Geophysical Research Abstracts
Vol. 15, EGU2013-7110, 2013
EGU General Assembly 2013

Tropical deep convection and density current signature on surface pressure: comparison of idealized and real WRF simulations with infra-sounder measurements

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In the framework of the ARISE (Atmospheric dynamics Research InfraStructure in Europe) project, which proposes to design a new infrastructure to integrate different atmospheric observation networks, we analyse moist deep convective processes responsible of intensive rainstorms in the tropics (making use of the Weather Research and Forecasting, WRF, numerical model) and compare the results with ground measurements of the CTBTO (Comprehensive nuclear-Test-Ban Treaty Organization) infra-sound stations in Ivory Coast.

In this work, we investigate the life cycle of singlecell deep convective cloud trough a bi-dimensional, non-hydrostatic, limited-area simulation in simplified model configuration ("idealized case"), at high spatial and temporal resolution. In this way, we expect to resolve explicitly the convective cloud dynamics, avoiding the use of sometimes questionable parametrization (e.g. PBL and convective cumulus) schemes. We also perform a three-dimensional numerical experiment at coarser resolution, guided by real meteorological data of the tropical Ivory Coast region, to compare "real case" results with the infra-sounder measurements for the same area.

Previous studies have shown that rain evaporation during intense precipitating events may cool the atmosphere and produce negative buoyancy that, together with falling rain, may give rise to particularly strong down-drafts (Betts, 1976, Tompkins, 2000). As the descending air column impacts the ground, it spreads out and creates a horizontal surface outflow (generally called "density current" or "cold pool") colder and denser than surrounding air.

Results from the 2D idealized case show that temporal and horizontal resolution of 2 seconds and 250 meters is fine enough to produce a density current, that moves outward up to several kilometers from storm center. The increase in surface density (up to 2% higher than the base state) is followed by a sudden variation of surface temperature and an increase in horizontal wind speed (between 10 and 20 m/s), somewhat proportional to the density change. We note that if the surface density variation is strong and rapid enough, the surface pressure filed results strongly affected as well. We observe a surface pressure peak (with maximum amplitude of about ±40 Pa), that moves together with the density current leading edge. At cold pool boundaries, the outflow converges with warmer and moister surface inflow and create a curl. As a consequence, warmer air is lifted up and transported above the denser layer where it may trigger new convection and provide the vapor supply to new cloud formation.

Results from the 3D real data case (that uses a horizontal resolution of 2 km and a convective cumulus parametrization scheme) show a very good agreement with ground measurements of pressure, wind speed and wind direction and confirm that this model configuration reliably reproduces the dynamical and thermodynamical evolution of a tropical deep convective storm. The simulated pressure peak (due to a strong density current that originates from a huge precipitating squall line) is very similar to that measured by the infra-sounders (with maximum amplitude of about ±50 Pa) and coherent with the idealized case. As in the 2D experiment, the development of tropical heavy rain events associated with strong density currents leads to a sub cloud layer which is not only denser and colder (as a consequence of rain evaporation, that works as a heat sink) but also sensibly dryer in correspondence of the gust front, sing that saturation mixing ration of subsiding air is lower than that of the boundary layer.