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Volcanic Forcing of Monsoonal Precipitation Variability in Selected Modern Eruptions

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1. Introduction

Volcanic eruptions affect climate by injecting gases and aerosol particles into the stratosphere (Robock, 2003). While temperature decline has been observed in the northern hemisphere after major eruptions e.g. Francis (1993), little is known about their regional-scale forcing of precipitation. In the present investigation, three modern major eruptions within the past fifty years have been selected for study. They are the February 1963 Agung eruption in Indonesia, the March 1982 El Chichón eruption in Mexico and the June 1991 Pinatubo eruption in the Philippines located in **Fig. 1**.

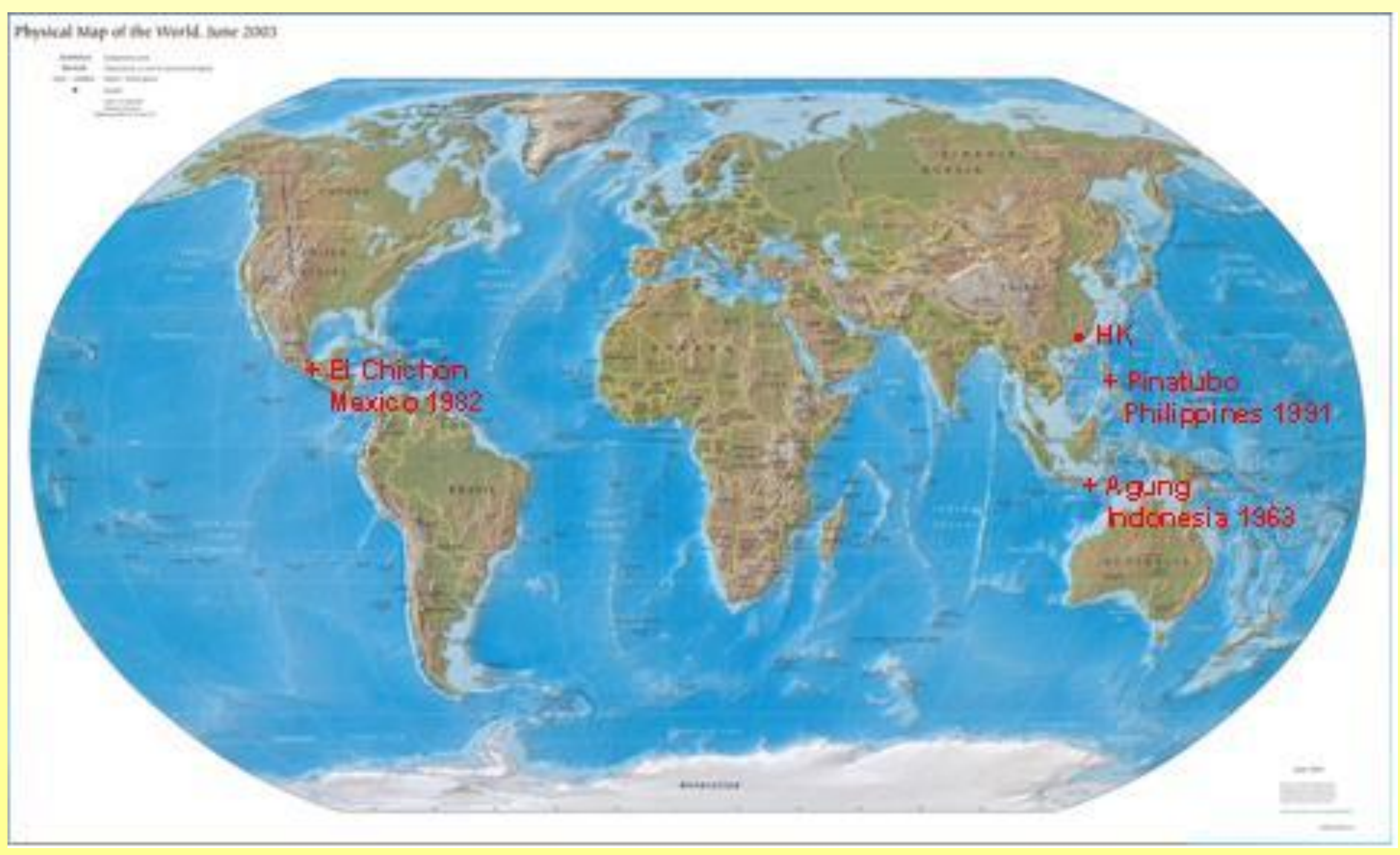


Fig. 1 Location map of the Agung, El Chichón and Pinatubo volcanoes and the Hong Kong Station of the Hong Kong Observatory.

There are two main reasons for choosing the three volcanic eruptions. Firstly, they have the greatest influence on reducing solar radiation over the past fifty years (**Fig. 2**). Secondly, the three eruption years are associated with the occurrence of either abnormally dry or abnormally wet years in southern China (**Table 1**).

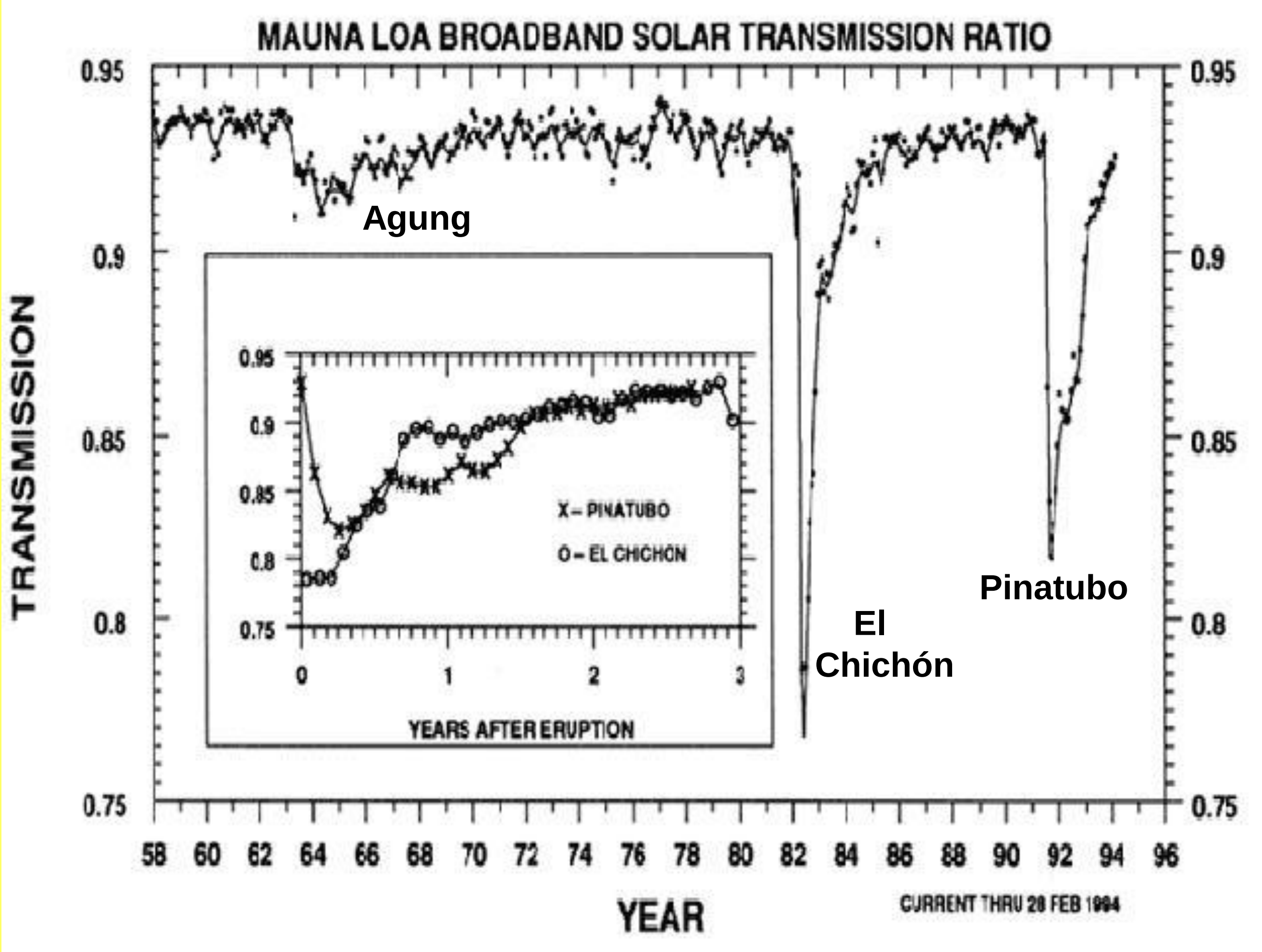


Fig. 2 Solar transmission ratio at Mauna Loa from 1958 to 1994 showing the influence of the three eruptions. From Self et al. (1999).

Table 1 shows the latitude, first eruption date, volume of materials erupted, volcanic explosivity index and annual precipitation at the Hong Kong Station during the three eruptions.

Table 1 Latitude, first eruption date, volume of materials erupted, volcanic explosivity index and annual precipitation at the Hong Kong Station during the Agung, El Chichón and Pinatubo eruptions.

Volcano	**Latitude**	**First eruption date**	**Volume of materials erupted**	**Volcanic explosivity index**	**Precipitation (mm)**	**Comment**
Agung, Indonesia	8ºS	February 18, 1963	~ 1 km^3 (Rampino and Self, 1982)	4	901.1	Driest year
El Chichón, Mexico	17ºN	March 28, 1982	~ 0.6 km^3 (Rampino and Self, 1984)	4	3247.5	2nd wettest year
Pinatubo, Philippines	15ºN	June 15, 1991	~ 5 km^3 (Self et al., 1999)	6	1639.1	10th driest year

Abnormally low annual precipitation was found in southern China during 1963 and 1991 respectively. Based on the total annual precipitation recorded at the Hong Kong Station, the precipitation was the driest and the tenth driest since record began in 1884 respectively. In contrast, abnormally high annual precipitation was found in southern China in 1982 with the Hong Kong Station recording the second wettest year since record began.

2. Precipitation connection

Volcanic eruptions occurring within Southeast Asia may be regarded as ‘near-field’ due to their relative short distances from southern China. During major eruptions, the rising thermal plumes generated cause the surrounding cool air to be drawn in (**Fig. 3**). Because of the coastal location of Hong Kong at the margin of the largest continental land mass in the world, the change from the ‘normal’ wind pattern to predominantly offshore would be conducive to drought (**Fig. 4**). The low annual precipitation in 1963 and 1991 at the Hong Kong Station may therefore be accounted for by the Agung eruption and the Pinatubo eruption respectively.

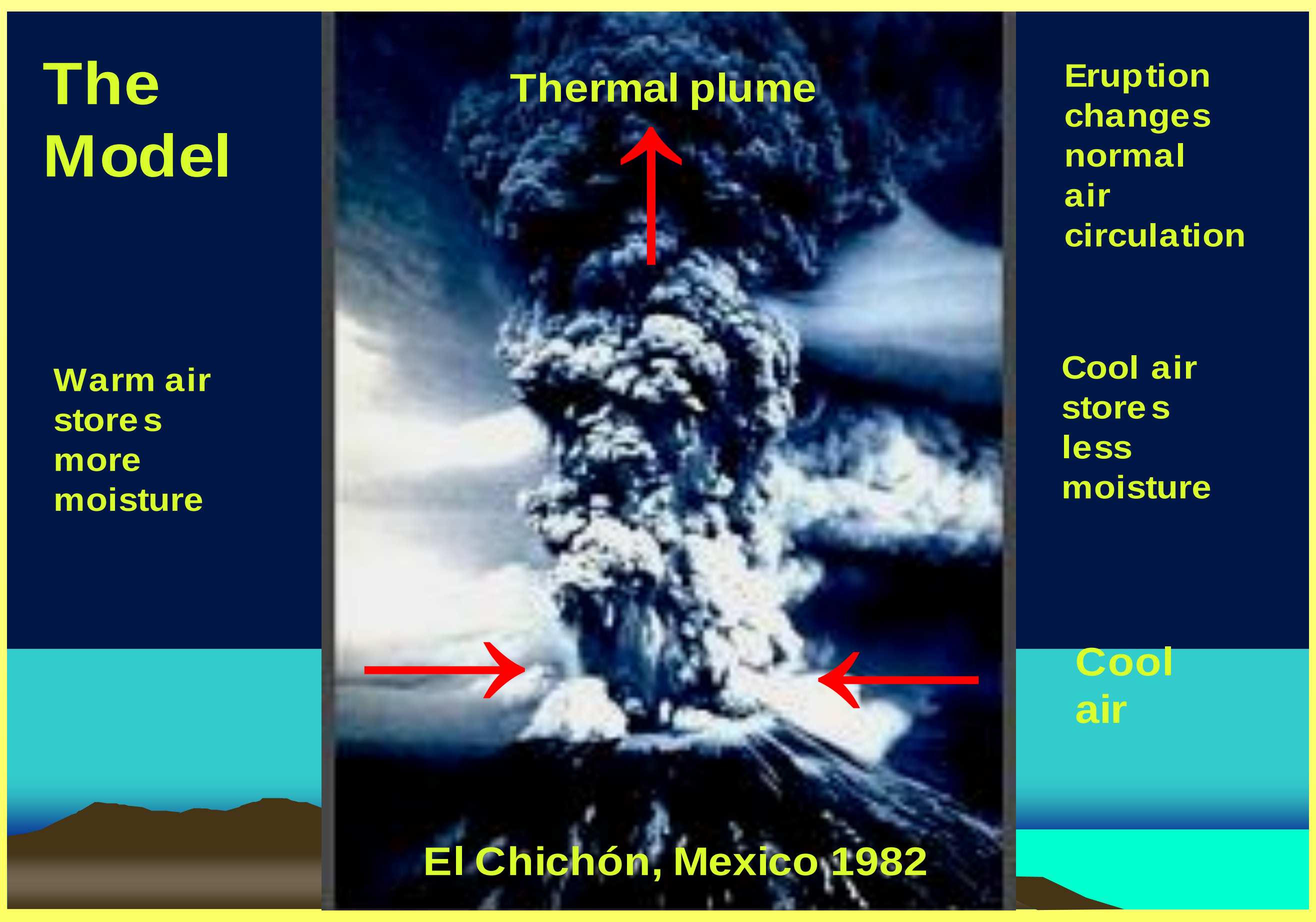


Fig. 3 The thermal plume generated during a major volcanic eruption and its impact.

Fig. 4 The change to predominantly offshore wind in southern China causing drought following the Agung and Pinatubo eruptions.

Fig. 5 Water rationing in Hong Kong during 1963. Water supply was limited to 4 hours in 4 days due to the severe drought.

The 1991 Pinatubo eruption is probably the best monitored major volcanic eruption within the past fifty years. A ground level view of the eruption is shown in **Fig. 6**. Thermal images taken immediately after the eruption and the tracking of the volcanic cloud via satellites are shown in **Figs. 7** and **8** respectively.

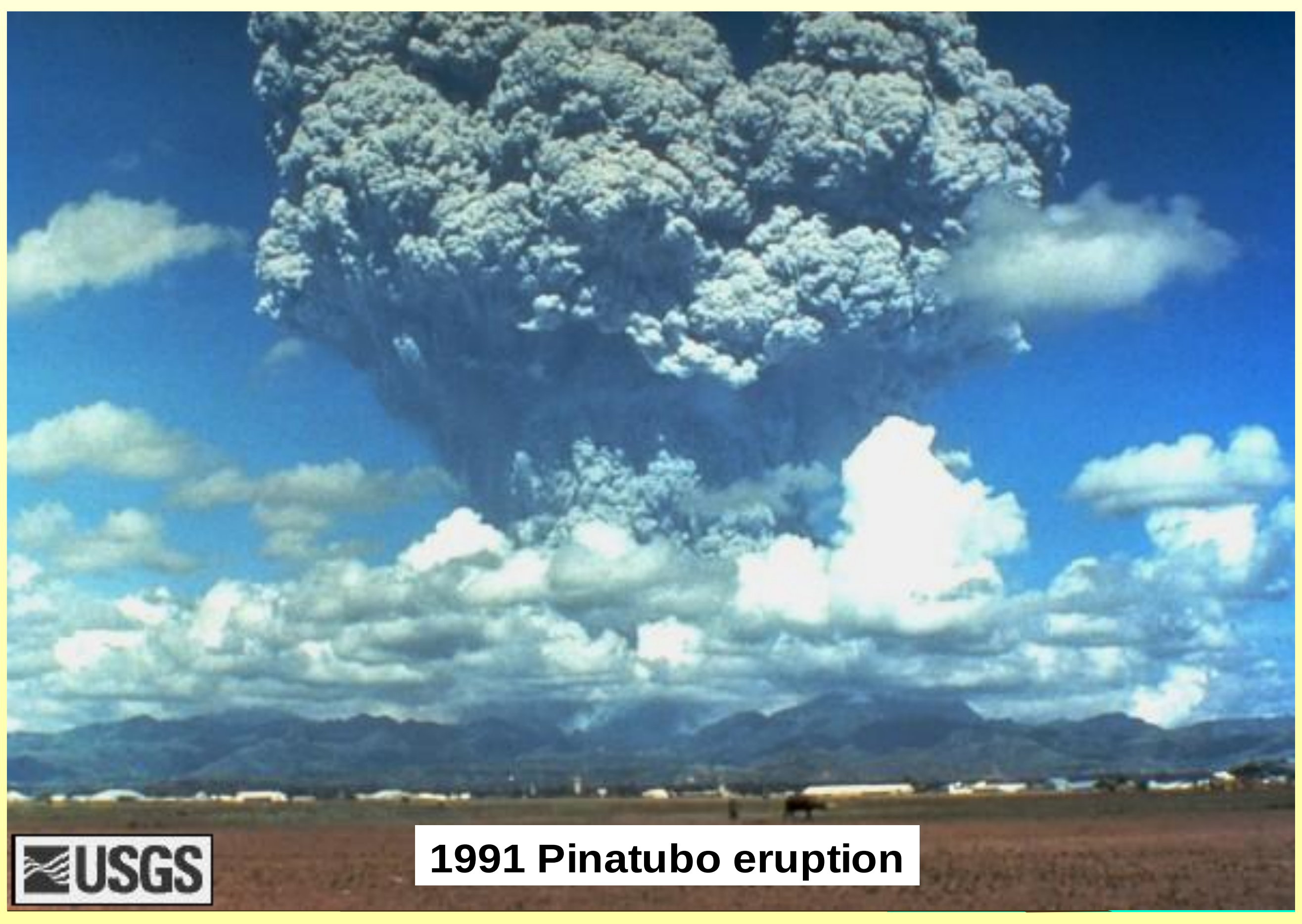


Fig. 6 The 1991 Pinatubo eruption from ground level.

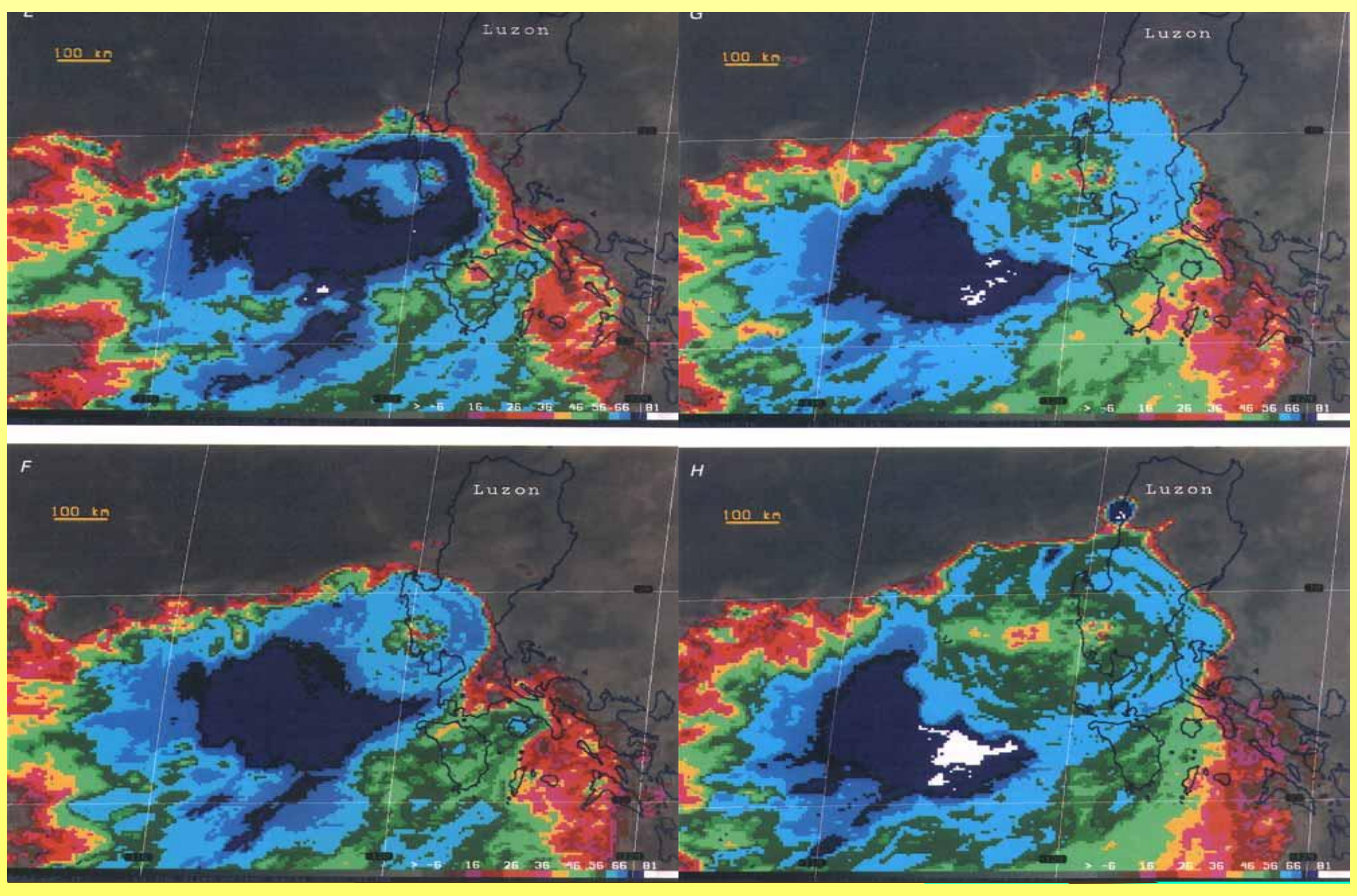


Fig. 7 Thermal-IR images of the Pinatubo thermal plume spanning 3 hours from 1340 to 1640 on June 15, 1991. From Self et al. (1999).

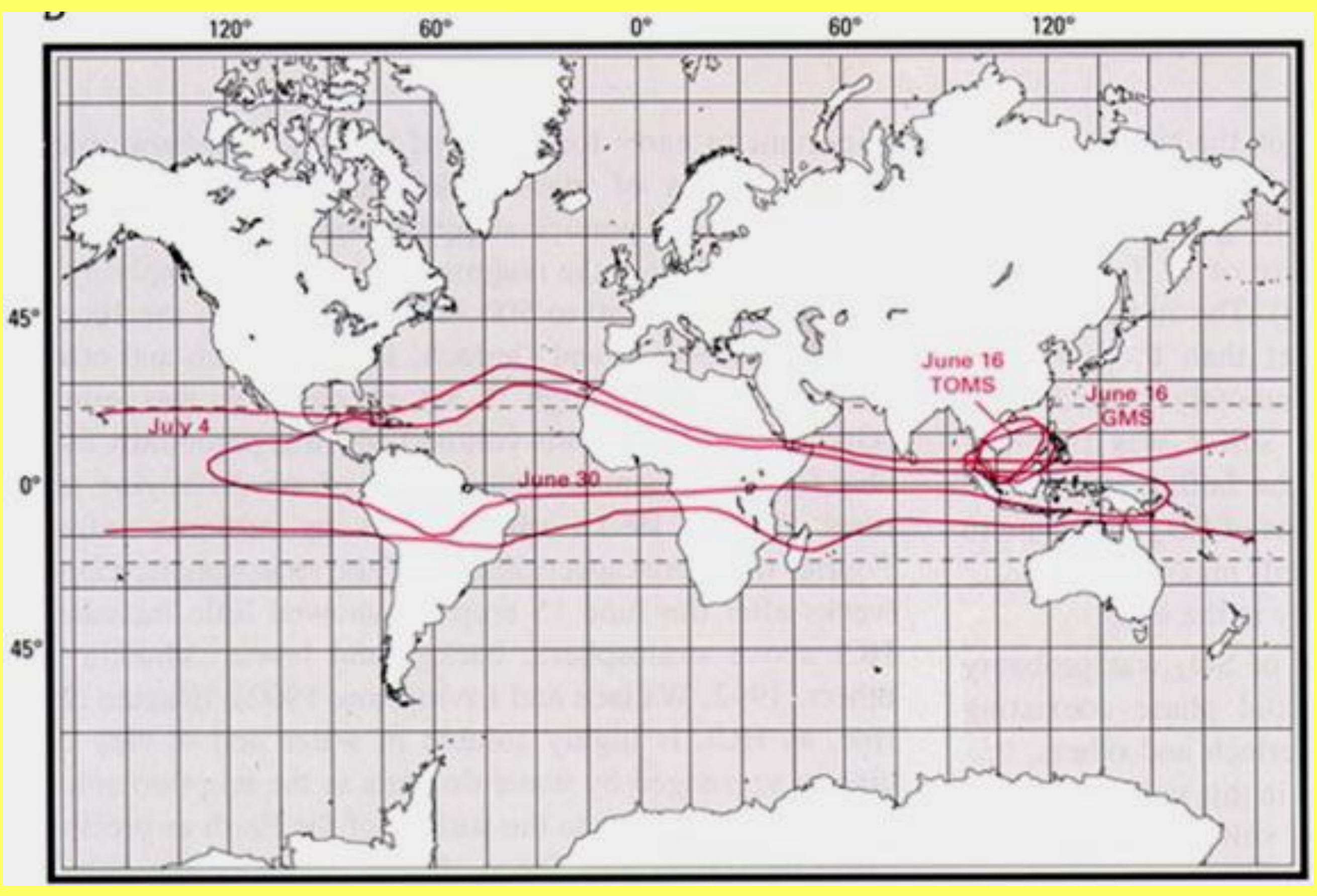
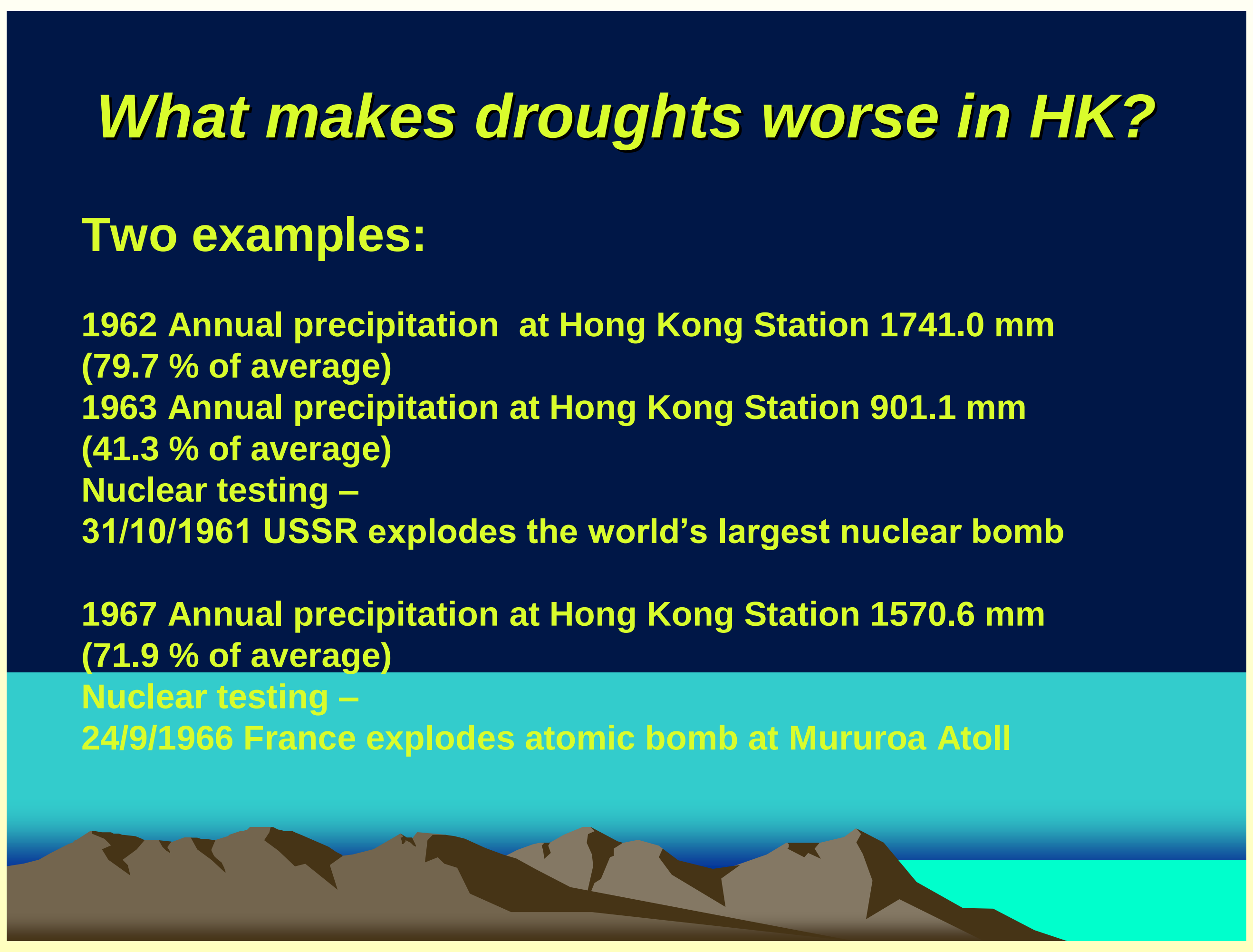


Fig. 8 Spread of the Pinatubo volcanic cloud on the dates indicated and the transition from ash-laden eruption cloud to SO_2-dominated stratospheric cloud mapped by TOMS satellite. From Self et al. (1999).

Fossil fuel-consuming power stations and nuclear tests also generate thermal plumes differing in time and scale. The former are relatively 'long' term while the latter are relatively 'short' term. Both may also impact the natural hydrological cycle to cause precipitation variability. Two examples of how droughts are made worse by nuclear testing are shown in **Fig. 9**.



What makes droughts worse in HK?

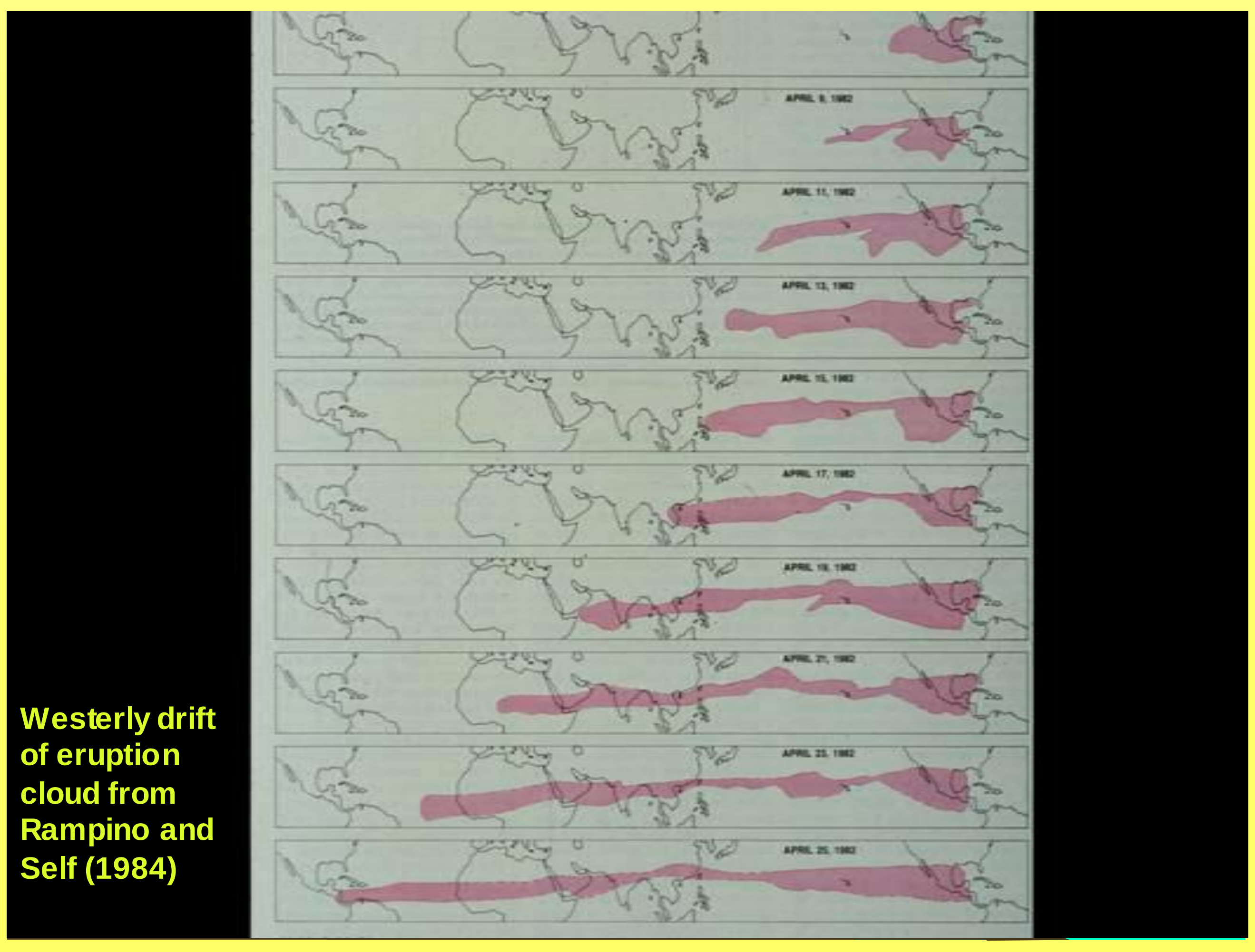
Two examples:

1962 Annual precipitation at Hong Kong Station 1741.0 mm (79.7 % of average)
1963 Annual precipitation at Hong Kong Station 901.1 mm (41.3 % of average)
Nuclear testing –
31/10/1961 USSR explodes the world's largest nuclear bomb

1967 Annual precipitation at Hong Kong Station 1570.6 mm (71.9 % of average)
Nuclear testing –
24/9/1966 France explodes atomic bomb at Mururoa Atoll

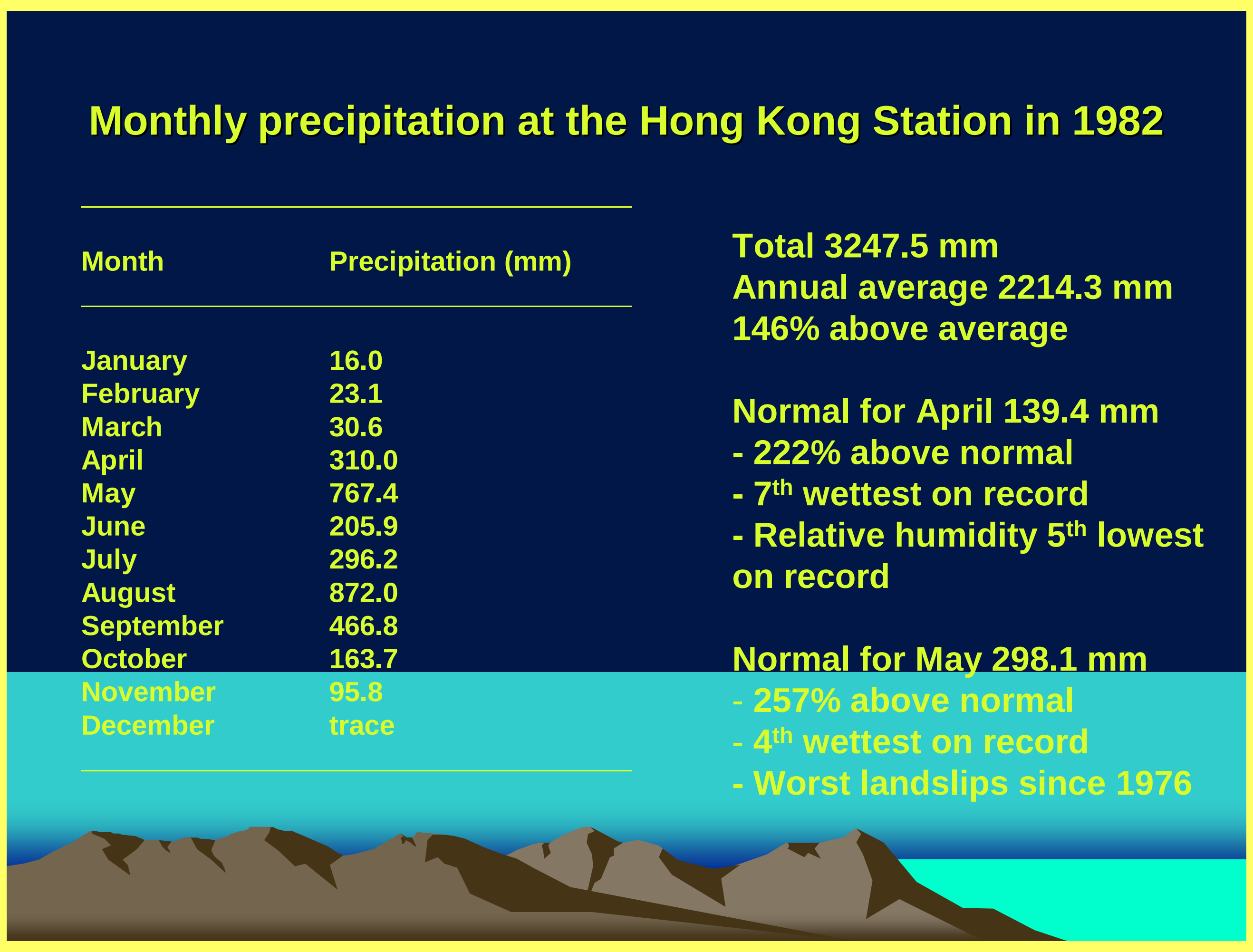
Fig. 9 Two examples of how nuclear testing may lead to abnormally dry years at the Hong Kong Station.

Volcanic eruptions in Central and South America may be regarded as 'far-field' due to their great distances from Hong Kong. The El Chichón eruption in 1982 at latitude 17°N in Mexico is a trans-Pacific Ocean event. By combining imagery from the geostationary GOES East and GOES West satellites which is received every 30 minutes, the volcanic cloud of the eruption spreading across the Pacific Ocean was tracked and found to have reached the South China Sea by 16th April 1982 (Robock and Matson, 1983). The abnormally heavy precipitation of 1041.2 mm from 22nd April to 31st May, 1982 may be attributed to the volcanic cloud providing condensation nucleus for this period and the remainder of the year making 1982 the second wettest year since record began in 1884.



Westerly drift of eruption cloud from Rampino and Self (1984)

Fig. 10 The westerly drift of the El Chichón volcanic cloud as observed by satellites in 1982. From Rampino and Self (1984).



Monthly precipitation at the Hong Kong Station in 1982

Month	Precipitation (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

Total 3247.5 mm
Annual average 2214.3 mm
146% above average

Normal for April 139.4 mm
- 222% above normal
- 7th wettest on record
- Relative humidity 5th lowest on record

Normal for May 298.1 mm
- 257% above normal
- 4th wettest on record
- Worst landslips since 1976

Fig. 11 Summary of precipitation statistics at the Hong Kong Station in 1982. Both the timing and the intensity are indicative of a role for volcanic forcing.

Fig. 12 shows the time series of annual precipitation in China from 1958 to 1988 after Prieler 1999). It can be seen that the normally wetter southeastern China was affected by abnormally lower precipitation in 1963 while the opposite was found during 1982.

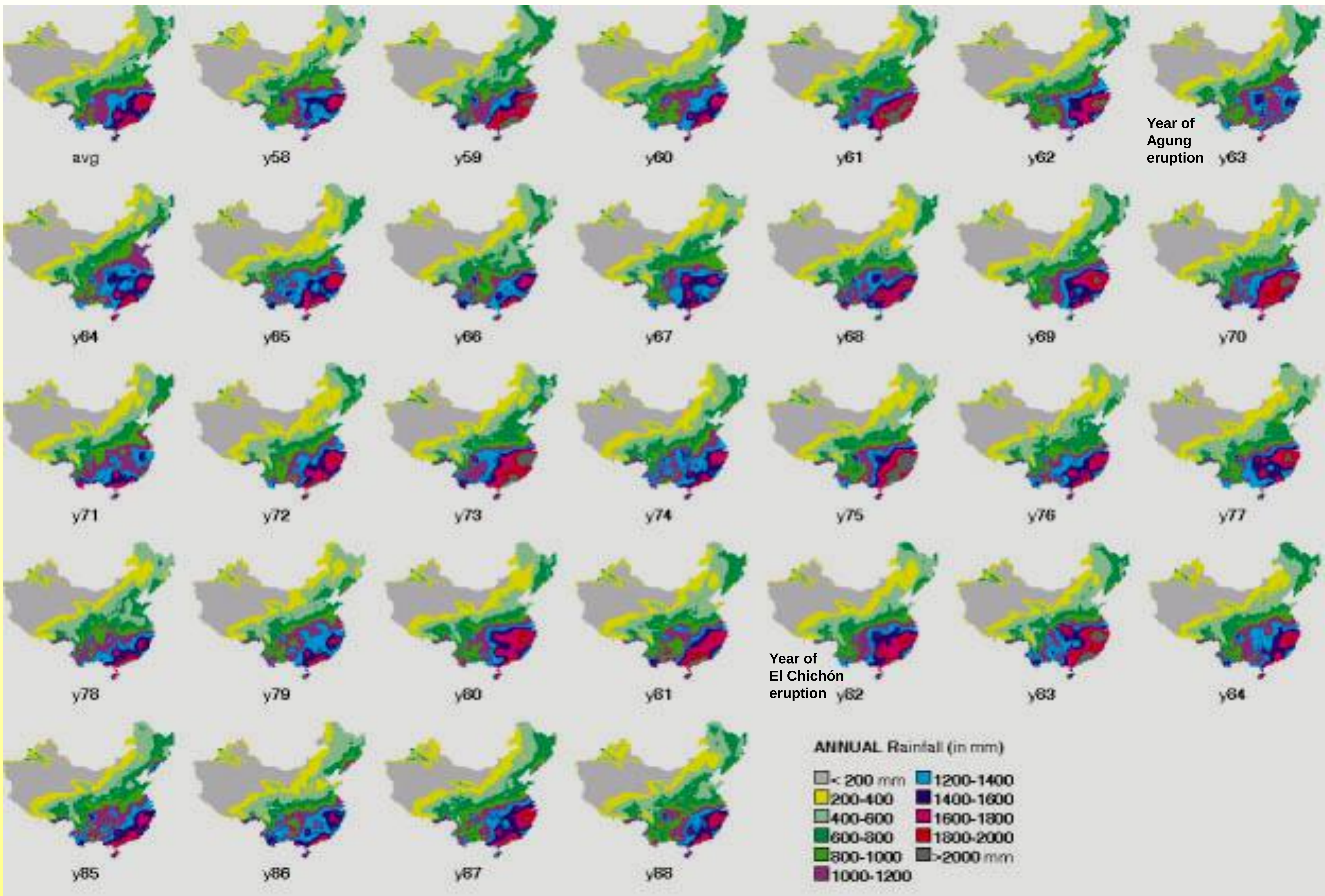


Fig. 12 Time series of annual precipitation in China from 1958-1988 from Prieler (1991).

3. Conclusions

(a) Major volcanic eruptions are a natural forcing of climate change including monsoonal variability and have been shown to cause extremely dry and wet years regionally.

(b) Because volcanic forcing is a natural phenomenon, it is dangerous to attribute the occurrence of floods and droughts to global change through the production of man-made greenhouse gases only.

(c) Volcanic eruptions, nuclear tests, fossil fuel-consuming power stations and urban heat islands caused by mega-cities generate thermal plumes differing in time and space. Unlike volcanoes all are caused by human impacts on the natural hydrological cycle.

(d) The volcanic forcing on regional precipitation should be investigated using the instrumental record to assist water resources management and precipitation variability studies.

4. Acknowledgements

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