mean surface air temperature for all the reports except for SAR for which the projections are shown for the winter (first bar) and summer (second bar).

**Precipitation**

Across the six IPCC assessment reports – FAR to AR6, precipitation projections for South Asia are inconsistent, varying considerably in magnitude and distribution. For instance, the contrasting sign of changes in annual precipitation across various scenarios considered from FAR to AR5 are noteworthy, despite the difference in their temporal range of projections. The change in precipitation from TAR to AR5 for an almost overlapping period of projection ranges from -15% in AR4 to 30% under RCP8.5 in AR5. It is to be noted that the time scale of projection was extended in TAR and the successive assessments until the end of the century, and the baseline period has been updated regularly (refer Fig. 2 for more details). The spatial distribution of changes in precipitation also varies across regions and in magnitude; for instance, the projected increase in precipitation in TAR was mainly contributed by a prominent increase (~20%) over the western part of South Asia, comprising Northwest India, Pakistan, Iran, and Afghanistan; but the increase in precipitation as reported in AR4 is contributed dominantly by an increase over the Indian subcontinent (10-20%), whereas the westernmost parts (~15%) are rather reported to be exhibiting a decrease in rainfall unlike TAR. Surprisingly, the projected increase in precipitation for both the scenarios in AR5 and AR6 is not statistically robust over most of the region, except for a few, indicating significant inter-model spread. To conclude, projected precipitation changes and their regional distribution for South Asia vary considerably across the reports, both in terms of magnitude and even the sign of change.

**Temperature**

The surface air temperature over the South Asia region is projected to increase over time in conjunction with related extreme events like heat waves and extreme rainfall and their associated impacts on human health, ecosystems, and energy demands. Across reports, there are considerable inconsistencies in magnitude of temperature change and more disparities in spatial distribution of the same. The magnitude of change in temperature ranges from 0.5 ˚C under RCP2.6 scenario in AR5 to 6 ˚C under RCP8.5 scenario in the same report. All other reported changes for different scenarios for different seasons across reports vary considerably within this range. Leaving aside the first two primitive reports in the series due to lack of spatial information, the regional distribution of temperature changes in the successive reports reveals that the northern part of South Asia is warming more than the southern part, with most intense warming (~4˚C) over the northwestern region (Afghanistan, Pakistan, and Northwest India), moderate (~3˚C) over central India, and modest (~2˚C) over the Indian peninsula and Myanmar, as disseminated by AR4. However, the projected change in temperature is spatially homogeneous over the region in the latest AR5 and AR6, with much smaller regional variations than in their predecessors.

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**Author information**

SKM and PU conceived the study and designed it with inputs from JTF. All the authors contributed to the analyses and in writing the manuscript.

**Competing Interest**

The authors declare no competing interest.