Volcanism and Climate Change

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40th Anniversary Conference on Living Geology, Geological Society of Hong Kong on 26th August, 2022

Plan

What are the connections?

2 case studies –

1982 Hong Kong's second wettest year

2014-2016 ENSO and Arctic sea-ice changes

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

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

Earth system science components

- Atmosphere (air)
- Hydrosphere (groundwater, lakes, rivers & oceans)
- Cryosphere (ice)
- Biosphere (living things)
- Pedosphere (soil)
- Lithosphere (Earth's crust including volcanoes)

Climate change is a product of astronomical forcing including solar variability and the interactions of the components

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)

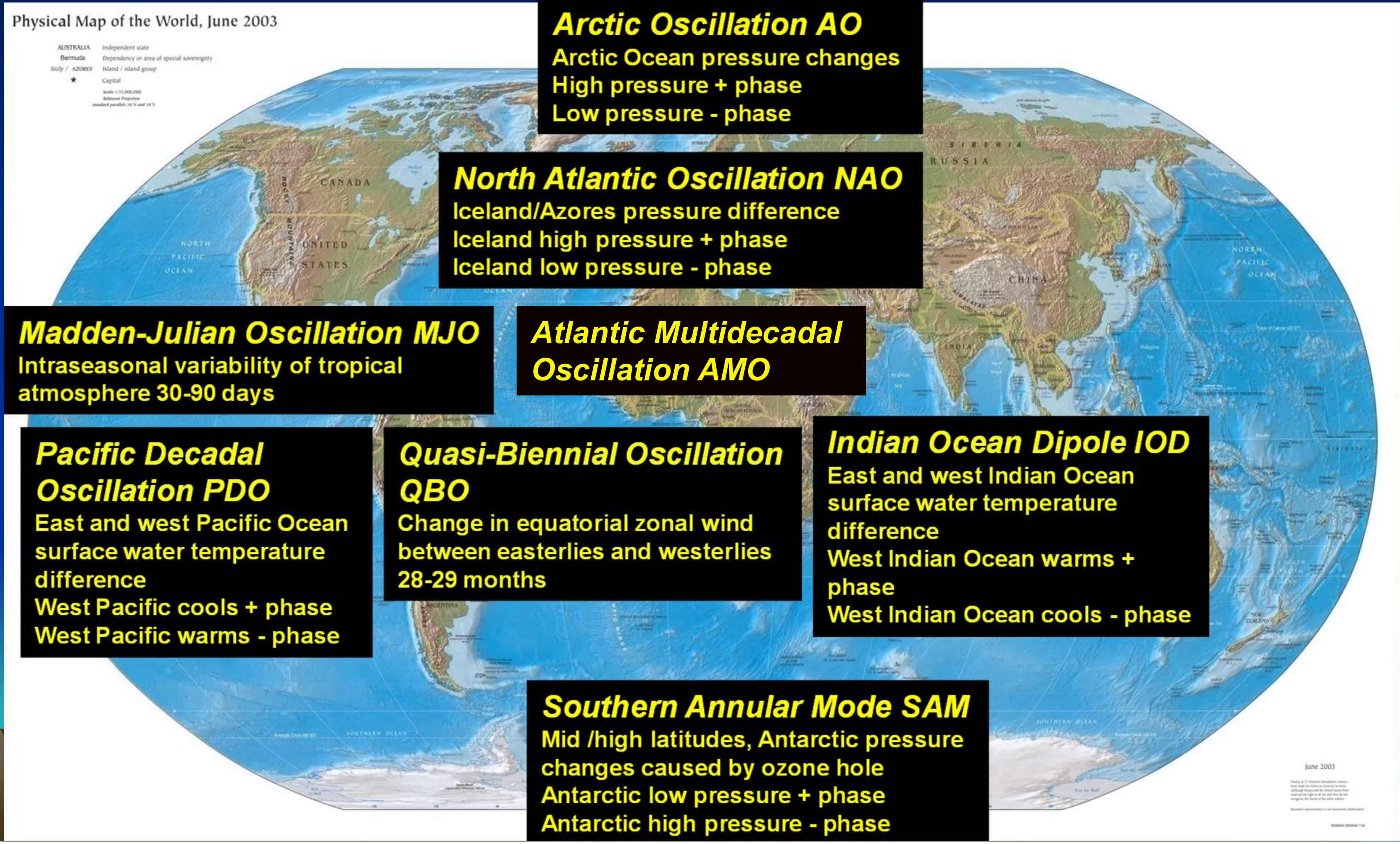
www.plateclimatology.com

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 emissions of greenhouse gases

Known regional climatic variability additional to monsoons



*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, severe weather)

(2) Submarine / sea floor

- switches on hot seawater (cause of sea-surface temperature anomalies, pressure changes, circulation changes, moisture redistribution, continental warming, severe weather events including cyclones)

(3) Mixed

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

*** Magmatic composition also important.**

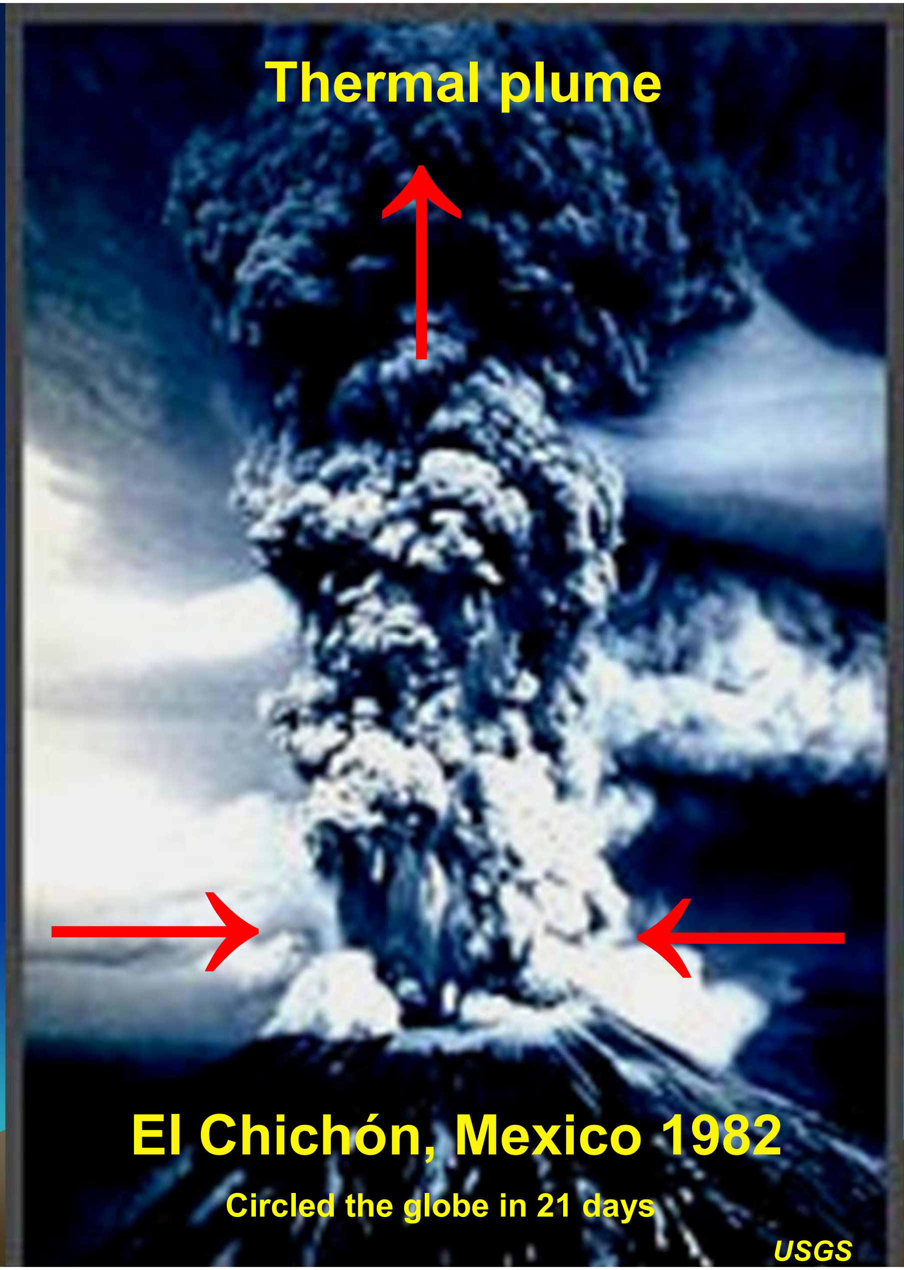
Sub-aerial volcano model

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

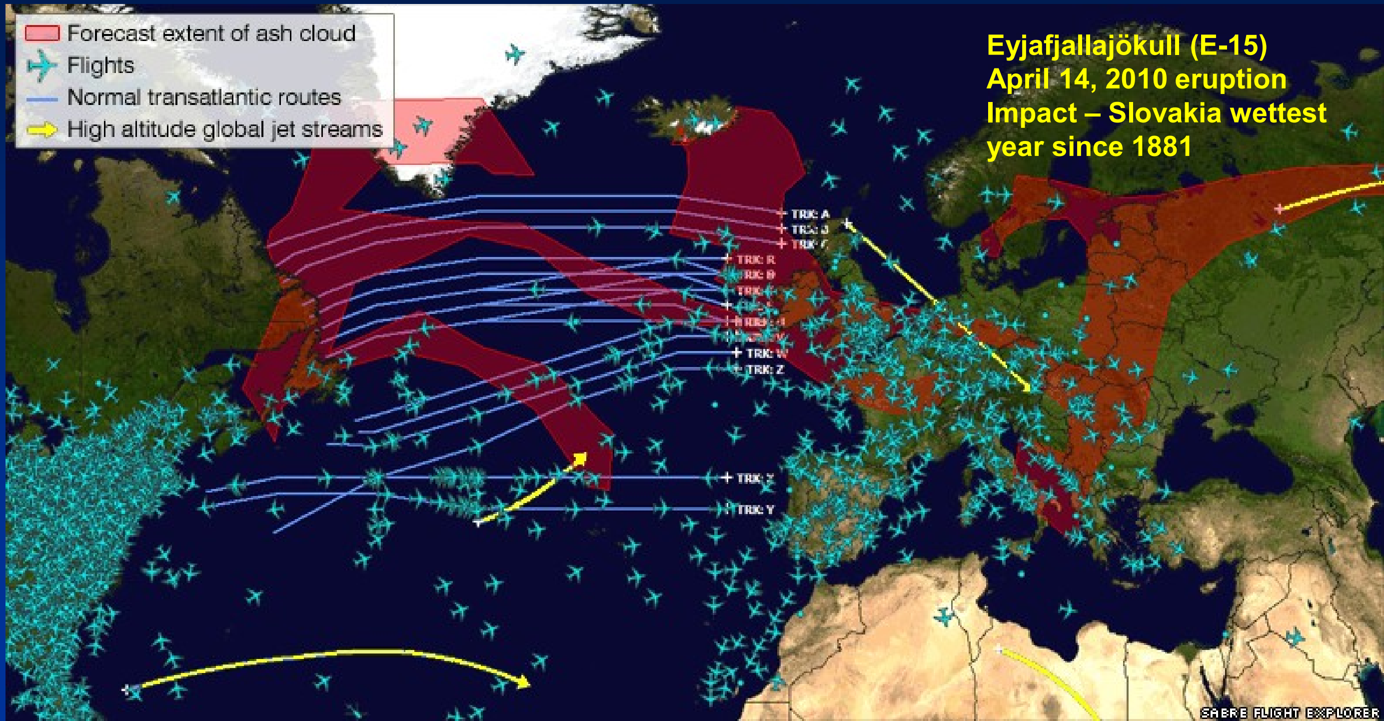
SO_2, HCl
CO_2 & H_2O degassing

Cool air stores less moisture

Cooler air

Impact longer lasting if higher VEI

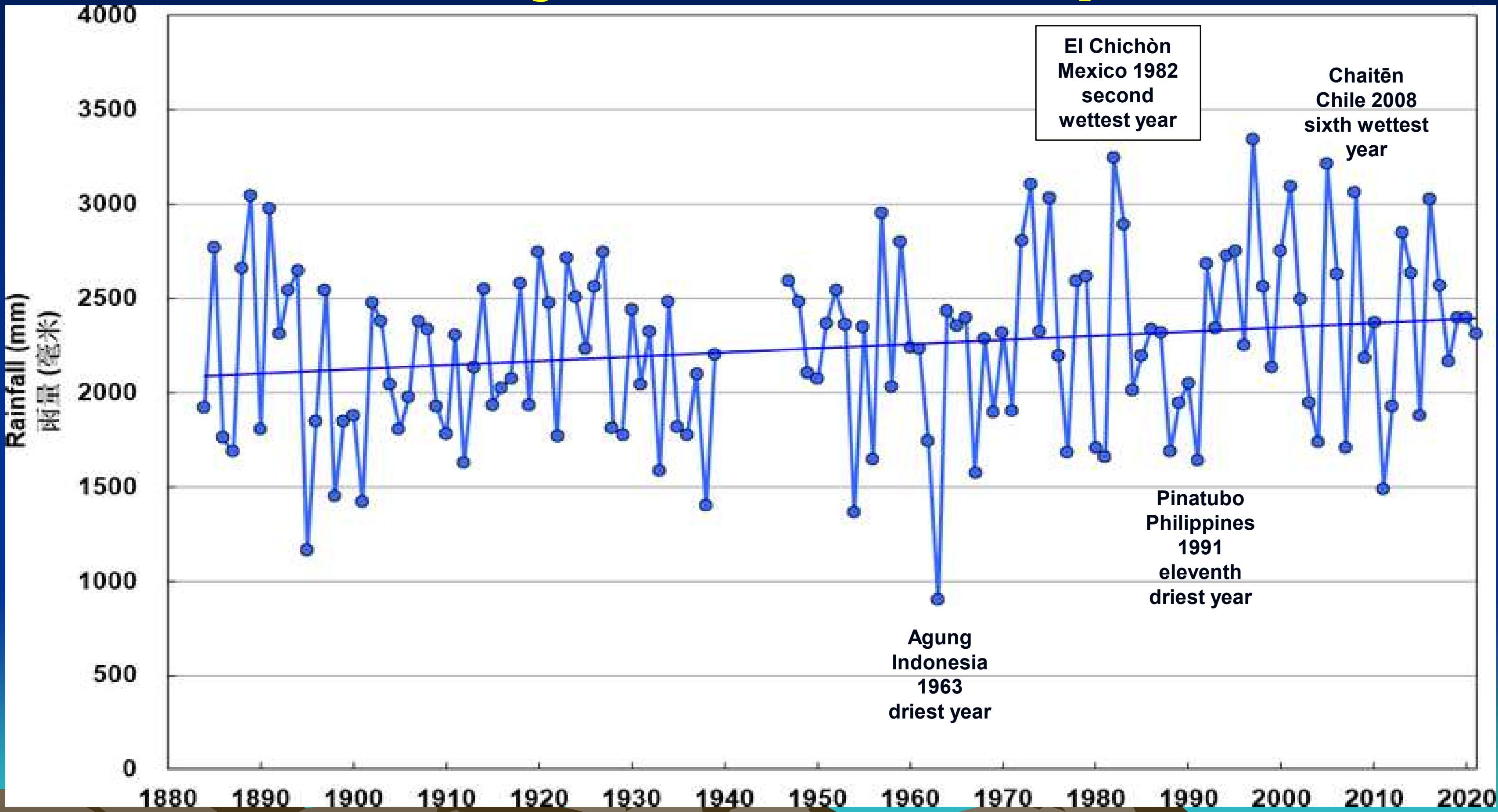
Why study the present? e.g. Iceland 2010



Most reliable record – Information age
Importance – societal e.g. farming, water supply, climate model testing

(Meteorological observations
(Satellite observations since late 1970s
(Weather disaster media reports
(Aviation safety studies

Examples of dry and wet years in HK caused by volcanic eruptions



Source: HKO

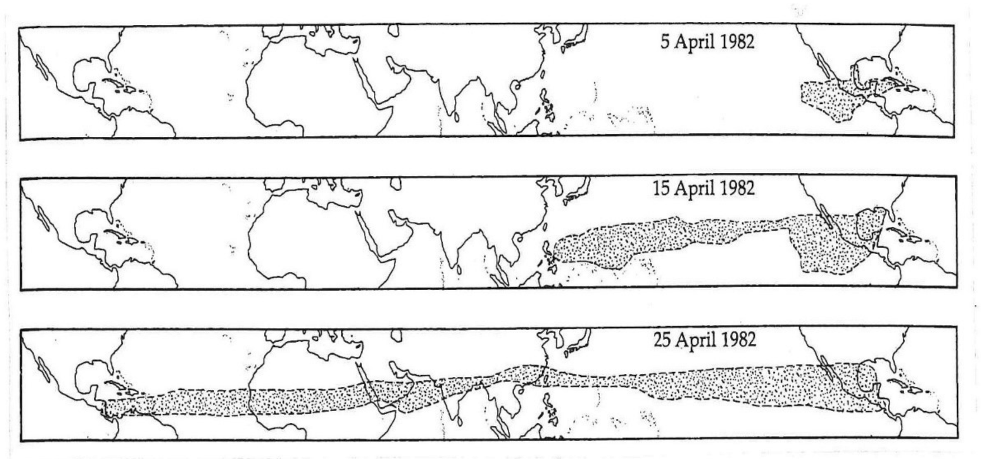
Statistics of the 1982 El Chichón eruption in Mexico

Location	Latitude 17.33'N Longitude 93.2'W
First/Second/Third eruptions	28th March / 3rd April / 4th April 1982
Volcanic Explosivity Index	5
Cloud column height	Maximum elevation 26 km
Average migration speed	20 m/second
Volume of tephra	<1 km^3 of trachyandesite
Aerosol	7 million tonnes of sulphur dioxide
Particulates	20 million tonnes
Major climatic impacts	Intense ENSO of 1982-83 through circulation changes; second wettest year since record began at Hong Kong Observatory's Headquarter Station

Source: Wikipedia and Global Volcanism Programme.

1982 El Chichón eruption, Mexico

VEI 5 column height 26 km
Travelled 14000 km to above HK in 11 days
21 days to circle the globe
Aerosols conducive to rainfall
Monthly rainfall April-November >50 mm
Annual rainfall 3247.5 mm
Second wettest year on record



Remote sensing satellites tracked the westerly drift of the eruption cloud continuously and precisely. Source: Rampino and Self (1984).

Rainfall distribution at Hong Kong Observatory's Headquarter 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

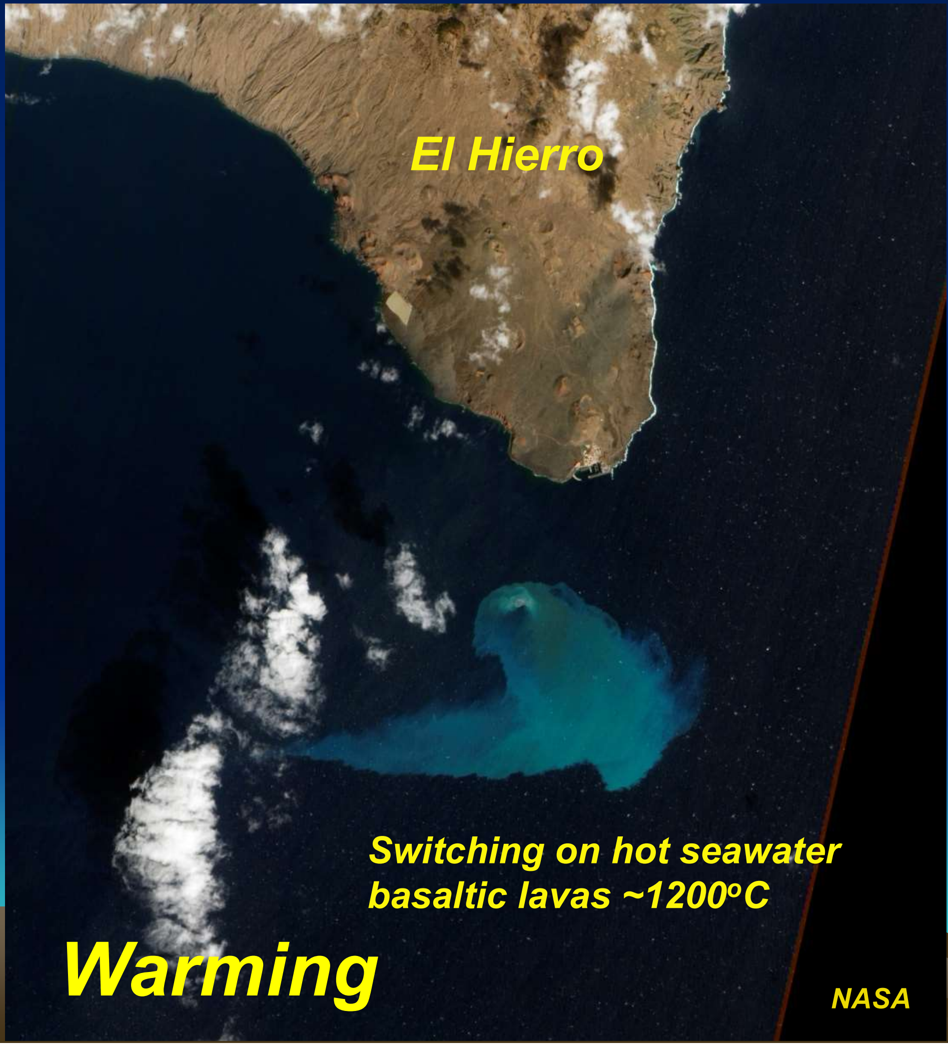
Annual 3247.5mm
Annual average 2214 mm
146% above average

Normal for April 139.4 mm
- 222% above normal
- 9th wettest on record
- Relative humidity 5th lowest on record

Normal for May 298.1 mm
- 257% above normal
- 5th wettest on record
- Worst landslips since 1976

Wet season extended to November

Submarine volcano model



Examples studied –

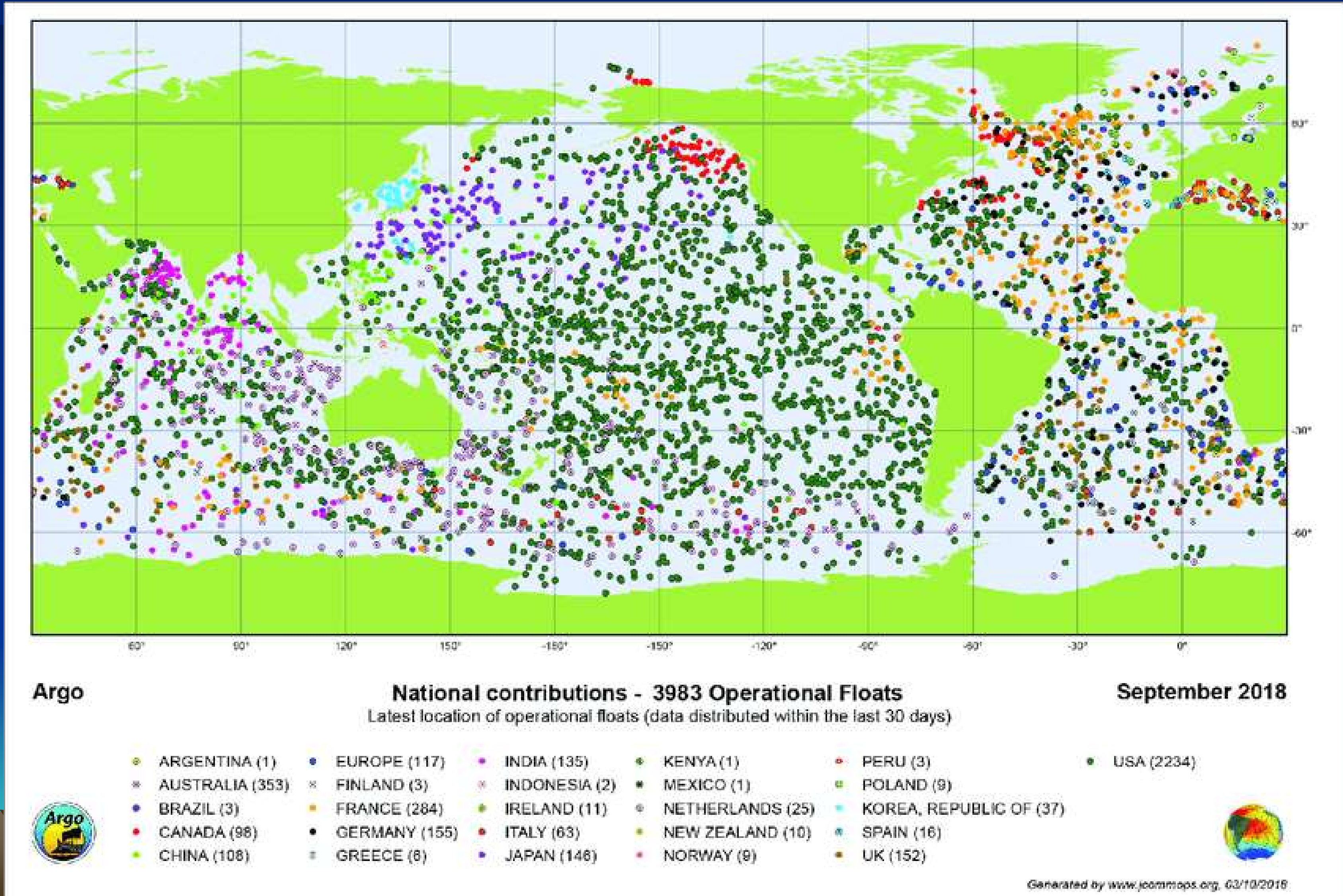
El Hierro volcano, Canary islands
10/2011 – 3/2012

Hunga volcano, Tonga
12/2014 – 1/2015

Nishinoshima, 940 km south of
Tokyo 3/2013-9/2015

Impacts –
Heating of seawater
Pressure changes
Surface wind changes
Sea-level changes
Ocean current changes
Arctic sea-ice changes

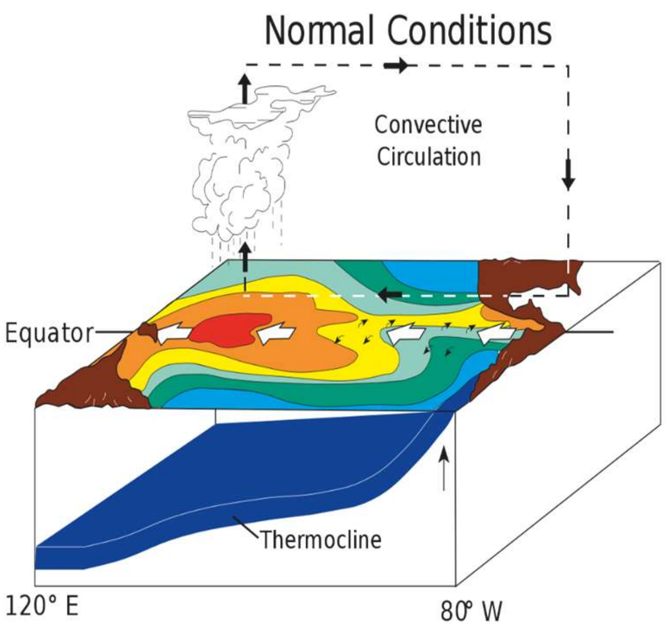
ARGO ocean network of operational floats since early 2000s



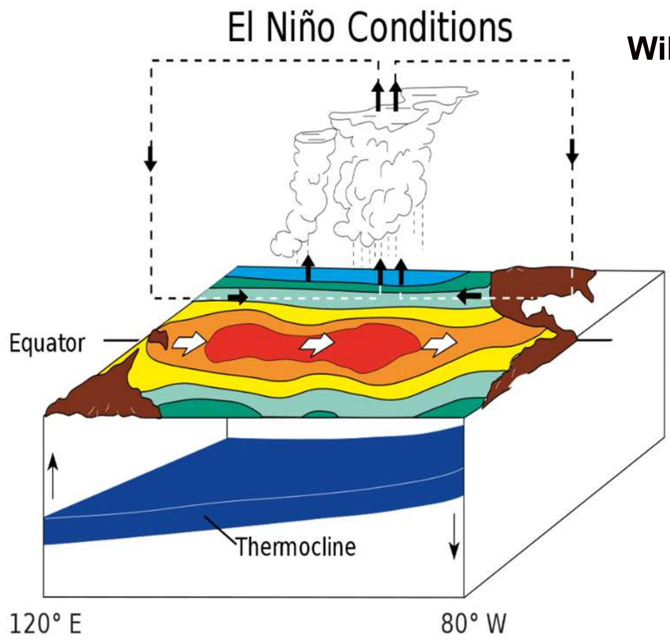
Ocean heatwaves caused by submarine volcanic eruptions supported by empirical evidence

2012	**North Atlantic Blob with Arctic sea-ice retreat**
2013-2016	**North Pacific Blob with Arctic sea-ice retreat**
2018-2019	**Southwest Indian Ocean Blob**
2019-2020	**South Pacific Blob with Antarctic sea-ice retreat**
2021-2022	**South Pacific Blob**

Normal and ENSO conditions



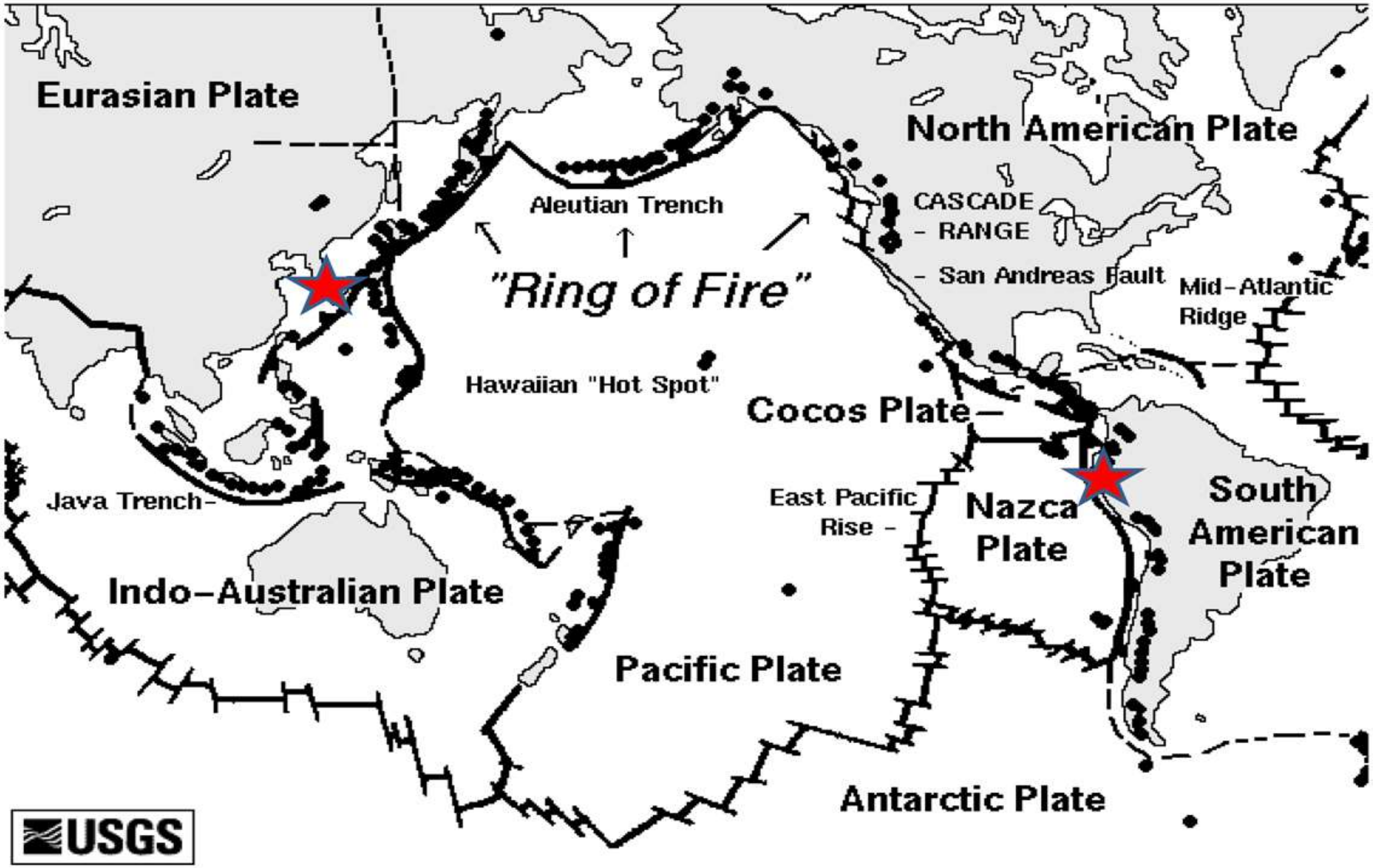
Warm pool in the west drives deep atmospheric circulation. Local winds cause nutrient rich cold waters to upwell along the South American coast.



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.

Why in the Pacific?



Topinka, USGS/CVO, 1997, Modified from: Tilling, Heliker, and Wright, 1987, and Hamilton, 1976

Note – Volcanism within the ocean basins currently comprises 70% of Earth's magma output.

2012-2016 volcanic eruptions in the Pacific

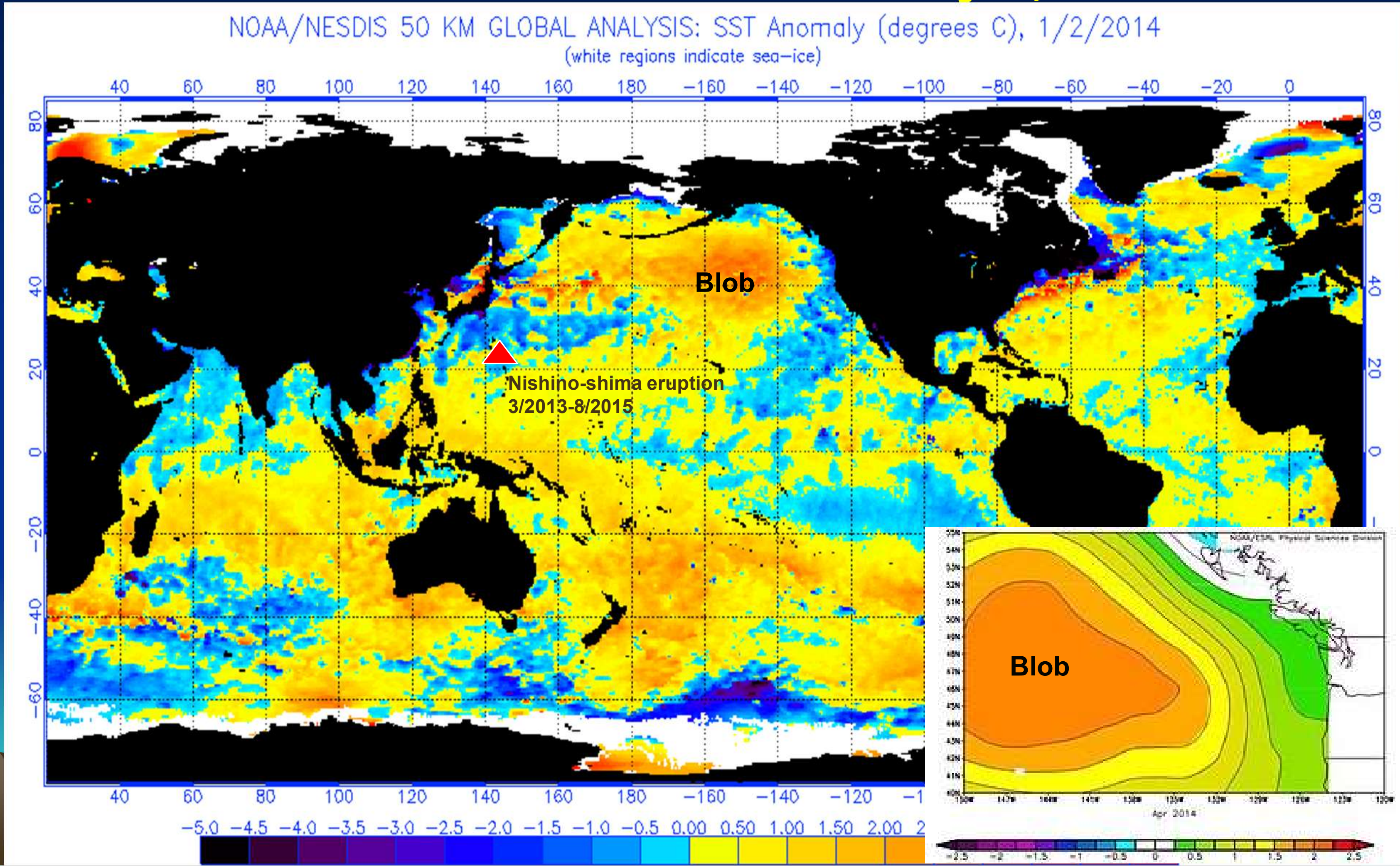
Date	Volcano	Activity
7/2012	Havre, north of New Zealand	Largest deep-ocean silicic eruption of the past century with a 400 km^2 pumice raft, lava sourced from 14 vents 900-1220 m depth
3/2013-9/2015	Nishino-shima, South of Tokyo	Eruption was initially submarine until a new island appeared in November 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 submarine/sub-aerial eruption 940 km south of Tokyo March 2013 to August 2015

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

Image on December 8, 2013: NASA

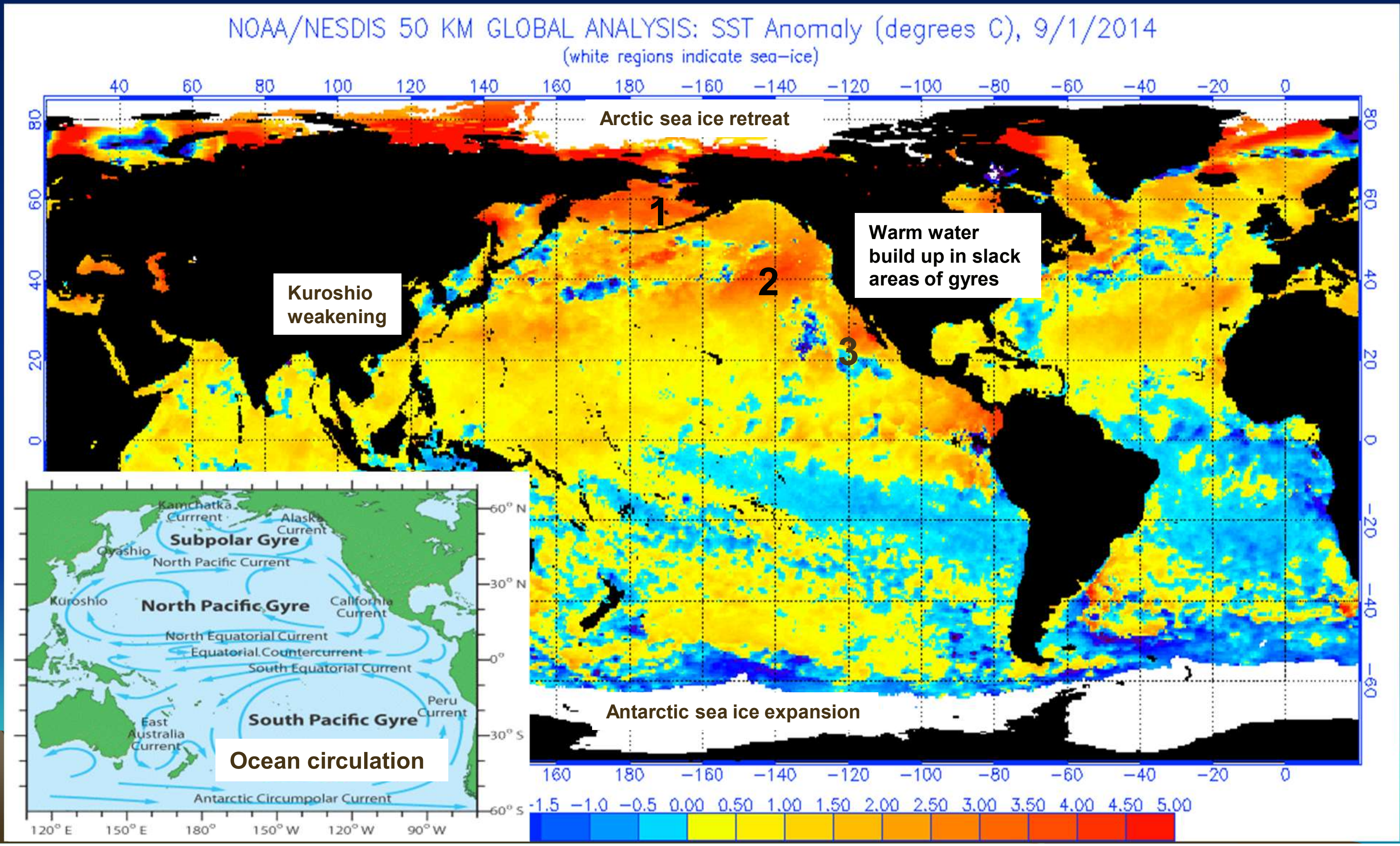
Main trigger of 2014-2016 ENSO sea-surface temperature anomalies created the North Pacific Blob on January 2, 2014



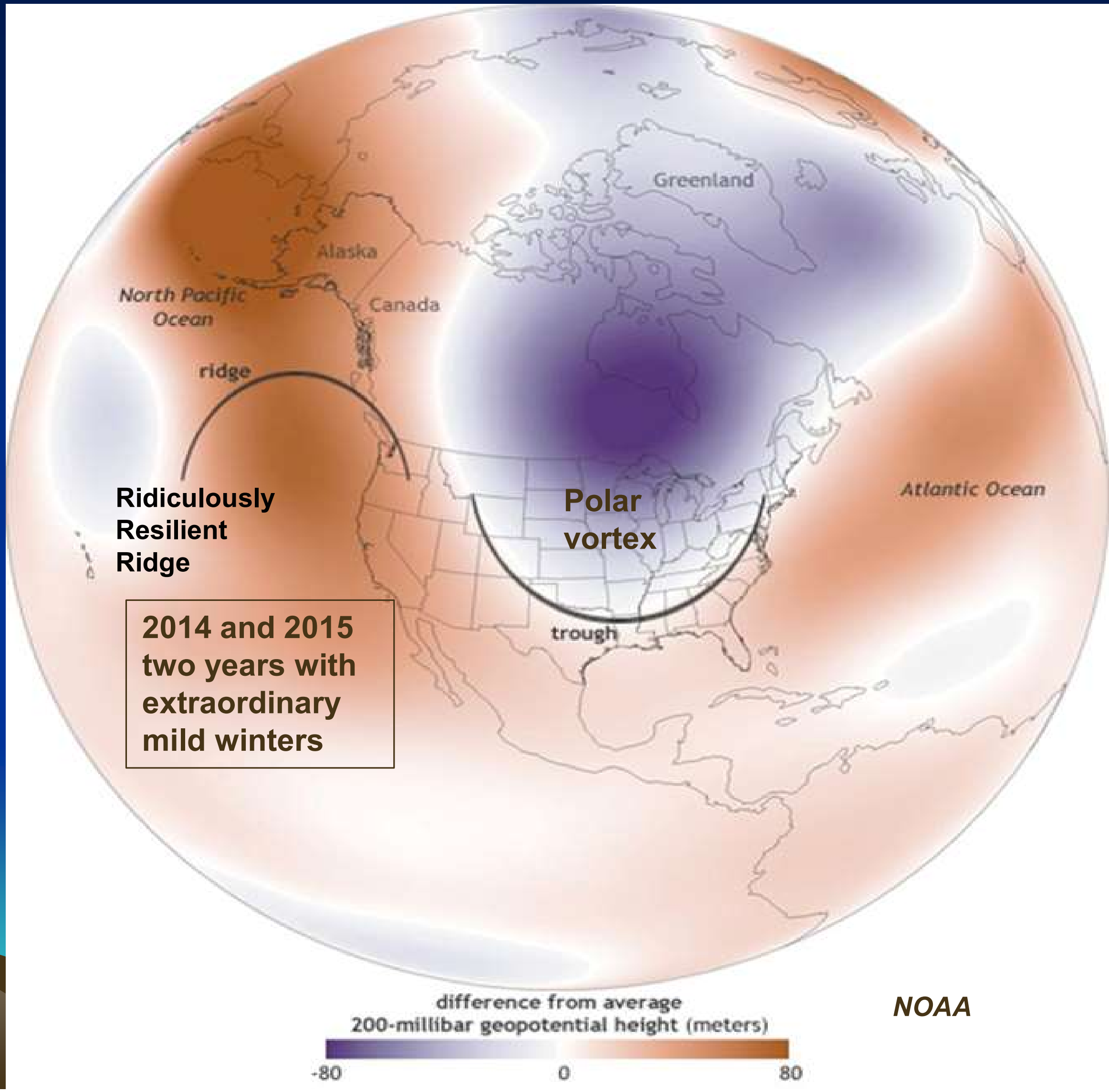
Events linking the Blob to the Nishino-shima eruption

Date	Nishino-shima eruption activity	Northern Pacific Blob
March 2013	Hot seawater first appeared	Initial warming in the northwest Pacific
November 2013	Appearance of a new island	Initial Blob 800 km wide and 91 m deep
December 2013	Island rose 20 to 25 m above sea level with an area of 5.6 km^2	-
February 2014	-	Temperature was around 2.5^{o}C above normal
June 2014	-	Name ‘Blob’ coined by Nicholas Bond, Blob size reached 1600 km x 1600 km and 91 m deep spread to coastal North America with three patches off Alaska, Victoria/California and Mexico
December 2014	Island nearly 2.3 km in diameter and rose to about 110 m above sea level	2014 year without winter western Pacific coast with major biodiversity impacts including algal bloom
January-August 2015	Volcanic eruption continued with episodic lava flows	Continuation of biodiversity impacts with sustained toxic bloom in Monterey Bay
Early 2016	-	Blob persisted and ended

Separation into three parts on September 1, 2014



Pressure distribution during the North Pacific Blob

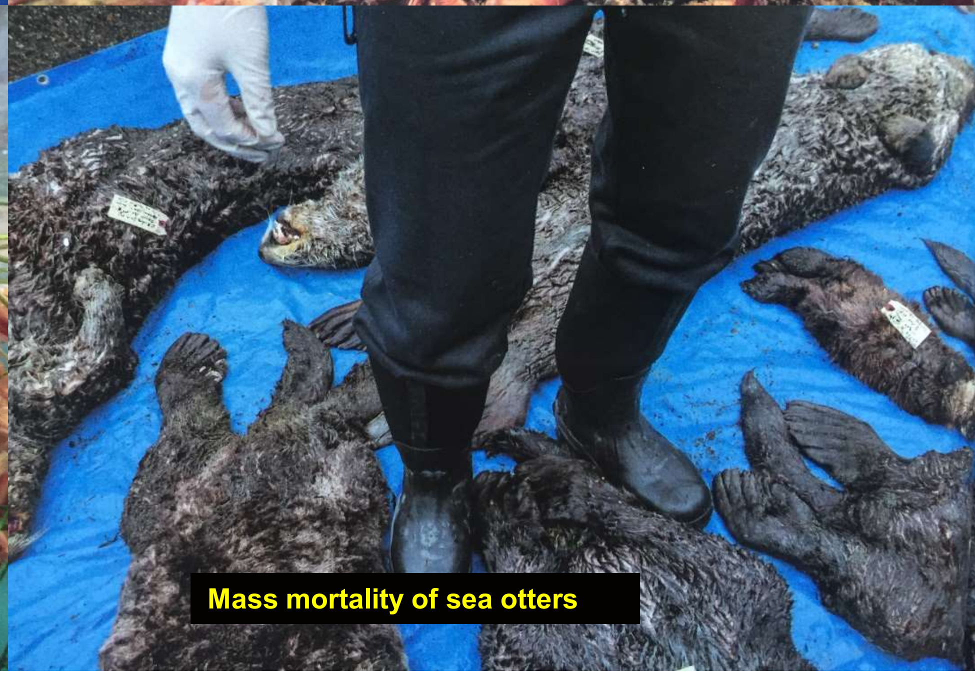


HEAT WAVE

National Geographic September 2016

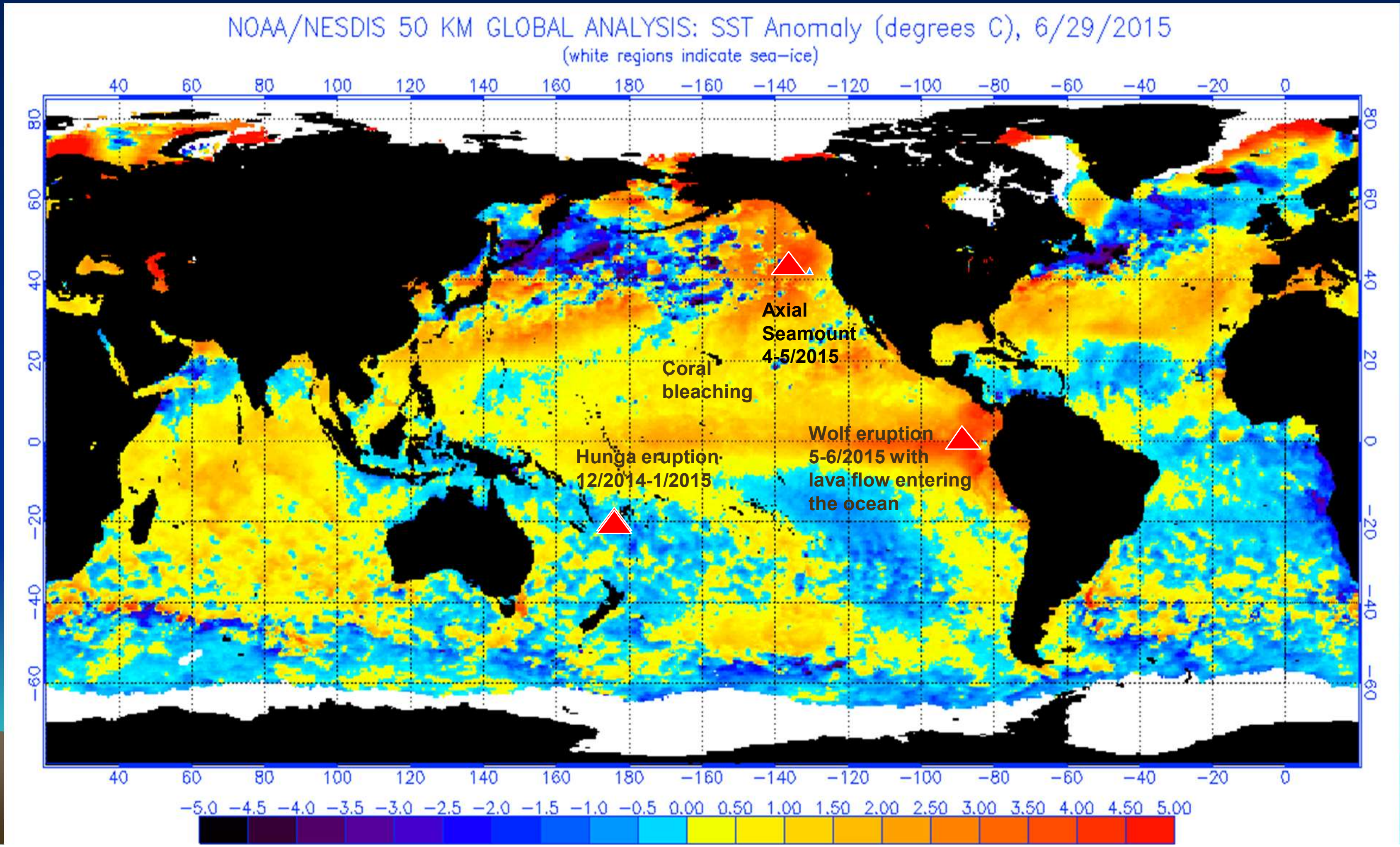
Mortality of benthic feeders eel and prawns

Mass mortality of red crabs



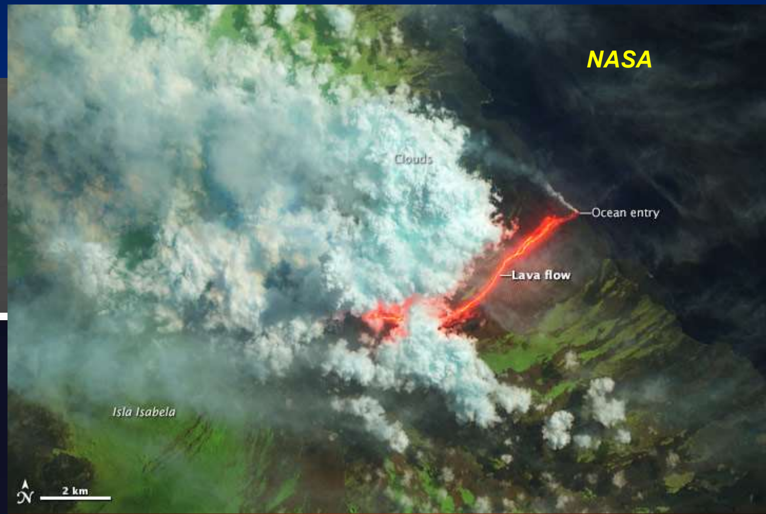
Mass mortality of sea otters

Sea-surface temperature anomalies on June 29, 2015 after the Wolf eruption ended

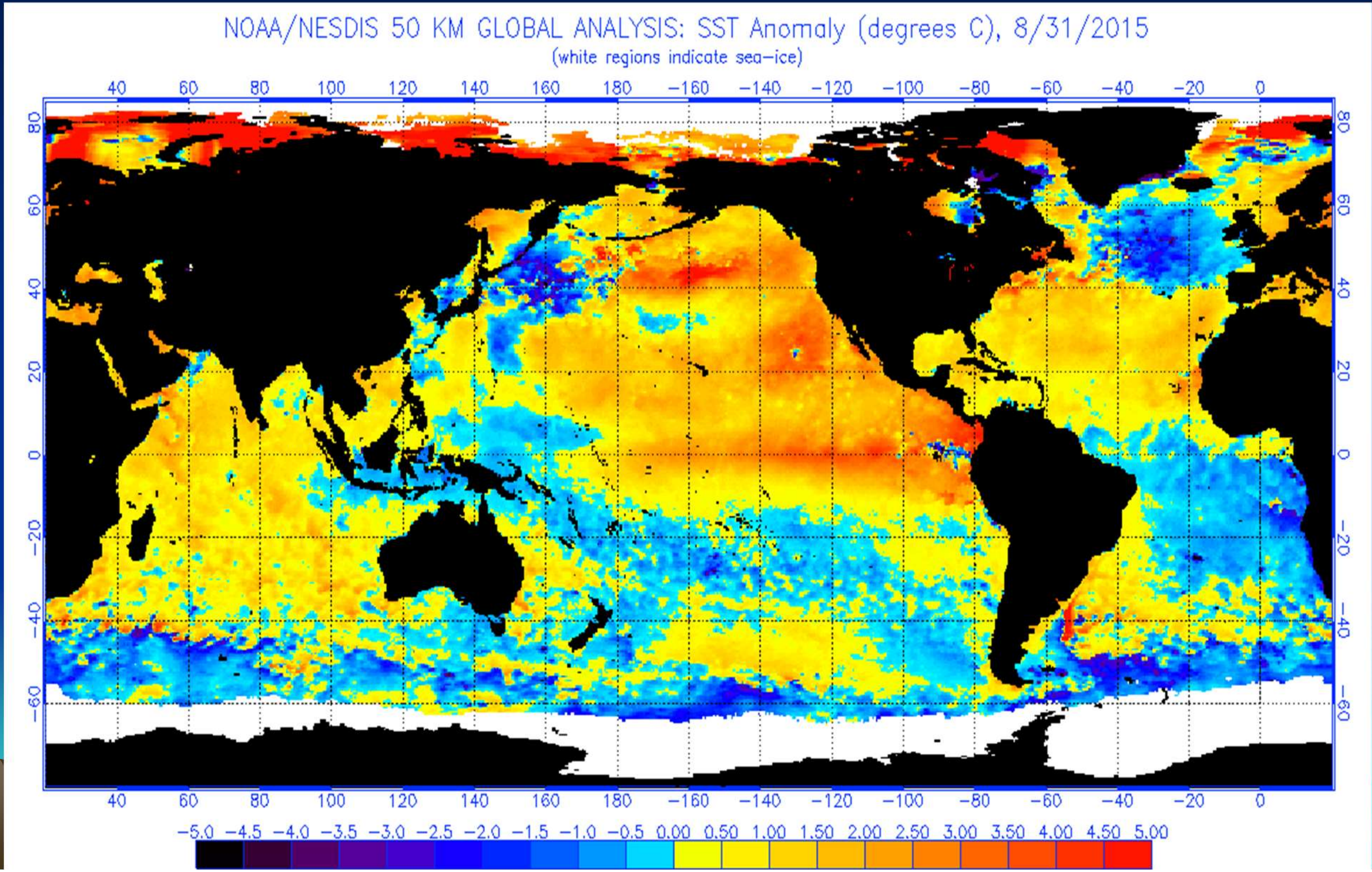


Hunga, Tonga submarine eruption created a new island in ~1 month December 2014-January 2015 followed by VEI 2 sub-aerial eruption

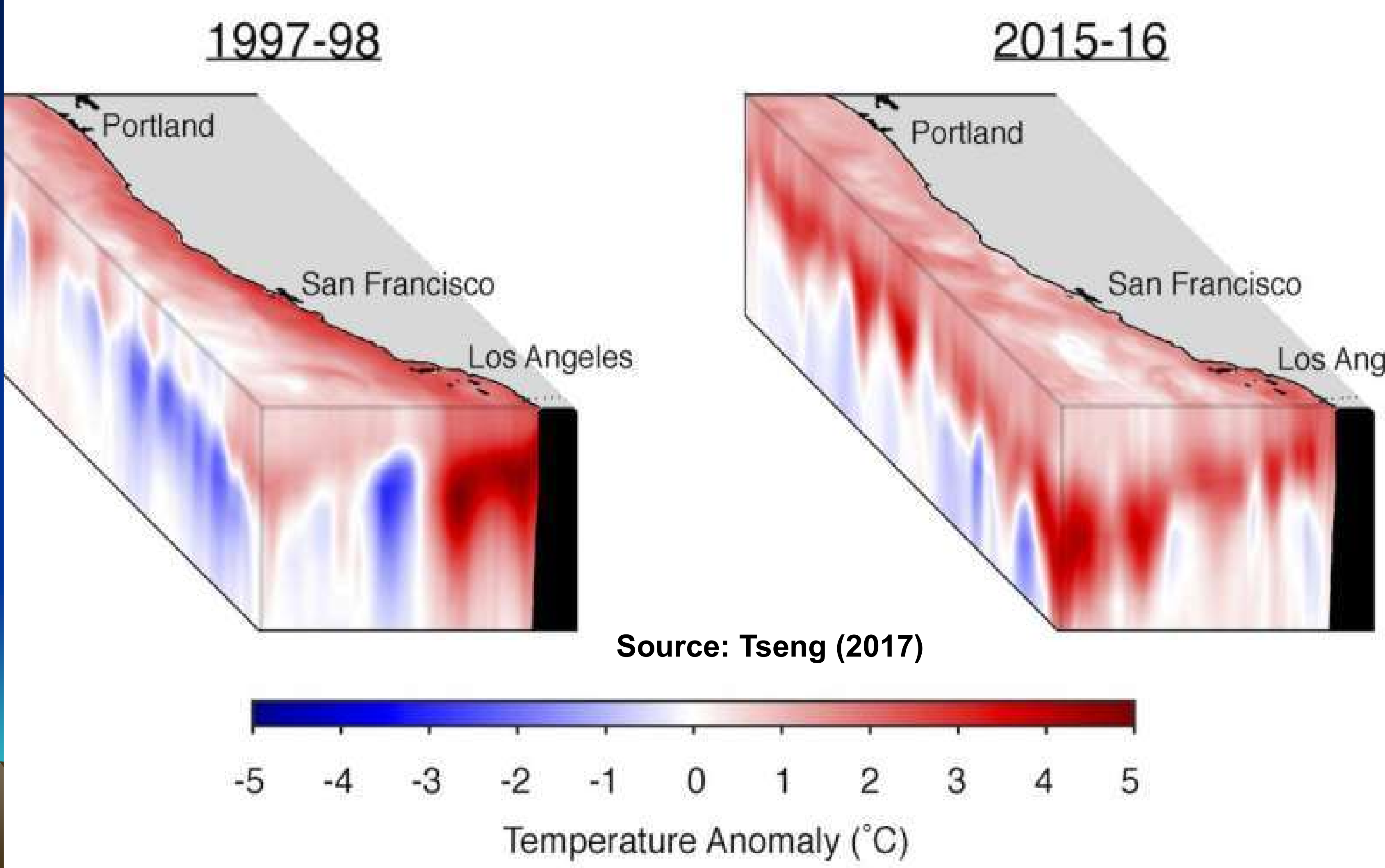
Eruption of Wolf volcano, Galapagos late May to June 2015 VEI 4



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



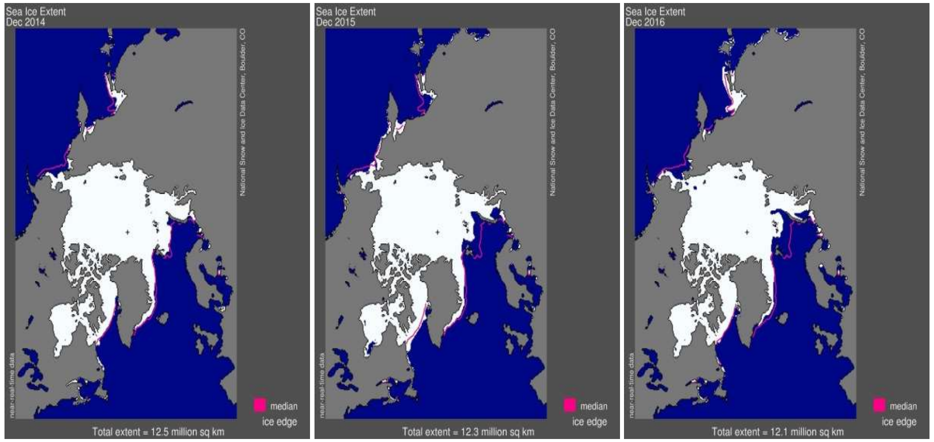
Comparison of seawater temperature anomaly US west coast during 1997-1998 and 2014-2016 ENSOs



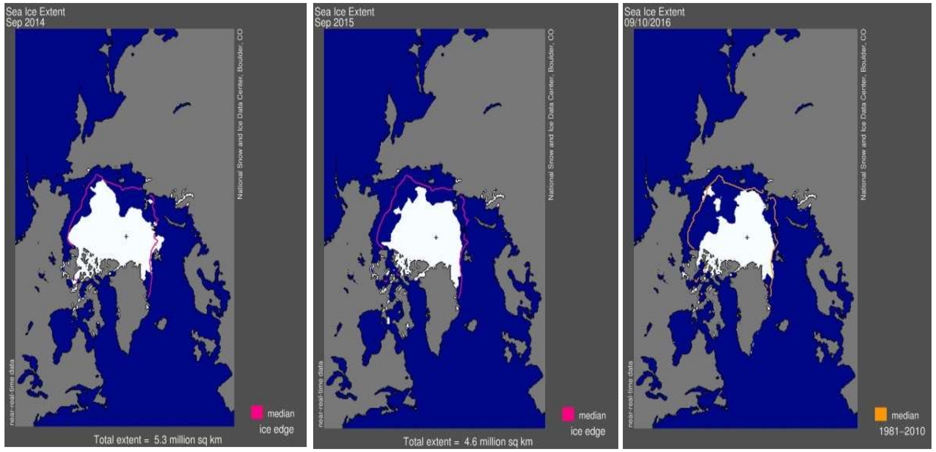
Source: Tseng (2017)

Impact of the North Pacific Blob on Arctic sea ice

December 2014-2016



September 2014-2016



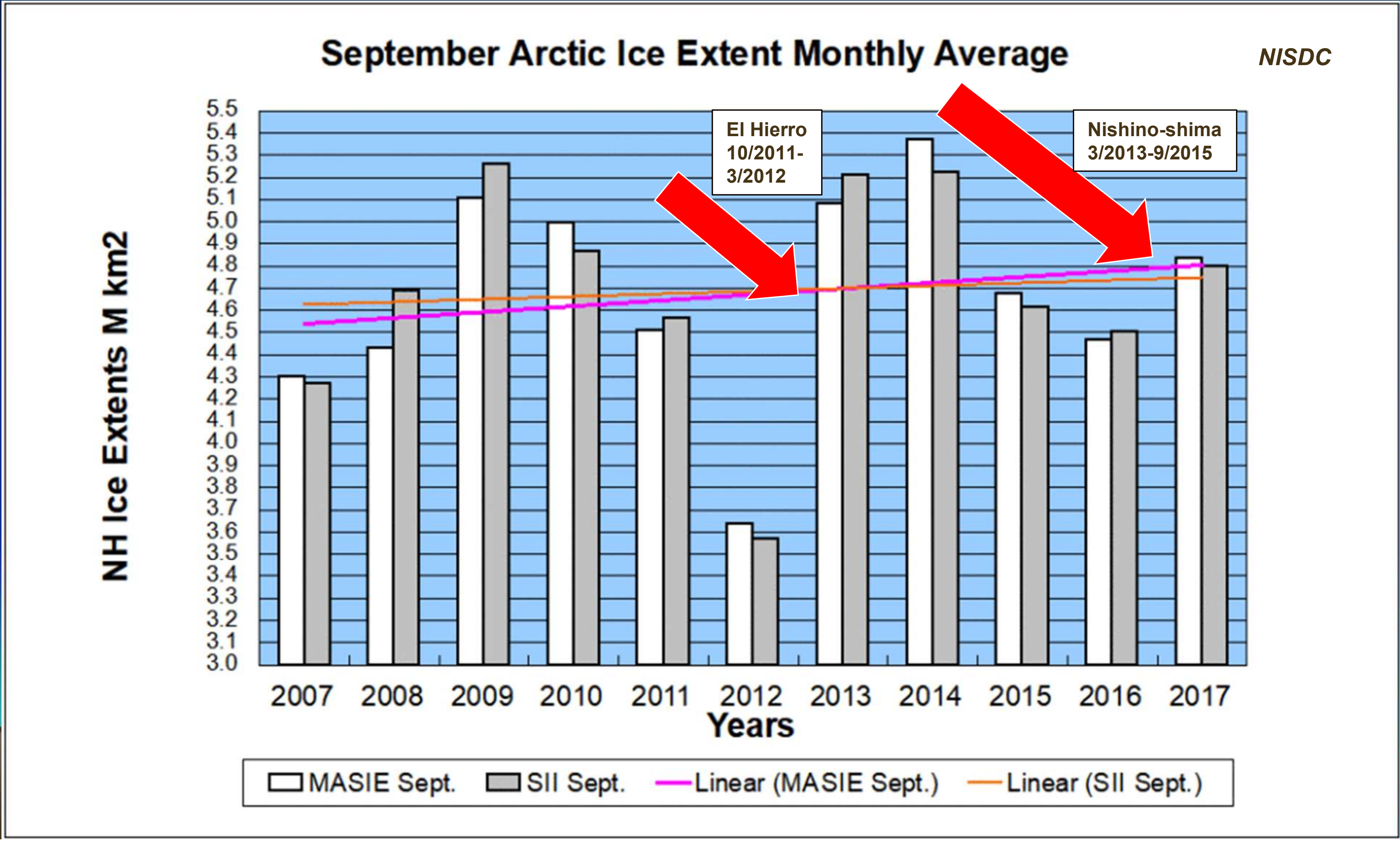
Abnormally warmer seawater in the Bering Straits

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: NISDC.org

Arctic sea-ice changes 2007-2017

Explained by the release of geothermal heat through volcanism



Main conclusions

- Based on observation records, the 2014-2016 ENSO was caused by a combination of terrestrial and submarine volcanic eruptions.

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

- Volcanic eruptions as a cause in climate change (both cooling and warming) is underestimated ….. our dynamic Earth.

The past is a key to the present and the future

Thank you