The Interaction between Cumulus and Microphysics Parameterizations in WRF across Convective Grey Zone Resolutions: A Case Study.

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Background

Cumulus and microphysics parameterization schemes determine together the local intensity and spatial extent of the total precipitation in Numerical Weather Prediction (NWP) models. While microphysics schemes yield large-scale precipitation at grid-scale condensation by representing the processes inside a cloud, cumulus parameterization schemes account collectively for unresolved vertical motion that can cause additional convective precipitation. For coarse resolutions, deep convection must be parameterized. However, when decreasing the horizontal grid spacing one enters the convective grey zone where cumulus-cloud processes become partially resolved and traditional closure assumptions break down. This study investigates the grid-scale dependent performance of different cumulus and microphysics schemes in WRF.

Model Setup & Experiments

Initial & boundary conditions
GFS Analysis Data (GFS-ANL)

NWP Model: **WRF**

- Dynamical core: ARW 3.9.1.1
- 51 vertical levels (top at 50 hPa)
- 5 one-way nested domains
- 15 hours spin up
- Adaptive time step
- Common physics:
  - MP = WSM5
  - Sfclay = MM5
  - Pbl =YSU
  - Ra_lw = RRTM
  - Ra_sw = Dudhia
  - Surface = Noah LSM

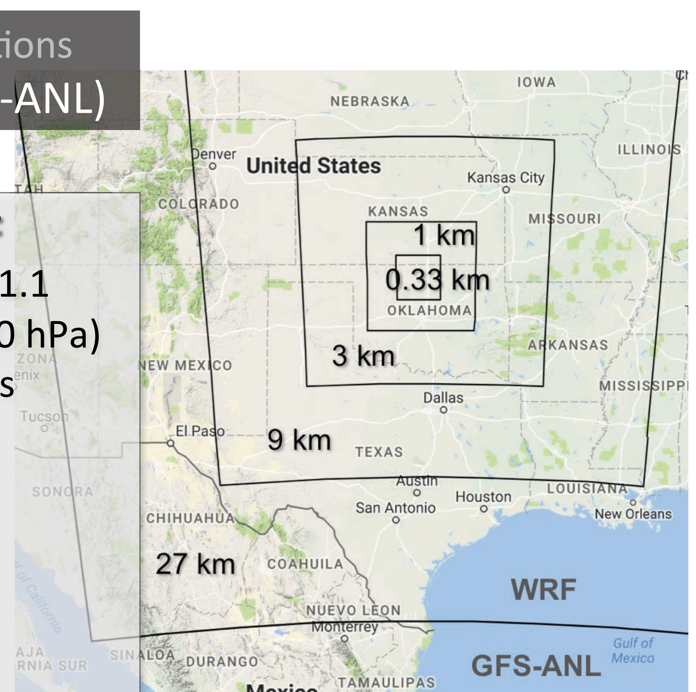


Fig. 1: Geographical location of the five nested WRF domains used in this study.

Case Study 1: Mesoscale convective system

Cumulus schemes:
- Kain-Fritsch
- BMJ
- Grell-Freitas
- Tiedtke

(1) Schemes on for all domains
(2) Schemes off for Δx ≤ 3 km

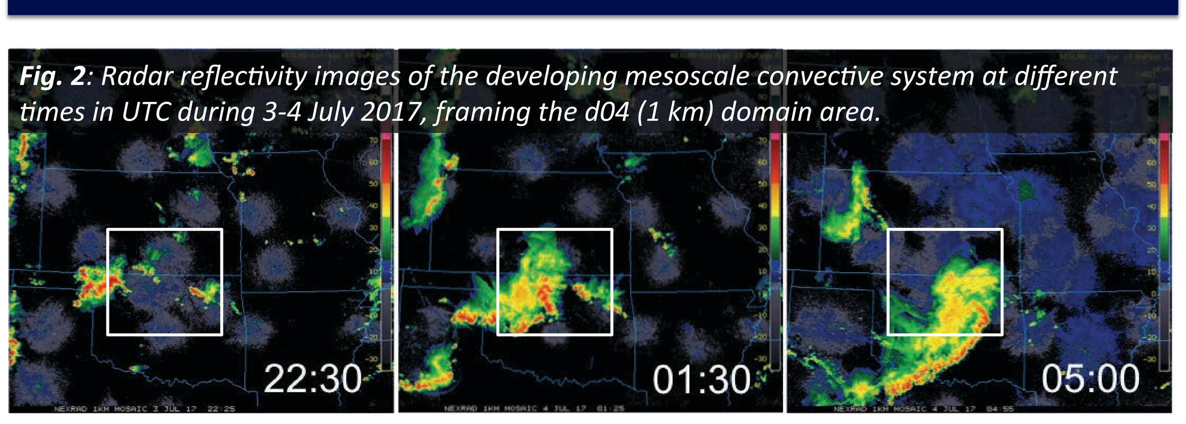
Case Study 2: Frontal passage

Microphysics schemes:
- WSM5 (1 moment)
- Thompson (1.5 moment)
- Morrison (2 moment)
- WDM5 (2 moment)

(1) Cumulus: Kain-Fritsch
(2) Cumulus: Grell-Freitas

Case Study 1: Cumulus schemes

Fig. 2: Radar reflectivity images of the developing mesoscale convective system at different times in UTC during 3-4 July 2017, framing the d04 (1 km) domain area.



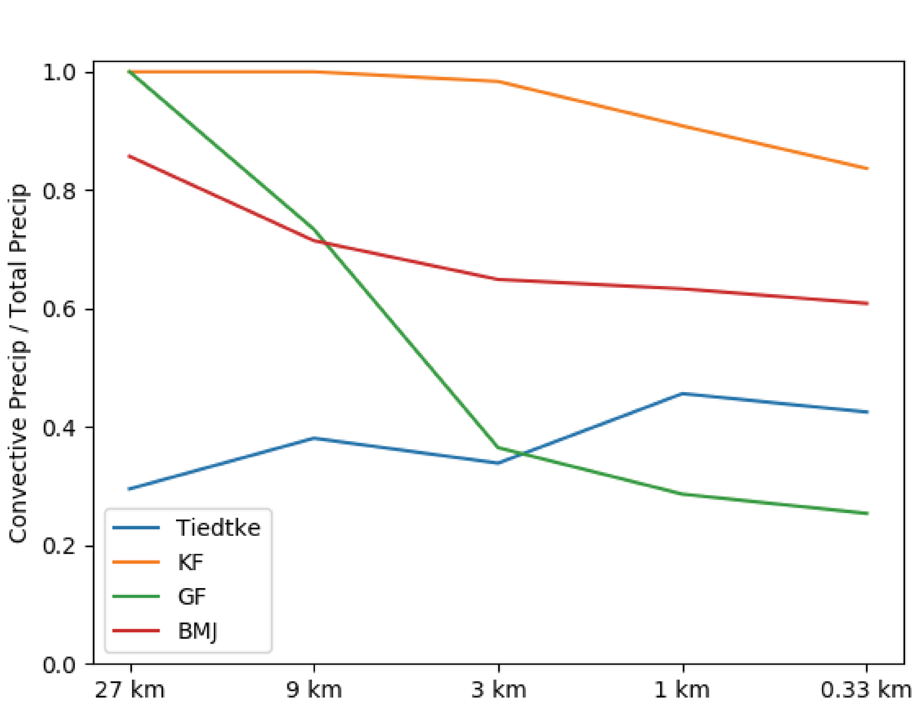


Fig. 3: Time and domain-averaged fraction of the convective over the total precipitation as function of grid length.

Case Study 1: Cumulus schemes

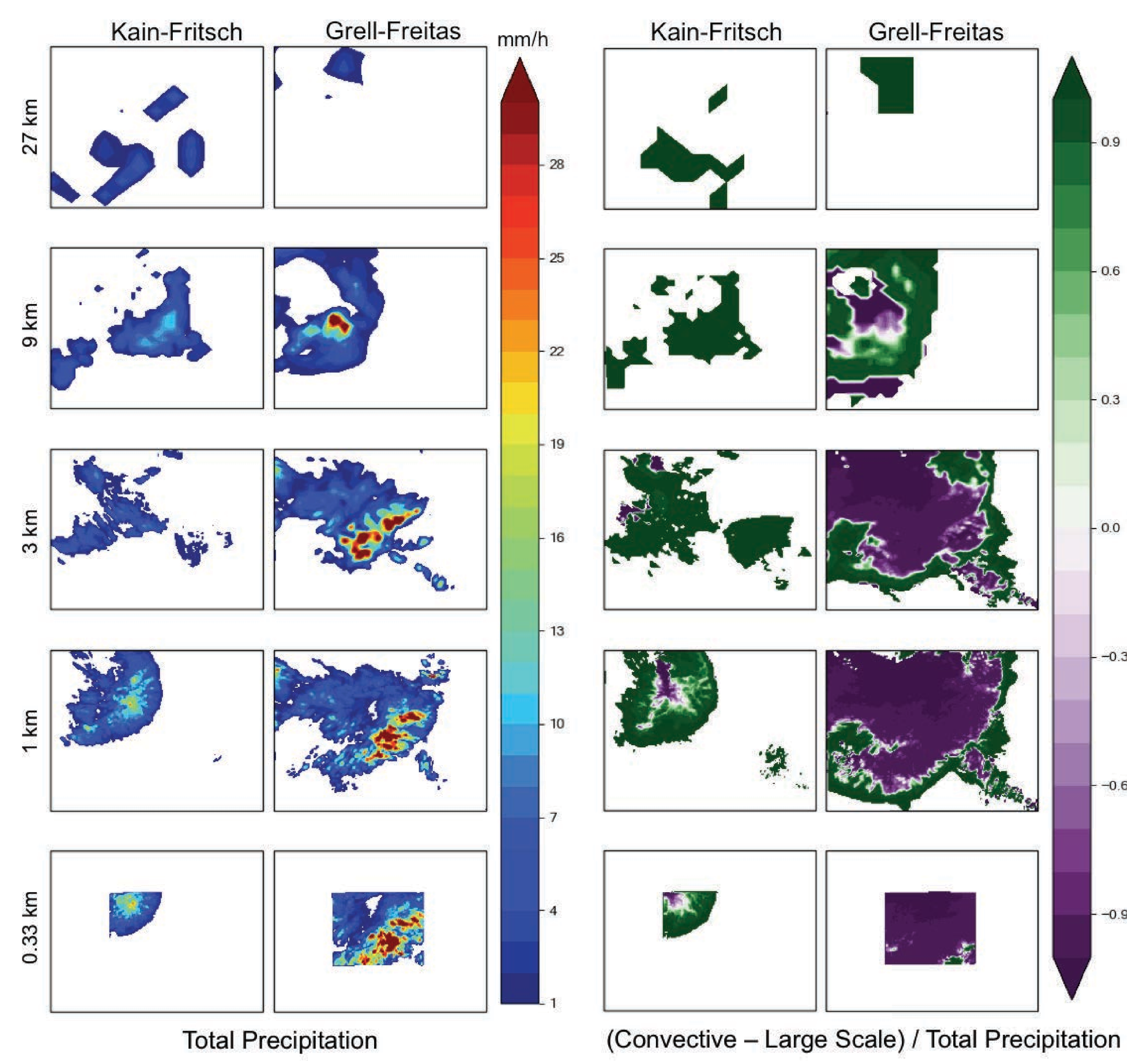


Fig. 4: Modeled total hourly precipitation at 02 UTC (left side) and contribution of precipitation rate from the cumulus scheme (green if predominant) and the microphysics scheme (purple if predominant) (right side).

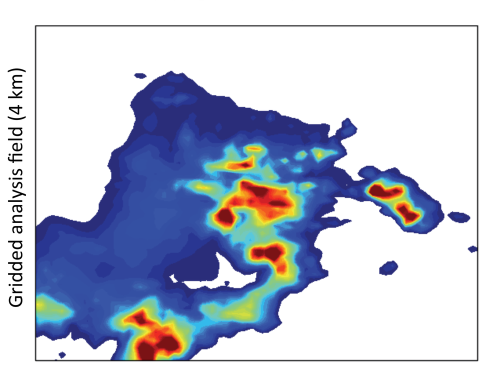
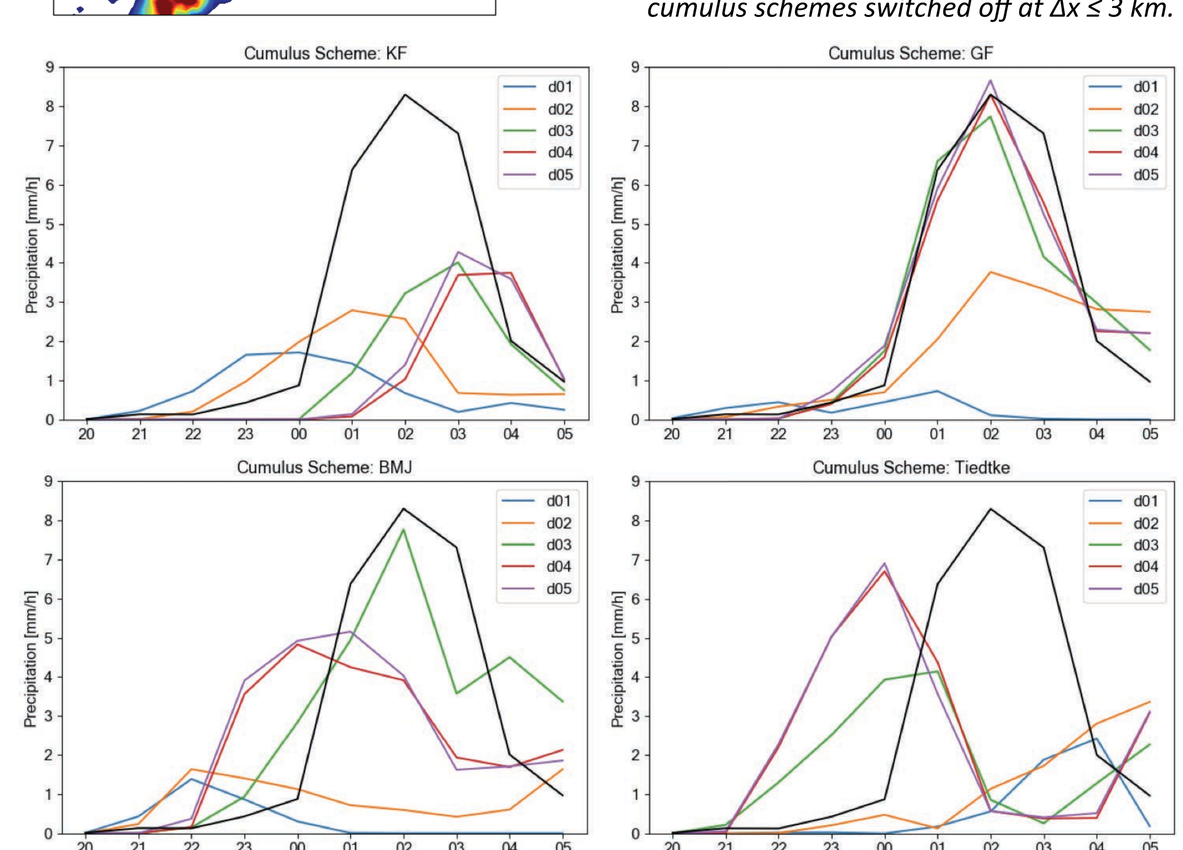
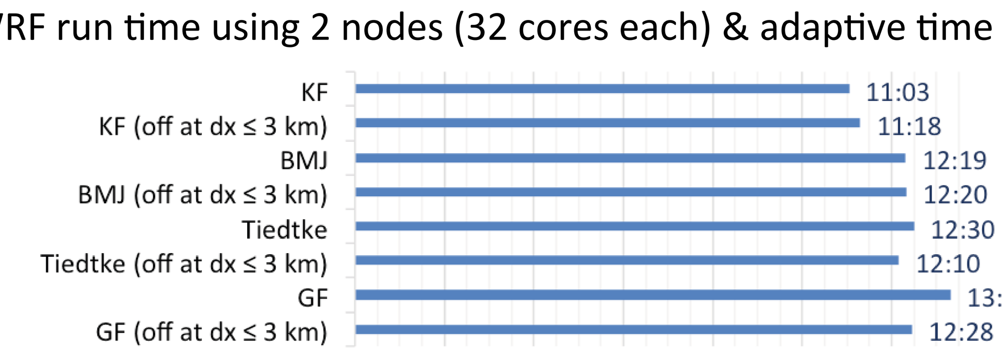


Fig. 5: Hourly precipitation rate (at same time and scale as Fig. 4) from the gridded multisensor precipitation estimate (MPE).

Fig. 6: Domain-averaged hourly precipitation rates from MPE (in black) and WRF model simulations for different cumulus schemes switched off at Δx ≤ 3 km.

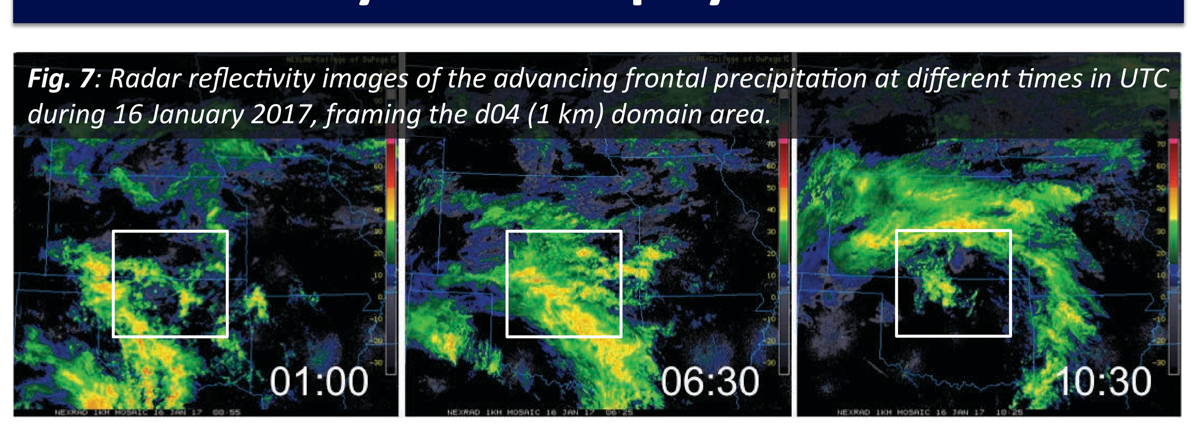


36h WRF run time using 2 nodes (32 cores each) & adaptive time step:



Case Study 2: Microphysics schemes

Fig. 7: Radar reflectivity images of the advancing frontal precipitation at different times in UTC during 16 January 2017, framing the d04 (1 km) domain area.



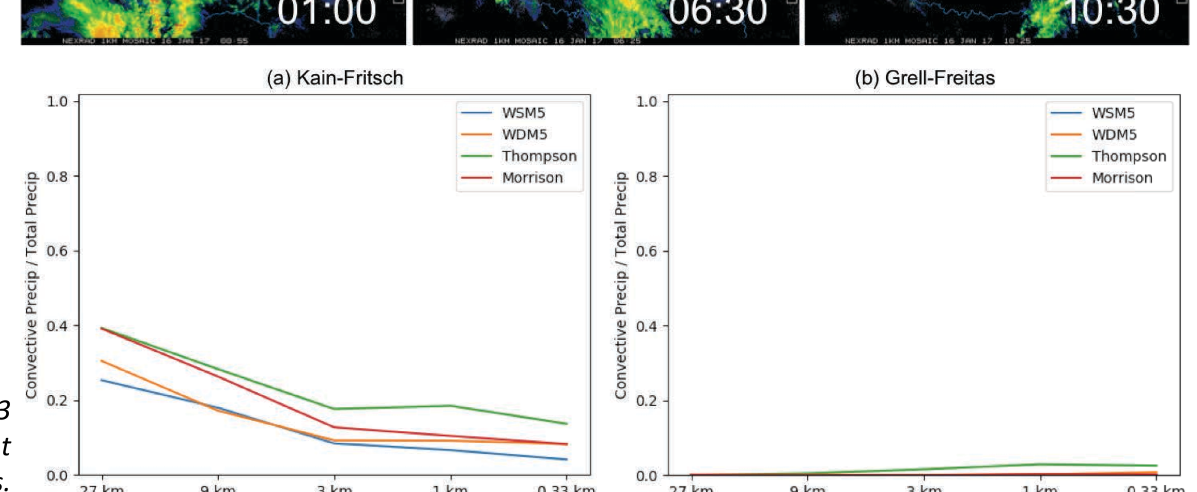


Fig. 8: Same as Fig. 3 for different microphysics schemes.

Case Study 2: Microphysics schemes

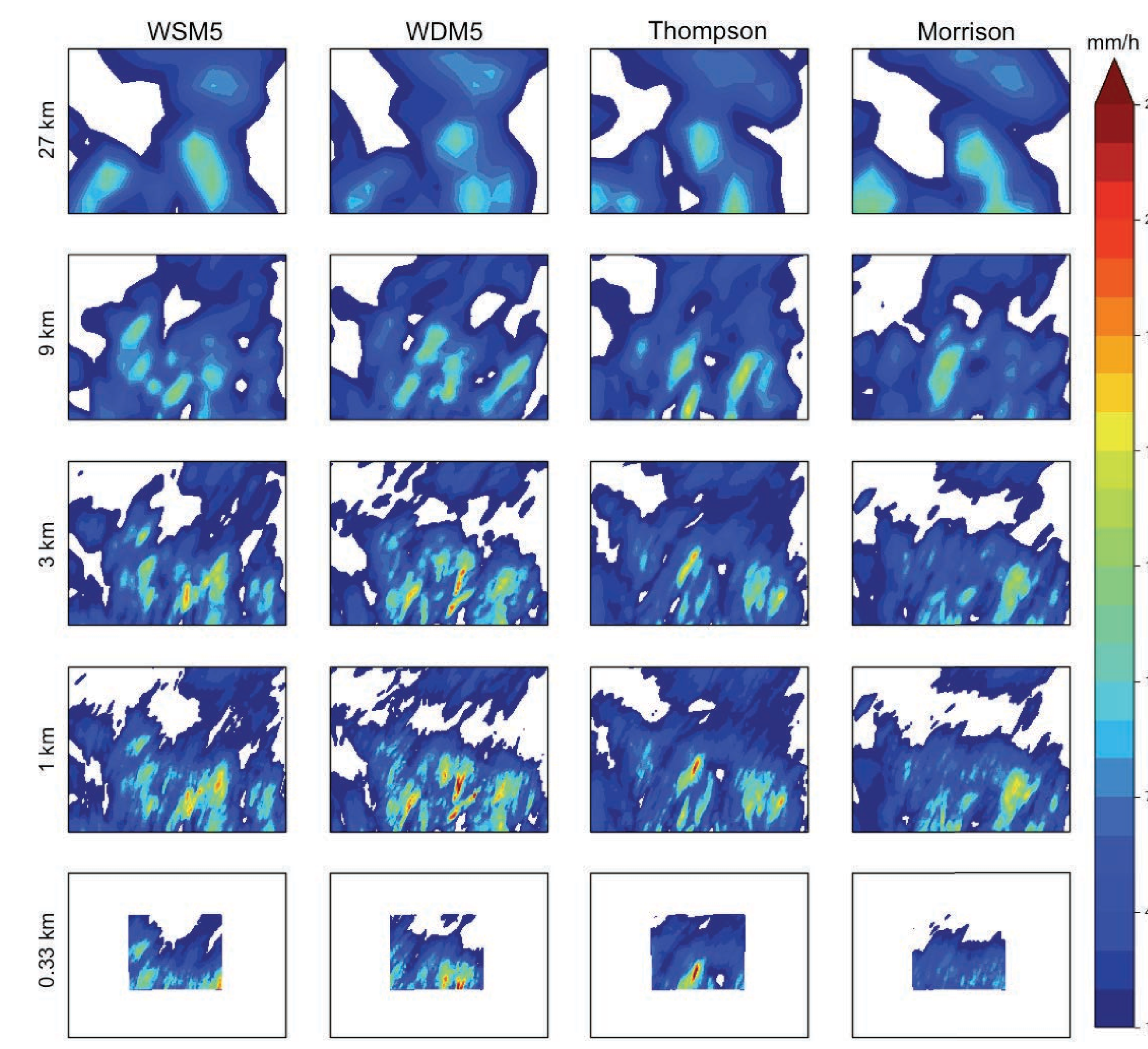


Fig. 9: Modeled total hourly precipitation at 04 UTC using Grell-Freitas as cumulus scheme.

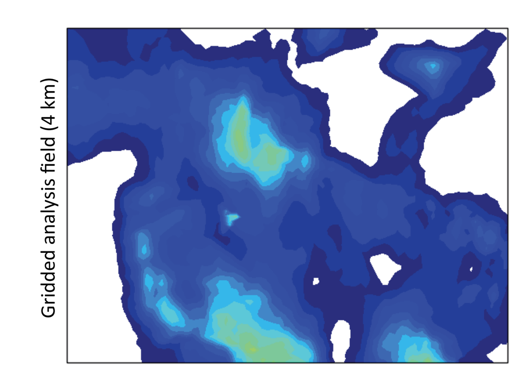
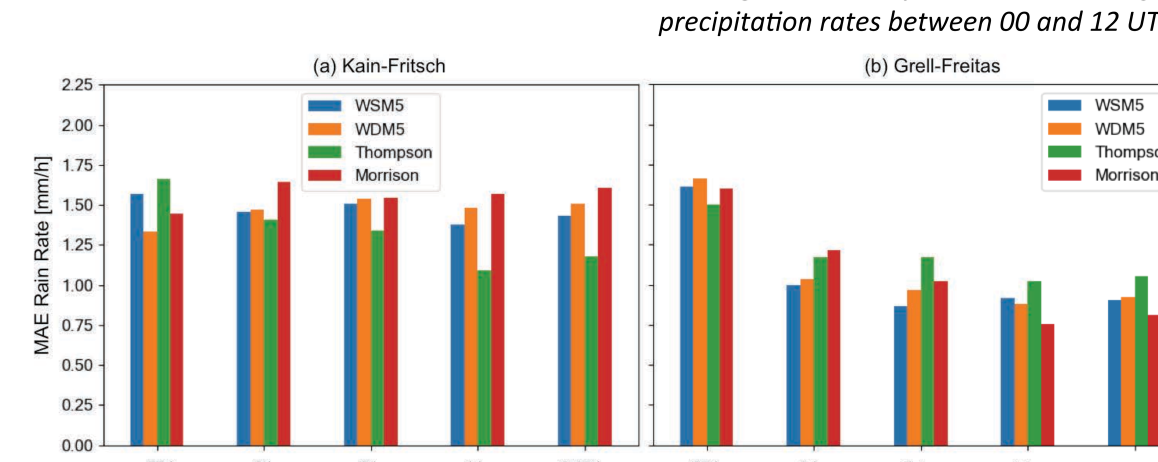
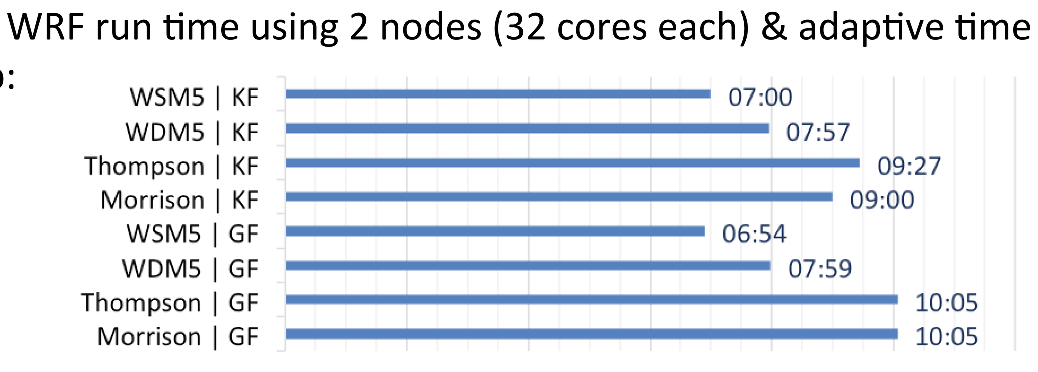


Fig. 10: Hourly precipitation rate (at same time and scale as Fig. 9) from the gridded MPE.

Fig. 11: MAEs of the domain-averaged precipitation rates between 00 and 12 UTC.



27h WRF run time using 2 nodes (32 cores each) & adaptive time step:



Conclusions

- The choice of the cumulus parameterization has a large effect on convective development.
- **Grell-Freitas** produces a smooth transition between sub-grid (cumulus) and grid-scale (microphysics) precipitation across grey-zone scales and outperforms the other schemes at high resolutions.
- All simulations for Case Study 1 are improved then the cumulus scheme is **turned off for Δx ≤ 3 km**.
- Different microphysics schemes produce very similar meteorological results, but **significant differences in run time** - sophisticated schemes may not be necessary. The best-performing microphysics scheme depends also on the choice of cumulus scheme.
- The forecast error for precipitation converges toward a minimum at ~**3 km grid spacing** for most cumulus and microphysics schemes.