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Climate Change and Air Quality: Science and Policy

Mario Molina

University of California, San Diego

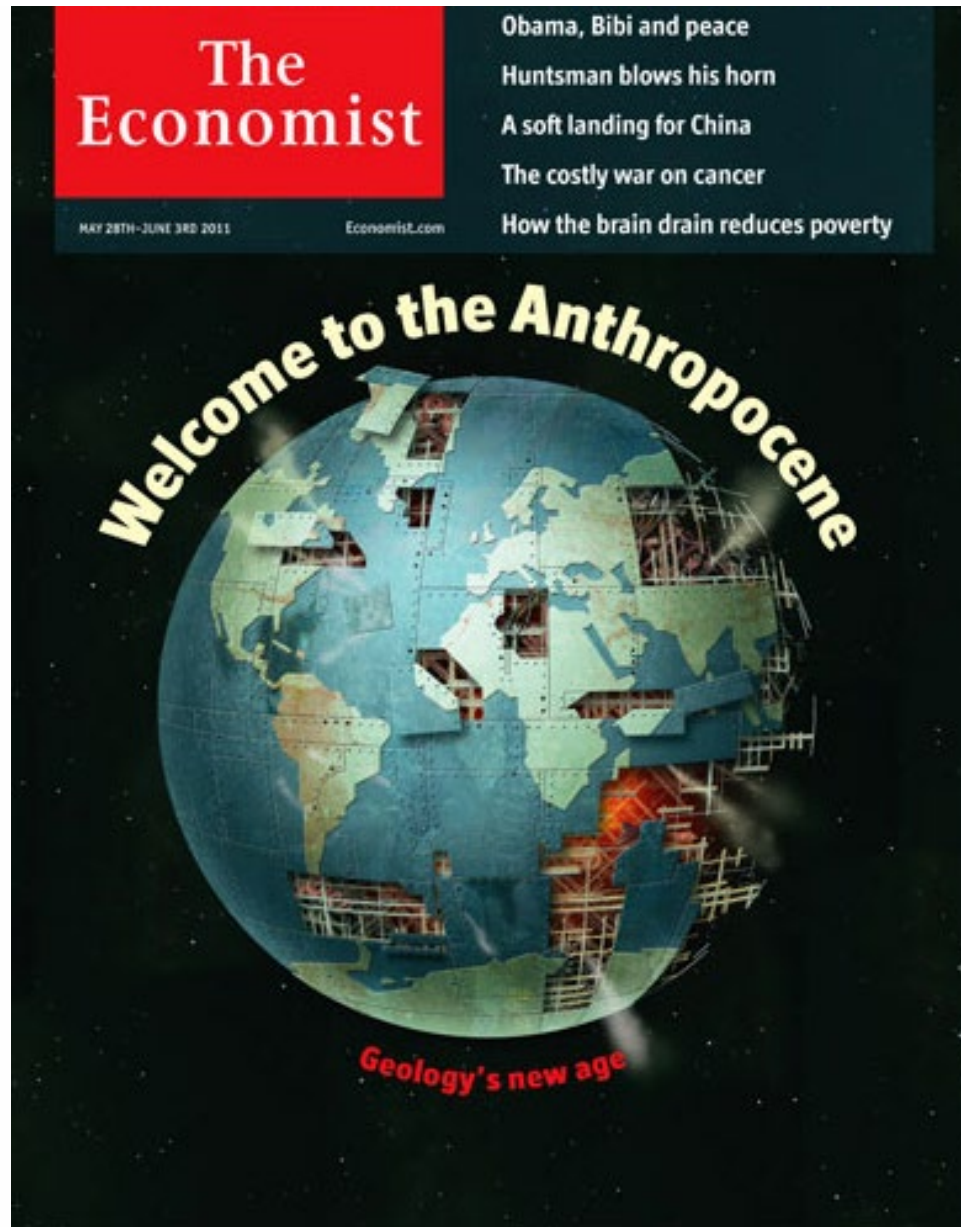
Mario Molina Center for Strategic Studies in
Energy and the Environment

**Climate, air quality and health: long-term goals
and near-term actions**

Orleans

June 28, 2019

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Crutzen, P. J., E. F. Stoermer (2000), *The Anthropocene*. Global Change Newsletter, 41,17–18.

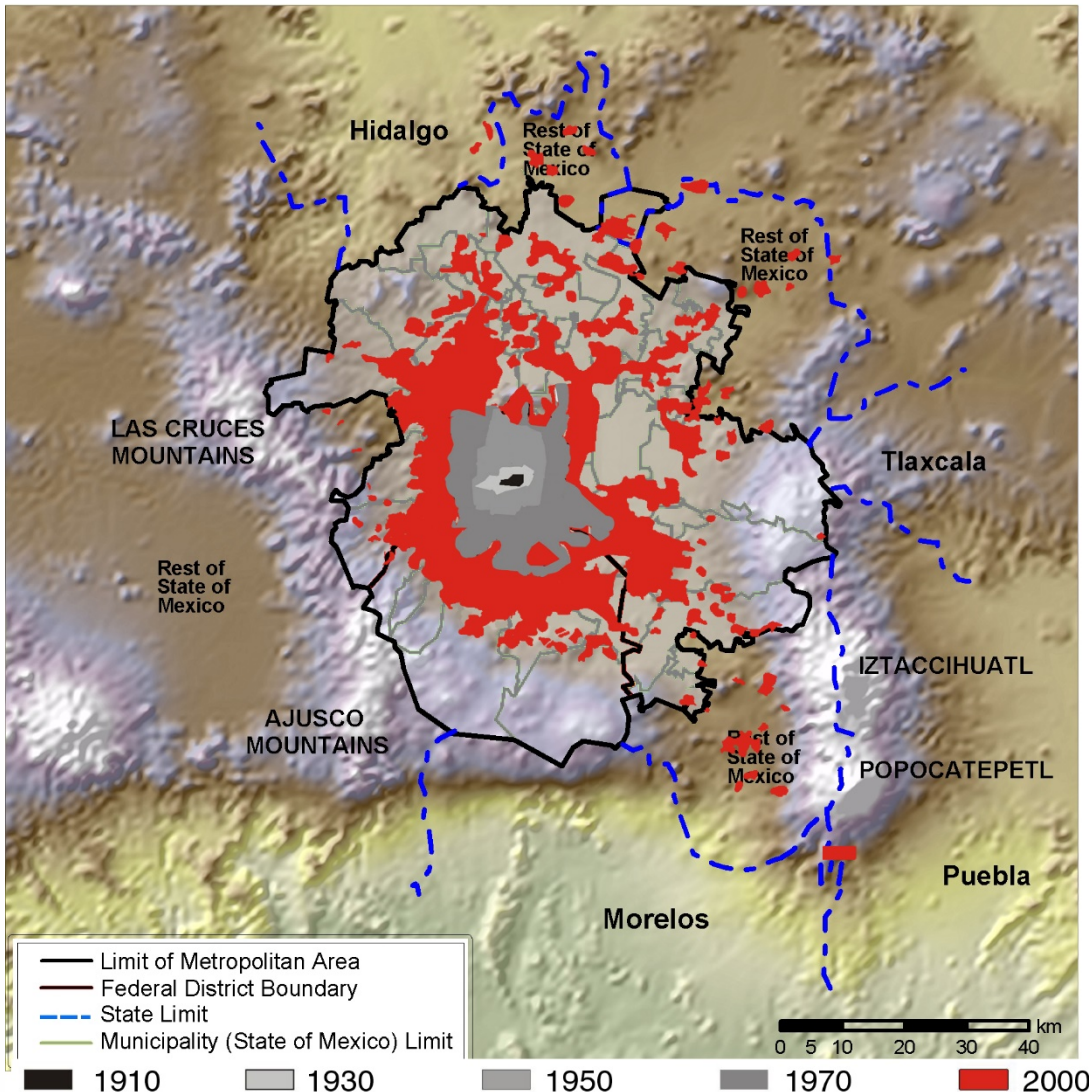
MEXICO CITY METROPOLITAN AREA

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Map of Mexico City Urban Expansion

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• Population Growth

> 20 million (2010):
20-fold increase
since 1900

• Urban Sprawl

> 1500 km² (2000):
10-fold increase
since 1960

• Geographic Conditions

High (2240m): less
efficient combustion
processes

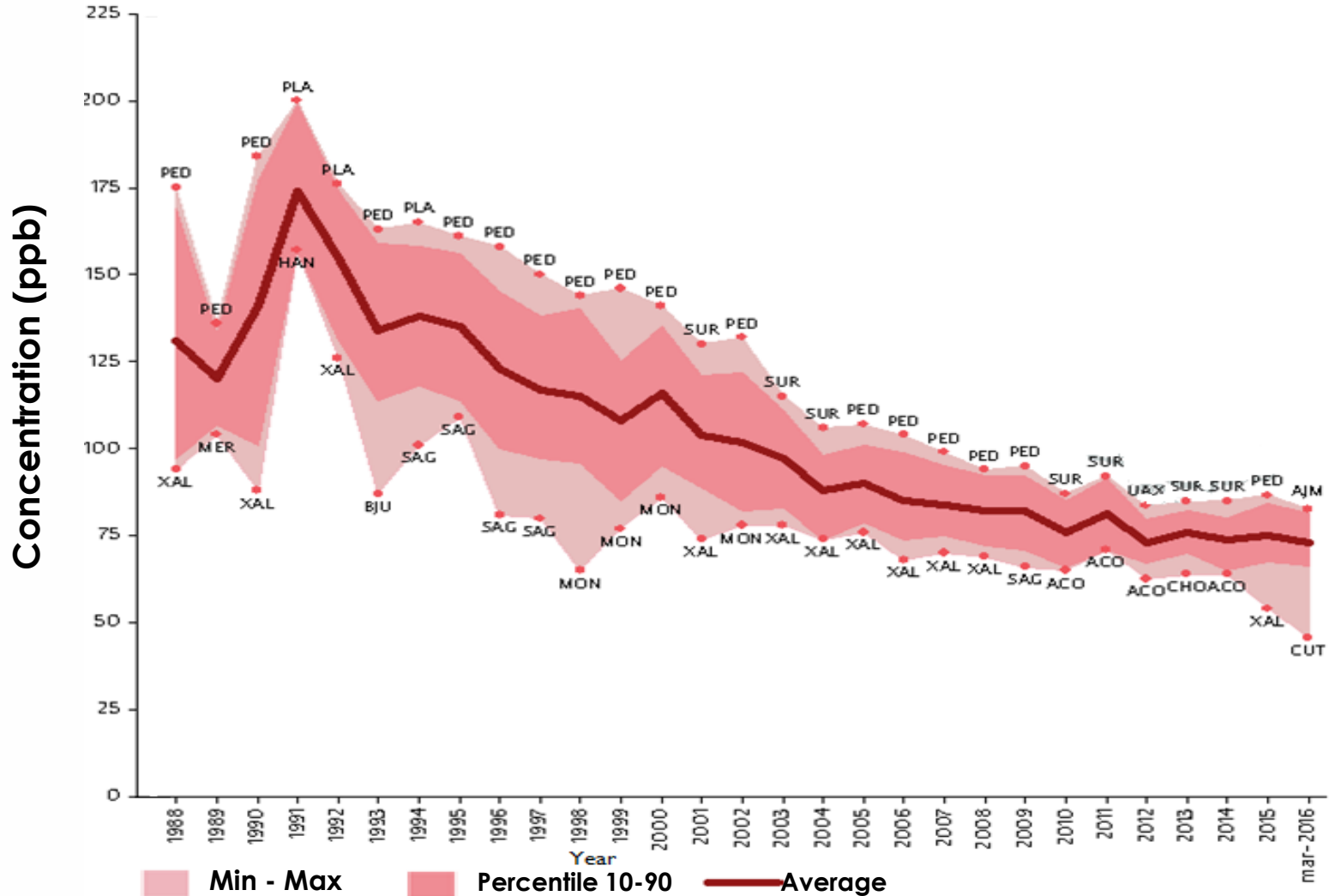
Soot Emissions from Diesel Engines

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Average Annual Ozone Concentrations in Mexico City (1986- 2016)

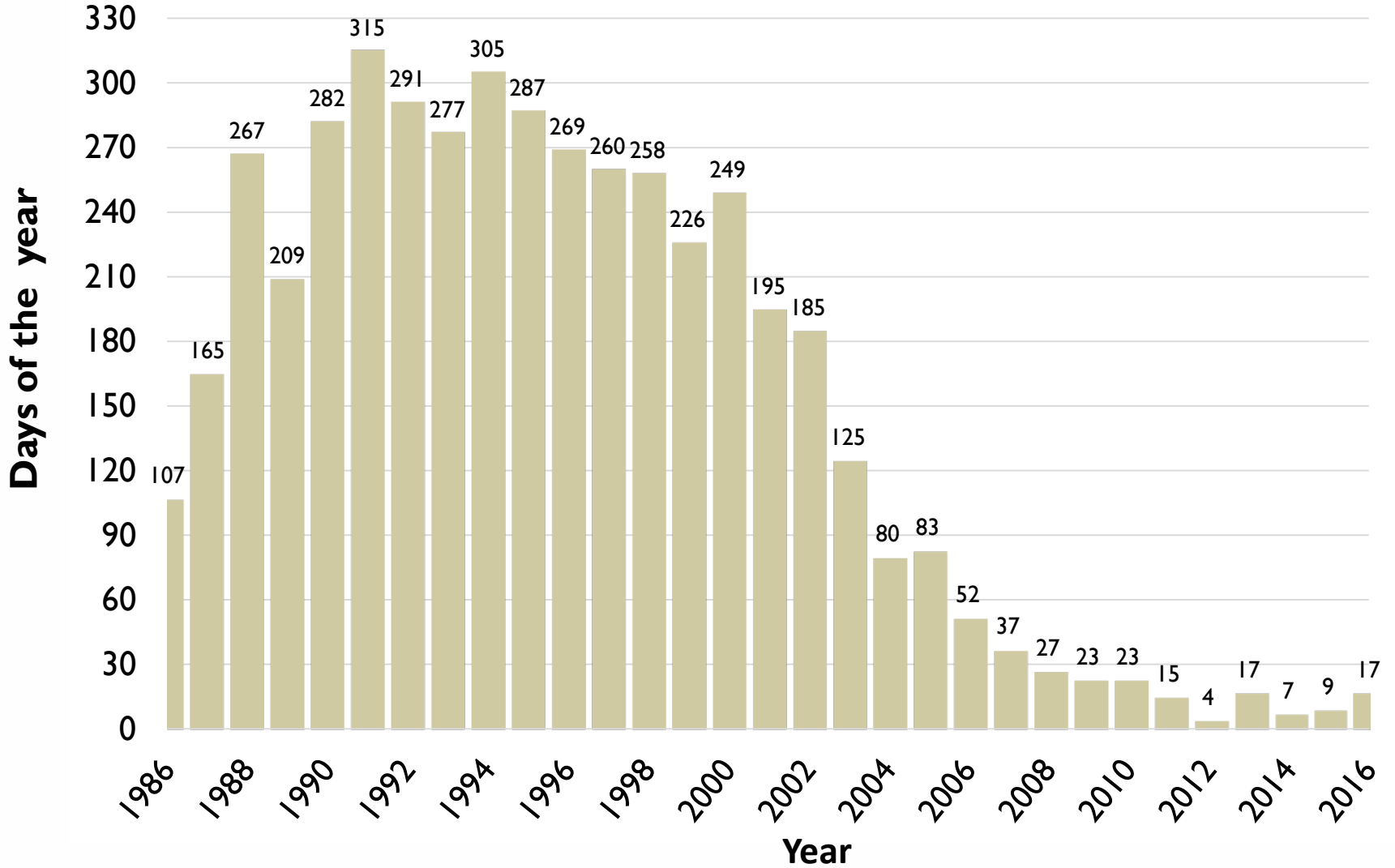
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Source: Secretaría de Medio Ambiente del Distrito Federal. Sistema de monitoreo atmosférico de la Ciudad de México

Days per Year Surpassing the Current Ozone Contingency Limit (154 ppb) in Mexico City

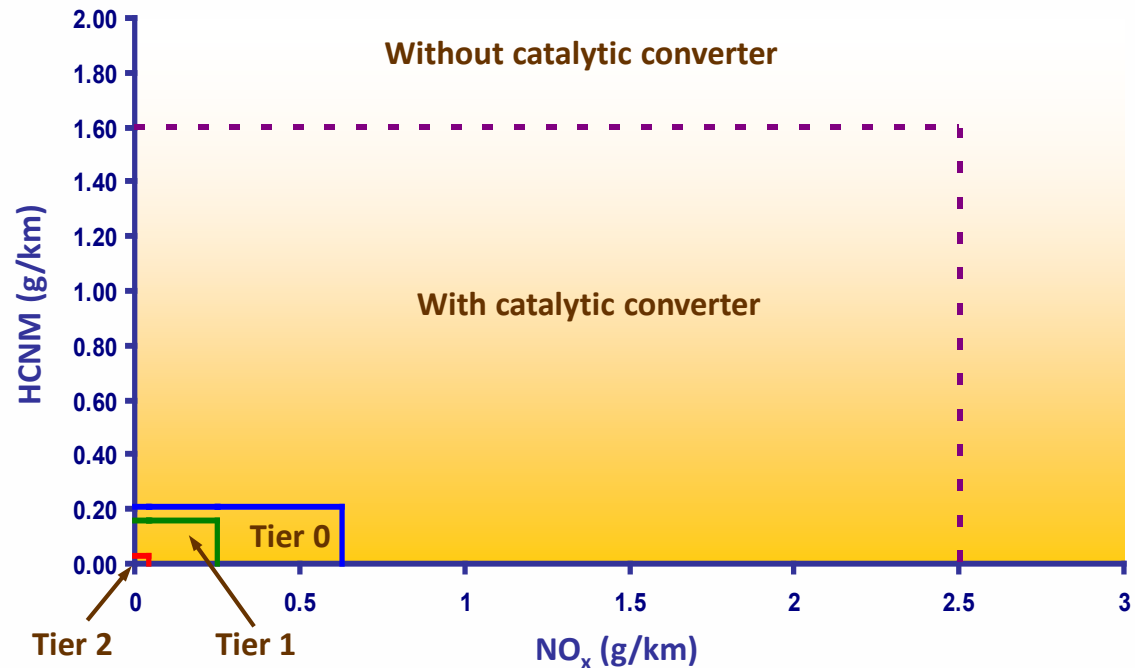
360 — This information is the courtesy of M. J. Molina and shall not be used without his written permission.



Source: Secretaría de Medio Ambiente del Distrito Federal. Sistema de monitoreo atmosférico de la Ciudad de México

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Emission Standards for Gasoline Vehicles in Mexico

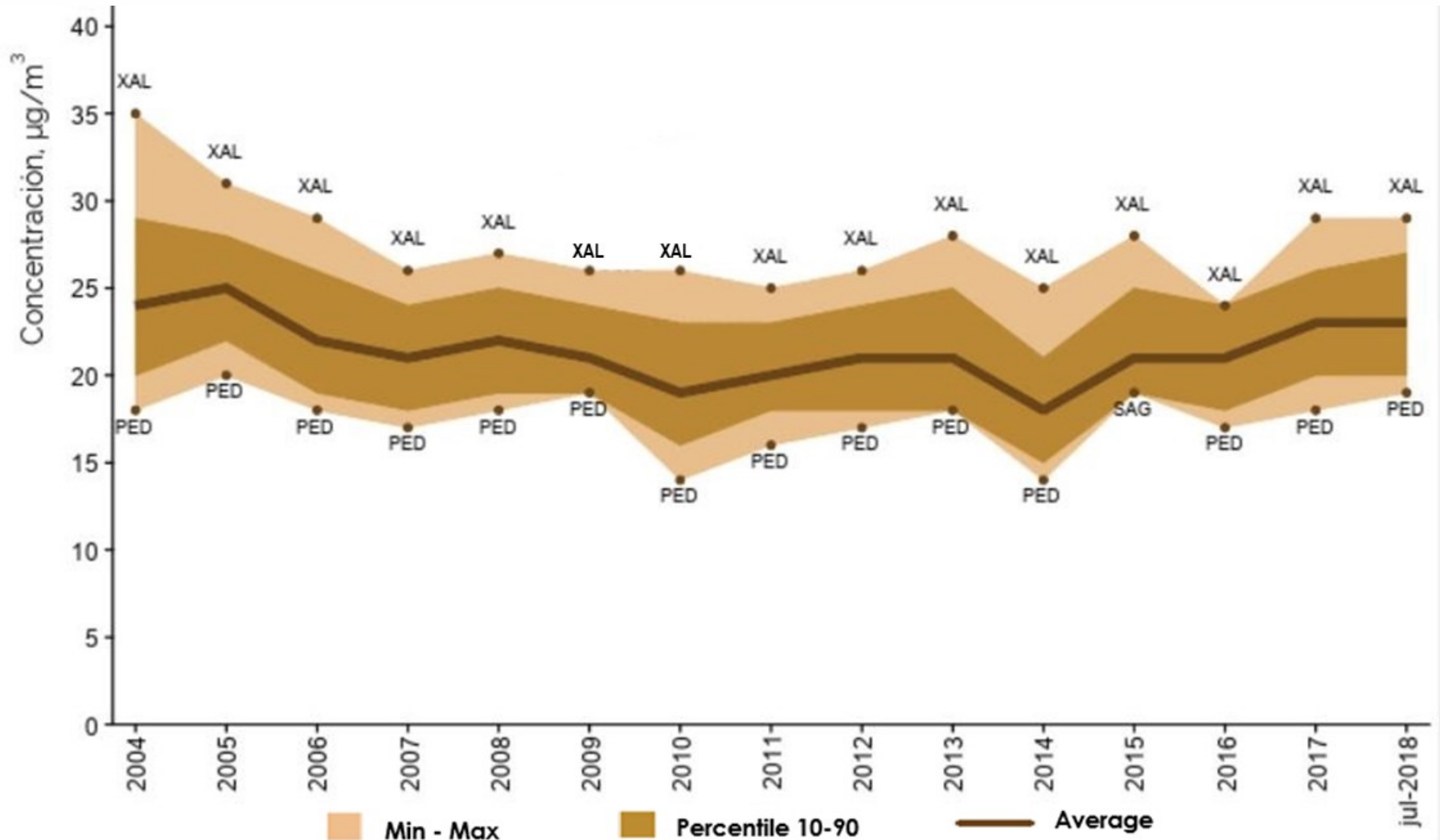


Maximum sulfur content:

30/80 p.p.m.	120/300 p.p.m.	1000 p.p.m.
Tier 2	Tier 1	Tier 0

- Tier 0: 2.11 g CO /km , 0.21 g HCNM /km and 0.63 g NO_x / km for 80,000 km (50,000 miles)
- Tier 1: 2.11 g CO /km , 0.16 g HCNM /km and 0.25 g NO_x / km for 160,000 km (100,000 miles)
- Tier 2: 1.31 g CO /km , 0.03 g HCNM /km and 0.04 g NO_x / km for 192,000 km (120,000 miles)

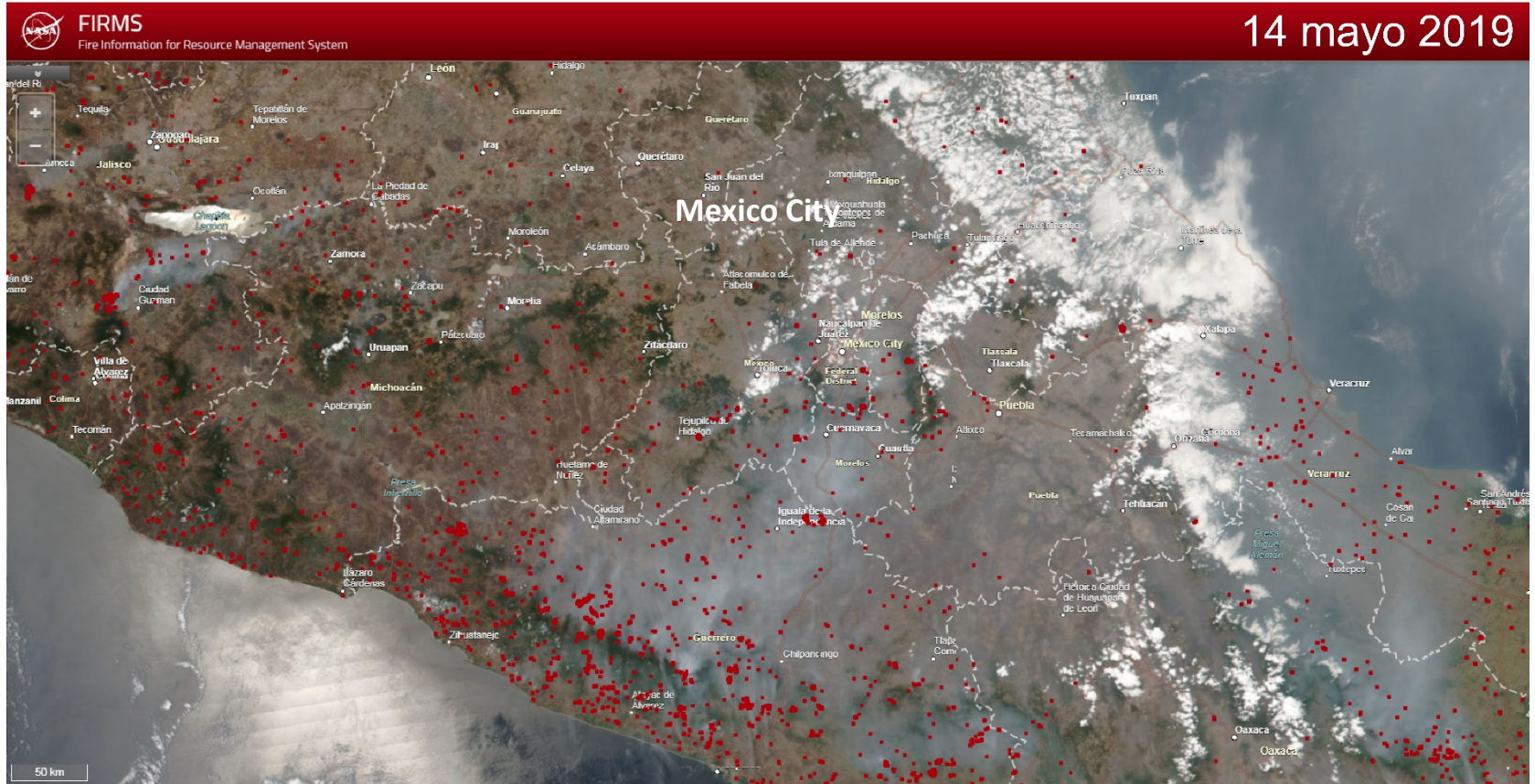
Average Annual PM_{2.5} Concentrations in Mexico City (2004- 2018)



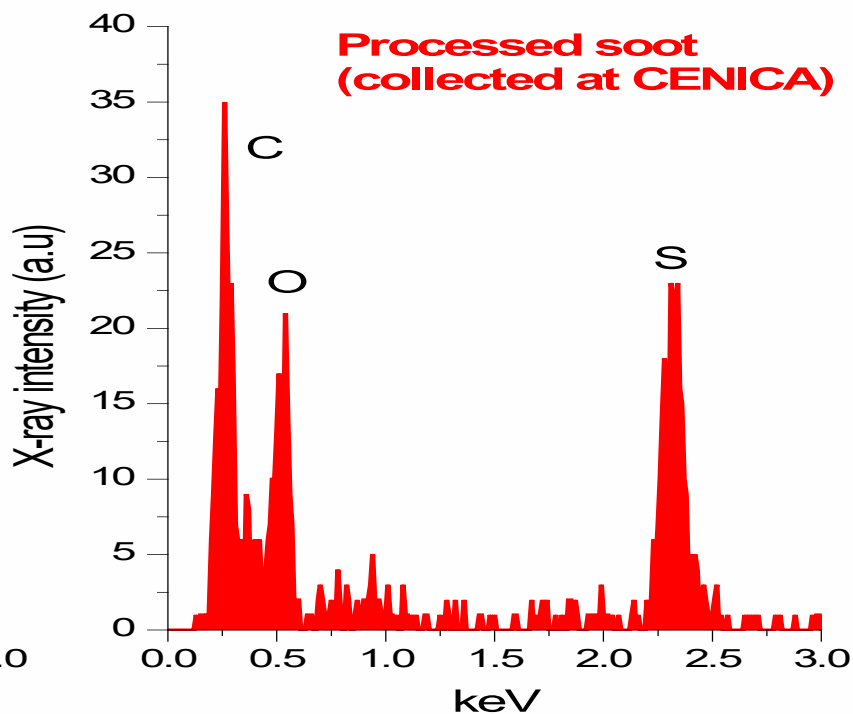
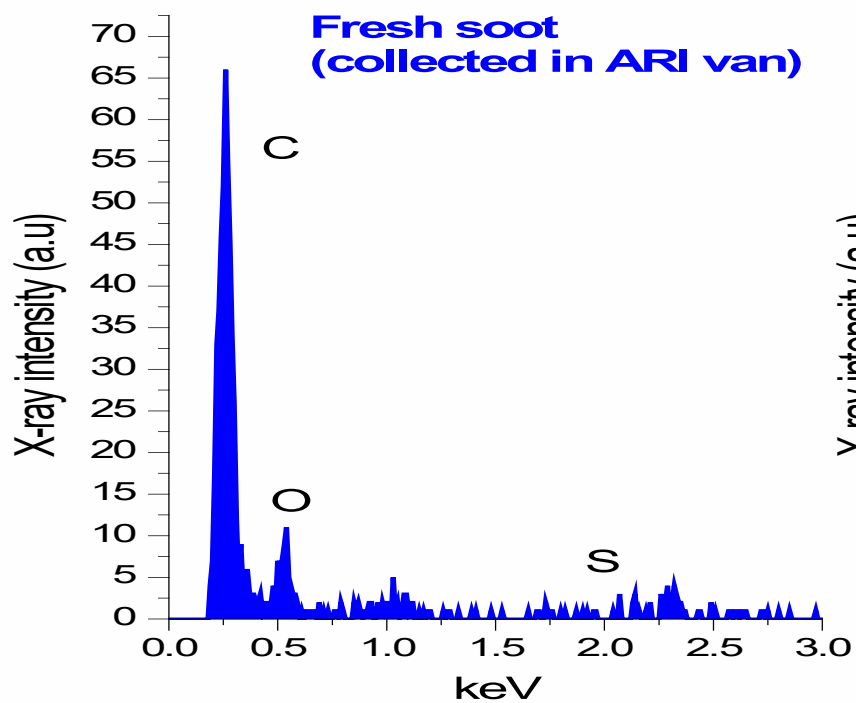
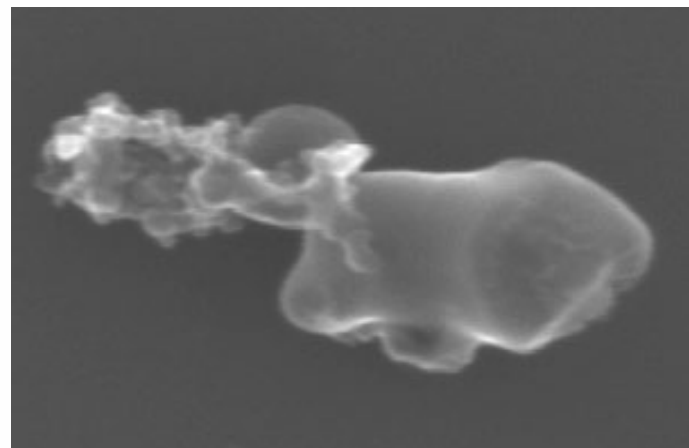
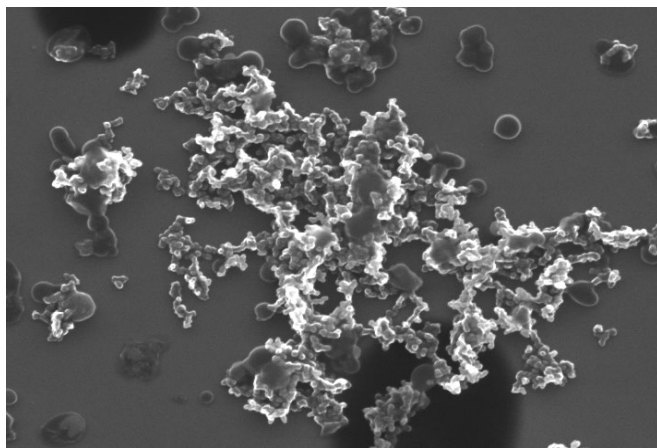
Source: Secretaría de Medio Ambiente del Distrito Federal.
Sistema de monitoreo atmosférico de la Ciudad de México.

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PM_{2.5} Contingency in Mexico City



Fresh soot particles (mobile van) vs Aged soot particles (supersite) in Mexico City



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Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

10.1002/2013JD021426

11 Sept 2014

Page 10,425

Enhanced sulfate formation during China's severe winter haze episode in January 2013 missing from current models

Yuxuan Wang^{1,2,3}, Qianqian Zhang^{1,4}, Jingkun Jiang^{4,5}, Wei Zhou⁴, Buying Wang⁴, Kebin He^{4,5}, Fengkui Duan⁴, Qian Zhang⁴, Sajeev Philip⁶, and Yuanyu Xie¹

Abstract:

... Observations show that inorganic aerosols (sulfate, nitrate, and **ammonium**) are the largest contributor to $PM_{2.5}$ during the haze period ...

The nested-grid GEOS-Chem model reproduces the distribution of $PM_{2.5}$... Yet on average, **the model is a factor of 3 and 4 lower in $PM_{2.5}$ and fails to capture the large sulfate enhancement from the clean to haze period.**

A doubling of SO_2 emissions over North China ... would be required to reconcile model results with surface SO_2 observations, but it is not sufficient to explain the model discrepancy in sulfate.

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Persistent sulfate formation from London Fog to Chinese haze

Gehui Wang^{a,b,c,d,e,1}, Renyi Zhang^{c,d,f,2}, Mario E. Gomez^{c,d,g}, Lingxiao Yang^{c,h}, Misti Levy Zamora^c, Min Hu^f, Yun Lin^c, Jianfei Peng^{c,f}, Song Guo^{c,f}, Jingjing Meng^{a,b,i}, Jianjun Li^{a,b}, Chunlei Cheng^{a,b,i}, Tafeng Hu^{a,b}, Yanqin Ren^{a,b,i}, Yuesi Wang^j, Jian Gao^k, Junji Cao^{a,b}, Zhisheng An^{a,b,l}, Weijian Zhou^{a,b,m}, Guohui Li^{a,b}, Jiayuan Wang^{a,b,i}, Pengfei Tian^{c,n}, Wilmarie Marrero-Ortiz^{c,d}, Jeremiah Secret^{c,d}, Zhuofei Du^f, Jing Zheng^f, Dongjie Shang^f, Limin Zeng^f, Min Shao^f, Weigang Wang^{c,o,p}, Yao Huang^{a,b,i}, Yuan Wang^q, Yujiao Zhu^{c,r}, Yixin Li^c, Jiayi Hu^c, Bowen Pan^c, Li Cai^{c,s}, Yuting Cheng^{a,b,i}, Yuemeng Ji^{c,t}, Fang Zhang^{c,l}, Daniel Rosenfeld^{c,u}, Peter S. Liss^{c,v}, Robert A. Duce^c, Charles E. Kolb^{c,w}, and Mario J. Molina^{x,2}

Contributed by Mario J. Molina, October 9, 2016 (sent for review July 8, 2016; reviewed by Zhanqing Li and Sasha Madronich)

13630–13635 | PNAS | November 29, 2016 | vol. 113 | no. 48

MECHANISM OF SEVERE HAZE FORMATION IN CHINA

Oxidation of SO₂ by NO₂:

Occurs efficiently in aqueous media on fine PM

with NH₃ neutralization

(as shown by atmospheric measurements and laboratory experiments)

EFFECTIVE HAZE MITIGATION:

NH₃ and NO₂ emission control measures

CLIMATE CHANGE MITHS

This information is the courtesy of M. J. Molina and shall not be used without his written permission.

- 1. Many experts believe that climate change is natural and has no connection with human activities**
- 2. If at all, climate change will occur towards the end of the century and will be most likely beneficial**
- 3. It is not prudent to regulate the use of fossil fuels because the cost would be prohibitive**

Scientific Evidence

Are scientists convinced?

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- There's a consensus of scientists because there's a consensus of evidence.
- Not only is there a vast difference in the number of convinced vs. unconvinced scientists there is also a considerable gap in expertise between the two groups.

YES
97%

Of climate scientist think climate change is significantly due to human activity

NO
3%

Of climate scientist do not think climate change is significantly due to human activity



Sources: Anderegg et al, **Expert credibility in climate change**, *PNAS*, 107(27), 2010
Doran PT and Zimmerman MK, **Examining the scientific consensus on climate change**, *Eos Trans AGU*, 90:22–23, 2009. <http://thinkprogress.org/romm/issue/>

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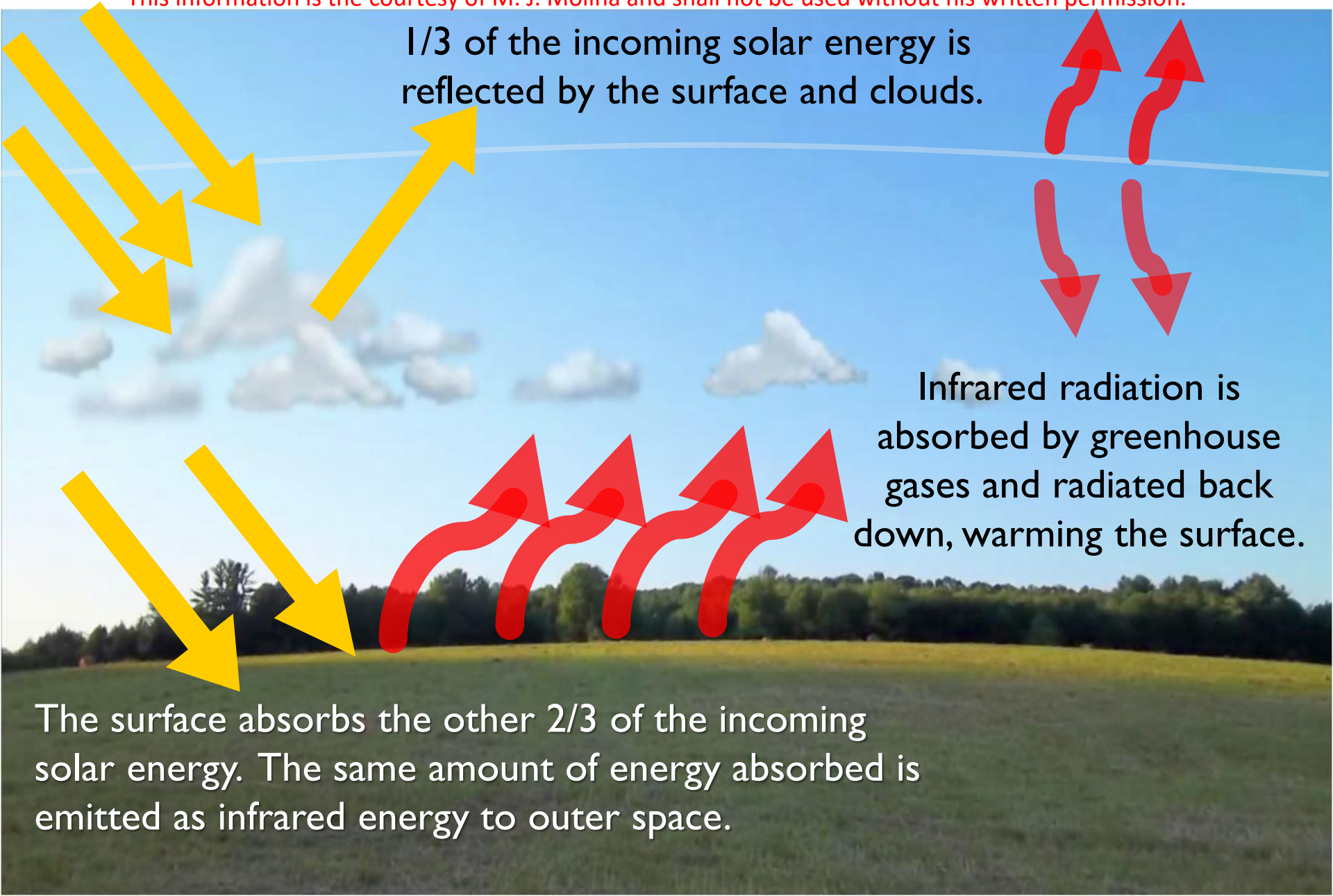
Earth's Greenhouse Effect

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1/3 of the incoming solar energy is reflected by the surface and clouds.

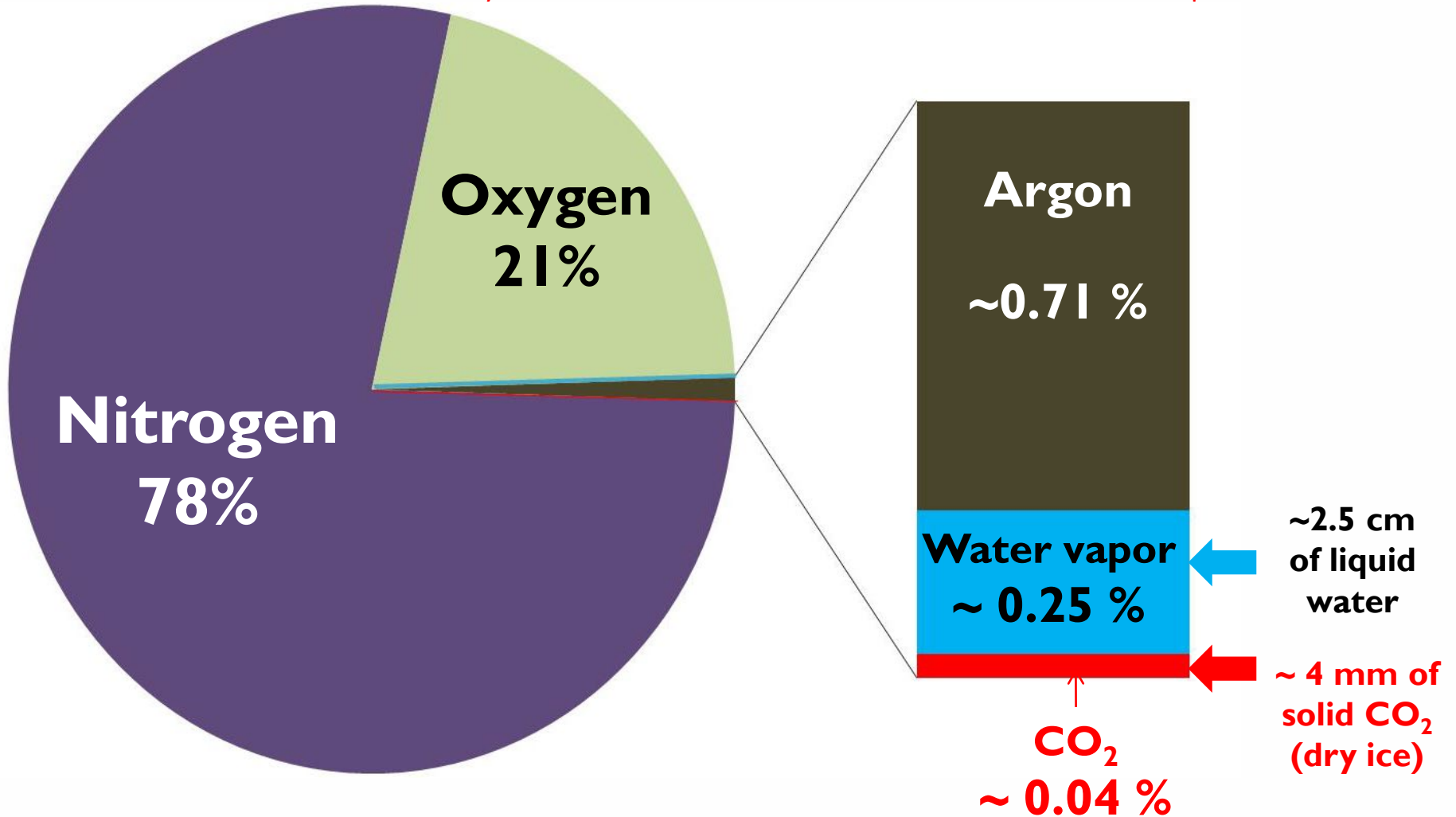
Infrared radiation is absorbed by greenhouse gases and radiated back down, warming the surface.

The surface absorbs the other 2/3 of the incoming solar energy. The same amount of energy absorbed is emitted as infrared energy to outer space.



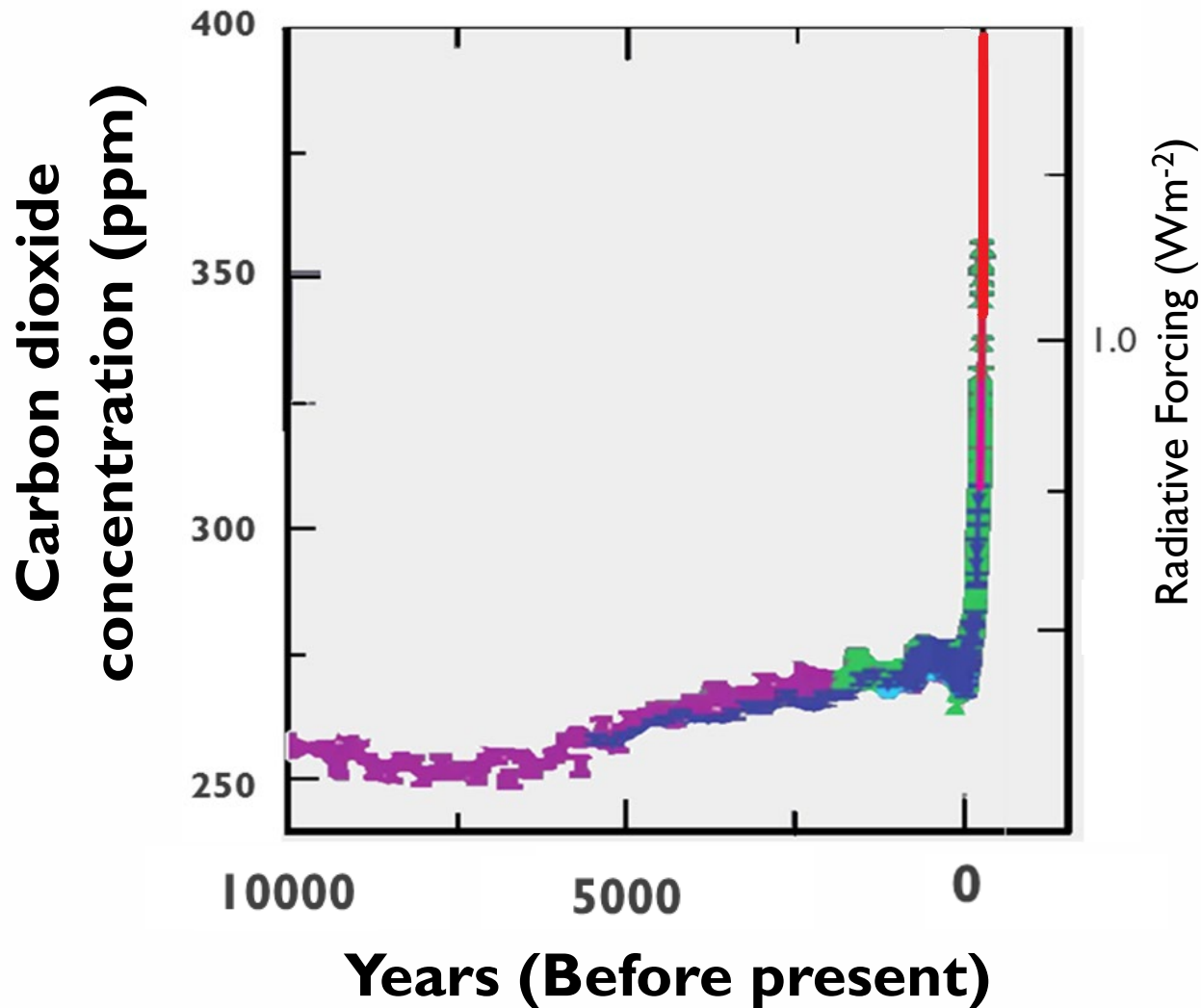
Chemical Composition of Earth's Atmosphere

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Atmospheric Concentration of CO₂ for the past 10,000 years

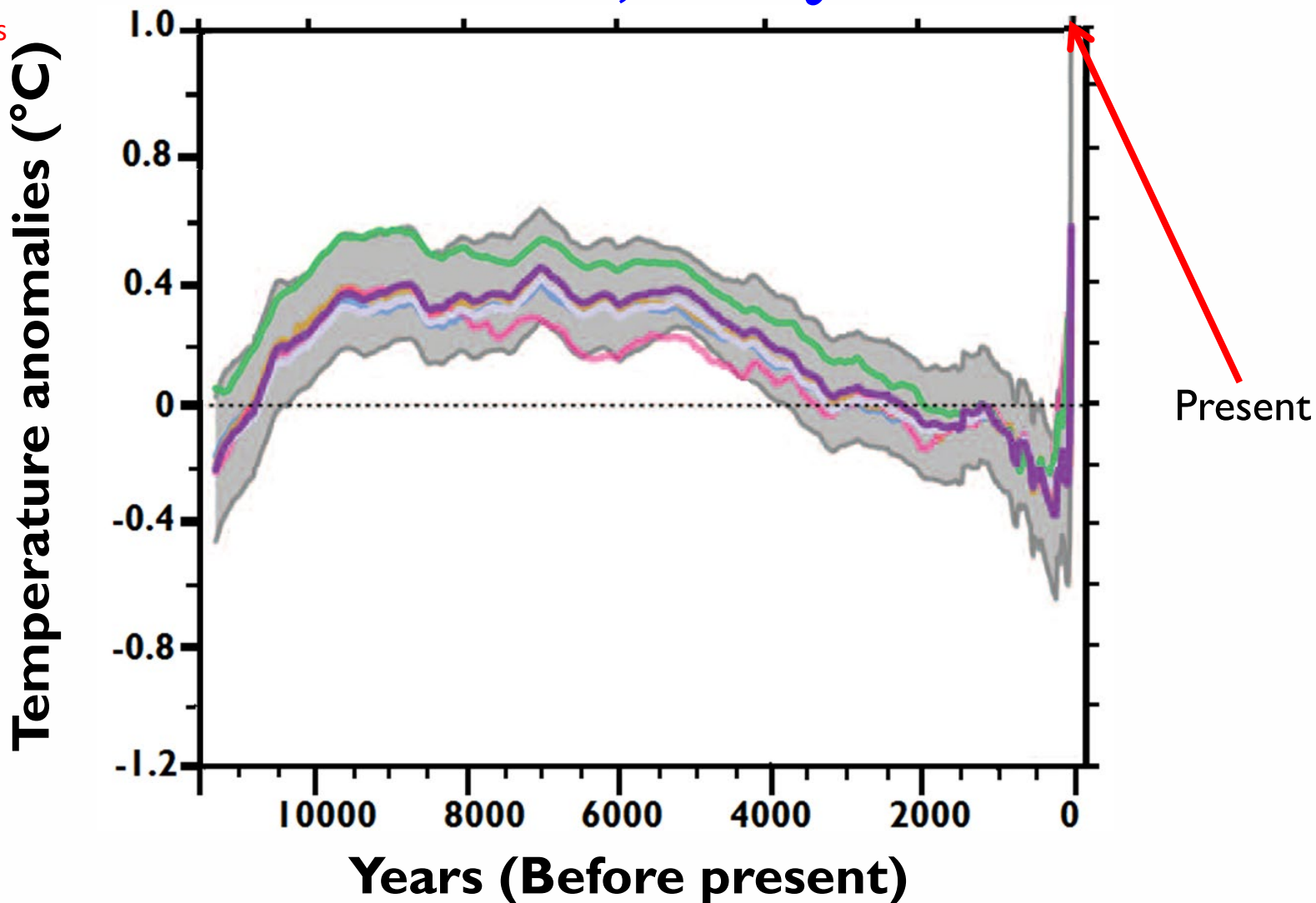
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Source: Based on WGI- AR4, IPCC 2007

Global Mean Surface Temperature in the last 11,000 years

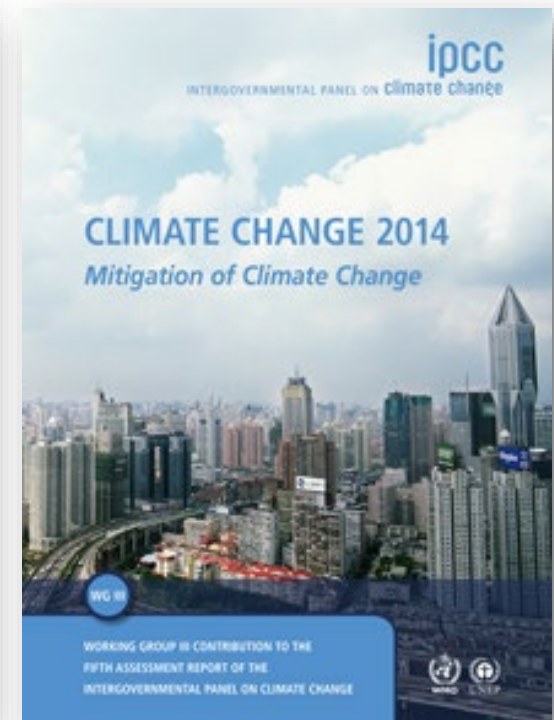
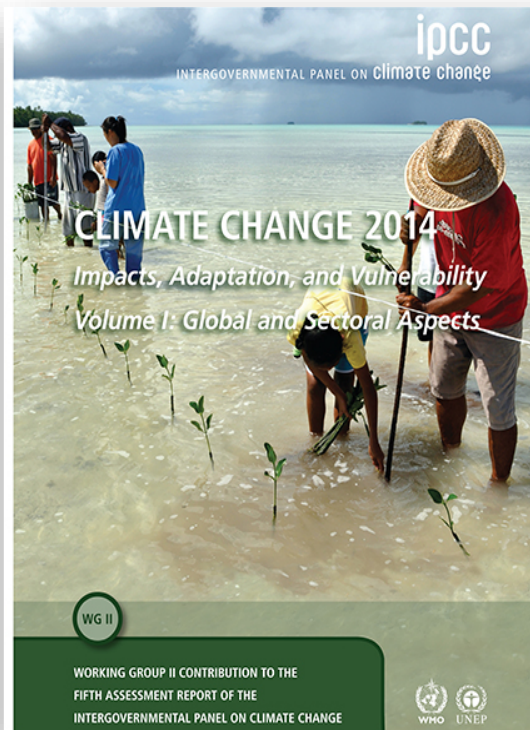
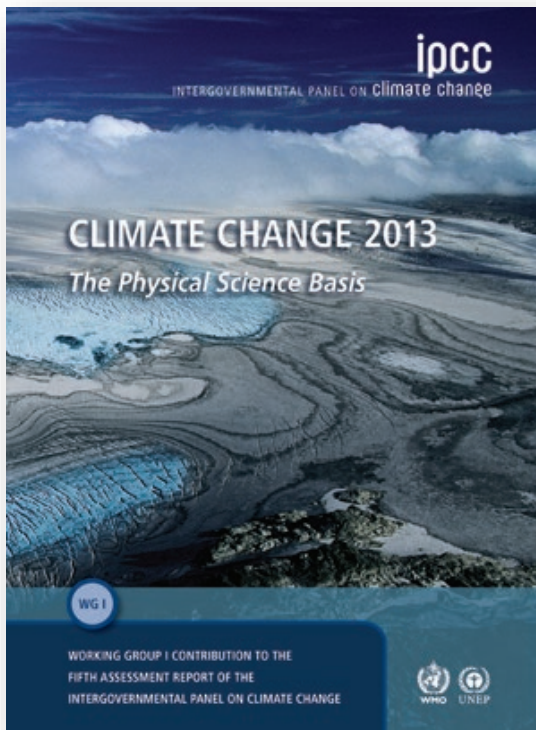
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Based on Marcott, S. et al., A Reconstruction of Regional and Global Temperature for the Past 11,300 Years. Science 339, 1198 (2013)

Fifth Assessment Report Intergovernmental Panel on Climate Change (IPCC) 2013/2014

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Arctic Sea Ice

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September 1979



September 2016

Source: NASA's Jet Propulsion Laboratory | California Institute of Technology /Vital-signs/arctic-sea-ice/June 2017

Sea ice in North West Greenland

2019

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Source: Steffen M. Olsen – Meteorological Institute of Denmark (IDK)

Floods in Houston in 2017

Hurricane Harvey

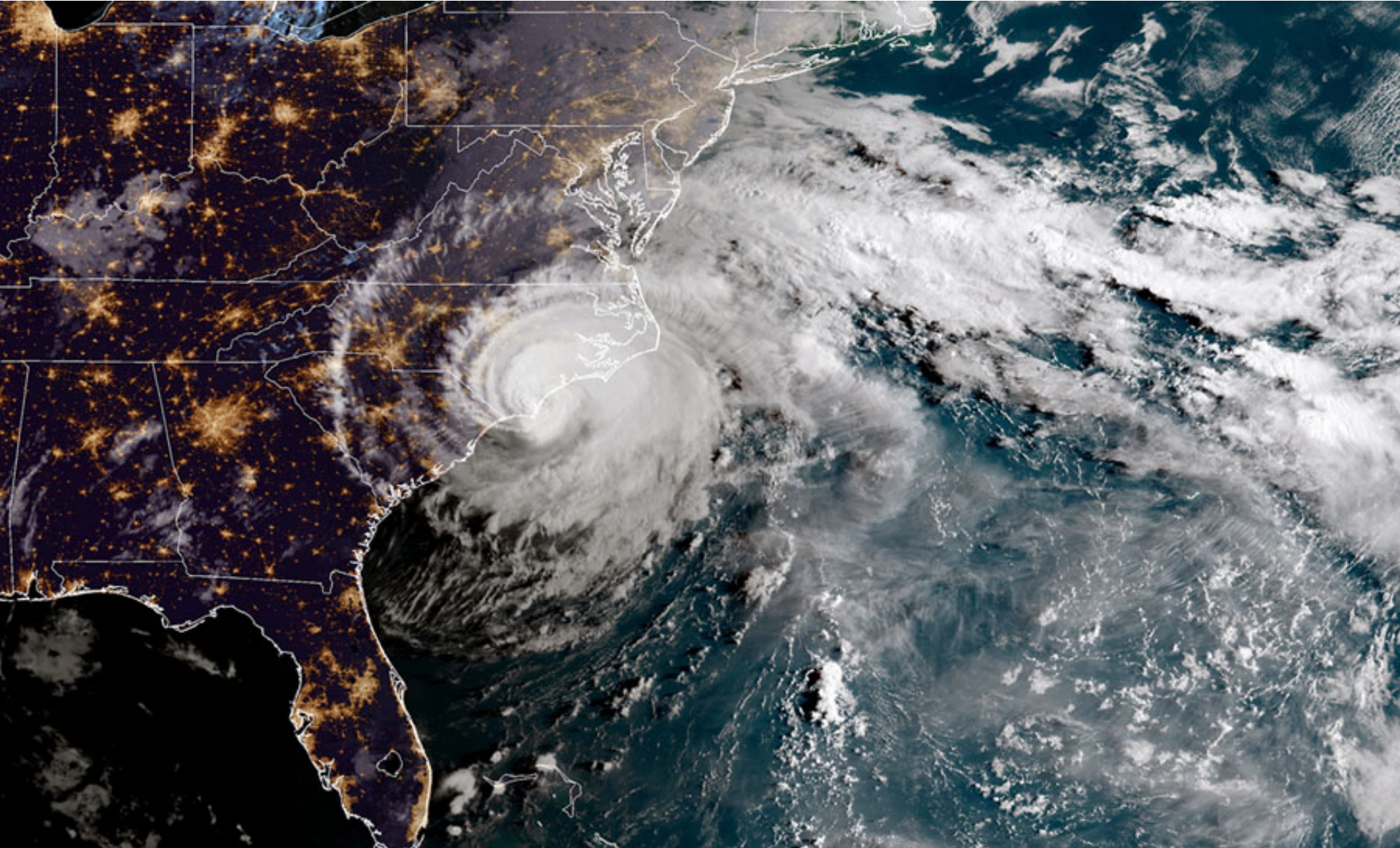
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Source: David J. Phillip/ AP, 2017

Hurricane Florence, 2018

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Source: NOAA, 2018

Mangkhut Typhoon, Philippines, 2018

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Kurashiki, Okayama Prefecture, Western Japan July 9, 2018

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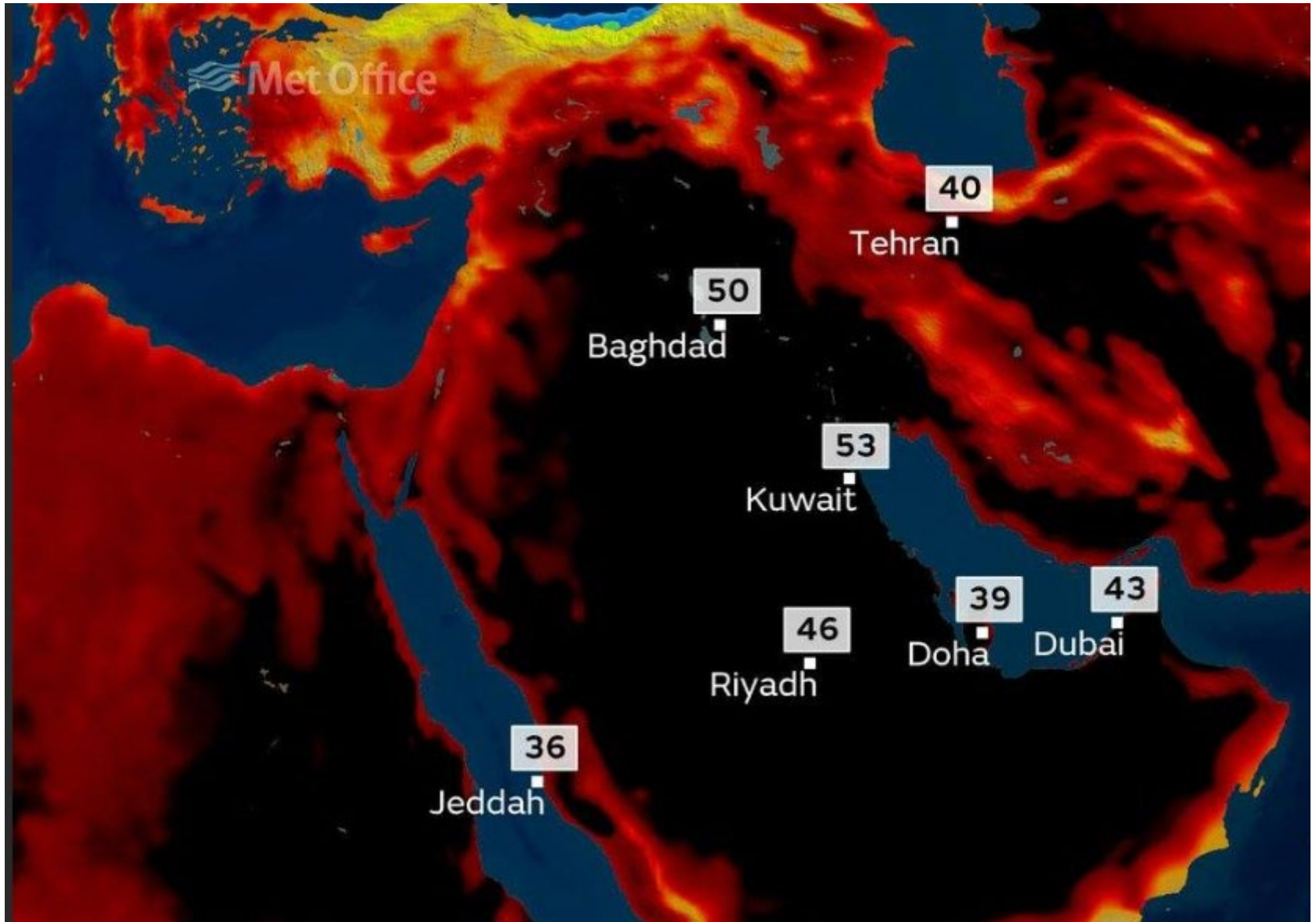
Heat wave in Pakistan in 2015: 530 fatalities

Temperature up to 44 °C in Karachi



Source: Notimex, June 23, 2015

Temperatures in Iraq and Kuwait in June 2016



Source: Met Office (blogs.agu.org)

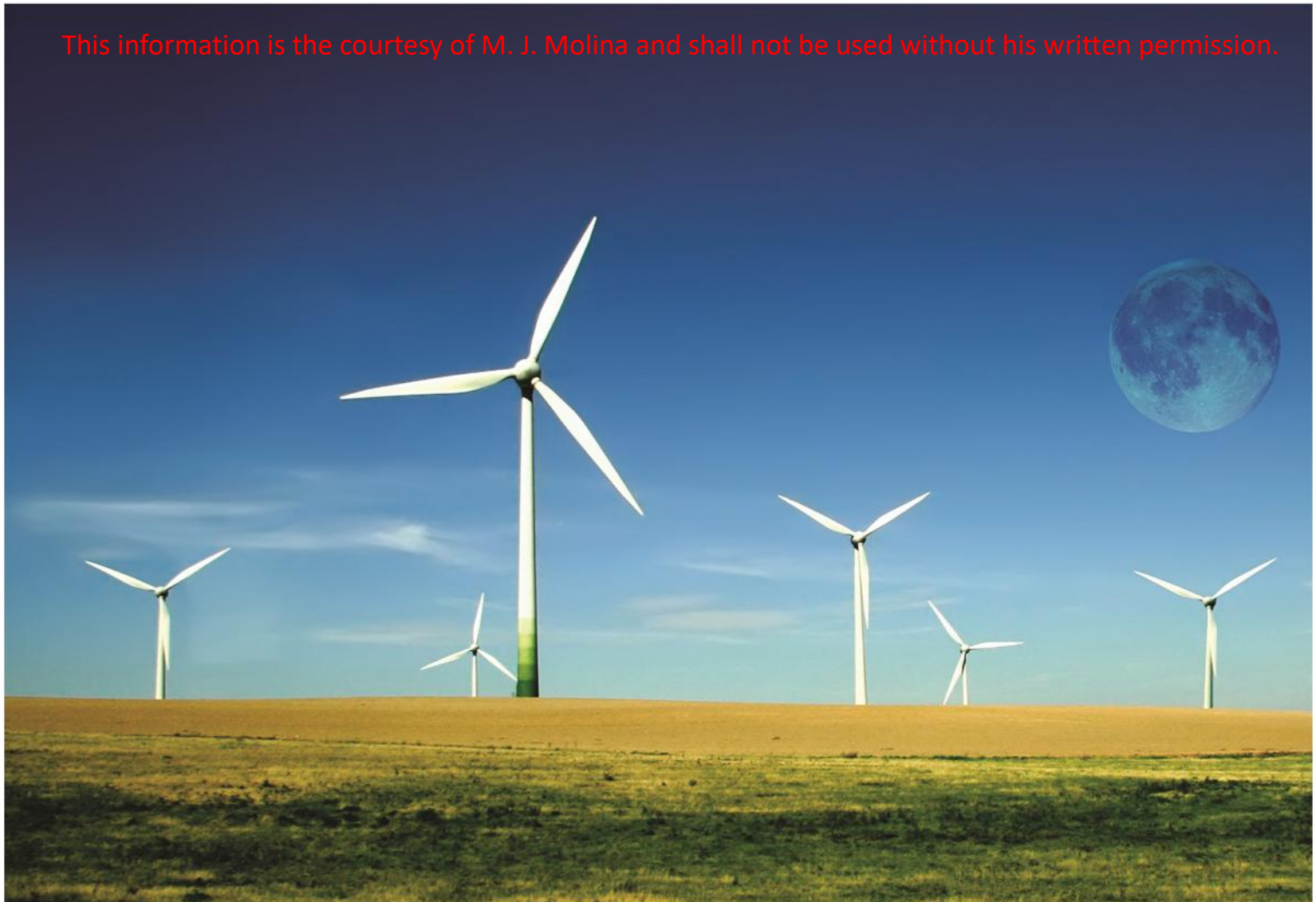
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Wind energy

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Solar Energy

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Park Aura Solar, Baja California, Mexico

The Paris Agreement

COP 21 Conference on Climate Change

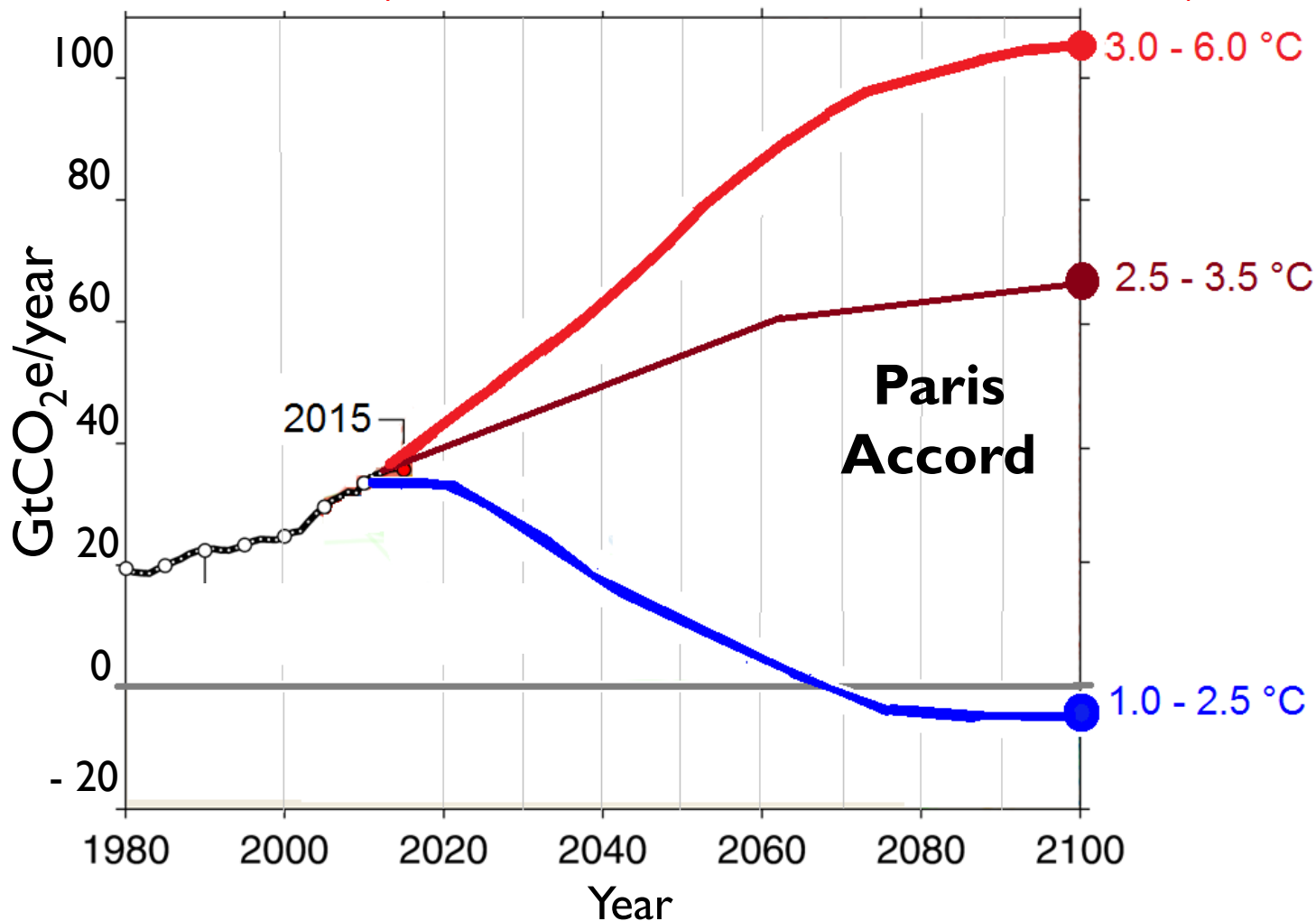
December 2015

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- **Includes approximately 90% of global emissions emitted.**
- **Establishes credible reporting and transparency requirements.**
- **Moves forward with finance for climate adaptation and mitigation.**
- **Agreement to return to negotiations periodically, such as every 5 years.**

Trajectory to Limit the Temperature Increment to 2°C

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Source: Emissions scenarios, Over 1000 scenarios from the IPCC 5th AR. Global Carbon Project, Dec. 2015; Climate Interactive & MIT, Oct. 2015

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Republican Party Views on Climate Change

"I mean, Obama thinks it's the number one problem of the world today. And I think it's very low on the list. ...

I believe there's weather. I believe it goes up and it goes down, and it goes up again. ...

I am not a believer, and we have much bigger problems."

Donald Trump, President-elect of the United States- September 2015

"There's no question that the activities that take place in this country and ... around the world have some impact on climate."

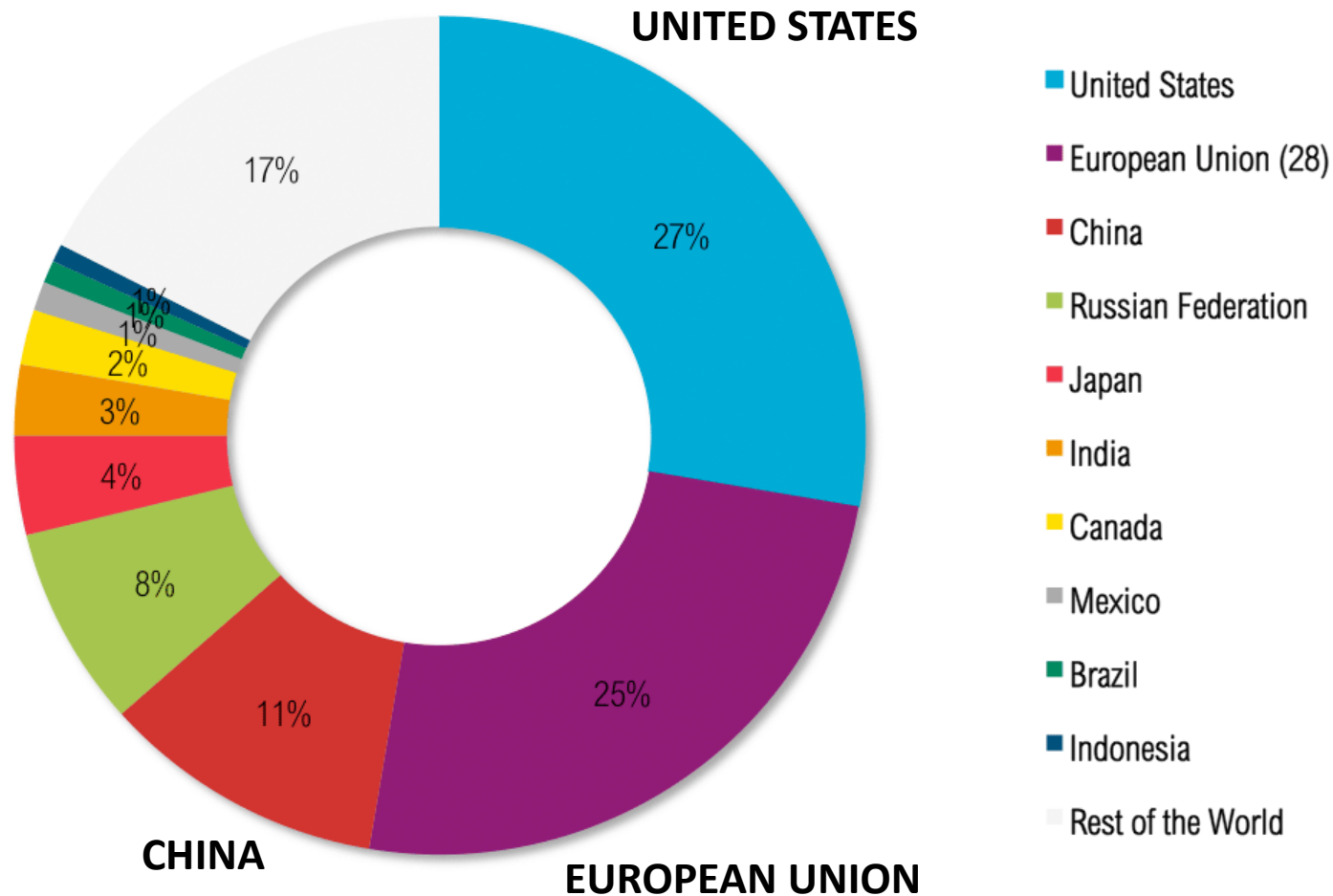
"Donald Trump and I say, let's follow the science, but for heaven's sakes let's not go rushing into the kind of restrictions on our economy that are putting Americans out of work."

Mike Pence, Vice President-elect of the United States September 2016



Cumulative CO₂ Emissions 1850-2011

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Merchants of Doubt

How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming

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Naomi Oreskes and Erik M. Conway

For years, free-market fundamentalists opposed to government regulation have sought to create doubt in the public's mind about the dangers of smoking, acid rain, and ozone depletion. Now they have turned those same tactics on the issue of global warming and on climate scientists, with significant success.

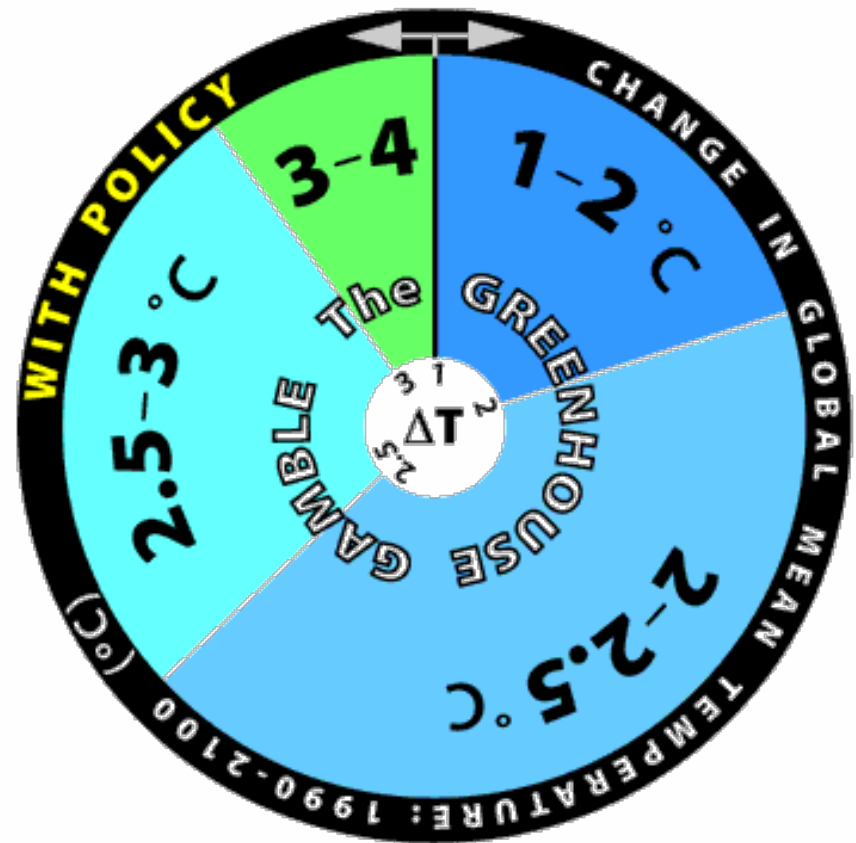
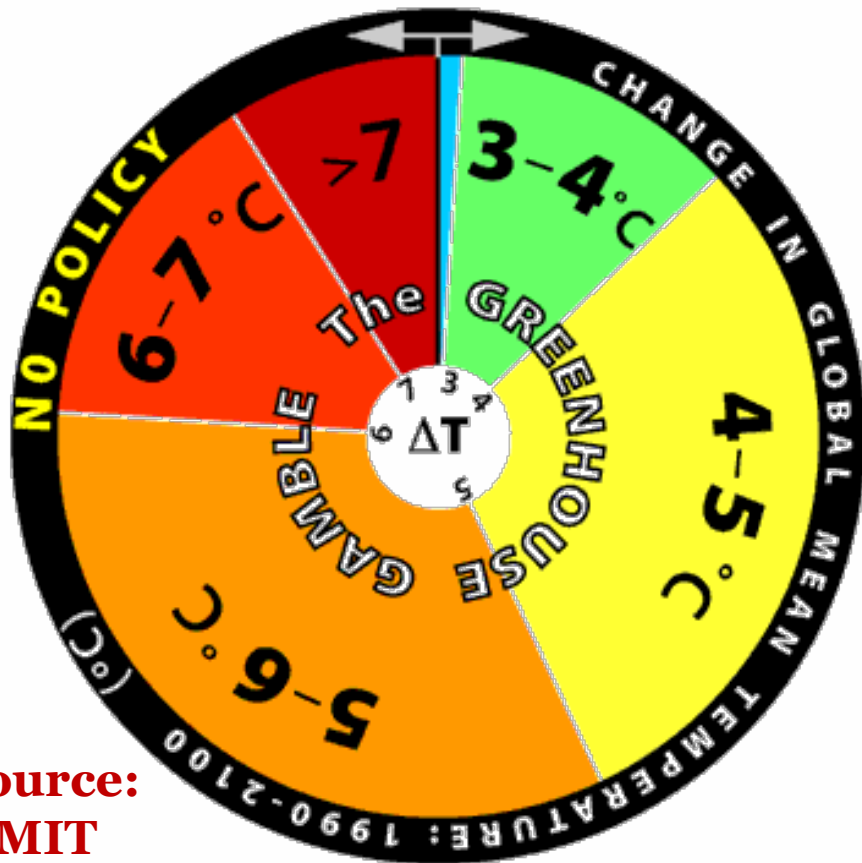
Value of a Climate Policy Under Uncertainty

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No Policy

What would we buy with STABILIZATION of CO₂ at 550 ppm?

A NEW WHEEL with lower odds of EXTREMES



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International Agreement to Control CFC Emissions

UNITED NATIONS ENVIRONMENT PROGRAM (UNEP)



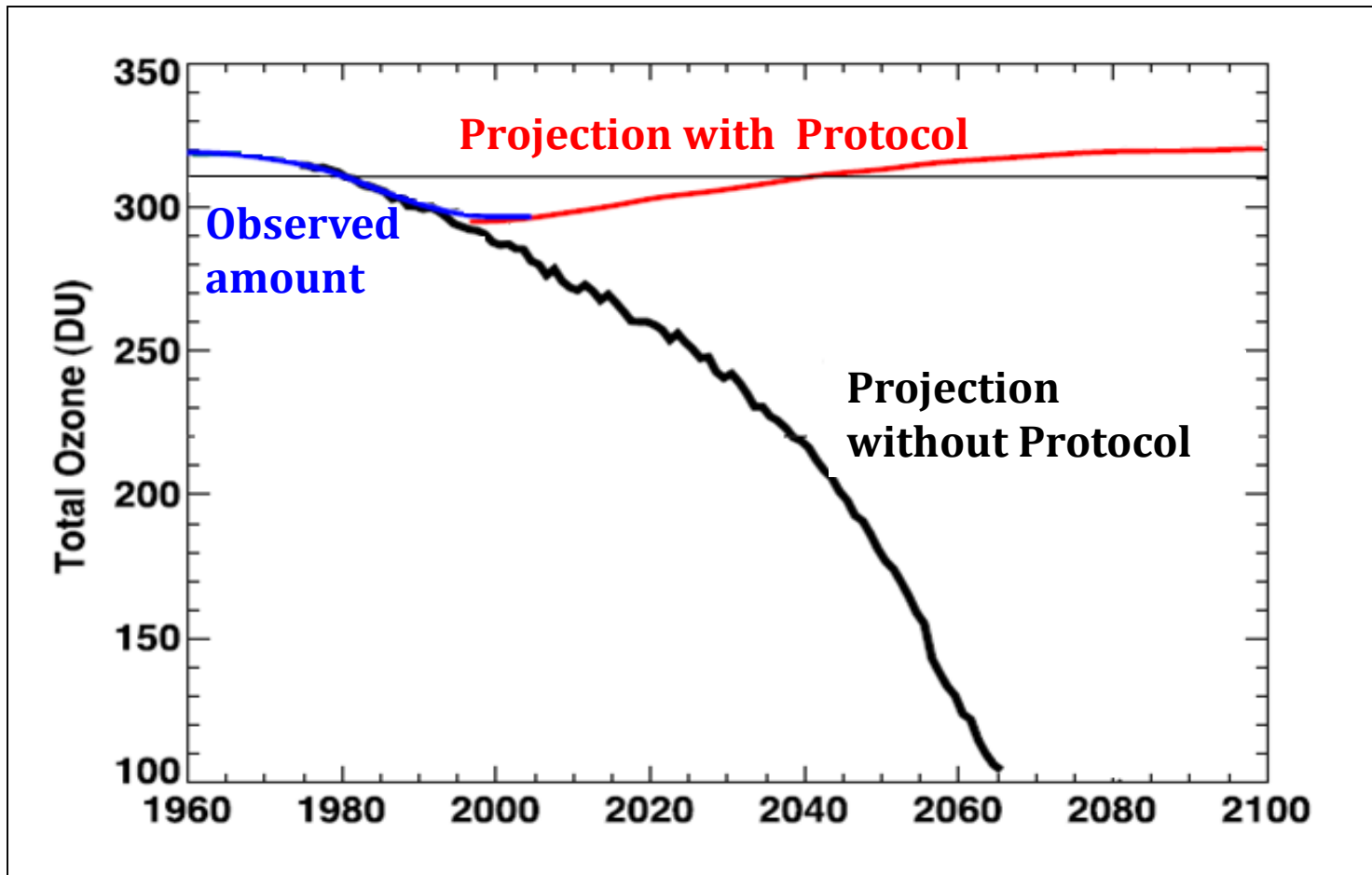
MONTREAL PROTOCOL ON SUBSTANCES THAT DEplete THE OZONE LAYER

FINAL ACT

1987

Montreal Protocol Achievements

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Source: Newman et al., *What would have happened to the ozone layer if chlorofluorocarbons (CFCs) had not been regulated?*

Atmos. Chem. Phys. Discuss., 9, 2113–2128, 2009

Halogenated Hydrocarbons In and Over the Atlantic

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J. E. Lovelock, R. J. Maggs,
and R. J. Wade

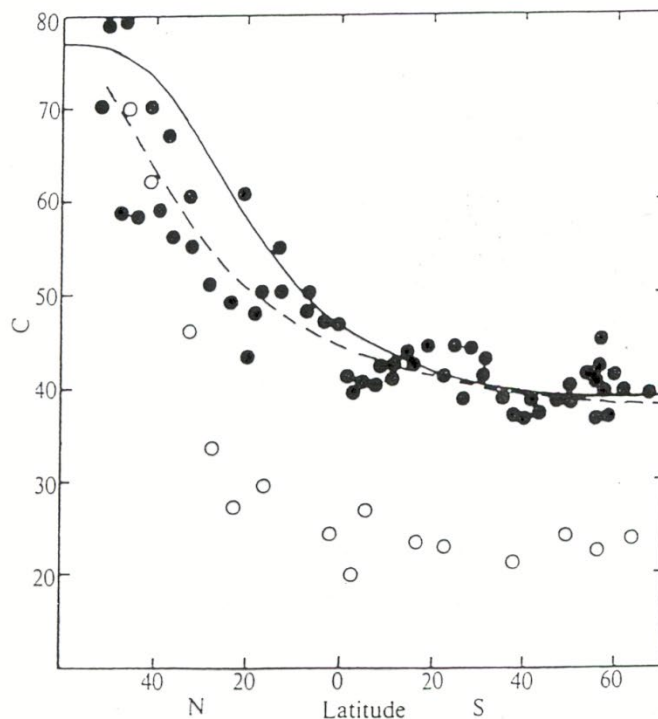
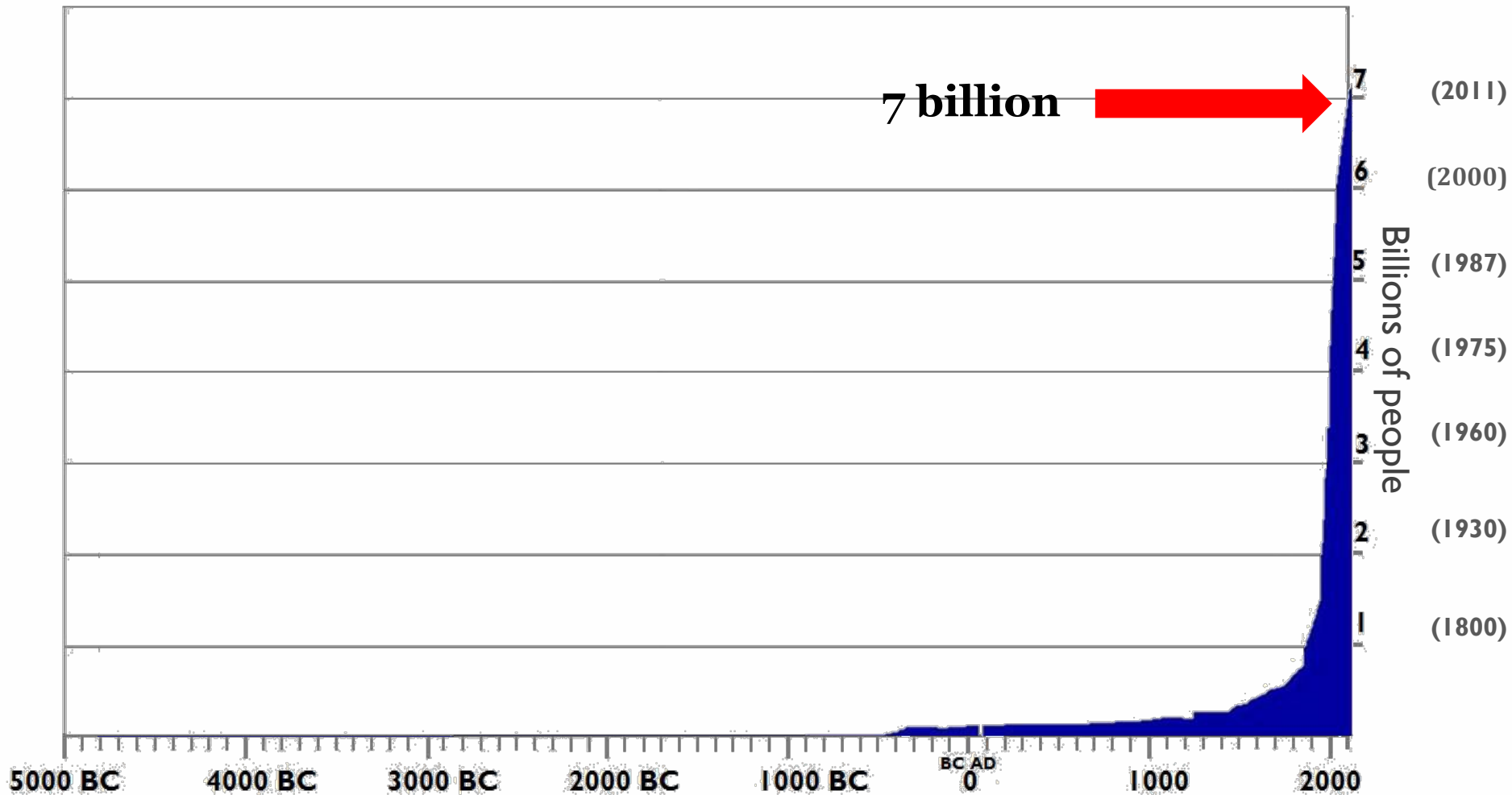


Fig. 1 Distribution of CCl_3F in and over the North and South Atlantic Ocean. ●, Aerial concentrations ($\times 10^{-12}$) by volume. ○, Seawater concentrations ($\times 10^{-12}$); as aerial concentrations in equilibrium with water. —, Theoretical prediction. ---, Best fit third degree polynomial.

Nature, January 1973

Human Population Growth

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Source: United Nations Population Division, World Urbanization Prospects, 2010.