SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Numerical modelling of boundary layer processes over complex terrain
Computer Project Account:	spATSERA
Start Year - End Year :	2012 - 2013
Principal Investigator(s)	Stefano Serafin
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Other Researchers (Name/Affiliation):	Johannes Sachsperger

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

The focus of the present project is to advance the understanding of boundary-layer (BL) processes over complex terrain by means of large-eddy simulations (LES). In particular, one phenomenon requiring high-resolution simulations of BL dynamics is investigated, namely wave-induced boundary-layer separation in the lee of orographic obstacles. The onset of turbulence is mostly related to shear production in this case. Findings from the project are expected, in the future, to contribute in the improvement of existing parameterizations of sub-grid-scale gravity wave drag.

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

The CM1 model was used for the present project's simulations. Early versions of the model were affected by coding errors in the implementation of metric terms related to terrain-following stretched coordinate systems. A bug-free version of the model code, also including improved numerics, was released only in early 2012 and customized during 2012 and 2013 (new features: adoption of turbulent perturbation recycling in the upstream boundary condition; on-line computation of first- and second-order turbulence moments). The delayed development of the model code caused one part of the scientific plan of the project to be discarded. That is, of the two originally envisaged investigation areas related to boundary layers over complex terrain (turbulent anabatic flows on one side and wave-induced boundary layer separation on the other), only the second was explored.

Experience with the Special Project framework

(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

The administration workload is excessive for such a small-scale HPC project. The requirements about intermediate reporting and renewed application every year (for already allocated resources!) could be relaxed for smaller projects.

Summary of results

(This section should comprise up to 10 pages and can be replaced by a short summary plus an existing scientific report on the project.)

Boundary layer separation (BLS) may occur when a strong adverse pressure gradient force is imposed on boundary layer flow, leading to strong deceleration and detachment of streamlines from the surface. This process commonly occurs at the salient edge of very sharp obstacles. However, in stably stratified flows, pressure perturbations strong enough to cause BLS can also be induced by internal gravity waves.

A well-known phenomenon related to wave-induced BLS is that of atmospheric rotors, i.e., boundary-layer zones characterized by strong turbulence, surface wind direction reversals, large values of spanwise vorticity and near-neutral stability. Due to the high intensity of turbulence, atmospheric rotors are known to pose a hazard to general aviation and road traffic.

In this project, the CM1 model is used to explore the impact of different upstream flow conditions, surface friction intensities and mountain shapes on the size and strength of rotors.

One-layer stably stratified atmospheric flow over an isolated mountain ridge is the simplest prototype scenario for the onset of BLS and the formation of rotors. In this case, BLS is favoured when upstream flow parameters (the Brunt Väisälä frequency and the wind speed) are such that wave perturbations on the lee side have a large amplitude. The resulting "hydraulic-jump-type" rotors occur preferentially in a relatively stable atmosphere with relatively low wind speeds and over broad mountain ranges.

Simulation results from one-layer flow tests confirm that the strength and size of atmospheric rotors mostly depends on the flow features upstream of the mountain [1], however not in an obvious way [2]. The most intense rotors, as measured by the strength of the surface reversed flow, tend to occur in strongly non-linear and non-hydrostatic flows. The largest rotors, instead, are unexpectedly found in moderately non-linear flows.

In strongly non-linear flows, in fact, the reflection of wave energy at a self-induced critical level favours the formation of a lee wave train and an attendant sequence of smaller rotors underneath the lee wave crests. Flow over this train of rotors, which behave essentially as virtual topography elements, excites propagating gravity waves that overlap with the wave field generated by the larger-scale flow above the mountain [2]. This process provides a possible feedback mechanism of BLS onto the environmental flow, and is expected to contribute significantly to wave drag.

The sensitivity of atmospheric rotors to surface friction was also explored: it was found that friction mainly influences the rotor's interior structure, without appreciably altering rotor size and strength [2].

Even if it reveals interesting new physics, the simple case of uniform ambient flow over isolated topography cannot explain the whole variety of wave-induced BLS events observed in nature. For instance, it is well known that two-layer stratified flow (with strong stratification near the surface and weaker stratification aloft, implying a decrease of the Scorer parameter with height), as well as flow with a sharp inversion layer located approximately at mountaintop level, can both be conducive to BLS and to "lee-wave-type" rotors. Also, secondary orographic obstacles on the lee side of the primary one are expected to significantly affect the overall mountain wave response.

Simulation results from layered flow tests are currently being investigated. Preliminary results [3,4] highlight that non-stationary mountain waves and rotors easily develop in these conditions. Furthermore, the presence of secondary orography has a non-negligible impact on rotor formation, through wave amplification or damping related to interference processes.

List of publications/reports from the project with complete references

The preparation of project results for publication on peer-reviewed journals is currently in progress. Preliminary results were presented at workshops and conferences:

[1] Sachsperger, J., S. Serafin and V. Grubišić (2013): Dependence of boundary-layer separation regimes on stability, wind speed and surface friction: An analysis based on large-eddy-simulations. 32nd International Conference on Alpine Meteorology, Kranjska Gora (SI), June 3-June 7 2013. http://homepage.univie.ac.at/stefano.serafin/stablest/downloads/ICAM2013_Sachsperger.pdf

[2] Sachsperger, J., S. Serafin and V. Grubišić (2014): Boundary layer separation in different mountain flow regimes: Investigations on rotor characteristics. EGU Annual Meeting 2014, Vienna (A), April 28-May 2 2014.
http://presentations.copernicus.org/EGU2014-5168_presentation.pdf

[3] Goger, B., S. Serafin, I. Stiperski and V. Grubišić (2013): Large eddy simulations of lee-wave interference over double mountain ridges. 32nd International Conference on Alpine Meteorology, Kranjska Gora (SI), June 3-June 7 2013.
http://homepage.univie.ac.at/stefano.serafin/stablest/downloads/ICAM2013_Goger.pdf

[4] Goger, B., S. Serafin, I. Stiperski and V. Grubišić (2014): Large eddy simulations of flow over double-ridge orography. EGU Annual Meeting 2014, Vienna (A), April 28-May 2 2014.
http://presentations.copernicus.org/EGU2014-5500_presentation.pdf

Simulations performed in the current Special Project are related to research activities in Project P24726-N27 “STABLEST - Stable boundary layer separation and turbulence”, funded by the Austrian Science Fund (FWF) in the period 2012-2015. A continuously updated list of all project publications is available at: http://homepage.univie.ac.at/stefano.serafin/stablest/publications.html.

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

Plans to continue scientific research on the themes of the present project exist, but do not involve the use of ECMWF computing resources.