Impact of Volcanic Eruptions on Regional Rainfall Pattern

Wyss W.-S. Yim

Guy Carpenter Asia-Pacific Climate Impact Centre,
City University of Hong Kong /
Department of Earth Sciences, The University of Hong Kong,
Hong Kong SAR, China

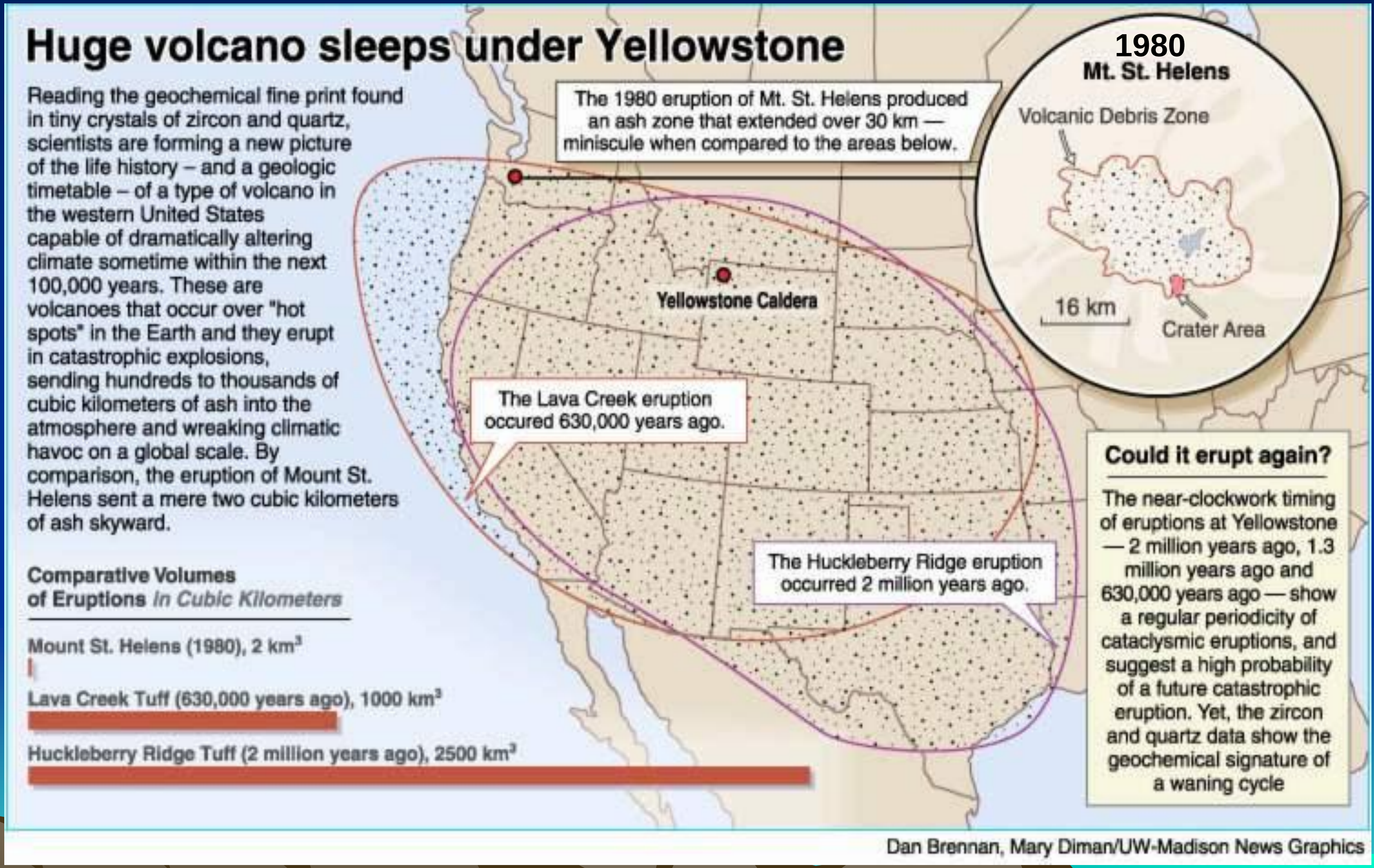
Background

Volcanic eruptions have long been suspected to be a cause of climate change e.g. lowering of global temperatures to the extent of causing ice ages.

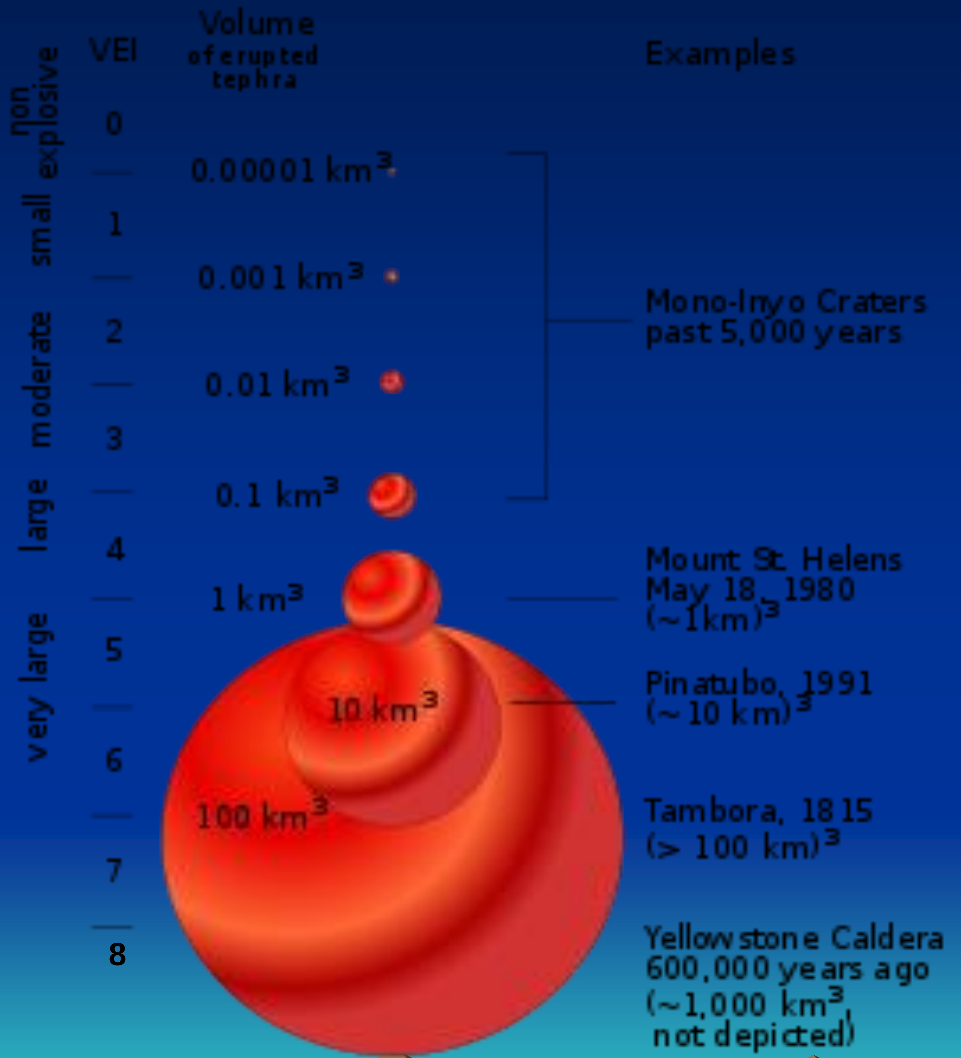
Main objective

To examine the impact of three volcanic eruptions occurring over the past 50 years on the rainfall distribution in Hong Kong.

Yellowstone supervolcano



Volcanic Explosivity Index (VEI)



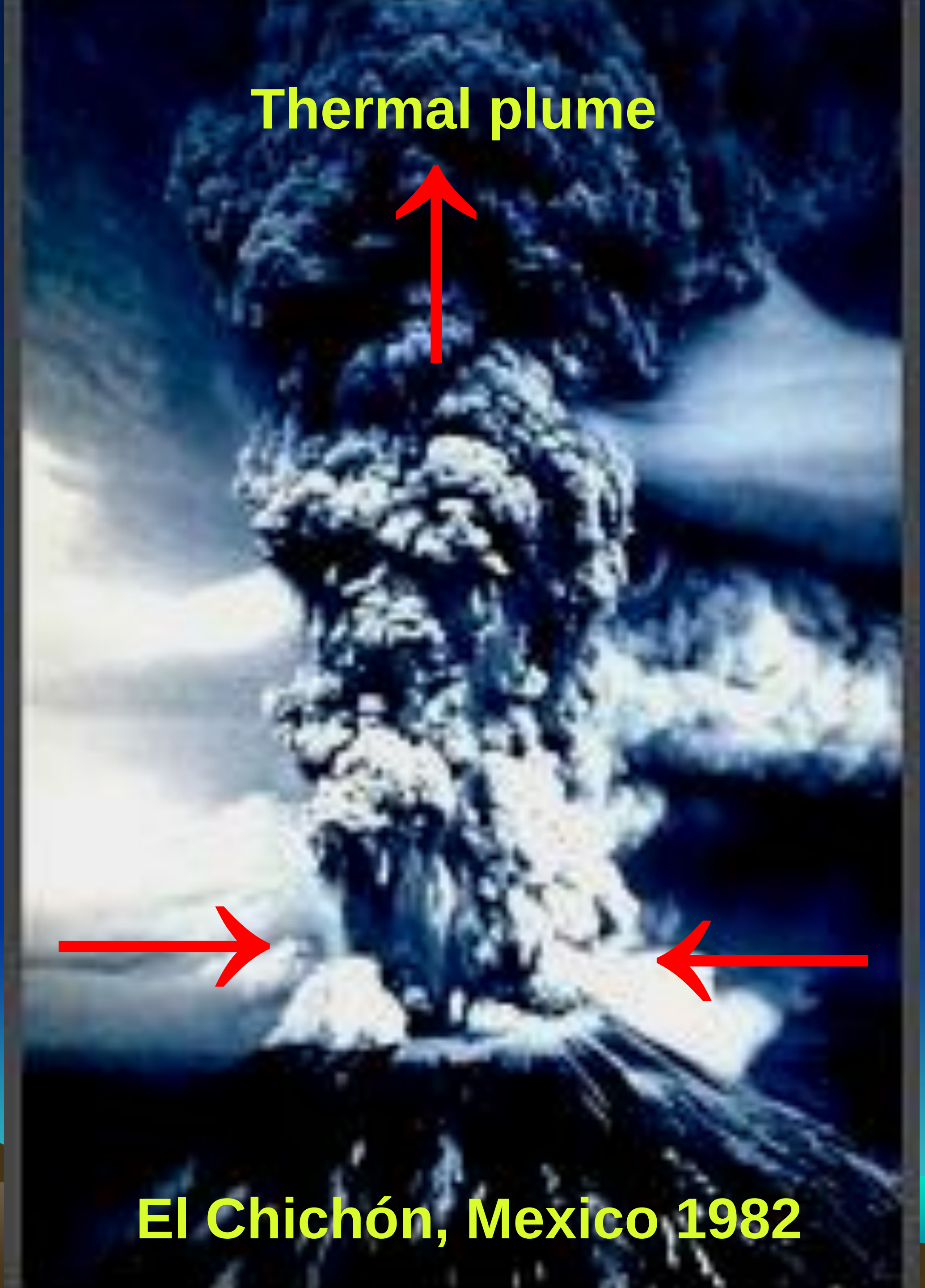
Comparison of some major historic eruptions after Francis (1993)

Eruption/ year	VEI*	Magma vol. (km^3)	Eruption column height (km)	H_2SO_4 aerosols (kg)	Temp. drop (^oC)
Tambora 1815	7	> 50	> 40	2×10^{11}	0.4-0.7
Krakatau 1883	6	> 10	> 40	5×10^{10}	0.3
St. Helens 1980	5	0.35	> 22	3×10^{8}	0-0.1

* Volcanic explosivity index.

The Model

Warm air stores more moisture



El Chichón, Mexico 1982

Eruption changes normal air circulation

Cool air stores less moisture

Cool air

Possible impacts of major volcanic eruptions

(1) Initially increase the temperature of the upper stratosphere followed by cooling of the troposphere.

(2) Volcanic clouds obstruct the incoming solar radiation causing the Earth's surface temperature to decrease.

(3) The thermal plumes interfere with the Earth's 'normal' air circulation.

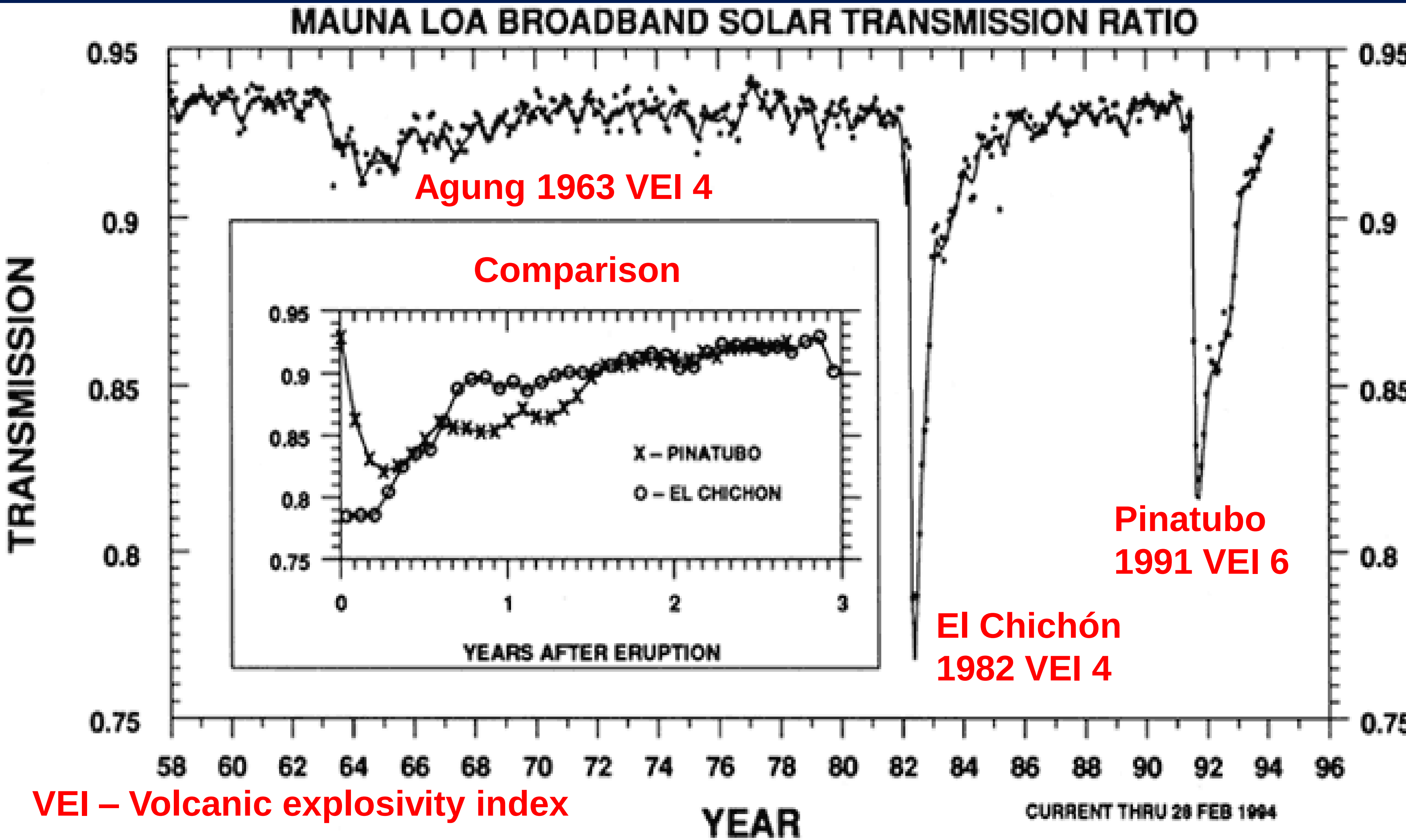
(4) The thermal plumes transport water vapour into the troposphere.

(5) Particulates and aerosols in the stratosphere form condensation nucleus.

(6) The sulphur oxides released may lead to acid precipitation which damage vegetation.

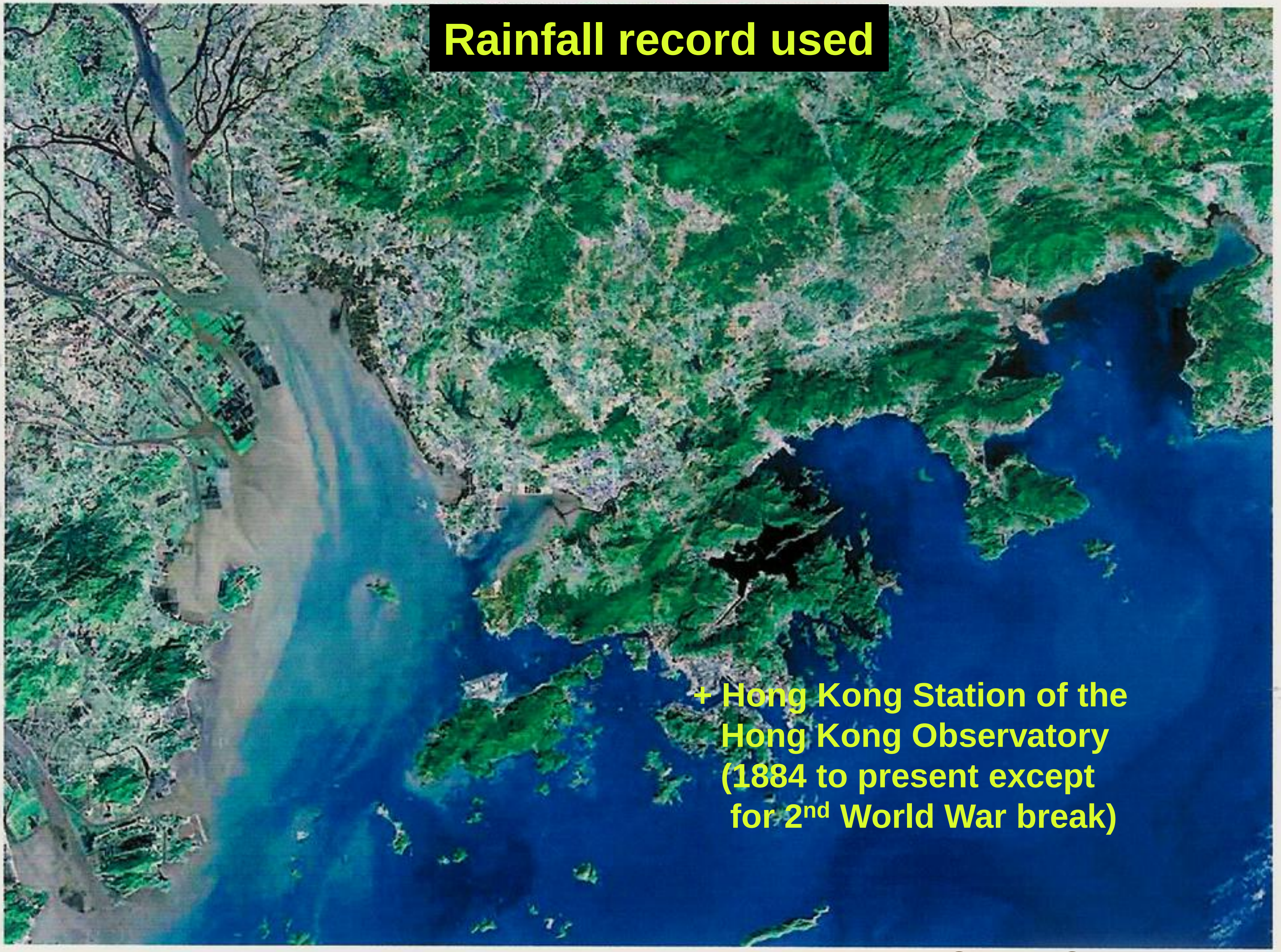
Location of the three volcanic eruptions selected for the present study

Solar radiation during the 3 volcanic eruptions



VEI – Volcanic explosivity index

Rainfall record used



Source: Geocarto

Latitude, first eruption date, volume of materials erupted and annual precipitation at the Hong Kong Station during the 1963 Agung, 1982 El Chichón and 1991 Pinatubo eruptions

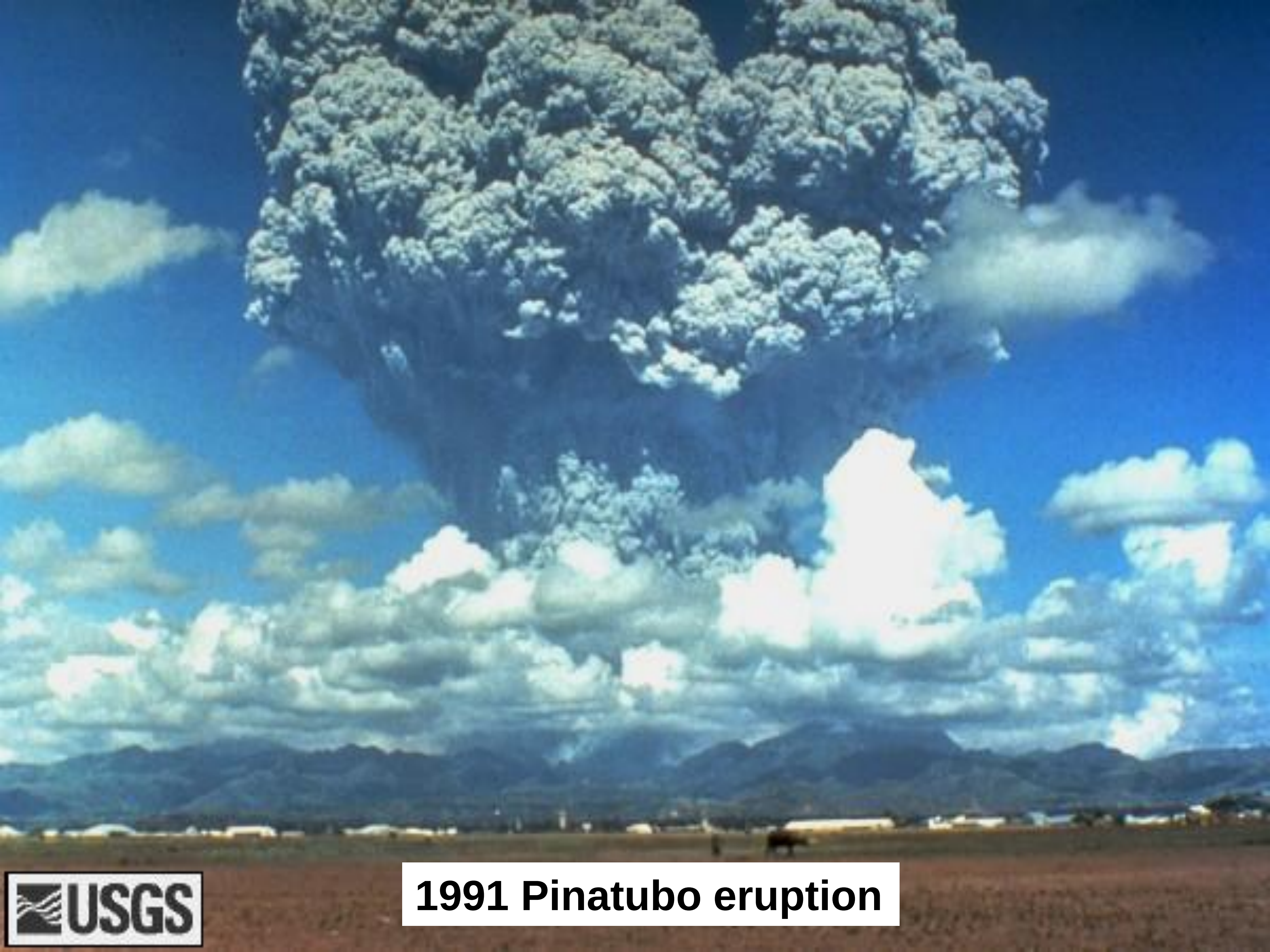
Volcano	Latitude	First eruption date	Volume of materials erupted	Precipitation^ (mm)	Comment
Agung, Indonesia	8°S	February 18, 1963	~1 km^3 (Rampino and Self, 1982)	901.1	Driest year
El Chichón, Mexico	17°N	March 28, 1982	~0.6 km^3 (Rampino and Self, 1984)	3247.5	2nd wettest year
Pinatubo, Philippines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

^ Mean ~2225 mm.

Water rationing in Hong Kong 1963 (4 hours supply in 4 days)
? trigger for the construction of the High Island Water Scheme

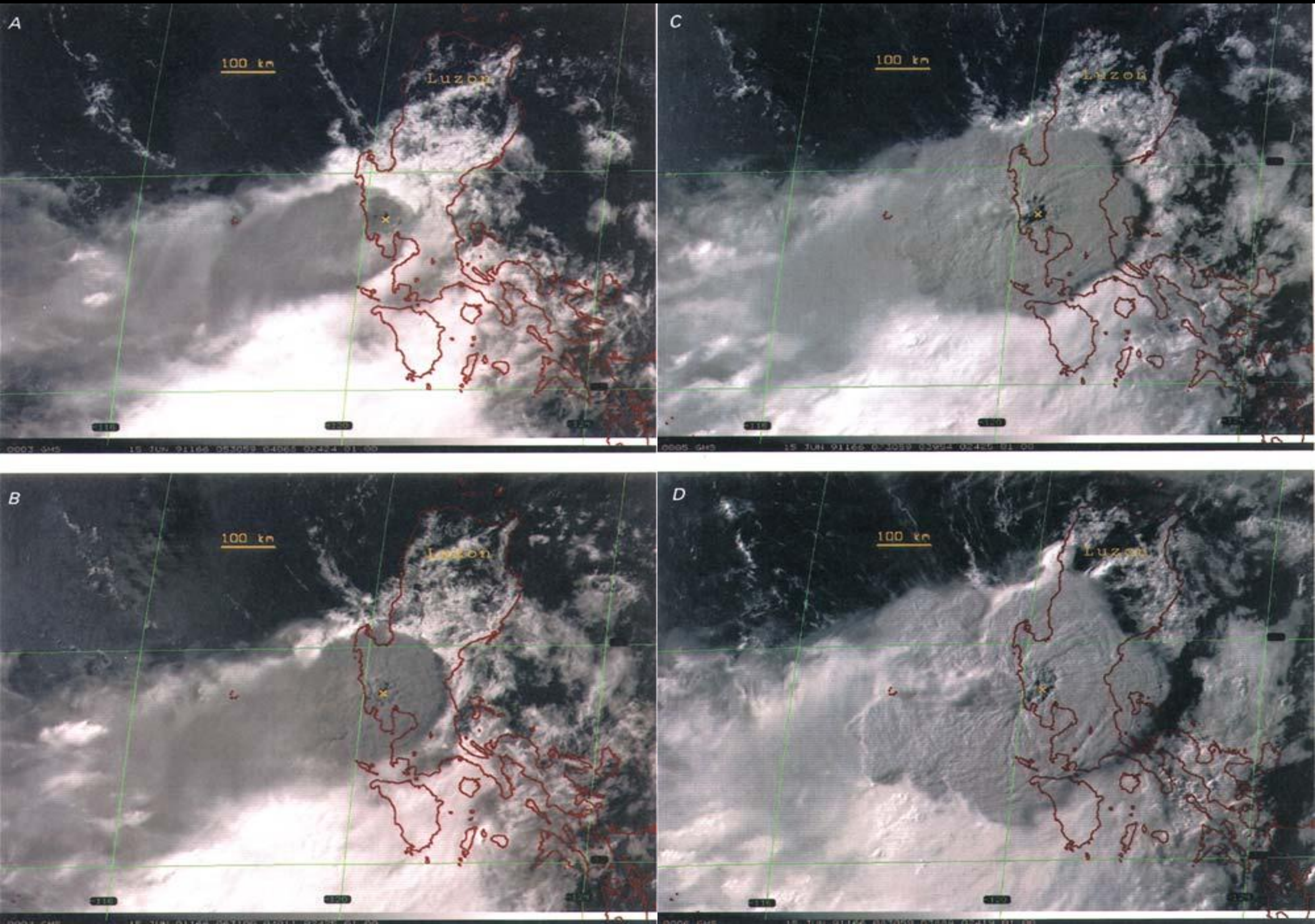
Reason for drought during Agung and Pinatubo eruptions

1000 kms

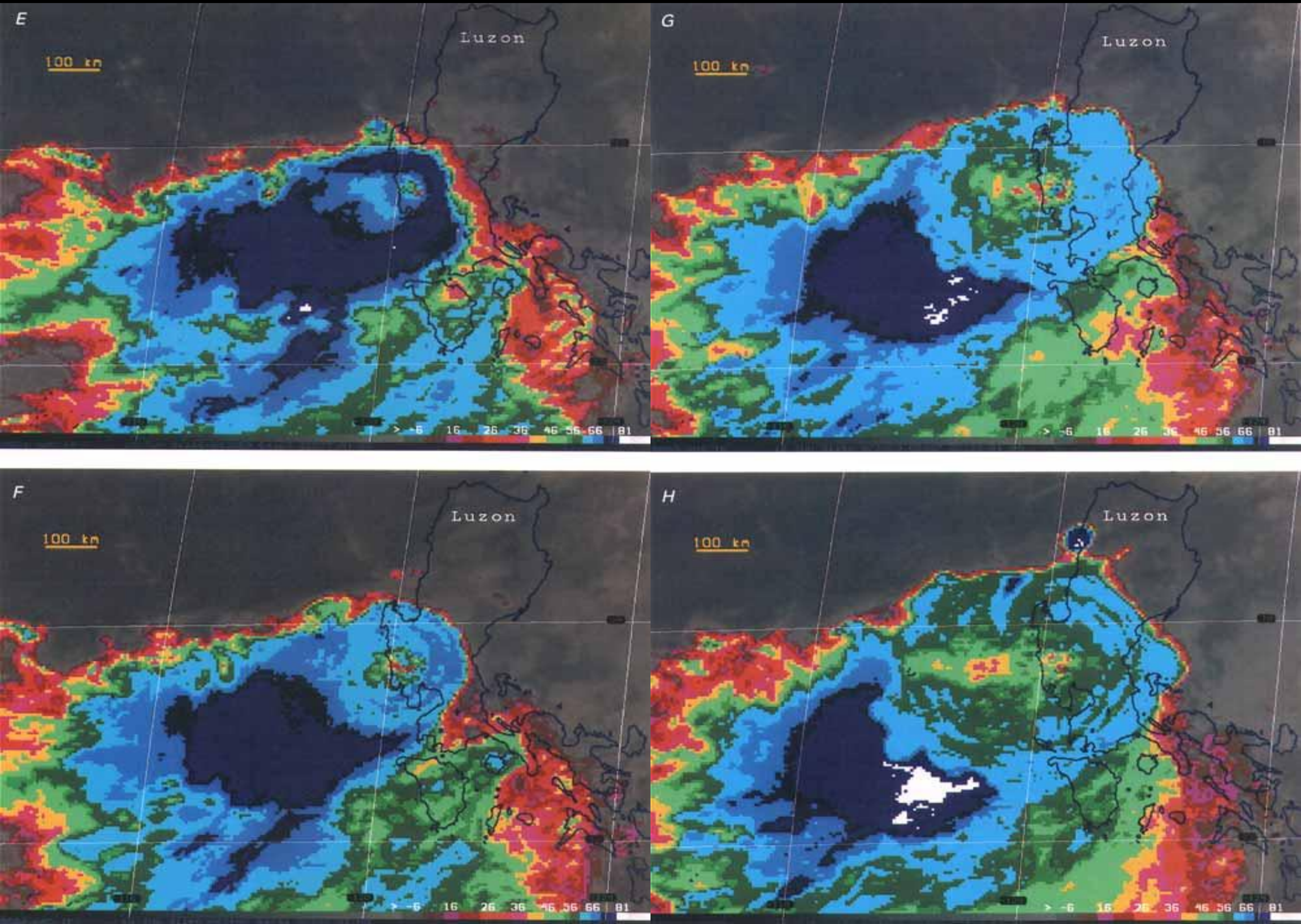


1991 Pinatubo eruption

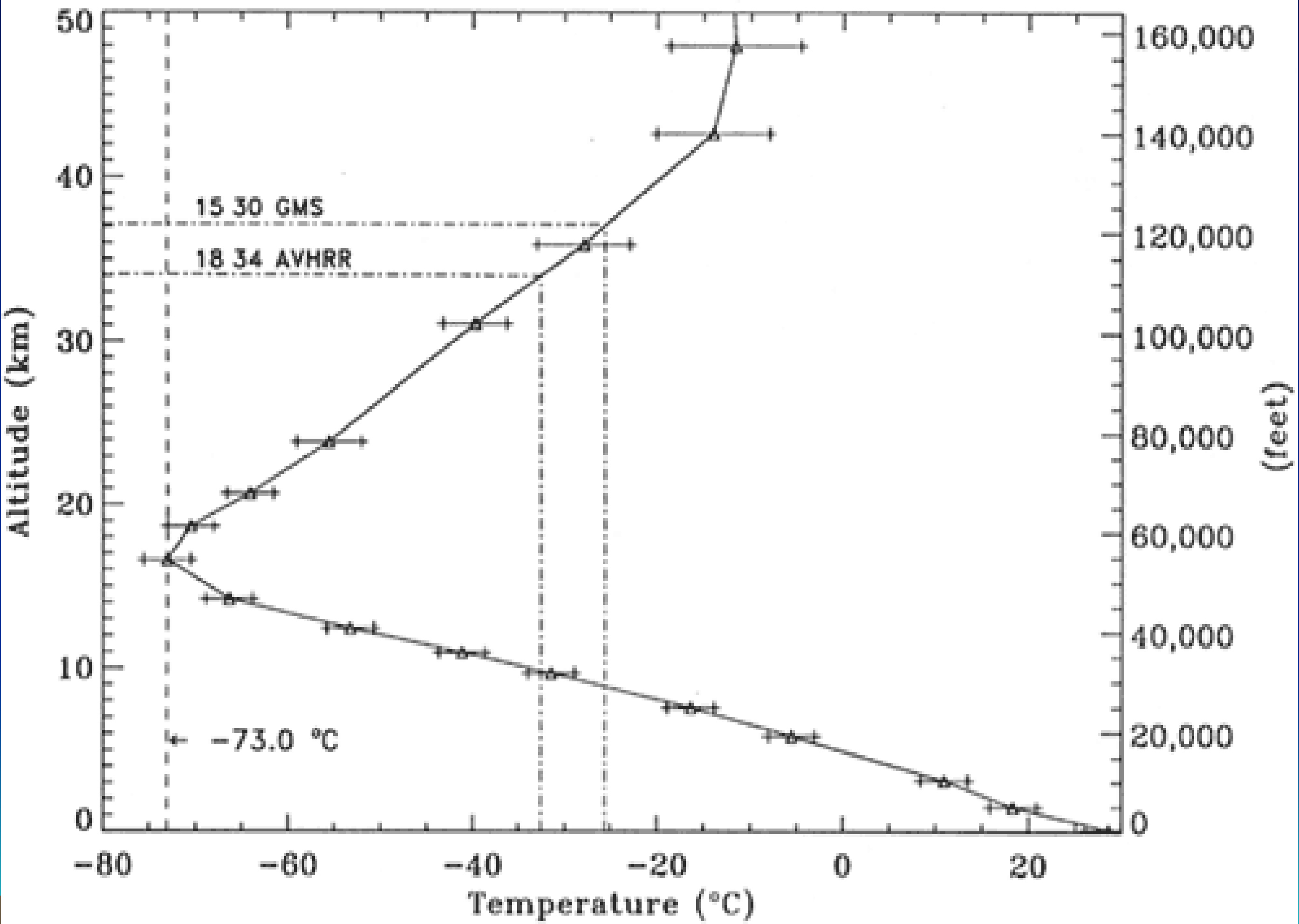
Visible IR-wavelength images spanning 3 h from 1340 to 1640 local time on June 15, 1991

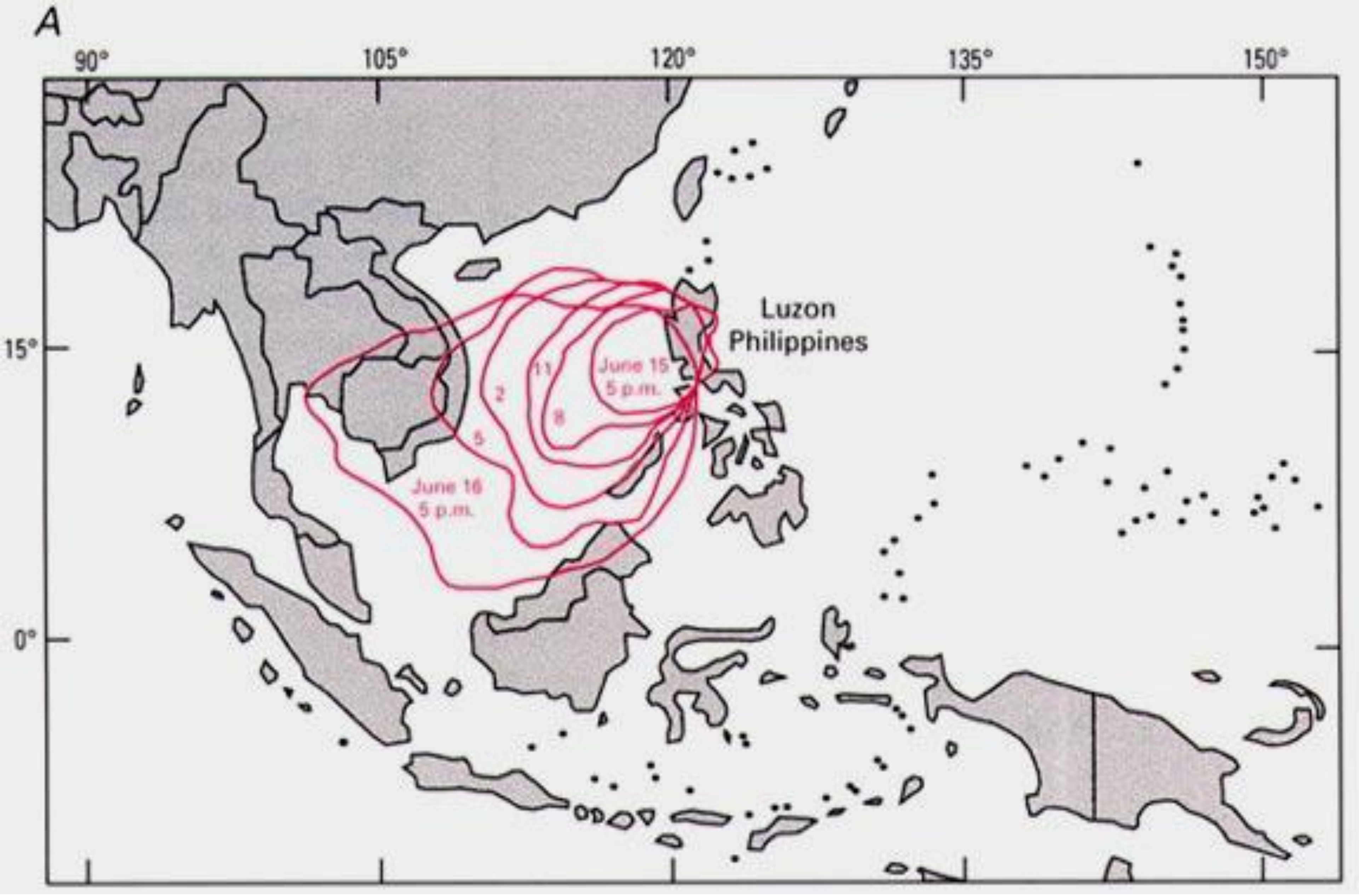


Thermal-IR images spanning 3 h from 1340 to 1640 local time on June 15, 1991

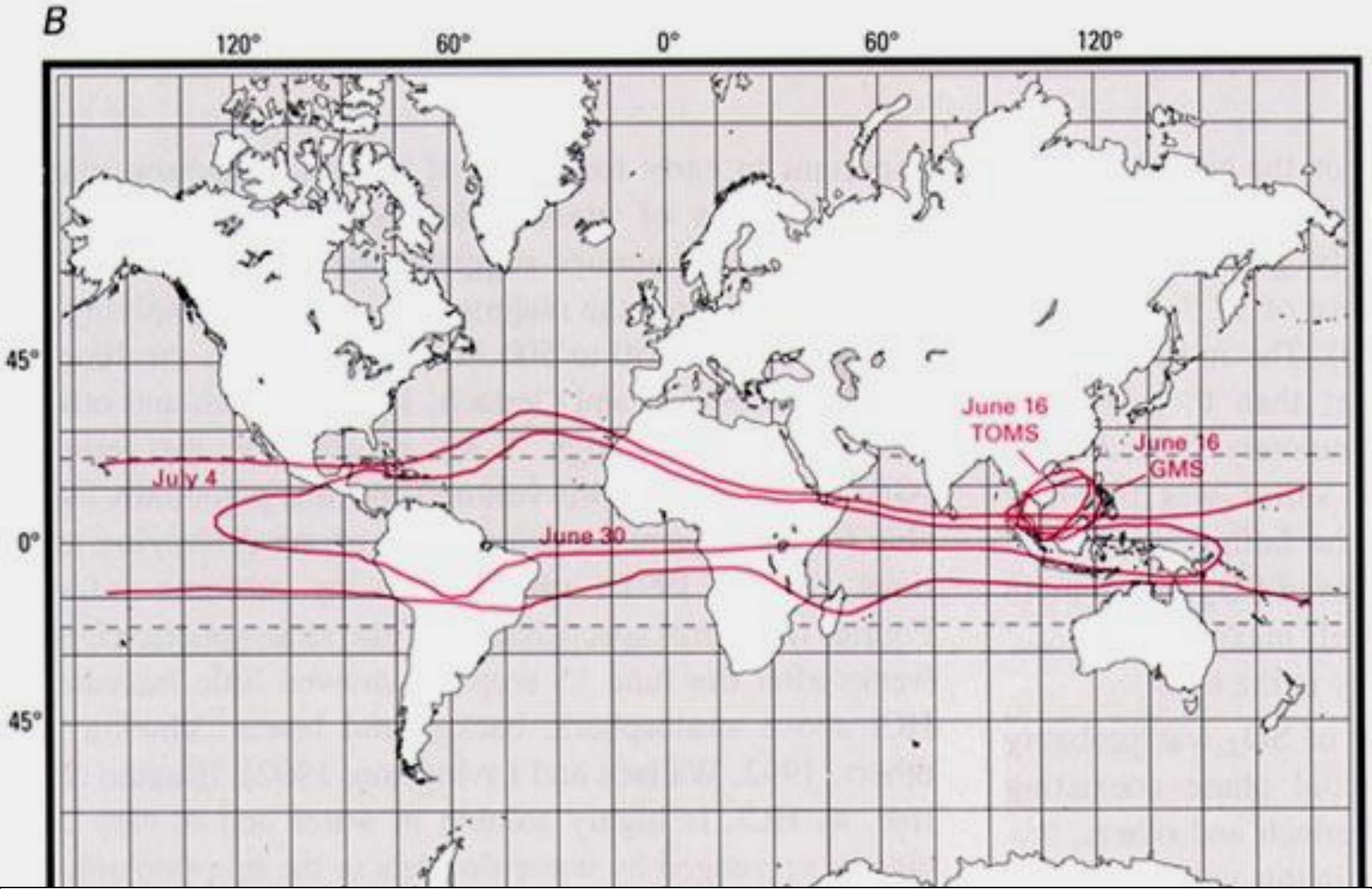


Temperature retrieved from weather satellite images of the relatively warm ash plume blowing westward off the overshooting top of the Pinatubo umbrella cloud.





Spread of the Pinatubo volcanic cloud at Philippine local time



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.

Space shuttle photograph of the earth over South America taken on August 8, 1991, showing double layer of Pinatubo aerosol cloud (dark streaks) above high cumulonimbus tops.

What makes droughts worse in HK?

Two examples:

1962 Rainfall at Hong Kong Station 1741.0 mm (79.7 % of average)
1963 Rainfall 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 Rainfall at Hong Kong Station 1570.6 mm (71.9 % of average)
Nuclear testing –
24/9/1966 France explodes atomic bomb at Mururoa Atoll

El Chichón volcano, Mexico

Before

After

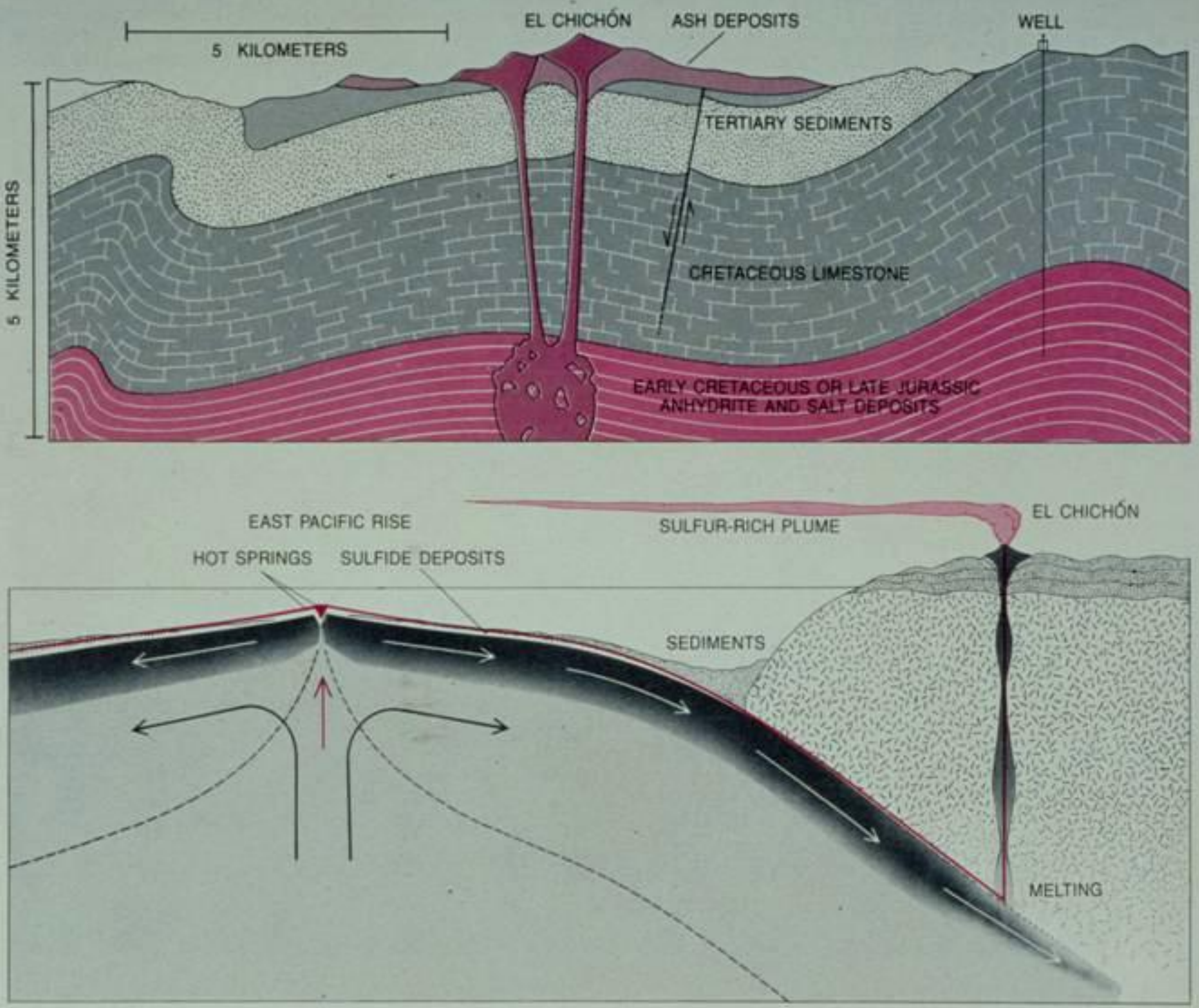
From Rampino & Self (1984)

Top ten wettest years at the Hong Kong Station and volcanic eruption since record began in 1884

Year	Annual rainfall (mm)	% of average	Notes
1997	3343.0	153.1	-
1982	3247.5	148.8	El Chichón, Mexico on March 28
2005	3214.5	147.2	-
1973	3100.4	142.0	-
1889	3041.8	139.3	-
1975	3028.7	138.7	-
1891	2974.5	136.3	-
1957	2950.3	135.1	-
1983	2893.8	132.6	-
1972	2807.2	128.6	-

TECTONIC MAP of southern Mexico shows the relation of El Chichón to the Mexican and Guatemalan volcanic belts and to local tectonic features. Three major plates of the earth's crust meet near this region. The Caribbean plate is sliding past the North American plate along a series of faults in Guatemala, and the Cocos plate is being subducted under the North American and Caribbean plates at the Middle American trench off the coast of Mexico. The volcanism is related to the subduction of the plate but has features that indicate the tectonics are not straightforward, such as the offset between the trans-Mexican and Guatemalan volcanic belts. The isolated position of El Chichón may be the result of a break in the downgoing plate where the Tehuantepec Ridge, an inactive fracture zone with which it is aligned, is being subducted.

From Rampino & Self (1984)



TWO SOURCES for the sulfur erupted by El Chichón have been proposed. A deep drill hole near the volcano tapped sedimentary deposits of anhydrite and salt formed by the evaporation of shallow seas some 100 million years ago (*top*). The magma may have assimilated large amounts of sulfur in passing through these layers on its way to the surface. The geologic cross section is based on the work of Robert I. Tilling and Wendell A. Duffield of the U.S. Geological Survey. It is also possible the sulfur was in the rock that melted to form the magma (*bottom*). In some sections of the midocean rifts where new oceanic crust is manufactured vents release sulfur-rich solutions. When the solutions precipitate, they coat the newly formed crust with sulfide deposits. A plate carrying such deposits may have produced a sulfùr-rich magma when it was subducted and melted. The sulfur in the magma El Chichón erupted may have come from both sources.

From Rampino & Self (1984)

El Chichón 1982 eruption

Location - Latitude17.33^{o}N

Longitude 93.2^{o}W

Timing - 1st eruption 11.32 pm March 28

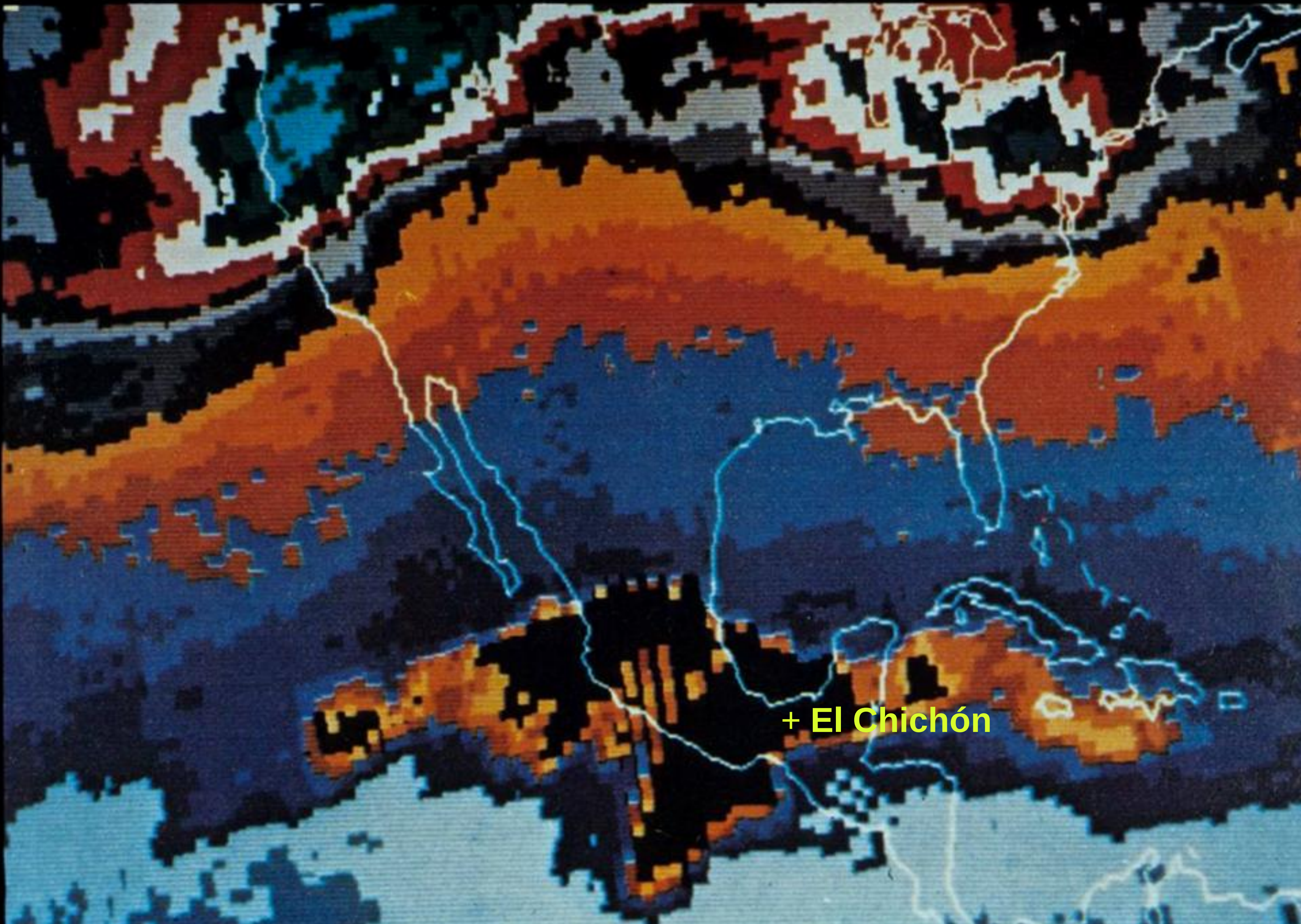
2nd eruption 7.35 pm April 3

3rd eruption 5.22 am April 4

Tephra - ~0.6 km^3 of trachyandesite

Aerosol - 3.3 million tonnes of SO_2

Impact - ? trigger of the intense El Niño of 1982-3 (2nd strongest on record)



Sulphur dioxide injected into the atmosphere by El Chichón shows up clearly in an image generated by the satellite *Nimbus 7* on April 5, 1982. From Rampino & Self (1984)

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

Observations of the El Chichón eruption cloud from Francis (1993)

Average velocity -	20 m / second
Westward drift -	Circled the world on April 26, 1982
Cloud dispersion -	Most of the cloud remained south of 30ºN for more than 6 months after the eruption, blocked by atmospheric circulation cells
Aerosol particles -	average diameters 3 to 6 microns 85% glass shards coated with sulphuric acid

Monthly rainfall at the Hong Kong Station in 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

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

Flooding of Kwai Chung Road on August 17, 1982

Statistics of mean annual temperature recorded at the Hong Kong Station during, 1-year after and 2-year after the eruption of Agung, El Chichón and Pinatubo

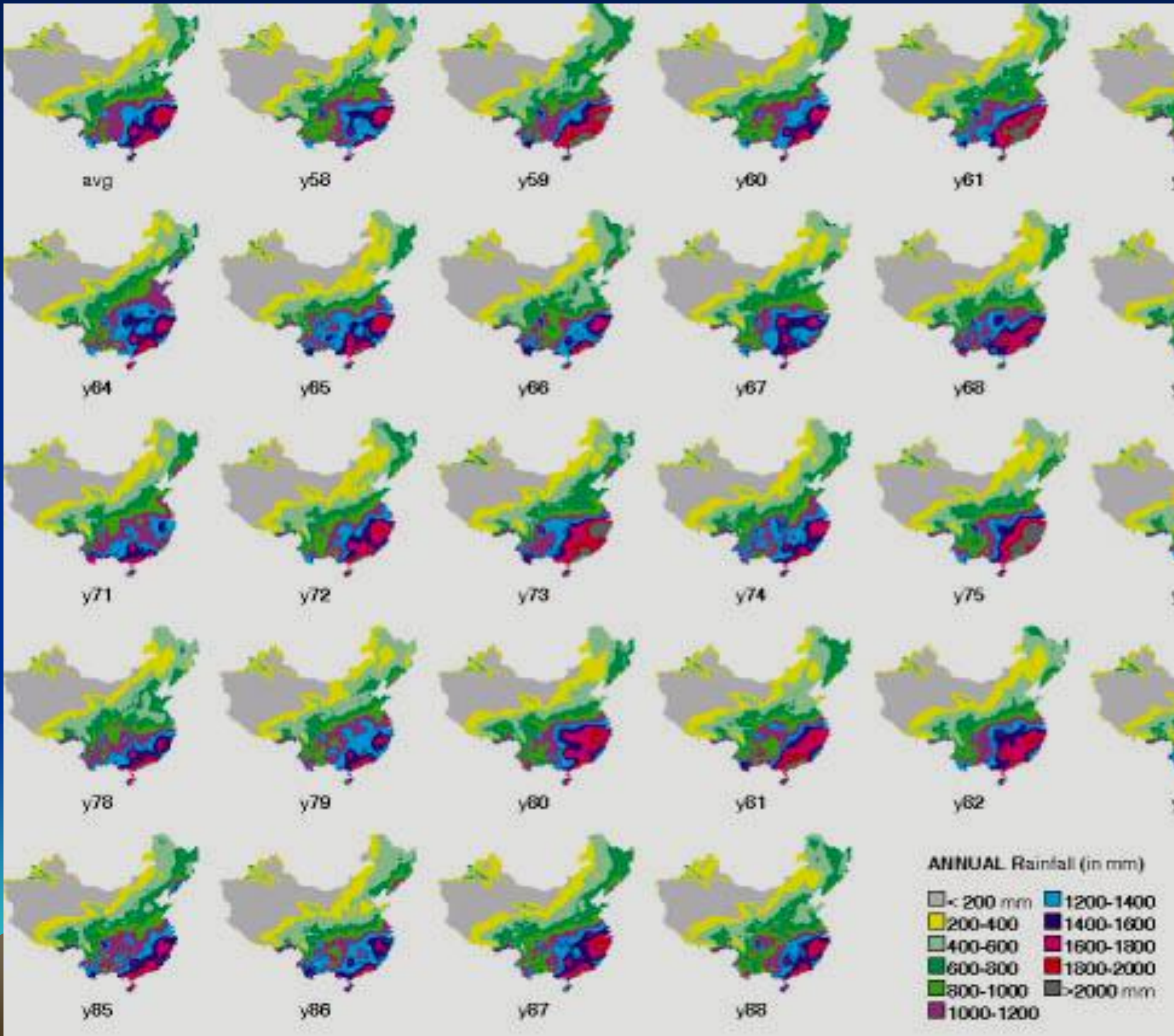
Volcano	Month and year of eruption	Mean annual temperature during year	Mean annual temperature after 1 year	Difference from year of eruption	Mean annual temperature after 2 years	Difference from year of eruption
Agung	2/1963	23.3	22.9	-0.4	23.1	-0.2
El Chichón	3/1982	22.9	23	+0.1	22.5	-0.4
Pinatubo	6/1991	23.5	22.8	-0.7	23.1	-0.4

Note: The annual precipitation in 1964 is 2432.1 mm which is 269.9% above 1963. The annual precipitation in 1992 is 2678.8 mm which is 145.1% above 1991.

Relevance to water resource management

- Volcanic eruptions are a natural forcing on the natural hydrological cycle because it interferes with the normal air circulation
- Can help to explain some of the extremely dry and wet years
- Findings on HK has regional implications to other coastal and inland regions of China

Time series of rainfall in China from 1958-1988

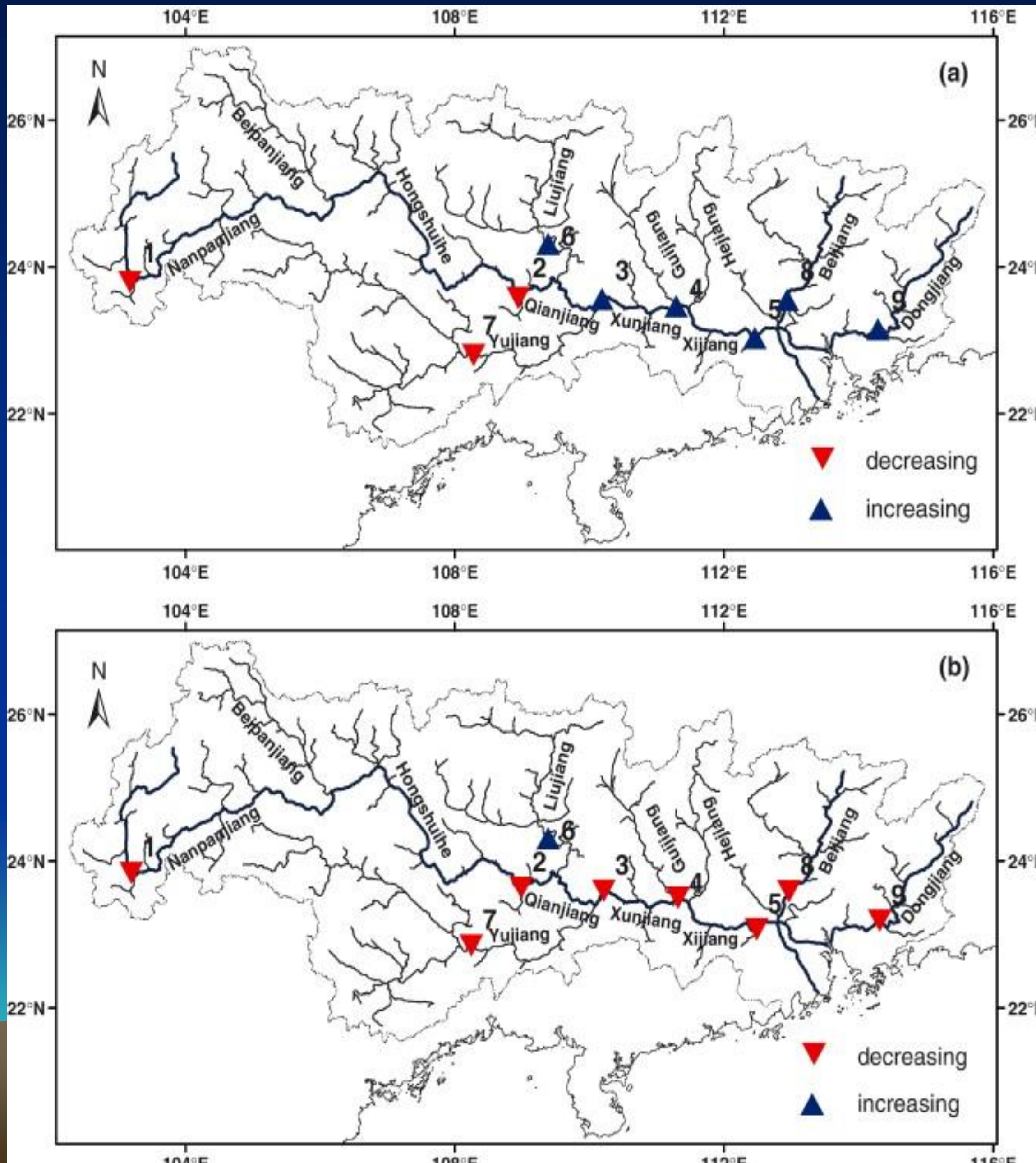


From
Prieler (1991)

1950s-2004 trends of water discharge (a) and sediment load (b) in the Pearl River drainage basin

Reflects precipitation variability

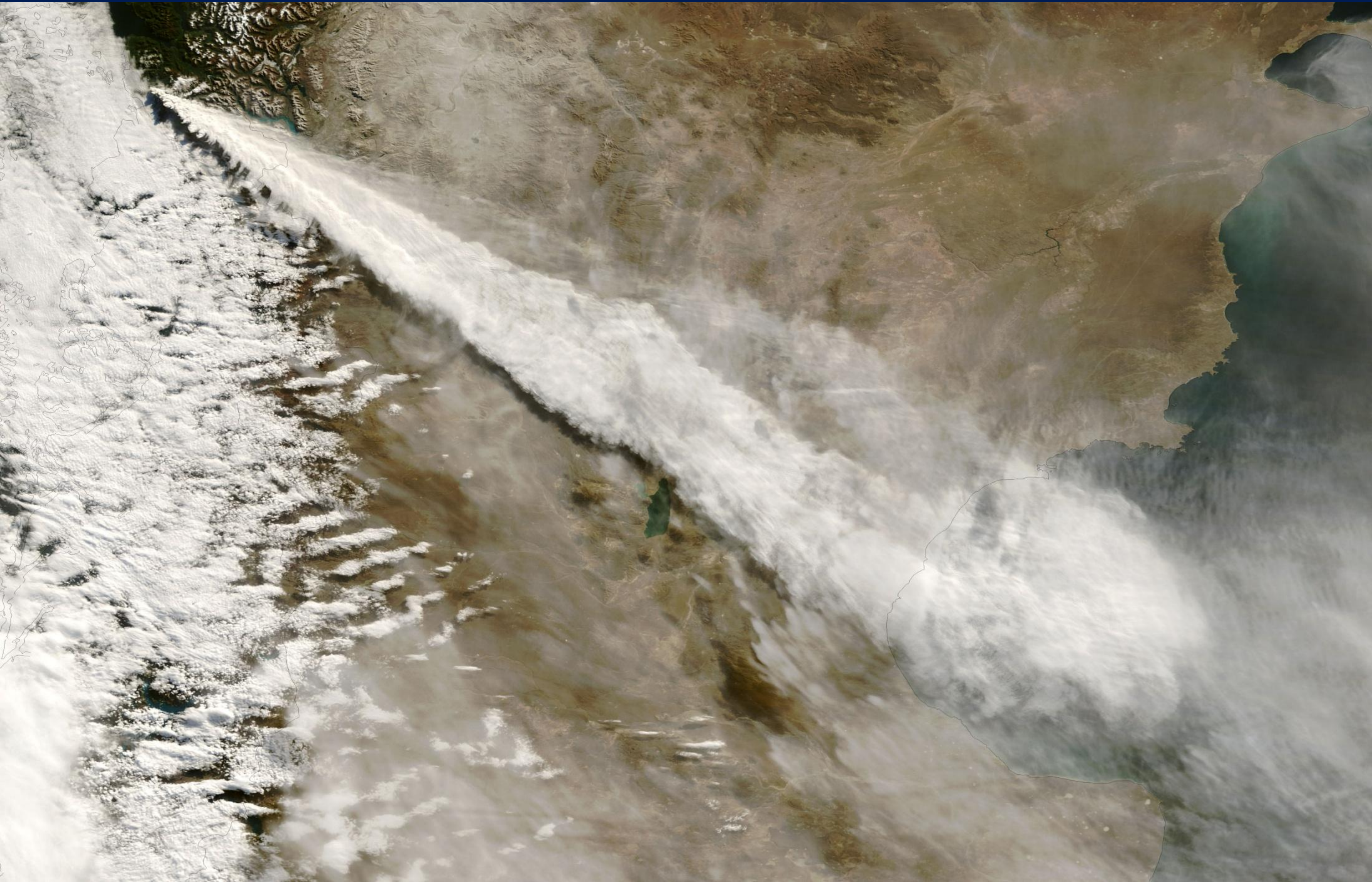
Reflects reservoir construction



From Zhang et al. (2008)

Inference – Human impact on the natural hydrological cycle is of concern

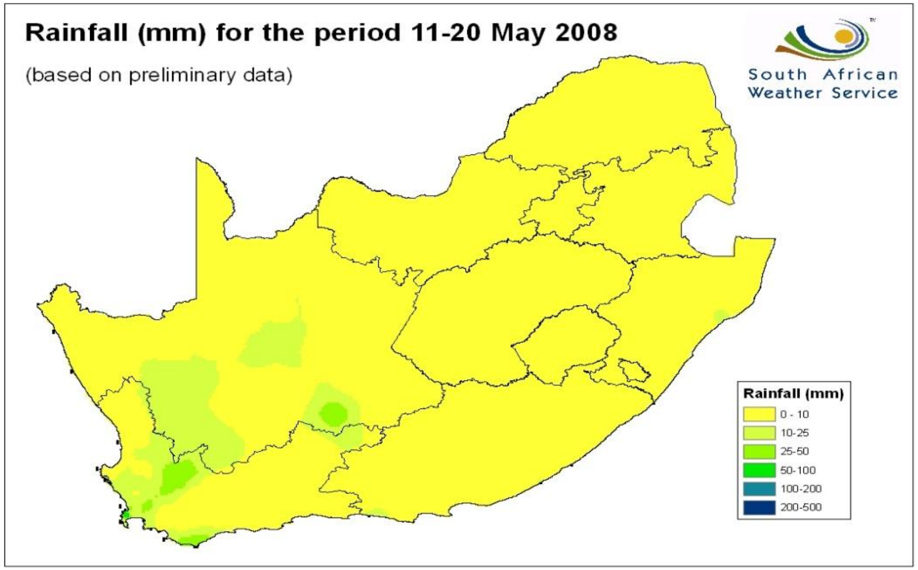
May 2, 2008 Chaiten eruption, Chile VEI=5

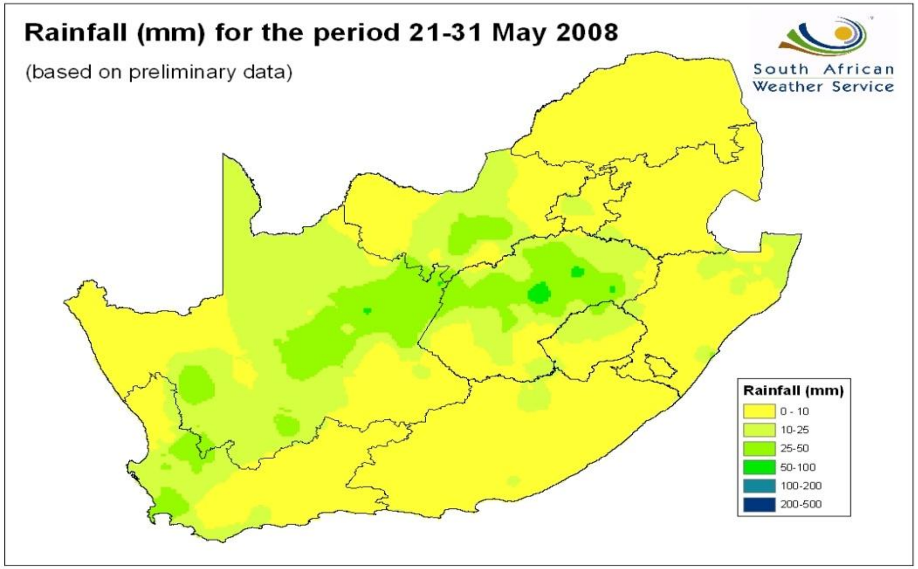


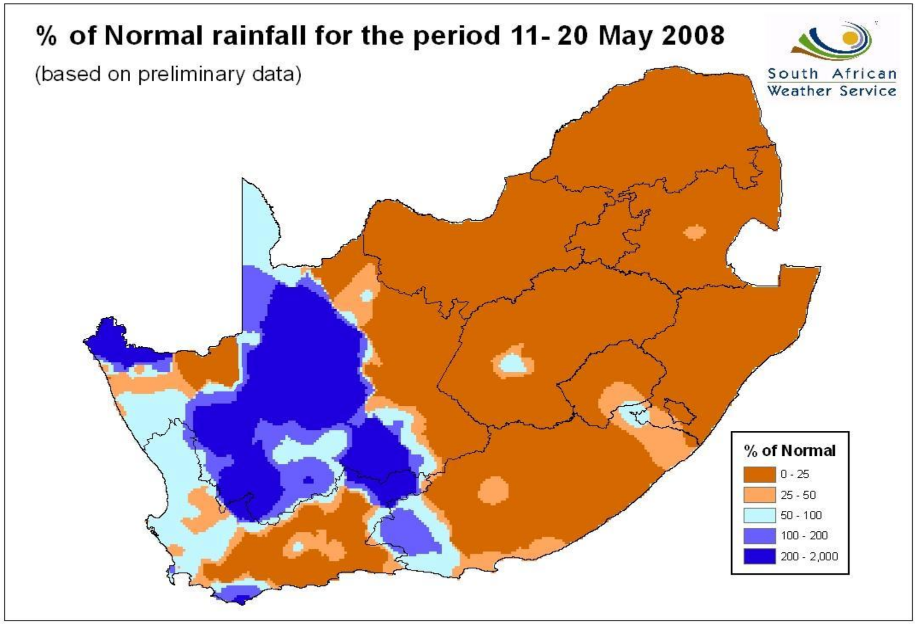
Impact on regional rainfall pattern

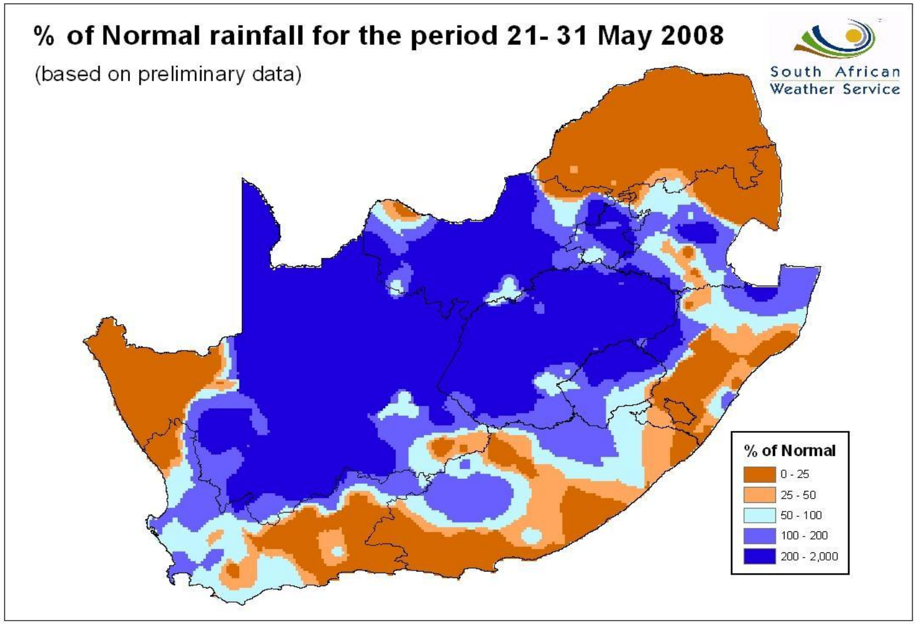
- A wet May/June in South Africa
- A wet June in Australia
- Wettest June in Hong Kong since record began in 1884 (1346.1 mm or 346.8% above average)

Rainfall 11-31 May 2008

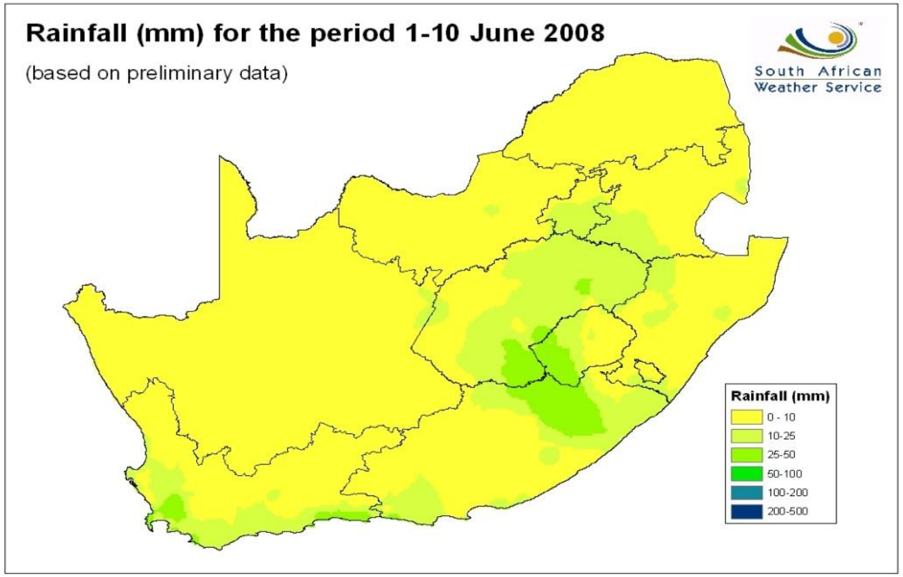


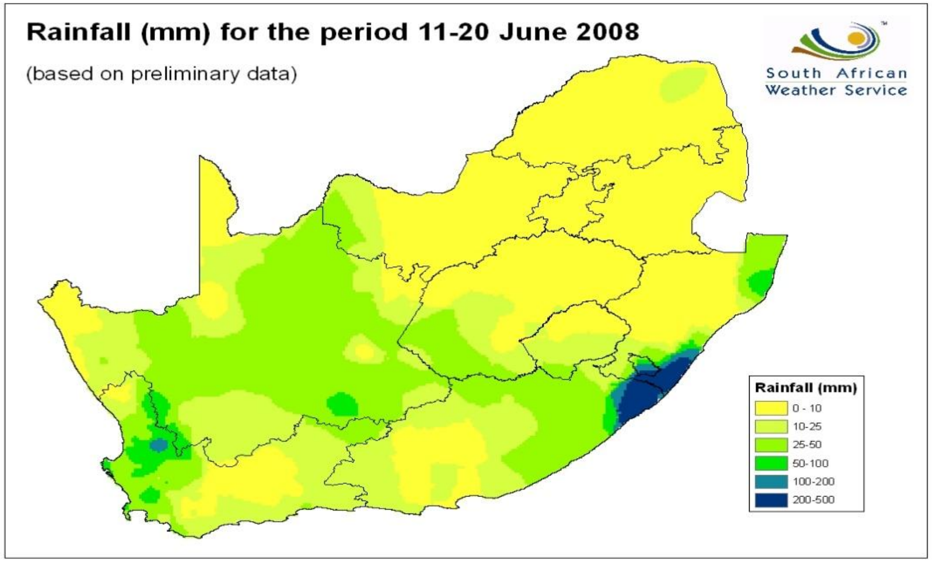


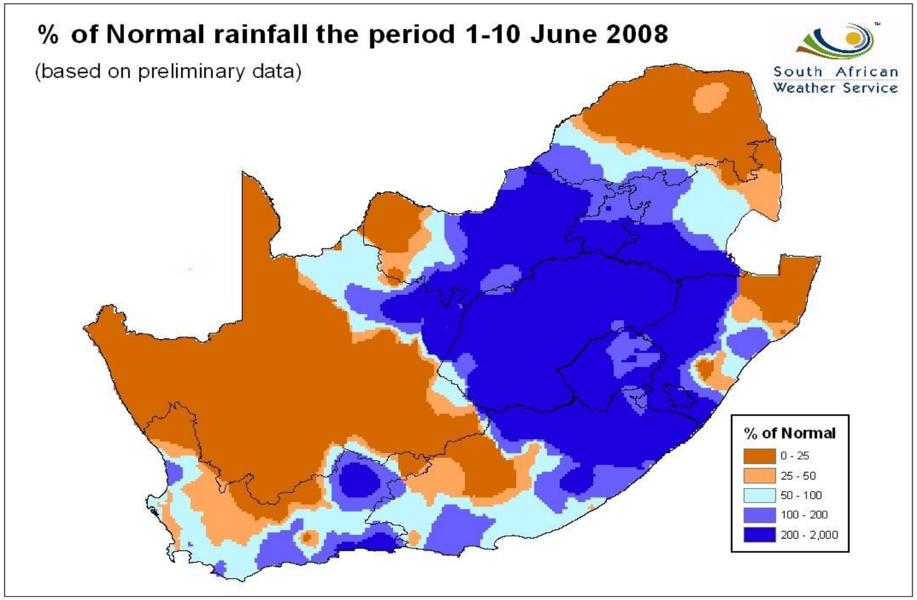


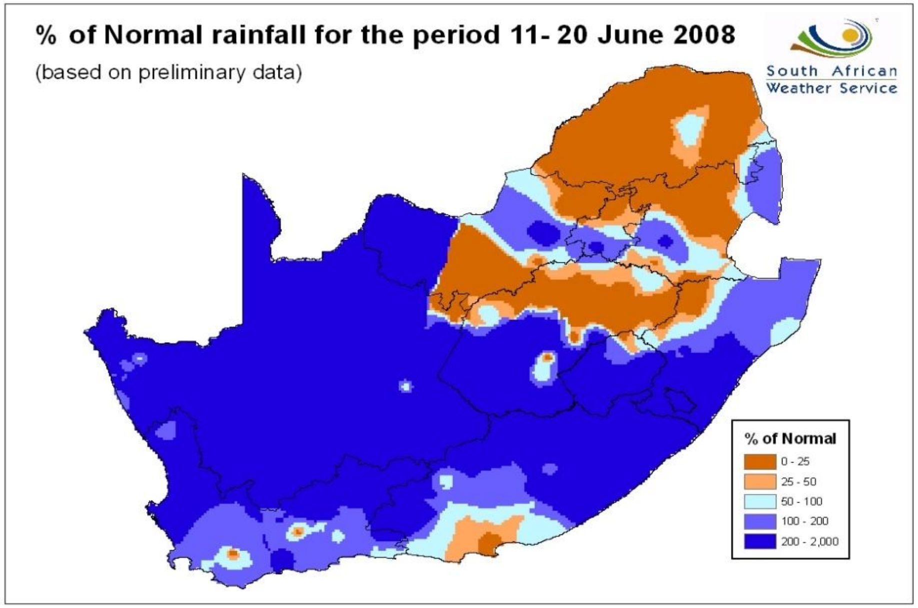


Rainfall 1-20 June 2008

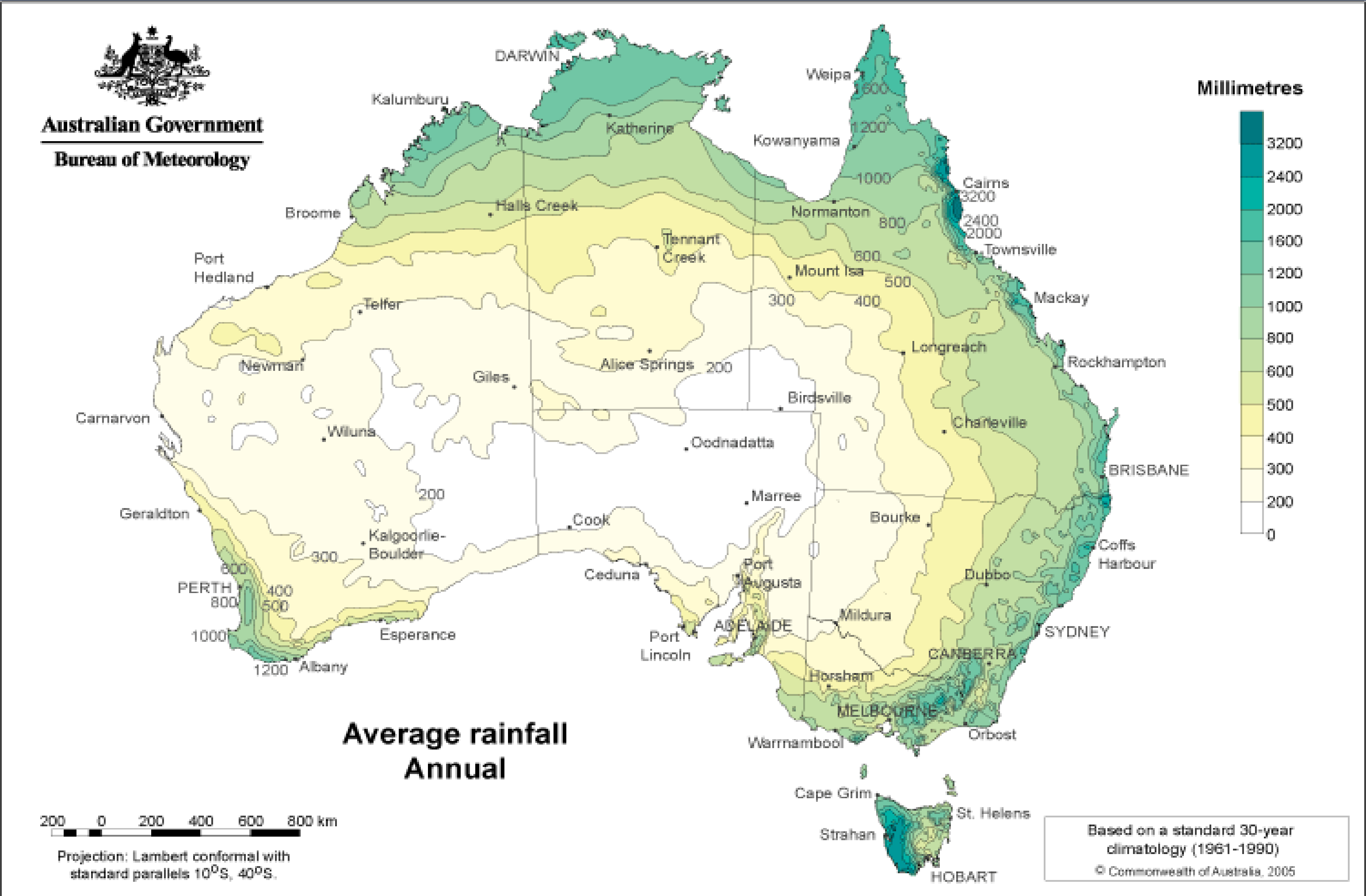




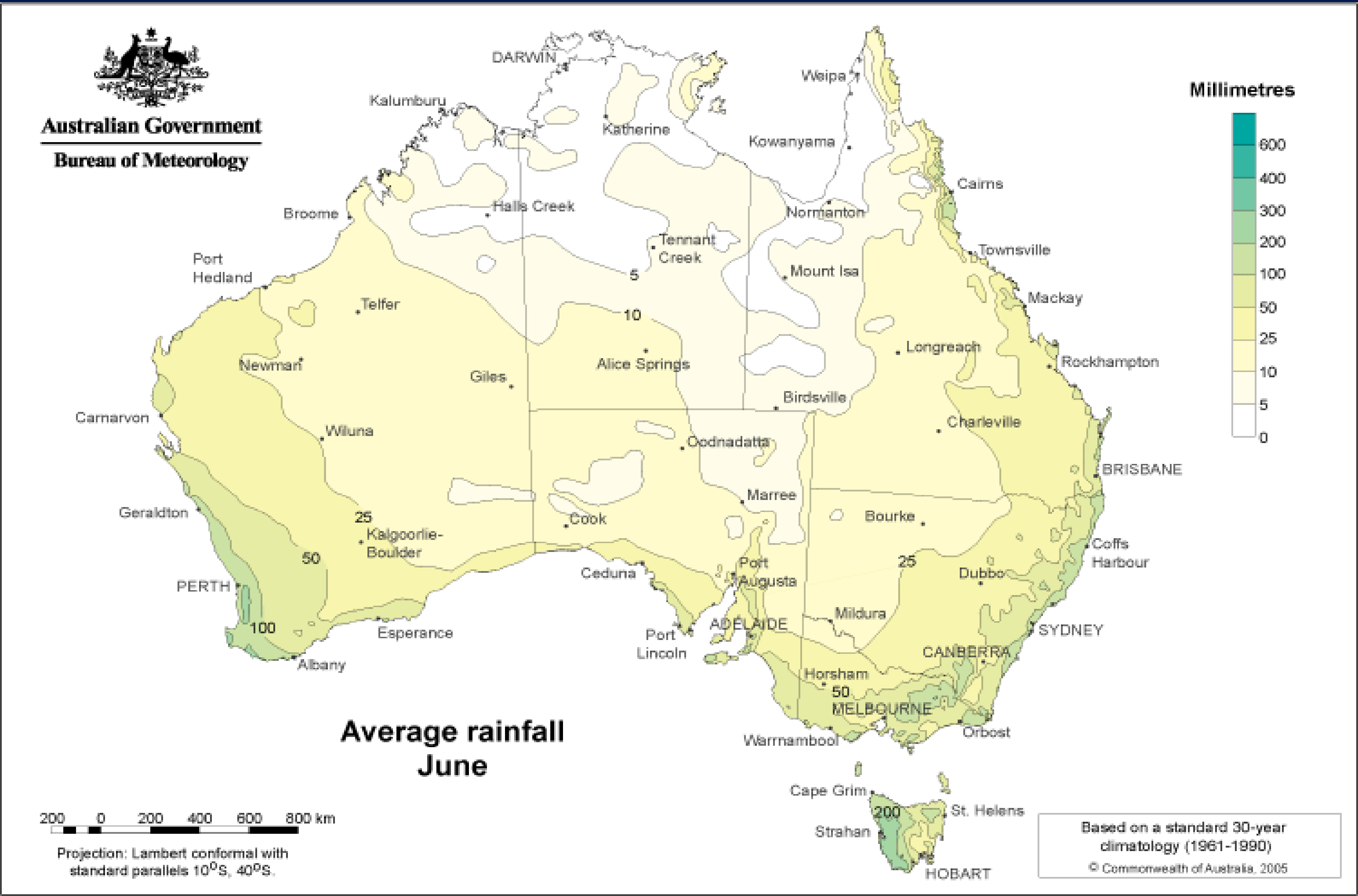




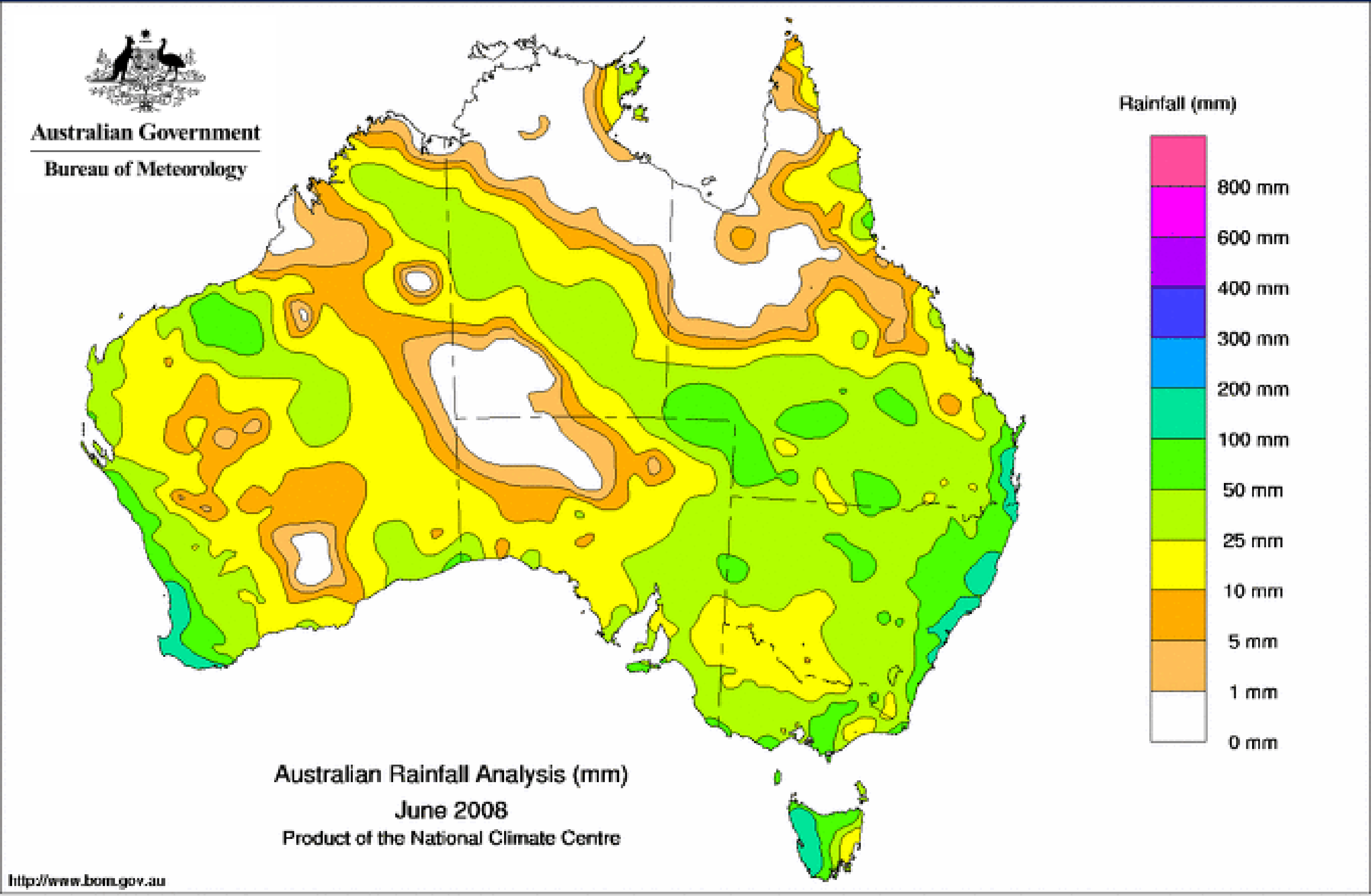
Annual rainfall in Australia 1961-1990



Average rainfall in June 1961-1990

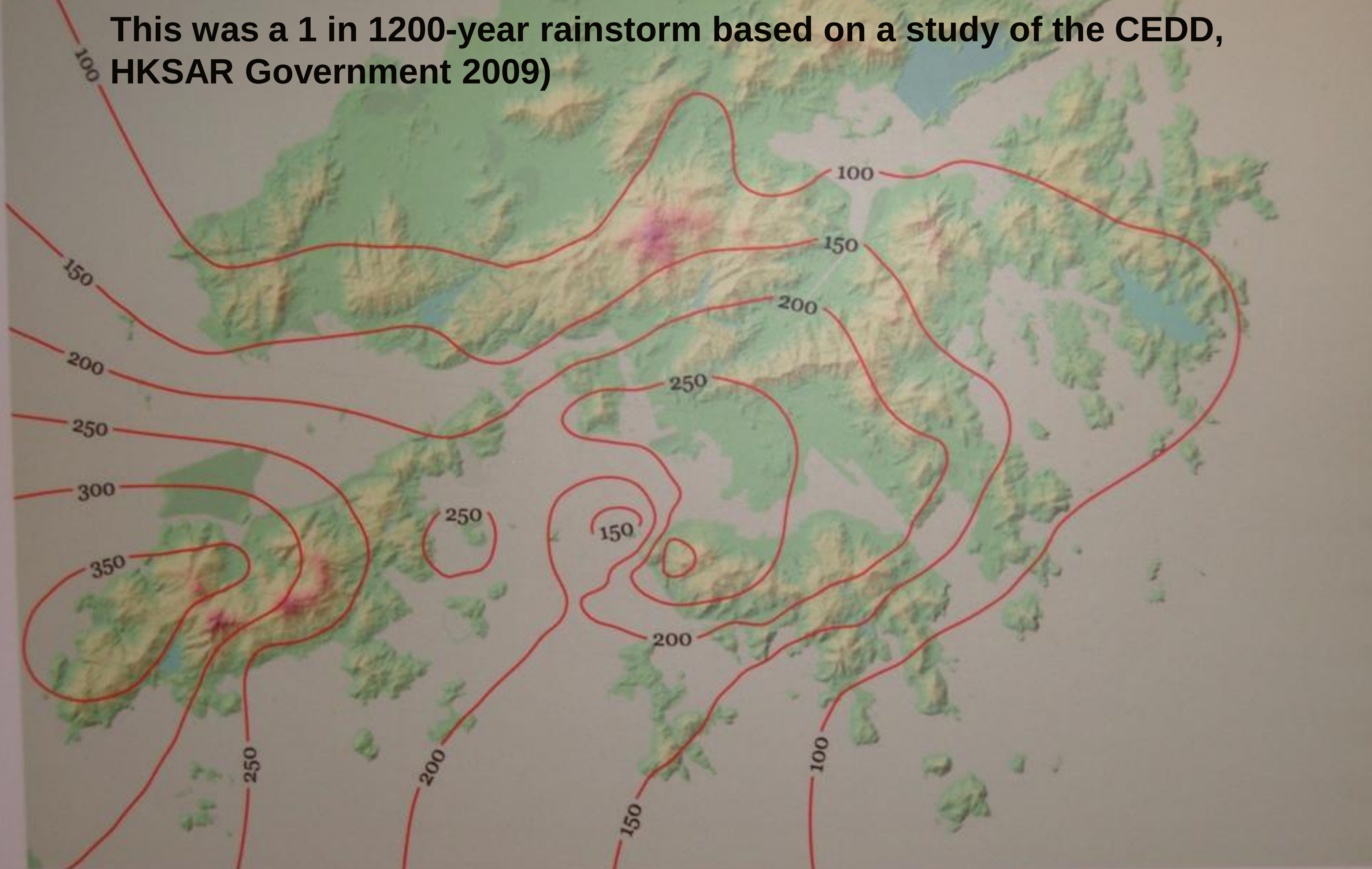


June 2008 rainfall in Australia



Issued: 30/06/2008

This was a 1 in 1200-year rainstorm based on a study of the CEDD, HKSAR Government 2009)

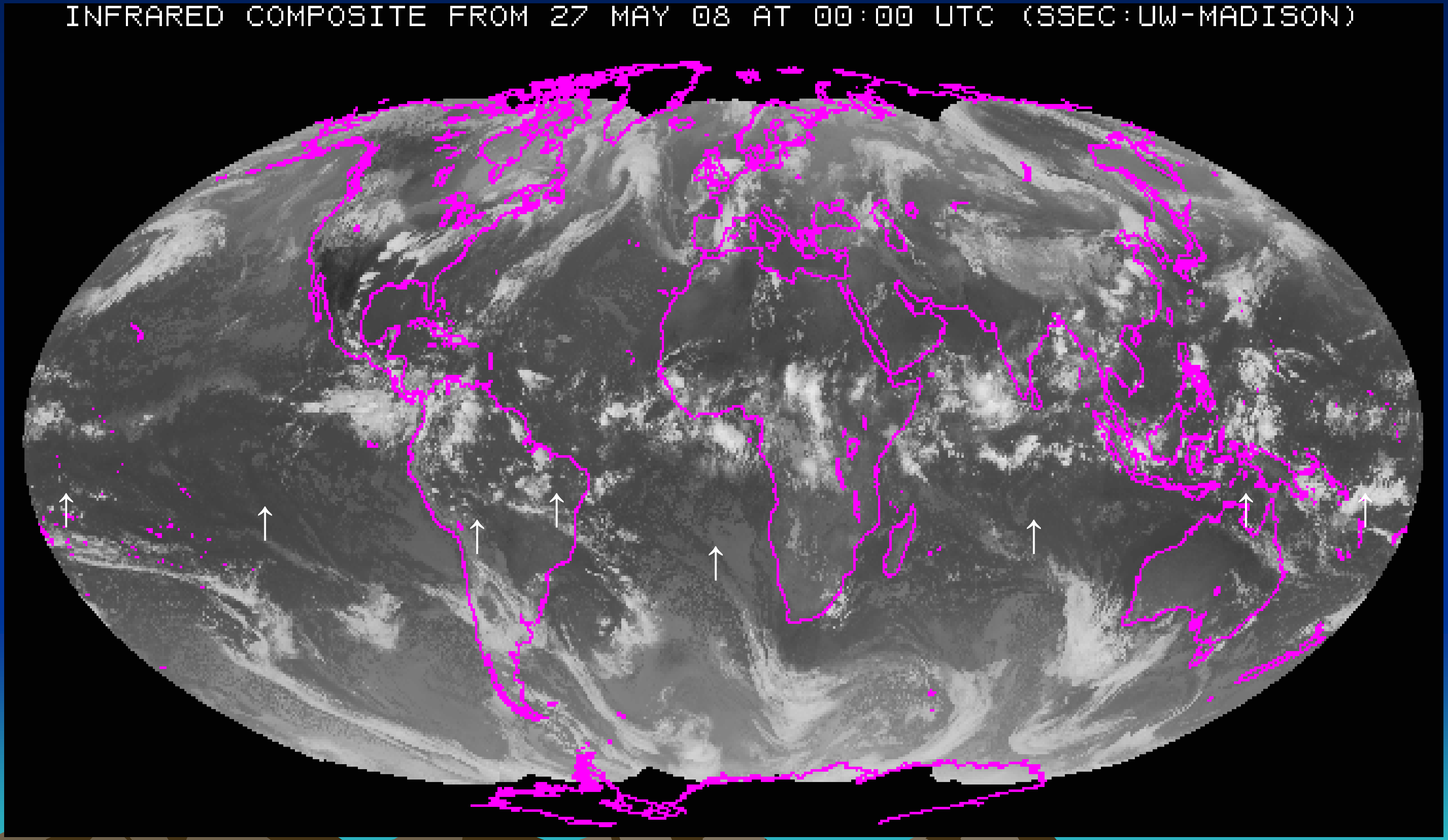


2008 年6月6-8日最高4小時累計雨量分佈圖

Max. 4-hour rolling rainfall distribution in the rainstorm of 6-8 June 2008

Some of the ~ 2400 landslides on Lantau Island caused by the rainstorm

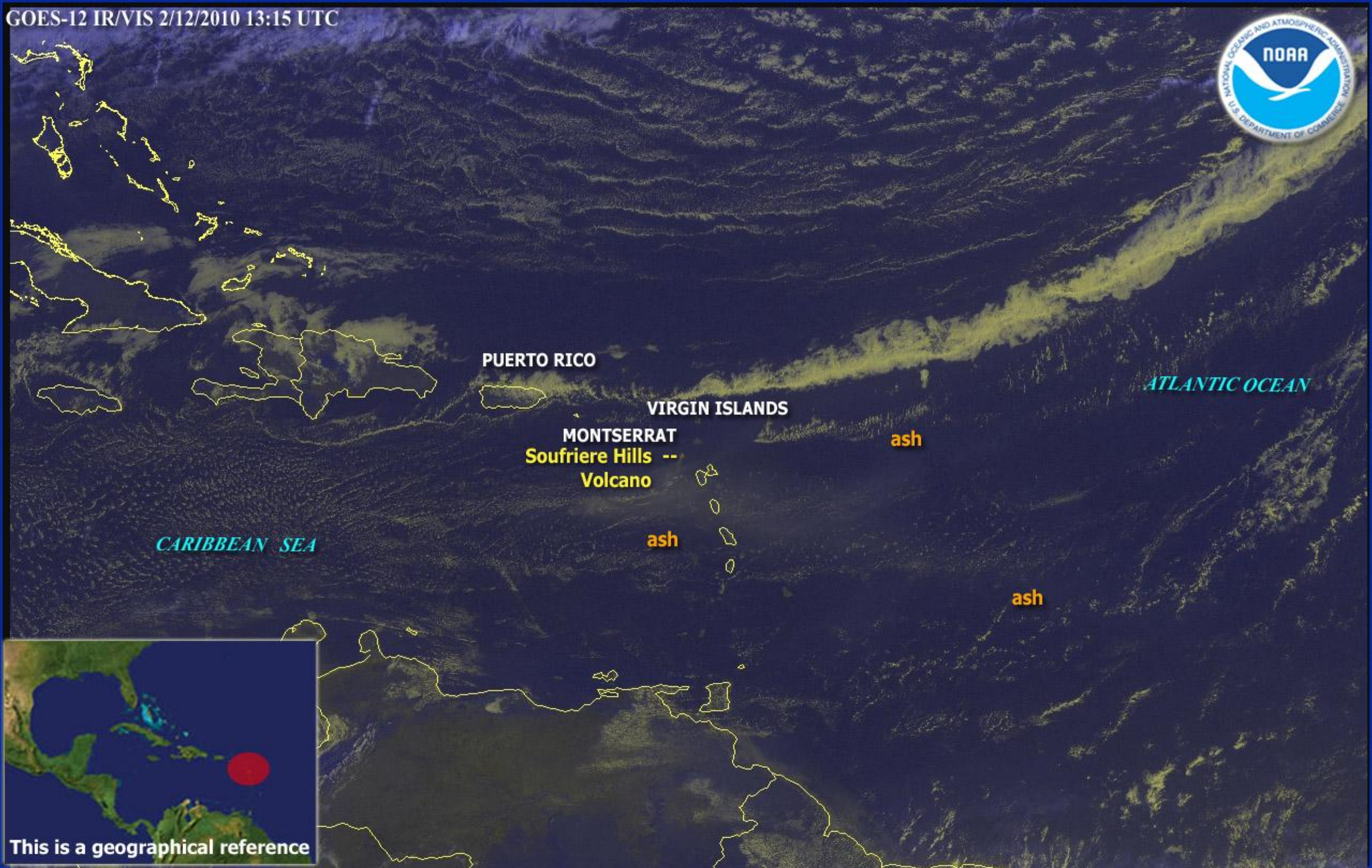
Southern hemisphere storm systems spreading aerosols into the northern hemisphere



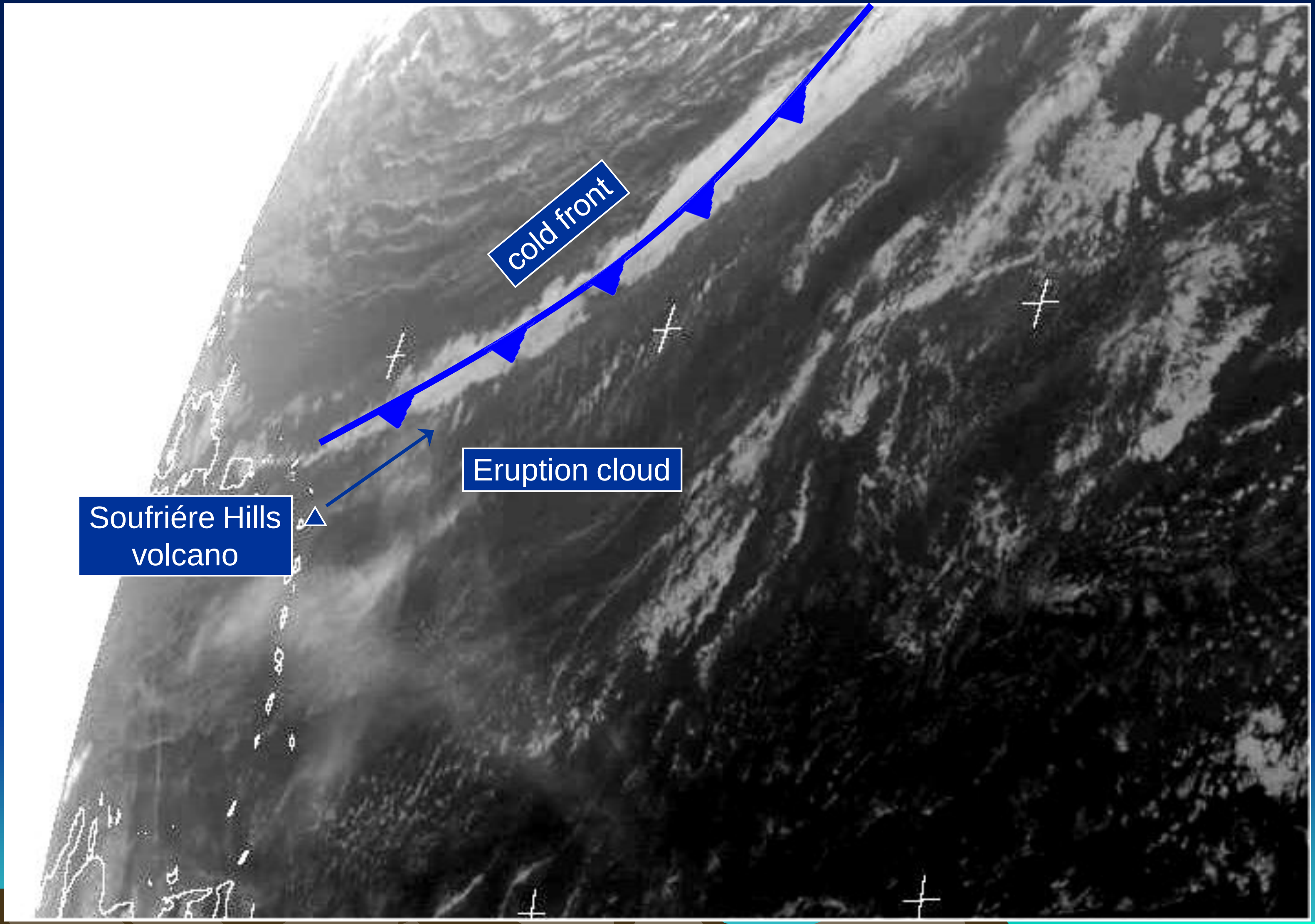
Residual ash from an explosive eruption yesterday at the Soufriere Hills Volcano located on the Caribbean Island of Montserrat. Currently the ash extends approximately 425 miles to the east of the summit.

February 11, 2010 1635 UTC eruption - ash plume reached 15.2 km altitude

Credit: NOAA



Ash plume caught up within the warm sector of frontal system



Frontal activity storm with torrential rainfall

20/2/2010 Madeira death toll > 48 death toll

28/2/2010 Western France > 62 death toll

Others countries affected – Spain, Belgium and Germany

Conclusion – Storms exacerbated by volcanic aerosol

Main conclusions

(1) Volcanic eruptions are a trigger of climate change (including monsoonal variability) and have been shown to cause extremely dry and wet years.+

(2) Because volcanic forcing on rainfall is a natural phenomenon, it is dangerous to attribute the occurrence of floods and droughts to global climate change through the production of man-made greenhouse gases without detailed investigations.

(3) Volcanic eruptions are mega-scale equivalents of power stations/urban heat islands caused by mega-cities. All are thermal plumes differing in time and space.

(4) The role of volcanic forcing on rainfall variability in other parts of the world is worthy of investigation using past records.

(5) Human impact of the natural hydrological cycle is a much underestimated cause of climate change.

+ There is also a possible role played by nuclear testing.

Cleveland, Aleutian islands

Thank you