Monitoring global methane emissions via satellite imagery;

General introduction of current industrial applications

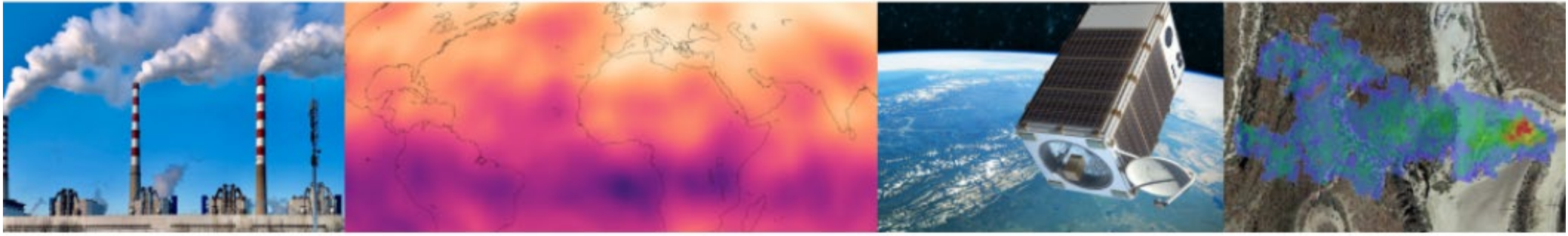

Photo credit: WGIC

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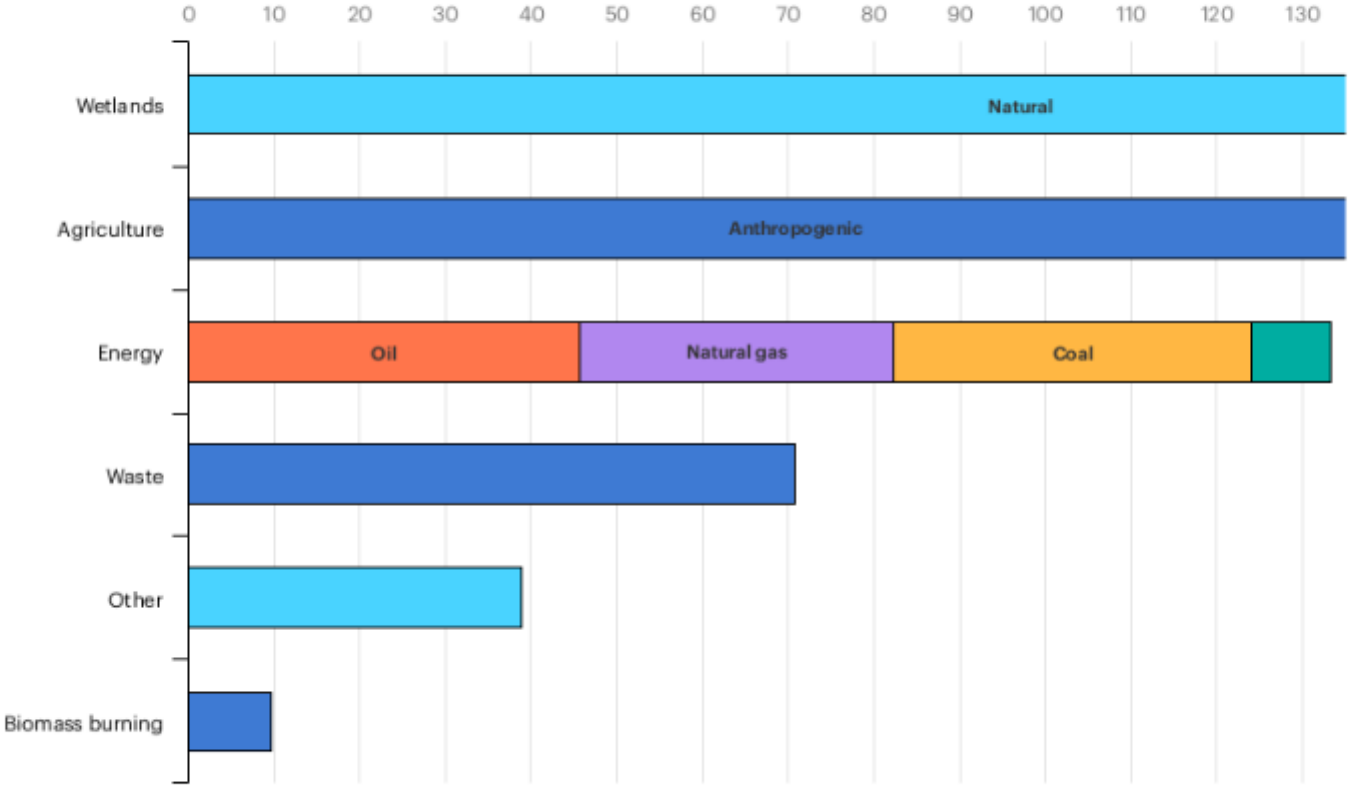
ASSOCIATION of GEOLOGICAL RESEARCHES

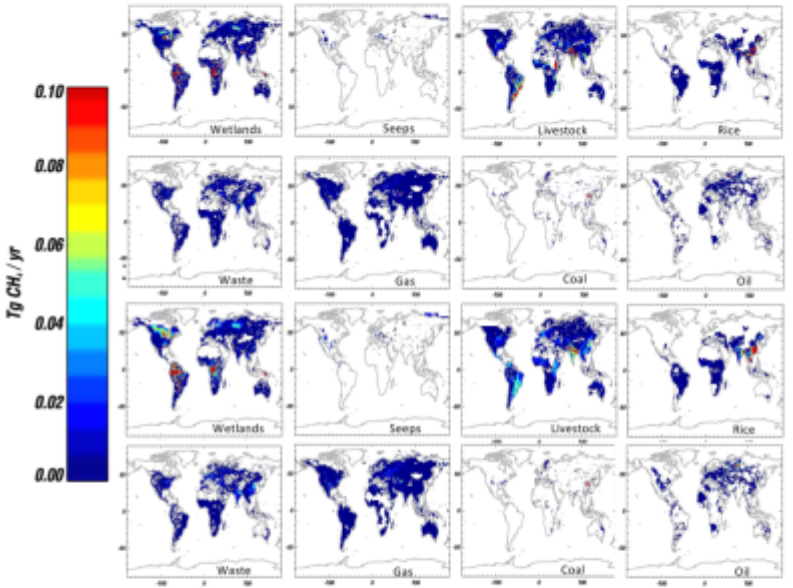
Global Methane Budget suggests that annual global methane emissions are around 580 Mt. This includes emissions from natural sources (around 40% of the total) and from human activity (around 60% of the total), also known as anthropogenic emissions. The largest anthropogenic source is agriculture, responsible for around one quarter of emissions, closely followed by the energy sector, which includes emissions from coal, oil, natural gas and biofuels.



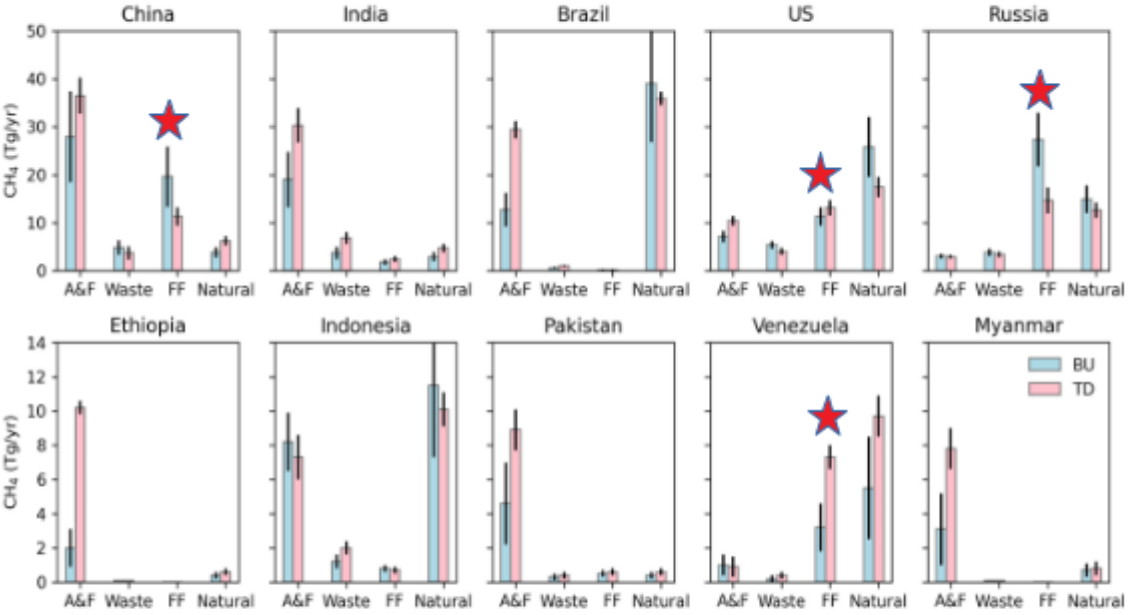
https://www.iea.org/reports/global-methane-tracker-2023/understanding-methane-emissions

2019 METHANE BUDGET OF THE WORLD

(Worden et al, 2022)



Top: posterior methane emissions. Bottom: posterior emissions uncertainty as calculated by the square root of the diagonal of the posterior covariance matrix.

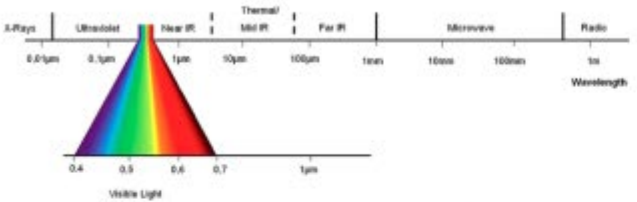


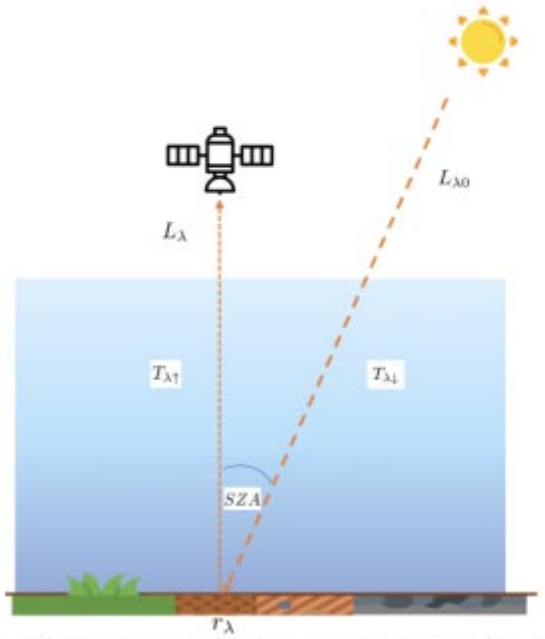
Emissions by sector for the top 10 emitters. AF represents agricultural and fires. FF represents fossil fuels or coal, oil, and gas. Natural represents wetlands, aquatic sources, and geological seeps. Bottom-up (BU) inventory estimates are shown as blue bars, and the remote sensing/top-down (TD) estimates are shown as pink bars. The uncertainties in both quantities are shown as black lines.

* Top FF emitting countries are shown in red star – author.

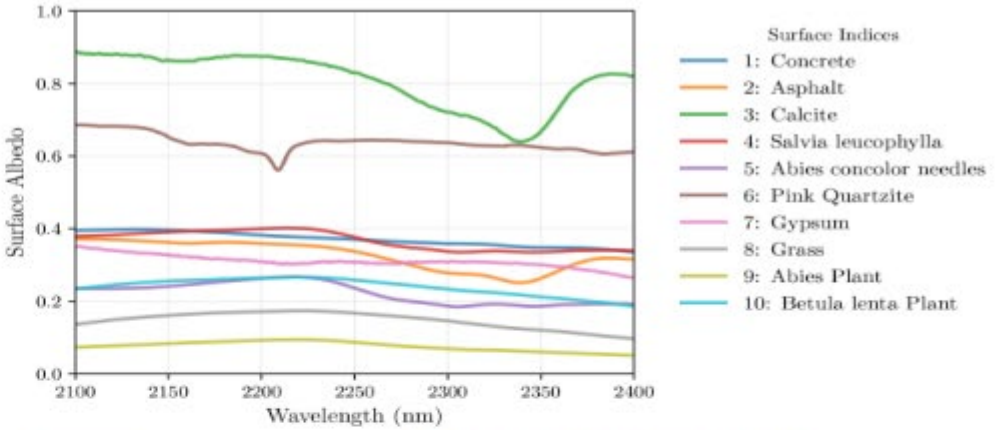
PRINCIPALS OF REMOTE SENSING AND SAMPLE METHANE MONITORING

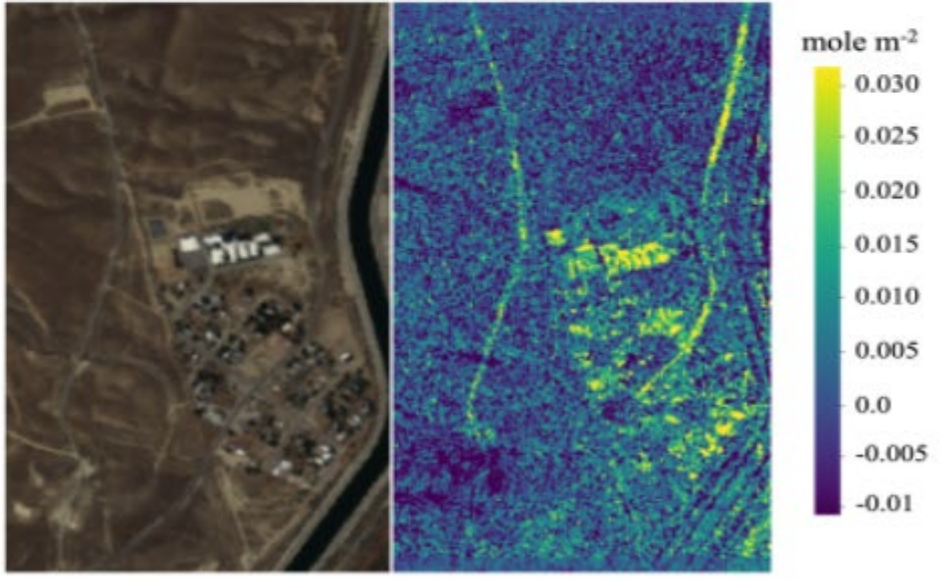
(S. Jongaramrungruang et al., 2021)



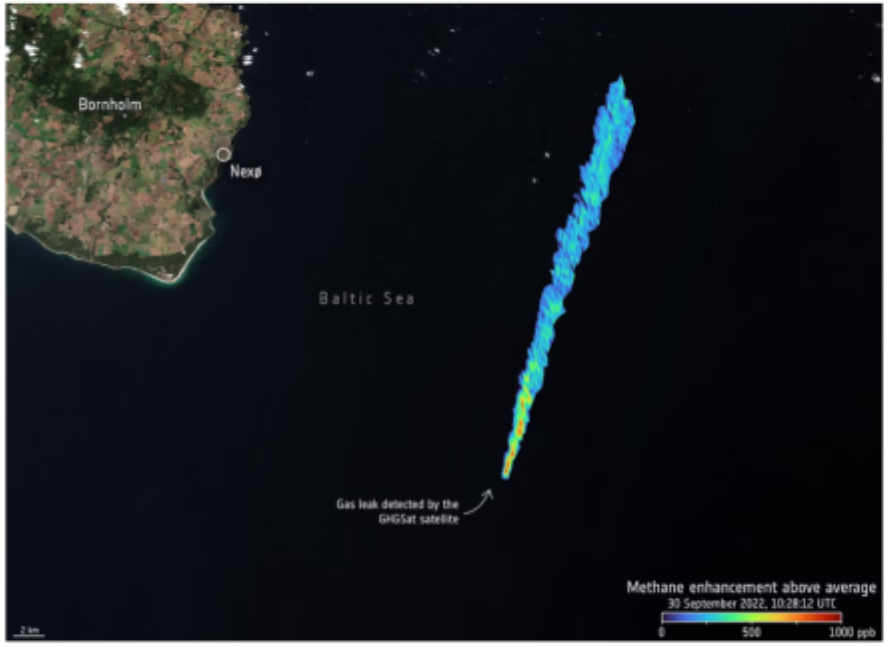


A schematic for reflected sunlight from the Sun through the atmosphere to a spectrometer in space.

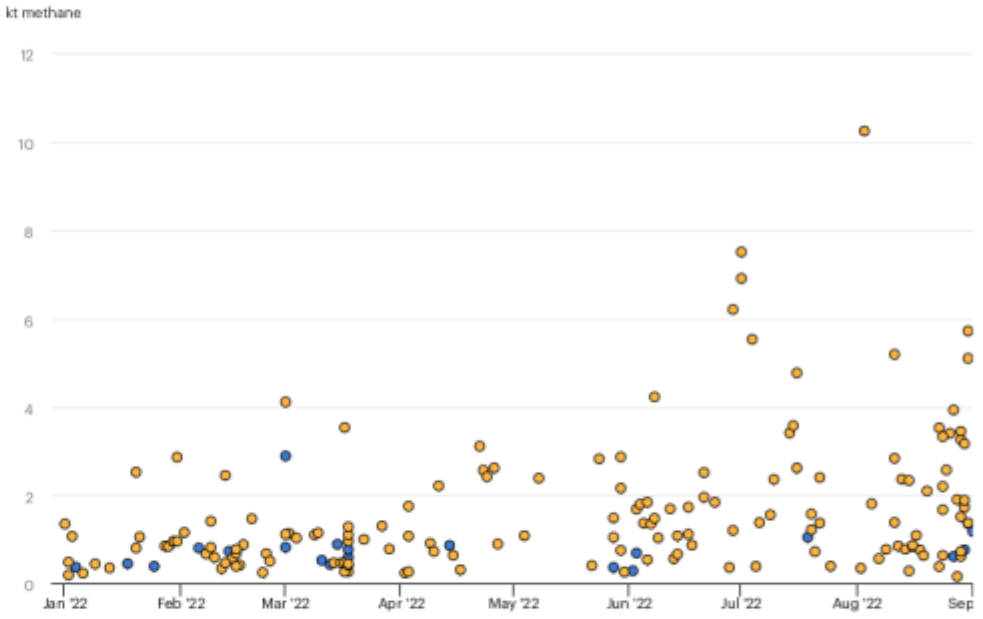




Advances in monitoring technologies, notably from satellites, have been a key to boosting our understanding of the level and nature of methane emissions. Current satellites and data processing techniques can be used to detect and quantify total emissions from major leaks over a large area, down to small leaks at the facility level. They also enable regional estimates of total methane emissions over longer periods of time.



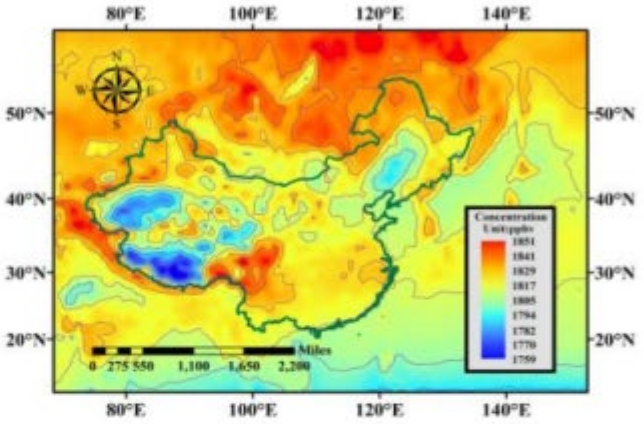
Detection of methane emissions from the Nord Stream leak
GHGSat (2022), Global emission monitoring.



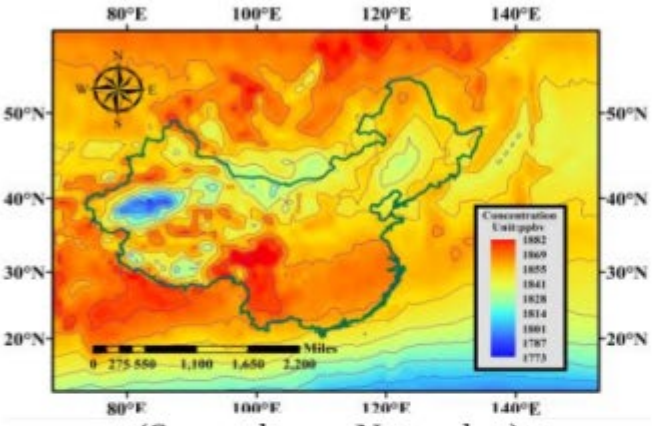
Satellite-detected large leaks from fossil fuel operations, 2022

Total Methane Column Concentration of China from 2003 to 2021

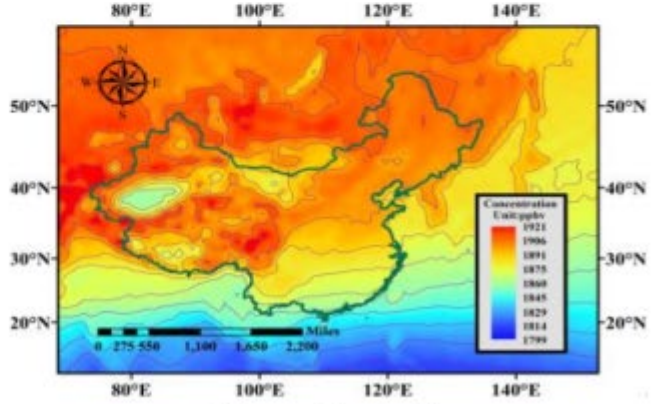
(Xu et al, 2023)



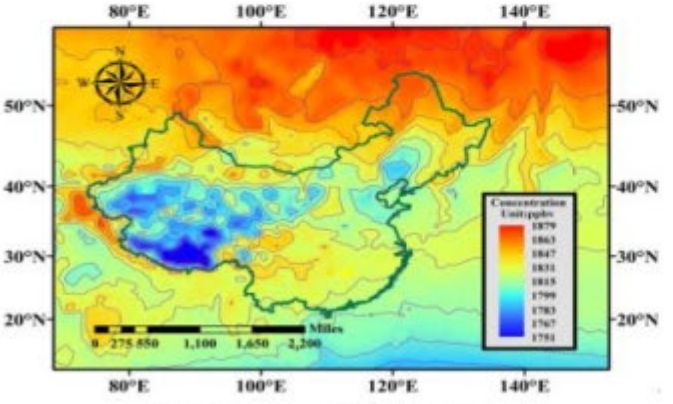
(March to May)



(September to November)



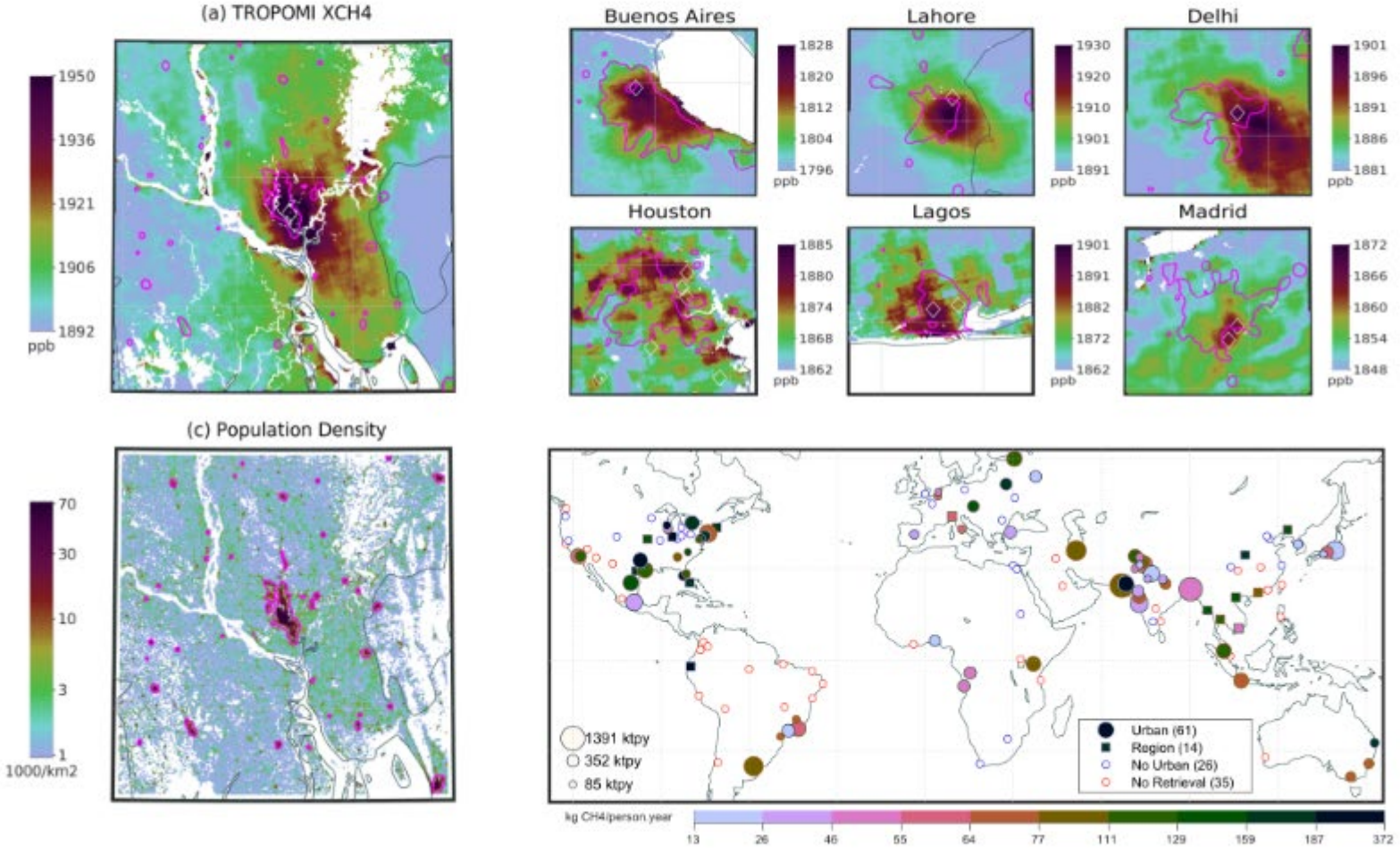
(June-August)



(December to February)

METHANE EMISSIONS FROM URBAN AREAS

(de Foy et al, 2023)



OPERATIONAL CH_4 MONITORING SATELLITES WITH PUBLIC DATA ACESS

(GEO, ClimateTRACE, WGIC, 2021, GHG Monitoring from Space: A mapping of capabilities across public, private, and hybrid satellite missions.)

COUNTRY/REGION, ORGANIZATION, MISSION AND INSTRUMENT					GHG MONITORED DIRECTLY			POTENTIAL POLICY-RELEVANT APPLICATION			DATA ACCESS
Country/ Region	Organization	Mission (Instrument)	Status	Mission Goal and Application	CO_2	CH_4	N_2O	Point-Source level	National level	Global level	Open access / Limited access / Paid subscription
Canada	CSA ESA NASA	SciSat-1 (ACE)	In orbit	Mission Goal: To monitor and analyze the chemical processes that control the distribution of ozone in the upper troposphere and stratosphere. Application: SciSat-1 can measure the vertical resolutions of all major GHGs identified for monitoring under the Paris Agreement.	CO_2	CH_4	N_2O				Open access
Europe	EC ESA NSO	Sentinel-5P (TROPOMI)	In orbit	Mission Goal: To perform atmospheric measurements with high temporal (daily) and spatial resolution that can be used for air quality, ozone & UV radiation, and climate monitoring & forecasting. Application: The global monitoring of GHGs (i.e., CH_4) and their tracers and aerosols relevant to climate forcing.		CH_4					Open access
Europe	EUMETSAT	Metop-A/B/C (IASI)	In orbit	Mission Goal: Acquire a wide range of land, ocean, and atmospheric measurements serving operational services for nowcasting, weather forecasting and climate. Application: Profiles in middle atmosphere for CO_2, CH_4, and N_2O are derived from IASI measurements.	CO_2	CH_4	N_2O				Open access

COUNTRY/REGION, ORGANIZATION, MISSION AND INSTRUMENT					GHG MONITORED DIRECTLY			POTENTIAL POLICY-RELEVANT APPLICATION			DATA ACCESS
Country/ Region	Organization	Mission (Instrument)	Status	Mission Goal and Application	CO_2	CH_4	N_2O	Point-Source level	National level	Global level	Open access / Limited access / Paid subscription
Italy	ASI	PRISMA (HYC)	In orbit	Mission Goal: To provide a global observation capability, monitoring of natural resources and atmospheric characteristic. The specific areas of interest to be covered are Europe and the Mediterranean region. Application: Carbon cycle monitoring and quantifying GHG emissions from sources.	CO_2	CH_4					Open access
Japan	JAXA MOE Japan NIES	GOSAT (TANSO-FTS)	In orbit	Mission Goal & Application: To monitor the global distribution of GHGs (i.e., CO_2 and CH_4) at a sub-continental scale and verify the reduction of GHG emissions.	CO_2	CH_4					Open access
Japan	JAXA MOE Japan NIES	GOSAT-2 (TANSO-FTS2)	In orbit	Mission Goal & Application: To continue the monitoring record started by GOSAT by measuring the global distribution of GHGs (i.e., CO_2 and CH_4) at a sub-continental scale and verify the reduction of GHG emissions.	CO_2	CH_4					Open access
US	NASA	Aqua (AIRS)	In orbit	Mission Goal: A multi-disciplinary study of Earth's interrelated processes and water cycle (involving the atmosphere, oceans, ice, and land surface) and their relationship to changes in the Earth system. Application: AIRS measures CO_2 and CH_4 in the middle troposphere allowing for the study of the atmosphere's response to increased GHGs.	CO_2	CH_4					Open access

SCISAT-1

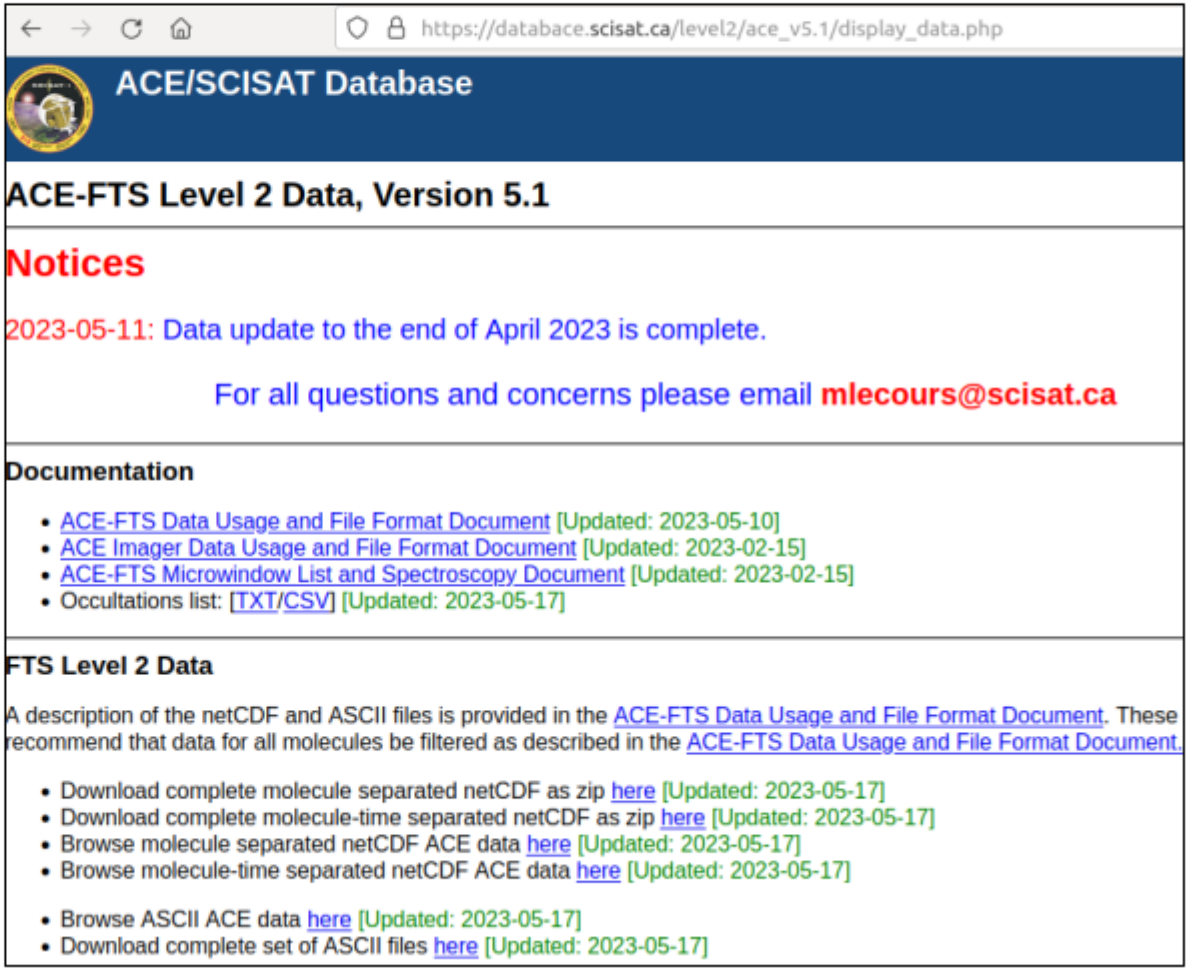
SCISAT-1 is an atmospheric science mission from the Canadian Space Agency which launched on 13 August 2003 and remains operational.

Mission Parameters

Orbit Altitude	650 km
Orbit Inclination	98.2°
Orbit Type	Circular high-inclination
Repeat Cycle	Annual

ACE-FTS Instrument Parameters

Parameter	Value
Spectral Range	2.4-13.3 μm (or 750-4100 cm-1)
Resolution	4-150 km (ACE-FTS); 1-2 km (MAESTRO)
Swath Width	FOV 1.25 mrad
Spectral Resolution cm-1	<0.028, 0.056, 0.11, 0.55
Sweep Duration	2, 1, 0.5, 0.1 s
Spectral Stability (relative)	3 x 10-7 rms for 180 s
Noise Equivalent Radiance	<0.5% of the radiance of a blackbody at 5800 K
Detectors	InSb, HgCdTe
Detector Cooling	Passive cooling <100 K
FOV (Field of View)	1.25 mrad



Sentinel-5P

The Copernicus Sentinel-5 Precursor mission is the first Copernicus mission dedicated to monitoring our atmosphere. Copernicus Sentinel-5P is the result of close collaboration between ESA, the European Commission, the Netherlands Space Office, industry, data users and scientists. The mission consists of one satellite carrying the TROPOspheric Monitoring Instrument (TROPOMI) instrument. The TROPOMI instrument was co-funded by ESA and The Netherlands.

The **main objective** of the Copernicus Sentinel-5P mission is to perform atmospheric measurements with high spatio-temporal resolution, to be used for air quality, ozone & UV radiation, and climate monitoring & forecasting.

Sentinel-5P uses a high inclination orbit (approximately 98.7°). The orbit inclination is the angular distance of the orbital plane from the equator.

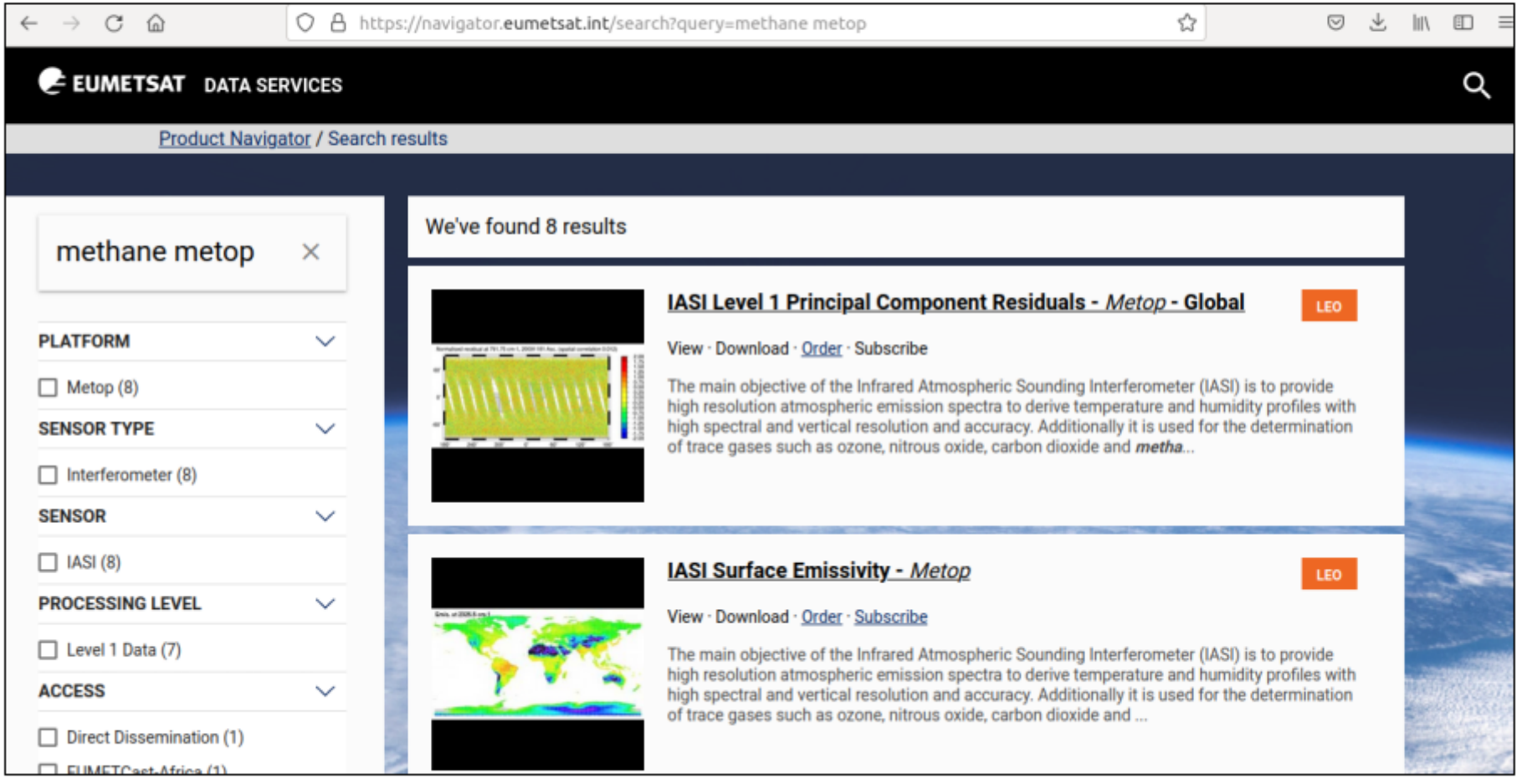
The Sentinel-5P orbit is a near-polar, sun-synchronous orbit with an ascending node equatorial crossing at 13:30 h Mean Local Solar time. In a sun-synchronous orbit, the surface is always illuminated at the same sun angle.

The orbital cycle is 16 days (14 orbits per day, 227 orbits per cycle). The orbit cycle is the time taken for the satellite to pass over the same geographical point on the ground.

The orbit reference altitude is approximately 824 km.

Metop

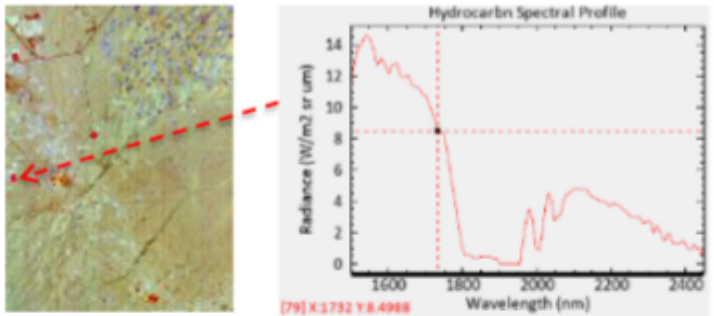
Meteosat imagery is used to characterise aerosols in the atmosphere, including volcanic a
dust, while onboard Metop, the IASI and GOME-2 instruments observe trace gases such
nitrogen dioxide, carbon monoxide, methane and aerosols.

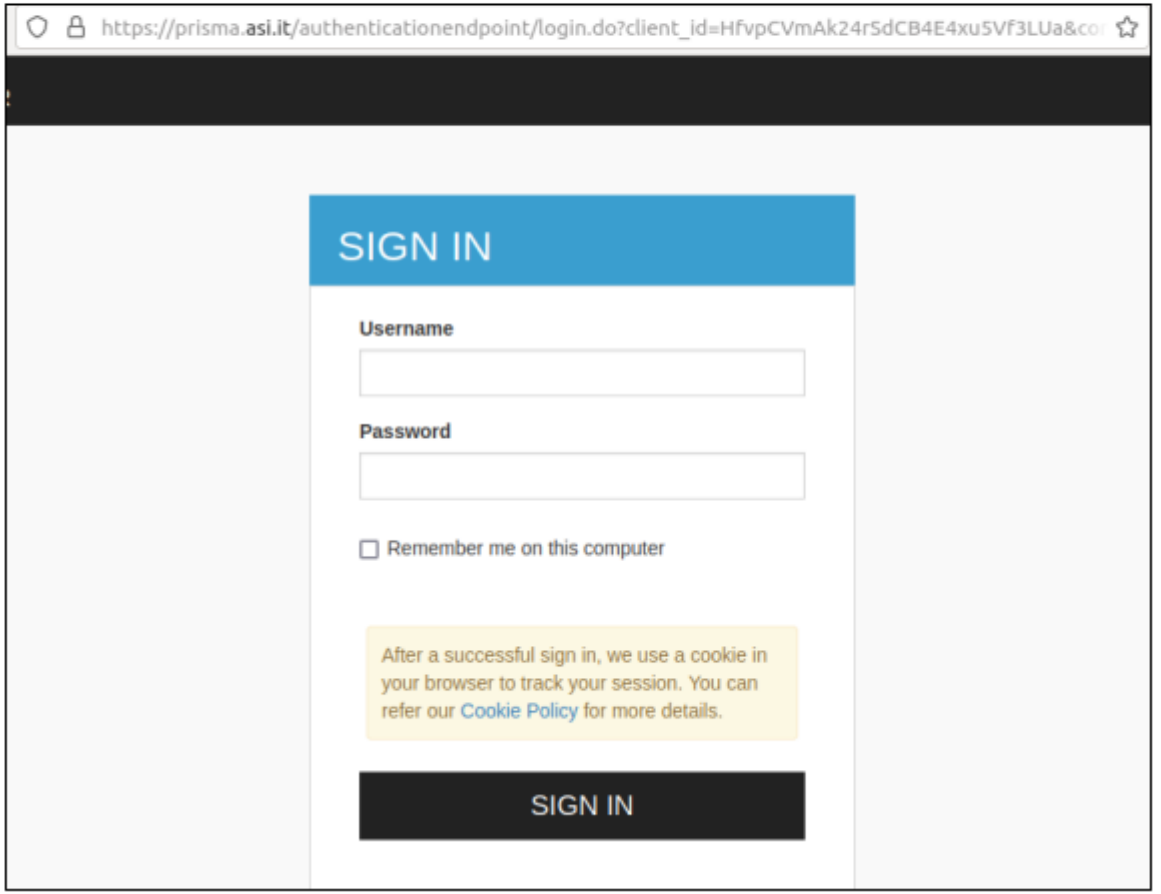


PRISMA

Launched on 22 March, 2019, PRISMA is a medium-resolution hyperspectral imaging satellite, developed, owned and operated by ASI (Agenzia Spaziale Italiana). It is the successor to the discontinued HypSEO (Hyperspectral Satellite for Earth Observation) mission and has a planned mission duration of 5 years. PRISMA carries two sensor instruments, the HYC (Hyperspectral Camera) module and the PAN (Panchromatic Camera) module. The HYC sensor is a prism spectrometer for two bands, VIS/NIR (Visible/Near Infrared) and NIR/SWIR (Near Infrared/Shortwave Infrared), with a total of 237 channels across both bands

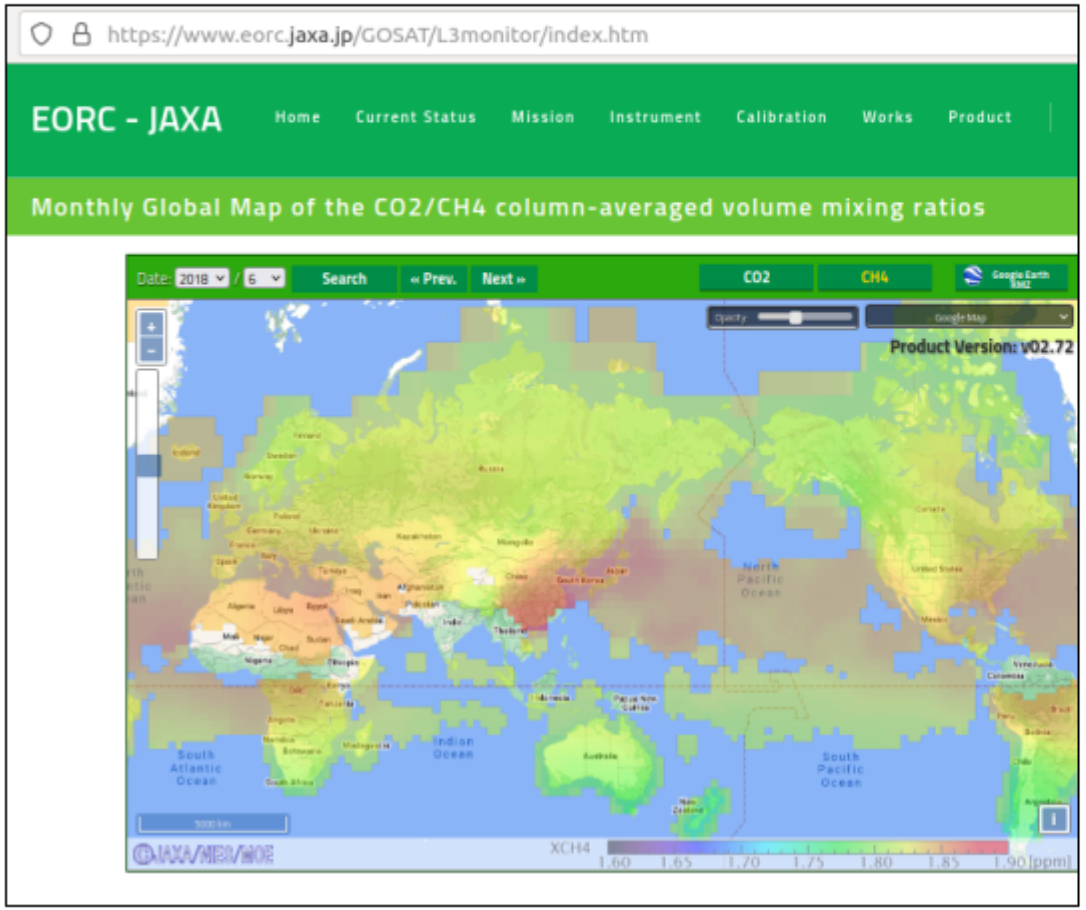
Hydrocarbons map





GOSAT

The IBUKI (GOSAT:Greenhouse Gases Observing Satellite) is an artificial satellite that observes the concentration distribution of greenhouse gases from outer space, and its purpose is to contribute to the international effort toward prevention of warming, including monitoring the greenhouse gas absorption and emission state.



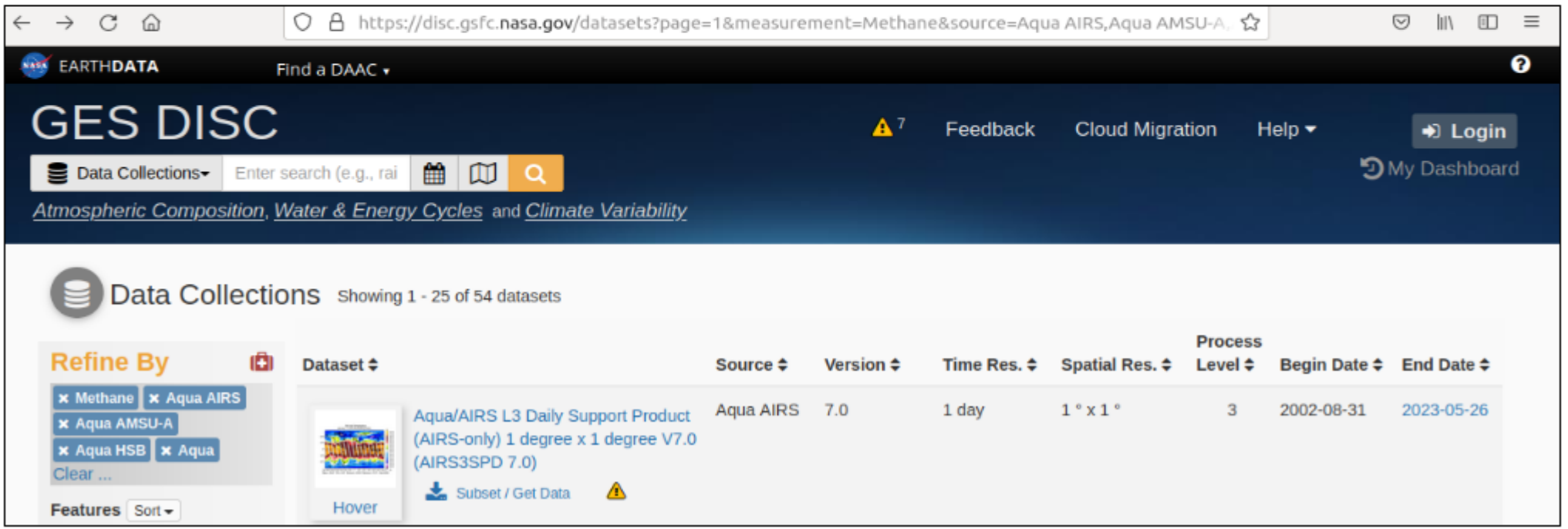
Major Characteristics

Weight	Approx. 1,750kg
Orbiter	Sun-Synchronous Sub-Recurrent
Altitude	Approx. 667km
Inclination	Approx. 98 degrees
Period	Approx. 98 minutes

Aqua

AIRS, the Atmospheric Infrared Sounder on NASA's Aqua satellite, gathers infrared energy emitted from Earth's surface and atmosphere globally, every day. Its data provides 3D measurements of temperature and water vapor through the atmospheric column along with a host of trace gases, surface and cloud properties. AIRS data are used by weather prediction centers around the world to improve their forecasts. They are also used to assess the skill of climate models and in applications ranging from volcanic plume detection to drought forecasting.

AIRS maps the concentration of carbon dioxide and methane globally. AIRS also provides simultaneous observations of the Earth's atmospheric temperature, ocean surface temperature, and land surface temperature and infrared spectral emissivity, as well as humidity, clouds and the distribution of greenhouse gases. This makes AIRS/AMSU a primary space instrument to observe and study the response of the atmosphere to increased greenhouse gases.



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