Utrecht University

Digital Twin Earth

Sixth Assessment Report

WORKING GROUP I

The Physical Science Basis

2021

ipcc

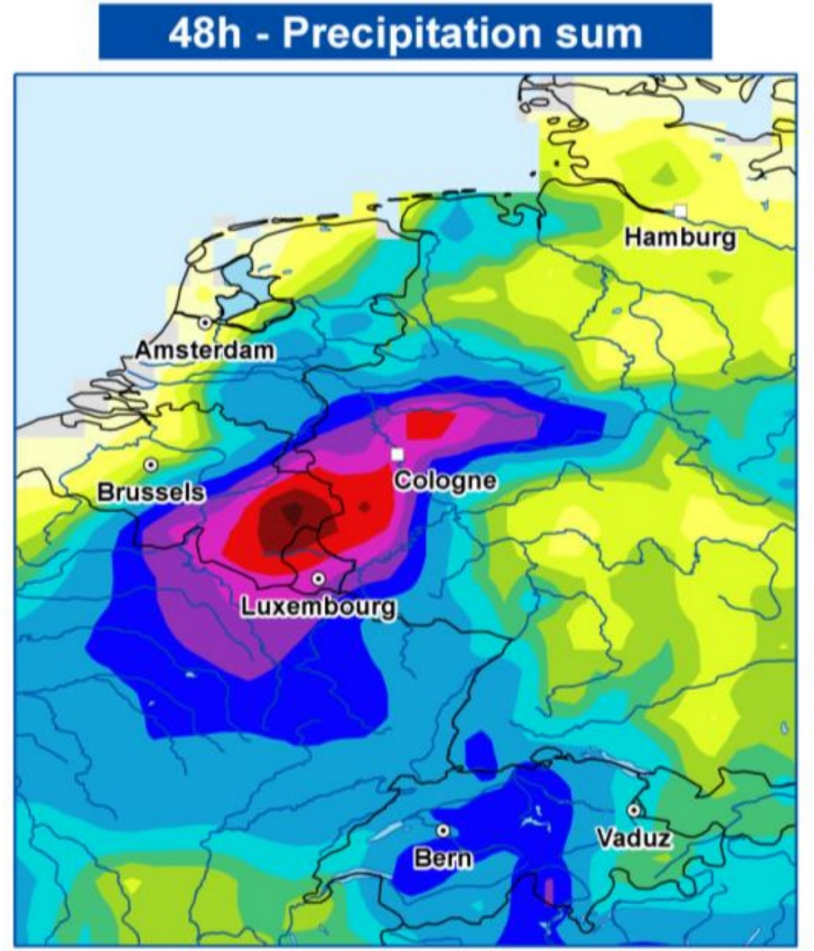
INTERGOVERNMENTAL PANEL ON climate change

WMO UNEP

Human-induced climate change is already affecting many weather and climate extremes in every region across the globe.

#IPCC

#ClimateReport

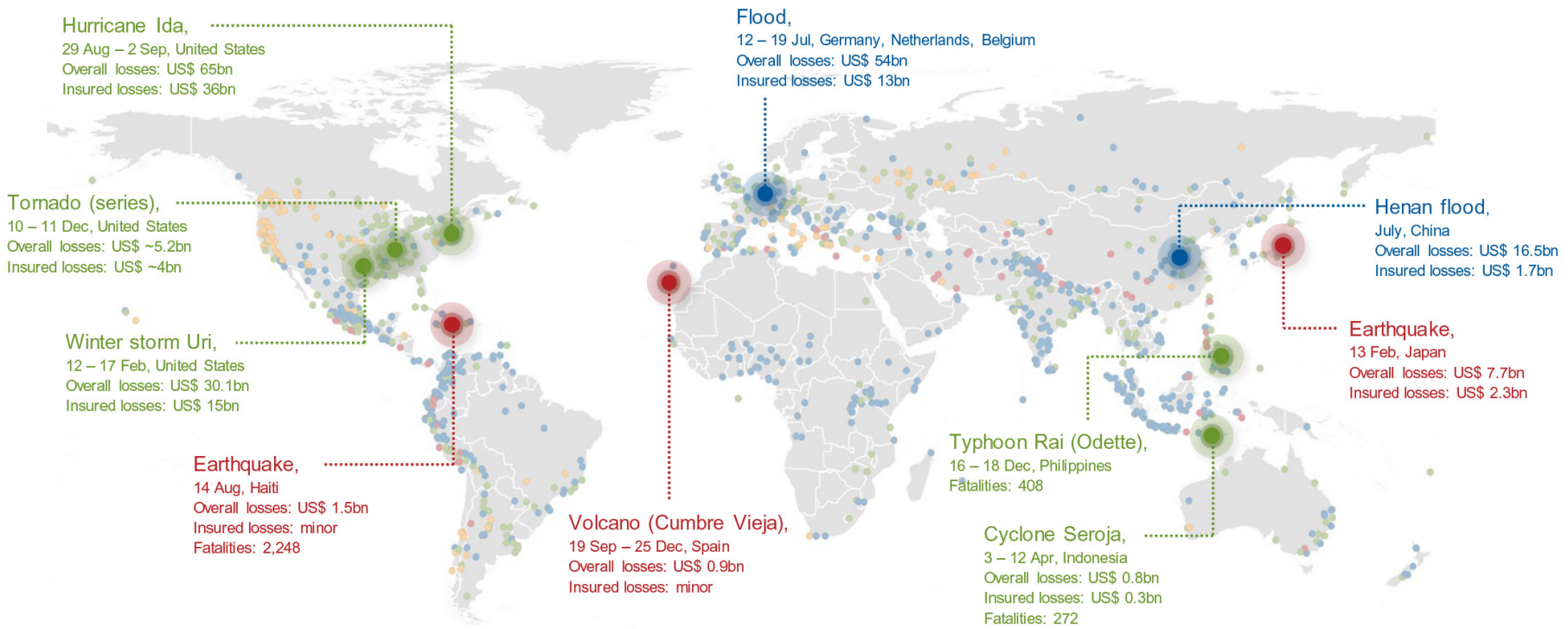

48h - Precipitation sum
Hamburg
Amsterdam
Brussels
Cologne
Luxembourg
Bern
Vaduz
Precipitation data: Extended version of E-OBS. Graphic credits: © Deutscher Wetterd
Geodata: © GeoBasis-DE/BKG 2020 (Last update: 01.01.2020).

NatCatSERVICE

Relevant natural catastrophe loss events worldwide 2021

Natural disasters caused overall losses of US$ 280bn

Munich RE



Geophysical events
Earthquake, tsunami, volcanic activity

Meteorological events
Tropical storm, extratropical storm, convective storm, local storm

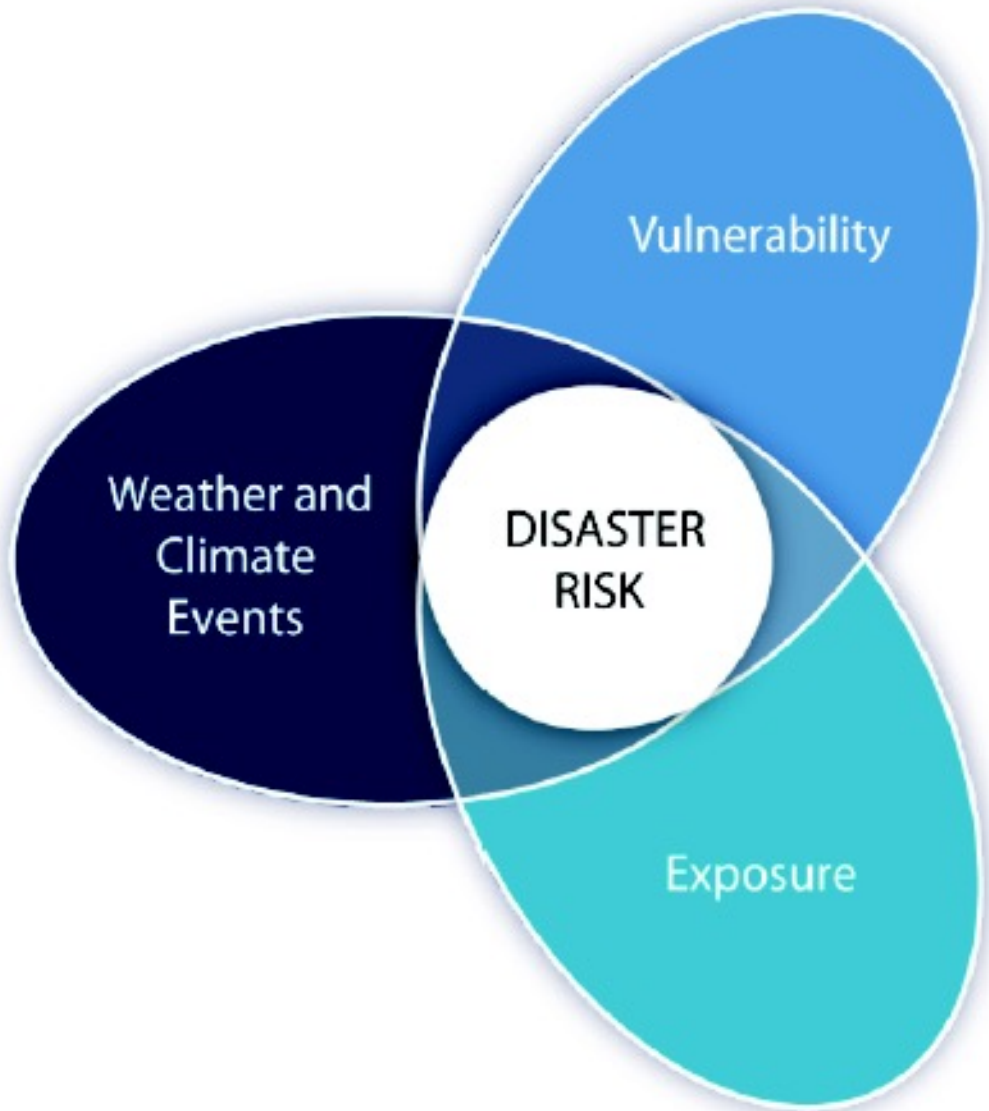
Hydrological events
Flood, mass movement

Climatological events
Extreme temperature, drought, wildfire

○ Significant catastrophes
○ Small, medium and large loss events

Source: Munich Re, NatCatSERVICE, 2022

Utrecht University



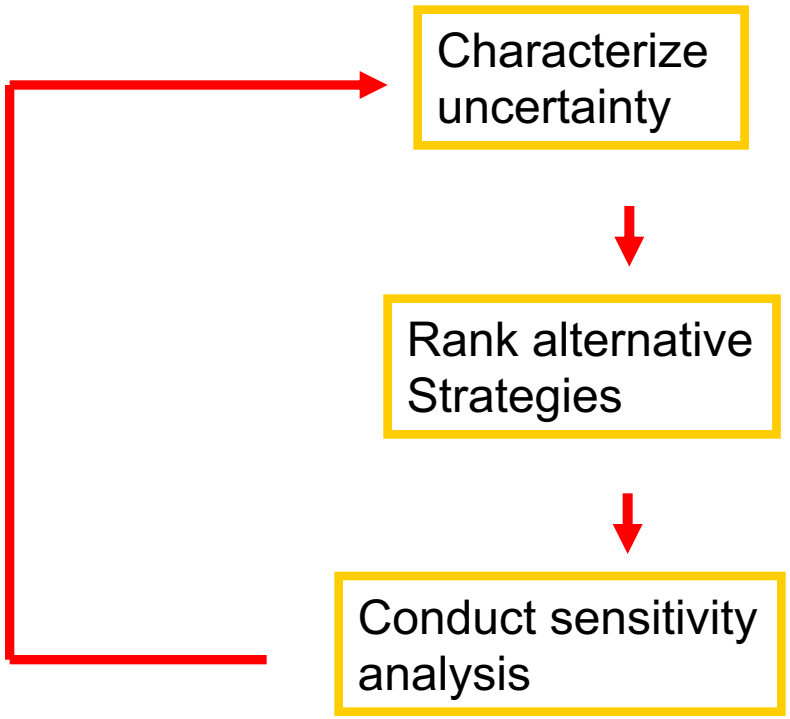
IPCC Special Report on Extremes and AR6

Current approaches to forecasting weather-induced extremes

Utrecht University

Predict then act

RANK STRATEGIES CONTINGENT ON CHARACTERIZATIONS OF UNCERTAINTIES



After Lempert and Groves 2006, and many others on Robust Decision Making

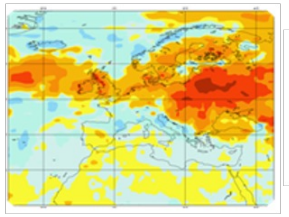
ECMWFs Flood Warning System

ECMWF seasonal meteorological forecasts (SEAS5)
Issued monthly
Daily time steps
7 month lead time
51 members
36 km

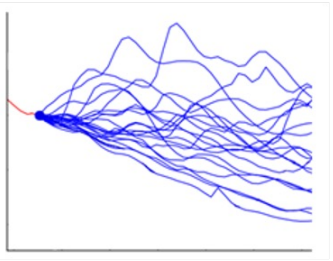
ECMWF seasonal discharge forecasts
5 x 5km

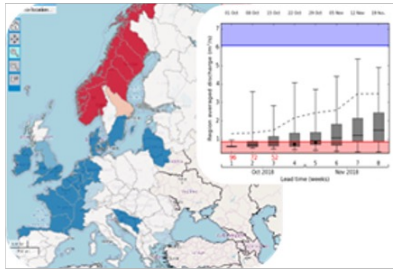
Weekly regional discharge averages

Seasonal outlook
Issued monthly
Weekly time steps
8-week lead time
Overview and pop-up plots



LISFLOOD





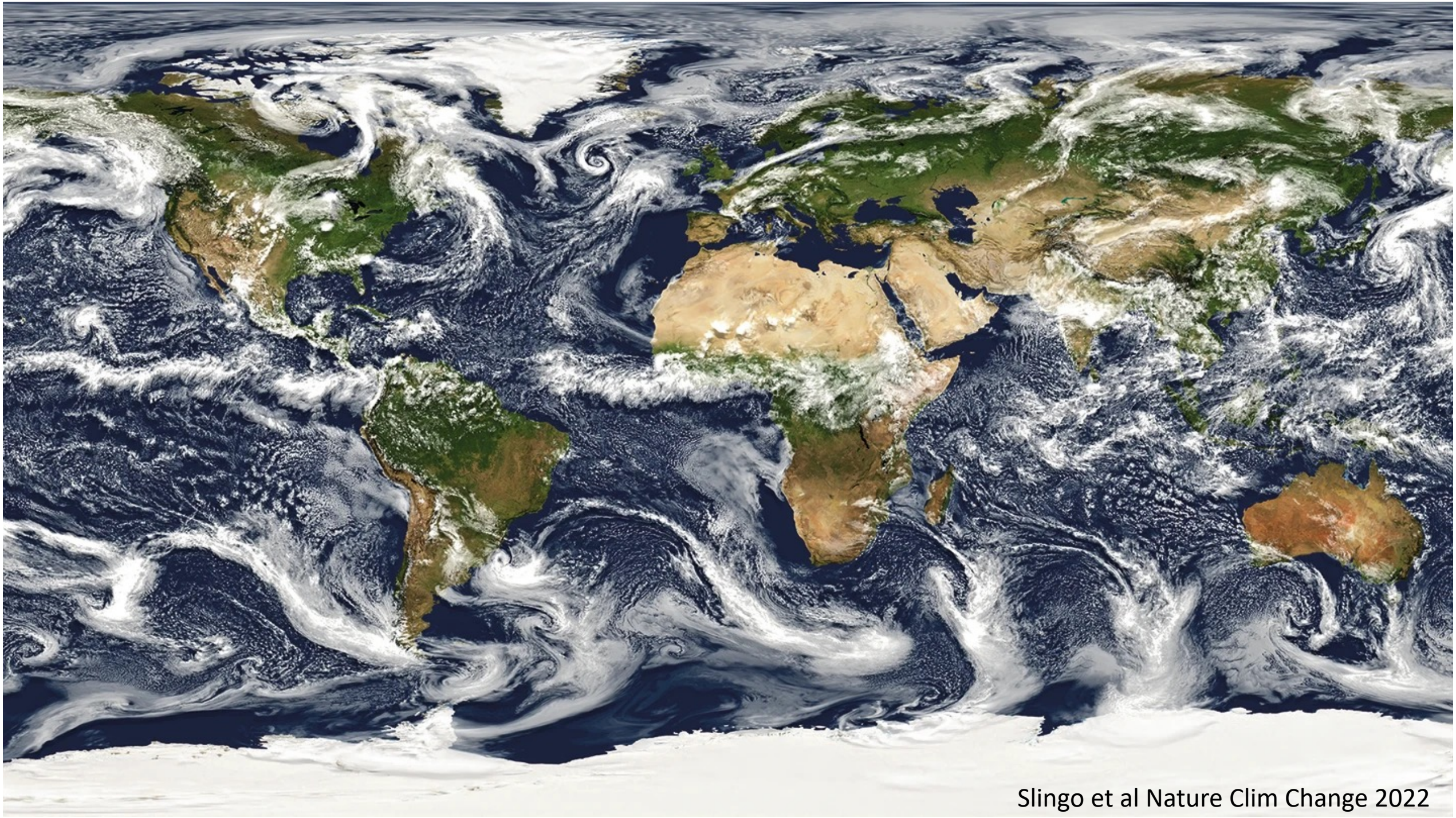
ECMWF sub-seasonal forecasts (S2S)
Issued twice weekly
Daily time steps
46 day lead time
51 members
18/36 km

ECMWF sub-seasonal discharge forecasts
5 x 5km

Weekly regional discharge averages

Sub-seasonal outlook
Issued twice weekly
Weekly time steps
8-week lead time
Overview and pop-up plots

https://confluence.ecmwf.int/display/COPSRV/EFAS+sub-seasonal+and+seasonal+forecasting



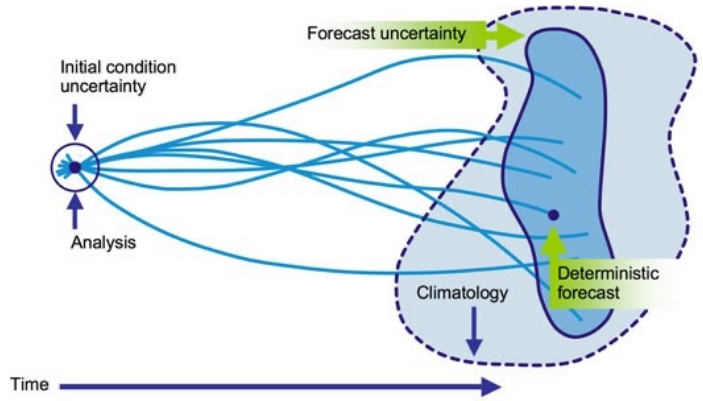
Slingo et al Nature Clim Change 2022

Advantages:

High-end model infrastructure and domain scientific knowledge

Quality controlled data

Probabilistic information (allows for quantitative risk assessment)



Challenges:

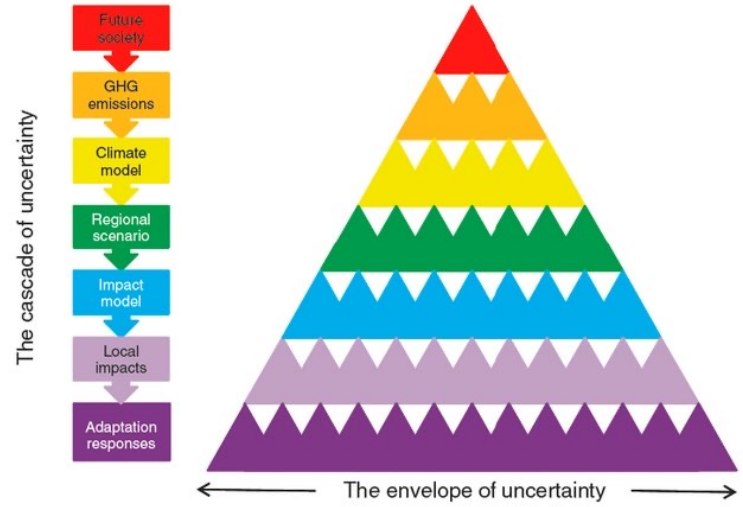
Representing extremes in simulations and data

Model accuracy and reliability, with cascading uncertainties

Latency in chain from observation to decision

Huge data volume, but limited use of disparate data

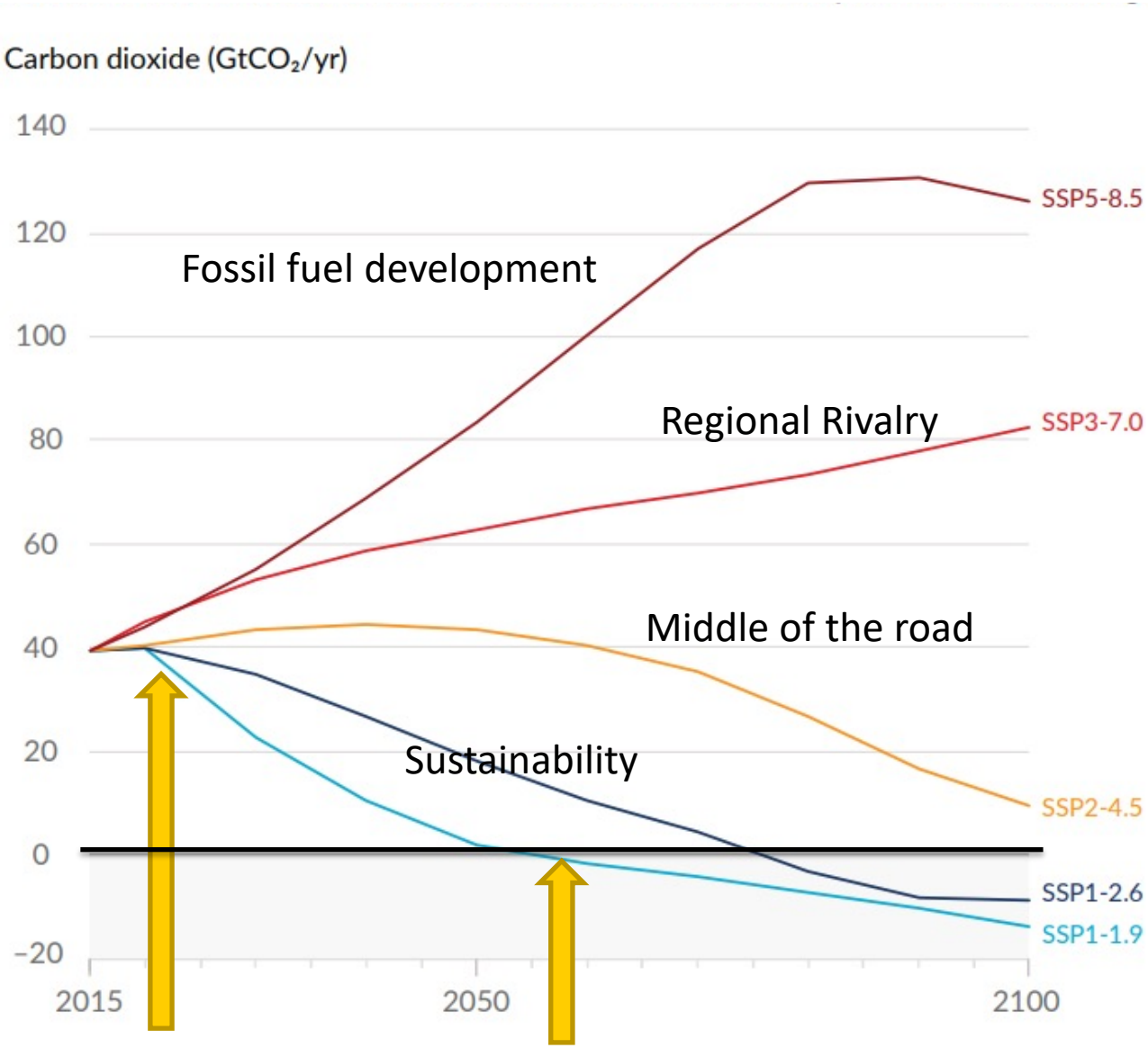
In the current situation user comes in at the very end !



Utrecht University

Societal choices and actions in the next decade determine the extent to which pathways will deliver climate resilient development

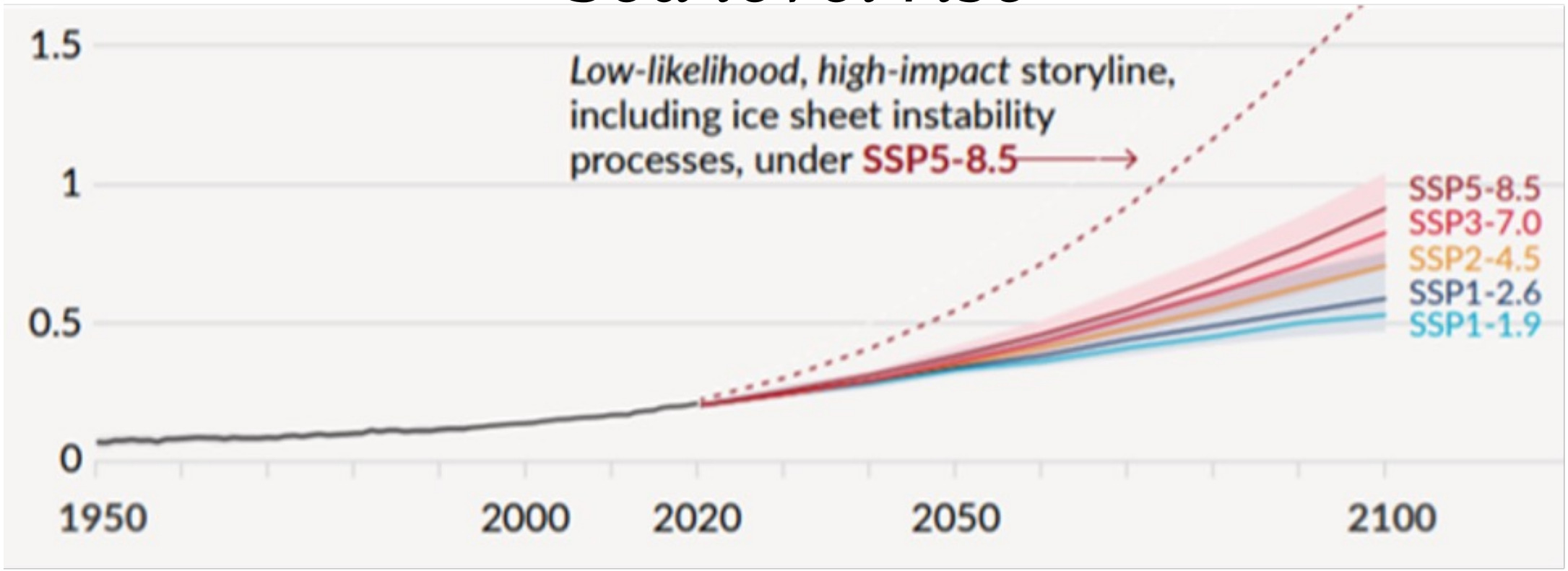
Abbreviated quote from IPCC AR6



PV implementation, Prof. van Sark

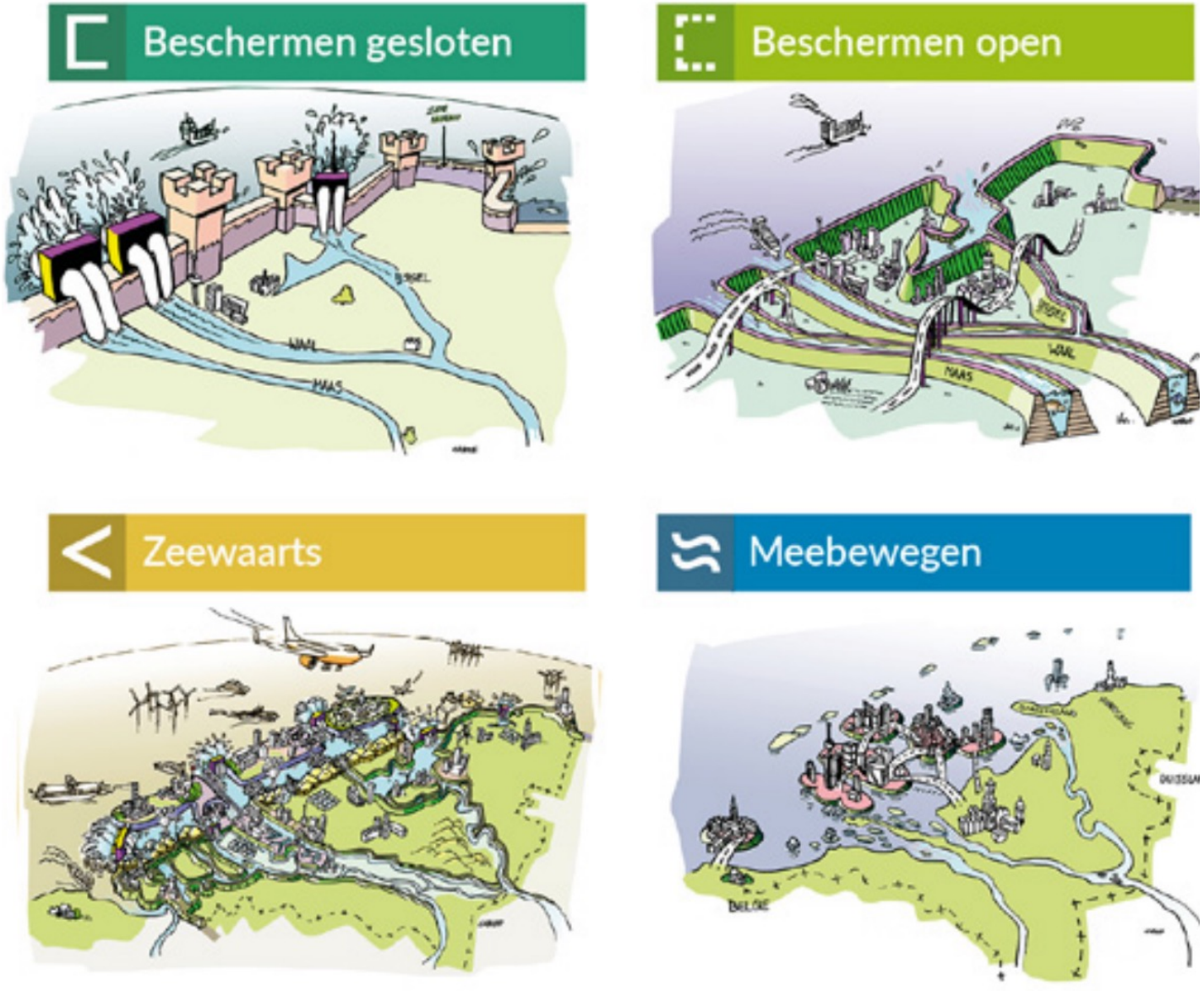
Utrecht University

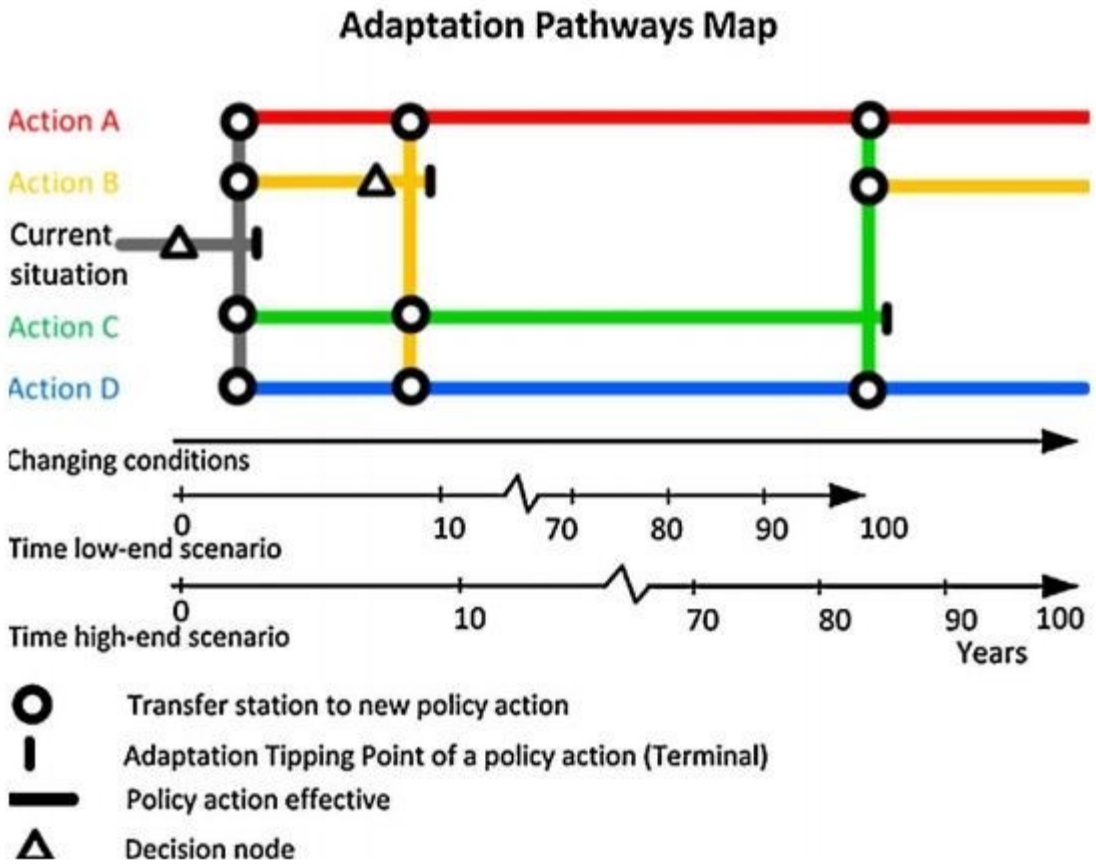
Sea level rise



Total high-end estimate [b]	Upper end of the range	**0.9**	**1.6**	**2.5**	**10**
	Lower end of the range	**0.7**	**1.3**	**2.2**	**9**

IPCC AR6
&
Update vd Wal et al 2022


Beschermen gesloten
Beschermen open
Zeewaarts
Meebewegen


Adaptation Pathways Map
Action A
Action B
Current situation
Action C
Action D
Changing conditions
0
10
70
80
90
100
Time low-end scenario
0
10
70
80
90
100
Years
Time high-end scenario
Transfer station to new policy action
Adaptation Tipping Point of a policy action (Terminal)
Policy action effective
Decision node

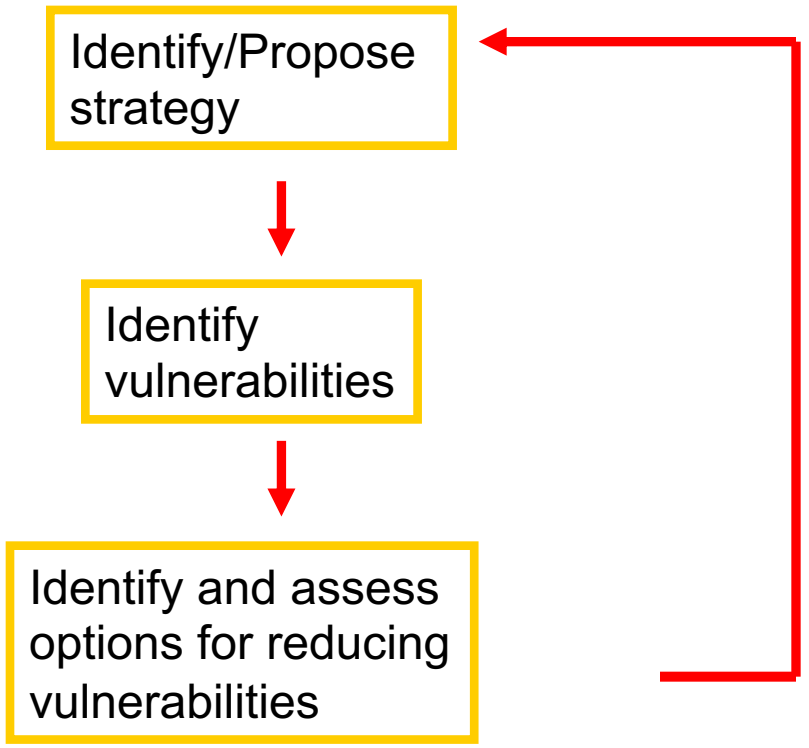
M. Haasnoot

Alternative Approaches and Concept of Digital Twins

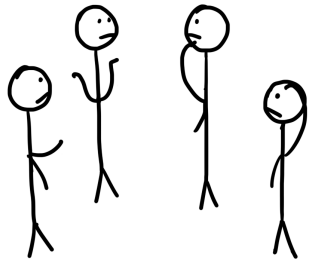
Utrecht University

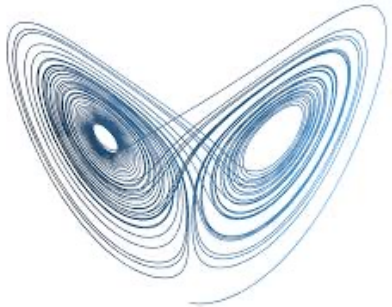
Changing the workflow

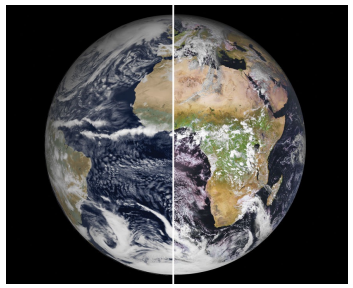
CHARACTERIZE UNCERTAIN VULNERABILITY CONTINGENT ON PROPOSED STRATEGY



After Lempert and Groves 2006; and many others on Robust Decision Making







Models : abstractions

Digital Twins: replicas

complexe models can be digital twins

Some characteristics of Digital Twins

Accurate and reliable simulators
convection resolving weather and ocean models

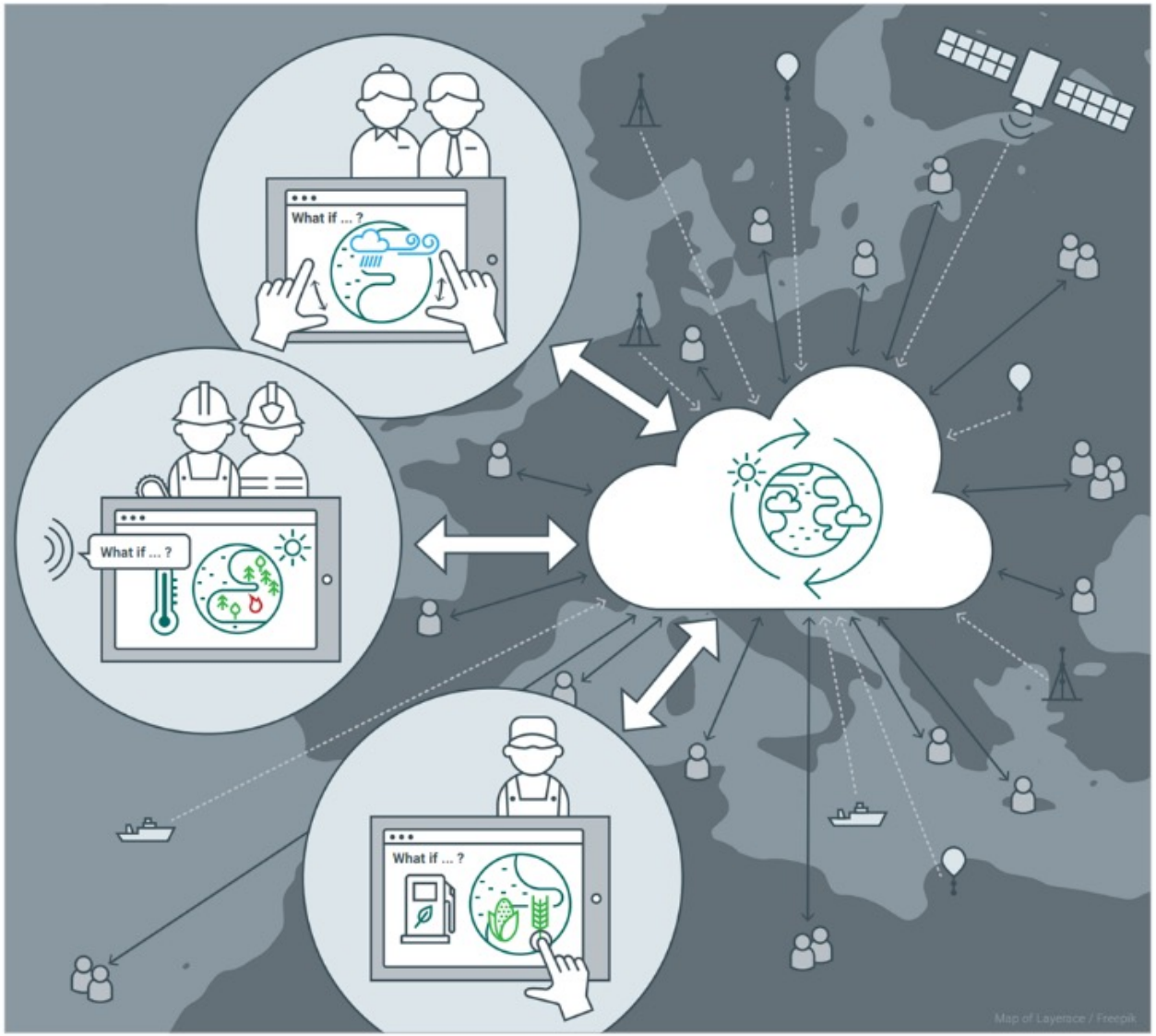
Full integration of data and simulators with a systems approach
integrating physical and social dimension; including data-driven approaches (AI/ML)

User interaction with low latency
flexible steering allowing for 'what if' scenarios

Bring together science, technology, and users

Destination Earth

DT family of weather-induced, climate and geophysical extremes



Bauer, Stevens, Hazeleger, NCC, 2020

EU's Destination Earth (DestinE) initiative

Towards a Digital Twin Earth

Entrusted entities

ECMWF esa EUMETSAT

Key elements

- Digital Twin Engine
- Digital Twins
- Data lake
- Core platform

A European Green Deal (2019)

A European strategy for data (2020)

Shaping Europe's digital future (2020)

ECMWF

2021-2023

- Operational cloud-based platform
- First two digital twins

2023-2025

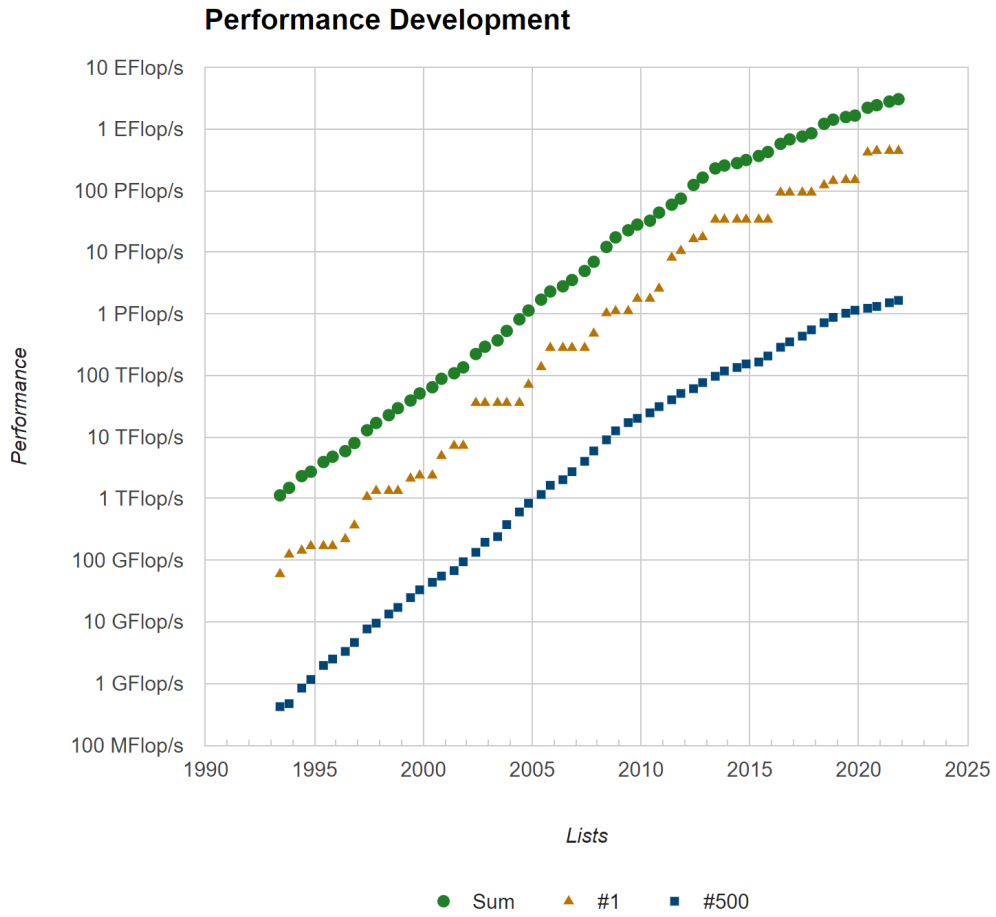
Platform integrates the next operational digital twins and offers services to public sector users

2025-2027+

Towards a full "digital twin of the Earth" through a convergence of multiple digital twins on the platform

Funded by the European Union

Enabled by digital technology: The exascale (10^{18} flops) era arrived



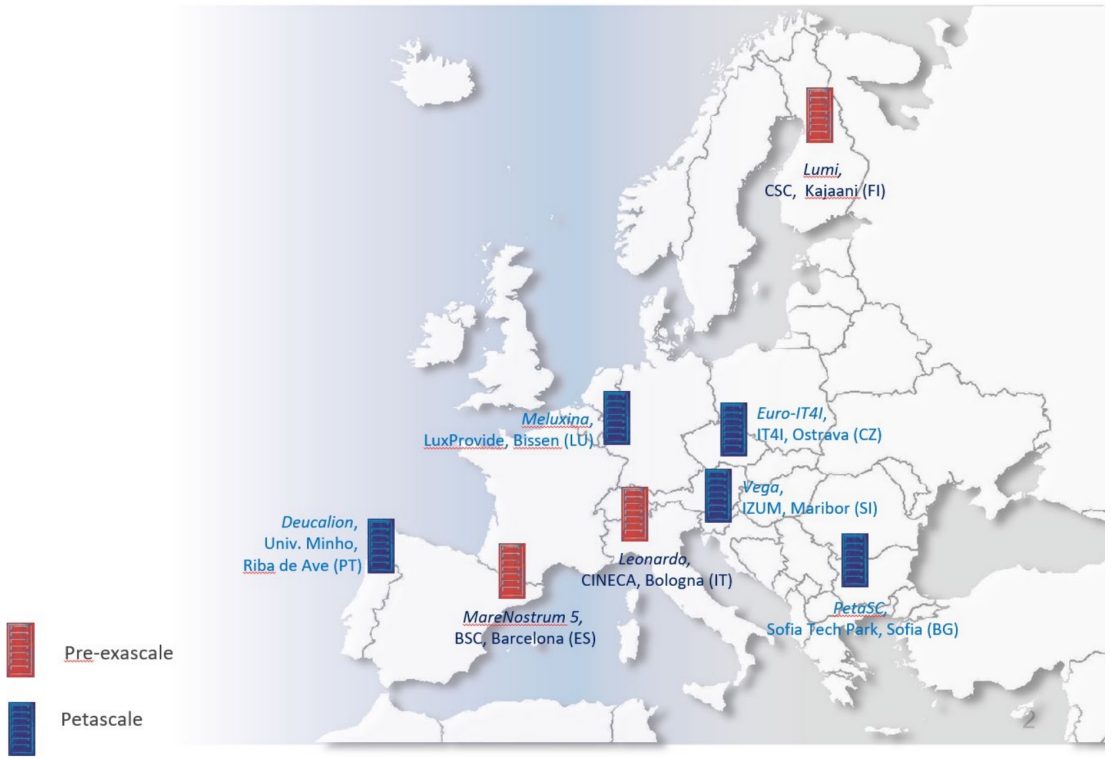
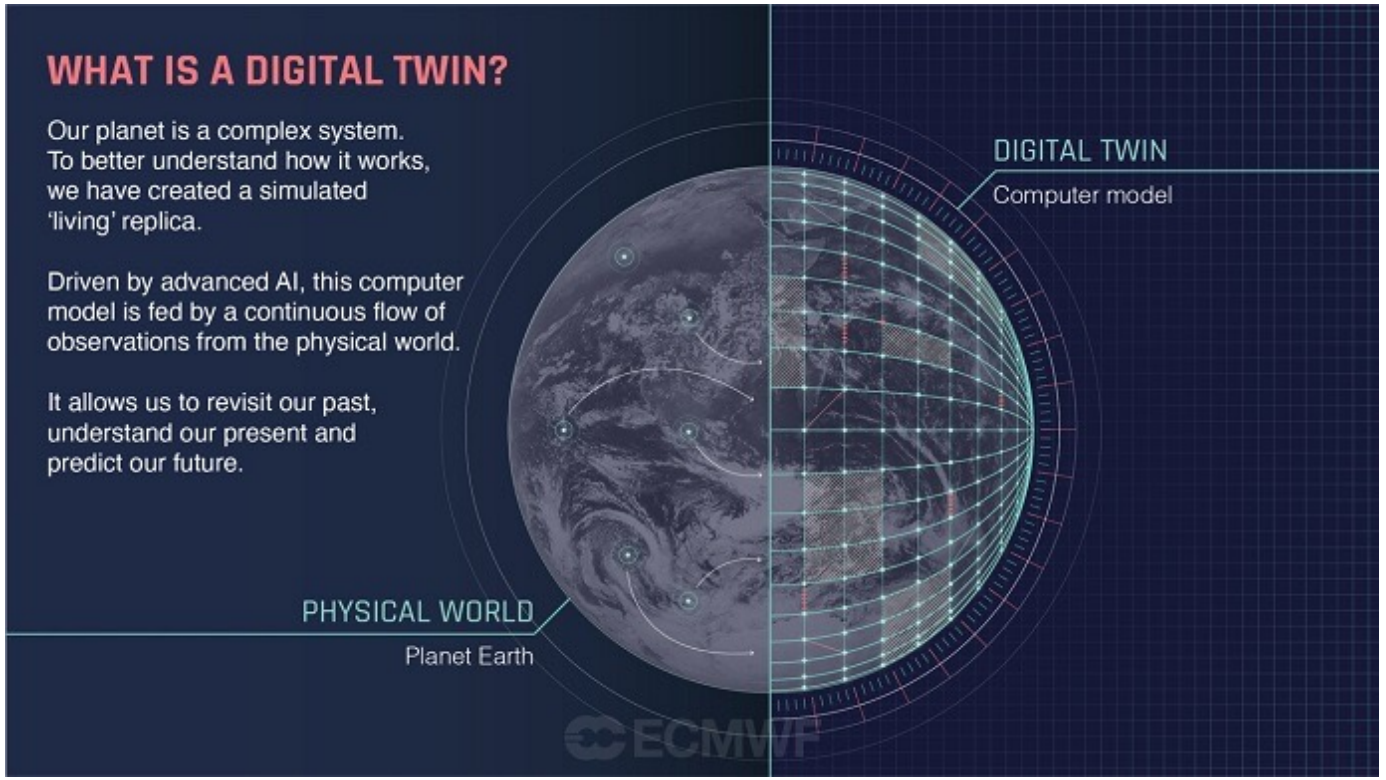


Figure 1 - Site locations of EuroHPC JU supercomputers

Global kilometer-scale and non-hydrostatic ensemble simulations are on the horizon Data-driven and physics aware methods



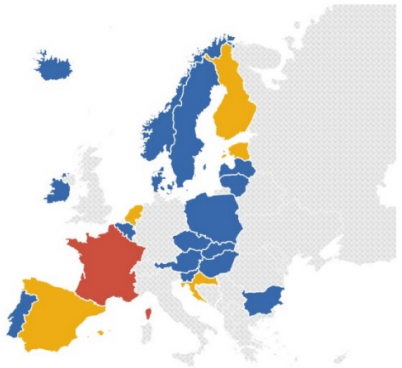
On-demand Extremes DT (procured)

Flexible and scalable workflows for the monitoring and short-range prediction of extremes at sub-km scales, that are configurable and operable on demand; builds on the ACCORD prediction system and selected impact models

Meteo-France led consortium

Participant countries and agencies from the ACCORD consortium

Sweden Spain Slovenia Slovakia Portugal Poland Netherlands Lithuania Latvia
Ireland Iceland Hungary Finland Estonia Denmark Czech Republic Croatia Bulgaria
Belgium Austria France Norway

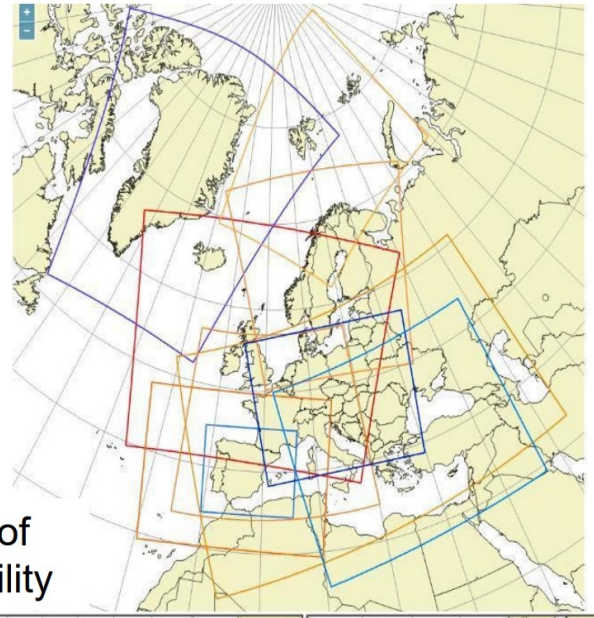


Source: MeteoFrance • Hover in the countries to read the entities involved.
Yellow: Countries with another agency involved in addition to the National Meteorological service.

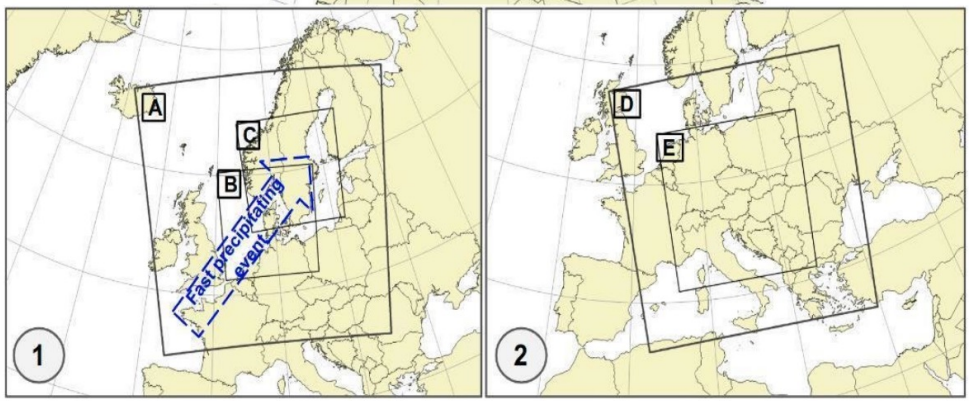
A Flourish map

ECMWF

Today's prediction systems



Examples of configurability

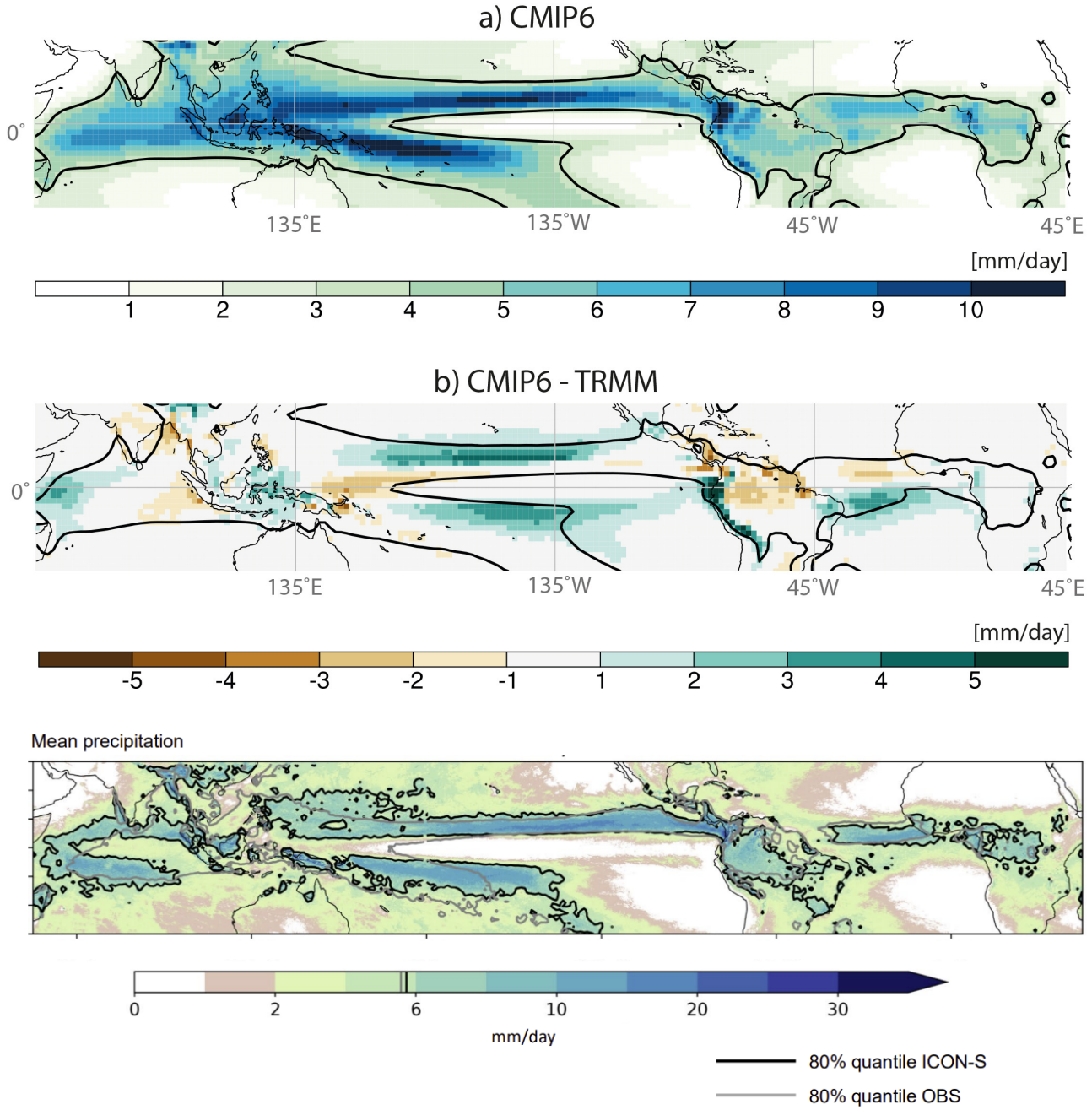


Remaining challenges

Utrecht University

Persistant biases in climate models

High resolution repairs some, but not all



Fiedler et al 2020 (WMR), Segura et al submitted

Technology

Flexible user steering
Replicate integrated systems
Low latency
Data – model fusion across systems

→ *federated & integrated data and compute infrastructure at extreme scale where user steers*

New software and hardware platforms needed
(EuroHPC, ESA, ECMWF etc don't do the job…yet)

A real human dimension

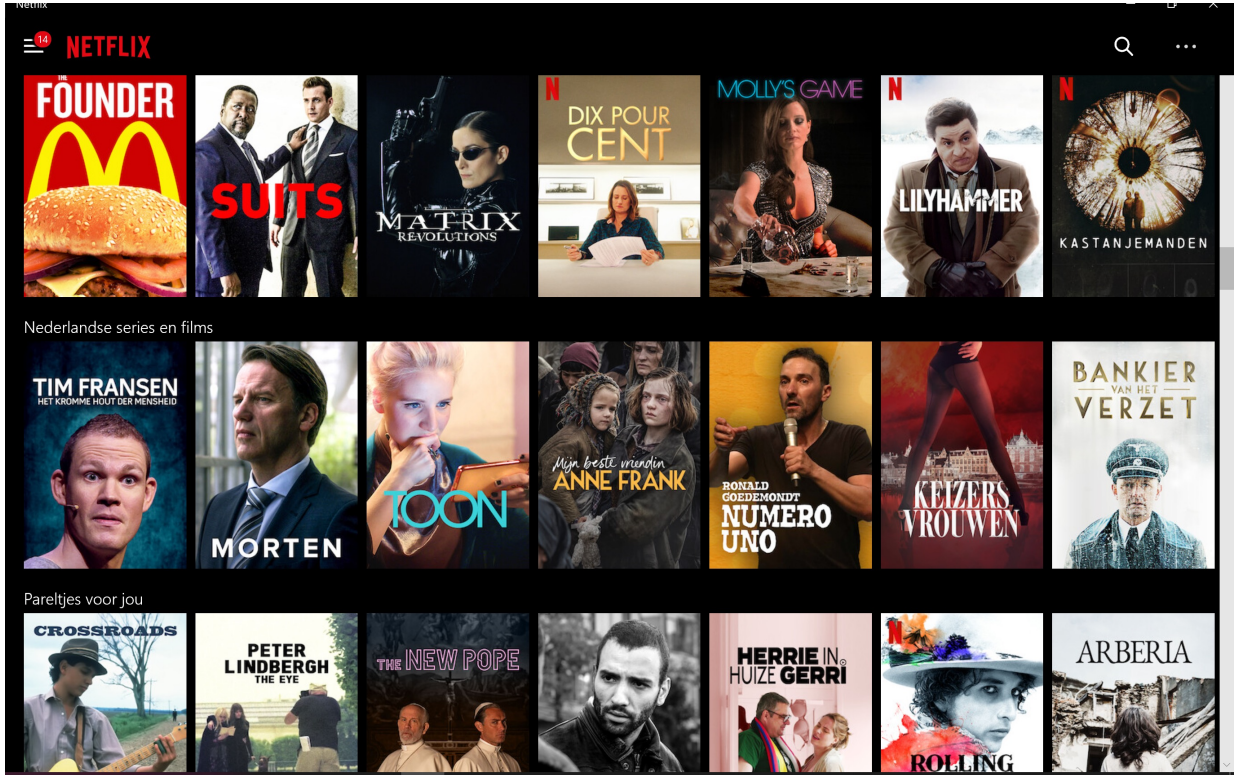
Proximate and distant social worlds are impacted by social and physical worlds, but also contribute to shaping it.
I.e. human behavior is part of feedback loops.

There is an epistemic stance of naieve realism. I.e. response of behavior is seen as objective, but trust is essential.

The interaction with digital tools matter.

Finkenauer, pers comm

Streamed data availability 'climate Netflix'



Many access same data, extract and process data that is produced on the fly

Utrecht University

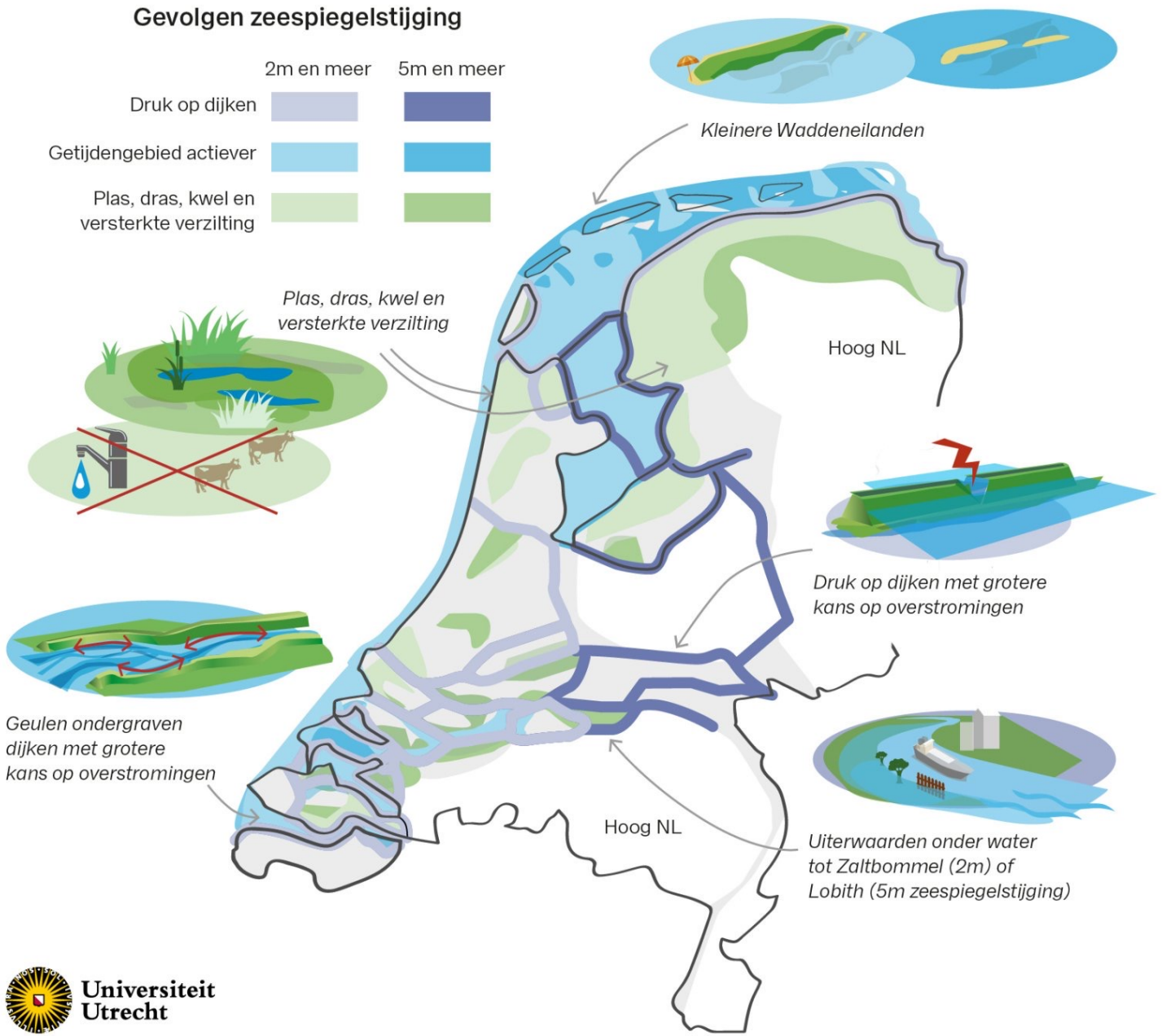
Climate Navigator; 'ClimClim'

Navigate your way in future climates and physical and social virtual realities

Utrecht University

Sharing science,
shaping tomorrow

The information in this presentation has been compiled with the utmost care,
but no rights can be derived from its contents.


Gevolgen zeespiegelstijging
2m en meer
5m en meer
Druk op dijken
Getijdengebied actiever
Plas, dras, kwel en versterkte verzilting
Kleinere Waddeneilanden
Plas, dras, kwel en versterkte verzilting
Hoog NL
Druk op dijken met grotere kans op overstromingen
Geulen ondergraven dijken met grotere kans op overstromingen
Hoog NL
Uiterwaarden onder water tot Zaltbommel (2m) of Lobith (5m zeespiegelstijging)

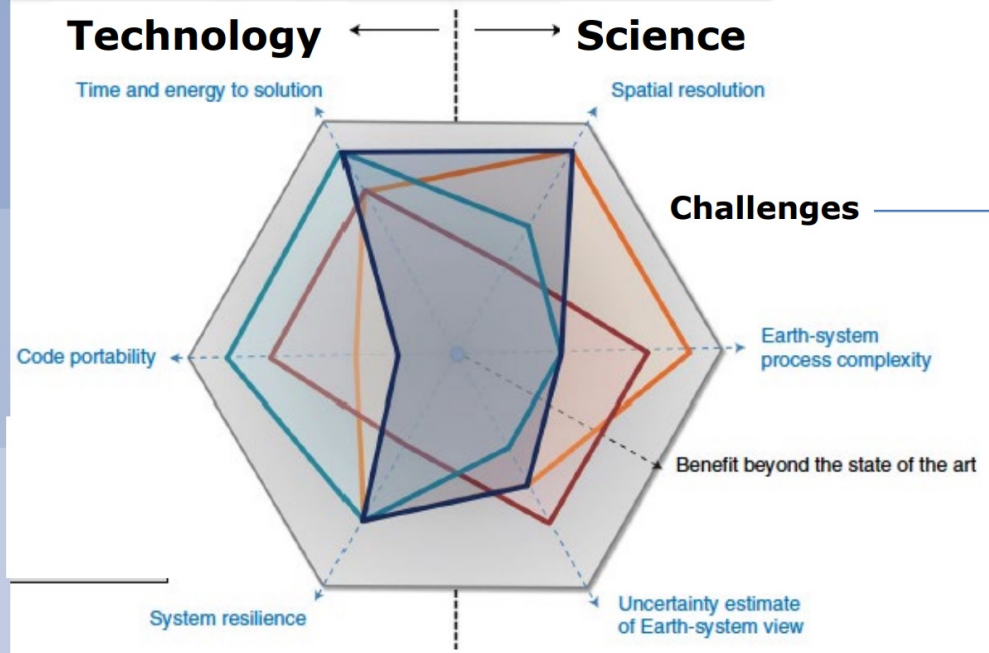
DestinE's Digital Twins: need extreme computing

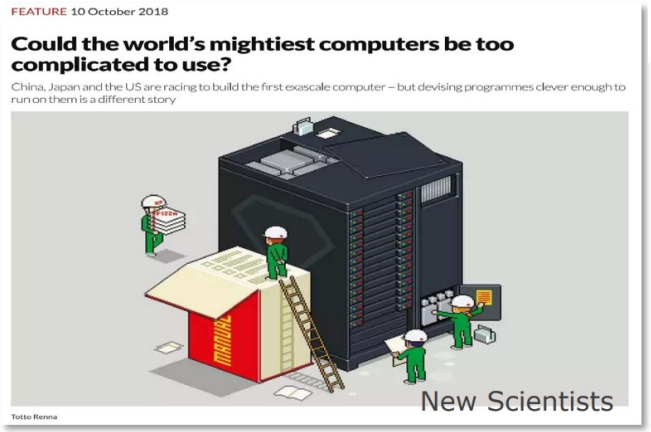
PERSPECTIVE
https://doi.org/10.1038/s43588-021-00023-0
nature computational science
Check for updates

The digital revolution of Earth-system science

Peter Bauer[1], Peter D. Dueben[1], Torsten Hoefler[2], Tiago Quintino[3], Thomas C. Schulthess[4] and Nils P. Wedi[1]

Computational science is crucial for delivering reliable weather and climate predictions. However, despite decades of high-performance computing experience, there is serious concern about the sustainability of this application in the post-Moore/Dennard era. Here, we discuss the present limitations in the field and propose the design of a novel infrastructure that is scalable and more adaptable to future, yet unknown computing architectures.





Solutions

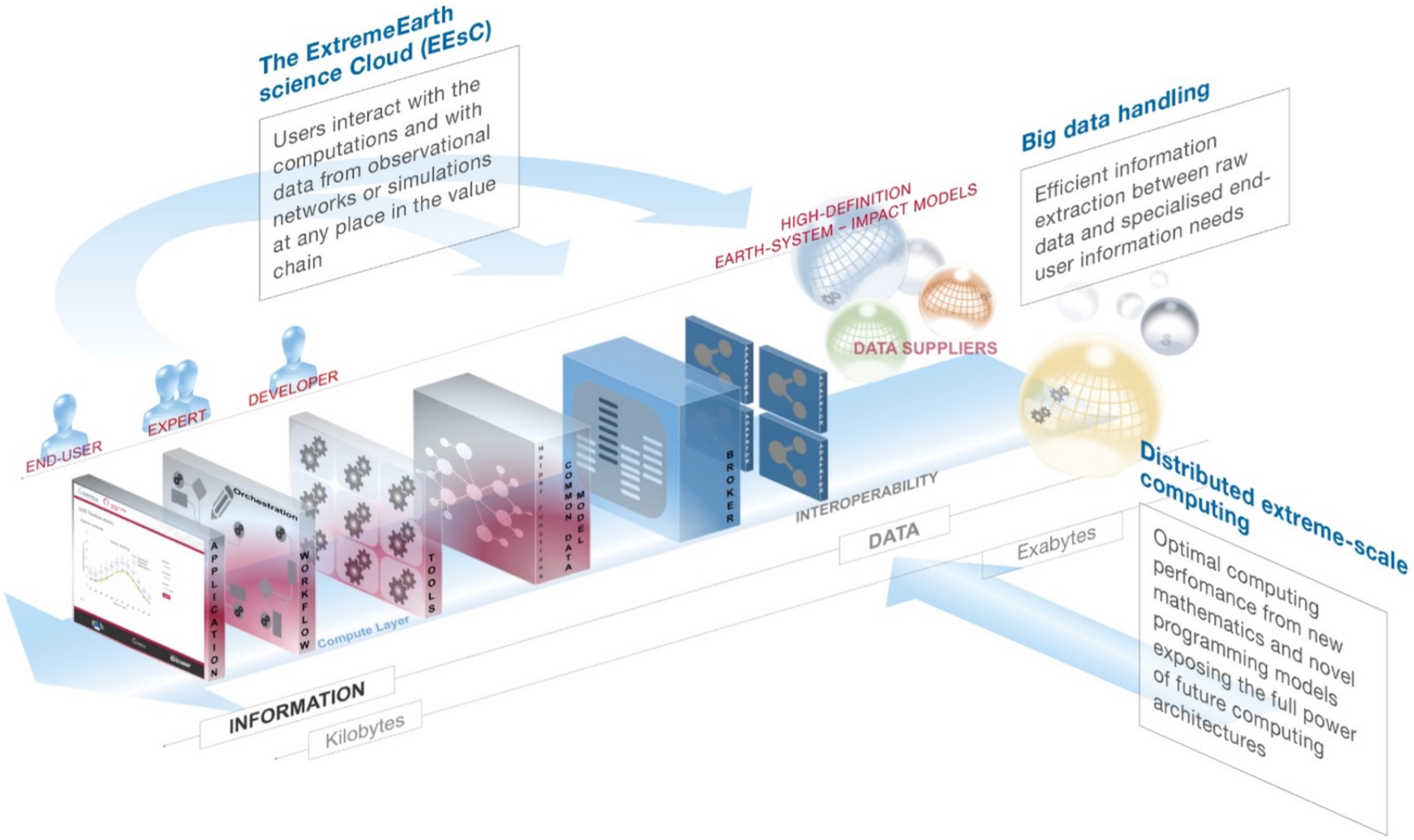
- Numerical methods, algorithms, data structures
- Machine learning
- Programming models
- Heterogeneous processing, memory, interconnect technology

EuroHPC Joint Undertaking

… make sure that technology is not running away from us!

Utrecht University

Geoinformation Digital Twin


The ExtremeEarth science Cloud (EEsC)
Users interact with the computations and with data from observational networks or simulations at any place in the value chain
Big data handling
Efficient information extraction between raw data and specialised end-user information needs
HIGH-DEFINITION EARTH-SYSTEM – IMPACT MODELS
DATA SUPPLIERS
END-USER
EXPERT
DEVELOPER
APPLICATION
Orchestration
WORKFLOW
TOOLS
COMMON DATA MODEL
BROKER
INTEROPERABILITY
DATA
Exabytes
Distributed extreme-scale computing
Optimal computing performance from new mathematics and novel programming models exposing the full power of future computing architectures
Compute Layer
INFORMATION
Kilobytes

Destination Earth: Core Platform