Earth System Modelling at 1 km

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- Why 1 km.
- Lessons from scaling.
- Where matters stand.
- The case for cooperation.

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Future Weather

Fires in southern Europe (July 2022)

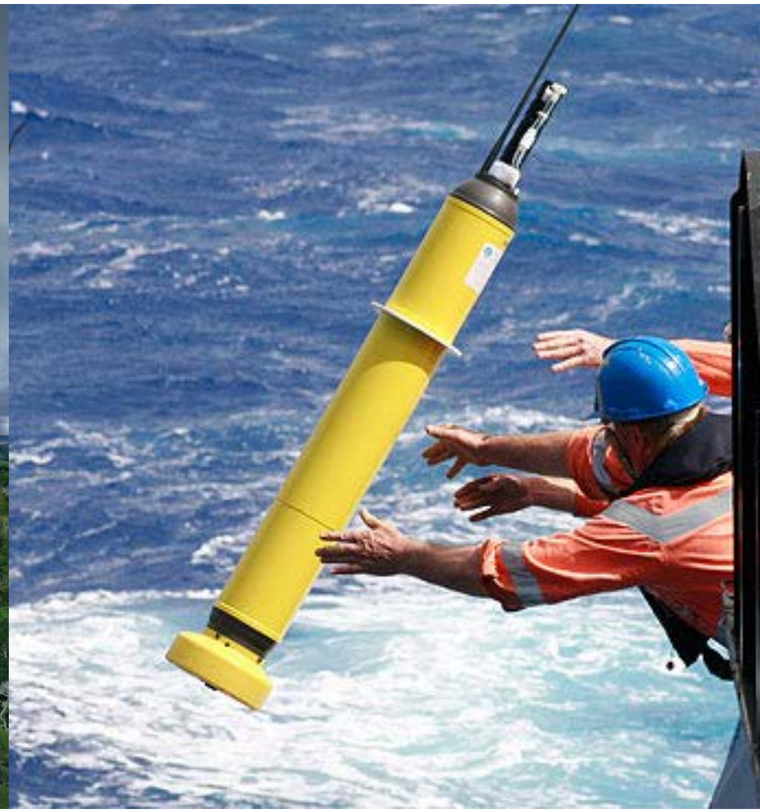
Monsoon flooding, Southern Asia.

Hurricane Ian, North America (August 2022) — $50 billion

The world is warming and we need to know what that means

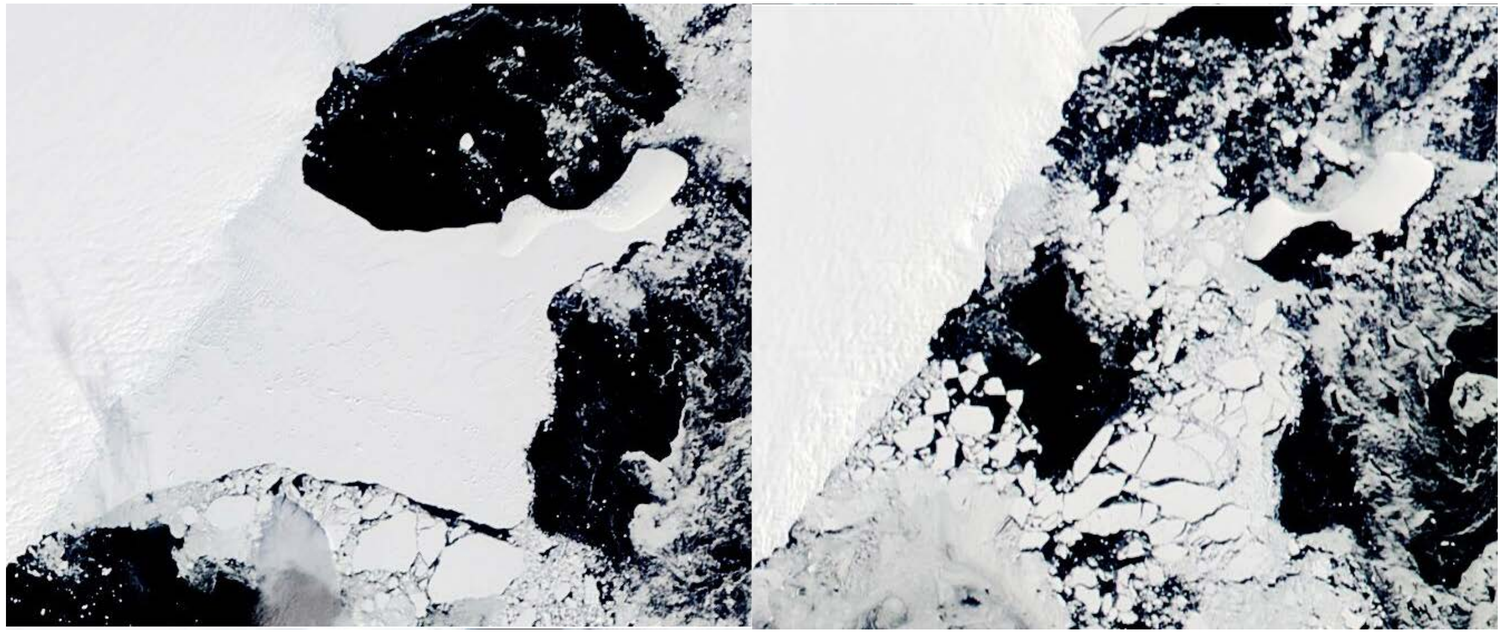
AP Photo/Wilfredo Lee (Ft Myers) Sky News (French Fires); AFP via Getty Images (Pakistan Floods)

Valorizing observations



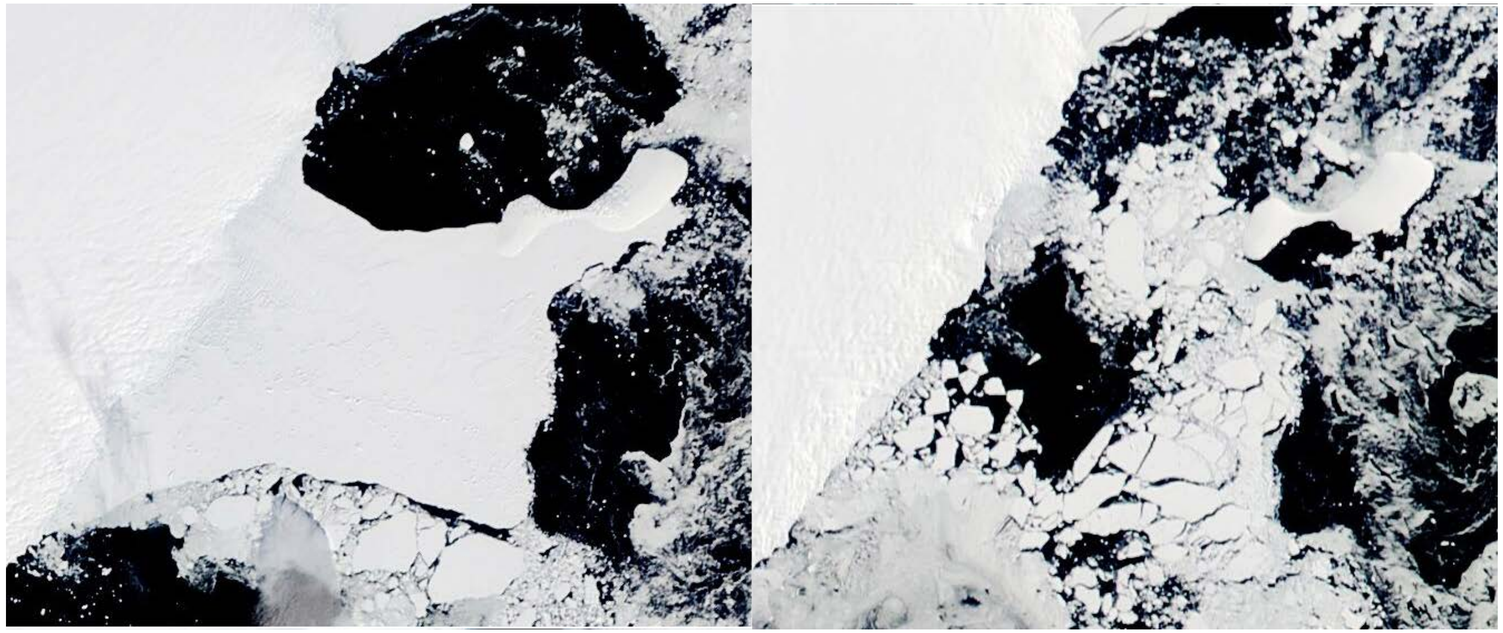
Our observing systems measure instances, not averages

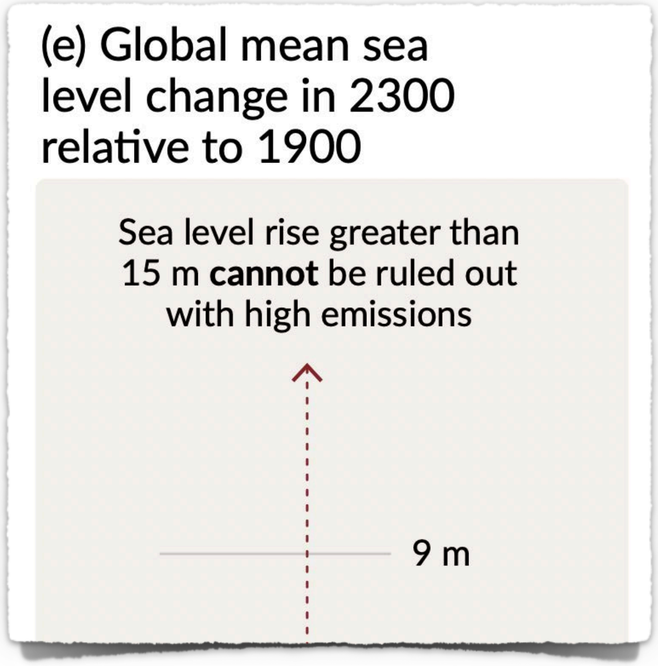
Anticipating catastrophes



Upscaling — the unanticipated consequences of small scale events

Anticipating catastrophes





Upscaling — the unanticipated consequences of small scale events

Laws

— a basis for extrapolation.

Scaling

Strong scaling | The ability to solve a problem more quickly by distributing the workload over a larger computer. Its is **strongly** limited by quantum physics, which bounds the speed of processing elements.

Weak scaling | The ability to solve a larger problem just as quickly by enlarging the computer commensurately with the size of the problem. Its is only **weakly** limited by our ingenuity in connecting many elements together.

- Making the problem larger means making the grid (Δx) finer, and the time-step (Δt) smaller.
- Time cannot be distributed — throughput is limited by timesteps to solution, finer grids require more timesteps which means you wait longer.
- How long you are willing to wait thus determines the number of timesteps, which then determines Δx.

Strong-scaling *means that to simulate a year a day requires* $\Delta x \geq 1\mathrm{km}$. ***Weak scaling*** *means that this does not depend on domain size. The time to solution for regional domains is the same as for global domains.*

Status

- 2009: First km scale atmosphere model (NICAM), ran for a few days at 1 km more than 10 years ago.
- 2019: Many groups (MPI, ECWMF, UTokyo/Riken, MeteoFrance, NASA, NOAA, DOE, NCAR) have begun experimenting with km-scale (2.5 km - 5.0 km) atmosphere simulations for periods of weeks to years.
- 2021: A few groups are running coupled models. At MPI we have performed multi-annual coupled simulations at 5 km, and multi-decadal simulations at 10km, and are extending the latter to incorporate the carbon cycle, and efforts are underway to couple ice-sheets.
- 2022: Benchmarks on LUMI lead us to expect to be able to perform 2.5 km global coupled simulations with a an expected throughput of 1 simulated year per day on a third of the machine.
- 2024: Europe's first exascale machine is expected to be twice as large as LUMI
- 2025: Improved algorithms and implementation expected to contribute to 5x increase in performance.

Modelling capabilities are increasing faster than Moore's law —
this shows how far behind we were.

Summary

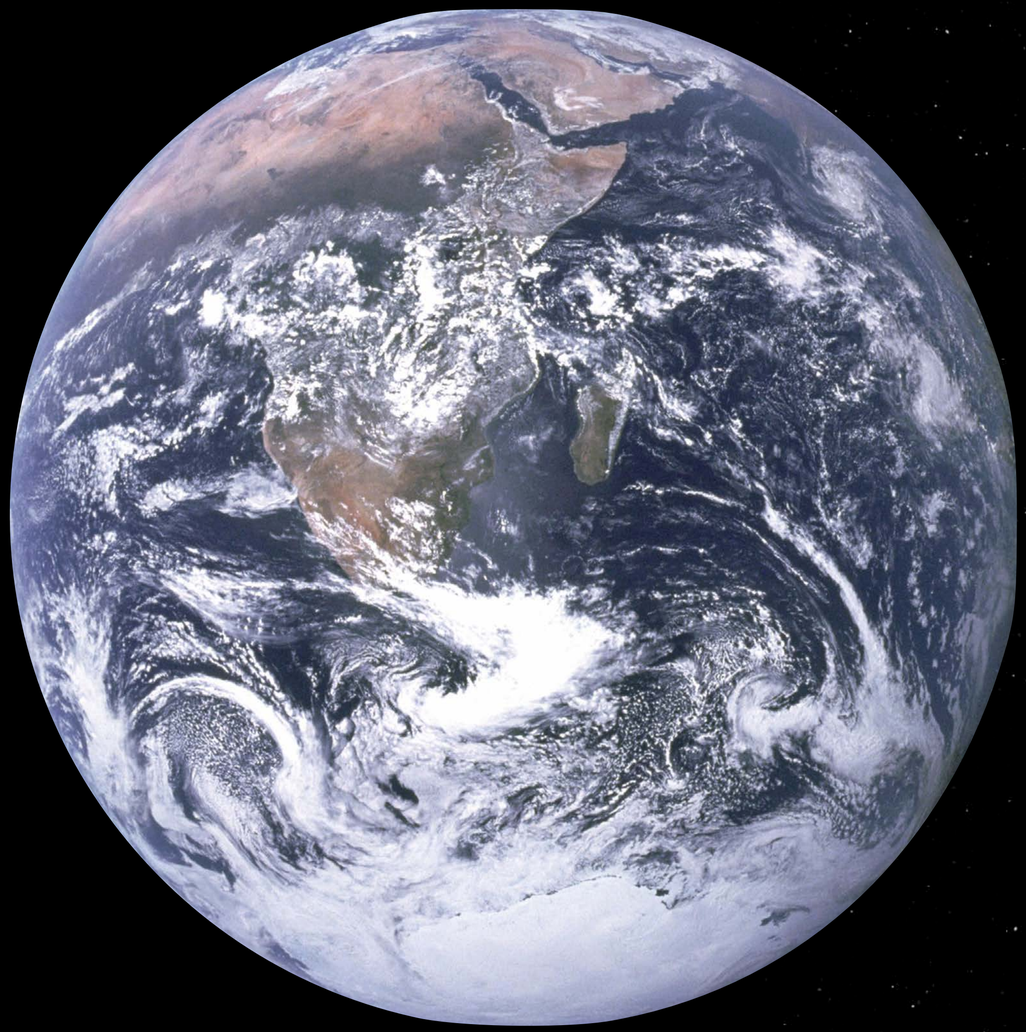
- Why 1 km? | impacts, observations, fidelity.
- Lessons from scaling | 1 km is a hard limit for multi-decadal scale prediction.
- Where matters stand | 1 simulated year per day on LUMI/3
- The case for cooperation ….

DestinE

Conclusions

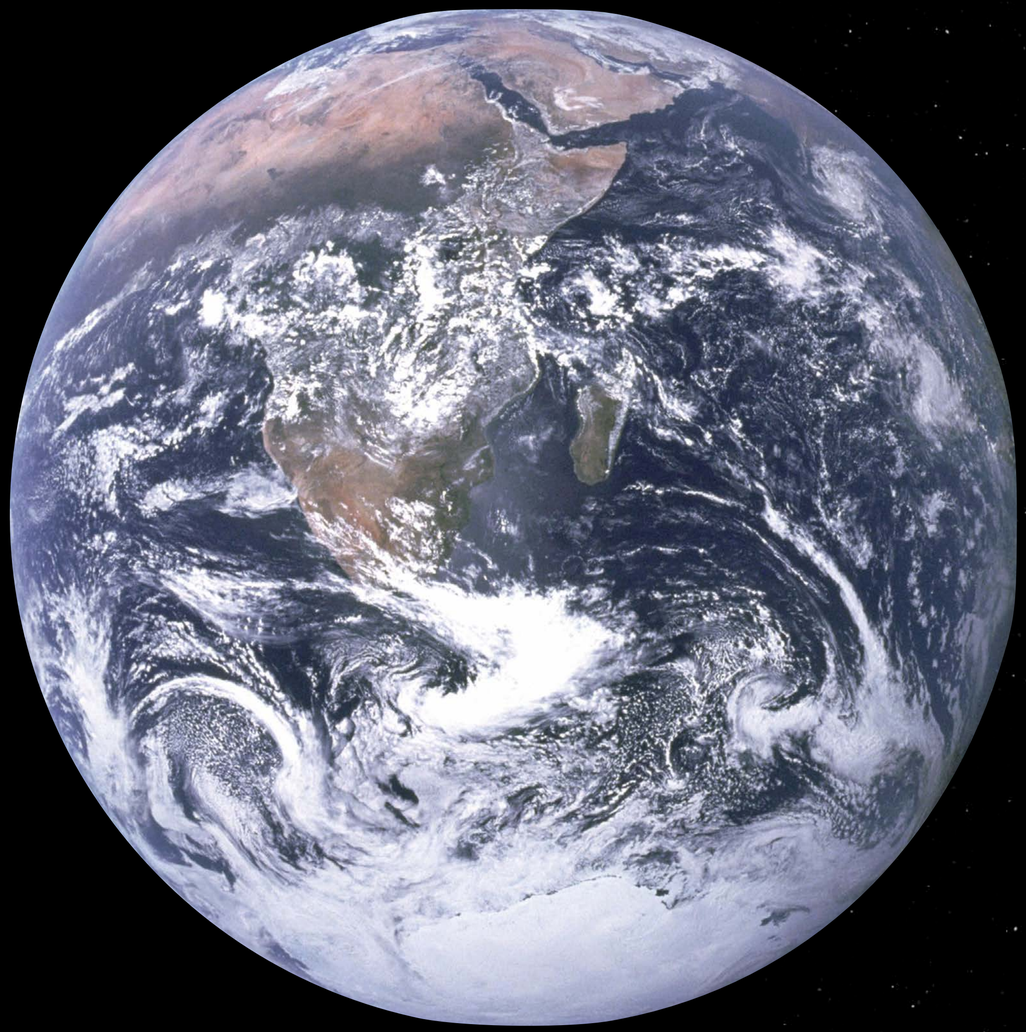
- Operational services and researchers are increasingly called upon to provide climate information. This trend will strengthen.
- We can continue to meet these demands by hoping for the continued vitality of out-dated community approaches (e.g., CMIP), complemented by downscaling efforts (CORDEX); but this only adds detail to models which lack fidelity, moreover it is fundamentally inequitable, inefficient and backward looking.
- Cooperating in the development, implementation and operationalization of km-scale climate models will change the game — also by highlighting the ability of operational services to be leaders in the development and application of digital technologies.
- DestinE is pioneering the latter approach, ECMWF (and its partners at ESA and EUMETSAT) is helping to articulate the most ambitious and foresighted undertaking by our community in at least 30 years. It needs our support.

— its time to reimagine our remit as a driver of digital innovation.



1972

2022



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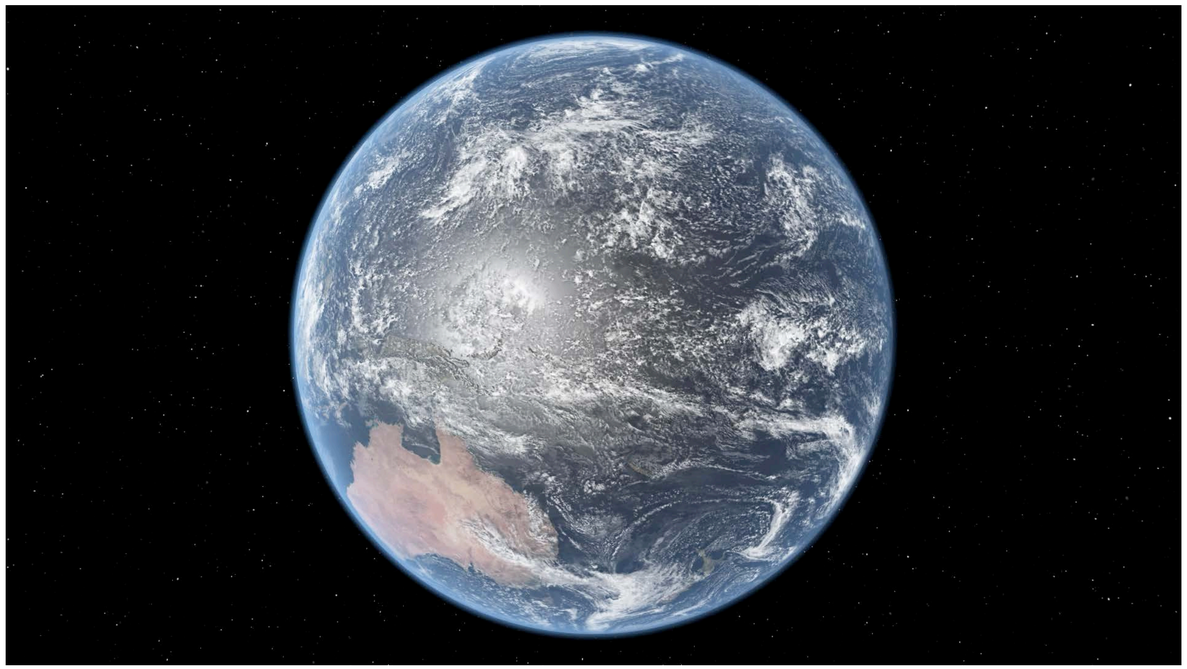
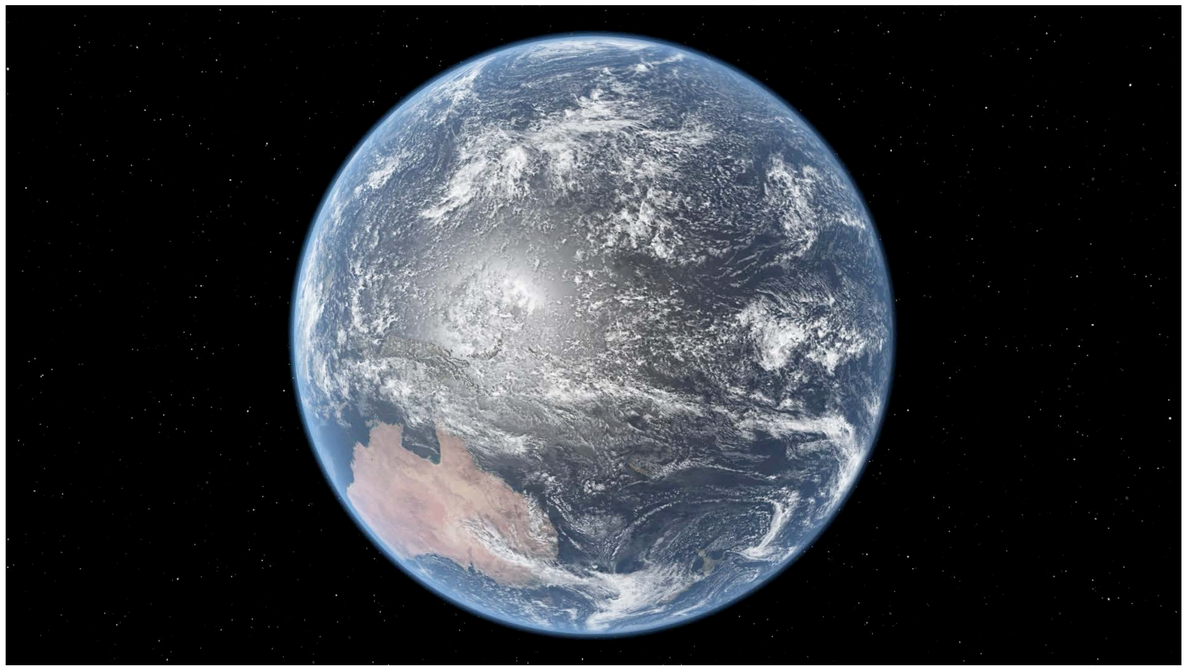
Reimagining Climate Information Systems for a Warming World



Berlin 3-7 July, 2023

Reimagining Climate Information Systems for a Warming World



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