Vertical mixing in the atmospheric boundary layer, part 1: case studies

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Different forms of vertical mixing and their impact on $O_3$ variability
- Moist deep convection in the tropic
- Mixed-phase clouds in the Arctic
- Low-Level Jets (LLJs) in the eastern US
- Nocturnal warming events in Oklahoma
Impact of moist deep convection, a case in Senegal on Aug. 31, 2006

Ozone increased when deep convection passed (Hu et al., 2010a)
Impact of moist deep convection, WRF/Chem 3D simulation

Ozone is transported down in the downdrafts.
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Impact of mixed-phase clouds, $O_3$ depletion events (ODEs) in the Arctic

While the reactions responsible for the occurrence of ODEs are understood, their termination mechanisms remain debatable.
Impact of mixed-phase clouds, WRF/Chem simulation

Surface $O_3$ increased when the clouds passed by (Hu et al., 2011)
Cloud-top radiative cooling induced strong downdrafts and updrafts, which mixed \text{O}_3\text{-richer} air downward, thus terminated the ozone depletion event.
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Impact of LLJs on BL O$_3$,
Classical view of the residual layer

The residual layer is often thought to be a reservoir of pollutants
Observation challenges the classical view of the residual layer.

The residual layer in Beltsville is rarely a reservoir of \( \text{O}_3 \) (Hu et al., 2012b)
LLJs occur frequently in the eastern costal area. (Figure: Air quality index during an ozone episode, Ryan and Piety, 2001)
LLJs formation in Beltsville

Thermal wind contributed to the formation of the Mid-Atlantic coastal LLJs
It appears a LLJ played an important role in vertical O₃ redistribution (Hu et al., 2012b)
Case study of August 10, 2010, 1D simulations

Simulation could capture the main features associated with the LLJ.

Control: Calm condition, no LLJ
Sensitivity: with LLJ

Simulation could capture the main features associated with the LLJ.
The presence of the LLJ reduces the RL O$_3$ substantially. Downward transported O$_3$ is removed near the surface by dry deposition and chemistry reactions. As a result the BL O$_3$ on the following day is reduced.
Time-height diagrams of simulated $O_3$

Calm condition

With LLJ

The RL is not a reservoir of $O_3$ in the presence of a strong LLJ
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Impact of nocturnal warming events

Temperature increases associated with cold-frontal passages (Nallapareddy et al., 2011)
Nocturnal warming events on Mar. 11, 2005

Ozone increased associated with the nocturnal warming events
Nocturnal warming events on April 3, 2006

Ozone increased by 40 ppbv when the nocturnal warming event occurred.
WRF/Chem could reproduce important characteristics of the nocturnal warming events
Spatial distribution of T2 and vertical mixing coefficient

2006-04-03 05:00:00

36°30'N

98°W 97°W

35°30'N

34°30'N

284 286 288 290 292 294 K

1 2 3 4 5 6 7 8 9
Spatial distribution of O\textsubscript{3} at surface and ~200 m AGL
Profiles before and after the cold-frontal passage

Vertical mixing associated with the cold front increased surface temperature and O$_3$. 
Contrast of T and O$_3$ around the front

Temperature and O$_3$ are vertically well mixed behind the cold front
Impact on $O_3$ budget

Ozone is more efficiently removed at the surface, thus reducing $O_3$ budget.
Impact on the downwind area

Ozone-richer surface air mass will reach Dallas in the next morning.
Conclusions and implications

1. Meteorological phenomena such as deep convection, mixed-phase boundary layer clouds, LLJs play very important roles in vertical redistribution of O₃.
2. The residual layer may not be a reservoir of pollutants in some cases (e.g., strong LLJs).
3. The nocturnal warming events play an important role for the distribution of boundary layer O₃.
4. Apart from LLJs and cold fronts, mesoscale motions such as gravity waves, density currents can also cause nocturnal vertical mixing events.
References


Observation from wind profiler on April 3, 2006