Review for the paper “The Impact of aerosol–ice nuclei-cloud interactions on a Typical Spring Dust-Precipitation Event in China” by Jian Zhang et al.

This study investigates how dust aerosols influence precipitation in China using an improved online aerosol–ice-nucleation (aerosol-IN) scheme implemented in the GRAPES/CUACE regional model. The topic is interesting and important in the field of aerosol–cloud–precipitation interactions. However, in many parts of the manuscript, the authors draw conclusions without sufficient observational evidence. This is the major drawback of the study. Therefore, I am on the negative side regarding publication of this paper.

General Comments

1. Lack of observational analysis:
   As mentioned in the overall assessment, this paper lacks observational analysis to support its conclusions. For example, in lines 317–321, the authors should evaluate model results against radar observations and include water and/or ice saturation information. In line 349, observational evidence for the mass ratio between cloud ice and snow (1:3) should be presented to justify its alignment with observations, as this ratio can vary from case to case. For lines 431–432, there is no analysis or evidence explaining the underestimation of ice nuclei concentrations in the original WDM6 scheme.
2. Incorrect or missing references:
   In several places, the manuscript either lacks proper references for the physical parameterizations used or cites incorrect previous studies. For instance, *Park and Lim (2023)* and *Kwon et al. (2023)* did not evaluate their results using MODIS observations, contrary to what is stated in line 94. The statement in lines 99–104 is also incorrect. The authors should carefully review and cite previous studies throughout the manuscript. Furthermore, *Hong et al. (2006)* is not the correct reference for the WDM6 scheme (line 155); the appropriate citation is *Lim and Hong (2010)*.
3. Need for microphysical budget analysis:
   To draw reliable conclusions about the vertical profiles of hydrometeors, the authors need to perform a detailed microphysics budget analysis. For example, they argue that increased cloud ice enhances accretion by snow, converting cloud ice to snow. However, this cannot be concluded without budget diagnostics, as other processes—such as aggregation of cloud ice or accretion of snow by rain—could also contribute. I strongly recommend that the authors conduct budget analyses for different stages of precipitation

development.

4. Aerosol–IN nucleation scheme:

- The authors should explicitly compare the ice nucleation parameterizations used in *Park and Lim (2023)* and in this study to clarify the differences among T_CTL, T_CCN, and T_CCNIN experiments. A comparative table would be useful. Notably, WDM6 with prognostic cloud ice number concentration (Park and Lim) did not use the formula $\rho qI0(kg\ m{-}3)= 4.92 \times 10^{-11} Nice^{1.33}$ to calculate nucleation of ice, which is Pigen, indicating all nucleation processes, in Hong et al., (2024). Instead, Park and Lim's version explicitly treats immersion, contact, and deposition nucleation separately.
- The comparison of IN concentrations between this study and *Park and Lim (2023)* also needs careful reconsideration. Even though the authors replaced the ice nucleation scheme in WDM6 with the prognostic version, they compare IN concentrations with those from older WDM6 versions (*Hong et al., 2024*; *Lim and Hong, 2010*). According to *Eqs. (4–6)* in *Park and Lim (2023)*, IN concentrations are treated differently for contact versus deposition/condensation processes, even though both are temperature-dependent.
- More clarification is needed for their new on-line aerosol-IN nucleation scheme. Does $n_{aer,0.5}$ in Eq.3 represent the same quantity as in Eq. (2)—the number concentration of insoluble aerosol particles larger than 0.5 μm (e.g., dust, black carbon, and some organic carbon)? What is ρ in Eq. (4)?

5. Physics parameterization references:
   The authors should cite appropriate references for the physics parameterizations used in their GRAPES/CUACE configuration (Section 2.2.1).

6. Support for the downstream transport conclusion:
   To substantiate the claim that suppressed cloud water is transported downstream in T_CCNIN, supportive figures should be presented.

Specific Comments

- Line 265:
  "As simulation time increases, integration errors tend to accumulate (Zhang et al., 2019), and to minimize the influence of initial conditions on precipitation, an additional test is conducted from 11 to 13 April."
  → This sentence is unclear. Did you perform another simulation starting from 11 April? Please clarify.

- Line 208:
  “It ignores the influence of IN size and heterogeneous ice nucleation processes.” → This is incorrect. The formula includes all heterogeneous ice nucleation processes because Nice represents IN concentration.
- Equations (4) and (6):
  These appear to be mathematically identical. Please verify.
- Line 233:
  Mark the locations of Ningxia, Shanxi, Hebei, etc., in Figure 1.
- Line 254:
  What is the ambient temperature between 3 km and 5 km altitude?
- Figure 2 (page 12):
  This should be Figure 3.
- Lines 304–305:
  Why do the authors analyze only one model time step (100 s)? What real time does 100 s correspond to?
- Line 306–307:
  The authors should show the underestimation of IN concentrations when the online aerosol–IN scheme is not used.
- Line 315:
  Besides dust, what other aerosol types serve as IN?
- Lines 329–330:
  Specify the actual dates and times corresponding to phases 1, 2, and 3.
- Line 338:
  Replace “below 6 km” with “above 4 km.”
- Line 340:
  Why is the cloud-top temperature higher under dusty conditions?
- Line 350:
  Include analysis of hydrometeor number concentrations as well.
- Lines 361–362:
  Check this sentence for clarity and correctness.
- Line 365:
  Provide further discussion on the precipitation types in the cited papers (*Wang et al., 2022; Zhu et al., 2023*).
- Lines 426–427:
  The statement “this study... mass concentrations” duplicates findings already reported by *Park and Lim (2023)*.