Aerosols in HARMONIE
Radiative Effects and further Perspectives

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1. Introduction

- High resolution NWP models resolve detail about local weather. Accurate treatment of the interactions of radiation with clouds and surfaces, and the direct and indirect effects of aerosols, thus becomes increasingly important.
- HARMONIE relies on external aerosols. Monthly climatologies of vertically integrated aerosol optical depth (AOD) at 550 nm [1] and parametrized optical properties (SSA, g, AOD scaling) [2] are used to estimate the direct effect of aerosols on radiation.
- An NWP model could in principle obtain 3D external aerosol concentrations from: (a) aerosol climatologies (b) chemical transport model simulations (c) analysis of aerosol observations.
- Our aim is to ensure that the HARMONIE radiation schemes make the best use of available 3D aerosol information.
- We are studying the effect on SW radiation under clear sky conditions using the HARMONIE-MUSC cycle 38.1 column model.

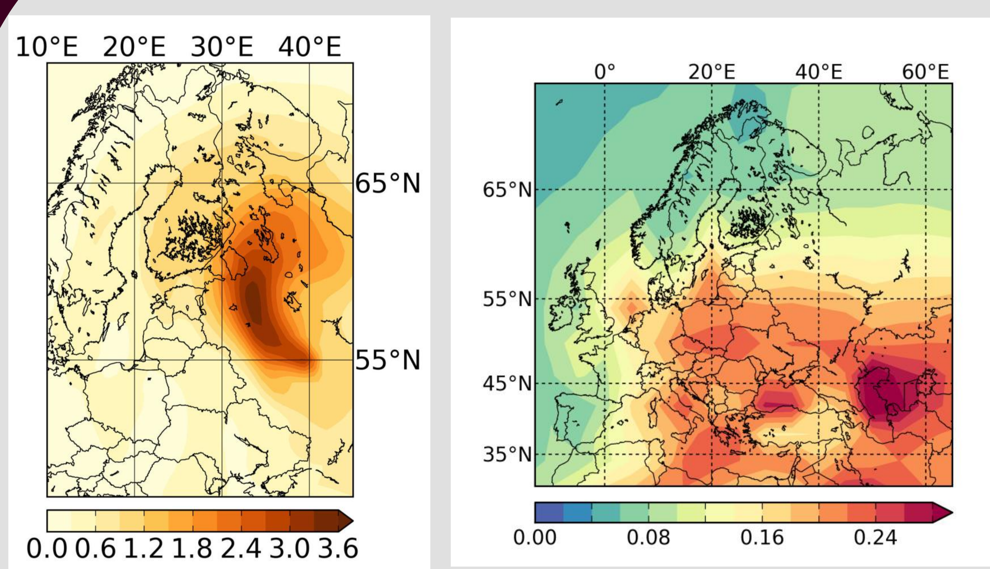
2. Model Set-ups and Datasets

The following were used in MUSC unless stated otherwise.

- **Case Study:** August 8th 2010, Tõravere, Estonia (Russian Wildfire event).
- **SW radiation schemes:** IFS (ECMWF cycle 25R1 with new cloud liquid optical parametrization by [3], 6 SW bands), HLRADIA (adapted from HiRLAM with new aerosol treatment [4], 1 SW band) and ACRANEB2 (ALARO v1 by [5], 1 SW band).

- **SW radiation measurements:** Baseline Surface Radiation Network (BSRN) archive [6].
- **Aerosol data:** no aerosols, climatological AOD at 550nm by [2] and optical properties by [3], AERONET [7] measurements of AOD, single scattering albedo (SSA) and asymmetry factor (g).
- **MUSC atmospheric and surface initial state:** Hourly input data generated from a 3D HARMONIE simulation over Estonia.
- **MUSC output:** SW fluxes were diagnosed for each of these hourly input files. Therefore, feedbacks from the radiation schemes to the rest of the model were eliminated.

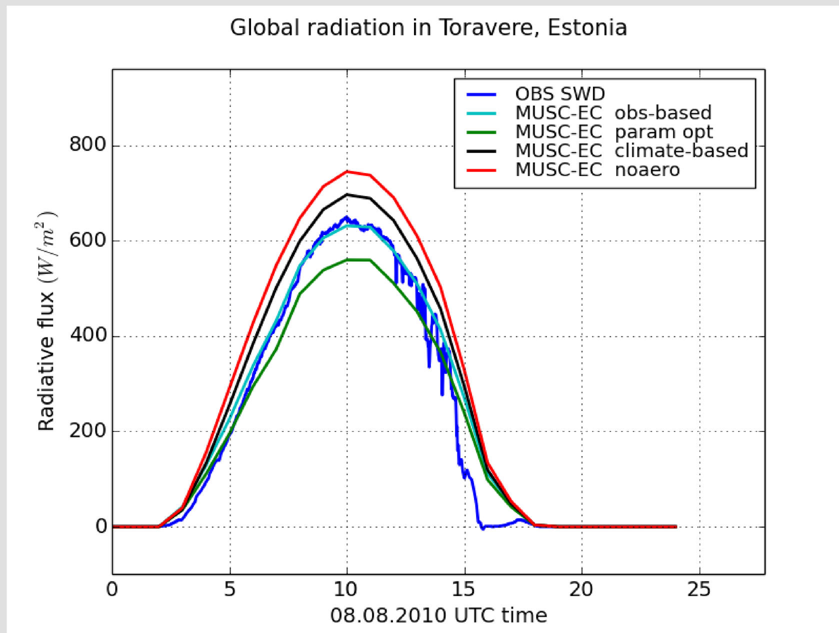
3. Russian Wildfire Case Study

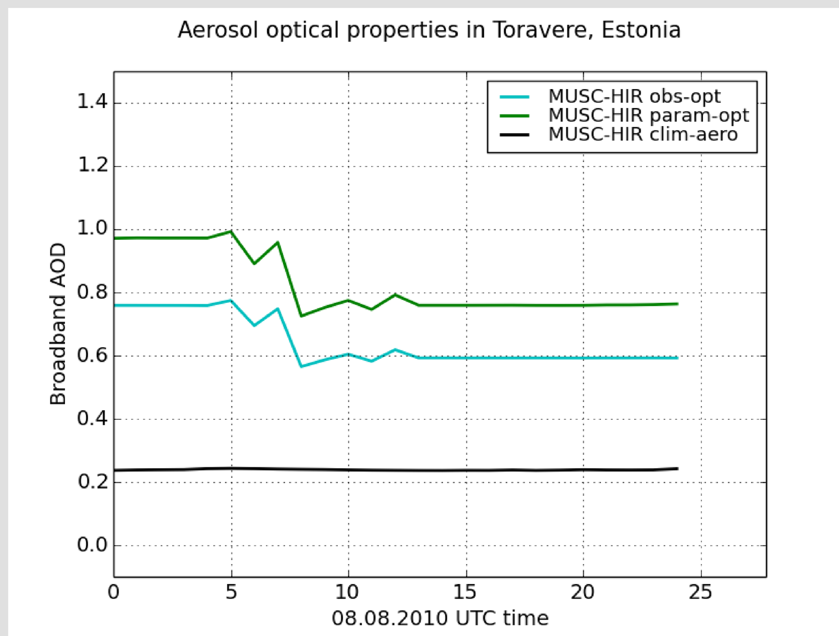


(left) Average AOD for August 8th 2010 [8]. **(right)** Annual average AOD in HARMONIE [1]

- Severe thunderstorms coincided with forest fires in the Baltic region on this date [9] but the point location selected for the simulations (Tõravere, Estonia) was mostly cloud free.
- We studied the influence of aerosols on SW radiation in HARMONIE by running the model under clear sky conditions.
- The **above figures** show the underestimation of AOD by HARMONIE.

- We compared global SW radiation from MUSC to BSRN observation data for each of the HARMONIE radiation schemes.
- By default, HARMONIE uses monthly climatologies of vertically integrated 550nm AOD and parametrized optical properties (SSA, g, broadband_AOD/550nm_AOD ratio). This results in an over prediction of SW radiation for heavily polluted situations, including this wildfire example.
- The use of AOD and optical properties derived from observations [AERONET archive] gives excellent agreement between modelled and observed global SW radiation for each of the 3 schemes (IFS results in **upper right figure**). The observed aerosols were assumed to be land aerosols; aerosol properties in MUSC were defined accordingly.
- Global radiation is underestimated, especially at high solar angles, when the observed 550nm AOD is used with parametrized optical properties.
- Of the optical properties, broadband AOD has the greatest effect on aerosol transmission, with SSA and g having a negligible effect (see **bottom right figure** of broadband AOD).
- After 14UTC the observations were affected by convective clouds, which were not taken into account in the simulations.

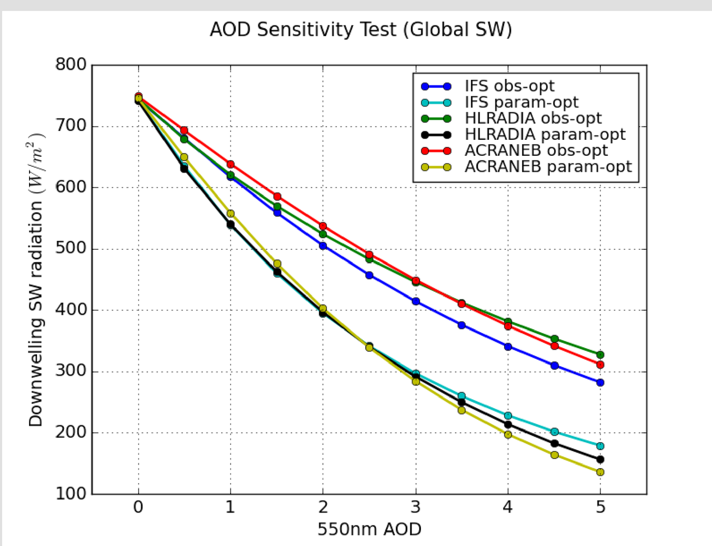


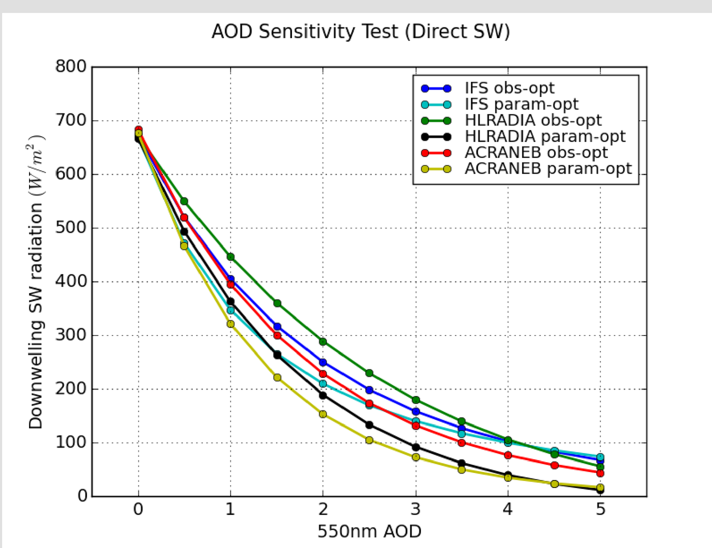


4. Aerosol Optical Depth and Relative Humidity Sensitivities

Varying vertically integrated 550nm land aerosol AOD:

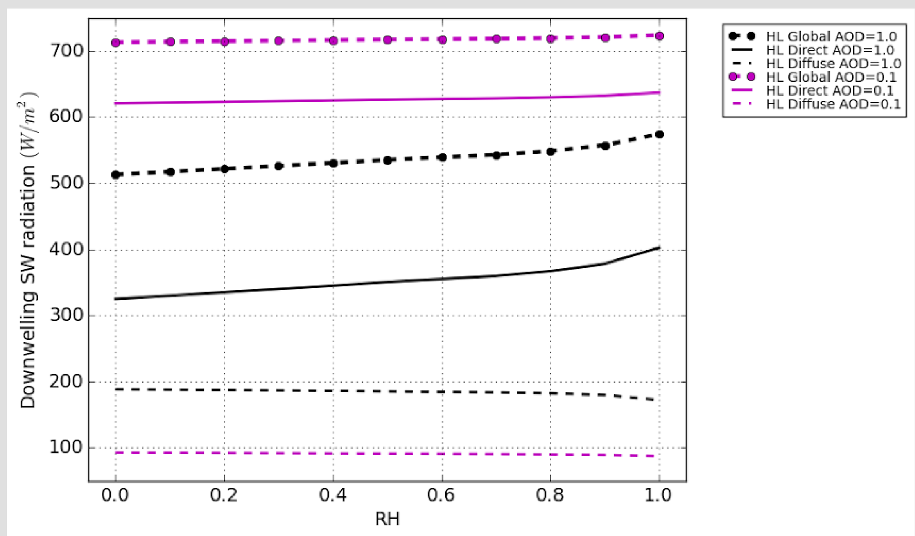
- Comparison of IFS, HLRADIA and ACRANEB downwelling SW radiation (global and direct shown) vs 550nm land AOD for both observed and parametrized optical properties.
- While this experiment is a sensitivity test, it clearly illustrates the significant effect that the optical properties have on SW radiation.
- Direct (shown) and diffuse fluxes cannot be compared to observations because direct radiation is not strictly parallel, as assumed in the models, and observed diffuse radiation does not include flux coming directly from the sun.

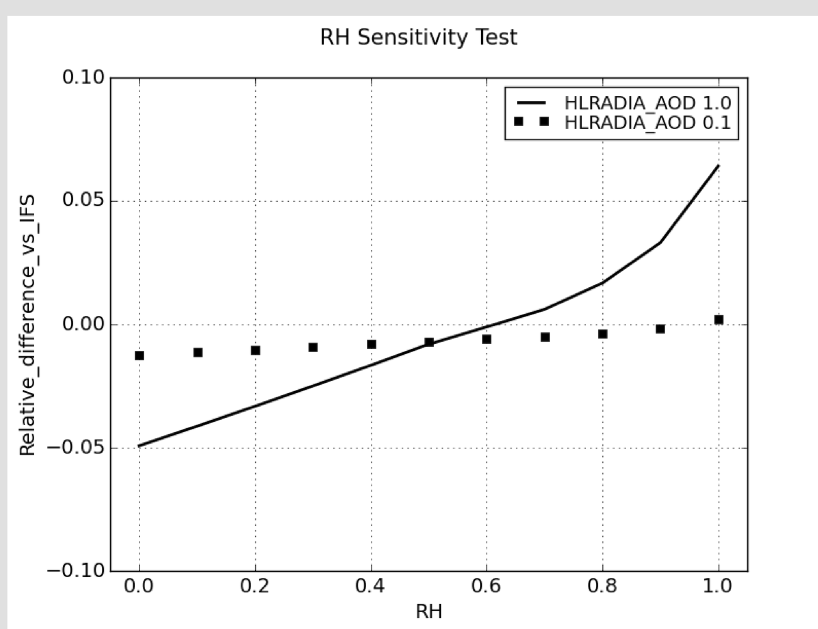




Effect of relative humidity

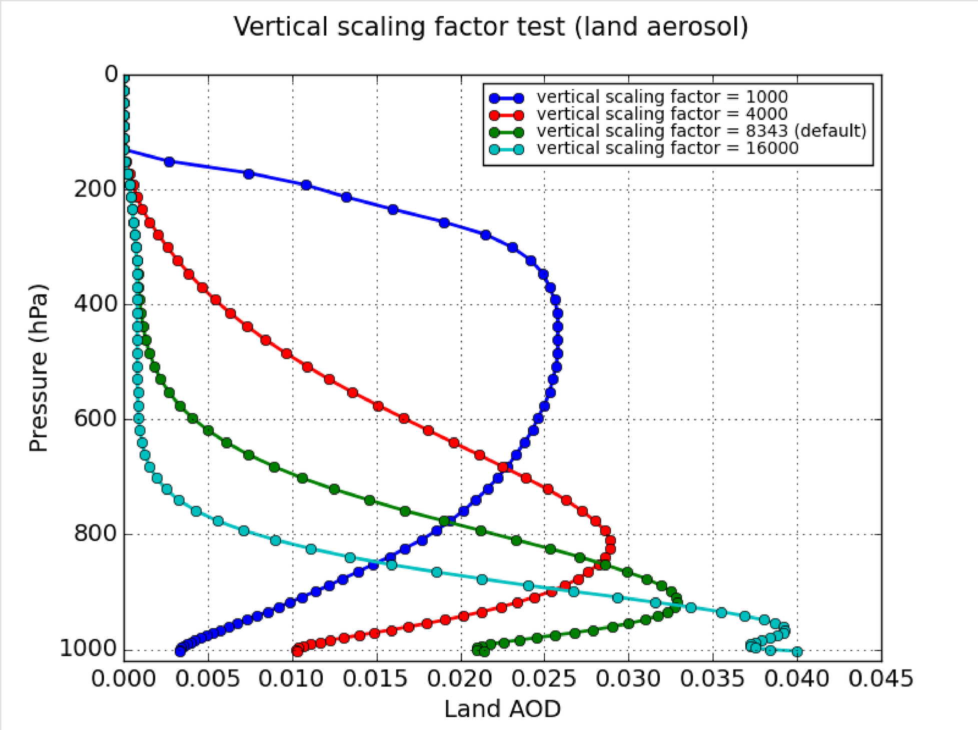
- In these experiments 550nm AODs of 0.1 and 1.0 were tested. The parametrized optical properties were used for each radiation scheme.
- The IFS optical properties parametrizations assume a relative humidity (RH) of 80% for the climatological land aerosols.
- In HLRADIA aero_rt6 RH, rather than an assumed value of RH, is used in the calculation of the optical properties of aerosols. See **top right figure** for global, direct and diffuse SW radiation from HLRADIA vs RH.
- The **lower figure** shows the relative difference in the HLRADIA downwelling SW radiation compared to IFS.

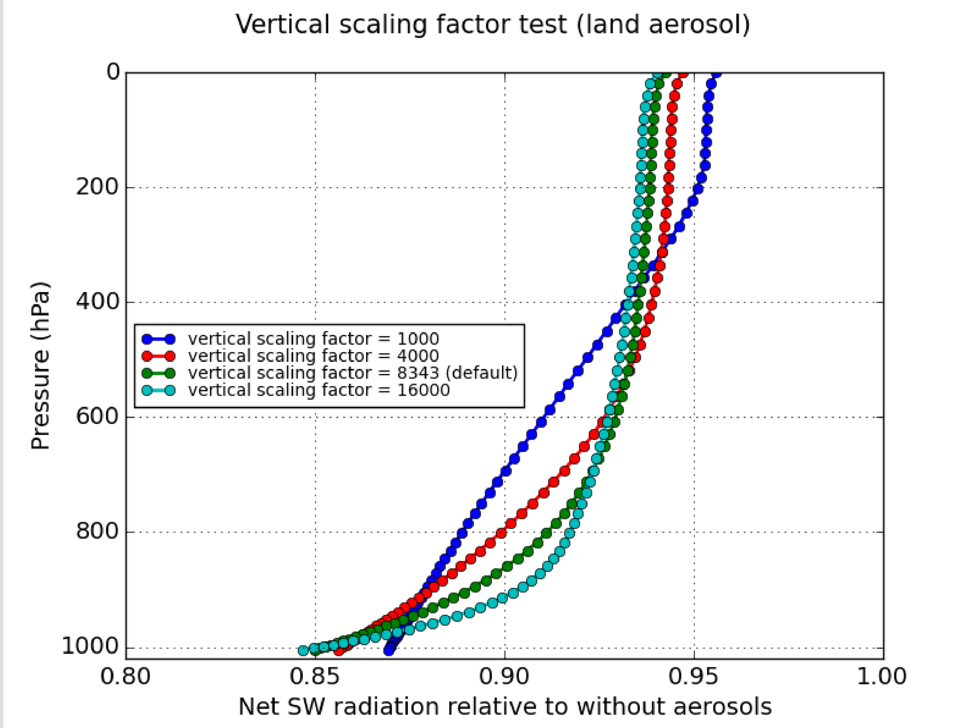




5. Sensitivity to Vertical Distribution of Aerosols

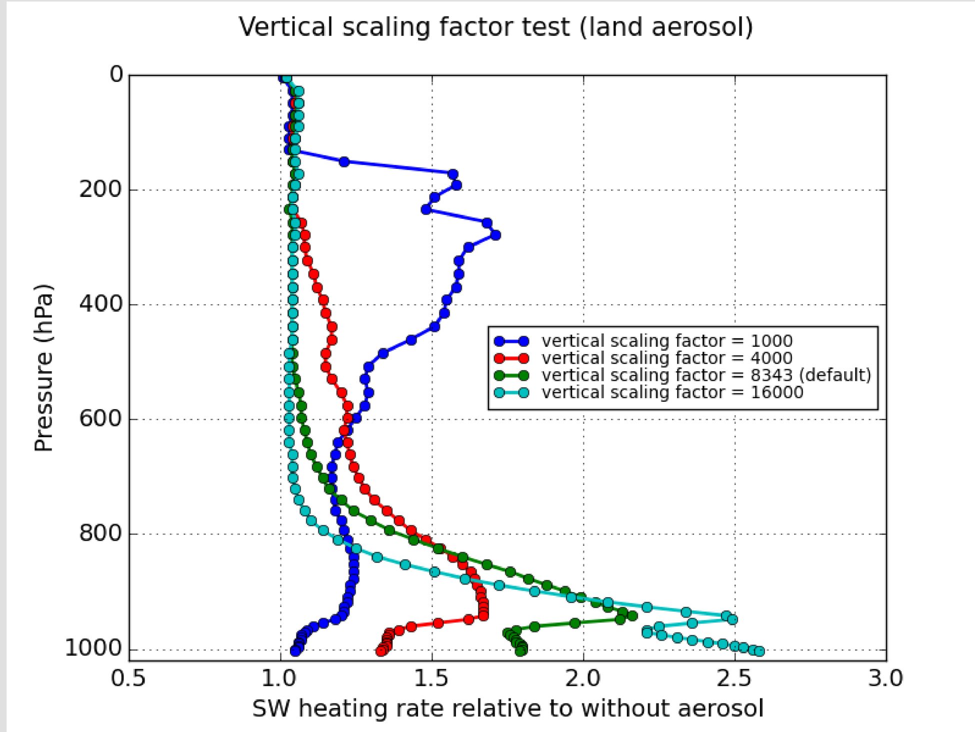
- In these experiments we used the 10UTC 550nm AOD for Tõravere on August 8th 2010.
- We varied the vertical scaling factor in the exponential function, used to distribute the total AOD across the model levels.
- See **figure below** for the IFS scheme. For lower scaling factors the aerosols are more concentrated in the stratosphere.





- The **figure above** shows net SW radiation relative to the case where aerosols are not included.
- At each model level, the relative net SW radiation for each of the vertical scaling factors, varies by less than 3%.
- This is reassuring because the HLRADIA scheme does not consider vertical profile for overall aerosol transmittance. However, vertical profile is considered for the heating rates.

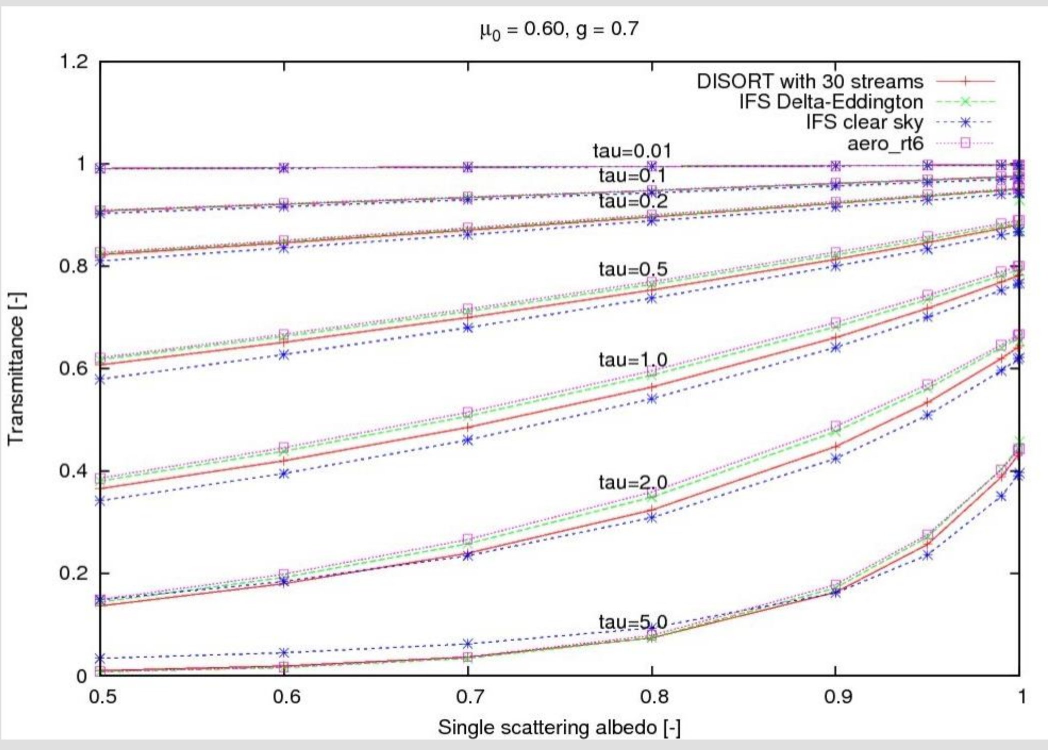
- The **figure below** shows the SW heating rate relative to the case where aerosols are not included.
- Unlike SW fluxes, where the difference remains within 3% throughout the atmosphere, the impact on SW heating rates is significant (ratio of up to ~2.5).
- One of the reasons for this is that the heating rate is proportional to flux divergence.

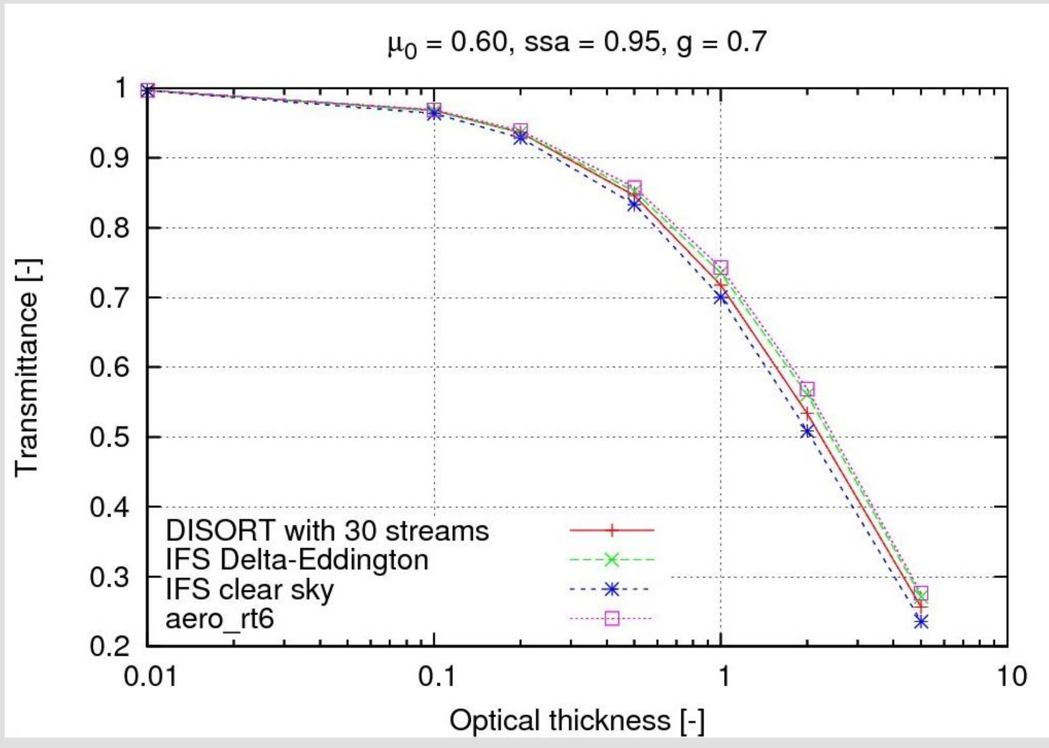


6. Aerosol Radiative Transfer Tests

Experiment

- Getting the aerosol radiative transfer right is of equal importance to getting the aerosol optical properties right.
- In HARMONIE we have tested three radiative transfer schemes:
  - IFS Delta-Eddington
  - IFS Fouquart & Bonnel clear sky
  - aero_rt6 in HLRADIA.
- against the accurate DISORT model



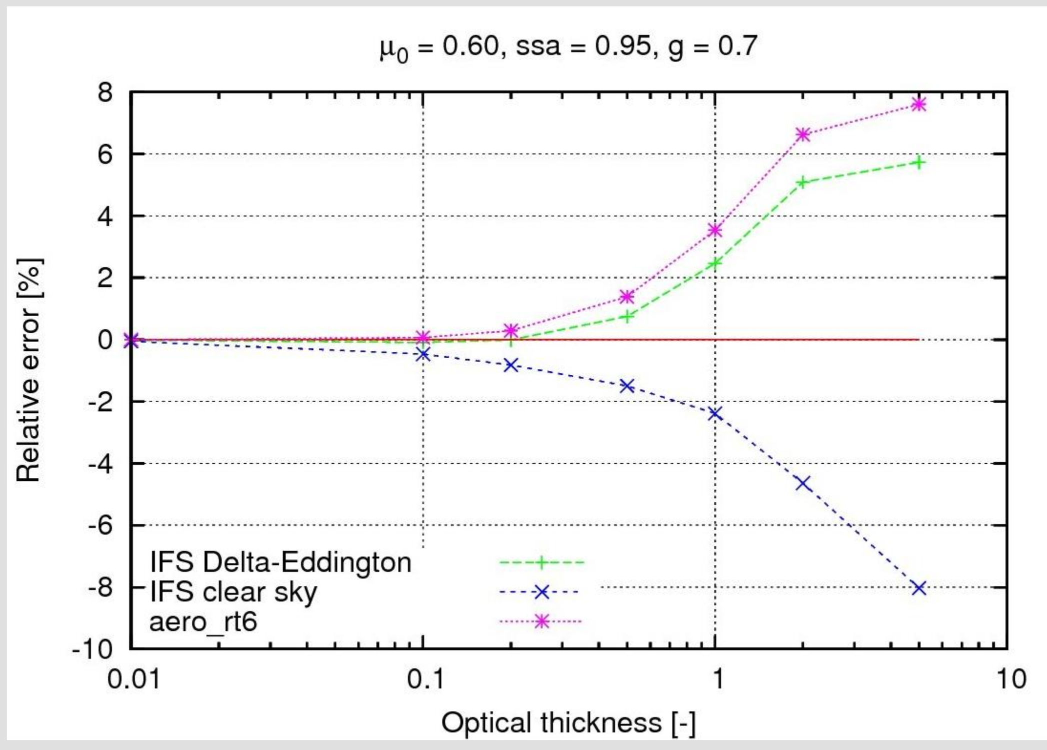


Results

- In the figure to the **left** we compare aerosol transmittances of the different schemes for cos(SZA)=μ_0=0.6, an asymmetry factor g=0.7, and varying optical thicknesses (tau) and single scattering albedos (ssa).
- In the figure **above** results are shown for ssa=0.95 only.
- In the figure to the **right** errors relative to the DISORT model are shown.

Discussion

- None of the schemes are perfect for optical thicknesses > 1.0.
- The IFS clear sky scheme [10], which was designed for climatological aerosols, has the largest errors overall (figure to the **left**).
- For optical properties similar to those in the Tõravere case, all schemes perform similarly with errors of up to ±8%.



7. Future Work

- Commence studies and comparisons using the longwave radiation schemes.
- 3D testing of the SW radiation schemes including the use of up-to-date rather than climatological aerosol data.
- Indirect effects of aerosols.
- Verification of the direct/diffuse irradiance split in the radiation schemes.
- Radiation coupling to SURFEX, the surface model in HARMONIE.
- Technical work on importing the radiation modifications to the next cycle of HARMONIE (cycle 40). The new cycle contains a flexible physics-dynamics interface.

8. References

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