# 臺灣區域豪雨觀測與預報實驗

# Taiwan-Area Heavy rain Observation and Prediction Experiment (TAHOPE)


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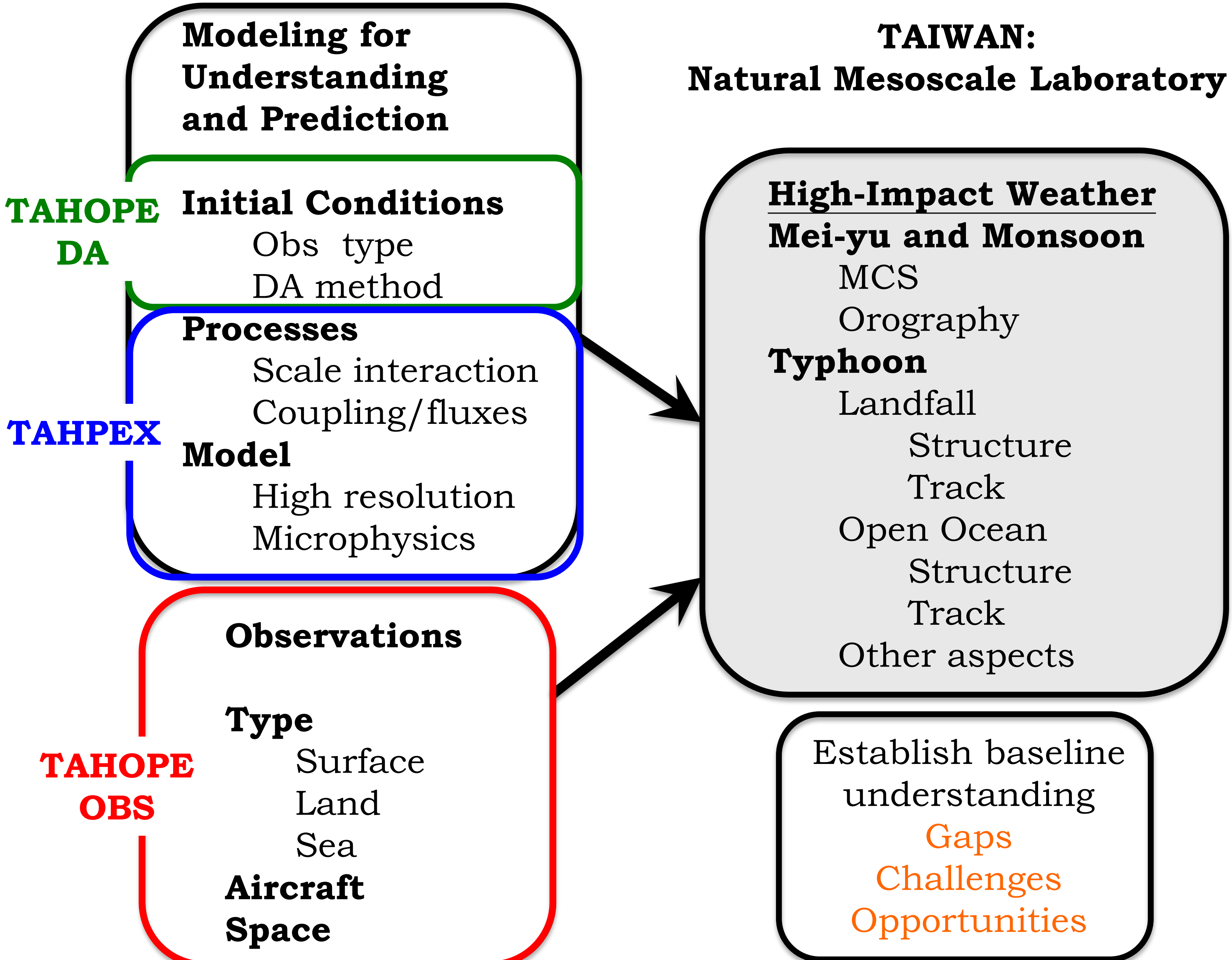


Modeling for Understanding and Prediction
TAHOPE DA
Initial Conditions
Obs type
DA method
TAHPEX
Processes
Scale interaction
Coupling/fluxes
Model
High resolution
Microphysics
TAHOPE OBS
Observations
Type
Surface
Land
Sea
Aircraft
Space
TAIWAN:
Natural Mesoscale Laboratory
High-Impact Weather
Mei-yu and Monsoon
MCS
Orography
Typhoon
Landfall
Structure
Track
Open Ocean
Structure
Track
Other aspects
Establish baseline understanding
Gaps
Challenges
Opportunities

# List of TAHOPE PIs

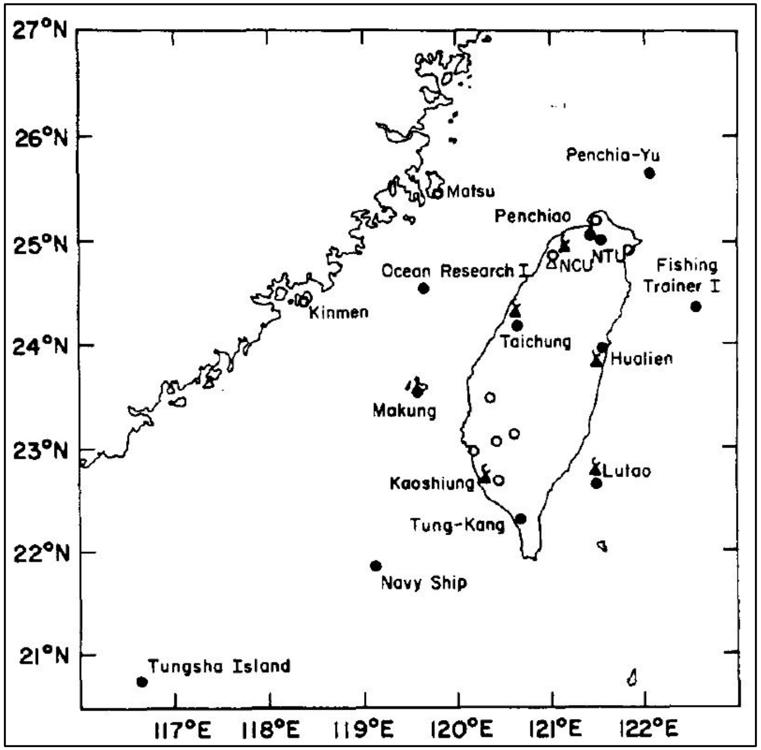
## 臺灣區域豪雨觀測與預報實驗計畫-總計畫
## Taiwan-Area Heavy-rain Observation and Prediction Experiment (TAHOPE)

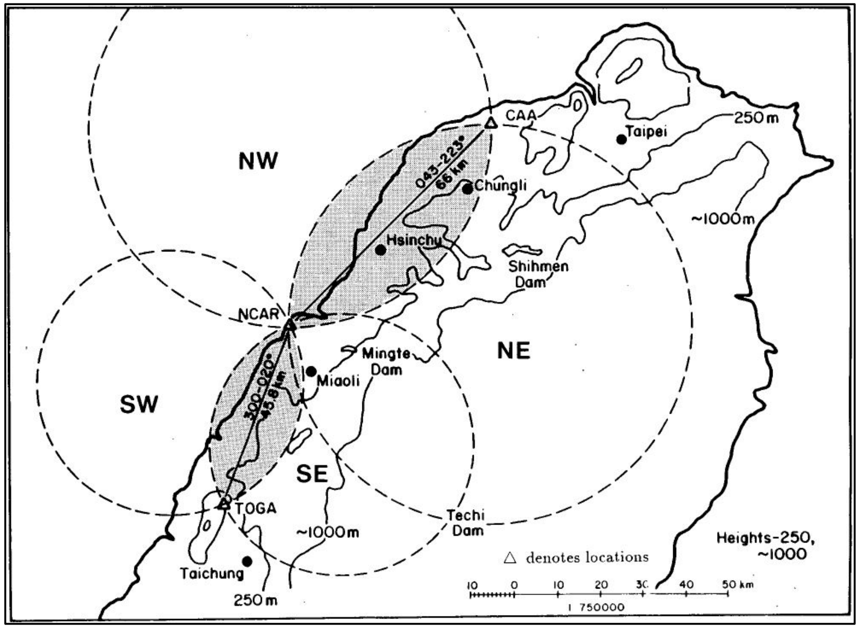
| | | | | |
|---|---|---|---|---|
| 子計畫 1 | 廖宇慶 | 中央大學/大氣科學系 | 教授 | 臺灣地區強降雨系統登陸前後結構與演化的觀測與分析 |
| 子計畫 2 | 林沛練 | 中央大學/大氣科學系 | 教授 | 低層噴流、邊界層與降雨雲物理之觀測分析與模擬研究 |
| 子計畫 3 | 張偉裕 | 文化大學/大氣科學系 | 助理教授 | 臺灣降雨雲物理過程研究-西南氣流實驗研究(2008)-III 及臺灣區域豪雨觀測與預報實驗(TAHOPE) |
| 子計畫 4 | 林品芳 | 中央氣象局/氣象衛星中心 | 博士課長 | 強對流天氣系統之雷達應用觀測研究 |
| | 張保亮 | 中央氣象局/氣象資訊中心 | 博士簡任技 | |
| 子計畫 5 | 楊明仁 | 台灣大學/大氣科學系 | 教授 | 臺灣地區中尺度對流系統與颱風降水效率之模擬研究 |
| 子計畫 6 | 李清勝 | 台灣大學/大氣科學系 | 教授 | 臺灣鄰近地區颱風結構變化之研究 |
| 子計畫 7 | 劉清煌 | 文化大學/大氣科學系 | 副教授 | 鋒前及颱風外圍雨帶內劇烈對流系統之研究 |
| 子計畫 8 | 楊舒芝 | 中央大學/大氣科學系 | 副教授 | Applying the multi-scale, multi-resolution data assimilation framework to investigate the predictability of severe weather in the Taiwan area |
| 子計畫 9 | 鍾高陞 | 中央大學/大氣科學系 | 助理教授 | Evaluating the impact of assimilating humidity parameters from scanning instruments during TAHOPE for storm-scale data assimilation system |
| 子計畫 10 | 侯昭平 | 國防大學/理工學院 | 助理教授 | 熱動力與地形作用影響下臺灣多重尺度線狀對流系統與颱風環流引發劇烈降水之個案觀測分析與模擬研究 |

# List of TAHPEX PIs

「臺灣地區豪大雨預報整合實驗」(TAHPEX)整合計畫：

| | | | | |
|---|---|---|---|---|
| 總計畫 | 王重傑<br>黃清勇<br>簡芳菁<br>洪景山 | 臺灣師範大學地球科學系<br>中央大學大氣科學系<br>臺灣師範大學地球科學系<br>中央氣象局 | 教授<br>教授<br>教授<br>博士 | 台灣地區豪大雨預報實驗計畫 |
| 子計畫一 | 黃清勇 | 中央大學大氣科學系 | 教授 | 台灣區域豪雨預報實驗：高解析度區域模式與全球模式劇烈天氣預報比較及動力診斷分析 |
| 子計畫二 | 王重傑 | 臺灣師範大學地球科學系 | 教授 | 台灣極端降水事件之尺度交互作用與可預報度研究 |
| 子計畫三 | 簡芳菁 | 臺灣師範大學地球科學系 | 教授 | 台灣地區梅雨與颱風伴隨西南氣流之高解析模擬與研究 |
| 子計畫四 | 劉千義 | 中央大學太空與遙測研究中心 | 副教授 | 適地性衛星觀測資料於臺灣及鄰近區域之數值模式衝擊評估及驗證 |
| 子計畫五 | 葉錫圻 | 真理大學通識教育中心 | 教授 | 多元觀測資料應用對台灣梅雨季豪大雨定量降水預報的改善評估 |
| 子計畫六 | 蔡孝忠 | 淡江大學水資源及環境工程系 | 副教授 | 颱風快速增強之環境、結構特徵及誤報分析研究 |
| 子計畫七 | 馮欽賜 | 中央氣象局資訊中心 | 副主任博士 | 臺灣區域先進對流尺度資料同化系統之發展 |
| 子計畫八 | 黃椿喜 | 中央氣象局預報中心 | 課長博士 | 颱風與梅雨期間短延時強降雨預報技術之研究-多維度系集大數據與雷達資料探勘 |
| 子計畫九 | 陳舒雅 | 中央大學GPS 科學與應用研究中心 | 專案助理研究員 | GNSS 掩星資料同化對於台灣劇烈天氣模擬之影響研究 |



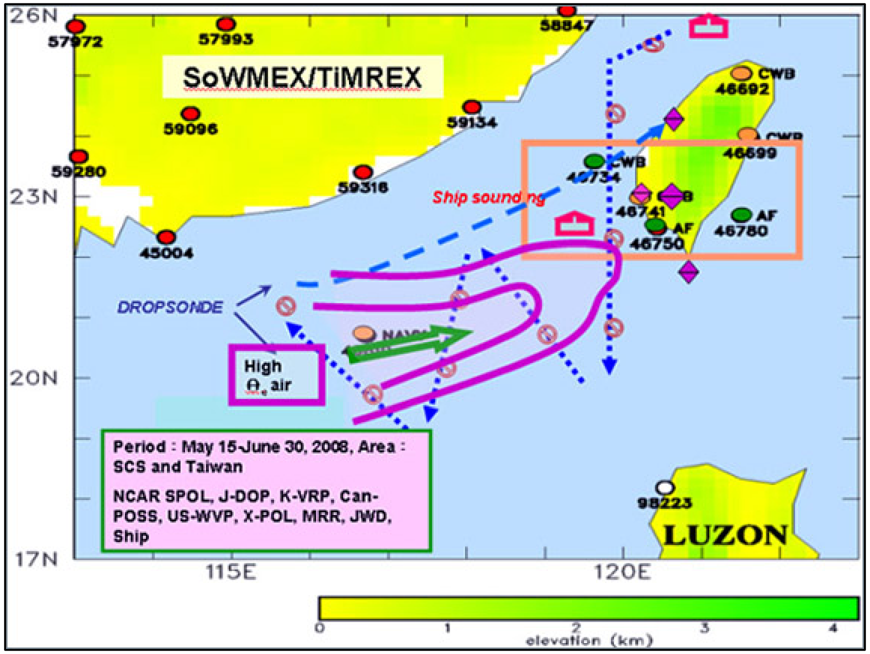



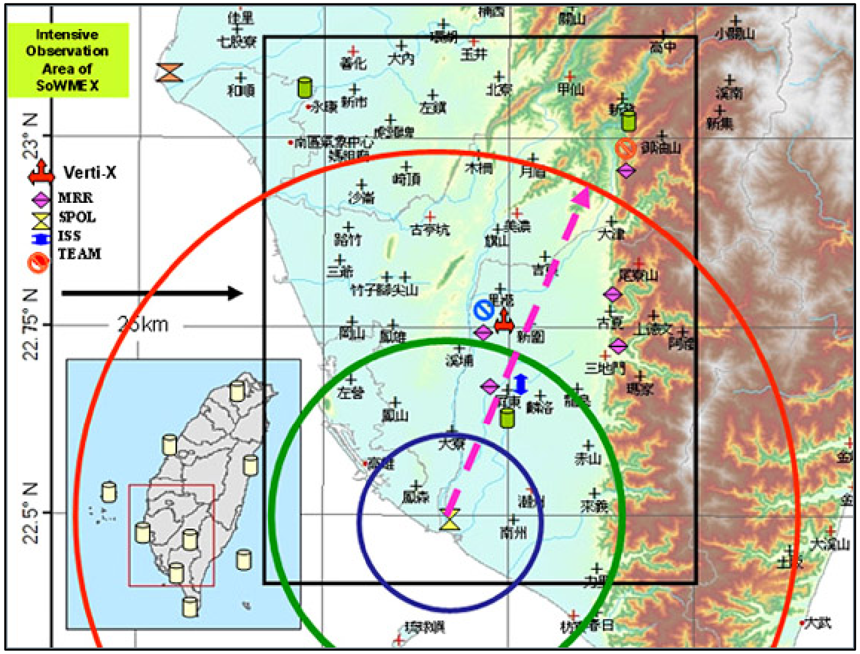

# TAMEX (1987)

- The mesoscale circulation associated with the Mei-Yu front.
- The evolution of mesoscale convective systems in the vicinity of the Mei-Yu front.
- The effects of orography on the Mei-Yu front and on mesoscale convective systems.
- First time to document detailed mesoscale structures of MCSs in Taiwan.
- Study confined to the vicinity of Taiwan, less investigation of oceanic convection.

Kuo and Chen (1990)

# SoWMEX/TiMREX (2008)

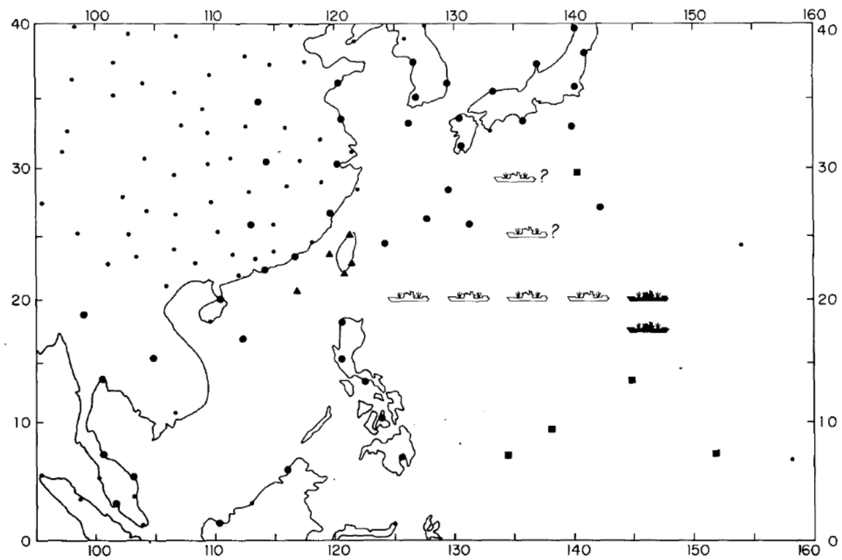


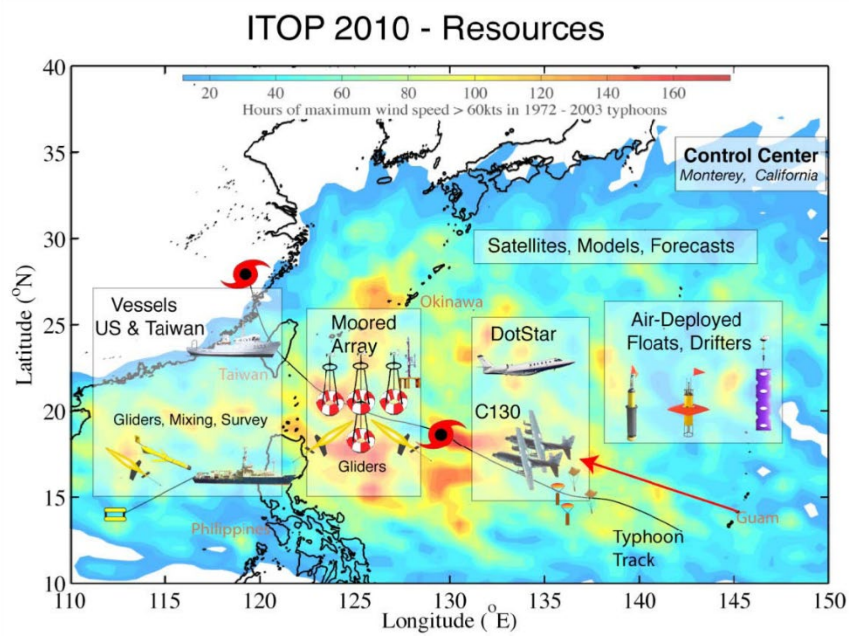




- The effects of orography and the characteristics of upstream monsoonal flow on rainfall distributions in southern Taiwan.
- The roles of Meiyu front and its mesoscale circulations in the development, maintenance and regeneration of heavy rain producing convection systems in southern Taiwan.
- The effect of boundary layer processes, such as, surface moisture distributions, land-sea contrasts and mountain-valley circulations on modulation of the precipitation pattern.
- The microphysical processes of heavy rain producing convective systems influenced by complex terrain.
- Improving QPE/QPF skill by better understanding of multi-scale precipitation processes and the assimilation of high-resolution observations into numerical models and nowcasting systems.

Jou, Lee and Johnson (2011)

# TCM-90 (1990) & ITOP (2010)

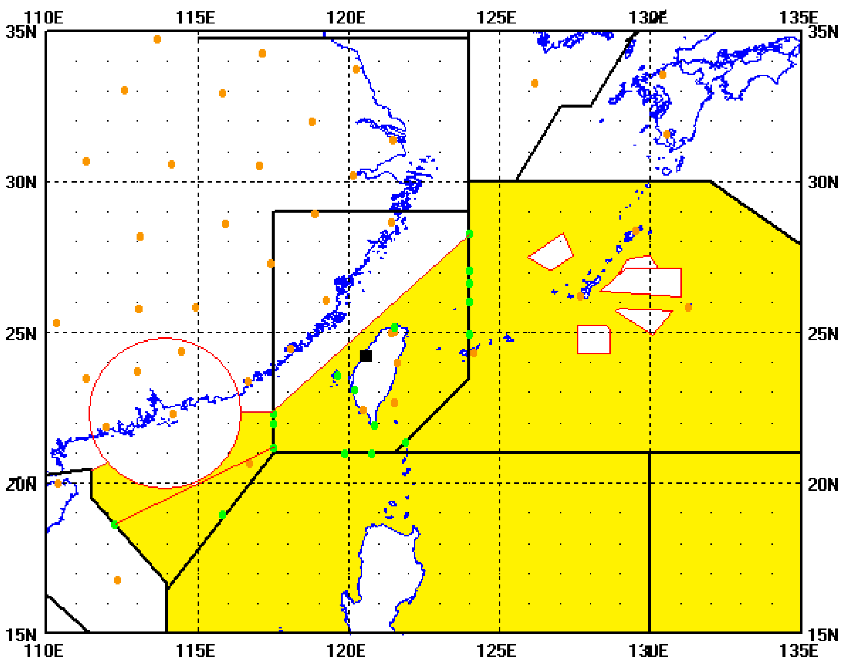





- Tropical Cyclone Motion (TCM).
- Understanding tropical cyclone motion and improving forecast accuracy.
- Surface Radiosonde and Doppler radar, Aircraft Dropsonde, Ship Sounding……etc.

- Impact of Typhoons on the Ocean in the Pacific (ITOP).
- Increase understanding of the interaction between the ocean and tropical cyclones over the tropical western North Pacific.
- Better understand the surface wave field under the forcing of typhoons.
- Aircraft Dropsonde, Ship, Buoy……etc.

# DOTSTAR (2003~Now)





Wu et al. (2005, BAMS)

- To evaluate how the dropsonde data influence track prediction, and to study the optimum observation strategies for improving typhoon forecasts.
- To validate the remote sensing data around typhoons and to help explore the typhoon dynamics and theories.
- To improve the adaptive observation strategy and data assimilation, which are at the forefront of typhoon forecast.
- promote the international status of Taiwan in the tropical cyclone research field and to play the leading role of typhoon research in the northwestern Pacific and East Asia region.

# 台美日聯合觀測實驗計畫背景說明 (TAHOPE/PRECIP/TPARC-II)

- Most of severe rainfall events in the vicinity of Taiwan are resulted from Mei-yu frontal systems and landfalling typhoons.
- The integrated observations near Taiwan are critical for improving quantitative precipitation forecast in numerical models.
- The joint field experiments may collect highly demanding observations for NWP through advanced data assimilation technique.

# Introduction of TAHOPE

- **Taiwan-Area Heavy rain Observation and Prediction Experiment (TAHOPE)** is an international joint project of Taiwan, U.S.A. (PRECIP 2020), and Japan (T-PARC II) that will conduct observations for severe weather (**Mei-yu** and **typhoon**) in the vicinity of Taiwan.
- The main themes of the project range from **large-scale monsoonal influence, typhoons**, **mesoscale convective systems** as well as **cloud microphysics processes**, under the special topography of Taiwan island with steep mountain.
- Through the joint network of intense observations, real-time or near real-time **data assimilation analysis and prediction** will be conducted using the advanced atmospheric models to **improve weather prediction**.

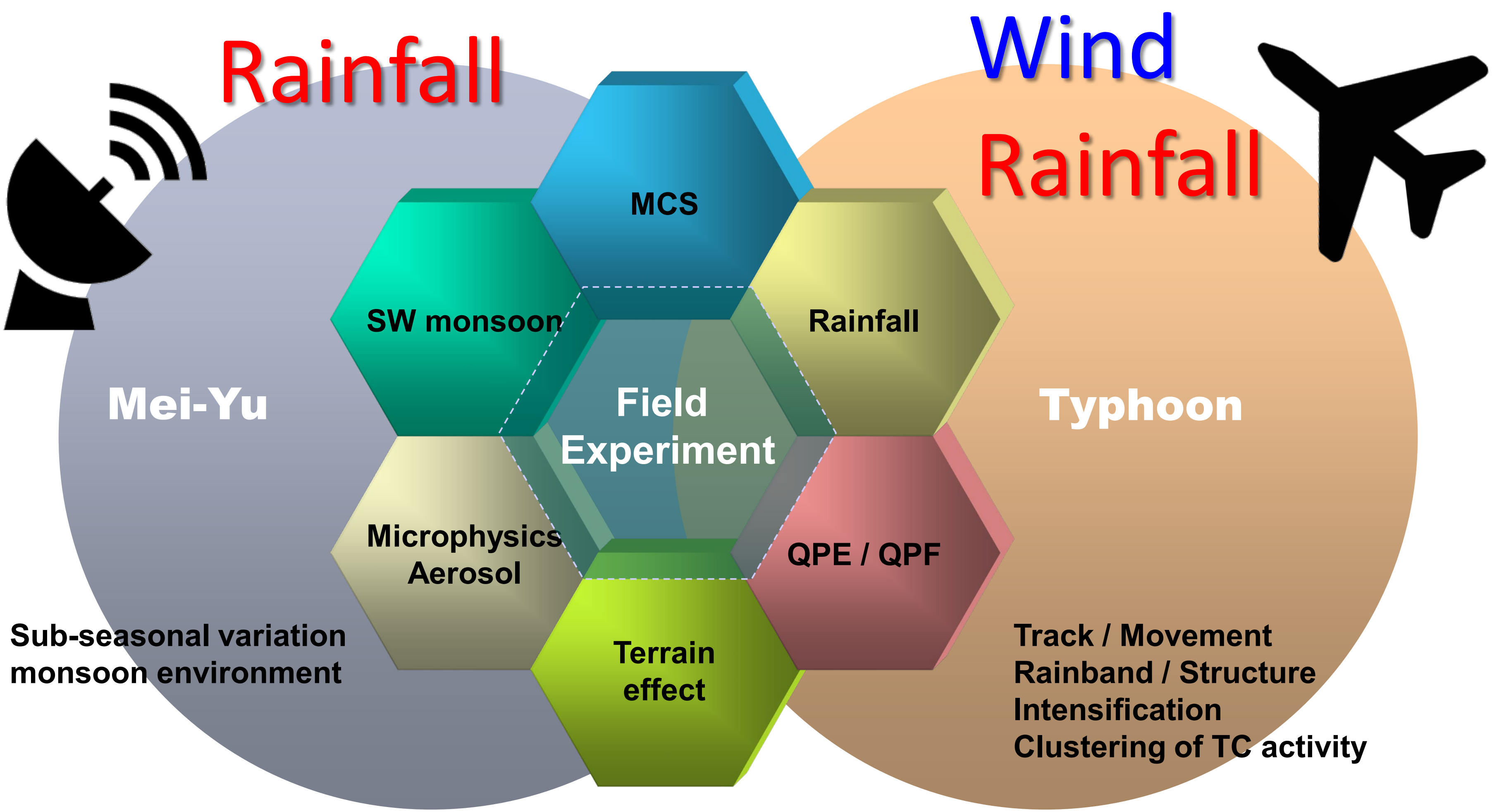
# Introduction of TAHOPE

- Taiwan operational observation facilities (radars and radiosondes), atmospheric measurements (C-Pol radar, wind profile, dropsonde and aerosonde) of NARLabs to perform joint observation experiment during **mid-May to end of September 2020**
- Evaluation of data impact on assimilation and prediction from own domestic satellite (**FORMOSAT-7**) GPS RO and reflectometry measurements will be carried out, in particular.

# Scientific goals of TAHOPE

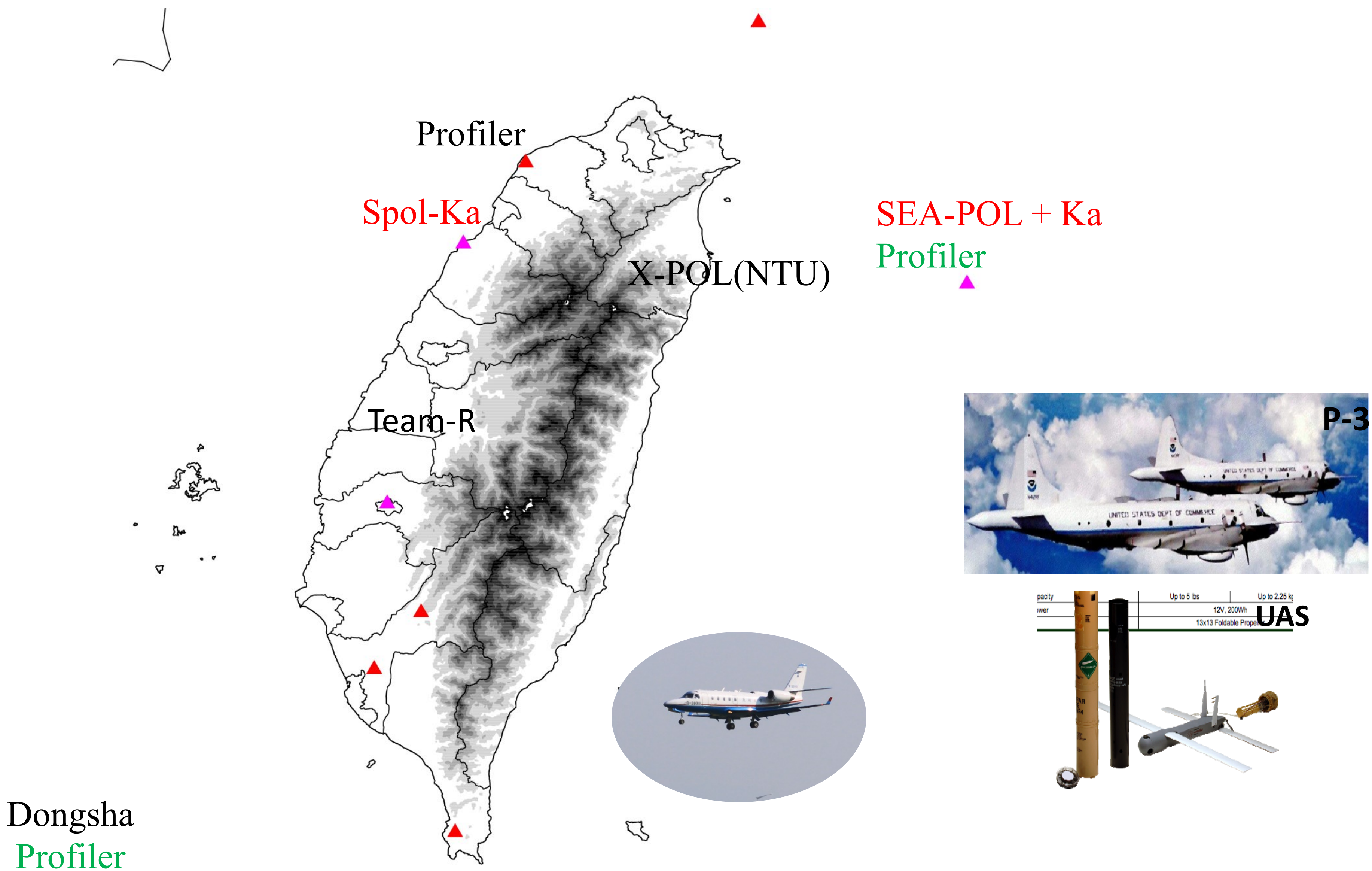
- To understand the essential **synoptic forcings** of the associated Mei-yu convective systems and typhoons in the vicinity of Taiwan complex terrain through international collaborative experimentation.
- To realize the **multiple-scale interactions** among large-scale flow environments, mesoscale systems and microscale cloud convections responsible for heavy rainfall in Mei-yu convective systems and typhoons.
- To identify and verify the characteristics of **cloud-microphysical processes** in extreme precipitation associated with the Mei-yu convective systems and typhoons over the Pacific ocean and the Central Mountain Range.
- To explore upstream TC track sensitivity and forecast bias through assimilation of satellite and aircraft observations and identify possible dominant factors **in TC structure and intensity changes** including effects of ocean and boundary-layer fluxes.
- To investigate the **predictability** of heavy precipitation and violent wind associated with the Mei-yu convective systems and typhoons, and highlight the contributions from radar, satellite and aircraft observations with advanced data assimilation systems.

# Focus on...



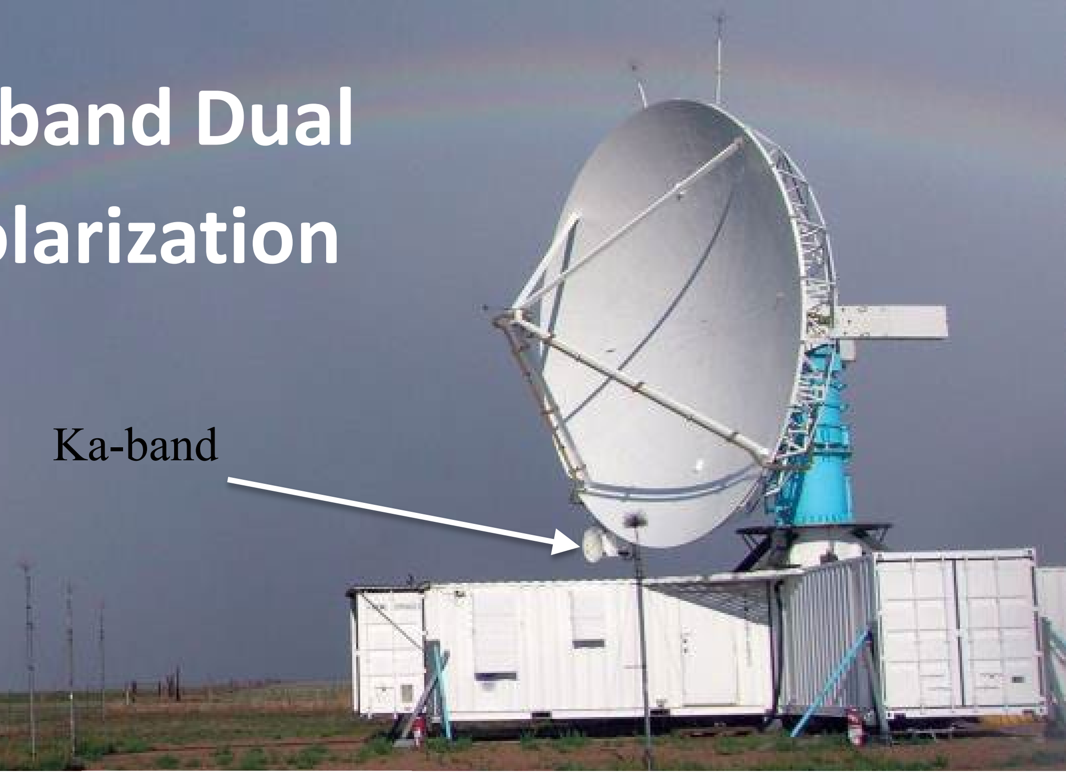
Rainfall
Wind
Rainfall
MCS
SW monsoon
Rainfall
Mei-Yu
Field Experiment
Typhoon
Microphysics Aerosol
QPE / QPF
Terrain effect
Sub-seasonal variation
monsoon environment
Track / Movement
Rainband / Structure
Intensification
Clustering of TC activity

# TAHOPE + PRECIP + T-PARCII plan

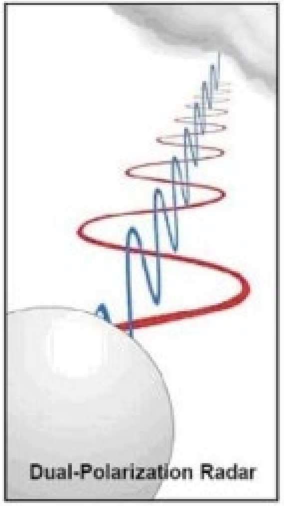


# S-Pol: S-band/$K_a$-band Dual wavelength, Dual Polarization

- *No concrete pad needed*
- *Transportable*
- *Shipped with 8 sea-containers*
- *Self-contained with generator power*

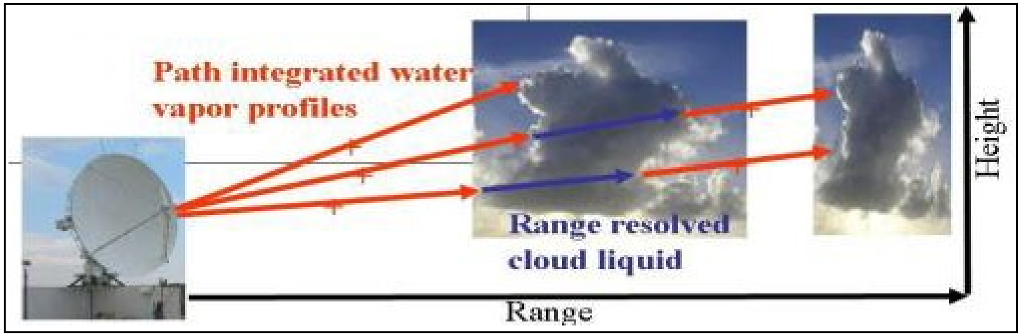



Transmit H & V Polarized Waves



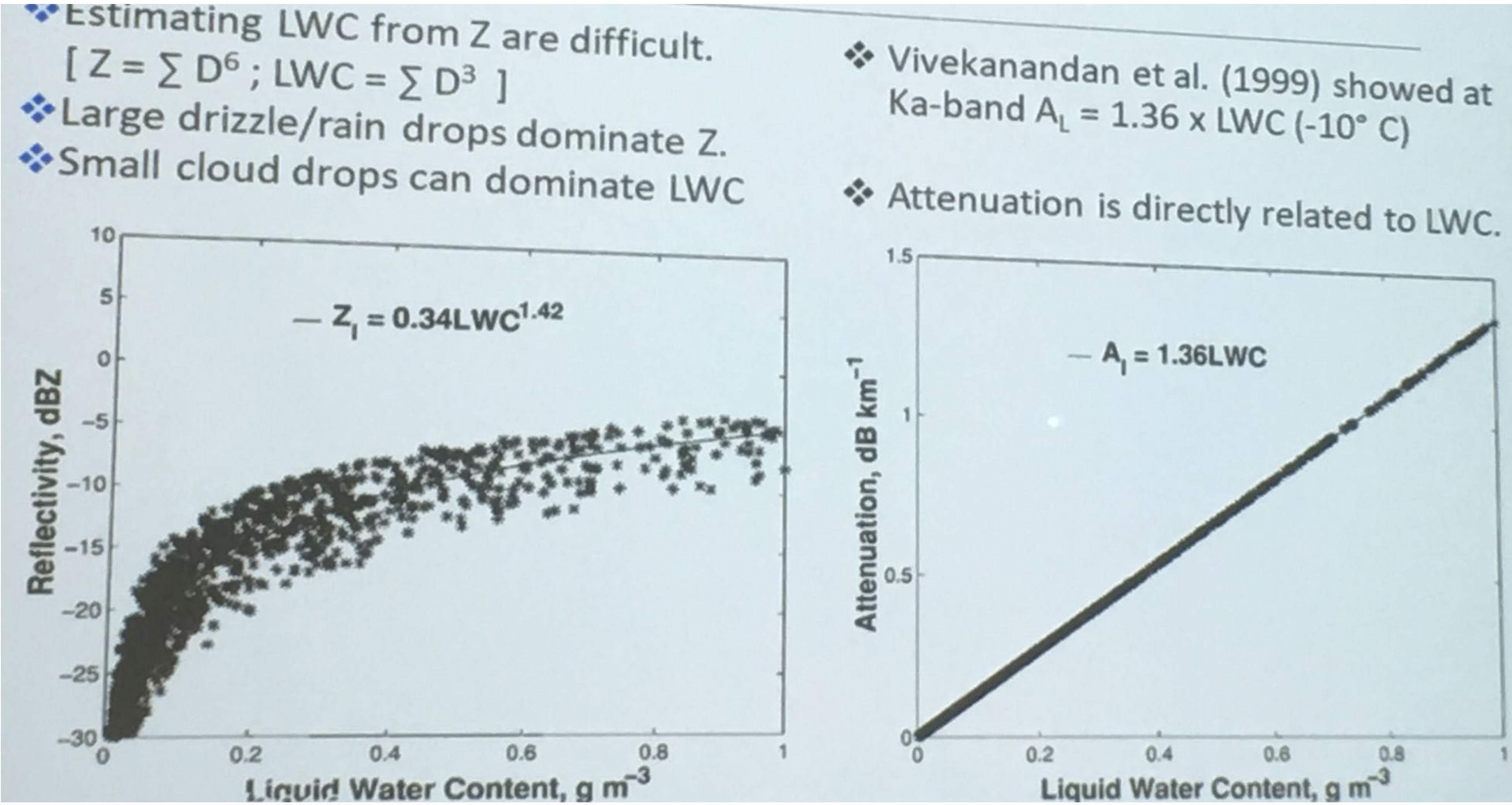

Rain Drop Shapes by Size


Drop size distribution
QPE and integrated rainfall
Clutter Mitigation
Hydrometeor Identification
Near surface humidity




Total cloud liquid water content
Path-integrated humidity and vertical profiles
Drop medium volume diameter
Full polarimetric variables

# Vivekanandan et al. (1999) showed that at Ka-band, $A_l = 1.36 \times LWC$ (-10$^o$C)




From Prof. Wei-Yu Chang at NCU (A2O Forum at CWB)

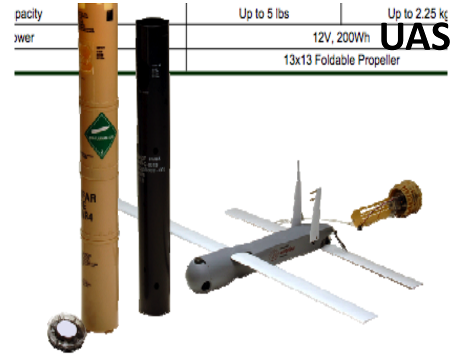
# NOAA airborne assets

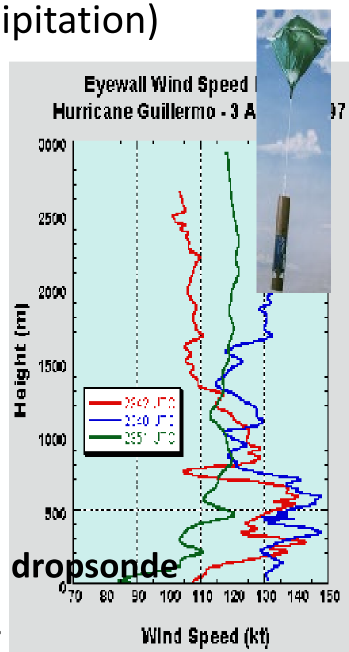
## Platforms

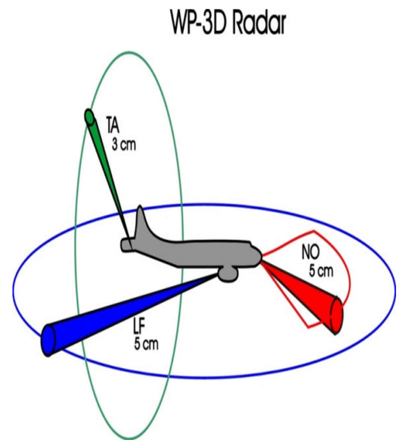
- P-3
- UAS (Coyote)

## Instrumentation

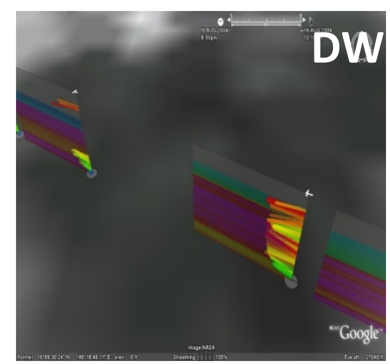
- **In-situ**
  - –Wind, press., temp., moisture
  - –Microphysics (cloud, precipitation)
  - –Electric field
  - –Chemistry
- **Expendables**
  - –Dropsondes
  - –AXBT, AXCP, buoy
- **Remote Sensors**
  - –Lower fuselage radar (LF)
  - –Tail Doppler Radar (TA)
  - –SFMR
  - –Scanning Radar Altimeter
  - –Scatterometer/ profiler
  - –Doppler Wind Lidar

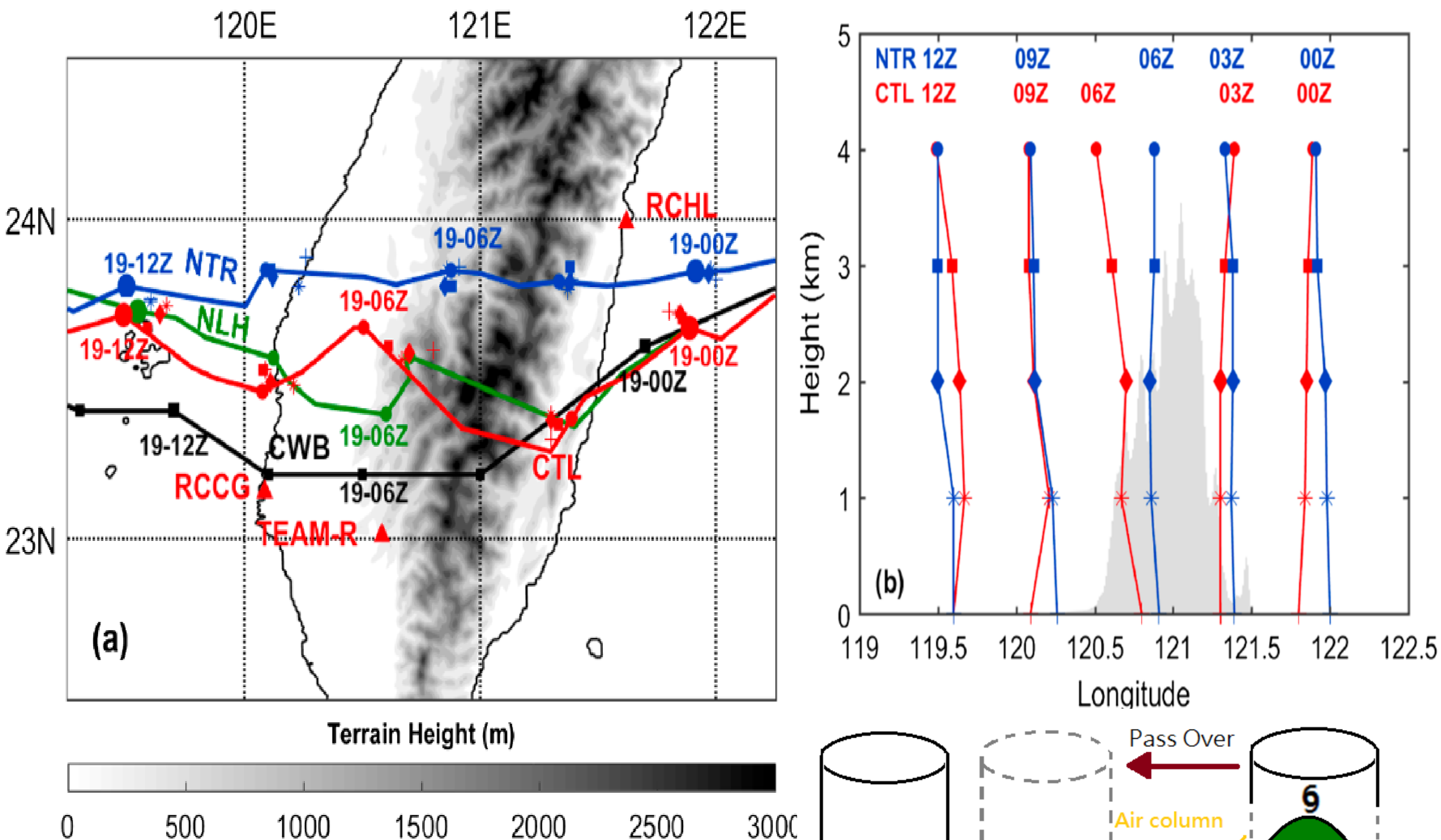



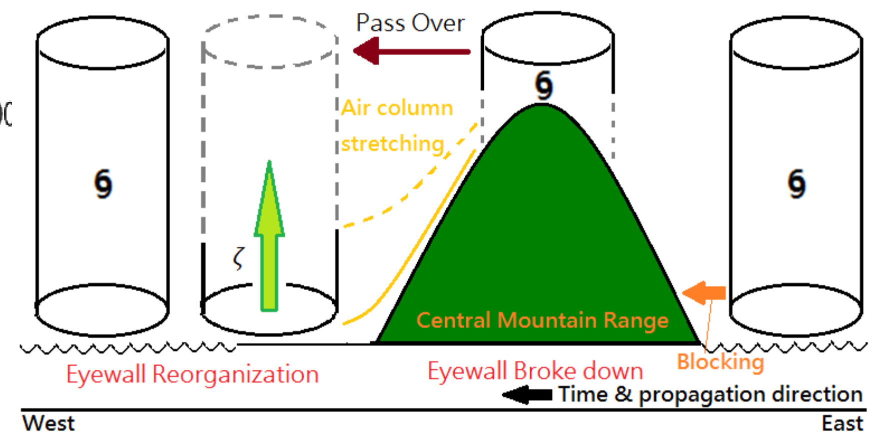


# Typhoon Fanapi (2010)'s Eyewall Reformation




Circle: 4-km center
Square: 3-km center
Diamond: 2-km cent
Star: 1-km center
Cross: SLP center




NLH: no latent heat

CTL: full-terrain

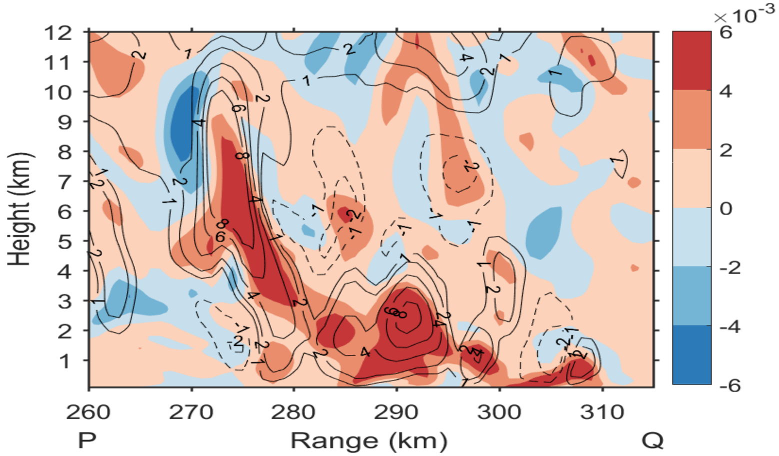
NTR: no terrain

CWB: Best-track

Liou et al. (2016) & Yang et al. (2018)

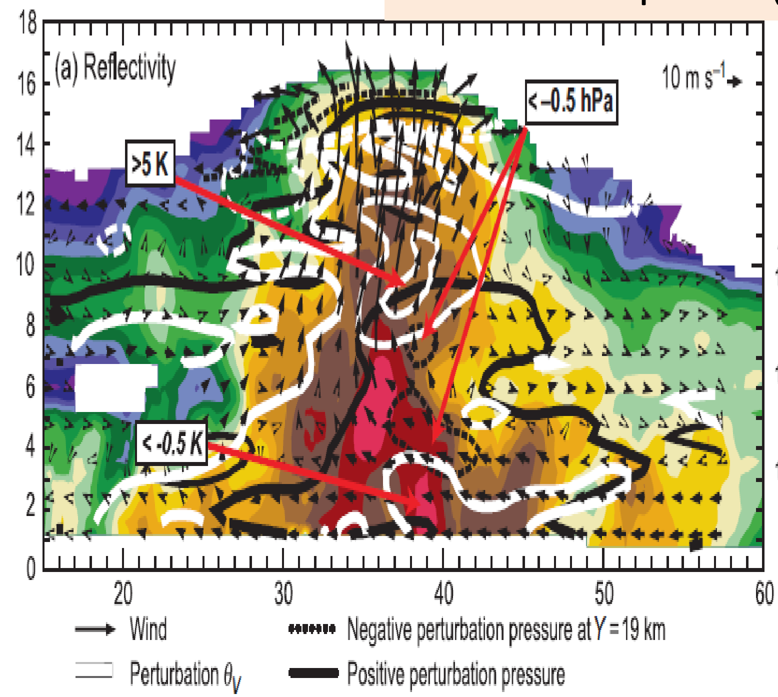
# Vertical Cross Section of VHT

Inland VHT within
Typhoon Fanapi (2010)




Liou et al. (2016) , Yang et al. (2018)

Oceanic VHT within
Hurricane Ophelia (2005)



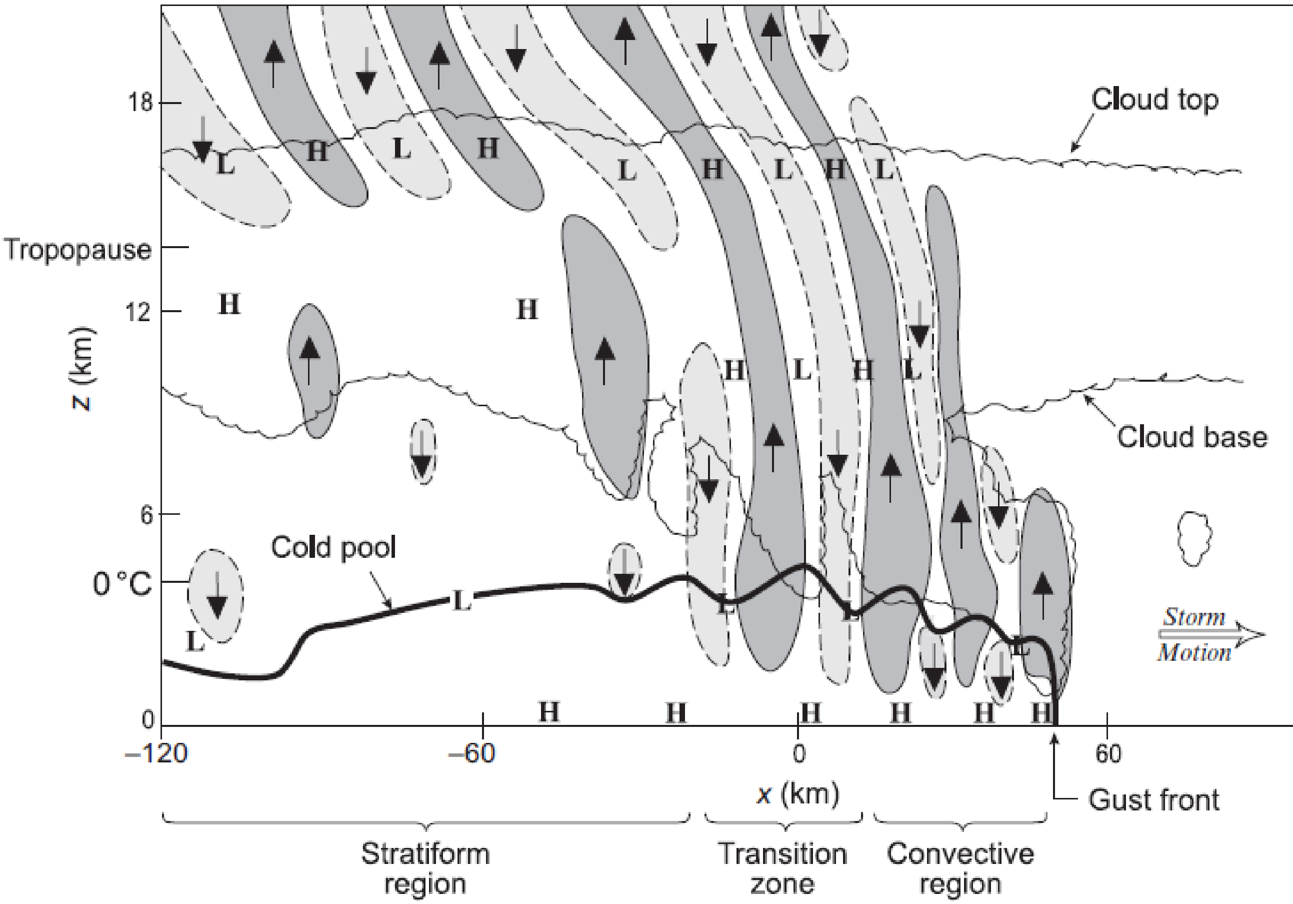

Houze et al. (2009)

⟹ From this cross section, the VHT of Fanapi (2010) in land has weaker maximum updraft, narrower diameter, and shallower depth, compared with the VHT over open ocean.


Liou, Y.-C, T.-C. C. Wang*, and P.-Y. Huang, 2016: The Inland Eyewall Reintensification of Typhoon Fanapi (2010) Documented from an Observational Perspective Using Multiple-Doppler Radar and Surface Measurements. *Mon. Wea. Rev.*, **144**, 241–261.

Yang, M.-J.*, Y.-C. Wu, and Y.-C. Liou, 2018: The study of inland eyewall reconstruction of Typhoon Fanapi (2010) using numerical experiments and vorticity budget analyses. *J. Geophys. Res. Atmos.*, **123**, 9604–9623. https://doi.org/10.1029/2018JD028281.

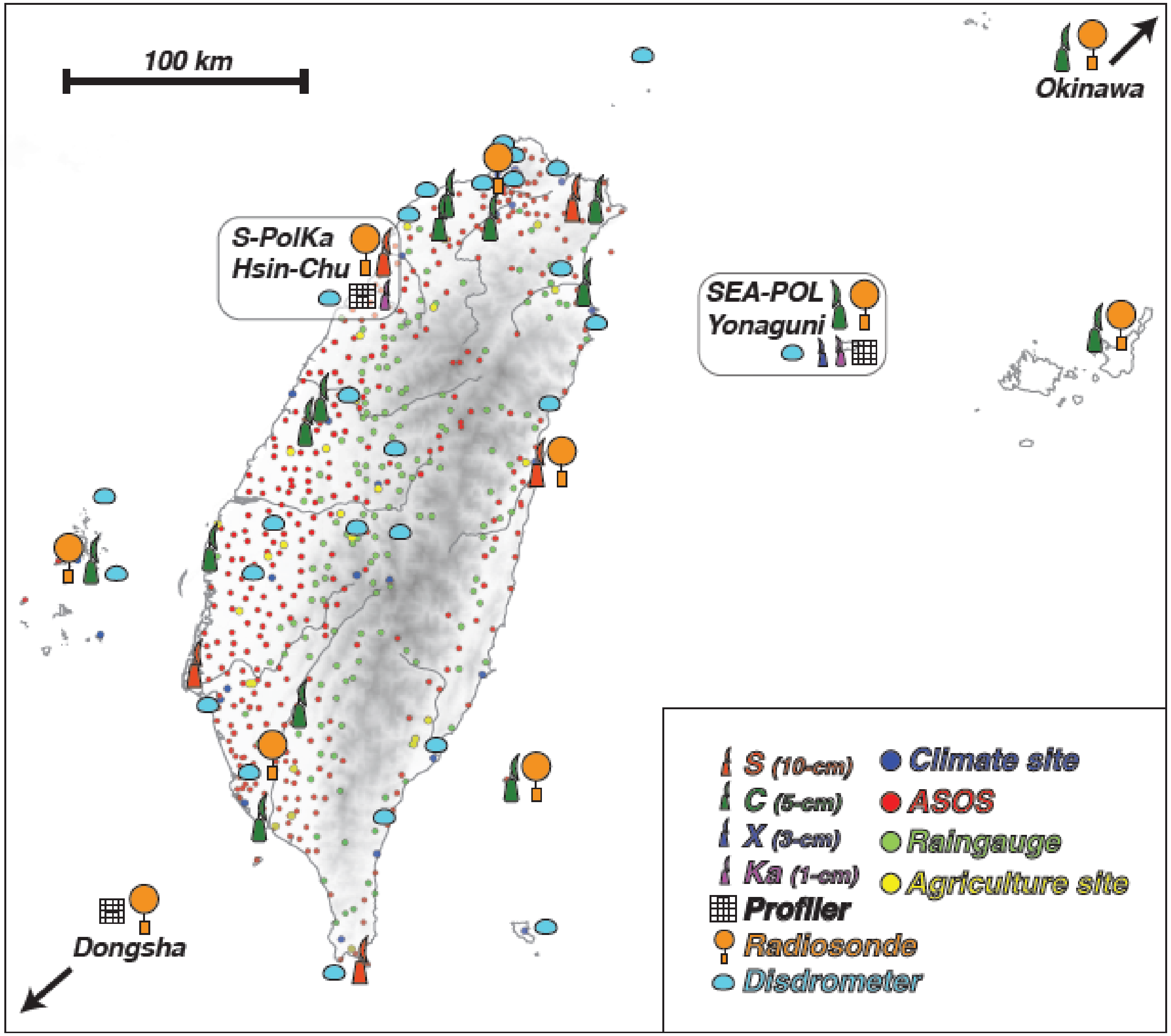
# Multicell characteristics in a sqaull line as a manifestation of vertically-trapped gravity waves




**See the paper of Yang and Houze (1995) for the trapping Mechanism of gravity waves.**

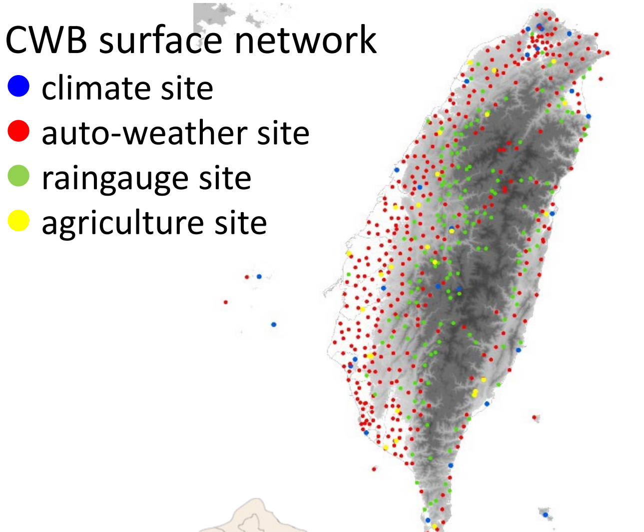
FIGURE 9.41 Schematic model of the gravity-wave structure of a simulated multicellular MCS at a mature stage of development. Updrafts $> 1 \text{ m s}^{-1}$ are heavily shaded. Downdrafts $< -1 \text{ m s}^{-1}$ are lightly shaded. Bold line is the cold pool outline defined by the $-1$ K potential temperature perturbation. Cloud outline is for the $0.5 \text{ g kg}^{-1}$ contour of nonprecipitating hydrometeor mixing ratio. L and H indicate centers of low and high perturbation pressure. *From Yang and Houze (1995). Republished with permission of the American Meteorological Society.*

Houze (2014): Cloud Dyanmics



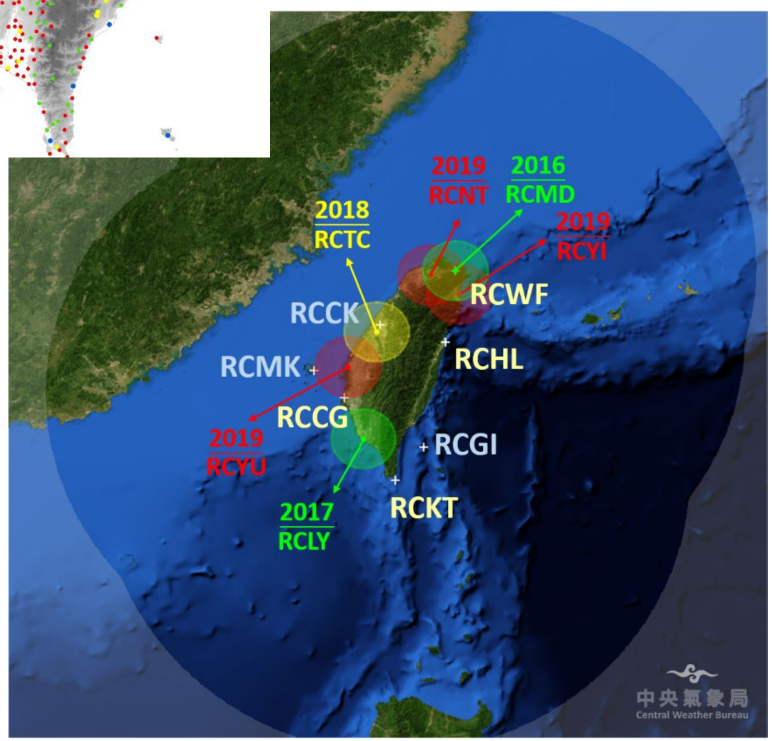

- Taiwan aircraft will release dropsondes in the Mei-Yu system and around the targeted typhoon.
- U.S. S-PolKa radar will be deployed near the central west coast of Taiwan (Hsinchu), and U.S. SEA-POL radar will be deployed over Yonguni (Japan).
- U.S. P3 aircraft departing from Okinawa will take flight measurements (dropsondes and radar) in the vicinity of Taiwan and offshore (penetrating the targeted typhoon)

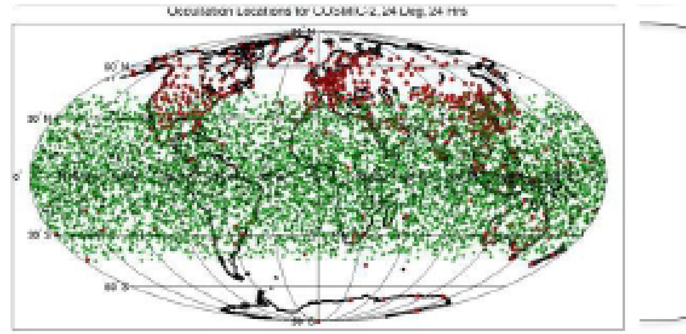
# Highest density of observation network from station, radar to satellite





Experimental Watershed

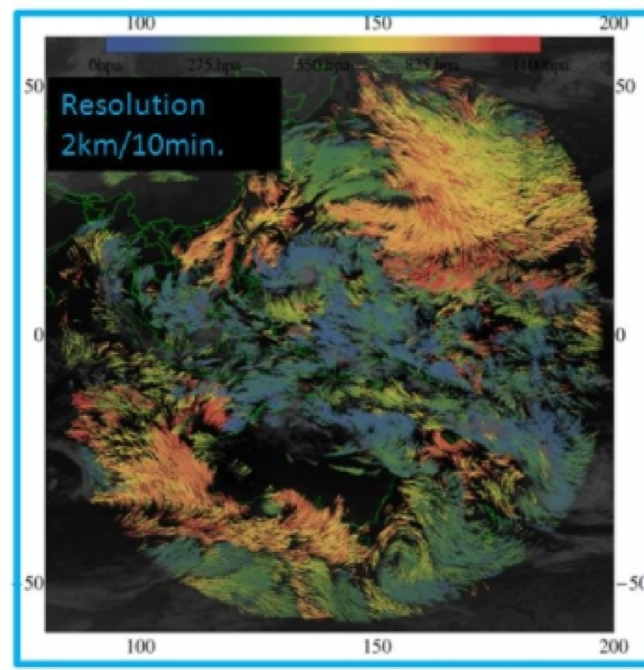


2019/06

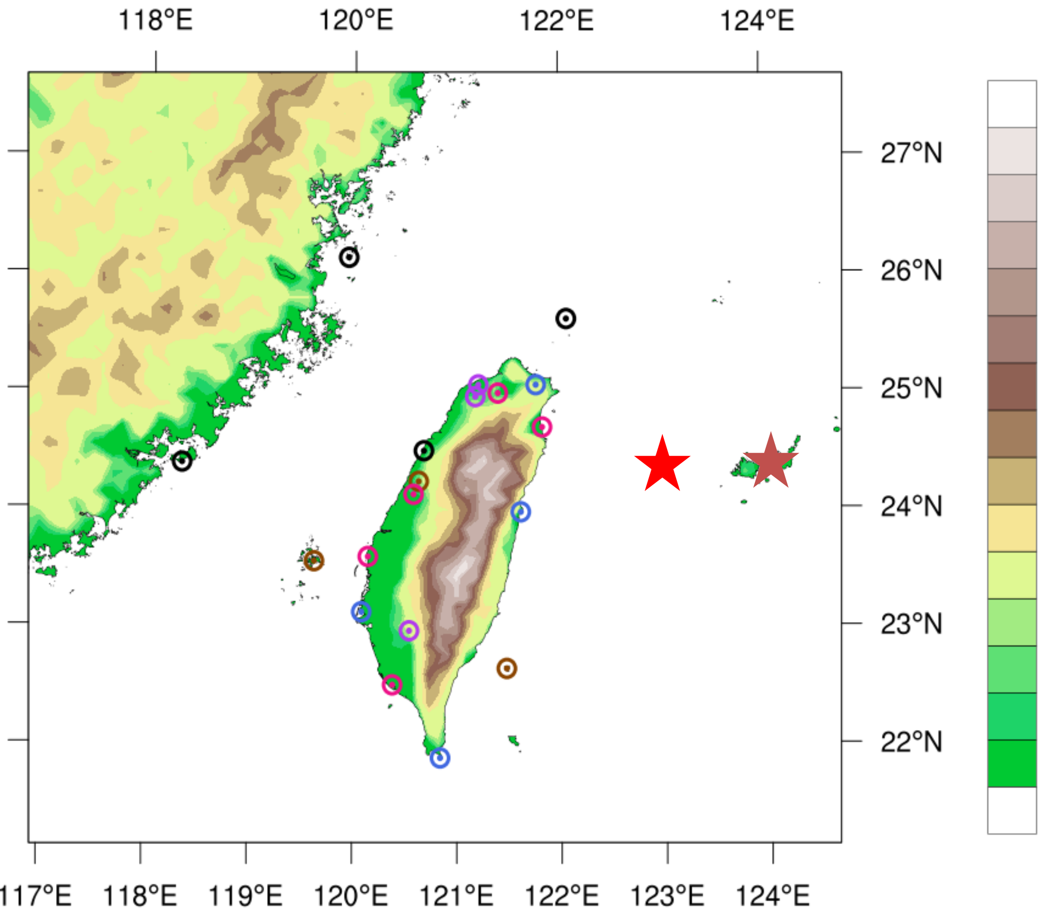
FORMOSAT-7 / COSMIC-2A
6 spacecraft
(24 degree)

**Himawari-8 AMVs** derived from Himawari-8 imagery with new algorithm



# Observation experiment Group

## Taiwan radar sites (all radars scan from 0.5 to 19.5 degree in elevation).




**CWB (4, S-band)**
RCWF, RCHL, RCKT, RCCG

**Air Force (3, C-band)**
RCCK, RCMK, RCGI

**Rain radar (6, C-band)**
RCNT, RCTC, RCYU, RCLY, RCYI, RCMD

**Other (3, C-band)**
NCU, RCTP, NARL

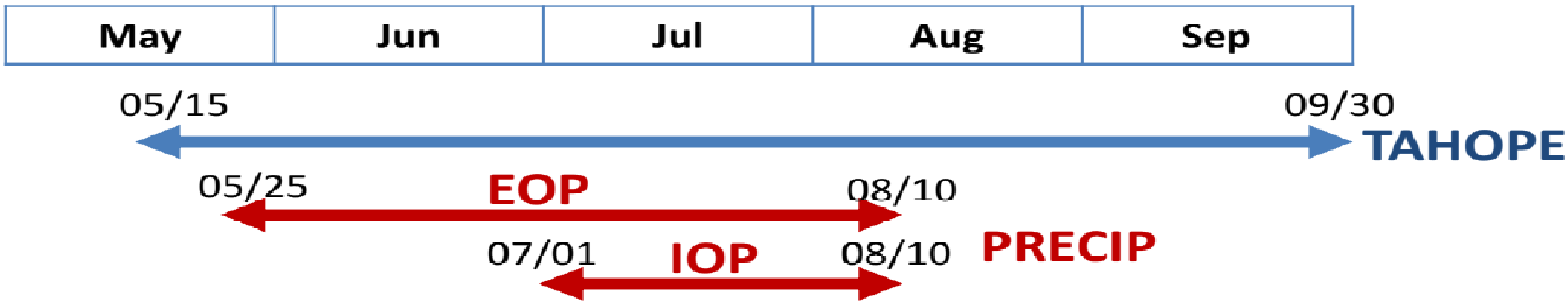
**Additional radar site (1, NCAR S-Polka)**
Hsinchu

**Additional radar site (1, NTU X-band)**
Yilan

**Additional radar site (1, CSU SEA-POL)**
Yonaguni

**Terrain blockage is considered**

# Field Campaign Timeline




**2020 Field Campaign Schedule**

- Experiment facilities
  Taiwan facilities: C-pol (NARL), Team-R (NCU), X-pol (NTU), Wind profiler (NARL), Radiometer (NARL), Dropsonde and Operational stations (CWB)
  U.S. facilities: S-PolKa & SEA-POL radars, and P3 aircraft
- Japan facilities: radar, profiler, and aircraft (T-PARCII)
- Previous Taiwan-US-Japan joint meetings: 2017/10 at ICMCS (Taipei, Taiwan), 2018/06 at AOGS (Hawaii, USA), 2019/03 after ICMCS (Okinawa, Japan).

# 2019 Dry run in Taiwan

- Time period: first 2 weeks in June (6/3 – 6/14)
- EOP/IOP decision procedure check
- Network testing & data communication
- Calibration & QC for instruments (soundings, distrometers, wind profilers, radiometers, etc)
- Data Catalog & Experiment website prototype
- Experiment Logo
- Others?


Thanks for your attention

**第一年度執行進度(2019/08~2020/07)：**

第一年期間(2019/08~2020/07)的加密觀測將以梅雨季 MCS 系統為主，(2020/05~2020/06)以及颱風季(2019/08~20149/09)的預實驗。由於實驗經費有限，在第一年的颱風季預實驗期間(2019/08~2019/09)只做網路及通訊測試，並不施放探空及人員加班加密觀測。第一年梅雨季(5/15–6/30)期間即為 EOP (Extensive Operation Period)時段，臺灣全島 5 探空測台（馬公、屏東、綠島、板橋及花蓮）與一新增站(地點未定,可能在 S-Polka 雷達的新竹地區)每天有 2 筆探空資料(00 及 12UTC),而在 IOP (Intenstive Operational Period)期間（假設有 3 次，每次的 IOP 有 3 天，共 9 天），則每站有 6 筆探空資料（00、06、12 及 18UTC)。詳細經費預估如下: 梅雨季自 5/15–6/30，共 48 天（預計 3 次 IOP，每次 3 天，共 9 天；non-IOP，共 39 天)。馬公、屏東、綠島、板橋及花蓮探空站 IOP 每日額外增加 2 次，共增加 90 次(2*5 站*9 天)；新增站在 non-IOP 每日 2 次、IOP 每日 4 次，共增加 114 次(2*39+4*9)；考量 10%失敗率，需 255 組探空。探空經費的原則是科技部 TAHOPE 計畫辦公室負擔 40%的經費(90 組探空),另外 60%的經費則是另外向水利署申請「水文大氣聯合密集觀測」委託計畫來負擔(135 組探空) ，探空釋放的人員差旅費由 TAHOPE 計畫辦公室與水利署申請「水文大氣聯合密集觀測」委託計畫共同負擔。DOTSTAR 投落送預計執行 5 次飛行任務，每次平均投擲 12 個，總計 60 個投落送。投落送耗材經費是由科技部 TAHOPE 計畫辦公室負擔。另外，中央氣象局已答應於梅雨季(5/15–6/30)期間，支援另外 6 小時的 DOTSTAR 投落送飛行時數。S-Polka 雷達之整地費用，因其場地為河川地，亦擬由水利署申請「水文大氣聯合密集觀測」委託計畫來負擔。

**第二年度執行進度(2020/08~2021/07)：**

第二年期間(2020/08~2021/07)的加密觀測將以颱風系統為主，假設在颱風季(2020/08~2020/09)的 2 個月中(8/1~9/30)共有 4 個颱風，每個颱風個案連續觀測 3 天，共有 12 天。詳細經費估算如下: 假設 2020 年颱風季(8/1~9/30)有 4 個颱風個案，每個案連續觀測 3 天，共 12 天。東沙、馬公、屏東、綠島、板橋及花蓮探空站，額外增加 2 次探空觀測，共增加 120 次(2*5 站*12)；新增站每日 4 次(4*12)，共增加 48 次；考量 10%失敗率，需 186 組探空。探空經費由 TAHOPE 計畫辦公室負擔 48%的經費(90 組探空)，另外 52%的經費則是另外向水利署申請「水文大氣聯合密集觀測」委託計畫來負擔(96 組探空)，探空釋放的人員差旅費由 TAHOPE 計畫辦公室與水利署申請「水文大氣聯合密集觀測」委託計畫共同負擔。DOTSTAR 投落送預計執行 4 次飛行任務，每次平均投擲 15 個，總計 60 個投落送，投落送耗材經費是由科技部 TAHOPE 計畫辦公室負擔。

**第三年度執行進度(2021/08~2022/07)：**

TAHOPE 第三年期間(2021/08~2022/07)不做加密觀測，而是舉辦國際研討會，邀請參與此 TAHOPE / PRECIP / TPARC-II 國際聯合觀測實驗的學者專家們與會，交換彼此的研究成果與經驗交流。會議的重點是臺、美、日三國的科學家們齊聚一堂，確定資料使用原則(Data Policy)，並且交換特別觀測資料（如 Team-R 雷達資料、S-Polka 雷達資料、SEA-Pol 雷達資料、P3 雷達資料及 COSMIC-II 福衛 7 號衛星資料等），最後將由 TAHOPE 計畫辦公室彙整而建立 TAHOPE 實驗中尺度再分析資料(TAHOPE Experiment Mesoscale Reanalysis)。

# TAHOPE Project Office 2019 progress log

- 1/24: Contact Water Resource Agency for possible support
- 1/28: Contact Director M.-T. Lin at MOST/Natural Sci. Division
- 2/1: First working meeting at NCU
- 2/21: Message from Prof. Michael Bell => **A positive decision to recommend PRECIP for funding**; NSF has approved both S-PolKa and SEA-POL for the requested period from 25 May - 10 August 2020.
- 2/28: Second working meeting at NTU => 2019 Dry Run
- 3/9: TAHOPE/PRECIP/TPARC-II planning meeting at U of Ryukyus
- 4/29 - 5/3: NCAR/EOL S-Polka radar site survey to Hsinchu
- Late April or May: 總計畫與大氣學門共同邀請相關單位 (CWB, WRA, 水保局, etc) 參加TAHOPE 2020年觀測實驗說明會
- 6/3 – 6/14: Dry run in Taiwan
- Sept or Oct: Severe Weather & TAHOPE Planning Workshop at Taipei