

CHARACTERIZING ANTHROPOGENIC EMISSIONS THROUGH CONTINUOUS ATMOSPHERIC CO₂ OBSERVATIONS IN BARCELONA

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METROPOLITAN AREA OF BARCELONA

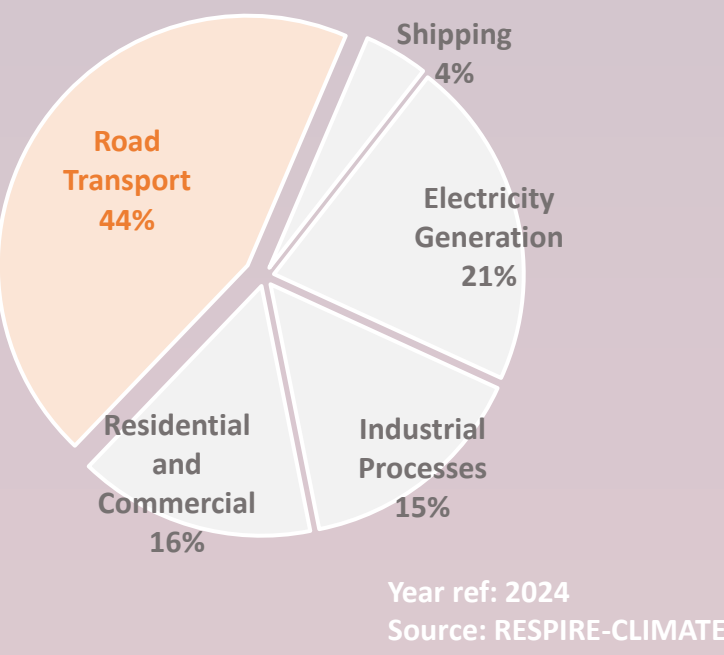
The Barcelona Metropolitan Area (Area Metropolitana de Barcelona - AMB) is a densely populated urban region of over 3 million people, characterized by a compact coastal city core surrounded by suburban and industrial zones, and framed by diverse landscapes including the Mediterranean coastline, river deltas, and nearby mountain ranges such as Collserola.



How much carbon dioxide (CO₂) does the AMB emit?

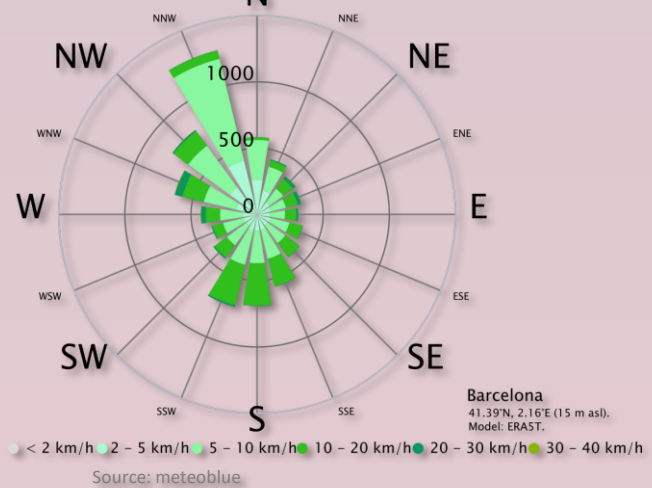
Urban areas are responsible for ~70% of atmospheric greenhouse gas (GHG) emissions.

In the AMB emissions are dominated by road transport, 44% of the total emissions, equivalent to 3206 Gt/year CO₂, followed by electricity generation, highlighting the strong influence of urban mobility and energy demand.



Wind pattern

- Mistral (NW): Strong, gusty wind
- Garbí (SW): Gentle, warm wind
- Llevant (E): Moist marine wind
- Tramuntana (N): Cold, strong wind



INSTRUMENTS



Five cavity ring-down spectroscopy instruments continuously measuring atmospheric carbon dioxide (CO₂) and methane (CH₄) with the goal to determine the efficacy of greenhouse gas emissions mitigation strategies.

MONITORING SITES



ICTA-UAB

Close to a very busy highway
2 km downwind from the Collserola range, at the Vallès Occidental valley and 13km west of the Mediterranean Sea.

Altitude: 147 mASL
Sampling height: 15 mAGL
Operational since 05/2021

IDAEA

Located in urban green spaces (parks), ~1 km east of the Collserola range, the station is surrounded by dense development (residences, businesses). It lies near Avinguda Diagonal (one of Barcelona's busiest roads) and ~5 km inland from the port.

Altitude: 80 mASL
Sampling height: 4 mAGL
Operational since 09/2021



FABRA

The station is located on the eastern end of the Collserola mountain range, the highest point in the AMB. It is characterized by dense forest and lies 7km west of the sea.

Altitude: 415 mASL
Sampling height: 15 mAGL
Operational since 02/2022

UPC-Agrópolis

Surrounded by the Agrarian Park of Baix Llobregat (one of the largest horticultural production areas in Catalonia), the station is ~1 km east of Barcelona-El Prat Airport, 8 km from the port, ~15 km NE of central Barcelona, and ~2 km north of the coast.

Altitude: 3 mASL
Sampling height: 8 mAGL
Operational since 01/2026



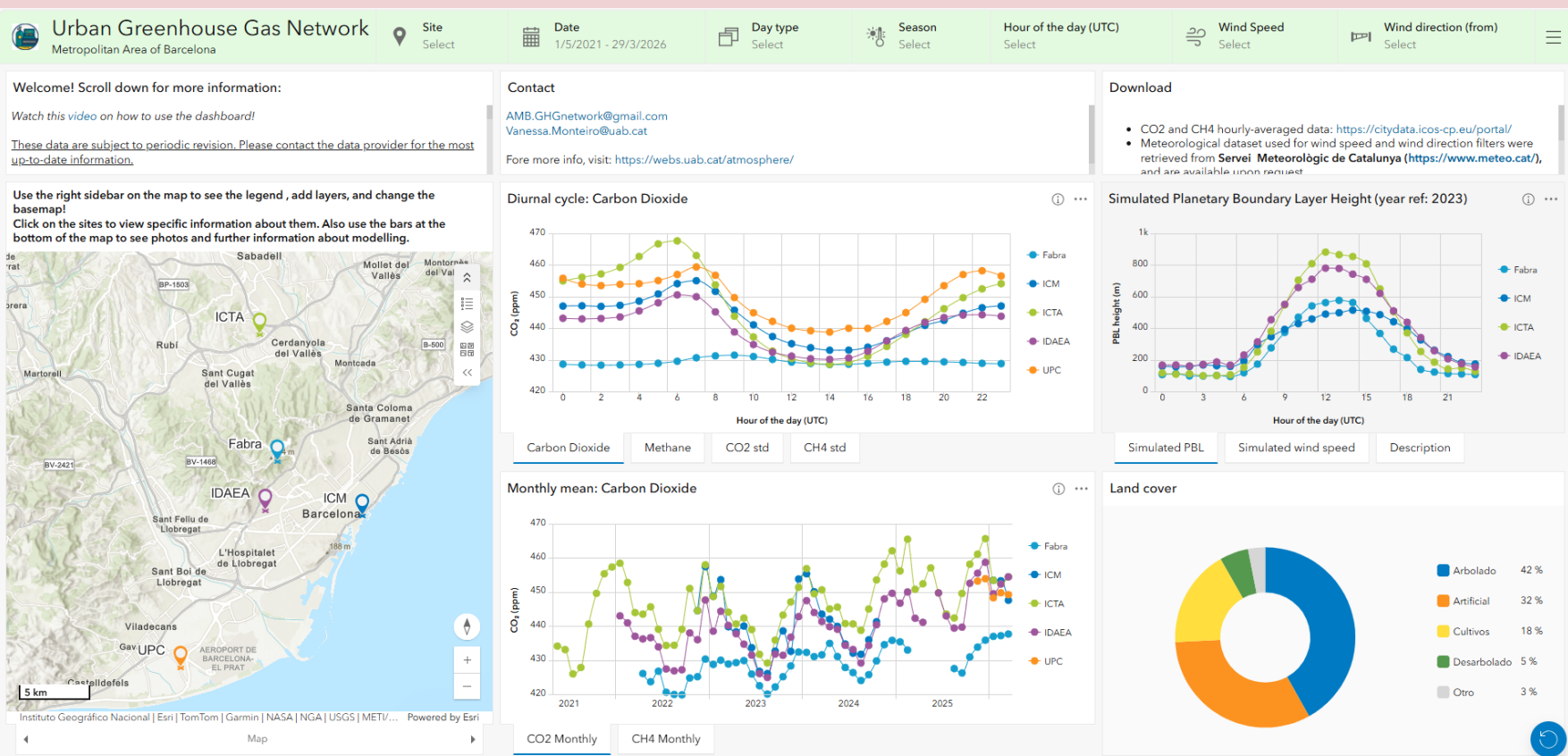
ICM

This station is in one of the densest areas of Barcelona (Barceloneta) and is characterized by high density of buildings and very little urban green. On the east side, however, the station faces the Mediterranean Sea.

Altitude: 8 mASL
Sampling height: 15 mAGL
Operational since 11/2022

ATMOSPHERIC CARBON DIOXIDE OBSERVATIONS

Tools for data visualization and interpretation



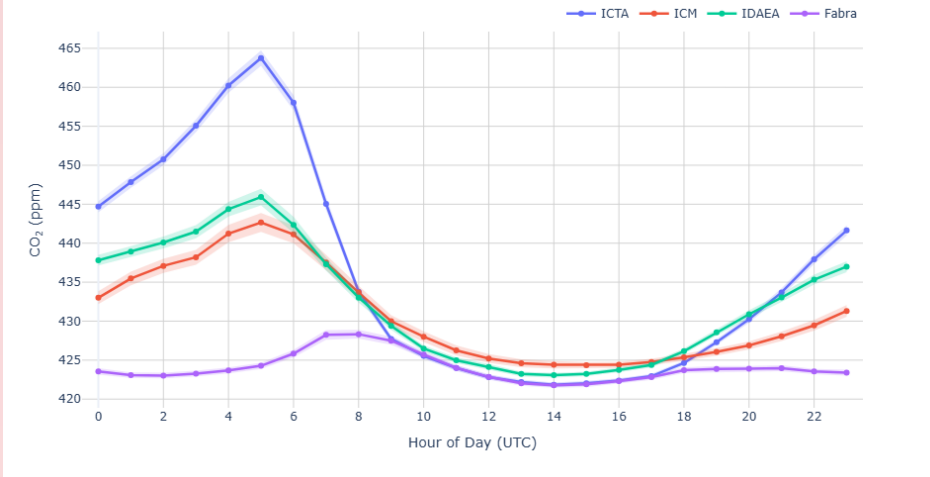
- The interactive dashboard facilitates interpretation of atmospheric observations by integrating measurements with weather data and transport model outputs, enabling characterization of mole fractions and identification of emission sources.
- The ICOS Jupyter Notebooks give more flexibility to access data directly from the ICOS Cities Portal, offering greater freedom for detailed data analysis and plotting.



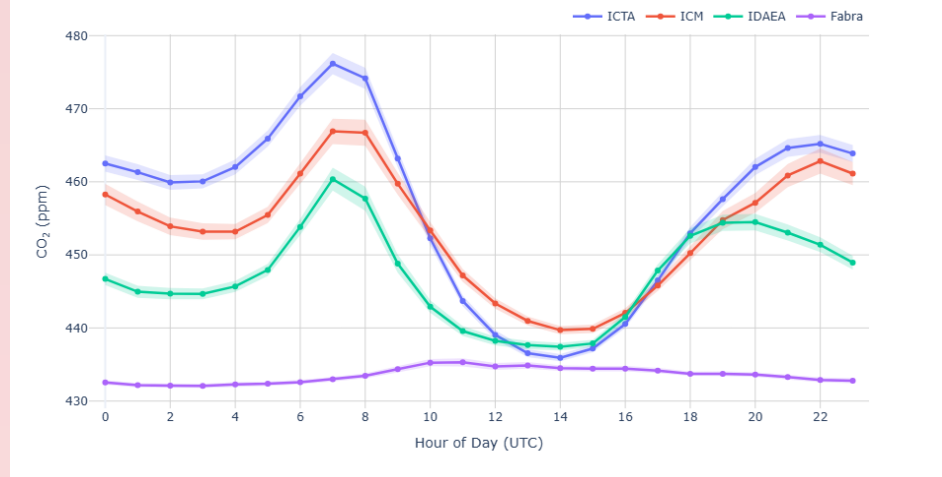
Diurnal cycle of CO₂ mole fractions

- Strong seasonality is present at all sites, driven by changes in anthropogenic emissions, vegetation, and planetary boundary layer (PBL) height.
- While traffic emissions in 2024 were only 1% higher in winter than in summer, residential and commercial emissions showed a 91% increase.¹
- Vegetation fluxes also change, with afternoon net ecosystem exchange (NEE) being 44% higher in winter.²
- Seasonal shifts in PBL height are on the order of 17%.³

Summer 2024 (JJA)



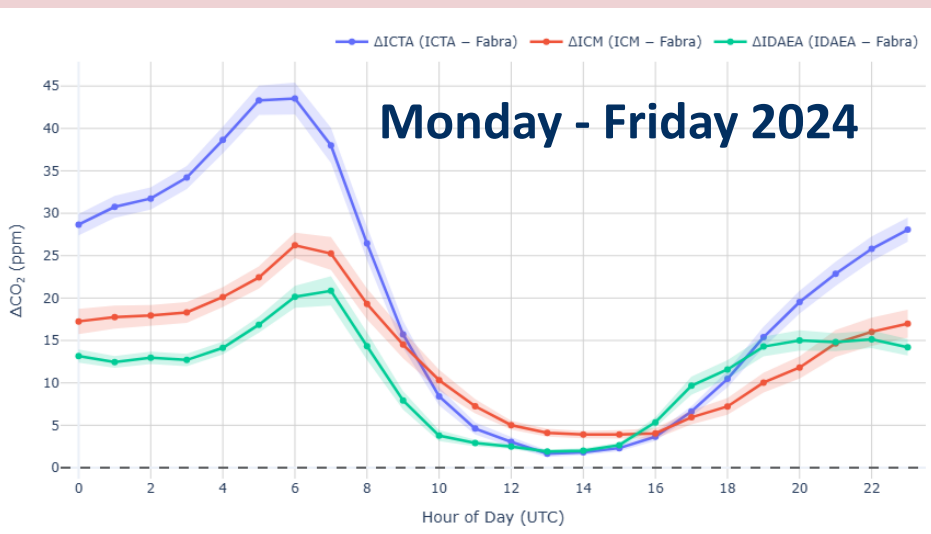
Winter 2024 (DJF)



* Visualization generated at ICOS Jupyter Notebook: Exploring Observational Data

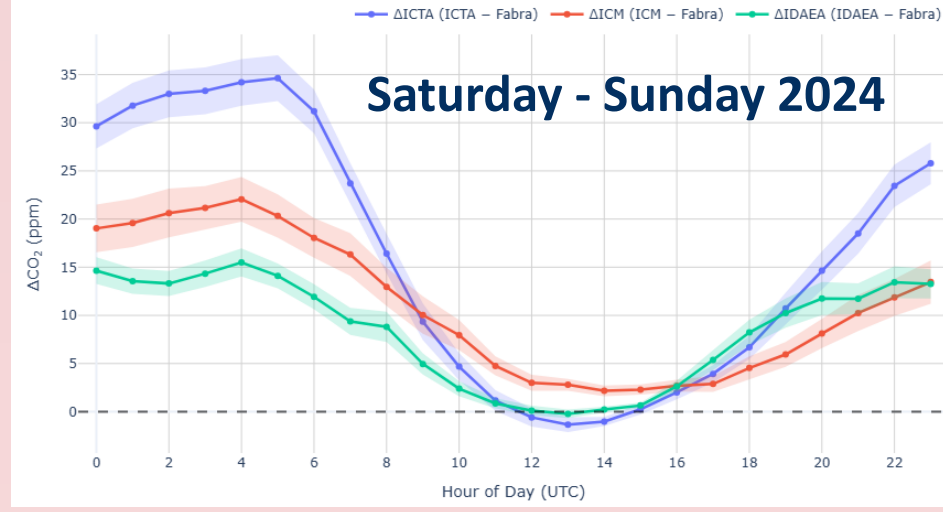
- The diurnal cycle reflects these features, showing higher mole fractions during wintertime (by approximately 15 ppm) compared to summertime.
- Differences in diurnal patterns, such as a narrower window for minimum mole fractions in winter (12:00 pm–4:00 pm) compared to summer (10:00 am–6:00 pm).
- Larger changes in mole fractions occur in highly urbanized areas (e.g., ICM and IDAEA), driven by local emission characteristics.

CO₂ excess (ΔCO₂)



- The shaded area is the standard error.
- Baseline: hourly averaged CO₂ from Fabra station.
- Visualization generated at ICOS Jupyter Notebook: Exploring Observational Data

Because neither the PBL nor vegetation distinguishes between weekdays and weekends, this offers a direct way to isolate the anthropogenic component.



- Traffic emissions on weekends are 25% lower than on weekdays.¹
- Based on CO₂ excess (ΔCO₂), all urban sites exhibit morning (06:00 UTC) concentrations 7 to 9 ppm higher on weekdays than on weekends, while nighttime concentrations show little difference.
- Although afternoon mole fractions are lower on weekends, the diurnal cycle amplitude is consistently larger on weekdays (by ~3.5 ppm), highlighting diurnal amplitude as a potential proxy for tracking fast emissions changes.
- These CO₂ patterns also align, on an hourly basis, with the times of peak traffic congestion in the city.⁴

¹ RESPIRE-CLIMATE : <https://respire-climate.aemet.es/>
² VPRM simulations for January and December 2023: from Luo et al. (submitted)
³ WRF simulations for January and December 2023: from Luo et al. (submitted)
⁴ TOMTOM Traffic Index : <https://www.tomtom.com/traffic-index/city/barcelona/>

TAKEAWAYS

- We need to understand the overall characteristics of a city (e.g., atmospheric behavior, biogenic fluxes) before interpreting its atmospheric CO₂ observations.
- However, a well-distributed atmospheric GHG network with long-term records enables us to detect different patterns in urban CO₂ emissions.
- These analyses on CO₂ observations are particularly important for designing new networks and determining what they can achieve based on observational data.
- Our ongoing analyses aim to refine how we can further use these observations to readily track changes in emissions in complex urban environments.

GASPOF

PERVASIVE GAS SENSING USING OPTICAL FIBERS, AS PART OF THE COMMUNICATION NETWORK OF THE FUTURE.

Use case: Greenhouse gases (GHG) monitoring

Goal: explore the potential of integrating innovative optical gas sensing nodes along optical fibers, towards their massive deployment in existing telecom infrastructures.

Approach: PTS and LHR system validated against the Barcelona GHG infrastructure and COCCON Spain.



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