HARMO18
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MODELLING THE DISPERSION OF SHIP EMISSIONS WITH DIFFERENT PLUME RISE APPROACHES AND SENSITIVITY ANALYSIS

Silvia Trini Castelli, Gianni Tinarelli, Giuseppe Carlino, Paola Radice, Luca Mortarini, Cristina Pozzi

Institute of Atmospheric Sciences and Climate, National Research Council, Torino, Italy
Arianet S.r.l., Milano, Italy
Simularia S.r.l., Torino, Italy

➢ Research activity

Topic. In the frame of a modelling study assessing the dispersion of ship emissions in the canals of Venice Lagoon, the **plume rise algorithm**, used to elaborate the source term in dispersion models, was modified in order to describe the pollutant emissions from moving ships.

Goal. To assess and quantify the differences in the concentration field due to the choice of the plume rise, the original one and the modified one. The response of the modified plume rise to the wind direction along the trajectory of the ship is investigated and discussed.

Approach. Two different emission scenarios for passenger ships > 40kTon were considered, the present one (Giudecca - S0) and one with a possible future variation of the ships' itinerary ('Tresse Nuovo' - S1). One-year-long simulations, for 2013, were performed. The evaluation of the results was carried out by comparisons with both meteorological and pollutant concentration observed data.

Methodology. A meteo-dispersive modelling suite reproducing the atmospheric circulation and dispersion from the mesoscale down to the local scale.

➢ The case study

Red line: present scenario for ships >40 kTon **S0**
Green line: future scenario for ships >40 kTon **S1**

➢ Methodology and modelling suites

RAMS/ISAN

Atmospheric model - meteorology

Hybrid prognostic/diagnostic simulation with observed data assimilation
4 nested domains, up to a 1 km resolution over a domain 100x100 km

↓

MINERVE

Diagnostic mass-consistent model for meteorology downscaling

Elaboration of meteorological fields up to a resolution of 200 m
1 domain ~ 25x25 km

↓

MIRSpro

Parameterization code for turbulence and atmospheric boundary layer

Elaboration of the ABL and turbulence variables needed by the dispersion model,
Integration of topographical data specific for the Venice Lagoon

↓

SPRAY

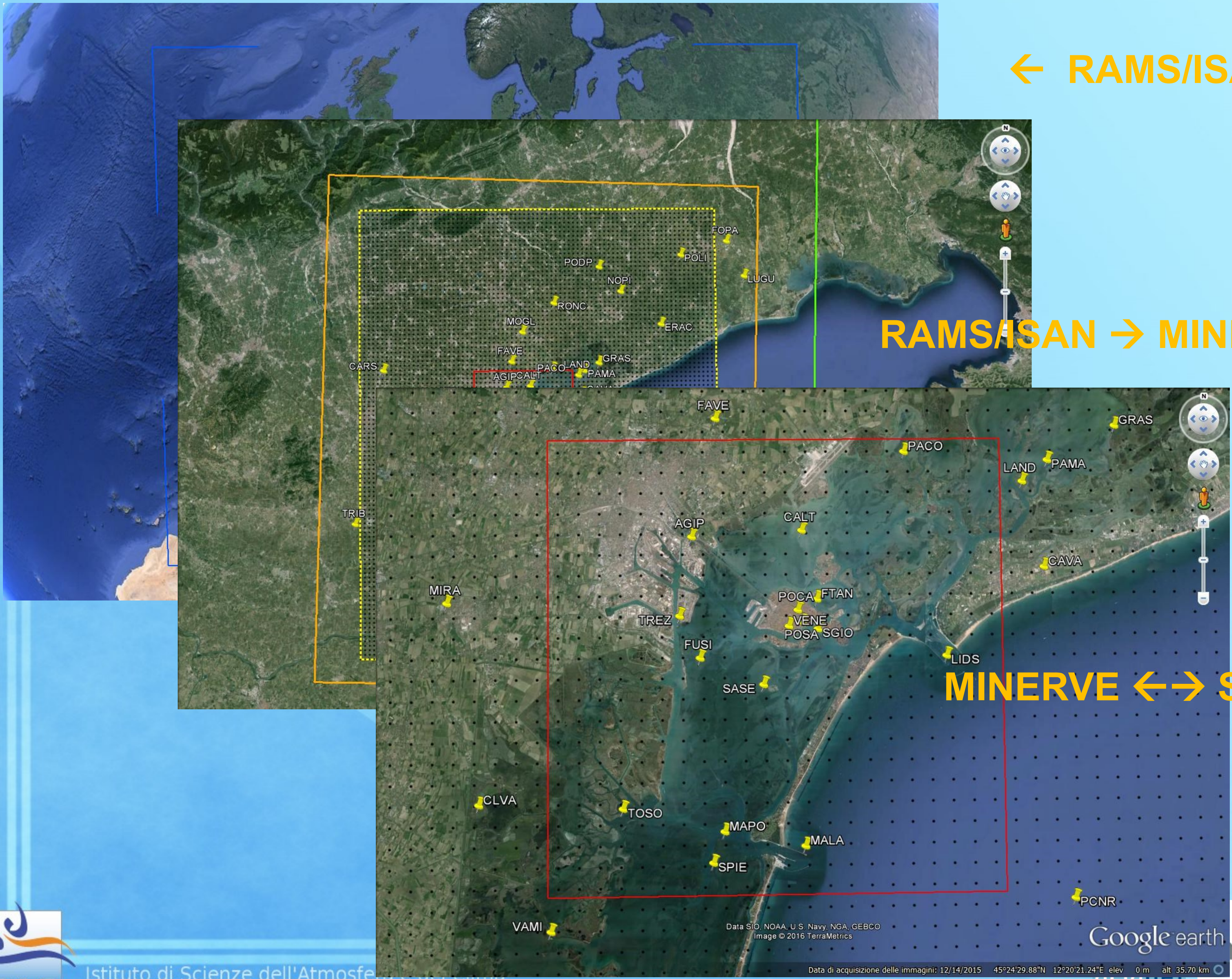
Lagrangian particle dispersion model

Simulation of the dispersion of the ship emissions in the two scenarios
Elaboration of concentration maps and impact indexes

← RAMS/ISAN

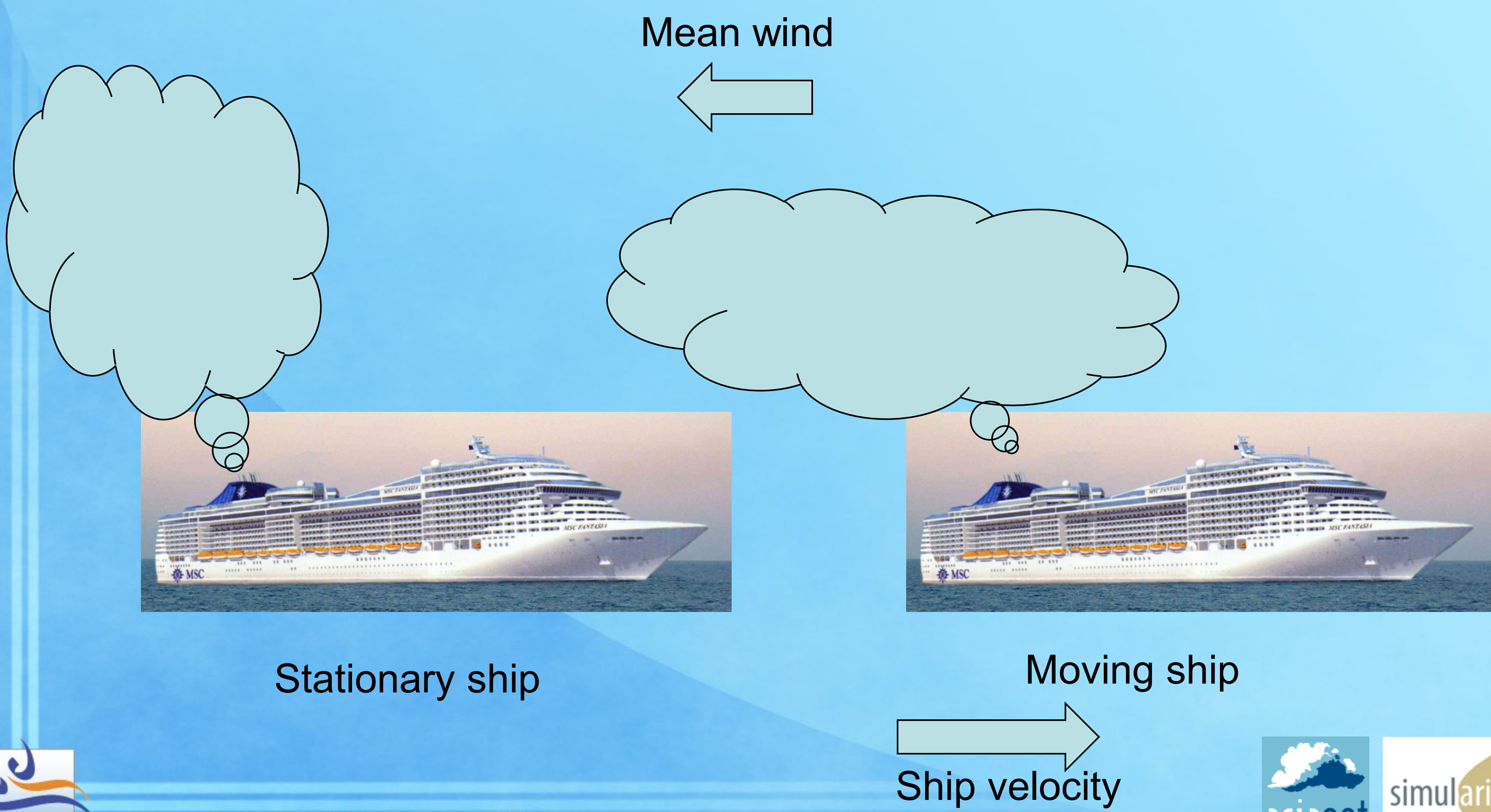
RAMS/ISAN → MINERVE

MINERVE ←→ SPRAY



➢ Plume rise from ships: modification

The idea is to consider, together with the effect of the mean wind, also the effect of the movement of the ship, generating an ‘apparent wind’: for example



➢ Plume rise from ships: modification

The idea is to consider, together with the effect of the mean wind, also the effect of the movement of the ship, generating an 'apparent wind': for example, defining the emission height $H_e(t)$

$$H_e(t) = f(F_b, u, t, s) = 2.6\left(F_b t^2 / u\right)^{1/3}\left(t^2 s + 4.3\right)^{-1/3}$$

$$F_b = g w_0 r_0^2 \frac{T_f - T_a}{T_a}$$

Buoyancy flux

$$s = \frac{g}{\vartheta}\frac{\partial \vartheta}{\partial z}$$

stability parameter

Anfossi D., Ferrero E., Brusasca G., Marzorati A., Tinarelli G. (1993). A simple way of computing buoyant plume rise in Lagrangian stocastic dispersion models, Atmospheric Environment 27A, 1443-1451.

where here $\vec{u} = \vec{u}_{WIND} + \vec{u}_{SHIP}$

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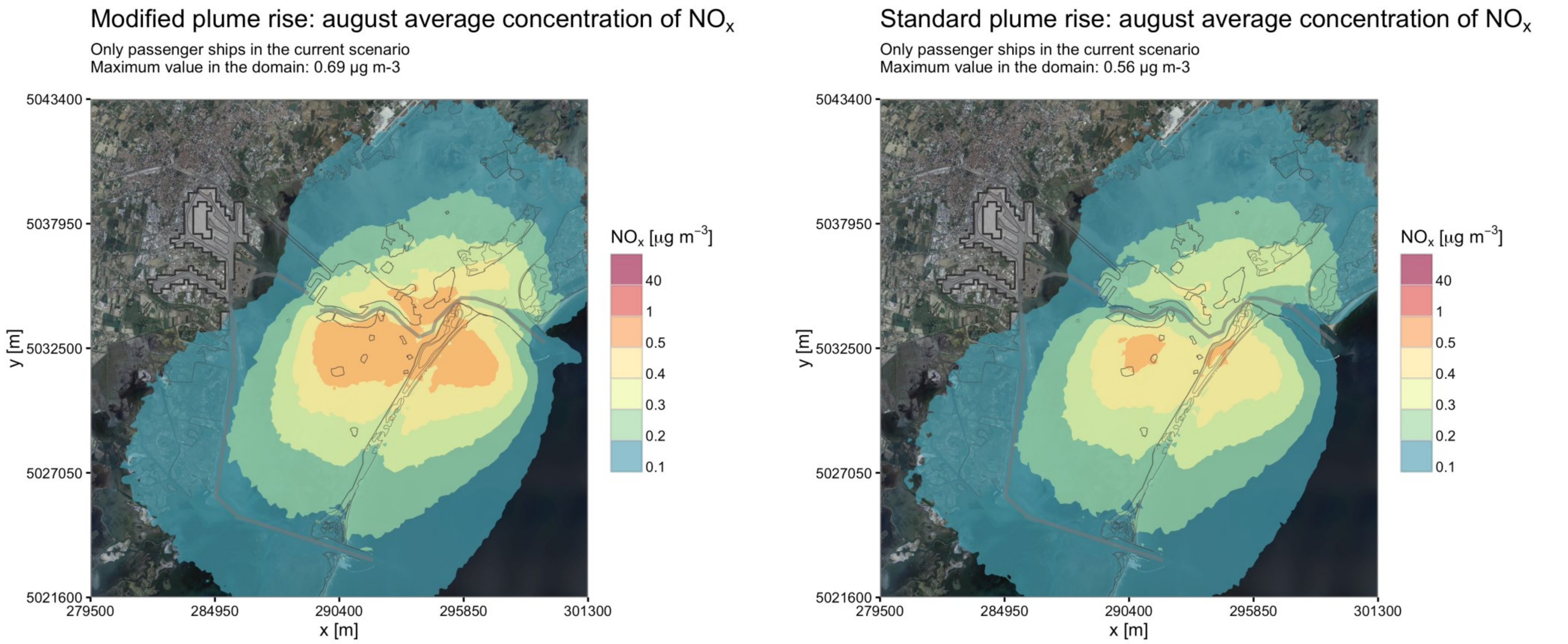
➢ Question I

What's the impact of modifying the plume rise to account for the motion of the ships **on the mean concentration**?

Examples for one-month simulation: August 2013

➢ Results

Simulation of the dispersion: comparison between the NEW plume rise and the OLD plume rise – **present scenario S0, only passenger ships >40 kTon**



SPRAY. August averaged concentration
Modified plume rise (left) vs standard plume rise (right)

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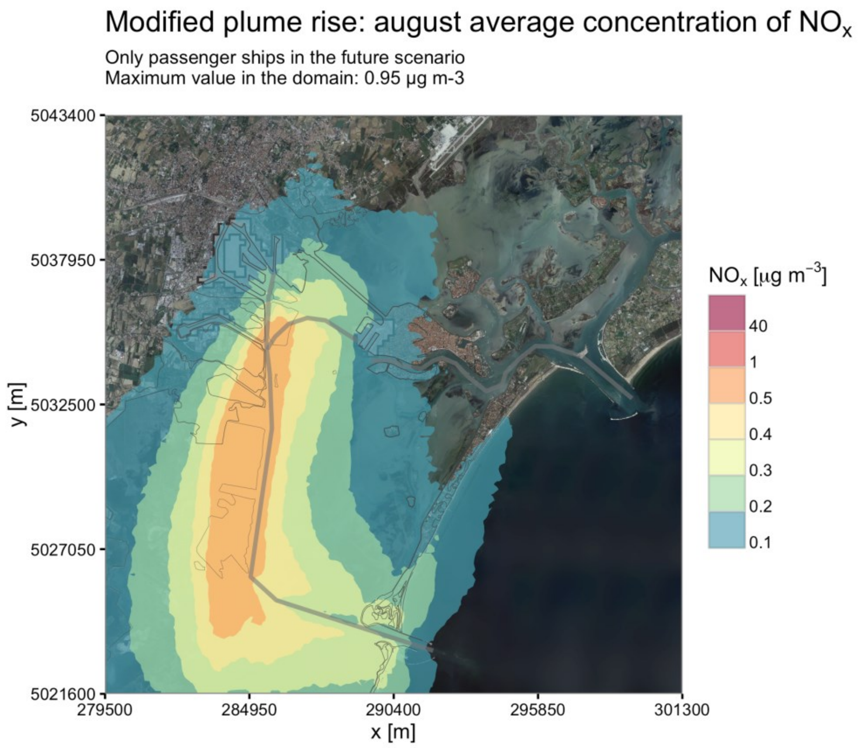
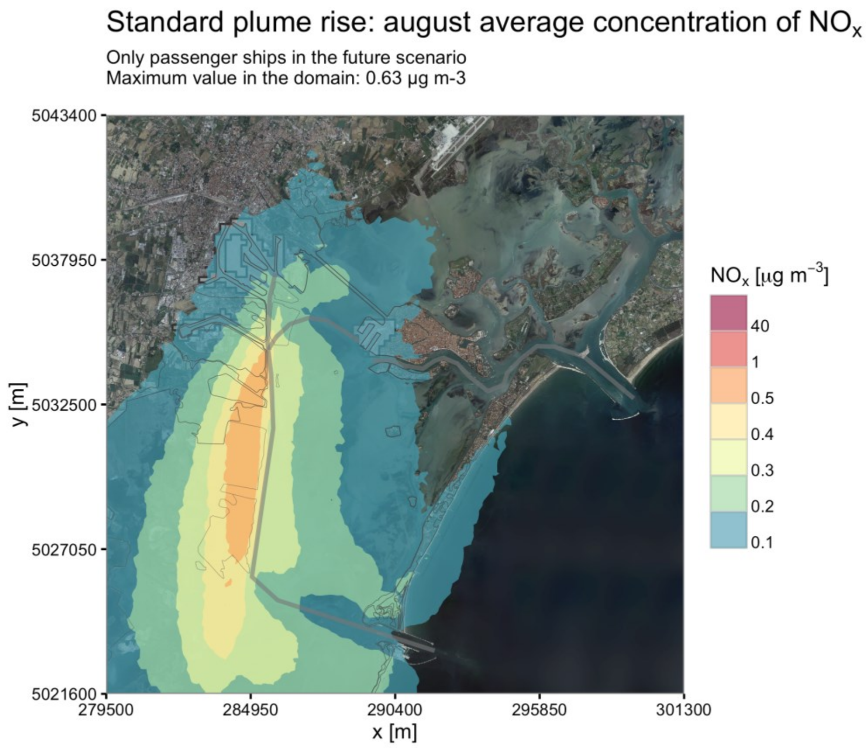
➤ Results

Simulation of the dispersion: comparison between the NEW plume rise and the OLD plume rise - **future scenario S1, only passenger ships >40kTon**

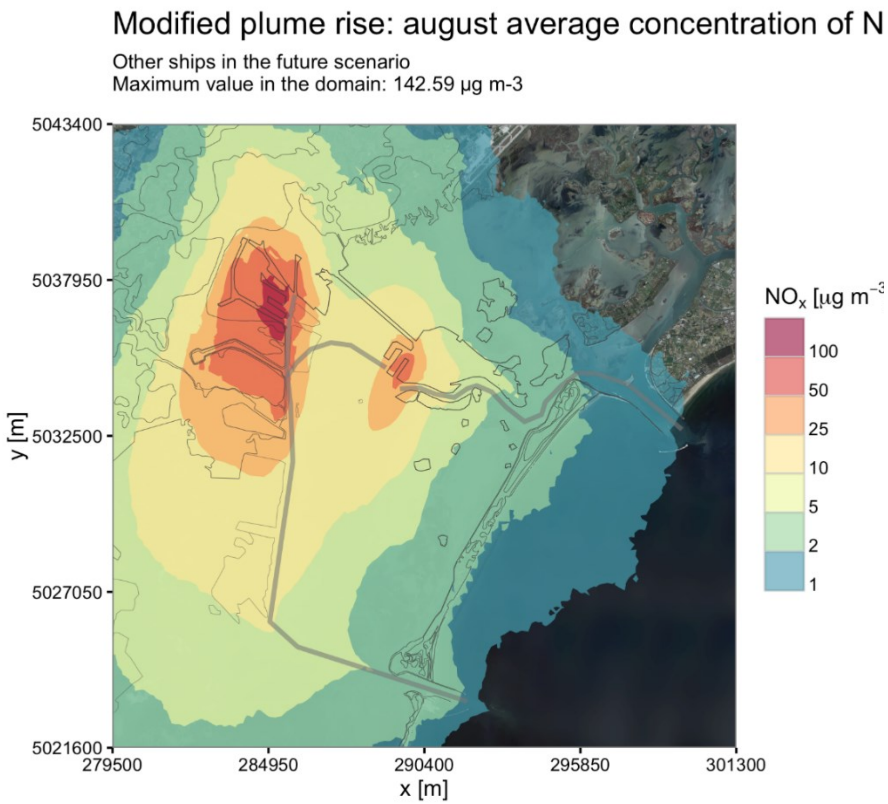


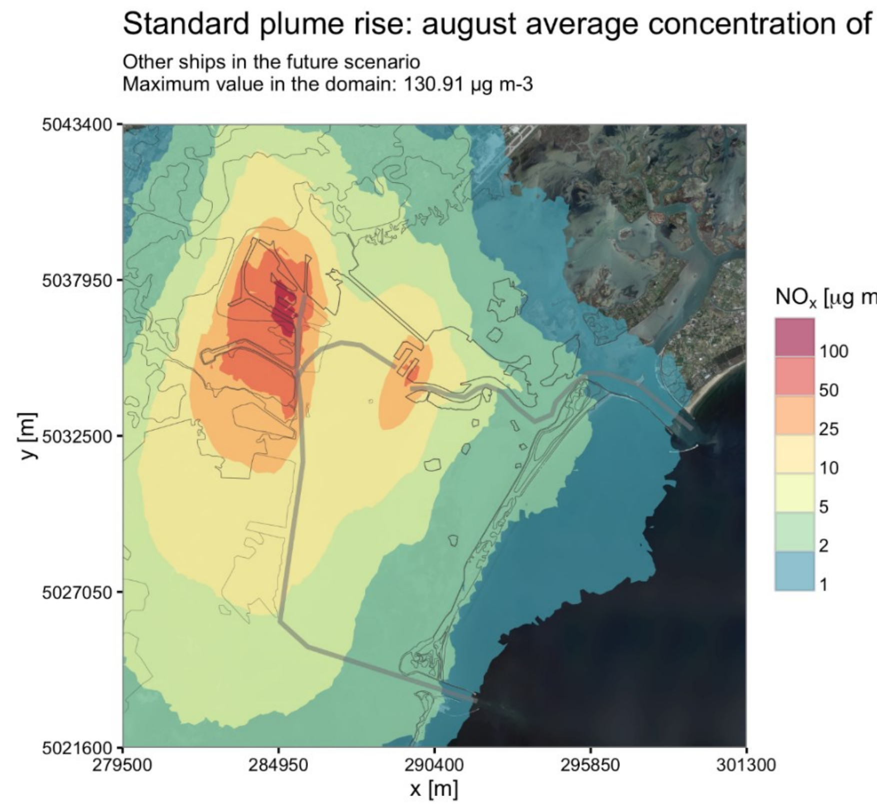


SPRAY. August averaged concentration
Modified plume rise (left) vs standard plume rise (right)

➢ Results

Simulation of the dispersion: comparison between the NEW plume rise and the OLD plume rise - **future scenario S1, all other ships**



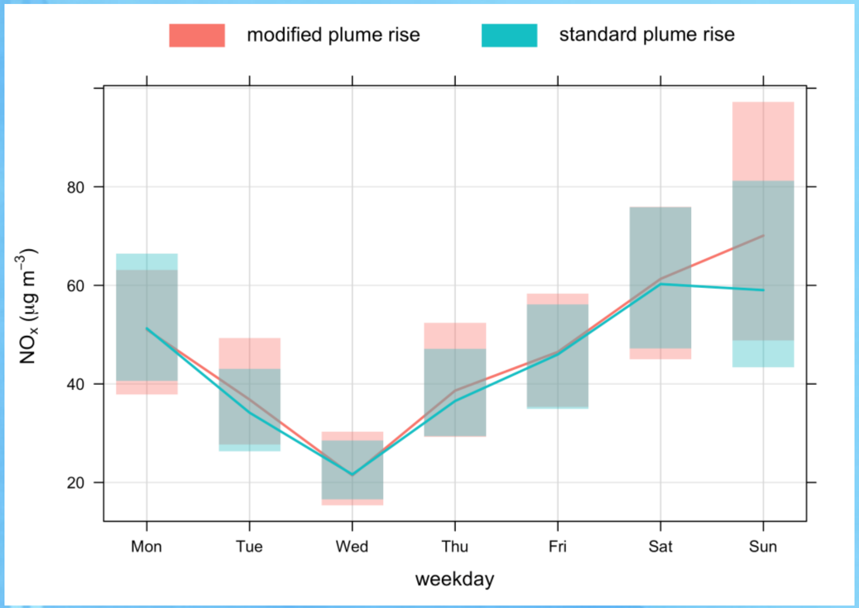


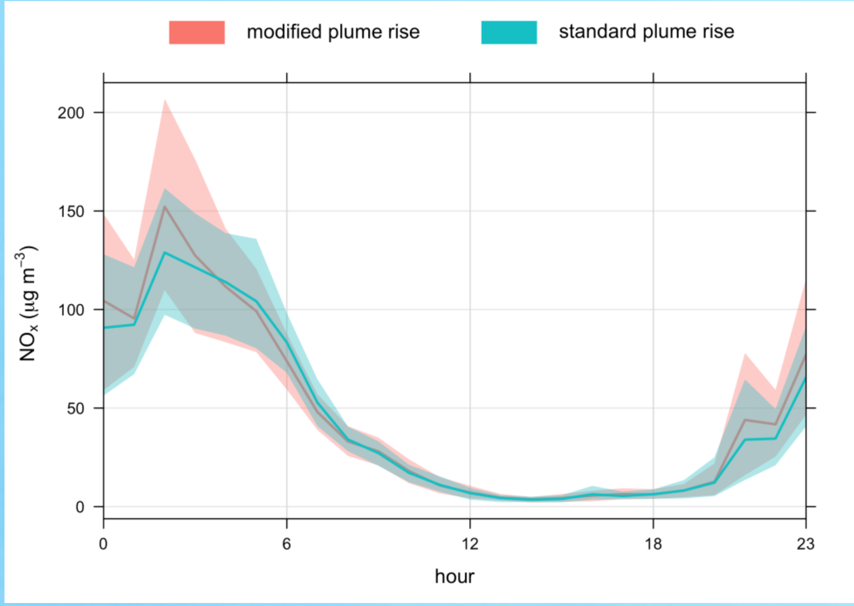
SPRAY. August averaged concentration
Modified plume rise (left) vs standard plume rise (right)

➢ Question I

What's the impact of modifying the plume rise to account for the motion of the ships **on the mean concentration**?

Examples at Sacca Fisola station, S1 scenario



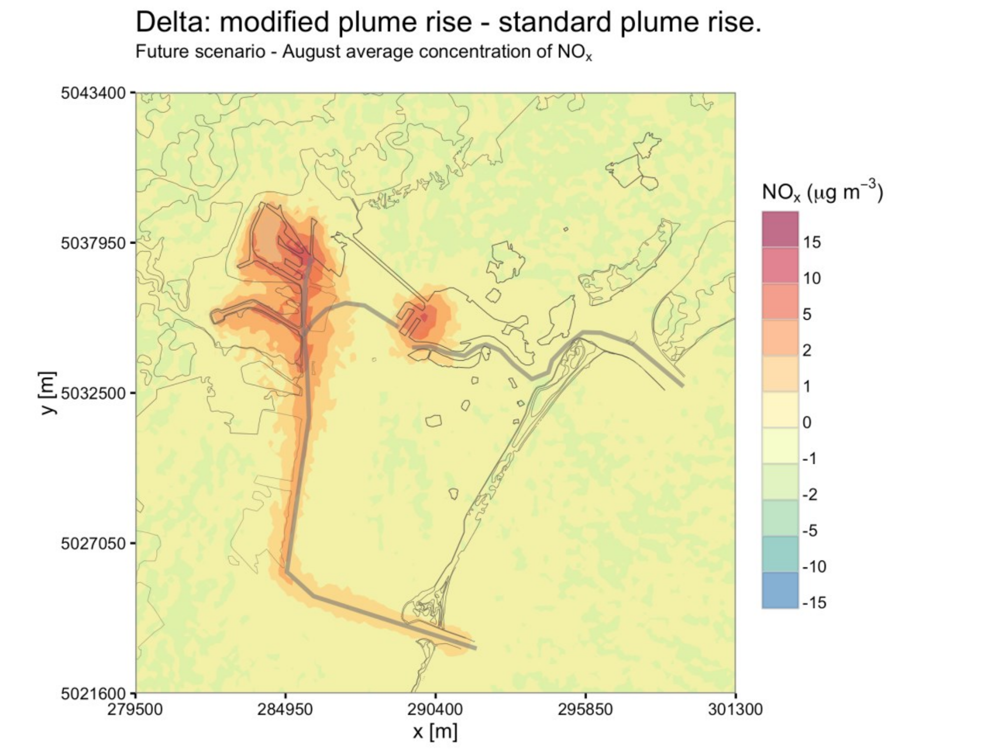


Daily Mean (left) and Hourly Mean (right), with 95% confidence interval

➢ Results

What's the impact of modifying the plume rise to account for the motion of the ships?

Examples for one-month simulation: August 2013, S1, all ships
difference between mean concentrations



The averaged concentrations systematically increase when adopting the modified plume rise, which accounts for the ships motion.

This may occur because on average the rise of the plume flattens due to the "relative velocity" to which the Lagrangian particles are subjected.

The difference is not negligible.

➢ Question II

How does the **relative direction** between the ship motion and the wind affect the plume rise?

Example for two months, July and August, 2013

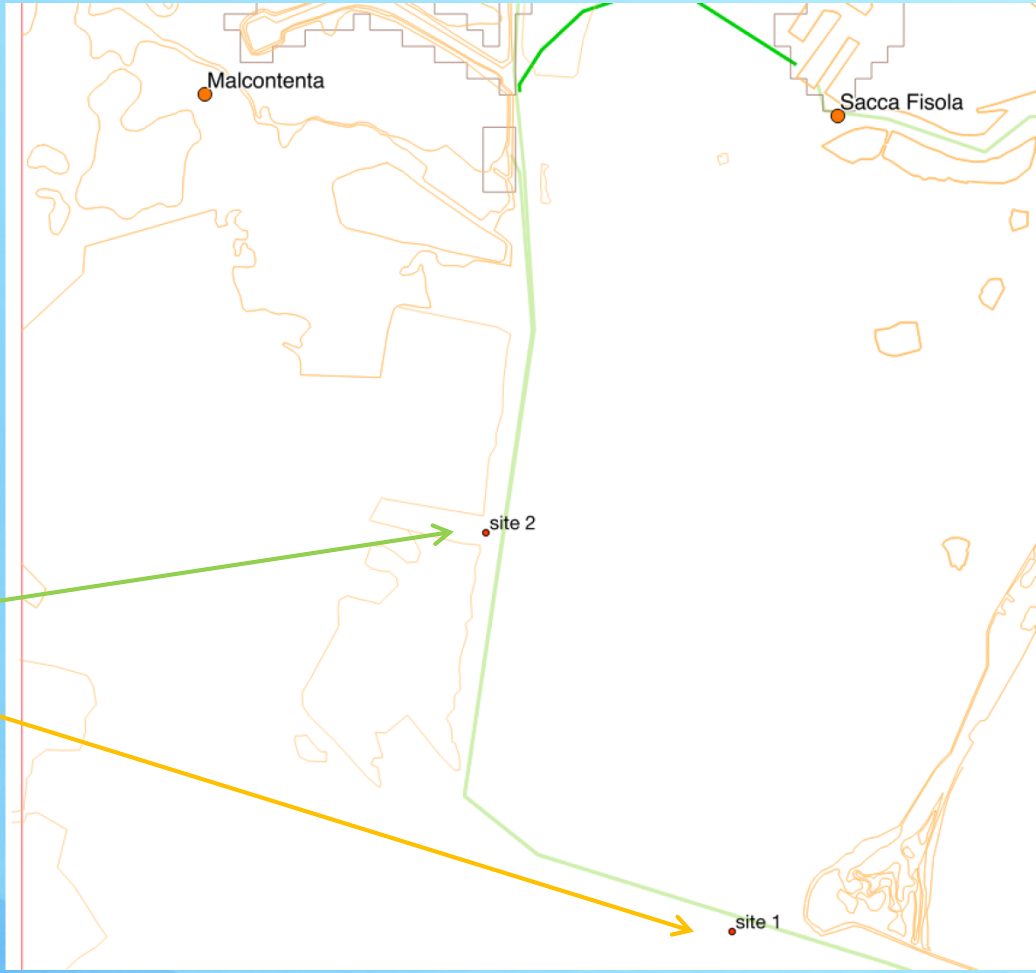
➢ Question II

How does the relative direction between the ship motion and the wind affect the plume rise?

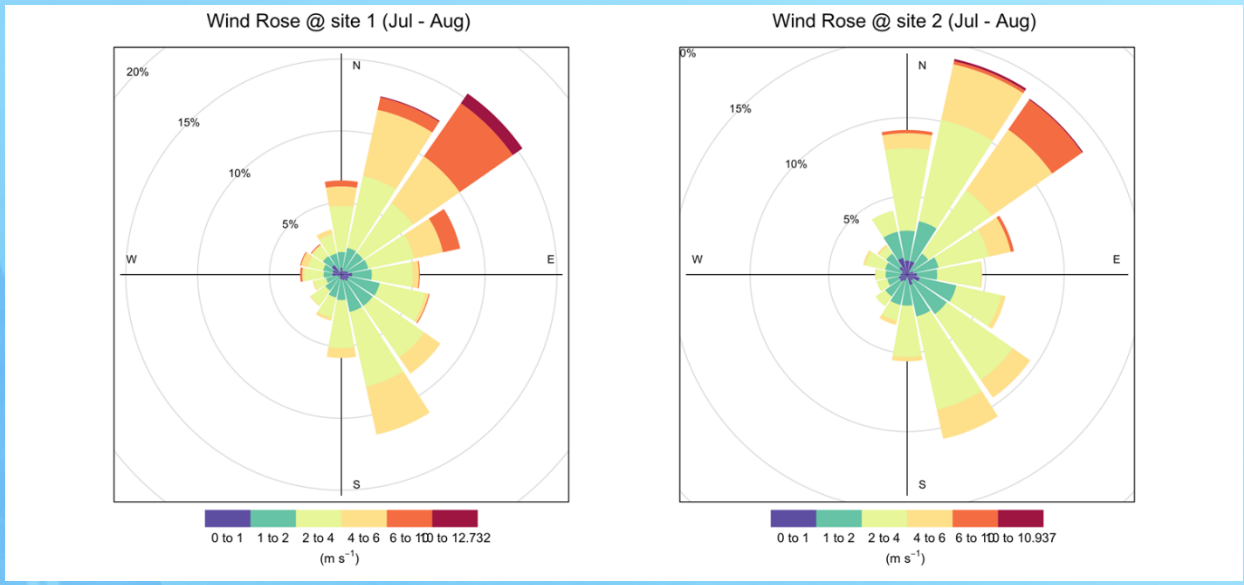
To investigate this possible interpretation, and to evaluate how the relative direction between the ship motion and the wind affects the plume rise, we selected two sites in proximity of the canals, about 200 m in the leeward of the ship trajectories.

Site 1: *the trajectory of the ship is about 17° clockwise the east-west direction and the wind direction tends to be orthogonal to it*

Site 2 *the trajectory of the ship is about 8° clockwise the north-south and the wind direction is mostly parallel to it.*

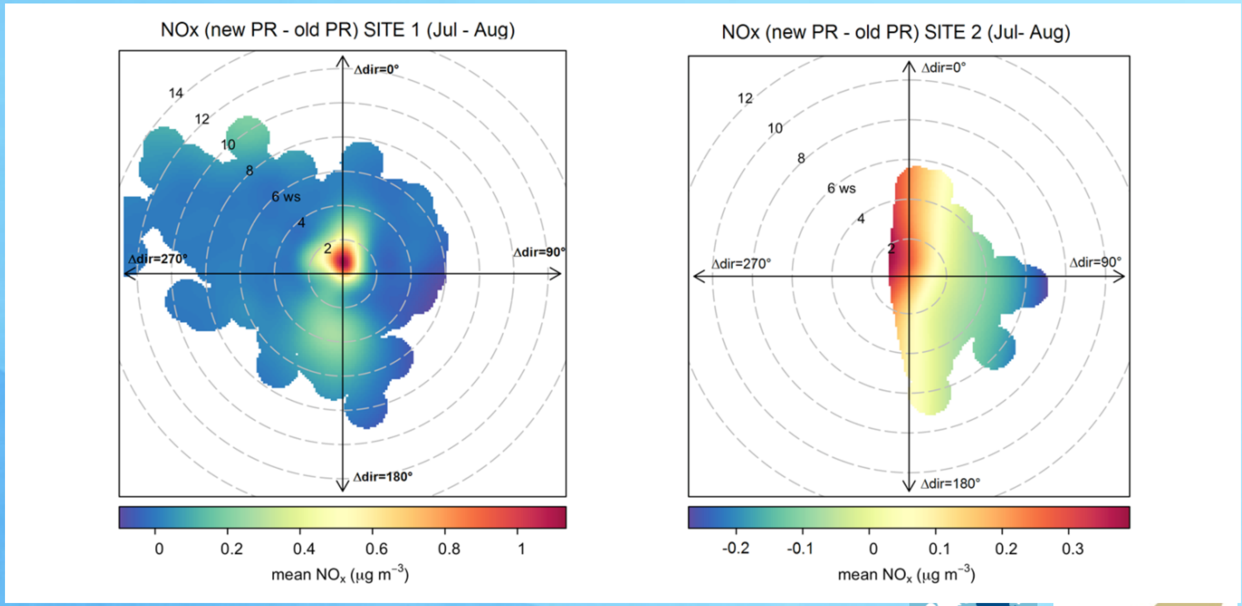


➢ Results



RMS simulation.
Wind roses at the two selected sites, Site 1 (left) and Site 2 (right), for the months of July and August 2013.

RMS simulation, **S1.**
Polar plot, **referred to the direction difference,** of the difference (NEW_PR – OLD_PR) in ground level concentrations at the two selected sites, Site 1 (left) and Site 2 (right)



Question II

How does the relative direction between the ship motion and the wind affects the plume rise?

An increase in the concentration occurs with the modified algorithm when the wind velocity and the ship trajectory are parallel (Δdir = 0° and 180°).

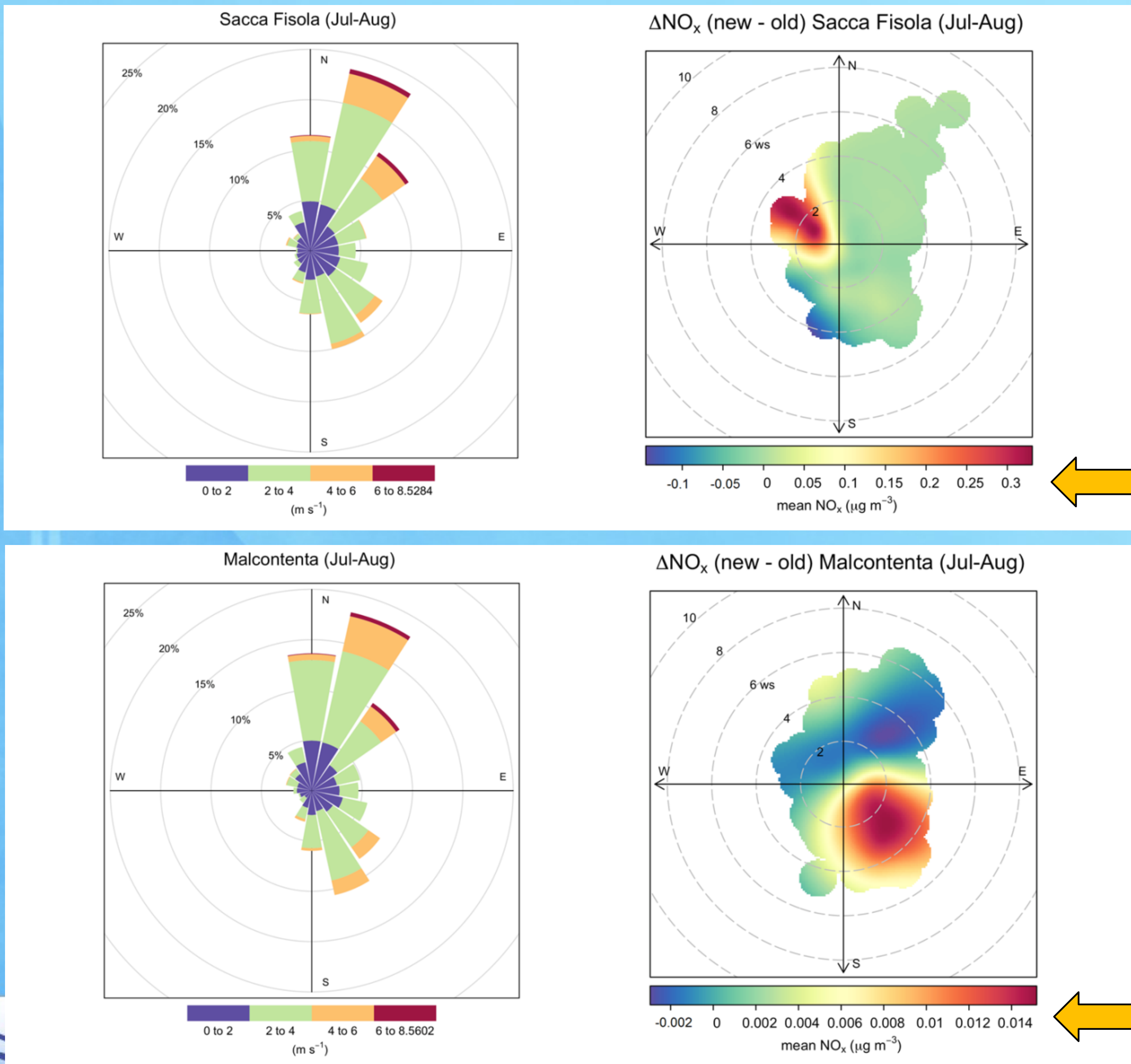
When the angle between the ship trajectory and the wind direction tends towards orthogonality (Δdir = 90° and 270°), the difference in concentration decreases (Site 1) and in some cases the modified plume rise algorithm produces even lower concentrations (Site 2).

This result seems to confirm the hypothesis that when the ships are moving on a trajectory aligned with the wind velocity direction, the plume tends to be flatten and its reduced rising induces higher ground level concentrations.

Instead, when the wind blows in the orthogonal direction with respect to the ship trajectory, on average the modification of the plume rise to account for moving ships is less effective, mainly due to a smaller contribution of the ship motion to the apparent velocity.

➢ Results

... And the final effect at measuring stations...



Wind roses (left) and polar plots (right) for the difference in concentration, **referred to the geographical system,** for Sacca Fisola (TOP) and Malcontenta (BOTTOM) locations.

July and August 2013.

➢ Results

... And the final effect at measuring stations...

The effect of the new plume rise, increasing the concentration, is clearly seen at **Sacca Fisola** in the NW sector, which includes the arc of the Tresse canal from where the ships arrive at the harbour close to the station.

In **Malcontenta** the effect is less enhanced, since this station is farther away from the canal and the ship emissions.

➢ Conclusions

Overall, the modification of the plume rise, to account for the ships motion for better representing the real physical processes, has non-negligible effects on the concentration field.

In this study, the ship emissions were treated as time-dependent linear sources. Therefore, it was not possible to detail the behaviour of a single plume when the ship is moving in the same or in the opposite direction with respect to the wind velocity one.

As future work to investigate and assess this issue, simulations for moving point sources will be performed.

Thanks for your attention!