Incorporating Cell Evolution into Object-based Convective Storm Nowcasting

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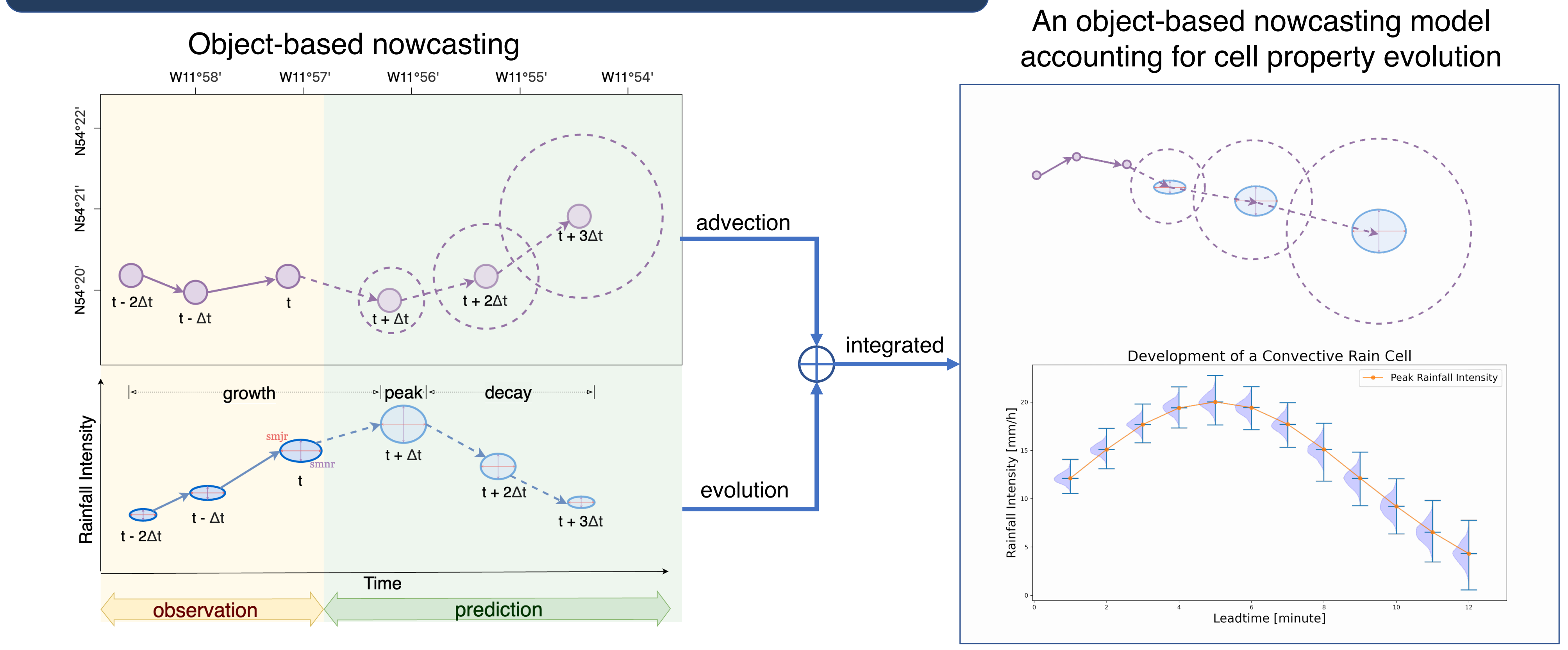
(1) Overview

- Many existing object-based nowcasting techniques focus primarily on positional forecasting and overlook the evolution of rainfall intensities.
- a recent study by Cheng et al. (2024) highlights the potential of 3D radar data and deep-learning techniques in accurately predicting the evolution of convective cell properties.
- This work aims at elaborating Cheng's evolution prediction model and further integrate it into a Kalman filter-based positional forecasting model, such that the rainfall intensity evolution can be accounted for through the nowcasting process.

(2) Methodology



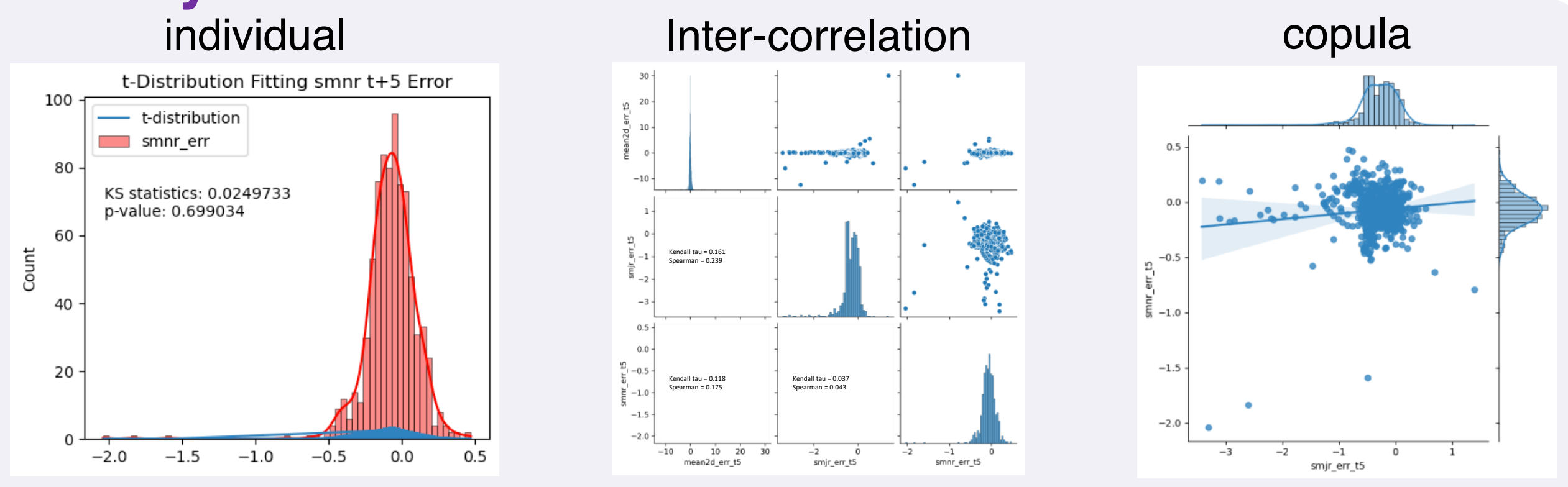
Main challenges and our solutions

① Quantification of evolution uncertainty

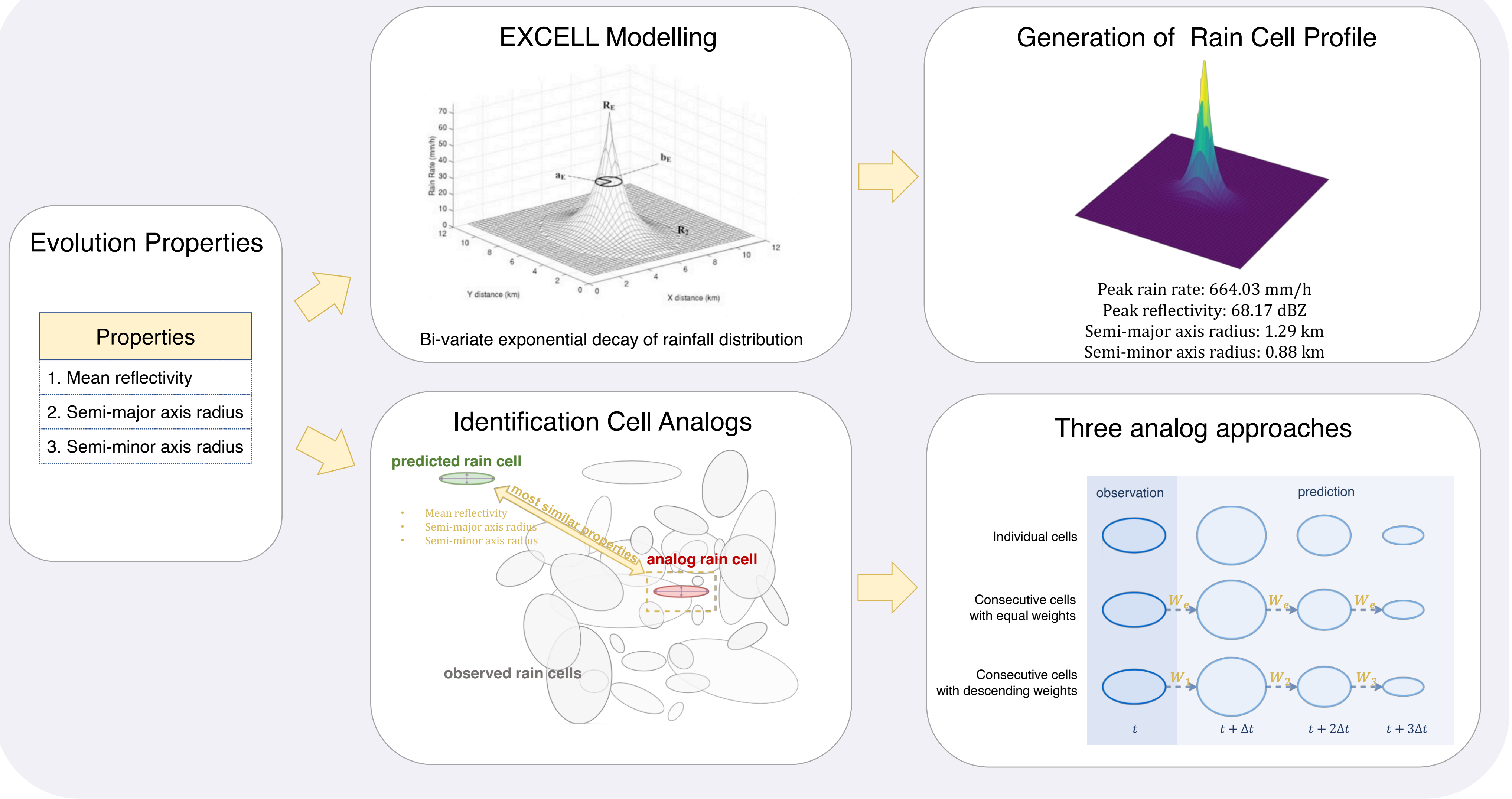
Prediction Errors

1. Mean reflectivity errors
2. Semi-major axis radius errors
3. Semi-minor axis radius errors

analysis



② Generation of spatially-distributed convective rain cells



Evolution Properties

Properties

1. Mean reflectivity
2. Semi-major axis radius
3. Semi-minor axis radius

EXCELL Modelling

Bi-variate exponential decay of rainfall distribution

Generation of Rain Cell Profile

Peak rain rate: 664.03 mm/h
Peak reflectivity: 68.17 dBZ
Semi-major axis radius: 1.29 km
Semi-minor axis radius: 0.88 km

Identification Cell Analogs

predicted rain cell

analog rain cell

observed rain cells

Three analog approaches

Individual cells

Consecutive cells with equal weights

Consecutive cells with descending weights

Fig 1. The overview of proposed methodology and approach to our research challenges

(3) Quantification of Evolution Uncertainty

Statistical characteristics and inter-correlation of cell properties

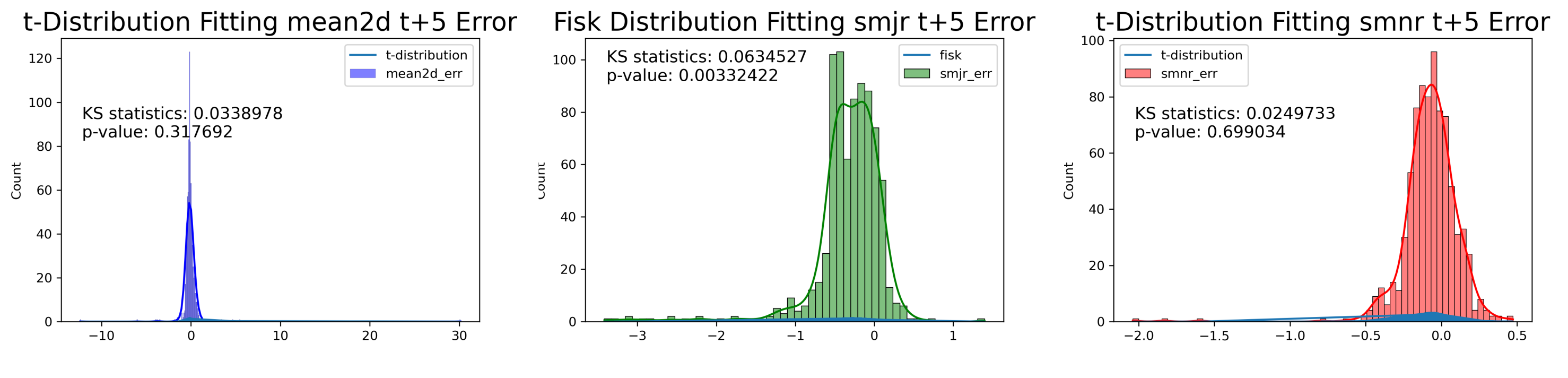


Fig 2. Comparative statistical fittings for the prediction errors of rain cell attributes at a 5-minute forecast lead time. The student-t distribution closely models the errors in mean reflectivity and semi-minor axis radius, as evidenced by the KS test. In contrast, the semi-major axis radius error aligns well with a log-logistic distribution.

To efficiently sample predicted rain cell properties, we analysed the evolution error characteristics and the non-negligible interdependencies between properties. A multivariate Gaussian copula model was utilised to flexibly capture the intricate dependence structure among these properties.

Multi-variate copula model generation for synthetic sampling

We can estimate the quality of synthetic data by visual analysis of Fig. 4(a). The Gaussian-copula model reproduce the dependence structure between pairs of cell evolution predicted errors. Besides, the marginal probability distribution of Gaussian-copula data preserves the characteristics of original predicted error data.

Fig 5. illustrates the probabilistic distribution of rainfall rates across a convective cell's major axis, integrating evolution uncertainty into the forecasting model. The grey dashed lines represent the range of possible outcomes, encapsulating the variability due to forecast uncertainty, while the solid red line indicates the central tendency of predicted rainfall intensity.

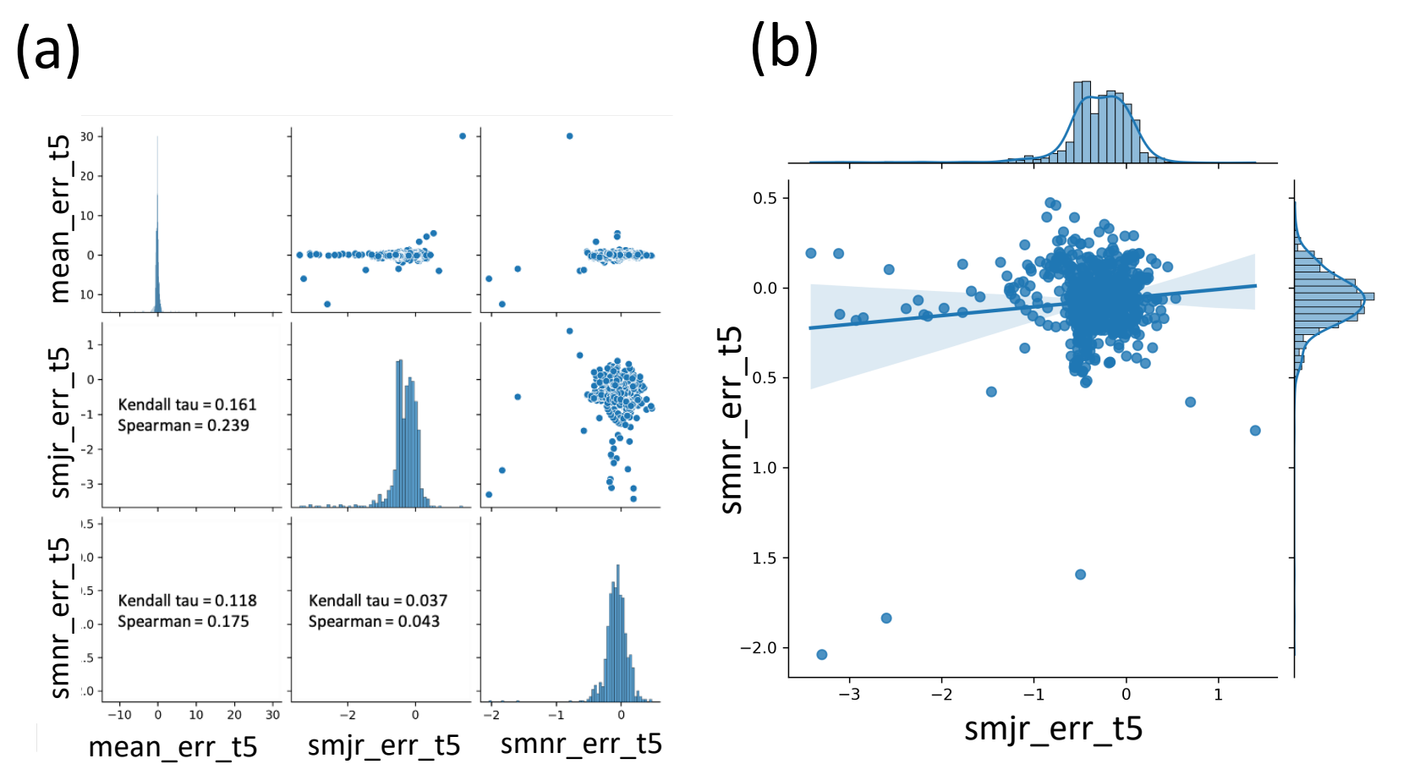


Fig 3. Multivariate analysis of forecast error distributions: (a) Pairwise scatter plots with corresponding Kendall's τ and Spearman's ρ values. (b) Joint distribution analysis combining scatter and marginal histogram plots.

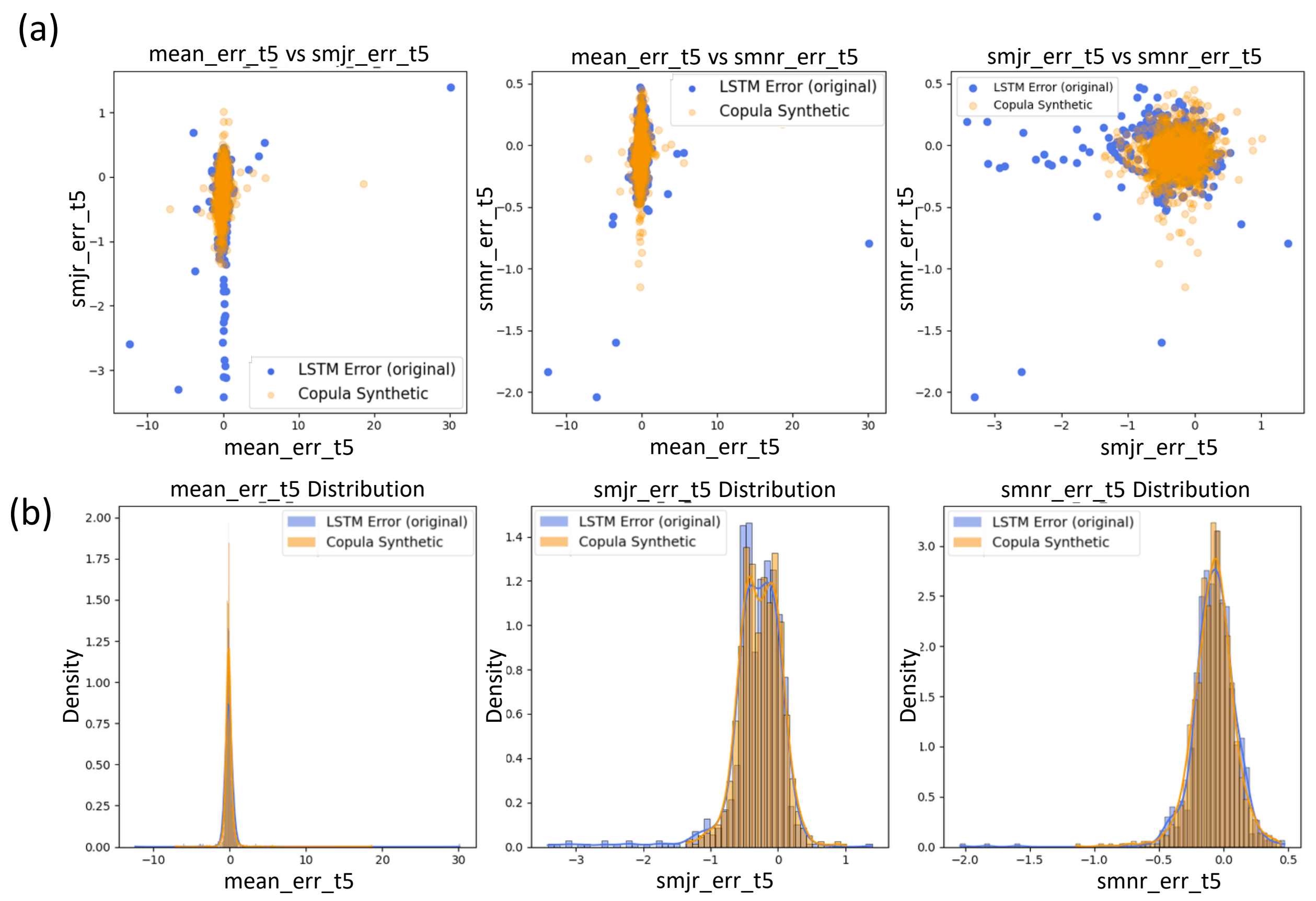


Fig 4. The comparison of original predicted errors from Cheng et al. (2024)'s evolution model and the synthetic error data generated from the Gaussian-copula model.

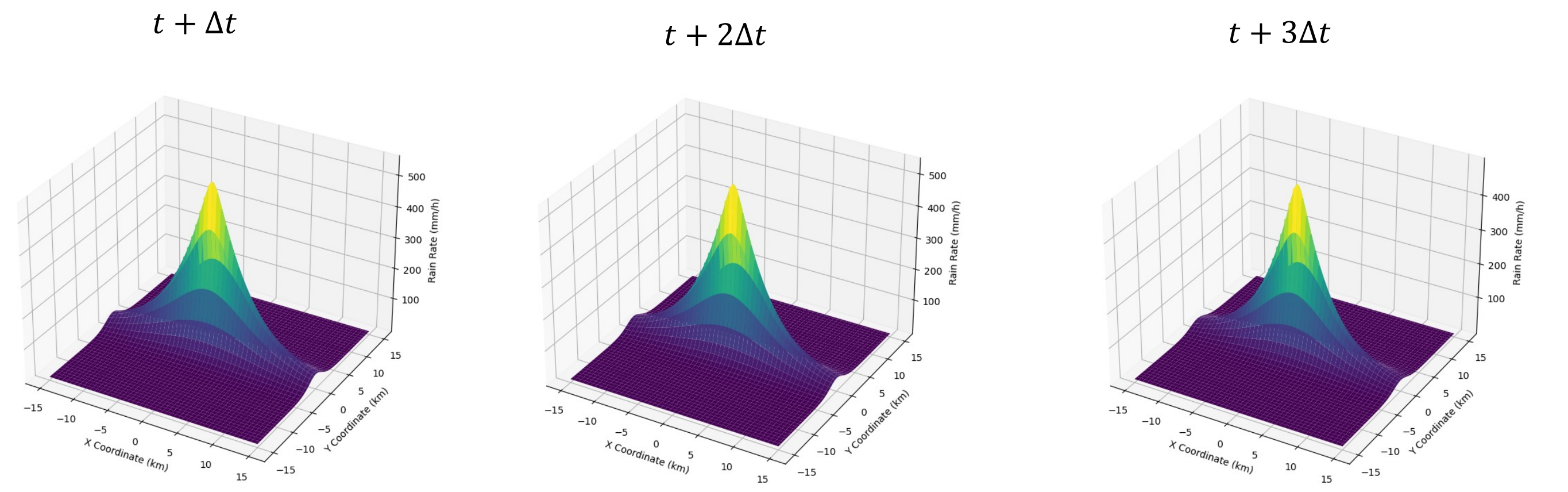
(4) Spatially-Distributed Rain Cells

Based on EXCELL model [1], the rain rate distribution within a cell is modelled as an exponential decay function with an elliptic horizontal shape characterised by peak rain rate R_E, semi-major axis a_E, and semi-minor axis b_E:

$$R(x,y) = R_E \exp\left[-\left(\frac{x^2}{{a_E}^2}+\frac{y^2}{{b_E}^2}\right)^{\frac{1}{2}}\right] for\ R \geq R_2 \cdots (1)$$

The peak rain rate R_E can be derived by fit-forcing a nonlinear equation using parameters determined from the radar observations:

$$\overline{R_r} = \frac{1}{A_r}\iint R(x,y)dxdy = 2R_E\left[1-\left(\frac{R_2}{R_E}\right)\left(1+ln\frac{R_E}{R_2}\right)\right]\Big/ln^2\left(\frac{R_E}{R_2}\right) \cdots (2)$$



Peak rain rate: 641.39 mm/h
Peak reflectivity: 67.92 dBZ
Semi-major axis radius: 5.29 km
Semi-minor axis radius: 1.01 km

Peak rain rate: 630.62 mm/h
Peak reflectivity: 67.81 dBZ
Semi-major axis radius: 4.99 km
Semi-minor axis radius: 0.97 km

Peak rain rate: 580.04 mm/h
Peak reflectivity: 67.23 dBZ
Semi-major axis radius: 4.61 km
Semi-minor axis radius: 0.99 km

Fig 2. The spatial-distributed of cells via fitting EXCELL model using predicted properties from the evolution model.

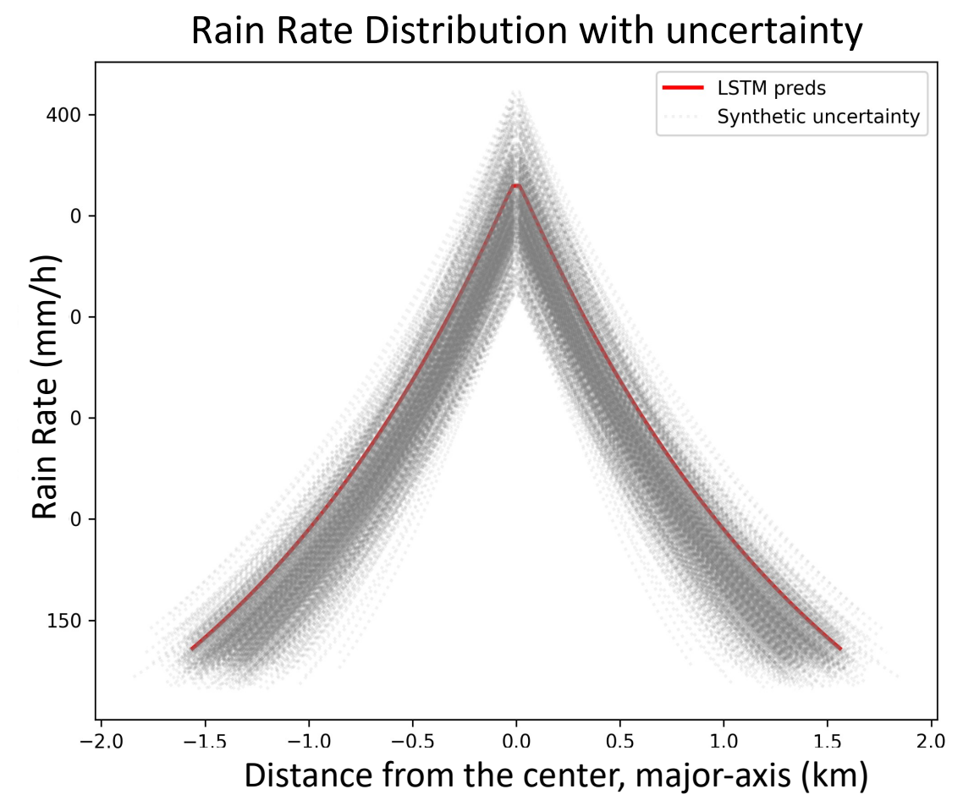


Fig 5. The distribution of rainfall rate considering the evolution uncertainty.

Abstract

Sharing is encouraged

(5) Future Work

Drawing from the established progress in adapting the evolution model, we have successfully constructed spatially-distributed rain cell profiles and quantified the associated prediction uncertainties. Our future endeavors will focus on refining the integration of the convective cell evolution model with the Kalman filter-based positional forecasting model [3], aiming to enhance the predictive accuracy and reliability of nowcasting high-intensity convective rainfall events.

References

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2. Cheng, Y. S., Wang, L. P., Scovell, R. W., & Wright, D. (2024). Exploring the use of 3D radar measurements in predicting the evolution of single-core convective cells. *Atmospheric Research*, 107380.
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