

Summer Monsoon and Tropical Cyclone Rainfall in Mainland China and Taiwan since Mid-20th Century

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I. Introduction

This study examines the long-term trend and decadal variations of station rainfall in the China summer monsoon region from 1958-2010. The region covers most of the Chinese continental area and two big islands off the southern coast, Hainan and Taiwan. Since most of the southern and eastern parts of the region is affected by tropical cyclones, the rainfall is partitioned into typhoon-related and monsoon-related (non-typhoon) categories to determine their respective roles. A particular focus is on the trend and variations of extreme rainfall, which has been reported as unprecedented in parts of the region and may indicate a possible effect of global warming.

II. Data and Methods

- 479 daily rainfall stations in Mainland China and 20 stations in Taiwan (10 used in EOF analysis).
- EOF Analysis of low pass filtered (9 years & +) data to focus on trend and decadal changes.
- Extreme rainfall is defined by the 90th percentile in CDF of daily rainfall by events or by amount.
- Typhoon rainfall over Mainland China is determined by the method proposed by Ren et al. (2006), which uses a 500 km range from center of named TCs and compares rainfall among neighboring stations up to 1100 km from TC center. Typhoon rainfall over Taiwan is defined as the rainfall during typhoon warning days.

III. Results

1. Climatology of total rainfall and typhoon rainfall

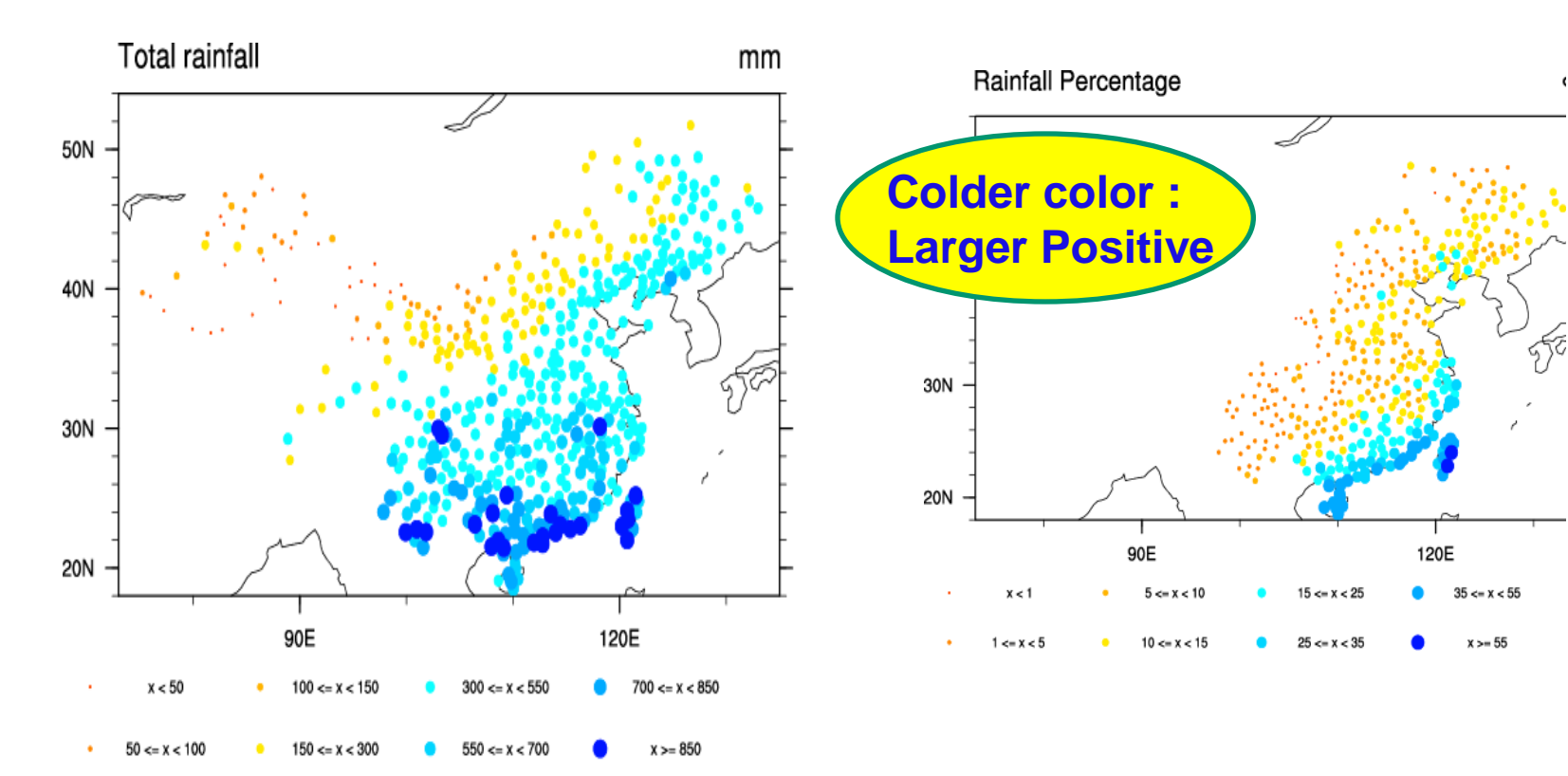
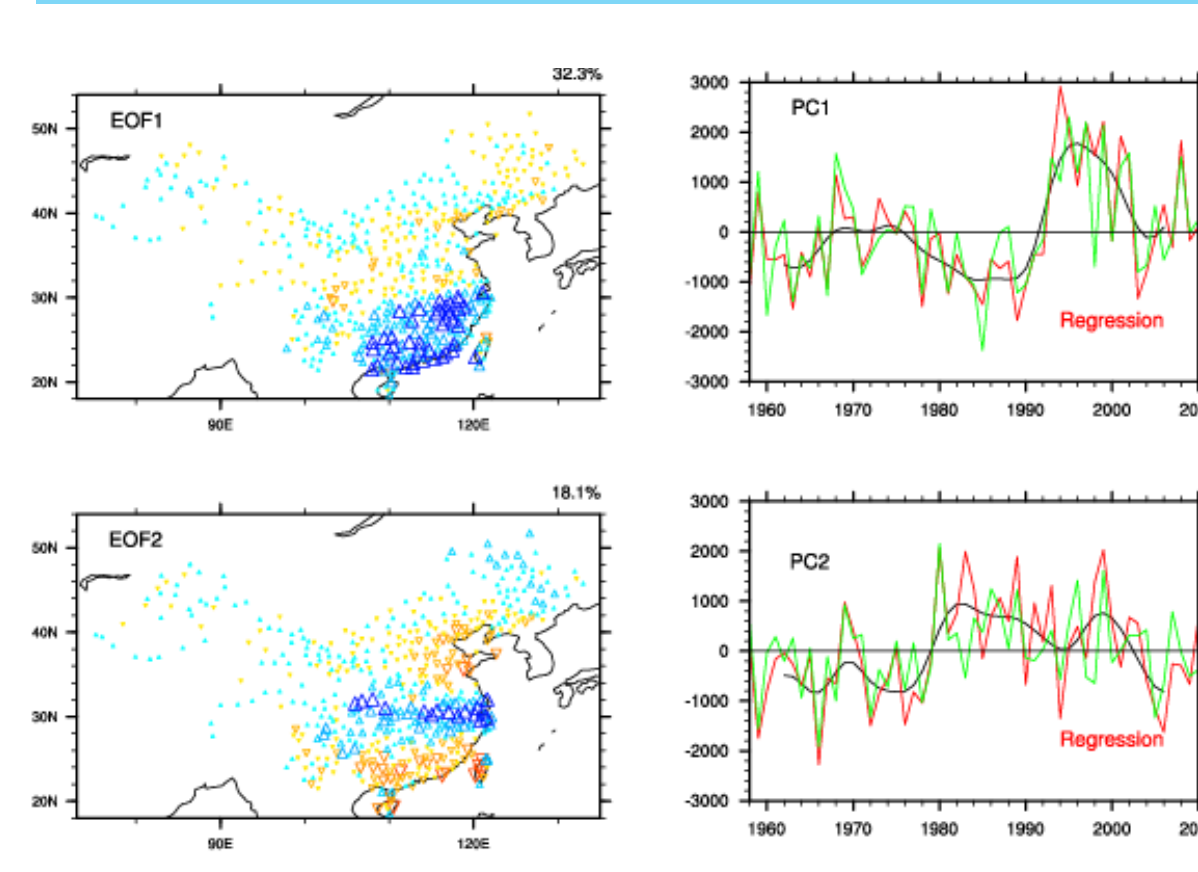


Fig. 1: Typhoon most important in Taiwan, followed by Hainan & southern coastal regions.

2. EOFs for total rainfall amount



Figures 2-7 are results of EOF analyses.

Fig. 2 shows the two leading EOFs of the total rainfall amount which is consistent with Lei et al. (2011). They are similar to patterns found in interannual studies even though interannual variations have been removed. Both PCs show large multi-decadal variations that is about five times the linear trend. PC1 for the Southern China (SC) pattern (~32%) peaks in mid-1990s. PC2 for the Tri-Pole (TP) pattern (~18%) flips phase in late 1970s, a period known for major regime change in Pacific SST.

3. EOF for total rainfall frequency

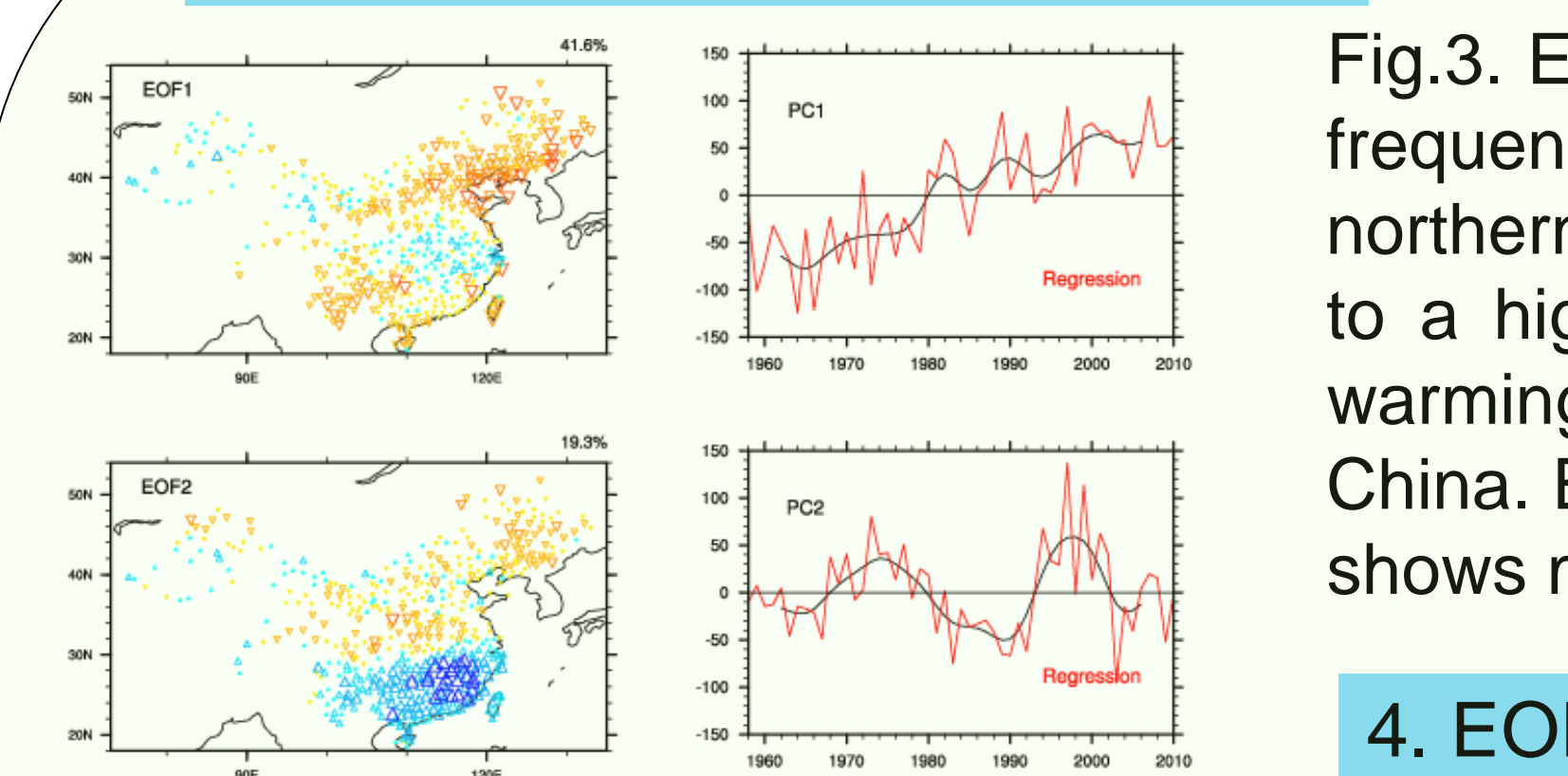


Fig. 3. EOF1 (~42%) resembles a tri-pole pattern that indicates a significant trend of less frequency in both northern and southern China. However, the causes are different. In northern China the decrease may be related to the reduction of light rain, which accounts to a higher portion of the total rainfall there. The reduction may be related to global warming (Lei et al. 2011). This is not the case with the reduction in frequency in southern China. EOF 2 (~19%) is probably related to the Southern China pattern in total rainfall. It shows mainly multi-decadal variations and very little trend.

4. EOF1 for monsoon (non-typhoon) rainfall frequency

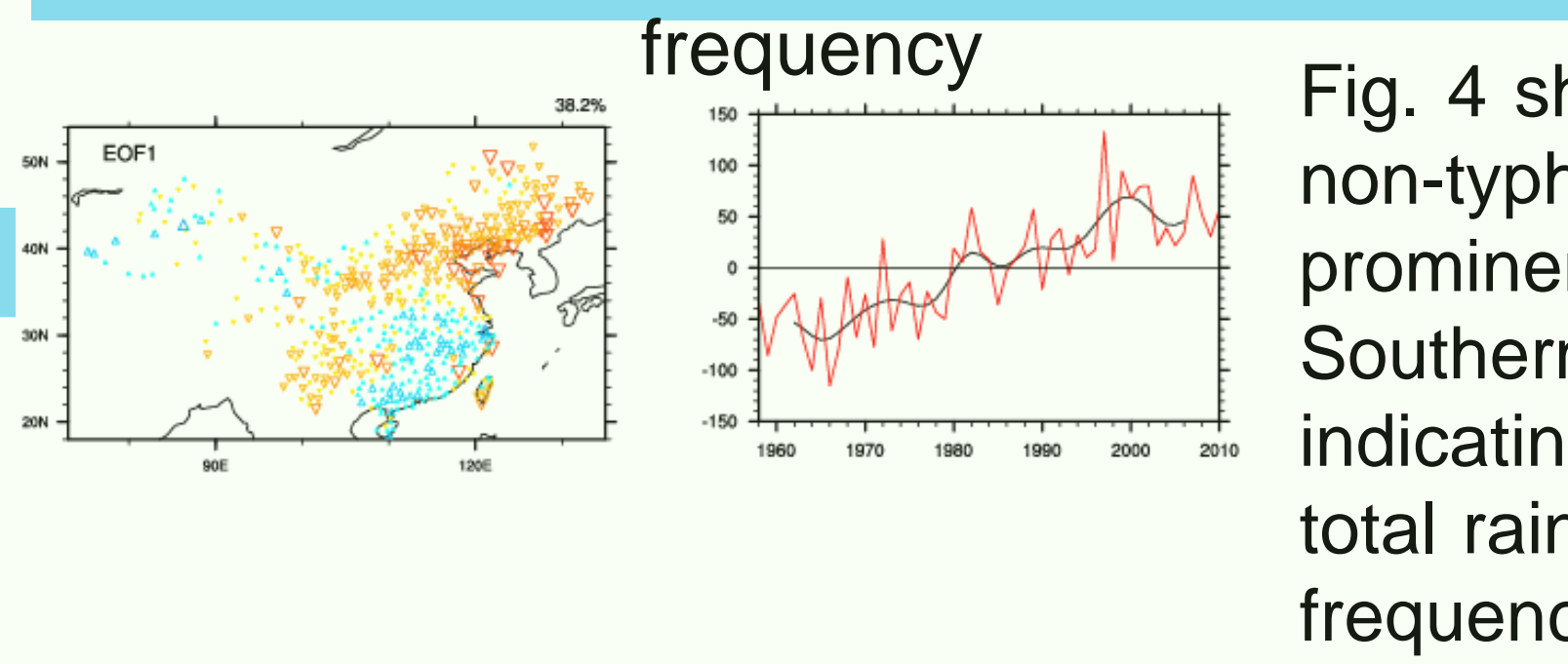


Fig. 4 shows that in the leading EOF (38%) for the non-typhoon frequency, the linear trend is similarly prominent, but the Tripole pattern disappears. Southern China now shows an increasing trend, indicating that the decreasing frequency trend in the total rainfall pattern (Fig. 3) is related to a declining frequency in typhoon rainfall. See in Fig 5.

5. EOFs for typhoon rainfall frequency

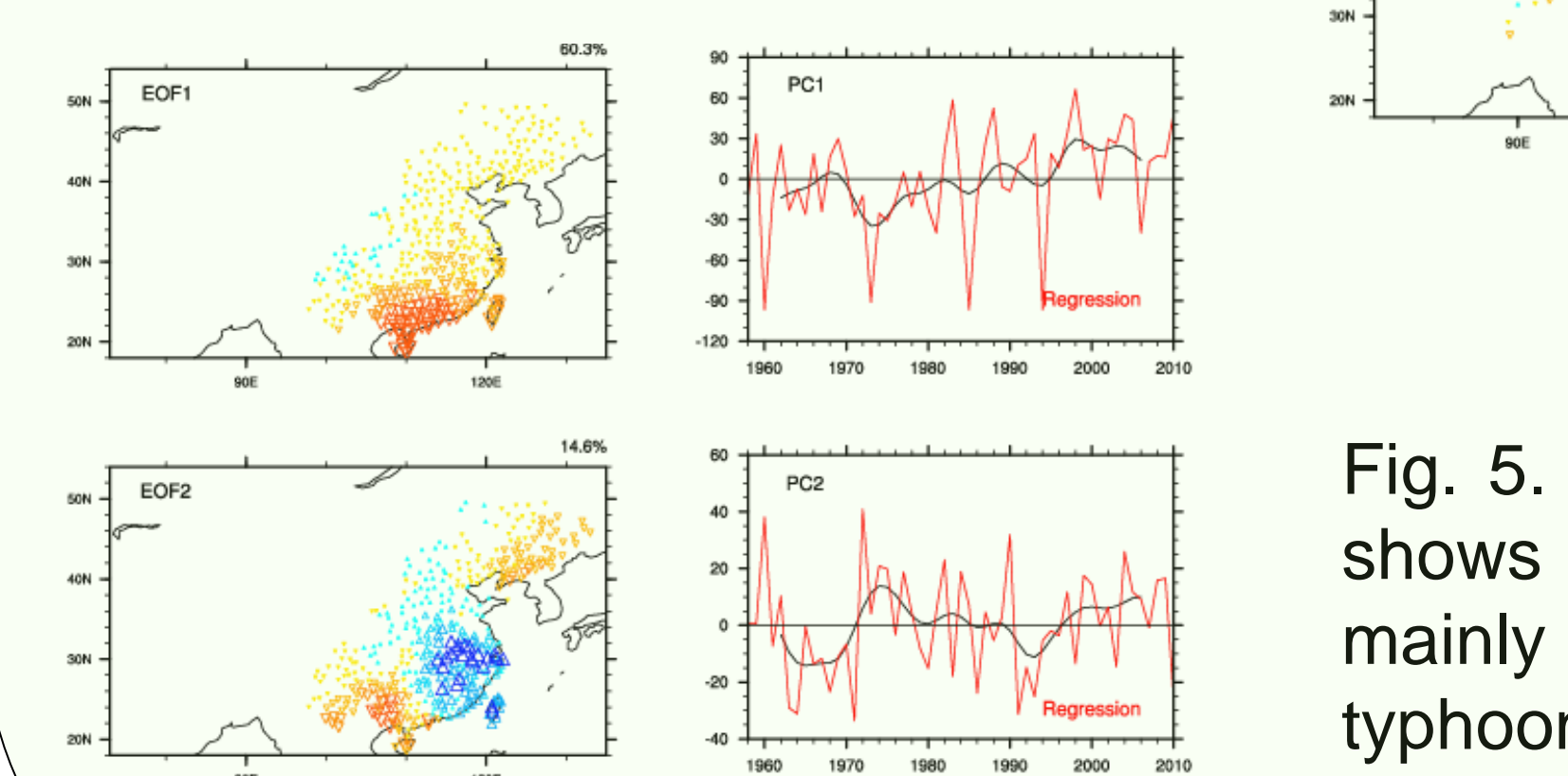


Fig. 5. The leading mode for the typhoon rainfall frequency (EOF1 60%) shows a general decreasing trend. The second mode (EOF2, 15%) is mainly a multidecadal seesaw between a "central track" mode indicating typhoons moving northwestward through the vicinity of Taiwan, and a wings track" mode of typhoons deflected to either side of the central track.

6. EOF for total rainfall intensity

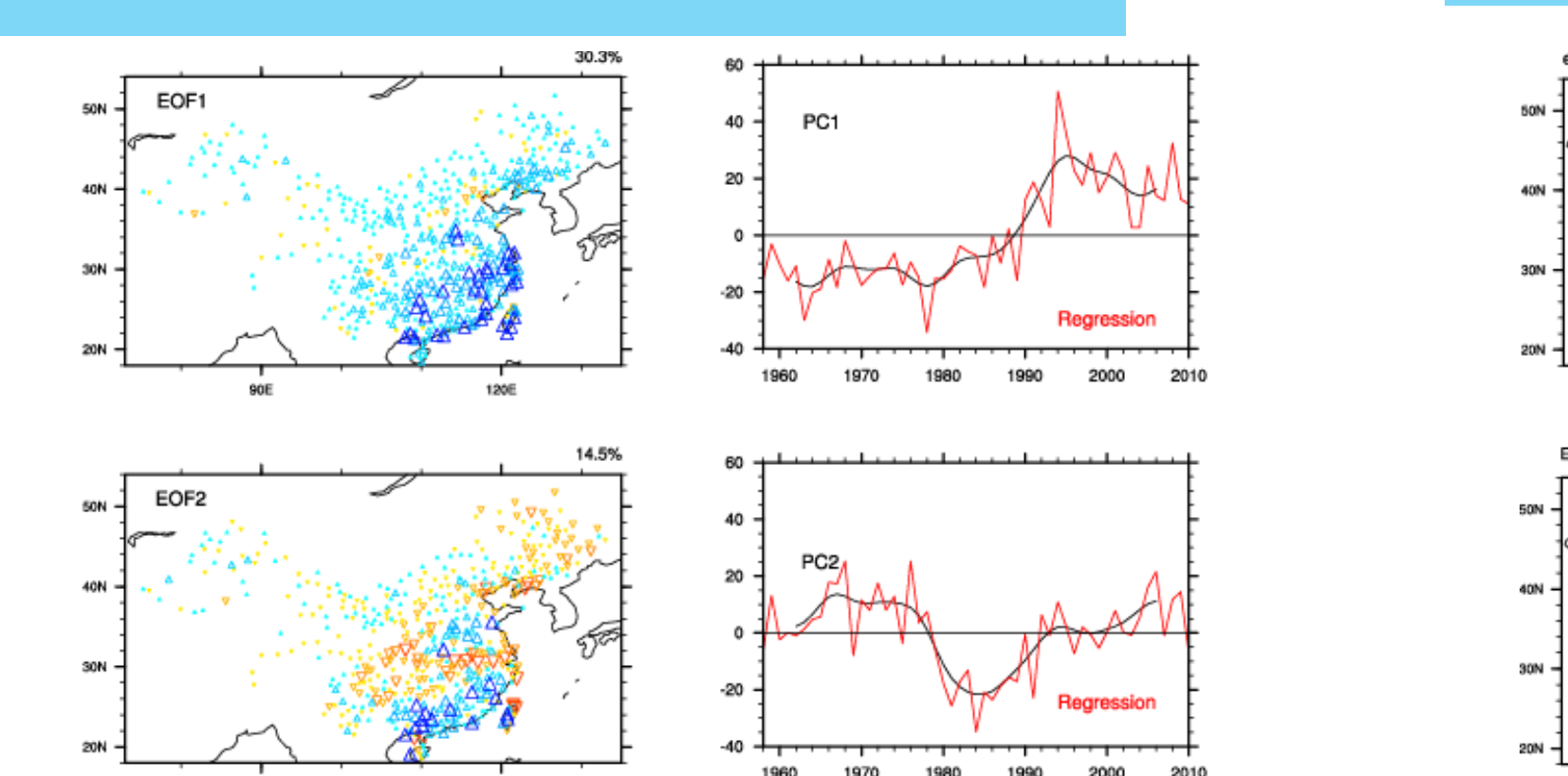


Fig. 6. EOF1 of rainfall intensity (30%) shows both a trend and a multi-decadal variation with maximum in the 1990s. EOF2 (15%) pattern is more complex and the variation is mainly decadal. The intensity of non-Typhoon rain shows similar results

7. Combined EOF1 for extreme events

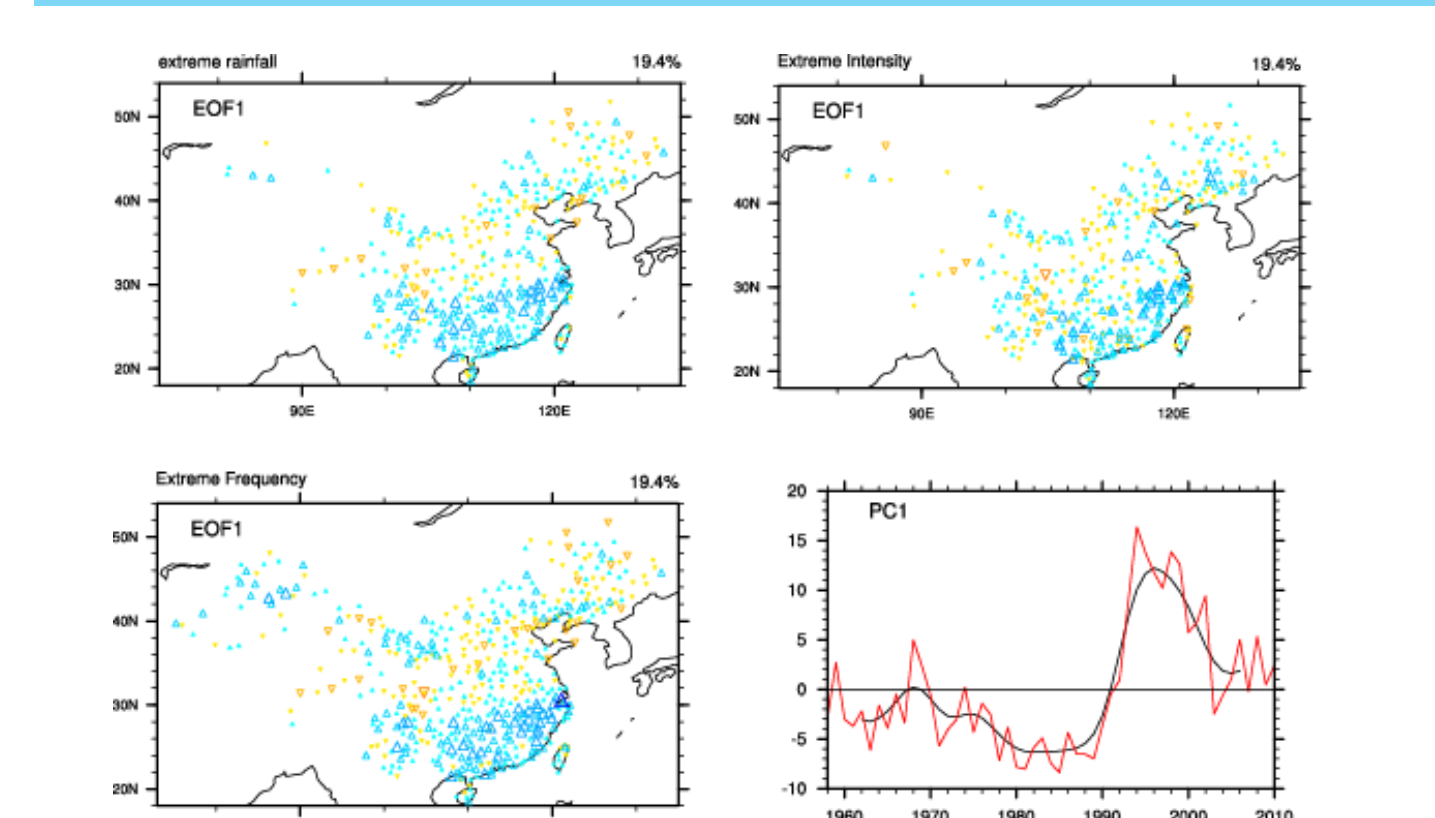


Fig. 7 shows the combined EOF1 for extreme rainfall amount, frequency and intensity. The patterns and the time variation of PC1 are similar to Fig. 2. These features basically remain when typhoon rainfall is removed. EOF2, not shown here, also resembles EOF2 in Fig. 2. Thus the leading organized patterns of extreme rainfall is mainly decadal, even though the intensity (Fig. 6) has a more discernible trend component.

8. Typhoon rainfall trends

Figures 8-12 are based on fixed point data. Fig. 8 shows that the typhoon rainfall, a), has an increasing trend north of 23°N-25°N and a decrease to the south. To the north of this latitude zone the general increasing trend in intensity, b), dominated over the general decreasing trend in frequency, c). The reverse is true to the south. The intensity and rainfall trend in north and northeast Asia may reflect effects of interacting mid-latitude systems and processes.

9. Extreme events rainfall

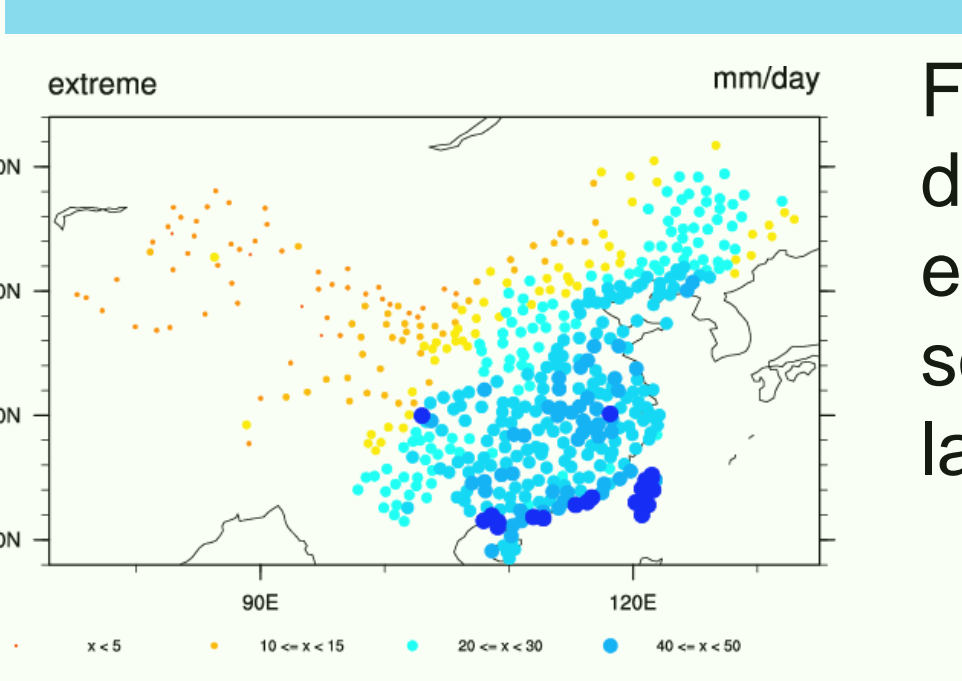


Fig. 9. The 90th percentile events are latitude dependent and decrease inland. The largest extreme event rainfall areas in Taiwan and southern coastal zone overlap with areas of largest typhoon rainfall (Fig. 1)

10. Extreme Rainfall (90th % Events) Monsoon and Typhoon contributions

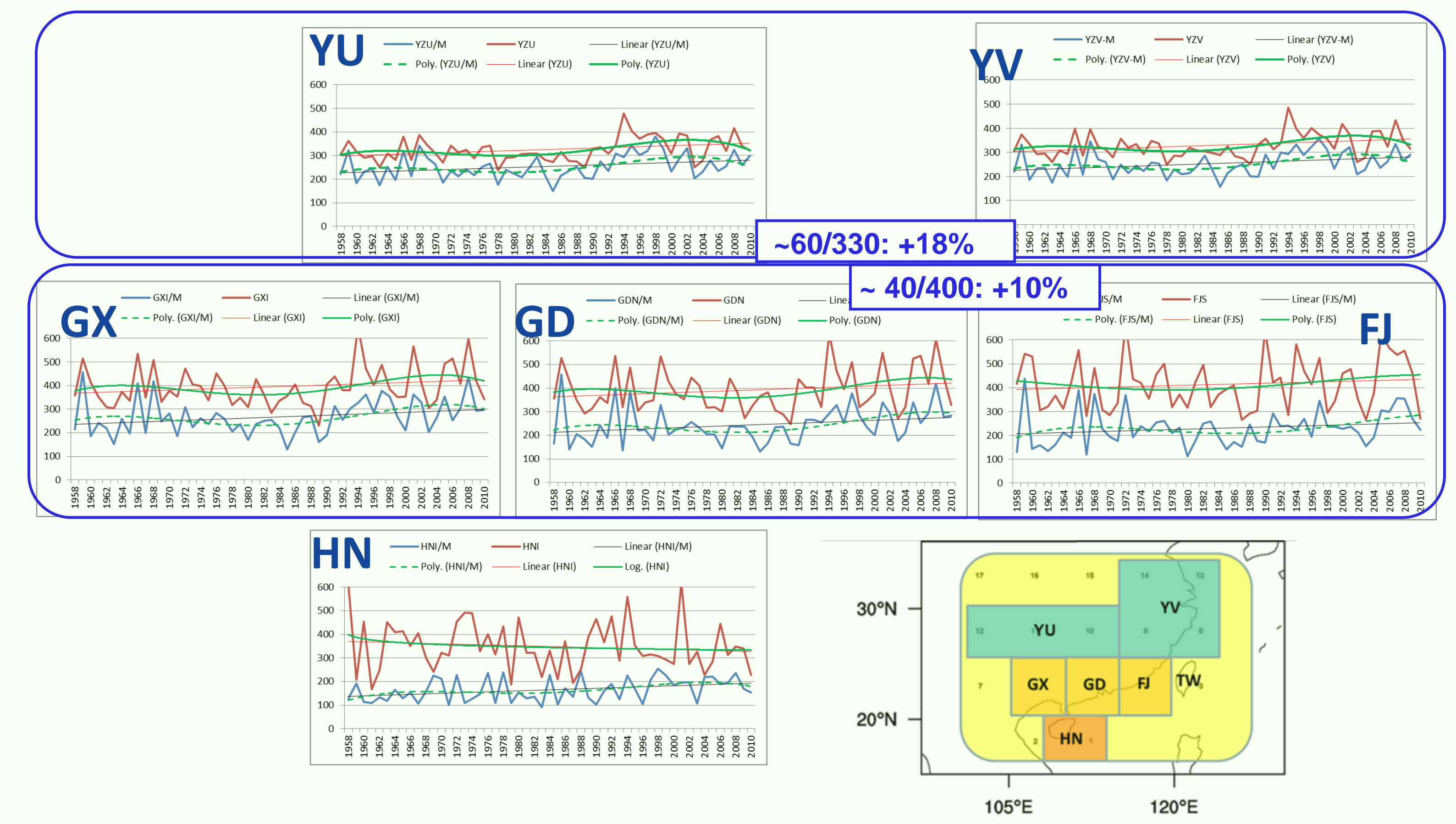


Fig. 10 shows the time series of area-averaged total extreme rainfall and monsoon (non-typhoon) extreme rainfall in six sectors (color boxes in the map inset). They are lower (YV) and middle (YU) Yangzi Valley north of 25°N; Guangxi (GX), Guangdong (GD) and southern Fujian (FJ) between 20°N-25°N along the southern coast; and the island Hainan (HN) south of 20°N. The linear trends are indicated by solid lines. The green curves are 4th order polynomial fits that indicate multidecadal variations. In both the Yangzi and the coastal regions the increasing trend and multidecadal changes are comparable and the changes of total, typhoon, and monsoon rainfall are similar. The 63-year trend is ~ 18% in the Yangzi valley and ~ 10% in the southern coastal regions. On the other hand, in Hainan the total extreme rainfall trend declines by ~23% but the monsoon extreme rainfall trend increases by ~50%. Being south of 20°N, the decrease in typhoon rainfall dominates over the increase in intense monsoon rainfall.

11. Very Extreme Rainfall (90th % Amount) Monsoon and Typhoon contributions

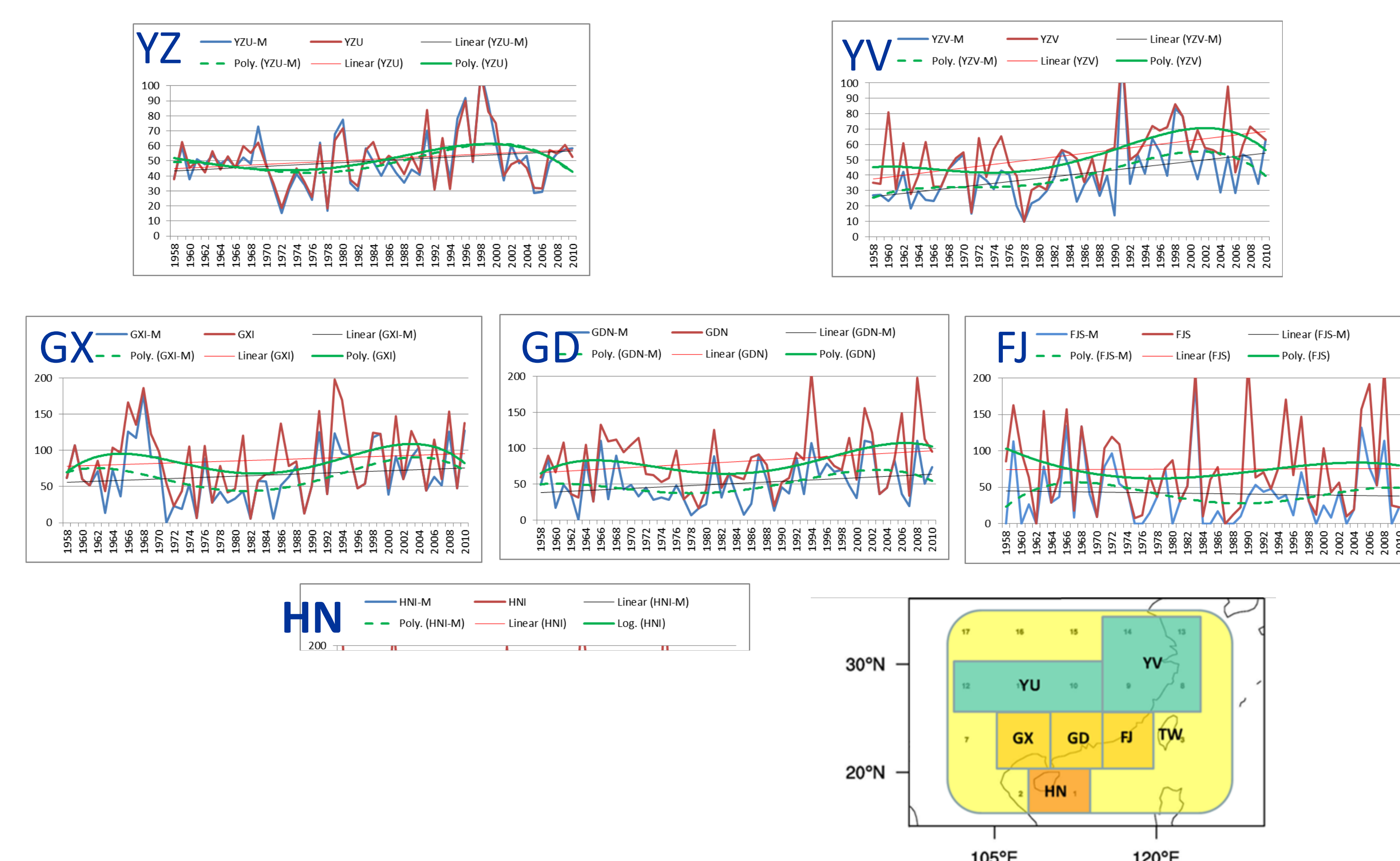


Fig. 11 shows the 90th percentile intense rainfall by amount. The thresholds are close to those of the 95th percentile events. Generally the trend is larger because the focus is on the more extreme end of the spectrum, but it also shows a more prominent multidecadal variations. For the eastern stations (YV, FJ, and GD), both the linear trends and the multidecadal changes are larger among the total, typhoon, and monsoon categories than shown in Fig. 11. In particular, FJ shows a slight upward trend in total extreme rainfall but a slight downward trend in monsoon extreme rainfall. In Hainan the trends show a large 30% decrease in total extreme rainfall, and a more than doubling increase in monsoon extreme rainfall.

12. Taiwan (all 20 stations) 90th % Extreme Rainfall

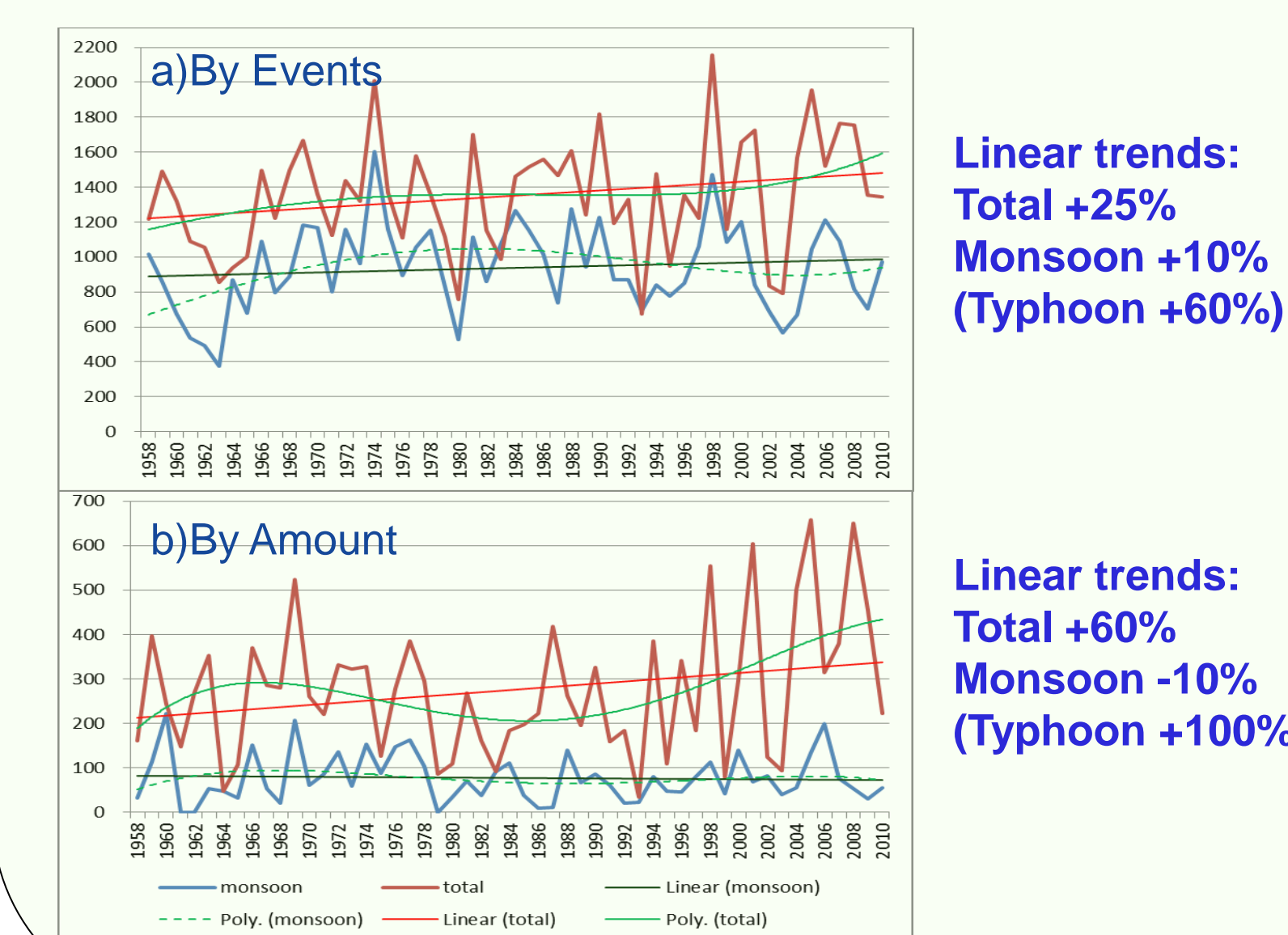


Fig. 12a shows the extreme rainfall in Taiwan based on all 20 stations average for the 90th percentile intense events. The linear trend of 20% is similar to the Yangzi valley. The increase is the result of a 10% increase in intense monsoon rainfall and a 60% increase in typhoon rainfall. When the criterion is raised to the 90th percentile amount (Fig 12b), the linear trend jumps to 60% due to four heavy rainfall typhoons in the 1998-2008 period, but the amount due to monsoon shows a 10% downward trend over the 63 years. The contrast of the changes between Hainan and Taiwan (and to a lesser degree FJ) clearly indicate the local effects of typhoons on the long-term extreme rainfall variations.

IV. Conclusions

- The two principal China summer rainfall EOFs, the South China pattern and the Tri-pole pattern, have strong decadal signals and no discernible linear trends over the last six decades. Similar features are found in the amount and frequency of the two leading EOFs of extreme rainfall events, with or without typhoon rainfall.
- Rainfall frequencies in both northern China and southern coastal region show a decreasing trend but the reasons are different. In the north it is mostly due to a decreasing trend in light rain. In the south it is mainly due to a decrease in typhoon rainfall frequency. The monsoon (non-typhoon) rainfall frequency actually increased.
- Linear trends of typhoon rainfall show decreasing frequency up to 1.5 day/10y in southern coastal region; and increasing intensity up to 5 mm/day/10y or more (around 30%-50% over 63 years) in Taiwan and NE China. The net result is a decrease of typhoon rainfall up to 30 mm/10y or more south of around 22°N-25°N, and an increasing trend to the north.
- The linear trends in South China extreme rainfall average to ~2% increase per decade, ranging from around 20% over 63 years in the middle and lower Yangzi Valley, and slightly less than 10% in the southern coastal region.
- In the first decade of the 21st century, increase of extreme rainfall in Taiwan accelerated, but the tendency reversed in the Yangzi and southern coastal regions. In Hainan a decreasing trend prevails over the entire 63-year period. These are all related to localized typhoon activities that masked the underlying moderate increases or even decreases of the monsoon extreme rainfall.