The Spatiotemporal Characteristics of Near-Surface Water Vapor in a Coastal Region Revealed from Radar-Derived Refractivity

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Outline

1. Introduction
2. Data and methodology
3. The spatiotemporal characteristics of the near-surface refractivity fields
4. Case studies of diurnal evolution refractivity
5. Discussion of the diurnal variation of refractivity
6. Conclusions

1. Introduction

- Solar heating/long wave radiation cooling → pressure gradient → ***land/sea breeze***
- ***Land/sea breeze*** can interact with:

  1. prevailing large-scale flow

  2. topography or rivers induced flow

  3. storm cold pools and outflow

  4. heterogeneous land use

  5. urban heat island effects

- The intertwined factors result in complex ***moisture distributions***.
- The lack of spatial and temporal surface observations limits the ability to represent the ***moisture variability***.

1. Introduction

- The ***moisture flux convergence by sea breeze*** is crucial to the development and growth afternoon thunderstorm under ***weak synoptic-scale forcing***.
- Moisture convergence usually occurs at ***foothills*** around noon.
- Rainfall frequently peak in ***midafternoon*** along the ***lower slopes*** of mountains.
- ***Warmer*** ($\Delta T = 0.5\sim1.5$℃) and ***more moist*** ($\Delta T_d = 0.5\sim2$℃) conditions are observed before convections occurred.
- Investigating the complex ***interaction between low-level moisture and local circulations*** are important to improve forecasts on diurnal precipitation.

1. Introduction

- ***High-spatiotemporal-resolution*** observations are necessary to sample highly variable moisture anomalies.
- Current low-level moisture observations are in the forms of:

  1. Point observation (*surface stations, aircraft*)

  2. Profile observation (*radiosonde, radiometers, space-based GPS receivers*)

  3. Areal observations (*satellites*), ***limited capability with cloud and precipitation***
- ***Refractivity*** fields estimated by ground-based weather ***radars*** can provide high-spatiotemporal-resolution low-level moisture distribution.

1. Introduction

- ***NCAR S-Pol*** is used during ***TiMREX/SoWMEX*** in southwestern Taiwan in 2008.
- The refractivity retrieval methodology is based on ***Fabry (2004)*** and ***Fabry and Pettet (2002)***
- The temporal resolution of retrieved refractivity is ***7.5 min***.
- ***The scientific questions:***

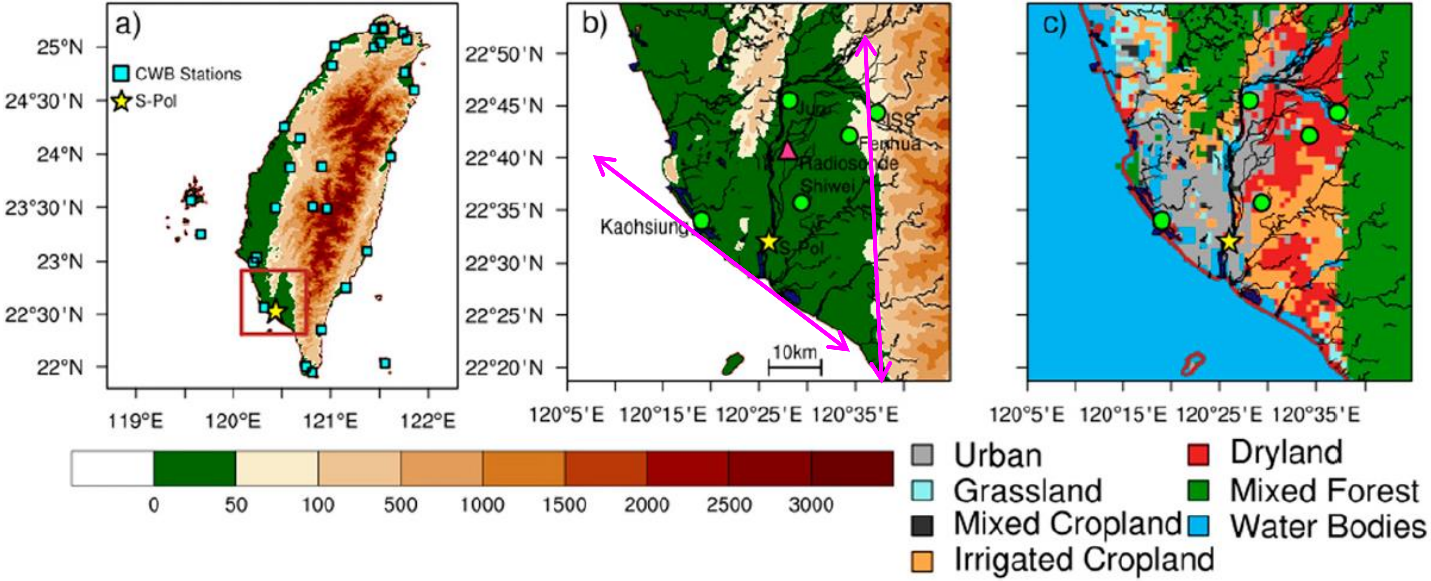
  1. What are the characteristics of the ***refractivity (moisture) fields*** in a moisture rich environment across various temporal scales?

  2. How do these moisture fields ***evolve*** with the atmospheric processes, terrain, and heterogeneous land use?

2. Data and methodology

- ***Domain***: southwestern Taiwan
- ***Coastline***: NW-SE oriented
- ***Mountain***: N-S oriented
- ***Land-use:***

  urban, rural dryland, and irrigated cropland



2. Data and methodology

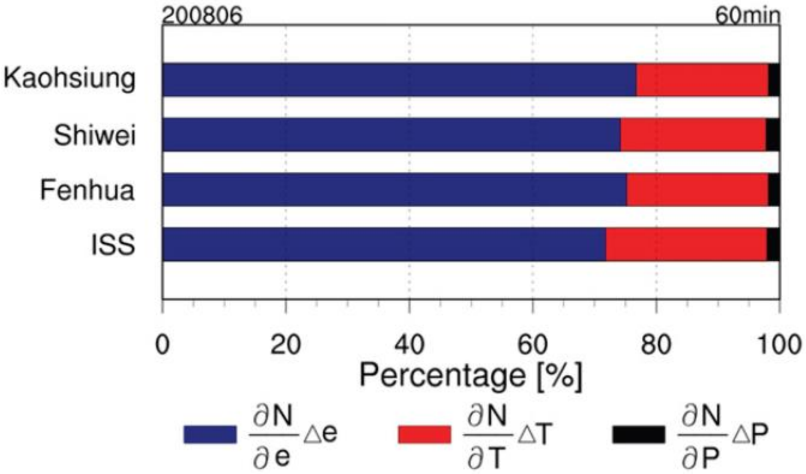
a. The relation ship between refractivity and moisture

- ***Refractivity*** N**:** (Bean and Dutton, 1966)

$$N = 77.6\frac{P}{T} + 373000\frac{e}{T^2}$$

density term | **wet term**

in which $\begin{cases} pressure\ P\ in\ [hPa] \\ temperature\ T\ in\ [K] \\ vapor\ pressure\ e\ in\ [hPa] \end{cases}$



- The evolving ***moisture e*** dominates the temporal change of N.
- The effect of ***temperature T*** is slightly higher at inland stations due to larger diurnal temperature change.

2. Data and methodology

b. Data quality of refractivity

- The retrieved refractivity is compared with that calculated from the surface observations based on $\mathbf{N} = 77.6\frac{\mathrm{P}}{\mathrm{T}} + 373000\frac{\mathrm{e}}{\mathrm{T}^2}$.
- The ***correlation coefficients (CC)*** over the month at 4 stations:

Station	Kaohsiung	Shiwei	Fenhua	ISS
CC	0.82	0.94	0.90	0.89

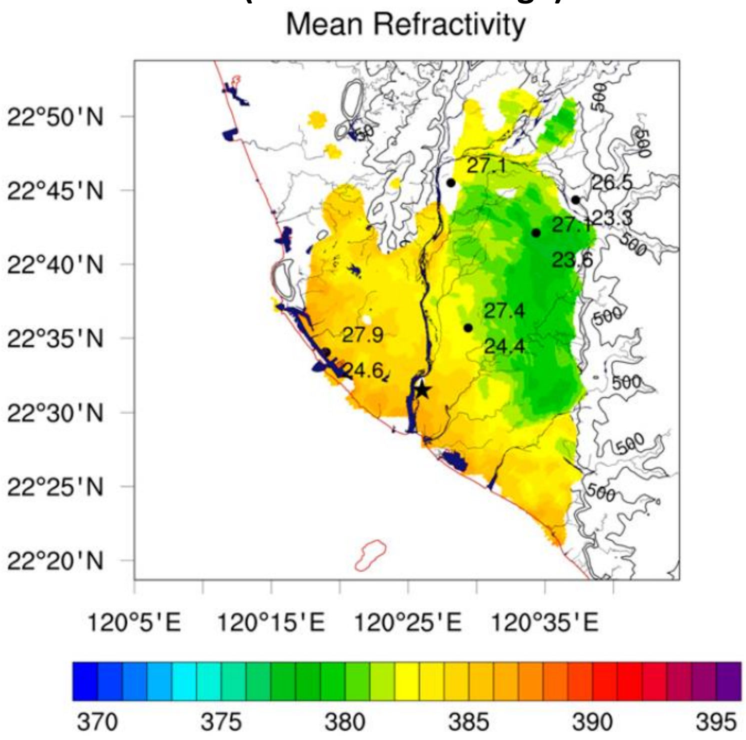
- ***Mean absolute difference*** of N : ***4.1 N-unit,*** i.e. 0.8 g/kg in q *(Hsu, 2019)*
- The bias may come from ***height difference*** between the surface measurement (***2m***) and the radar retrieval (***~20m***).

3. The spatiotemporal characteristics of the near-surface refractivity fields

a. The average spatial distribution of refractivity

- The refractivity (moisture) gradient is perpendicular to the ***coastline***.
- The gradient is $\sim 10\ N\ unit/30km$.
- High $\boldsymbol{N}$ extends further inland in the northern ***urban*** area compared to southern ***rural*** area.
- Low $\boldsymbol{N}$ area is ***bounded*** by hills and rivers and parallel to the N-S oriented mountain.

(one month average)



3. The spatiotemporal characteristics of the near-surface refractivity fields

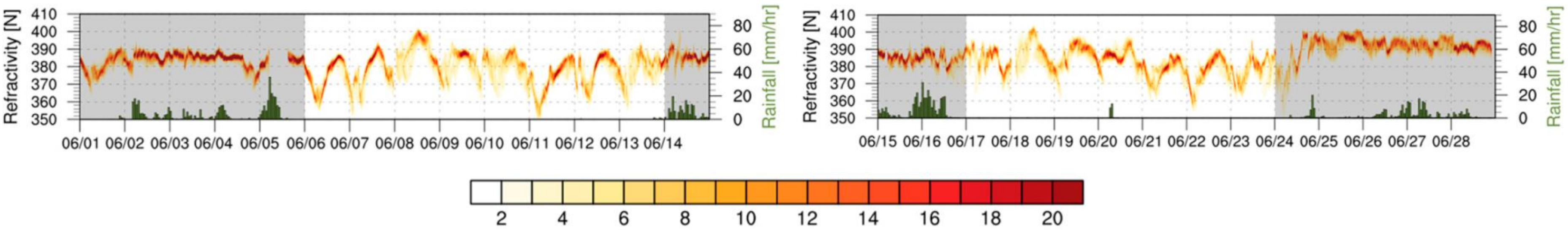
b. The temporal variation of refractivity

- Three intensive observation periods (***IOP***):

June 1st – 5th	June 14th – 16th	June 24th – 28th
Mei-yu front	Mesoscale convective system	Typhoon FengSeng rainband

- Two patterns based on rainfall duration:

Rainfall Duration	Forcing	N value	N spread
> 6hr (IOP)	Synoptic system	Uniform and high	Spatial homogeneous
< 6hr (non-IOP)	Local circulation	Periodic diurnal cycle	Spatial heterogeneous



3. The spatiotemporal characteristics of the near-surface refractivity fields

c. Diurnal characteristics of refractivity of IOP and non-IOP events

- ***IOP***:

  1. No diurnal signal of ***N***, since large-scale forcing dominates the low-level moisture.

  2. Small standard deviation all the time indicates spatial homogeneity of moisture.

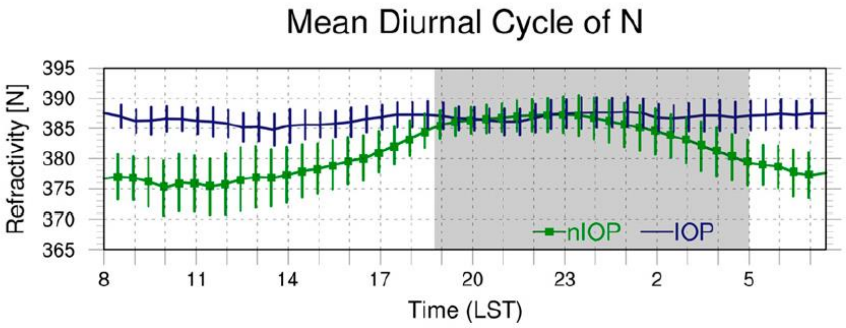
- ***nIOP***:

  1. Maximum at 20~23 LST, minimum at 09~12 LST (diurnal change ~10 N-unit)

  2. Moisture is more homogeneous in evening.

  3. The diurnal pattern is in contrast to continental environment .

  (peaks at dawn and lowers in evening)



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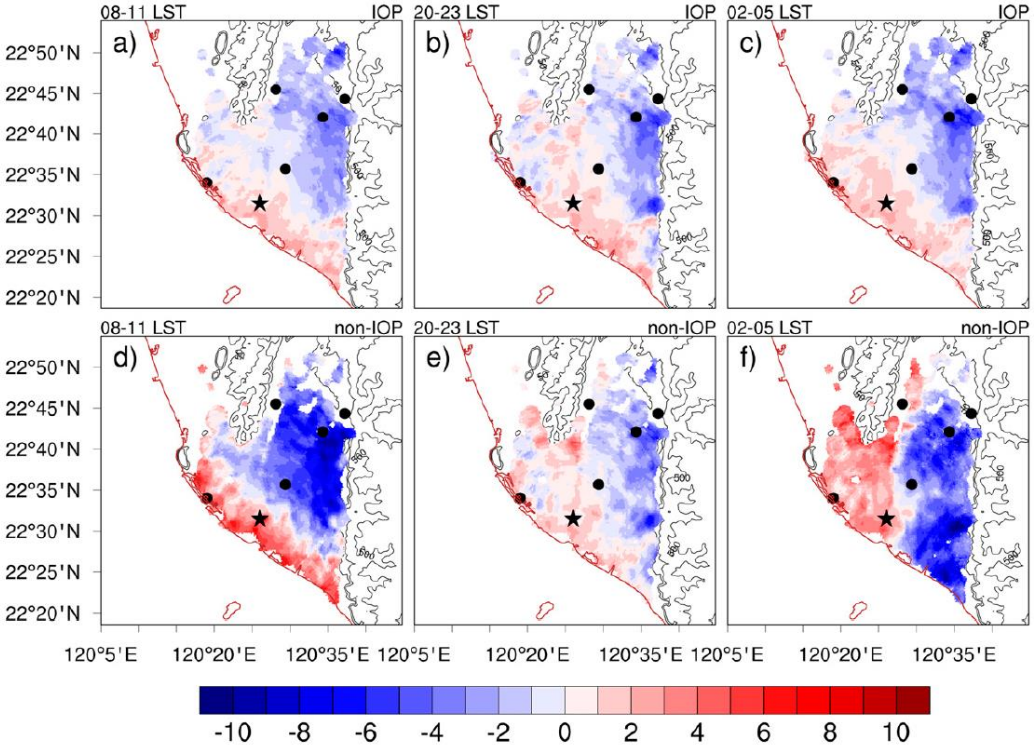
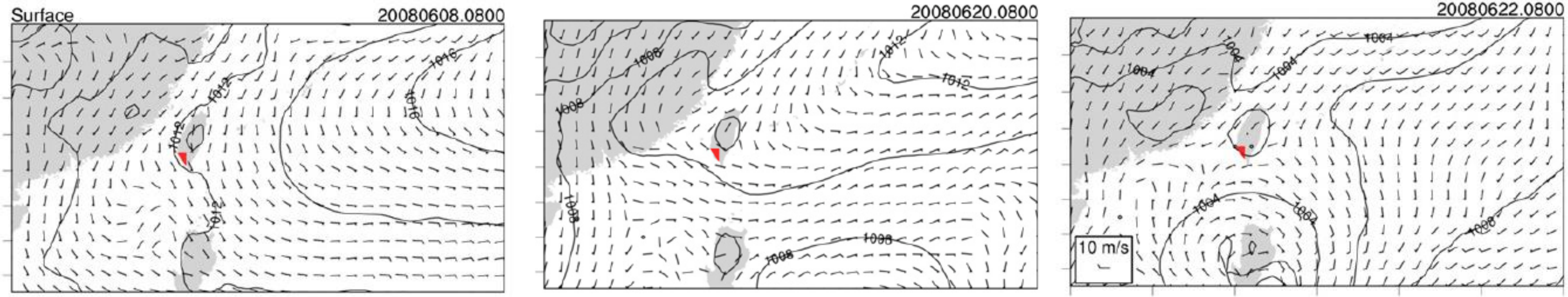


- ***IOP***:
  1. Synoptic scale system dominates
     → Persistent N pattern
  2. Land-sea geographical environment
     → N gradient toward the coast
- ***nIOP***:
  1. Daytime sea breeze
     → NW – SE oriented pattern
  2. Nighttime land breeze
     → N-S oriented pattern

4. Case studies of diurnal evolution refractivity

- The local circulation can be influenced by:
  land-sea breeze, ***mountain-valley flow***, and prevailing ***large-scale flow***
- Three types of diurnal refractivity patterns under different weak synoptic conditions and local circulation are analyzed.
- The synoptic wind at southwestern Taiwan are:
  south-southeasterly (6/8), ***easterly*** (6/20), and ***northerly*** (6/22)



4. Case studies of diurnal evolution refractivity

a. 8th June case study

- ***08~17 LST***:

  N ***gradient*** is persistently observed

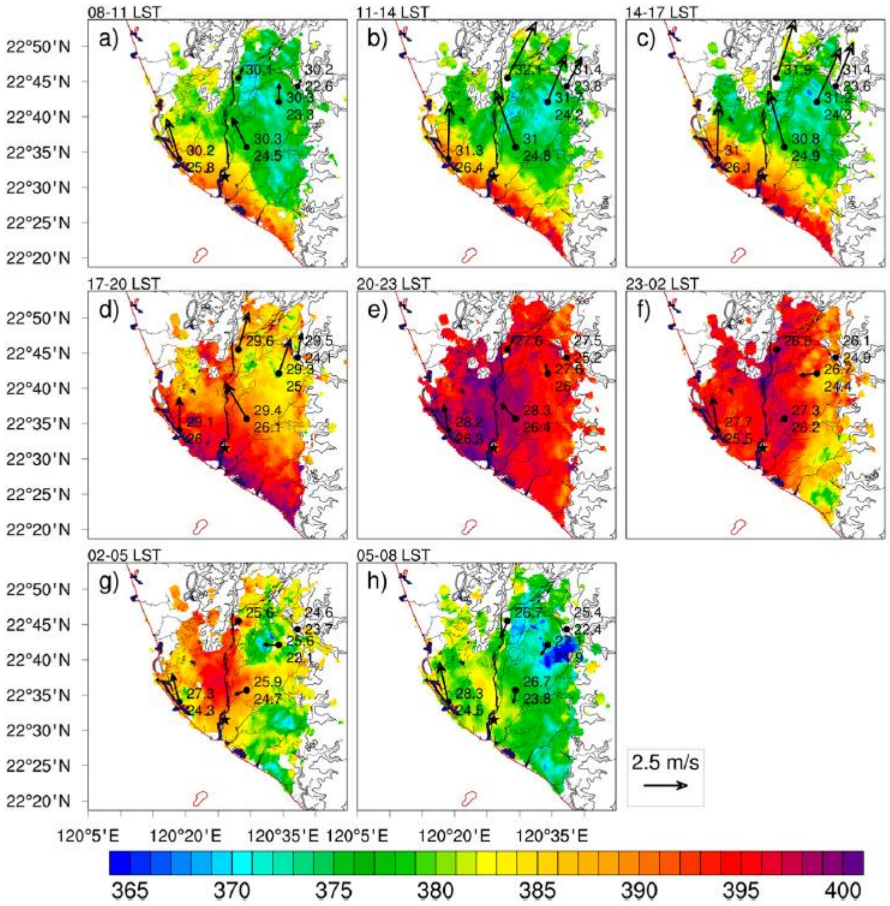
- ***17~23 LST***:

  N continuously ***increase*** and become spatially ***homogeneous***

- ***23~05 LST***:

  N ***decreases*** from the foothills and move ***westward***

- ***Land uses*** can influence N values



4. Case studies of diurnal evolution refractivity

a. 8th June case study

- ***Persistent daytime refractivity gradient***

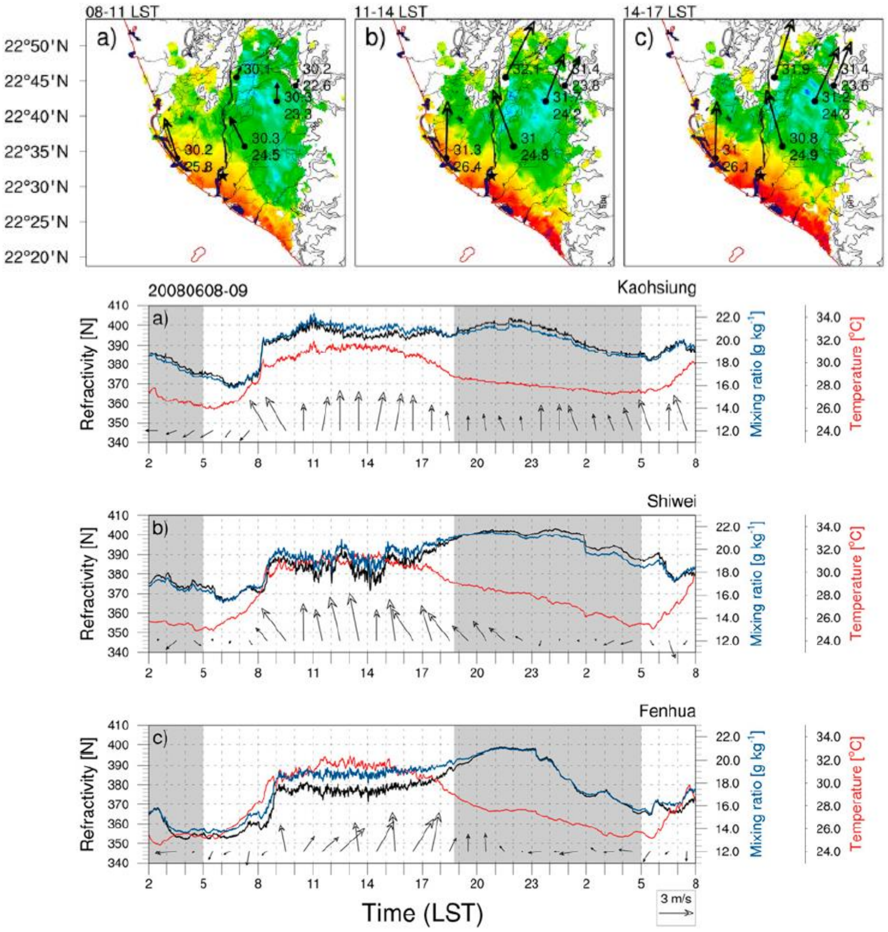
  1. Higher **moisture along the coast**

  $$\left\{\begin{array}{l}\text{S wind at } \textit{Kaohsiung} \\ \text{SE wind at } \textit{Shiwei}\end{array}\right. \rightarrow \textit{Convergence}$$

  2. Lower **moisture inland**

  $$\left\{\begin{array}{l}\text{SW wind at } \textit{Fenhua} \\ \text{SE wind at } \textit{Shiwei}\end{array}\right. \rightarrow \textit{Divergence}$$

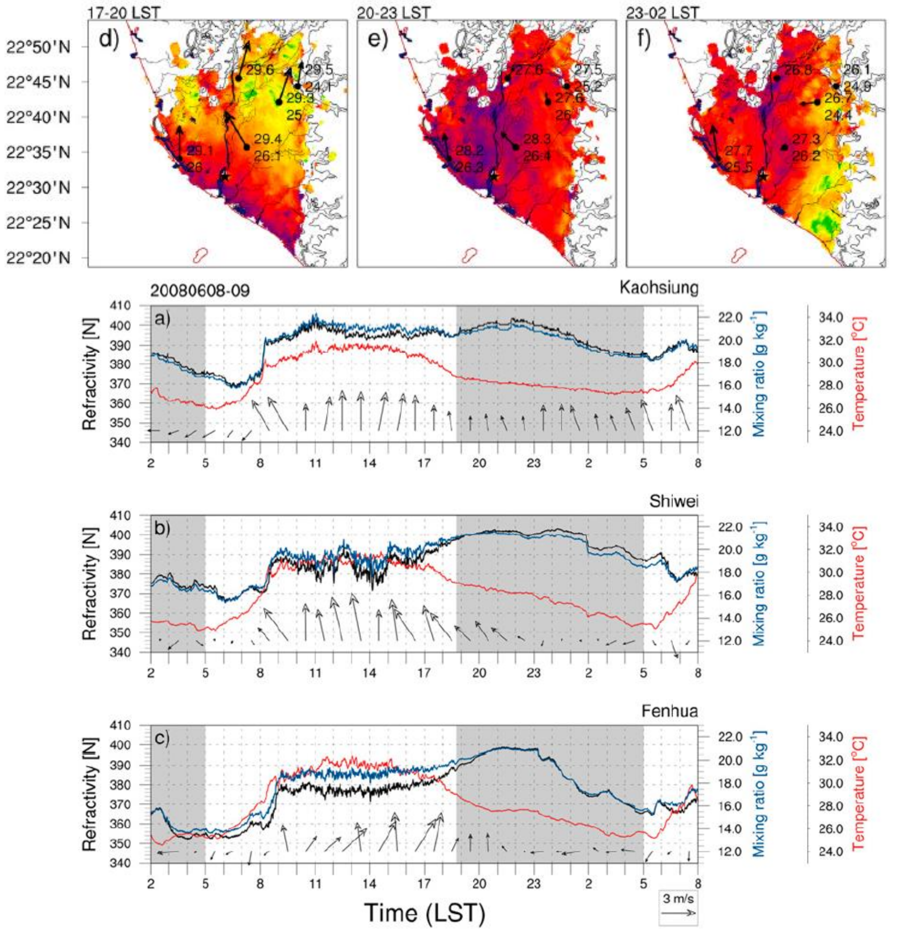
  3. The wind at ***Shiwei*** plays a critical role in moisture distribution and N gradient.



4. Case studies of diurnal evolution refractivity

a. 8th June case study

- ***The evening homogeneous and maximum refractivity field***



1. Greater increase in ***q*** is observed inland compared to along the coast.

2. The increasing moisture is related to the larger ***evapotranspiration*** and weaker ***vertical mixing*** processes.

4. Case studies of diurnal evolution refractivity

a. 8th June case study

- ***The nighttime refractivity gradient***

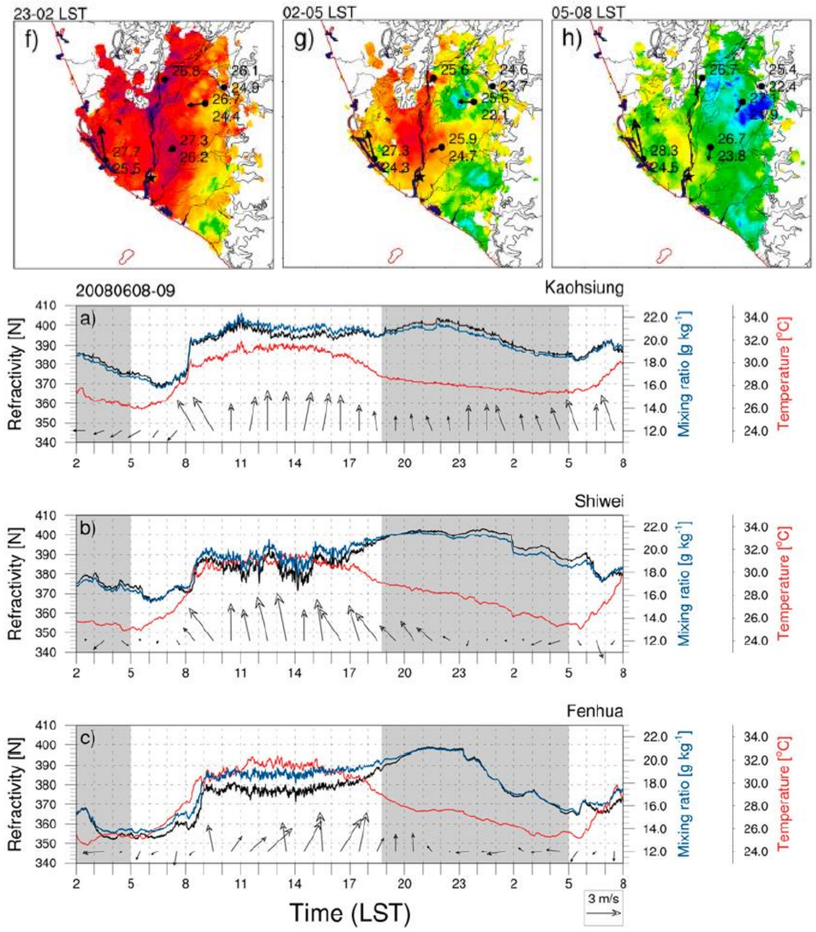
1. The reduction of water vapor mixing ratio is affected by the easterly dry ***downslope wind*** from the mountains.

2. q decreases at

~2300 LST at *Fenhua* (foothill)

~0200 LST at *Shiwei* (plain area)

3. Meridionally oriented low refractivity pattern moves from foothill to coast.



4. Case studies of diurnal evolution refractivity

b. 20th June case study

- ***08~14 LST***:

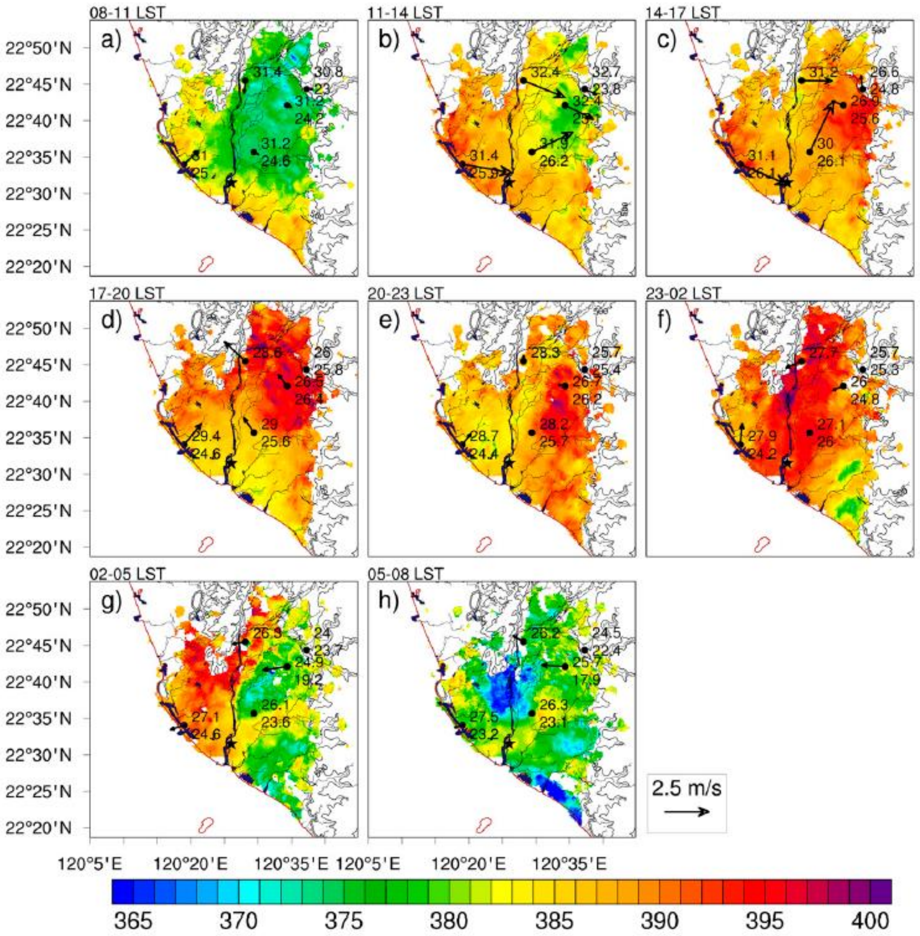
  Moist ***sea-breeze*** front moves inland and low-level ***convergence*** at foothill

- ***14~20 LST***: (storm: 1345~1900 LST)

  High moisture area moves westward with ***storm outflow***

- ***20~08 LST***:

  N ***decreases*** from the foothills and move ***westward (similar to 8th June)***

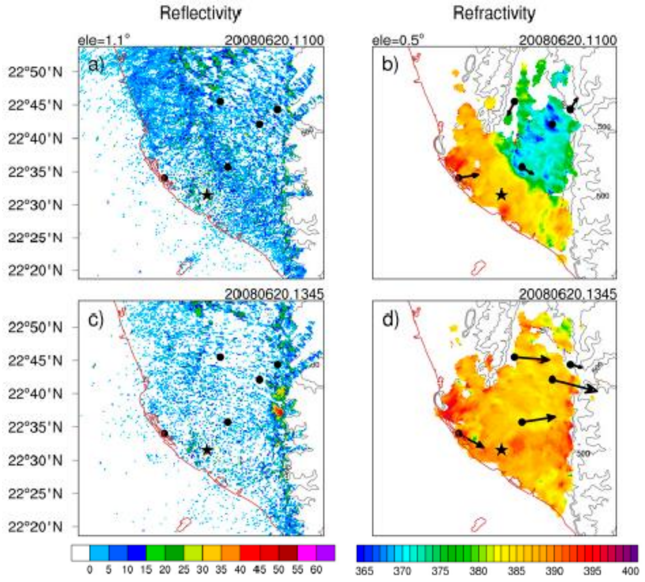


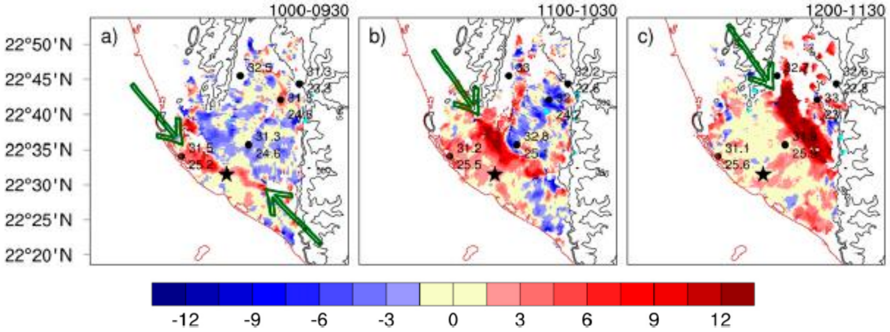
4. Case studies of diurnal evolution refractivity

b. 20th June case study

- ***The evolving sea-breeze front***

  1. The see-breeze front observed by diffuse ***reflectivity fine line*** is correspond to ***N gradient***
  2. The sea-breeze front move from coast to inland
  3. There is a sea-breeze ***time lag*** between northern-urban and southern-rural area
  4. The larger ***moisture contrast*** between sea-breeze and the environment inland can be observed by ΔN_{30min}





4. Case studies of diurnal evolution refractivity

b. 20th June case study

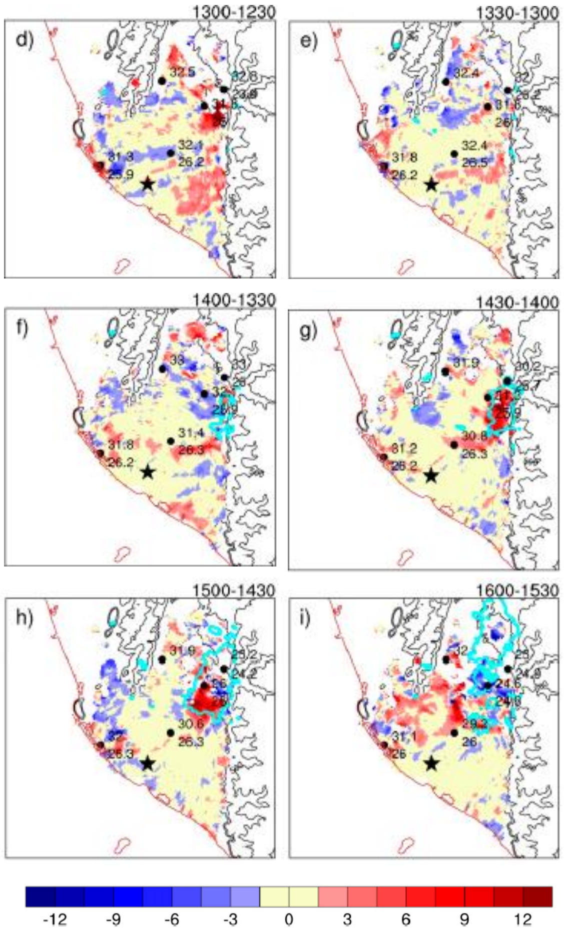
- ***The refractivity in storm environment***

  1. The increasing ***moisture accumulate*** at the foothills about ***1h*** ahead of convection initiation (CI).

  2. The time lag of ΔN_{30min} and relative high N field can be ***precursors*** of CI nowcasting.

  3. The storm and its outflow cause N to decrease mainly by ***cooling*** $(T\downarrow)$ rather than adding mixing ratio (q).

  4. The N increase westward more than southward due to land use differences.

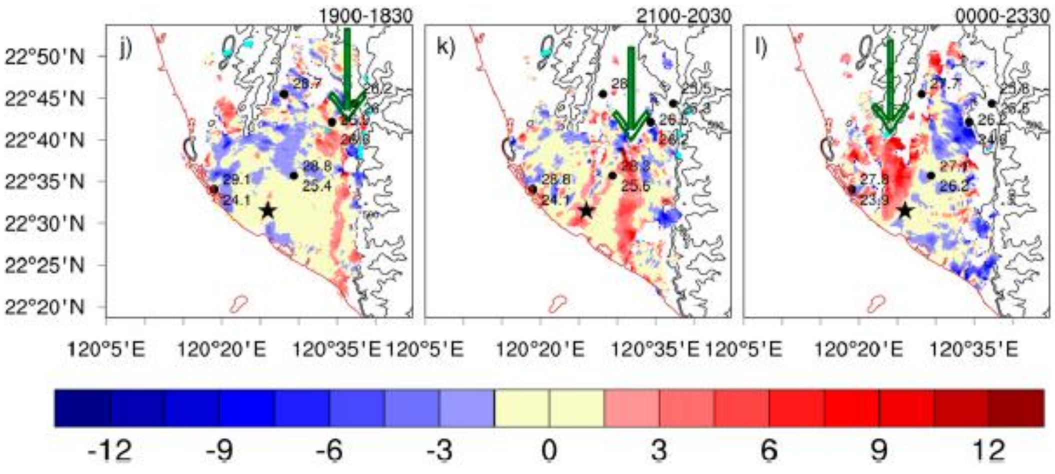


4. Case studies of diurnal evolution refractivity

b. 20th June case study

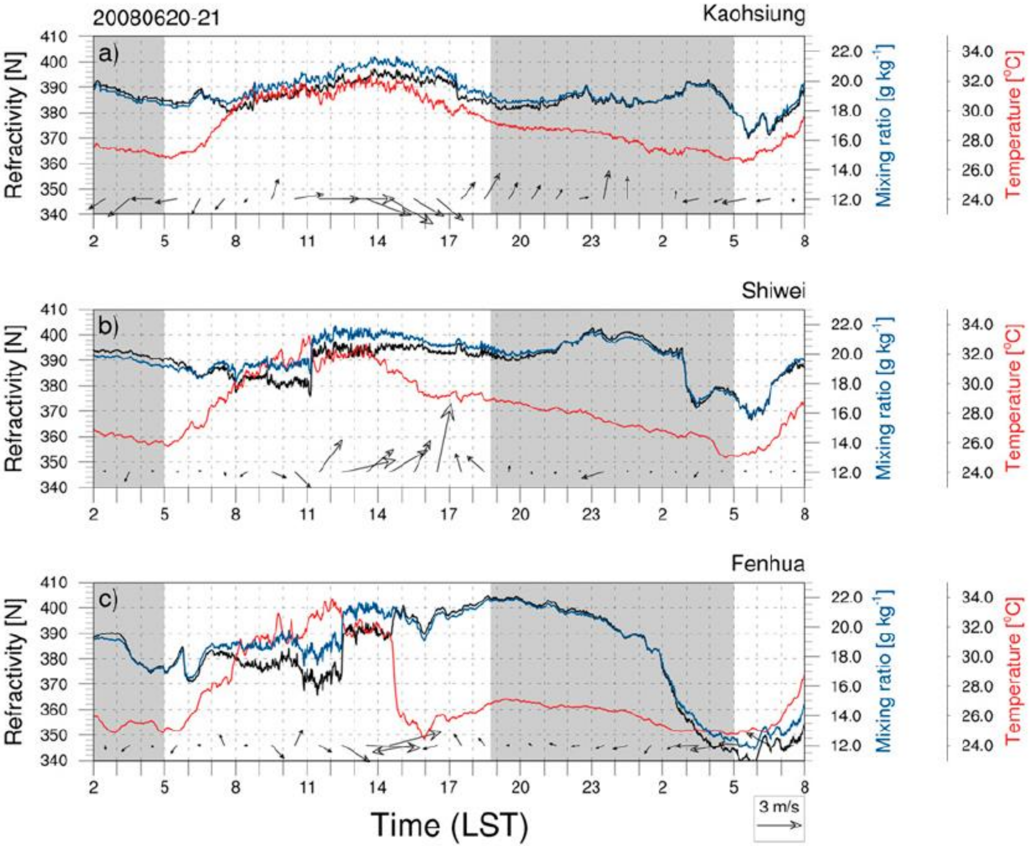
- ***The obscure evening propagating moisture gradient***

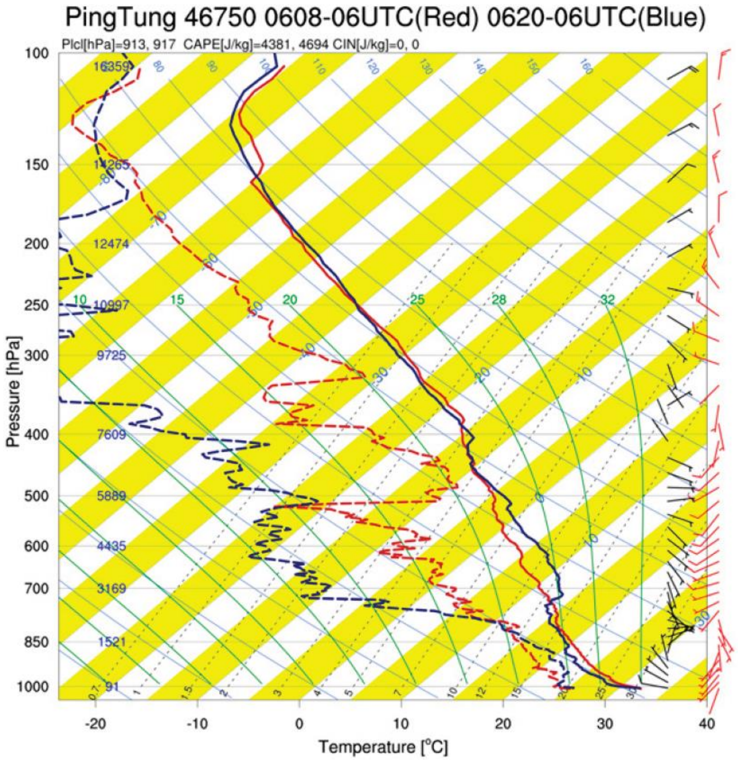
  1. A positive ΔN_{30min} area propagate from foothill to coastline after 1830 LST.
  2. ΔN_{30min} is caused by the increase of mixing ratio (q) suggested by observation data.
  3. What causes the mixing ratio (q) to increase at foothill is still ***not clear***.



4. Case studies of diurnal evolution refractivity

b. 20th June case study



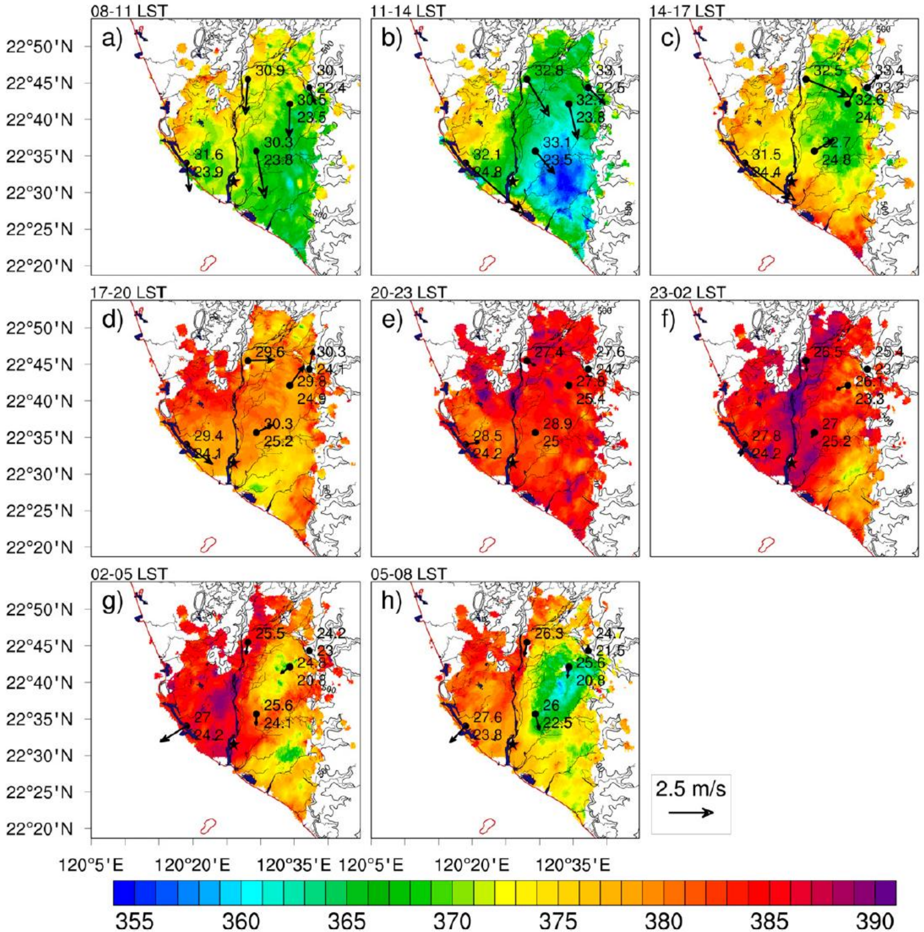


4. Case studies of diurnal evolution refractivity

c. 22nd June case study

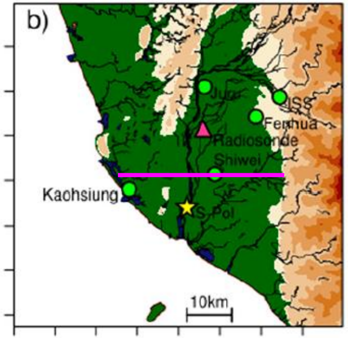
- ***08~14 LST***:
  1. The northerly-northwesterly wind transport ***drier air*** from the northern hill.
  2. Unusual daytime ***low N*** value
- ***14~20 LST***:
  1. Surface wind change from N to SW
  2. Moisture is transported inland
- ***20~08 LST***:

  The pattern is similar to 8th and 20th June

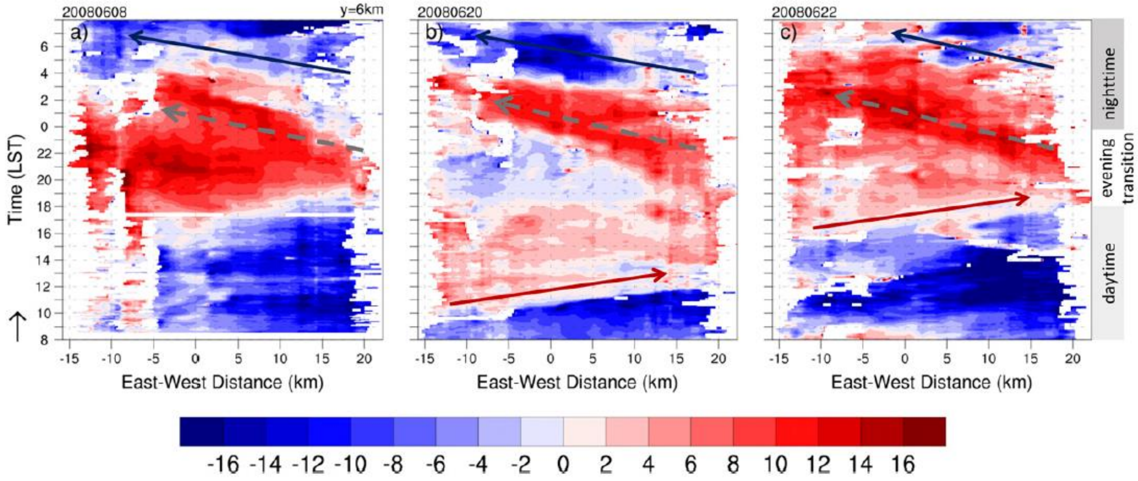


5. Discussion of the diurnal variation of refractivity

a. Hovmöller diagram



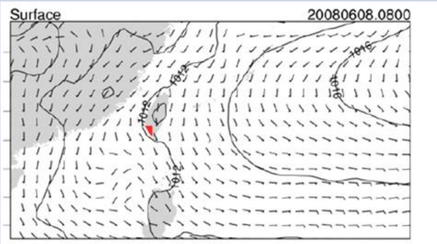
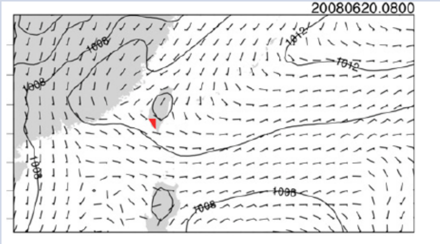
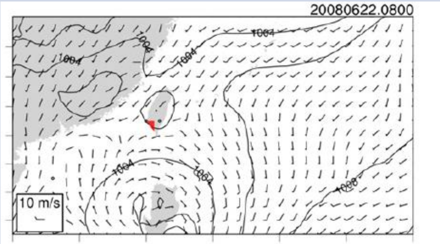
- ***Three time phase:***
  1. daytime
  2. evening transition
  3. nighttime

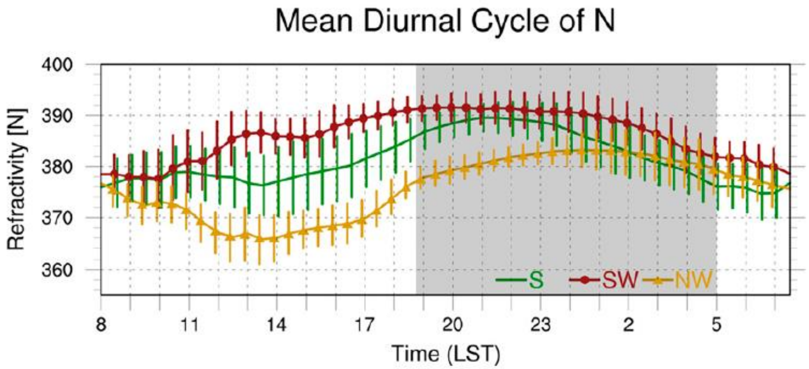


- The characteristics are ***different in daytime but similar in evening and nighttime*** among the three cases.
- The sea-breeze penetrate inland to the foot hill ***before noon*** only in the 20th June case.
- The ***low-level moisture*** is a key factor to whether a storm can be initiated.

5. Discussion of the diurnal variation of refractivity

b. Three types based on surface wind

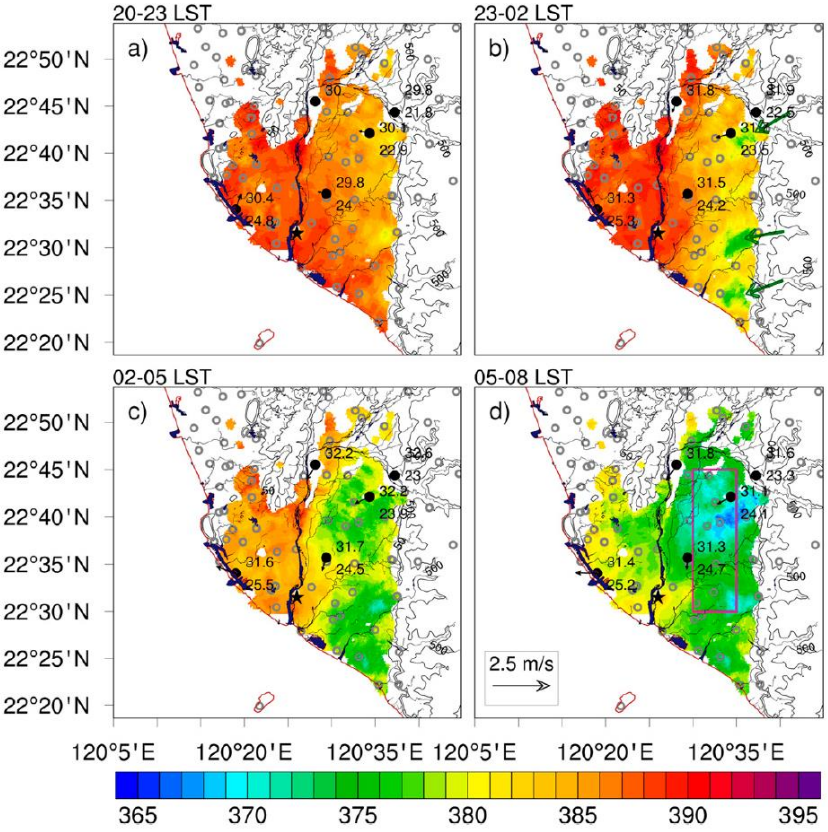
Surface wind	S	SW	NW
Synoptic chart			



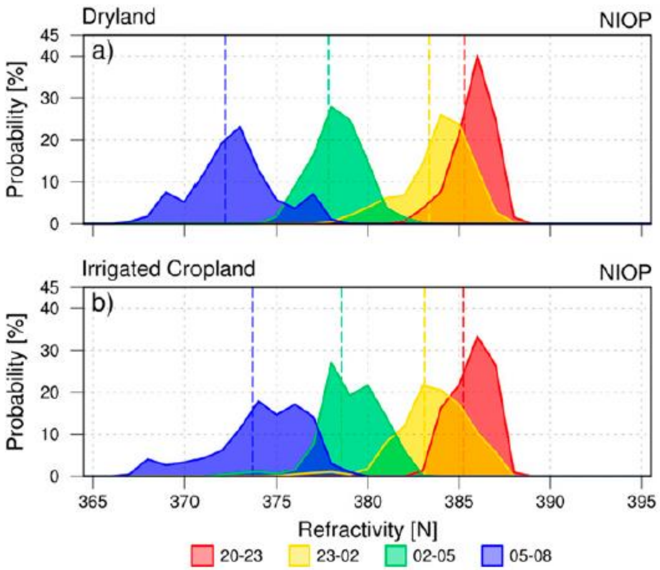
- ***Similarity***: Moisture minimized at daytime and maximized at nighttime.
- ***Difference***: SW cases had the highest mean N value and favorable to afternoon thunderstorm initiation.

5. Discussion of the diurnal variation of refractivity

c. Nocturnal mean refractivity of nIOP cases



- The downslope wind initiate at ***river valleys*** embedded in the mountains.
- The N of ***dry land*** is lower than ***irrigated croplands*** after 0200 LST.



6. Conclusions

- The ***radar retrieved refractivity*** is analyzed to reveal the ***near-surface moisture*** distribution in the summer time tropical coastal areas.
- In the ***IOP*** cases:

  The refractivity are persistently high while the spatial gradient are still exist from coast toward inland.
- In the ***non-IOP*** cases:

  The moisture distribution is affected by the ***complicated interaction*** between synoptic forcing, coastal processes, complex terrain, and land use.
- The ***meso-γ-scale moisture variability*** can be revealed from high-spatiotemporal resolution refractivity data, which can complement the limited number of surface observations.