How And Why Pandemics Happen

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HREM, Oahu, March 10, 2025

Disclosures

I have nothing to disclose

Ten Deadliest Natural Disasters*

Rank	Death toll (est.)	Cause	Location	Date
1.	~7 million	Flood	China (Yellow River)	1332 - 1333
2.	1 – 4 million	Flood	China	1931 (July)
3.	900,000–2,000,000	Flood	China (Yellow River)	1987 (September)
4.	830,000	Earthquake	China (Shaanxi)	1556 (January 23)
5.	≥500,000	Cyclone	Bangladesh (Bhola)	1970 (November 13)
6.	300,000	Cyclone	India	1839 (November 26)
7.	300,000	Cyclone	India (Calcutta)	1737 (October 7)
8.	242,769–655,000	Earthquake	China (Tangshan)	1976 (July 28)
9.	273,400	Earthquake	China (Haiyuan)	1920 (December 16)
10.	250,000–300,000	Earthquake	Byzantium (Antioch)	526 (May)

** Of Non-Biological Origin*

Deadliest Pandemics / Epidemics

Rank	Death toll (est.)	Disease	Location	Date
1.	~330 million	Tuberculosis	Worldwide	1900 – now
2.	~300 million	Smallpox	Worldwide	1900 – 1980
3.	~200 million	Measles	Worldwide	Last 150 yrs
4.	80 – 250 million	Malaria	Worldwide	1900 – now
5.	>50 million	2nd Yersinia pestis ("Black Death")	Worldwide	1320-1879
6.	~50 million	Great Flu of 1918	Worldwide	1918 – 1920
7.	>40 million	Cholera	Worldwide	1817 - now
8.	>30 million	AIDS	Worldwide	1960 – now
9.	*7 – 37 million*	*COVID-19*	*Worldwide*	*2019 – now*
10.	>15 million	1st Yersinia pestis ("Plague of Justinian")	Eurasia, Africa	541 – 590
11.	~12 million	3rd Yersinia pestis	Worldwide	1898 – 1960
12.	>5 million	Antonine Plague	Roman Empire	165 – 180

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6.	*~50 million*	*Great Flu of 1918*	*Worldwide*	*1918 – 1920*
7.	*>40 million*	*Cholera*	*Worldwide*	*1817 - now*
8.	>30 million	AIDS	Worldwide	1960 – now
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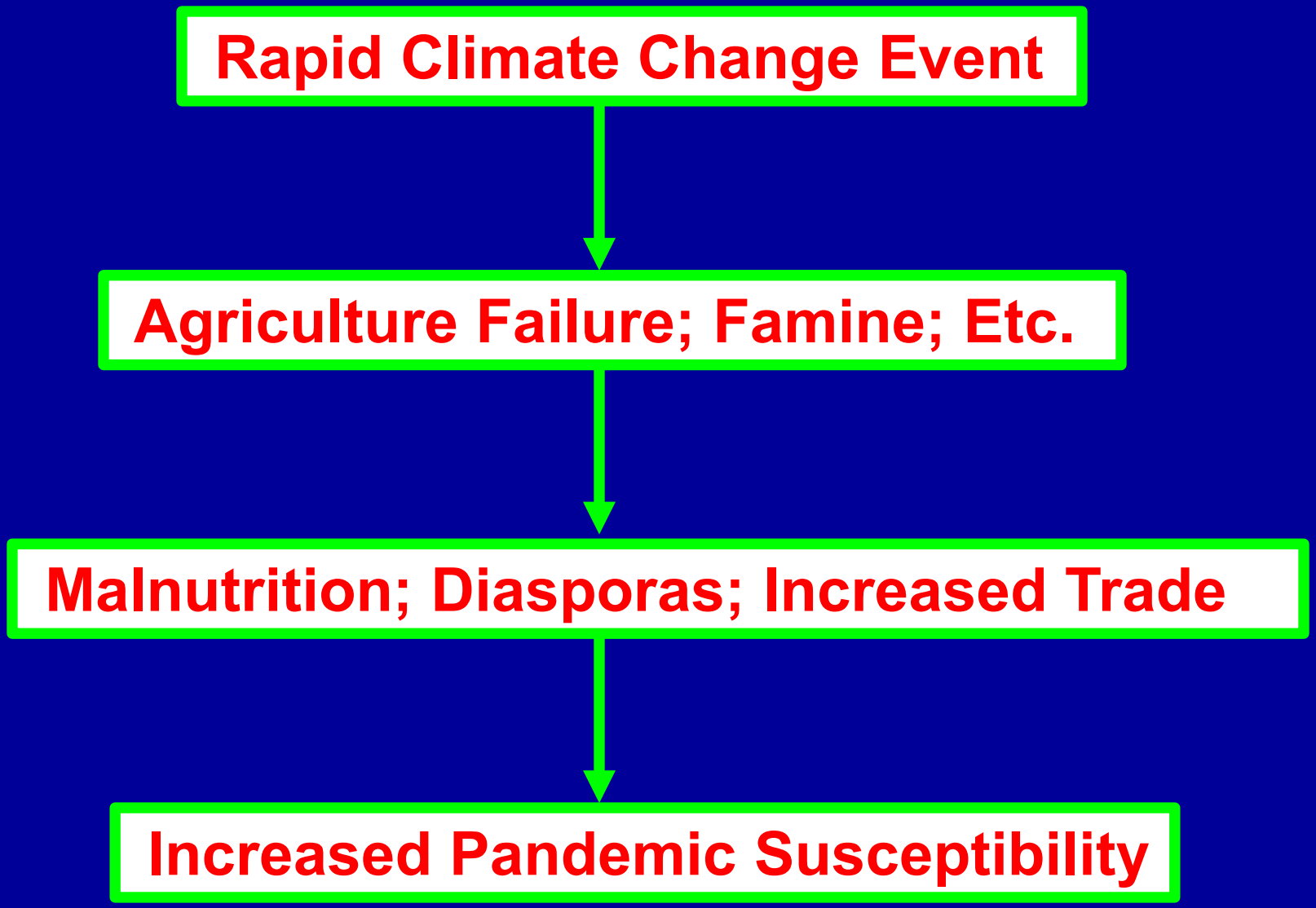
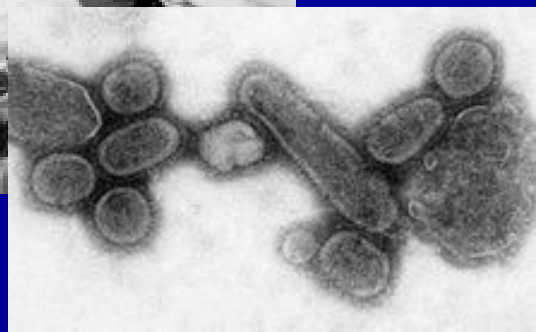
12.	*>5 million*	*Antonine Plague*	*Roman Empire*	*165 – 180*

Connection between Climate Change and Pandemics:



1) Great Flu Pandemic ("Spanish Flu"): 1918 - 1920



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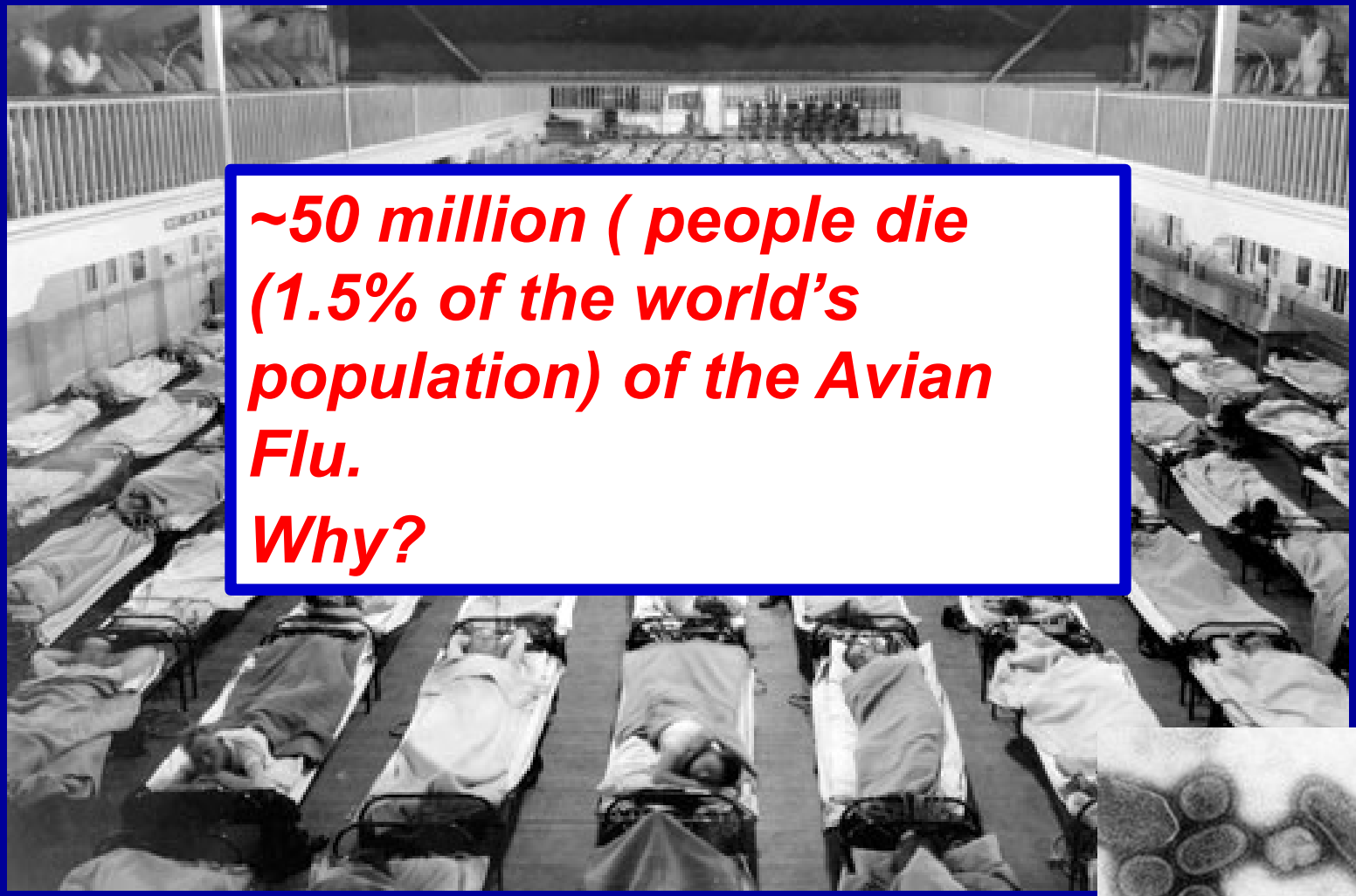
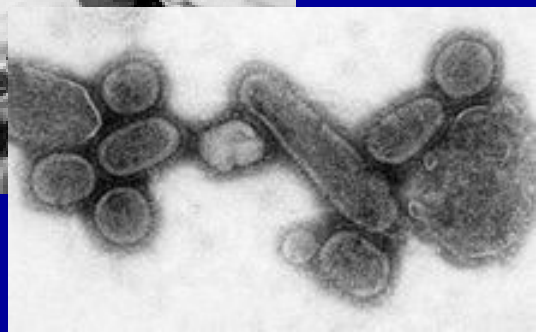


~50 million (people die (1.5% of the world's population) of the Avian Flu.

Why?

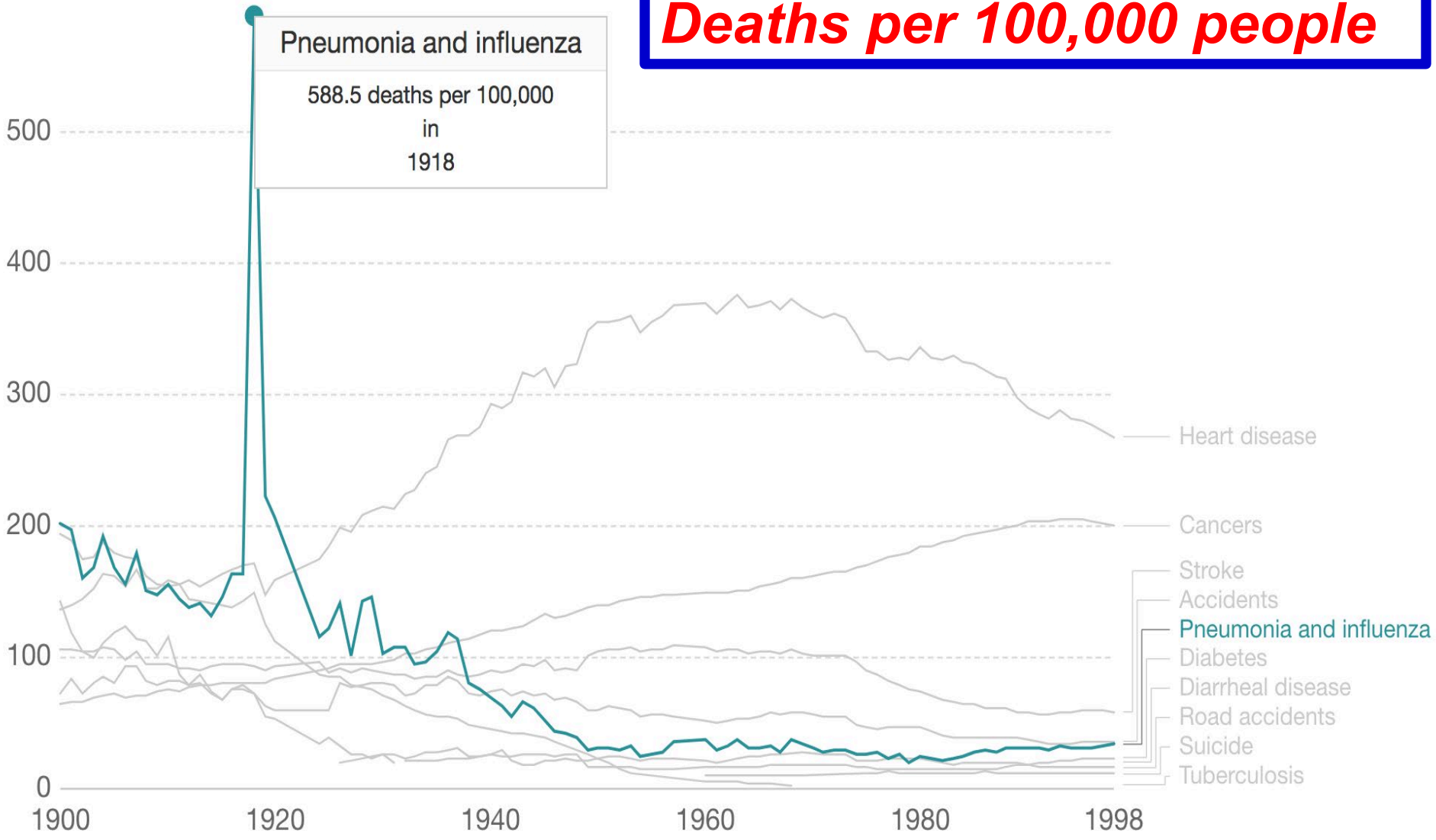


Death rates through the 20th century, United States

Total mortality rates by cause of death, measured as the number of deaths per 100,000 population. Death rates are given as all-age rates (not age-standardized). Data for specific causes of death may be missing or intermittent where it enters or falls out of the top 10 reported causes of deaths in any year.

Our World in Data

Deaths per 100,000 people



Source: Centre for Diseases Control (CDC)

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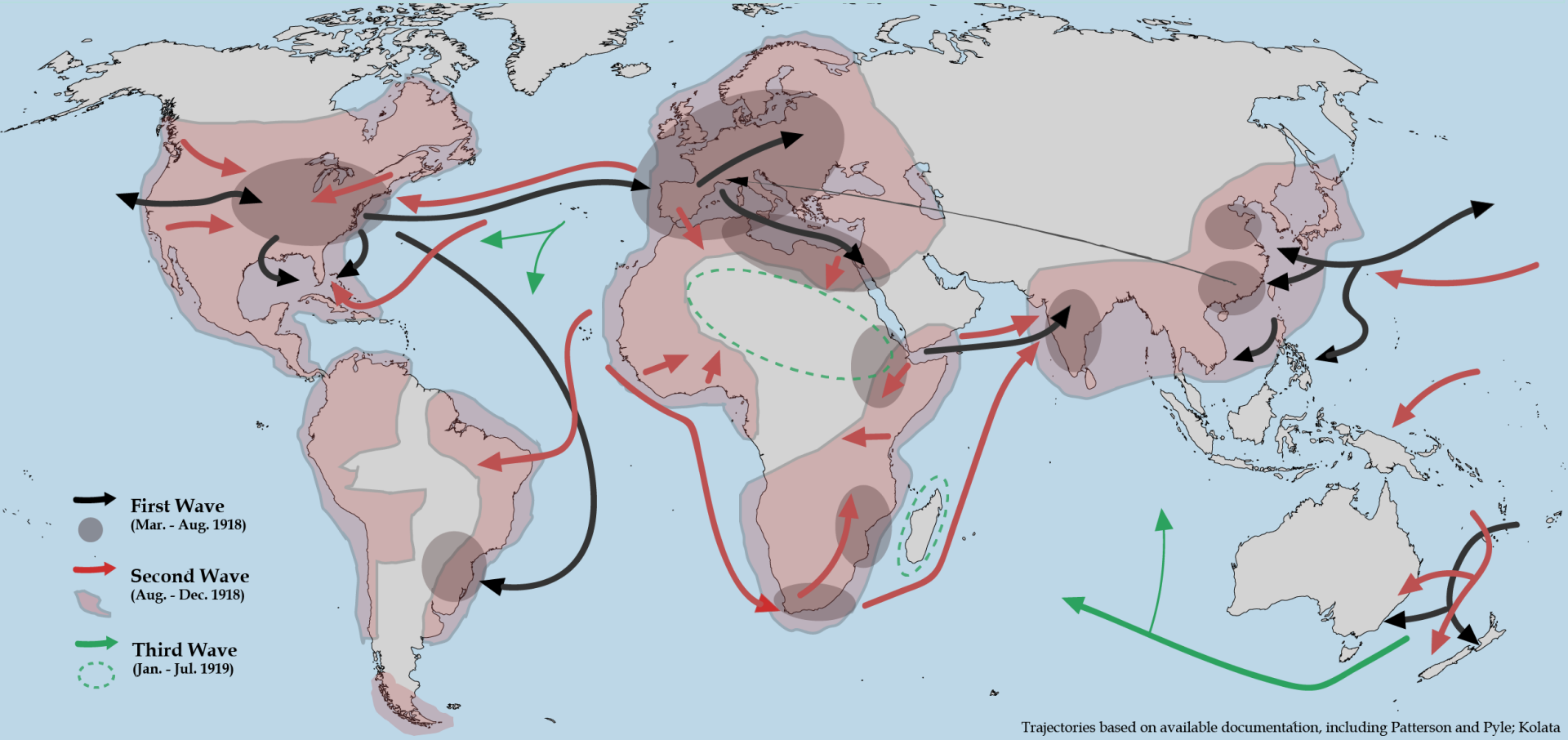
March 4, 1918: Started in Kansas (U.S. Army Camp Funston)
→ 500 men sick within days

After 1 week: Spread to New York City

Within a Month: Had Spread Throughout the WWI Western Front (But We Don't Know Where!)

Global Trajectories of the Spanish Flu



Wartime Inversion of Typical Human Viral Selection

Wartime Inversion of Typical Human Viral Selection

NORMAL SITUATION:

Mild Case: Go to Work

Wartime Inversion of Typical Human Viral Selection

NORMAL SITUATION:

Mild Case: Go to Work

Severe Case: Stay at Home

Wartime Inversion of Typical Human Viral Selection

WARTIME SITUATION:

Mild Case: Stay in Trenches

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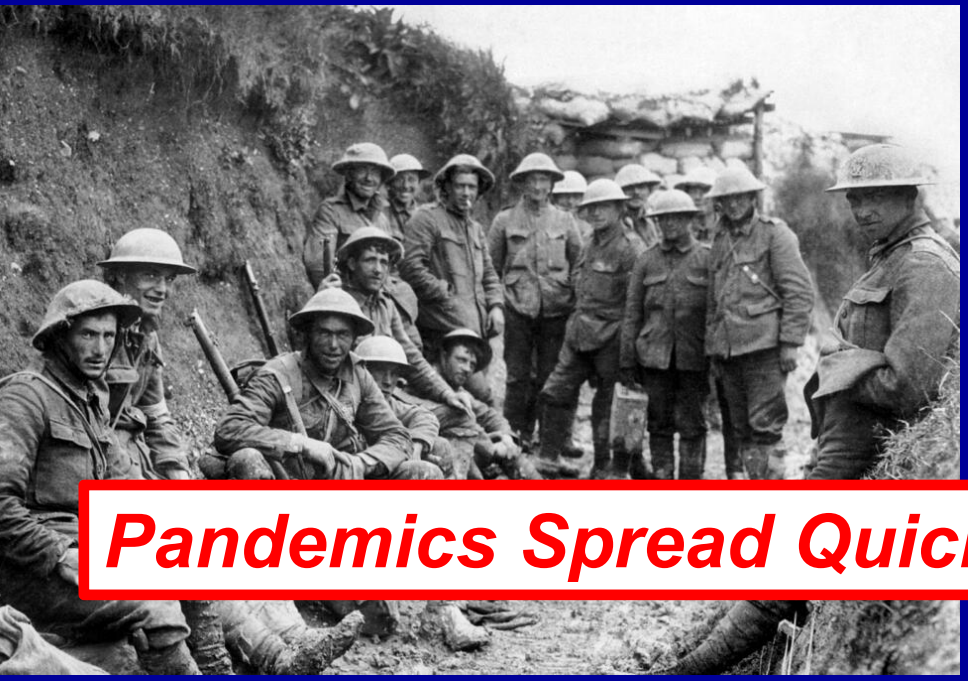

Severe Case: Transported Out

Pandemics Spread Quickly in Times of Conflict!

1914-1919: Exceptionally Cold and Rainy Period in Europe

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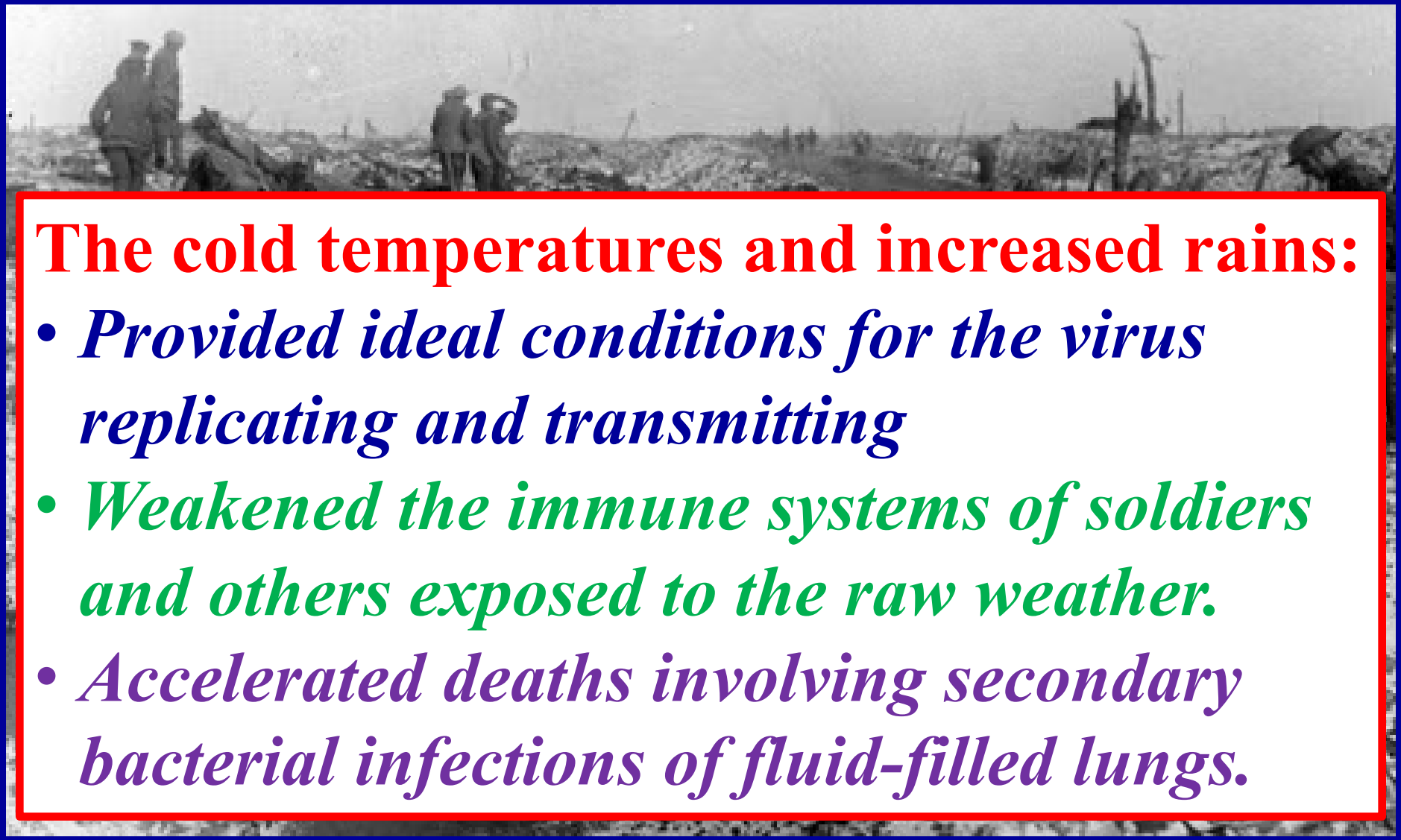
The numbers of deaths closely followed increases in rain and snow and decreases in temperatures.

1914-1919: Exceptionally Cold and Rainy Period in Europe

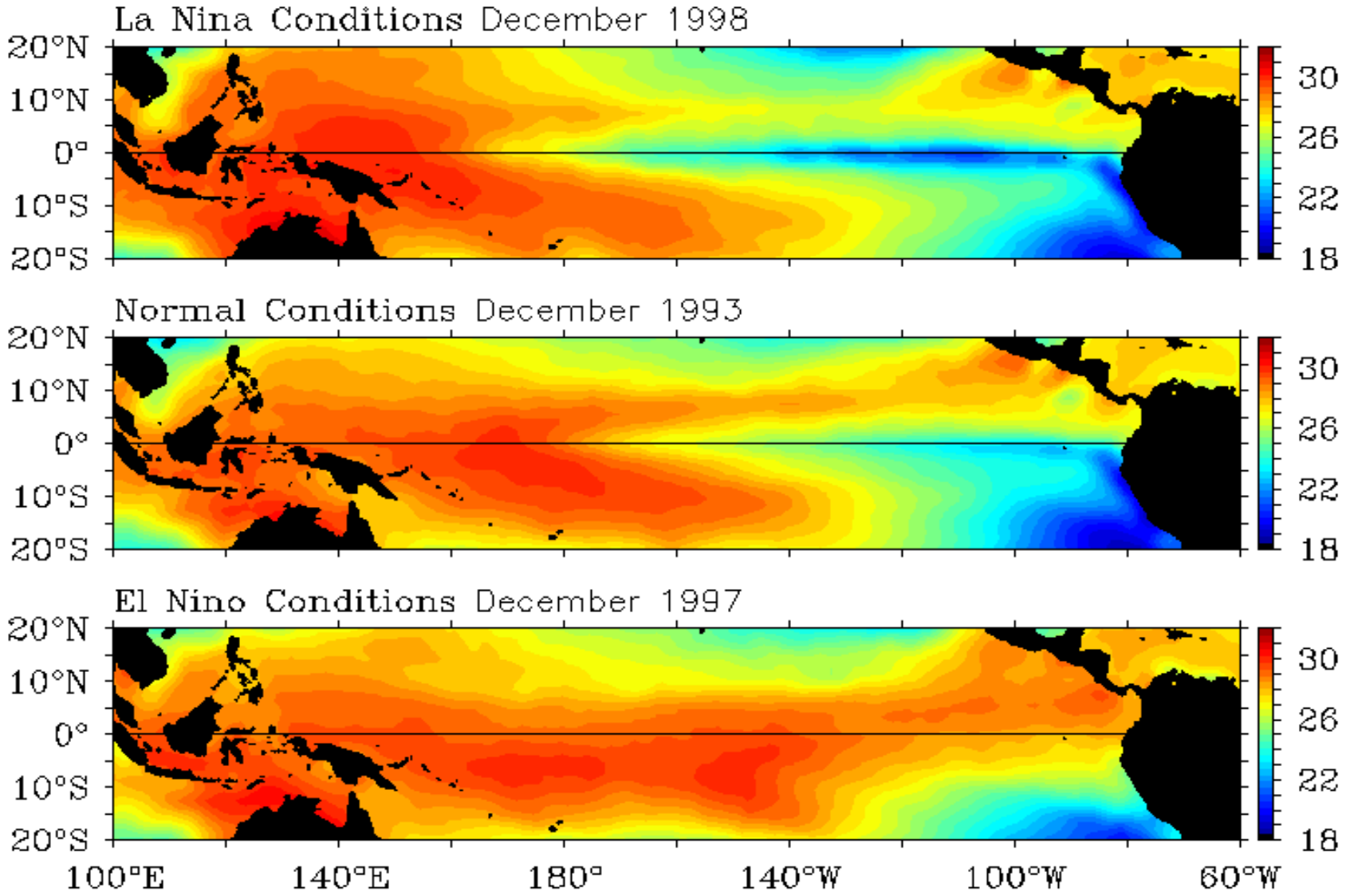


The cold temperatures and increased rains:

- ***Provided ideal conditions for the virus replicating and transmitting***
- ***Weakened the immune systems of soldiers and others exposed to the raw weather.***
- ***Accelerated deaths involving secondary bacterial infections of fluid-filled lungs.***

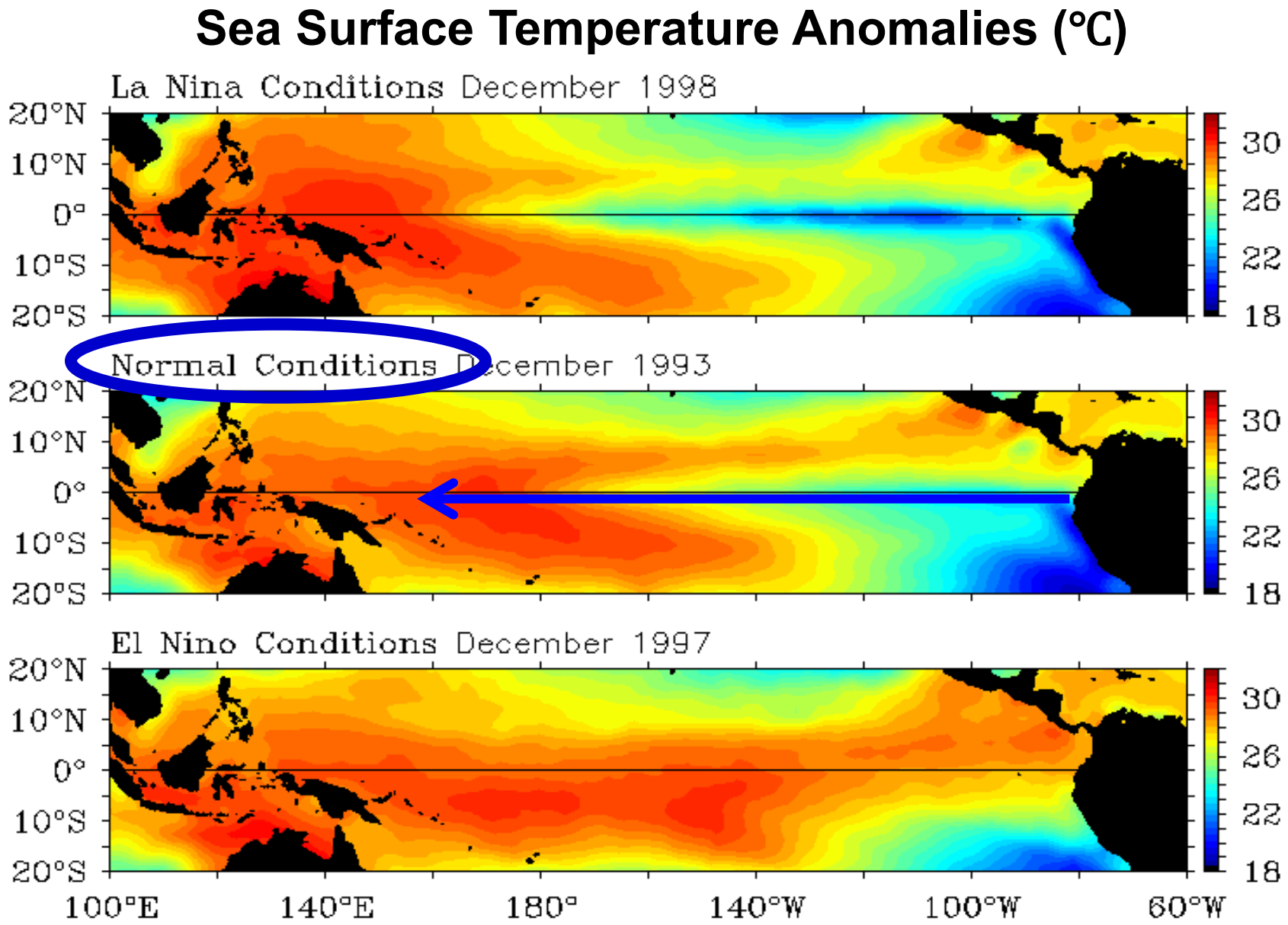
El Niño / La Niña: ENSO ("El Niño / Southern Oscillation")

Sea Surface Temperature Anomalies (℃)



TAO Project Office/PMEL/NOAA

El Niño / La Niña: ENSO ("El Niño / Southern Oscillation")



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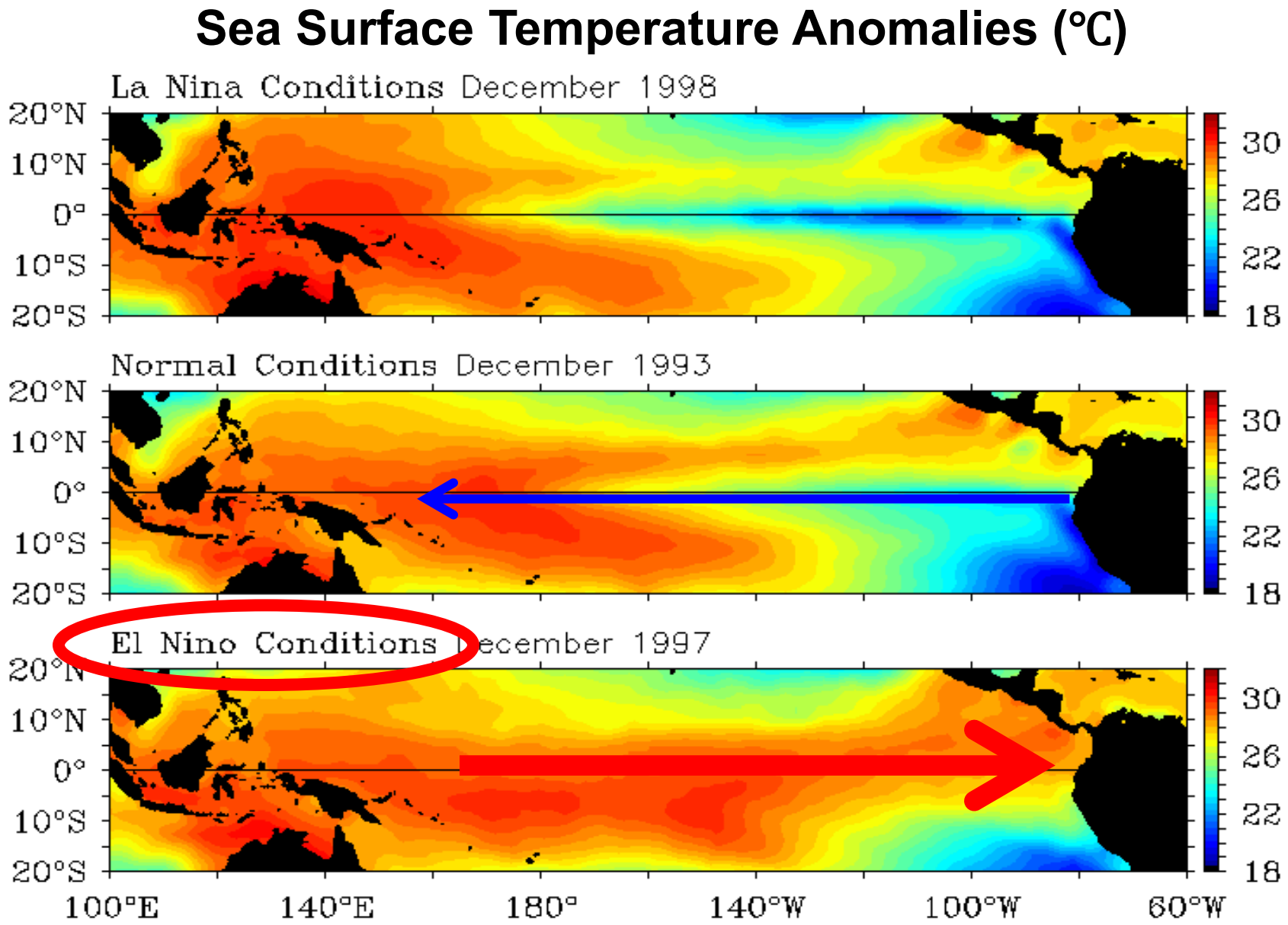

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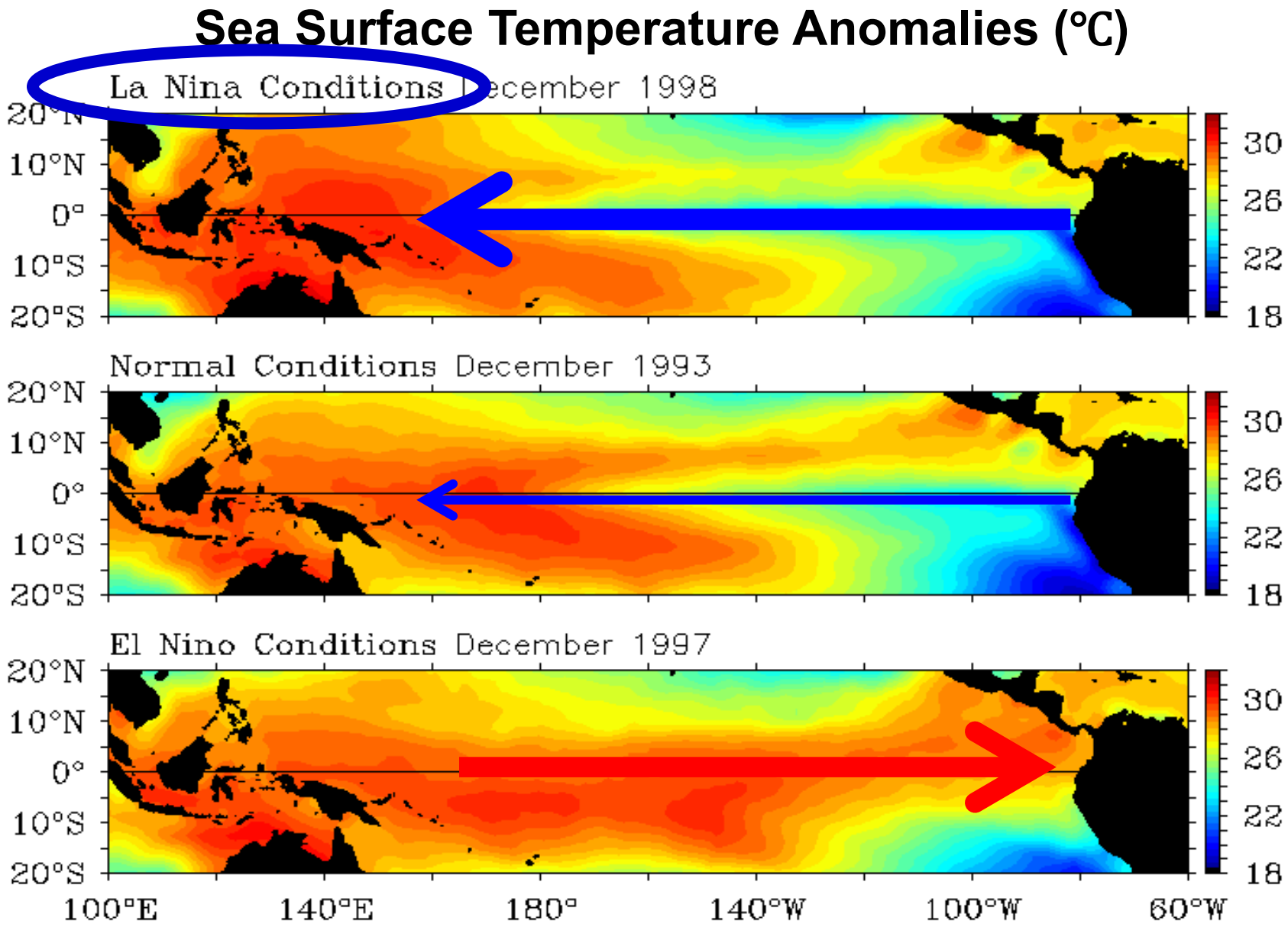
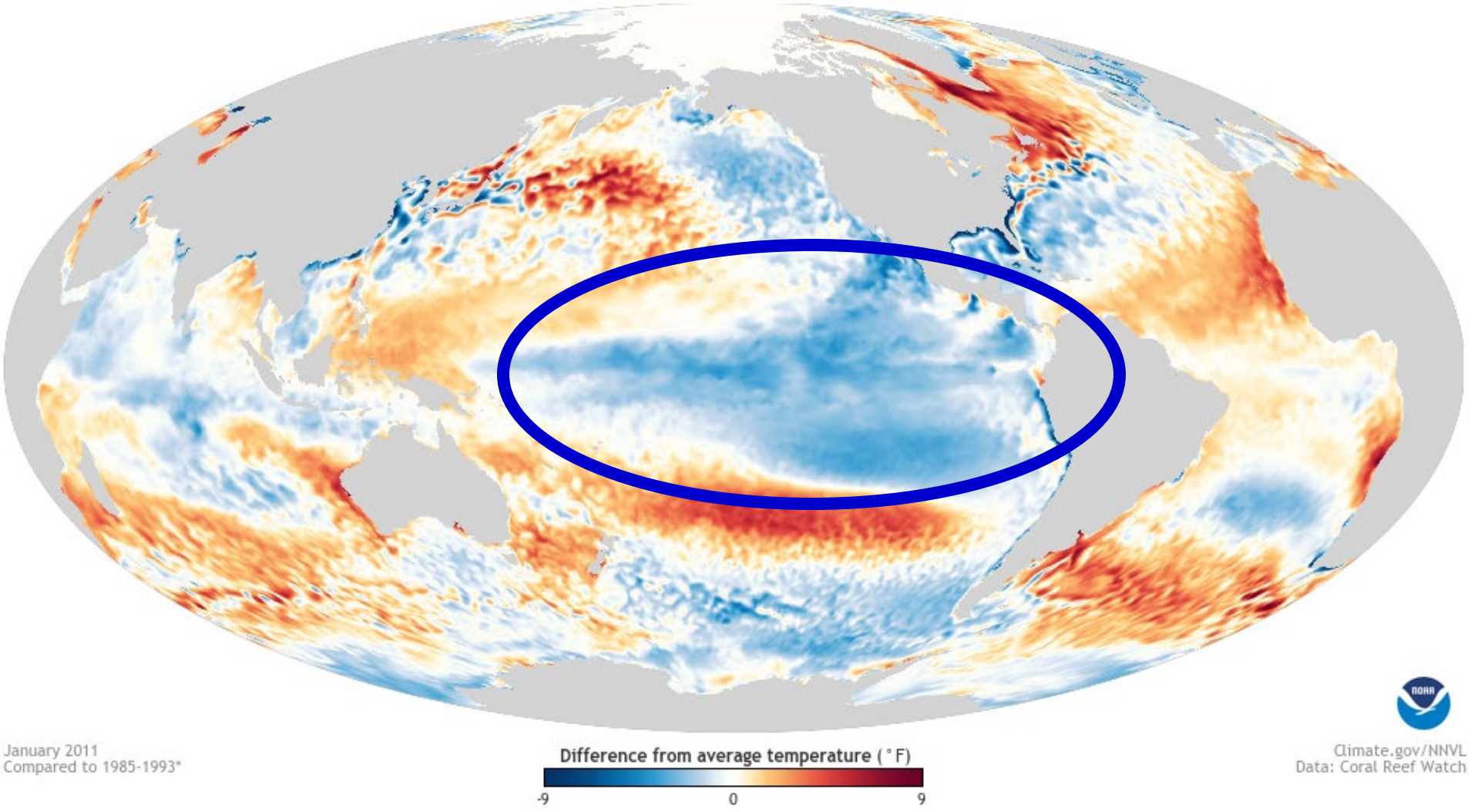
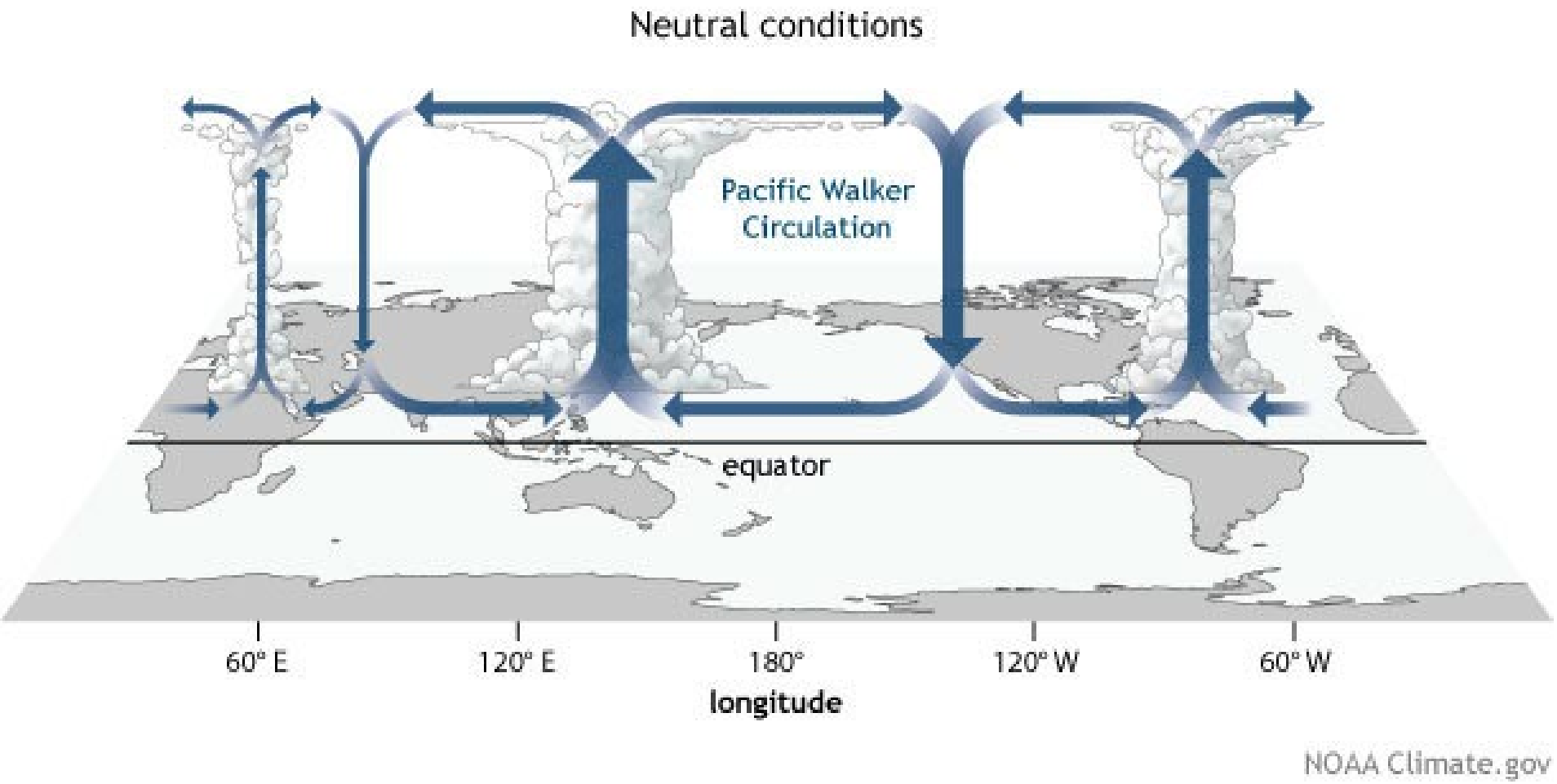


A Three-Year La Niña Precededvthe Great 1918 Flu Pandemic (A “Trip-Dip”)



Pacific Ocean Currents Change Atmospheric Currents



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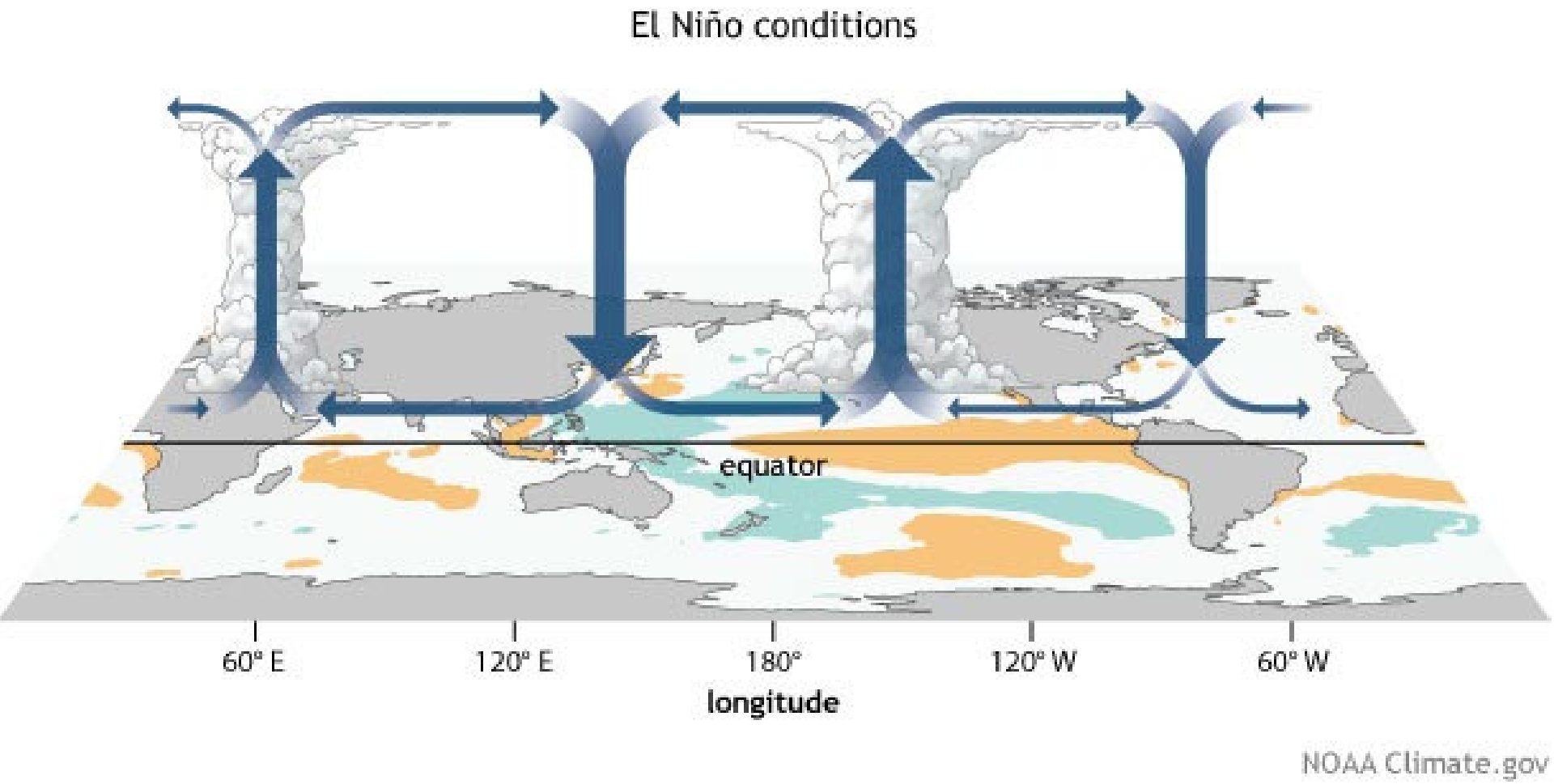

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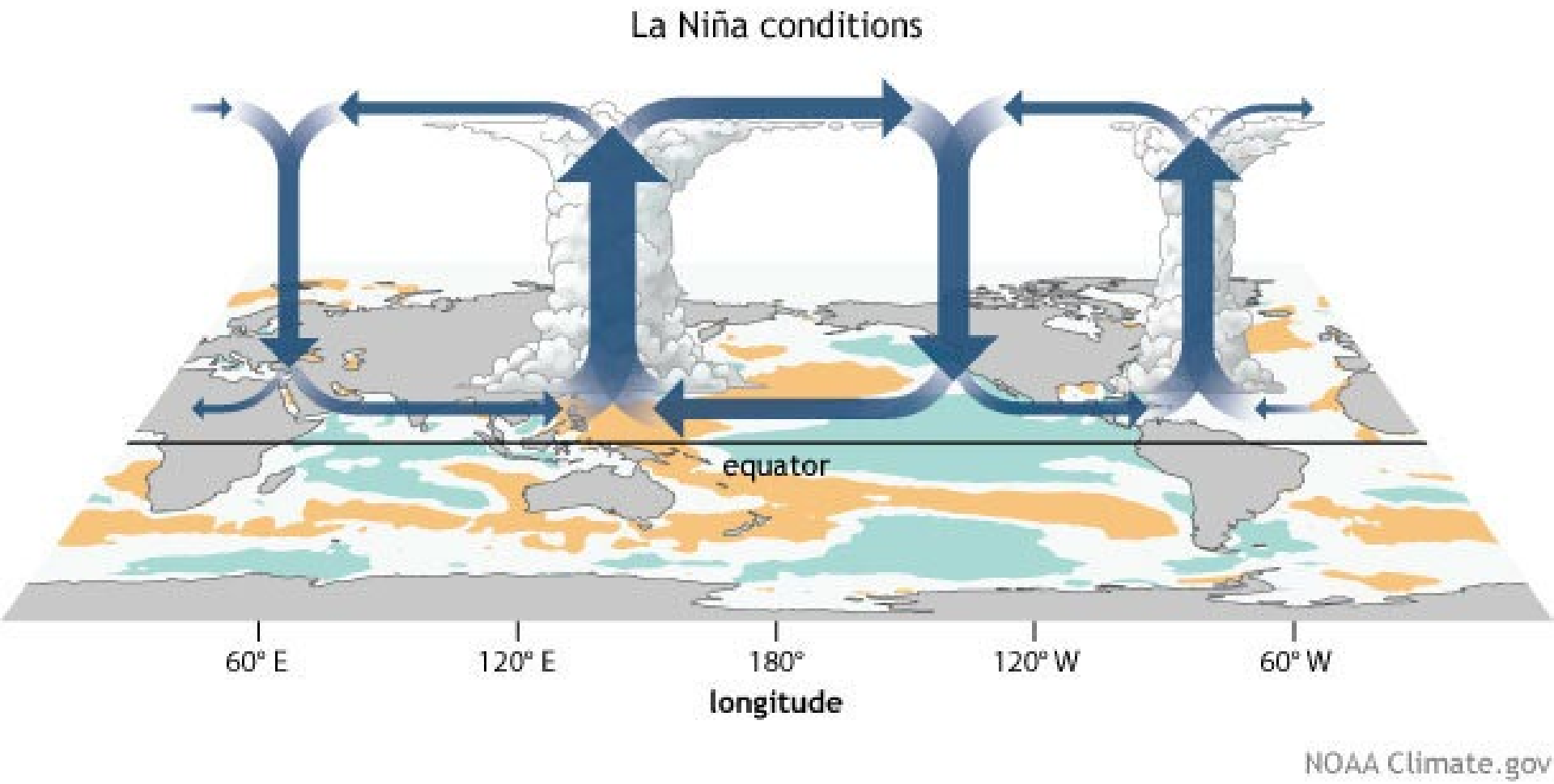

This Changes Jet Stream Patterns

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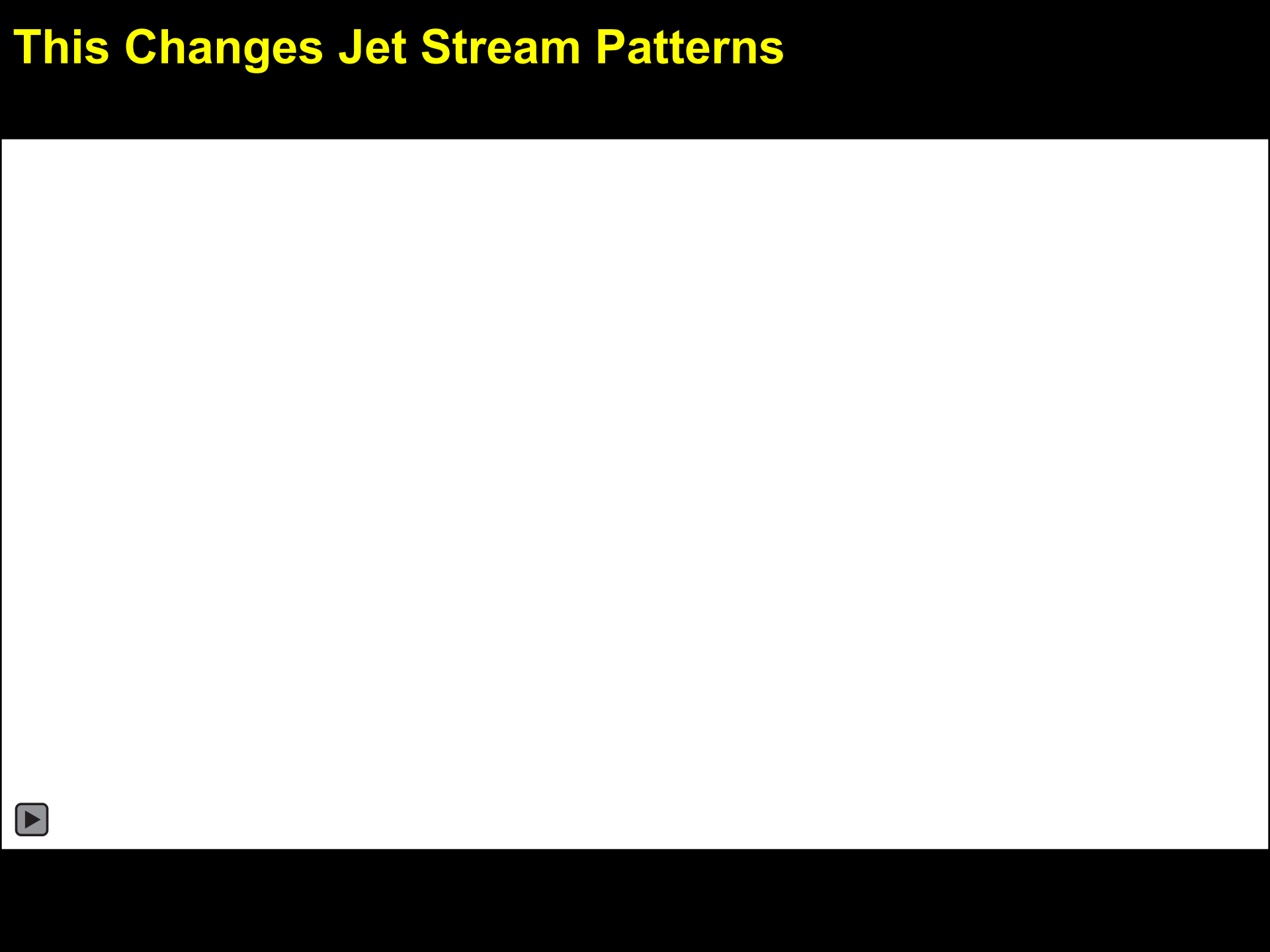
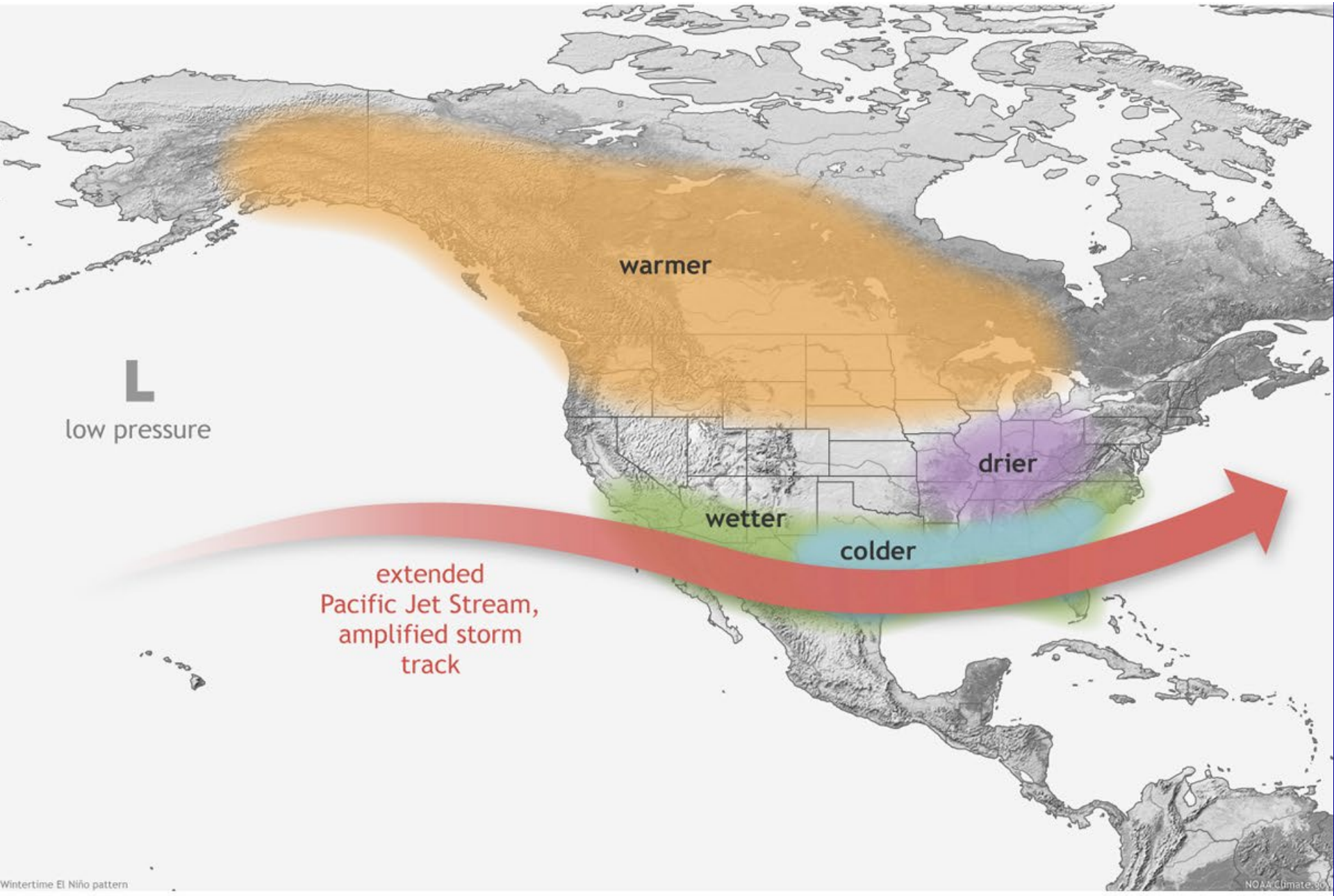
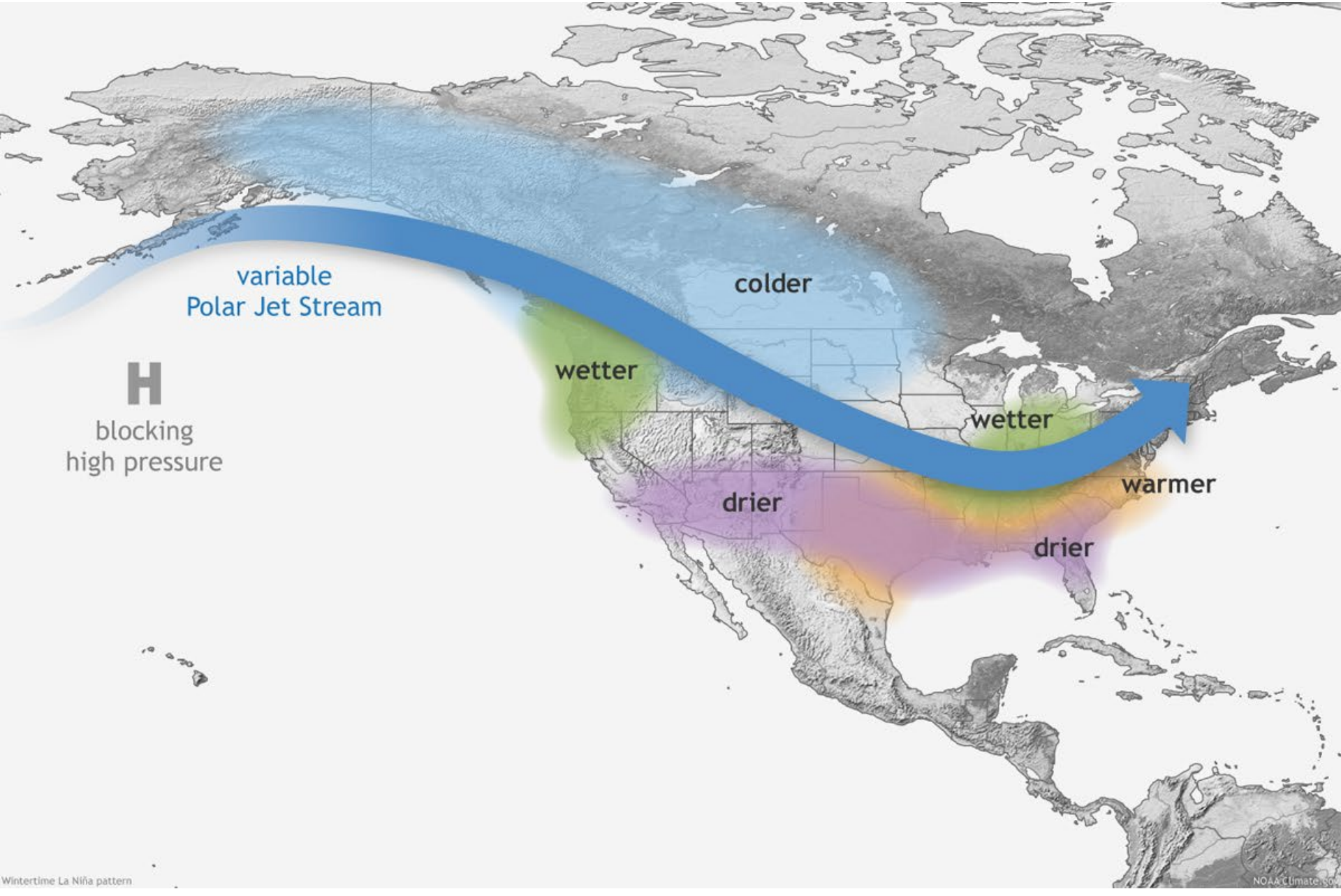


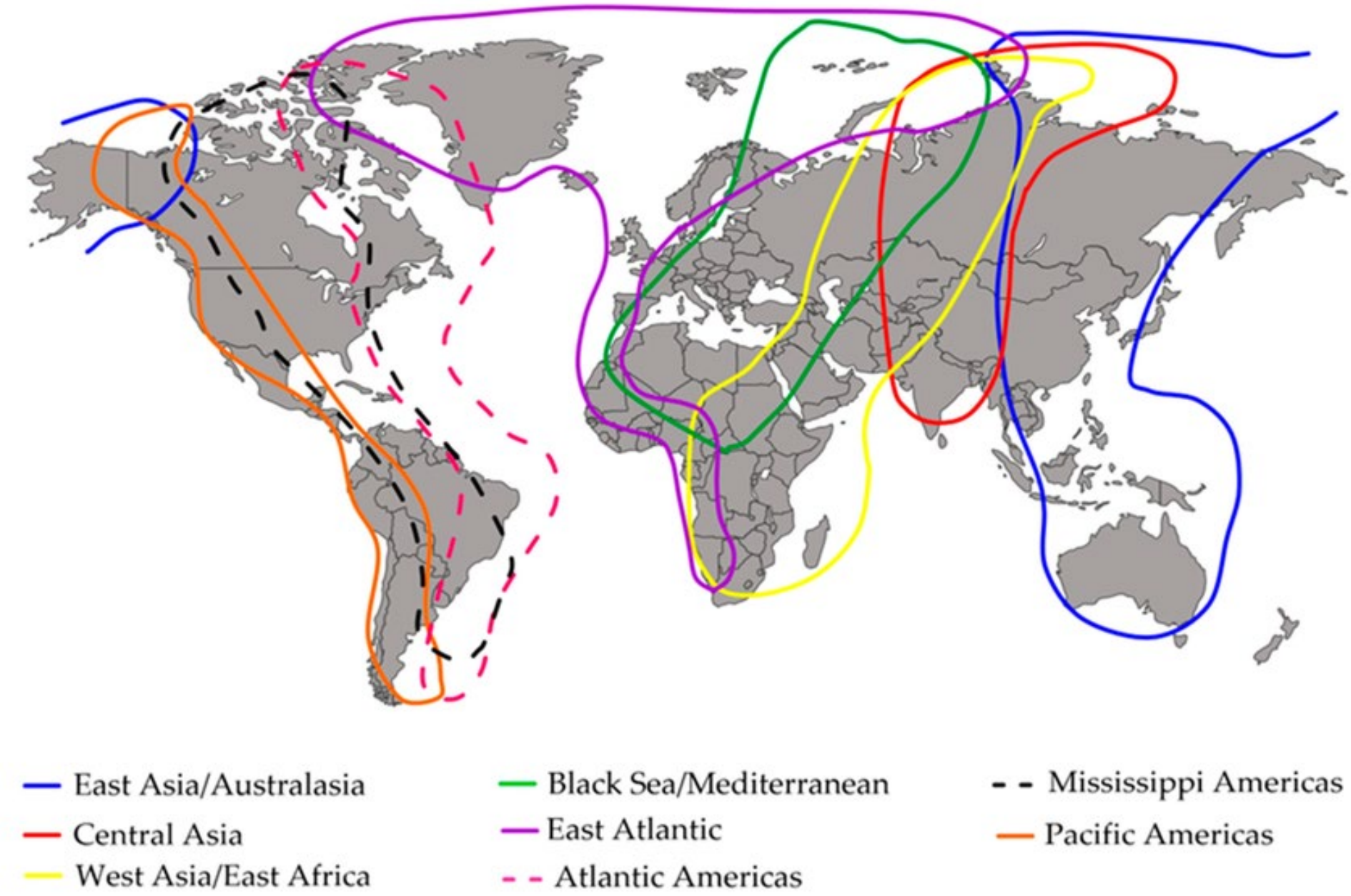
Typical El Niño Winter Jet Stream Patterns



Typical La Niña Winter Jet Stream Patterns



This Changes Bird Migration Patterns



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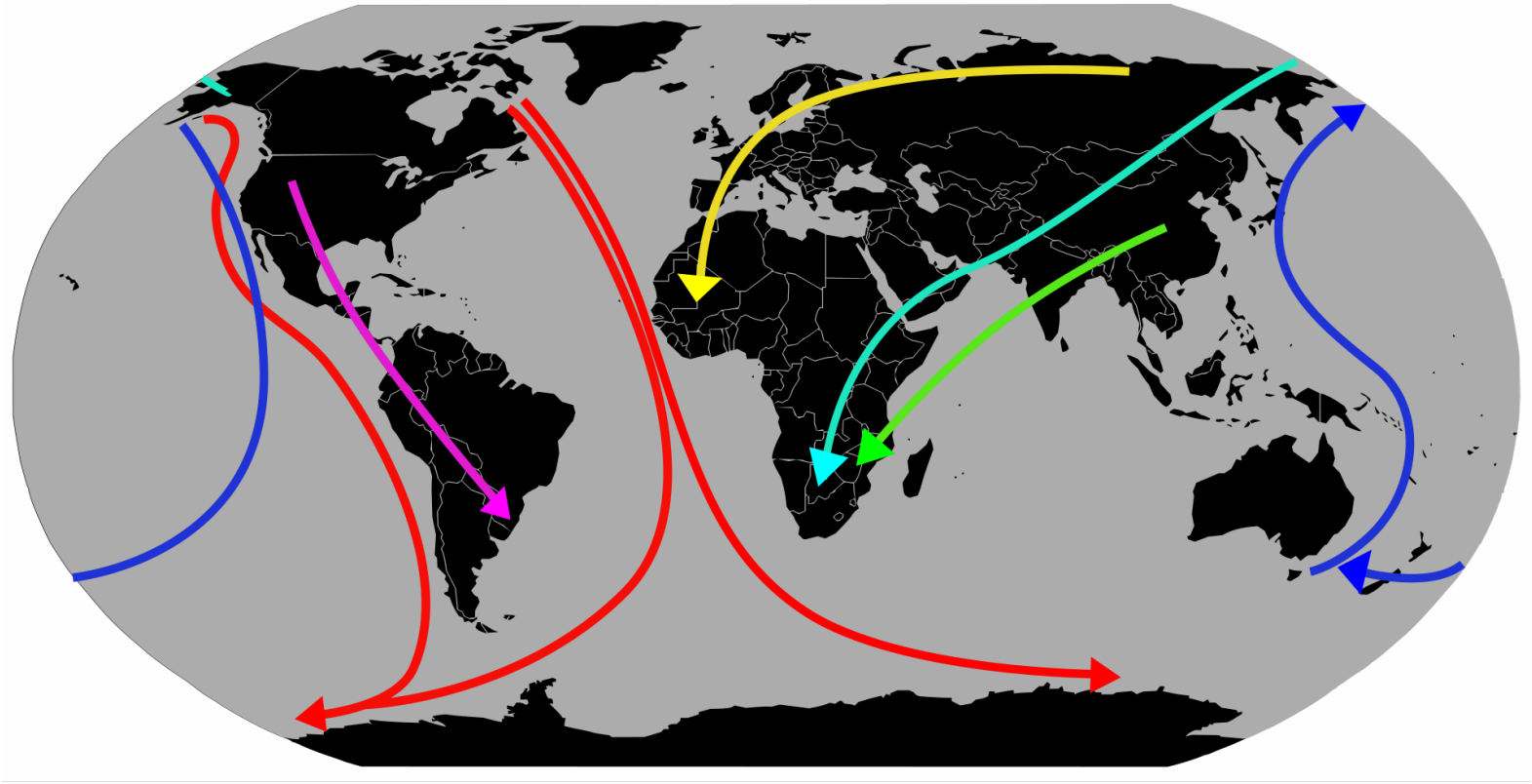
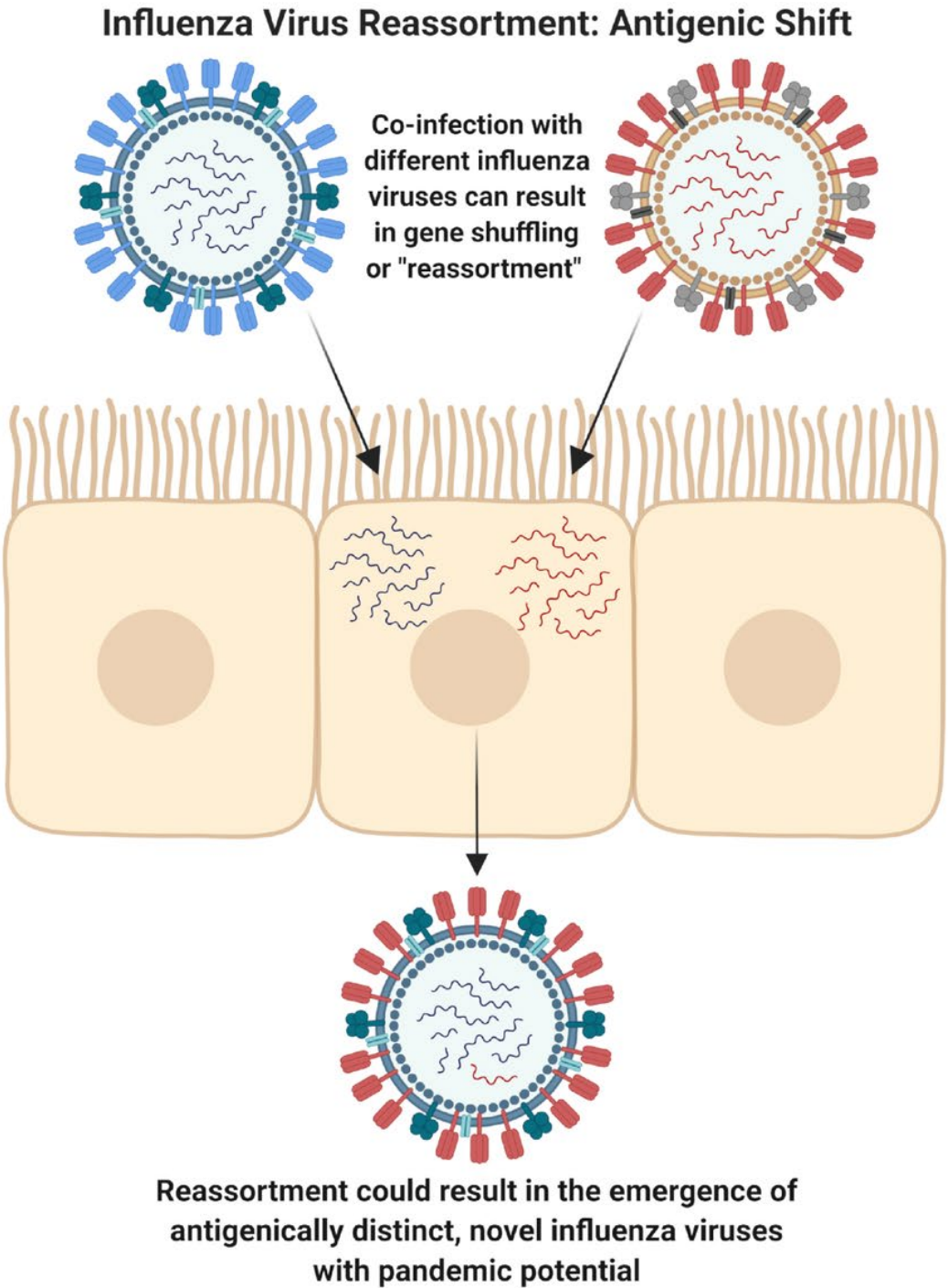
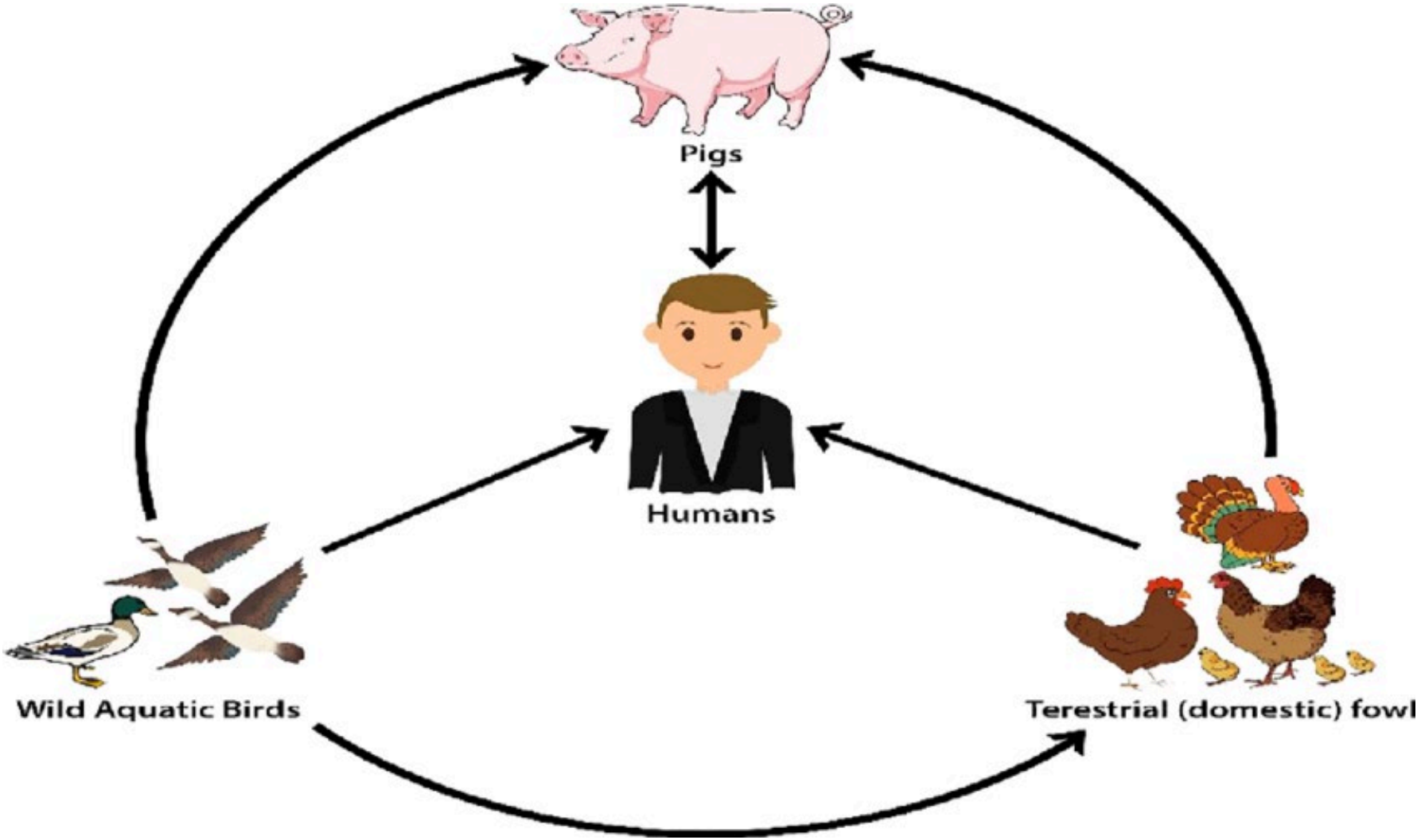


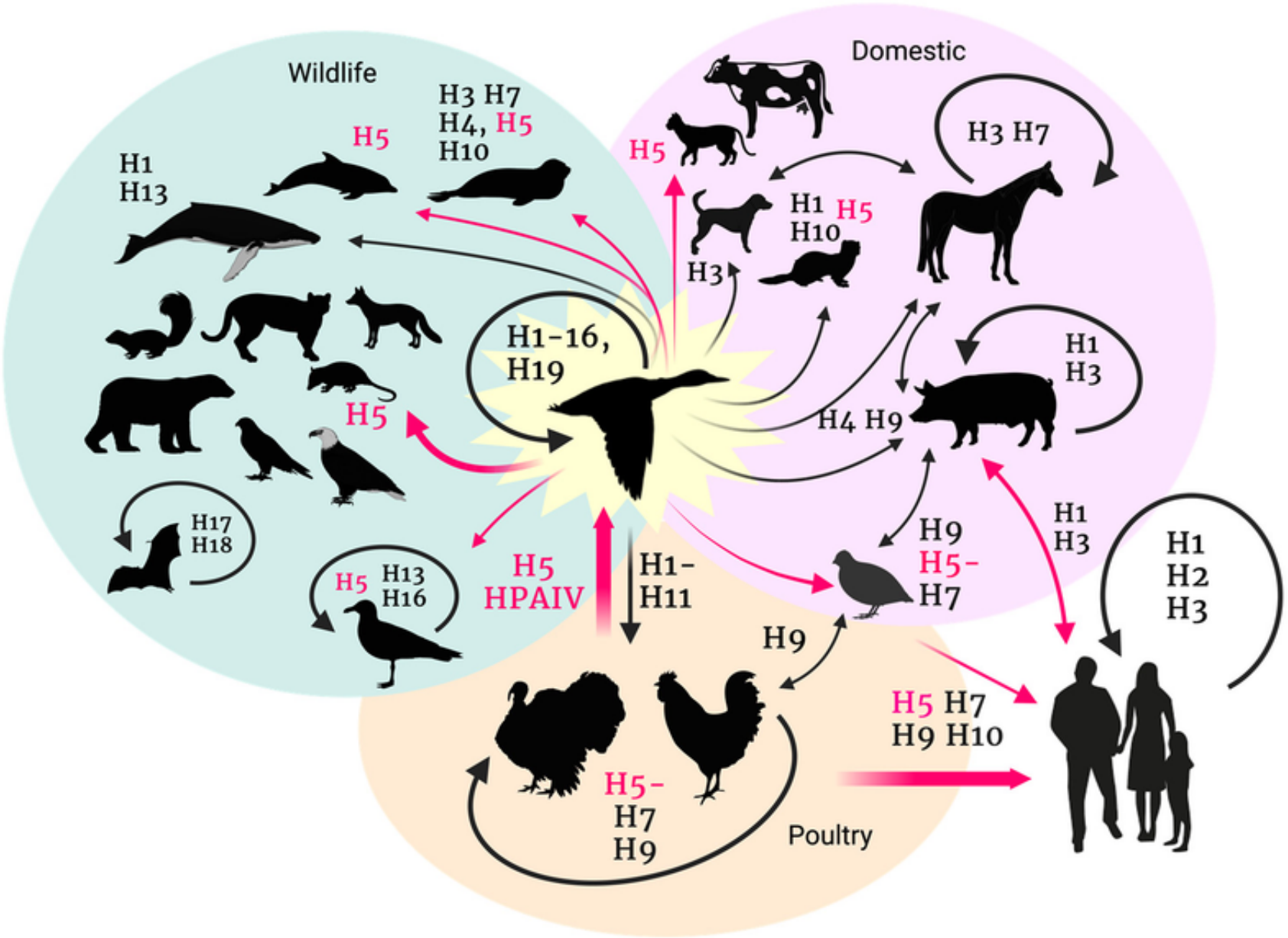
Oenanthe oenanthe	Northern Wheatear
Sterna paradisaea	Arctic Tern
Falco amurensis	Amur Falcon
Puffinus tenuirostris	Short-tailed Shearwater
Philomachus pugnax	Ruff
Buteo swainsoni	Swainson's Hawk

Pandemics Can Occur When RNA Viruses Such as Avian Influenza A Undergo Virus Reassortment

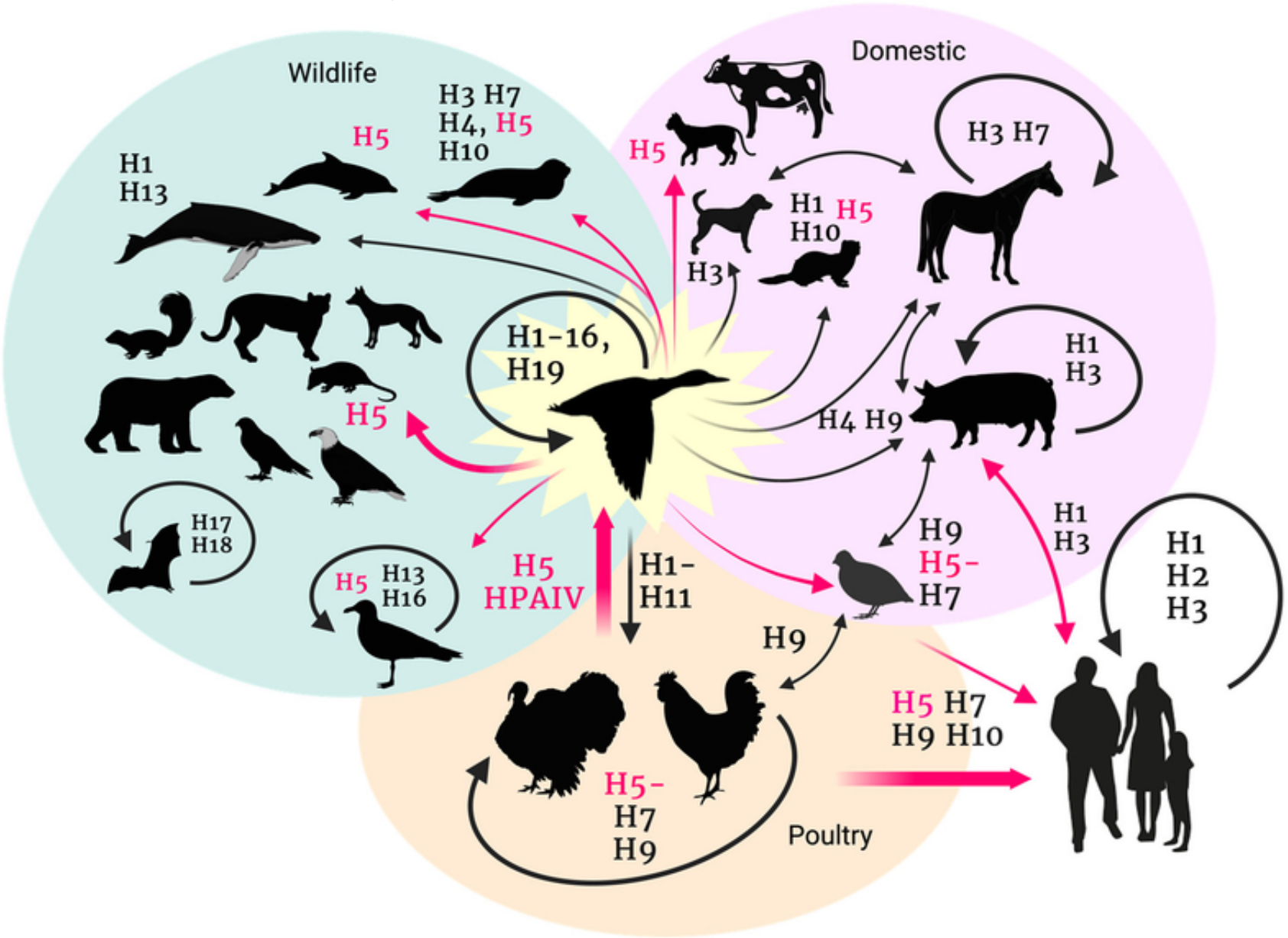


Migrating Wild Aquatic Birds Carry a Huge Reservoir of RNA Viruses That They Infect Other Species With During Migration Stopovers




Wildlife
Domestic
Poultry
H1
H13
H3 H7
H4, H5
H10
H5
H5
H1
H10
H5
H3
H3 H7
H1-16,
H19
H5
H4 H9
H1
H3
H17
H18
H5
H13
H16
H5
HPAIV
H1-
H11
H9
H5-
H7
H1
H3
H1
H2
H3
H9
H5 H7
H9 H10
H5-
H7
H9

Each Avian Flu Pandemic (1918, 1957, 1968, 2009) Was Preceded by a Pacific La Niña



The El Niño–Southern Oscillation (ENSO)–pandemic Influenza connection: Coincident or causal?

Jeffrey Shaman[a,1] and Marc Lipsitch[b]

[a]Department of Environmental Health Sciences, Mailman School of Public Health, Columbia University, New York, NY 10032; and [b]Center for Communicable Disease Dynamics, Harvard School of Public Health, Harvard University, Boston, MA 02115

Edited by Rita R. Colwell, University of Maryland, College Park, MD, and approved September 19, 2011 (received for review May 26, 2011)

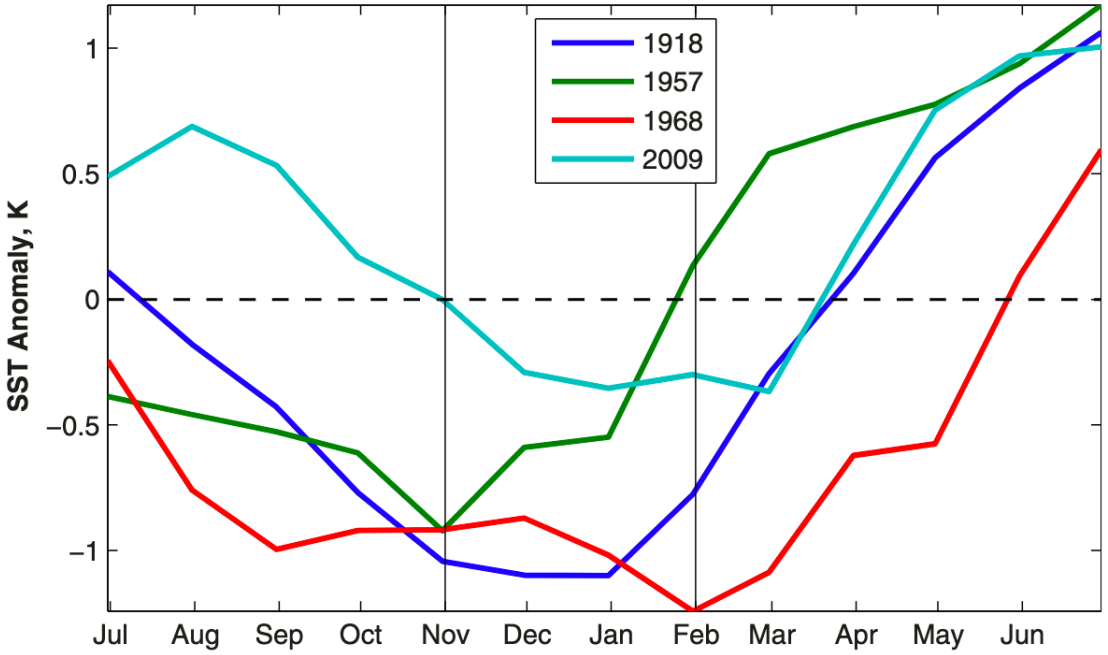


Fig. 1. Time series of Niño 3.0 SST anomalies in units of Kelvin from July of the year preceding the appearance of a novel pandemic influenza strain to July of the year during which the novel pandemic strain emerged. The dashed line shows the 0 K SST anomaly level. The vertical solid black lines demark the period of November through January.

(PNAS, 2012)

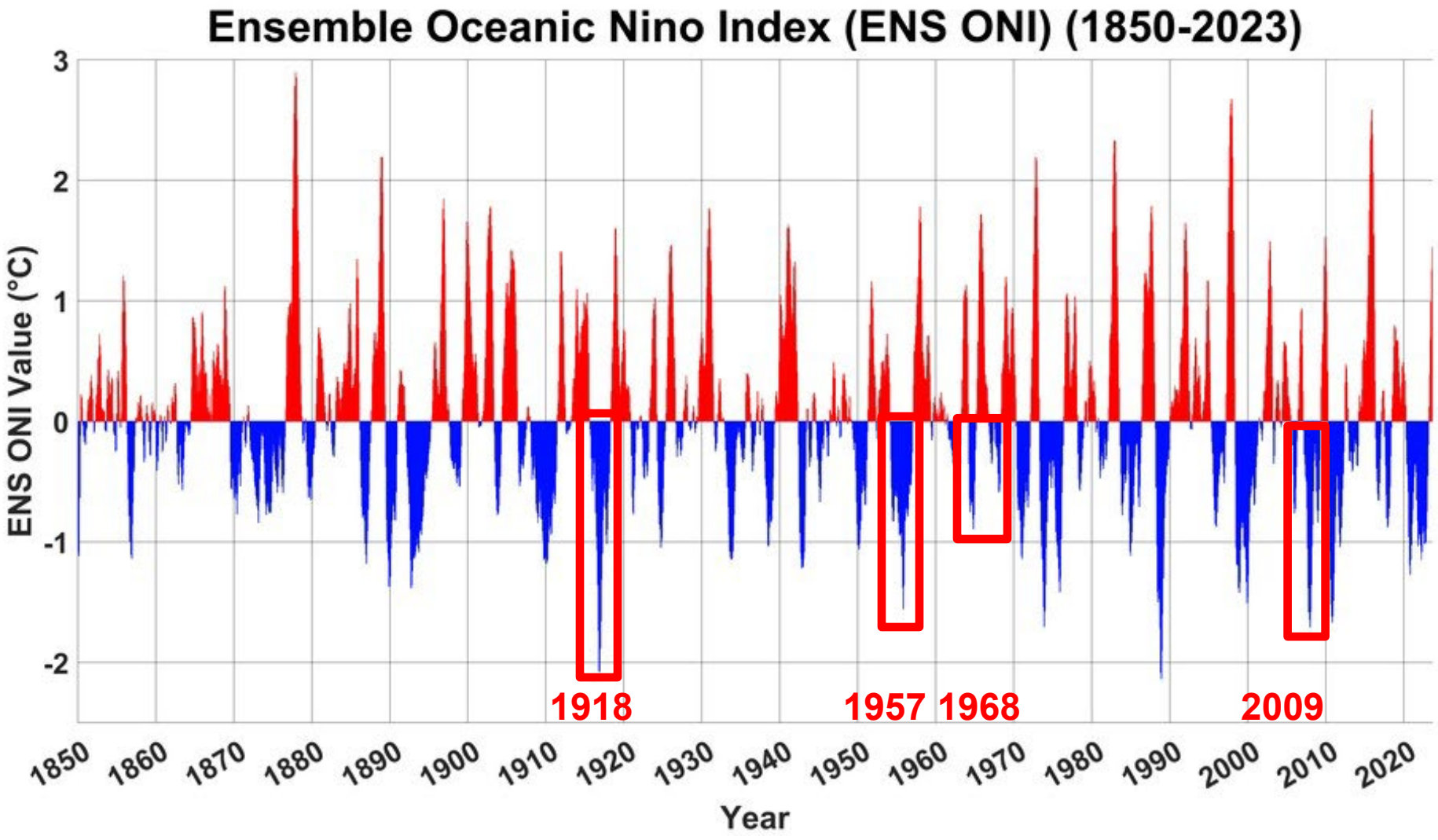

Ensemble Oceanic Nino Index (ENS ONI) (1850-2023)
ENS ONI Value (°C)
3
2
1
0
-1
-2
1918
1957
1968
2009
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Year

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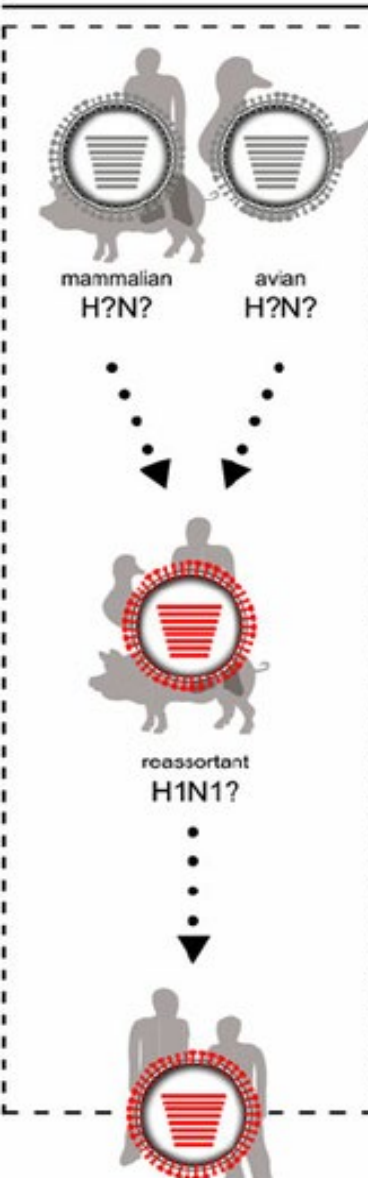
Table 2. Potential mechanisms underpinning the ENSO–pandemic influenza association

	Potential mechanisms
1	Changes in bird number in SE Asia during La Niña
2	Changes in bird fitness/viral shedding in SE Asia during La Niña
3	Changes in bird stopover time in SE Asia during La Niña (more time in residence to mix with local population)
4	Changes in bird species composition in SE Asia during La Niña caused by migration changes that bring new virus segments to the region (testable by both bird species composition and virus diversity in bird-exploited waters)
5	Changes in water habitat type and abundance in SE Asia during La Niña that facilitate fecal–oral avian and swine infections, multiple infections, and reassortments

These changes would likely differ from region to region. As an example, we focus on southeast Asia. SE, southeast.

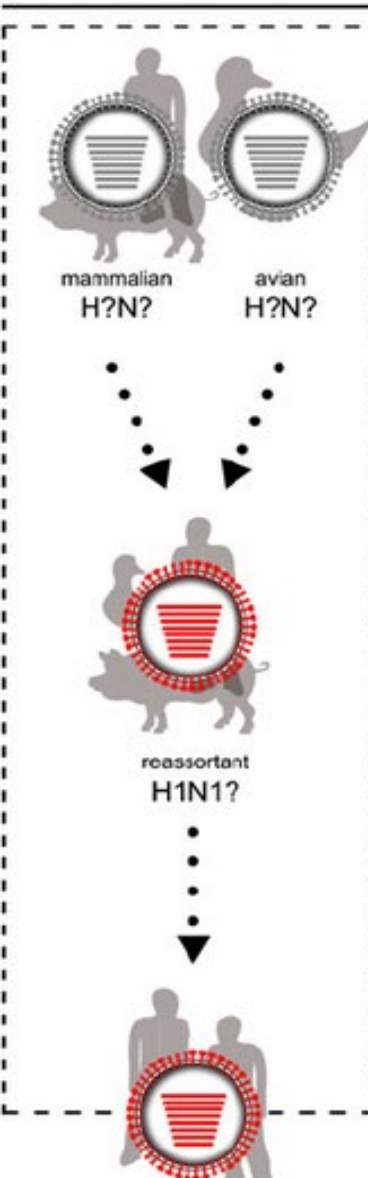
(PNAS, 2012)

“Spanish” Influenza
1918
H1N1



[Schrauwen et al., *Eur J Clin Microbiol Infect Dis*., 2014]

“Spanish” Influenza
1918
H1N1



Where did the human flu strains come from?

[Schrauwen et al., *Eur J Clin Microbiol Infect Dis*., 2014]

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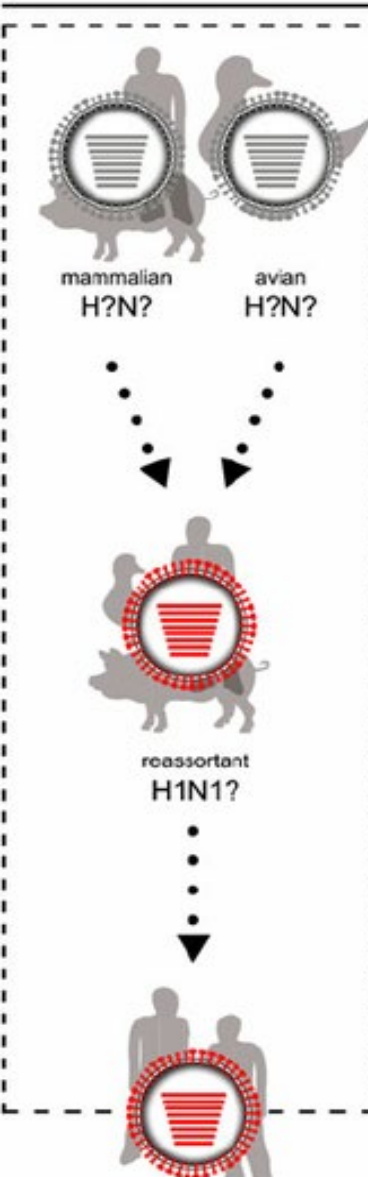

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The 1889 “Russian Flu”

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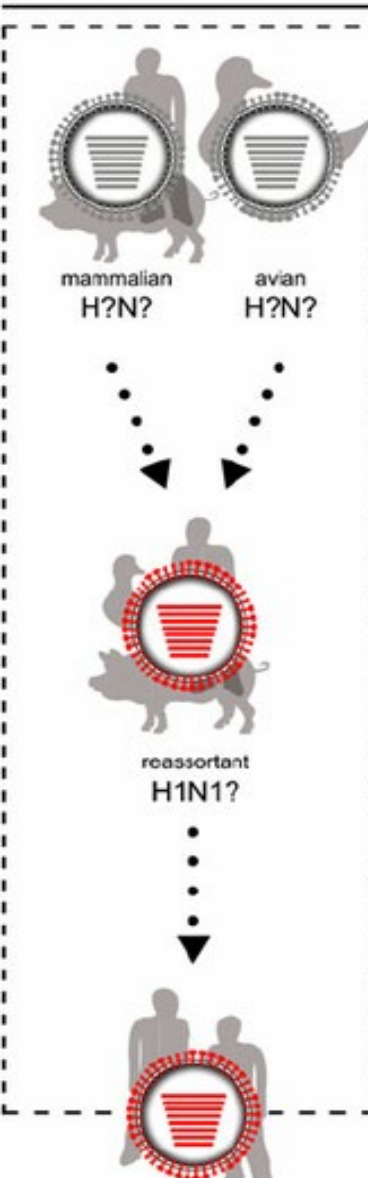

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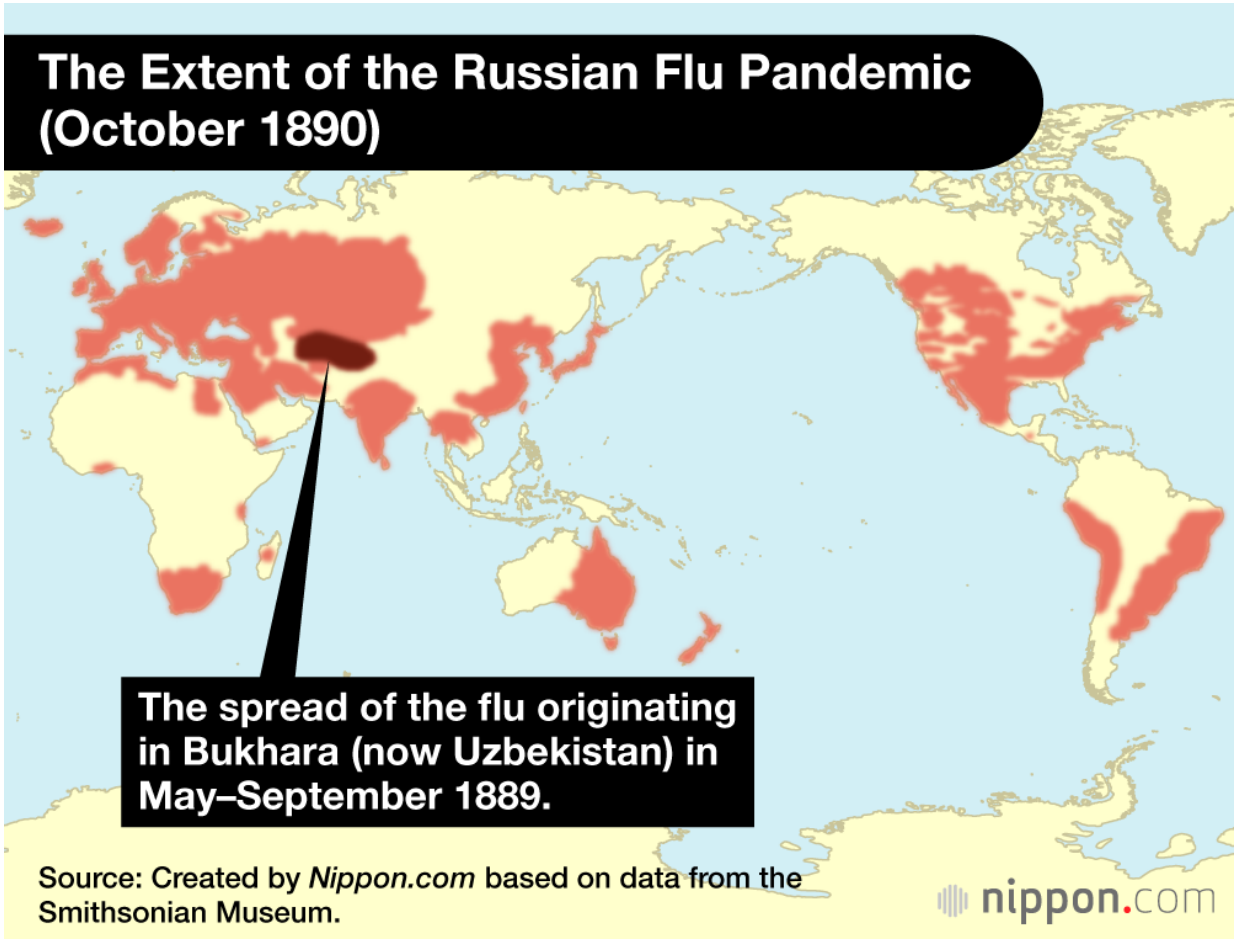
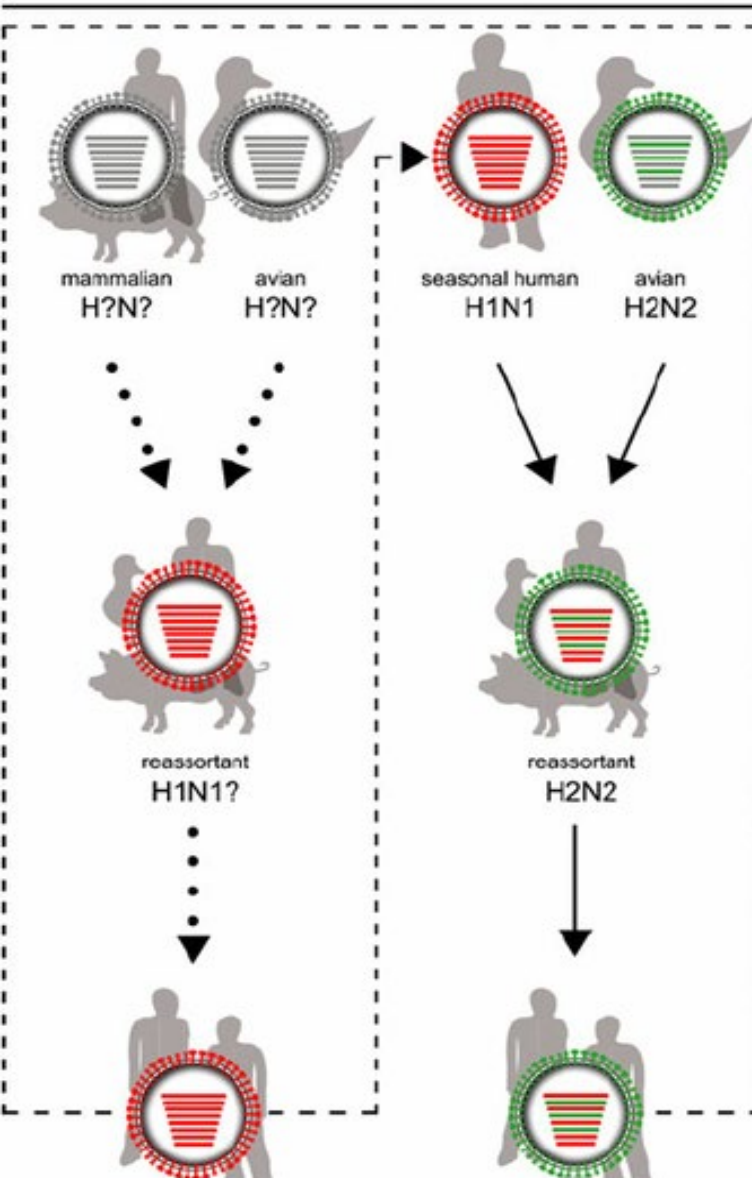


“Spanish” Influenza
1918
H1N1

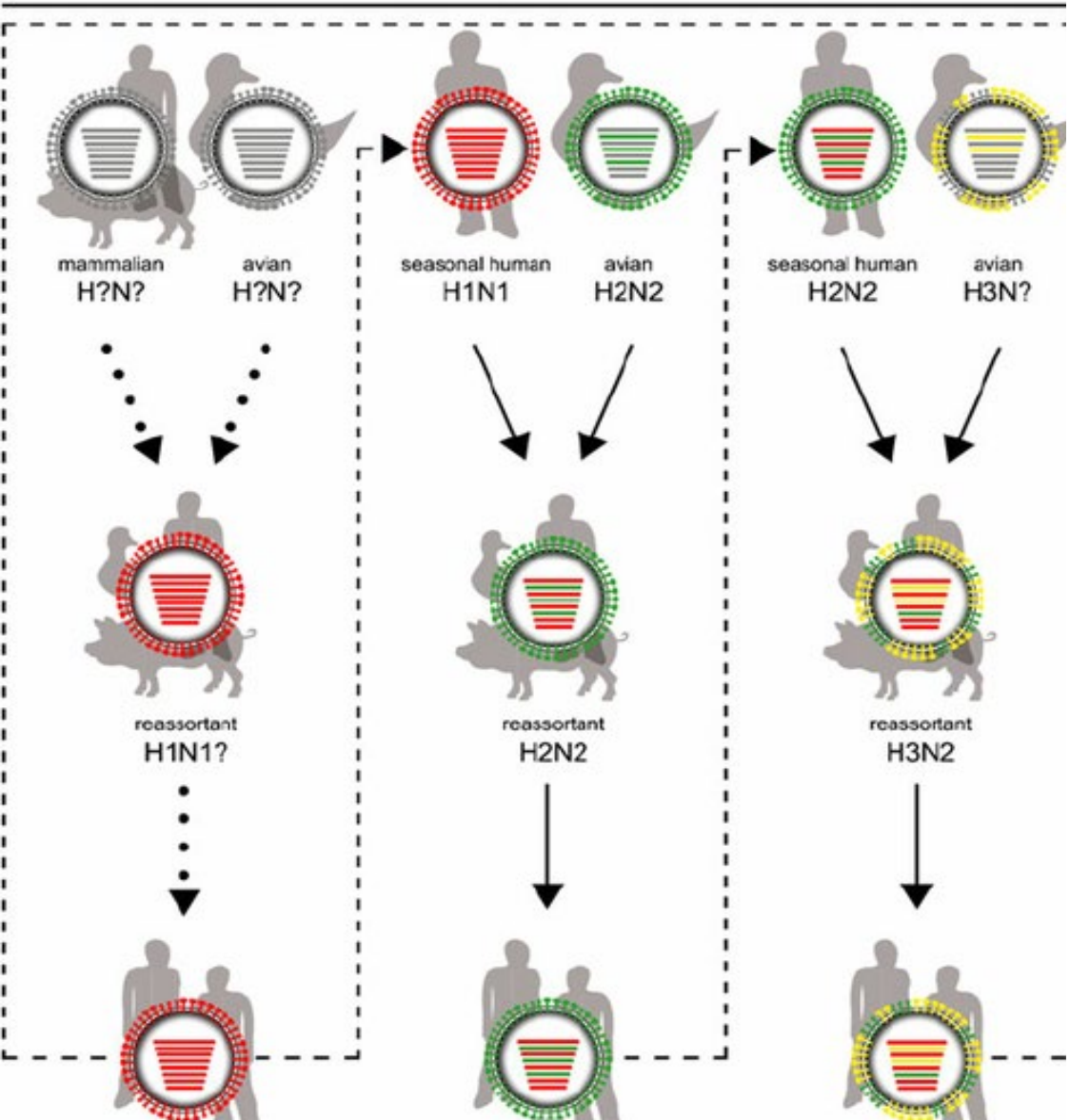
“Asian” Influenza
1957
H2N2



“Spanish” Influenza
1918
H1N1

“Asian” Influenza
1957
H2N2

“Hong Kong” Influenza
1968
H3N2

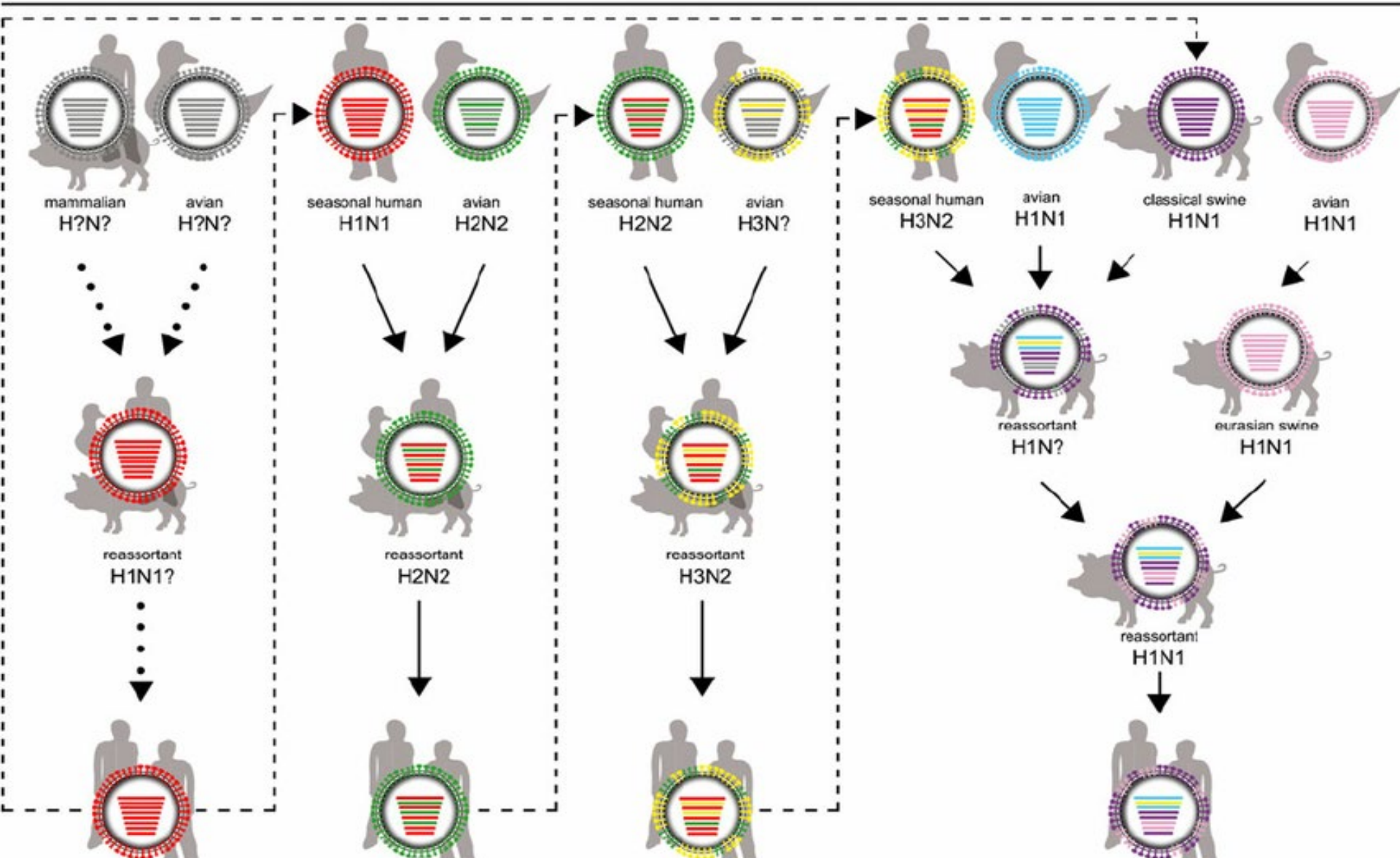


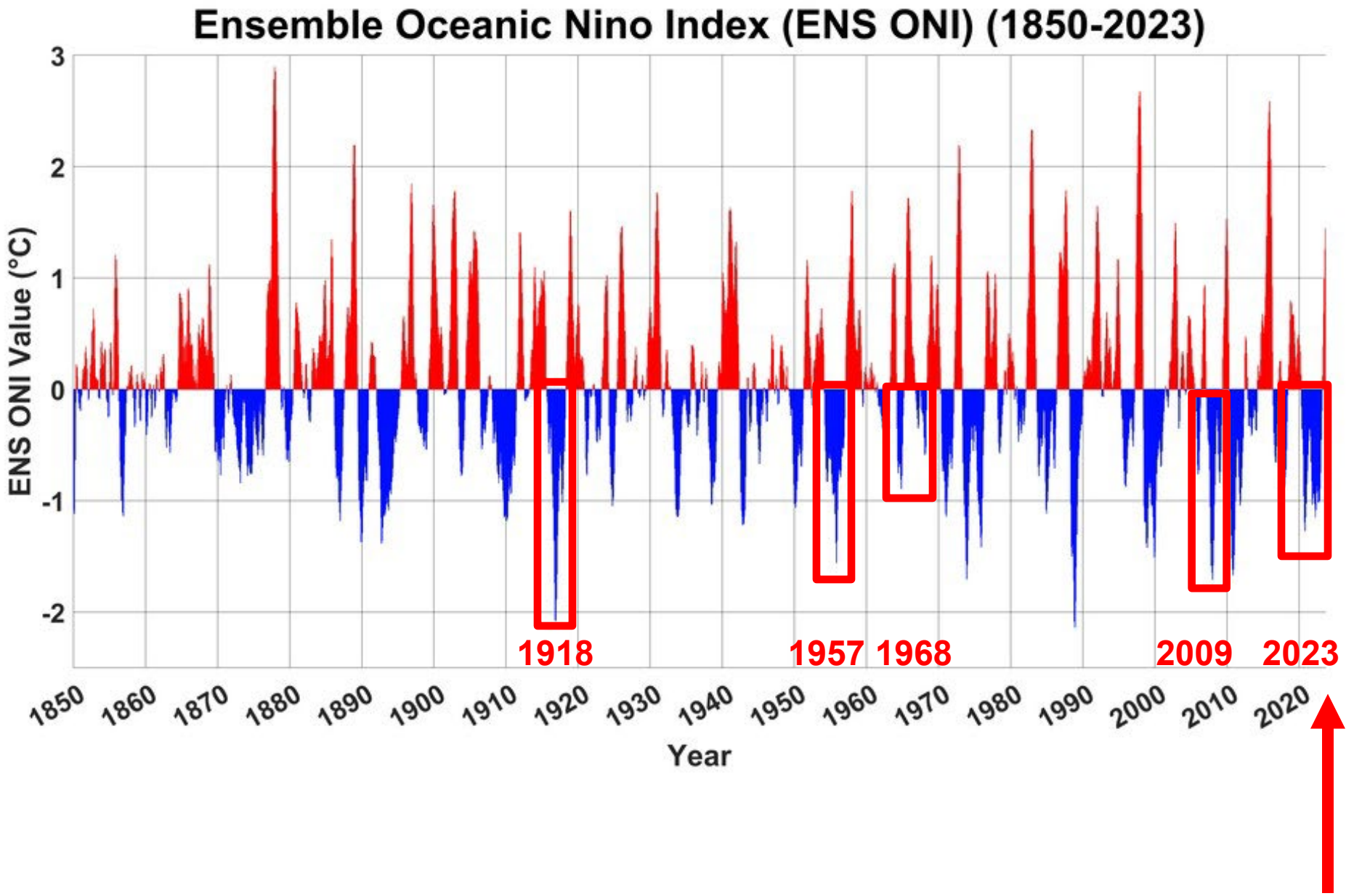
“Spanish” Influenza
1918
H1N1

“Asian” Influenza
1957
H2N2

“Hong Kong” Influenza
1968
H3N2

“Mexican” Influenza or “Swine Flu”
2009
H1N1

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2
1
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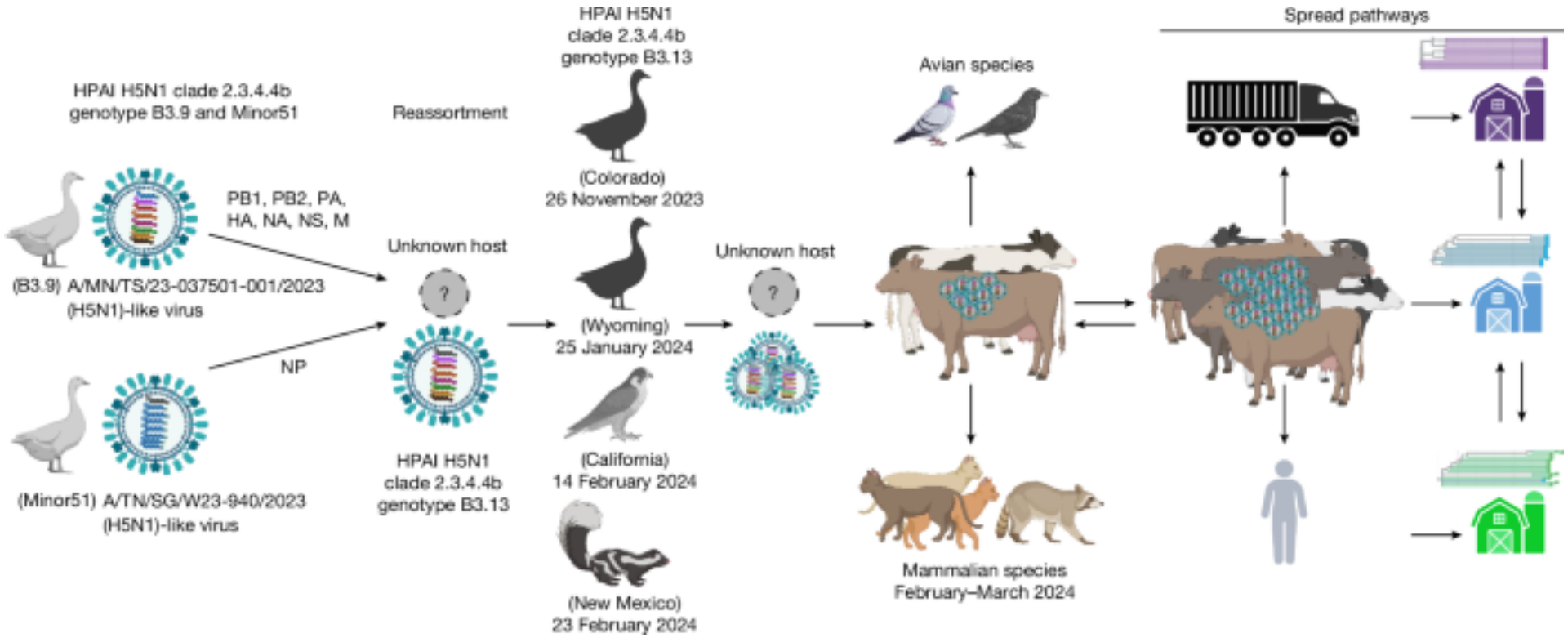
-1
-2
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Year
1918
1957
1968
2009
2023

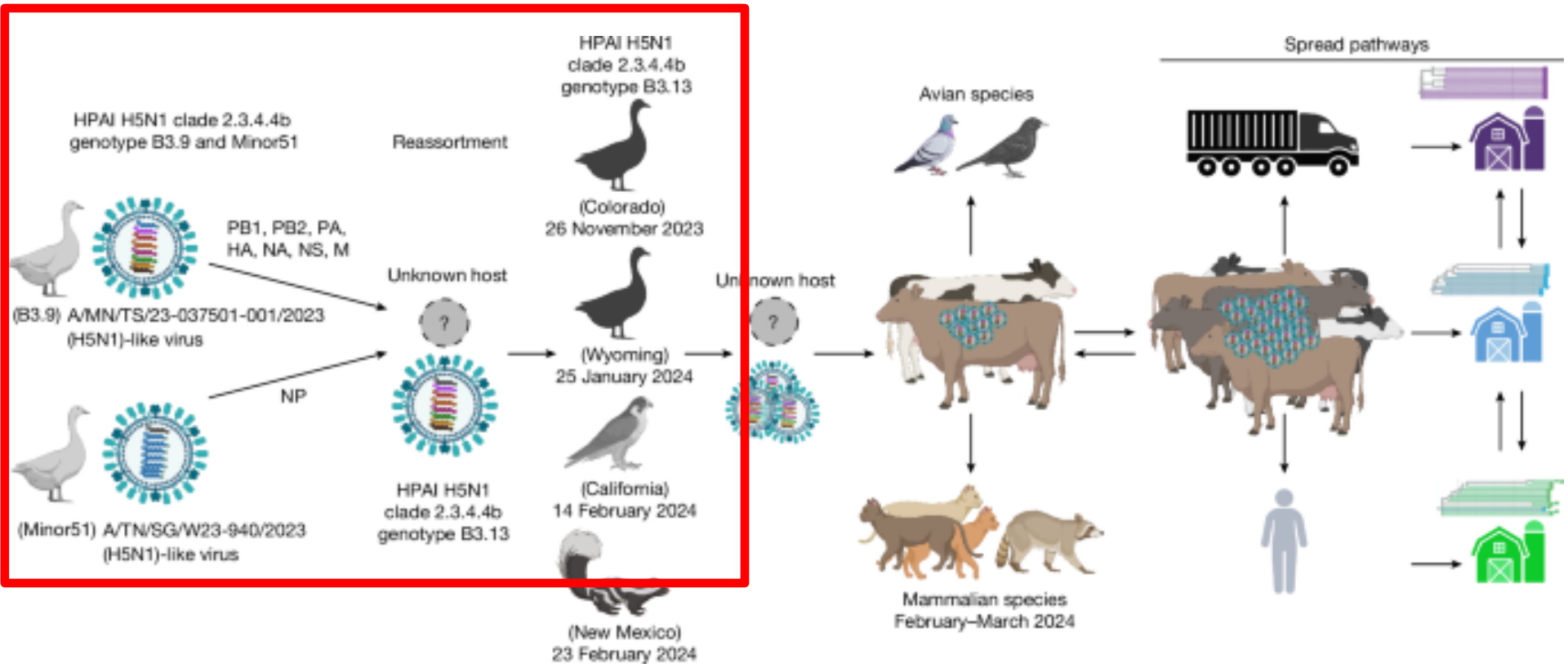
2023 H5N1 Avian Flu



[Rosenke et al., *Nature*, 2025]

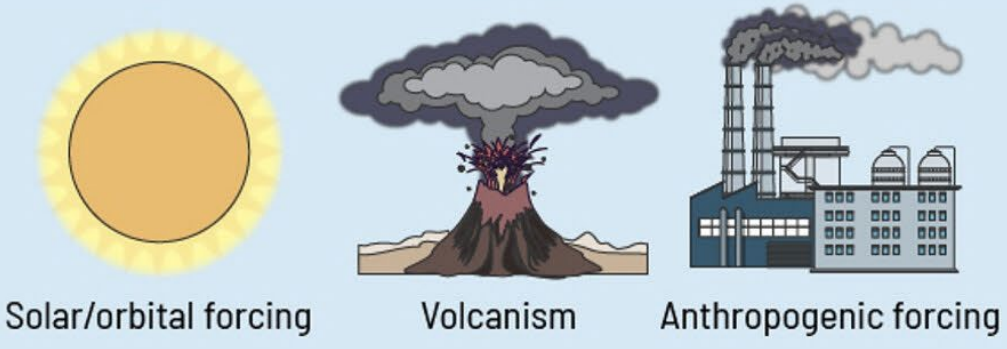
2023 H5N1 Avian Flu

2023-2024

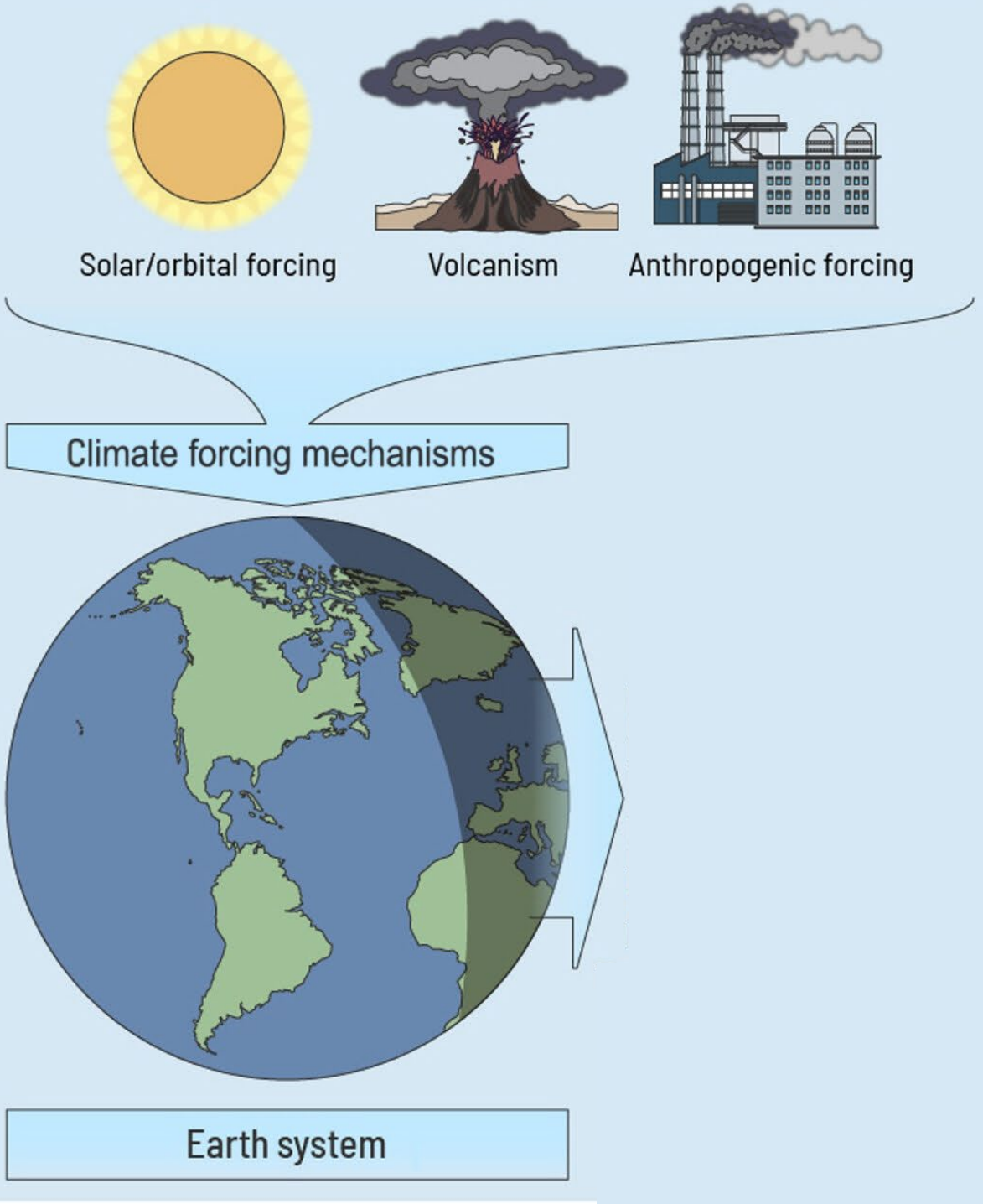


[Rosenke et al., *Nature*, 2025]

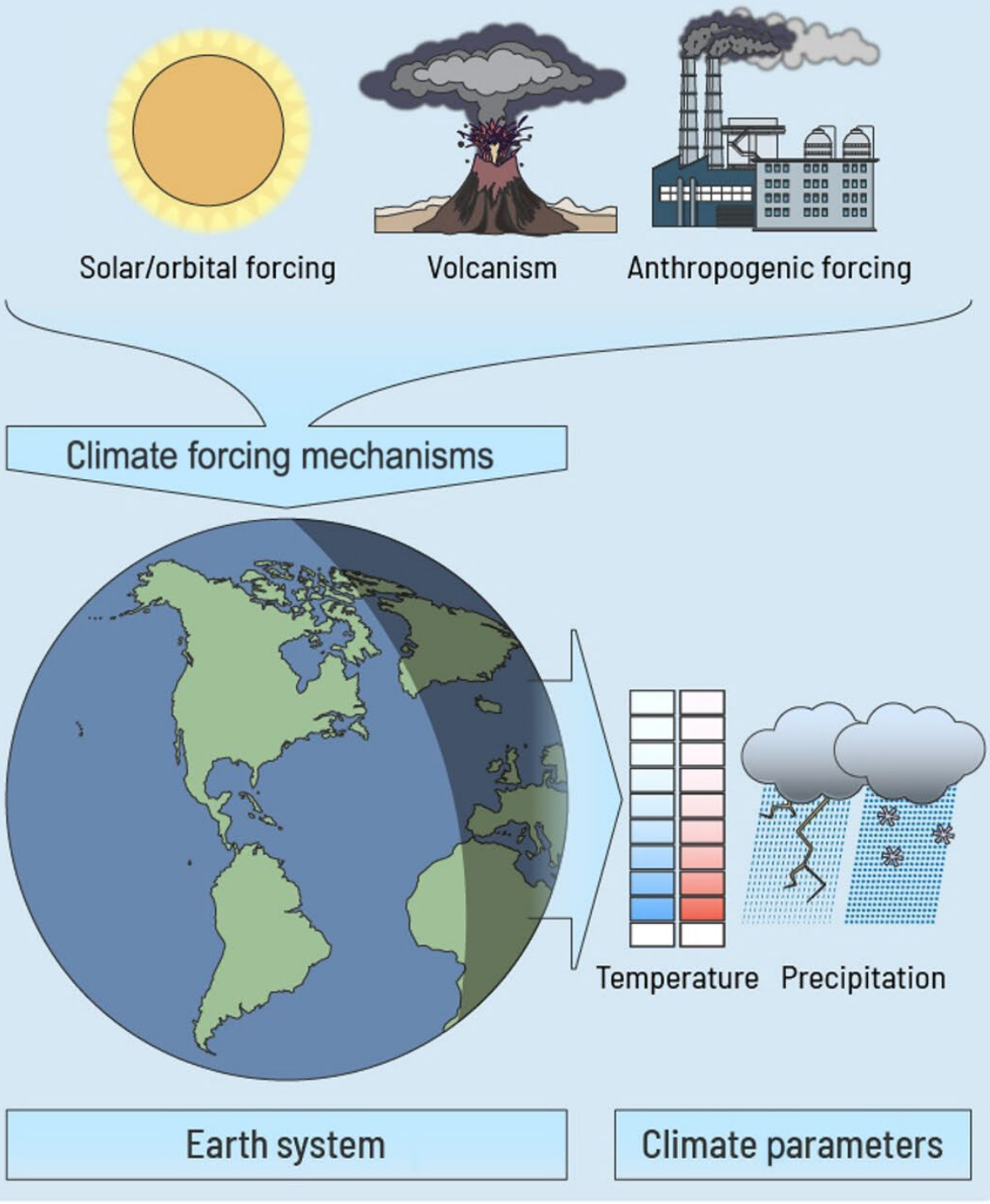
Climate-Infectious Disease Nexus



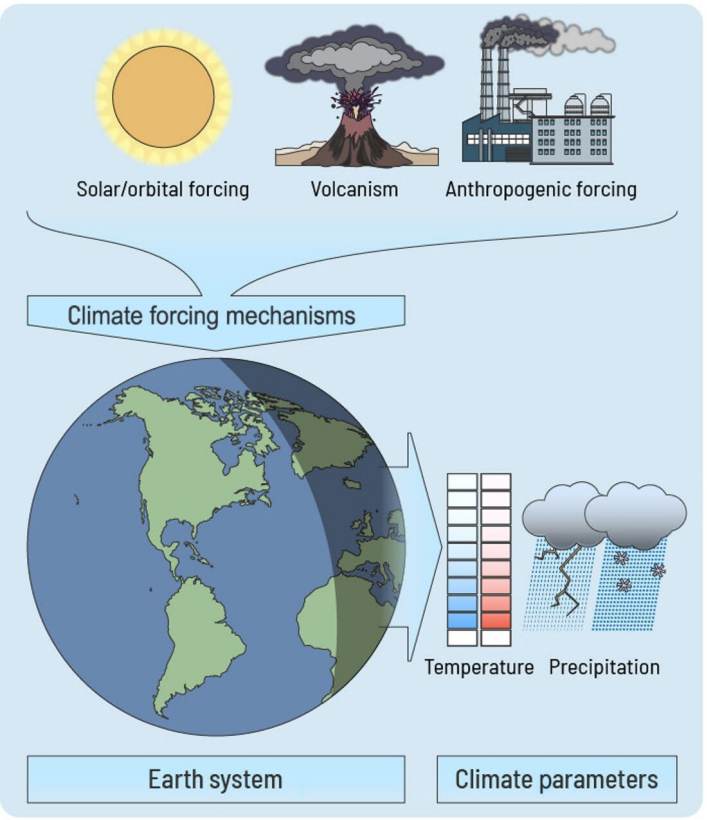
Climate-Infectious Disease Nexus

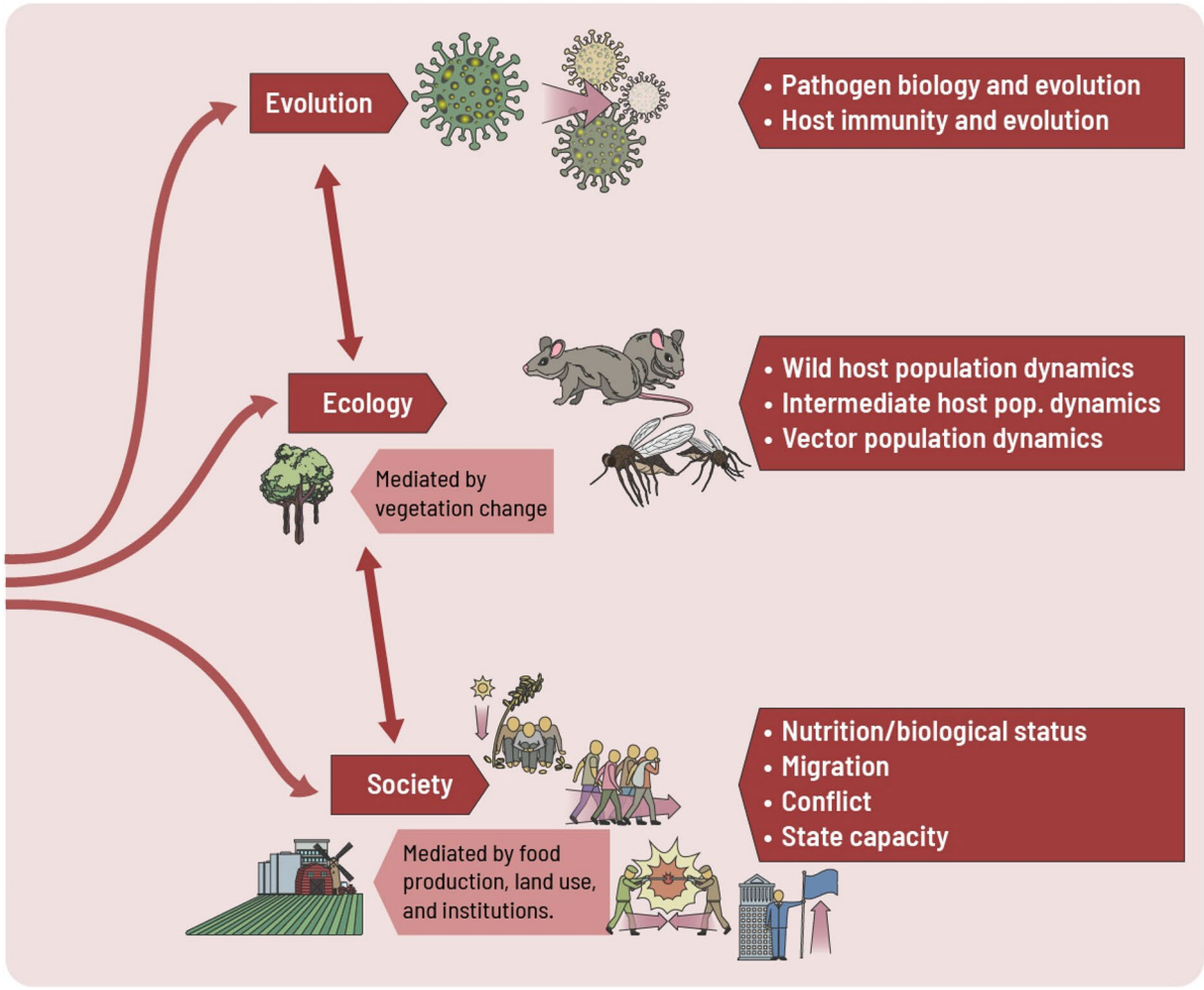


Climate-Infectious Disease Nexus

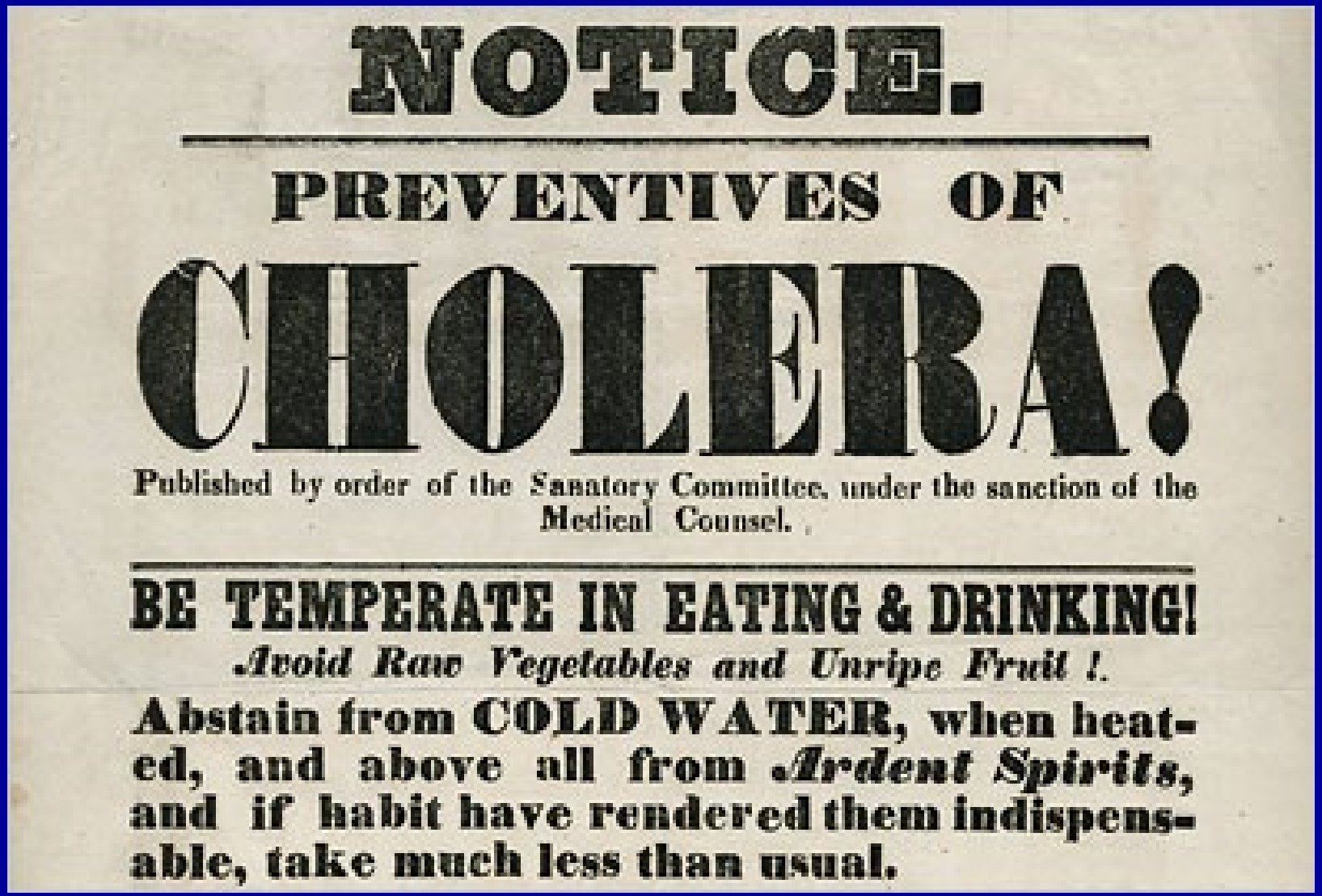


Climate-Infectious Disease Nexus





2) Cholera Pandemics: 1817 – 1851



NOTICE.

PREVENTIVES OF

CHOLERA!

Published by order of the Sanatory Committee, under the sanction of the Medical Counsel.

BE TEMPERATE IN EATING & DRINKING!

Avoid Raw Vegetables and Unripe Fruit !.

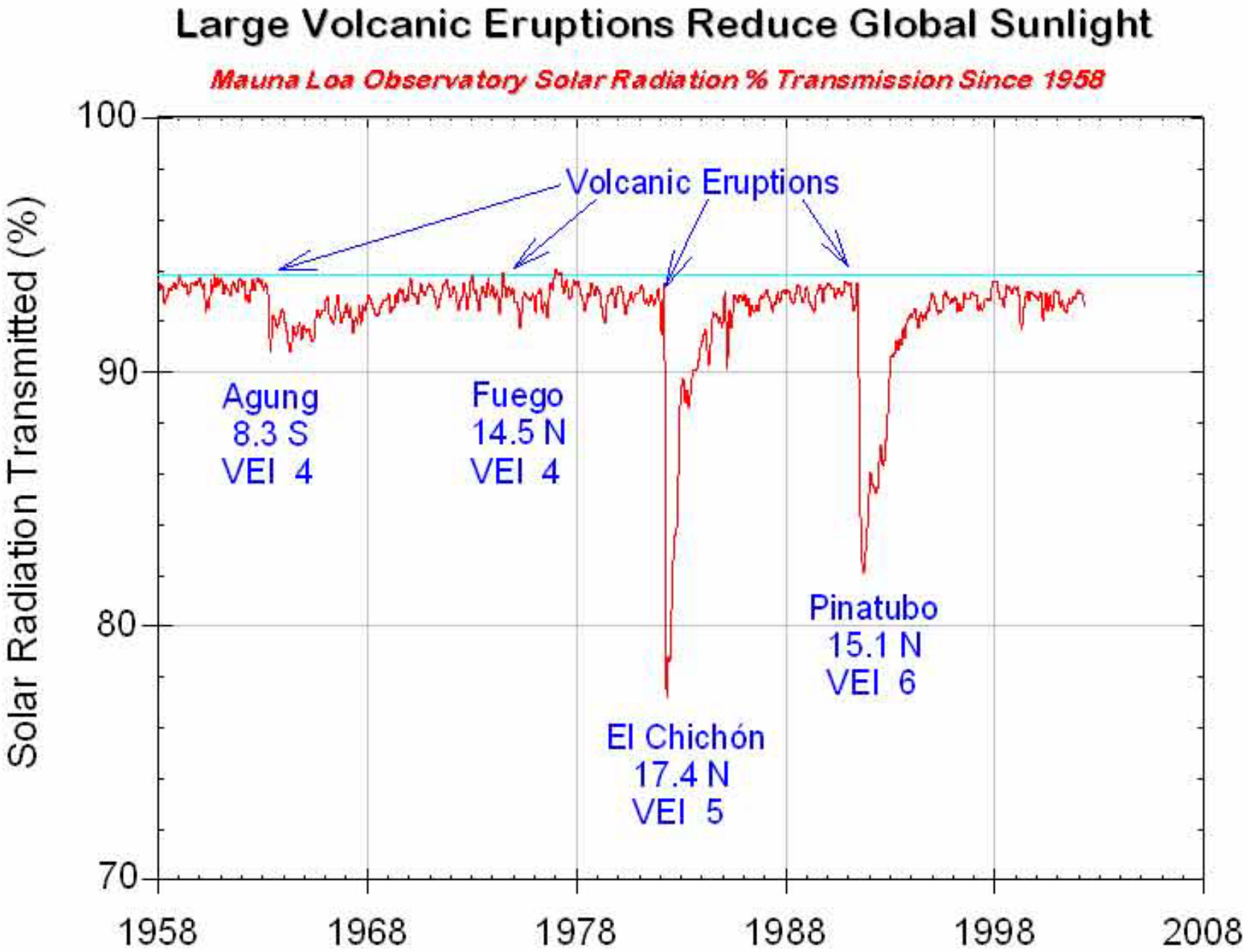
Abstain from COLD WATER, when heated, and above all from *Ardent Spirits*, and if habit have rendered them indispensable, take much less than usual.

Hand bill from the New York City Board of Health, 1832

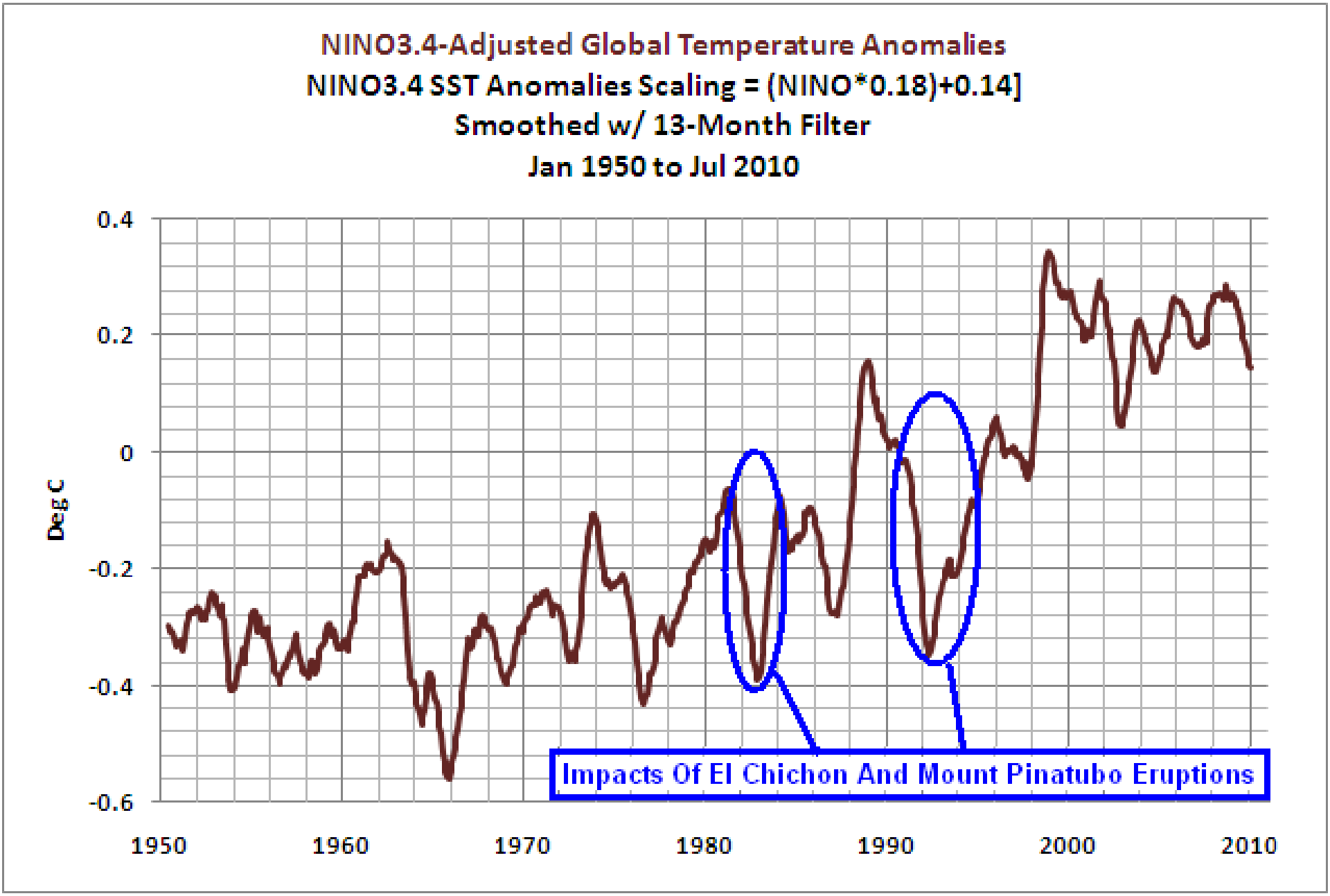
Mt. Tambora (Indonesia): 1815 Volcanic Eruption

Triggered the first global Cholera Pandemic, spreading from the Ganges Delta

Volcanic Eruptions: Sulfate Aerosols Reduce Sunlight

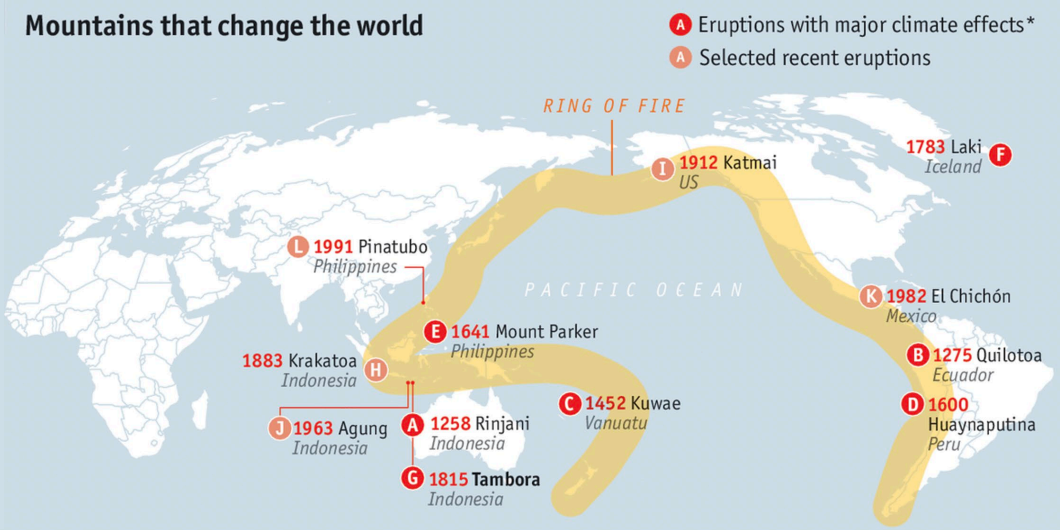


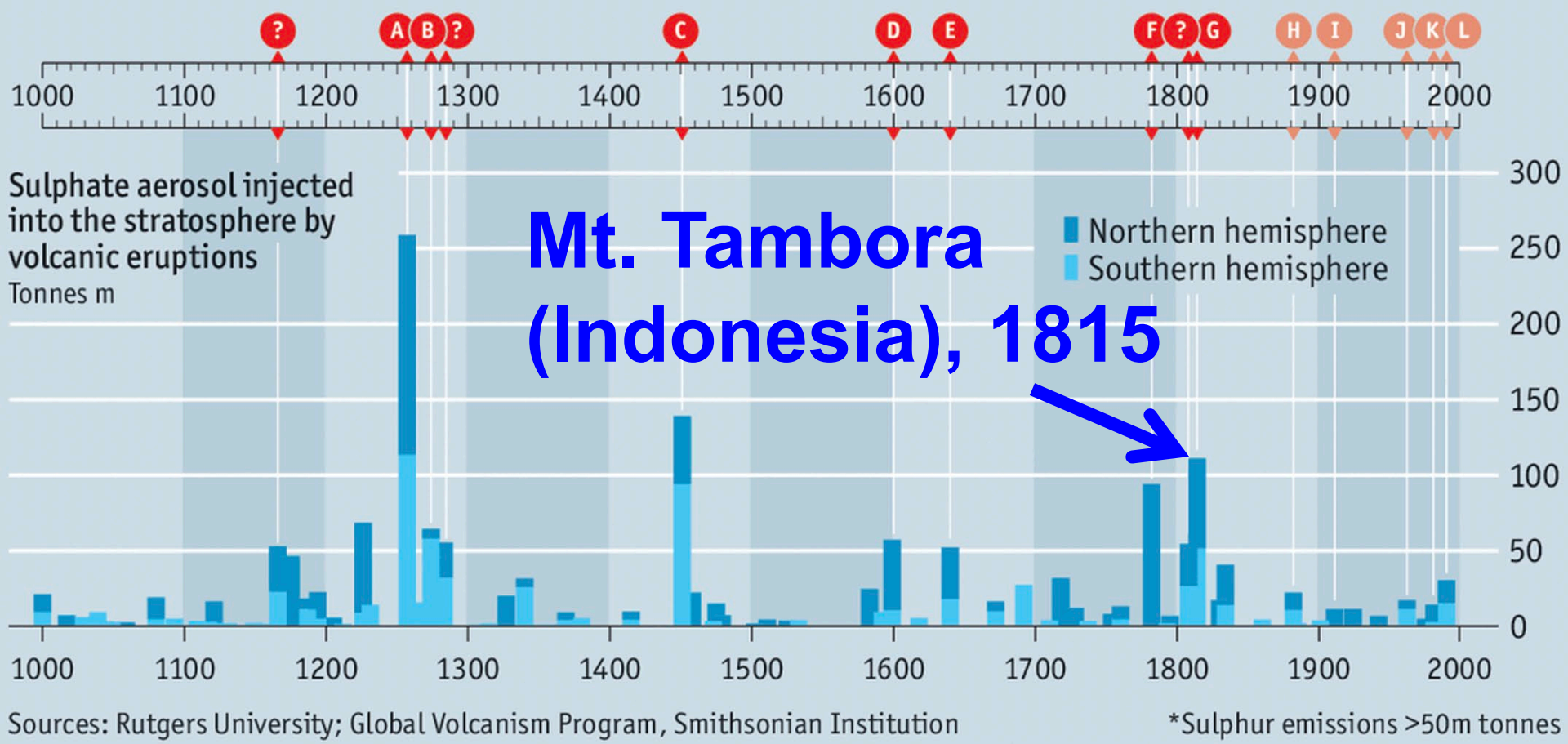
Volcanic Eruptions: Sulfate Aerosols Lower Temperatures



Sulfate Aerosols from Volcanic Eruptions

(in millions of tonnes)



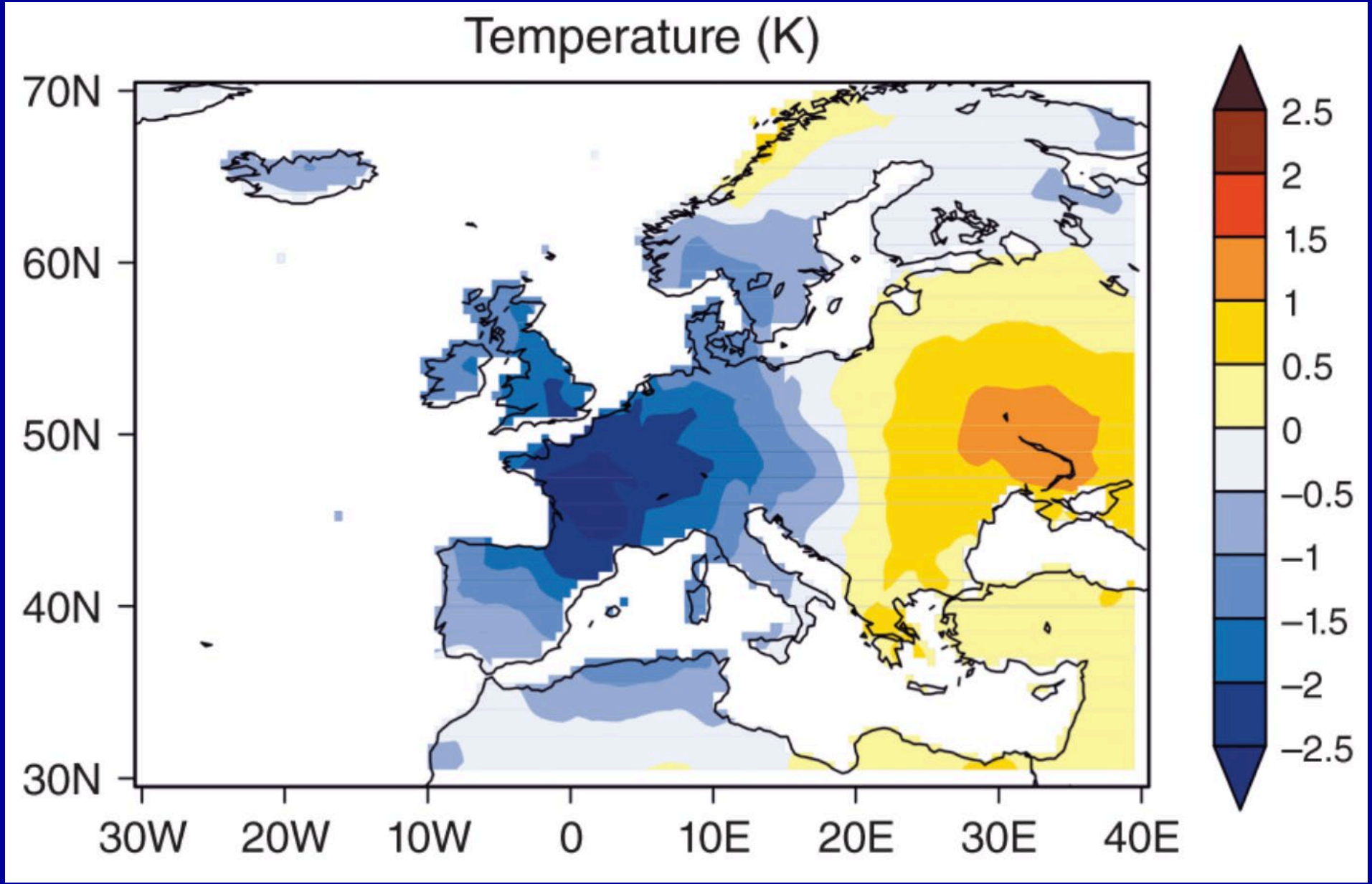


1816 is known as the “Year Without a Summer”

1816: Cold Weather and Crop Failures in Europe and N. Amer.

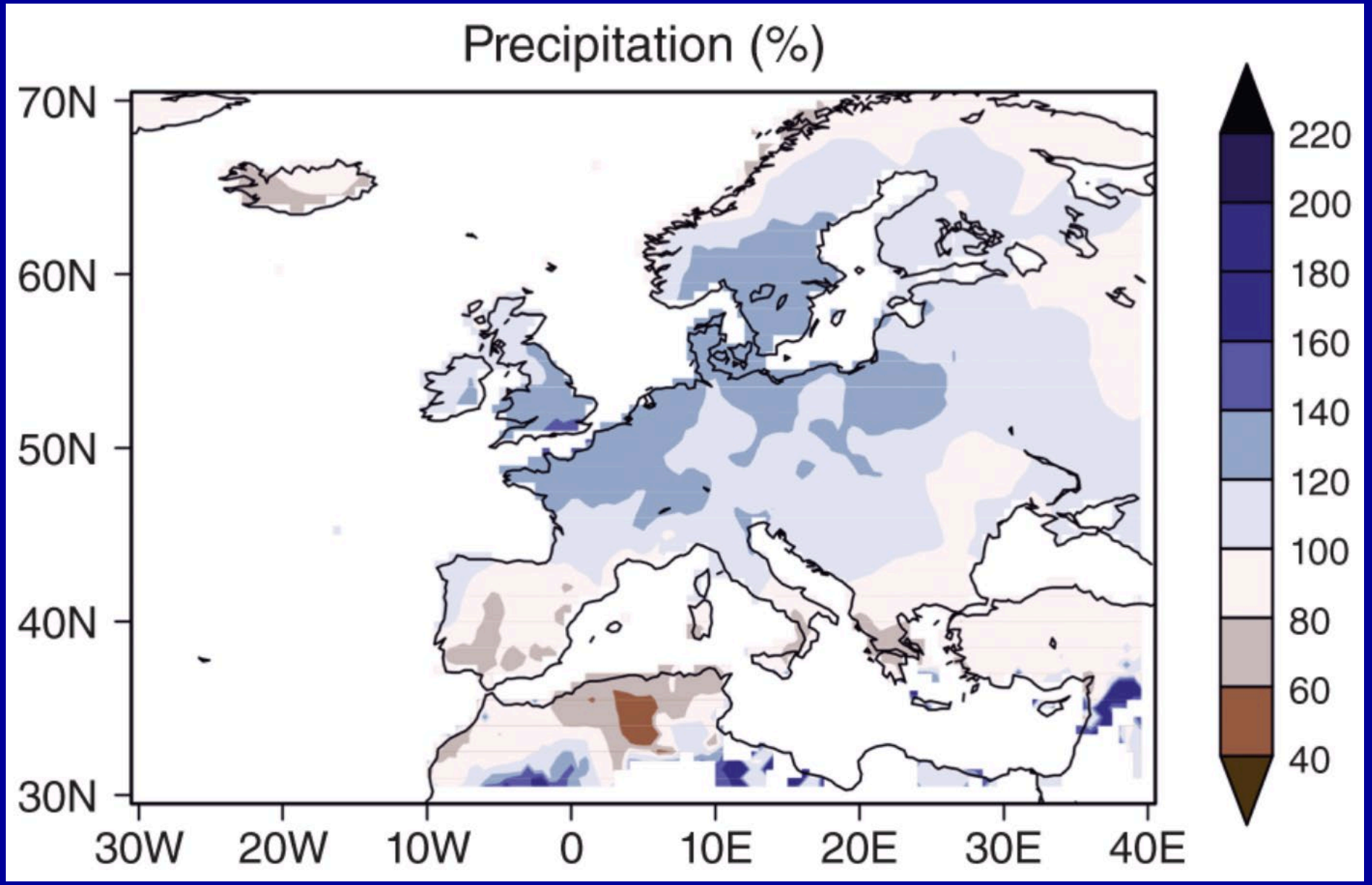
(New England Historical Society)

1816: Summer *Drop in Temperature* in Western Europe



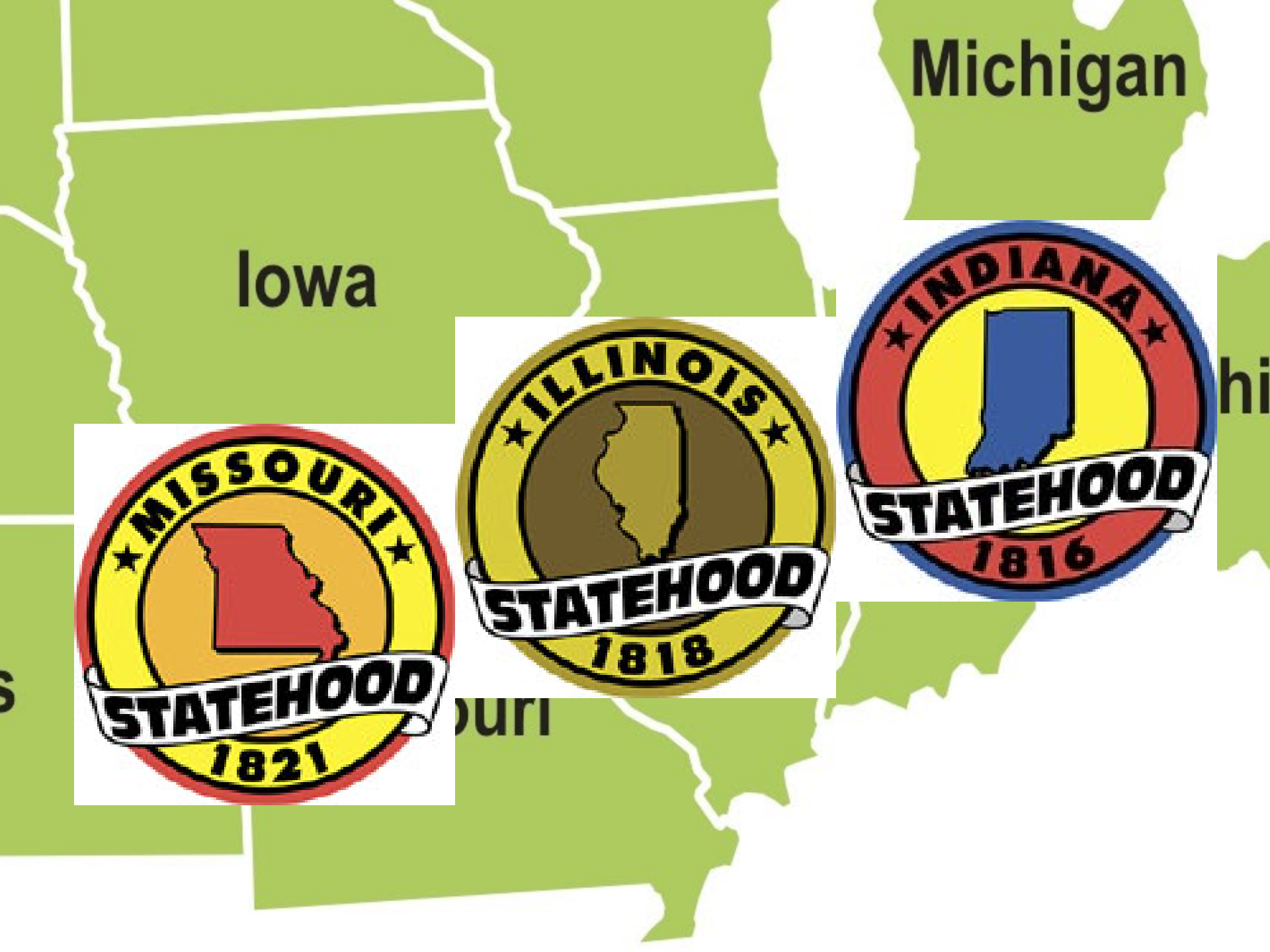
[Raible et al., 2016 (WIREs)]

1816: Summer *Increase in Precipitation* in Western Europe



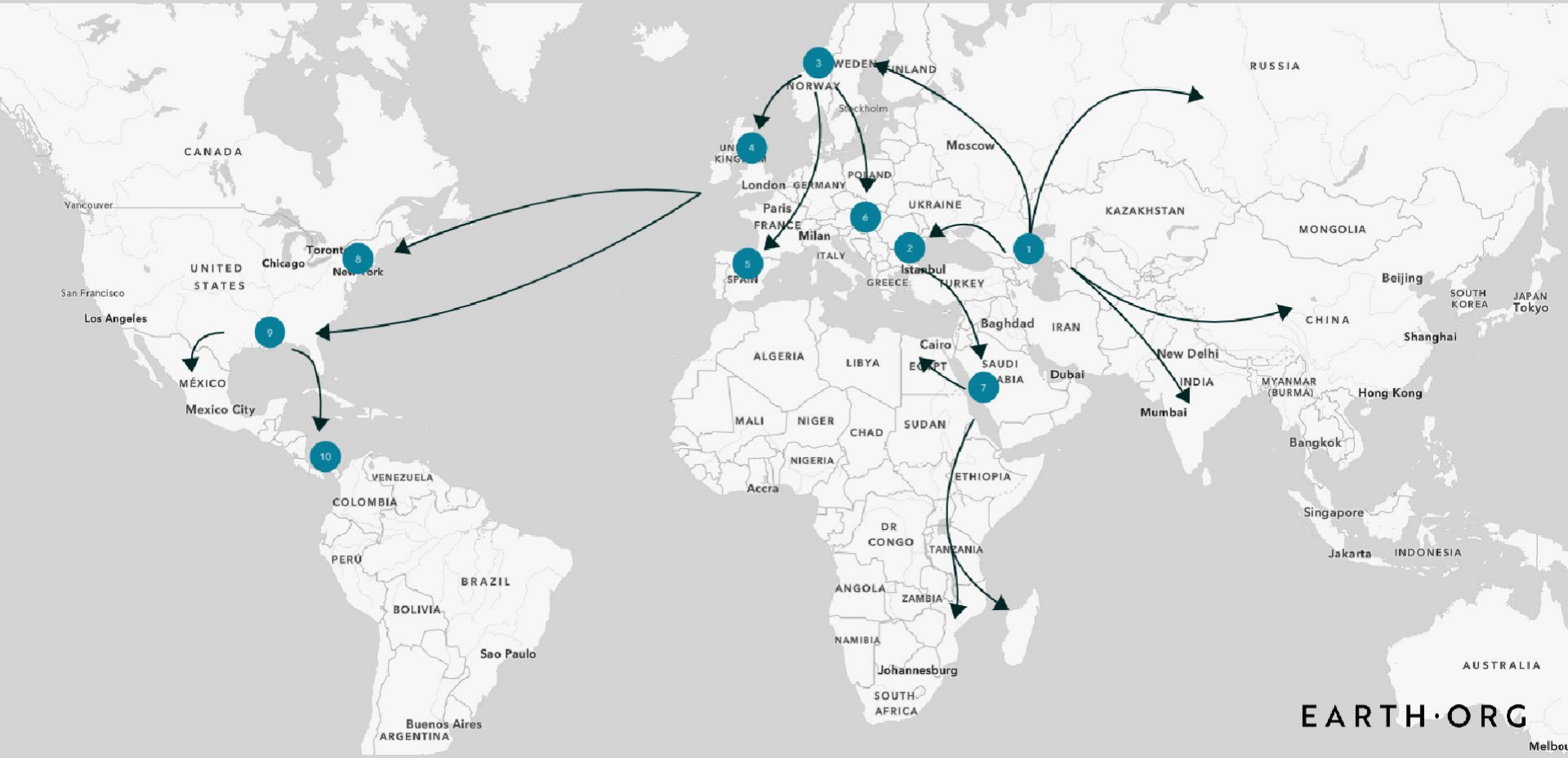
[Raible et al., 2016 (WIREs)]

After 1816 there is a huge push of U.S. Westward Expansion


Michigan
Iowa
MISSOURI
STATEHOOD
1821
ILLINOIS
STATEHOOD
1818
INDIANA
STATEHOOD
1816

Cholera Pandemic: Phase 1 (1816-1823)

Cholera Pandemic: Phase 2 (1826-1851)



1832: Cholera first reaches St. Louis

1849: Cholera epidemic kills 4317 (almost 5%)

St. Louis Bellefontaine Cemetery (1849)

3) 2nd *Yersinia pestis* ("Black Death"): 1320s – 1879

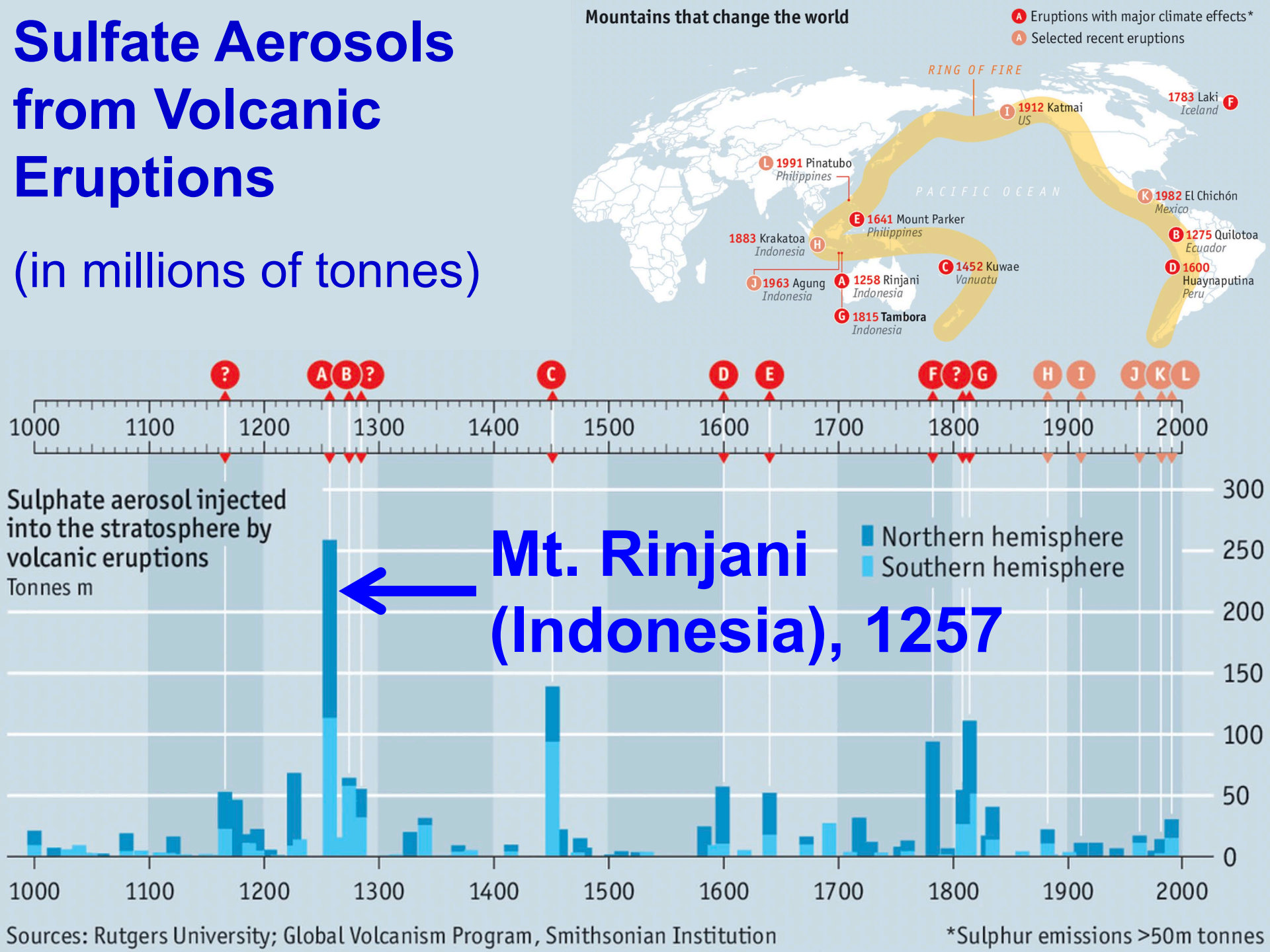
~1250 CE Onward: Increasing regional colder climate

→Great famine of 1315-1317

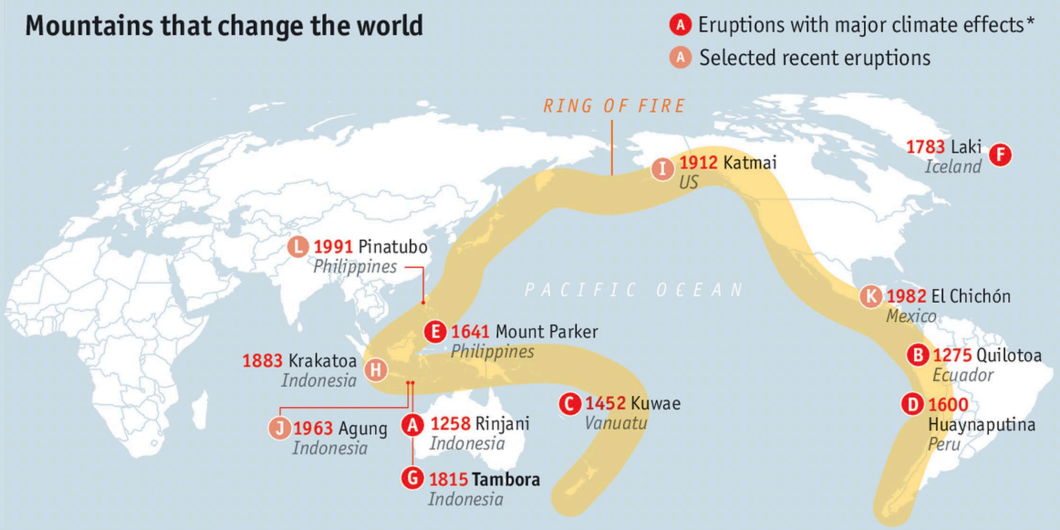
→Plague reaches Western Europe, 1345

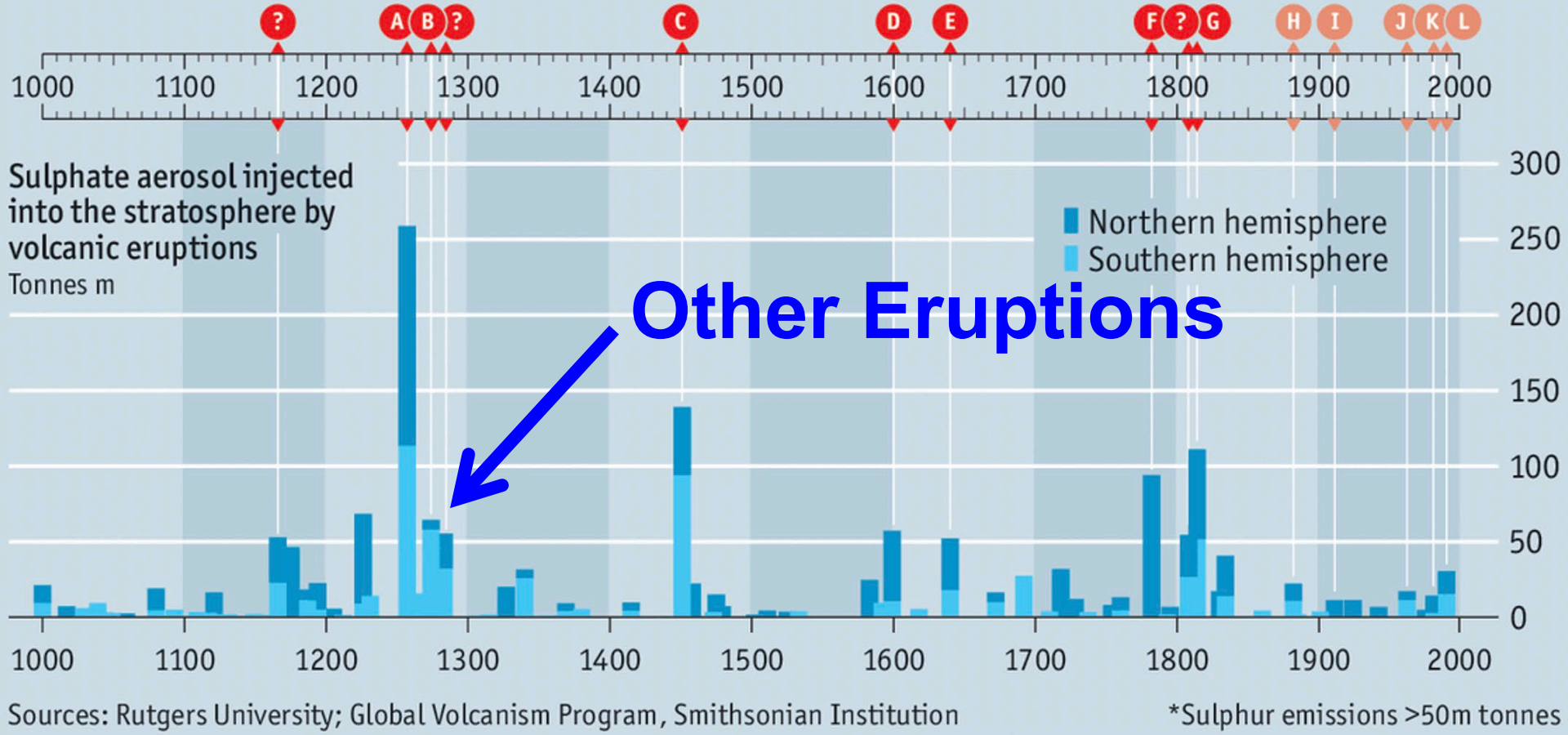
Sulfate Aerosols from Volcanic Eruptions

(in millions of tonnes)

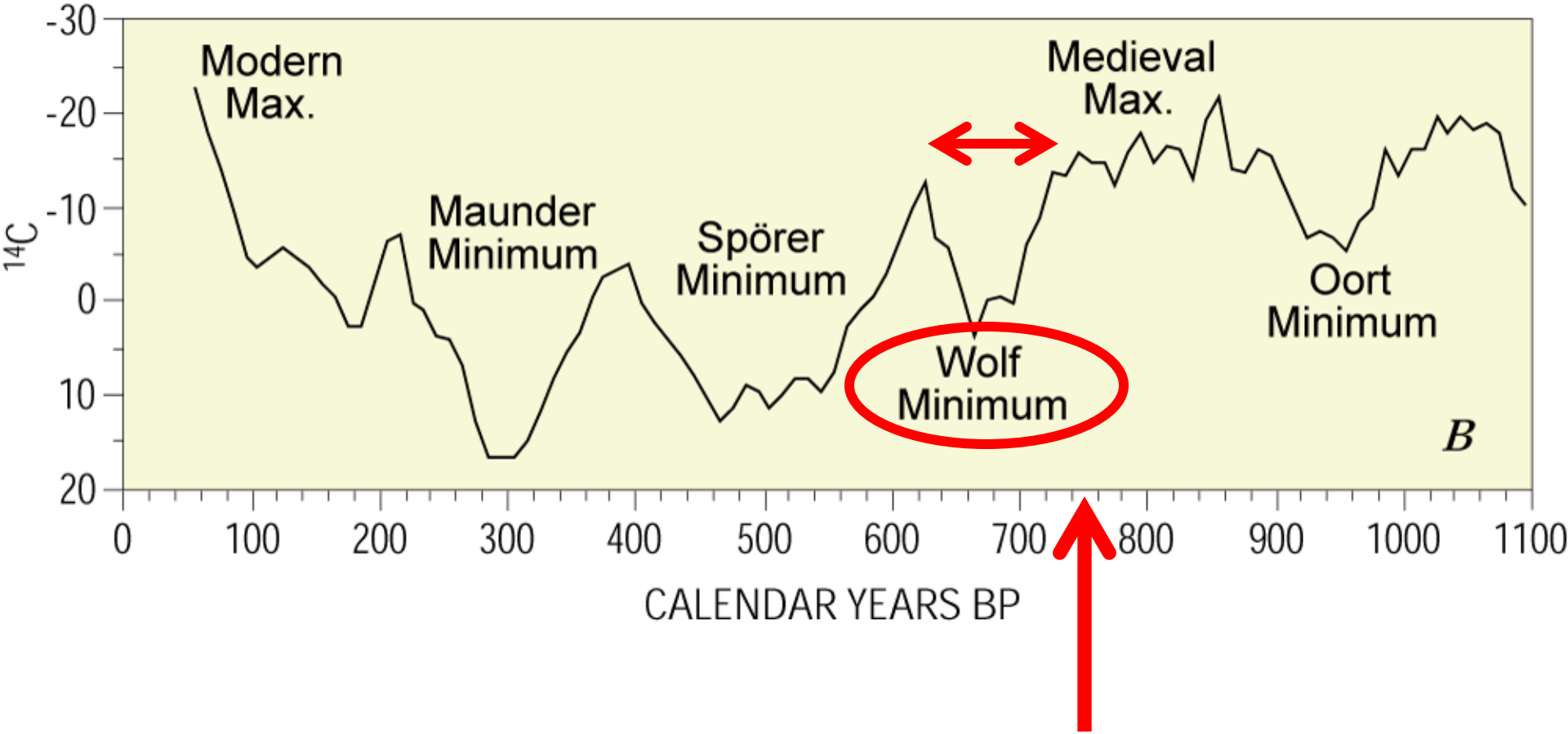


Multiple Regional Climate Disruptions, 1258-1300

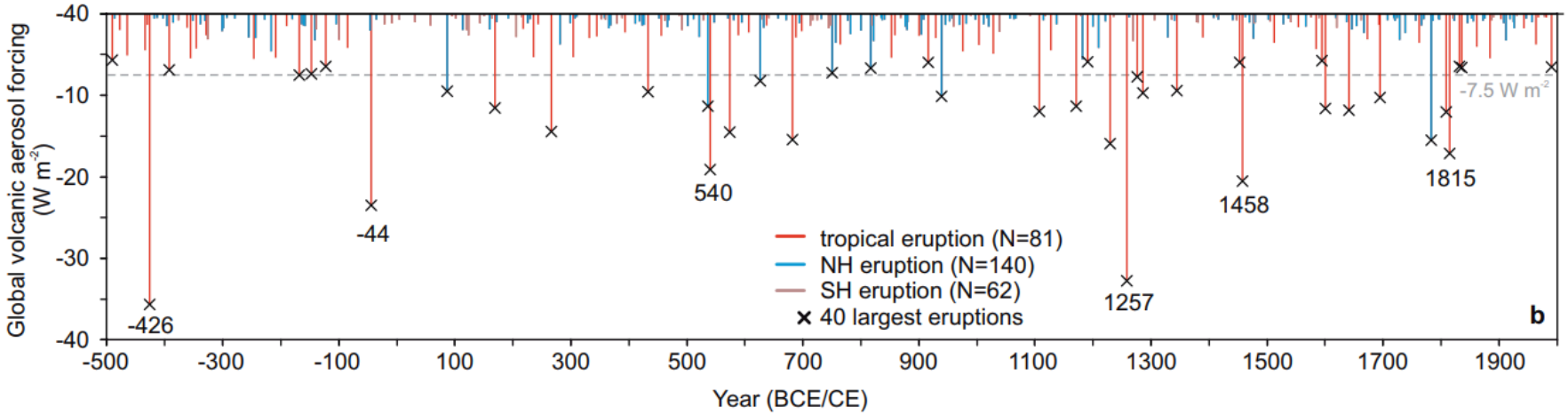




Wolf Solar Minimum: ~1280 – 1360 CE
(First Stage of the Little Ice Age)



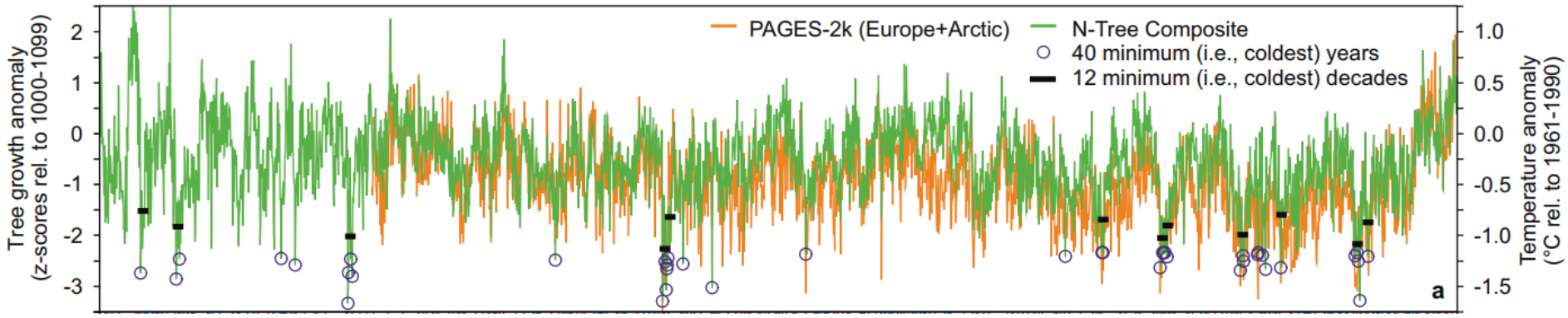
Eruption of Mt. Rinjani



Climate Forcing (W/m^2), from Volcanic Eruptions

[*Timing and climate forcing of volcanic eruptions for the past 2,500 years*, Sigl et al., *Nature*, 2015]

Temperatures, from Tree Rings



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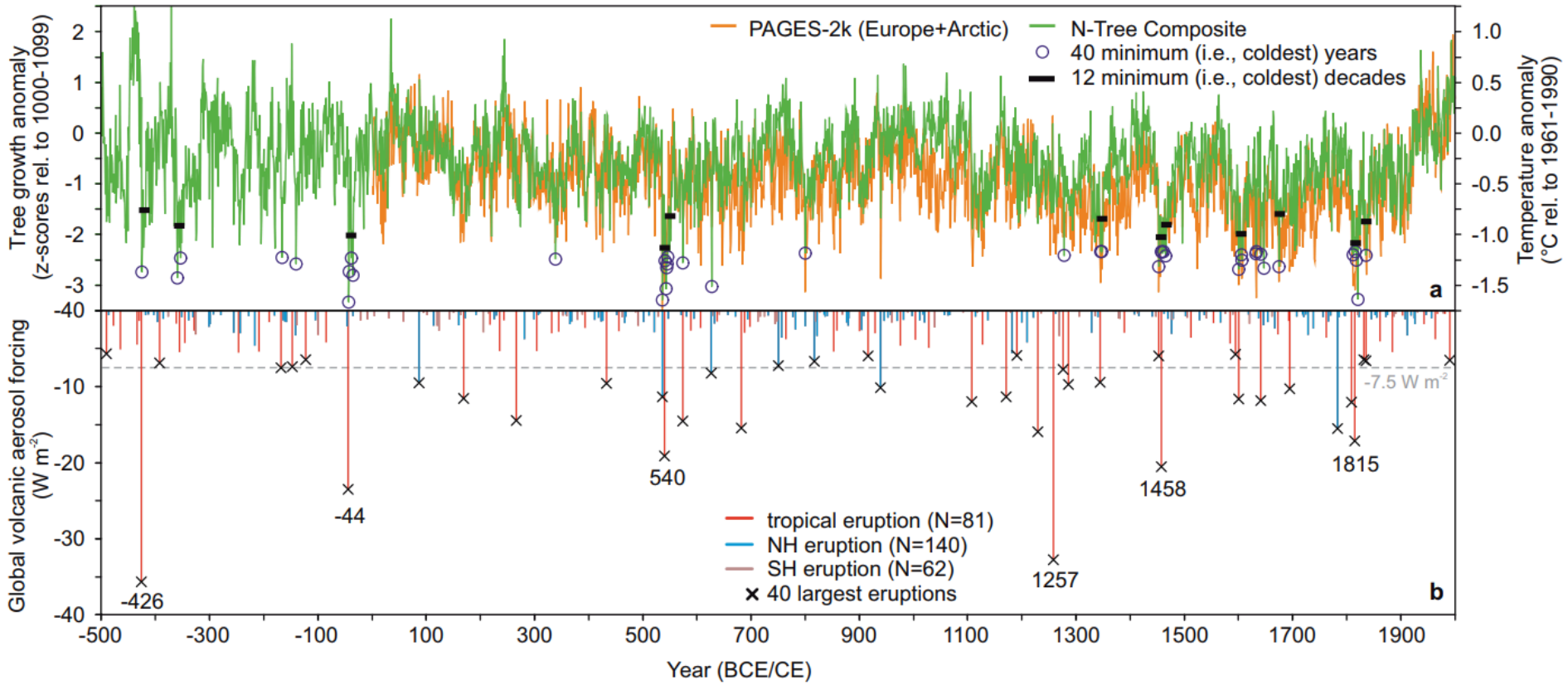

Climate Forcing (W/m^2), from Volcanic Eruptions

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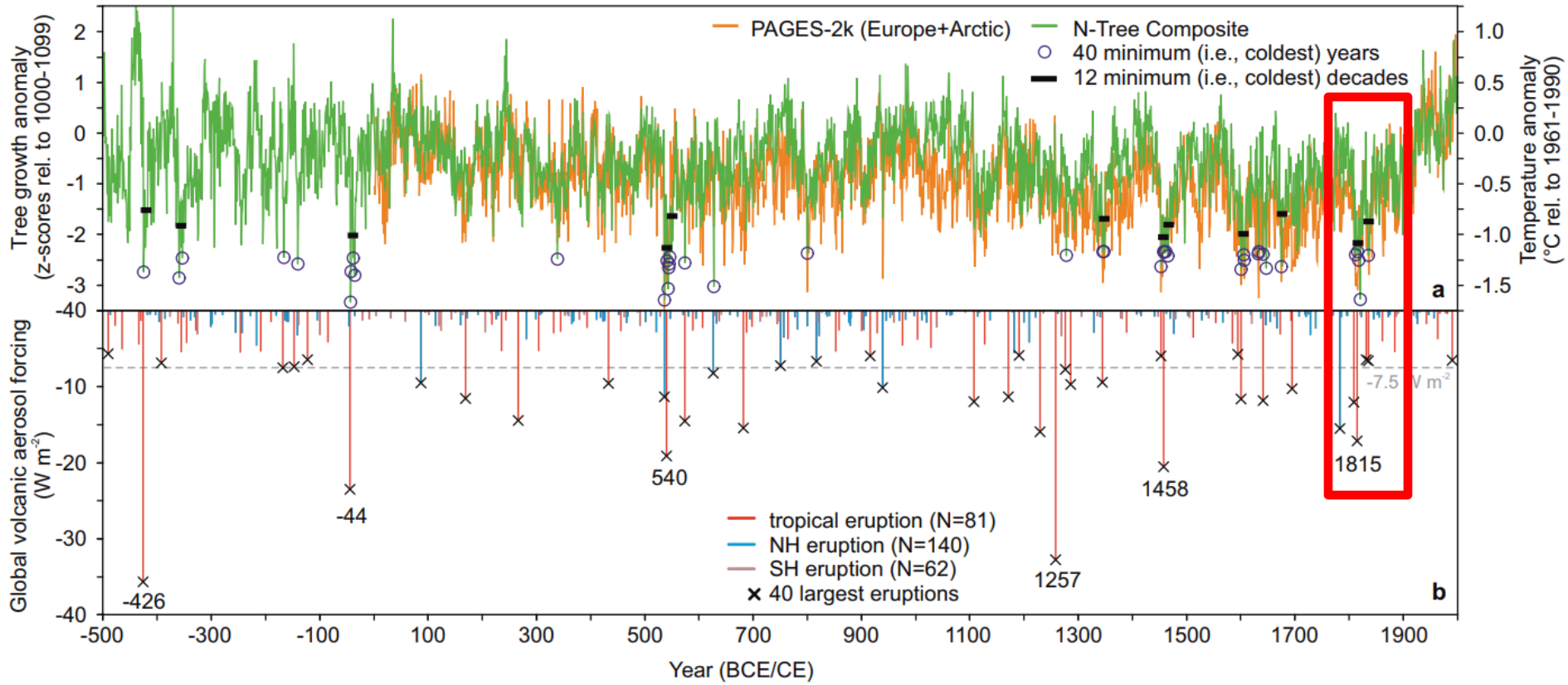
1815: Mt. Tambora: → Cholera Pandemics

Temperatures, from Tree Rings



Climate Forcing (W/m^2), from Volcanic Eruptions

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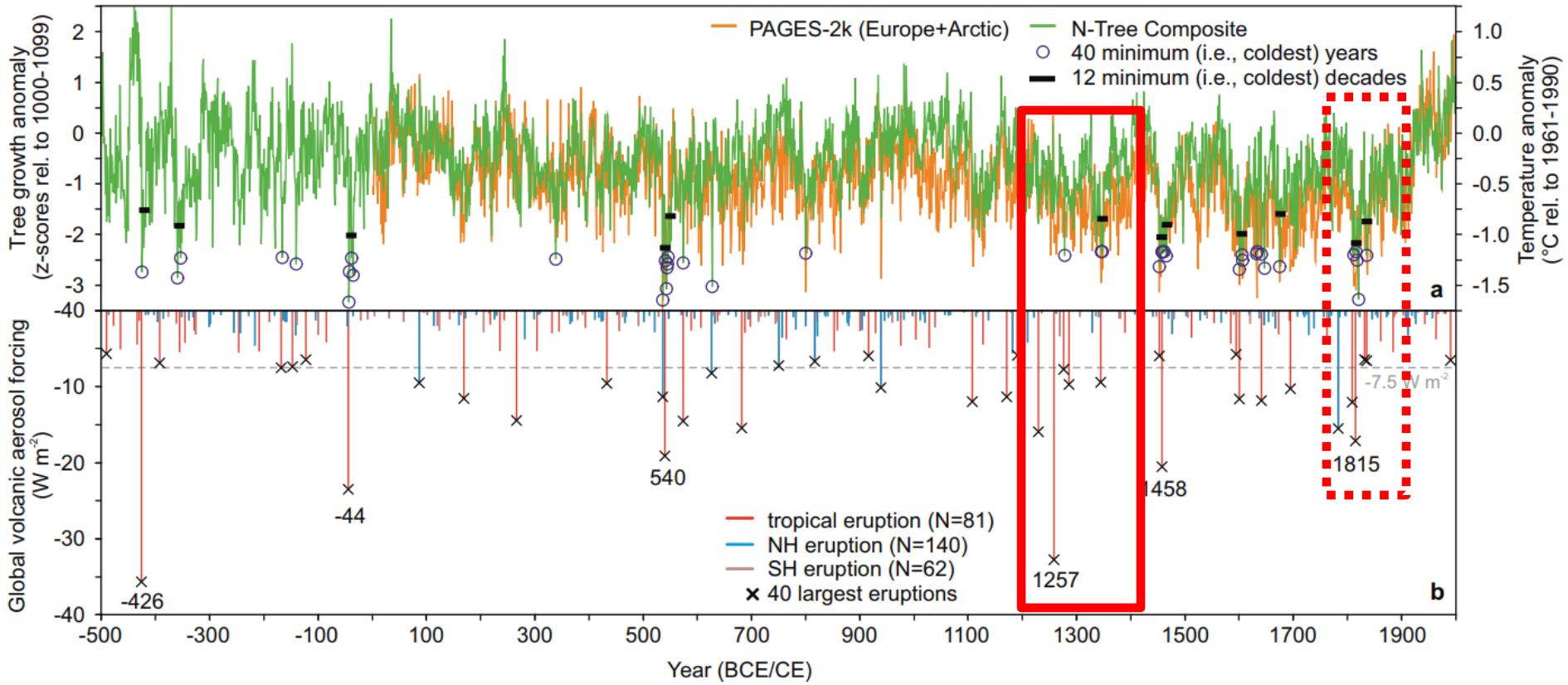
1257: Mt. Rinjani: → Black Death

Temperatures, from Tree Rings



Climate Forcing (W/m^2), from Volcanic Eruptions

[*Timing and climate forcing of volcanic eruptions for the past 2,500 years*, Sigl et al., *Nature*, 2015]

Climate Impacts Following the 1257 Eruption of Mt. Rinjani

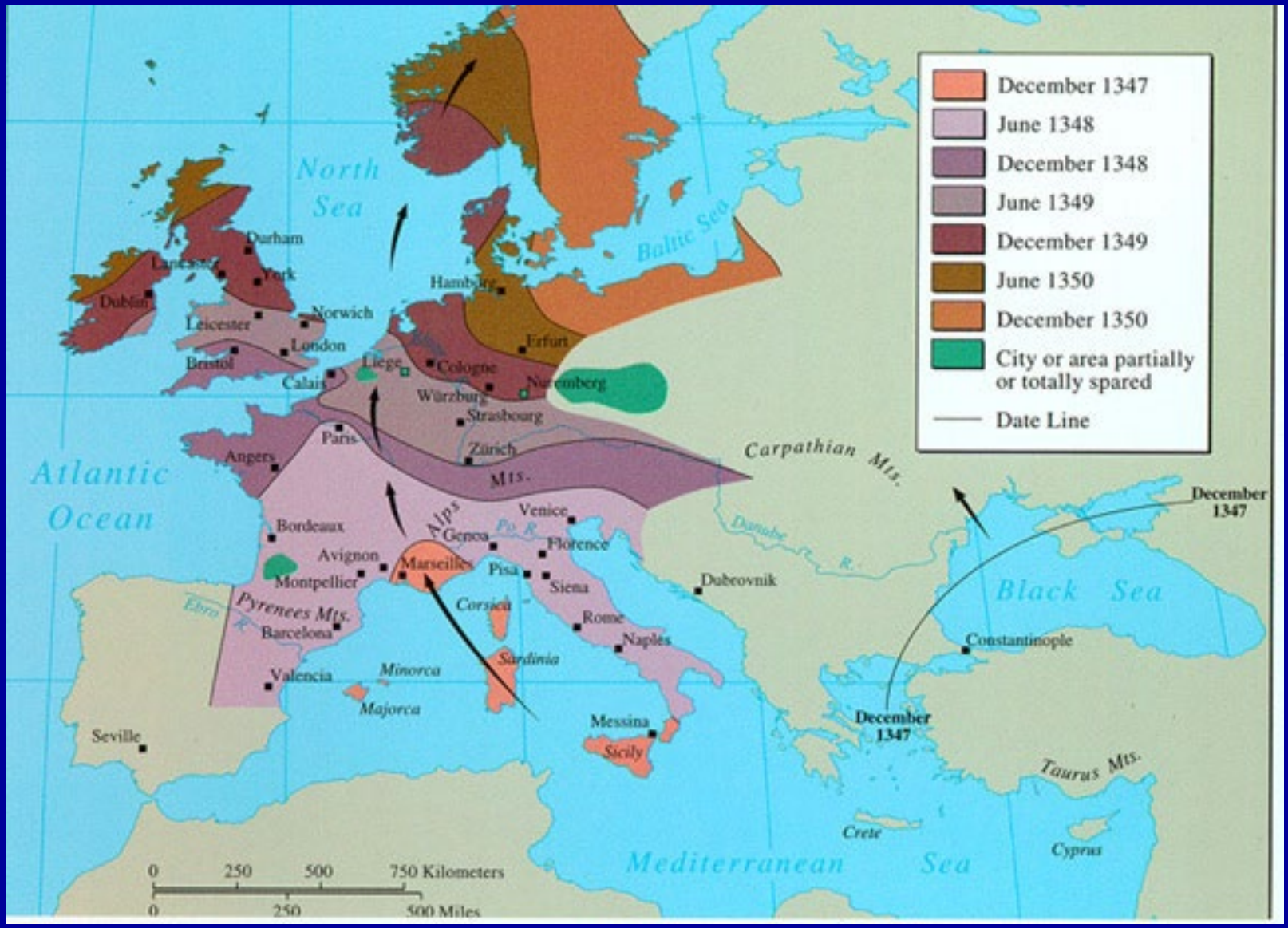
→Various modeling of regional data has suggested:

- Strong negative Antarctic Oscillation (Southern Annual Mode – SAM)
- Prevalence of El Niño conditions
- Redistribution of locations of hurricanes
- Changes in the Atlantic subpolar circulation and a weakening of the Atlantic thermohaline circulation
- A modification of the North Atlantic Oscillation (NAO) with a predominance of the negative mode
- A stronger East Asian winter monsoon and colder regional sea surface temperatures
- An excitation of the Pacific Meridional Mode (PMM)
- A decline in European moisture availability

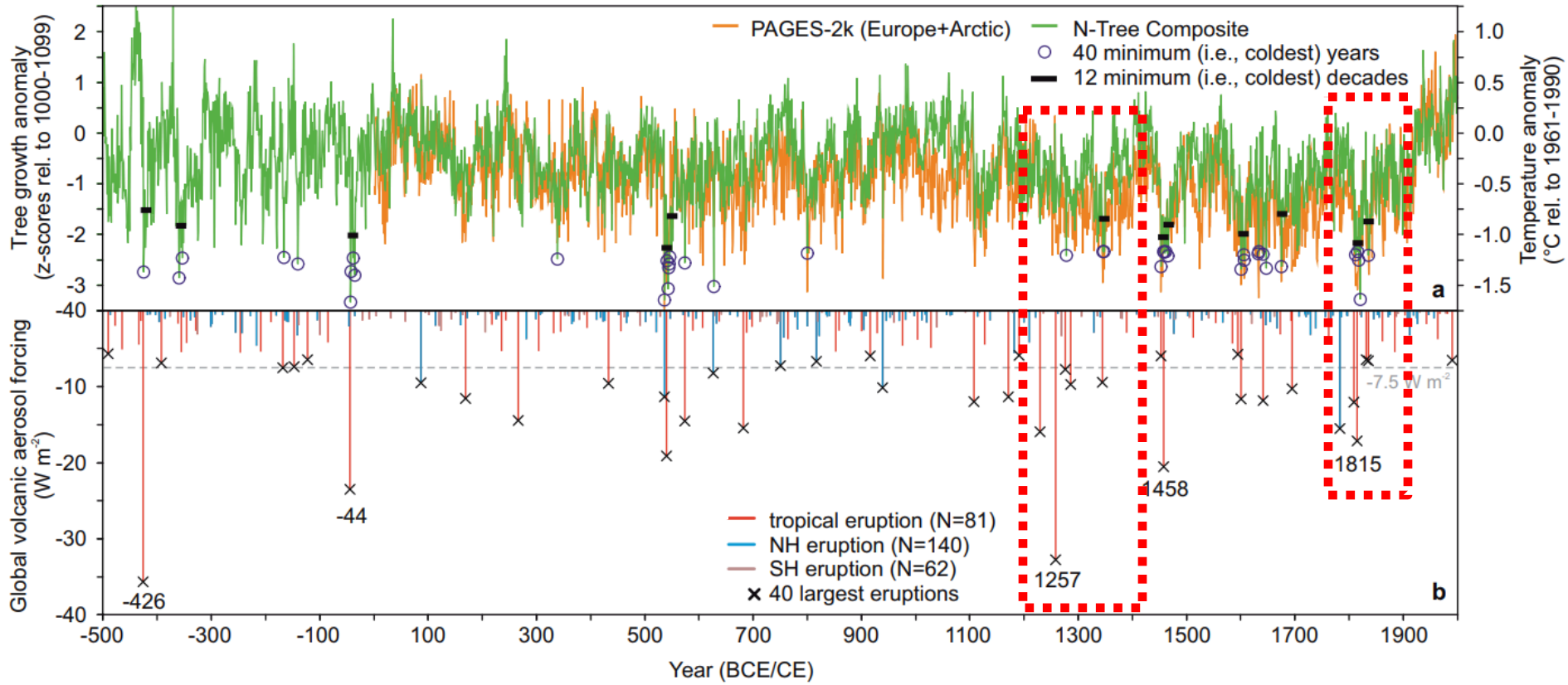
Human Impacts: Harder to assess for 13th century than the 1820's

Written records suggest unusual weather phenomena (and/or famines and human migrations) in lands that are now Indonesia, Oceania, New Zealand, England, France, Holland, Germany, Russia, Greenland, Iceland, Anatolia, Southwest North America, Ecuador, China, Japan, and Korea.

Spread of *Yersinias pestis* through Europe



Changes the social dynamics of Western/Eastern Europe



Climate Forcing (W/m^2), from Volcanic Eruptions

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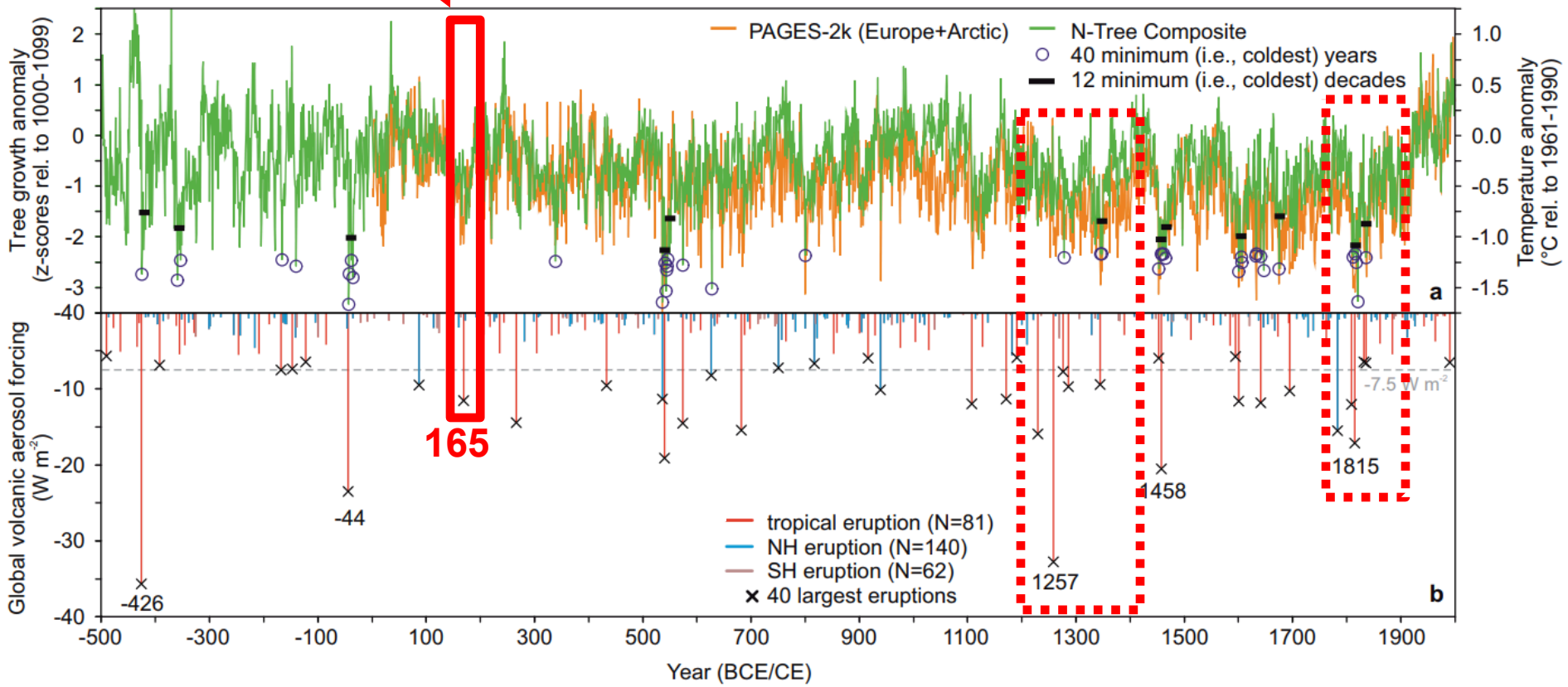
Antonine Plague



Climate Forcing (W/m^2), from Volcanic Eruptions

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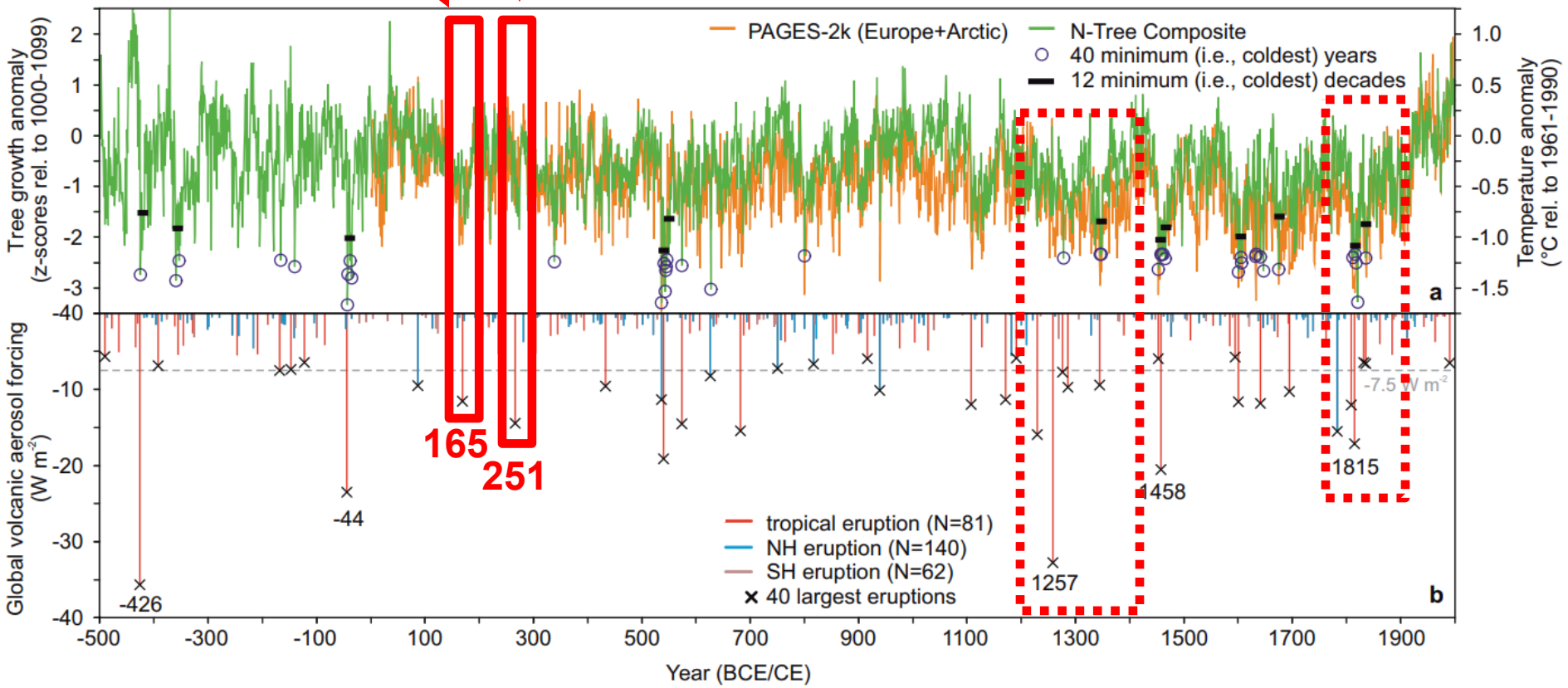
Plague of Cyprian

Antonine Plague



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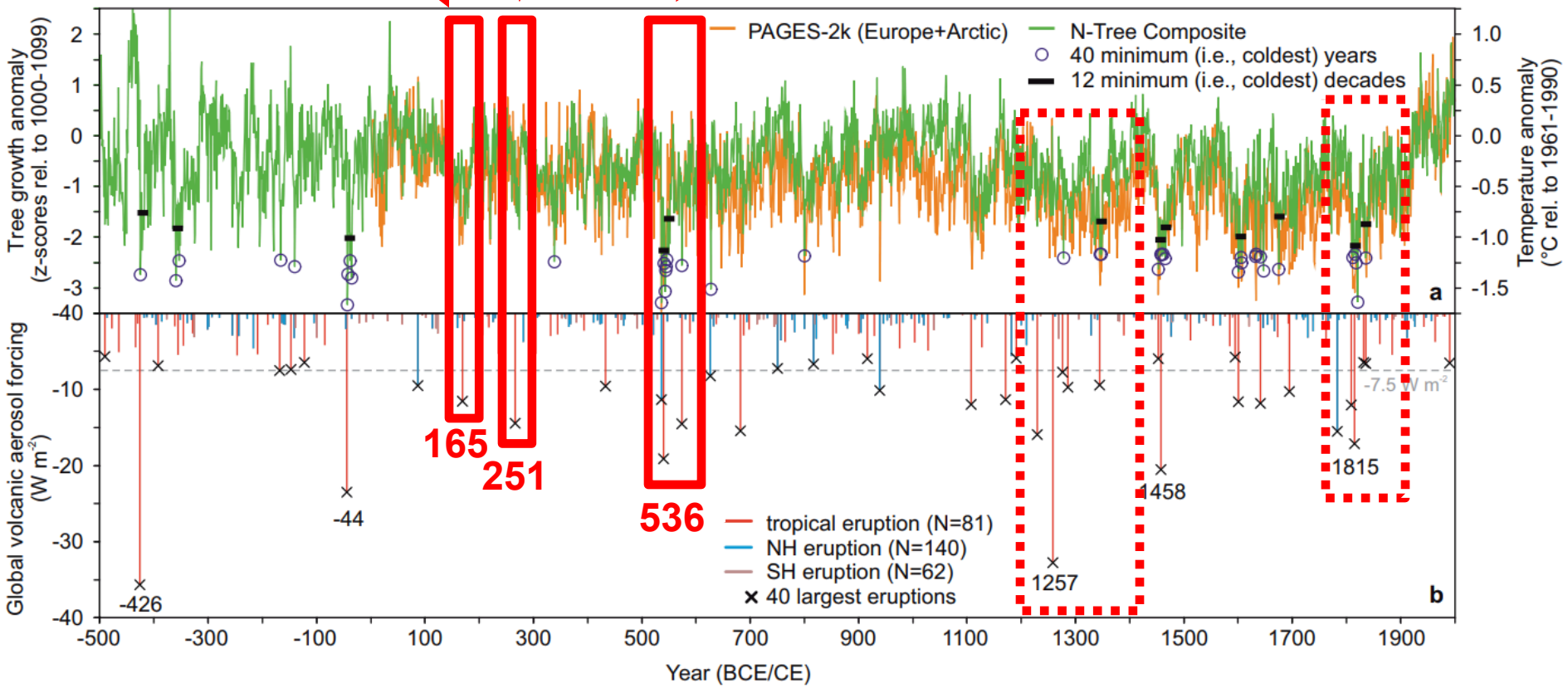
Plague of Cyprian

Antonine Plague

Plague of Justinian



Climate Forcing (W/m^2), from Volcanic Eruptions

[*Timing and climate forcing of volcanic eruptions for the past 2,500 years*, Sigl et al., *Nature*, 2015]

4) Antonine Plague: 165 – 180

The angel of death striking a door during the plague of Rome.
Engraving by Levasseur, after J. Delaunay

Brought by Roman Army from Wars with Seleucia (Mesopotamia) in 165 CE

→Devastates Roman Army (1/4 to 1/3?)

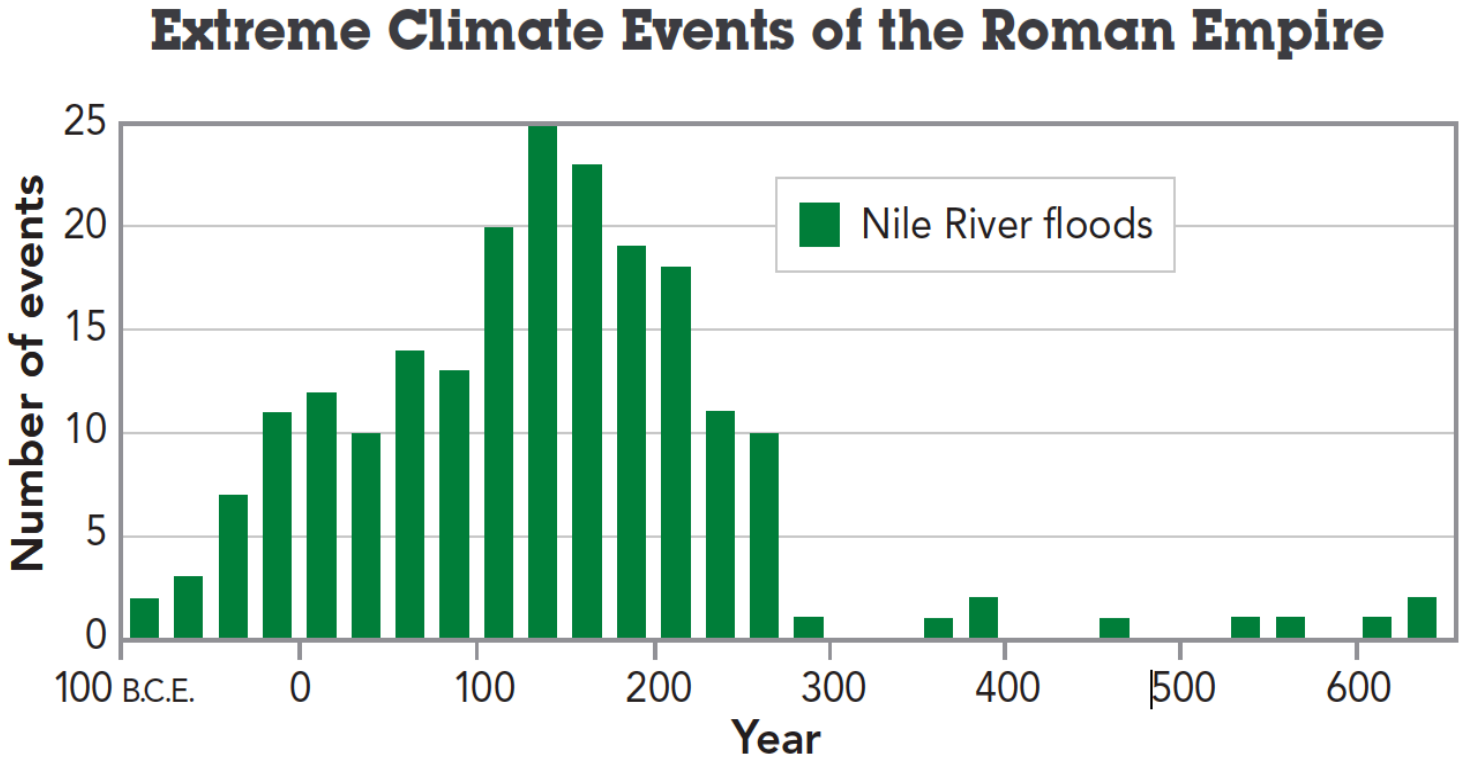
→Kills more than 5 million? (Smallpox? Measles?)

Brought by Roman Army from Wars with Seleucia (Mesopotamia) in 165 CE

→Occurred during a cold pulse between ~160 – 180 CE that followed several decades of cooling and dryness

→Coincided with the end of the Pax Romana ("Roman Peace"), 27 BCE – 180 CE

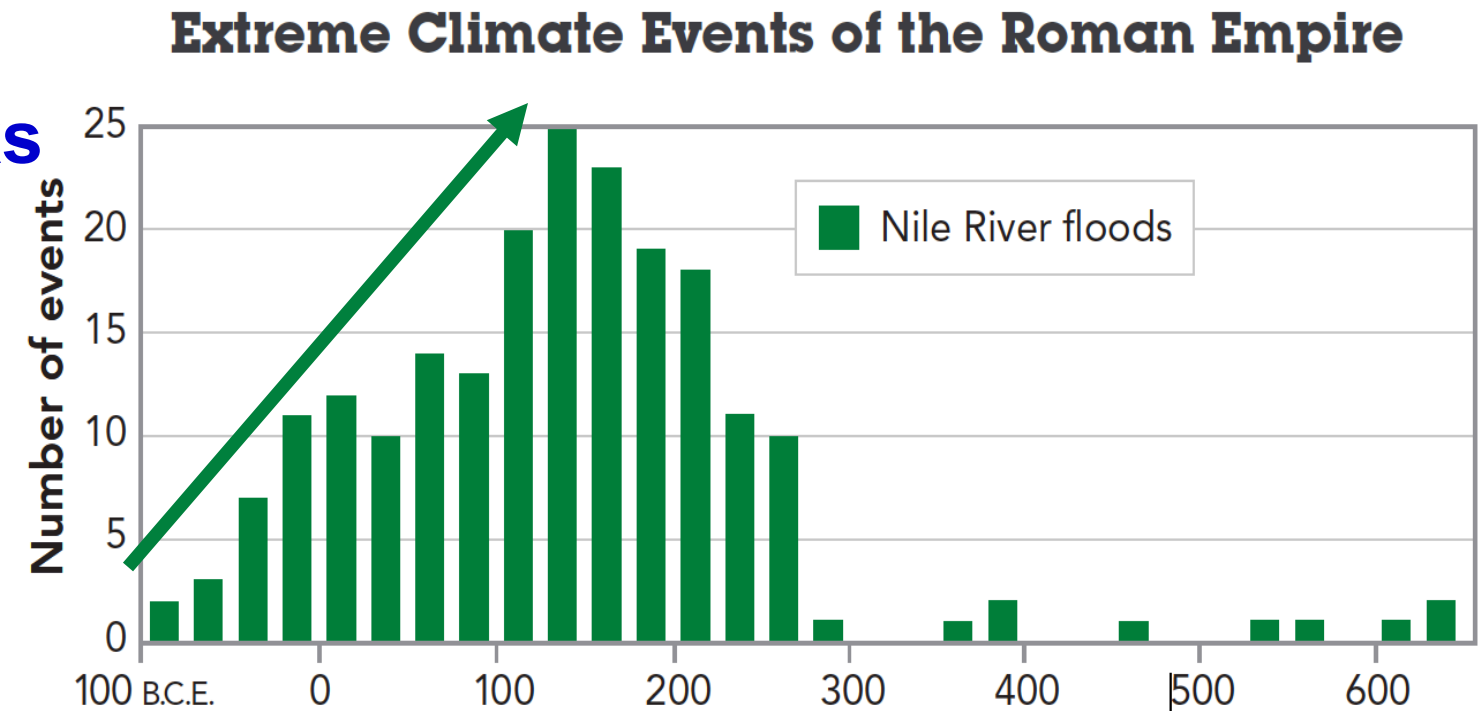
→Coincided with the start of the decline of the Western Roman Empire



Climate Change During and After the Roman Empire: Reconstructing the Past from Scientific and Historic Evidence, by Michael McCormick, Ulf Buntgen, Mark A. Cane, Edward R. Cook, Kyle Harper, Peter Huybers, Thomas Litt, Sturt W. Manning, Paul A. Mayewski, Alexander F. M. More, Kurt Nicolussi, Willy Tegel, *Journal of Interdisciplinary History, 43(2), pp. 169-220, 2012.*

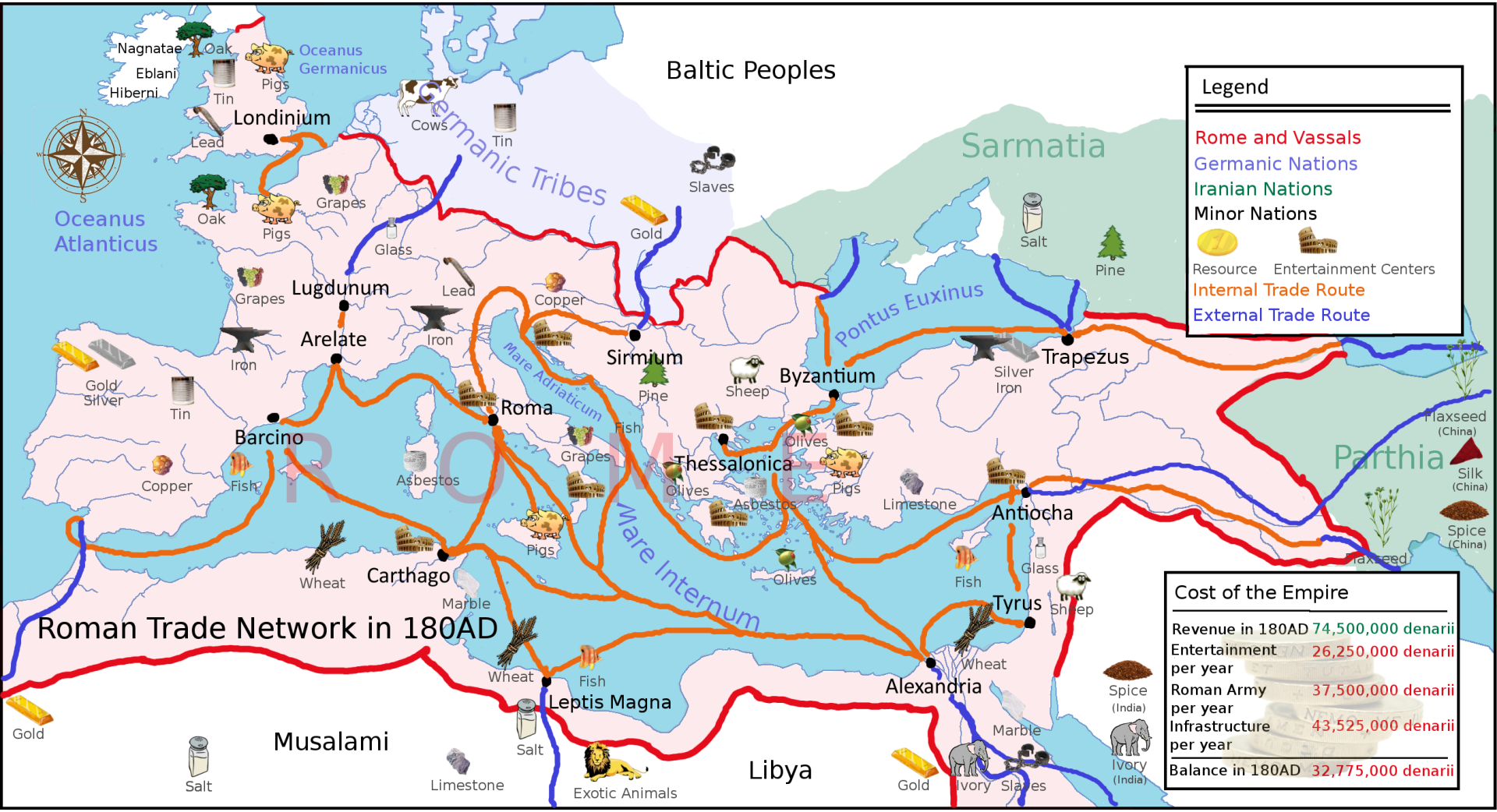
Grain from Egypt peaks at ~150 CE with frequent Nile flooding

(→ good crops!!)



Roman Empire Increasingly Relies on Egyptian and Other North African Grain grain to Pay Expenses

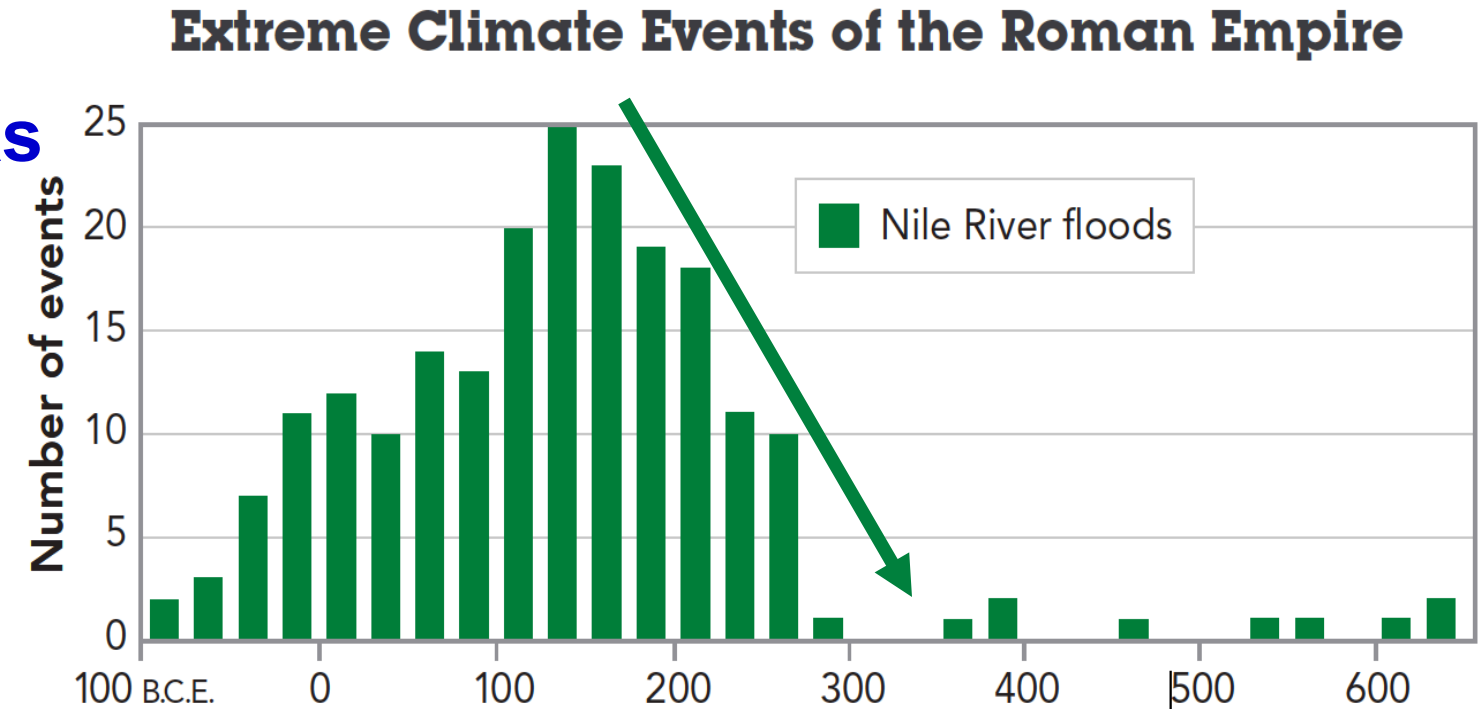
(Army rations, Daily bread/grain dole, etc.)



Grain from Egypt peaks at ~150 CE with frequent Nile flooding

(→ good crops!!)

But declines after 200 CE



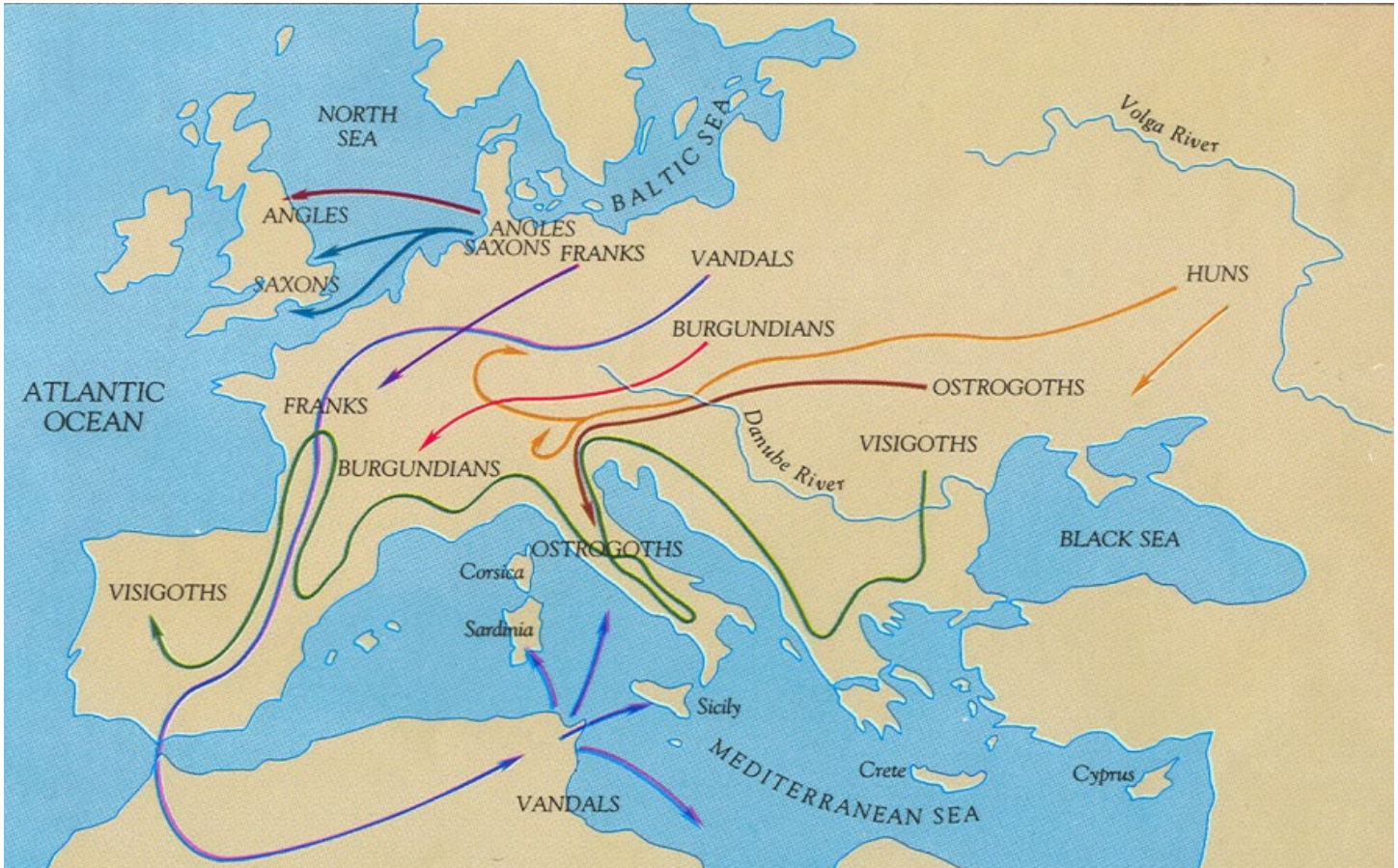
5) Plague of Cyprian: c. 250-270 CE

Origin and cause unclear: Possibly Smallpox, Measles, or Ebola; Possibly starting in Ethiopia

→Brief phase of severe cooling and dryness

→Occurs in the middle of the "3rd-Century Crisis"

→Devastating for North Africa (Alexandria, Carthage)



6) 1st *Yersinia pestis* Pandemic ("Plague of Justinian"): 541 – 590

Plague of Justinian starts in 541

→ Kills up to 20% of the population of the Byzantine capital Constantinople

→ Devastates populations all around the Mediterranean

536 CE: Iceland Eruption

Volcanic glass in Swiss ice cores matches the composition of Iceland volcanoes

[Loveluck et al., *Antiquity*, 2018]

536 CE: Iceland Eruption

Volcanic glass in Swiss ice cores matches the composition of Iceland volcanoes

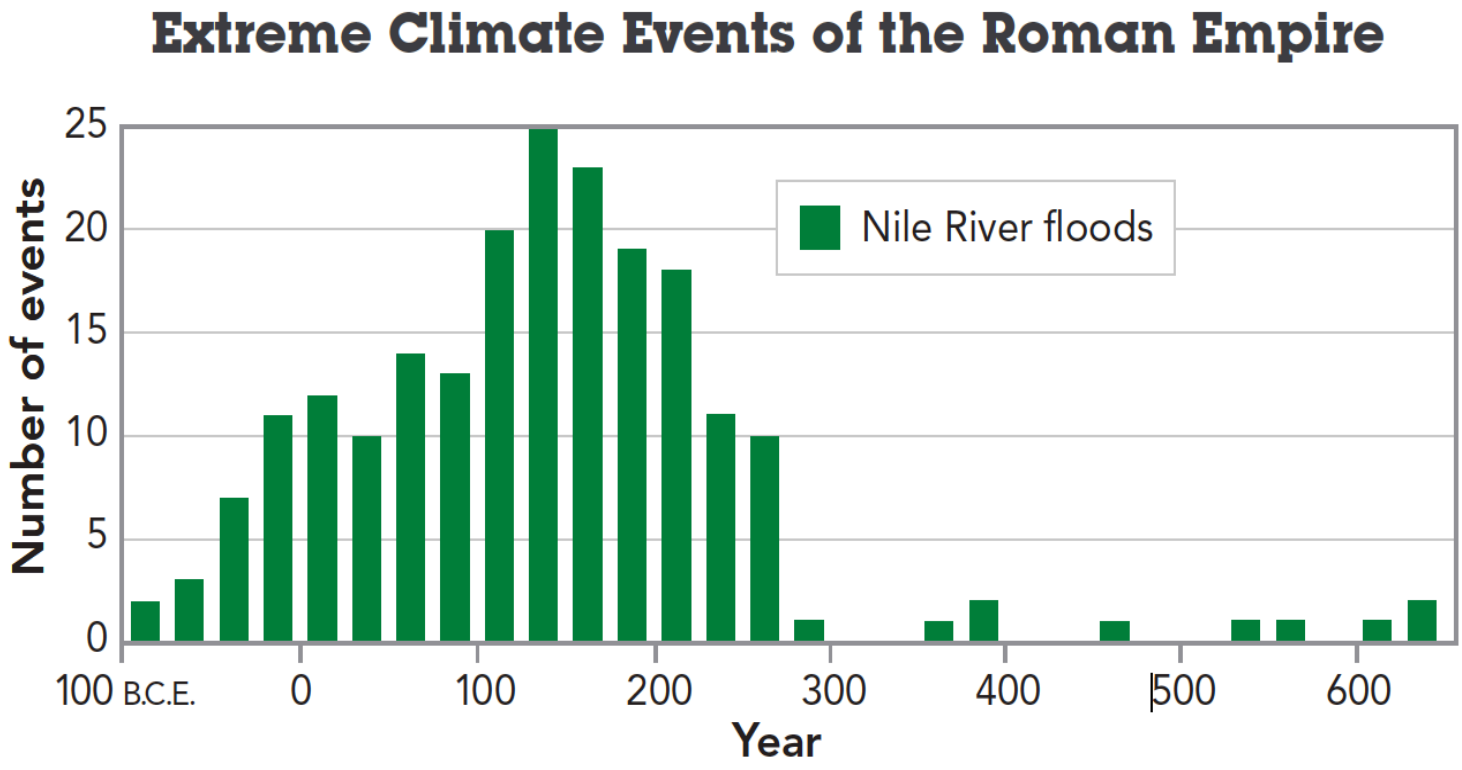
[Loveluck et al., *Antiquity*, 2018]

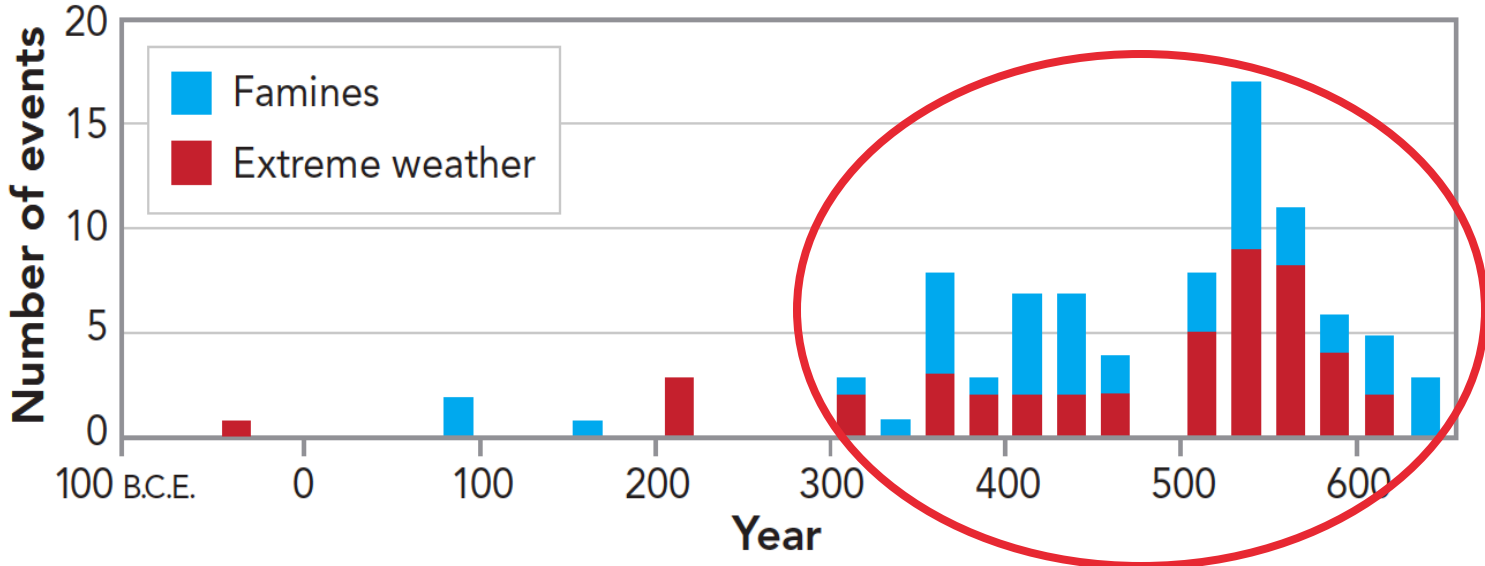
540 CE: El Salvador Eruption (Ilopongo Caldera)

→ Erupted ~80 km^3 of tephra

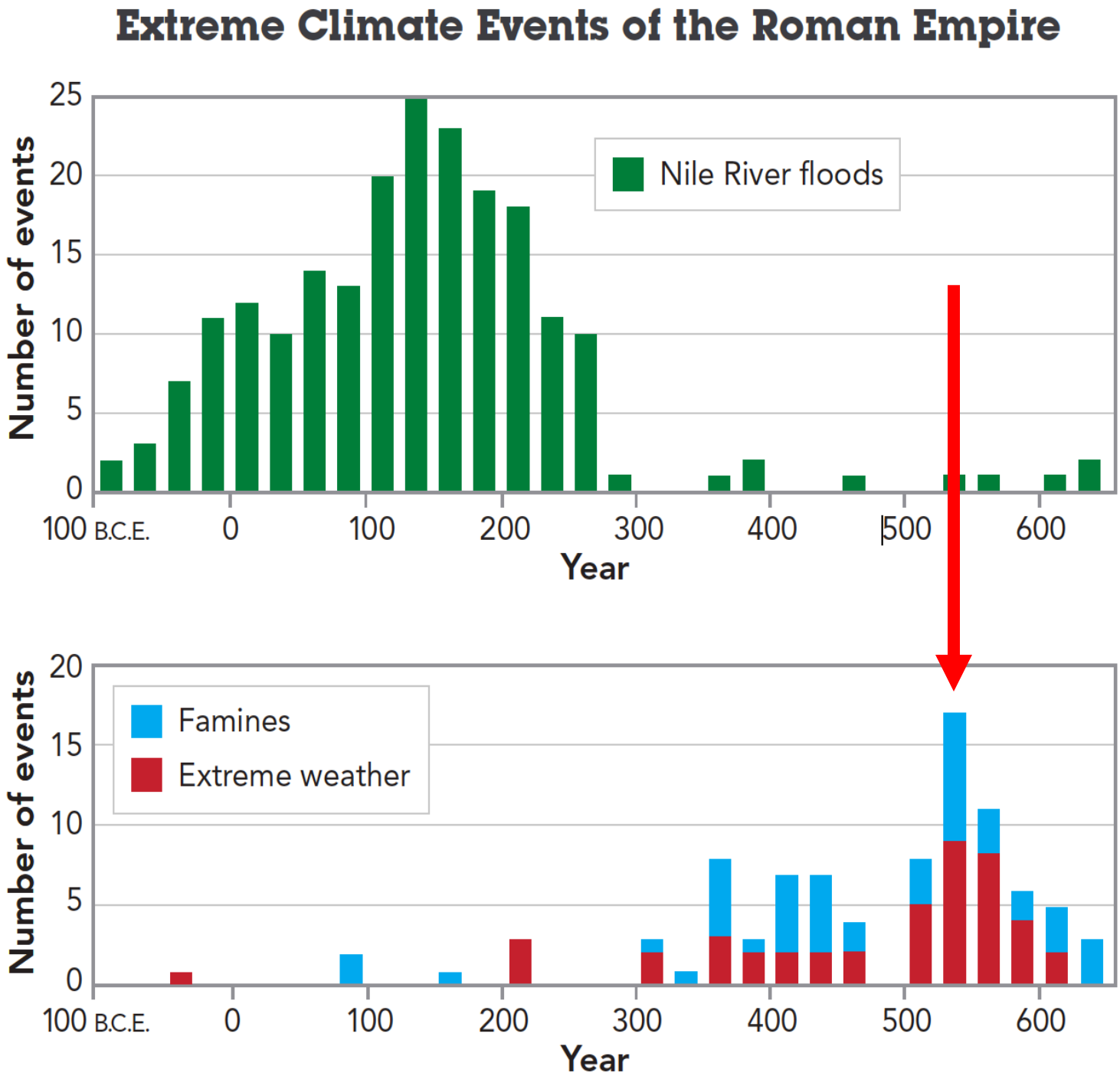
Droughts and famines frequent after ~300 CE

(→ Crops less reliable)





Extreme, extended cold period starting at 536 CE



Plague of Justinian starts in 541

→ Extreme cooling for two decades

→ Called the “Late Antiquity Little Ice Age”

→ Massive GLOBAL disruptions to:

- Food production
- Animal host populations
- Human social patterns

Plague of Justinian starts in 541

→ Extreme cooling for two decades

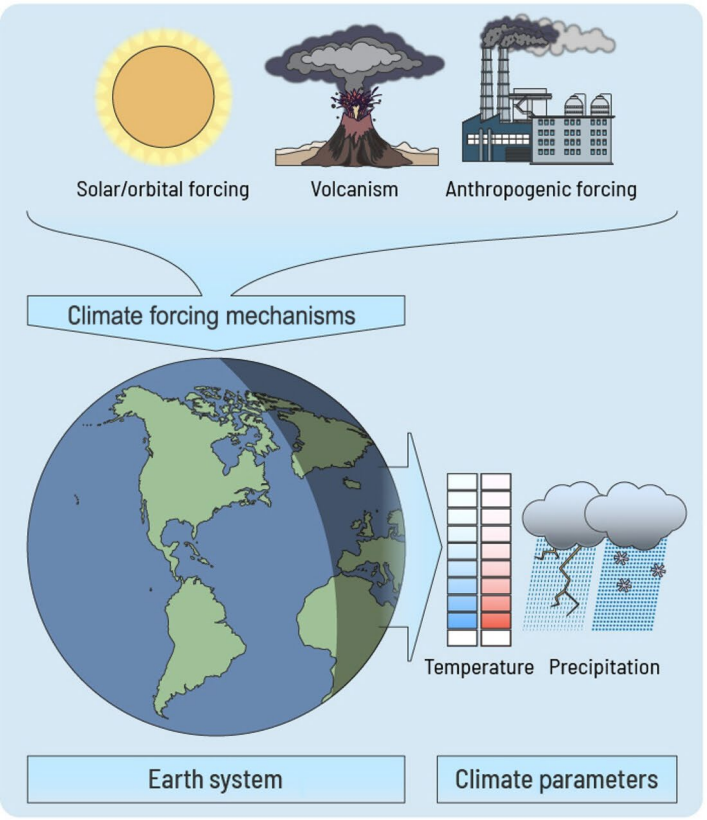
→ Called the "Late Antiquity Little Ice Age"

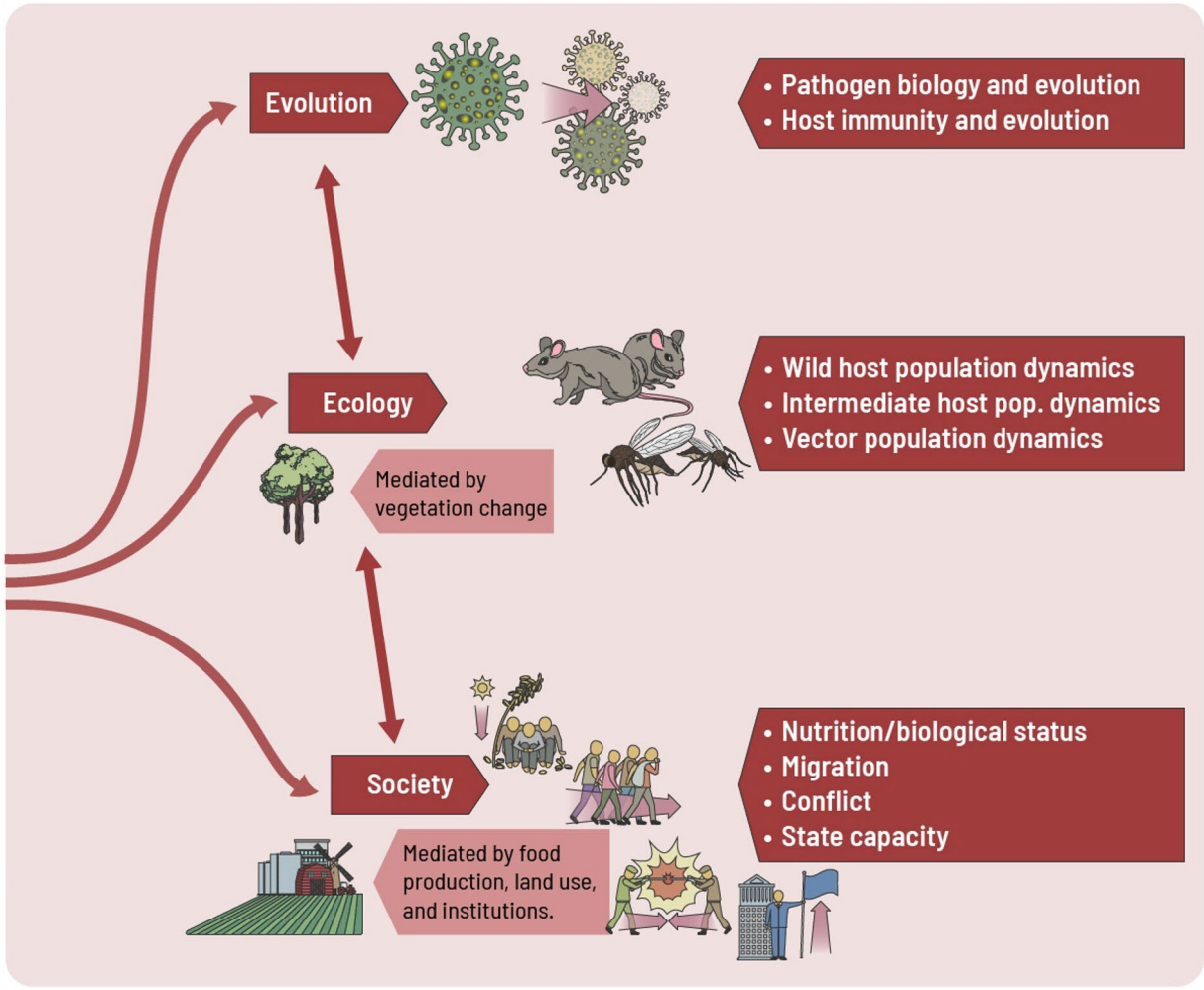
→ Massive GLOBAL disruptions to:

- Food production
- Animal host populations
- Human social patterns

→ *Kills 10-20% of the World's Human Population*

Climate-Infectious Disease Nexus





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