The promise of km-scale modelling

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1. Why km-scale modelling at ECMWF?

There are at least three compelling reasons why we want to model the Earth System at the kilometre scale with the IFS :

- **Improving the large-scale flow** by simulating extra physical processes that the current operational forecasts miss.
- **Predicting extreme weather** with increased accuracy by better resolving the convective scale and the mesoscales.
- **Higher-quality information** tailored to the scale users need.

Several projects have paved the way to meet those three objectives at ECMWF. INCITE (short forecasts pioneering the physics needed to predict tropical cyclones up to 1.4km resolution), nextGEMS (performing multidecadal coupled simulations at km-scale) and Destination Earth (setting the pathway to an operational use of km-scale forecasts).

2. The added-value of the km-scale

When the horizontal resolution of IFS is increased from 9km to 4.4km or 2.8km, several aspects are improved almost immediately.

- **Tropical cyclones** exhibit from an improved axisymmetric structure of the inner core and a better-defined eye (Figure 1). This matters for capturing the correct TC intensity and the rapid intensification mechanism.
- **Orographic precipitation** benefits from the steeper slopes of mountains, which favour the uplift of moist air (Figure 2). This benefits in turn the prediction of flood peak through improved runoff.

However, assessing the benefits of km-scale presents challenges, requiring accurate observations in mountainous area which are difficult to obtain and the development of new metrics to avoid the "double penalty effect" when evaluating fine-grained data with standard NWP metrics.

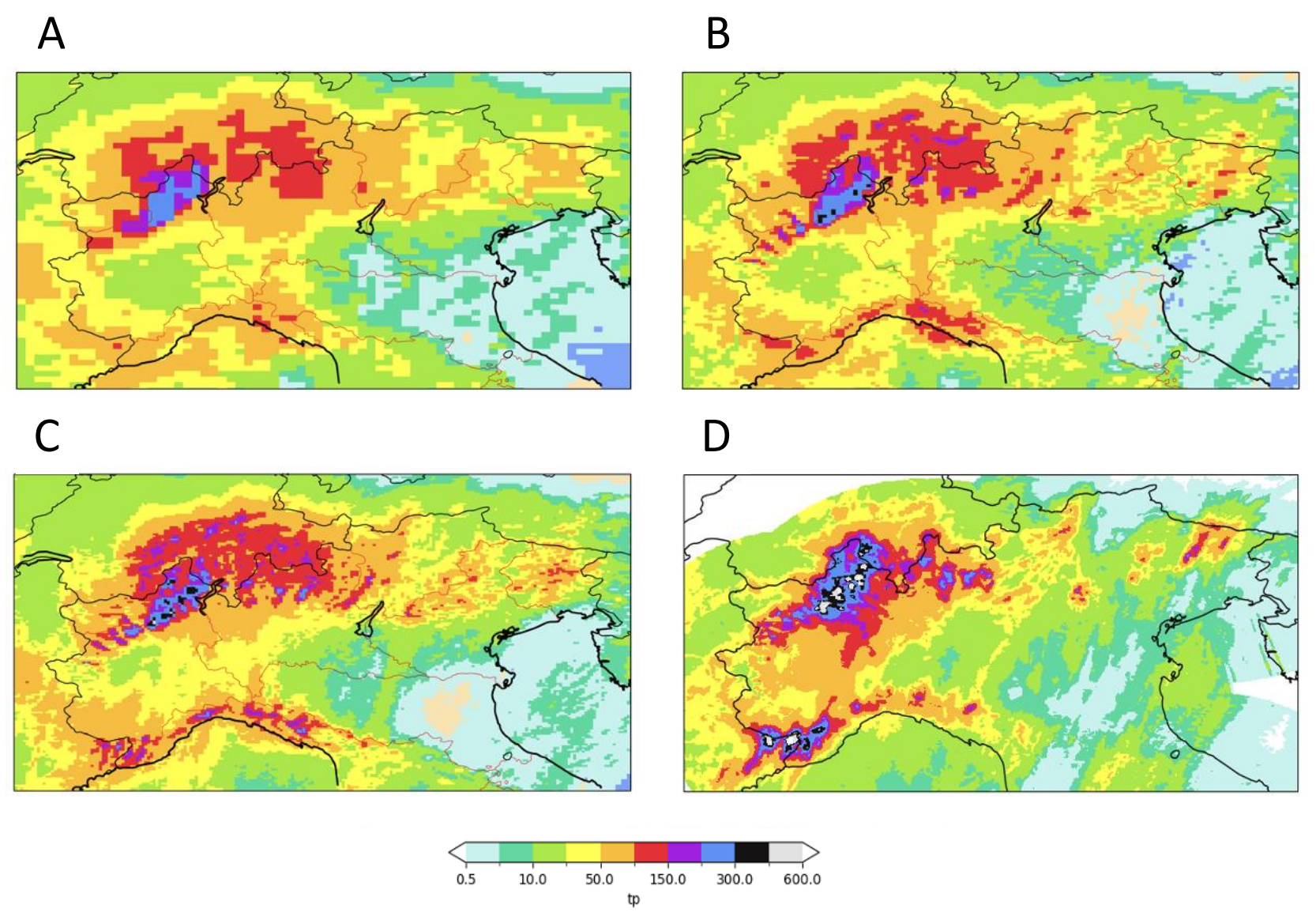


Figure 1| *Storm Alex*, 24h accumulated precipitation averaged between T+36h and +60h for forecasts initialized on 2020/10/01 at (A) 9km, (B) 4.4km, (C) 2.8km resolution and (D) regridded rain gauges and radar product (ARPAE).

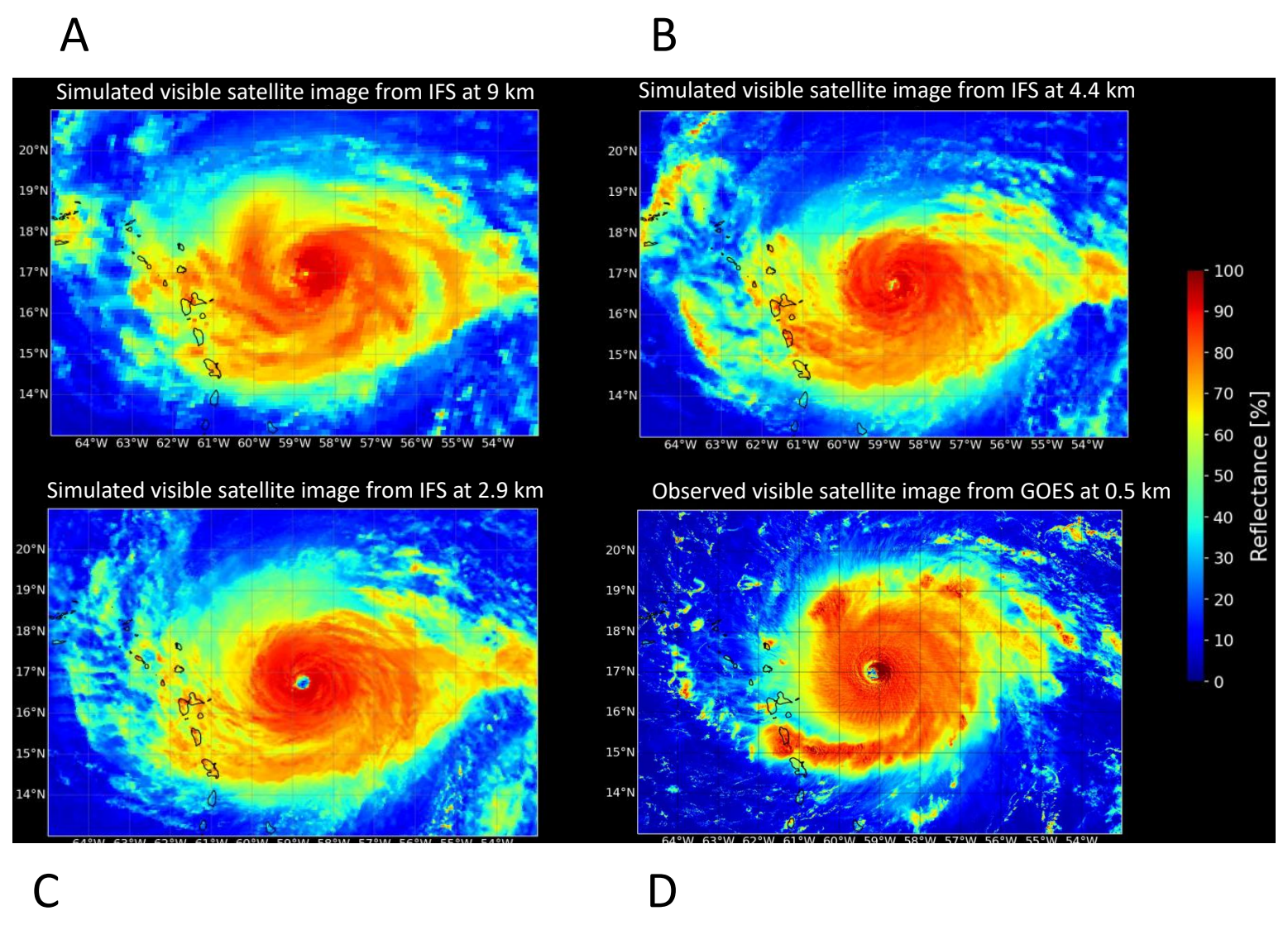


Figure 2| Reflectance simulated with the radiative tBansfer code RTTOV for forecasts at (A) 9km, (b) 4.4km, (C) 2.8km resolution and (D) reflectance retrieved from the satellite GOES for TC Irma (2017/09/05 at 18 UTC).

4. Km-scale forecast scores

When the operational model is taken out of the box and resolution is increased from 9 to 4.4km, NWP scores are degraded. This is caused by the mishandling of gravity over high-orography by the H model and time-step sensitivities in the model. Filtering the mean orography, increasing the implicitness of the SISL scheme and revising the limiters in the convection scheme have significantly improved NWP scores (Figure 3).

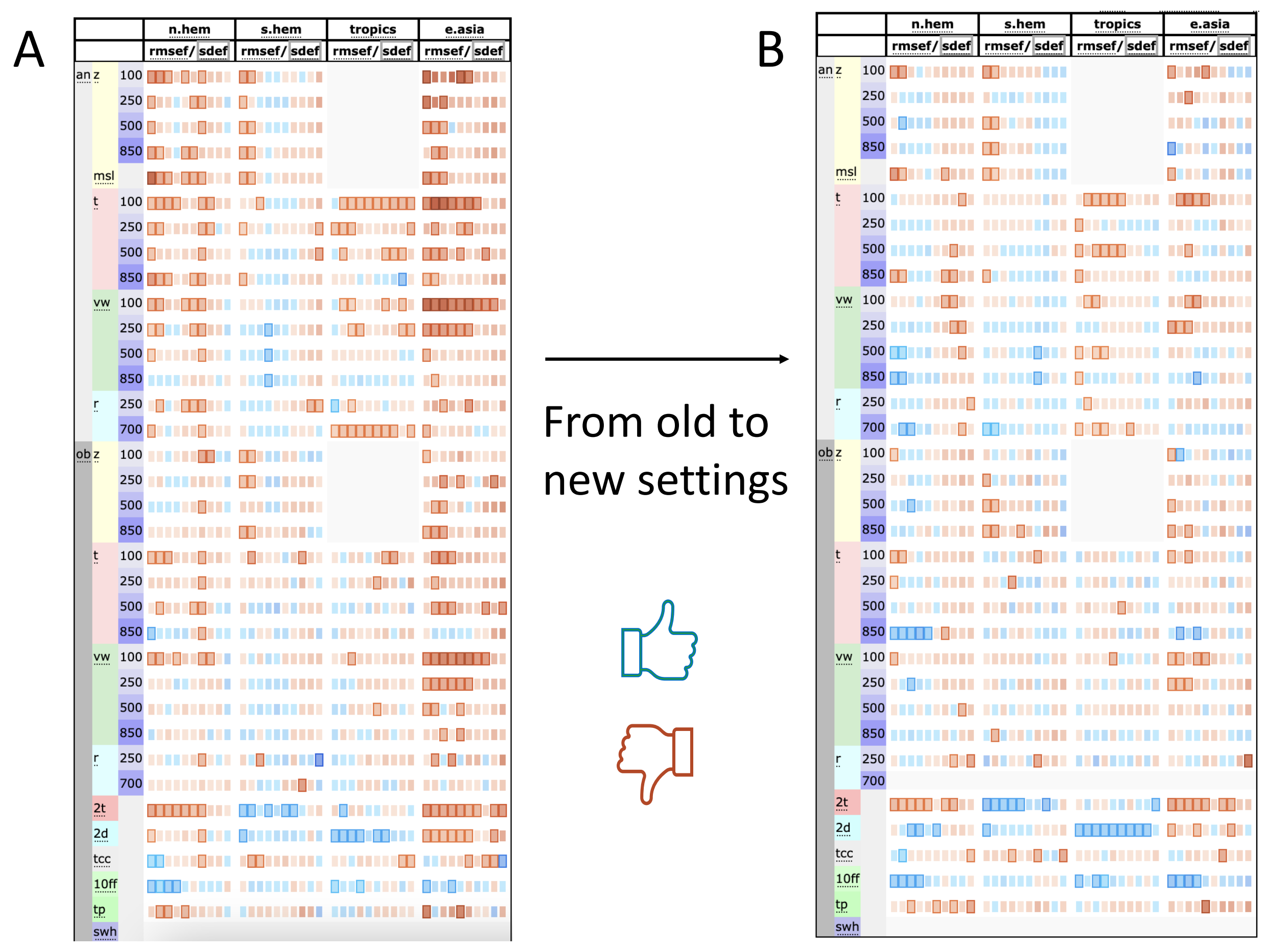


Figure 3| 4.4km – 9km deterministic forecast For 15 initial dates, (A) old settings and (B) new settings

3. The challenges of km-scale modelling

Km-scale modelling poses some challenges, which have been addressed by limited area NWP, but may become more significant at the global scale. These challenges require model development :

- **Deep convection:** the parameterization produces excessive light rain and artificial convective gravity waves. However, relying entirely on explicit deep convection is also problematic because it generates intense rain and strong updrafts. One solution is to reduce the cloud base mass flux, resulting in more realistic convection (Figure 5). But despite improving realism, it also reduces NWP score accuracy compared to parameterized deep convection…
- **Hydrostatic (H) assumption:** it matters for the representation of gravity waves. But the different between H and non-H dynamical core is significant only for strong flows over high orography at 2.8km. Therefore, we continue to rely on the H, which is 2.5x more computationally efficient (Fig. 6).
- **Mean orography**: trade-off exists between preserving as many small-scale features as possible that benefit extreme precipitation and filtering small-scale features to get rid of the gravity waves that the H dynamics cannot handle well. We have increased the filtering of small scales.

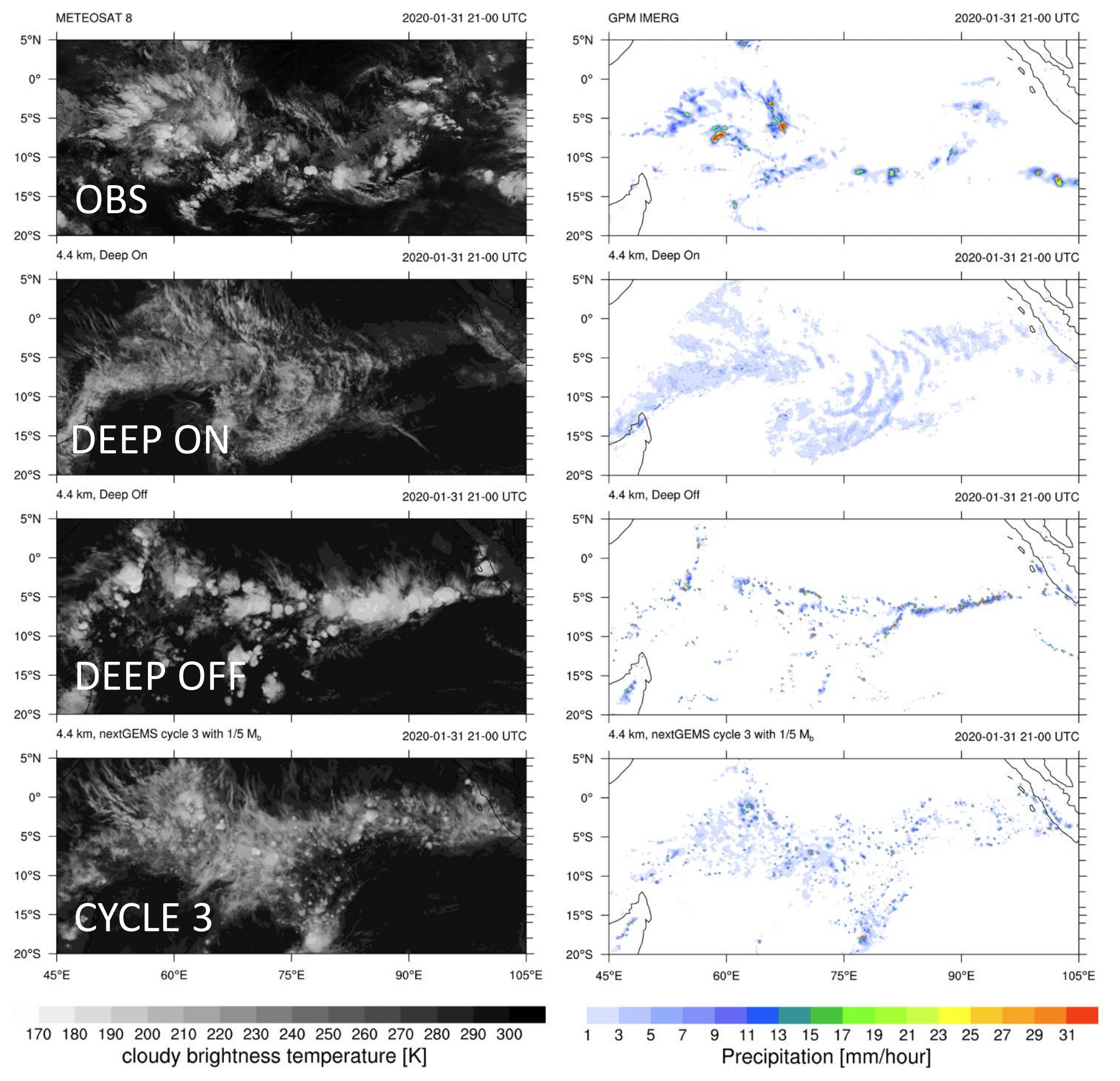


Figure 5| Convection settings explored in project nextGEMS

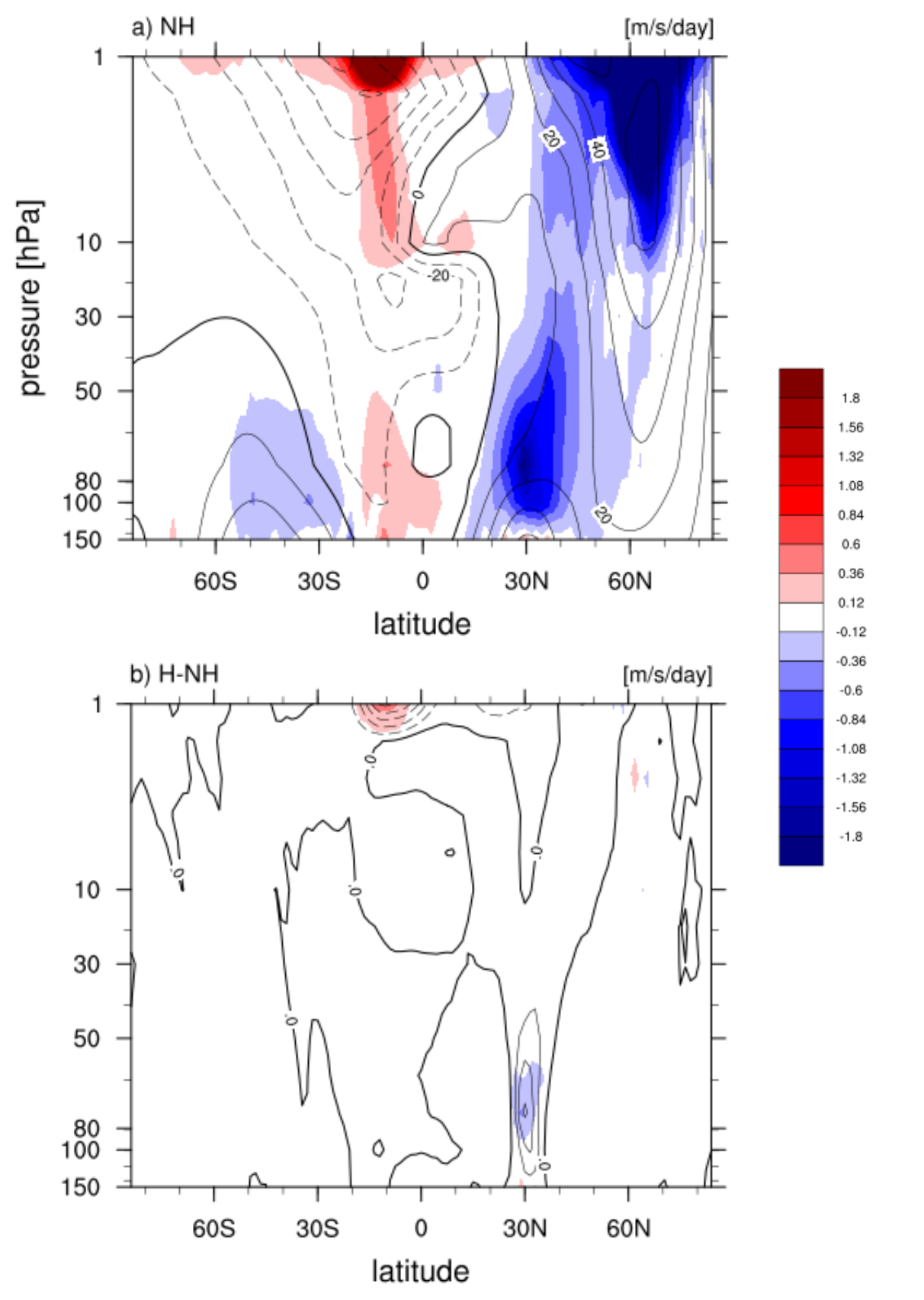


Figure 6| Resolved gravity waves drag in IFS at 2.8km resolution. (A) non-H and (B) difference between H and non-H

5. Better exploiting km-scale information

To fully exploit the added value of km-scale, and deliver a better information to users, several impact sector models have been integrated into the IFS :

- **Urban tiles** allow the representation of the urban heat island effect (Figure 7)
- **CAMA-Flood**: physical treatment of floods through closer integration to IFS
- **Hybrid aerosol scheme**: allowing a flexible treatment of aerosol species (prognostic or climatological) and bringing finer details where needed

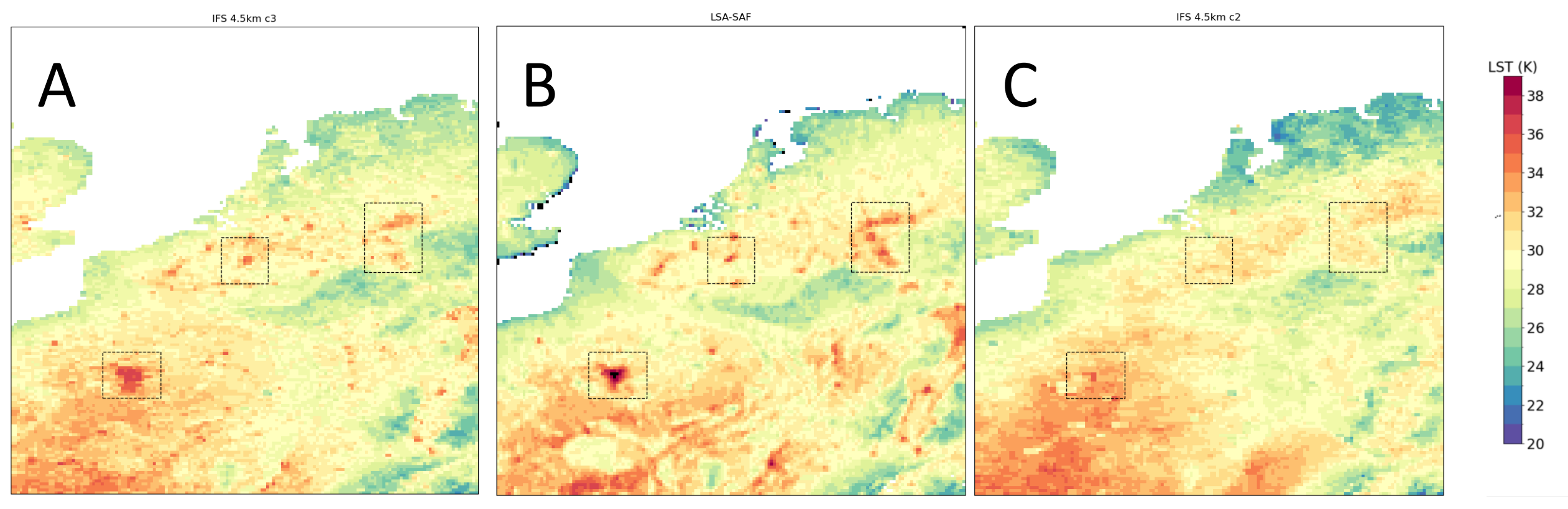
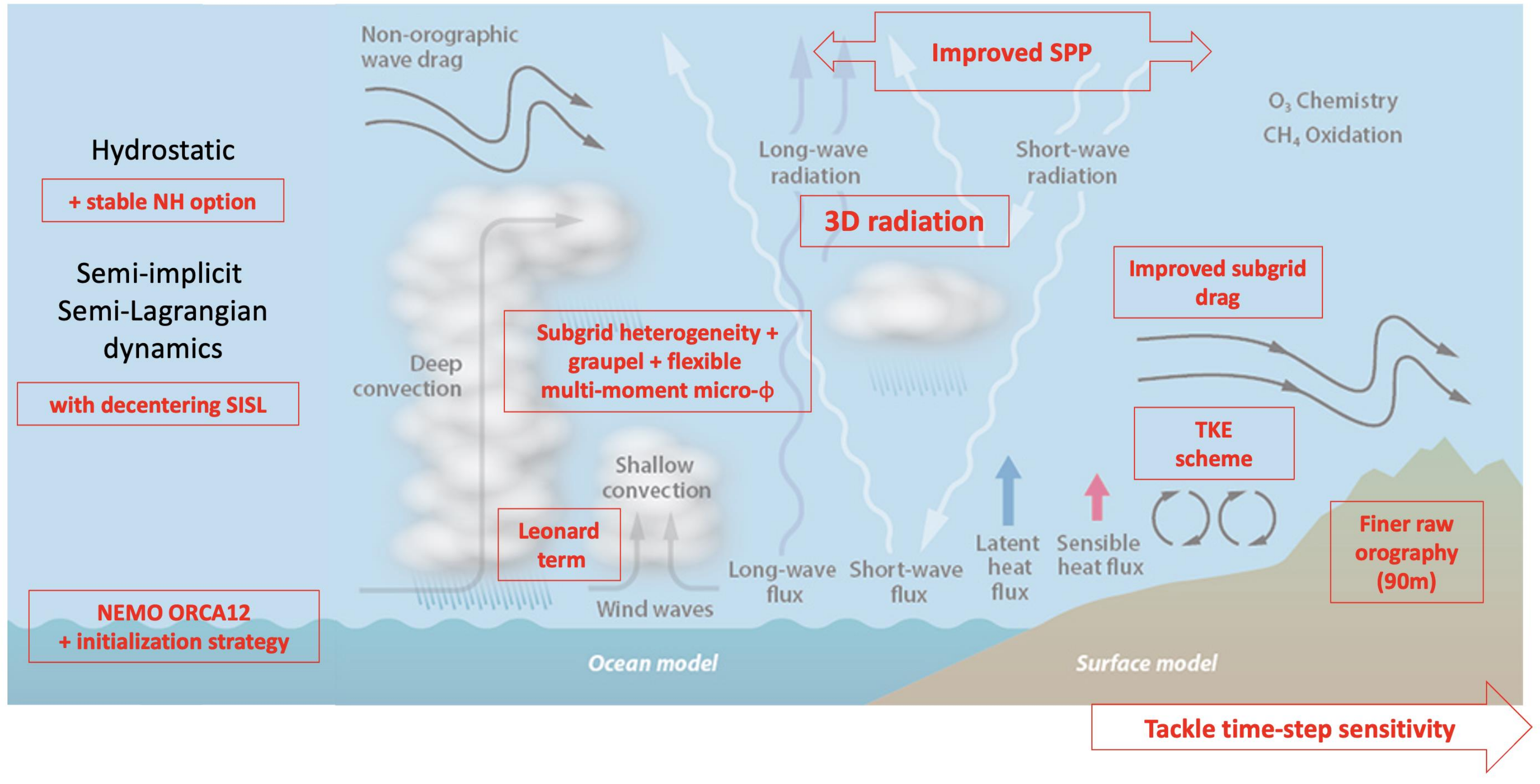


Figure 7| 2m-temperature, (A) nextGEMS cycle 3 with urban tiles, (B) LSA-SAF land analysis, (C) nextGEMS cycle 2 without urban tiles

6. Next steps



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