SPECIAL PROJECT PROGRESS REPORT

Progress Reports should be 2 to 10 pages in length, depending on importance of the project. All the following mandatory information needs to be provided.

Reporting year	2013
Project Title:	Numerical modelling of boundary layer processes over complex terrain
Computer Project Account:	SPATSERA
Principal Investigator(s):	Dr. Stefano Serafin
Affiliation:	Institut für Meteorologie und Geophysik, Univ. Wien
Name of ECMWF scientist(s) collaborating to the project (if applicable)	………………………………………………………… …………………………………………………………
Start date of the project:	1st January 2012
Expected end date:	31st December 2013

Computer resources allocated/used for the current year and the previous one

(if applicable)

Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	230000	4643.26	230000	19652.73
Data storage capacity	(Gbytes)	1800	0	1800	292.26

Summary of project objectives

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, two phenomena requiring high-resolution simulations of BL dynamics should be investigated, namely (I) turbulent anabatic flow and (II) wave-induced boundary-layer separation in the lee of orographic obstacles. The onset of turbulence is mostly related to buoyant production in the former case and to shear production in the latter one. Findings from the project are expected to contribute in the future to the formulation of parameterizations for the vertical heat and mass fluxes operated by unresolved slope circulations, as well as to the improvement of existing parameterizations of sub-grid-scale gravity wave drag.

Summary of problems encountered (if any)

The scientific proposal of this project envisaged the possible use of three different NWP models. These were respectively the CM1, WRF and ARPS codes. In view of their application in the present study, all of them would have to undergo minor modifications (e.g., the implementation of wave-absorbing lateral boundaries and recycling of turbulent perturbations in the streamwise direction, online computation of large-eddy simulation statistics). It was found that only the CM1 model allows a straightforward implementation of these features. Only with version 16 of the model, available since 6 February 2012, an important bug affecting simulations with stretched terrain-following grids (like those envisaged in research line II of this project) was fixed. After successful testing of CM1 release 16, the implementation of perturbation recycling and on-line LES averaging was completed in early 2013. All the code development was carried out on in-house facilities. Due to the considerable delay accumulated in the process, and the resulting loss of the major part of the resources allocated for 2012, research line I of the present project was dropped.

Summary of results of the current year

The customized version of CM1 release 16 was successfully compiled on c2a and a first successful simulation of turbulent flow over idealized topography (research line II) was made.

The simulation considers a simplified 2D geometry where the complex topographic obstacle is represented as a linear mountain ridge, but is fully 3D allowing for realistic turbulence dynamics. Surface friction is parameterized using a bulk transfer (drag) relationship. The upstream atmospheric profile consists of two layers with stronger (below 3000 m) and weaker (above 3000 m) stability, generating a temperature duct which favours the onset of trapped lee waves. A rather high obstacle (385 m) is considered, which causes wave perturbations to become nonlinear. As a consequence of ensuing wave triad instabilities, horizontally propagating wave modes are excited, which cause the flow field downstream of the obstacle to become highly unsteady. These results are in very good agreement with existing literature (Nance and Durran, 1998, J. Atmos. Sci., 55, 1429-1445). The simulation employs a grid of 2048x32x300 nodes, a horizontal resolution of 50 m and a maximum vertical resolution of 5 m.

Figure 1 provides sample cross-sections through the turbulent flow field. The near-surface downslope wind embedded within the first wave detaches from the ground slightly downstream of the hill top (i.e., wave-induced boundary-layer separation is observed). A rotor circulation, with reverse horizontal flow near the surface, is apparent further downstream. Strong vertical velocity perturbations are apparent in the flow field above the boundary layer, but not within the rotor. The regions of strongest turbulence are located at the shear lines between the stagnant interior of the rotor and the outer region, in particular along the descending branch of the rotor circulation.

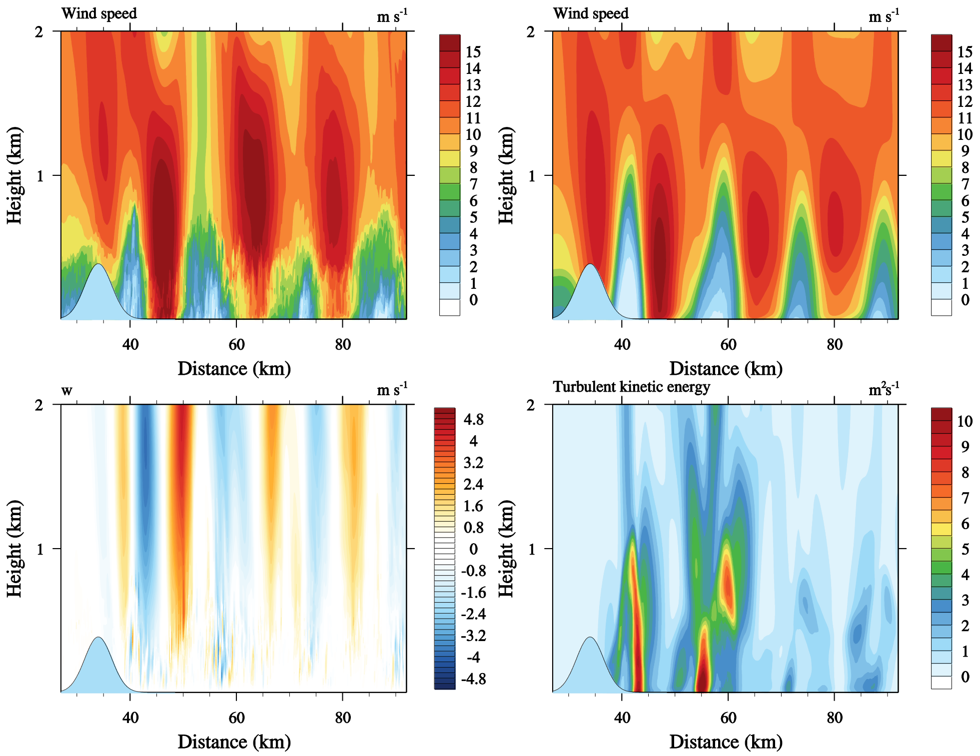

Figure 1*: Vertical cross-sections (x-z) of the flow field at the middle of the computational domain in the y direction. From top left: instantaneous u wind component at t = 6 h; mean u wind component between t =5.5 h and t = 6 h; instantaneous w wind component at t = 6 h; explicitly resolved turbulent kinetic energy between t =5.5 h and t = 6 h.*

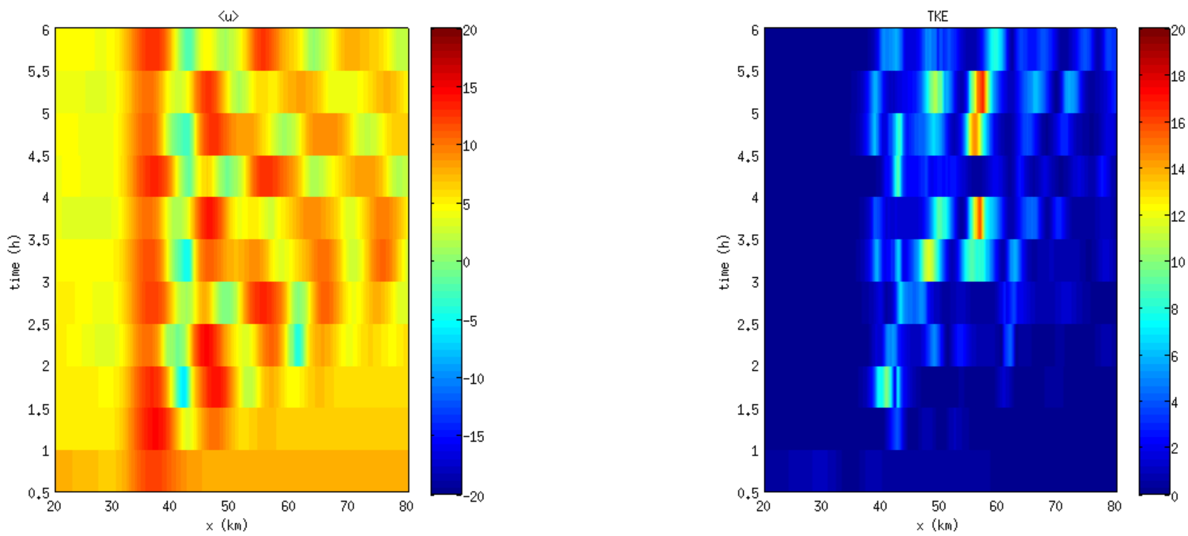

Figure 2*: Hövmöller diagram (x-t) of the flow field 10 m above ground. Left: mean u wind component. Right: explicitly resolved turbulent kinetic energy.*

Figure 2 presents a Hövmöller diagram of the mean horizontal wind speed and of the resolved-scale turbulence near the ground, with a temporal resolution of 30 minutes. The considerable unsteadiness of the flow downstream of the hill (located between x = 30 and x = 40 km) is apparent.

To the knowledge of the author, accurate (LES-type) simulations of stratified turbulent flow downstream of orographic obstacles, like the one presented above, have seldom been reported in the scientific literature. Further research in this area is motivated both by practical and theoretical considerations. From a practical perspective, strong turbulence related to unsteady rotor circulations poses a considerable threat to aviation safety. From a theoretical perspective, the interaction between momentum fluxes generated respectively by gravity waves and turbulence in a mountain-wave rotor system is still poorly understood.

The results of the simulation presented here (and of those that will follow) will be analysed in detail, with focus on the quantitative estimation and on the characterization of the temporal variability of (vertical) energy and momentum fluxes, as well as on wave-turbulence interaction.

List of publications/reports from the project with complete references

Preliminary results were presented in workshops and conferences:

S. Serafin, L. Strauss and V. Grubišić (2012): Idealized simulations of wave-induced boundary-layer separation in the lee of mesoscale topography. Croatian-USA Workshop on Mesometeorology, Pisarovina (HR), June 18-June 20 2012.

S. Serafin, L. Strauss and V. Grubišić (2012): Idealized simulations of wave-induced boundary-layer separation in the lee of mesoscale topography. 15th International Conference on Mountain Meteorology, Steamboat Springs (USA), August 20-August 24 2012.

Summary of plans for the continuation of the project

As mentioned above, research line I was dropped. The first successful simulation in research line II used slightly less than 20000 SBU (1000 core hours). The remaining 210000 SBU in 2013 will be used to perform 10-11 LES runs for research line II (as previously planned) in the final six months of the project.