Volcanic eruptions, a driver of climate variability – ignored by IPCC

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Plan

General introduction

Selected examples 2010 to present –

- Extreme weather events
- Ocean heatwaves / hot blobs
- Polar sea-ice changes
- 2014 - 2016 ENSO

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

Order of importance

1^{st} order

Astronomical forcing and the Sun e.g. glacial/interglacial cycles, monsoons, seasons and day-to-day (mid-day sun)

2^{nd} order

Geothermal heat / plate climatology (James Kamis 2014)

www.plateclimatology.com

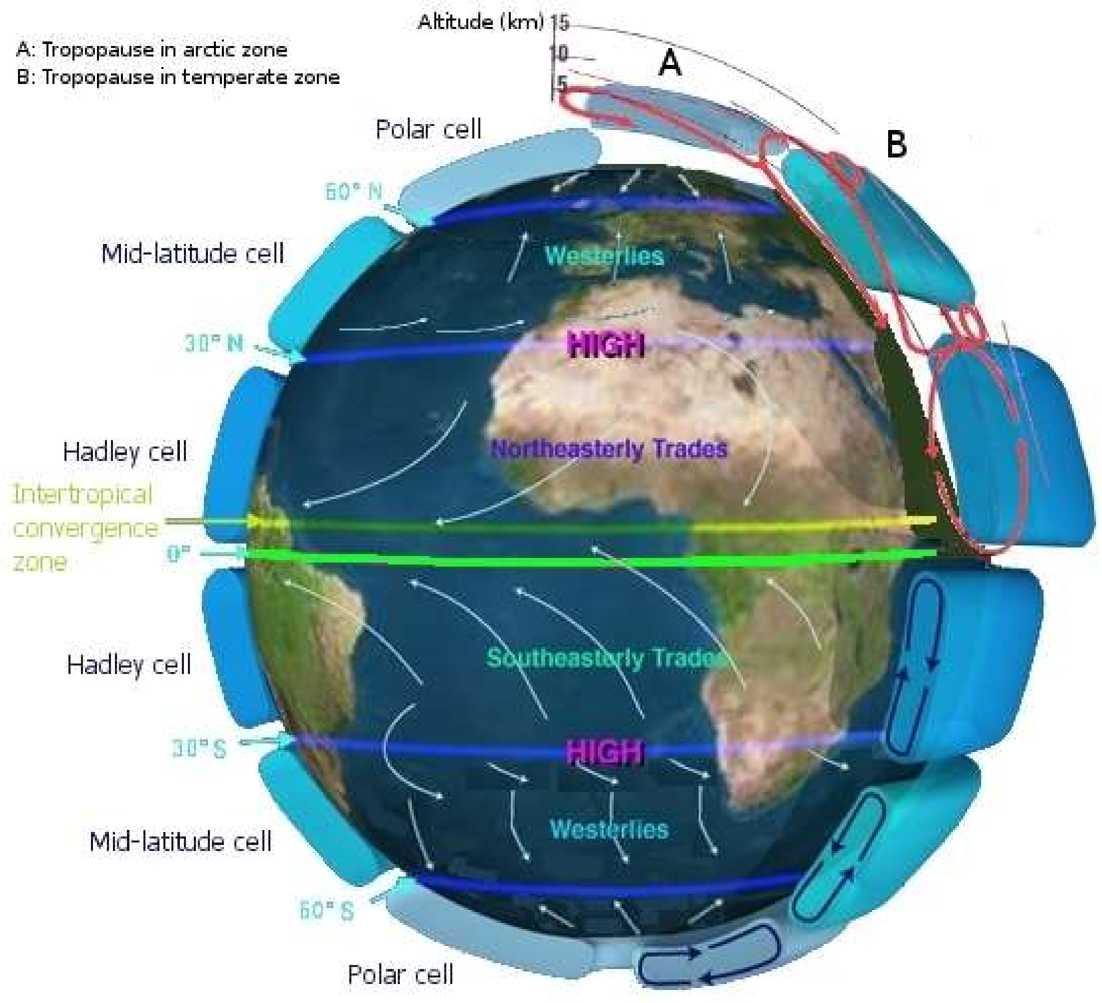
How geological forces affect the hydrosphere and atmosphere including terrestrial and submarine volcanic eruptions, their associated circulation changes and gases released including water vapour, SO_2 and CO_2

3^{rd} order

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

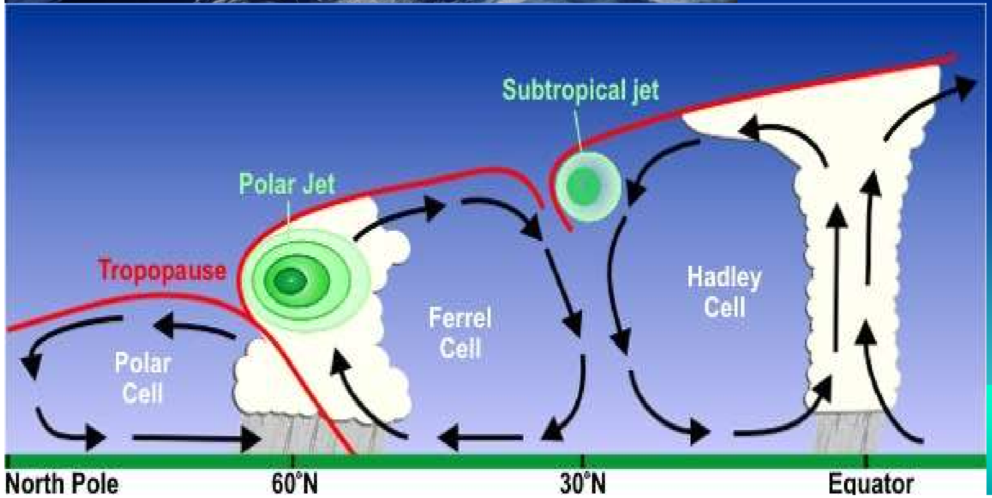
Volcanic plumes penetrating the stratosphere

injects water vapour, interferes with jet streams creating atmospheric rivers



Jet stream over western Canada

Source: Wiki



*Classification of volcanic eruptions**

(1) Terrestrial / sub-aerial –
switches on hot air followed by cooling (injection of ash, gases and aerosols, blockage of shortwave radiation, cloud formation, pressure changes, moisture redistribution, continental cooling, ozone depletion, circulation changes, severe weather events); measured by VEI

(2) Submarine / sea floor –
switches on hot seawater (cause of SST 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)

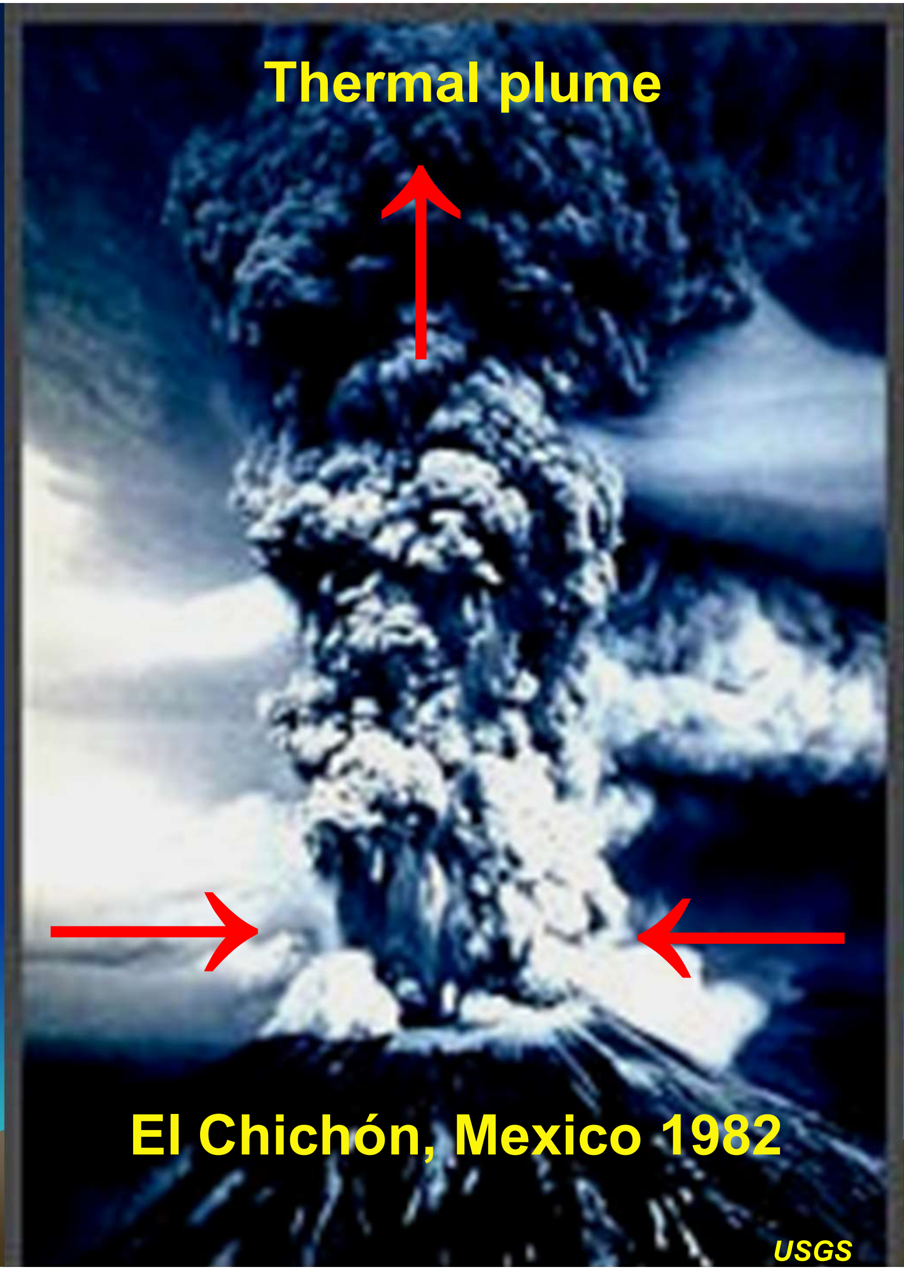
*** Magmatic composition also important e.g. acidic – more explosive.**

Terrestrial volcano model

Ash & aerosols reduce solar radiation leading to cooling

Warm air stores more moisture – water vapour redistribution

Air pressure changes (low)



Eruption changes normal air circulation / creats clouds / destroys O_3

SO_2, HCl, CO_2 & H_2O degassing

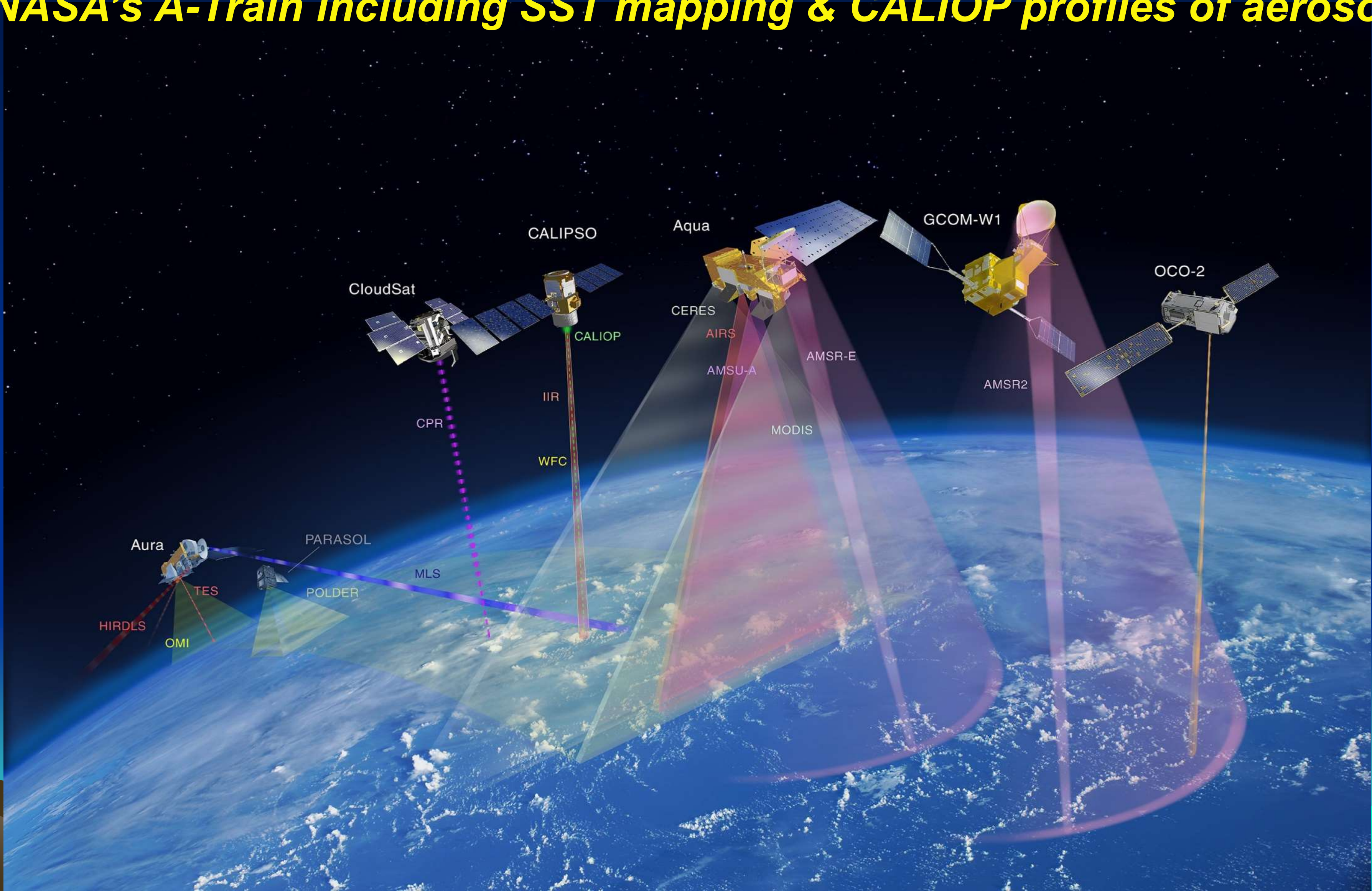
Cool air stores less moisture

Cooler air

Impact longer lasting if higher VEI

Cooling

Satellite records since late 1970s
NASA's A-Train including SST mapping & CALIOP profiles of aerosols

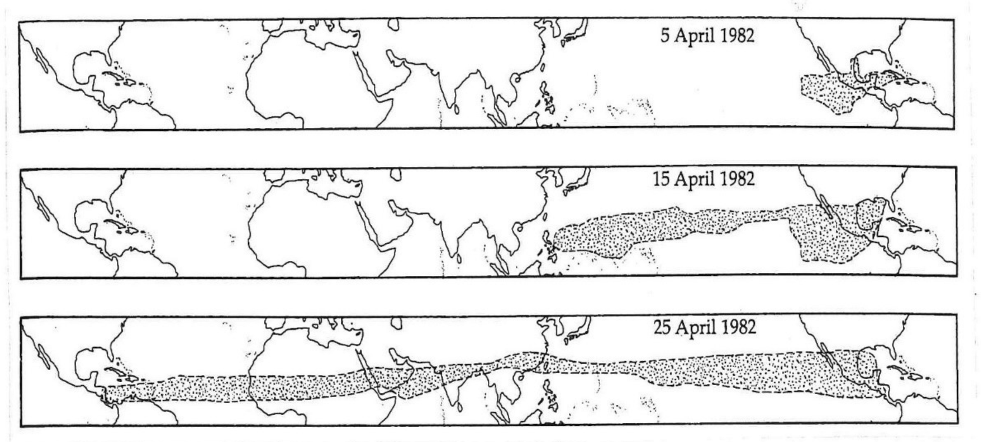


Tracking of volcanic clouds

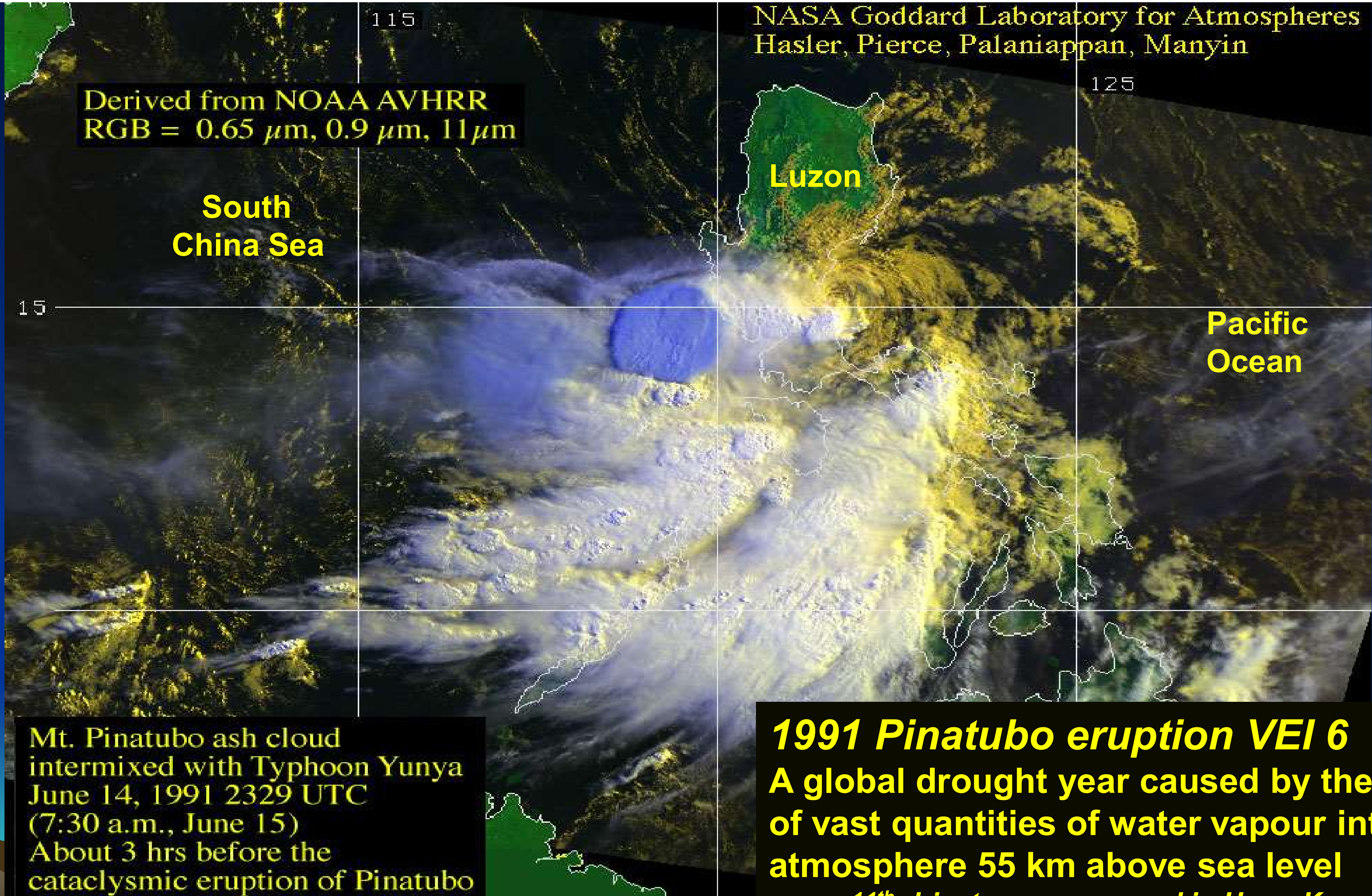
1982 El Chichón eruption, Mexico

VEI 5 column height 26 km
21 days to circle the globe
Strong ENSO 1982-1983
Travelled 14,000 km reaching HK in 11 days
1982 rainfall 3247.5 mm
Second wettest year on record
Extended wet season from April to November
Disastrous year of floods and landslides

Importance of timing



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



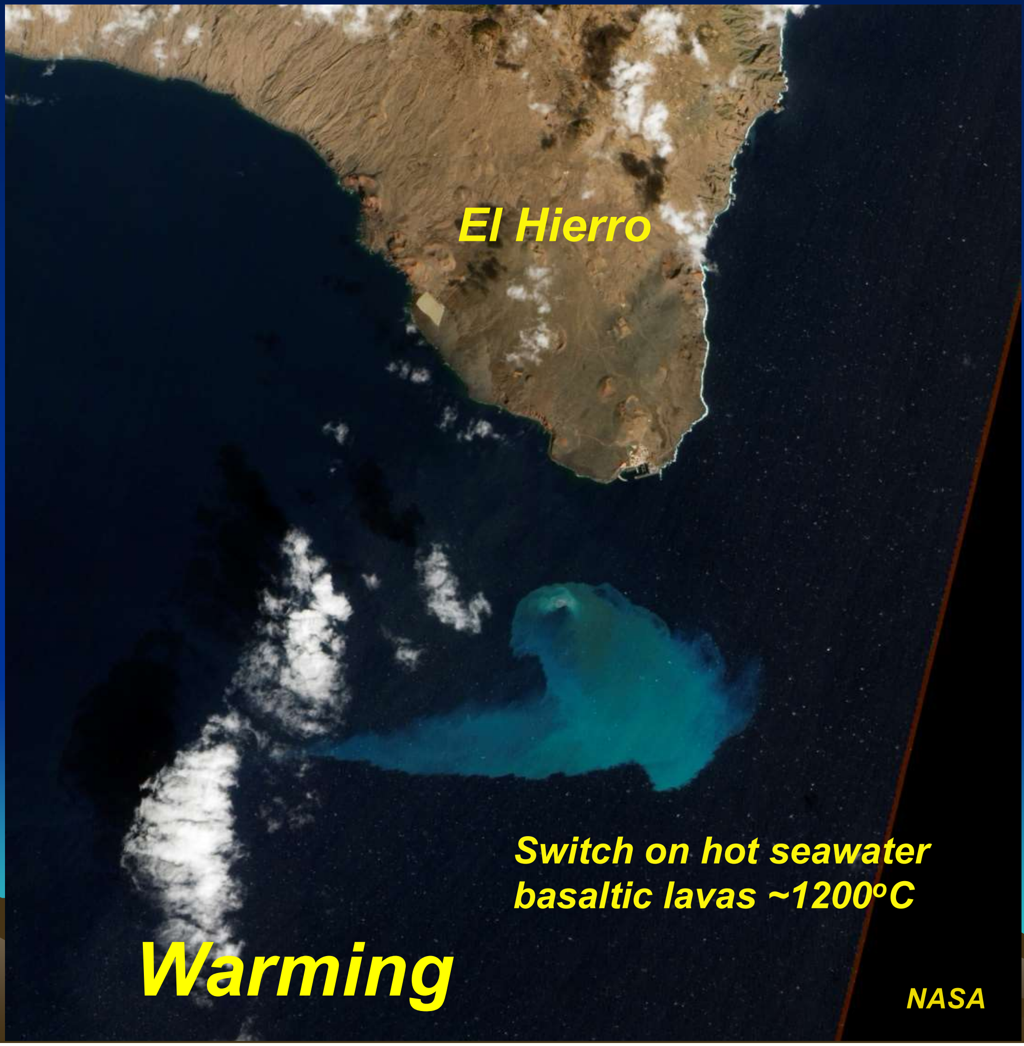
1991 Pinatubo eruption VEI 6

A global drought year caused by the transfer of vast quantities of water vapour into the atmosphere 55 km above sea level

11th driest year on record in Hong Kong

E-folding time of sulphur dioxide ~35 days reduction in solar radiation

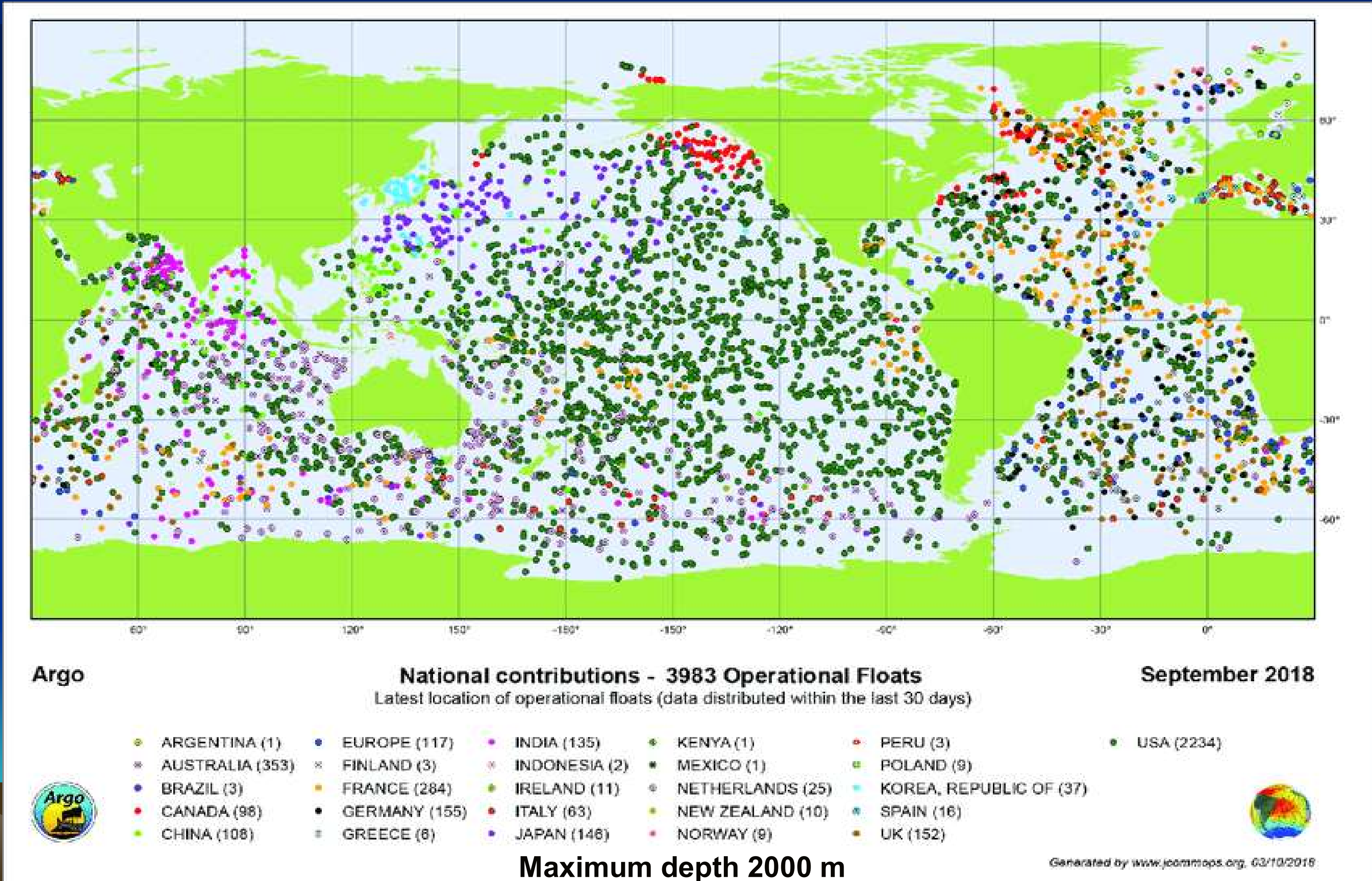
Submarine volcano model



Examples –
El Hierro volcano, Canary islands 10/2011 – 3/2012
Nishino-shima, 940 km south of Tokyo 3/2013 – 9/2015
Hunga, Tonga 12/2014 – 1/2015
Mayotte, Comoros 11/2018
Volcano F, Tonga 6/8/2019
Lateiki, Tonga 13/10/2019
Hunga Ha'apai, Tonga 12/2021

Impacts –
Ocean heatwaves
Pressure changes
Surface wind changes
Sea-level changes
Ocean current changes
Polar sea-ice changes

ARGO ocean network of operational floats since early 2000s



Maximum depth 2000 m

Submarine volcanic eruption detection measures conductivity temperature pressure

Selected volcanic eruptions 2010 – 2012 and their major climatic impact(s)

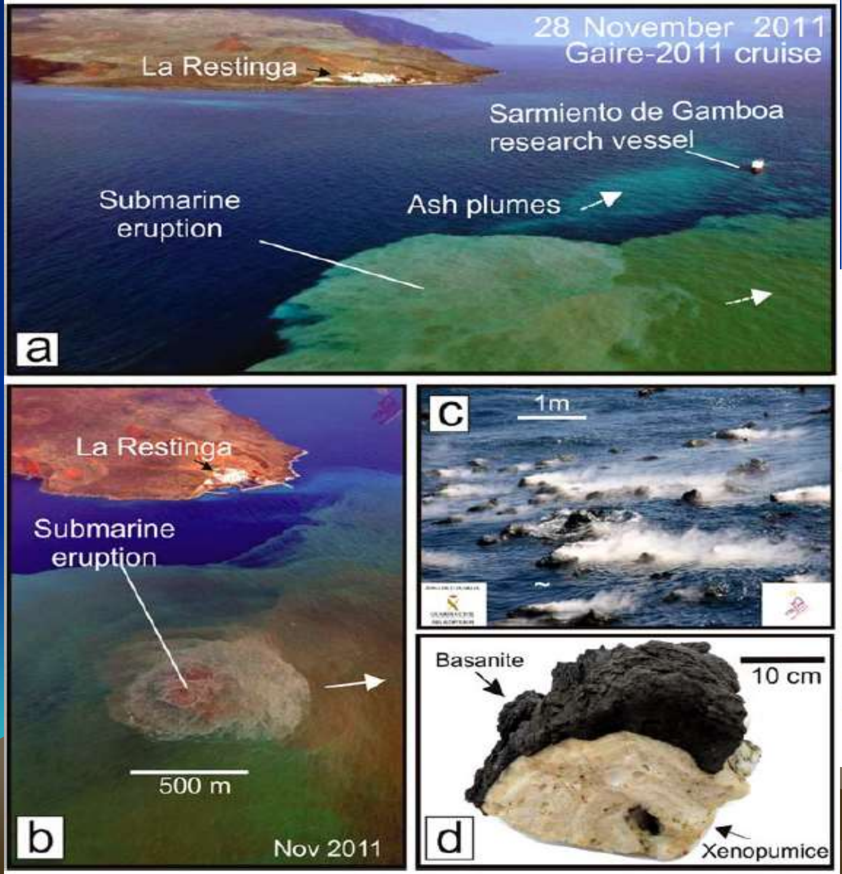
Volcano	Location	Date	VEI / type*	Climatic impact (s)
Soufriére Hills	*Montserrat*	*11//2/2010*	*3*	*Disastrous east Atlantic winter storm in Madeira 20/2/2010; Cyclone Xynthia flood and wind damage in western Europe 26-28/2/2010*
Eyjafjallajoküll	*Iceland*	*14/4/2010*	*4*	*Moisture penetration info continental interiors; 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*
Nishino-shima	*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 the vicinity of Bering Straits; biodiversity changes including mass mortality; two successive years without winter in northeast Pacific coast*
Hunga	*Tonga*	*12/2014-1/2015*	*2, M*	*Identified contributor of the 2014-2016 ENSO; super cyclone Pam which devastated 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 eruptions*
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*	*Minor “ ; 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*	*12/2021-15/1/2022*	*5, M*	*Identified main contributor of the 2022 South Pacific Blob; severe flooding and record rainfall in eastern Australia and New Zealand*

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

El Hierro submarine eruption, Canary Islands
October 2011 – March 2012

The discoloured seawater at least 20-30 km wide and 100 km long spreaded southwards

Source: Somoza et al. (2017)



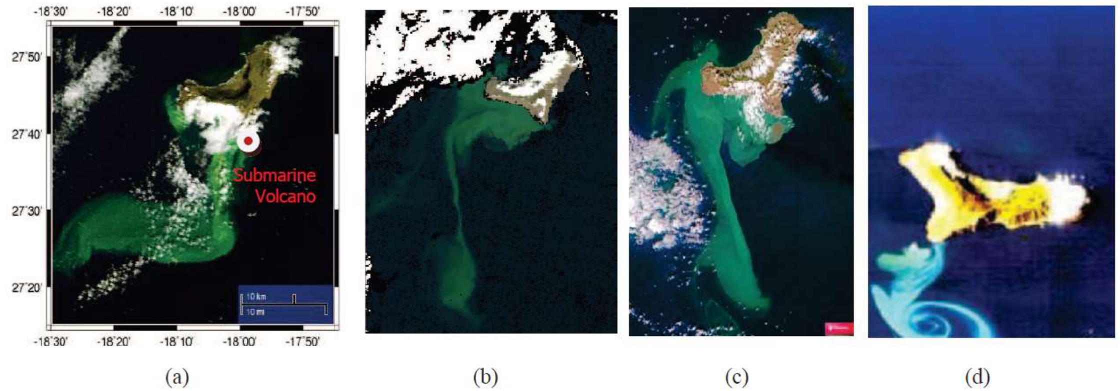


Figure 1. (a) MODIS image of El Hierro submarine volcano location (27.78N, -18.04W) and, (b)-(d) multisensorial MERIS ((ESA©), RAPIDEYE© and hyperspectral HYPERION remote sensing images of El Hierro volcanic plume.

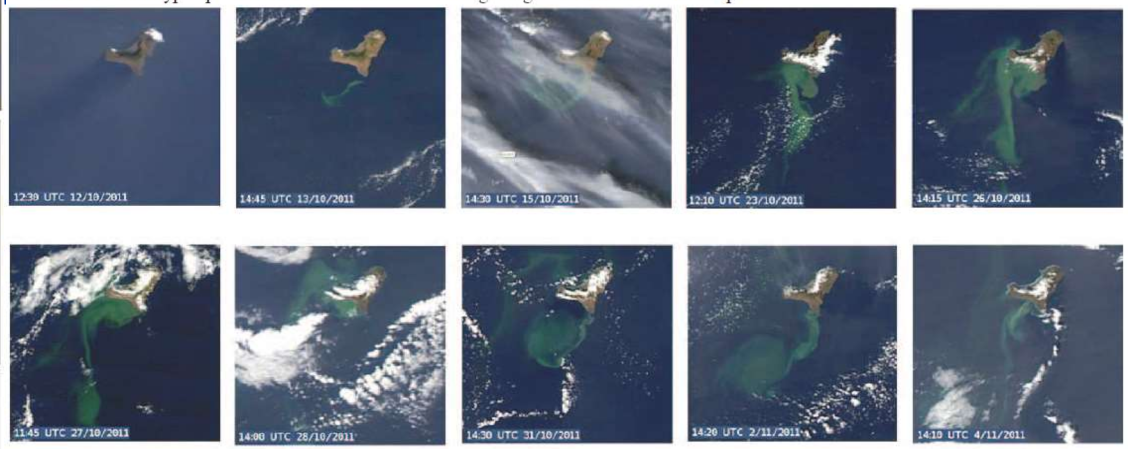
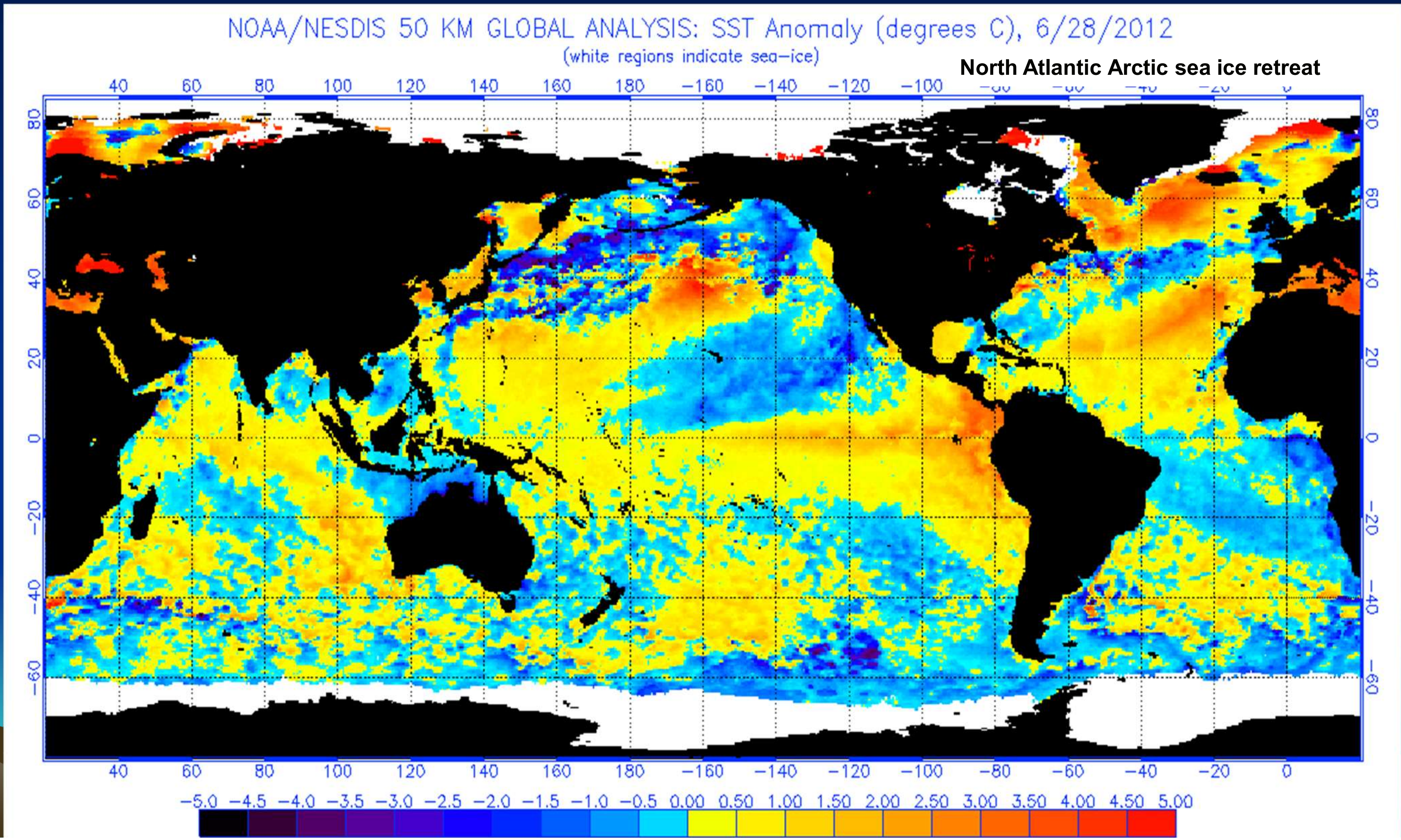


Figure 2. NASA MODIS RGB multitemporal images monitoring El Hierro submarine volcano.

Source: Eugenio et al. (2014)

Combined effect of the Sun and El Hierro on SST on 28 June 2012



North Atlantic warming

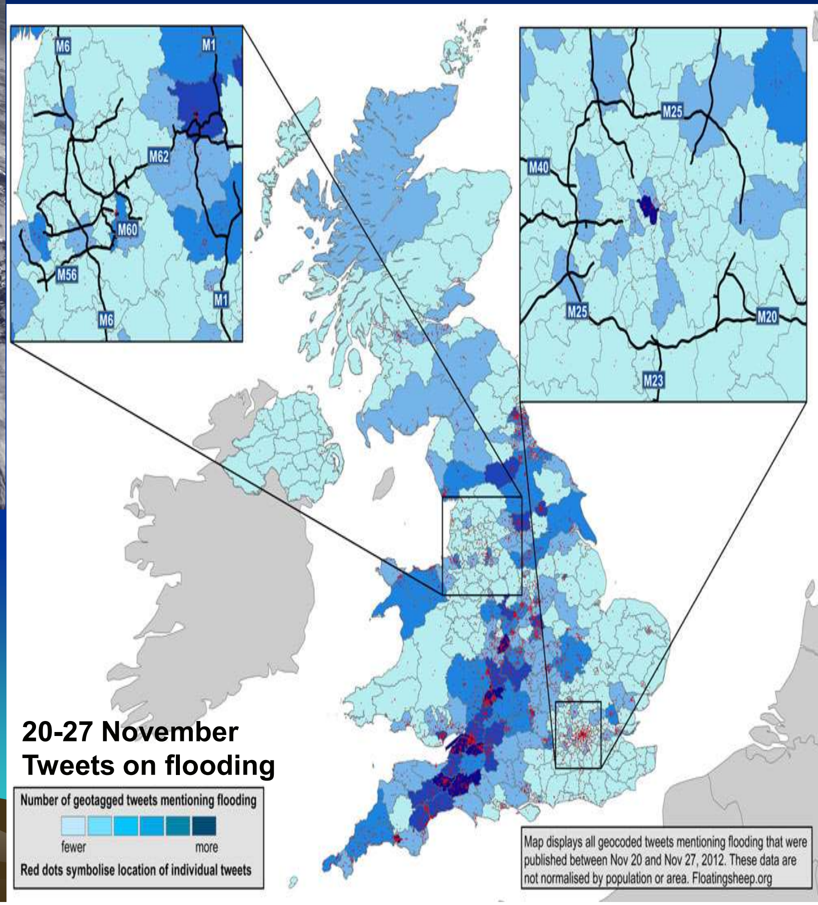
Weather-related events or pattern in the North Atlantic Basin during 2012

Date	Affected region	Events or pattern
April-July	England and Wales	Wettest summer in 100 years with annual rainfall of 1331 mm (115% above average) and severe flooding
May-August	Central North America	Drought estimated damage US$30 billion; most severe since 1895
Summer	Northern/central Europe	Abnormally wet summer with deep moisture penetration into continental interiors
June-November	US east coast	Active hurricane season, tied with 1887, 1995, 2010 and 2011 for having the third most named storms on record but few made landfall
July	Virginia	Hottest on record
July	Greenland	Period of extended surface melting across almost the entire ice sheet
July-October	Western/central Africa	Abnormally wet with flood conditions
September	Arctic sea ice	Lowest on record
October	US east coast	Hurricane Sandy estimated damage US$65 billion; 147 fatalities
October	North Atlantic	Tropical storm Nadine tied record for the longest lasting Atlantic storm
November	England	Wettest week in last 50 years with severe flooding
Winter	US east coast	Abnormally cool and wet due to the active polar airstream
Winter	British isles	Abnormally cold due to the active polar airstream

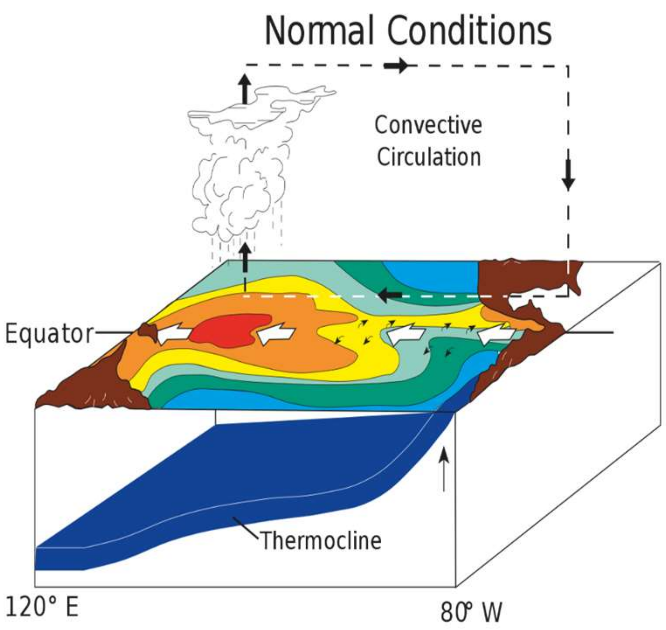
Notable severe weather events 2012

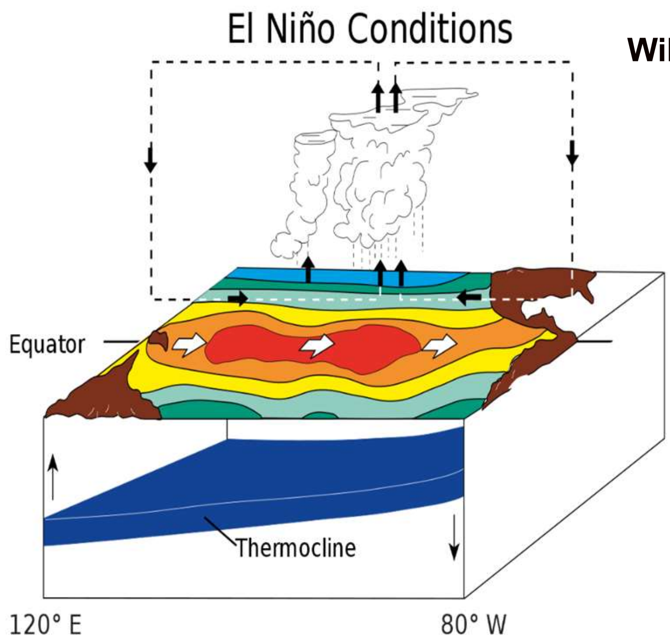
Hurricane Sandy in October
147 fatalities; estimated damage US$65 billion

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



2014-2016 ENSO
Why is it so long and strong?



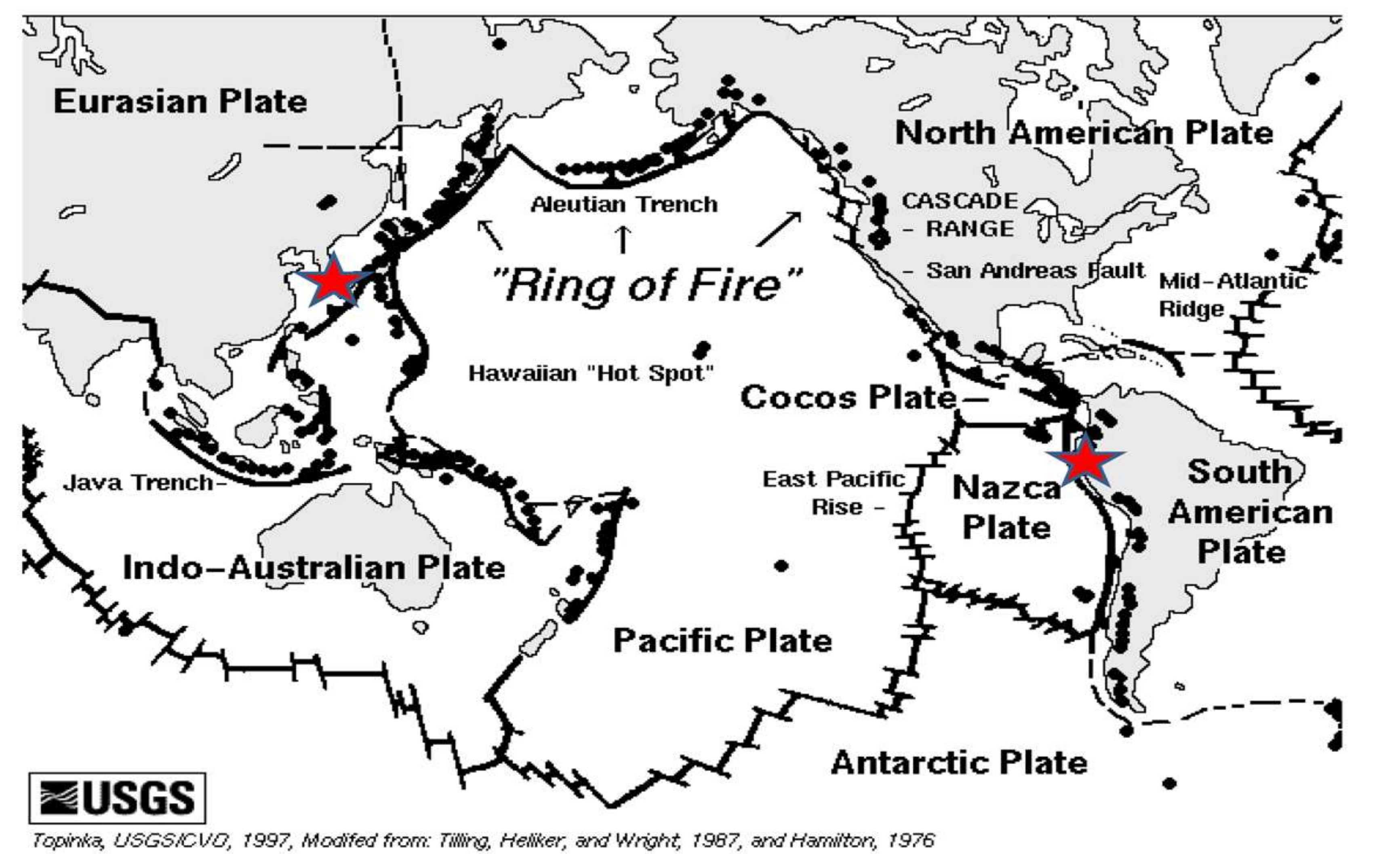


Wiki

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

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

Pacific – major source of geothermal heat



Note – Magma output of volcanism within the ocean basins is currently ~70%.

Numerous active terrestrial and submarine volcanoes

2012-2016 Pacific volcanic eruptions

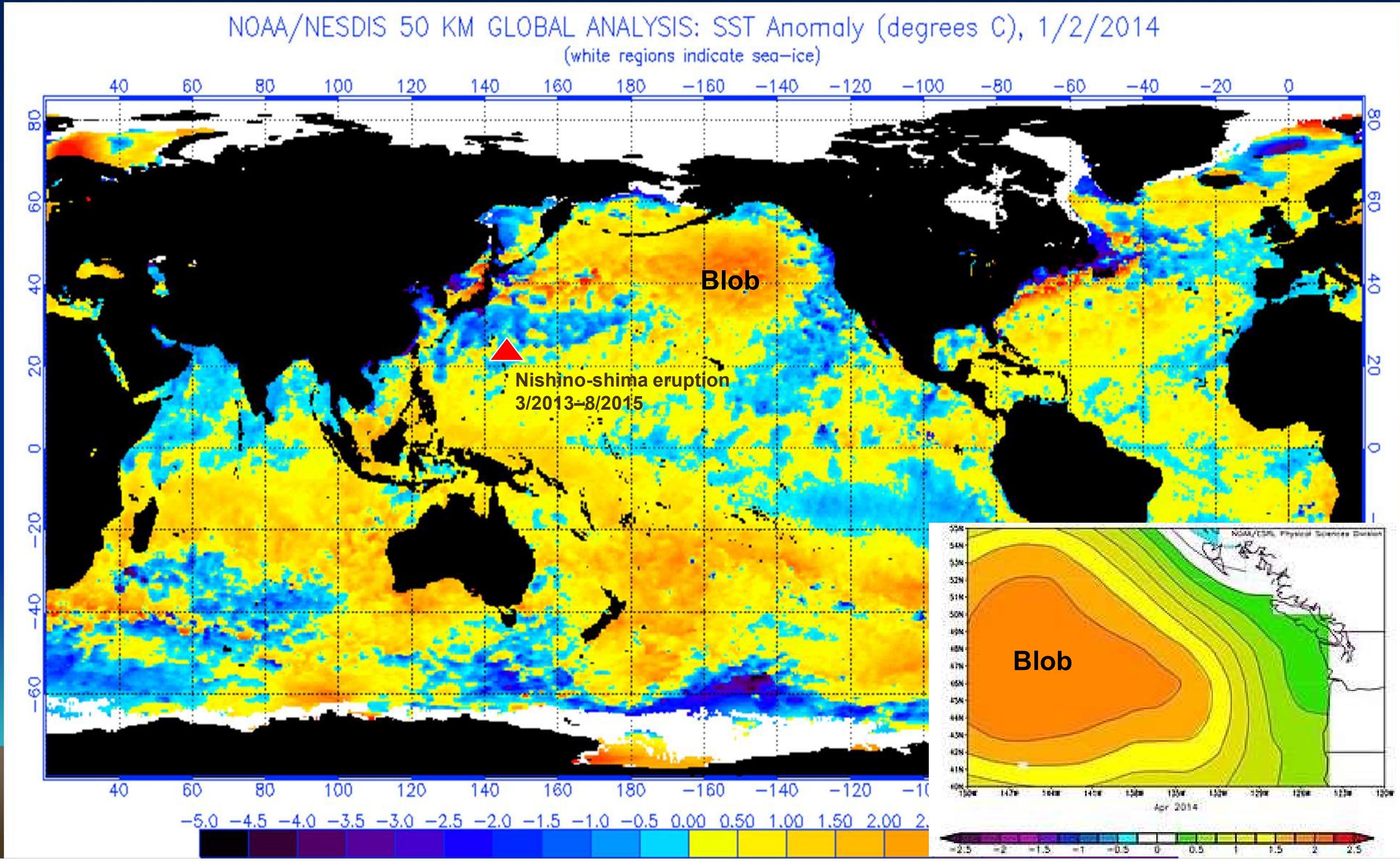
Date	Volcano	Activity
7/2012	Havre, north of New Zealand	Largest deep-ocean silicic eruption of the past century with a 400 km^2 pumice raft, lava sourced from 14 vents 900-1220 m depth (Carey et al. 2018)
3/2013-9/2015	Nishino-shima, South of Tokyo	Eruption was initially submarine until a new island appeared in November 2013; later mixed
12/2014- 1/2015	Hunga, Tonga	Initially submarine later mixed VEI 2
4/2015-5/2015	Axial Seamount	Submarine eruption (Wilcock et al. 2016)
5/2015-6/2015	Wolf, Galapagos	Basaltic lava flows into the Pacific Ocean VEI 4
7/2016-onwards	Kilauea, Hawaii	Basaltic lava flows into the Pacific Ocean

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

November 13, 2013 image: Japan Coast Guard

Image on December 8, 2013: NASA

Initial trigger of 2014-2016 ENSO SST anomalies created the North Pacific Blob on January 2, 2014

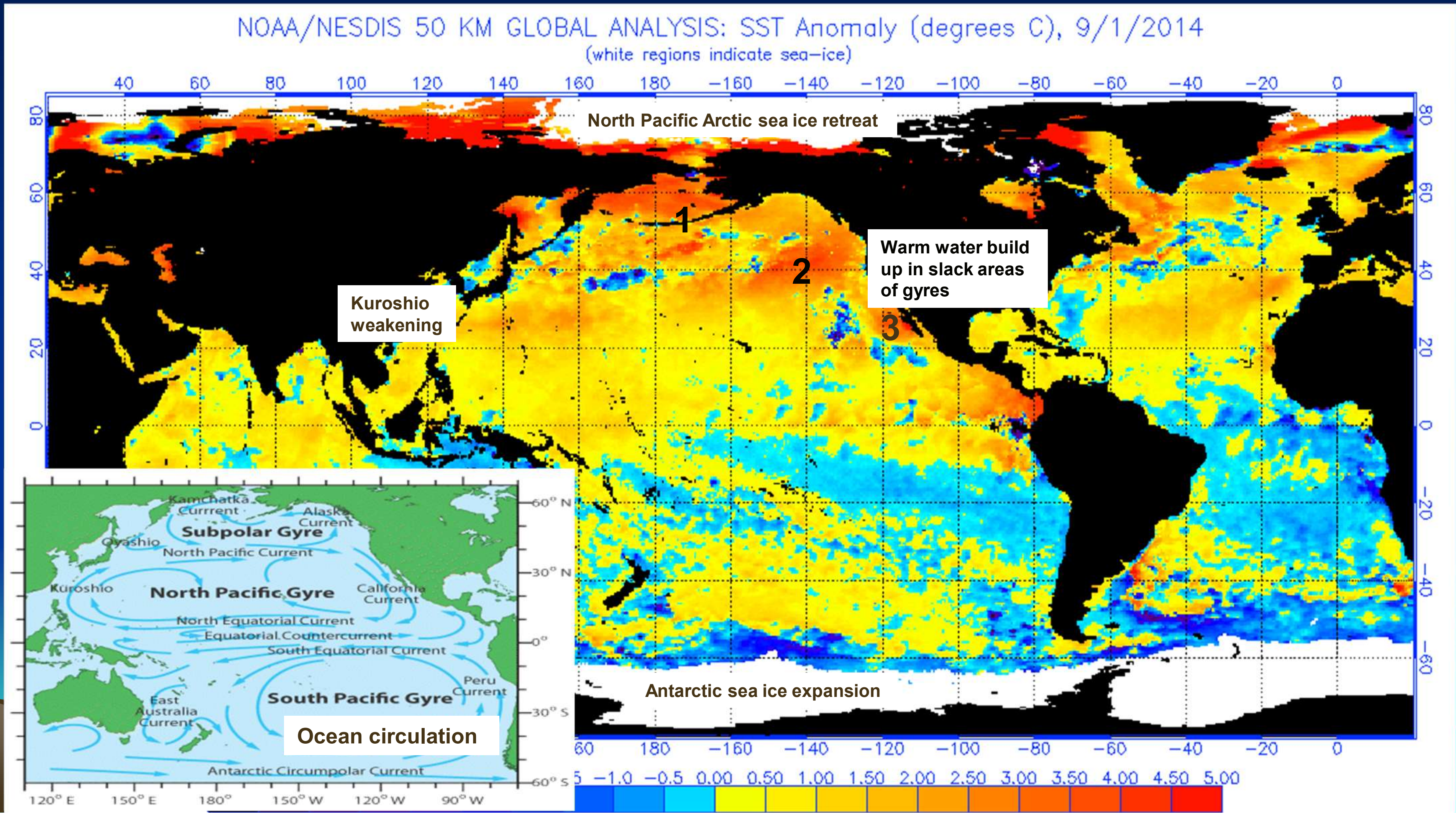


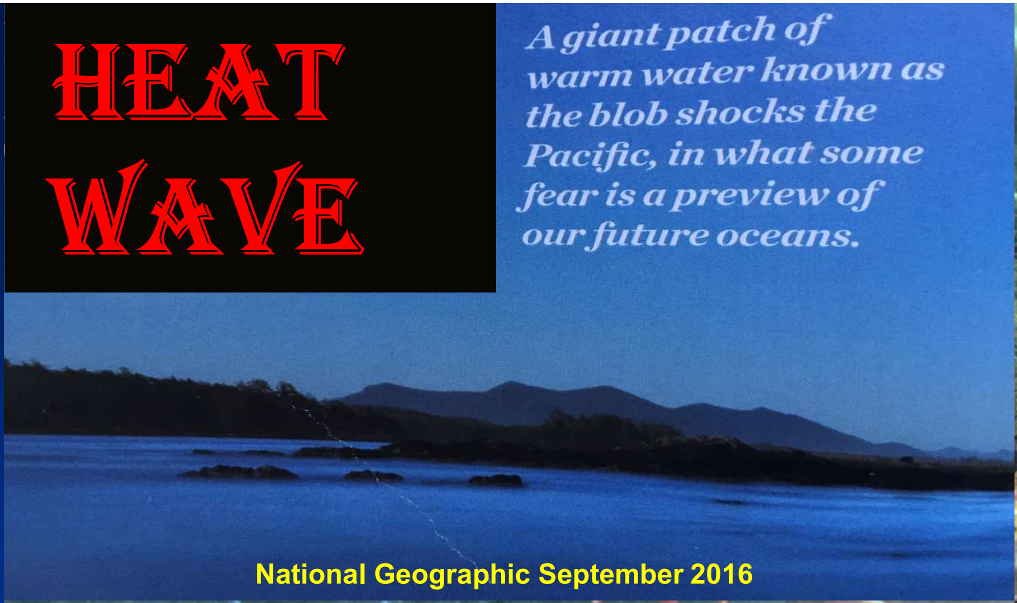
Located near Marianas Trench

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 Increase in size to 1600 km x 1600 km and 91 m deep spreading to coastal North America through 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	Two years without winter in the 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 algal bloom in Monterey Bay
Early 2016	-	Blob persisted and ended

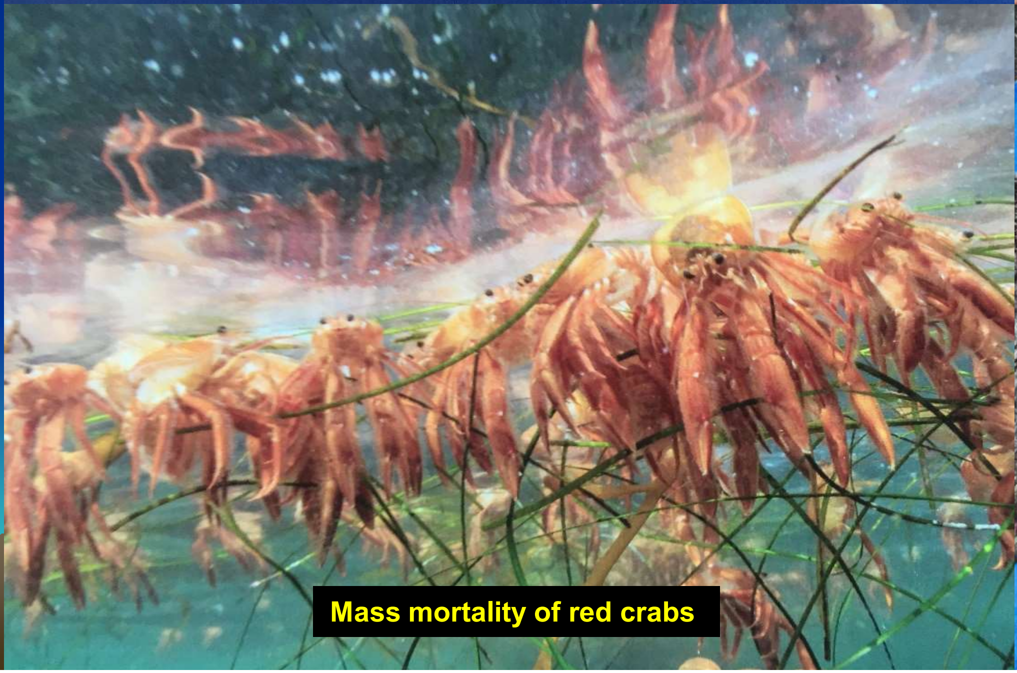
Evolved into 3 patches on September 1, 2014





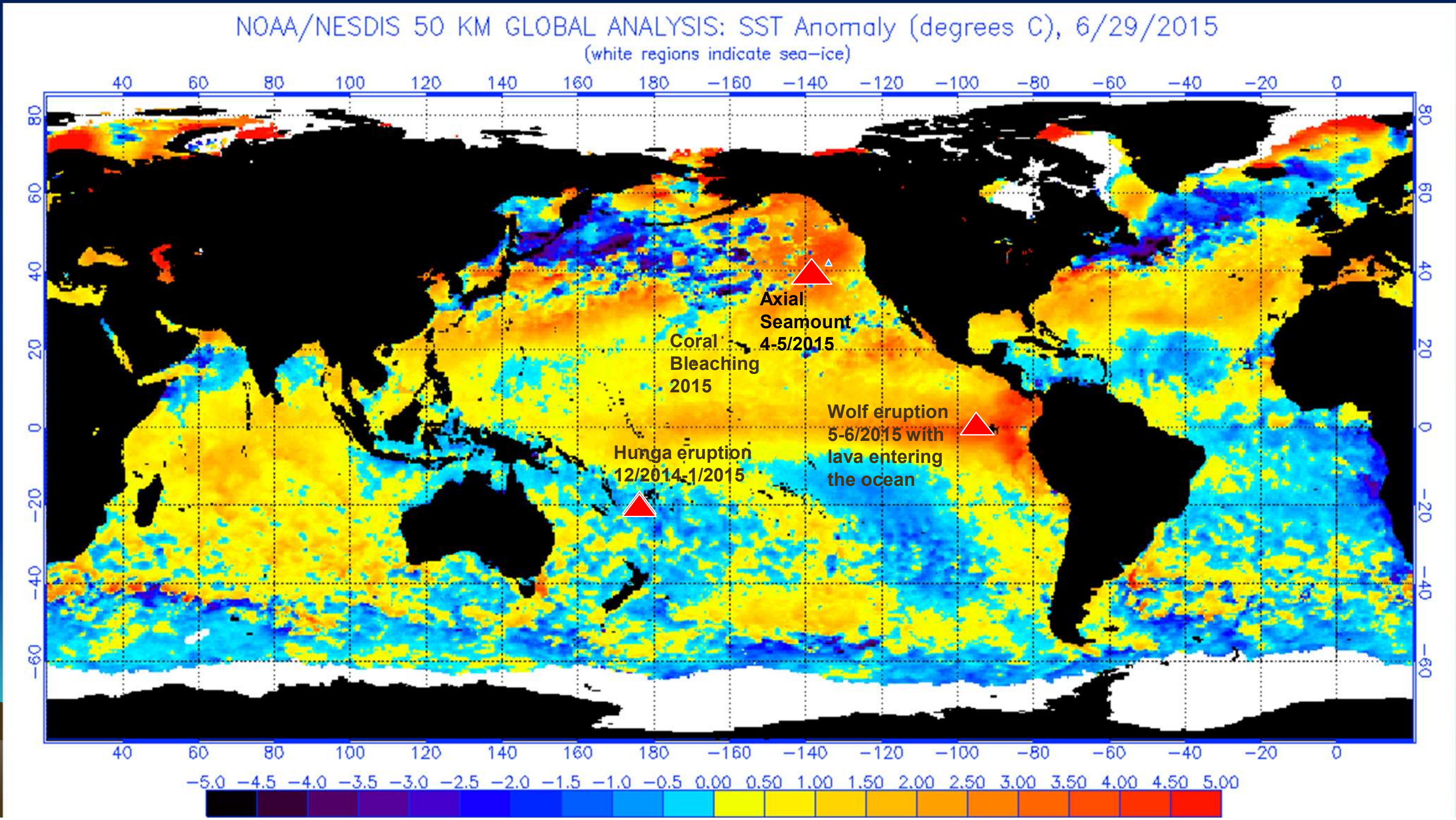
National Geographic September 2016


Mass mortality of eel and prawns

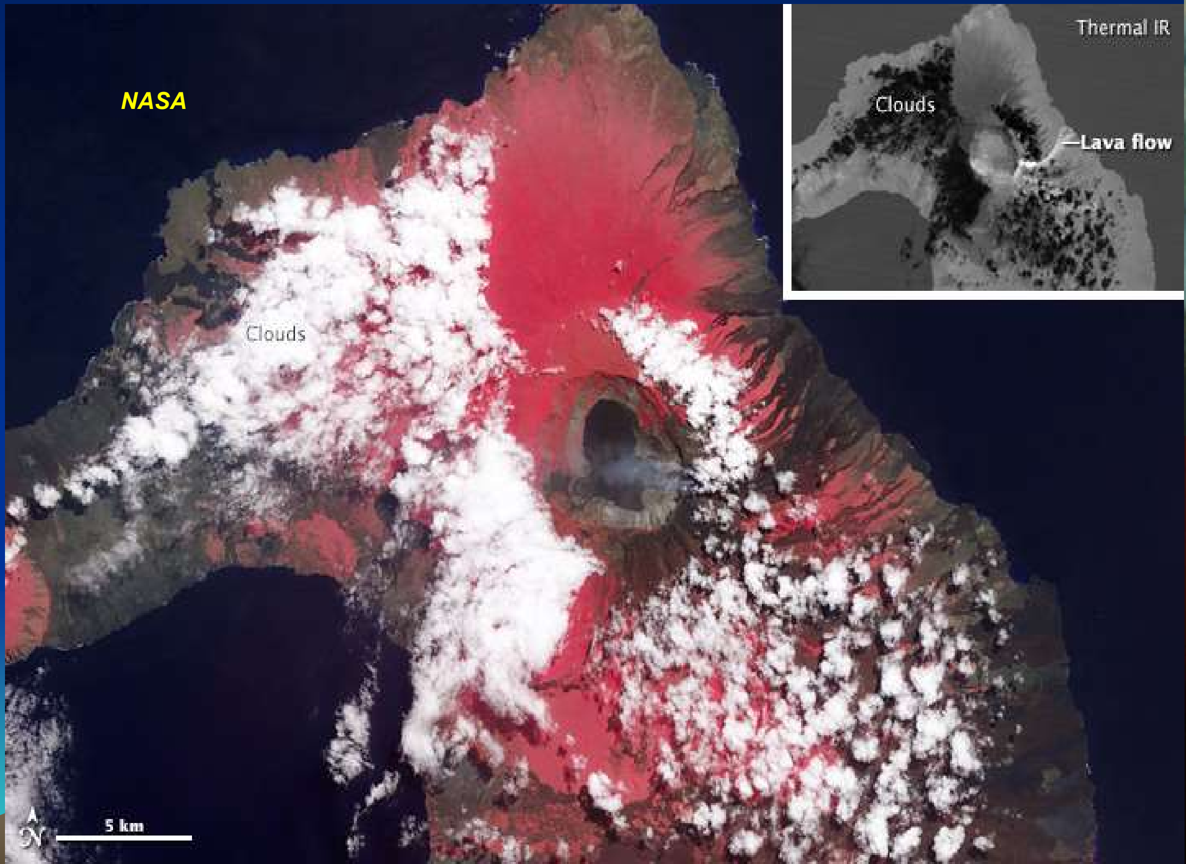

Mass mortality of red crabs

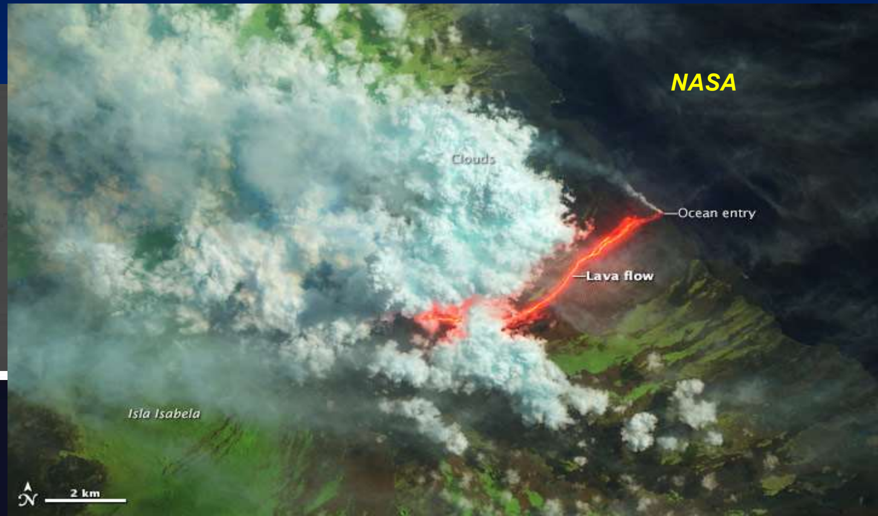

Mass mortality of sea otters

SST anomalies on June 29, 2015 after the Wolf eruption ended

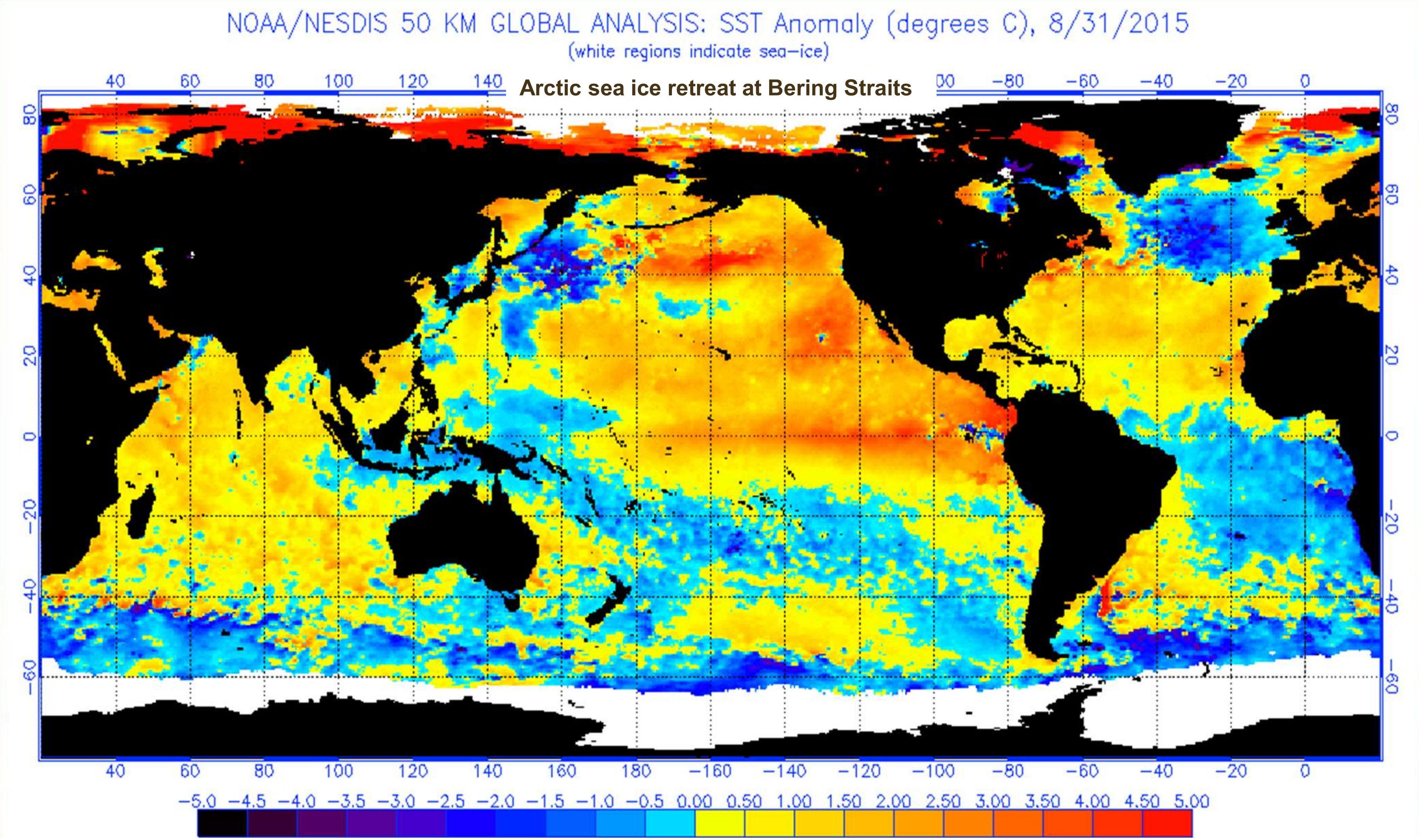


Eruption of Wolf volcano, Galapagos late May to June 2015 VEI 4



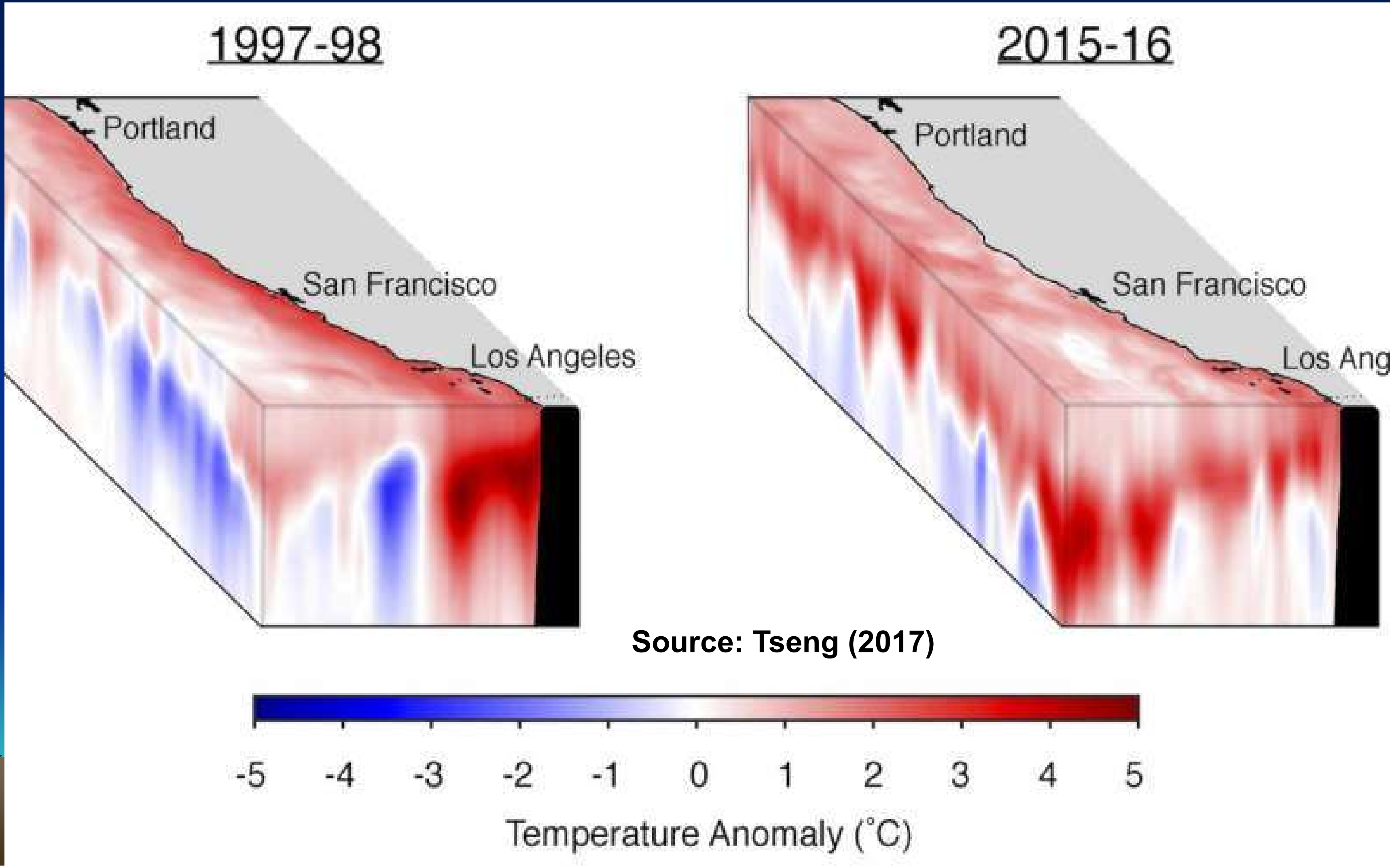


Establishment of the strong and long-lasting 2014-2016 ENSO August 31, 2015

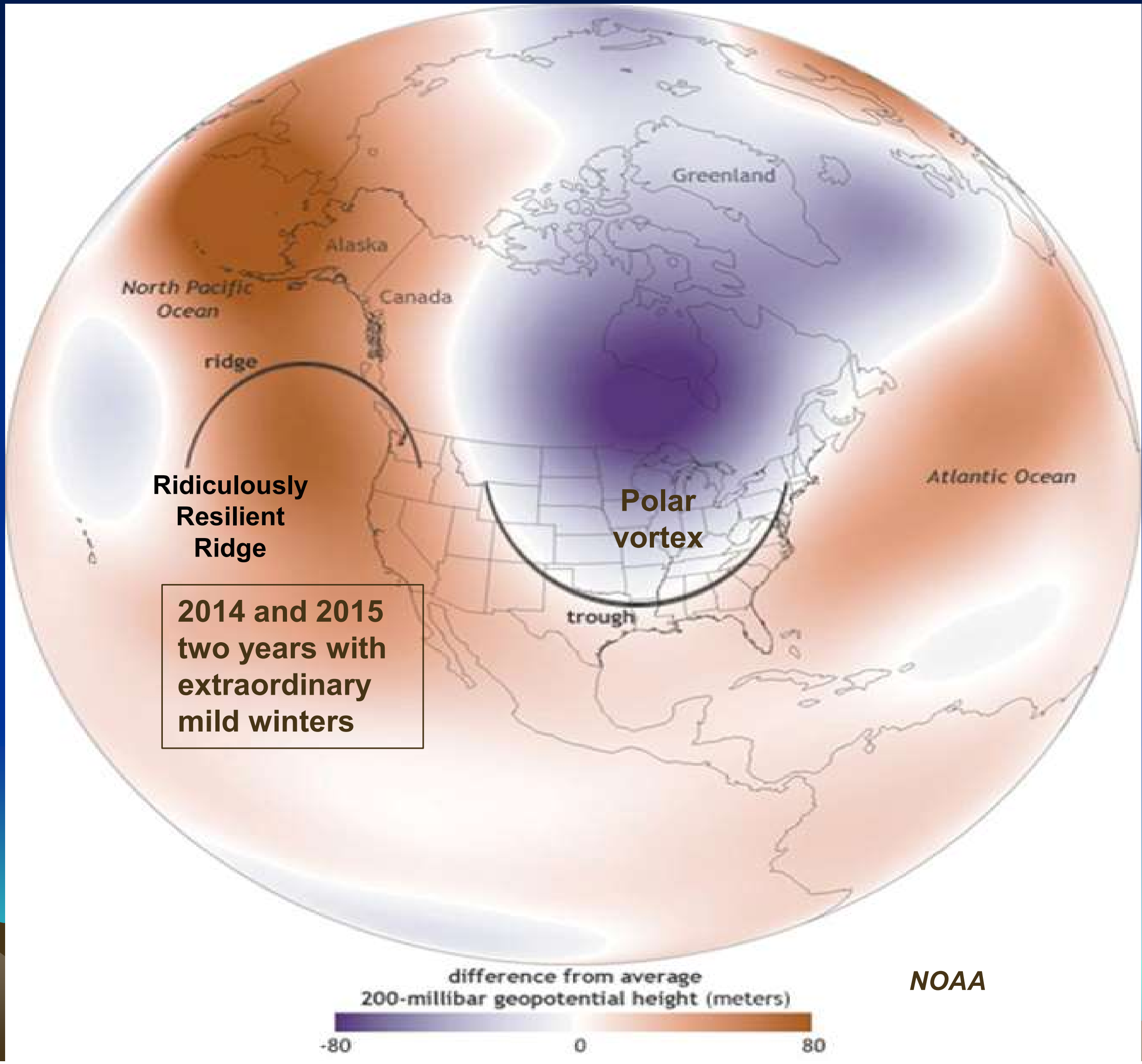


Note – August peak

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



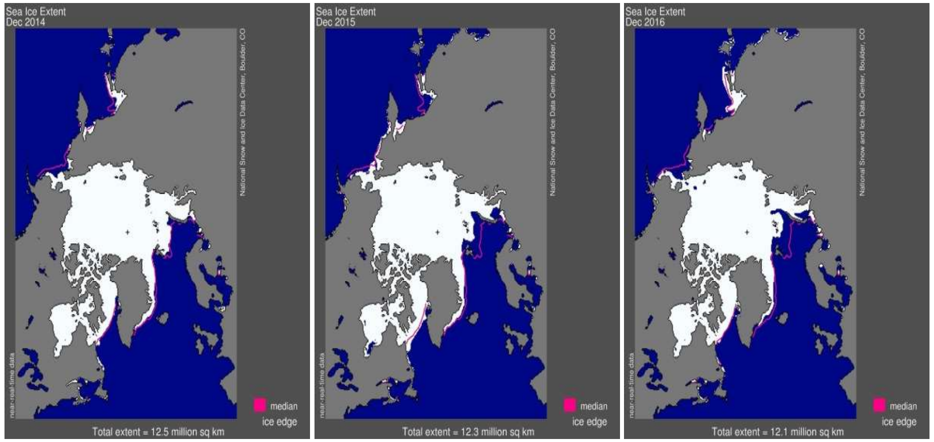
Pressure distribution during winter/spring



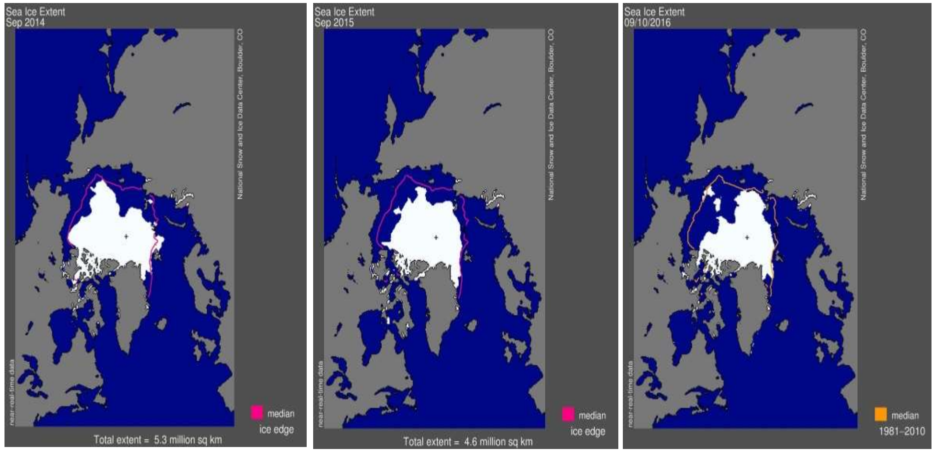
Polar vortex enables cold polar air to penetrate far south

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	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

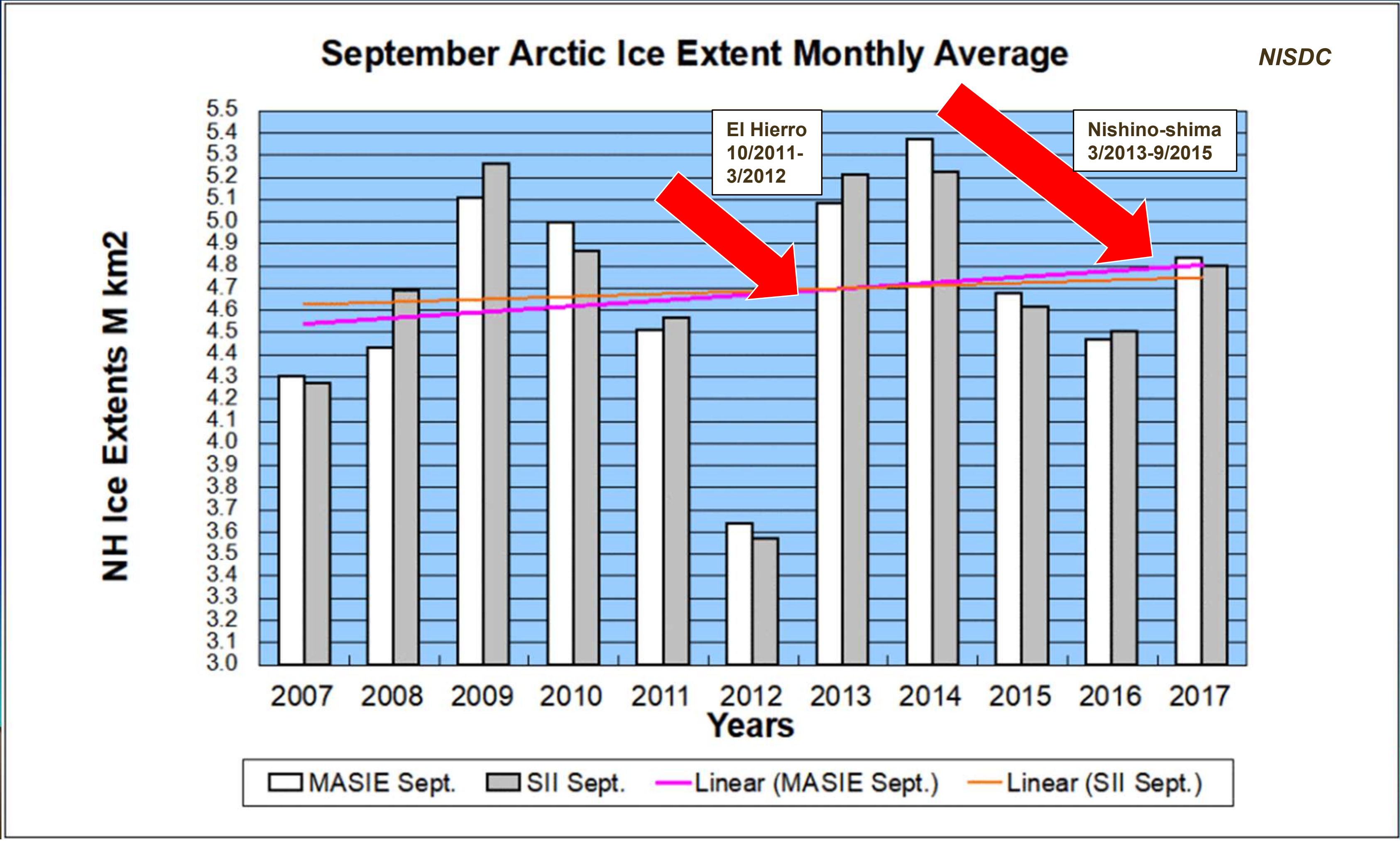
El Hierro record low

North Pacific Blob gradual decline

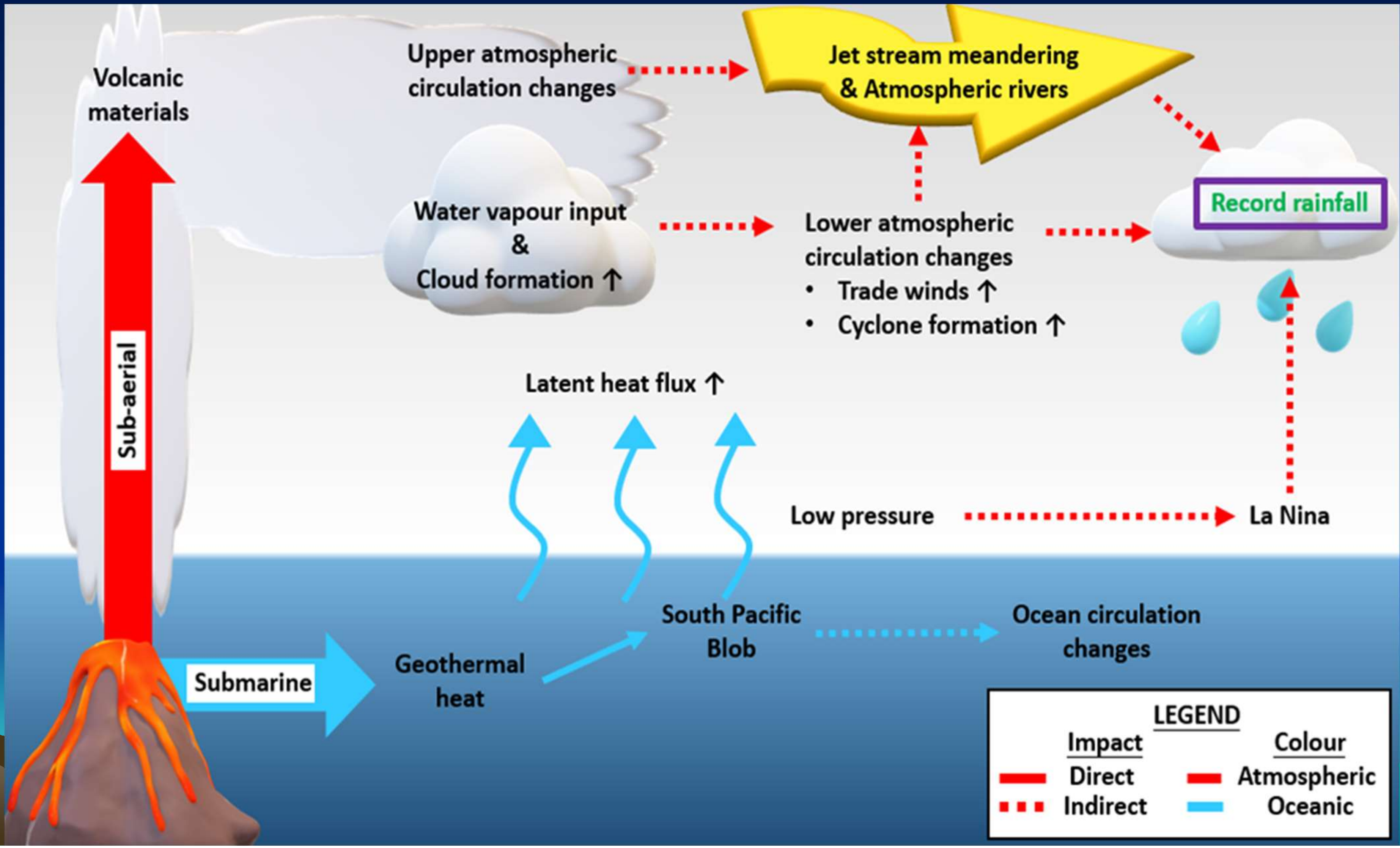
Source: NISDC.org

Arctic sea-ice changes 2007-2017

Explained by the release of geothermal heat through submarine volcanism

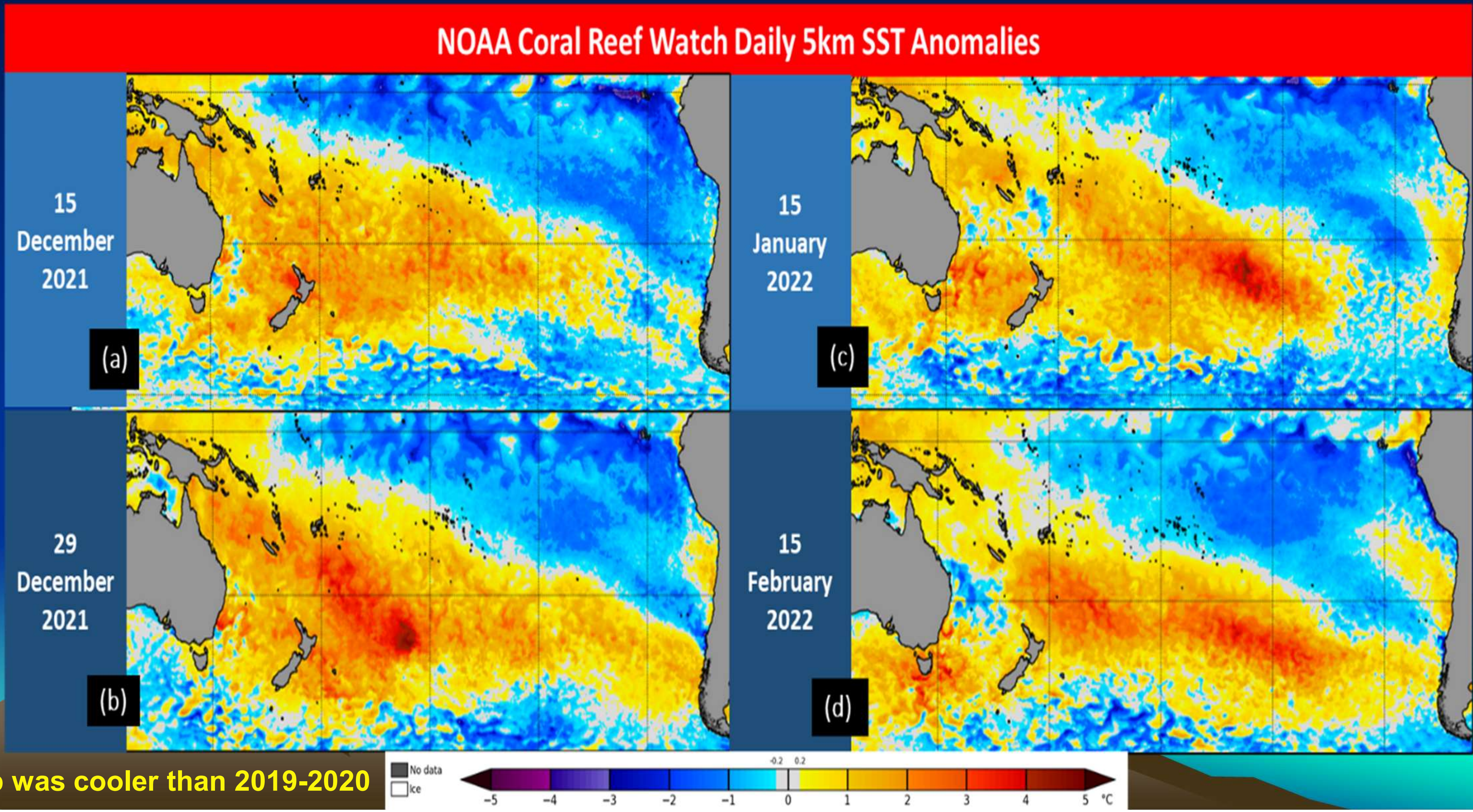


Simplified diagram of the 2021-2022 Tongan mixed eruption



South Pacific Blob "short" life span

Development stages of the 2021-2022 South Pacific Blob at fortnightly intervals

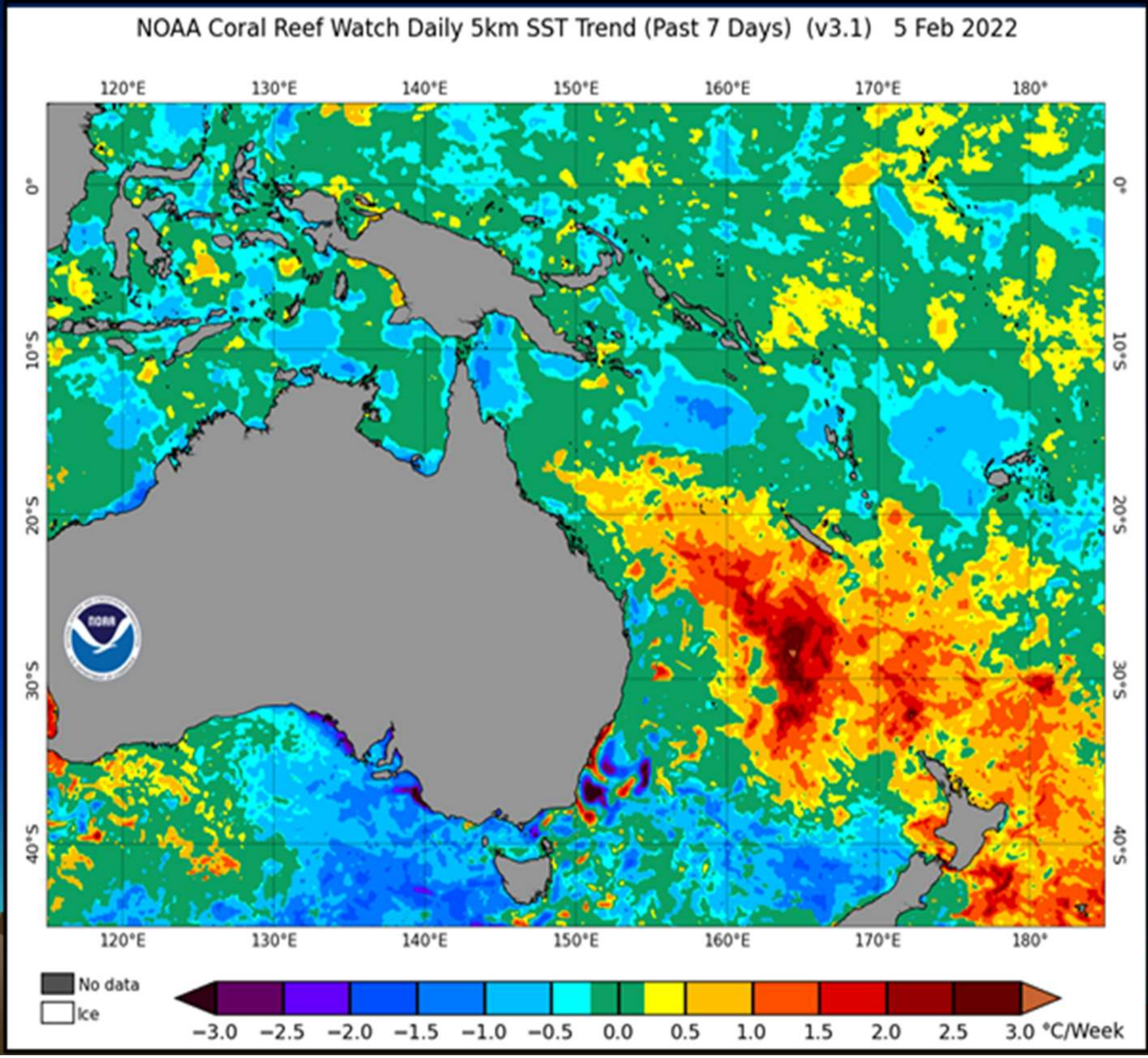


Blob was cooler than 2019-2020

The Tongan sub-aerial eruption on 15th January, 2022

Plume height 58 km shifted to cooling

2021-2022 South Pacific Blob during 30th January to 5th February



Hot blob > 2°C above normal maximum area 170,000 km^2 cooled after the sub-aerial eruption on 15th January

Factors contributing to record rainfall in eastern Australia / NZ after the 2021/2022 Tonga mixed eruption (Wong & Yim 2022 with modifications)

(1) The formation of a relatively short life span South Pacific Blob compared to the 2019-2020 South Pacific Blob.
(2) The transfer of large amounts of water vapour from the ocean into the atmosphere during the sub-aerial eruption on 15th January, 2022.
(3) The low pressure condition on the ocean surface.
(4) The formation of clouds and the provision of condensation nuclei.
(5) The reduction of solar radiation caused by gases and other volcanic materials entering the atmosphere.
(6) The strengthening of trade winds.
(7) The meandering of jet streams.
(8) The development of atmospheric rivers.
(9) The additional cooling caused by torrential rainfall.
(10) The switch to La Niña conditions.

Main conclusions

- Based on timing and observation records volcanic eruptions are an important regional driver of natural climate variability. Carbon dioxide identified by the IPCC for AGW cannot be the cause.

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

- Volcanic eruptions contributing 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.

- Polar sea-ice changes can be explained by ocean heatwaves caused by the release of geothermal heat through submarine volcanic eruptions.

- Climate modelling can be improved by taking 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 eruptions.

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

Terrestrial and submarine volcanic eruptions –
a natural experiment to learn from

May 23, 2006 Cleveland, Aleutian islands

NASA

The present assisted by observation records is a key to the past and the future

Thank you

Publications providing 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