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The Oceanographic Multipurpose Software Environment: Introduction and Applications

Inti Pelupessy[1], Gijs van den Oord[1], Ben van Werkhoven[1], Maria Chertova[1], Merijn Verstraaten[1], Henk Dijkstra[2], Fredrik Jansson[3], Arjen van Elteren[4], Simon Portegies Zwart[4] (and many others!)

[1]Netherlands eScience Center, [2]IMAU, Universiteit Utrecht, [3]CWI, [4]Leiden Observatory

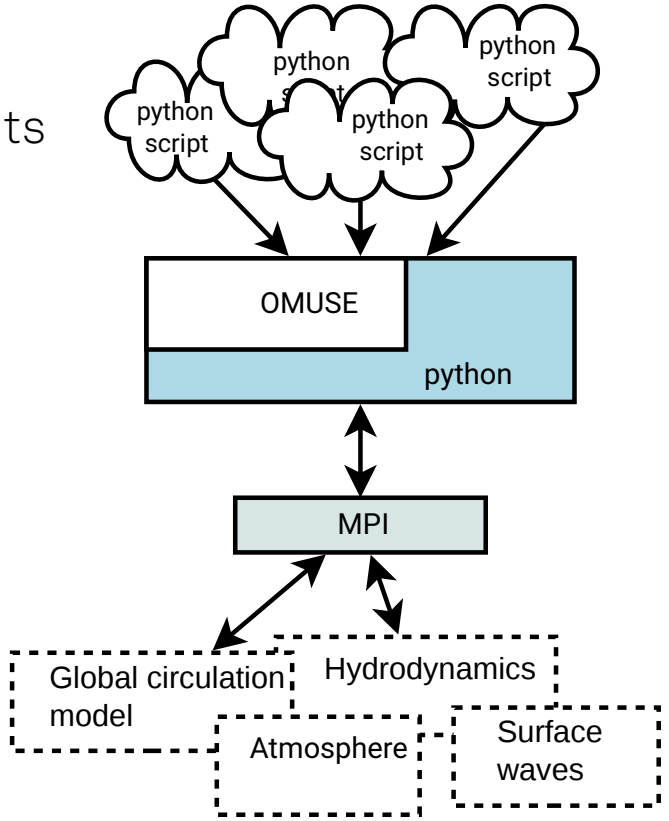
5th Workshop on Coupling Technologies for Earth System models,
21-24 september 2020

What is OMUSE?

→ Oceanographic Multi-PUrpose Software Environment
→ OMUSE is a Python environment for numerical experiments in oceanography and other climate sciences
→ based on *AMUSE*

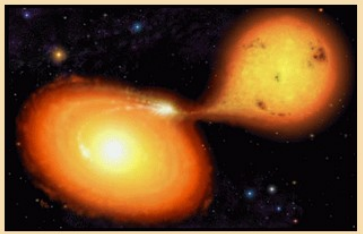
Goals:

- provide a homogeneous enviroment to run *community* codes
- enable new code couplings and interactions between components
- facilitate multi-physics and multi-scale simulations



a short history of AMUSE & OMUSE

- AMUSE has its origins in the astrophysical MODEST community



MODEST

Modeling and Observing DEnse STellar systems

- developed, with funding from NOVA, NWO and the NLeSC, at Leiden Observatory

- actively being used by 15+ groups worldwide, 60+ publications, 8+ theses

- 2014 – 2016: NLeSC project @IMAU (Pelupessy, van Werkhoven) to generalize this approach → OMUSE

- 2017- present: OMUSE being used in research (see part II), extension with new codes and general improvements in useability and installation procedures.

'Hello Ocean'

“imports”

```
from omuse.units import units
from omuse.community.qgmodel.interface import QGmodel
from amuse.io import read_set_from_file
```

“initial conditions”

```
input=read_set_from_file('initial_condition')
```

“instantiate code”

```
code=QGmodel()
```

“initialize model”

```
code.parameters.dt=0.5 | units.hour
code.grid.psi=input.psi
```

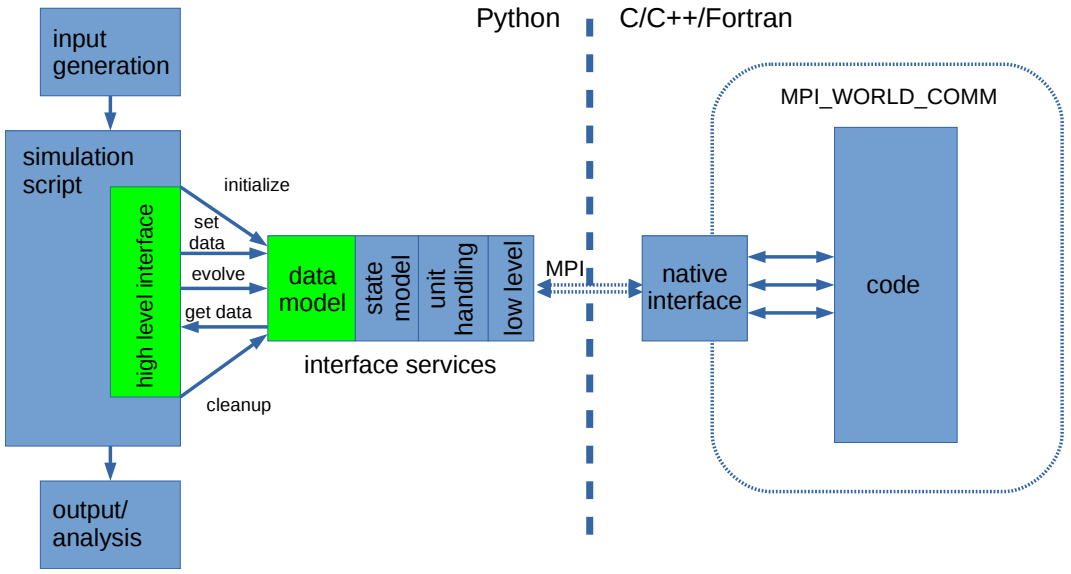
“evolve”

```
code.evolve_model(1.| units.day)
```

“analysis”

```
print code.grid.psi.max().in_(units.Sv/units.km)
```

The OMUSE interface: a bird's eye view



– OMUSE is based on remote code interfaces

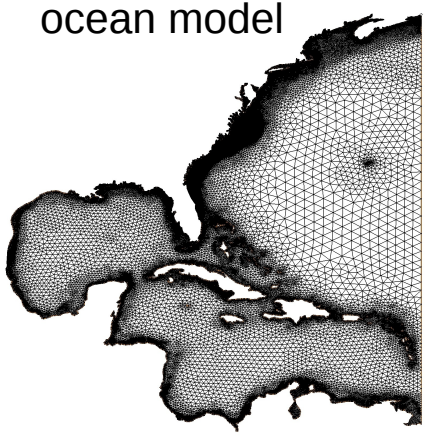
– codes run in parallel & calls can be asynchronous

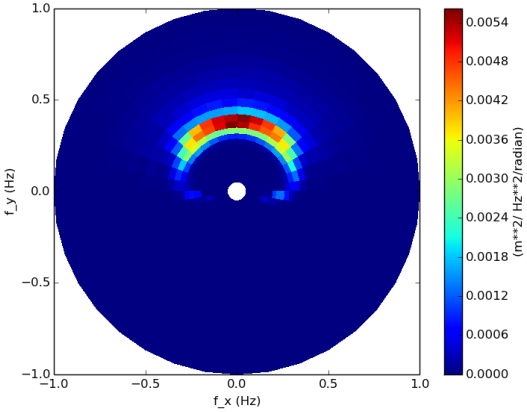
– OMUSE provides a number of *interface services:* unit handling, data structures, code state handling etc..

– the user is presented with uniform high level interfaces, which integrate into a scientific python workflow

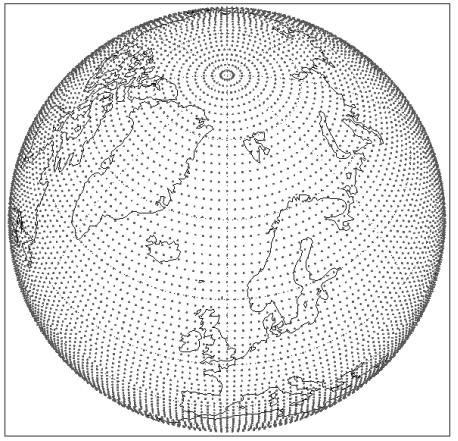
current codes in OMUSE

ADCIRC regional ocean model

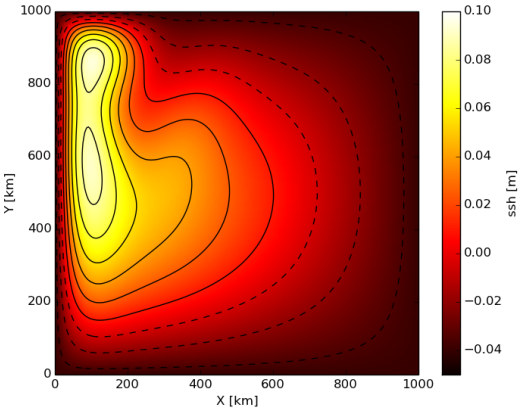




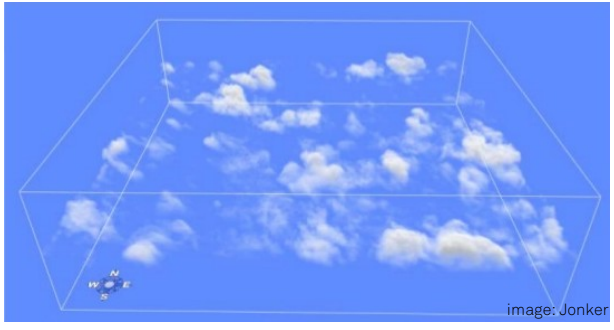
SWAN wave transport



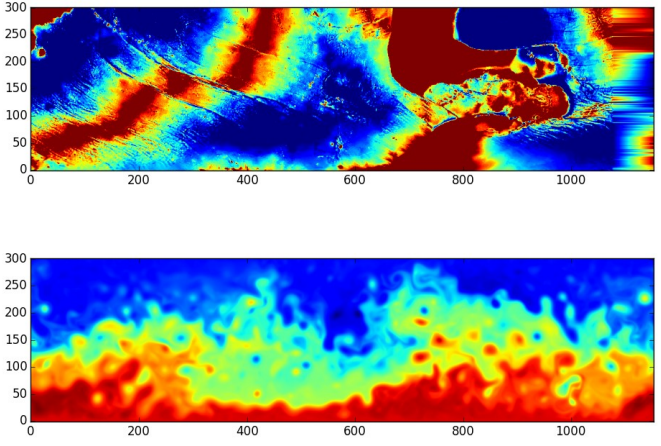
openIFS global atmosphere



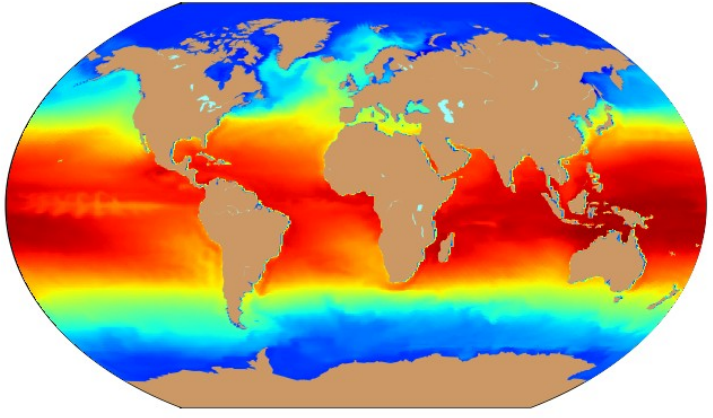
QGmodel



DALES cloud resolving model

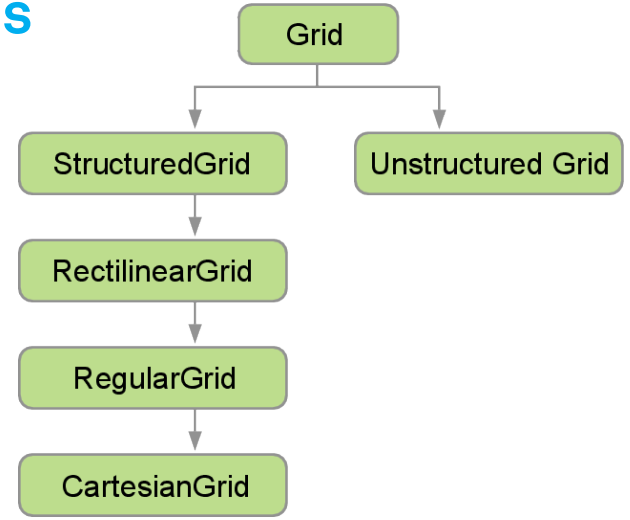


QGCM



POP global ocean model

OMUSE data structures

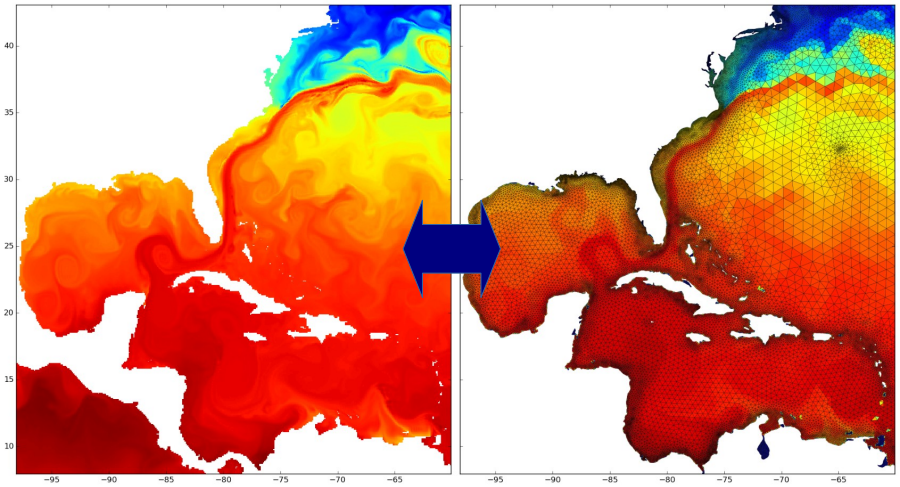


– high level interface uses grid data structures

– grids have domain specific attributes

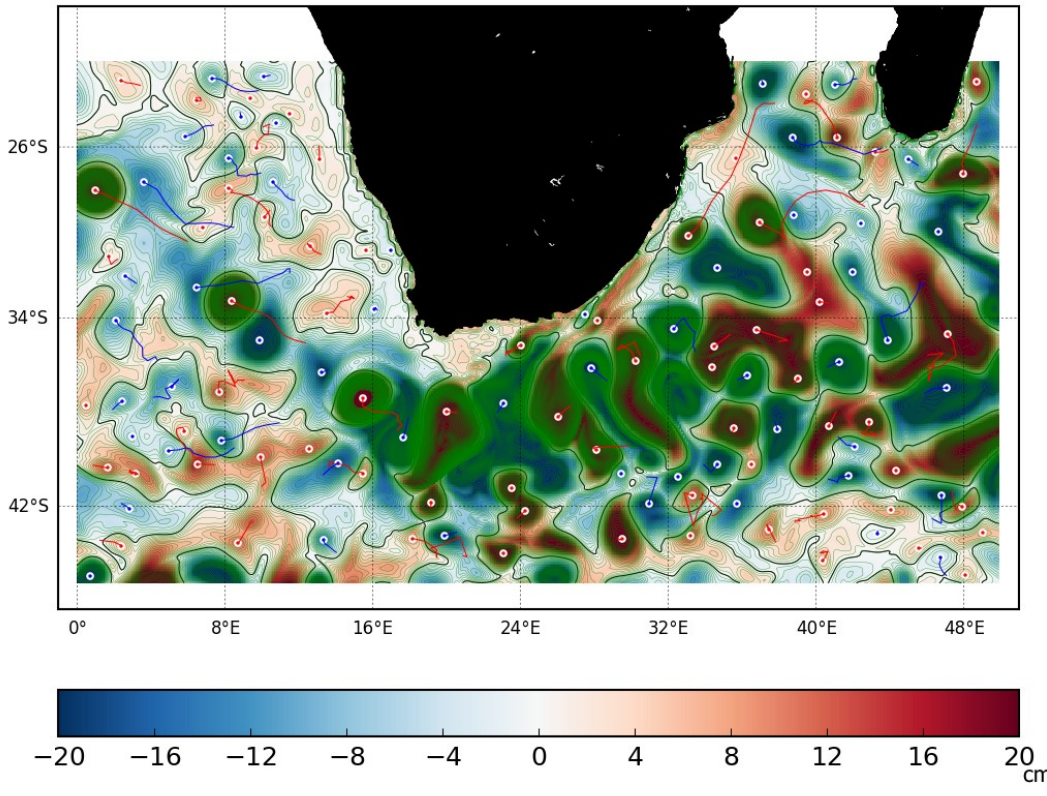
– OMUSE improved grid support:

  – different grid types
  – add grid remapping channels
  – add grid (functional) transform
  – (some) grid generation routines
  – improved support for large parameter sets and files

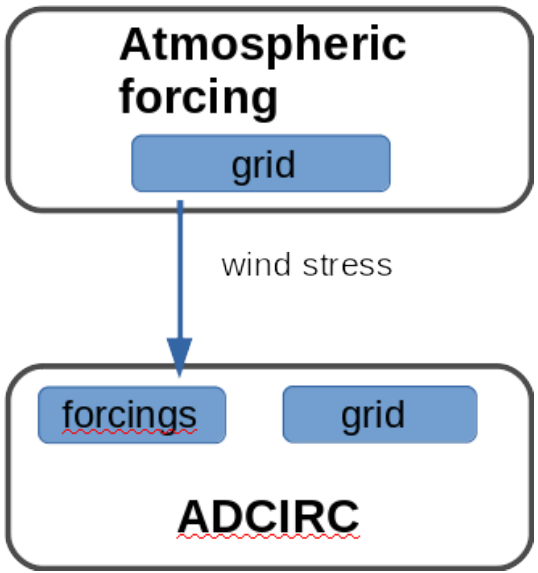


What can you do with OMUSE?

- simplify model setup and runs,
- scripting:
  - event detection,
  - stopping conditions
- 'online' data analysis
- ensemble simulations:
  - parameters searches
  - optimizations (e.g. MCMC)
  - data assimilation
- model comparison: running problems with different codes and methods
- coupling different codes to construct new solvers

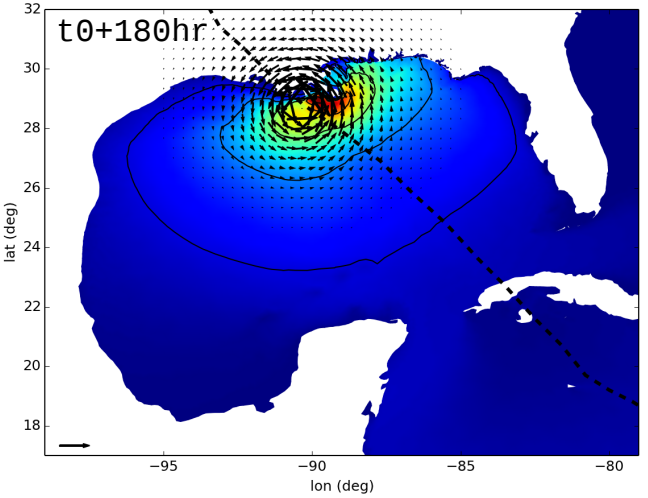


Code couplings with AMUSE

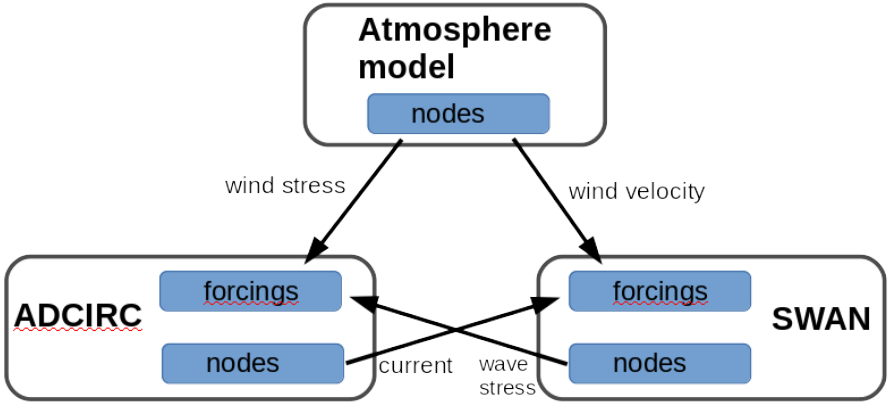



```
from omuse.community.adcirc.interface import Adcirc
from omuse.community.era5.interface import ERA5

adcirc = Adcirc()
meteo  = ERA5(variables=[ "10m_u_component_of_wind",
                          "10m_v_component_of_wind",
                          start_datetime=start_date )

channel = meteo.grid.new_remapping_channel_to(adcirc.forcings,
                                              interpolating_lonlat_remapper)

while adcirc.model_time<tend:
    meteo.evolve_model( adcirc.model_time + dt )
    channel.copy_attributes([ "_10m_u_component_of_wind",
                              "_10m_v_component_of_wind"],
                              target_names=["wind_vx","wind_vy"])
    adcirc.evolve_model( adcirc.model_time + dt )
```

Hurricane Gustav with a coupled hydrodynamic/ wave model



(Pelupessy+ 2017)




```
channel1=hurricane.grid.new_channel_to( swan.forcings )
channel2=hurricane.grid.new_channel_to( adcirc.forcings )
channel3=adcirc.nodes.new_channel_to( swan.forcings )
channel4=swan.nodes.new_channel_to( adcirc.forcings )
while time<tend:
    hurricane.evolve_model(time+dt/2)
    channel1.copy_attributes(["vx","vy"])
    channel2.copy_attributes(["tau_x","tau_y"])
    adcirc.evolve_model(time+dt/2)
    swan.evolve_model(time+dt/2)
    channel3.copy_attributes(["current_vx","current_vy"])
    channel4.copy_attributes(["wave_tau_x","wave_tau_y"])
    time+=dt
```

part II: Applications

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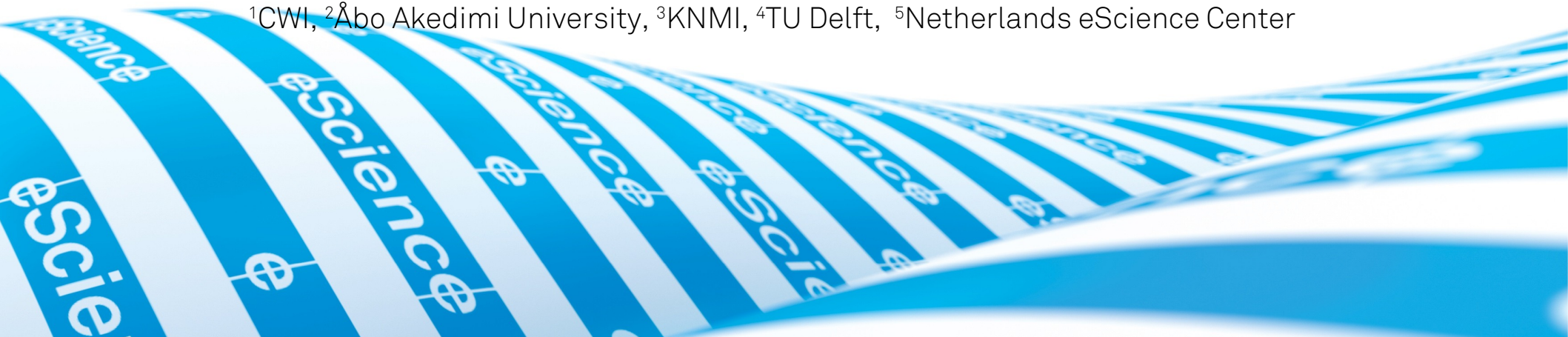
Regional superparameterization in a Global Circulation Model using Large Eddy Simulations

Fredrik Jansson[1], Daan Crommelin[1], Joanna Grönqvist[2], Pier Siebesma[3,4], Maria Chertova[5], Gijs van den Oord[5], Inti Pelupessy[5]

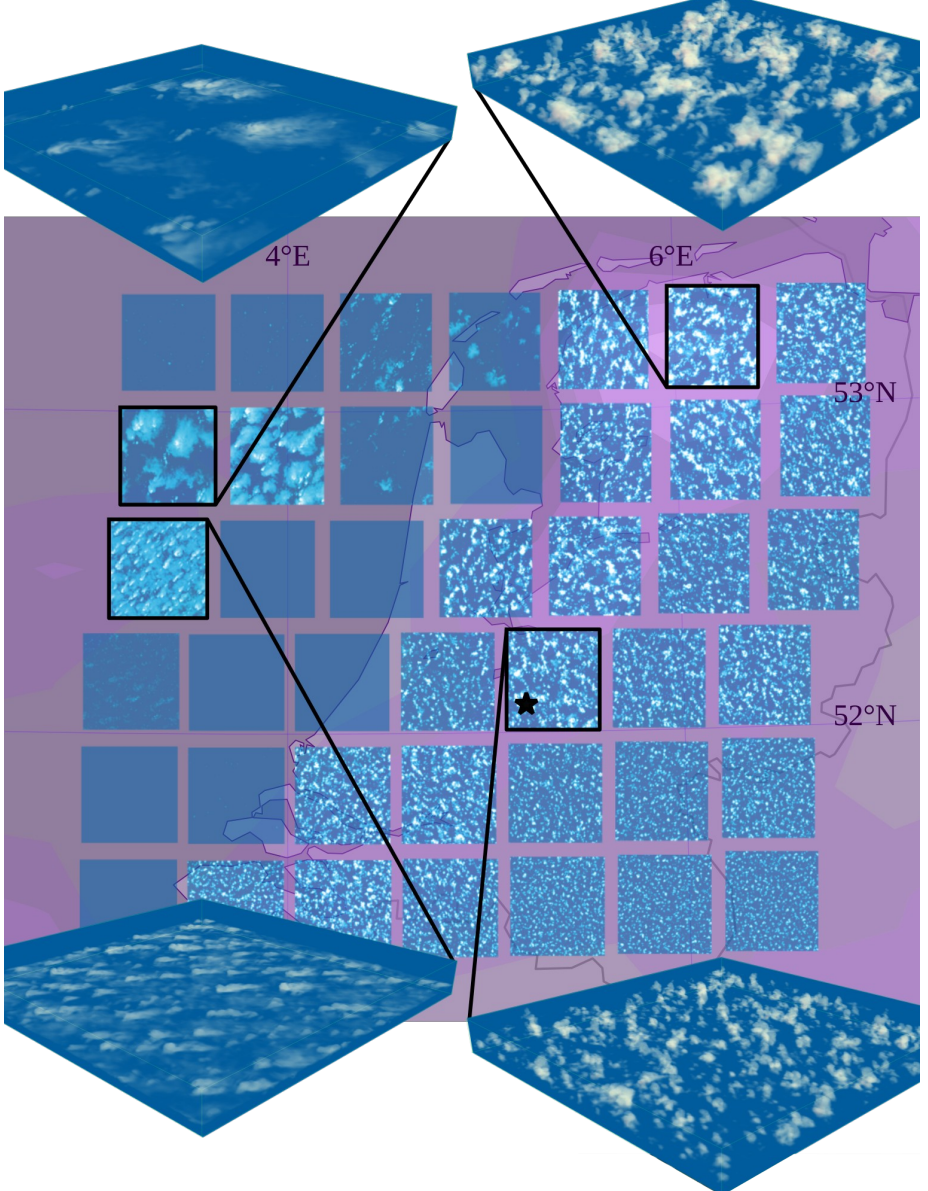
[1]CWI, [2]Åbo Akedimi University, [3]KNMI, [4]TU Delft, [5]Netherlands eScience Center



DALES – OIFS coupling

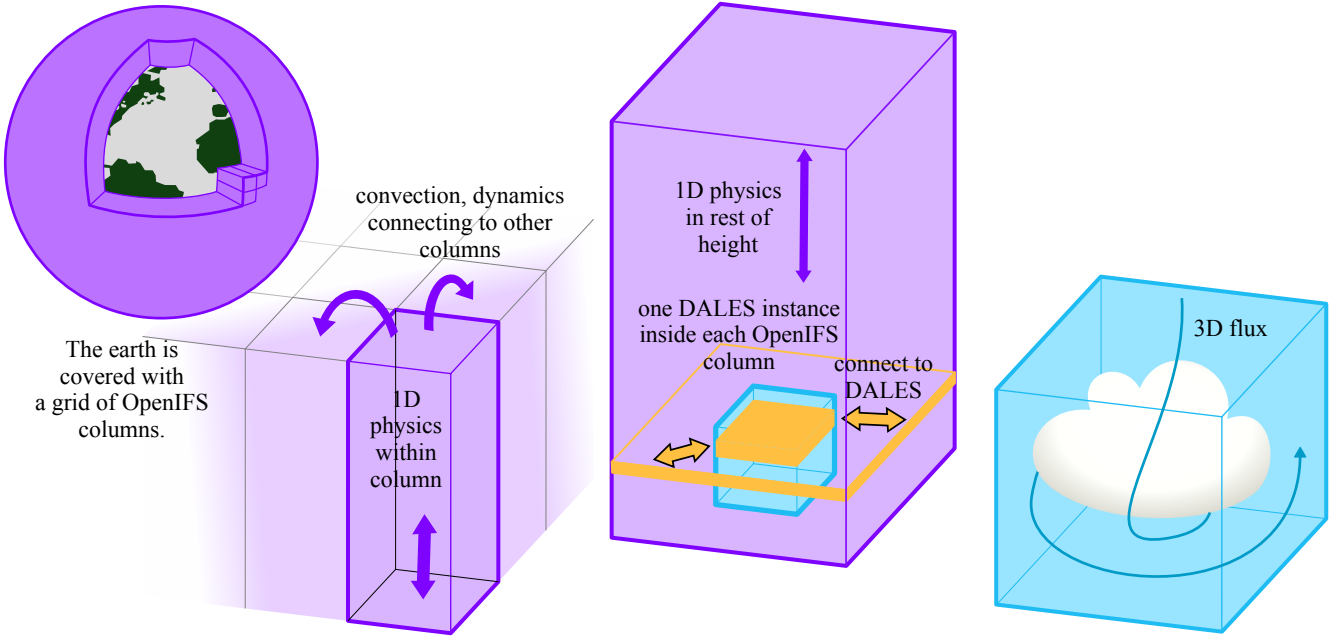
DALES: Dutch Atmospheric Large Eddy Simulation
OpenIFS: community version of ECMWF operational IFS model

– superparametrization
– embedding of cloud resolving in global atmosphere model
– two way coupling
– N models in single global instance

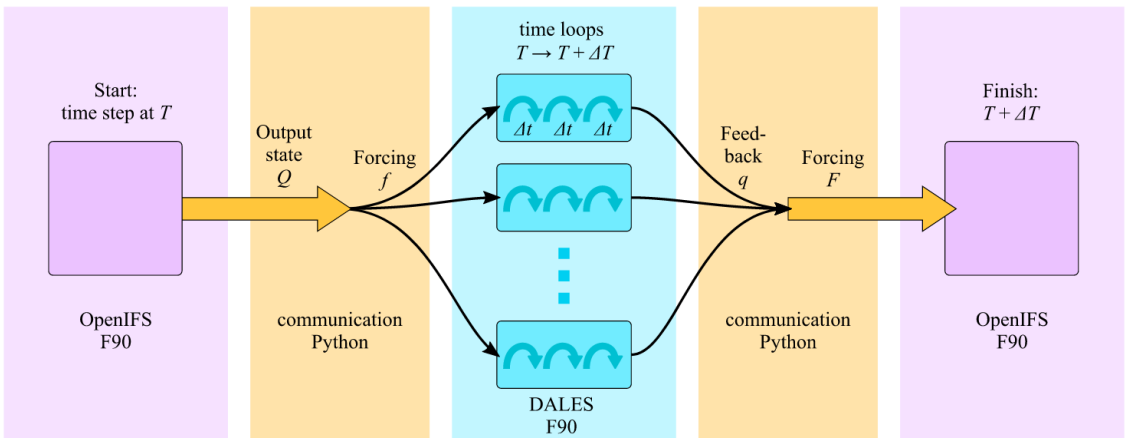


Jansson et al. 2019, JAMES 11, 2958
van den Oord et al. 2020, SoftwareX, submitted

Superparametrization: model overview

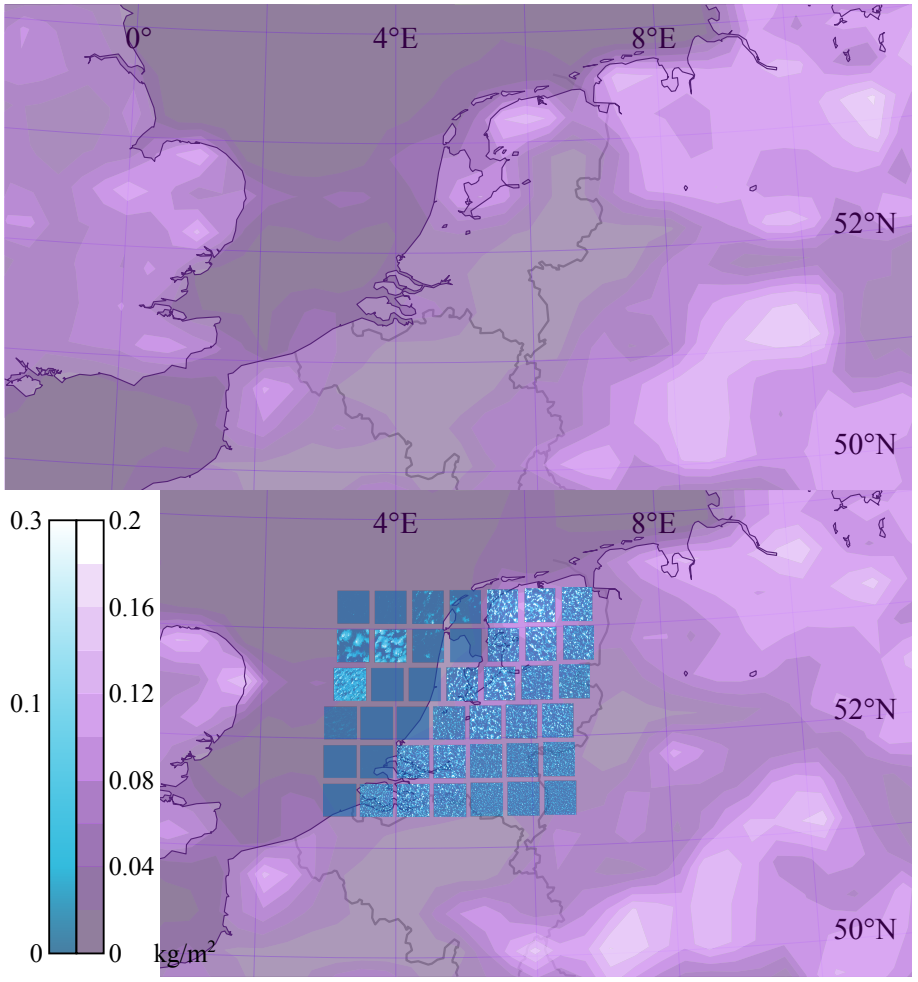


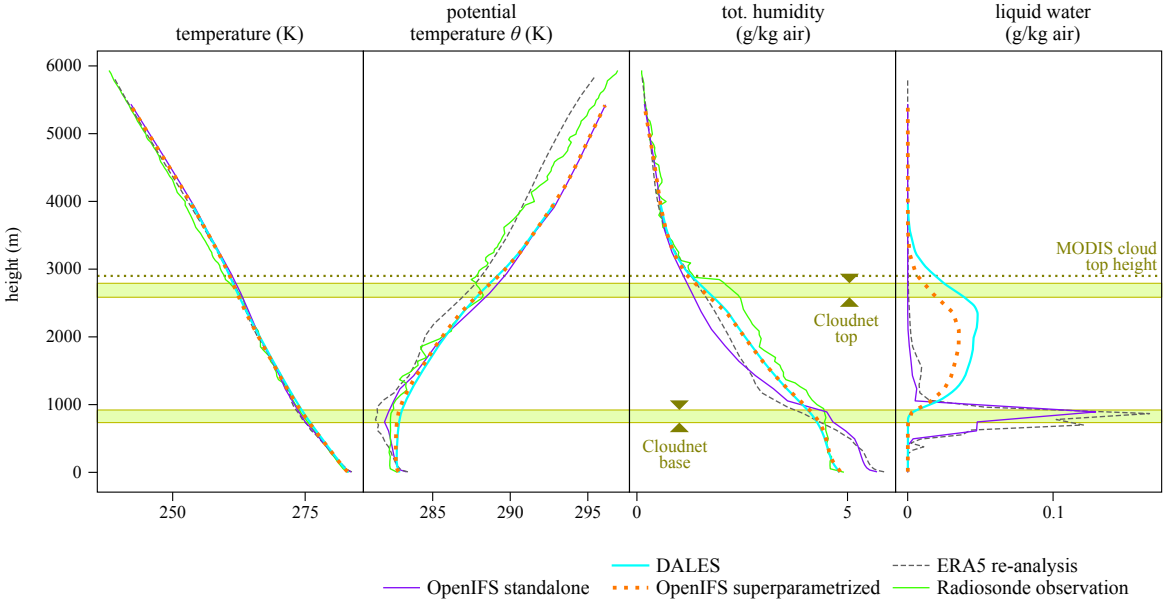
timestepping



purple: OpenIFS
yellow: model coupling
cyan: DALES

Superparametrization results: summary





- superparametrization improves predictions for cloud cover, water content and cloud layer heights
- probably due to improved convective mixing
- experiments have shown problems with advection of clouds, which may remedied (paper in preparation)

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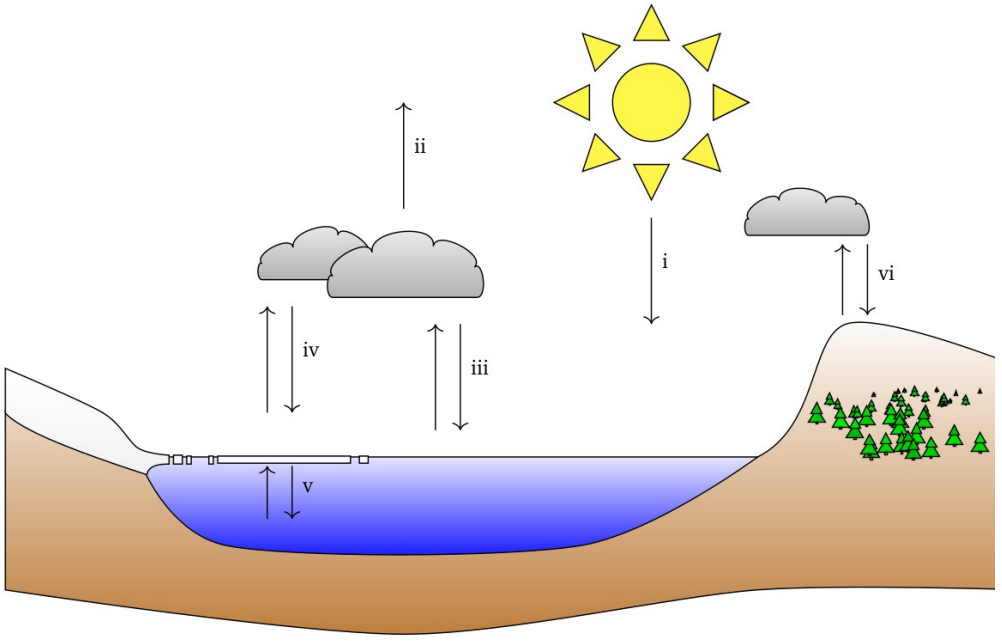
SMCM: Stochastic Multi-scale Climate Models

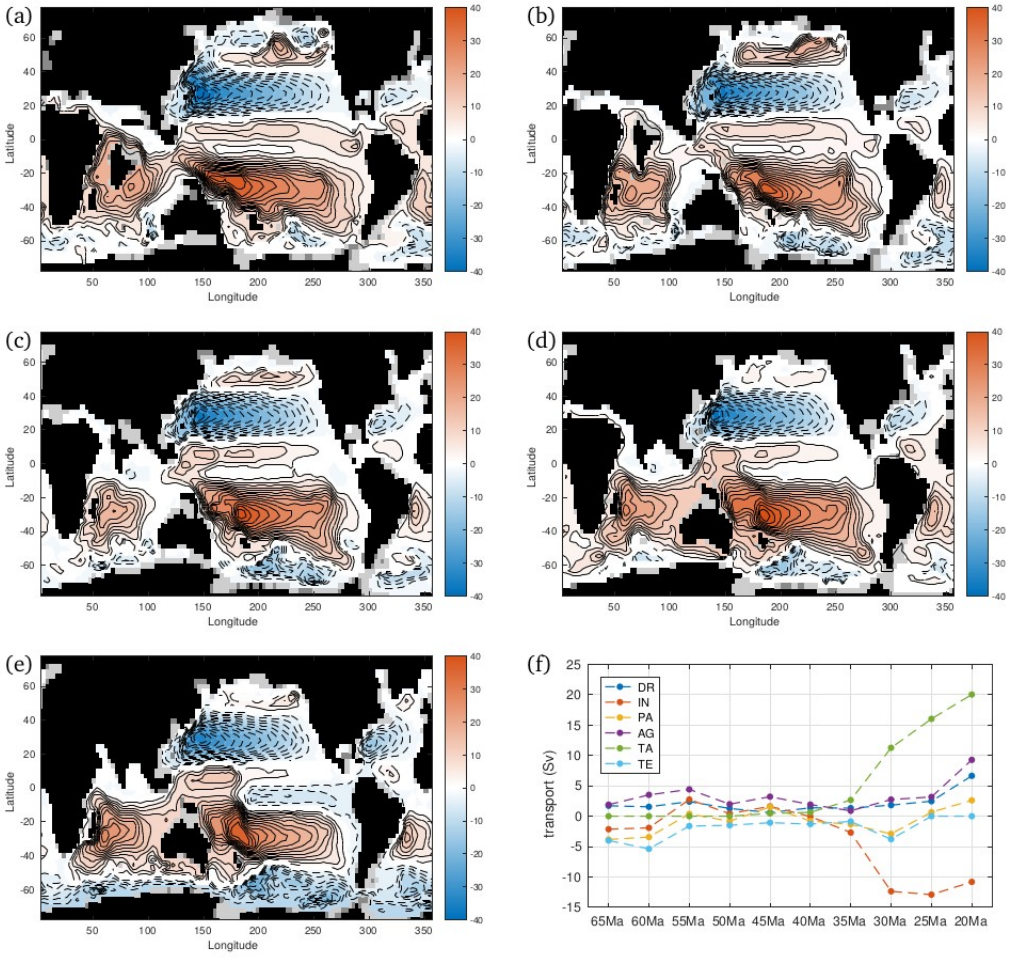
Erik Mulder[1], Sven Baars[1], Fred Wubs[1], Henk Dijkstra[2],
Maria Chertova[3], Merijn Verstraaten[3], Inti Pelupessy[3]

[1]Bernoulli Instituut, RUG, [2]IMAU, Utrecht University [3]Netherlands eScience Center

I-EMIC: An Implicit Earth System Model of Intermediate Complexity

- primitive equation ocean model
- diffuse transport of atmospheric heat and moisture
- evaporation and precipitation
- sea ice formation
- albedo adjustment



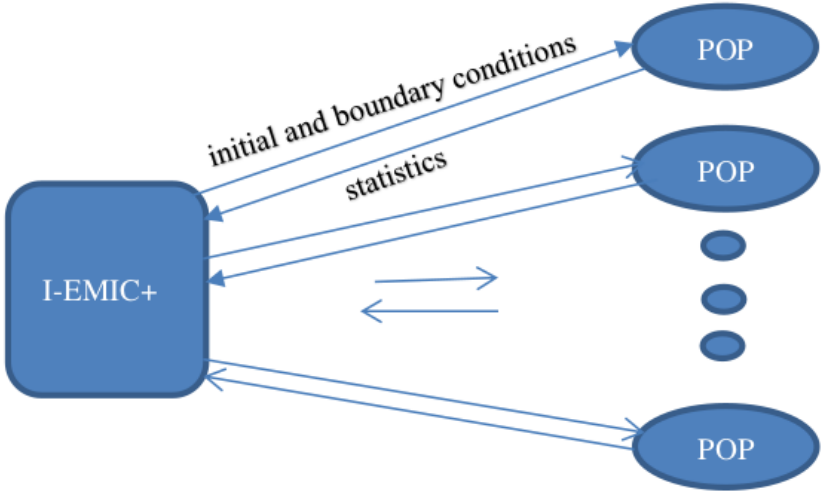


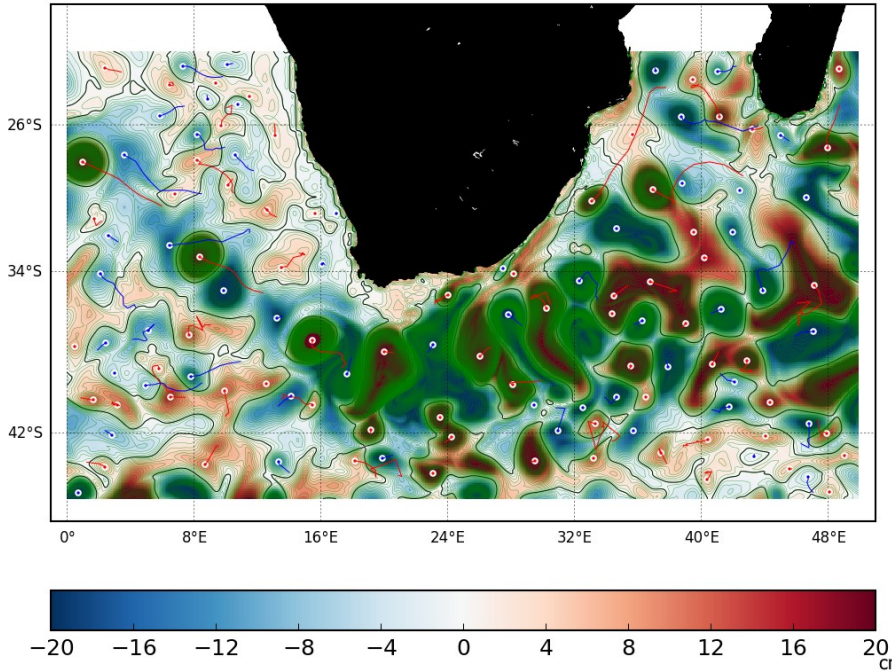
(Steady state barotropic stream function for the global ocean model from 60 to 20 Ma, Mulder 2019)

Stochastic Multiscale Climate Modelling project

Implicit earth system models like I-EMIC allow in-depth study of the climatic state transitions and long term projections for e.g. paleo-earth modelling. However, their ocean component cannot be run at eddy-permitting resolution, and do not properly account for ocean eddy transport.

Solution: Couple I-EMIC with an eddy resolving model (e.g. POP)





SMCM: development highlights

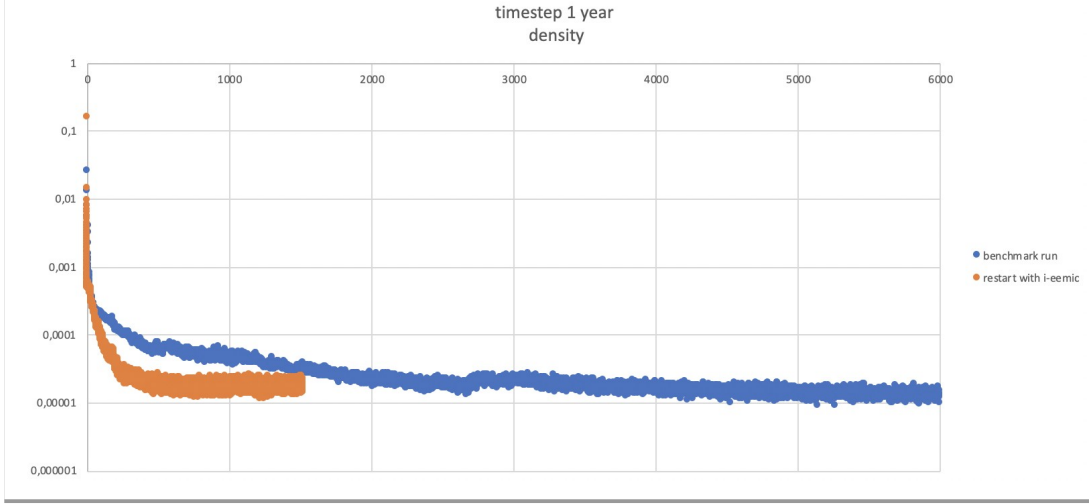
– IEMIC published on github, development on user friendliness; parameters, documentation and installation issues,

– work on performance (new HyMLS preconditioner),

– OMUSE IEMIC interface, and development of `RemoteStateVector` class (wraps mixed C++/ Fortran manipulations),

– Python implementations of continuation and timestepping

– example application:
acceleration of POP spin up
(slow due to meridional overturning circulation)



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IVM VU
Institute for Environmental Studies

NWO
Netherlands Organisation for Scientific Research

Deltares
Enabling Delta Life

MOSAIC:
MOdelling Sea level and Inundation for Cyclones

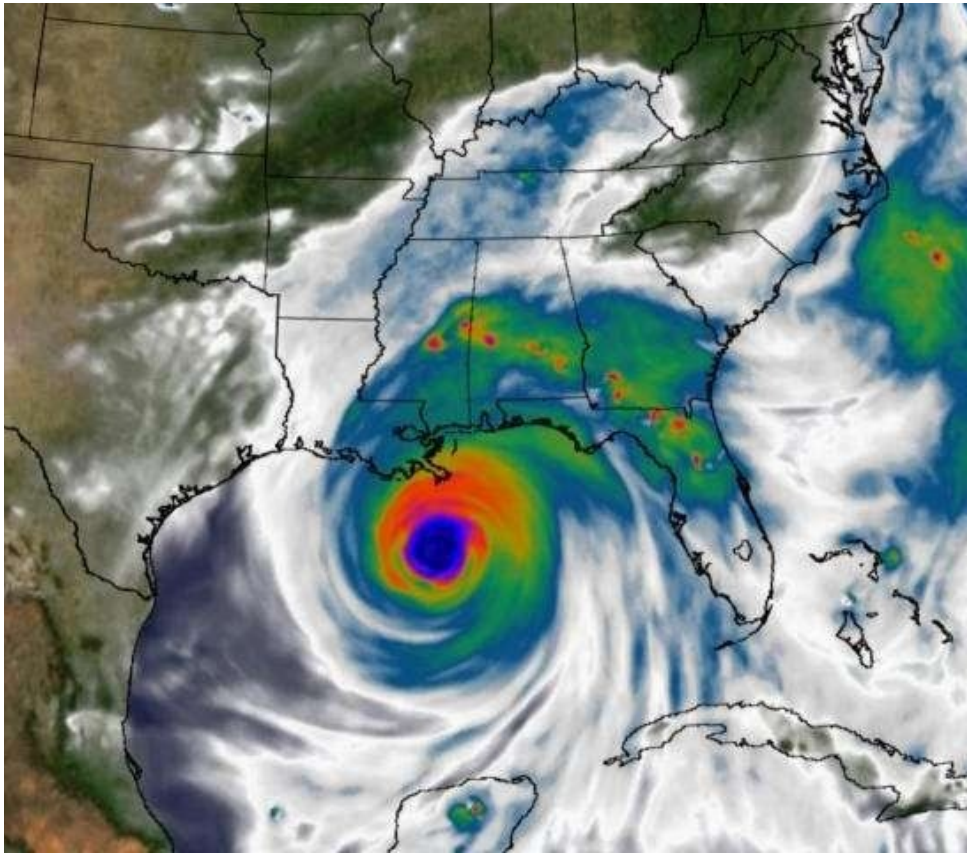
Sanne Muis[1], Job Dullaart[1], Nadia Bloemendaal[1],
Philip Ward[1], Maria Chertova[2], Inti Pelupessy[2]

[1]IVM, VU, [2]Netherlands eScience Center

MOSAIC: MOdelling Sea level and Inundation for Cyclones

Tropical Cyclones(TC):

- One of the deadliest and costliest natural hazards
- Affect coastal areas across the globe
- Storm surge, waves, wind, precipitation

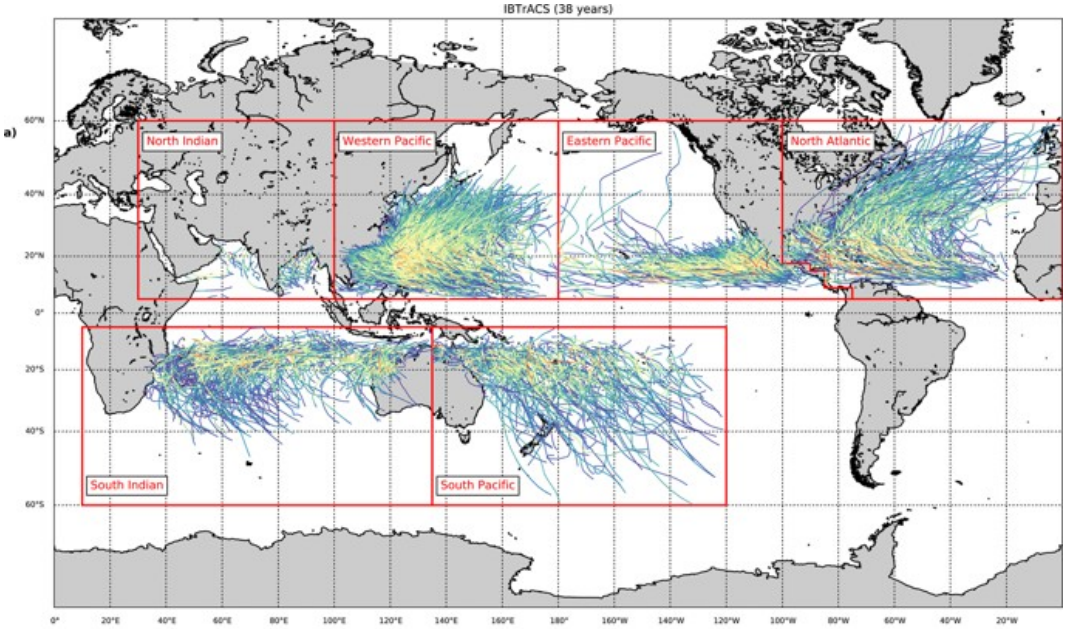


Goal:

developing and validating a computationally efficient, scalable, framework for large-scale flood risk assessment that incorporates synthetic TCs and couples global sea level prediction models to hydrodynamic inundation modelling.

Generating a database of model cyclones

Historical events:
too few to reliably estimate extreme values



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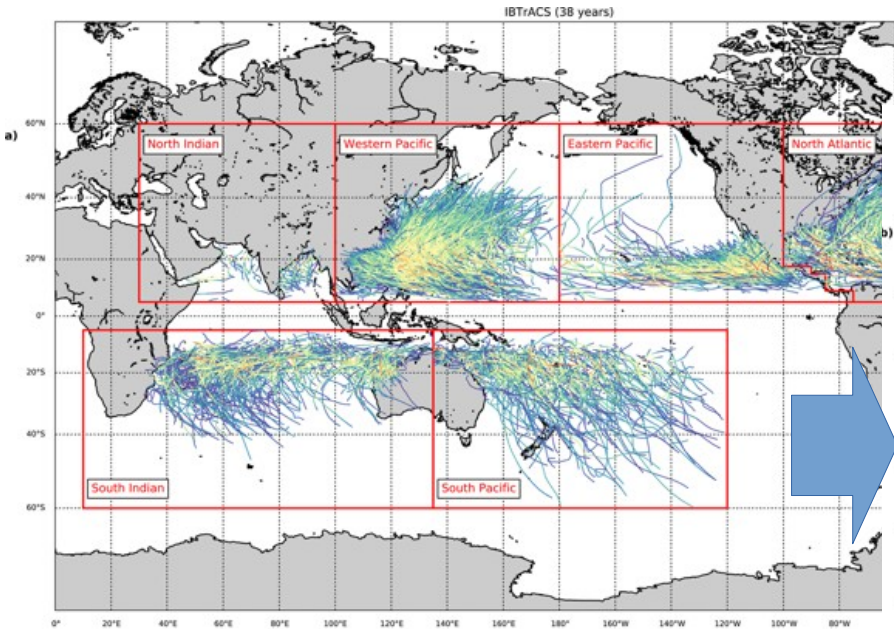

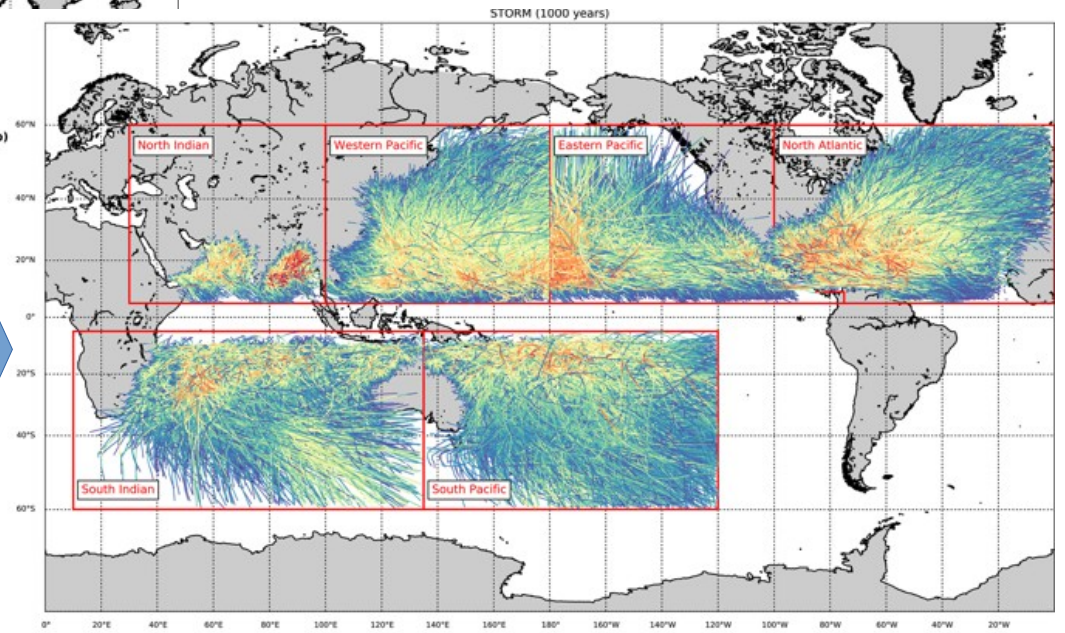

Synthetic database: statistical resampling of historical events extended to 10,000 years of events. (Bloemendaal et al. 2020)

Status/plan

- use the Global Tide and Surge Model (GTSM), based on the Dflow-FM engine of Delft3D
- OMUSE interface based on BMI interface of Dflow-FM
- use database of synthetic cyclones to base statistics on
- Optimize by combining multiple TC in one simulation (Dullaart, Chertova in prep.)
- model nesting: couple local inundation model with GTSM within OMUSE
- (semi) automatic grid extraction and refinement tools

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Conclusions

- OMUSE is a user friendly platform to conduct numerical experiments in Earth System modelling. OMUSE allows the user to express intricate couplings in readable & portable Python scripts

- OMUSE builds on the experience gained with AMUSE..
  ...it has been an interesting experience in cross-domain thinking!

- Current work is on extending the framework and make it more performant for massively parallel simulations

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Resources

OMUSE repository:

github.com/omuse-geoscience/omuse

OMUSE example scripts:

github.com/omuse-geoscience/omuse-examples

Project repositories:

github.com/CloudResolvingClimateModeling
github.com/nlesc-smcm
github.com/nlesc-mosaic

OMUSE Code paper:

Pelupessy et al. 2017, GMD 10, 3167