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Dealing with unresolved scales of motion and systematic errors in the assimilation of cloud-affected satellite radiances

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1. Problem and Motivation

The increasing resolution of satellite observations aggravates deficiencies in the model representation of clouds.

- **Zero-gradient problem (for the Ensemble Kalman Filter)**
  Creating clouds by assimilation is impossible if all prior ensemble members show clear sky.

  → *Considering a larger area increases the likelihood for clouds in the prior ensemble.*

- **Systematic model error**
  Sub-optimal parameterizations induce systematic errors in hydrometeor fields and cloud properties. The ensuing model biases can lead to the introduction of bias through assimilation.

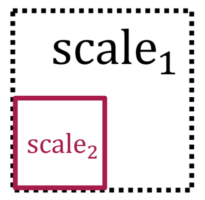
  → *Mitigation strategies are needed.*

2. Methods

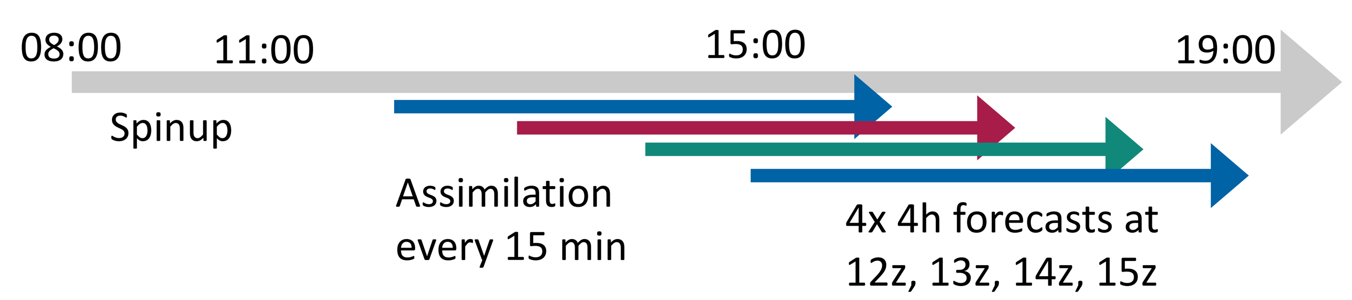
- **Thinning**
  Samples the high-resolution field at a lower resolution to mitigate observation-error correlation
- **Super-obs** (spatial averages)
  - **mitigate instrument noise,**
  - **increase representativeness** (discard unresolved scales), and
  - **increase the likelihood for clouds** in the prior ensemble, which enables the creation of clouds using the EnKF.
- **Cloud fractions**
  Defined as the fractional area exceeding a threshold,

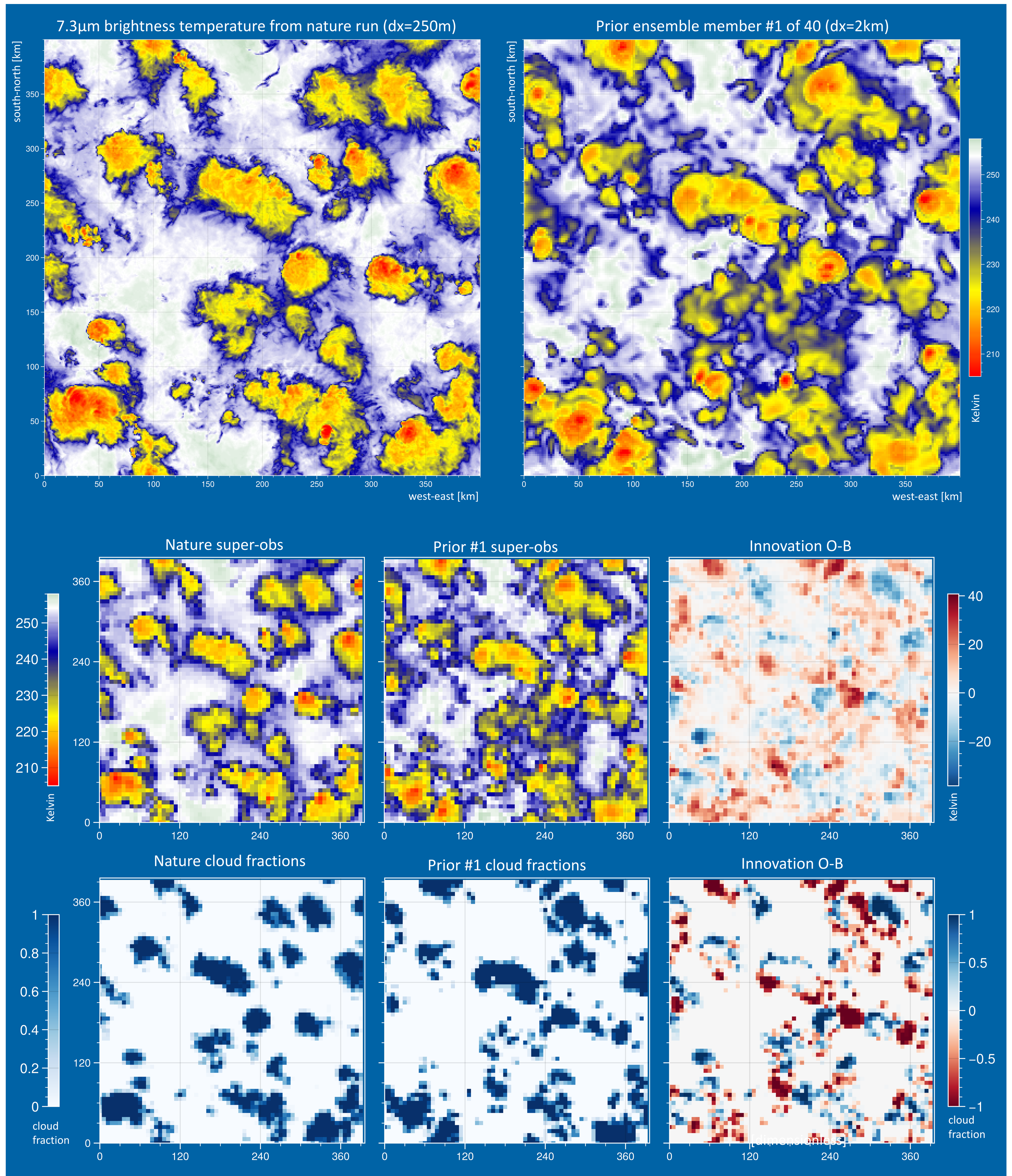
$$y_{cloudfraction} = \frac{1}{N}\sum_i^N (y_{observed} > \text{threshold})_i \qquad i \text{ ... pixel}$$

  similar to the Fraction Skill Score (Roberts & Lean, 2008)
  For example:
  visible reflectance > 0.6 or *infrared brightness temp. < 230 K*
  - It filters out random errors above and below the threshold and
  - Can mitigate systematic errors in the distributions of observations y and model equivalents $H(x)$
- **Multiscale variants ("Δ")**



  Cloud fields can be decomposed into different scales.
  The overlap of large and small areas introduces substantial obs-error correlation. To reduce it, we define observations of smaller scales as difference:
  (largest scale obs unchanged) $\quad \text{obs}_1 = y_1$
  (smaller scales are perturbations) $\quad \text{obs}_k = y_k - \text{obs}_{k-1} \quad (k > 1)$
  k ... scale
- **Experiments** in an OSSE (with a simulated truth)
  Weather: Deep moist convection scattered throughout the domain
  Resolution (nature run: 250 m; forecast ensemble: 2 km)
  Observations: SEVIRI channel VIS or WV 7.3µm
  Assimilate 12 km-scale every 15 min, larger scales hourly





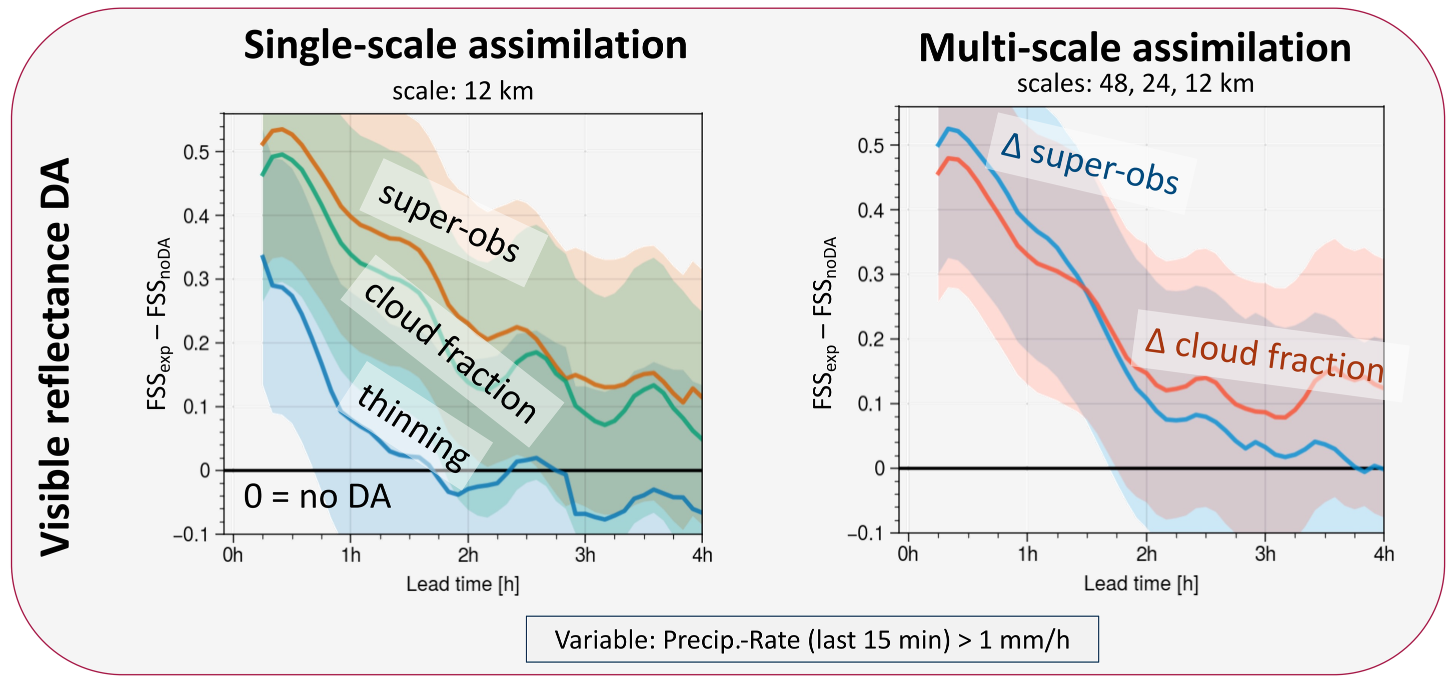
Super-observations and cloud fractions (6x6 km² window)

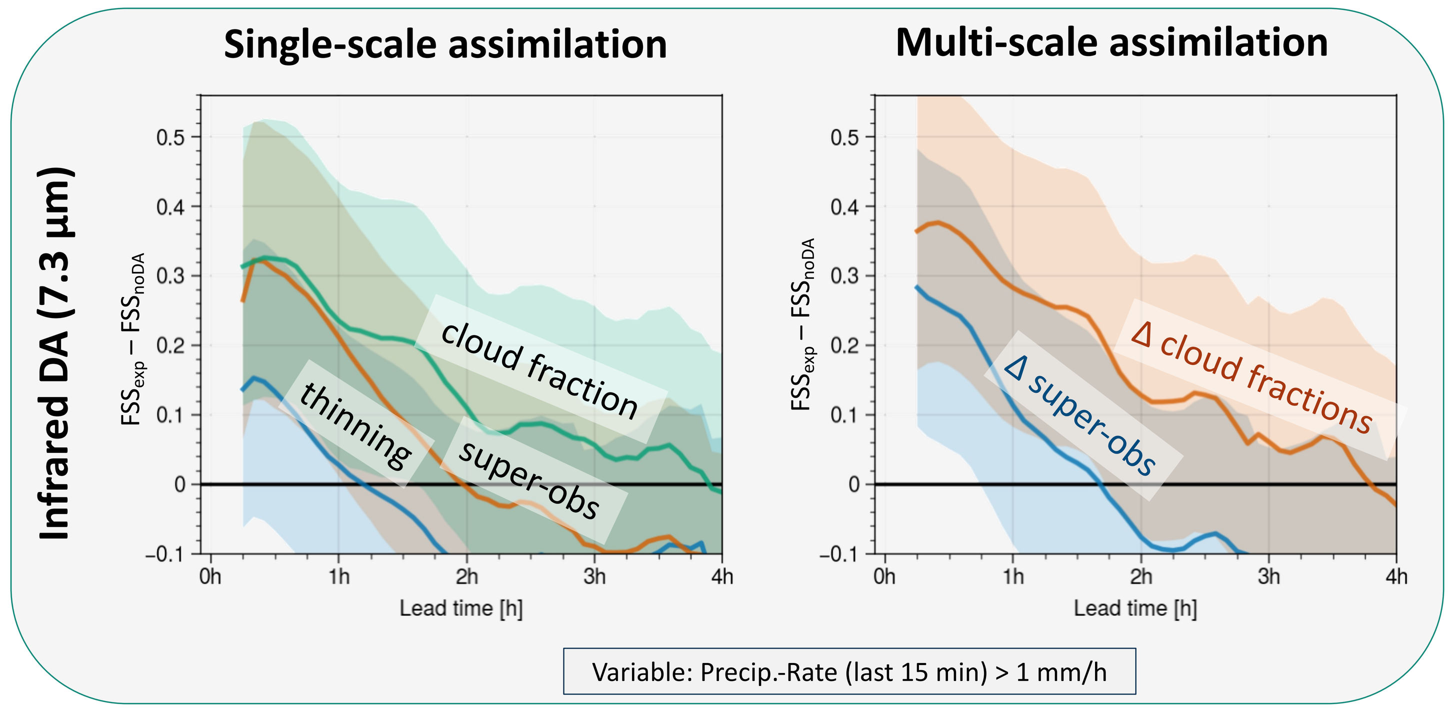
4. Results

Comparison of methods

- What is the forecast skill of precipitation?

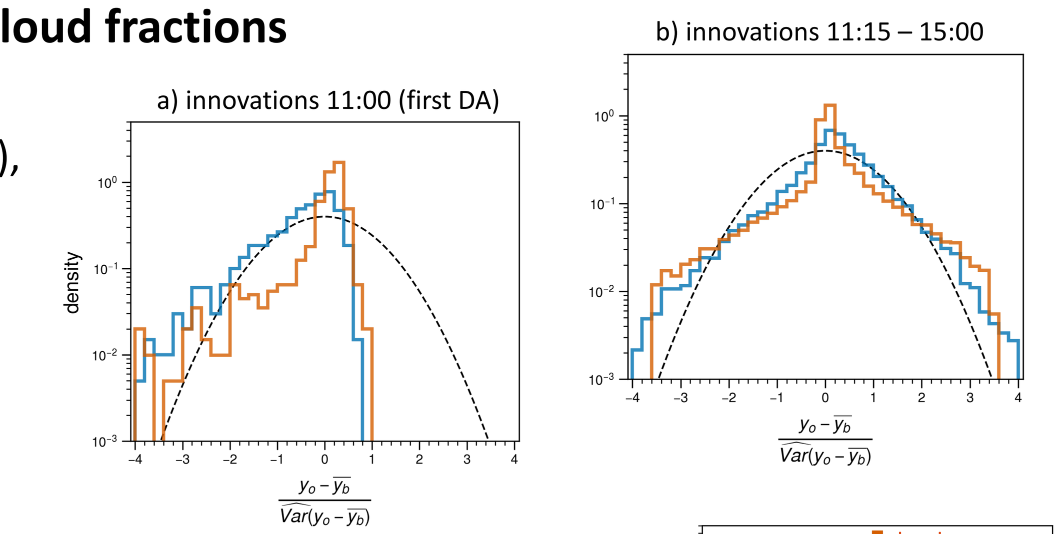
solid/shading: Average/STDEV over 4x 4-h forecasts.



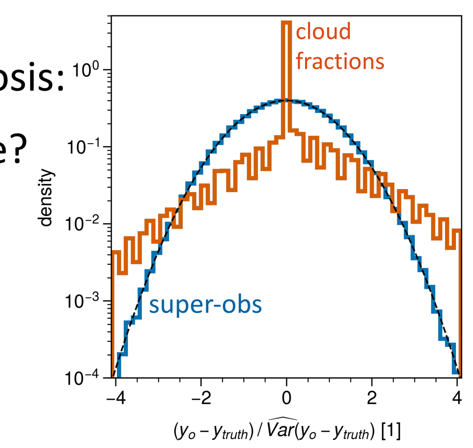


Pros and Cons of cloud fractions

- Innovations are less biased (a),
- but kurtosis increased (b).



- Observation error distribution gets increased kurtosis:
- Multiscale beneficial for infrared but not for visible?
- The assimilation benefit depends on the chosen threshold and the degree of noise.



Note: Results can depend on the chosen resolution; work in progress.

5. Conclusions / Take home messages

1. Super-obs mitigate noise, zero-gradient issues, and increase Gaussianity.
2. Cloud fractions (CF) can mitigate the effect of biases, but it requires good knowledge of these biases and suitable tuning.
3. Benefits of multi-scale assimilation methods yet unclear.

6. References

Otsuka et al. 2023. "Assimilating Precipitation Features Based on the Fractions Skill Score: An Idealized Study with an Intermediate AGCM." In Numerical Weather Prediction: East Asian Perspectives, 283–94.

Roberts & Lean 2008. "Scale-Selective Verification of Rainfall Accumulations from High-Resolution Forecasts of Convective Events." Monthly Weather Review 136(1): 78–97.