

Volcanism generated ocean heat waves and biodiversity

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

Presentation to the Creative Society on April 30th, 2022

A stylized, low-poly silhouette of a mountain range in shades of brown and grey, spanning the width of the slide at the bottom.

Plan

Background information

Four regional examples of ocean heat waves studied –

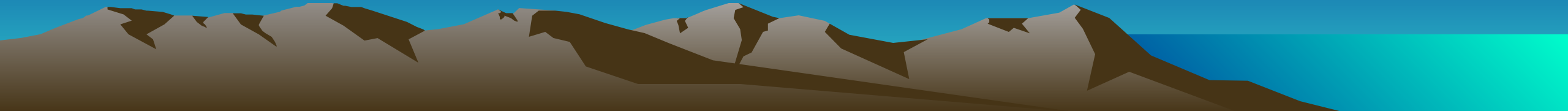
2012 North Atlantic Blob

2013-2016 North Pacific Blob

2018-2019 Southwest Indian Ocean Blob

2019-2020 South Pacific Blob

Conclusions



Possible factors controlling ocean heat waves?

Air circulation/pressure changes (heat redistribution)

Greenhouse gases mainly –

Carbon dioxide CO_2

Methane CH_4

Water vapour H_2O (most important)

Water/cloud/ice distribution

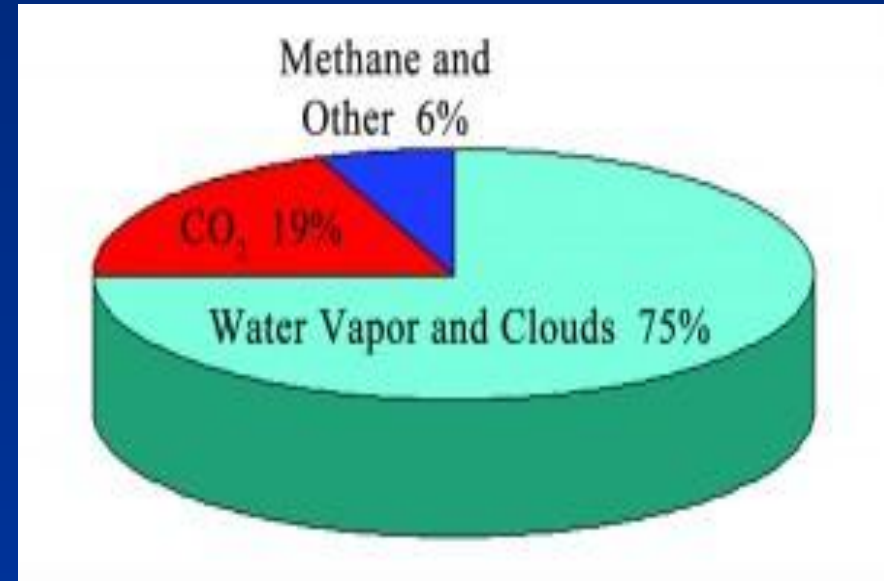
Vegetation distribution

Ocean circulation changes

Astronomical factors e.g. sun & orbital changes

Submarine volcanic eruptions/lava flows into oceans

Heat generation through human activities



What is the order of importance?

1st order

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

2nd order

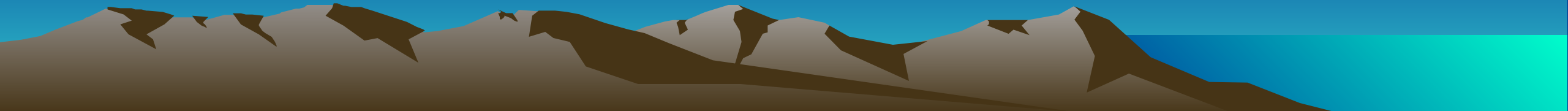
Volcanism generated geothermal heat/plate climatology

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

3rd order

Human-induced changes including urbanization, water cycle changes and emissions of greenhouse gases



Known regional climatic variability additional to monsoons

Physical Map of the World, June 2003

AUSTRIA
Germany
Italy / Austria
★
Scale 1:100,000,000
Reference: 1990
United Nations

Arctic Oscillation AO
Arctic Ocean pressure changes
High pressure + phase
Low pressure - phase

North Atlantic Oscillation NAO
Iceland/Azores pressure difference
Iceland high pressure + phase
Iceland low pressure - phase

Madden-Julian Oscillation MJO
Intraseasonal variability of tropical atmosphere 30-90 days

Atlantic Multidecadal Oscillation AMO
Sea-surface temperature variability

Pacific Decadal Oscillation PDO
East and west Pacific Ocean surface water temperature difference
West Pacific cools + phase
West Pacific warms - phase

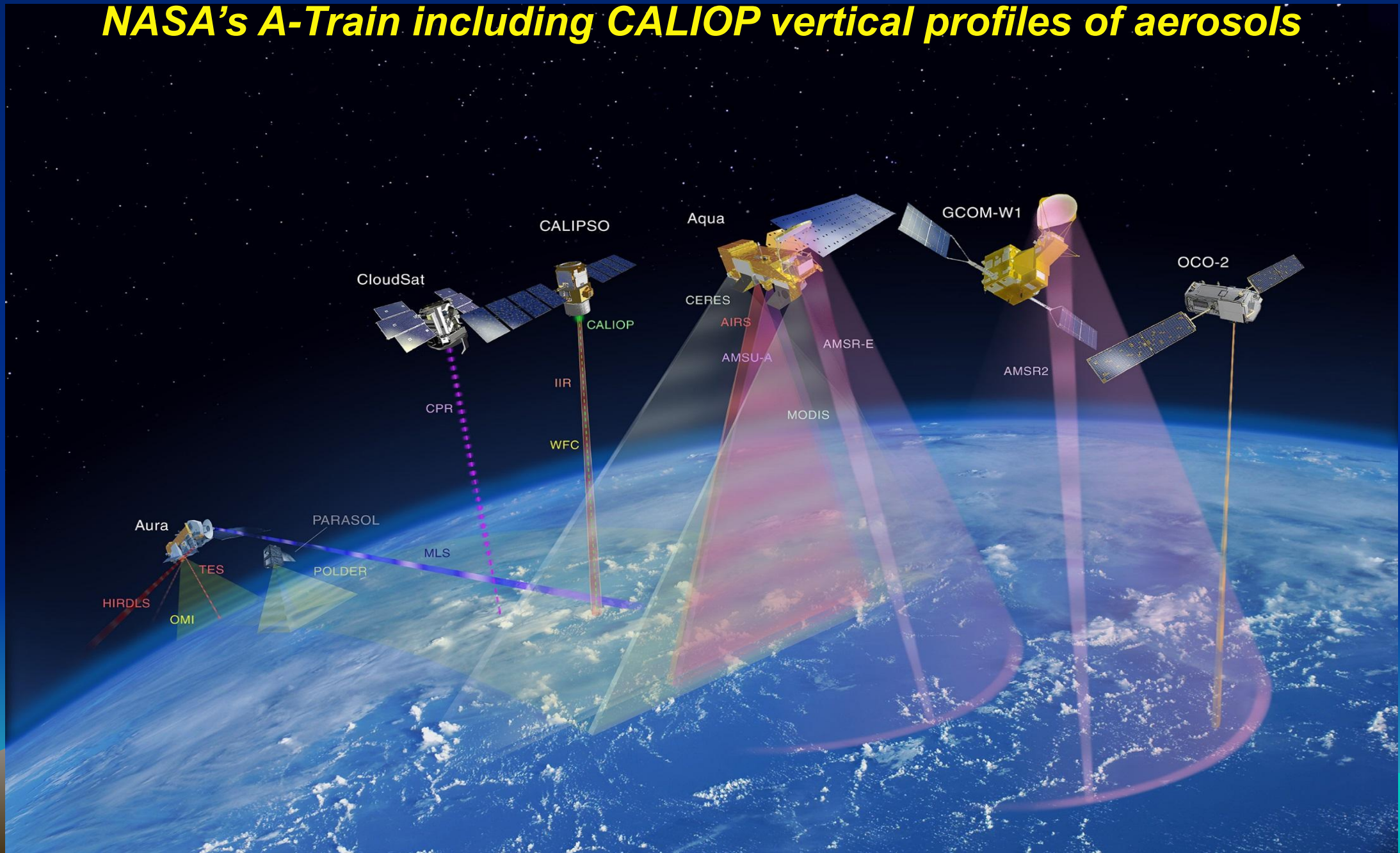
Quasi-Biennial Oscillation QBO
Change in equatorial zonal wind between easterlies and westerlies 28-29 months

Indian Ocean Dipole IOD
East and west Indian Ocean surface water temperature difference
West Indian Ocean warms + phase
West Indian Ocean cools - phase

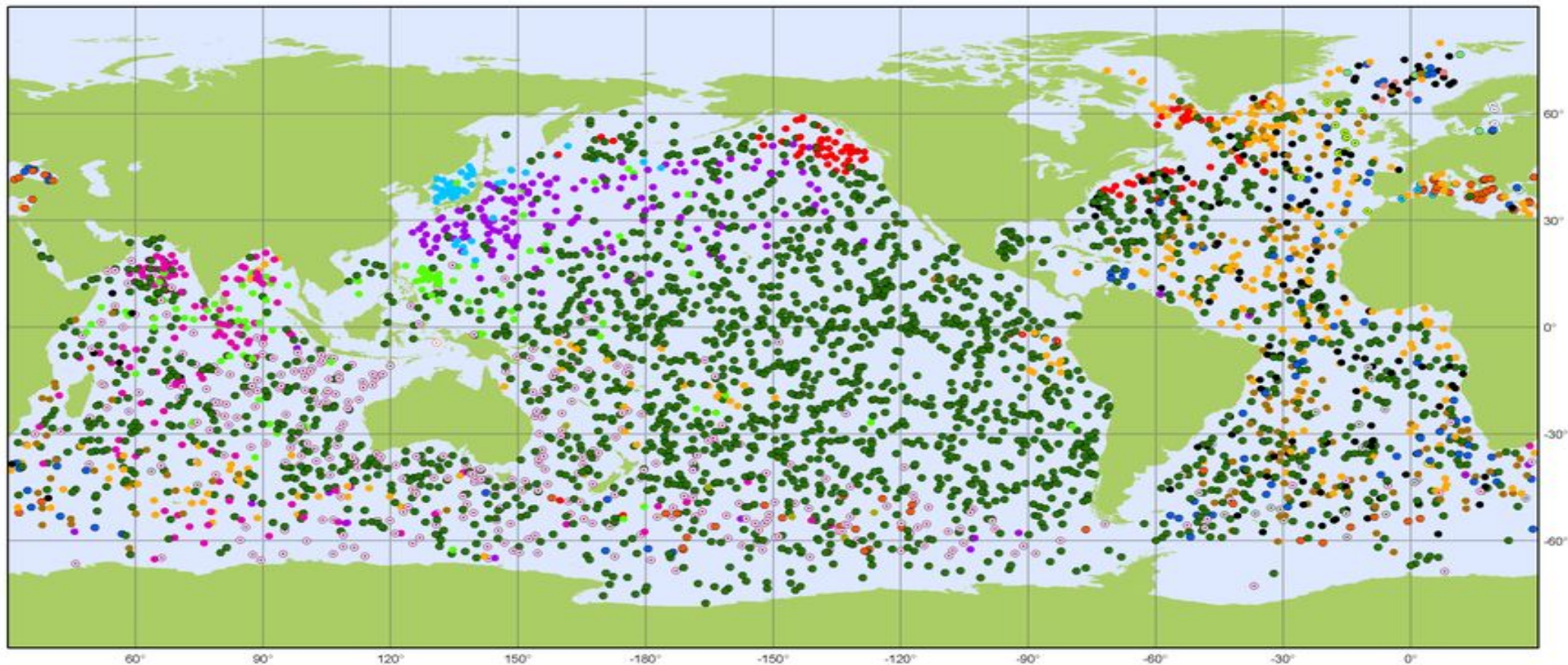
Southern Annular Mode SAM
Mid /high latitudes, Antarctic pressure changes caused by ozone hole
Antarctic low pressure + phase
Antarctic high pressure - phase

Satellite observations since the late 1970s

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



ARGO ocean network of operational floats since early 2000s



Argo

National contributions - 3881 Operational Floats

February 2018

Latest location of operational floats (data distributed within the last 30 days)

● ARGENTINA (1)	● EUROPE (94)	● INDIA (124)	● KENYA (1)	● PERU (3)	● USA (2179)
● AUSTRALIA (361)	● FINLAND (3)	● INDONESIA (1)	● MEXICO (2)	● POLAND (5)	
● BRAZIL (3)	● FRANCE (277)	● IRELAND (12)	● NETHERLANDS (24)	● KOREA, REPUBLIC OF (53)	
● CANADA (87)	● GERMANY (142)	● ITALY (65)	● NEW ZEALAND (6)	● SPAIN (5)	
● CHINA (105)	● GREECE (2)	● JAPAN (156)	● NORWAY (7)	● UK (163)	

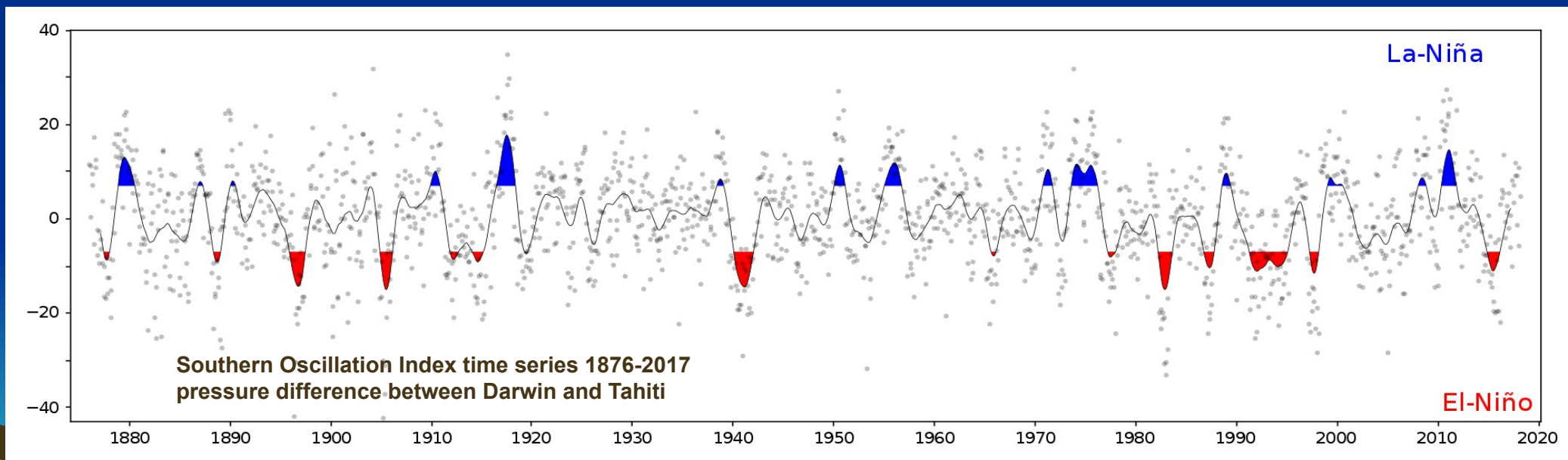


What is ENSO?

El Niño Southern Oscillation

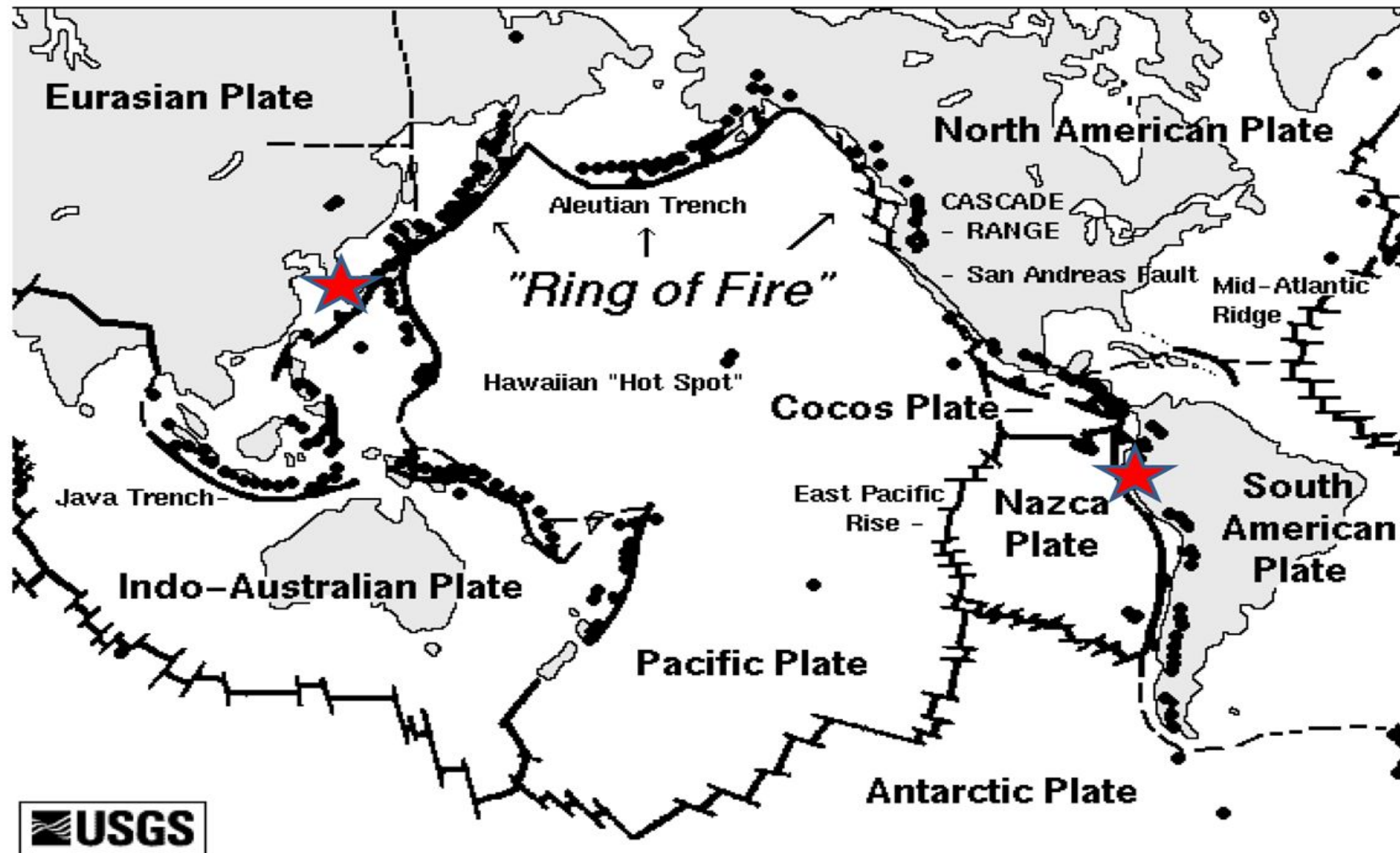
Note – Pre-industrial era existence shown by coral archives.

An irregularly periodic variation in winds and sea surface temperatures over the tropical eastern Pacific Ocean, affecting the climate of much of the tropics and subtropics. The warming phase of the sea temperature is known as *El Niño* and the cooling phase as *La Niña*. The *Southern Oscillation* is the accompanying atmospheric component, coupled with the sea temperature change: *El Niño* is accompanied by high air surface pressure in the tropical western Pacific and *La Niña* with low air surface pressure there.



Source: Wiki

Why ENSOs occur 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.

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

Thermal plume



El Chichón, Mexico 1982

Circled the globe in 21 days

USGS

**Eruption
changes
normal air
circulation /
creates clouds
/ destroys O_3**

**SO_2 , HCl
 CO_2 & H_2O
degassing**

**Cool air
stores less
moisture**

Cooler air

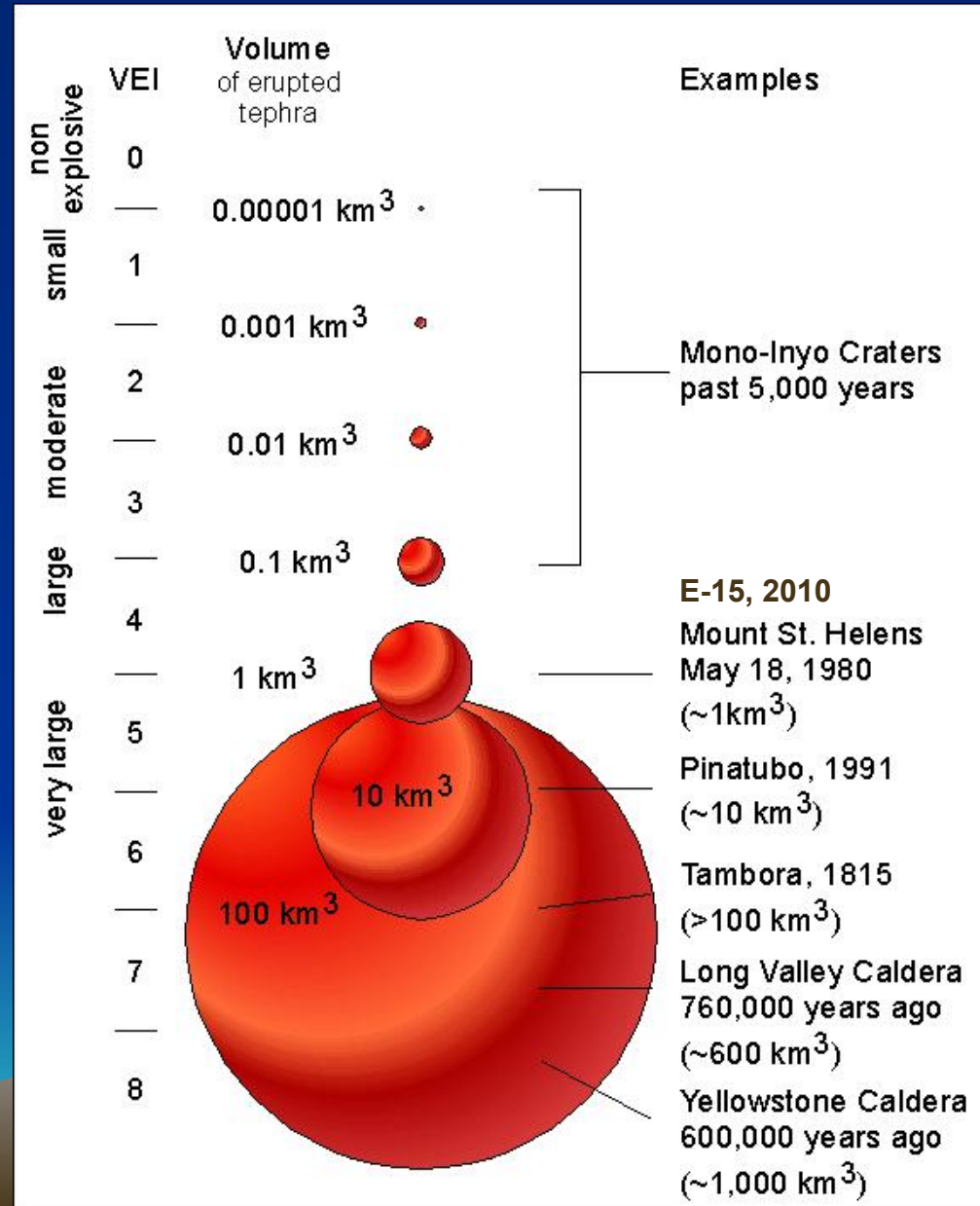
**Impact longer
lasting if
higher VEI**

Volcanic Explosivity Index (VEI)

Used for the estimation of explosiveness of volcanic eruptions on land (subaerial)

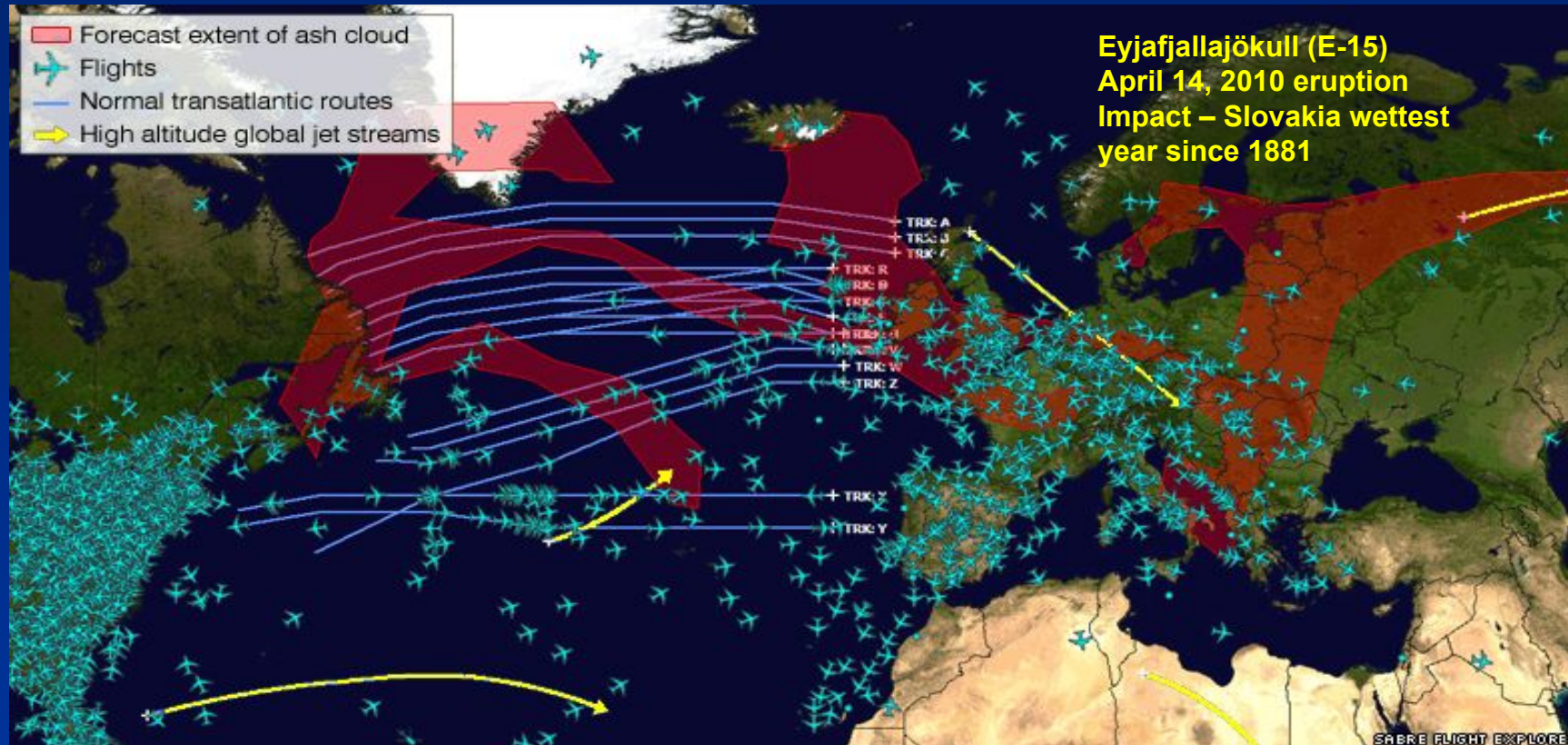
(Newhall and Self 1982)

Acid magma most explosive



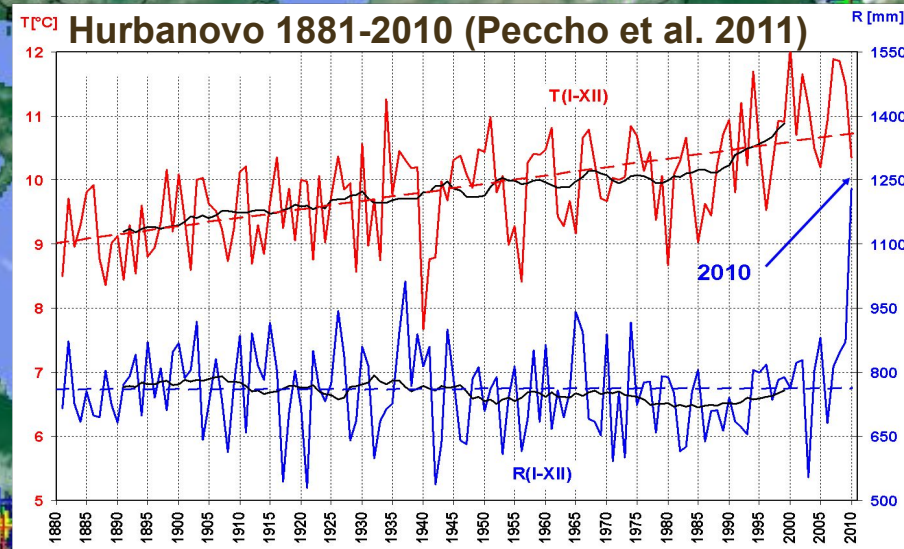
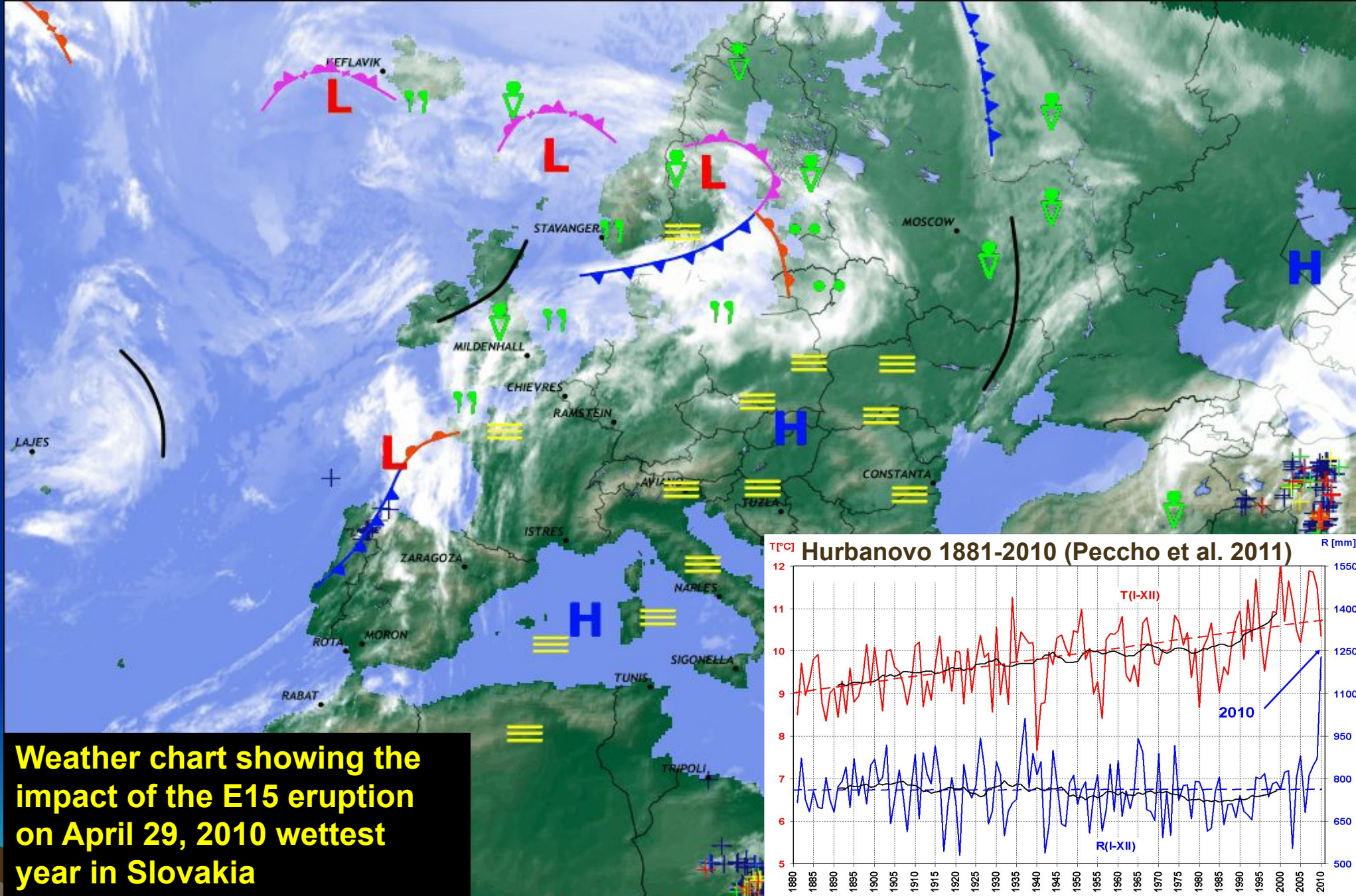
Above VEI 2 regional impacts on weather already detectable

Why study the present day? e.g. Iceland 2010 event



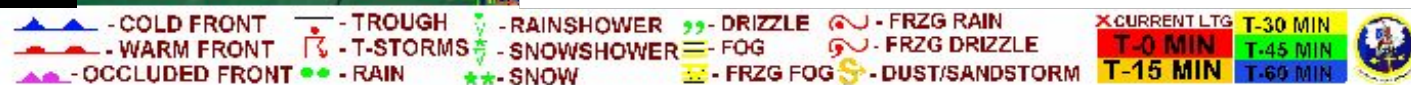
Most reliable record – Information age
Importance – societal e.g.
farming, climate model testing

(Meteorological observations
(Satellite observations since ~1980
(Weather disaster media reports
(Aviation safety studies

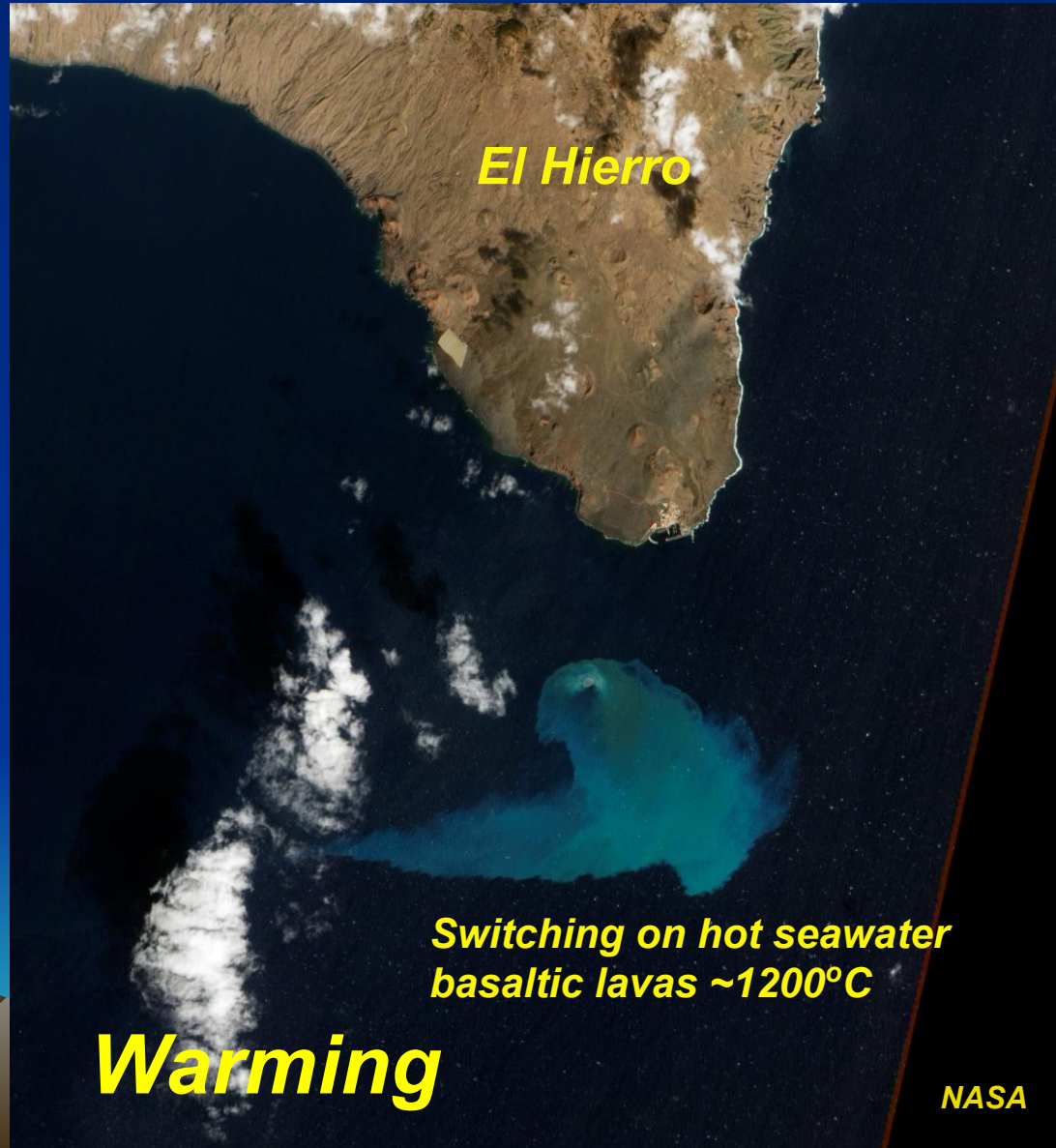


SATELLITE ANALYSIS

VT: 29 APR 03Z POSTED AT: 29/0326Z



Submarine volcano model



Examples –

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

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

Off Mayotte 11/2018-4/2019

Possible effects –

Heating up seawater

Pressure changes

Surface wind changes

Sea-level changes

Ocean current changes

Polar sea ice changes

Biodiversity 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 –

Geothermal heat is released during eruptions changing the ‘normal’ ocean circulation

Known for volcanic ecosystems



El Hierro submarine eruption, Canary Islands

October 2011-March 2012

- The discoloured water was at least 20-30 km wide and 100 km long
- Spread southward

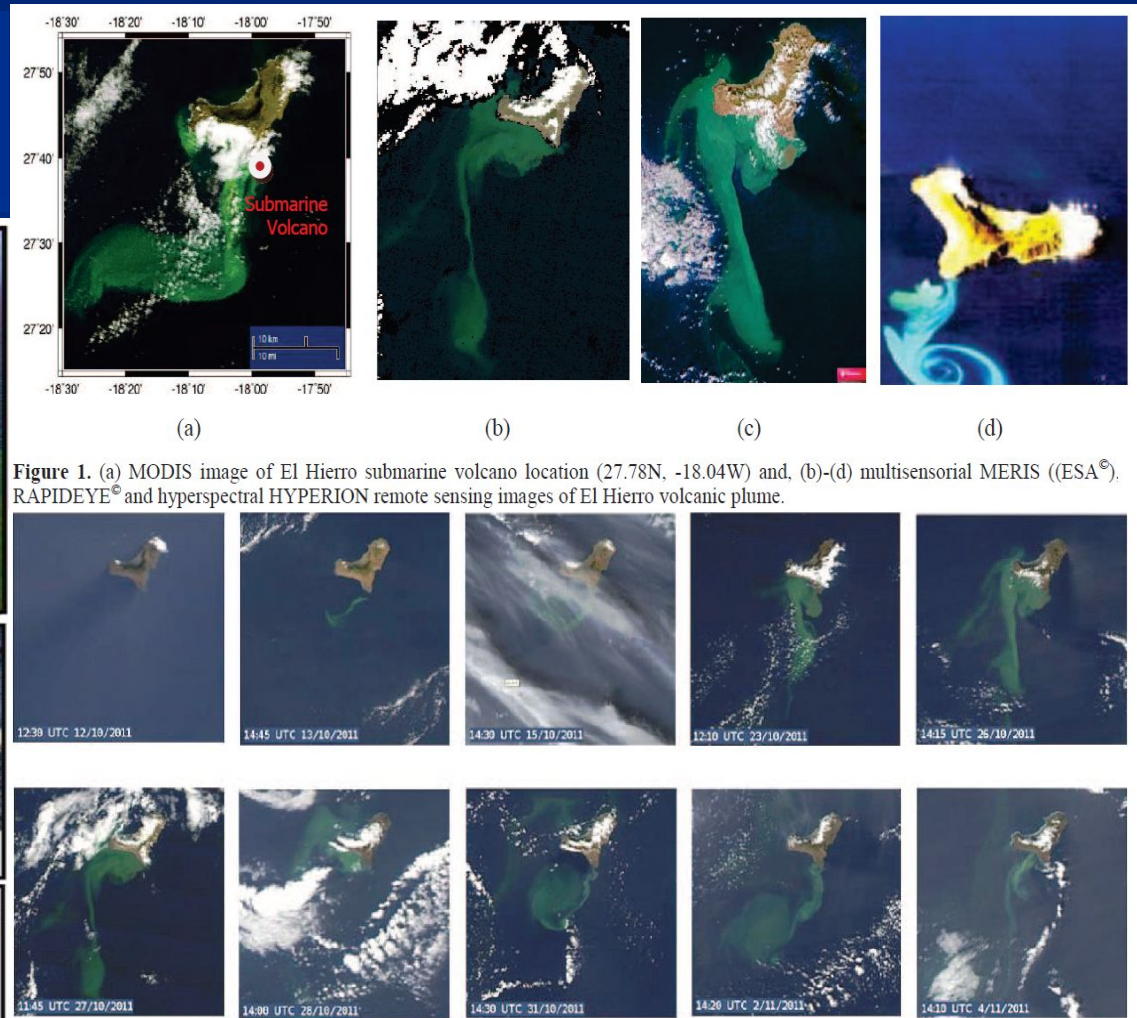
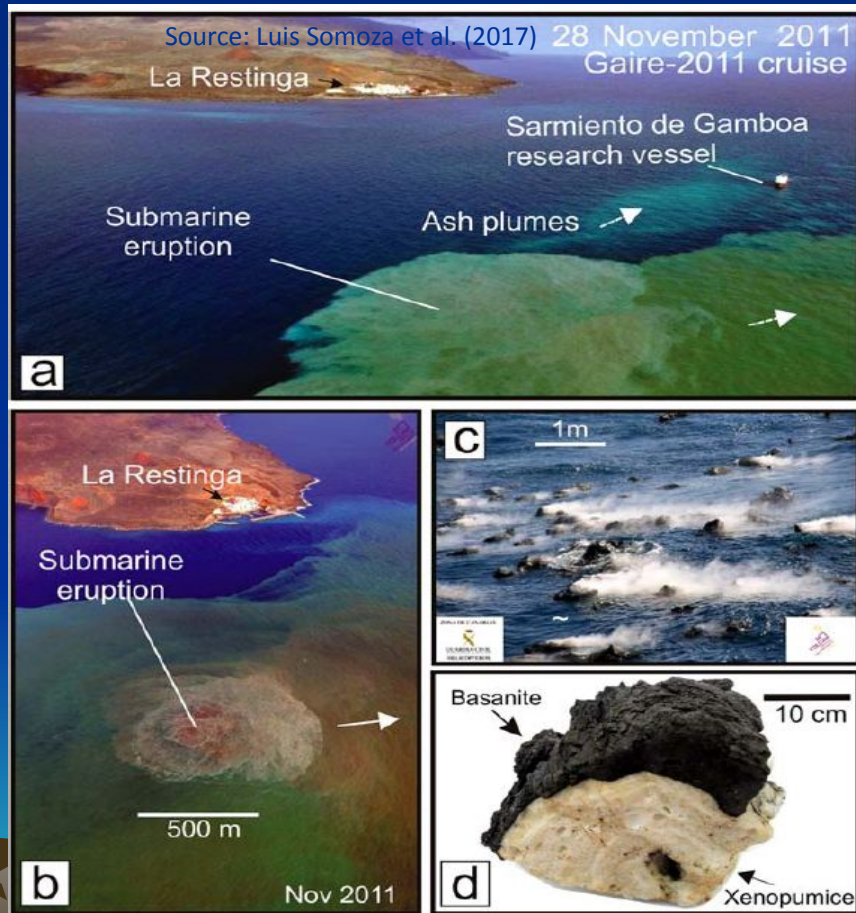


Figure 2. NASA MODIS RGB multitemporal images monitoring El Hierro submarine volcano.

Source: Eugenio et al. (2014)

What was the observed impact of the hot seawater in the North Atlantic Basin overlooked by atmospheric scientists?

Brownish plume created

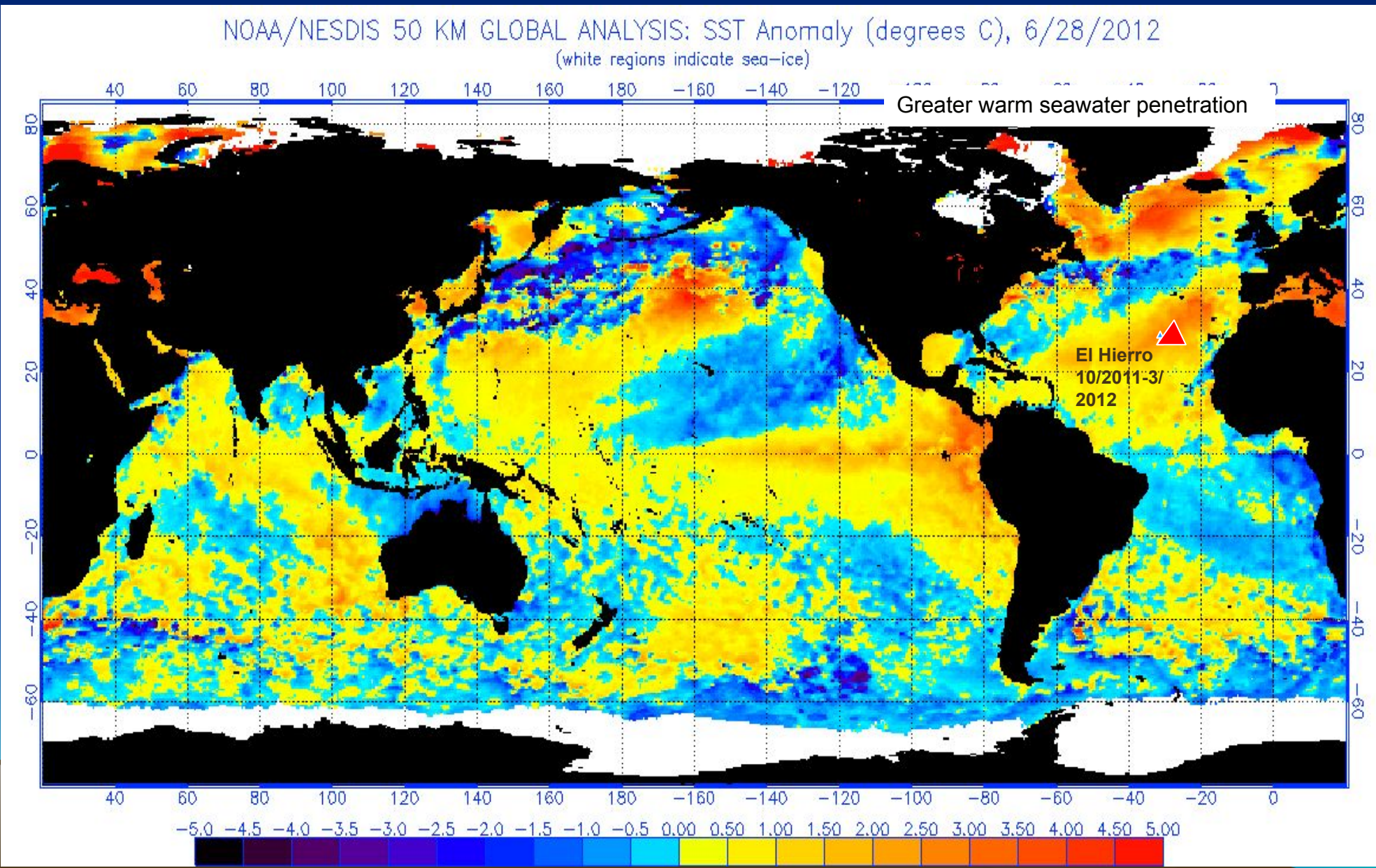


Source: Daily Mail



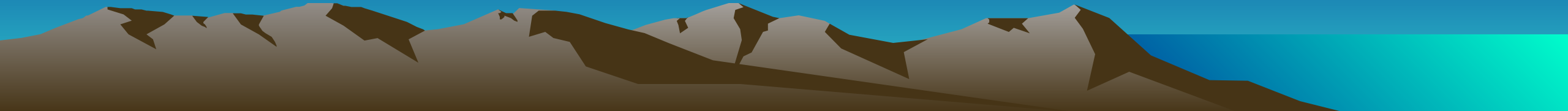
**A new island emerged briefly from the sea
along the coast of Restinga, Canary Islands**

North Atlantic Blob – combined effect of the Sun and El Hierro on SST on 28 June 2012

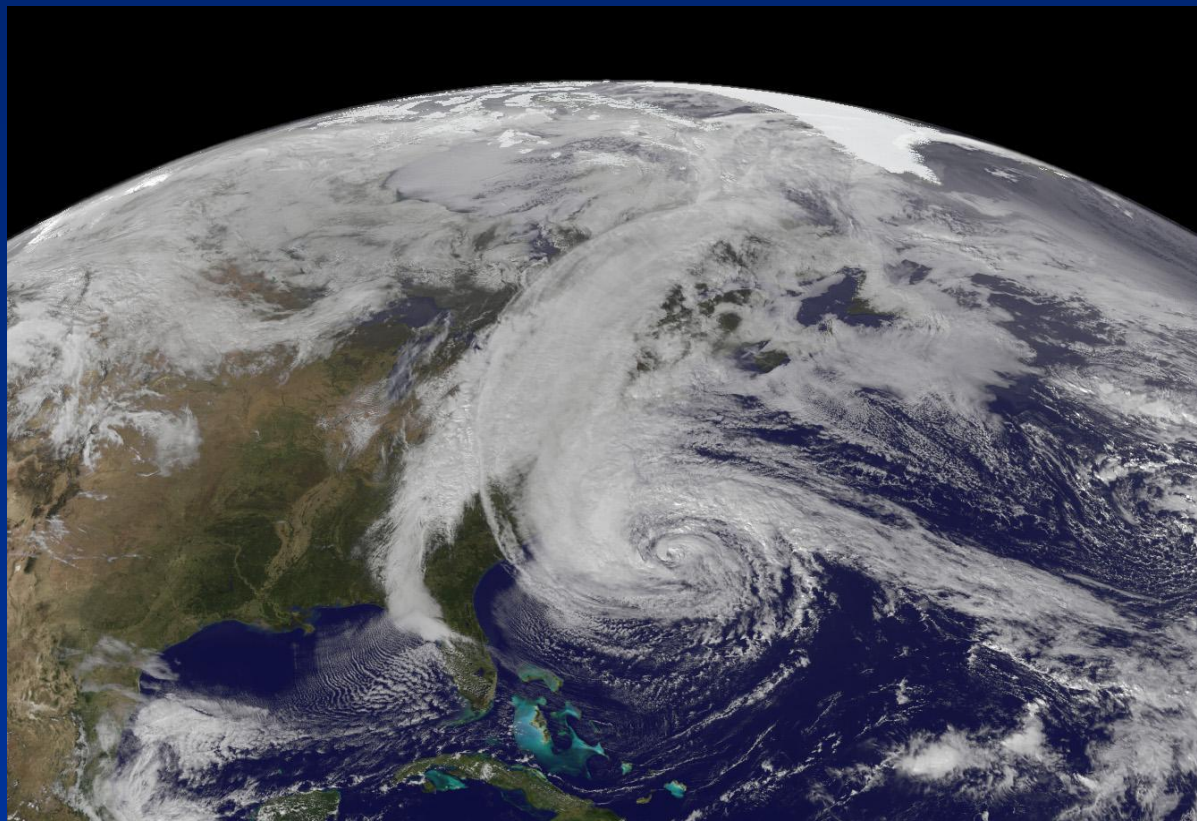


Weather-related events or pattern in the North Atlantic Basin during 2012

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

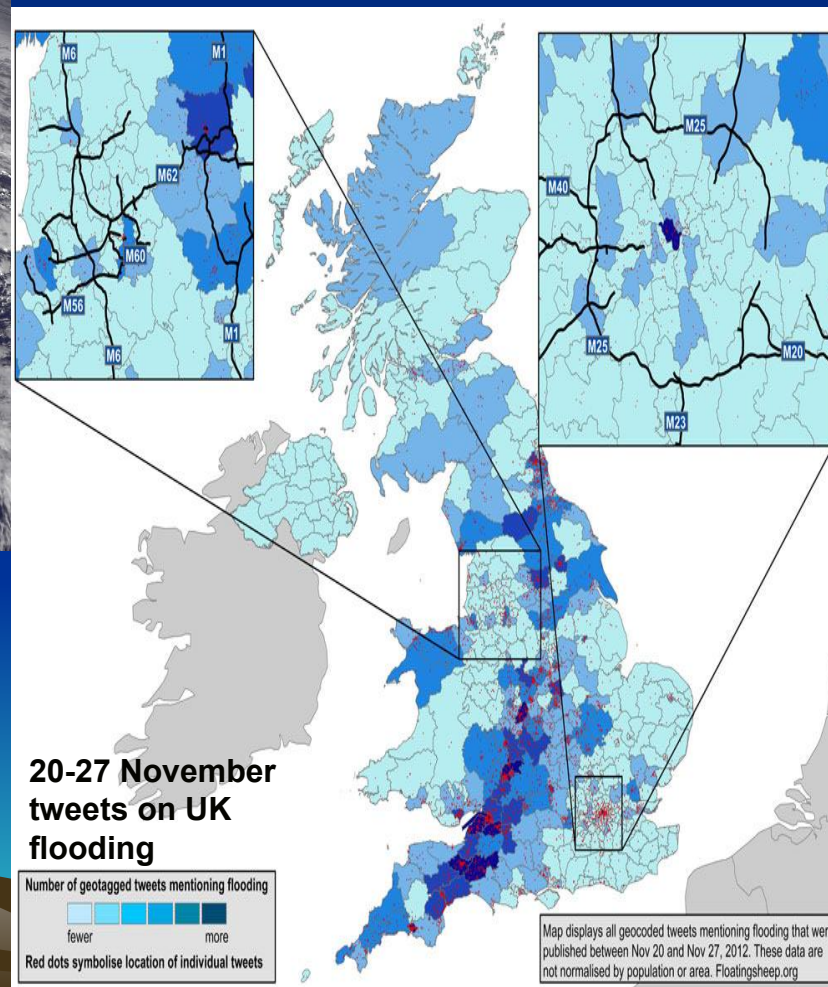


Notable severe weather events in 2012



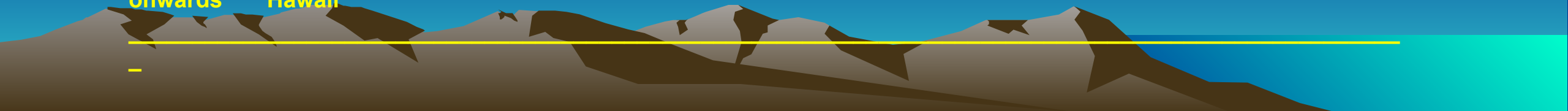
Hurricane Sandy October 2012
147 fatalities; estimated damage US\$65 billion

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

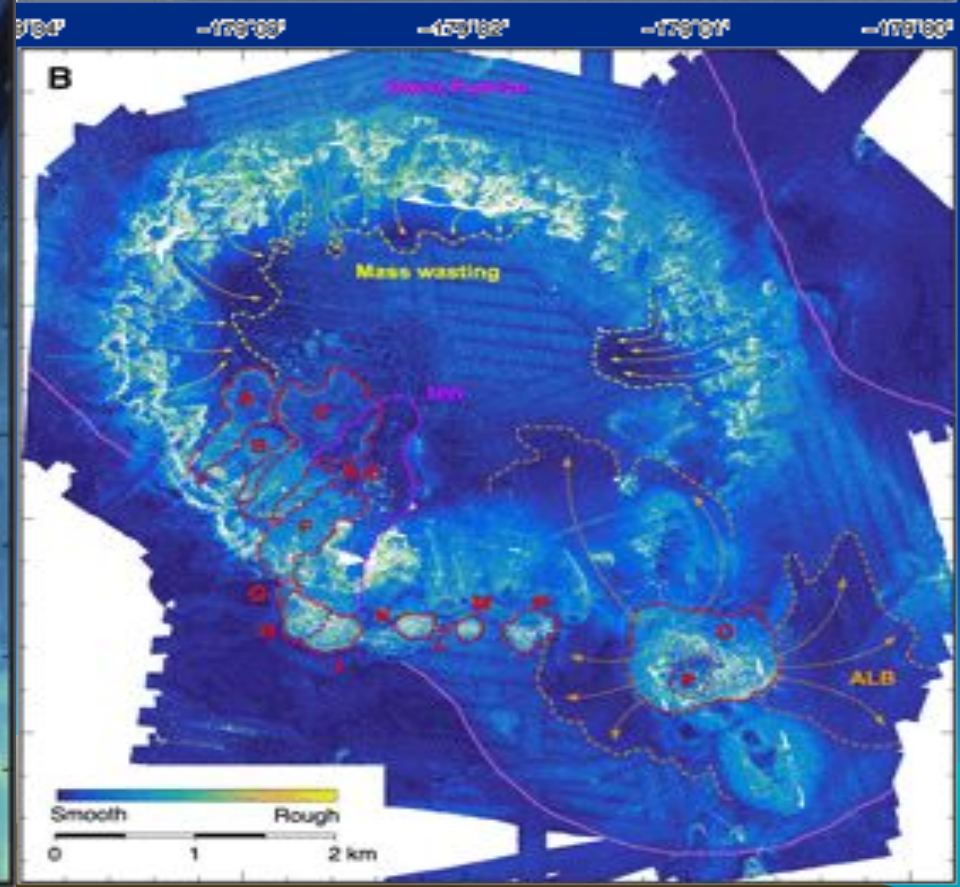
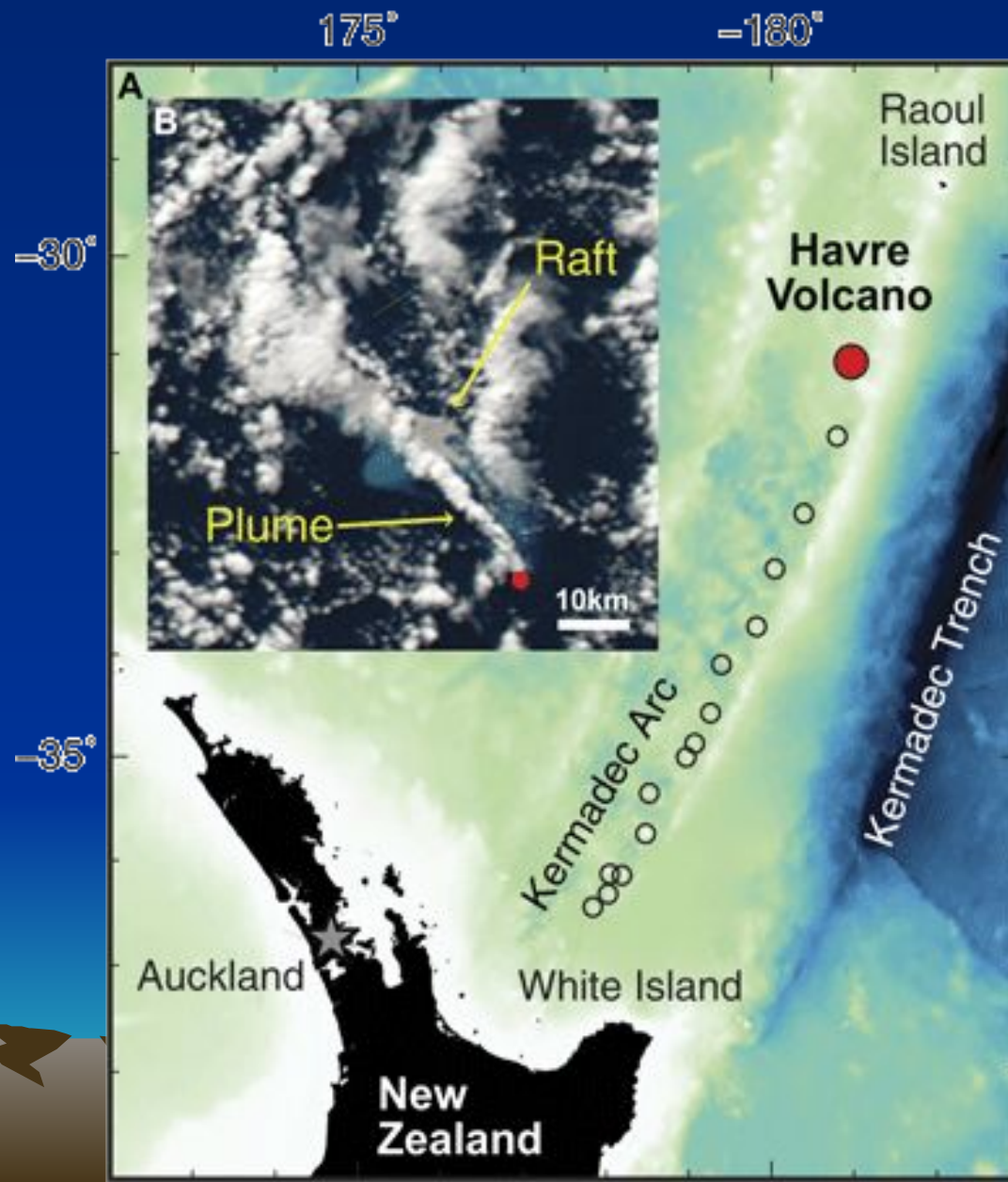


2012-2016 volcanic eruptions in the Pacific

Date	Volcano	Activity
<hr/>		
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, 940 km 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
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



Havre July 18-19, 2012 - largest silicic submarine eruption of the past century 14 vents 900 to 1220 m depth (Carey et al. 2018)



Nishino-shima submarine/terrestrial eruption

940 km south of Tokyo

March 2013 to August 2015

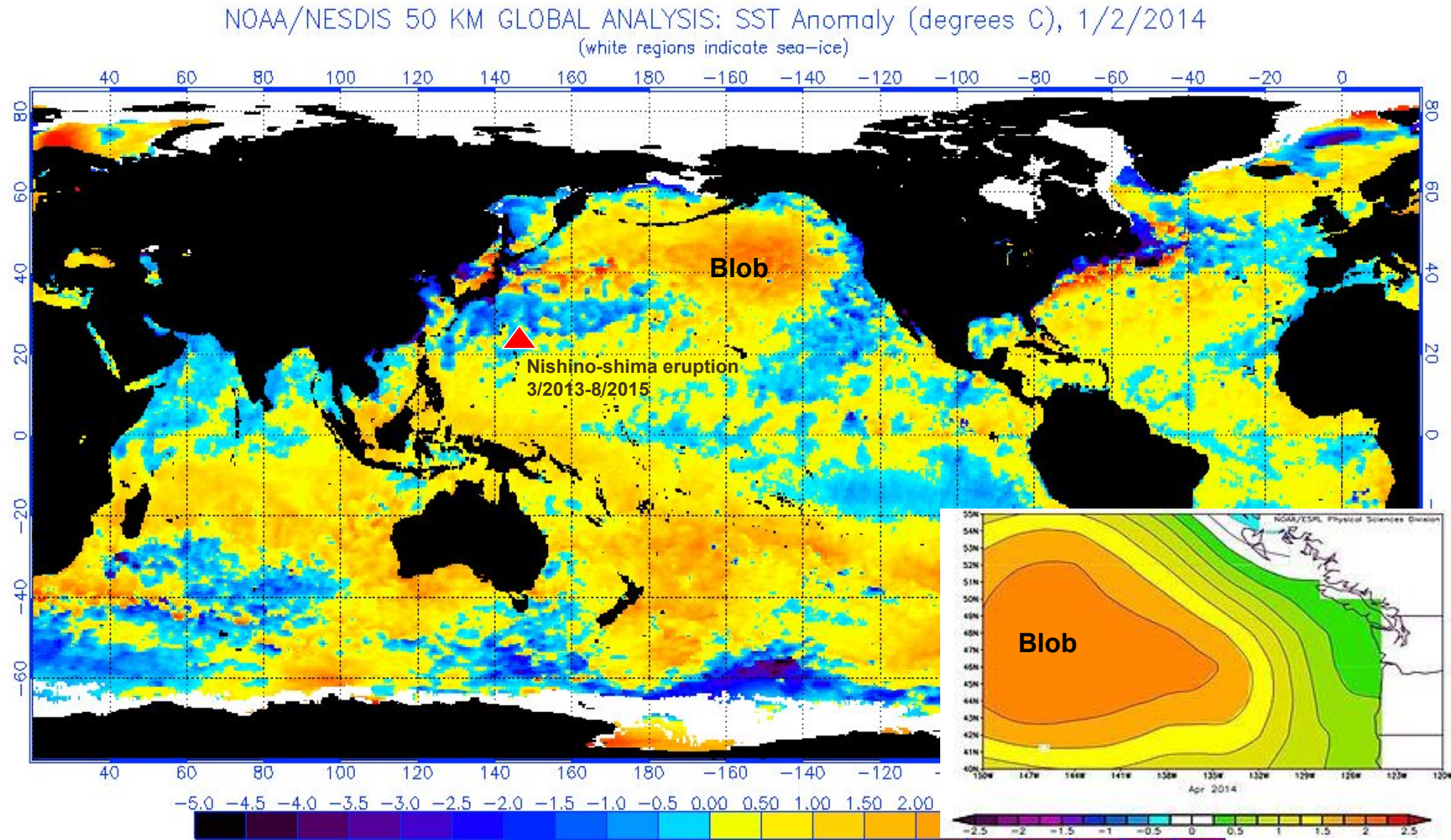


Image on November 13, 2013: Japan Coast Guard
Submarine eruption began in March 2013



Image on December 8, 2013: NASA

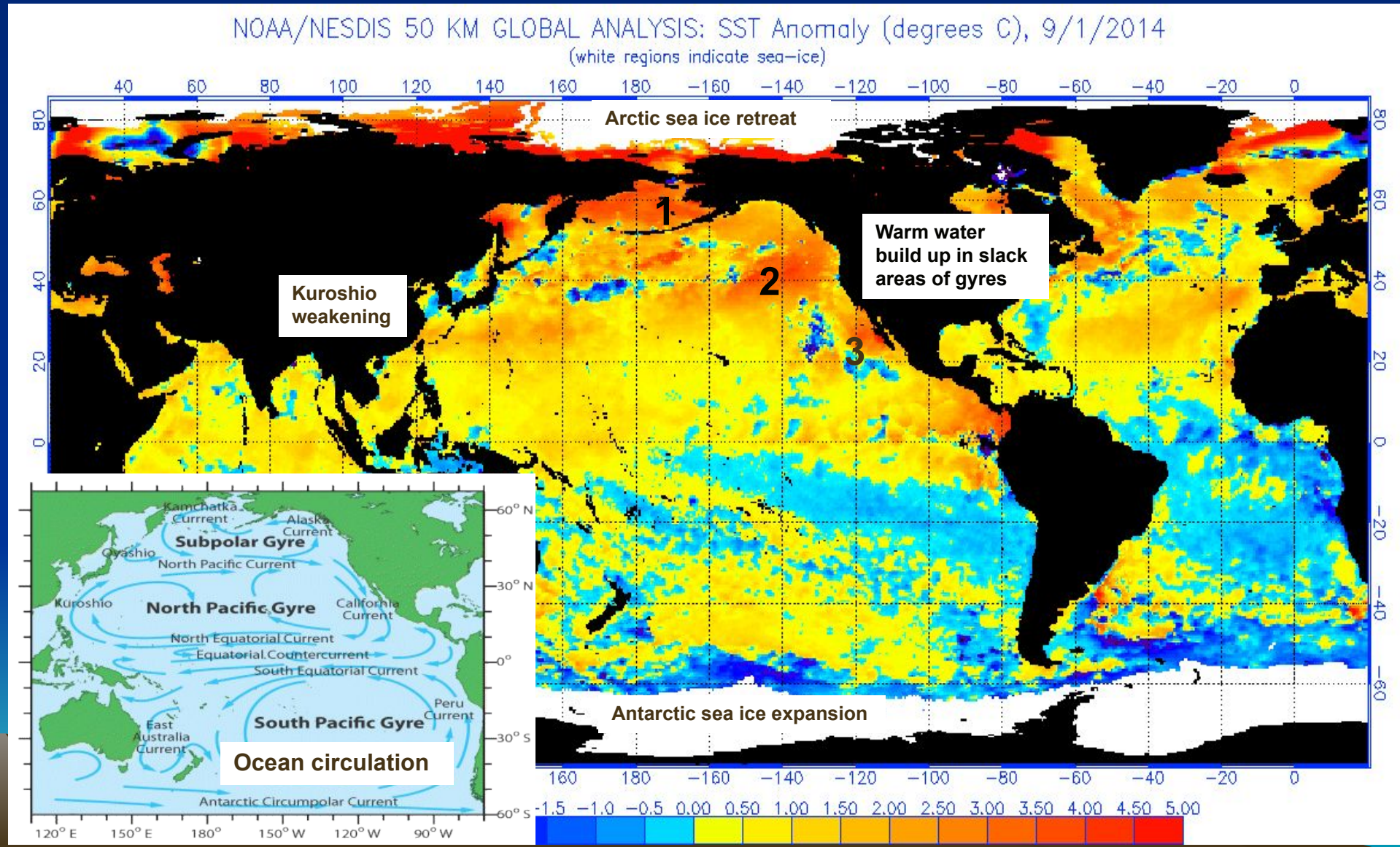
Main trigger of 2014-2016 ENSO sea-surface temperature anomalies created the North Pacific Blob on January 2, 2014



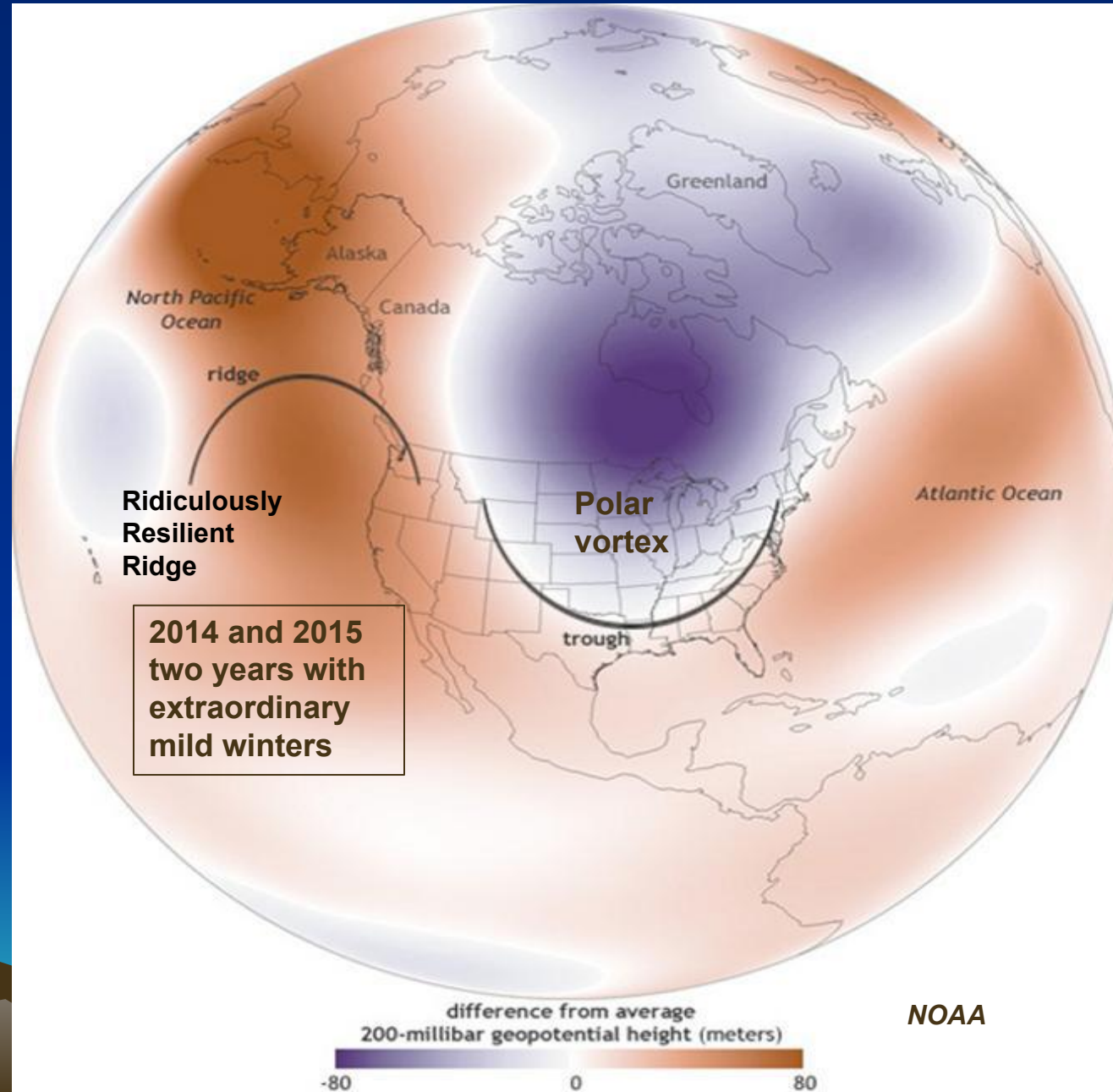
Events linking the Blob to the Nishino-shima eruption

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°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 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

The Blob separated into three parts on September 1, 2014



Pressure distribution during the North Pacific Blob



Heat wave

**National Geographic
September 2016**



Dead sea lion



Dying sea otter



Starving sea lion pups



Mass mortality of sea otters



Carcass of orca

**Food pattern change
for octopus**



Dying eel



Spawning squids off Alaska



Mass mortality of crabs



Beached sperm whale



Jellyfish mass mortality



Humpback whale in Monterey Bay



Sunfish migration



Ecosystem changes

Warm seawater much less nutrient rich than cold seawater

Impacts –

Reduction in coastal upwelling

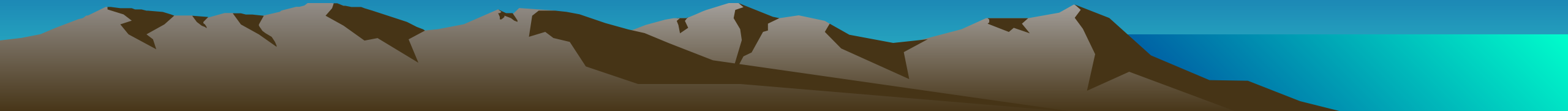
Reduction in phytoplankton productivity with knock on effects on zooplankton

Food chain effect

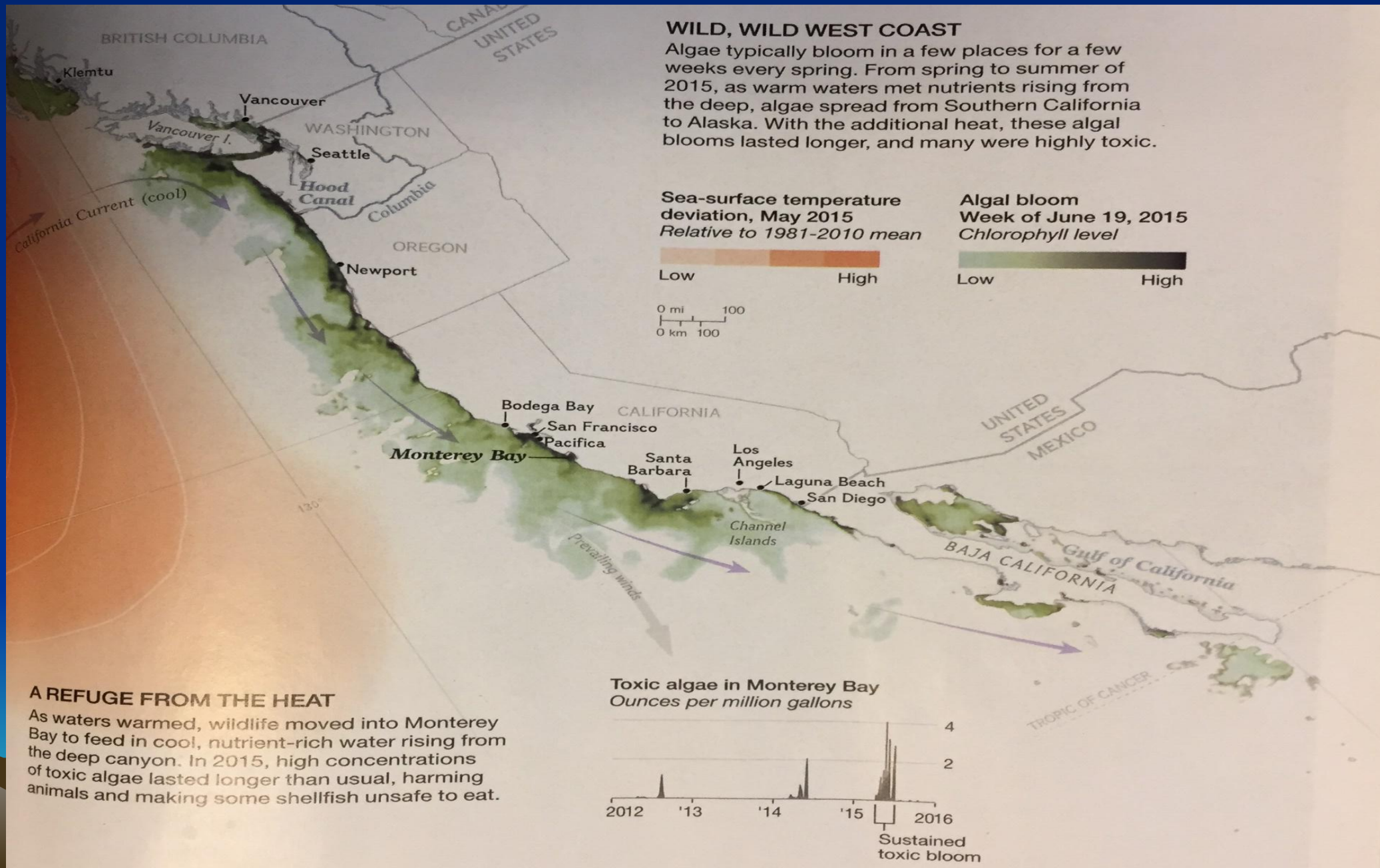
Salmon catches dropped drastically

Death of almost 1 million birds between summer 2015 to Spring 2016 (reported by the Guardian on January 16, 2020)

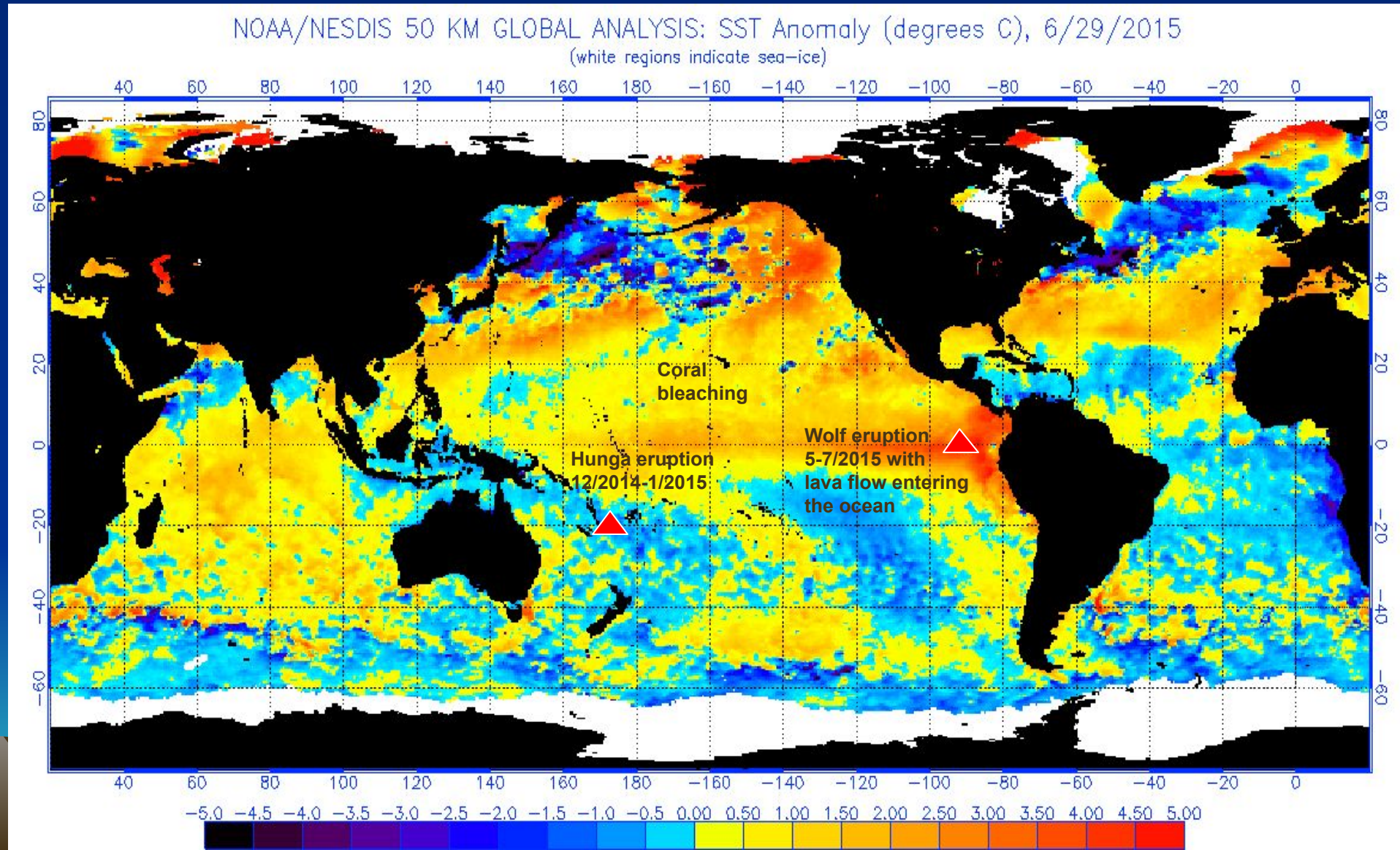
Tropical organisms including squids migrated to Alaskan coast



Toxic algal bloom along the west coast of North America



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



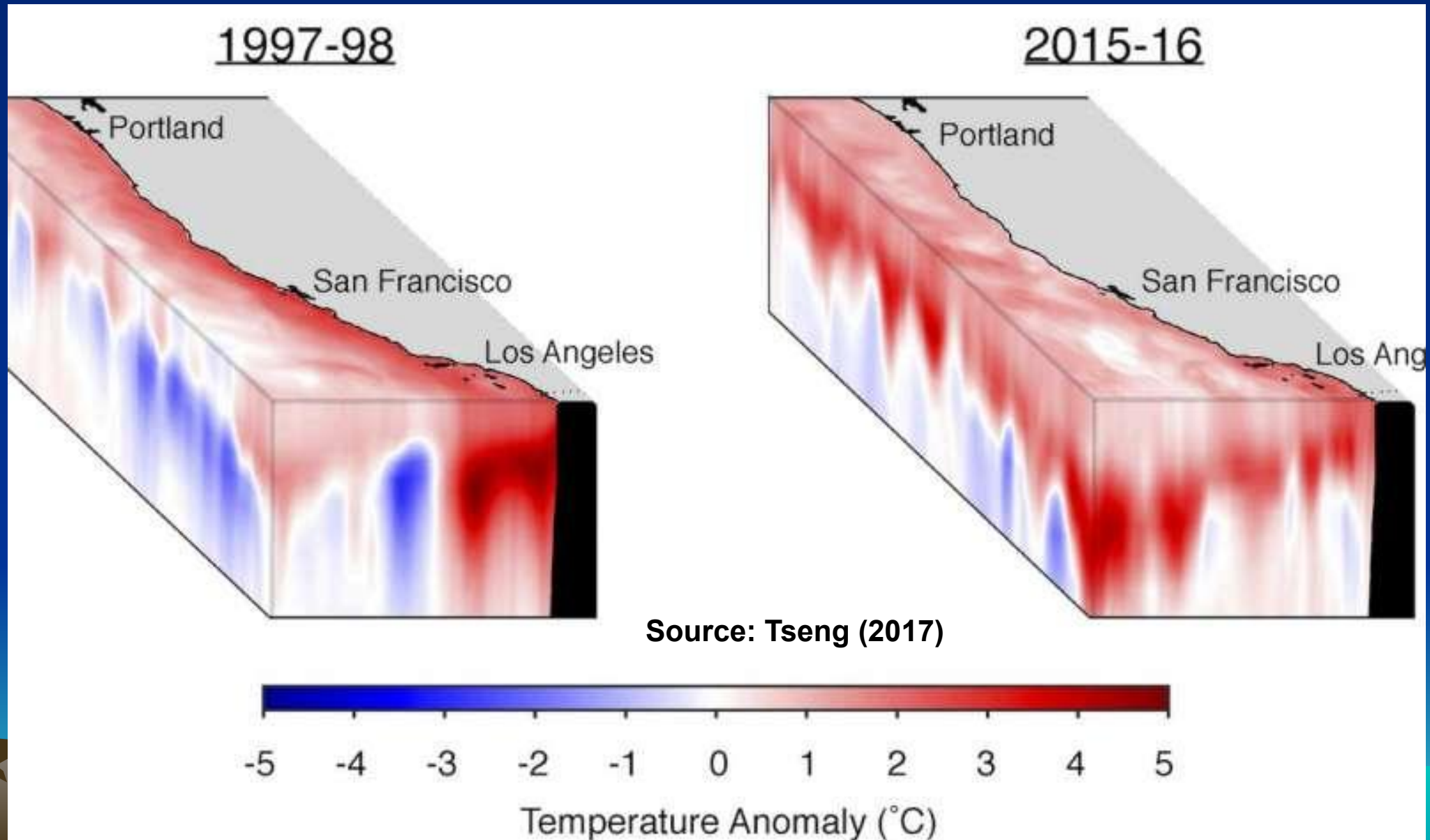
A natural cause of Great Barrier Reef coral bleaching in January 2015



Note - Rise in ocean acidity caused by SO_2 degassing may also be at work.

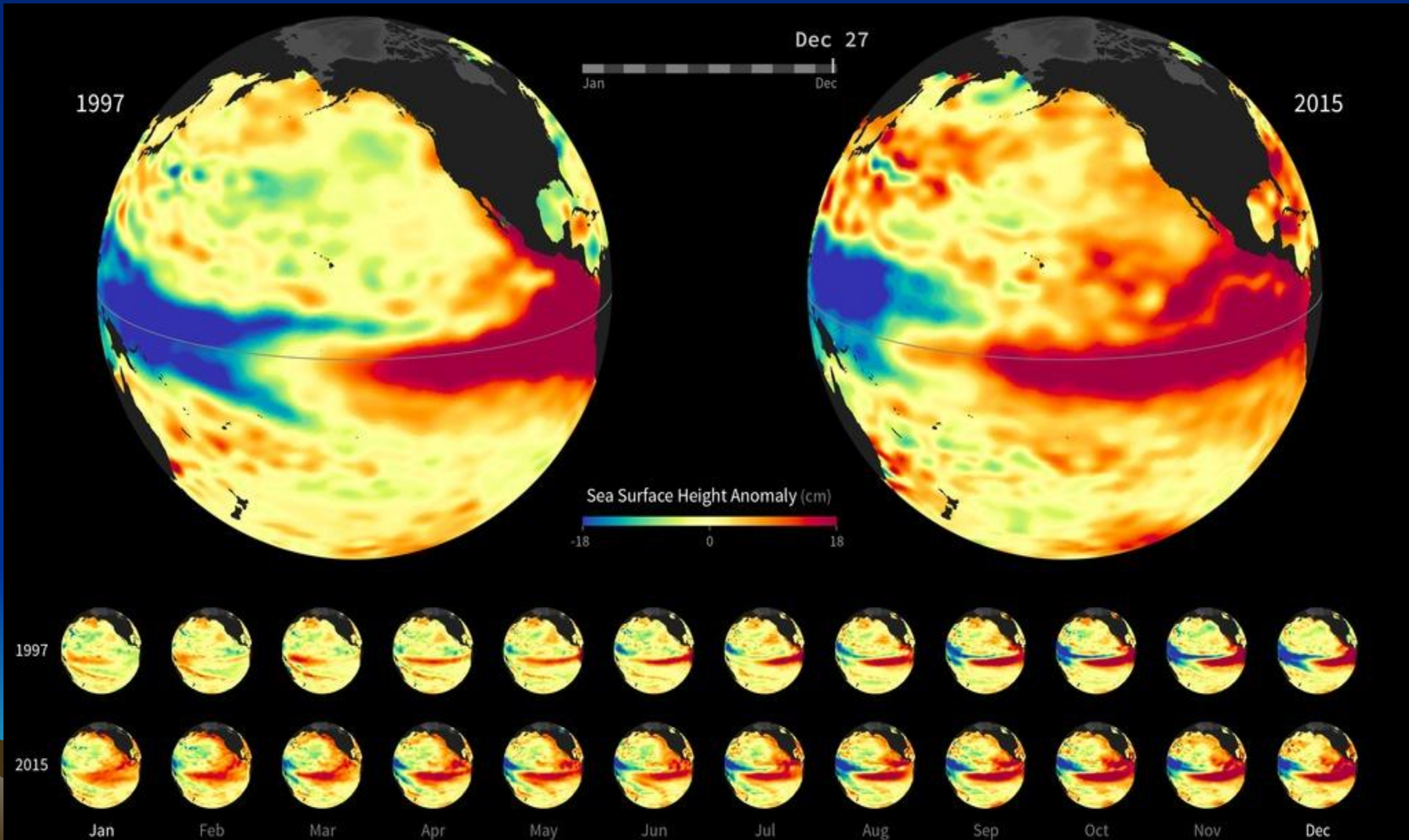
ENSO 2014-2016 was stronger because of the Blob

comparison of seawater temperature anomaly US west coast

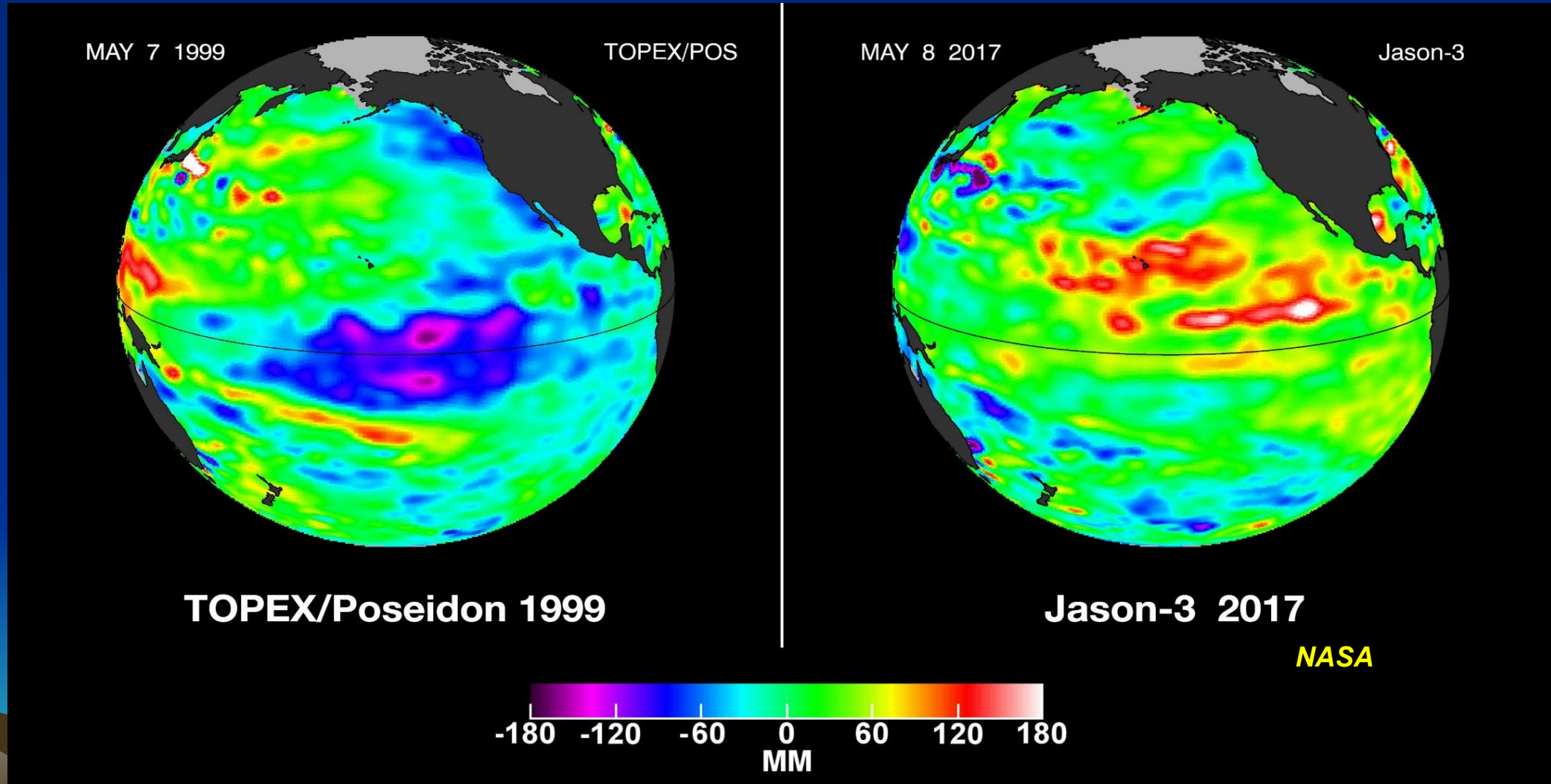


Comparison of sea-level anomaly 1997 and 2015

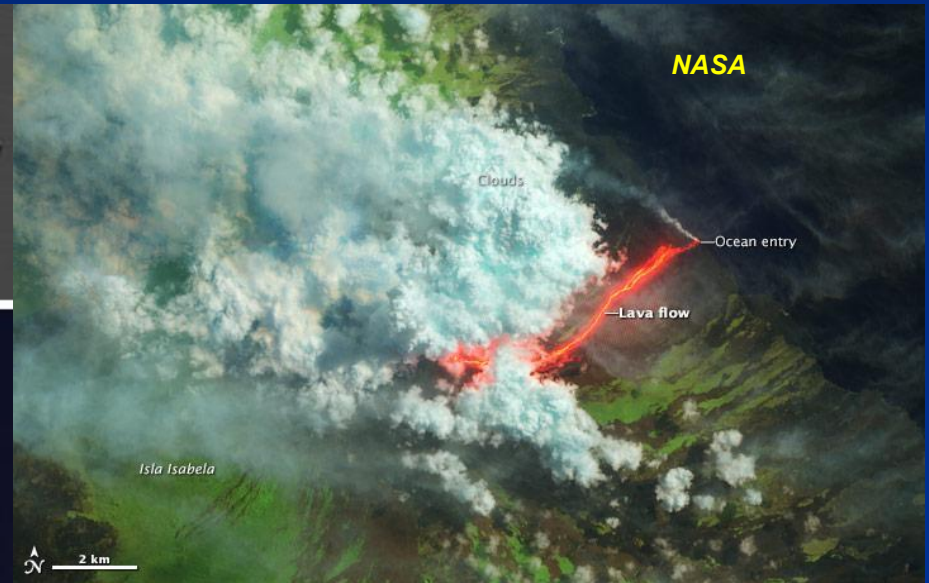
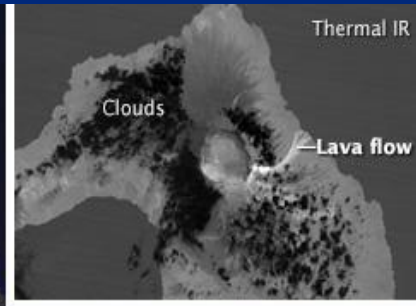
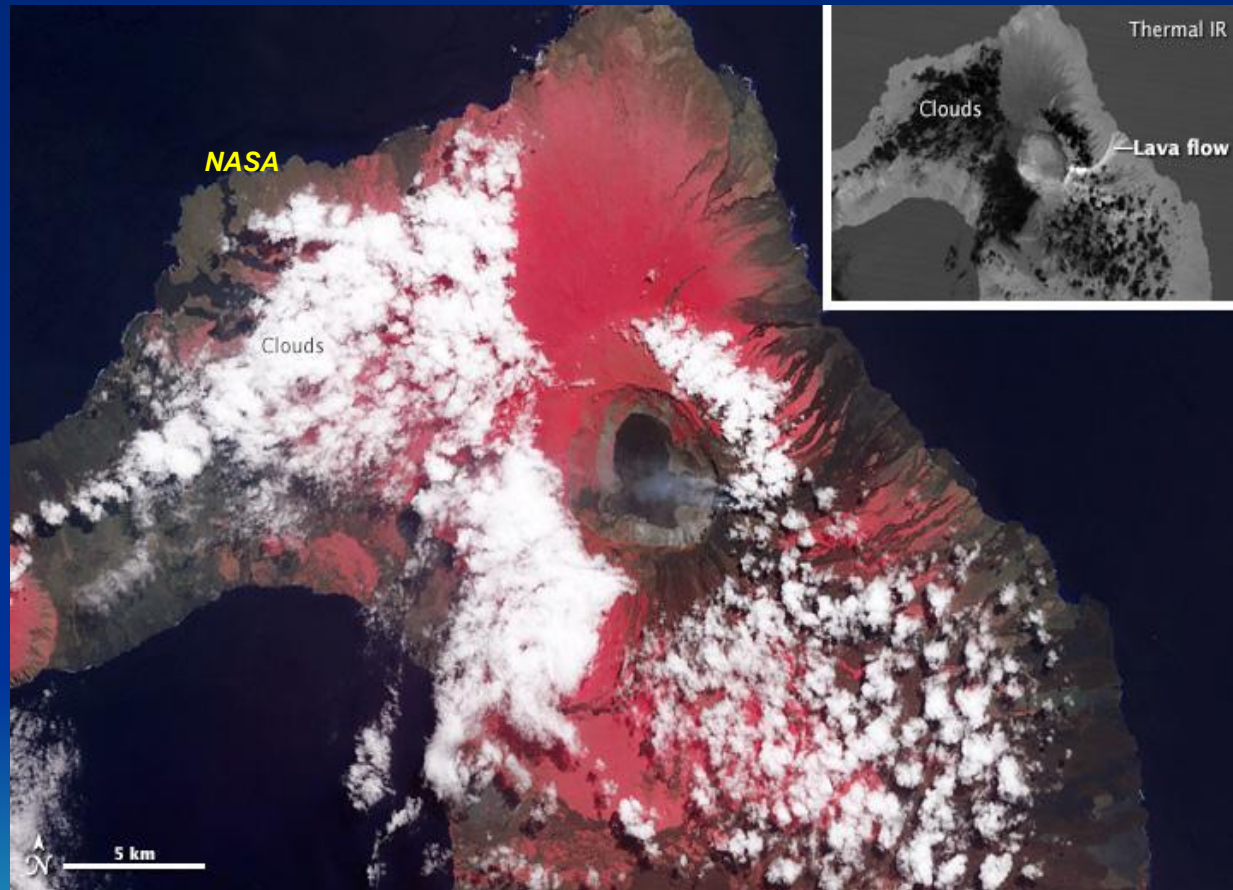
Source: Jentoft-Nilsen (2015)



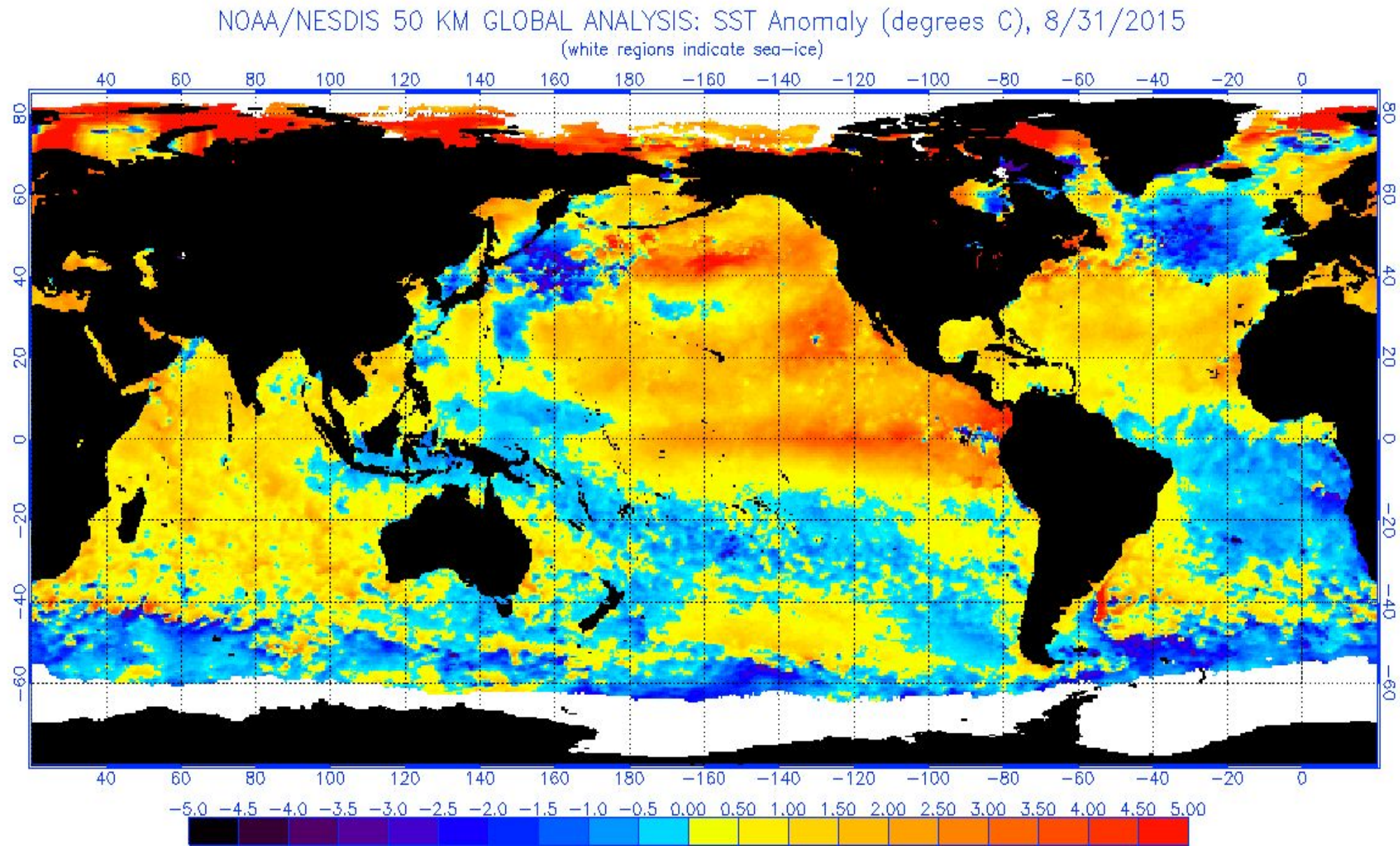
Comparison of ocean surface topography during El Niño 1997-1998 and 2015-2016



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



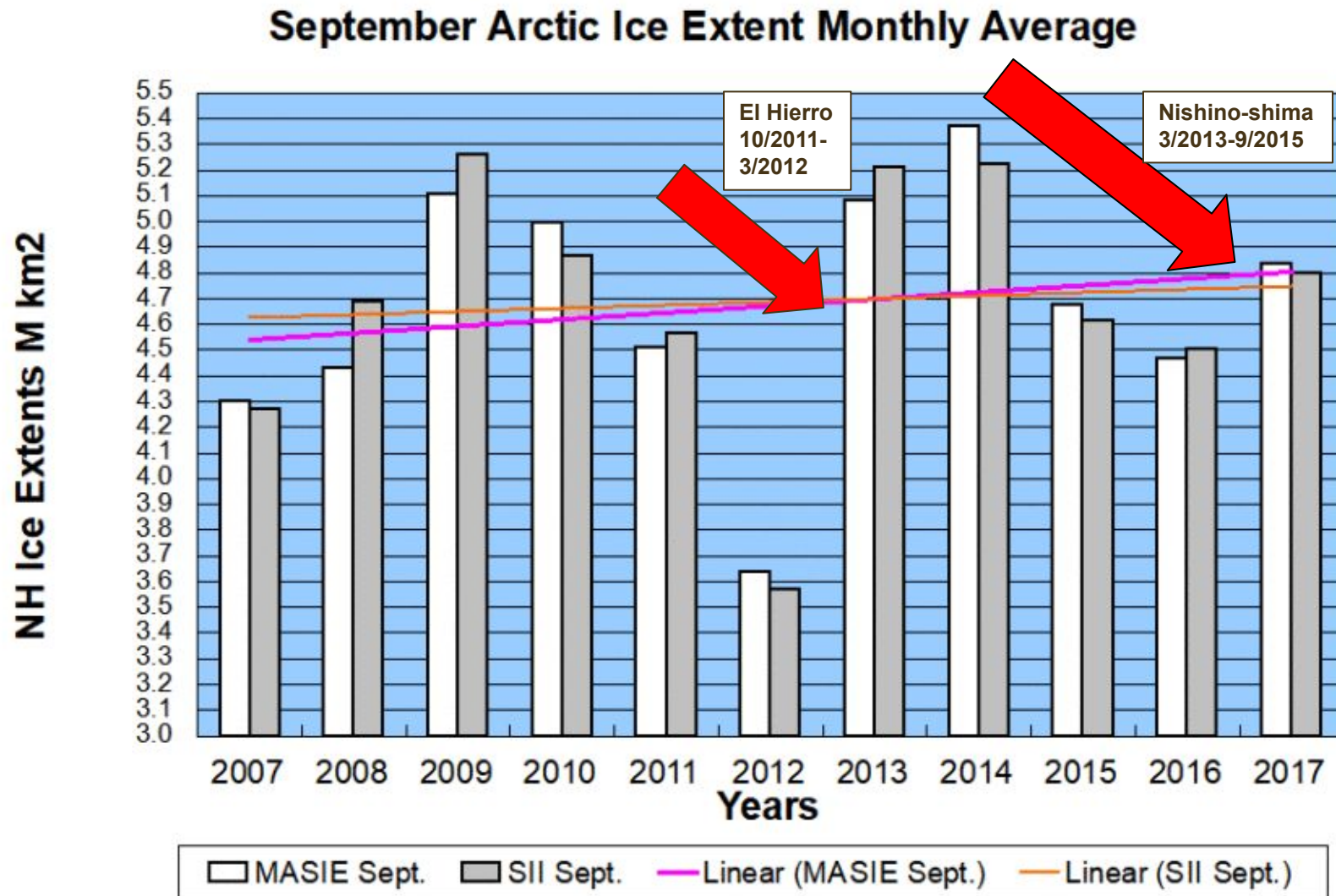
Establishment of the strong and long-lasting 2014-2016 El Niño August 31, 2015



Arctic sea ice changes 2007-2017

Explained by the release of geothermal heat through volcanism

(Source: Clutz 2017)



Arctic sea ice extent 2007-2016

Source: National Snow & Ice Data Centre

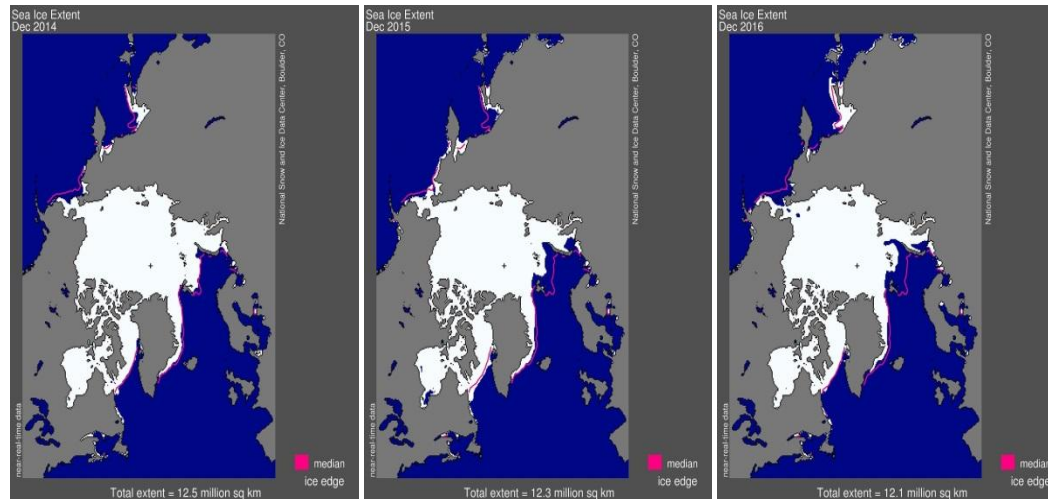
YEAR,	MINIMUM ICE EXTENT,		DATE,
	IN MILLIONS OF SQUARE KILOMETERS,	IN MILLIONS OF SQUARE MILES,	
2007,	4.15,	1.6,	Sept. 18,
2008,	4.59,	1.77,	Sept. 20,
2009,	5.12,	1.98,	Sept. 13,
2010,	4.62,	1.78,	Sept. 21,
2011,	4.34,	1.67,	Sept. 11,
2012,	3.39,	1.31,	Sept. 17,
2013,	5.06,	1.95,	Sept. 13,
2014,	5.03,	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,

Record minimum

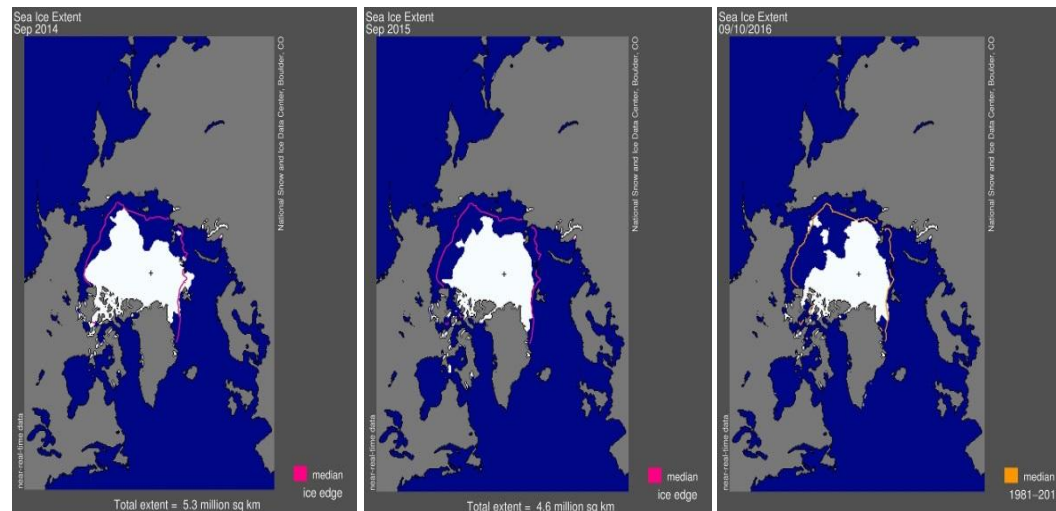
Gradual decline

Influence on minimum Arctic sea ice extent

Winter 2014-2016



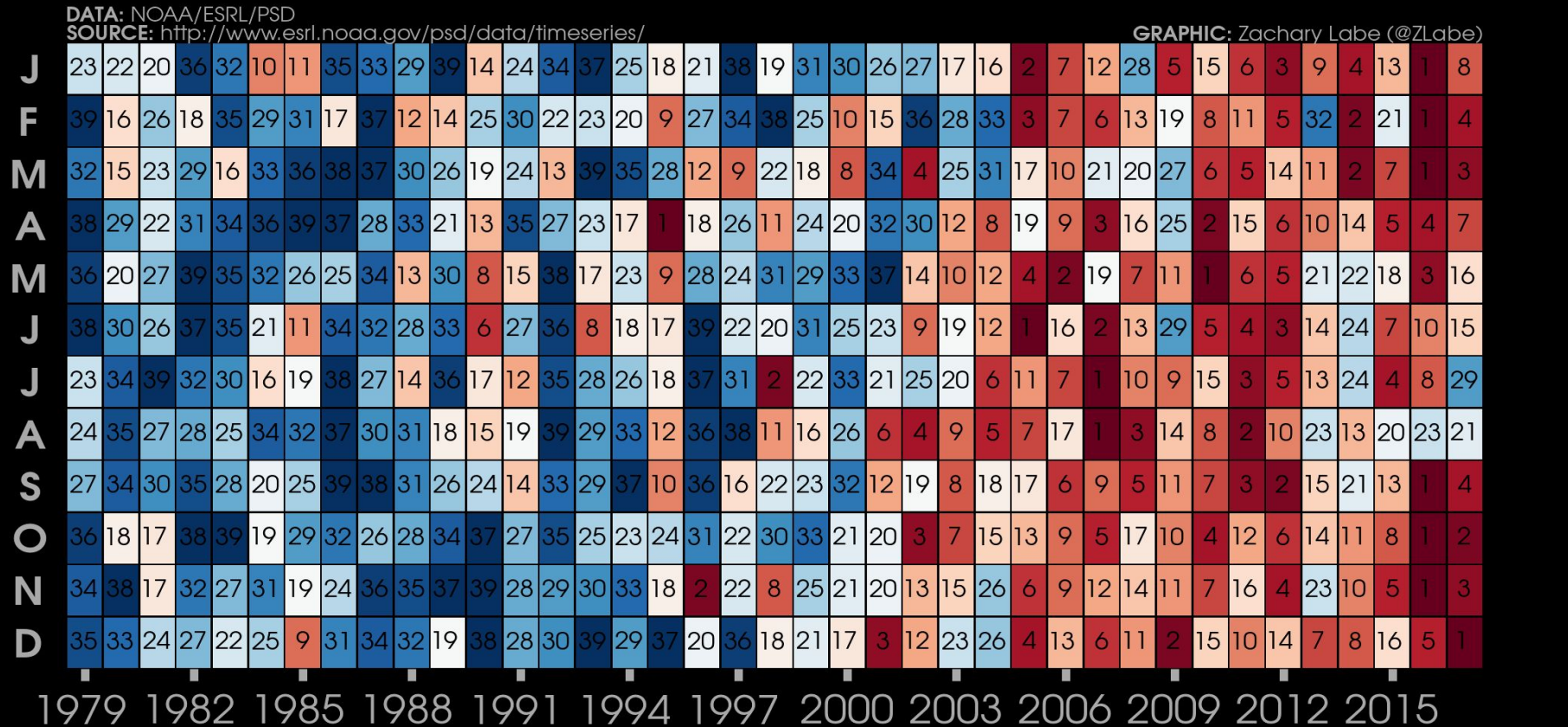
Summer 2014-2016



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,
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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

Ranking of Arctic monthly air temperatures 1979-2017



Coldest

AIR TEMPERATURE RANK BY MONTH

(NCEP/NCAR Reanalysis : 925 hPa, Arctic, 70N+)

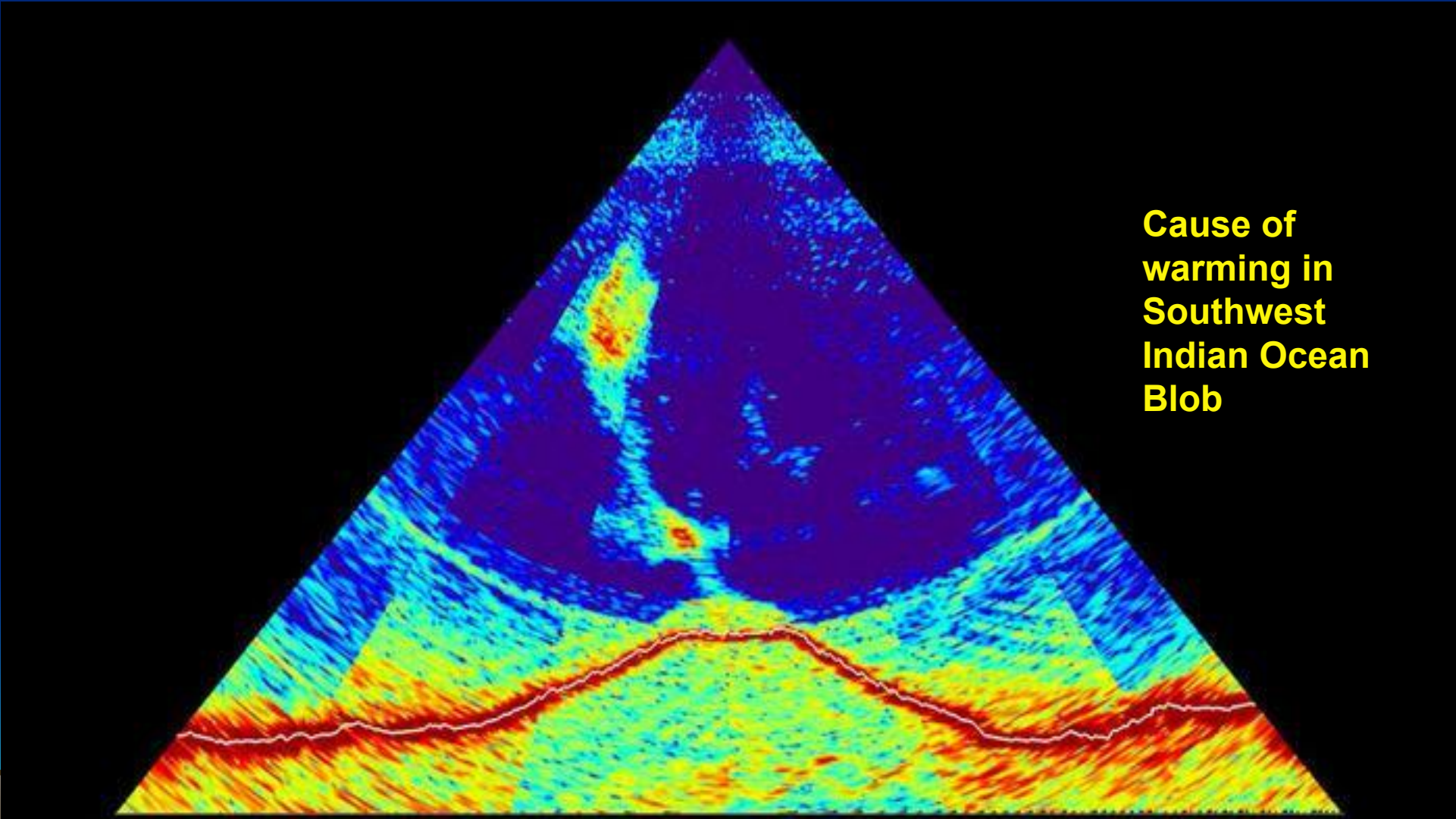
NOAA

Warmest

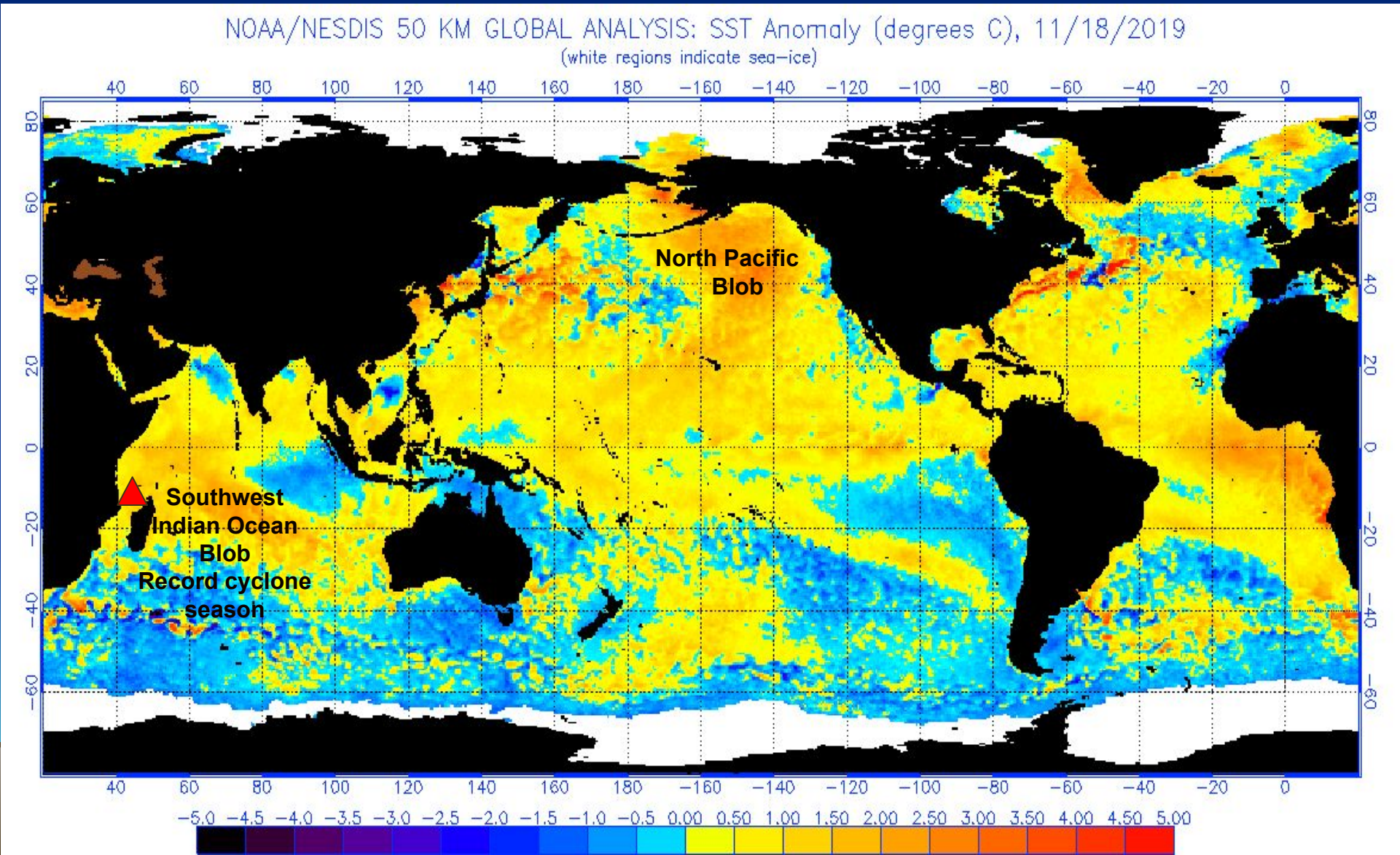
New submarine volcanic eruption discovered in the Mozambique Channel November 2018-May 2019



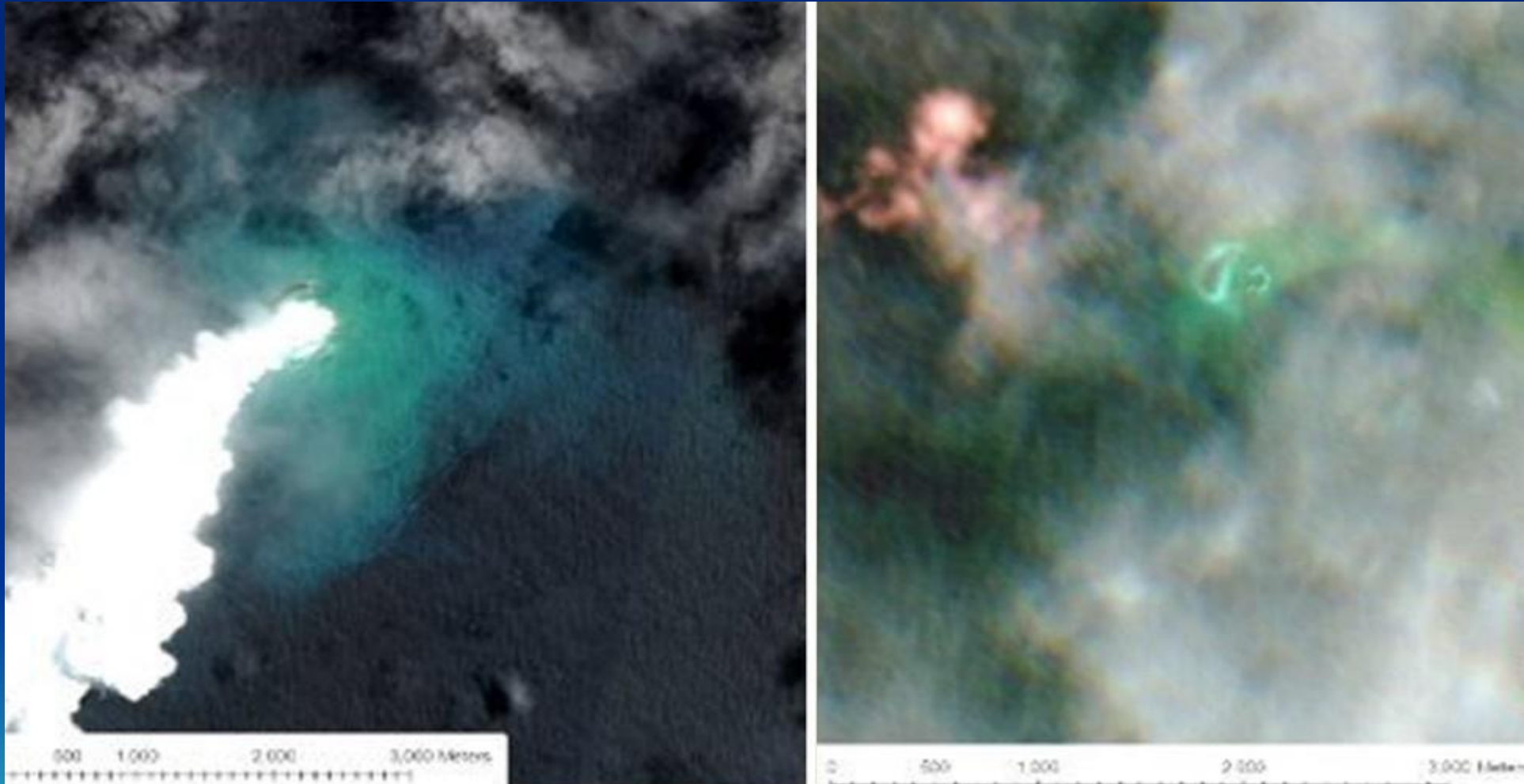
***Multibeam sonar waves, reflecting off the sea floor
southeast Mayotte, showing an 800-m-tall volcano
with a 5 km diameter and a rising gas-rich plume***



Global map of sea-surface temperature anomalies on November 18, 2019

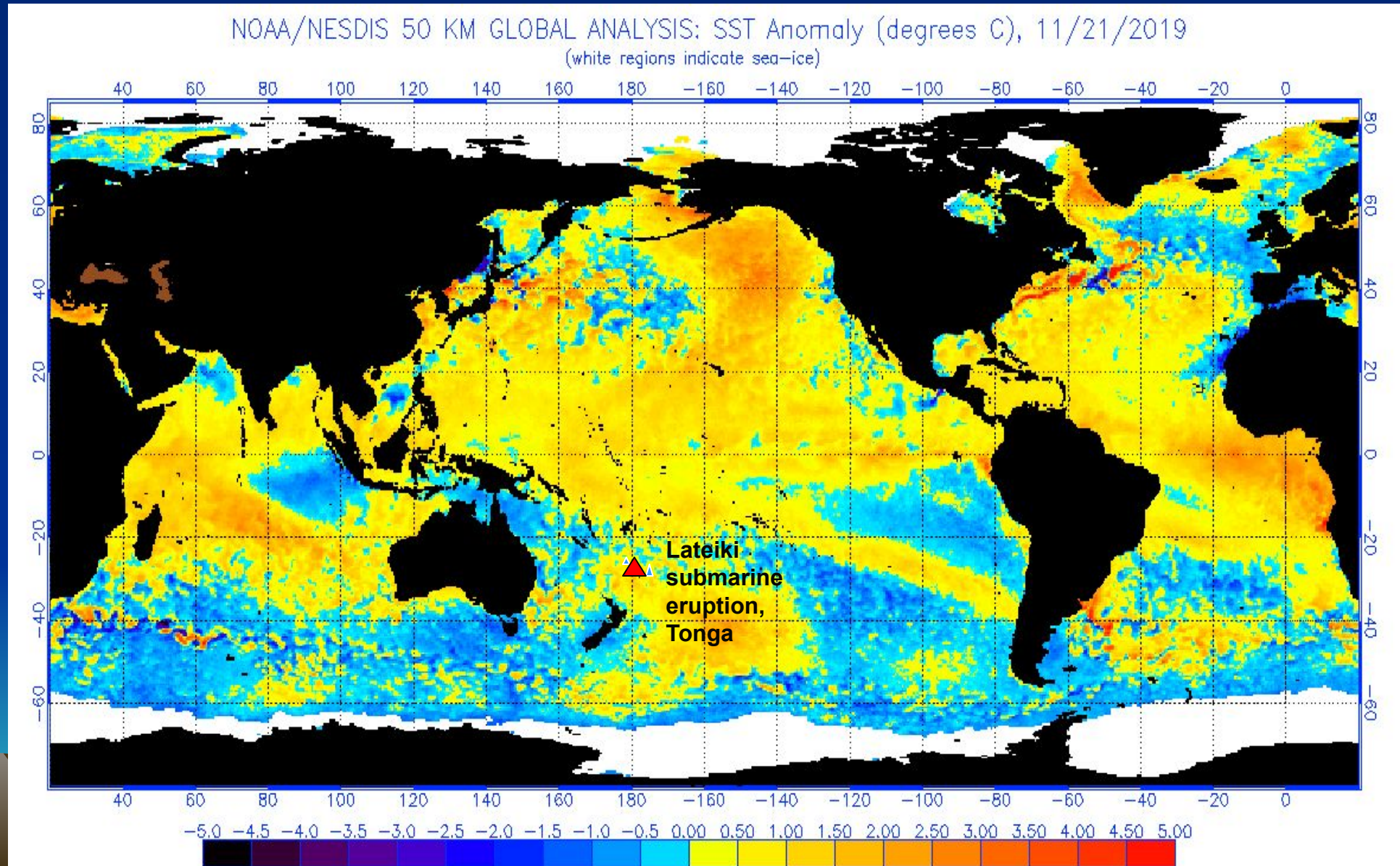


Lateiki submarine eruption, Tonga new island created November 7, 2019

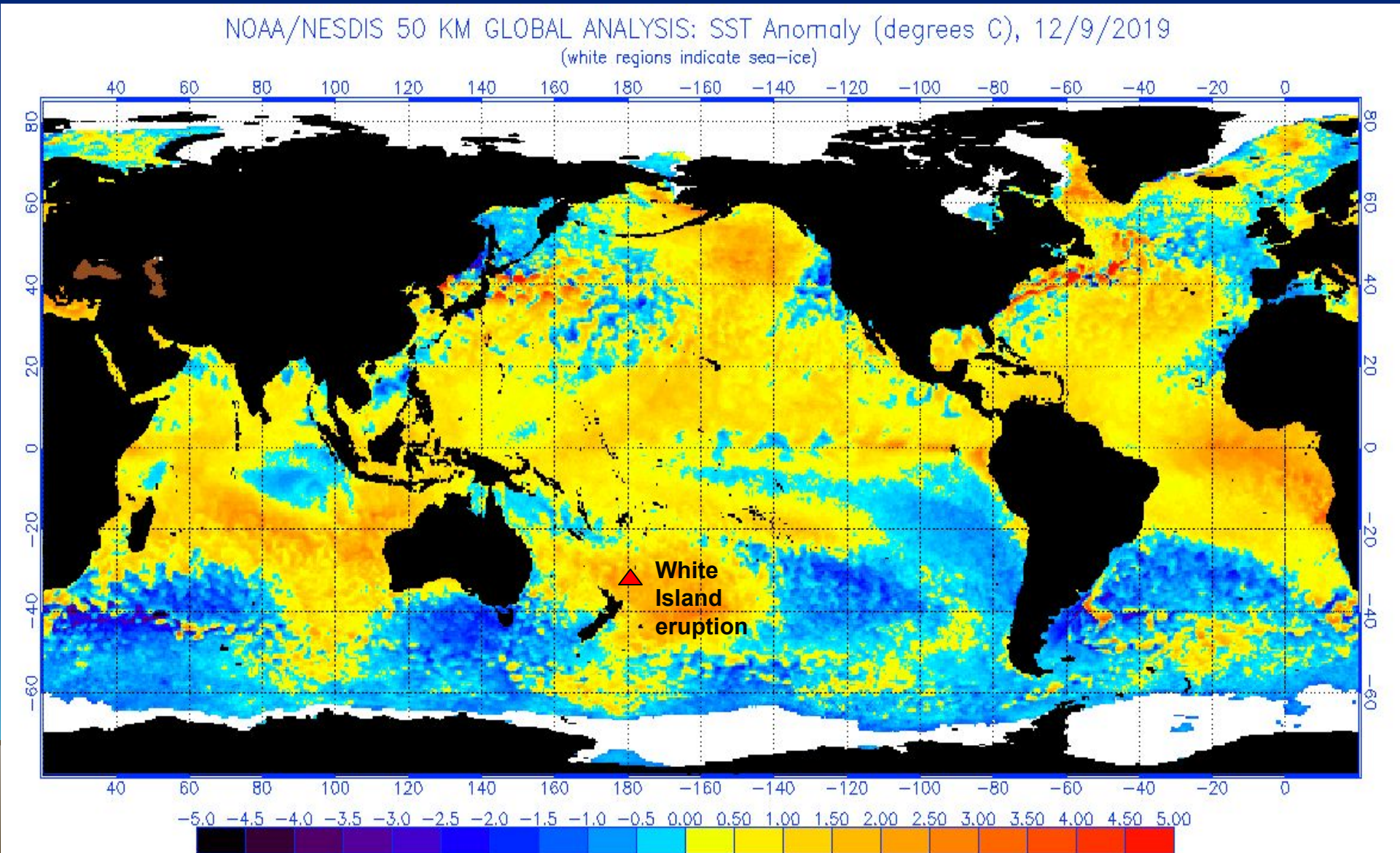


Old island destroyed and replaced by a bigger new island

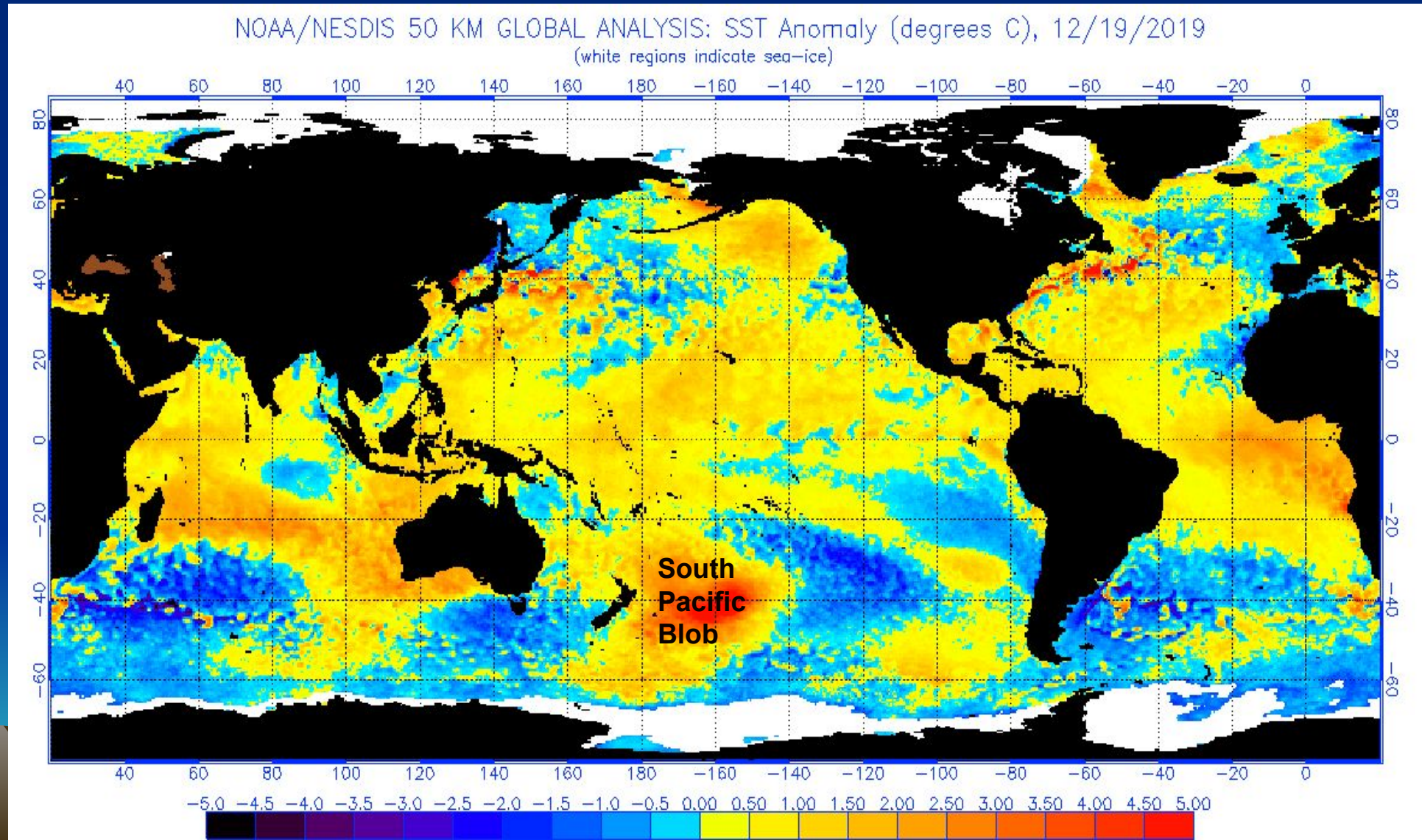
Global map of sea-surface temperature anomalies on November 21, 2019



Global map of sea-surface temperature anomalies on December 9, 2019



Global map of sea-surface temperature anomalies on December 19, 2019



Statistics of the South Pacific Blob

Marine heat wave east of New Zealand – High pressure, sunny sky and light wind

1 million square kilometers (size of Texas)

6 degree Celsius above normal

Total thickness of hot seawater 50 metres

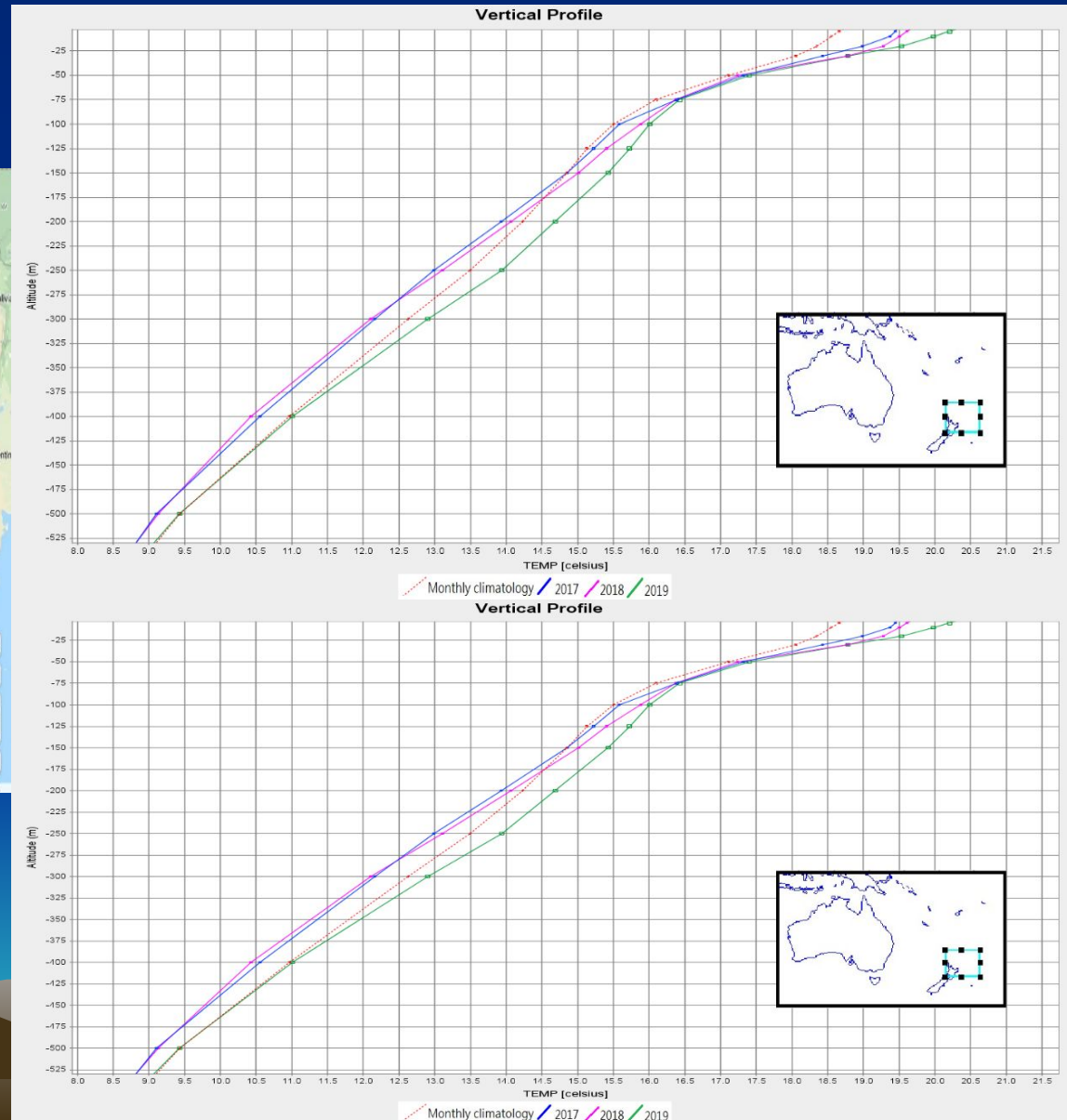
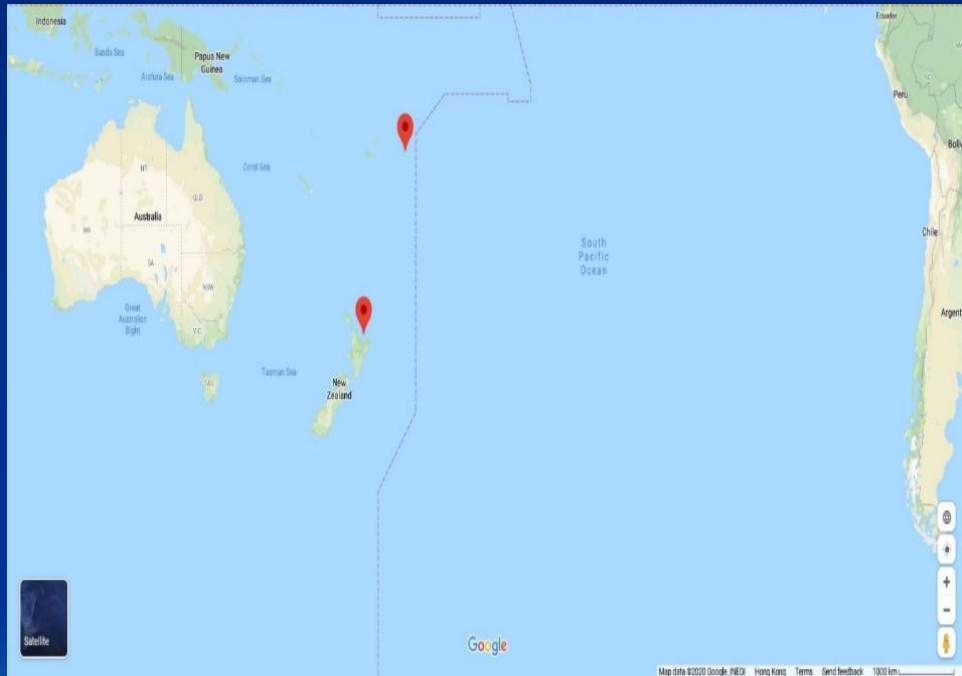
Prof. J. Renwick – Heated by the sun through natural causes not by global warming



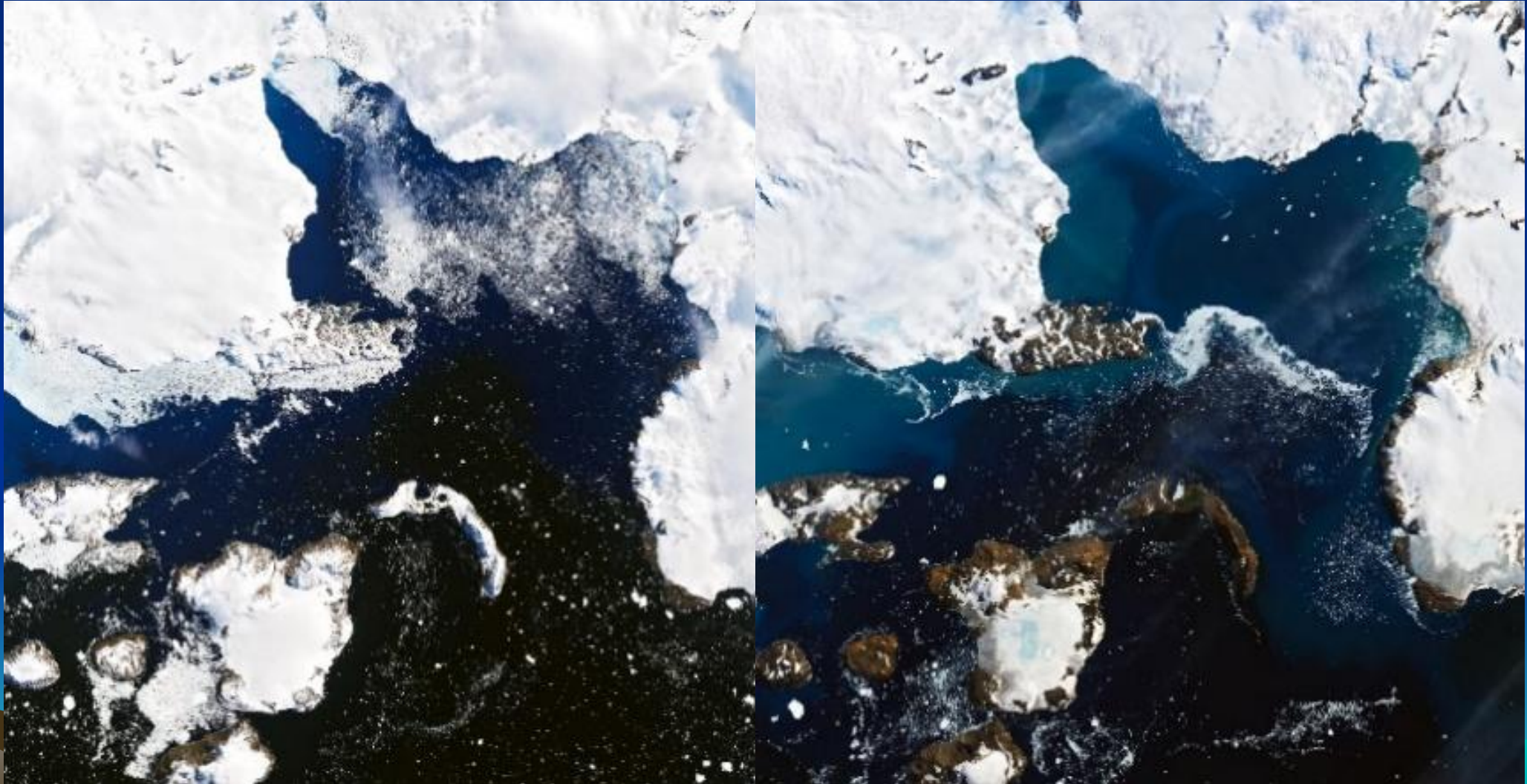
***Marine heatwave brings tropical grouper from
3000 km away to New Zealand waters***



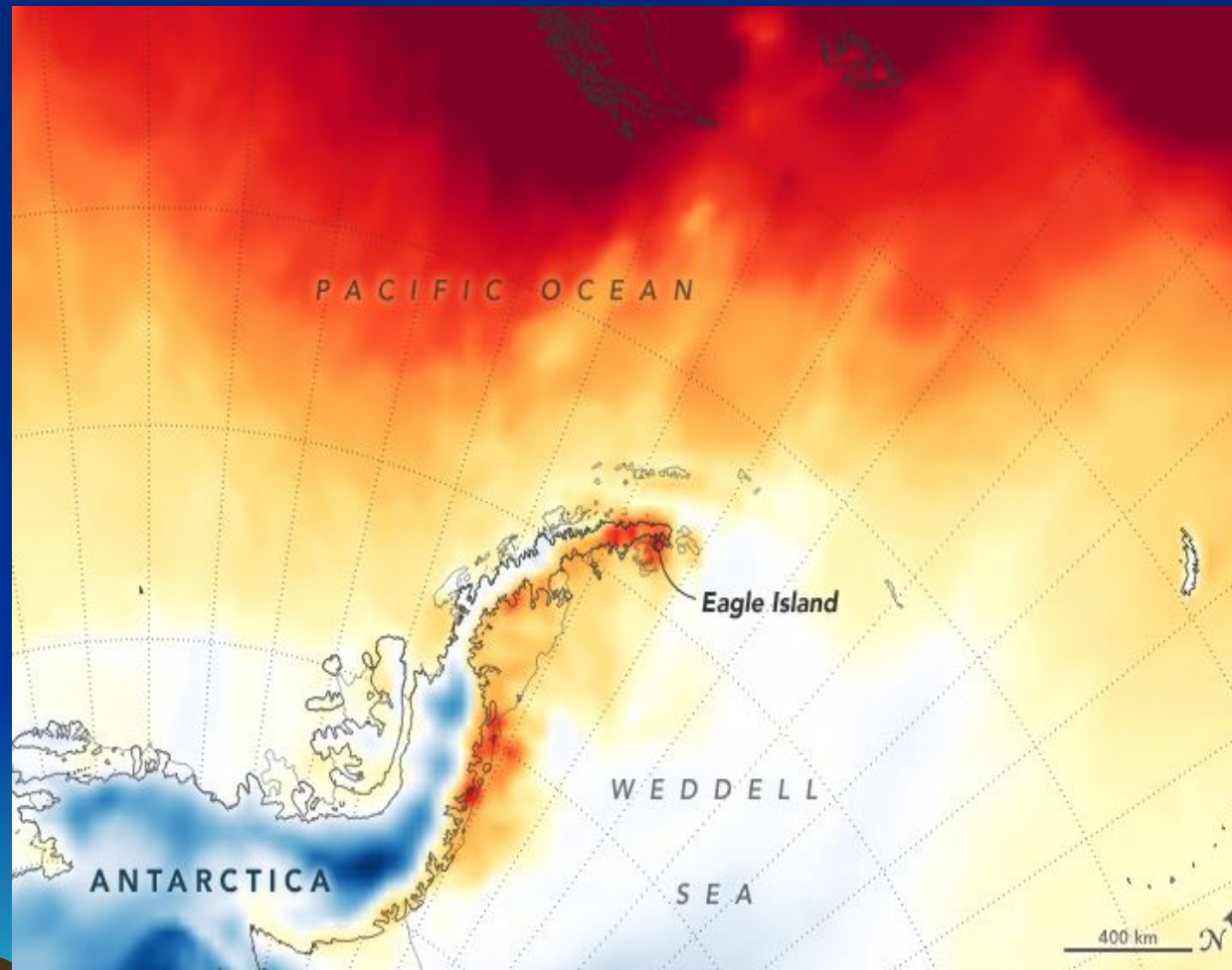
Submarine volcanic eruptions contributing geothermal heat to the South Pacific Blob



Landsat images showing dramatic melting in the Eagle Island region of Antarctica on February 4, 2020 in comparison to February 13, 2020. Source: NASA



Map derived from the Goddard Earth Observing System model representing air temperatures at 2 m above the ground on February 9, 2020. Source: NASA.



2-meter Air Temperature (°C)



Conclusions

- (1) Volcanism is an underestimated natural cause of ocean heat waves.
- (2) All 4 case studies of regional ocean heatwaves were caused mainly by the release of geothermal heat through volcanism.
- (3) Man-made carbon dioxide from fossil fuels are not responsible for such heat waves.
- (4) The occurrence of heat waves may influence the sea-ice extent in both the Arctic and the Antarctic.
- (5) The biodiversity changes observed were of a temporary nature which is inconsistent with global warming.
- (6) Because sulphur oxides released into seawater through volcanism is much more acidic than carbon dioxide, it is more likely to cause coral bleaching.

