# 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

|  |  |
| --- | --- |
|  | (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

|  |  |
| --- | --- |
|  | (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:

|  |  |
| --- | --- |
|  | (S3) |

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

|  |  |
| --- | --- |
|  | (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.

图表, 直方图

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AI 生成的内容可能不正确。图表, 直方图

AI 生成的内容可能不正确。图表, 直方图

AI 生成的内容可能不正确。图表

AI 生成的内容可能不正确。图表, 直方图

AI 生成的内容可能不正确。图表, 散点图

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**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.**

图表

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**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.**

图表, 直方图

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AI 生成的内容可能不正确。图表

AI 生成的内容可能不正确。图表, 直方图

AI 生成的内容可能不正确。图表, 直方图

AI 生成的内容可能不正确。图表

AI 生成的内容可能不正确。图表

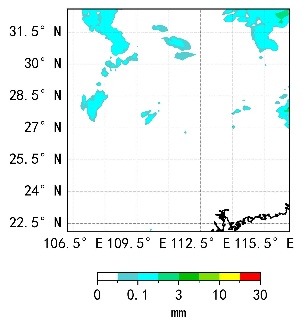
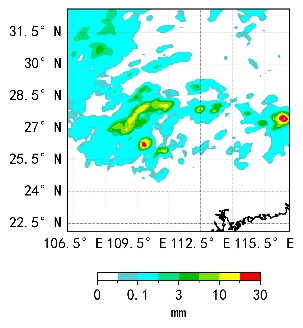
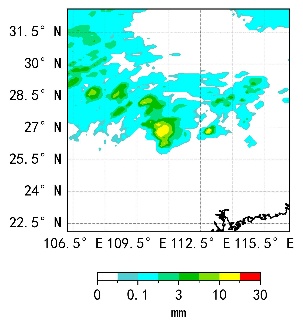
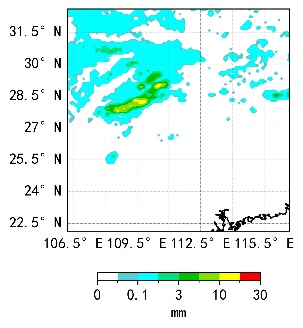
AI 生成的内容可能不正确。

**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

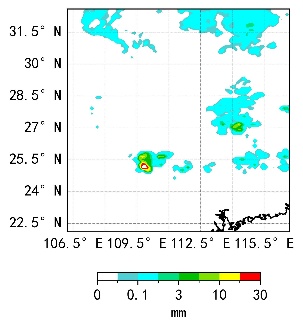
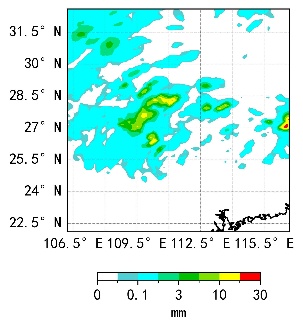
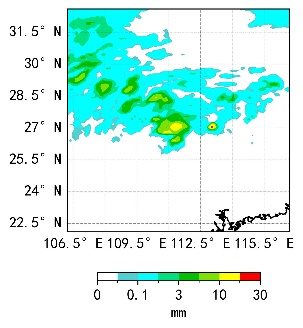
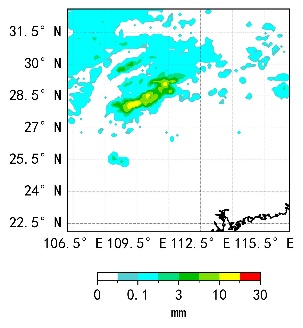
In all questions, the order of forecast precipitations is always: MESO, GD, SH. However, to prevent experts from forming preconceived judgments about the weather prediction models, the specific names of the forecast precipitations are omitted in the questions.

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



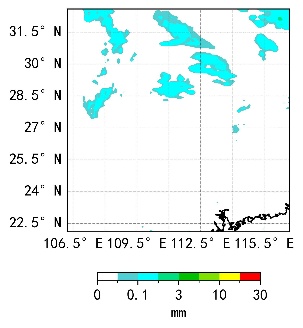
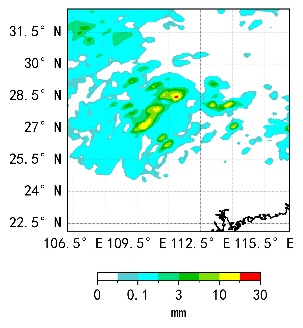
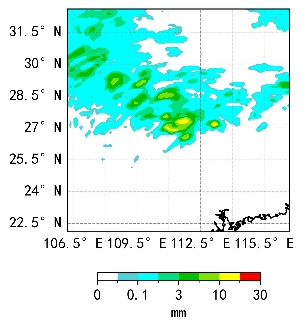
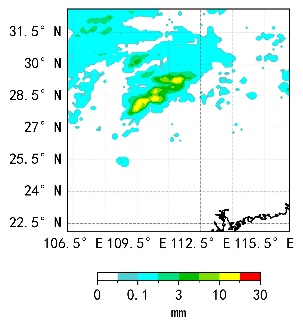
From left to right: observed precipitation, forecasted precipitation 1, forecasted precipitation 2, forecasted precipitation 3.

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



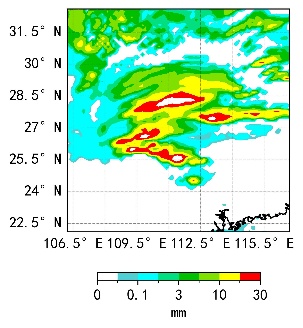
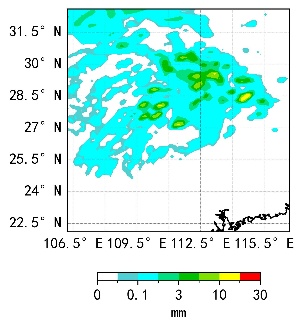
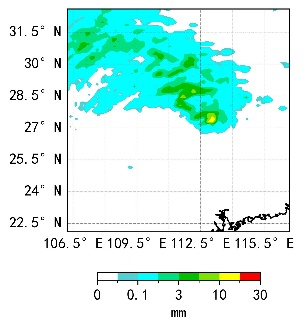
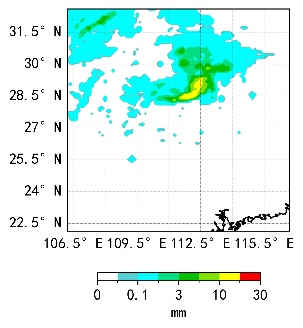
From left to right: observed precipitation, forecasted precipitation 1, forecasted precipitation 2, forecasted precipitation 3.

**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)\_\_\_\_.

图表, 散点图

AI 生成的内容可能不正确。图表, 散点图

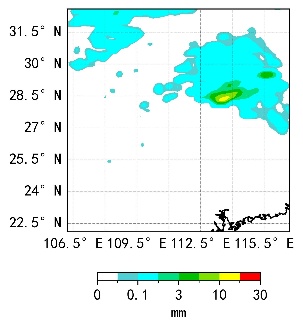
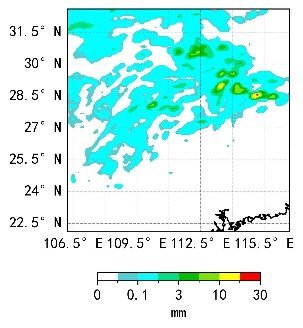
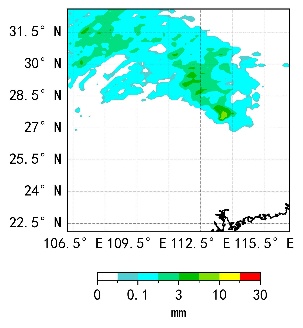
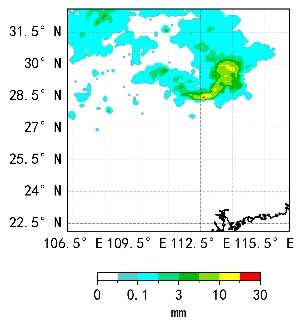
AI 生成的内容可能不正确。图表

AI 生成的内容可能不正确。图表, 散点图

AI 生成的内容可能不正确。

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)\_\_\_\_.

图表, 散点图

AI 生成的内容可能不正确。图表, 散点图

AI 生成的内容可能不正确。图表

AI 生成的内容可能不正确。图表, 散点图

AI 生成的内容可能不正确。

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

o folder 01: contains raw data for three models: grapes\_3km (MESO), GZ\_grapes (GD), and SH

o folder 2021: raw data of CMPA (observed precipitations of CMA dataset)

o to-user\_survey\_data.ipynb: read the file and match the spatio-temporal resolution, outputting user\_survey\_accumulate\_data.npz cumulative data

o 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