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Higher-resolution projections needed for small island climates

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Projections of the future climate of small island states and territories are currently limited by the coarse resolution of models. We call for rapid global and regional cooperation to develop projections compatible with small island scales, providing relevant local information and decision-making tools.

Small island states and territories are among the most vulnerable to climate change impacts, particularly sea-level rise[1]. Indeed, sea-level rise poses an existential threat to some low-lying atolls, and brings into question the long-term liveability of the usually densely populated coastal areas of taller islands. Although sea-level rise is an important impact of climate change on small islands, it is not the only one. The populations of small islands are impacted by a variety of climatic hazards, including marine and atmospheric heatwaves (which increasingly threaten fragile ecosystems such as coral reefs), extreme ocean wave events, heavy precipitation and floods, storms, landslides, drought, severe winds, and wildfire, among others. Furthermore, the concentration of strategic assets, such as airports, harbours, hospitals and emergency services, as well as endemic ecosystems and historical or cultural sites over a limited area (especially for mountainous islands with limited flat terrain), often associated with high population density and with remoteness, makes island populations particularly vulnerable to such hazards[2,3]. To better grasp the future risk to small islands posed by climate change, we need to understand how it will impact this wide variety of oceanic and atmospheric hazards, beyond large-scale sea-level rise.

The latest IPCC assessment reports[4,5] provide evidence of sea-level rise and increasing hot extremes on islands, which are projected to continue increasing with high confidence. Yet, future projections of other climate hazards (for example, floods, landslides, drought, severe winds, fire weather) have only low confidence. An examination of the studies assessed by the IPCC reveals a likely reason for such low confidence. In the 'Small islands' chapter of the Working Group II report[1], about 90% of the climate projections used came from global climate models (25 out of 28 studies with climate projections). These global models use coarse horizontal resolution, generally 100 km or larger, such that many small islands simply do not exist in these models (Fig. 1). On the ocean side, coastal and lagoon environments that provide essential ecosystem services and food resources are also not resolved. This means that most of the climate change projections used at the location of small islands are actually representative of the open and deep ocean rather than an island and its shallow waters.

Higher-resolution regional projections have also been produced, mostly through the Coordinated Climate Downscaling Experiment (CORDEX)[6]. They rely on regional climate models with resolutions ranging from 50 km down to 12.5 km, which is enough to represent the larger islands, but they are still unable to represent small islands and lagoons (Fig. 1). We also note that the CORDEX projections mostly use domains centred over continental regions, excluding vast fractions of the world ocean and the embedded islands, particularly in the Pacific Ocean. This means that the CORDEX projections are also not ideal for simulating island climates as the islands are often found near the boundaries, where the projections are less reliable, or the islands may not be included at all.

Whether obtaining projections from global or regional climate models, these issues are problematic as we know that the climate on islands differs from that of the open ocean around them[7]. This is due to climatic processes such as the differential heating of land and ocean that leads to local atmospheric circulations such as sea breezes, convection, and the presence of sometimes steep topography that typically leads to precipitation enhancement on the windward side of mountains and the formation of rain shadows on the leeward side, particularly for tropical islands in a stable trade-wind regime[8,9]. Extreme events such as tropical cyclones also lead to complex impacts when making landfall on islands due to topography and other local effects[10]. In lagoons, where most coral reefs reside and are under increasing threat of bleaching, shallow waters and complex geomorphology combine to produce specific hydrodynamic processes[11]. How these island climate processes will change with global warming remains largely unknown but is key to understanding how climate change risks will evolve over small island states and territories.

Enhancing climate projections for small island states

Clearly, small island states and territories need more reliable, higher-confidence projections of changes in all relevant climate hazards to understand and adapt to the risks they pose to human societies and ecosystems. The characteristics of the required projections should include:

- Model resolution high enough to accurately capture the island topography, shallow water lagoons, local circulations, ocean–atmosphere–land coupling and precipitation mechanisms.
- Computational domains large enough to adequately capture important regional features such as the Inter-tropical Convergence Zone, the South Pacific Convergence Zone, tropical cyclones and mid-latitude storm tracks, among others.
- Ensembles designed to span plausible climate futures, including emissions scenarios aligned with the Paris Agreement and higher emissions scenarios in line with current emissions trajectories.

For most islands, this will require projections at convection-permitting (about 1 km) resolution nested within large domains

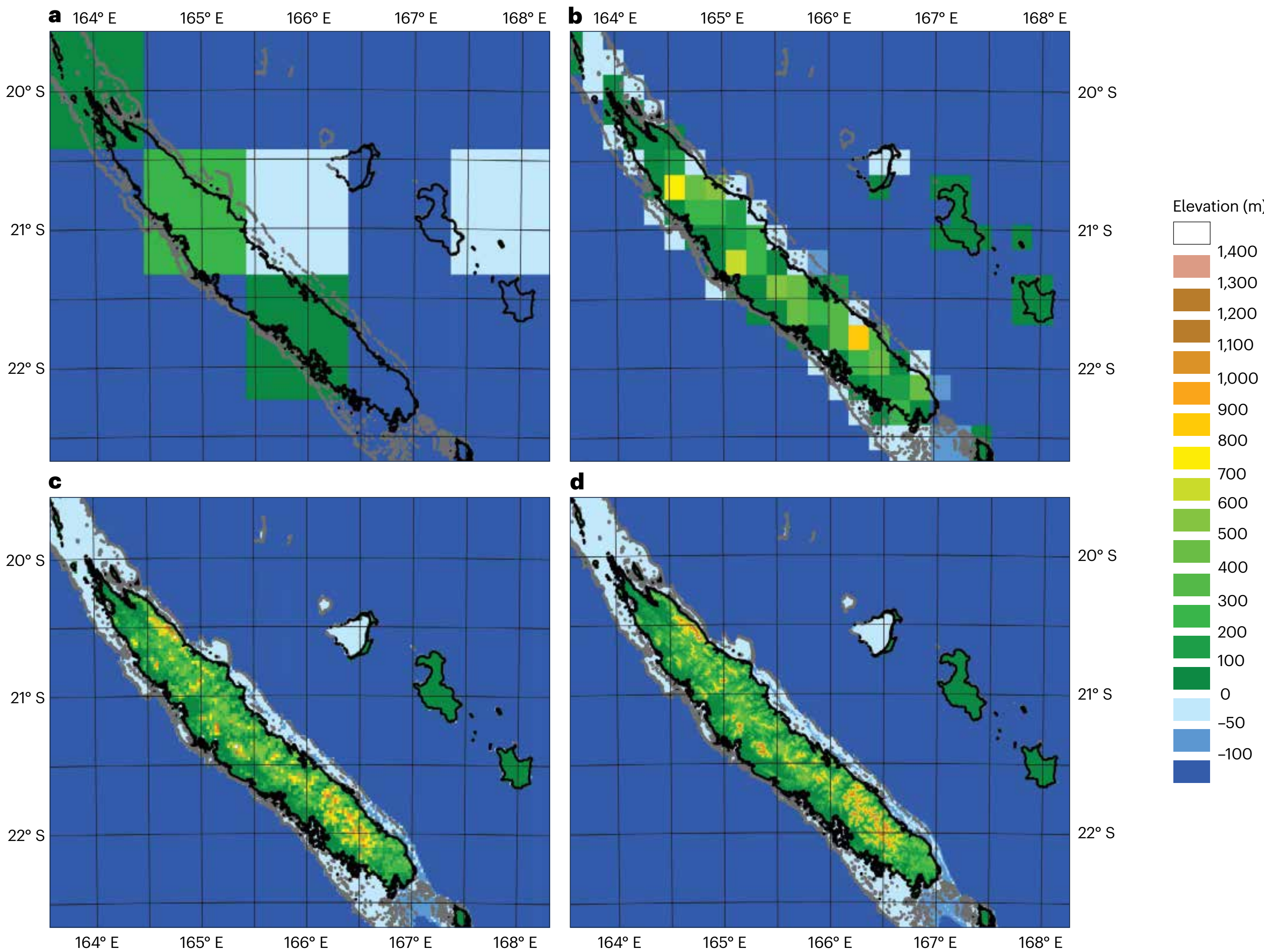

Fig. 1 | The topography and bathymetry of New Caledonia in the southwest Pacific at various resolutions. a–d, New Caledonia's official topography (https://georep.nc/actualites/service-imagerie-sur-le-mnt) and bathymetry (https://georep.nc/actualites/bathymetrie-du-parc-naturel-de-la-mer-de-corail) regridded at 100 km (**a**), 25 km (**b**), 2.5 km (**c**) and 100 m (**d**) resolution. The original horizontal resolution of the topography is 10 m and the bathymetry is 100 m. The colours show the elevation above (or below) the mean sea level at Nouméa. The land border is shown in black. The lagoon and reef limits are shown in grey.

simulated at resolutions in the 10–20 km range, which are only starting to become available[9,12]. Islands surrounded by lagoons will require embedding even higher resolution[13]. Ensuring adequate ensemble size will require the collaborative work of many regional climate modelling groups around the world, as well as novel approaches combining dynamical and statistical downscaling or artificial intelligence to reduce computational costs[14]. Such an effort could be enabled through existing international collaborative frameworks such as CORDEX. To enable the creation of these required projections we need to:

- Invest in the development of very high-resolution regional climate models to better represent physical processes at the local scale, on land and its coastal surroundings. This requires models capable of long simulations with resolutions of a kilometre or better for atmospheric processes and even higher resolution to represent their often-complex coastal environments.
- Explore the use of artificial intelligence and machine learning techniques as a complementary method to simulate local climates, quantify internal climate variability and better sample the full range of climate uncertainty. Such methods may provide a very cost-effective way to produce the large simulation ensembles needed to increase the robustness of, and confidence in, local climate projections.
- Enhance the collection, sharing and analysis of climate-related observational and model data through regional cooperation and partnerships between island states and territories, research institutions and international organizations. This could expand the role of the World Meteorological Organization Regional Climate Centres and requires capabilities similar to those available through EU Copernicus.
- Empower local research communities, regional organizations and governments with the knowledge and tools to participate in and contribute to the climate modelling and communication

process, ensuring that projections are relevant and utilized in decision-making on the islands.
- Secure increased international funding and support for climate research in small islands, including targeted efforts within international initiatives such as CORDEX, recognizing their limited resources and heightened vulnerability.

Small island states and territories are at the forefront of climate change impacts. There is a critical need for more accurate and comprehensive climate change projections for the islands. We call for rapid global and regional cooperation to develop high-resolution projections compatible with small island scales. It will require a funded, coordinated, international collaborative effort to ensure that small island states and territories can move beyond sea-level rise impacts and understand their full spectrum of climate change-related risks.

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References

1. Mycoo, M. et al. in *Climate Change 2022: Impacts, Adaptation and Vulnerability* (eds Portner, H.-O. et al.) 2043–2122 (IPCC, Cambridge Univ. Press, 2023).
2. Monioudi, I. N. et al. *Reg. Environ. Change* **18**, 2211–2225 (2018).
3. Barnett, J. & Waters, E. in *The Palgrave Handbook of International Development* (eds Grugel, J. & Hammett, D.) 731–748 (Palgrave Macmillan, 2016).
4. IPCC *Climate Change 2021: The Physical Science Basis* (eds Masson-Delmotte, V. et al.) (Cambridge Univ. Press, 2021).
5. IPCC *Climate Change 2022: Impacts, Adaptation, and Vulnerability* (eds Portner, H.-O. et al.) (Cambridge Univ. Press, 2022).
6. Giorgi, F., Jones, C. & Asrar, G. R. *WMO Bull.* **58**, 175–183 (2009).
7. Cantet, P., Déqué, M., Palany, P. & Maridet, J.-L. *Tellus A* **66**, 24065 (2014).
8. Lefèvre, J., Marchesiello, P., Jourdain, N. C., Menkes, C. & Leroy, A. *Mar. Pollut. Bull.* **61**, 413–431 (2010).
9. Dutheil, C. et al. *Clim. Dyn.* **56**, 87–108 (2021).
10. Cécé, R. et al. *Nat. Hazards Earth Syst. Sci.* **21**, 129–145 (2021).
11. Monismith, S. G. *Annu. Rev. Fluid Mech.* **39**, 37–55 (2007).
12. Fandrich, K. M., Timm, O. E., Zhang, C. & Giambelluca, T. W. *J. Geophys. Res. Atmos.* **127**, e2021JD035684 (2022).
13. Martins, K. et al. *Ocean Model.* **179**, 102110 (2022).
14. Rampal, N. et al. *Artif. Intell. Earth Syst.* **3**, 230066 (2024).

Competing interests

The authors declare no competing interests.