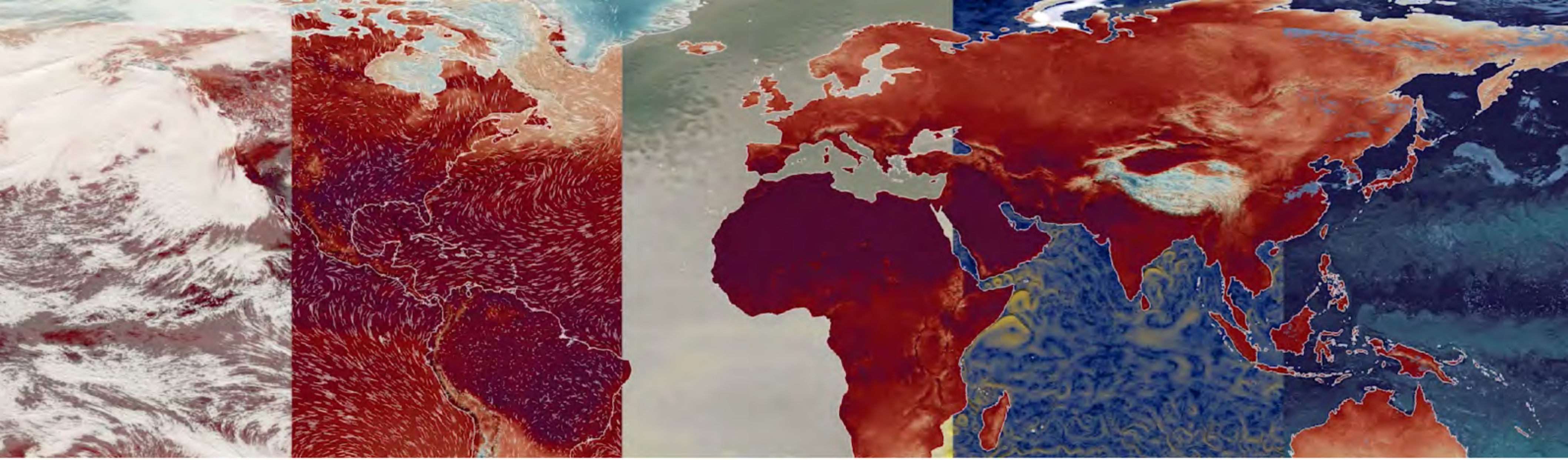


NextGEMS — Next Generation Earth Modelling Systems

H2020 project ; started on 1 Sept 2021 (4 years)

Coordinators : Bjorn Stevens (MPI) and Irina Sandu (ECMWF)

Consortium : 26 institutes from 14 countries (13 European + Senegal)

Objective : to develop and apply global coupled Storm-Resolving Earth System Models (SR-ESMs) to the study of anthropogenic climate change

So far : DYAMOND

First intercomparison of Global Storm Resolving Models

- 10+ models
- short simulations (40 days)

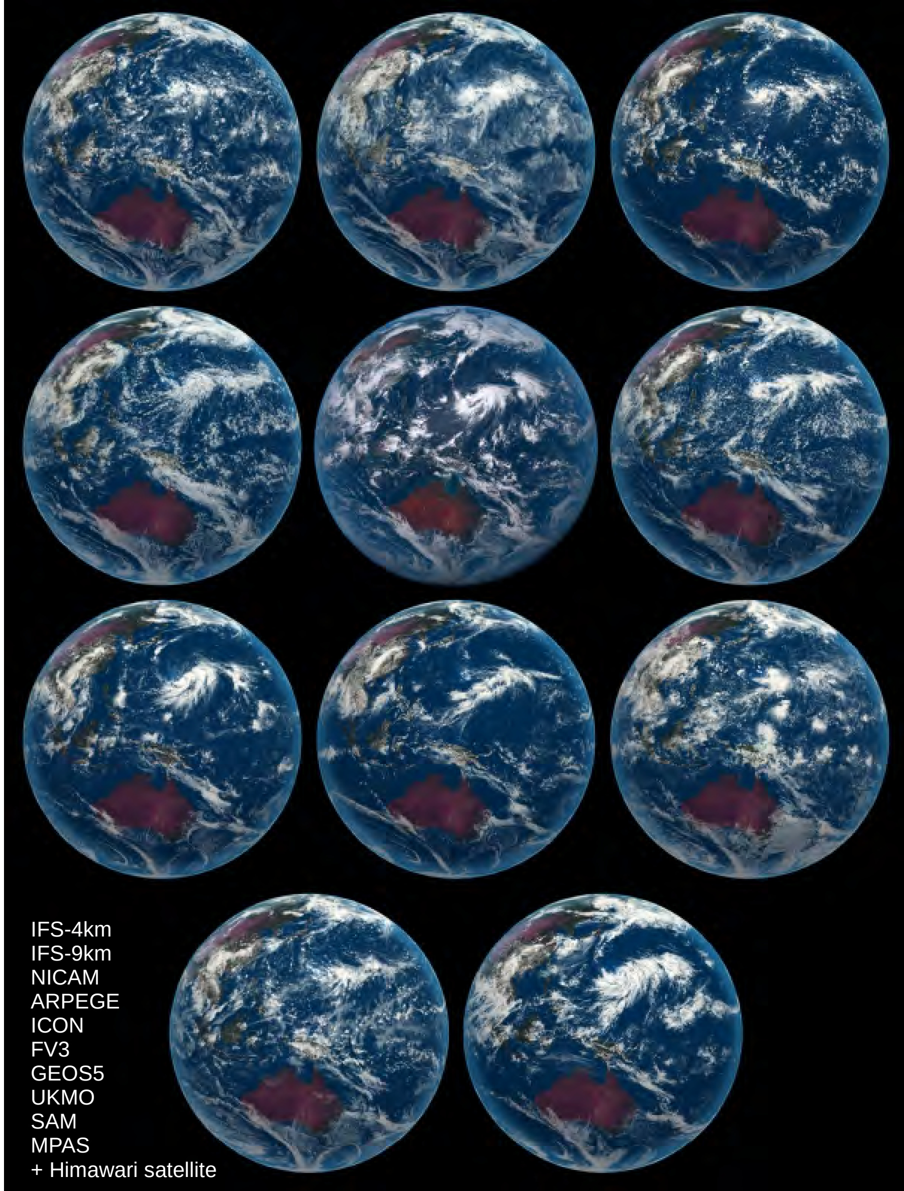
Phase 1 (DYAMOND summer, Aug 2016):
atmosphere only

Phase 2 (DYAMOND winter, Jan-Feb 2020):
atmosphere-only + coupled

Name	Grid	$\#_{Mcol}$	$\#_{lev}$	$\#_{\mu}$	$\sqrt{A_{max}}$	H_{top}	H_{spng}	CP	BL	FC
ARPEGE-NH	Kurihara	82	75	5	2.5 km	70 km	34 km	N	T	Yes
FV3	Cube	57	79	6	3.3 km	39 km	25 km	S	K	Yes
GEOS	Cube	57	132	5	3.3 km	80 km	75 km	F	K	Yes
ICON	Icoso	84	90	5	2.5 km	75 km	44 km	N	T	Yes
IFS	Octo	26	137	5	4.8 km	80 km	65 km	S	K	Yes
MPAS	Voronoi	42	75	6	3.8 km	40 km	30 km	F	T	Yes
NICAM	Icoso	42	78	5	3.5 km	50 km	25 km	N	K	No
SAM	La-Lo	43	74	5	4.3 km	37 km	22 km	N	S	No
UM	La-Lo	20	85	6	7.8 km	85 km	42 km	S	K	Yes

Tabulated are the number of columns ($\#_{Mcol}$, in millions), the vertical levels ($\#_{lev}$, not counting soil levels), the microphysical variables ($\#_{\mu}$), the linear dimension of the area, the A of the largest tile ($\sqrt{A_{max}}$), the vertical span of the column (H_{top}), and the height (H_{spng}) where the sponge layer begins. The last three columns denote parameterization assumptions. For cumulus parameterization (denoted CP), the letters "N," "S," and "F" denote none, shallow, or full parameterization, whereby for the latter, some assumptions are usually included in an attempt to account for the scale of motions being parameterized. For the boundary layer parameterization (denoted BL), the letters "T," "K," and "S" denote either a TKE-like model (including an additional prognostic equation), a diagnostic eddy diffusivity, or a Smagorinsky-like three-dimensional closure as is common for large-eddy simulation. Finally, some indication is given as to whether fractional cloudiness (denoted FC) is parameterized

Stevens *et al.* *Progress in Earth and Planetary Science* (2019) 6:61



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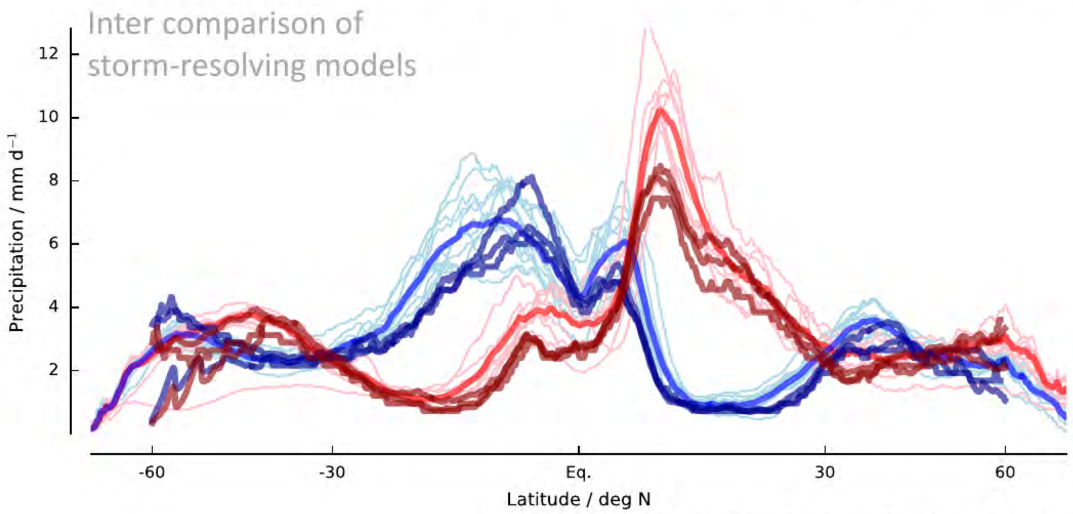
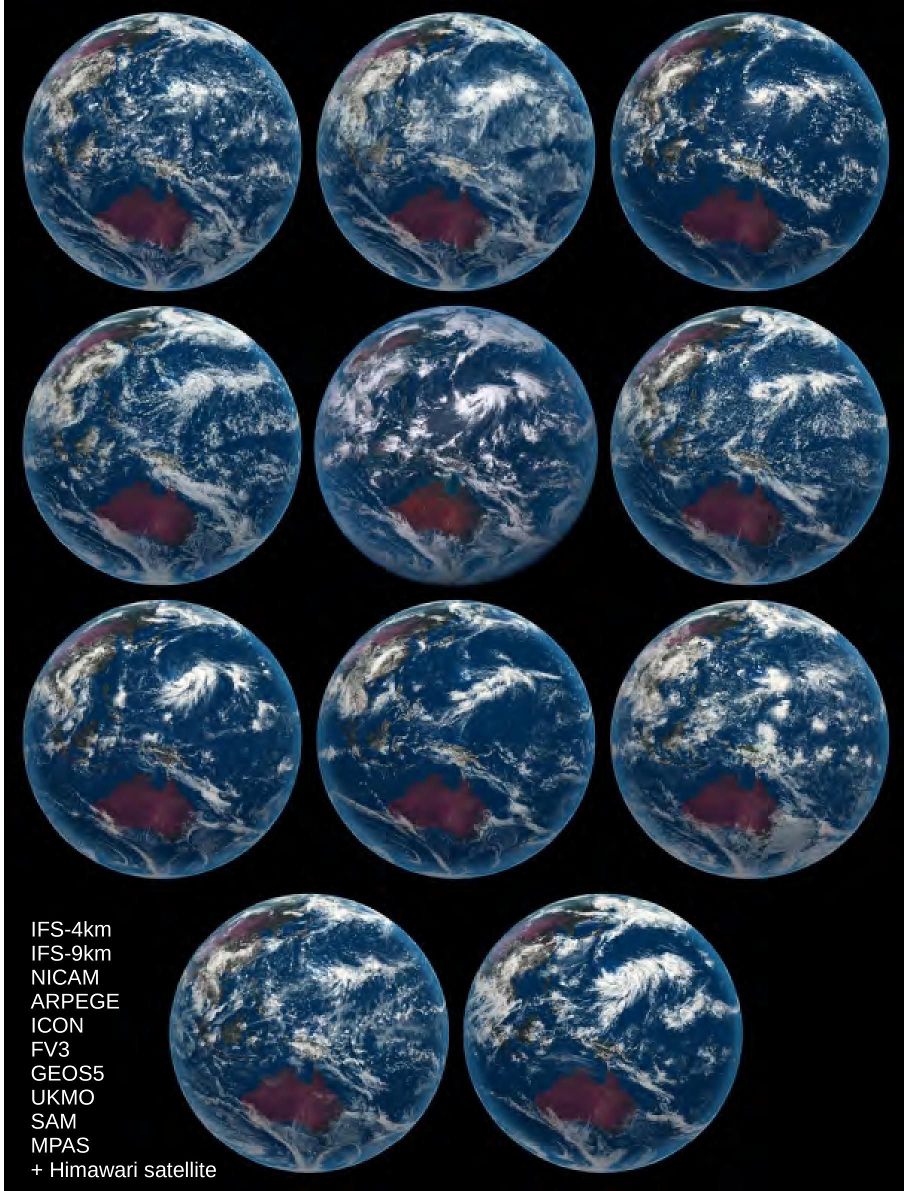


Including ICON coupled and IFS-FESOM coupled



NextGEMS's objectives

Two Storm-Resolving Earth System Models

O1 to develop two SR-ESMs (O(3km) in the atmosphere & ocean*)*

O2 to use SR-ESMs to study the Earth-system and test emerging and long-standing hypotheses underpinning our understanding of climate change

O3 to build new, more integrated, communities of ESM users, through Knowledge-Coproduction activities

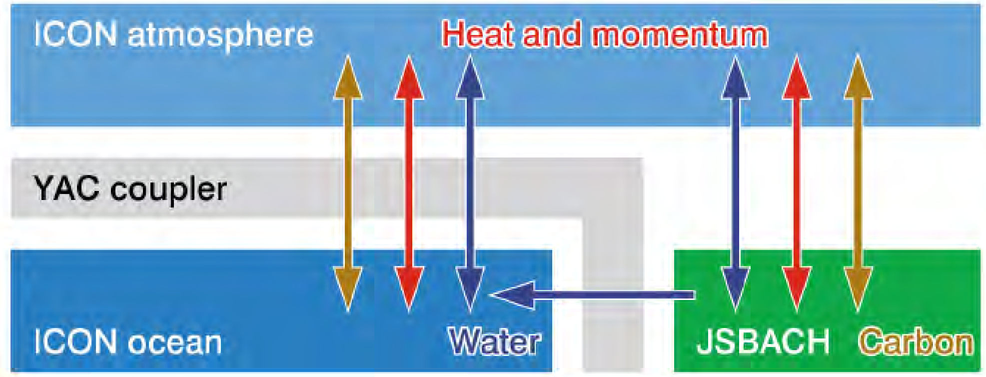
Developing NextGEMS' SR-ESMs - a pan-European collaborative endeavour

Hackathons

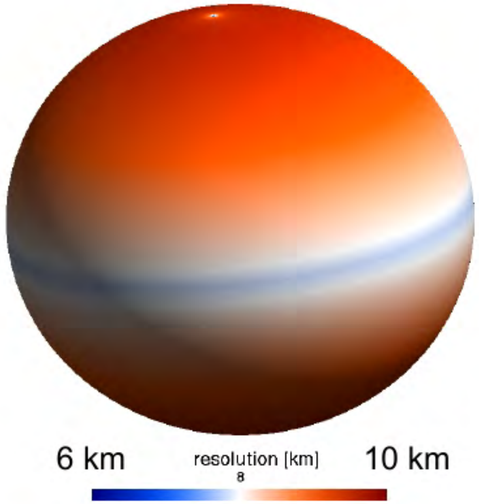
Model development
Science applications
Knowledge-coproduction

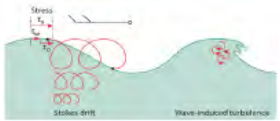
NextGEMS partners

ICON SRM

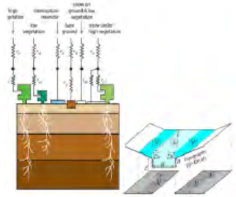


IFS SRM

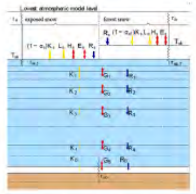




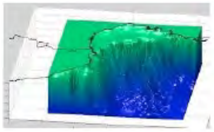
EC-WAM



H-TESSEL
CAMA-FLOOD



SL/(ML) SNOW



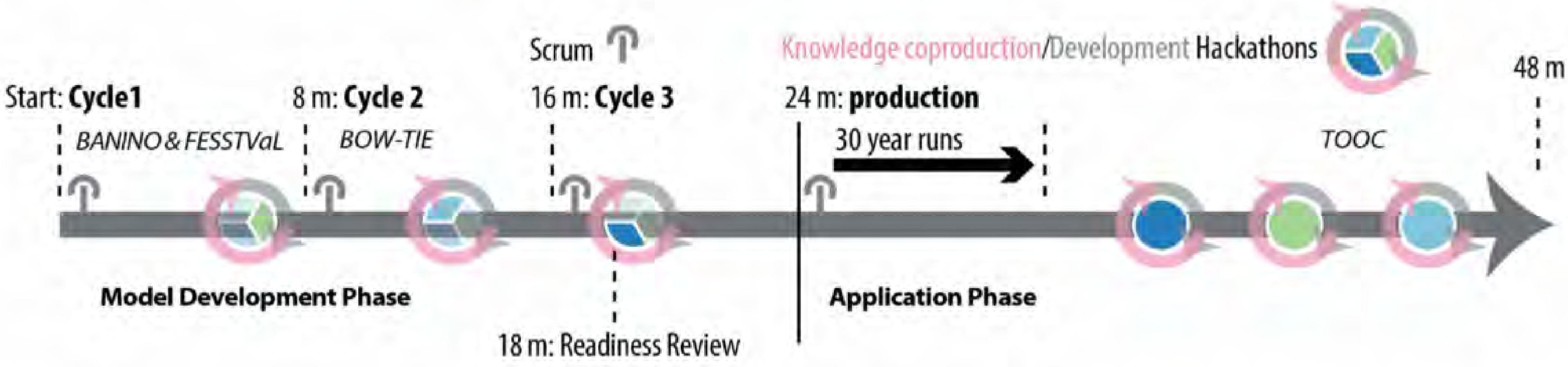
NEMO3.4

+

LIM2

new ocean/sea-ice option: FESOM

NextGEMS' methodology



Model development cycles:

- longer simulations (from months to the 30 years runs)
- higher resolution (5 km to 3 km)
- model developments (land, ocean, atmosphere)
- including selected applications (wind/solar power, fisheries)

Storms and Radiation (MISU lead)
Storms and Ocean (UiB/UCPH lead)
Storms and Land (MPI-M/WUR lead)
Storms and Society (BSC/Latest Thinking lead)

Storms and Radiation

The theme Storms and Radiation will focus on attaining realistic simulations of the top of the atmosphere (TOA) energy budget during model development. Ensembles of short simulations combined with data assimilation techniques and observations will be used to inform parameter choices and reduce expected cloud biases. Structural limitations related to remaining sub-grid scale processes, such as cloud-microphysics and turbulent mixing, will be assessed and used to guide the development of new parametrisations of these micro and smaller-scale processes. A computationally efficient aerosol scheme designed to exploit the ability of SR-ESMs to better represent physical source and sink processes, as well as transport and interaction with cloud systems, will be developed and implemented.

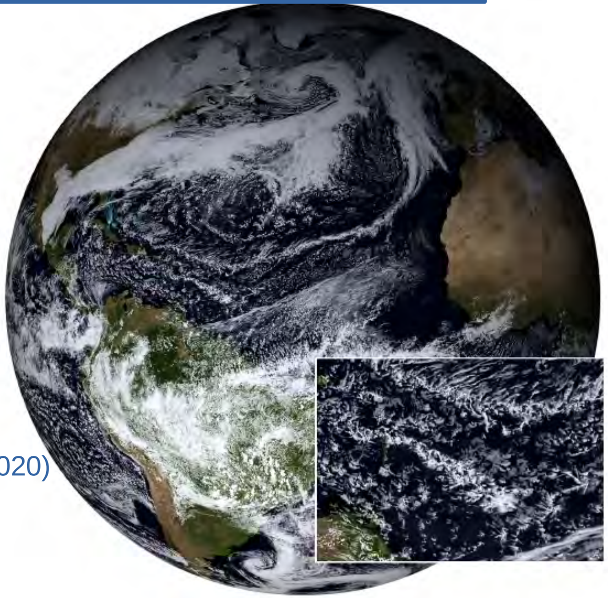
This theme will study the effect of convective organization and 'pattern-effects' on cloud feedbacks and climate sensitivity, how clouds and precipitation affect aerosol forcing and how in turn aerosols affect the hydrological cycle through deep convection, by better representing source and sink processes, and making convection aerosol-aware, and how these processes respond to warming.

French participation in NextGEMS (LMD) :

→ Analysis of the mesoscale organization of tropical convection (shallow & deep) in NextGEMS models

→ How much do the models reproduce the impact of convective organization on the tropical Earth's radiation budget, humidity, cloudiness and precipitation extremes that is observed from satellites?

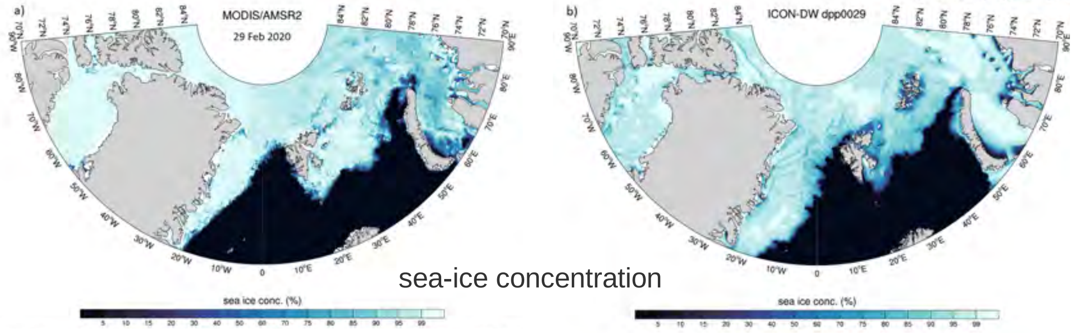
(*e.g.* Tobin et al. *J. Climate* 2012, Bony et al., *AGU Advances* 2020, Bony et al. *GRL* 2020, Semie and Bony *GRL* 2020)



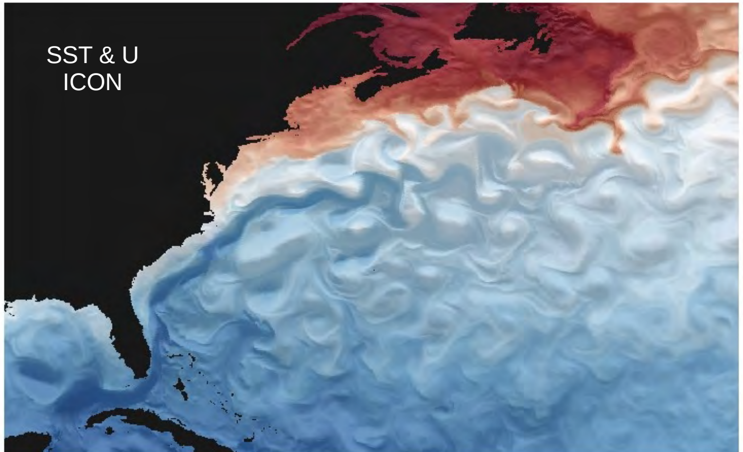
Storms and Ocean

The theme Storms and Ocean will focus on the ability of the SR-ESMs to realistically represent the surface energy budget over the tropical ocean, as well as atmosphere-ocean coupling. It will do so by studying the role of high-frequency coupling, upper ocean and atmospheric boundary layer processes in the tropics, and assumptions related to ocean and atmosphere discretisation and vertical mixing, so as to optimise existing or develop/propose new representations. Particular attention will be given to air-sea interaction across fine scale oceanic features and during intense tropical cyclones. Extensive use will be made of data from three field studies over the tropical Atlantic: EUREC4A in the trade-winds, BOW- TIE/TOOC and buoy measurements in the Intertropical Convergence Zone (ITCZ) region, and within the project Benguela Niños: Physical processes and long-period variability (BANINO) in the Eastern Boundary Current region, as well as 10 years of data collected to observe upper ocean mixing and satellite observations.

This theme will explore how resolving convective storms, ocean mesoscale eddies, and air-sea interaction on these scales influences the development of tropical SST anomalies; how this influences the mean climate (ITCZ biases), variability (diurnal to inter-annual), global teleconnections, and extremes; and how this alters the simulation of climate change. There will be a specific focus on the tropical Atlantic (where model biases are large with implications for high impact events), including the effects on the West African Monsoon, and the intensity, number and spatial distribution of Atlantic Hurricanes.



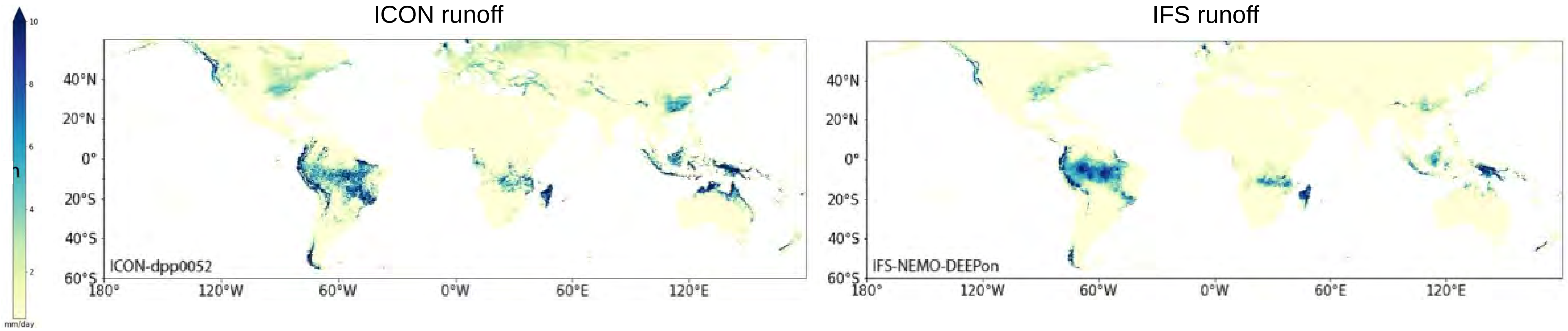
sea-ice concentration



Storms and Land

The theme Storms and Land will focus on attaining realistic simulations of the components of the surface energy budget, water cycle, momentum balance as well as near-surface meteorology over land, in terms of mean and temporal variability, and by updating the representation of the land surface. For this purpose, land observational networks, including observational super-sites and FLUXNET measurements, and a field study (FESSTVaL in the boreal summers of 2020 and 2021) targeted to observe variability in the planetary boundary layer on scales 2 km to 20 km over Germany will be exploited. Methods will be explored to set up an offline carbon model driven by the output of one SR-ESM.

This theme will study whether SR-ESMs produce a more realistic climatology of blocking, dry and warm spells and surface radiation and whether this is due to a more realistic representation of land surface heterogeneities, or due to better resolved convective storms. Furthermore, upscale effects whereby a better representation of storm and landscape scale circulations becomes manifest in the large-scale circulation will be studied. Implications for the carbon (emissions) stock-take will also be investigated.



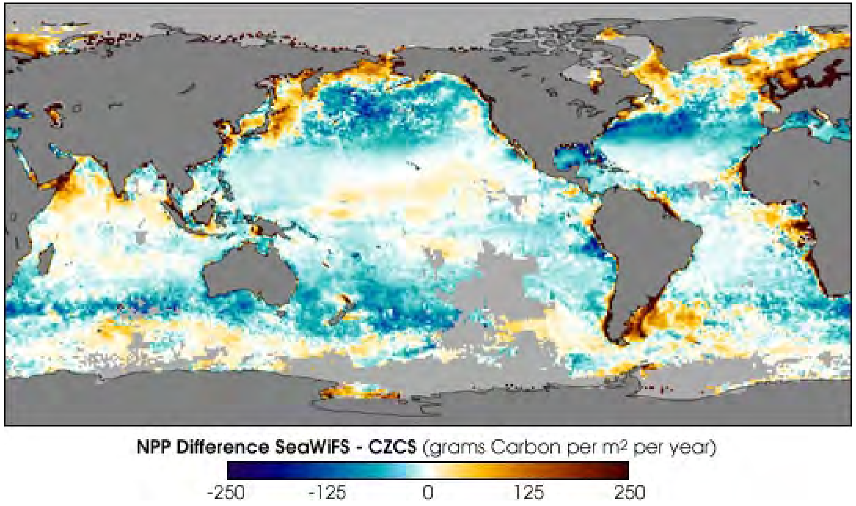
Storms and Society

In addition to leading traditional dissemination and exploitation activities, the Storms and Society theme will work closely with each physical science theme (Storms and Radiation, Storms and Ocean, Storms and Land) to develop two broad types of activities – Knowledge Coproduction activities at Hackathons and a NextGEMS VideoBlog.

This theme builds the coproduction process by defining and solving Challenge Problems: 'real-world' scientific and societal questions developed together with stakeholders. The first Challenge Problems will be developed with the users from the NextGEMS User Network from renewable energy and fishery. Knowledge exchange will continue throughout the project, supported by innovative communication and dissemination activities. These activities are aimed at bringing in new stakeholders, enhancing project visibility and improving usability of project outcomes for impact assessment and risk management.

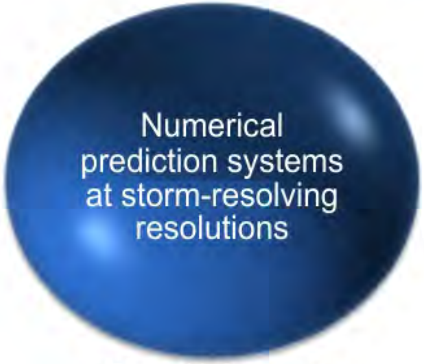
solar and wind energy production

coastal marine ecosystems and fisheries



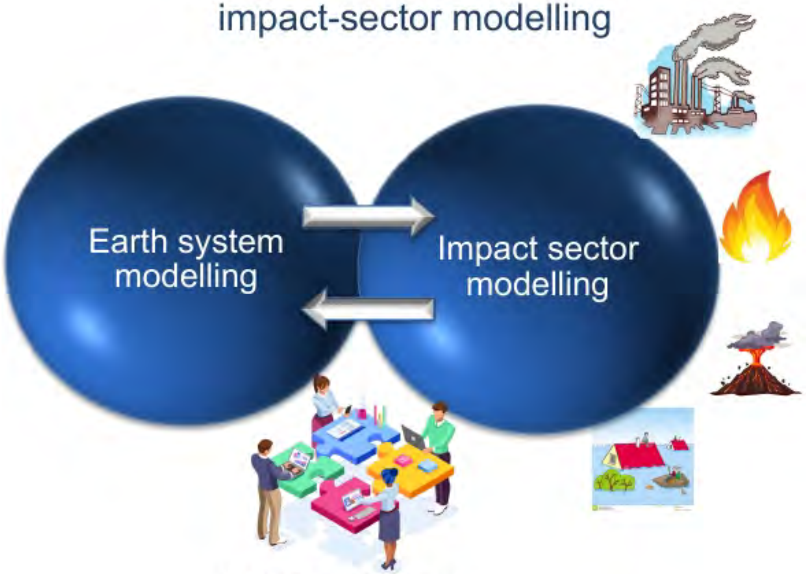
NextGEMS is feeding into….

Stronger convergence of weather & climate prediction systems



Shared infrastructure, data assimilation, km-scale resolution

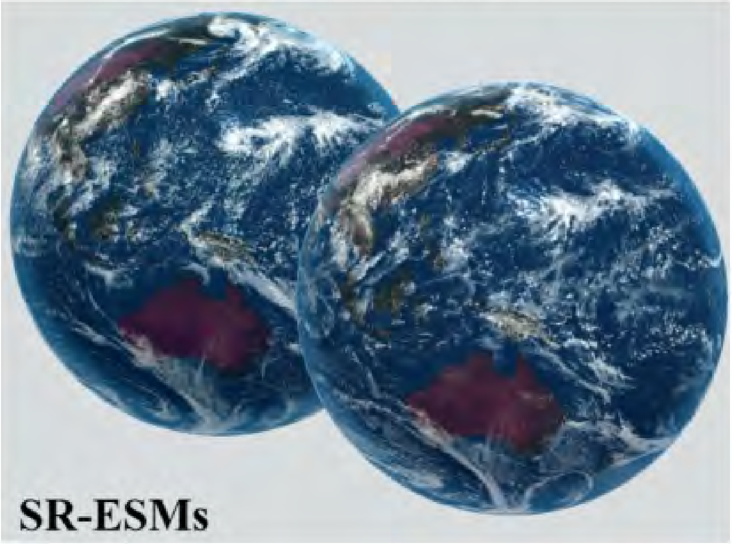
Integrated Earth-system & impact-sector modelling



Codesign with users

NextGEMS's objectives

Two Storm-Resolving
Earth System Models



A model development project to :

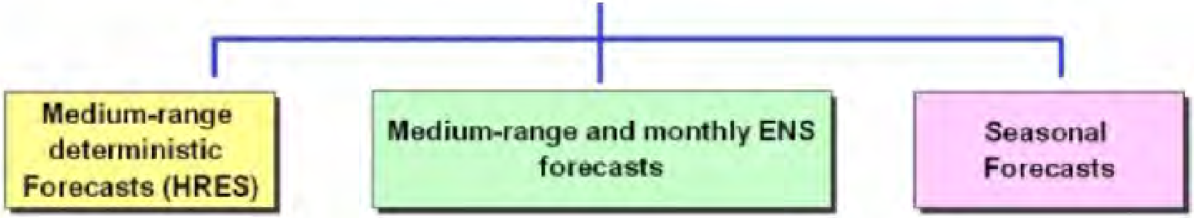
- Explore the ability and the usefulness of simulating climate at km scales

- Learn about the interation of the mesoscale with the large-scale/planetary scale

Will be interesting as much for the problems it solves as for the ones it doesn't.

Extra slides

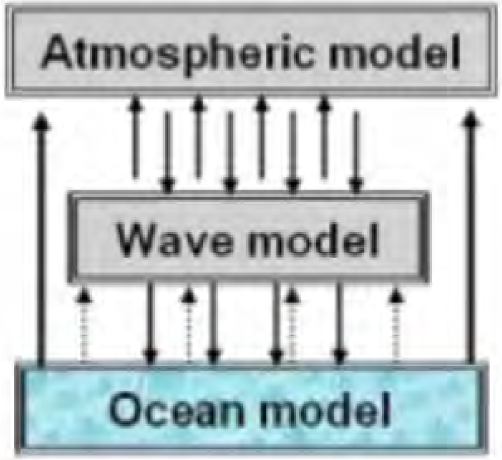
The ECMWF Integrated Forecasting System (IFS)



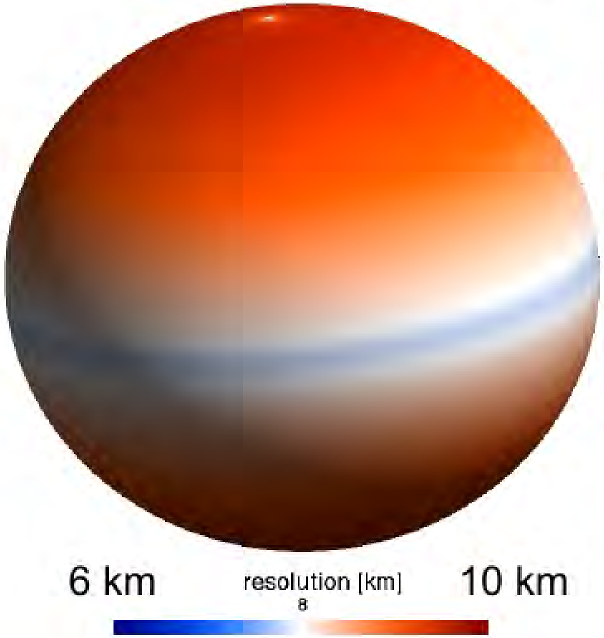
9 km / L137
0.25 deg L75 ocean

18/32 km L137
0.25 deg L75 ocean

32 km L91
0.25 deg L75 ocean

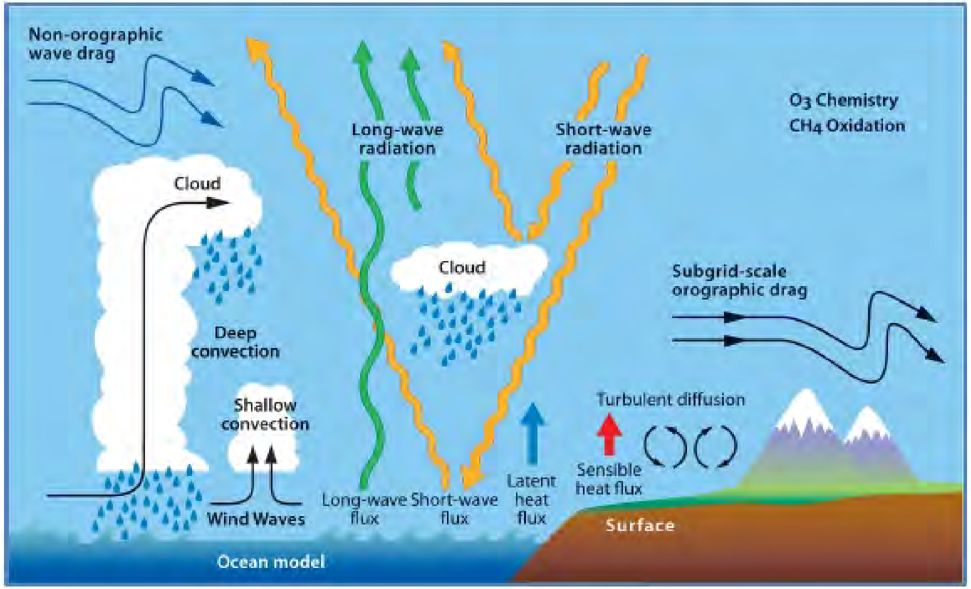


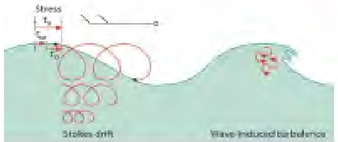
Cubic octahedral reduced grid



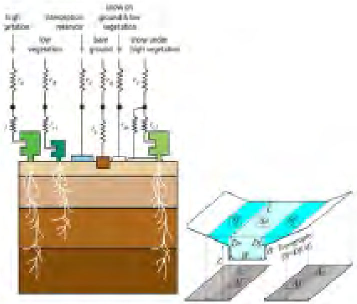
O1280 T_{Co}1279 (cubic, 9km)
≈ 6.6 mil pts/lev

The ECMWF Integrated Forecasting System (IFS)

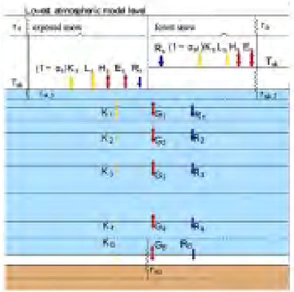




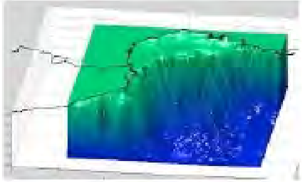
EC-WAM



H-TESSEL
CAMA-FLOOD



SL/(ML) SNOW



NEMO3.4

+

LIM2

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

new ocean/sea-ice option: FESOM

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

The Cycle 1 NextGEMS runs:

IFS-NEMO – IFS Cy47r3

- IFS-NEMO-**4km** - deep convection off , all other parametrizations on
- IFS-NEMO-DEEPon-**4km** - all parametrizations on (like OPER)
- IFS-NEMO-**9km** - all parametrizations on (like OPER)

IFS-FESOM – IFS Cy46r1

- IFS-FESOM2-**4km** - deep convection off , all other parametrizations on

ICON - ICOsahedral Nonhydrostatic

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

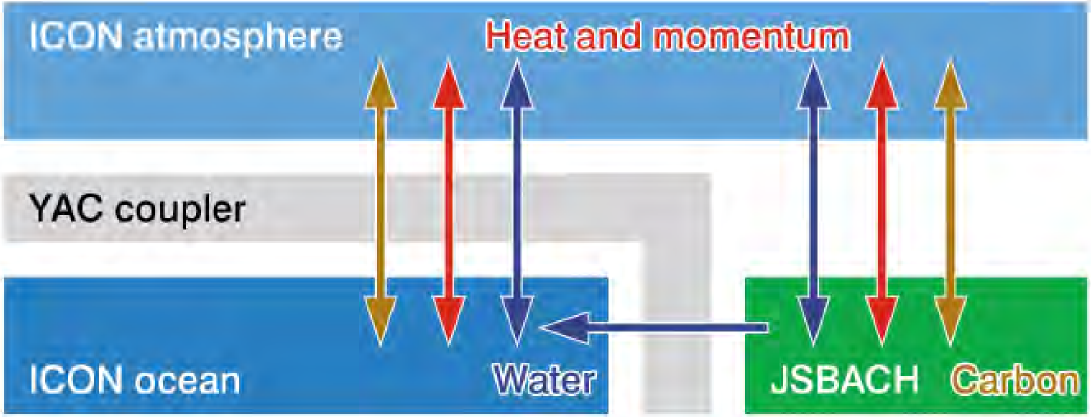
Applicable on wide range of scales

Non-hydrostatic equations on global Domains

Scaleable to be able to use the biggest computers

Good conservation properties (mass and energy)

Mesh refinement for one- and two-way nesting



NextGEMS

ICON horizontal grid (and lingo)

Unstructured grid originating from an icosahedron

RnBk: initial division into n parts, followed by k bisections

R02B09: 5km (square root of mean cell area)

Δ_h	L_{atm}	L_{ocn}	Nodes	Machine	SDPD
5.0 km	90	n/a	300	Mistral (2×Intel BDW 36-cores)	28
2.5 km	90	n/a	510	Mistral (2×Intel BDW 36-cores)	7
2.5 km	n/a	112	262	Mistral (2×Intel BDW 36-cores)	51
5.0 km	90	128	420	Mistral (2×Intel BDW 36-cores)	25
5.0 km	191	n/a	128	JUWELS-Booster (4×A100)	300

NextGEMS

The Ocean Component ICON-O

Numerics

- **Equations:** hydrostatic Boussinesq equations of global ocean dynamics
- **Grid:** triangular grid with Arakawa-C-type staggering of variables
- **Discretization:** numerical design aims at discrete equivalents of continuous conservation laws.
- **Discrete conservation props:** volume, energy and enstrophy. This improves model stability
- **Time-stepping:** semi-implicit Adams-Bashford

Physics:

- Vertical mixing

This run:

- spin-up run initialised with ORAS5 (30km), spun-up with ERA5 forcing (10 years at 10km and 5 years at 5km)
- 128 level in the vertical
- New vertical coordinate z^*: variable coordinate system, which allows thin layers (here 2m at top) and thick sea-ice

NextGEMS