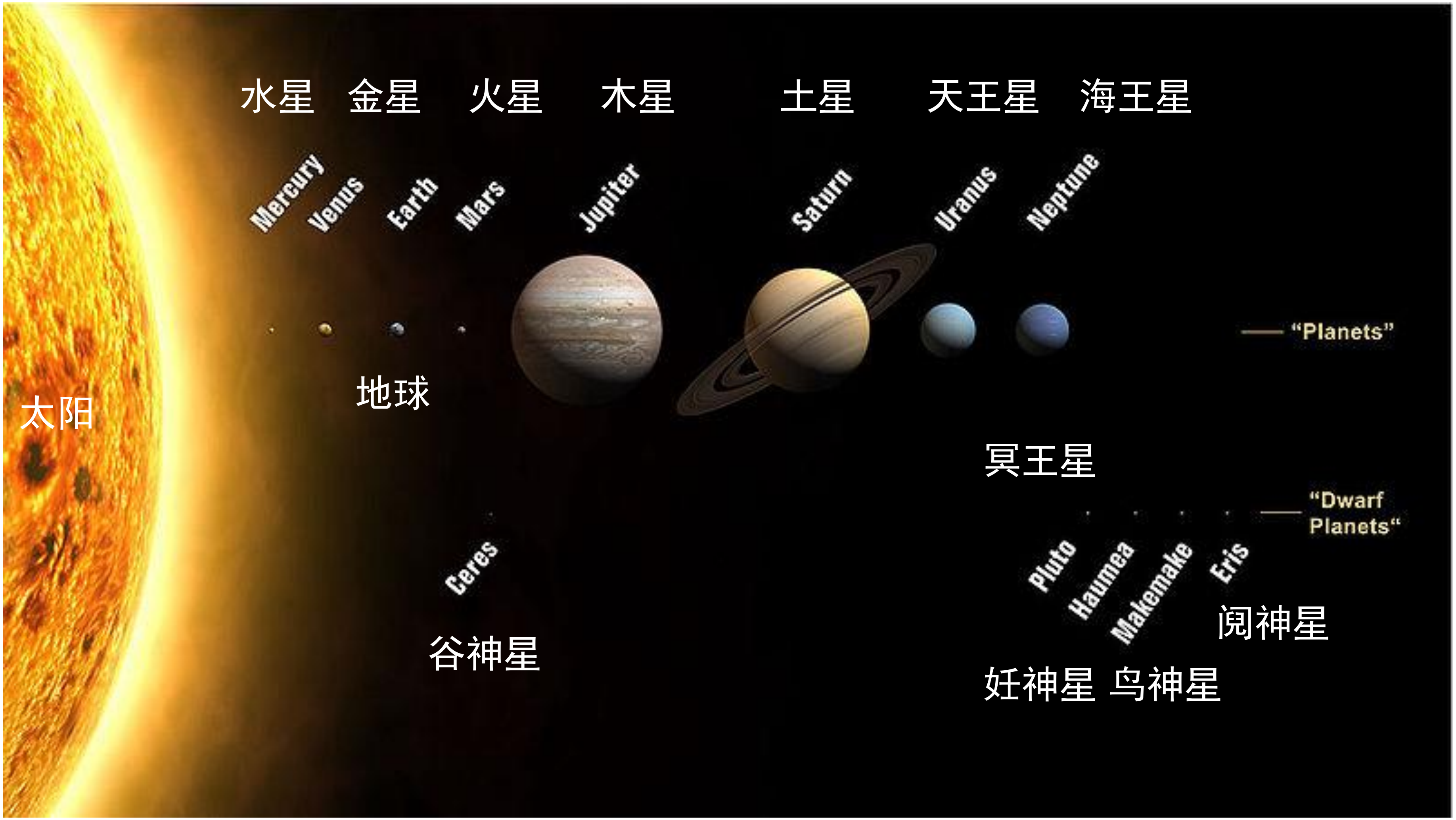
CHAPTER 2

EARTH SYSTEM
&
GLOBAL BIOGEOCHEMICAL CYCLE

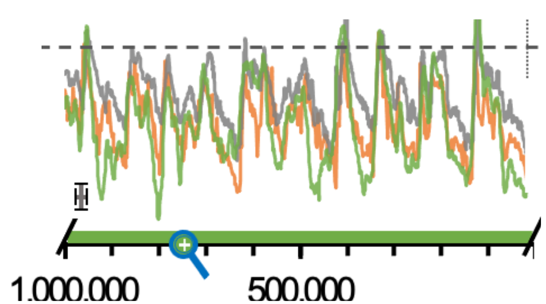
Earth in the Solar System



地球基本参数

- 日地距离: 平均1.496e8 km, or 1 AU （range：0.973–1.017 AU）
- 地球轨道偏心率：0.0167（周期：40万年、10万年）
- 地球自转轴角度：～23.5º（周期：4.1万年）
- 地球自转轴进动（岁差；周期：2.6万年）
- 地球公转周期：1年，自转周期：1天
- 地球半径：～6371 km（极半径 6357 km，赤道半径 6378 km）
- 太阳常数：日地平均距离处的太阳辐射，1361–1362w/m^2
- 地球系统的太阳辐射返照率：～29%，太阳辐射量净量：～240 w/m^2

米兰科维奇理论？



地球简史：地质年代

地质年代及其代号				同位素年龄(百万年)	构造运动		生物界开始繁殖的年代		生物空前繁盛的时代	
宙(宇)	代(系)	纪(系)	世(统)		发生年代	阶段	植物	动物		
显生宙	新生代 K_Z	第四纪 Q	全新世 Q_4	–.01–						
			更新世 Q_1、Q_2、Q_3	–2–3–						
		第三世 R 晚第三纪 N	上新世 N_2	10		喜山阶段		–人类出现	被子植物	哺乳动物
			中新世 N_1	25	喜山运动(II)					
		早第三纪 E	渐新世 E_3	40						
			始新世 E_2	60	喜山运动(I)					
			古新世 E_1	70				–哺乳动物		
	中生代 M_Z	白垩纪 K	晚白垩世 K_2		晚期运动		–被子植物			
			早白垩世 K_1	140	中期燕山运动	燕山阶段			裸子植物	爬行动物
		侏罗纪 J	晚侏罗世 J_3							
			中侏罗世 J_2		早期燕山运动					
			早侏罗世 J_1	195				–爬行动物		
		三叠纪 T	晚三叠世 T_3		印支运动		–裸子植物			
			中三叠世 T_2							
			早三叠世 T_1	230		印支阶段				
	古生代 P_Z 晚古生代 PZ_2	二叠纪 P	晚二叠世 P_2		海西运动				蕨类	两栖动物
			早二叠世 P_1	280						
		石炭纪 C	晚石炭世 C_3			海西阶段				
			中石炭世 C_2							
			早石炭世 C_1	350						
		泥盆纪 D	晚泥盆世 D_3						裸蕨	鱼类
			中泥盆世 D_2							
			早泥盆世 D_1	400	加里东运动					
	早古生代 PZ_1	志留纪 S	晚志留世 S_3				–陆生裸蕨		藻类	笔石
			中志留世 S_2					–鱼类		
			早志留志 S_1	440		加里东阶段				
		奥陶纪 O	晚奥陶世 O3							
			中奥陶世 O_2							
			早奥陶世 O_1	500						
		寒武纪 π	晚寒武世 π_3							三叶虫
			中寒武世 π_2							
			早寒武世 π_1	600						
隐生宙	元古代 P_t	震旦纪 Z		800	晋宁运动		–高级藻类	–小壳动物		
				1800	吕梁运动			–裸露动物		
	太古代 A_r			2500	阜平运动			–多细胞动物		
	前太古代 A_nA_r			3800			–生物现象			

- 地球年龄：约46亿年
- 地质年代：宙（Eon）、代（Era）、纪（Period）、世（Epoch）、期（Stage/Age）、时（Chron）
- 现在地球处于显生宙、新生代、第四纪、全新世
- 人类世(Anthropocene)?

地球系统

10^{26} g 岩石圈（陆地、土壤）

10^{22} g 冰圈（冰川、两极）

$10^{18} \sim 10^{19}$ g 生物圈

10^{24} g 水圈（河湖海、降水）

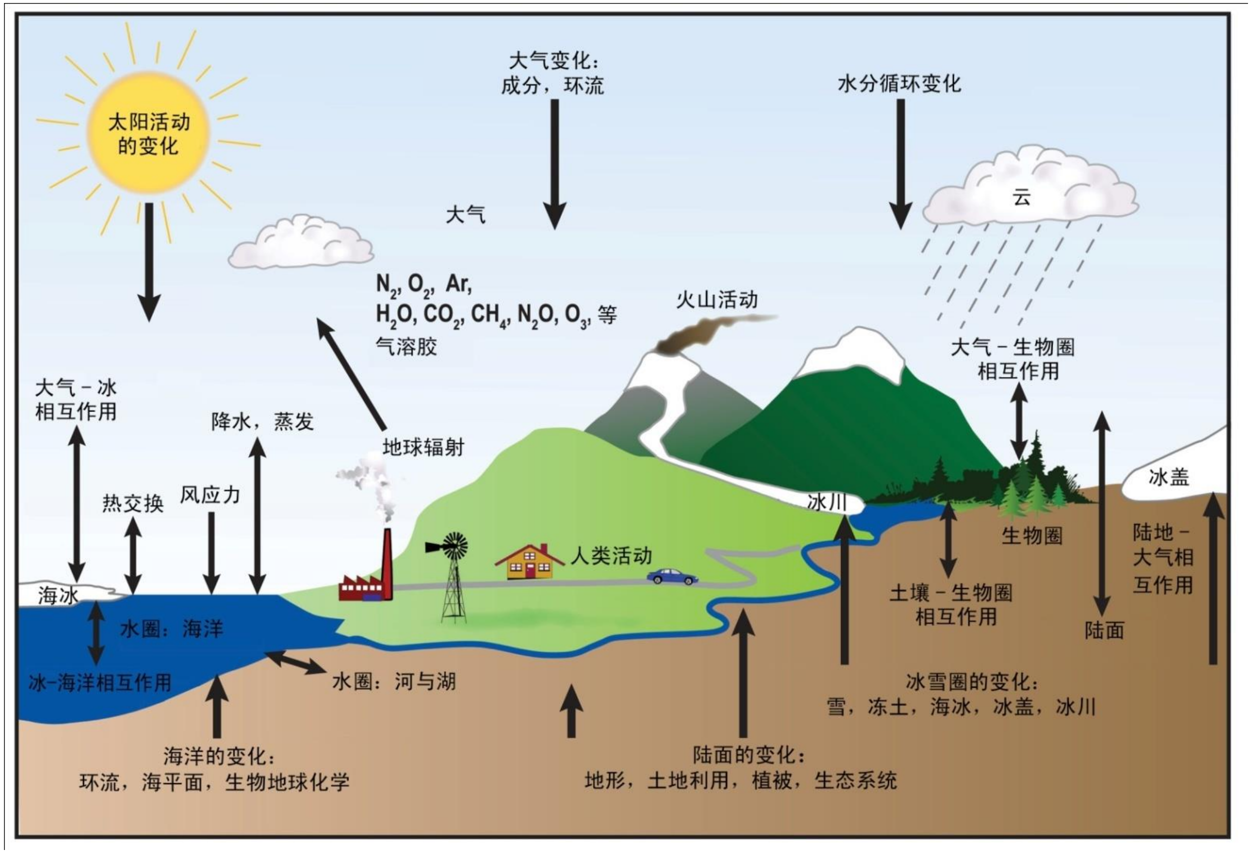
10^{21} g 大气圈

大气体积百分比：

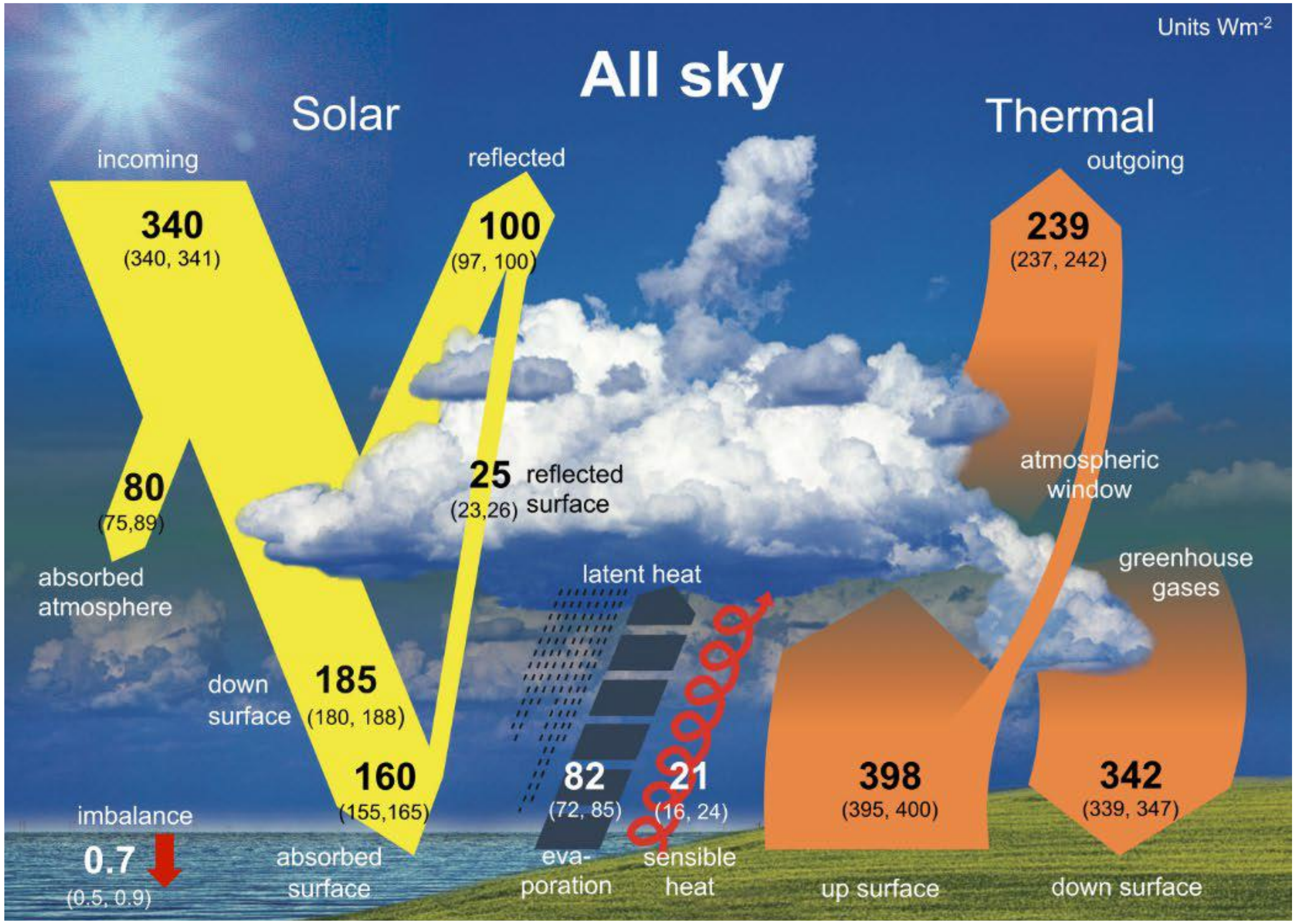
N_2：78%，O_2：21%，Ar：0.93%，CO_2：0.04%，H_2O：< 6%，可变

地球系统中的气候和生地化循环

- ➢气候态
- ➢碳循环
- ➢氮循环
- ➢硫循环



Earth Energy Balance (Start of 21st Century)



IPCC, 2021

- Planetary albedo: ~29% (surface 7%, atmosphere 22%)
- Thanks to GHGs, the Earth surface temperature increases from -15ºC to 18ºC

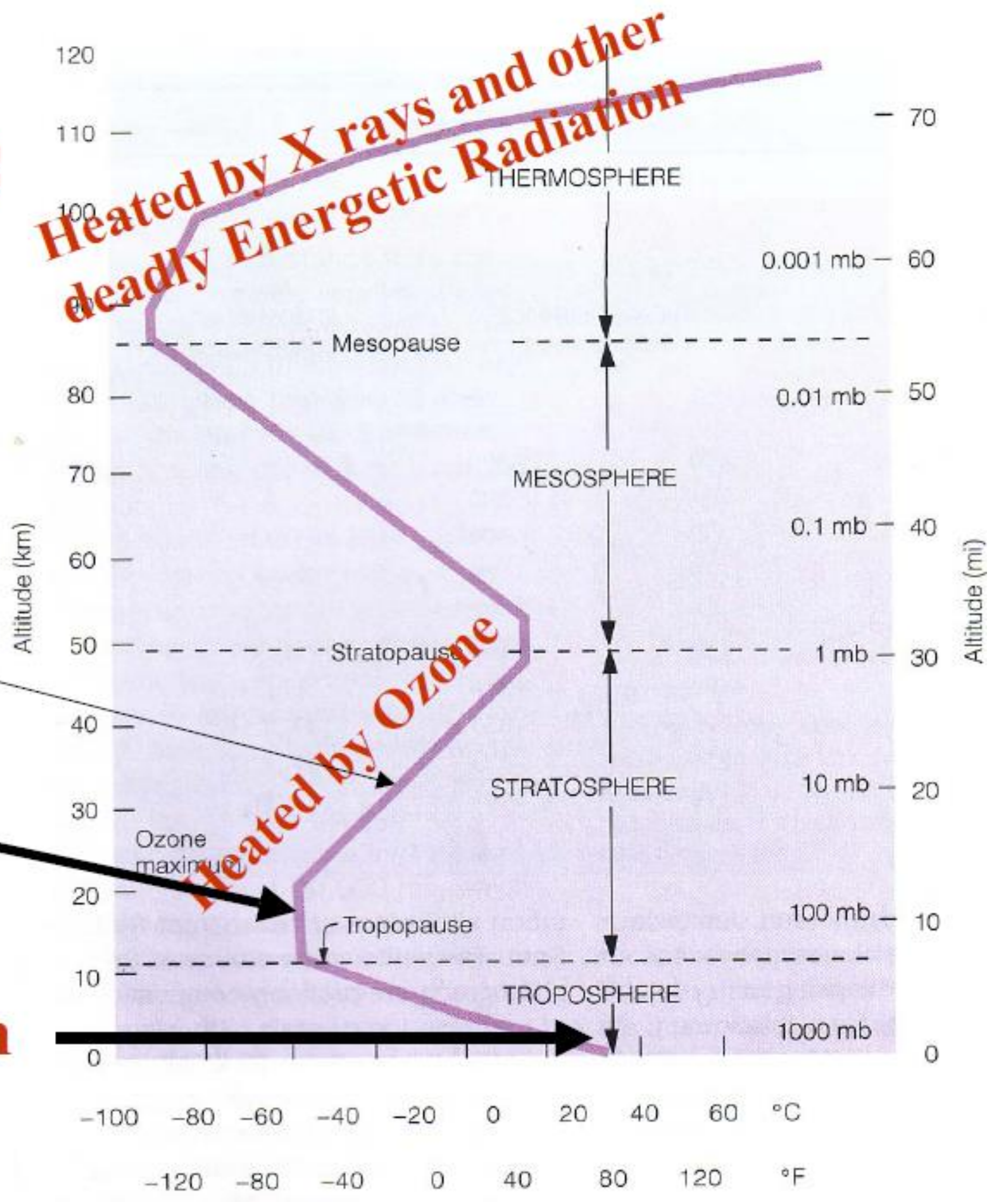
Vertical Distribution of Air Temperature and Its Drivers

Temperature Structure of the Atmosphere

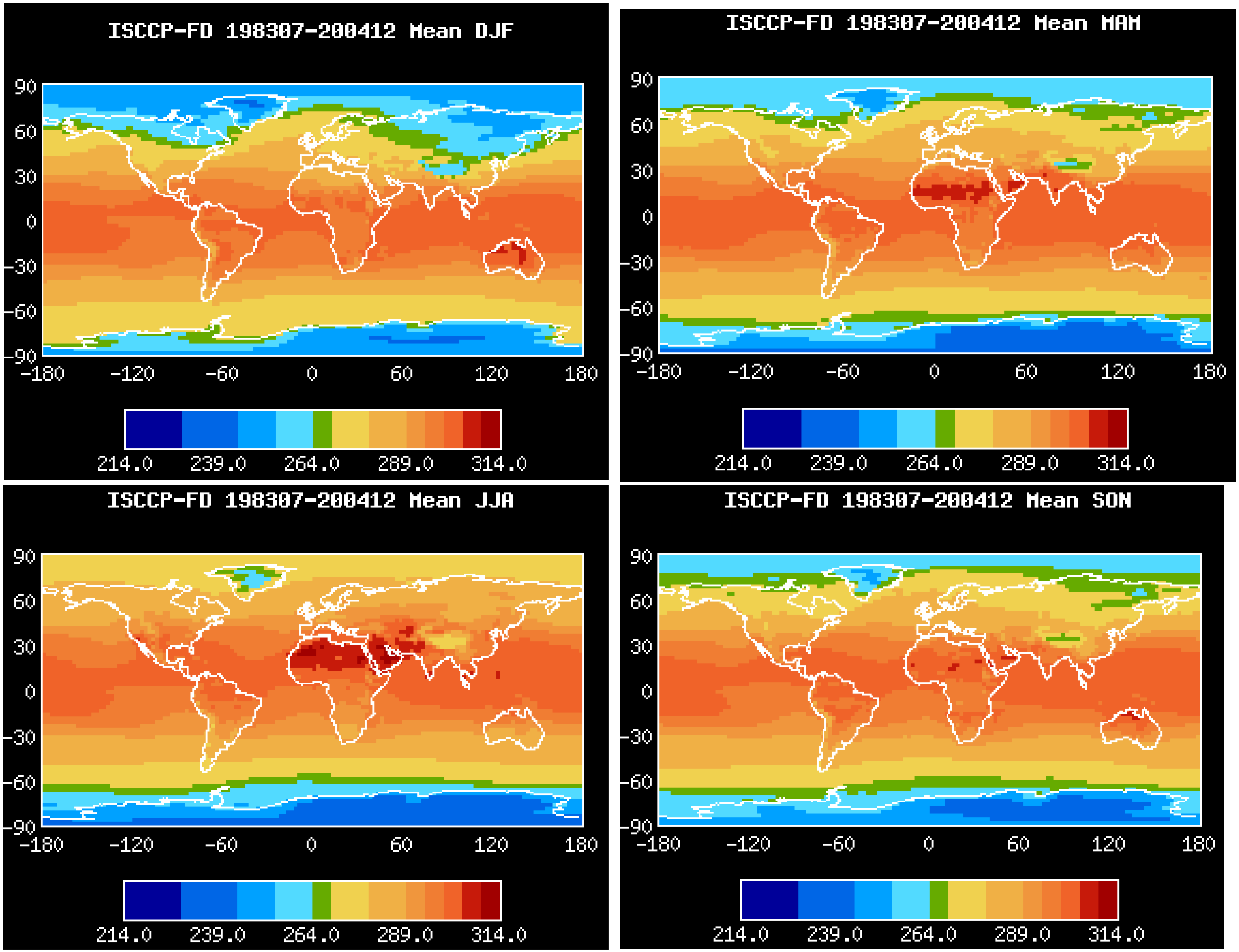
Inversion Layer

Isothermal Zone

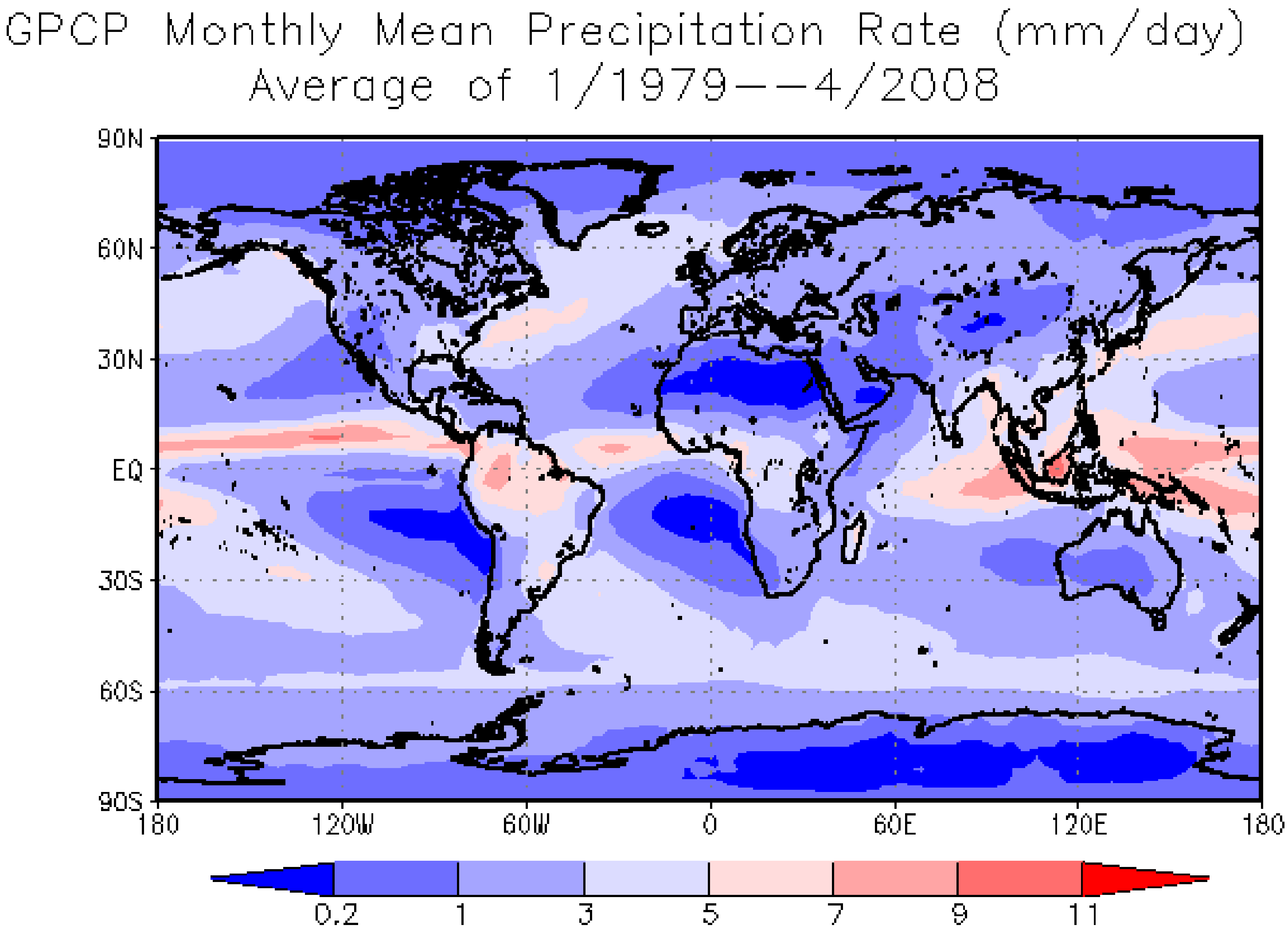
Heated by the Sun



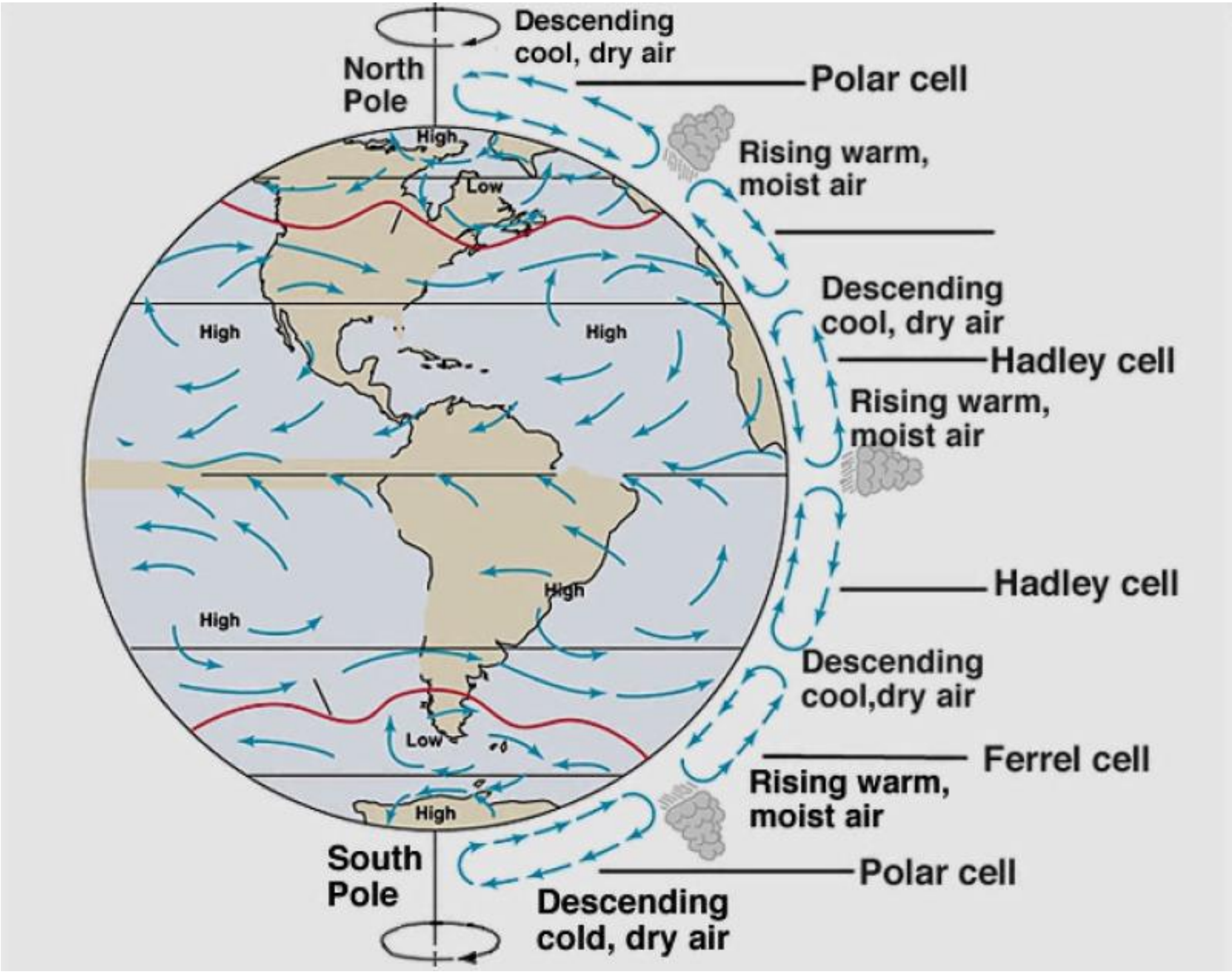
Global Seasonal Surface Air Temperature: 1983-2004



Global Precipitation: 1979-2008



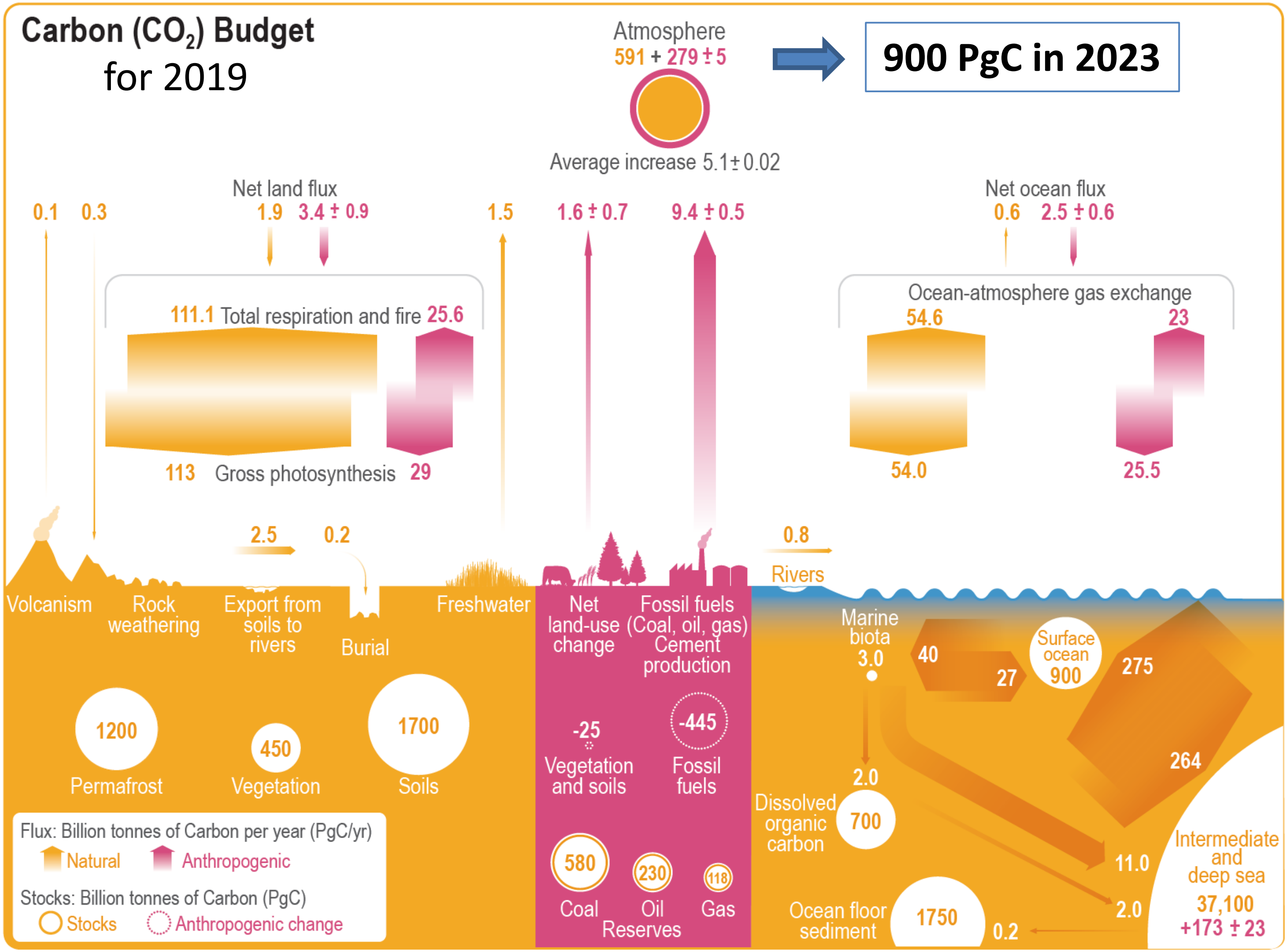
Atmospheric Circulation (三圈环流)



Understanding the Global Carbon Cycle

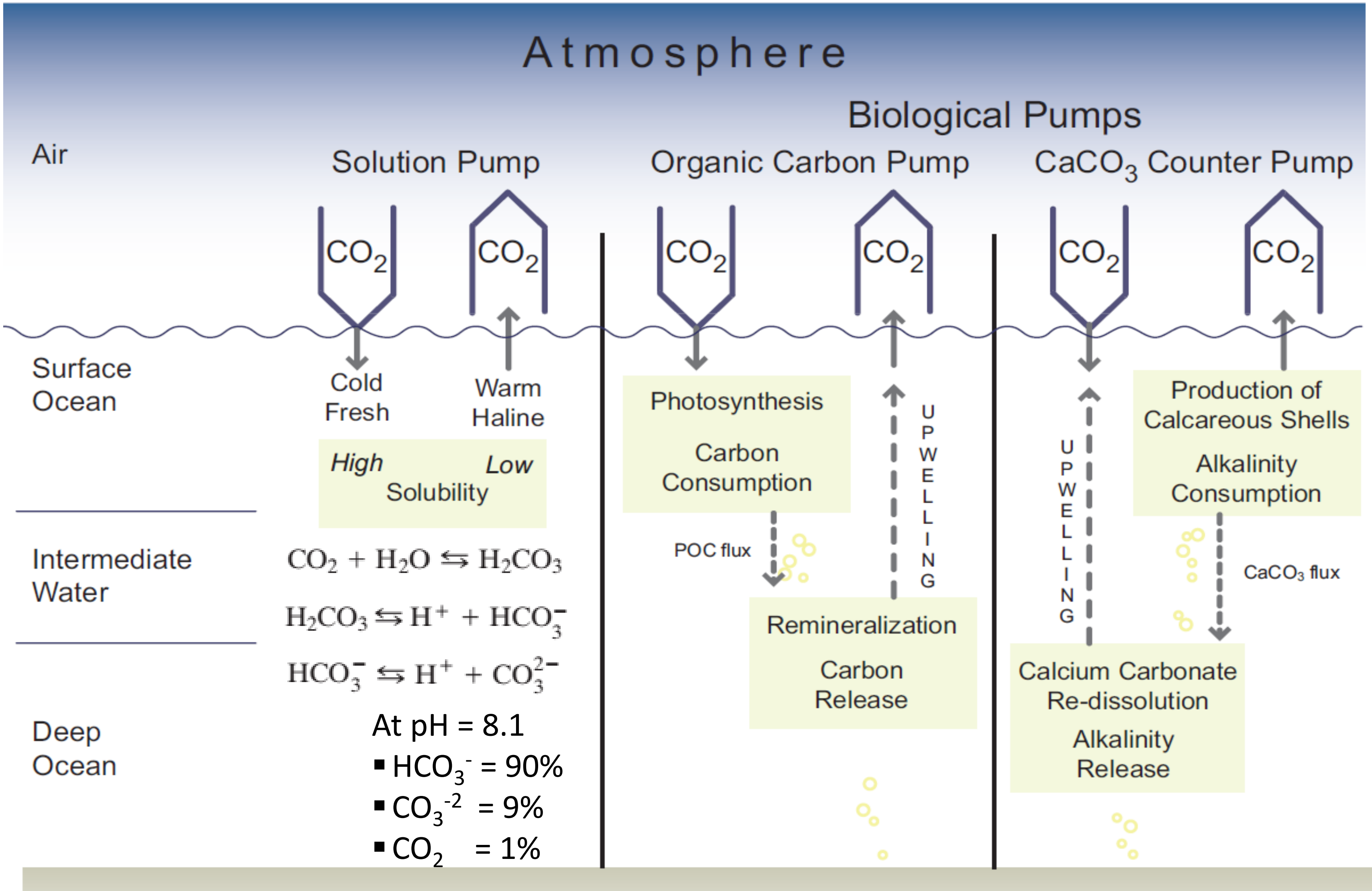
- The global CO_2 cycle and budget have significantly intertwined with the climate system in the Earth history
- Human-induced CO_2 increases have profoundly affected the climate and biosphere in the past centuries
- Increasing CO_2 in the future would continue to impact our living environment to an extent that damage is irreversible
- To understand and predict future climate, we need to be able to predict future CO_2 cycle and budgets

Global Carbon Cycle



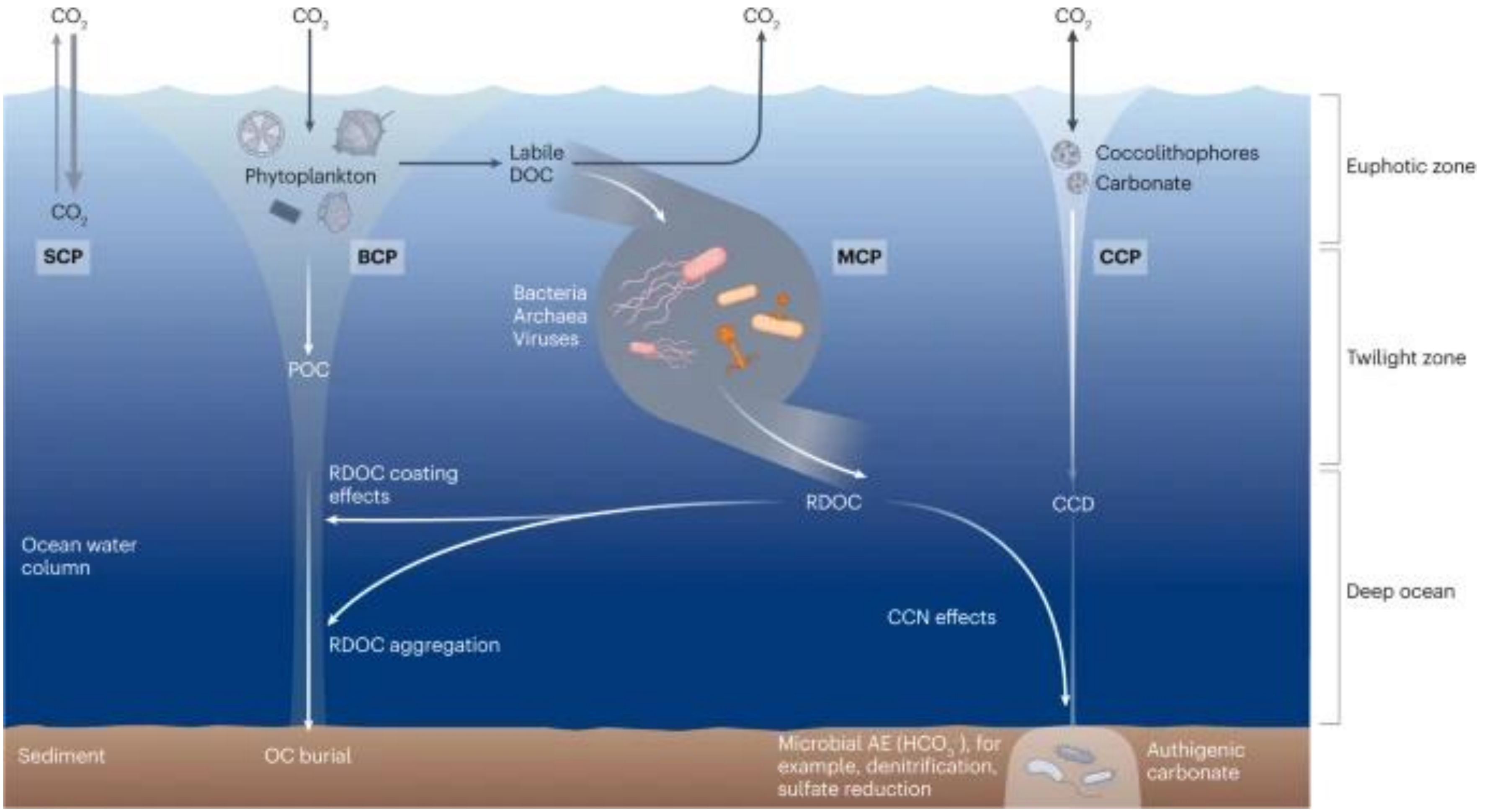
IPCC, 2021

Ocean-Air Carbon Flux



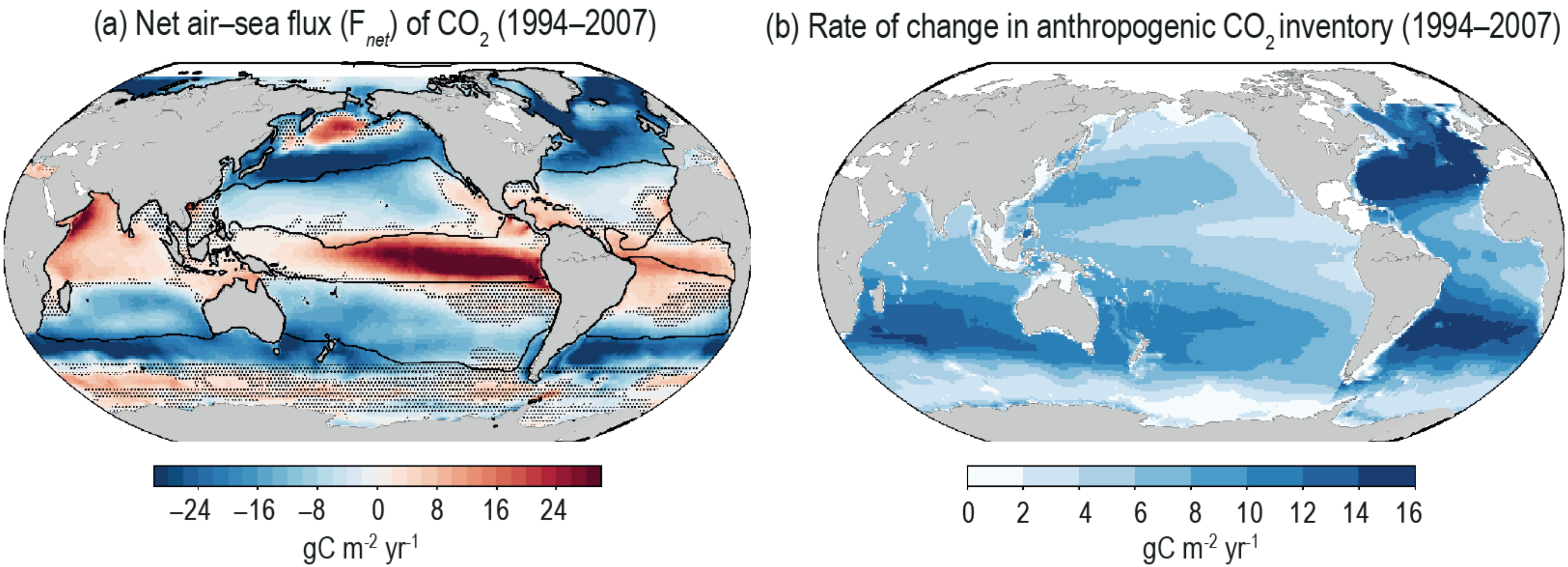
$$CO_2 + CO_3^{2-} + H_2O \leftrightarrow 2\,HCO_3^-$$

Ocean-Air Carbon Flux



Jiao Nianzhi et al., Nature Reviews Microbiology, 2024

Ocean-Air Carbon Flux



正值为净排放

IPCC, 2021

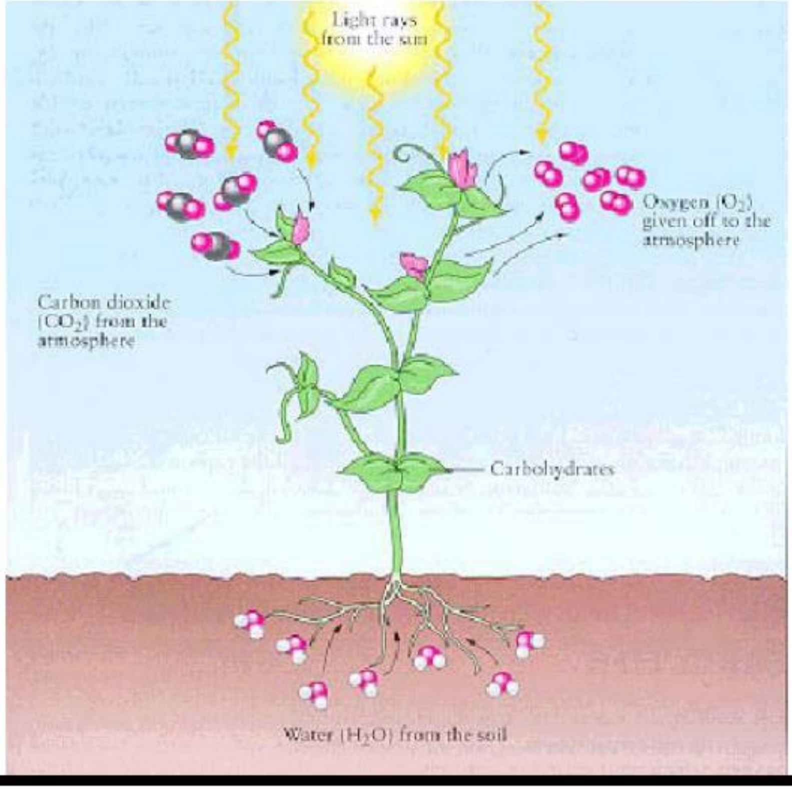
DIC: CO_2， HCO_3^-， CO_3^{2-}
DOC
POC

Land-Air Carbon Flux

How do plants process carbon?

Photosynthesis: $CO_2 + H_2O + \text{energy} \rightarrow O_2 + \text{organic C}$

Flux of CO2 from the atmosphere through photosynthesis is 120 billions of metric tons/year



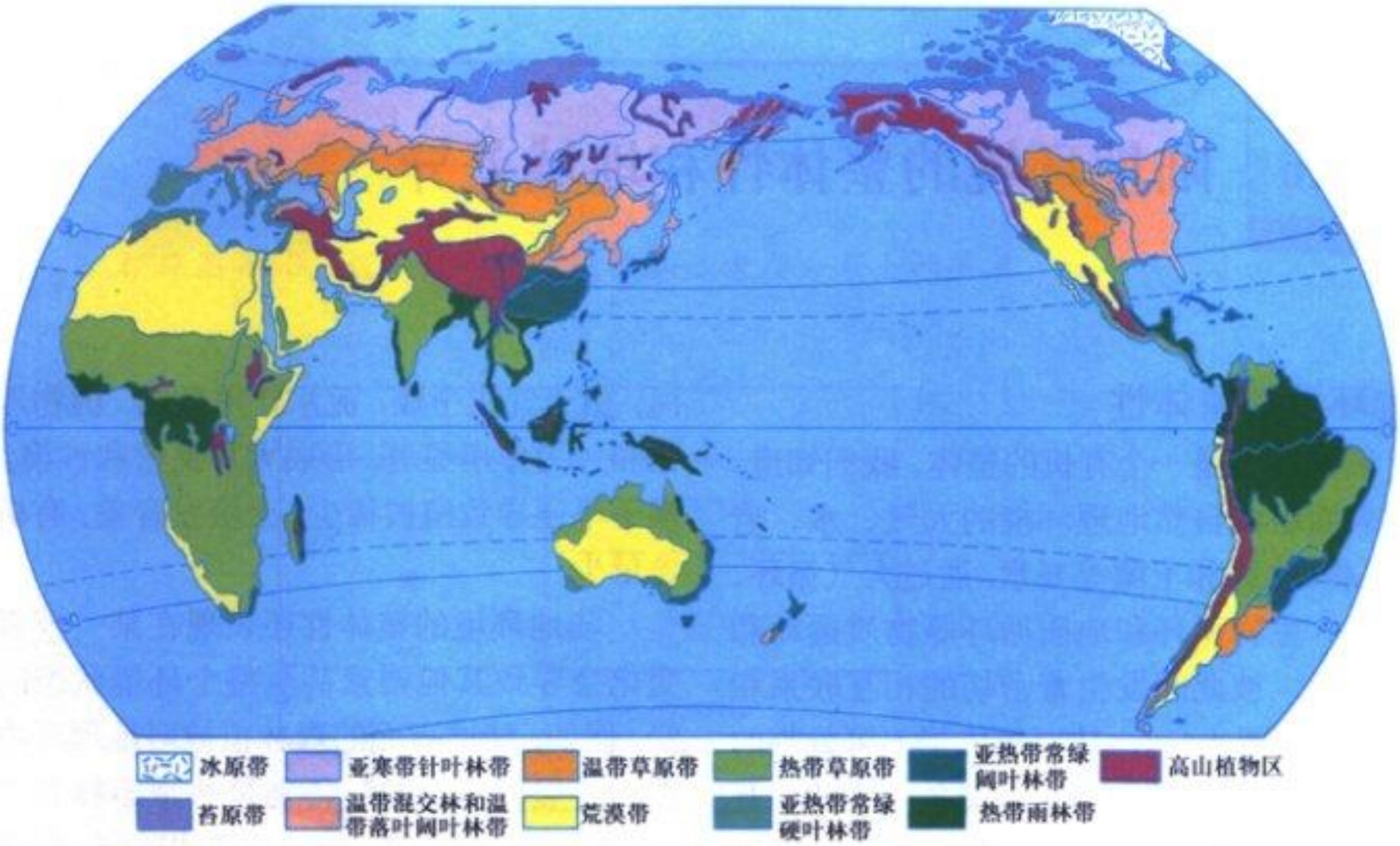
Residence time of carbon in plants ~5 years

Respiration: $C_6H_{12}O_6 + O_2 \longrightarrow CO_2 + H_2O + \text{energy}$

glucose **Oxygen** **Carbon dioxide** **water**

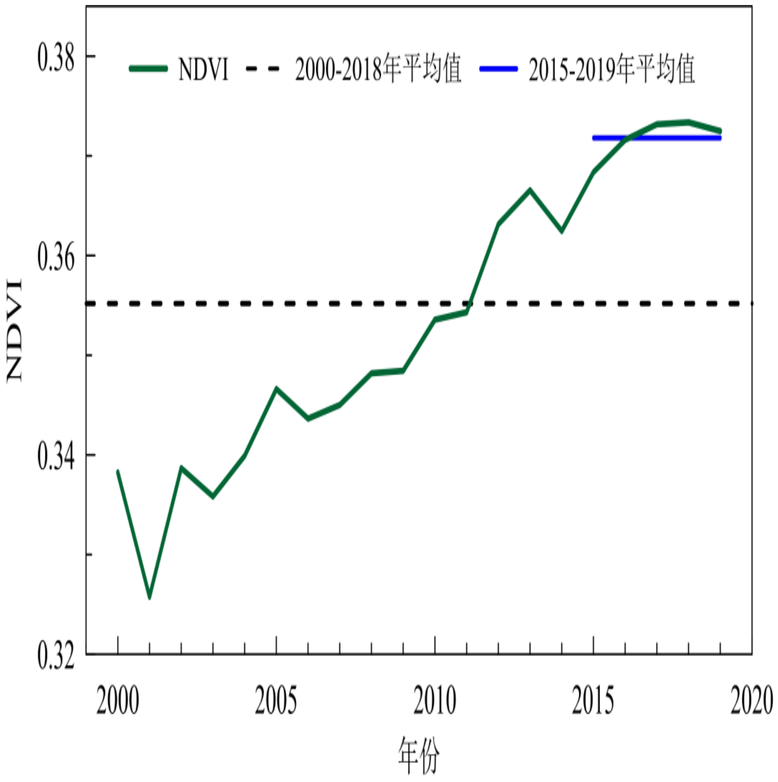
Flux of CO2 from land plants back to the atmosphere through respiration is 120 billions of metric tons/yr

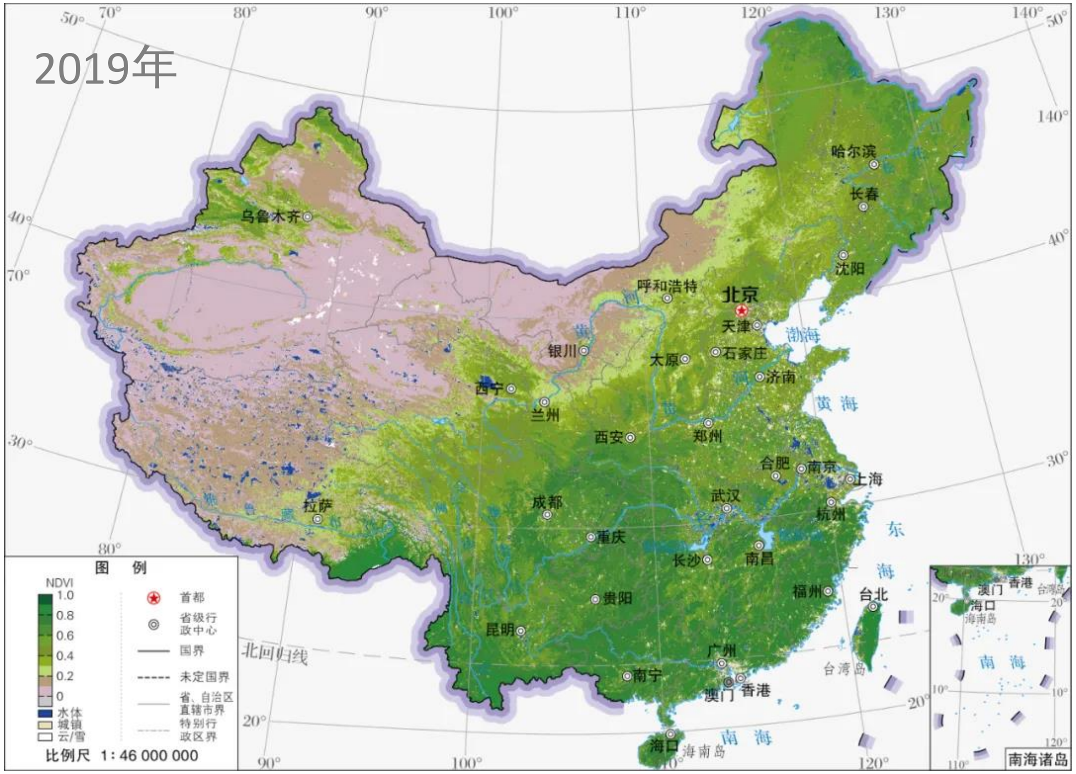
全球植被分布图


冰原带
亚寒带针叶林带
温带草原带
热带草原带
亚热带常绿阔叶林带
高山植物区
苔原带
温带混交林和温带落叶阔叶林带
荒漠带
亚热带常绿硬叶林带
热带雨林带

Greening in China in the 21st Century

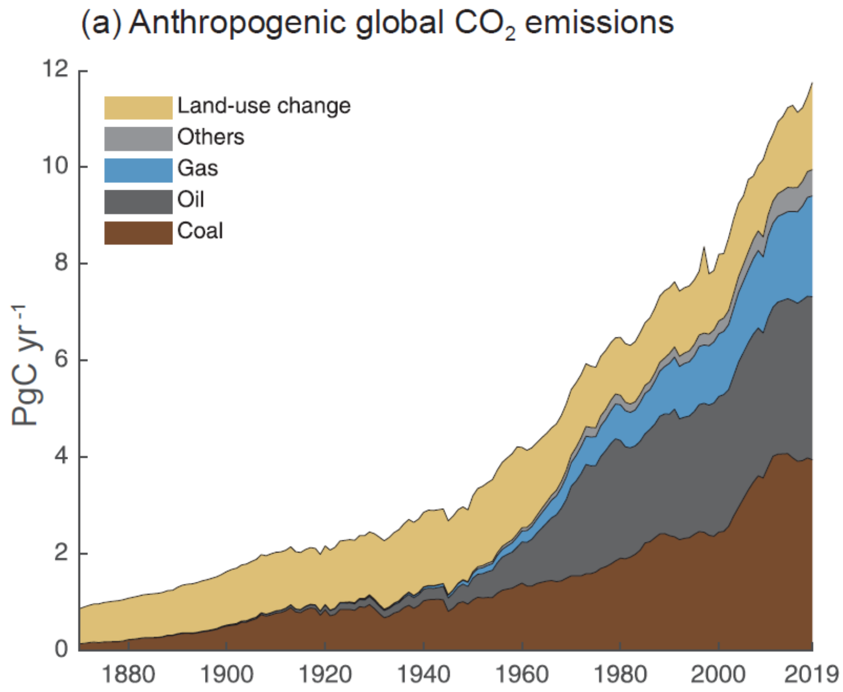
中国归一化差植被指数(MODIS)

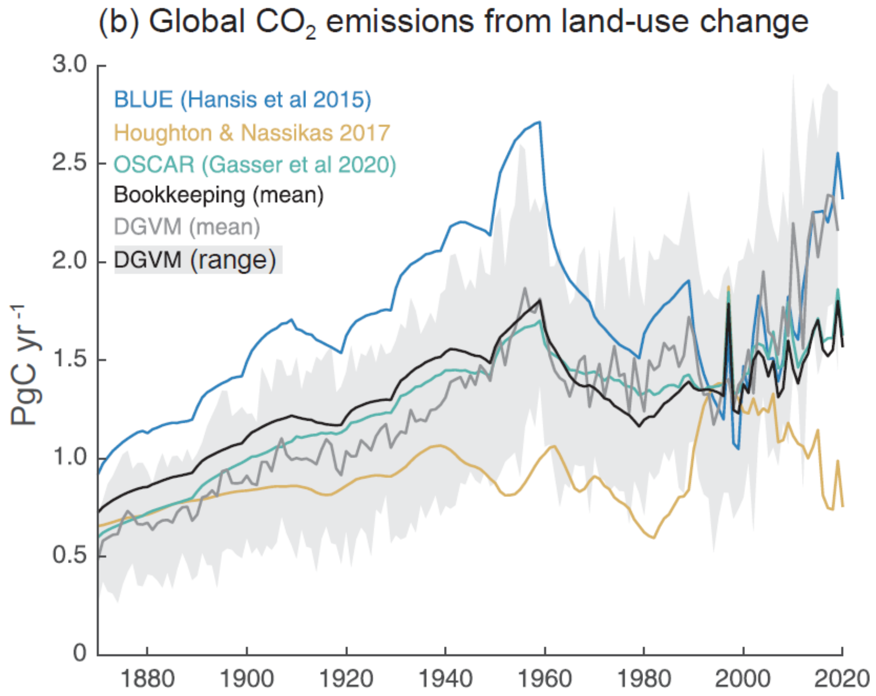




中国气候变化蓝皮书 2020

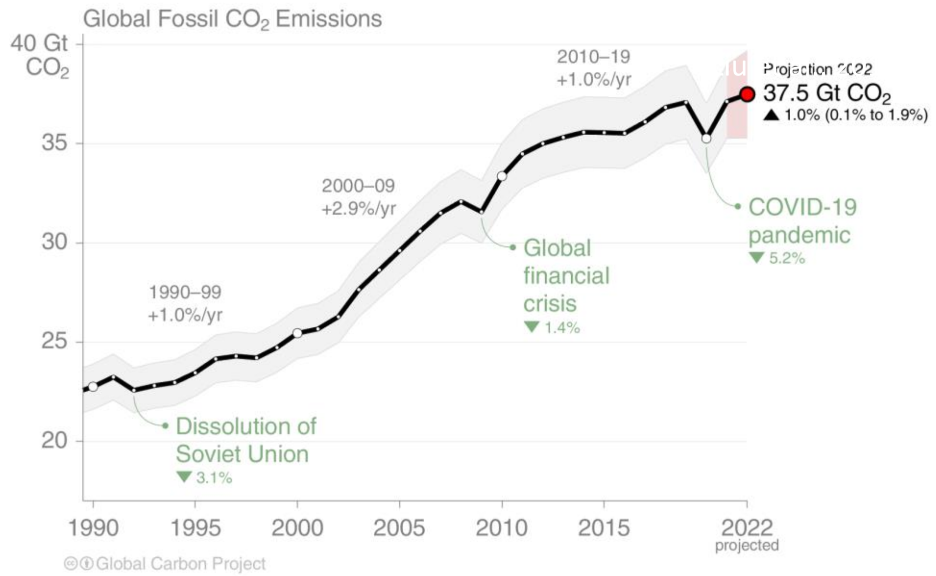
Changes in Global CO_2 Emissions



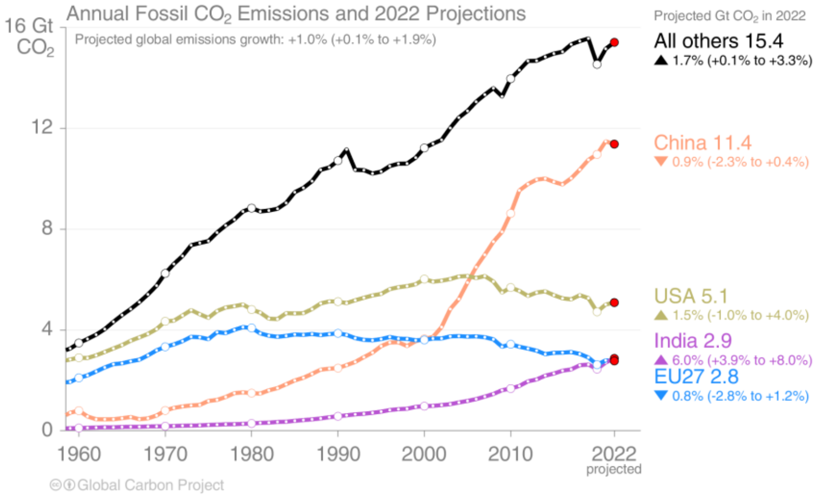


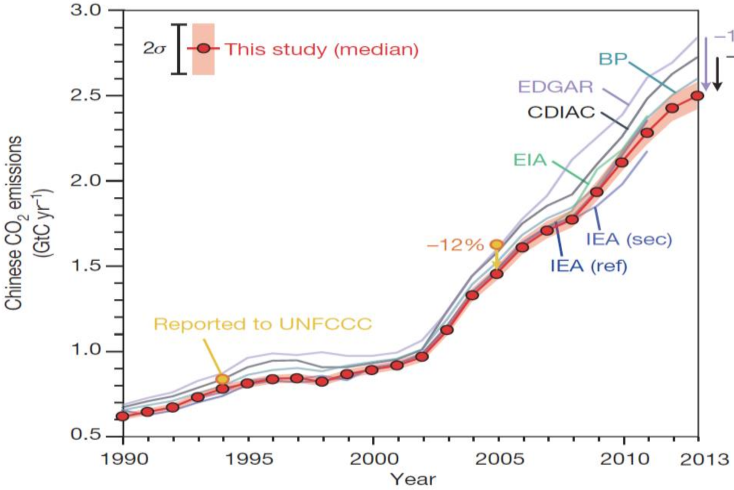
IPCC, 2021

Changes in Global Anthropogenic CO_2 Emissions

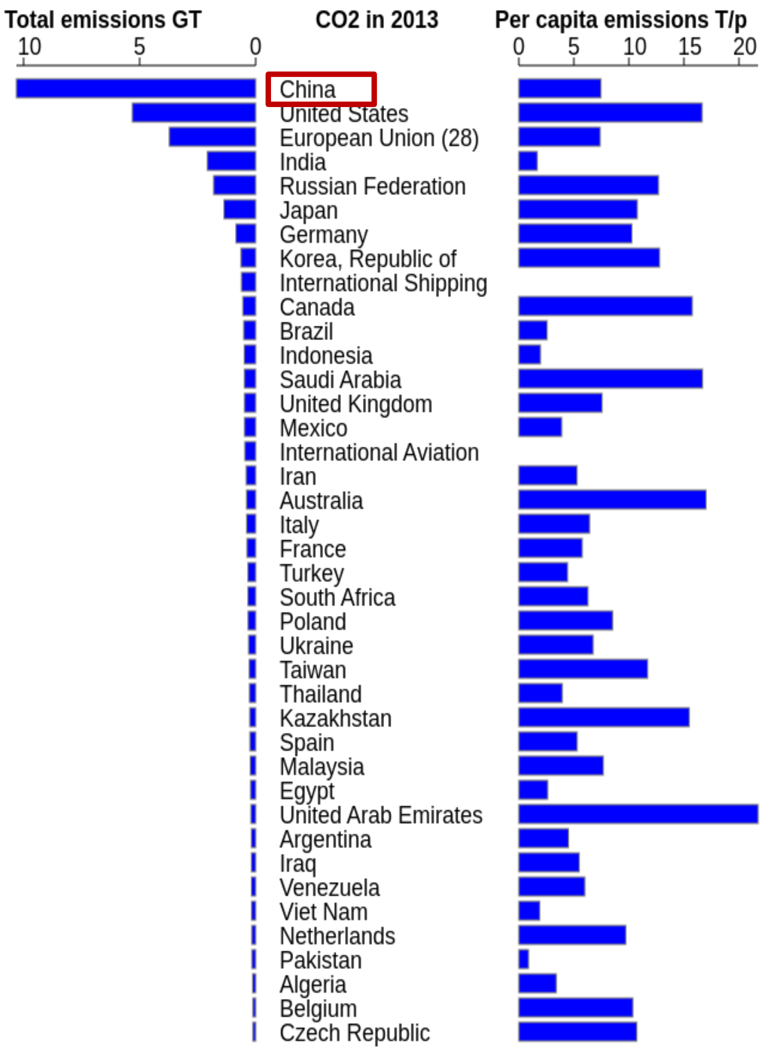


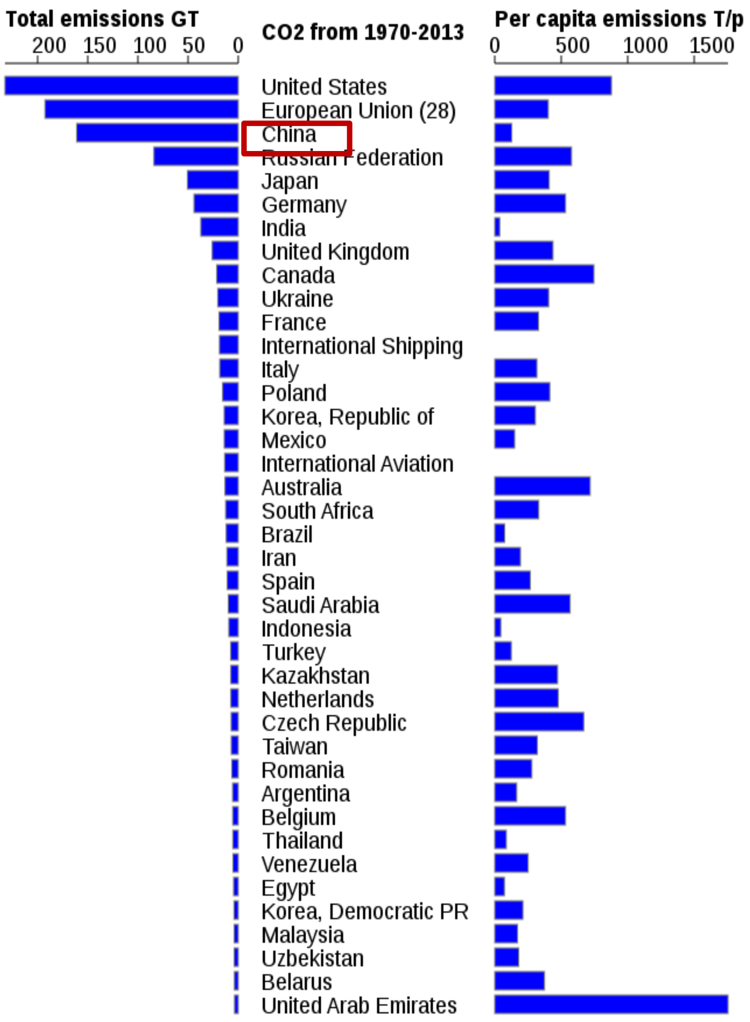
Liu et al., Nature, 2015





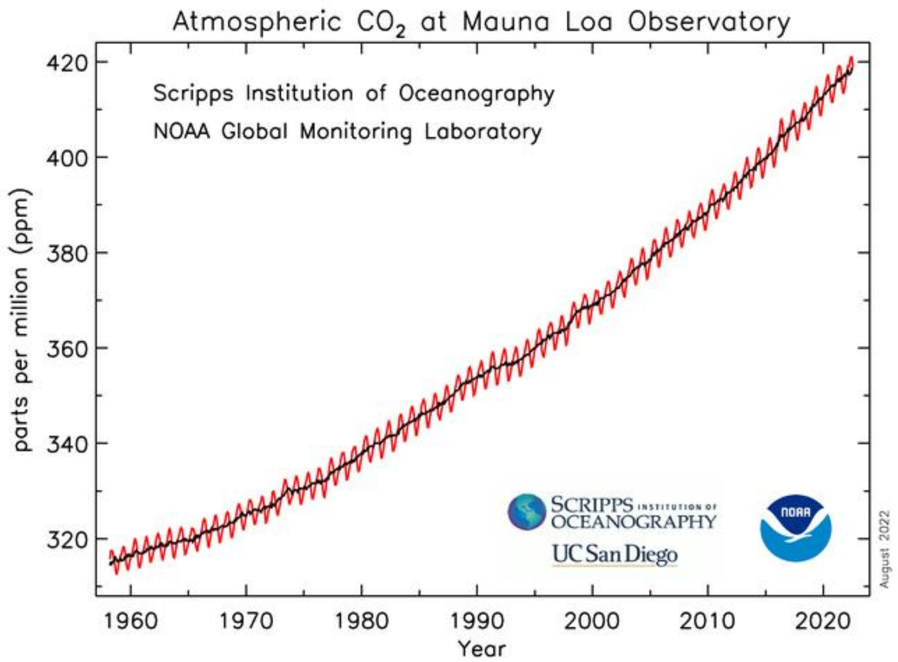
Changes in Global Anthropogenic CO_2 Emissions

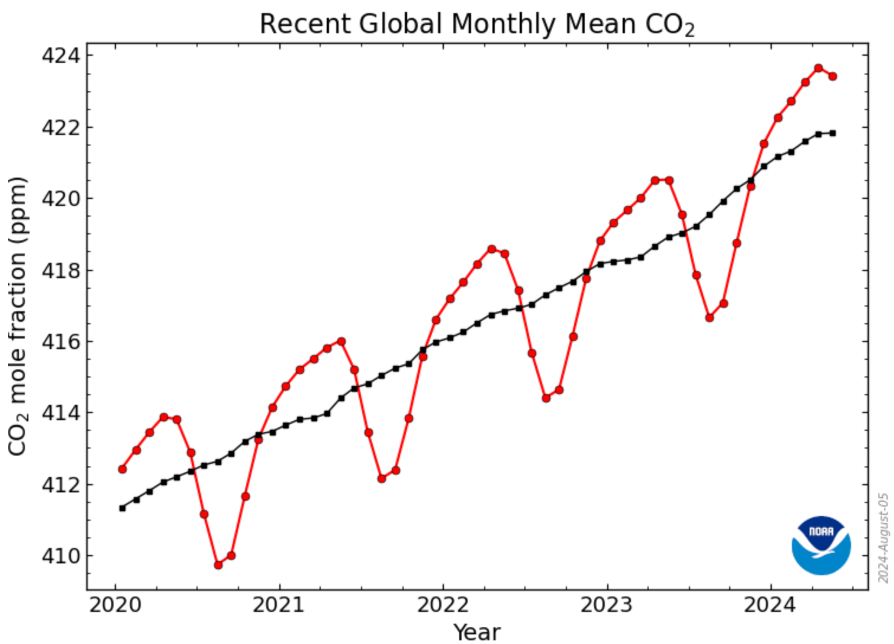




Wikipedia

Recent Trend in CO_2 Concentrations: 1958/03–Present

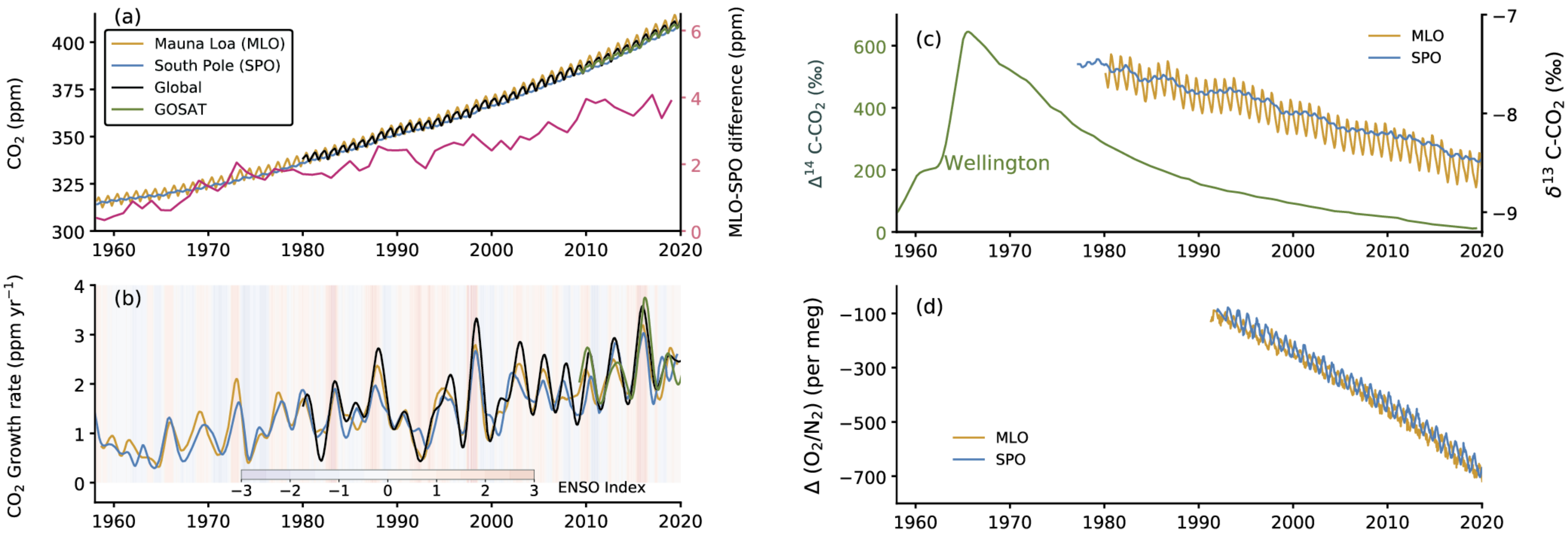




https://gml.noaa.gov/ccgg/trends/

Accelerating Global Atmospheric CO_2 Growth

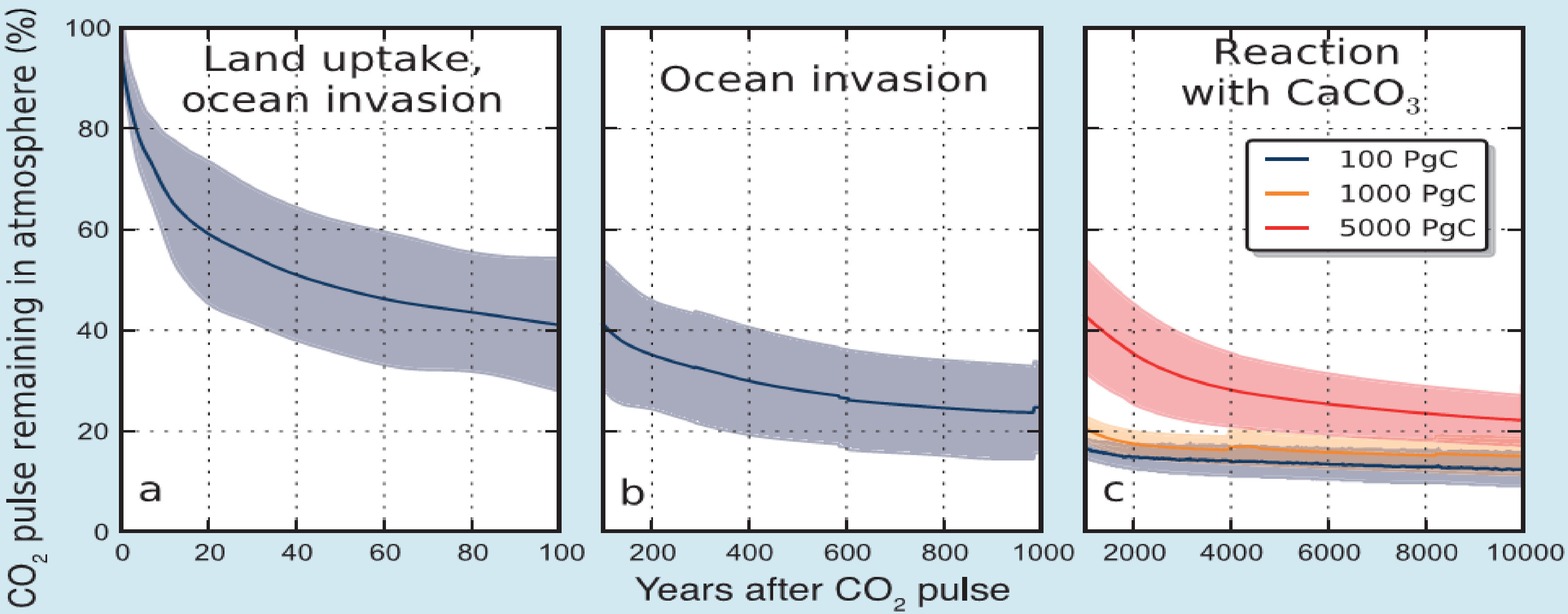
Atmospheric Carbon dioxide (CO_2) and Oxygen (O_2)



IPCC, 2021

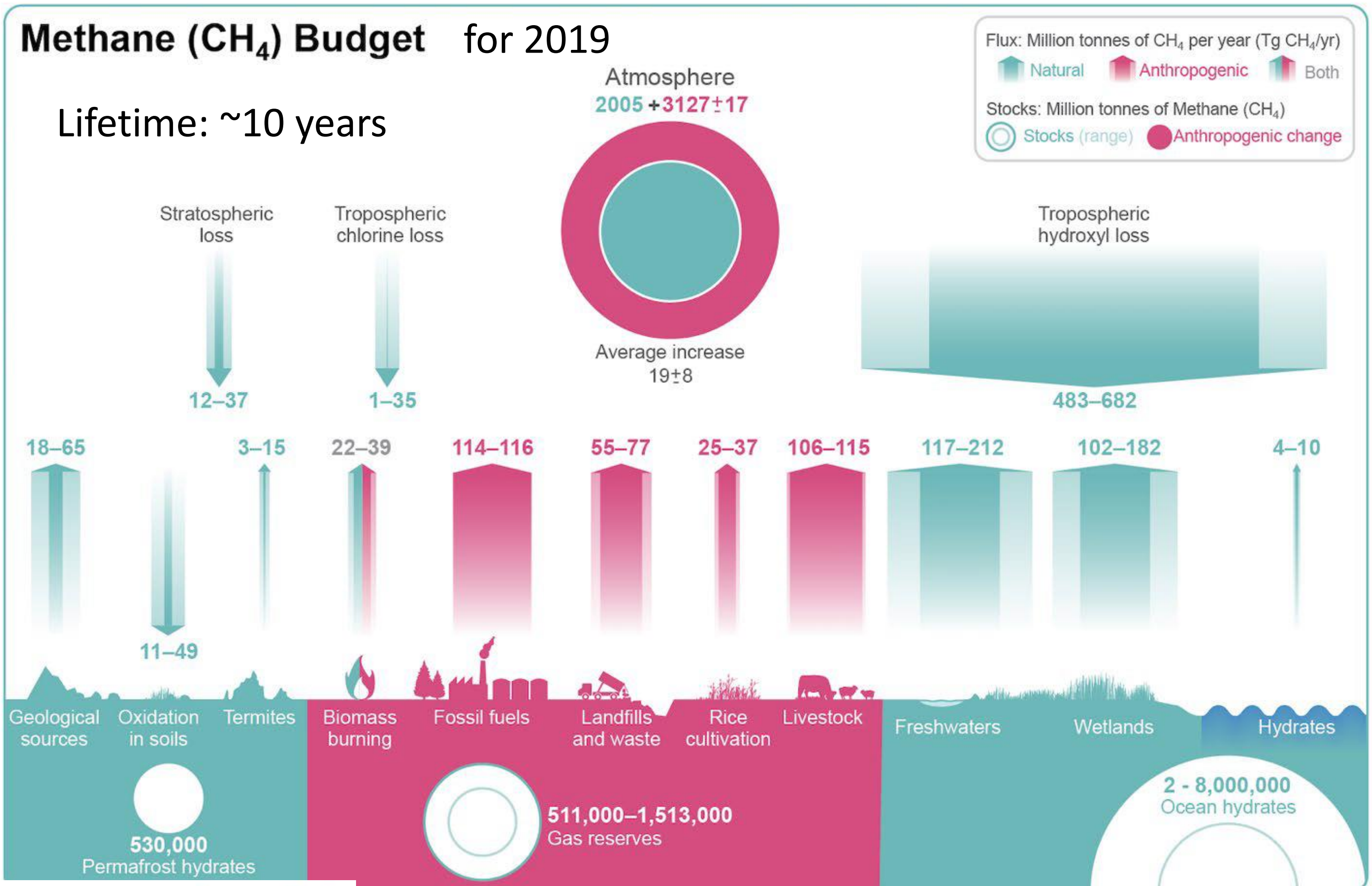
CO_2 Lifetimes

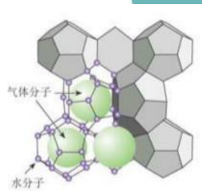
Processes	Time scale (years)	Reactions
Land uptake: Photosynthesis–respiration	$1–10^2$	$6CO_2 + 6H_2O + photons \rightarrow C_6H_{12}O_6 + 6O_2$ $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + heat$
Ocean invasion: Seawater buffer	$10–10^3$	$CO_2 + CO_3^{2-} + H_2O \rightleftharpoons 2HCO_3^-$
Reaction with calcium carbonate	$10^3–10^4$	$CO_2 + CaCO_3 + H_2O \rightarrow Ca^{2+} + 2HCO_3^-$
Silicate weathering	$10^4–10^6$	$CO_2 + CaSiO_3 \rightarrow CaCO_3 + SiO_2$



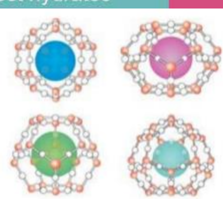
IPCC, 2013

Global Methane Cycle





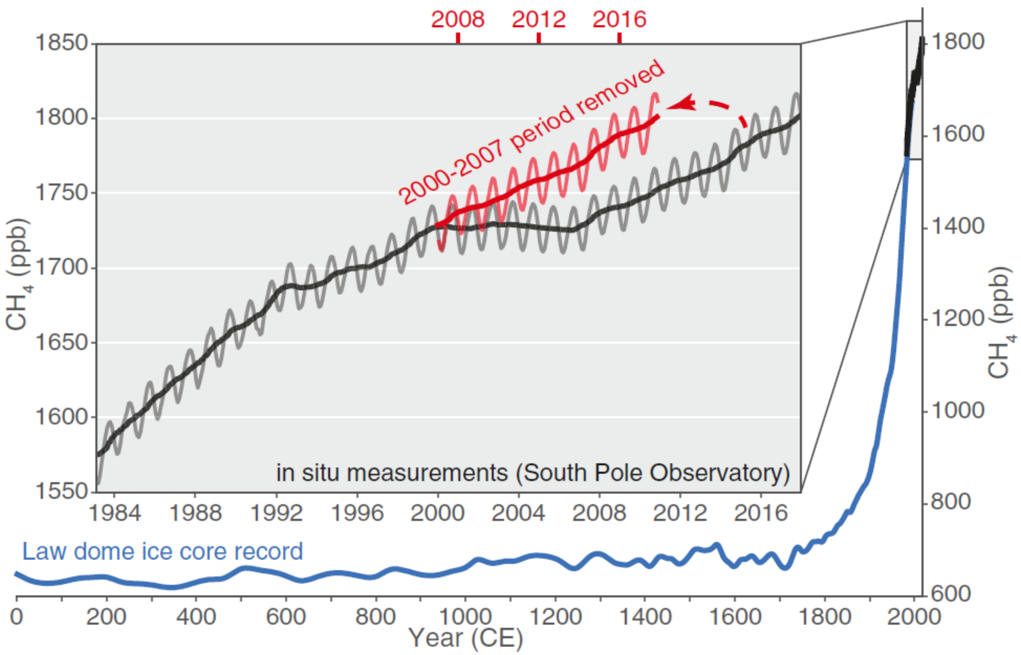
天然气分子藏在水分子笼内


水分子笼是多种多样的

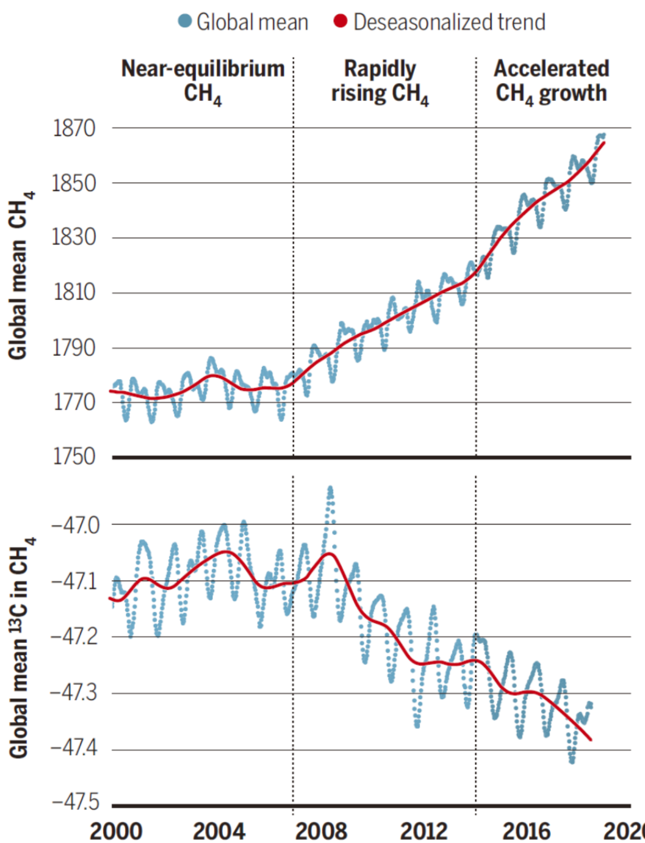
IPCC, 2021

可燃冰：CH4水合物

Global CH_4 Growth



Turner et al., 2019, PNAS

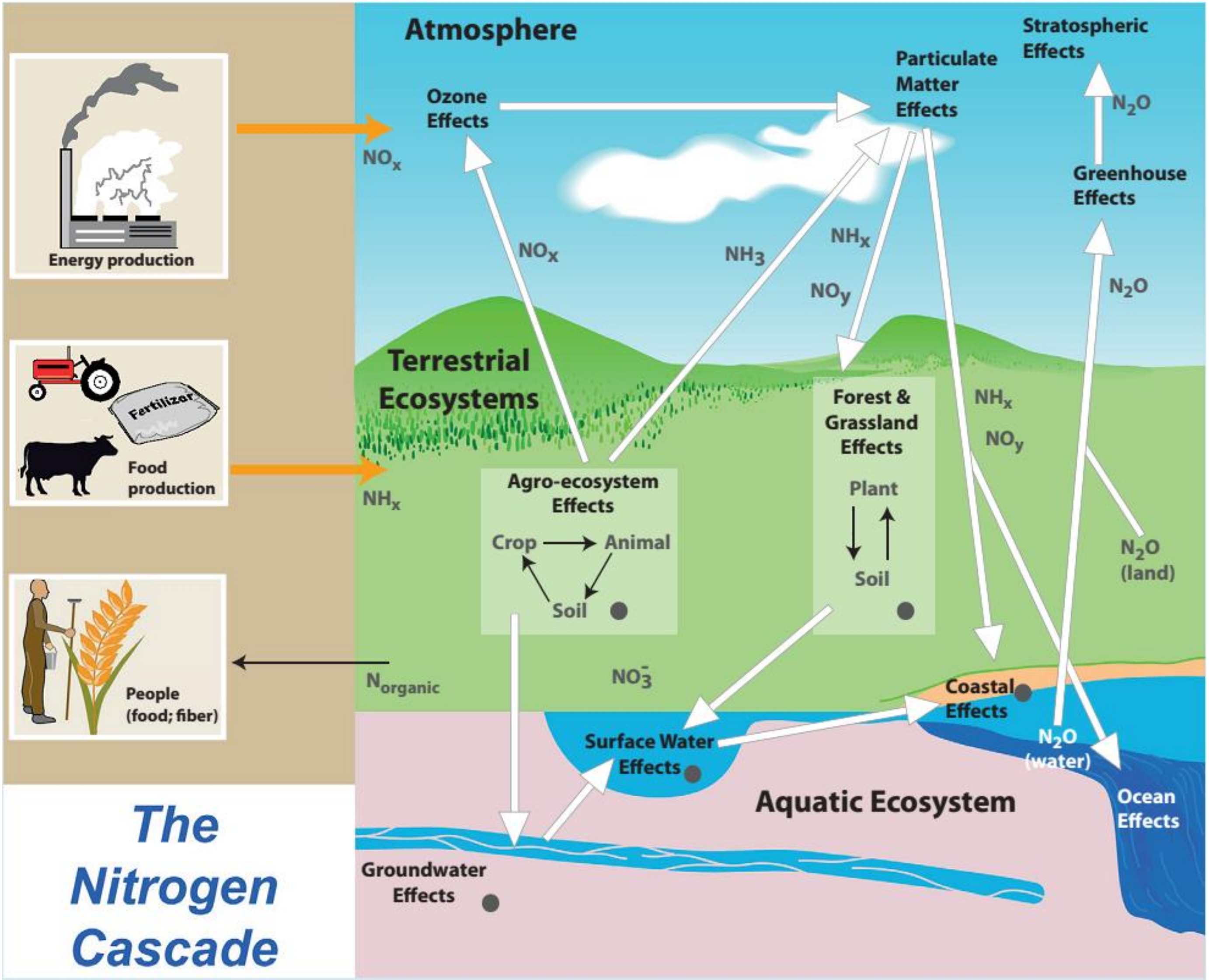


Fletcher et al., 2019, Science

Global Nitrogen Cycle: Why Should We Care?

- **Good: Important nutrition for agriculture, ecosystem**
- **Bad: Precursor of ozone, aerosols**
- **Bad: Adverse effects on air quality, climate, acid deposition, eutrophication, biodiversity threat**
- **Species: NOx, NOy, NH3, NH4, N2O**

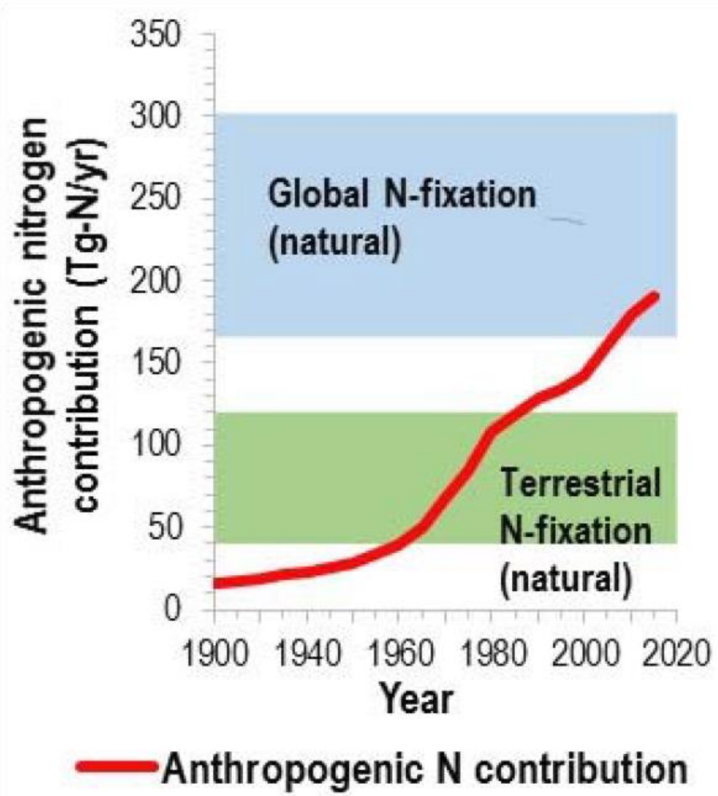
Global Nitrogen Cascade

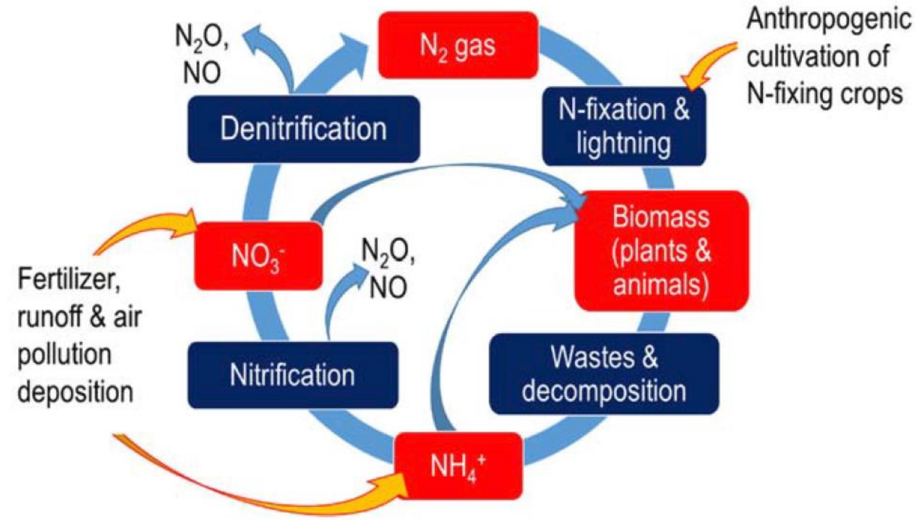


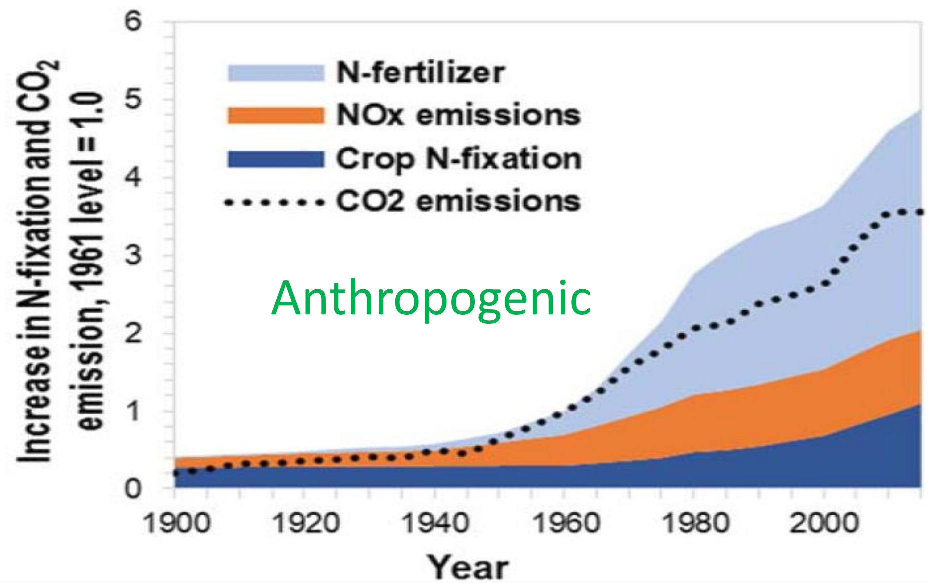
Haber-Bosch Process: $N_2 + 3H_2$ (+ Catalyst) $\leftrightarrow 2NH_3$

IPCC, 2013

Global Reactive Nitrogen Creation

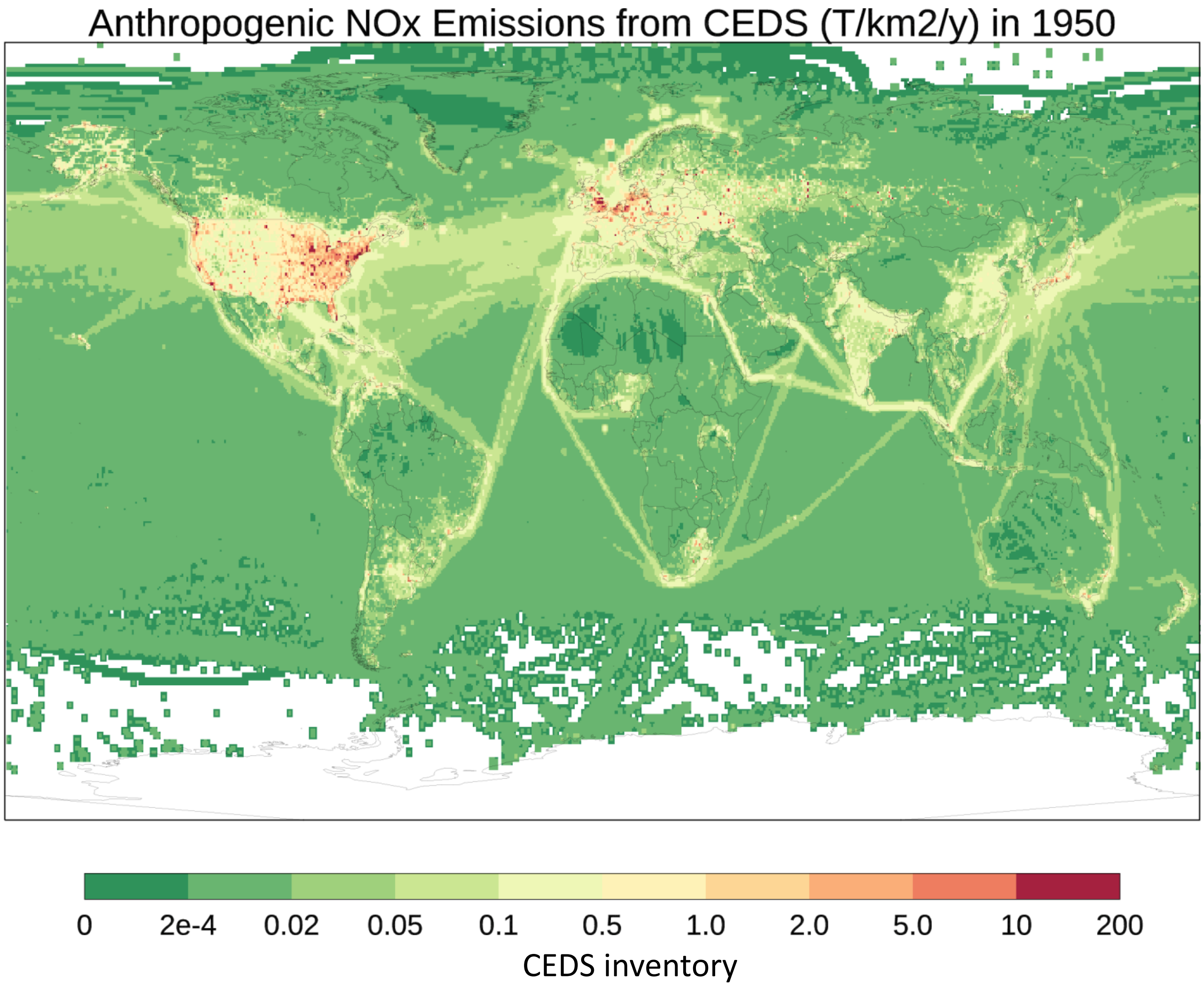






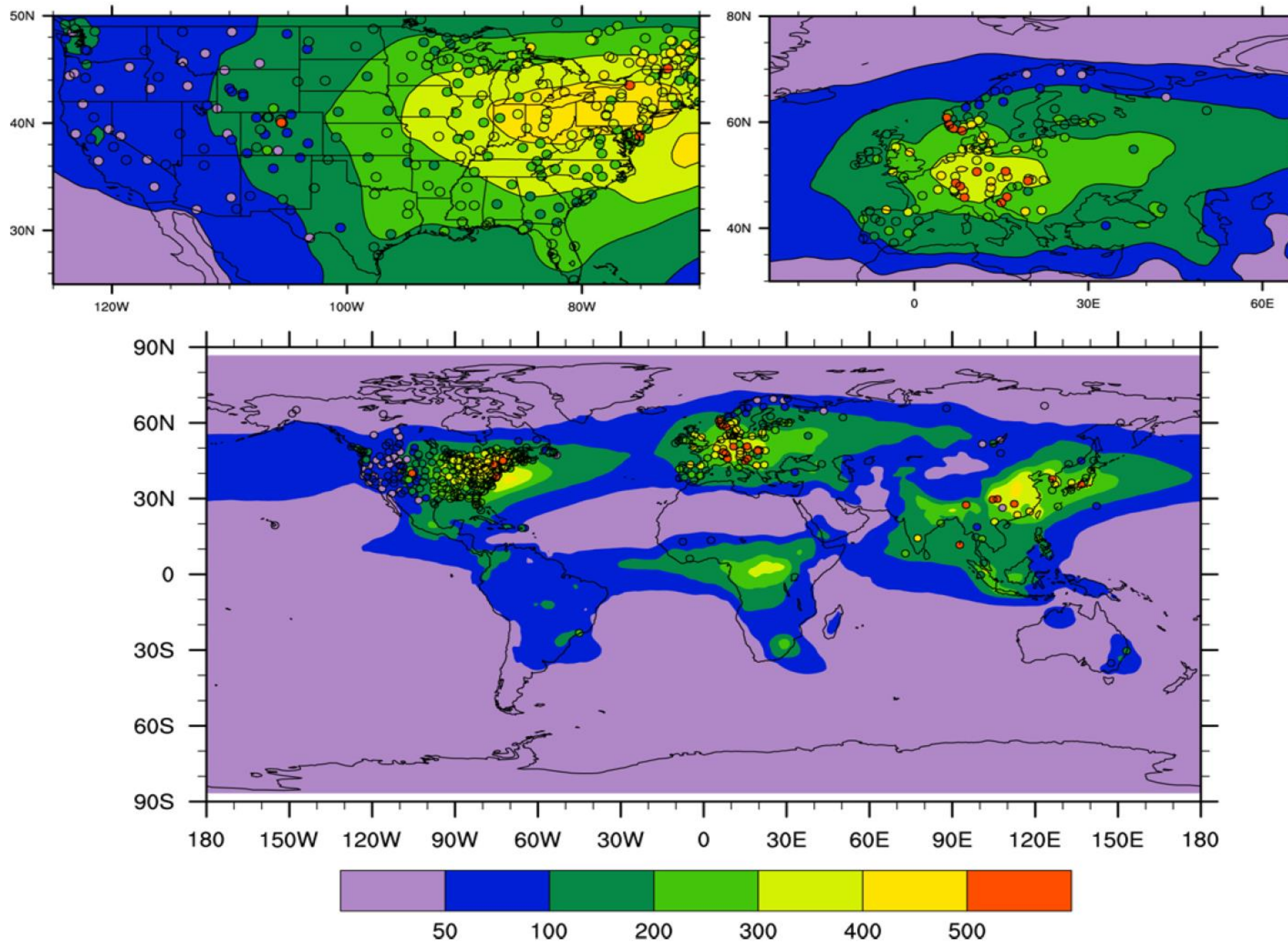
Battye et al., 2017

Anthropogenic NOx Emissions: 1950-2014

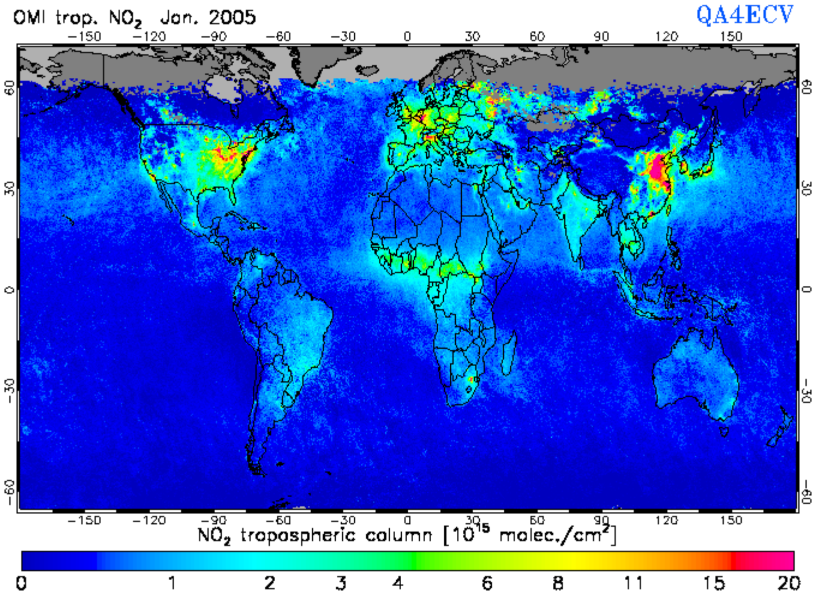


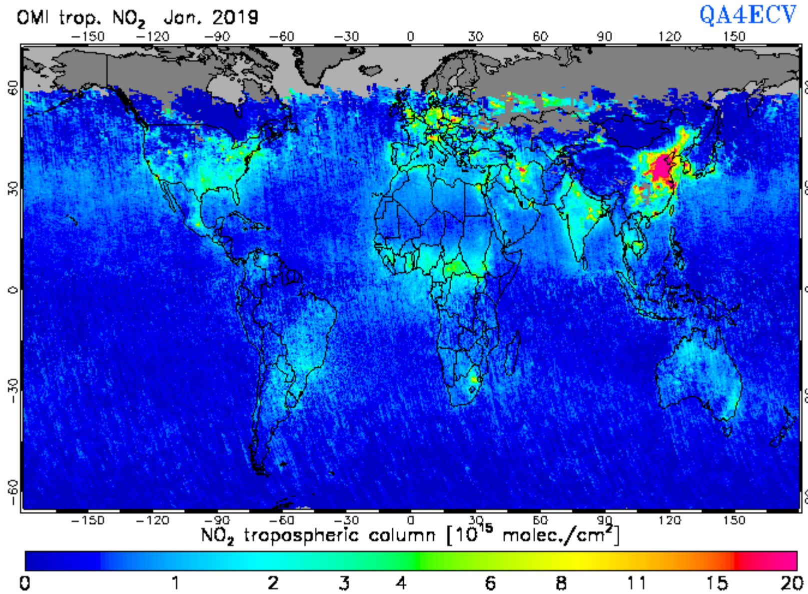
NO_3^- Wet Deposition in 2000

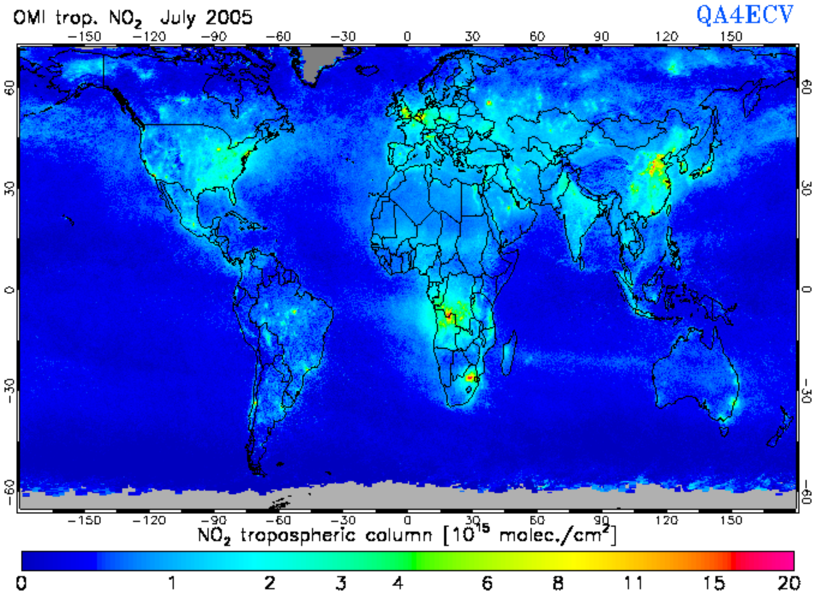
Lamarque et al., 2013, ACP, Multi-model mean

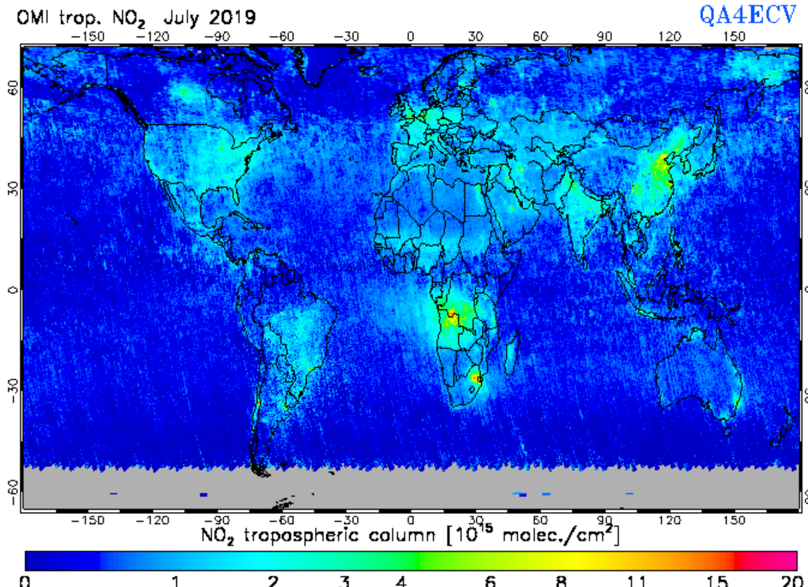


Tropospheric NO_2 Column: 2005-2019



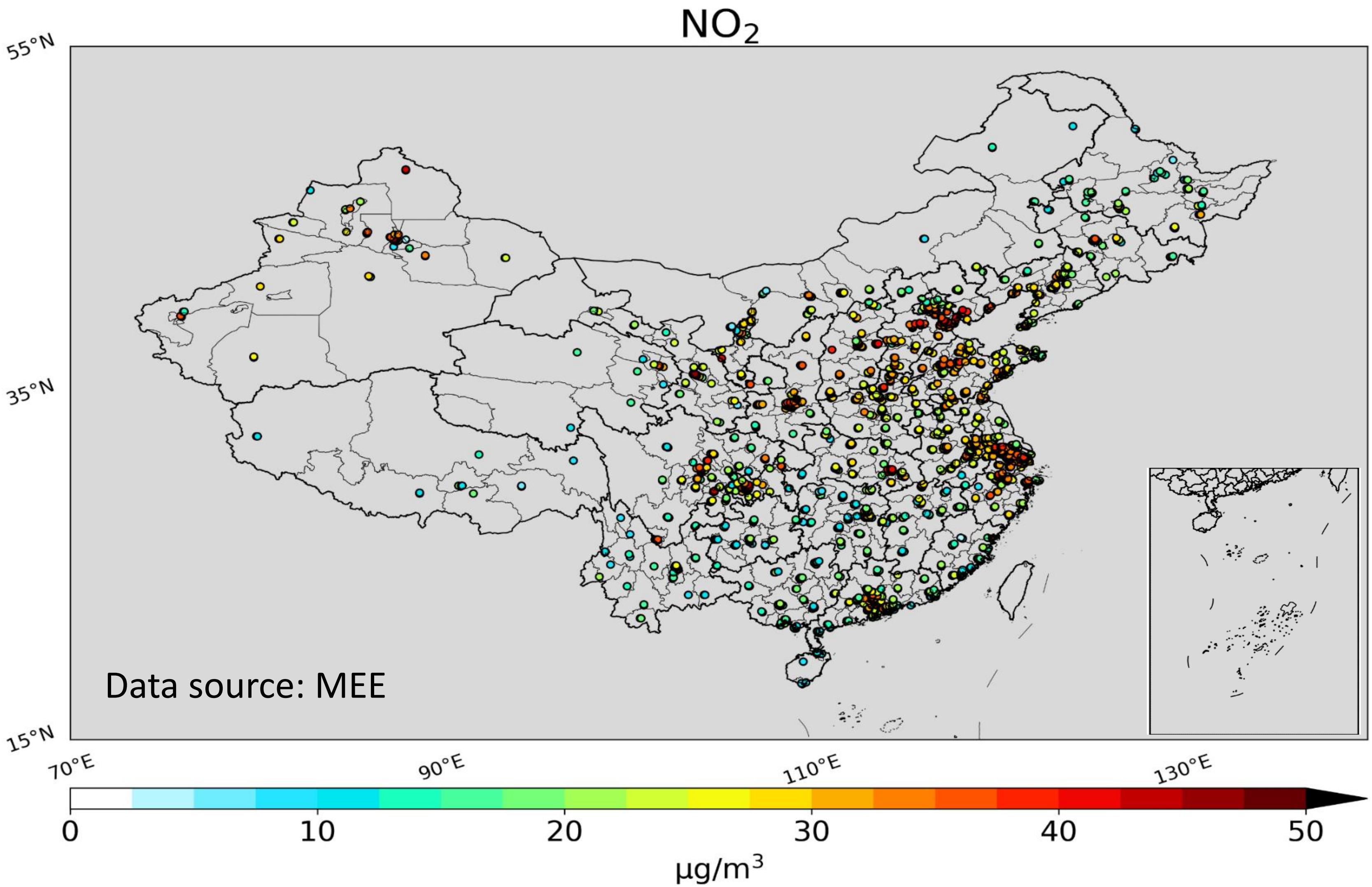






www.temis.nl

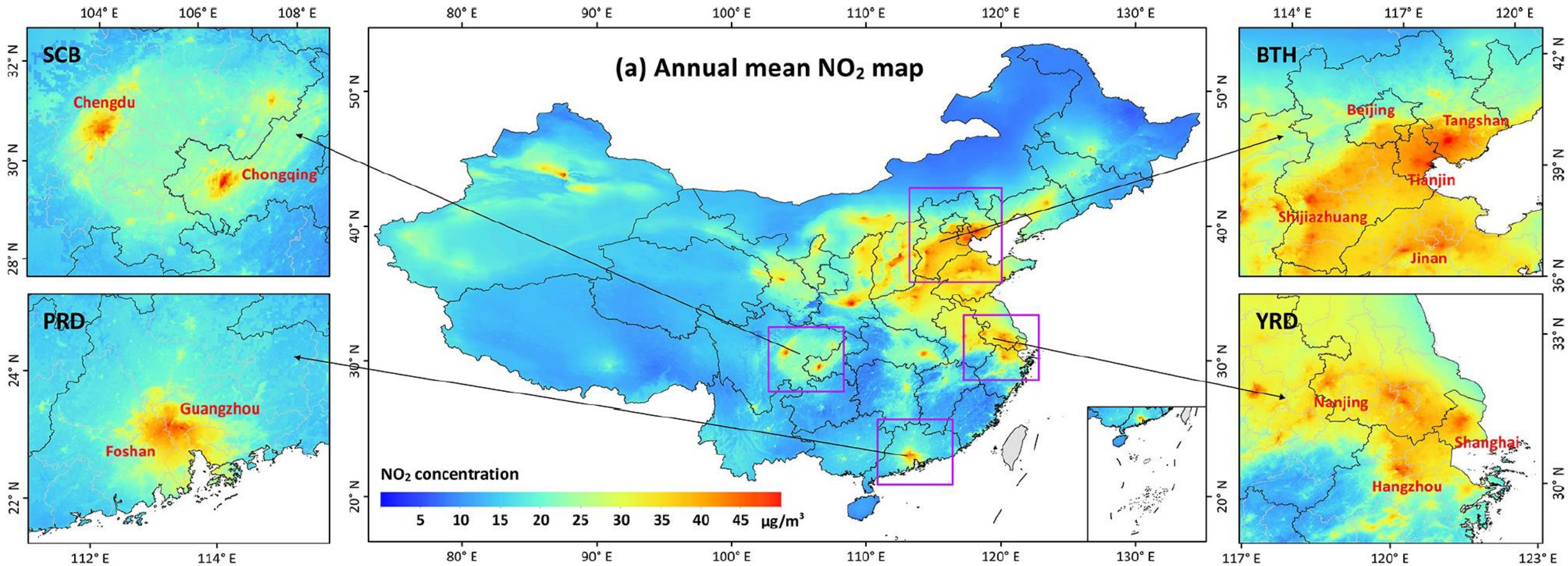
Near Surface NO_2 Concentrations Over China: 2021



国家标准：40（年均），80（24小时），200（1小时）
WHO指导值：10（年均），25（24小时）

Near Surface NO_2 Concentrations Over China: 2019-2020

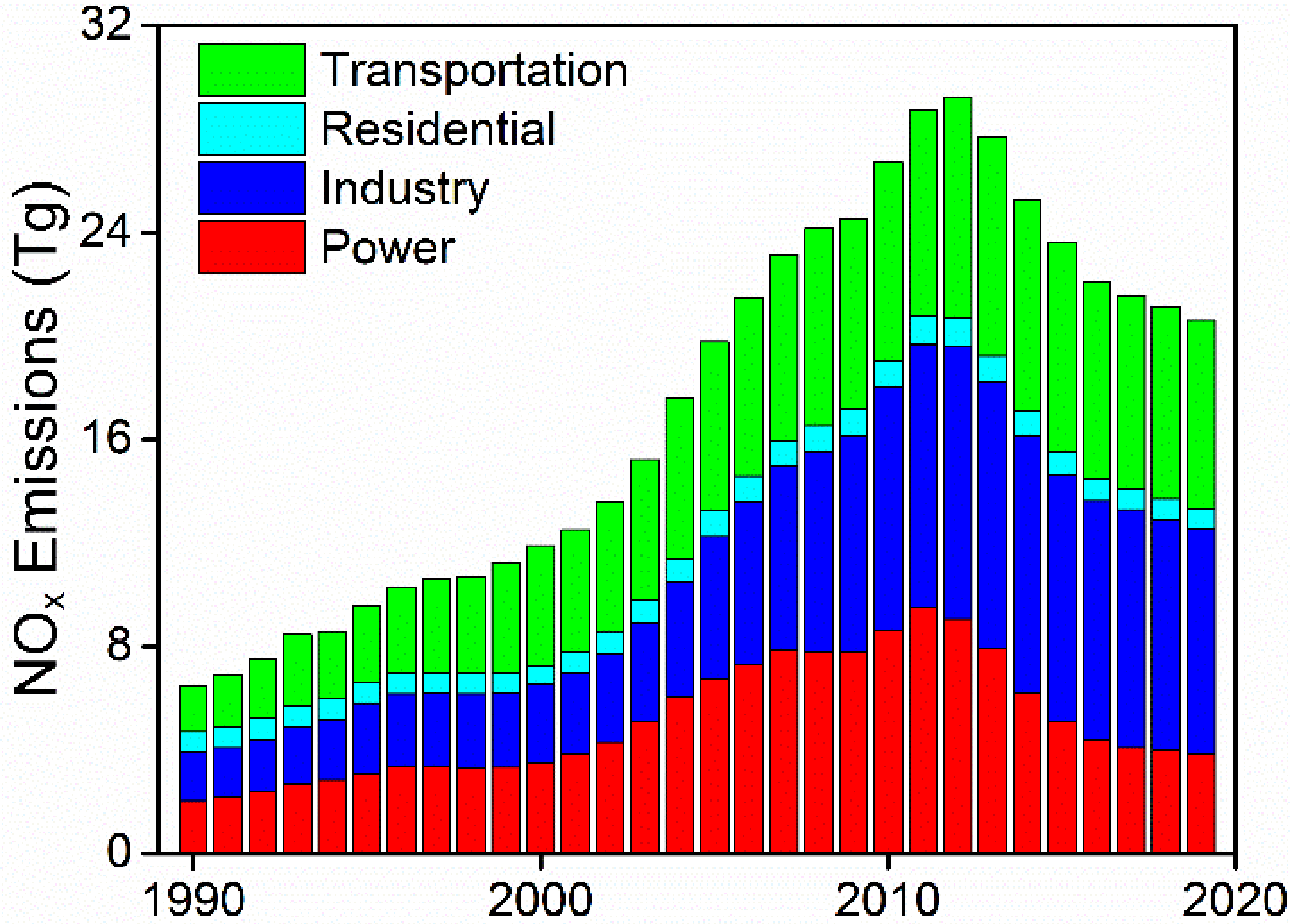
Estimated based on satellite NO_2 VCDs and machine learning



Wei et al., EST, 2022

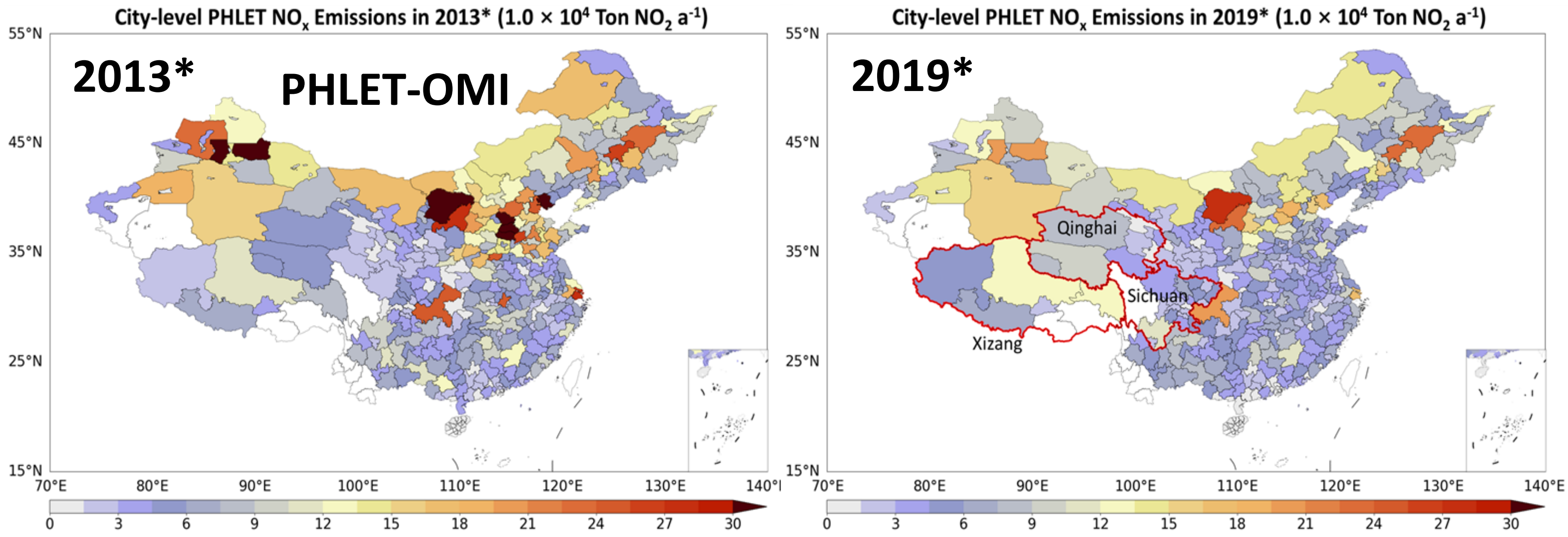
国家标准：40（年均），80（24小时），200（1小时）
WHO指导值：10（年均），25（24小时）

Emission Trends in MEIC Database: NO_x

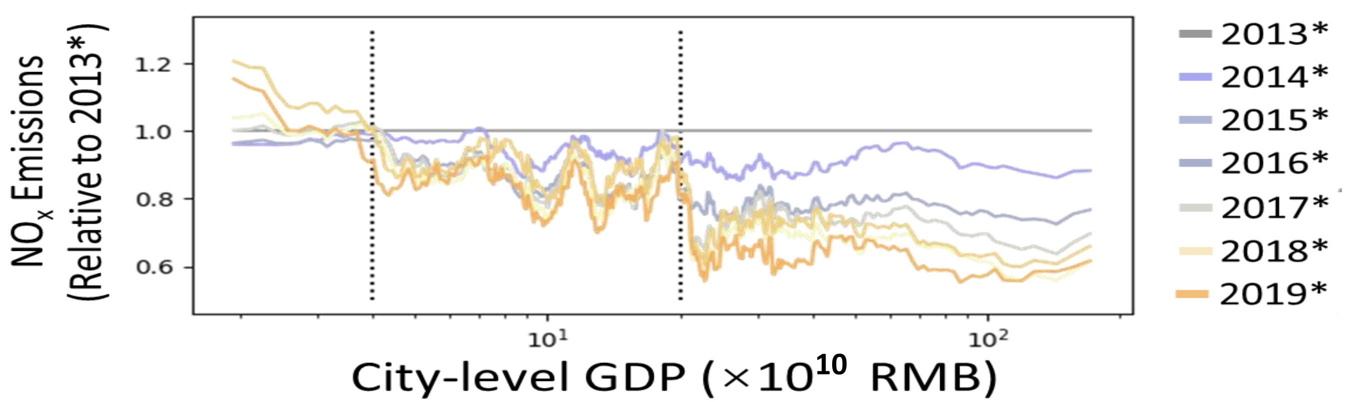


Source: Bo Zheng

High-Resolution NOx Emission Retrieval Data
Reveal Large Inter-City Disparity in Anthro. Emis. Trends

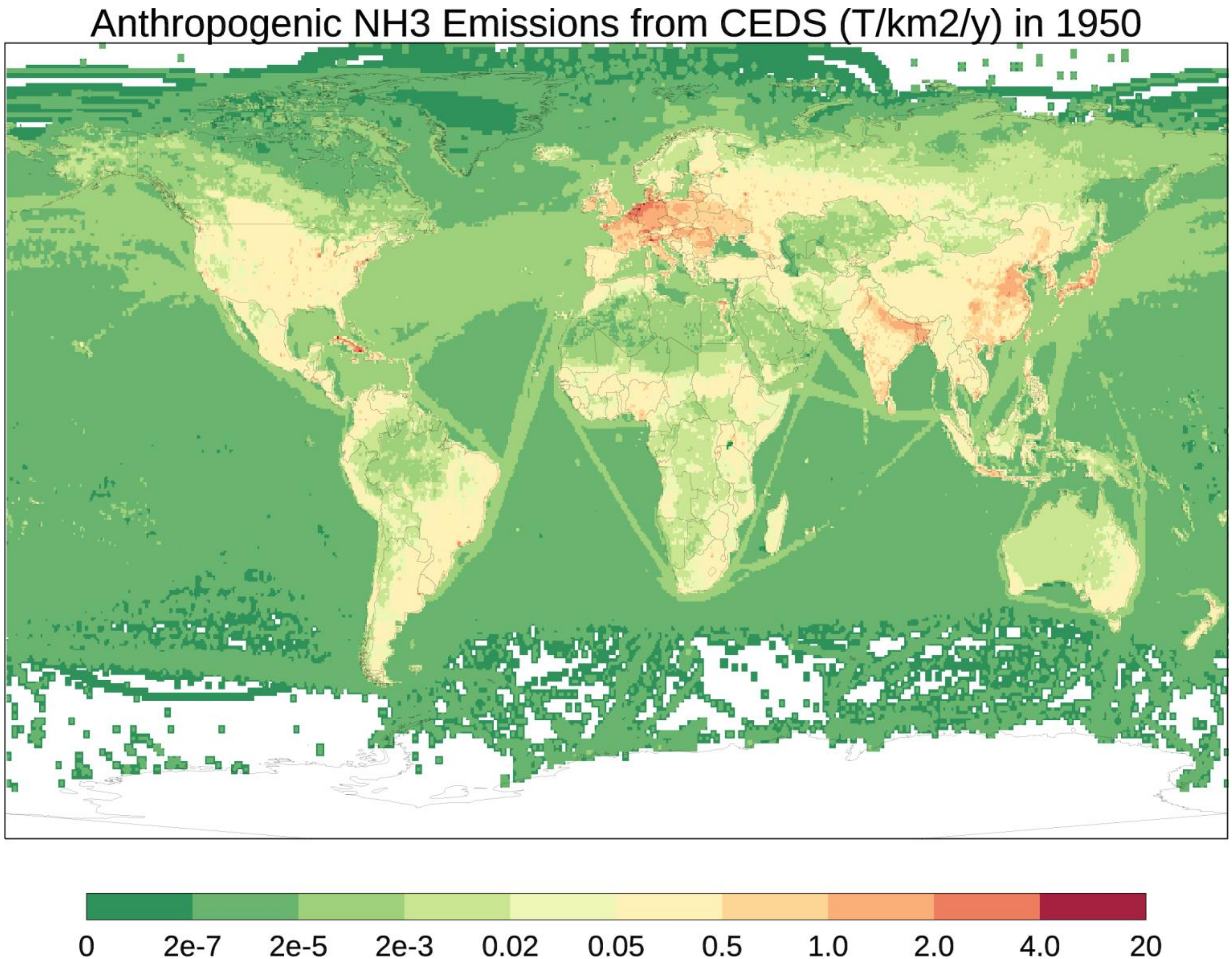


Emission change versus Economic volume



Kong et al., in prep

Anthropogenic NH_3 Emissions: 1950-2014



CEDS inventory

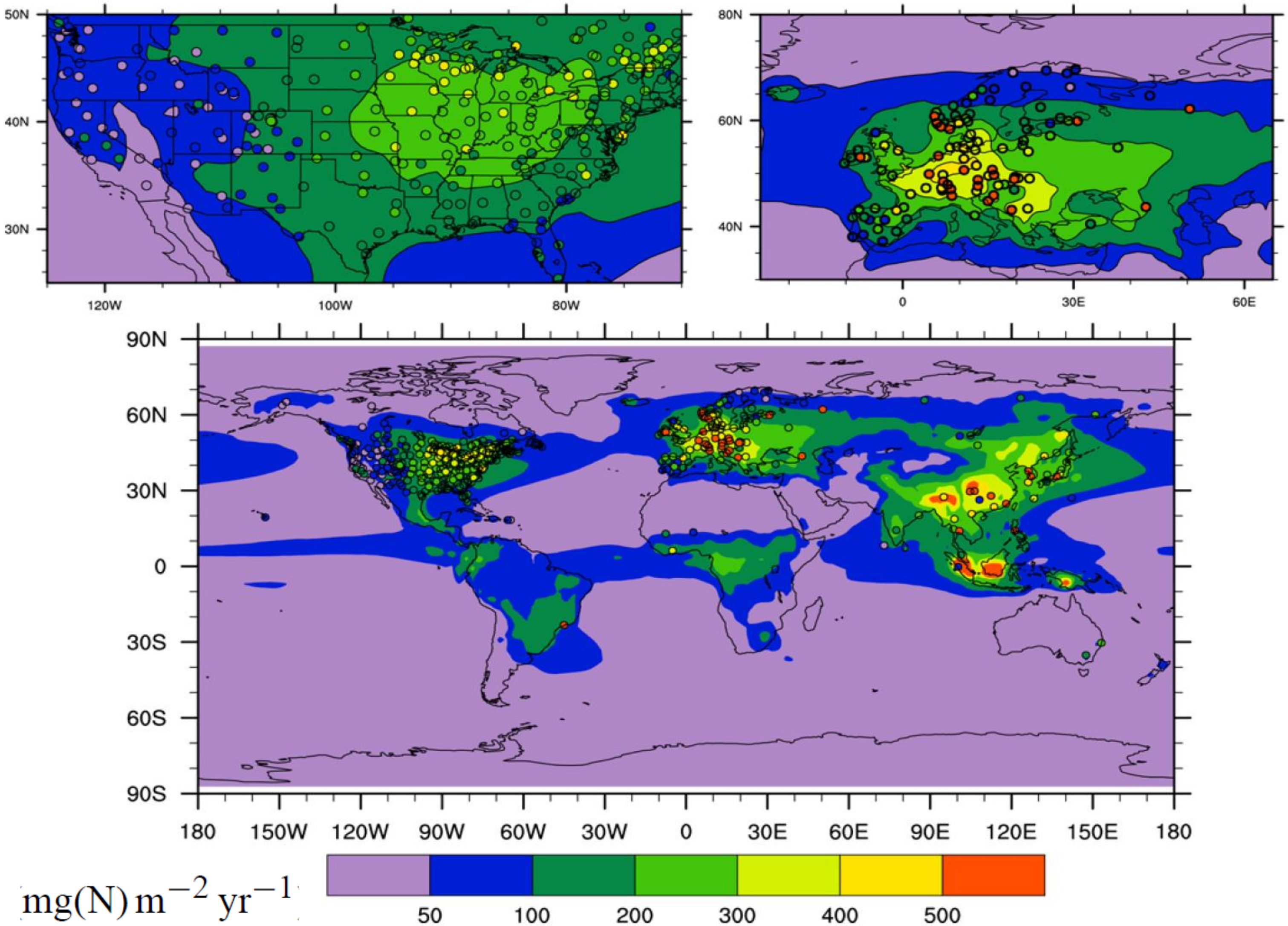
Large Uncertainty in Anthropogenic NH_3 Emissions in China

References	Base year	Fertilizer application	Livestock waste	Human	Others[2]	Total
Yan et al. (2003)	1995	4.32	2.48[3]	0.21		7.01
Streets et al. (2003)	2000	6.8	5.17	1.63		13.6
Li and Li (2012)	2004	1.82	8.30	1.67	0.21	12.0
Wang et al. (2009)	2005	4.3	8.82	0.26		13.38
Zhang et al. (2011)	2005	4.31				
Dong et al. (2010)	2006	8.68	6.61	0.65	0.14	16.08
Huang et al. (2012)	2006	3.2	5.3	0.2	1.1	9.8
Cao et al. (2010)	2007	3.62	9.58		2.8	16.0
EDGAR	2008	8.1	3.1	0.1		11.3
Xu et al. (2016)	2008	3.3	3.8[3]	0.7	0.6	8.4
Paulot et al. (2014) (MASAGE)	2008	3.6	5.8	0.8		10.2
Kurokawa et al. (2013) (REAS v2)	2008	9.46	2.88	1.81	0.85	15.0
Zhao et al. (2013)	2010	9.82	7.36	1.12		18.3
Fu et al. (2015)	2011	3				
Kang et al. (2016)	2012	2.8	4.99	0.12	1.71	9.62
This study	2008	5.05	5.31	1.30[4]		11.7

Zhang et al., 2017, ACP

NH_4^+ Wet Deposition in 2000

Lamarque et al., 2013, ACP, Multi-model mean

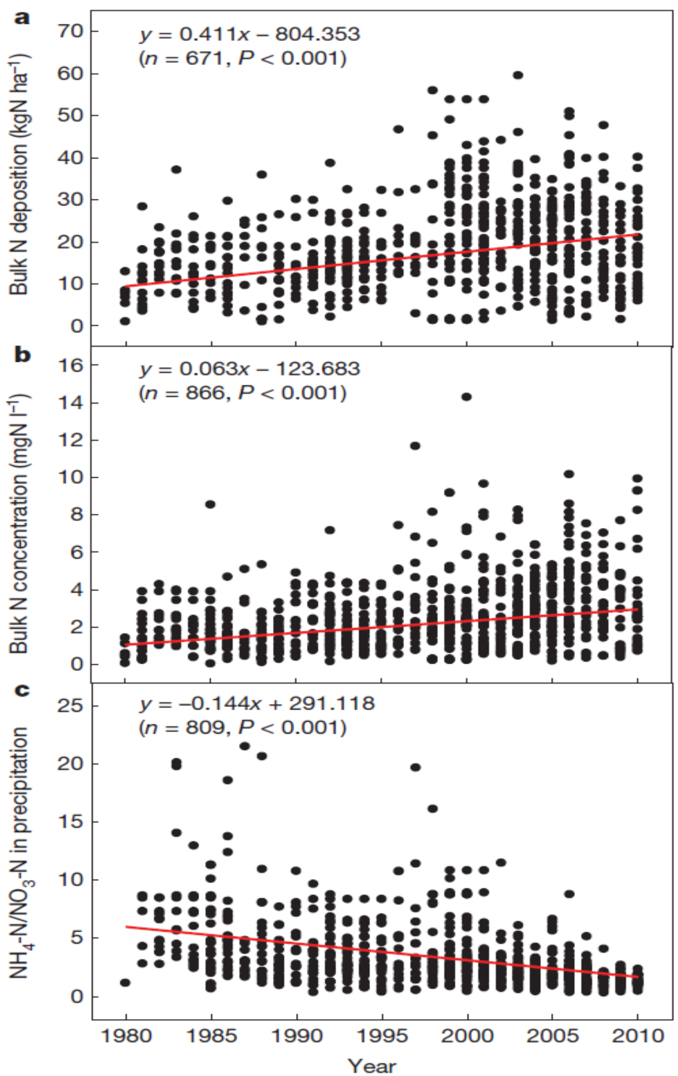


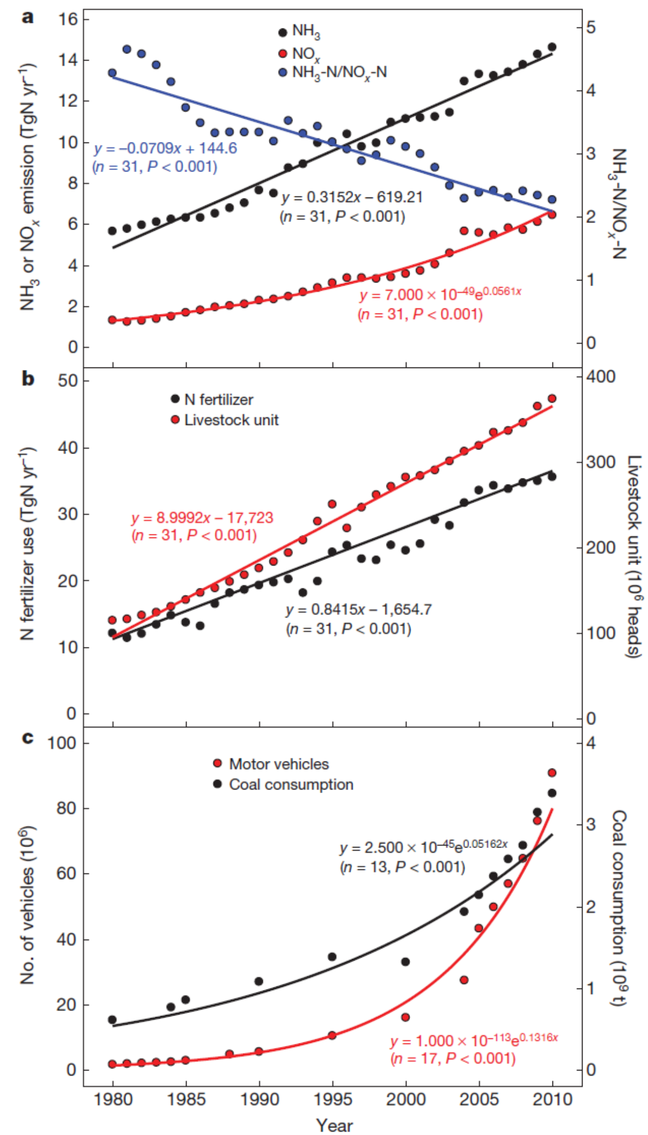
Bulk Nitrogen Deposition in China: 1980-2010

Liu et al., 2013, Nature

Wet +
some Dry

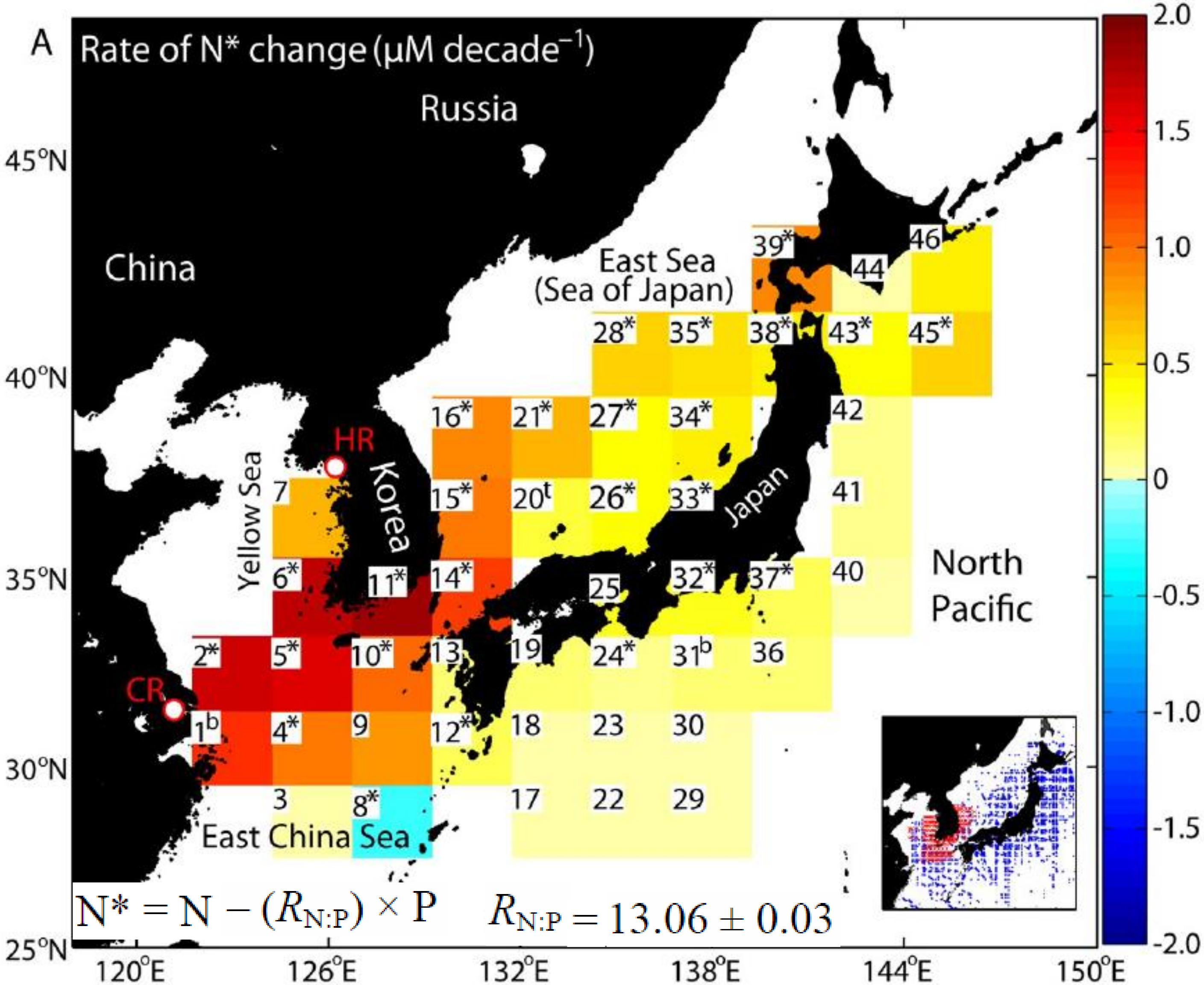
Mostly
inorganic





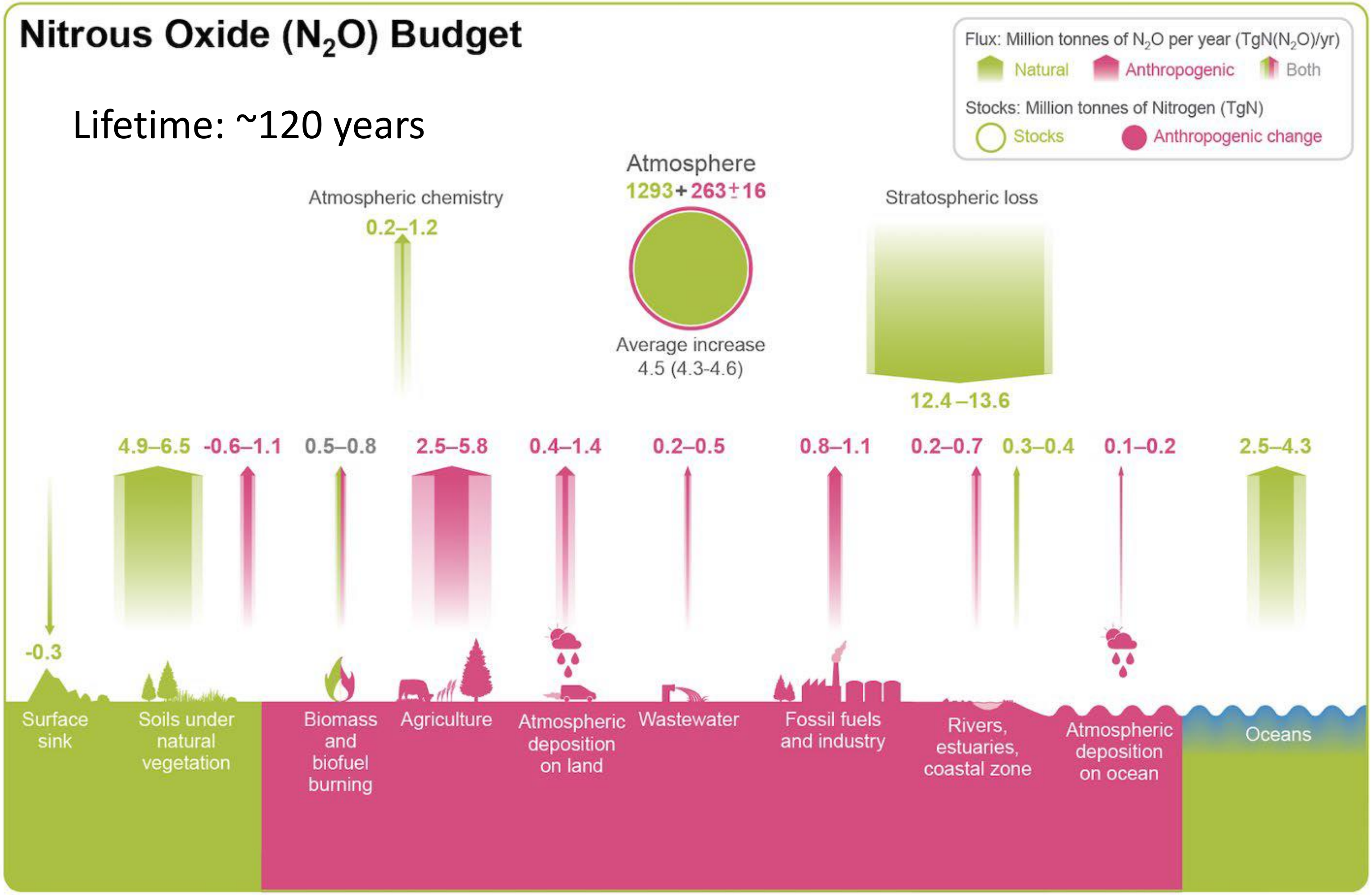
Excess Nitrogen (N*) in Surface Ocean: 1980-2010

Kim et al., 2011, Science



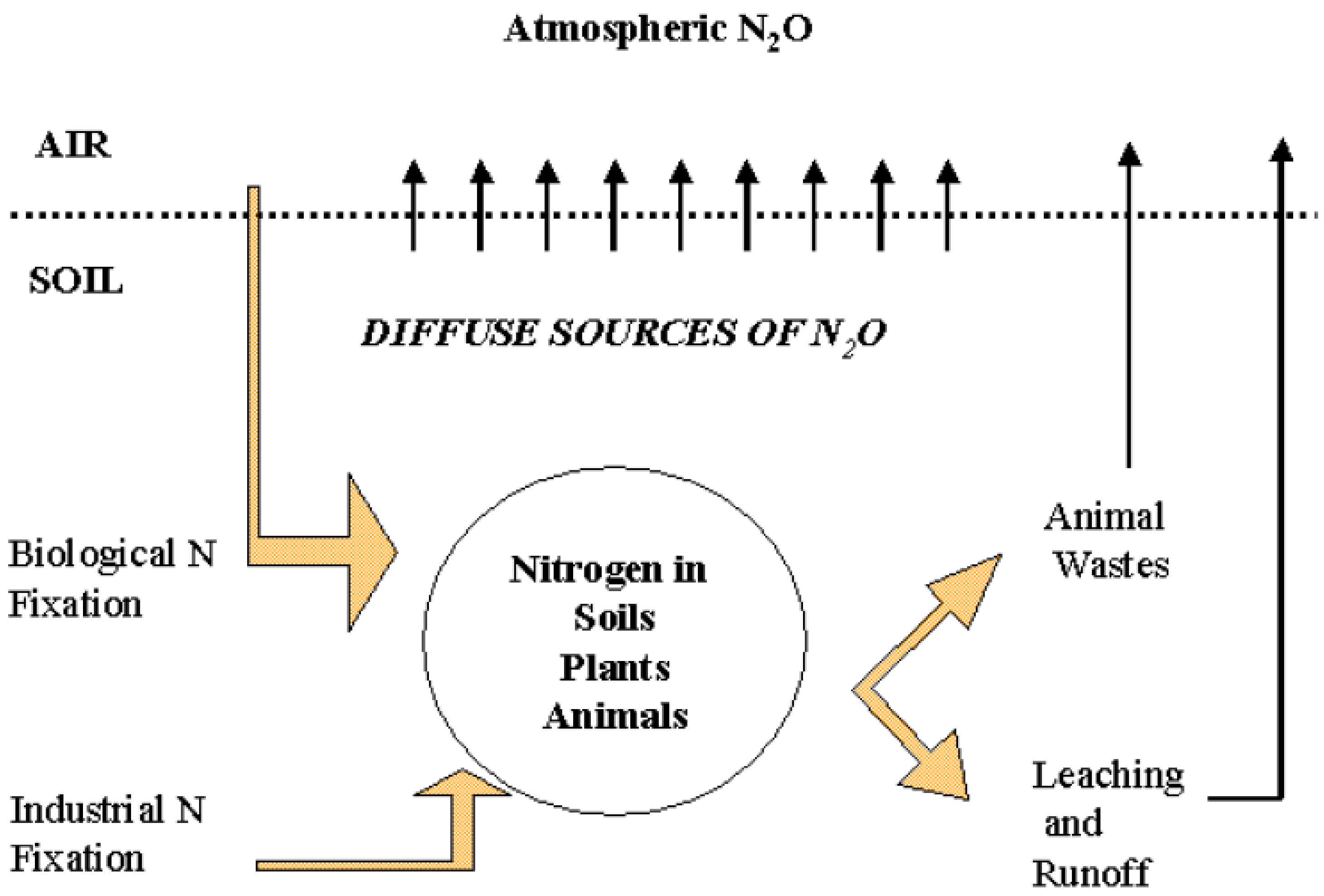
$N* = N - (R_{N:P}) \times P \qquad R_{N:P} = 13.06 \pm 0.03$

Nitrous Oxide Budget: 2007–2016



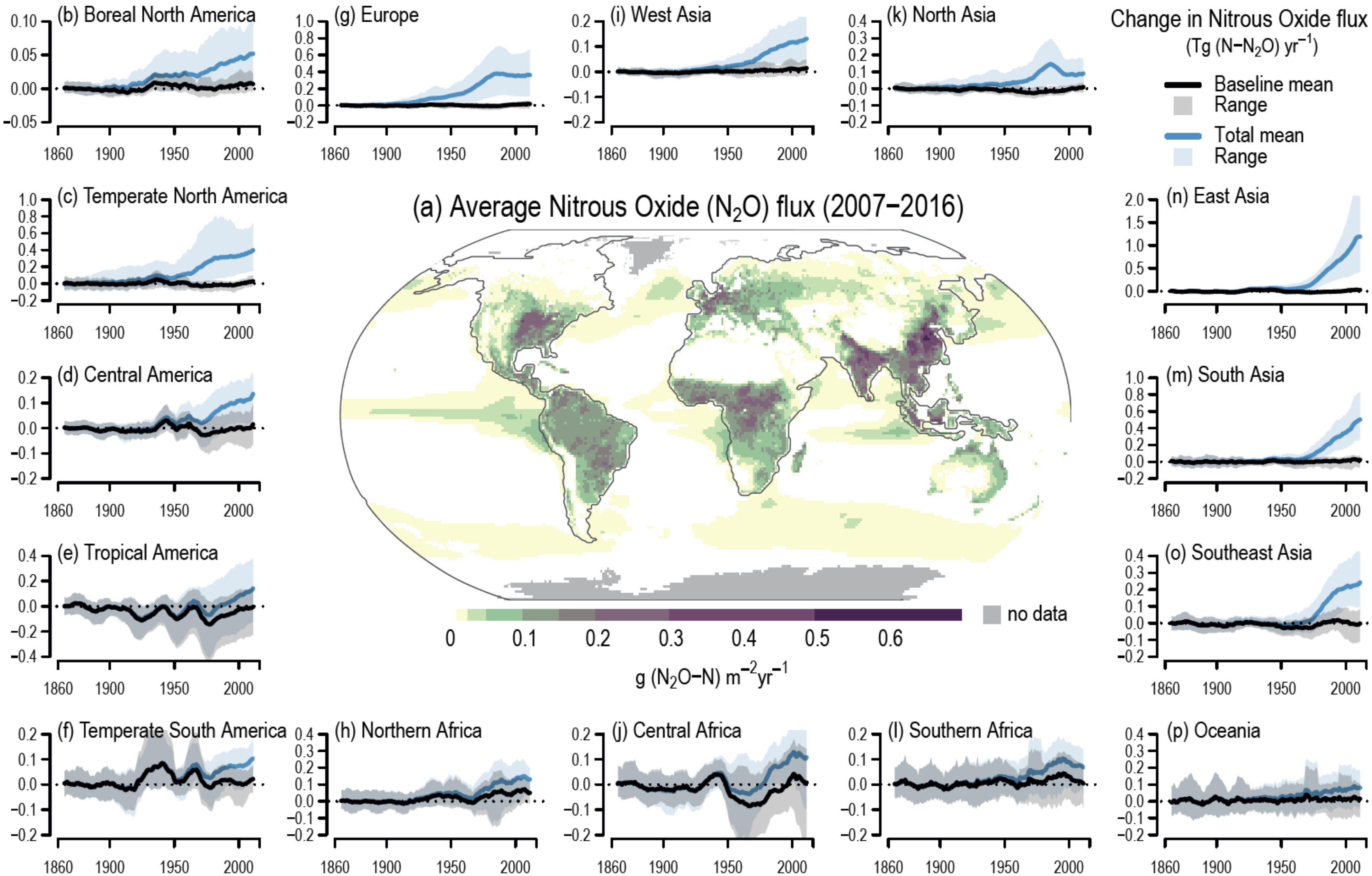
IPCC, 2021

N_2O Emitted from Agriculture/Biosphere



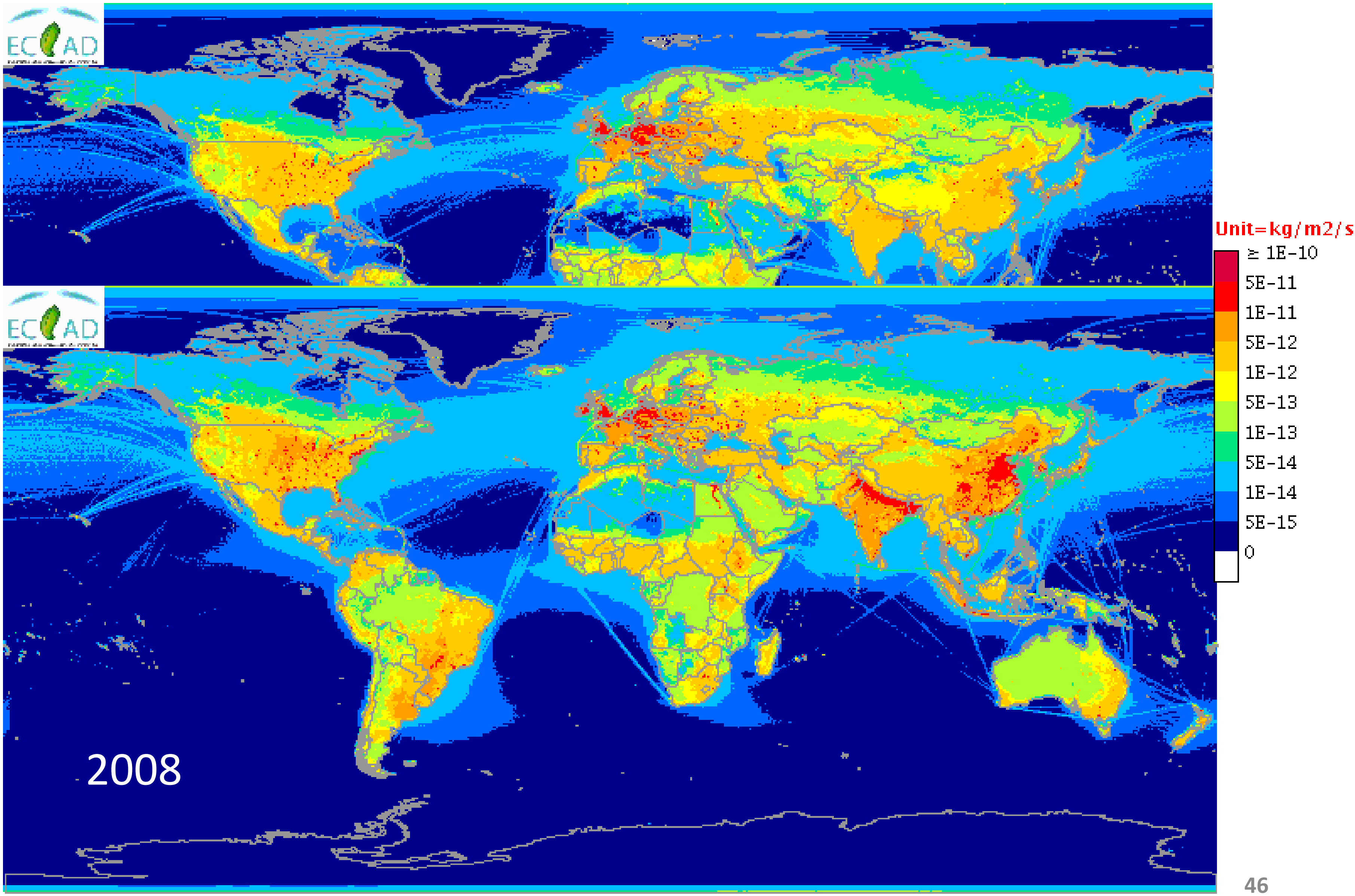
Soil processes involved in the formation of N_2O from agriculture

Emissions of N_2O and Their Changes

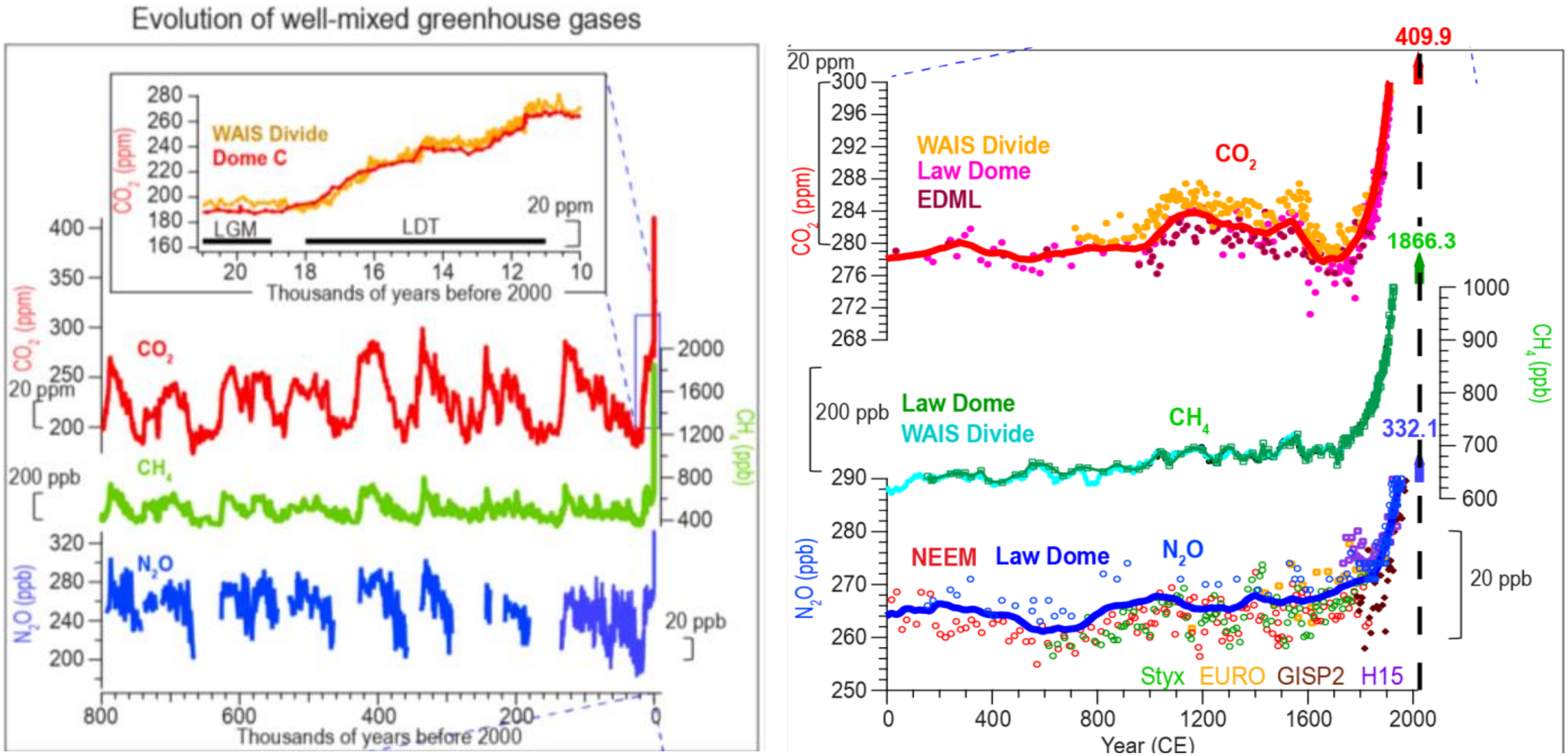


IPCC, 2021

Anthropogenic N_2O Emissions: 1970-2008

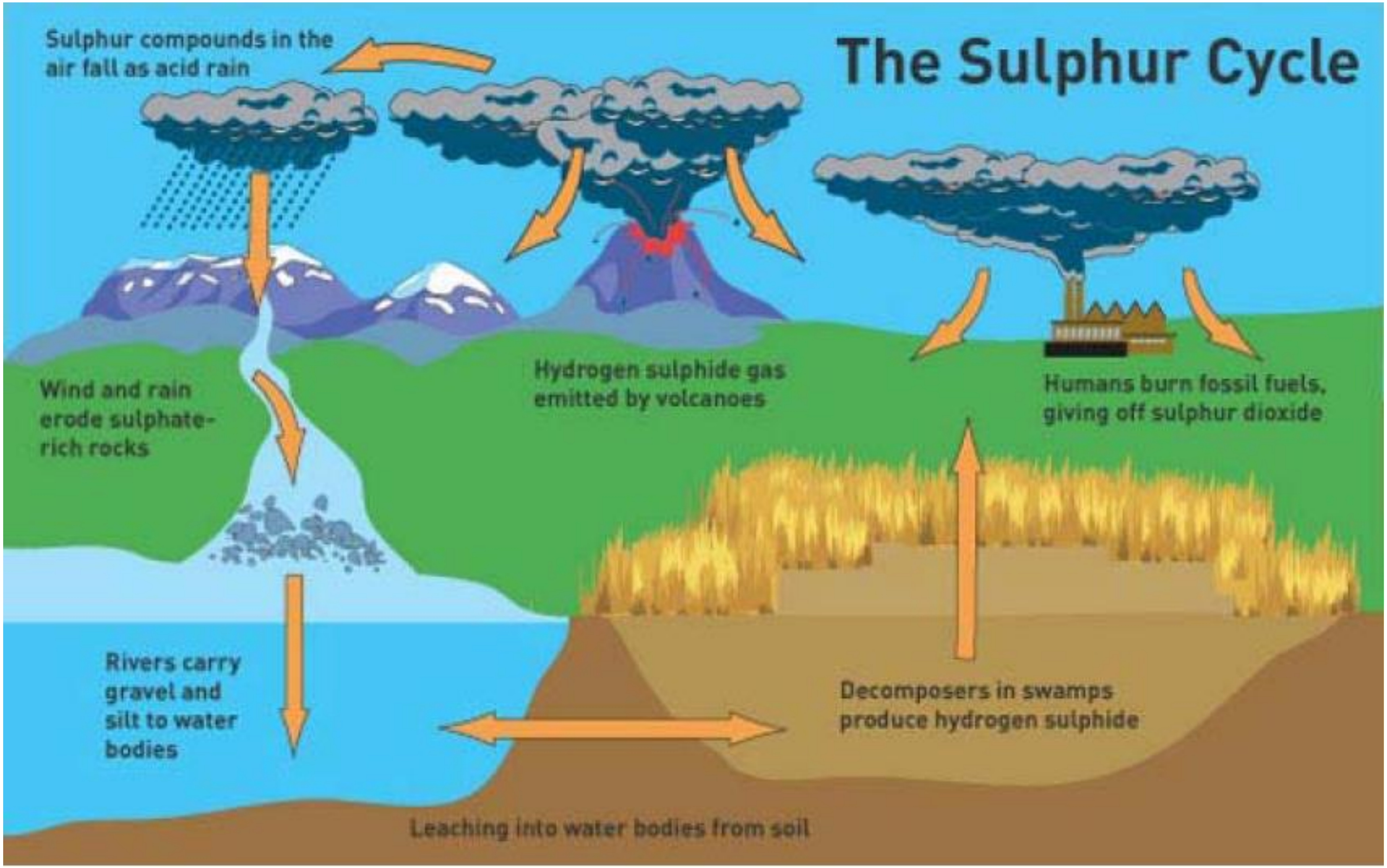


Growth in N_2O Concentrations



IPCC, 2021

Global Sulfur Cycle

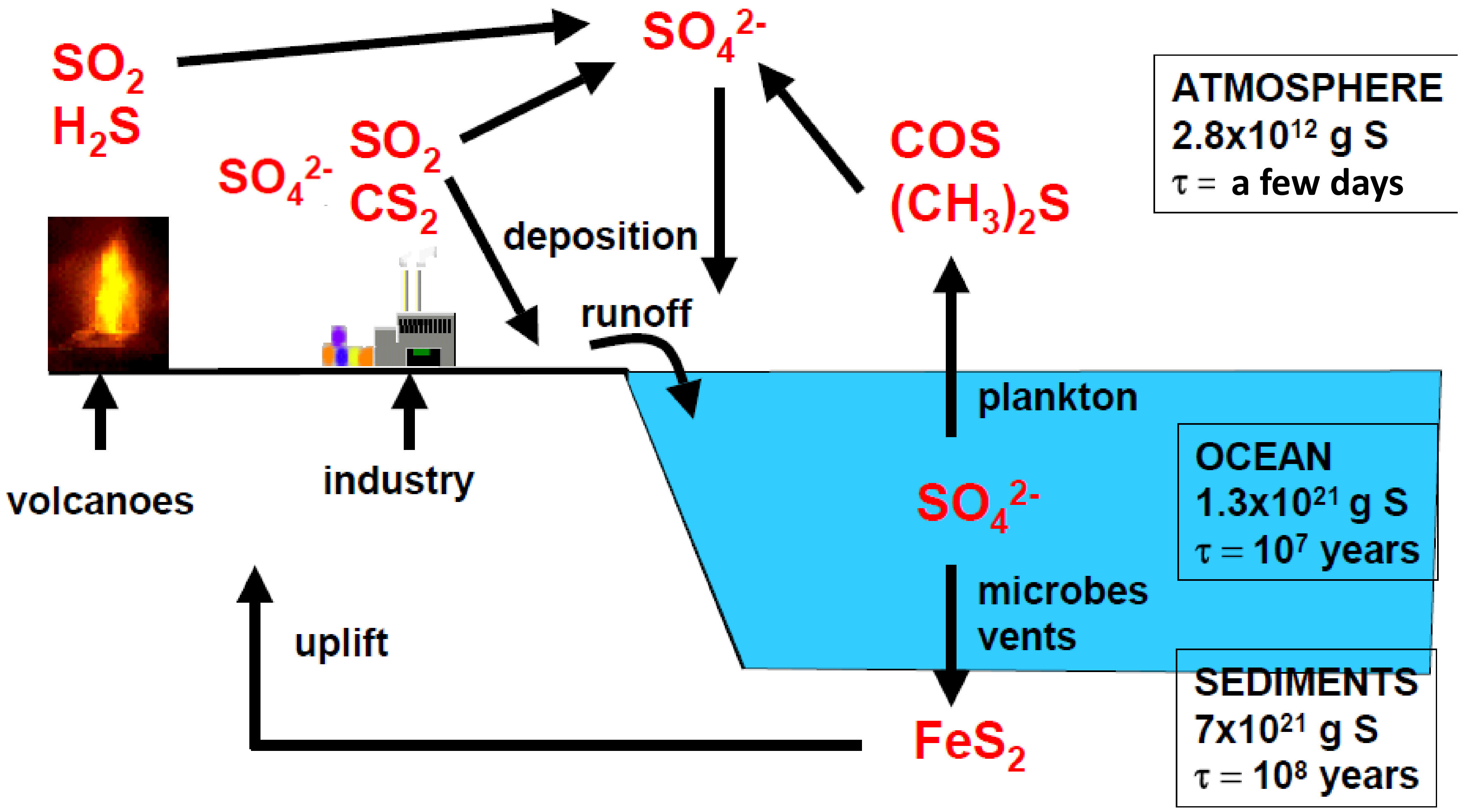


Oxidation States of Sulfur

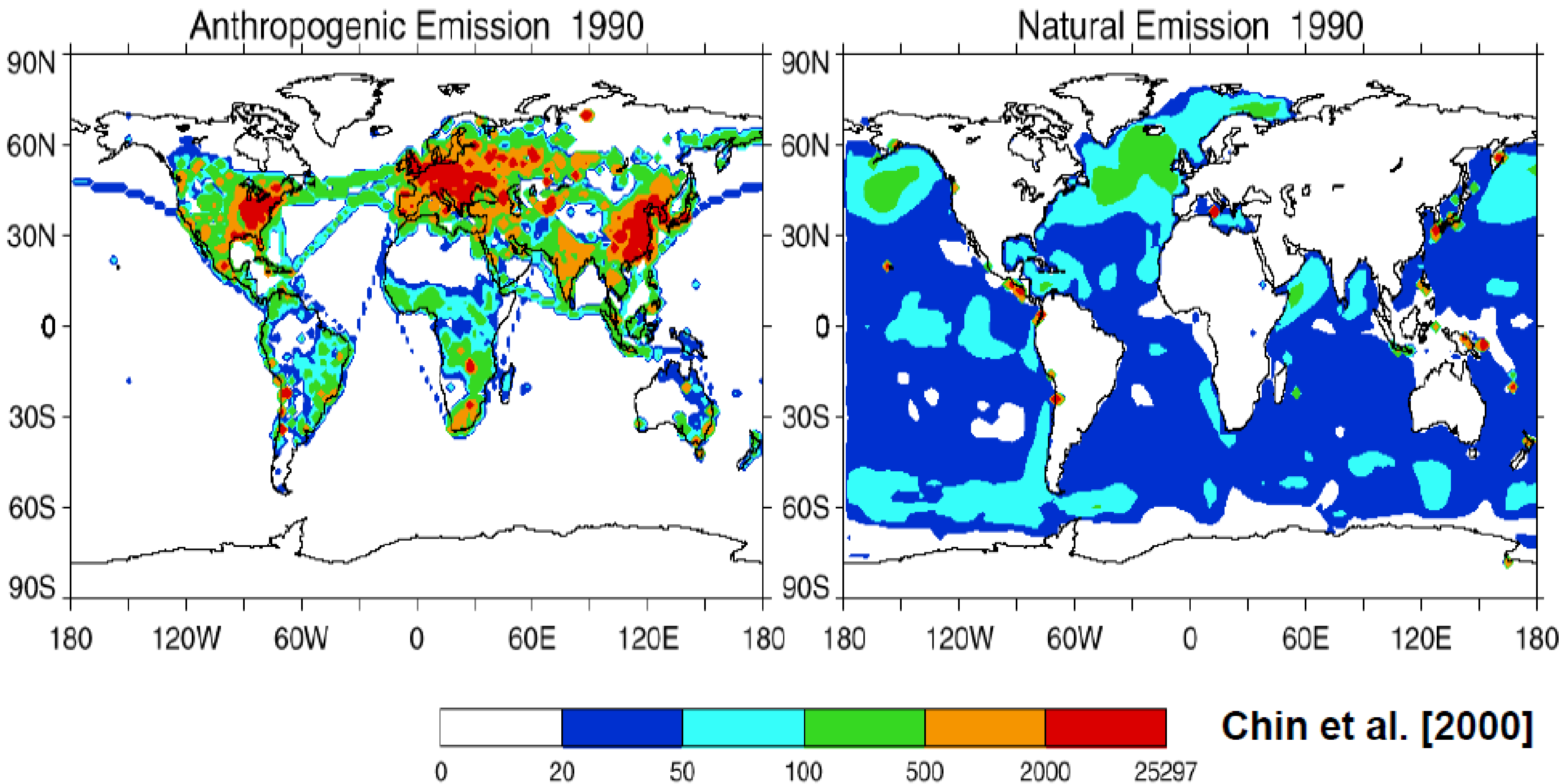
Increasing oxidation number (oxidation reactions) →

-2	+4	+6
FeS_2 二硫化铁 Pyrite H_2S Hydrogen sulfide $(CH_3)_2S$ 二甲基硫醚 Dimethylsulfide (DMS) CS_2 二硫化碳 Carbon disulfide COS 羰基硫 Carbonyl sulfide	SO_2 Sulfur dioxide	H_2SO_4 Sulfuric acid SO_4^{2-} Sulfate

Global Sulfur Cycle

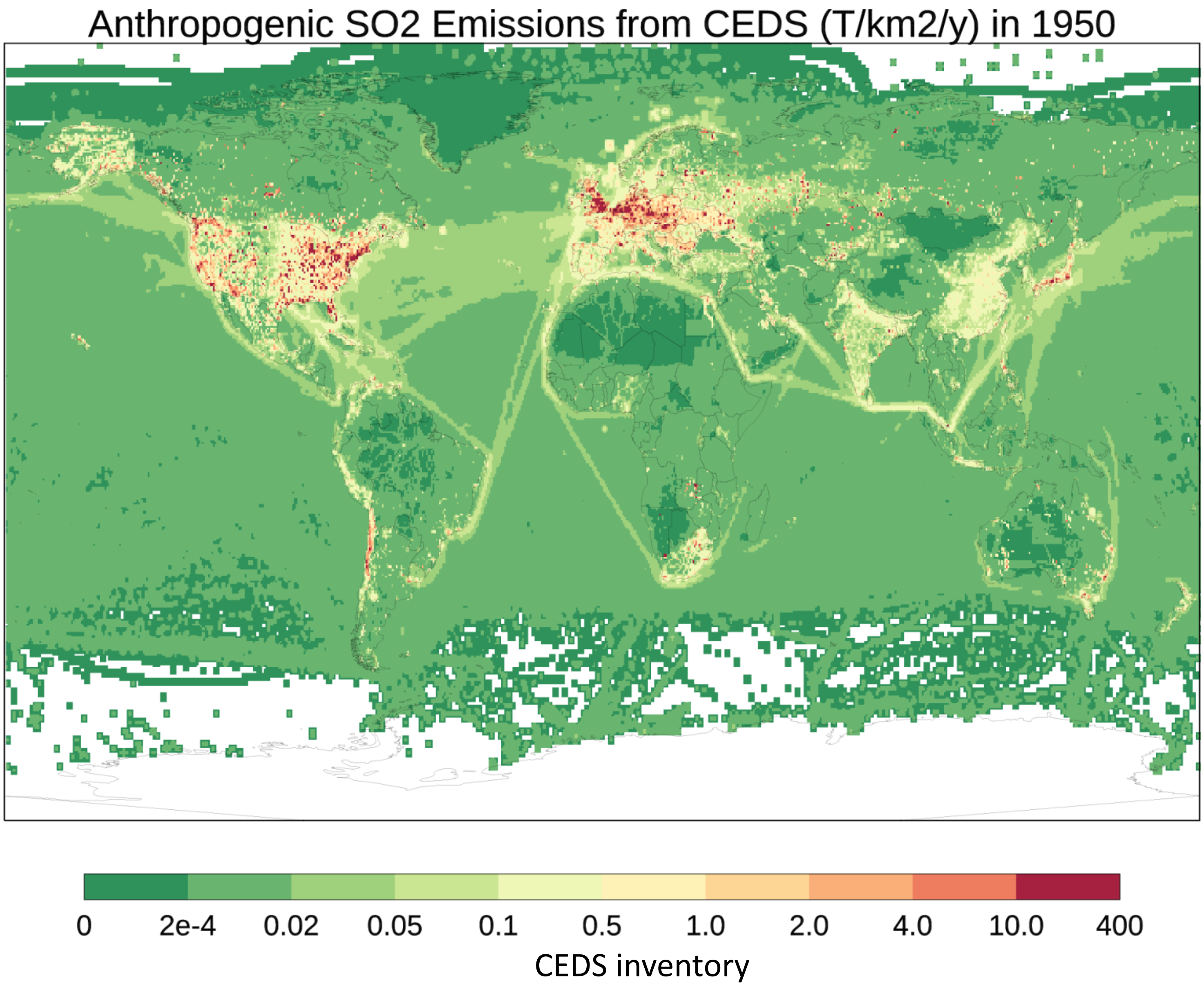


Global Sulfur Emissions



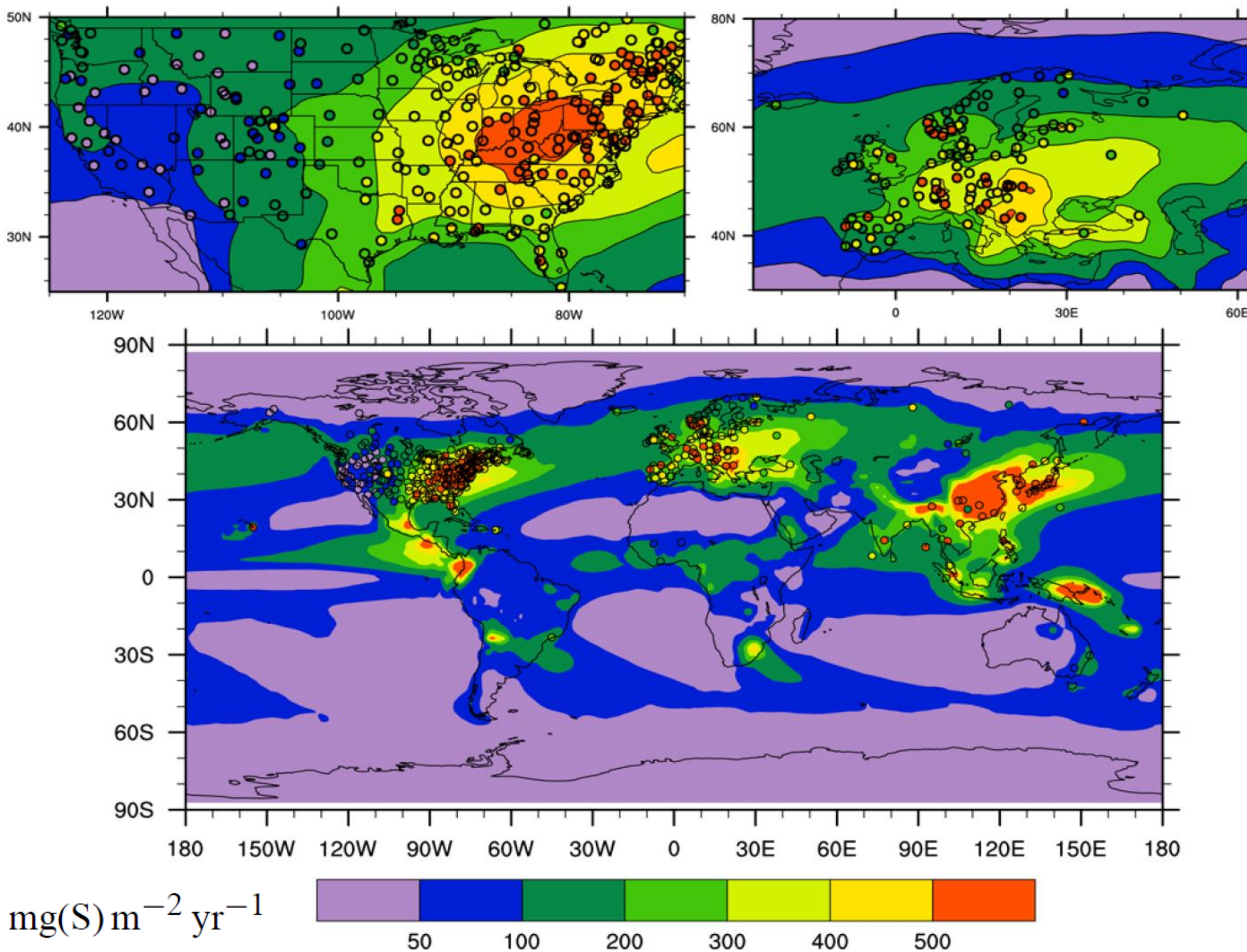
Chin et al. [2000]

Anthropogenic SO_2 Emissions: 1950-2014

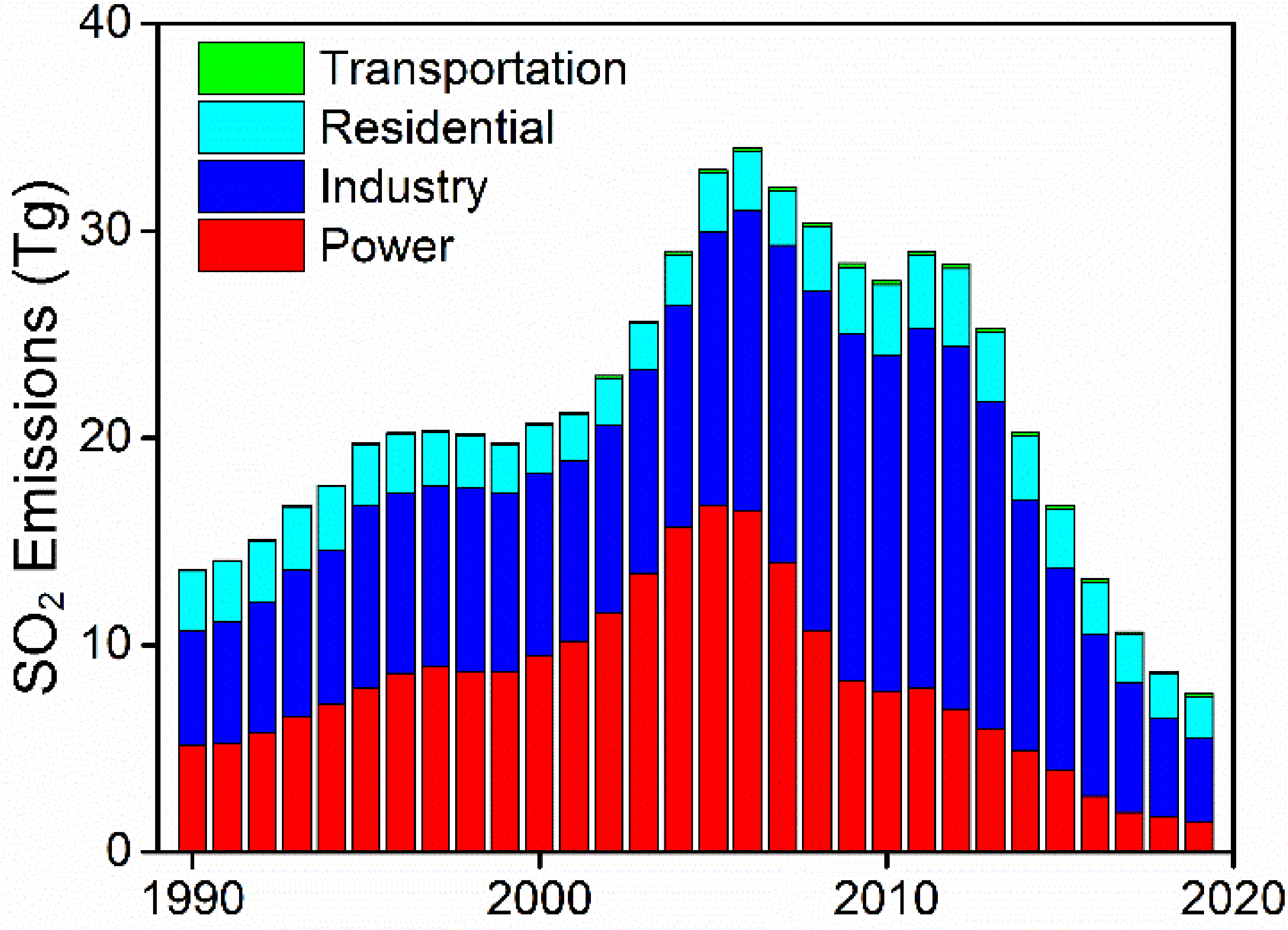


SO_4^{-2} Wet Deposition in 2000

Lamarque et al., 2013, ACP, Multi-model mean

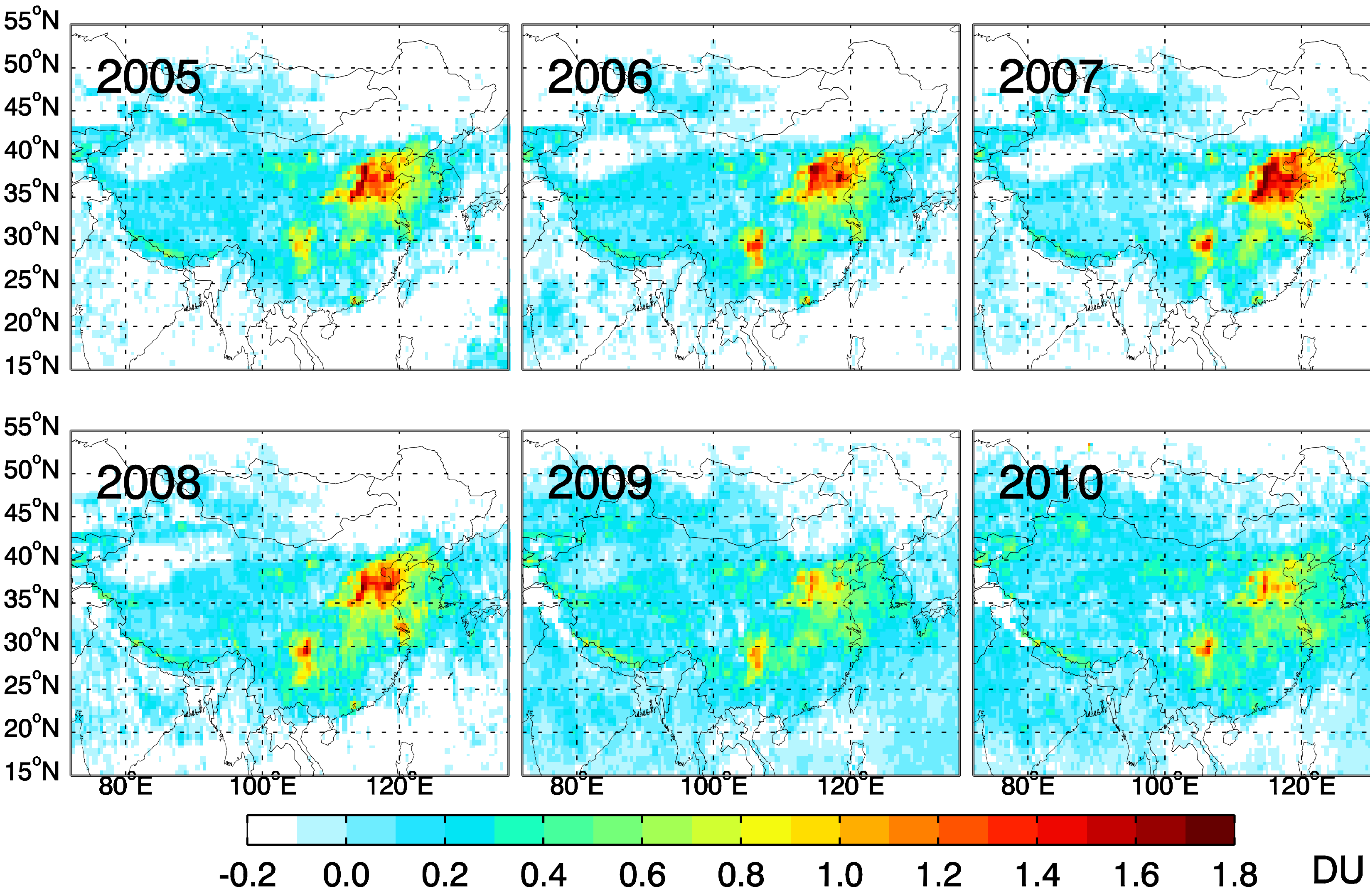


Emission Trends in MEIC Database: SO_2

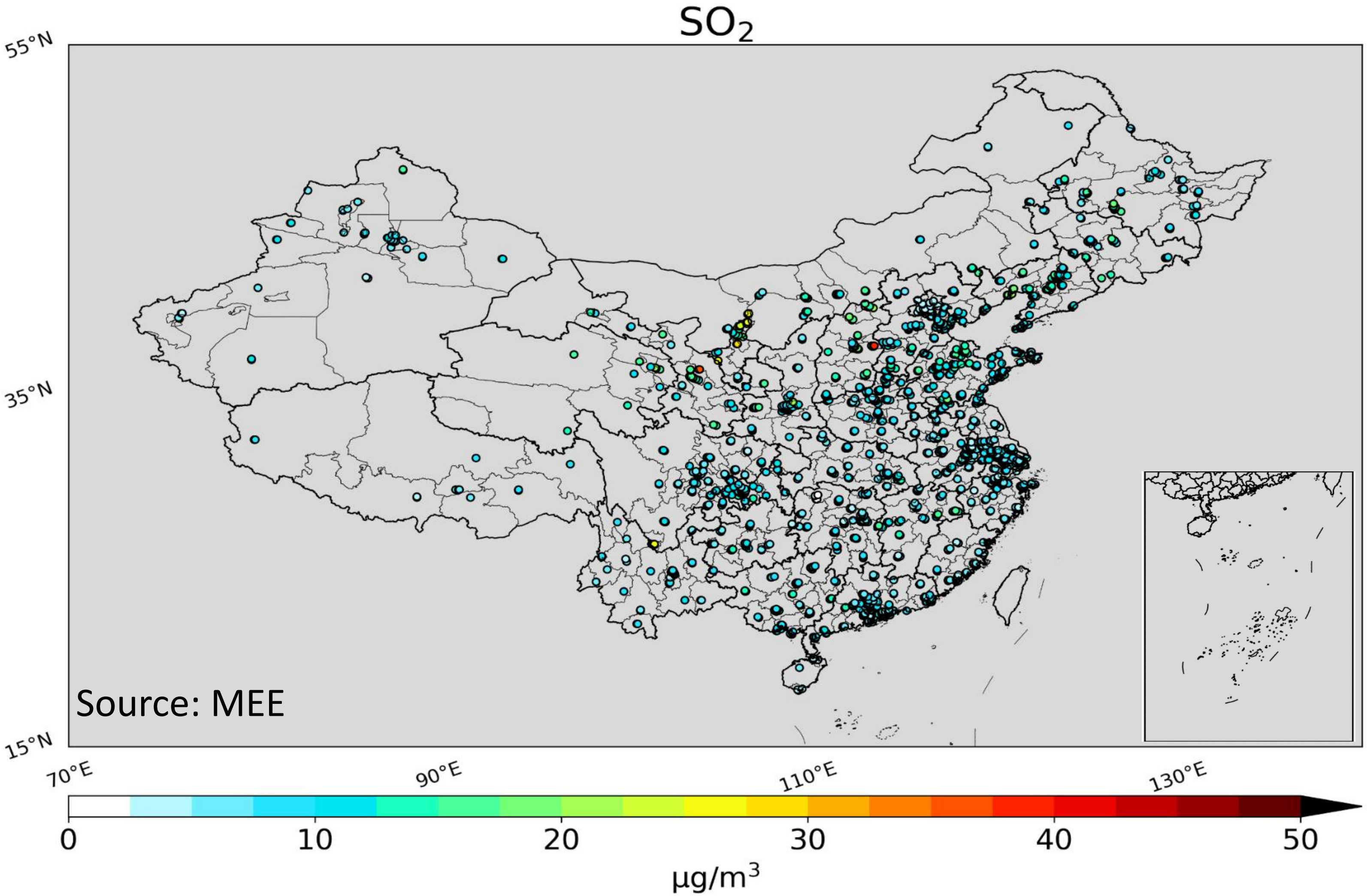


Source: Bo Zheng

Trends of SO_2 VCD from OMI: 2005-2010

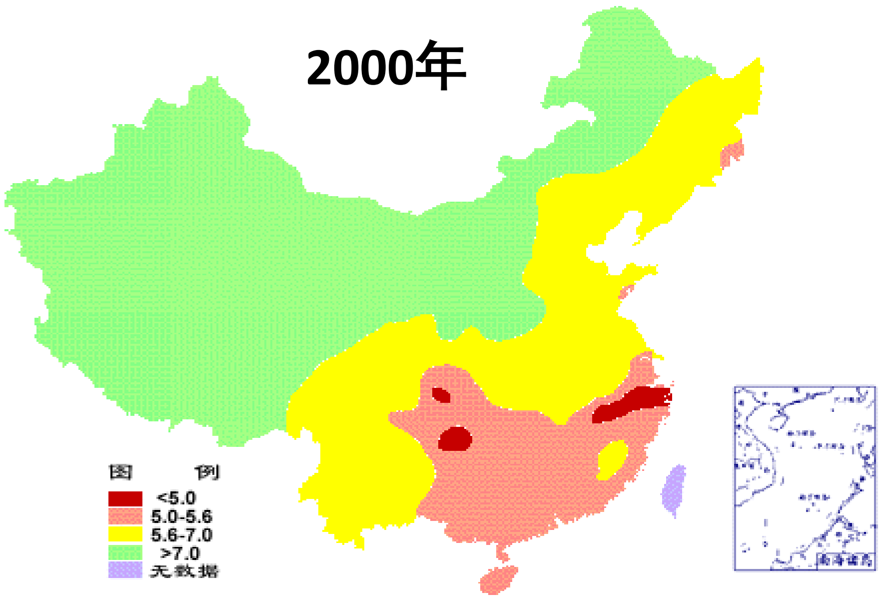


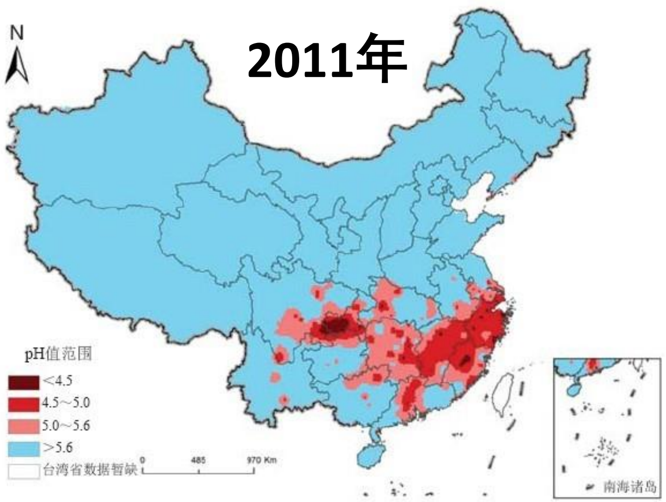
Near Surface SO_2 Concentrations over China: 2021

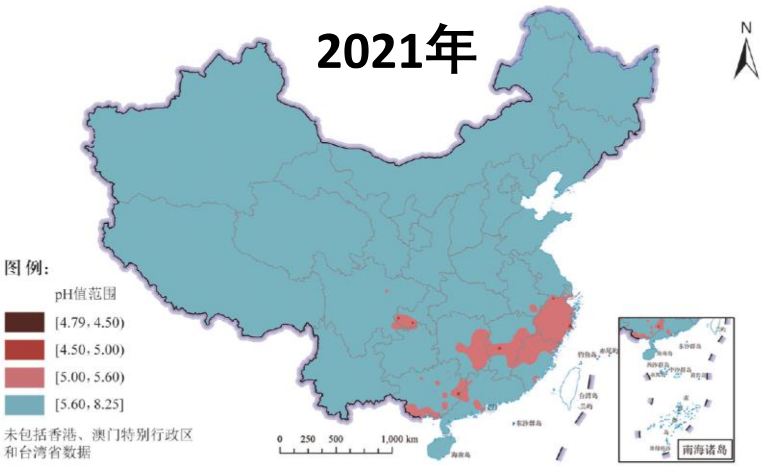


国家标准：60（年均），150（24小时），500（1小时）
WHO指导值：40（24小时）

pH Value in Precipitation

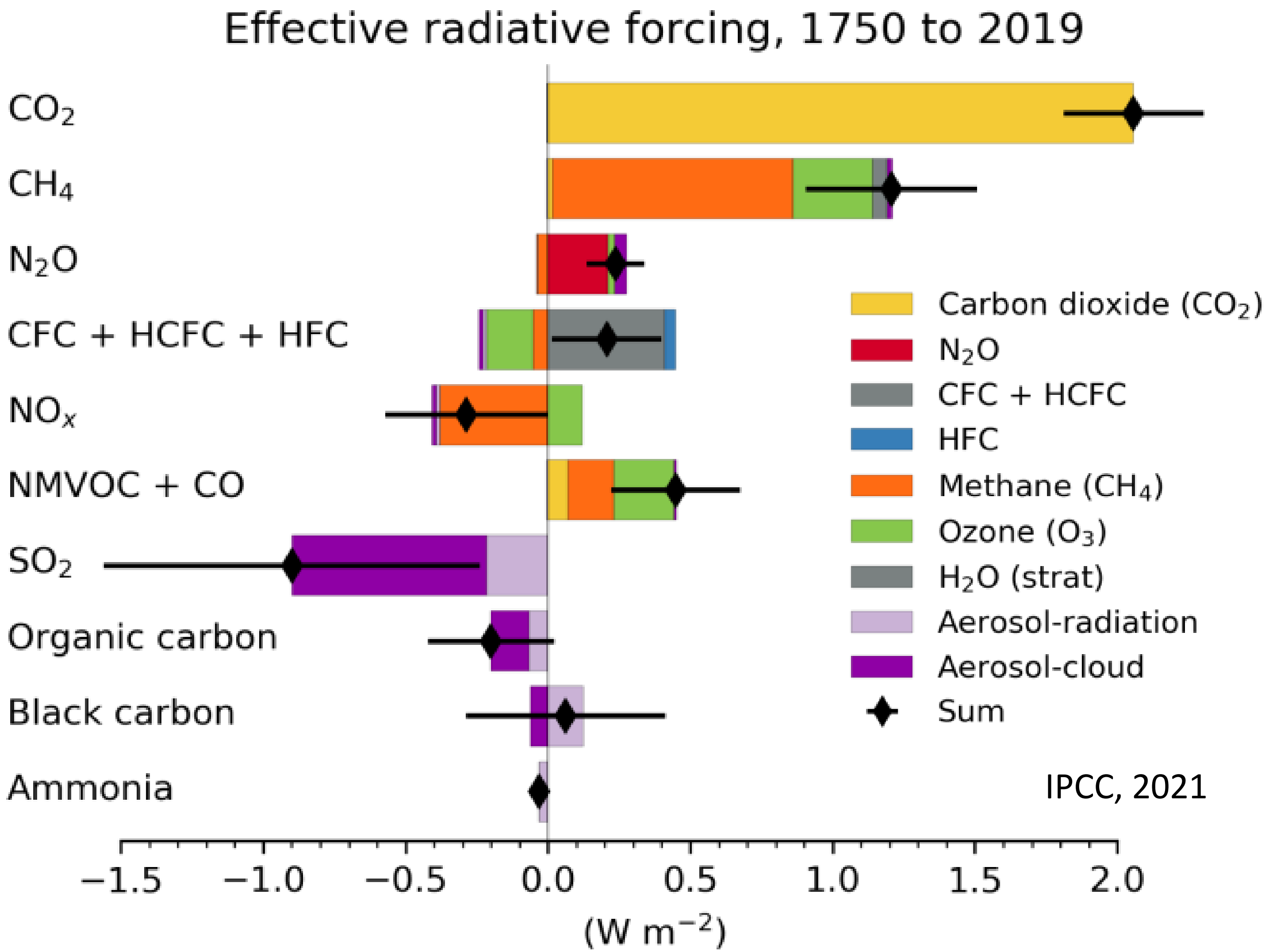






中国环境状况公报

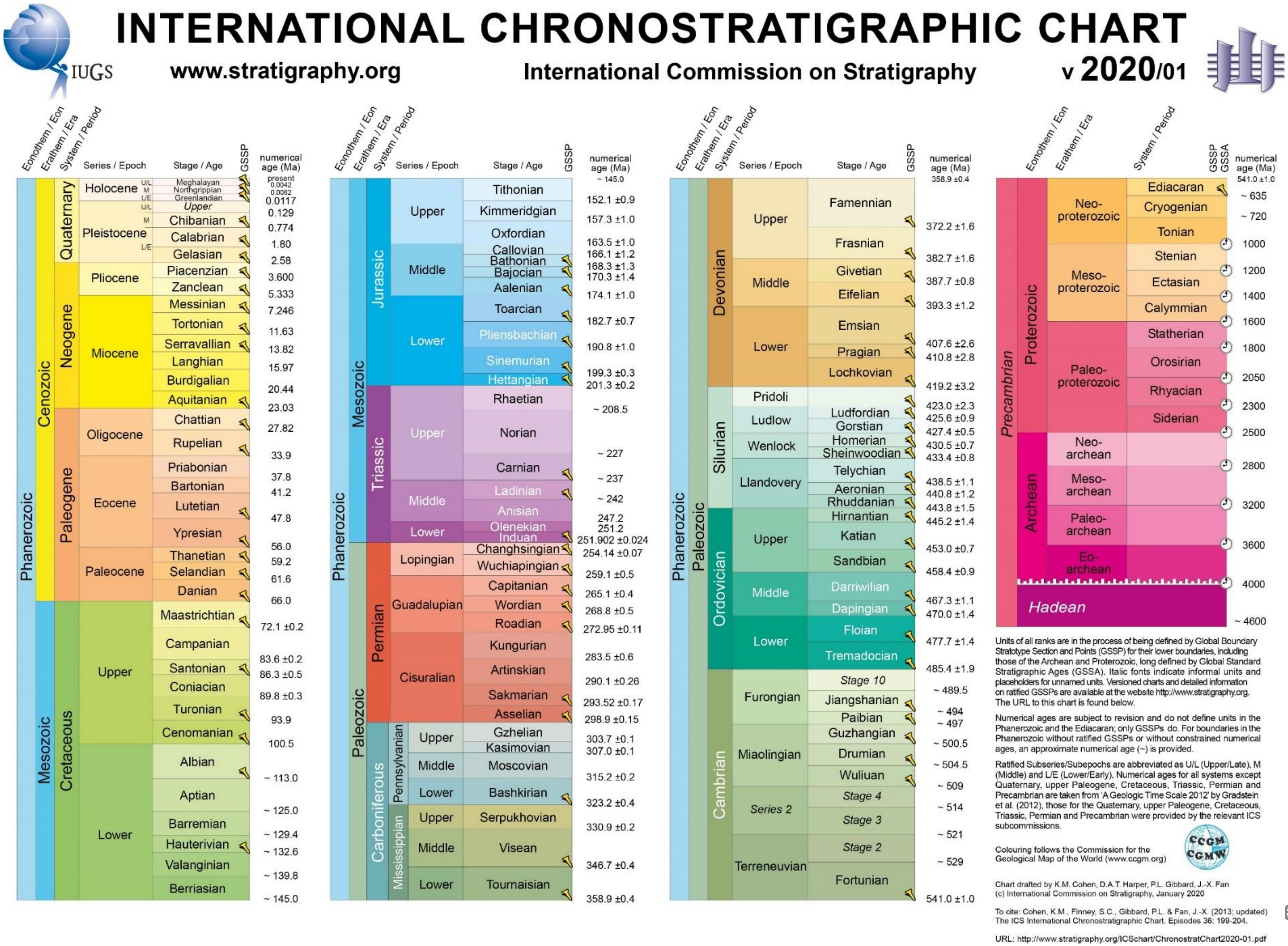
Radiative Forcing of Emitted C, N and S



Quiz

1. Causes of difference in air temperature between the Arctic and the Antarctic
2. Causes of slow-down in atmospheric CH_4 growth rate in the 1980s-1990s and regrowth since 2007
3. Causes of seasonality in atmospheric CH_4
4. Causes of seasonality in atmospheric NO_2
5. Causes of horizontal distribution in sulfur emissions from oceans

地球简史：地质年代



INTERNATIONAL CHRONOSTRATIGRAPHIC CHART
IUGS
www.stratigraphy.org
International Commission on Stratigraphy
v 2020/01
Eonothem / Eon
Erathem / Era
System / Period
Series / Epoch
Stage / Age
GSSP
numerical age (Ma)
Phanerozoic
Cenozoic
Quaternary
Holocene
Meghalayan
Northgrippian
Greenlandian
Pleistocene
Upper
Chibanian
Calabrian
Gelasian
present
0.0042
0.0082
0.0117
0.129
0.774
1.80
2.58
Neogene
Pliocene
Piacenzian
Zanclean
3.600
5.333
Miocene
Messinian
Tortonian
Serravallian
Langhian
Burdigalian
Aquitanian
7.246
11.63
13.82
15.97
20.44
23.03
Paleogene
Oligocene
Chattian
Rupelian
27.82
33.9
Eocene
Priabonian
Bartonian
Lutetian
Ypresian
37.8
41.2
47.8
56.0
Paleocene
Thanetian
Selandian
Danian
59.2
61.6
66.0
Mesozoic
Cretaceous
Upper
Maastrichtian
Campanian
Santonian
Coniacian
Turonian
Cenomanian
72.1 ±0.2
83.6 ±0.2
86.3 ±0.5
89.8 ±0.3
93.9
100.5
Lower
Albian
Aptian
Barremian
Hauterivian
Valanginian
Berriasian
~ 113.0
~ 125.0
~ 129.4
~ 132.6
~ 139.8
~ 145.0
Jurassic
Upper
Tithonian
Kimmeridgian
Oxfordian
~ 145.0
152.1 ±0.9
157.3 ±1.0
163.5 ±1.0
Middle
Callovian
Bathonian
Bajocian
Aalenian
166.1 ±1.2
168.3 ±1.3
170.3 ±1.4
174.1 ±1.0
Lower
Toarcian
Pliensbachian
Sinemurian
Hettangian
182.7 ±0.7
190.8 ±1.0
199.3 ±0.3
201.3 ±0.2
Triassic
Upper
Rhaetian
Norian
Carnian
~ 208.5
~ 227
~ 237
Middle
Ladinian
Anisian
~ 242
247.2
Lower
Olenekian
Induan
251.2
251.902 ±0.024
Paleozoic
Permian
Lopingian
Changhsingian
Wuchiapingian
254.14 ±0.07
259.1 ±0.5
Guadalupian
Capitanian
Wordian
Roadian
265.1 ±0.4
268.8 ±0.5
272.95 ±0.11
Cisuralian
Kungurian
Artinskian
Sakmarian
Asselian
283.5 ±0.6
290.1 ±0.26
293.52 ±0.17
298.9 ±0.15
Carboniferous
Pennsylvanian
Upper
Gzhelian
Kasimovian
303.7 ±0.1
307.0 ±0.1
Middle
Moscovian
315.2 ±0.2
Lower
Bashkirian
323.2 ±0.4
Mississippian
Upper
Serpukhovian
330.9 ±0.2
Middle
Visean
346.7 ±0.4
Lower
Tournaisian
358.9 ±0.4
Devonian
Upper
Famennian
Frasnian
358.9 ±0.4
372.2 ±1.6
382.7 ±1.6
Middle
Givetian
Eifelian
387.7 ±0.8
393.3 ±1.2
Lower
Emsian
Pragian
Lochkovian
407.6 ±2.6
410.8 ±2.8
419.2 ±3.2
Silurian
Pridoli
Ludlow
Ludfordian
Gorstian
423.0 ±2.3
425.6 ±0.9
427.4 ±0.5
Wenlock
Homerian
Sheinwoodian
430.5 ±0.7
433.4 ±0.8
Llandovery
Telychian
Aeronian
Rhuddanian
438.5 ±1.1
440.8 ±1.2
443.8 ±1.5
Ordovician
Upper
Hirnantian
Katian
Sandbian
445.2 ±1.4
453.0 ±0.7
458.4 ±0.9
Middle
Darriwilian
Dapingian
467.3 ±1.1
470.0 ±1.4
Lower
Floian
Tremadocian
477.7 ±1.4
485.4 ±1.9
Cambrian
Furongian
Stage 10
Jiangshanian
Paibian
~ 489.5
~ 494
~ 497
Miaolingian
Guzhangian
Drumian
Wuliuan
~ 500.5
~ 504.5
~ 509
Series 2
Stage 4
Stage 3
~ 514
~ 521
Terreneuvian
Stage 2
Fortunian
~ 529
541.0 ±1.0
Precambrian
Proterozoic
GSSP
GSSA
541.0 ±1.0
Neo-proterozoic
Ediacaran
Cryogenian
Tonian
~ 635
~ 720
1000
Meso-proterozoic
Stenian
Ectasian
Calymmian
1200
1400
1600
Paleo-proterozoic
Statherian
Orosirian
Rhyacian
Siderian
1800
2050
2300
2500
Archean
Neo-archean
2800
Meso-archean
3200
Paleo-archean
3600
Eo-archean
4000
Hadean
~ 4600
Units of all ranks are in the process of being defined by Global Boundary Stratotype Section and Points (GSSP) for their lower boundaries, including those of the Archean and Proterozoic, long defined by Global Standard Stratigraphic Ages (GSSA). Italic fonts indicate informal units and placeholders for unnamed units. Versioned charts and detailed information on ratified GSSPs are available at the website http://www.stratigraphy.org. The URL to this chart is found below.
Numerical ages are subject to revision and do not define units in the Phanerozoic and the Ediacaran; only GSSPs do. For boundaries in the Phanerozoic without ratified GSSPs or without constrained numerical ages, an approximate numerical age (~) is provided.
Ratified Subseries/Subepochs are abbreviated as U/L (Upper/Late), M (Middle) and L/E (Lower/Early). Numerical ages for all systems except Quaternary, upper Paleogene, Cretaceous, Triassic, Permian and Precambrian are taken from 'A Geologic Time Scale 2012' by Gradstein et al. (2012), those for the Quaternary, upper Paleogene, Cretaceous, Triassic, Permian and Precambrian were provided by the relevant ICS subcommissions.
Colouring follows the Commission for the Geological Map of the World (www.ccgm.org)
CCGM CGMW
Chart drafted by K.M. Cohen, D.A.T. Harper, P.L. Gibbard, J.-X. Fan
(c) International Commission on Stratigraphy, January 2020
To cite: Cohen, K.M., Finney, S.C., Gibbard, P.L. & Fan, J.-X. (2013; updated) The ICS International Chronostratigraphic Chart. Episodes 36: 199-204.
URL: http://www.stratigraphy.org/ICSchart/ChronostratChart2020-01.pdf

Global Carbon Reservoirs

How Much Carbon is in the Reservoirs?

Atmosphere	750 GtC	~900 GtC in 2023
Biosphere		
↸ Terrestrial Vegetation	610 GtC	
↸ Soil	1500 GtC	
↸ Marine Biota		
Ocean (hydrosphere)		
↸ Surface Ocean	1000 GtC	
↸ Deep ocean	38000 GtC	
Fossil Fuels		
↸ Coal	4000 GtC	
↸ Oil	500 GtC	
↸ Natural gas	500 GtC	
Sedimentary rocks	50,000,000 GtC	

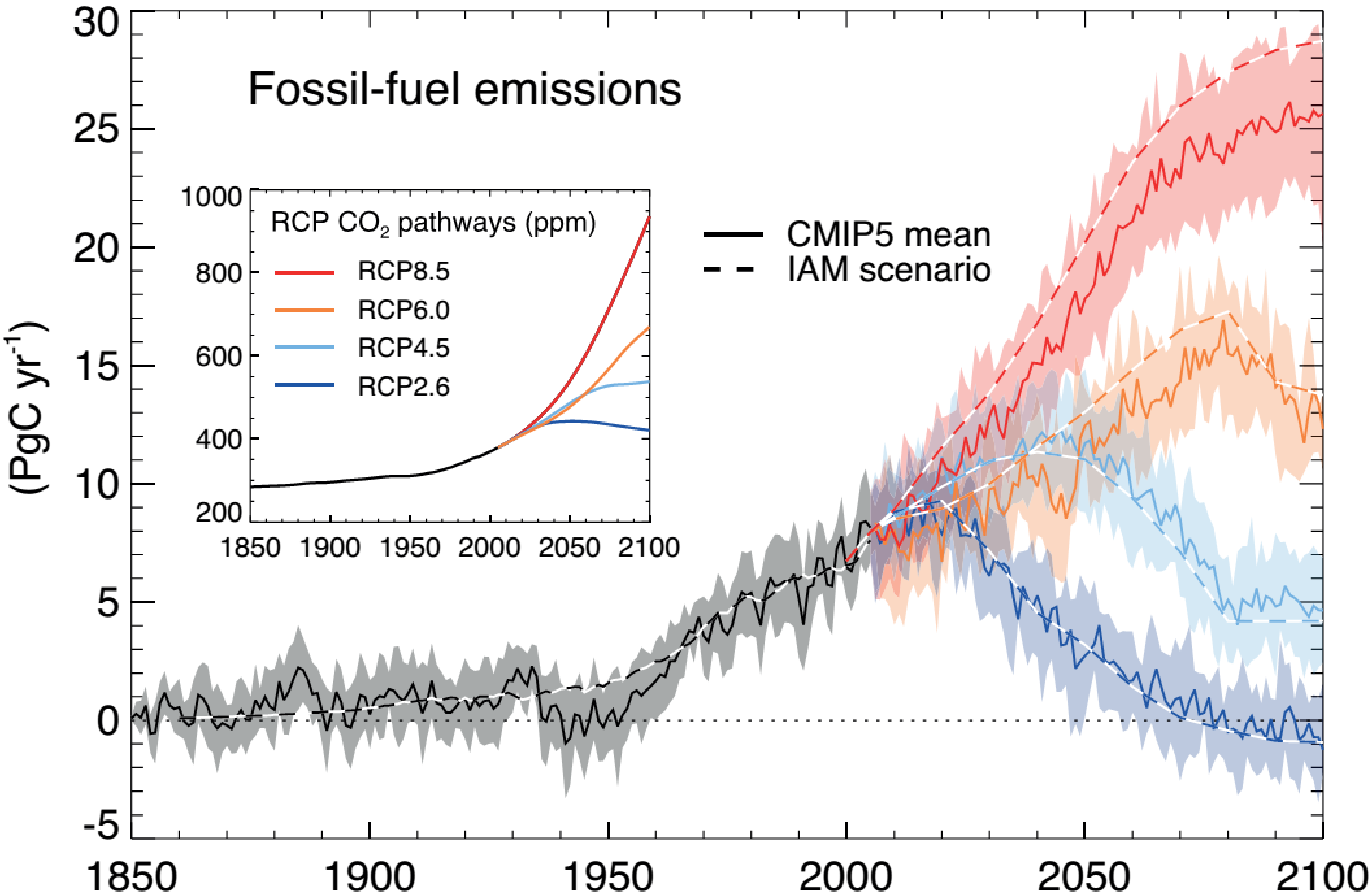
*Most carbon is in carbonates and marine sediments.

*Most carbon not in rocks is in the ocean

Gigaton (Gt) = 1 billion tonnes

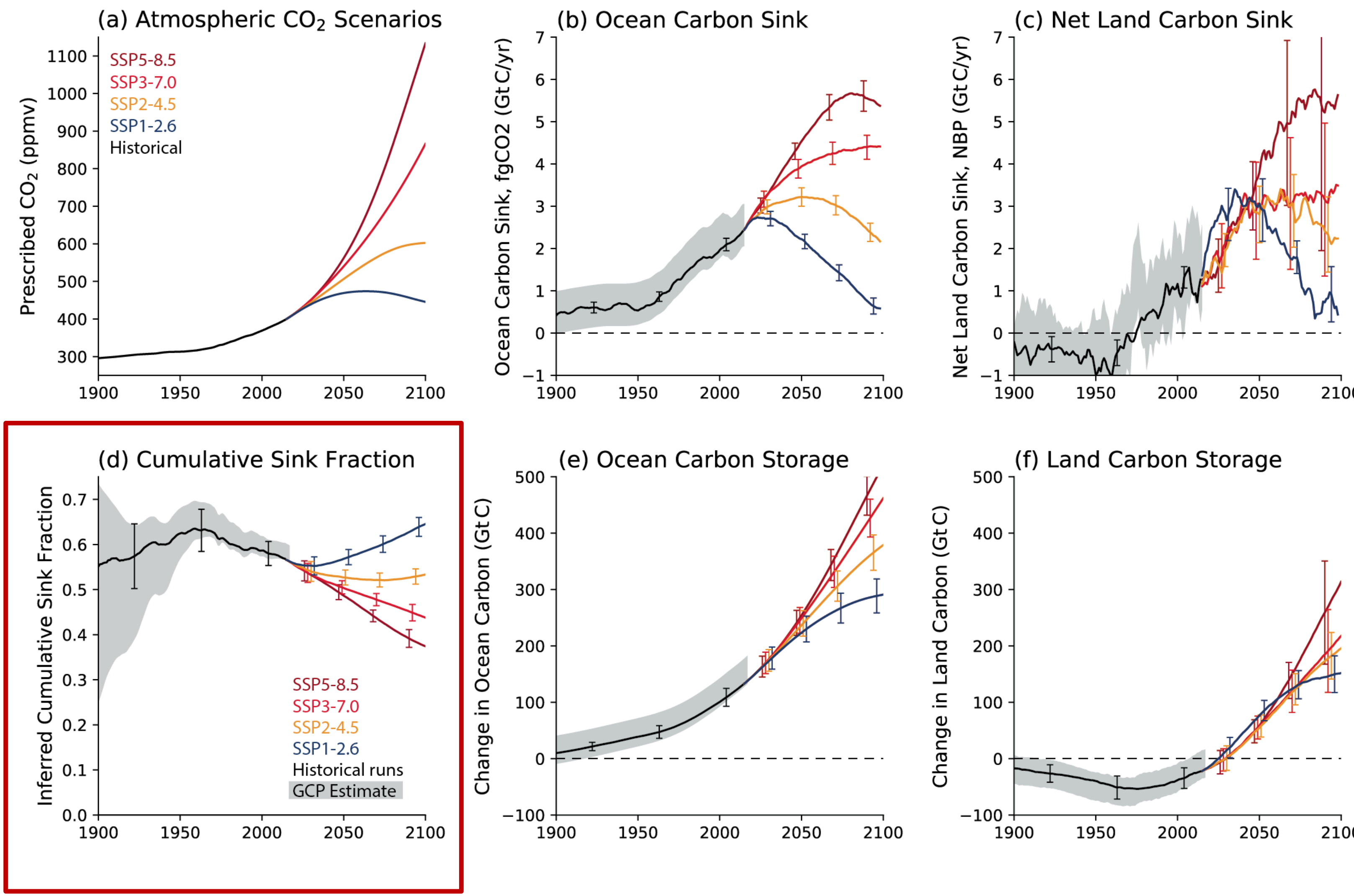
Old estimates

Future Changes in Fossil Fuel Carbon



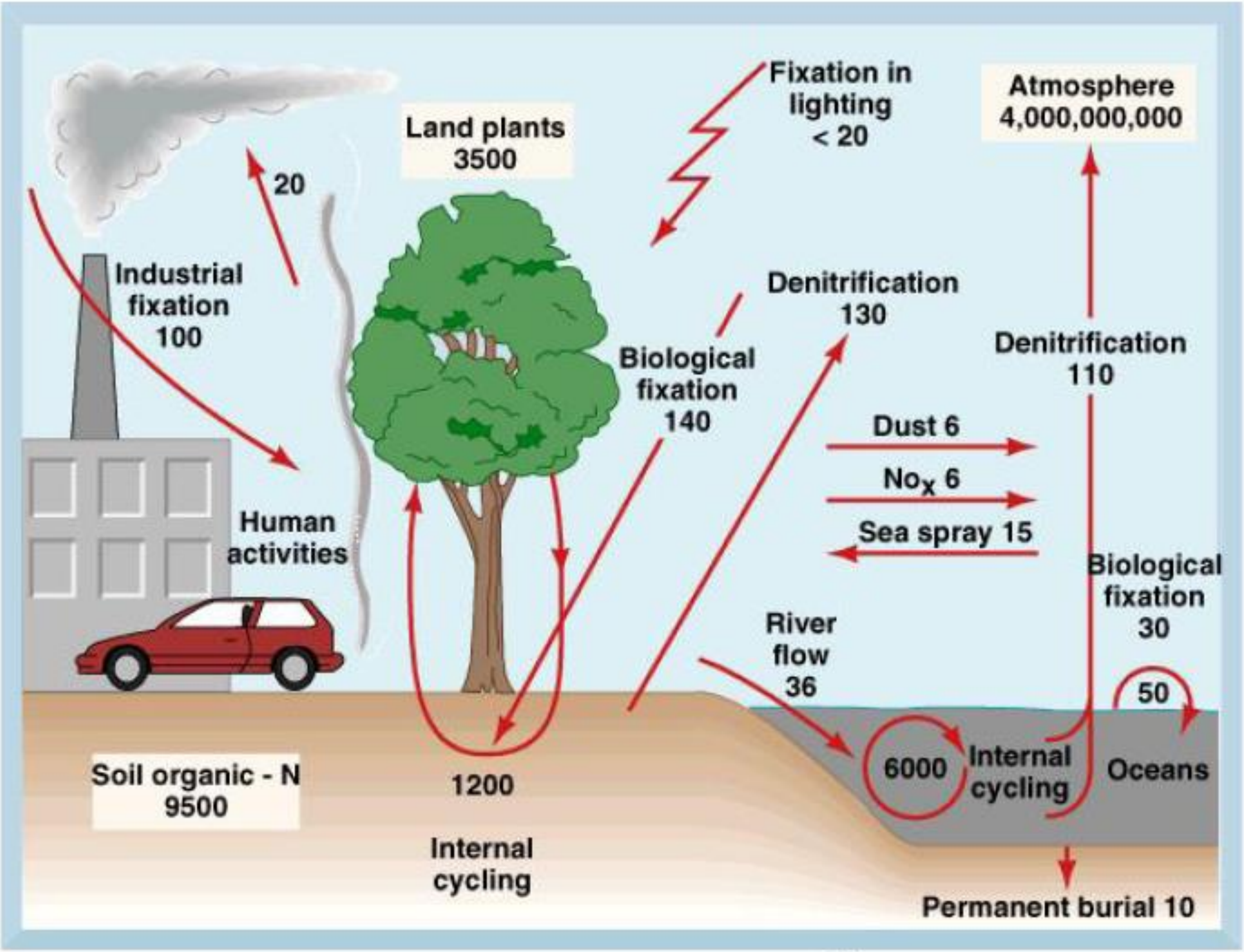
IPCC, 2013

Future Changes in CO_2 Burden and Sinks



IPCC, 2021

Global Nitrogen Cycle



The global nitrogen cycle. Pools (□)and annual (→) flux in $10^{12}gN_2$. Note that the industrial fixation of nitrogen is nearly equal to the global biological fixation. (*SOURCE:* Data from Söderlund, and T. Rosswall, 1982 , O. Hutzinger (ed.), *The Handbook of Environmental Chemistry*, Vol 1, Pt. B., Springer-Verlag New York, Inc., New York).

NOx Emissions by Source

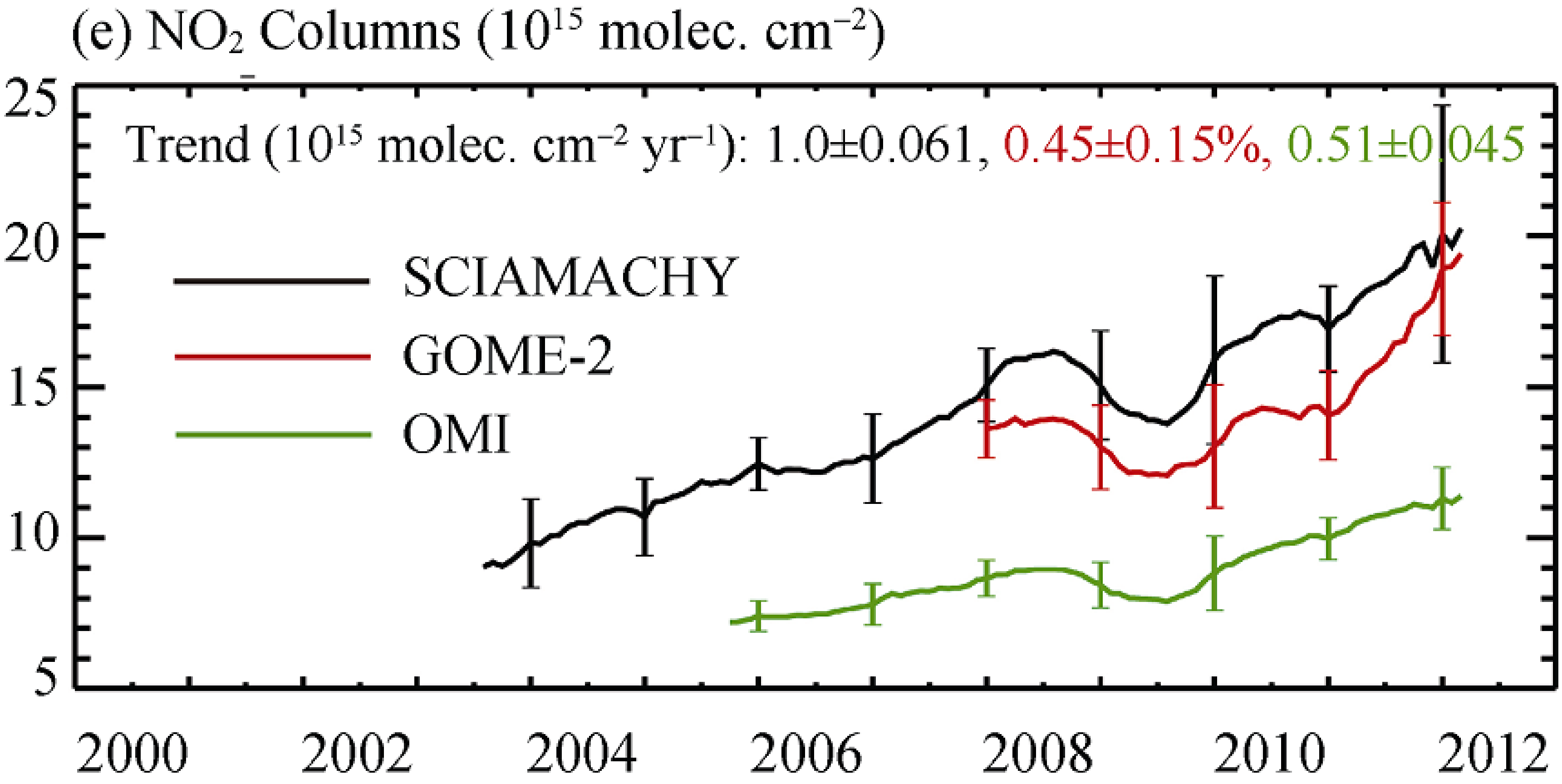
NOx Budget

Table 4.8: Estimates of the global tropospheric NO_x budget (in TgN/yr) from different sources compared with the values adopted for this report.

Reference:	TAR	Ehhalt (1999)	Holland *et al.* (1999)	Penner *et al.* (1999)	Lee *et al.* (1997)
Base year	**2000**	**~1985**	**~1985**	**1992**	
Fossil fuel	33.0	21.0	20 - 24	21.0	22.0
Aircraft	0.7	0.45	0.23 -0.6	0.5	0.85
Biomass burning	7.1	7.5	3 - 13	5 - 12	7.9
Soils	5.6	5.5	4 - 21	4 - 6	7.0
NH_3 oxidation	-	3.0	0.5 - 3	-	0.9
Lightning	5.0	7.0	3 - 13	3 - 5	5.0
Stratosphere	<0.5	0.15	0.1 - 0.6	-	0.6
Total	**51.9**	**44.6**			**44.3**

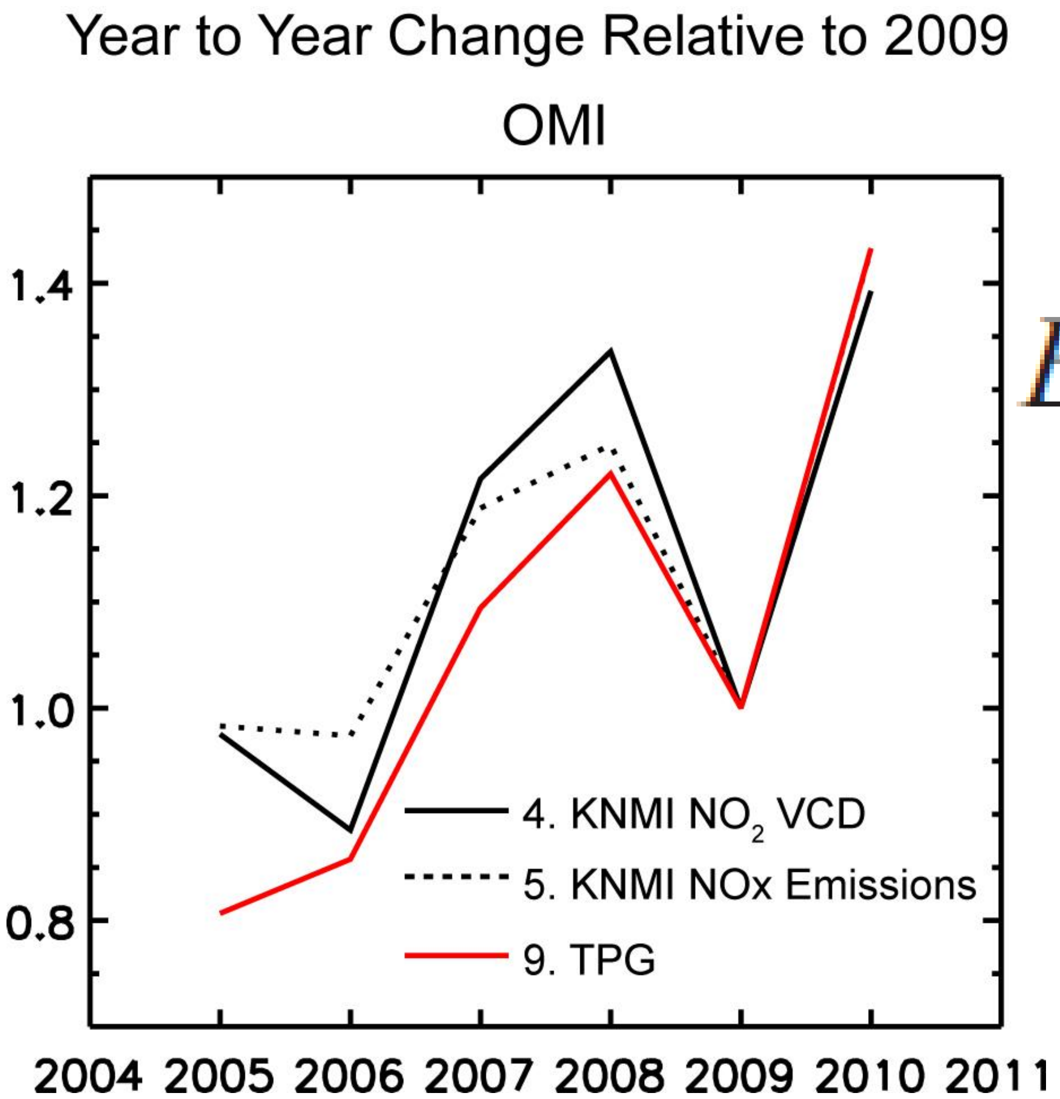
卫星观测：中国东部NOx污染每年增长 7%

2002-2011年华北地区NO_2年际变化



Lin et al., 2013

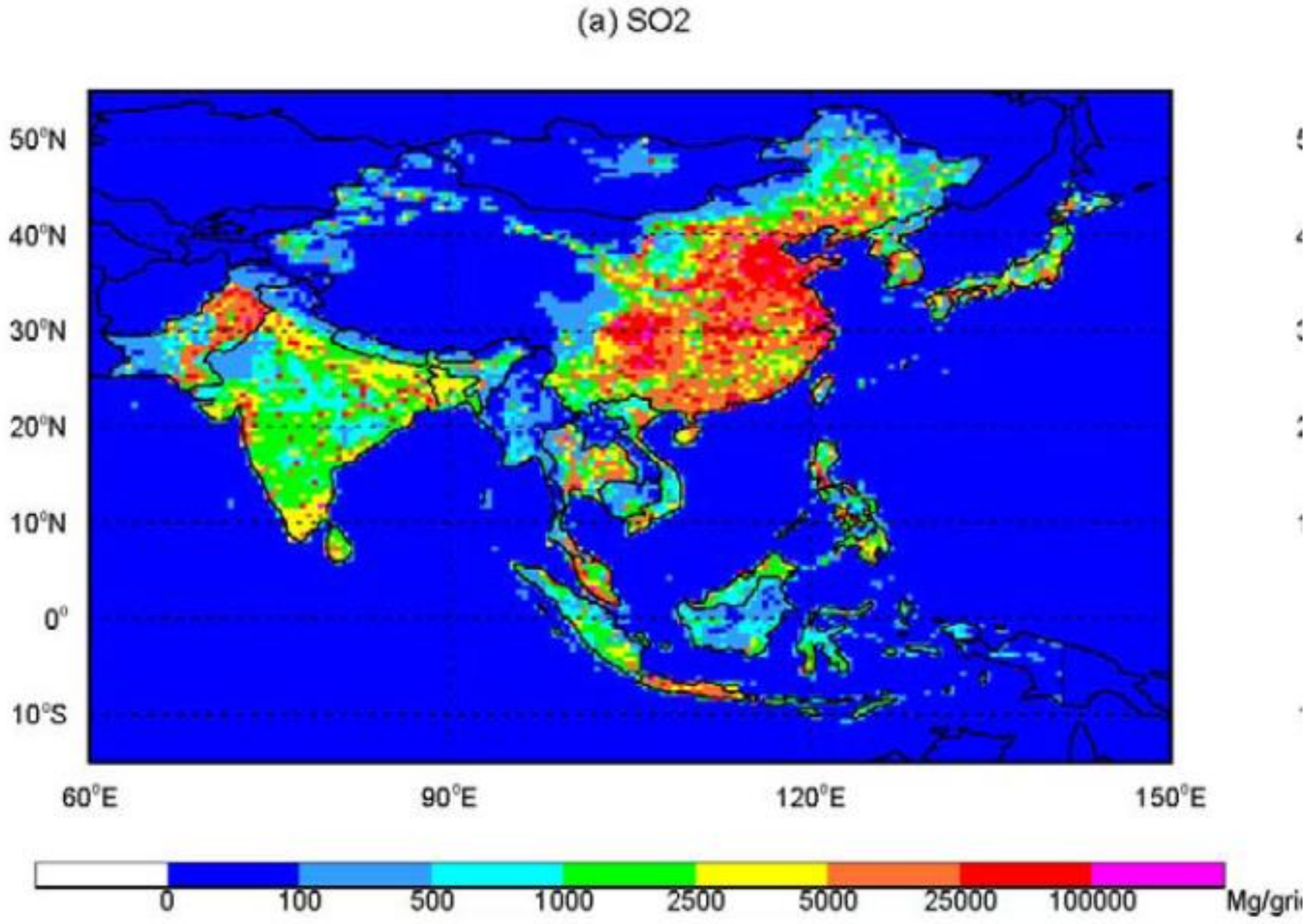
Increasing NOx Emissions Observed from Space



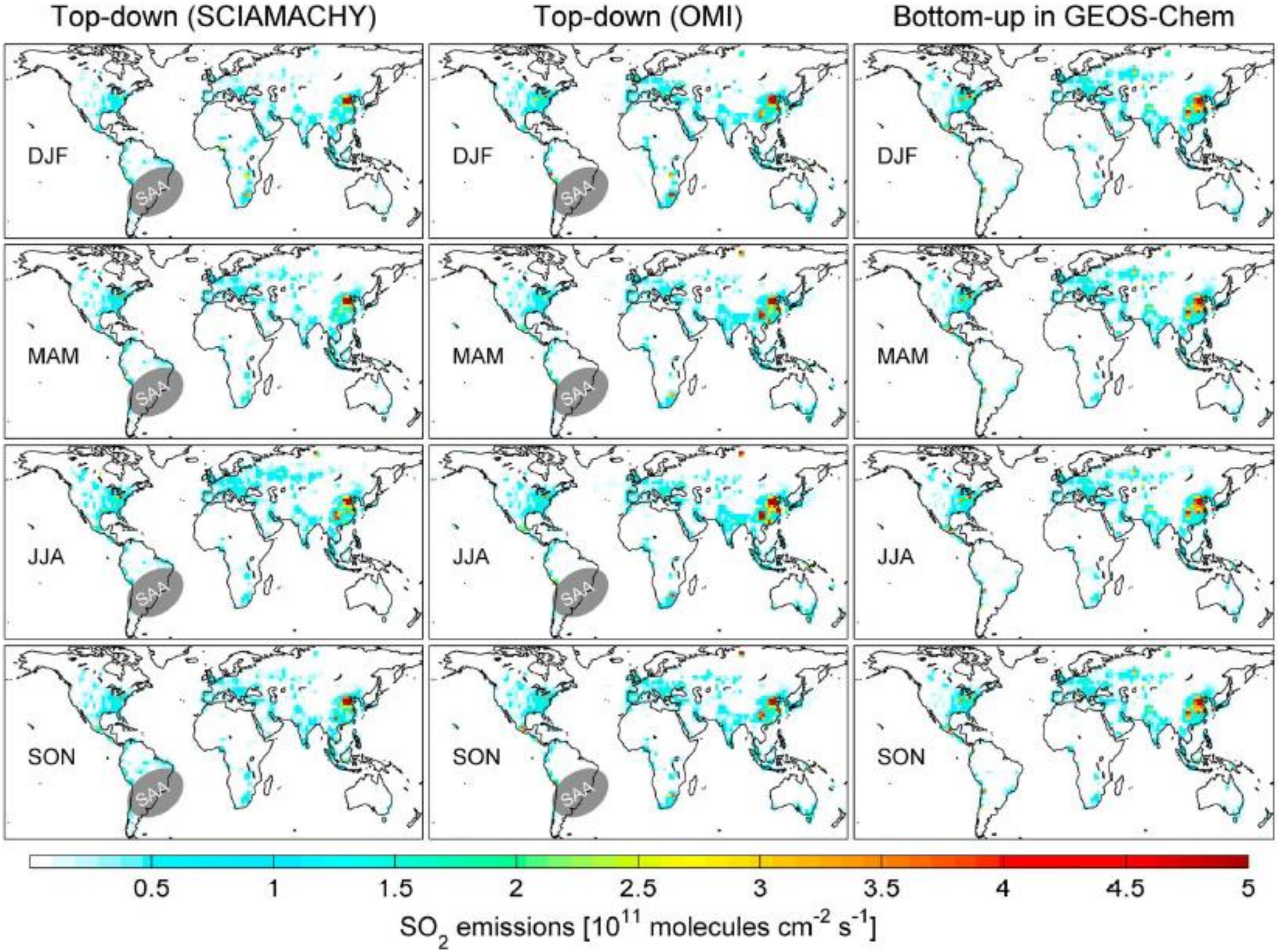
$$E_t = \alpha \Omega_r$$

Lin and McElroy, 2011

Anthropogenic Emissions of SO_2 for 2006 in Asia



SO_2 Emissions



Decreases in SO_2 over Central Eastern China after 2007