Chapter 1

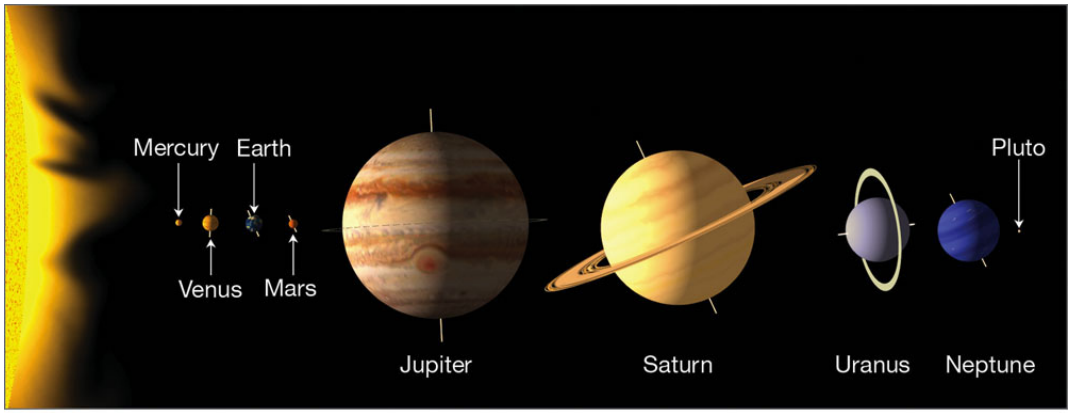
Composition and Structure of the Atmosphere

Overview of the Earth's Atmosphere

- The atmosphere of Earth is a layer of gases surrounding the planet Earth that is retained by Earth's gravity. The atmosphere protects life on Earth by absorbing ultraviolet solar radiation, warming the surface through heat retention (greenhouse effect), and reducing temperature extremes between day and night (the diurnal temperature variation)
  - (*Adopted from wikipedia*)

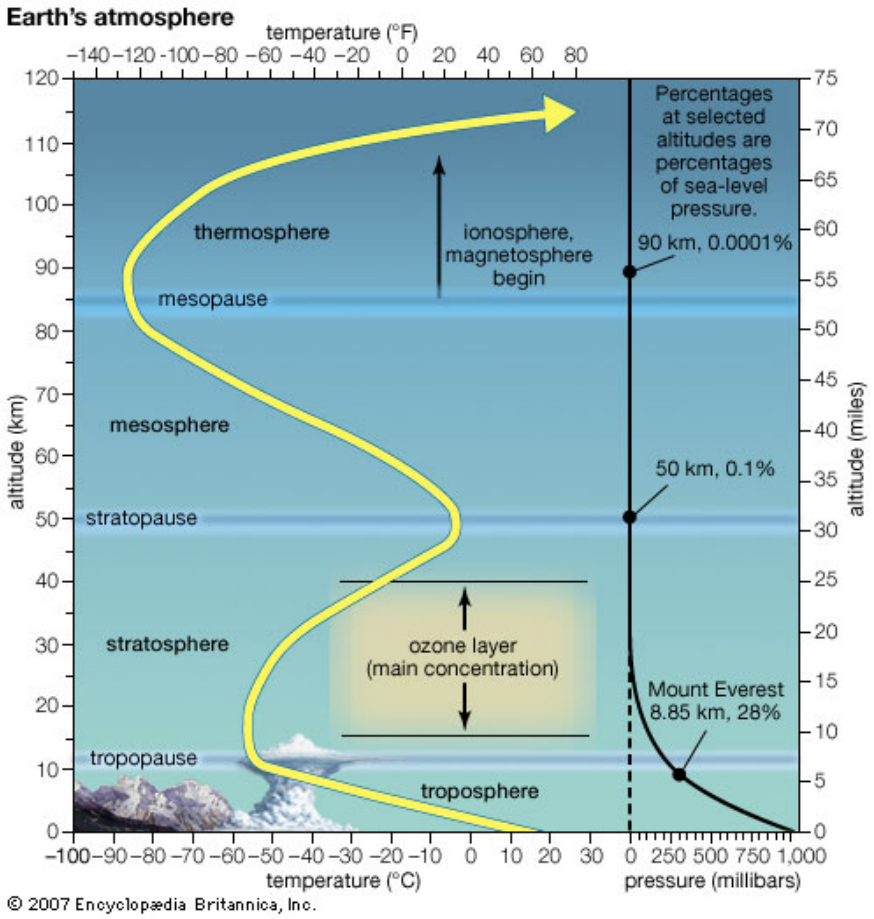
Overview of the Earth's Atmosphere

- A mixture of gas molecules, suspended particles (solid and liquid), and falling precipitation (solid and liquid)
- The atmosphere is a delicate life giving blanket of air surrounding the Earth.
- Without the atmosphere the Earth would not have lakes or oceans.
- Radiant energy from the sun energizes the atmosphere driving day to day weather.



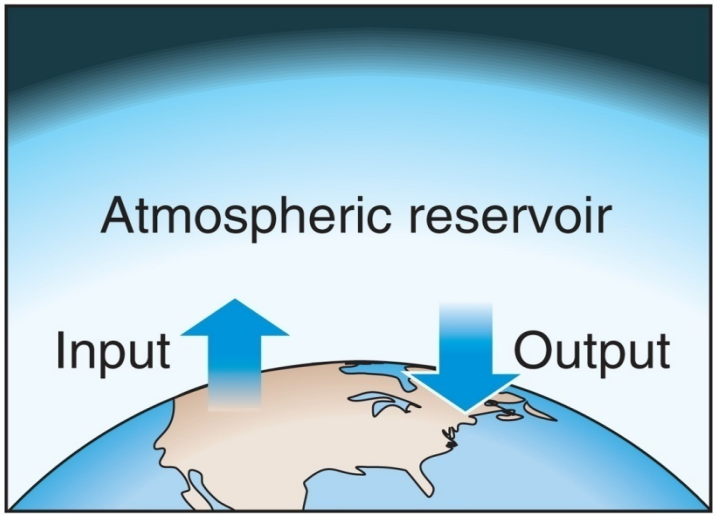
The Thickness of the Atmosphere

- Density decreases rapidly with height
  - Sea level (100%), 16 km (10%), 50 km (1 %)
  - The top of the atmosphere is undefined
  - Majority of mass is compressed near the surface
  - 99.99997% of atmosphere is below 100 km, and 99% of the atmosphere is within 30km of the Earth's surface
  - Total air mass ~ 5.14 x 10^{15} kg

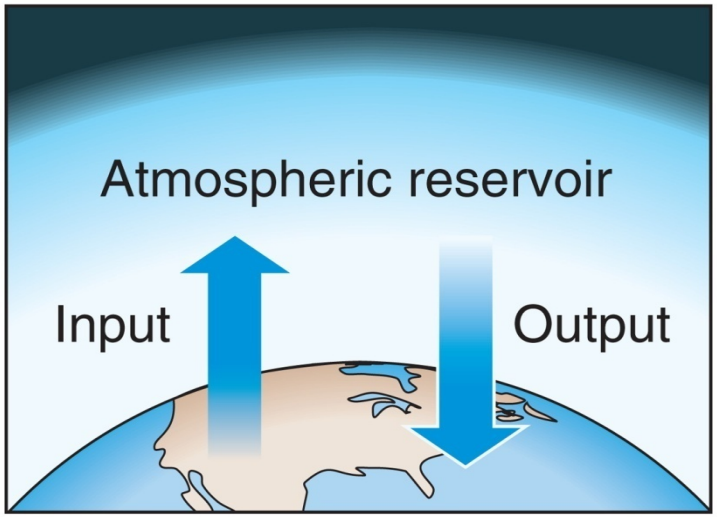


Composition of the Atmosphere

- Reservoir (Storage)
  - Atmosphere, hydrosphere, lithosphere, biosphere…
- Residence time
- Storage vs. flux
- Gases and particles are exchanged between the surface and atmosphere



(a) Longer residence time



(b) Shorter residence time

Composition of the Atmosphere

- Permanent Gases
  - 99% of the atmosphere is within 30km of the Earth's surface
  - N_2 78.08% and O_2 20.95% (total: 99.03 %)
  - The residence time of oxygen in the atmosphere is ~5000 years
  - The percentages represent a constant amount of gas but cycles of destruction and production are constantly maintaining this amount.

TABLE 1–2 Permanent Gases of the Atmosphere

Constituent	Formula	Percent by Volume	Molecular Weight
Nitrogen	N_2	78.08	28.01
Oxygen	O_2	20.95	32.00
Argon	Ar	0.93	39.95
Neon	Ne	0.002	20.18
Helium	He	0.0005	4.00
Krypton	Kr	0.0001	83.8
Xenon	Xe	0.00009	131.3
Hydrogen	H_2	0.00005	2.02

Molecular weight of air, $M_a = (78\% \cdot 28 + 21\% \cdot 32 + 1\% \cdot 40) = 28.96$ g mole^{-1}

Composition of the Atmosphere

- Variable gases

Table 1.1 Composition of the Atmosphere near the Earth's Surface

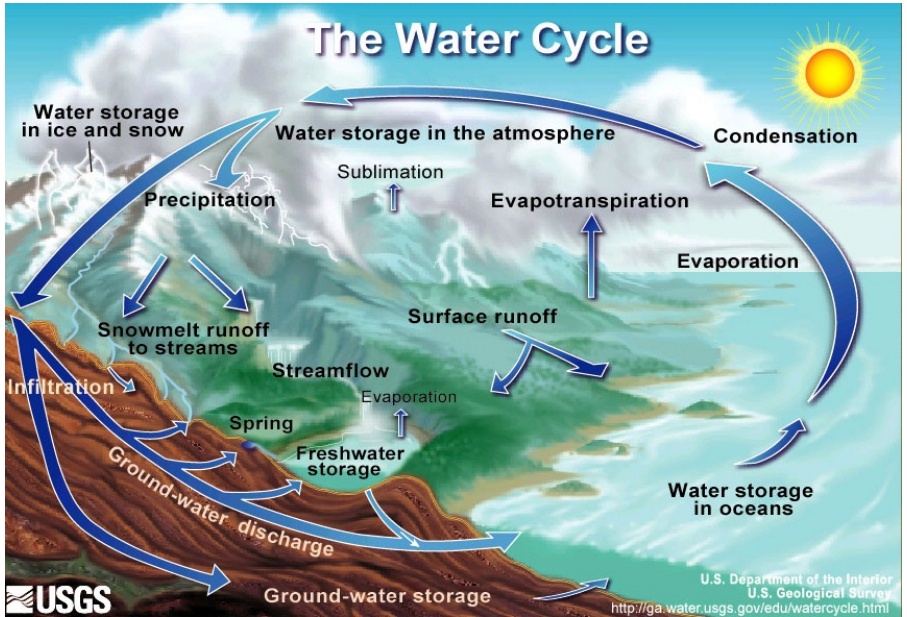
PERMANENT GASES			VARIABLE GASES			
Gas	Symbol	Percent (by Volume) Dry Air	Gas (and Particles)	Symbol	Percent (by Volume)	Parts per Million (ppm)*
Nitrogen	N_2	78.08	Water vapor	H_2O	0 to 4	
Oxygen	O_2	20.95	Carbon dioxide	CO_2	0.040	400*
Argon	Ar	0.93	Methane	CH_4	0.00018	1.8
Neon	Ne	0.0018	Nitrous oxide	N_2O	0.00003	0.3
Helium	He	0.0005	Ozone	O_3	0.000004	0.04†
Hydrogen	H_2	0.00006	Particles (dust, soot, etc.)		0.000001	0.01–0.15
Xenon	Xe	0.000009	Chlorofluorocarbons (CFCs) and hydrofluorocarbons (HFCs)		0.00000001	0.0001

*For CO_2, 400 parts per million means that out of every million air molecules, 400 are CO_2 molecules.
†Stratospheric values at altitudes between 11 km and 50 km are about 5 to 12 ppm.

Variable Gases: water vapor

- Water Vapor
  - Most abundant variable gas
  - Added/ removed to air through the hydrologic cycle
  - Concentrations = nearly 0% to nearly 4%
  - Most atmospheric vapor is found in the lowest 5km of the atmosphere
  - Important to energy balance and many atmospheric processes
  - **Key element to impact the meteorological phenomena**

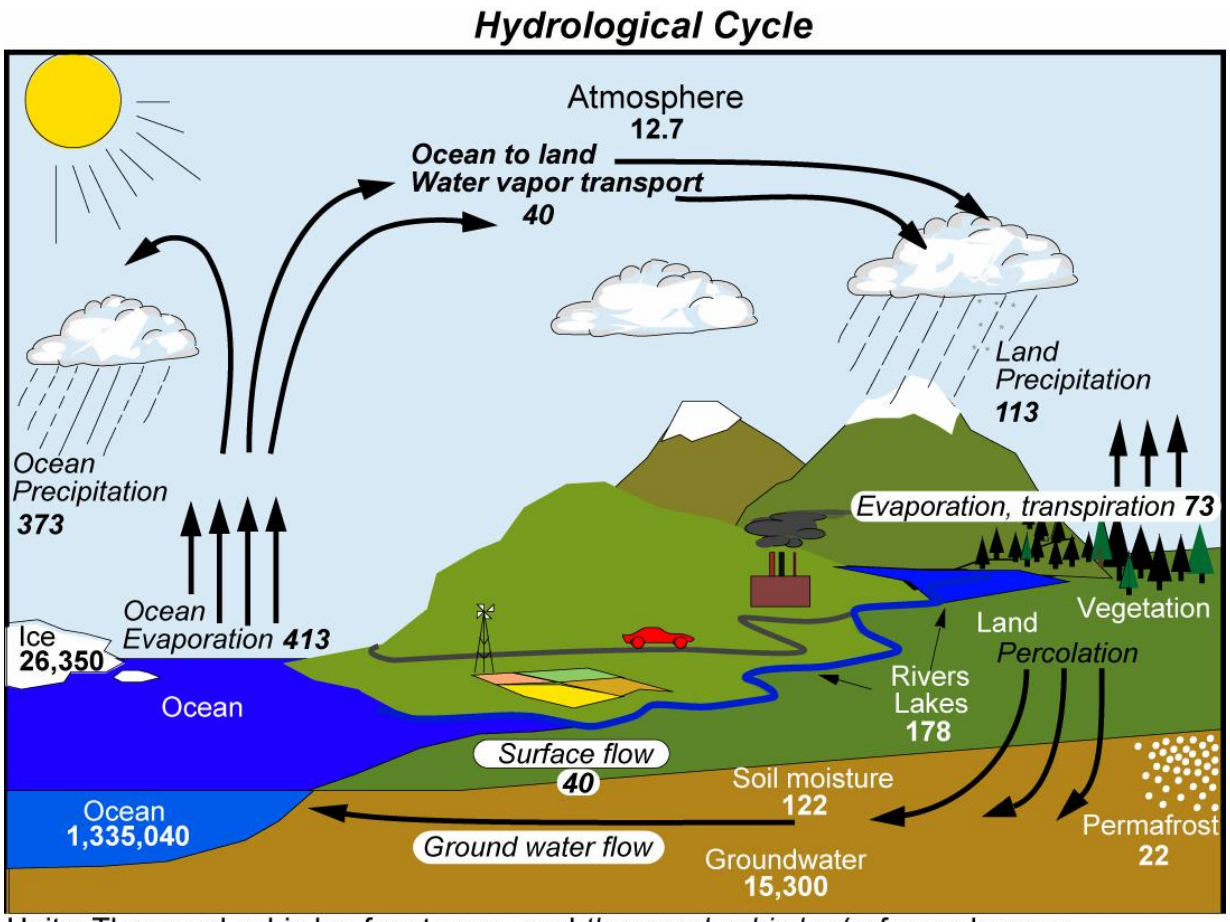
Water cycle
(Hydrological cycle)



Variable Gases: water vapor

- Global hydrological Storage and pathways

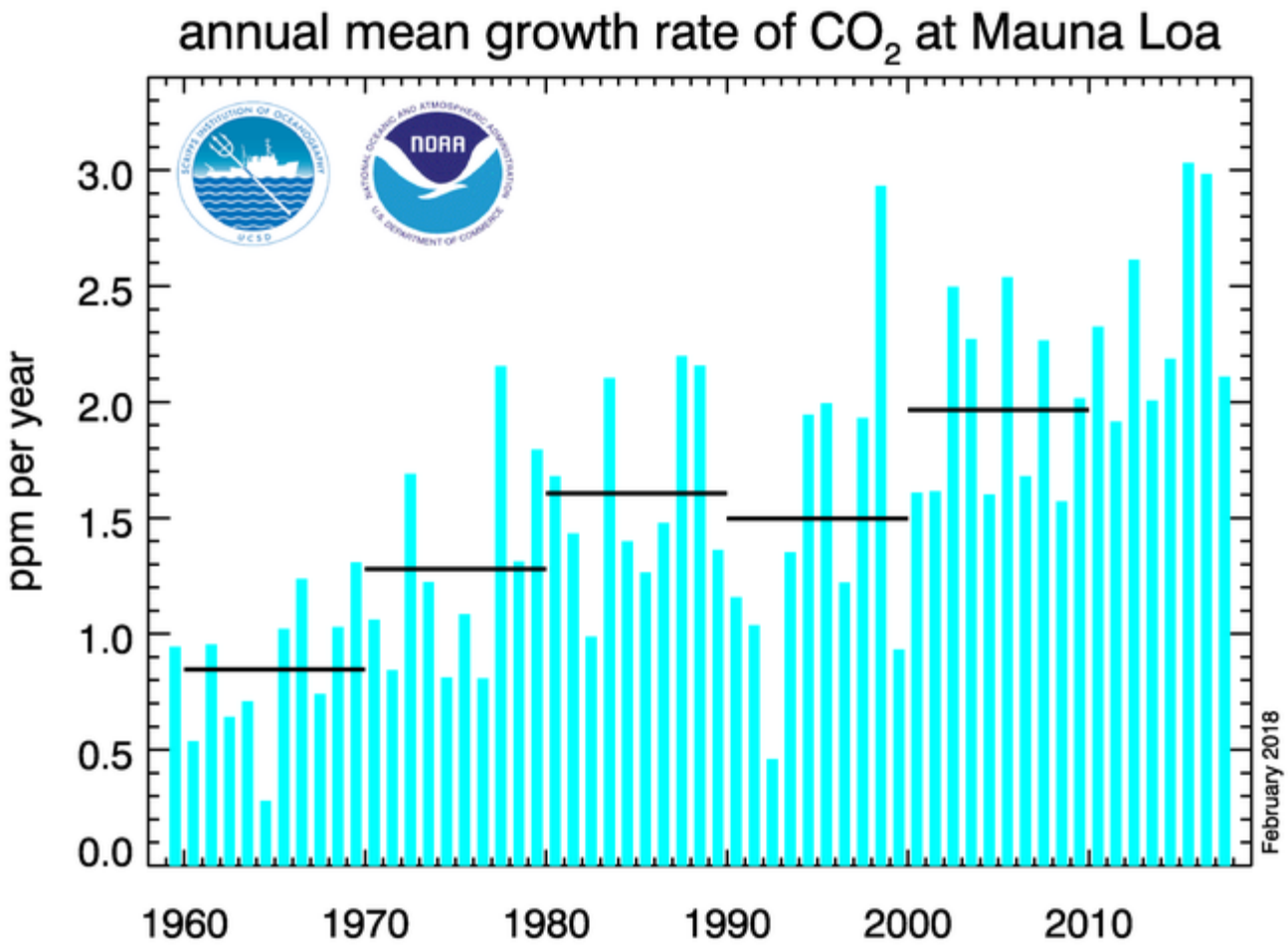
Estimates of the current global water budget and its annual flow using observations from 2002-2008 (1000 km3 for storage and 1000 $km^3\ yr^{-1}$ for exchanges). Based on K.E. Trenberth, J. Fasullo, and J Mackaro, 2011: Atmospheric Moisture Transports from Ocean to Land and Global Energy Flows in Reanalyses. J. Climate, 24, 4907–4924. doi: http://dx.doi.org/10.1175/2011JCLI4171.1

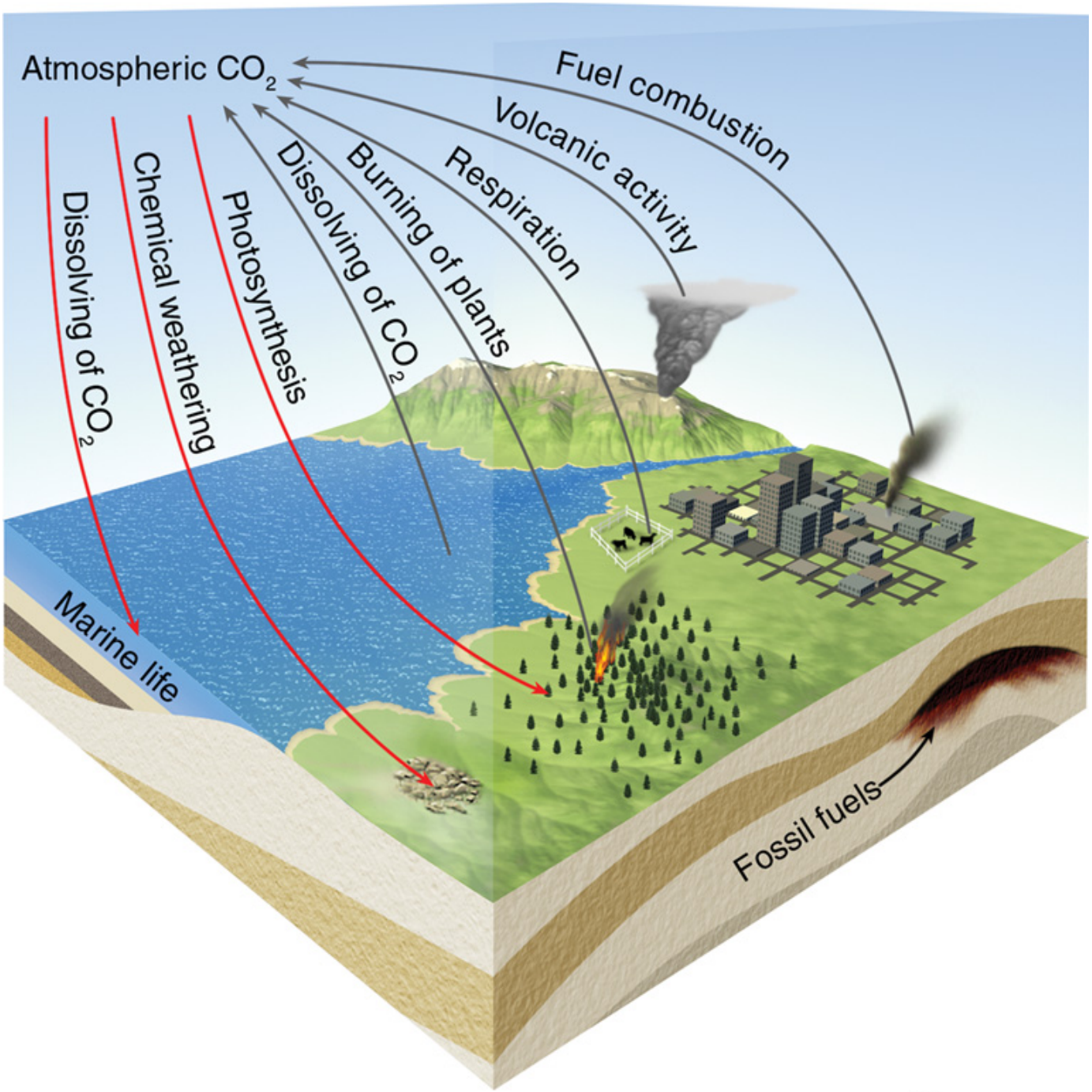


Variable gases: carbon dioxide

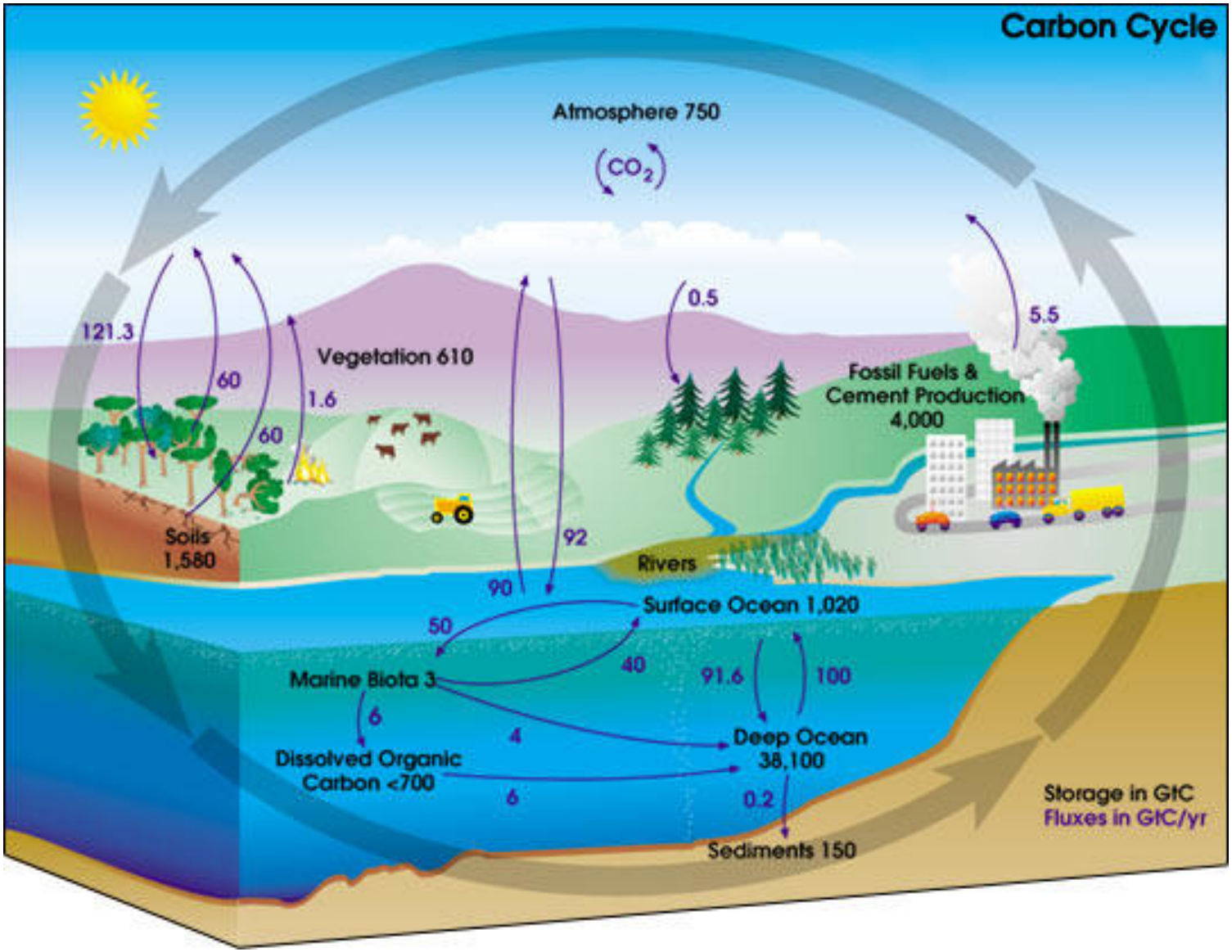
- Carbon Dioxide
  - A trace gas
    - More than **0.04%** of atmosphere's mass
  - Important to Earth's energy balance
  - Added through biologic respiration, volcanic activity, decay, and natural and human-related combustion
  - Removed through photosynthesis, or dissolved in the water body
  - Since the 1950s, the concentration of atmospheric carbon dioxide has increased at a rate of about 2.15 ppm/year

Carbon Dioxide

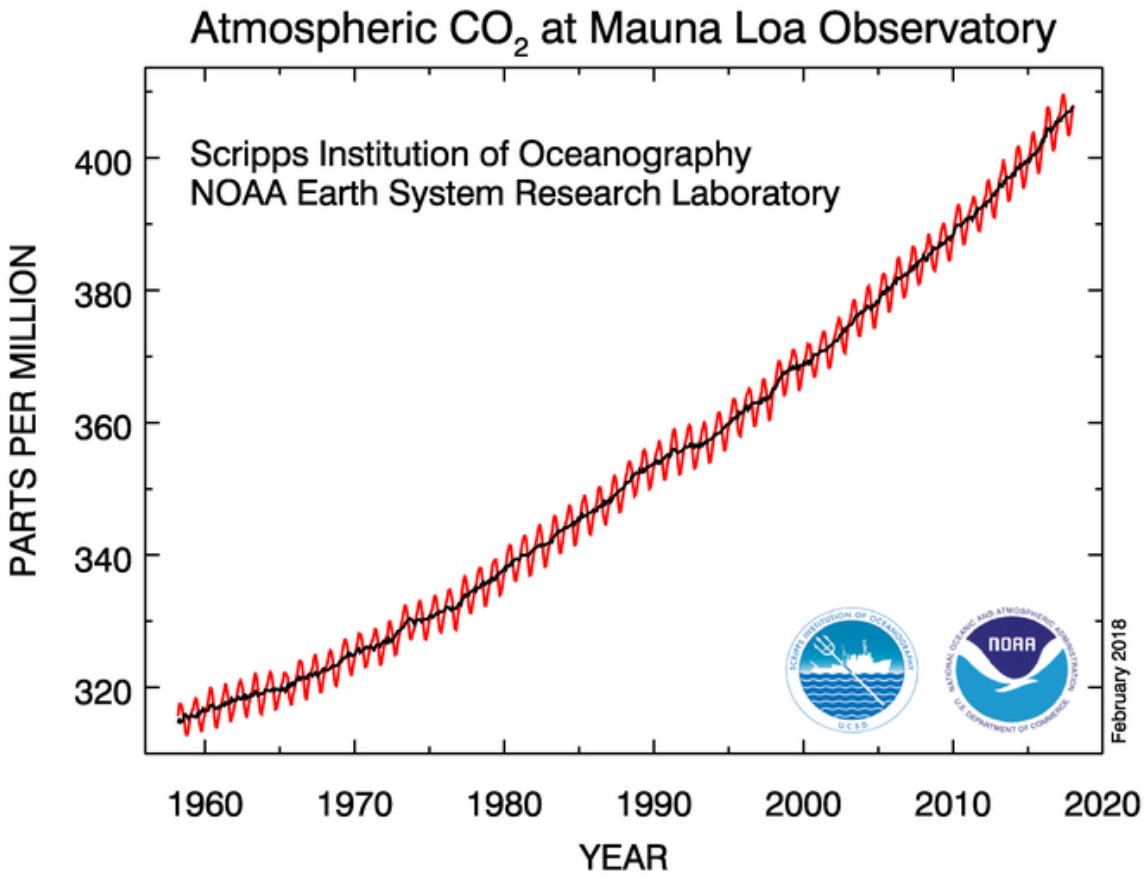




Variable gases: carbon dioxide

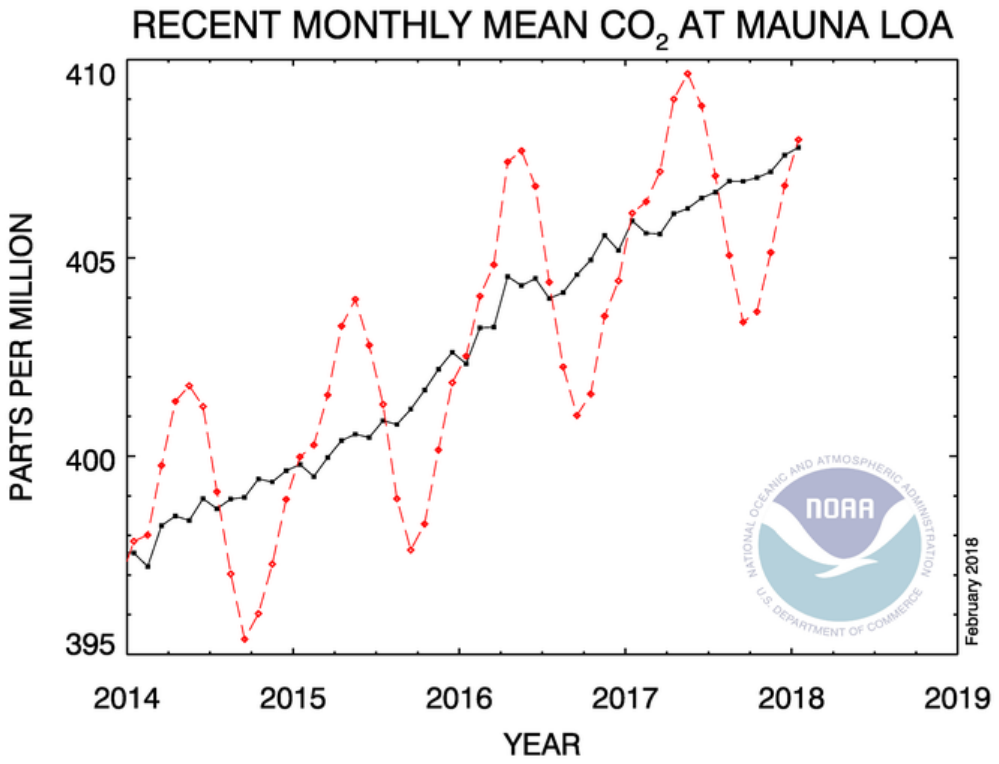


Variable gases: carbon dioxide



http://www.esrl.noaa.gov/gmd/webdata/ccgg/trends/co2_data_mlo.png

Variable gases: carbon dioxide



January 2019: 410.83 ppm
January 2018: 407.98 ppm
January 2017: 406.13 ppm
January 2016: 402.52 ppm
January 2015: 399.96 ppm
January 2014: 397.80 ppm

January 1998: 365.26 ppm

March 1958: 315.71 ppm

1000-1750 : ~280 ppm
(Ice Core)

http://www.esrl.noaa.gov/gmd/webdata/ccgg/trends/co2_trend_mlo.png

Atmospheric CO2 Hits 400 Parts Per Million Mark

http://goo.gl/F00Ej

MAUNA LOA OBSERVATORY, Hawaii, May 11, 2013 (ENS) – For the first time in human history, concentrations of the greenhouse gas carbon dioxide, CO2, have risen above 400 parts per million, ppm. Many climate scientists warn that 350 ppm is the safe upper limit for CO2 in the atmosphere.

On May 9, the daily mean concentration of carbon dioxide in the atmosphere of Mauna Loa, one of the volcanoes on the Big Island of Hawaii, surpassed 400 parts per million for the first time since measurements began in 1958, when CO2 concentrations averaged 318 ppm.

Independent measurements made by both the National Oceanic and Atmospheric Administration, NOAA, and the Scripps Institution of Oceanography have been approaching this level during the past week. Having two programs independently measure the greenhouse gas provides confidence that the measurements are correct.

NOAA's Mauna Loa Observatory on the Big Island of Hawaii (Photo courtesy NOAA)

It marks an important milestone because Mauna Loa, as the oldest continuous carbon dioxide, CO2, measurement station in the world, is the primary global benchmark site for monitoring the increase of this heat-trapping gas.

"Carbon dioxide pumped into the atmosphere by fossil fuel burning and other human activities is the most significant greenhouse gas contributing to climate change," said NOAA, announcing the 400 ppm concentration level.

CO_2 Concentration Exceed 400mm

9 NOVEMBER 2015

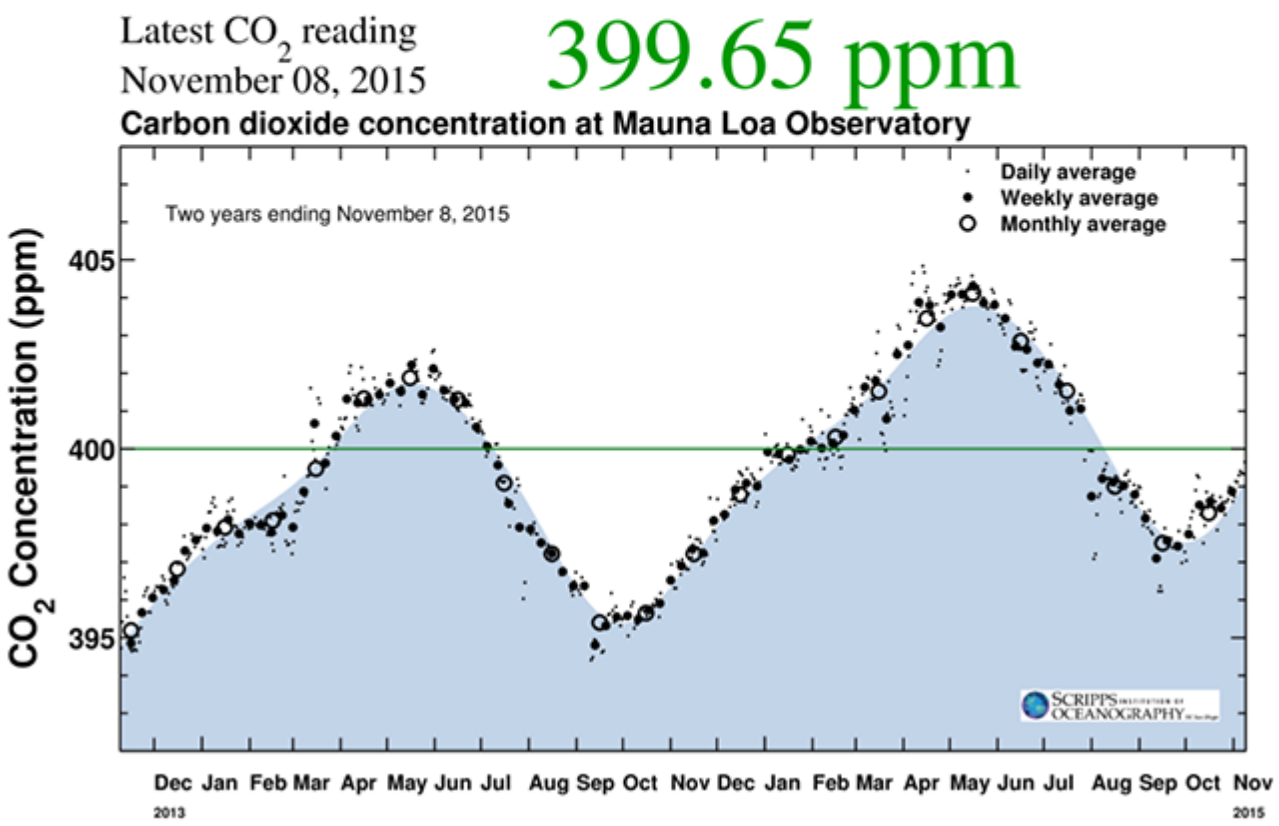
The final days of sub-400 ppm carbon dioxide

Posted by Callan

Here are the last two years of measurements at the Mauna Loa CO_2 sampling station:

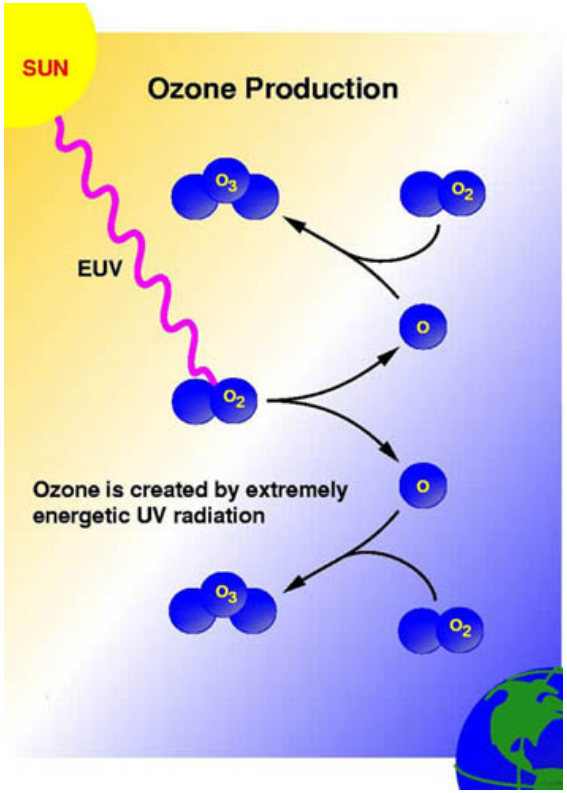
Latest CO_2 reading
November 08, 2015

399.65 ppm



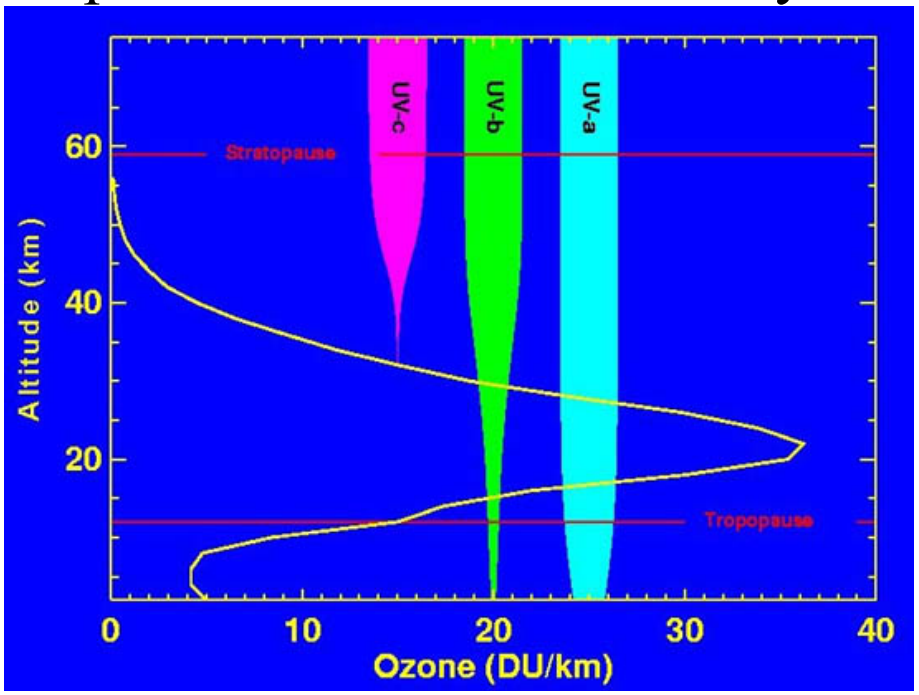
Variable gases: ozone

- Ozone (in stratosphere平流層)
  - Tri-atomic form of oxygen
  - Absorbs ultraviolet radiation
  - Chlorofluorocarbons (CFCs) destroy ozone
  - Destruction peaks over southern hemisphere
  - Antarctic circumpolar vortex limits latitudinal mixing
    - Leads to an O3 “hole”



Attenuation of UV in the atmosphere

- Strong absorption of UV-C and UV-B by stratospheric ozone



DU: Dobson unit

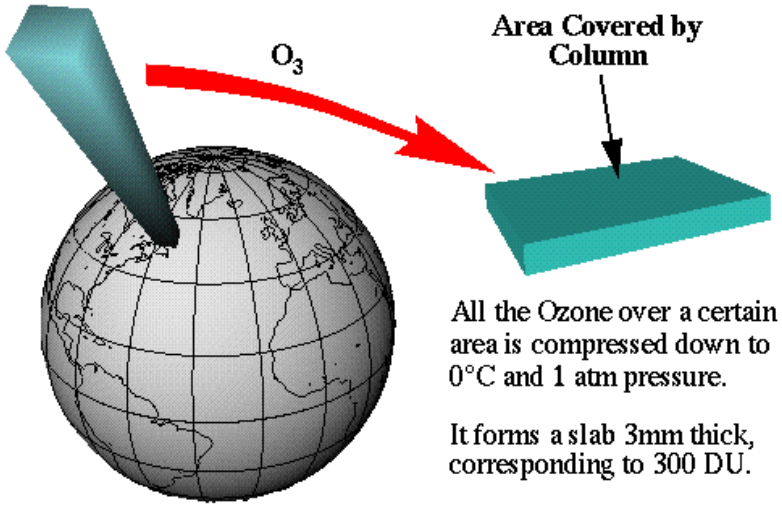
Table 5.1

Common Names for Regions of the UV Spectrum

λ (nm)	Name	Species Absorbing	Location
10–240	Far-UV	O_2, N_2	Thermosphere, mesosphere
250–290	UV-C	O_3	Stratosphere
290–320	UV-B	O_3	Stratosphere, troposphere
320–380	UV-A	NO_2	Polluted troposphere
400–750	Visible	many	Earth's surface

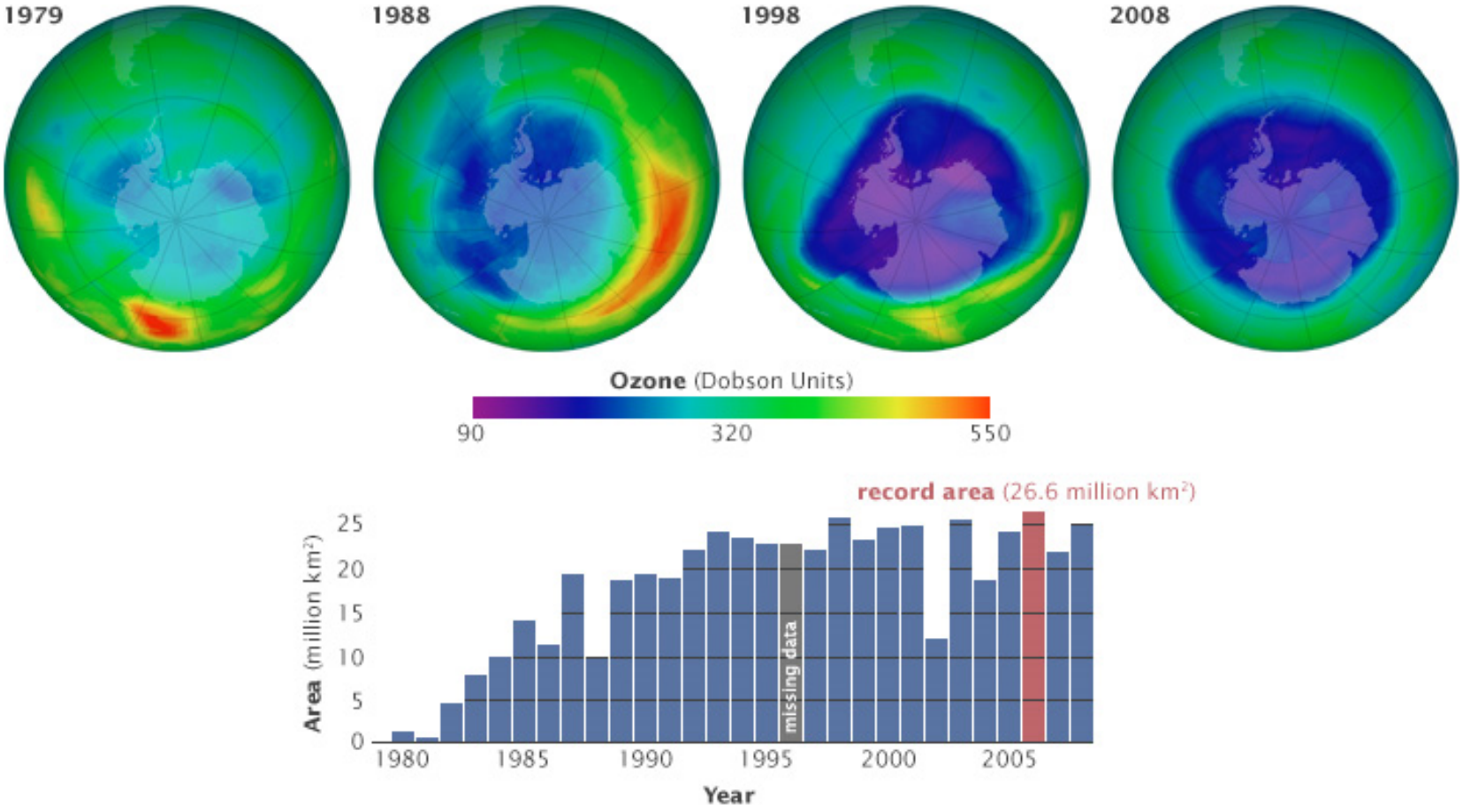
Ozone layer: Dobson Unit

- The "Dobson unit" indicates how much ozone there is in the air above a certain point on Earth. A proper unit would thus be "Kilogram per square meter".
- 1 Dobson Unit (DU) is defined to be 0.001 cm thickness at STP
  - 2.6867E+20 molecules m-2
  - 4.4615E-04 mole m-2
  - 2.1415E-05 kg m-2



- In 2000, the average abundance is 293.4 DUs

Ozone depletion

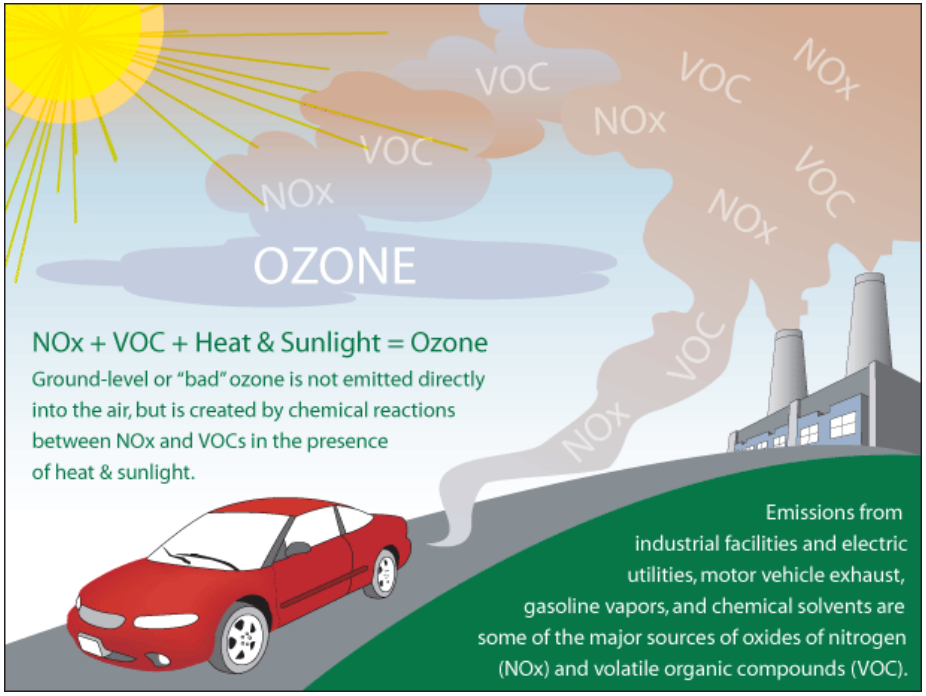


Variable gases: ozone

- Ozone (in troposphere對流層)
  - A very important secondary air pollutant (二次污染物、衍生性污染物)
  - Ozone is a powerful oxidizing agent readily reacting with other chemical compounds to make many possibly toxic oxides.
  - Tropospheric ozone cause irritation to lungs and eyes and damage to vegetation

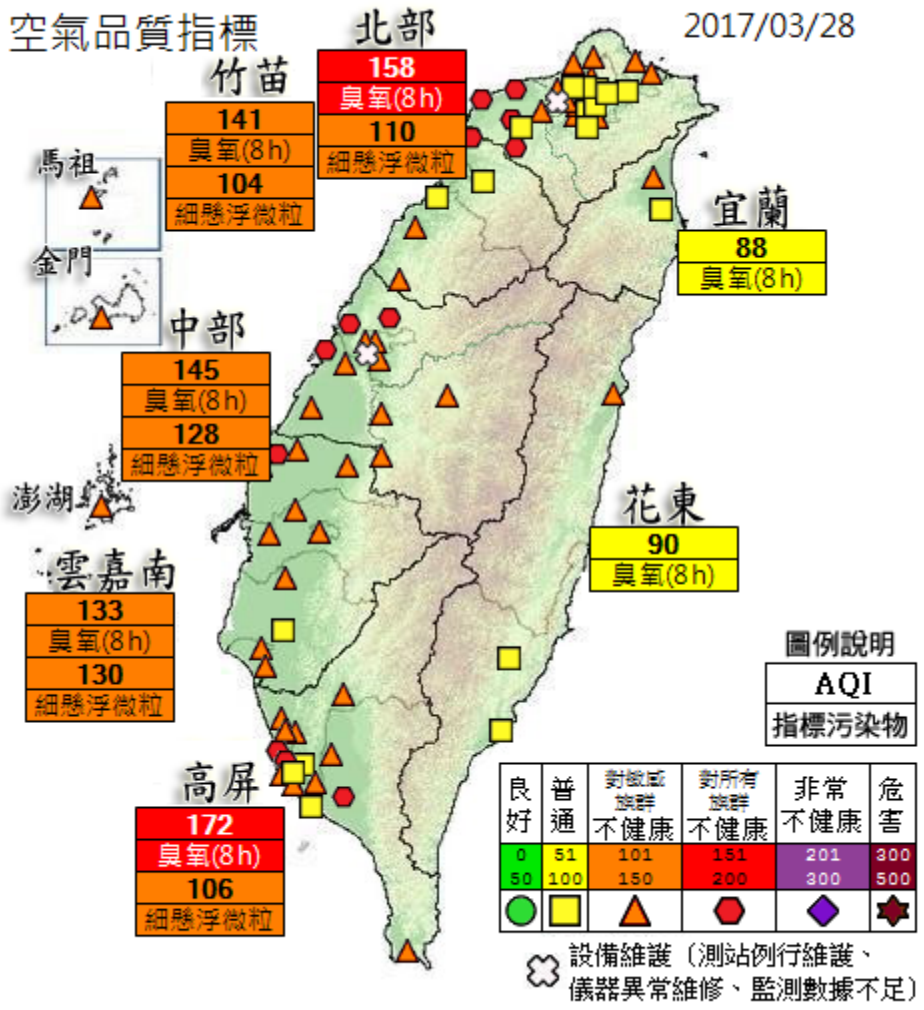
Photochemical smog

- Photochemical smog
  - A photochemical smog is the chemical reaction of sunlight, nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in the atmosphere, which leaves airborne particles (called particulate matter) and ground-level ozone.



https://www.airnow.gov/index.cfm?action=aqibasics.ozone

環保署空氣品質監測網



2017 年 03 月 切換

2017年3月

星期日	星期一	星期二	星期三	星期四	星期五	星期六
26	27	28	1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	1
2	3	4	5	6	7	8

2017年03月28日空氣品質概況：

一、今日空氣品質概況：

臺灣今天晨間受輻射冷卻影響，各地氣溫仍低，西半部日夜溫差較大；臺灣各地及外島為晴到多雲，僅東部及東南地區有零星短暫雨。

金門及中南部地區為橘色提醒(對敏感族群不健康)，其他地區多為普通等級，指標污染物為細懸浮微粒。

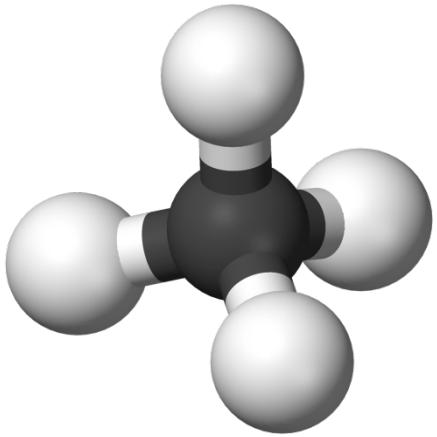
二、明日空氣品質概況：

臺灣明日受鋒面接近影響，東半部地區及中部以北山區有局部短暫雨，其他地區及澎湖、金門、馬祖為多雲到晴。

中部及雲嘉南地區為橘色提醒(對敏感族群不健康)，高屏地區為紅色警示(對所有族群不健康)，其他地區為良好至普通等級，指標污染物為細懸浮微粒。

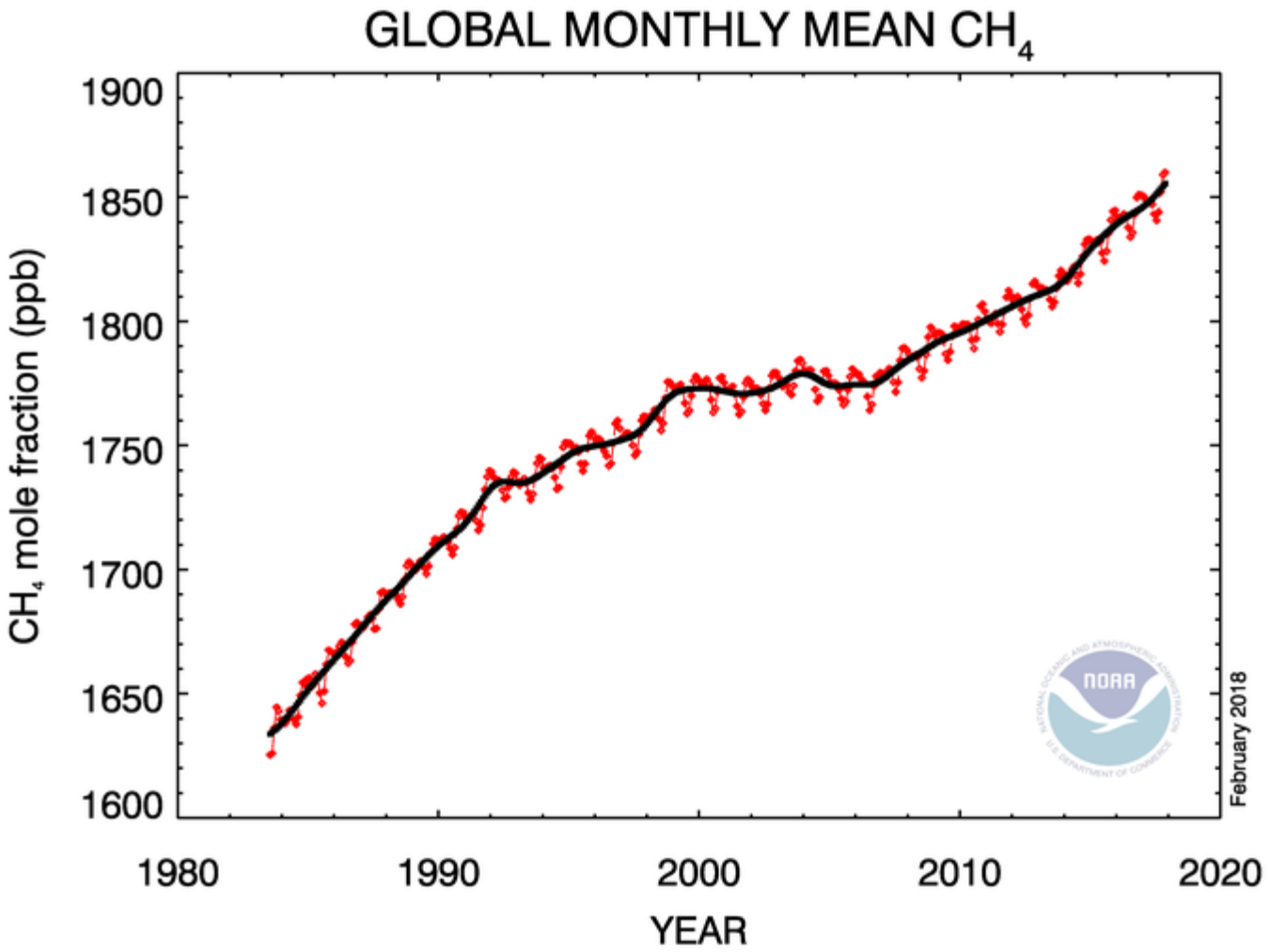
Variable gases

- Methane (CH4)
  - A variable gas in small but recently increasing concentrations
  - Increases mainly due to biomass burning, agriculture cultivation (esp. rice), fossil fuel extraction (coal and petroleum mining), and livestock digestion.
  - The residence time for methane is about 10 years.
  - Effective absorber of terrestrial radiation
    - Plays a role in near-surface warming

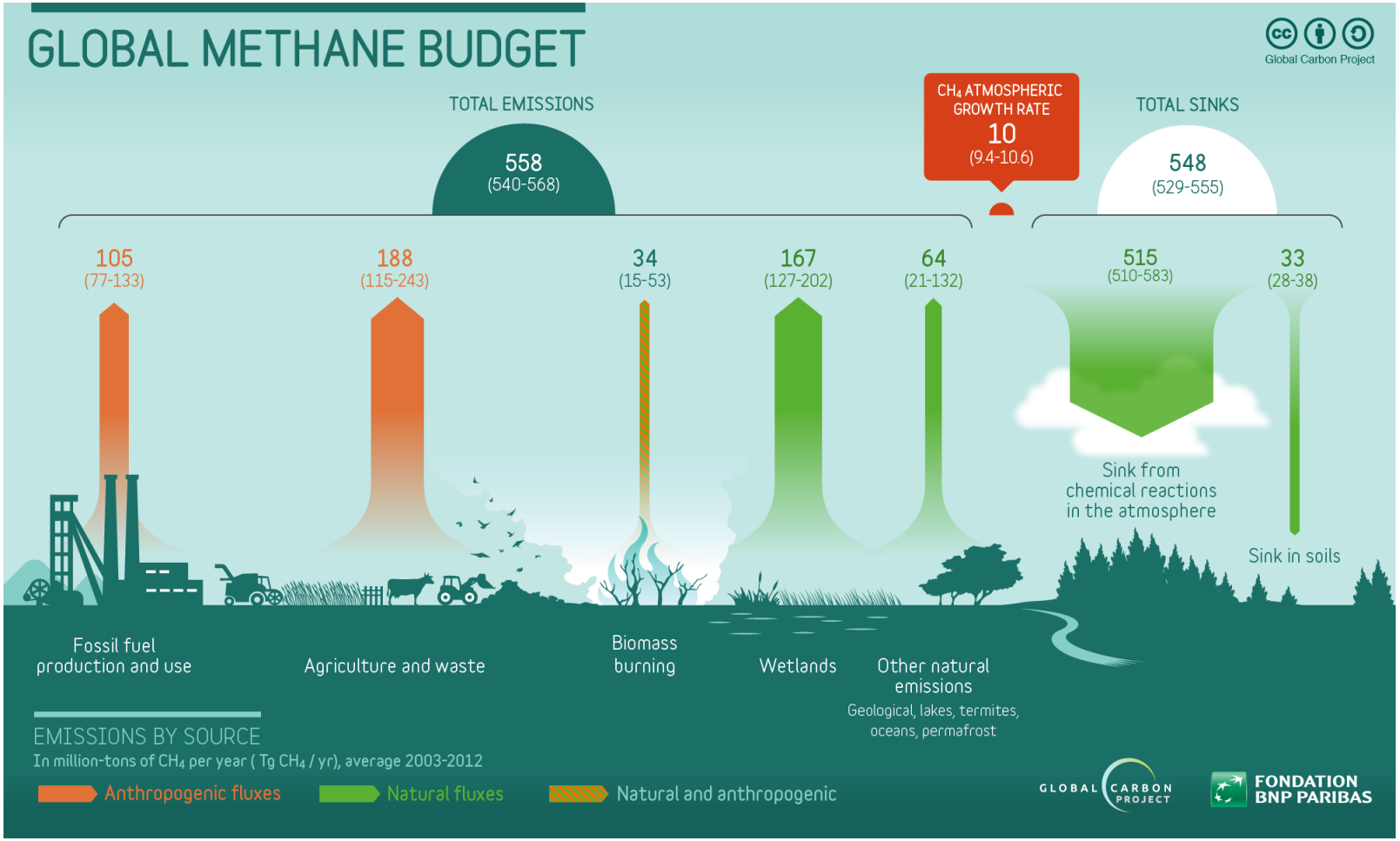


Methane

- The annual increases in atmospheric methane (in ppb)



Global methane budget

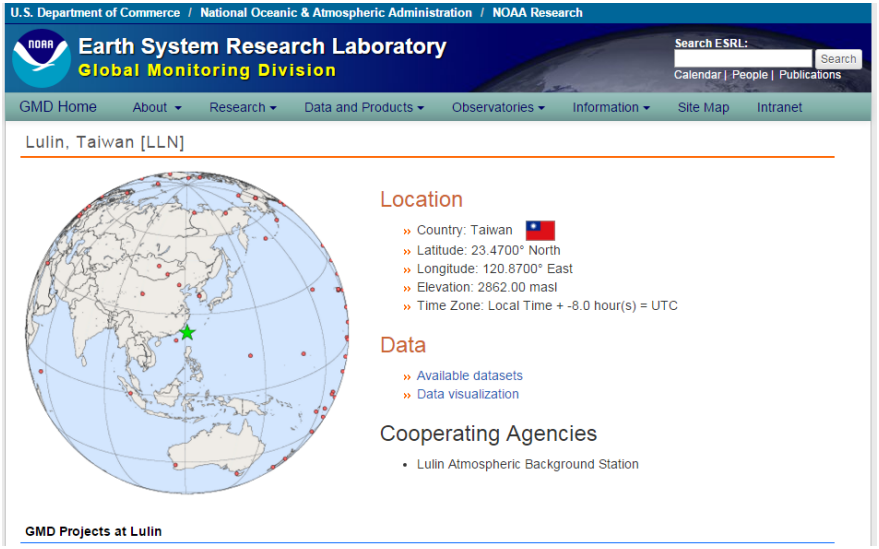


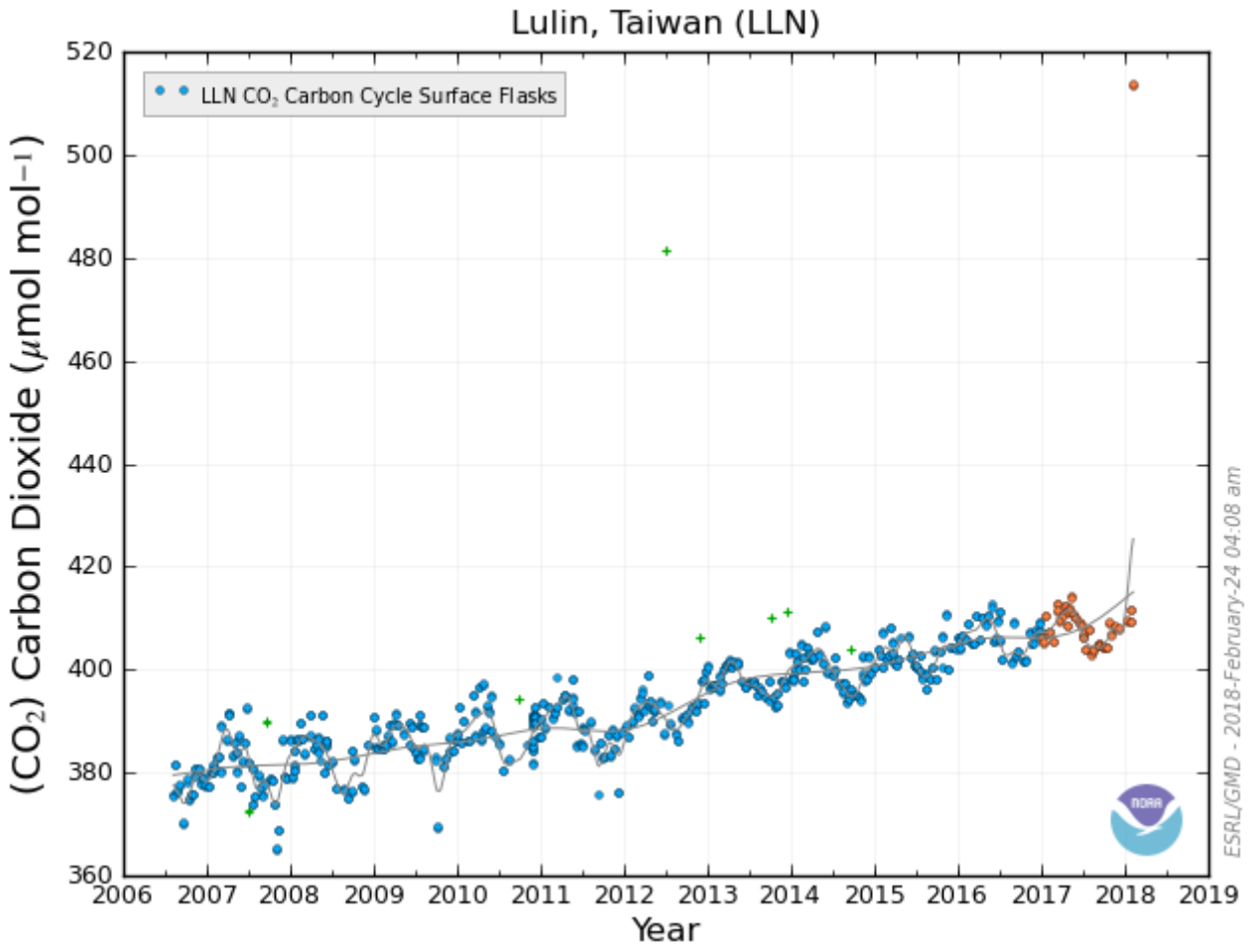
http://www.globalcarbonproject.org/methanebudget/16/files/MethaneInfographic2016.png

環保署鹿林山監測站

http://taqm.epa.gov.tw/lulin/default.aspx?pid=b0101&cid=b0101

http://www.esrl.noaa.gov/gmd/dv/site/site.php?code=LLN





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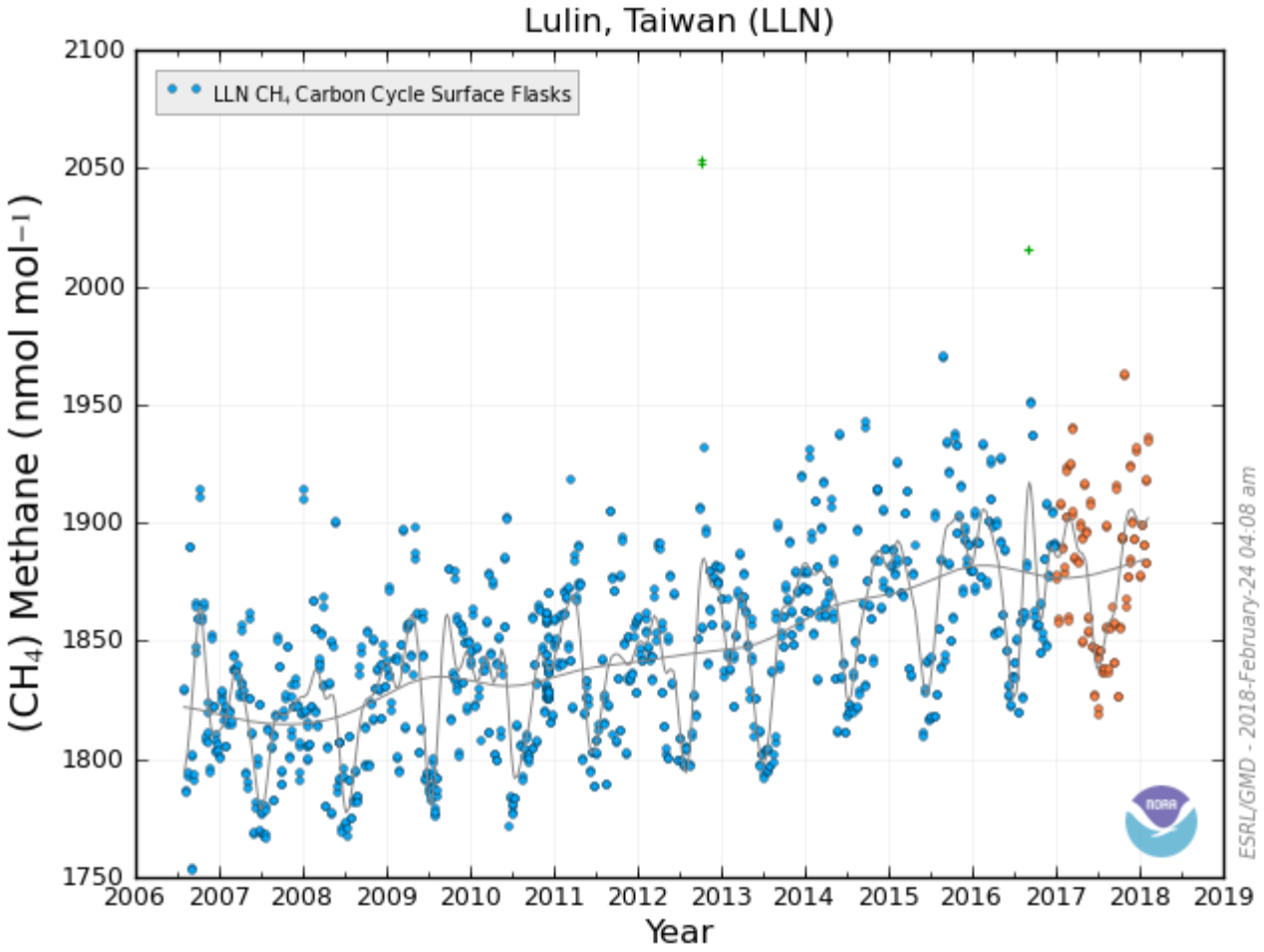
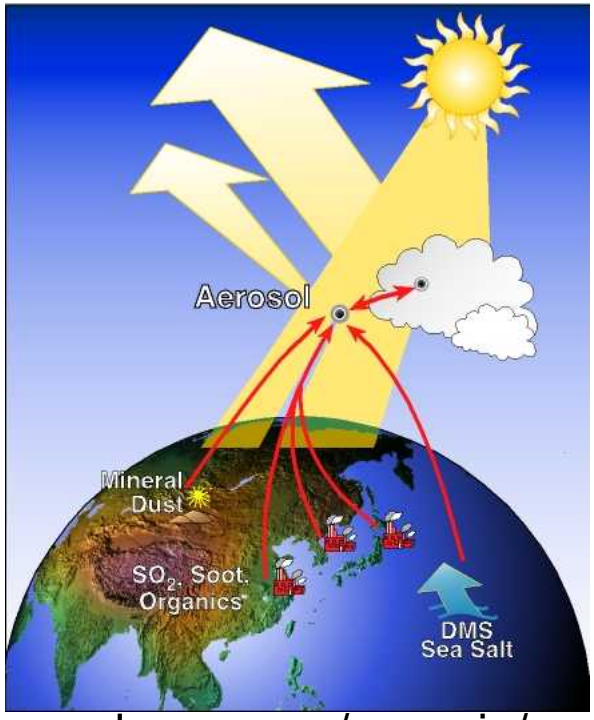


https://www.esrl.noaa.gov/gmd/webdata/iadv/ccgg/graphs/ccgg.LLN.ch4.1.none.discrete.all.png

Variable gases

- Aerosols (particulates)氣膠
  - Any solid and/or liquid particle, other than water
  - Both natural (sea spray, dust, combustion) and human (combustion) sources
  - Long residence times for some types
  - Acts as condensation nuclei

攝影：易繼中



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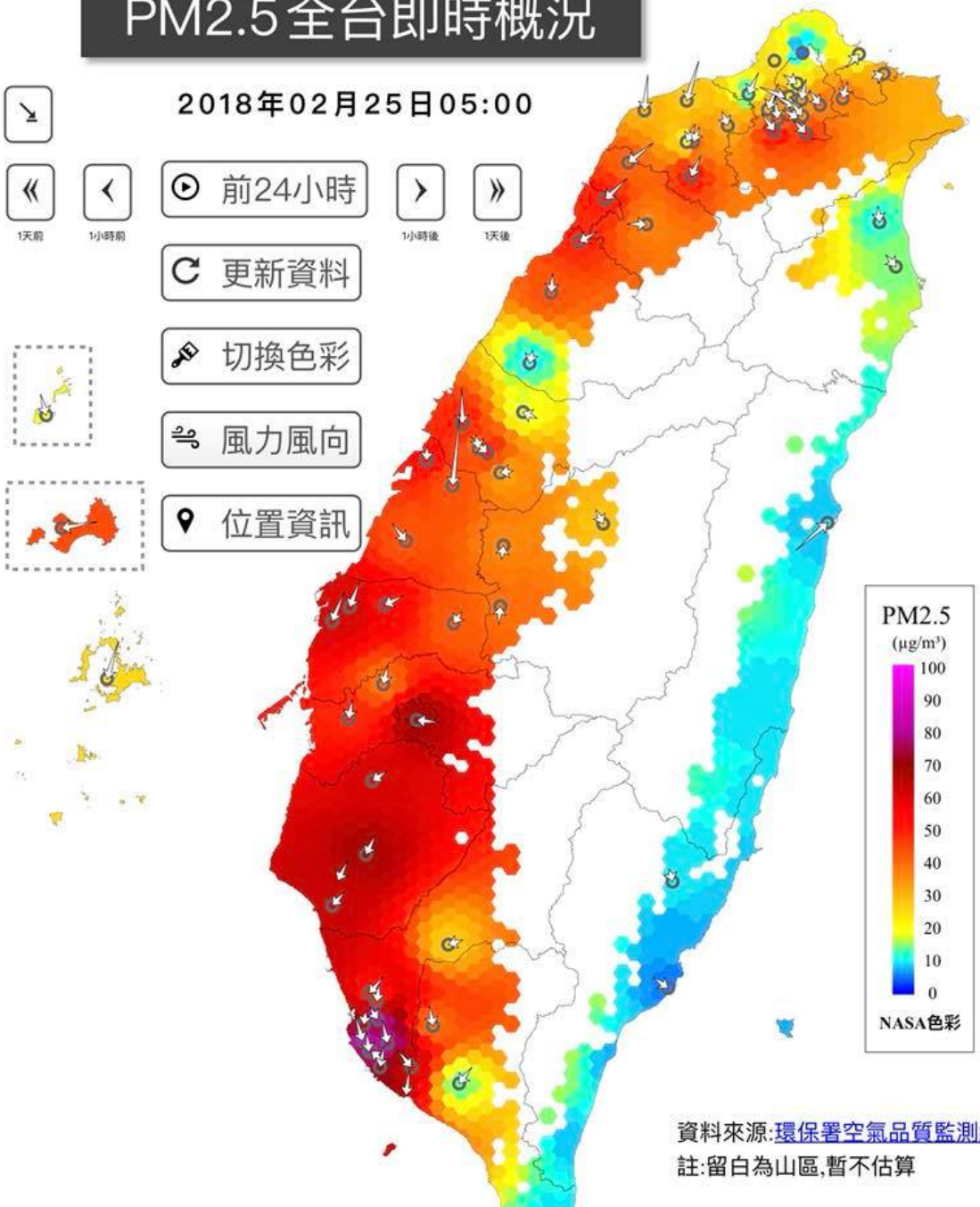
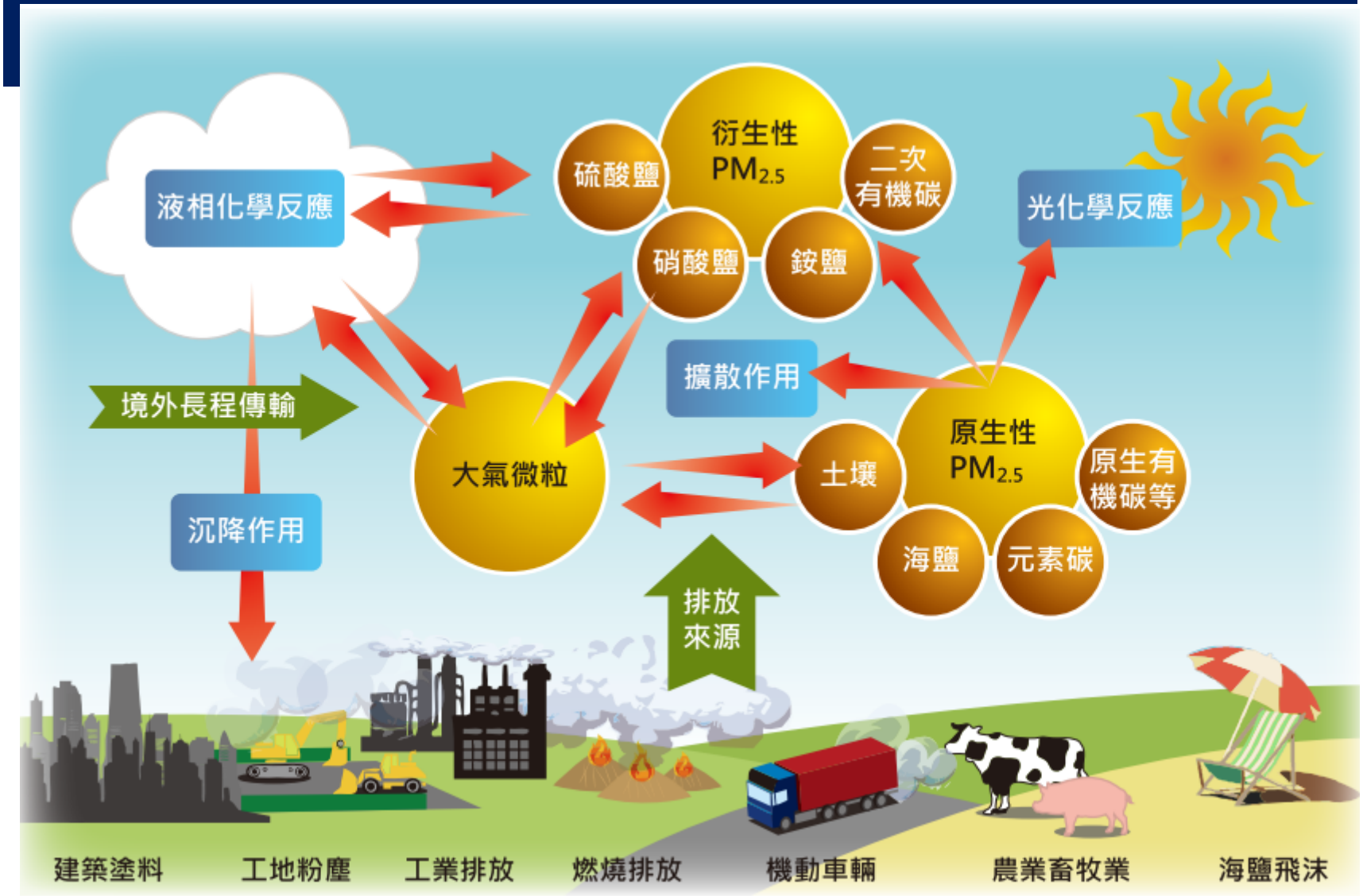
PM2.5全台即時概況



資料來源:環保署空氣品質監測網

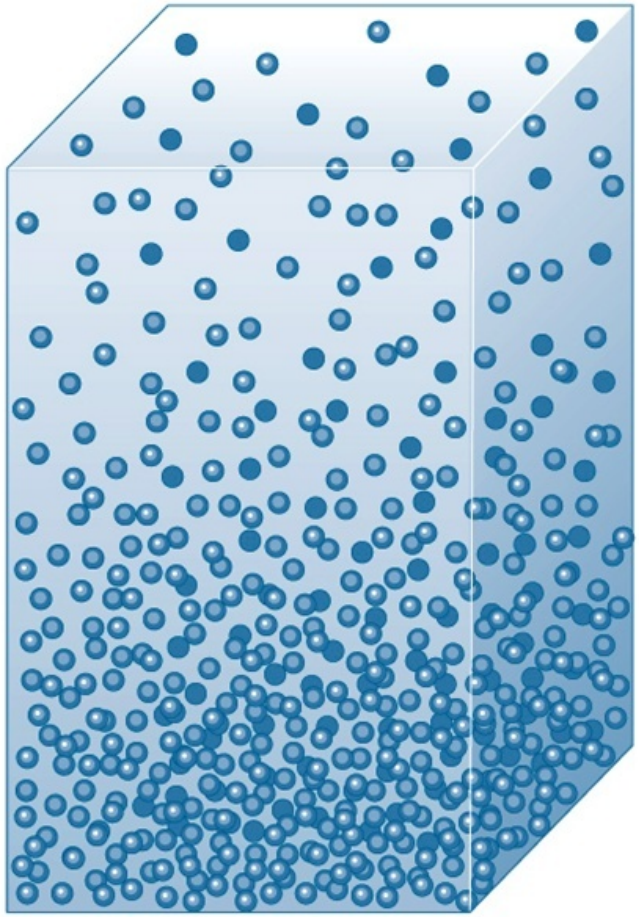
註:留白為山區,暫不估算



http://www.epa.gov.tw/

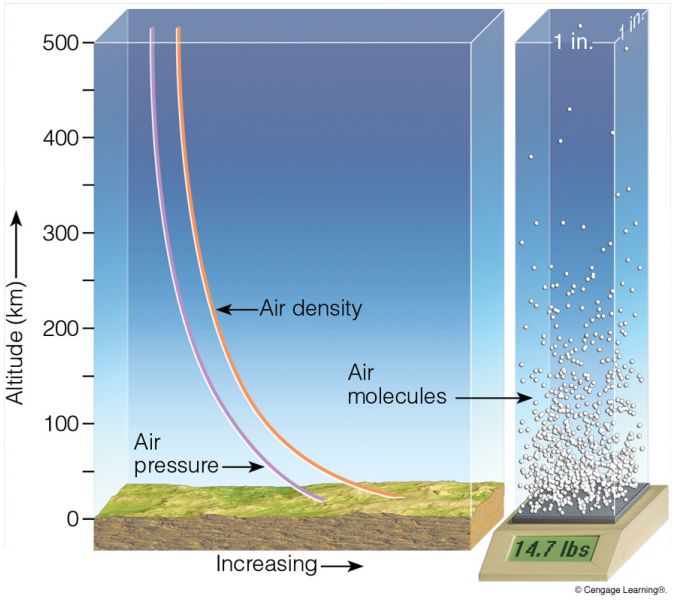
Vertical Structure of the Atmosphere

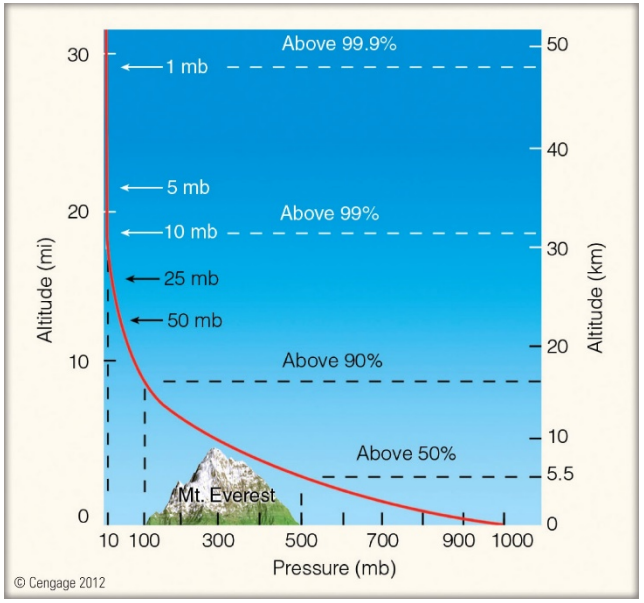
- Density
  - Mass (kg) per unit volume (m3)
    - Sea level average = 1.2 kg/m3
  - Near surface air is more dense
    - Compressibility
    - Mean free path
      - At surface = 0.0001 mm
      - At 150 km = 10 m



Vertical Structure of the Atmosphere

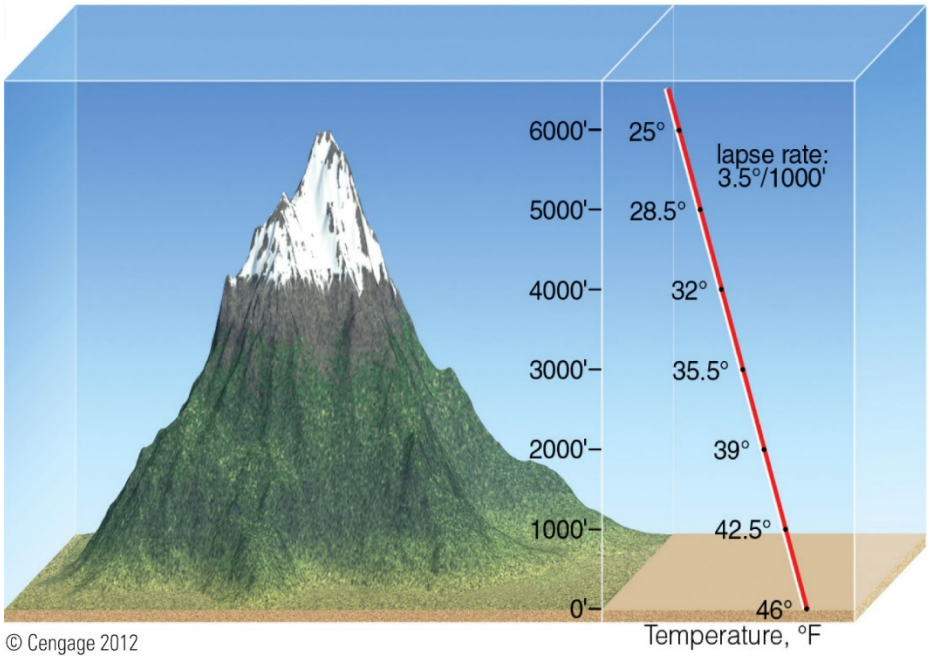
- Air Pressure and Air Density
  - Weight = mass x gravity
  - Density = mass/volume
  - Pressure = force/area
  - Standard sea level pressure is1013.25 mb = 1013.25 hPa = 760 mm Hg
  - Atmospheric pressure decreases with an increase in height.





Layers of the Atmosphere

- *Lapse rate*: rate at which the air temperature decreases with height is called the lapse rate
  - The average (standard) lapse rate is 6.5 degrees C for every 1000 m
- *Temperature inversion*: a measured increase in air temperature with height



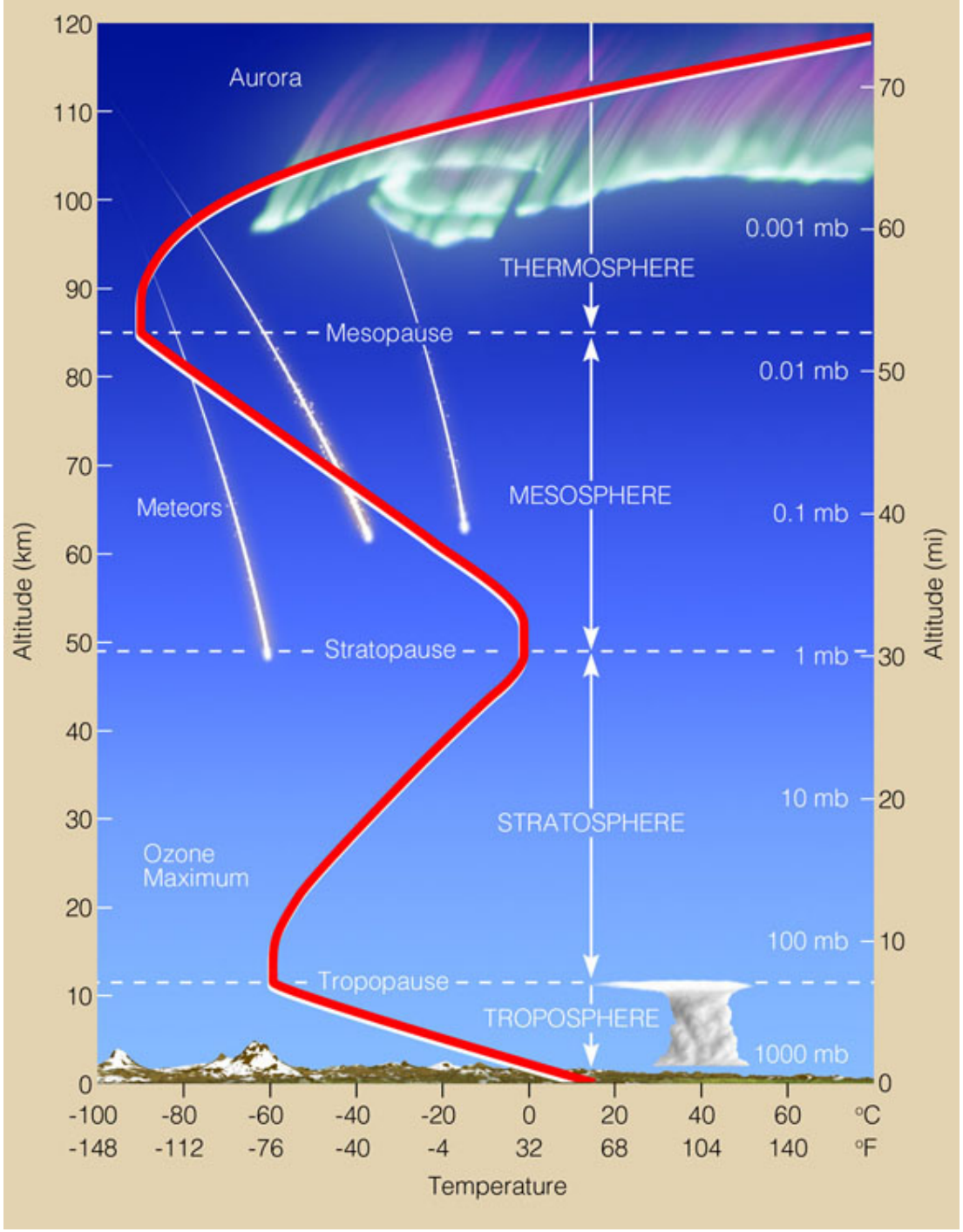


FIGURE 1.11 Layers of the atmosphere as related to the average profile of air temperature above Earth's surface. The heavy line illustrates how the average temperature varies in each layer.

Ideal gas law 理想氣體定律

- An ideal gas is a hypothetical gas consisting of identical particles of zero volume, with no intermolecular forces. Additionally, the constituent atoms or molecules undergo perfectly elastic collisions with the walls of the container
- To a good approximation, the atmosphere can be assumed to have the properties of an ideal gas

$$PV = nRT$$

R (universal gas constant)

$= 0.08205784\ \mathrm{L \cdot atm \cdot K^{-1} \cdot mol^{-1}} = 8.314472\ \mathrm{J\ mol^{-1} \cdot K^{-1}}$

In alternative form: $PV = \frac{m_a}{M_a} RT$ $P = \frac{m_a}{V}\frac{RT}{M_a} = {}_a\frac{RT}{M_a}$

or: $P = {}_a\frac{RT}{M_a} = {}_a\frac{R}{M_a}T = {}_aR_aT$ R_a: gas constant for the air

Partial pressure

- Abundance of a gas in the atmosphere is sometimes expressed in terms of its partial pressure (p_i), which is defined as the pressure if only consistent i occupied the whole volume
- Ideal gas law holds for air and individual gas
  - For air $PV = nRT$
  - For gas i $P_iV = n_iRT$

Or $P = {}_aR_aT$

$P_i = {}_iR_iT$