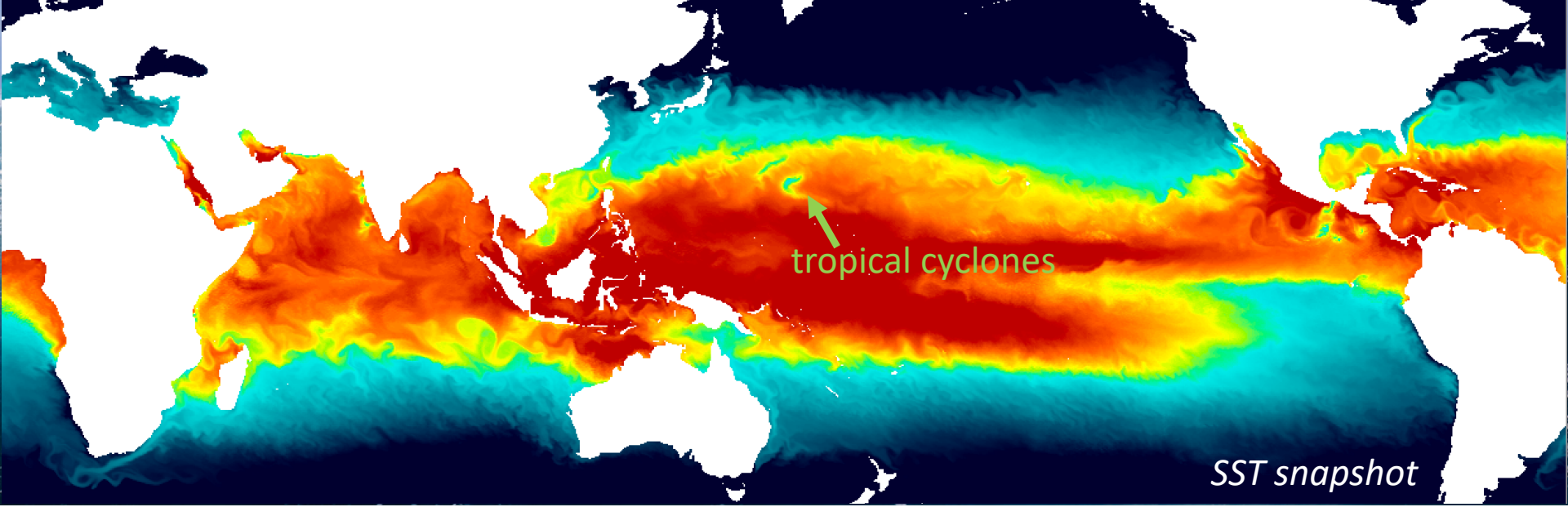

On the way to a coupled Digital Twin - DYAMOND simulations with IFS-FESOM2

Thomas Rackow, Nils Wedi (ECMWF), Kristian Mogensen (ECMWF),
with contributions from Jan Hegewald, Lorenzo Zampieri, Helge Goessling (all AWI)

AWI

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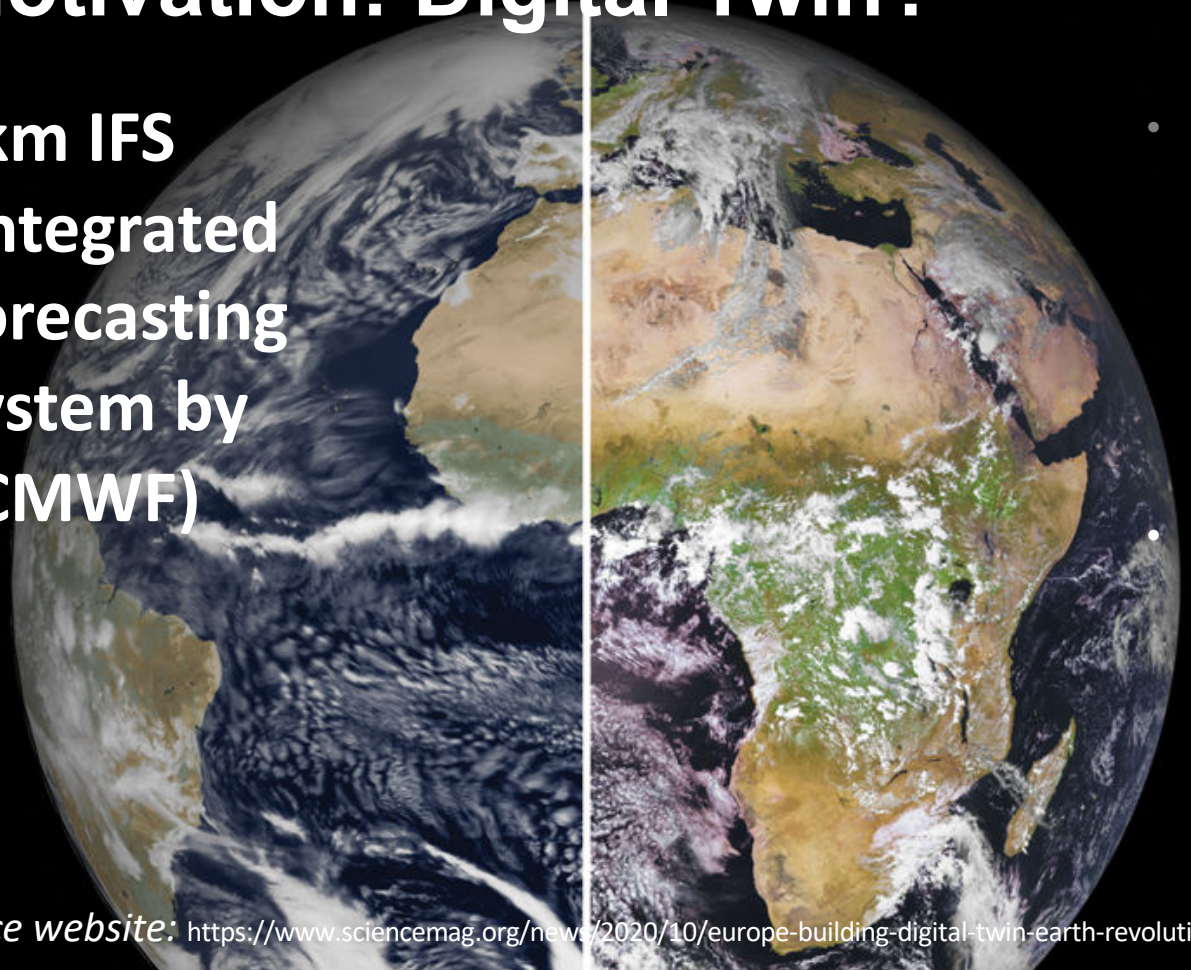
Motivation: Digital Twin?

- ***A digital twin is a digital replica of a living or non-living physical entity***.
- *Expert and non-expert users get access to high-quality information, services, **models**, **scenarios**, **forecasts** and visualisations (e.g. in **climate modelling and weather forecasting**, hurricane evolution).*
- *Digital twins rely on the integration of **continuous observation, modelling and high performance simulation**, resulting in highly accurate predictions of future developments.*

From EU Destination Earth website: https://ec.europa.eu/digital-single-market/en/destination-earth-destine

Motivation: Digital Twin?

1km IFS (Integrated Forecasting System by ECMWF)



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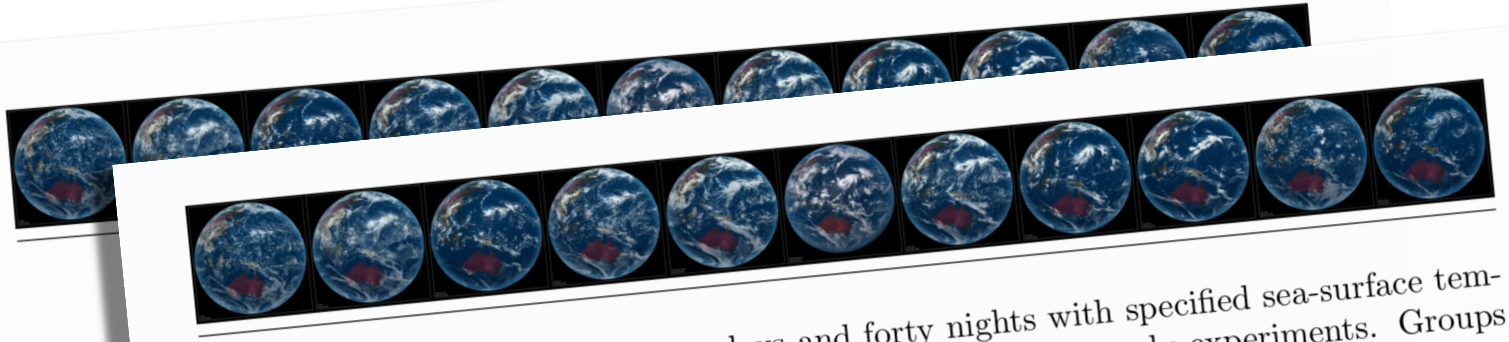
Science website: https://www.sciencemag.org/news/2020/10/europe-building-digital-twin-earth-revolutionize-climate-forecasts

Motivation: DYAMOND++?



analysis, and run for forty days and forty nights with specified sea-surface temperatures (7 day running mean) for the atmosphere only experiments. Groups are left free to initialize soil moisture according to their sense of best practice.

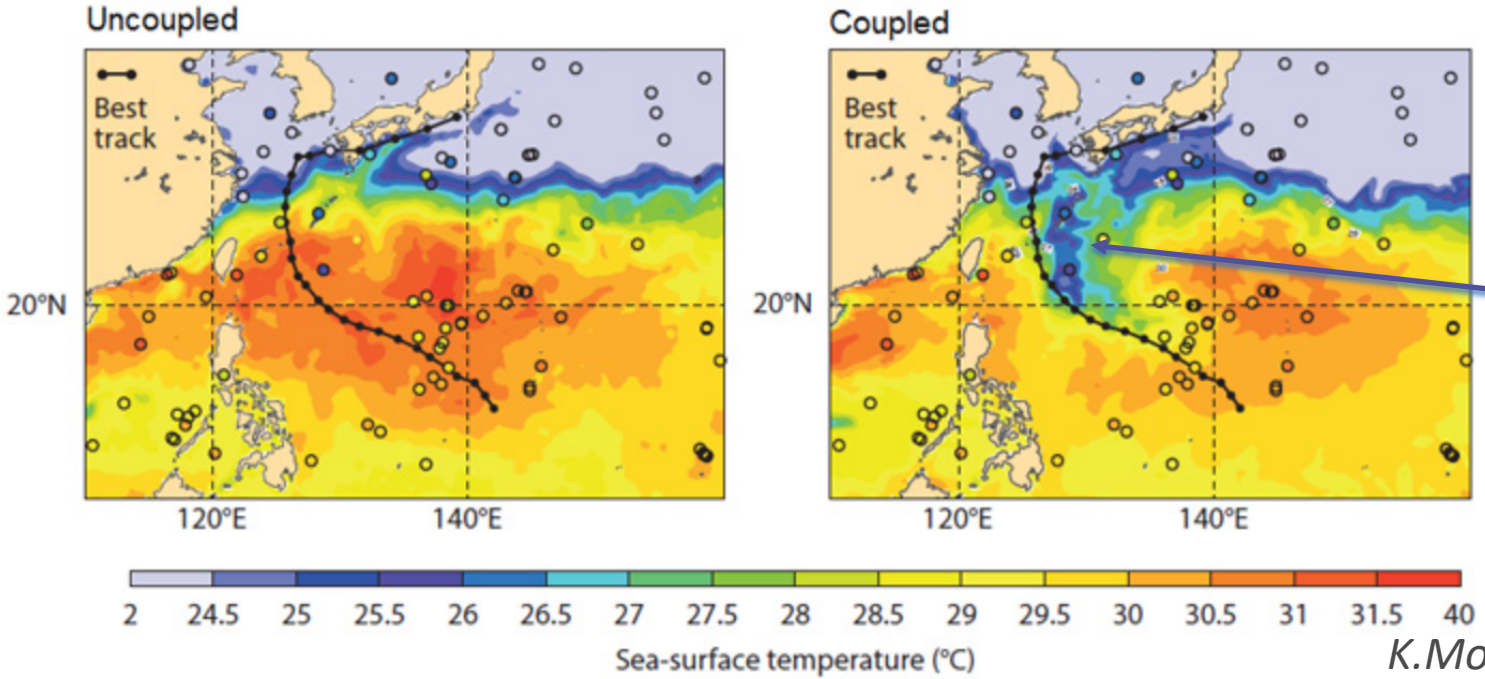
(2) The same period will be simulated by coupled atmosphere-ocean models by groups capable of running coupled systems at storm resolving scales. Groups are free on how to initialize the ocean (nudged run-up to the initial date, or ocean analysis at initial date).

(3) To participate the host model must be run at a grid spacing of 5 km or less for the atmosphere and a comparable resolution for the model ocean (if possible) and not incorporate a parameterized representation of atmospheric deep convection. The vertical domain should extend to well above the troposphere (25 km or higher), and the convening participants are targeting model versions with about 75 levels or more for the atmosphere and a sufficient number of levels for the ocean to approximate observed SSTs and that allows to study atmosphere-ocean coupling

ERA5-forced until 20 Jan 2020

CORE2, ORCA025, soon Rossby4.2

Motivation: ocean coupling

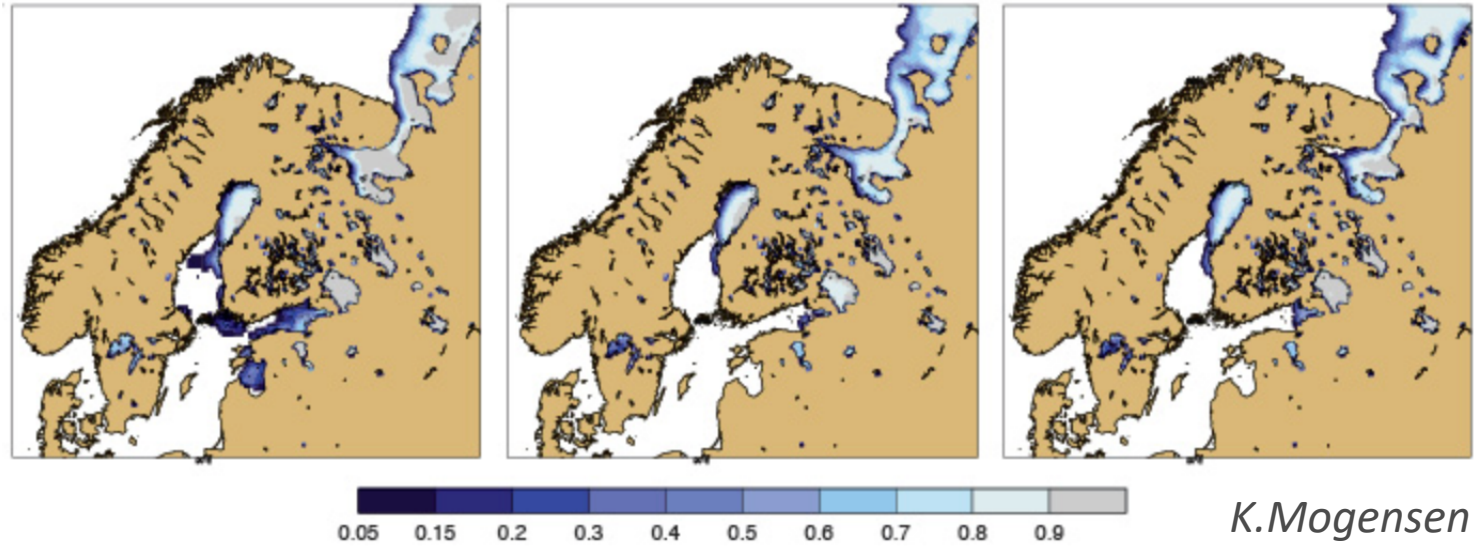


1. heat loss to atmosphere
2. vertical mixing in the ocean
3. upwelling by Ekman pumping

K.Mogensen (ECMWF)

SST forecasts (Neoguri) using the uncoupled model (left) and the coupled model (right). **SST observations from ships and buoys (circles); 'best track' cyclone data: black line**

Motivation: sea-ice coupling

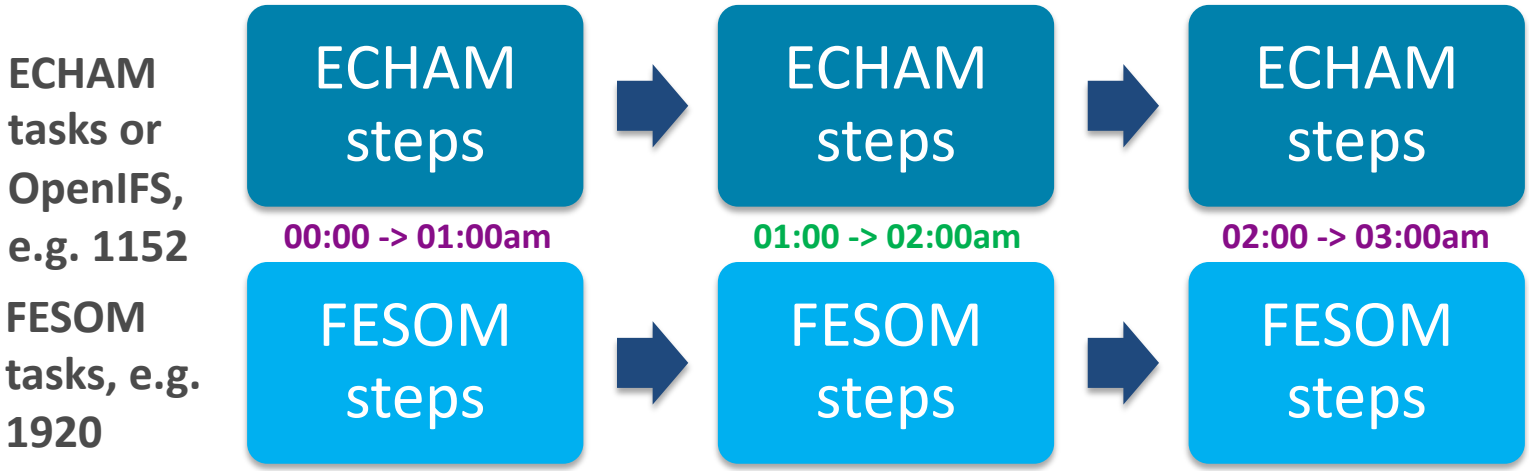


K.Mogensen (ECMWF)

Sea-ice concentration in the Baltic Sea evolved considerably between 1 April (**left**) and 11 April 2018 (**middle**), according to ECMWF's *OCEAN5* analysis. A coupled 10-day forecast for 11 April (**right**) captured this.

Our usual coupling schematic

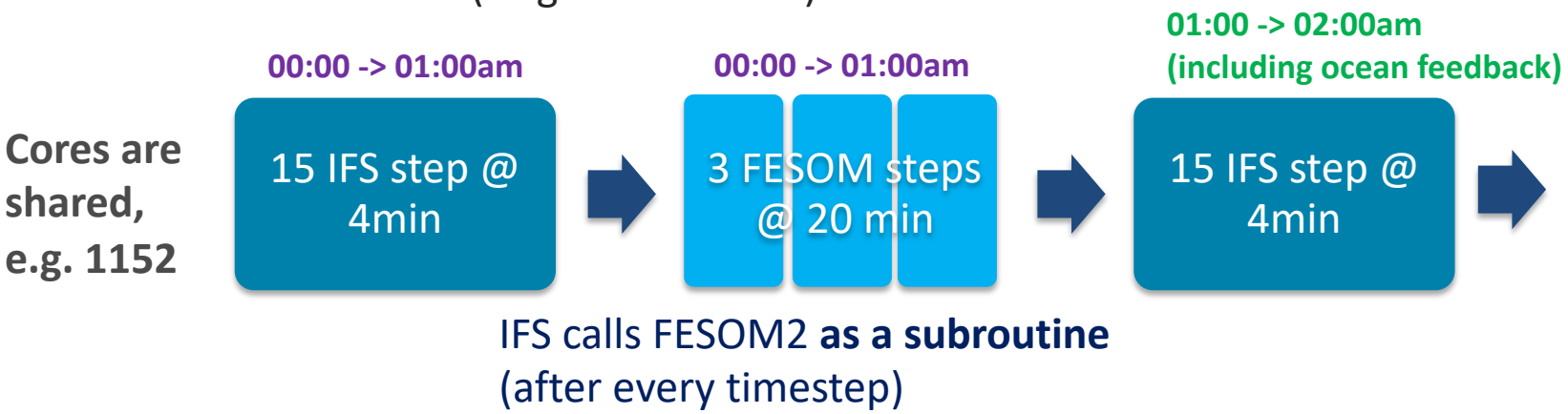
… in configurations with the OASIS coupler (2 executables)



- FESOM2 uses fluxes from the atmosphere that were averaged over the *previous coupling time step* -> **introduces some lag;**
- It is desirable that both models take the same amount of time

A different coupling schematic

... in IFS-FESOM2 (single executable)



- FESOM2 uses fluxes from IFS *for the same period*; FESOM surface fields are forwarded in time for 1h and used in IFS' next time step
- Important for fast processes like tropical cyclones etc.?
- Technically difficult: Hybrid MPI/OpenMP parallelization vs MPI-only

Creating a FESOM2 “library”

Split main into 3 parts (parts callable from within IFS)

```fortran
#ifndef __ifsinterface
program main

  use g_PARSUP, only: mype
  integer :: nsteps

  call main_initialize(nsteps)
  if (mype==0) write(*,*) 'Initialization complete.'

  call main_timestepping(nsteps)
  if (mype==0) write(*,*) 'Timestepping complete...'

  call main_finalize
  if (mype==0) write(*,*) 'Finalization complete...'

end program main
#endif
```

- The stand-alone FESOM2 is not significantly affected by this technical change because the **new main** just calls these 3 parts one after the other
- If FESOM2 is compiled as library, **__ifsinterface** is True, and the “main” block to the left is neglected

Creating a FESOM2 “library”

One example how the interface routines look like

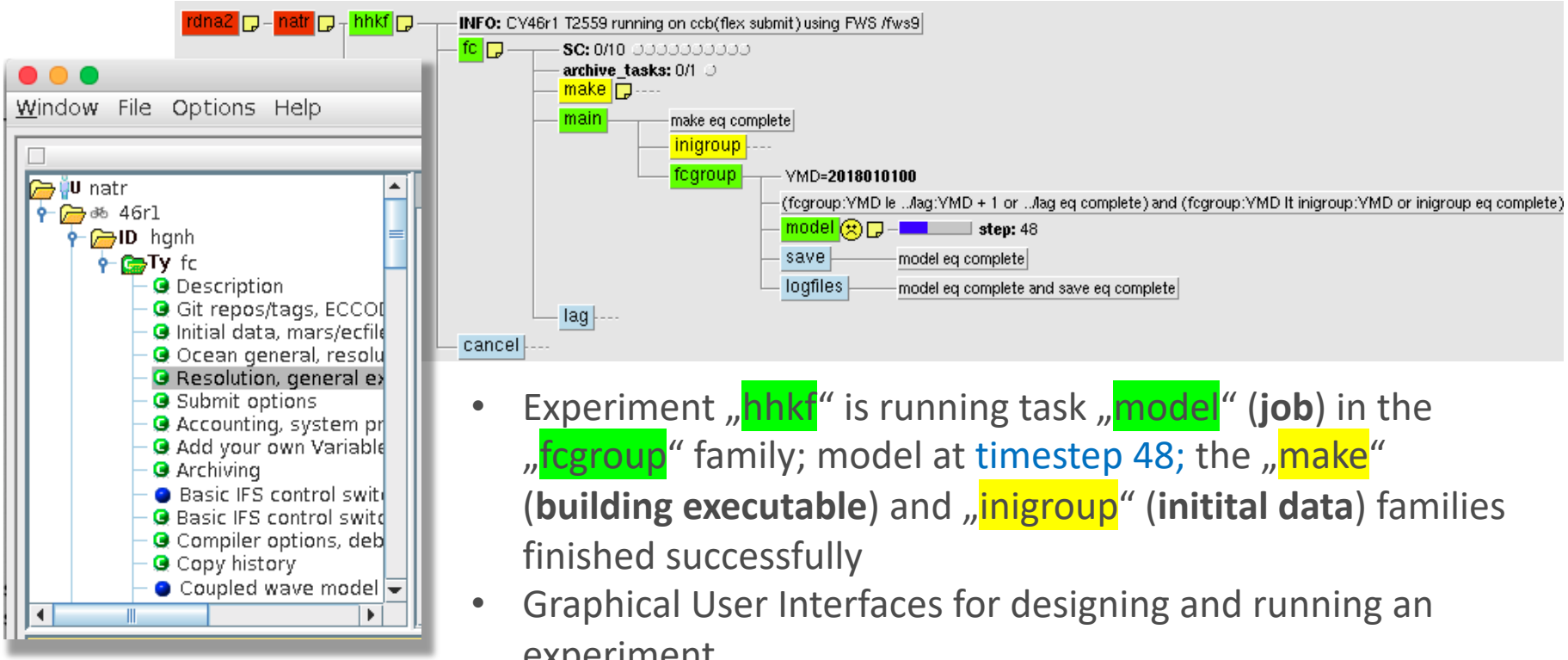
ocean

```
13  SUBROUTINE nemogcmcoup_init( icomm, inidate, initime, itini, itend, zstp, &
14     & lwaveonly, iatmunit, lwrite )
15
16
17
18
19
20
21
22
23
24
```

```
53      MPI_COMM_FESOM=icomm
54      itini = 1
55      CALL main_initialize(itend_fesom) !also sets mype and npes
56      itend=itend_fesom/substeps
57      if(mype==0) then
58      WRITE(0,*)'!=========================================='
59      WRITE(0,*)'! FESOM is initialized from within IFS.'
60      WRITE(0,*)'! get MPI_COMM_FESOM. ==================='
61      WRITE(0,*)'! main_initialize done. ================'
62      endif
```

Controlling the experiment (with GUI)

With ‘prepIFS’ and ‘ecflow’:



- Experiment „hhkf“ is running task „model“ (**job**) in the „fcgroup“ family; model at timestep 48; the „make“ (**building executable**) and „inigroup“ (**initital data**) families finished successfully
- Graphical User Interfaces for designing and running an experiment

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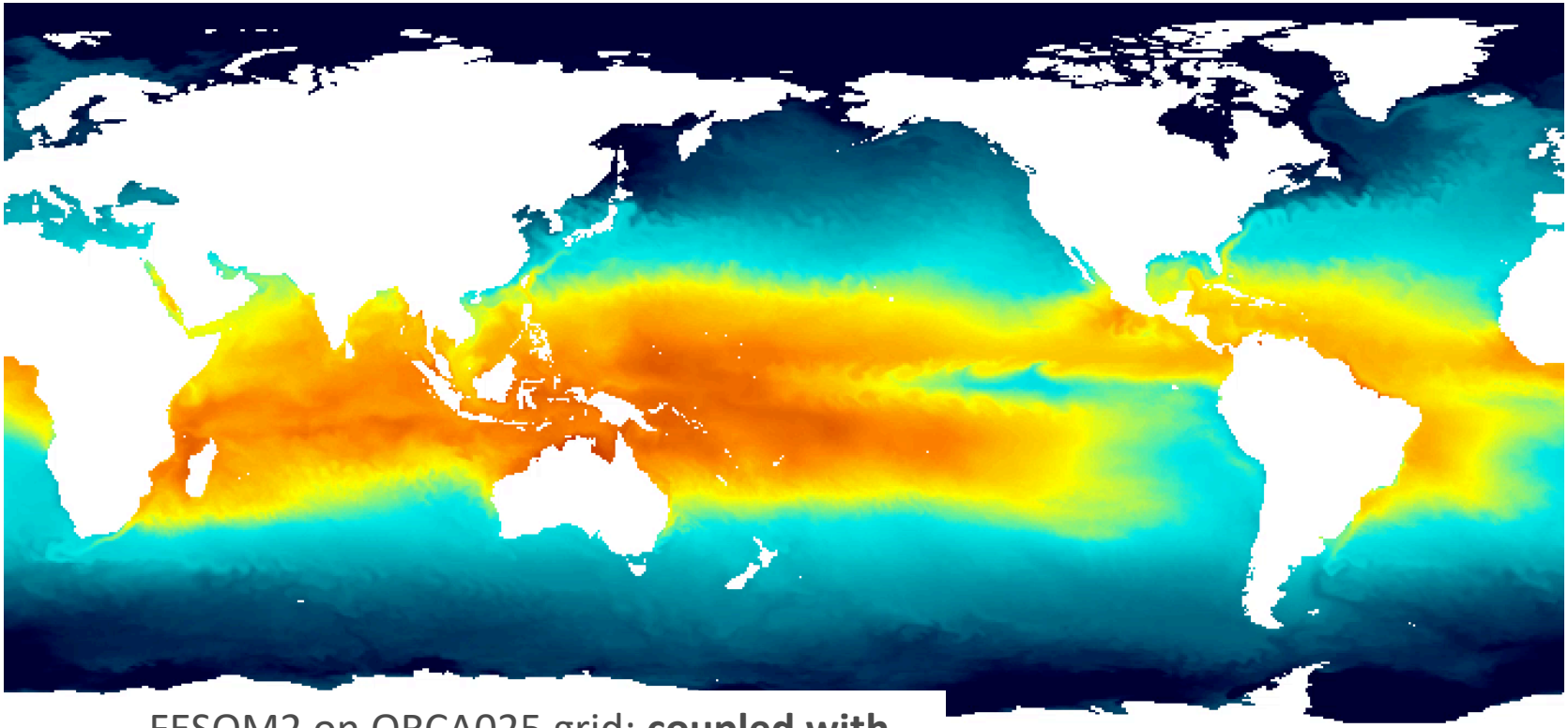
1yr free-running SST, IFS-FESOM2



FESOM2 on ORCA025 grid; **coupled with the full IFS (here about 18km)**

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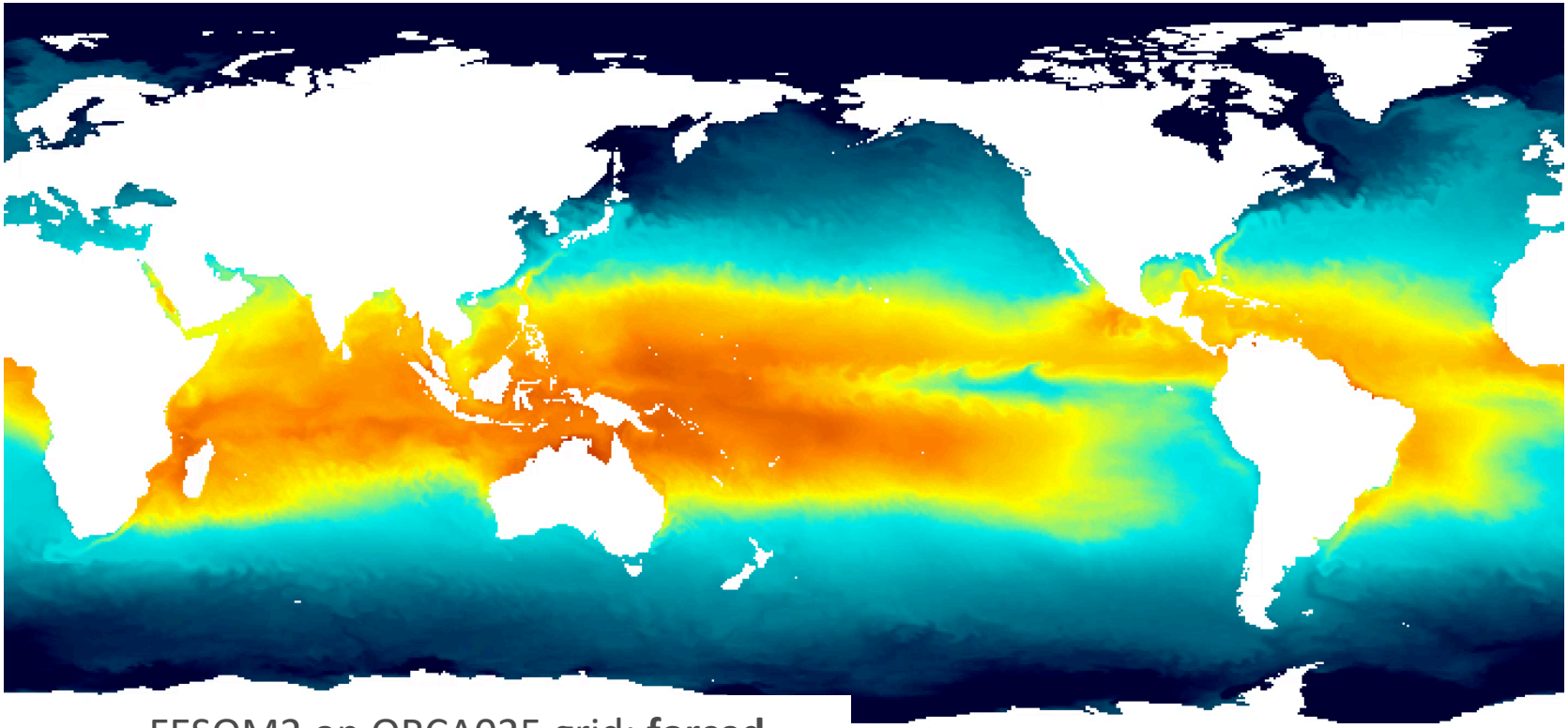
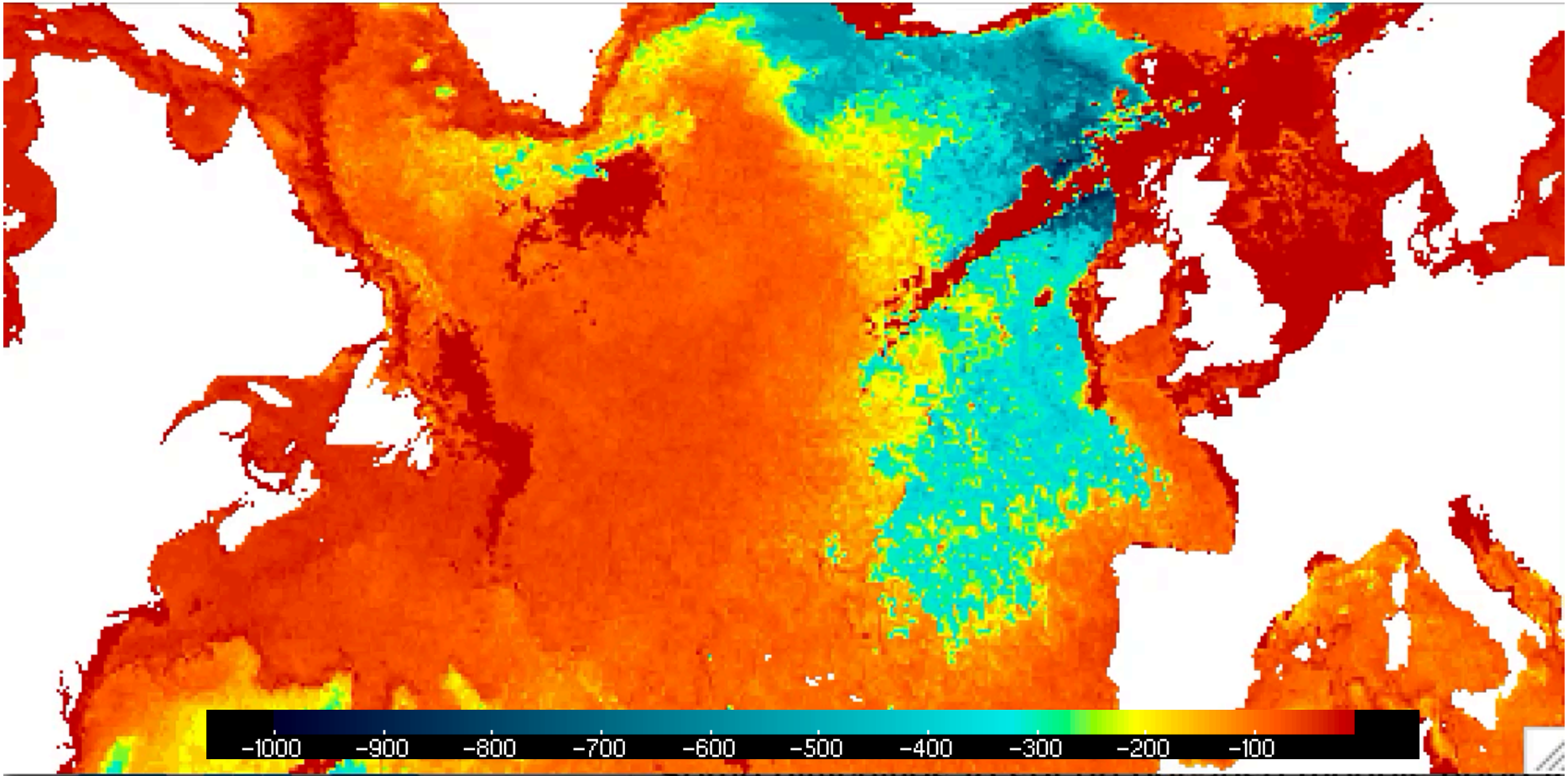
1yr forced SST, FESOM2 standalone

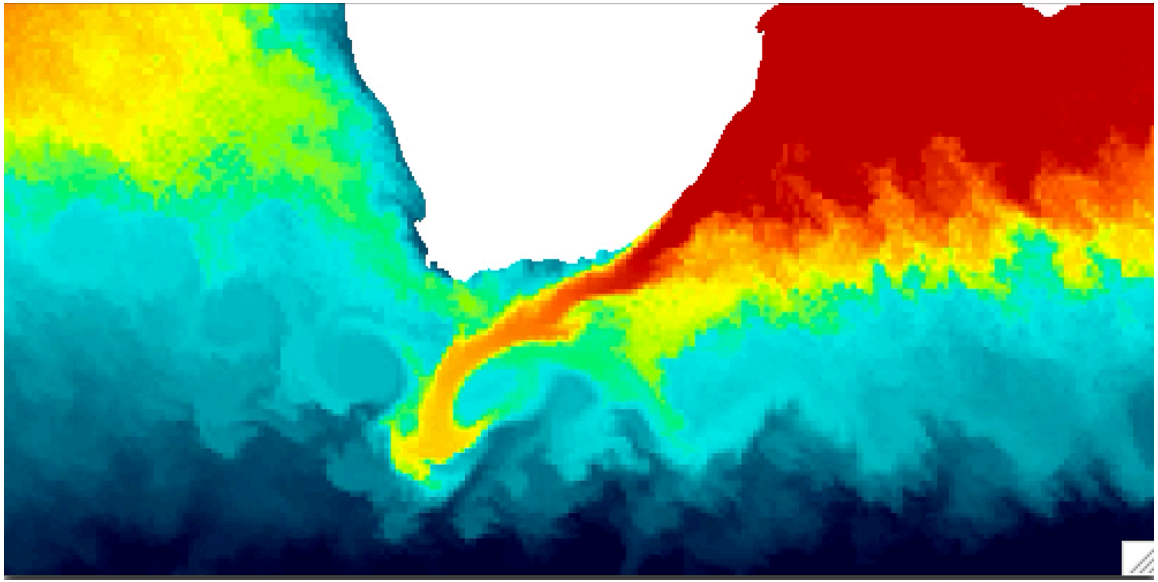


FESOM2 on ORCA025 grid; **forced** with CORE2 (about T63, approx. 1.8°)

40day free-running MLD, 4km IFS



40day free-running SST, 4km IFS



- One example zoom:

  Agulhas retroflection zone

- A ring is forming

- One can clearly see the diurnal cycle

Outlook

- IFS-FESOM2 DYAMOND simulations are currently in the machine; most severe technical difficulties are overcome
  - The DYAMOND models will produce a wealth of information, overlapping with (part of) **MOSAiC** and the **EUREC4A** tropical field campaign, which is 20 Jan 2020 until 1st Mar 2020 (40 days)
  - Potential candidate model for the 4-5 Digital Twins in DestinE?
  - Rossby4.2 already set up -> impact of eddies/leads on 1km atmo?
- With ECMWF's ERA5 forcing, FESOM2 can already be "***run until yesterday***"
- Coupled to IFS, FESOM2 can now also be "***run until next season***", using **full data assimilation in the atmosphere**