# Volcanism generated ocean heat waves and biodiversity

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*Presentation to the Creative Society on April 30th, 2022*

# *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

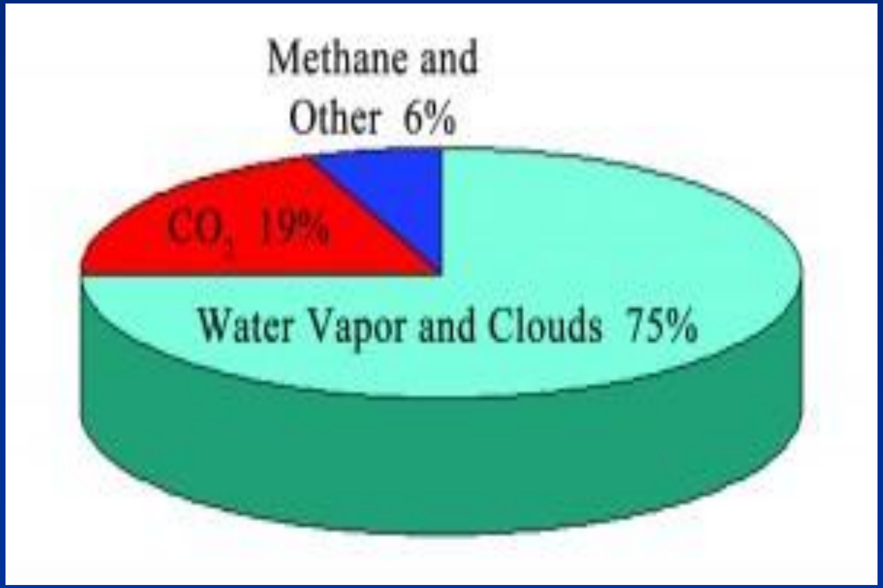
2019-2020 South Pacific Blob

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?*

1$^{st}$ order

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

2$^{nd}$ order

Volcanism generated geothermal heat/plate climatology

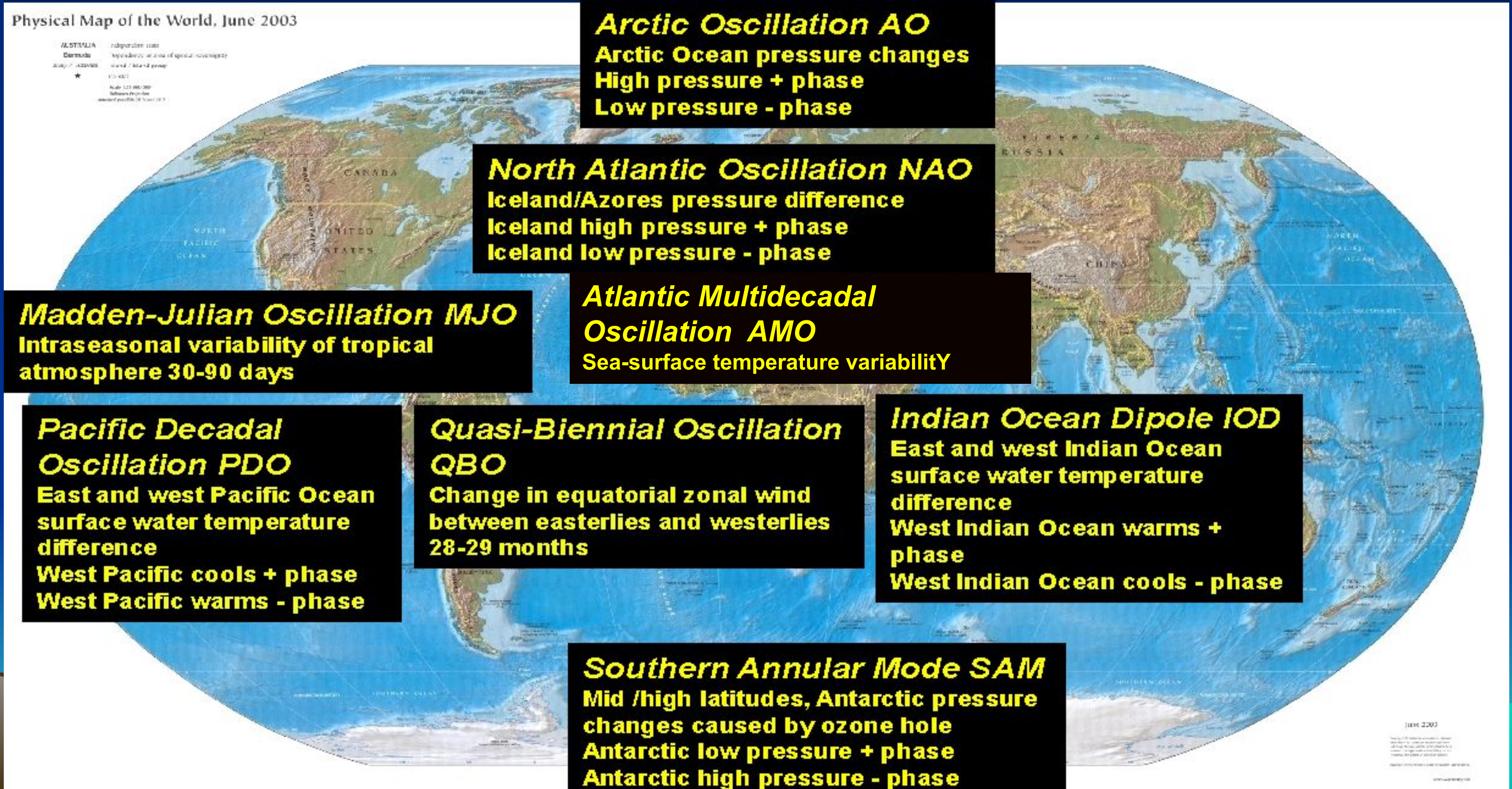
www.plateclimatology.com

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

3$^{rd}$ order

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

# Known regional climatic variability additional to monsoons




**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

**Atlantic Multidecadal Oscillation AMO**
Sea-surface temperature variabilitY

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

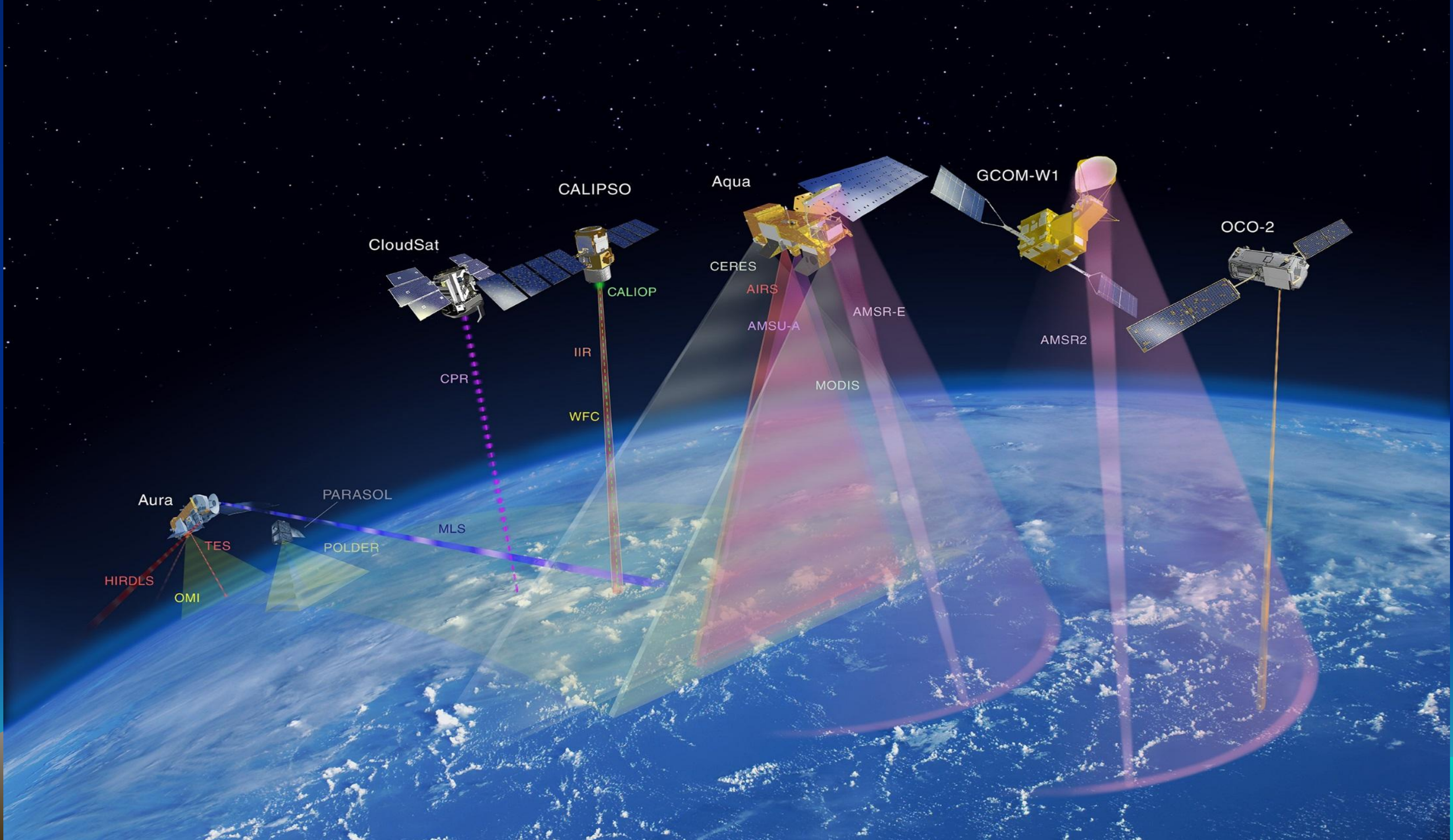
**Pacific Decadal Oscillation PDO**
East and west Pacific Ocean surface water temperature difference
West Pacific cools + phase
West Pacific warms - phase

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

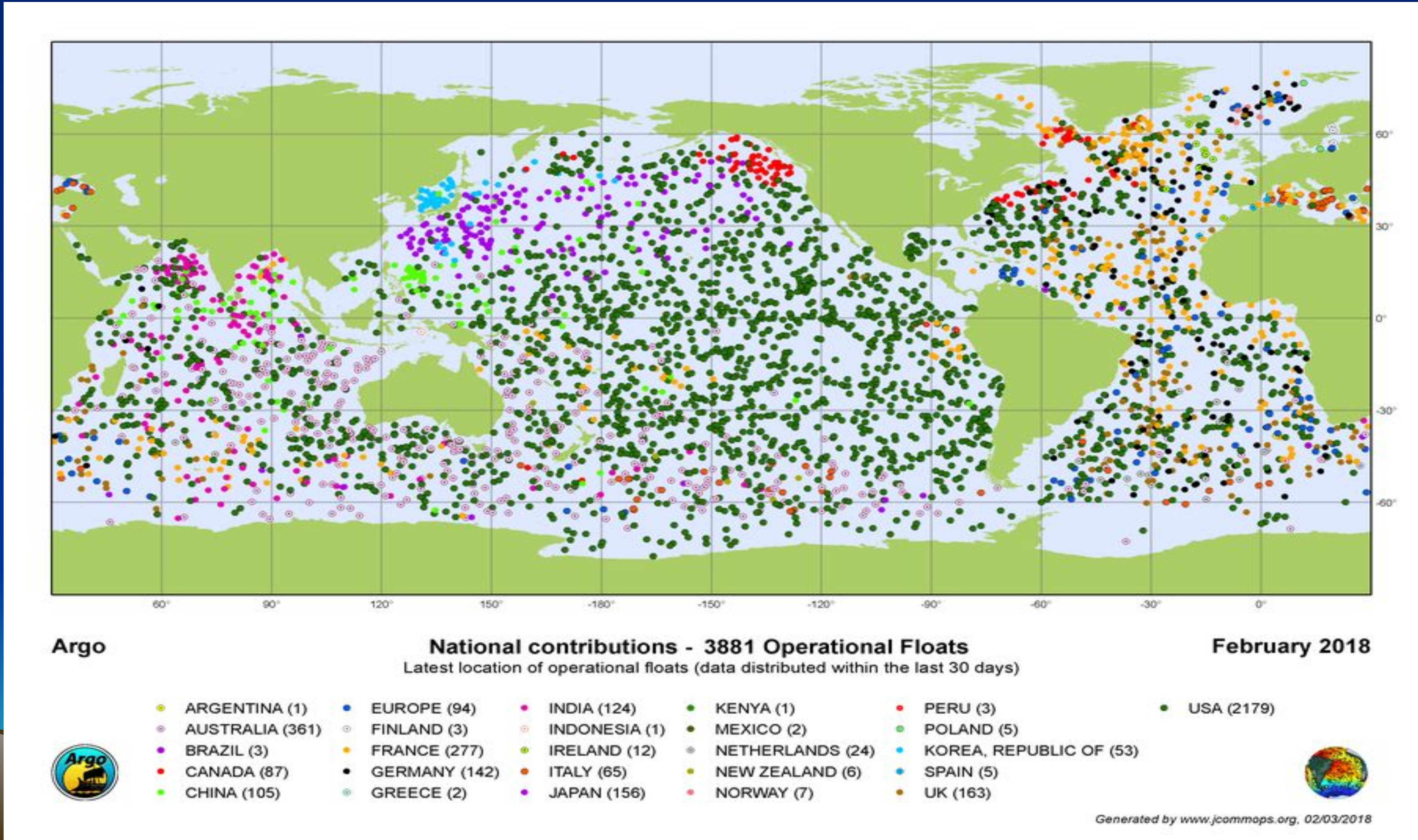
**Indian Ocean Dipole IOD**
East and west Indian Ocean surface water temperature difference
West Indian Ocean warms + phase
West Indian Ocean cools - phase

**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*

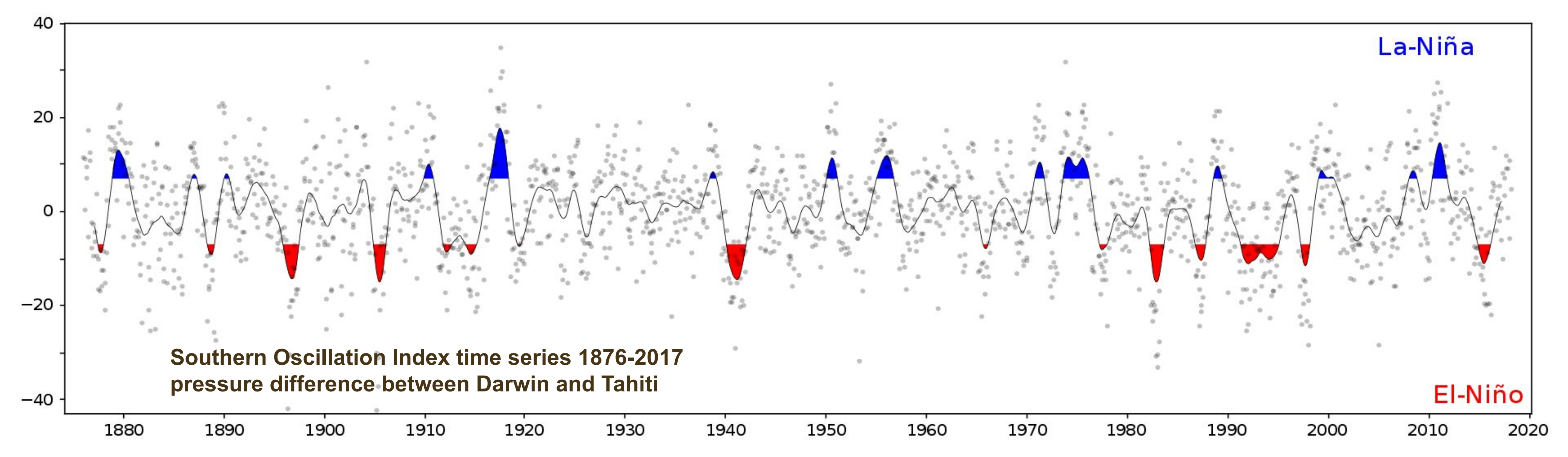


# *What is ENSO?*

## *El Niño Southern Oscillation*

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

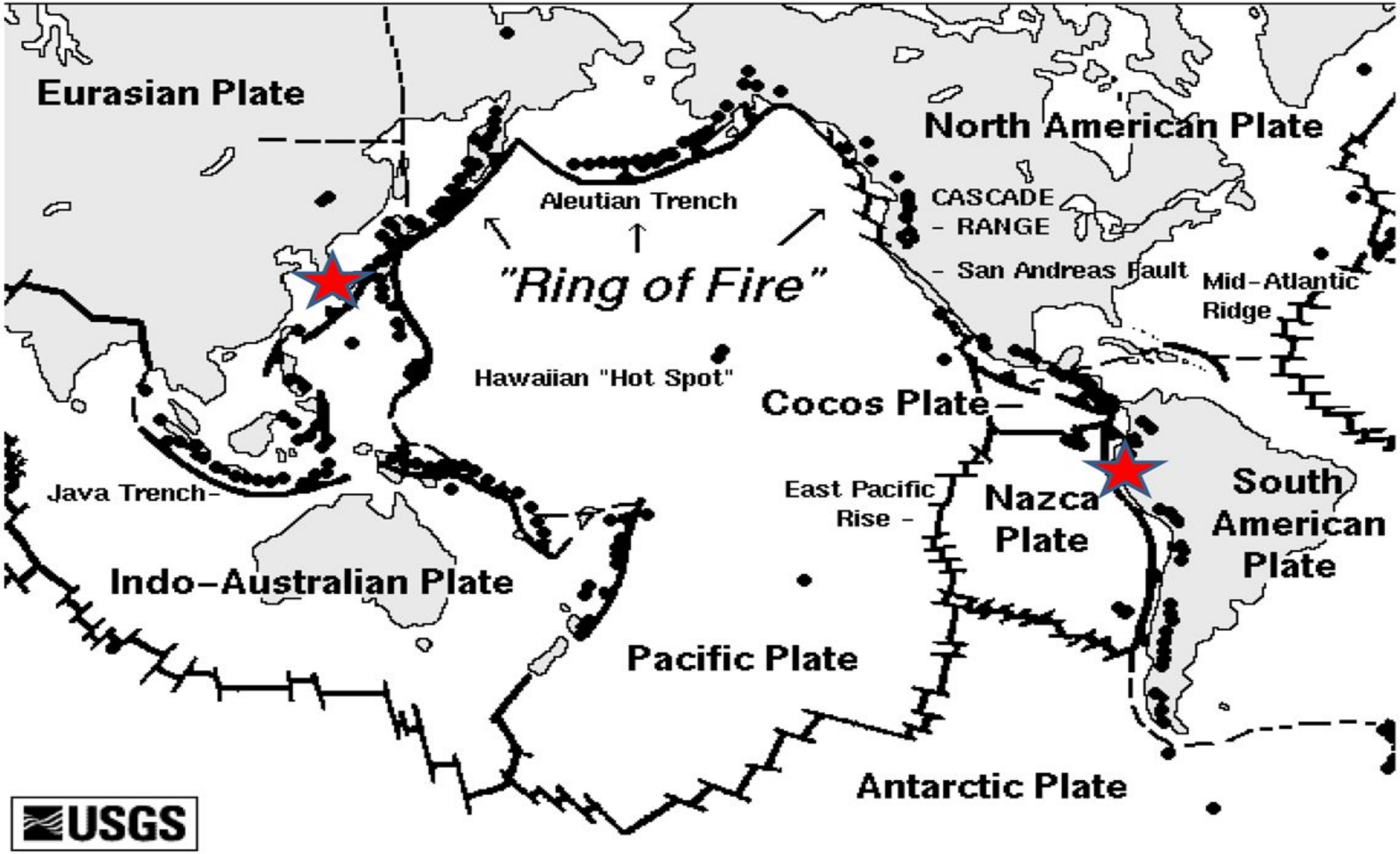
**An irregularly periodic variation in winds and sea surface temperatures over the tropical eastern Pacific Ocean, affecting the climate of much of the tropics and subtropics. The warming phase of the sea temperature is known as *El Niño* and the cooling phase as *La Niña*. The *Southern Oscillation* 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.**



**Southern Oscillation Index time series 1876-2017**
**pressure difference between Darwin and Tahiti**

**Source: Wiki**

# Why ENSOs occur in the Pacific?




Topinka, USGS/CVO, 1997, Modifed 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.

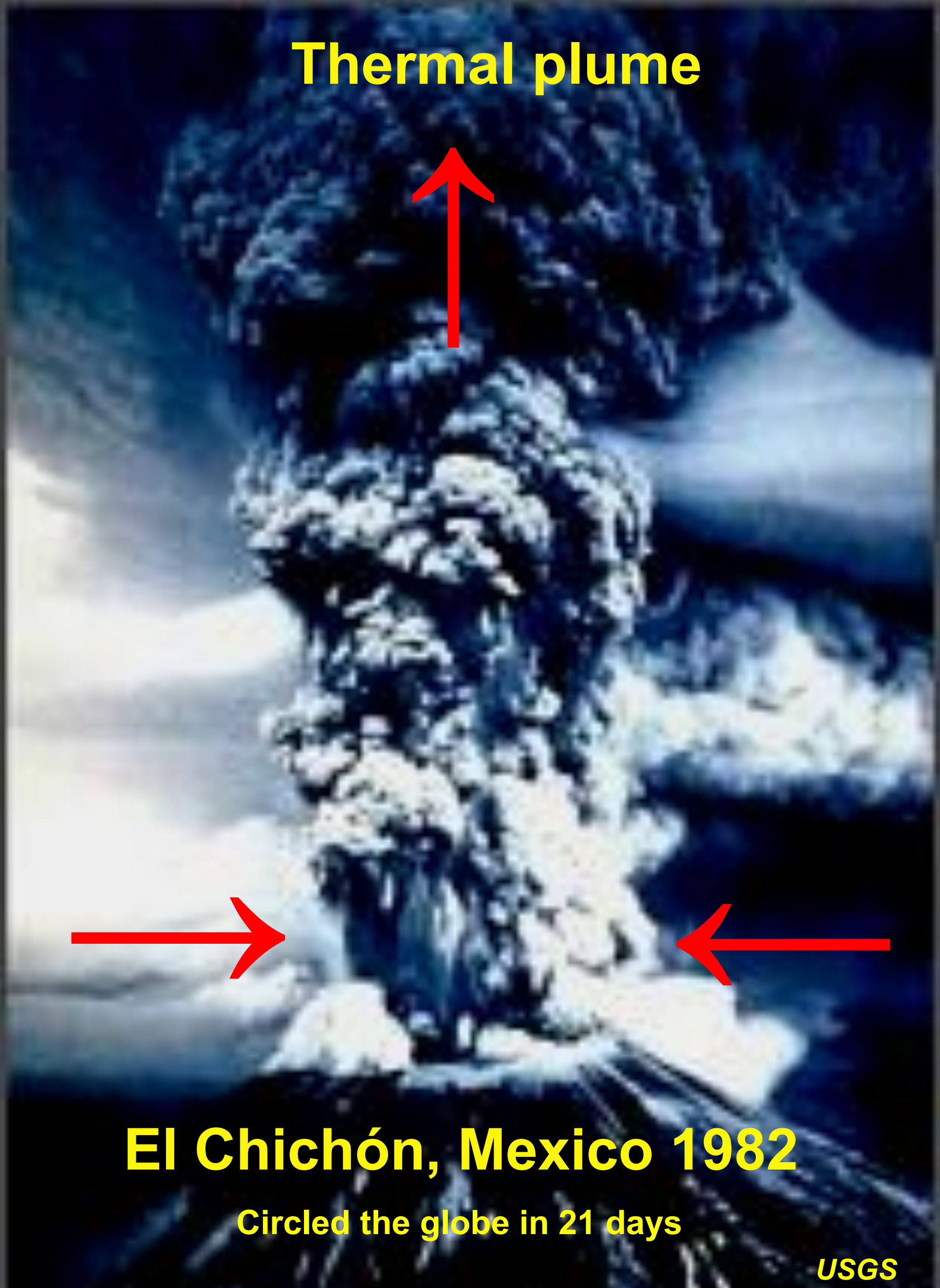
***Sub-aerial volcano model***

**Ash & aerosols reduce solar radiation leading to cooling**

**Warm air stores more moisture – water vapour redistribution**

**Air pressure changes (low)**

***Cooling***




**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**

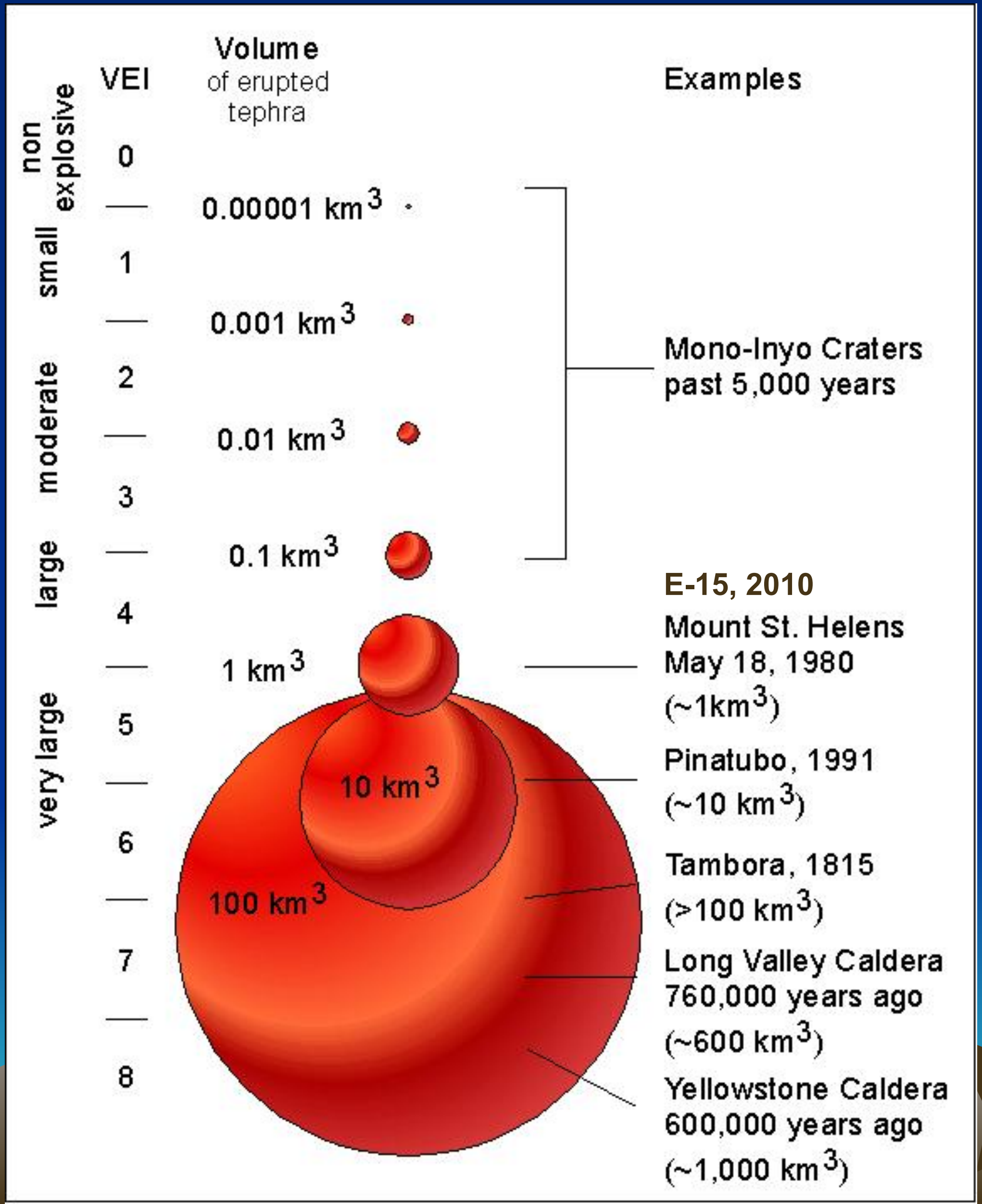
**Impact longer lasting if higher VEI**

# Volcanic Explosivity Index (VEI)

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

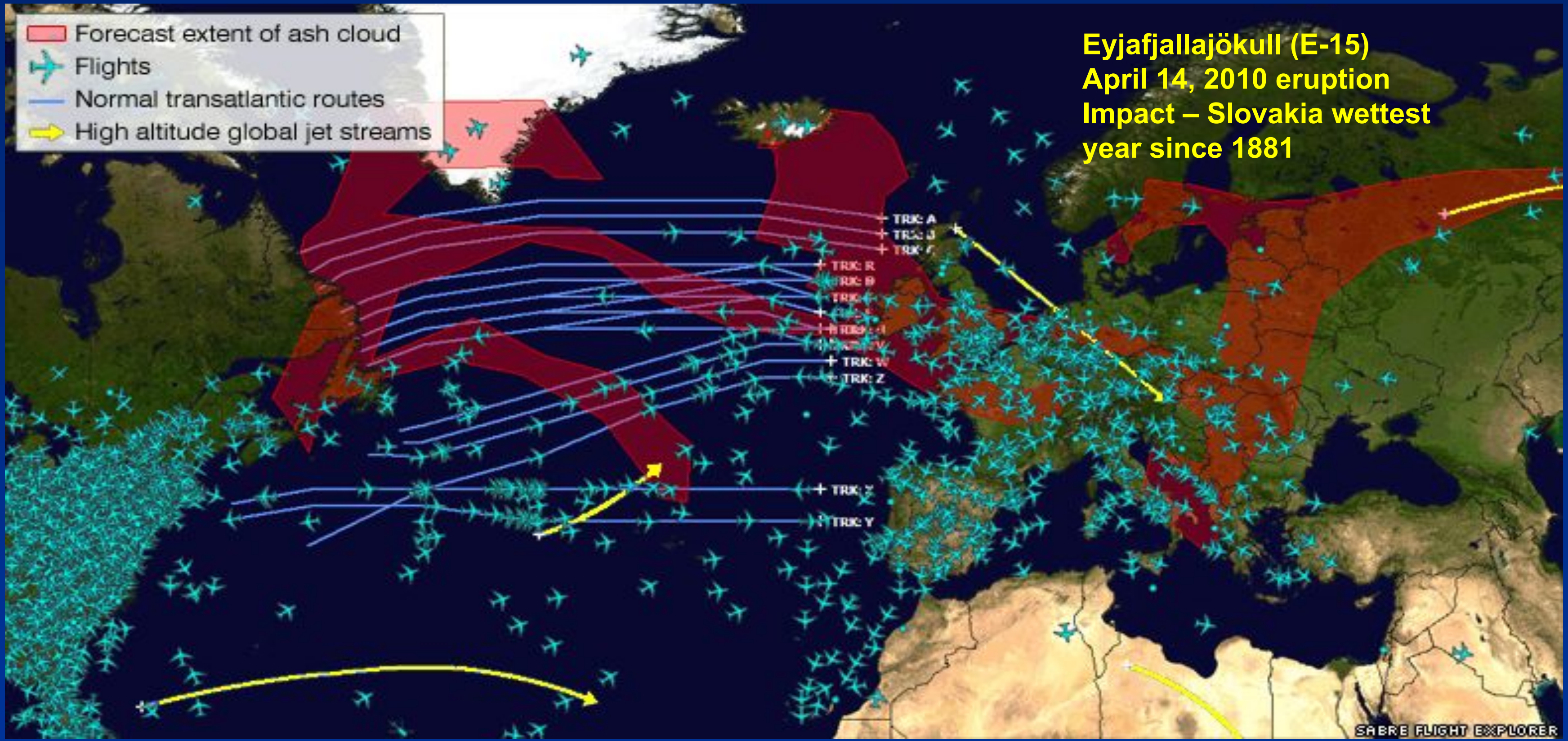
(Newhall and Self 1982)

Acid magma most explosive



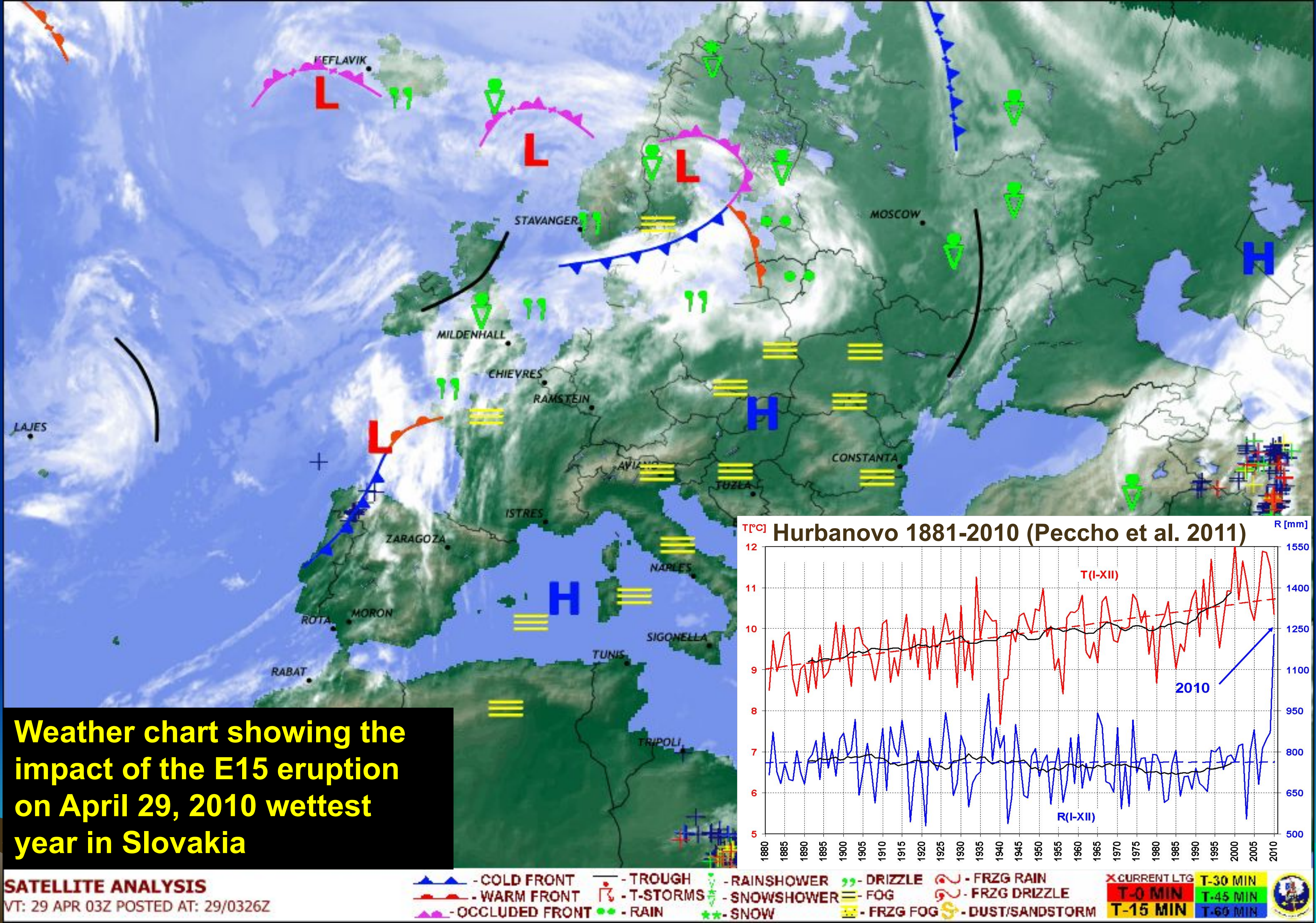

Above VEI 2 regional impacts on weather already detectable

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



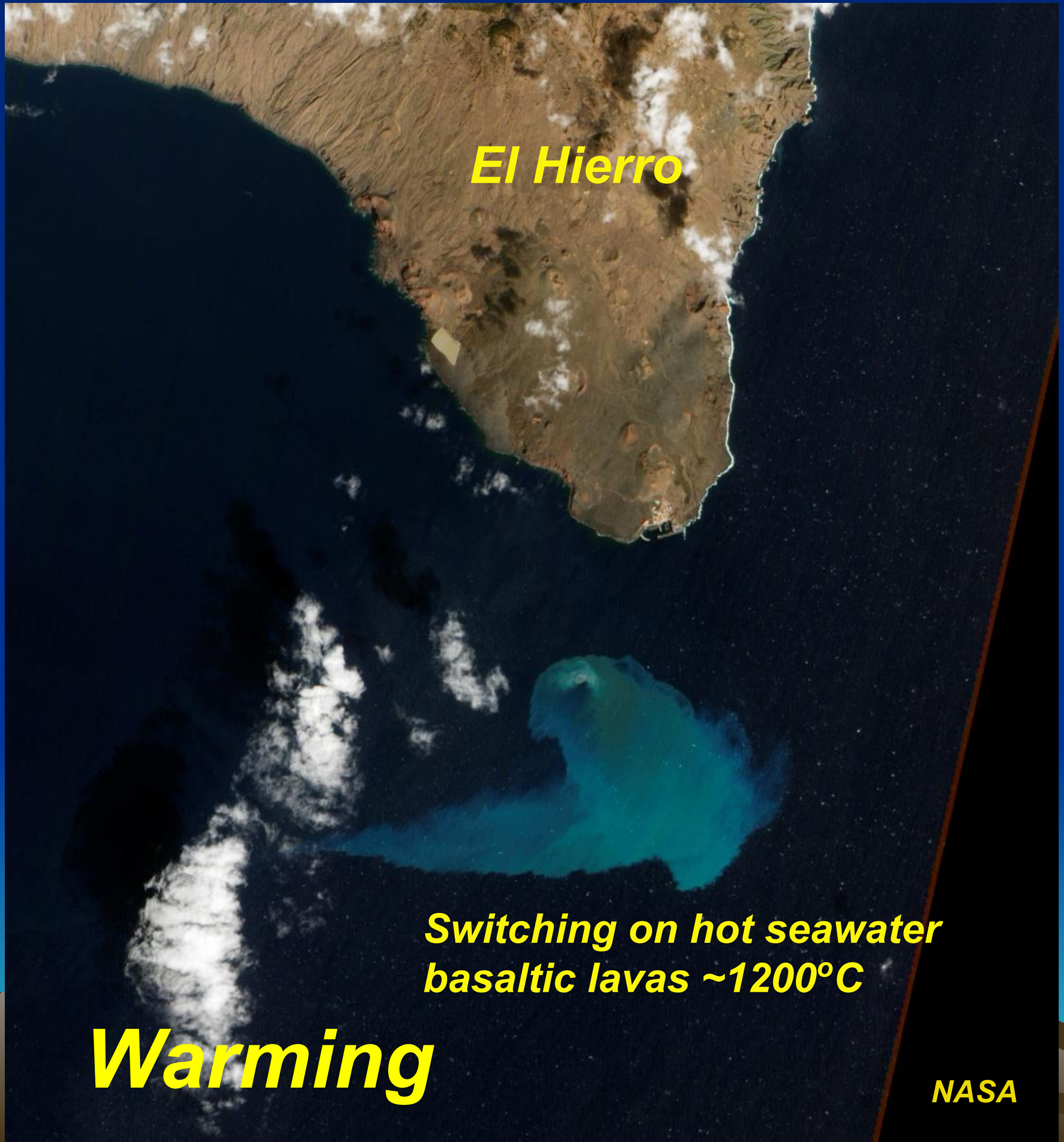

**Most reliable record – Information age**
**Importance – societal e.g. farming, climate model testing**

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




**Weather chart showing the impact of the E15 eruption on April 29, 2010 wettest year in Slovakia**

# 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 |

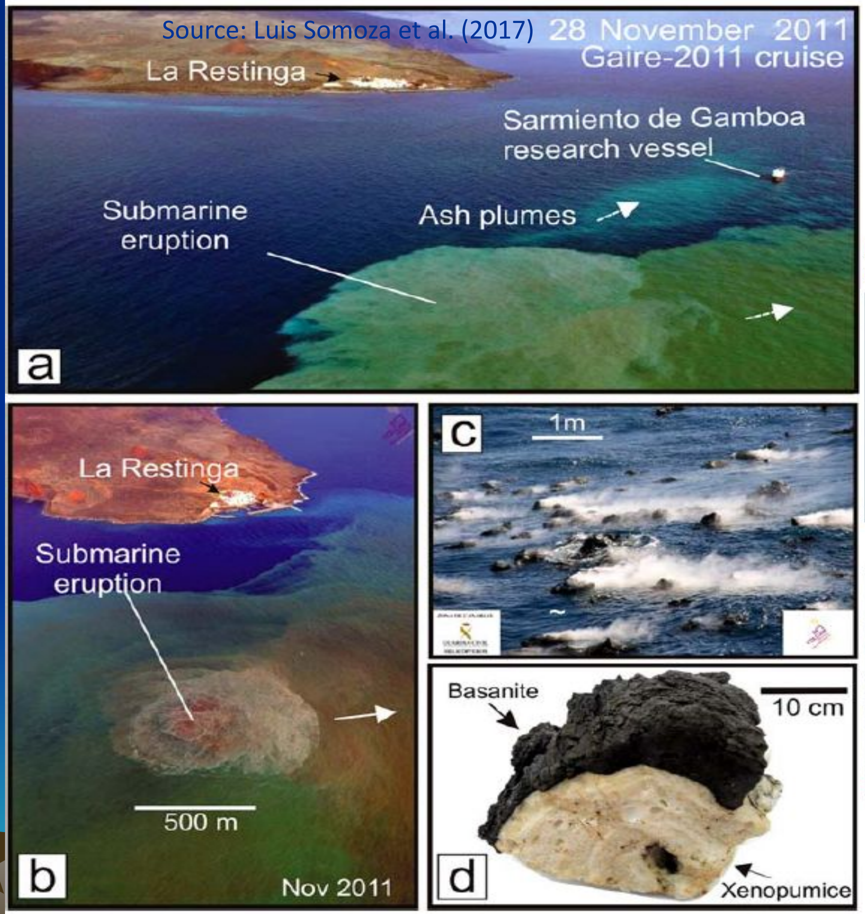
Important facts –

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**



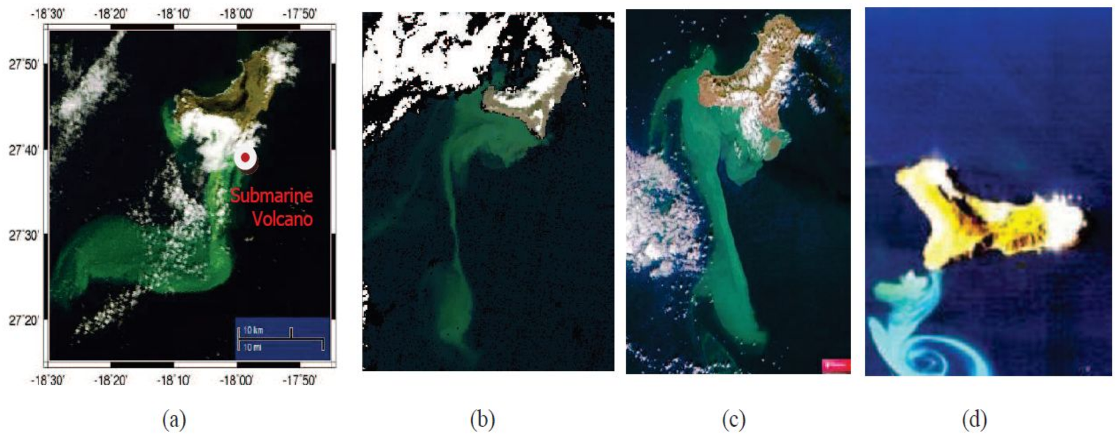




**Figure 1.** (a) MODIS image of El Hierro submarine volcano location (27.78N, -18.04W) and, (b)-(d) multisensorial MERIS ((ESA©), RAPIDEYE© and hyperspectral HYPERION remote sensing images of El Hierro volcanic plume.

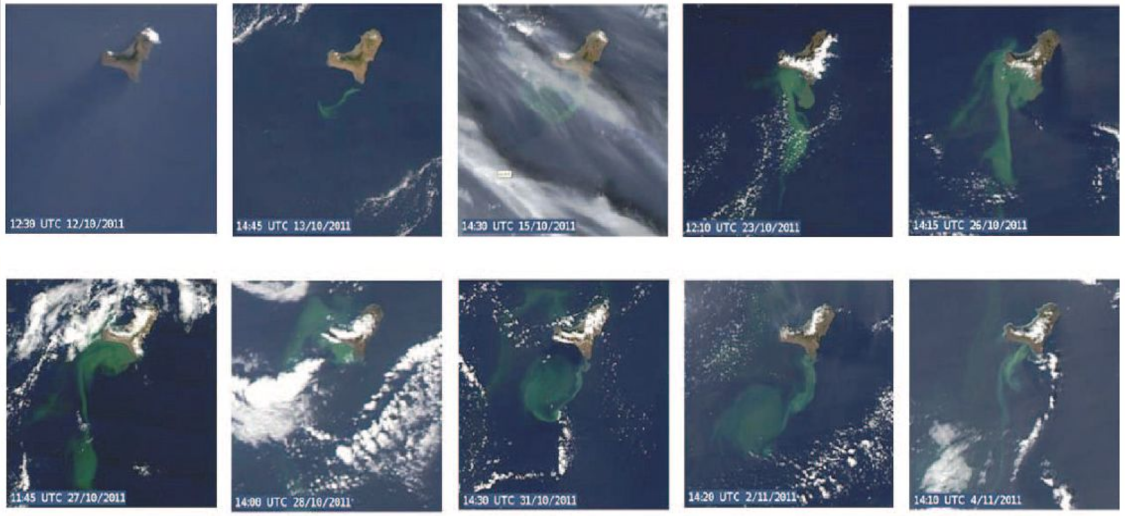



**Figure 2.** NASA MODIS RGB multitemporal images monitoring El Hierro submarine volcano.

Source: Eugenio et al. (2014)

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

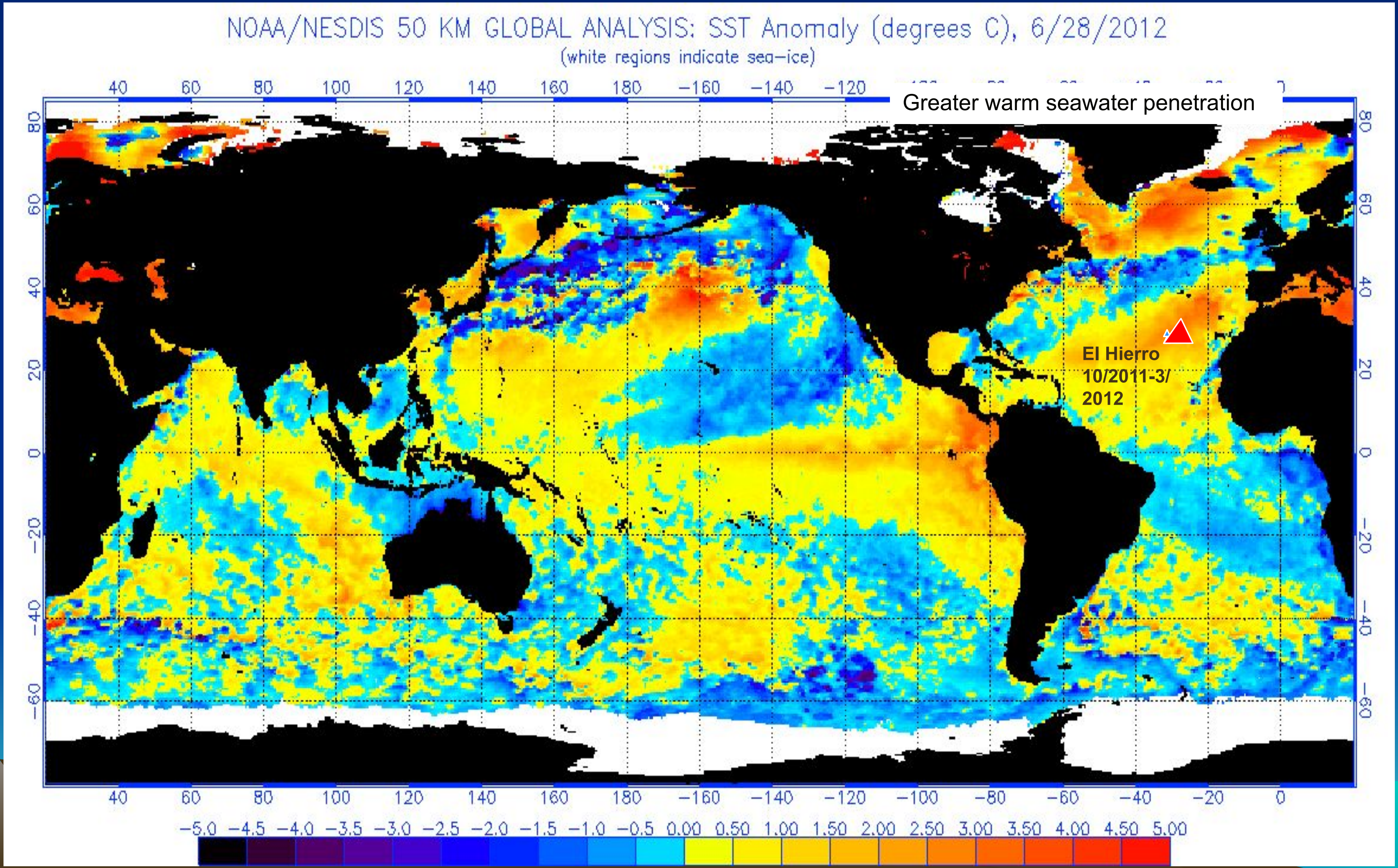
**Brownish plume created**



**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



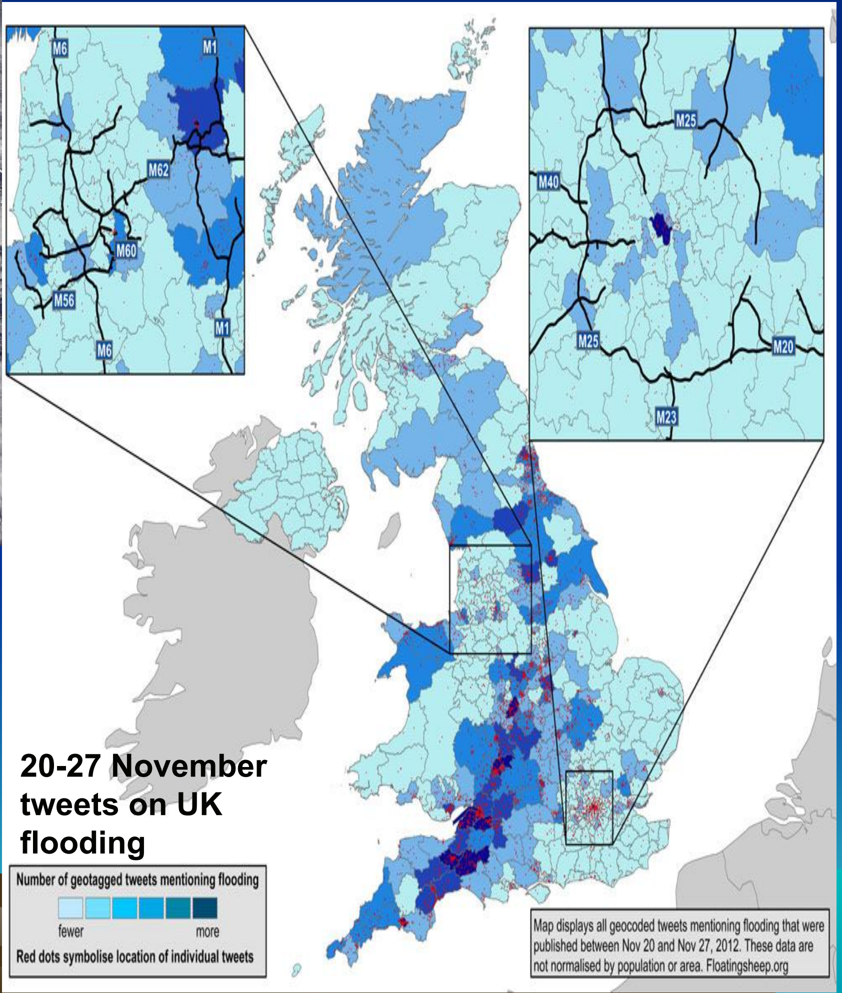
# *Weather-related events or pattern in the North Atlantic Basin during 2012*

| Date | Affected region | Events or pattern |
|---|---|---|
| *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* | *Arctic Ocean* | *Record low sea ice* |
| *Summer* | *Northern/central Europe* | *Abnormally wet summer with moisture able to penetrate the continental interiors* |
| *June-November* | *US east coast* | *Extremely 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* |
| 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 in 2012*

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

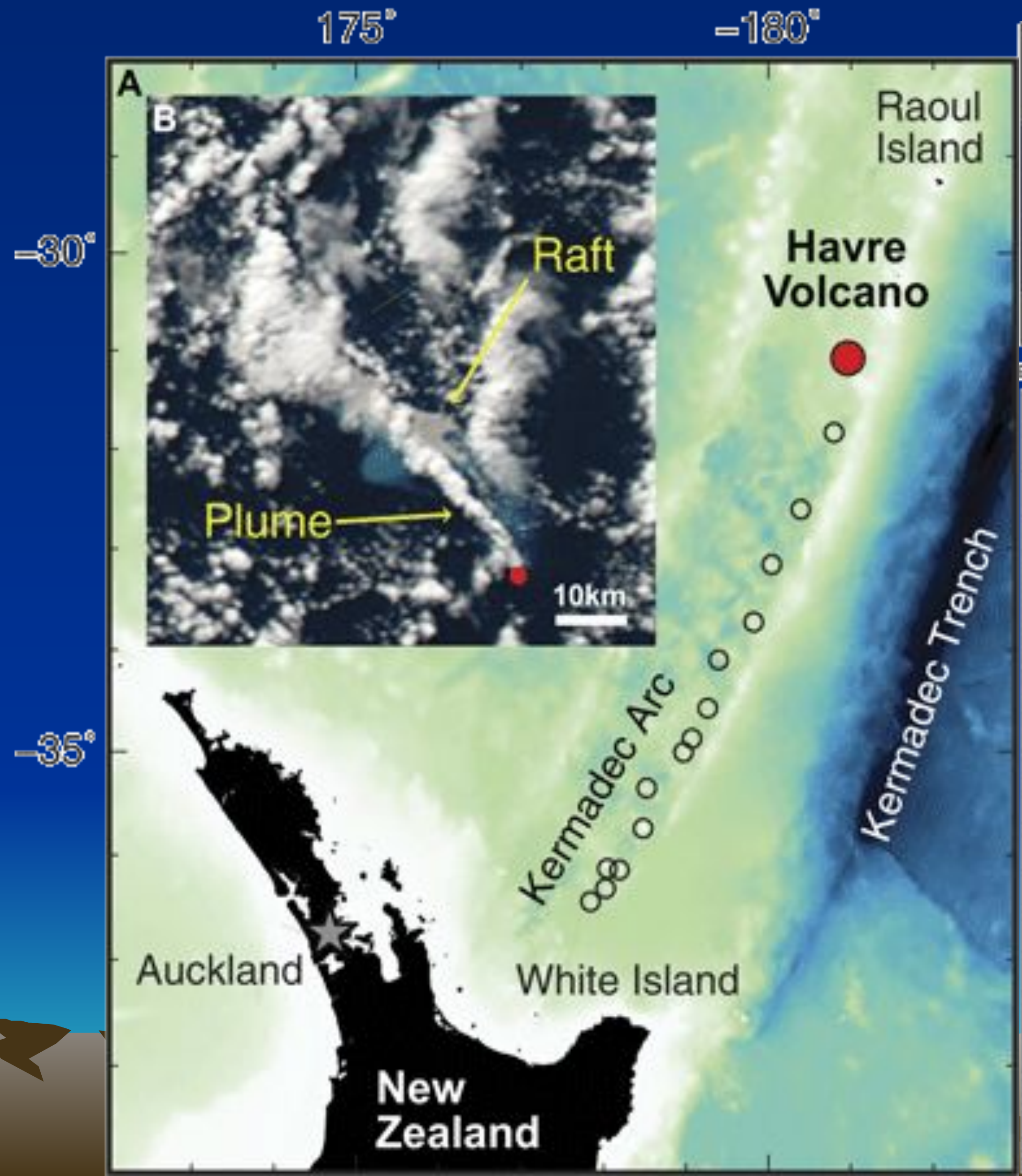
**New records for England & Wales –**
**wettest summer in 100 years**
**wettest week in last 50 years**
**explained by increase in storms**

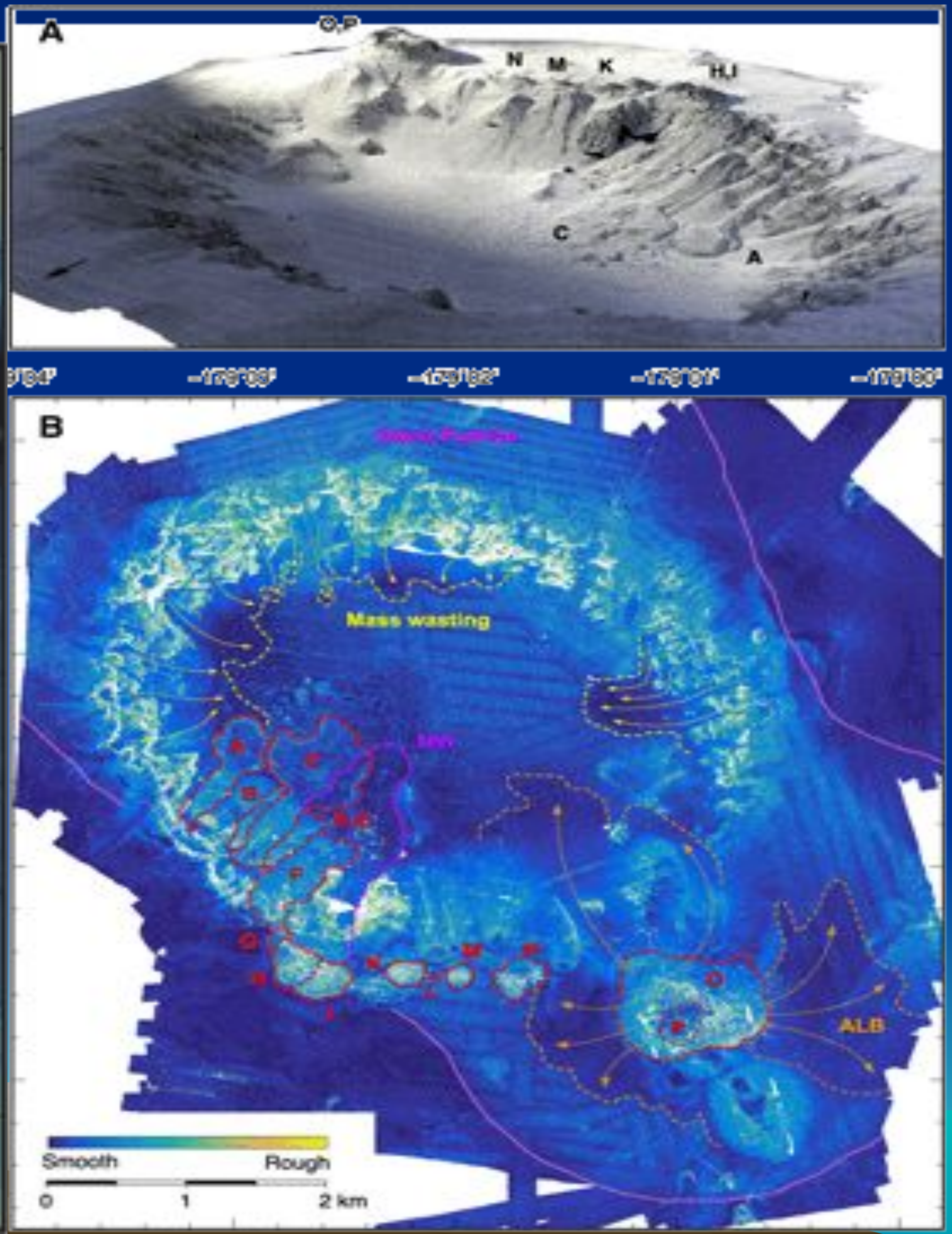


# *2012-2016 volcanic eruptions in the Pacific*

| Date | Volcano | Activity |
| --- | --- | --- |
| 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)



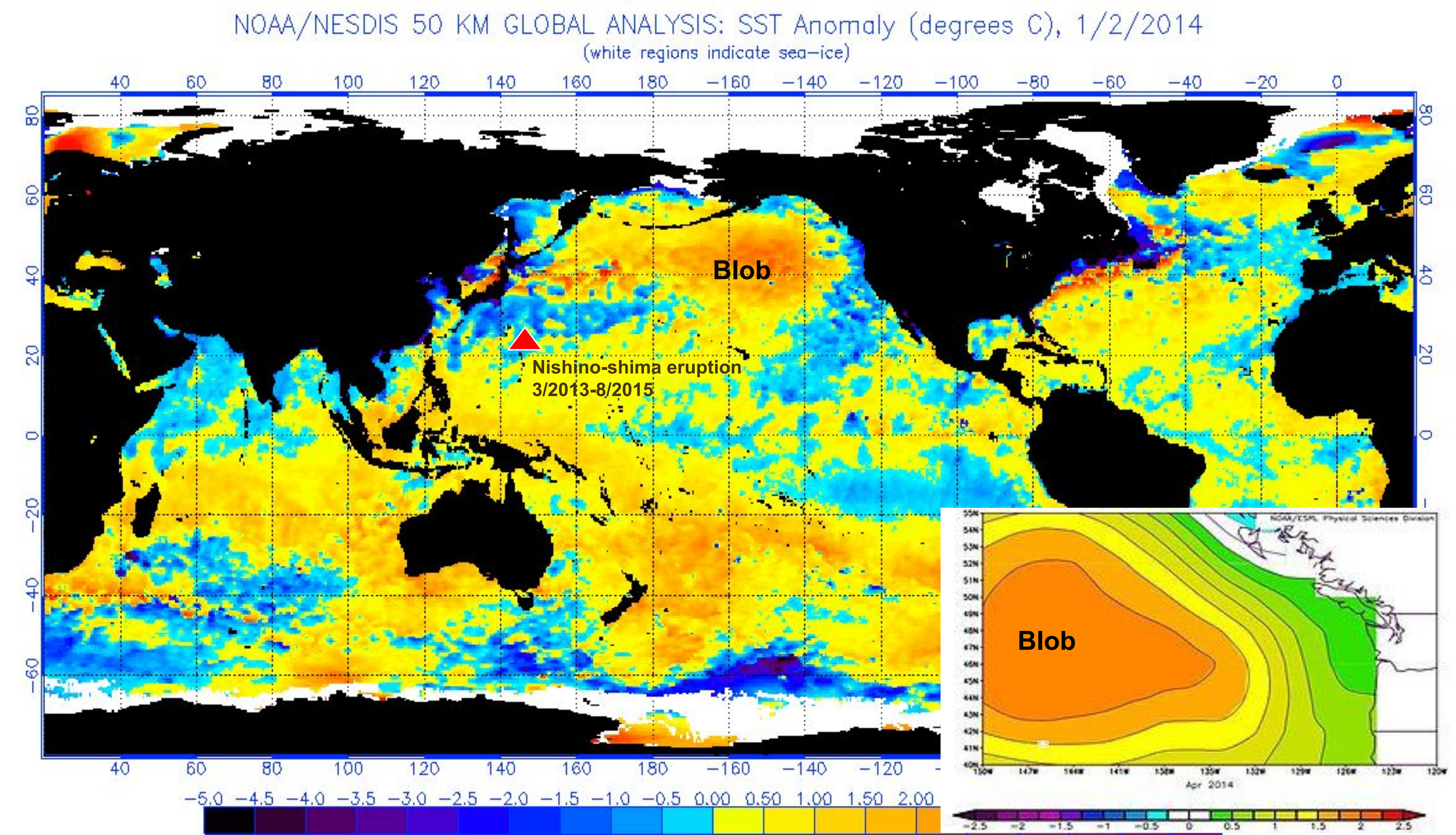



# Nishino-shima submarine/terrestrial eruption
# 940 km south of Tokyo
# March 2013 to August 2015

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


Image on December 8, 2013: NASA

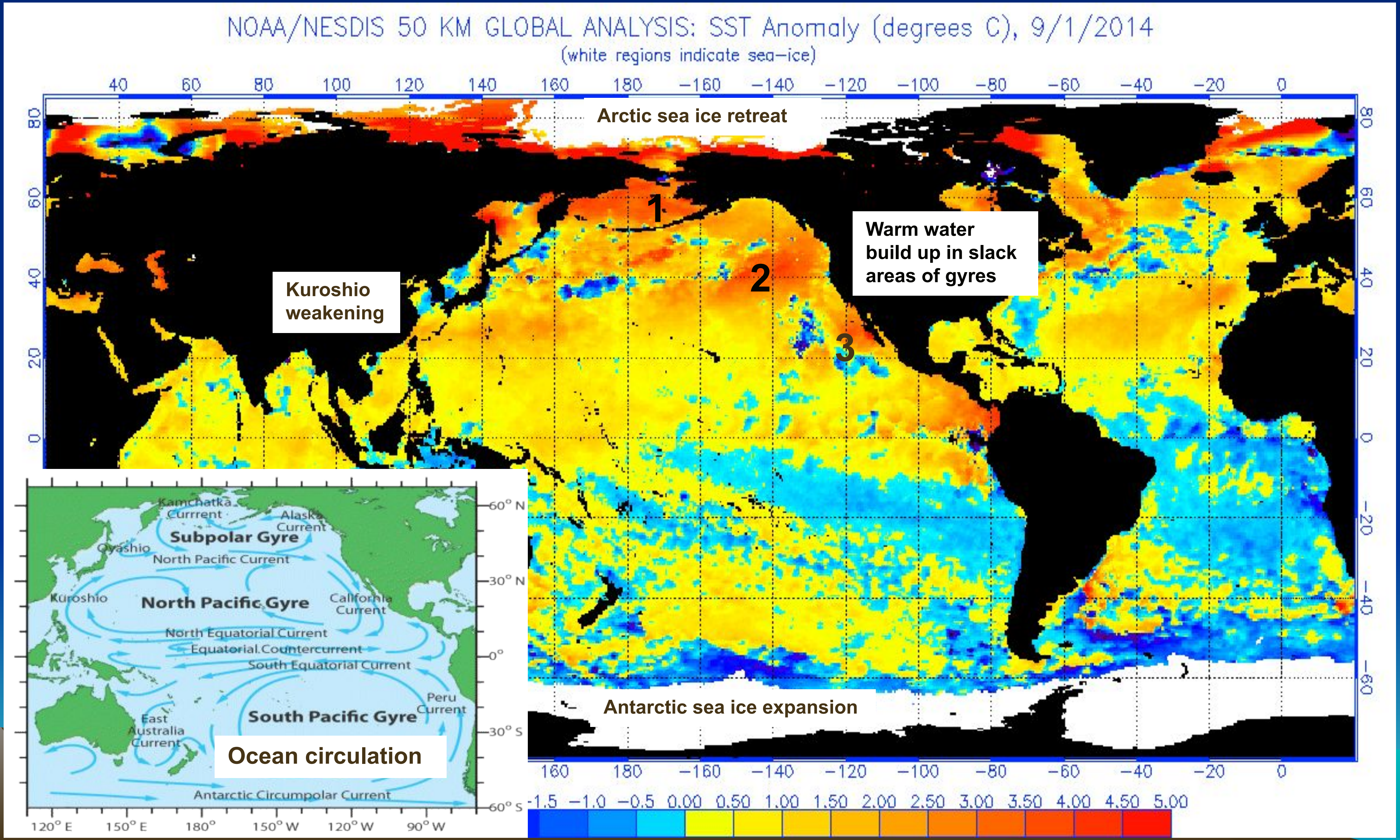
# Main trigger of 2014-2016 ENSO sea-surface temperature anomalies created the North Pacific Blob on January 2, 2014



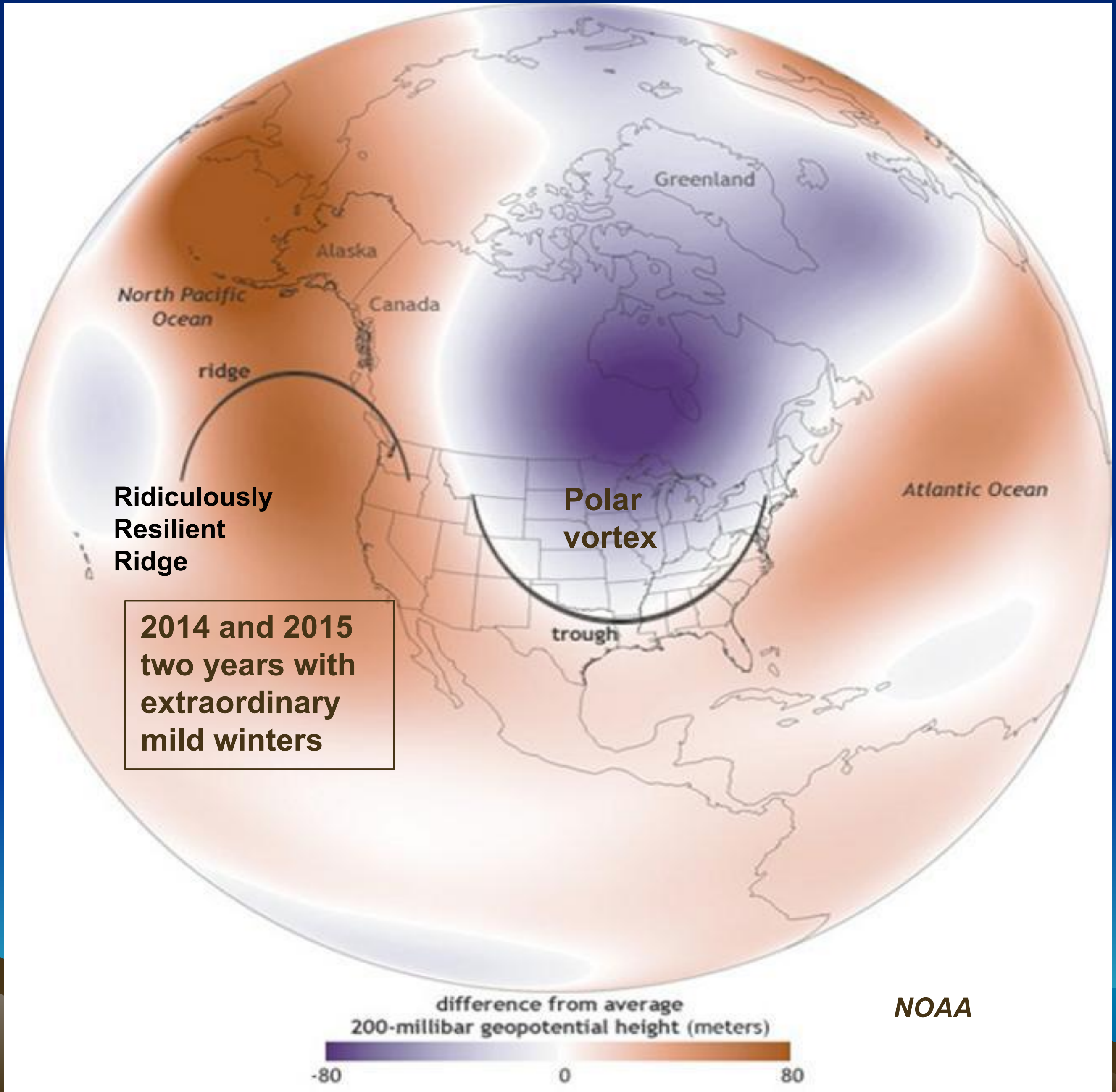
# Events linking the Blob to the Nishino-shima eruption

| 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*




*NOAA*


Heat wave
National Geographic
September 2016
Dead sea lion


Dying sea otter


Starving sea lion pups


Mass mortal ty of sea otters


Carcass of orca


Food pattern change
for octopus


Dying eel


Mass mortality of crabs


Spawning squids off Alaska


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

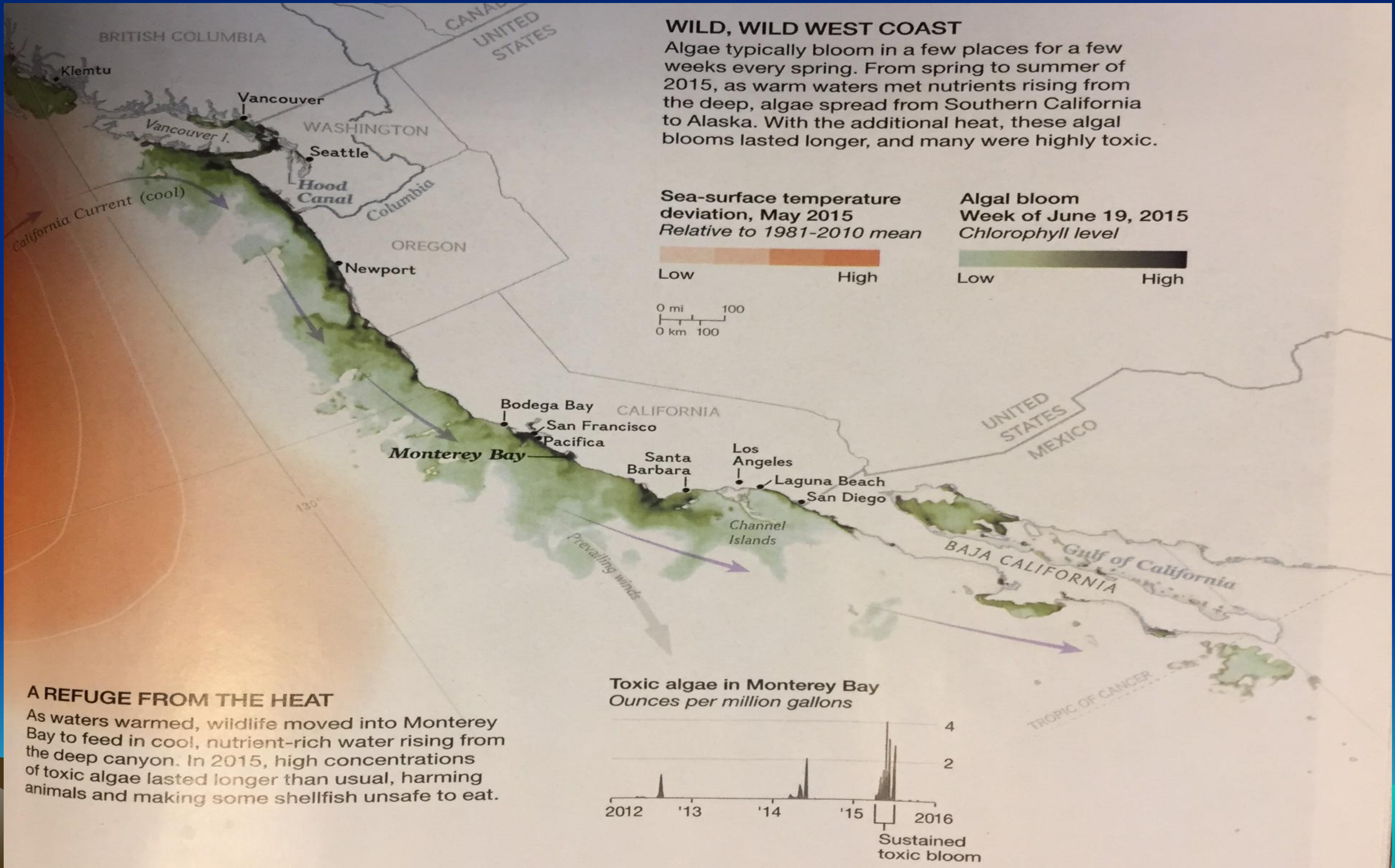
Food chain effect

Salmon catches dropped drastically

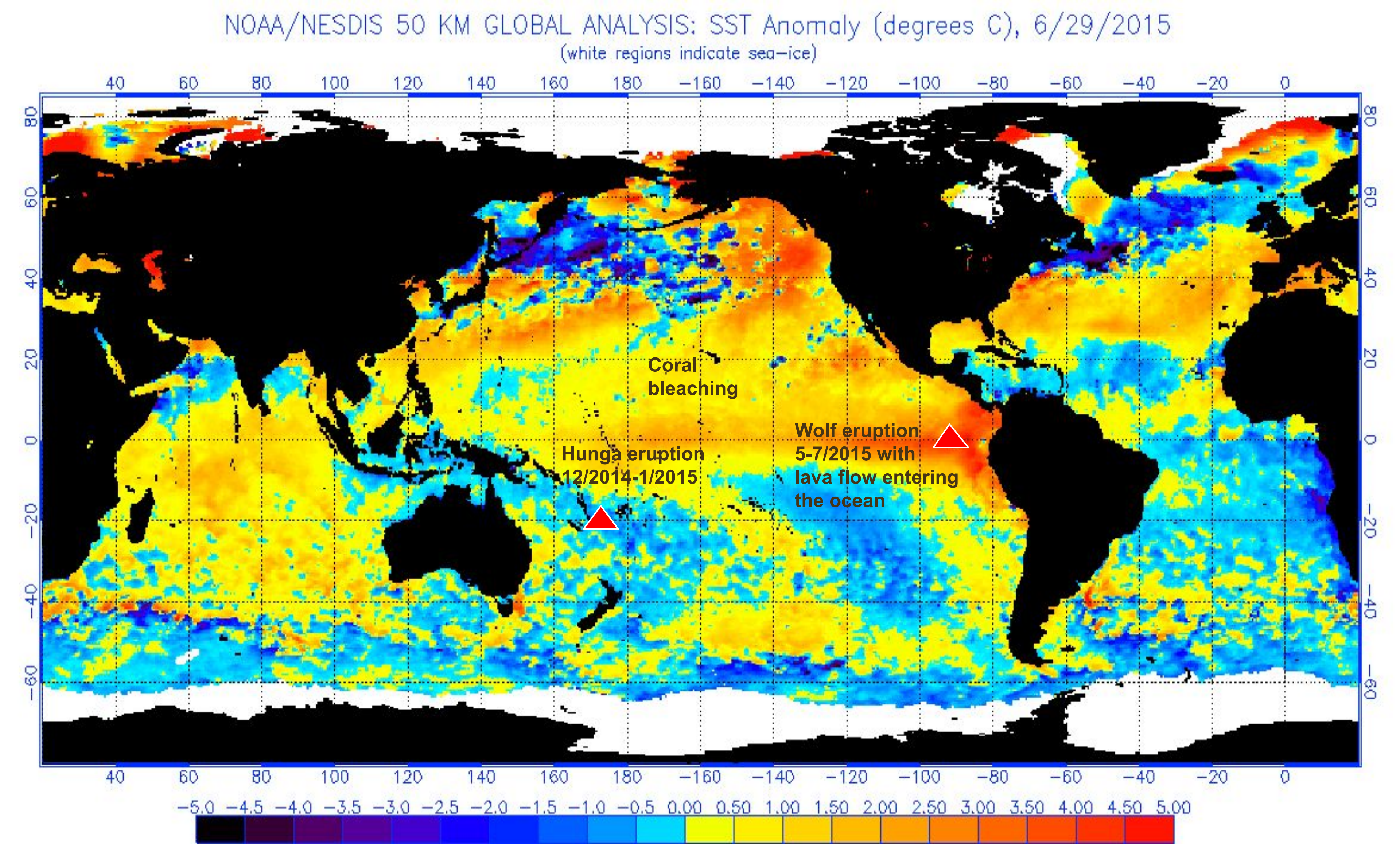
Death of almost 1 million birds between summer 2015 to Spring 2016 (reported by the Guardian on January 16, 2020)

Tropical organisms including squids migrated to Alaskian coast

# Toxic algal bloom along the west coast of North America



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

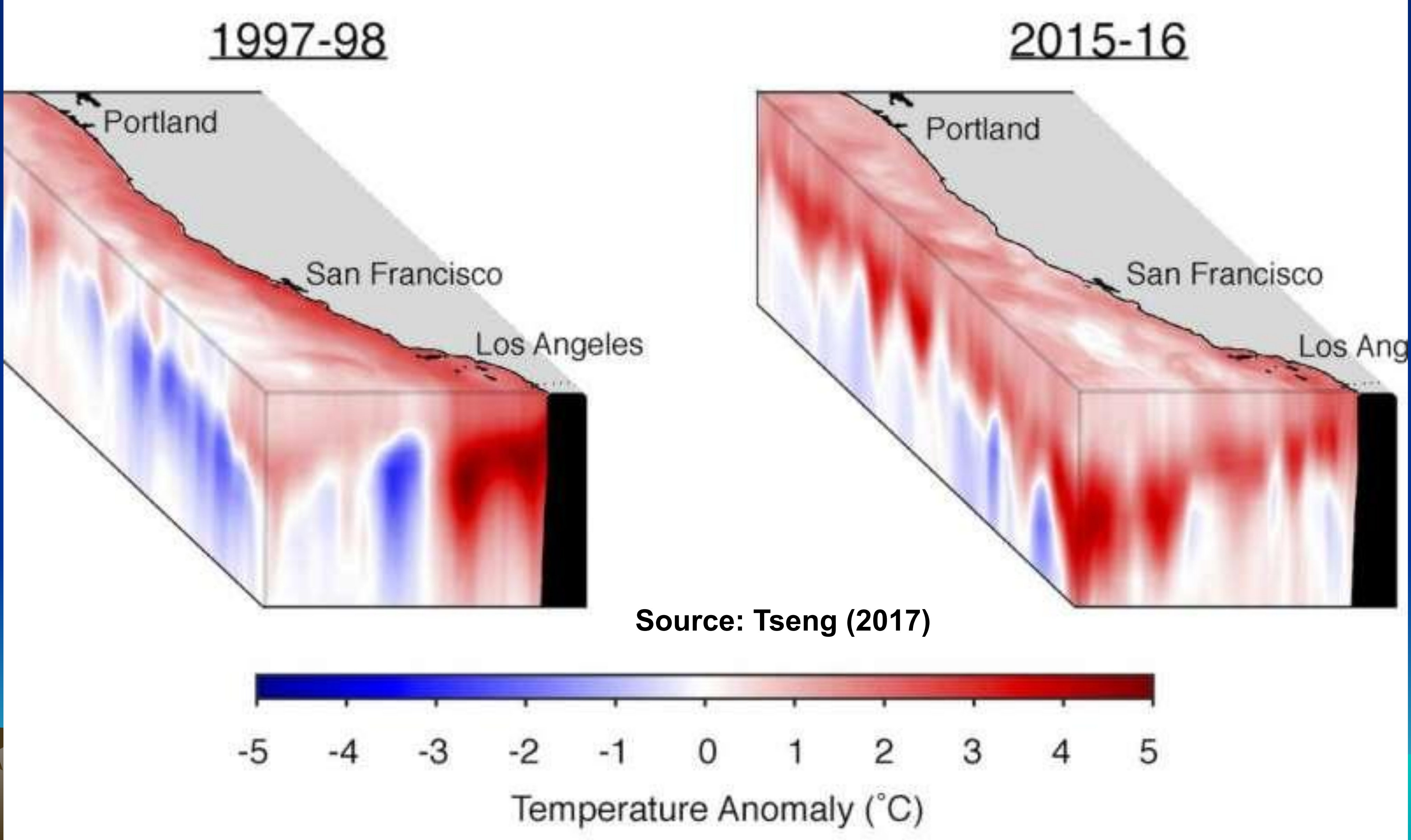


# *A natural cause of Great Barrier Reef coral bleaching in January 2015*


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

# ENSO 2014-2016 was stronger because of the Blob

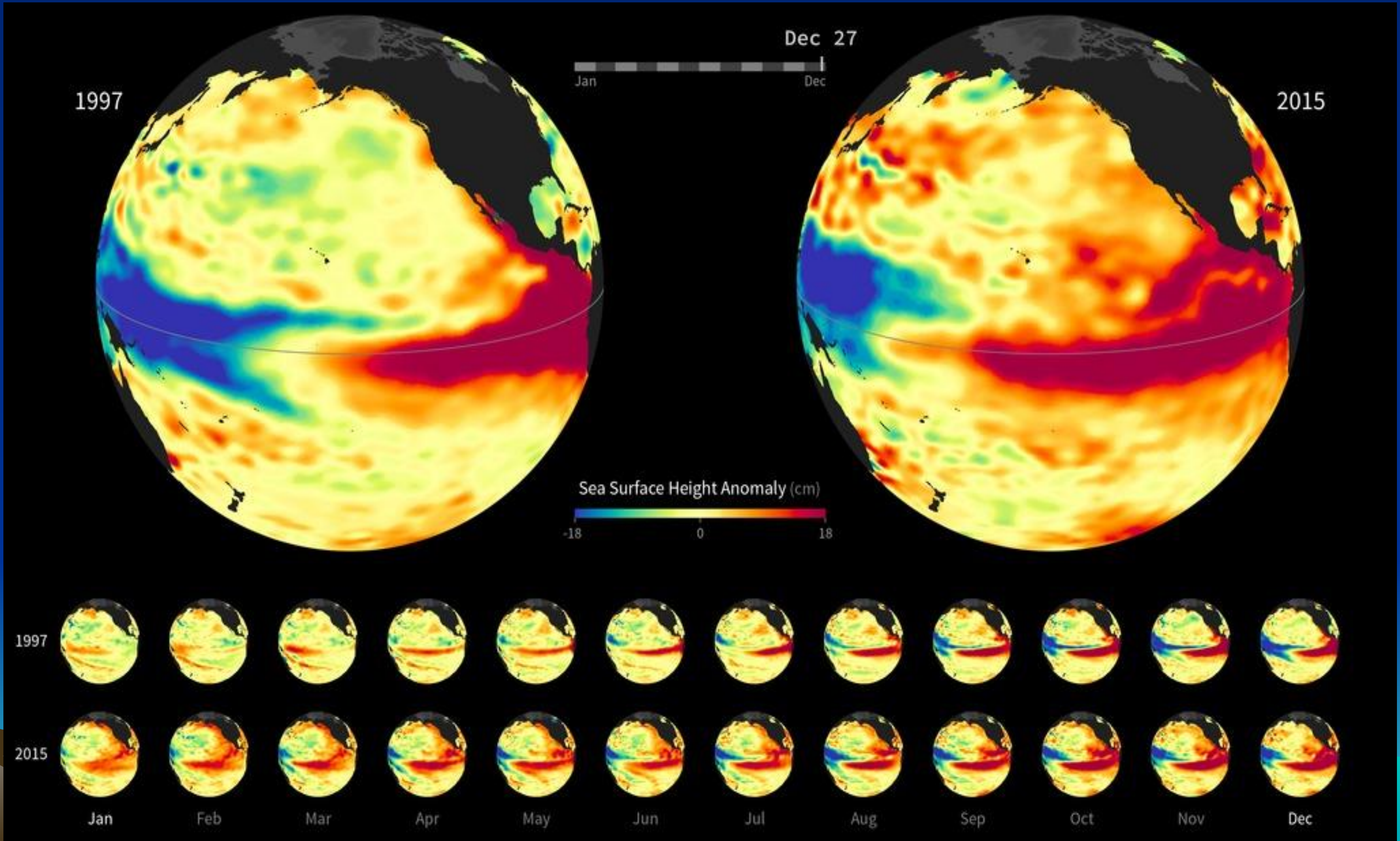
*comparison of seawater temperature anomaly US west coast*



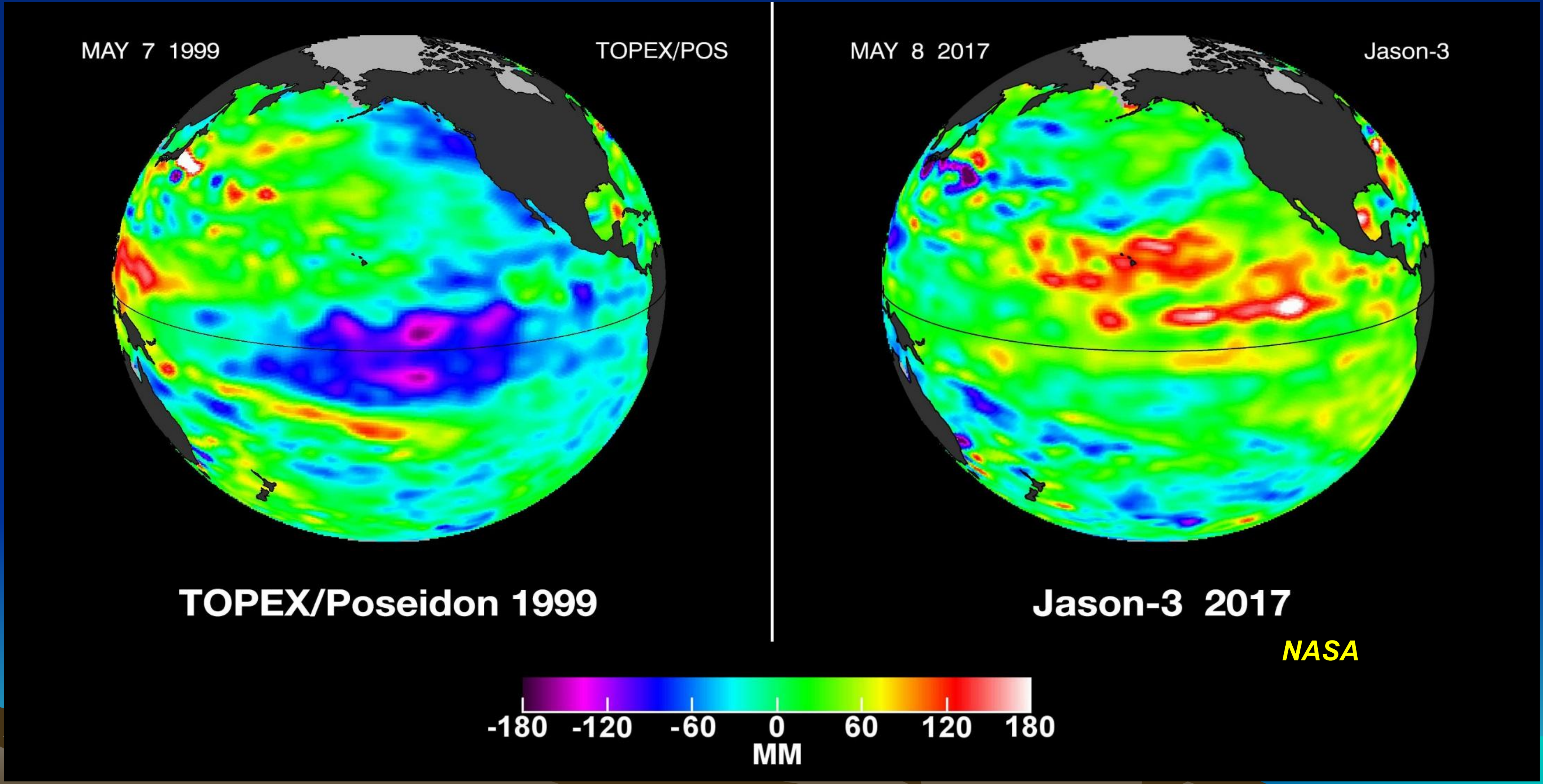

Source: Tseng (2017)

# Comparison of sea-level anomaly 1997 and 2015

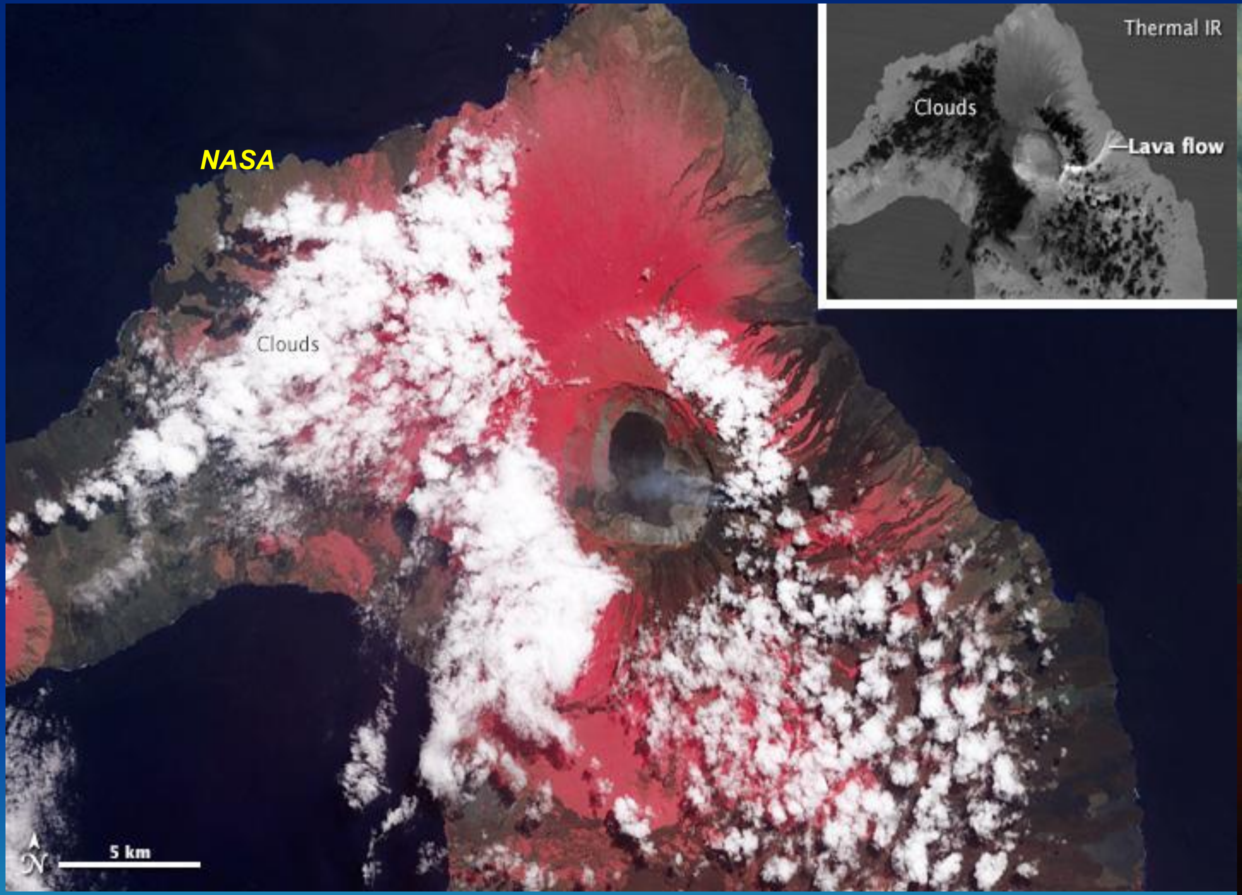
**Source: Jentoft-Nilsen (2015)**

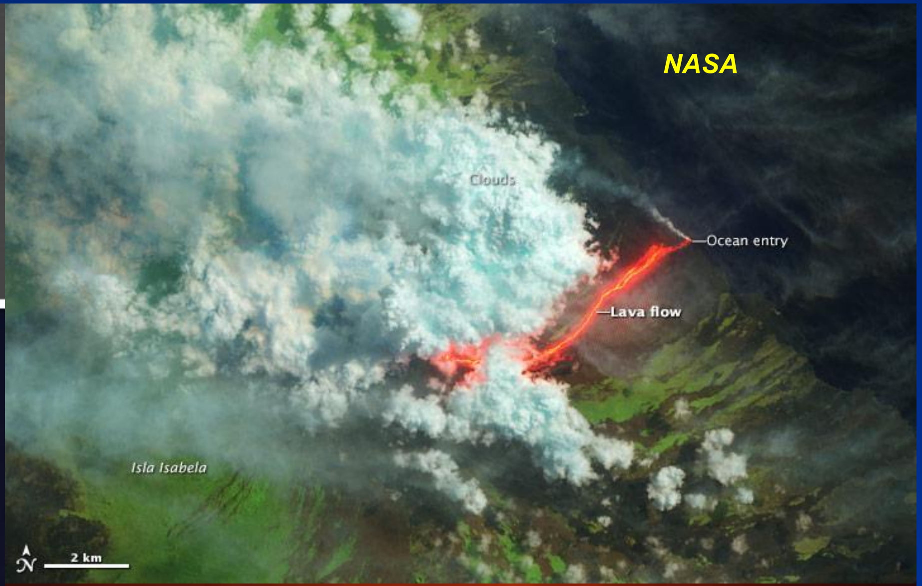


# Comparison of ocean surface topography during El Niño 1997-1998 and 2015-2016

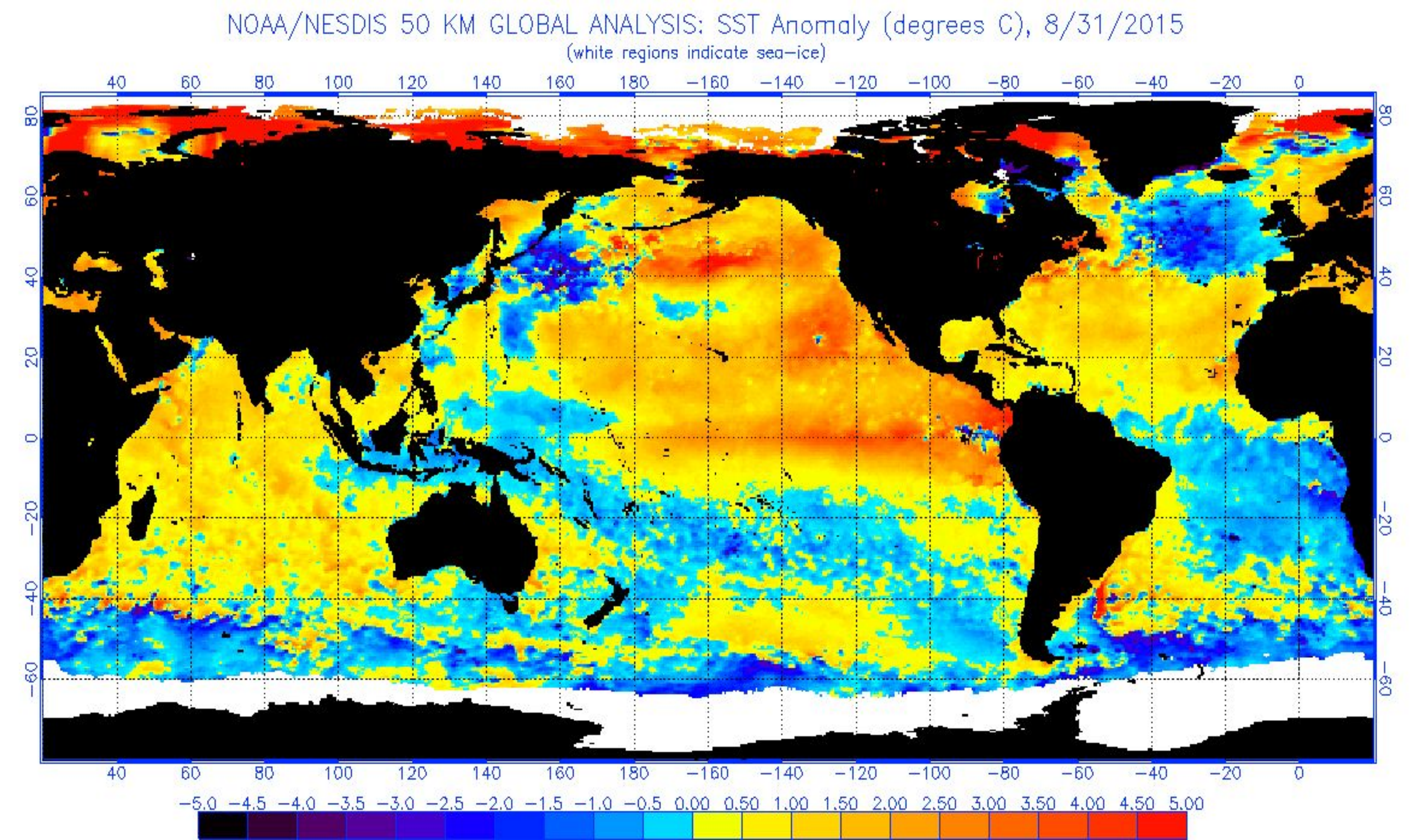


# Eruption of Wolf volcano, Galapagos late May to June 2015 VEI 4



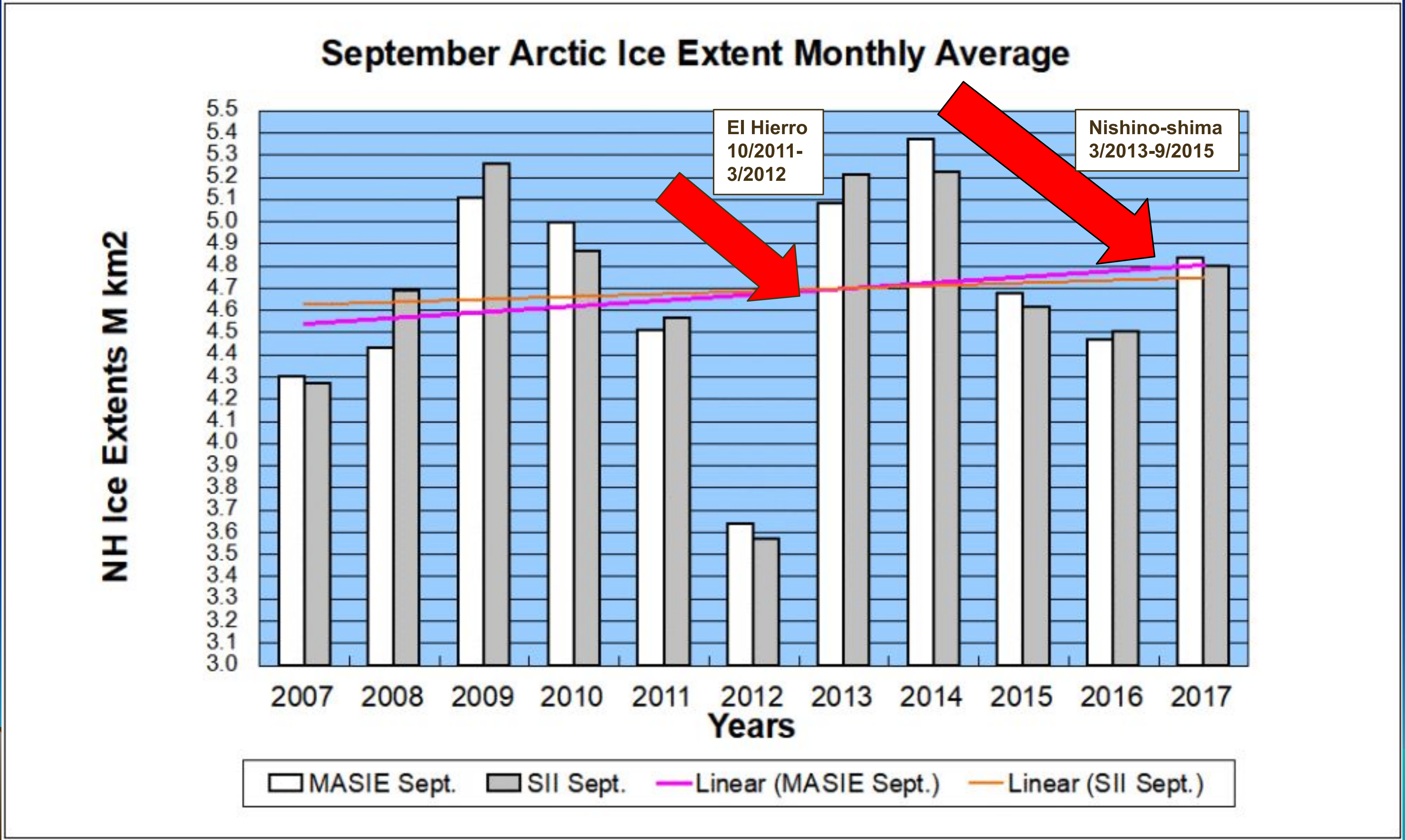

# *Establishment of the strong and long-lasting 2014-2016 El Niño August 31, 2015*



# Arctic sea ice changes 2007-2017

## *Explained by the release of geothermal heat through volcanism*

(Source: Clutz 2017)

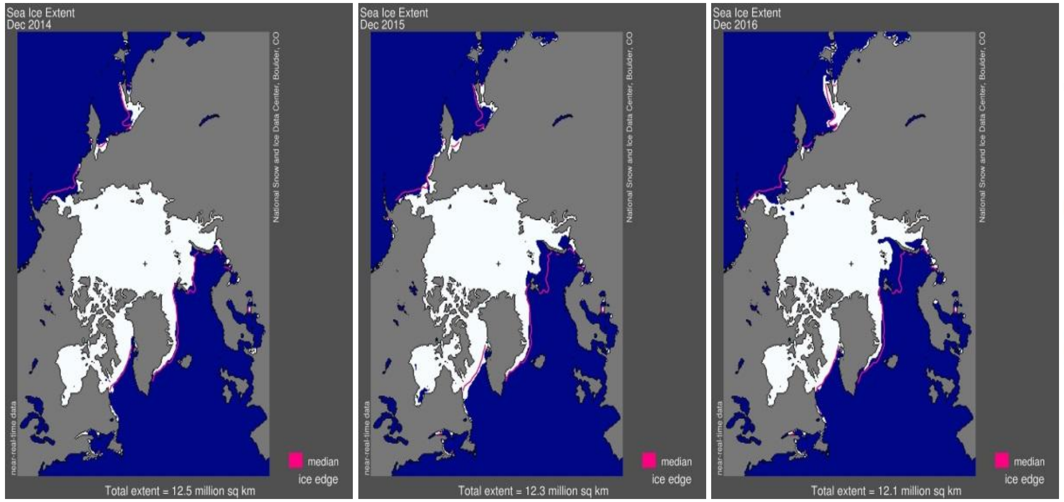


# Arctic sea ice extent 2007-2016
# Source: National Snow & Ice Data Centre

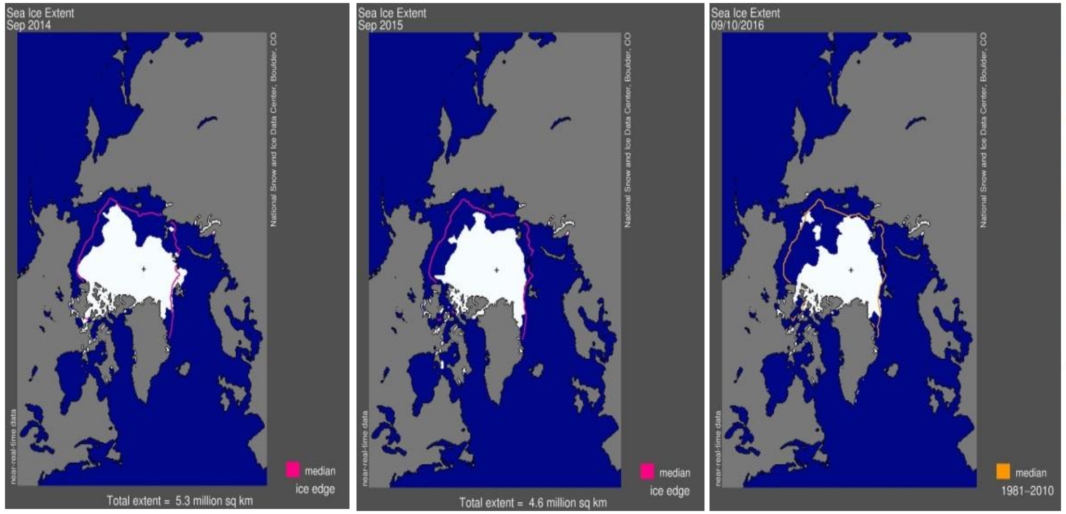
| YEAR | MINIMUM ICE EXTENT | | DATE |
|---|---|---|---|
| | IN MILLIONS OF SQUARE KILOMETERS | IN MILLIONS OF SQUARE MILES | |
| 2007 | 4.15 | 1.6 | Sept. 18 |
| 2008 | 4.59 | 1.77 | Sept. 20 |
| 2009 | 5.12 | 1.98 | Sept. 13 |
| 2010 | 4.62 | 1.78 | Sept. 21 |
| 2011 | 4.34 | 1.67 | Sept. 11 |
| 2012 | $\boxed{3.39}$ Record minimum | 1.31 | Sept. 17 |
| 2013 | 5.06 | 1.95 | Sept. 13 |
| **2014** | **5.03** | **1.94** | **Sept. 17** |
| **2015** | **4.43** Gradual decline | **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 |

# *Influence on minimum Arctic sea ice extent*

**Winter 2014-2016**




**Summer 2014-2016**




| YEAR | MINIMUM ICE EXTENT | | DATE |
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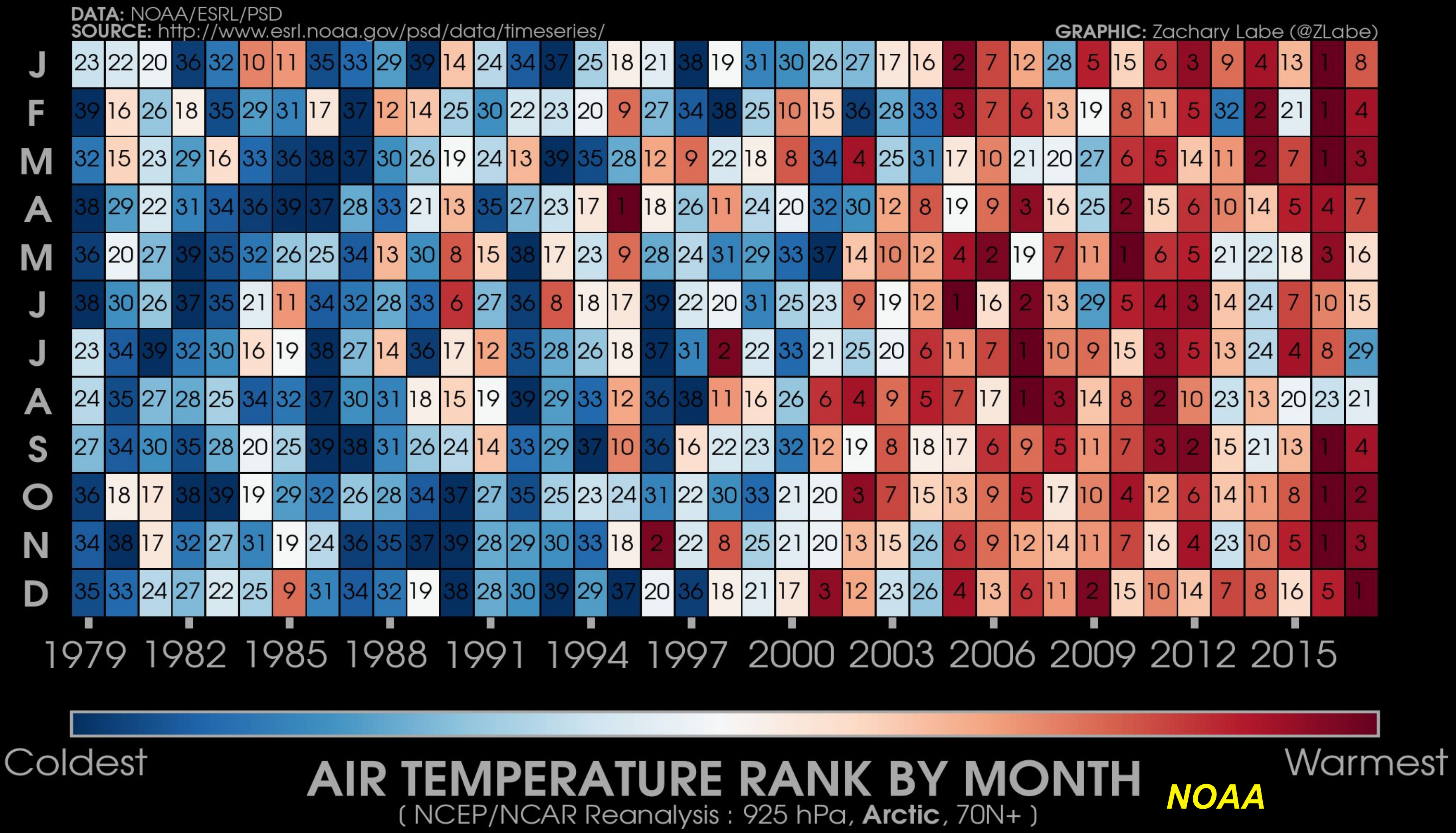
| 1979 to 2000 average | 6.7 | 2.59 | Sept. 13 |
| 1981 to 2010 average | 6.22 | 2.4 | Sept. 15 |

**Source: NISDC.org**

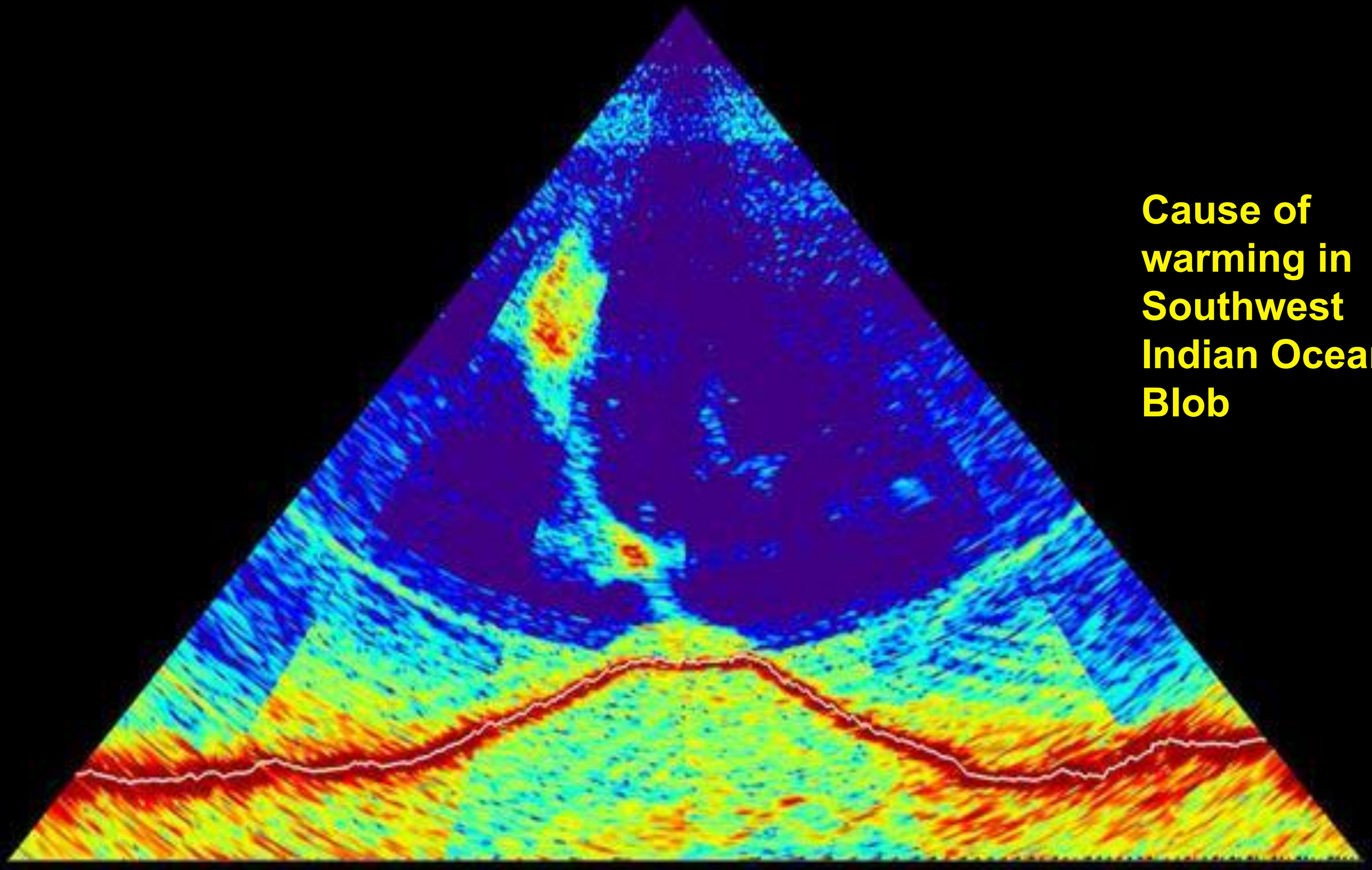
# *Ranking of Arctic monthly air temperatures 1979-2017*




*NOAA*

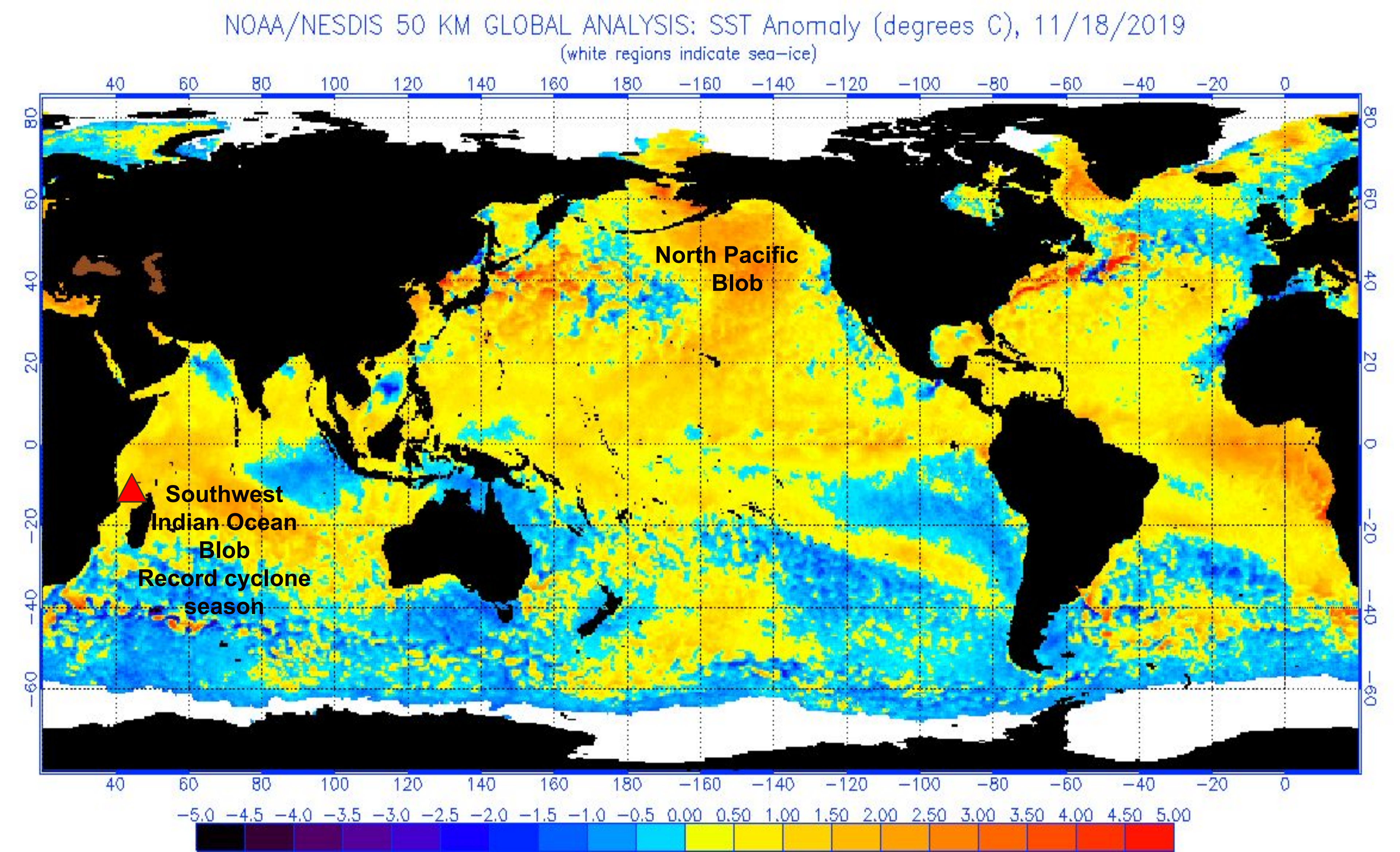
# New submarine volcanic eruption discovered in the Mozambique Channel November 2018-May 2019


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

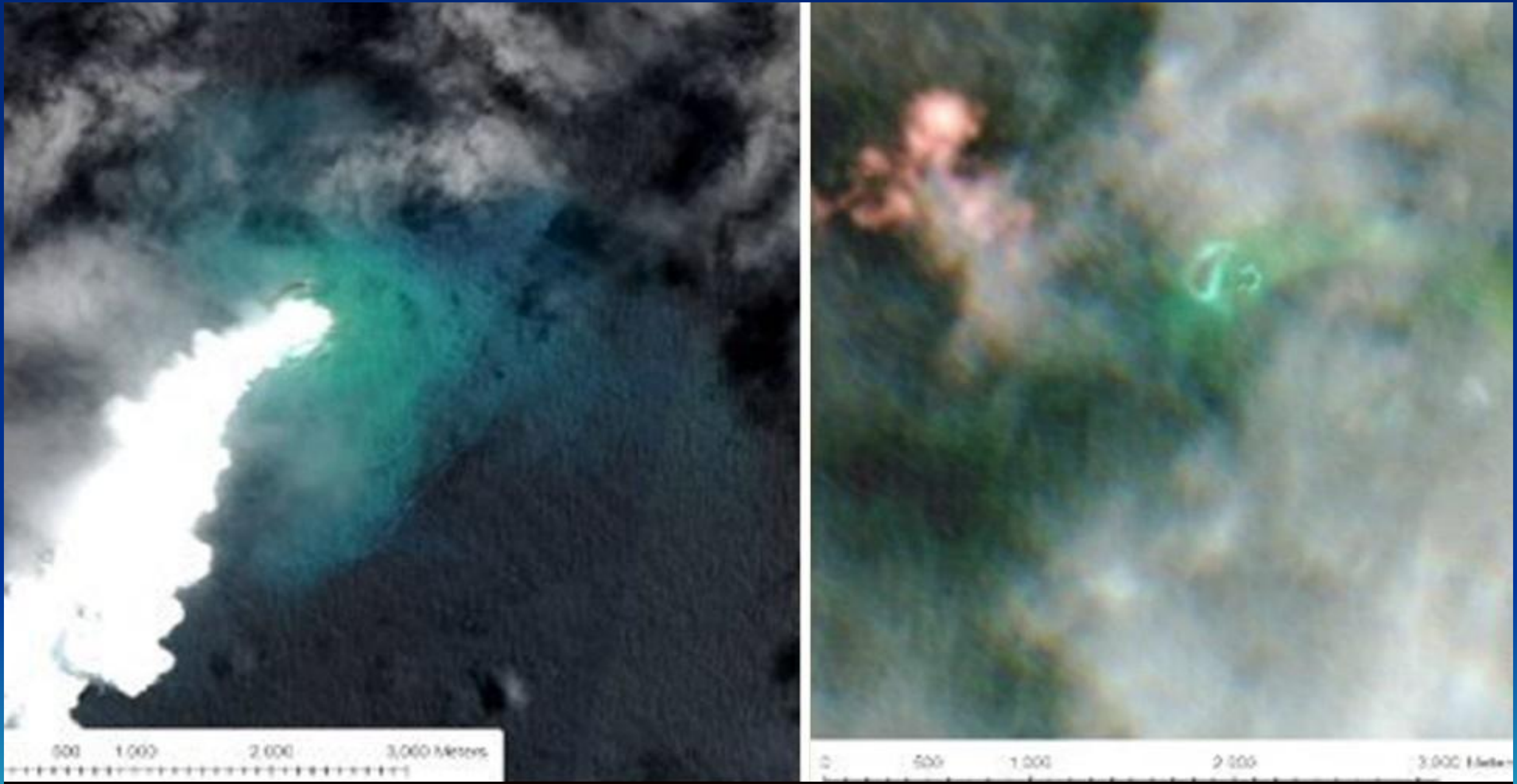


**Cause of warming in Southwest Indian Ocean Blob**

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

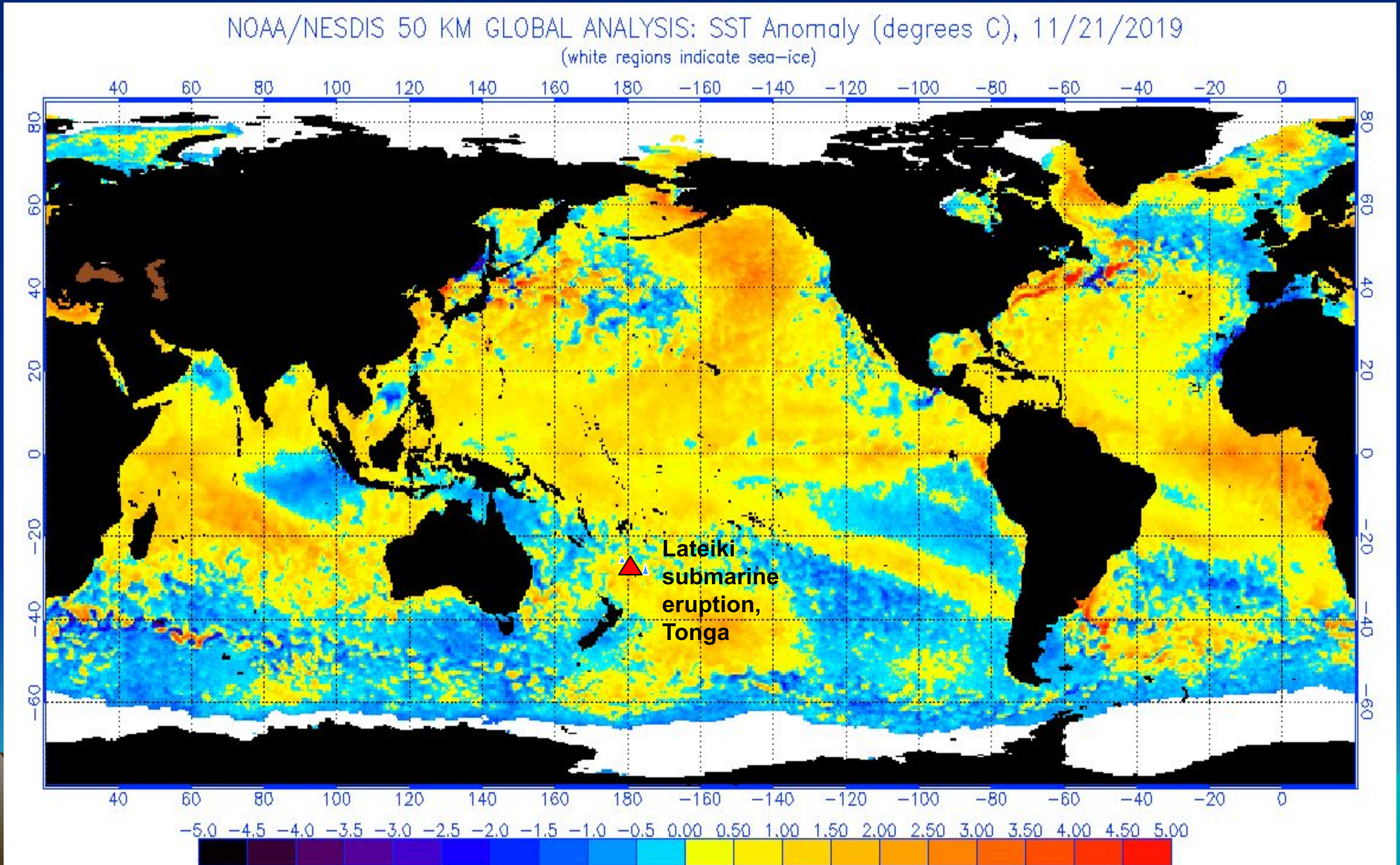


# Lateiki submarine eruption, Tonga
# new island created November 7, 2019

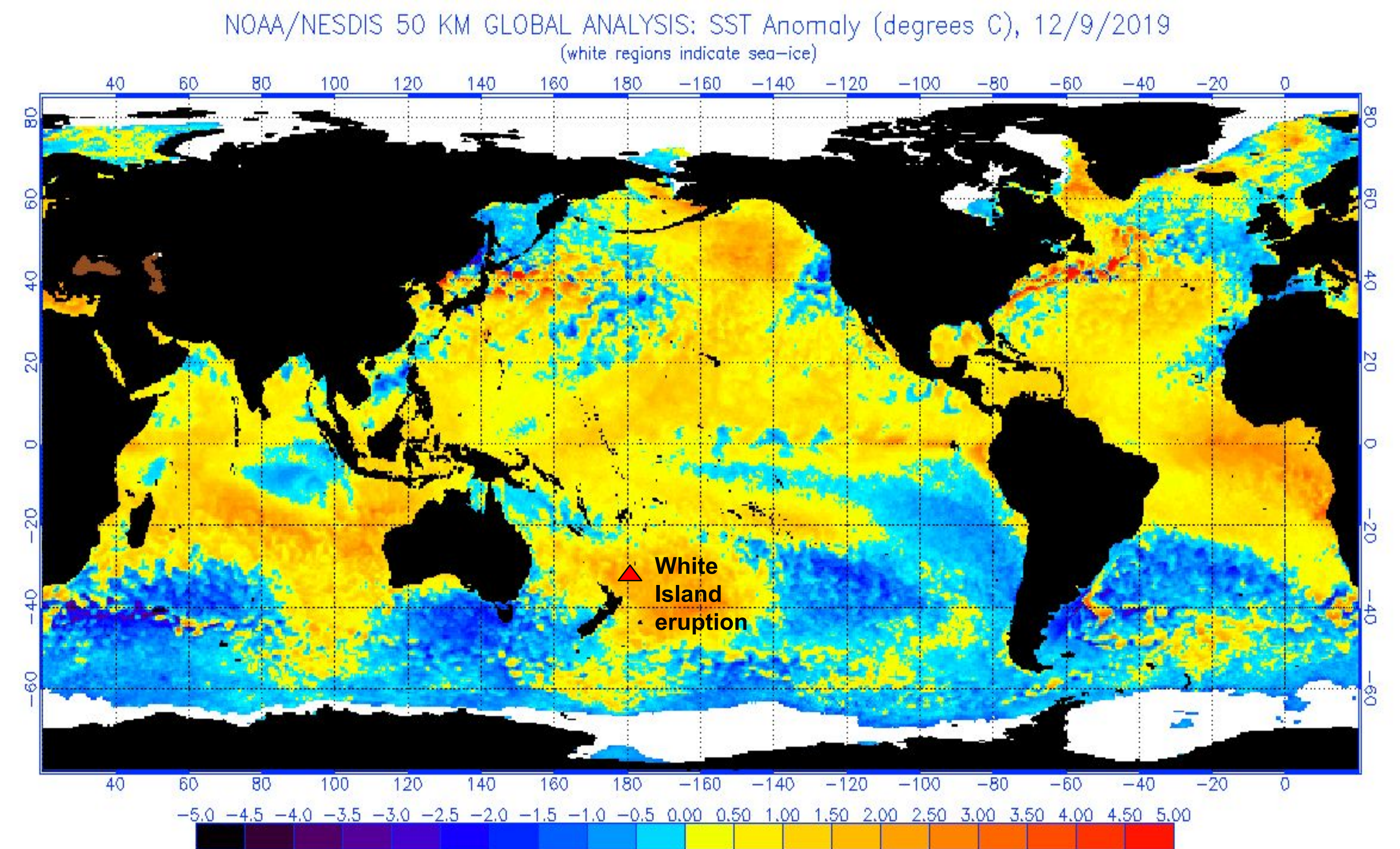



**Old island destroyed and replaced by a bigger new island**

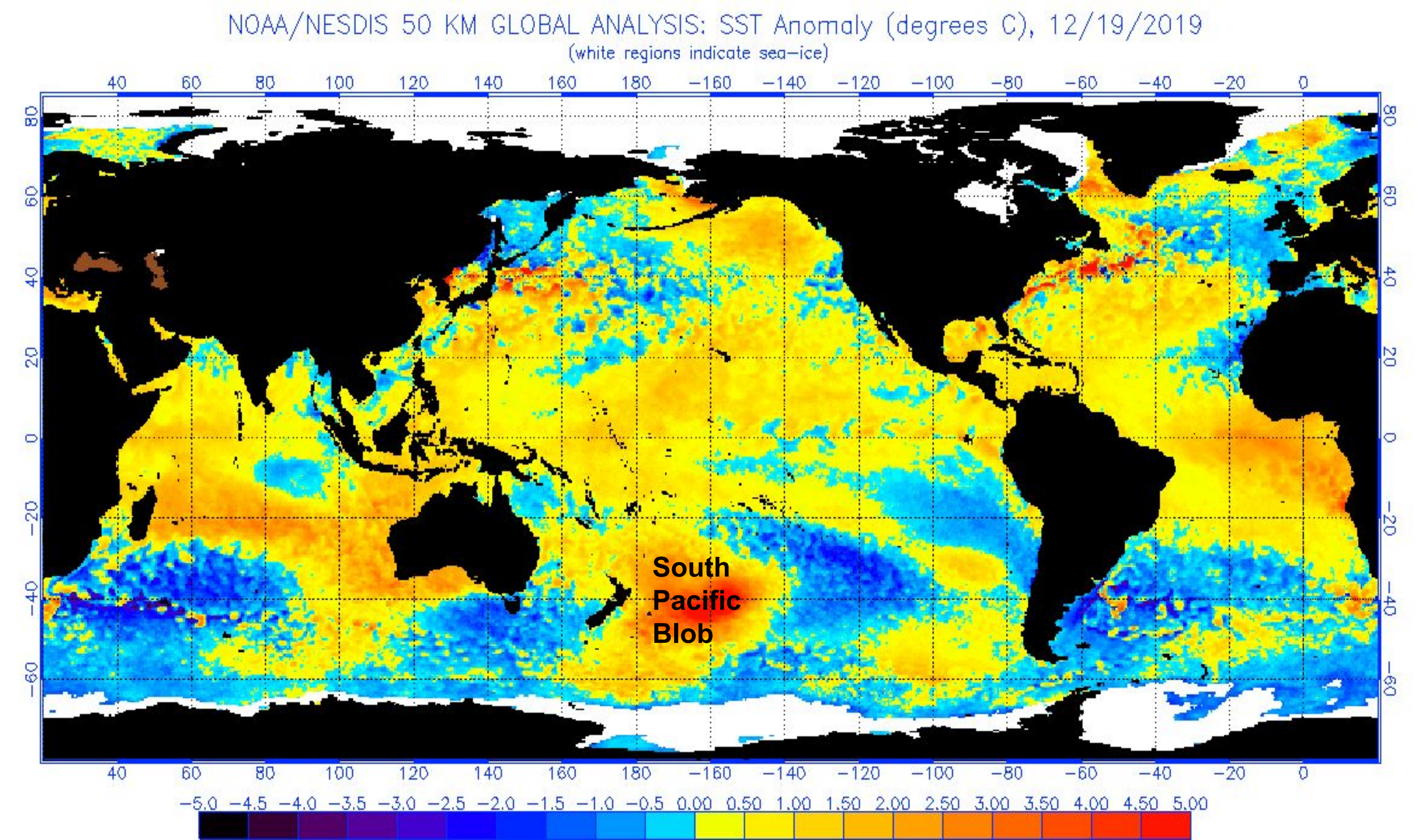
# Global map of sea-surface temperature anomalies on November 21, 2019



# 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)

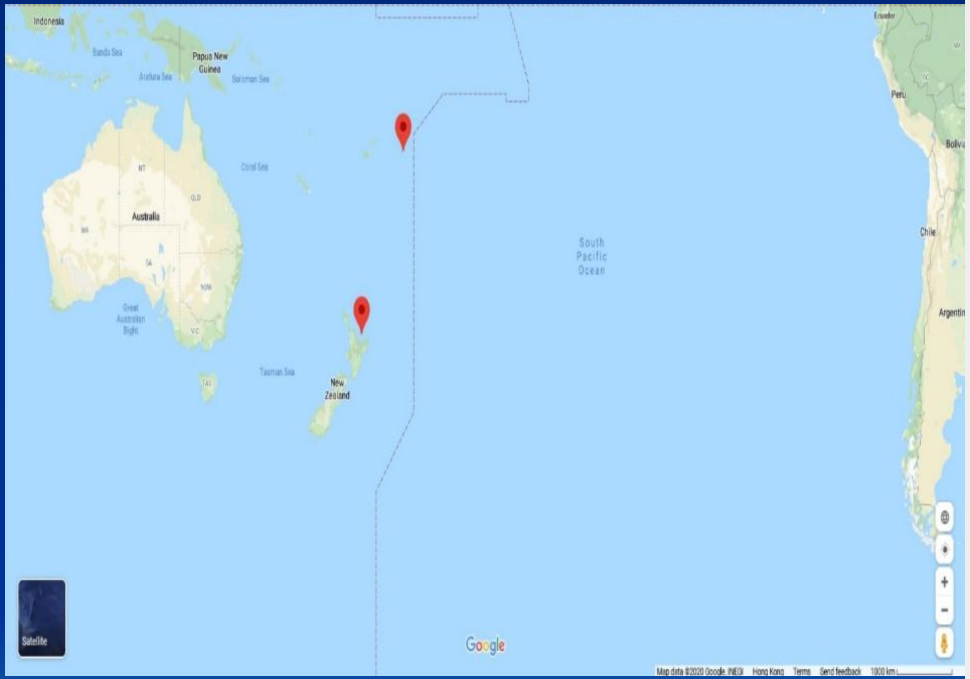
6 degree Celsius above normal

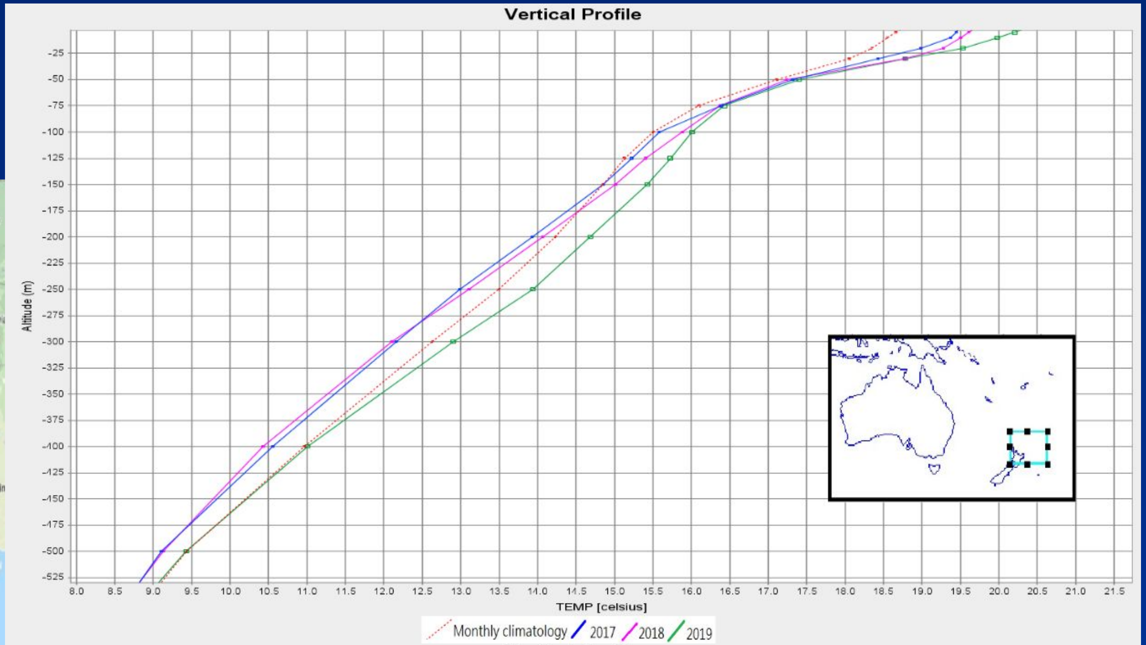
Total thickness of hot seawater 50 metres

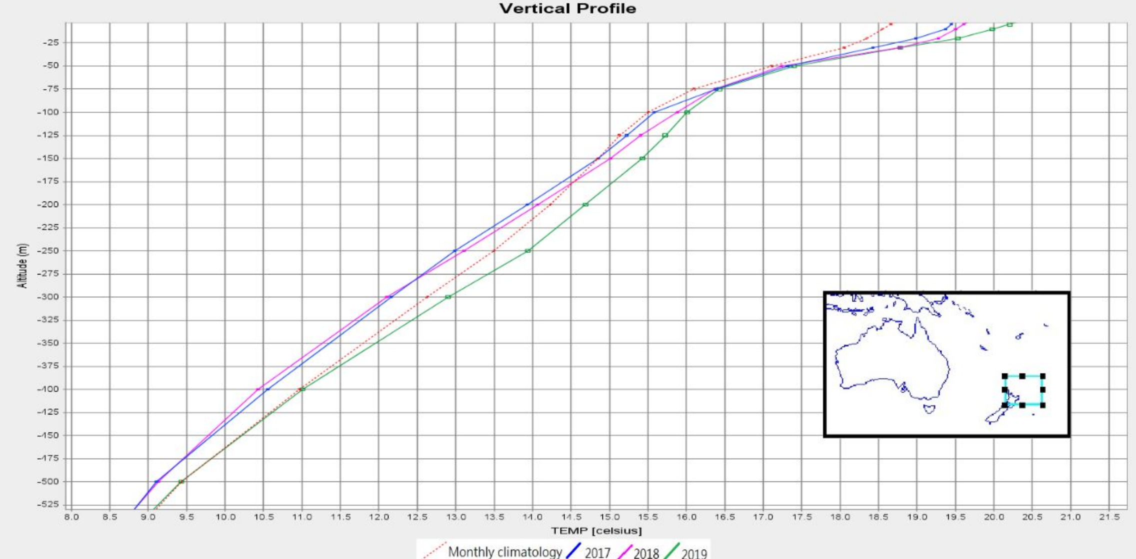
Prof. J. Renwick – Heated by the sun through natural causes not by global warming

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

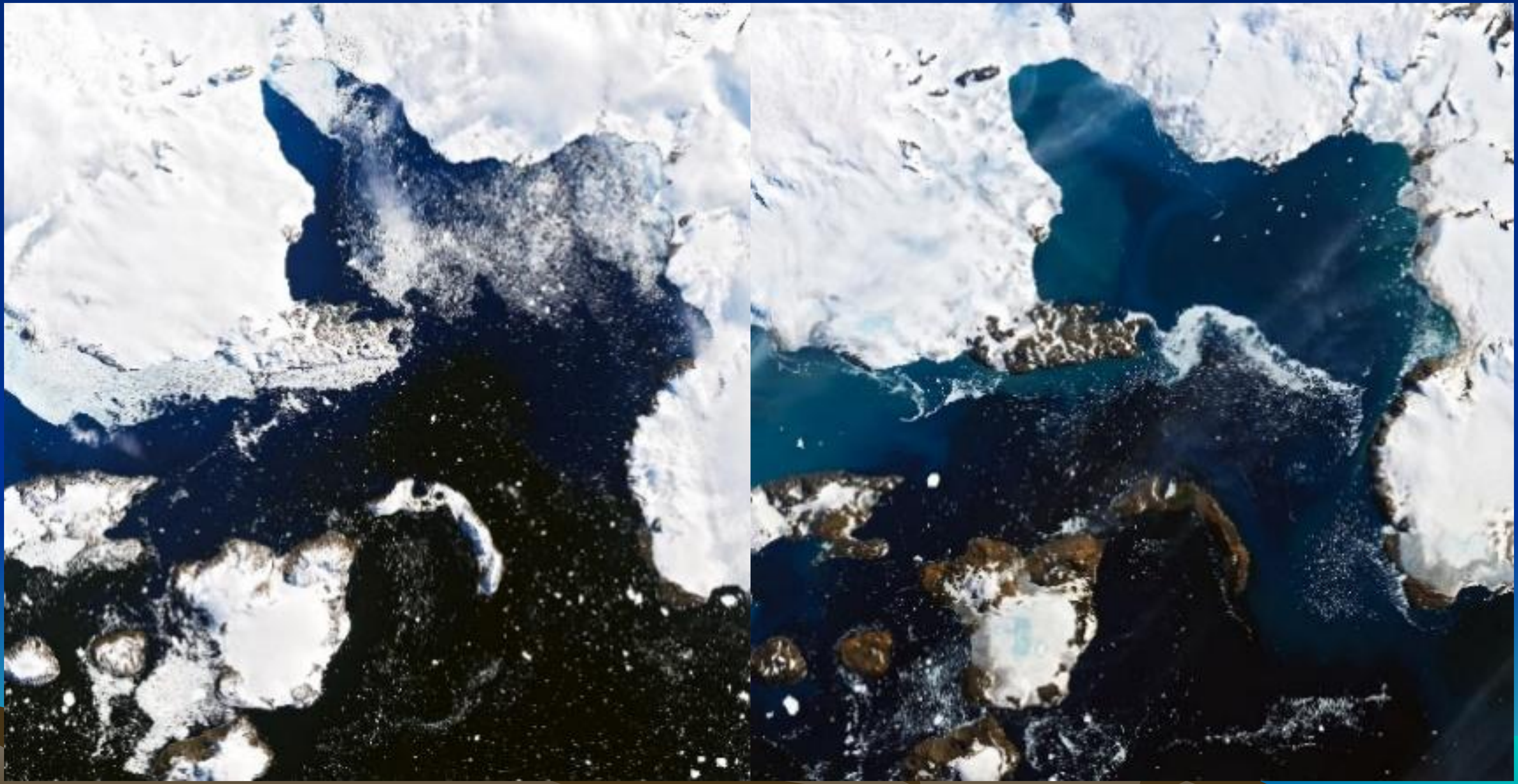
# Submarine volcanic eruptions contributing geothermal heat to the South Pacific Blob



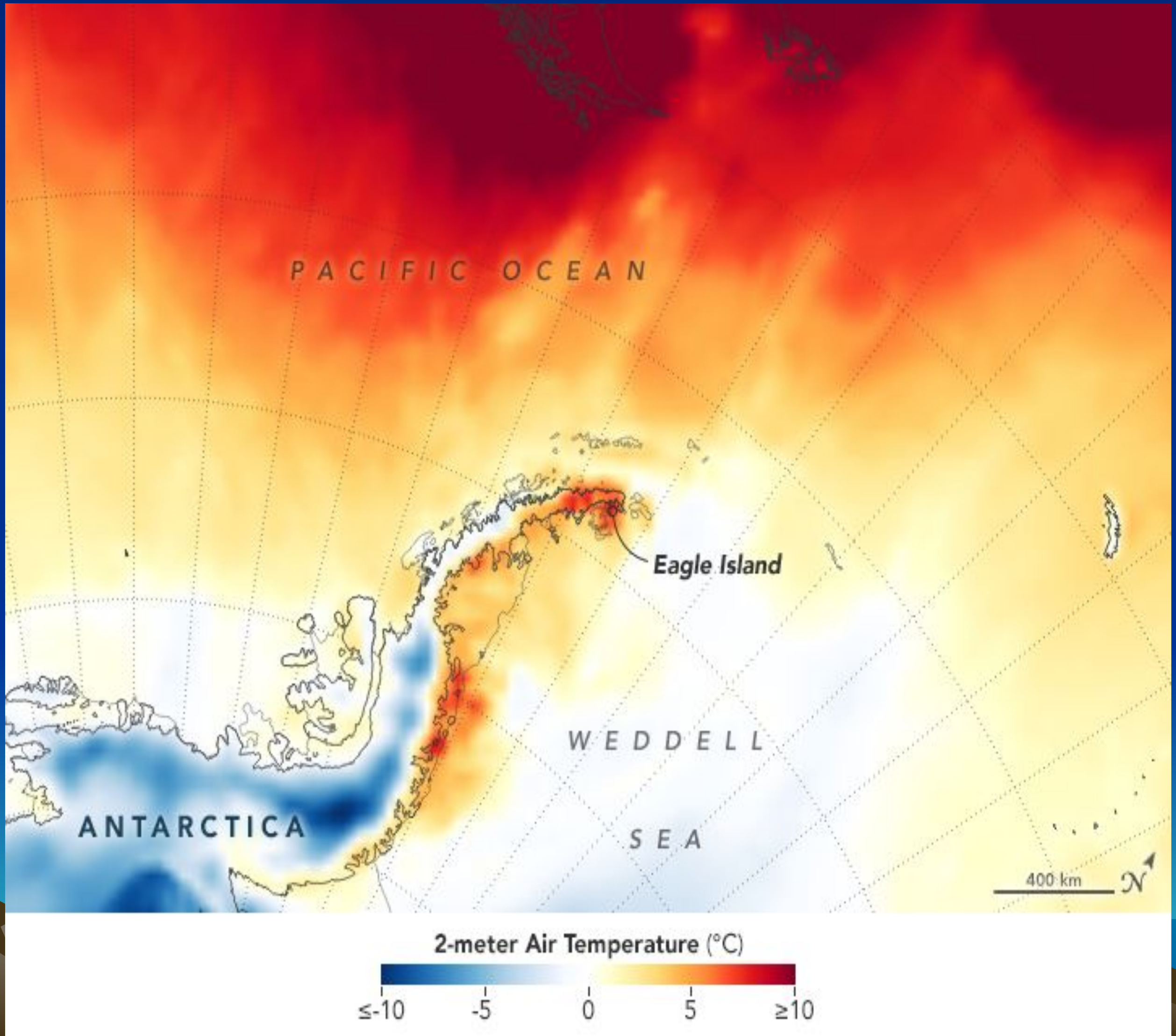



**Landsat images showing dramatic melting in the Eagle Island region of Antarctica on February 4, 2020 in comparison to February 13, 2020. Source: NASA**



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



# 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.