Project: **1070**

Project title: **ARIA**

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Report period: **2024-01-01 to 2024-12-31**

The ARIA numerical experiments on Levante in 2024 are separated in three groups:

1- Surface fluxes of gases and aerosols

Vegetation fires: Vegetation fires release a variety of gases and particles, which can be transported over long distances, impacting the atmosphere's radiative balance, weather, and air quality. The transport of these emissions depends on various factors, one of which is the emission height, a source of considerable uncertainty and strongly affected by the heat released by the fire and the atmospheric conditions. We extended the ICON-ART model and are now able to account for heat and moisture release by the fire as well as the emission of aerosols and chemical tracers. The preliminary results show that the model is able to reproduce the observation.

Coupled atmosphere-land-ocean: Within the HErZ project ICON-SmART from 2023-2028, the main objective is to enable full atmospheric physics and chemistry simulations for seasonal and decadal climate predictions in the ICON modeling framework. The achieve this, the first step is to couple ICON-Seamless with ART with the main focus on surface fluxes. This includes emission and removal of mineral dust and biogenic species in a coupled land-atmosphere framework as well as the emission of sea salt in a coupled ocean-atmosphere framework. The coupling is completed for sea salt and dust emission as well as the dry deposition. Preliminary results are shown in Fig. 1. A separate project will be submitted for the ICON-SmART experiments.

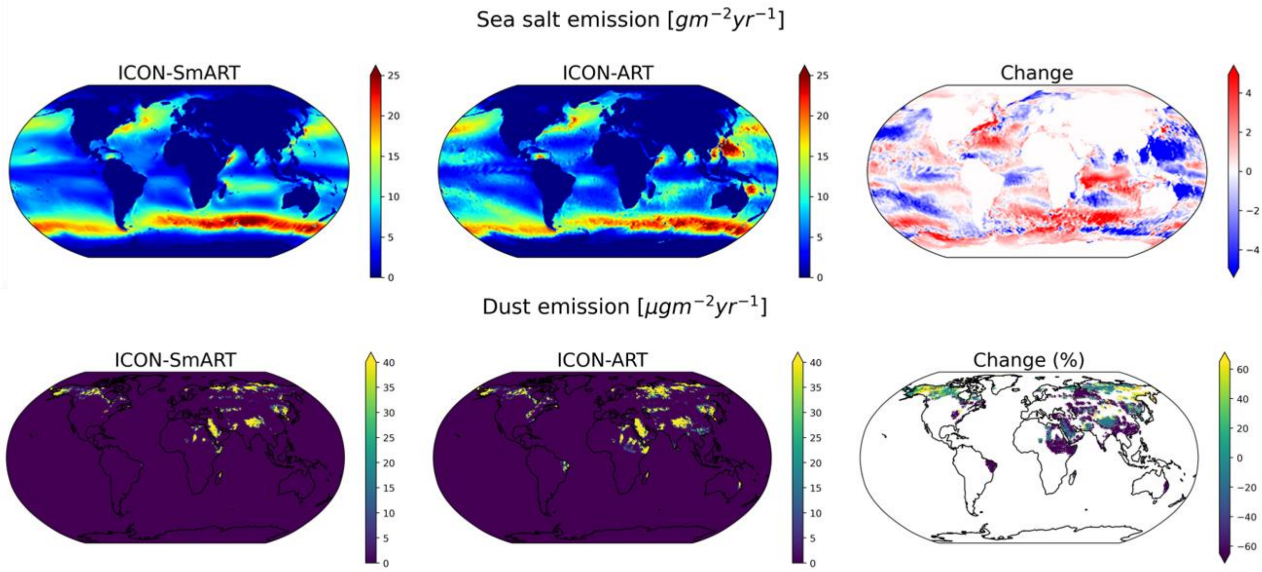

Figure 1: the annual emission flux of sea salt (top) and dust (bottom)

Volcanic eruptions: The 2022 submarine Hunga Tonga eruption in the Pacific Ocean injected ash, SO_2 and large amounts of water vapor and ice into the stratosphere. Interestingly, satellite observations show that, different from previous eruptions, the majority of ash was removed from the atmosphere within one day. We performed different ICON-ART experiments on the R2B06 grid to study the water vapor, ash and sulfate evolution after the Hunga Tonga eruption. Within the scope of the master thesis by Charlotte Wedler (Wedler, 2024), we better understood the physical constraints of water vapor emissions after the eruption and the fast formation of ice after the emission into the model by using ensemble simulations. Additionally, we investigated the role of ash-radiation interaction on the conversion of vapor to ice in sensitivity experiments. As the eruption was ash-poor, the effect of ash-radiation is negligible for the phase changes of water in the plume.

2- *Aerosol-radiation-cloud Interactions (ARCI)*

The Australian New Year's event of 2019 serves as a case study to analyze the ARCI processes. A reference simulation (REF) and a simulation accounting for aerosol-radiation interaction (ARI) were performed for a limited area over southeast Australia. Figure 2 outlines the impacts of aerosol-radiation interaction on the shortwave net flux at the surface. There is an evident reduction of solar radiation in the ARI simulation due to the presence of aerosols, and a reduction in LWP+IWP when accounting for aerosol radiative effects. The absorption of solar radiation by aerosols in the upper levels not only reduces the radiation reaching the surface, but warms the aerosol layer and reduces the temperature below. This causes atmospheric stabilization, which reduces cloud formation. This effect is known as the semi-direct aerosol effect, as the simulation does not account for aerosol-cloud interaction directly. Another suit of experiments is ongoing that focuses on global transport of aerosols and lofting of the aerosol layer in the stratosphere.

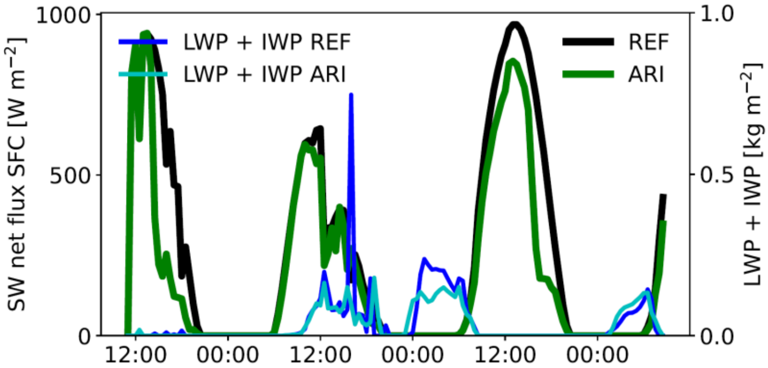

Figure 2: Temporal evolution of sum of LWP and IWP (REF in blue, ARI in turquoise) and short-wave net flux at the surface (REF in black, ARI in green) at 148.9725°E, 36.2939°S

3- *Machine learning for atmospheric composition modeling*

Atmospheric chemistry: In *NACHMO* project, funded by Helmholtz-AI, KIT and Hereon are designing and training neural networks to accelerate simulations of atmospheric chemistry, using specialized architectures and loss functions to enforce conservation laws, maintain accuracy and ensure long-term numerical stability. In 2024 we planned to generate the training data using ICON-ART to perform atmospheric chemistry simulations with MOZART (>100 species/reactions) chemical mechanisms. <u>However, we faced several technical issues and where not able to perform the experiments as planned. This is the main reason for the expired resources in 2024.</u>

Aerosol optics: Aerosol optical properties further depend on the aerosol mixing state and chemical composition. Aging processes significantly alter these optical properties. Most atmospheric models struggle to incorporate this variability because they use pre-calculated tables to handle aerosol optics, resulting in substantial errors in estimating the radiative impacts of aerosols along with posing significant computational burdens. To address this challenge, we develop a computationally efficient and robust machine learning approach called MieAI. It allows for relatively inexpensive calculation of the optical properties of internally mixed aerosols with a log-normal size distribution (Kumar et al. 2024).

Fire dynamics emulation: Wildfire behaviour is influenced by complex physical processes, including turbulent atmospheric transport, mixing of air with gases from vegetation pyrolysis, and heat transfer between flames and vegetation. A synthetic plume dataset, created by combining the WRF model with the SFIRE fire spread algorithm, simulates diverse fire and atmospheric conditions. This dataset enables AI-driven predictions of heat and emissions from wildfires to improve wildfire modelling within the ICON-ART framework. Various machine learning models, especially convolutional neural networks (CNNs), are used to refine these predictions. For this part the GPU resources has been necessary.

Publications:

Kumar, et al. "MieAI: a neural network for calculating optical properties of internally mixed aerosol in atmospheric models." *npj Climate and Atmospheric Science* 7, no. 1 (2024): 110.