Review Comments

Title: Improving the fine structure of intense rainfall forecast by a designed adversarial generation network

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Recommendation

This manuscript proposes a Generative Adversarial Fusion Network (GFRNet) for short-term precipitation forecasting in North China, aiming to improve the accuracy of 3-h accumulated precipitation predictions over a 24-h period. The study optimizes data sampling strategies, loss functions, and model architecture, demonstrating GFRNet's superiority over numerical weather prediction (NWP) models in metrics such as TS, FSS, and RMSE. The paper is well-structured, with a logical experimental design and thorough result analysis, showing both innovation and practical value.

However, limitations remain in model generalization analysis, physical interpretability, and stability in extreme precipitation forecasting, which require further discussion and improvement, and methodological details (e.g., hyperparameter selection) should be expanded.

The English of the paper is generally good enough to be understood, but with some polishing, the paper could achieve more professional, natural-sounding academic English. The technical content is clear, but the language could be more precise in places. None of the issues seriously impede understanding but correcting them would elevate the paper's professionalism. I would recommend having the English grammar professionally checked by a specialized editing

service.

The paper is recommended for publication after major revisions, and future work could explore advanced architectures and broader applications.

General Comments

I suggest ablation studies or explainability analyses (e.g., SHAP, DeepLIFT, or similar tools) are needed for the AI-based precipitation forecasting paper.

(1) Ablation Studies (Highly Recommended)

- Purpose: Validate the necessity of GFRNet's key components (GAN strategy, SE blocks, weighted loss).

- Suggested Tests:

- Remove GAN discriminator (compare with FRNet results).

- Ablate SE attention blocks.

- Test without weighted loss (standard MSE/MAE).

- Justification: The paper claims GANs address blurring, but quantitative evidence is needed to isolate its contribution versus other components.

(2) Explainability Methods (Conditionally Useful)

- SHAP/DeepLIFT Value: Limited for pure precipitation prediction, as:

- Input variables are homogeneous (all are precipitation forecasts + topography/temporal features).

- The model’s nonlinear fusion process matters more than individual feature importance.

- Alternative Approaches:

- Sensitivity Analysis: Perturb input NWP models (e.g., mask

ECMWF/CMA-3KM inputs) to quantify their relative contributions.

- Physical Interpretability: Analyze whether GFRNet's predictions align with meteorological principles (e.g., orographic precipitation patterns near Taihang Mountains).

Specific Comments

1. Methodology

- Strengths:

- The GAN strategy (WGAN-GP) mitigates blurry predictions, producing more realistic precipitation structures and intensities.

- The weighted loss function with exponential weighting enhances extreme precipitation learning.

- Suggestions for Improvement:

- The choice of hyperparameters (e.g., gradient penalty coefficient γ, loss weights a and b) lacks justification (e.g., grid search or ablation studies). Sensitivity analysis should be added.

- The generator (U-Net + SE block) and discriminator (DCGAN-based) architectures are conventional. Advanced generative models (e.g., Diffusion Models) or spatiotemporal attention mechanisms could further improve fine-scale precipitation capture. Some discussion is necessary.

2. Results and Analysis

- Strengths:

- Quantitative metrics (TS, FSS, RMSE) show GFRNet outperforms NWP models, particularly for heavy precipitation (e.g., significant TS improvement at 20 mm threshold).

- Case studies demonstrate GFRNet's ability to capture precipitation band evolution and intensity changes.

- Suggestions for Improvement:

- Some results are contradictory: e.g., GFRNet's TS for 40 mm (0.056) is lower than FRNet's (0.077). The authors should analyze whether this is due to GAN's conservative generation strategy (missed events).

- Spatial analysis shows higher BIAS in mountainous regions (e.g., west of Taihang Mountains). Terrain effects on model performance should be further discussed (e.g., elevation-dependent constraints).

3. Discussion and Future Work

- Strengths:

- Clear future directions (e.g., higher resolution, physics-informed learning, ensemble forecasting) are proposed.

- Suggestions for Improvement:

- Limitations are under-discussed: e.g., GFRNet relies on multi-model inputs—how does it handle systematic biases in individual models (e.g., CMA-3KM)?

- Computational costs (3-h training on A100 GPU) are not evaluated for operational feasibility. Real-time deployment constraints should be addressed.

Minor Issues

- The title emphasizes "intense rainfall," but the paper does not justify the 40 mm/3h threshold (is it a standard benchmark?).

- In Figure 6 (FSS spatial gain), white regions (FSS=0) are unexplained and could be misleading.

- Consistency Check:

    - Ensure consistent use of terms (e.g., "deep learning" vs. "Deep Learning").

    - Check all acronyms are defined at first use.

    - Verify all citations follow the same style.

- Line 2: "the accuracy of precipitation forecasts remains significantly inadequate" --> "the accuracy...remains inadequate" or "is significantly inadequate".

- Line 6: "based on the outputs of multiple numerical weather models" --> "based on outputs from multiple numerical weather models".

- Line 74: "We apply the GAN strategy in developing the GFRNet model" --> "We implement a GAN strategy to develop the GFRNet model".

- Line 81: "The target area features a complex topography" --> "The target area features complex topography".

- Line 85: "CMA Multi-source merged Precipitation Analysis System(CMPAS)" --> Needs spaces: "CMA Multi-source merged Precipitation Analysis System (CMPAS)"; Similarly, a space is required between the preceding English word and the opening parenthesis. Please check all parts of the paper.

- Line 101-102: "Let r3(T) denote the accumulated precipitation over the past 3 hours at time T, with the learning target being r3(T) from CMPAS." --> "Let r3(T) denote the 3-hour accumulated precipitation at time T, where the learning target is the corresponding CMPAS r3(T) observation."

- Line 143: "a U-Net with encoder-decoder architecture" --> "a U-Net with an encoder-decoder architecture".

- Table 1 Title: "Data Sources and Features Used in Model" --> "Data sources and features used in the model".