Ruisdael Science Day - Monday 30.09.2024

CO_2 plume dispersion simulated at hectometer scale: DALES formulation and observational evaluation

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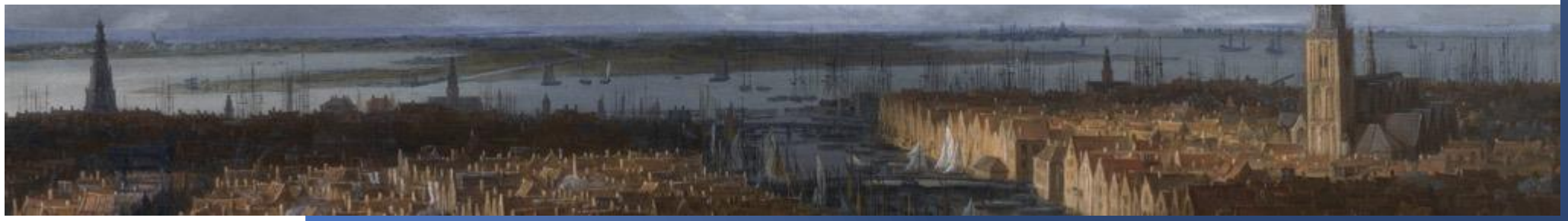

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1. Urban area complexity
2. Spatiotemporal Variability
3. High-Resolution Data Requirement

Industry

How challenging is to

Dynamics within ABL

Exchange with biosphere

The monitoring and evaluation of GHG urban emissions must include the integration of highly accurate measurements and high-resolution atmospheric modelling

Traffic

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High-resolution simulation of CO_2 emissions in the Netherlands

Dutch Atmospheric Large-Eddy Simulation (DALES)

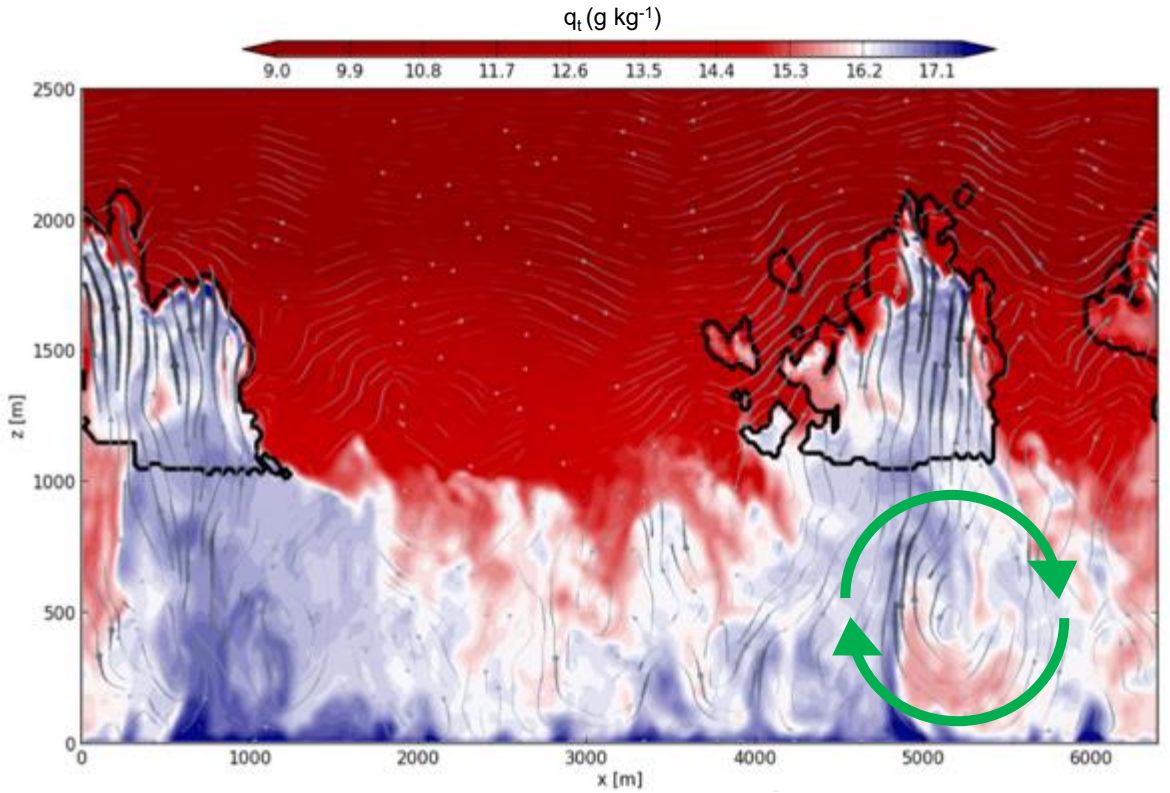
Advantages:

- LES explicitly resolves grid-scale turbulent structures of the flow
- Resolution: sub-mesoscale (horizontal: ~20m)
- Timestep: 2s

Academic Tool to Study Atmospheric Physics and ABL Dynamics: Transport and other thermodynamic processes

- **High requirements on computational power**
- **Large output size**
- **Low rate of simulation (~1m/day)**
- **Highly accurate emission input is required!**

Why DALES?

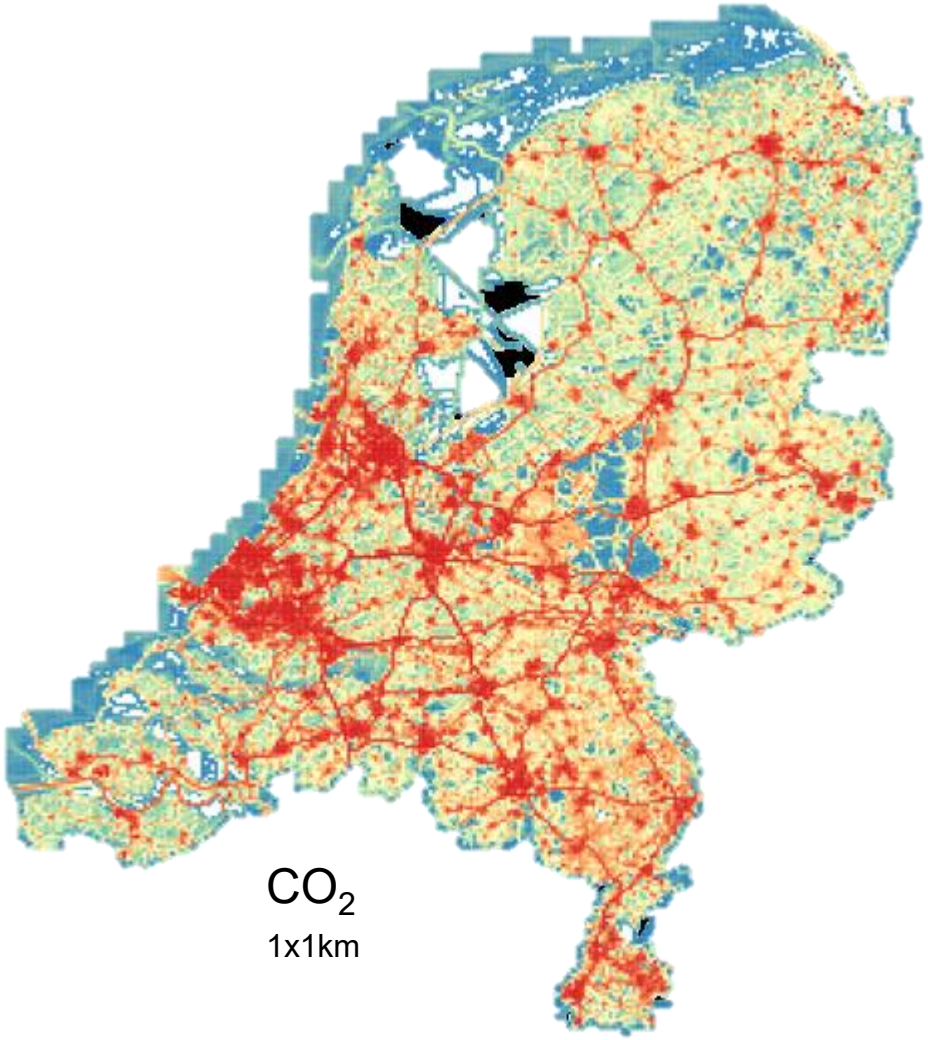


Sikma (2014)

Total water specific humidity

TNO WAGENINGEN UNIVERSITY & RESEARCH TU Delft VU VRIJE UNIVERSITEIT AMSTERDAM Ruisdael observatory

Emission data



CO_2
1x1km

Annual National Emission Inventory

(Collected and processed by RIVM)

Classified into groups according to the Standard Nomenclature for Air Pollution (SNAP).

- **Types of Data:**

1.Point Sources (from industry):

1. Can be used in DALES as the location is exactly available. Vertical allocation is required!

2.Gridded Area Emission Data:

1. Available on km-scale resolution.
2. Too coarse for DALES; downscaling is required!

To justify the high resolution of DALES, we need emissions to be aligned to DALES spatiotemporal resolution and vertically allocated!

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This study addresses three main objectives:

Develop the downscaling emission workflow to prepare emission inventories for realistic urban-scale simulation of CO_2 emissions.

Enhance the DALES model to simulate anthropogenic point sources and area-based CO_2 emissions, as well as CO_2 exchange with biosphere.

Evaluate the developed framework against in-situ observations and LOTOS-EUROS with prescribed turbulence to demonstrate the benefits of 100m-scale simulations via LES.

Before Refinement

Proxy data

After Refinement

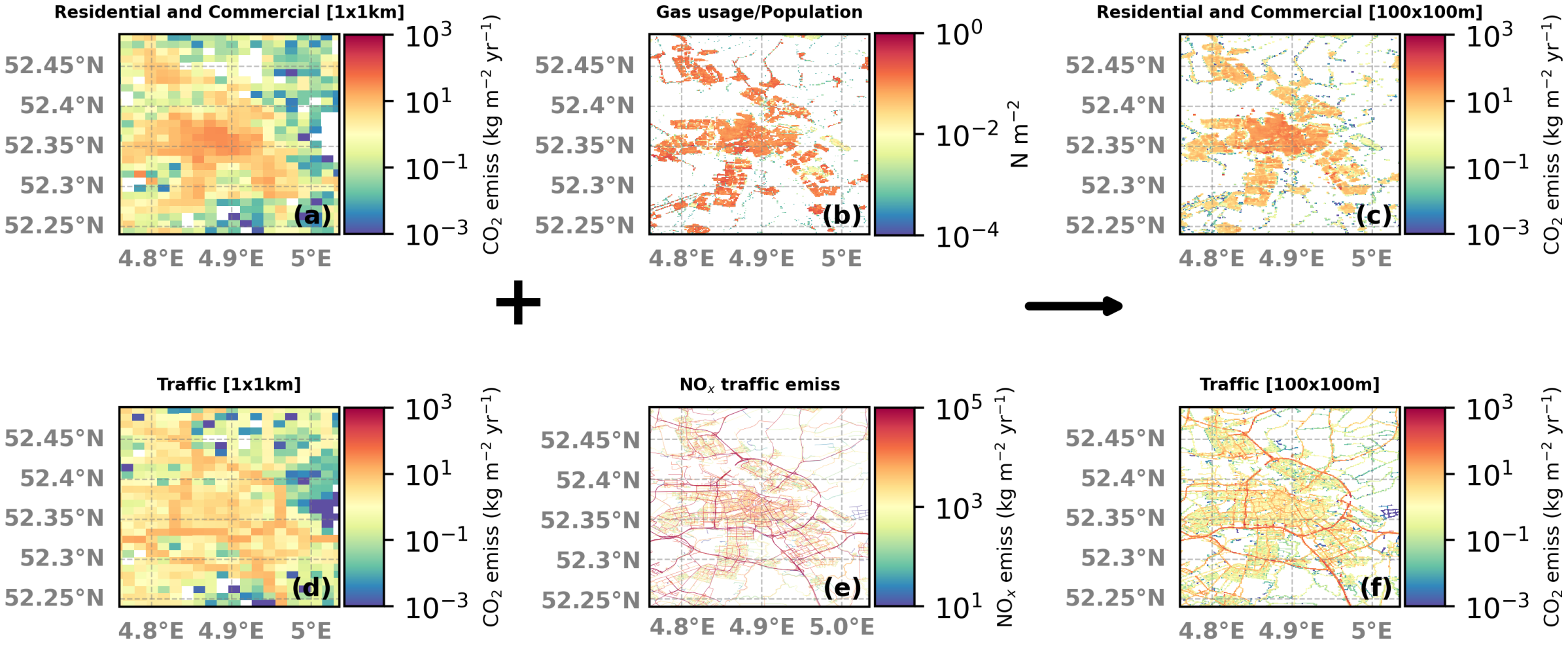

Illustration of spatial redistribution of annual CO_2 area emissions (kg m^{-2} yr^{-1}) from a coarse resolution of 1x1km to a finer resolution of 100x100m

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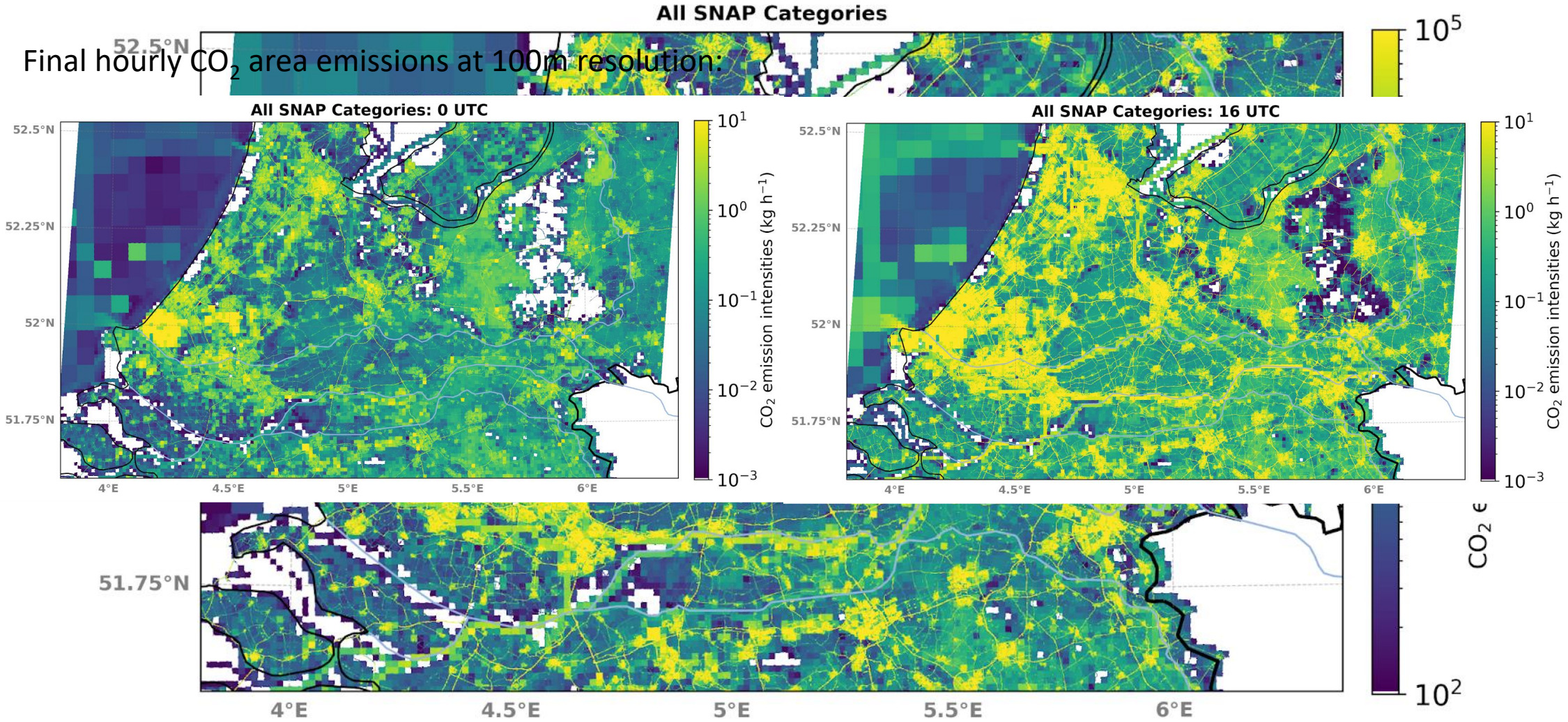
1. Downscaling emission workflow

Example of total static CO_2 emissions at 100m resolution:

Final hourly CO_2 area emissions at 100m resolution:



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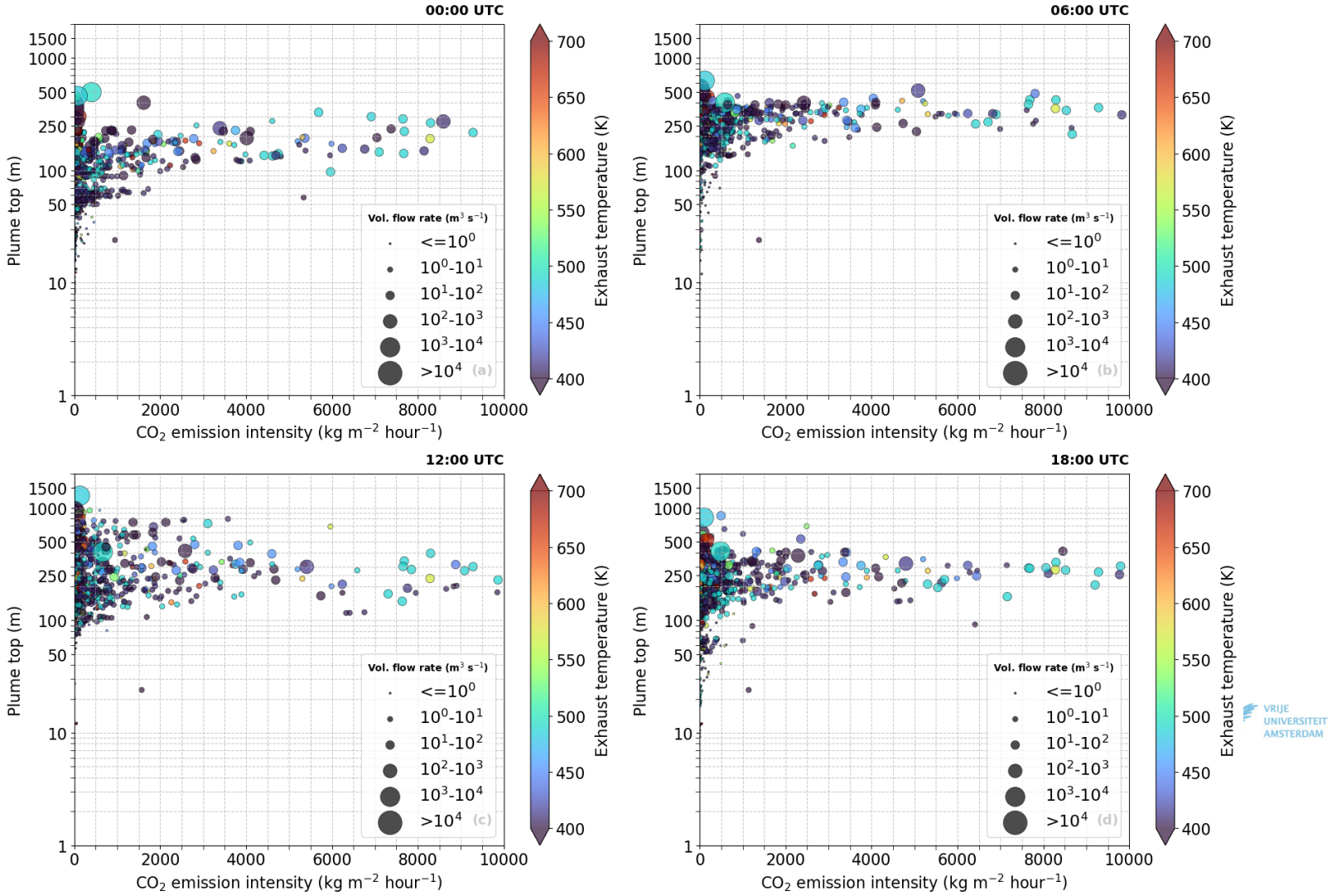
2. DALES extensions to simulate CO_2 emissions



a) Vertical allocation of CO_2 exchange with biosphere in DALES:

Emission height above the canopy is (...) between emission parameters and atmospheric conditions.

b) CO_2 exchange with biosphere emissions:

Land Surface Model coupled to DALES includes A-gs (net CO_2 assimilation rate (**A**) stomatal conductance (**gs**)) model (Ronda et al., 2001) to simulate net CO_2 flux from vegitation: soil respiration and assimilation (photosynthesis) by grass and trees (modified after Ronda et al., 2001; Gordon et al., 2017 and Arrington et al., 2018).

Model experiment setup

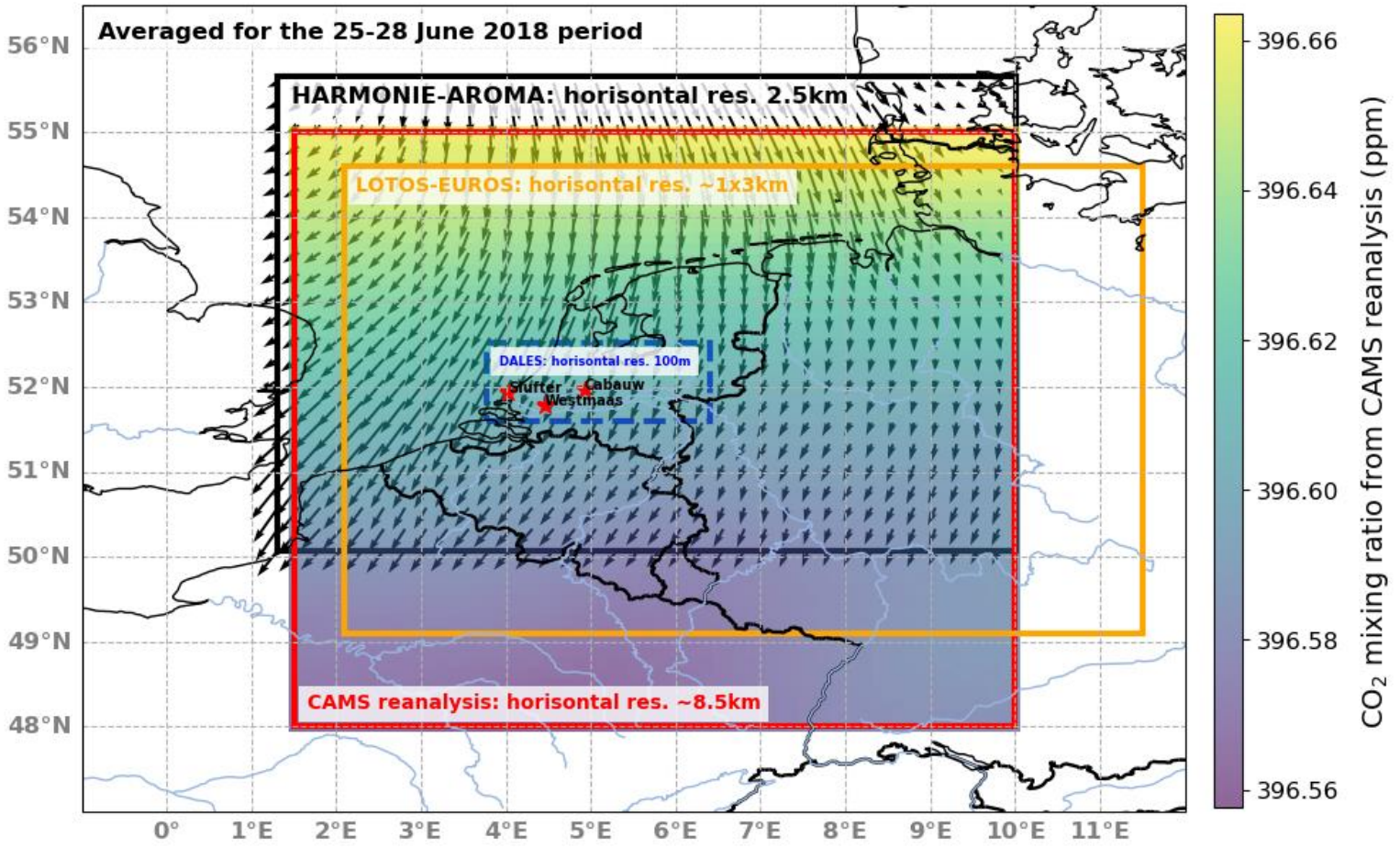
Lathernal Boundary conditions (periodic):

- Meteorology: HARMONIE-AROMA weather forecast
- background CO_2 levels: CAMS reanalysis (6-houly)

Period of simulation: 25-28 June 2018

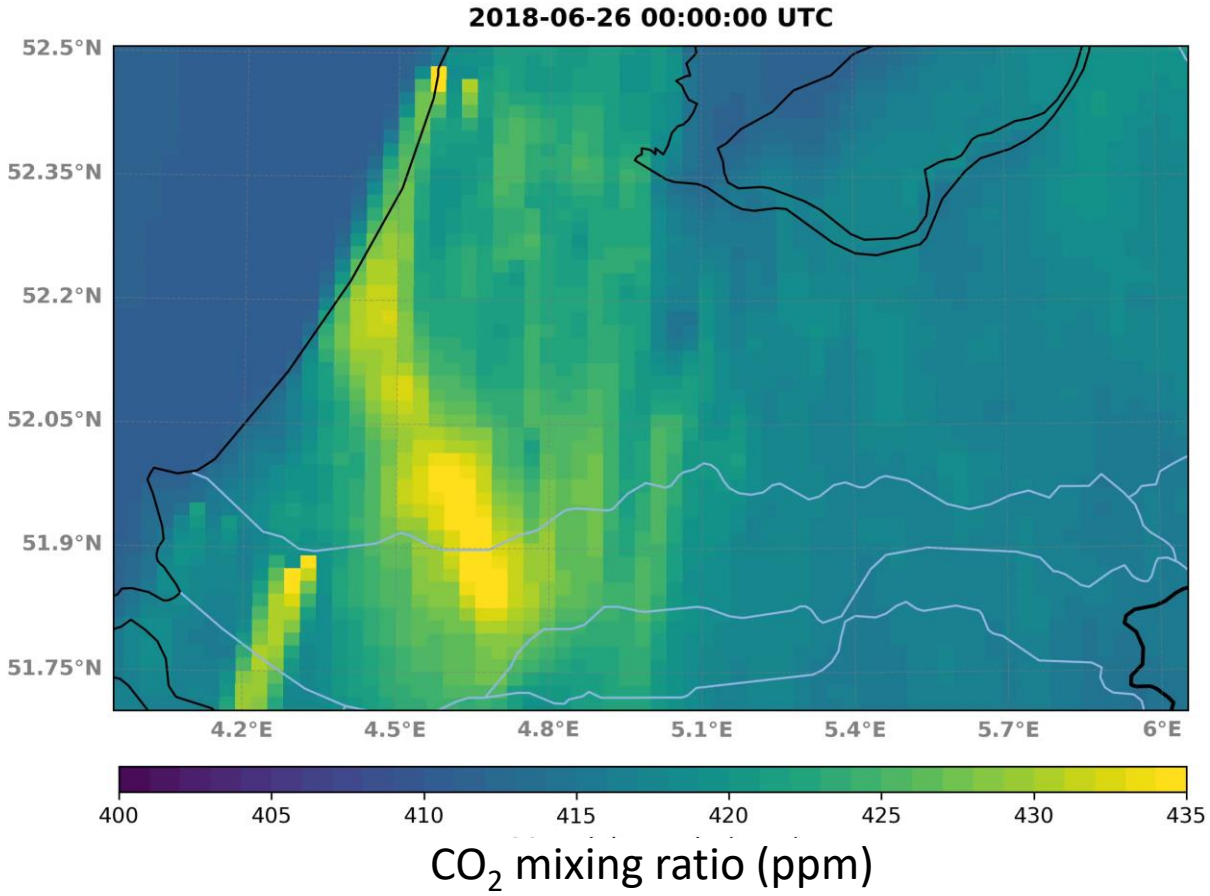
Four distinct model tracers:

1. **CO2BG**: background concentration only.
2. **CO2BG_EMISS**: **CO2BG** + anthropogenic emissions.
3. **CO2BG_EMISS_RESP**: **CO2BG_EMISS +** net soil respiration.
4. **CO2_SUM**: the sum of CO2BG, CO2EMISS, CO2RESP, including the net CO_2 assimilation (CO2PHOTO).



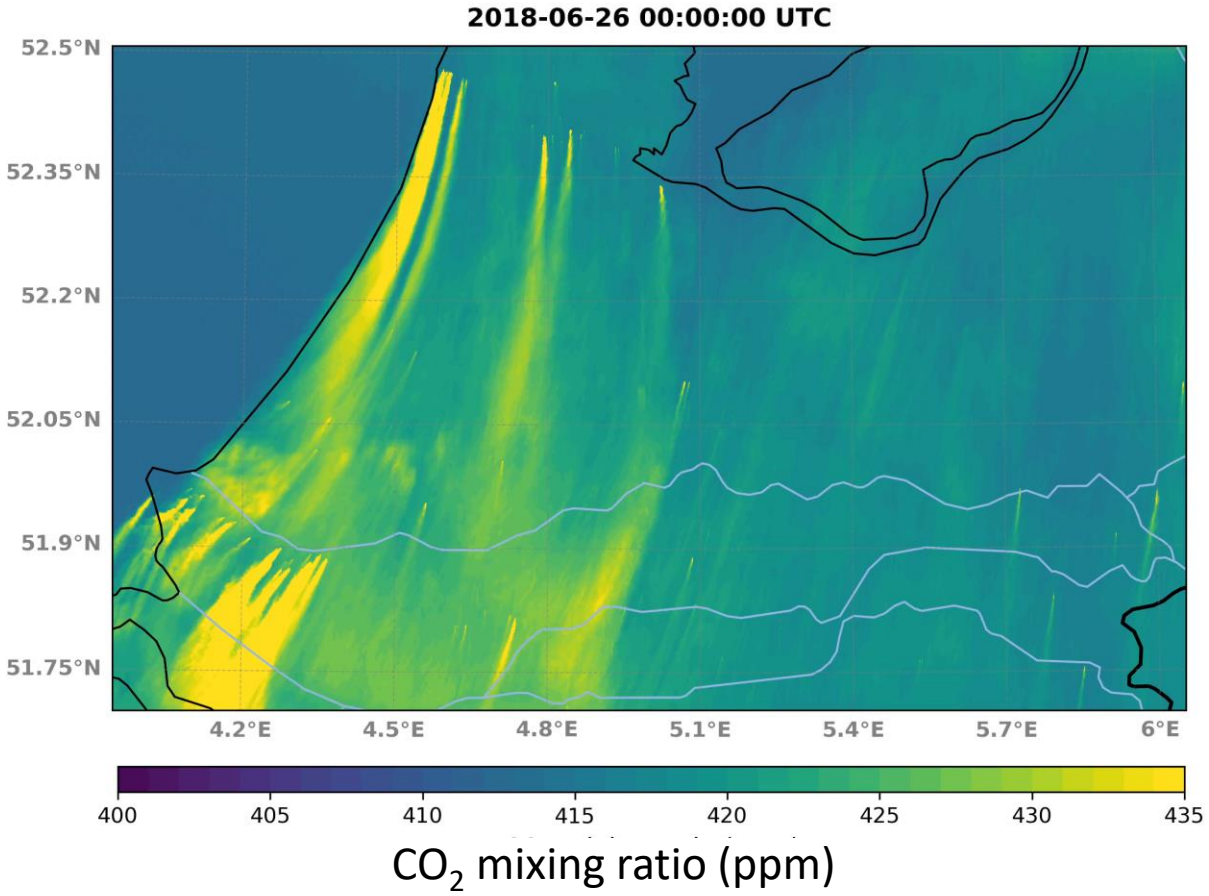
Results of simulation: diurnal cycle of near-surface CO_2

LOTOS-EUROS CTM [~1x3km horisontal res.]



CO_2 mixing ratio (ppm)

DALES [100m horisontal res.]



CO_2 mixing ratio (ppm)

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Model evaluation

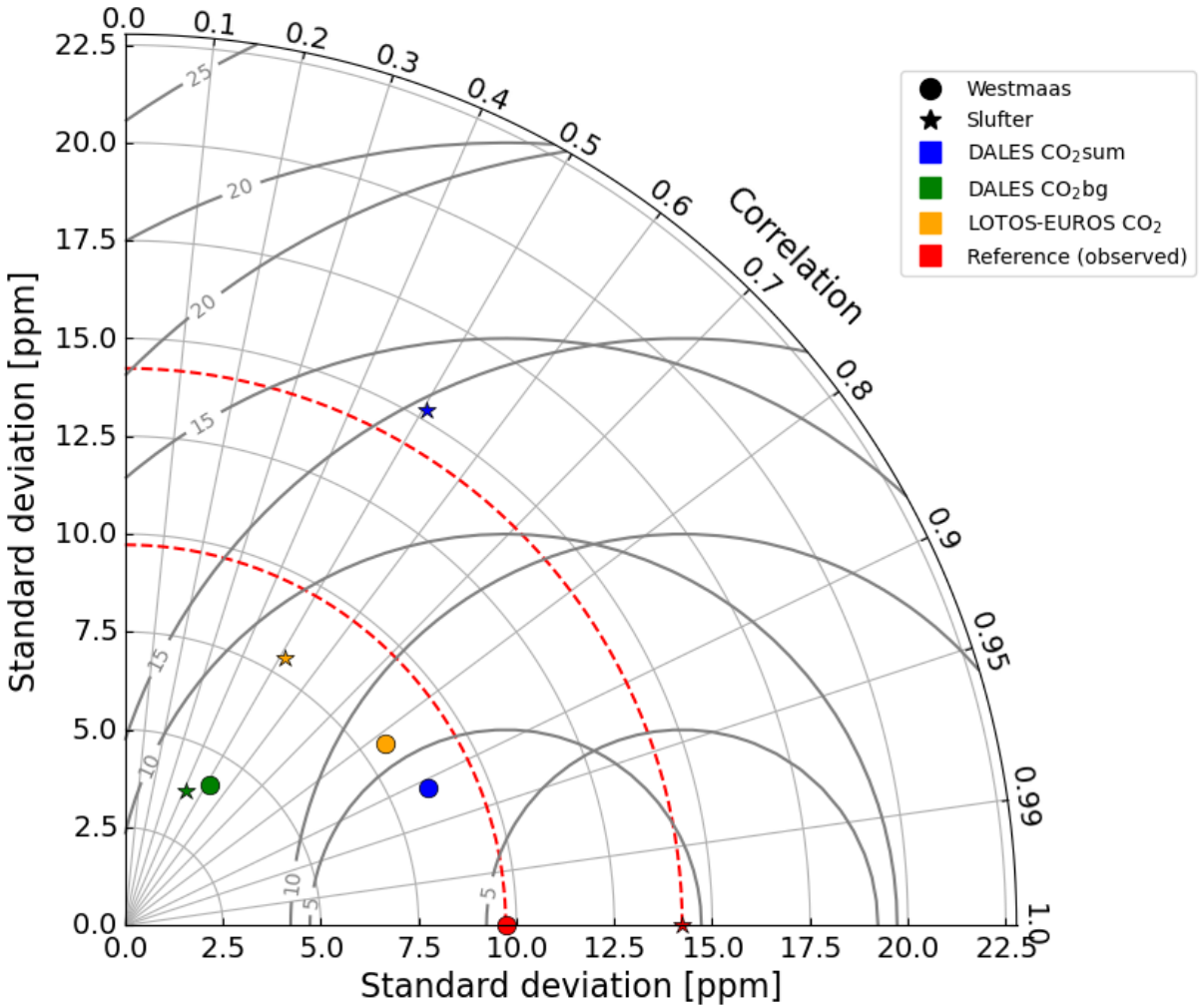
- Three measurement sites:
  - ICOS Cabauw tower (51.971 °N, 4.927 °E) :
  - four heights: 27, 67, 127, and 207m

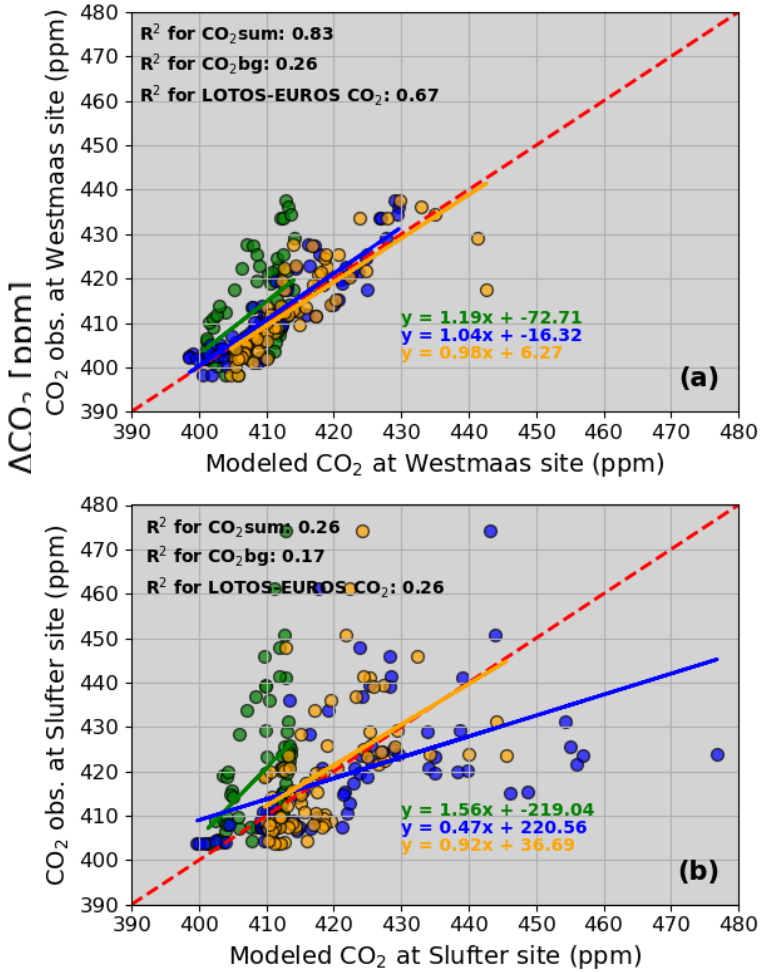
- Near-ground TNO measurements:

- 2. Westmaas (51.79°N, 4.45°E) (urban area)
- 3. Slufter (51.9461°N, 4.048°E) (North sea shore)

- State-of-the-art LOTOS-EUROS CTM

Evaluation against Westmaas and Slufter measurements





Model	CO_2 Measurement	MBE	RMSE
WESTMAAS	CO_2sum	-0.63	4.13
	CO_2bg	-4.53	9.55
	LOTOS-EUROS CO_2	0.85	5.63
SLUFTER	CO_2sum	3.14	15.03
	CO_2bg	-10.39	16.74
	LOTOS-EUROS CO_2	-1.50	12.33

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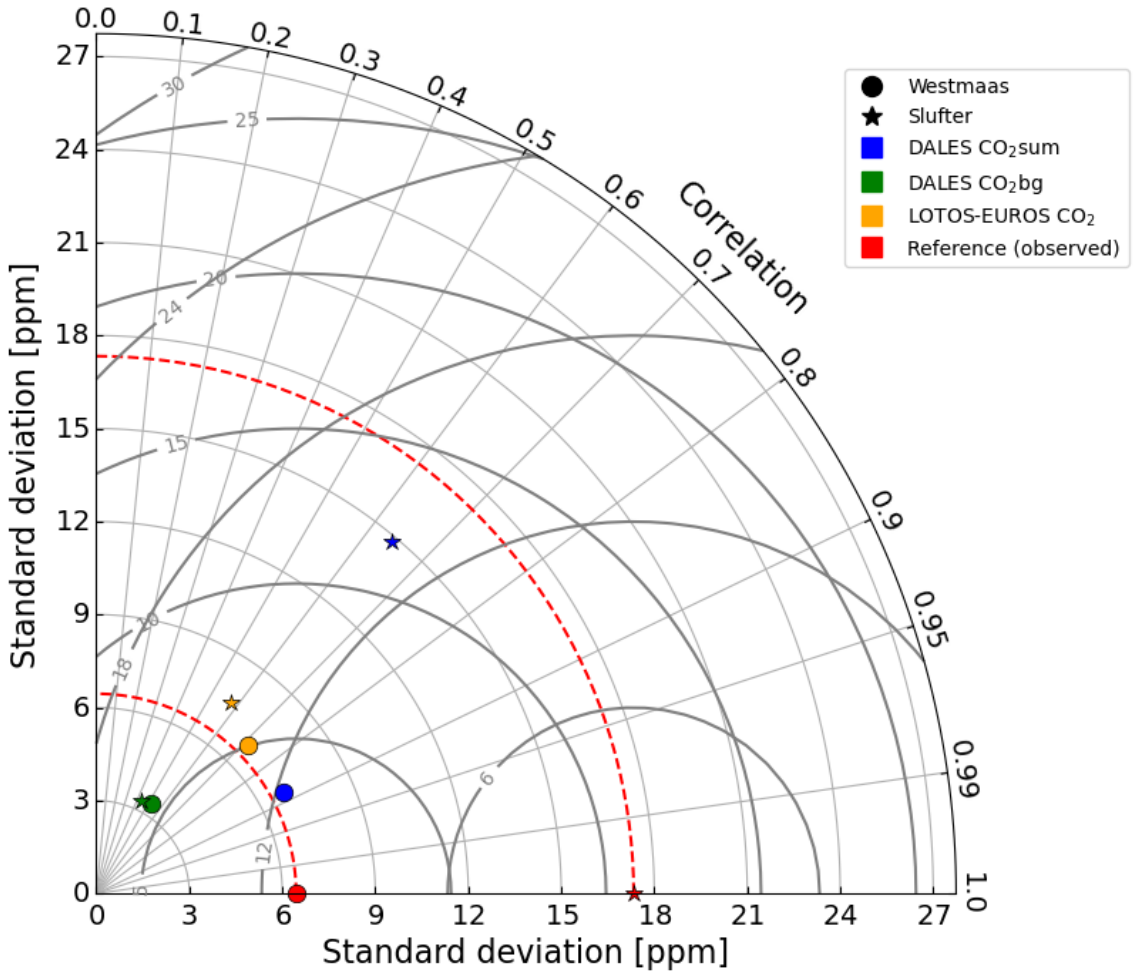
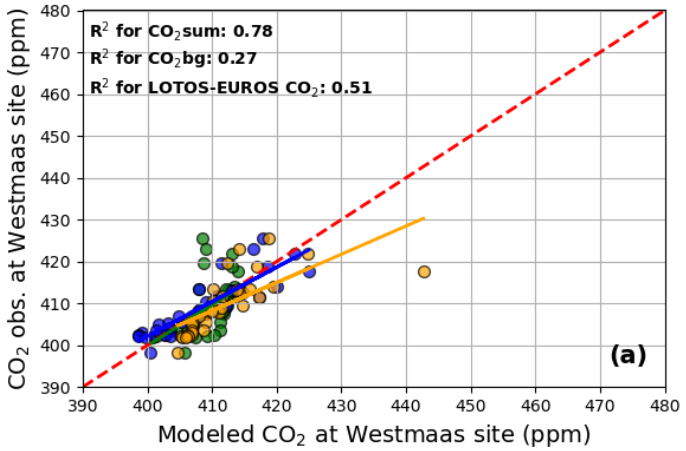
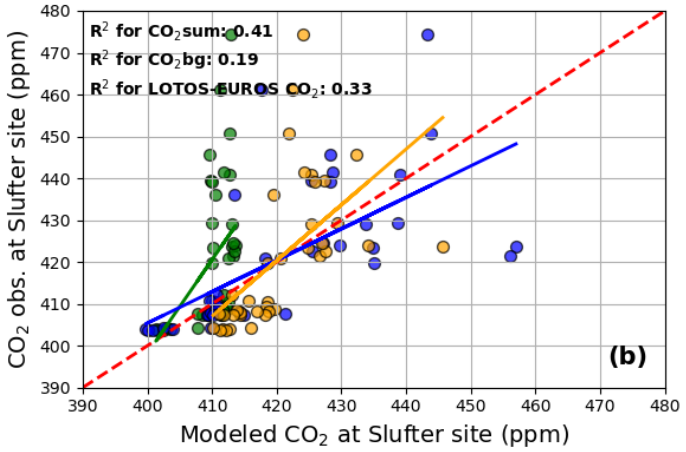
Evaluation against Westmaas and Slufter measurements (excluding night-time periods)







Model	CO_2 Measurement	MBE	RMSE
WESTMAAS	CO_2sum	-3.70	3.33
	CO_2bg	-1.94	5.52
	LOTOS-EUROS CO_2	-0.72	5.53
SLUFTER	CO_2sum	-8.01	13.79
	CO_2bg	-15.47	19.40
	LOTOS-EUROS CO_2	-6.63	14.37

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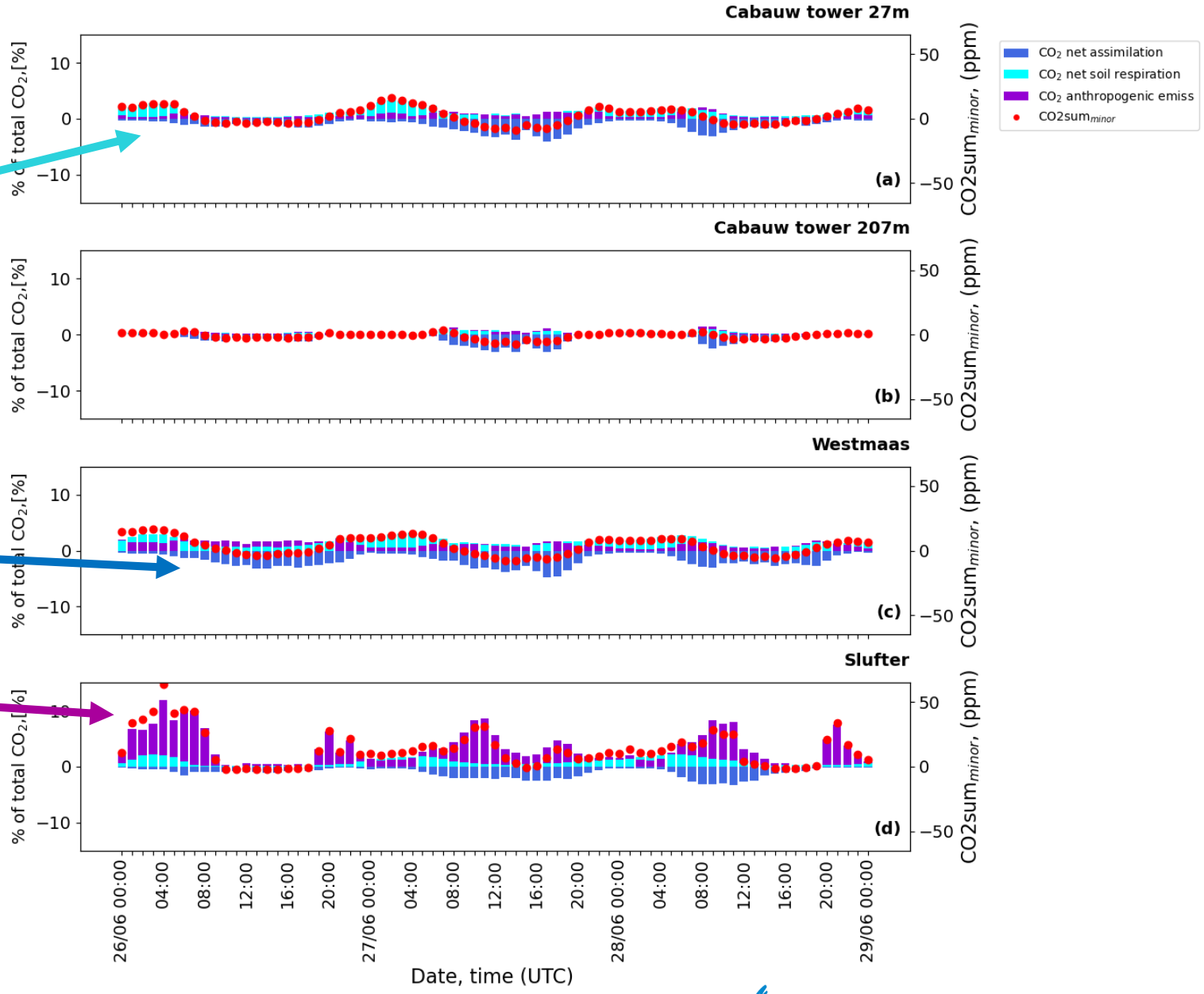
Contribution of modeled minor CO_2 components to regional the CO_2 enhancement

Net soil respiration

Net assimilation

Anthropogenic fluxes



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Perspectives on LES development towards the simulation of chemical species emissions

Downscaling of emission inventory in space and time and refinement using proxy data. Unsertanties?

Increasing the spatial res of simulation (<100m)

Evaluation of NFF fluxes

Vertical allocation of emissions (stack heights, plume parameters) prescribe a heat source at the chimney top?

Shift from Periodic to non-paramentric open boundaries

Topograthy, forest maps and urban area landscapes in LES

Advance chemical sheme (gas-phase + heterogeneous + how chemistry be affected if resolution change?

Updating atmospheric dynamic in LES (night time stable condition issue)

LES ensemble experiment within unsertanty of emissions

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Conclusions

- A new simulating platform (downscaling emission workflow + DALES extensions) aims at calculating spatiotemporal CO_2 concentration variability at 100m resolution has been developed.
- The main novelty is to calculate upward CO_2 fluxes in the Netherlands with the turbulent mixing and transport explicitly by means of the LES.
- The validation against in-situ observations and LOTOS-EUROS CTM demonstrates the improvements and current limitations of incorporating explicit turbulence in high-resolution CO_2 emission modeling.

For more information, please contact me at:
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For more general information on the Ruisdael Observatory:
www.ruisdael-observatory.nl

DALES model code:
https://github.com/adoyenne/dales_ruisdael_emission_new.git

Emission workflow:
https://github.com/ruisdael-observatory/ghg_emission_inventory_workflow.git

Thank you for your attention! Any questions?

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