A project and meetings on the planetary boundary layer theory, modelling and applications

by Sergej Zilitinkevich[1,2], Hannu Savijärvi[1], Alexander Baklanov[3], Branko Grisogono[4], and Kai Myrberg[5]

[1] Division of Atmospheric Sciences, University of Helsinki, Finland

[2] Finnish Meteorological Institute, Helsinki, Finland

[3] Danish Meteorological Institute, Copenhagen, Denmark

[4] Andrija Mohorovičić Department of Geophysics, University of Zagreb, Croatia

[5] Finnish Institute of Marine Research, Helsinki, Finland

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[1] Division of Atmospheric Sciences, University of Helsinki, Finland
[2] Finnish Meteorological Institute, Helsinki, Finland
[3] Danish Meteorological Institute, Copenhagen, Denmark
[4] Andrija Mohorovičić Department of Geophysics, University of Zagreb, Croatia
[5] Finnish Institute of Marine Research, Helsinki, Finland

In this short communication we attract attention of readers of ”Boundary-layer Meteorology” to the ongoing EU Marie Curie Chair Project ”Planetary boundary layers – Theory, modelling and role in earth systems” (PBL – TMRES, Contract MEXC-CT-2003-509742, started on 1 May 2004 (www.atm.helsinki.fi/PBL/) and to the following events associated with the above project: NATO Advanced Research Workshop (ARW) “Atmospheric Boundary Layers: Modelling and Applications for Environmental Security”, to be held in Dubrovnik, Croatia, 18-22 April 2006 (http://pbl-nato-arw.dmi.dk); ”Summer School on Air-Sea Interaction” to be held in Helsinki, Finland, 28 August – 1 September 2006 (http://www.scasi.fi).

These activities complement each other and focus on new demands from a wide range of environmental problems to boundary-layer physics and its applications. They aim at further advancement in fundamental and applied aspects of boundary-layer meteorology, better disseminating of modern knowledge in these fields, and initiating of new interdisciplinary contacts, co-operative researches and practically oriented developments called by necessity to understand, model, predict and as needed mitigate environmental changes caused by global climate change and local anthropogenic impacts.

Marie Curie Chair Project

In the earth systems, the turbulent planetary boundary layers (PBLs) represent very sensitive and changeable coupling agents that regulate the fluxes of energy, momentum and matter (gases and aerosols) between the atmosphere and the sea or land over a range of scales, from local to global. This project focuses on the nature and theory of PBLs with the basic application to improved parameterisation of PBLs in modern environmental models including numerical weather prediction (NWP), climate and air-pollution general circulation models (GCMs), coupled atmosphere-hydrosphere GCMs, and GCM-ecosystem model suites.

Along with development of very high-resolution models, requirements to the PBL parameterisation schemes dramatically increase. Impressive recent achievements in atmospheric modelling are at least partially restrained if the lower boundary conditions provided through PBL schemes remain uncertain or erroneous. Physical processes in the atmospheric PBLs essentially control local features of microclimate, extreme weather events and extreme cases of air pollution. The interacting PBLs in the air and water control the turbulent fluxes of momentum, energy and mass through the water surface. The importance of this mechanism cannot be overemphasised. The air-water energy and momentum fluxes are the driving forces for the physical processes in the sea or a lake – water currents, thermal regimes and turbulent mixing – which in turn control functioning of water ecosystems. A further principal mechanism in the climate-environment system is the exchange (emission or deposition) of gases and particles between the atmosphere and the sea or the biosphere.

Thus advanced PBL models and schemes become the key elements of the modern high-resolution coupled GCMs and model suites that address essential features of the environment at the management scale (10 to 100 km).

Recall that the principal features of the traditional PBL models and schemes were designed long ago – for use in low-resolution GCMs of the day. To a large extent, they were based on physical concepts and assumptions that are now being revised (such as the ideas of fully chaotic turbulence and local flux-gradient correspondence). Traditional schemes are adequate over flat and horizontally homogeneous surfaces in the steady-state conditions with neutral or weakly stable/unstable stratification. However, they cannot cope anymore with the increased resolution of models, which requires a more adequate representation of various physical processes and physiographical features. They fail also to realistically reproduce non-local features of PBLs in the regimes of strongly stable stratification and strong convection, as well as PBL flows over complex terrain, archipelago, pack ice or polynyas. A gap thus occurs between the modern vistas of the PBL physics and the limited applicability of the PBL schemes still used in operational GCMs. To fill up this gap is precisely the general objective of this project. Latest conferences stress this gap, see e.g. http://meteo.hr/ICAM2005/.

One of the deliverables from this project will be a new textbook “Planetary Boundary Layers –Theory, Modelling and Role in Earth Systems” (to be written by the chair holder, Sergej Zilitinkevich, and the scientist in charge, Hannu Savijärvi, on the basis of their recent and current works). It will not duplicate existing textbooks on atmospheric PBLs and air-sea interaction (Arya, 1988; Stull, 1988; Garratt, 1992; Kraus and Businger, 1994). Instead it will focus on fundamental aspects of the PBL physics and the recent achievements most important for environmental applications. This new book is designed for a wide audience including students and researchers in meteorology, oceanography and environmental modelling, as well as environmental engineers and managers interested in practical use of operational models and observing systems.

This project is being implemented at the Division of Atmospheric Sciences, Department of Physical Sciences, University of Helsinki, Finland in close cooperation with Finnish Meteorological Institute (FMI), Finnish Institute of Marine Research (FIMR) and many institutions / groups in Europe and beyond – see www.atm.helsinki.fi/PBL/ for details of the project and complementary summer schools, lecture courses etc. The next important international event is briefly presented below.

NATO Advanced Research Workshop

The main objectives of this ARW are to summarise and assess modern knowledge on the PBL physics and operational PBL schemes; to promote exchange of ideas and know how between physicists, meteorologists and environmental modellers; and to essentially set an agenda for improving PBL parameterizations in air-quality, climate and numerical weather prediction models, with emphasis on being able to tackle and mitigate from extreme events and threats to society's security. The ARW directors are Alexander Baklanov (Denmark, alb@dmi.dk) and Branko Grisogono (Croatia, bgrisog@gfz.hr).

In the last decade, major advances have been made in quantifying the PBL physics through theoretical studies, field and wind tunnel/tank experiments, numerical large-eddy simulations (LES) and direct numerical simulations (DNS). The importance of turbulent processes in sustaining larger-scale phenomena has become widely recognised. However, our knowledge of interactions between turbulence and large-scale geophysical processes remains insufficient. Advanced understanding of the basic question "how the climate system works?" will be achieved by considering fundamental processes related to turbulence at all relevant scales. At this ARW, the current state of the art in PBL physics will be critically reviewed with the purpose to promote and assess the potential of recent achievements and novel ways throughout the range of key applications. The ARW covers the following key topics.

1. Physical nature of stable, neutral, and convective planetary boundary layers: Theory, experimental data, DNS and LES. Turbulent energy budgets and exchanges. Classical similarity theories and the concept of the turbulent viscosity / conductivity / diffusivity: advantages and limits of applicability. Stability dependence of the turbulent Prandtl number, flux Richardson number, anisotropy and other basic parameters. The critical Richardson number – does it exist? Semi-organised motions: internal waves in stable stratification and large-scale buoyancy-driven eddies in convection. Achievements and limitations of direct numerical simulation (DNS) and large-eddy simulation (LES). Needs for high quality field/lab experiments.

2. Turbulence closure problem: Advanced schemes for research and "minimal" schemes for use in operational modelling. Counter-gradient fluxes and other non-local effects. Transport properties of internal waves in stable stratification. Transport properties of semi-organised convective eddies. Limits of applicability of modern schemes. Sub-grid scale closures and lower boundary conditions in LES. How to verify / validate turbulent closures? Alternatives to the traditional type of turbulence closures (optimal-resolution LES?).

3. Complex boundary layer type flows: Analytical and numerical models of relevant meso-scale flows. Radiative heat transfer in PBLs. Sea breezes and other circulations driven by the thermal contrasts at the surface (e.g. over openings in ice-covered ocean). Katabatic and other mountain-valley winds. Jets. Boundary-layer clouds and marine, cloud-topped PBLs. Internal boundary layers and PBLs over heterogeneous terrain, archipelago and coastal zones. Effective roughness lengths. Parameterization of the sub-grid scale circulations in operational models (flux aggregation).

4. Interaction of the air flow with land/sea surfaces and calculation of surface fluxes: Re-evaluation of the traditional "constant-flux" surface-layer model and the Monin-Obukhov similarity theory. The surface layer within shallow stable PBLs (no room for the constant-flux layer concept; non-local effect of the free-flow stability). The surface layer in strong convection (non-local effect of "convective winds" caused by semi-organised eddies). Alternative surface-flux schemes based on the PBL bulk resistance and heat/mass transfer laws. Interaction of air flows with the sea surface and land surfaces: roughness lengths for momentum and scalars, their variability and parameterization. Modelling and parameterization of air flows above and within the vegetation and the urban canopies.

5. Planetary boundary layer schemes in operational and environmental security models: Overview and critical discussion of PBL parameterizations currently used in state-of-the-art numerical weather prediction, climate and other environmental and emergency-response models. Turbulence closures and PBL-depth parameterisations in pollution-dispersion models. Specific demands from urban air quality and emergency preparedness models. Overview of urban boundary-layer schemes. Presentation and discussion of selected PBL-controlled weather/climate phenomena. Role of PBL schemes for micro- and regional climate.

Summer school on Air-Sea interaction

This summer school, organised by Kai Myrberg (Finnish Institute of Marine Research, myrberg@fimr.fi), Sergej Zilitinkevich and Hannu Savijärvi (University of Helsinki), focuses on experimental, observational (including remote sensing) and modelling studies of air-sea interactions including sufficiently understood physical processes in the coastal and archipelago areas where the PBLs are very complex and often characterised by extreme air-water temperature differences. An important example is the vertical turbulent transport in strongly stable or unstable atmospheric and oceanic boundary layers. Special attention is also paid to PBLs in both the atmosphere and in the sea accounting for the effects of sea ice. Another key issue is modelling of the coupled atmosphere - Baltic Sea systems, including biogeochemical cycles in water and the gas exchange between the air and the sea.

The following specific topics are selected for detailed discussion due to their sensitivity to the PBL and air-sea interaction mechanisms: (i) climate and weather impacts on water ecosystems and coupled air-sea modelling of water quality and coastal upwellings (the latter enhance algae blooming by replenishing the euphotic zone with the nutritional components that are limiting factors for biological production over the most of the growth season); (ii) the role of the meteorological forcing in extreme events, such as high sea-levels and waves. The summer school includes a visit to the FIMR Research Vessel "Aranda".

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