Impact of Air-Sea Thermodynamics and Orographic Lifting on Heavy Northeast Monsoon Rainfall in Northeastern Taiwan

(海氣熱力與地形抬升對台灣東北部東北季風強降雨之影響研究)

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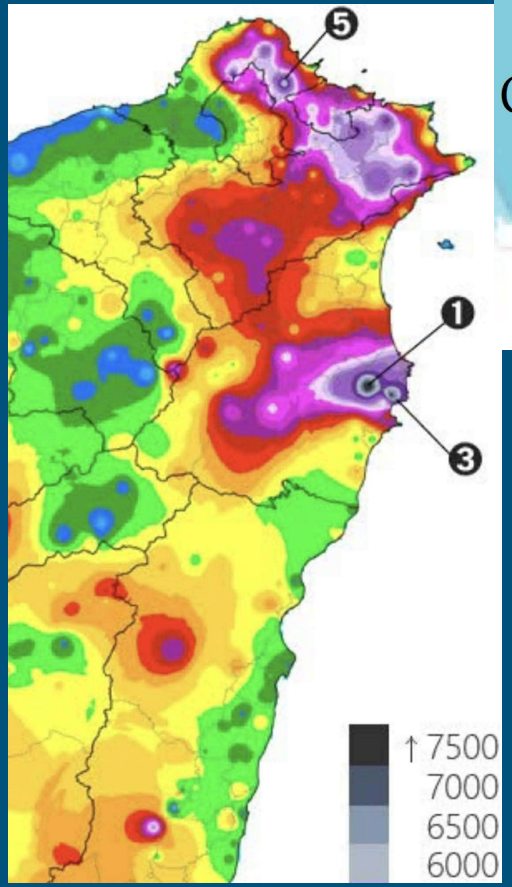
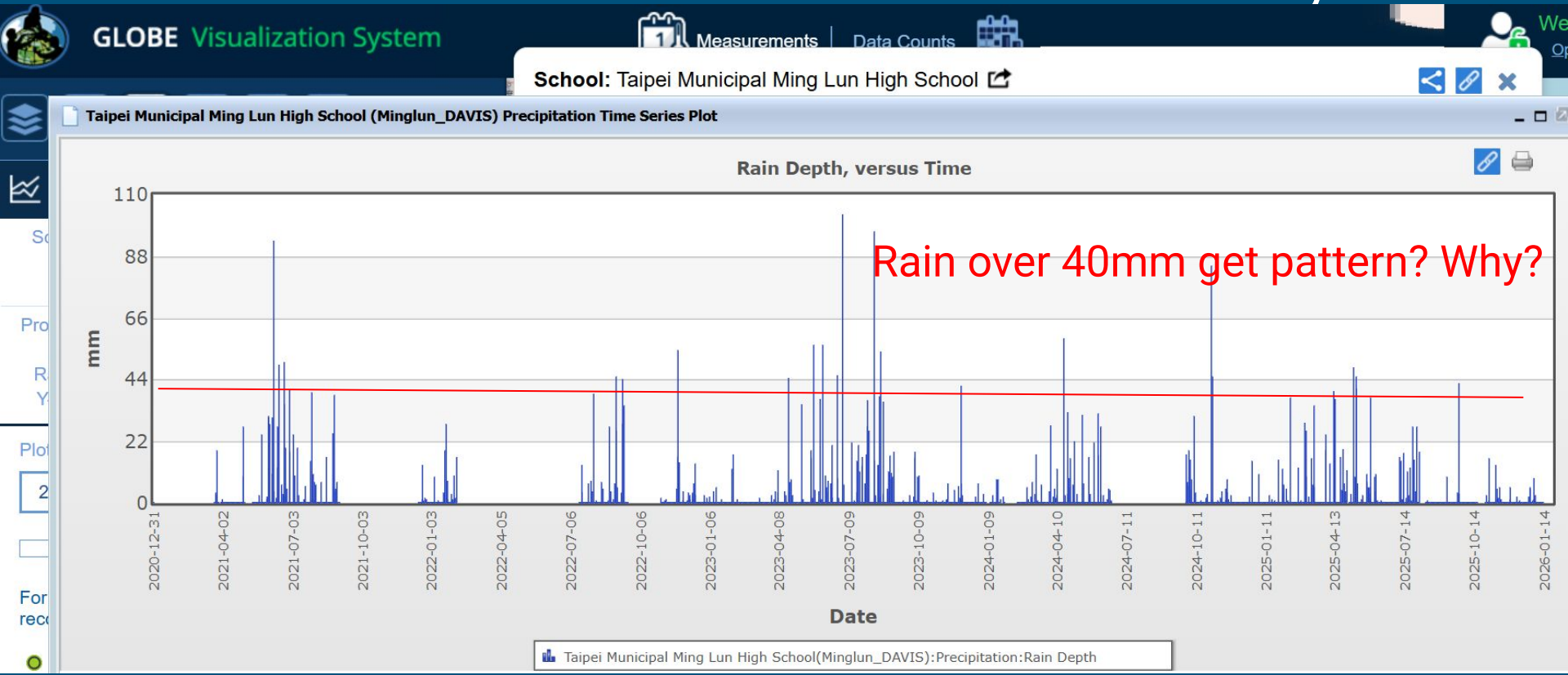
Research Motivation

- **Topographic Effects:**
  The combination of the Northeast Monsoon and topography easily leads to heavy rainfall and flood disasters.
- **Kuroshio Intrusion:**
  Does the intrusion of the Kuroshio current into the East China Sea shelf area change rainfall conditions?
- **Prediction Accuracy:**
  Why are rainfall estimates sometimes inaccurate?



Graph Note: 2025 Annual Rainfall (CWA), highlighting1,3 present Yilan Nan'ao (7908mm) and 5 present New Taipei Wanli (6306.5mm).

Rainfall at Taipei Ming Lun High School from GLOBE Visualization System

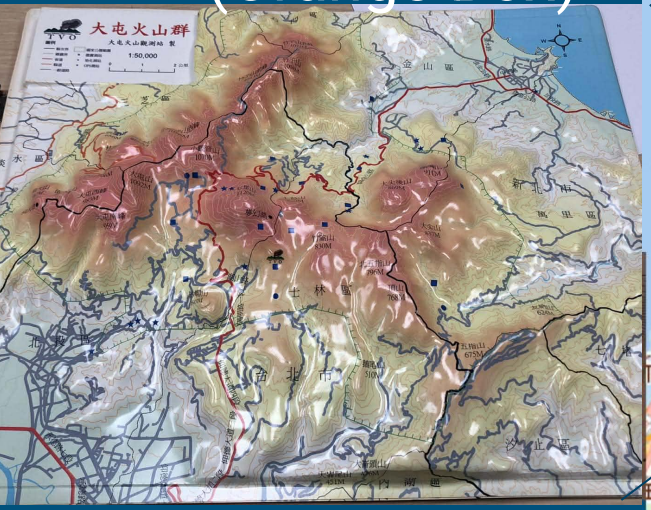


Study Objectives (GOALS)

- **Thermodynamic Model:** Analyzing the relationship between Sea Surface Temperature (SST), Wind Speed, and Wind Direction.
- **Hypothesis 1:**
  Does higher water temperature lead to heavier rain?
- **Hypothesis 2:**
  Does a larger temperature difference between air and water (Air-Sea Temperature Gap) lead to heavier rain?

Study Area

- Northern Taiwan topography
- Target sea area (Orange Box)



PengJia islet

Kuroshio current

Taiwan

S

W

C

Flow chart on this study

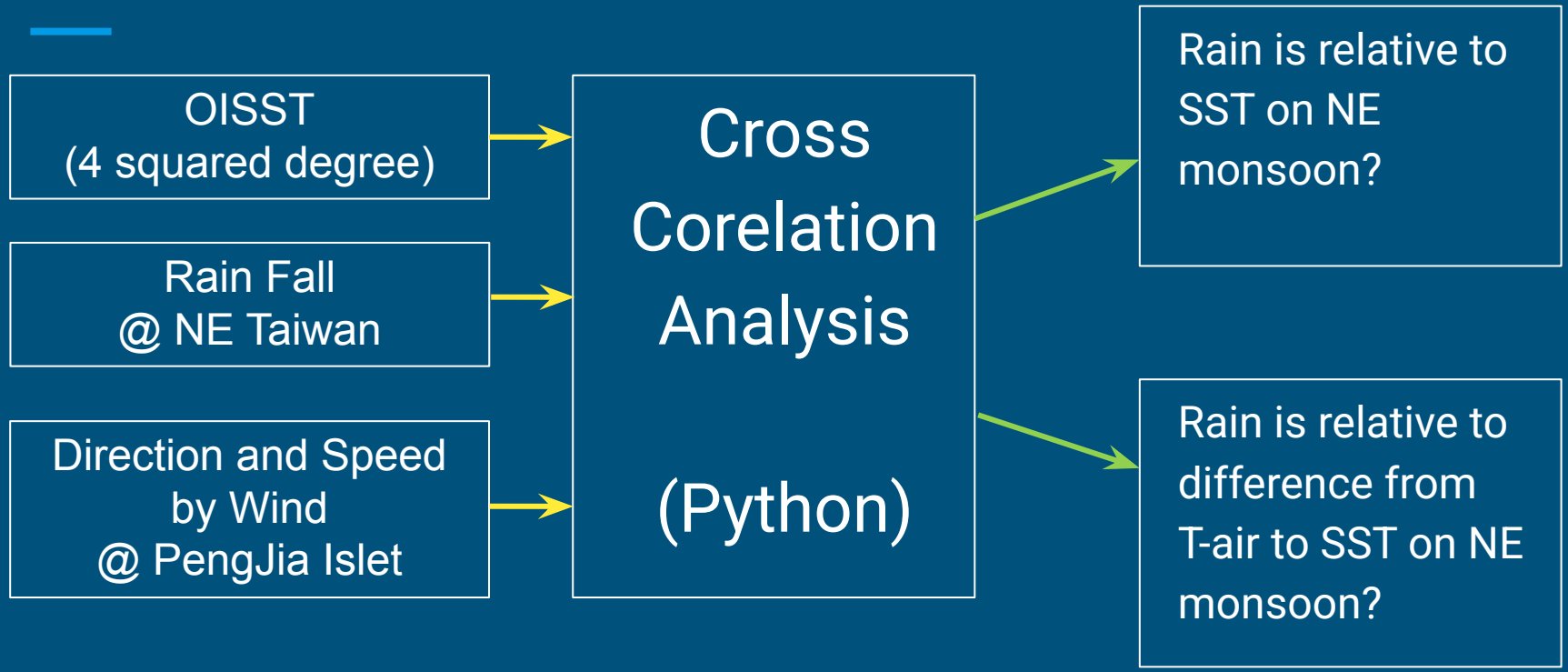
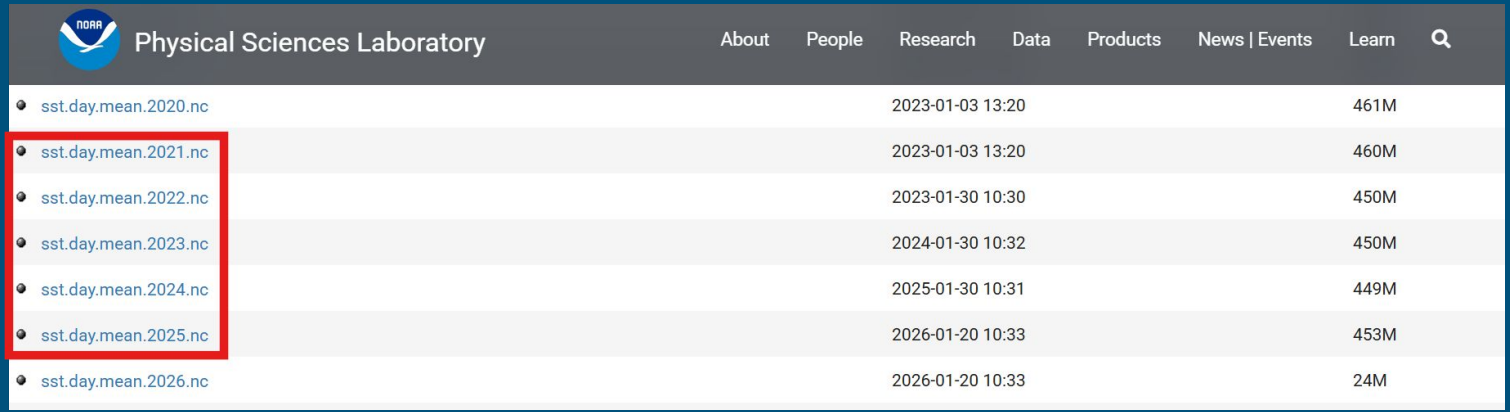


Image Source from OISST

1. Preview of project (NASA vs NOAA)
   a. Optimum Interpolation Sea Surface Temperature
   b. Grid Resolution 0.25 x0.25 degree
   c. Accuracy (RMSE) 0.2°C ~ 0.3°C
2. Data selection 2021~2025;
   25~27°N; 122~124°E
3. Workflow: Download NetCDF→transfer to CSV

Data Acquisition & Processing

Acquisition of SST from NOAA Physical Sciences Laboratory (2021-2025)



website https://downloads.psl.noaa.gov/Datasets/noaa.oisst.v2.highres/

Data Acquisition & Processing

- **Download:** Obtained SST data (2021-2025) from the NOAA Physical Sciences Laboratory.
- **Extraction:** Converted NetCDF to CSV and extracted specific coordinates (25–27°N, 122–124°E) to reduce file size.
- **Organization:** Used Python to divide the data into a 2x2 grid (1° unit) and calculated daily averages for each block.
- **Storage:** Data hosted on GitHub for accessingl.

SST Characteristics of the Study Area

°C	2021	2022	2023	2024	2025	5 year Mean
Mean SST in winter	24.67	24.71	24.67	24.45	26.35*	24.97
Jan	22.03	23.03	23.69	23.27	27.38	23.88
Feb	22.79	22.87	22.07	22.47	25.67	23.17
Mar	22.91	23.31	22.93	21.47	23.12	22.75
Sep	28.87	28.29	28.36	29.35	29.28	28.83
Oct	27.53	27.05	26.80	27.38	28.23	27.40
Nov	25.88	25.77	25.55	25.91	26.23	25.87
Dec	24.87	24.28	24.23	23.71	24.90	24.40

* 2025 shows a notably higher winter average (26.35°C) compared to previous years (~24.6°C).

Kuroshio Influenced on OISST

(°C)	2021	2022	2023	2024	2025	5-Year Average
Average OISST (Kuroshio)	26.3	27	27	27	26.5	26.8
Winter Influence on Study Area *	0.9	2.1	2.6	2.3	2	1.98

* Difference between Max temp to Min temp in study area

Kuroshio Water Temperature: Five-year average of 26.8°C.

Impact on Study Area: Measured as the difference between maximum and minimum temperatures in the study area during winter.

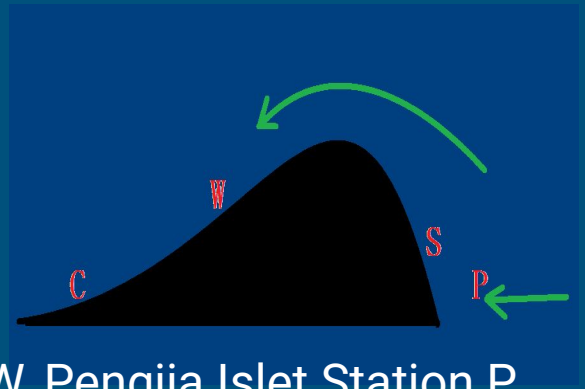
Datum from CODiS_CWA, Taiwan

1. Station selection
2. Pengjia Islet @ NorthEast Taiwan
3. Criteria for Rainfall
4. Criteria for Wind direction and Speed

https://codis.cwa.gov.tw/

Weather Stations Selection

- **The NE monsoon passes over the ocean before blowing towards the main island of Taiwan. Since Pengjia Islet Station is located exactly on the windward side, it represents the atmospheric water vapor and wind direction. When the airflow is lifted by the terrain, it condenses and causes rainfall; therefore, the windward side can directly reflect the influence of the NE monsoon and marine conditions on precipitation.**
- **This study selected stations located on the windward side of the northeast monsoon, including:**
  Sanhe Station (Code: S, 216 m, Jinshan District), Quchi Station (Code: C, 76 m, Xindian District), and Wuzhishan Station (Code: W, 685 m, Xizhi District).
- **For the wind direction station,**
  we selected data from Pengjia Islet Station (Code: P, 101.7 m).



Sanhe S, Quchi C, Wuzhishan W, Pengjia Islet Station P, NE Monsoon: Green Arrow

Data download

Downloaded the temperature, wind direction, and wind speed of Pengjia Islet, as well as the precipitation of Wuzhishan, Sanhe, and Quchi stations from the CODiS meteorological observation data inquiry service platform.

	Press		Temperature	dew point	RH	WD/WS				Precp		SunShine	
觀測時間 (hour)	測站氣壓 (hPa)	海平面氣壓 (hPa)	氣溫 (°C)	露點溫度 (°C)	相對溼度 (%)	風速 (m/s)	風向 (360degree)	最大瞬間風 (m/s)	最大瞬間風風向 (360degree)	降水量 (mm)	降水時數 (h)	日照時數 (h)	全天空日射量 (MJ/㎡)
ObsTime	StnPres	SeaPres	Temperature	Td dew point	RH	WS	WD	WSGust	WDGust	Precp	PrecpHour	SunShine	GloblRad
01	1010.6	1023.4	12.0	9.6	85	12.8	20	19.8	28	T	0.1	0.0	0.00
02	1010.6	1023.4	11.9	9.5	85	8.7	26	17.8	30	T	0.3	0.0	0.00
03	1010.5	1023.2	12.3	9.0	80	11.6	22	20.7	10	T	0.1	0.0	0.00
04	1010.8	1023.6	11.9	9.5	85	12.7	19	18.7	8	T	0.2	0.0	0.00
05	1011.2	1024.0	11.1	8.7	85	12.9	13	19.8	26	T	0.3	0.0	0.00
06	1011.9	1024.7	11.1	8.9	86	11.1	21	19.1	22	0.5	0.6	0.0	0.00
07	1012.5	1025.3	10.7	8.6	87	12.3	18	19.4	15	1.0	0.6	0.0	0.00
08	1012.6	1025.4	10.7	8.8	88	10.3	25	18.6	14	T	0.5	0.0	0.03
09	1012.9	1025.7	11.1	9.2	88	11.4	21	18.1	21	T	0.4	0.0	0.08
10	1012.8	1025.6	11.3	8.3	82	9.6	25	18.8	14	T	0.1	0.0	0.19
11	1012.6	1025.4	11.3	8.3	82	9.9	19	19.8	13	T	0.3	0.0	0.18
12	1011.6	1024.4	11.2	9.0	86	10.8	16	18.1	37	0.5	0.5	0.0	0.24

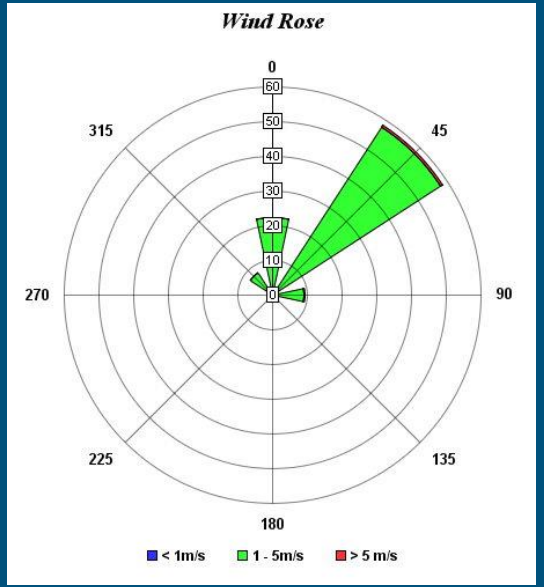
Data Filtering Criteria: Rainfall >=100mm

- **Ensuring Significance:** To ensure all analysis samples are significant rainfall events and to exclude interference caused by localized occasional showers or trace amounts of moisture, daily rainfall of **100mm or more** is selected as the sample for analysis.
- **Atmospheric Indicators:** Reaching 100mm or more typically represents **extremely abundant moisture transport** in the atmosphere (correlated with Sea Surface Temperature) and **strong orographic lift** (terrain-induced lifting).
- **Meteorological Standards:** Referring to the Central Weather Administration (CWA) standards for "Heavy Rain" and "Extremely Heavy Rain," 100mm falls between Heavy Rain (80mm/24h) and Extremely Heavy Rain (200mm/24h). It serves as an **important indicator for measuring the strength of the Northeast Monsoon**.

* Definition by CWA (Central Weather Administration) Rainfall is measured in millimeters (mm). Heavy Rain is defined as 24h accumulated rainfall >= 80mm or hourly rainfall >= 40mm; Extremely Heavy Rain is defined as 24h rainfall >= 200mm or 3-hour rainfall >= 100mm.

Data Selection: Wind Direction 1°~90°

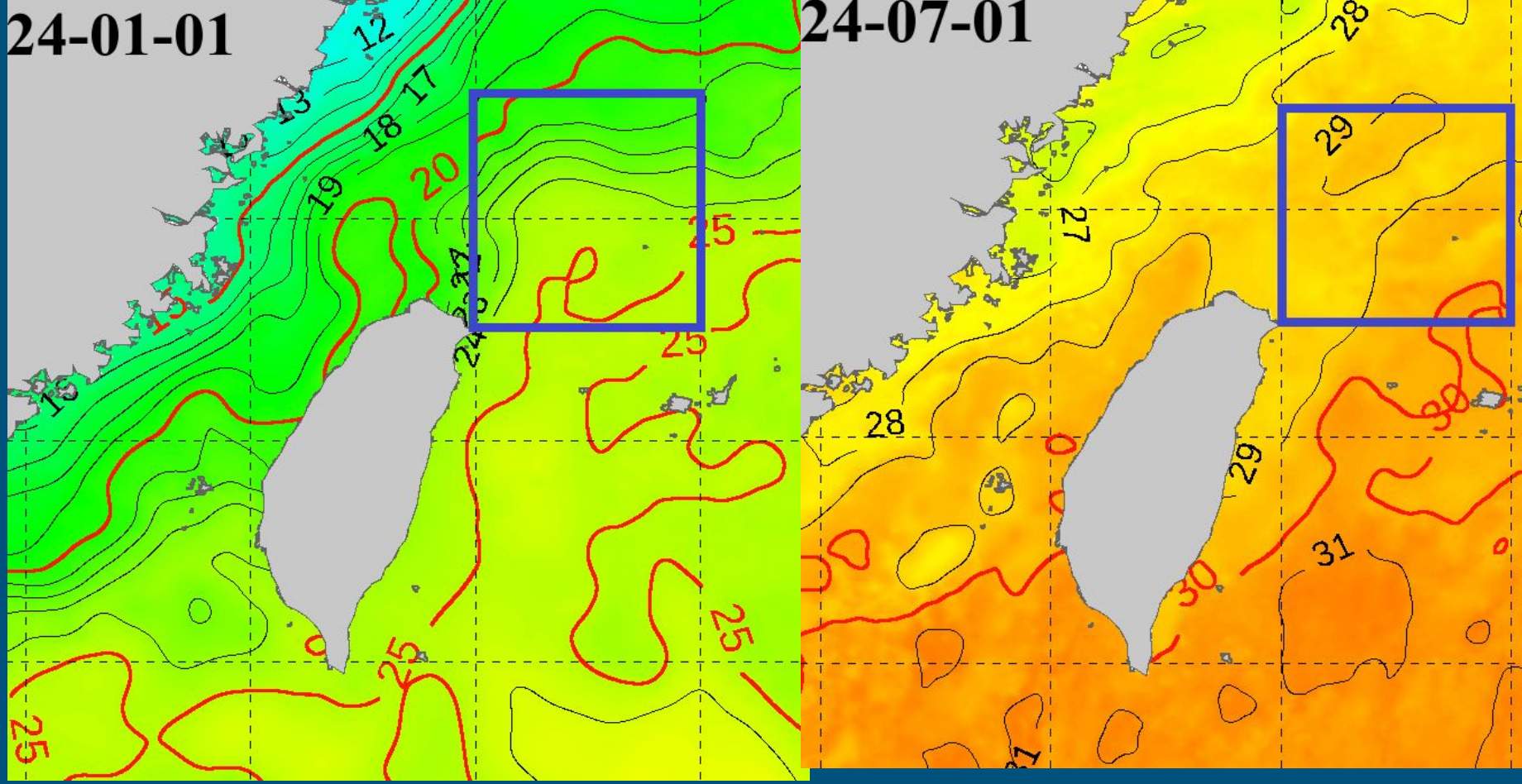
- Selecting 1°~90° is to ensure that the rainfall in the study is indeed brought by the northeast monsoon.
- Furthermore, for stations such as Keelung and Yilan, only when the wind blows from 1° ~90° will water vapor blow directly from the East China Sea and the Pacific Ocean toward the land and produce rainfall due to topographic lifting.



Source: http://hyshgeo.blogspot.com/2013/07/blog-post.html

Criteria of wind speed : >8 m/s

- According to the Beaufort scale, speeds above 8 m/s have reached Level 5 wind force.
- In Taiwan's coastal areas and windward sides, this indicates a strong NE Monsoon, which provides stable moisture transport dynamics.
- Weak winds (<5 m/s) are easily affected by local land-sea breezes, urban heat island effects, or turbulence from micro-topography. Selecting 8 m/s ensures that the captured signals represent large-scale circulation.
- Strong winds increase the surface roughness of the sea, thereby accelerating evaporation.
- Studying events with speeds above 8 m/s allows for a clearer observation of how water vapor generated by "warm seawater" is efficiently carried to land by "strong monsoons."



Overview on SST in study area (Blue box is 2X2 degree, and Left one means in Winter, Right is in Summer)

Result from correlation on relation between rain and SST

R^2	Daily Rain >100 mm	Daily Rain>1 mm
Sanhe (S)	0.17 (44, 679)	0.11 (315, 731)
Wuzhishan (W)	**0.57** (25, 12.3e+03)	0.41 (324, 727)
Quichi (C)	0.26 (10, 1.94e+03)	0.30 (284, 696)

→Extreme rainfall is highly sensitive to SST

(brackets contains sample numbers and Condition Number)

Cross Corelation Analysis

- $y=\beta_0+\beta_1x_1+\beta_2x_2+\beta_3x_3+E$ (E means Error in Random)
- y: Rainfall, x1: SST, x2: Wind direstion, x3: Wind Speed
- **Example (Wuzhishan):** Specific coefficients provided for significant vs. minor rain.

	β_0	β_1	β_2	β_3	E
Rain >100 mm	-788.11	21.93	-4.65	33.90	
Rain >1 mm	-344.29	18.74	-0.66	9.39	

Relation number

- Regression by Rainfall and temperature difference between SST and T-air

R^2	Daily rain >100 mm	Daily rain >1 mm
Sanhe (S)		
Wuzhishan (W)	0.014	
Quichi (C)		

- The relation number is lower to 0.014, which means there are no any relation.~

Discuss 1

- **Statistical Validity:** Sample sizes (10-44 for heavy rain; 284-324 for all rain) provide sufficient scientific significance.
- **Dynamic Process:** Mechanical lifting and advection caused by wind hitting mountains.
- **Thermodynamic Process:** Latent heat release and atmospheric instability caused by warm sea surface temperatures.

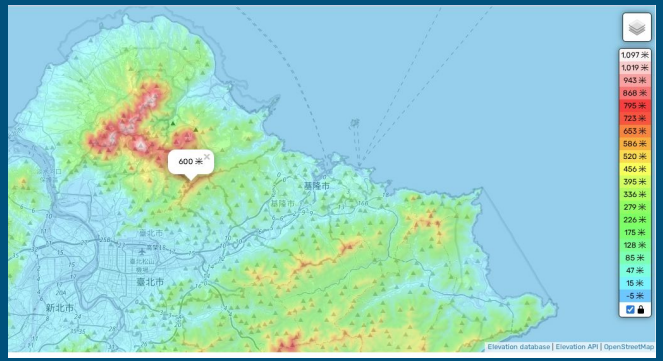
Discuss 2

Clausius-Clapeyron Relationship: For every 1°C rise in SST, atmospheric moisture capacity increases by 7%.

Instability:

Warm lower layer (SST) + Cold upper layer (Monsoon)
= Extreme instability inducing deep convection

(thunderstorms/downpours).



Discuss 3 (Scientific Sampling)

- **Remote Sensing:** OISST and MGDSST are accurate tools despite cloud cover.
- **Time Lag:** Investigating whether there is a delay (in days) between SST changes and rainfall.
- **Correlation (R):** Wuzhishan's R^2 = 0.57 corresponds to a high correlation coefficient (R = 0.76).

Discuss 4

- **Uncertainties:** Normalization of climate data and the impact of Global Warming vs. El Niño/La Niña.
- **Hysteresis (Lag):** Future work is needed to determine the exact time delay for SST effects to manifest as rainfall.

CONCLUSION

- **Strong Positive Correlation**: High SST provides significant latent heat and moisture, directly increasing rainfall intensity during the Northeast Monsoon.
- **Topographic Amplification**: Orographic lifting is the primary driver of extreme events. The **Wuzhishan Station** showed the highest correlation ($R^2 = 0.57$), proving that mountainous terrain catalyzes heavy precipitation.
- **Dynamic-Thermodynamic Synergy**: Extreme rainfall requires a "perfect storm" of high SST (thermodynamics) and strong monsoonal winds (> 8 m/s, NE direction) to effectively transport moisture inland.
- **Predictive Value**: Incorporating SST data and "Air-Sea Temperature Gaps" into forecasting models can significantly improve the accuracy of early warnings for Northeast Taiwan.

Future Work

- Investigating SST effects during typhoon events.
- Correlation between Kuroshio warm water and Yilan's extreme rain.
- For every 1°C increase in SST, the water vapor content increases by 7%. Will this directly lead to an increase in rainfall? Quantifying the moisture increase per 1°C of SST rise.

References

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