中華民國科技部
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Orographic Influences on Typhoon Tracks in the Vicinity of Taiwan

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Motivation

- Taiwan's position in the Pacific ocean subjects itself to the passage of 3 to 4 tropical cyclones (TCs) each year. The climatology suggests that Taiwan Island sits in the common pathway where most of the TCs passed through over the western North Pacific ocean.
- Taiwan's Central Mountain Range (CMR), and the island's geographical orientation provide a unique environment for the TC interaction.
- The terrain effects on TC tracks can be applied to other geographical locations with steep mountain which are also prone to TCs.

Objective

Use the RADAR data to observe tropical cyclone tracks, to understand why a tropical cyclone may either steer around or cross over Taiwan Island, to observe and understand what influences orographic effects have on typhoon tracks, and to observe other meteorological phenomena as a result of Taiwan terrain.

Methodology

- Froude Number: $\boldsymbol{Fr} = \frac{\boldsymbol{U}}{\boldsymbol{NH}}$
- Brunt- Vaisala Frequency: $\mathbf{N} = \sqrt{\frac{g}{\theta}\frac{d\theta}{dz}}$
- Steering flow: U is the TC's propagation speed; V_{max} is the TC's maximum sustained wind speed.
- RADAR data quality control software: RaKit.
- Radar data study of Typhoon Maria (2018).
- Radar data study of Typhoon Fanapi (2010).

Tropical Cyclone Track Influences

- Typhoon track climatology shows the most common paths of typhoons which moved across or around Taiwan Island. Typhoon Maria (2018) had a track of Category 1 type, while Typhoon Fanapi (2010) had a track of Category 3 type.
- Track can be affected by the TC's propagation speed; higher propagation speeds tend to facilitate a more straight TC path over the ocean environment.
- Typhoon Maria (2018) tracked to the north of Taiwan, eventually making landfall on mainland China. Maria moved around the northern tip of the island because of both the terrain effect and the slower propagation speed while crossing the northern tip of Taiwan.
- Typhoon Fanapi (2010) made landfall on Taiwan, interacting with the CMR as it moved across the island. The overall kinetic energy of the storm was strong enough to over take the terrain.

Fig. 1a

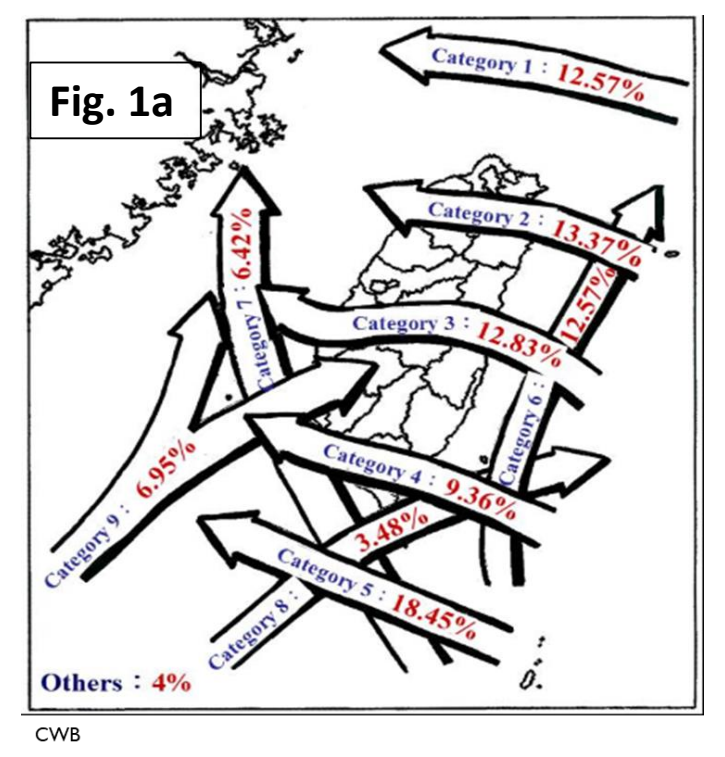


Fig. 2a

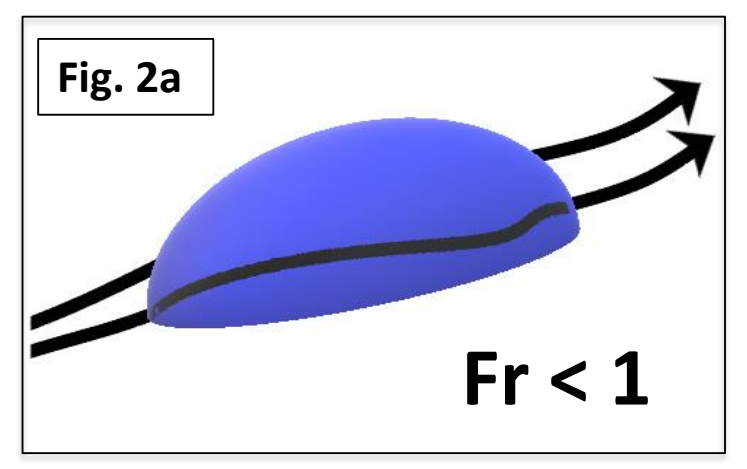


Fig. 2b

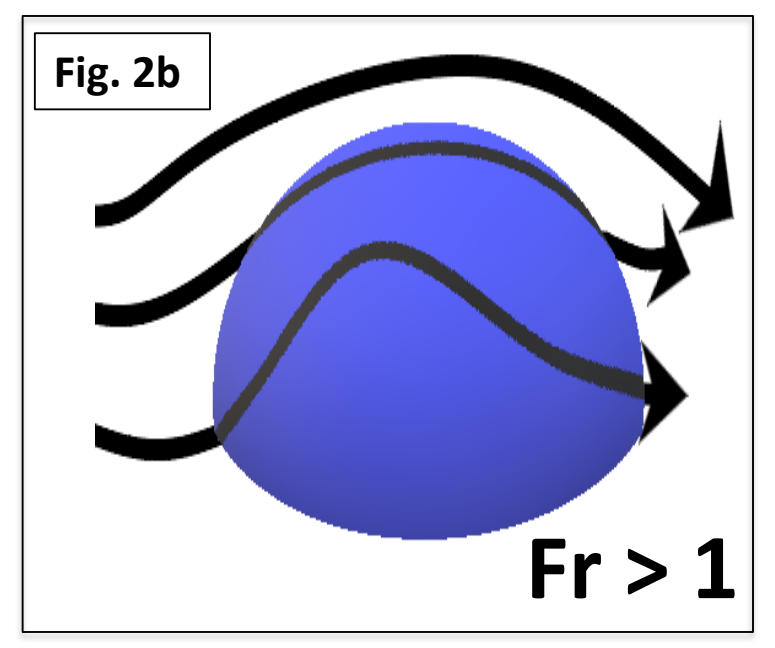


Fig. 1a: Typhoon track climatology around Taiwan (CWB)
Fig. 2a: Typhoons with a low Froude number will skirt around terrain
Fig. 2b: Typhoons with a high Froude number will pass across terrain

References

- Ming-Jen Yang, Da-Lin Zhang, Hsiao-Ling Huang, A Modeling Study of Typhoon Nari (2001) at Landfall. Pt. 1: Topographical Effects, JAS, v65, October 2008.
- Ming-Jen Yang, Yao-Chu Wu, and Yu-Chieng Liou, The study of inland eyewall reconstruction of Typhoon Fanapi (2010) using numerical experiments and vorticity budget analyses. JGR-Atmos., D54902, 2018.
- Yu-Chieng Liou, Tai-Chi Chen Wang, and Pei-Yu Huang. The Inland Eyewall Reintensification of Typhoon Fanapi (2010) Documented from an Observational Perspective Using Multiple-Doppler Radar and Surface Measurements, MWR, December 2015.
- Chun-Chieh Wu* and Ying-Hwa Kuo, Typhoons Affecting Taiwan: Current Understanding and Future Challenges. BAMS vol. 80 N1, January 1999.
- Johnny C. L. Chan, William Gray, Tropical Cyclone Movement and Surrounding Flow Relationships, MWR, 1982 vol. 110.

RADAR Limitations

Beam Obstruction and Noise

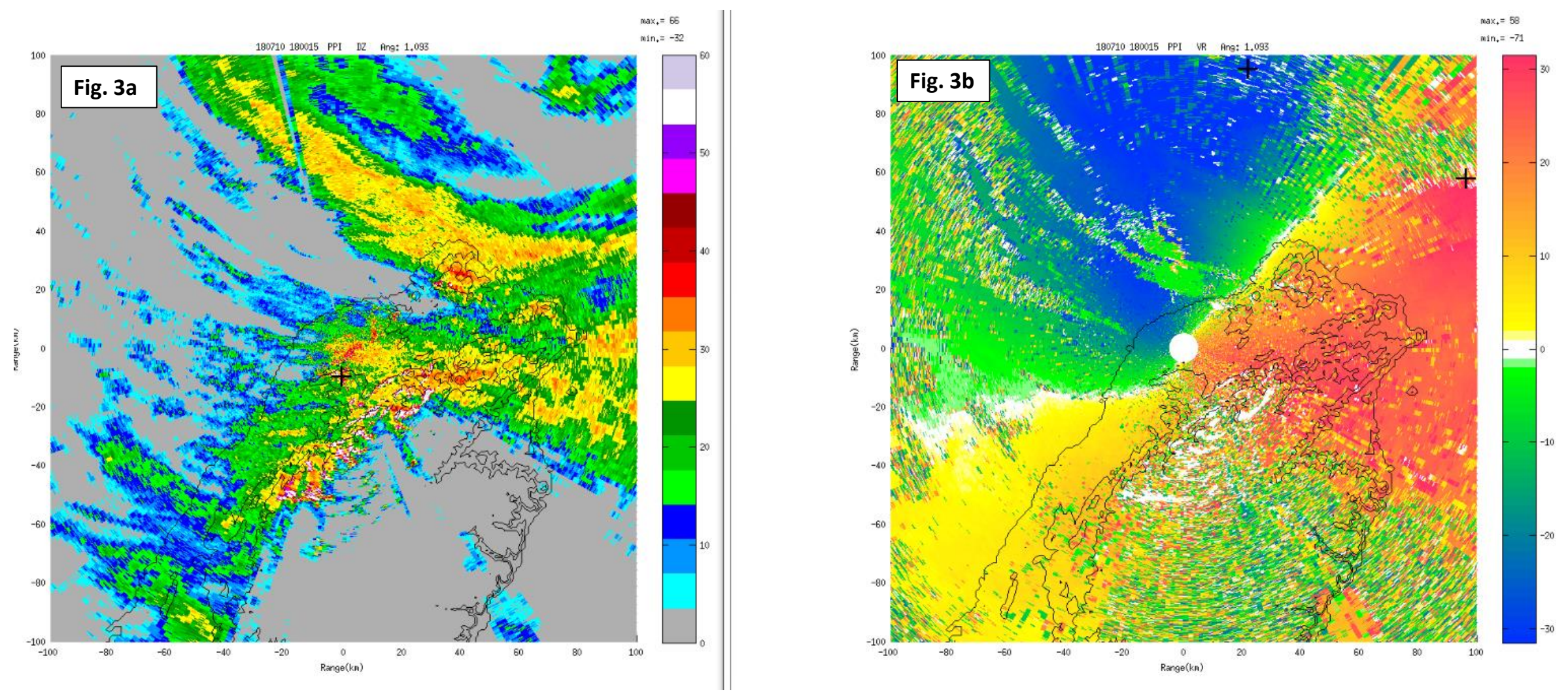
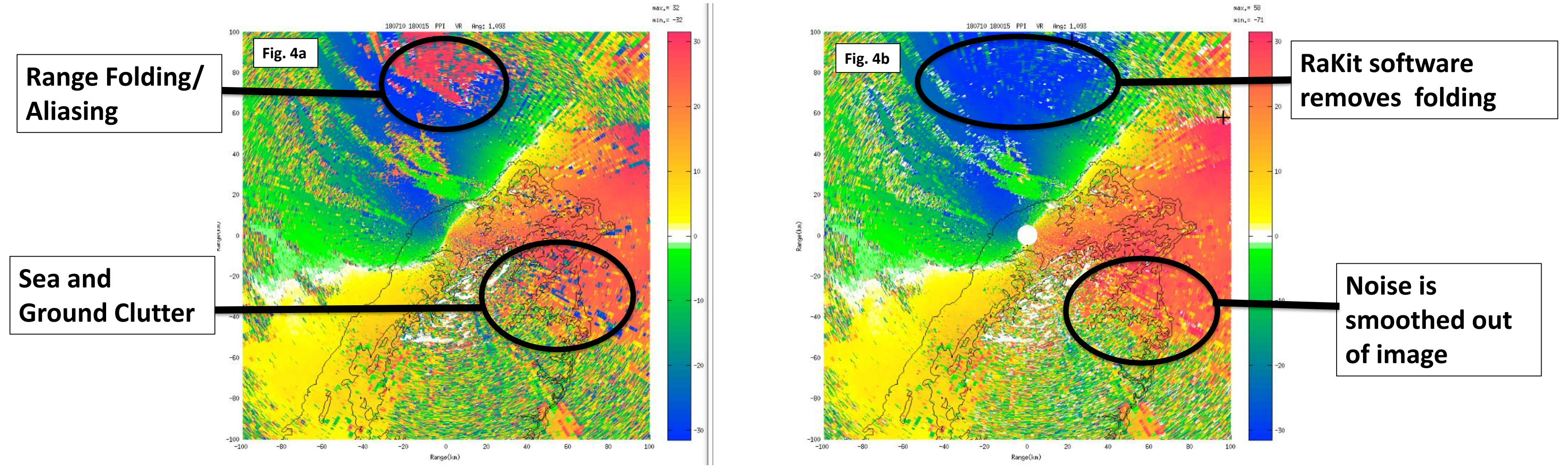


Fig. 3a: Terrain related beam obstruction at 1.1 elevation angle, both parameters show a shadow which follows the outline of the terrain. The DZ image illustrates the shadow created by the RADAR beam not being able to penetrate the terrain, as shown with empty space
Fig. 3b: Radial Velocity image displays sea and ground clutter noises inside the terrain shadow.

Quality Control/ Noise Removal



Range Folding/ Aliasing

Sea and Ground Clutter

RaKit software removes folding

Noise is smoothed out of image

Fig 4a: Raw RADAR image with error signals. The red area on the northern tip of Taiwan was embedded in an otherwise homogenous wind field.
Fig 4b: Corrected image with noise removal. RaKit software was used to filter out clutter, range folding and other noise, showing a realistic image of actual conditions.

Terrain Effects

Blocking

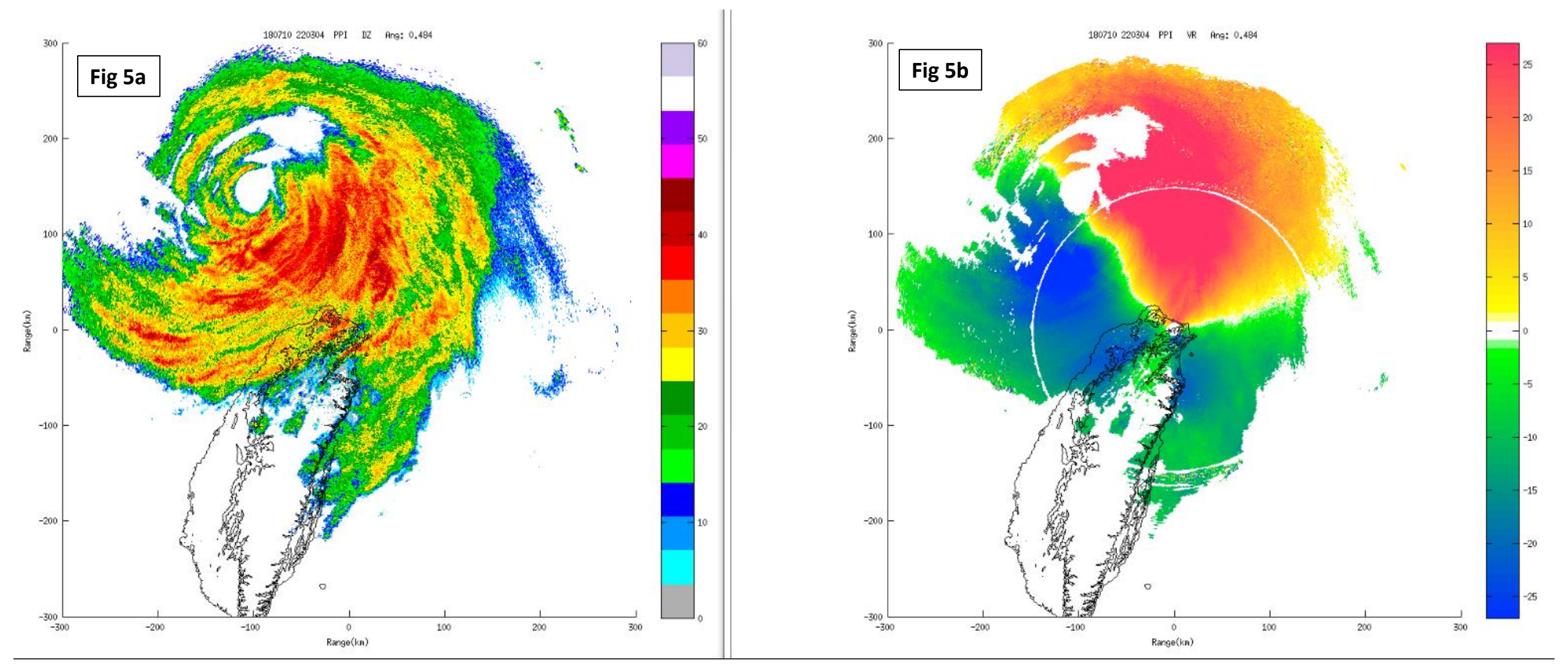


Fig 5a: Terrain blocking of the wind field channels the flow around mountains. Locally enhanced rain bands can be observed at the apex of this convergence
Fig. 5b: Terrain occupies in the empty area, creating a wind blockage.

Flow Channeling

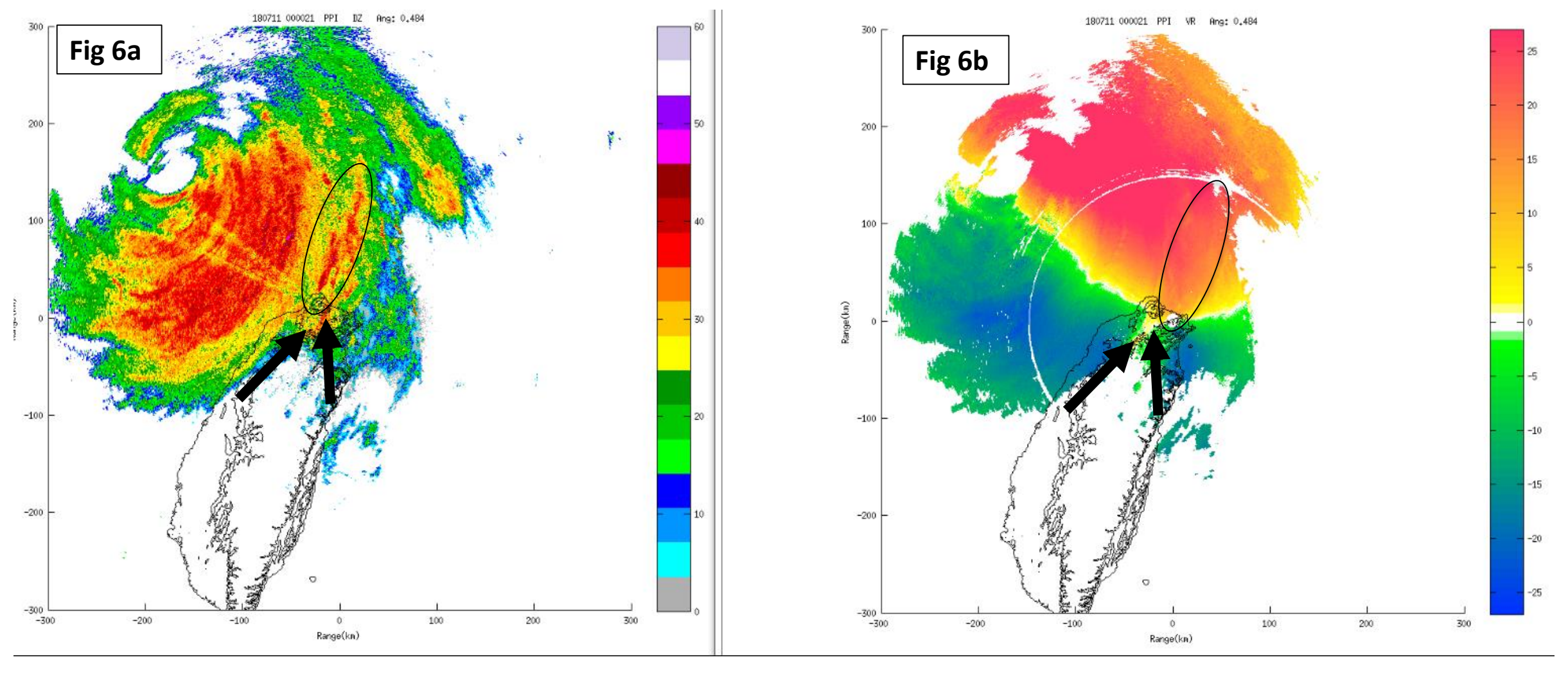


Fig. 6a: Locally enhanced rain bands can be observed at the apex of this convergence, possibly caused by the directed flow around the terrain.
Fig. 6b: A narrow streak of high wind velocity extends down from a homogenous high wind area, through a wide homogenous area of lesser winds closer to the zero line.

Typhoon Tracks

Track Category 1: Typhoon Maria (2018)

* Forecast track placed Typhoon Maria out to sea, northeast of Taiwan at 0200 UTC on 11 July 2018.

- Faster propagation than forecasted. Maria made landfall on mainland China at 0110 UTC on 11 July 2018.
- $RMW \approx 13\ km$*
- $V_{max} \approx 55\ ms^{-1}$
- $U \approx 35\ km\ h^{-1}$
- Due to large radius and fast movement, Maria steered a relatively straight path over the ocean.

RMW is the Radius of Maximum Winds
**Eyewall size before replacement cycle*

Fig. 7a

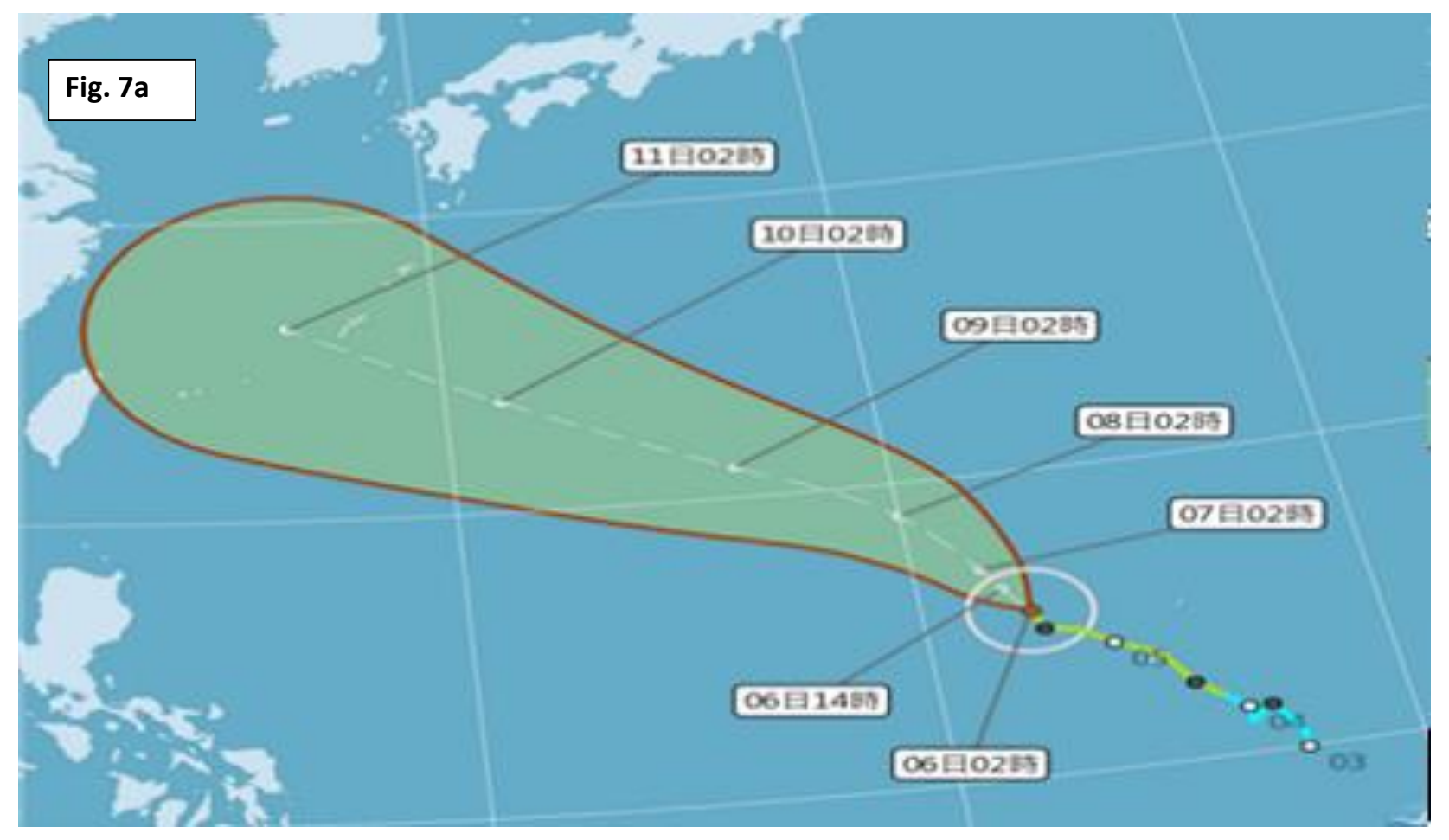


Fig. 7b

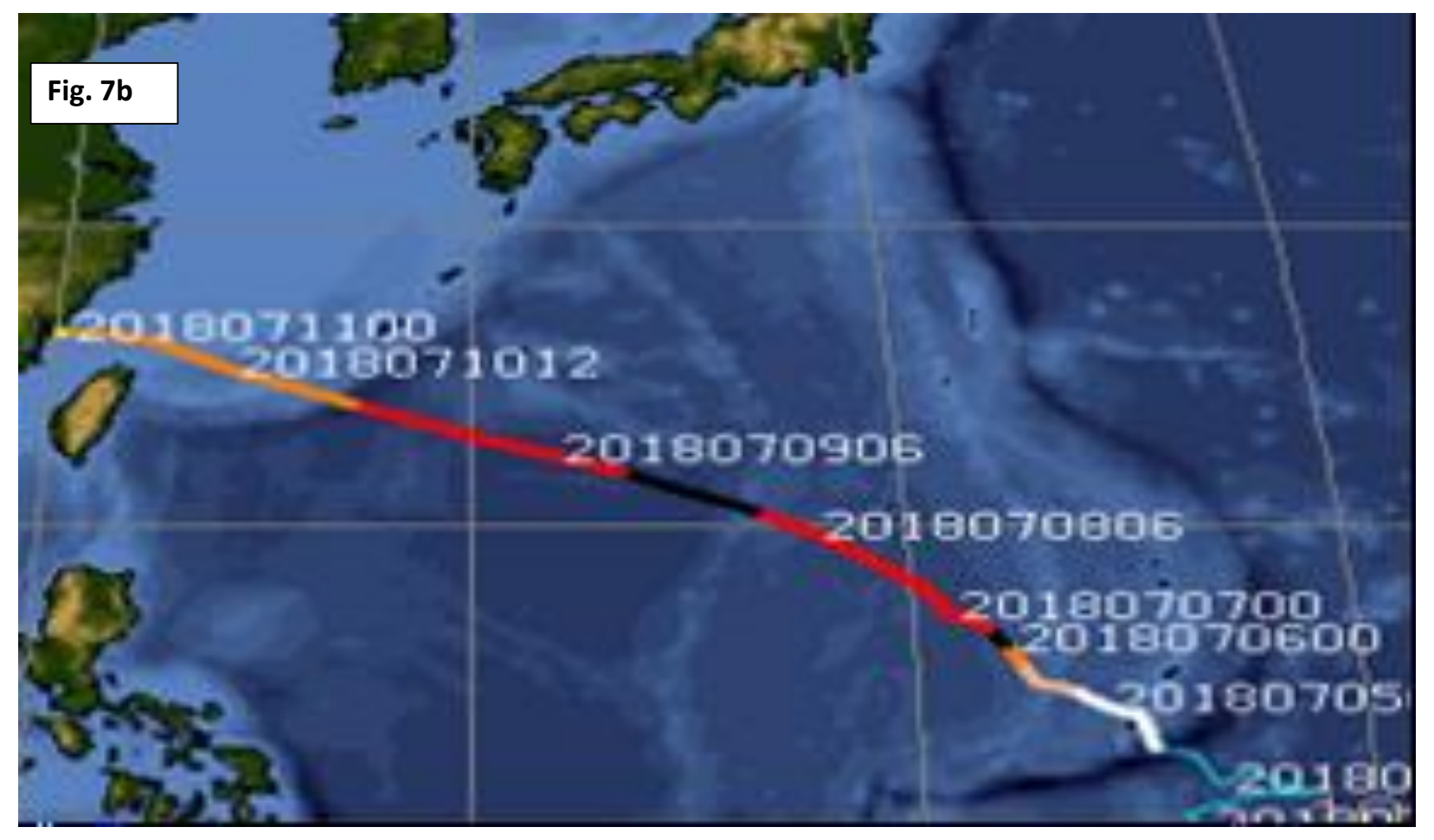


Fig 7a: Central Weather Bureau forecast for Typhoon Maria on 06 July 2018 shows no notable curvature or wobble in track path. (CWB website)
Fig 7b: Maria's observed track was similar to the CWB forecasted path. (https://tropic.ssec.wisc.edu)

Track Category 3: Typhoon Fanapi (2010)

- Forecasted track called for TC's landfall over Taiwan, and then moved straight across the CMR before exiting the island into Taiwan Strait.
- Terrain blocking guided Fanapi's westward course over Taiwan. The track followed the outline of the highest elevation mountain peaks, moving south, and then continued westward over the top of lower elevation mountain ridge lines.

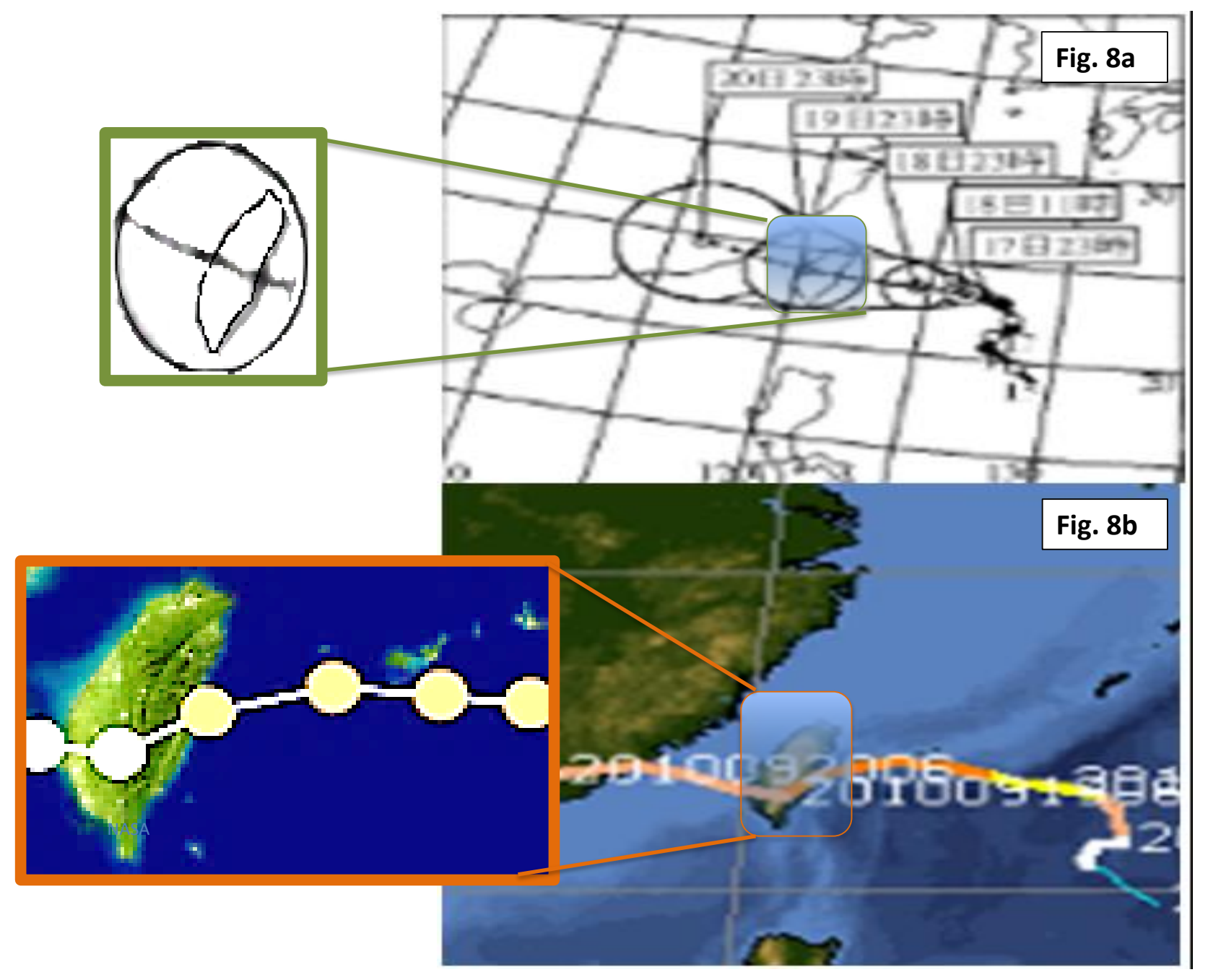
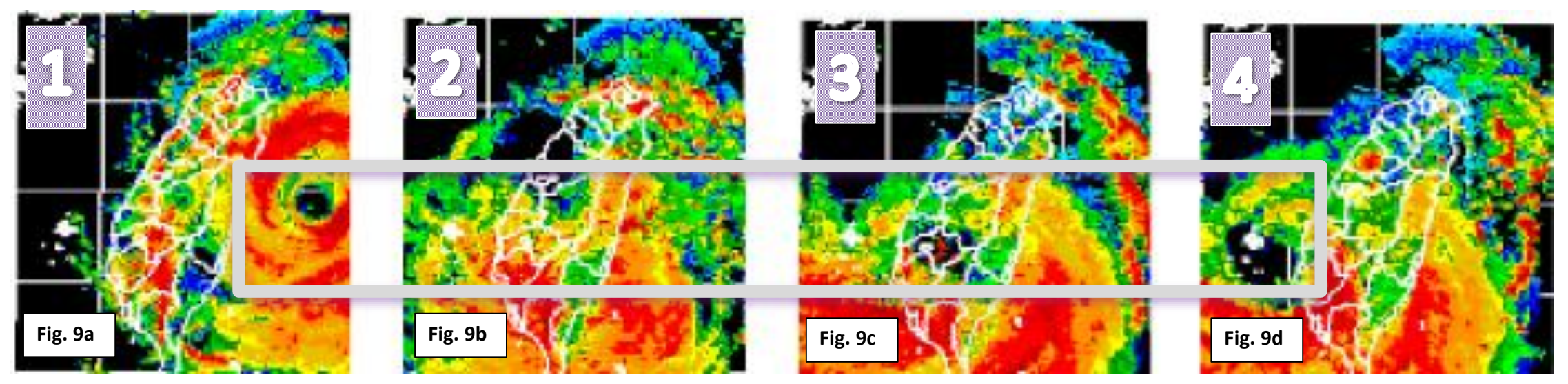


Fig 8a: Central Weather Bureau forecast track showed a near linear, westward track across Taiwan.(CWB official warning map)
Fig 8b: Fanapi's observed track showed a southward deviation in tack, as it followed the outline of breach-able terrain across Taiwan.(https://tropic.ssec.wisc.edu/ NASA)

Eyewall Breakdown and Reconstruction

1. Fanapi approached Taiwan with a well-defined eyewall.
2. After landfall, Fanapi's eyewall broke down over the CMR.
3. Fanapi began to track westward after clearing highest terrain elevations, and a new eye began to form.
4. A fully developed eye was present upon Fanapi's exit out, to the Taiwan Strait (Yang et al. 2018).



Figs 9a,b,c,d: Compiled mosaics of RADAR images show Fanapi's eyewall breakdown and rebuild during the storm's transition across Taiwan. The rectangular box indicates Fanapi's track area. (CWB website)

Conclusions and Future Research

- RADAR data has certain limitations and poses several challenges around Taiwan's steep and complex terrain.
- Froude number is an indicator of a tropical cyclone's ability to overcome terrain barrier along its projected track. When Fr > 1, the storm will likely be able to move across Taiwan's terrain; when Fr <1, the storm will likely to move around the terrain.
- Terrain effect plays an significant role in determining the TC's track near Taiwan.
- Friction will warp a TC core, and could shear vortex apart.
- How does the island orography affect a tropical cyclone compared to the background environmental wind shear?
- What causes a broken-down TC eyewall to reconstruct? Is the eyewall reconstruction a bottom-up or top-down process?
- Continued research into RADAR data analyses for TCs over mountainous regions.