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Shortwave Heating Rate at the Cloud-Aerosol Transition Zone from Radiative Parameterizations in the Weather Research and Forecasting Model (WRF)

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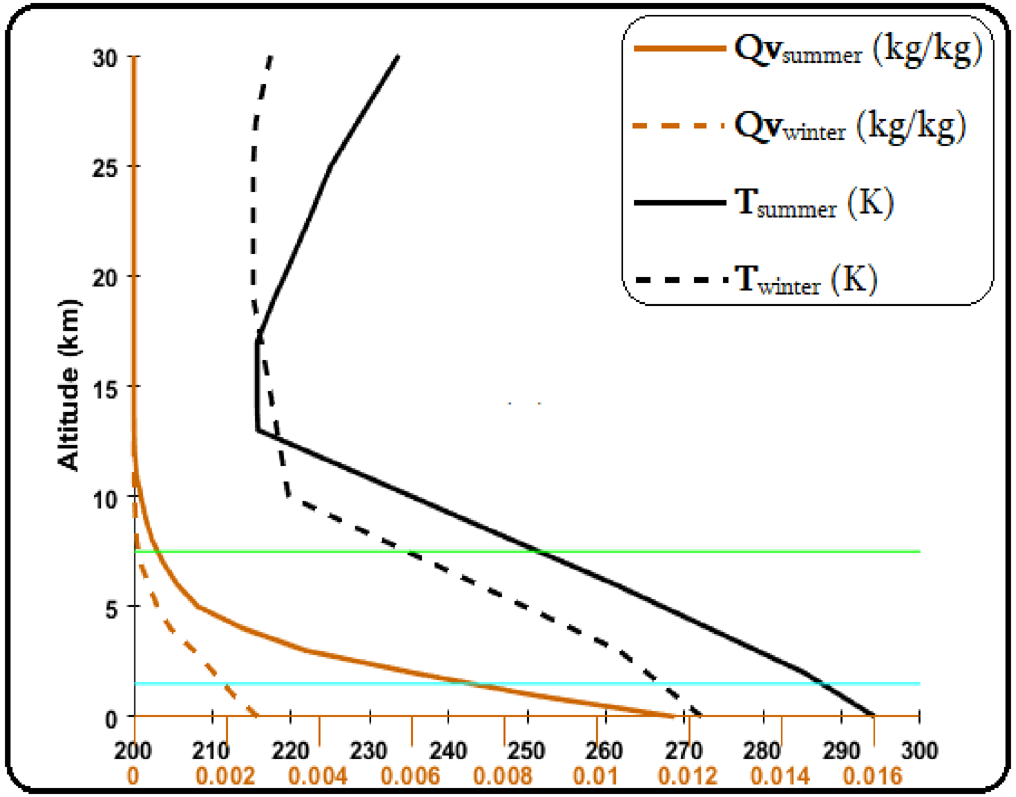
The conditions between cloudy and cloud-free air, named “Transition (or twilight) Zone”, are a major source of uncertainty in the climate and meteorological studies. The transition zone involves microphysical and radiative characteristics which lay on the border between those corresponding to a pure cloud and those corresponding to pure atmospheric aerosols. Several studies show that a notable proportion of cloudless sky at any time may correspond to this phase. However, as the information available about radiative effects of this phase is still very limited in most meteorological and climate studies the condition of sky is assumed to be either cloudy (fully developed cloud) or cloud-free (dry aerosol), neglecting the transition zone. This implies that these models consider the area/layer corresponding to the transition zone as either cloud or aerosol. The authors of the current communication have shown in a previous work that there are substantial uncertainties associated with modeling the surface shortwave irradiances under this assumption [Jahani et al. (2019) JGR: Atmospheres, 124]. The present communication aims to show the uncertainties in modeling the heating rate in the atmosphere (due to shortwave solar radiation) driven from different treatments of the transition zone. For this purpose, the relatively detailed shortwave radiation parameterizations included in the Weather Research and Forecasting model (WRF) version 4.0, which allow users to consider different treatments of aerosols and clouds (RRTMG, NewGoddard and FLG), were isolated from the whole model. These parameterizations were then utilized to perform a number of simulations under ideal “cloud” and “aerosol” modes, for different values of (i) cloud optical thicknesses resulting from different sizes of ice crystals or liquid droplets, cloud height, mixing ratios; and (ii) different aerosol optical thicknesses combined with various aerosol types. The optical thickness under both aerosol and cloud modes was considered to vary between 0.01 and 2.00. The differences in the resulting atmosphere column averaged heating rate were analyzed. The results showed (i) the simplified assumption about the state of the sky may lead to a large difference among the atmospheric shortwave heating rate, (ii) magnitude of these uncertainties are slightly higher when parameterizations which cope with the Radiative Transfer Equation in more detail (RRTMG and NewGoddard) are used.

Methods: Reference Atmospheres

- Cloud-and aerosol-free ("clean") Standard mid-latitude Summer and Winter atmospheres (Anderson et al., 1986).
- Surface Albedo: 0.14



Anderson, G. P., Clough, S. A., Kneizys, F. X., Chetwynd, J. H., & Shettle, E. P. (1986). AFGL atmospheric constituent profiles (0.120 km). AIR FORCE GEOPHYSICS LAB HANSCOM AFB MA

Methods: Cloud and Aerosol Comparison Cases

- Ice clouds and aerosols at high altitudes (I-a)
- Liquid Clouds and aerosols at low altitudes (L-a)

I-a	L-a
Cristal size: 10 – 120 μm	Droplet size: 2.5 – 15.0 μm
Altitude of the layer: ~ 7.5 km	Altitude of the layer: ~ 1.5 km
Aerosol type: Urban, Continental, Marine	
Cloud/aerosol optical depth at 550 nm (τ): 0.01 – 2.00	

Methods: Heating Rate

$$\mathbf{H}_{\mathrm{par}}^{\alpha}(\tau) = \frac{\mathrm{g}}{\mathrm{c_p}} \frac{\Delta \mathbf{F}_{\mathrm{par}}}{\Delta \mathbf{P}}$$

$$\Delta \mathbf{F}_{\mathrm{par}}(\tau) = \mathbf{F}_{\mathrm{par}}^{\mathrm{top}}(\tau) - \mathbf{F}_{\mathrm{par}}^{\mathrm{bot}}(\tau)$$

H: Column average heating rate due to the cloud/aerosol layer with optical depth at 550 nm equal to τ ($\mathrm{K\ day^{-1}}$) and the permanent atmospheric components.

F: Net Shortwave Flux ($\mathrm{W\ m^{-2}}$)

bot: Earth Surface

top: Top of the Atmosphere

par: Parameterization

α: Run case

Methods: Heating Effect

$$\mathbf{HE}_{\mathrm{par}}^{\alpha}(\tau) = \mathbf{H}_{\mathrm{par}}^{\alpha}(\tau) - \mathbf{H}_{\mathrm{par}}^{0}$$

HE: Heating Effect due to the cloud/aerosol layer with optical depth at 550 nm equal to τ ($\mathrm{K\ day^{-1}}$)

par: Parameterization

$\boldsymbol{\alpha}$**:** Run case

0: Reference Case

Methods: Heating Effect Uncertainty

$$\Delta\mathbf{HE}_{\mathrm{par}}(\tau) = \max(\mathbf{HE}_{\mathrm{par}}(\tau)) - \min(\mathbf{HE}_{\mathrm{par}}(\tau))$$

$$\overline{\mathbf{HE}}_{\mathrm{par}}(\tau) = 0.5[\max(\mathbf{HE}_{\mathrm{par}}(\tau)) + \min(\mathbf{HE}_{\mathrm{par}}(\tau))]$$

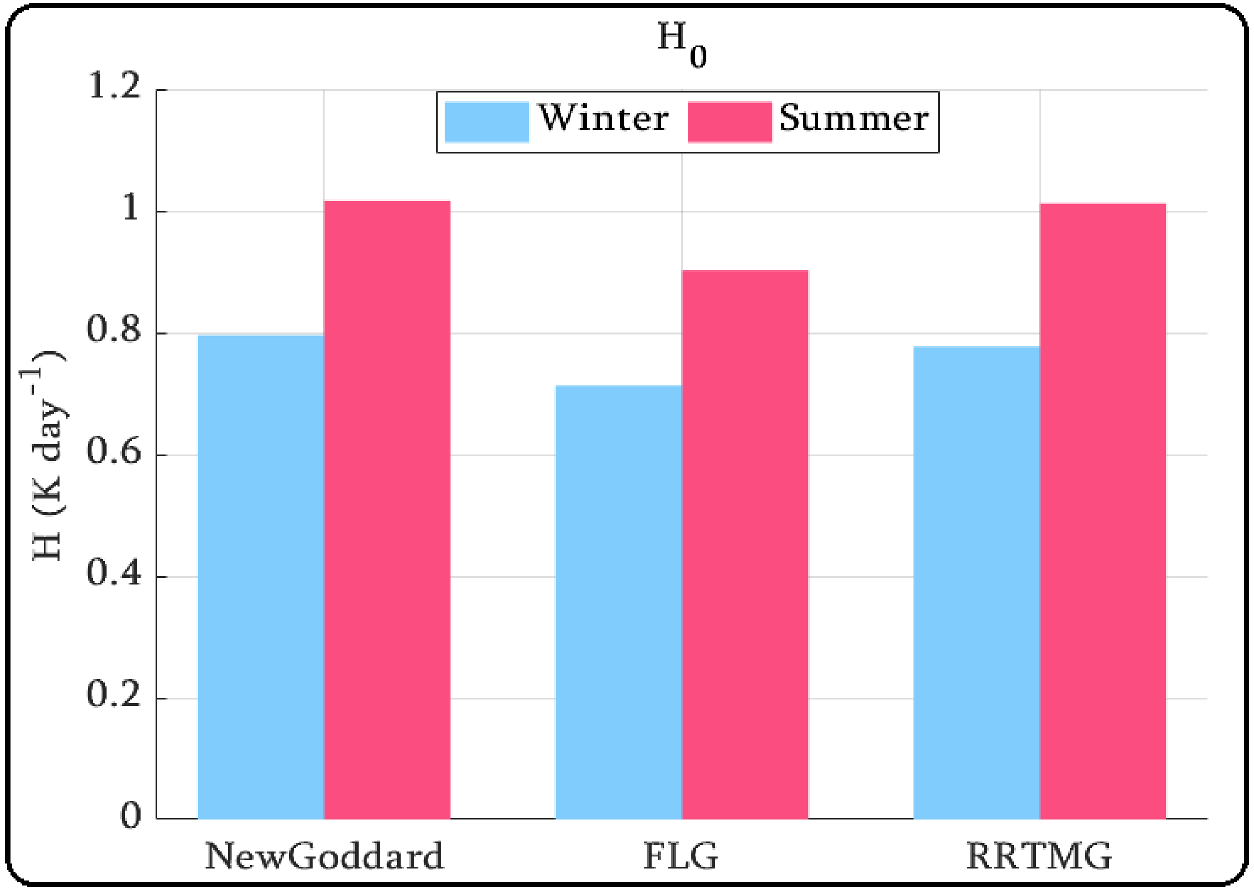
$$\mathbf{R\Delta HE}_{\mathrm{par}}(\tau) = \Delta\mathbf{HE}_{\mathrm{par}}(\tau)/\overline{\mathbf{HE}}_{\mathrm{par}}(\tau)$$

$$\overline{\mathbf{R\Delta HE}}_{\mathrm{par}} = \frac{100}{2 - 0.01}\int_{0.01}^{2} \mathbf{R\Delta HE}_{\mathrm{par}}(\tau)\, d\tau$$

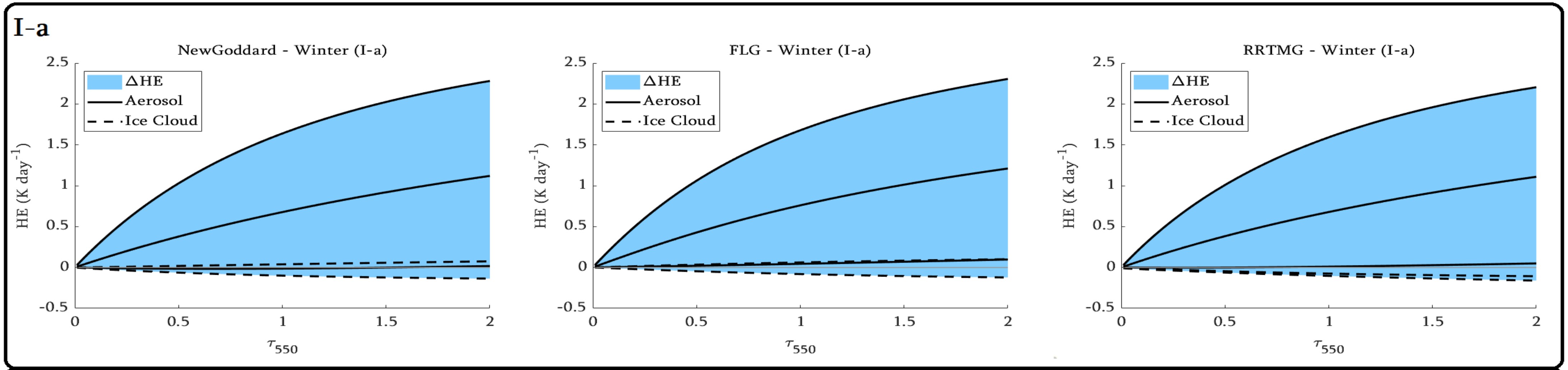
$\Delta\mathbf{HE}$**:** Heating Effect Uncertainty ($\mathrm{K\ day}^{-1}$)

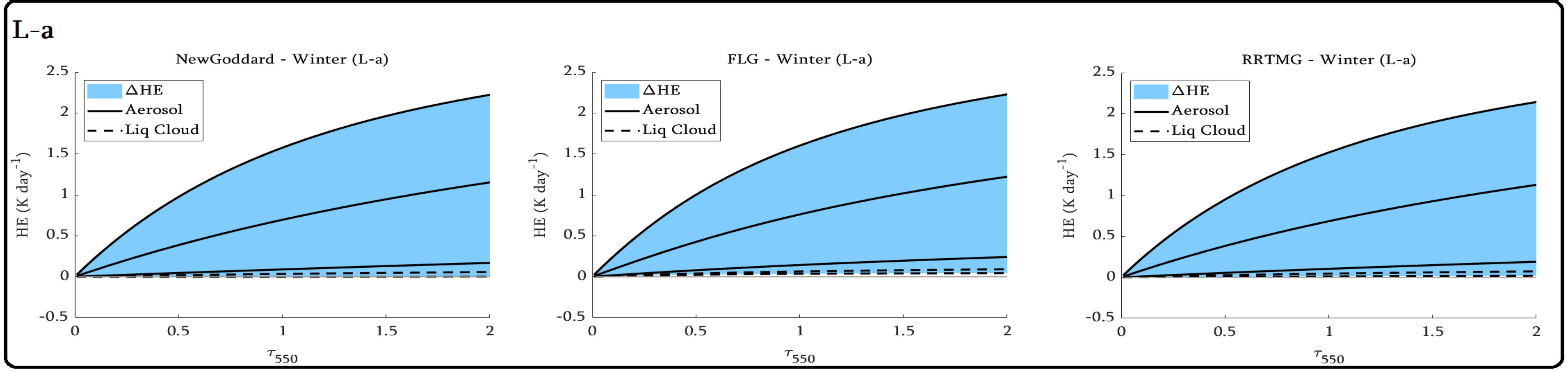
$\overline{\mathbf{R\Delta HE}}_{\mathrm{par}}$: Mean Relative Heating Effect Uncertainty (%)

Results: $\mathbf{H}_{\text{par}}^{0}$



Results: **HE** - Winter





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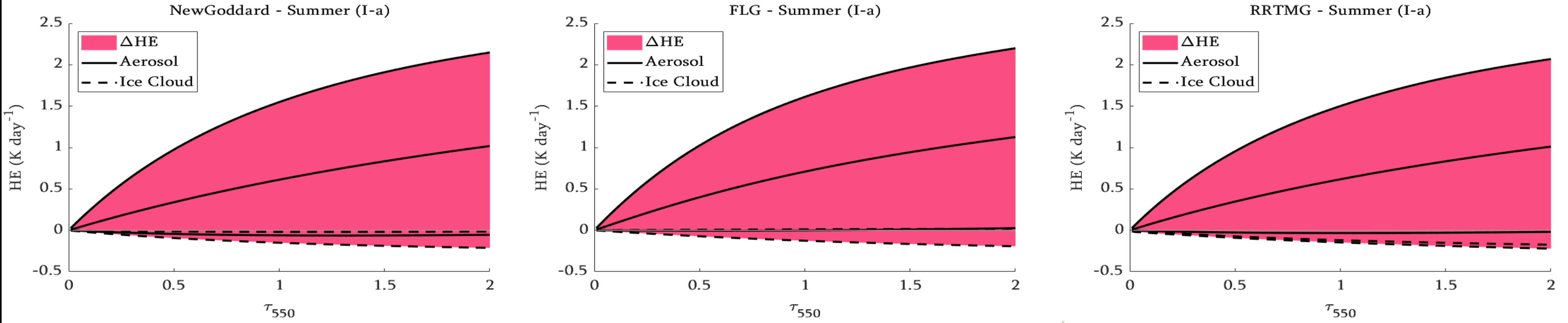
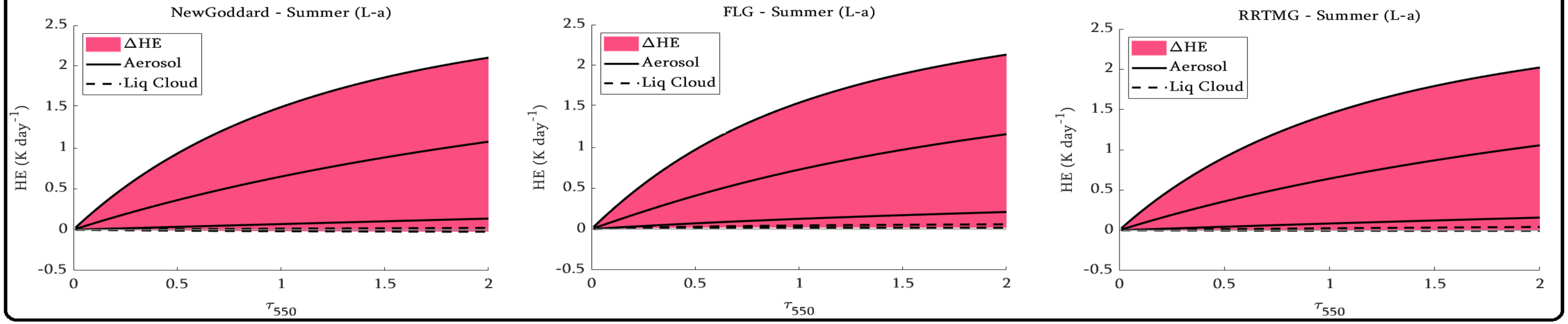
Results: **HE** - Summer

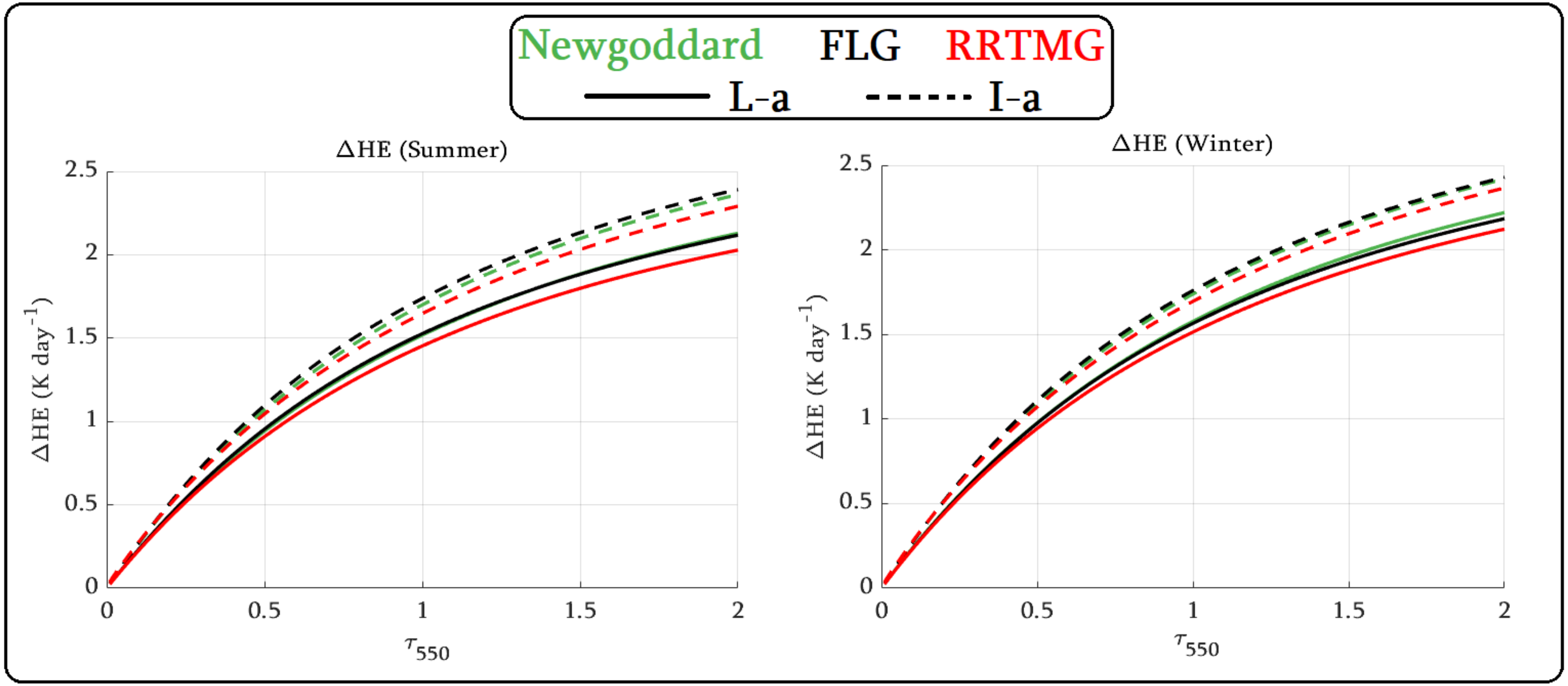
I-a



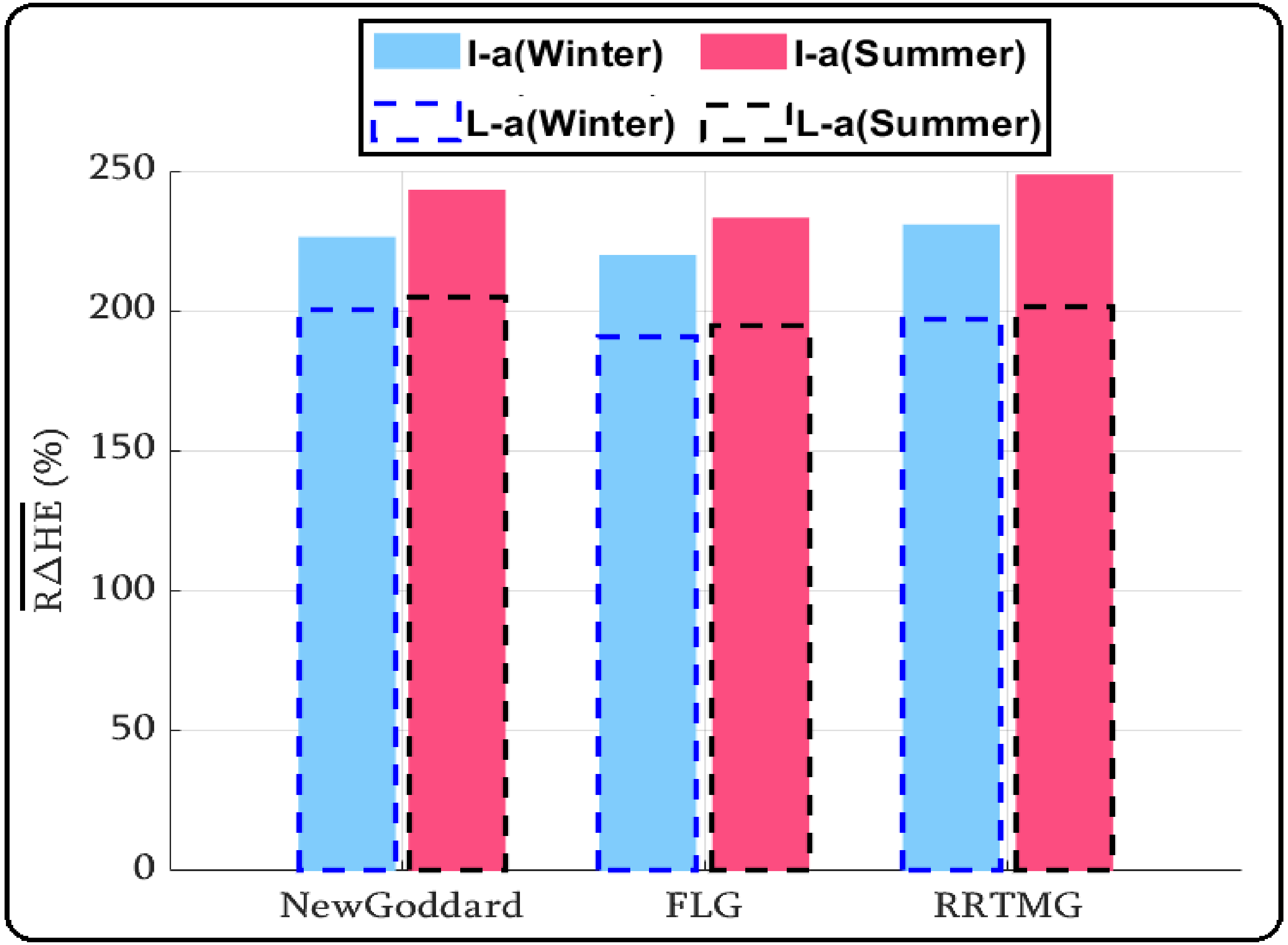
L-a



Results: ΔHE



Results: $\overline{\mathbf{R\Delta HE}}$



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