Max-Planck-Institut für Meteorologie

Small-Scale Turbulence in the Atmospheric Boundary Layer

A series of recent papers from the Max Planck Research Group "Turbulent Mixing Processes in the Earth System" at the Max Planck Institute for Meteorology demonstrates for the first time how small-scale turbulence affects the properties and evolution of the atmospheric boundary layer. This break-through offers new possibilities to validate old theories about how the boundary layer grows or how it interacts with the surface - or invalidate them and propose new ones.

Whenever we travel by plane, we often experience that the flight gets a little bumpy quite suddenly during the descent. This phenomenon causes not only excitement or discomfort to the passengers, but also a few headaches to climate scientists, whose models depend critically on these effects. The sudden agitation indicates that we are abandoning the relatively calm, upper troposphere and entering into the turbulent atmospheric boundary layer (see Fig. 1). Within this transition region - let us refer to it by EZ, as an acronym for "excitement zone" (*entrainment zone*) - there is somewhat like a battle going on between the turbulence below and the smooth troposphere above, the turbulence trying to conquer troposphere territory. Scientists need to understand better how this battle really takes place because climate models suffer from major uncertainties in related quantities, like the speed of conquest.

Advances in super-computing has made it possible to address this problem, unveiling some of nature´s hidden details. It is now possible to simulate directly the details of the turbulent motions inside of the atmospheric boundary layer, covering a range of scales of several orders of magnitude, from the large, organized plumes to the small, random vortices, and obtain thereby information about the EZ. In this way, we have learned that, even in the most simple of circumstances, the EZ, about 100 meters high, comprises in reality two different layers: one layer dominated by the characteristics of the crests, or domes, and a layer beneath dominated by the characteristics of the troughs between those crests (see Fig. 1). The upper layer is where the troposphere opposes most strongly the advance of turbulence. This newly found structure implies in turn a new understanding of the equations describing EZ properties, e.g., the speed of conquest, technically known as the rate at which turbulence advances into the upper troposphere.

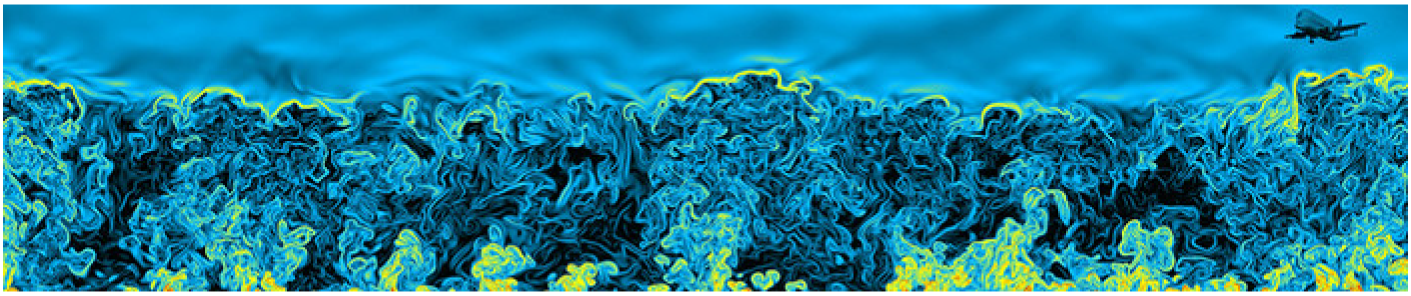

Figure 1: Vertical cross-section showing the distinct nature of the turbulent boundary layer, filled with chaotic motions of many different scales, and the upper troposphere, characterized by gentle undulations. The color indicates the magnitude of the local variation of the density field, increasing from black to yellow. Simulation performed by J. R. Garcia using 5120_5120_840 grid points. (The plane on the top right corner is included for illustration purposes and it is not part of the simulations.)

The speed of conquest and the small-scale features of the EZ become even more important in the presence of clouds. Cloud processes, like the cooling caused by the evaporation of droplets or the cooling due to radiative processes, alter the battle between the turbulence and the troposphere. Computers allow us to solve accurately idealized problems in which we can switch on and off those processes selectively, learning thereby how important these processes really are (see Fig. 2). This information is crucial because, as the turbulence advances into the troposphere, the properties of the conquered and the conquering territory can experience dramatic changes - for instance, that the cloud disappears - and climate models have some difficulties capturing these changes.

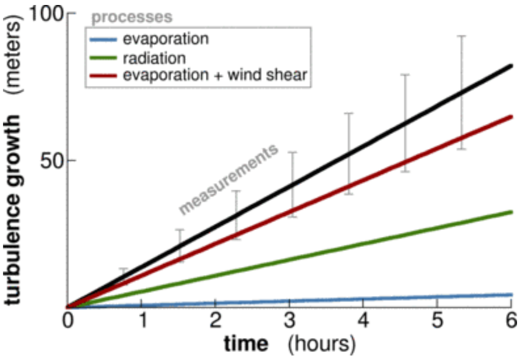

Figure 2: Turbulence growth into the upper troposphere due to different cloud-top processes inside the transition region between the turbulent boundary layer and the troposphere (see Fig. 1). Evaporation alone (blue line) cannot explain the measurements (black line), whereas radiation and in particular wind shear can, indicating that these last two processes are more important in the turbulence growth.

The ability to simulate accurately the small-scale motions inside the EZ, which is key for these results, was impossible merely 10 years ago; the possibilities that will emerge in the coming decades are opening new frontiers in climate research.

Paper:

1. A. de Lozar and J. P. Mellado. Direct numerical simulations of a smoke cloud-top mixing layer as a model for stratocumuli. J. Atmos. Sci., 70, 2013.
2. J. R. Garcia and J. P. Mellado. Analysis of the entrainment zone in the convective boundary layer using direct numerical simulation. J. Atmos. Sci., 2013, submitted.
3. J. P. Mellado, B. Stevens, and H. Schmidt. Wind shear and buoyancy reversal at the stratocumulus top. J. Atmos. Sci., 2013, submitted.

More information:

Max Planck Research Group "Turbulent Mixing Processes in the Earth System"

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