Project: **1233**

Project title: **DataWave**

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The goal of the international project DataWave is to improve our understanding and the representation of atmospheric gravity waves with the help of data-driven methods. Gravity waves can have wavelengths between a few and several thousand kilometres. In low resolution climate models, small-scale gravity waves are thus not explicitly resolved and parameterizations are needed. In DataWave, we use machine learning (ML) techniques to improve these parameterizations. This requires training data for neural networks that include the small-scale waves. We produce these data with high-resolution simulations of the ICON model.

In a first step, we used output from the DYAMOND winter initiative to assess the ability of storm-resolving models to simulate gravity waves since this is crucial for the quality of the ML parameterization. To this end, we compared the DYAMOND winter models with superpressure balloon data from the project Loon. We considered the variance of vertical velocity since this variable is dominated by gravity waves in the lower stratosphere where the balloons drifted. For the models, we also calculated the gravity wave momentum flux. Since convection is the main source of gravity waves in the tropics, to which we restricted the analysis, we considered the quantities as function of distance to closest convection. We found large differences in the wave amplitudes between the models and the observations. However, the qualitative decay behaviour of the parameters with distance from convection is similar. This implies that we can train neural networks based on storm-resolving model data to improve our understanding of the underlying physics of gravity waves [1].

We started to (re-)run ICON-NWP and ICON-Sapphire with R02B10 resolution for ML training. Reruns were necessary because of a bug fix in ICON-NWP which led to a temperature drift, i.e., a cooling of the troposphere by several Kelvin.

The responsible postdoc then went on a 6-week ship campaign und worked on a different project, namely the publication of the collected data. For this reason, we decided to continue our work with output from the nextGEMS cycle 3 R02B09 simulation. The 5 km resolution is coarser than originally planned (2.5 km) but the 5-year period is much longer than the 12 weeks we were going to run. We coordinated this effort with the nextGEMS team to obtain extra variables, mainly heating tendencies. Moreover, they stored winds and temperature on the original icosahedral ICON grid for us, using the resources of this project bm1233.

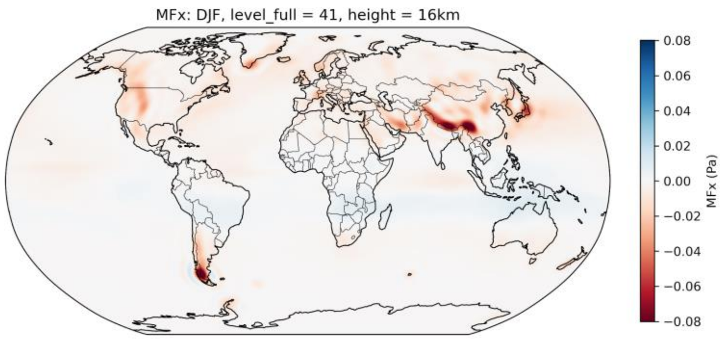

Figure 1: Seasonal mean for DJF of the gravity wave momentum flux component MF_x from the nextGEMS cycle 3 simulation at 16 km altitude (full level 41).

To use neural networks in order to improve the parameterizations of gravity waves in coarser models, one has to provide the gravity wave momentum flux associated with sub-grid scale gravity waves on the coarse model grid for training.

We calculated the horizontal momentum flux components

$$MF_{hor} = (MF_x, MF_y) = (\bar{\bar{\rho}}\,(\overline{\overline{uw}} - \bar{\bar{u}}\,\bar{\bar{w}})\ ,\bar{\bar{\rho}}\,(\overline{\overline{vw}} - \bar{\bar{v}}\,\bar{\bar{w}})),$$

where u and v are the horizontal wind components, w is the vertical wind velocity interpolated to full levels, and ρ is the density of air. The bar denotes coarse graining. For the coarse resolution, we use a healpix grid with nside = 128 which corresponds to 50 km resolution. The tilde refers to a low pass filter. This is obtained by truncating the wave number l in spectral space. The healpix grid is ideal for spherical transformations. Thus, we performed the spherical harmonics transformation for the nextGEMS output on the healpix grid. We tested two different low pass filters, one with a maximum wave number $l_{max} = 71$ and one with $l_{max} = 214$, respectively. To avoid artifacts from the filter, a taper was applied on the spherical harmonics coefficients to smoothen the hard cut-off at l_{max}.

We calculated the horizontal momentum flux for all five years available from the nextGEMS run. Figure 1 shows the seasonal mean for winter (DJF) of the gravity wave momentum flux MF_x with $l_{max} = 71$ at 16 km altitude. We can clearly see signatures of the prominent mountain ranges, for example the Andes, the Rocky Mountains, and the Himalayas. This momentum flux originates from orographic sources.

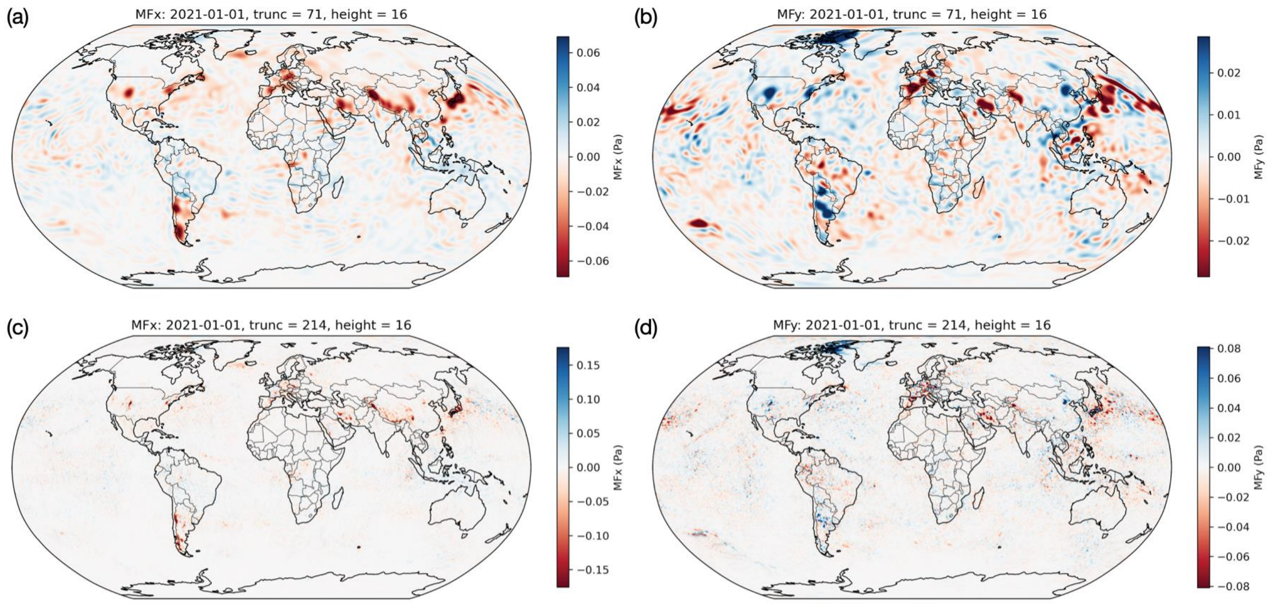

Figure 2: Gravity wave momentum flux on 1 Jan 2021 00:00 at 16 km altitude. (a), (c) MF_x and (b), (d) MF_y with (a), (b) $l_{max} = 71$ and (c), (d) $l_{max} = 214$, respectively.

Figure 2 shows a snapshot on 1 January 2021 00:00 of the fluxes (a), (c) MF_x and (b), (d) MF_y at 16 km with both truncations, i.e. (a), (b) $l_{max} = 71$ and (c), (d) $l_{max} = 214$, respectively. Here, we find wave activity also over the oceans. These waves originate from convective sources. We are particularly interested in convective gravity waves since it is challenging to represent them correctly in models which do not explicitly resolve convection. We are currently using these derived momentum fluxes for ML applications. We have also begun to address science questions that this long data set can answer. For instance, we analyse how much data is needed to train a neural network in order to obtain results that are robust to internal variability, where we also quantify the effects of internal variability on gravity wave momentum fluxes. Since the nextGEMS simulations do not simulate a Quasi-Biennial Oscillation (QBO), we focus on levels below the QBO. A second investigation focusses on frontal waves, as these do not depend on the presence of the QBO.

Overall, the nextGEMS setup is far from optimal for our project. Hence, we plan on running our own ICON-NWP simulations again starting now, with a new postdoc, who has already started and is capable of and dedicated to numerical modelling. We are currently running ICON-NWP at R2B10 resolution, sampling the model as satellite observations, as part of our International Space Science Institute's team Synthetic Gravity Wave Analyses for New Exploitation of Satellite Data.

[1] L. Köhler, B. Green, & C. C. Stephan. (2023). Comparing Loon superpressure balloon observations of gravity waves in the tropics with global storm-resolving models. JGR: Atmospheres, 128, e2023JD038549. https://doi.org/10.1029/2023JD038549