Surface drag and momentum transport

Irina Sandu, Louise Nuijens, Annelize van Niekerk

Motivation

Despite playing a key role in the atmospheric circulation, the representation of surface drag and momentum transport processes has been largely overlooked by the model development community over the past decade, at least compared with diabatic and radiative processes. There are a multitude of processes exerting drag and contributing to momentum transport in the atmosphere that affect the atmospheric circulation on a wide range of spatial and temporal scales. It is widely acknowledged that the accuracy of both numerical weather predictions (NWP) and climate projections crucially depends on an accurate representation of unresolved components of the momentum budget, such as turbulent drag due to surface roughness, orographic drag (including turbulent form drag, low-level blocking and gravity-wave drag), convective momentum transport, turbulent momentum transport in the boundary layer or non-orographic gravity-wave drag. Indeed, key NWP skill scores (e.g. geopotential height anomalies) are very sensitive to the choices made within the orographic drag parametrizations and to the representation of convective momentum transport. Moreover, the formulation of gravity-wave drag, both orographic and non-orographic, has been shown to have significant impact on aspects of the large-scale circulation, such as the Quasi-Biennial Oscillation, the breakup of the polar vortex, the amplitude of stationary planetary waves and the Brewer-Dobson circulation.

Making advances in the representation of drag processes involves both exciting fundamental science questions related to process understanding and parametrization development and has the potential to make a real and significant difference to the quality of weather and climate predictions. Work in this area therefore fully aligns with the objectives of both GASS and WGNE.

Building on the WGNE 'Drag project' legacy

By exposing the large uncertainties associated with the representation of surface drag processes across several NWP and climate models, the recent WGNE 'Drag project' (Zadra et al.,2013) was instrumental in reviving the interest of the community in this important topic. These uncertainties translate into a large inter-model spread in the magnitude of the parametrized surface drag (stress) and in its partitioning between the various processes, particularly over orographic regions. A follow-up inter-comparison study in the framework of WGNE demonstrated that the inter-model differences in parametrized stress in regions with orography are partly due to differences in the underlying subgrid orography fields (Elvidge et al, in preparation). Differences in surface stress comparable to those found in the WGNE inter-comparisons were shown to affect predictions on scales ranging from a few days to climate timescales in a number of recent studies, i.e. Sandu et al., 2016a,b, Pithan et al.,2016, Simpson et al.,2017, van Niekerk et al., 2017.

The absence of direct observations of momentum fluxes at global or even at regional scales lies at the heart of the uncertainties in the representation of surface stress and momentum transport. The representation of these processes therefore relies heavily on parametrized approximations based on theoretical understanding, limited observations and empirical relationships derived from idealised experiments, and is very much exposed to tuning. As the atmospheric circulation is very sensitive to the representation of drag processes, parameter choices made in drag parametrizations are often the result of tuning exercises aimed at improving NWP skill or model climatology. Repeated tuning exercises are likely one of the reasons for the large inter-model spread found in the WGNE Drag inter-comparison project.

The recognition of this model sensitivity to drag and momentum transport has recently led to an increased focus on these aspects and resulted in some progress towards constraining uncertain parameters and identifying deficiencies within certain drag parametrization schemes. This progress has relied on the use of both in-situ observations from field campaigns (Kruse et al., 2016, Vosper et al. 2015) and remote sensing observations, such as the measurement of gravity wave characteristics derived from satellite brightness temperatures (Holt et al., 2017). Analysis of model drift at short lead times and nudging (or relaxation) techniques have also proven fruitful for understanding model errors associated with momentum transport and drag (Simpson et al., 2017, van Niekerk et al. 2016). Sophisticated data assimilation, as well as ensemble based methods, designed to find parameters that minimise the large-scale circulation errors relative to observations, are now starting to be employed to constrain drag parametrizations (Van Niekerk et al, Ollinaho et al in preparation). Furthermore, with the availability of increased computational power, comprehensive high-resolution regional simulations over complex orography and Large Eddy Simulations of convection over large domains are being applied to constrain parametrized orographic drag (Vosper et al., 2016,2018, van Niekerk et al., 2018) and convective momentum transport (Schlemmer et al., 2016), respectively.

The time is right for a GASS project

The above approaches are providing new knowledge. However, there are still many questions that remain unanswered and avenues that remain unexplored: Can high-resolution/LES simulations really be used as a proxy for the truth? At which resolutions are we fully resolving particular processes? How can we make better use of existing observations (e.g. lidars) or upcoming satellite data (ESA's Aeolus mission)? Is there scope for targeted observational campaigns (e.g. like DEEPWAVE, EUREC4A-Wind)? What can we learn from model inter-comparisons of drag processes?

GASS provides the natural framework for bringing together the observational and modelling communities and for crystallising these efforts to constrain and thereby improve the representation of drag processes. A common focus on drag and momentum transport is timely for several reasons:

(i) it builds on recent efforts to highlight the importance and the potential benefits of improving the representation of these processes for both NWP and climate models, such as the WGNE Drag project, two dedicated workshops organized in 2016 and 2016 by University of Reading and ECMWF (Sandu and Zadra, 2016c), and the last WGNE systematic errors workshop in June 2017.

(ii) the use of kilometre scale simulations to identify caveats of orographic drag parametrizations has become mature enough to be able to propose project at the pan-GASS meeting (we will add a couple of phrases during/after the pan-GASS meeting, but this project aims at using global high and low resolution simulations to identify caveats of blocking and gravity wave drag parametrizations).

(iii) alignment with parallel efforts in the framework of the ongoing EUREC4A (http://eurec4a.eu/) and CloudBrake ERC (http://www.louisenuijens.com/cloudbrake.html) ERC projects. EUREC4A aims at understanding the interplay between clouds, convection and circulation and their role in climate change, while CloudBrake strives to expose the coupling of clouds and the vertical structure of wind, thereby aiding development of parameterizations for improved numerical weather prediction, climate modelling, and wind energy design. EUREC4A-Wind (http://eurec4a.eu/index.php?id=4252) is an initiative building on these two projects to focus on the coupling of winds, convection and clouds and their importance for weather and climate prediction. Additionally, EUREC4A-Wind tackles the lack of wind profile and wind flux measurements over open ocean by designing strategies for ground-based and airborne wind lidar measurements, which will also be used to validate the upcoming Aeolus mission by ESA (the first wind lidar from space). Conjointly with the EUREC4A community on (high-resolution) modelling, a workshop on these topics will be organized taking place early 2019 (one year preceding EUREC4A).

Leads

Irina Sandu's early work was instrumental in motivating the WGNE Drag project (Sandu et al. 2013), and since Irina has played a central role in the efforts to revive the interest of the community in surface drag and momentum transport through involvement in related work (Sandu et al, 2016 a,b,c, Pithan et al., 2016, Simpson et al. 2017, van Niekerk et al, Vosper et al, Elvidge et al., in preparation) and by playing a major role in the organization of the workshop on Drag processes and their links to the large-scale circulation at ECMWF in September 2016.

Louise Nuijens leads efforts to understand the coupling between winds, convection and clouds, and to derive constraints on the convective momentum transport. Louise leads both the CloudBrake project and EUREC4A wind initiative.

Annelize van Niekerk has worked on understanding the relationship between systematic model errors and orographic drag processes using various modelling techniques, including high resolution simulations, nudging and ensemble methods. She will lead the orographic drag intercomparison project.

irina.sandu@ecmwf.int

Louise.Nuijens@tudelft.nl

annelize.vanniekerk@metoffice.gov.uk