Volcanic eruptions and climate variability

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Acknowledgements –
NOAA, NASA, Wikipedia and the Global Volcanism Program. This research is a contribution to the Volcanic Impacts on Climate and Society (VICS) Working Group of the Past Global Changes Project.

Thomas Nelson Podcast presentation on 1st December, 2023

Plan

Introduction

Recent volcanic eruptions and climate variability –

Ocean heatwaves / extreme weather events /
2014-2016 ENSO / polar sea-ice changes /
1995 acceleration in sea-level rise

Conclusions

Climate change definitions

UN Framework Convention on Climate Change (UNFCCC)
Climate change that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere

Intergovernmental Panel on Climate Change (IPCC)
A change in the state of the climate that can be identified for an extended period, typically decades or longer (driven by CO_2)

All weather changes are now included because of the pause in temperature rise

A product of astronomical forcing including solar variability and the interaction of the Earth systems (atmosphere, hydrosphere, biosphere, cryosphere, pedosphere and lithosphere including volcanism)

Order of importance

1st order

Astronomical forcing and the Sun e.g. glacial/interglacial cycles, monsoons, seasons and daily

2nd order

Geothermal heat/plate climatology (James Kamis 2014)

www.plateclimatology.com

How geological forces affect the hydrosphere and atmosphere including terrestrial and submarine volcanic eruptions, their associated circulation changes and the release of gases including water vapour, SO_2 and CO_2

3rd order

Human-induced changes including heat generation, water cycle changes and greenhouse gases

*Classification of volcanic eruptions**

(1) Sub-aerial / terrestrial –
switches on hot air followed by cooling (atmospheric warming, injection of ash, gases and aerosols, blockage of shortwave radiation, cloud formation, pressure changes, moisture redistribution, continental cooling, ozone depletion, circulation changes and extreme weather)

(2) Submarine / sea floor –
switches on hot seawater (cause of sea-surface temperature anomalies, pressure changes, circulation changes, moisture redistribution, continental warming and extreme weather)

(3) Mixed –
initially submarine later sub-aerial (combination of 1 and 2).

*** Magma composition is important.**

Sub-aerial volcano model

Ash & aerosols reduce solar radiation leading to cooling

Warm air stores more moisture – water vapour redistribution

Air pressure changes (low)

Cooling

Eruption changes normal air circulation / creats clouds / destroys O_3

SO_2, HCl CO_2 & H_2O degassing

Cool air stores less moisture

Cooler air

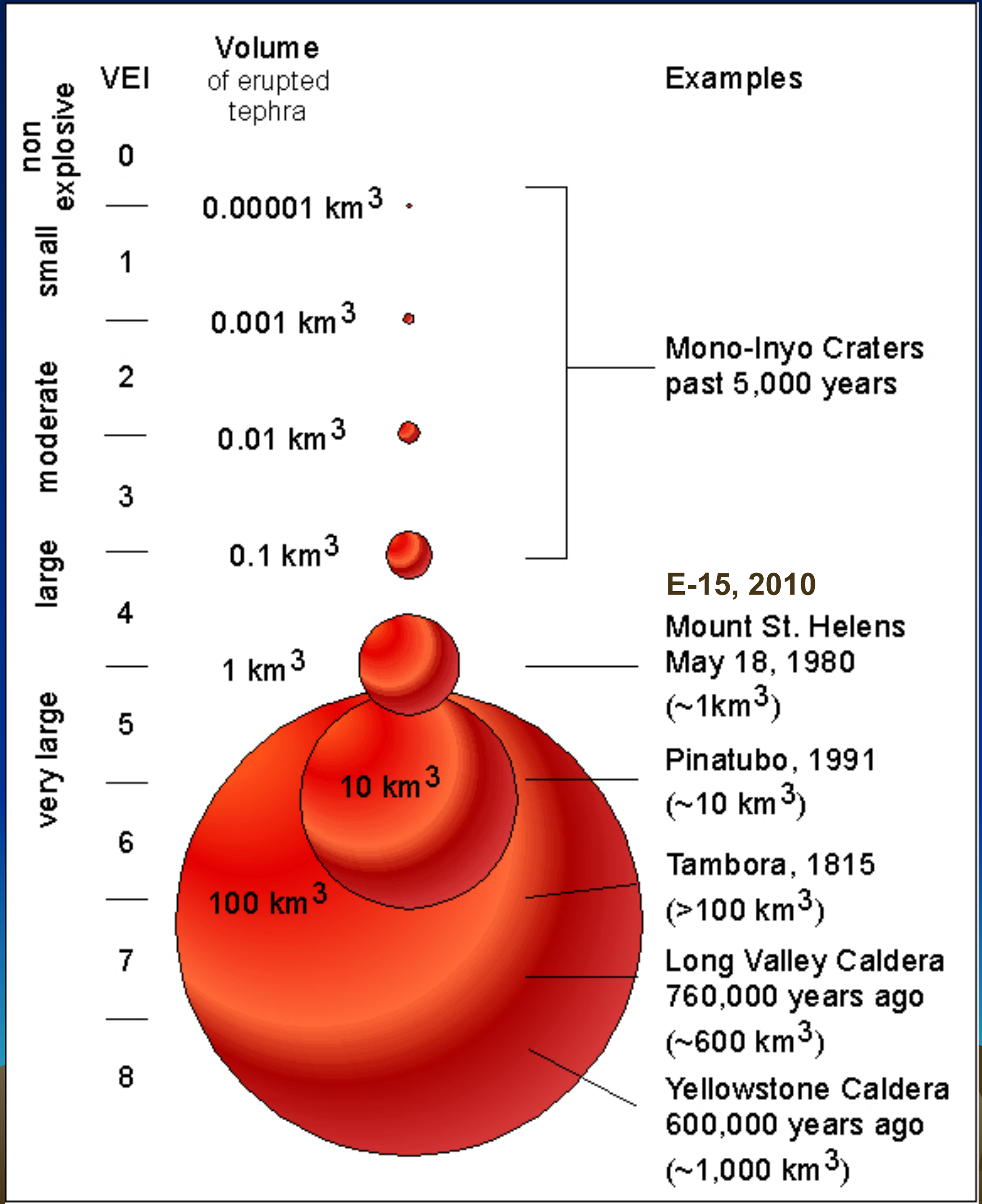
Impact longer lasting if higher VEI

Volcanic Explosivity Index (VEI)

Used for the estimation of explosiveness of volcanic eruptions on land (sub-aerial)

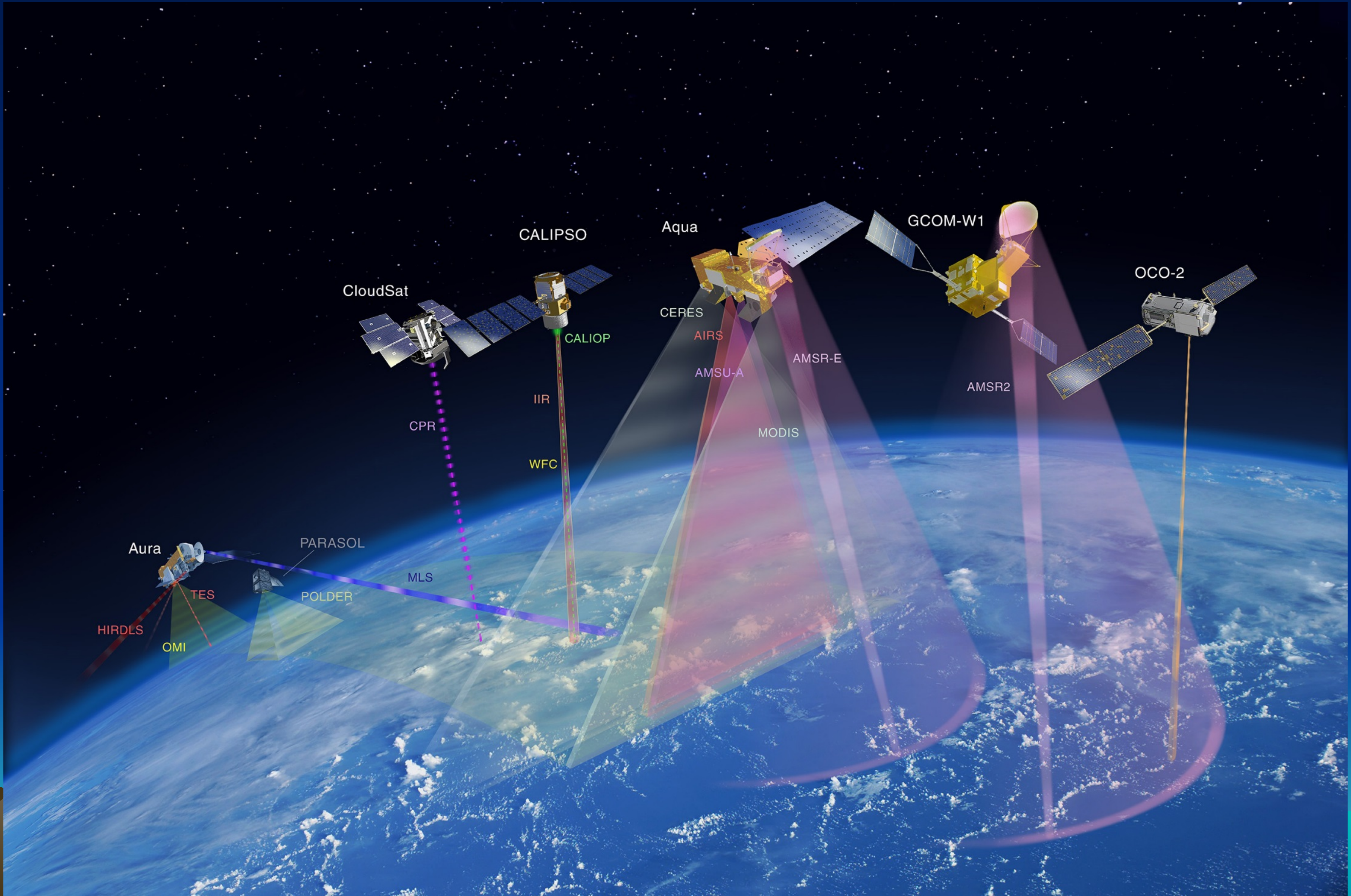
(Newhall and Self 1982)

Acid magma
most explosive



Above VEI 2
regional impacts
on weather
already detectable

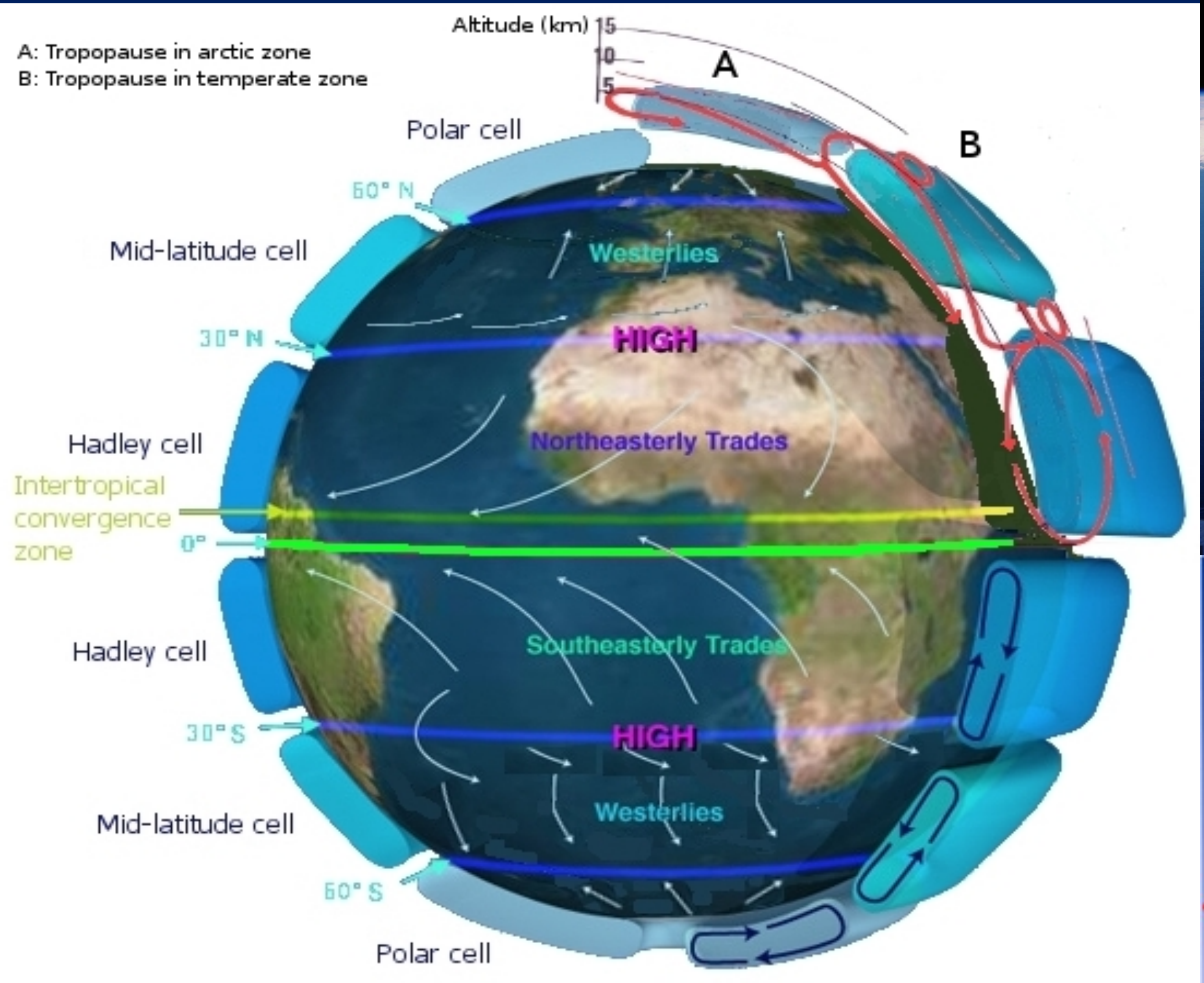
NASA's A-Train including CALIOP vertical profiles of aerosols



Satellite observations since late 1970s

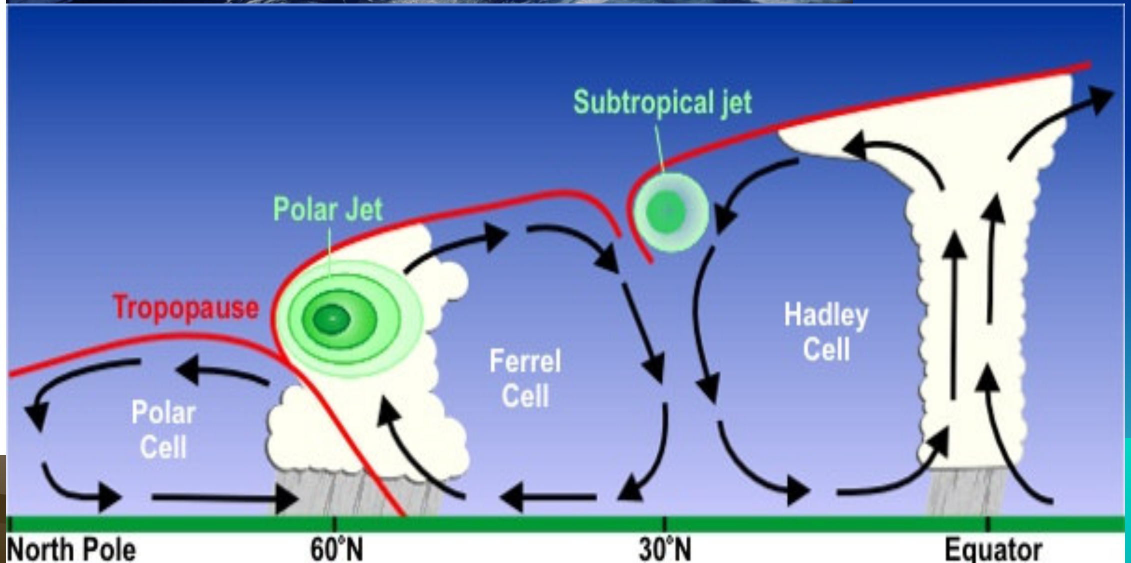
Volcanic eruption clouds reaching the stratosphere

Interferes with jet streams creating atmospheric rivers

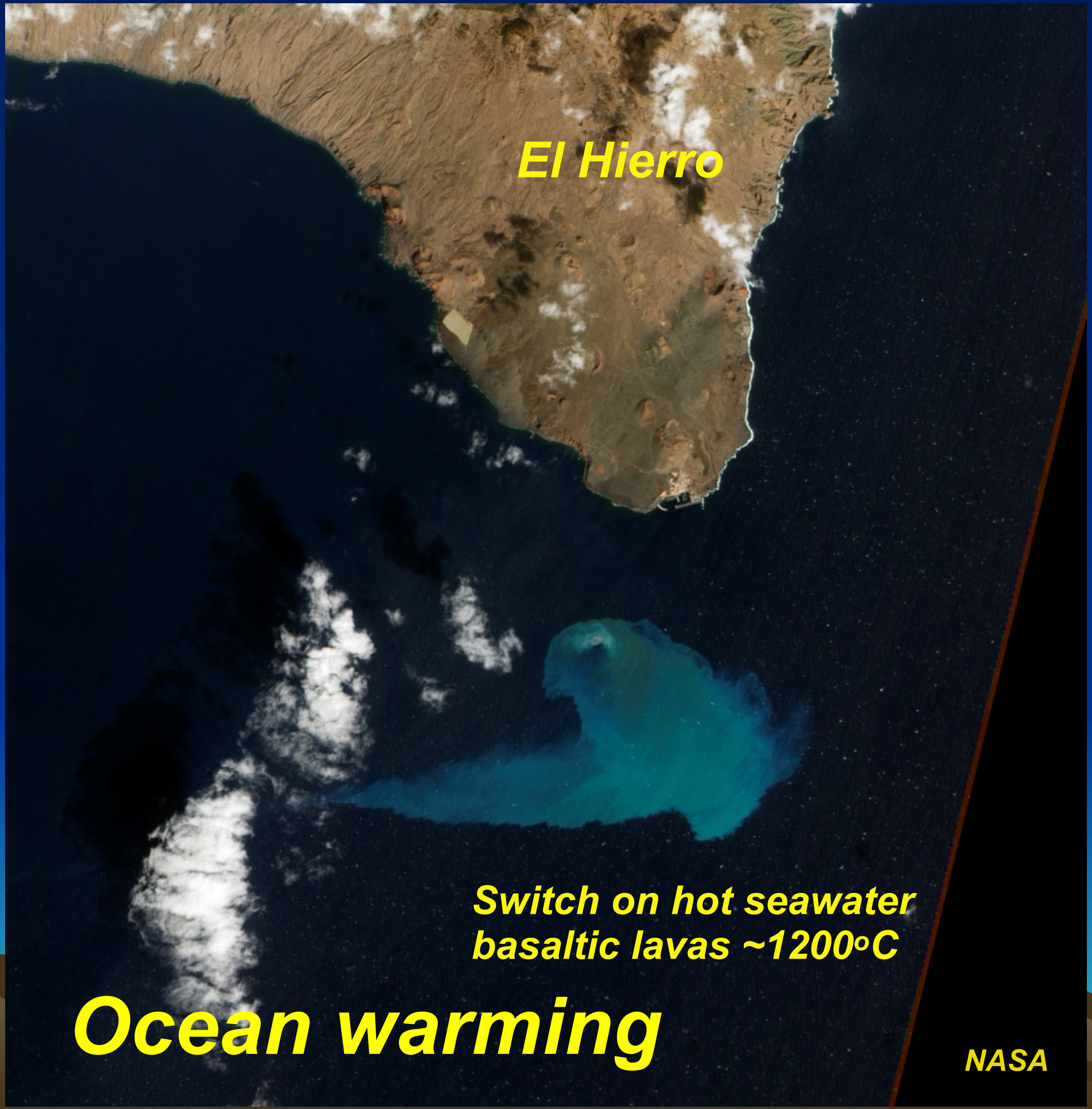


Jet stream over western Canada

Source: Wiki



Submarine volcano model



Examples –

El Hierro volcano, Canary islands
10/2011 – 3/2012 (north Atlantic)

Hunga volcano, Tonga
12/2014 – 1/2015 (south Pacific)

Nishinoshima, 940 km south of
Tokyo 3/2013 – 9/2015 (north
Pacific)

Impacts –
Formation of blobs
Pressure changes
Surface wind changes
Sea-level changes
Ocean current changes
Polar sea-ice changes

Statistics on submarine volcanoes

Total number	~1 million
Number rising 1 km from seabed	75,000
Magma output in oceanic ridges	75%
Active submarine volcanoes	~5000

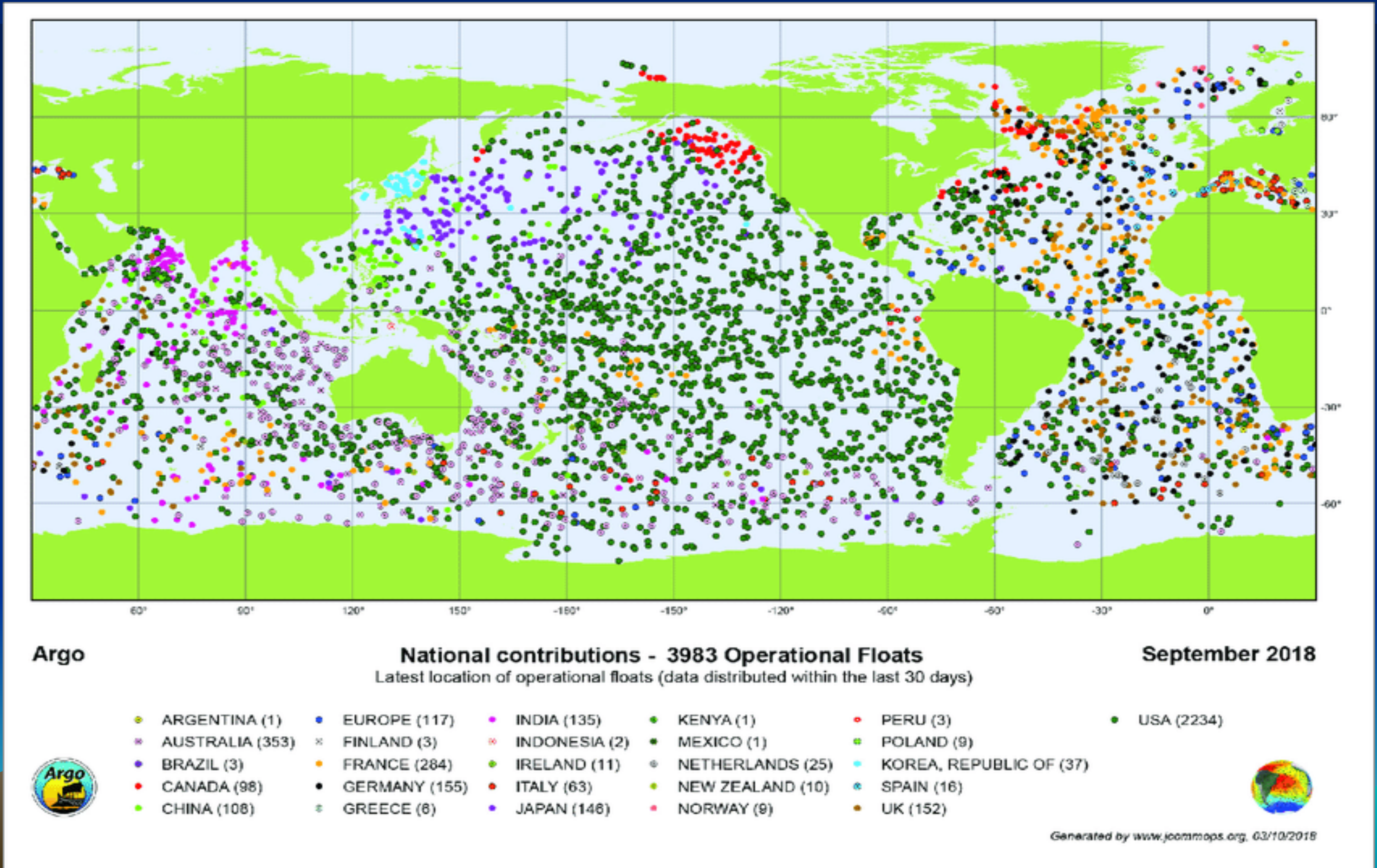
Important facts –

Basaltic magma hotter; acidic magma more explosive

Geothermal heat is released during eruptions changing the ‘normal’ oceanic and/or atmospheric circulation

Ocean warming and ecological changes

ARGO network of oceanic floats since early 2000s



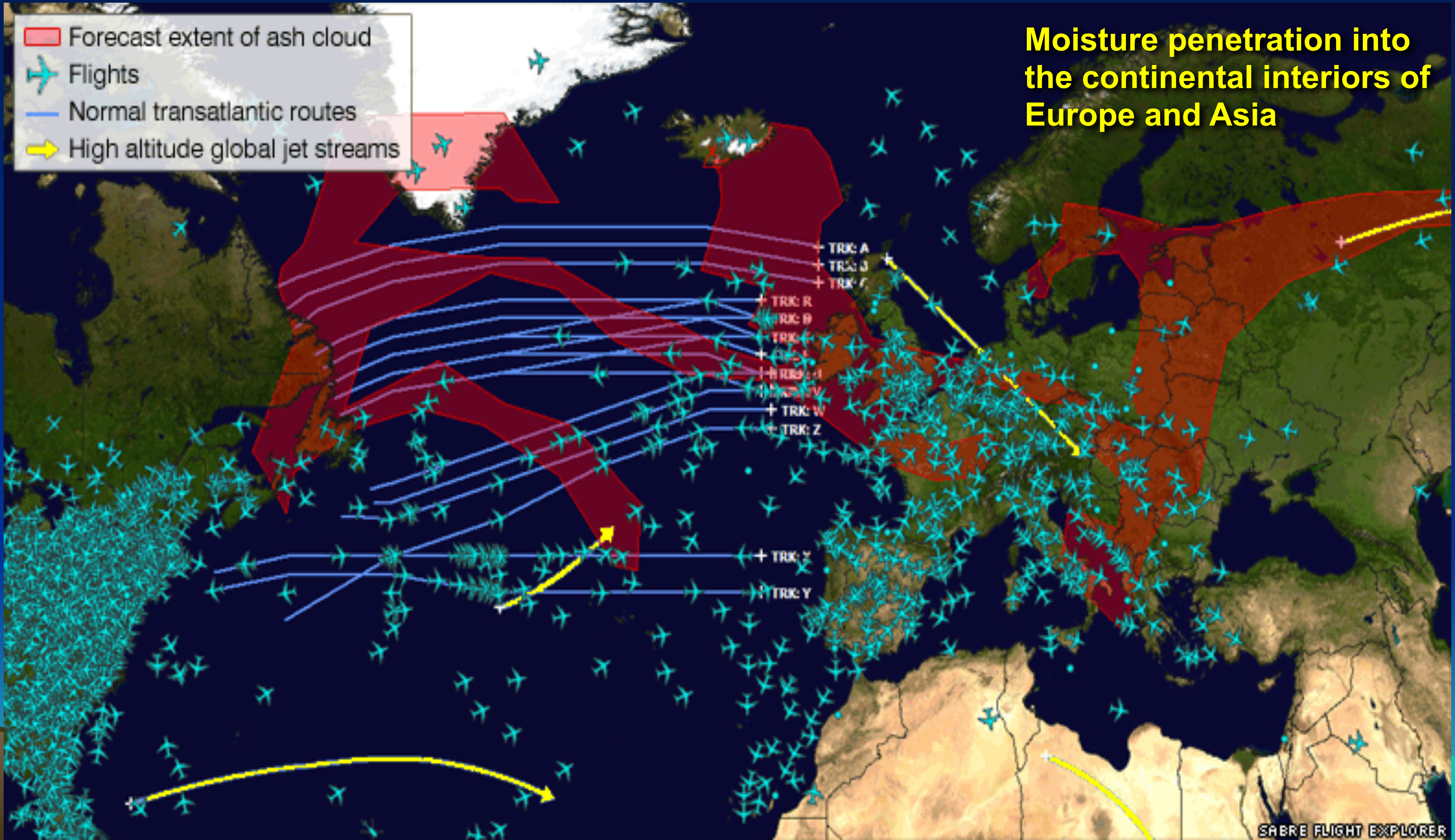
Temperature salinity profiling

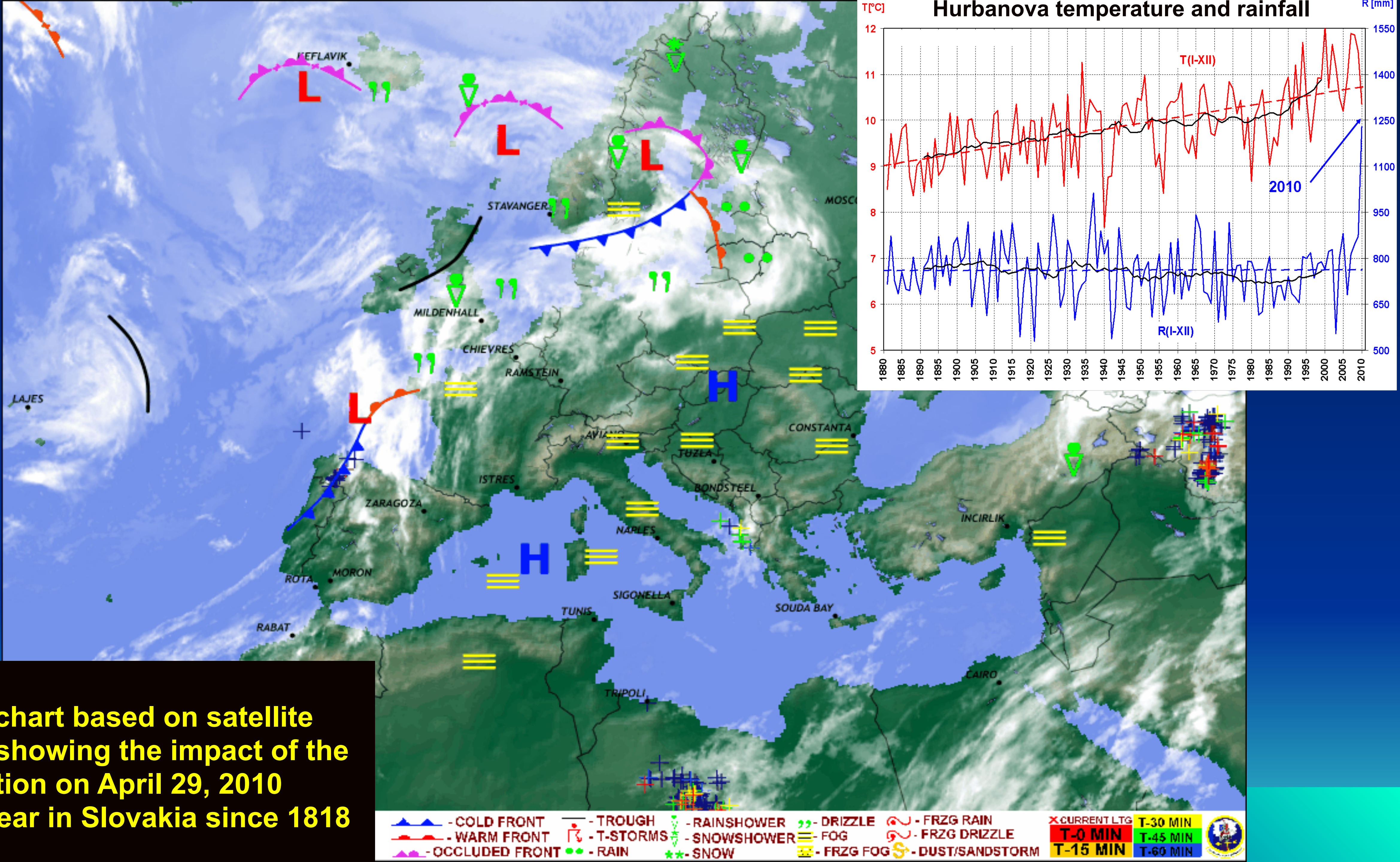
Selected volcanic eruptions since 2010 and their major climatic impact(s)

Name	Location	Date	VEI/type*	Climatic impact(s)
Soufriére Hills	*Montserrat*	*11//2/2010*	*3*	*Disastrous east Atlantic winter storm in Madeira 20/2/2010; Cyclone Xynthia flood and wind damage in western Europe 26-28/2/2010*
Eyjafjallajokull	*Iceland*	*14/4/2010*	*4*	*Deep continental penetration of moisture; 1881 wettest year in Slovakia on record; disastrous flooding in central Europe; severe winter*
El Hierro	*Canary Island*	*10/2011-3/2012*	*S*	*Development of the North Atlantic Blob; record low Arctic sea ice; wettest summer in England and Wales in 100 years; period of extended surface melting across almost the entire Greenland ice sheet; extremely active hurricane season including Sandy*
Nishinoshima	*north Pacific*	*3/2013-9/2015*	*M*	*Main contributor of the 2014-2016 North Pacific Blob; gradual decline of Arctic sea ice during 2014 to 2016 especially in regions near the Bering Straits; biodiversity changes including mass mortality; two years without winter in northeast Pacific*
Hunga	*Tonga*	*12/2014-1/2015*	*M*	*Identified contributor of the 2014-2016 ENSO; super cyclone Pam devastating Vanuatu*
Axial Seamount	*north Pacific*	*4//2015-5/2015*	*S*	*Identified contributor of the 2014-2016 North Pacific Blob and the 2014-2016 ENSO through submarine eruption*
Wolf	*Galapagos*	*25/5/2015-2/7/2015*	*4*	*Identified contributor of the 2014-2016 ENSO through lava flows entering the sea*
Kilauea	*Hawaii*	*7/2016 onwards*	*A*	*“ ; coral bleaching*
Mayotte	*Comoros*	*~11/2018*	*S*	*Identified contributor of the 2018-2019 Southwest Indian Ocean Blob; record season of intense tropical cyclones during 2018-2019*
Volcano F	*Tonga*	*6/8/2019*	*S*	*Identified contributor of the 2019-2020 South Pacific Blob; record temperature at Esperanza Base; Antarctic sea ice melting in February 2020*
Lateiki	*Tonga*	*13/10/2019*	*S*	*“ “ “*
White Island	*New Zealand*	*9/12/2019*	*A*	*“ “ “*
Hunga Ha’apai	*Tonga*	*2/2021-15/1/2022*	*M5*	*Identified main contributor of the 2022 South Pacific Blob; severe flooding and record rainfall in eastern Australia*

** VEI – Volcanic Explosivity Index; S – Submarine; A – Sub-aerial; M – Mixed.*

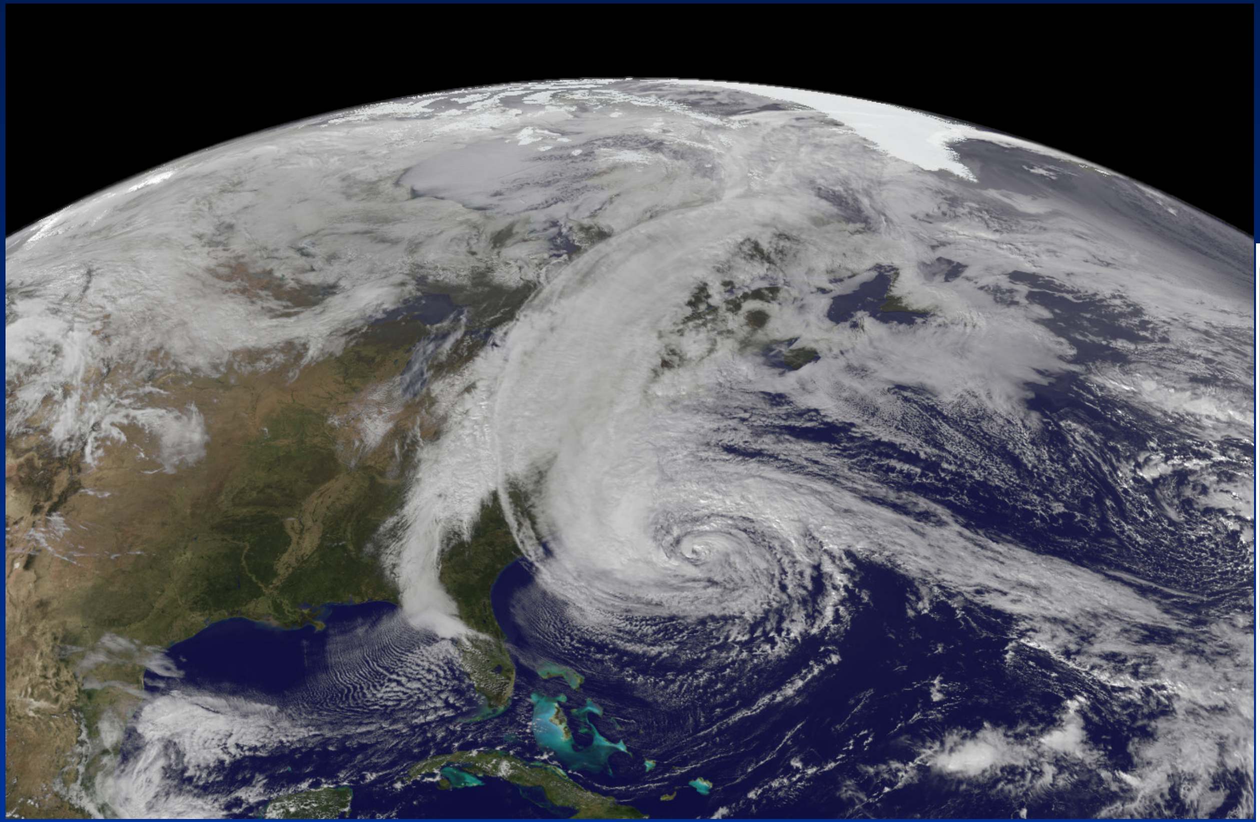
Eyjafjallajökull (E15) eruption, Iceland April 14, 2010





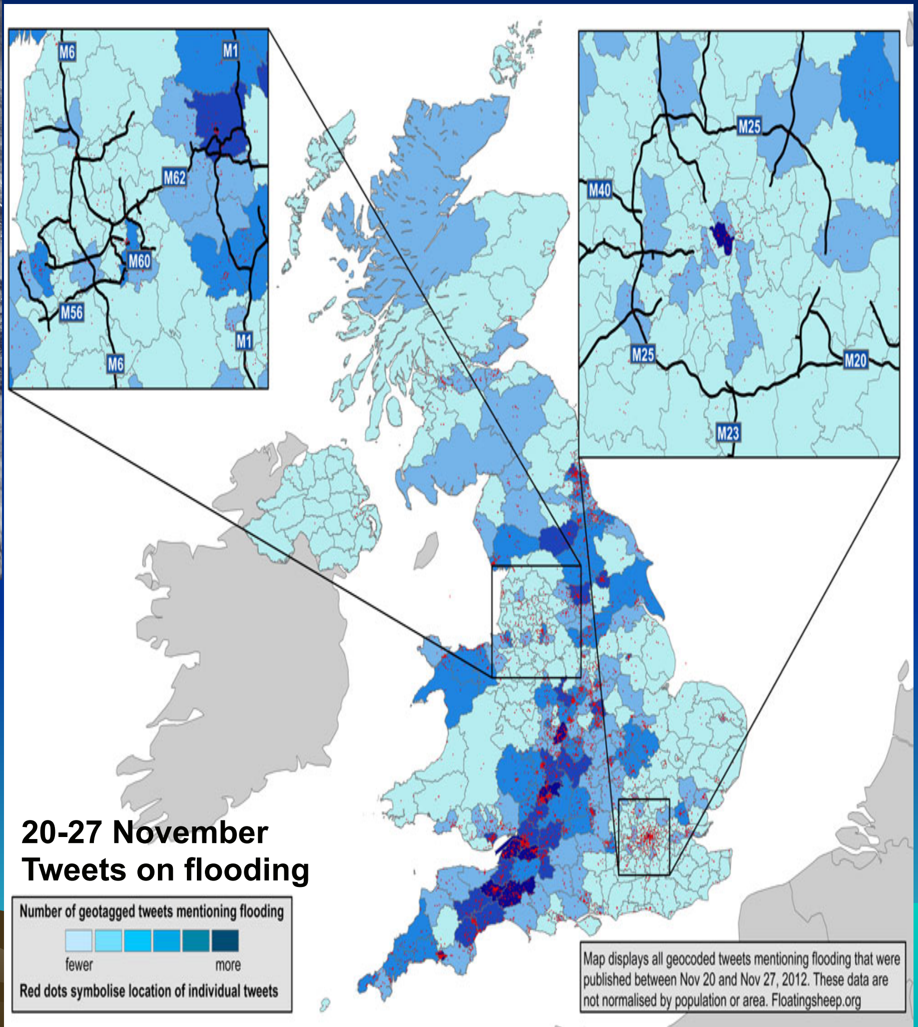
Weather chart based on satellite analysis showing the impact of the E15 eruption on April 29, 2010 wettest year in Slovakia since 1818

Notable extreme weather in 2012 caused by El Hierro warming



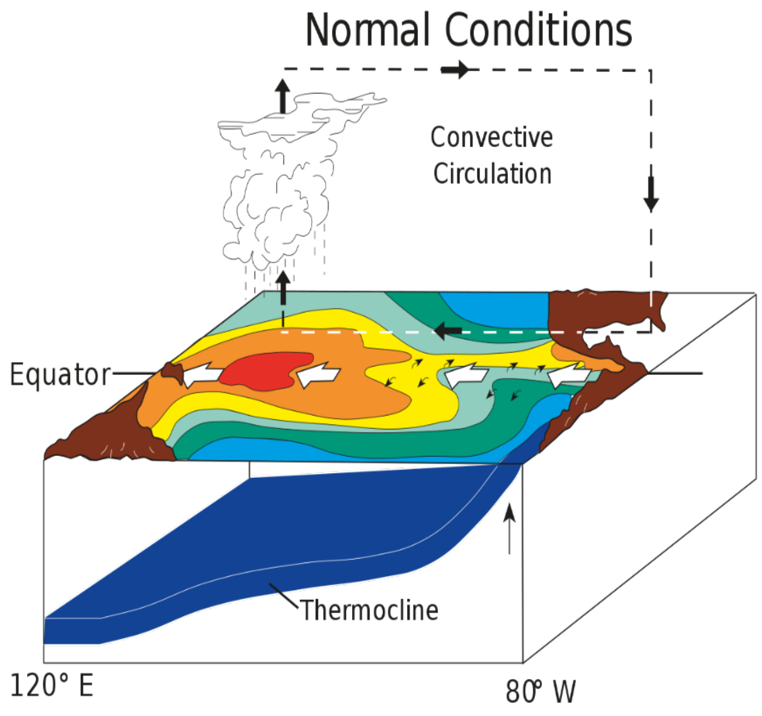
Hurricane Sandy October 2012
147 fatalities; estimated damage US$65 billion

New records for England & Wales –
wettest summer in 100 years
wettest week in last 50 years
explained by increase in storms

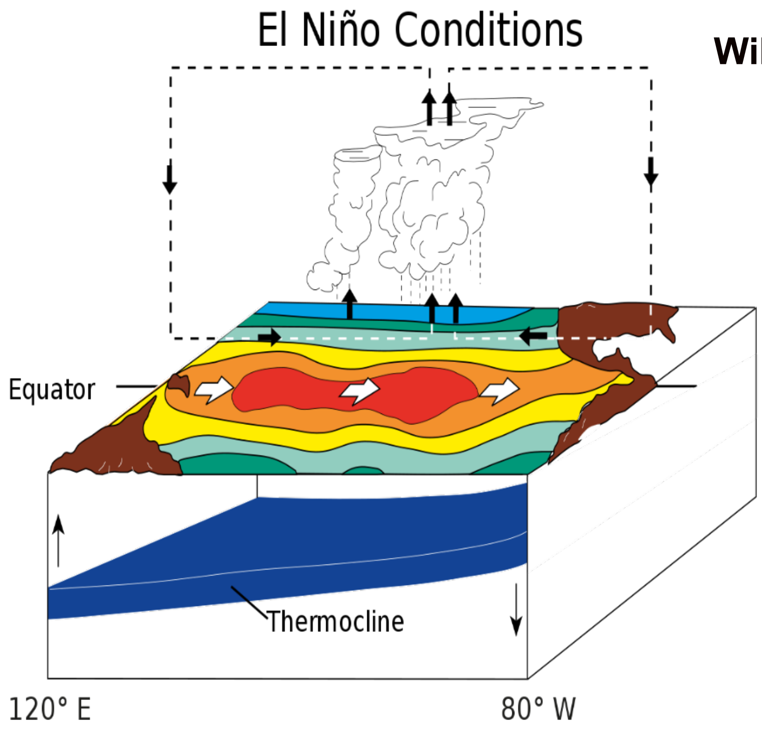


20-27 November
Tweets on flooding

The long and strong 2014 – 2016 ENSO



Warm pool in the west drives deep atmospheric circulation. Local winds cause nutrient rich cold waters to upwell along the South American coast.



Wiki

Warm water and atmospheric circulation moves eastwards. In strong El Niños deeper thermocline off south America means upwelled water is warm and nutrient poor.

Volcanic eruptions in the Pacific 2012-2016

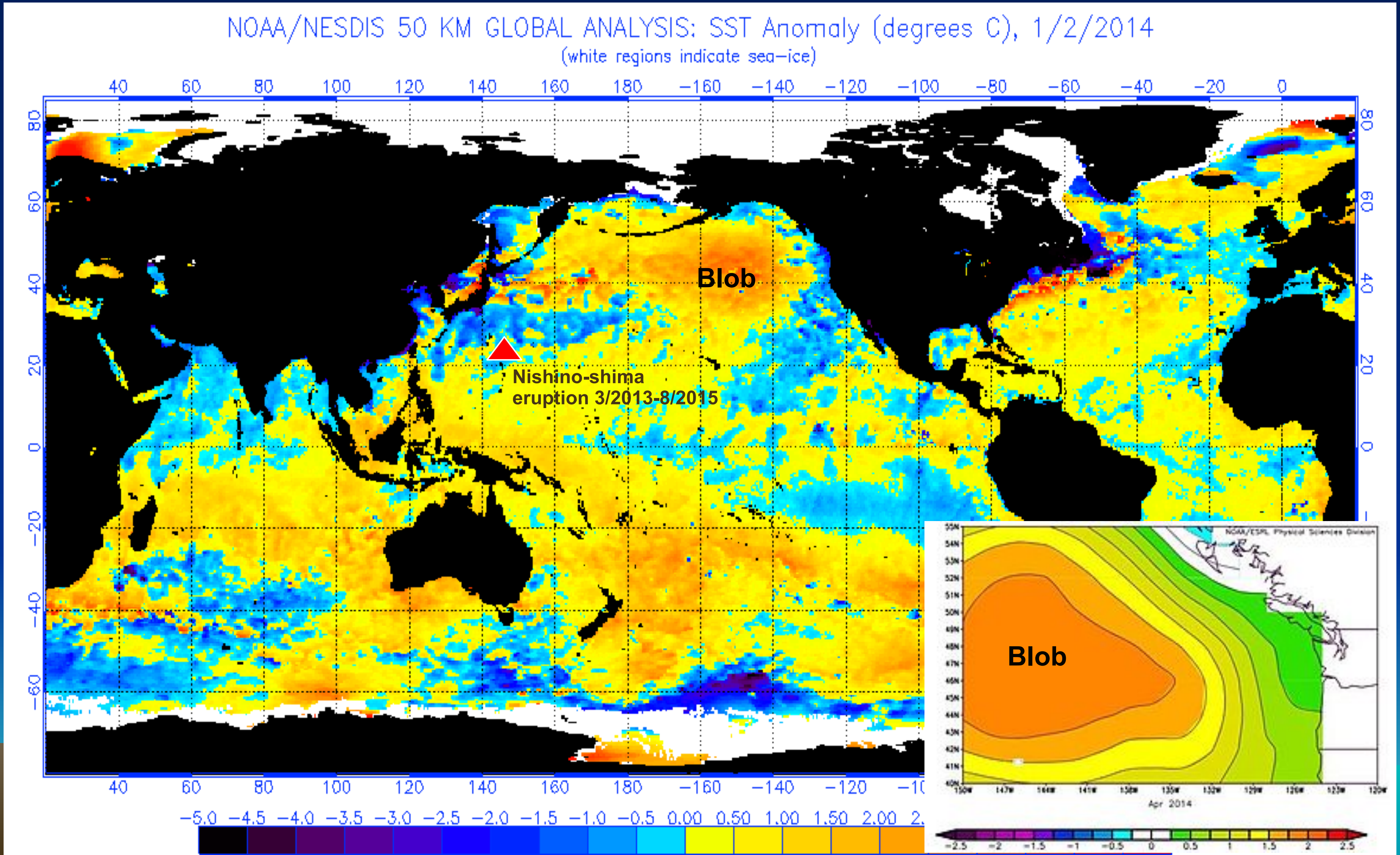
Date	Volcano	Activity
7/2012	Havre, north of New Zealand	Largest deep-ocean silicic eruption of the past century with a 400 km^2 pumice raft, lava sourced from 14 vents 900-1220 m depth
3/2013-9/2015	Nishino-shima, South of Tokyo	Eruption was initially submarine until a new island appeared in November 2013
12/2014- 1/2015	Hunga, Tonga	Initially submarine until a new island was created
4/2015-5/2015	Axial Seamount	Submarine eruption
5/2015-6/2015	Wolf, Galapagos	Basaltic lava flows into the Pacific Ocean
7/2016-onwards	Kilauea, Hawaii	Basaltic lava flows into the Pacific Ocean

Nishino-shima mixed eruption
940 km south of Tokyo
March 2013 – August 2015

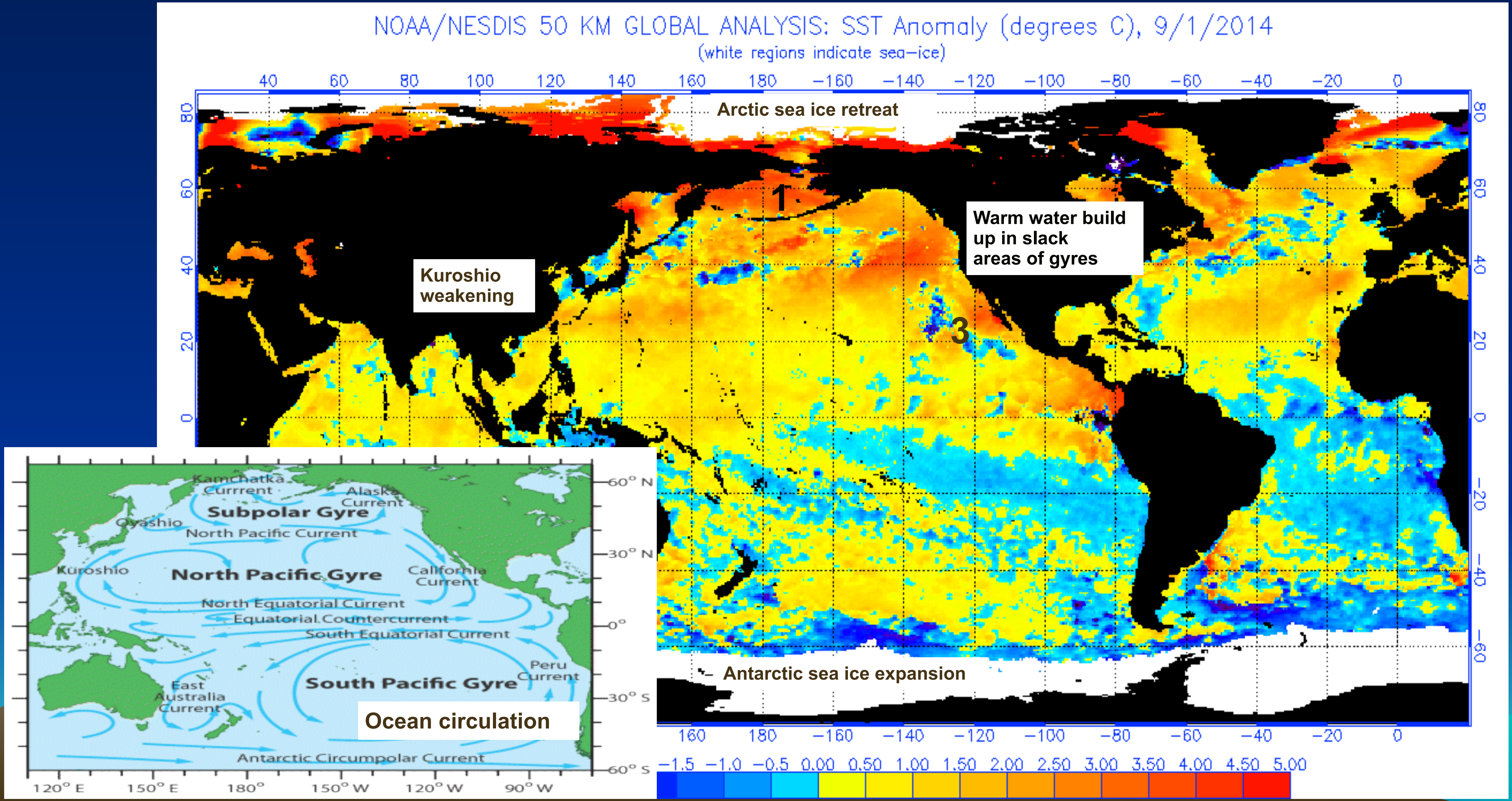
Image on November 13, 2013: Japan Coast Guard
Submarine eruption began in March 2013

Image on December 8, 2013: NASA

Geothermal heat released from the submarine eruption created the North Pacific Blob on January 2, 2014



Blob separated into three parts on September 1, 2014



HEAT WAVE

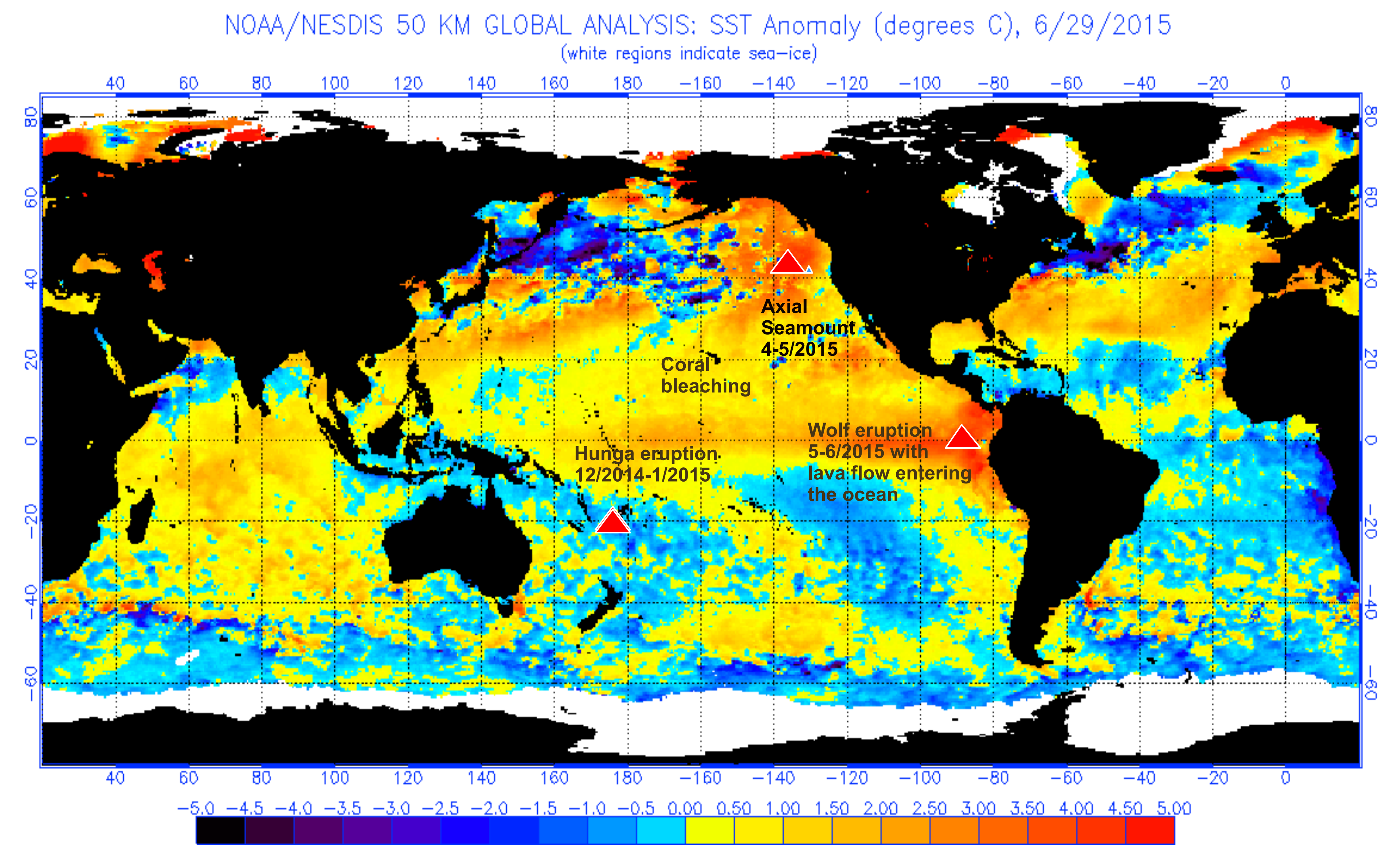
National Geographic September 2016

Mortality of benthic feeders eel and prawns

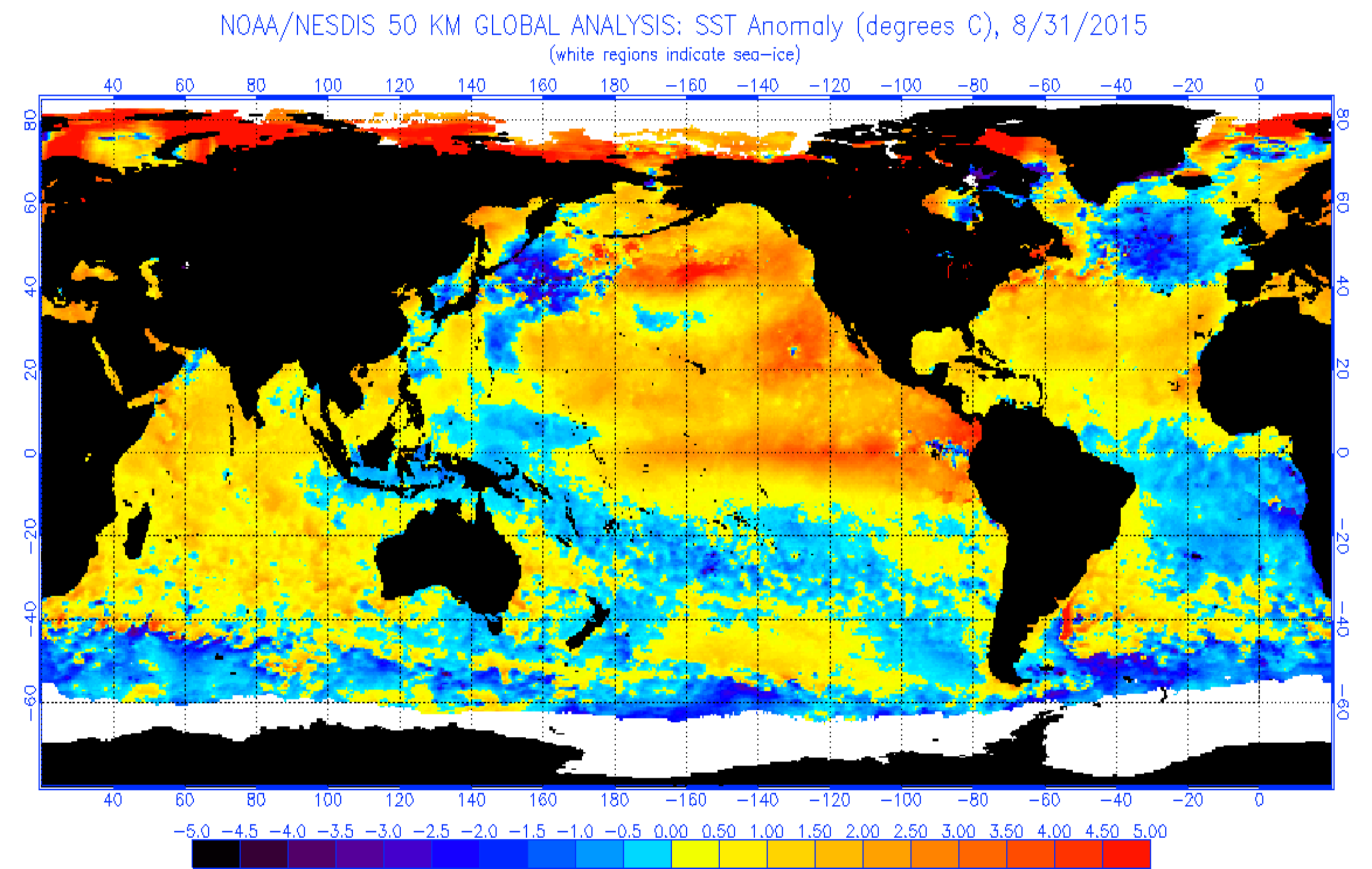
Mass mortality of red crabs

Mass mortality of sea otters

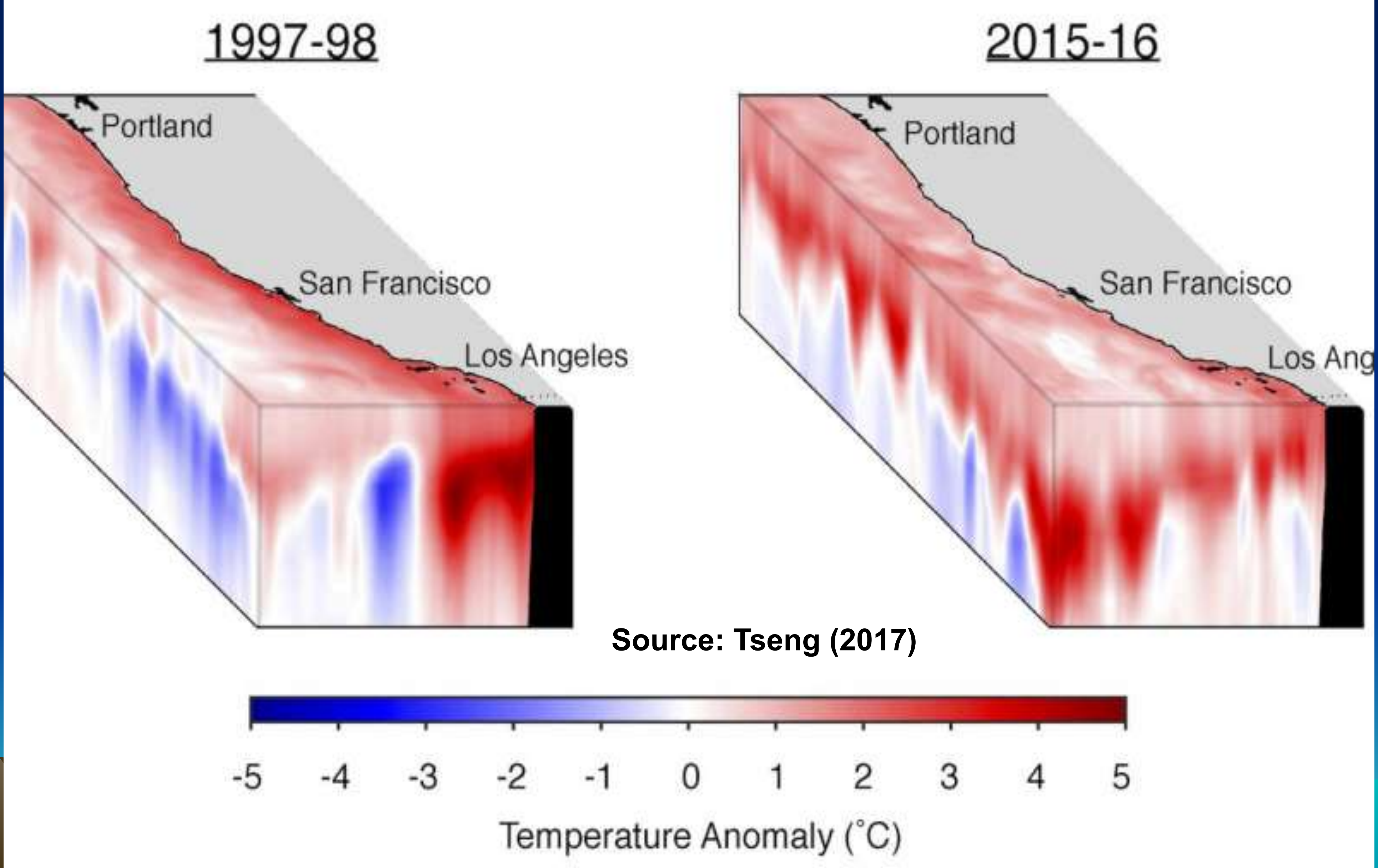
Sea-surface temperature anomalies after multiple eruptions ended on June 29, 2015



Establishment of the strong and long-lasting 2014-2016 ENSO August 31, 2015



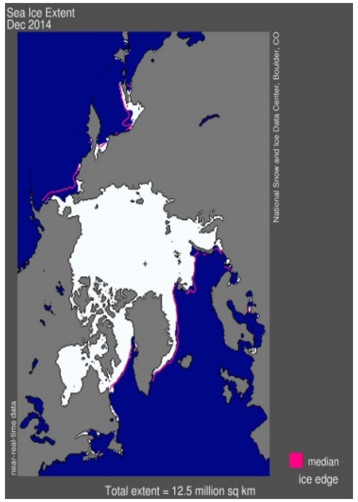
Comparison of seawater temperature anomaly US west coast during 1997-1998 and 2014-2016 ENSOs



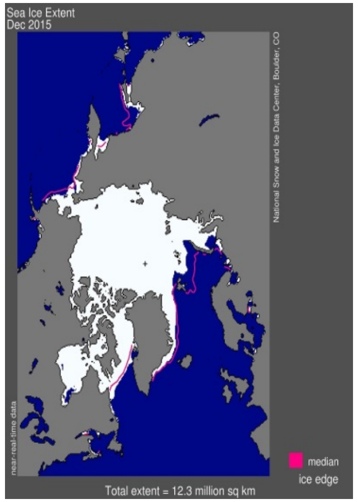
Source: Tseng (2017)

Impact of warming on Arctic sea ice

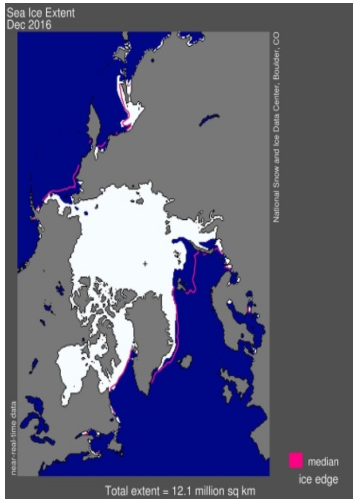
December 2014



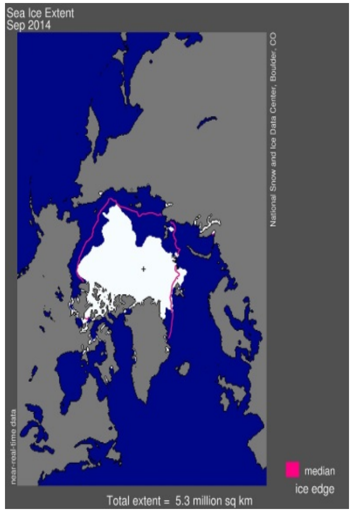
2015



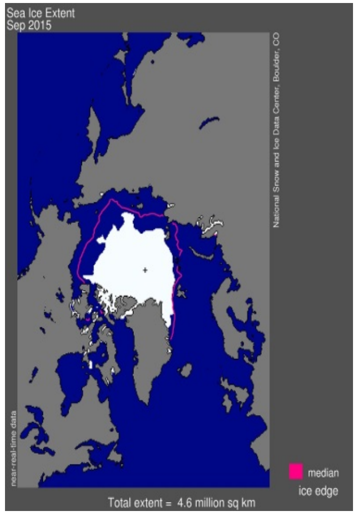
2016



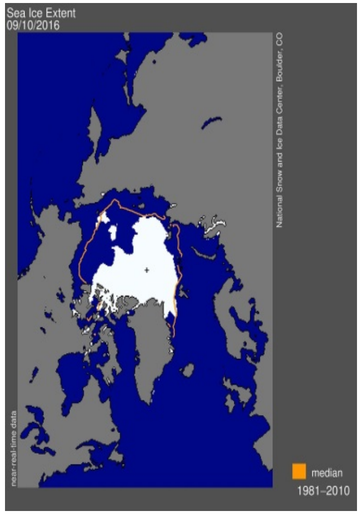
September 2014



2015



2016



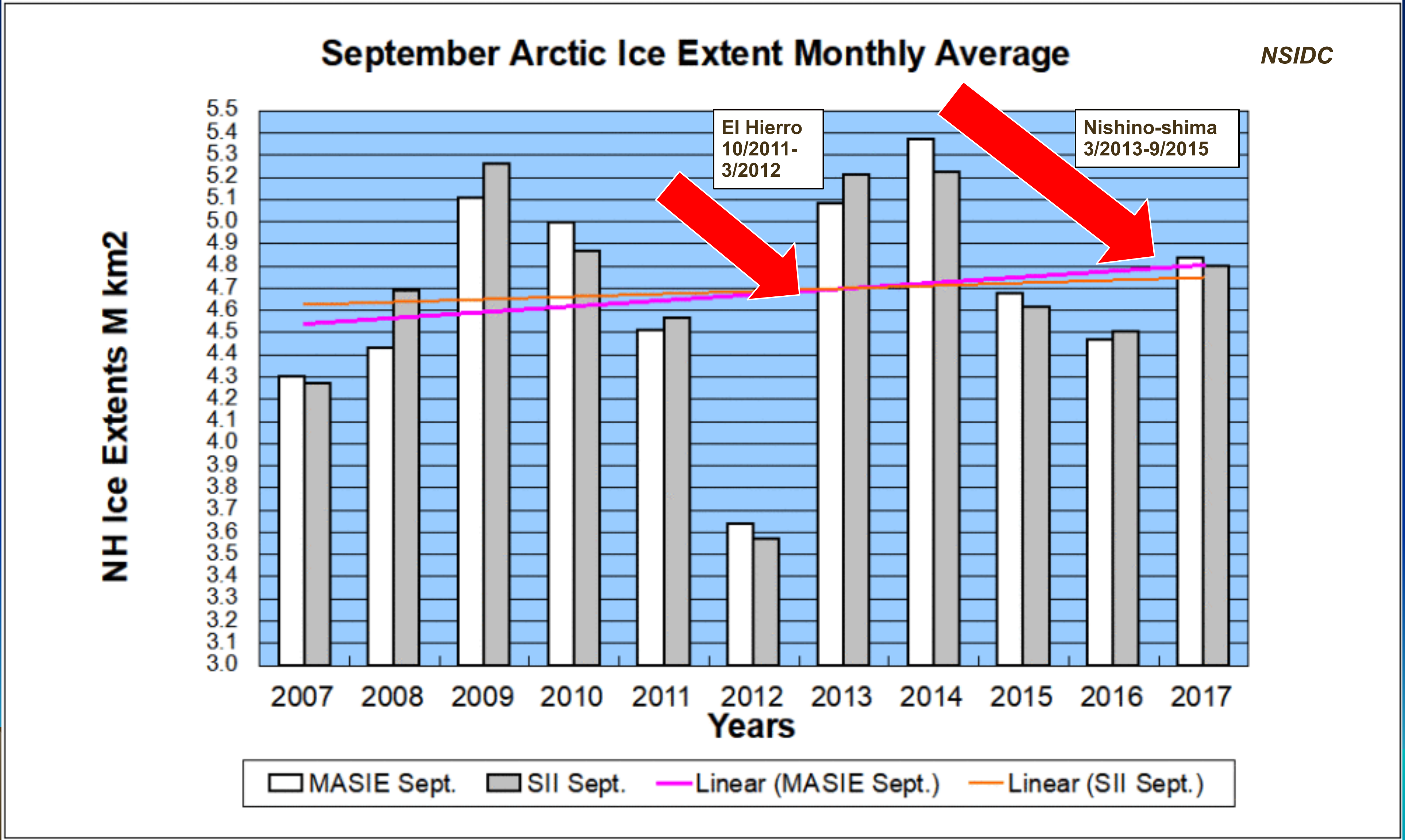
Abnormally warm seawater in the Bering Straits

YEAR	MINIMUM ICE EXTENT		DATE
	IN MILLIONS OF SQUARE KILOMETERS	IN MILLIONS OF SQUARE MILES	
2007	4.15	1.6	Sept. 18
2008	4.59	1.77	Sept. 20
2009	5.12	1.98	Sept. 13
2010	4.62	1.78	Sept. 21
2011	4.34	1.67	Sept. 11
2012	3.39 Record low	1.31	Sept. 17
2013	5.06	1.95	Sept. 13
2014	**5.03**	**1.94**	**Sept. 17**
2015	**4.43**	**1.71**	**Sept. 9**
2016	**4.14**	**1.6**	**Sept. 10**
1979 to 2000 average	6.7	2.59	Sept. 13
1981 to 2010 average	6.22	2.4	Sept. 15

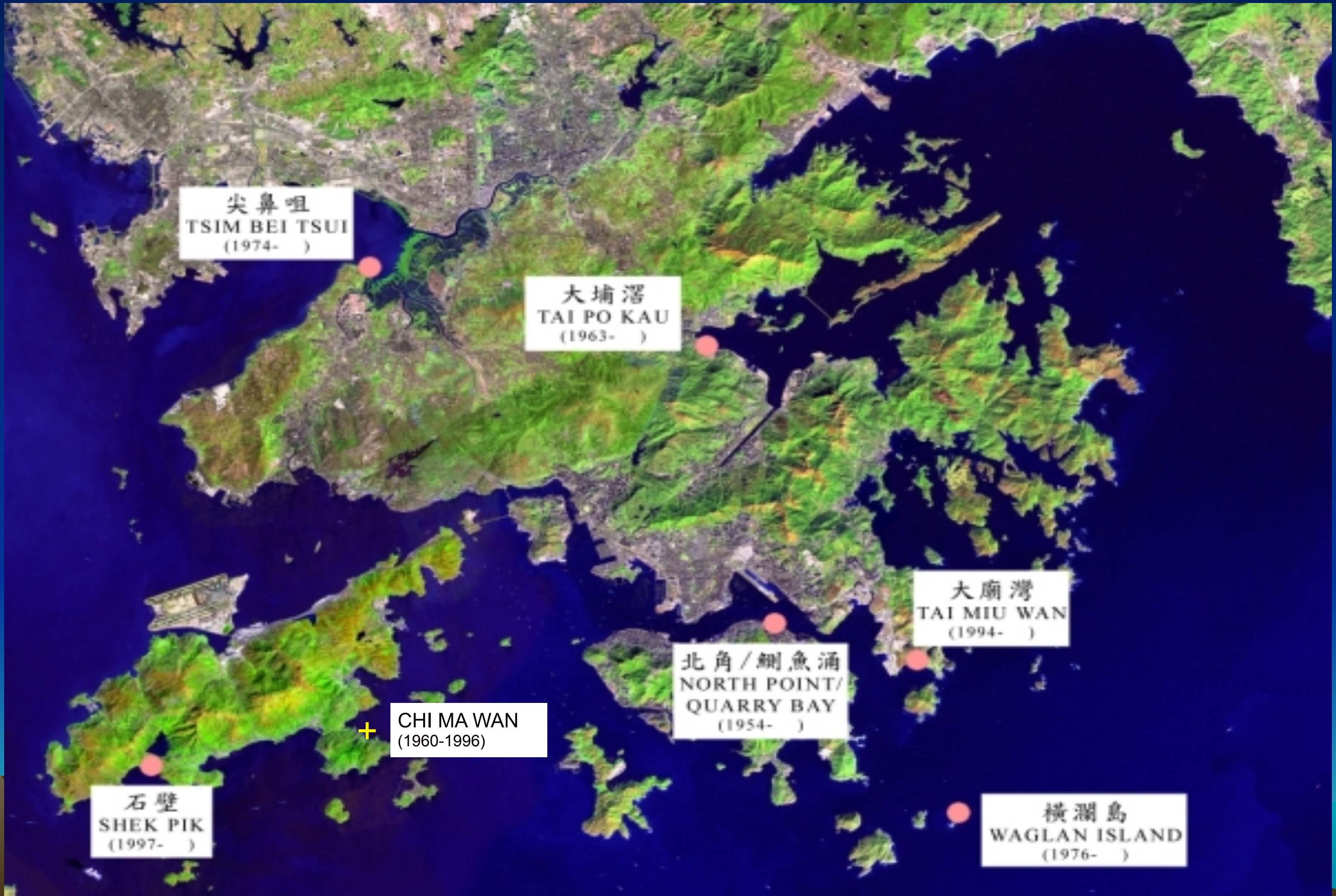
Source: NSIDC.org

Arctic sea-ice changes 2007-2017

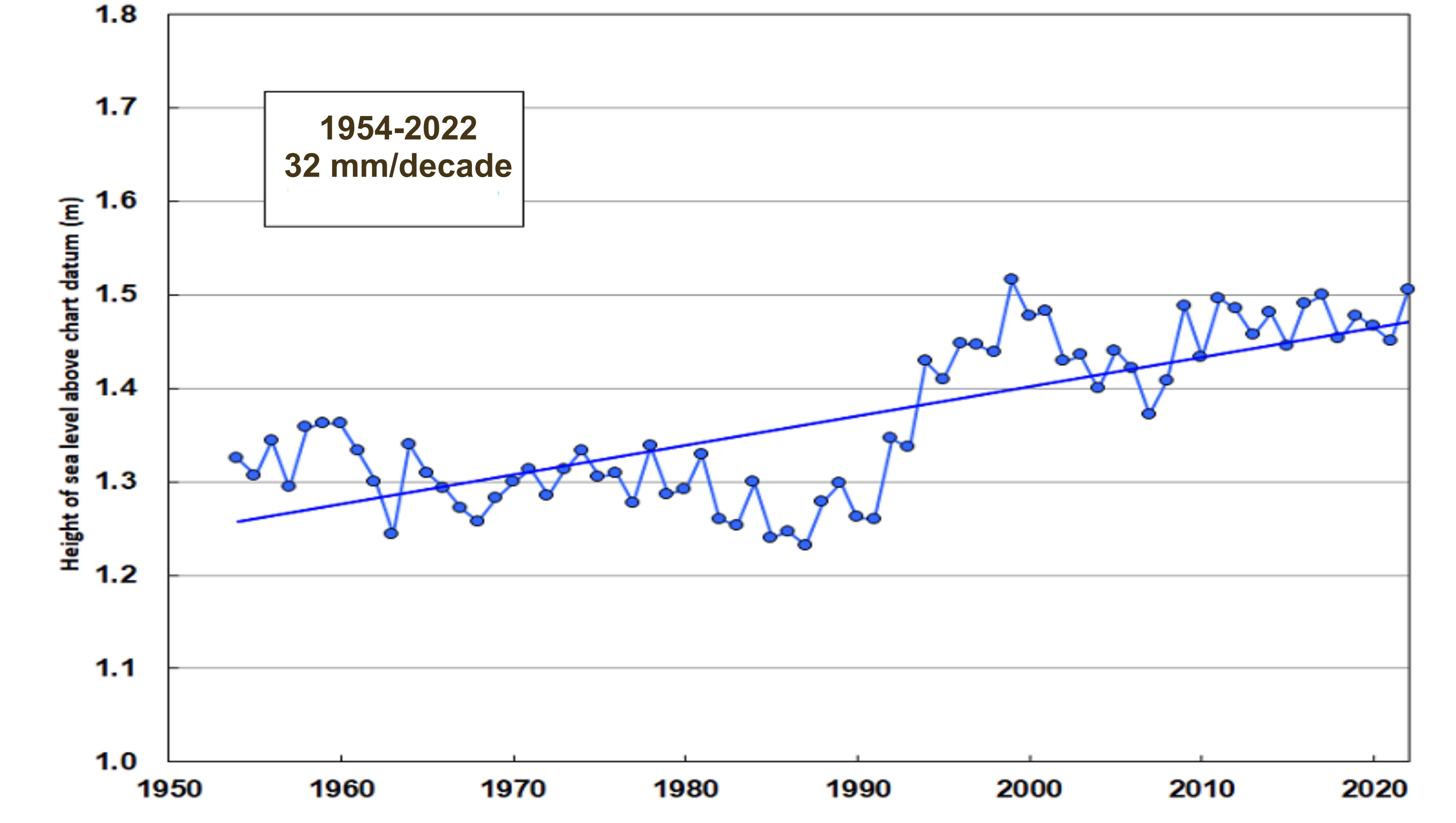
Explained by geothermal heat released through volcanism



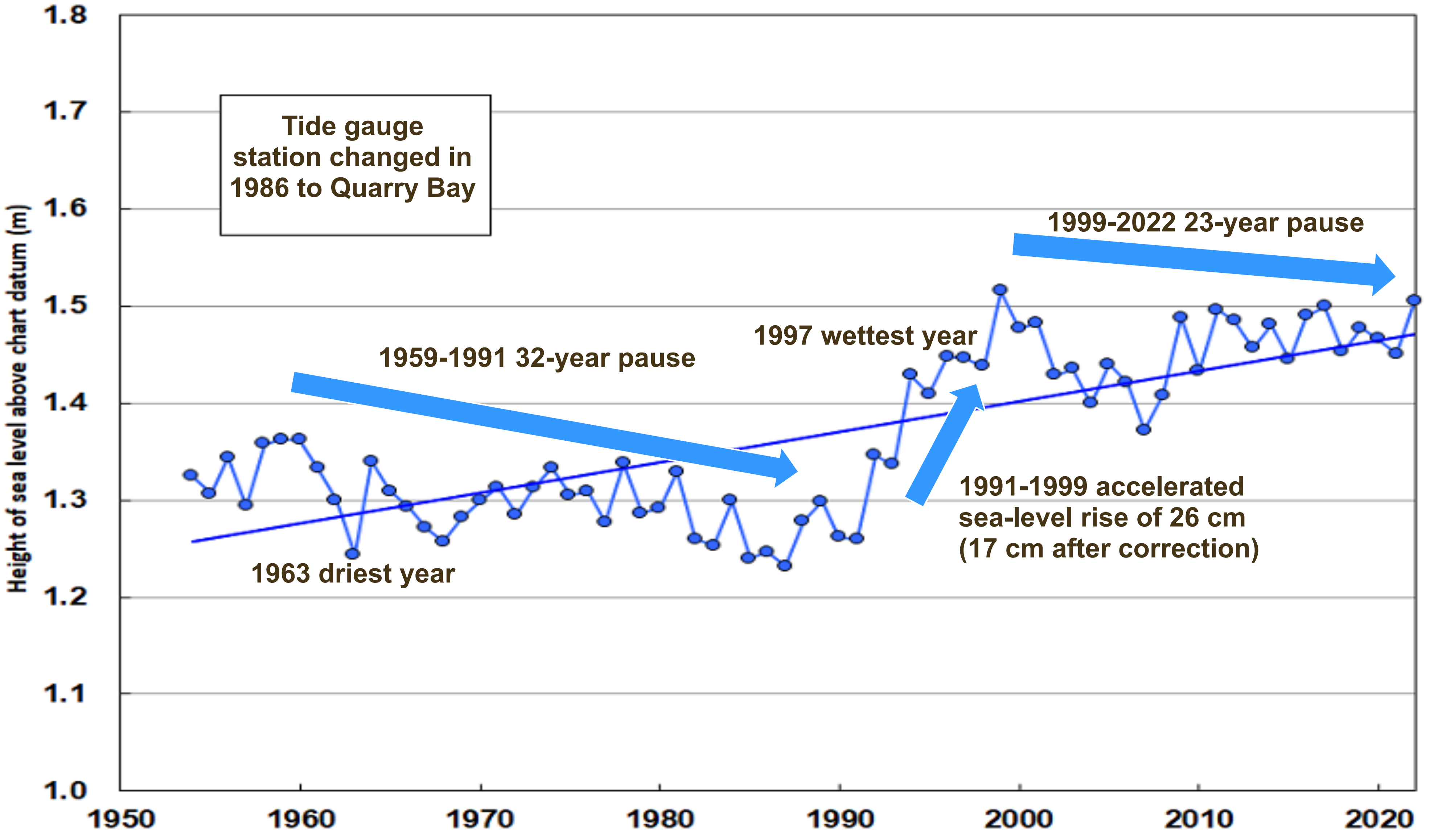
Hong Kong tide gauges measuring sea levels



Projected rate of sea-level rise in Victoria Harbour based on the combined records of the North Point/Quarry Bay Stations



Source: HK Observatory



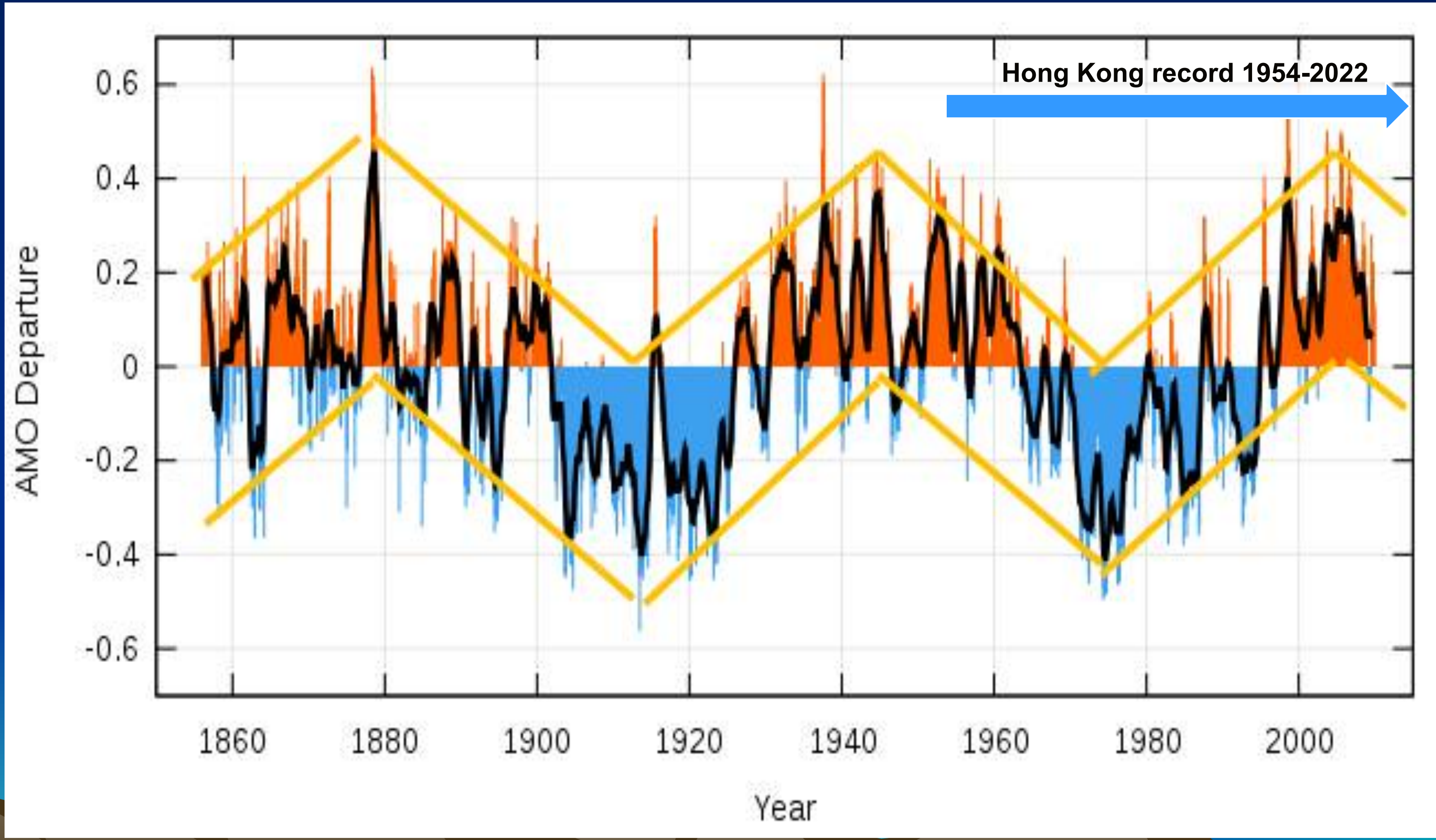
Accelerated sea-level rise between 1991-1999 may be caused by thermal expansion through the 1995 marine seismicity inflection point of Viterito (2022)

Controlling factors of sea levels in Hong Kong

Type	Feature	Explanation
– Astronomy	Cyclic changes in sea level	Cycle length approximately 60 years tracking the Atlantic Multidecadel Oscillation
– Tectonics	Crustal instability through loading and unloading	Tectonic movement, erosion and deposition including sedimentation and earthquakes
– Climate	Lowest uncorrected mean sea level of 1.28m above Chart Datum in 1963	Driest year since record began in Hong Kong's Observatory's Headquarters Station, high regional pressure and low Pearl River discharges
	Highest uncorrected mean sea level of 1.51m above Chart Datum in 1999	Influenced by the wettest year on record in 1997; low regional pressure and high Pearl River discharges
	Accelerated sea-level rise 1991-1999	17 cm; partially explained by cyclic changes
– Man-made	Low relative sea level 1985-1987	Uncertainty introduced by the relocation of the North Point Station to Quarry Bay
	Isostasy related sea-level change	Activities including coastal reclamation, construction loading, landfills, quarrying and dredging
–		

Atlantic Multidecadal Oscillation time series with a 12 month moving average 1856-2013 with 62-year cycles (Knudsen et al. 2011)

Maxima at 1878, 1943 and 2004 *Minima at 1912 and 1974*



Main conclusions

- Based on observation records, the selected volcanic eruptions studied and climatic variability found are consistent with their timing which cannot be explained by other means.

- Atmospheric water vapour and cloud distribution are much more important in weather changes than carbon dioxide.

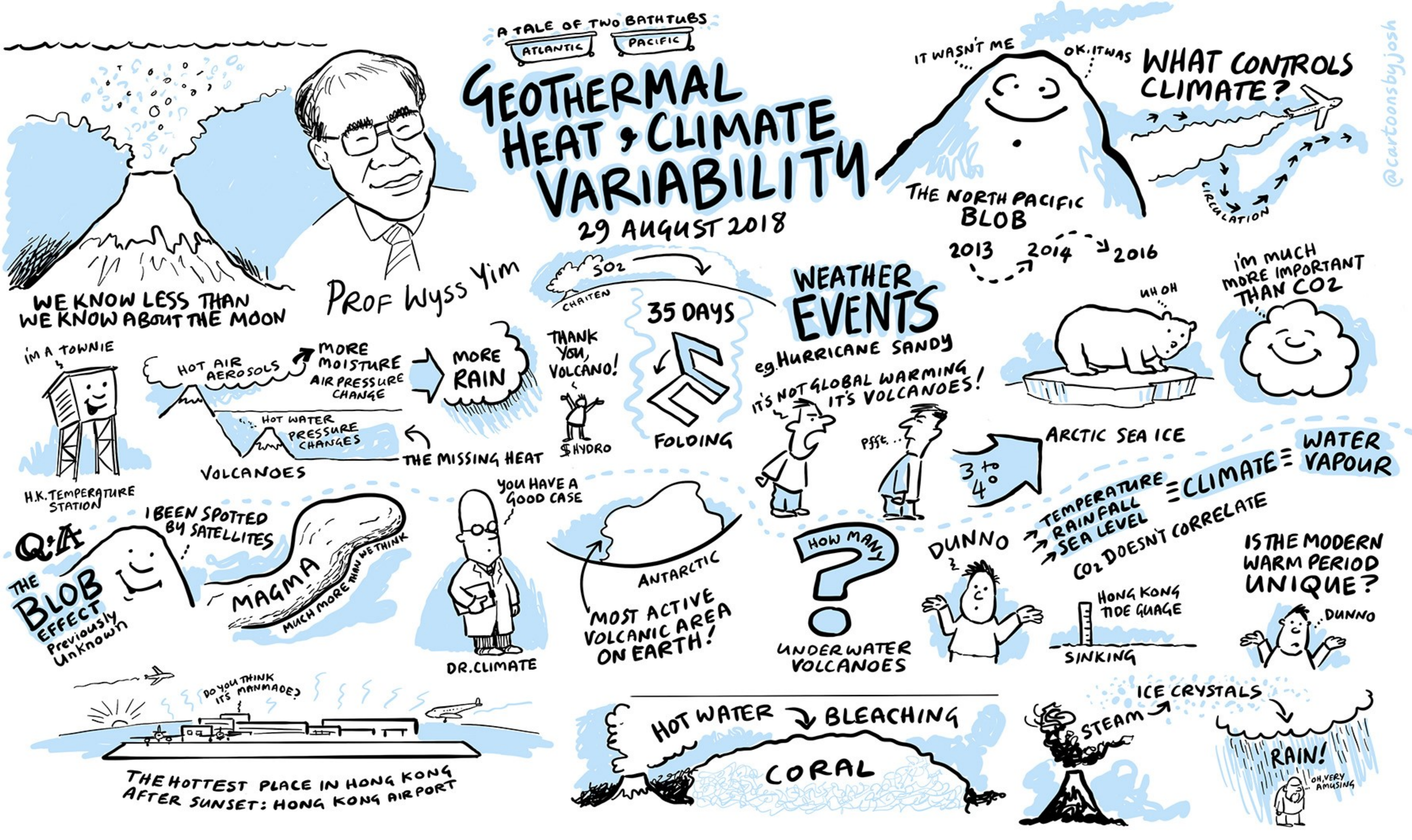
- Contributors to the long and strong 2014-2016 ENSO include the Nishino-shima eruption from March 2013-August 2015, the Hunga eruption from December 2014-January 2015, the Axial Seamount eruption from April to May 2015 and the Wolf eruption from May to June 2015. This is also supported by Arctic sea-ice changes.

- Climatic models must take into account the influence of volcanic eruptions on atmospheric and oceanic circulation. The role of submarine volcanism in regional oceanic warming is greatly underestimated.

- The missing heat attributed to carbon dioxide storage in oceans is better explained by the release of geothermal heat through submarine volcanism.

- Sea-level rise acceleration in 1995 may be caused by the marine seismicity inflection point. Tide gauge records in Hong Kong are too short for 60-year cycles.

- Volcanic eruptions as a cause in both cooling and warming is underestimated … Our dynamic Earth.



Volcanic eruptions a natural experiment to learn from

By Josh (2018)

The recent past is a key to the future

Thank you

Further information

Topic	Reference
2008. Chaitén eruption, Chile	Imperial Engineer 11, Spring 2010, 10-11.
1991 Pinatubo eruption, Philippines	Imperial Engineer 13, Spring 2011, p. 10.
2011 EL Hierro eruption, Canary Islands	Imperial Engineer 18, Autumn 2013, 12-13.
2010 Soufriere Hills eruption, Montserrat	Imperial Engineer 23, Spring 2016, p. 19.
Explanation for North Pacific Blob	Imperial Engineer 24, Autumn 2016, p. 15.
Geothermal heat: an episodic heat source in oceans	Imperial Engineer 25, Spring 2017, 14-15.
Arctic sea ice variability	Imperial Engineer 27, Spring 2018, p. 26.
Geothermal heat and climate variability	Imperial Engineer 28, autumn 2018, 24-26.
Southwest Indian Ocean Blob	Imperial Engineer 30, Autumn 2019, 24-25.
El Chichón eruption, Mexico	Imperial Engineer 34, Autumn 2021, 14-15.
Sea-level change in Hong Kong's Victoria Harbour	Imperial Engineer 35, Spring 2022, 24-25.
2019-2020 South Pacific Blob and Antarctica warming in February 2020	(With Alvin Wong) Https://saltbushclub.com/2020/04/28/south-pacific-blob.
Tongan volcanic eruption and record rainfall in eastern Australia and New Zealand	(With Alvin Wong) Https://saltbushclub.com/2022/07/04/2021-2022-tonga-volcanic-eruption.
Hot? Blame the urban heat island	Science Focus: South China Morning Post April 1, 2012.
How volcanic activity has influenced our rainfall	Science Focus: South China Morning Post April 8, 2012
CO_2 not our only contribution to warming	Science Focus: South China Morning Post October 9, 2014
Volcanism and climate change	40th Geological Society of Hong Kong Anniversary Conference on Living Geology August 26, 2022