Modelling the diurnal cycle of the Aerosol-filled PBL

with the Eddy Diffusivity/Mass Flux model coupled with the Radiative Transfer model

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The presentation plan

1. What is the Eddy Diffusivity/Mass Flux model?
2. How was the radiation transfer model parameterized?
3. How were these two models joined together?
4. A quick look at the results
5. Summary
Motivation

- Cities of Poland often experience a carbon-based pollution, concentrated mainly in the PBL
- The PBL diurnal cycles and its evolution affects the aerosol spatial distribution and therefore influences the radiation transfer
- Our group collected a lot of data concerning the radiation fluxes and aerosol concentration in the PBL

Idea: Let’s try to join a model describing the PBL evolution and the radiative transfer model

fig. 9 - The panorama of Krakow, Poland on 29th Nov 2019. Taken from the deck of an observation balloon located near the Wawel Castle
1. Eddy Diffusivity/Mass Flux model
What is the EDMF model?

- Eddy Diffusivity: addressing downward fluxes
- Mass Flux: addressing the limitations of the ED. Introducing a strong thermal updraft motion

fig. 1 - The simplistic drawing depicting the EDMF framework\cite{1}
Equations in the EDMF Model

The prognostic equation for a scalar field \( \phi \):\
\[
\frac{\partial \phi}{\partial t} = \frac{\partial}{\partial z} \left[ -K_\phi \frac{\partial \phi}{\partial z} + M(\phi_u - \phi) \right] + F
\]

The additional prognostic equation for TKE closure:\n\[
\frac{\partial e}{\partial t} = -\frac{\partial}{\partial z} \left( -K_e \frac{\partial e}{\partial z} \right) + \frac{g}{\theta_v} \overline{w'\theta'_v} - D
\]

+ additional equations for K, M, D, F, \( \phi_u \) etc.
Short description of the implementation

- Written fully in MATLAB
- The model operates in one dimension
- The spatial range: [0; 4] km, the spatial resolution: 20m
- The temporal resolution: 1 min
- Modelling the dry conditions

and other, less relevant settings...
2. Fu-Liou Model
δ-four-stream model with Fu-Liou parametrization

- The δ-four-stream approach is a natural extension of the popular two-stream radiative transfer model commonly used in atmospheric sciences.
- The parameterization proposed by Fu, Liou and Ackermann\cite{3} proves to be relatively accurate and not much more complex.
- The legacy code in fortran works relatively fast.
- The fortran solver was embedded in the MATLAB shell to make it more user friendly.
What parameters were used?

- Spectral resolution: 6 short wave and 12 long wave bands
- Spatial resolution: 78 levels from 0 to 100 km above the ground
- Near the ground (>600 hPa) the grid is denser. In the range [0; 4] km the spatial resolution is 80m
- The clear-sky case (with the aerosol present)
- The sun position was calculated for a user defined DOY and location

and other, less relevant settings...
3. EMDF/RT Coupling
How were these two models combined?

**Fig. 2** - The block diagram showing how two models were joined together in one time loop and how they exchange data.
Initial profiles: Potential temperature and Heating rate

fig. 3a - The evolution of the PBL temperature with time

fig. 3b - The evolution of the PBL Heating rate with time
Additional remark: The extinction suppression

The extinction profile was calculated as follows:

\[ \mu_e(z) = \begin{cases} \mu_e,0 & \text{if } z \leq z^* \\ \mu_e,0 \int_{z^*}^{\infty} e^{-\frac{z-z^*}{H}} \, dz & \text{if } z > z^*. \end{cases} \]

with the normalization condition:

\[ \tau_a = \int_0^\infty \mu_e(z) \, dz \]

or after the integration:

\[ \tau_a = \mu_e,0(z^* + H) \]

fig. 4 - Examples of extinction profiles. Dashed lines denote profiles at the end of the simulation. ‘x’ denotes the PBL top.
4. Results
The PBL Height vs Aerosol optical depth

fig. 5a - The PBLH vs AOD. The extinction suppression: 0.2 km

fig. 5b - The PBLH vs AOD. The extinction suppression: 1 km
The PBL mean temperature difference vs Aerosol optical depth

fig. 6a - The PBL mean temp. difference vs AOD. The extinction suppression: 0.2 km

fig. 6b - The PBL mean temp. difference vs AOD. Case for the extinction suppression: 1 km
The PBL Height vs Aerosol single scattering albedo

**fig. 7a - The PBLH vs SSA.**
The extinction suppression: 0.2 km

**fig. 7b - The PBLH vs SSA.**
The extinction suppression: 1 km
The PBL mean temperature difference vs Aerosol single scattering albedo

fig. 8a - The PBL mean temp. difference vs SSA. The extinction suppression: 0.2 km

fig. 8b - The PBL mean temp. difference vs SSA. The extinction suppression: 1 km
4. Summary
Summary

• The coupled model is relatively fast: 6 h of simulation with 1 min time step took about 2 min to run on a standard personal PC

• Output suggests:
  ○ Non-absorbing aerosol and low amounts of aerosol have a small impact on the PBLH and the temperature difference
  ○ The more absorbing the aerosol, the higher the temperature of the PBL
  ○ The more polluted the PBL the higher its temperature

• The extinction profile suppression effect:
  ○ Low suppression → Aerosol above the PBL → Smaller PBLH, Lower Temperature
  ○ High suppression → Aerosol only in PBL → Higher PBLH, Higher Temperature
References


Thank you for your attention!

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fig. 9 - The panorama of Krakow, Poland on 29th Nov 2019. Taken from the deck of an observation balloon located near the Wawel Castle