CRISP
National University of Singapore

NUS
National University of Singapore

Air pollution:
Air Quality Overview

SG Remote Sensing Workshop 2023

Dr. Fernando Santos
Centre for Remote Imaging, Sensing and Processing
National University of Singapore

1

a. Why is air quality important?

b. Which species are problematic in your country?

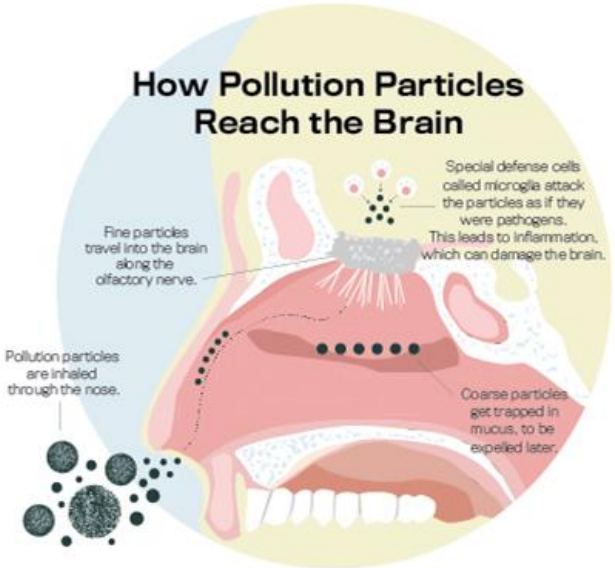
c. How much water do you drink a day?

d. How much food do you eat a day?

e. How much air do you breathe a day?

Air Quality Overview

Why does air quality matter?



- Health impacts
- Climate change
- Aesthetics (visibility and odor)

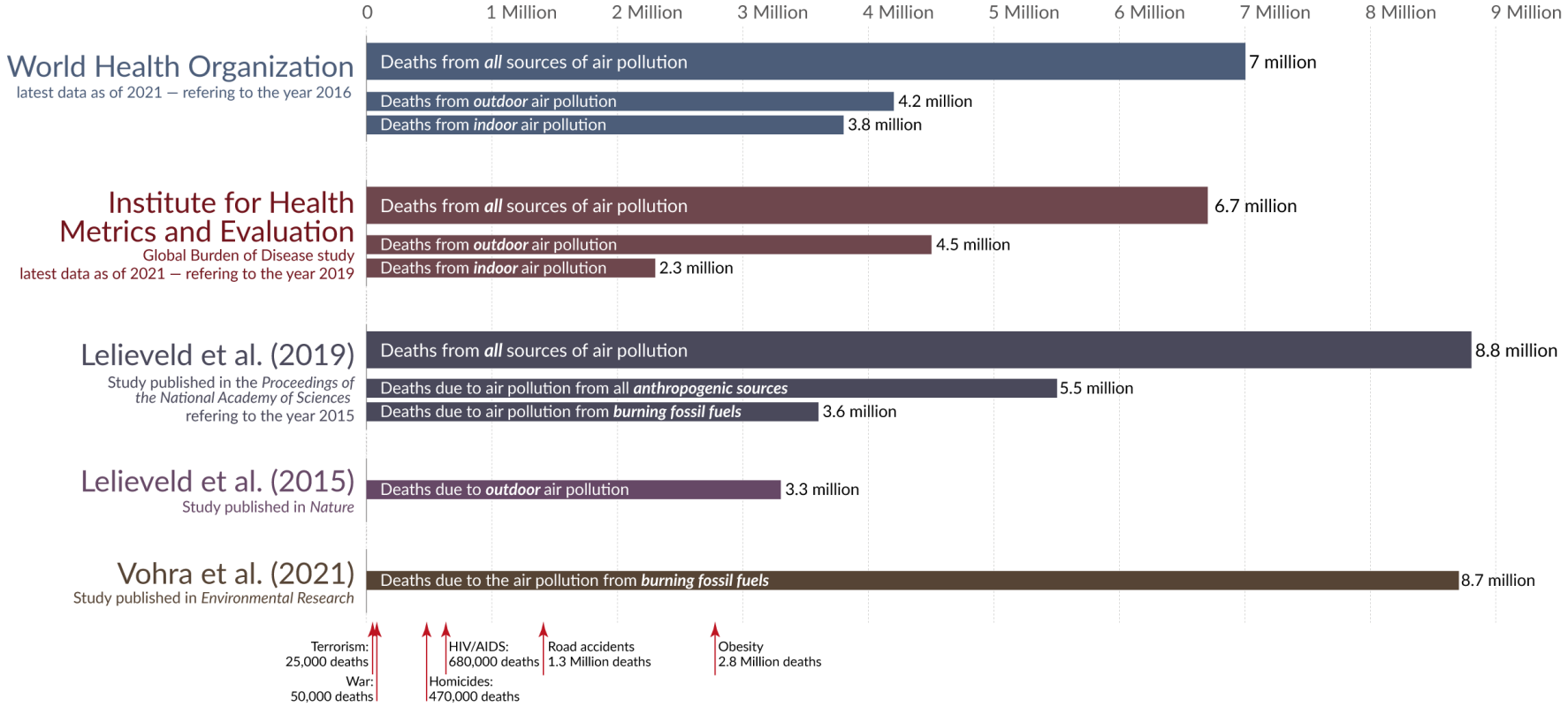
How many people die from air pollution each year?

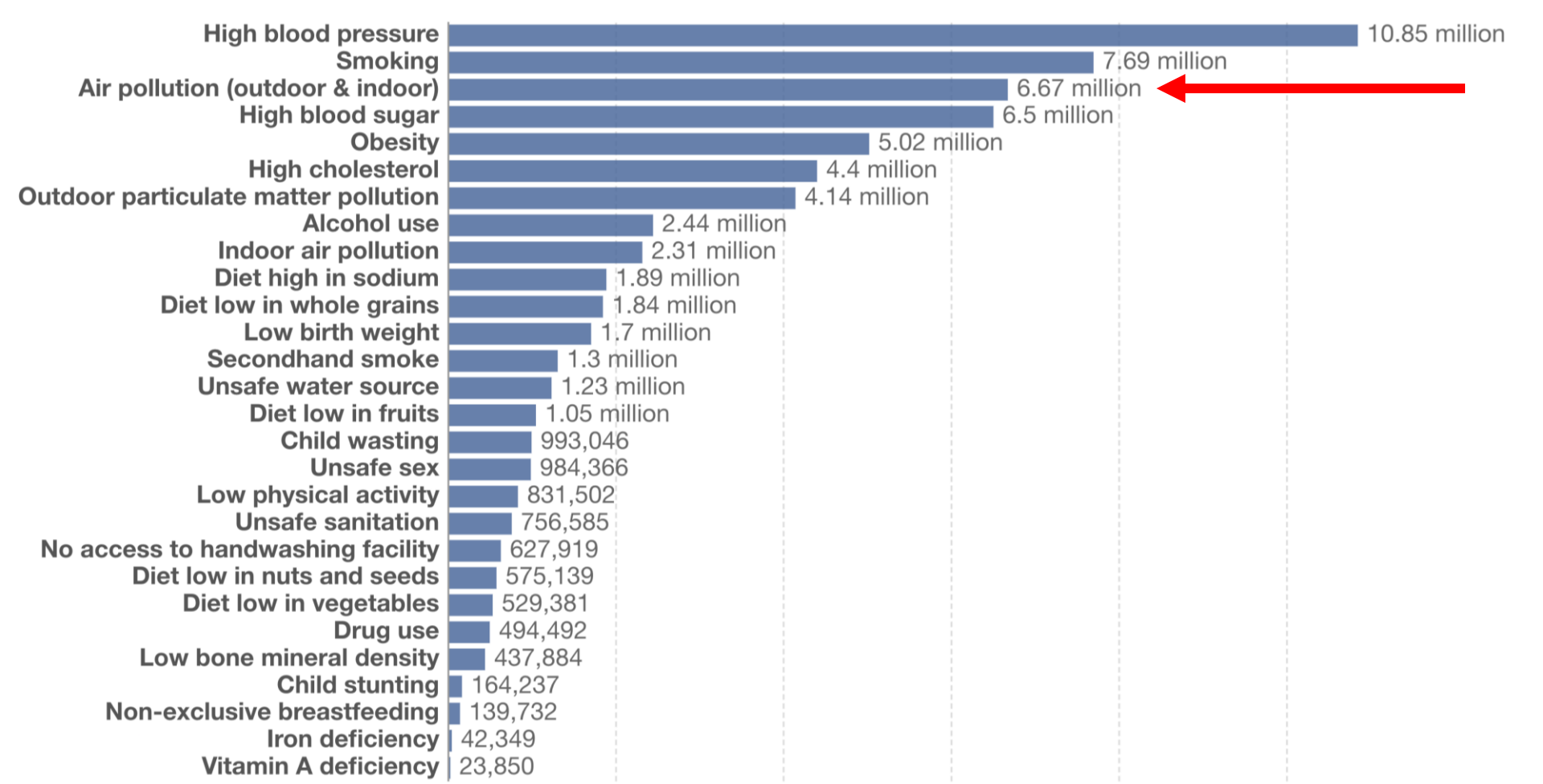
Estimates of the global death toll from air pollution published in major recent studies

Our World in Data

'All sources' includes both anthropogenic and natural sources:

- The largest source of natural air pollution is airborne dust in the world's deserts. Other natural sources are fires, sea spray, pollen, and volcanoes.
- Anthropogenic sources include electricity production; the burning of solid fuels for cooking and heating in poor households; agriculture; industry; and road transport.





Data source: IHME, Global Burden of Disease (2019)

OurWorldInData.org/causes-of-death | CC BY

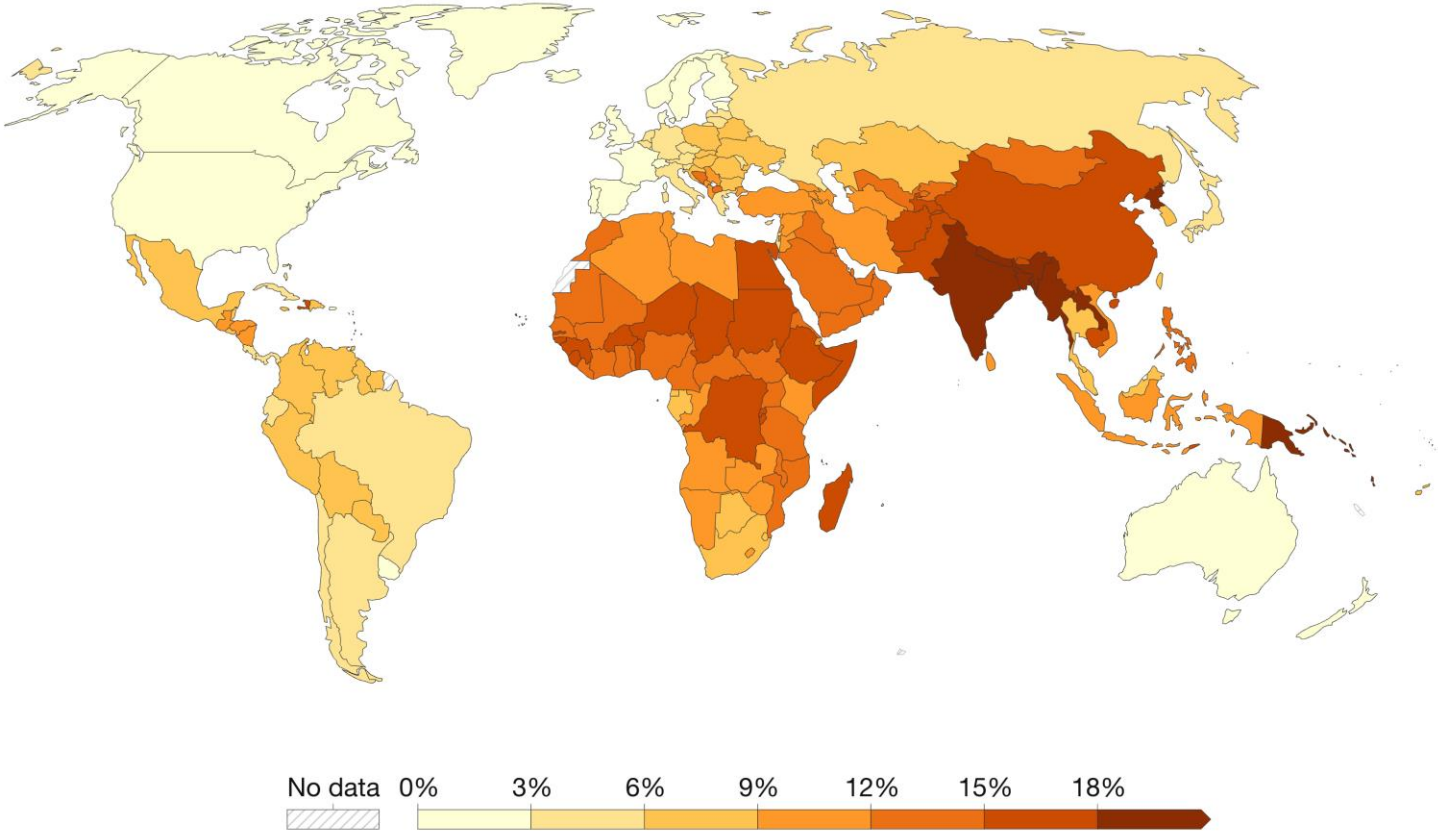
Note: Risk factors are not mutually exclusive: people may be exposed to multiple risk factors, and the number of deaths caused by each risk

5

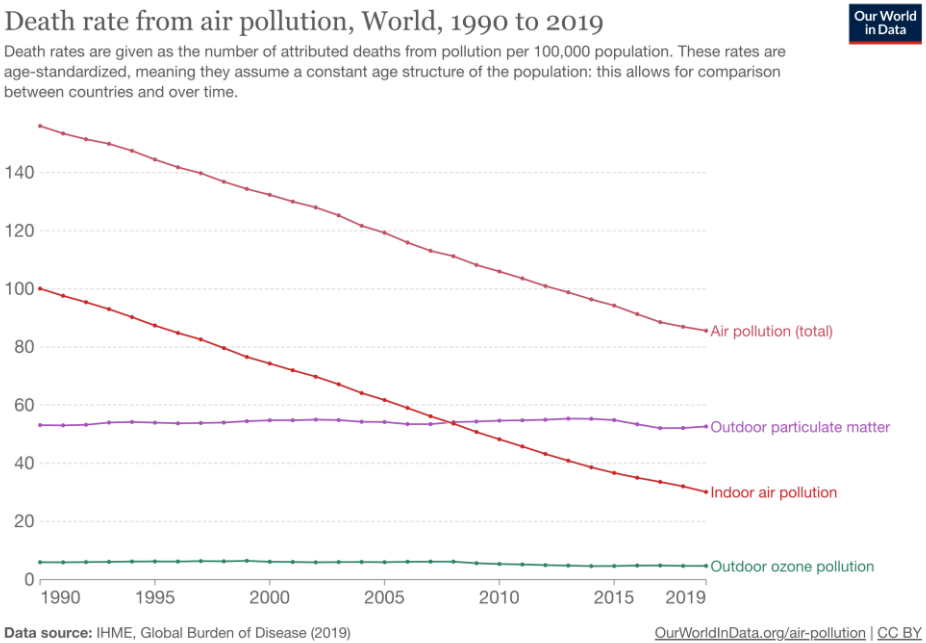
Share of deaths attributed to air pollution, 2019

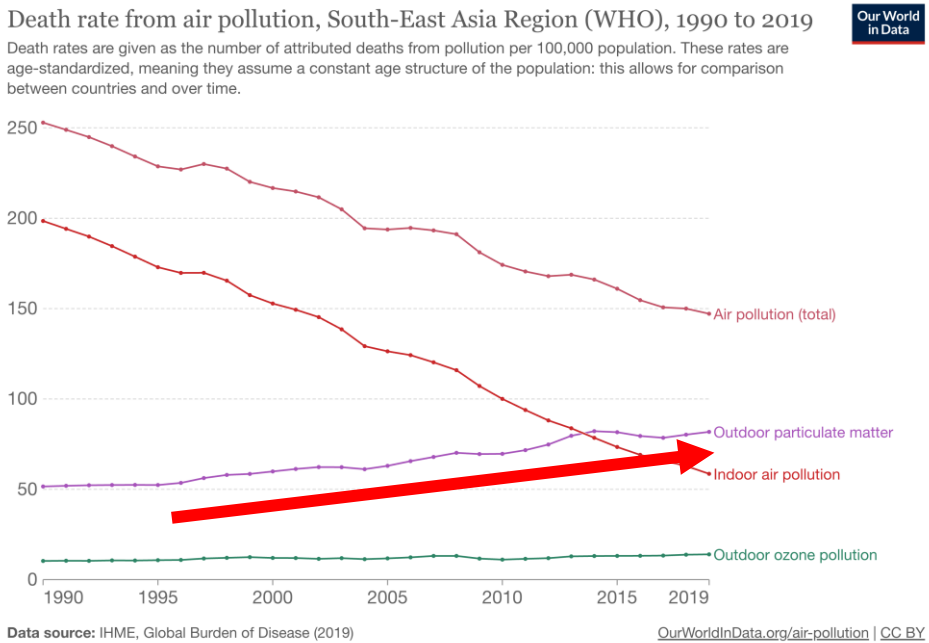
Share of deaths, from any cause, which are attributed to air pollution – from outdoor and indoor sources – as a risk factor.

Our World in Data



Outdoor particulate matter (PM) increasing in Southeast Asia

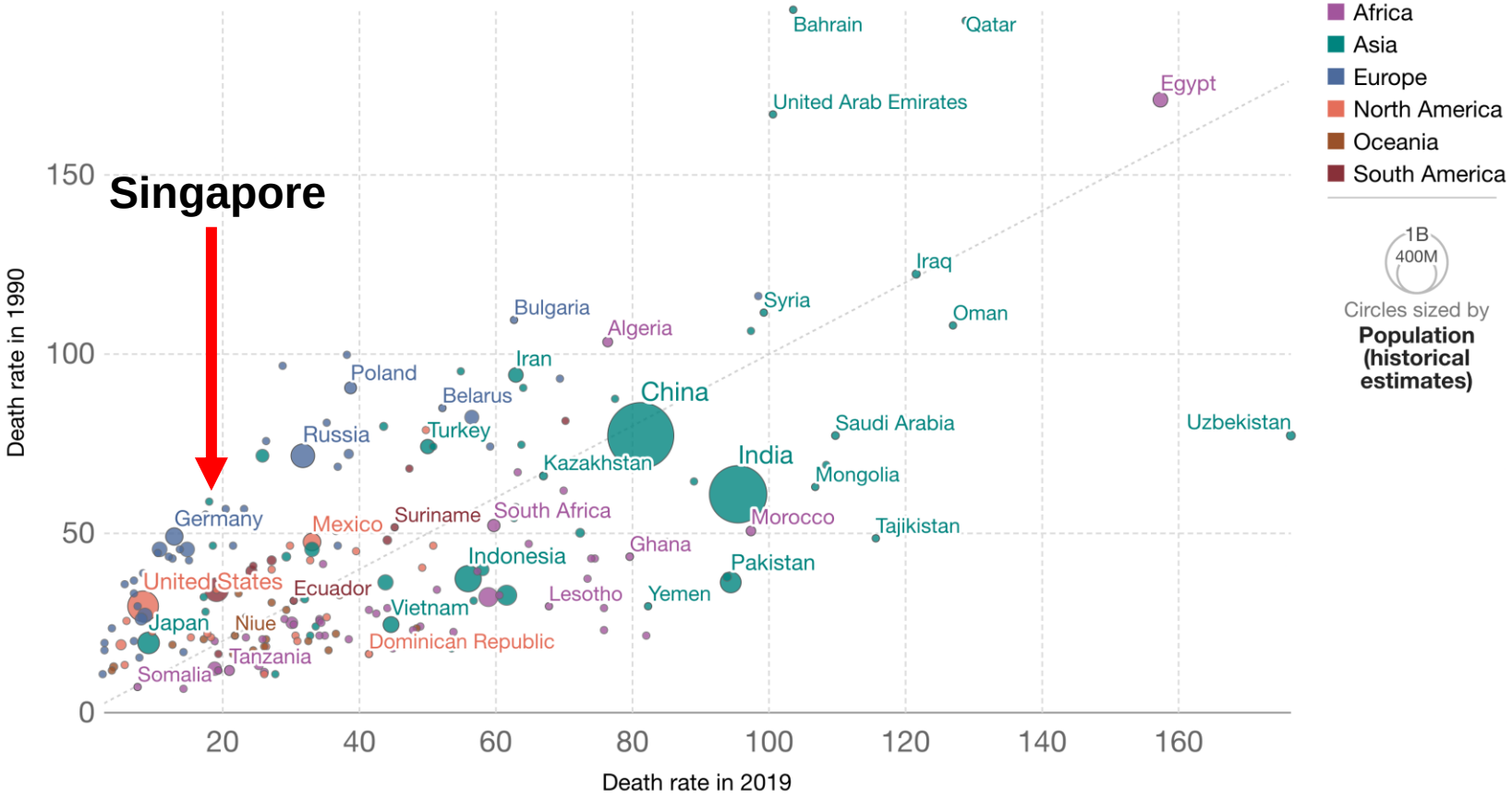




Death rate from outdoor air pollution in 1990 vs. 2019

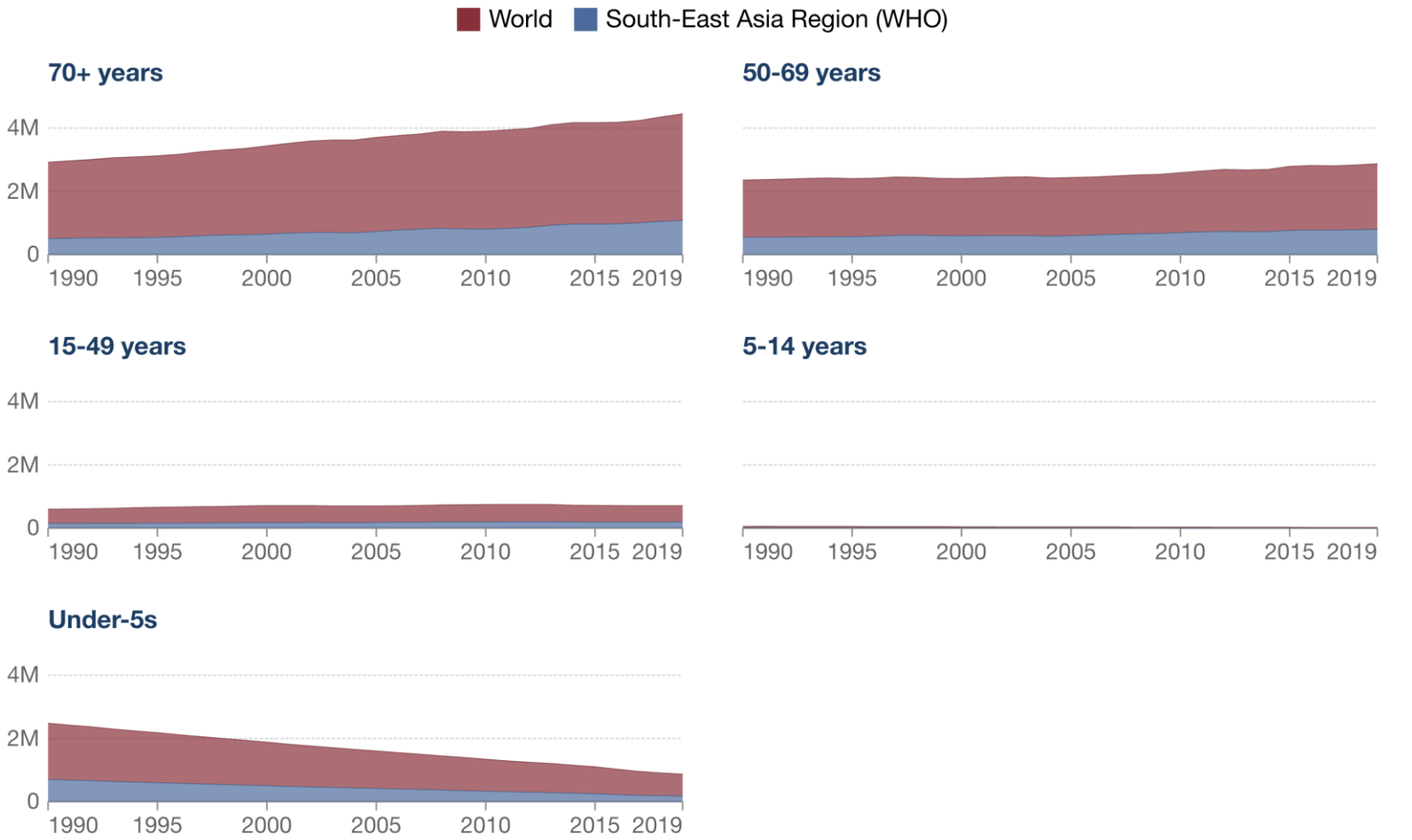
Deaths from outdoor particulate matter air pollution per 100,000 people. Countries below the diagonal line have experienced an increased death rate, whilst those above the line have seen a decreased death rate.

Our World in Data



Deaths from air pollution, by age

Our World in Data



A BRIEF GUIDE TO ATMOSPHERIC POLLUTANTS

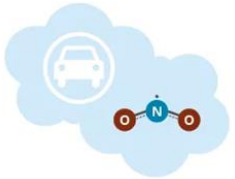
A number of different chemical entities, from a range of sources, can contribute towards atmospheric pollution, the consequences of which can include global warming and smog. This graphic looks at a selection of major groups of atmospheric pollutants, their major sources, and their effects.

CARBON MONOXIDE

A gas generated by the incomplete combustion of fuels – primarily from road transport. Affects human health, as it reduces oxygen-carrying capacity of the blood. It also reacts with other atmospheric gases to produce ozone.

CARBON DIOXIDE

A gas generated by the burning of fossil fuels in the production of electricity. Also emitted by natural processes. Human emissions are linked with rising atmospheric CO_2 levels and anthropogenic global warming.

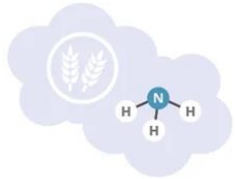


NITROGEN OXIDES

Primarily created by combustion in road transport. Nitrous oxide is an important global warming contributor, whilst nitrogen dioxide is involved in ground-level ozone forming reactions, and is also a component of smog.

SULFUR DIOXIDE

The primary source of sulfur dioxide is the burning of fossil fuels to generate electricity. It can contribute to smog, reacts with water to produce acid rain, and can also cause wheezing and breathing problems for asthmatics.



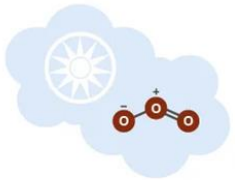
AMMONIA

Ammonia's primary atmospheric source is from its use in agriculture, such as manure & fertilisers. It can react with other pollutants to produce particulate matter. It also has the ability to over-enrich ecosystems with nitrogen.

Formaldehyde

VOCs

VOCs (volatile organic compounds) are emitted naturally by vegetation. Amongst significant human sources is road transport, as well as solvents. They can contribute to formation of ground-level ozone and smog.

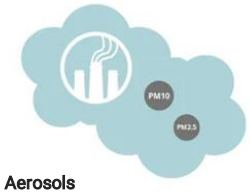


OZONE

The ozone layer shields us from UV radiation, but ground-level ozone is a major pollutant. It's formed from other pollutants in the presence of sunlight. Ozone is a major component of smog, and can also cause health effects.

POPs

POPs (persistent organic pollutants) are volatile chemicals released into the atmosphere, often from agricultural or industrial uses. They persist in the environment and can have health effects on both wildlife & humans.



Aerosols

PARTICULATE MATTER

Particulate matter is composed of a huge number of different components. Some are directly emitted, while others are generated by reactions in the atmosphere. They cause haze and can also cause lung problems if inhaled.

HEAVY METALS

Heavy metals are released into the atmosphere from a range of sources, including burning of fossil fuels and road transport emissions. Some, such as mercury and lead, have toxic health effects in humans.

What sets the Earth apart from other planets & makes it possible for us to live here?

Agree/Disagree

- Earth's atmosphere is mostly oxygen. Agree/Disagree
- Air is weightless. Agree/Disagree
- Without the atmosphere, we would burn up. Agree/Disagree
- We live in the warmest part of the atmosphere. Agree/Disagree
- Our atmosphere is over 100 miles thick. Agree/Disagree

What sets the Earth apart from other planets & makes it possible for us to live here?

Agree/Disagree

• Earth's atmosphere is mostly oxygen.	Agree/**Disagree**
• Air is weightless.	Agree/**Disagree**
• Without the atmosphere, we would burn up.	**Agree**/Disagree
• We live in the warmest part of the atmosphere.	Agree/**Disagree**
• Our atmosphere is over 100 miles thick.	**Agree**/Disagree

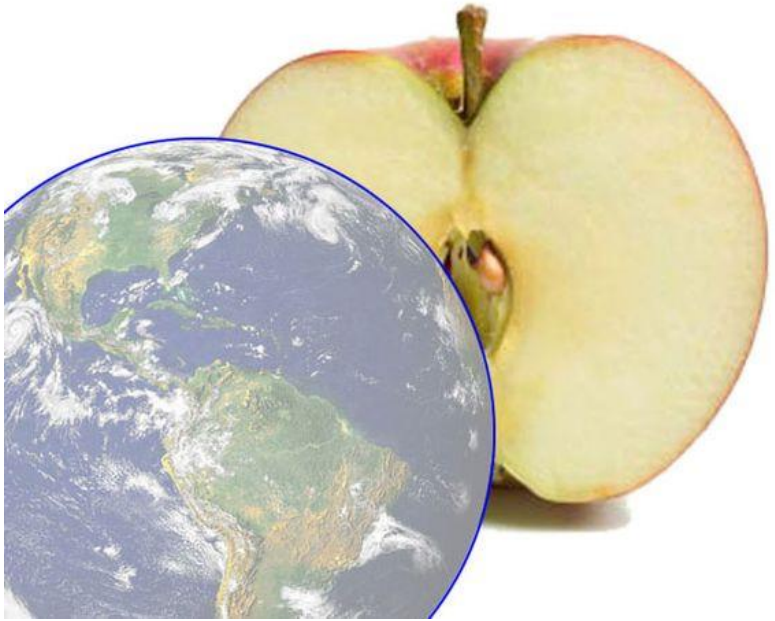
What sets the Earth apart from other planets and makes it possible for us to live here?

The Atmosphere

- Images of an Earth and an ordinary Apple

- The diameter of the Earth at the equator is 7,926.41 miles (12,756.32 kilometers)

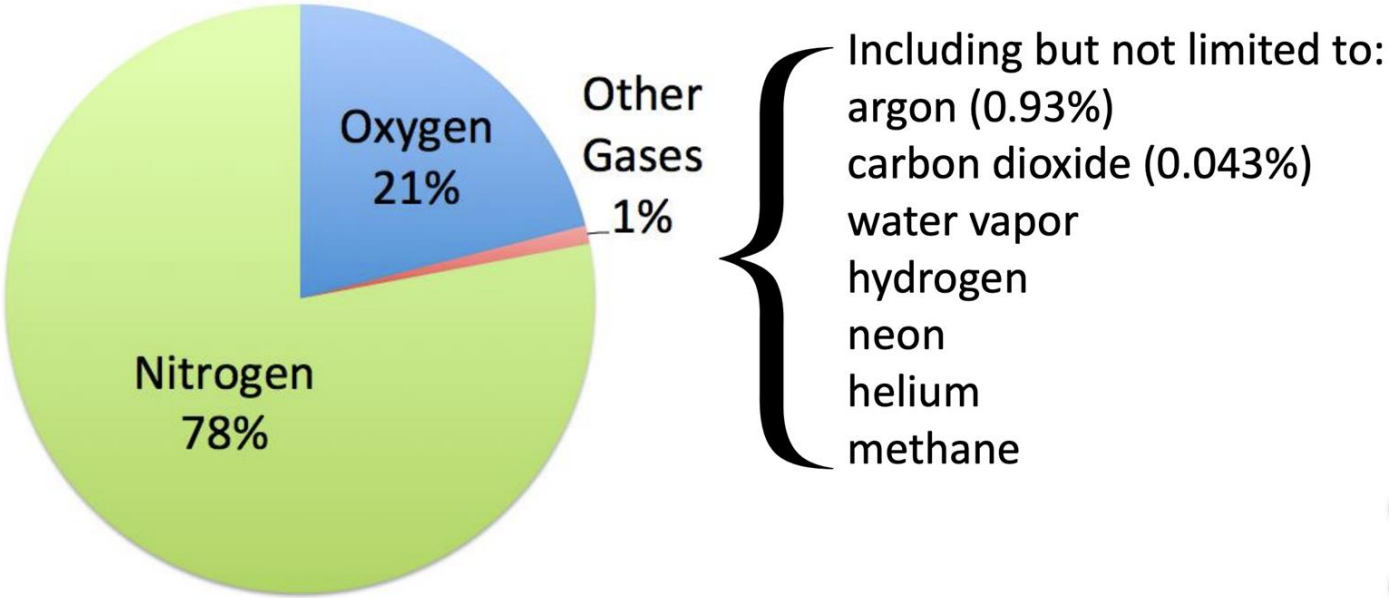
- Suppose the Earth were the size of an apple, about 3 inches across. If the Earth were the size of an apple, the atmosphere would be *no thicker* than the apple skin!



Radius=6000 km
Atm=12 km
Radius/Atm=500

Radius=75 mm
Atm=0.5 mm
Radius/Atm=150

What gases make up our atmosphere?



- Three-fourths of all air resides in the troposphere, the lowest layer of the Earth's atmosphere.

What do you think of when you hear “air quality”?

Sandstorm in Morocco

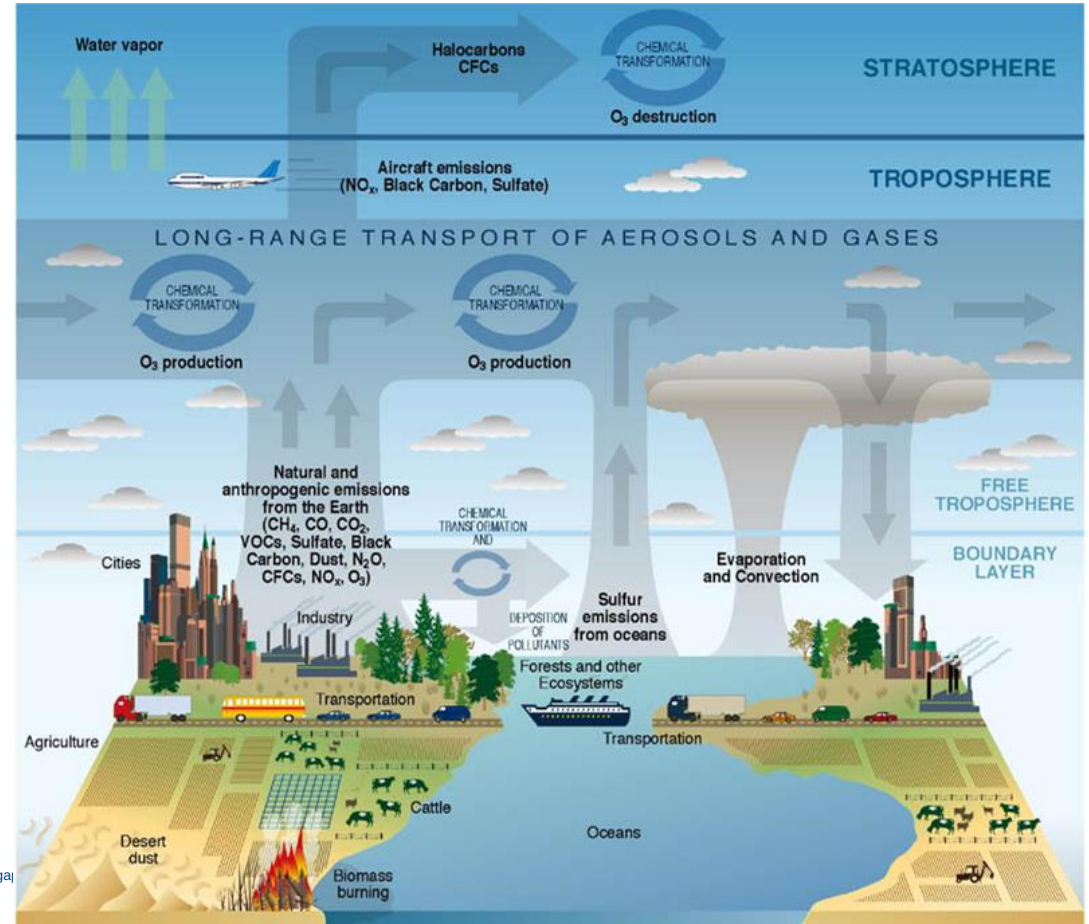
Smog in Malaysia

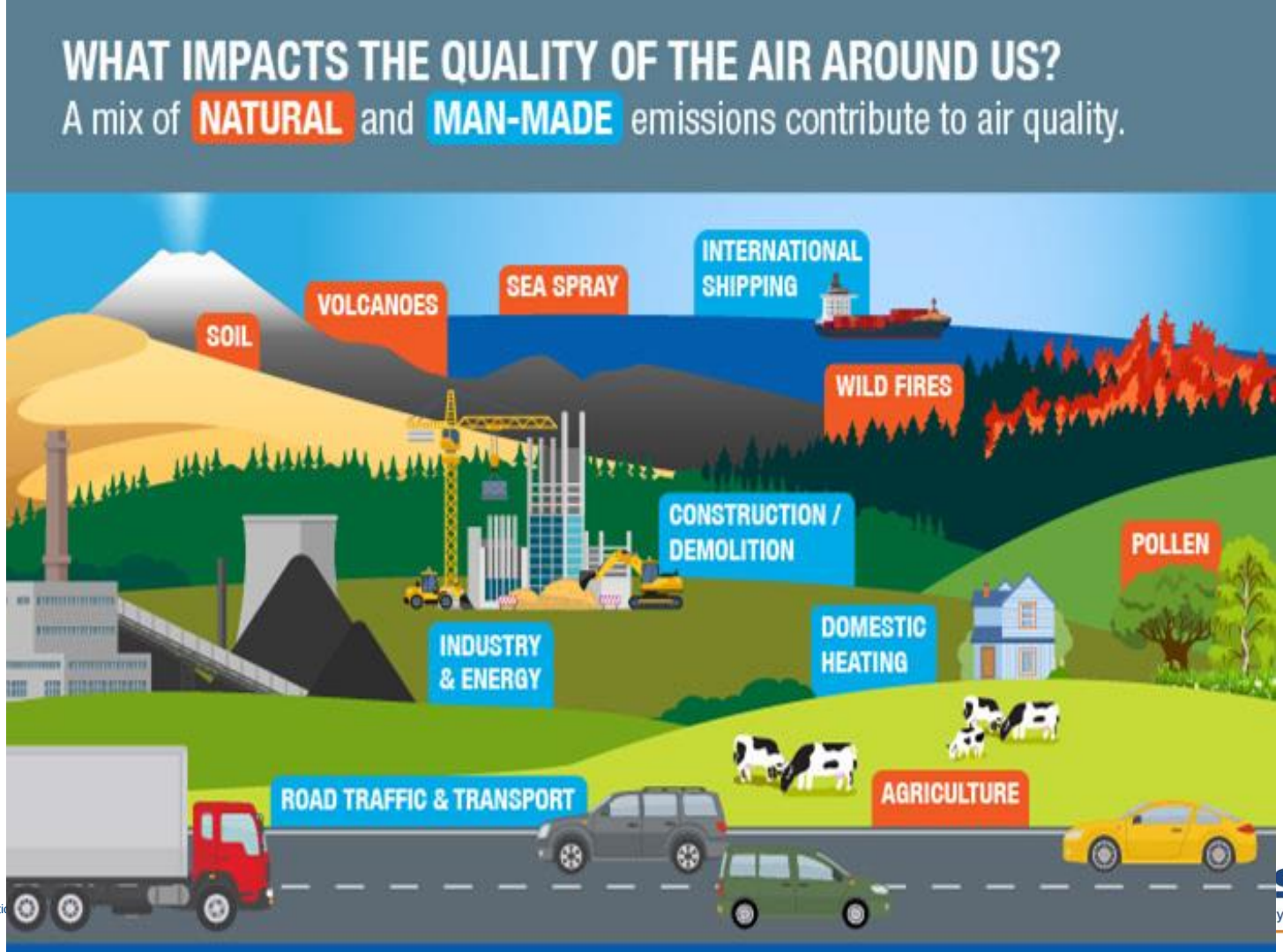
Clear day in Los Angeles

Is air quality the same all over the planet? Why or why not?

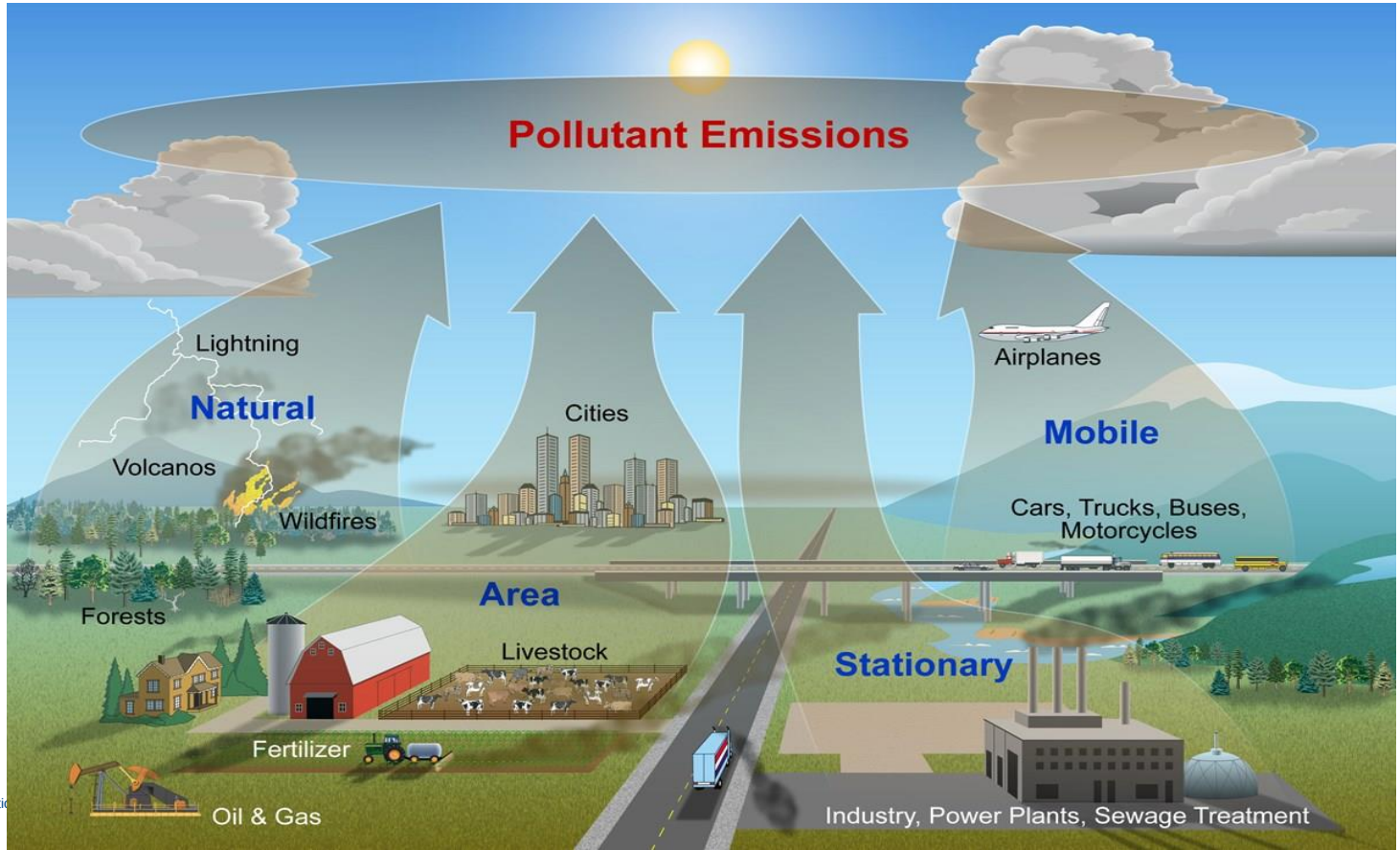
History of SMOG and its Health Effects

Our Earth Atmosphere's Layers

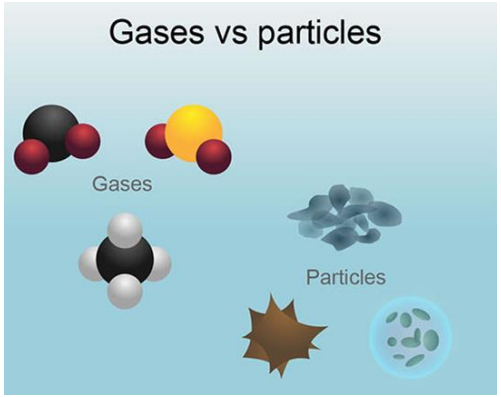


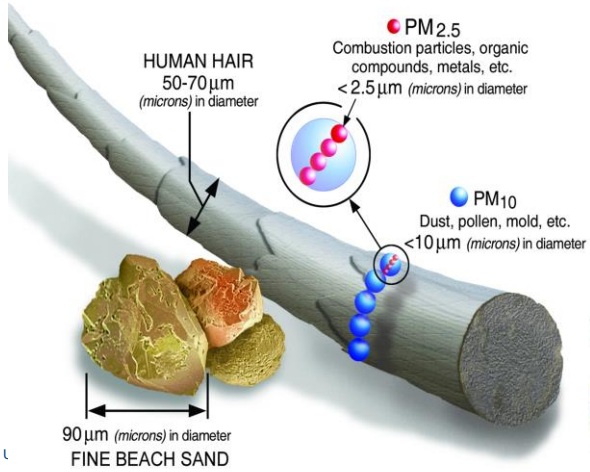


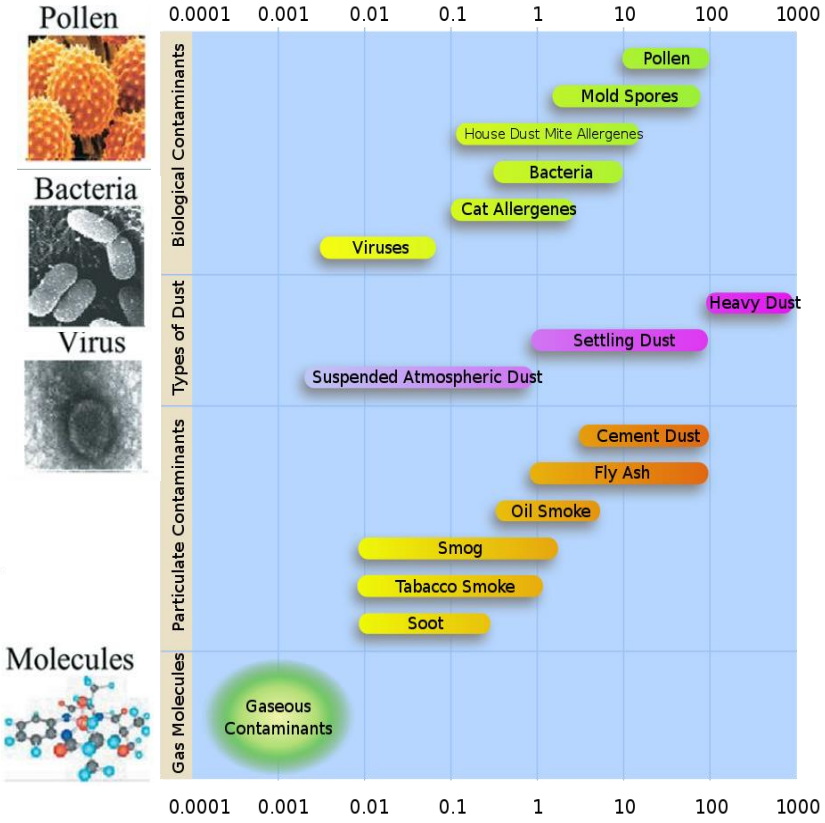
What are the main types of air pollution?
Types of Emission Sources



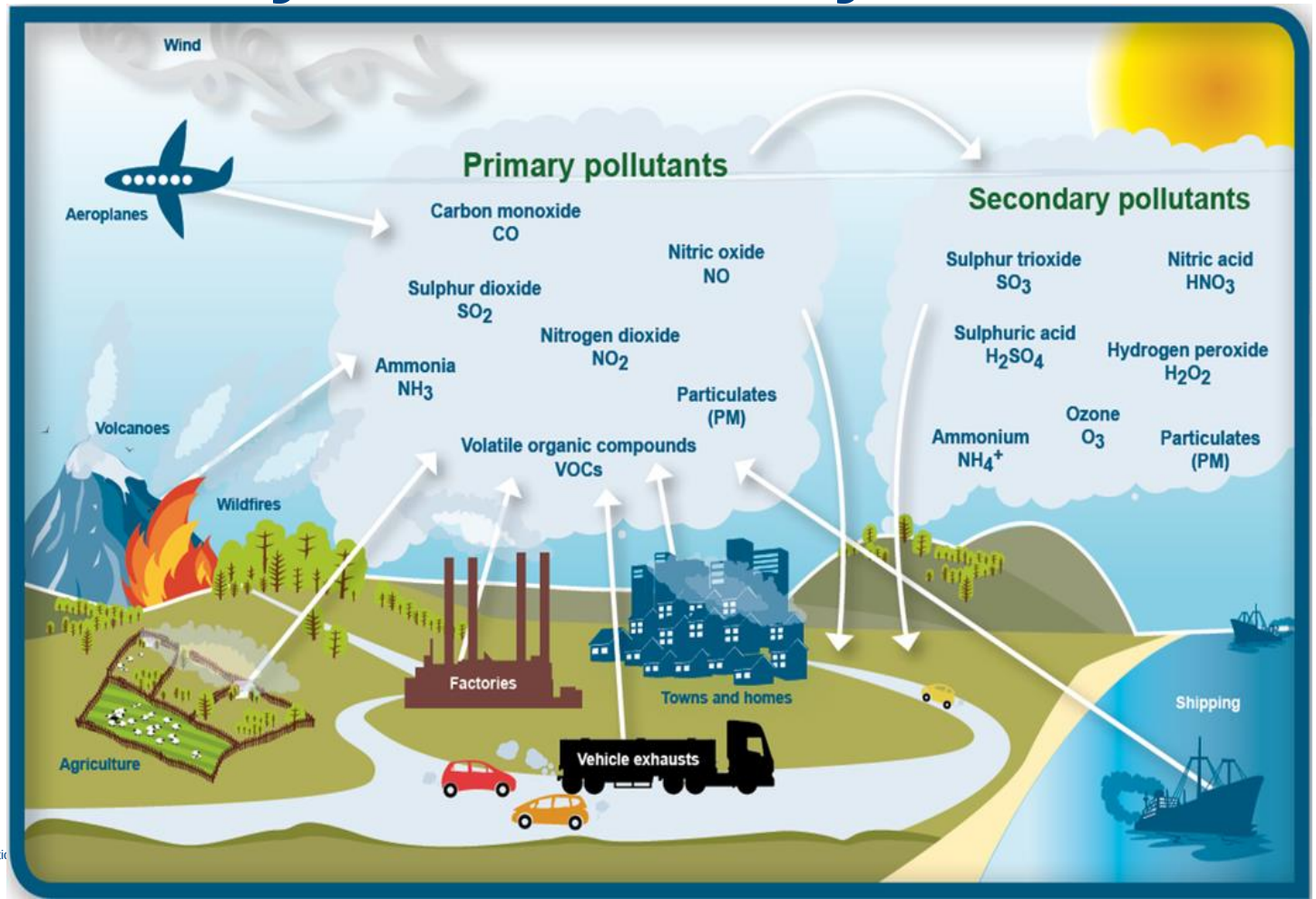
Pollutant Classification and Size



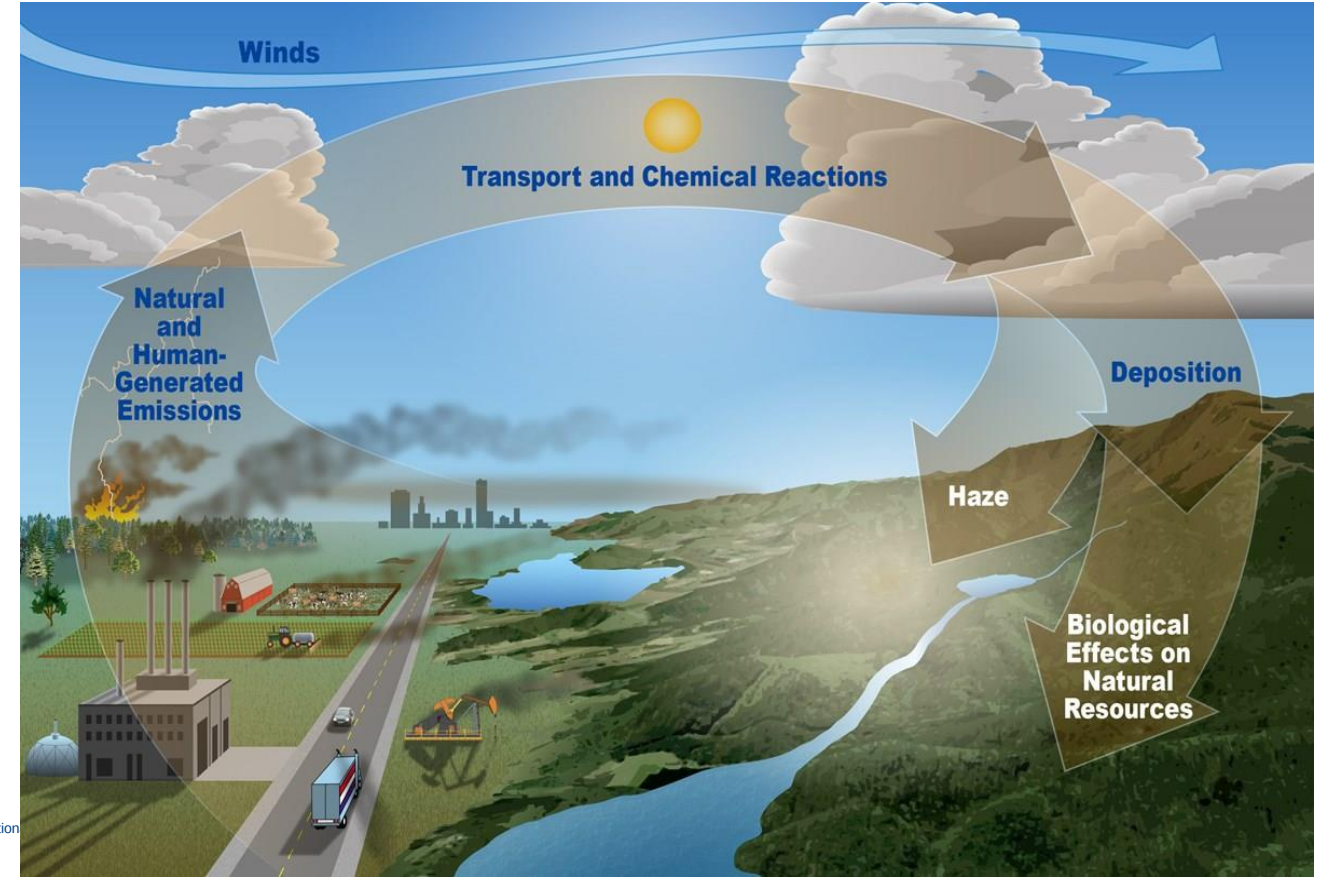




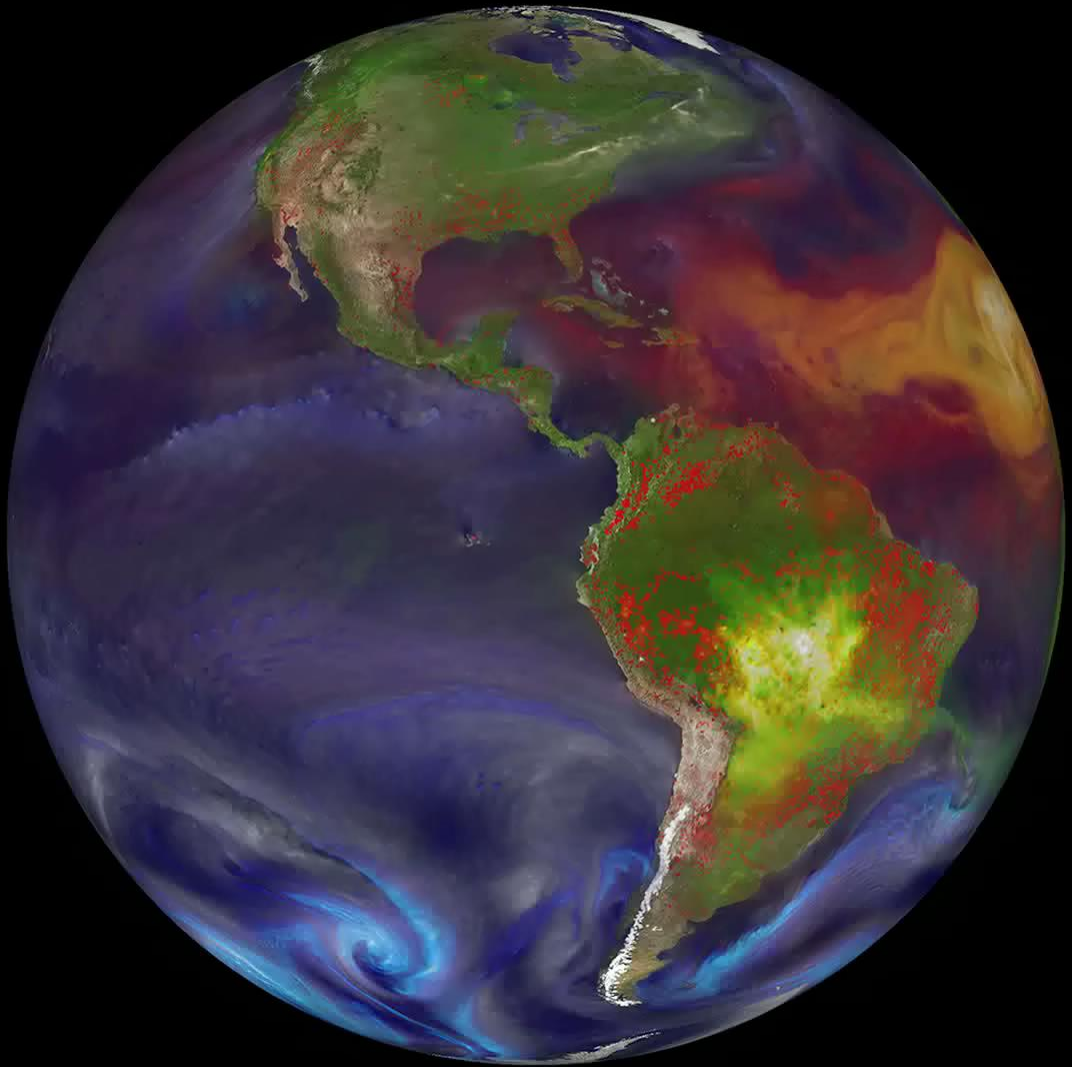
Primary vs. Secondary Emissions



Air Pollution Emission and Transport Mechanisms



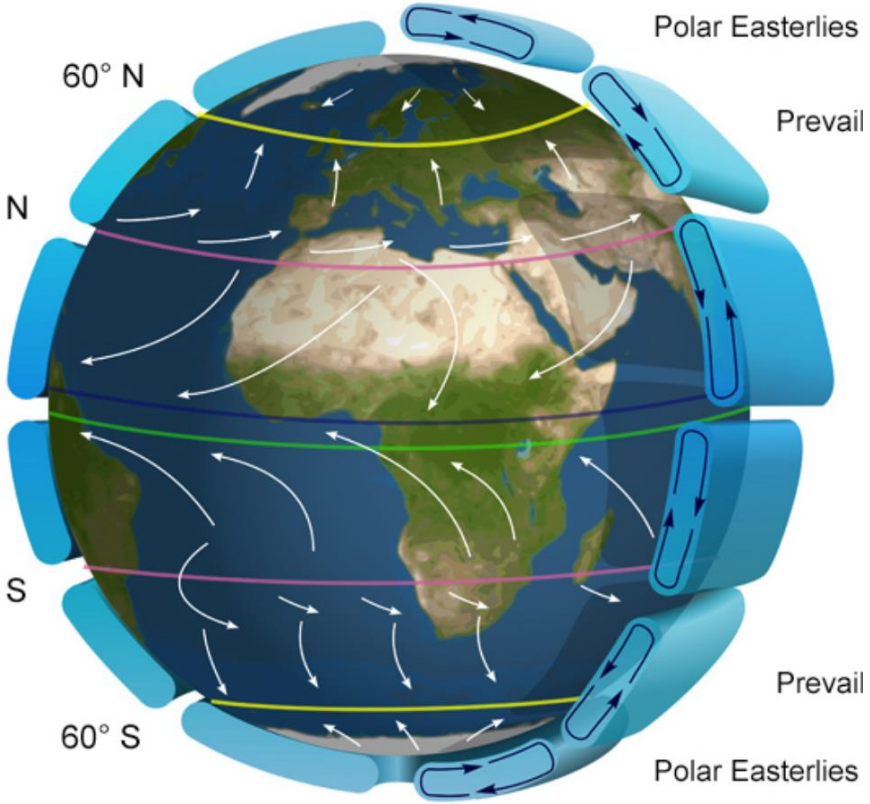
Aerosol Emission Transport From Space

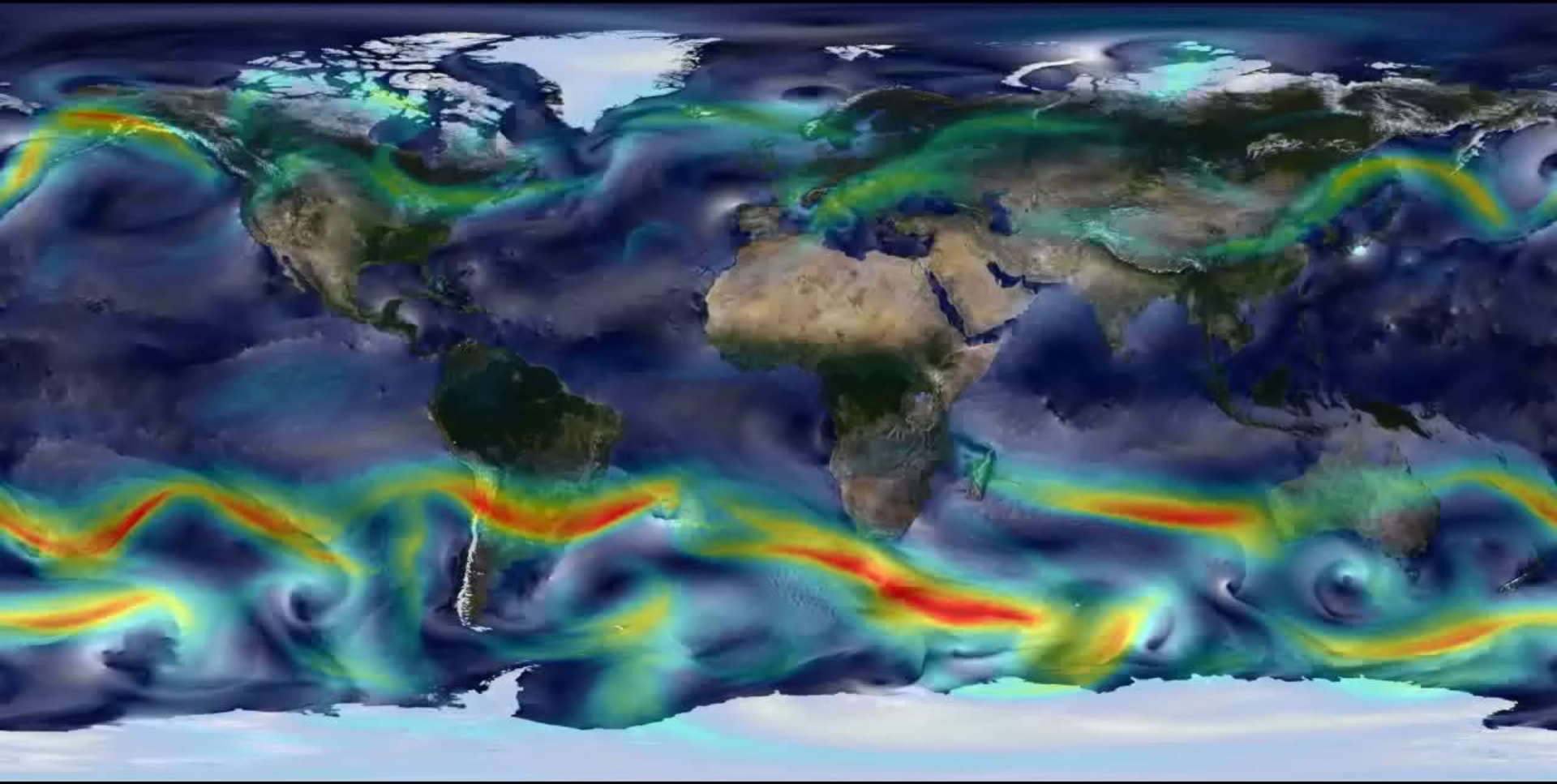


Coriolis effect

- What happens is that **hot air in the Equator rises and moves toward the Poles**, while the cooler air at the Poles sinks and travels toward the Equator, creating a continuing wind system.

- As Earth rotates from west to east and the Coriolis Effect kicks in, the **winds on the Northern Hemisphere curve to the right**, and the **winds on the Southern Hemisphere curve to the left**.



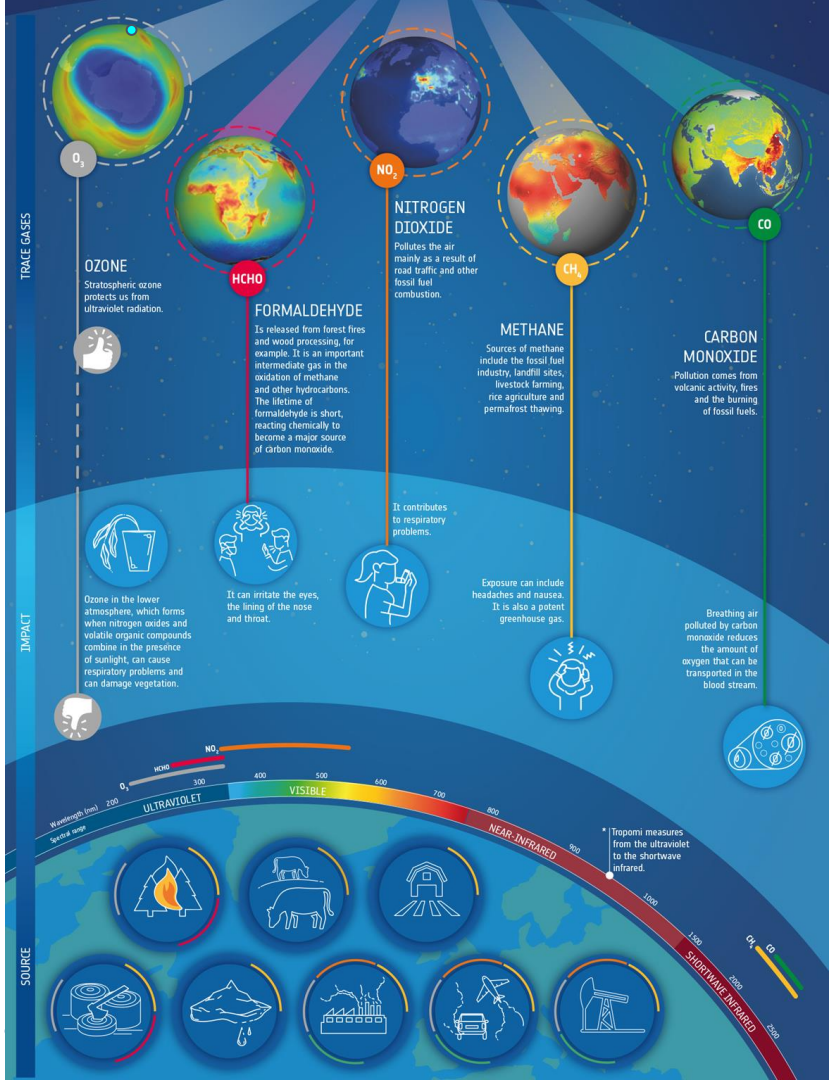


Air pollution:

Air Quality Overview

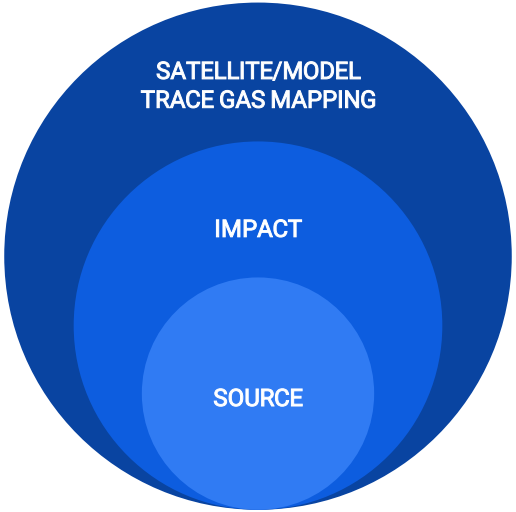
SG Remote Sensing Workshop 2023

Dr. Santo Salina
Centre for Remote Imaging, Sensing and Processing
National University of Singapore



The air we breathe…

- ✓ Satellite data and computer models can show how pollution accumulates and how it is carried in the air.
- ✓ Mapping the global atmosphere every day/hour makes it possible to provide data on trace gases and aerosols that affect air quality and the climate.

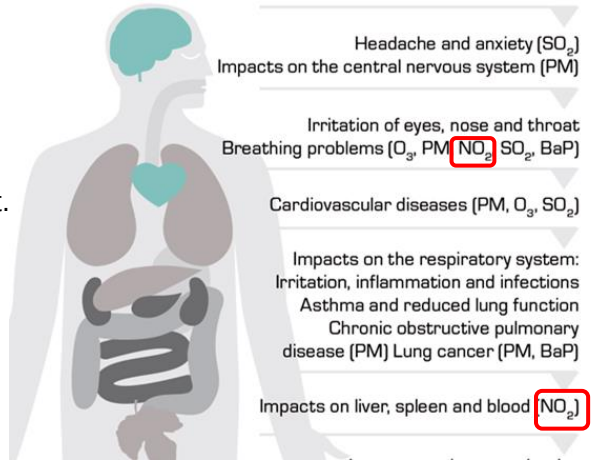


Nitrogen Dioxide

Sources
Combustion (cars, trucks and buses, power plants, and off-road equipment.

Reactions

- NO_2 interact with water, oxygen and other chemicals in the atmosphere **to form acid rain**. Negative impact: lakes and forests.
- The **nitrate particles** that result from NO_x make the air hazy and difficult to see though (affects national parks view)
- contributes to **nutrient pollution in coastal waters** (caused by excess nitrogen and phosphorus).



Songdo International Business District, South Korea

Health effects

- Irritate airways in the human respiratory system (respiratory diseases, particularly asthma
- Leading to respiratory symptoms such as: coughing, wheezing or difficulty breathing → asthma and potentially respiratory infections).

NO2 along with other NOx → **reacts with other chemicals in the air** → **form both (a) particulate matter and (b) ozone**

A toxic brown haze descends on the Capitol viewed from Alexandria, USA.

Volatile Organic Compounds (VOCs)

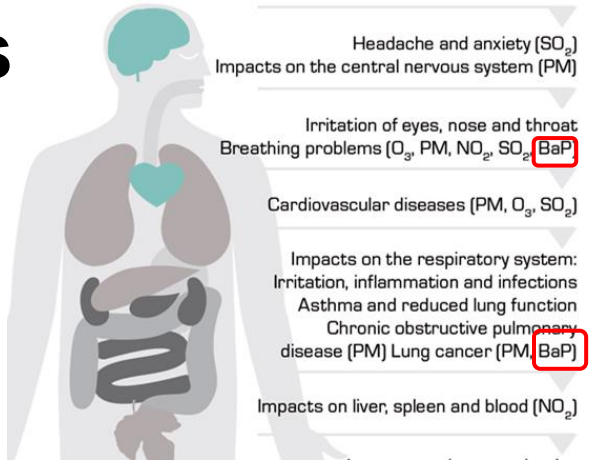
Also called hydrocarbons

Source includes:

- Large quantities occur naturally (CH_4, methane)
- In cities incomplete combustion of gasoline
- Paints, glues and household products.

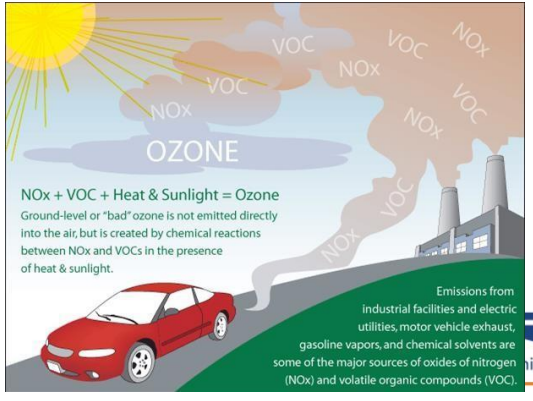
Reactions in the atmosphere

- If they react with other chemicals in the atmosphere they can produce harmful **secondary pollutants**



Reactions:

VOC + NO_2 → (Heat and Sunlight) → **form ozone (O_3)**



Sulfur Dioxide (SO_2)

Man-made Source – Combustion of fossil fuels

Natural source – Volcanoes

SO_2 Sulfur dioxide

Reduce sulfur dioxide pollution by Flue Gas Desulfurisation

Health problem- Breathing Difficulties Lungs inflammation

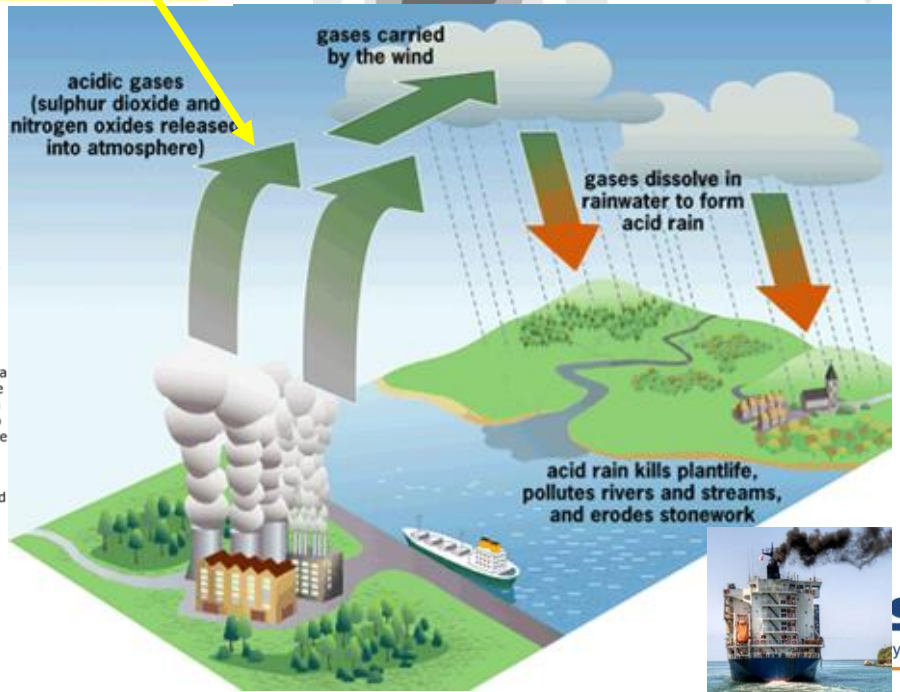
Environmental Problem- Acid Rain

Headache and anxiety (SO_2)
Impacts on the central nervous system (PM)

Irritation of eyes, nose and throat
Breathing problems (O_3, PM, NO_2, SO_2, BaP)

Cardiovascular diseases (PM, O_3, SO_2)

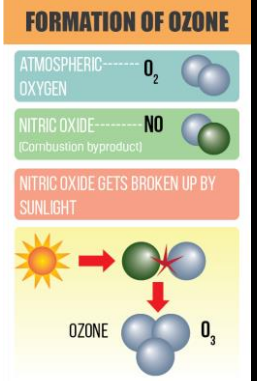
Impacts on the respiratory system:
Irritation, inflammation and infections
Asthma and reduced lung function
Chronic obstructive pulmonary disease (PM) Lung cancer (PM, BaP)

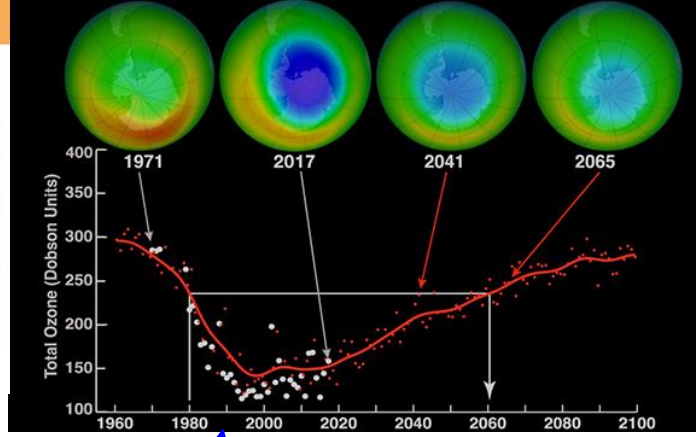


Ozone (O_3)

BAD Ozone

- Found in the troposphere
- Urban air pollution causes ozone formation (photochemical reaction)
- Is an irritant to lungs and is dangerous to those with lung conditions.

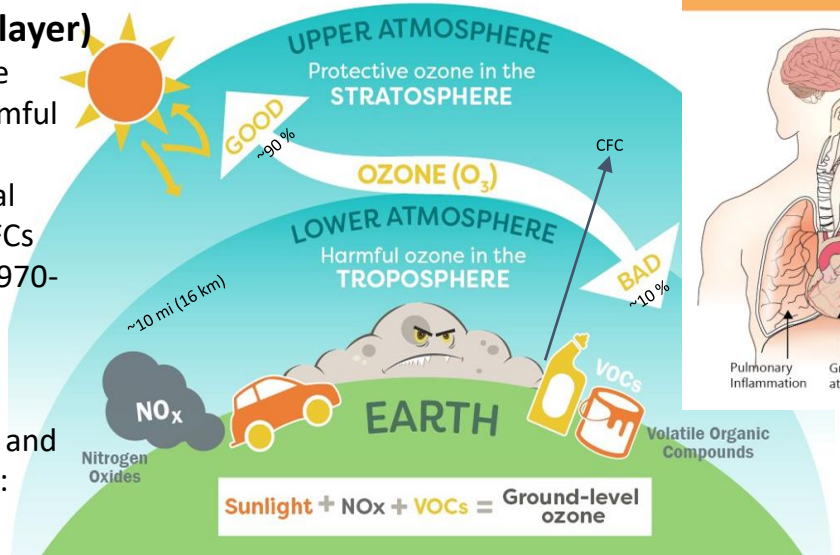


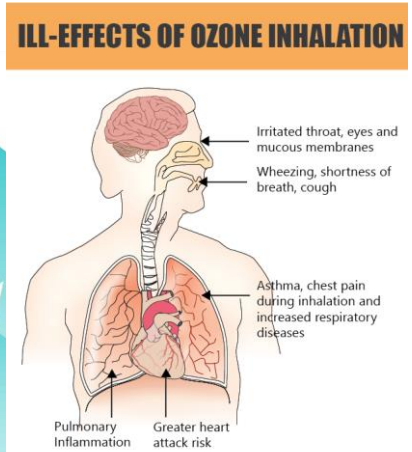


Montreal Protocol

Good Ozone (Ozone layer)

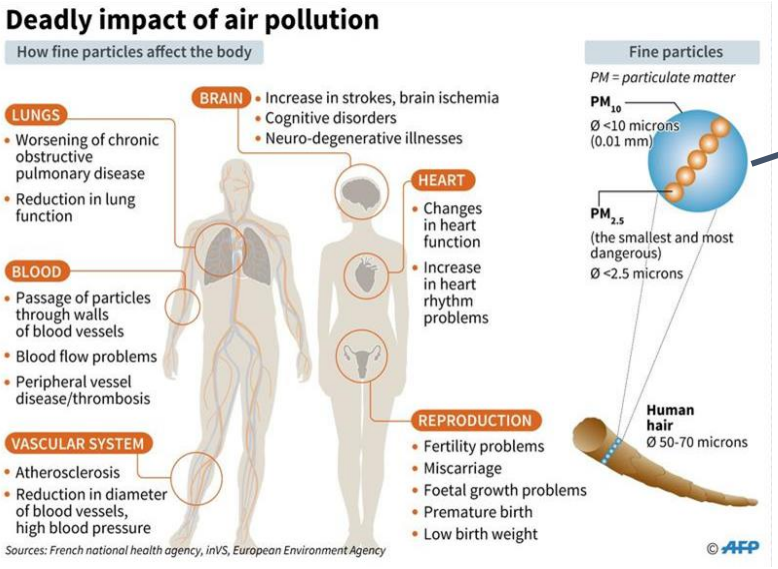
- Found in Stratosphere
- Protects life from harmful UV radiation
- Destroyed by chemical reactions involving CFCs
- Reduced in the mid 1970-1990
- Ozone hole problem remediated by the international political and scientific cooperation: Montreal

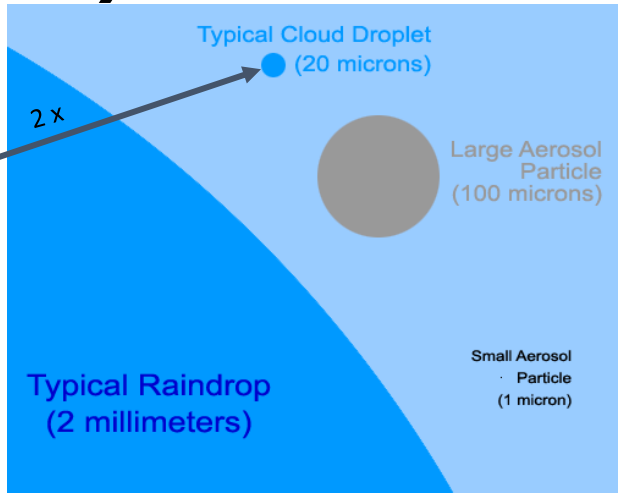


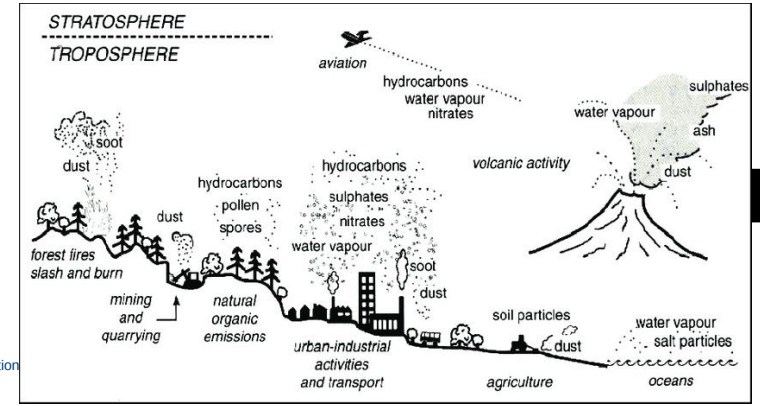


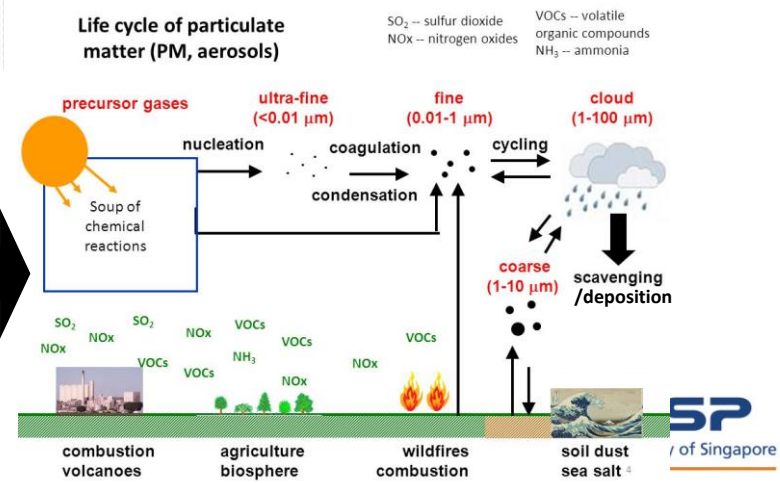
CRISP
National University of Singapore

Particulate Matter (PM) or Aerosols

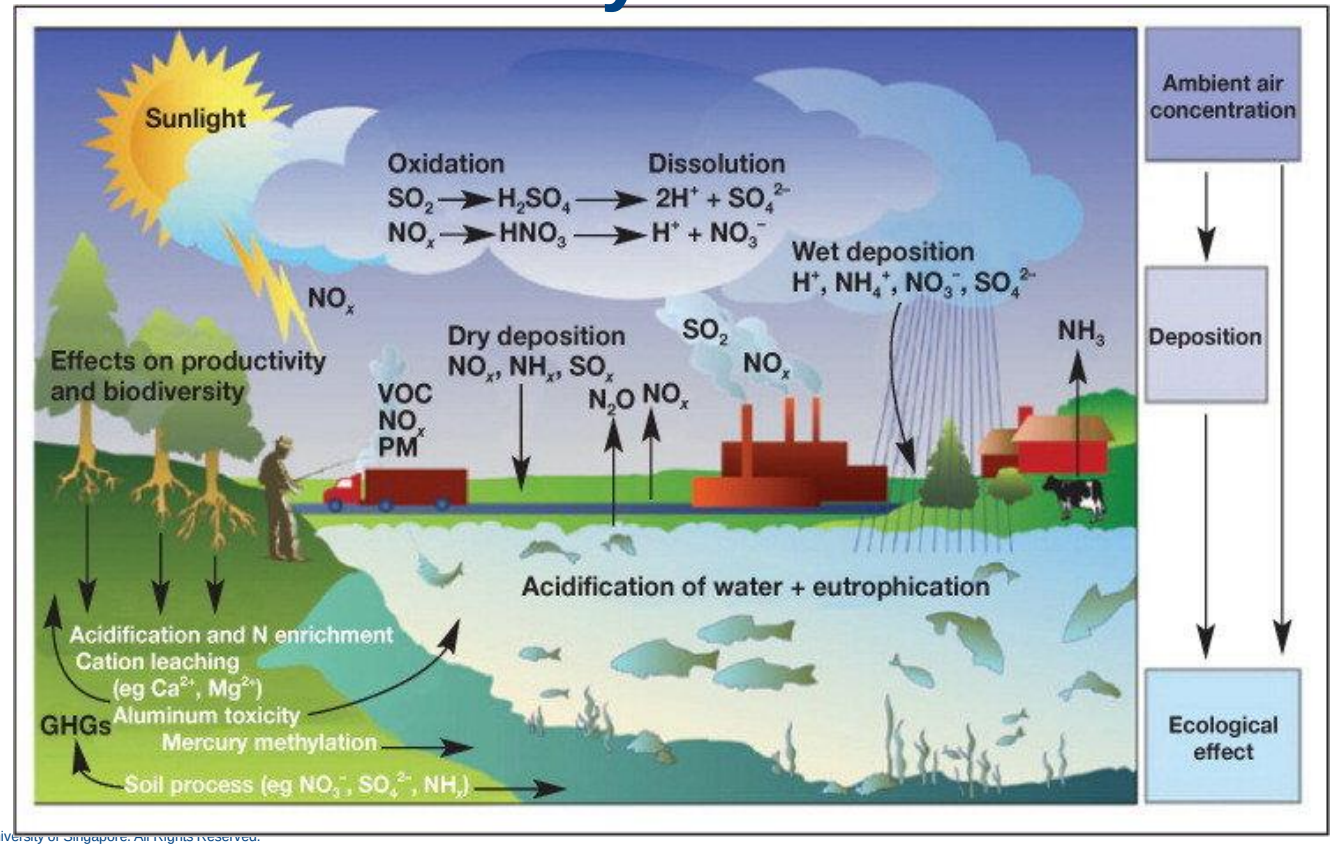








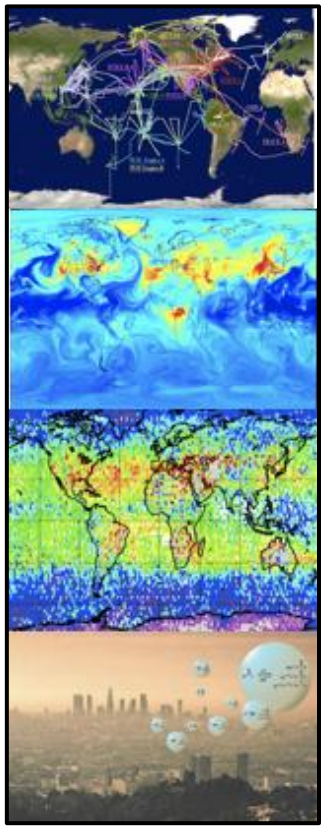
How does air quality affect our ecosystem?



Air Quality Tools

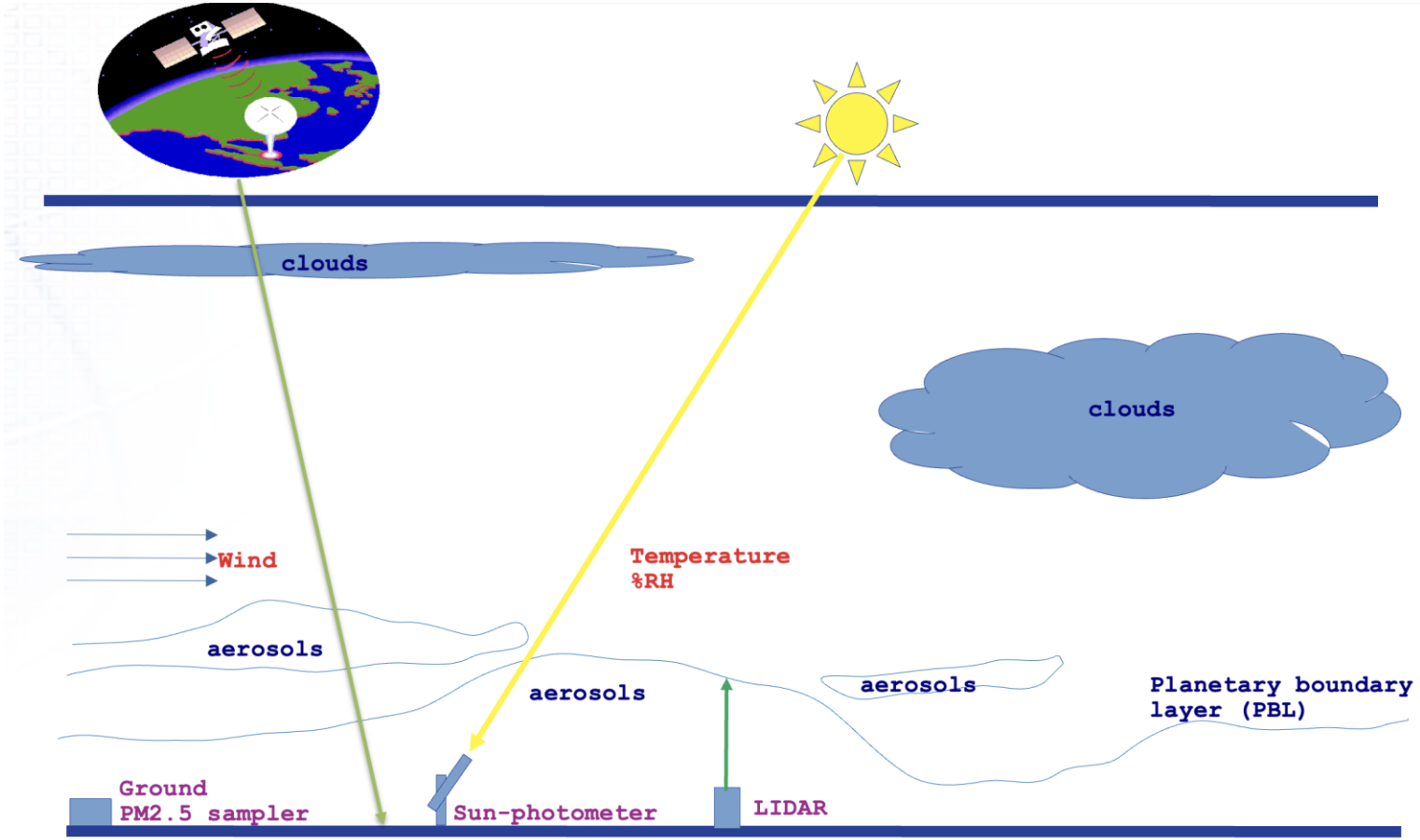
NUS National University of Singapore

Historical perspectives



- **1990’s:** A large number of surface and airborne field campaigns are organized in different regions of the world (e.g., NASA)
- **1990’s:** First global chemical transport models are developed and used to assess the changes in the oxidizing capacity of the atmosphere.
- **1990’s-2000’s** Space observations of chemical compounds (and air pollution in the lower atmosphere).
- **2000’s** The role of aerosols in the climate system is highlighted.
- **2000’s** Emphasis on urban air quality in megacities
- **2000's-2010's** Increasing the complexity of atmospheric models. Computational cost/benefit of chemistry schemes

AQ Observations: Multiplatform Capability



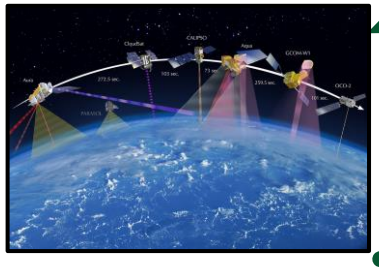
4. MODELING AIR POLLUTION

Mathematical theory to understand, or predict the way pollutants behave in the atmosphere.

1. LABORATORY MEASUREMENTS

Chemical experiments and its dependence on environmental conditions

How do we know/ determine what we know regarding Air Quality?



3. SATELLITE OBSERVATIONS

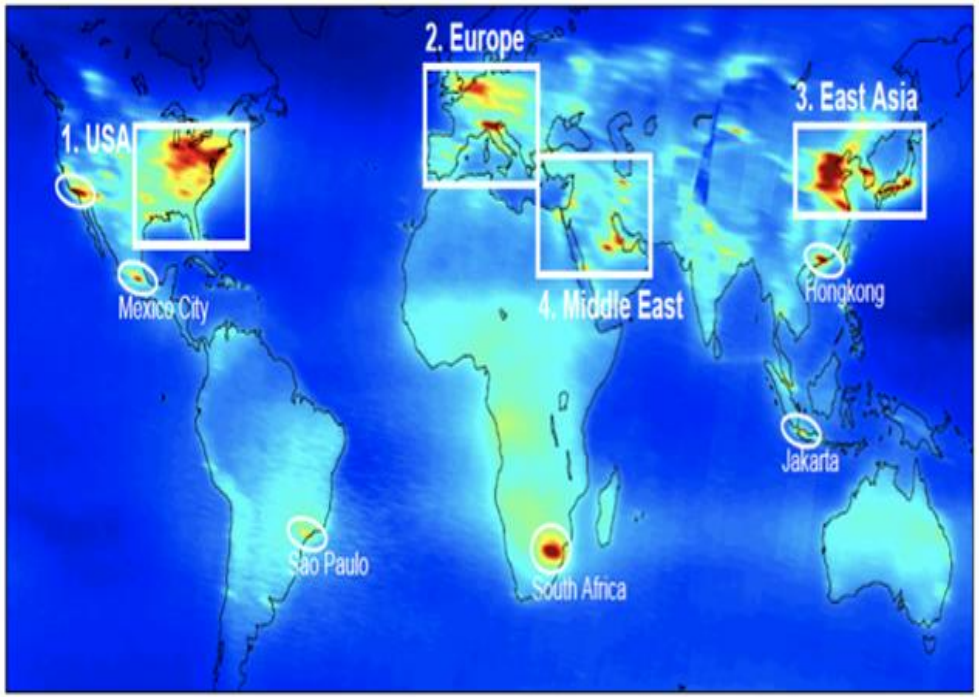
Satellite observations are an important source of information on the Earth and its subsystems (atmosphere, oceans, continental surfaces, cryosphere, and biosphere)

2. IN-SITU MEASUREMENT TECHNIQUES/OBSERVATION

In situ instrumentation often starts off in the lab and is later adapted for field and aircraft use

Two orbits, one Earth

Global Satellite observations

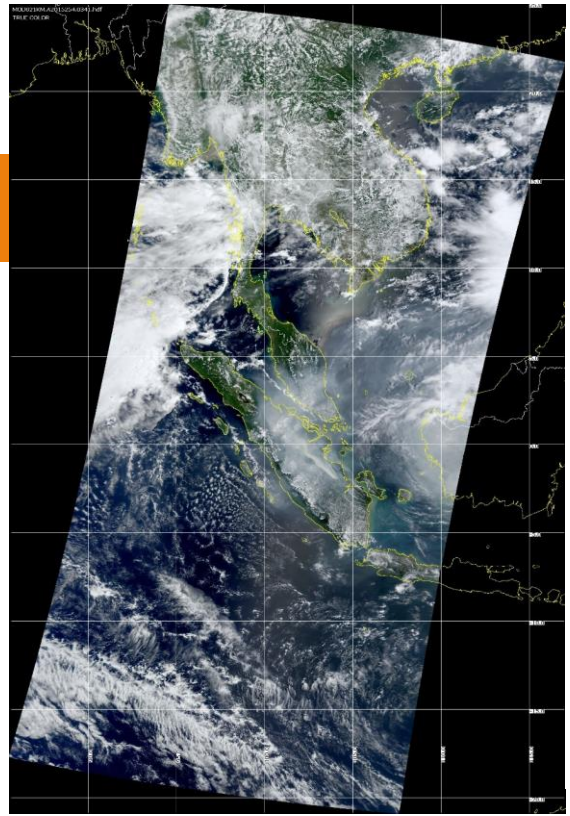


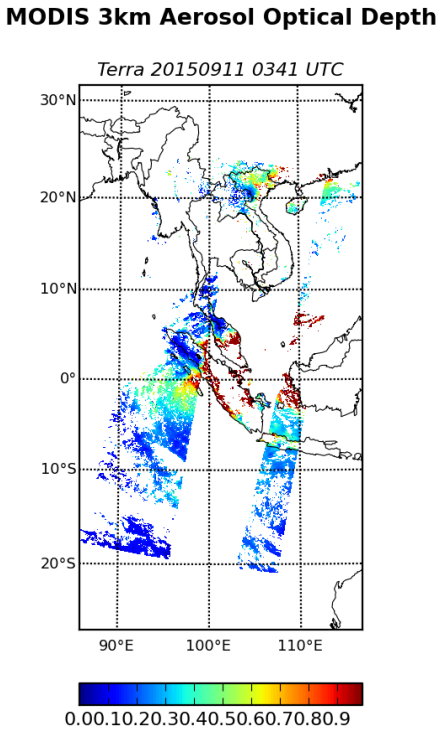
NO2 Vertical Column Density

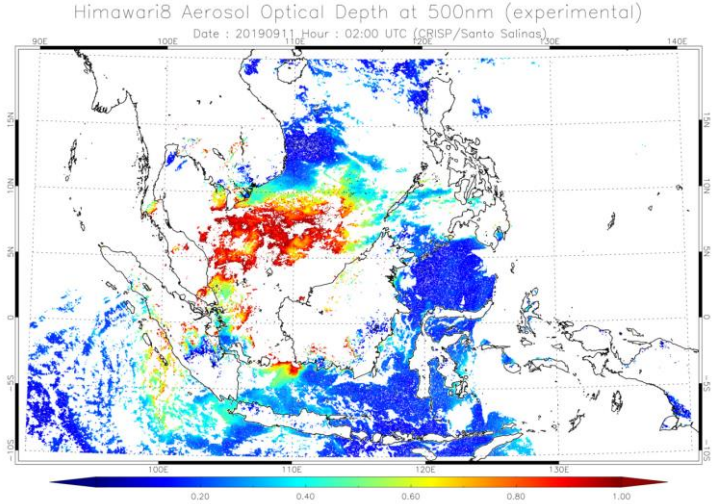
(10^{15} molecules/cm^2)

- 6 years mean (1996-2001)
- Framed and individual metropolitan areas

Regional Satellite observations

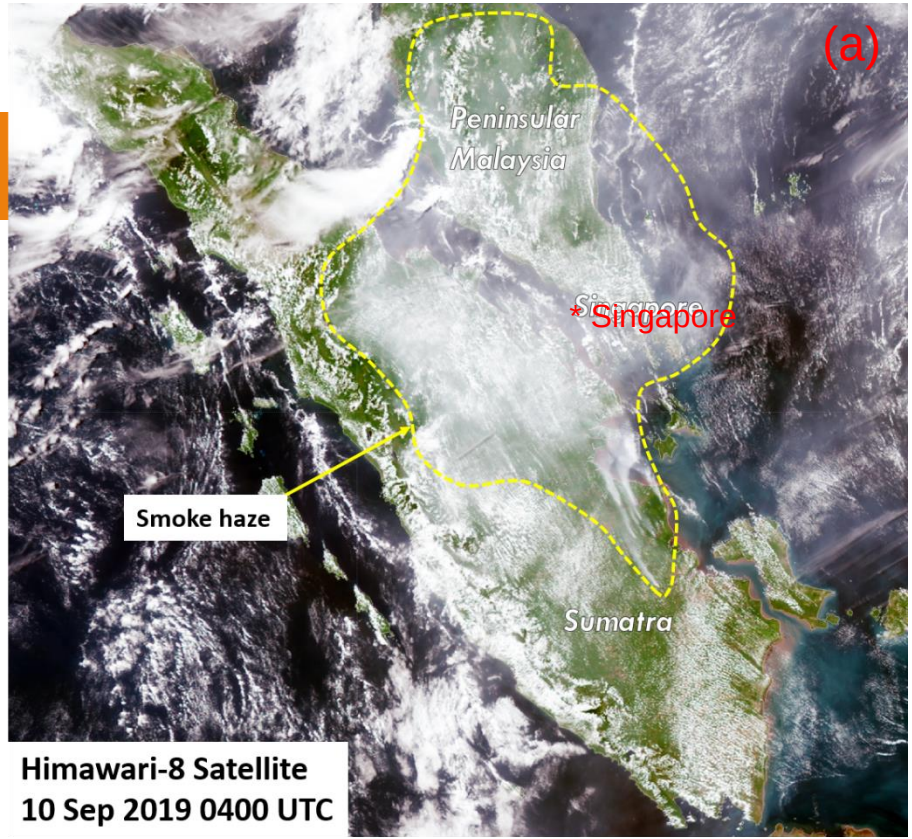




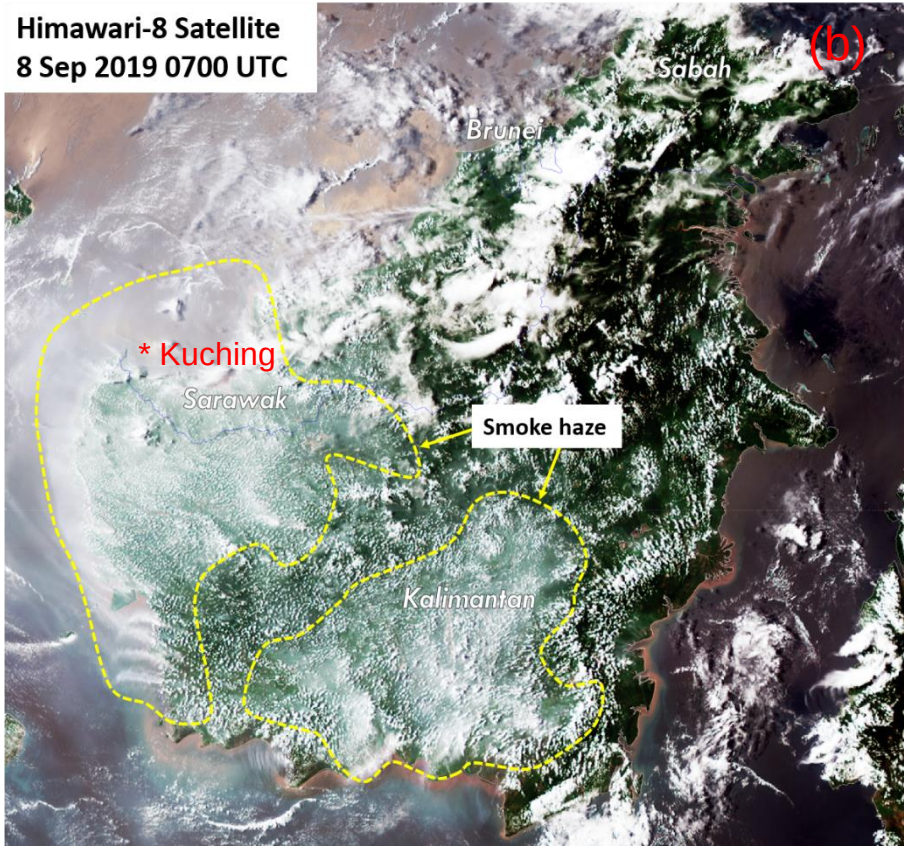


Regional Satellite observations

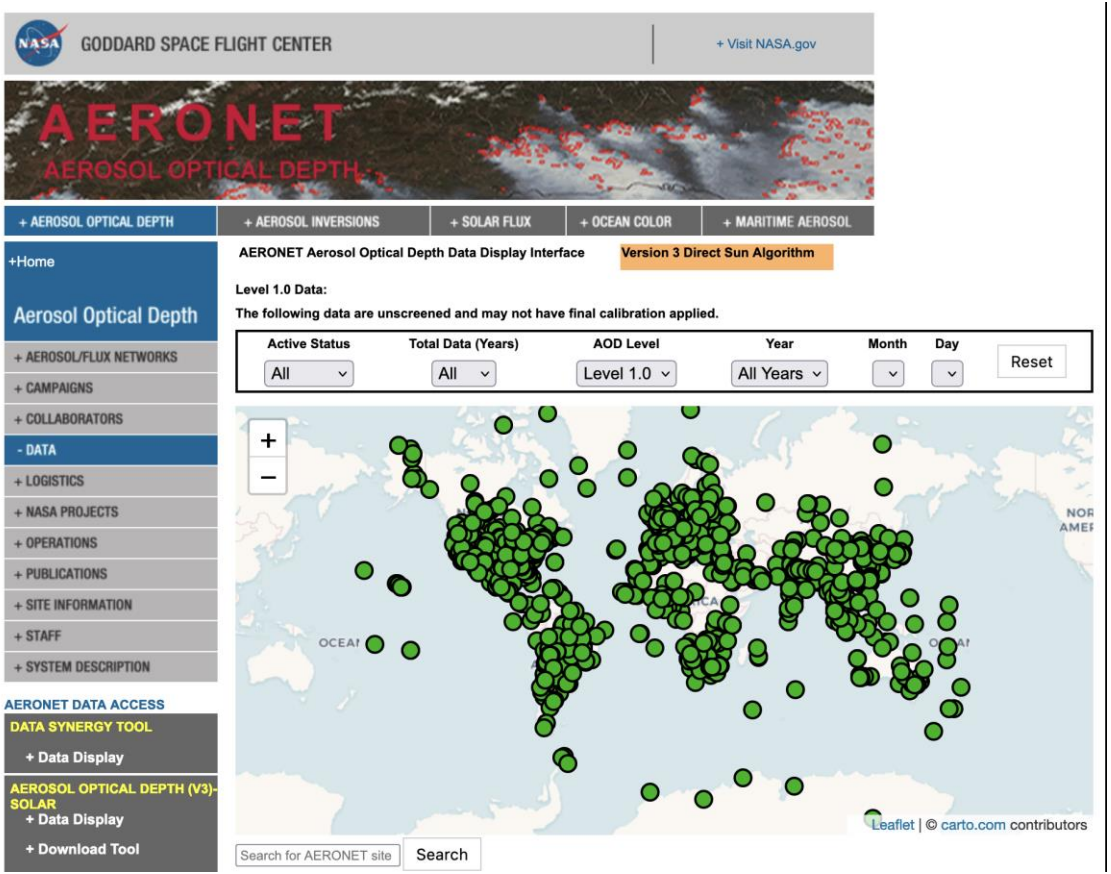
Sumatra



Borneo



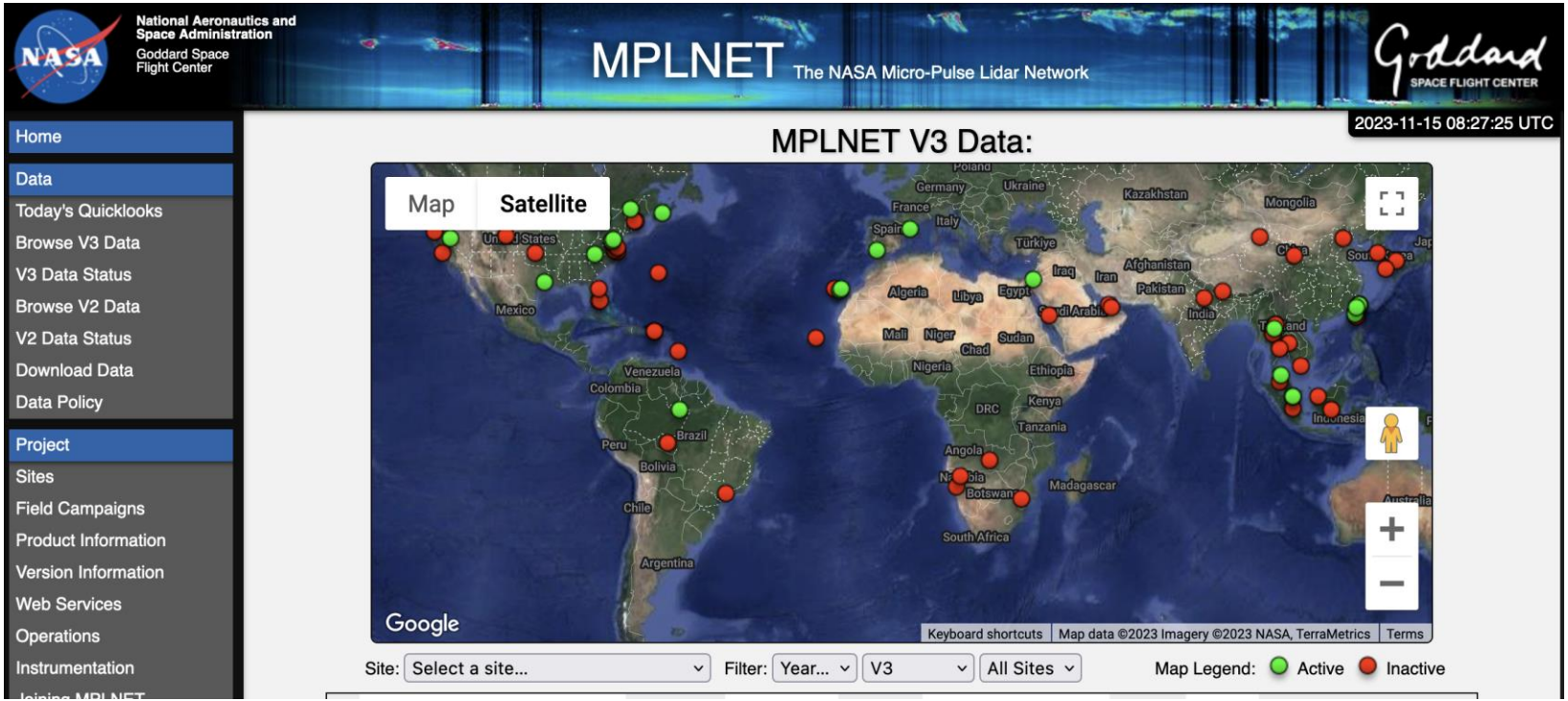
Global Ground observations



NASA AERONET site:

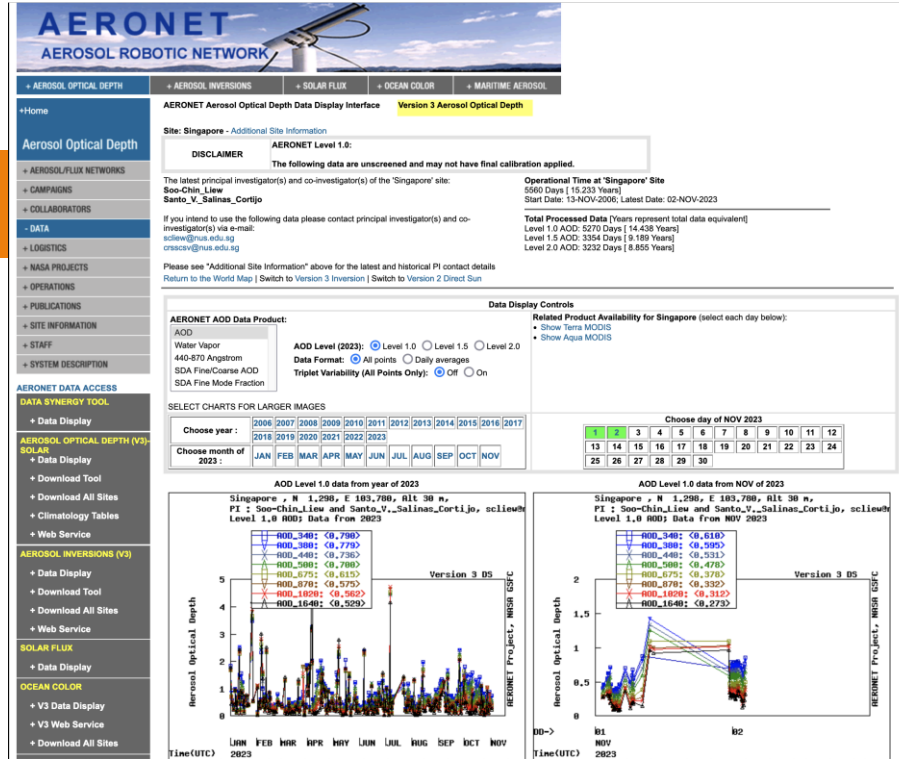
https://aeronet.gfs.nasa.gov

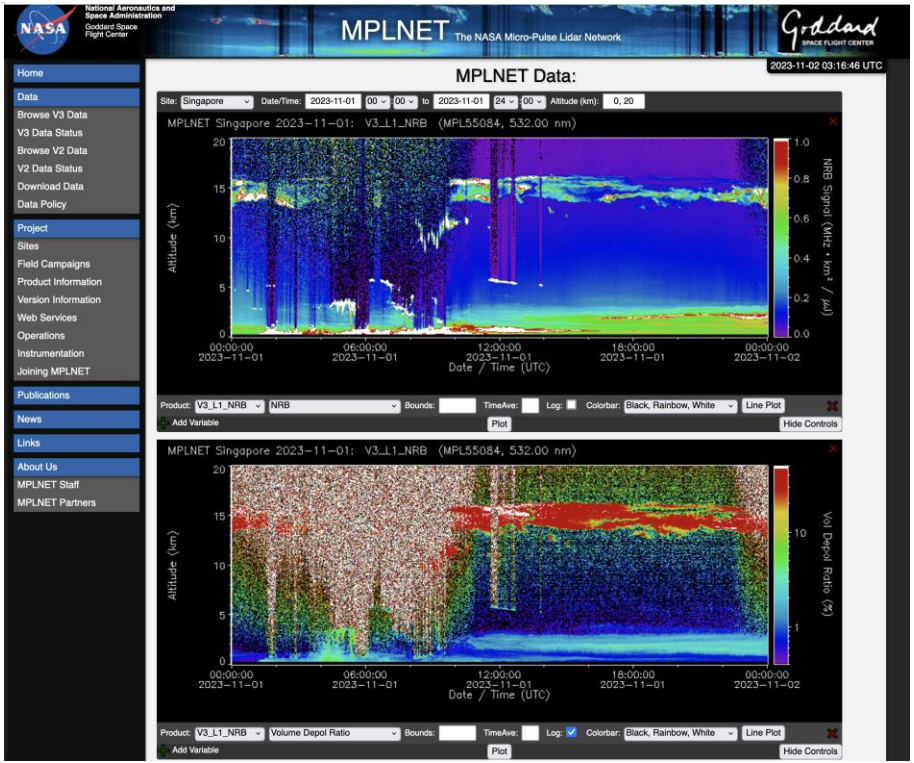
Global Ground observations



NASA MPLNET site: https://mplnet.gfs.nasa.gov

Local Ground observations

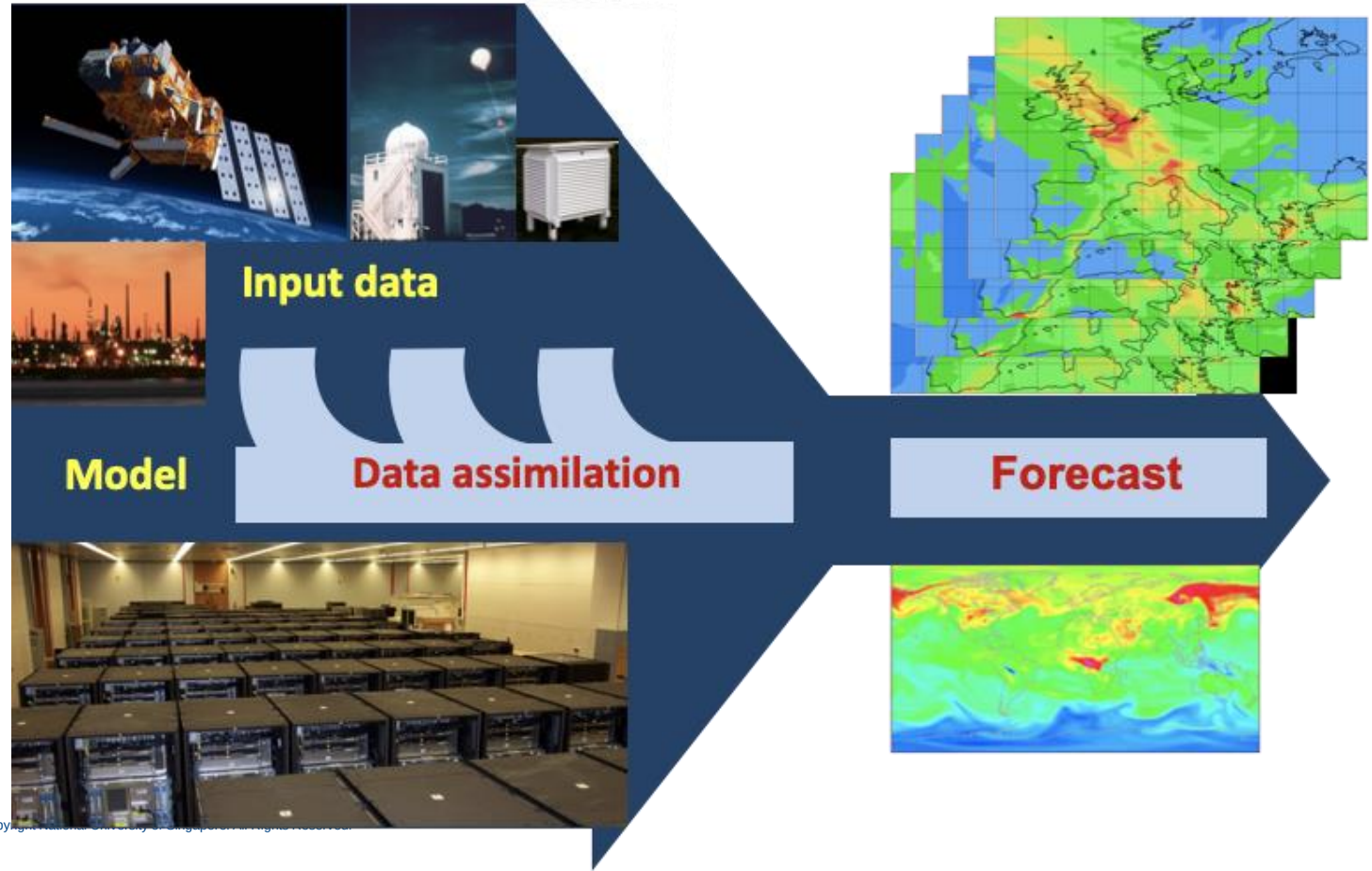




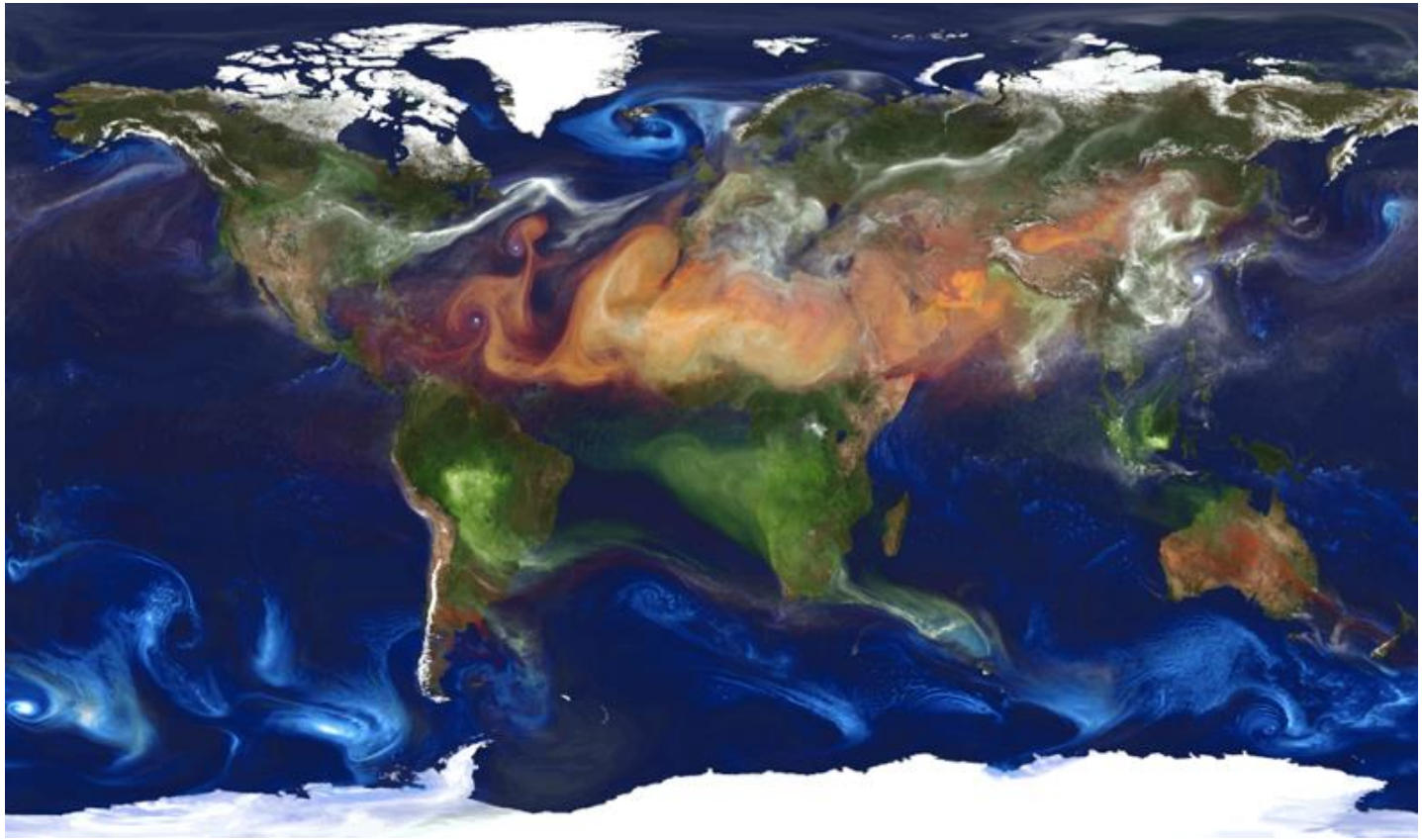
Singapore AERONET site:
https://aeronet.gsfc.nasa.gov

Singapore MPLNET site:
https://mplnet.gfs.nasa.gov

Predictive Models

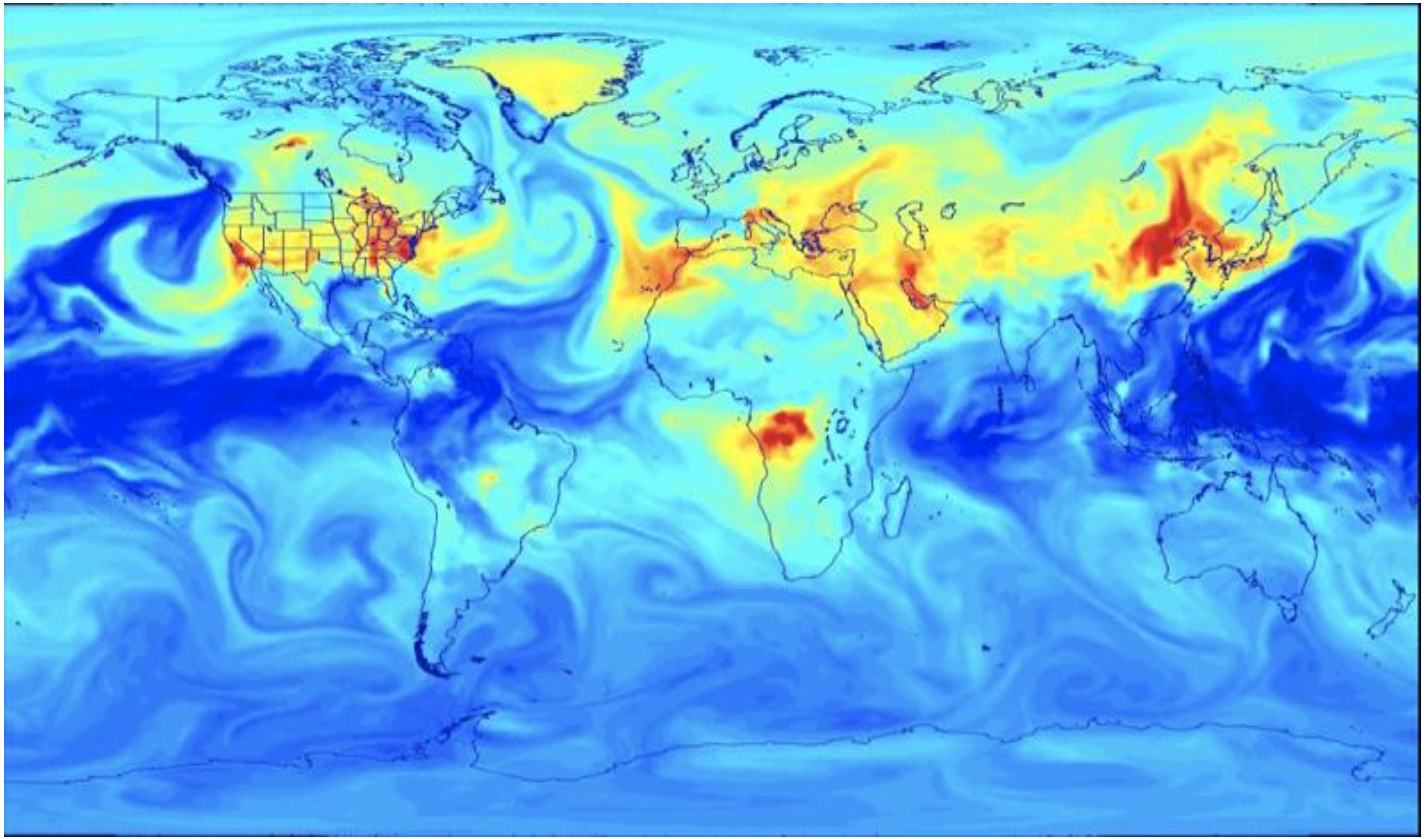


Global Predictive Models



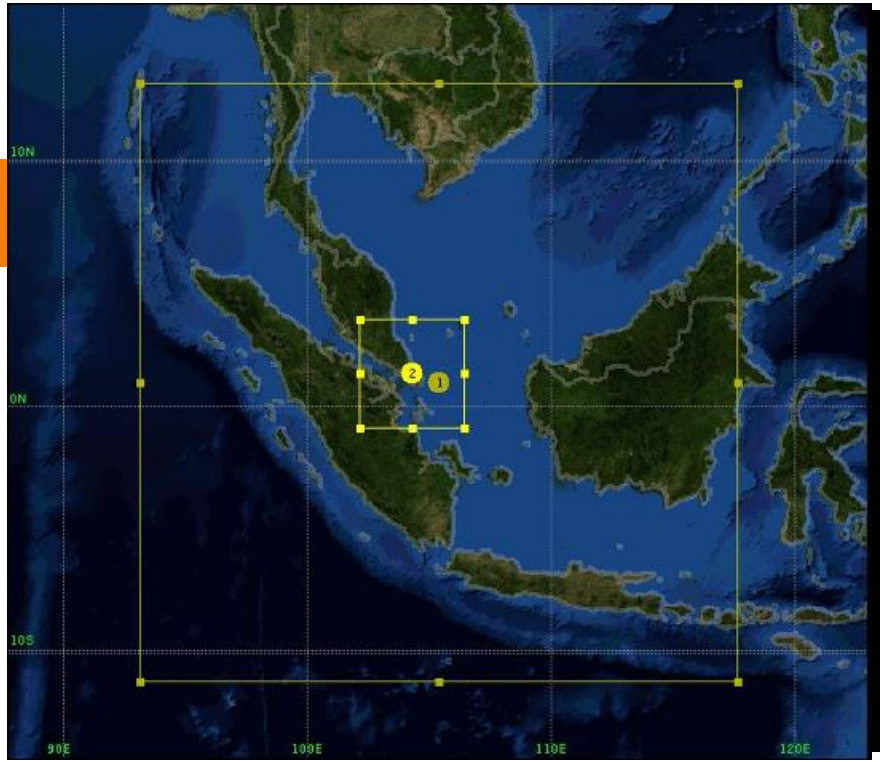
NASA (10 km res.) global distribution of aerosols: dust (red), sulfate (white), smoke from fires (green), sea salt (blue)

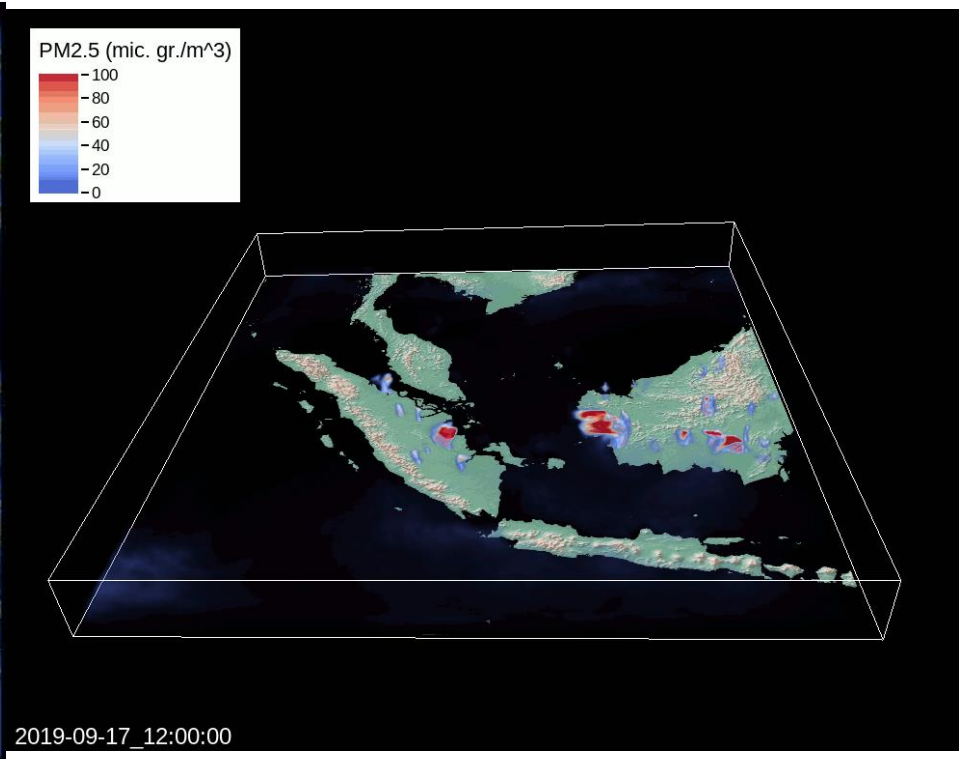
Global Predictive Models



CAM-chem at 0.5° (NCAR) - Surface Ozone: Strong diurnal variation, particularly evident in the Northern Hemisphere

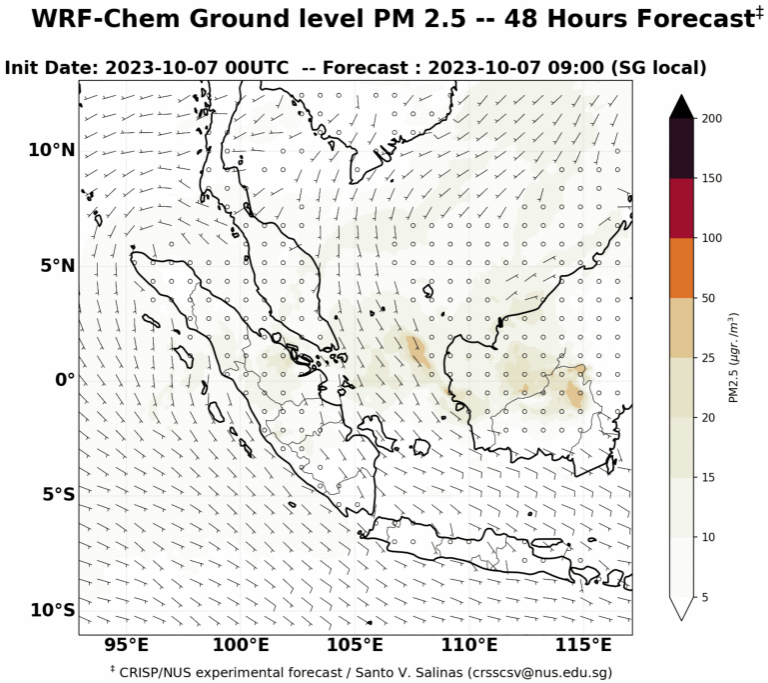
Regional Predictive Models

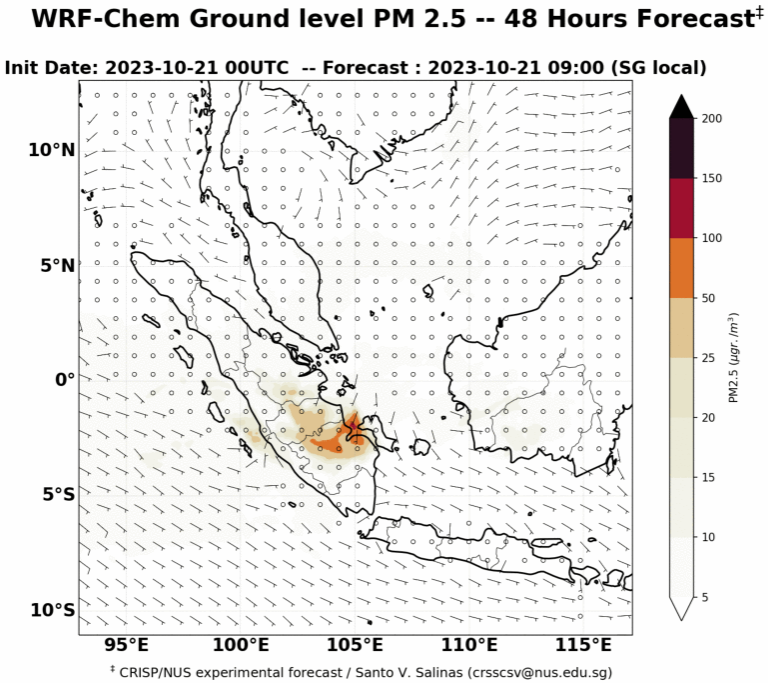




WRF-Chem simulation of regional aerosol dispersion during the 2019 smoke event. Model initialization is on 15 Sep. 2019 00 UTC.

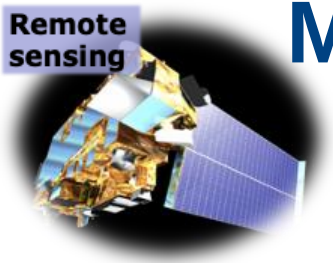
Regional Forecast Models

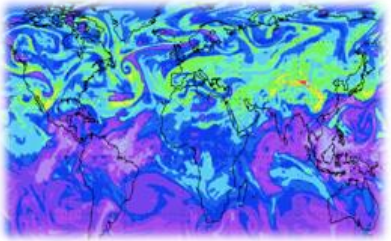




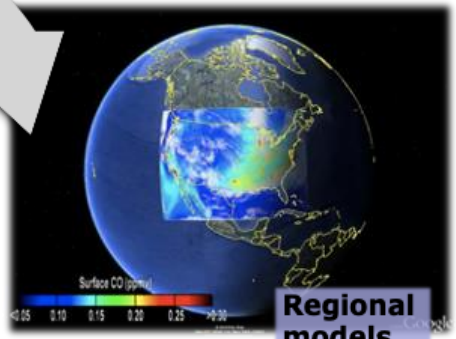
WRF-Chem PM2.5 48 hours forecast dispersion map for October 7th and 21st.

Multidisciplinary science





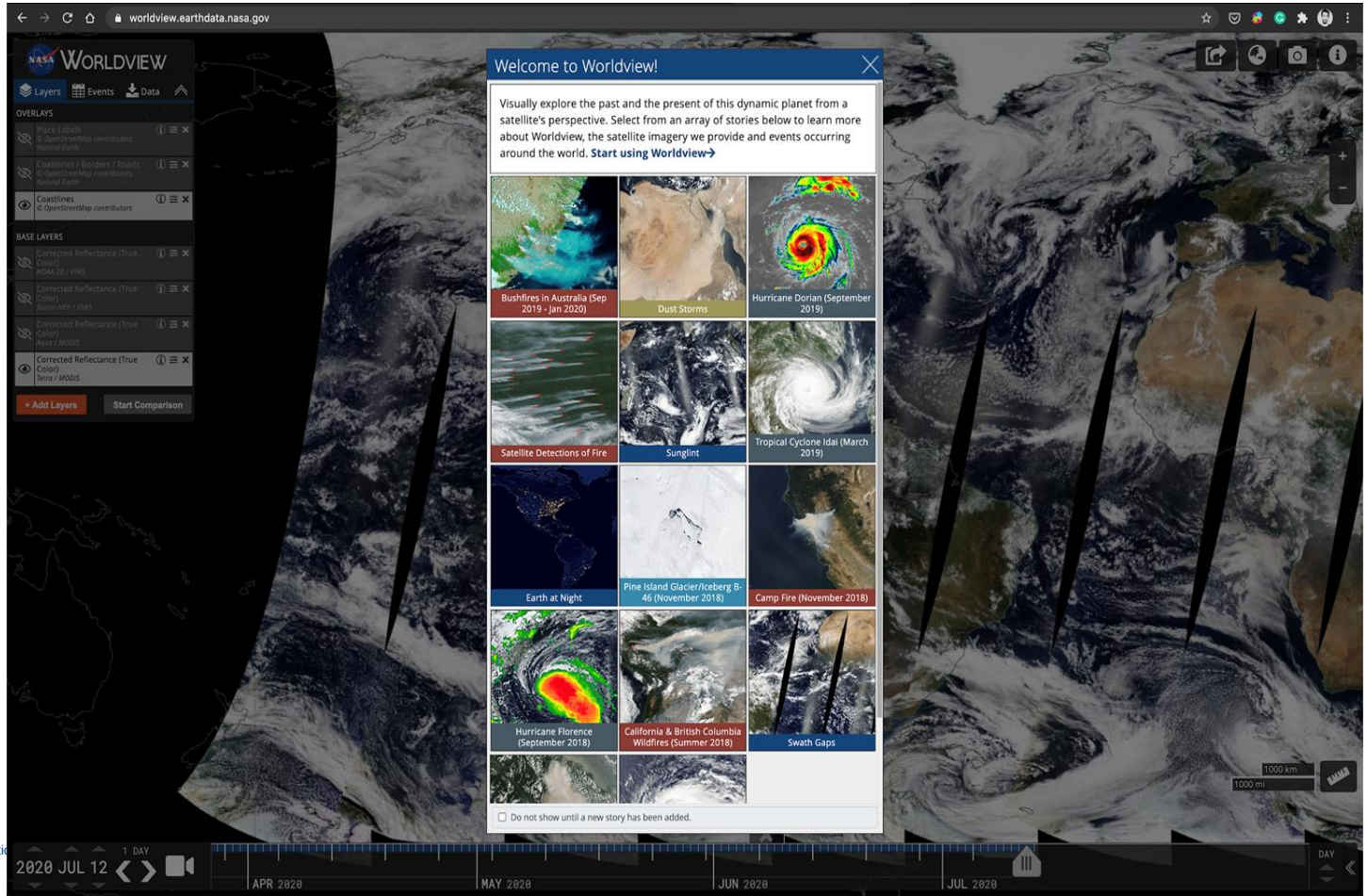
Data assimilation



Data characterization

Where are the Air Quality data and how can we access them?

worldview.earthdata.nasa.gov



THANK YOU