# Estimates of anthropogenic $CO_2$ emissions from satellite and ground based measurements

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# How to estimate anthropogenic $CO_2$ emissions?

1. **Bottom-up**

2. **Top-down**

## Emission inventory

- Based on anthropogenic activity which can emit $CO_2$ (e.g. transport, power plants, cement industry, etc.)

## Measurement data

- Local (e.g. gas analyzers)
- Remote (e.g. ground-based, aircraft, satellite )

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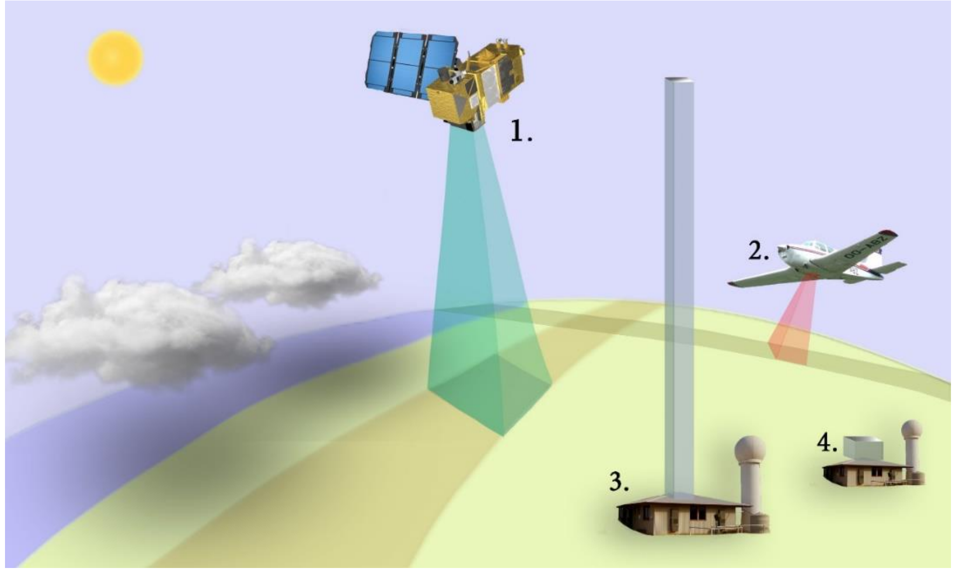
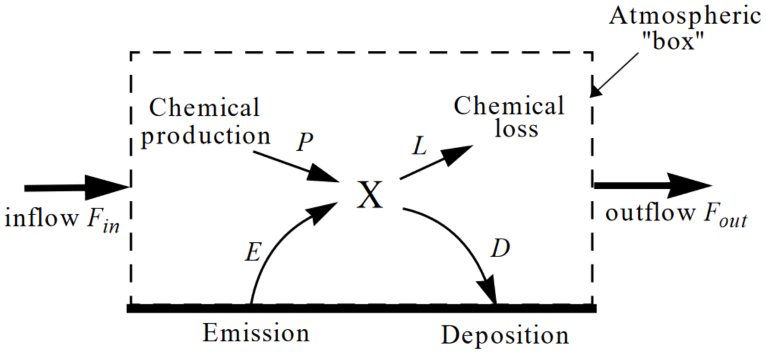
## Techniques

- Mass balance
- Box models
- Puff models
- Plume dispersion models
- Atmospheric inversion systems
- Source pixel




Types of $CO_2$ measurements (1 – satellite, 2 – aircraft, 3 – remote ground-based, 4- local ground-based)




Example of a box model
Orig.: Daniel J. Jacob 1999, "Introduction to Atmospheric Chemistry"

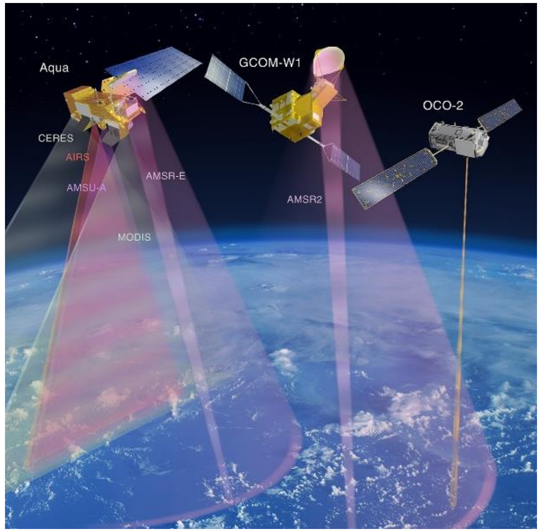
# How to estimate anthropogenic $CO_2$ emissions?

## $CO_2$ remote measurement systems

**Satellite measurements**

(errors in range 30-50%)

- OCO-2
- GOSAT
- SCIAMACHY (sat. EnviSat)
- AIRS (sat. Aqua)




Model of satellite measurements with OCO-2 on the right and AIRS (Aqua) on the left

Orig.:https://ocov2.jpl.nasa.gov/galleries/spacecraft/

**Ground-based measurements**

(errors in range 20-30%)

- FT-IR (Fourier-Transform Infrared) spectrometers


Bruker FT-IR spectrometers EM27/SUN (left) and 125HR (right)

Orig.: https://pdf.medicalexpo.com/pdf/bruker-optik-gmbh/em-27-sun-series-atmospheric-measurements/96471-173355.html; https://www.bruker.com/fileadmin/user_upload/8-PDF-Docs/OpticalSpectrospcopy/FT-IR/IFS125/AN/AN120_Atmospheric_applications_IFS125HR.pdf

# Motivation and aim

## Motivation

- Studying of $CO_2$ variations in the atmosphere is of a big importance since it is main anthropogenic greenhouse gas;
- The relatively high spatial resolution of a number of ground-based and satellite instruments allows to study spatial and temporal $CO_2$ variations more accurately;
- That makes possible to estimate $CO_2$ anthropogenic emissions from different cities.

## Aim

- To demonstrate **comparison** of **$CO_2$ anthropogenic emissions** retrieved using **ground-based** and **satellite** measurements and emissions obtained by the **bottom-up** method for the territory of **St. Petersburg**.

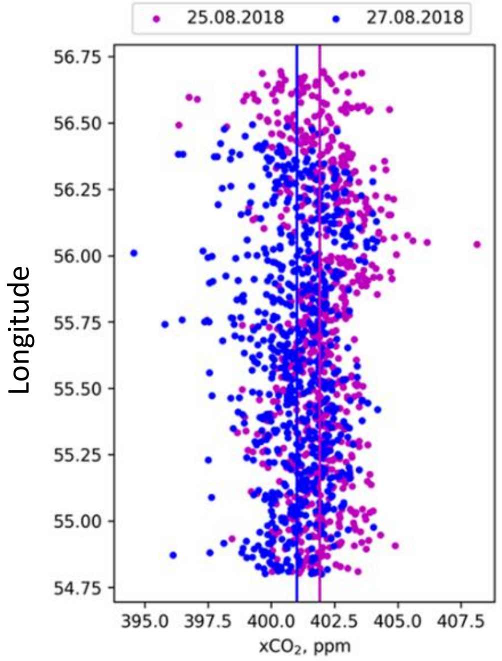
# Retrieving of $CO_2$ anthropogenic emissions using satellite measurements

1. **OCO-2 data** for the period 2014-2018 near the territories of **Moscow** and **St. Petersburg** (Russia)

2. Using simple **box model** (1) to retrieve **$CO_2$ anthropogenic emissions**

$$F_a = \frac{\Delta TC_{gas} * \bar{V}}{L} \qquad (1)$$

$\boldsymbol{F_a}$-emissions of the gas per units of area and time;
**$\Delta TC_{gas}$**-a difference between total column content of the gas in a clean and polluted air masses;
$\bar{\boldsymbol{V}}$ – average wind speed;
**L** – path of air mass, driven by the wind speed.




Latitudinal distribution of $XCO_2$ measured by OCO-2 for the clean (blue points) and polluted (pink points) air in Moscow, 25 and 27 Aug 2018

Orig.: Timofeev Yu.M., Berezin I.A., Virolainen Ya.A., Poberovsky A.V., Makarova M.V., Polyakov A.V. Estimates of anthropogenic CO2 emissions for Moscow and St. Petersburg based on OCO-2 satellite measurements. // Optika Atmosfery i Okeana. 2020. V. 33. No. 04. P. 261–265

# Retrieving of $CO_2$ anthropogenic emissions using satellite measurements

## Estimation of $CO_2$ anthropogenic emissions in St. Petersburg and Moscow

| City | $CO_2$ emissions, $tCO_2/km^2$ per day | $CO_2$ emissions, $ktCO_2/km^2$ per year | $CO_2$ emissions, $MtCO_2$ per year per city`s area |
|---|---|---|---|
| **St. Petersburg (OCO-2)** | 74–80 | 27–29 | 38 – 41 |
| **St. Petersburg (Bottom-up, 2015)** | 58 | 21 | 30 |
| **Moscow (OCO-2)** | 123–186 | 45–68 | 112 – 170 |

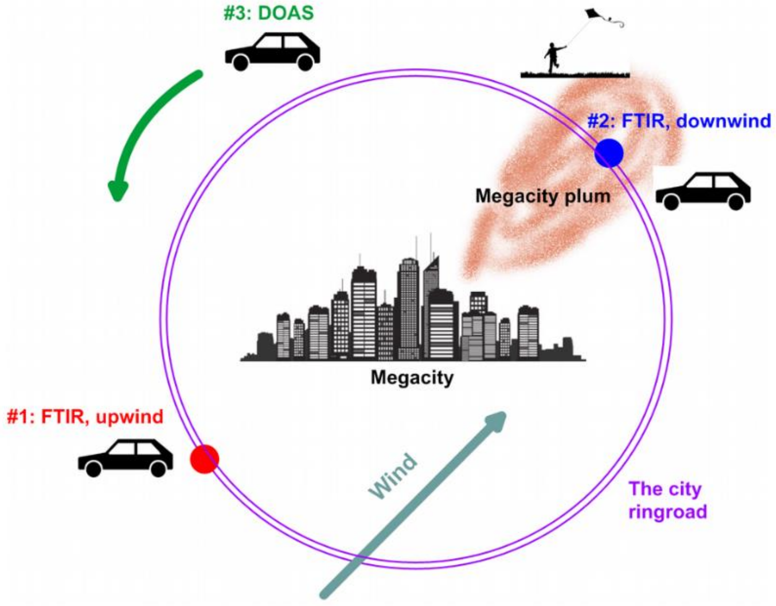
# Retrieving of $CO_2$ anthropogenic emissions using ground-based measurements

## Emission Monitoring Mobile Experiment (EMME)
## St. Petersburg, Mar-Apr 2019

1. **Two** portable **FT-IR spectrometers** Bruker EM27/SUN were used to estimate **total column** amount of **$CO_2$** at upwind (**clean air**) and downwind (**polluted air**) locations on the opposite sides of the city;

2. Using simple **box model** (1) to retrieve **$CO_2$ anthropogenic emissions;**

3. Estimations of **integral** anthropogenic **$CO_2$ emissions** from the territory of **St. Petersburg** using **various sources** of $CO_2$ anthropogenic emissions data.




Concept of EMME

Orig.:https://doi.org/10.5194/amt-2020-87

# Retrieving of $CO_2$ anthropogenic emissions using ground-based measurements

## Estimation of $CO_2$ anthropogenic emissions in St. Petersburg per 1 $km^2$

| Source of data | $CO_2$ emissions, $ktCO_2/km^2$ per year |
|---|---|
| **EMME (2019)** | 89±28 |
| **OCO-2 (2014-2018)** | 27–29 |
| **Bottom-up (2015)** | 21 |

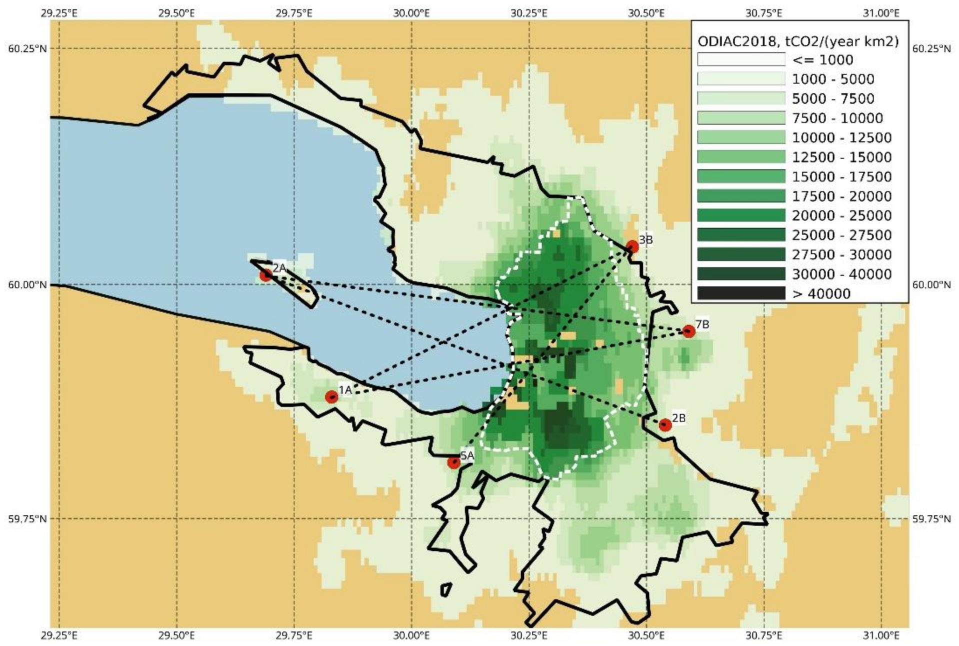
# Retrieving of $CO_2$ anthropogenic emissions using ground-based measurements

## Correction of ODIAC data using EMME measurements

1. Using simple **box model** (1) to retrieve $\Delta TC_{CO2}$ from ODIAC data base of **CO2 fossil fuel emissions** with **1 km spatial resolution** for 2018 results along paths of EMEE measurements (dashed lines on the picture);

2. Calculating **correction parameter** by comparing **EMME** and **ODIAC** $\Delta TC_{CO2}$;

**3. Correction** of **ODIAC** results by **multiplying** them with the correction parameter (approximately 1.935).




ODIAC $CO_2$ emissions with 1 km spatial resolution for the territory of St. Petersburg in 2018

Red dots on the picture – sites of EMME measurements which were used in retrieving $\Delta TC_{CO2}$ from ODIAC

# Retrieving of $CO_2$ anthropogenic emissions using ground-based measurements

## Estimation of integral $CO_2$ anthropogenic emissions from the territory of St. Petersburg

| Source of data | $CO_2$ emissions, $MtCO_2$/ year |
|---|---|
| **Corrected ODIAC (2019)** | 65 |
| **CAMS (2018)** | 67 |
| **Bottom-up (2015)** | 30 |

# Concluding remarks

Our measurements in **2019** for the territory of **St. Petersburg** showed:

- **Bottom-up** $CO_2$ anthropogenic emission estimation for **St. Petersburg** is **lower** than emissions retrieved using
    1. The **satellite** OCO-2 measurements (approximately in **1.3 times**);
    2. The **ground-based** measurements obtained during EMME campaign (more than in **3-4 times**).

- The **corrected ODIAC** $CO_2$ emission estimation has **good agreement** with **CAMS** data for the territory of **St. Petersburg** (**65.3** vs **66.8** $MtCO_2$/ year);

- The **corrected ODIAC** $CO_2$ emission estimation is almost in **2 times higher** than **bottom-up** retrieval (**65.3** vs.**29.6** $MtCO_2$/ year).

# References


1. **Timofeev Yu.M**., Berezin I.A., Virolainen Ya.A., Poberovsky A.V., Makarova M.V., Polyakov A.V. Estimates of anthropogenic CO2 emissions for Moscow and St. Petersburg based on OCO-2 satellite measurements. // Optika Atmosfery i Okeana. 2020. V. 33. No. 04. P. 261–265

2. **M.V. Makarova**, F. Hase, D.V. Ionov, T. Blumenstock, T.Warneke, S.C. Foka, Y. A. Virolainen, V.S. Kostsov, C.Alberti, M. Frey, A.V. Poberovskii, Y. M. Timofeyev, K.A. Volkova, N.A. Zaitsev, E.Y. Biryukov, S.I. Osipov, B. K. Makarov, A.V. Polyakov, N.N. Paramonova, V.M. Ivakhov, H.H. Imhasin, E. F. Mikhailov. Emission Monitoring Mobile Experiment (EMME): an overview and first results of the St. Petersburg megacity campaign-2019. Atmos. Chem. Phys. https://doi.org/10.5194/amt-2020-87

# Thank you for your attention!