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	2012
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)	N/A	N/A	230000	4643.26
Data storage capacity	(Gbytes)	N/A	N/A	1800	0

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 are 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, the dynamical cores of all of them need to undergo minor modifications. In fact, simulations in research line I (anabatic flows) requires the adoption of a rotated (slope-parallel) reference frame, where the direction of the gravity acceleration is not normal to the ground. Simulations in research line II (gravity waves) require instead the use of wave-absorbing regions at the lateral boundaries in the streamwise direction. It was found that only the CM1 model allows a straightforward implementation of these necessary changes. This model was therefore chosen as the primary tool to be adopted and the necessary modifications were implemented.

However, preliminary model runs highlighted that CM1 simulations are extremely sensitive to some details of the integration algorithm. These are namely: A. The adoption of an implicit scheme for the integration of vertical diffusion terms. B. The acoustic-time-step integration of advection terms in the energy equation. C. The conservative formulation of metric terms arising from the terrain-following coordinate system. These unexpected sensitivies motivated us to suspend production runs until problems with the model setup are solved. This is expected to occur within summer 2012, after intensive collaboration with the model developers.

Summary of results of the current year

Preliminary simulations with the CM1 model were carried out mainly within research line II, i.e., the study of wave-induced boundary-layer separation in the lee of orographic obstacles.

The flow of a stably stratified air mass over a semi-idealised mountain ridge is analysed. A computational grid with increments of 50 and 20 m respectively in the horizontal and vertical directions is in use. The upstream profiles of wind speed and potential temperature as well as the orographic profile refer to a boundary-layer separation event observed on January 26th 2006 in the lee of the Medicine Bow range in Wyoming, USA. Simulations consider a simplified 2D geometry where the complex topographic obstacle is represented as a linear mountain ridge, but they are fully 3D allowing for realistic turbulence dynamics. Surface friction is parameterized using a drag relationship. Model runs differ in the specification of the drag coefficient. C_d, allowing an investigation of the impact of friction on BLS.

Figure 1 shows a representative snapshot from one of our LES runs. Downslope flow with intensity in excess of 30 m s^{-1} detaches from the ground with a strong updraft in the lee of the mountain. Further downstream, a patch of considerably lower wind intensities is found, with embedded occasional reverse flow. The thin sheet of positive horizontal vorticity at the ground breaks down into several small vortices within the rotor region. The near-surface rotor circulation is associated with a large hydrostatic wave aloft, breaking at an altitude between 2000 and 5000 m AGL.

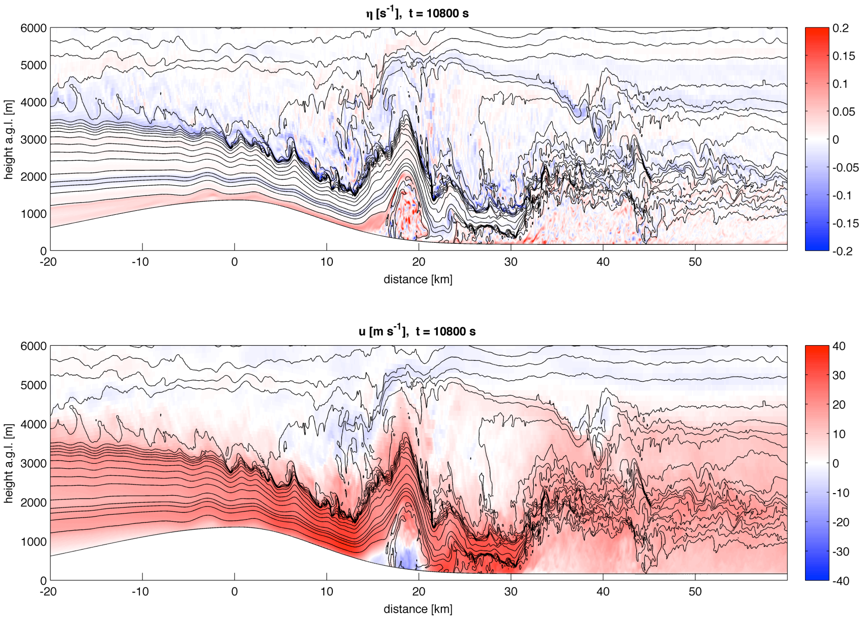

Figure 1*: Cross-section of horizontal vorticity, η (top), and horizontal wind speed, u (bottom), in a simulation with C_d = 0.002. Black lines represent isentropes every 0.5 K. The cross section refers to 3 hours after the beginning of the simulation.*

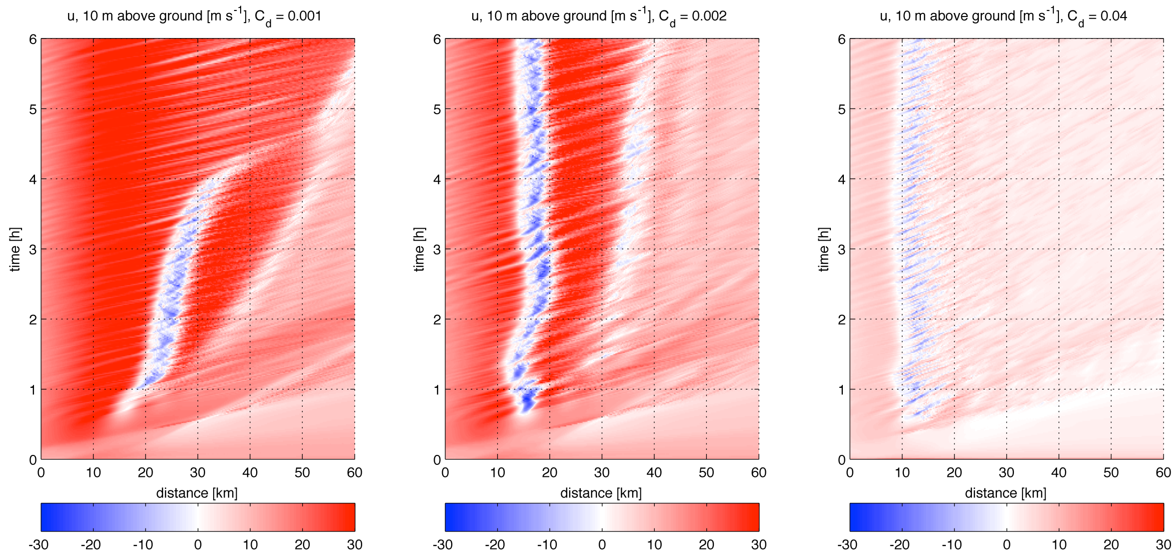

Figure 2*: Hövmöller diagrams of near-surface (10 m) horizontal wind speed (u) in simulations with the drag coefficient C_d equal to 0.001 (left), 0.002 (middle), 0.04 (right). The vertical axis represents time after the simulation start, while the horizontal axis represents distance downstream from the mountain top*

Figure 2 presents Hovmöller diagrams of the near-surface wind field in three different simulations. It shows that surface friction causes the transition from a regime where the rotor circulation moves steadily downstream to another where the location of the separation point is stationary in time. In the case of extremely high bottom friction separation tends to occur only slightly downstream of the mountaintop, suggesting that increasing friction may drive the system towards the bluff-body BLS regime observed in neutrally stratified flows.

Another apparent feature in Figure 2 is the occurrence of pulsations in the intensity of both the downslope flow and the reverse flow in the rotor region. These are most likely related to the onset of Kelvin-Helmholtz instability in a shear layer between the core of downslope flow and the overlying stagnant and neutrally stratified wave-breaking region. While the occurrence of pulsations in downslope flows is a well-known feature, documented both in Chinook and Bora winds, their detection also in the rotor region is likely a novel result.

The results presented here were obtained adopting a "narrow channel" configuration, where the size of the domain along the spanwise direction is considerably smaller than its size along the streamwise direction. Production runs performed at ECMWF will use domains enhanced along the spanwise direction, allowing an accurate estimation of turbulence statistics in a vertical plane parallel to the stream.

List of publications/reports from the project with complete references

Refereed publications are not available yet. Preliminary results were presented in a recent workshop:
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.

Summary of plans for the continuation of the project

After the setup of the CM1 model is complete (expected in summer 2012), production runs will be performed. These will consist approximately of 10 LES runs for research line I (2013) and 10 LES runs for research line II (late 2012).