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Supplement of

A self-supervised precipitation forecast verification based on contrastive learning

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S1. Supplemental Contents of weather prediction models in the CMA dataset

Table S1 shows the supplemental contents of the CMA dataset used in experts survey experiments of this research.

Table S1. Supplemental contents of weather prediction models in the CMA dataset

Abbreviation in this research	Full name	Developing instruction	Original data spatial coverage	Recommended applicable region
MESO	Global/Regional Assimilation Prediction System (GRAPE) - short-term and mesoscale (MESO)	China Meteorological Administration	20.02°N-34.99°N，105.01°E-119.98°E	All over China with mesoscale
GD	China Meteorological Administration (CMA)- Guangdong Rapid Refresh Assimilation Numerical Prediction System (GD)	Guangdong Meteorological Service	20.02°N-34.99°N，105.01°E-119.98°E	South China regions
SH	China Meteorological Administration (CMA)- Shanghai Rapid Refresh Assimilation Numerical Prediction System (SH)	Shanghai Meteorological Service	20.03°N-35.00°N，106.00°E - 119.98°E	East China regions

S2. Normalization of FAR and SAL.

The value range of FAR is [0, 1], with lower values indicating more accurate precipitation forecasts. Its normalization is as Eq. (S1) shows

$$normalized\ FAR = 1 - FAR \tag{S1}$$

The value ranges of S and A are [-2, 2], with lower absolute values indicating more accurate precipitation forecasts. Their normalizations are as Eq. (S2) shows

$$normalized\ S\ (or\ A) = \frac{2 - |S\ (or\ A)|}{2} \tag{S2}$$

The value range of L is [0, 2], with lower absolute values indicating more accurate precipitation forecasts. Its normalization is as Eq. (S3) shows:

$$normalized\ L = \frac{2 - L}{2} \tag{S3}$$

Finally, the normalized SAL is as Eq. (S4) shows, calculated by averaging normalized S, normalized A, and normalized L.

$$normalized\ SAL = \frac{normalized\ S + normalized\ A + normalized\ L}{3} \tag{S4}$$

S3. Raw results of comparative experiments

Fig. S1, S2, S3 are raw results of displacement biases, intensity biases, and area size biases experiments respectively.

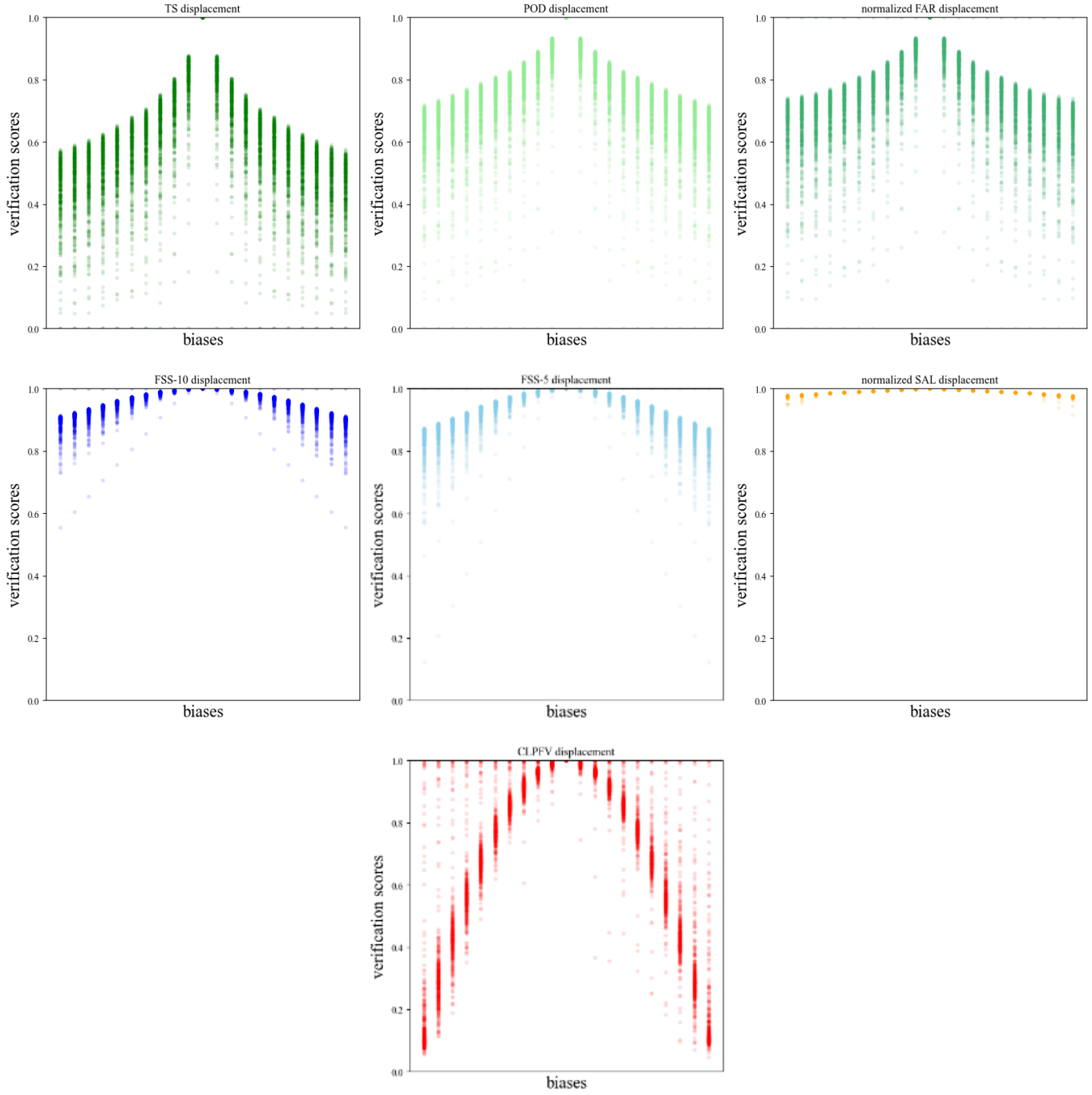


Figure S1. Raw results of displacement biases experiments. First row, from left to right: TS, POD, normalized FAR. Second row, from left to right: FSS-10, FSS-5, normalized SAL. Third row: CLPFV.

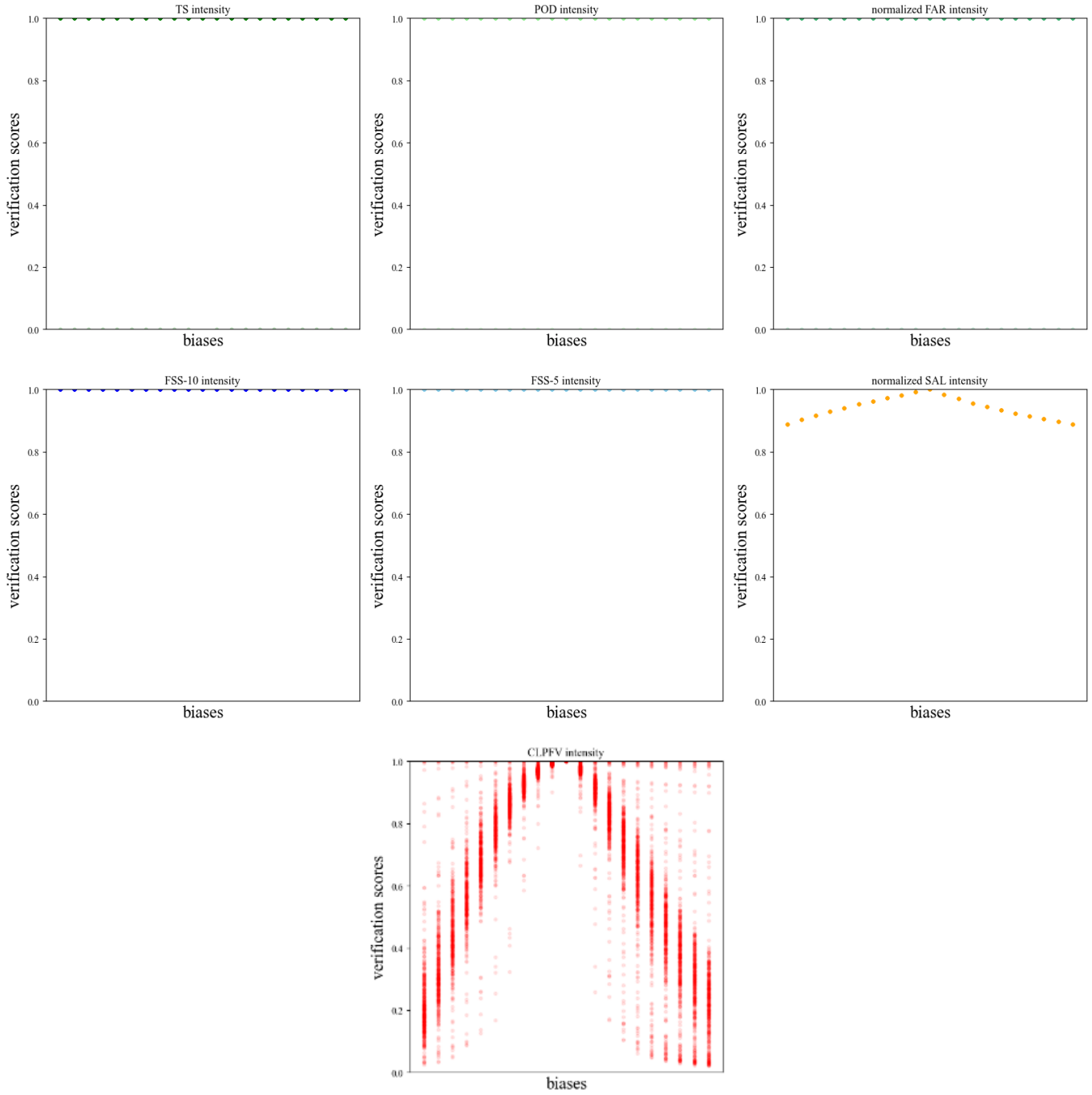


Figure S2. Raw results of intensity biases experiments. First row, from left to right: TS, POD, normalized FAR. Second row, from left to right: FSS-10, FSS-5, normalized SAL. Third row: CLPFV.

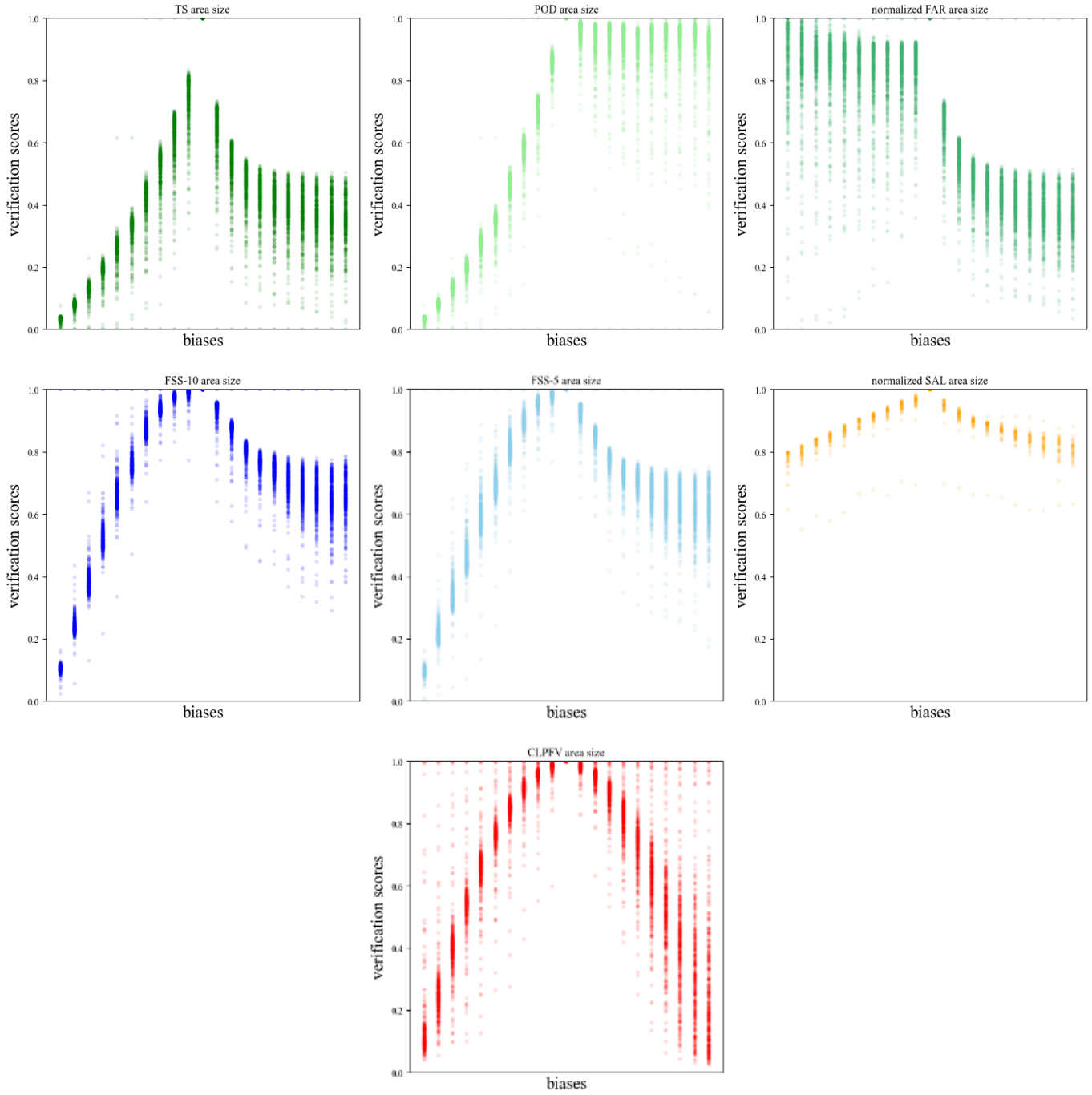
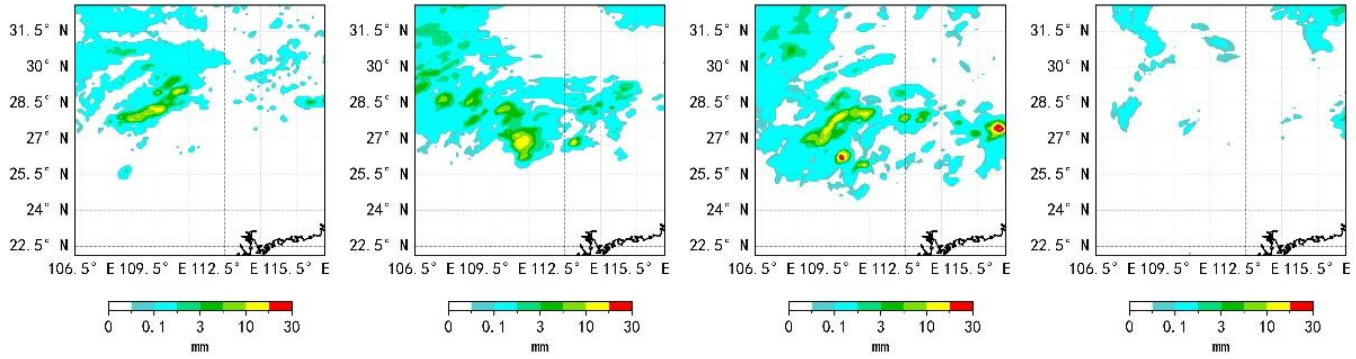


Figure S3. Raw results of intensity biases experiments. First row, from left to right: TS, POD, normalized FAR. Second row, from left to right: FSS-10, FSS-5, normalized SAL. Third row: CLPFV.

S4. Questionnaire of experts survey

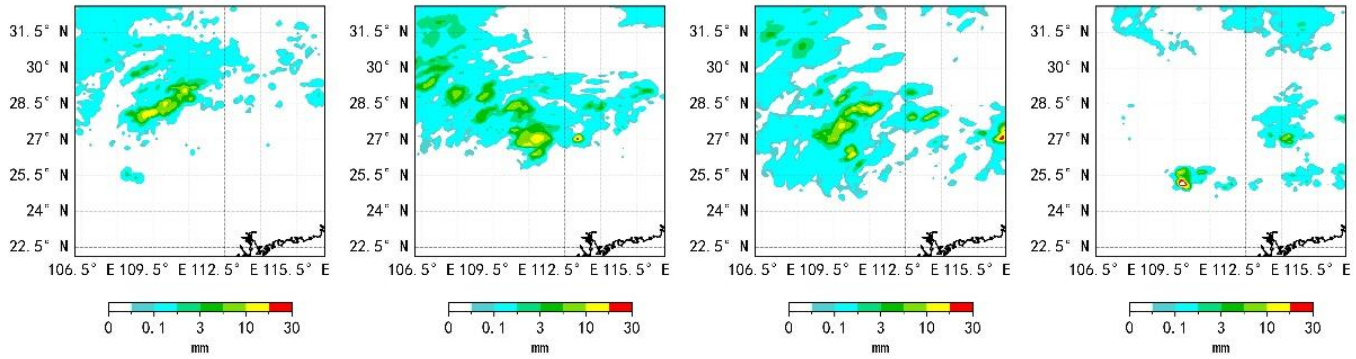
In all questions, the order of forecast precipitations is always: MESO, GD, SH. However, to prevent experts from forming preconceived judgments about the weather prediction models, the specific names of the forecast precipitations are omitted in the questions.

Question 1: Please rank the three forecasted precipitations in descending order of accuracy: (1)____, (2)____, (3)____.



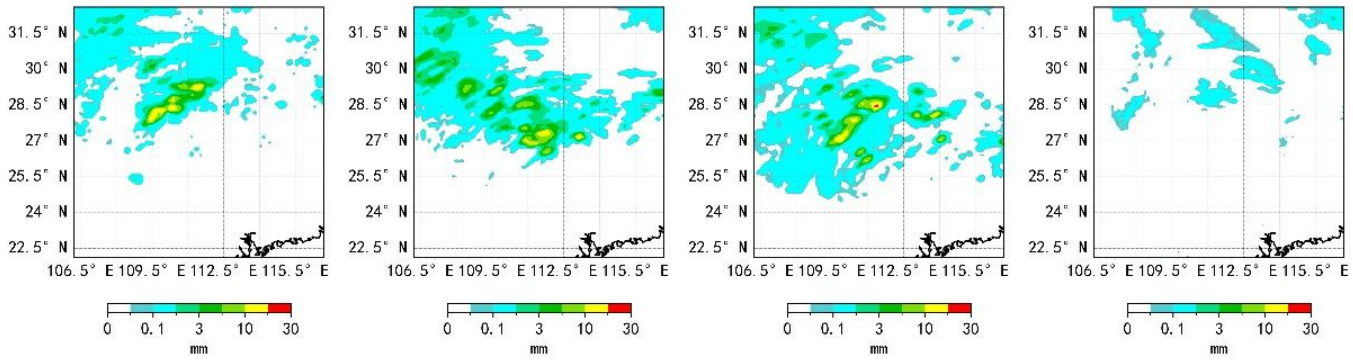
From left to right: observed precipitation, forecasted precipitation 1, forecasted precipitation 2, forecasted precipitation 3.

Question 2: Please rank the three forecasted precipitations in descending order of accuracy: (1)____, (2)____, (3)____.



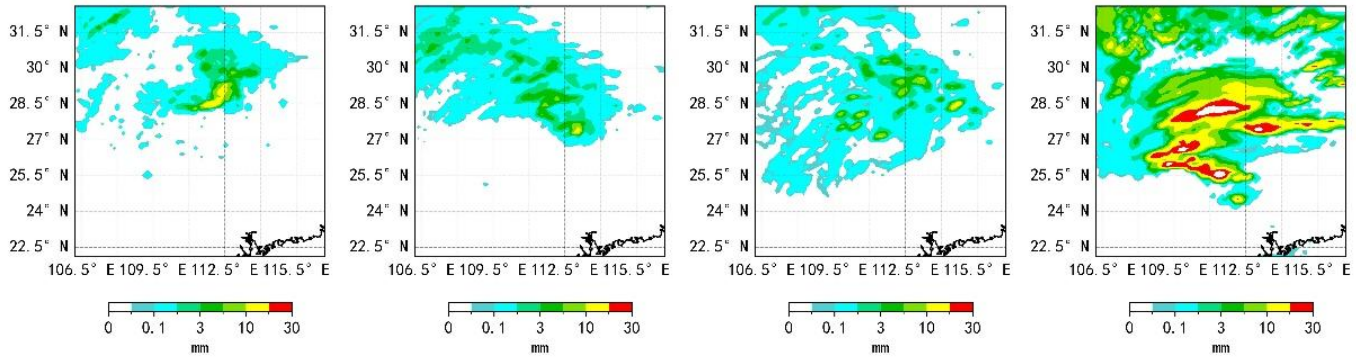
From left to right: observed precipitation, forecasted precipitation 1, forecasted precipitation 2, forecasted precipitation 3.

Question 3: Please rank the three forecasted precipitations in descending order of accuracy: (1)____, (2)____, (3)____.



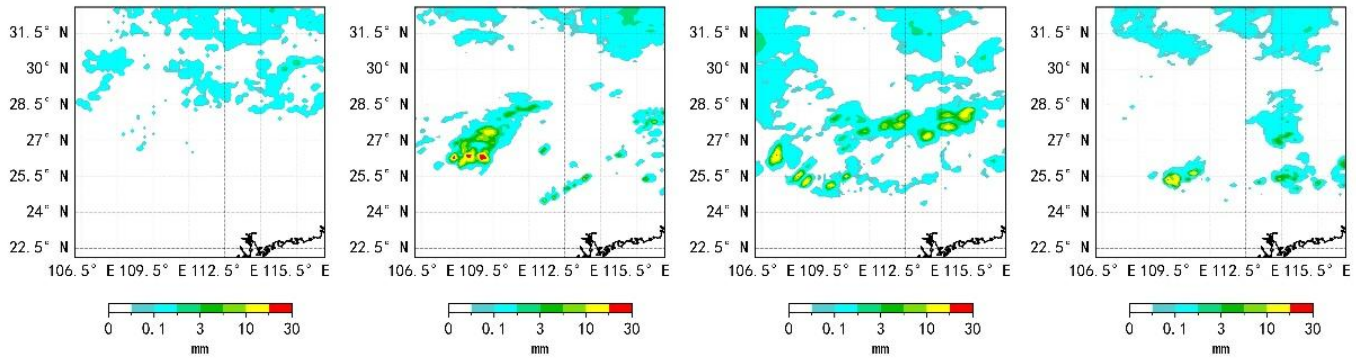
From left to right: observed precipitation, forecasted precipitation 1, forecasted precipitation 2, forecasted precipitation 3.

Question 4: Please rank the three forecasted precipitations in descending order of accuracy: (1)____, (2)____, (3)____.



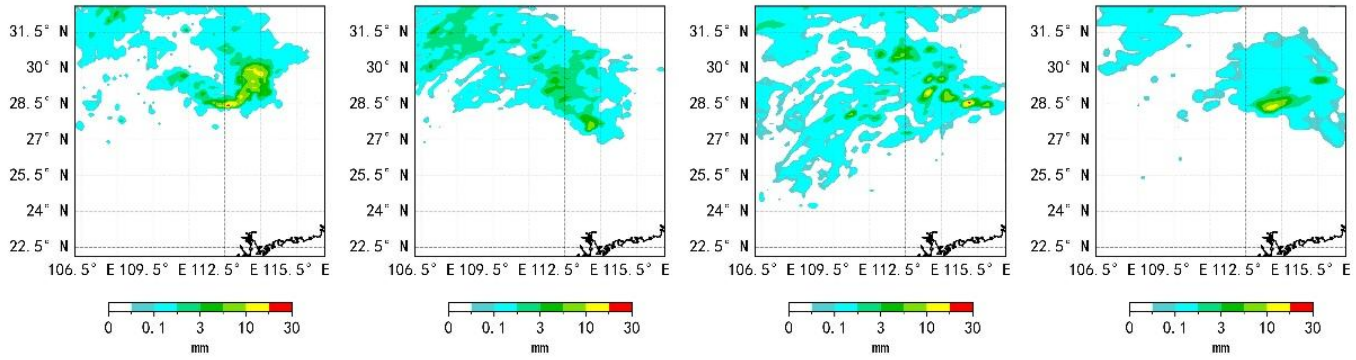
From left to right: observed precipitation, forecasted precipitation 1, forecasted precipitation 2, forecasted precipitation 3.

Question 5: Please rank the three forecasted precipitations in descending order of accuracy: (1)____, (2)____, (3)____.



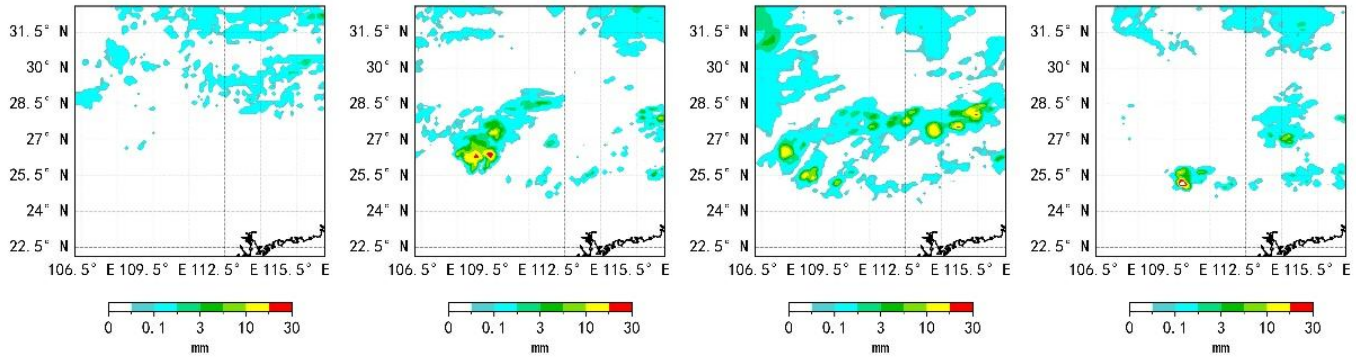
From left to right: observed precipitation, forecasted precipitation 1, forecasted precipitation 2, forecasted precipitation 3.

Question 6: Please rank the three forecasted precipitations in descending order of accuracy: (1)____, (2)____, (3)____.



From left to right: observed precipitation, forecasted precipitation 1, forecasted precipitation 2, forecasted precipitation 3.

Question 7: Please rank the three forecasted precipitations in descending order of accuracy: (1)____, (2)____, (3)____.



From left to right: observed precipitation, forecasted precipitation 1, forecasted precipitation 2, forecasted precipitation 3.

S5. Raw results of experts survey experiments

Table S2 shows the collected raw results of questionnaires from 36 experts.

Table S2. Collected raw results of questionnaires from 36 experts.

Question	Experts ranking benchmark	Rank 1st			Rank 2nd			Rank 3rd		
		MESO	GD	SH	MESO	GD	SH	MESO	GD	SH
1	MESO, GD, SH	20	15	1	15	19	2	2	2	32
2	GD, MESO, SH	16	20	13	20	13	3	3	1	32
3	GD, MESO, SH	4	28	4	28	6	2	2	3	31
4	MESO, GD, SH	23	12	1	14	20	2	1	3	32
5	SH, GD, MESO	3	15	18	10	12	14	18	11	7
6	MESO, SH, GD	15	6	15	12	13	11	9	10	17
7	SH, GD, MESO	8	12	16	11	10	15	14	12	10

Table S3 shows the calculated verifications of PFV methods for questions.

Table S3. Calculated verification scores of PFV methods.

TS				
Question	Ranking	MESO	GD	SH
1	MESO, GD, SH	0.34	0.28	0.20
2	MESO, GD, SH	0.38	0.28	0.22
3	MESO, GD, SH	0.38	0.30	0.29
4	MESO, GD, SH	0.42	0.33	0.28
5	SH, MESO, GD	0.21	0.18	0.24
6	MESO, SH, GD	0.45	0.35	0.38
7	SH, MESO, GD	0.15	0.14	0.22

POD				
Question	Ranking	MESO	GD	SH
1	GD, MESO, SH	0.74	0.76	0.34
2	MESO, GD, SH	0.79	0.75	0.37
3	GD, MESO, SH	0.81	0.77	0.48
4	GD, MESO, SH	0.81	0.89	0.79
5	GD, SH, MESO	0.50	0.67	0.58
6	GD, MESO, SH	0.83	0.91	0.81
7	GD, SH, MESO	0.41	0.64	0.57

normalized FAR				
Question	Ranking	MESO	GD	SH
1	MESO, SH, GD	0.40	0.31	0.32
2	MESO, SH, GD	0.42	0.31	0.37
3	SH, MESO, GD	0.42	0.34	0.43
4	MESO, GD, SH	0.42	0.35	0.29
5	SH, GD, MESO	0.27	0.20	0.29
6	MESO, SH, GD	0.64	0.21	0.33
7	SH, GD, MESO	0.20	0.17	0.26

FSS-10				
Question	Ranking	MESO	GD	SH
1	SH, MESO, GD	0.74	0.64	0.78
2	MESO, SH, GD	0.77	0.65	0.76
3	SH, MESO, SH	0.77	0.66	0.80
4	MESO, GD, SH	0.80	0.65	0.62
5	SH, MESO, GD	0.72	0.46	0.75
6	MESO, SH, GD	0.82	0.67	0.78
7	SH, MESO, GD	0.59	0.41	0.73

FSS-5				
Question	Ranking	MESO	GD	SH
1	MESO, SH, GD	0.67	0.58	0.65
2	MESO, SH, GD	0.70	0.59	0.63
3	MESO, SH, GD	0.71	0.60	0.69
4	MESO, GD, SH	0.75	0.62	0.57
5	SH, MESO, GD	0.61	0.43	0.63
6	MESO, SH, GD	0.78	0.63	0.74
7	SH, MESO, GD	0.48	0.37	0.62

SAL				
Question	Ranking	MESO	GD	SH
1	MESO, GD, SH	0.80	0.66	0.60
2	MESO, GD, SH	0.80	0.75	0.55
3	MESO, GD, SH	0.86	0.79	0.60
4	MESO, GD, SH	0.87	0.80	0.62
5	SH, MESO, GD	0.57	0.42	0.68
6	MESO, GD, SH	0.87	0.83	0.77
7	SH, MESO, GD	0.57	0.51	0.64

CLPFV				
Question	Ranking	MESO	GD	SH
1	MESO, GD, SH	0.47	0.45	0.11
2	GD, MESO, SH	0.53	0.77	0.10
3	GD, MESO, SH	0.47	0.66	0.28
4	MESO, GD, SH	0.54	0.49	0.22
5	SH, GD, MESO	0.28	0.14	0.46
6	MESO, SH, GD	0.64	0.21	0.33
7	SH, GD, MESO	0.25	0.12	0.43

S6. Codes

All data and codes are shared in Zenodo platform, https://doi.org/10.5281/zenodo.16777790, including a ReadMe document, just as follows:

Training and validation

You can directly execute it in the ipynb file and use it:

- train.ipynb: documents used for training
- valid-exp1.ipynb: code for experiment 1
- valid-exp2.ipynb: code for experiment 2

Experimental results

Trunk folder:

- weight file for training
- the results of various verification scores under three operations: translation, rainfall transformation, and scaling

Datasets

1. training data
   - trainset_results.npz: training set of IFS dataset
   - result_223.npz: test set of IFS dataset
   - lon_69.npy, lat_69.npy: latitude and longitude
2. validation Data
   - user_survey_accumulate_data raw data
     - folder 01: contains raw data for three models: grapes_3km (MESO), GZ_grapes (GD), and SH
     - folder 2021: raw data of CMPA (observed precipitations of CMA dataset)
     - to-user_survey_data.ipynb: read the file and match the spatio-temporal resolution, outputting user_survey_accumulate_data.npz cumulative data
     - lon_84.npy, lat_84.npy: longitude and latitude
   - 84-ob_grape_3km_gz_grape_sh.npz: hourly data
   - 84-ts_bias_far_pod_sal_fss5-10.npy+84-clpv.npy: results of various verification scores

others: intermediate results of data verification

- lon_210.npy, lat_210.npy: ongitude and latitude
- 210-ob_grape_3km_gz_grape_sh.npz: hourly data
- 210-ts_bias_far_pod_sal_fss5-10.npy+210-clpv.npy: results of various verification scores

Tool category

- CLPV.py: CLPFV method tool class
- utils.py: used tools in codes