Modelling the diurnal cycle of the Aerosol-filled PBL

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

Florczyk, G. M.[1], Markowicz, K.[1] and Witek, M. L.[2]

[1]Institute Of Geophysics, University Of Warsaw, Warsaw, Poland
[2]Jet Propulsion Laboratory, California Institute Of Technology, Pasadena, California

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

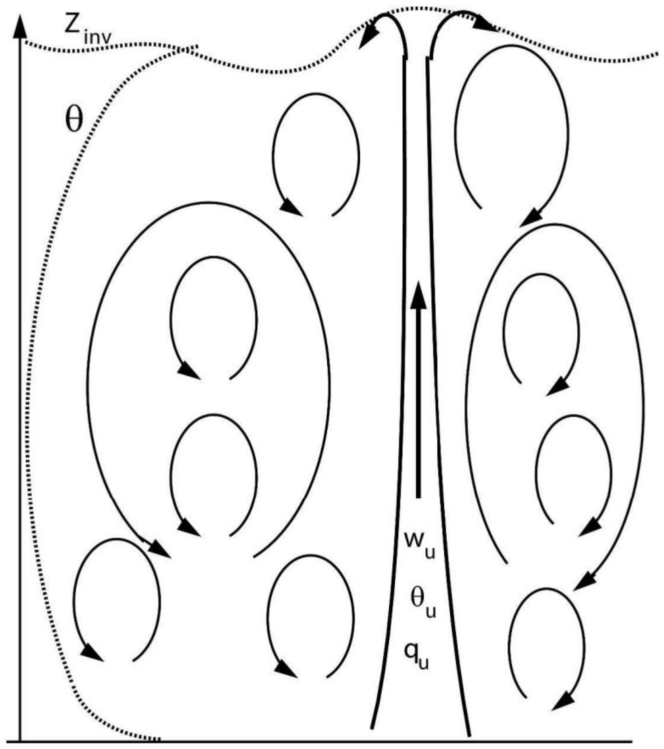

fig. 1 - The simplistic drawing depicting the EDMF framework[1]

Equations in the EDMF Model

The prognostic equation for a scalar field ϕ[2]:

$$\frac{\partial \bar{\phi}}{\partial t} = \frac{\partial}{\partial z}\left[-K_{\phi}\frac{\partial \bar{\phi}}{\partial z} + M(\phi_u - \bar{\phi})\right] + F$$

The additional prognostic equation for TKE closure[2]:

$$\frac{\partial e}{\partial t} = -\frac{\partial}{\partial z}\left(-K_e\frac{\partial e}{\partial z}\right) + \frac{g}{\bar{\theta}_v}\overline{w'\theta_v'} - D$$

+ additional equations for K, M, D, F, ϕ_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[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?

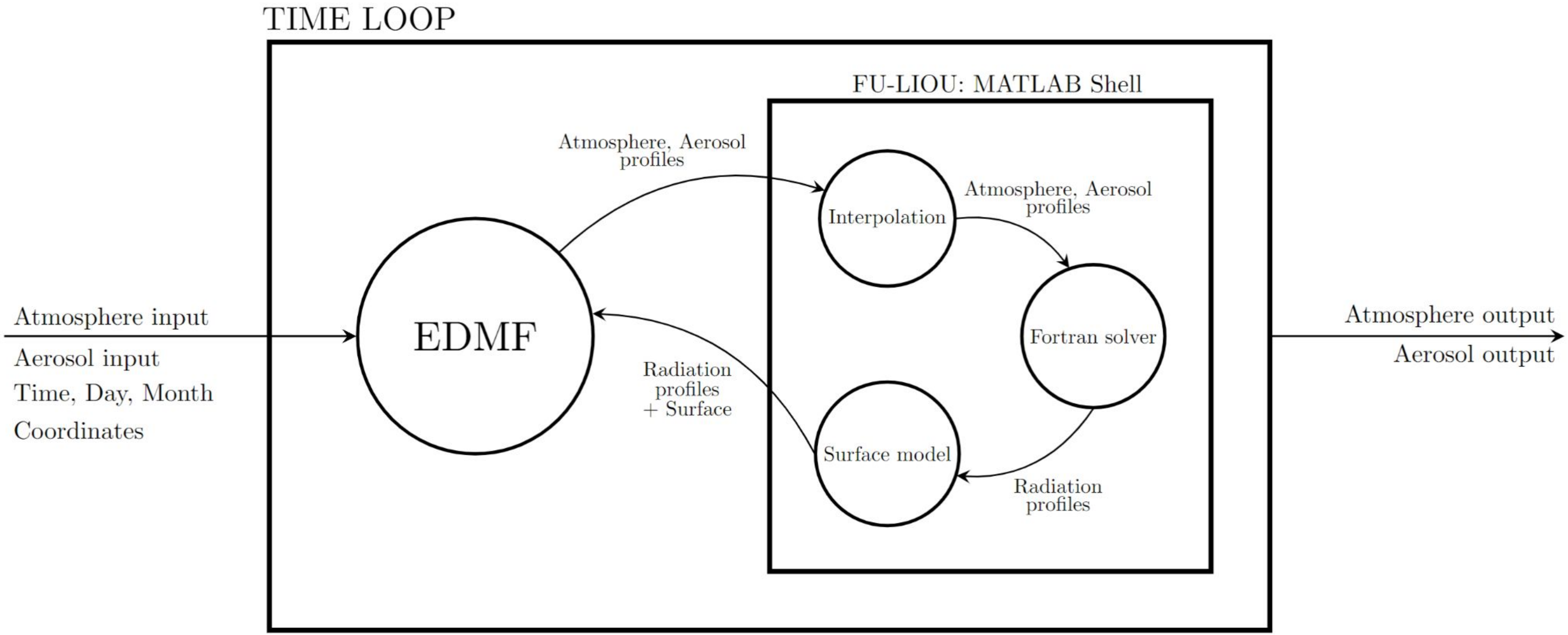

fig. 2 - The block diagram showing how two models were joined together in one time loop and how they exchange data

Initial profiles: Potential temperature and Heating rate

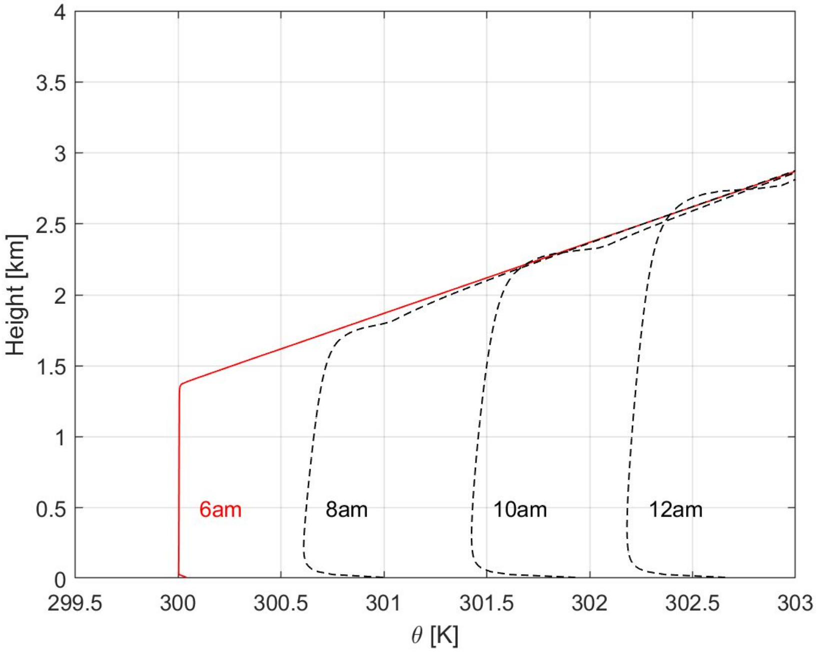

fig. 3a - The evolution of the PBL temperature with time

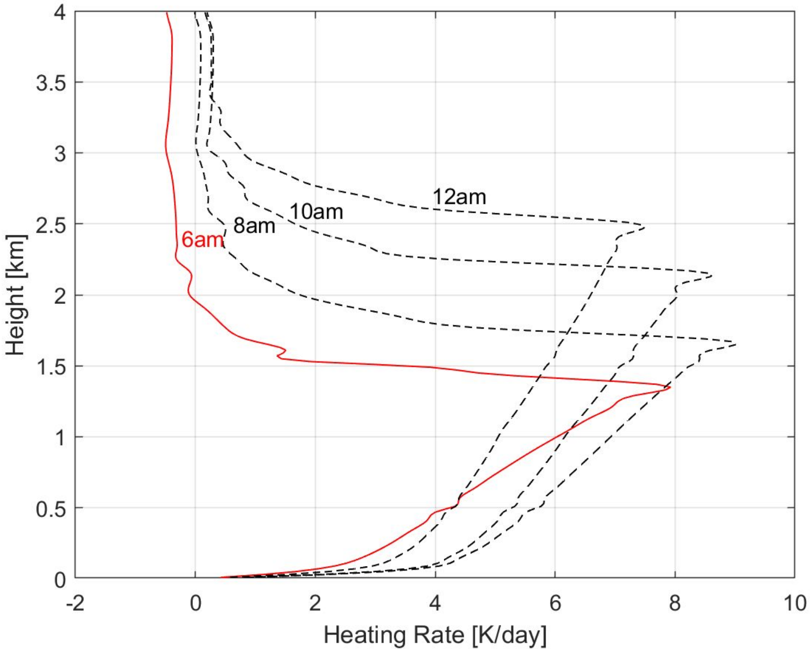

fig. 3b - The evolution of the PBL Heating rate with time

Additional remark: The extinction suppression

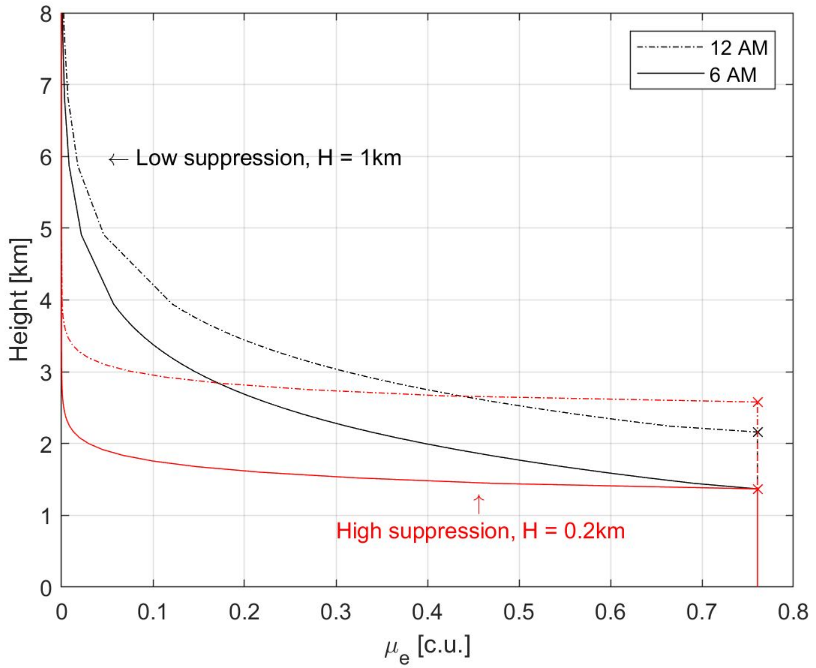

fig. 4 - Examples of extinction profiles. Dashed lines denote profiles at the end of the simulation. 'x' denotes the PBL top

The extinction profile was calculated as follows:

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

with the normalization condition:

$$\tau_a = \int_0^{\infty} \mu_e(z) dz$$

or after the integration:

$$\tau_a = \mu_{e,0}(z^* + H)$$

4. Results

The PBL Height vs Aerosol optical depth

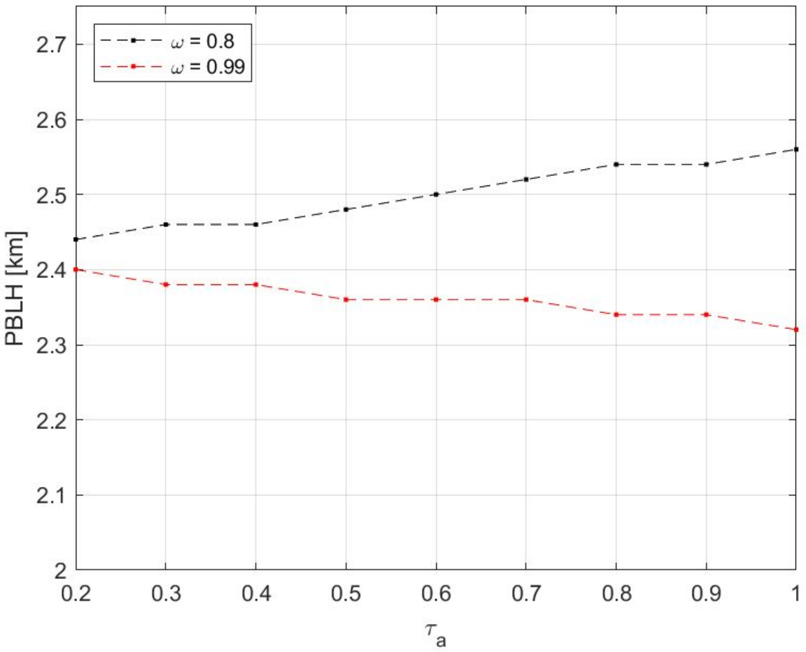

fig. 5a - The PBLH vs AOD.
The extinction suppression: 0.2 km

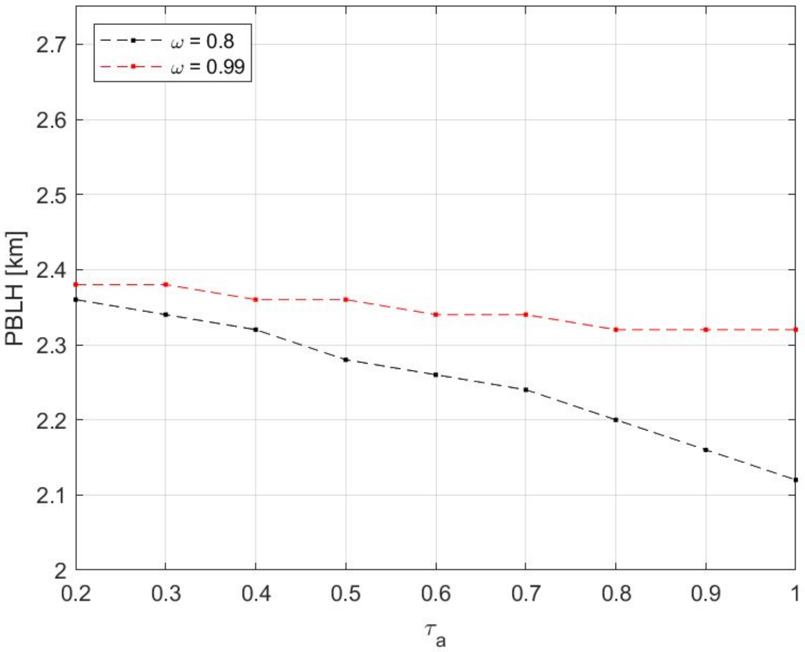

fig. 5b - The PBLH vs AOD.
The extinction suppression: 1 km

The PBL mean temperature difference vs Aerosol optical depth

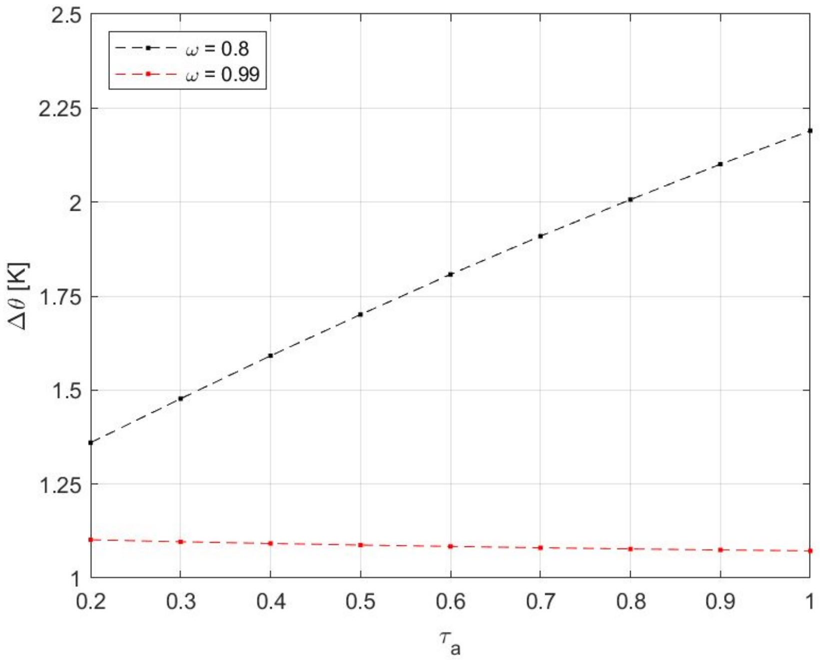

fig. 6a - The PBL mean temp. difference vs AOD.
The extinction suppression: 0.2 km

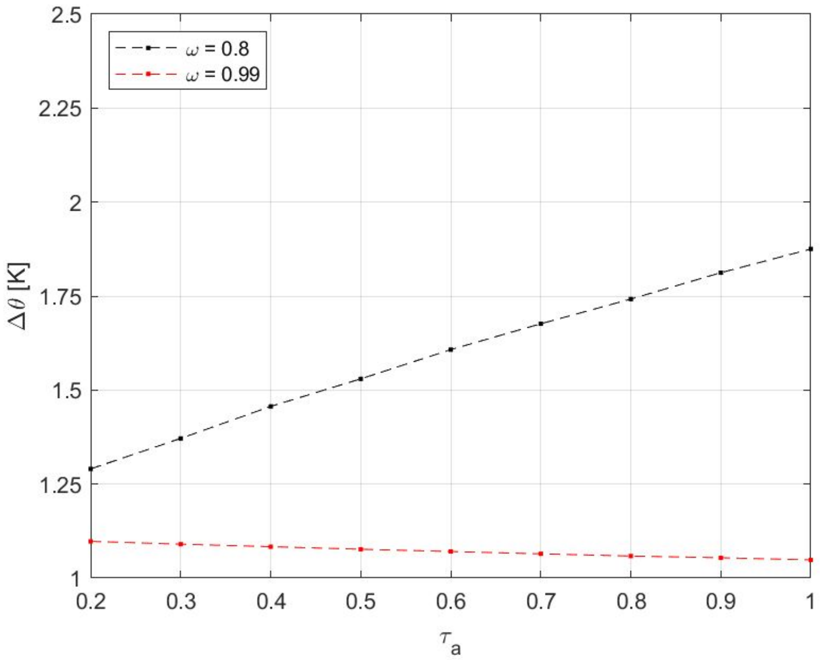

fig. 6b - The PBL mean temp. difference vs AOD.
Case for the extinction suppression: 1 km

The PBL Height vs Aerosol single scattering albedo

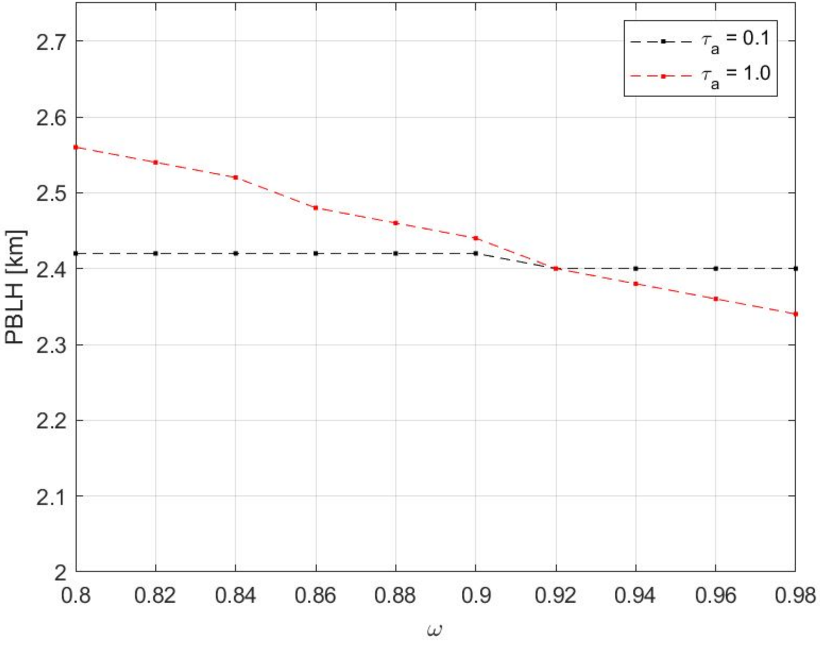

fig. 7a - The PBLH vs SSA.
The extinction suppression: 0.2 km

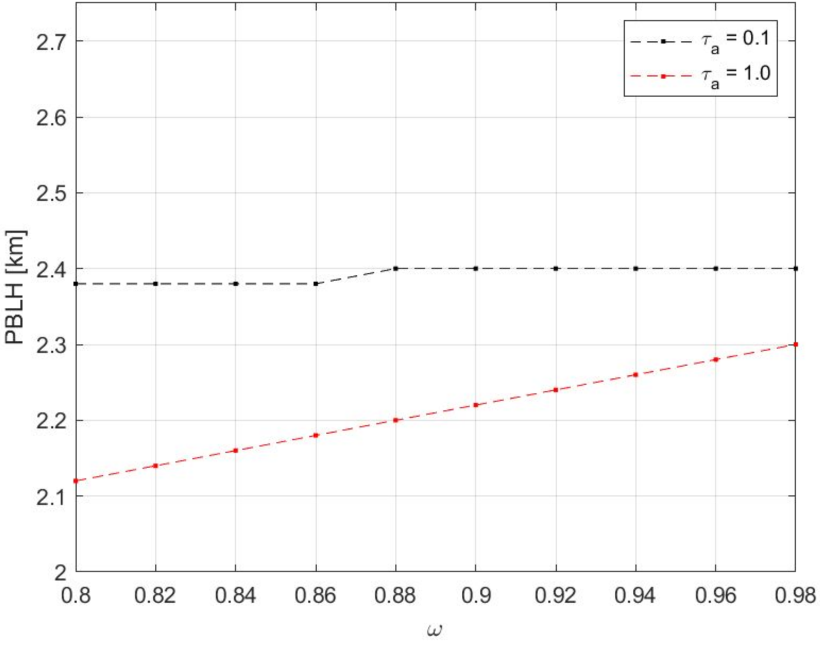

fig. 7b - The PBLH vs SSA.
The extinction suppression: 1 km

The PBL mean temperature difference vs Aerosol single scattering albedo

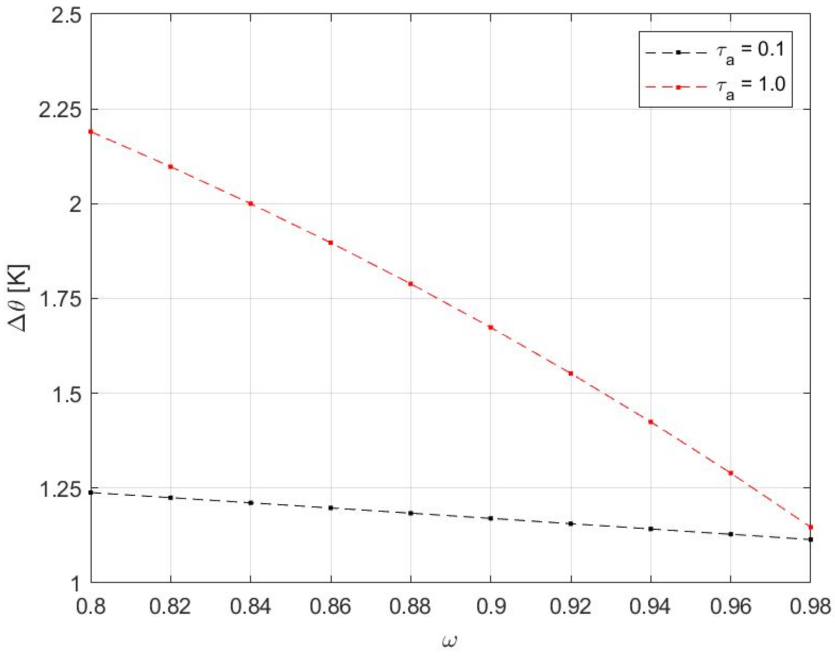

fig. 8a - The PBL mean temp. difference vs SSA.
The extinction suppression: 0.2 km

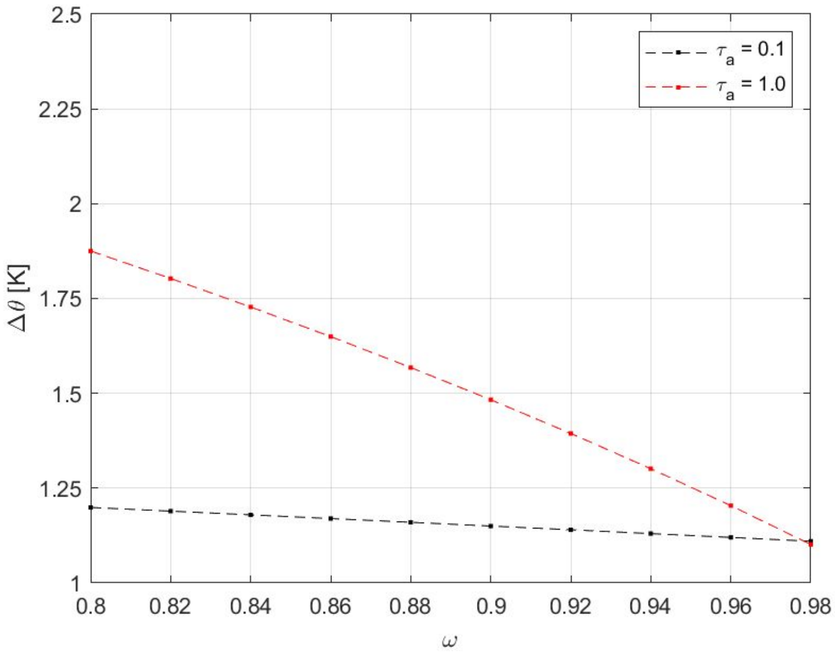

fig. 8b - The PBL mean temp. difference vs SSA.
The extinction suppression: 1 km

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

[1] Siebesma, A. P., Soares, P. M. M., Teixeira, João (2007) A Combined Eddy-Diffusivity Mass-Flux Approach for the Convective Boundary Layer. *Journal of The Atmospheric Sciences*, 64, 1230–1248, doi: 10.1175/JAS3888.1

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[3] Liou, K. & Fu, Q. & Ackerman, T. (1988). A Simple Formulation of the Delta-Four-Stream Approximation for Radiative Transfer Parameterizations. Journal of the Atmospheric Sciences. 45. doi: 10.1175/1520-0469(1988)045<1940:ASFOTD>2.0.CO;2.

Thank you for your attention!

G. M. Florczyk: gflorczyk@fuw.edu.pl

K. Markowicz: Krzysztof.Markowicz@fuw.edu.pl

M. L. Witek: marcin.l.witek@jpl.nasa.gov

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

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