

Local observation, global investment: A framework for next-generation precipitation monitoring networks

Xing Wu¹ and Xudong Zhou^{2,3,*}

¹State Key Laboratory of Regional and Urban Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100875, China

²School of Civil Engineering and Future Cities, Ningbo University, Ningbo 315211, China

³Institute of Hydraulic and Ocean Engineering, Ningbo University, Ningbo 315211, China

*Correspondence: zhouxudong@nbu.edu.cn

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Reliable precipitation observations underpin weather forecasting, climate adaptation, disaster risk reduction, water resources management, and the emerging development of Earth system artificial intelligence. As climate change intensifies hydrometeorological extremes and socioeconomic exposure increase, strengthening global observing networks has become increasingly urgent. In this context, Su et al.¹ present the first global assessment of precipitation gauge density and introduce the Priority for Siting New Gauges (PSNG) framework, offering an important step from identifying observational gaps to prioritizing future observation infrastructure. While PSNG provides valuable guidance on where new gauges are most needed, translating these priorities into effective implementation requires further consideration of implementation capacity, the broader value generated by local observations, and investment mechanisms.

FROM OBSERVATIONAL GAP TO PRIORITIZING NEW GAUGES

This first assessment of the global precipitation observing network reveals a system that is sparse, geographically unequal, and progressively deteriorating.¹ Only 13.4% of the global land surface meets the World Meteorological Organization (WMO) density standards, exposing pronounced spatial disparities. Dense monitoring networks across North America and Europe contrast sharply with vast data deserts in Africa, South America, and Central Asia. This imbalance creates a Global North-centric knowledge bias, leaving many climate-vulnerable populations without sufficient precipitation information. Moreover, the number of available stations, especially long-term monitoring sites, has steadily declined since the 1980s, threatening climate record continuity that underpin scientific understanding and climate adaptation.

The study's most significant contribution lies not only in documenting these deficiencies but also in fundamentally changing how they are interpreted. It introduces the novel PSNG framework, incorporating climate and socioeconomic factors.¹ Using PSNG, the authors identify more than 25% of global land area, including vast swathes of Africa, South America, high-lati-

tude regions, and the Tibetan Plateau, as high-priority locations for new gauges. The proportion increases to 32.1% under SSP5-8.5 when integrating future scenarios. This approach represents an important paradigm shift, transforming gap identification into an evidence-based framework for prioritizing new climate infrastructures.

While the PSNG framework represents a valuable advance, several methodological aspects warrant further examination. The current framework assigns a dominant contribution to precipitation variability (0.97) compared with historical gauge density (0.03). Although this weighting reflects the importance of climate variability, alternative weighting strategies or definitions of observational adequacy may influence priority patterns. Future studies should evaluate the robustness of PSNG rankings under different weighting schemes. Second, the PSNG framework relies on gridded datasets with coarse resolution (> 0.5°), whereas precipitation gauges represent point-scale observations with limited spatial representativeness. Further investigation is therefore needed to translate regional priority maps into optimal deployment locations. Finally, while PSNG identifies where new observations are most needed, implementation also depends on financial capacity, institutional support, and broader benefits. Recognizing that local observations create global value provides an additional perspective for developing future investment strategies. We therefore propose that a next-generation of prioritization is essential for translating observational priorities into globally coordinated investment strategies (Figure 1).

FROM OBSERVATIONAL PRIORITY TO IMPLEMENTATION CAPACITY

High priority does not necessarily imply high feasibility for deploying new gauges. Although GDP has been incorporated into the PSNG, its contribution is unclear, whether it reflects socioeconomic exposure or constrained financial and institutional capacity to establish and sustain new stations. As stated in Extended Data Fig.6,¹ GDP contributes the most in almost the top 15 PSNG counties, including developed nations (e.g., France, Spain) but mostly devel-

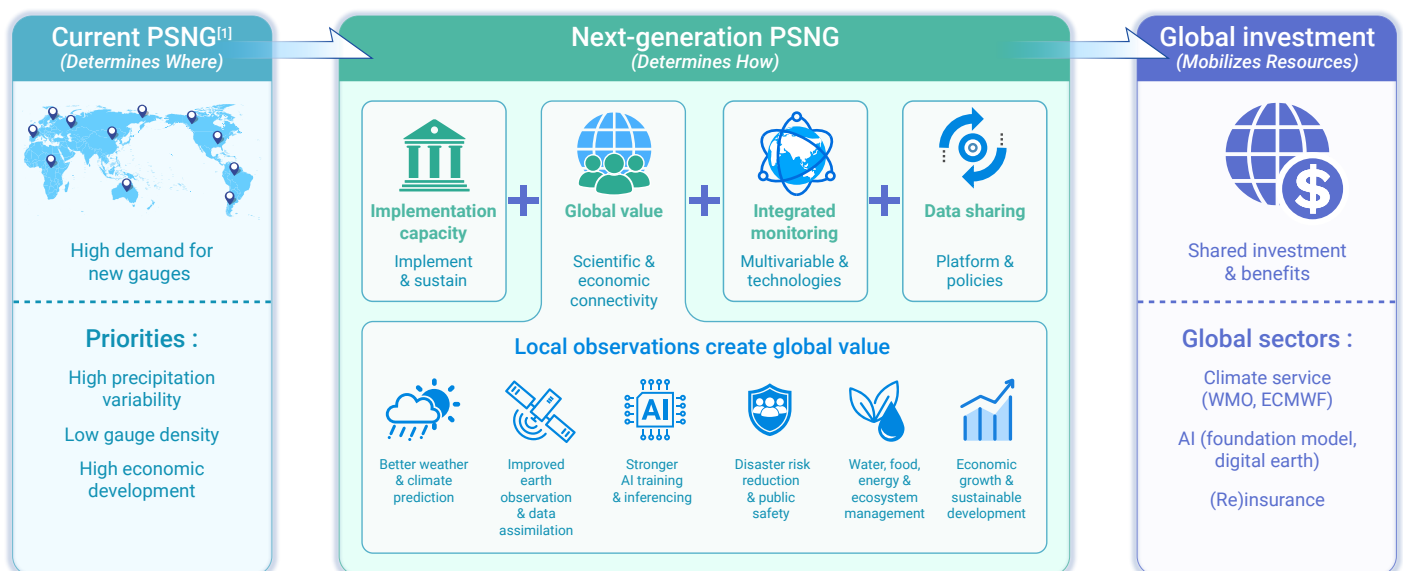


Figure 1. From identifying observational gaps¹ to guiding global investment: A conceptual framework for the next generation of PSNG.

oping ones (e.g., Zambia, Afghanistan).¹ Consequently, a high PSNG score does not necessarily indicate where new gauges can be implemented most affordably, particularly in resource-limited regions.

Meteorological observing networks are traditionally national public infrastructure. Therefore, national adaptation priorities, institutional capacity, and economic development largely determine the ability to expand and sustain networks.² Small island states and low-income countries often face the greatest climate risks,¹ yet possess the least capacity to maintain dense monitoring networks. By contrast, larger economies such as China, the United States, and Canada can distribute investment across regions, making long-term network expansion more financially sustainable.

These considerations suggest that prioritizing new observations should extend beyond identifying where gauges are most needed. Future strategies should also evaluate where implementation is feasible and how financial responsibilities can be shared. This raises the question of whether local measurements can generate broader scientific and socioeconomic benefits, and whether the investment and benefits can be shared internationally.

LOCAL OBSERVATIONS CREATE GLOBAL VALUE

Meteorological gauges offer much more than local data along. They are essential for verifying, calibrating, assimilating, and integrating global Earth observation datasets. Gauge-based data are commonly used to assess ERA5 reanalysis products and to correct satellite products (e.g., GSMaP). Advanced datasets like MSWEP combine gauge, satellite, and reanalysis data to leverage their respective strengths. Furthermore, the scientific impact of individual gauges varies across regions. New gauges in data-scarce areas such as Africa or the Tibetan Plateau offer especially significant value by reducing global uncertainties. Future strategies should therefore evaluate where gauges will most improve Earth system observations.

The emergence of artificial intelligence (AI) has further increased the strategic importance of high-quality observations. While advances in computation and model architectures have accelerated Earth system AI, observational data have become the principal bottleneck for building reliable and transferable models (e.g., foundation models, Digital Earth).³ Uneven observation networks introduce geographical biases into AI systems, creating a self-reinforcing cycle where data-rich regions continue to improve while data-poor regions become increasingly underrepresented. Expanding observations in under-monitored regions is therefore essential not only for improving local prediction, but also for developing more robust, equitable, and globally applicable AI models.

The benefits of local rainfall observations extend far beyond scientific research. High-quality measurements support flood forecasting, reservoir operation, agricultural management, and hydropower generation, while their value propagates through global food supply chains, energy systems, and trade networks. Reliable observations also underpin climate services, insurance, and reinsurance, where accurate local measurements are critical for quantifying climate risks and assessing losses associated with extreme weather events. As economies become increasingly interconnected, these benefits are shared well beyond national borders. Rainfall observations should therefore be regarded as global public goods justifying internationally coordinated investment.

NEXT GENERATION OF PSNG: FROM PRIORITIZATION TO GLOBAL INVESTMENT

Building upon these perspectives, the next generation of PSNG should evolve beyond identifying observational needs to supporting practical implementation and globally coordinated investment.

From observational need to implementation capacity

Future PSNG frameworks should incorporate implementation capacity by considering factors such as political stability, institutional strength, infrastructure investment, technical workforce, and long-term funding.² In addition, identifying the dominant drivers of high-PSNG regions would help distinguish where conventional gauges are most appropriate from where complementary systems (e.g., weather radar) could provide more efficient coverage. This would enable PSNG to move from identifying priorities to supporting actionable investment decisions.

From local priorities to global benefits

Future frameworks should explicitly account for the global scientific and socioeconomic value generated by local observations. Measurements in

strategically important regions, such as deserts, mountain water towers, and key atmospheric circulation pathways, often contribute disproportionately to improving global climate products despite occurring in undeveloped regions. Likewise, global food production, international supply chains, and insurance systems all benefit from improved observations in climate-sensitive hotspots. Economic connectivity and risk maps can be incorporated into the new framework, enabling international organizations, development agencies, and private stakeholders to co-invest in observation networks generating sharable global benefits.

From single-variable observations to integrated monitoring

Although PSNG currently evaluates priorities for rainfall gauges, future observing strategies should recognize that modern meteorological stations measure multiple atmospheric variables, including temperature, humidity, wind, radiation, and precipitation. Integrating priority assessments across multiple variables would provide a more comprehensive framework for planning next-generation observing networks. At the same time, emerging observing technologies, including crowdsourced rainfall observations and low-cost sensors, could complement conventional gauge networks,⁴ particularly in regions where standard meteorological stations remain difficult to deploy.

From infrastructure to open data sharing

Expanding observation networks alone cannot maximize the value of meteorological information if observations remain inaccessible. In many regions, existing gauge data are restricted by institutional, administrative, or national policies, limiting their contribution to global research and climate services.⁵ Future PSNG frameworks should therefore incorporate data availability alongside observational density, recognizing that improving data sharing may yield greater benefits than installing additional stations in some regions. International investment in new observing infrastructure should therefore be linked to open data policies, collaborative governance, and equitable sharing of the scientific and socioeconomic value generated by these observations.

CONCLUSION

PSNG has transformed current observational gaps in gauge density into priorities for where new rainfall gauges are needed. The next challenge is to determine how those priorities can be implemented through globally coordinated investment. As local observations increasingly generate global scientific, technological, and socioeconomic value, precipitation observing networks should be recognized as global public goods. Future observation strategies should therefore move beyond merely identifying observational gaps toward building a coordinated framework that integrates current needs, implementation capacity, and global benefits.

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AUTHOR CONTRIBUTIONS

All authors contributed to the manuscript and approved the final version.

DECLARATION OF INTERESTS

The authors declare no competing interests.