

Ecology and Sustainable Development.

9. Third Industrial Revolution:

9.1 Climate and Energy

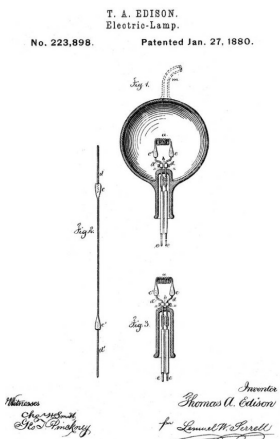
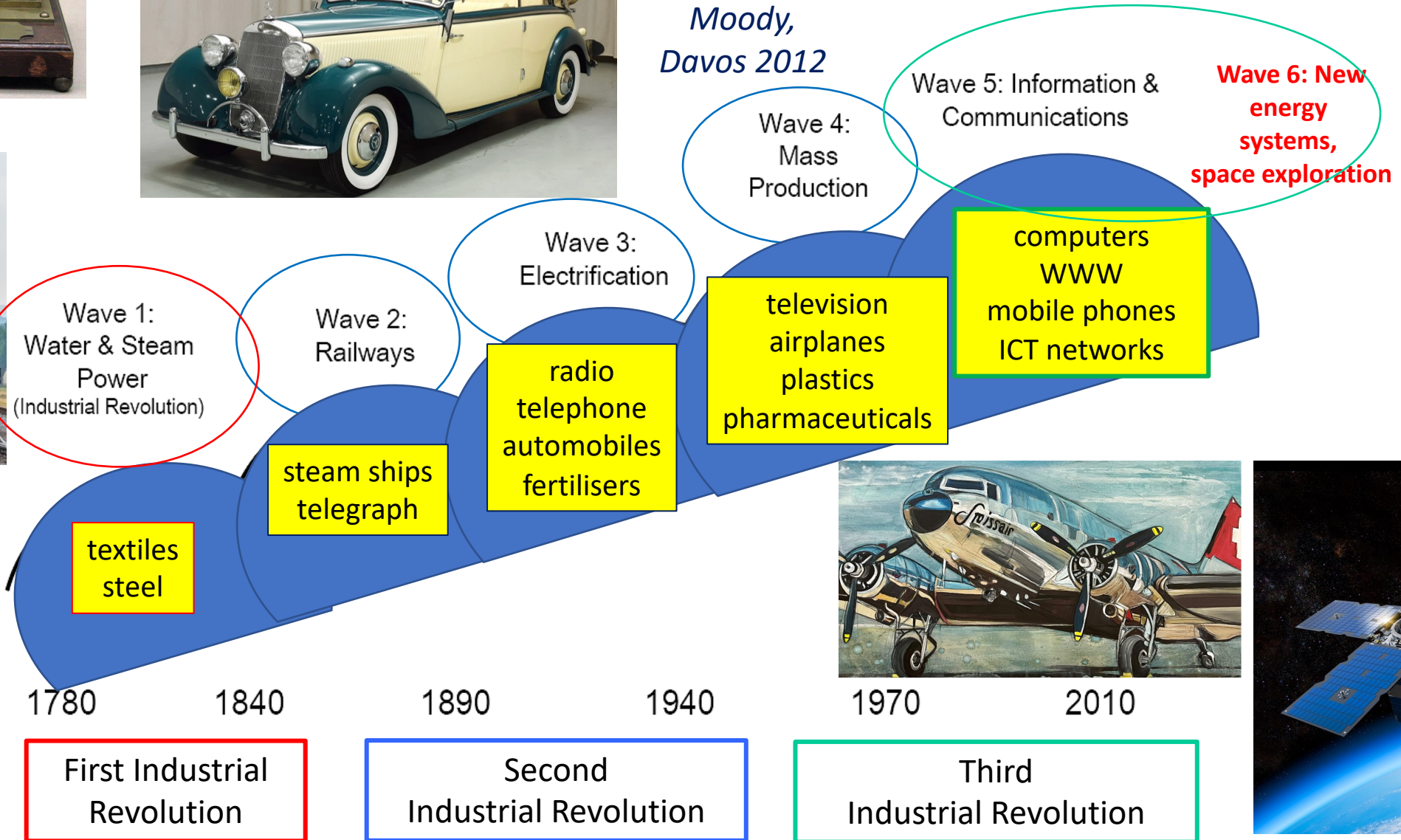
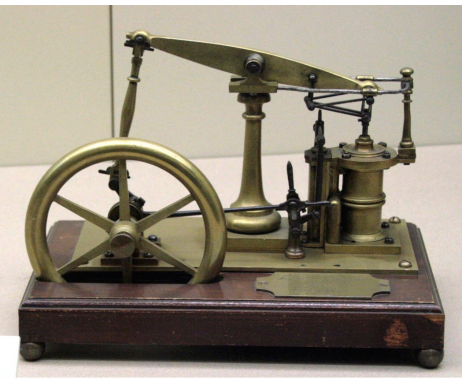
9.2 Space Exploration

9.3 Global Earth Observation

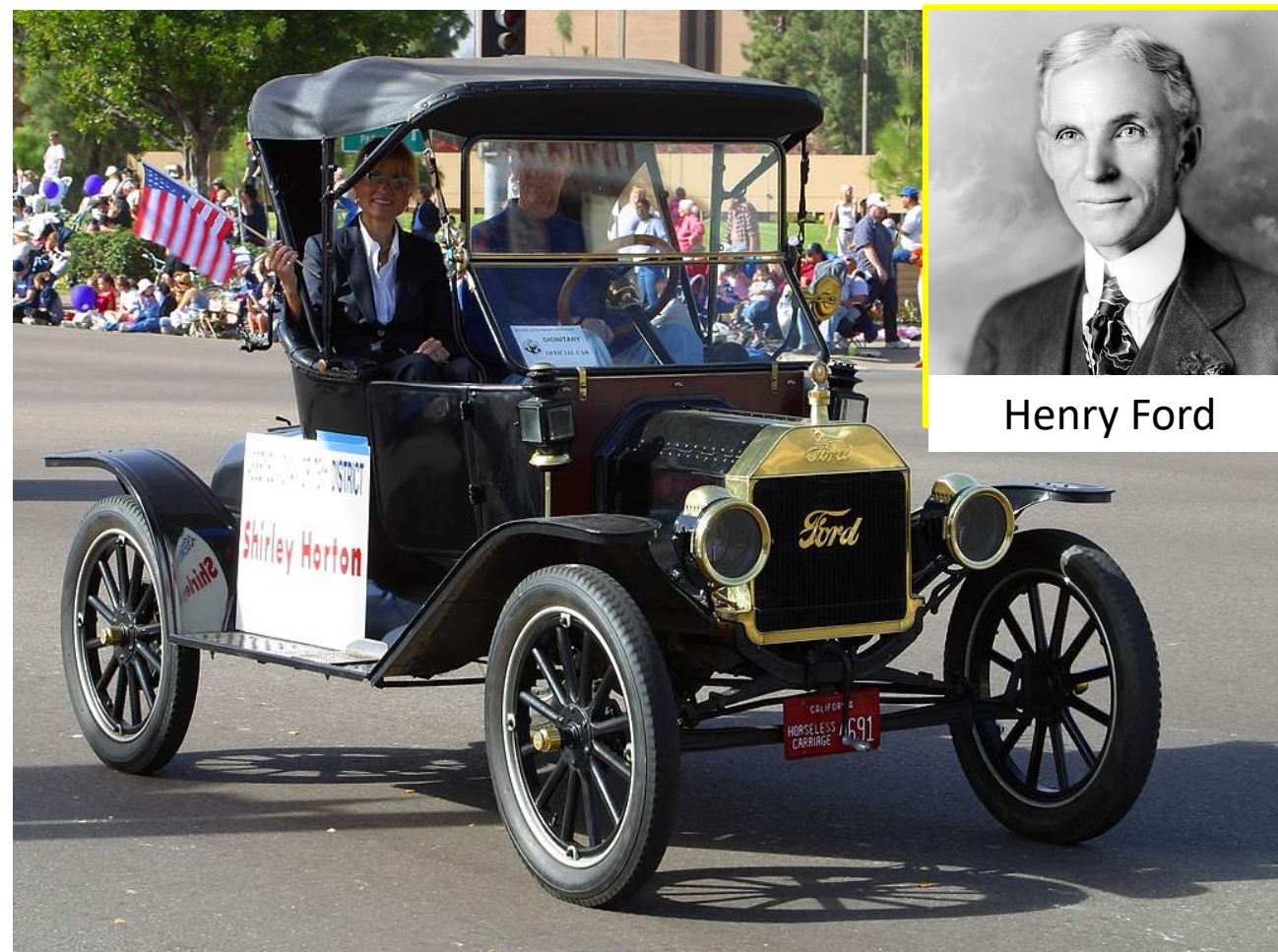


The Industrial Revolutions: Six Waves of Innovation.

Source: James
Bradfield
Moody,
Davos 2012



The “Third Industrial Revolution”: Major Drivers of Technological Change.



- **Major drivers of innovation today:**
 - Enhancing competitiveness of industry, trade and services in a situation of international competition to secure the living and social standards of a political entity (state, region like the EU).
 - Gains (profits of enterprises) securing the living standard of the employees and their dependents.
- **Priority areas for innovation:**
 - Mitigation of global warming: new energy systems.
 - Sustainable production: reduced use of resources.
 - Reduction of environmental pollution: „clean“ technologies and mobility.
 - Extending frontiers of human activity: space exploration.
 - Sustainable management of the whole earth system: earth observation.
 - Industry 4.0 based on Artificial Intelligence.

The historic model for technological change:
Ford Model T “Tin Lizzie”:
First car produced in assembly line 1908-1927,
15 million sold.

Mitigation of Global Warming (Climate Change).

- **Evolution since preindustrial times (1850):**

- The concentration of the Green House Gases (GHGs) in the atmosphere - mainly CO₂, CH₄ and N₂O - increased from 280 to 508 ppmv CO₂eq.
- According to the IPCC this caused a temperature rise of 1,2°C.

- **“Business as Usual” scenario:**

- By 2100 a doubling of the annual emissions from 50 to > 100 Gto CO₂eq. Global warming 4,6°C (3,5 - 5,7°C).

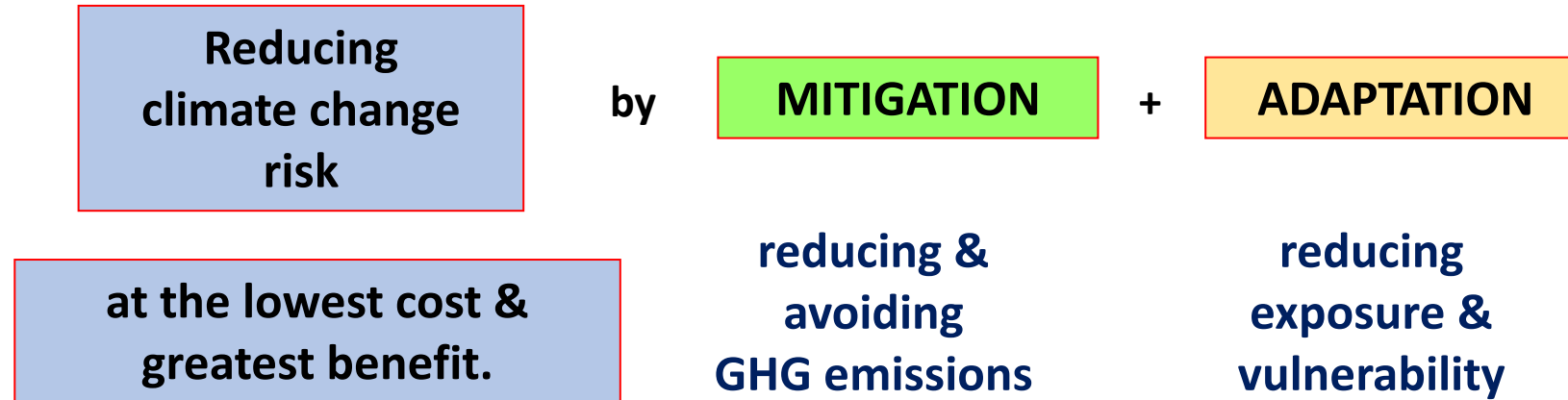
- **Combating Climate Change:**

- Climate Agenda discussed at UN-level in Conferences of the Parties (COP1 Berlin 1997 - COP29 Baku 2024).
- COP21 (Paris 2015): Global agreement to set a goal of limiting global warming to **"well below 2°C"** (aiming at 1,5°C) compared to 1850.
- COP24 (Katowice 2018): **Limit global warming to 1,5°C.**

Global emissions of the Green House Gases must be reduced by 90% compared to now.

EU Climate Policy.

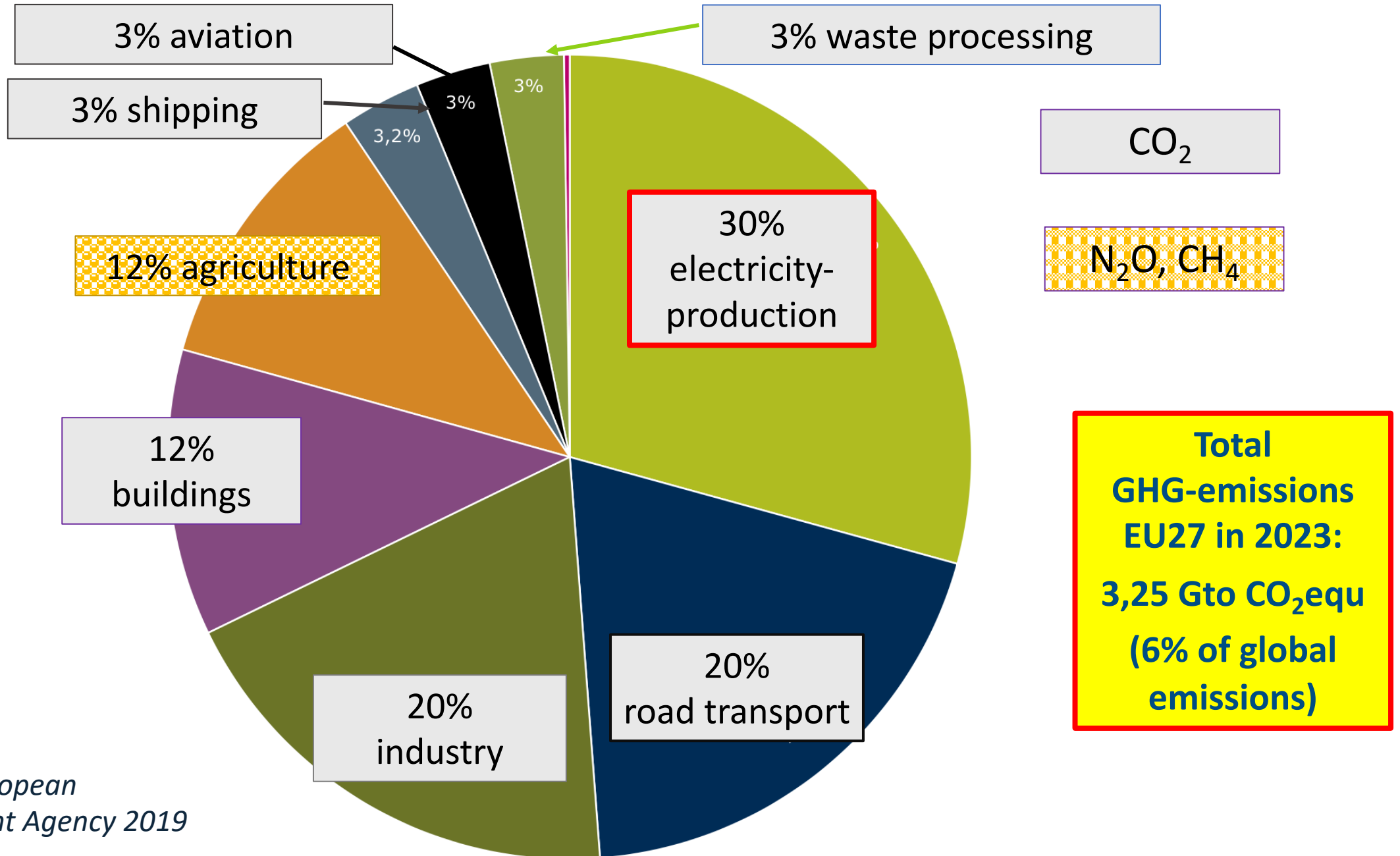
Principles established 1990:



European Council 2019:
Decision on Green Deal „A Carbon Neutral Europe by 2050“.

Legal targets for emission reduction of GHGs (base year 1990):
2020: minus 20% (achieved)
2030: minus 55% (measures in implementation, - 37% achieved in 2023)
2050: minus 90% (roadmap in development)

EU Green House Gas Emissions by Sector (2018).



Source: European
Environment Agency 2019

Transformation of Electricity Production.

Electricity Production in EU 2.600 TWh/a (2024):

- **CO₂-emission free production 71%**

- 25% nuclear
- 14% hydro
- 3% biomass
- 19% wind
- 10% solar

stable supply

volatile supply

- **fossil production 29%**

- 14% natural gas
- 10% coal
- 3% oil
- 2% garbage

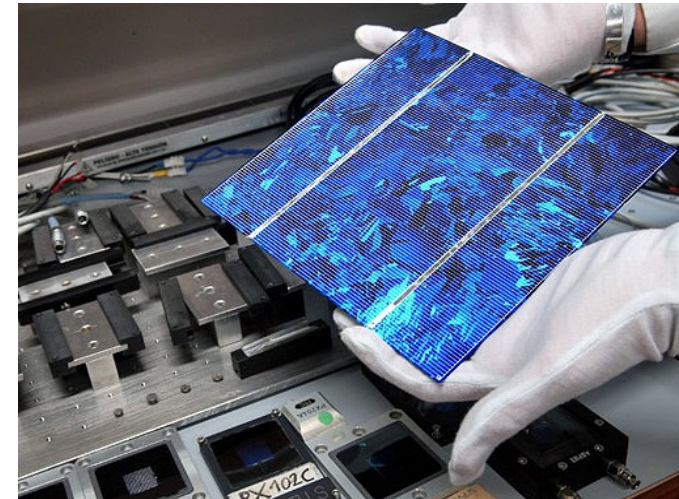
stable supply

- **Substitution of fossil fuels by wind (50%) and solar (50%) energy:**

- 50.000 new wind turbines.
- 5.000 km² new photovoltaic panels.
- Tens of thousands kilometer new power lines.
- Costs: 3.000 billion EUR (?)

58% of EU electricity production then volatile.

**PV-modules:
polycrystalline silicon.**



Av. yield in EU is 12% of nominal peak output.
Production of 1 TWh/a needs 10 km² PV panels.
90% imports from China.

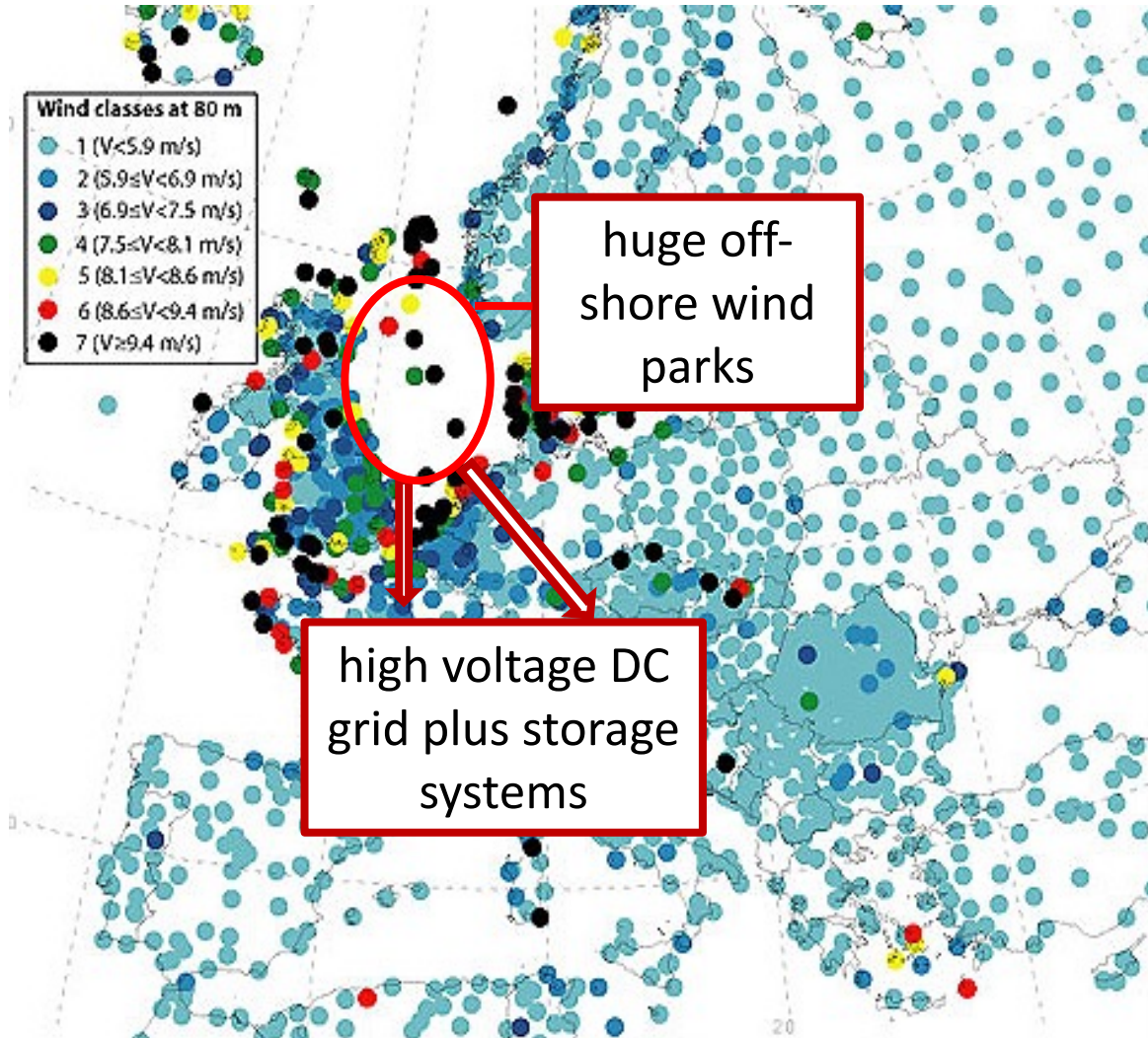
Source: Statistica 2025



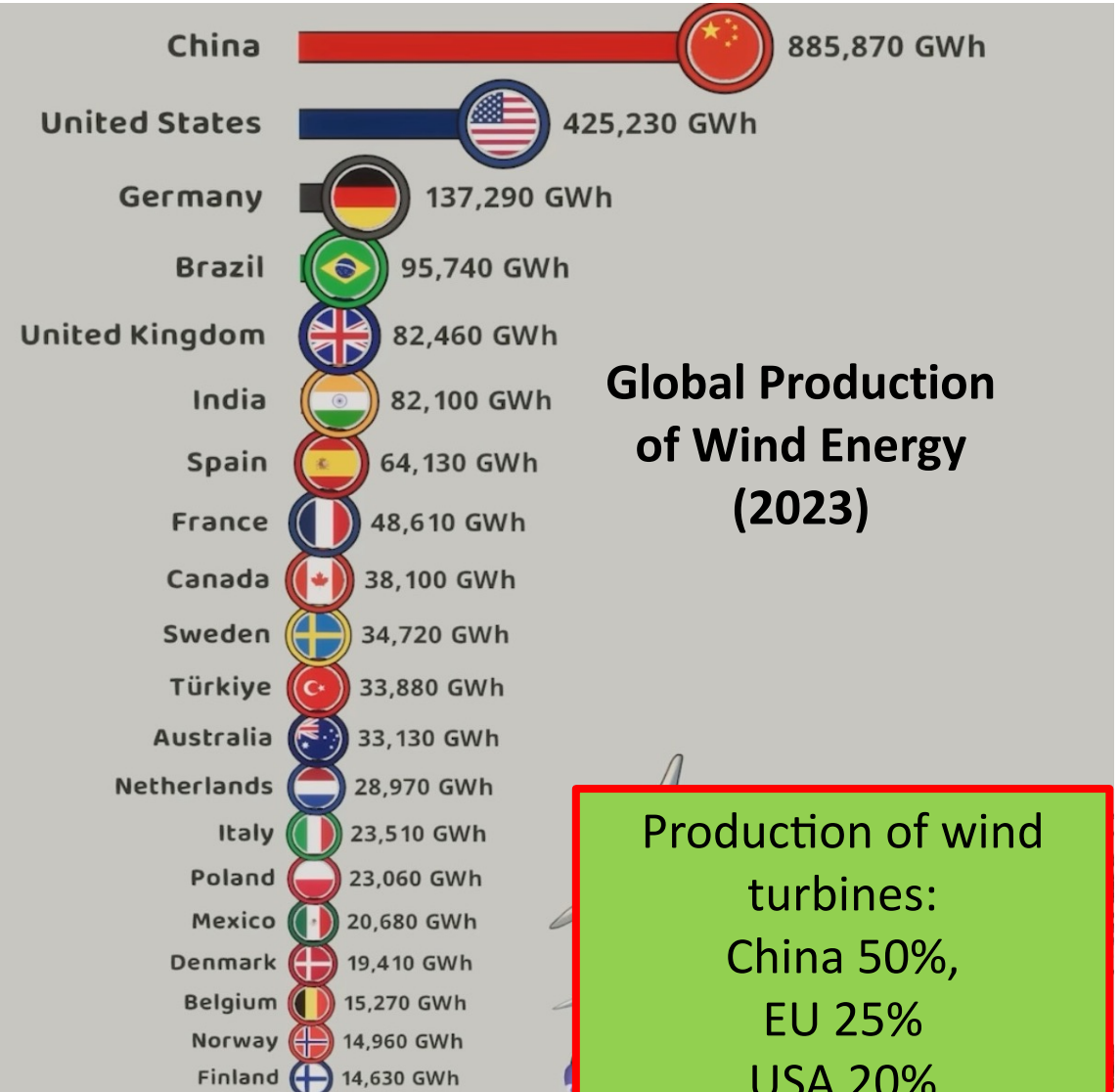
Enercon E-147: 5 MW,
height 155 m,
rotor 62 m
Av. Yield in EU: 26%
Production 10 GWh/a.

The Transformation of Electricity Production: Wind Power.

Share in electricity production 2022: 16 % in EU, annual growth 8%



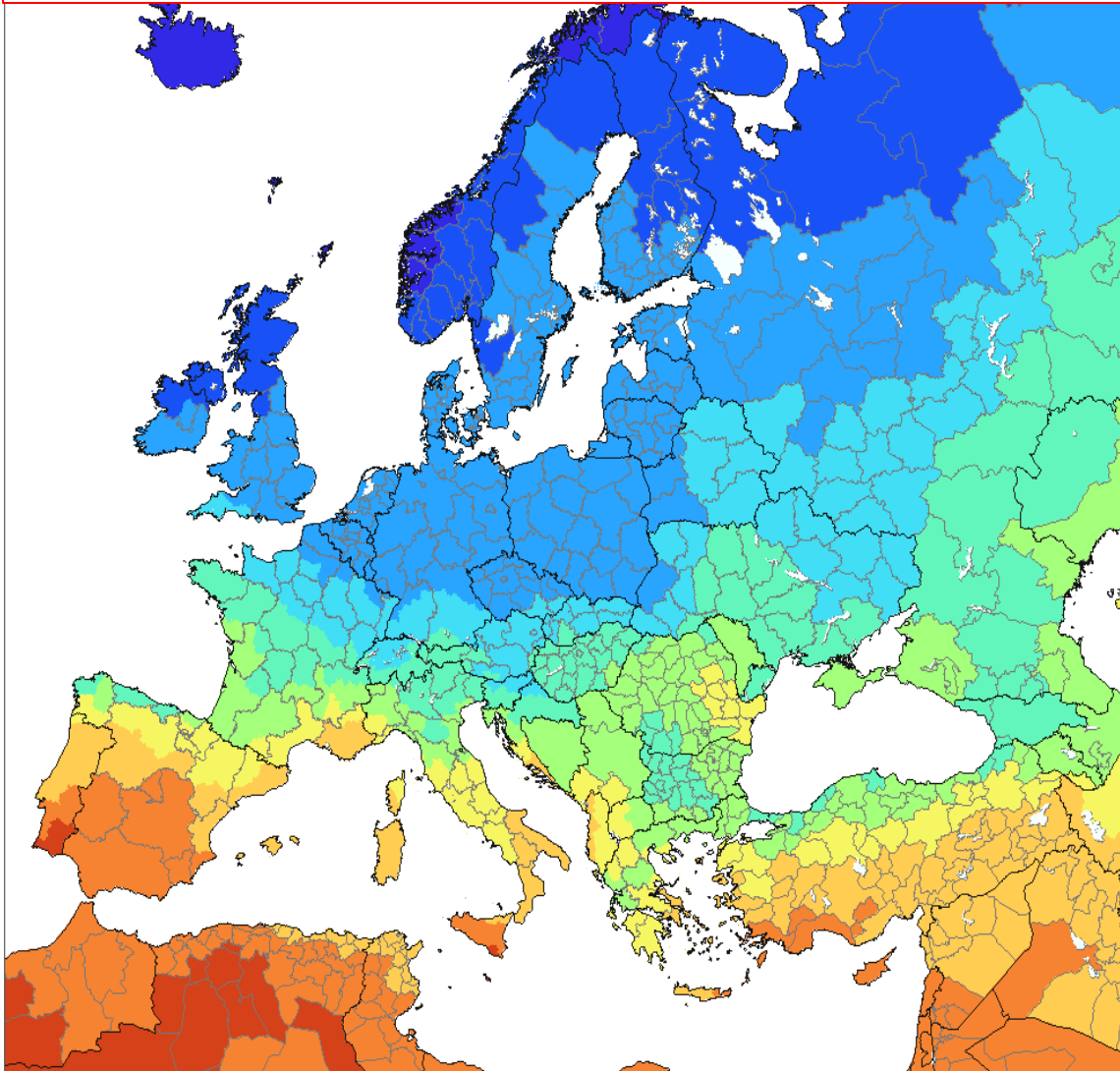
80.000 wind turbines now installed in EU.



The Transformation in Electricity Production: Solar Power.

Share in electricity production 2022: 8 % in EU, annual growth 16%

European Potential for Solar Power.

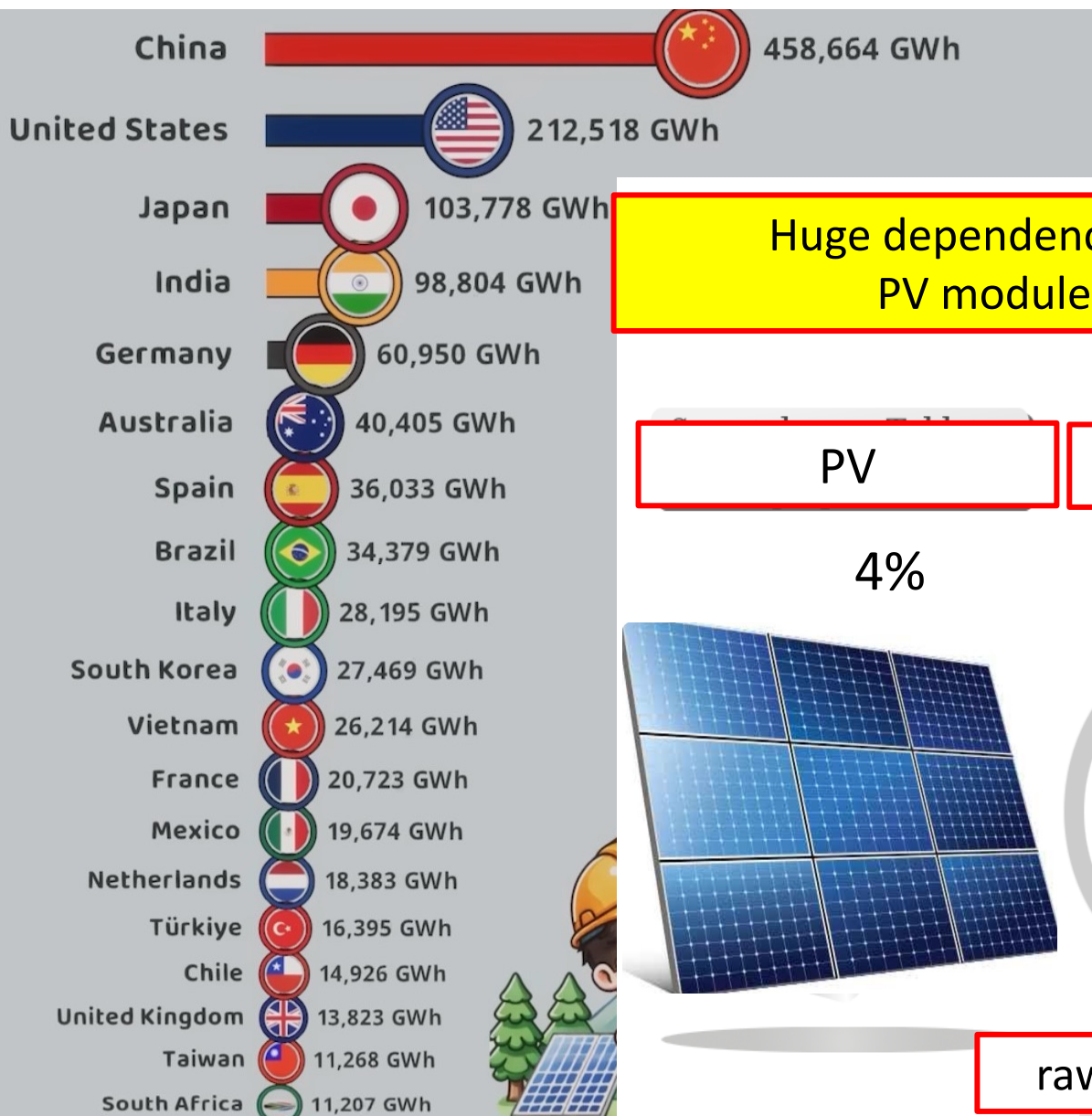


Solar farms established or in development in Europe.



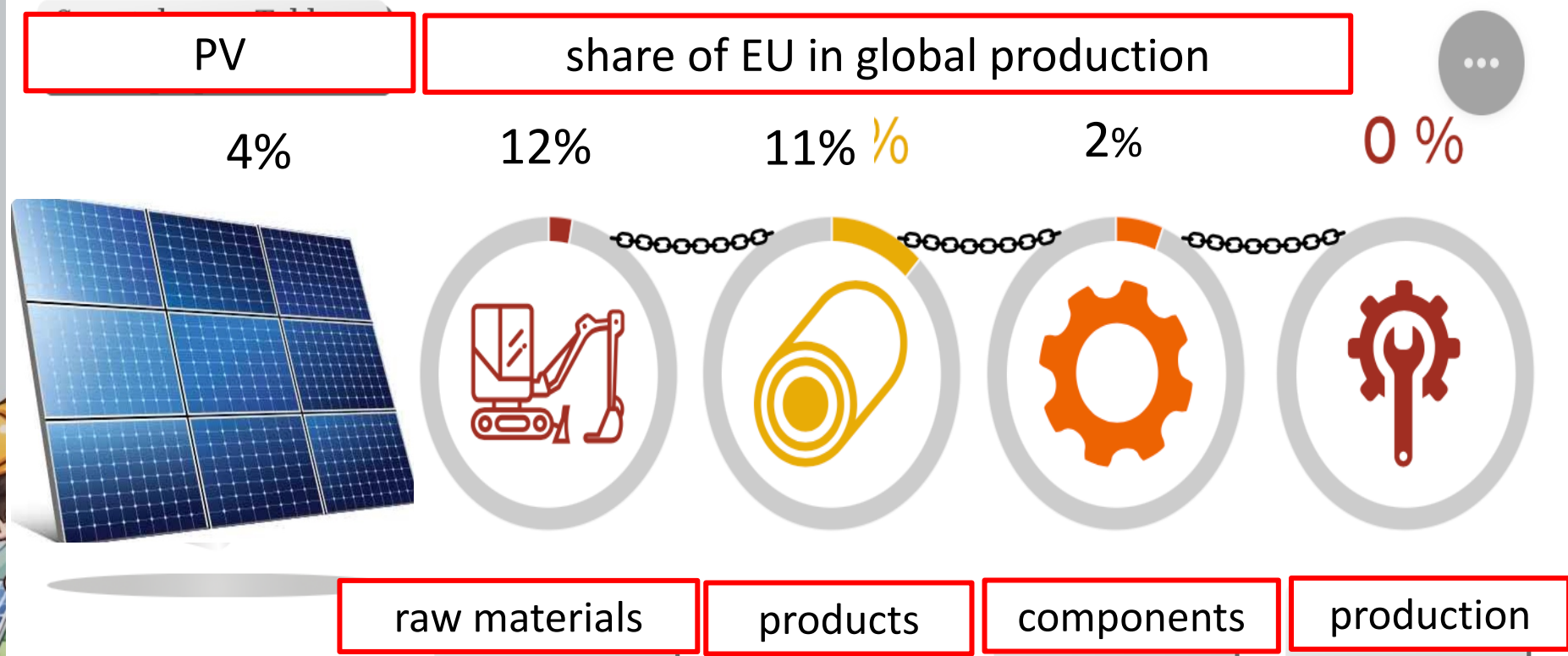
Presently 2.000 km² PV area in EU.

Global production of solar electricity.



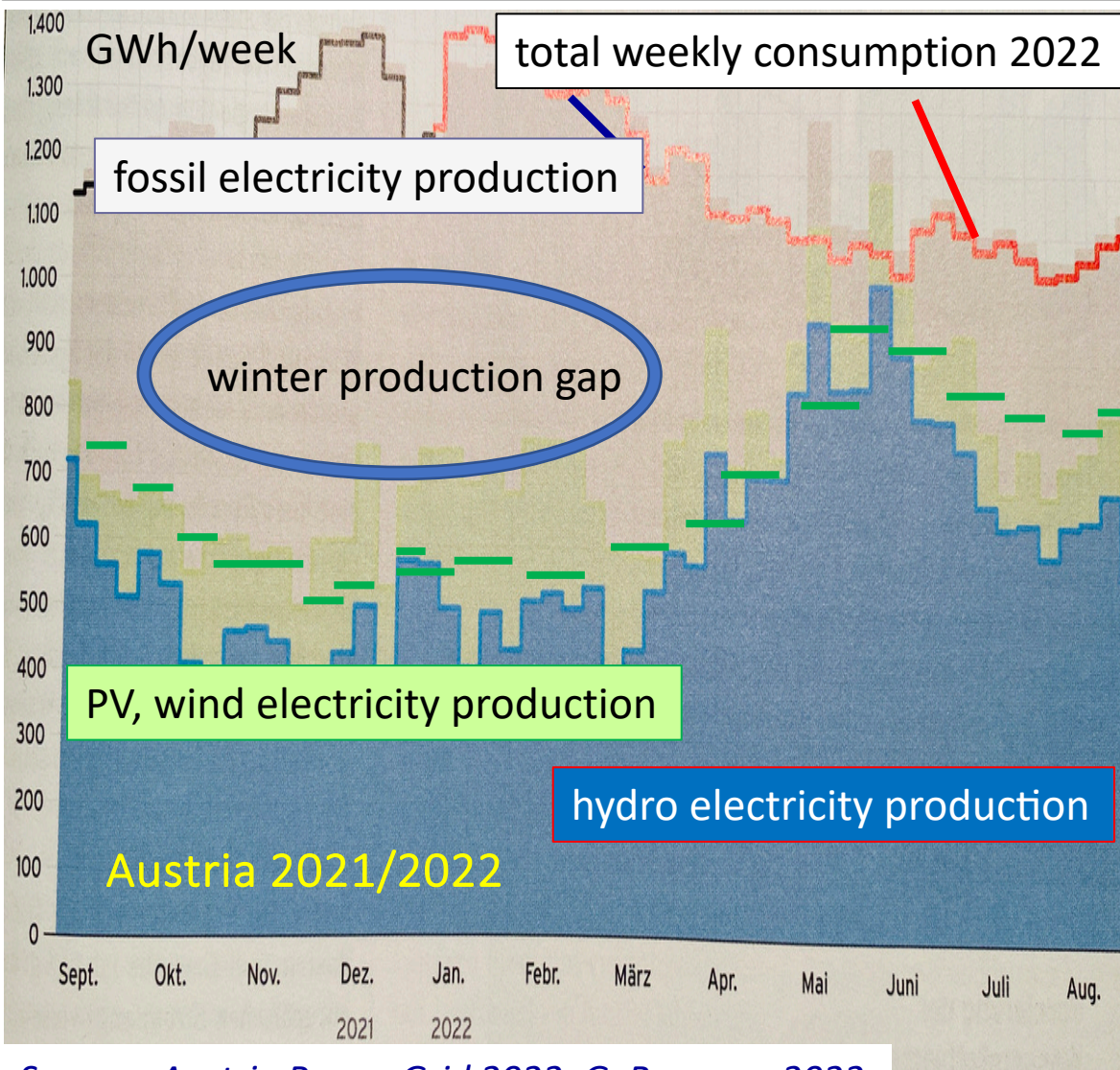
European Value Generation in Transformation.

Huge dependence of EU on other economies:
PV modules 90% produced in Asia.

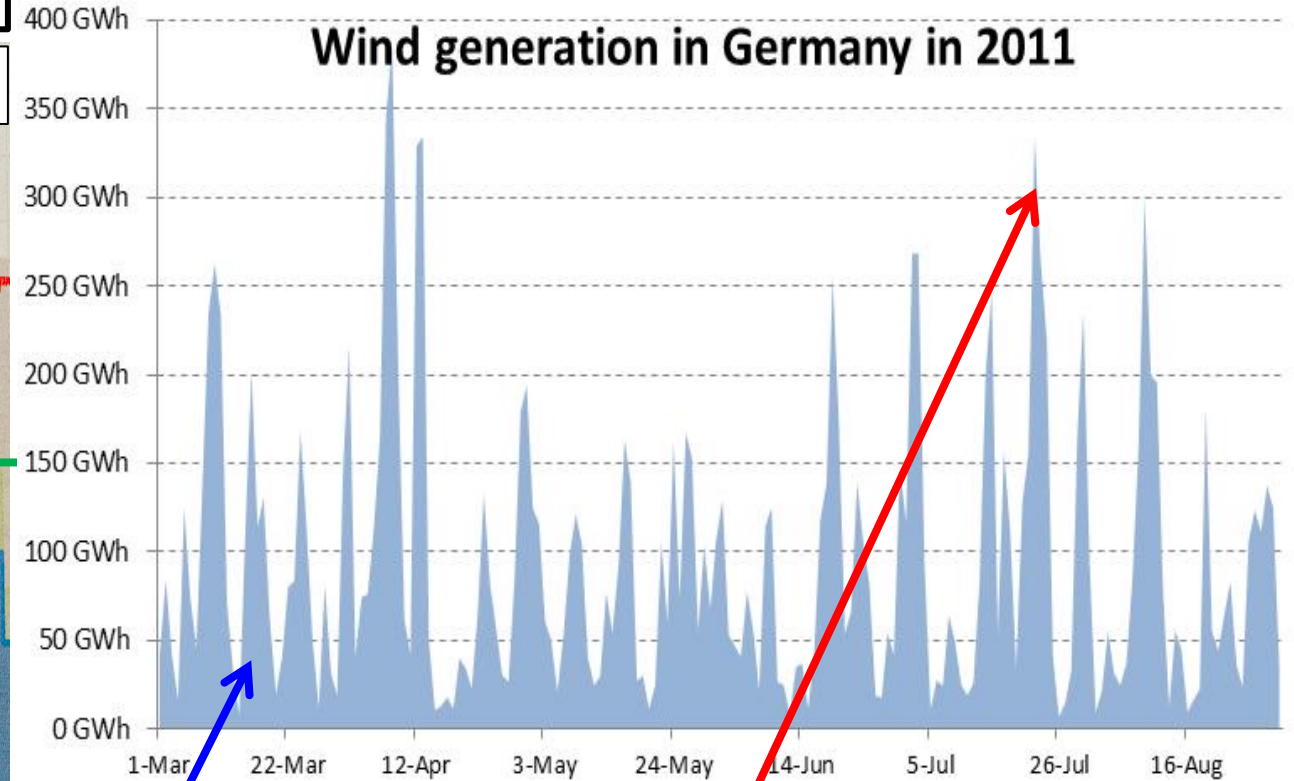


Volatility of RE Production.

Seasonal variations:
winter gap in RE and hydro production



Daily/weekly variations in production of wind power.

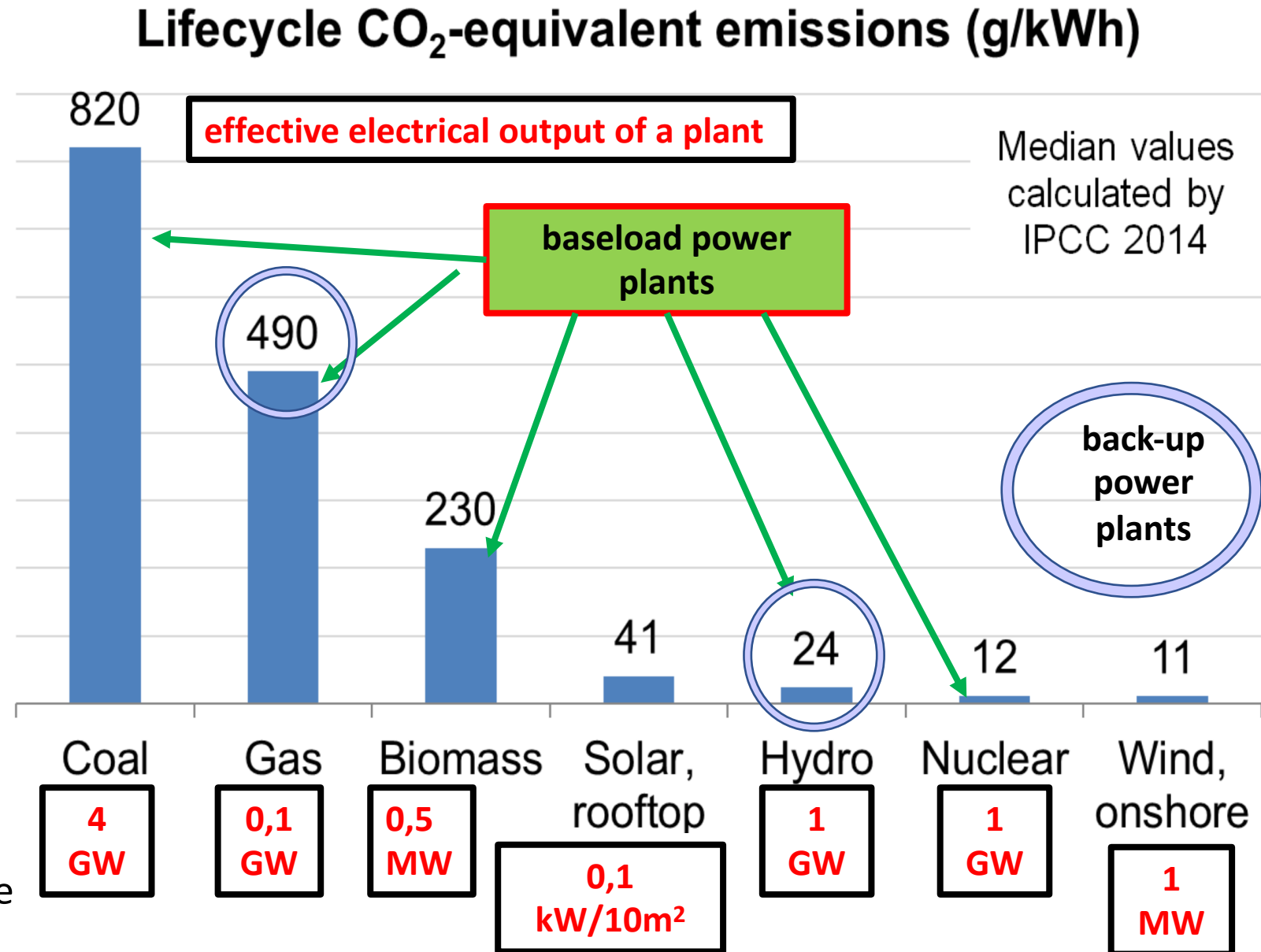


base load/back-up
power plants:
hydro, gas,
(nuclear, coal)

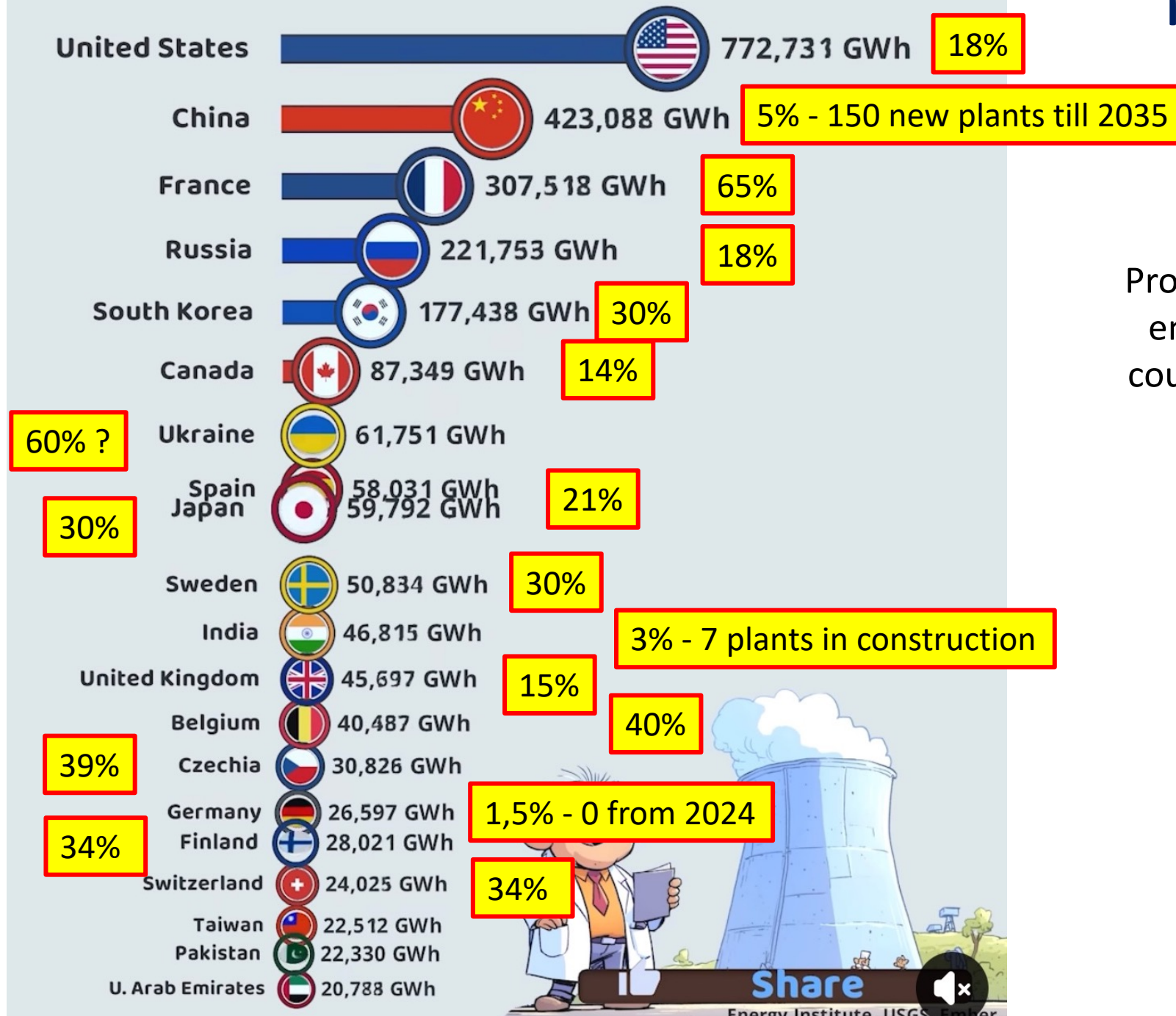
storage of surplus electricity:
hydro (Kaprun), batteries,
production of hydrogen

Base Load/Back-Up Power Plants: CO₂-Emissions and Electricity Output.

- **Hydro power plants:** only limited possibilities for new plants in EU.
- **Hydro storage plants:** low capacity!
- **Gas and coal power plants (with CCS)**
 - EU 400 coal fired power plants.
 - Gas fired power plants needed for a high consumption volume, can be brought into operation very quickly.
 - Back-up power plants must cover the whole volume of wind and PV electricity production minus stored electricity: will be operational only a fraction of the normal availability – high standby costs and poor economical performance.
- **Nuclear power plants:** presently 104 in operation in EU, 440 globally; future small nuclear power plants ?



Nuclear Base Load Power Plants.



Production of nuclear energy of different countries in GWh per year (2023)

Share of nuclear in total electricity production (%)

Back-up Power Plants: Hydro Storage Power Plants.



Kaprun 500 MW output

Capacity of all Austrian hydro storage power plants:
electricity supply for 2 days

EU 3 GW storage capacity =
26 TWh/a = 1% of electricity
consumption
Potential for expansion very
limited.

- **Alternative Solutions:**

- Hundreds of caloric back-up plants operated with natural gas or/and hydrogen.
(40 large new gas power plants in Germany by 2030).
- Increase of base load in electricity production: more nuclear plants, gas, coal (CCS).



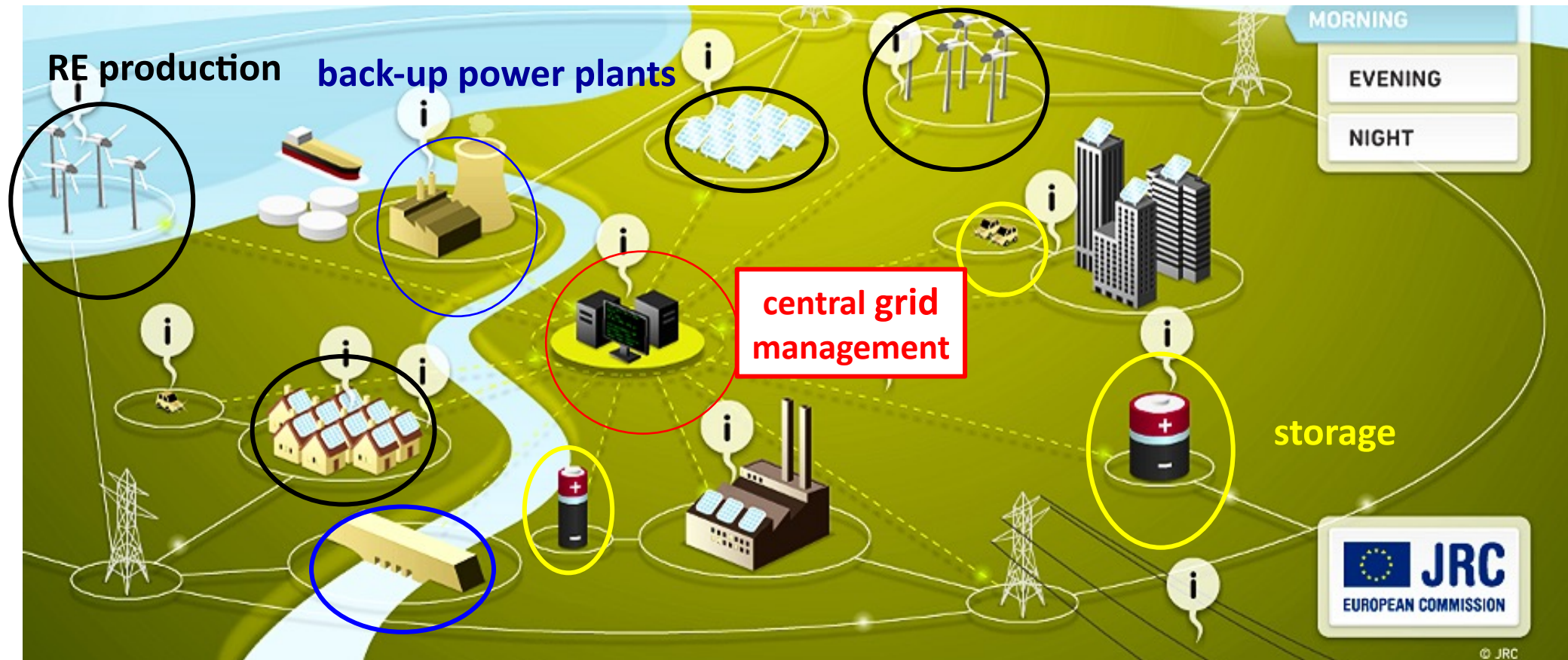
Back-up Power Plants: Solar-Hydro Power Plant.

- **Kela photovoltaic (PV) power station (China):**
 - Largest hydro-solar power plant globally with 16 km² PV-panels.
 - It generates 2 GWh annually, meeting the energy needs of around 700,000 households.
 - The station has 527,000 photovoltaic foundation piles.
 - Combining these two sources helps regulate power fluctuations and addresses the intermittency issues associated with solar power alone.

„Smart Grids“.

“Intelligent” network of electricity production, storage and consumption through local, regional and continental grids.

Smart meters enable production oriented supply and consumption oriented pricing.



Hugely complex and expensive system:

Enormous technical and sociological challenge for the European Union.
Investments in Austria estimated 20 billion EUR (EU 1.000 billion EUR?).

Large Scale Storage of Green Electricity: Production of Hydrogen.



**Electrolysis of water with (surplus)
wind or solar power:**



- Addition to natural gas or replacement of natural gas for power generation or heating, but volumetric energy content only 3,0 kWh/m³ (methane 33,3 kWh/m³)
- Fuel for large electric vehicles (trucks, buses) operated with fuel cells:
anode $2 \text{H}_2 + 4 \text{H}_2\text{O} = 4 \text{H}_3\text{O}^+ + 4\text{e}^-$ /electrical motor/ cathode $\text{O}_2 + 4 \text{H}_3\text{O}^+ + 4 \text{e}^- = 6 \text{H}_2\text{O}$
- Production of “climate neutral” synthetic fuels (Syn/E-fuel).
- Raw material for chemical industry (e.g. ammonia synthesis for fertilizer production).
- Replacement of coal in steel production.

Green Hydrogen as an Energy Carrier.

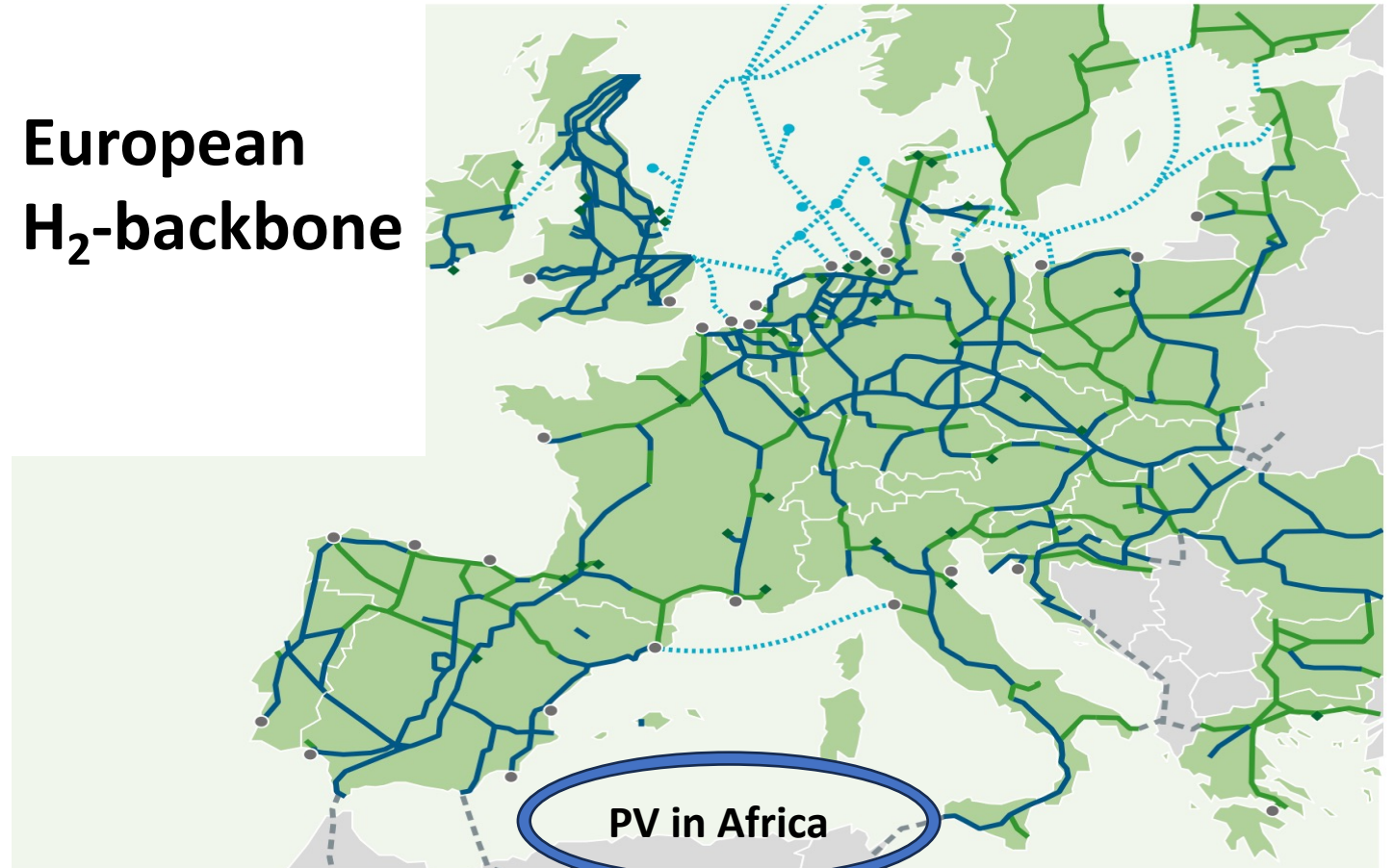
- **Production of carbon neutral hydrogen:**

- EU aims at an electrolysis capacity of 40 GW till 2030.
- 10 million tons of hydrogen per year, equivalent 320 TWh = 3% of total EU energy production.
- Price per unit energy estimated 3 – 5 times higher than natural gas (presently 25 cts/kWh).

- **Storage and distribution:**

- Hydrogen can be stored in underground caverns and transported in pipelines (at 1 – 70 bar) or tanks (pressure 350-700 bar or cooled at – 256°C) on ships (presently max. 2.000 tons per tanker) and vehicles.
- Existing pipeline network needs to be adapted and new lines built.
- Hydrogen grid of 31.500 km in Europe in planning phase.
- Investment costs unclear.

European H₂-backbone



Hydrogen-Powered Trains and Cars.



Hydrogen-Powered Electric Train

- Built by Stadler (CH) is called FLIRT-H2.
- It has two passenger cars with one power pack in the middle.

Hydrogen driven garbage truck of the city of Wiesbaden:

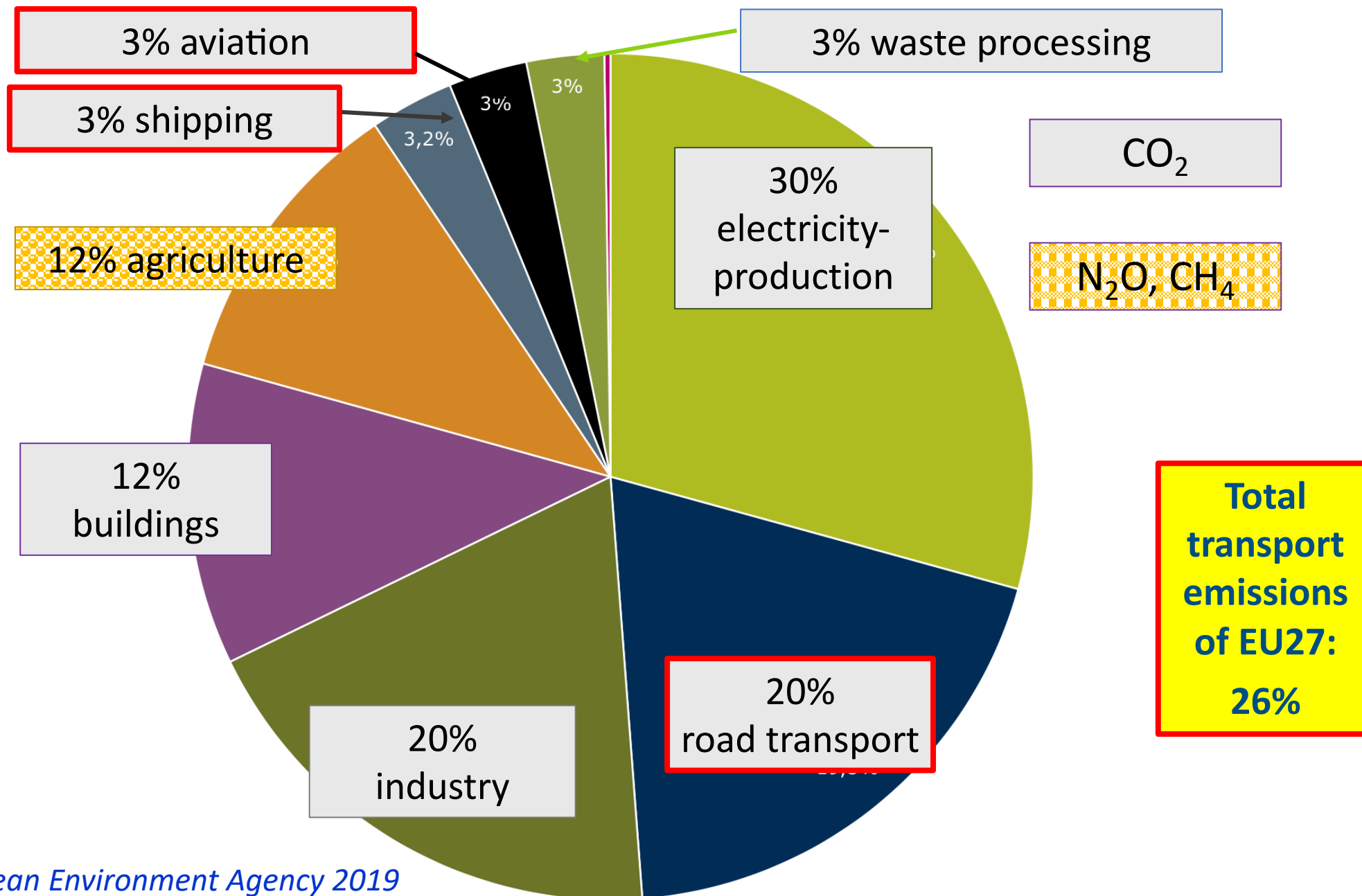
Costs 1,1 million EUR (Diesel truck 300.000 EUR).
Ca 50 garbage trucks in operation (Vienna 270).



Operational distance each day: 50km
Hydrogen consumption 3-4 kg/100km

Source: FAZ 2023, Facebook 2024

EU Green House Gas Emissions by Sector (2018).



Transformation of Road Transport Sector.

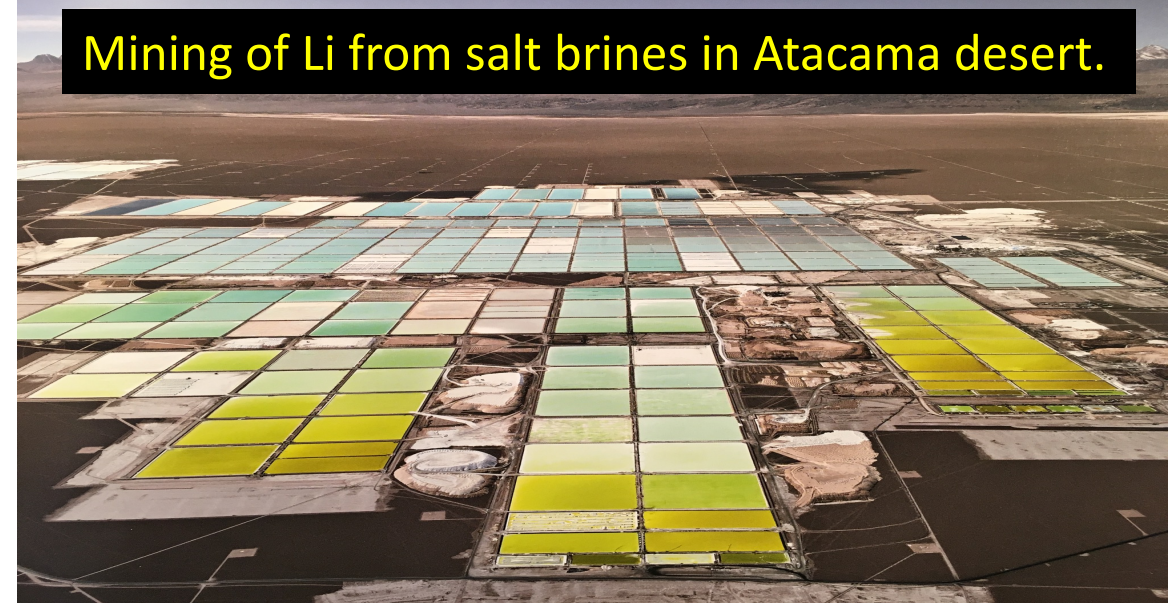


Katy Freeway
Houston Texas
26 lanes

- **Light vehicles (50% of emissions):**
 - Zero CO₂ emissions for new cars by 2035.
 - Only electric cars, battery driven (or use of synthetic fuels in new combustion engines cars?).
- **Heavy duty vehicles (trucks, buses):**
 - Minus 90% emissions by 2040 (?).
 - Electric vehicles (batteries, fuel cells) or synthetic fuels.
 - Hybrid vehicles.
- **Additional electricity in EU:**
 - 1.000 TWh/a (50.000 wind turbines, plus 5.000 km² PV).
- **Charging stations:**
 - 25 million required.
- **Challenge on global level:**
 - By 2050 global vehicle fleet to increase from 1 billion to between 2 and 3 billion.

Batteries for Light Vehicles.

- **High performance Li-Co-batteries:**
 - Complex structure, expensive, heavy: 200kg/100km range (gasoline 8kg!).
 - Production: EU 50 million/yr at full electrification (325 million vehicles).
- **Challenges for Chemistry:**
 - Performance enhancement.
 - Alternative battery systems: solid state batteries..... ?
- **Resource issues:**
 - Annually 300.000 tons of Li and 400.000 tons of Co needed in EU (twice the present global production).
 - Recycling of batteries needs to be fully developed.
 - Development of efficient and sustainable mining of raw materials.



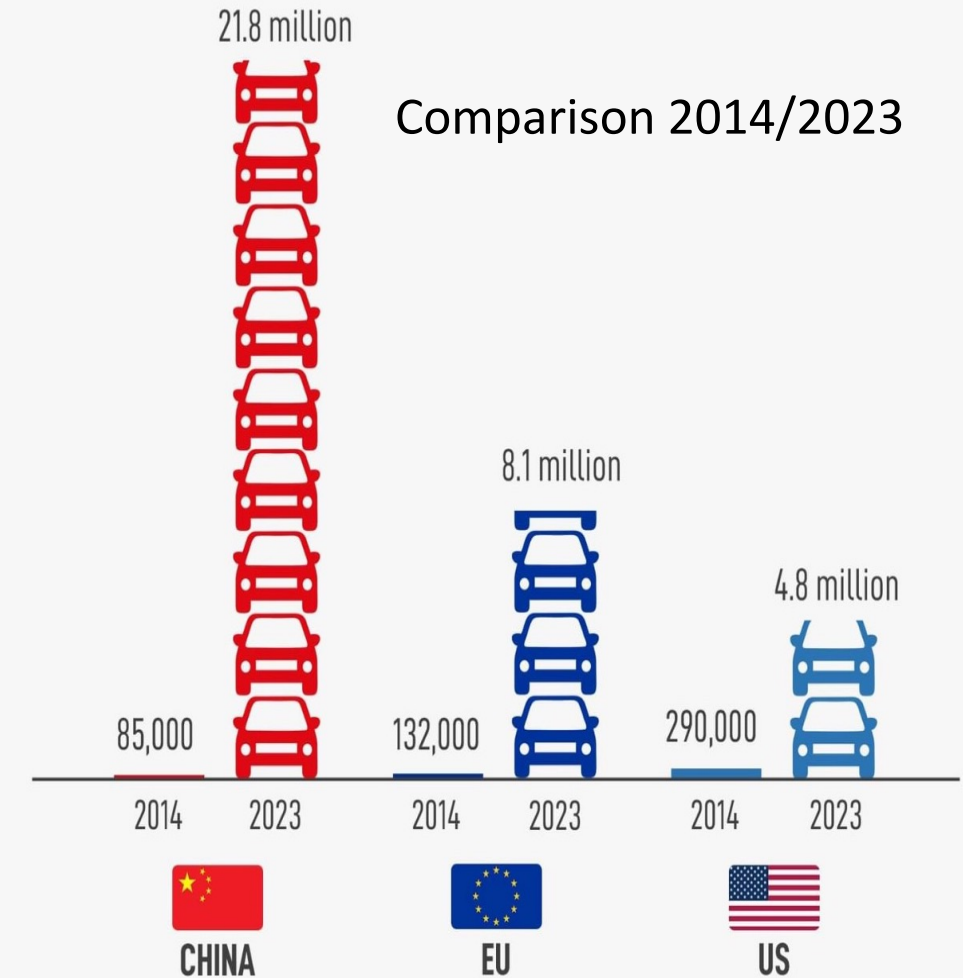
Transformation of Road Transport Sector in China.

Advanced public transportation in Chinese cities:
80% of buses are "new energy vehicles" - BEVs,
plug-in hybrids, and fuel cell vehicles.



40 % of new light vehicles are fully electric (BEV).

NUMBER OF ELECTRIC CARS ON ROAD



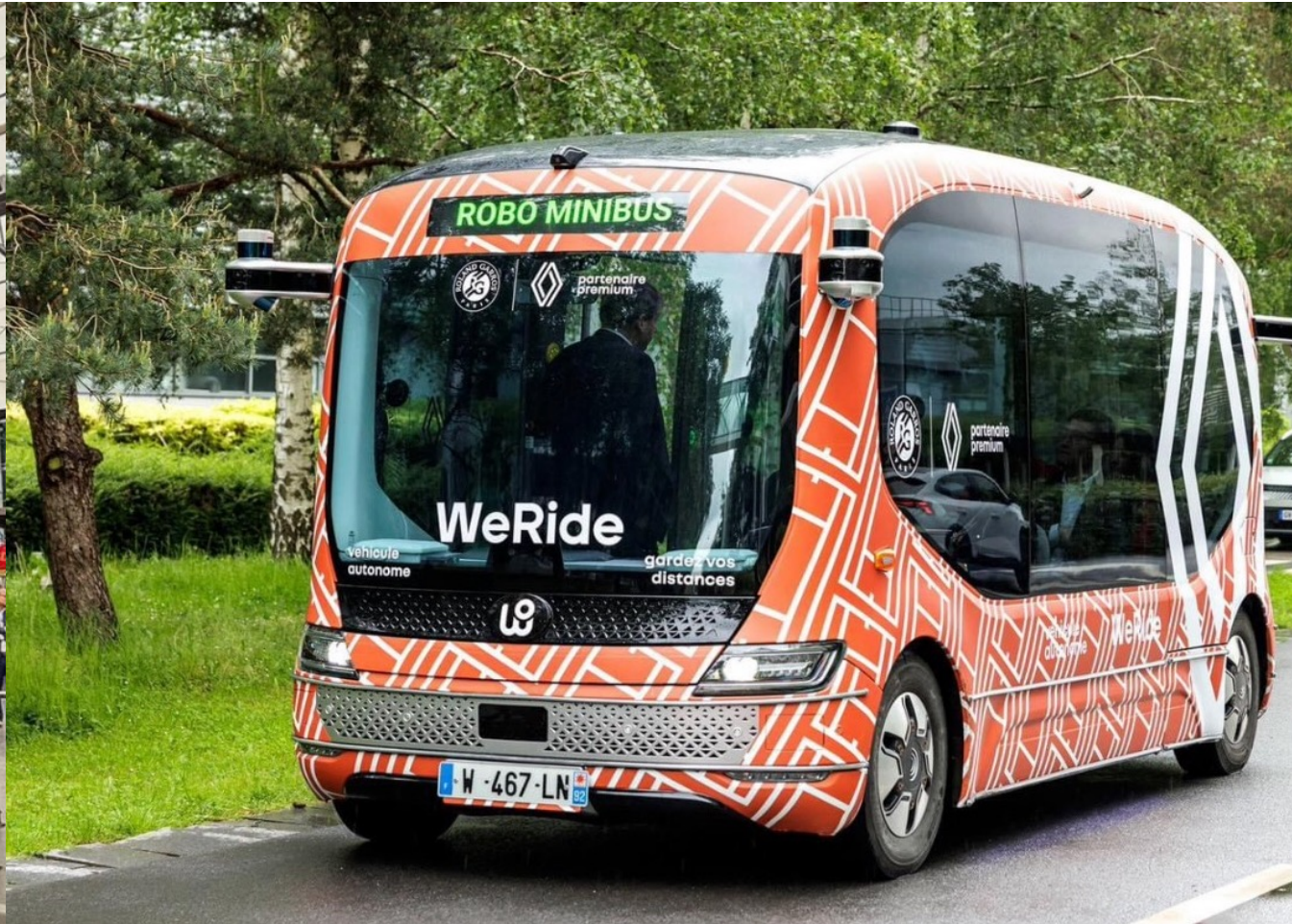
Note: Electric cars include fully battery-electric vehicles and plug-in hybrids.
Sources: Our World in Data, Global EV Outlook 2024

China – the Global Leader in Electromobility.

Advanced public transportation by buses or autonomous taxis.



BYD bus, battery 520 kWh, range 400 km



Driverless shuttle service at French Open:
Autonomous transport with WeRide minibuses for
players and media representatives along a 5-km route.

Global Prohibition of Combustion Engine Cars?



No indication
that other countries
will follow the EU.

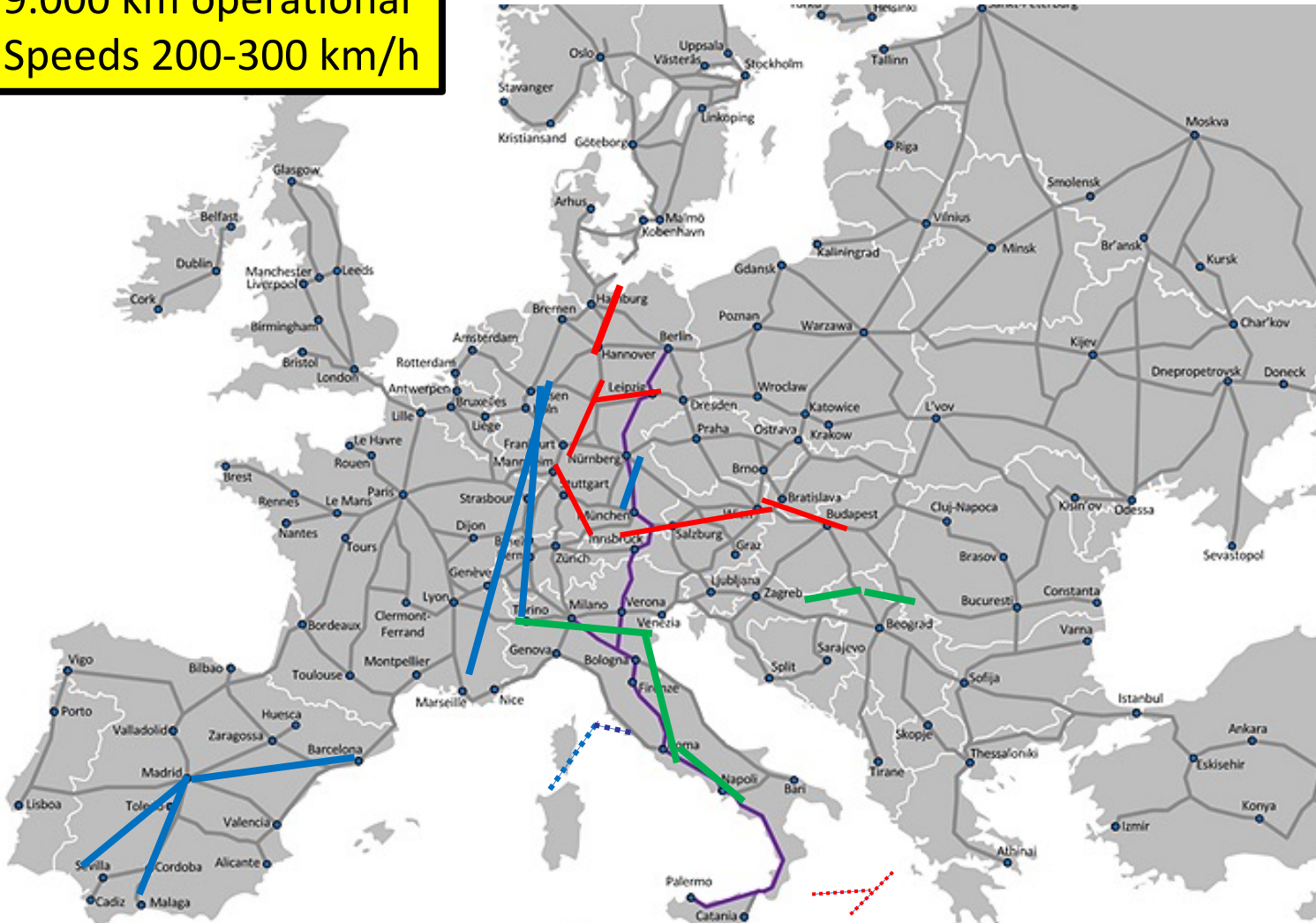
- **Significance of automobile industry in EU:**
 - 13 million jobs and 8% of GDP
 - 102 billion EUR export surplus
 - 59 billion investments in R&D

Hybride vehicles with high efficiency combustions engines would combine the advantages of electrical motors (energy yield 70%) with the high energy density of conventional fuels enabling a large driving range.
(G. Brasseur).

The Trans European Networks.

Trans-European Networks (TENs) are large infrastructure networks of transport, energy and telecommunications.

9.000 km operational
Speeds 200-300 km/h



High efficiency rail systems:
connecting high speed trains with
regional and local systems

- **High speed railway lines:**
 - Berlin-Munich-Innsbruck-Verona-Bologna-Florence-Rome-Naples-Palermo
 - Lisbon-Madrid-Marseille-Paris-Brussels-Amsterdam
 - Paris-Strasbourg-Stuttgart-Vienna-Bratislava/Budapest
- Problems: National systems very different – 11.000 different regulations exist in EU.

Massive capacity problems limit shift from road to rail.

Source: European Commission

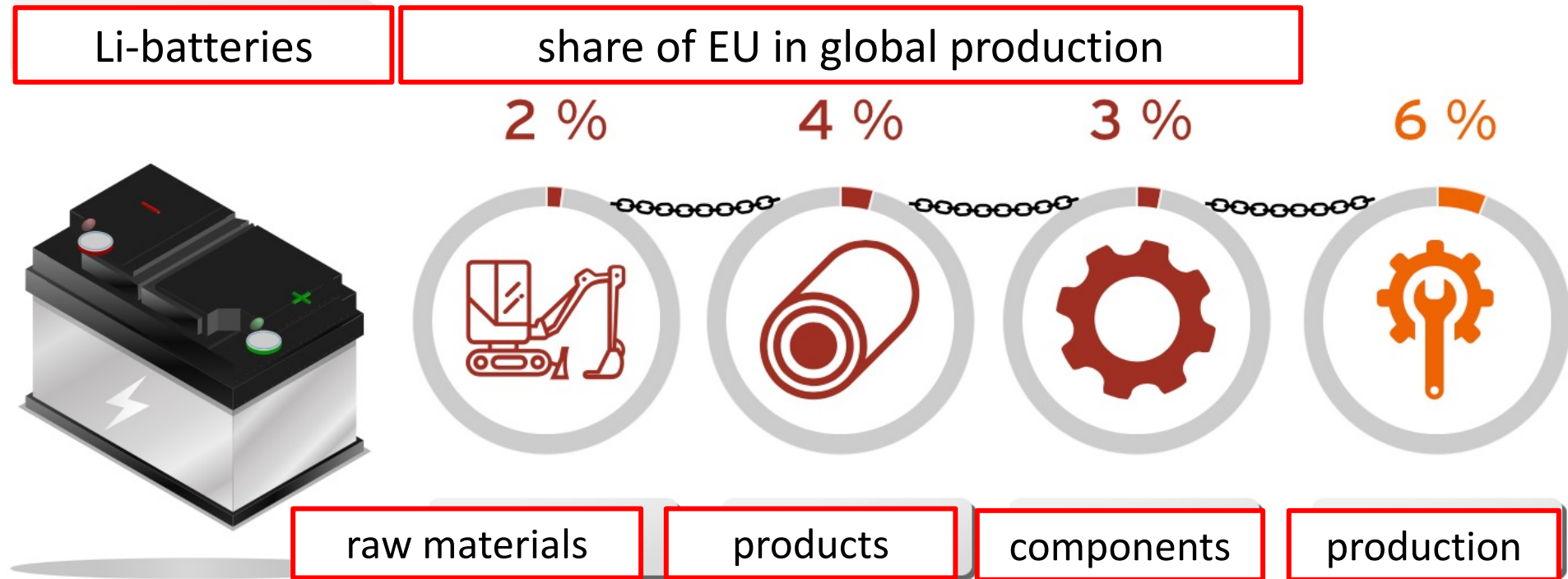
European Value Generation in Transformation.

Massive shift of value generation.

Combustion cars: Most expensive part is motor (made in Europe).

Significance of automobile industry in EU: 13 million jobs and 8% of GDP.

E-cars: Most expensive part is battery (made in Asia).



China world leader: batteries: 80%, electric cars 75%

Transformation of Air Transport Sector.

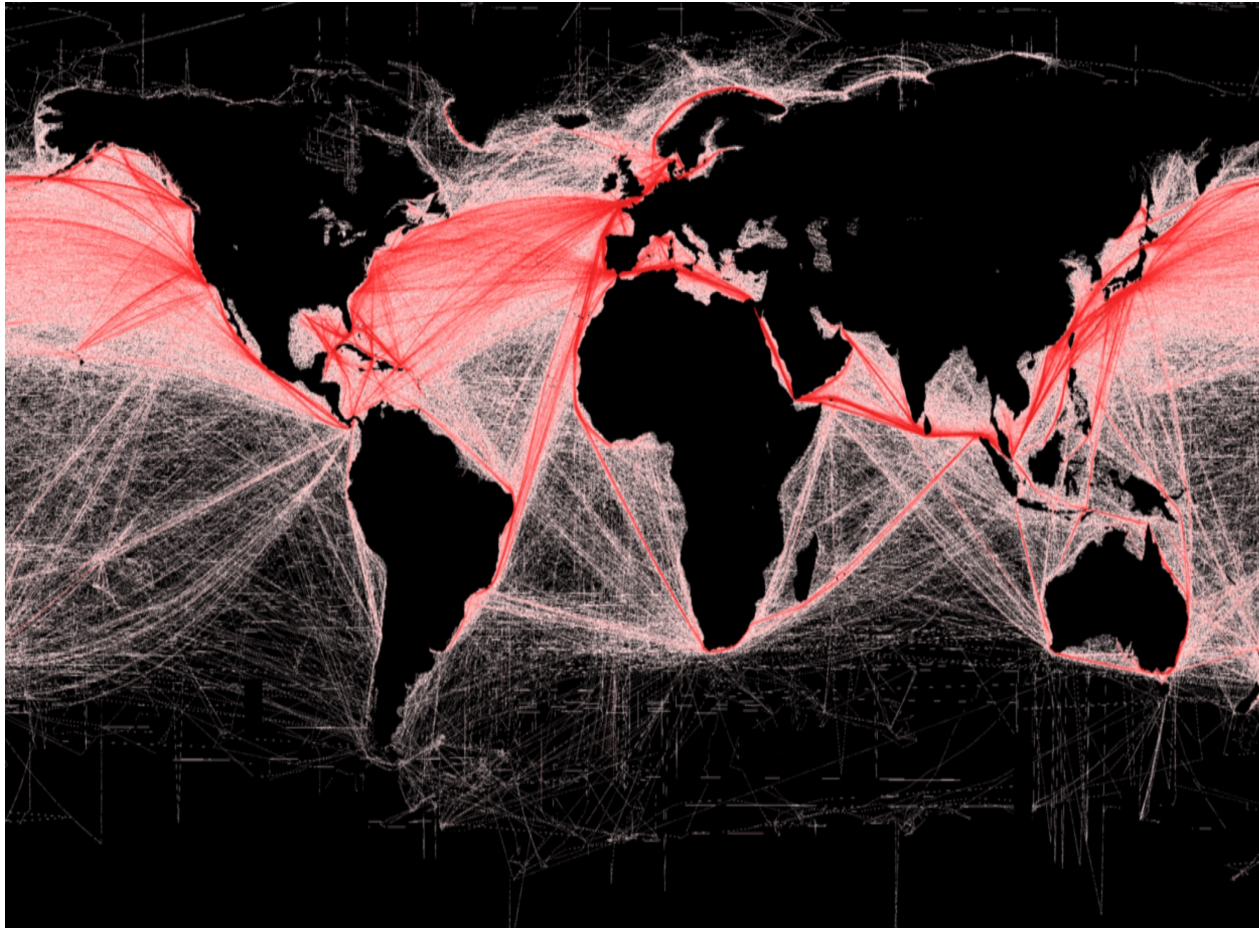
- **Global air traffic (2023):**
 - 26.000 airplanes
 - 40 million flights per year
 - 9,4 billion air passengers

- **Air transport:**
 - Synthetic fuels produced from H₂ and CO₂
- **Challenge:**
 - Globally air traffic will increase by a factor 3 – 5 till 2050.
 - Fastest growing airline: Air India
- **Transfer to rail:**
 - Fragmented system in EU with 11.000 different regulations.
 - High CO₂-emissions for building new rail infrastructure.
 - High speed railway network in EU underdeveloped (9.000 km).
 - World leader China with 45.000 km high speed railway network.



Transformation of Shipping Transport Sector.

- **Global shipping transports (2023):**
 - 60.000 cargo ships
 - 11 billion tons transported (90% of traded goods)
 - Commercial value 25% of global GDP.



- **Carbon neutral shipping:**
 - Synthetic fuels produced from H_2 and CO_2
 - Electric engines (nuclear or batteries).
- **Challenge:**
 - Maritime shipping is the backbone of global trade.
 - Volume expected to double till 2050.

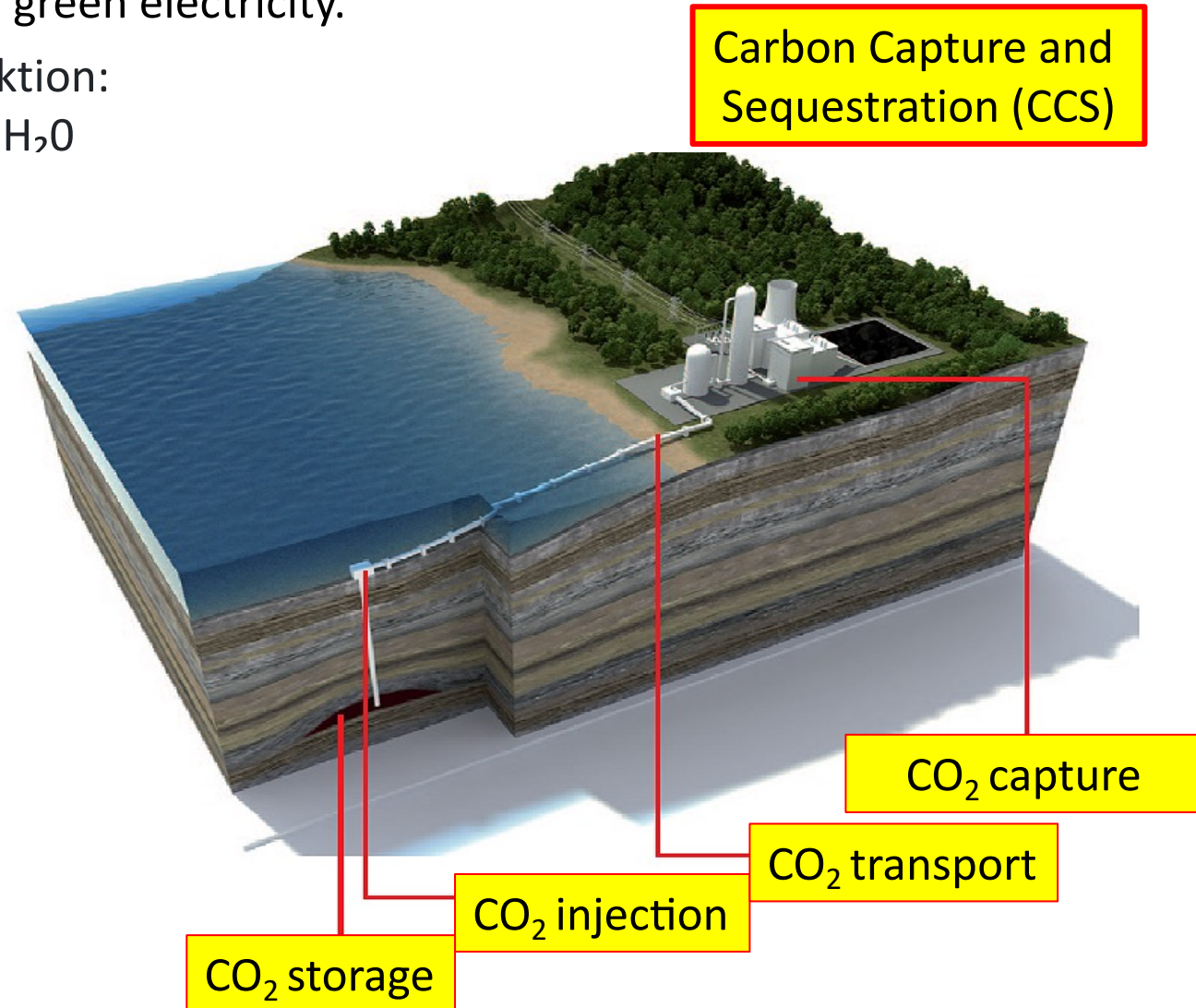


First nuclear-powered ship for 24,000 containers planned by China State Shipbuilding Corporation.

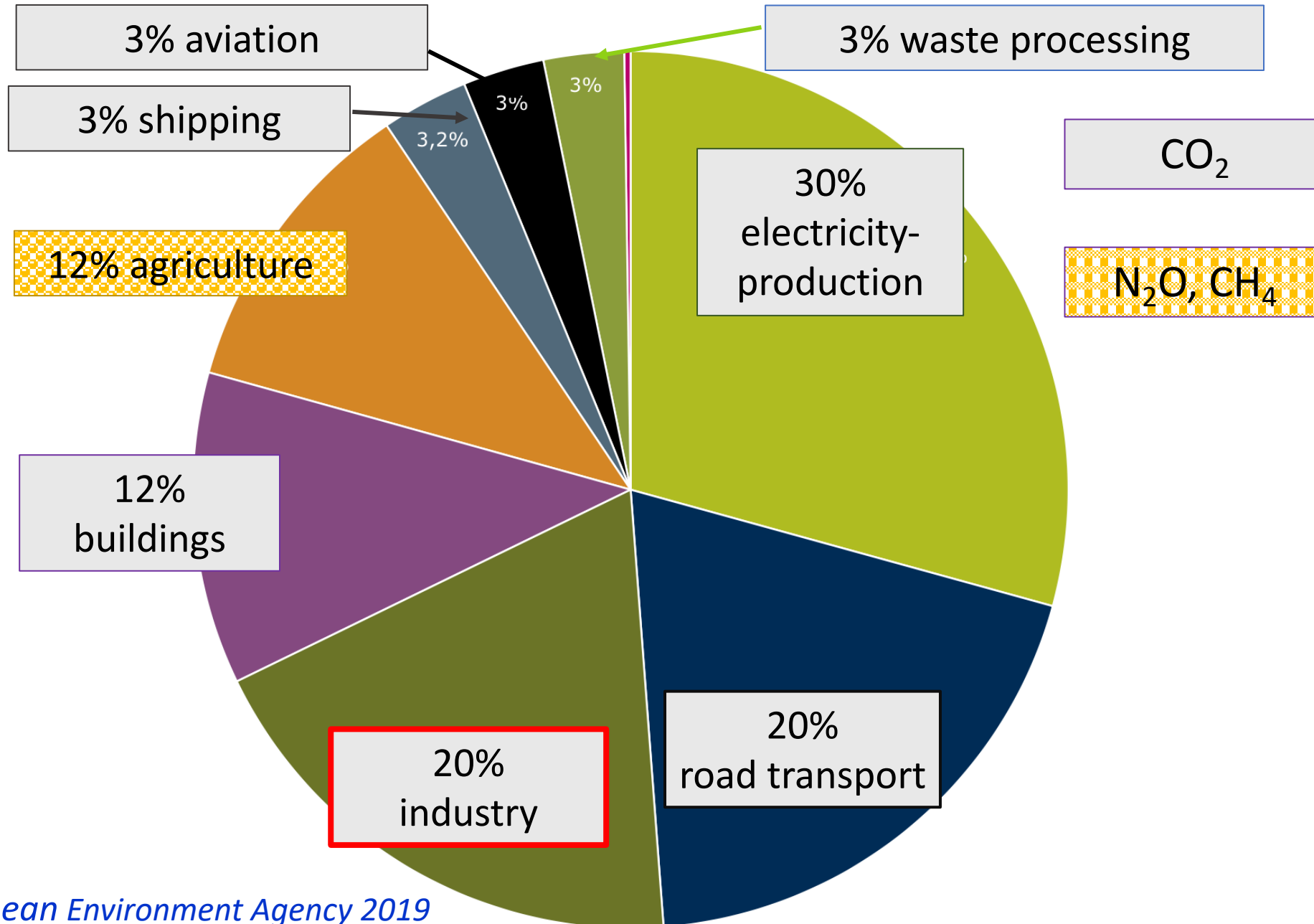
E-Fuels for Aviation and Shipping.

- Use of sequestered CO₂ from natural gas or coal fired power plants.
- Hydrogen produced by electrolysis of water with green electricity.
- Synthesis of liquid fuel with Fischer-Tropsch-Reaktion:
$$[2n+1]H_2 + nCO \Rightarrow C_nH_{[2n+2]} + nH_2O$$
- Technology still in R&D phase and costs unclear.
- Estimated implementation time 20 years.

- E-Fuel is regarded as “CO₂-neutral”, but complete life-cycle analysis missing.
- E-fuel is at least 5 times as expensive.
- Preferred fuel for trucks, ships and airplanes.

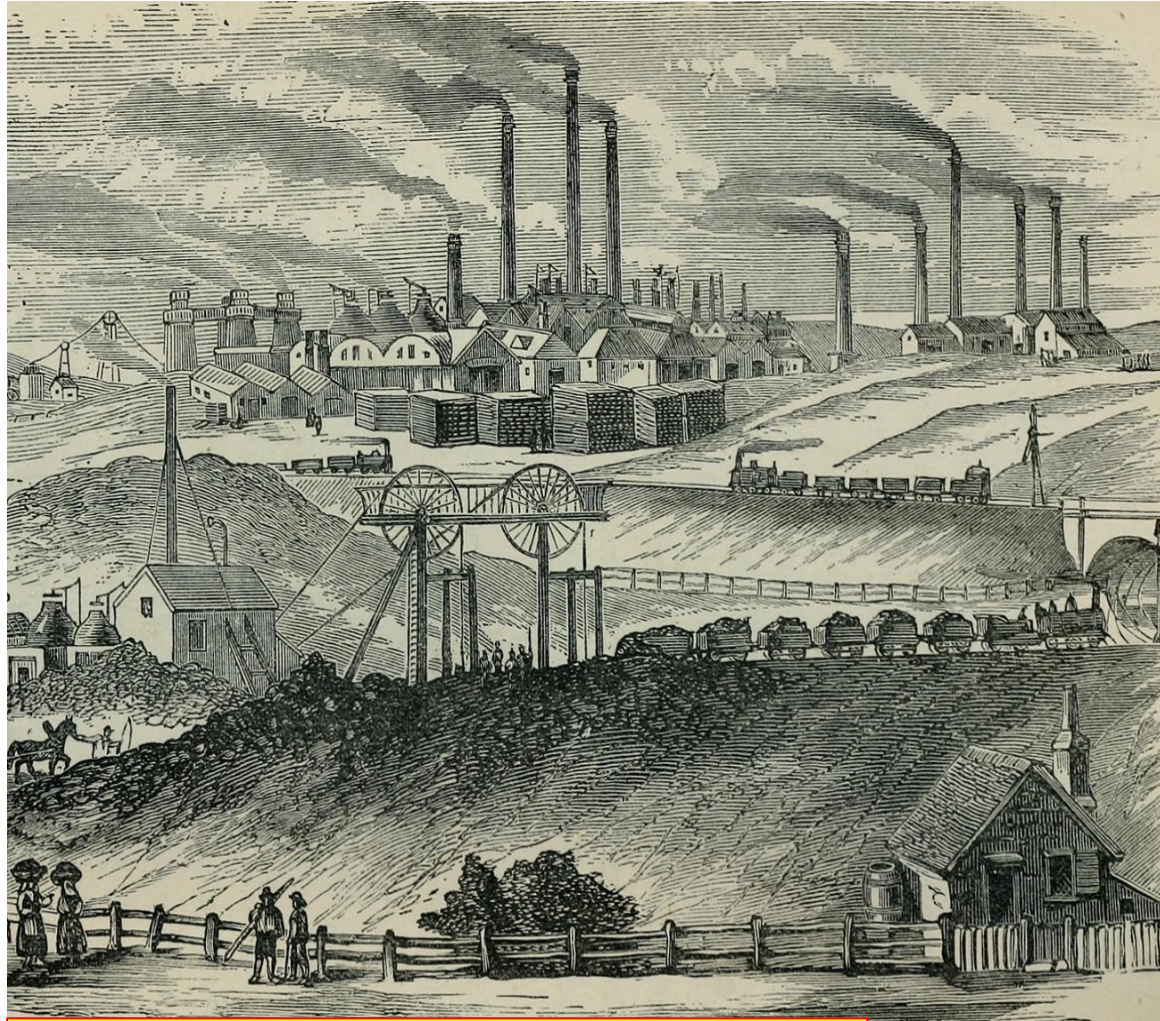


EU Green House Gas Emissions by Sector (2018).



Transformation of European Industry.

- Industry is since 200 years the basis for the high social standard of Europe.
- European industry generates 25% of the GDP (with indirect contributions 50%).



Black country near Birmingham 1850.

- **General Approaches:**
 - **BAT (Best Available Technologies):**
To achieve a maximum in energy and resource efficiency.
 - **Modal change in process energy:**
Replacement of gas, coal and oil by hydrogen, electricity or biomass (?).
 - **Circular economy:**
Maximise recycling of materials, EU recycling goals for various materials up to 85%.
- **Specific solutions for major industrial sectors:**
 - Chemical Industry – integrated approach for an extremely complex system necessary.
 - Steel production – hydrogen for reduction of iron oxides.
 - Cement production – CCS.

Transformation of Chemical Industry.

- European chemical industry is the second largest in the world.
- Chemical sales amount to 760 billion EUR (2022) = 14% of global sales.
- One third of the sales is generated from export: chemical industry must be globally competitive.
- Chemical industry responsible for 5% of EU CO₂ emissions.

- **Key processes:**

- Production of Green Hydrogen with electrolysis for feedstock.
- Production of chemicals from CO₂ and Green Hydrogen:
 - Syngas (CO + hydrogen) and its use for synthesis of gasoline or kerosene (Syn/E-fuels).
 - Green methanol from CO₂ and water and conversion into olefins, polymers etc.



Transformation of Chemical Industry.

- **Enhancing efficiency in the chemical production process:**
 - Catalyst improvements.
 - New chemical pathways and highly integrated value chains („Use every atom!).
- **New technologies:**
 - New methods for ammonia production (e. g. electrochemical production from nitrogen and water).
 - Power to chemicals (e. g. electrochemical production of fine chemicals).
 - Low temperature processes based on biocatalysis.
 - Replacement of distillation by membrane separation.
- **Actual situation of transformation:**
 - Mostly only theoretical feasibility studies available.
 - Experimental piloting is not far developed; only few and only stand-alone parts are operated, with no overall concepts.

Sources: <https://news.industrial-europe.eu/>;
Schmidt, Köster, Strube 2022

**Ammonia plant BASF Ludwigshafen:
380.000 tons NH₃ per year**



Transformation of Haber-Bosch process:
Production with Green Hydrogen requires
1.500 electrolyzers
(each 100 MW production capacity),
investment of 100 billion EUR.

Production of “Green Steel”.

- **Iron and steel industry responsible for 5% of EU CO₂ emissions.**
- 60% of EU steel is made via the energy- and CO₂-intensive blast furnace process, and 40% from recycled steel scrap in electric arc furnaces.
- **Technical approaches to achieve carbon neutrality:**
 - Direct reduction of iron oxides using hydrogen (H-DRI) – 20 pilot projects in EU (often starting with natural gas with gradual increase of H₂ additions).
 - Green hydrogen production would need 350 TWh/a in EU.
 - Further technologies in early R&D phase: CCS, iron ore electrolysis.
- **Economic aspects:**
 - Cost of green steel production 3x (?) higher.
 - Competitive prices can only be achieved with high CO₂-prices in ETS system plus CO₂-import tax on steel imports.



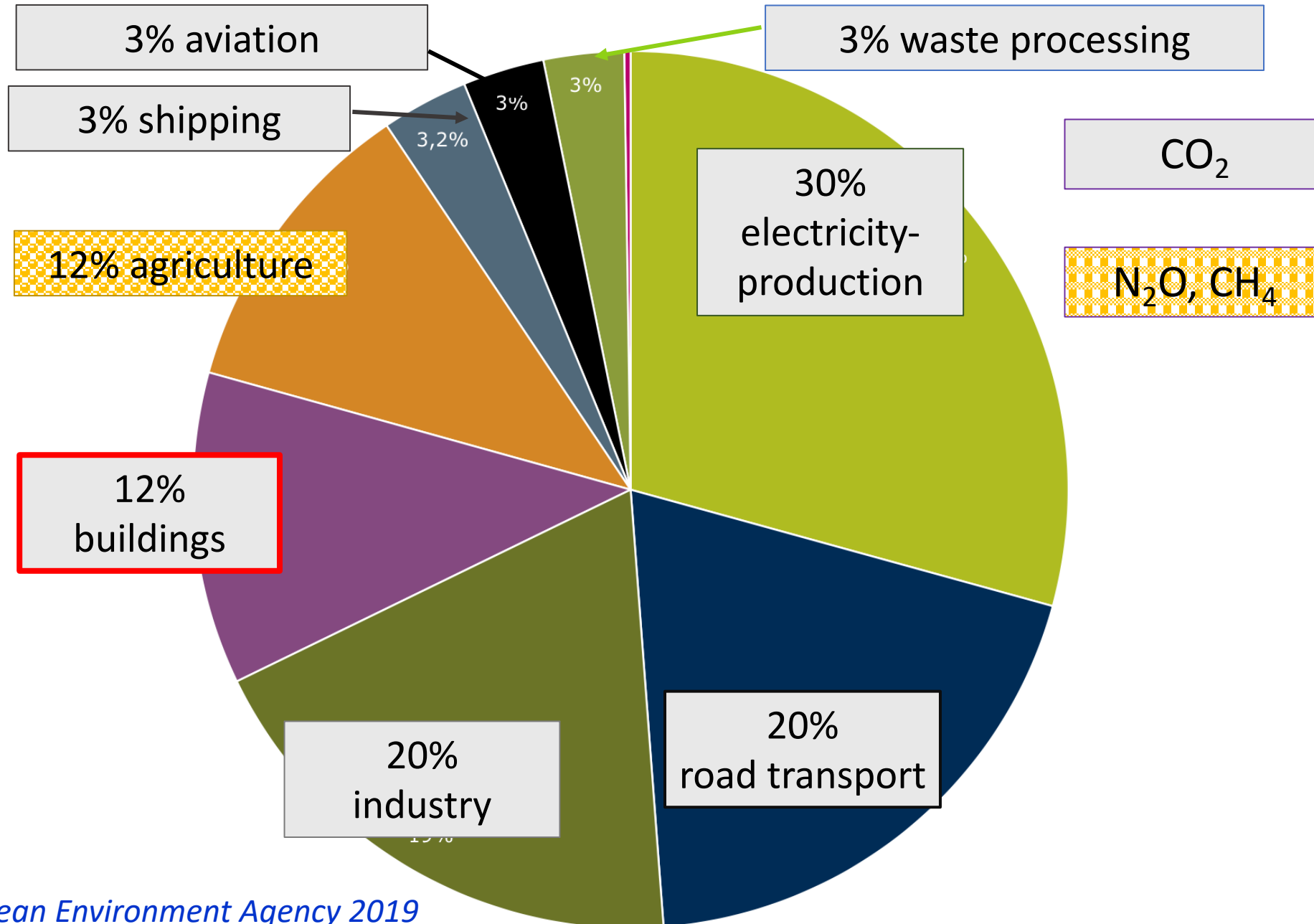
- **First integrated HDRI-steel plant in Boden (SE):**
 - 7 billion investment costs.
 - 700 MW hydrogen production capacity.
 - 5 TWh/a electricity needed.
 - Production 2,5 million tons of steel in 2026.
 - European production is 150 million tons/year.

Carbon Neutral Cement Production.

- **Cement industry responsible for 4% of EU CO₂ emissions.**
- 60% of cement emissions stem from the calcination of limestone; about 30% stem from the necessary heating.
- **Technical approaches towards carbon neutrality:**
 - Enhancing process efficiency with advanced kiln technology.
 - Reducing CaO content in cement.
 - Carbon capture and sequestration.
- **Economic aspects:**
 - Costs of transformation of cement production (170 million tons annually) ?
 - Additional costs cannot be covered with ETS.
 - Storage capacities for CO₂ limited: Holcim Austria intends to capture 2.000 tons CO₂/day; transport in 280 railway wagons to underground storage in Northern Germany.



EU Green House Gas Emissions by Sector (2018).



Transformation of Building Sector.

- **EU energy standards:**
 - 75% of European buildings do not fulfill these standards – extensive improvement programs necessary.
 - Replacement of local heating with oil or gas by district heating (Fernwärme), heat pumps, geothermal energy, biomass.
 - Austria: phase out of 400.000 oil (2035) and 1,2 million gas (2040) heating devices.
- **New buildings:**
 - Passive houses (insulation, PV, heat pumps).
 - Energy surplus buildings (PV).
 - “Smart Building” Management.
 - “Smart Cities”.
 - “Carbon Neutral Ecocities”.
- **Economic aspects:**
 - Financing this enormous transition?

**“Every house can
become a power plant.”**

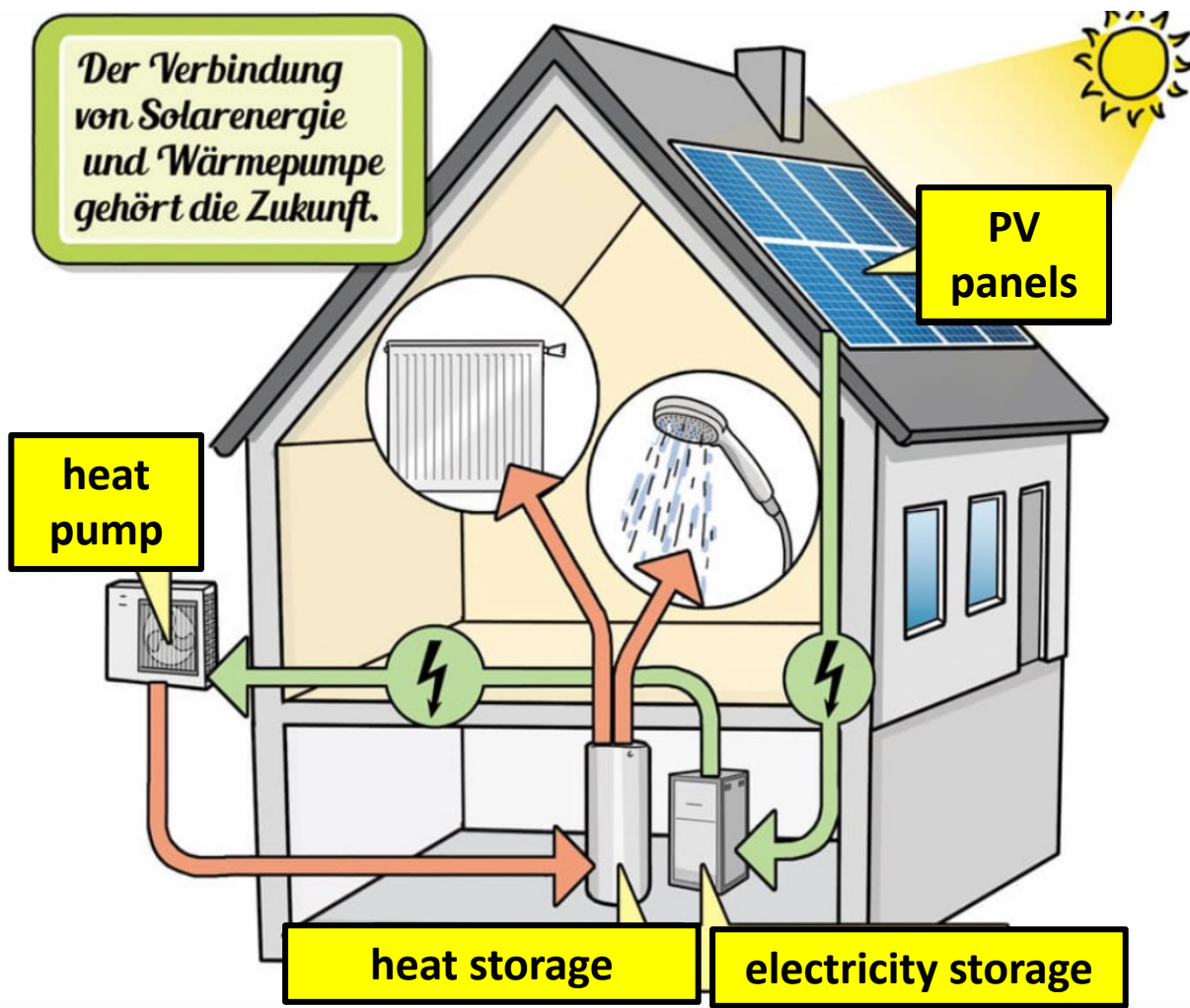


**Energy Plus Building TU Wien-
Getreidemarkt:**

Architects:
Hiesmayr, Gallister, Kratochwil

Energy Transformation for Houses and Cities.

Photovoltaics – Battery Storage – Heatpump.



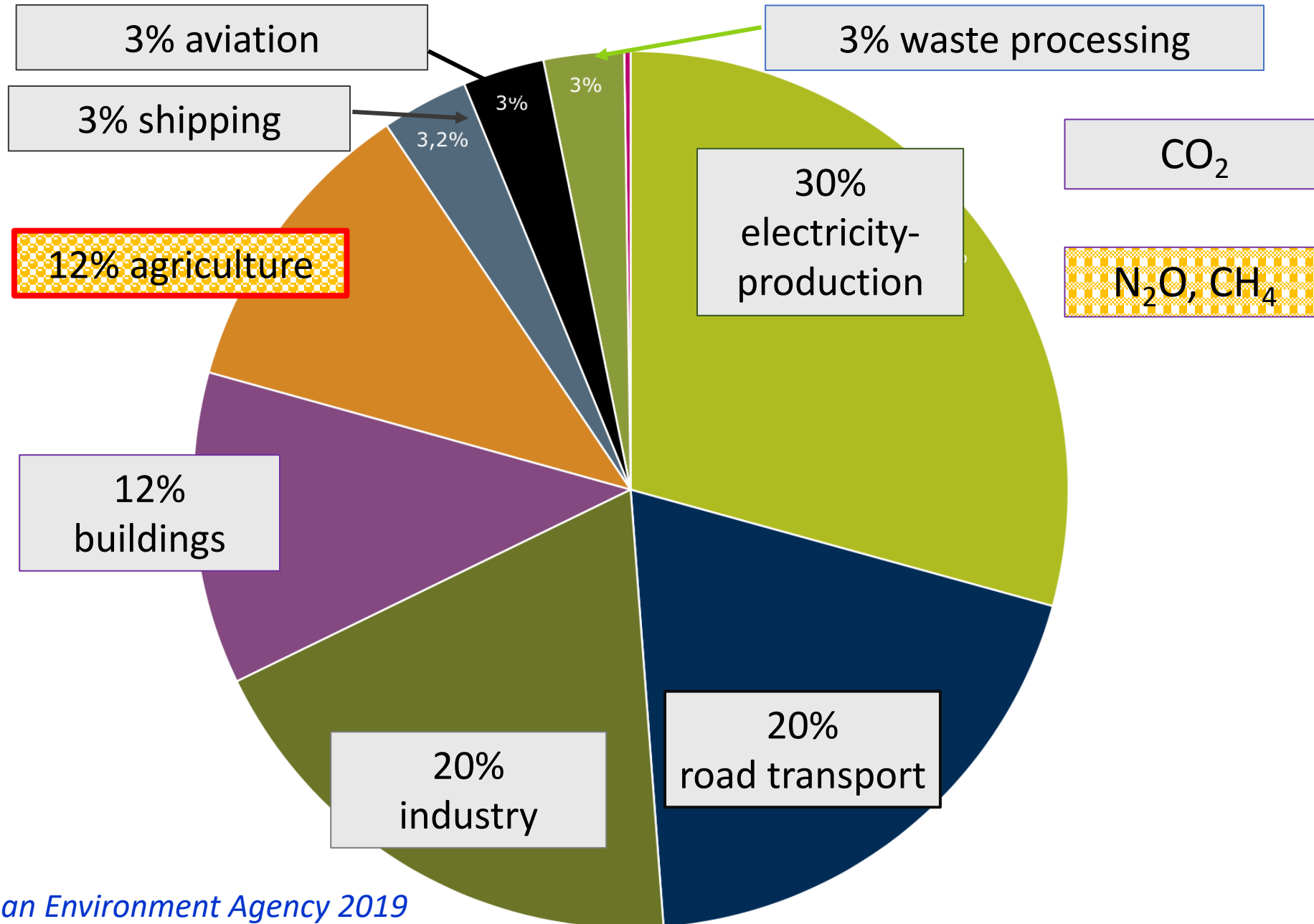
“Carbon-neutral” ecocities:
Dongtan Ecocity planned for 500.000 people by 2050.



Energy balance: 30% electricity , 70% environmental heat
High installation costs: 30.000 – 50.000 EUR

75% of energy consumed in urban areas.
50% of world population lives in cities with more than 1 million inhabitants.

EU Green House Gas Emissions by Sector (2018).



Transformation of Agriculture.

- **Agriculture is the basis of our civilisation.**
- **Improvement of agricultural practices and technologies:**
 - Reduction of N_2O emissions: more efficient fertilisation („Precision Farming“) and chemical efficiency enhancers (nitrification inhibitors).
 - Reduction of CH_4 emissions: reduced cattle farming, less meat consumption.
 - Production of biofuels from plants (maize) or agricultural residues (cellulosis methanol) and biogas from manure.
 - Reforestation for binding of CO_2 .
- **Challenges:**
 - Enhancement of food production necessary due to a growing global population and to eliminate present food shortages.
 - Area for food production limited (12% of terrestrial area), cannot be increased.
 - Growing standards of living in emerging economies increases demand for meat.

Successful transformation path for agriculture not obvious.



Vincent van Gogh: „Farmer“.

Biofuels.

EU-Directive:
10% of fuel from renewable
(bio)resources

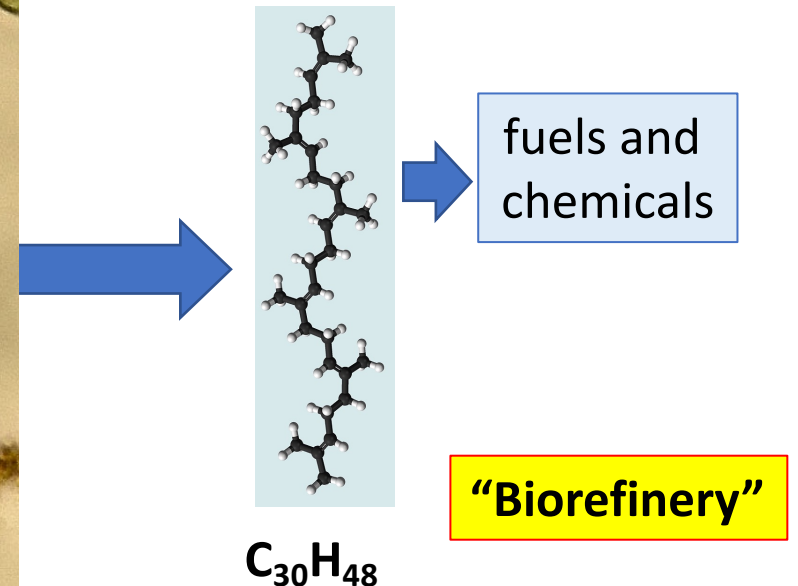
- **First generation:**
 - ethanol from cereals and sugar, diesel from plant oils.
- **Second generation:**
 - ethanol from wood – not economic
- **Third generation:**
 - hydrocarbons (gasoline, diesel) from algae.

Algae of the chlorophyceae class produce hydrocarbons (mainly triterpenes), which can amount to 50% of their mass (“Oilgae”).

Source: European Commission



Biofuel factory
Babilafuente
produces
annually 200.000
tons ethanol
from cereals.
In USA 40% of
maize used for
ethanol.



Global Primary Energy Production and Consumption 1960 – 2022.

In 2022: 149.600 TWh
ohne traditionelle Biomasse

Globaler direkter Primärenergieverbrauch

2018 → 2019: **+0,7 %**

1,4 %

2019 → 2022: **+1,8 %**

2,3 %

Wind + Sonne

Fossil free energy production 8,3%

2019 → 2022

Min. CO₂:

7,5 %

10 960 TWh

Min. CO₂:

8,3 %

12 420 TWh

Zunahme PV + Wind:
61 %

Fossil:

92,5 %

136 100 TWh

Fossil:

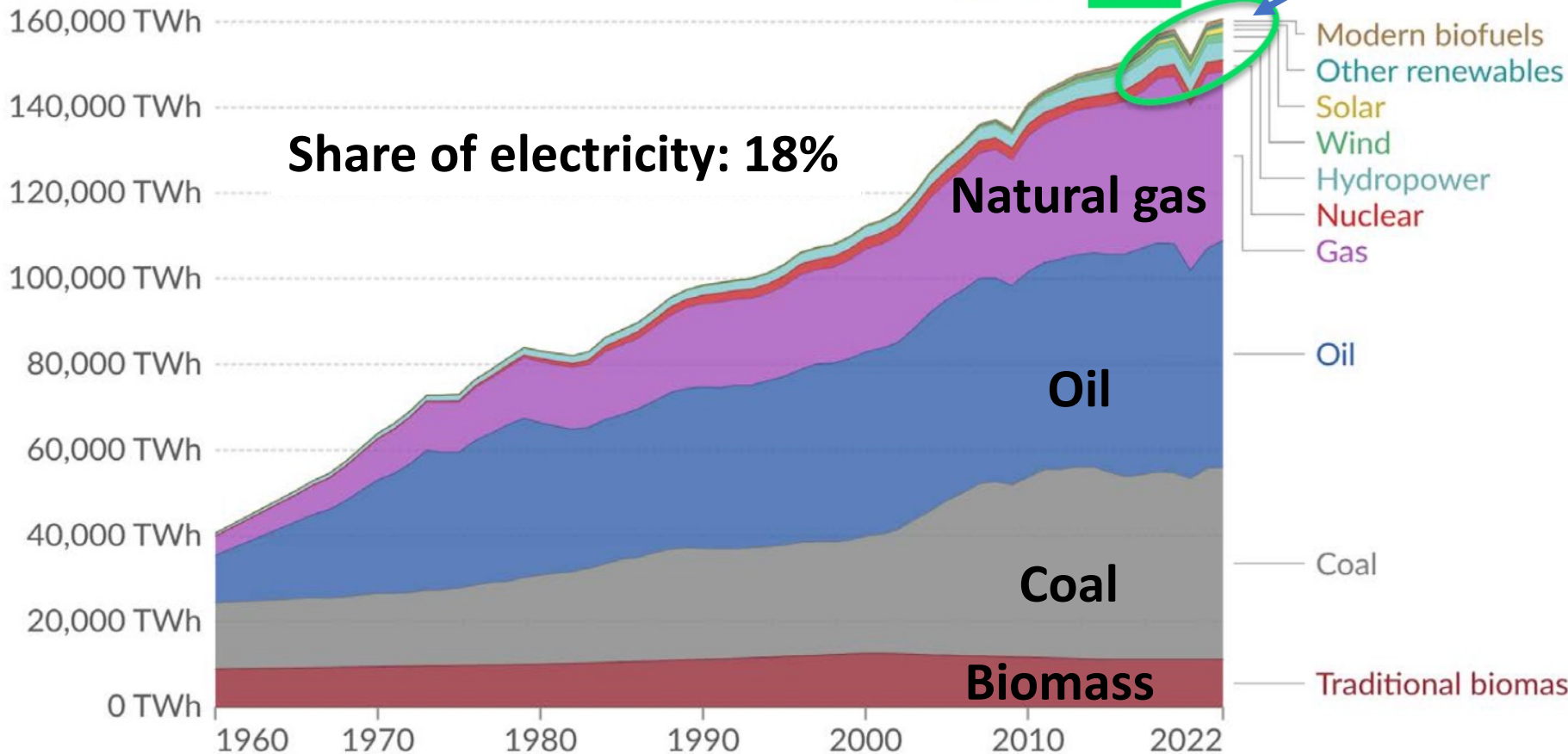
91,7 %

137 200 TWh

Source: G. Brasseur 2024

Nicht angesprochen,
da fossil CO₂ neutral

Share of electricity: 18%



Data source: Energy Institute - Statistical Review of World Energy (2023); Smil (2017) Note: In the absence of more recent data, traditional biomass is assumed constant since 2015. | [CC BY](#)

Based on: Our World in Data, <https://ourworldindata.org/grapher/global-primary-energy?time=1960..latest>, abgerufen 31.3.2024.

Georg Brasseur, 14. Okt. 202

9.2 Space Exploration – the Last Frontier.

The the ultimate challenge for human ambition and ingenuity:

- **Unmanned robotic probes or human spaceflights:**

- 1957 first human-made object to orbit (*Sputnik*)
- 1969 first moon landing (*Apollo 11*)
- 1970 landing of *Venera* on Venus
- 1971 landing of *Mars 3* on Mars
- 1971 first space station (*Salyut 1*)
- 1977 *Voyager 2* to study outer planets
- 1982 Space shuttle programme
- 1998 International Space Station (ISS)
- 2004 Rosetta mission to comet

- **Major launch vehicles:**

- *Saturn*
- *Sojus*
- *Ariane*
- *SpaceX*

ESA Ariane 6:

Able to lift 1.000 tons to geostationary orbit (40.000km altitude), 4 bio EUR development costs, 98 mio EUR/launch, start July 2024 (Airbus Defence and Space)



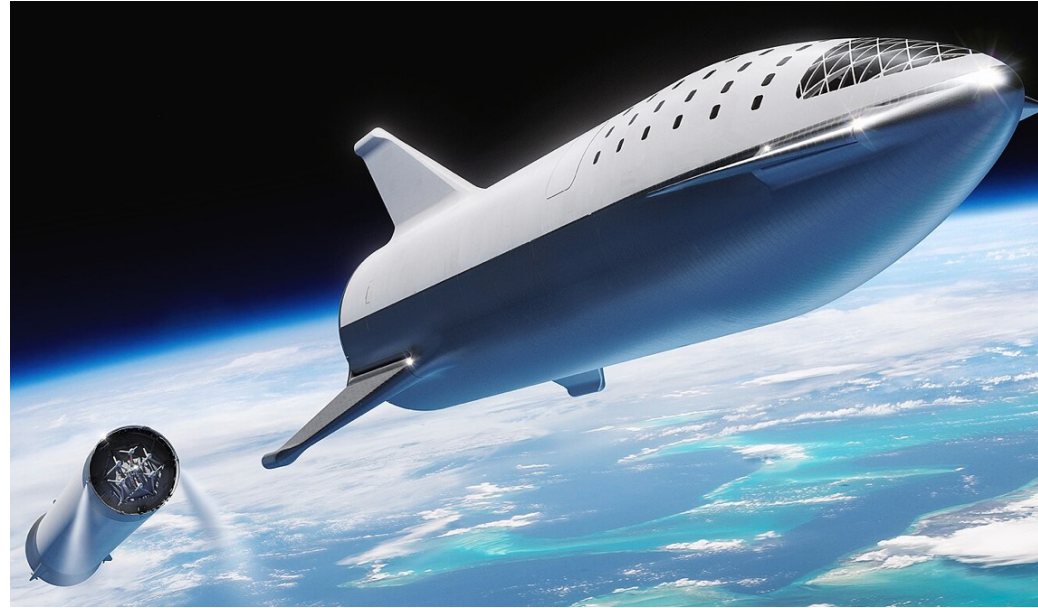
STARSHIP 31

spaceship
50 m

booster
71 m

weight:
5.000 tons

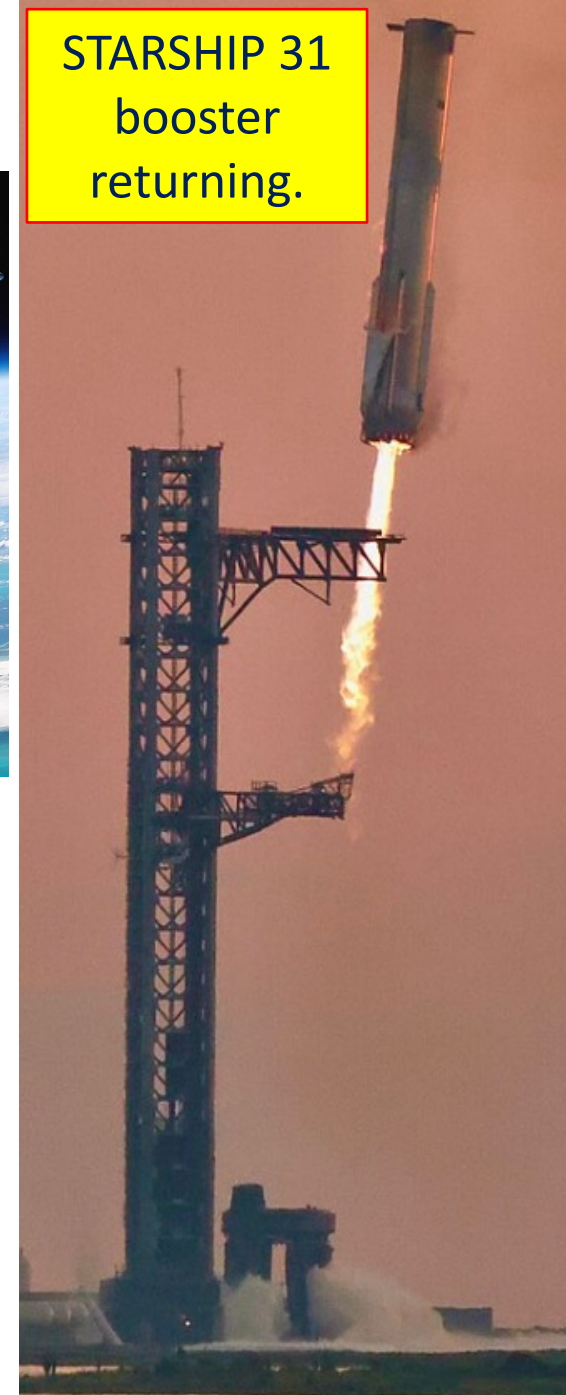
Starship of SpaceX.



separation of booster and spaceship

STARSHIP 31 –
booster returning to start ramp:
landing burn requiring
movement of liquid methane/oxygen fuel
in milliseconds for accurate positioning.
Oct. 13, 2024

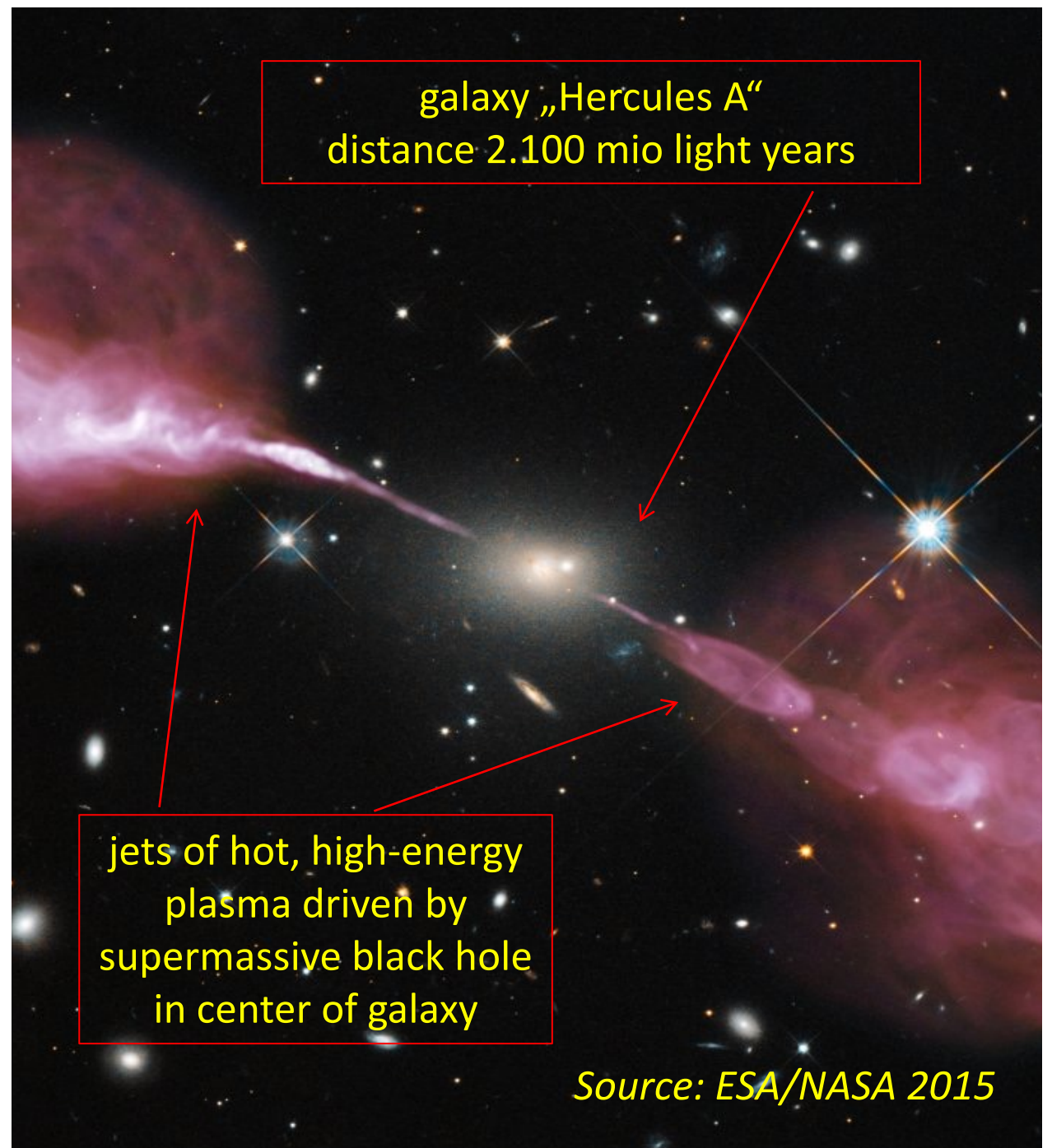
STARSHIP 31
booster
returning.



Space Exploration: Hubble Space Telescope.

Search for Evolution of Universe:

- 4 m² mirror telescope for high resolution imaging in IR, VIS, UV and radio wave range, positioned in low earth orbit (550km) to explore galactic evolution in the early Universe.
- active 1990 – 2009
- serviced by space shuttle missions
- Example: emission of plasma jets travelling at nearly speed of light from black hole in center of galaxy Hercules A and formation of huge „material clouds“ due to expansion and slowing down of the plasma jets.



Space Exploration: Hubble Space Telescope.

Search for Evolution of Universe:

- The BOSS Great Wall, also known as the Baryon Oscillation Spectroscopic Survey, is a galaxy supercluster that spans over 1 billion light-years.
- This wall consists of 830 galaxies organized by gravity into four superclusters connected by massive filaments of hot gas.

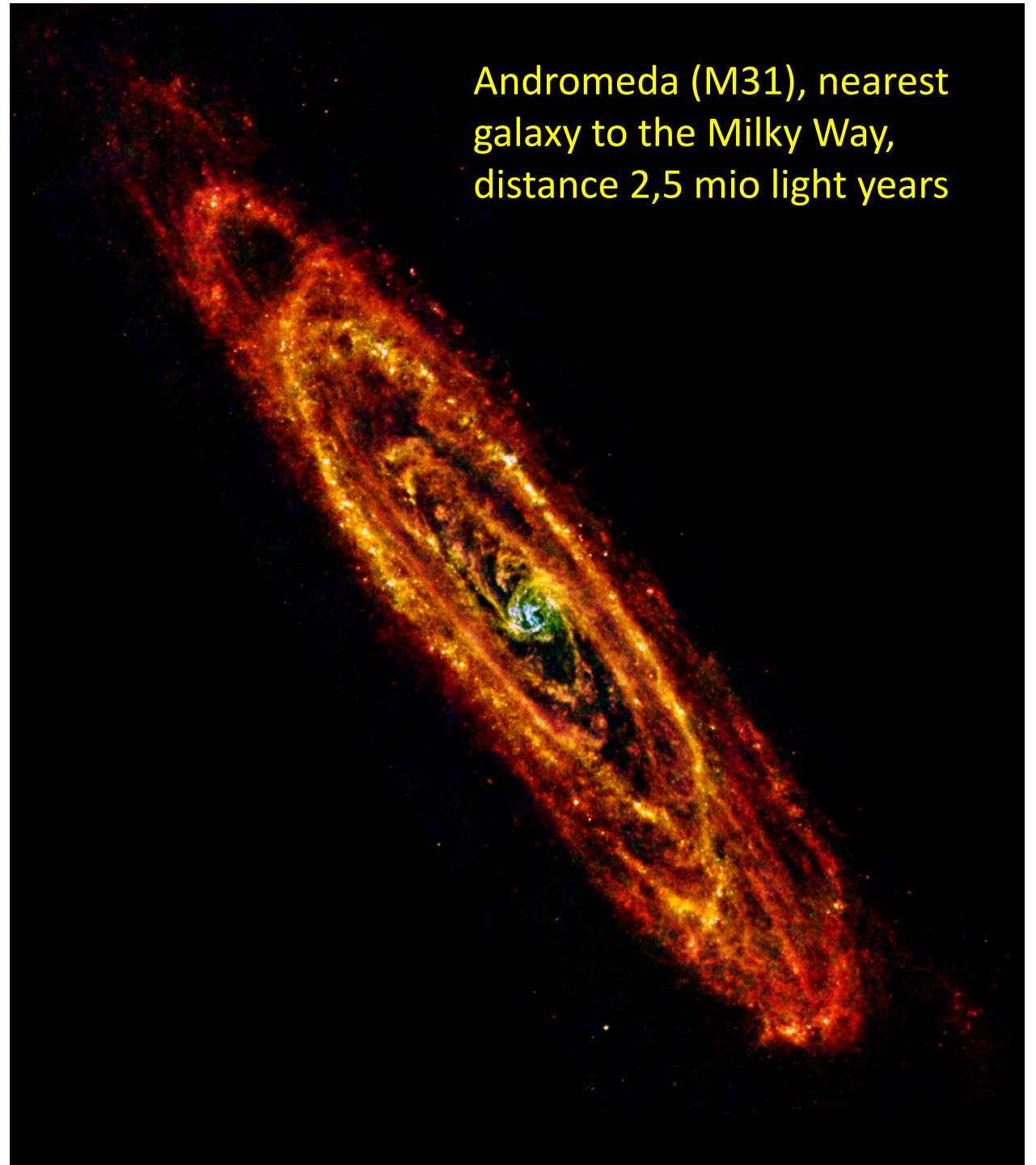


Space Exploration: Herschel Space Telescope.

Search for Life in Universe:

- Largest infrared telescope ever launched (diameter of mirror 3,5m) positioned 1,5 mio km from earth
- active 2009 – 2013
- imaging and spectroscopic measurements in IR and sub-mm-wave range
- search for oxygen, water ... in galactic and extragalactic objects
- studies of star and galaxy formation

Source: ESA 2015



Andromeda (M31), nearest galaxy to the Milky Way, distance 2,5 mio light years

Space Exploration: James Webb Telescope.



Black Hole of our galaxy.

**Search for
evolution of
universe by
NASA.**

Launch 2021.
25 m² mirror
telescope for high
resolution imaging
in IR and VIS.

Position 1,5
million km from
earth.

Can observe more
distant and older
galaxies than
Hubble.



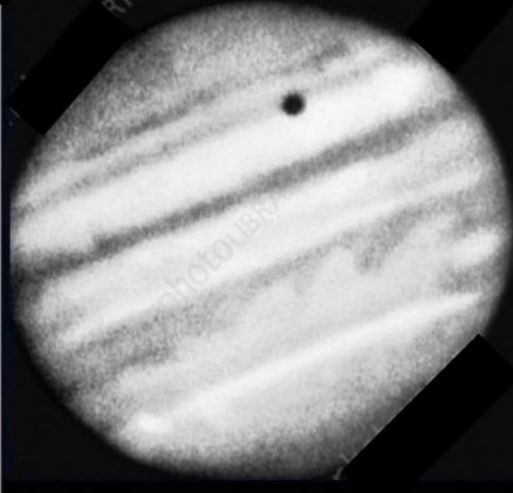
**Comet Jaques and
Heart and Soul Nebulae.**

Space Exploration: James Webb Telescope.

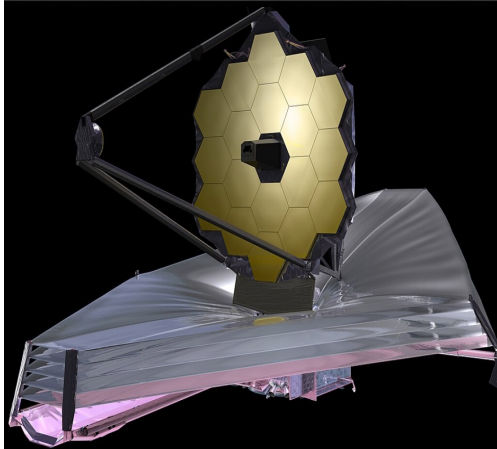
IMAGES OF JUPITER OVER 100 YEARS



1879



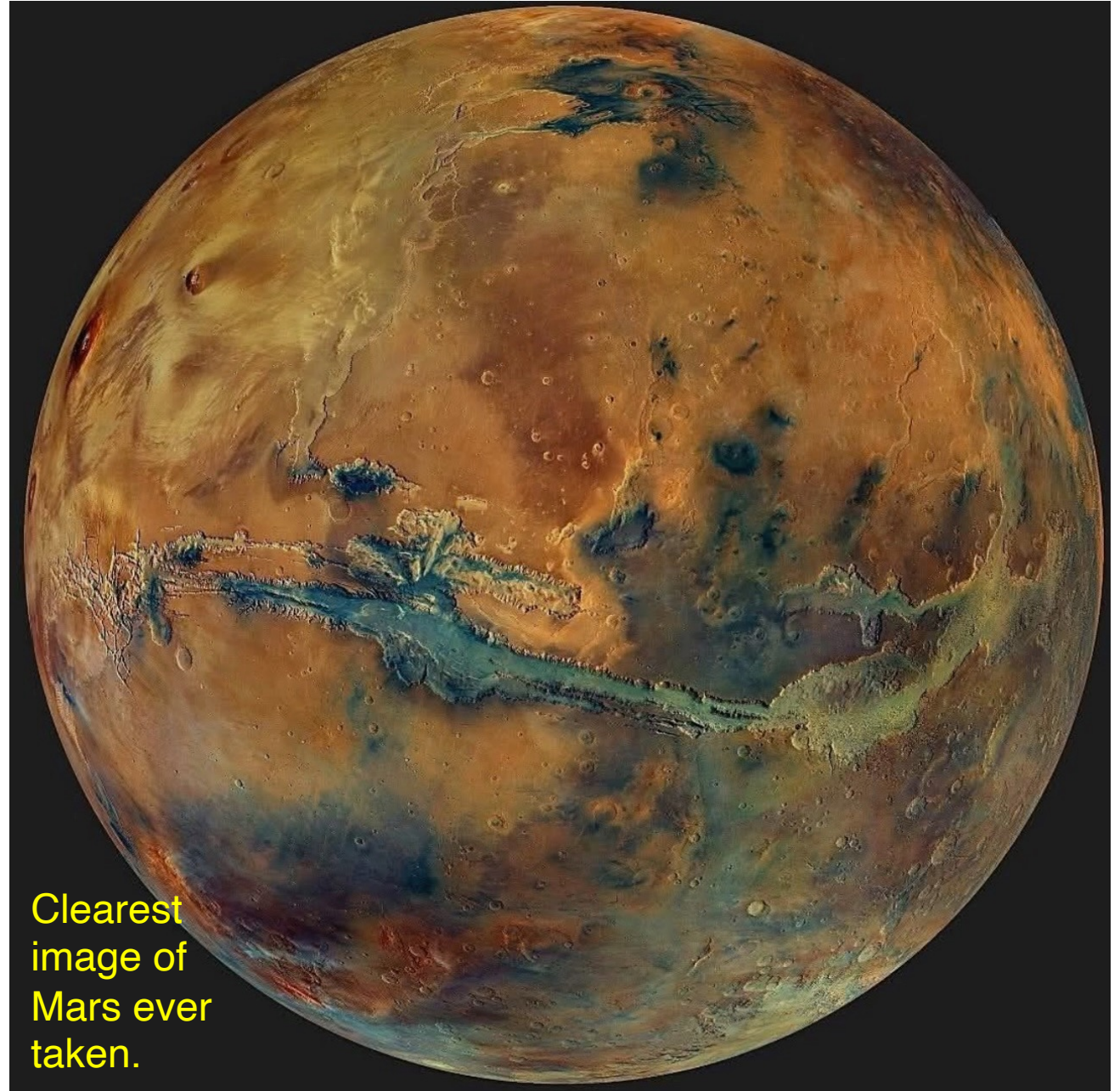
1950



Jupiter in high resolution.



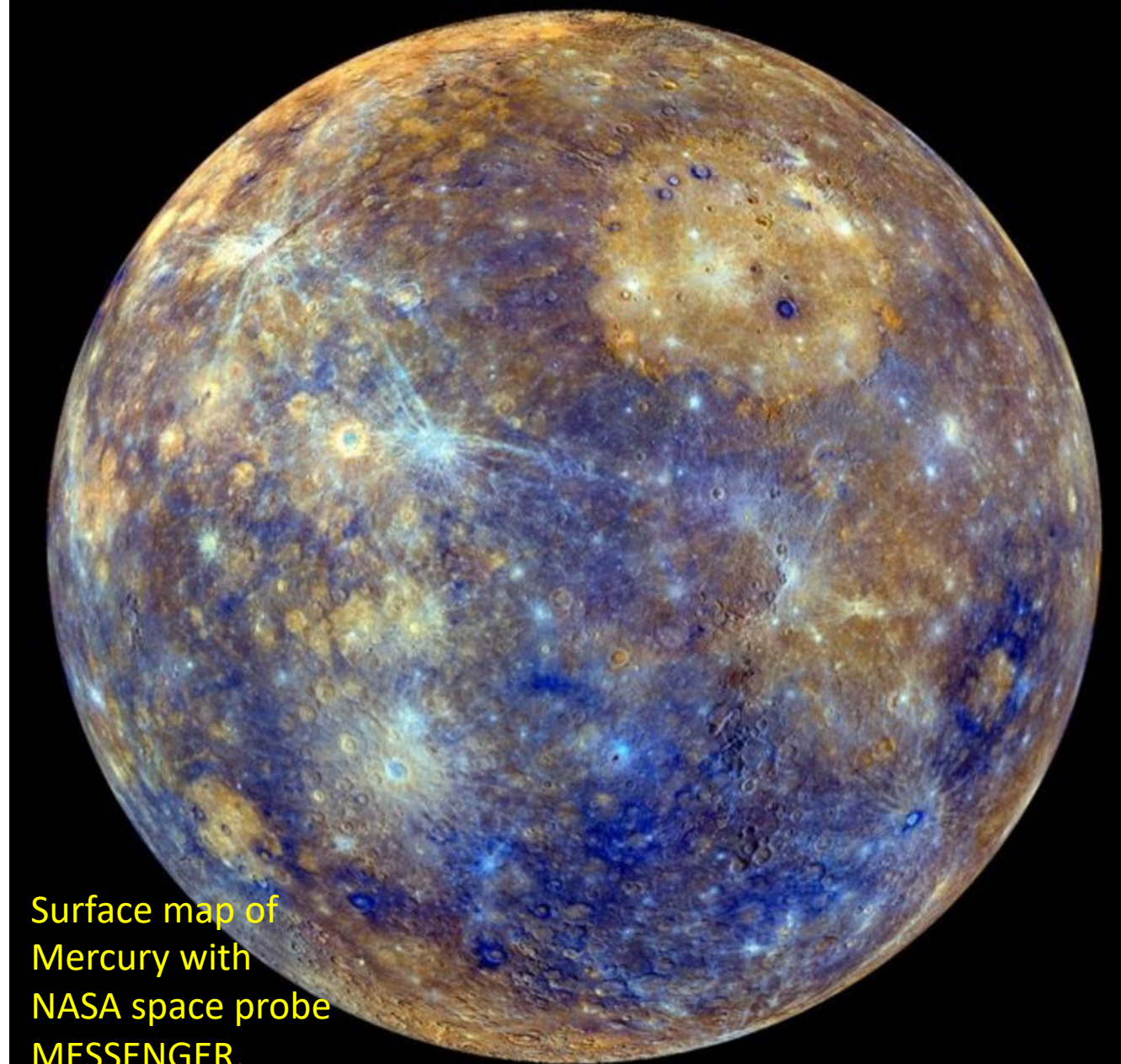
2020



Clearest
image of
Mars ever
taken.

Exploring our Solar System.

Image of the sun
with Webb
telescope of
NASA.



Surface map of
Mercury with
NASA space probe
MESSENGER.

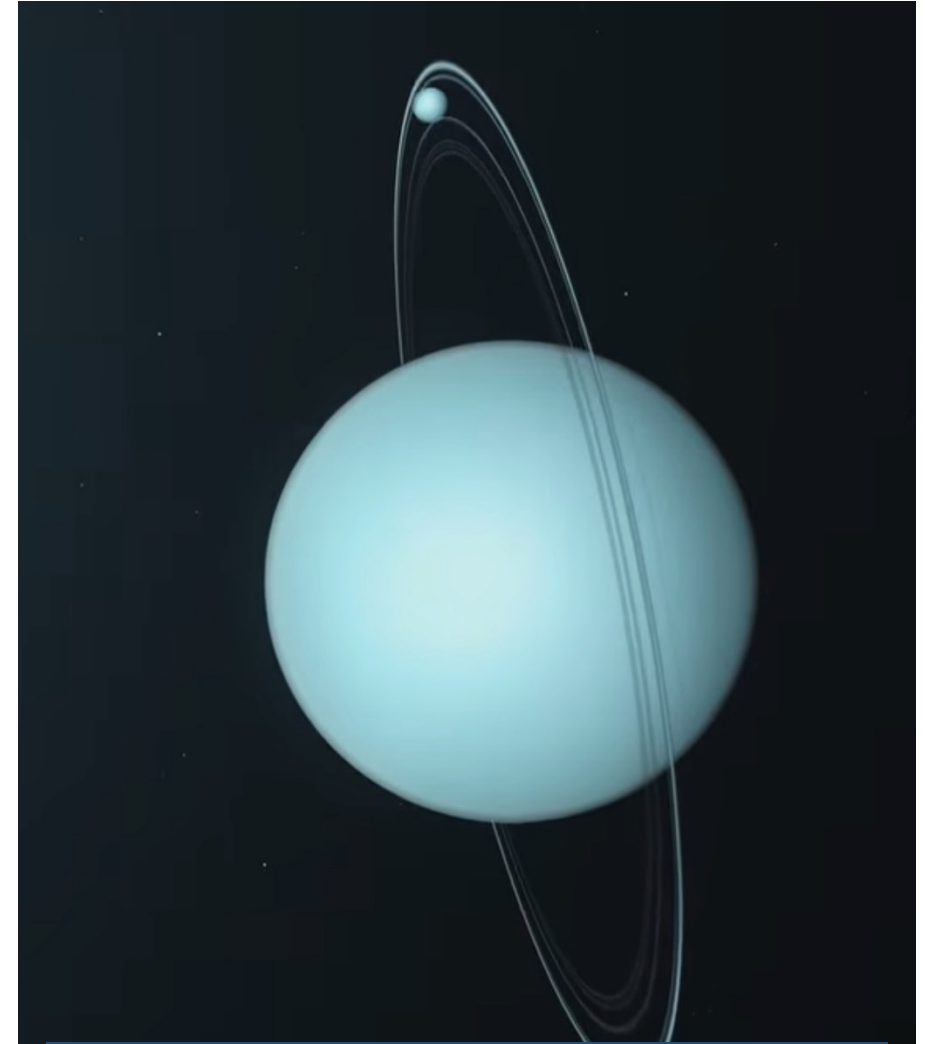
Space Exploration: Planets Beyond our Solar System.



The clearest
image of
Pluto
captured by
the New
Horizons
spacecraft.
of NASA.

Image of
Uranus
captured by
the James
Webb
Telescope.

Source: NASA 2024



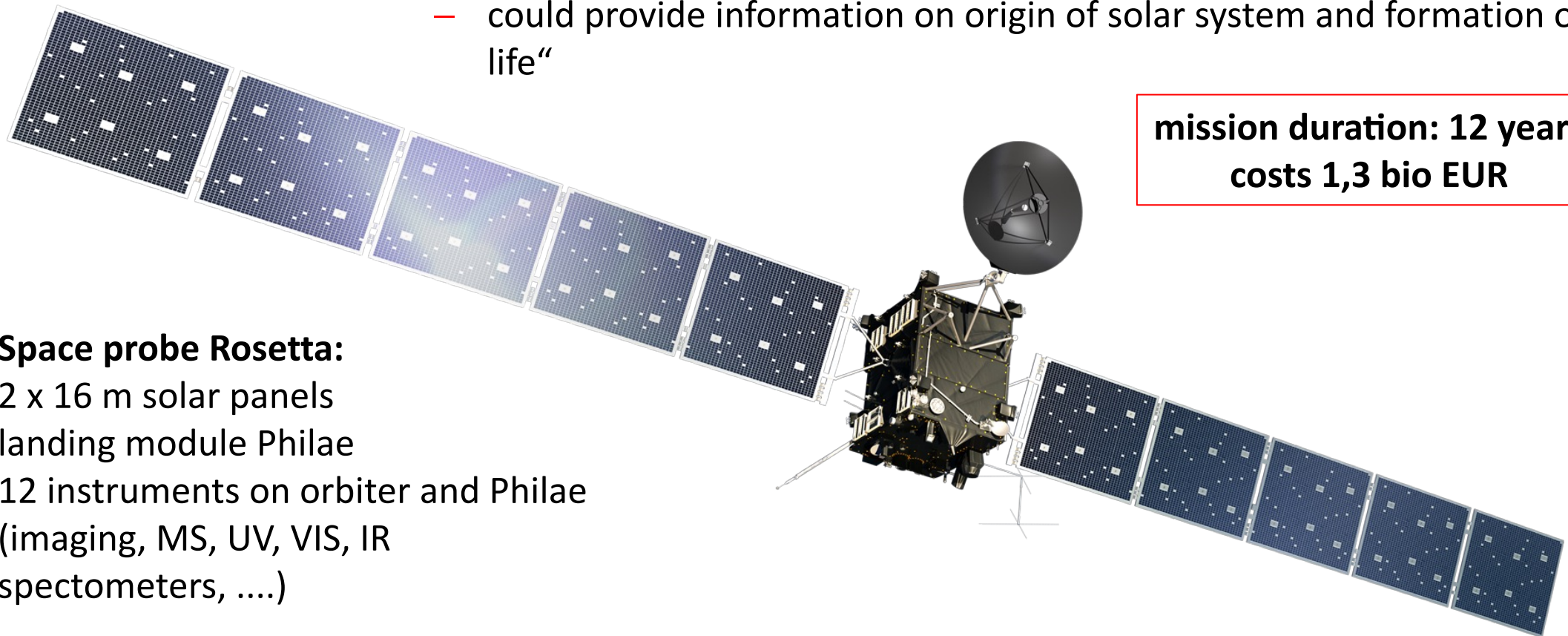
Atmosphere hydrogen-helium-
methane. Diameter 51.000km.
Distance from sun 2,9 billion km.

Space Exploration: Search for Life in Outer Space - Rosetta

- **ESA mission to Comet 67P/Churyumov–Gerasimenko:**
 - „Chury“ discovered 1969 on photographic plates (Kiev)
- **Comets:**
 - „outer-space“ objects with size of a few km
 - matter: mainly of H₂O (plus CO₂, trace organic compounds..... ?)
 - could provide information on origin of solar system and formation of „early life“

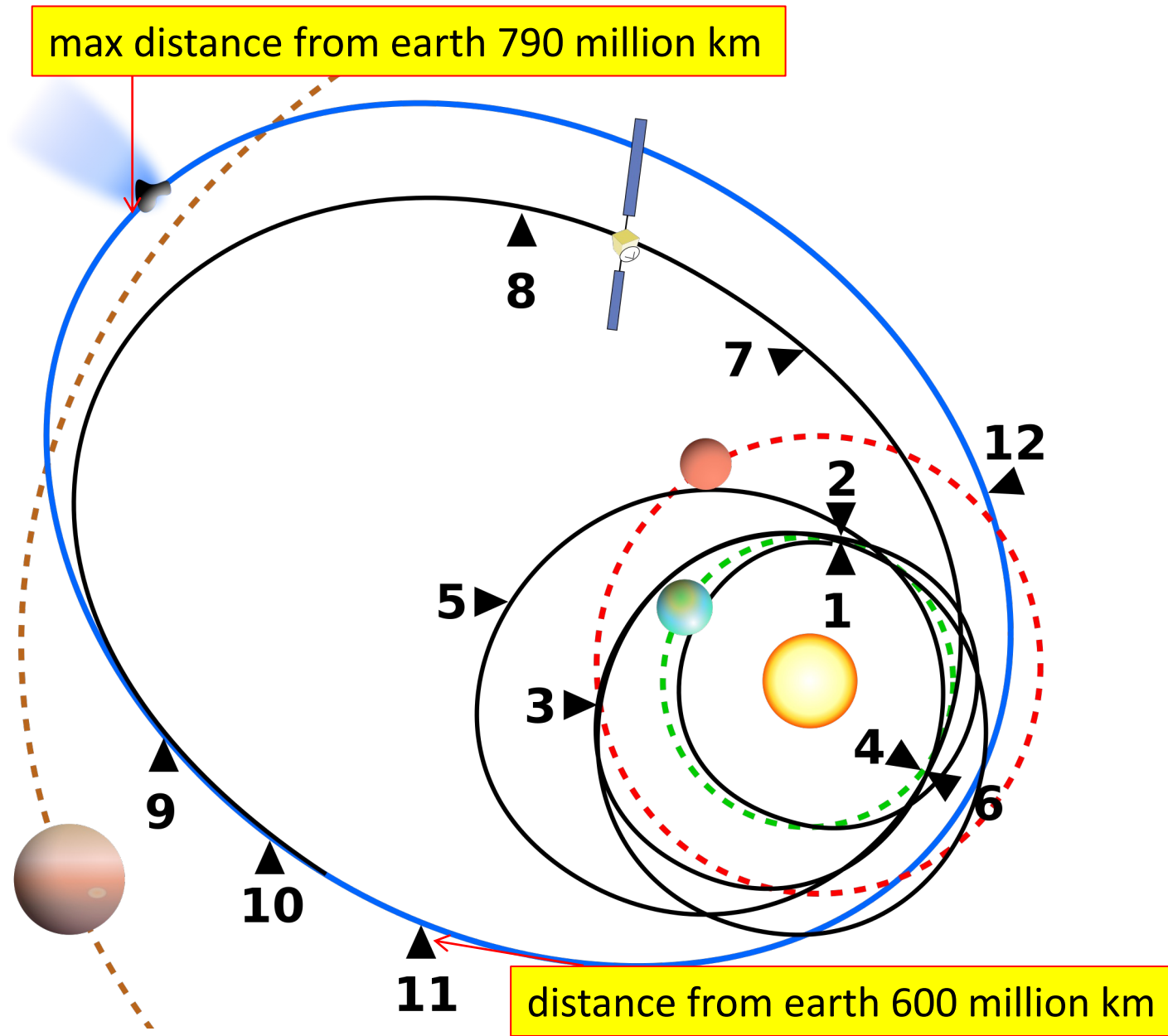
mission duration: 12 years
costs 1,3 bio EUR

- **Space probe Rosetta:**
 - 2 x 16 m solar panels
 - landing module Philae
 - 12 instruments on orbiter and Philae (imaging, MS, UV, VIS, IR spectrometers,)



Source: ESA 2015

Trajectory of Rosetta.



1 start March 2004
(Guiana, Ariane 5)

2, 4, 6 swing-by earth ---

3 swing-by Mars ---

8 July 2011 hibernation
mode

9 Jan 2014 wake-up

10 Aug 2014 swing-in Chury

11 Nov 2014 landing of
Philae

12 Aug 2015 crash landing
of spacecraft on Chury

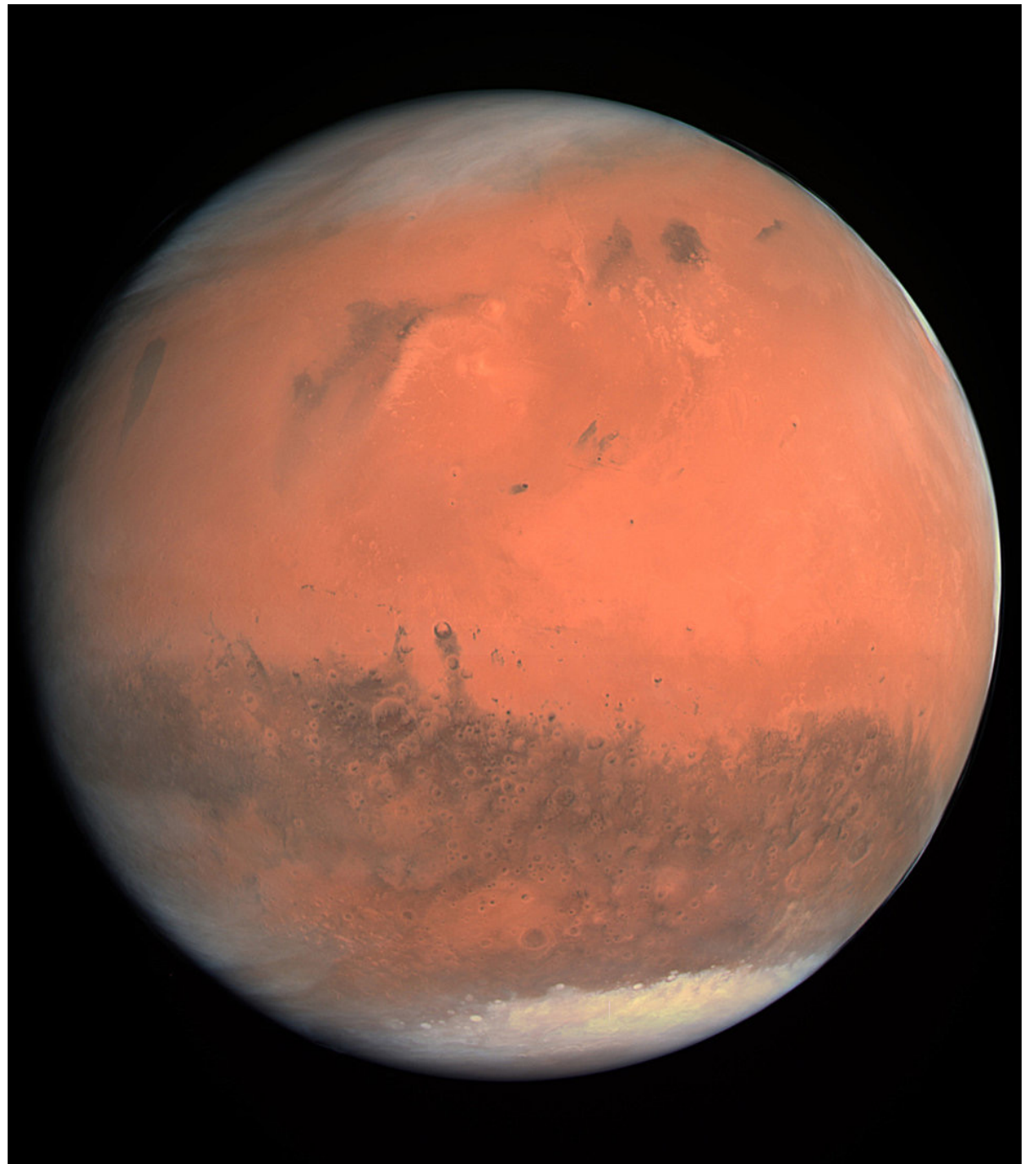
Source: ESA 2015

Swing-in of Rosetta at Mars.

TRUE-COLOUR IMAGE OF MARS SEEN BY ROSETTA

- The first true-colour image generated using orange (red), green and blue colour filters.
- The image was acquired on 24 February 2007 at 19:28 CET from a distance of about 240.000 km; image resolution is about 5 km/pixel.

Source: ESA 2007



Rosetta Orbiting Comet.

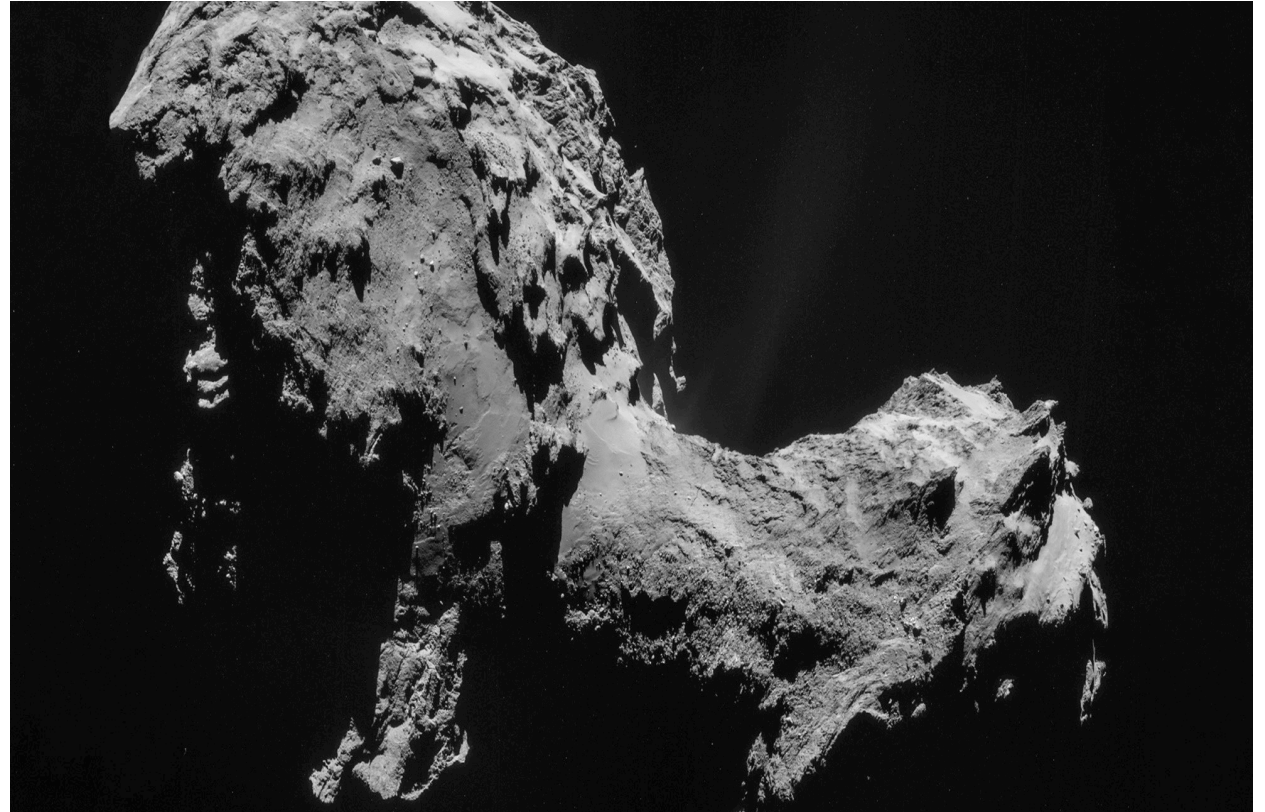
- **Rosetta was first spacecraft to orbit a comet**

- distance ca 30 km
- duration of orbiting:
17 months

- **High resolution images**

- **First direct analysis of matter of comet:**

- mass spectrometric analysis of particles emitted from comet due to solar impact

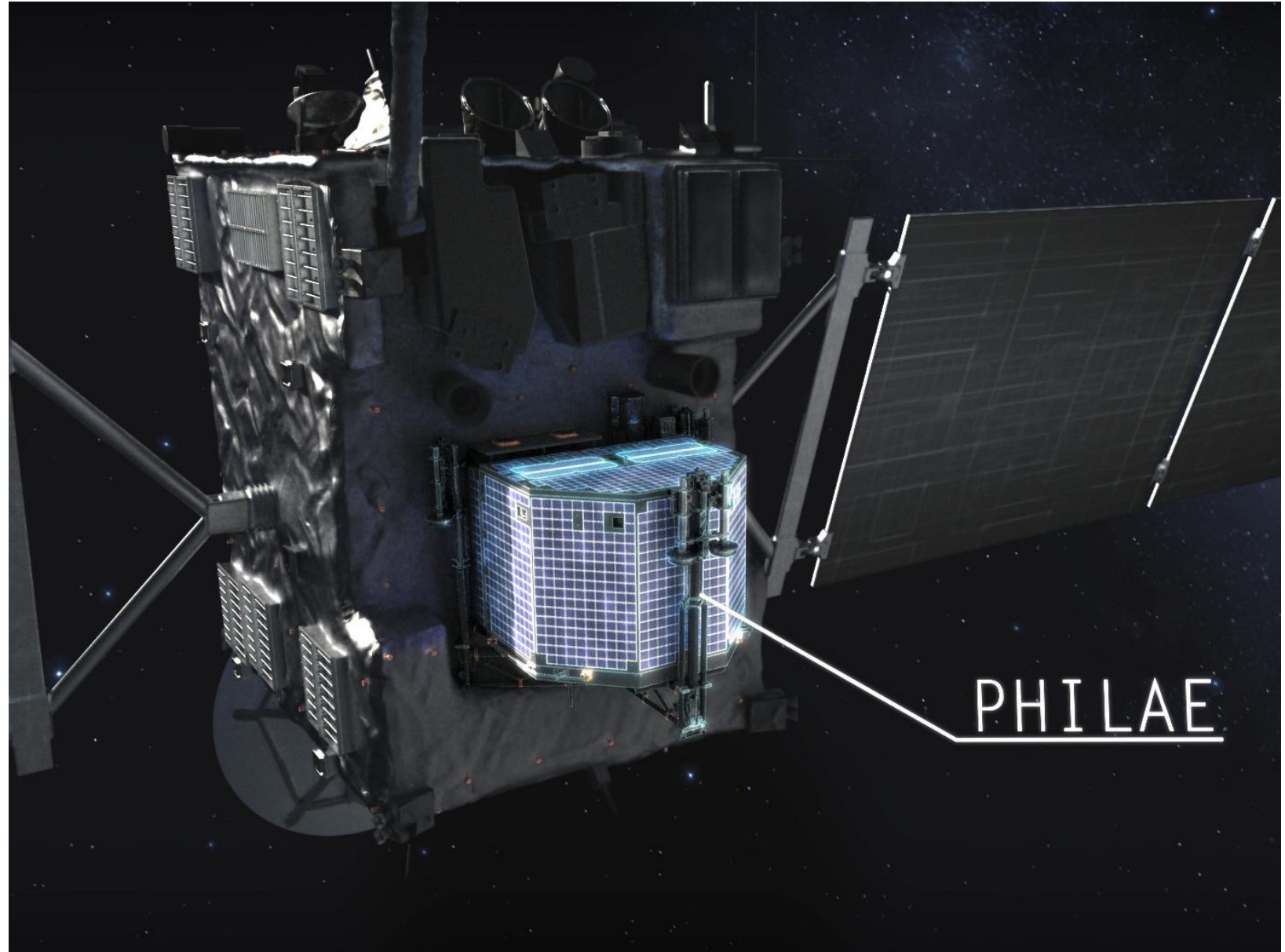


- detection of a large number of small organic molecules: hydrocarbons up to C7, alcohols up to C5, aromatic compounds, sulfur compounds, aminoacid glycine....
- detection of elements vital for life: Na, K, Mg, P.....
- measurement of isotopic ratio $^2\text{H}/^1\text{H}$ in comet water: higher than on earth

Rosetta's Landing Module.

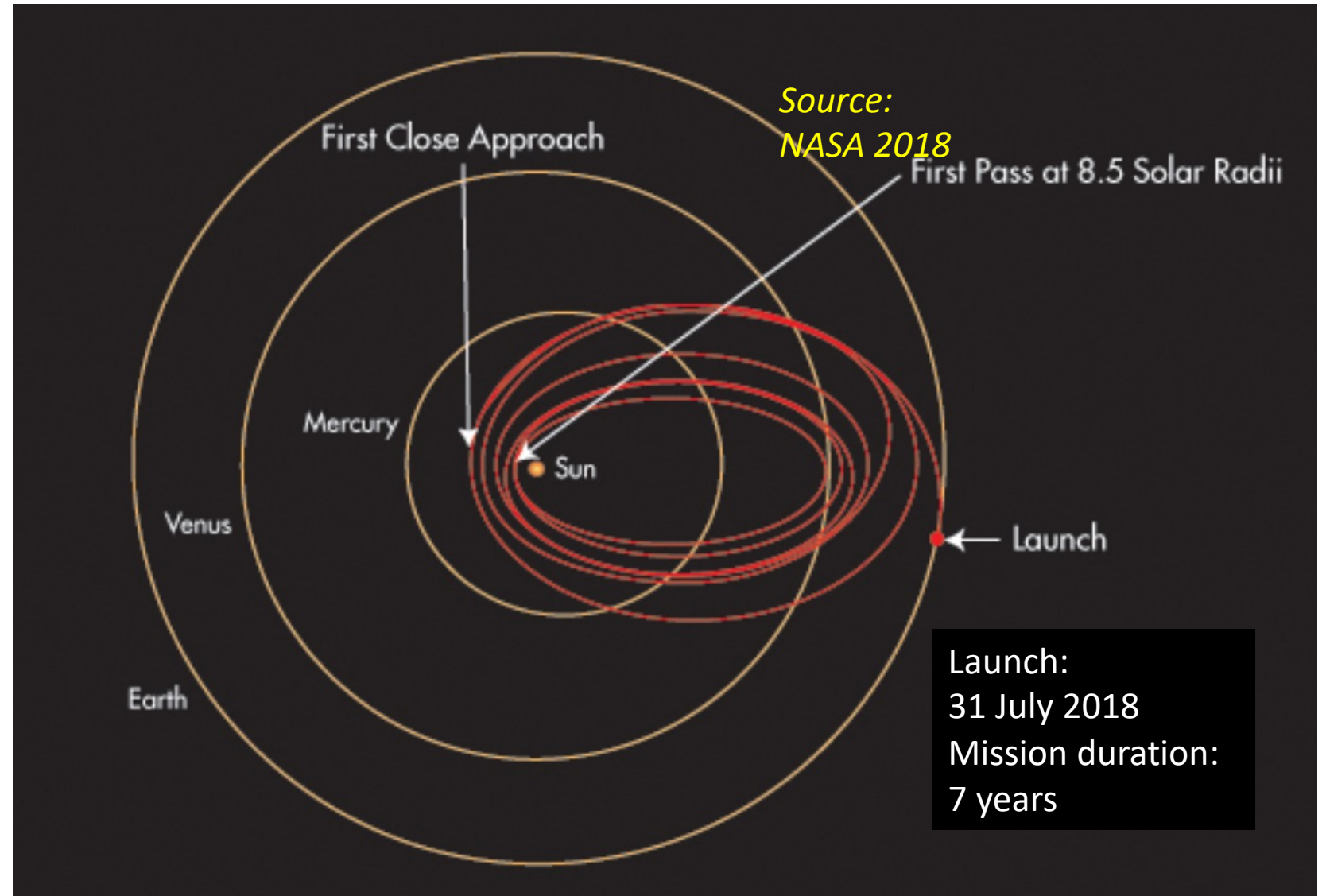
- Rosetta dispatched Philae on 12 Nov. 2014.
- Landing speed 1m/s due to low gravitational field of comet (actual weight of the 100kg lander was there 1g).
- Philae delivered data for about 20 hours (over a period of 8 months):
 - First images of a comet's surface.
 - First *in situ* analysis of its composition.

Source: ESA 2014

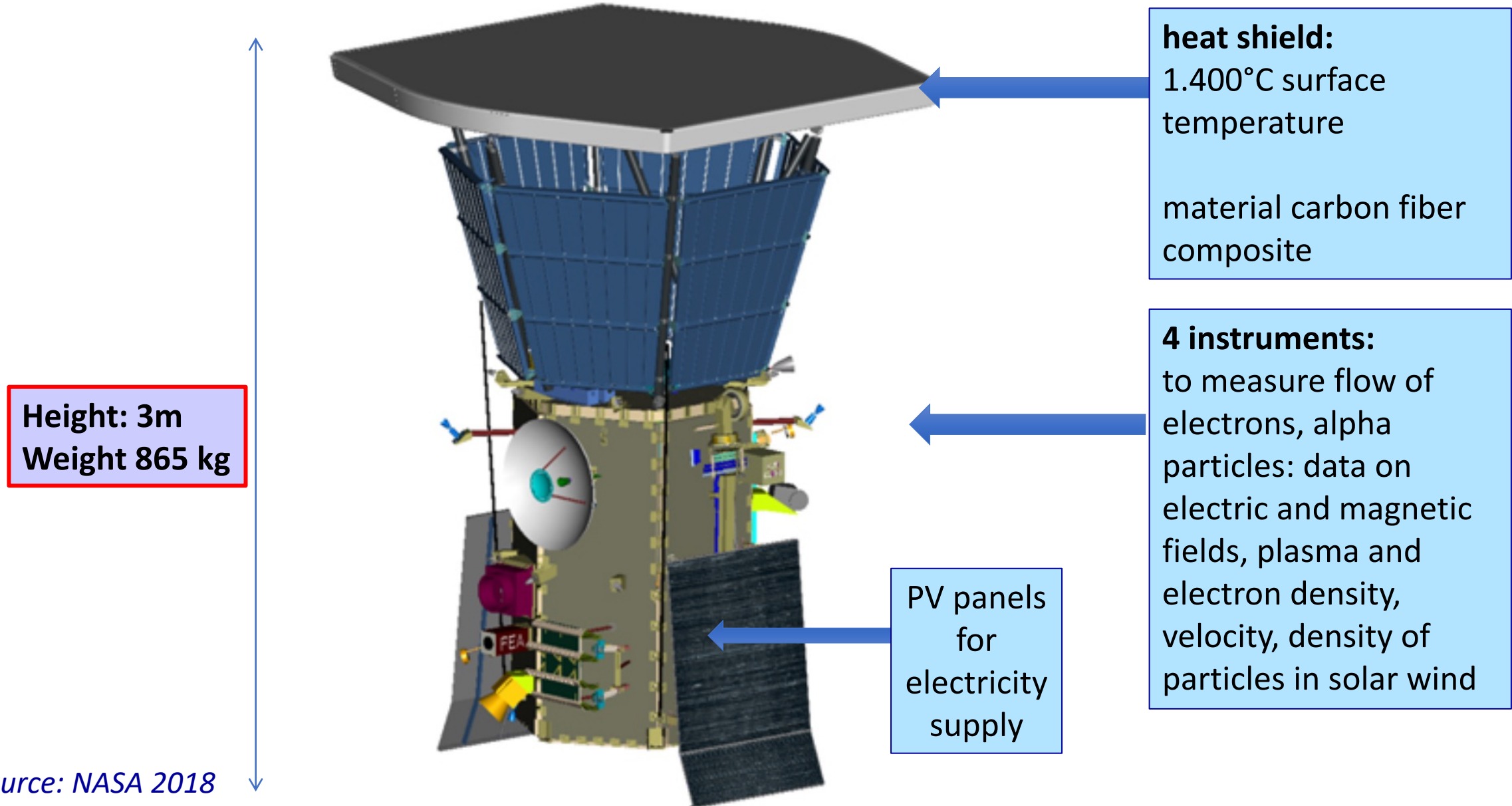


Space Exploration: Particle Flows from the Sun – Parker Solar Probe.

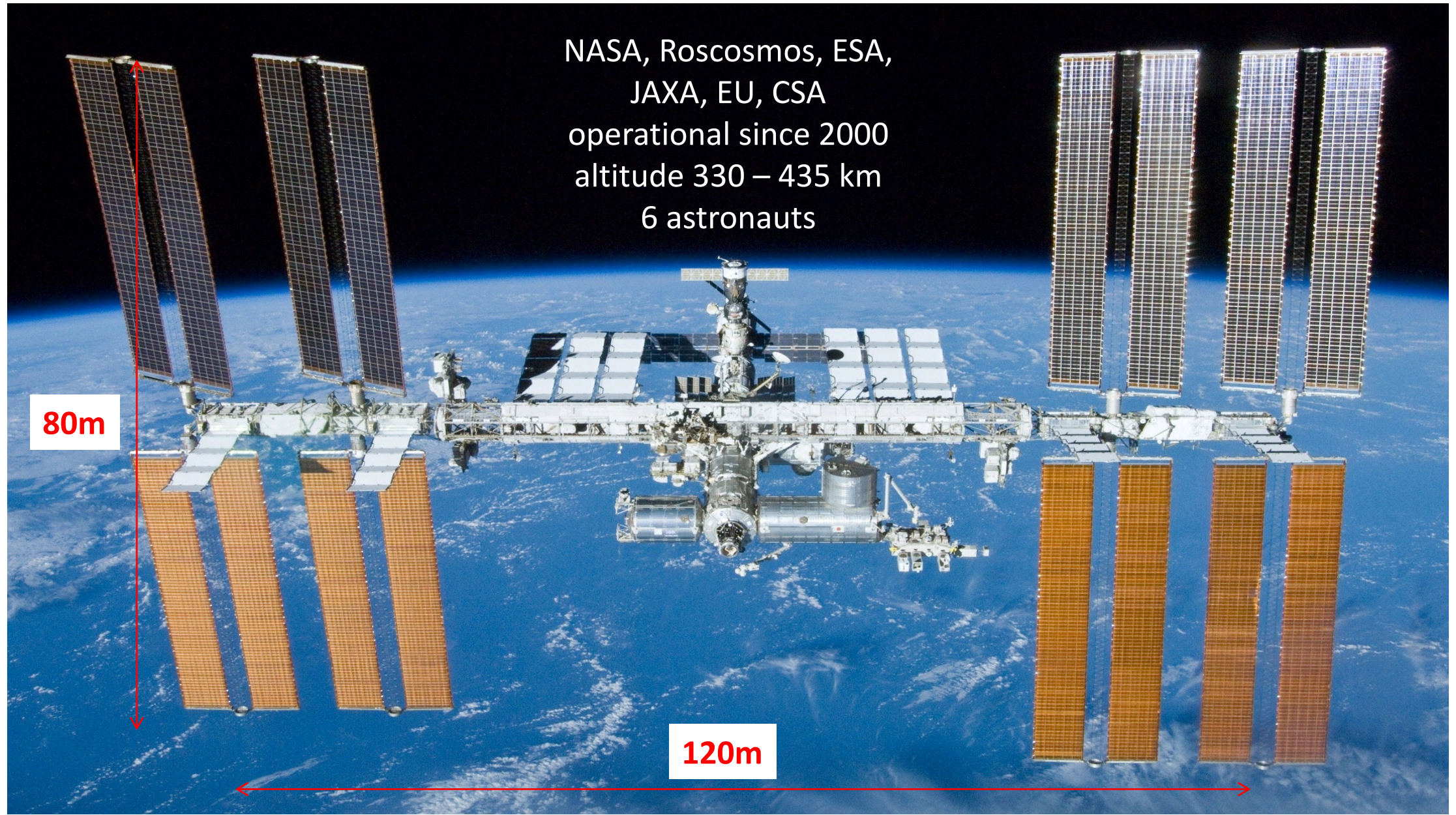
- Unique mission to study the processes occurring at the surface of the sun leading to solar wind, corona, aurora in earth atmosphere.....
- Distance earth - sun: 150 million km
- Closest distance to the sun: 5 million km
- 24 cycles around the sun (each 88 days), heliocentric speed 200 km/s



Space Exploration: Particle Flows from the Sun – Parker Solar Probe.



International Space Station: Laboratory, Observatory, Factory.



International Space Station.

International
Space Station
passing in front
of the Moon.

*Source:
Facebook 2024*

Credit: Andrew McCarthy



9.3 Global Earth Observation.

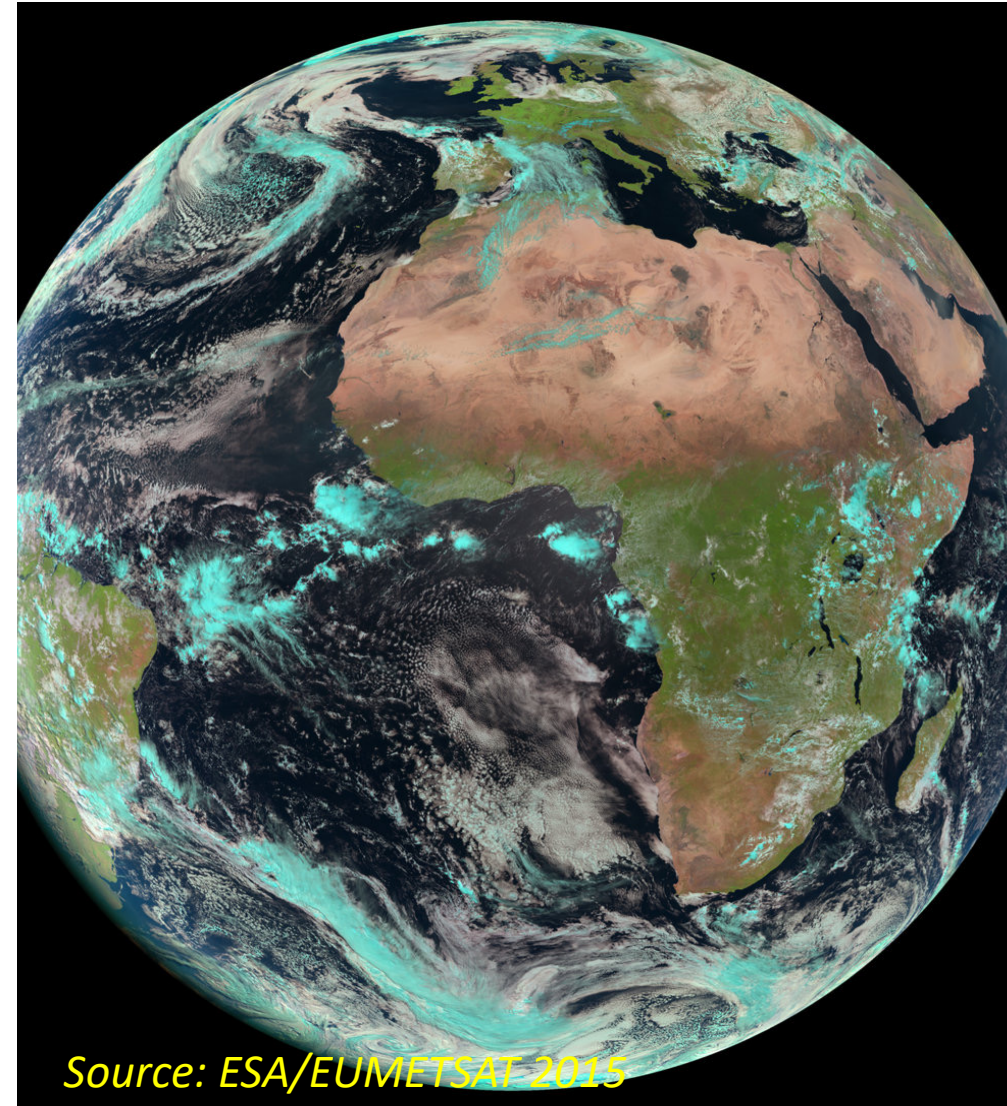
Global Sustainable Development Requires Monitoring the Whole Planet.



Source: NASA Space Shuttle

Global weather observation:

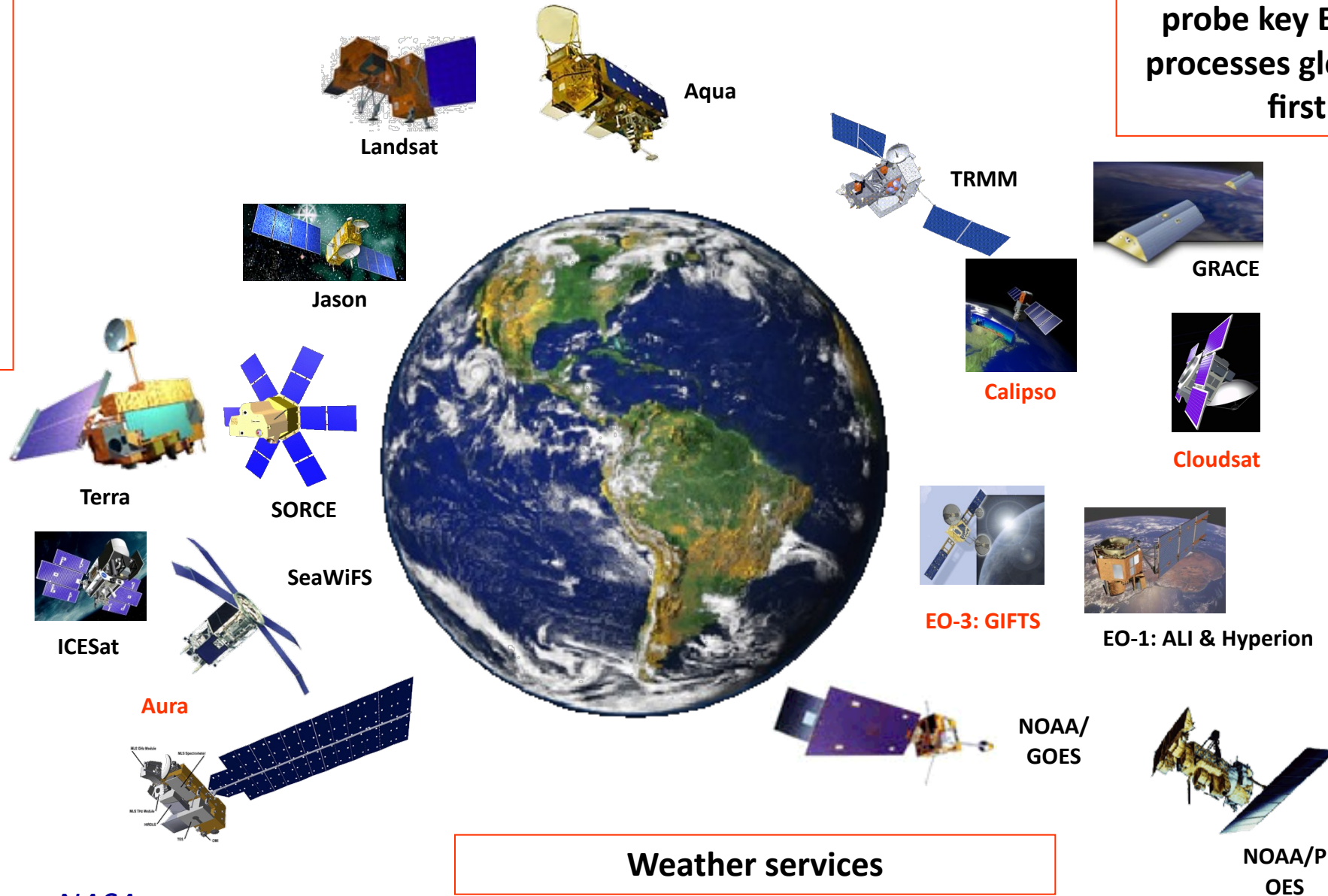
Spinning
Enhanced
Visible and
Infrared Imager
(SEVIRI)
instrument on
Meteosat-10 in
operation) on
22 April 2015.



Source: ESA/EUMETSAT 2015

**The Earth
Observing System
-- systematic
measurement of
interactions
among land,
oceans,
atmosphere, ice
& life**

Exploratory missions to probe key Earth system processes globally for the first time



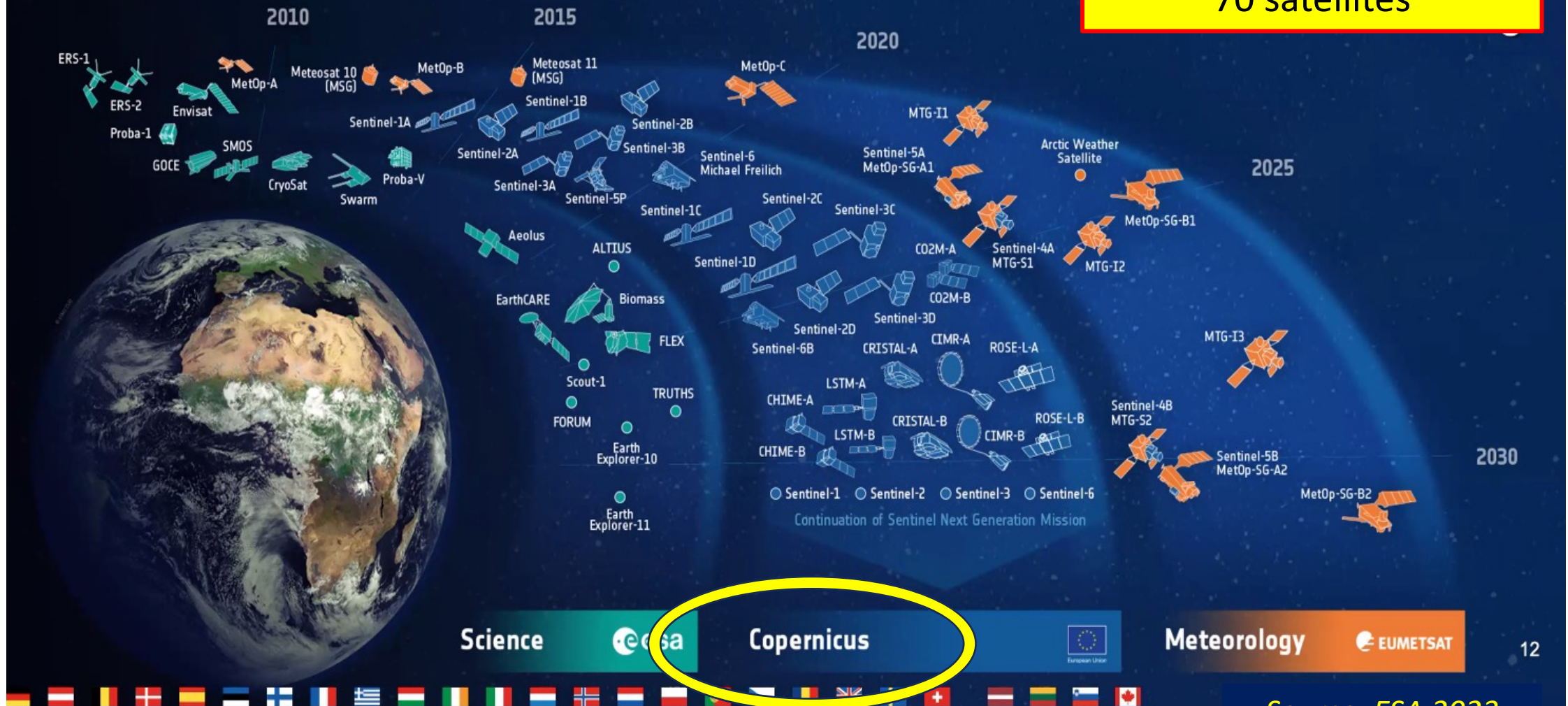
Source: NASA

Weather services

European Space Agency.

Intergovernmental organisation of 22 States
dedicated to the exploration of space.

Annual budget:
7 billion EUR
70 satellites



Global Monitoring for Environmental Security

A Manifesto for a New European Initiative



GMES – Copernicus.

- **Operational dimension:**
 - **Land Monitoring:** information on land use and land cover changes of interest for climate change, water management, biodiversity, agricultural production, urban planning.
 - **Marine Services:** delivers information on the state of the coastal and marine environment.
 - **Atmospheric services:** monitoring air pollution and climate change variables.
 - **Crisis Management:** delivers information important for response to crises and emergencies associated with natural and man made disasters, like floods, fires, earthquakes, landslides, tsunamis, industrial accidents.

<http://www.copernicus.eu/>

The Baveno Manifesto of the European Commission, ESA and national space agencies initiated by the JRC 1996.

GMES – Copernicus.

R



25 years of Copernicus

Klimawandel • Der Begriff „Klimawandel“ bezeichnet langfristige Temperatur- und...

Teilen

sentinel-2

sentinel-1

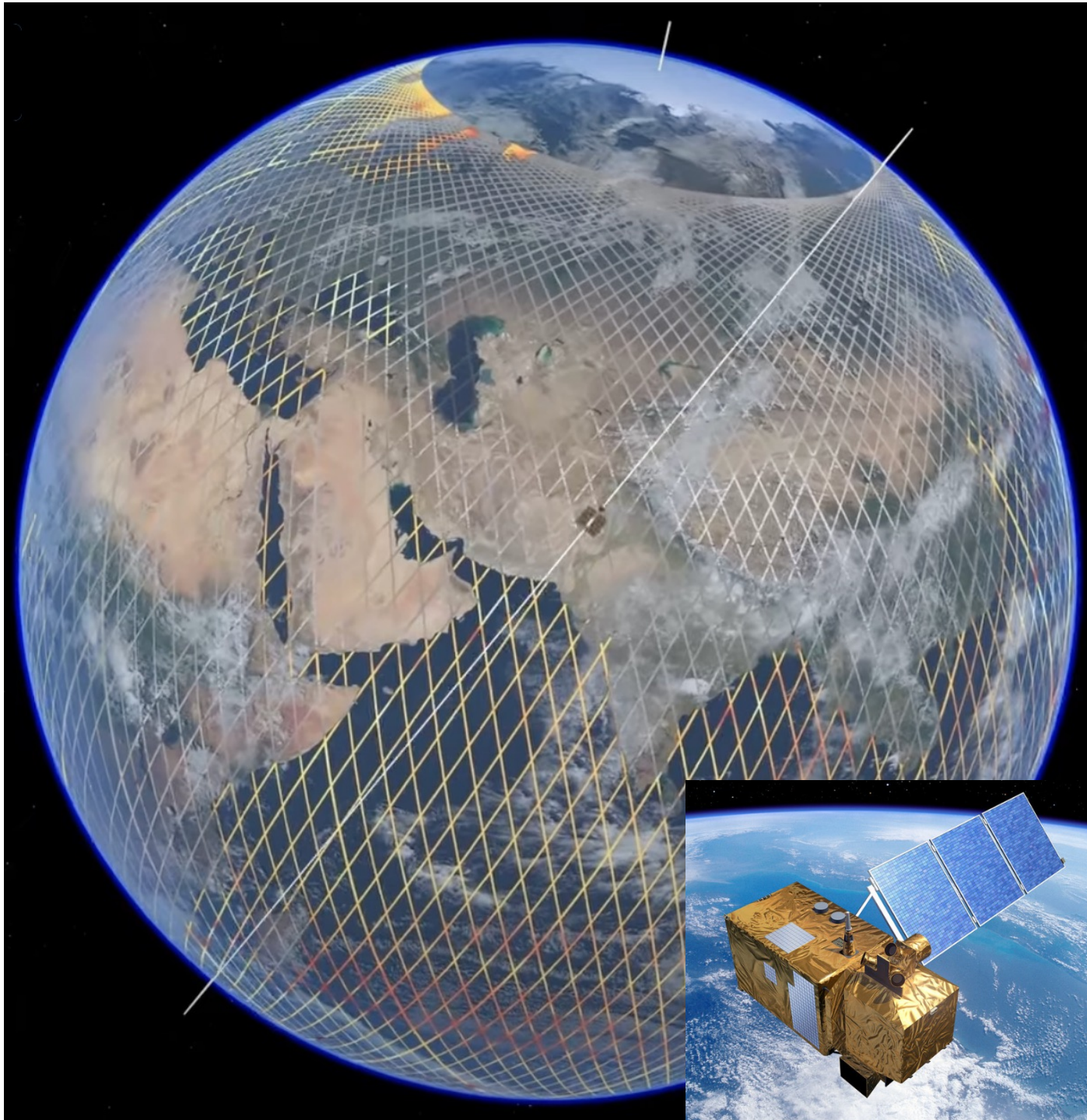
Operational
since 2014

Source: ESA 2023

sentinel-5p

WEITERE VIDEOS

Subscribe



Copernicus Services: Global Earth Observation

Sentinels 1-6:

weight 1-2 tons

circulation height
700-800km

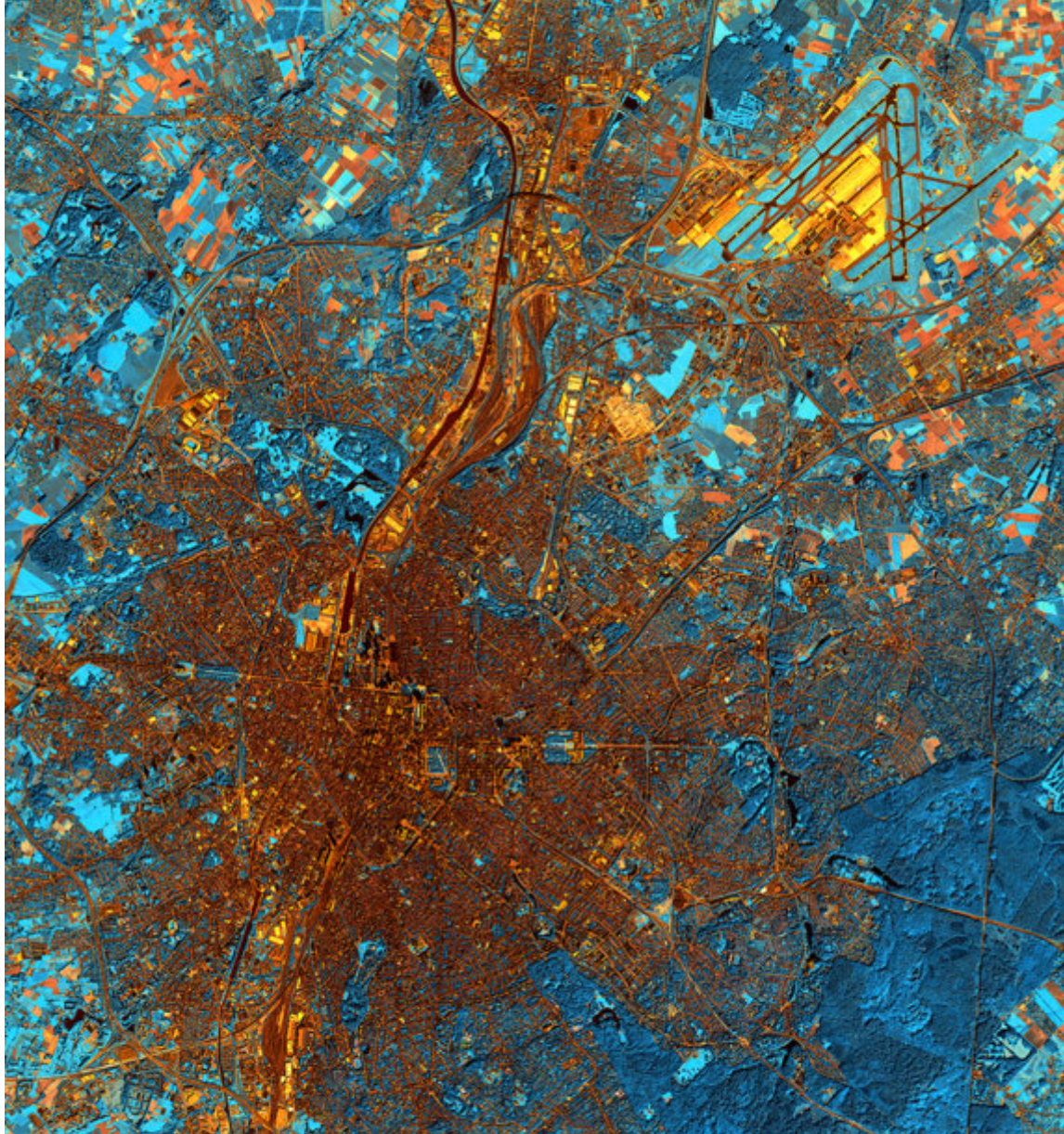
width of
observation path:
300-1.000km

Copernicus

budget:

1,5 billion
EUR/year

Copernicus Services: Land Monitoring.



BRUSSELS false-colour image (resolution 10m)

Copernicus Services: Land Monitoring.

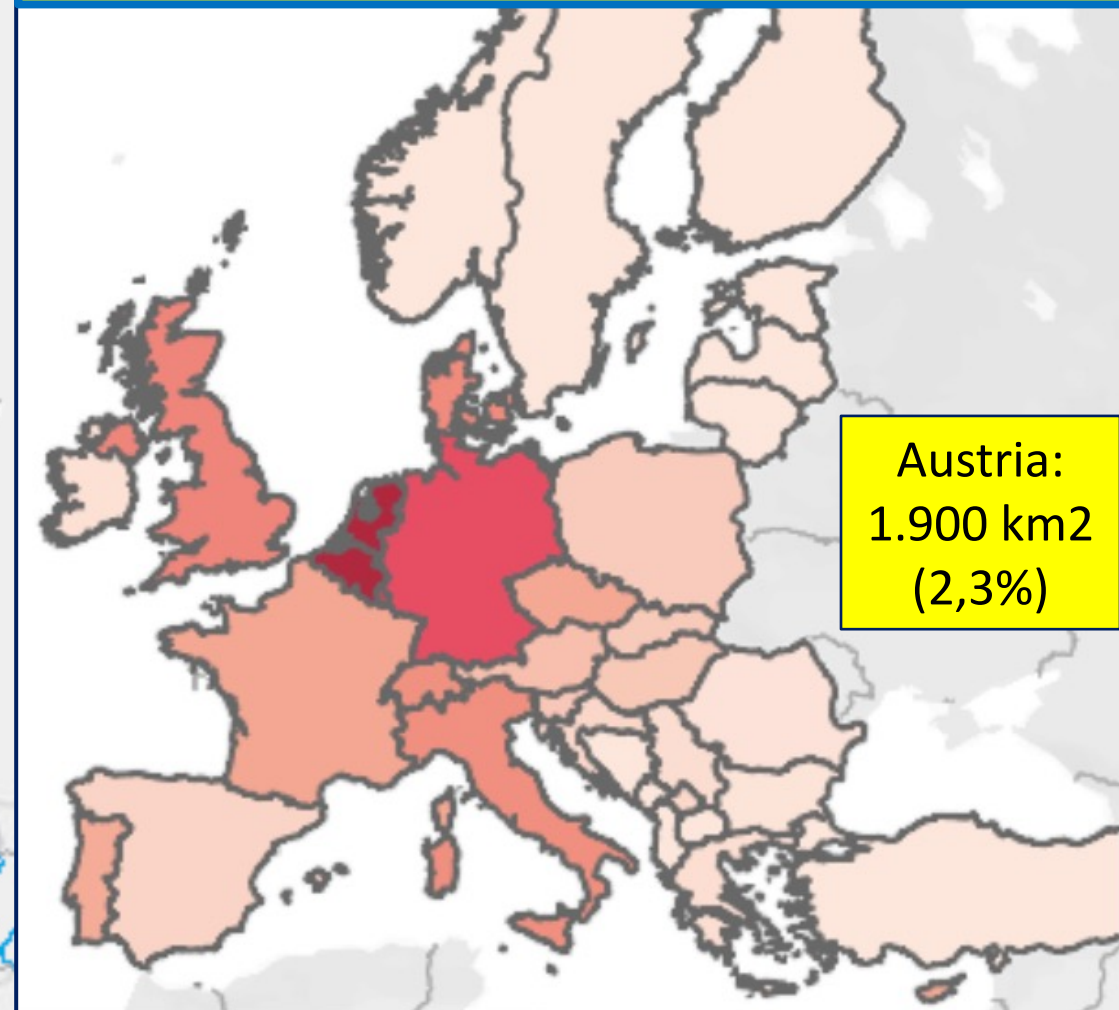
EU river network data base.

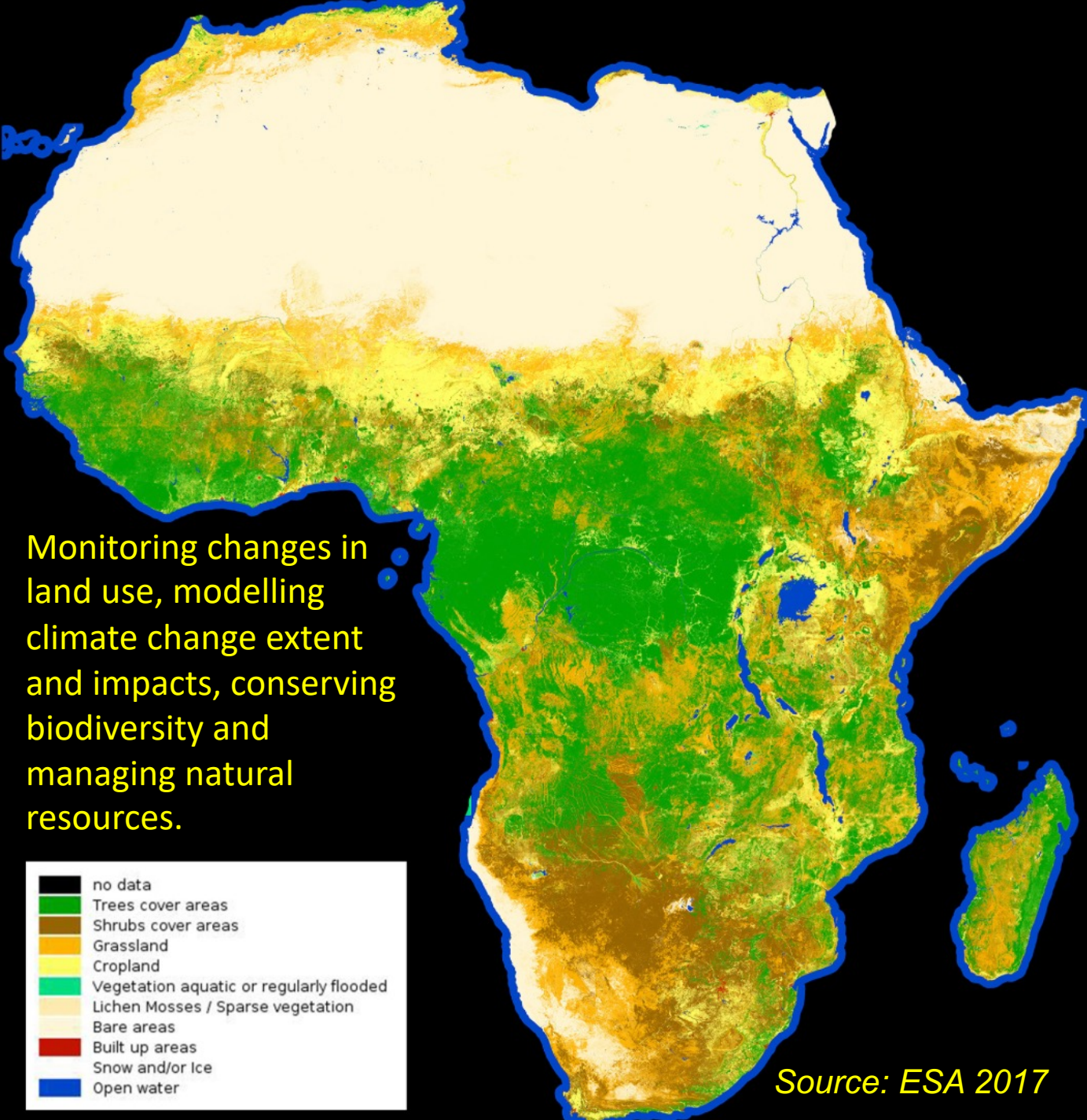
Support to
implementation
of Water
Framework
Directive



Determination of the sealed surfaces:

EU initiative 2023: Renaturalisation of EU land and water bodies, reduction of sealed surfaces.

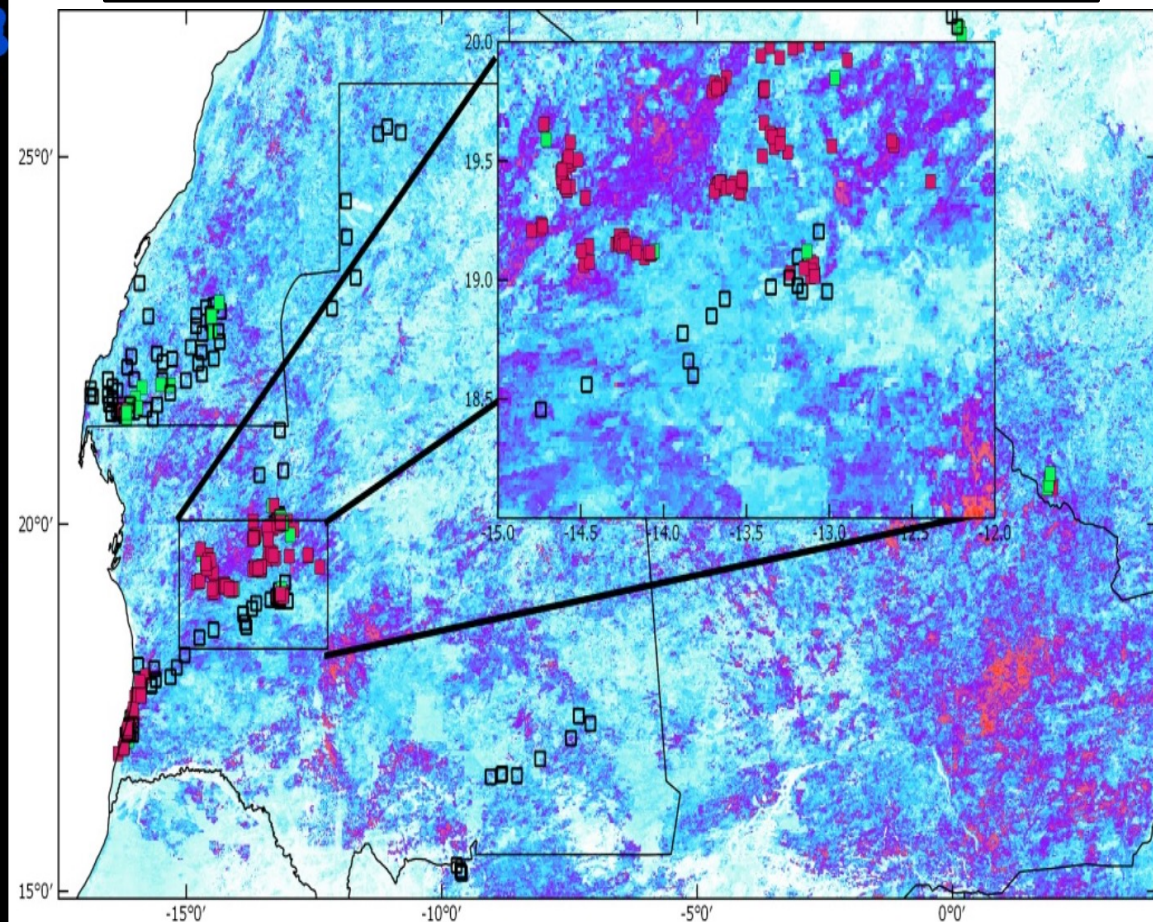




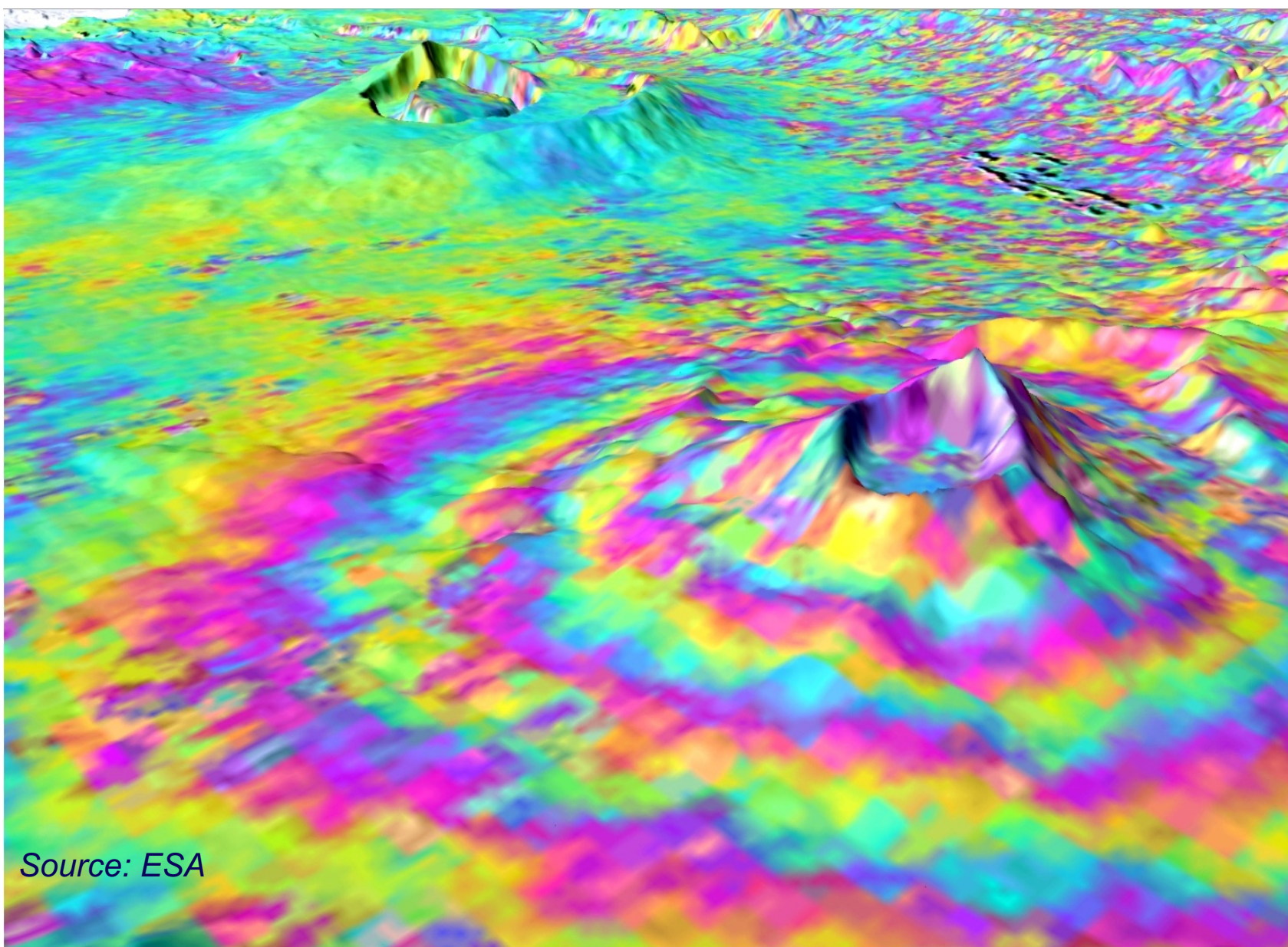
Monitoring changes in land use, modelling climate change extent and impacts, conserving biodiversity and managing natural resources.

Copernicus Services: Land Monitoring

Identification of favourable areas for locust swarming in Africa (red) derived from soil moisture data.



Copernicus Services: Land Monitoring.



Monitoring volcanic activities before eruptions (Kenya):

Synthetic Aperture Radar interferogram over the Kenyan section of the Great Rift Valley shows small surface displacements of the Longonot Volcano that are not visible to the naked eye (front right).

From 1997 – 2000 the Longonot Volcano experienced an uplift of around 9 cm.

Interferogram images appear as rainbow-coloured interference patterns.

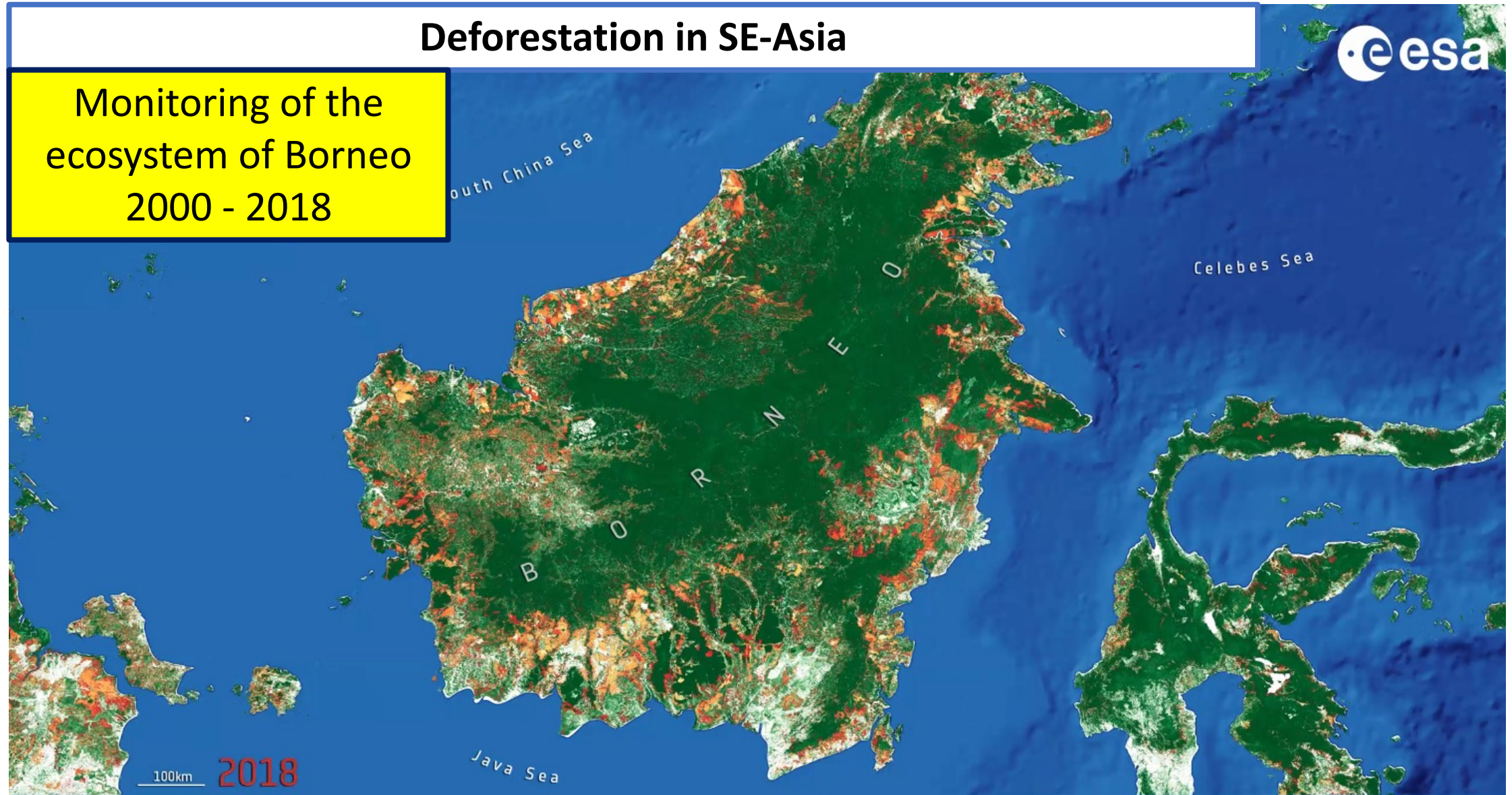
The Suswa volcano in the background was stable.

Source: ESA

Copernicus Services: Land Monitoring.

Deforestation in SE-Asia

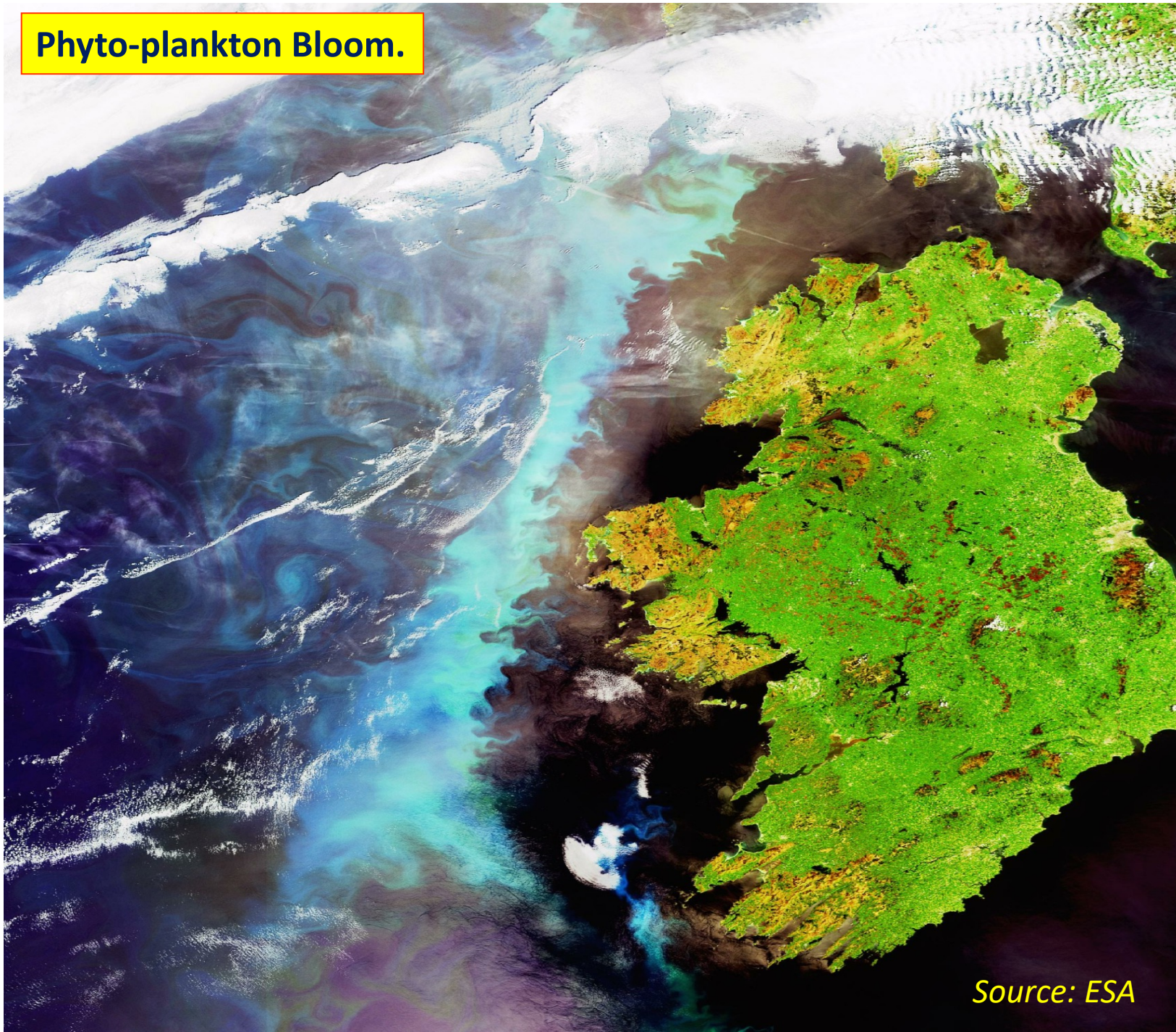
Monitoring of the
ecosystem of Borneo
2000 - 2018



Source: ESA 2019

8

Phyto-plankton Bloom.

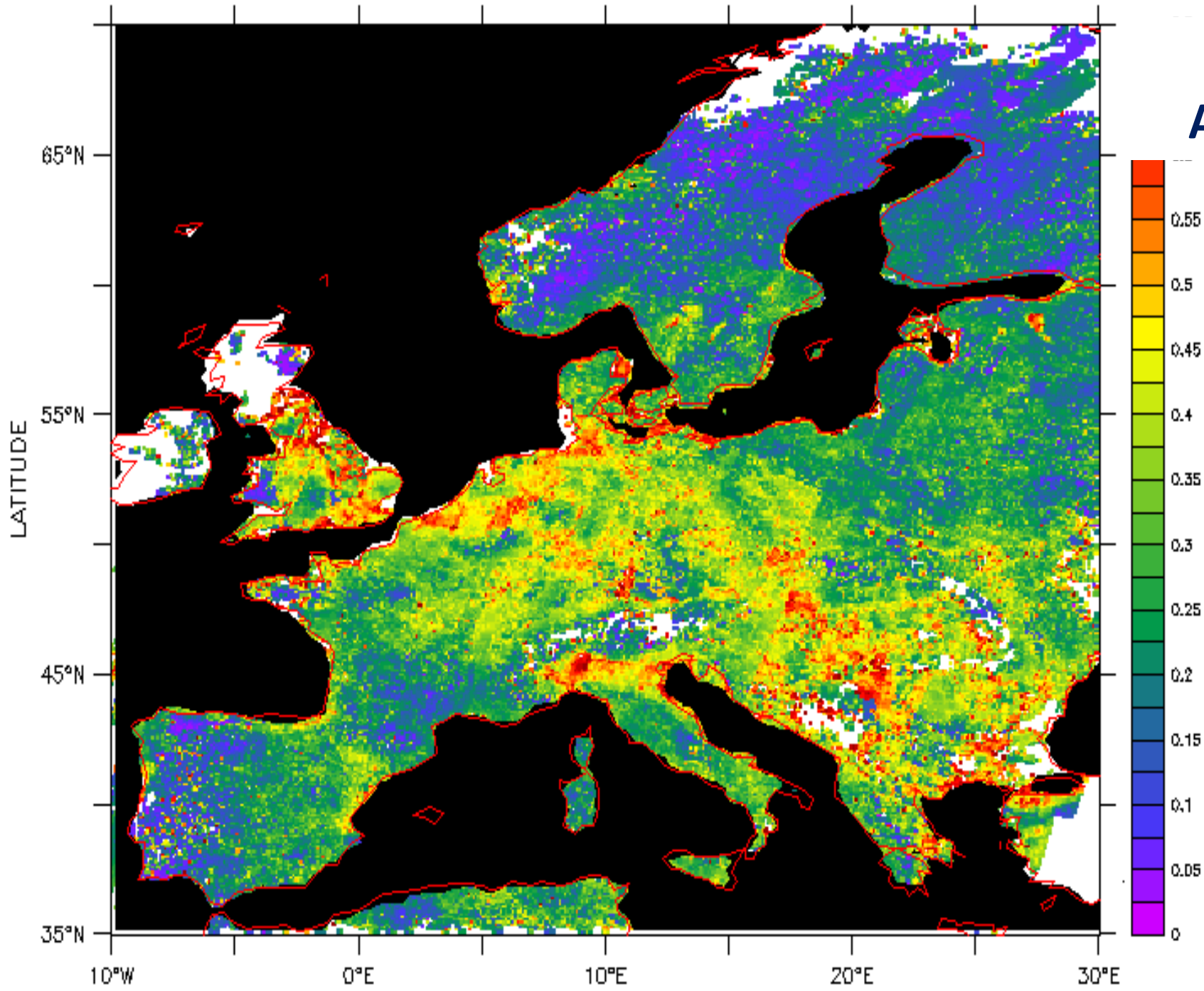


Copernicus Services: Marine Monitoring.

A large aquamarine-coloured plankton bloom is shown stretching across the length of Ireland in the North Atlantic Ocean.

Source: ESA

Copernicus Services: Atmospheric Monitoring.



**Measurement
of particulate
matter from
space.**

Monthly
composite map
of aerosol
optical depth.

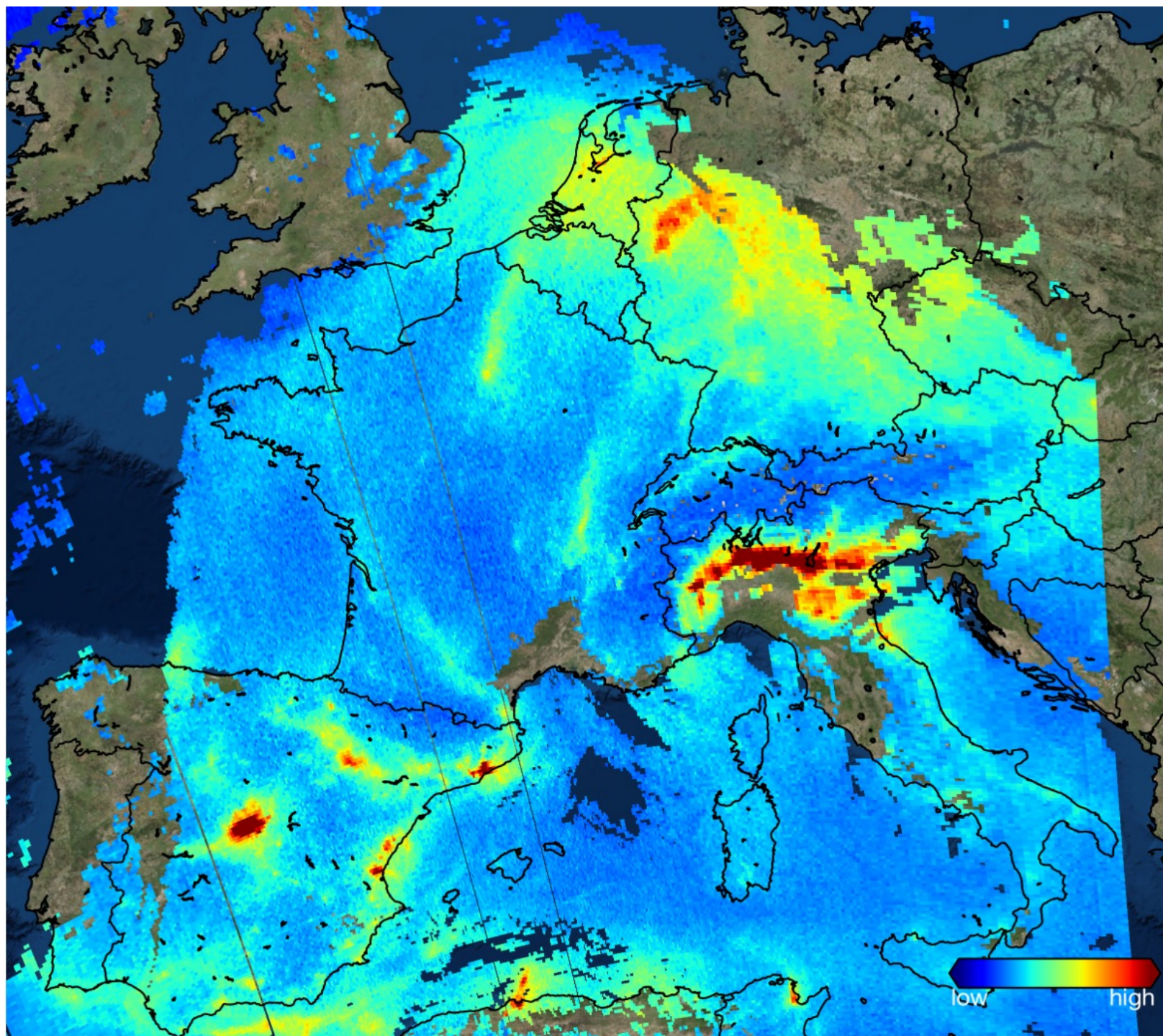
Copernicus Services: Atmospheric Monitoring.

Nitrogen dioxide over Europe:

Sentinel-5P measurements
April 2018 (averaged).

Air pollution emitted by big
cities and shipping lanes is
clearly visible.

With a resolution of up to 7 x
3.5 km, Sentinel-5P's Tropomi
instrument can detect air
pollution over individual
cities.

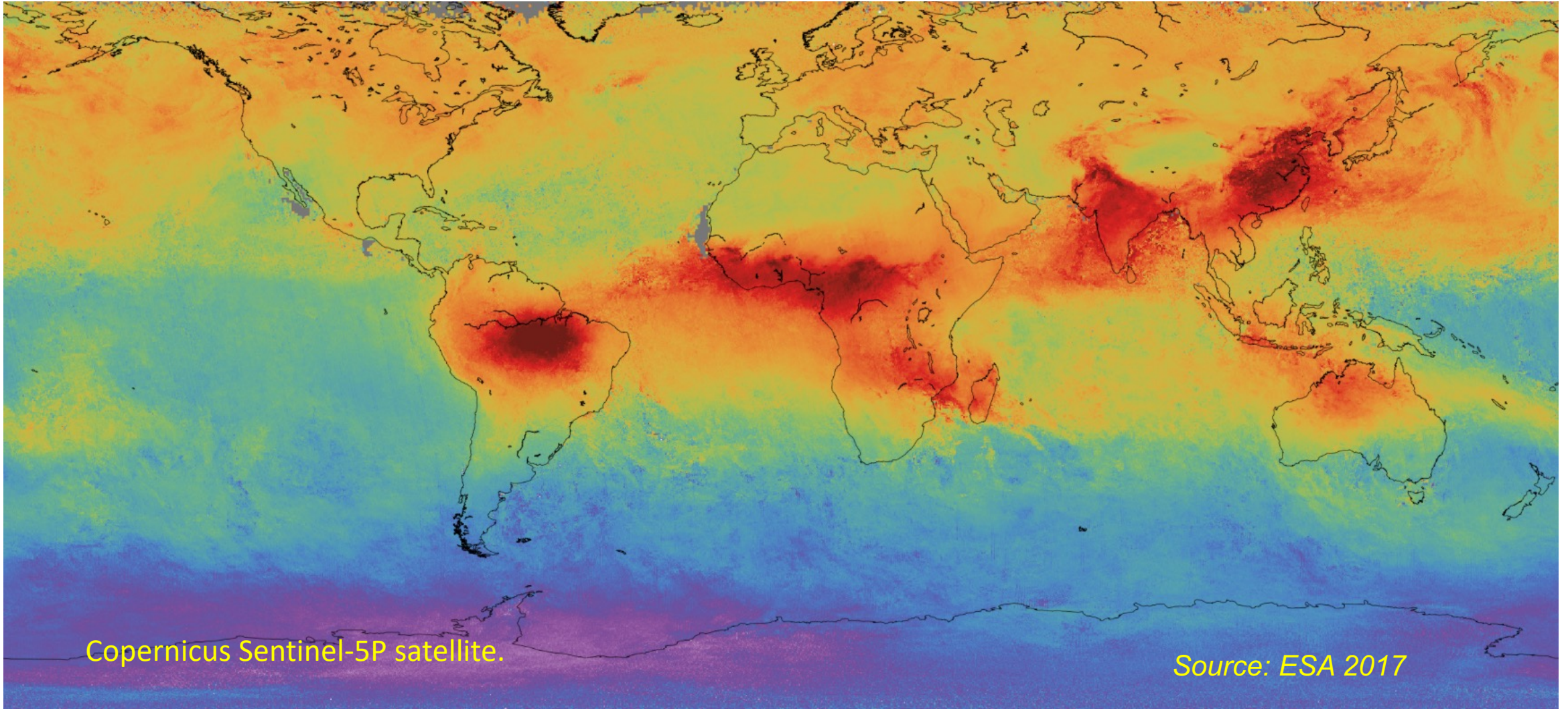


Copernicus Services: Atmospheric Monitoring.

Global carbon monoxide map (2017):

Image shows high levels of CO over parts of Asia, Africa and South America.

The mission has a swath width of 2600 km, which allows the whole planet to be mapped every 24 hours.



Copernicus Sentinel-5P satellite.

Source: ESA 2017

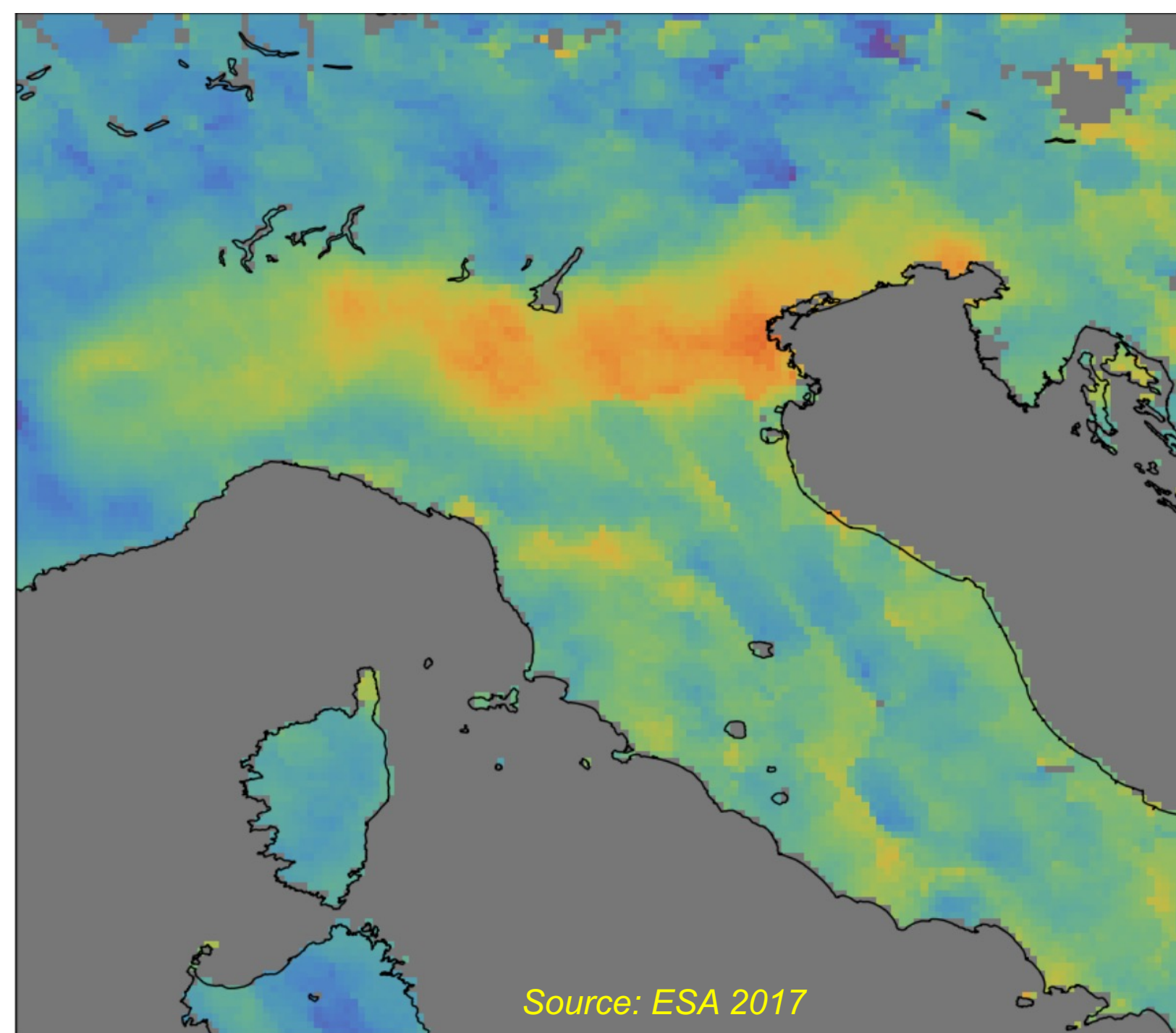
Copernicus Services: Atmospheric Monitoring.

Carbon monoxide over Northern Italy (2017):

Copernicus Sentinel-5P satellite image shows high levels of CO over the Po valley and the industrial zones of Mestre and Trieste.

Main sources of CO are traffic and industrial activities.

Source: ESA 2017

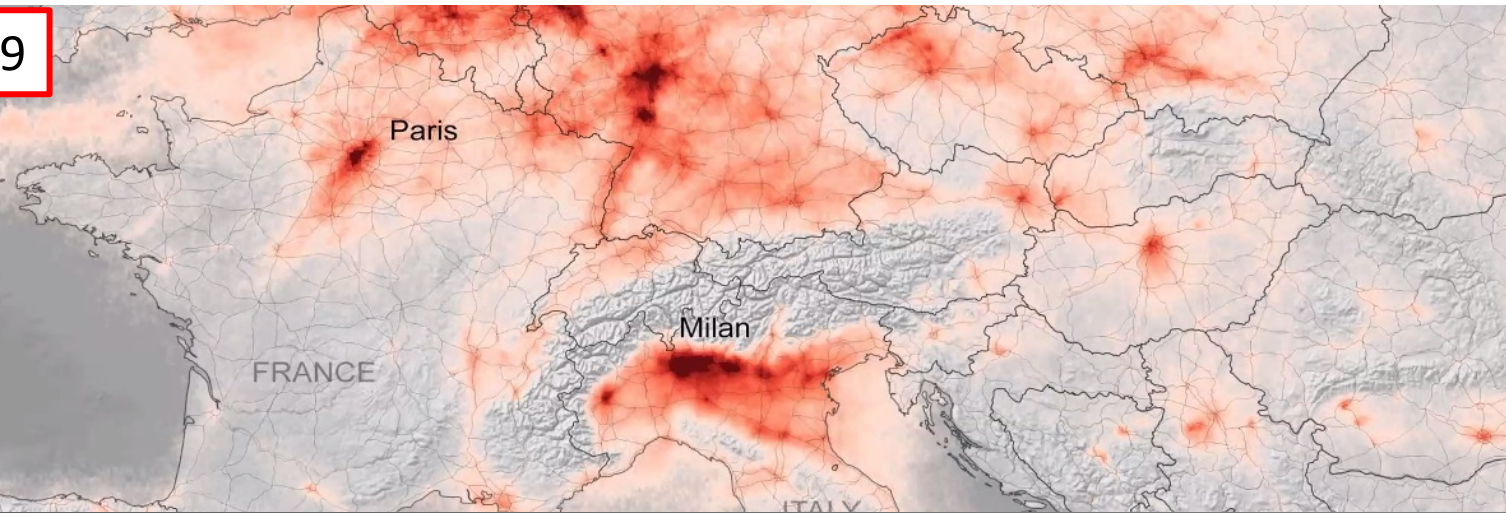


Copernicus Services: Atmospheric Monitoring.

March-April 2019

Copernicus
Sentinel-5P

NO₂ tropospheric column
20 $\mu\text{mol}/\text{m}^2$ 160



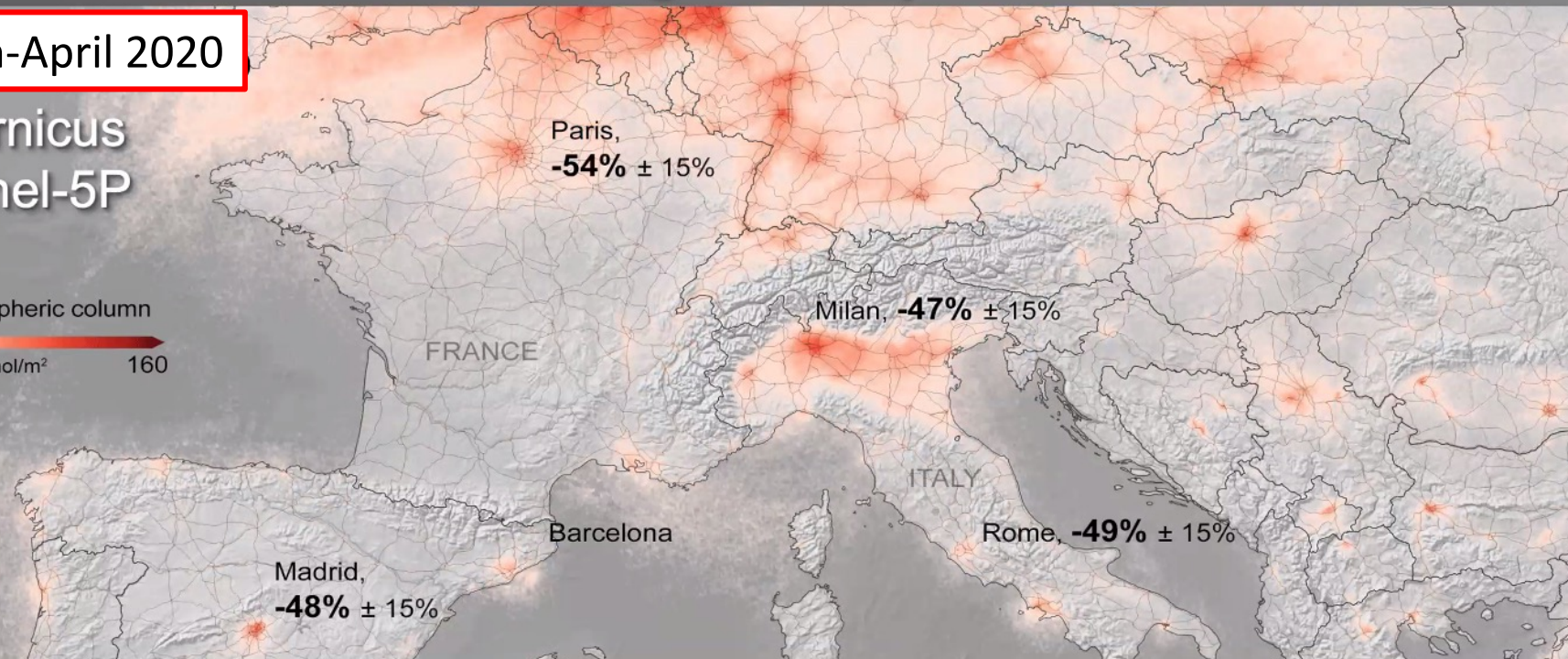
Effect of Corona lockdown on air quality



March-April 2020

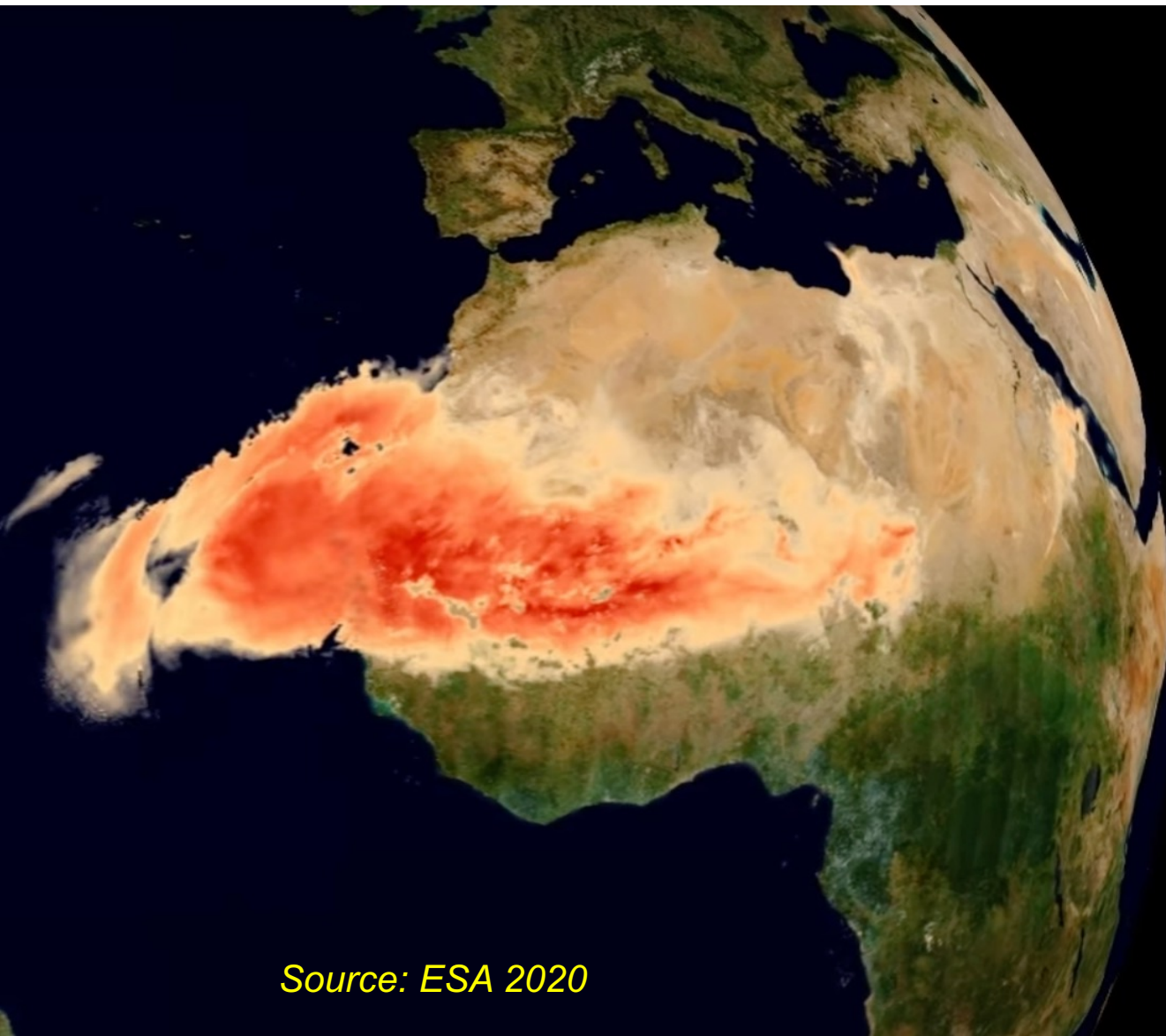
Copernicus
Sentinel-5P

NO₂ tropospheric column
20 $\mu\text{mol}/\text{m}^2$ 160



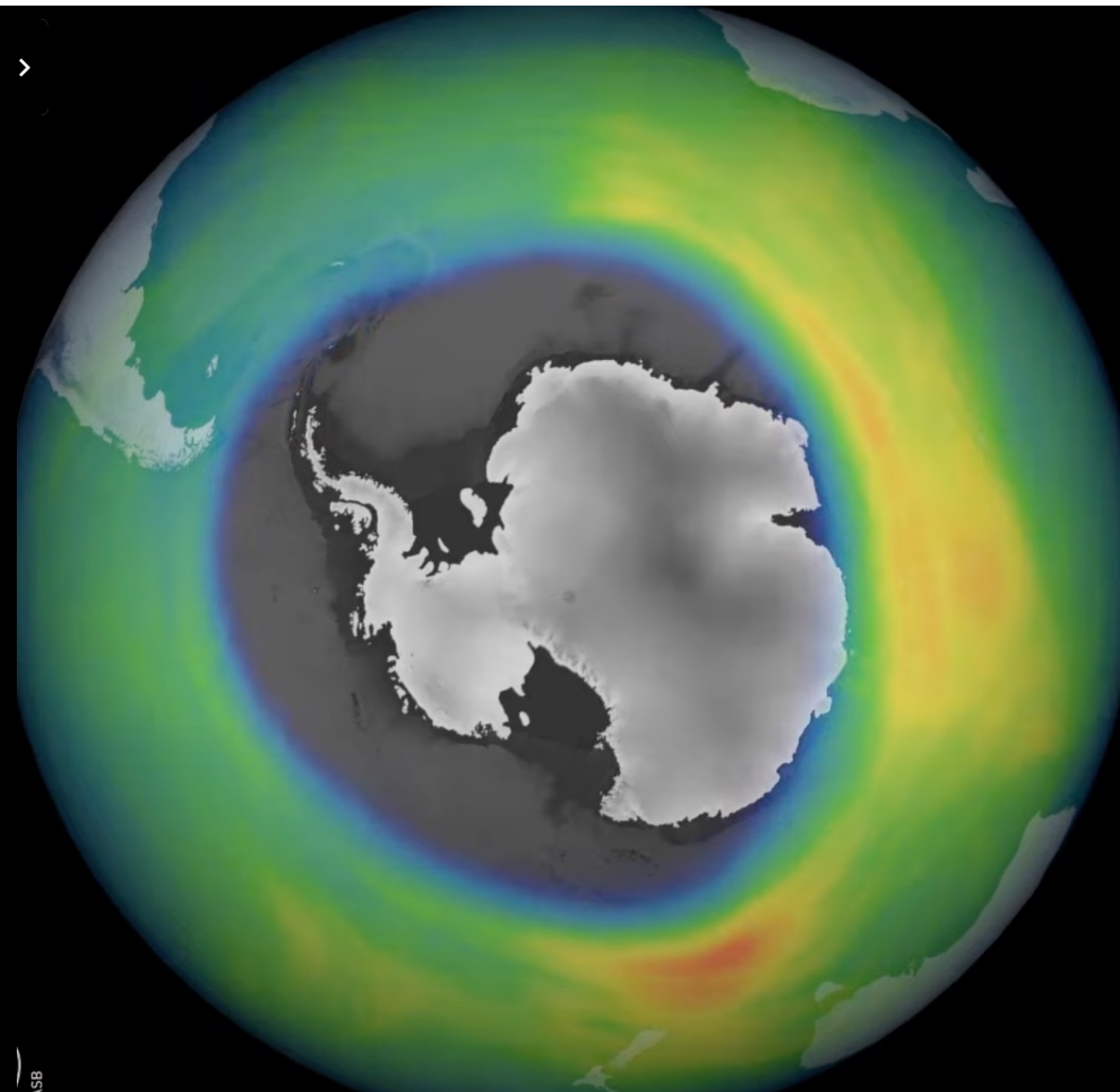
Copernicus Services: Atmospheric Monitoring.

Sahara dust cloud affecting the Canary Islands.



Source: ESA 2020

Ozone hole over Antarctica.

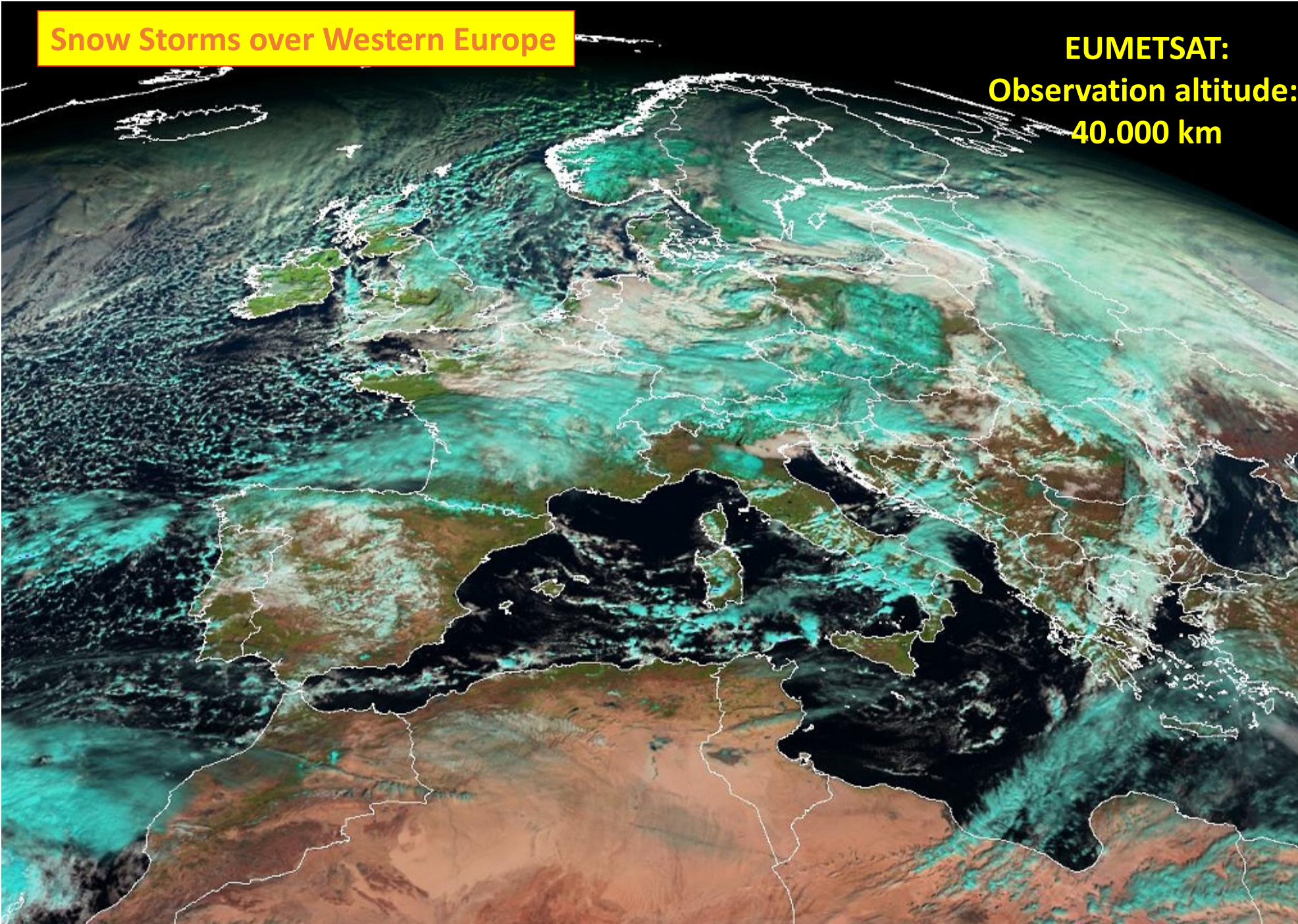


Snow Storms over Western Europe

EUMETSAT:
Observation altitude:
40.000 km

**Copernicus
Services:
Crisis
Management.**

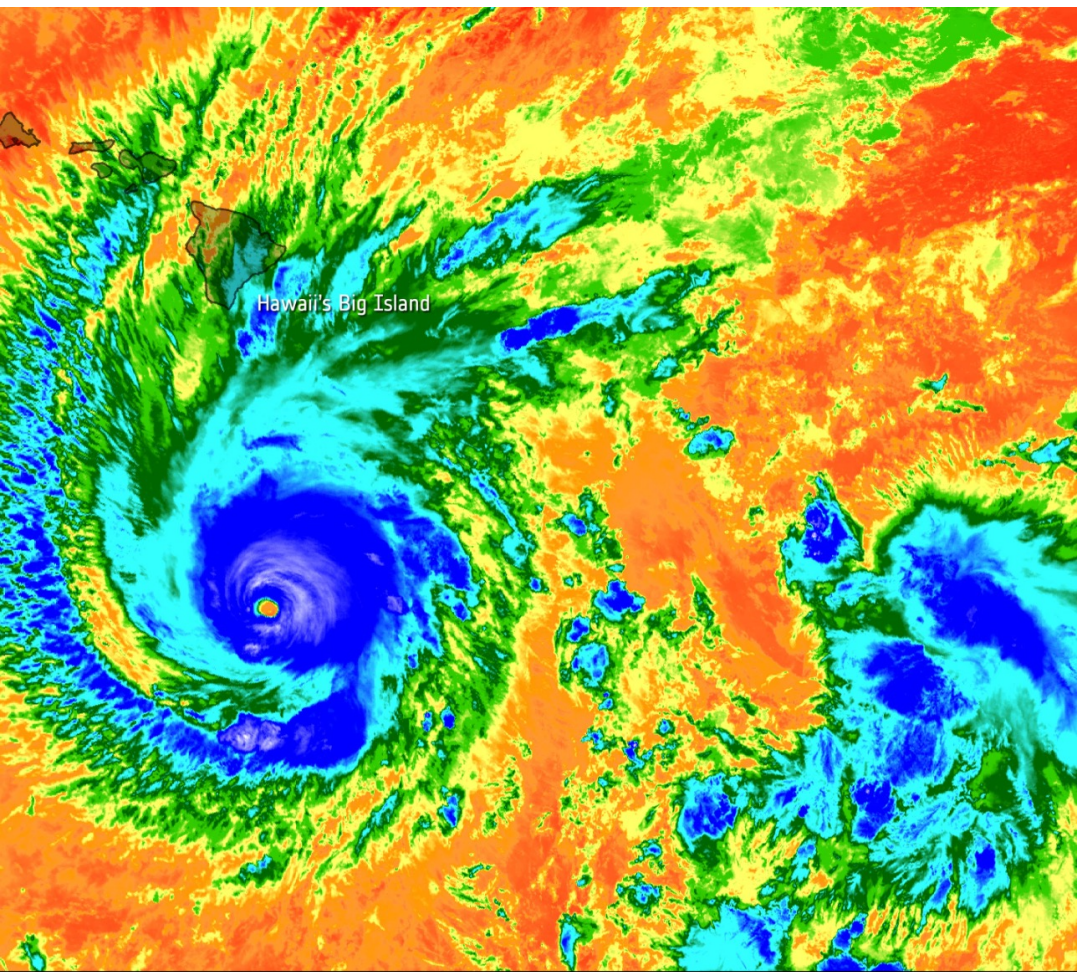
Severe winter weather swept over parts of Europe paralyzing public transport and roadways and cutting electricity for 250.000 people.



Copernicus Services: Crisis Management.

Hurricane Lane near Hawai Aug. 2018.

Radiative temperature at 15 km altitude:
blue: -80°C, orange: + 15°C:

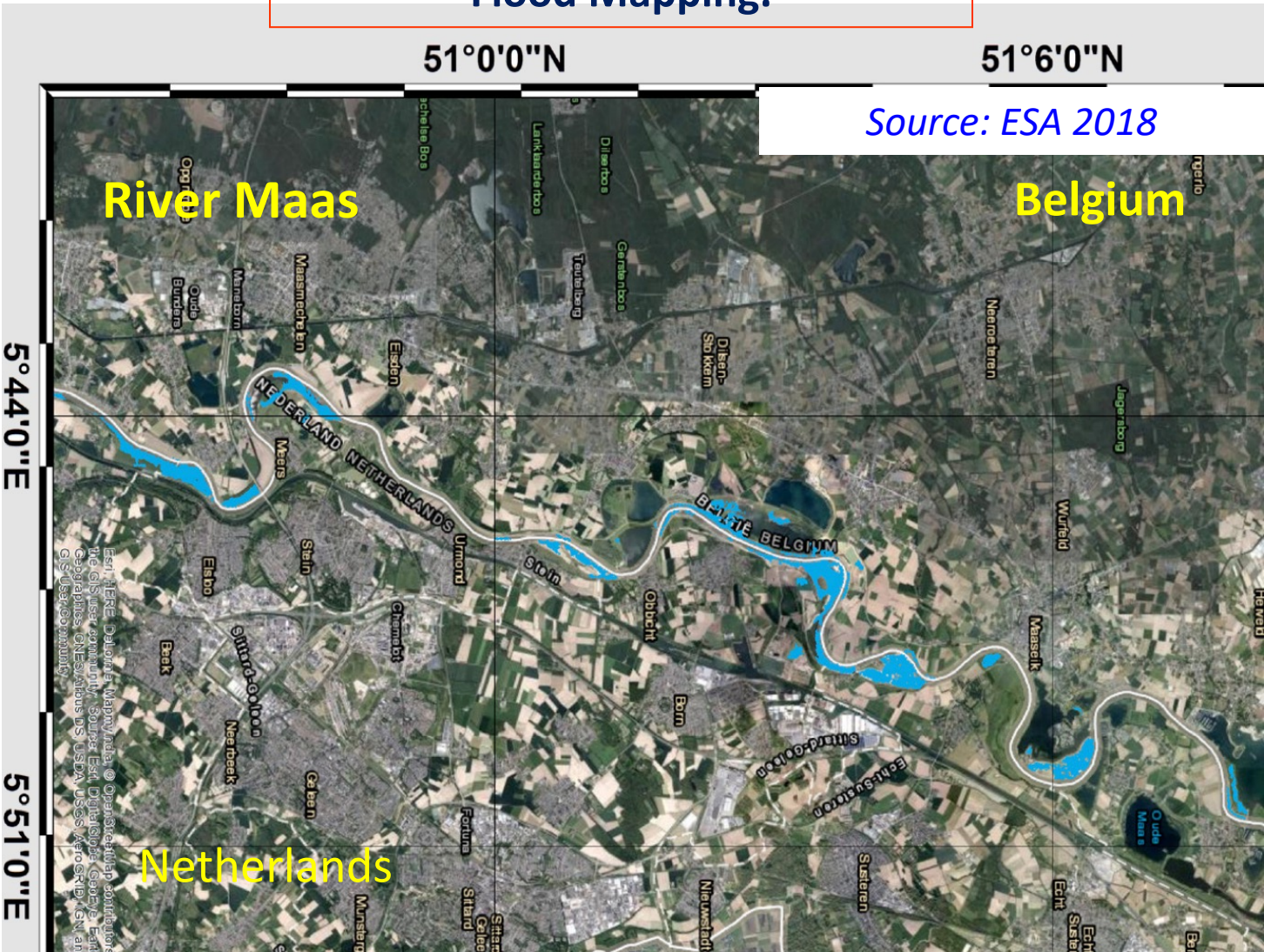


300 km

Top of atmosphere
brightness temperature [°C]



Flood Mapping.



Source: ESA 2018

European Flood Alert System and Global Flood Monitoring System.

Copernicus Services: Crisis Management.

European
Forest Fires
Information
System:
Fires 12. Aug.
2021

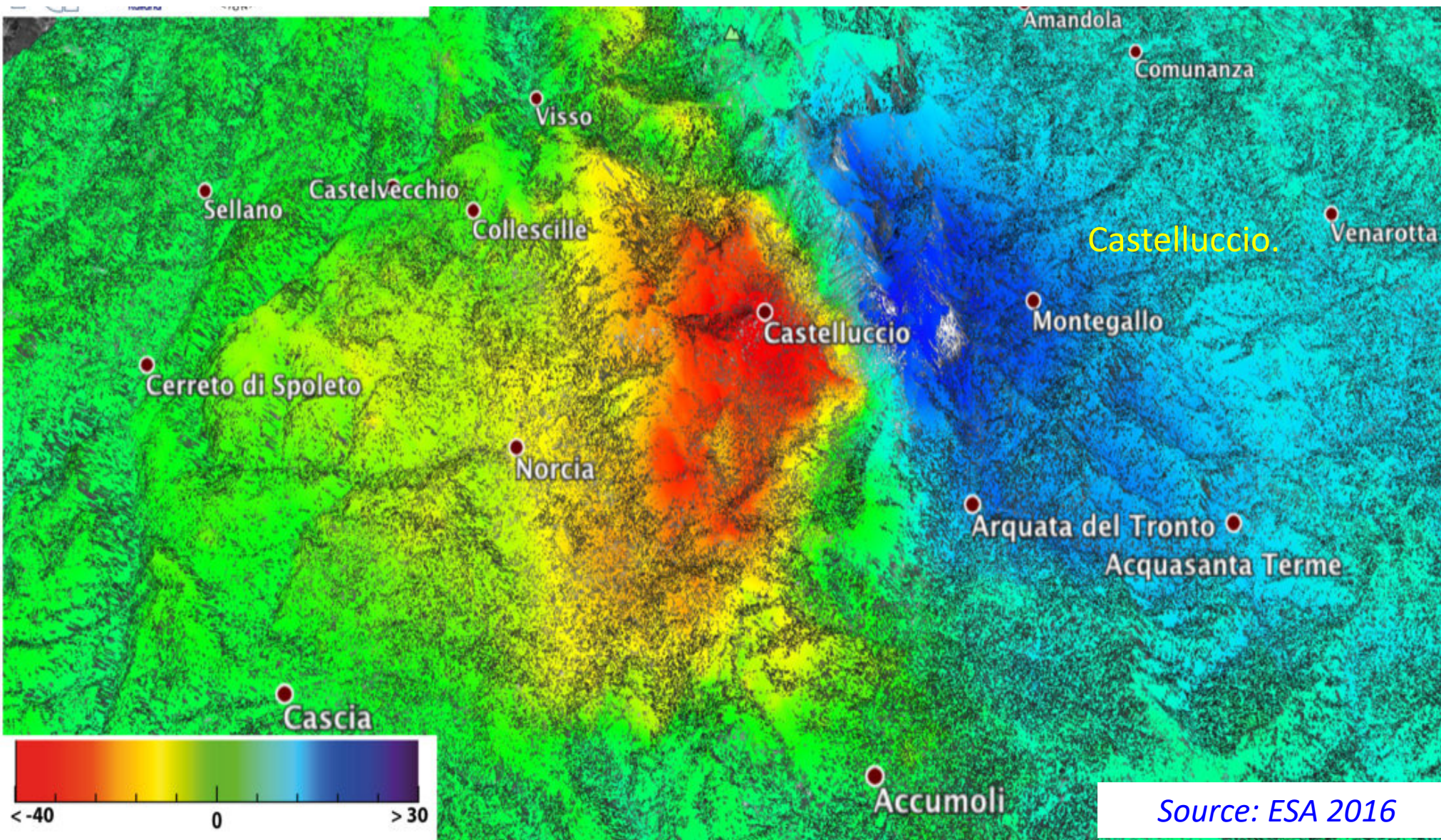


Evvia 50.000 ha burnt

Source: ESA-JRC Copernicus Aug. 2021

Copernicus Services: Crisis Management.

EARTHQUAKE in ITALY 30 OCTOBER 2016 (magnitude 6,5).



The results show ground deformations extending across about 130 km² with a maximum displacement of about 70 cm (in the direction of the satellite).

Source: ESA 2016

Copernicus Services: Crisis Management.

Satellite images show destroyed Rohingya village

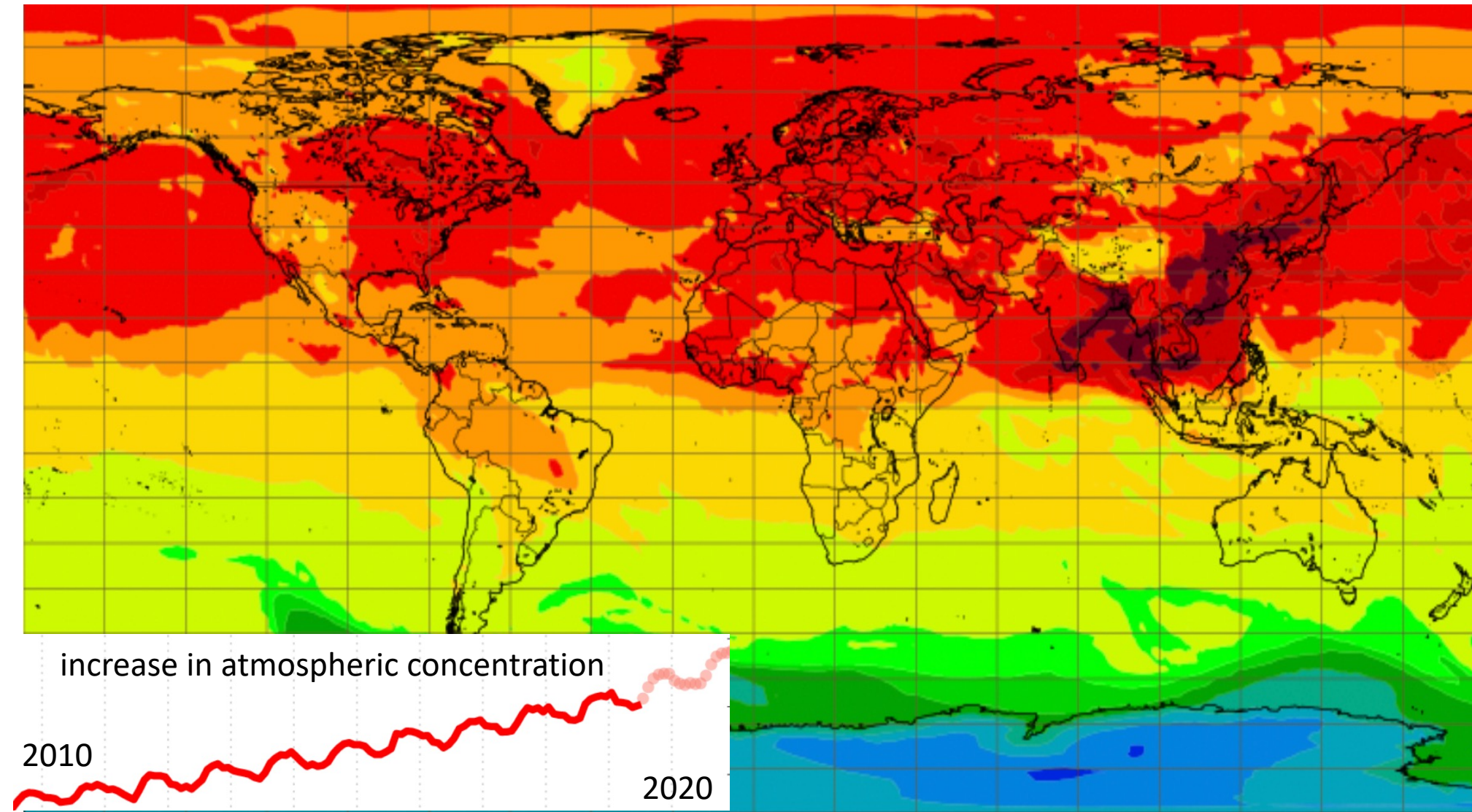


Source: BBC 2018

During the Rohingya crisis in Myanmar at least 288 villages were partially or totally destroyed by fire in northern Rakhine state after August 2017 while nearby ethnic Rakhine villages were left intact.

Copernicus Services: Climate Change.

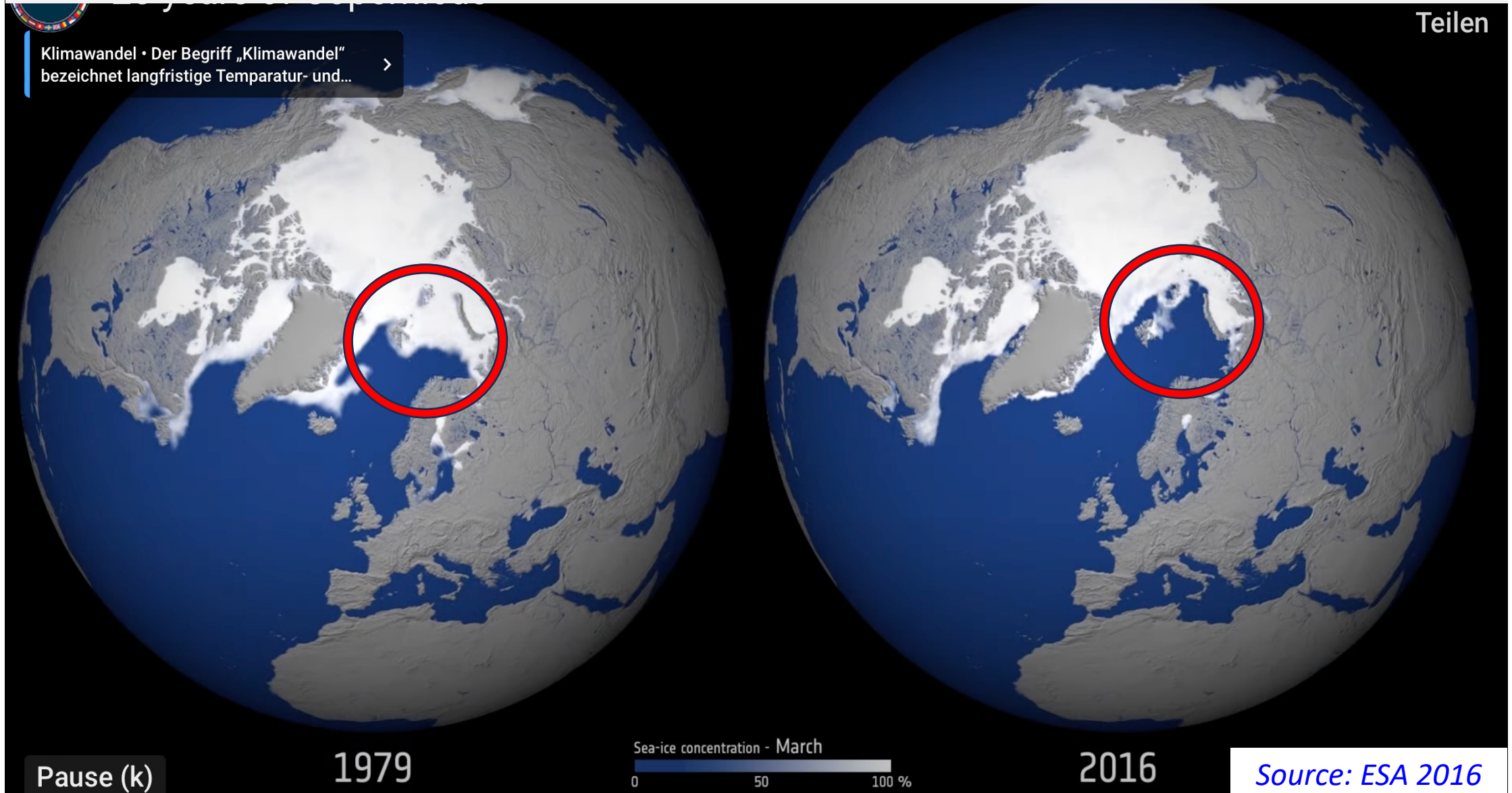
Monitoring emissions of GHG methane:
average concentration 1.812 ppb (2022), climate forcing factor 25x times higher than CO₂, half live in atmosphere 10 years, 50% natural, 50% anthropogenic.



CAMS methane forecast total column on 3 November 2022. Credit: CAMS

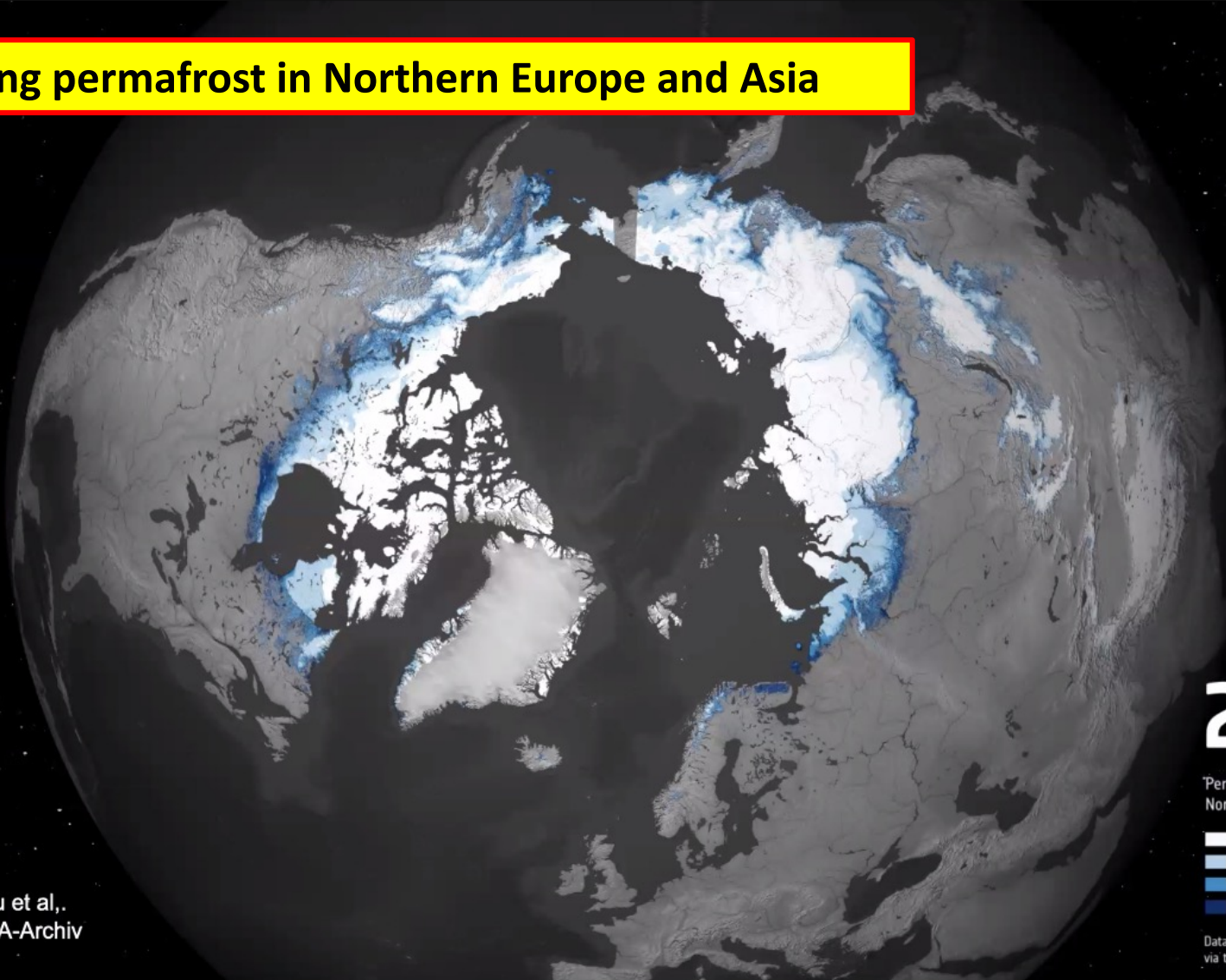
Source: ESA 2022

Determination of the loss of Arctic ice.



Copernicus Services: Climate Change.

Thawing permafrost in Northern Europe and Asia



2017

Permafrost extent for the Northern Hemisphere

- Continuous
- Discontinuous
- Sporadic
- Isolated

Data source: Permafrost CCI, Obu et al., 2019
via the CEDA archive

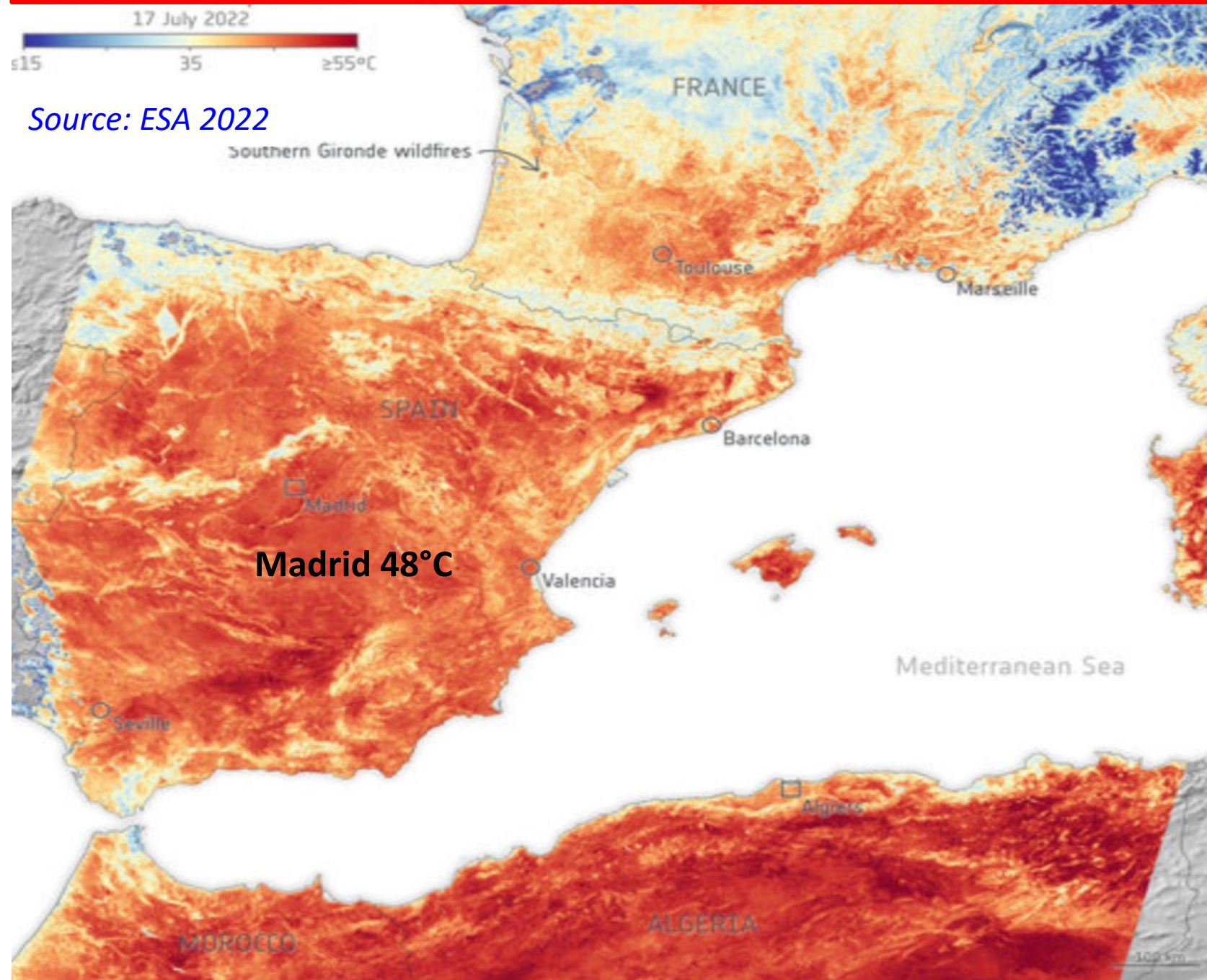
15

Permafrost CCI, Obu et al.,
2019 aus dem CEDA-Archiv



→ Source: ESA 2017

European map of land surface temperature.



Copernicus Services: Climate Change

Heat wave Europe July 2022:

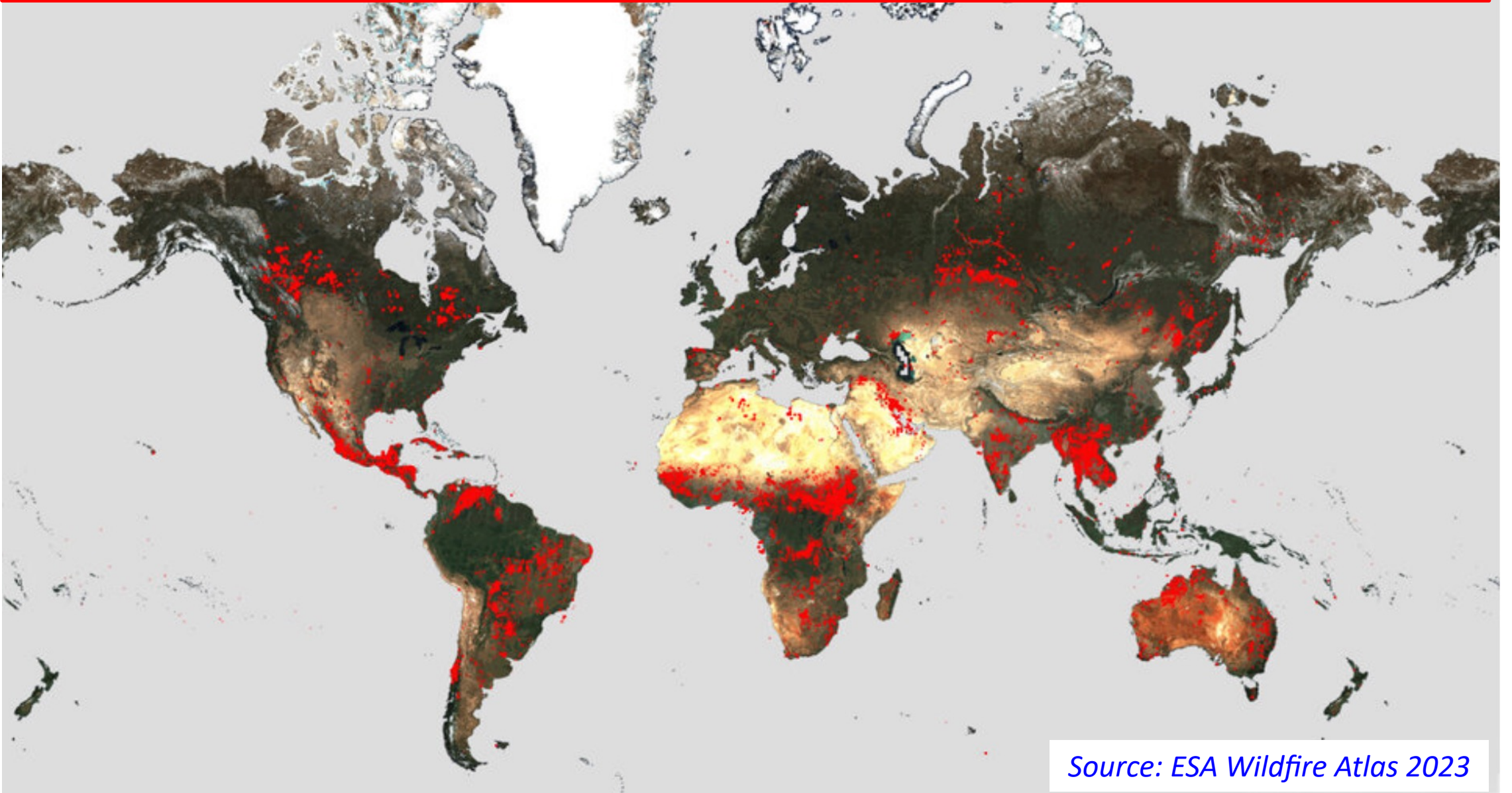
Measurement of land surface
temperatures 20 July, 2022
with accuracy of 0,3°C

Maximum 45°C

Attention: land surface
temperatures are much higher
(5 – 10°C) than the air
temperatures at the same
place.
Often mixed up by the media!

Copernicus Services: Climate Change.

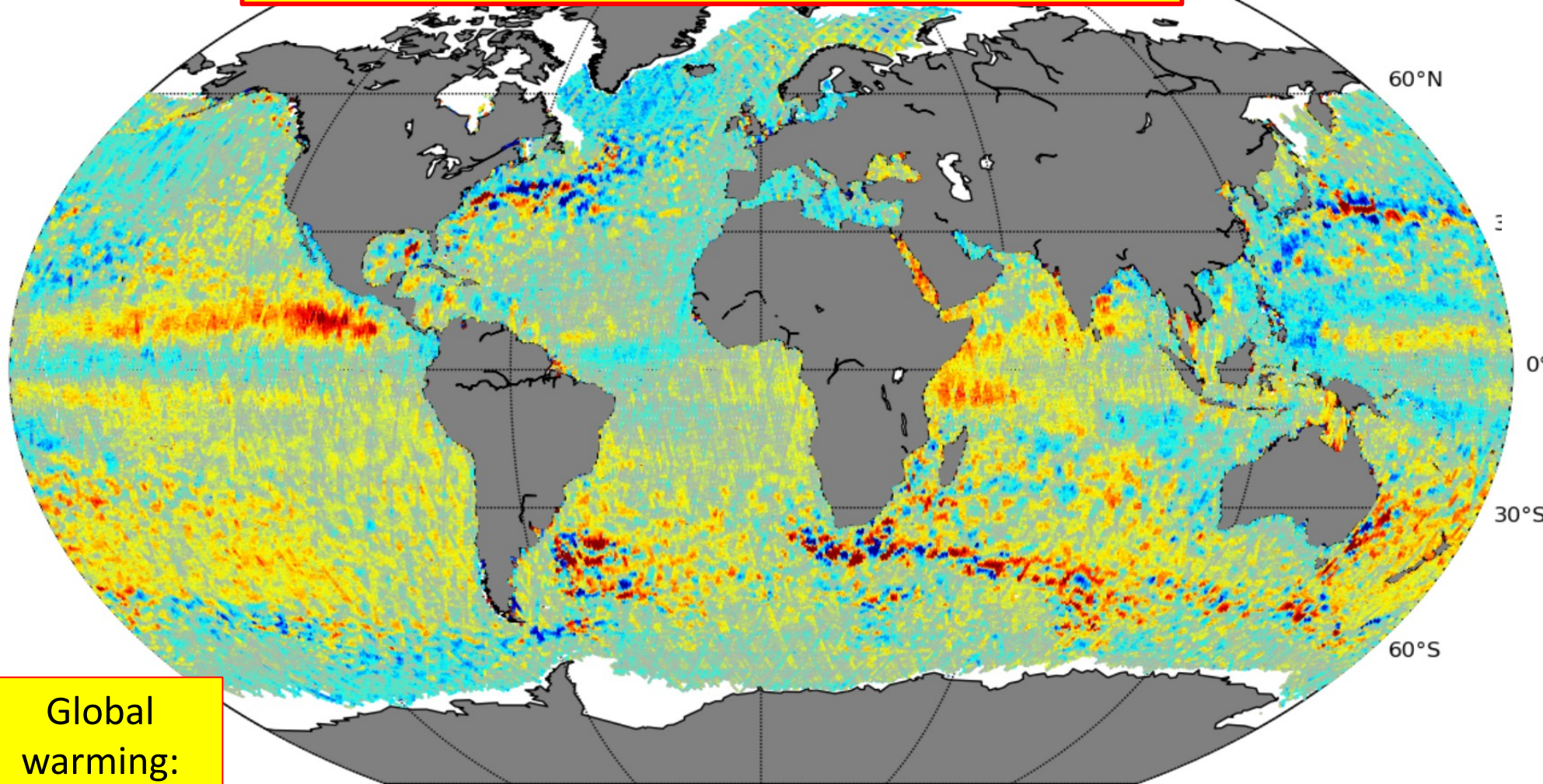
Global map of wildfires detected with Copernicus Sentinel 3A in 2023.



Source: ESA Wildfire Atlas 2023

Measurement of sea level with Sentinel-3's altimeter:

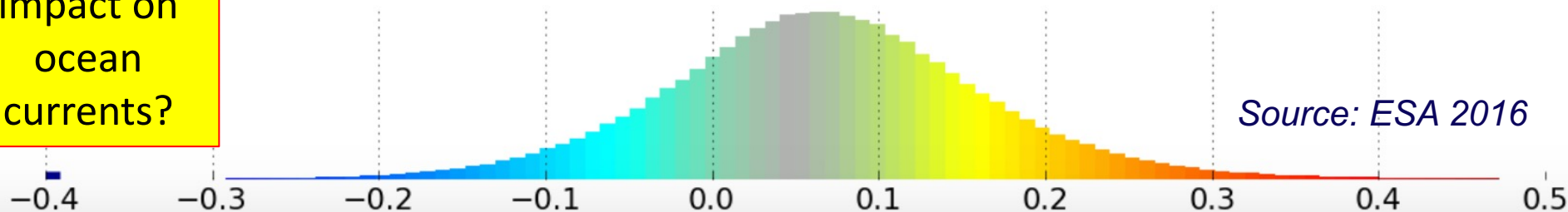
Copernicus Services: Climate Change



Global
warming:
impact on
ocean
currents?

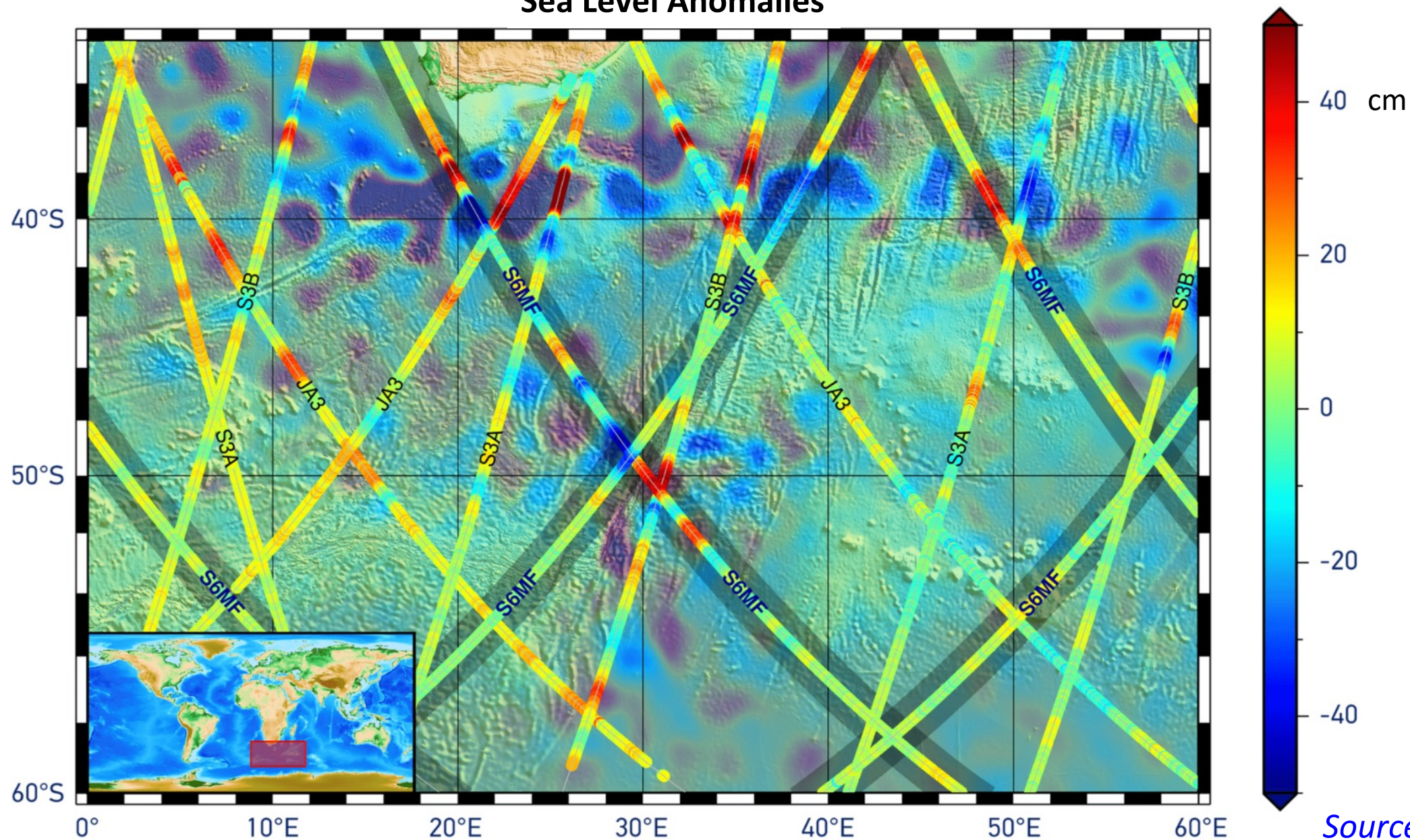
Using local sea-level variations and comparing them to a reference level, major ocean currents can be computed and mapped. Mesoscale local hills and valleys can be observed in the sea surface.

Source: ESA 2016



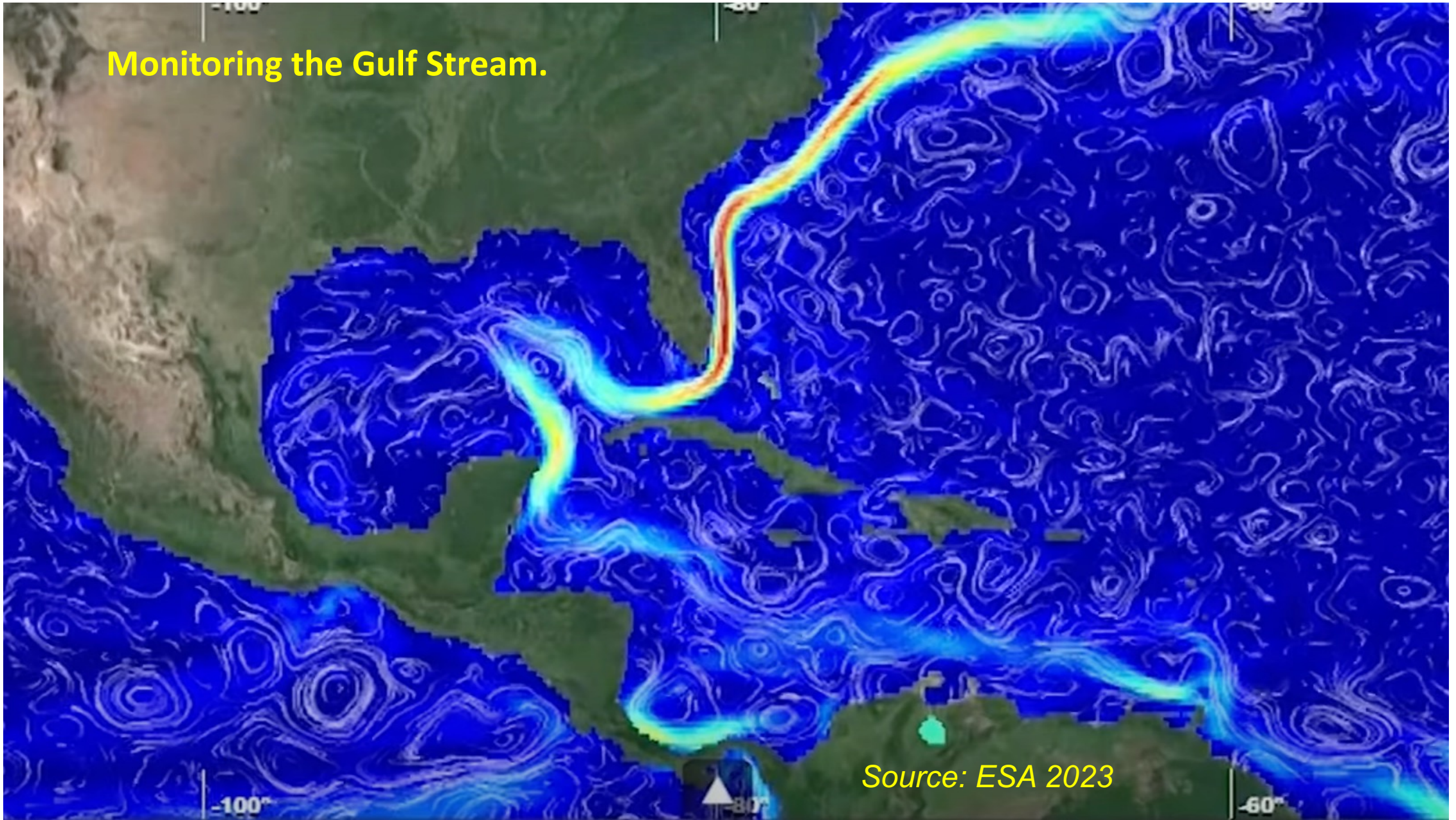
Copernicus Services: Climate Change.

Sea Level Anomalies



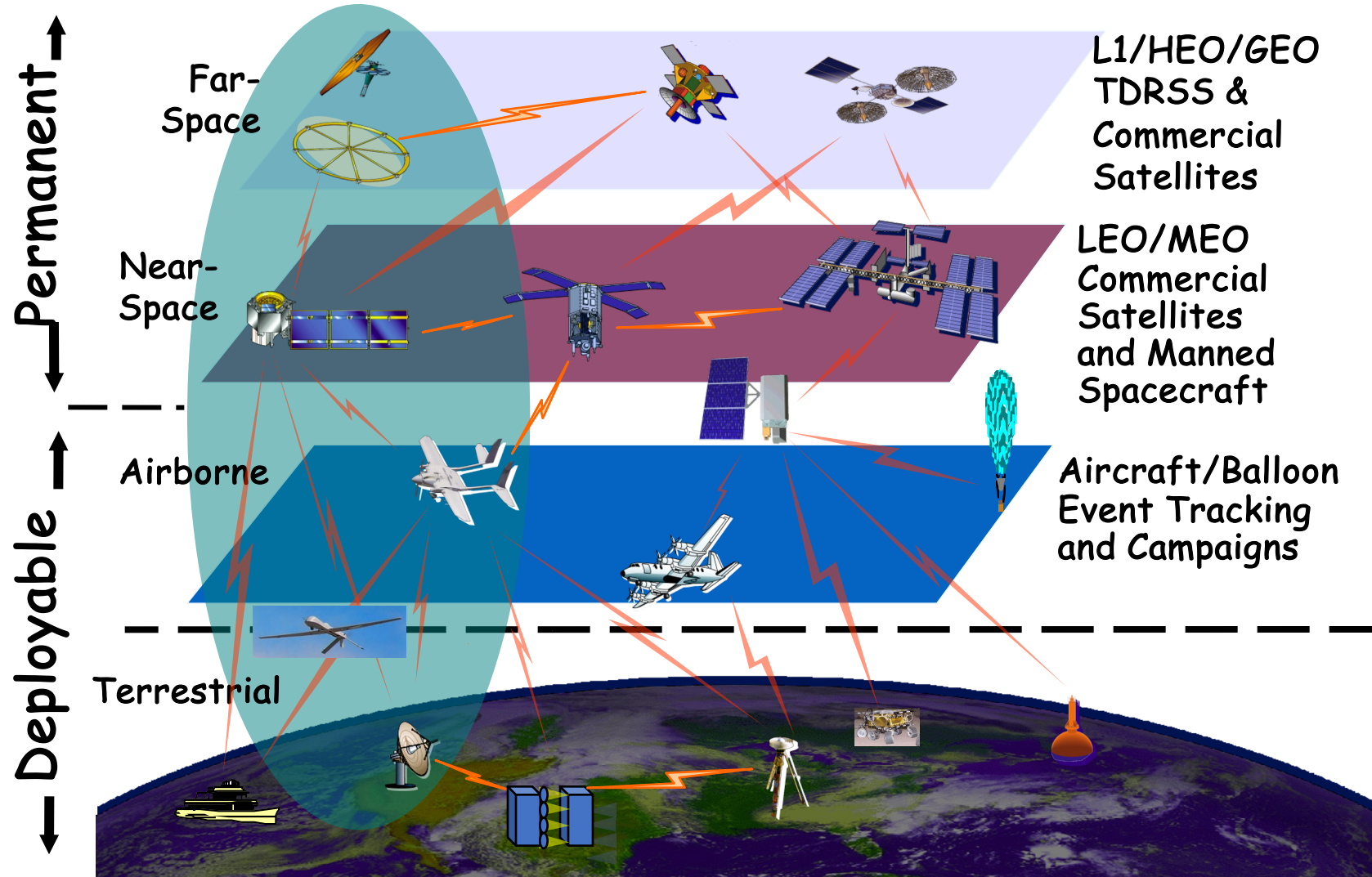
Copernicus Services: Climate Change.

Monitoring the Gulf Stream.



Source: ESA 2023

Global Earth Observation: GEOSS.



Source: NASA

GEOSS: Global Earth Observation System of Systems (USA, EU, Japan, China, India, Brazil, South Africa, Korea.....).

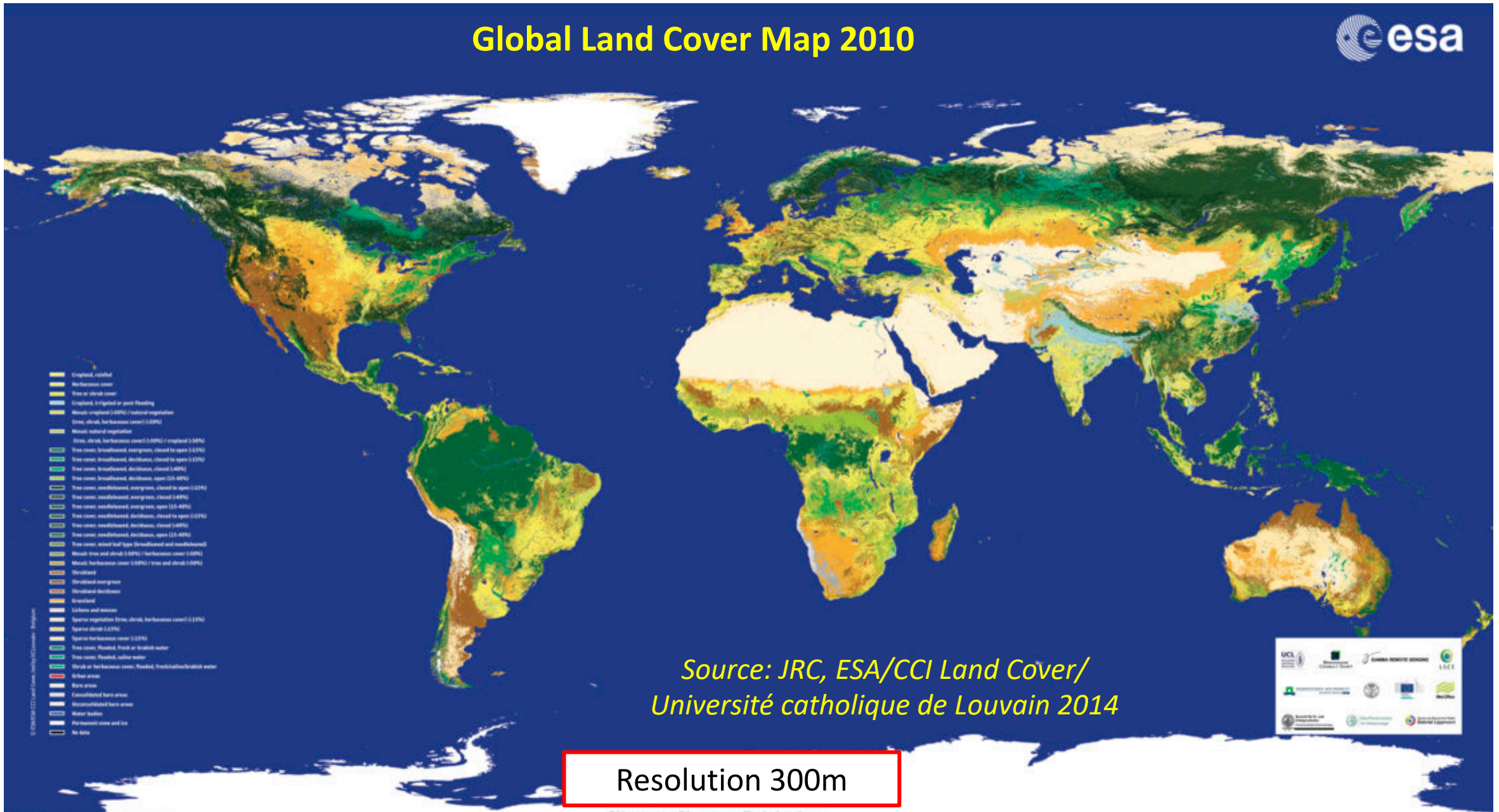
Global Earth Observation: GEOSS.

- **Annual business volume of space industry:**
 - 300 billion EUR
- **6.300 satellites:** (Aug. 2022)
 - 4.000 USA (of these 2.500 Starlink)
 - 1.000 Europe
 - 600 China
 - 200 Russia
- **Number rapidly increasing:**
 - 100.000 by 2030?

Source: ESA 2016

Global Earth Observation: GEOSS.

Global Land Cover Map 2010

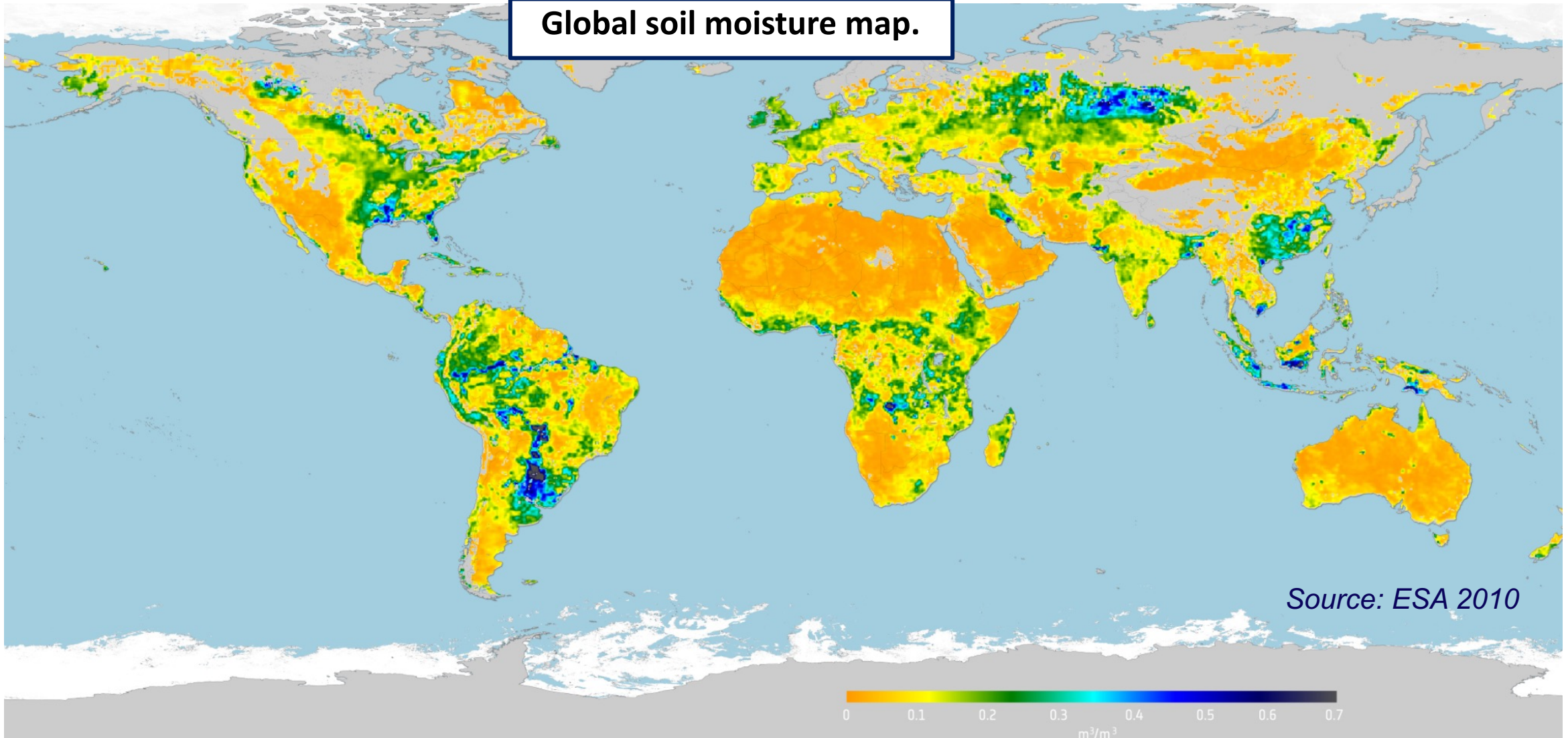


Source: JRC, ESA/CCI Land Cover/
Université catholique de Louvain 2014

Resolution 300m

Global Earth Observation: GEOSS.

Global soil moisture map.

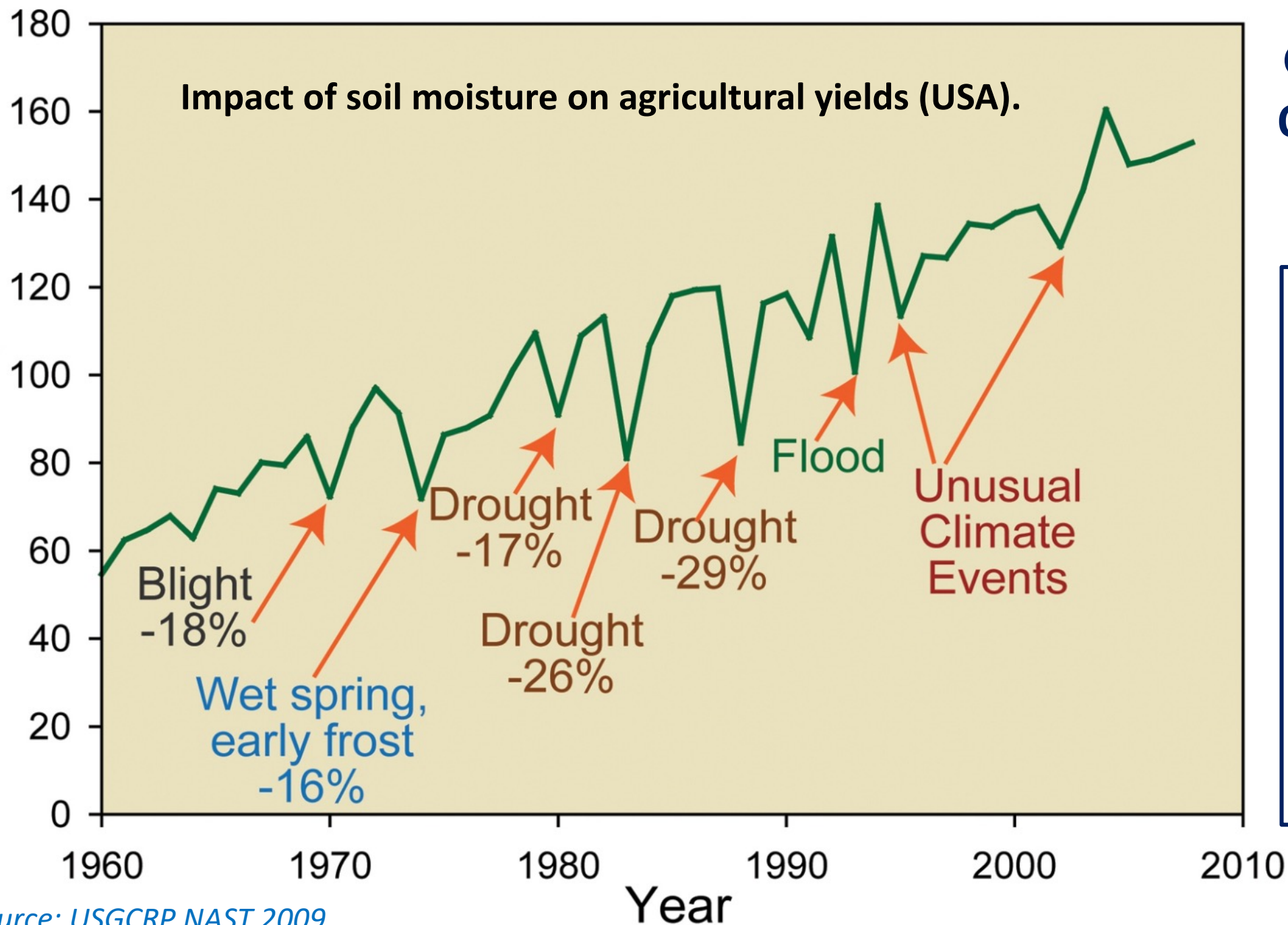


Satellite carries an interferometric radiometer operating in the L-band microwave range to capture 'brightness temperature' images used to obtain Global maps of soil moisture (accuracy of 4%, resolution of about 50 km.

Global Earth Observation: GEOSS.

Yield: Bushels per Acre

Impact of soil moisture on agricultural yields (USA).



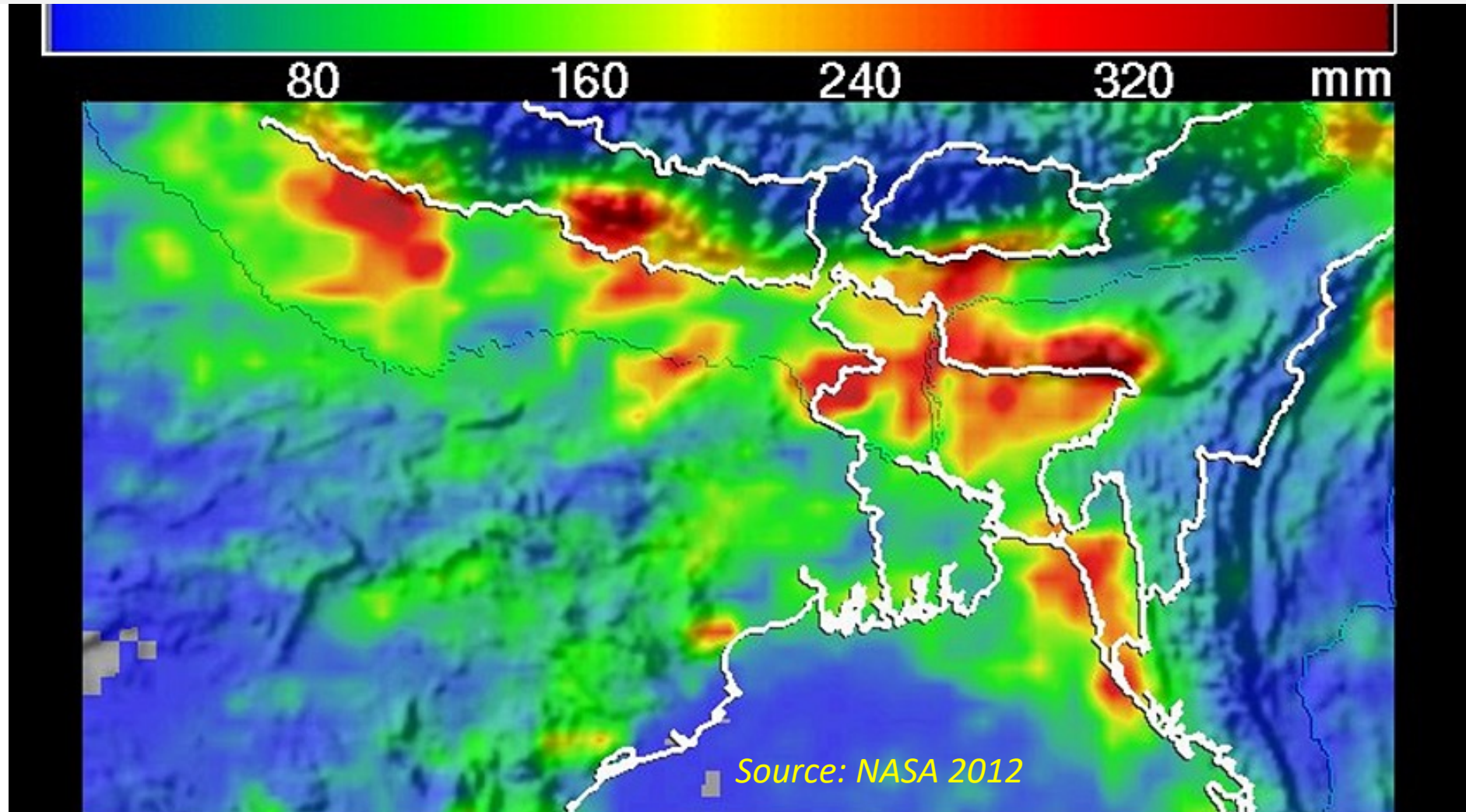
Source: USGCRP NAST 2009

Drought events are responsible for major year-to-year reductions in agricultural productivity.

Accurately monitoring root-zone soil moisture is critical to detect these events early.

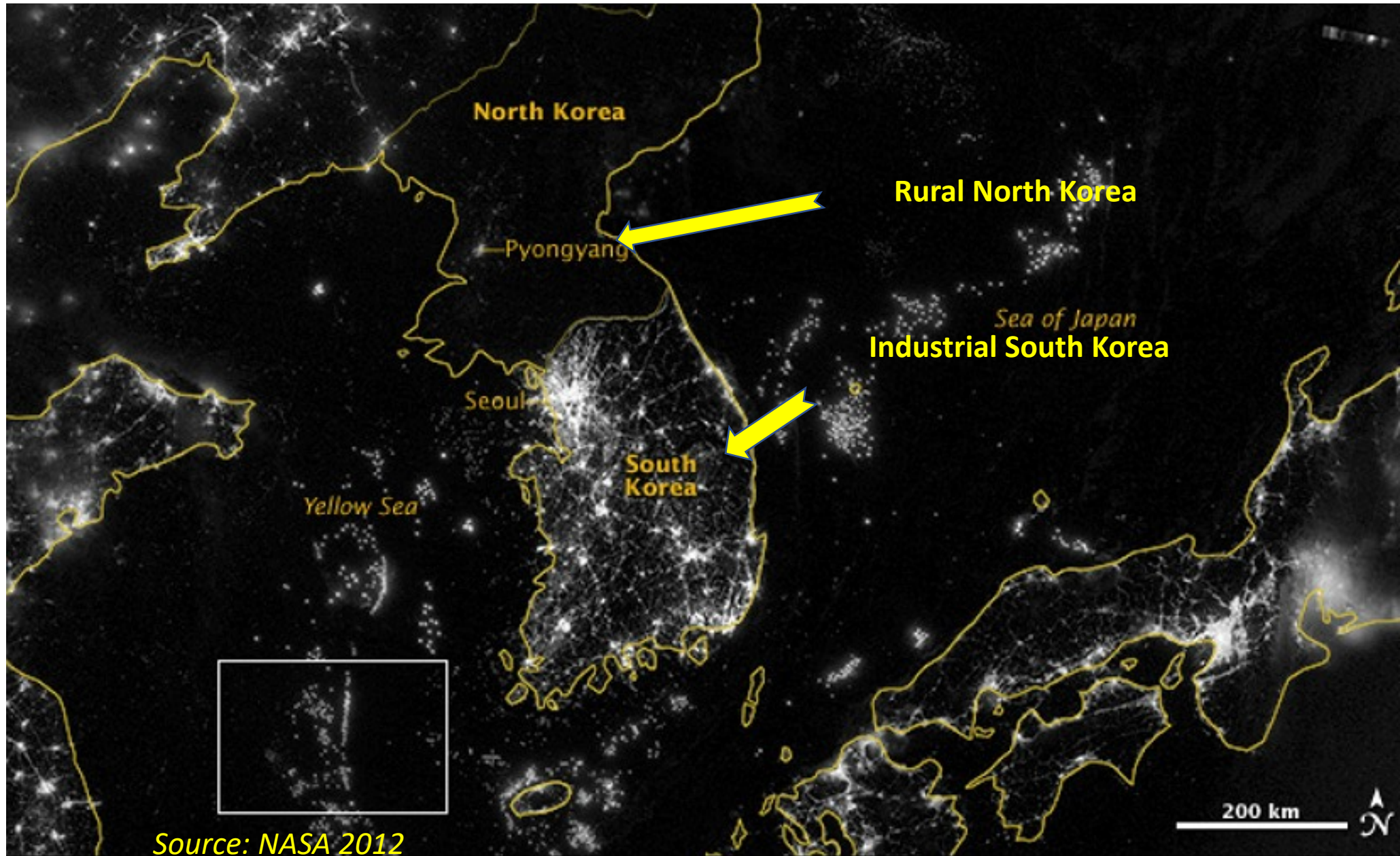
Global Earth Observation: GEOSS.

Monitoring excessive rainfalls for flood forecasting.



Tropical Rainfall Measuring Mission satellite (TRMM – NASA/JAXA) monitored heavy rainfalls occurred along southern Nepal, northern India and northern and southeastern Bangladesh leading to widespread flooding.

Global Earth Observation: GEOSS.



Global Earth Observation: GEOSS.

- **Composite image taken from 6 different satellites:**
 - Land image in true color from SeaWiFS of NASA.
 - Oceanic aerosol caused by biomass burning and windblown dust over Africa by NOAA.
 - Clouds from infrared images from four geostationary weather satellites (NOAA's GOES 8 and 9, the ESA's METEOSAT, and Japan's GMS 5).

Our Planet - Our Future: Six Major Transformations.

