The next generation climate models:
Simulating land and atmosphere at global km-scale resolution

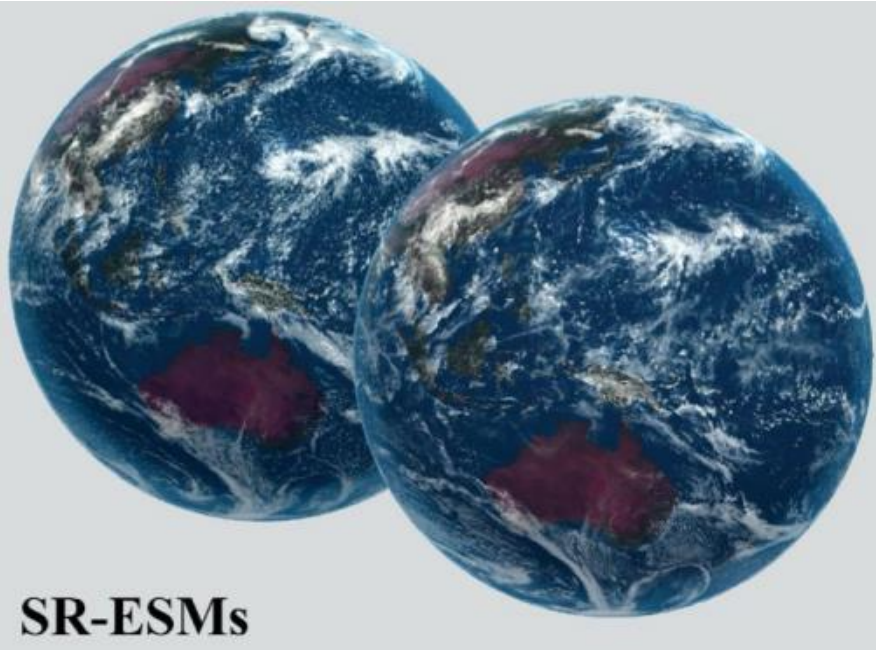
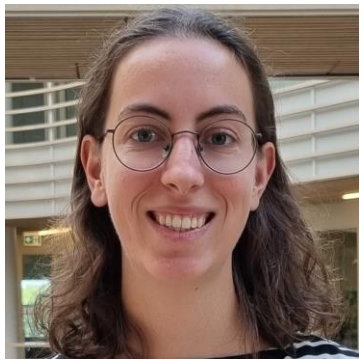


Figure from nextGEMS proposal
SR-ESM = Storm-Resolving Earth System Model

Chiel van Heerwaarden (PI)
Energy balance

Imme Benedict
Hydrological cycle

Menno Veerman
Radiation



Sarah Warnau
Land-atmosphere interaction

Teaser video

- Media Library | nextGEMS (nextgems-h2020.eu)

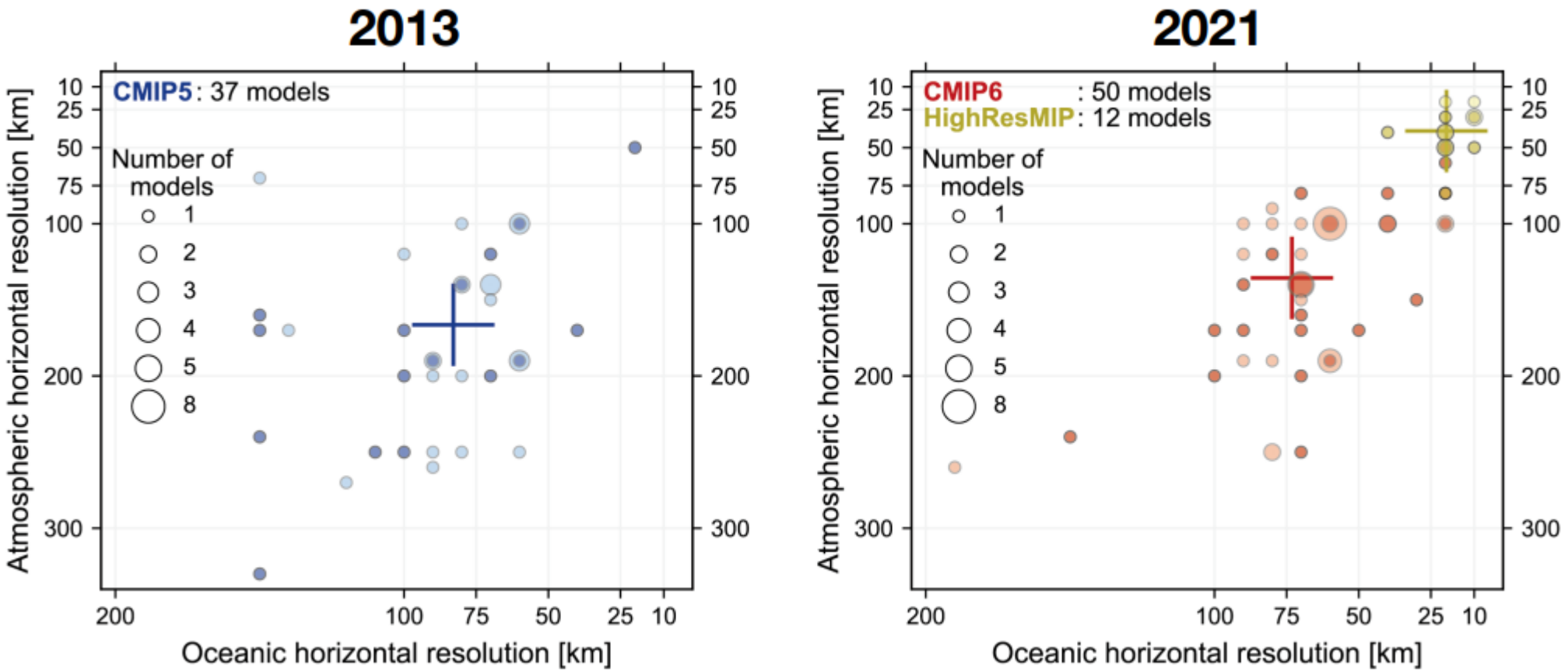
or

- https://youtu.be/z487L1ykhAc

Contents of this presentation

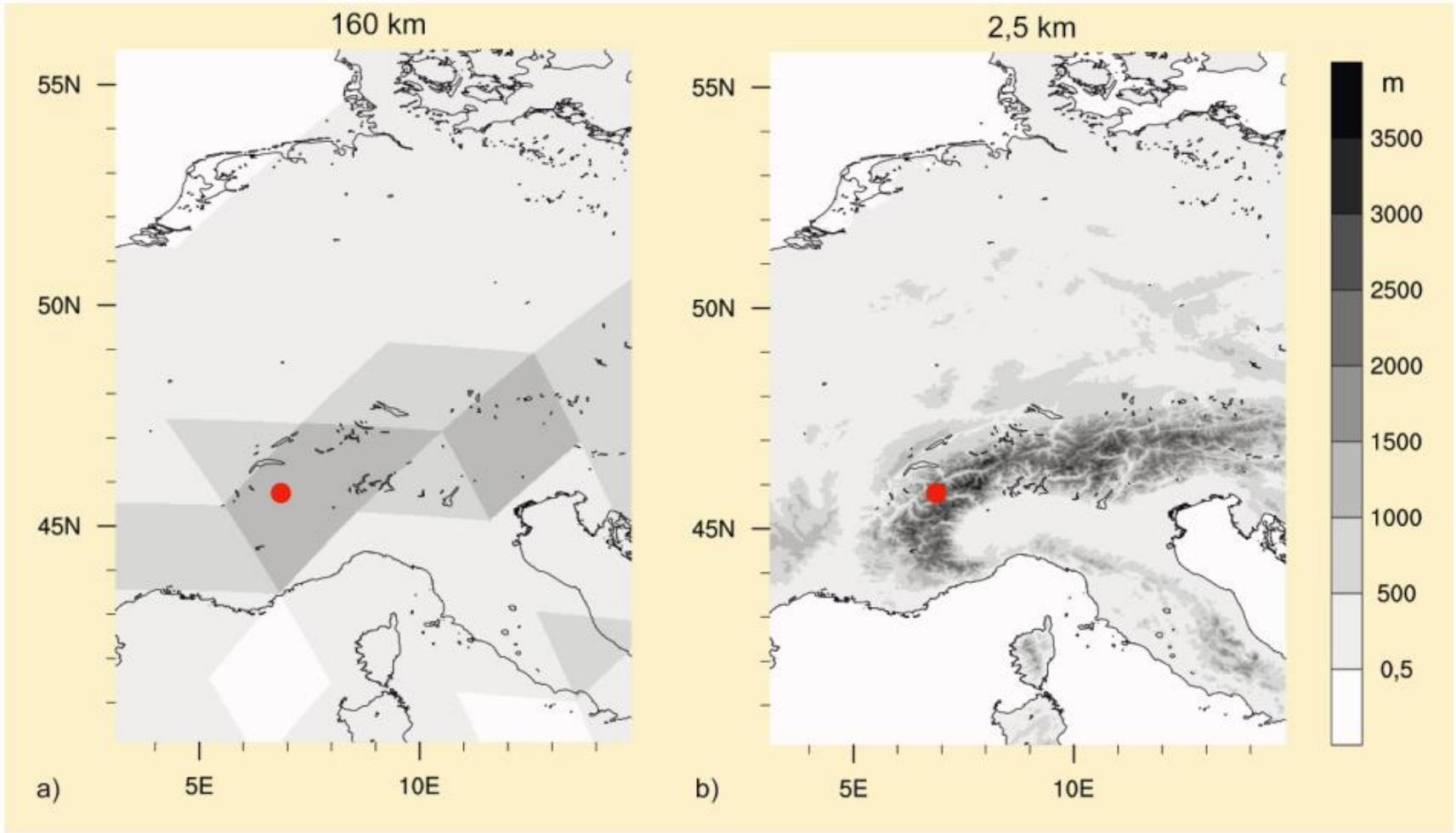
- Why run km-scale global models?
- Introducing the nextGEMS project
- First results from km-scale simulations; focus on water balance & precip
- My experience so far working with output from these models

Climate/earth-system models move to higher horizontal resolution



IPCC 2021

Resolving orography at km-scale

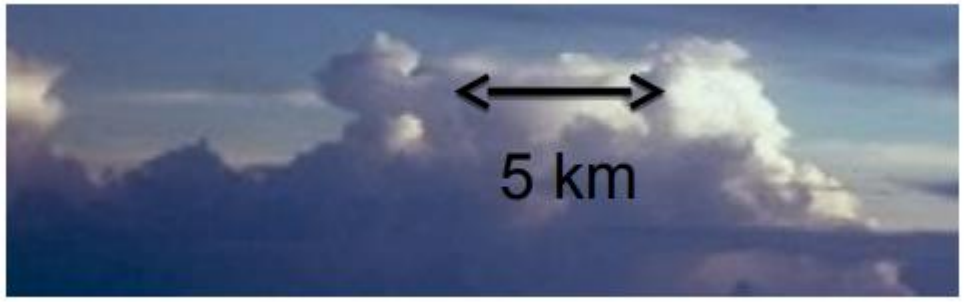


‚tradtional' climate model : 1394 m

Storm-resolving climate model : 4018 m

Hohenegger and Klocke, 2020

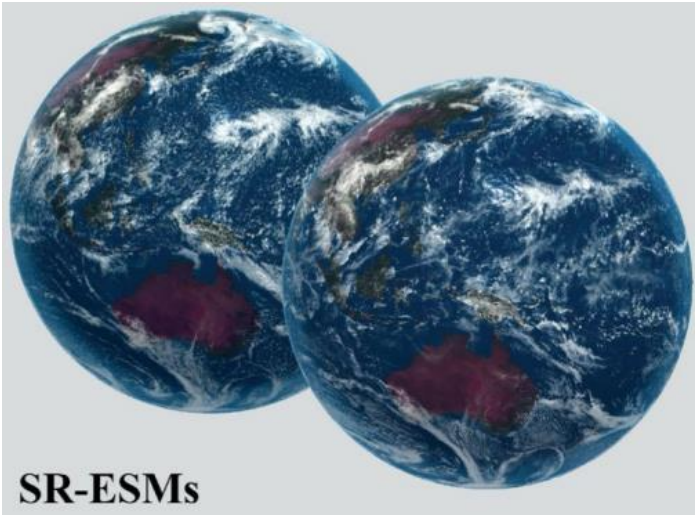
Why run km-scale global models?



- Connect large-scale with local processes
- No need for downscaling
- Better representation of the land-surface and orography
- Resolve ocean eddies
- Less parameterizations, start resolving convective systems
- Reduce long-standing biases in climate modelling
  - Resolving convective clouds improves precipitation diurnal cycle (Honehegger et al., 2008) & mesoscale convective systems (Becker et al., 2021)

nextGEMS (EU H2020 project)

- Aims to develop two **Storm-Resolving Earth-system models** (SR-ESM) to the study of anthropogenic climate change



- Lay foundation for Destination Earth initiative of the European Commission (digital twins)

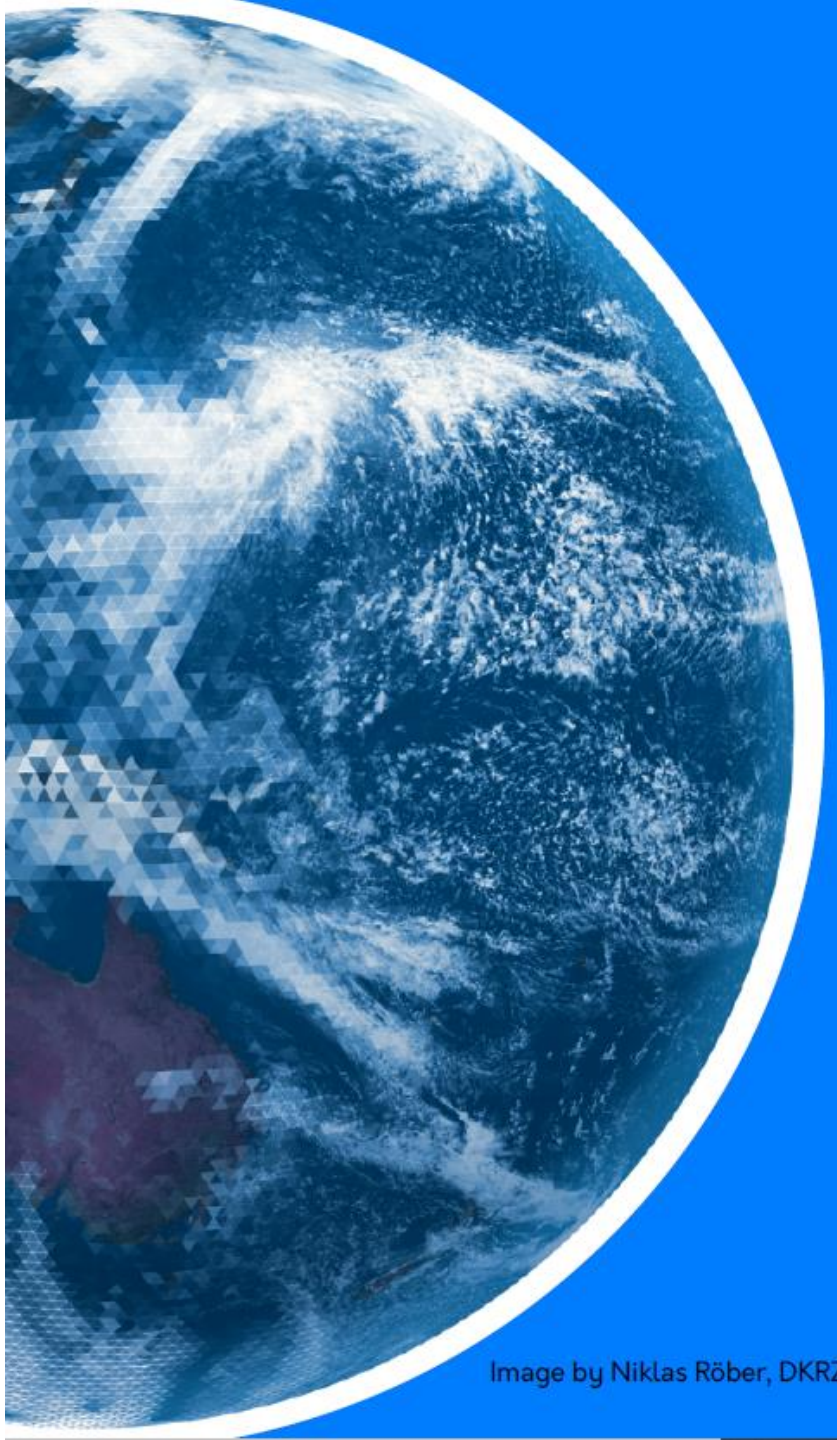


Image by Niklas Röber, DKRZ

next GEMS

next **G**eneration **E**arth **M**odelling **S**ystems

4 year project with start in Sep 2021

Lead PIs: Bjorn Stevens (MPI-M) & Irina Sandu (ECMWF)

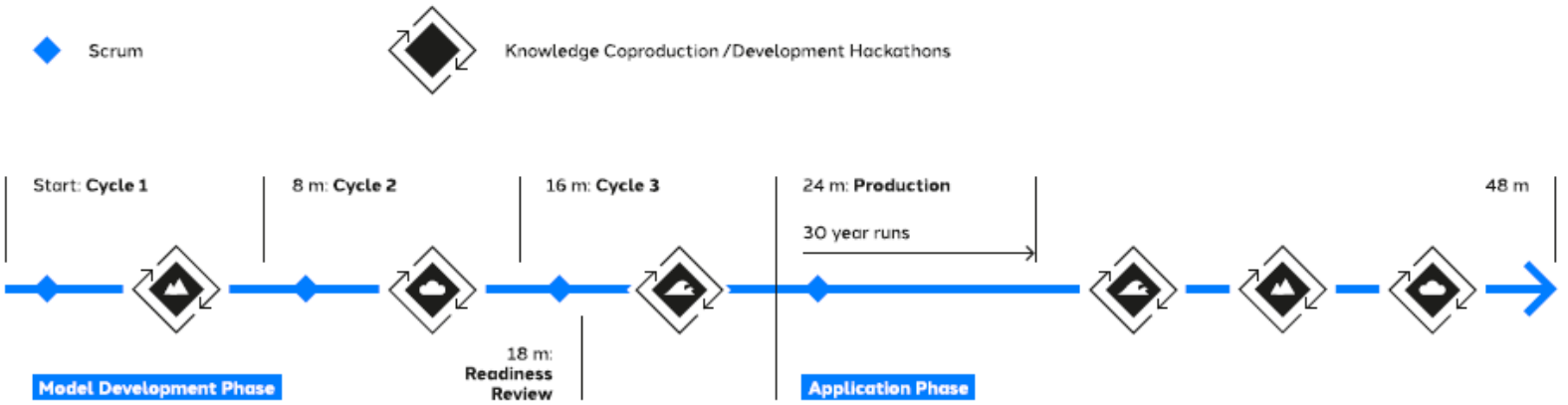
nextGEMS is funded through the European Union's Horizon 2020 research and innovation program under the grant agreement number 101003470.

nextGEMS in a nutshell

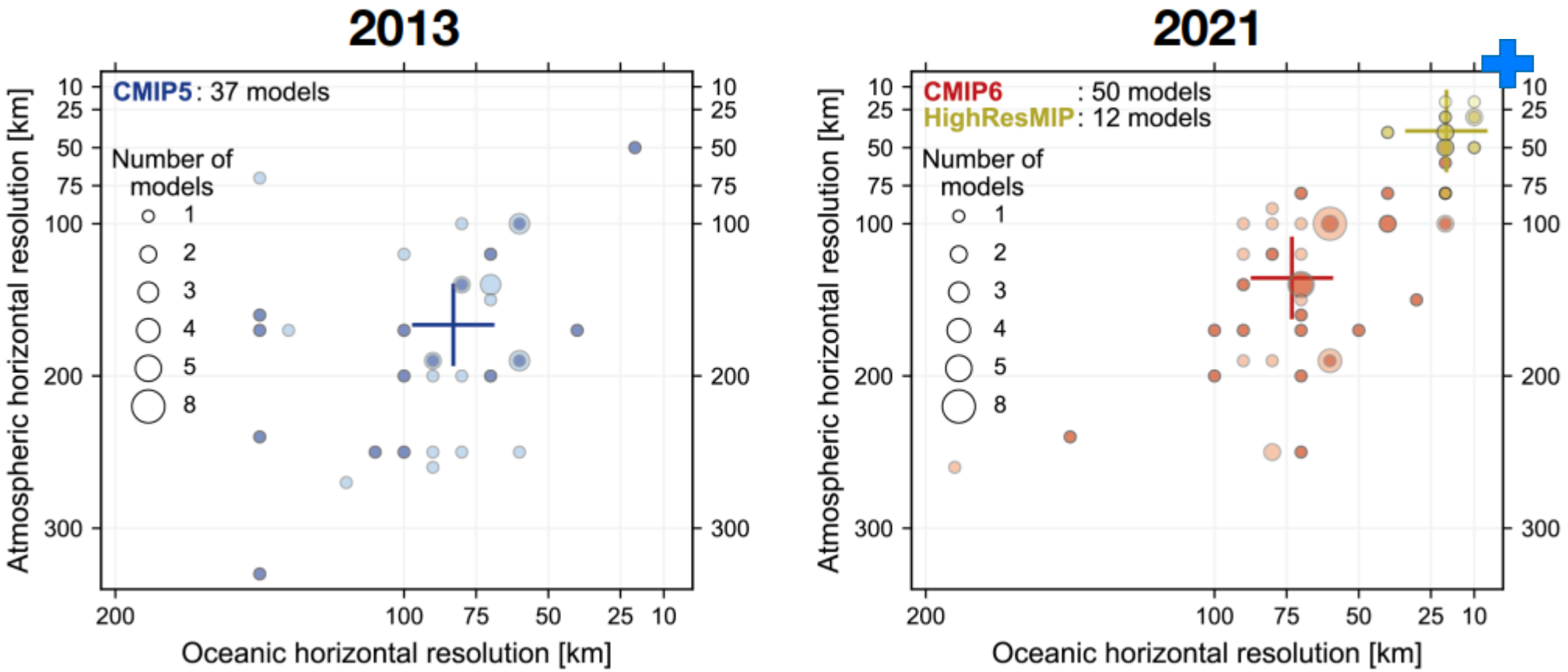
Objectives

- We develop two SR-ESMs for applications and perform the first global multi-decadal (30 y) SR-ESM based climate projections
- We use SR-ESMs to test emerging and long-standing hypotheses underpinning our understanding of climate change, e.g. how convective organisation impacts the strength of cloud feedbacks
- We'd like to build more integrated communities of ESM users

Timeline

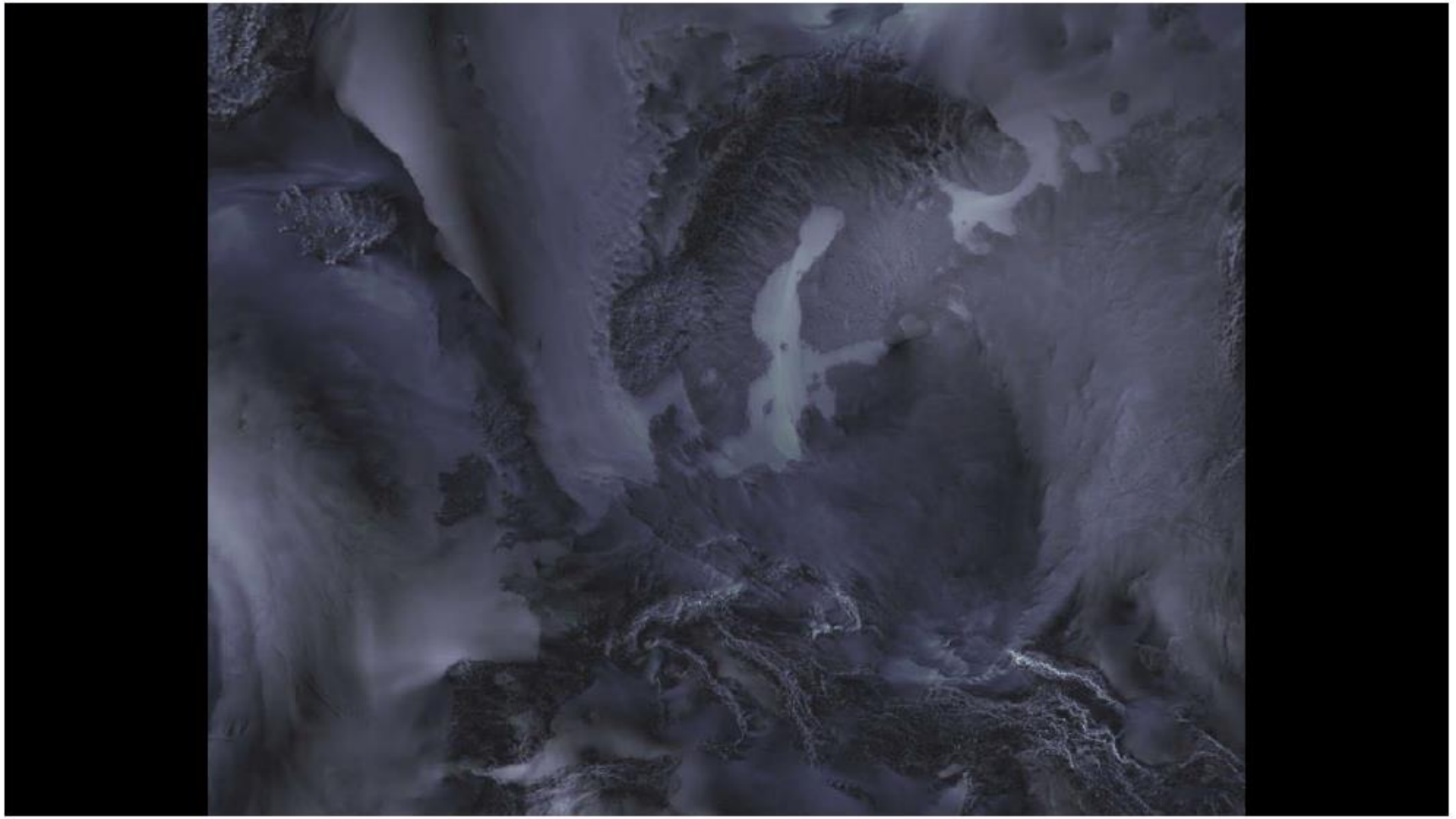


Storm-resolving means km-scale atmosphere and ocean simulations



IPCC 2021

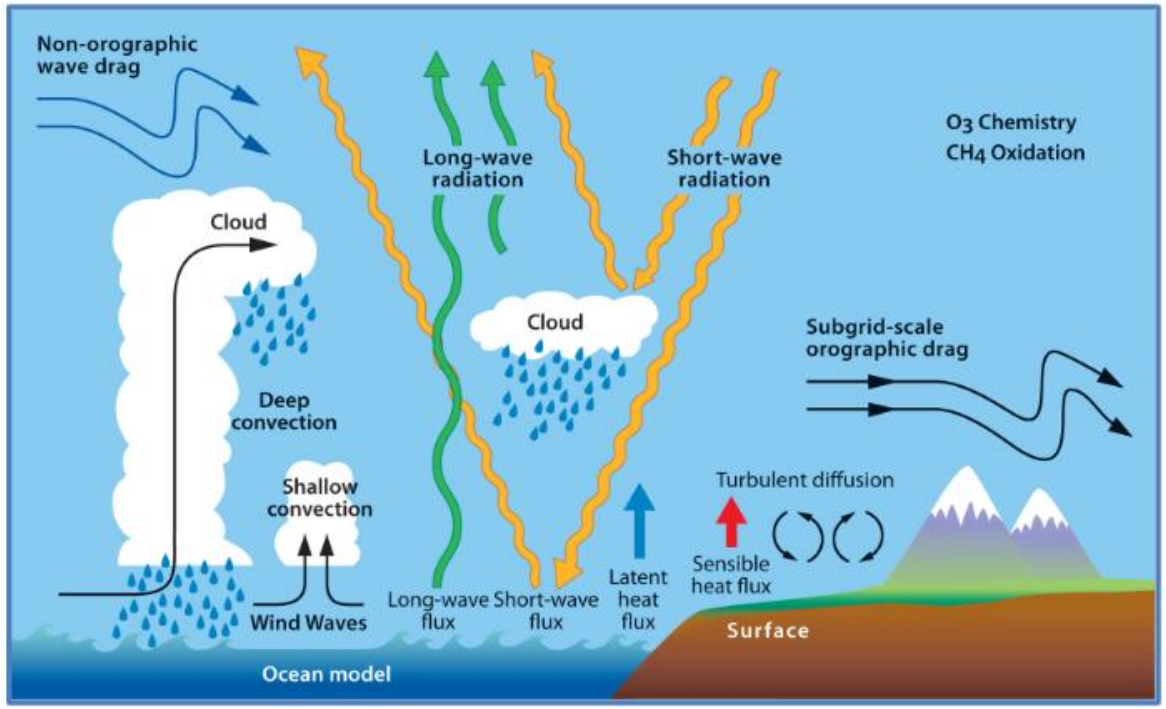
Wind gusts over Europe

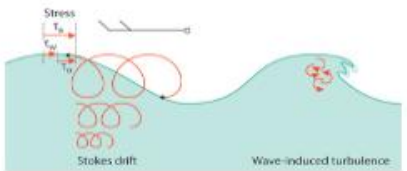


The color scale is from 0 to 40 m/s. | Model: IFS | Domain: Global | The number of surface nodes: 28 million | Resolution: 4 km | Machine: Mistral at DKRZ | Data: Thomas Rackow, ECMWF | Visualization: Nikolay Koldunov, AWI

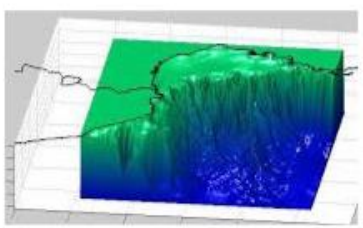
The ECMWF Integrated Forecasting System (IFS)

Slide by Thomas Rackow (ECMWF)





EC-WAM



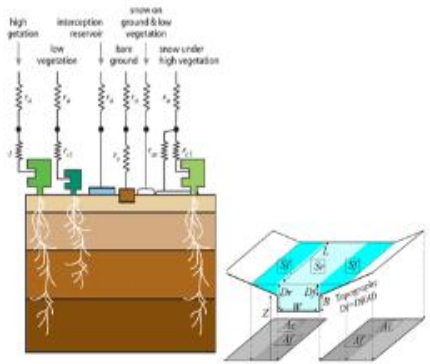
NEMO3.4

+

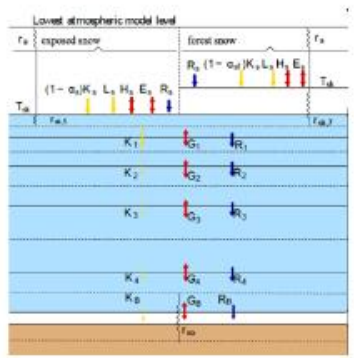
LIM2

https://fesom.de/media/video/

new ocean/sea-ice option: FESOM



H-TESSEL
CAMA-FLOOD



SL/(ML) SNOW

IFS Cy47r3 documentation
Mogensen 2018
Keeley and Mogensen 2018
Boussetta et al, 2021
Arduini et al., 2019

ICON - ICOsahedral Nonhydrostatic

Developed by DWD, MPI-M, DKRZ, KIT and C2SM

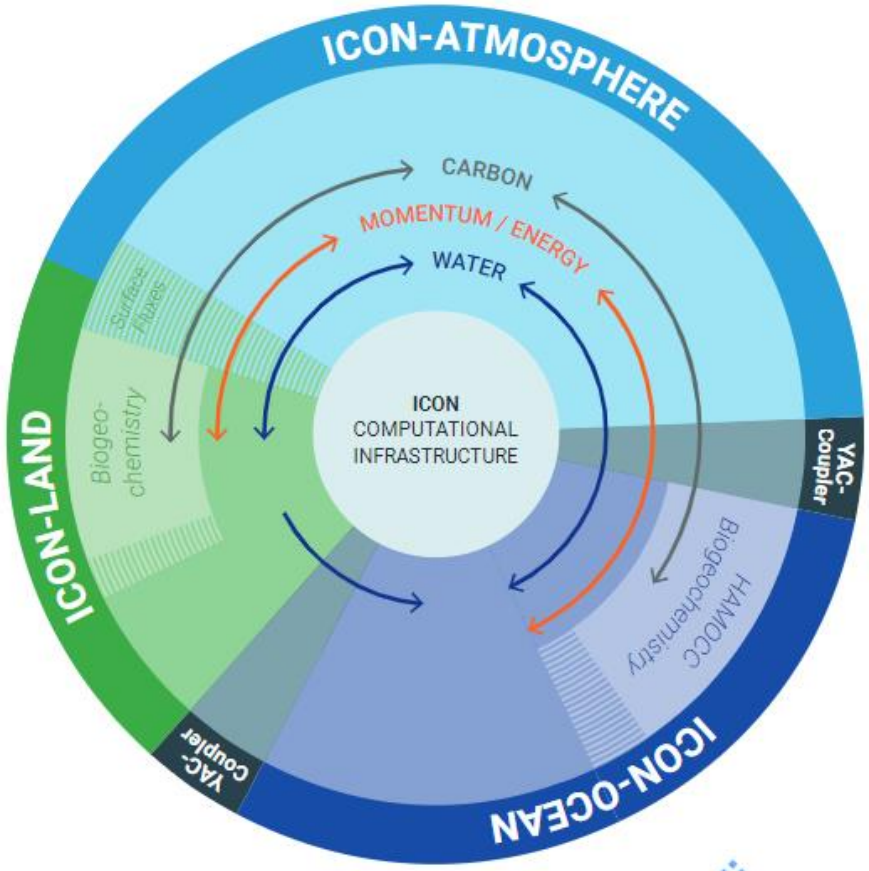
Non-hydrostatic equations on global Domains

Good conservation properties (mass and energy)

Applicable on wide range of scales (global, regional, local)

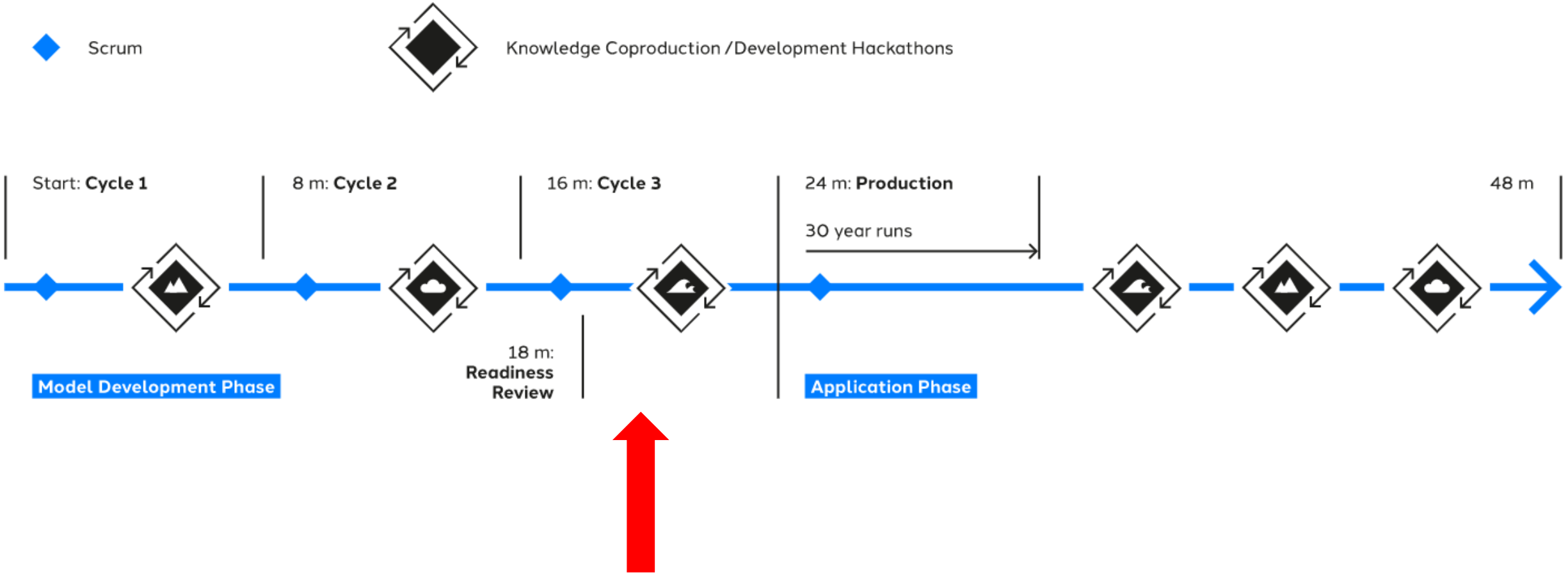
Scaleable to be able to use the biggest computers

Mesh refinement for one- and two-way nesting



Hohenegger et al. (2022)

Timeline producing simulations



Once the simulations are there → do the science

Project focuses on ocean, aerosols, tropical circulation, ..

Focus from WUR on land & atmosphere

Painting by Jacob van Ruisdael

Water imbalance

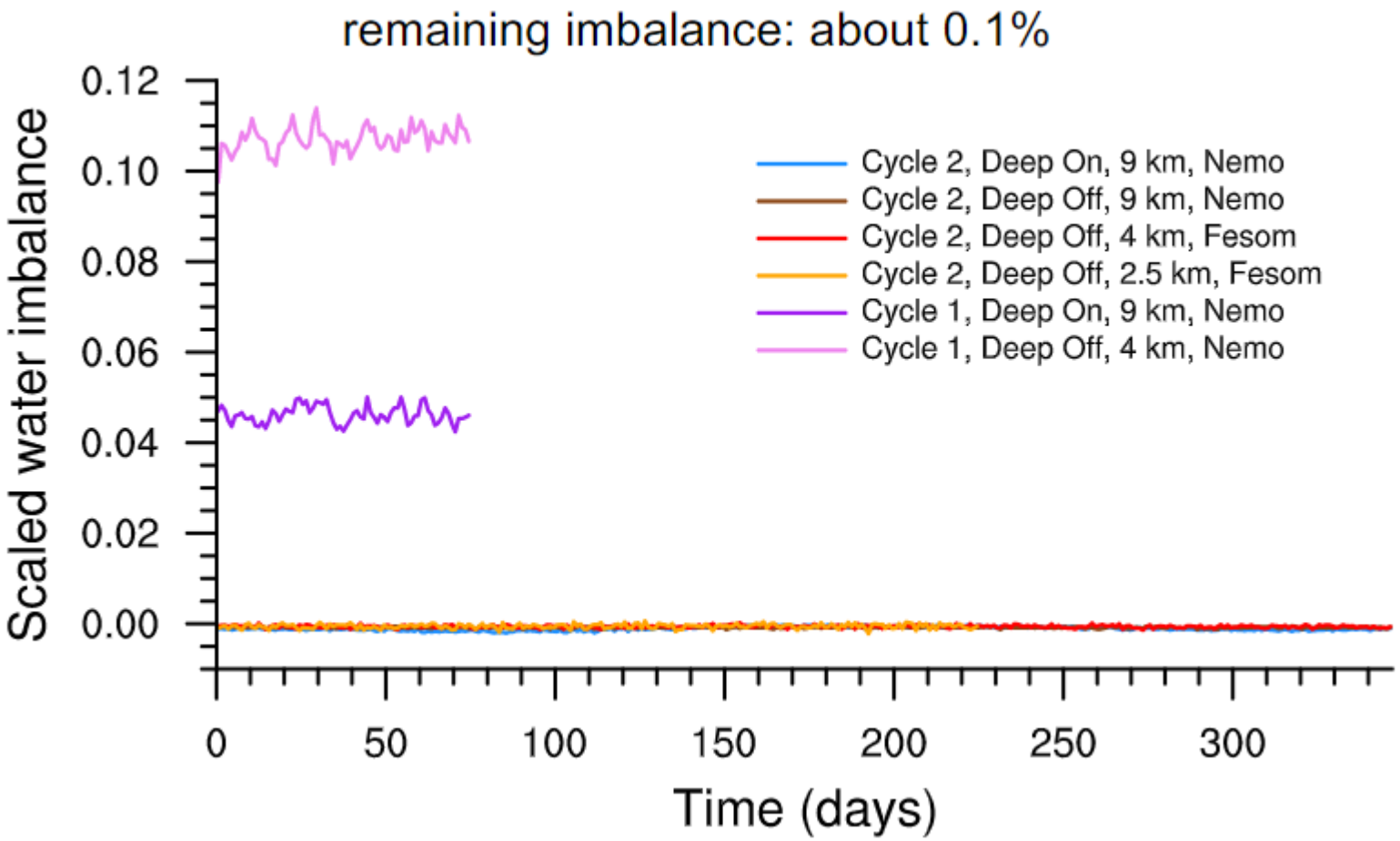
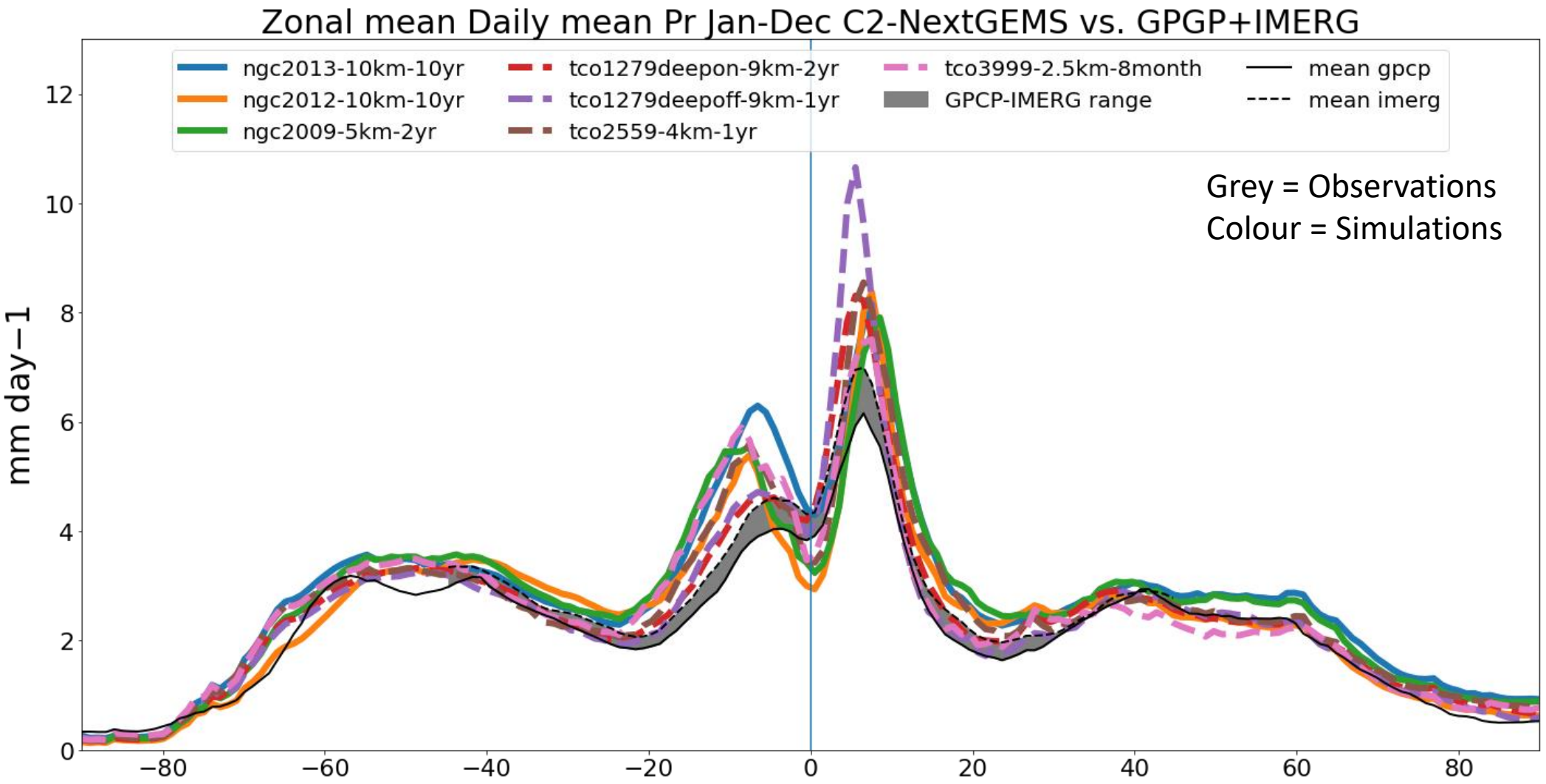


Figure by Tobias Becker (ECMWF)

Cycle 1: pink & purple

Cycle 2: red, yellow, brown, blue
→ improved water balance
(evaporation minus precipitation)

Precipitation



Rain bombs

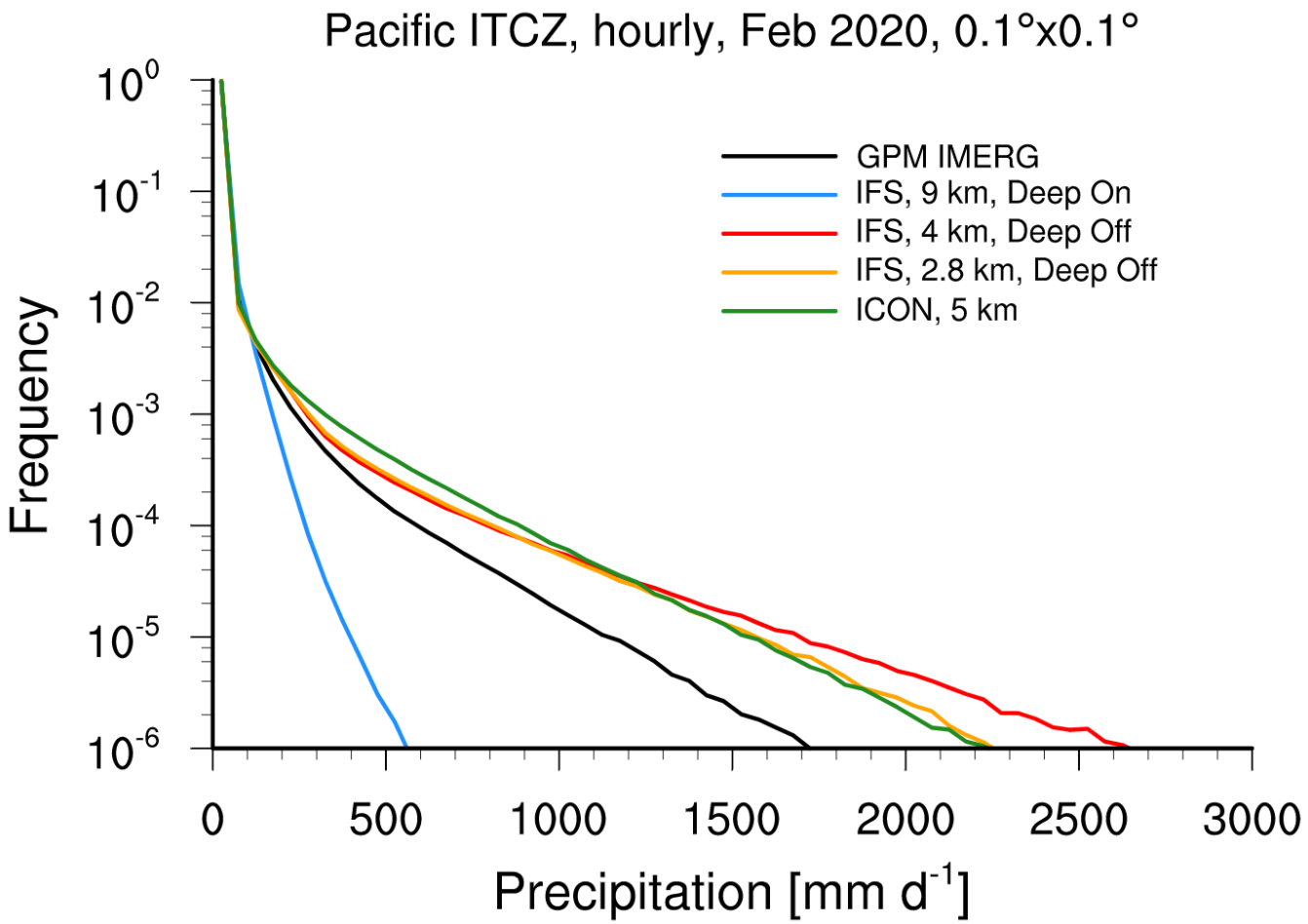


Figure by Tobias Becker (ECMWF)

Deep on → deep convection is parameterized
Deep off → deep convection is resolved

GPM IMERG = precip satellite product

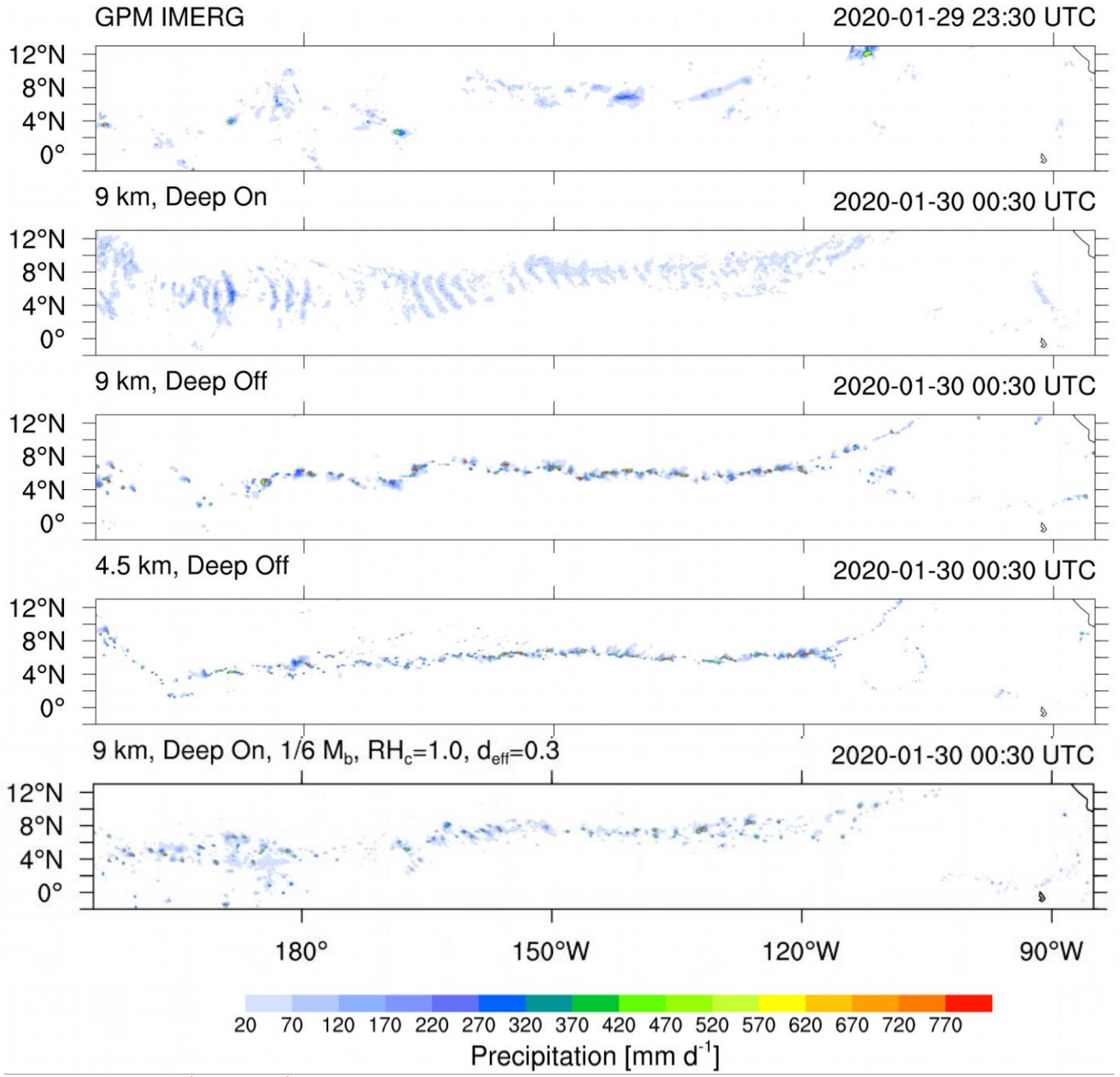
Rain structures

Figure by Tobias Becker (ECMWF)

GPM IMERG = precip satellite product

Compared to IFS simulations

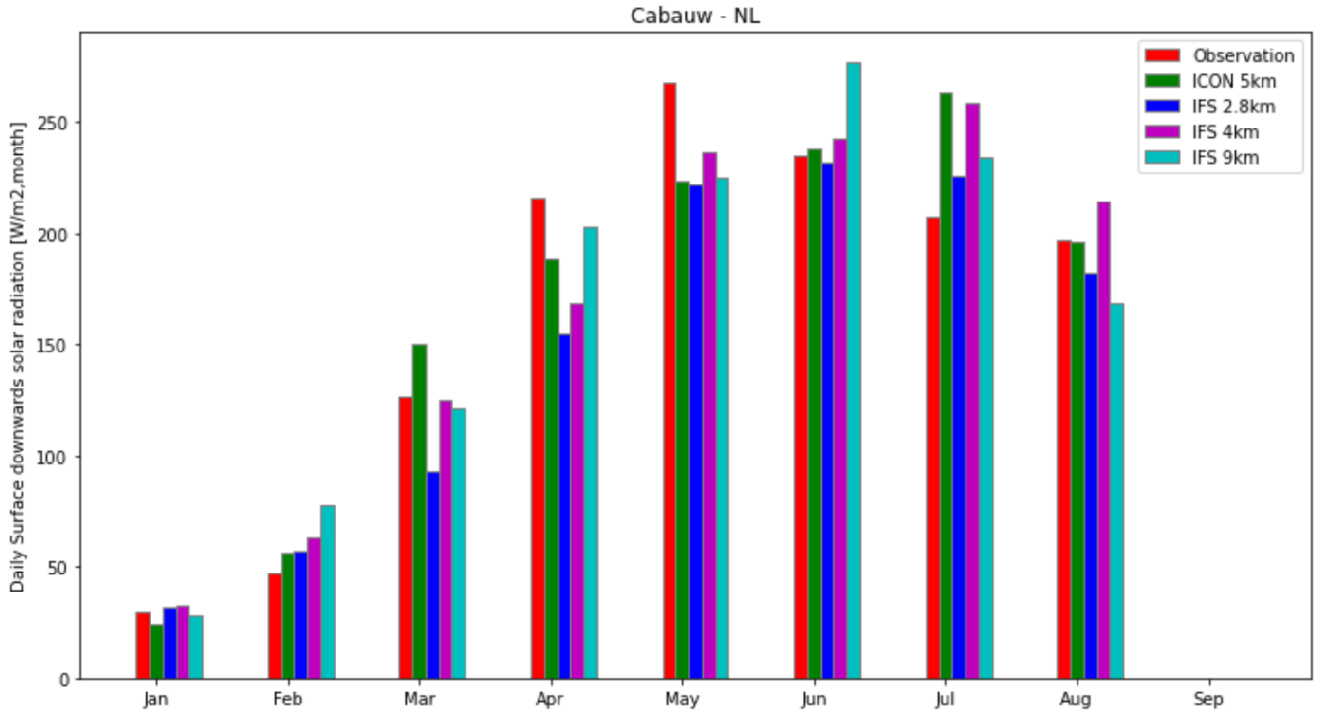
Deep on → deep convection is parameterized
Deep off → deep convection is resolved



Directly from model results to impact

- Local scale information is globally available

- Interesting for:
  - Renewable energies
  - Fisheries
  - Hydrology
  - And many more



Surface downward solar radiation compared against observations of Cabauw (NL) station (Figure by Sebastian Zainali, Mälardalen University)

My experience so far working with km-scale global models

- Pioneering project; New challenges appear by solving at km-scale such as improving the land-surface maps, coupling of ocean and atmosphere, fixing energy leakages

- So far, free simulations of 1 year, validation is challenging
- For spatial validation you also need spatial observations at these km-scale resolutions

- Workflow to assess terabytes of data is still under investigation (constantly changing), no local copies on your own machine
- You need technical support on how to efficiently handle data

- Hackathons are fun!
- Movies are appealing and get media attention

More information – please get in contact

- https://nextgems-h2020.eu/
- https://www.linkedin.com/company/nextgems-eu-horizon2020/

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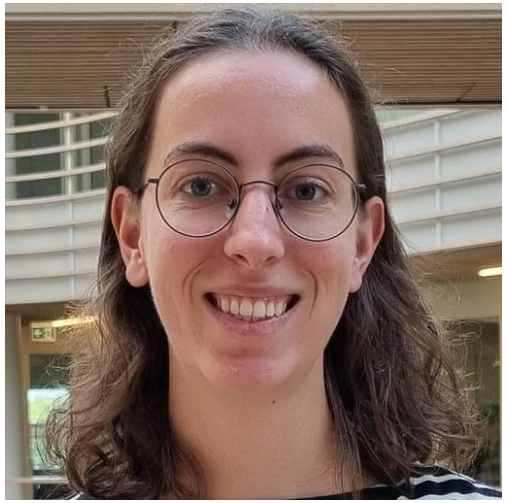

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