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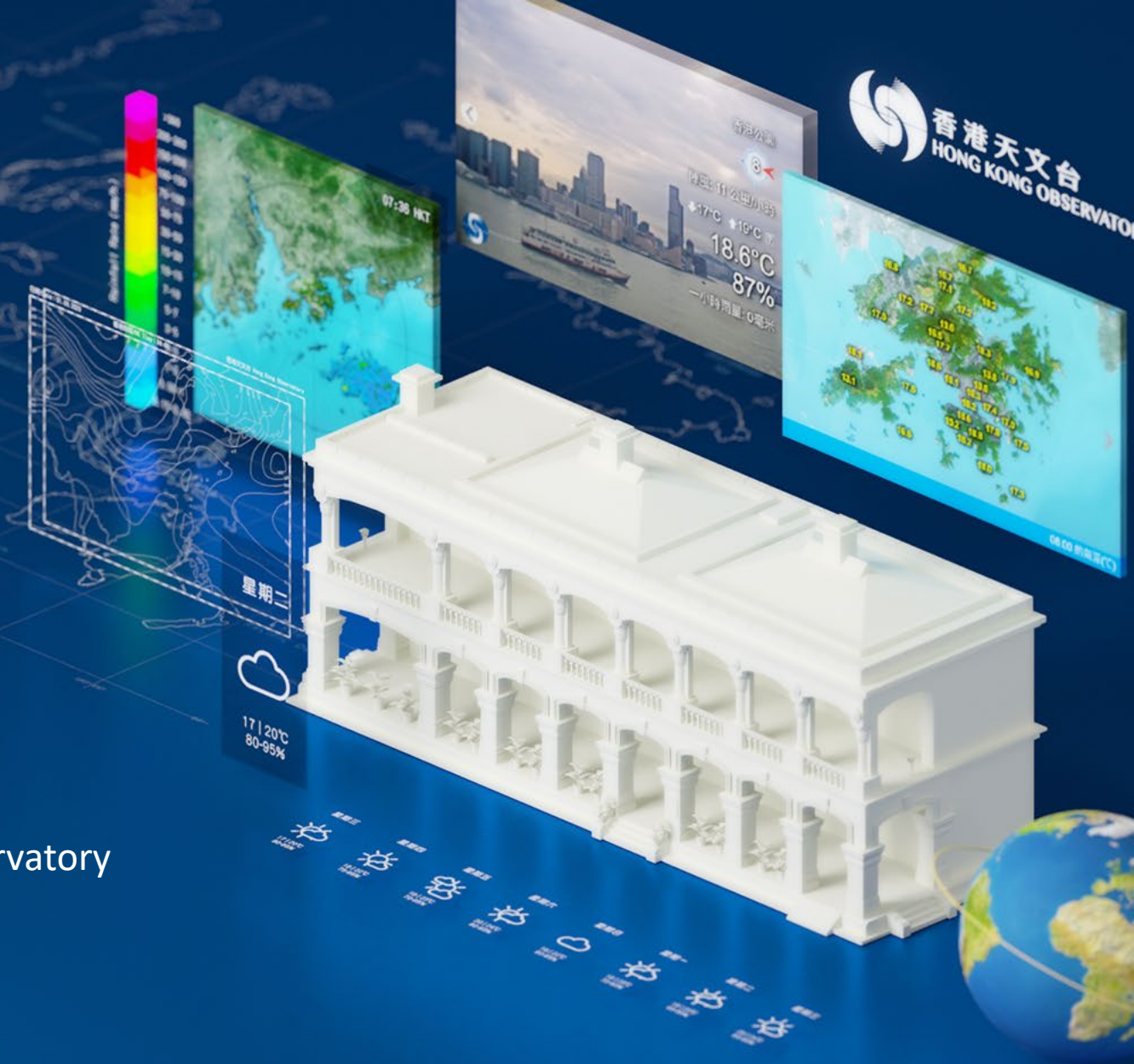
VERIFICATION AND ANALYSIS OF AVIATION JETSTREAM FORECAST FROM ARTIFICIAL INTELLIGENCE MODELS

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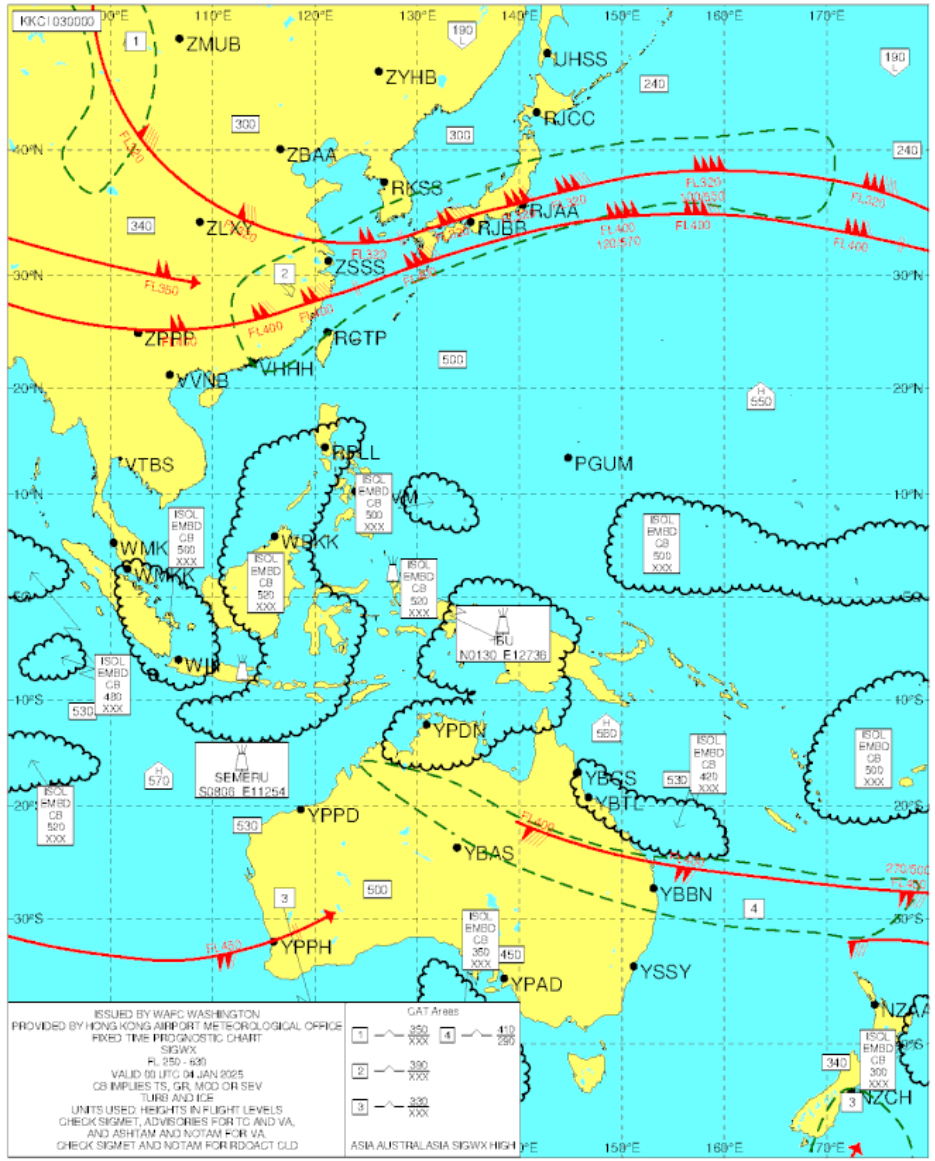


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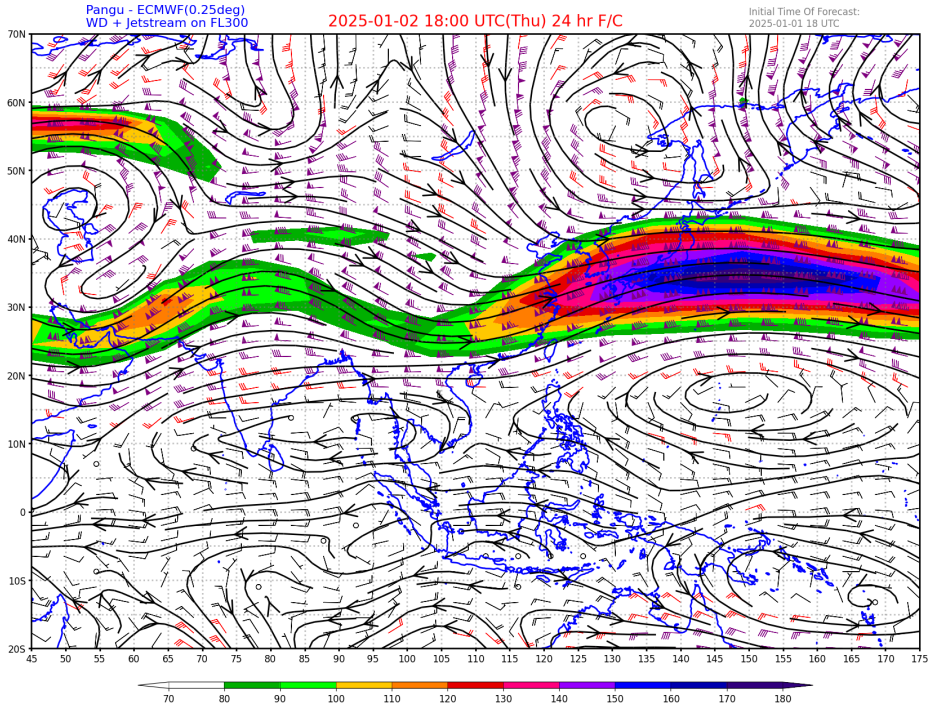
BACKGROUND

- Jet streams are strong, narrow bands of fast moving upper air flow in the upper troposphere.
- According to the World Meteorological Organization, the jet stream is a strong narrow current concentrated along a quasi-horizontal axis in the upper troposphere or in the stratosphere characterized by strong vertical and lateral wind shears and featuring one or more velocity maxima.
- With reference to the Annex 3 of International Civil Aviation Organization, forecast areas with wind speeds greater than 40 m/s or 80 knots are highlighted as the jet using wind arrows and jet axis on the significant weather charts (SIGWX charts).



INTRODUCTION

- Flights can take advantage of high wind speeds within jet streams to significantly reduce flight time, thus reducing fuel consumption
- However, strong wind shear near the jet stream may cause clear air turbulence (CAT)
- In recent years, artificial intelligence (AI) data-driven deep learning models have become increasingly popular in various forecasting tasks and some proven to have higher accuracy or longer predictability ability than traditional NWP models
- The motivation of the project:
  - To verify, compare and analyse the performance of three AI data-driven deep learning models and NWP model [ECMWF IFS] on jet stream forecasting



METHODOLOGY



Credit: CH Yip (HKO)

DATA

- Verification period: 23 May to 13 June 2024
- Ground truth: 00Z and 12Z of ERA5 Reanalysis data
- Covers 6 forecast hours:
  - T+12, T+24, T+36, T+48, T+60, T+72
- Covers 7 vertical levels:
  - 100 hPa, 150 hPa, 200 hPa, 250 hPa, 300 hPa, 400 hPa, 500 hPa

Model type	Model	Resolution	Initialised by
Physical NWP	ECMWF IFS	0.125°	---
AI data-driven	Pangu-Weather	0.25°	ECMWF
AI data-driven	Fengwu	0.25°	ECMWF
AI data-driven	Fuxi	0.25°	ECMWF

For fair comparison, ECMWF IFS resolution has been reduced by nearest neighbor interpolation.

VERIFICATION METRICS



Credit: KK Cheung (HKO)

METRICS FOR CONTINUOUS VARIABLES

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_i - \hat{y}_i)^2}$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|y_i - \hat{y}_i|$$

- Variables to be verified:
  - U-component of wind
  - V-component of wind
  - Wind speed magnitude
  - Wind direction
- The verification was only calculated when the data points of either the ground truth or the forecast model showed a wind speed of over 80 knots, which are defined as part of the jet streams.

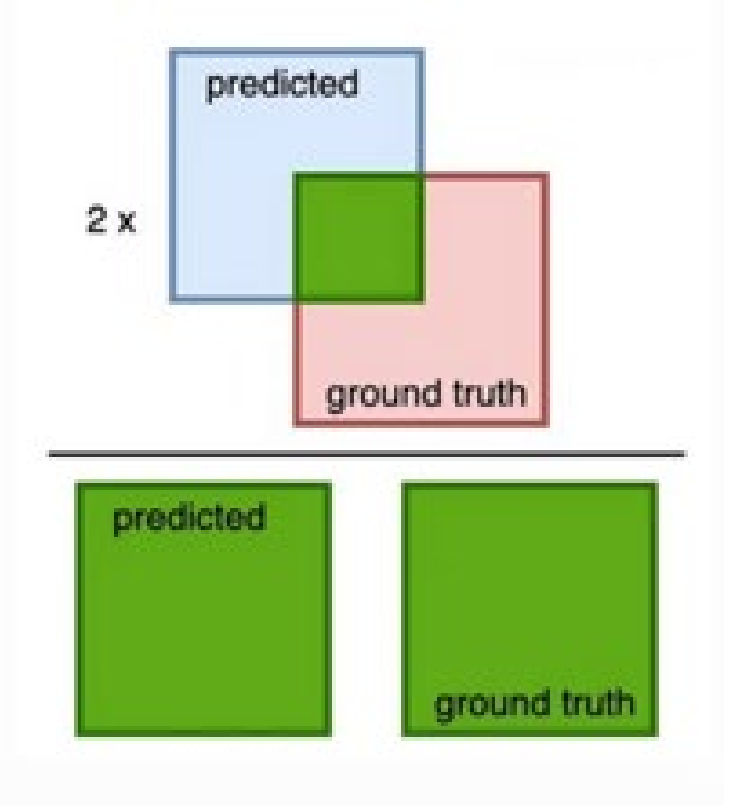
METRIC FOR JET STREAM POSITION

Assessment of the overlapped area of jet stream
Only for areas with observed/predicted wind speed > 80knots

$$Dice\,loss = 1 - \frac{2|Y \cap \hat{Y}|}{|Y| + |\hat{Y}|} = 1 - \frac{2\sum_{i=1}^{N}(y_i \cdot \hat{y}_i)}{\sum_{i=1}^{N} y_i + \sum_{i=1}^{N} \hat{y}_i + \epsilon}$$

$$y_i = \begin{cases} 1, & \text{if predicted magnitude} > 80 \text{ knots} \\ 0, & \text{otherwise} \end{cases}$$

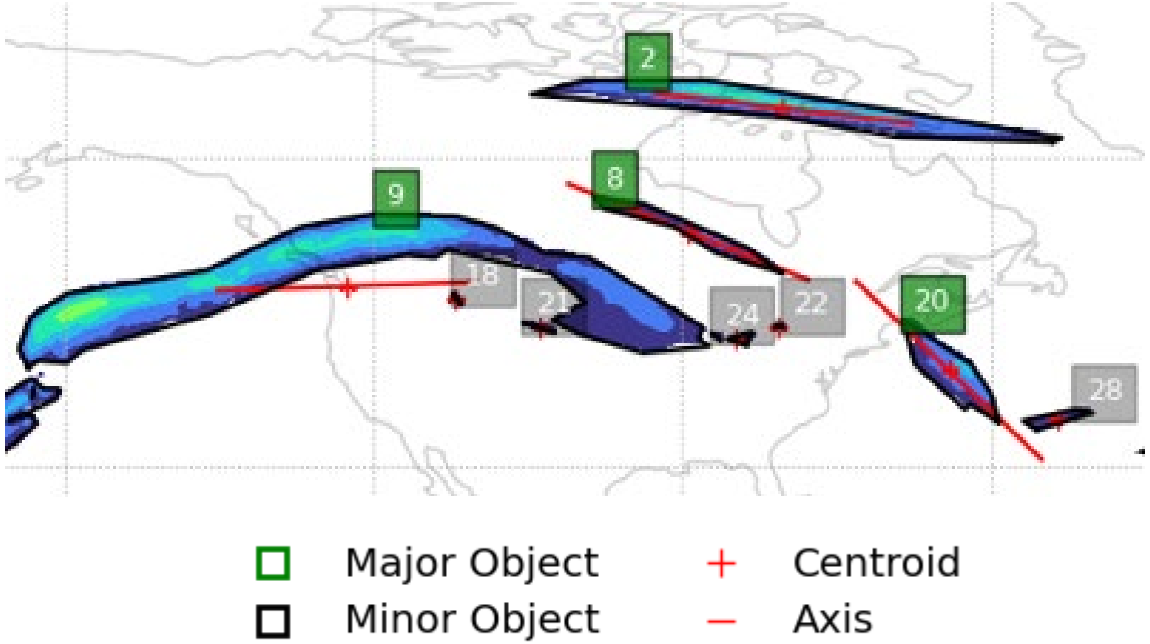
$$\hat{y}_i = \begin{cases} 1, & \text{if true magnitude} > 80 \text{ knots} \\ 0, & \text{otherwise} \end{cases}$$



OBJECT-BASED VERIFICATION

- For comparing different characteristics of jet streams
- Resolving objects
  - Thresholding: > 80 knots
  - Connected piece in the mask is counted as a simple object
- Ground truth objects with area ~3.5° x 3.5° as major objects
- Defined an interest function to map the forecast and ground truth objects

$$T(g,f) = \begin{cases} \frac{(a_{g,f}+1)(r_{g,f})}{d_{g,f}} & \text{if } a_{g,f} \neq 0 \text{ or } d_{g,f} \leq 12.5^\circ \\ 0 & \text{otherwise} \end{cases}$$



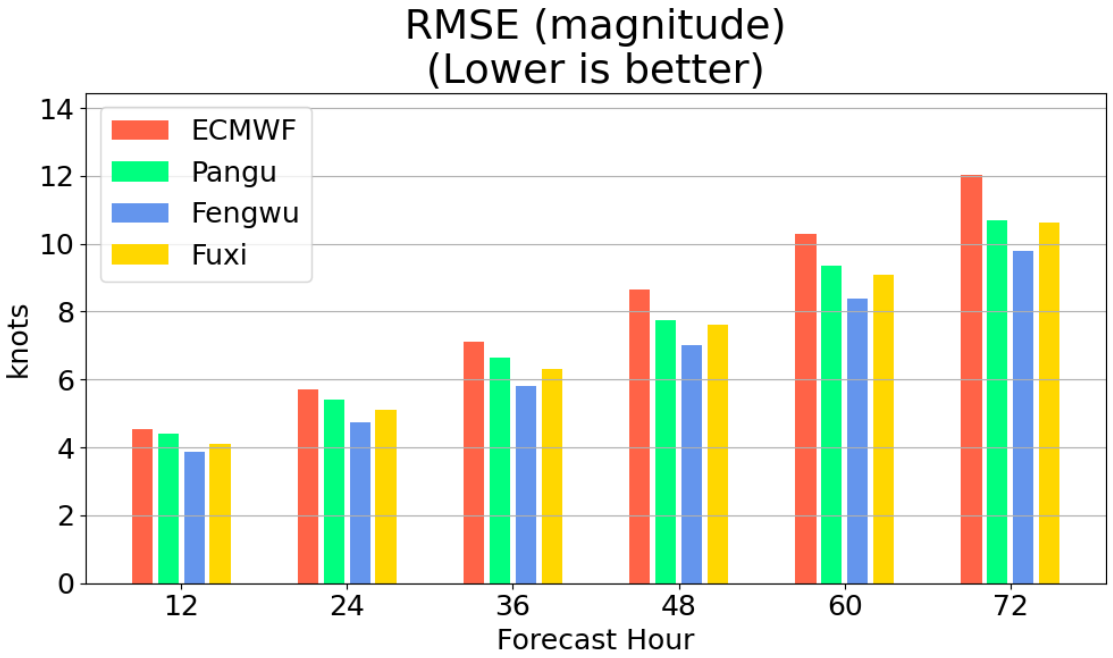
- Centroid distance
- Orientation error
- Overlapping area ratio
- Maximum magnitude error
- Unmatched objects

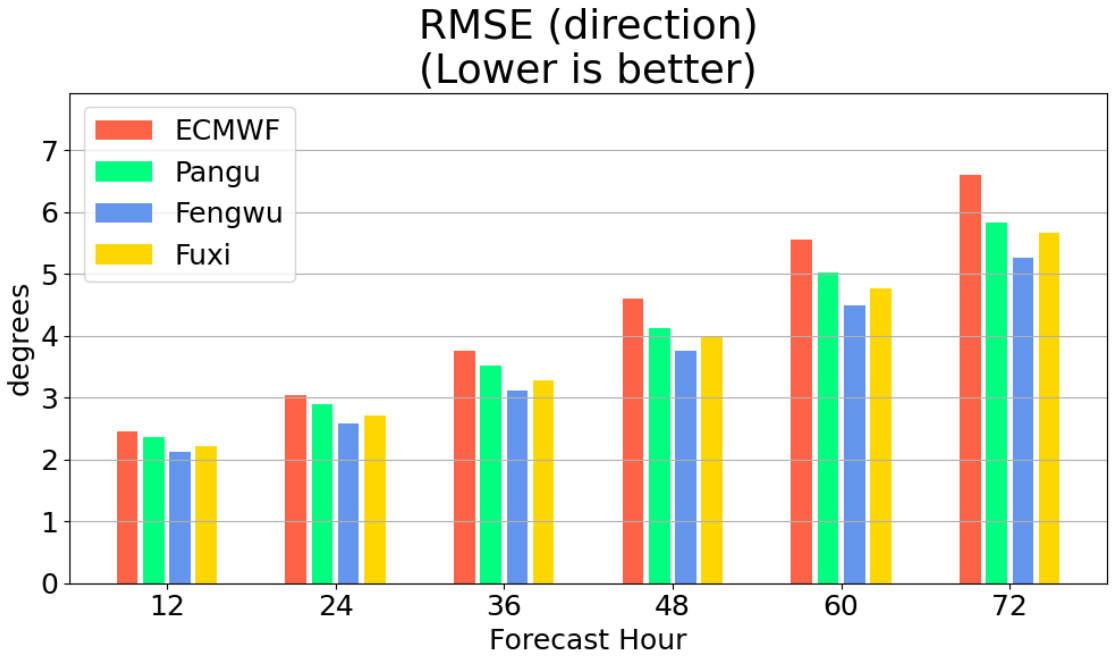
RESULT



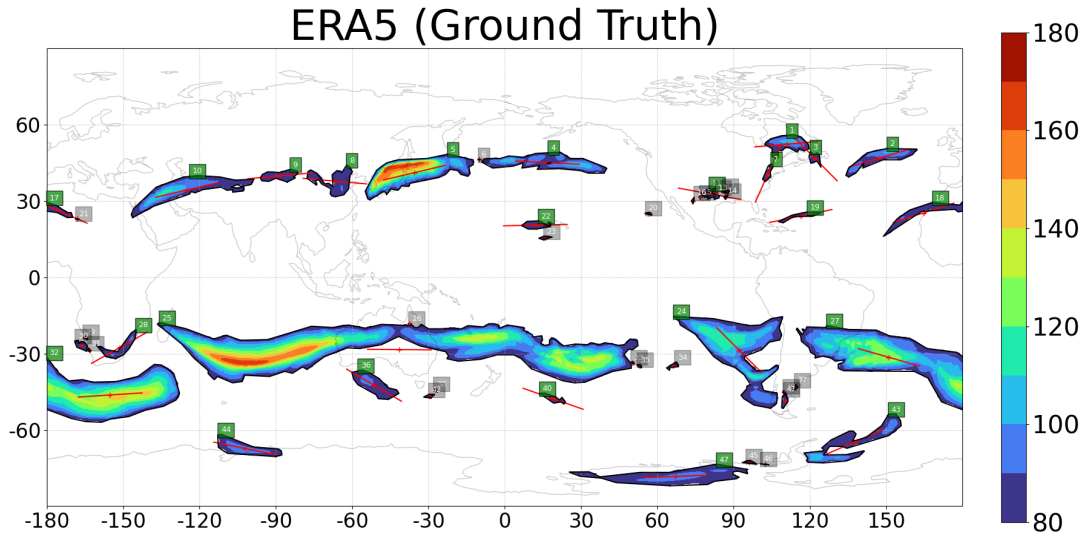
Credit: CH Lam(HKO)

CONTINUOUS VARIABLES

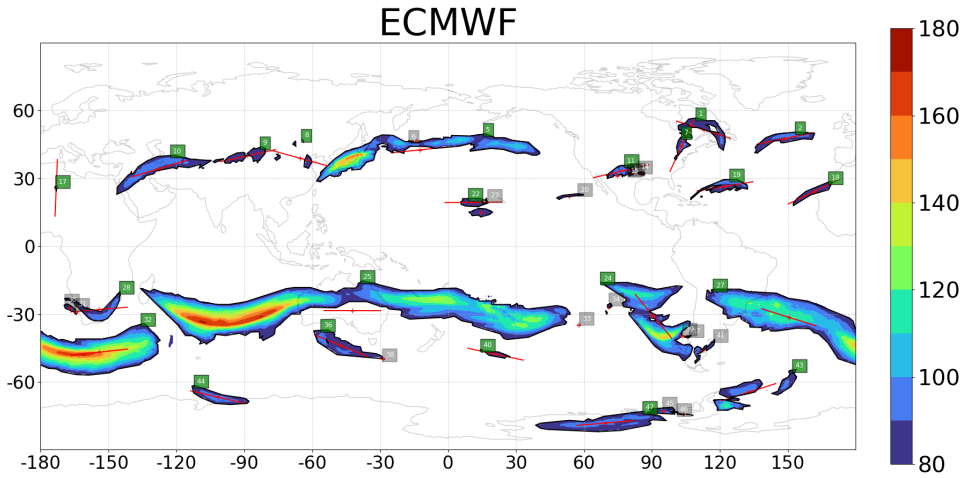


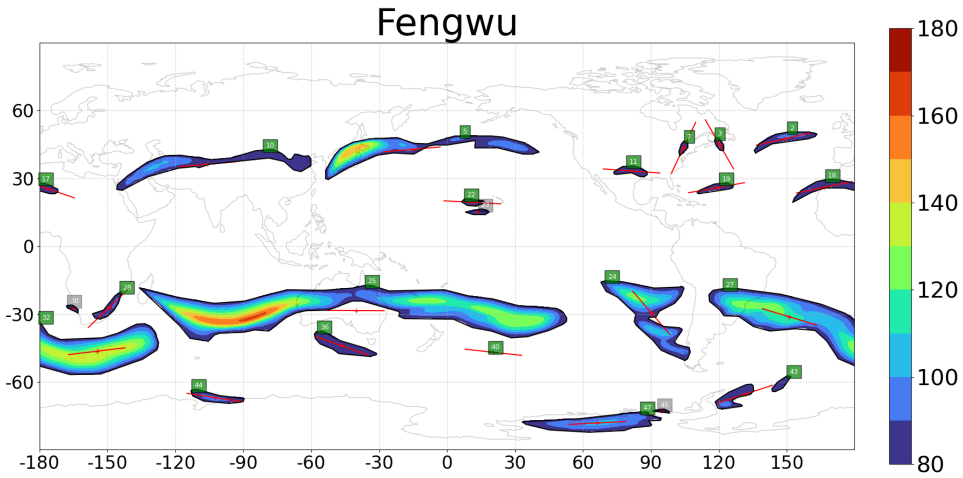


CONTINUOUS VARIABLES - CASE

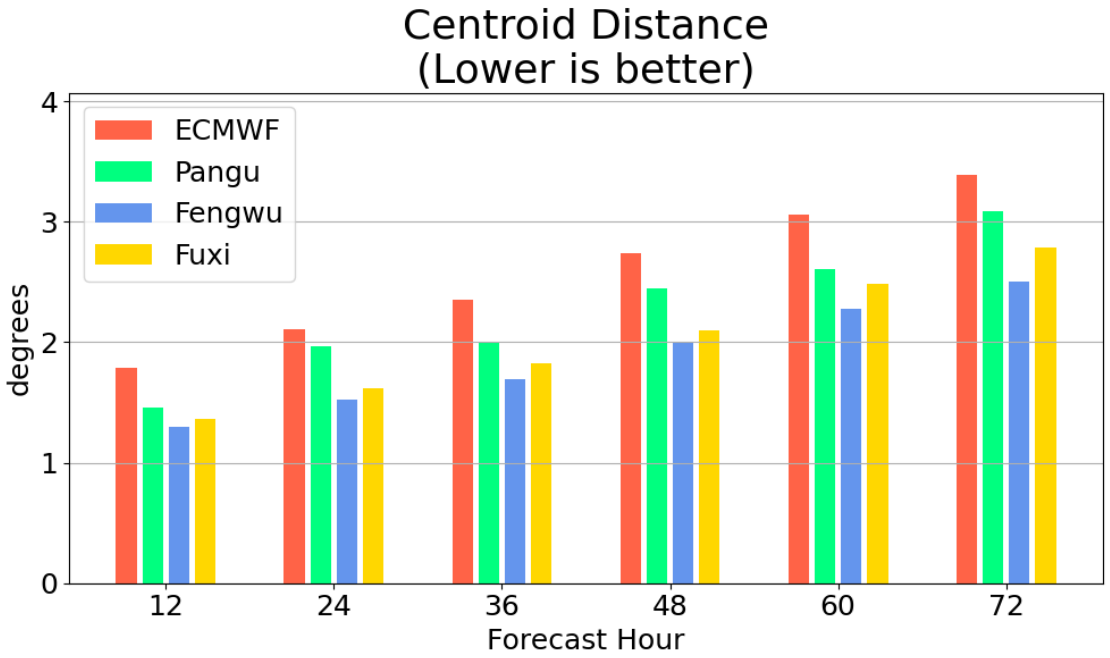


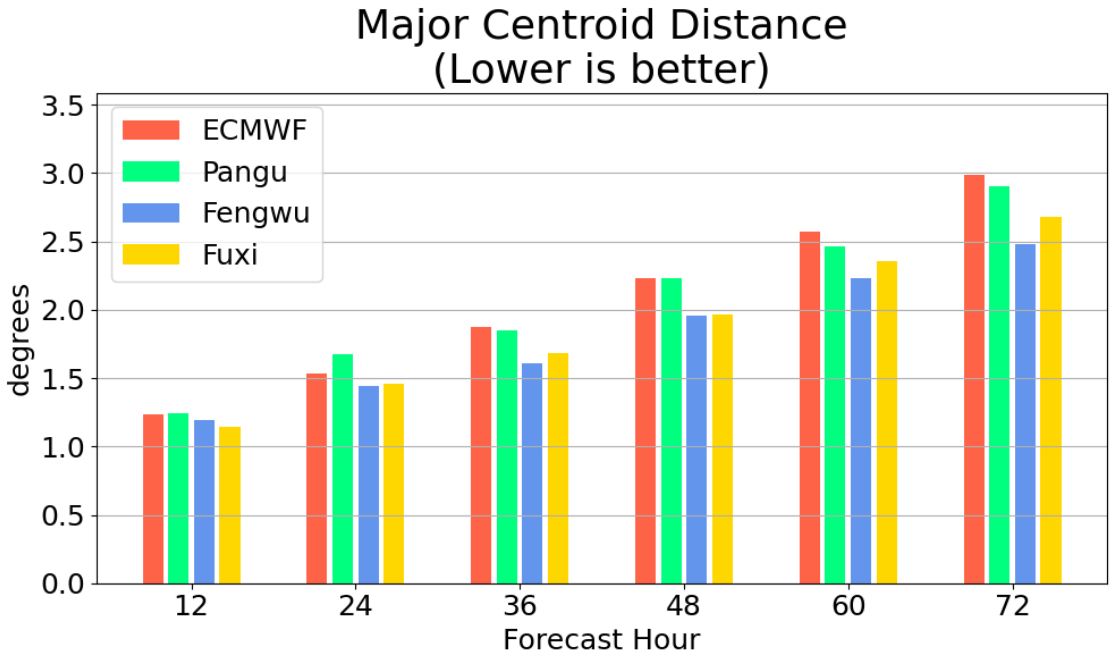
2024-05-28 0000 (T+72 hrs, 200 hPa)
RMSE (magnitude) = 14.2003, 9.2807





CENTROID DISTANCE

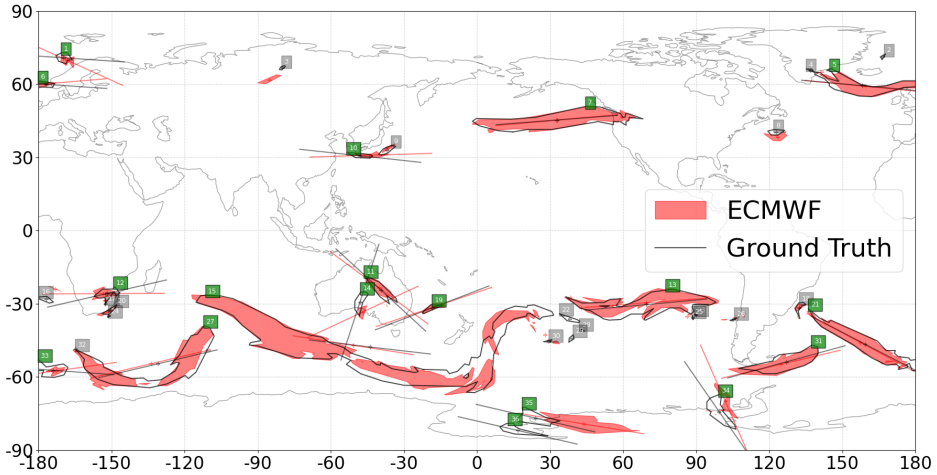




CENTROID DISTANCE- CASE

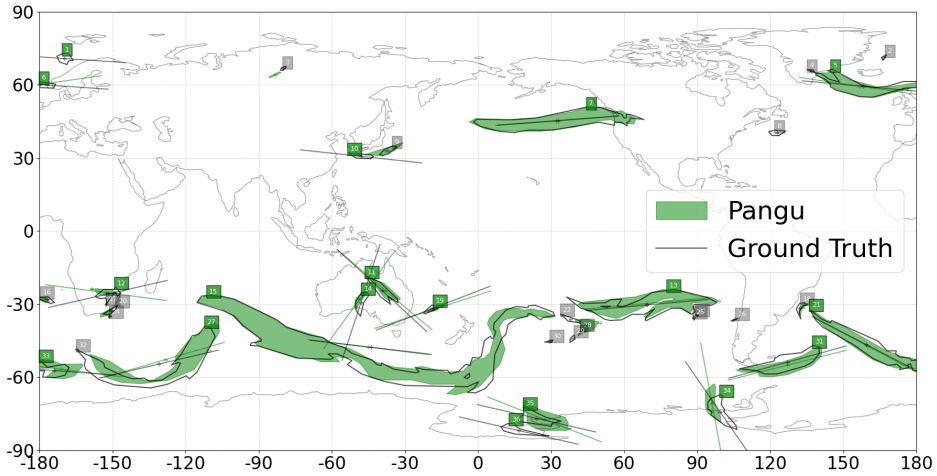
ECMWF

2024-06-04 0000 (T+72 hrs, 400 hPa)
RMSE (magnitude) = 17.8404, RMSE (direction) = 11.6753
Major Centroid Distance = 13.4068, Orientation Error = 0.1425



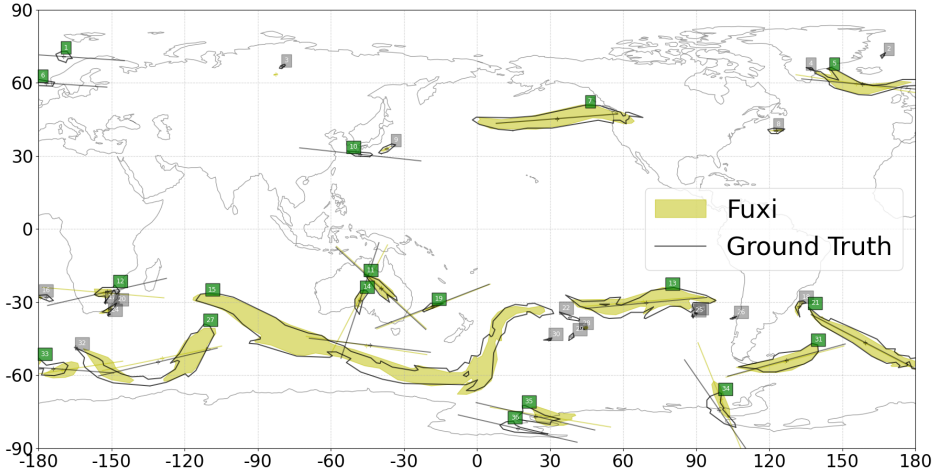
Pangu

2024-06-04 0000 (T+72 hrs, 400 hPa)
RMSE (magnitude) = 14.9592, RMSE (direction) = 8.3179
Major Centroid Distance = 7.3839, Orientation Error = 0.1156



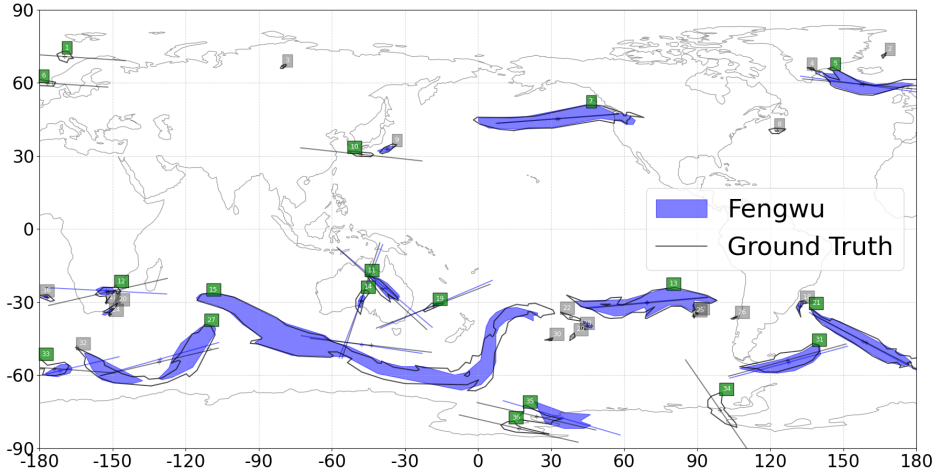
Fuxi

2024-06-04 0000 (T+72 hrs, 400 hPa)
RMSE (magnitude) = 13.2422, RMSE (direction) = 7.3898
Major Centroid Distance = 7.6479, Orientation Error = 0.0811



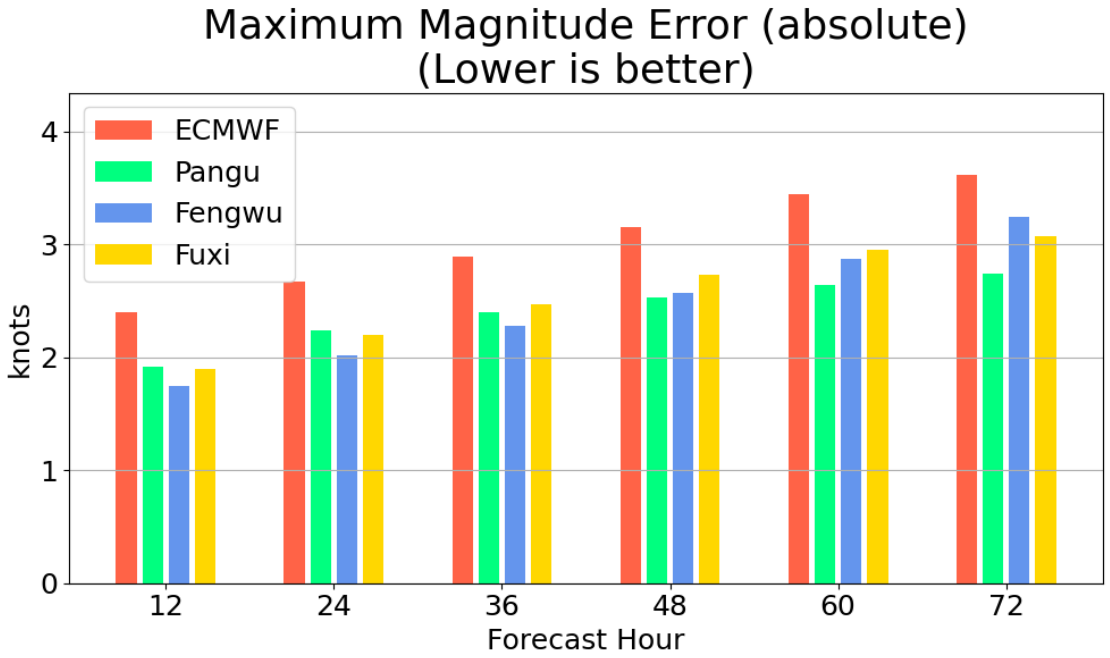
Fengwu

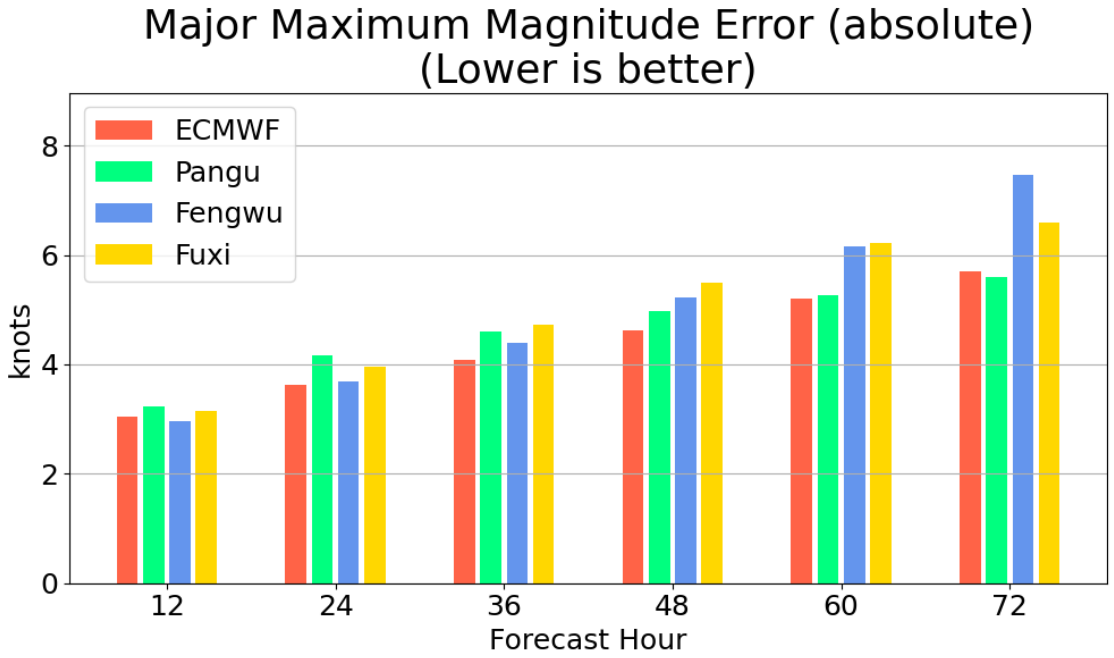
2024-06-04 0000 (T+72 hrs, 400 hPa)
RMSE (magnitude) = 14.1136, RMSE (direction) = 8.2188
Major Centroid Distance = 8.1755, Orientation Error = 0.0702



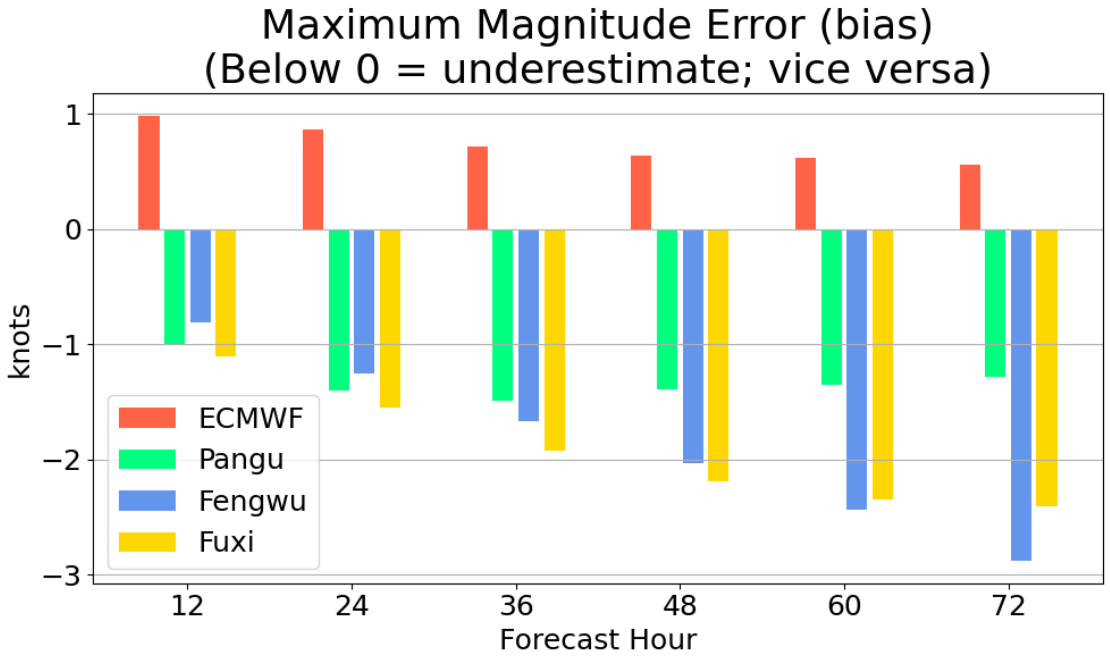
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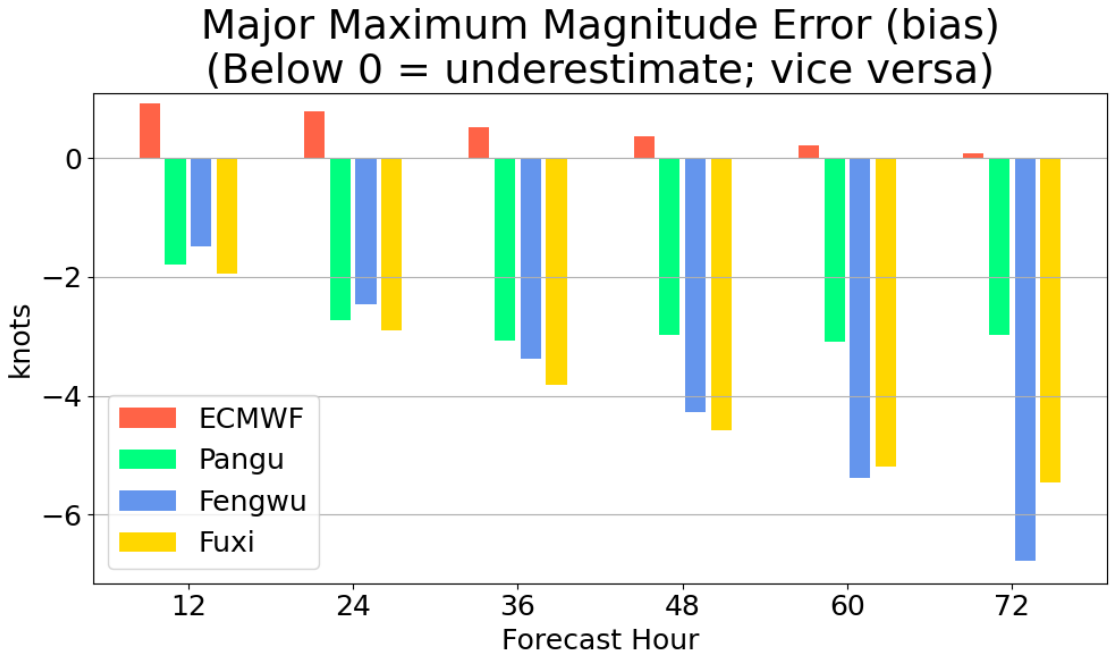
MAXIMUM MAGNITUDE



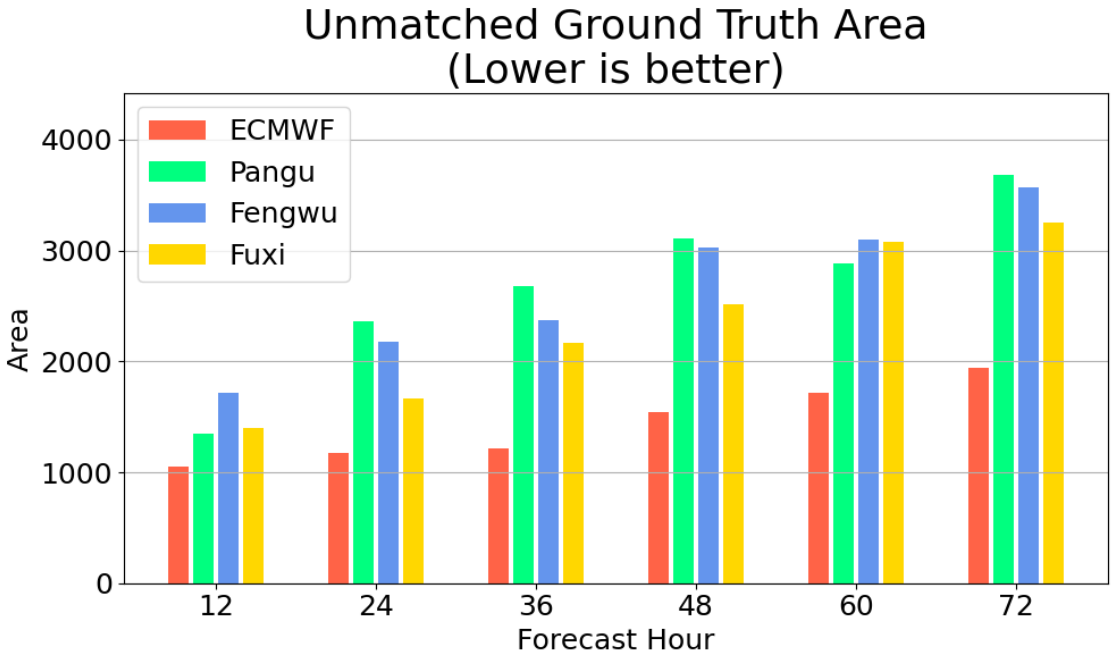


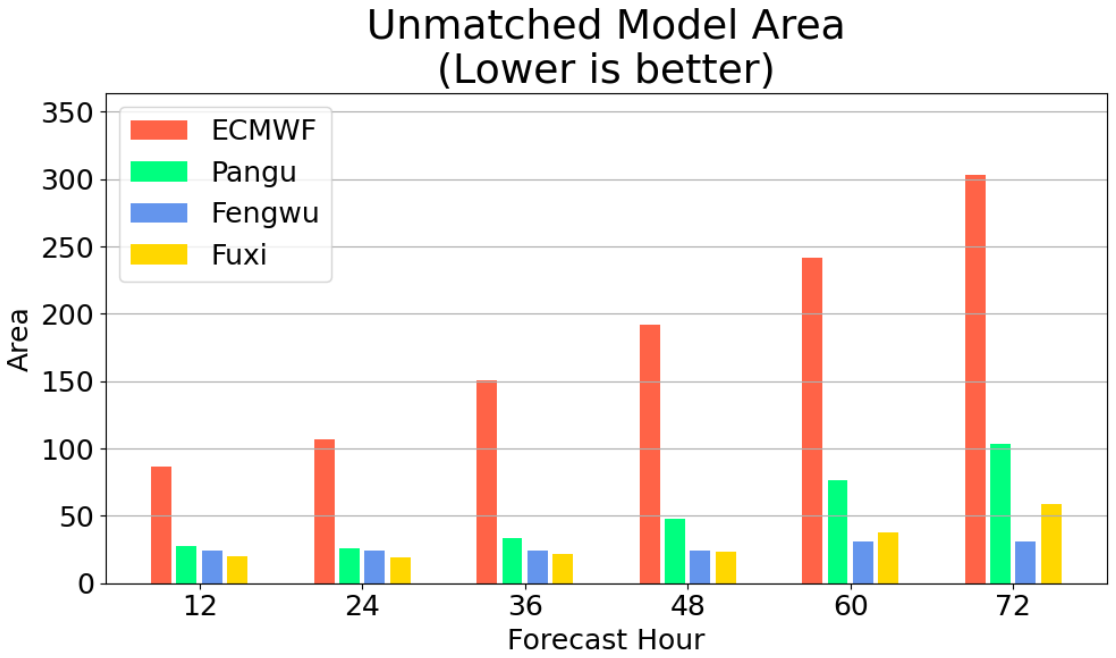
BIAS


Maximum Magnitude Error (bias)
(Below 0 = underestimate; vice versa)
knots
1
0
−1
−2
−3
ECMWF
Pangu
Fengwu
Fuxi
12
24
36
48
60
72
Forecast Hour

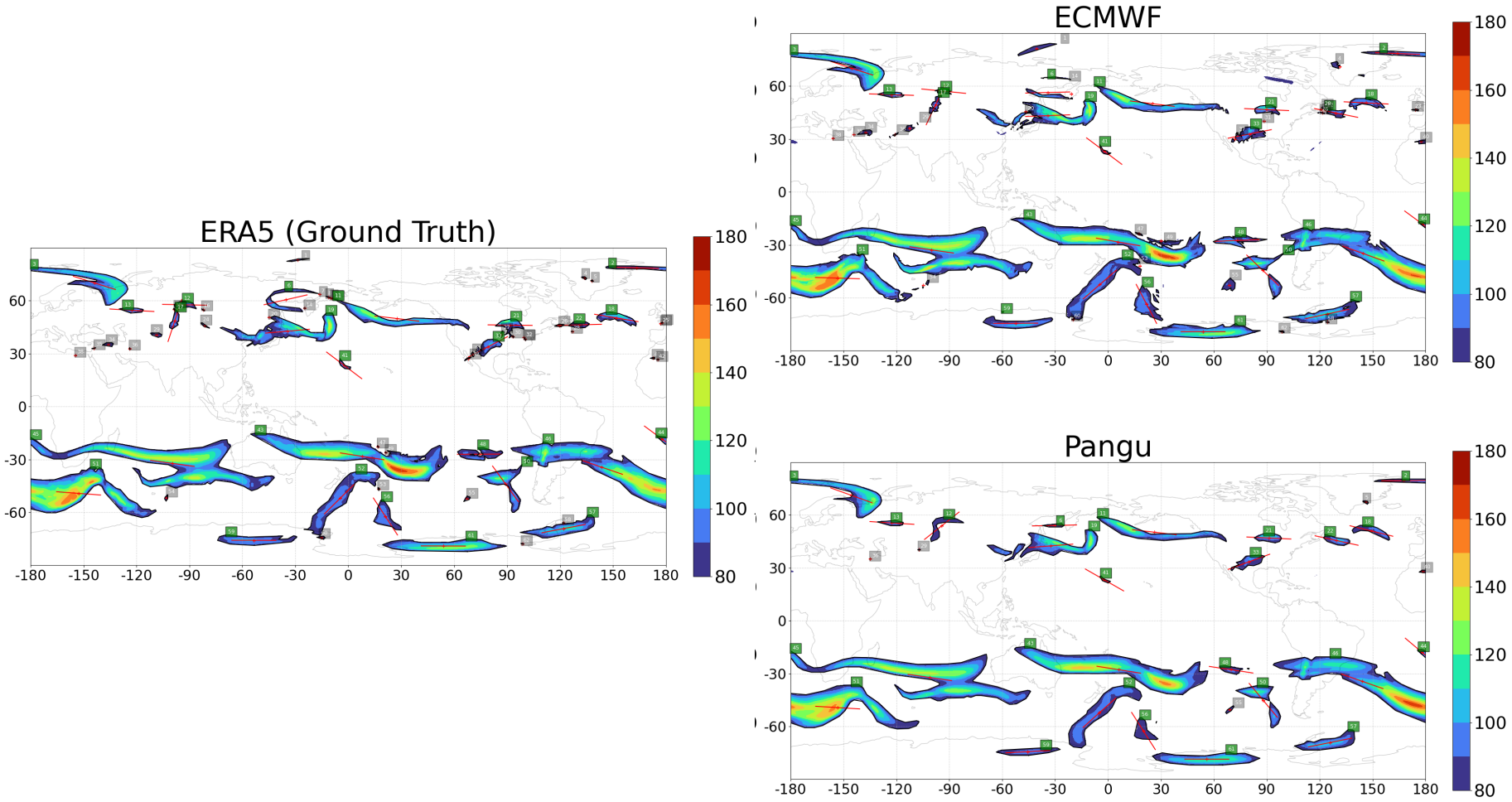

Major Maximum Magnitude Error (bias)
(Below 0 = underestimate; vice versa)
knots
0
−2
−4
−6
ECMWF
Pangu
Fengwu
Fuxi
12
24
36
48
60
72
Forecast Hour

UNMATCHED OBJECTS





UNMATCHED OBJECTS - CASE



CONCLUSION

- The study reveals that the AI data-driven models outperformed the traditional NWP models in most of the metrics, including the continuous variables or object-based verification metrics.
- Among the AI models, Fengwu is more superior that the other two deep learning models (Pangu and Fuxi).
- However, due to the nature of the transformers utilised in training the AI models, these models tend to produce overly smooth results and cannot capture the extreme or finer details of jets, for examples, the maximum intensity of jet or small and weak jet objects.
- Since both the coverage of jets and the absolute magnitude of jets are crucial in the flight planning process, each type of model still have their own advantage over the other type at this stage.

Thank you! Any questions?



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