Trends of Tropical Cyclone and China Summer Monsoon Extreme Rainfall and Taiwan Typhoon Rain Intensity

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Introduction

- Global Warming → Increasing vapor capacity → increasing rain intensity and extreme rainfall.
- Increasing trend of extreme rainfall simulated over NH land area; correspondence good over Europe & N. America, but mixed over Asian monsoon region.
- Very large increasing trend of extreme rainfall reported in Taiwan since 1998, attribution to global warming is the subject of ongoing debate.

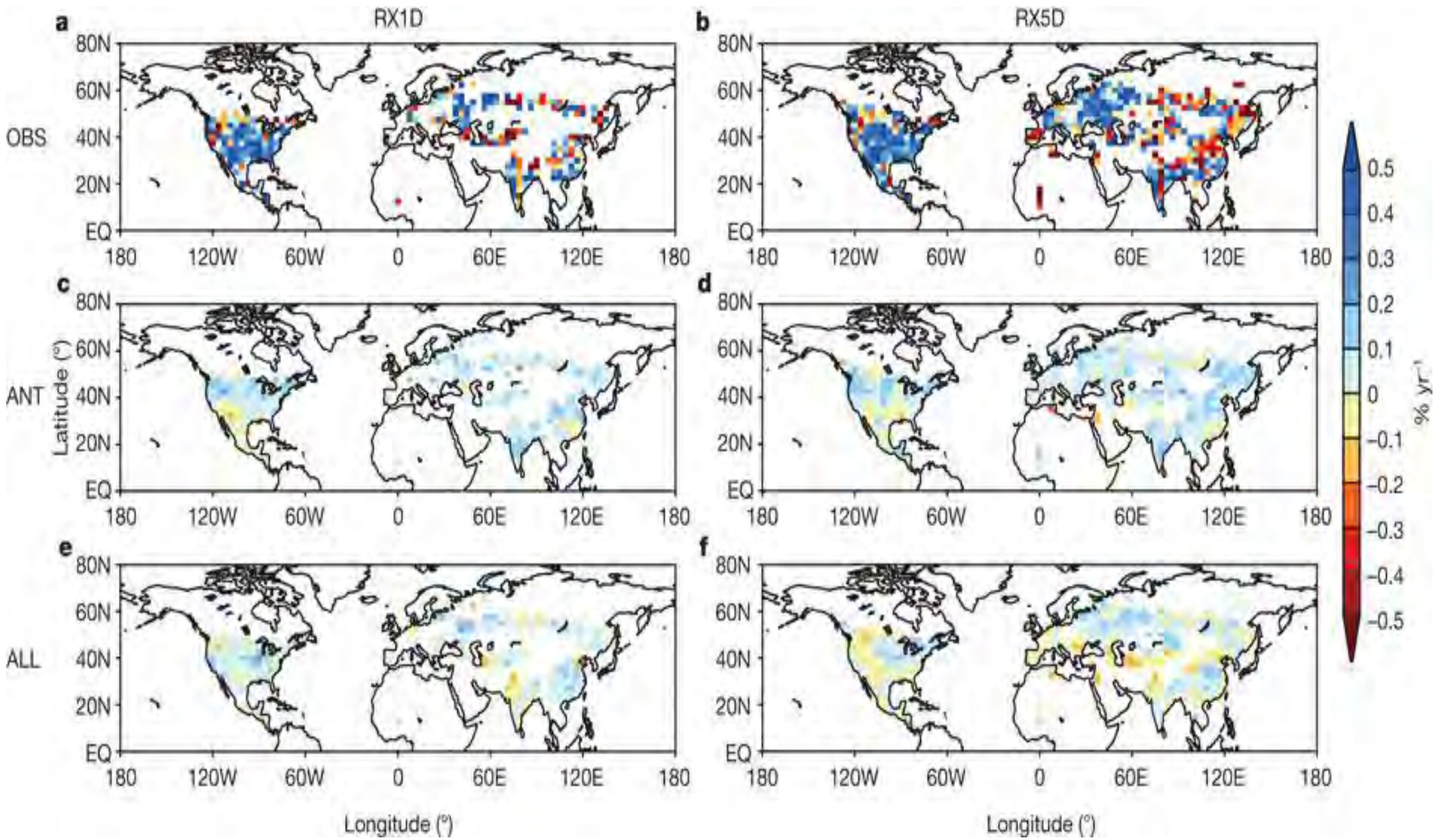
Outline

1. TC and China Summer Monsoon Extreme Rainfall (90th percentile) since 1958

2. TC Rain Intensity in Taiwan since 1961

3. TC Summer Extreme Rainfall in Taiwan since 1911 (preliminary)

Geographical distribution of trends of extreme precipitation indices (PI) during 1951–99.



S-K Min *et al. Nature* **470**, 378-381 (2011) doi:10.1038/nature09763

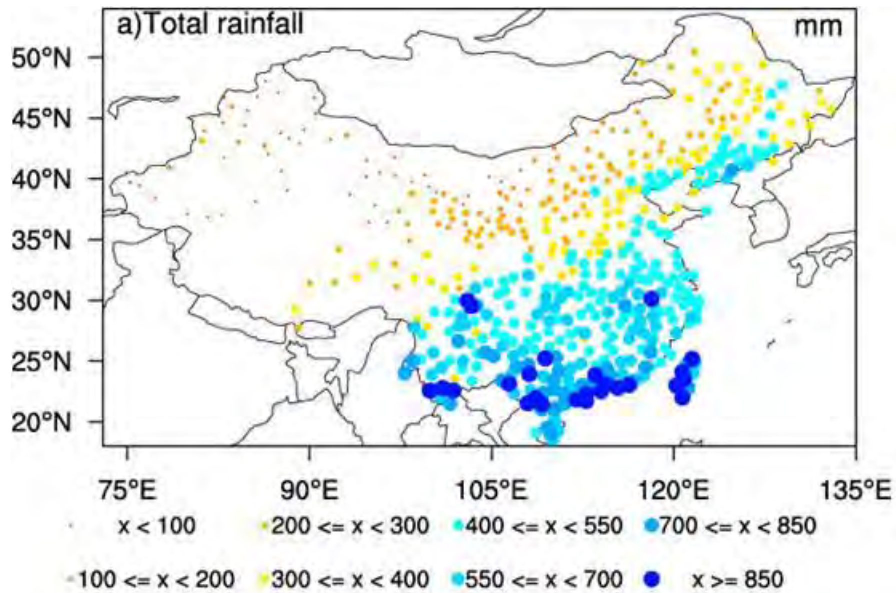
Rainfall in East Asia Summer Monsoon

- Extreme rainfall contributed by both monsoon and Tropical Cyclones (TCs)
- TCs influenced by tropical western North Pacific conditions (upstream of East Asian landmass)
- Extreme rainfall influenced by external factors not part of local thermodynamic conditions

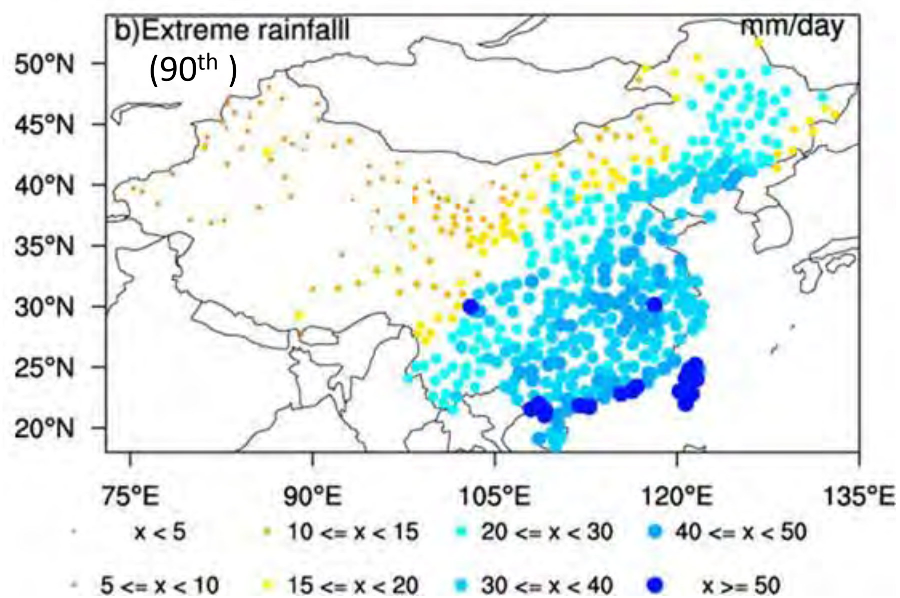
Data

- JJA 1958-2010, 53 years;
- Daily rain stations: 479 (out of 776) from China mainland including Hainan Island, 20 from Taiwan; $\geq$95% complete;
- Extreme rainfall defined locally at 90th percentile;
- Each rain day is either TC or Monsoon (non-TC);
- TC events identified with Objective Synoptic Analysis Technique (OSAT, Ren *et al.,* 2006), Influence range 500-1100 km.

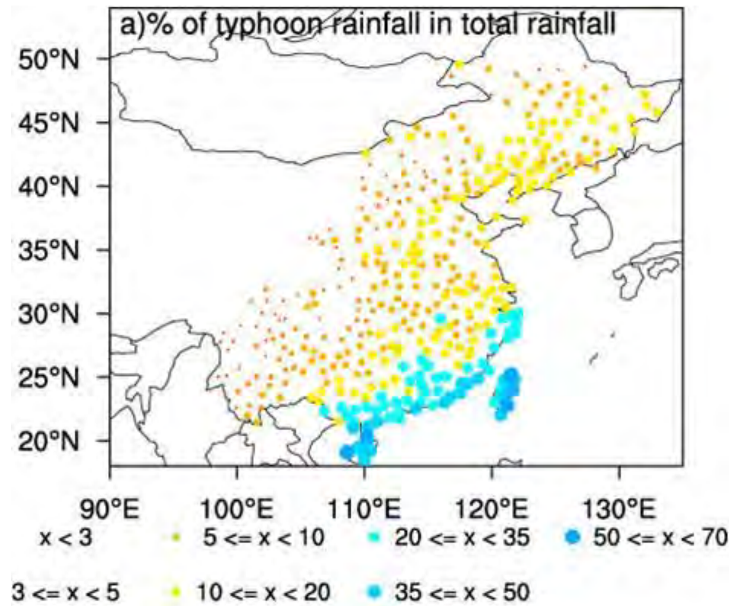
Total Rainfall



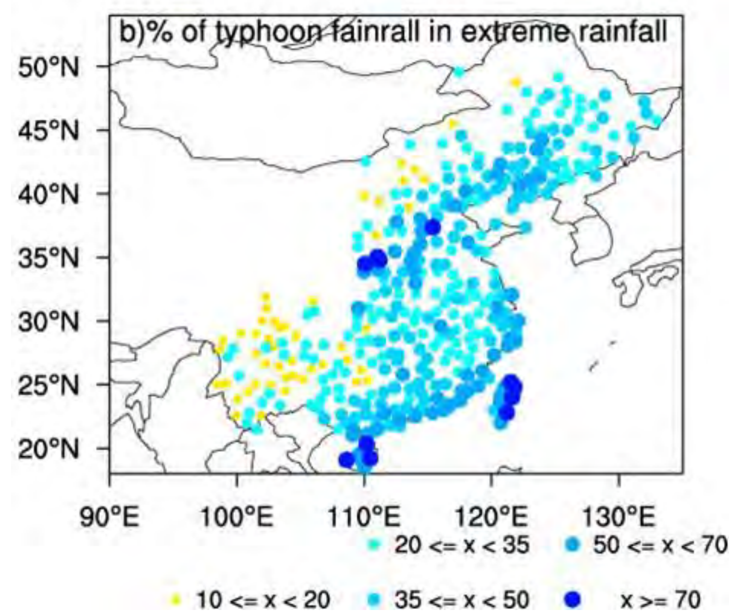
Extreme Rainfall



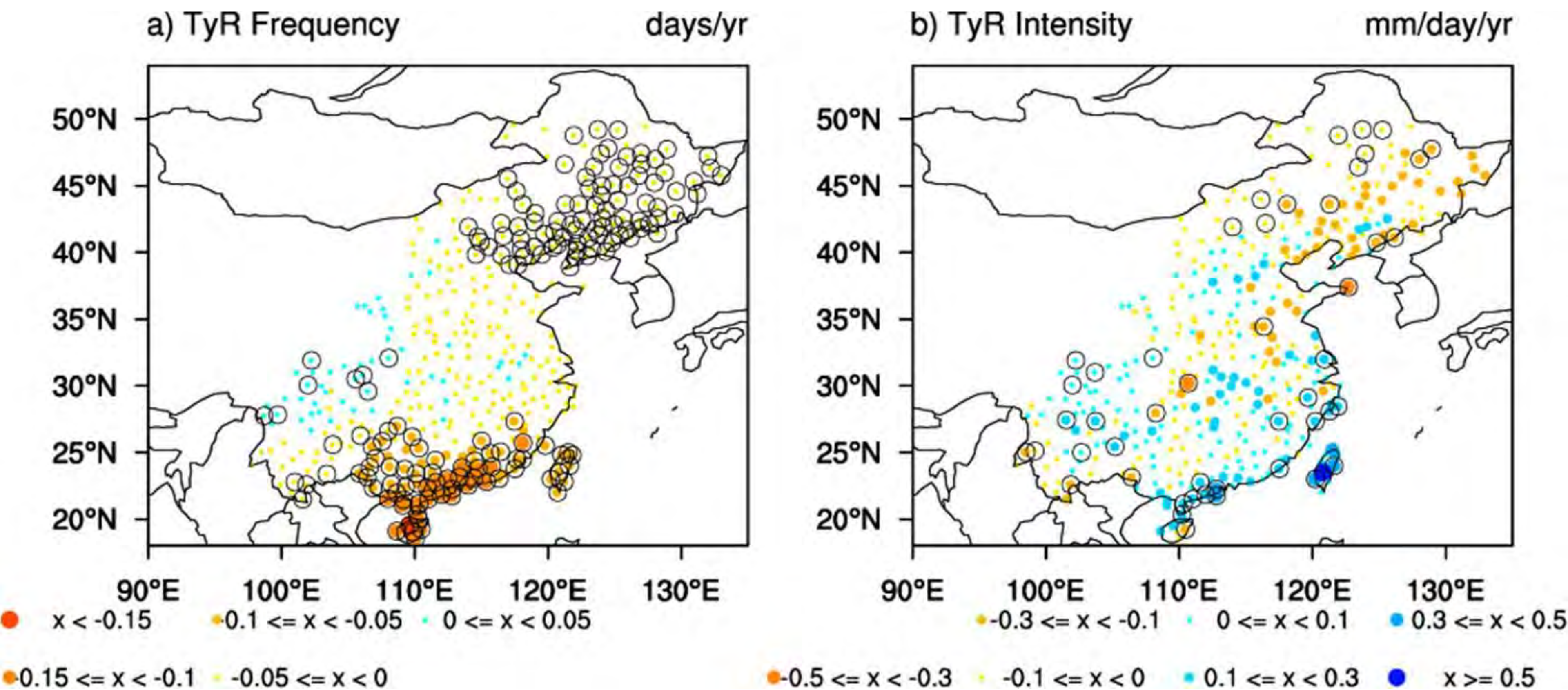
Percentage of TC rainfall in Total Rainfall



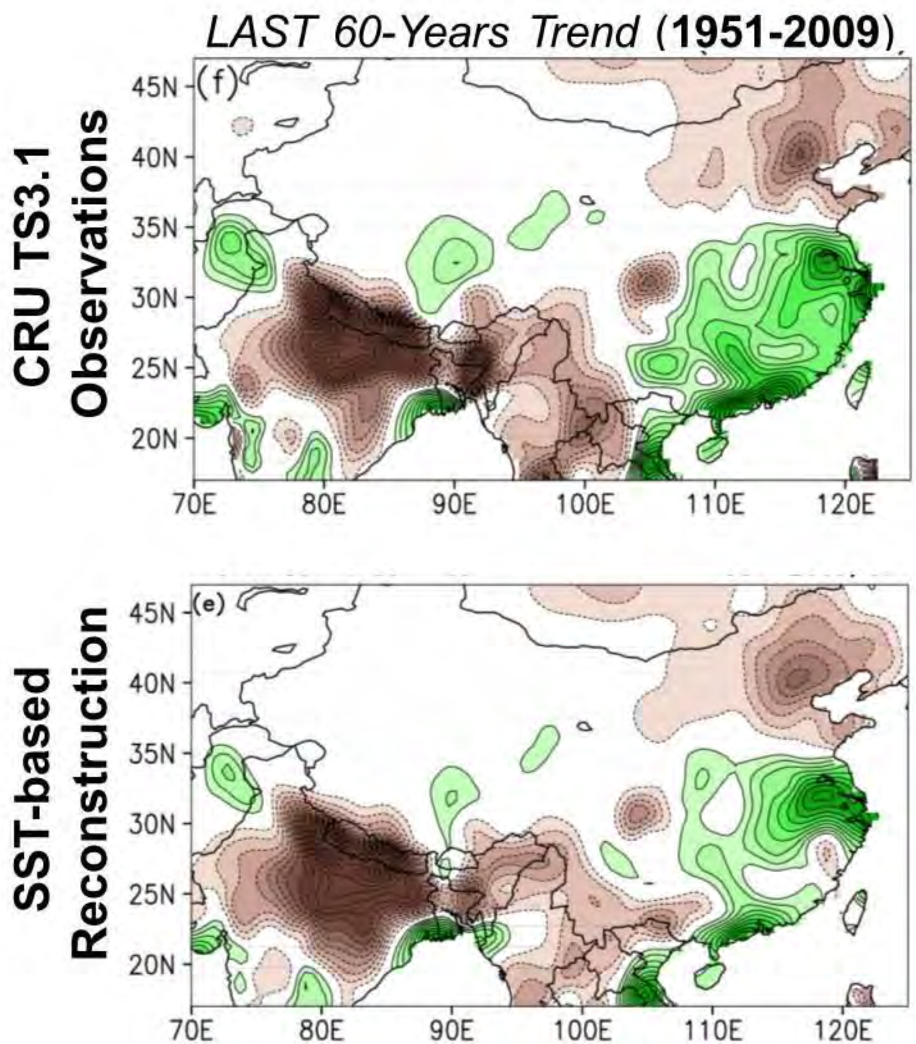
Percentage of TC rainfall in Extreme Rainfall



Typhoon rainfall linear trends

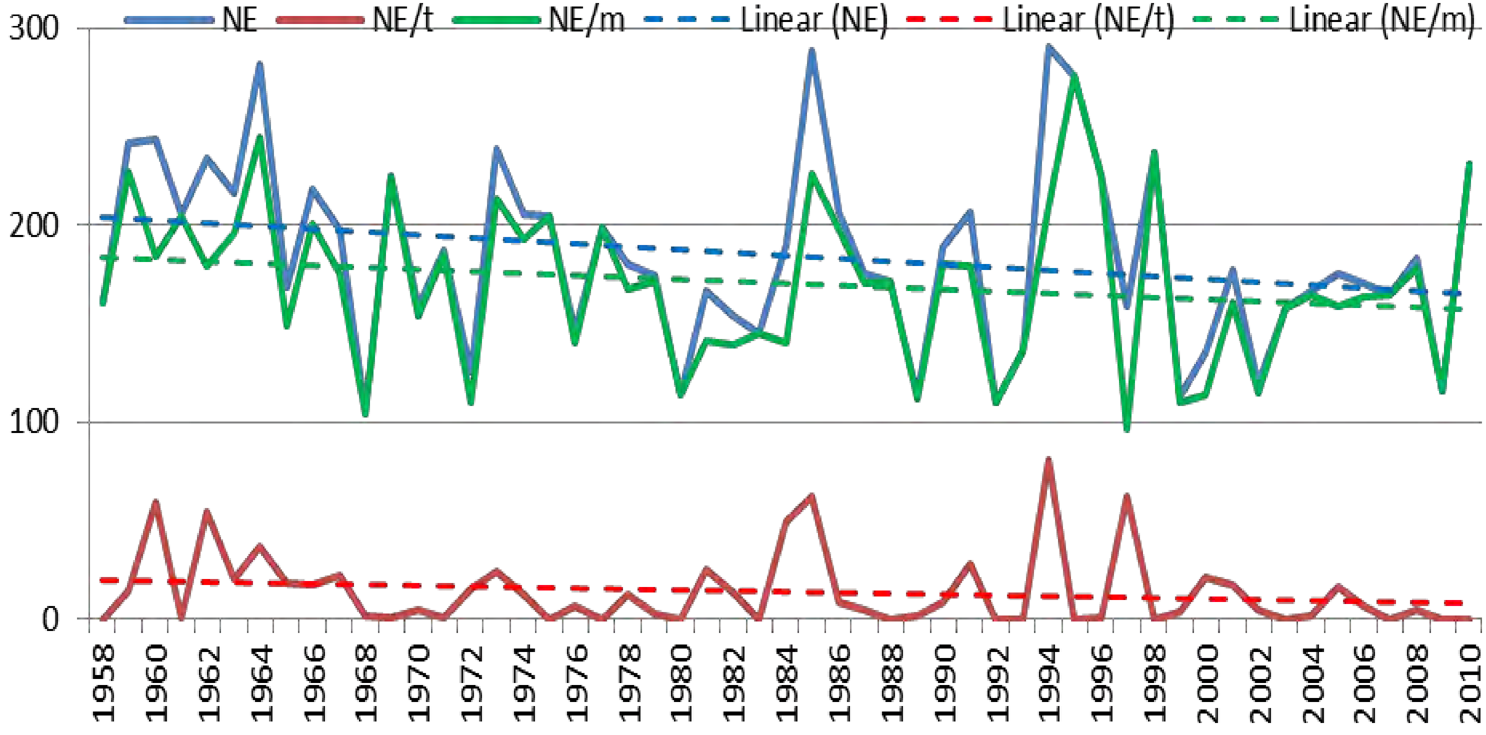


South-Flood North-Drought (SFND)



Nigam and Zhou (2012)
NTU International Science Conference on Climate Change

NE China


NE
NE/t
NE/m
Linear (NE)
Linear (NE/t)
Linear (NE/m)
300
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1966
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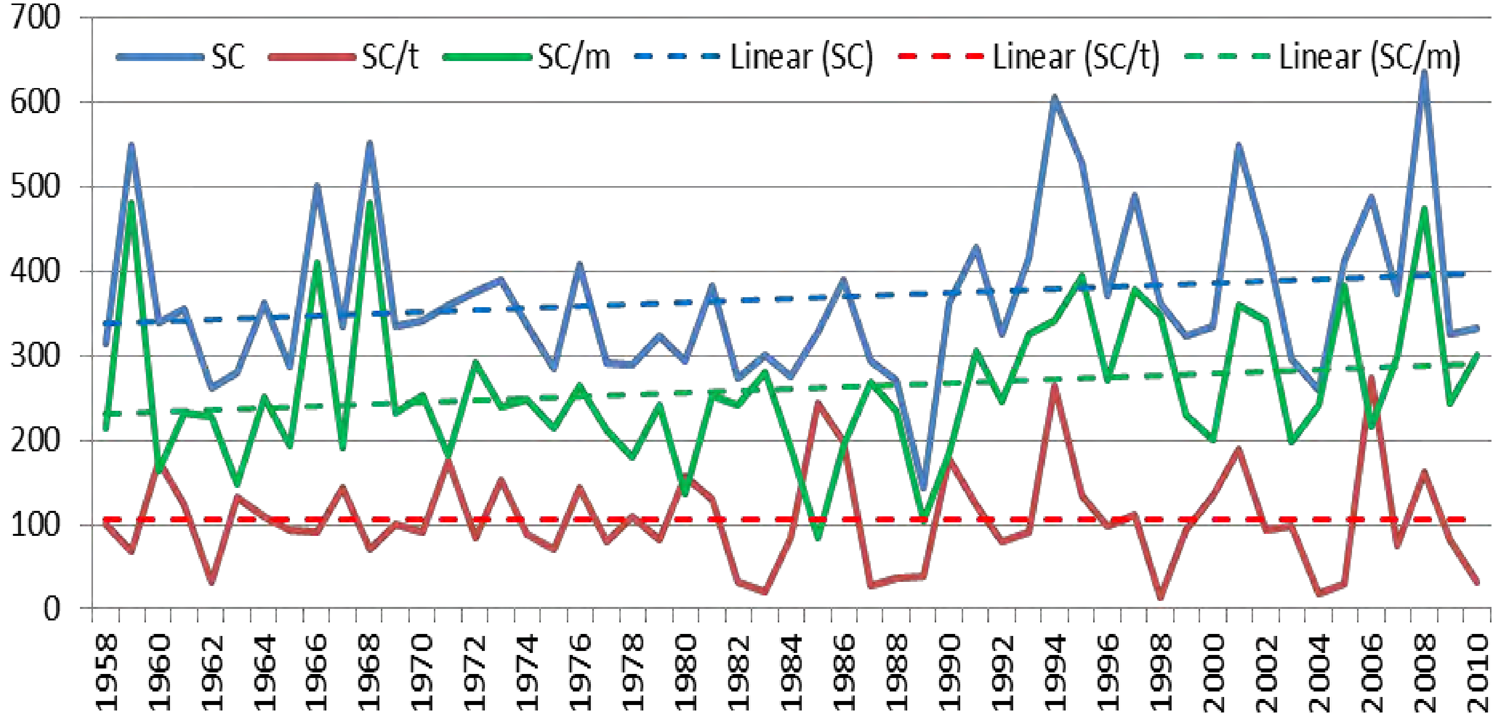
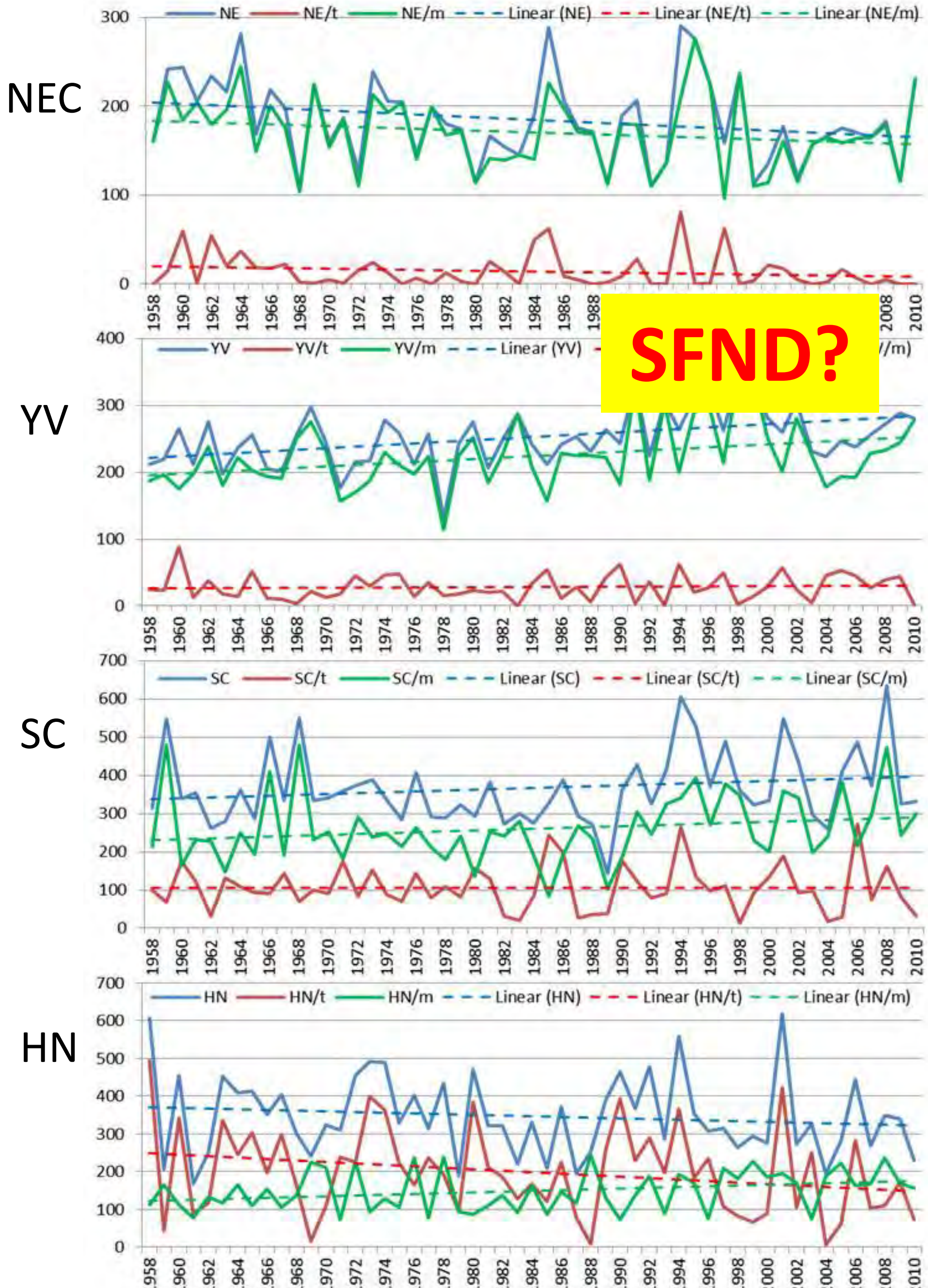
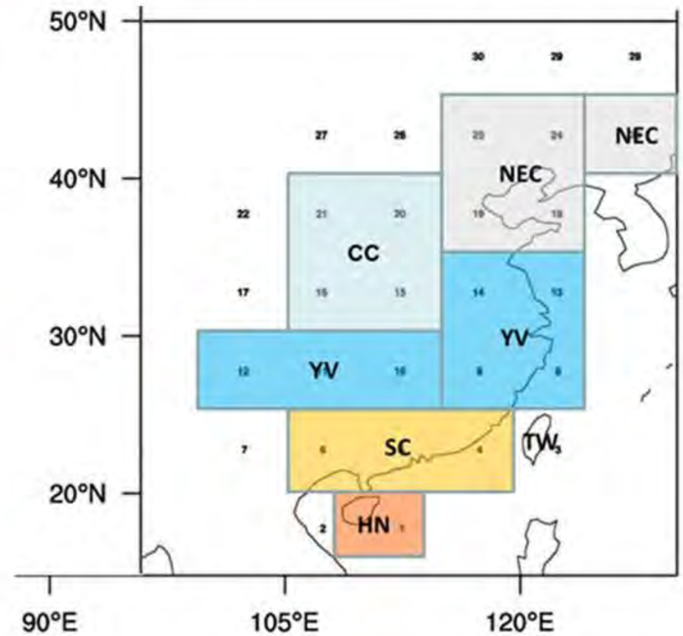
Southern China

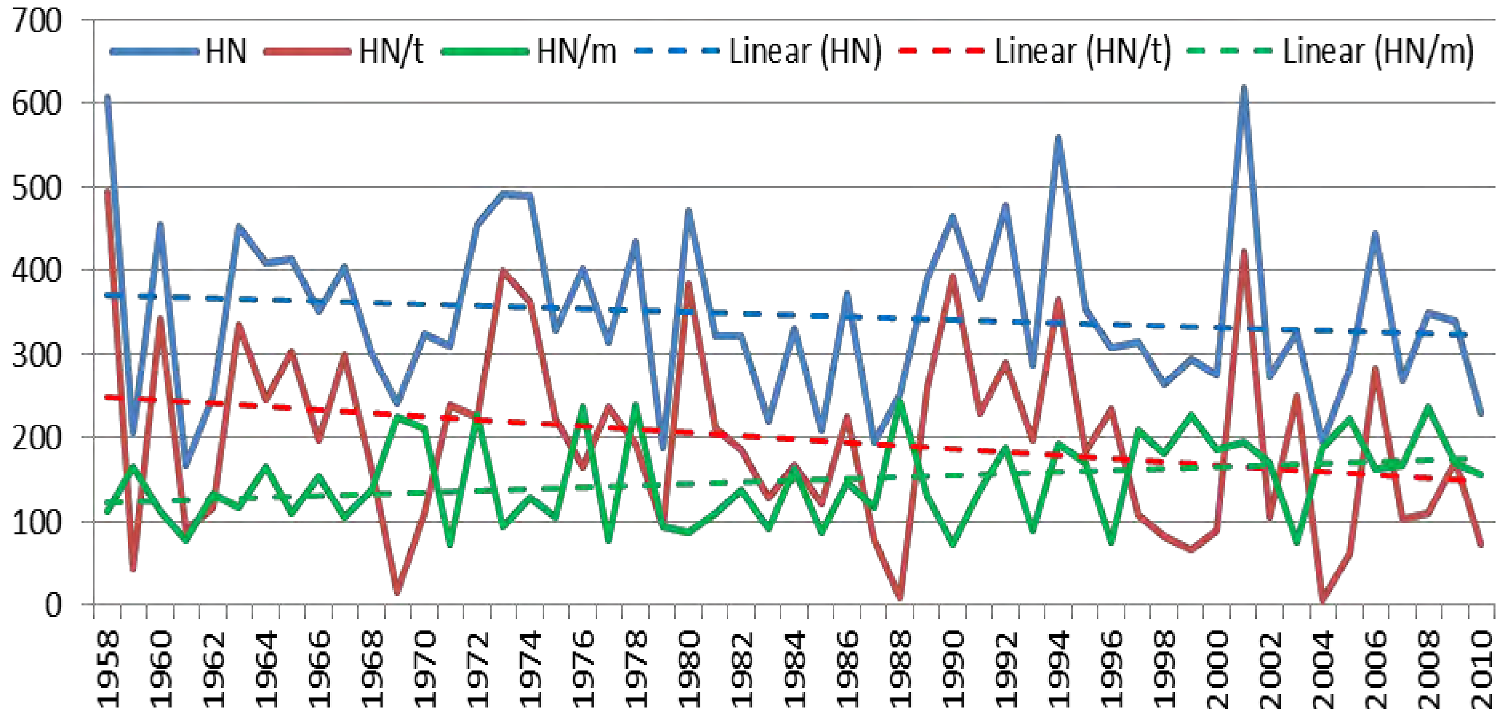






	Total	Monsoon	underestimate
NE China	**-21.4%**	-16.3%	32%
Central China	6.5%	7.3%	11%
Yangzi Valley	***25.1%***	***26.1%***	4%
Southern China	16.5%	**23.3%**	29%
Hainan Island	-14.8%	**35.1%**	∞

Hainan



HN
HN/t
HN/m
Linear (HN)
Linear (HN/t)
Linear (HN/m)
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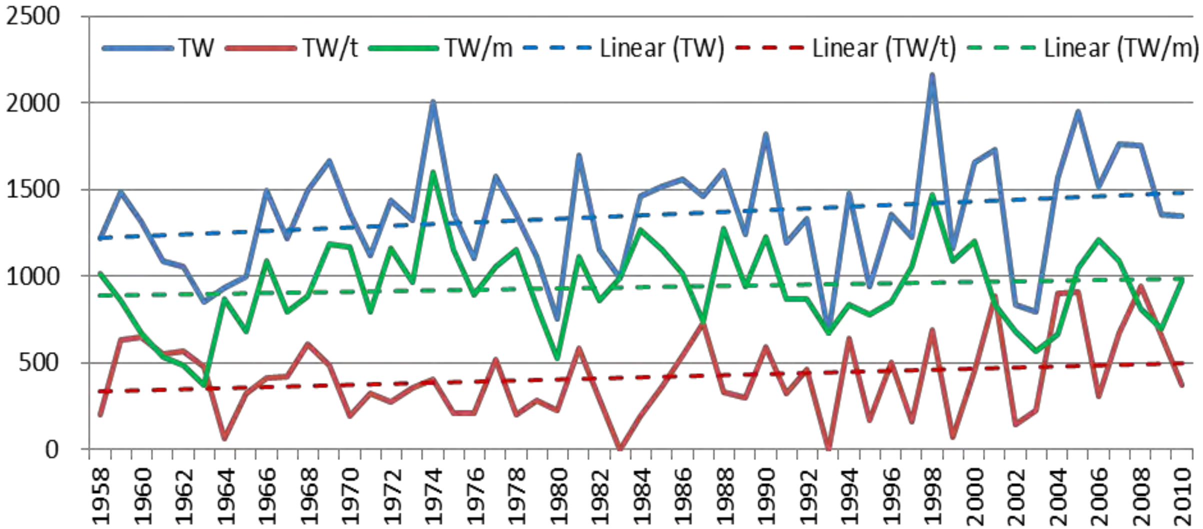
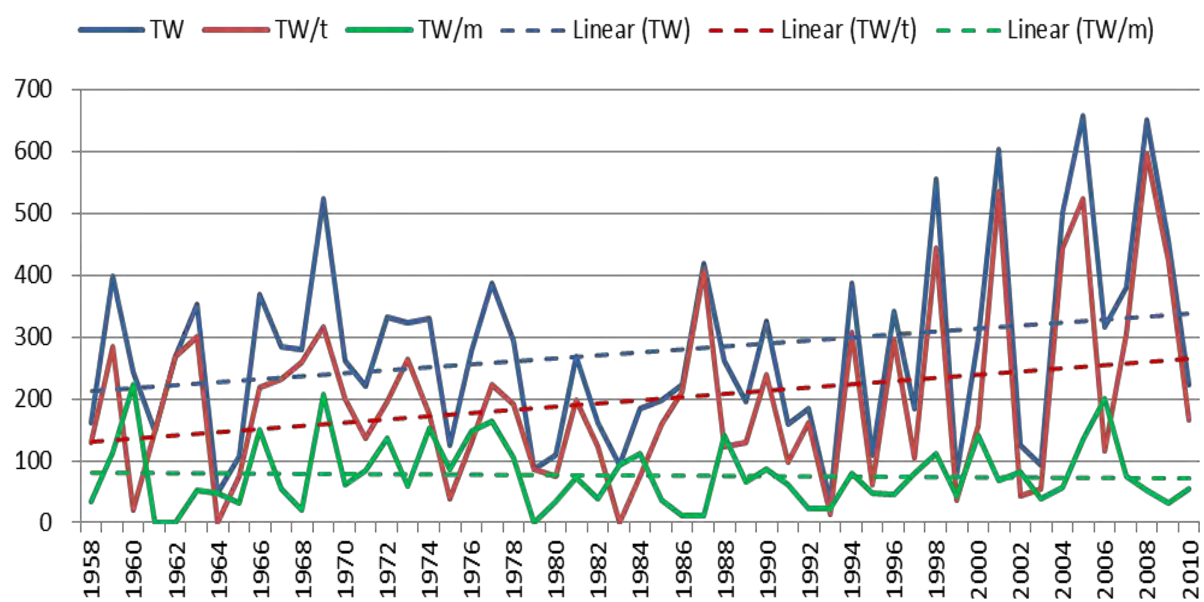
Taiwan



Total 19.5%

Monsoon 10.9%

Overestimate
~ 79%



Total 46.2%

Monsoon -12.2%

Overestimate ∞

Monsoon extreme rainfall trend (XRT)

- Since mid-20C, Decreasing TC rainfall frequency dominate increasing TC rainfall intensity. In most region TC XRT < monsoon XRT.
  - Intrinsic monsoon XRT is underestimated.
- Sign remains mostly negative in NE China.
  - A broader scale positive trend may emerge if SFND variation can also be isolated?
- Drastically opposite effects on Hainan and Taiwan.
  - Large Taiwan XRT cannot be attributed to thermodynamic effect of global warming.

Taiwan Typhoon Rain Intensity

- 21 hourly stations 1960-2011
- 84 landfalling typhoons (all seasons)
- Re-analyzed TC tracks by CWB & NTU, focusing on the three leading types: **N**, **C**, **S**
- 3 Track Phases: **PR**e-landfall, **O**ver**L**and, **EX**it
- Rainfall affected by
  - Interaction with Terrain
  - Interaction with Monsoon

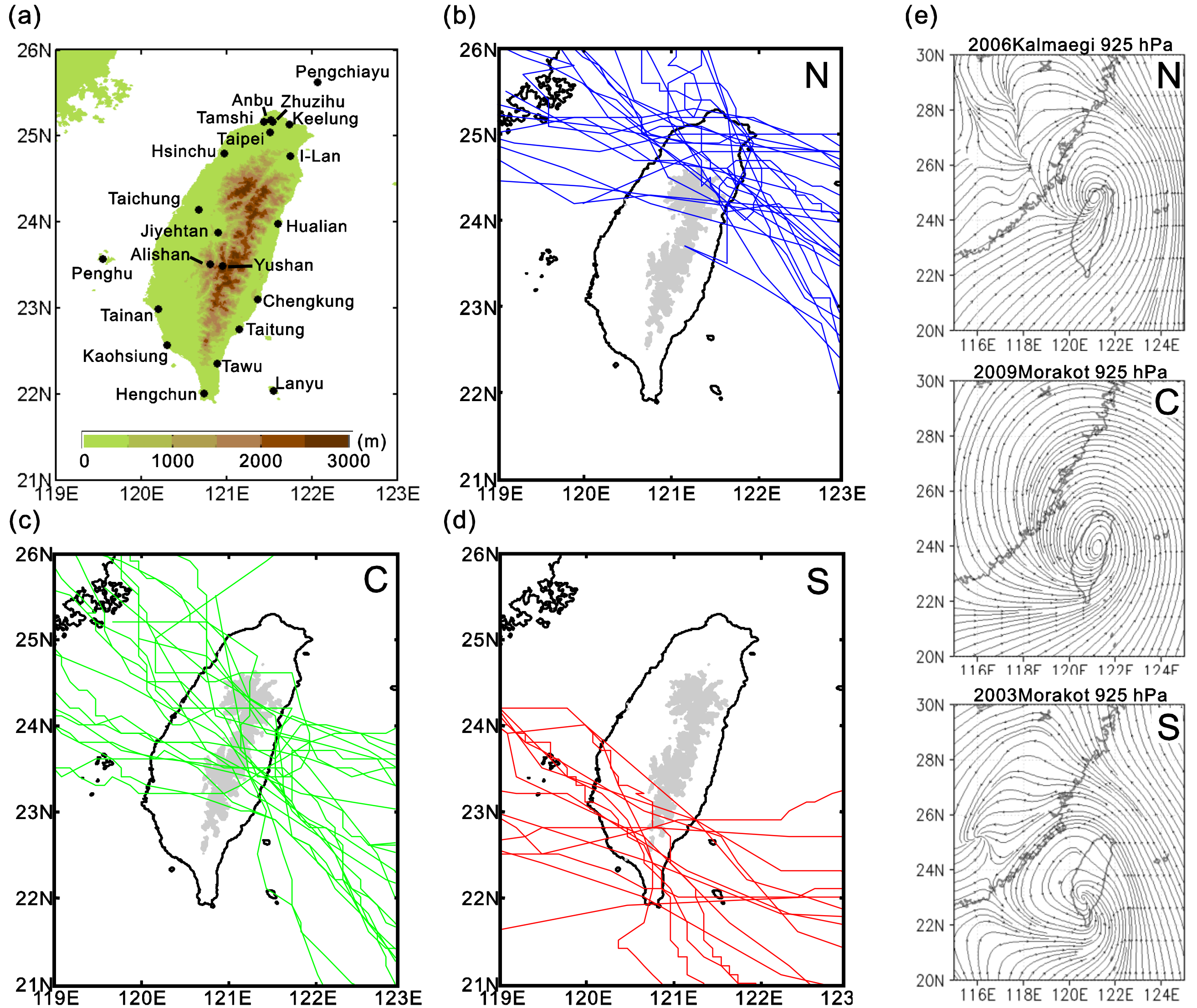
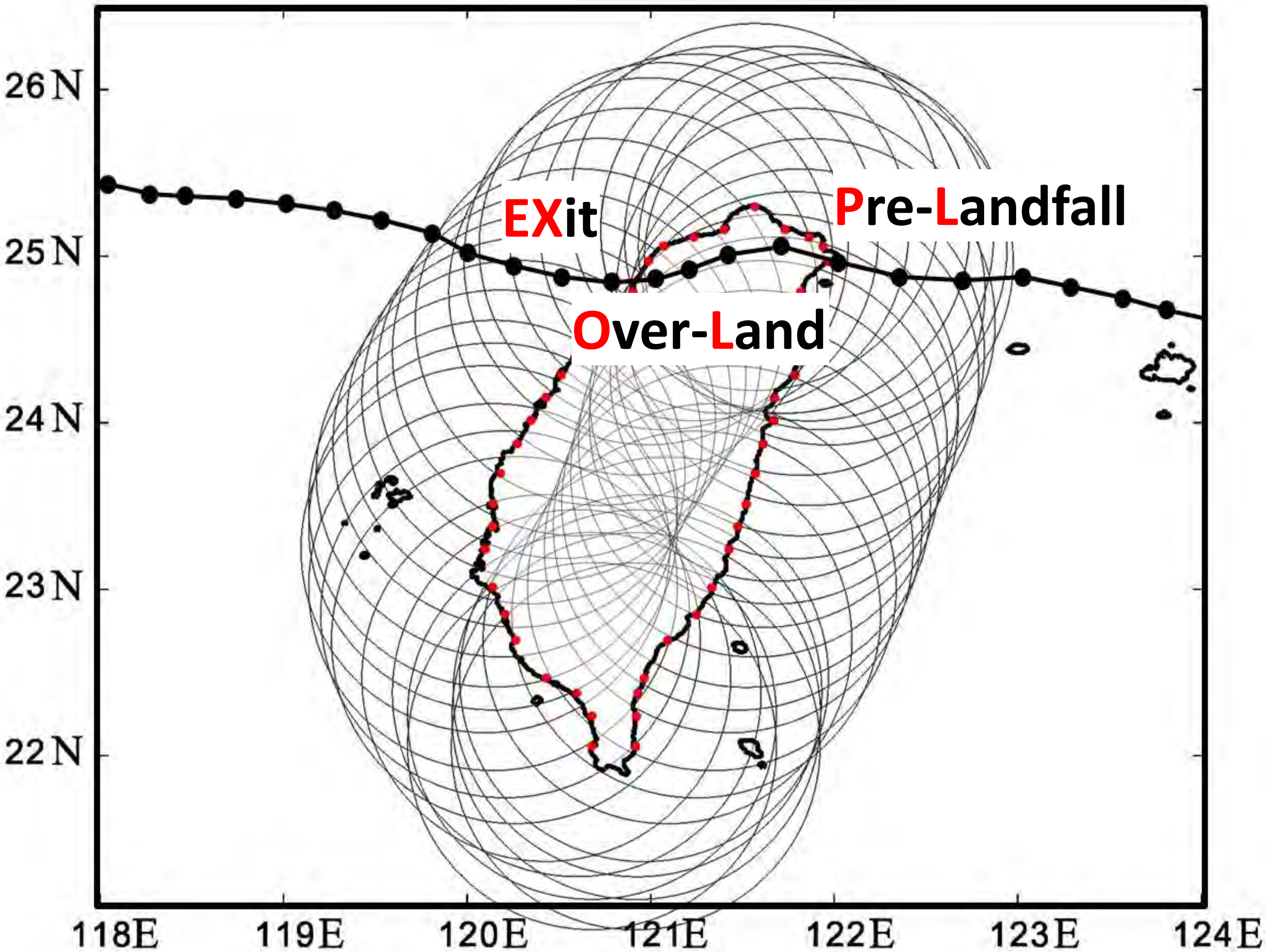
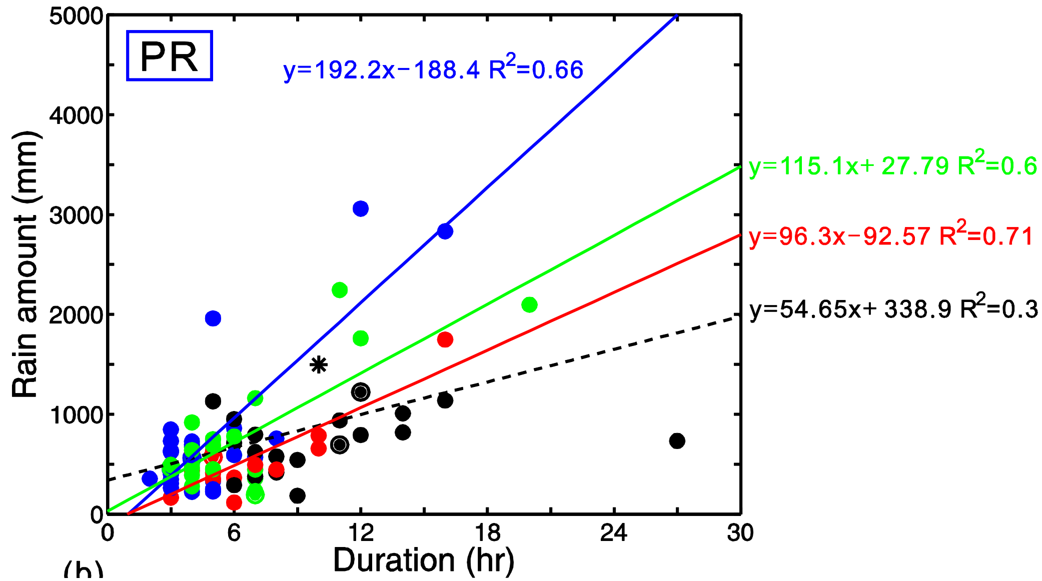


Figure 1. a) Taiwan topography and rainfall stations. b) The northern (N) type tracks. c) The central (C) type tracks. d) The southern type (S) tracks. e) Examples of 925 hPa streamlines for the three track types: N: Typhoon Kalmaegi (2006), C: Typhoon Morakot (2009), and S: Typhoon Morakot (2003).

Typhoon Track Phases



(a)



(b)

Figure 2. a) Rainfall amount (mm) versus duration (hr) during the pre-landing (PR) phase. The blue, green, and red dots mark typhoons of the three leading track types, N, C, and S, respectively. Black dots mark typhoons of the other six track types that made landfall in Taiwan during 1960-2011. Circled dots indicate two overlapping dots. The star symbol indicates Typhoon Nari (2001), an unusual case that broke the record of overland duration. The linear fitting lines and formulas for the N, C, S and All types are colored in blue, green, red, and black. The All type includes all 84 typhoons in the nine track types. b) The coefficient of determination (R^2) for typhoons with pre-landing durations up to six hours, nine hours, and 12 hours, and all cases.

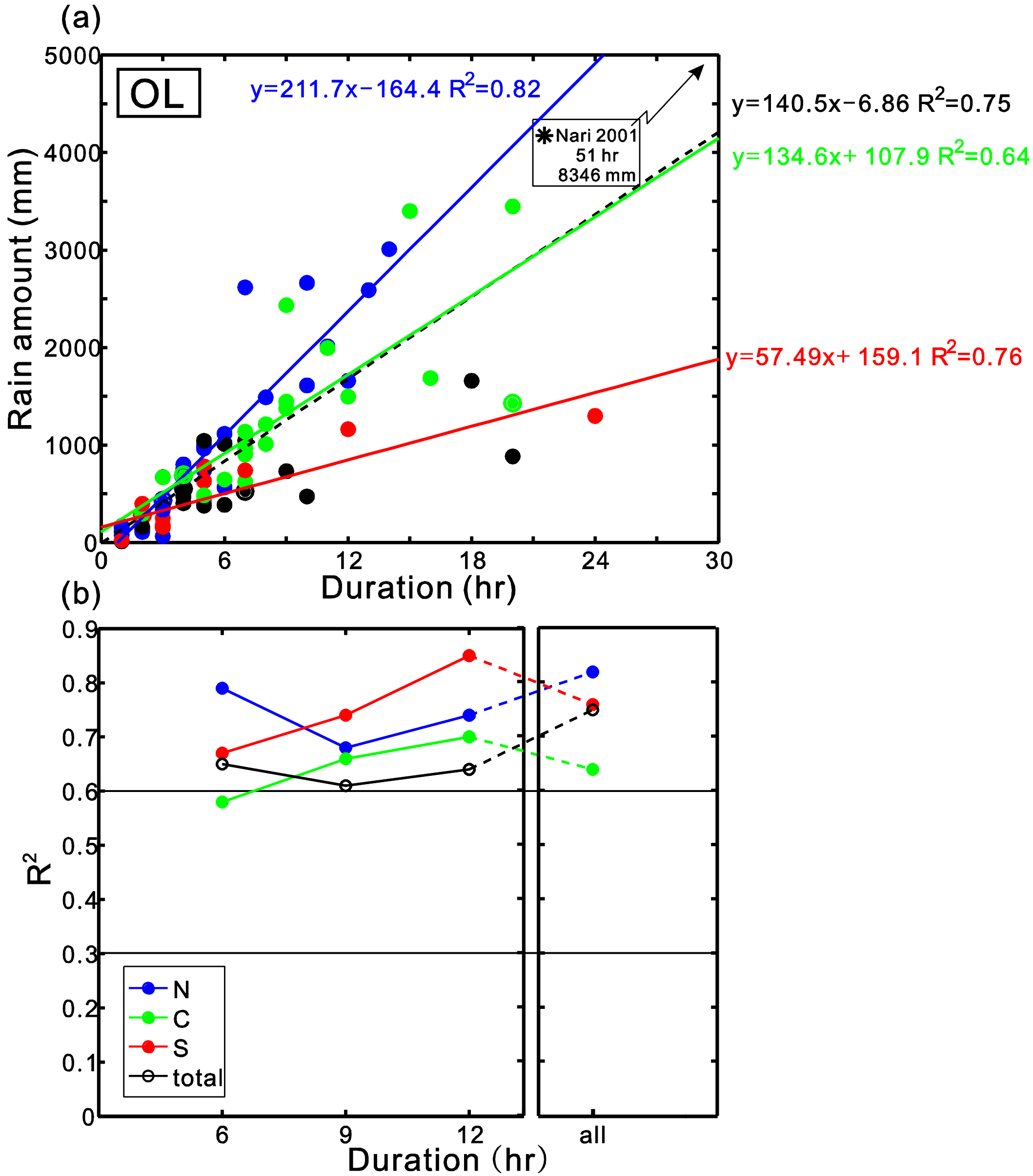


Figure 3. Same as Fig. 2 except for the overland (OL) phase.

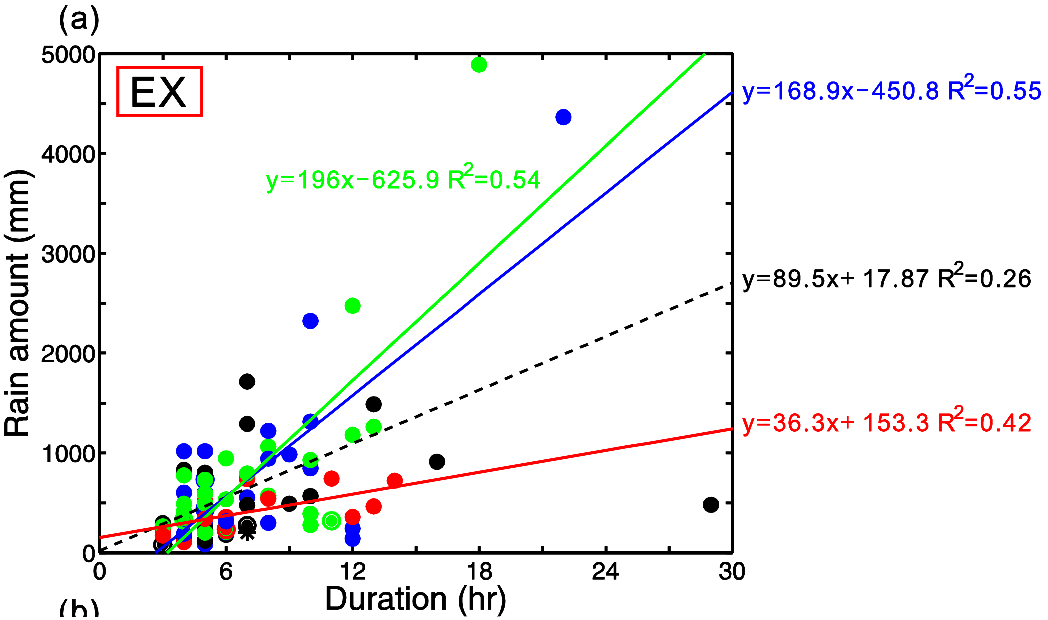


Figure 4. Same as Fig. 2 except for the exit (EX) phase.

Table 1: The ten typhoons in 1960-2011 with the highest total rainfall over Taiwan during the three phases. The seven since 2001 are highlighted in boldface.

Rank	Year	Typhoon Name	PR	OL	EX	Total (h)	Rainfall (mm)	Track type
1	**2001**	**Nari**	**10**	**51**	**14**	**75**	**10253**	**CWB Special**
2	**2009**	**Morakot**	**12**	**15**	**18**	**45**	**10045**	**CWB 3 (C)**
3	**2008**	**Sinlaku**	**16**	**10**	**22**	**48**	**8804**	**CWB 2 (N)**
4	**2005**	**Haitang**	**11**	**9**	**12**	**32**	**6162**	**CWB 3 (C)**
5	1996	Herb	5	7	4	16	5591	CWB 2 (N)
6	1989	Sarah	5	20	13	38	5455	CWB 3 (C)
7	1960	Shirley	3	11	10	24	4637	CWB 2 (N)
8	**2007**	**Krosa**	**12**	**1**	**10**	**23**	**4540**	**CWB 2 (N)**
9	**2004**	**Mindulle**	**16**	**18**	**7**	**41**	**4508**	**CWB 6**
10	**2008**	**Kalmaegi**	**8**	**10**	**5**	**23**	**4435**	**CWB 2 (N)**

Cat. 1,2,3

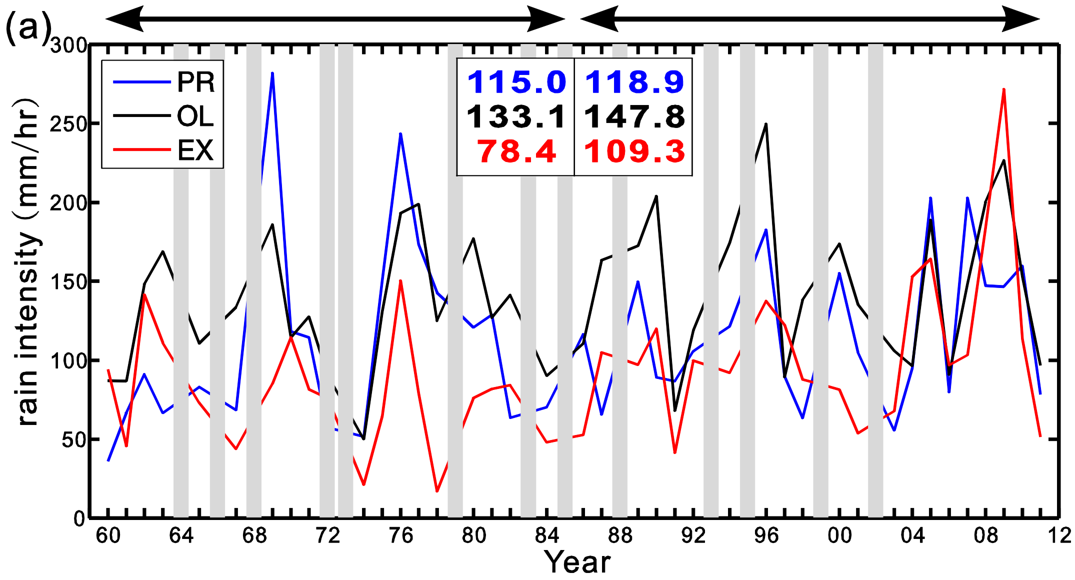


Figure 5. a) Time series of rainfall intensity from 1960 to 2011 for the pre-landing (PR, blue), overland (OL, black) and exit (EX, red) phases for weak and medium intensity (Category 1-3) typhoons. Grey vertical columns indicate years with no typhoons of the three leading track types. The table inside the panel lists the averaged rainfall intensities of the three phases during the first half (1960-1985, left column) and second half (1986-2011, right column) of the 52 year period. The two sub-periods are indicated by double end arrows above the panel. b) Same as a) except strong types (Category 4-5) are included. The rainfall intensity of each strong typhoon is indicated by the respective colored dots.

Huge increase of TC rain signifies global warming/climate change effects?

- Pre-landfall and Over-land, the increase is due to longer duration and slight change of tracks.
  - Not thermodynamic effect of global warming
  - Link to global climate change less likely
- After center exits Taiwan, increase due to stronger monsoon-TC interaction. (but not TC intensity)
  - Link to global climate change possible
- Terrain effect contributes to a false impression of climate change, yet it strongly controls the rain intensity and masks the climate change.

Taiwan Summer TC and Extreme Rainfall – Centennial Trend

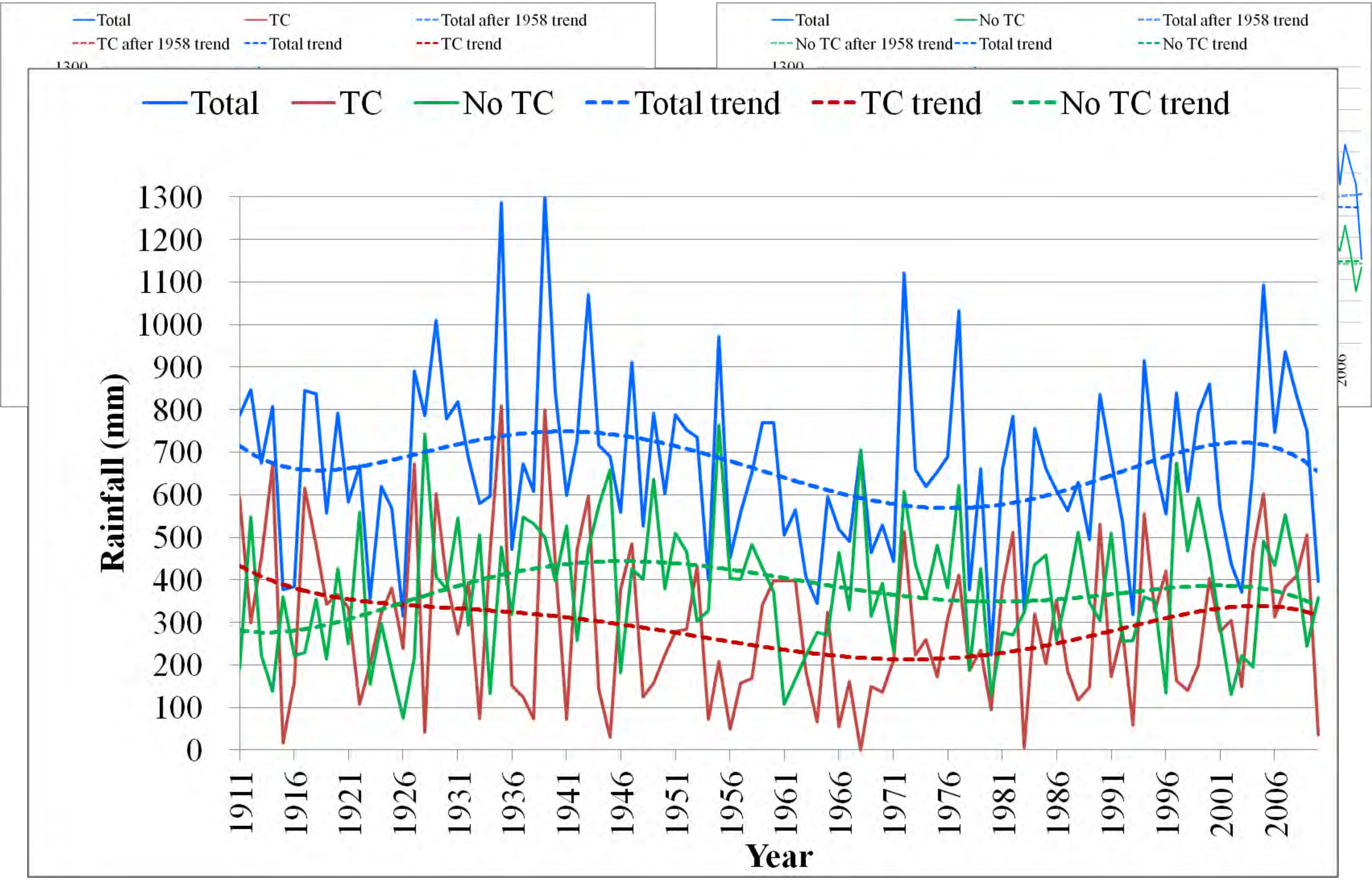
- 1911-2010; 100-years
- Six daily rainfall stations
- Typhoon rain = center within 600 km of station
- Tracks

    CWB 1958-2010

    JTWC 1945-1989

    NOAA-NCDC IBTrACS 1911-1957

Taiwan JJA 90th% (6 stations)

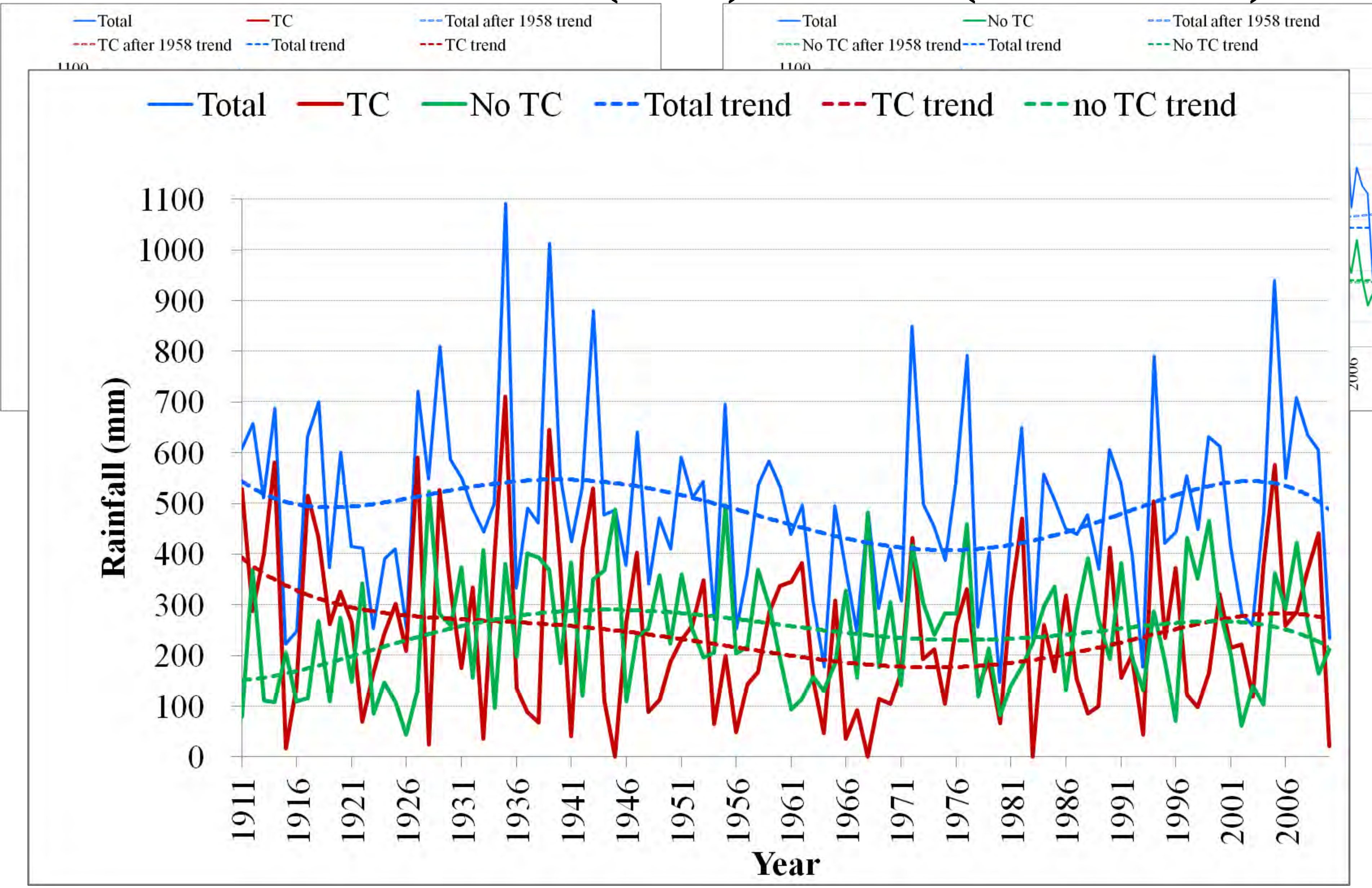


Summary

- Since mid-20C, China summer monsoon XRT mostly underestimated due to decreasing TC rain
  - After removing TC rain, more increase in south and less decrease in north
- A noted exception: Taiwan summer monsoon XRT hugely overestimated due to increasing TC rain
  - Caused by duration and track changes (terrain effects) and interaction with monsoon wind after TC exits.
  - Opposite to the centennial trend, but inherent monsoon XRT (~1%/decade) steady throughout the 100 years.
  - Different multidecadal variations for the TC and monsoon rainfall.

Thank You!

Taiwan Summer (JJA) 95th% (6 stations)



Large increase in Taiwan typhoon rain intensity in recent decade

- Mostly related to meso-α scale terrain effects : largest when center over land and smallest when exits to the Taiwan Strait.
- Within each track type rain intensity is near constant, heavier rain in recent decades mostly due to longer duration and more northern tracks.
- Increasing intensity in the last decade in the exit phase cannot be explained by the terrain effect, suggesting a decadal scale increase in the effect of monsoon-TC interactions.
  - Before exit phase, strong terrain control masked the increasing trend of TC rain intensity?