REQUEST FOR A SPECIAL PROJECT 2024–2026

MEMBER STATE: The Netherlands

Principal Investigator[1]: Prof. dr. A. Pier Siebesma

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Project Title:

EUREC4A-MIP

To make changes to an existing project please submit an amended version of the original form.)

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** ………….	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2024	
Would you accept support for 1 year only, if necessary?	YES X ☐	NO ☐

Computer resources required for project year:	**2024**	**2025**	**2026**
High Performance Computing Facility [SBU]	40 Million	*	*
Accumulated data storage (total archive volume)[2] [GB]	2 Tb	*	*

EWC resources required for project year:	**2024**	**2025**	**2026**
Number of vCPUs [#]			

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.
[2] These figures refer to data archived in ECFS and MARS. If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.
[3]The number of vGPU is referred to the equivalent number of virtualized vGPUs with 8GB memory.

Total memory [GB]			
Storage [GB]			
Number of vGPUs[3] [#]			

Continue overleaf.

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Extended abstract

Summary

Marine shallow cumulus is the most abundant cloud type on our planet and a prime source of climate feedback uncertainty, due to our lack of knowledge how this cloud type responds to global warming. From satellite observations it has become clear that these clouds often organised in clusters of various sizes and shapes. Recent research has shown that these mescoscale cloud structures are partly the result of spontaneous self-organization emerging from the small turbulent scales but are also partly shaped by the large-scale conditions. This requires high-resolution simulations on very large domains with suitable open boundary conditions. As part of a current ECMWF special project we have created a new release of the Dutch Atmospheric Large Eddy Simulation (DALES) model that has the capability of repeated nesting with open boundary conditions within the IFS system. In this new ECMWF special project "EUREC4A-MIP" we propose to simulate a 10-day period from the EUREC4A field campaign and in addition we propose a perturbed run over the same period with a 4K-warming of the Sea surface Temperature (SST) by using the so-called Pseudo Global Warming (PGW) technique. These model experiments will provide answer what the cloud radiative effect will be of organized shallow cumulus clouds when subjected to global warming.

Motivation

In a previous special project : "Mesoscale Organisation of Shallow Cumulus Convection" we explored the capability of different model hierarchies to represent realistic cloud mesoscale structures such as observed during the EUREC4A Field Campaign. Examples of these model hierarchies are

1) OpenIFS, regionally superparameterized with different instances of the DALES (Jansson et al. 2022) (See fig 1).
2) DALES with periodic boundary conditions forced with tendencies for the operational mesoscale HARMONIE model (Savazzi et al 2023) (See fig. 1).

Although both these model hierarchies have been useful in understanding the dynamics of shallow cumulus convection and its parameterization, they are not optimal configurations to realistically reproduce the observed mesoscale shallow cloud structures as can be observed by satellite.

The reason for this is that recent research demonstrates that under very general conditions, cloud mesoscale structures emerge spontaneously from the small turbulent scales (Janssens et al 2023) but their precise form depends also on more large-scale conditions such as the strength of the inversion and the intensity of the large scale wind (Bony et al 2019). This implies that high turbulence resolving resolutions are required but also the possibility to laterally import larger mesoscale structures into the simulation domain. This last requirement demands the use of open lateral boundary conditions. Therefore, the purpose of this project is to generate a simulation with DALES using open boundary conditions of 10 days and evaluate the results with observations from the EUREC4A campaign. In addition we also propose a 4K SST warming experiment where the boundary field are perturbed using a Pseudo Global Warming (PGW) method. These simulations are part of a international model intercomparison project EUREC4A-MIP for which we (the authors) are the Co-Pi's. Further information we refer to https://eurec4a.eu/motivation.

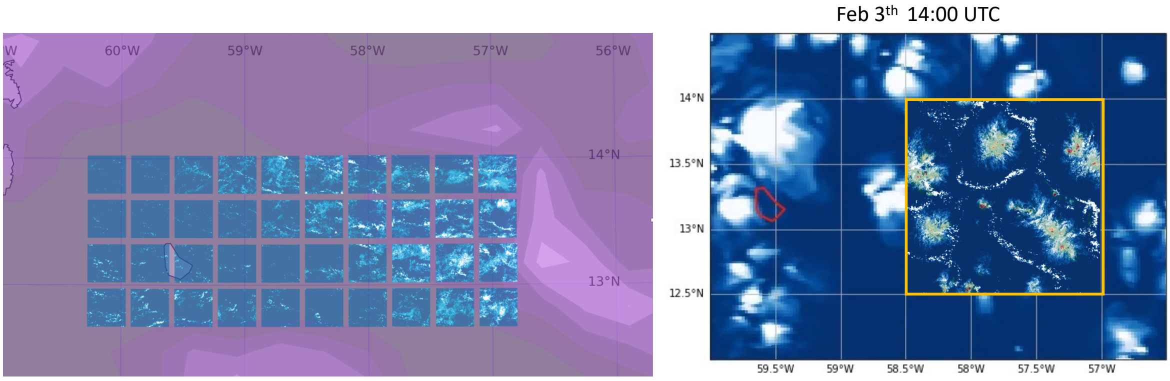

Figure 1: Left Panel: Snapshot of an IFS simulation where 40 grid boxes of each 25x25 km^2, are superparameterized with 40 DALES instances. The different colors correspond to different values of the liquid water path. Right Panel: A large DALES simulation (within the orange box) of 150m resolution on a 150x150 km^2 using periodic boundary conditions. Large scale conditions are obtained from HARMONIE which is the coarser resolution model (2.5 km resolution) outside the organge box and from which advective tendencies are derived and imposed on all the grid points of DALES.

Methodology

In the last 2 years we developed a new implementation for open boundary conditions in our LES model DALES which runs now stable and provides smooth transitions from the coarser model to the finer model provided that the jump in resolution is not larger that a factor of 4 and that the boundary fields are frequently updated. The configuration that we have developed for simulating the EUREC4A period is visualized in Figure 2 where the cloud albedo for three embedded models is visualized for a snapshot at the end of a simulation of 24 hours of February 2nd 2020. The other box marks the boundary of HARMONIE that runs at a resolution of 2.5 km. Harmonie receives lateral boundaries from ERA5. The next nest is DALES that runs at a resolution of 625m on a domain of around 1500 X1500 km^2. The final nest is another DALES instance that runs at a turbulence resolving resolution of 156m on a domain of 300x500 km^2.

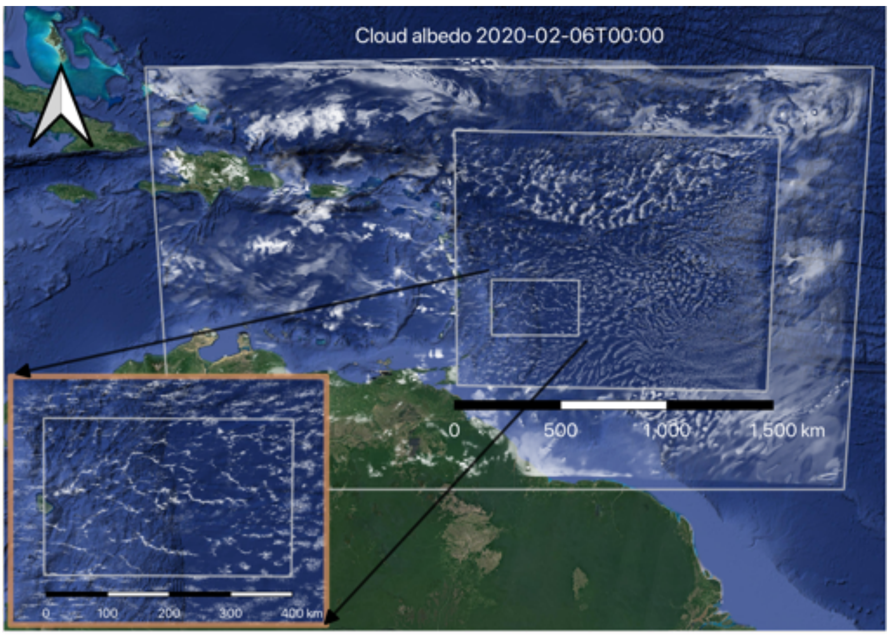

Figure 2: A snaphot of a 24 hr cloud resolving three-way nested simulation of the subtropical Atlantic Ocean. The three nested simulations include in order of domain size from large to small: HARMONIE (2.5km resolution)), DALES 625m resolution) and DALES (156,25m).

The proposal is, as part of an international intercomparison EUREC4A-MIP, to simulate 10 days (01-02-2020 to 10-02-2020) and to assess the capability of a hierarchy of models to represent the mesoscale cloud structures as observed during this period of the EUREC4A field campaign. This hierarchy includes LES models (100-500m resolution) , Regional Storm Resolving Models (500m-2km resolution) and Global Storm Resolving models ((1-5 km resolution). For the last category we will make use of the Dyamond Intercomparison Project that has coordinated global runs over the same period (Stevens et al 2019). In addition, the 10 day present day simulations will be repeated with a 4K warmer ocean Sea Surface Temperature (SST) driven by the same ERA5 boundaries plus a perturbation signal derived from centennial global climate runs using the Pseudo Global Warming (PGW) technique. For more detailed information on the set up of the simulations, the required output we refer to the EUREC4A website (https://eurec4a.eu/motivation). This way we will be able to simulate a consistent future weather realisation and will allow us to asses cloud radiative response. This will be the first time that we will be able to quantify the cloud radiative response of realistic mesoscale shallow cumulus cloud conditions. This is of prime importance since the uncertainty of the cloud feedback due to these type of clouds in climate models remains to largest source of uncertainty in climate sensitivity of climate models.

Justification of the Computer Resources

Dales simulations have been executed as the HPC of the ECMWF for a long time and the model exhibits a perfect weak scaling behaviour on multiple nodes. The typical DALES run requires 2 10^{-6} sec per grid point per time step per core on the ATOS machine of ECMWF. The typical time step of the model is 1 sec.

For the runs in phase 1 this implies that a simulation of 1 day on a domain of 300 by 500 km with a resolution of 100 m requires 900 000 SBU's and at present a similar cost for the 600m run on the larger domain. However we have succeeded to make DALES run on single precision which will make it possible to simulate but nested runs at a cost of around 10^6 SBU's per day. For the complete standard present and future day climate this will amount to an amount of 20 million SBUs. In addition we anticipate to include sensitivity experiments where we will vary the concentration of the cloud condensation nuclei (CCN) to assess to possible influences of aerosols.

We only require resources for one year as we anticipate to start with the simulations possibly already in 2023 but they will need to be finalized in 2024.

Embedding

The proposed model runs are of crucial importance for the modelling efforts of EUREC4A to investigate our simulation capability of the rich observed modes of cloud organisation. It is part of an international model intercomparison project endorsed by CFMIP and GASS where a number of Storm Resolving Models (SRMs)will participate (ICON-LAM, HARMONIE and AROME) as well as a number of Large Eddy Models (LEMs) such as DALES, ICON-LES and Meso-NH. We will also make use of the DYAMOND runs of high resolution global models for this same period including the IFS. This will provide an opportunity to compare a range of model resolutions that completely resolve, partly resolve or fully parameterise cumulus convection and will provide new insights in how to deal with shallow cumulus convection in the grey zone.

References

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