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A role for ‘major’ volcanic eruptions in monsoonal precipitation variability

Wyss W.-S. Yim[1, 2*]

[1] Guy Carpenter Asia-Pacific Climate Impact Centre, School of Energy and Environment, City University of Hong Kong, Kowloon, Hong Kong

[2] Department of Earth Sciences, The University of Hong Kong, Hong Kong

* Contact author e-mail: wswyim@cityu.edu.hk

1. Introduction

Monsoon is traditionally defined as a seasonal reversing wind accompanied by seasonal changes in precipitation but is now used to describe seasonal changes in atmospheric circulation and precipitation (Wikipedia). An estimated one-third of the world's current total population of about 7 billion is distributed in the monsoonal regions of the world. Out of these southern China under the influence of the East Asian Monsoon is amongst the most densely populated and is increasingly facing a freshwater shortage crisis. The present study is an examination of the role of 'major' volcanic eruptions defined by a volcanic explosivity index (VEI) of 5 and above on monsoonal precipitation variability in the coastal region of southern China based on an analysis of the temperature and precipitation record of the Hong Kong Station.

2. 'Major' volcanic eruptions

A chronological list of the 13 major volcanic eruptions investigated including their location details, first eruption date, VEI, volume of tephra and ranking is shown in **Table 1** and a location map of the volcanoes and the Hong Kong Station is shown in **Figure 1**. Out of the 13 eruptions 5 are tropical with Krakatau, Agung and Pinatubo located in Southeast Asia within 3500 km from Hong Kong.

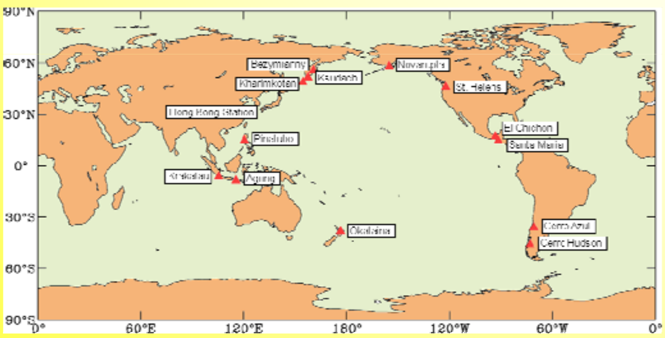


Figure 1 *Location map of the Hong Kong Station and the 13 volcanoes responsible for the eruptions investigated.*

Volcano	Latitude & longitude	Location	First eruption date	VEI	Volume of tephra	Ranking
Krakatau, Indonesia	6°6'6"S 105°25'22"E	Tropical	August 27, 1883	6	$2.0 \pm 0.2 \times 10^{10}$ m^3	=2
Okataina, New Zealand	38°7'0"S 176°30'0"E	Temperate	June 10, 1886	5	2.0×10^9 m^3	10
Santa Maria, Guatemala	14°45'21"N 91°31'6"W	Tropical	October 24, 1902	6?	2.0×10^{10} m^3	=2
Ksudach, Russia	51°48'0"N 157°32'0"E	Temperate	March 28, 1907	5	2.4×10^9 m^3	8
Novarupta, USA	58°16'0"N 155°9'24"W	Temperate	June 6, 1912	6	2.8×10^{10} m^3	1
Cerro Azul, Chile	35°39'12"S 70°45'39"W	Temperate	April 10, 1932	>5	9.5×10^9 m^3	5
Kharimkotan, Russia	40°7'0"N 154°30'30"E	Temperate	January 8, 1933	5	1.0×10^9 m^3	13
Bezymianny, Russia	55°58'42"N 160°35'12"E	Temperate	March 30, 1956	5	2.8×10^9 m^3	7
Agung, Indonesia	8°20'30"S 115°30'30"E	Tropical	February 18, 1963	5	$>1.0 \times 10^9$ m^3	12
St. Helens, USA	46°12'0"N 122°11'0"W	Temperate	May 18, 1980	5	1.2×10^9 m^3	11
El Chichón, Mexico	17°21'36"N 93°13'40"W	Tropical	March 28, 1982	5	2.3×10^9 m^3	9
Pinatubo, Philippines	15°8'0"N 120°21'0"E	Tropical	June 15, 1991	6	$1.1 \pm 0.5 \times 10^{10}$ m^3	4
Cerro Hudson, Chile	45°54'0"S 72°58'0"W	Temperate	August 12, 1991	5	4.3×10^9 m^3	6

Table 1 *Chronological list of the 13 major volcanic eruptions investigated showing their location, first eruption date, VEI, volume of tephra and eruption size ranking.*

3. Precipitation variability

The volcanic eruption factors causing precipitation variability include:

(a) Eruption cloud reduces incoming solar radiation leading to cooling.
(b) Cooling reduces water vapour content of the atmosphere.
(c) Eruption cloud interferes with the 'normal' atmospheric circulation.
(d) Tephra and aerosols provide of condensation nuclei.
(e) Transfer of moisture from the troposphere into the stratosphere.
(f) Acid rain and related carbon cycle impacts.

A simplified model of how a volcanic eruption interferes with 'normal' atmospheric circulation to affect both incoming solar radiation and atmospheric moisture distribution is illustrated in **Figure 2**. Monsoonal precipitation variability may result through the shift in wind circulation pattern from predominantly offshore to predominantly onshore causing abnormally dry and wet years respectively in the coastal region of southern China.

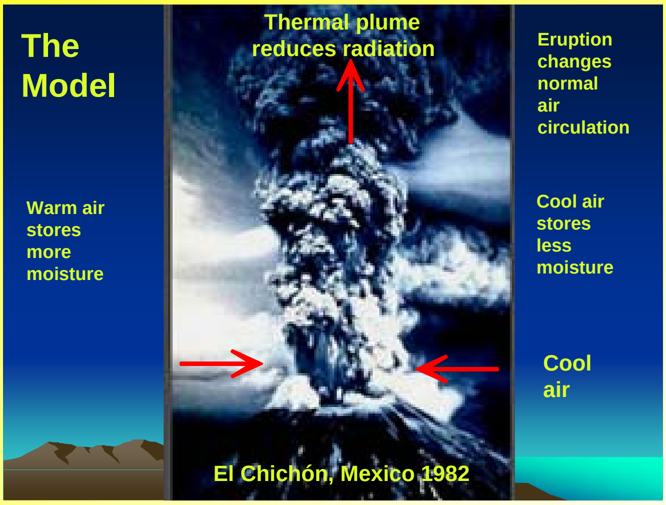


Figure 2 *Model showing how a volcanic eruption interferes with normal atmospheric circulation to affect incoming solar radiation and atmospheric moisture distribution.*

Annual mean temperatures of years immediately following the eruption year and annual precipitations during the eruption year at the Hong Kong Station and climatic observations of the 13 volcanic eruptions are shown in **Table 2**. It can be seen that some of the coldest and driest years including 5 top twenty coldest and 5 top twenty driest years are included. Also included is the 1982 El Chichón eruption an exceptionally wet year ranked second wettest since the record began in 1884.

Volcanic eruption	AMT after eruption year (°C)	Annual mean precipitation (mm)	% of average	Climatic observations
Krakatau 1883	21.3	1918.0[a]	86.4	Coldest year
Okataina 1886	21.7	1756.9	79.1	=5 coldest year; 20th driest year
Santa Maria 1902	21.9	2477.2[b]	107.1	=9 coldest year
Ksudach 1907	22.1	2377.7	107.1	=19th coldest year
Novarupta 1912	22.2	1625.2	73.2	9th driest year
Cerro Azul 1932	22.5	2325.9	104.8	-
Kharimkotan 1933	21.9	2482.9	71.4	=9 coldest year
Bezymianny 1956	22.3	1649.3	74.3	11th driest year
Agung 1963	22.9	901.1	40.6	Driest year
St. Helens 1980	23.1	1710.6	77.0	17th driest year
El Chichón 1982	23.0	3247.5	146.3	2nd wettest year
Pinatubo 1991	22.8	1639.1	87.3	10th driest year
Cerro Hudson 1991	22.8	1639.1	87.3	10th driest year

a – 1884 and b – 1903.

Table 2 *Annual mean temperatures (AMT) of years immediately following the eruption year and annual precipitations during the eruption year at the Hong Kong Station located in* **Figure 1** and their climatic observations. *The overall annual mean temperature and the annual mean precipitation of the Hong Kong Station from 1884-2009 is 22.62°C and 2220 mm respectively.*

The abnormally dry 1963 and 1991 may be explained by the Agung and Pinatubo eruptions respectively causing the ‘normal’ wind circulation in southern China to shift to predominantly offshore (**Figure 3**). The exceptionally wet year in 1982 is explained by the spread of the El Chichón eruption cloud across the Pacific Ocean which was tracked by satellites (**Figure 4**). This cloud reached the South China Sea by ca. 16th April 1982 resulting in 1041.2 mm rainfall during the period 22nd April to 31st May 1982 (**Figure 5**). The unseasonal early heavy rainfall, the abnormally low surface humidity observed during April and the bimodal peaks of monthly rainfall in May and August are in support of the influence of the stratospheric eruption cloud from the eruption.

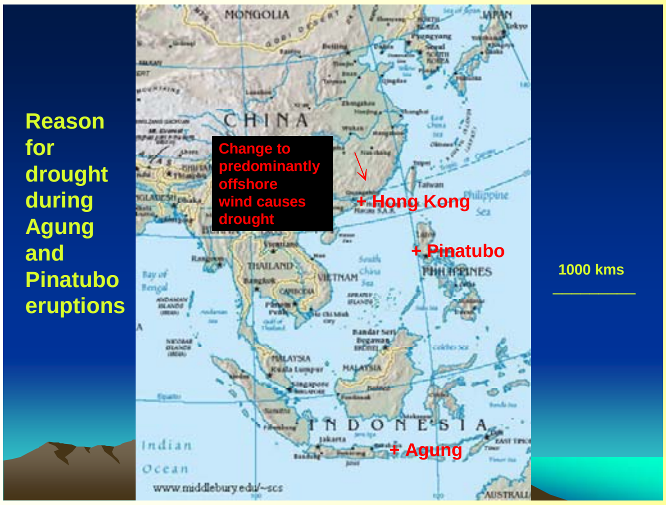


Figure 3 *Predominantly offshore wind causing drought years during the 1963 Agung and 1991 Pinatubo eruptions.*

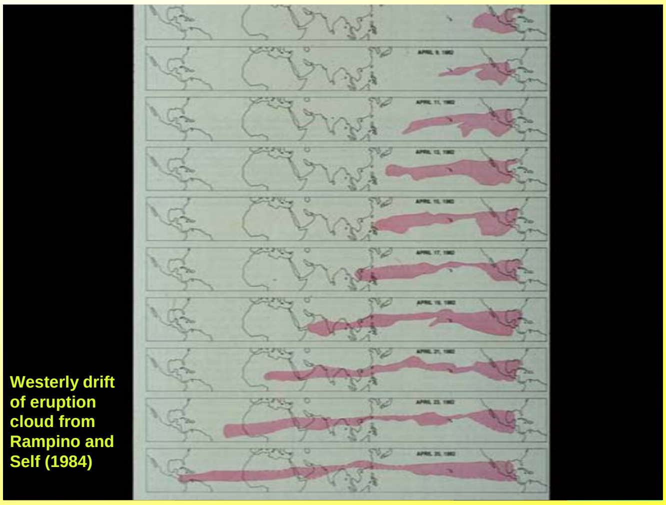
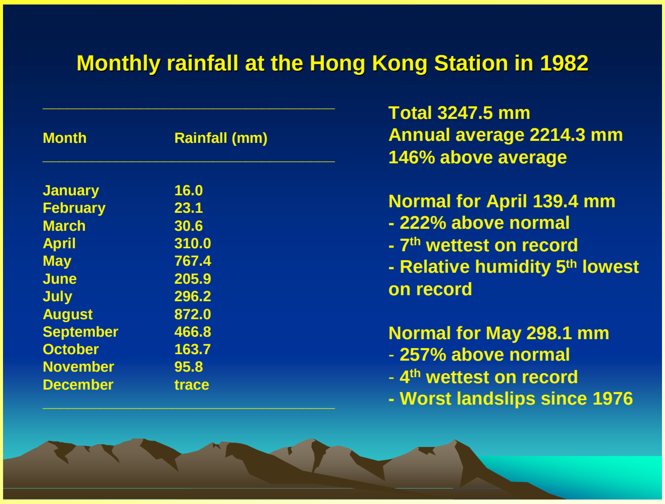


Figure 4 *Maps showing the spread of the El Chichón eruption cloud during the first 3 weeks after the eruption made by combining information from satellites. Heavy rain fell over Hong Kong 17 days after the eruption in April and May 1982.*



Month	Rainfall (mm)
January	16.0
February	23.1
March	30.6
April	310.0
May	767.4
June	205.9
July	296.2
August	872.0
September	466.8
October	163.7
November	95.8
December	trace

Figure 5 *Monthly rainfalls and rainfall-related statistics at the Hong Kong Station during April 1982. Bimodal peaks of monthly rainfall can be seen during May and August.*

Figure 6 shows the time series of annual precipitation in China from 1958 to 1988 after Prieler (1999). It can be seen that the normally wet southeastern China was affected by abnormally low precipitation in 1963 while the opposite was found during 1982.

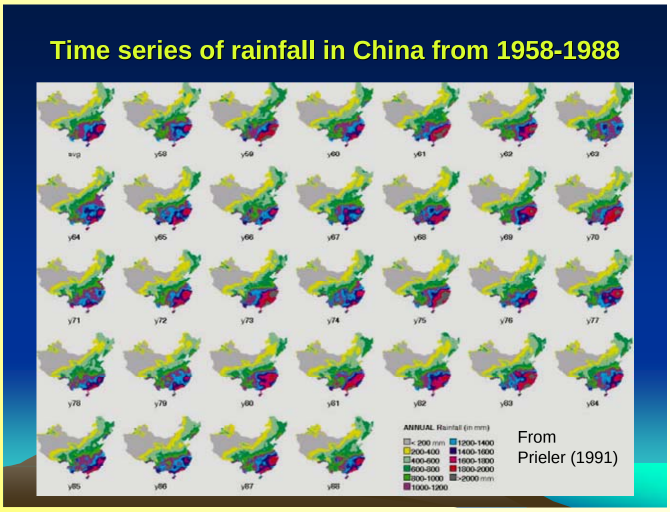


Figure 6 *Time series of precipitation variability in China from 1958-1988. 1963 and 1982 can be seen to be an abnormally dry year and abnormally wet year in southern China respectively.*

5. Conclusions

(a) 'Major' volcanic eruptions are a natural forcing of monsoonal precipitation variability and have been shown frequently to cause abnormally dry years (monsoon weakening) and occasionally abnormally wet years (monsoon strengthening).
(b) Severe climatic disasters including droughts, floods and landslides linked to monsoons may be the result of 'major' volcanic eruptions. This is attributed mainly to the stratospheric volcanic cloud interfering with the 'normal' atmospheric circulation.
(c) Near-field 'major' volcanic eruptions in Southeast Asia usually result in abnormally dry years in southern China.
(d) Under special circumstances as in the case of the 1982 El Chichón eruption abnormally wet years in southern China may result. The unseasonal early heavy rainfall, the abnormally low surface relative humidity during April and the bimodal peaks of monthly rainfall are indicators.
(e) More studies should be carried out on the impact of individual 'major' volcanic eruptions on monsoonal precipitation variability particularly on other coastal monsoonal regions of the world.

6. Acknowledgements

This poster prepared with the help of Terence Lam and Dr Judy Huang is a contribution to UNESCO's International Year of Planet Earth under the Climate Change theme.

7. References

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Rampino MR, Self S (1984) The atmospheric effects of El Chichón. Scientific American 250: 34-43.