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4B.3

Derivation and Application of Three-dimensional Horizontal Winds from Geostationary Hyperspectral Infrared Observations

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Outline

- Background and motivation
- Exploring the 3-D wind from geostationary hyperspectral infrared sounder（GeoHIS） measurements
- Added-value from 3-D wind for tropical cyclone forecasts
- Summary

1. Background and motivation

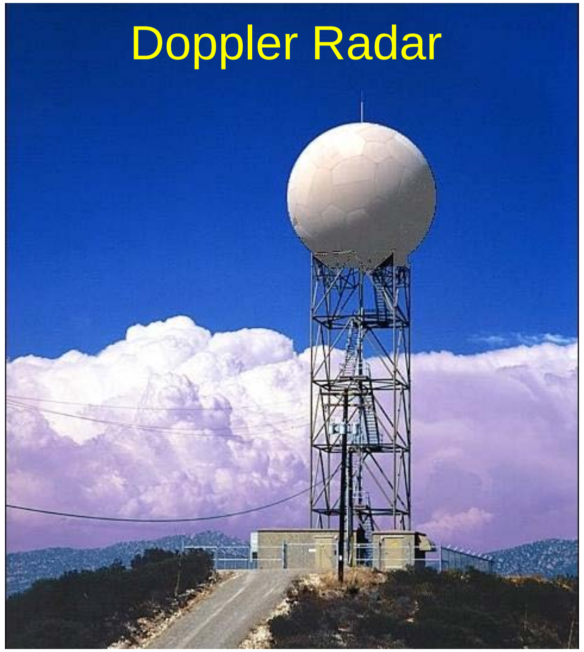
3D wind information is critical to nowcasting (monitoring and warning) the severe weather events

Severe Weather on 30 April 2021, Nantong, causing 11 deaths

3D wind information is important to Numerical Weather Prediction: Temperature, pressure, wind and humidity are the most important basic elements of Numerical weather prediction. Meteorological satellite remote sensing is currently the main means of obtaining temperature, pressure, and humidity observations, but the wind field observations, especially the three-dimensional (3D) wind field observations, are still lacking.

Ground-based observations for 3D wind are limited

Anemometers and Wind Vanes
SONDE(Balloon-borne sounding system)
Sodar (Sonic Detection and Ranging)
Doppler Radar
Lidar (Light Detection and Ranging)



Images are from internet

Satellite-based wind remote sensing – current status

(1). Active remote sensing: for example, Aeolus for 2D wind. Limited to 2D.

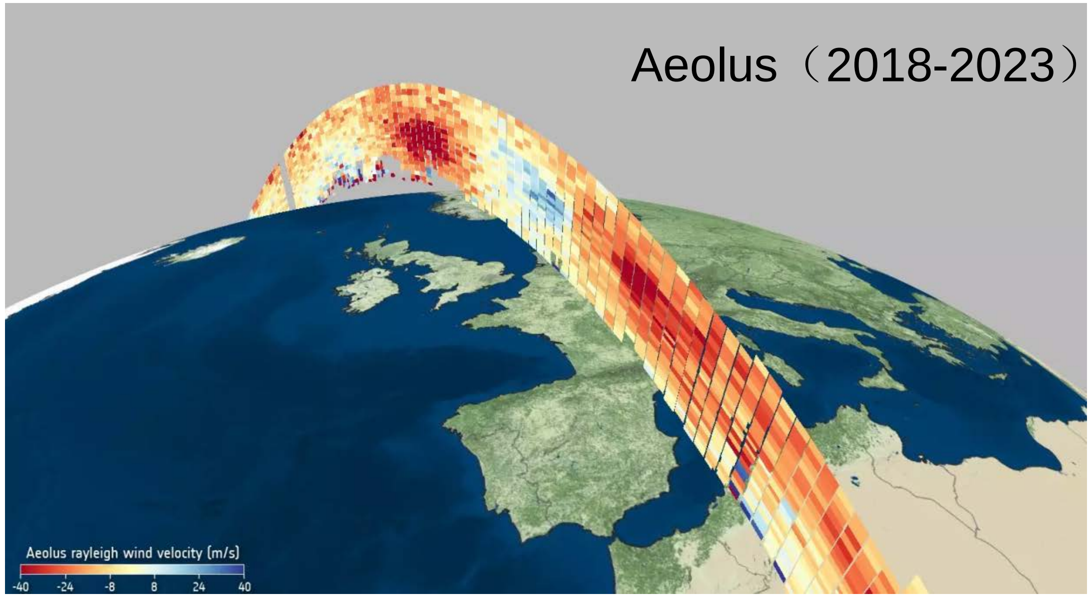


Image from internet

(2). Passive remote Sensing: for example, geostationary imager for atmospheric motion vectors (AMVs), and low earth orbit imager for AMVs over high latitude and polar regions. Limited to spectral band related atmospheric layers.

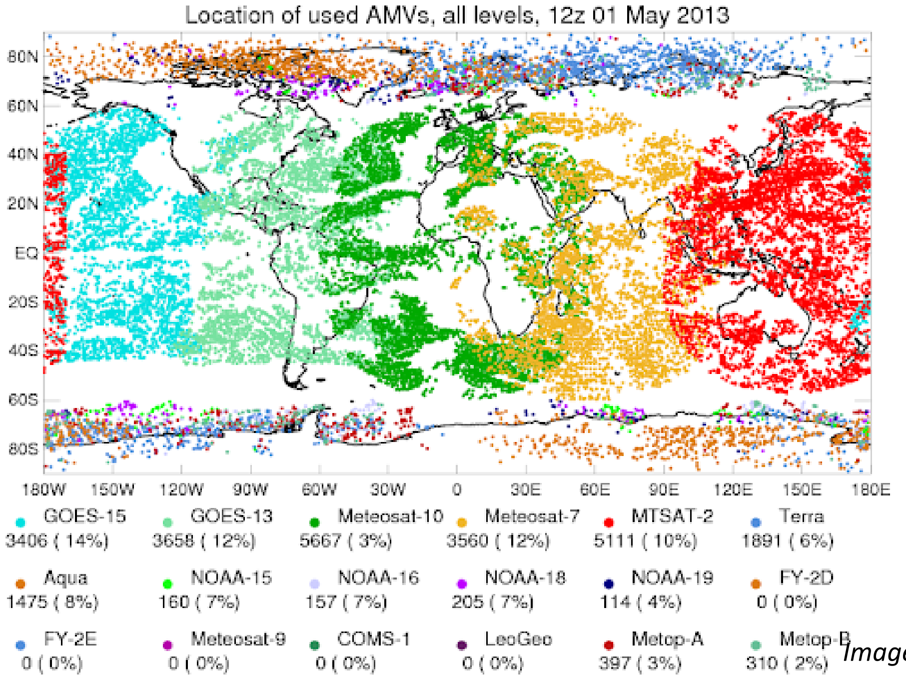


Image from internet

Satellite-based wind remote sensing - future development:

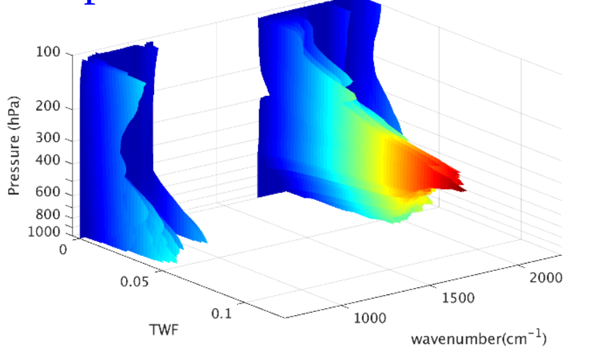
1. Combined active and passive remote sensing;

2. The geostationary hyperspectral infrared measurements offer great opportunity for 3D wind product and applications

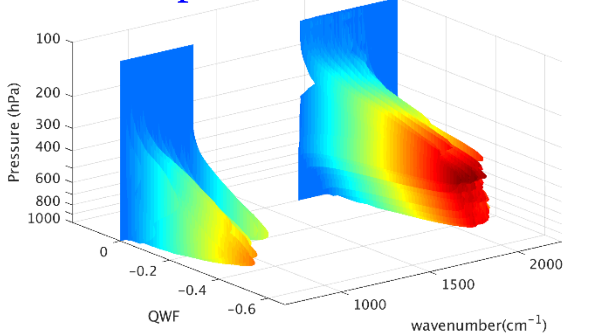
2. Three-dimensional wind from GeoHIS measurements

The Geosynchronous Interferometric Infrared Sounder (GIIRS) onboard the Chinese Fengyun-4 series is the first geostationary hyperspectral IR sounder, which can continuously observe the temporal and spatial changes of atmospheric temperature and water vapor profiles. Such information can be used to derive winds.

Temperature Jacobian functions

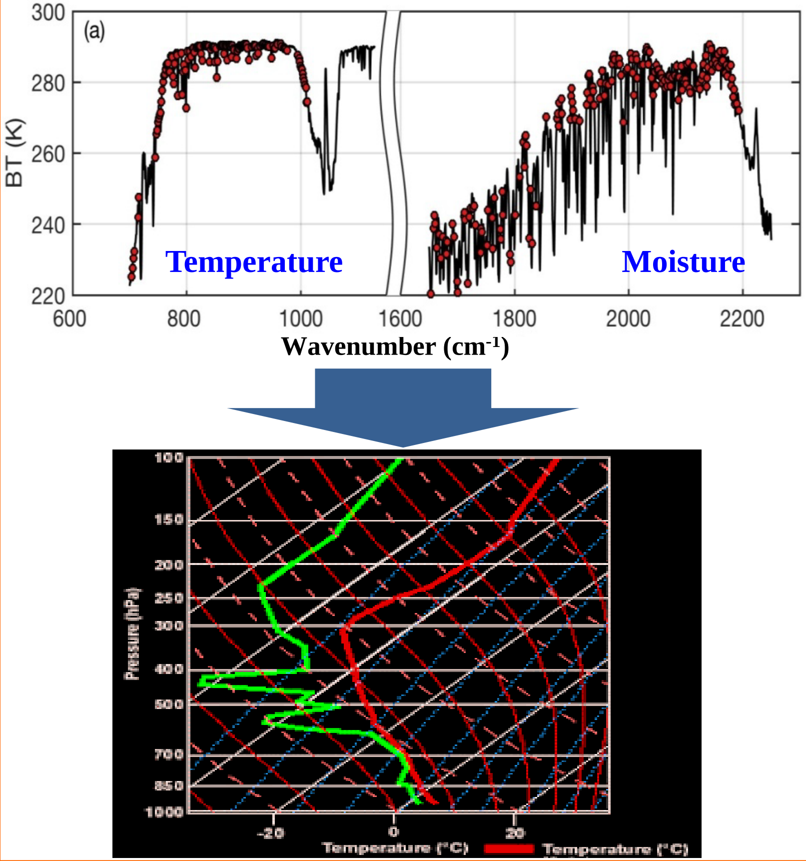


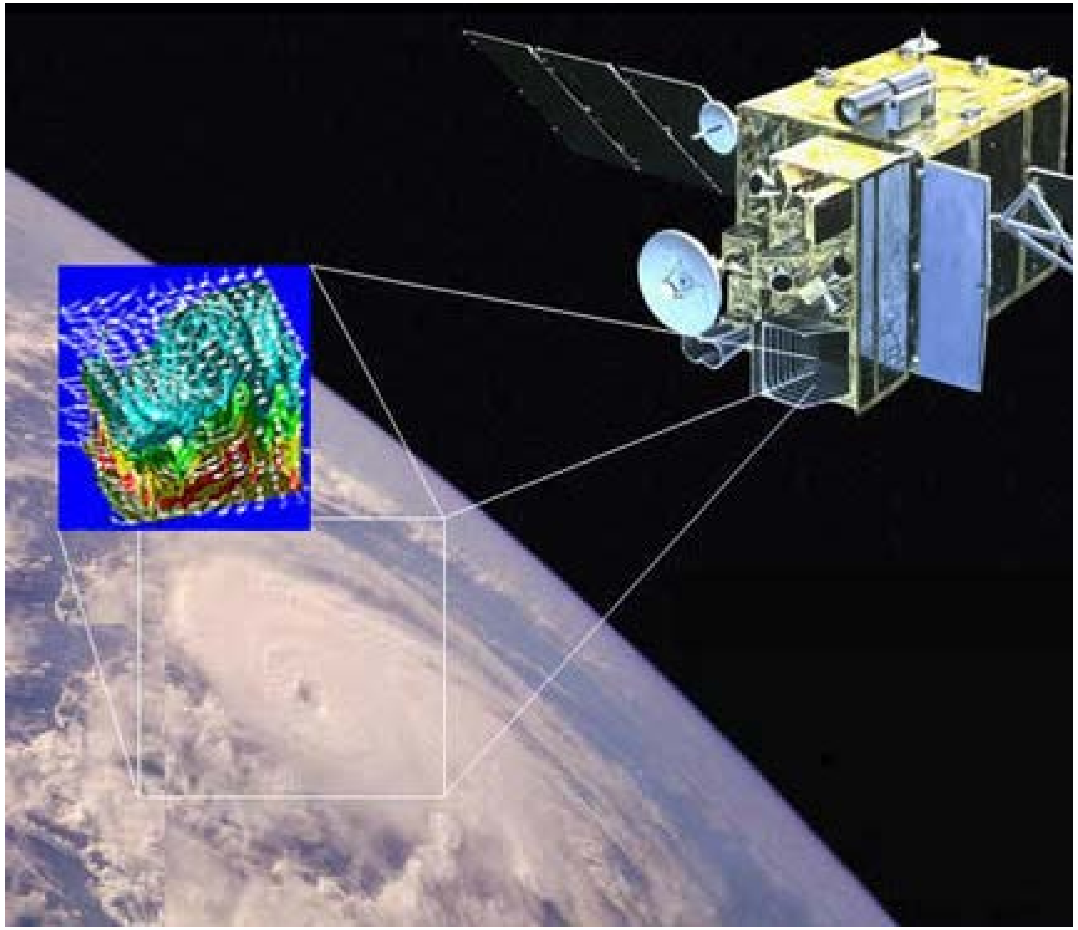
Water vapor Jacobian functions



Images from UW/CIMSS

GIIRS has 1650 channels for observations

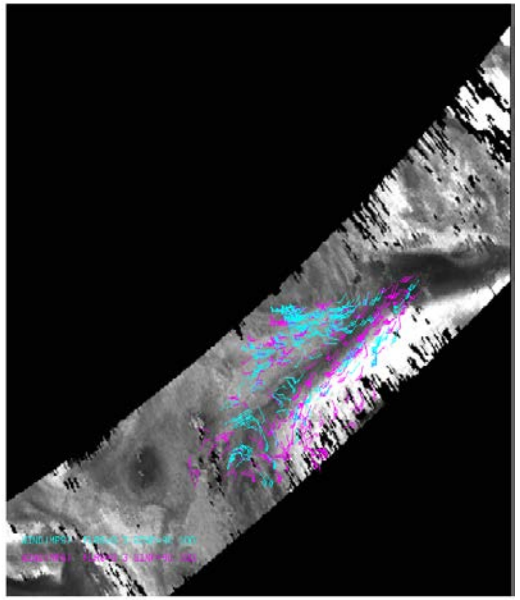




(Li, J., et al., 2022, GRL)

Traditional methods for tracking winds from imager/sounder measurements

Type of winds	Instruments	Approaches	Height assignment	Primary sources of error
AMV	Imager	Tracking radiances	CO_2-Slicing	Height assignment
3D wind	Sounder	Tracking retrieved water vapor or ozone	N/A	Water vapor or ozone retrievals



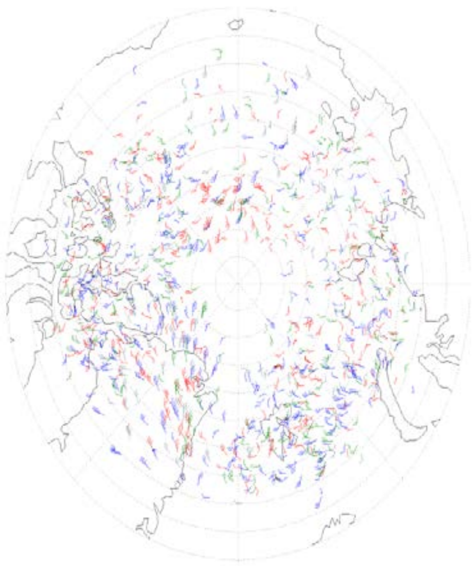
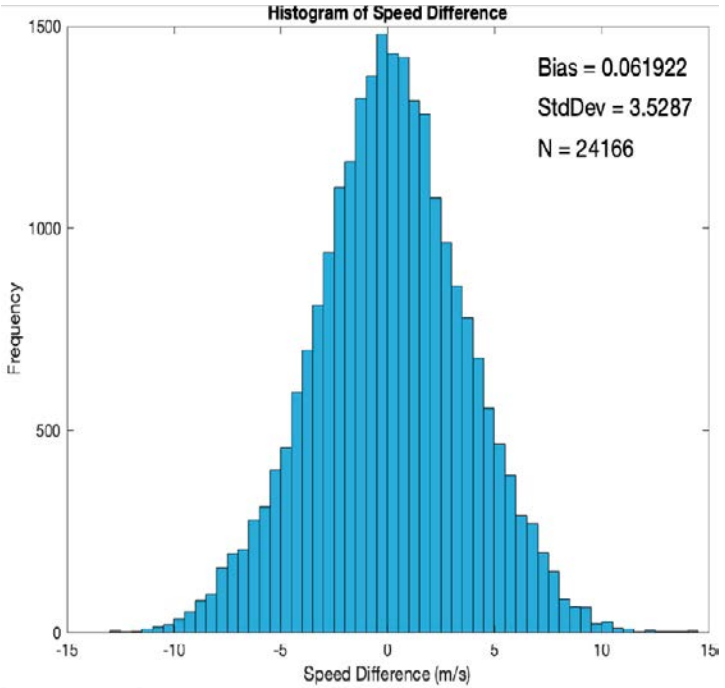


Figure 5. All derived winds from 5 January 2011 color-coded by level: 700–600 hPa (red), 550–450 hPa (green), 400–300 hPa (blue), 150 hPa ozone (gray).

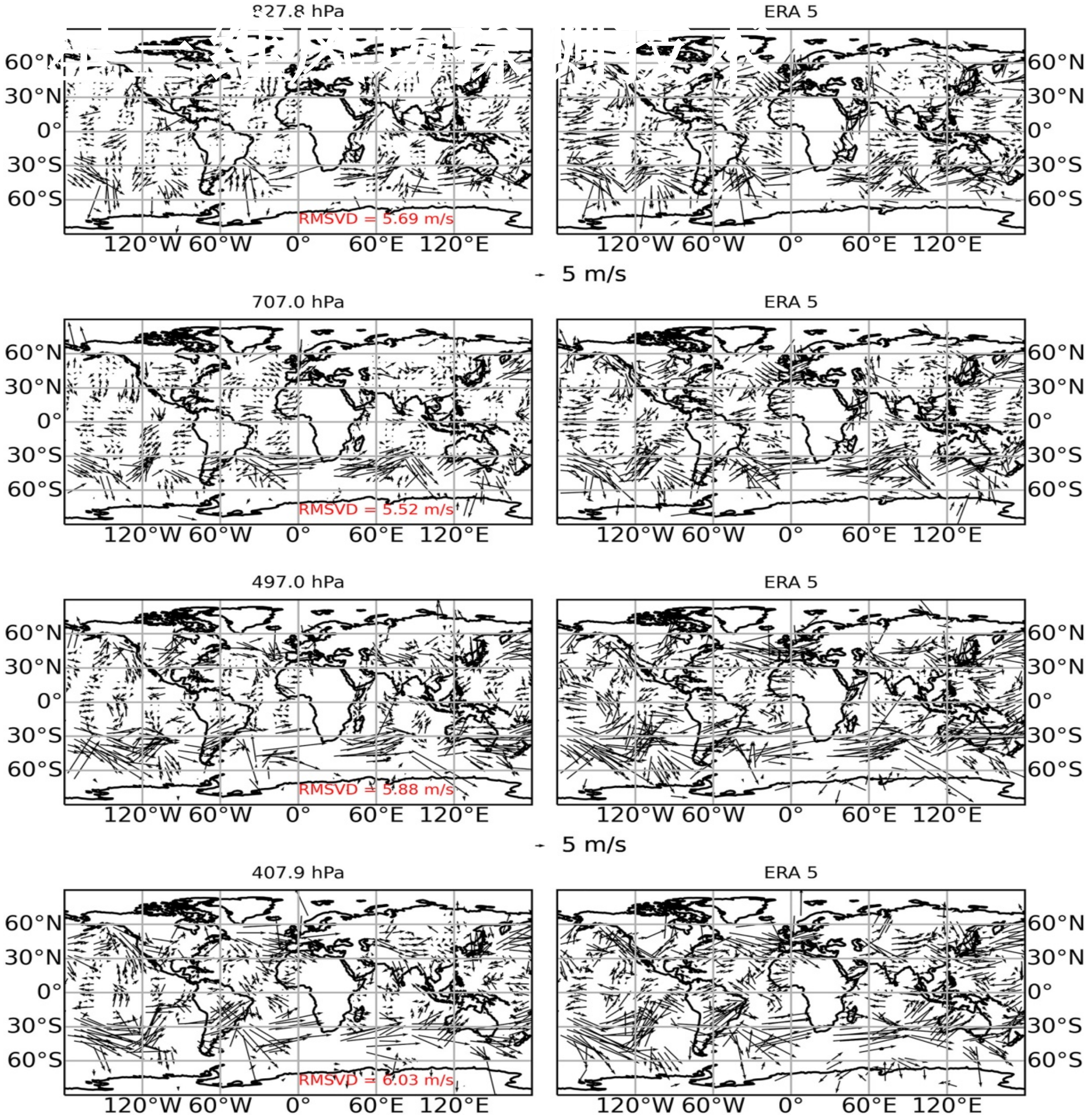


3D winds from AIRS moisture and ozone retrievals in polar regions

(Santek, D. et al., 2019)

Tracking water vapor features for 3-D wind using hyperspectral infrared sounder data from two overlapped polar orbit satellites (SNPP, NOAA20) for tropics and midlatitudes at the horizontal resolution of 1°.

(Ouyed, A., et al., 2023)



3D winds retrieved from CrIS water vapor aboard two polar satellites

Q: What are the possible solutions for satellite-based 3D winds?

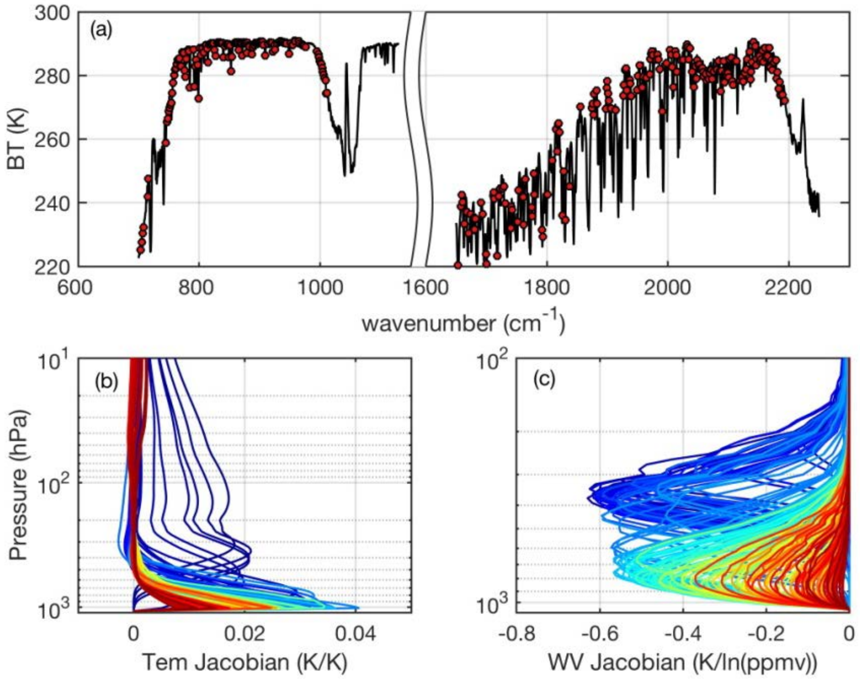
- One thought: Passive measurements (large coverage) trained on active measurements (accurate product)

Training Dataset:

- **Predictors:** GIIRS radiances (338 selected channels from LW+MW using Di et al. 2021 – IEEE TGRS) with both spatial and temporal information
  - **Re-sampled data** generated by R. Knuteson at SSEC, spectral calibration error used to resample input radiances
  - **Spatial information:** five FOVs: target FOV and four neighboring FOVs surrounding it (top, bottom, left, and right)
  - **Temporal information:** two consecutive observations: current and 15 minutes before
- **Predictands:** ERA5 U and V wind components at 27 fixed pressure levels (100 ~ 1000hPa)
  - Spatiotemporally mapped to GIIRS FOVs via linear interpolation

Validation Dataset:

- **Independent ERA5 dataset**: 00 minute scans of each hour used for validation, others(15, 30, 45) used in training
- **GDAS analysis**
- **Dropsondes**



Simulated BT spectrum of GIIRS from U.S. Standard Atmosphere with selected channels (upper), the temperature Jacobian of LW selected channels (lower left), and the water vapor mixing ratio (lnq) Jacobians (lower right).

(Ma and Li et al., 2021,GRL)

3D wind datasets from GIIRS target observations (15 – 30 minutes)

100 - 1000 hPa horizontal winds at 27 pressure levels;　QF: 0-good, 1-influenced by clouds, 2-not useful

Observations	Time Periods	Satellite	Temporal Resolution	Data Availability (Link)
Typhoon Maria	2018.7.10~11	FY4A	15-min	https://doi.org/10.5281/zenodo.5048464
Typhoon Ampil	2018.7.23~24	FY4A	30-min	https://doi.org/10.5281/zenodo.7428475 (combined output)
Typhoon Lekima	2019.8.8~10			
Typhoon Mangkhut	2018.9.12~15			
Northeast Cold Vortex	2022.6.24~26	FY4B	15-min	https://doi.org/10.5281/zenodo.7428597
Typhoon Mulan	2022.8.8~10	FY4B	15-min	https://doi.org/10.5281/zenodo.7427907
Typhoon Khanun	2023.8.2 – 5	FY4B	15-min	https://doi.org/10.5281/zenodo.10258292

References:

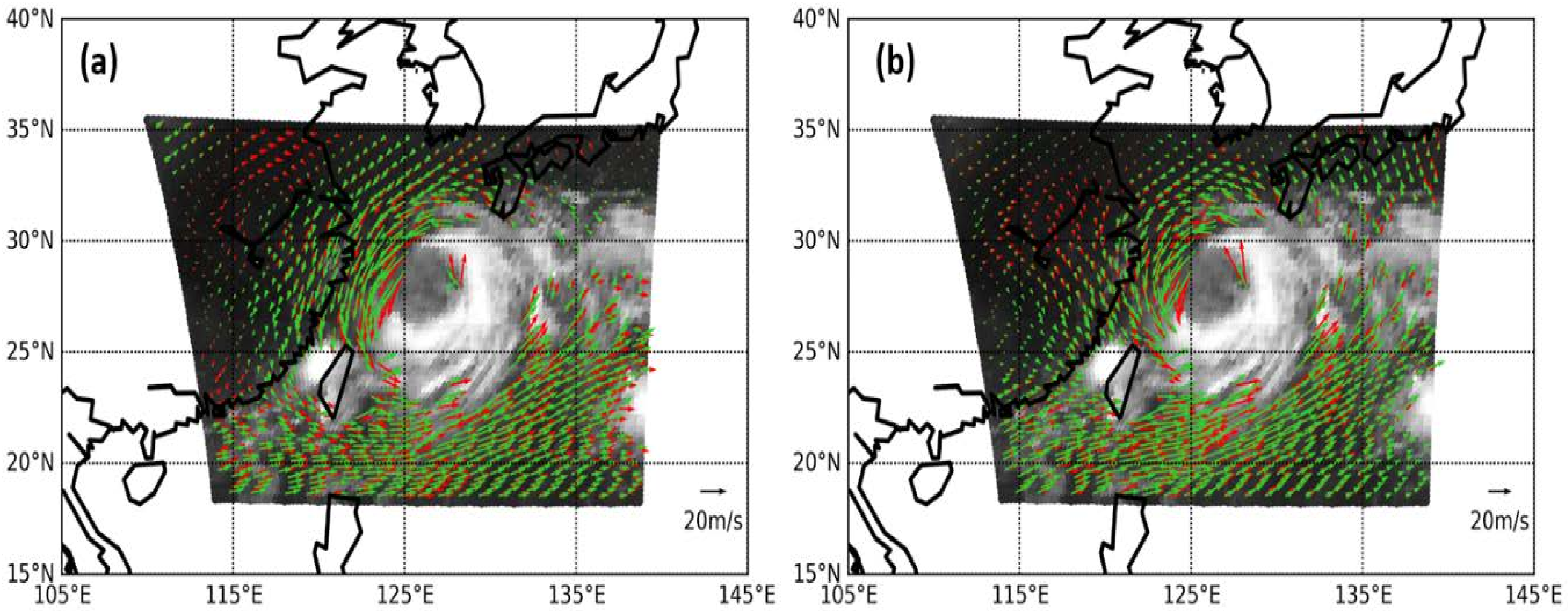
Ma and Li et al. 2021：　Four-Dimensional Wind Fields From Geostationary Hyperspectral Infrared Sounder Radiance Measurements With High Temporal Resolution. Geophysical Research Letters, 48, e2021GL093794.

Li, J., et al., 2022：The Influence of Sub‐Footprint Cloudiness on Three‐Dimensional Horizontal Wind From Geostationary Hyperspectral Infrared Sounder Observations. Geophysical Research Letters 49(11), e2022GL098460.

Super Typhoon Khanun (2023)

20230804_2348, UV500

20230804_2348, UV850



- **Green: GIIRS wind; Red: ERA5 wind.**

The horizontal winds at different pressure levels are overlaying on GIIRS 11 µm channel brightness temperature image

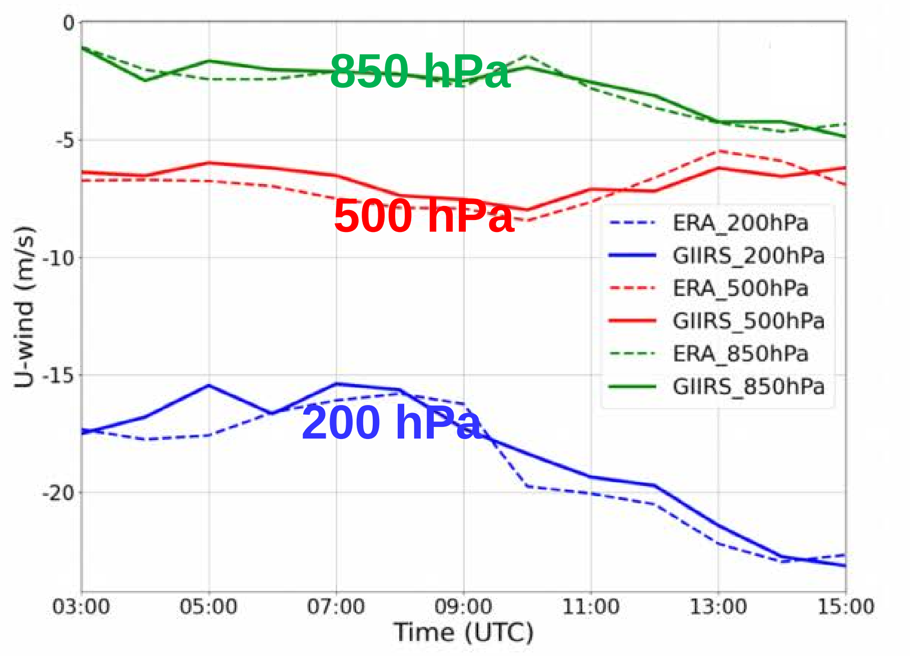
(Ma and Li et al., 2021,GRL)

GIIRS 3D wind can capture the temporal changes

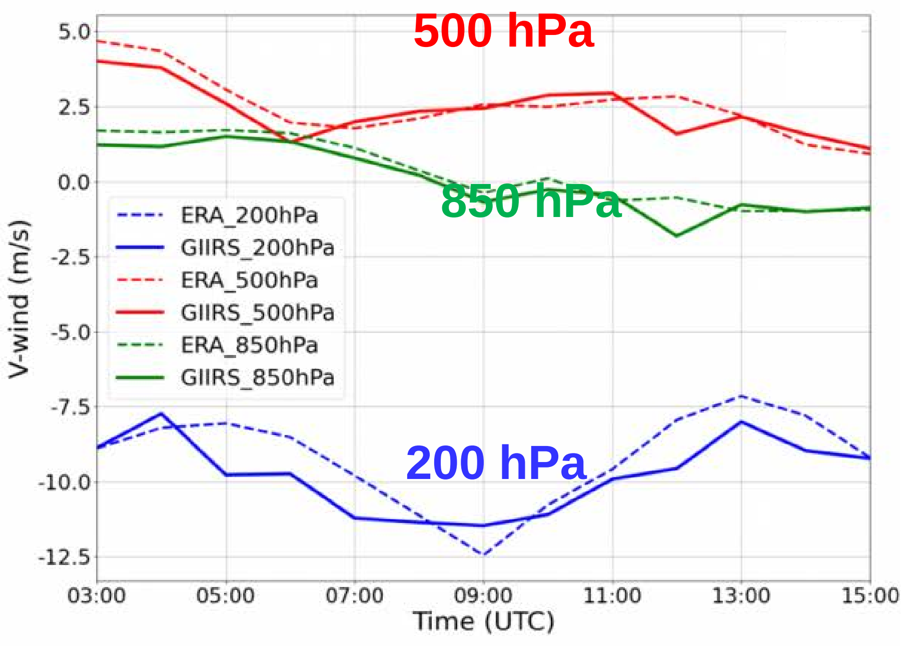
(solid lines：GIIRS; dashed lines：ERA5)

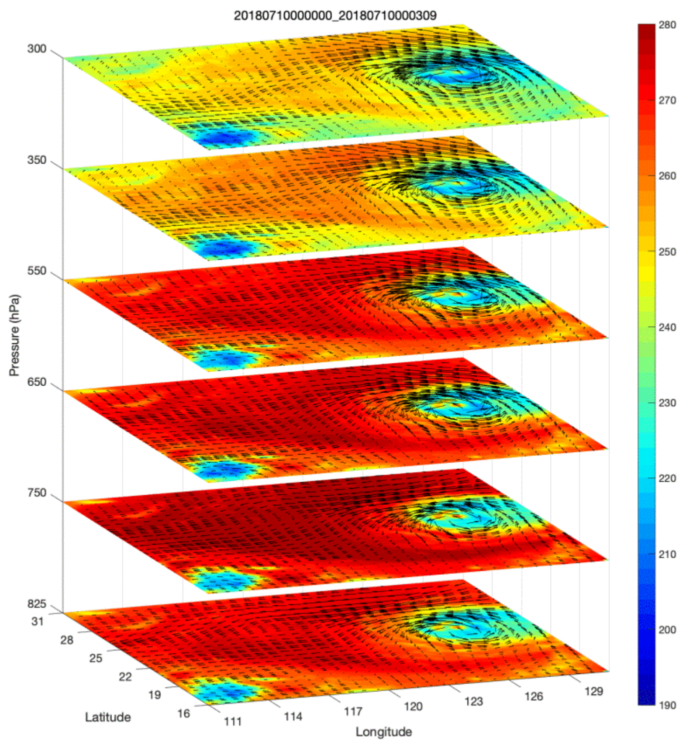
The vertical structure of horizontal wind vectors

U time series



V time series

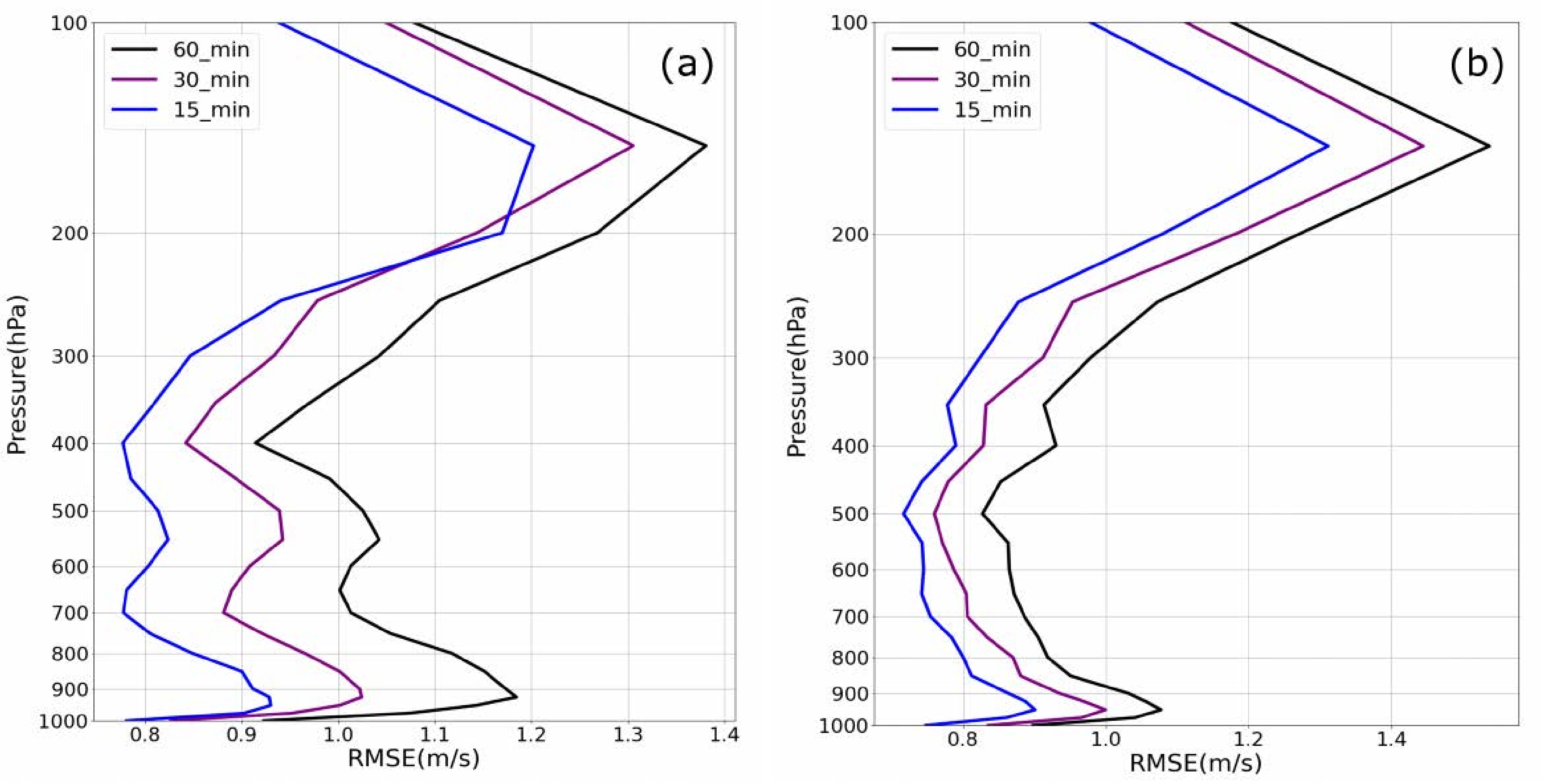




The comparison of time variations of U-component and V-component of wind at the location of (113.1° E, 27.0° N) from GIIRS and ERA5.

(Ma and Li et al., 2021,GRL)

Higher temporal resolution provides 3D wind with better quality

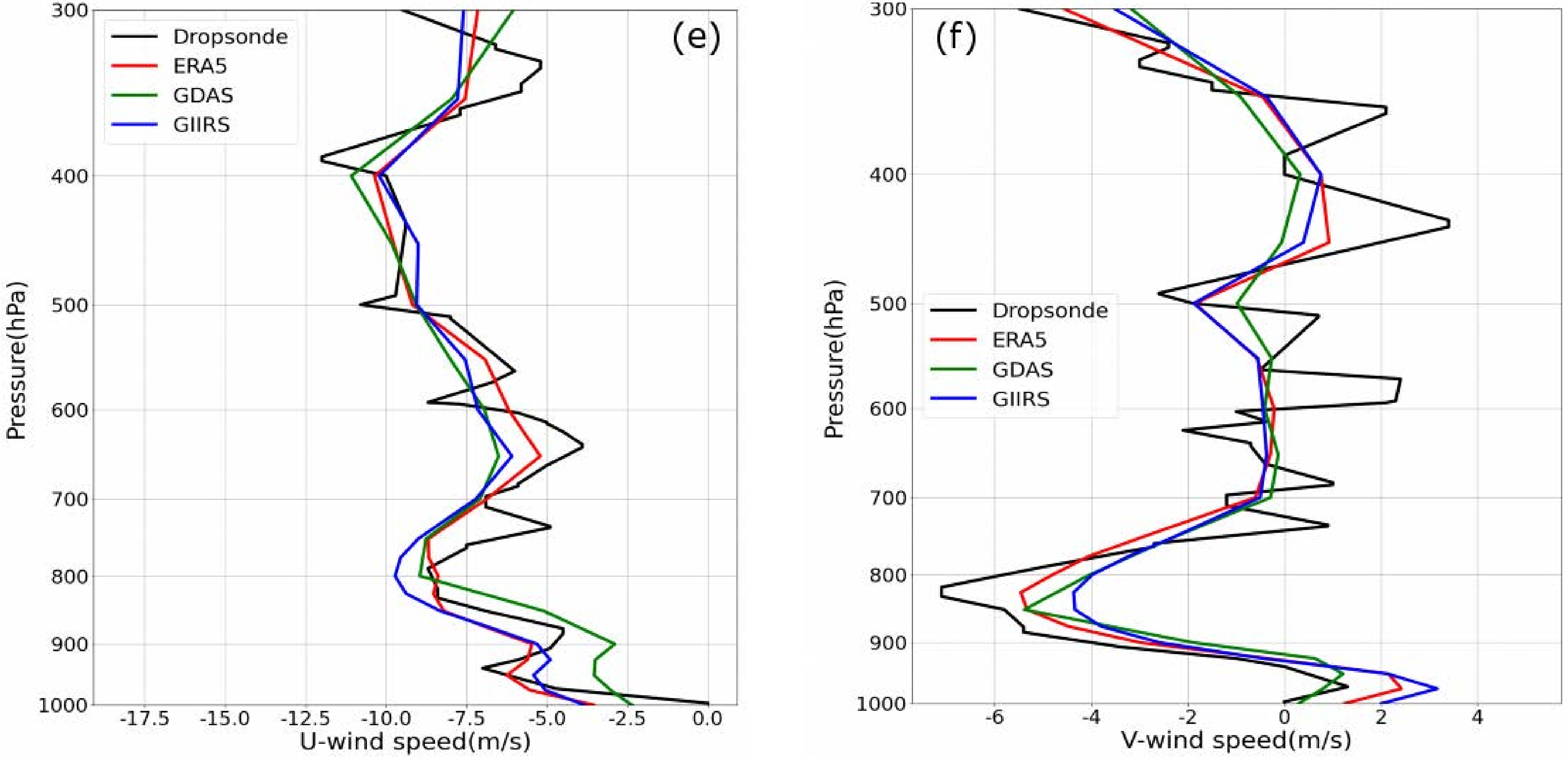


U RMSE and V RMSE based on different temporal resolutions (15-minutes, 30 minutes and 60 minutes).

(Ma and Li et al., 2021,GRL)

GIIRS 3D wind Validation

Reference: dropsonde
Independent 3D wind datasets: ERA5, GDAS, GIIRS



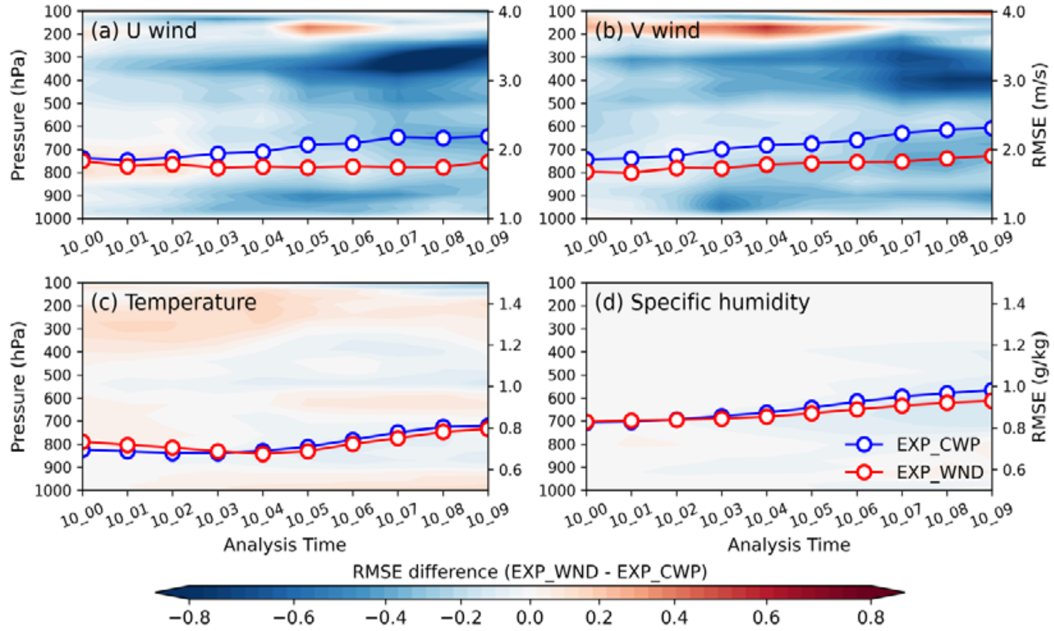
Dropsonde observations at (114.2° E, 22.3° N) on 1200 UTC, 10 July 2018.

3. Added-value from 3-D wind for tropical cyclone forecasts

Added value on analysis

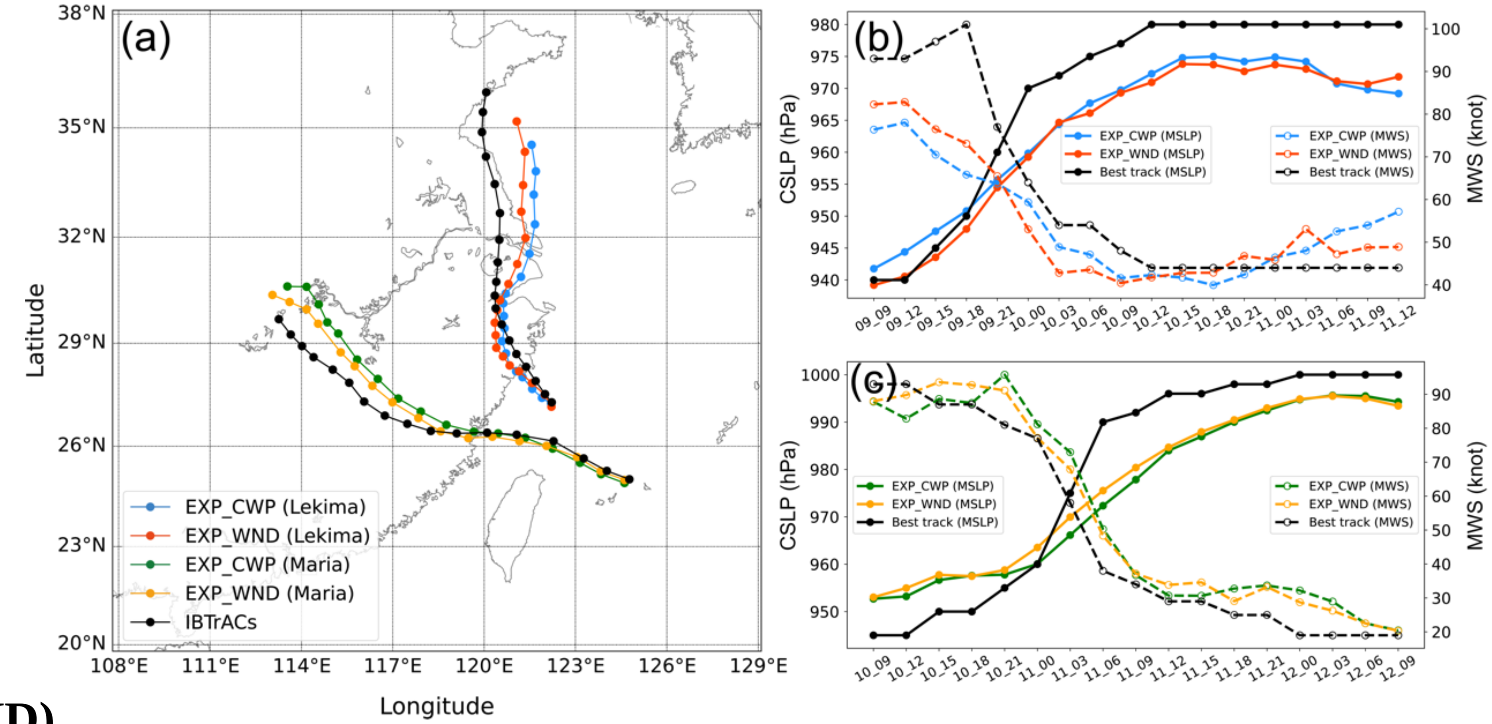
Experiments	Data assimilated
EXP_CWP	GTS + AHI LWP & IWP
EXP_WND	GTS + AHI LWP & IWP + GIIRS Wind

RMSE difference between EXP_WND and EXP_CWP



- **Assimilating the GIIRS 3D wind (EXP_WND) improves the wind analysis, as well as the T and Q fields.**

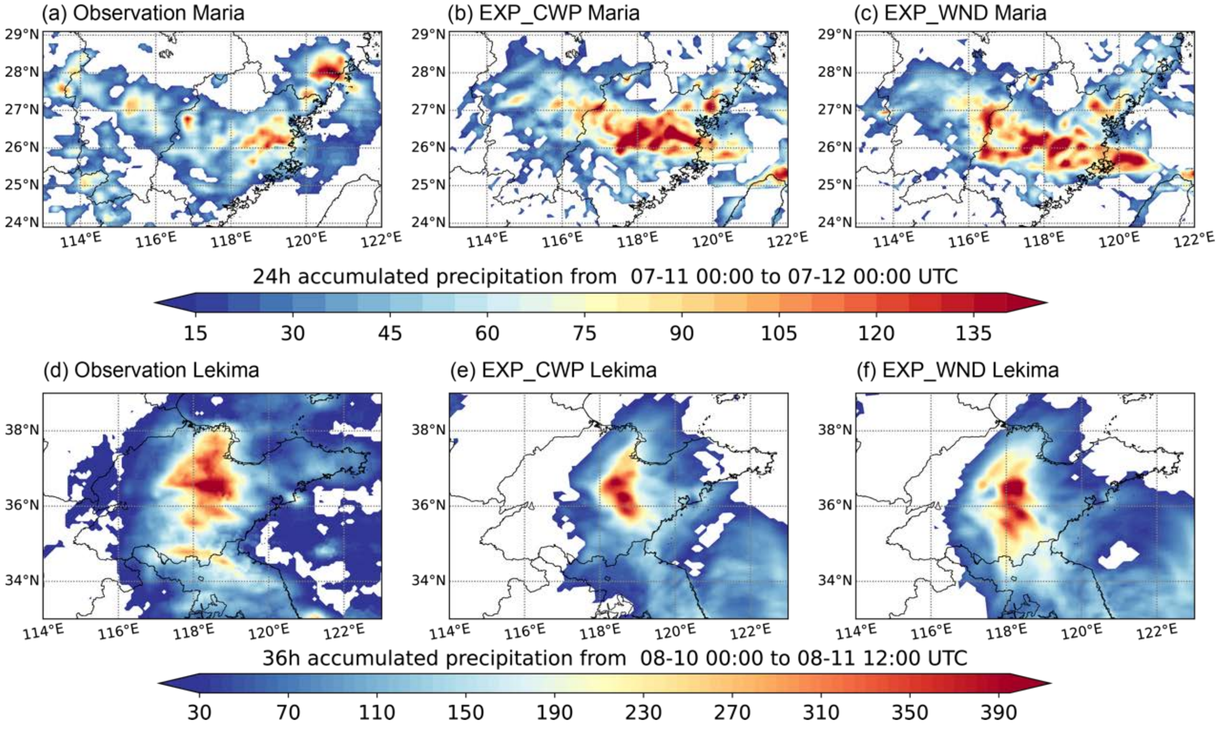
Track and Intensity Forecasts in Maria(2018) and Lekima(2019)

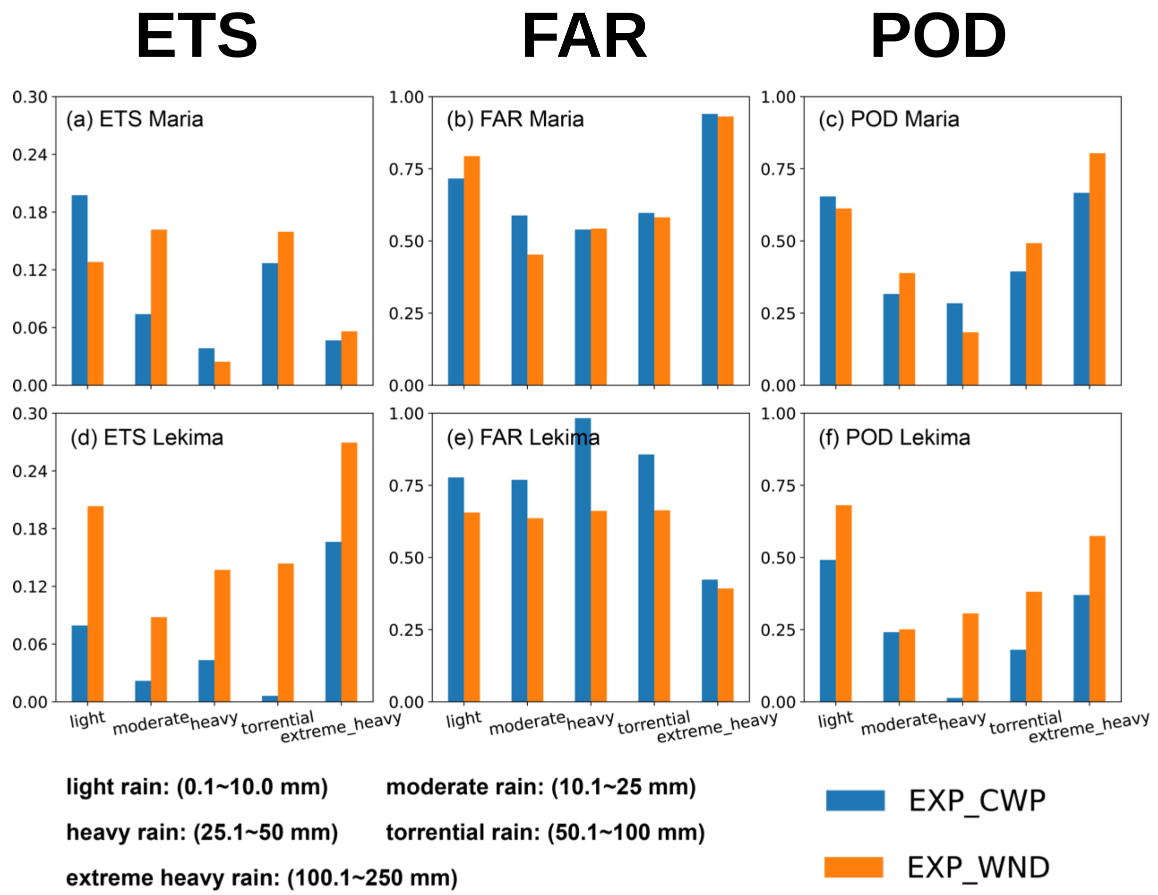


- **It also improves the TC track and intensity forecasts.**

(Meng et al., 2024, submitted)

Added value on rain forecast





The rain forecasts in Maria and Lekima show better results after GIIRS 3D wind assimilation.

The results show lower FAR and better ETS scores especially for heavy rains.

(Meng et al., 2024, submitted)

4. Summary

(1) It is feasible to derive 3D horizontal winds from geostationary hyperspectral IR sounder (GeoHIS) observations; higher temporal resolution is beneficial；

(2) Dynamic information provides added value on high impact weather forecast through data assimilation. We are carrying out more numerical experiments to better understand the value of the GIIRS 3-D winds using different NWP models such as WRF model, operational CMA-GFS and CMA-Meso.

(3) Further development of high-precision and efficient 3D wind algorithms are desired(e.g., combining traditional methods and artificial intelligence).

Poster#83: Li, Z., Z. Ma, J. Li and D. Di: Retrieval of Hourly Three-dimensional Horizontal Winds using Combined GIIRS Radiances Observations from Fengyun-4A and Fengyun-4B, 3:00 -4:30 p.m., Monday, Jan 29, 2024.

References

Li, J., et al., 2022: The influence of sub-footprint cloudiness on three-dimensional horizontal wind from geostationary hyperspectral infrared sounder observations. Geophysical Research Letters, 49, e2022GL098460.

Ma and Li et al. 2021： Four-Dimensional Wind Fields From Geostationary Hyperspectral Infrared Sounder Radiance Measurements With High Temporal Resolution. Geophysical Research Letters, 48, e2021GL093794.

Meng et al. 2024: Added value of three-dimensional horizontal winds from geostationary hyperspectral infrared sounder for typhoon forecast in a regional NWP model. (submitted to JGR)

Ouyed, A., et al., 2023： Global Three‐Dimensional Water Vapor Feature‐Tracking for Horizontal Winds Using Hyperspectral Infrared Sounder Data From Overlapped Tracks of Two Satellites. Geophysical Research Letters 50(7), e2022GL101830.

Santek, D. et al., 2019: Demonstration and Evaluation of 3D Winds Generated by Tracking Features in Moisture and Ozone Fields Derived from AIRS Sounding Retrievals. Remote Sens. 2019, 11, 2597

Thank you!

Happy and Healthy Dragon Year in 2024!

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