The high-resolution boundary layer wind fields under clear sky revealed by multiple-lidar observations and WISSDOM

廖宇慶[a], 楊伯謙[a], 陳韡鼐[b], 蔡嘉倫[c]

林沛練[a], 李育棋[d], 許玉金[d], 藍嘉偉[e]

[a] *Department of Atmospheric Sciences, National Central University*

[b] *Research Center for Environmental Changes, Academia Sinica*

[c] *Department of Atmospheric Sciences, Chinese Culture University*

[d] *Central Weather Administration, Taipei, Taiwan*

[e] *Civil Aviation Administration, Taipei, Taiwan*

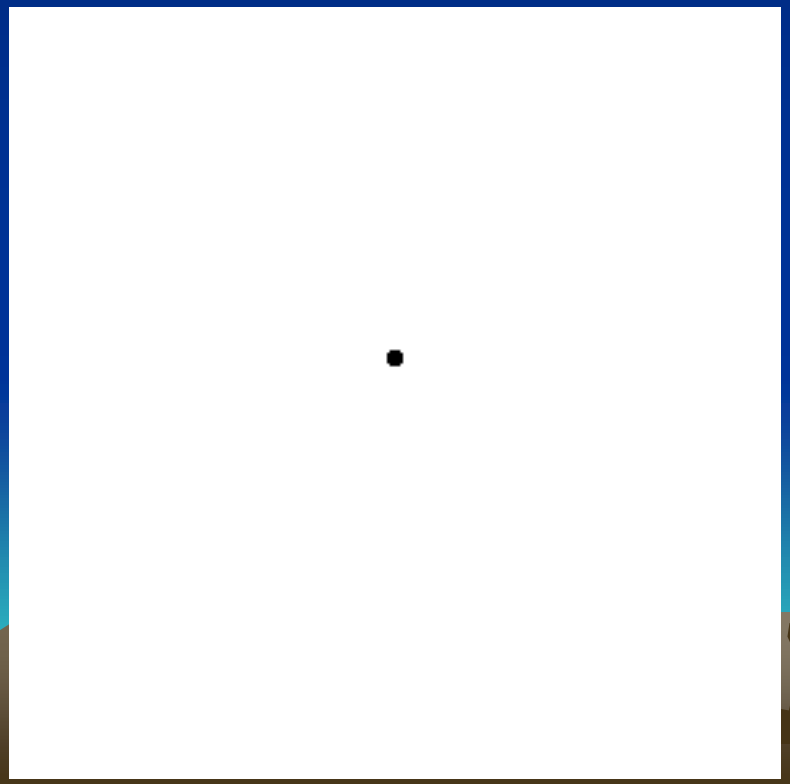
Outline

1. 雷達/光達量測之徑向風介紹。
2. WISSDOM演算法介紹。
3. 多光達實驗設計。
4. 2023/09 彰化田中個案。
5. 2024/04 桃園國際機場個案。
6. 總結。

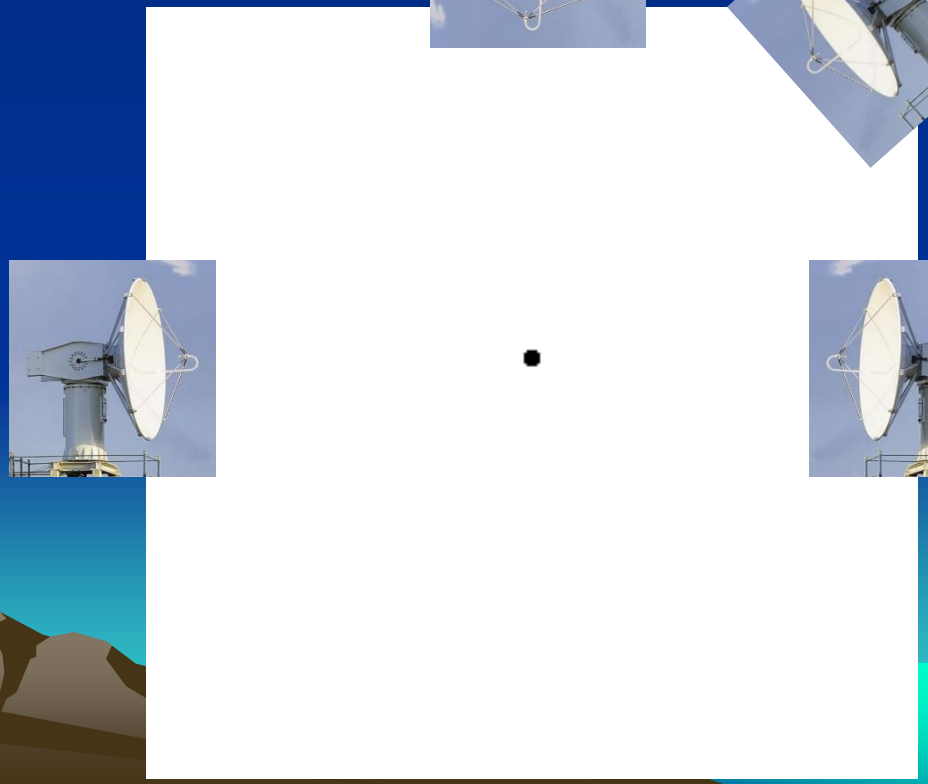
利用都卜勒效應計算風速

- 當波源在運動時，回波的頻率會改變，而改變的量與波源的速度有關。如：救護車經過時，聲音由高亢變低緩。

波源靜止時



波源運動時



雷達/光達 徑向風(Vr)

$$V_r = u \cdot \frac{x}{r} + v \cdot \frac{y}{r} + (w + V_t) \cdot \frac{z}{r}$$

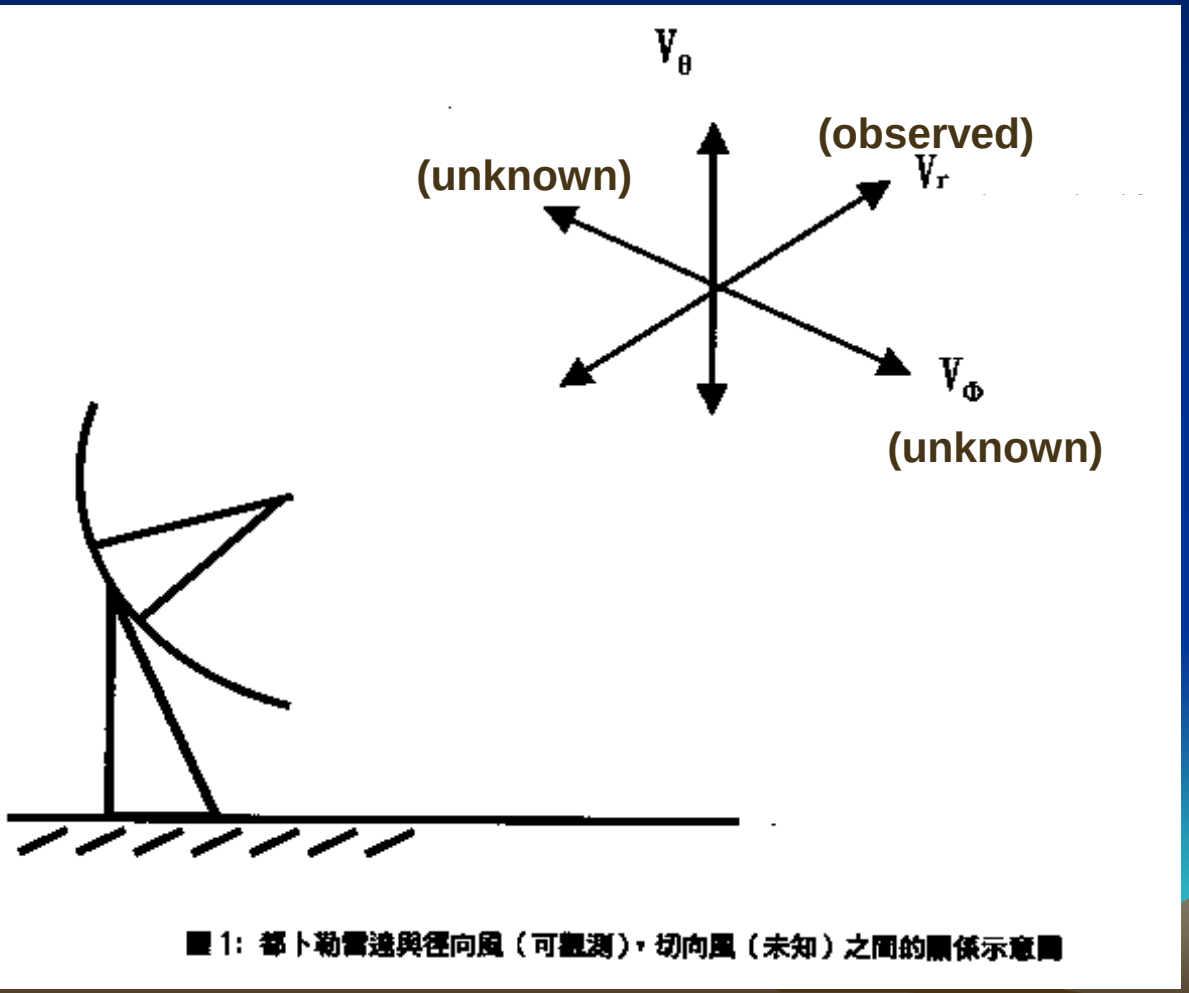
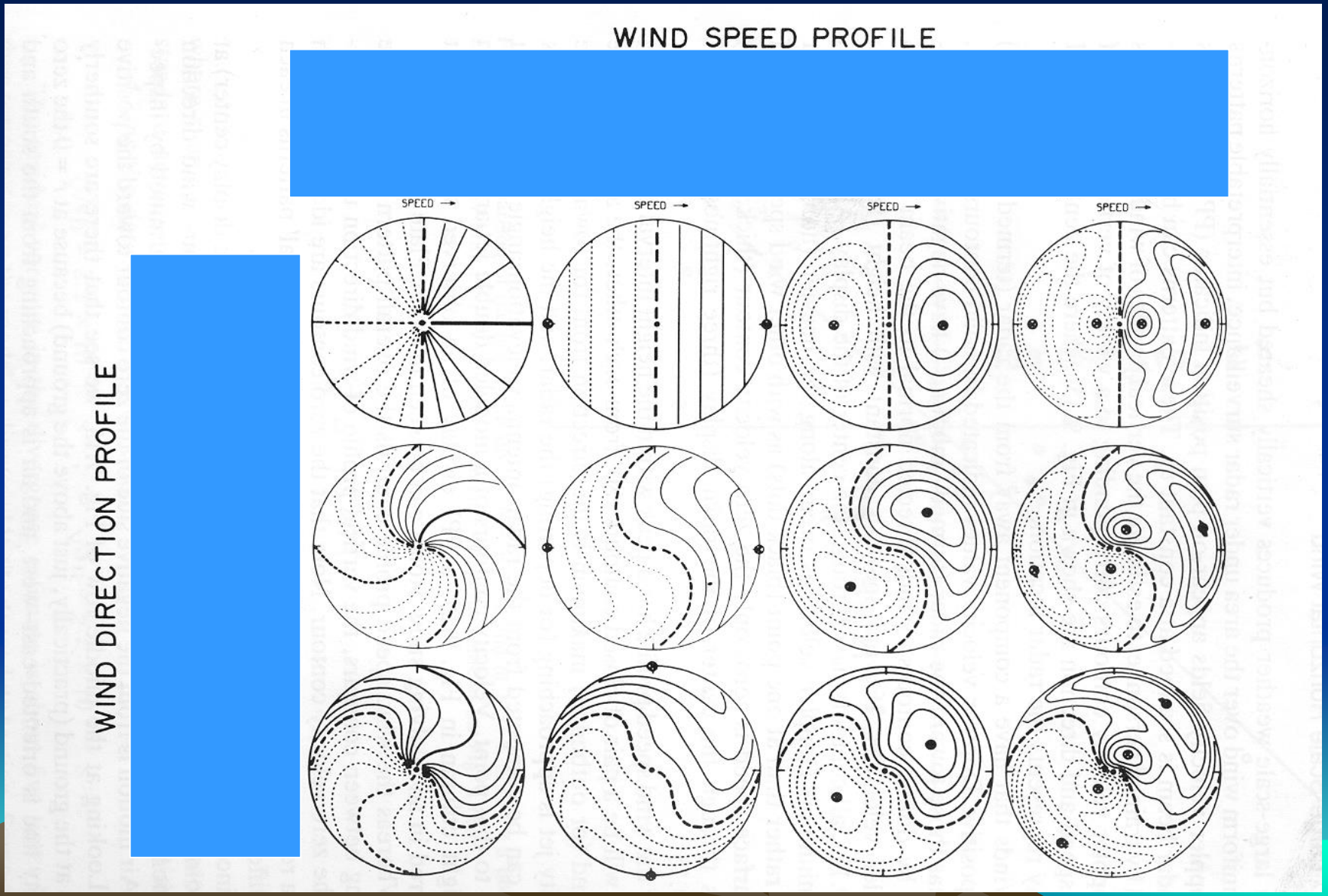
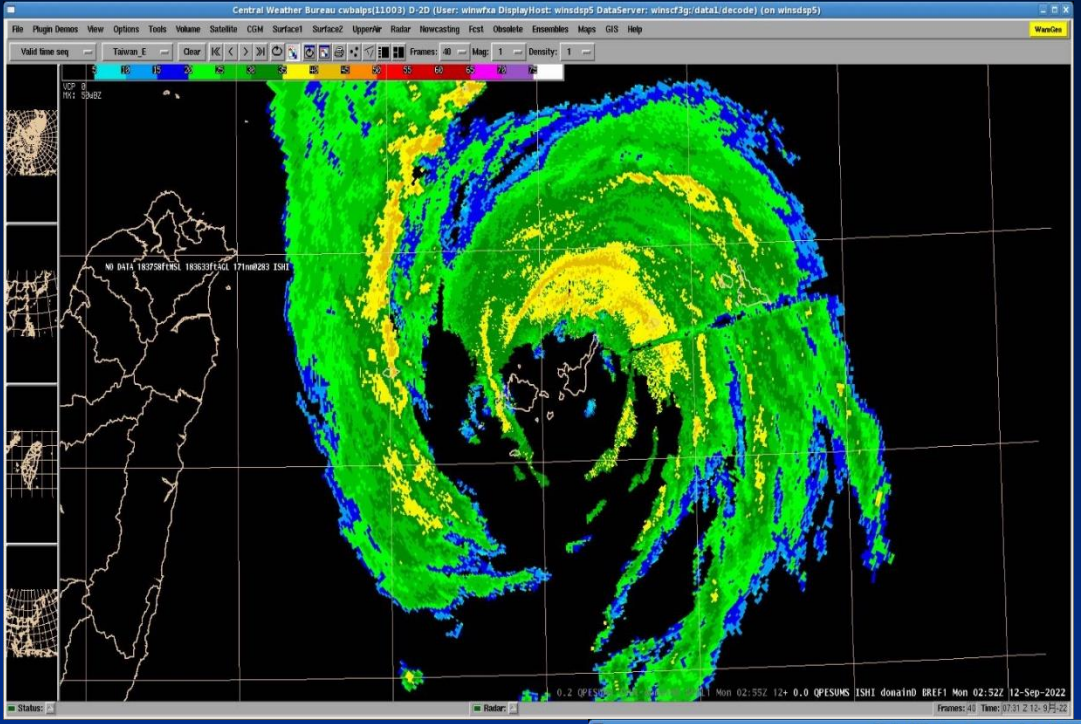


圖1：都卜勒雷達與徑向風（可觀測），切向風（未知）之間的關係示意圖

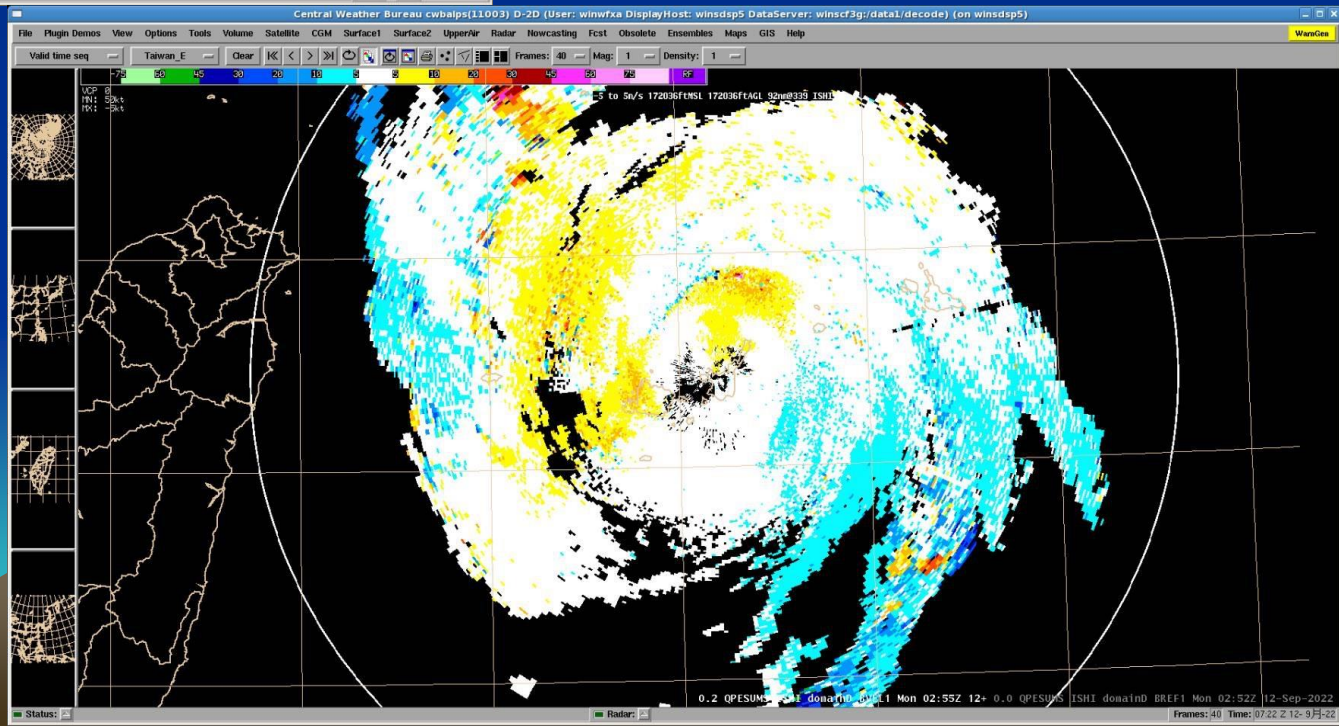
Vr：正值: 吹離雷達
負值: 吹向雷達

Doppler radial wind signature for idealized flows (Doviak and Zrnic, 1992)



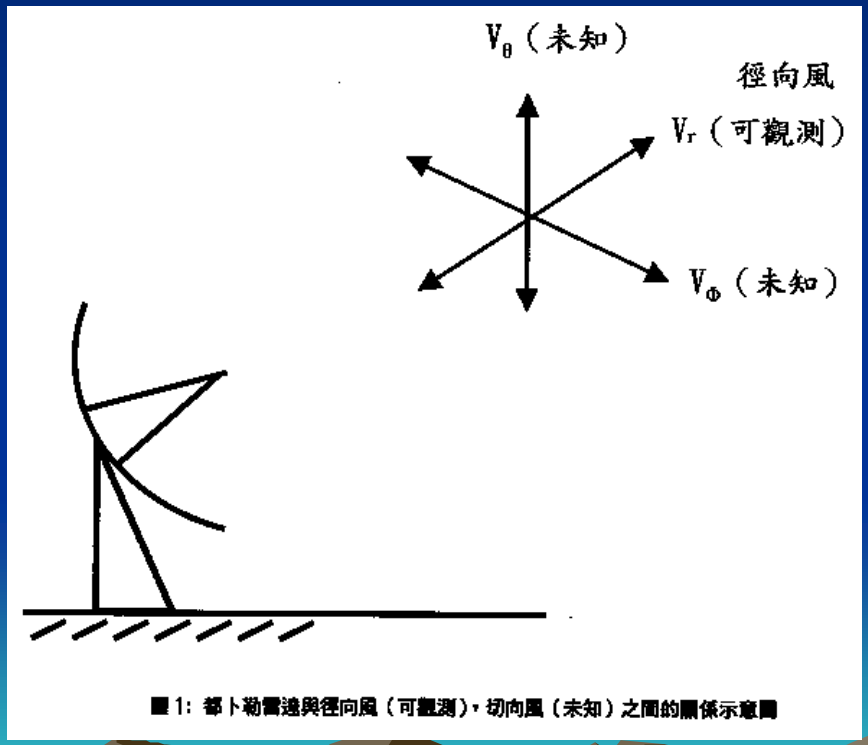


颱風梅花 (2022)
Typhoon Muifa



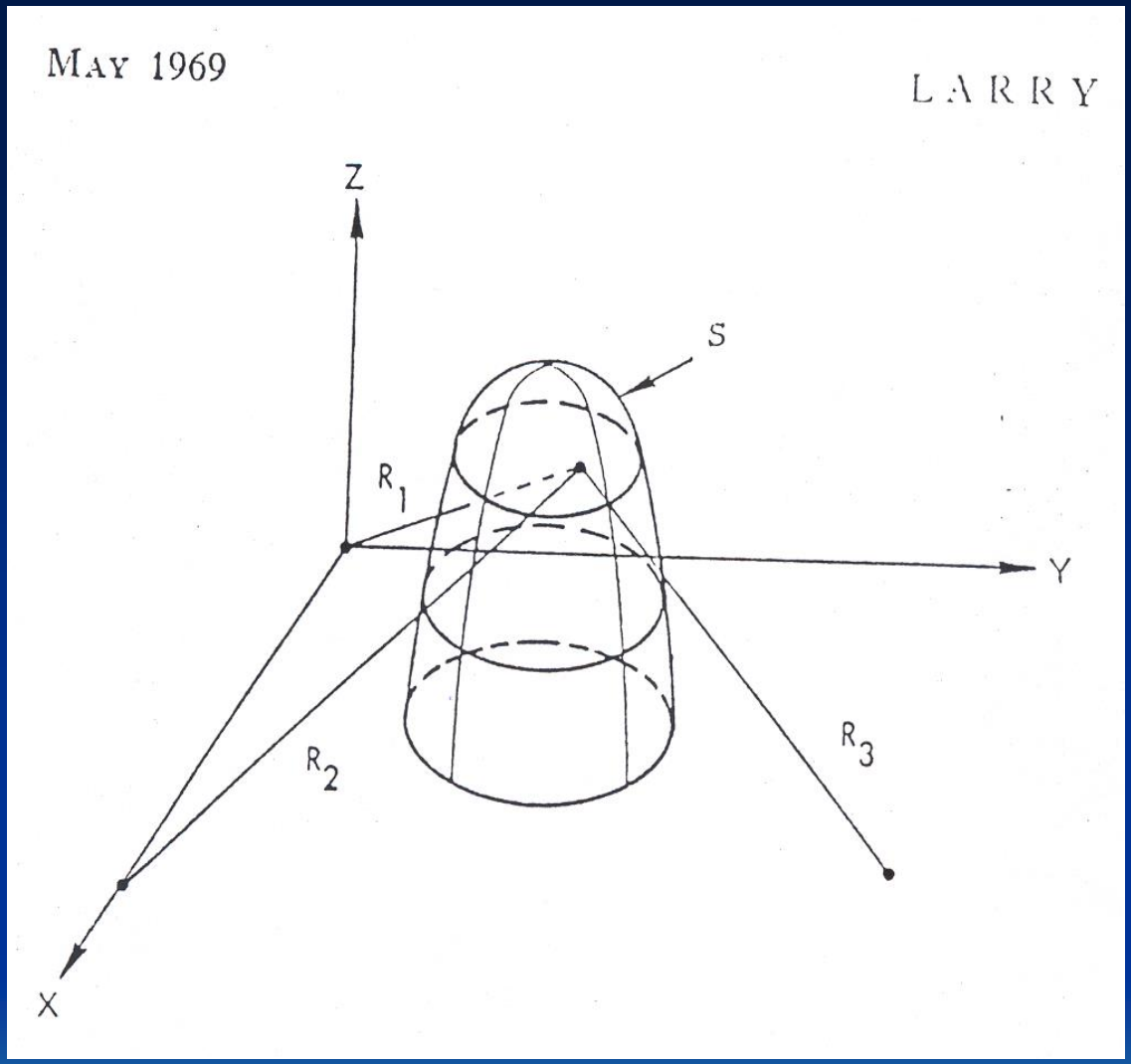
Doppler radial wind (都卜勒徑向風; *Vr*)

$$V_r = u \cdot \frac{x}{r} + v \cdot \frac{y}{r} + (w + V_t) \cdot \frac{z}{r}$$



■1: 都卜勒雷達與徑向風（可觀測），切向風（未知）之間的關係示意圖

1. 徑向風對大氣風場的描述是不完整的。
2. 實際應用往往需要三維的(*u*, *v*, *w*) 風場。
3. 多雷達合成。



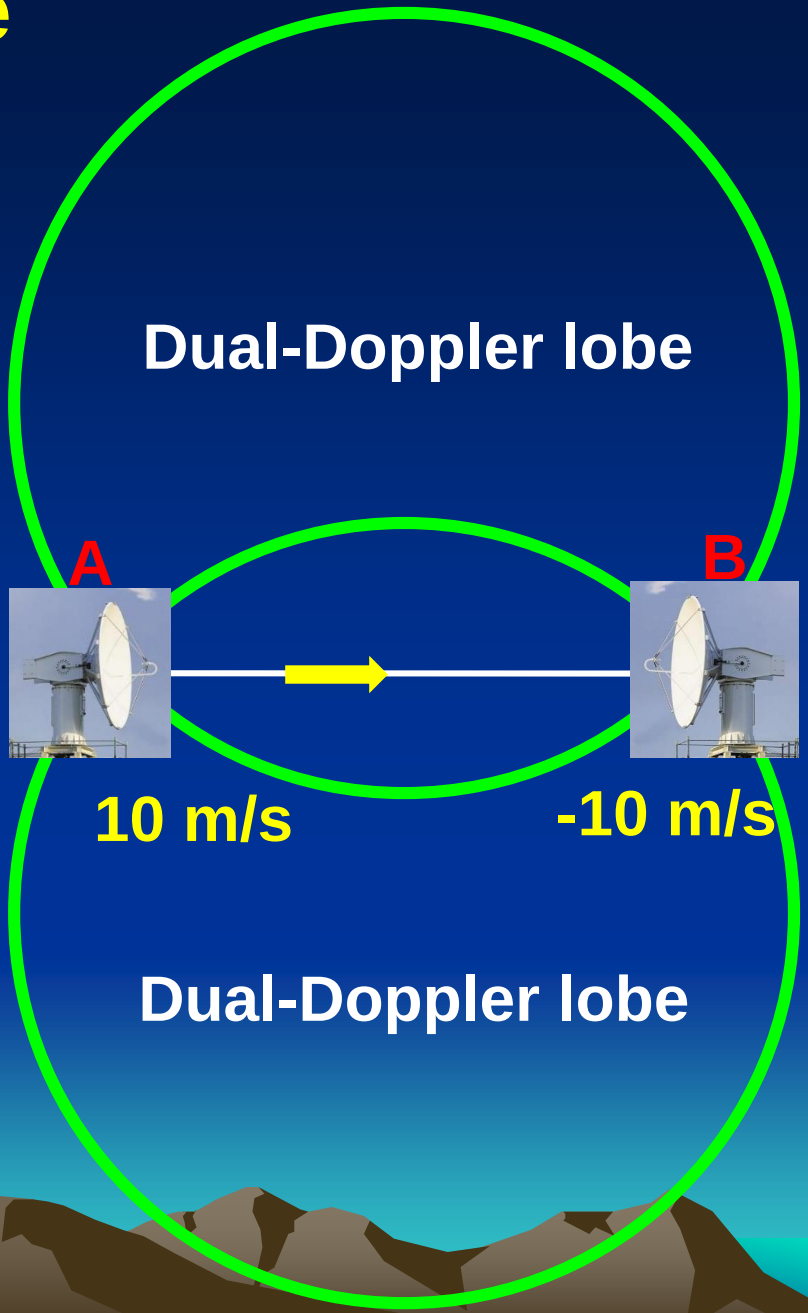
使用多雷達合成風場示意圖

WInd Synthesis System using DOppler Measurements (WISSDOM)

(Liou and Chang 2009, Liou et al. 2012, Liou et al. 2014)

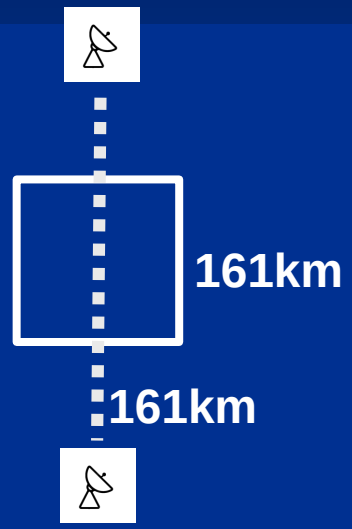
- 可反演沿雷達baseline上的三維風場。
- 使用Immersed Boundary Method計算流體在地表的受力，故可在地形上合成三維風場。
- 可同時結合任何數目雷達的資料及其他風場資訊，如：光達、剖風儀、探空、篩選後的模式預報風場、地面測站、衛星近海表面風場等。

Radar Baseline

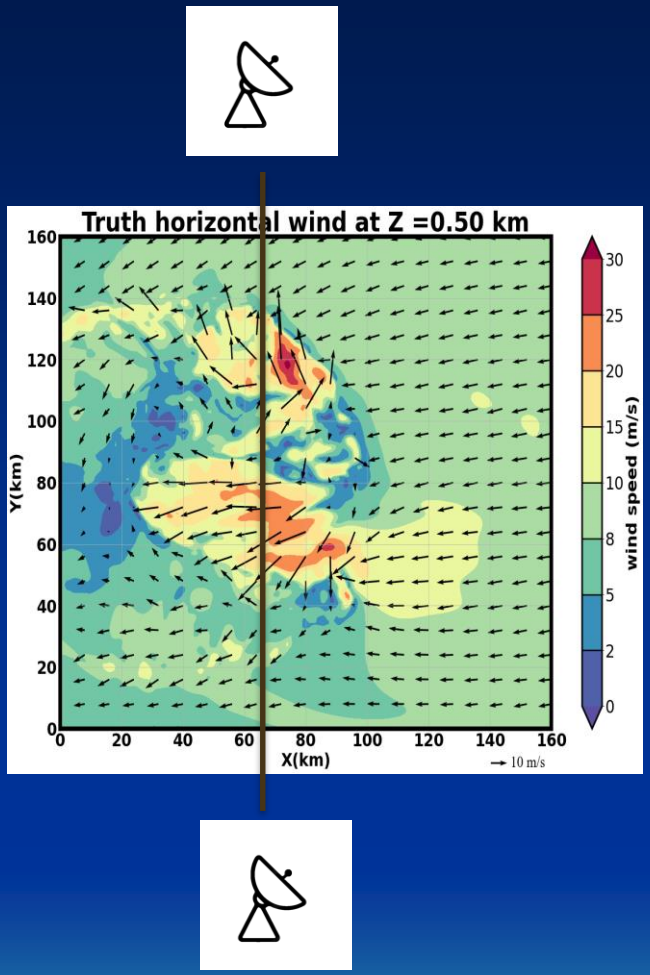


實驗設定

R2 (81, 181, 0)



R1 (81, -20, 0)



$$V_r = u \cdot \frac{x}{r} + v \cdot \frac{y}{r} + (w + V_t) \cdot \frac{z}{r}$$

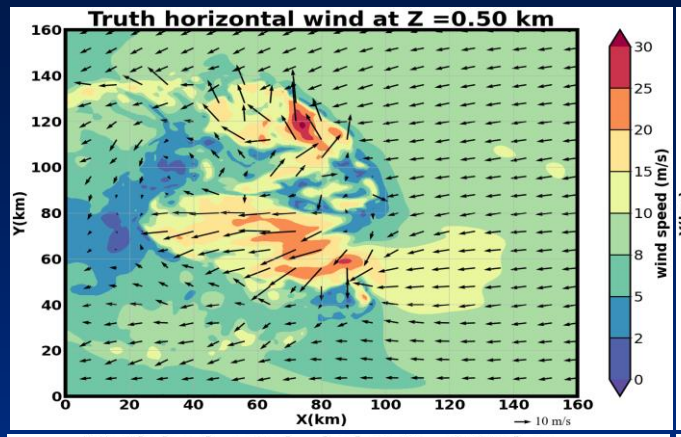
Model Truth

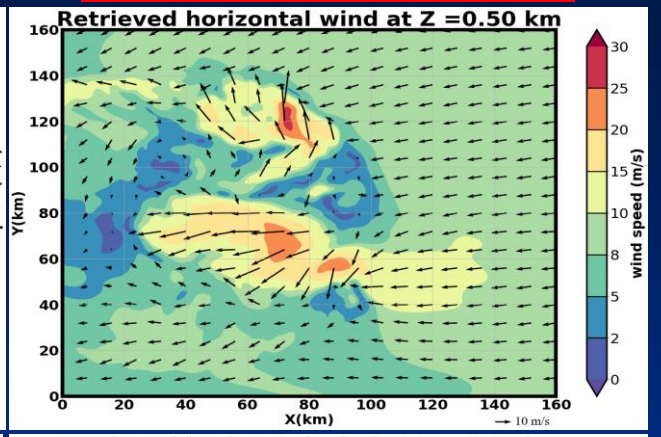
WISSDOM Retrieval

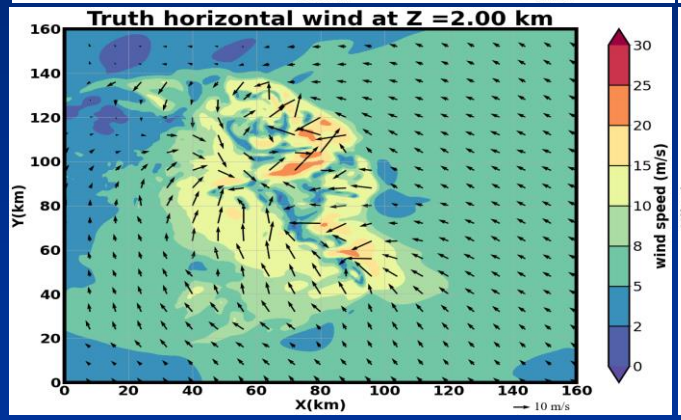
Z=0.5km

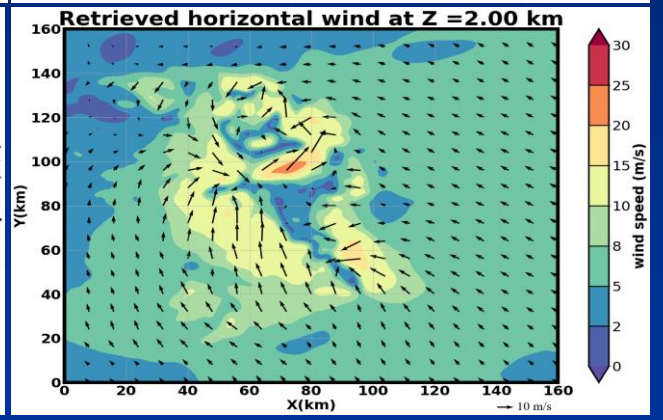
Z=2.0km

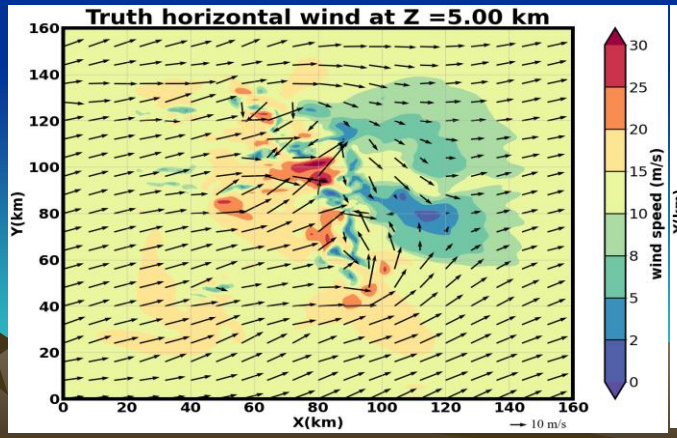
Z=5.0km

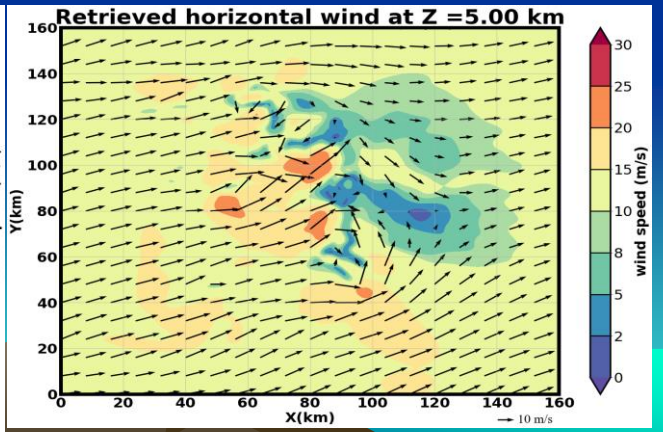




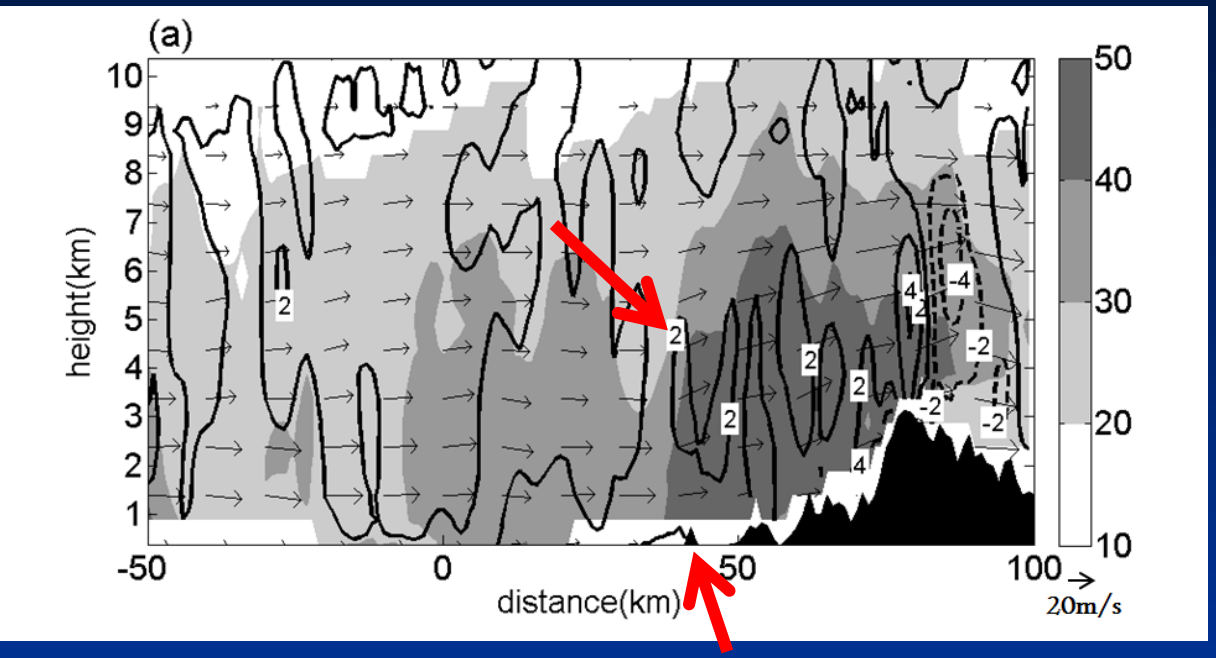




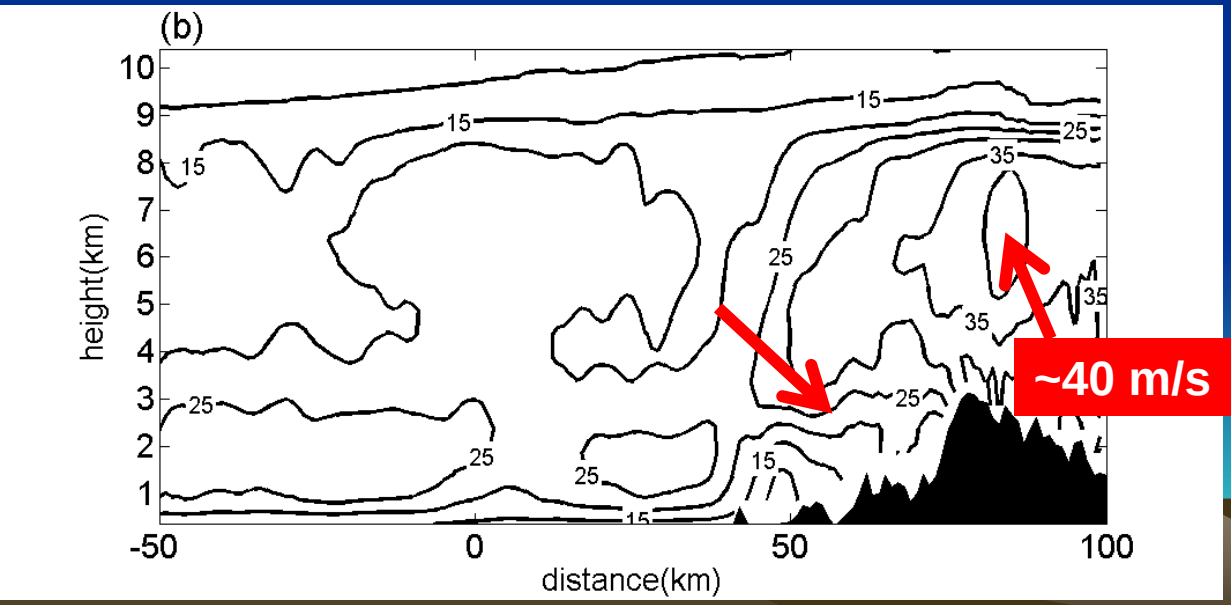




莫拉克颱風(2009)雨帶內在地形上WISSDOM反演的風場結構

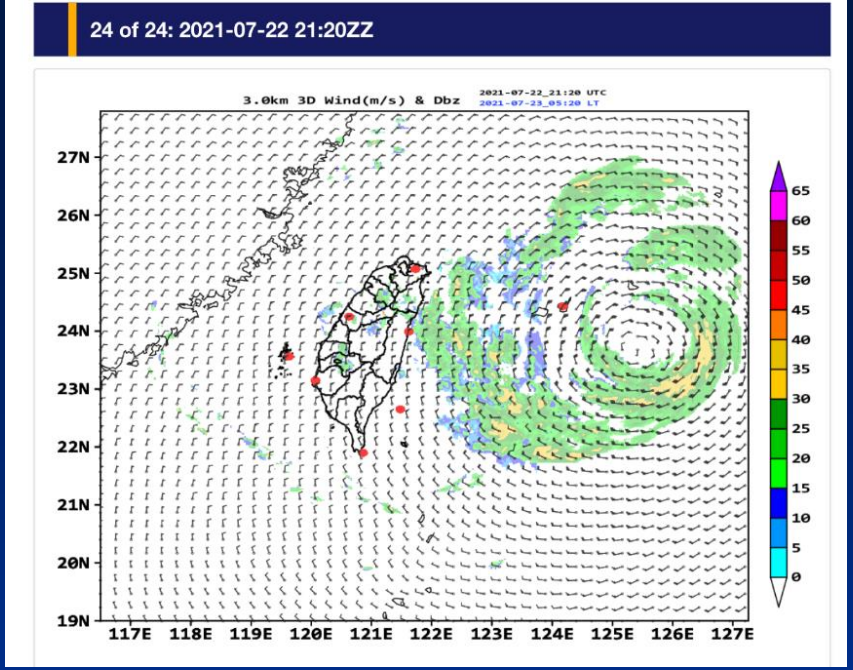


中央山脈西/東側有明顯的上升/下沉氣流。

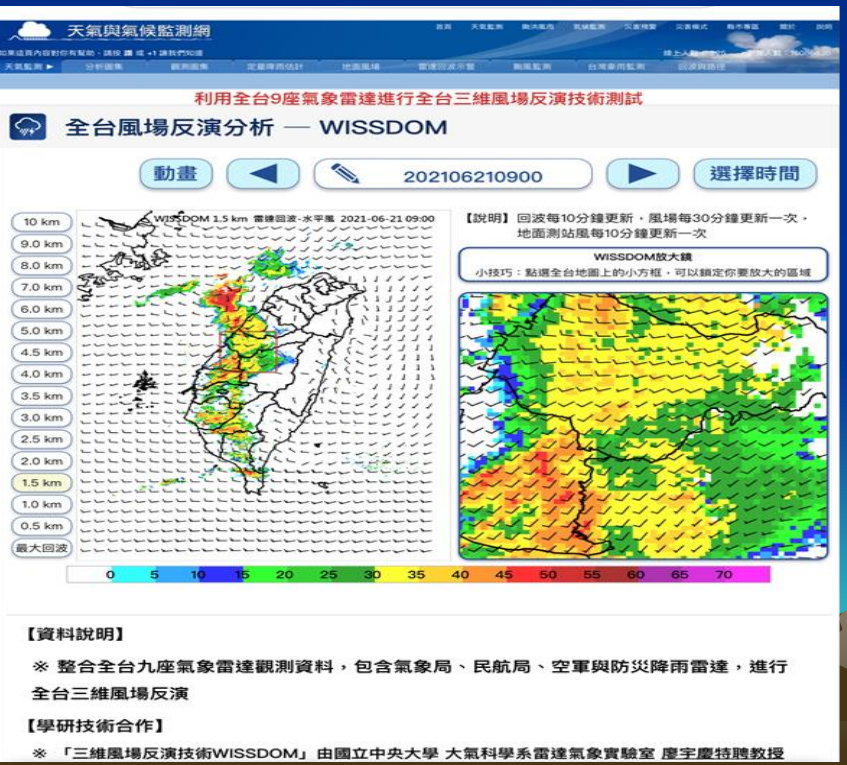


東-西方向風速沿斜坡隨高度而增強，在山頂上方有極大值。可用一shallow water model解釋。

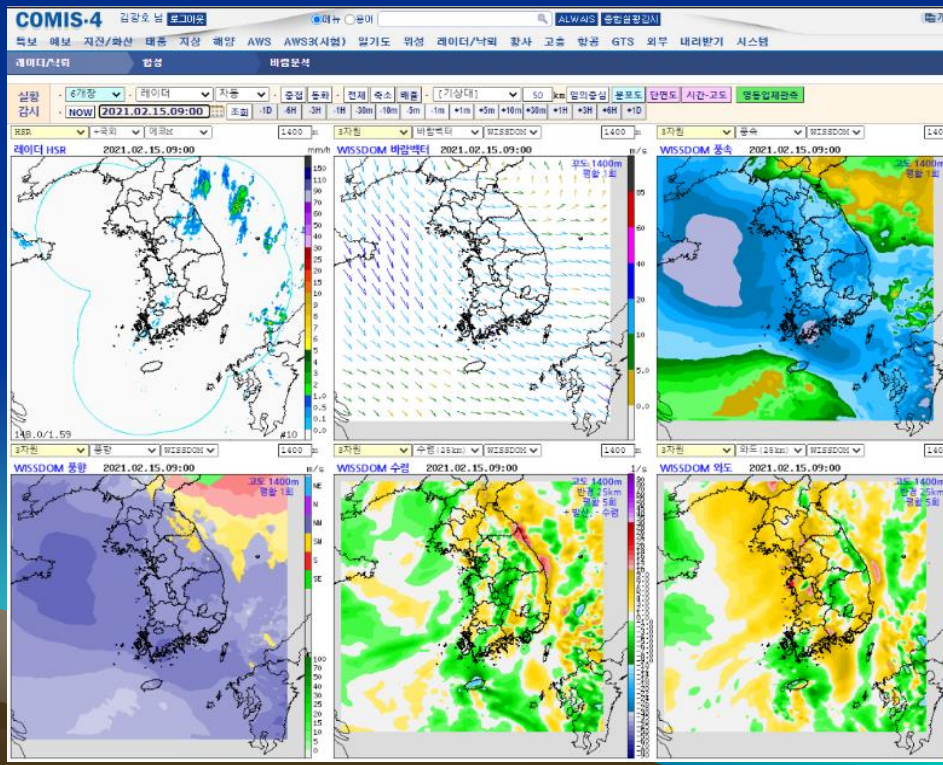
CWA
(10 Taiwan radars + 1 Ishigaki radar, 10 min)



NCDR
(9 radars, 30 min)



KMA
(10 radars, 10 min)



WISSDOM users in Universities
NCU, NTU, CCU, NDU, KNU, PKNU

Liou, Y.-C., T.-C. Chen Wang, Y.-C. Tsai, Y.-S. Tang, P.-L. Lin, and Y.-A. Lee, 2013: Structure of precipitating systems over Taiwan's complex terrain during Typhoon Morakot (2009) as revealed by weather radar and rain gauge observations, *J. Hydrology*, 506, 14-25.

Lee, J.-T., D.-I. Lee, C.-H. You, H. Uyeda, Y.-C. Liou, I.-S. Han, 2014: Dual-Doppler radar analysis of a near-shore line-shaped convective system on 27 July 2011, Korea: a case study. *Tellus A*, 66,23453.

Liou, Y.-C., J.-L. Chiou, W.-H. Chen, H.-Y. Yu, 2014: Improving the model convective storm quantitative precipitation nowcasting by assimilating state variables retrieved from multiple-Doppler radar observations. *Mon. Wea. Rev.*, 142, 4017-4035.

Chang, W.-Y., W.-C. Lee, Y.-C. Liou, 2015: The kinematic and microphysical characteristics and associated precipitation efficiency of subtropical convection during SoWMEX/TiMREX. *Mon. Wea. Rev.*, 143, 317-340.

Liou, Y.-C., T.-C. Chen Wang, and P.-Y. Huang, 2016: The inland eyewall re-intensification of Typhoon Fanapi (2010) documented from an observational perspective using multiple-Doppler radar and surface measurements. *Mon. Wea. Rev.*, 144, 241-261.

Lee, J.-T., K.-Y. Ko, D.-I. Lee, C.-H. You, Y.-C. Liou, 2018: Enhancement of orographic precipitation in Jeju Island during the passage of Typhoon Khanun (2012). *Atmos. Res.*, 201, 58-71.

Tsai, C.-L., Kim K., Y.-C. Liou, G. Lee, C.-K. Yu, 2018: Impacts of topography on airflow and precipitation in the Pyeongchang area seen from multiple-Doppler radar observations. *Mon. Wea. Rev.*, 146, 3401-3424.

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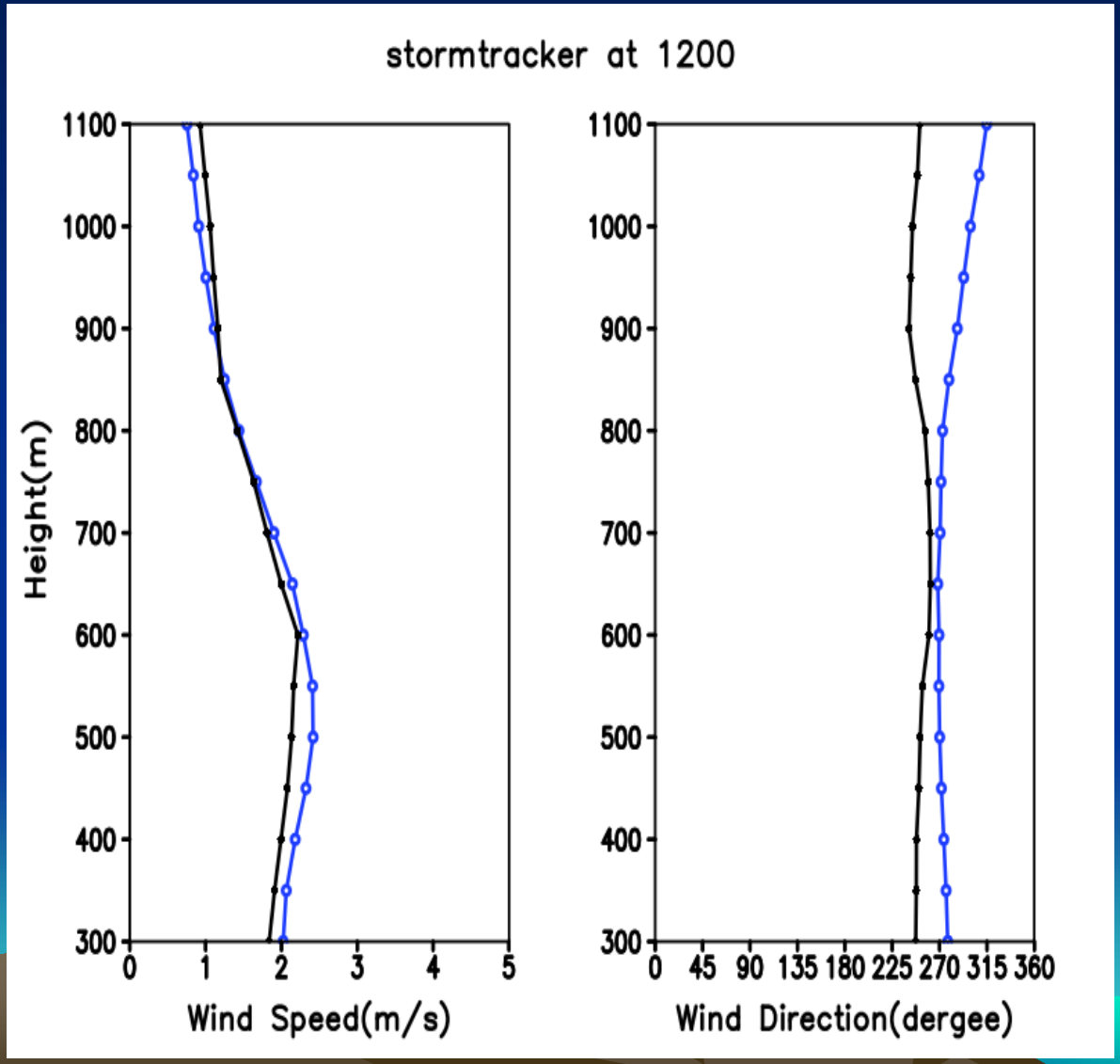
Tsai, C.-L., K. Kim, Y.-C. Liou, J.-H. Kim, Y. Lee, and G.-W. Lee, 2022: Orographic-induced strong wind associated with a low-pressure system under clear-air condition during ICE-POP 2018. Journal of Geophysical Research - Atmospheres. https://doi.org/10.1029/2021JD036418.

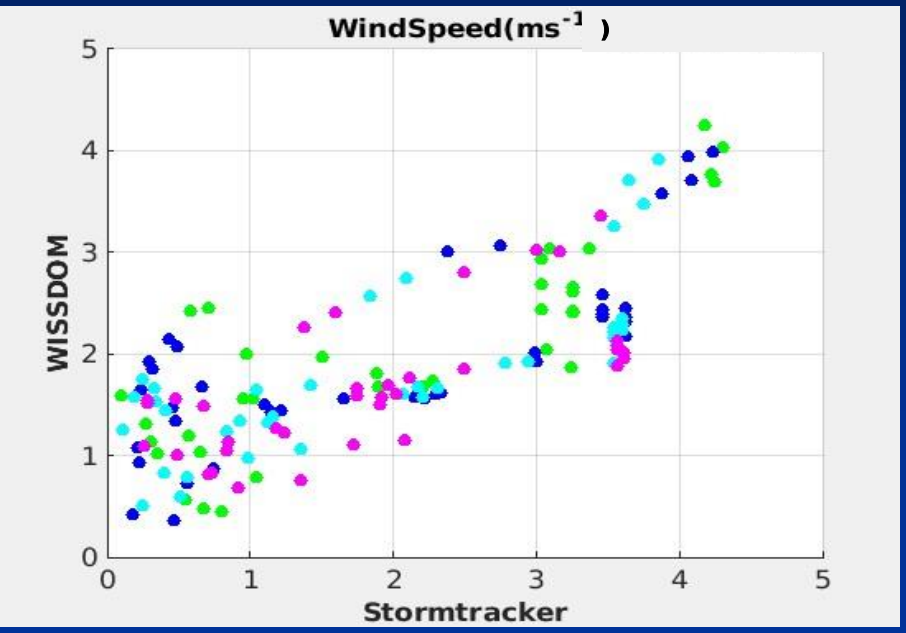
Tsai, C.-L., K. Kim, Y.-C. Liou, and G. Lee, 2023: High-resolution 3D winds derived from a modified WISSDOM synthesis scheme using multiple Doppler lidars and observations. Atmos. Meas. Tech., 16, 845–869.

將WISSDOM應用在
高解析度 (50~100 米)
多部掃描式光達
晴空三維風場合成

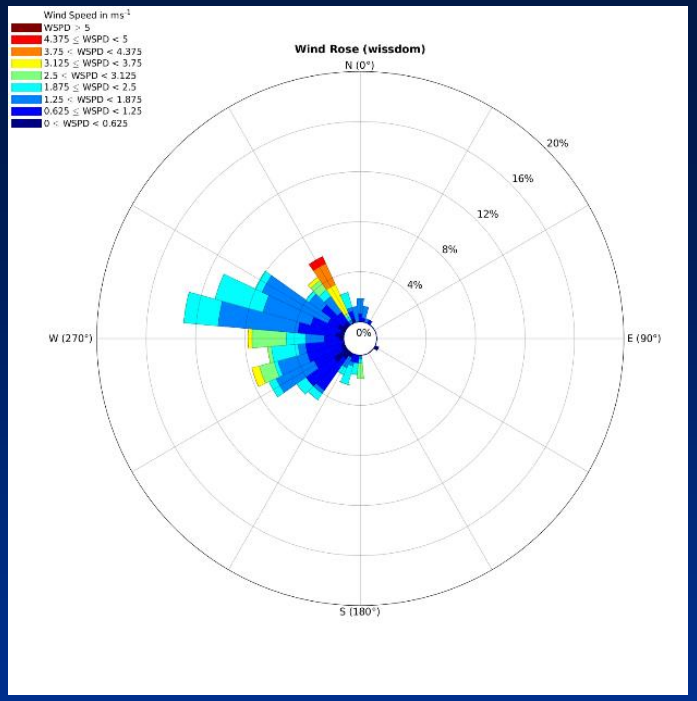
(2023/09/19~ 9/22)

Dual-lidar (blue line) vs. ST (black line) Verification (2023/09/19 1200LST)

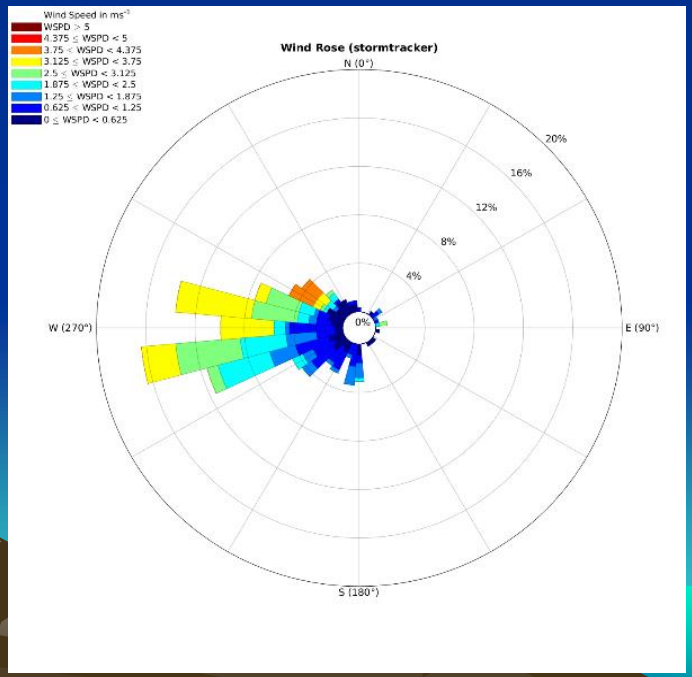




Corr = 0.80

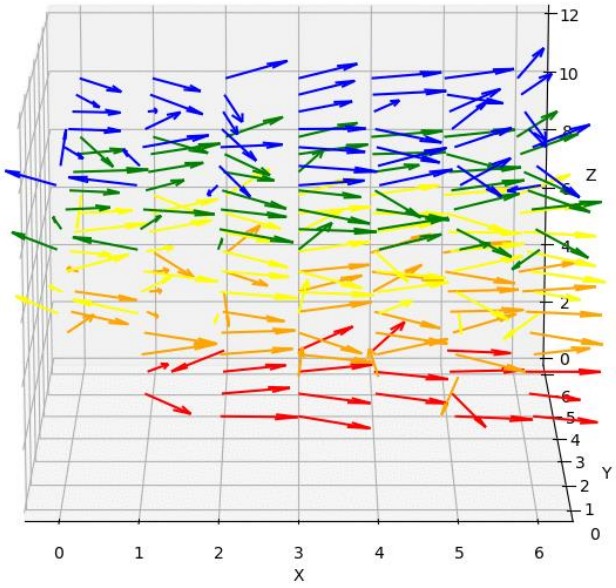


dual-lidar by WISSDOM

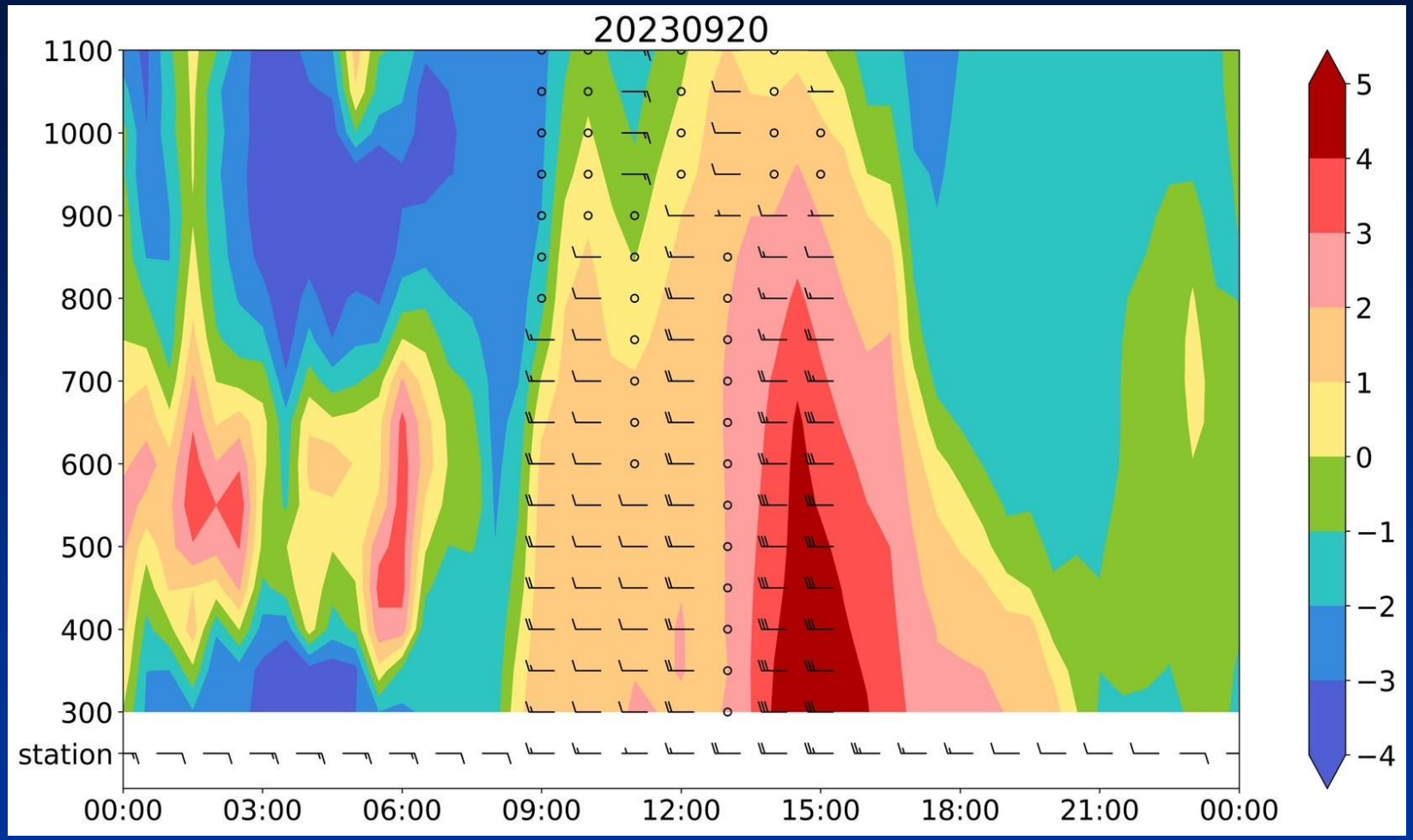


Storm Tracker

Dual-lidar WISSDOM synthesized wind field (2023/09/19 1200LST)



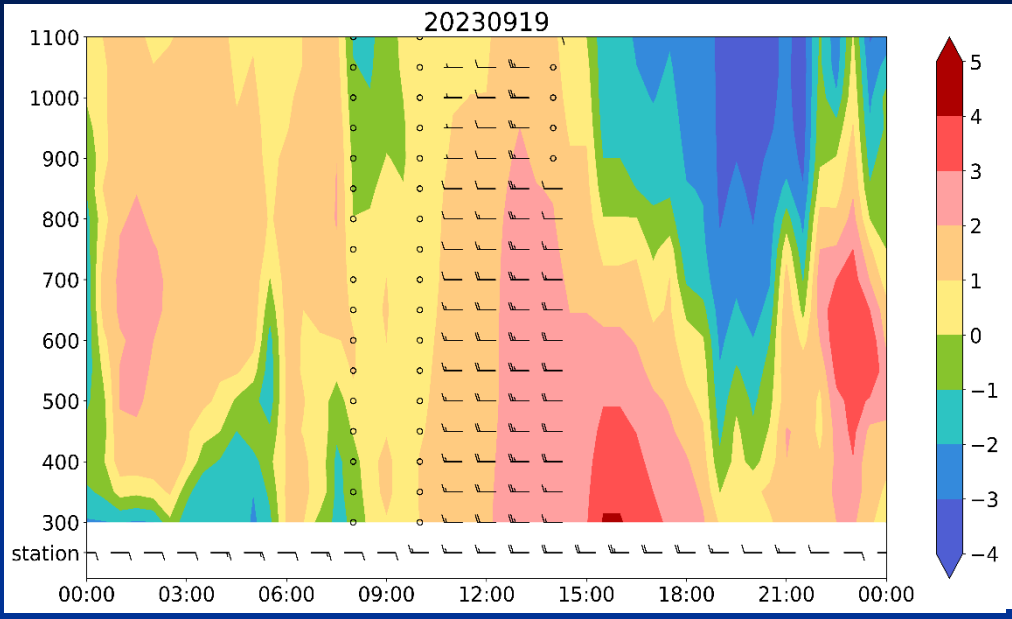
X(km); Y(km); Z (100 m)



色階 (雙光達合成)，風標 (探空和地面站)
海風由9:00 LST開始持續到21:00 LST
雙光達/探空/地面站三者均呈現明顯的海陸風環流日夜變化

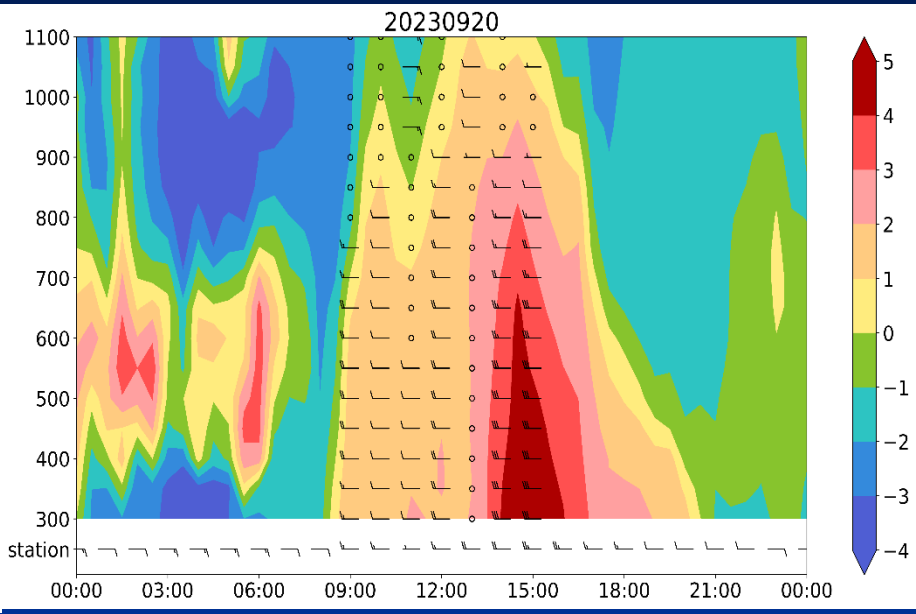
比較雙光達/探空，雙光達/地面站所求出之海陸風分量的吻合程度

2023/09/19



Surface station: 88.0%
Storm Tracker: 98.4%

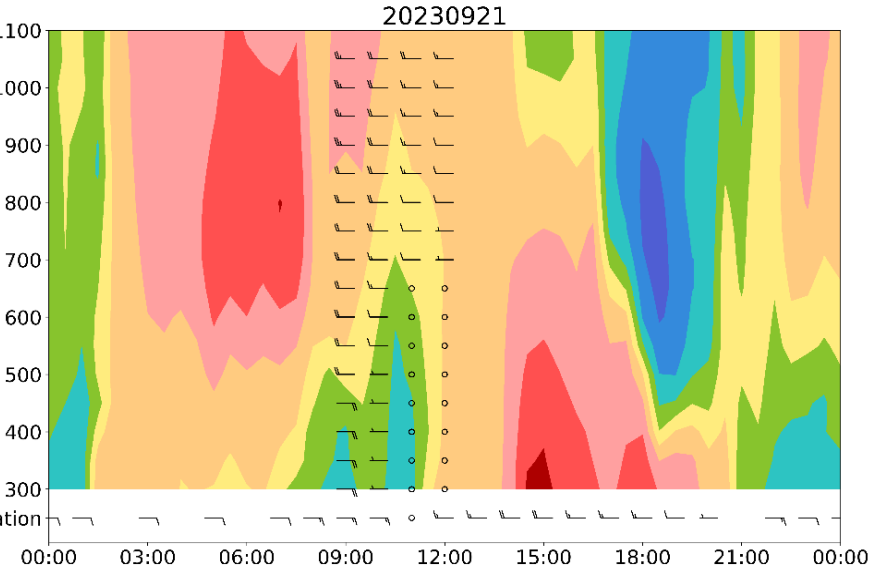
2023/09/20

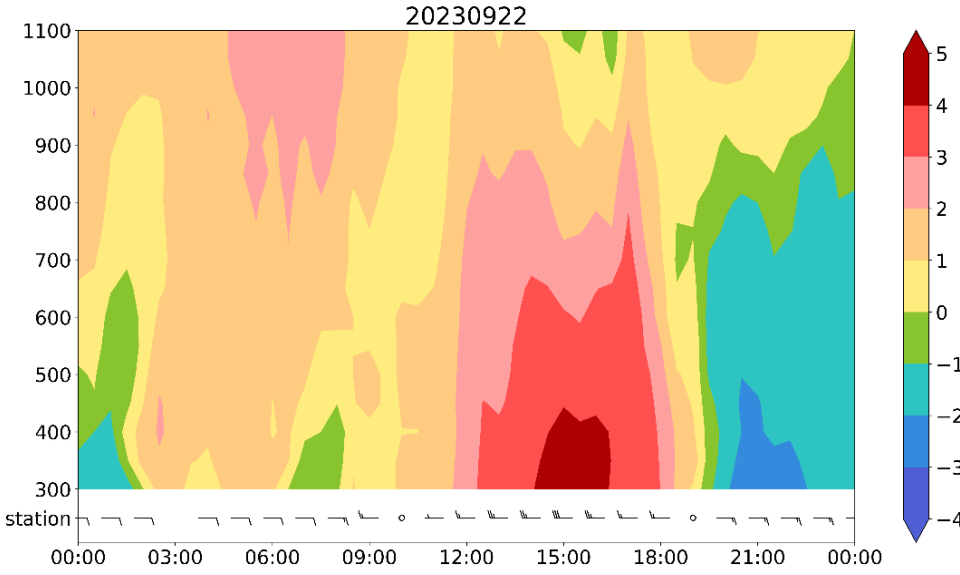


Surface station: 91.7%
Storm Tracker: 98.9%

2023/09/21

2023/09/22



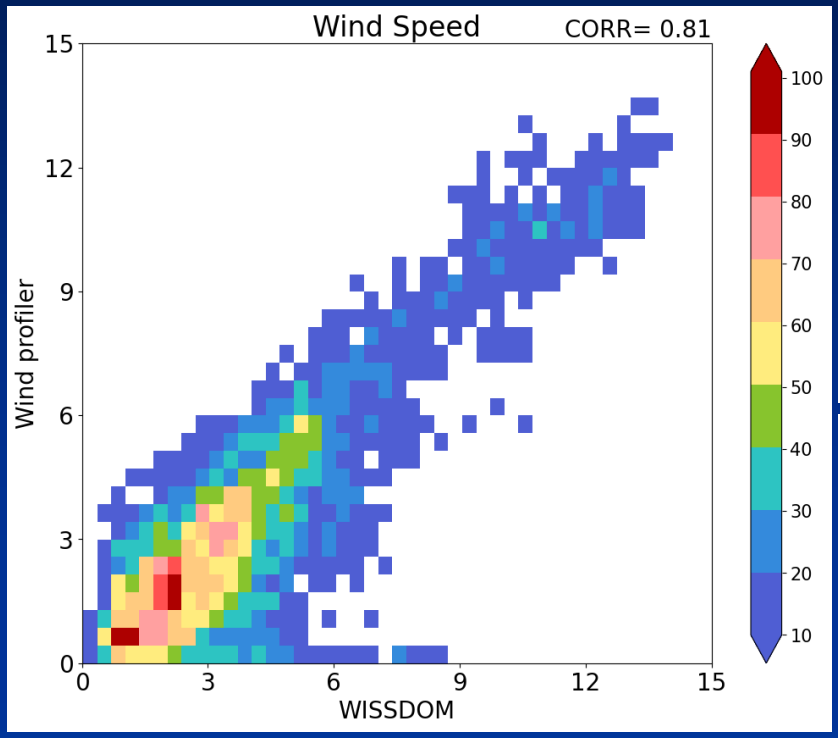


Surface station: 84.2%
Storm Tracker: 88.5%

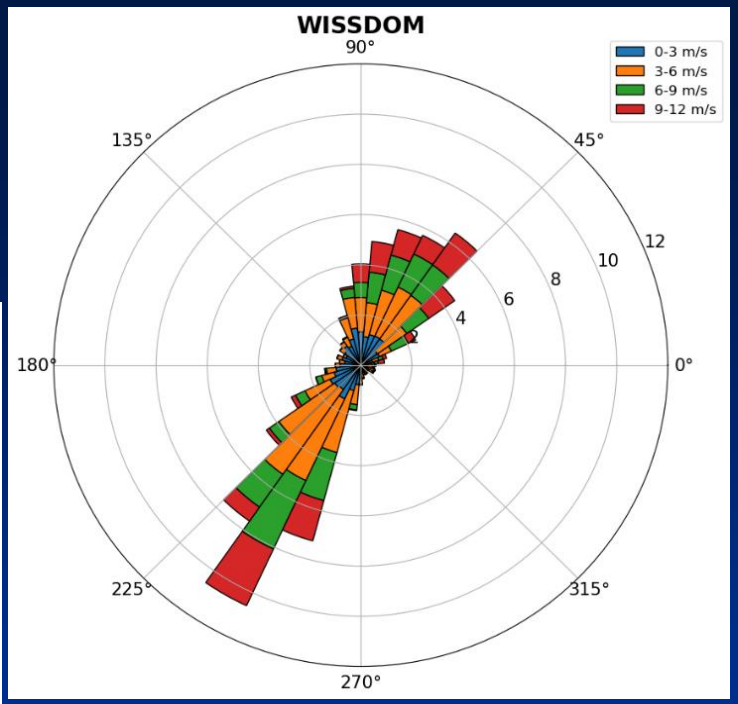
Surface station:86.4%

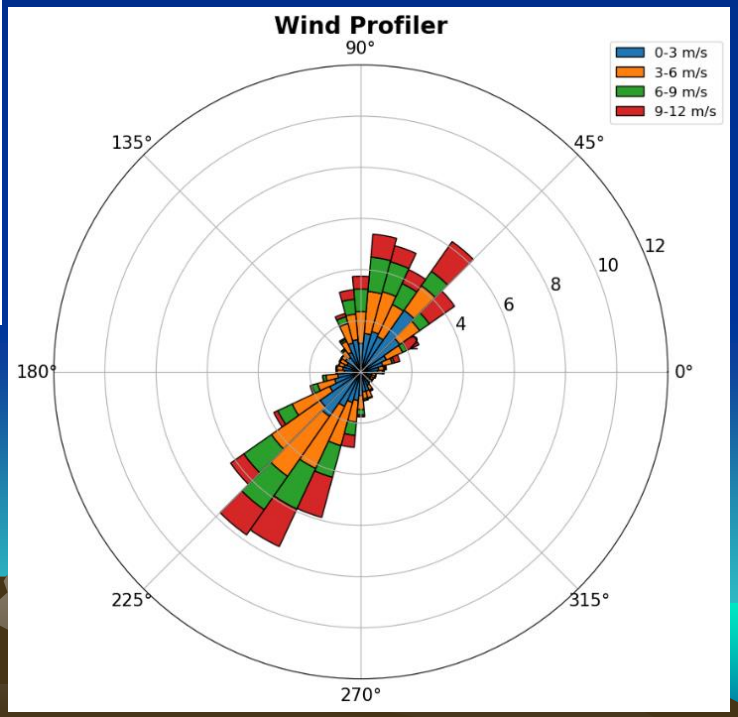
April 2024
Taoyuan International Airport (TIA)
Dual-lidar low-level wind shear experiment (50-m resolution)

Z < 600 m
WS diff. > 15 kts/km



Corr = 0.81

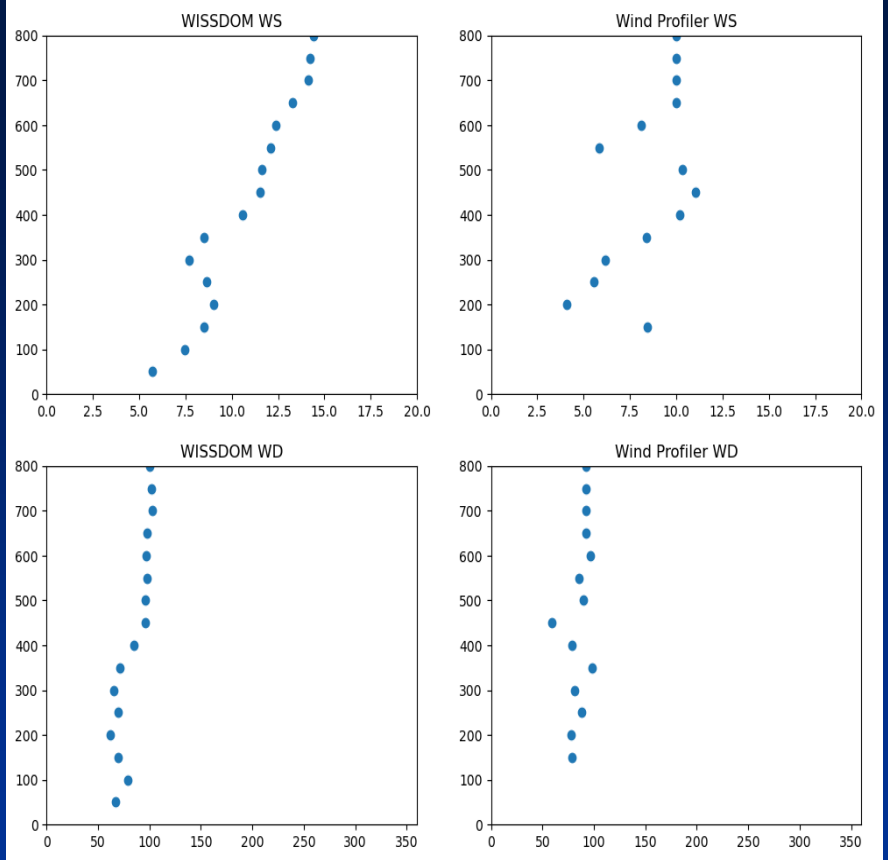




dual-lidar by WISSDOM

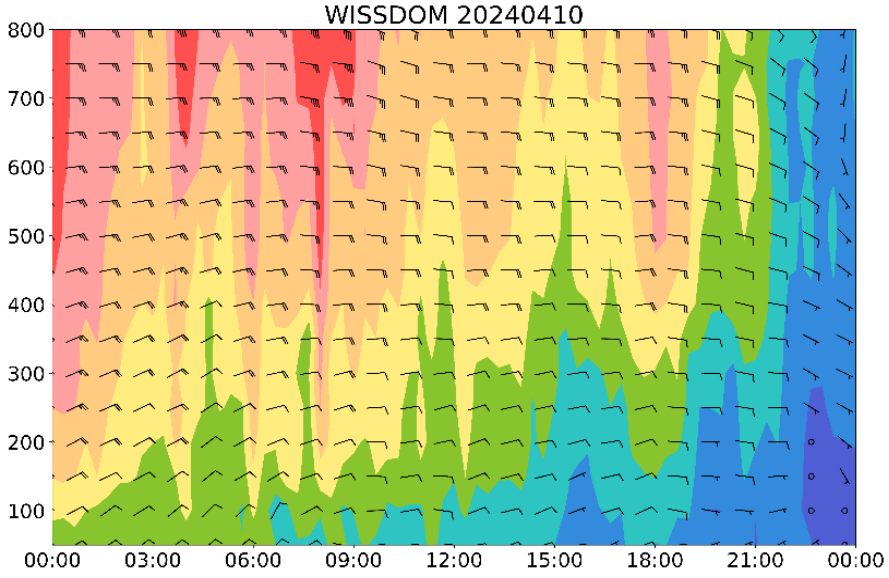
Wind Profiler

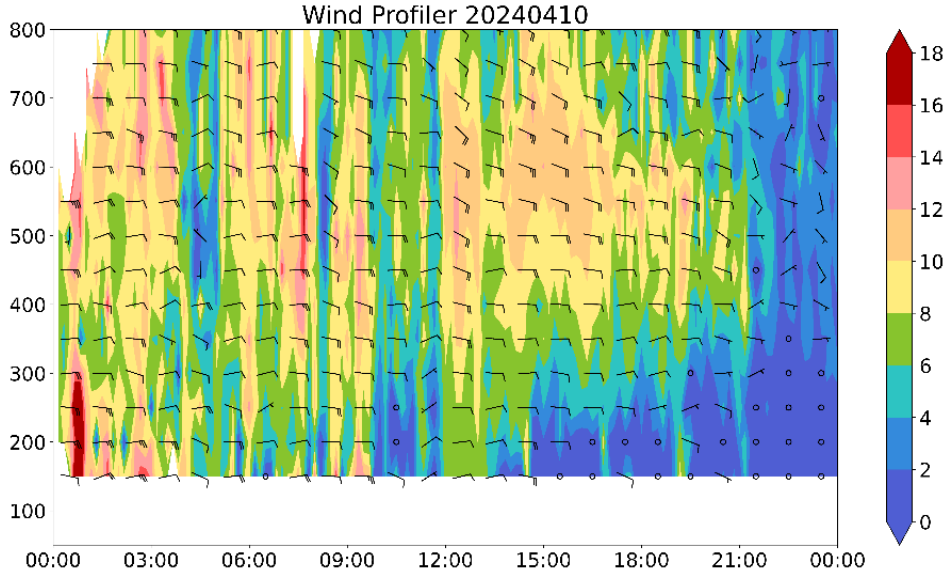
2024/04/10
0720 LST



WISSDOM

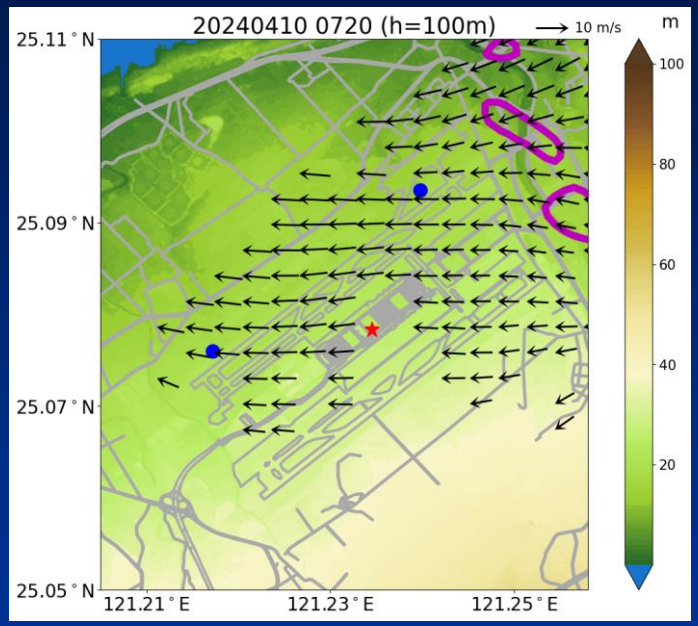
Profiler



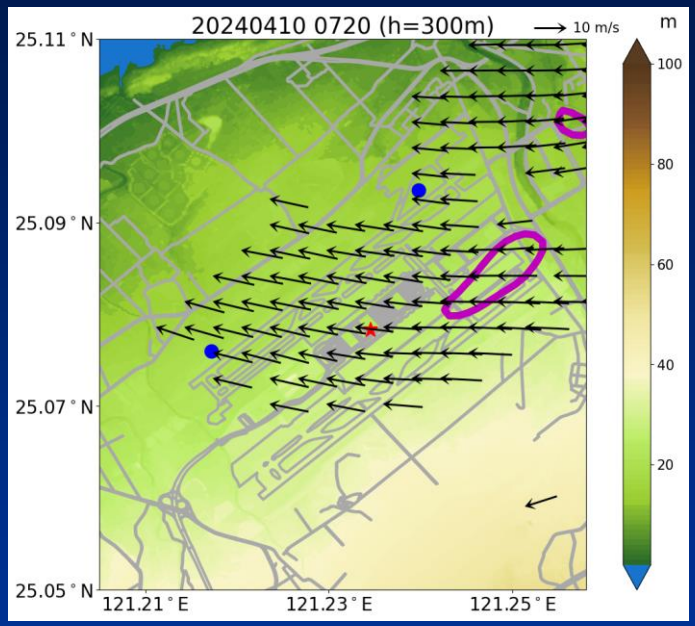


2024/04/10 0720 LST

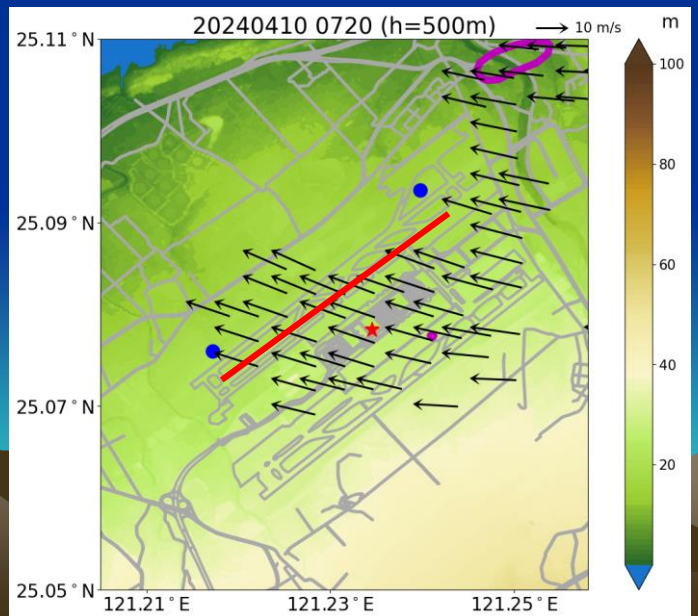
100 m

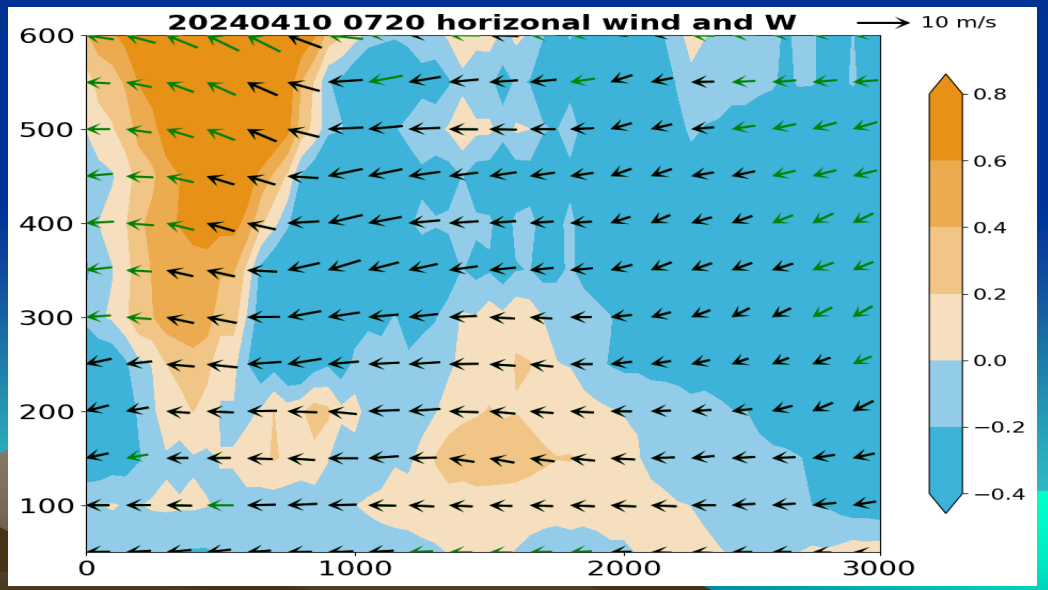


300 m

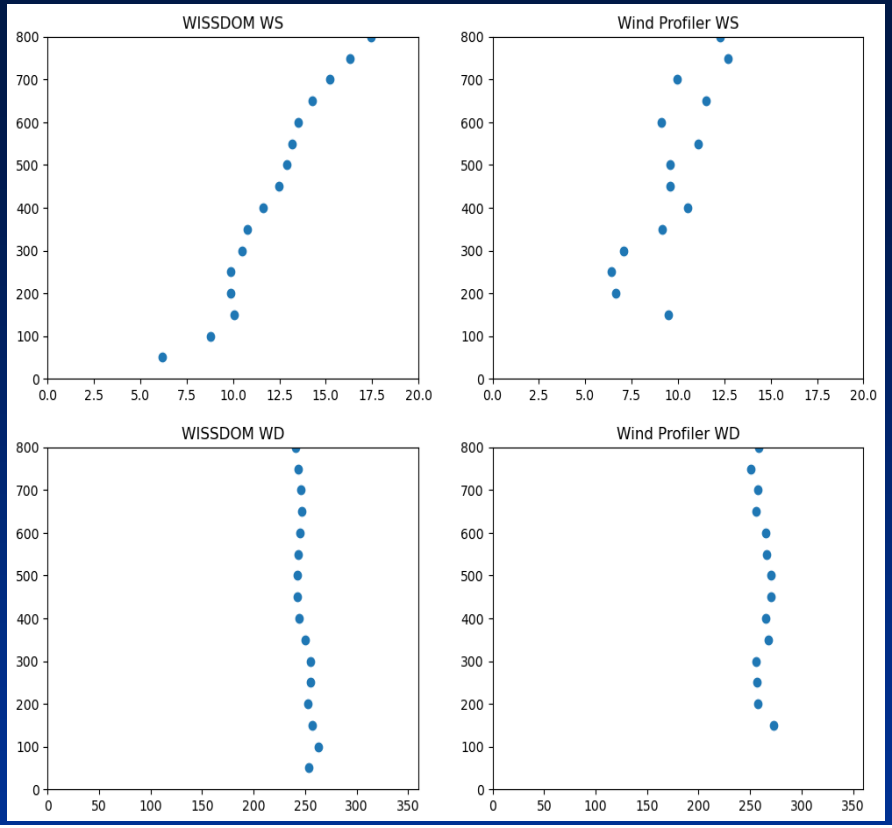


500 m



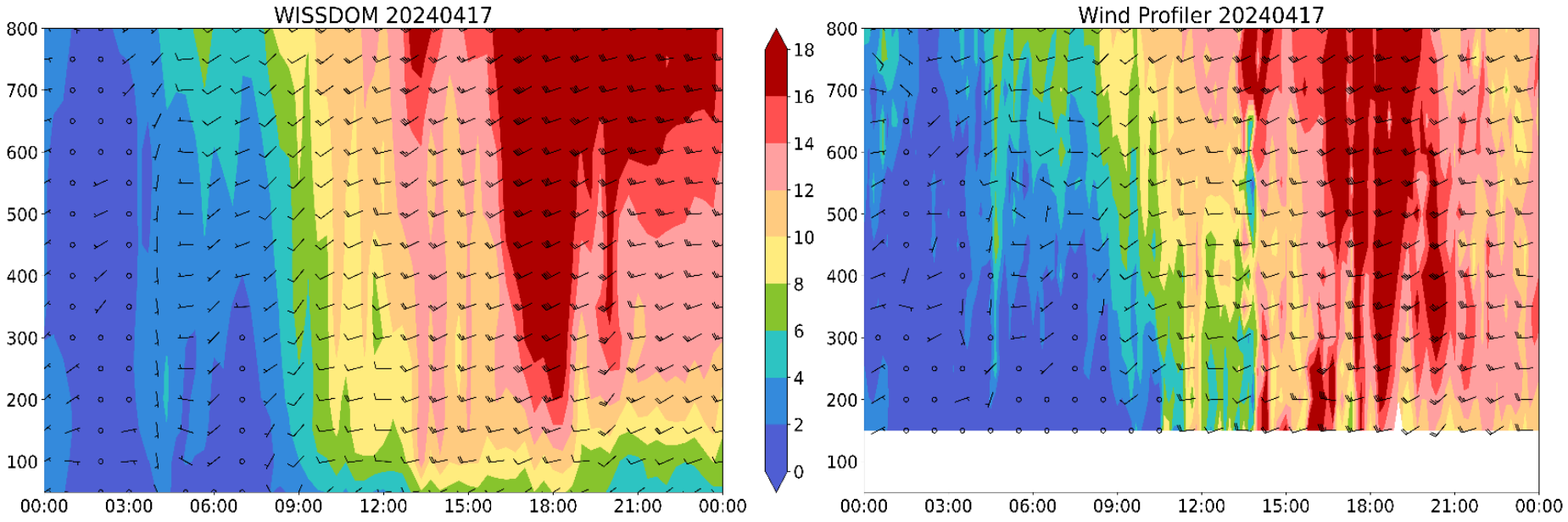


2024/04/17
1300 LST



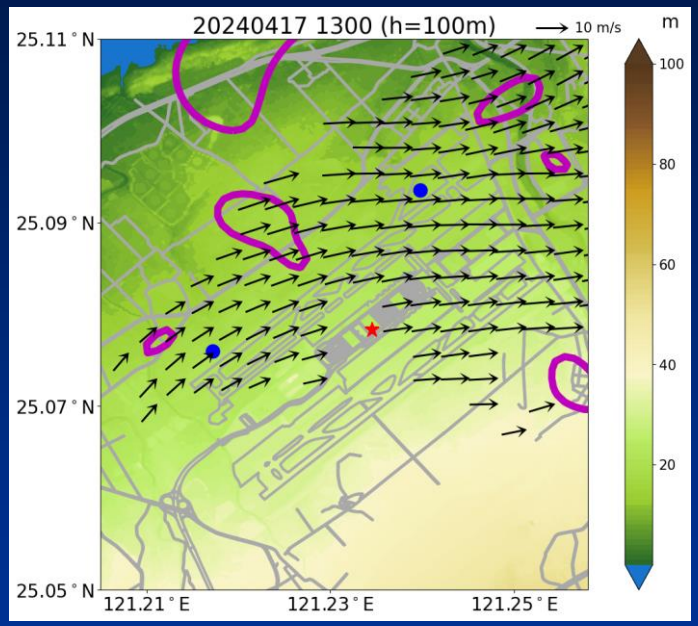
WISSDOM

Profiler



2024/04/17 1300 LST

100 m



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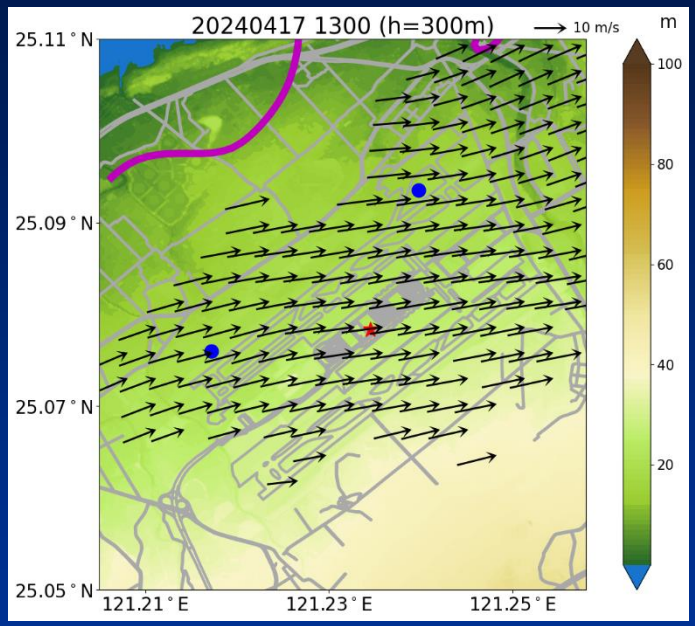
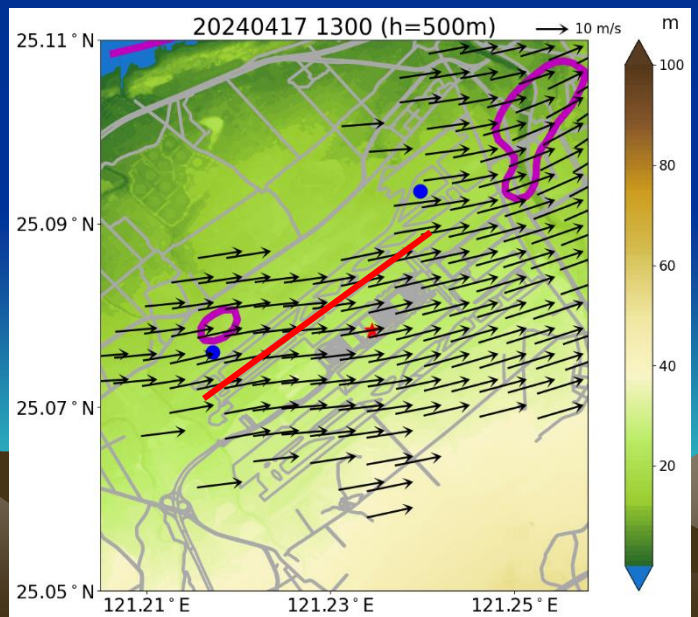
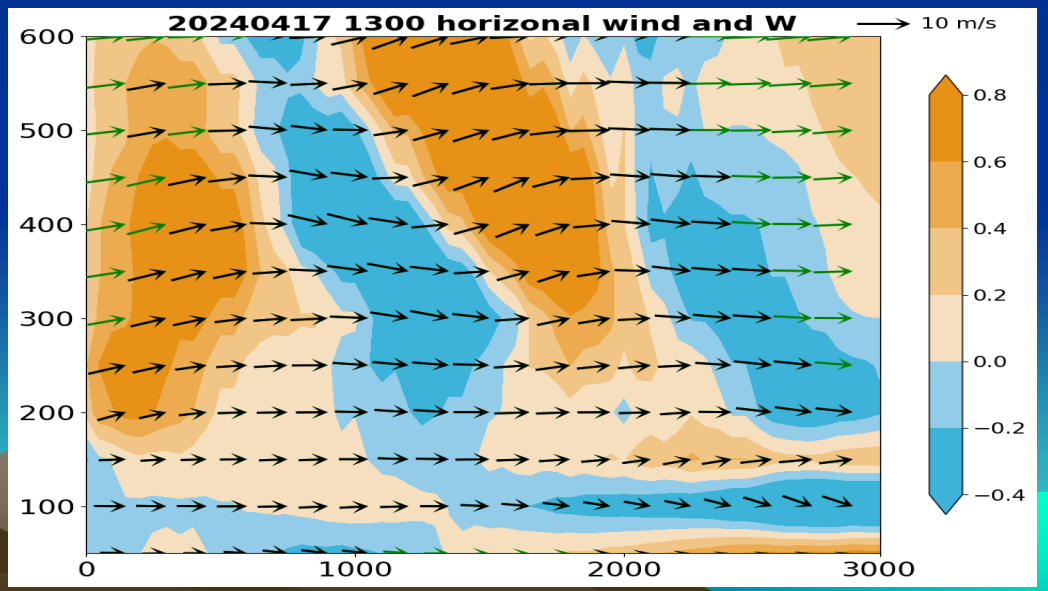


500 m





總結

(1)國內首次採用WISSDOM演算法及多部掃描式光達，反演晴空下百米級解析度的邊界層大氣三維風場。

(2)彰化個案顯示光達反演結果和探空/地面站觀測極為吻合，可清楚呈現海陸風環流的日夜變化。

(3)桃機個案顯示光達反演結果與剖風儀觀測一致，光達反演的三維風場可用於計算低空風切（Z < 600 m，WS diff. > 15 kts/km)。

(4)遙測儀器具長期且連續觀測的優勢，本研究可應用於:

探討大氣邊界層的時空特徵
午後雷暴前兆
機場飛航安全低空風切監測
大氣污染物擴散
風機發電場風場即時監測
高解析度數值模式驗證

謝謝聆聽