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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Cheng-Shang Lee 李清勝[1], Chung-Chieh Wang 王重傑[4], Ching-Hwang Liu 劉清煌[5],
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2020 International Workshop on Extreme Rainfall and PRECIP Planning Workshop at CSU on 2-3 March 2020

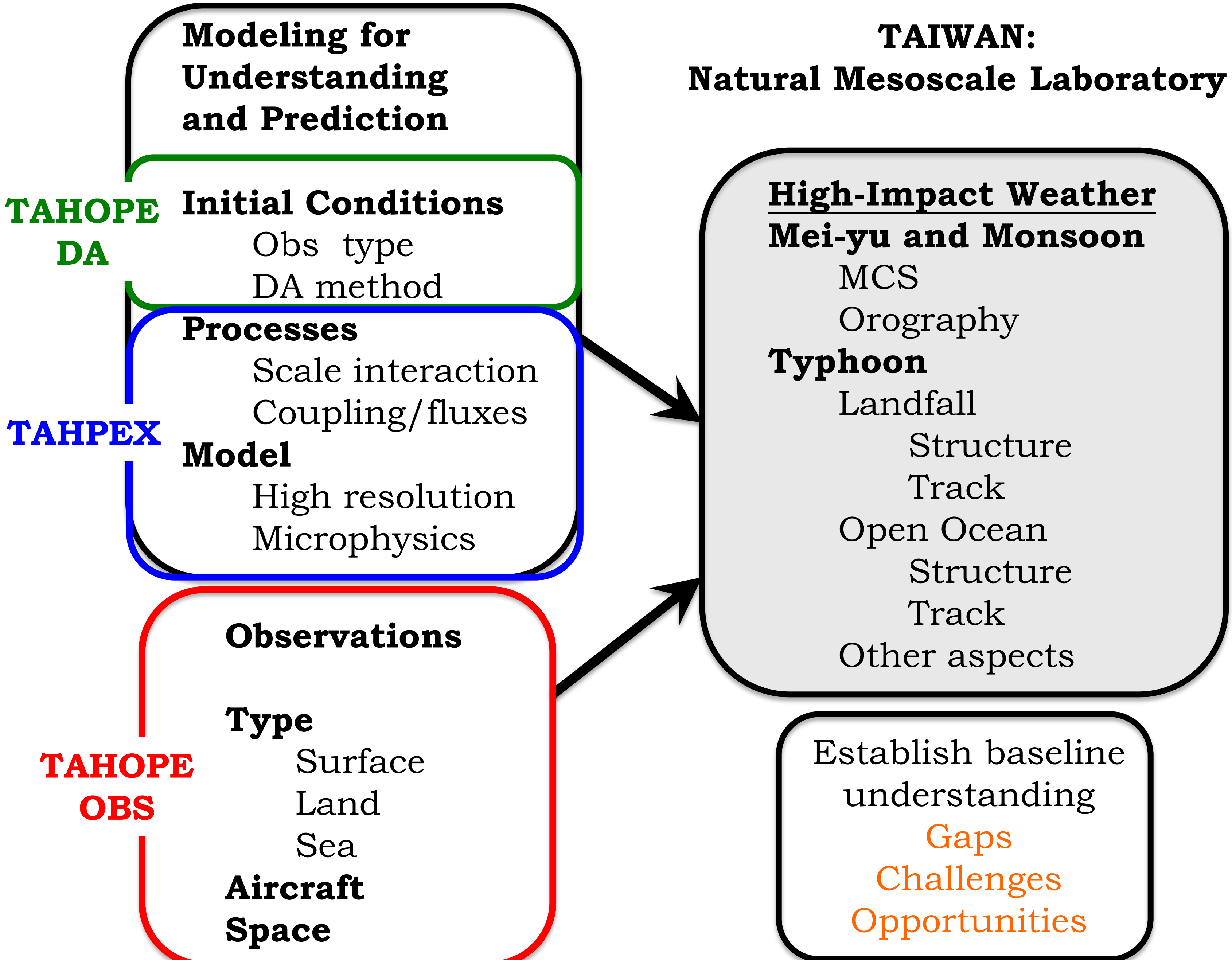
國家實驗研究院 NARLabs National Applied Research Laboratories

MOST 科技部 Ministry of Science and Technology

Background

- 2014/7：MOST science team led by Minister Dr. San-Cheng Chang visited NSF and had intense discussion on mutual cooperation. One of the mutual interests from the meeting was the severe weather and extreme rainfall, thus scientists from both countries decided to promote further cooperation.
- 2015/5: 1st Taiwan-USA Severe Weather Workshop at Taipei
- 2016/6: 2nd Taiwan-USA Severe Weather Workshop at Hawaii
- 2017/6: PRECIP 2020 workshop at Colorado State University
- 2017/9: First TAHOPE Planning meeting at TTFRI
- 2017/10/16: First Taiwan-USA working meeting
- 2017/10/18：The 1st Planning Meeting for the Joint Projects (with scientists from Taiwan, USA, Japan, and Korea)

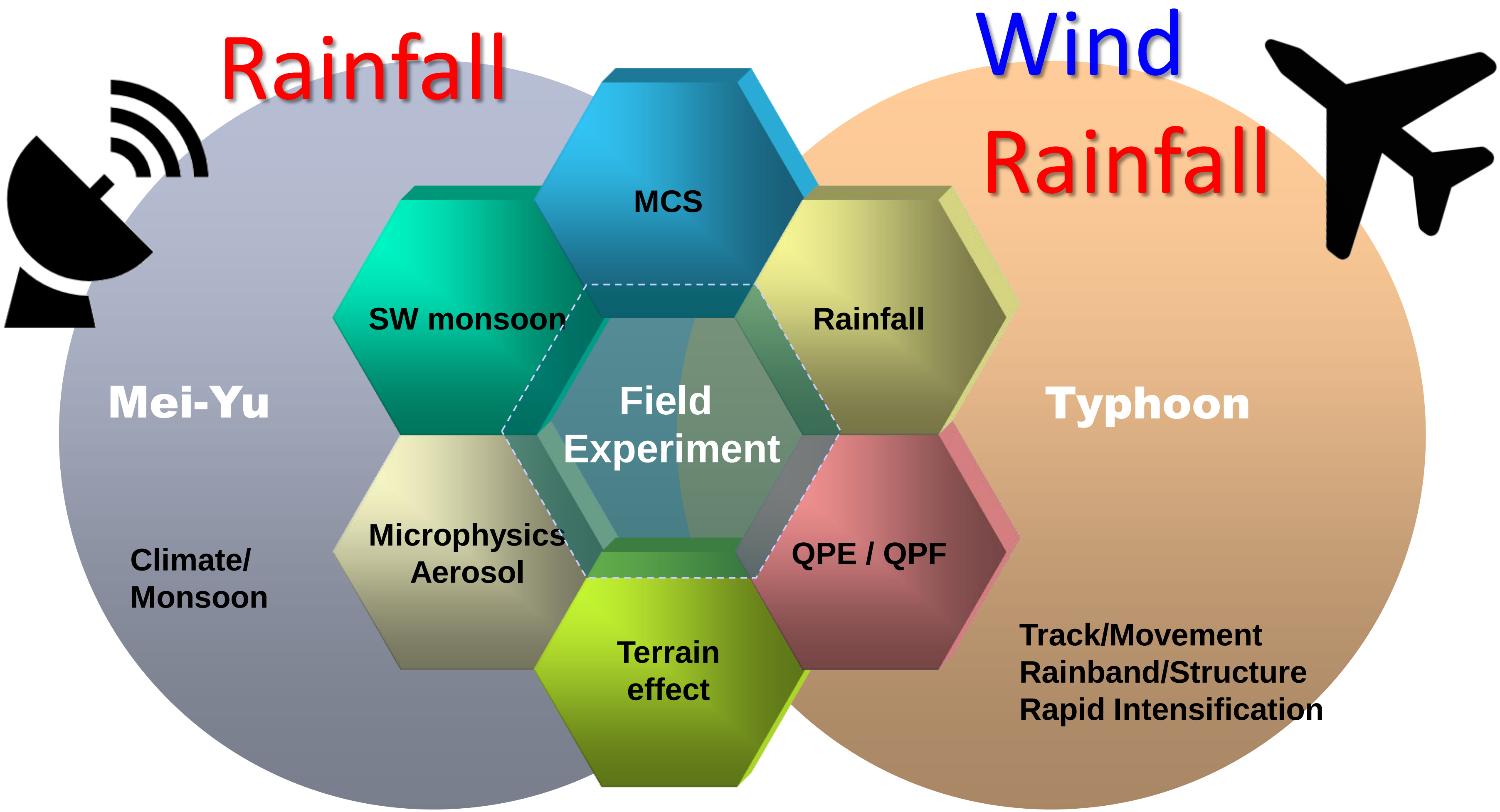
- 2017/9 - 12: 6 working meetings at TTFRI, and 1 meeting at CWB
- 2017/12/14-15: Second Taiwan-USA working meeting
- 2018/3: Radar site survey and 3rd Taiwan-USA working meeting
- 2018/5: 4th Taiwan-USA working meeting
- 2018/6: Taiwan-USA-Japan joint meeting at AOGS
- 2018/10: Prof. Ming-Jen Yang served as the TAHOPE lead PI


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

Dr. Bill Kuo’s briefing to President Tsai on TAHOPE/PRECIP 2020

Photo from Cidny Ramirez (Albany/NTU)

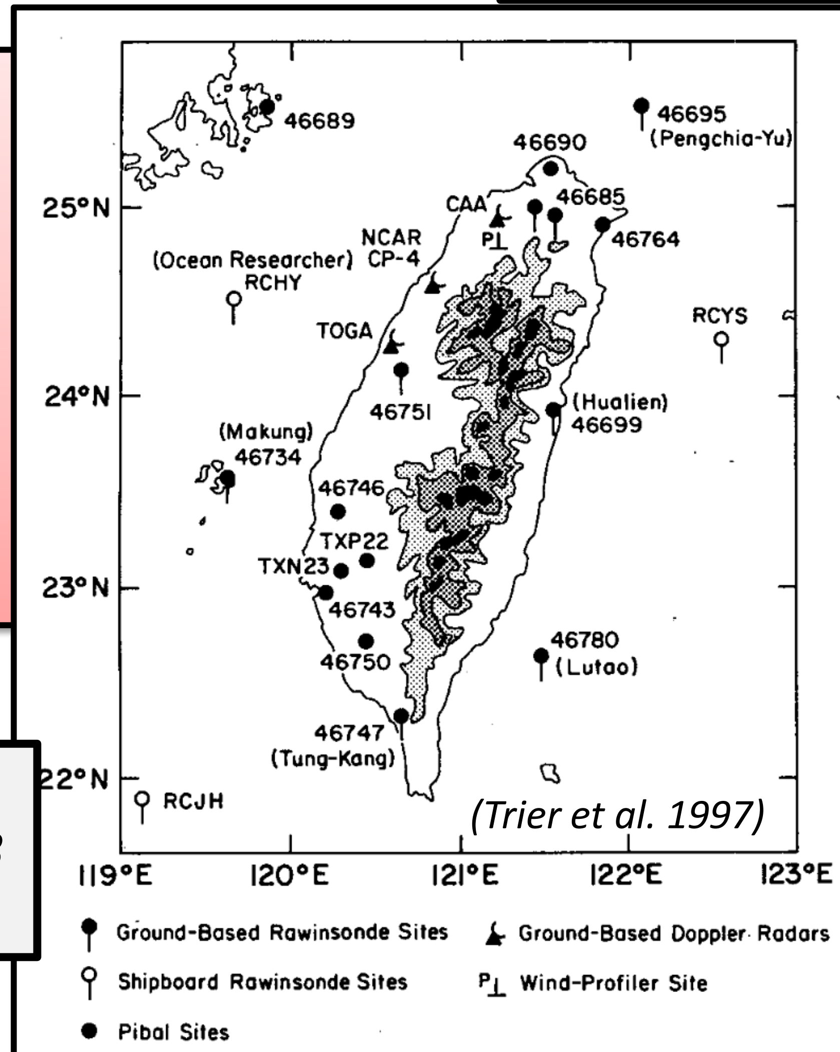
Focus on…


Rainfall
Wind
Rainfall
MCS
SW monsoon
Rainfall
Field Experiment
Microphysics Aerosol
QPE / QPF
Terrain effect
Mei-Yu
Climate/
Monsoon
Typhoon
Track/Movement
Rainband/Structure
Rapid Intensification

The Taiwan Area Mesoscale Experiment
(TAMEX, May-June 1987)

Taiwan-USA

Study of heavy rainfall
- ***Meiyu front***
- ***Mesoscale convective systems***
- ***Orographic effects***
- ***Local circulations***

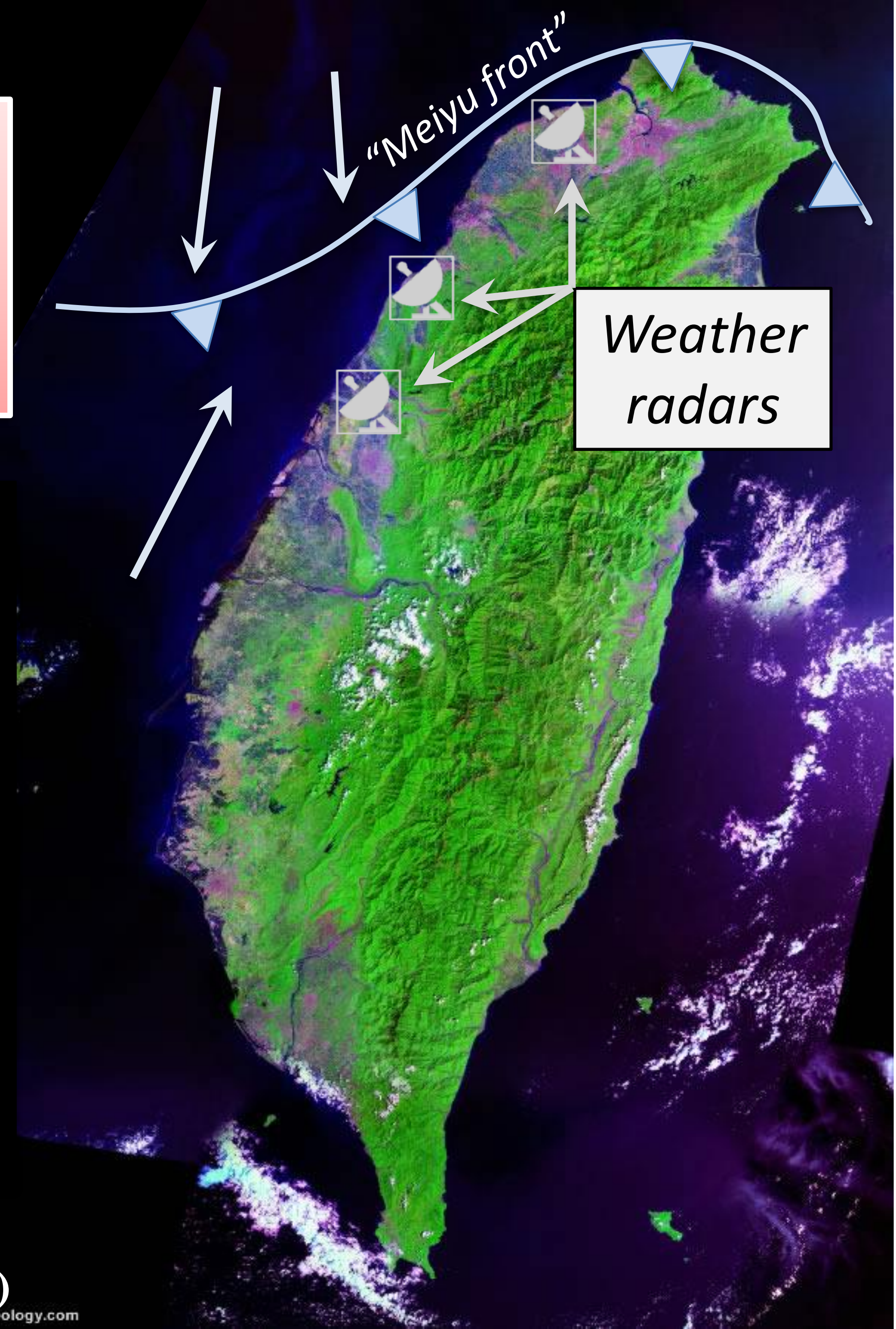


(Trier et al. 1997)

Doppler radars, soundings, surface stations, NOAA P-3 aircraft

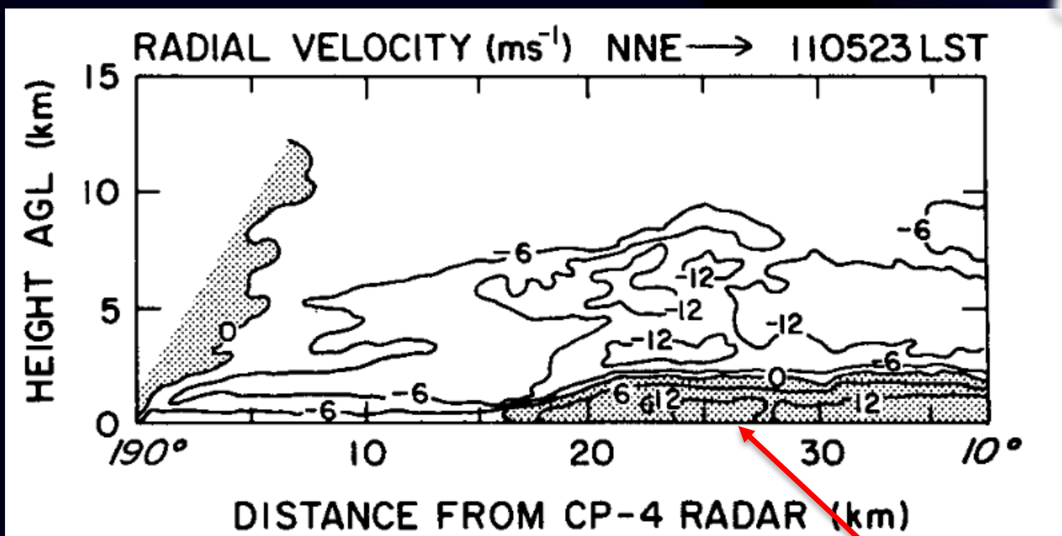
Johnson (2019; TAHOPE Planning Workshop)

TAMEX observations of convection
(Chen et al. 1989; Trier et al. 1990; Ray et al. 1991; Lin et al. 1992; Chen and Chou 1993; Chen and Li 1995; Li et al. 1997; others)

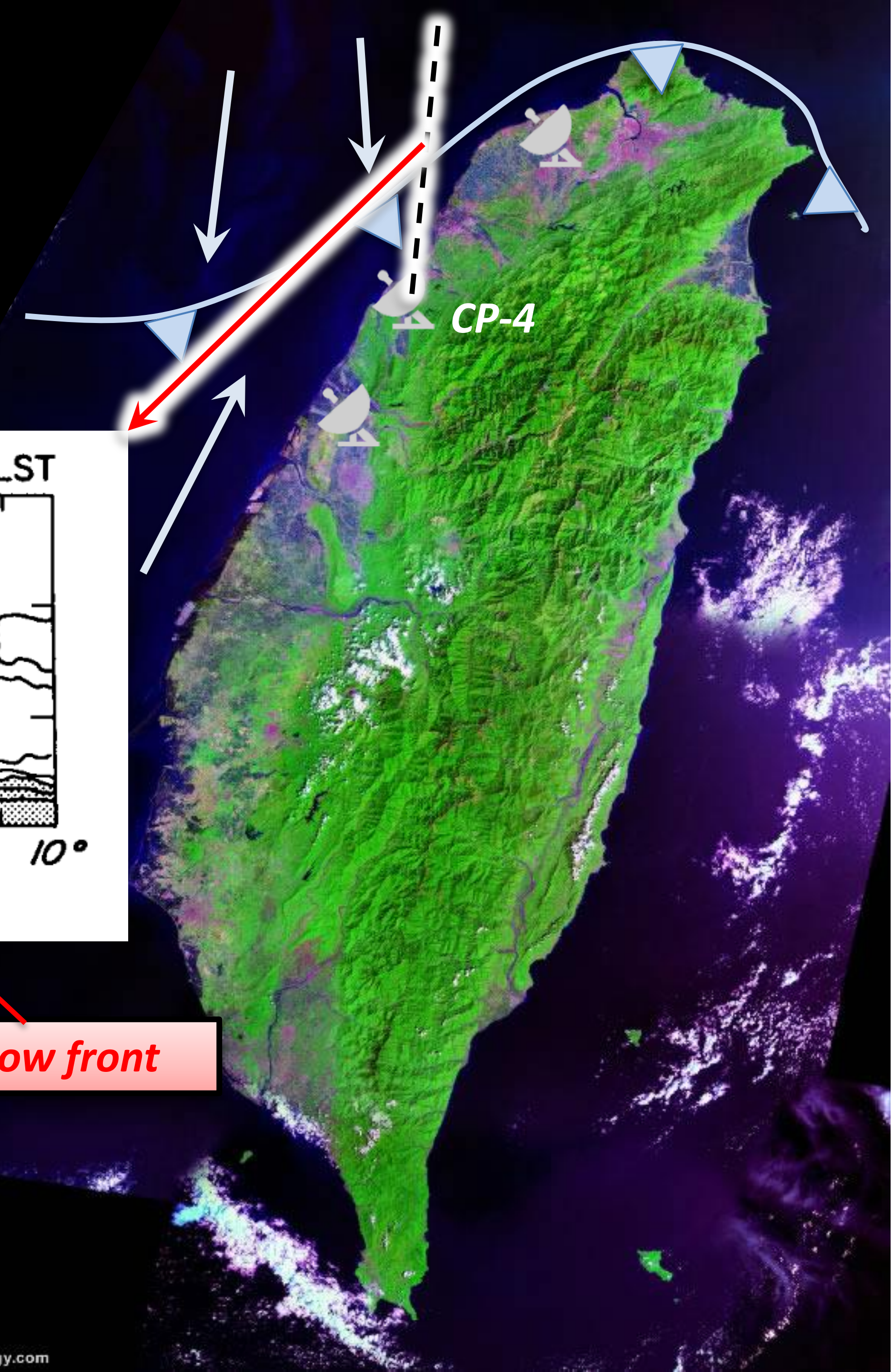


Johnson (2019; TAHOPE Planning Workshop)

TAMEX Radar observations along "Meiyu" front *(Trier et al. 1990; Lin et al. 1990, 1992; Wang et al. 1990; Chen and Chou 1993; Chen and Li 1995; Li et al. 1997; others)*

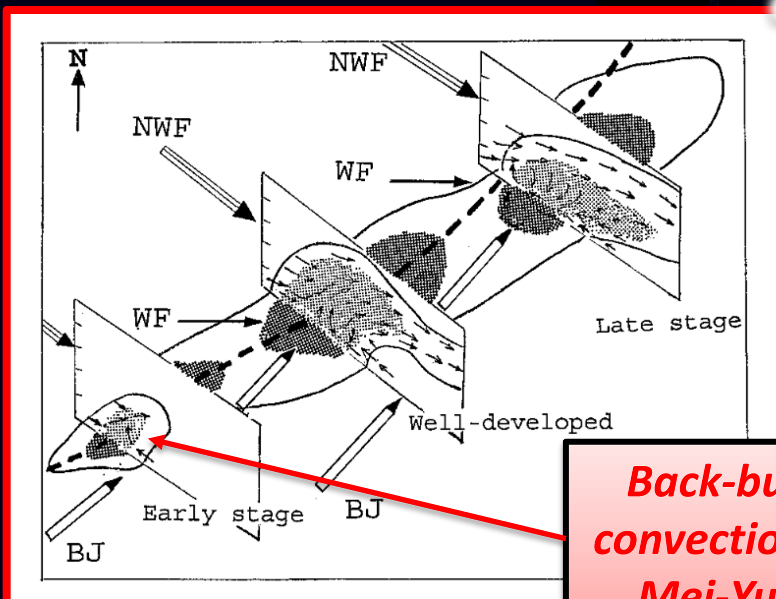


(Trier et al. 1997)



Johnson (2019; TAHOPE Planning Workshop)

TAMEX Radar observations of convection along "Meiyu" front *(Trier et al. 1990; Lin et al. 1990, 1992; Wang et al. 1990; Chen and Chou 1993; Chen and Li 1995; Li et al. 1997; others)*

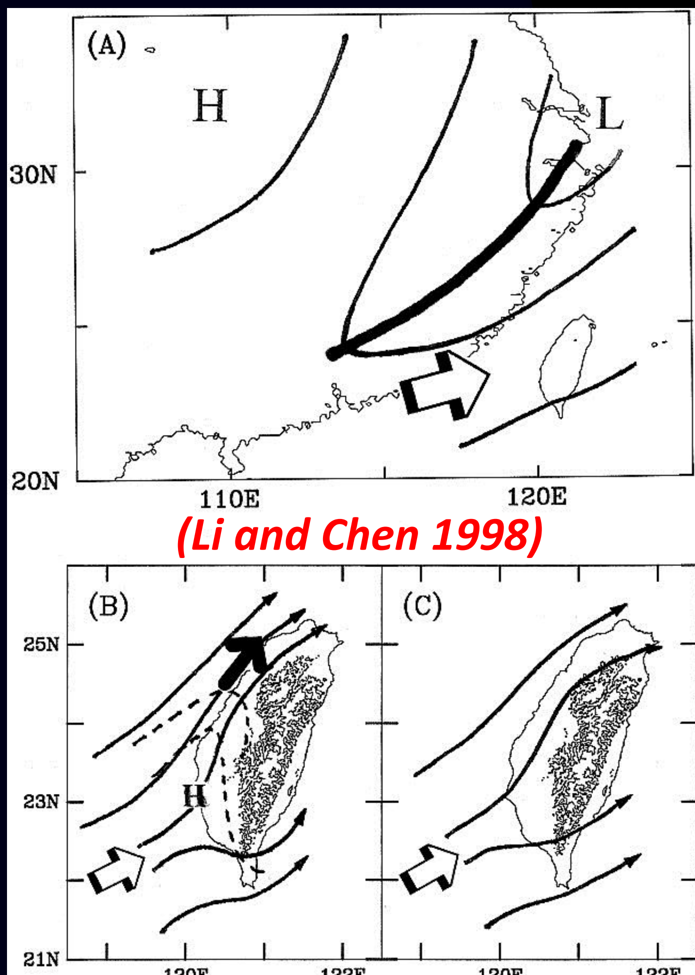


Back-building convection along Mei-Yu front

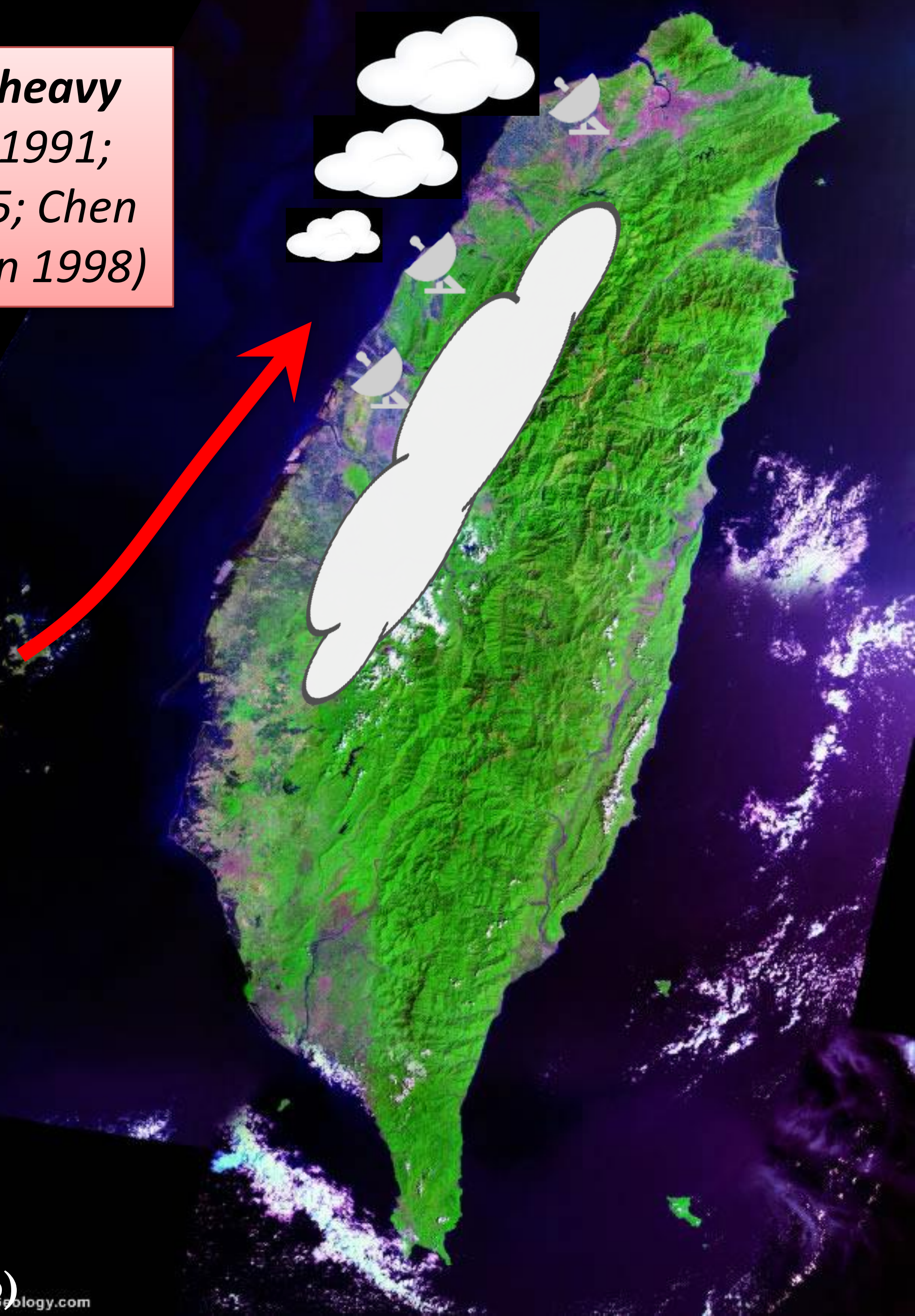
(Li, Chen and Lee 1997)

Johnson (2019; TAHOPE Planning Workshop)

Barrier jets frequently associated with heavy rainfall; orographic effects *(Chen et al. 1991; Akaeda et al. 1995; Chen and Chen 1995; Chen et al. 1994; Chen et al. 1997; Li and Chen 1998)*

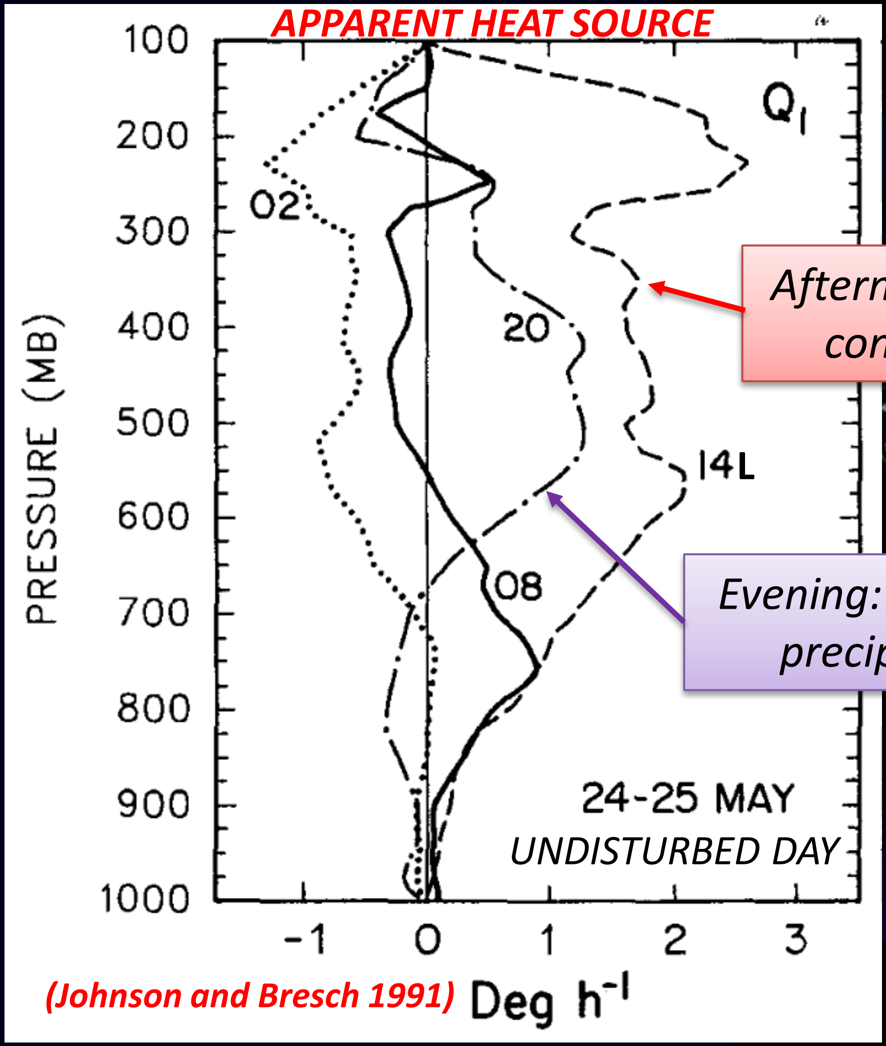


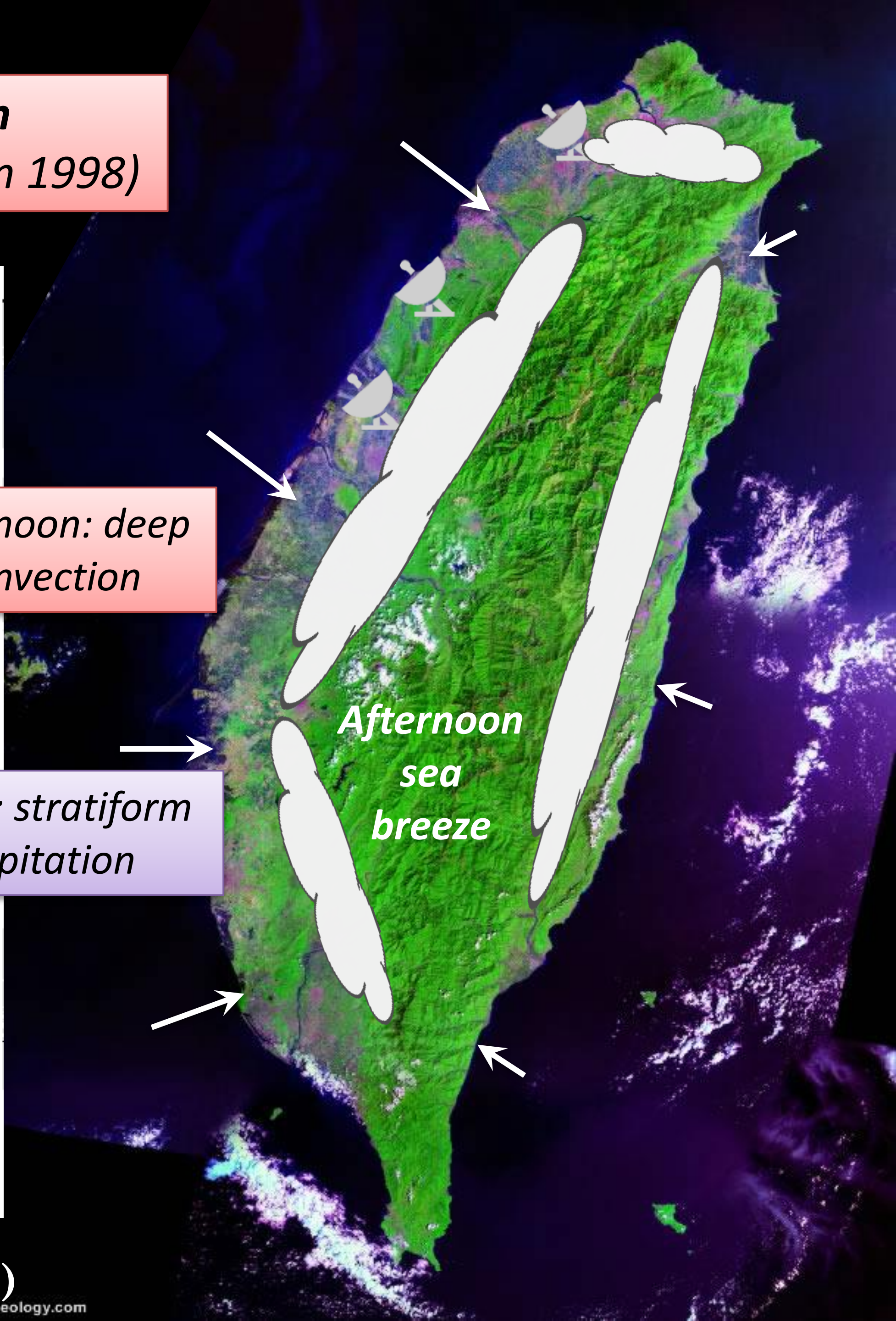
(Li and Chen 1998)



Johnson (2019; TAHOPE Planning Workshop)

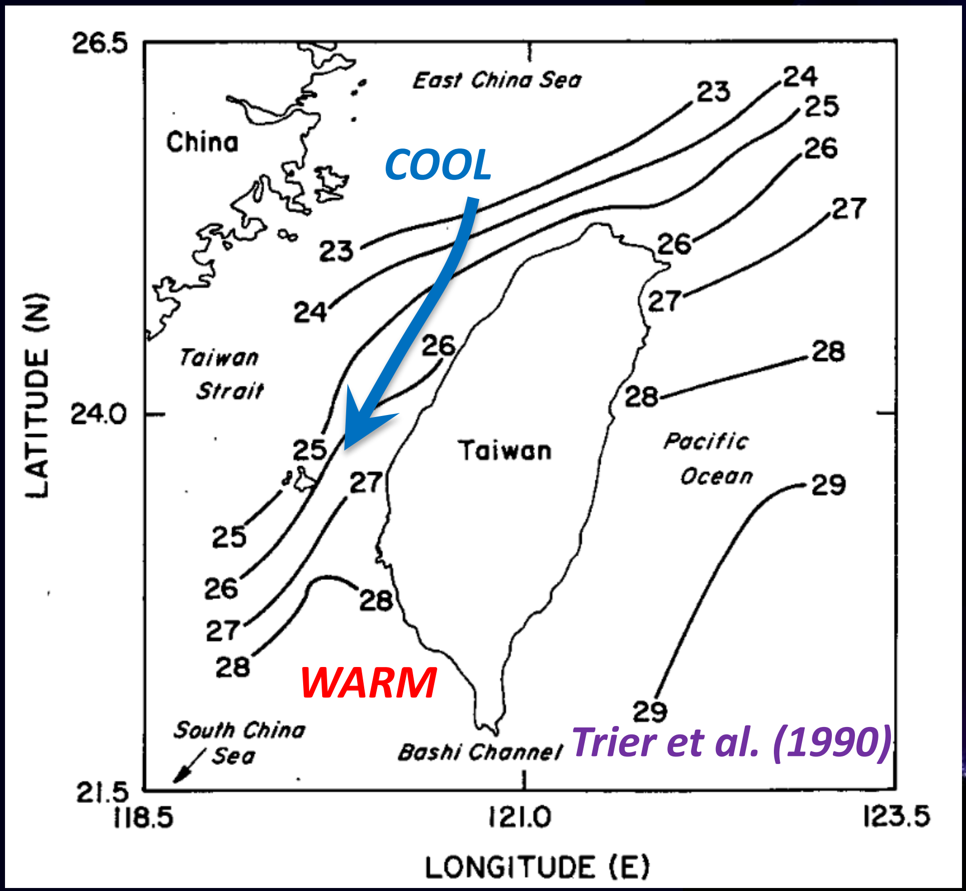
Diurnal cycle of convection over Taiwan
(Johnson and Bresch 1991; Yeh and Chen 1998)

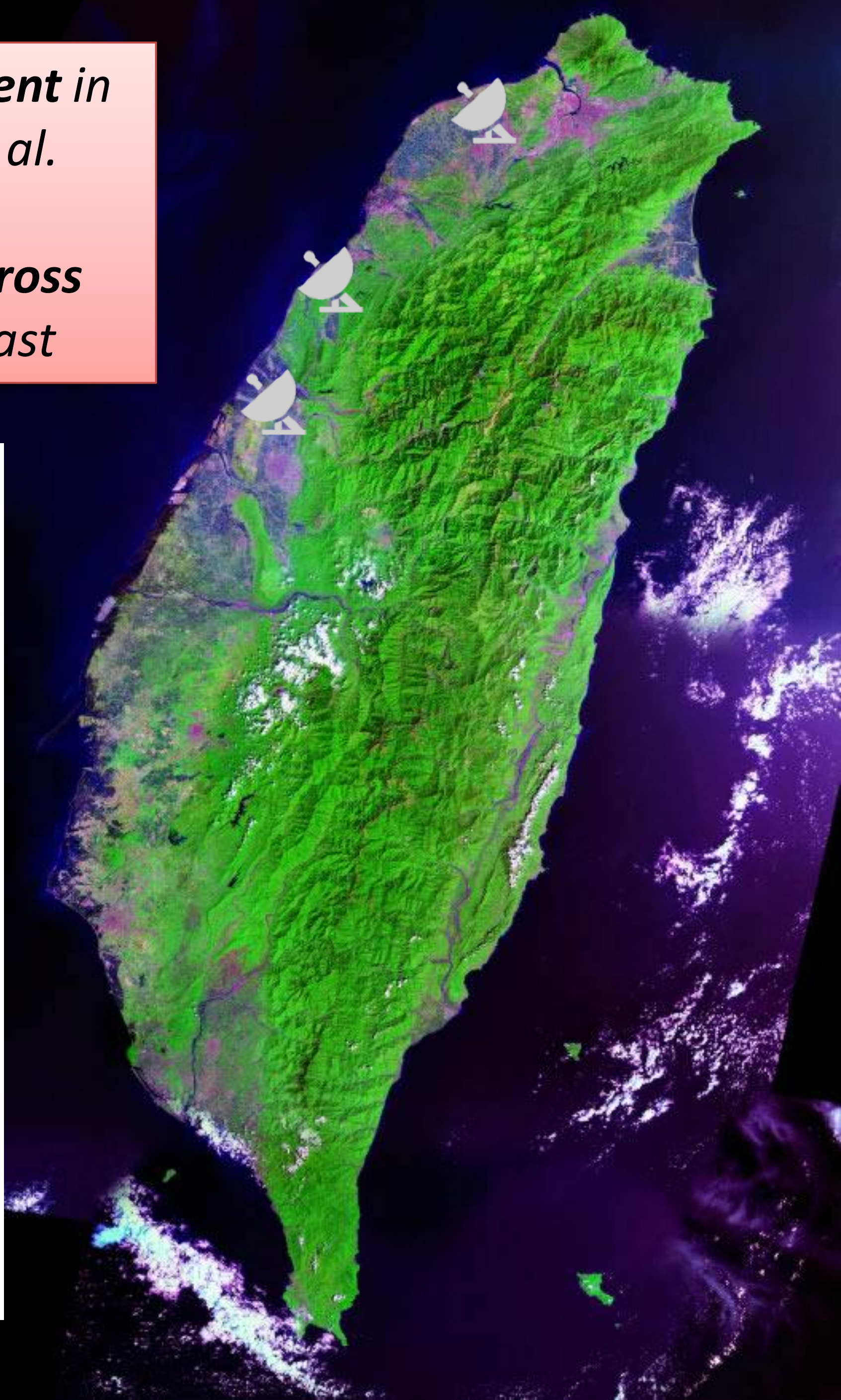




Johnson (2019; TAHOPE Planning Workshop)

- ***Air mass modification by strong SST gradient*** *in northern SCS during Meiyu season (Trier et al. 1990)*
- ***Surface fluxes moderate the T gradient across front*** *as it moves southward along west coast*

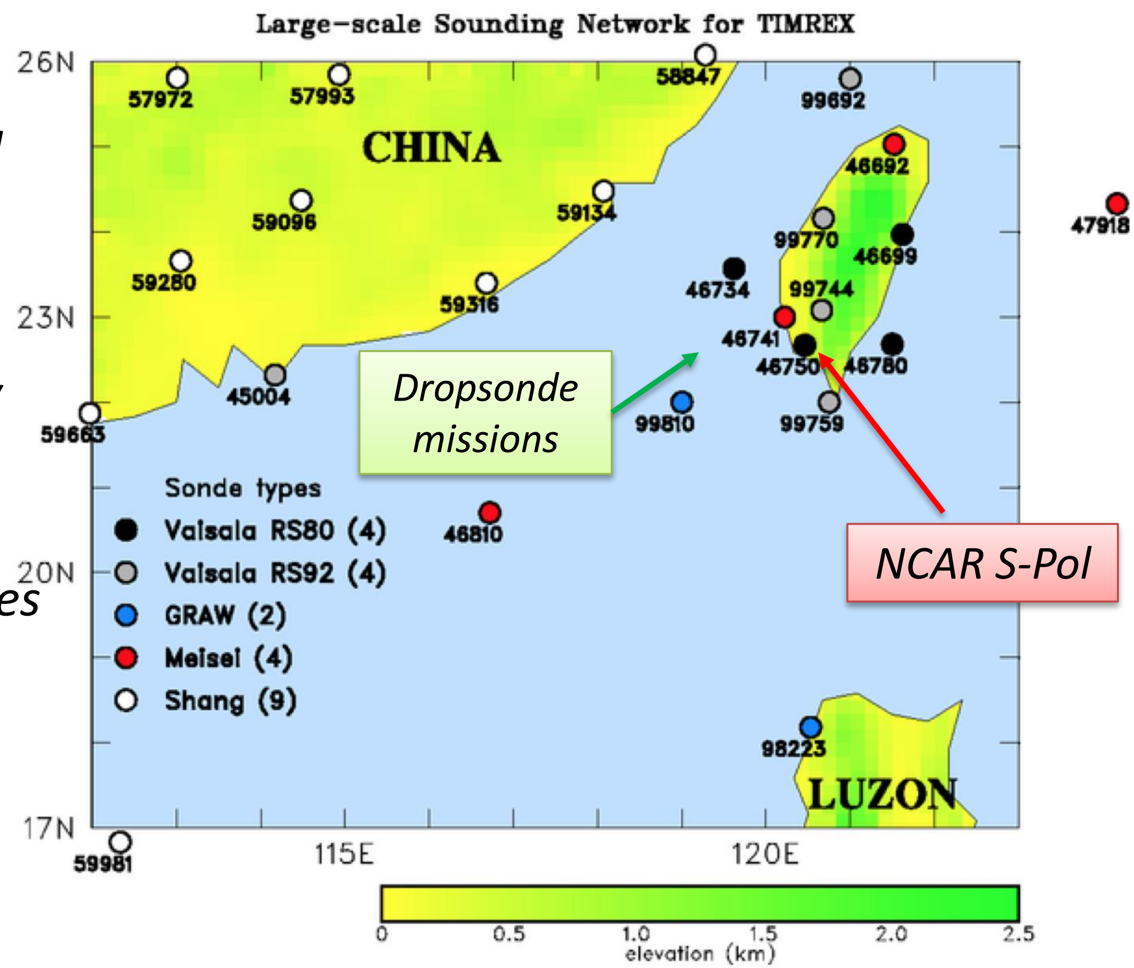




Johnson (2019; TAHOPE Planning Workshop)

Scientific Objectives

- *Terrain effect on the flow and MCSs*
- *MCS dynamics, microphysics, and predictability*
- *Mesoscale data assimilation/ QPF*
- *Convective initiation/diurnal cycle/boundary layer processes*



Participants

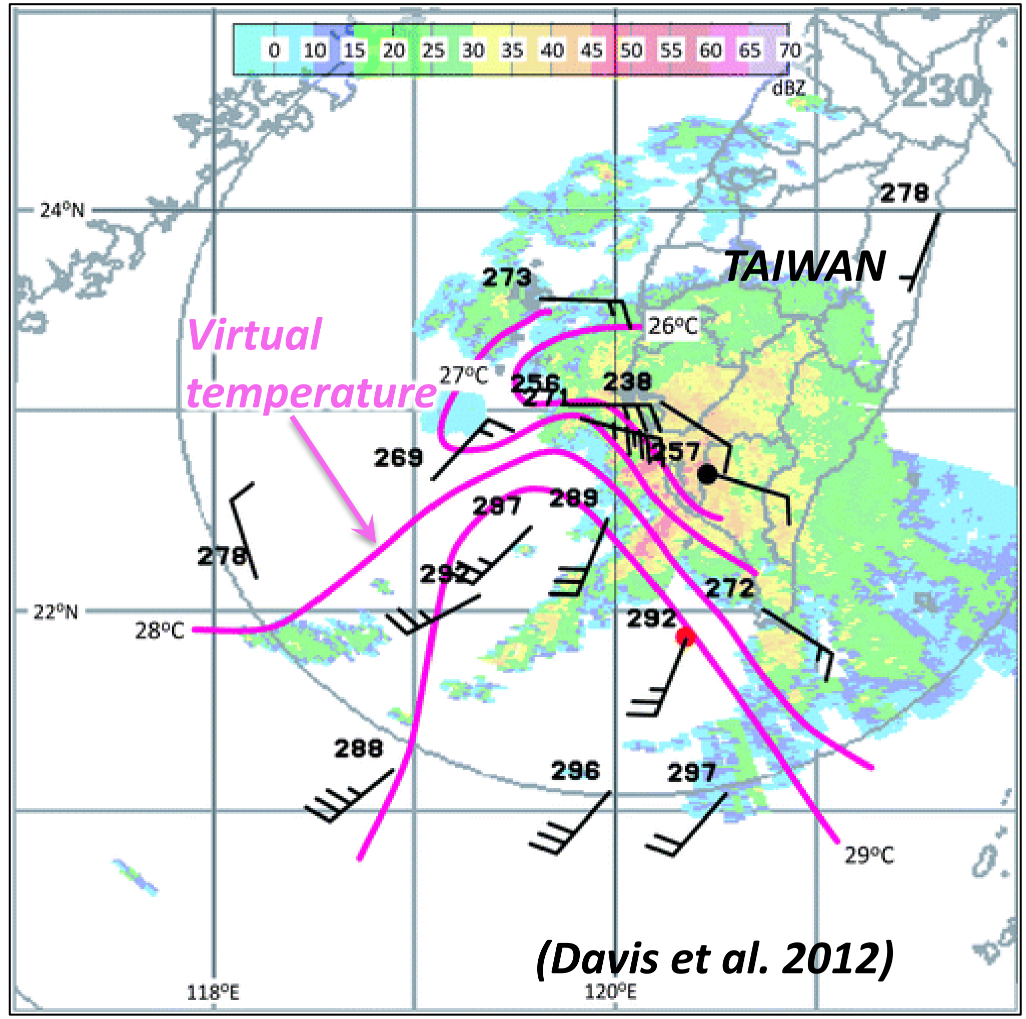
- *Field phase: US-Taiwan*
- *Post-field phase activities/ workshops: Korea, Japan, Viet Nam, PRC*

Johnson (2019; TAHOPE Planning Workshop)

Observations of shallow fronts (Davis et al. 2012)

- *Despite shallowness and weak T gradient, impact on convection is significant due to moist, unstable conditions*
- *T contrast reinforced by cool downdrafts over land*
- *Analogous to coastal fronts at higher latitudes*

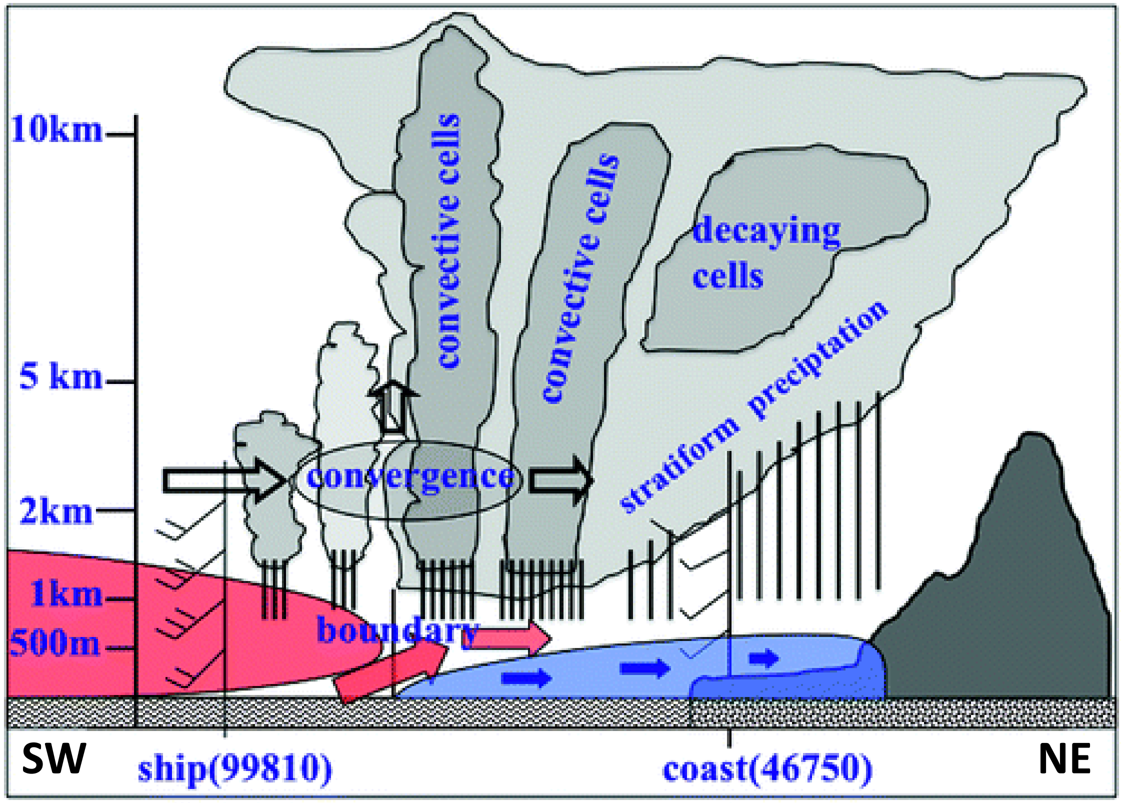
990 hPa wind, T_v at 06Z on 5 June 2008



Johnson (2019; TAHOPE Planning Workshop)

Extreme rainfall 14-16 June 2008 (Xu et al. 2012)

- *Convective cell triggering by low-level jet impinging on shallow cold pool*
- *Cold pool reinforced by continuous precipitation*
- *Cold pool trapped by terrain*
- *Virtual extension of island barrier to the southwest*

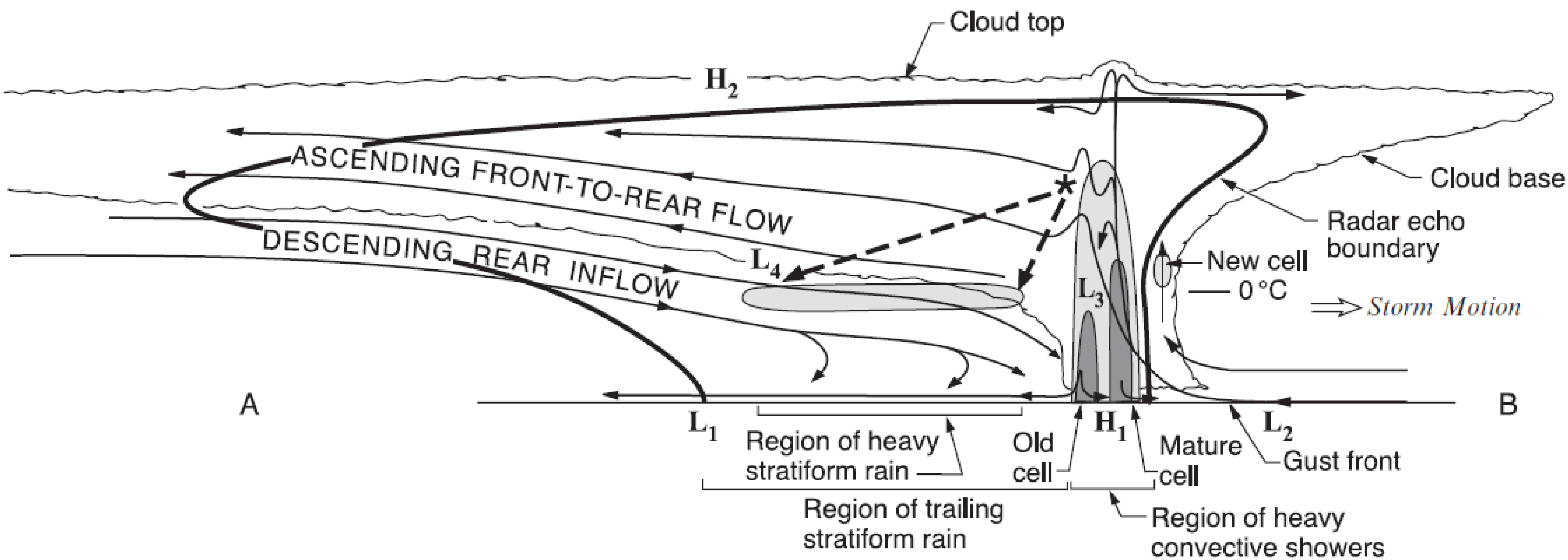


Red: unstable air Blue: cold pool Wind barbs: winds from soundings
boundary: between the cold pool and upstream flows

(Xu et al. 2012)

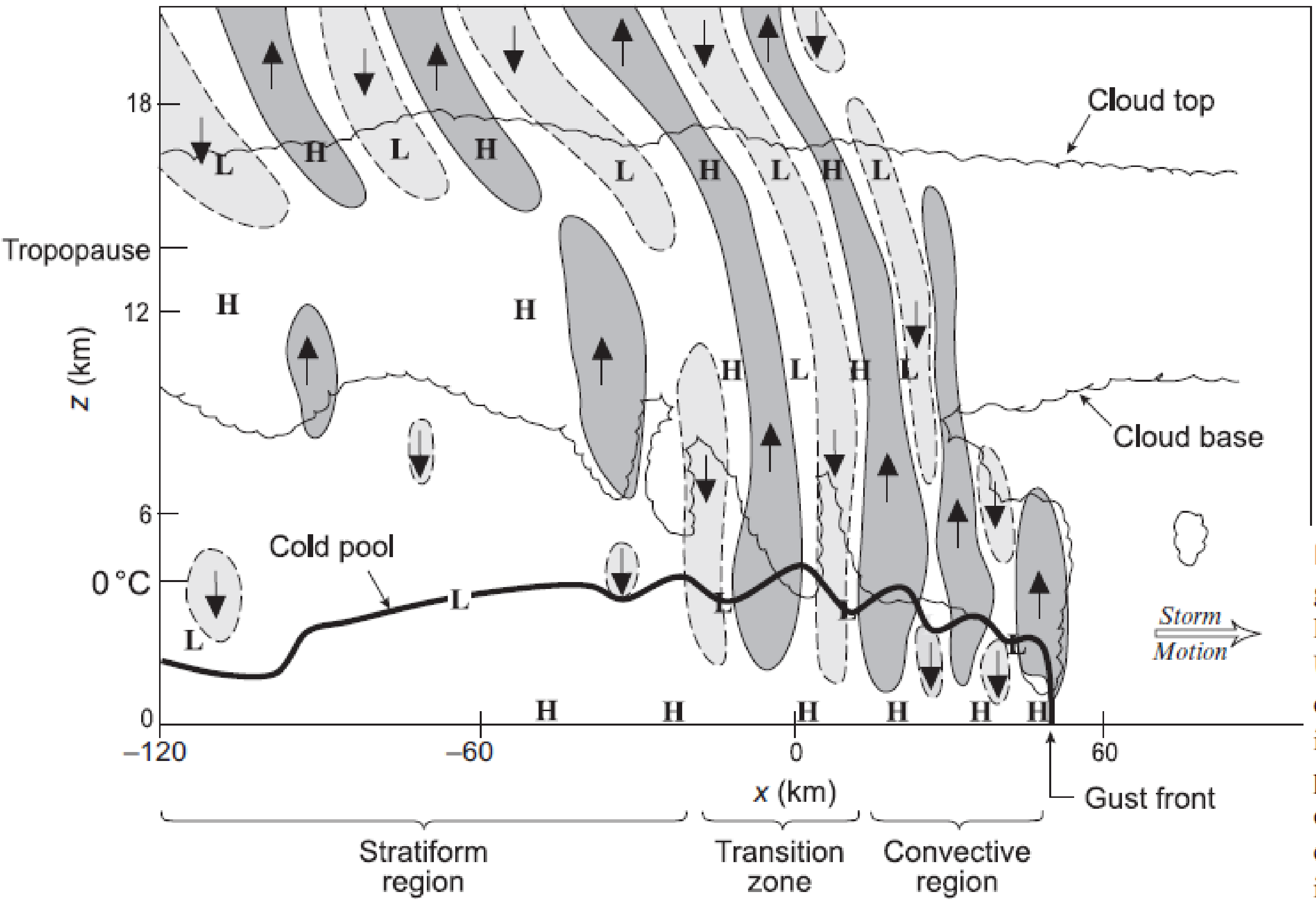
Johnson (2019; TAHOPE Planning Workshop)

MCS Conceptual Model



Houze et al. (1989) Houze (2014): Cloud Dynamics textbook

Multicell characteristics in a squall-line MCS as a manifestation of vertically-trapped gravity waves



See Yang and Houze (1995; MWR) for GW generation and trapping mechanisms.

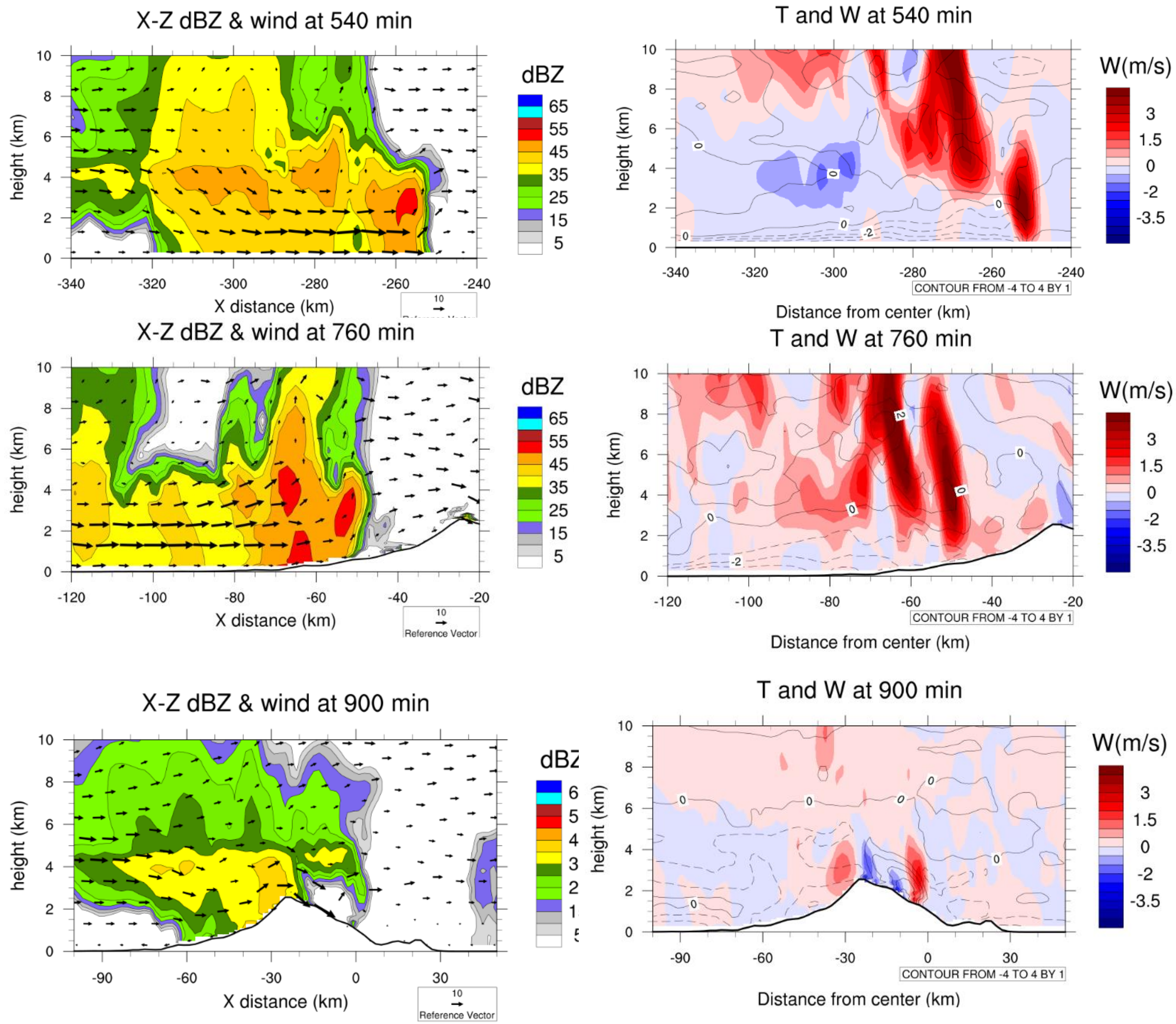
FIGURE 9.41 Schematic model of the gravity-wave structure of a simulated multicellular MCS at a mature stage of development. Updrafts $> 1 \text{ m s}^{-1}$ are heavily shaded. Downdrafts $< -1 \text{ m s}^{-1}$ are lightly shaded. Bold line is the cold pool outline defined by the -1 K potential temperature perturbation. Cloud outline is for the 0.5 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 Dynamics

Topics: 1) interplay between convective GW and mountain GW
2) How does GWs affect precipitation?
3) interaction between squall line and Island terrain

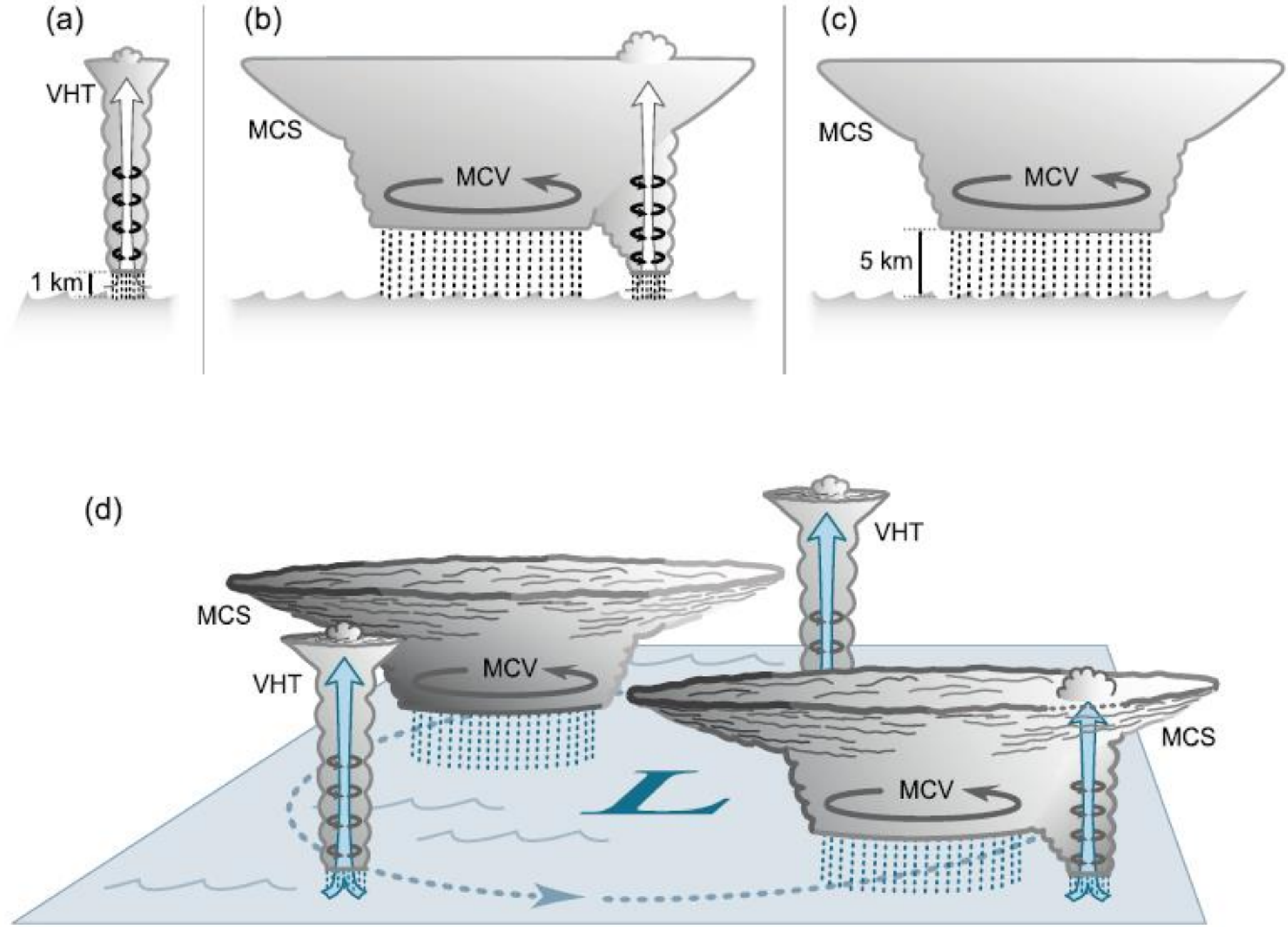
Include the Terrain Effect in the RKW theory

- mature-stage MCS before interacting with mountain
- The leading edge is Intensified by terrain
- Convection is suppressed on the lee side



Pan and Yang (2020; AOGS conference)

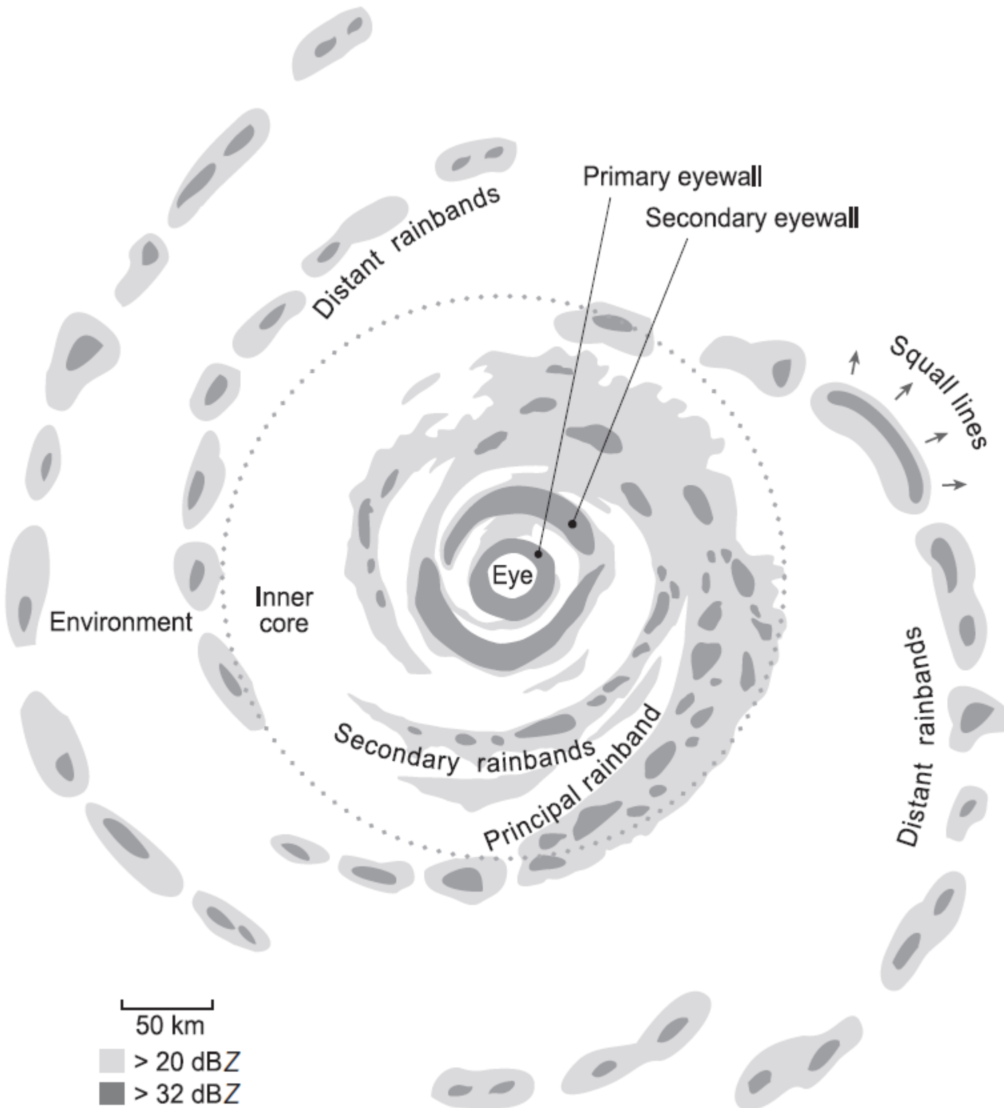
VHT, MCV, and Cyclogenesis



Houze et al. (2009)

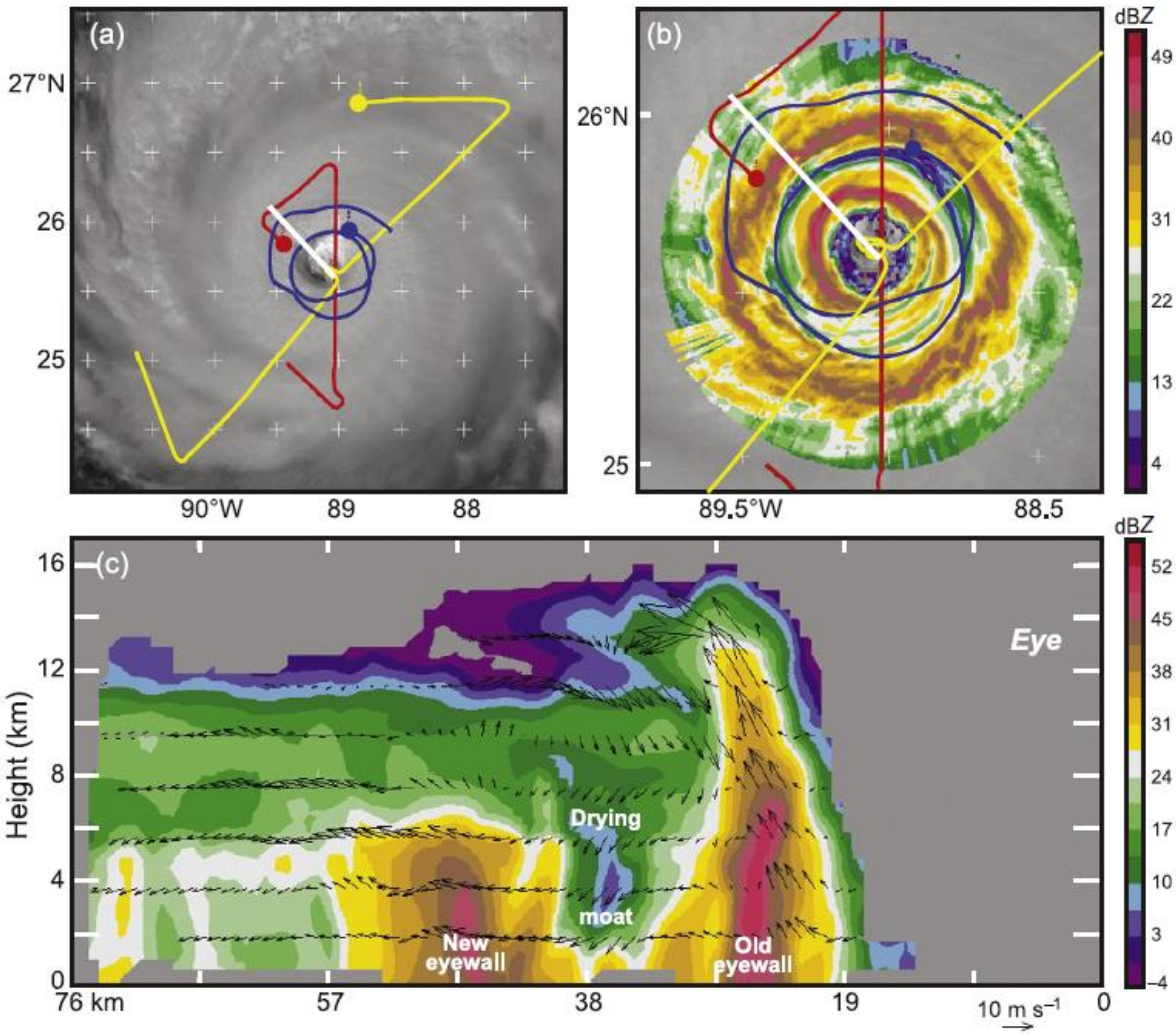
Houze (2014): Cloud Dynamics textbook

RADAR sees the eyewalls and rainbands in a Tropical Cyclone



Willoughby (1988) Houze (2010) Houze (2014): Cloud Dynamics textbook

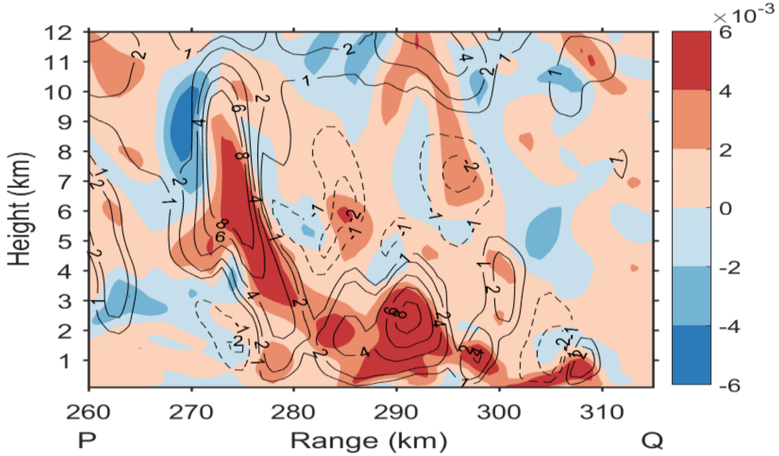
Aircraft data collected in Hurricane Rita (2005)



Houze et al. (2007) Houze (2014): Cloud Dynamics textbook

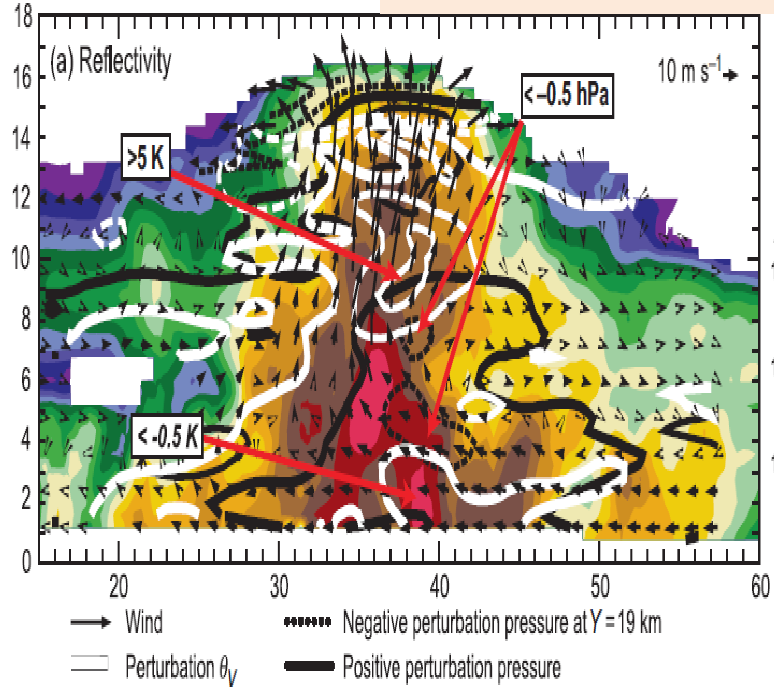
Vertical Cross Section of Vertical Hot Tower (VHT)

Inland VHT within Typhoon Fanapi (2010)



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

Oceanic VHT within Hurricane Ophelia (2005)



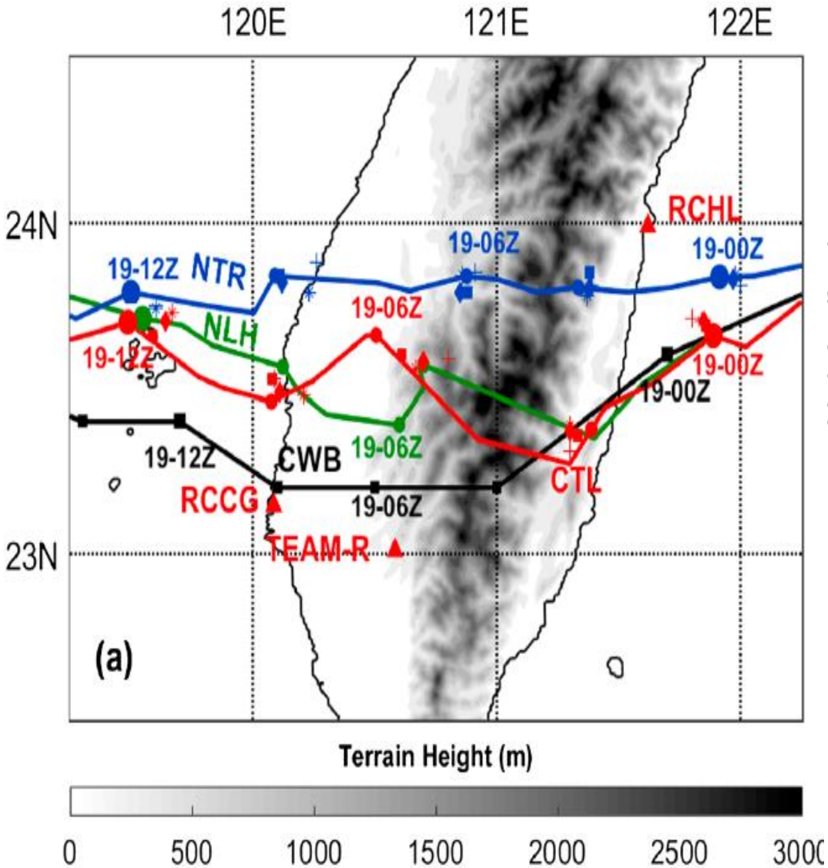
Houze et al. (2009)

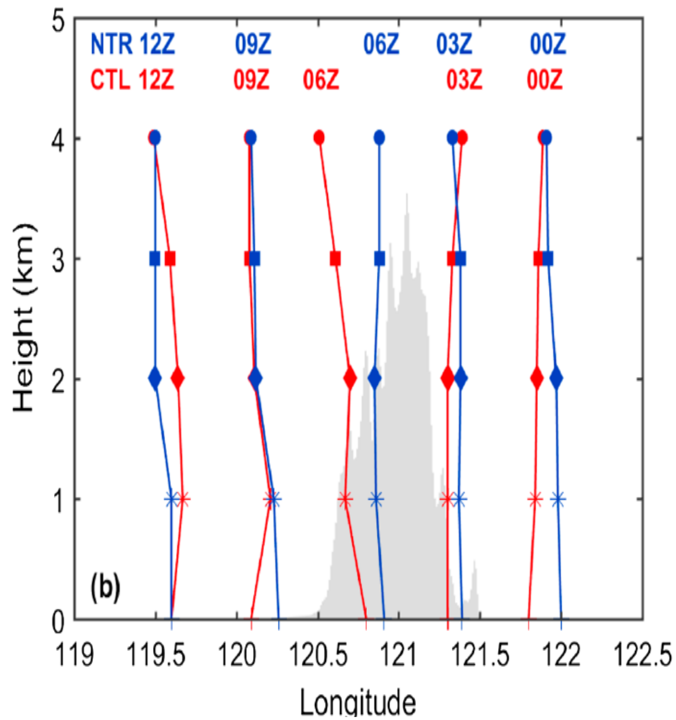
⟹ From this cross section, the VHT of Fanapi (2010) in land has weaker maximum updraft, narrower diameter, and shallower depth, compared with the VHT over open ocean.

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.

Typhoon Fanapi (2010)'s Eyewall Reformation

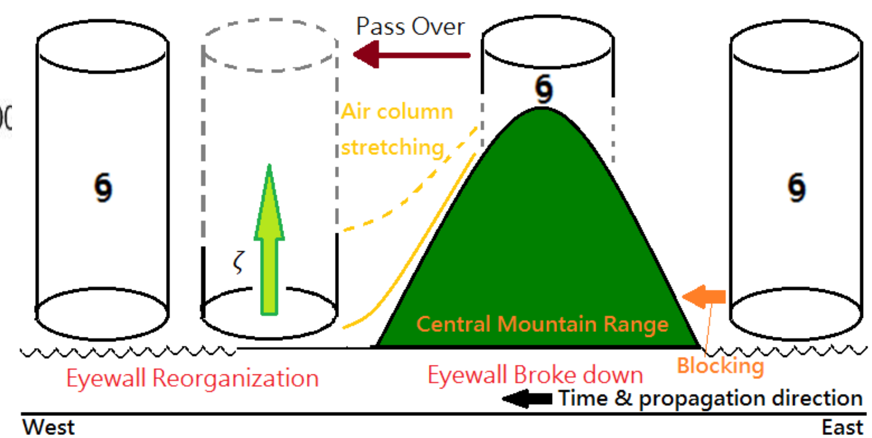




Circle: 4-km center
Square: 3-km center
Diamond: 2-km center
Star: 1-km center
Cross: SLP center

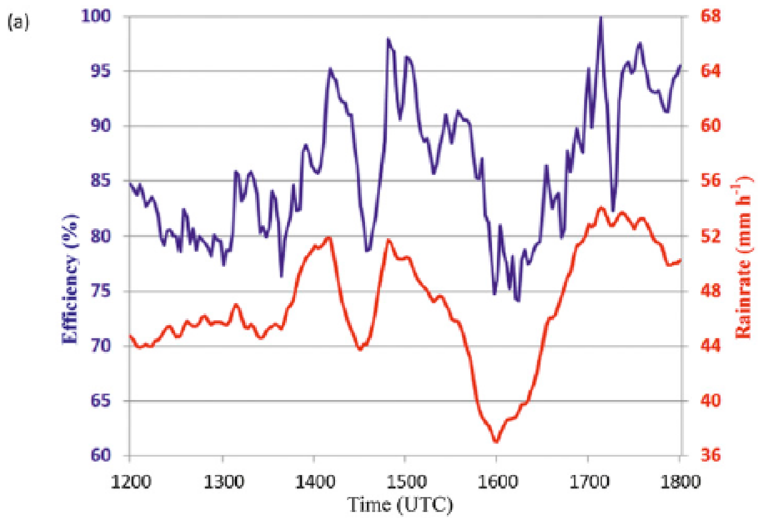
NLH: no latent heat
CTL: full-terrain

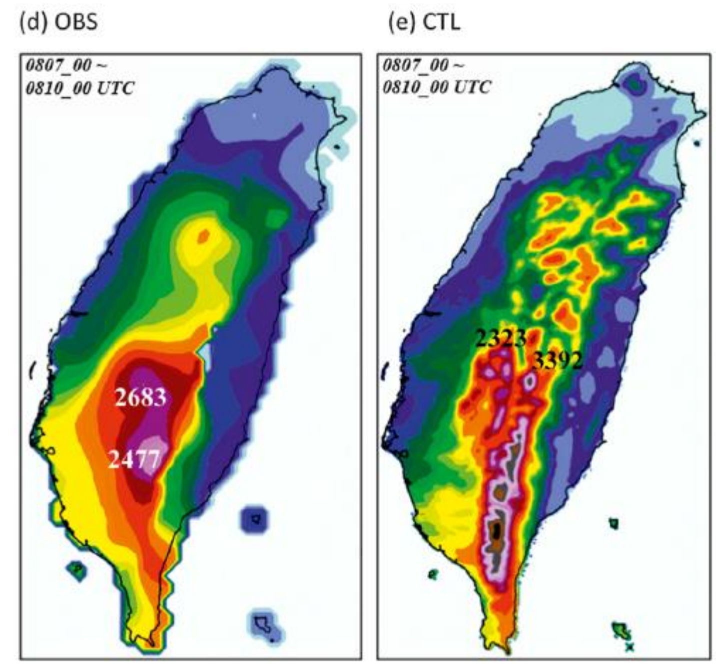
NTR: no terrain
CWB: Best-track

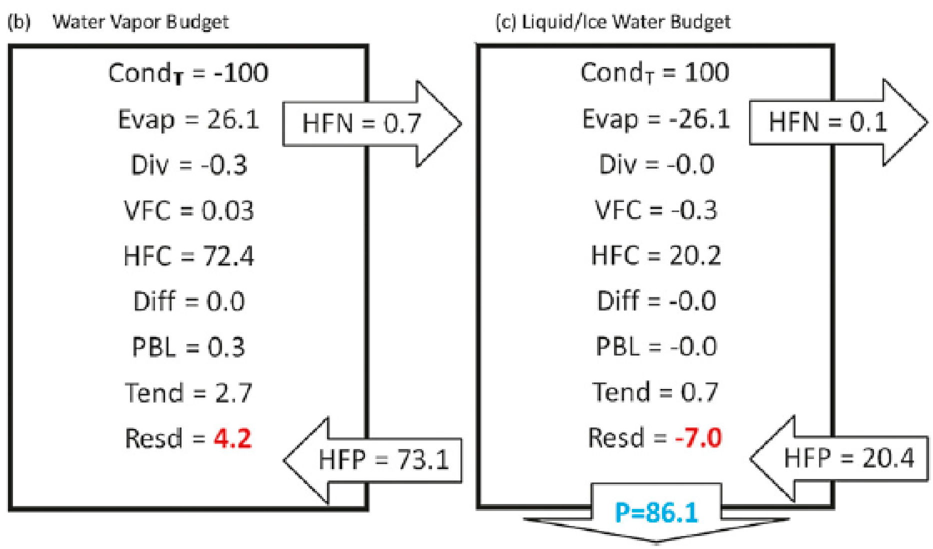


Liou et al. (2016) & Yang et al. (2018)

Nearly Perfect PE for Typhoon Morakot (2009)



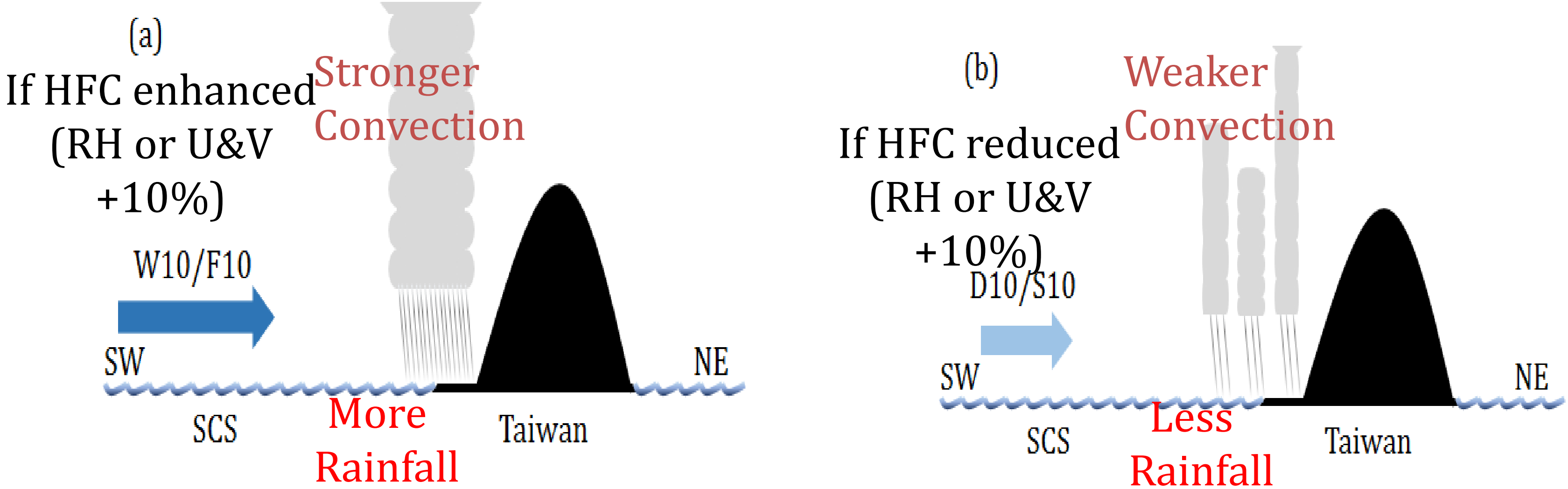




See Huang et al. (2014) for details of water budget and PE calculations.

Huang, H.-L., M.-J. Yang***,** and C.-H. Sui, 2014: Water budget and precipitation efficiency of Typhoon Morakot (2009). *J. Atmos. Sci.*, **71**, 112–129.

Topic: PEs for west-PAC typhoons in 2020?

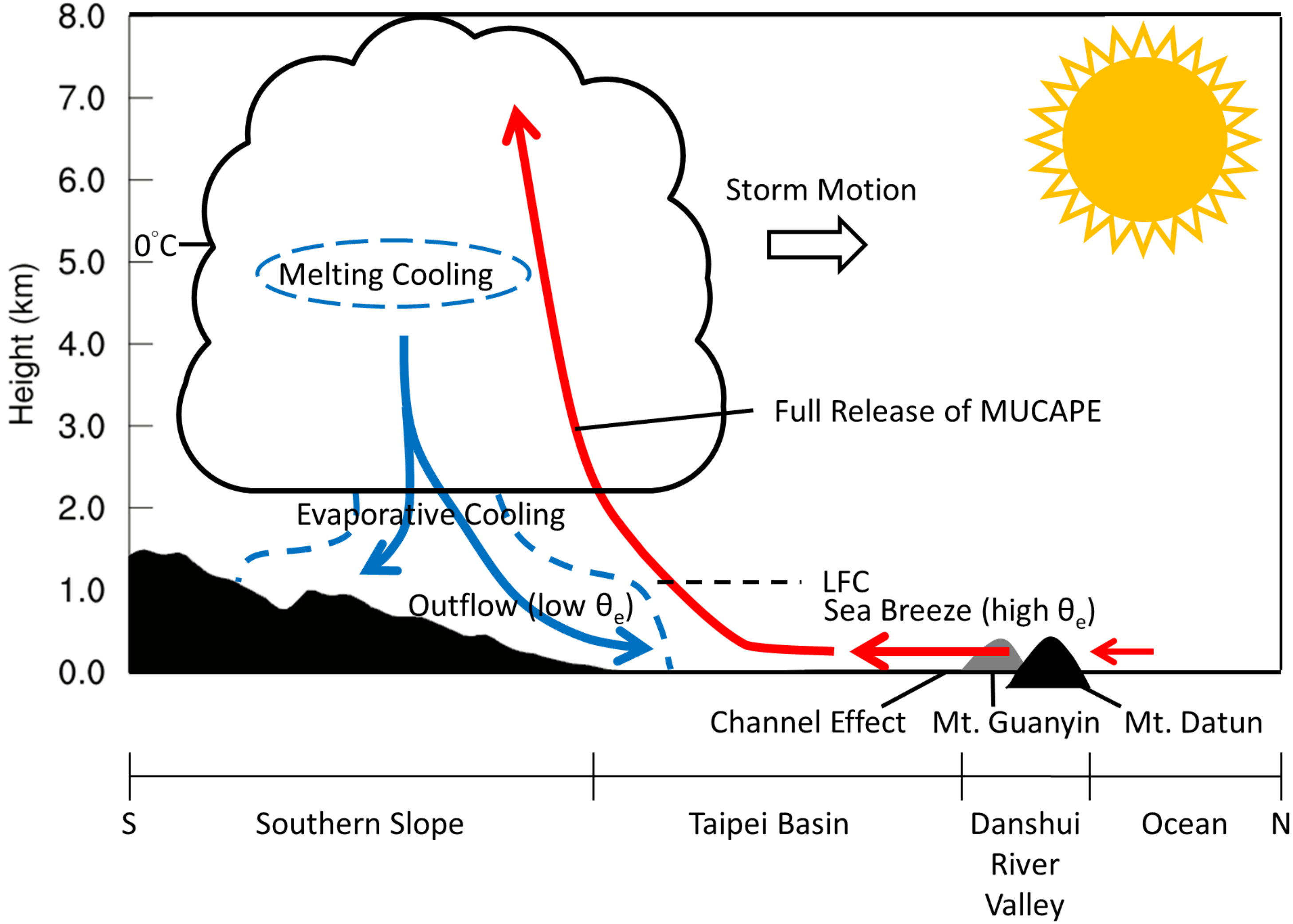


Relative change of Sensitivity Experiment wrt. CTL

	IWV	IMT	IVT	HFC	P
RH+10%	↑5%	↑15%	↑20%	↑15%	↑20%
U&V+10%	—	↑5%	↑5%	↑<1%	↑<5%
U&V-10%	—	↓5%	↓5%	↓5%	↓5%
RH-10%	↓5%	↓15%	↓20%	↓40%	↓40%

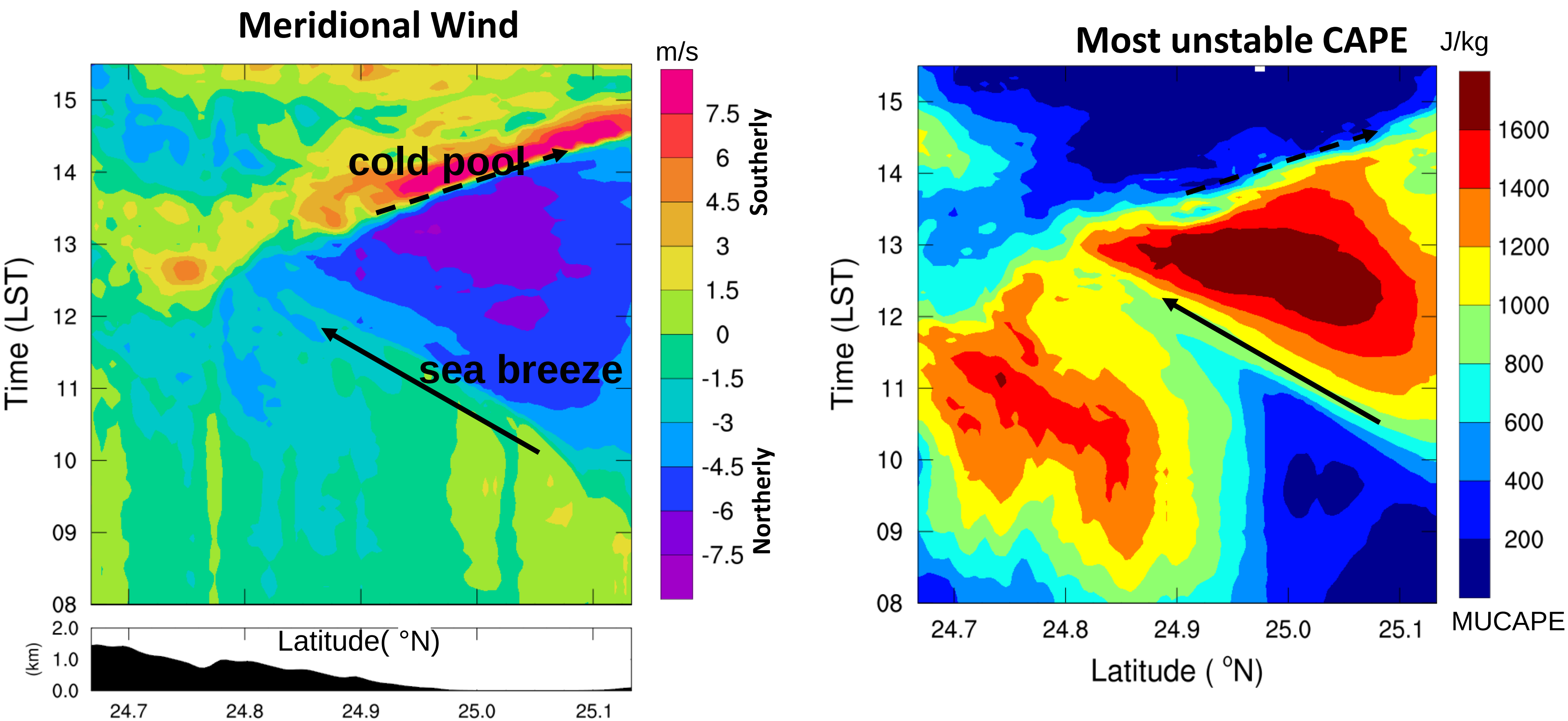
Topics:
Moisture Budget
Hydrometeor Budget
PEs for different MCSs

Reference: Wu, Y.-C., M.-J. Yang*, and P.-H. Lin, 2020: Evolution of water budget and precipitation efficiency of mesoscale convective systems over the South China Sea. *Terr., Atmos., and Oceanic Sci.*, in press. DOI: 10.3319/TAO.2019.07.17.01



Schematic diagram of the interactions between sea breeze, cold pool and coastal terrain for the development of afternoon thunderstorm over Taipei basin.

Reference: Miao, J.-E., and M.-J. Yang*, 2020: A modeling study of the severe afternoon thunderstorm event at Taipei on 14 June 2015: The roles of sea breeze, microphysics, and terrain. *J. Meteor. Soc. Japan*, **98.** https://doi.org/10.2151/jmsj.2020-008. .



Hovmöller diagrams along the N-S sea breeze from Danshui

=> sea-breeze propagation speed ~4.6 m/s, cold pool propagation speed ~ 6.5 m/s
=> The MUCAPE is highly related to the meridional wind associated with sea-breeze circulation!

Reference: Miao, J.-E., and M.-J. Yang*, 2020: A modeling study of the severe afternoon thunderstorm event at Taipei on 14 June 2015: The roles of sea breeze, microphysics, and terrain. *J. Meteor. Soc. Japan*, **98.** https://doi.org/10.2151/jmsj.2020-008. .

Taiwan-Area Heavy-rainfall Prediction Experiment (TAHPEX)

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Department of Earth Sciences, National Taiwan Normal University, Taipei, Taiwan

Co-PI: Jing-Shan Hong (CWB), Fang-Ching Chien (NTNU), and Ching-Yuang Huang (NCU)

Participants: *Ming-Jen Yang (NTU), Pay-Liam Lin (NCU), Rosimar Rios-Berrios (NCAR), Chian-Yi Liu (NCU), Hsi-Chyi Yeh (Aletheia Univ.), Hsiao-Chung Tsai (TKU), Guo-Chen Leu (CWB), Chin-Tzu Fong (CWB), Treng-Shi Huang (CWB), Ling-Feng Hsiao (CWB), Chien-Her Chen (CWB), Shu-Ya Chen (NCU), Guo-Yuan Lien (CWB), and Cheng-Chin Liu (CWB)*

Project Goal and Major Scientific Issues of TAHPEX

- ***Overall Project Goal:***

  To improve understanding of physical processes and predictability, and the QPF skills for extreme/heavy rainfall in and near Taiwan

- ***Phenomena/Systems near Taiwan:***
  - *Mei-yu and southwesterly Monsoon*
  - *Typhoon/tropical cyclone*

- ***Major Scientific Issues:***
  - *Convective-scale processes and cross-scale interactions*
  - *Topographic/diurnal effects (including PBL processes)*
  - *QPF/QPE and (mesoscale) predictability*
  - *Cloud microphysics*

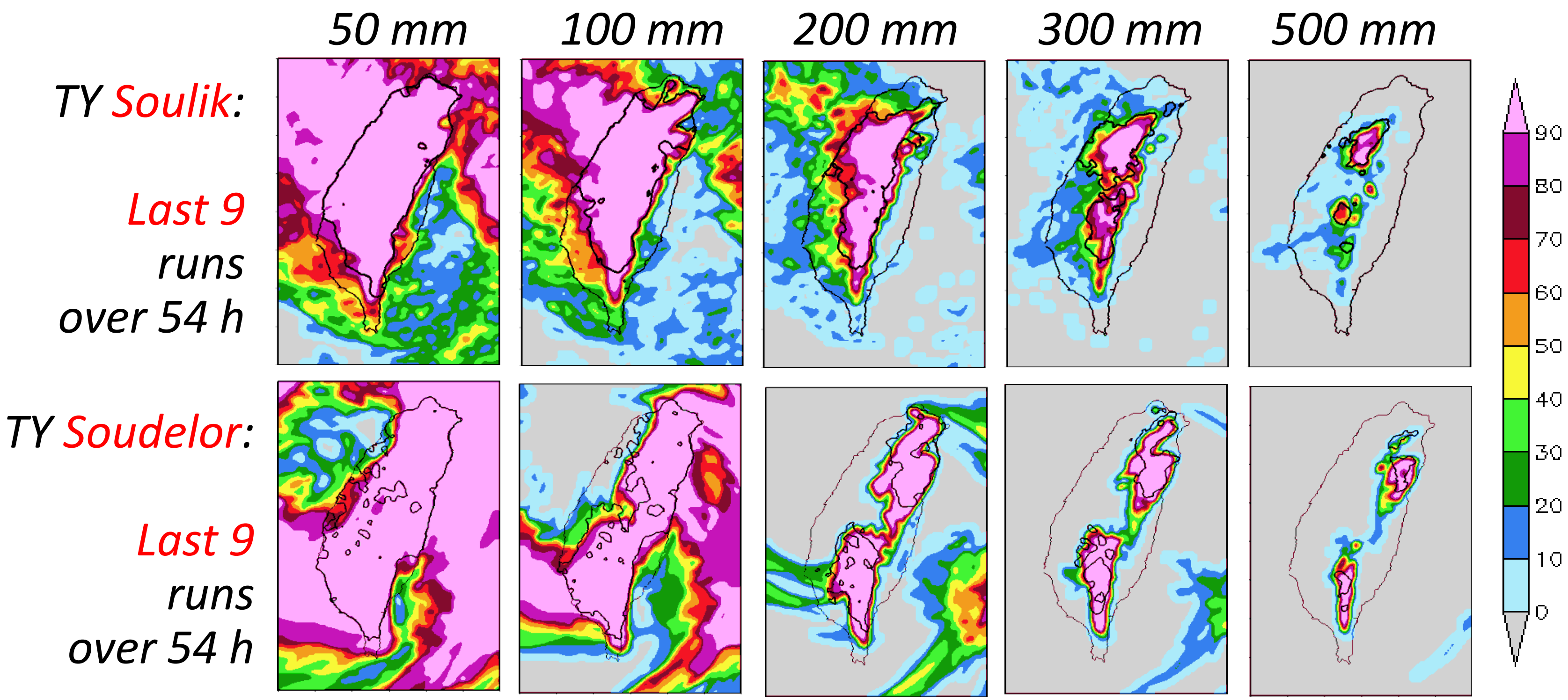
- ***Primary Research Tool: Cloud-Resolving Models (CRMs)***
  - *Two components: Science (basic) and applications (applied)*

    Science (basic) → *Individual PIs (~15)*

    applications (applied) → *Multi-model ensemble prediction system*

Focus and Progress of TAHPEX General Project before TAHOPE '20

- Probability information (24-h rain) by a single CRM (2.5-km CReSS, every 6 h):



- **Build a multi-CRM time-lagged ensemble prediction system**
- **Minor emphases: by individual PIs**
  - More thorough studies of past cases (e.g., those in 2008, 2012, 2017)
  - Understanding large-scale background and processes
  - Understanding convective- and storm-scale processes

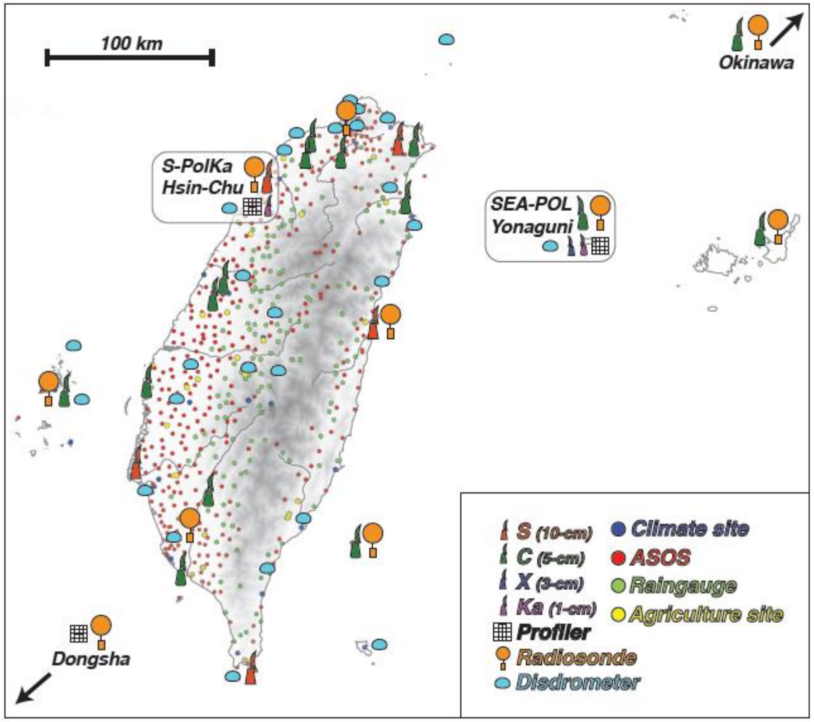
Expected Benefits of the TAHPEX ensemble prediction system

- ***Time-lagged ensemble by multiple CRMs is the best approach***
  - *Resources likely too big for any single agency/group at present time*
  - *Multiple CRMs provide a larger (better) spread to cover the true scenario, and each one may perform better under different conditions*
- ***For TAHOPE field experiment (PI: Prof. MJ Yang, need real-time):***
  - *To support the science team to determine IOPs and target regions*
  - *Probability and ensemble-based sensitivity analysis (ESA) available*
- ***For future study in the TAHPEX project (beyond summer of 2020):***
  - *Also good for ensemble-based simulation of observed events*
  - *Study scale-interaction processes and cloud microphysics in a more complete way, important for future model improvement*
  - *Study the predictability issues from an ensemble approach with a large enough size*
  - *Coordinated studies of processes covering a fuller spectrum (or across a wider range of scales) among different participating PIs*

Benefits from intensive observations of TAHOPE campaign

- **Detailed structure/evolution of heavy rainfall systems:**
  - *Mei-yu front, MCS, TC rainband, convective storms, isolated/local convection*
  - *Including TC observations*
  - *Focused more in northern Taiwan, in contrast to SoWMEX*

TAHOPE/PRECIP2020



- **For model comparison:**
  - *Structure/evolution of heavy-rainfall systems (scale interaction)*
  - *Cloud microphysics (for future model improvement)*
- **For data assimilation:**
  - *Convective scale data assimilation for improved initial fields*
  - *Evaluate importance and best strategy/location for key observations (through OSSE studies)*

Cloud-resolving Time-lagged Ensemble Prediction System

- ***A total of 13 members, from universities, CWB, and research sector***
- ***Members and status during dry run (1-14 Jun 2019):***

Mem.	Model	PI in charge	Δx	Status	Freq.	Range	Plot	FTP
M01	NTNU CReSS	CC Wang	2.5 km	O	2/d	120 h	Y	Y
M02	NTNU WRF	FC Chien	3 km	Y	2/d	120 h	Y	Y
M03	NTU WRF	MJ Yang	3 km	Y	1/d (00)	120 h	Y	Y
M04	CWB WRF-D	JS Hong	3 km	O	4/d	120 h	Y	--
M05	CWB TWRF	JS Hong	3 km	O	4/d	120 h	Y	--
M06	NCU WRF	PL Lin	3 km	Y	2/d	120 h	Y	Y
M07	NCU MPAS	CY Huang	~3 km	N	--	--	N	N
M08	CReSS-NHOES	CC Wang	2.5 km	N	--	--	N	N
M09	NCAR MPAS	R Rios-Berrios	~3 km	Y	1/d (12)	72 h	Y	Y
M10	CWB FV3GFS	LF Hsiao	~4.8 km	O*	2/d	120 h	Y	--
M11	NTNU CReSS	CC Wang	1 km	Y	1/d (12)	96 h	Y	Y
M12	CWB WRF	JS Hong	1 km	O	1/d (12)	24 h	Y	--
M13	CWB SUM	CH Chen	1 km	O	1/d (12)	120 h	Y	--

PS:

1. Run status keys: O: operational, O*: slightly delayed, Y/N: yes/no.
2. Parenthesis: initial time in UTC.

Brief model specification of TAHPEX members:

Mem.	Model	Δx	Levels	Nests	Coupled		IC/BC	DA	CMP (M)	CPS	PBL
M01	CReSS v3.4.2	2.5 km	40	N	N	***R***	NCEP-GFS/FV3	N	Cold rain (1.5)	N	D80
M02	WRF v3.9.1	3 km	45	Y (3)	N	***R***	NCEP-GFS/FV3	N	Goddard	Tiedtke	YSU
M03	WRF v3.9.0	3 km	41	Y (3)	N	***R***	NCEP-GFS/FV3	N	WDM6 (2)	K-F	YSU
M04	CWB WRF-D	3 km	52	Y (2)	N	***R***	NCEP-GFS/FV3	Y	Goddard	K-F	YSU
M05	CWB TWRF	3 km	52	Y (2)	N	***R***	NCEP-GFS/FV3	Y	Goddard	K-F	YSU
M06	WRF v.3.9.1	3 km	45?	Y (3)	N	***R***	NCEP-GFS/FV3	N	Goddard	K-F	MYNN
M07	NCU MPAS	3 km	55	VR	N	***G***	NCEP-GFS/FV3	N	WSM6 (1)	Tiedtke	YSU
M08	CReSS-NHOES	2.5 km	40	N	Y	***R***	NCEP-GFS/FV3	N	Cold rain (1.5)	N	D80
M09	MPAS v6.3	3 km	55	VR	N	***G***	NCEP-GFS/FV3	N	WSM6 (1)	Tiedtke	YSU
M10	CWB FV3GFS	~4.8 km	63	Y (2)	N	***G***	NCEP-GFS/FV3	N?	GFDL	SAS	TKE-EDMF
M11	NTNU CReSS	1 km	45	N	N	***R***	NCEP-GFS/FV3	N	Cold rain (1.5)	N	D80
M12	CWB WRF	1 km	52	Y (3)	N	***R***	NCEP-GFS/FV3	Y	Goddard	K-F	YSU
M13	CWB SUM	1 km	42	Y (2?)	N	***G***	NCEP-GFS/FV3	Y	WSM3 (1)	N	MRF

Regional/Global

PS:

1. IC/BC: initial/boundary condition, DA: data assimilation, CMP (M): cloud microphysics (moments), CPS: cumulus parameterization scheme, PBL: planetary boundary layer, VR: variable resolution, SUM: Spectral Unified Model (CWB GFS+MSM, MSM: Mesoscale Spectral Model).
2. For CMP: WDM6: WRF double-moment 6 class, WSM6: WRF single-moment 6 class, etc.
3. For CPS: K-F: Kain-Fritsch; for PBL: D80: Deardorff (1980), MRF: medium-range forecast.

Current status for HAHOPE 2020 (updated: 26 Feb 2020):

Mem.	Model	PI in charge	Δx	Status	Freq.	Range	Plot	ESA
M01	NTNU CReSS	CC Wang	2.5 km	O	4/d	120 h	Y	Y
M02	NTNU WRF	FC Chien	3 km	Y	4/d	96-120 h	Y	Y
M03	NTU WRF	MJ Yang	3 km	Y	≥2/d	96-120 h	Y	Y
M04	CWB WRF-D	JS Hong	3 km	O	4/d	120 h	Y	Y
M05	CWB TWRF	JS Hong	3 km	O	4/d	120 h	Y	Y
M06	NCU WRF	PL Lin	3 km	Y	4/d	96-120 h	Y	Y
M07	NCU MPAS	CY Huang	3 km	Y	1/d	96-120 h	Y	Y
M08	CReSS-NHOES	CC Wang	2.5 km	Y	2/d	96-120 h	Y	Y
M09	NCAR MPAS	R Rios-Berrios	3 km	Y	1/d (12)	72 h?	Y	Y
M10	CWB FV3GFS	LF Hsiao	~4.8 km	O*	2/d	120 h	Y	Y
M11	NTNU CReSS	CC Wang	1 km	Y	2/d	72-96 h	Y	N
M12	CWB WRF	JS Hong	1 km	O	1/d (12)	24 h	Y	N
M13	CWB SUM	CH Chen	1 km	O	1/d (12)	102 h	Y	N

Ensemble-based sensitivity analysis

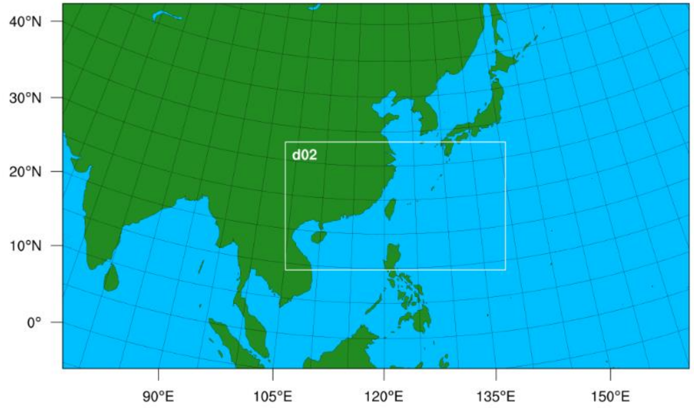
Fine domain too small

PS:

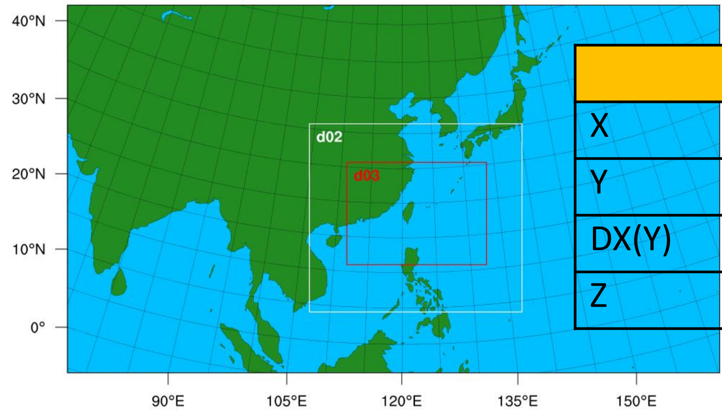
1. Run status keys: O: operational, O*: slightly delayed, Y/N: yes/no, Y: yes as planned.
2. Parenthesis: initial time in UTC.
3. ESA: ensemble-based sensitivity analysis.

Design of domain for TAHPEX WRF members from universities:

CWB domain

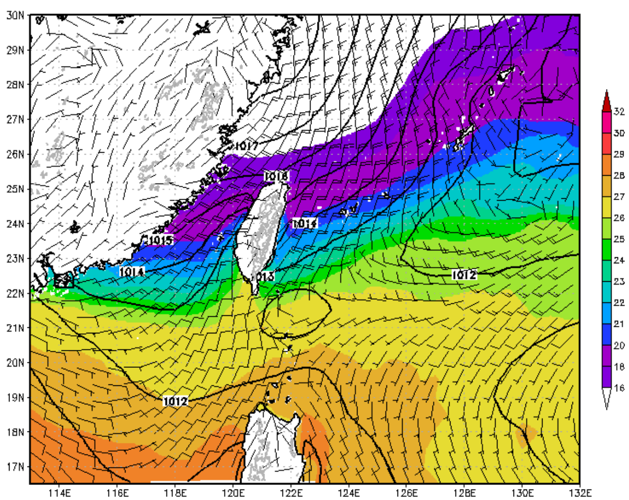


TAHPEX domain

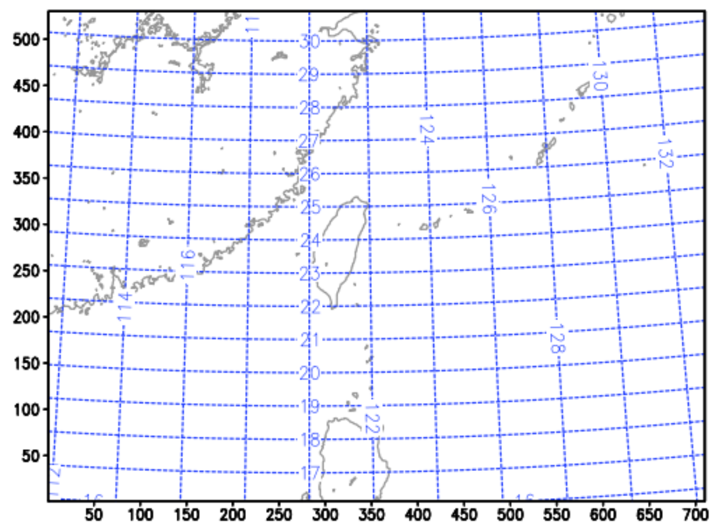


	D01	D02	D03
X	222	217	711
Y	128	196	531
DX(Y)	45 km	15km	3km
Z	45	45	45

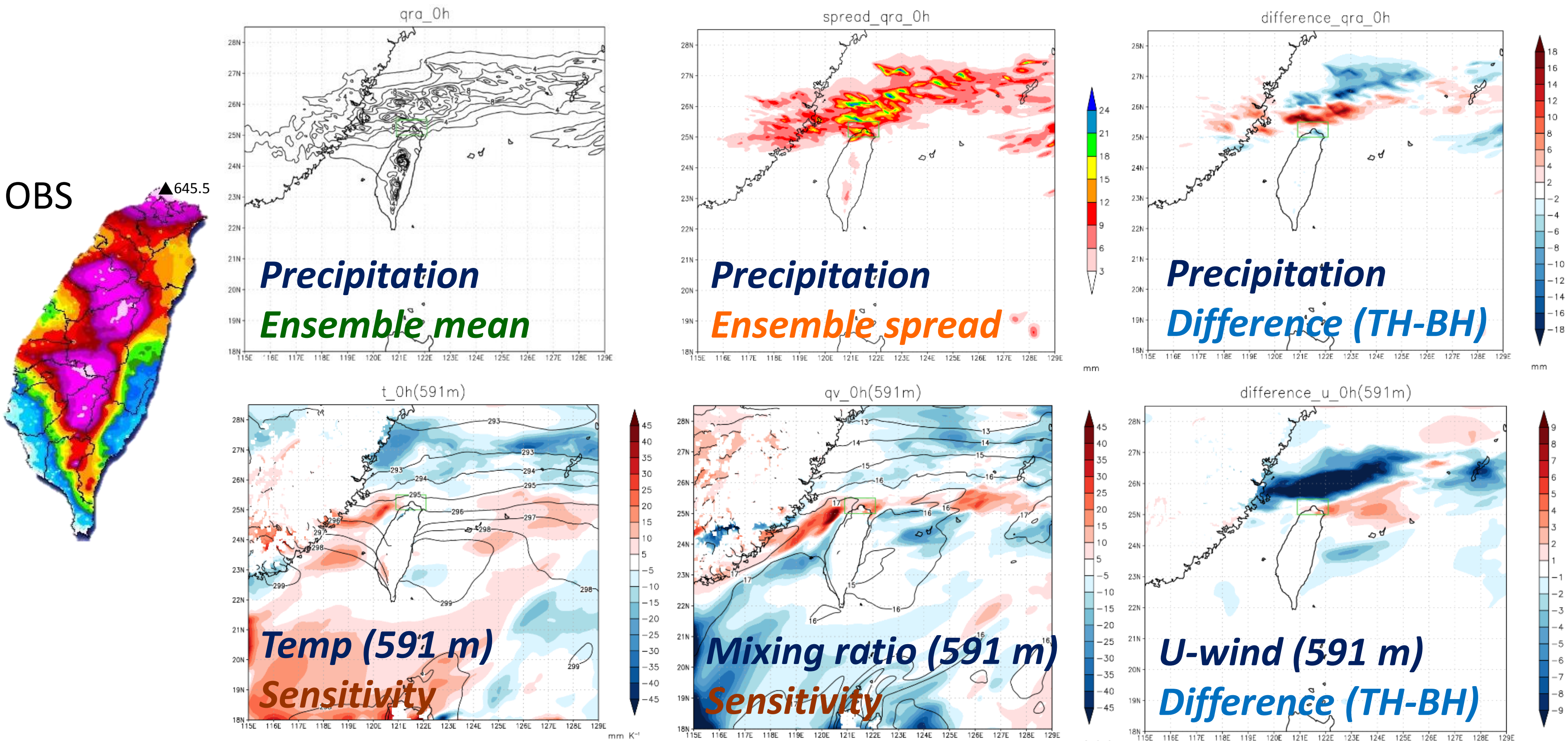
CReSS domain



TAHPEX domain-03



- **_Three casts selected for testing of products:_**
  - _Typhoon: TY Nesat 2017 (1200 UTC 25 Jul to 1200 UTC 30 Jul 2017)_
  - _Meiyu: 2-3 Jun 2017 (0000 UTC 31 May to 0000 UTC 3 Jun 2017)_
  - _Dry-run case (0000 UTC 9 Jun to 0000 UTC 15 Jun 2019)_
- **_An Example of ESA products:_** _2-3 Jun 2017 case_



Expected Achievements

- Complete **the first field experiment** on typhoons affecting Taiwan with integrated new radar network and airborne radar for **rainfall and structure changes**.
- Complete **the first field experiments** with unmanned and manned aircraft measurements for **both Mei-yu fronts and typhoons.**
- Verify hypotheses of various **rainfall mechanisms/enhancements** in different systems and improvement on state-of-the-art modeling skill of severe rainfall.
- Improve operational **QPE and QPF** and forecast skill of **violent winds** in the Mei-yu systems and typhoons for decision making.
- Provide cross validations among a variety of observations and their error characteristics for **data assimilation** purpose.
- Transfer the research outcome into government operational agencies like **Central Weather Bureau, and Water Resource Agency** to benefit the society.
- Publish scientific journal articles and books
- Train **future talents (students & postdocs)** in universities and government agencies
- Promote **the visibility of Taiwan** in international scientific communities.


TAHOPE
Thanks for your attention