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Surface Ocean Processes in the Anthropocene

Preliminary results of the SOPRAN seawater gas exchange experiment in the Heidelberg Aeolotron

Kerstin Krall

J. Kunz, M. Bopp, D. Kiefhaber, M. Ribas Ribas, J. Rahlff, O. Wurl, C. Sun, M. Sperling, A. Engel, A. Nölscher, B. Derstroff, C. Stönner, J. Williams, B. Schneider and B. Jähne

Heidelberg Collaboratory for Image Processing

Leibniz-Institut für Ostseeforschung Warnemünde

Max-Planck-Institut für Chemie

ICBM

GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel

Goal of the Experiments

study the effects of the natural sea surface microlayer on the transfer of

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Xenon
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DMS
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heat transfer
momentum transfer

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posters: Kunz et al. & Bopp et al.

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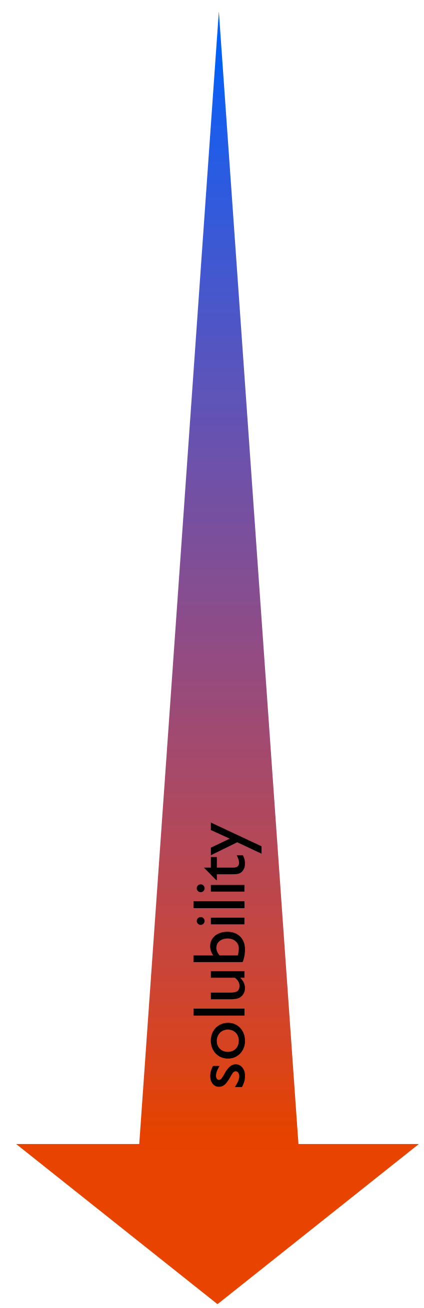
Acetonitrile
Butanol
Methanol 5380



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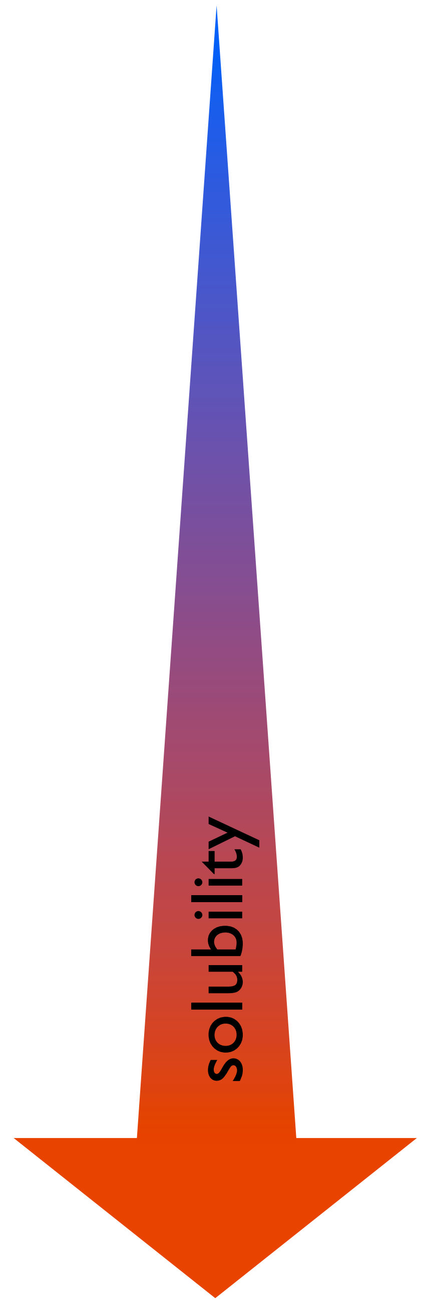

5380

heat transfer
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in a controlled lab setting

Sea Water

20 000 liters transported to Heidelberg

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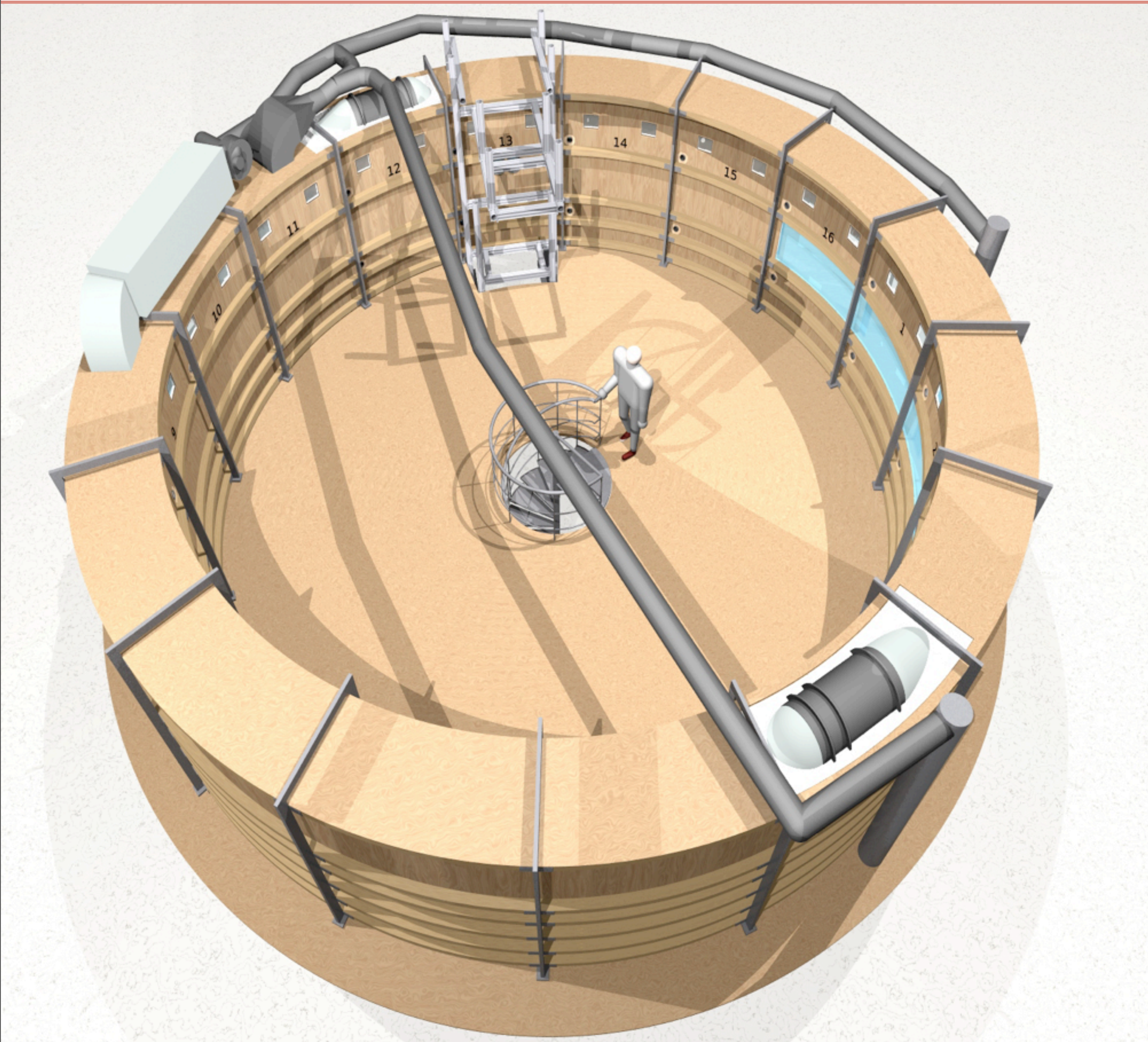
The Heidelberg Aeolotron

The World's Largest Annular Wind-Wave Tank in Operation



annular shape

diameter:	~10 m
flume width:	61cm
flume height:	240 cm
water level:	~100cm
wind speed u_{10}:	<22 m/s

thermally insulated
air-tight

air conditioning

bubble generator
(porous tubes)

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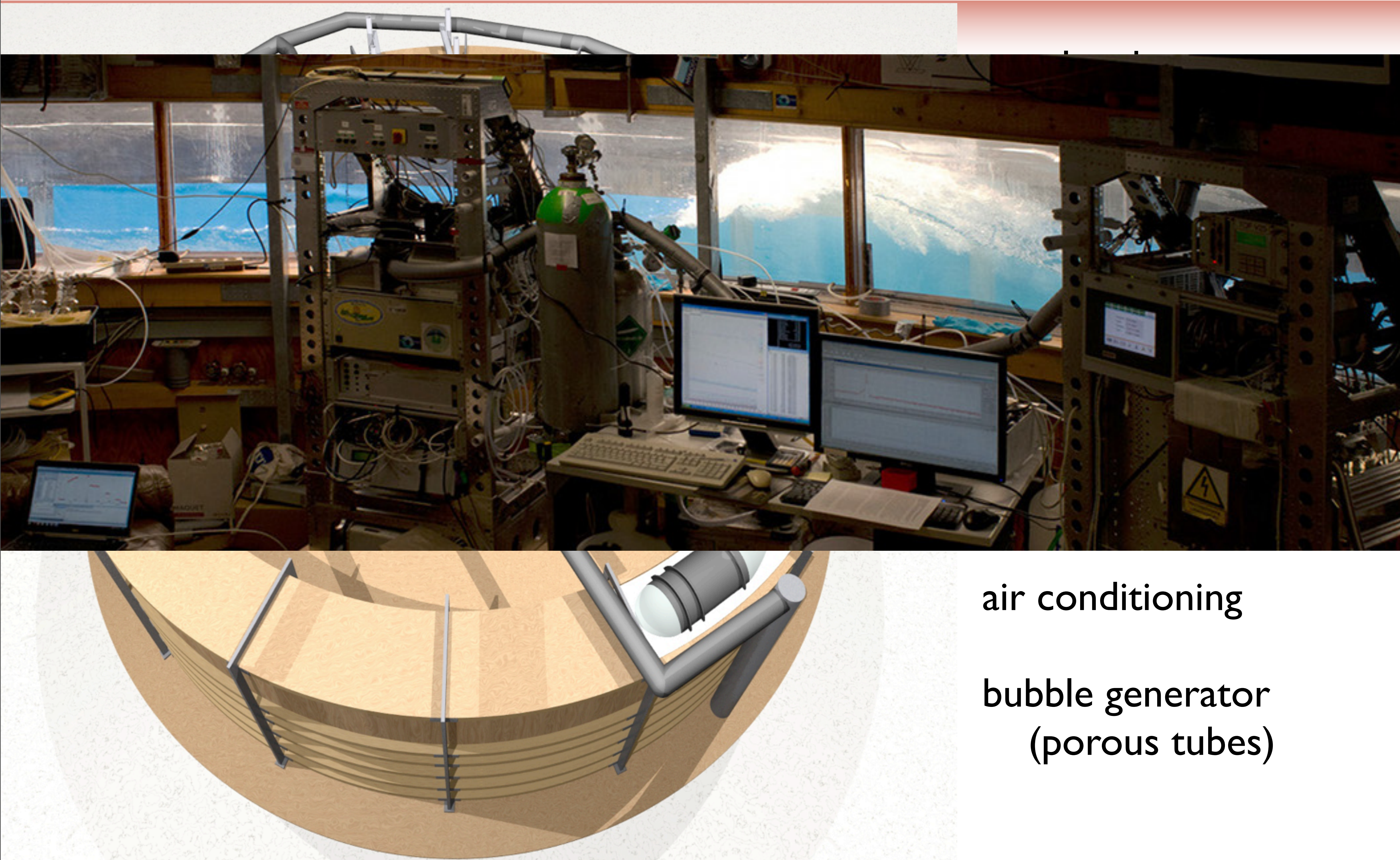

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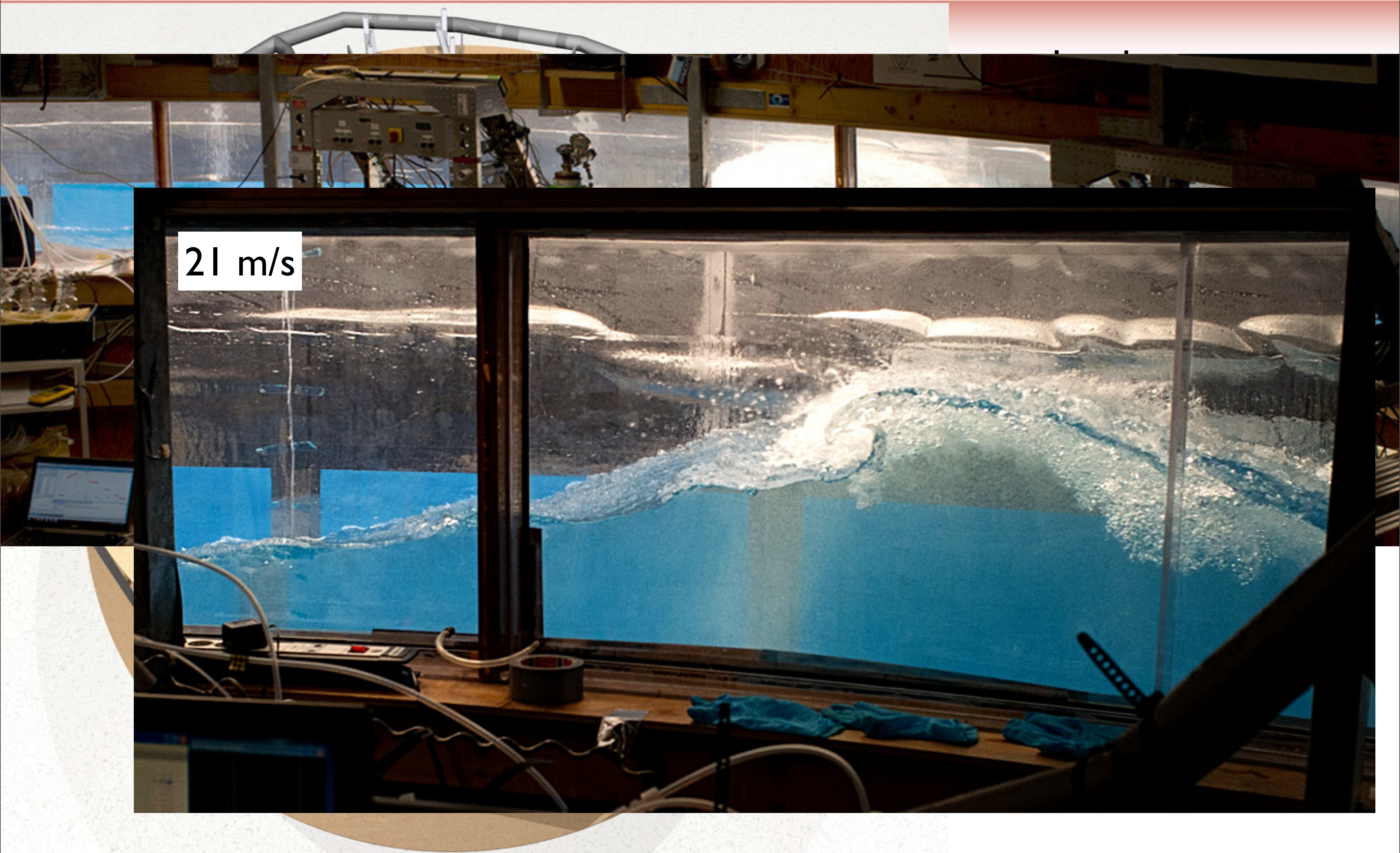

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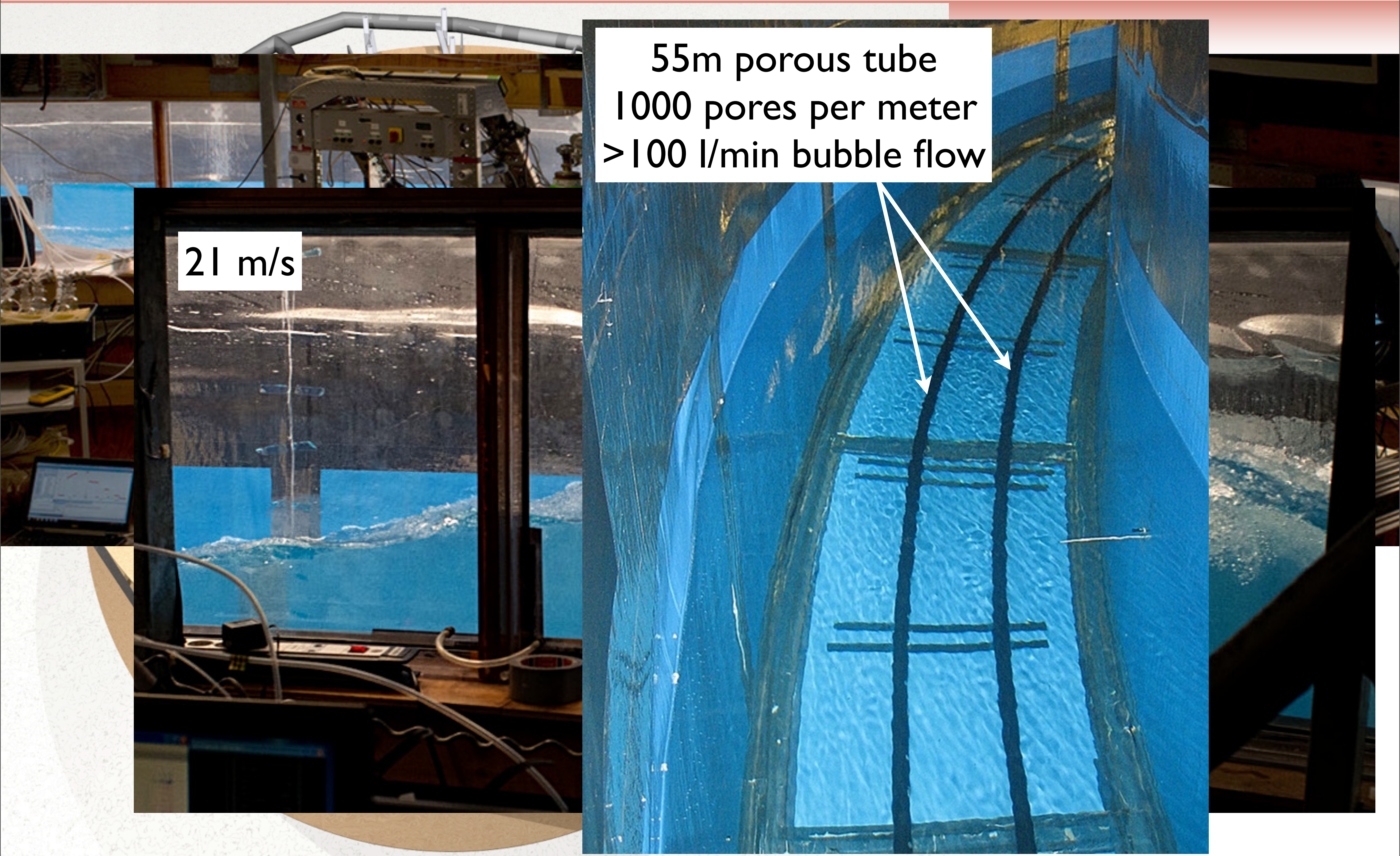

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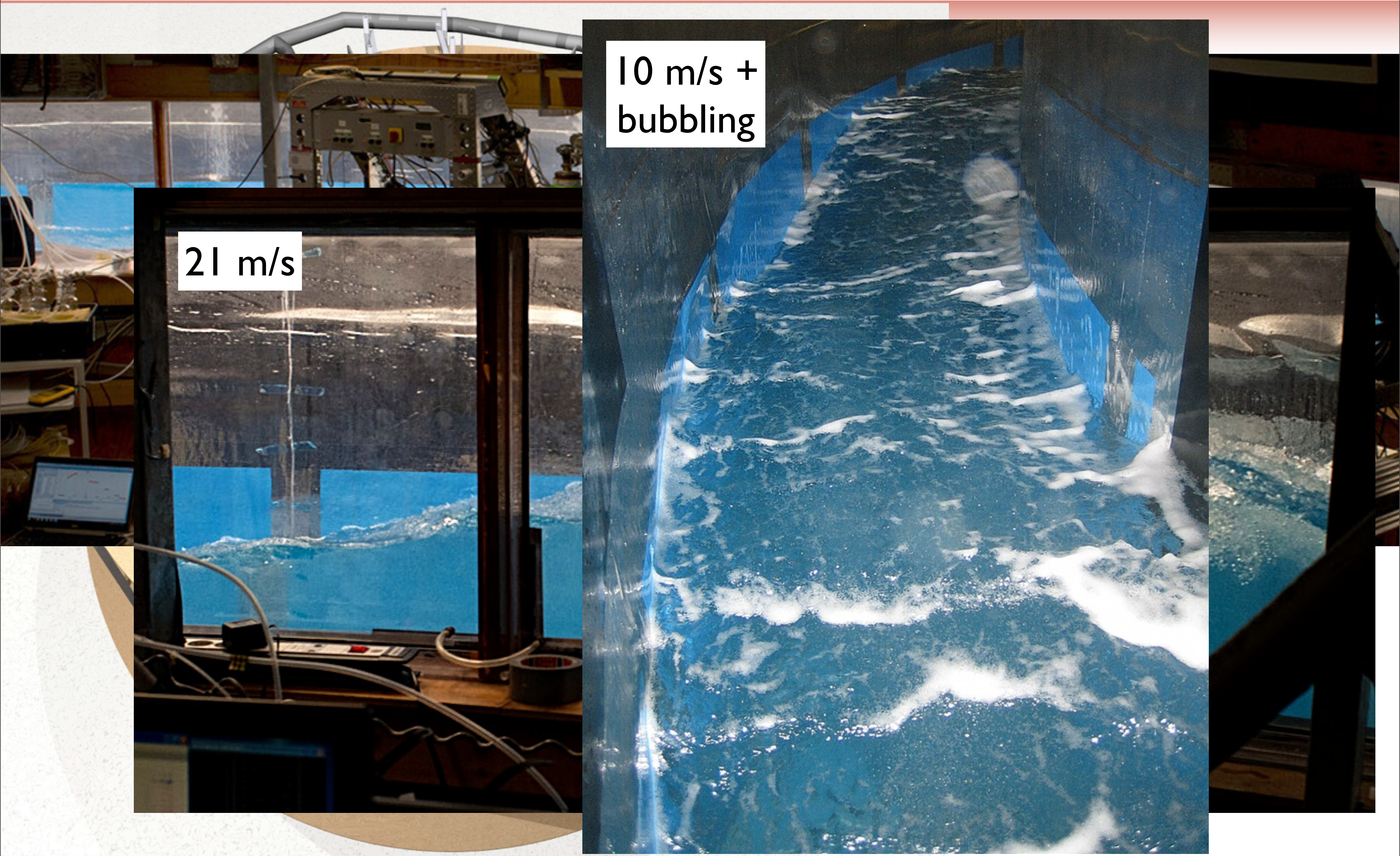
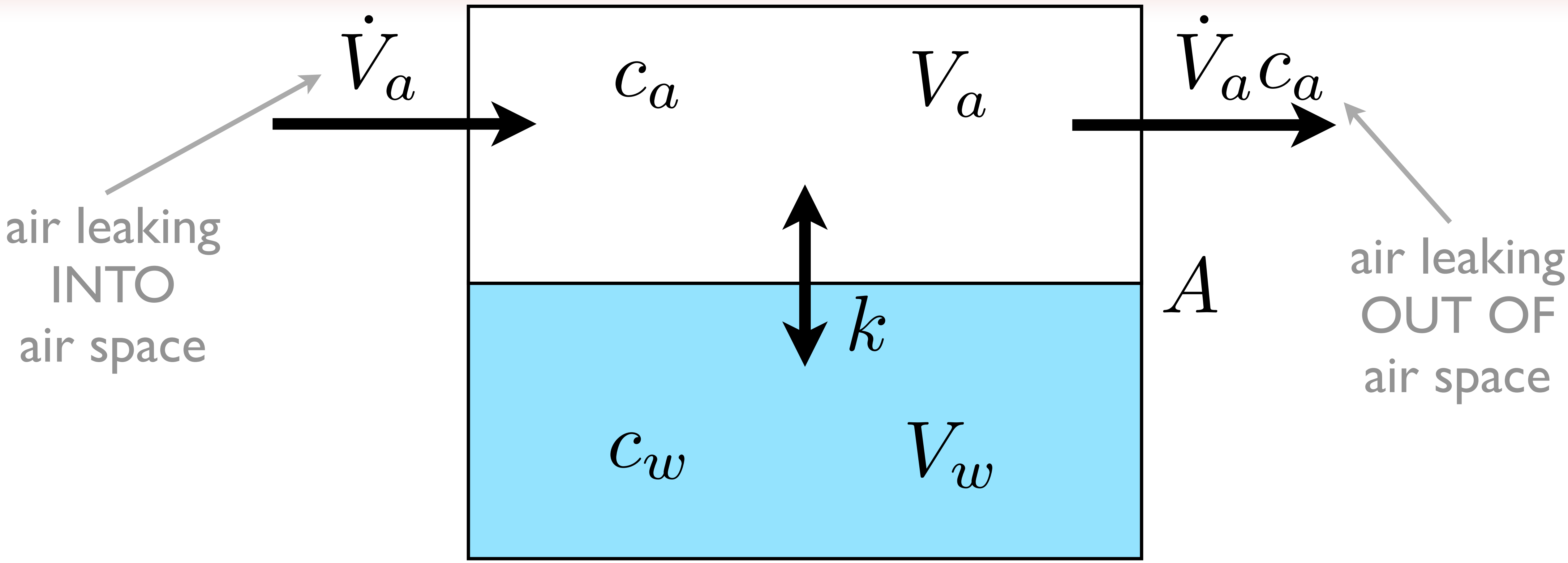


The Mass Balance Method

to measure the gas transfer velocities



Mass balance equation: $\Delta m = m_{in} - m_{out}$

air side: $$V_a \dot{c}_a = \quad A k_w (c_w - \alpha c_a) - \dot{V}_a c_a$$

method explained in detail in Mesarchaki et. al 2015

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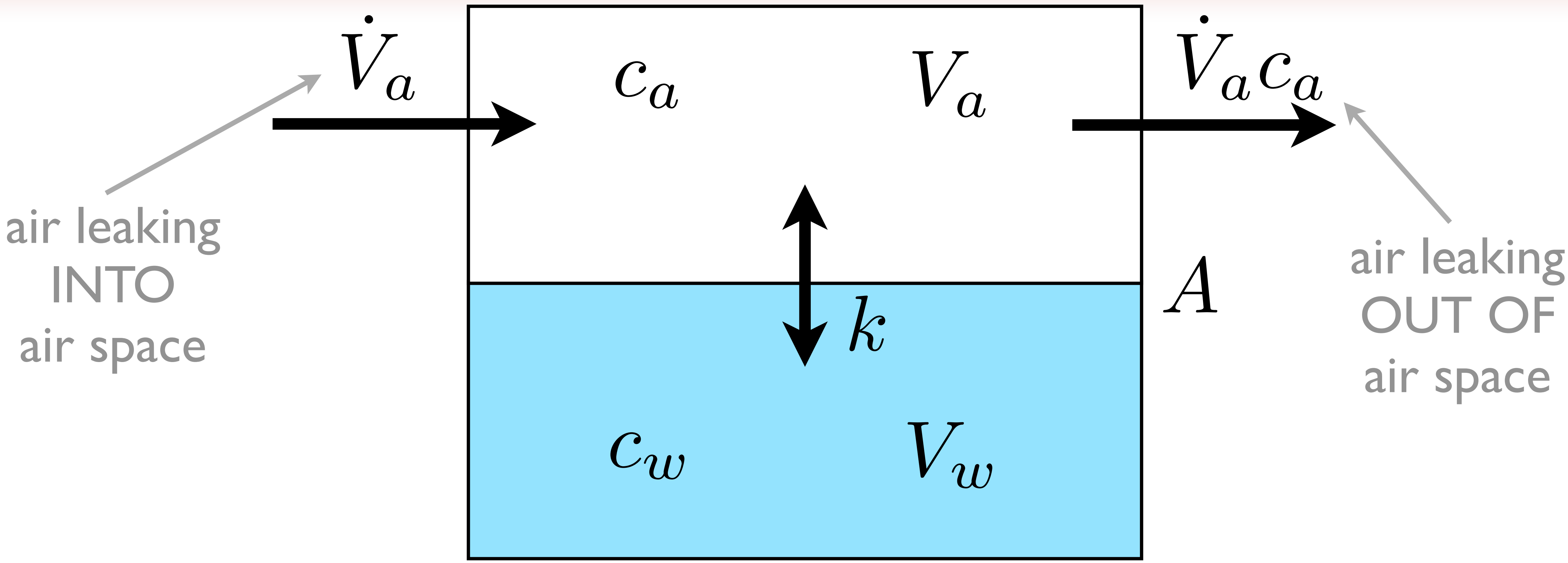

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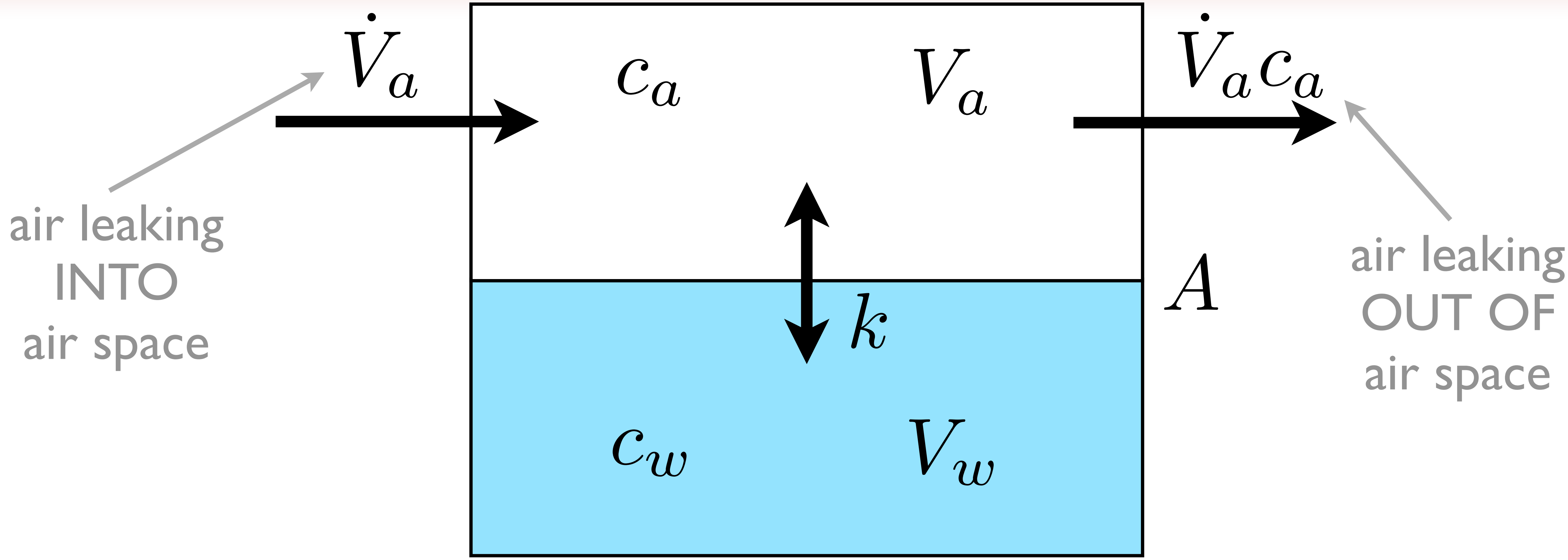

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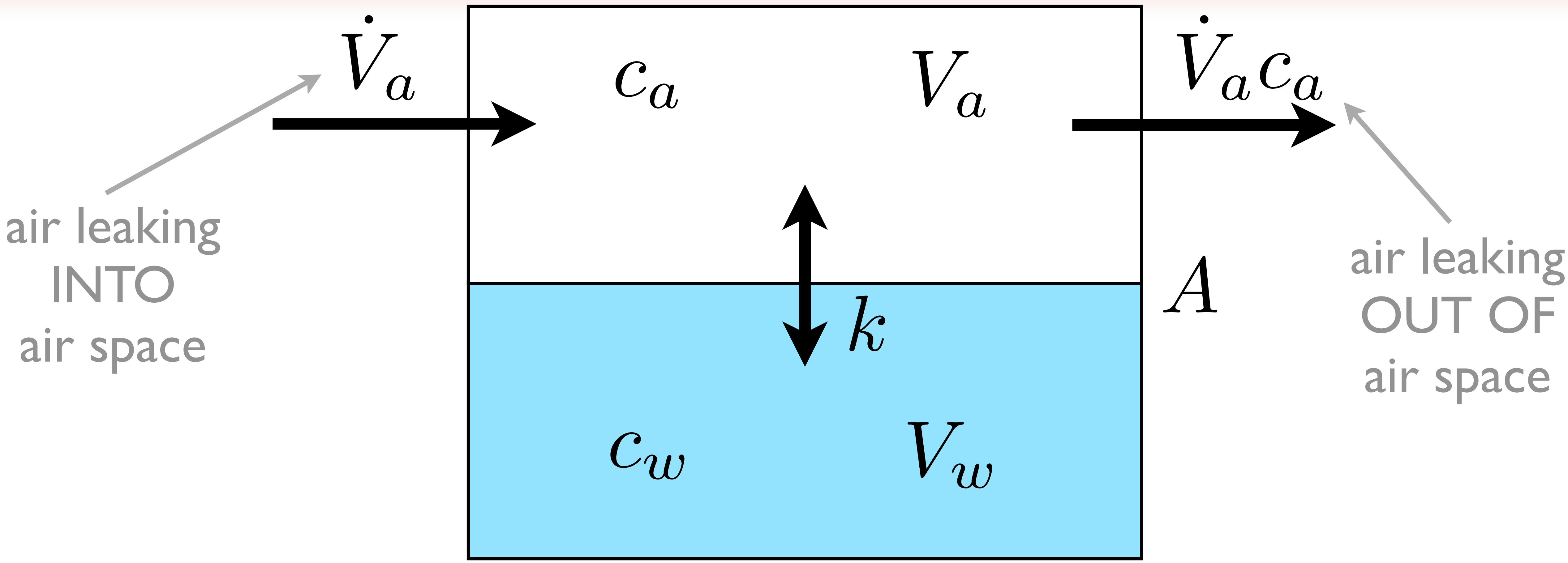

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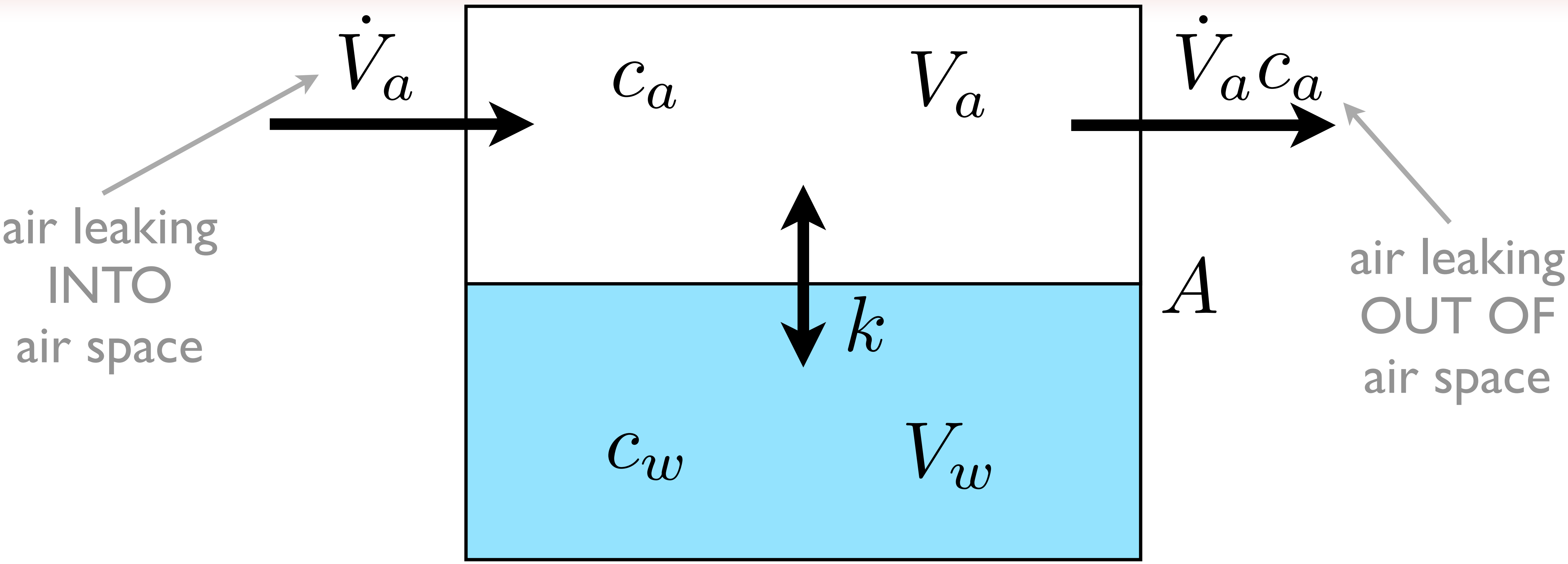

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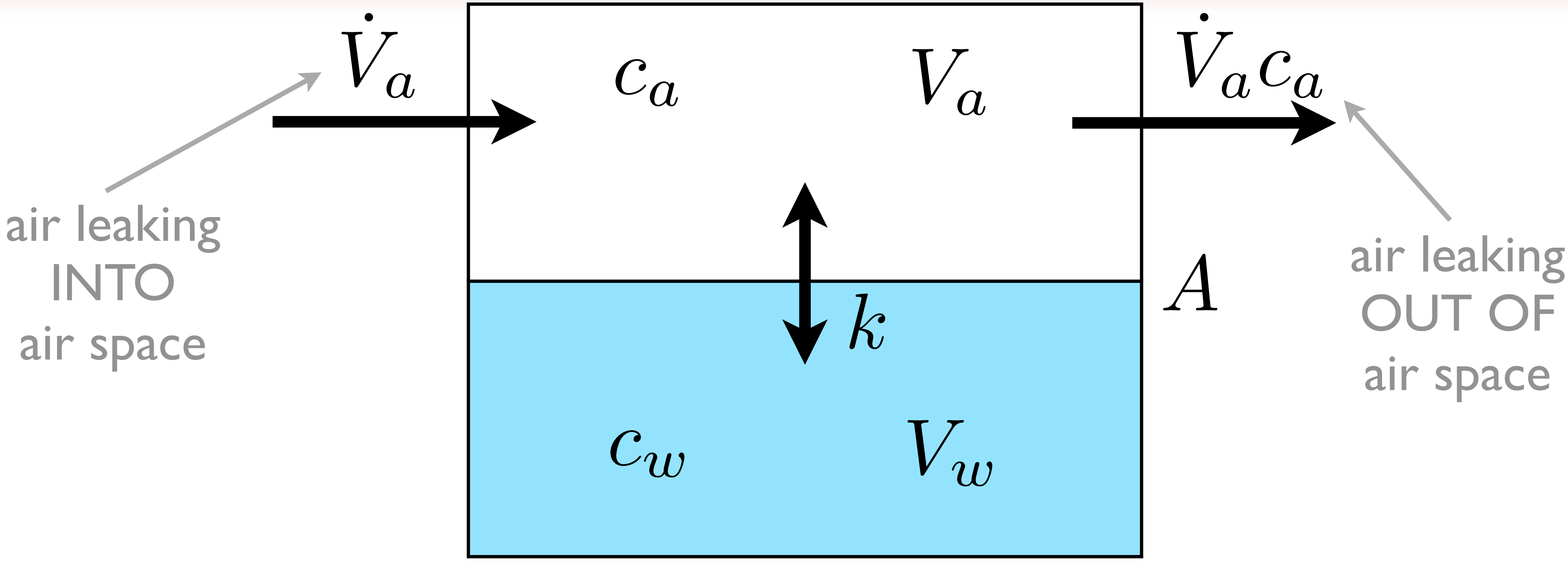

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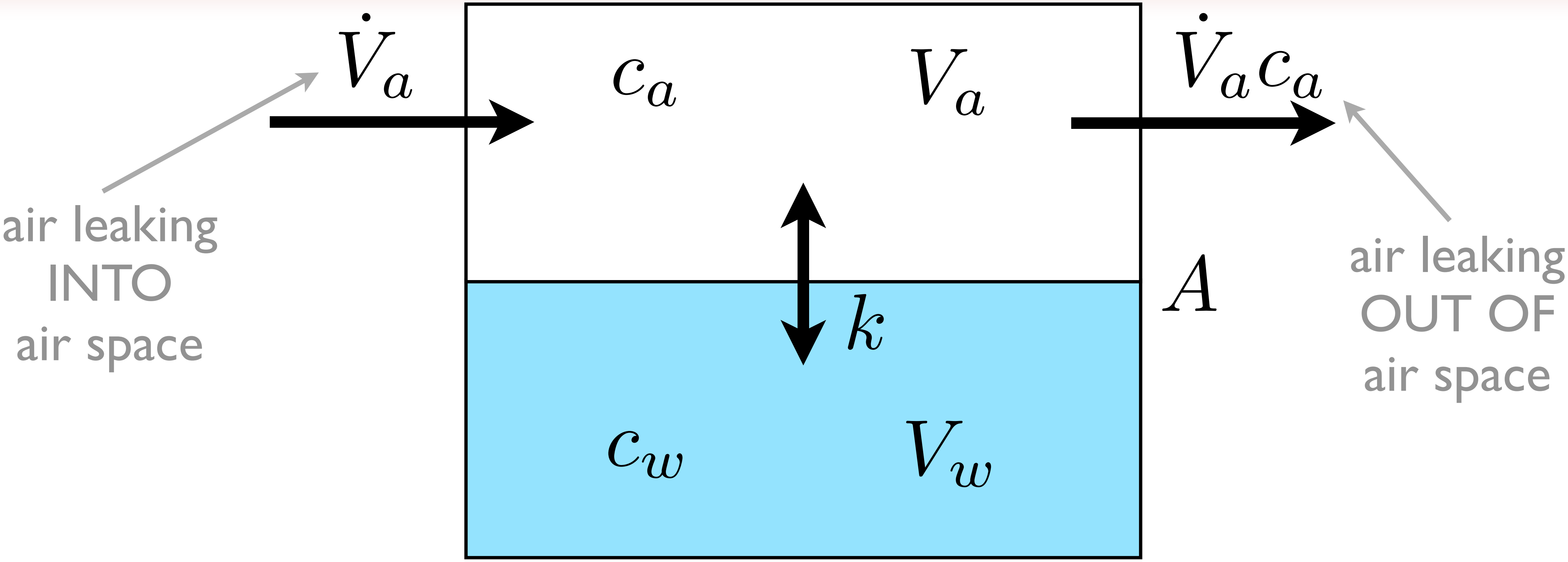

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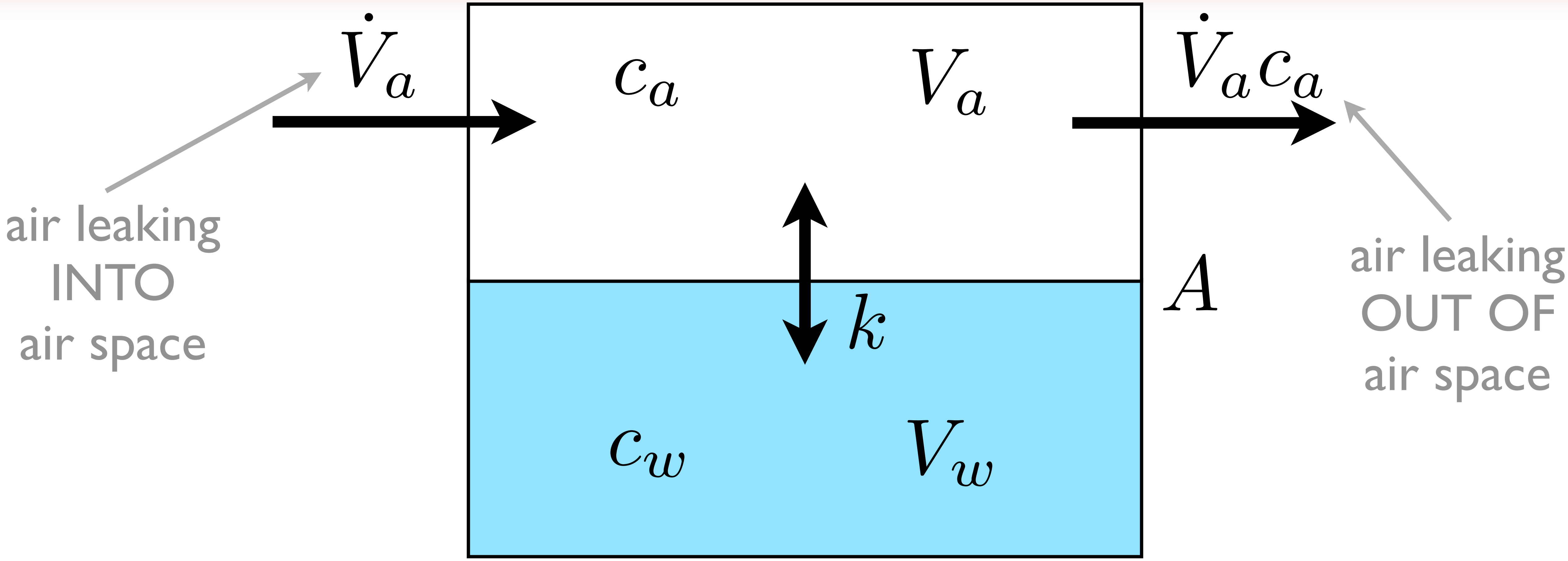

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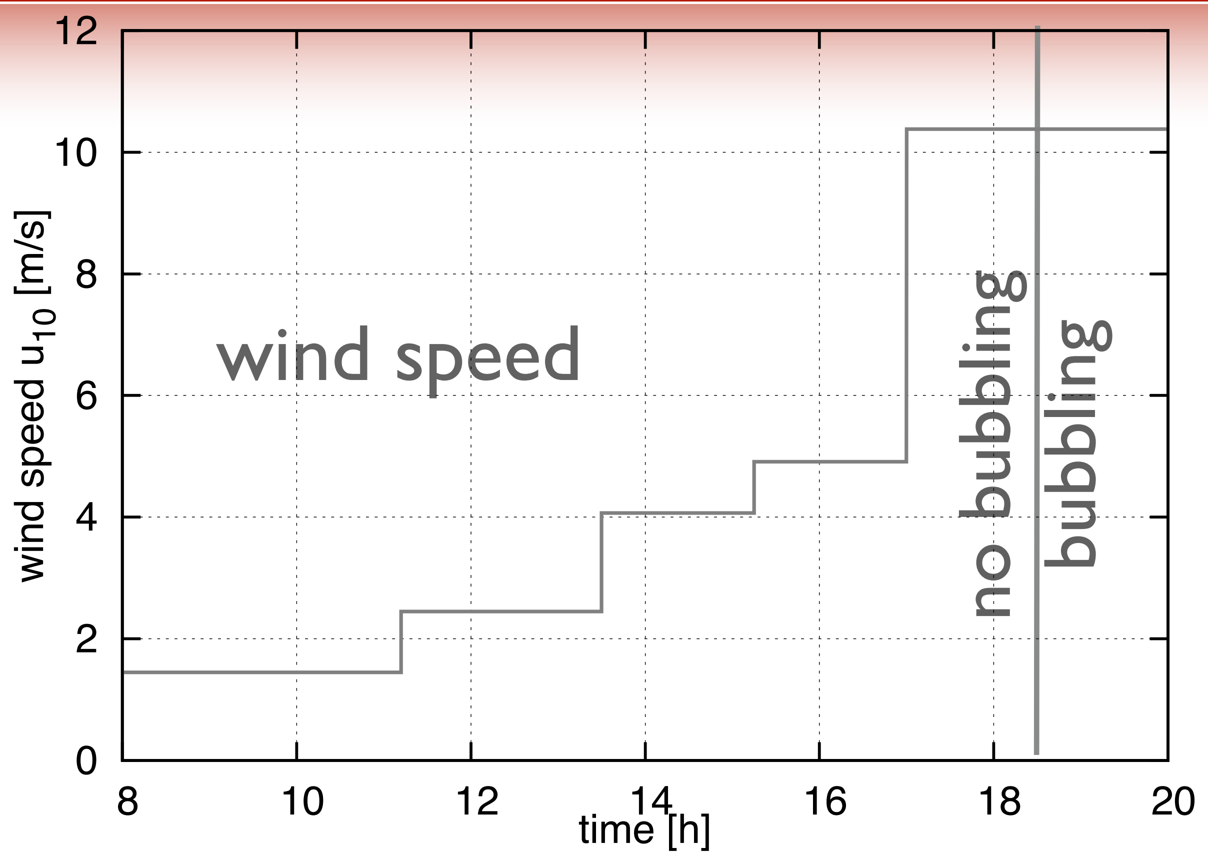
A typical evasion experiment

Evasion of N_2O - concentration time series and transfer velocity



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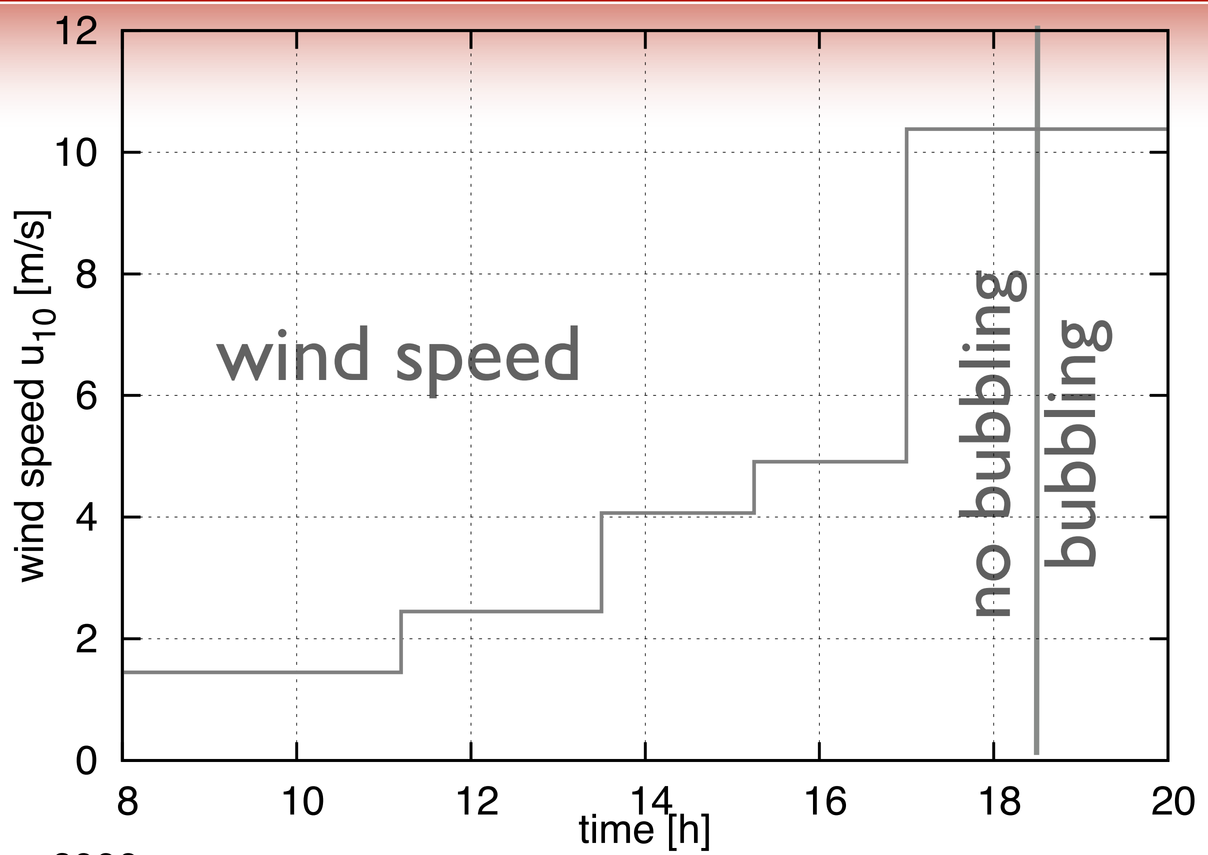

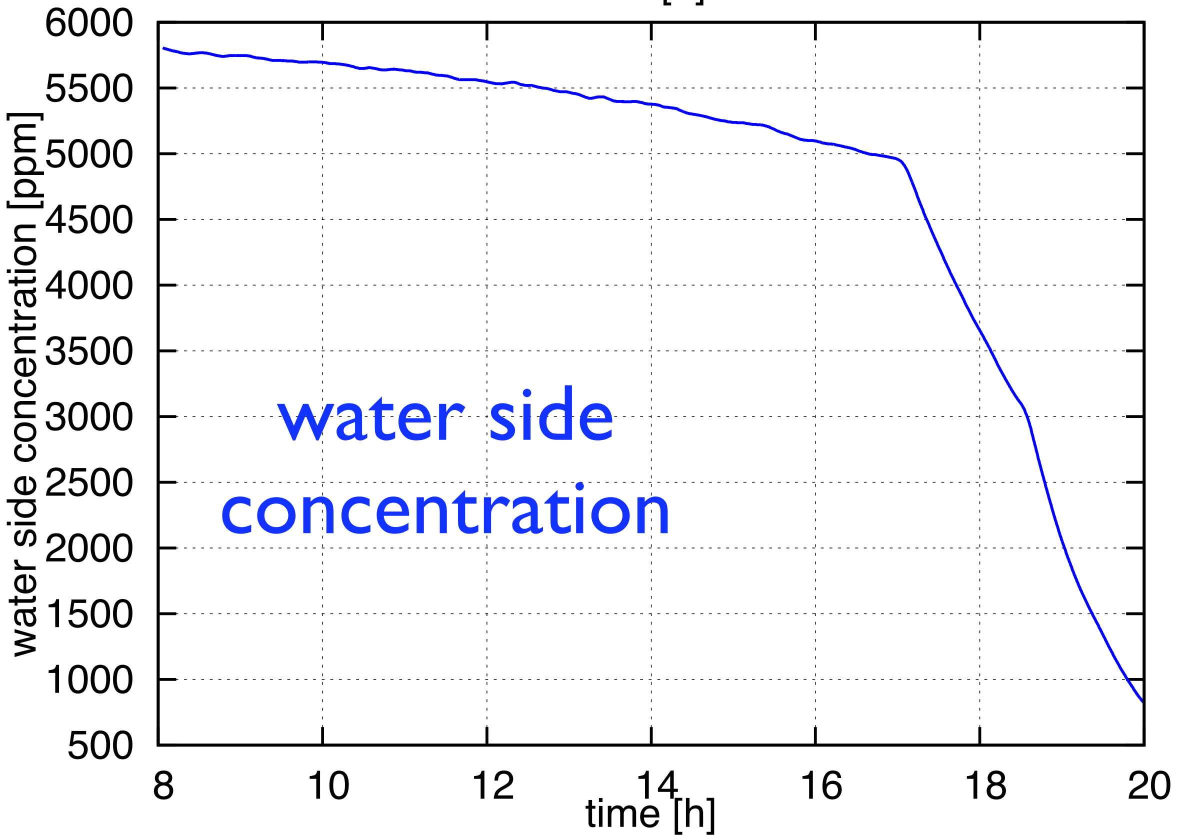

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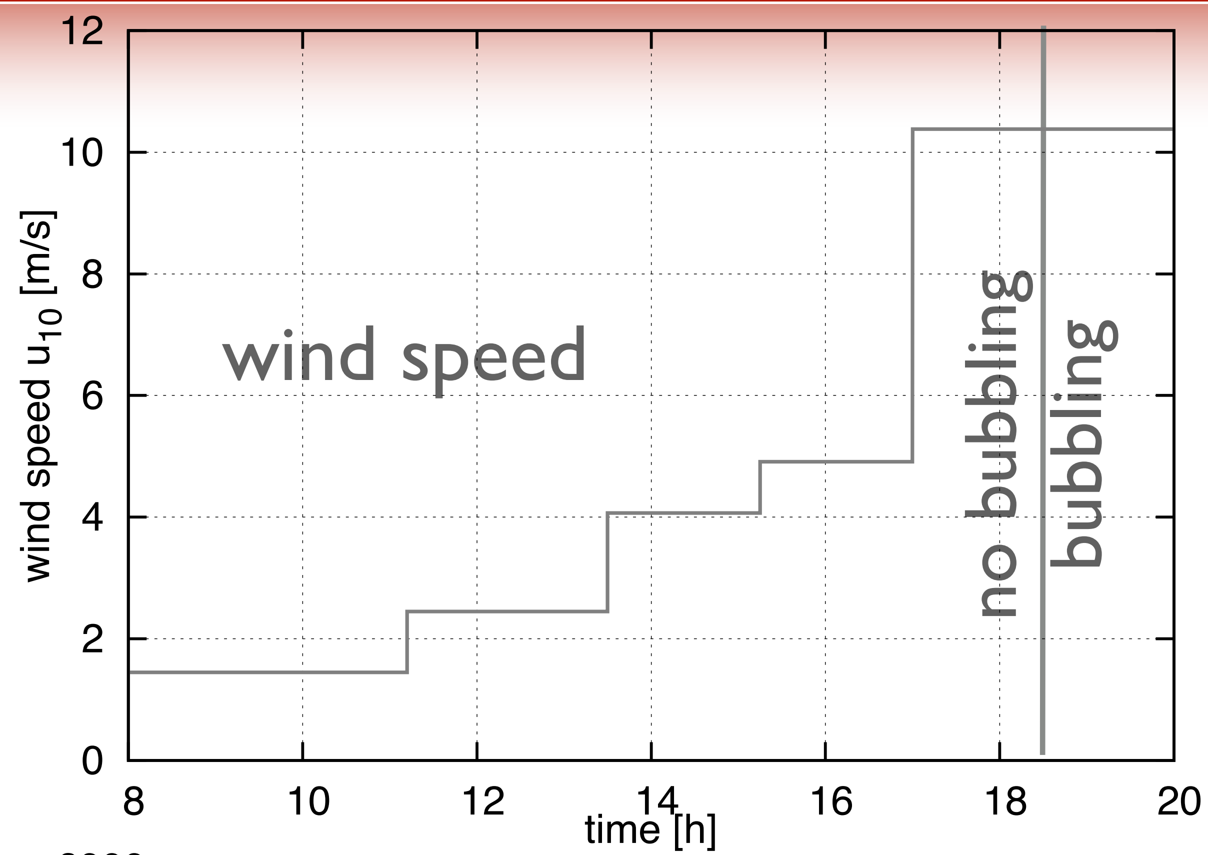

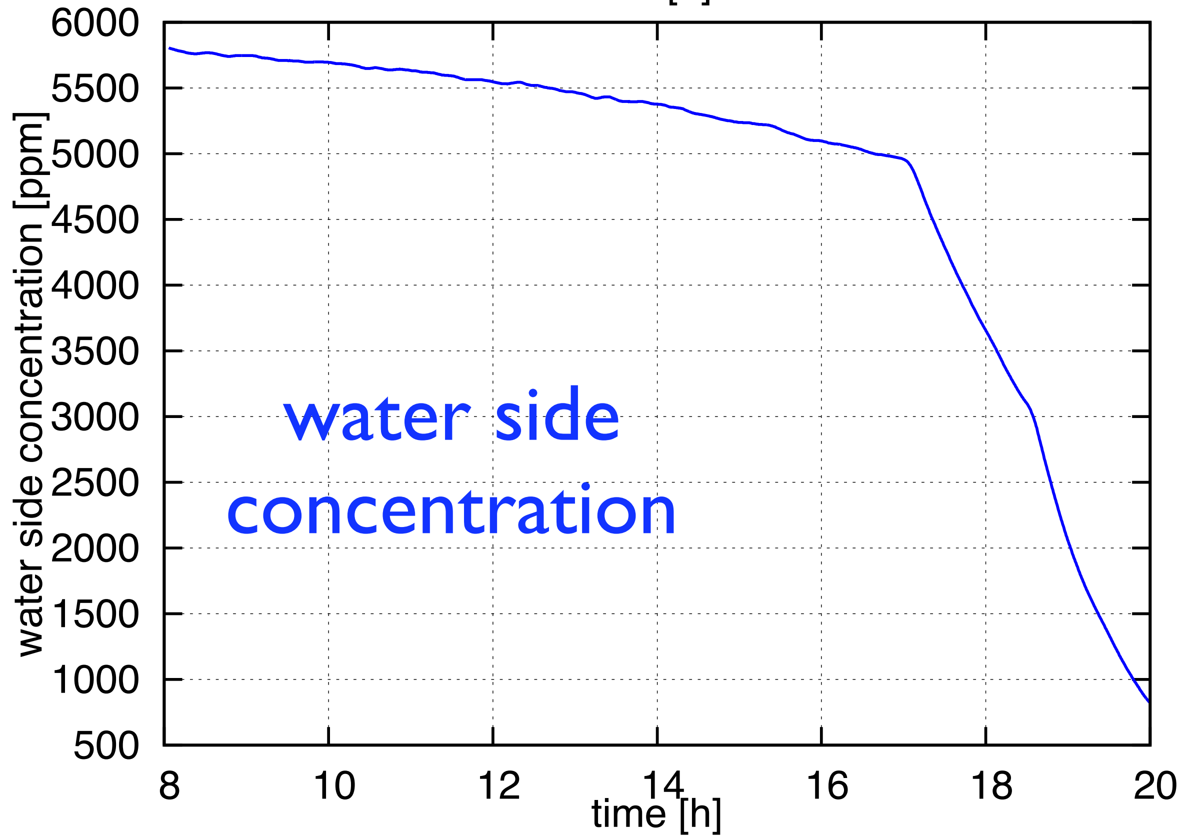

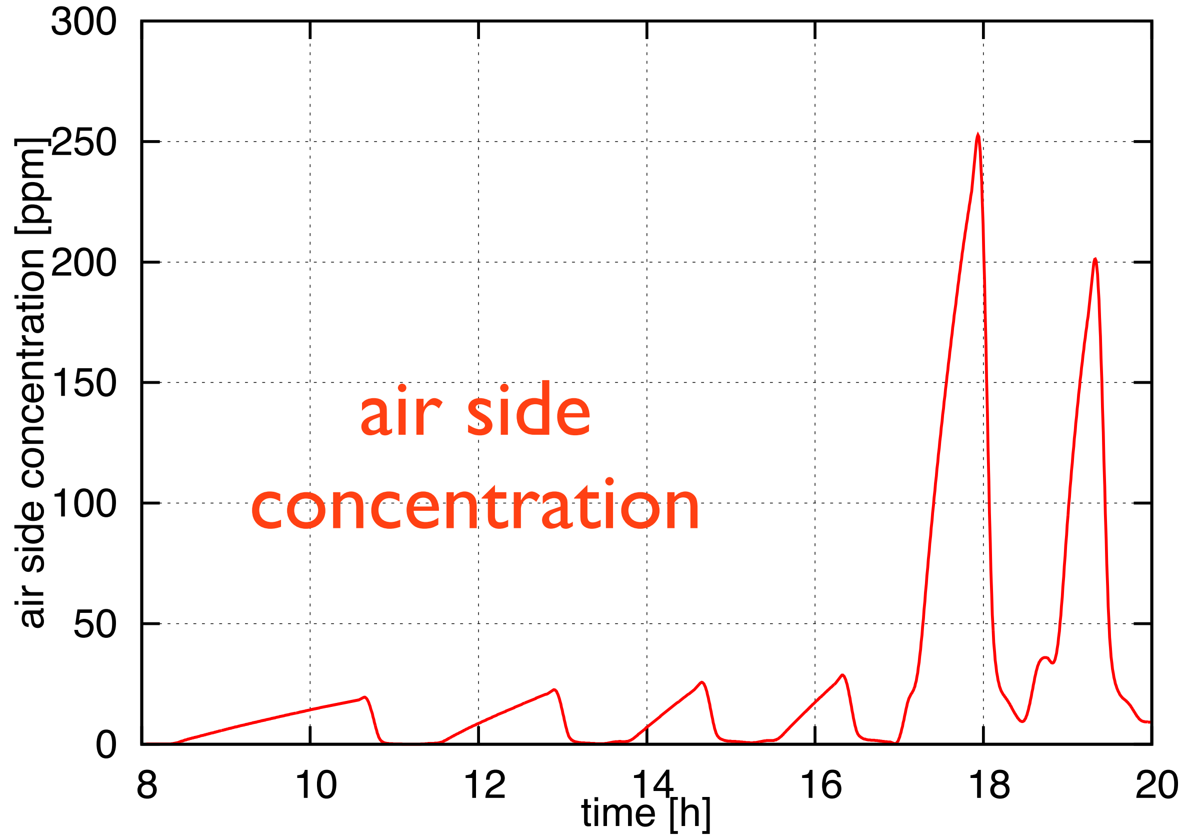

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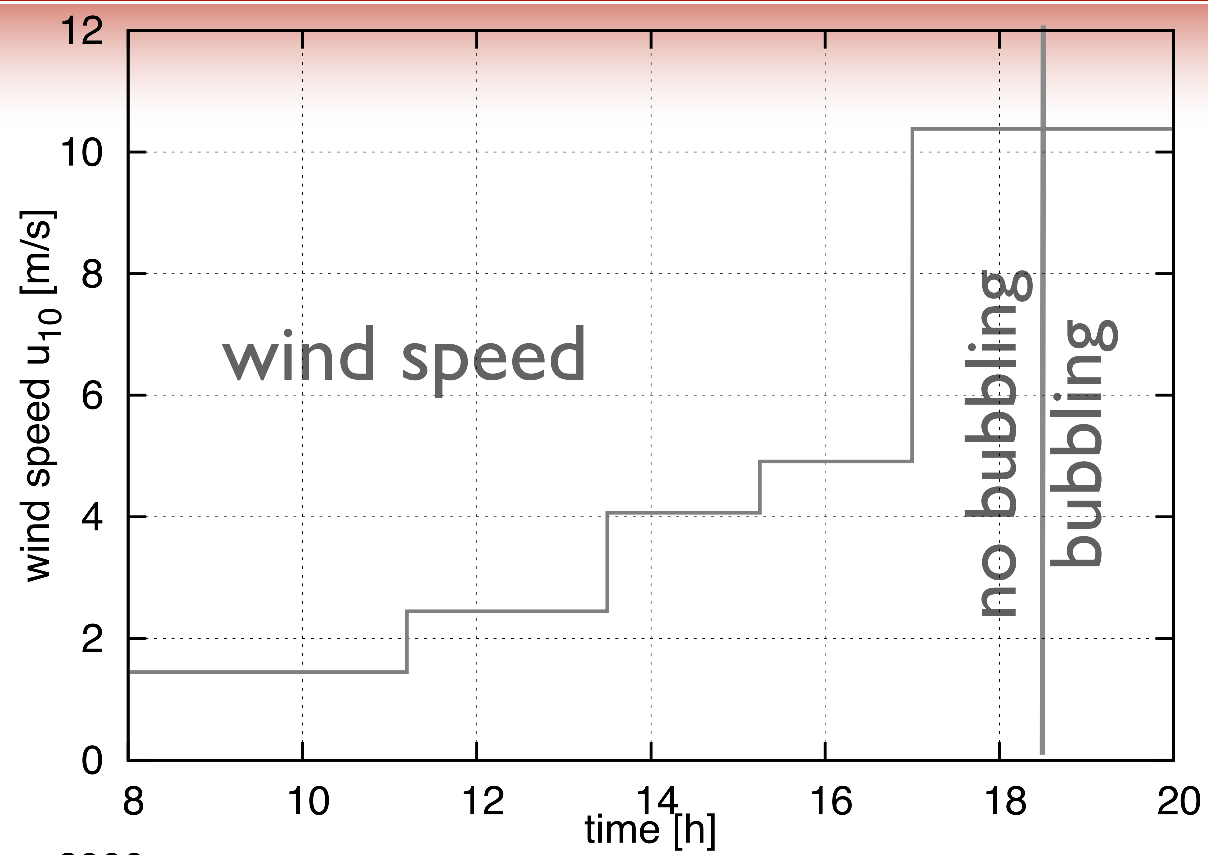

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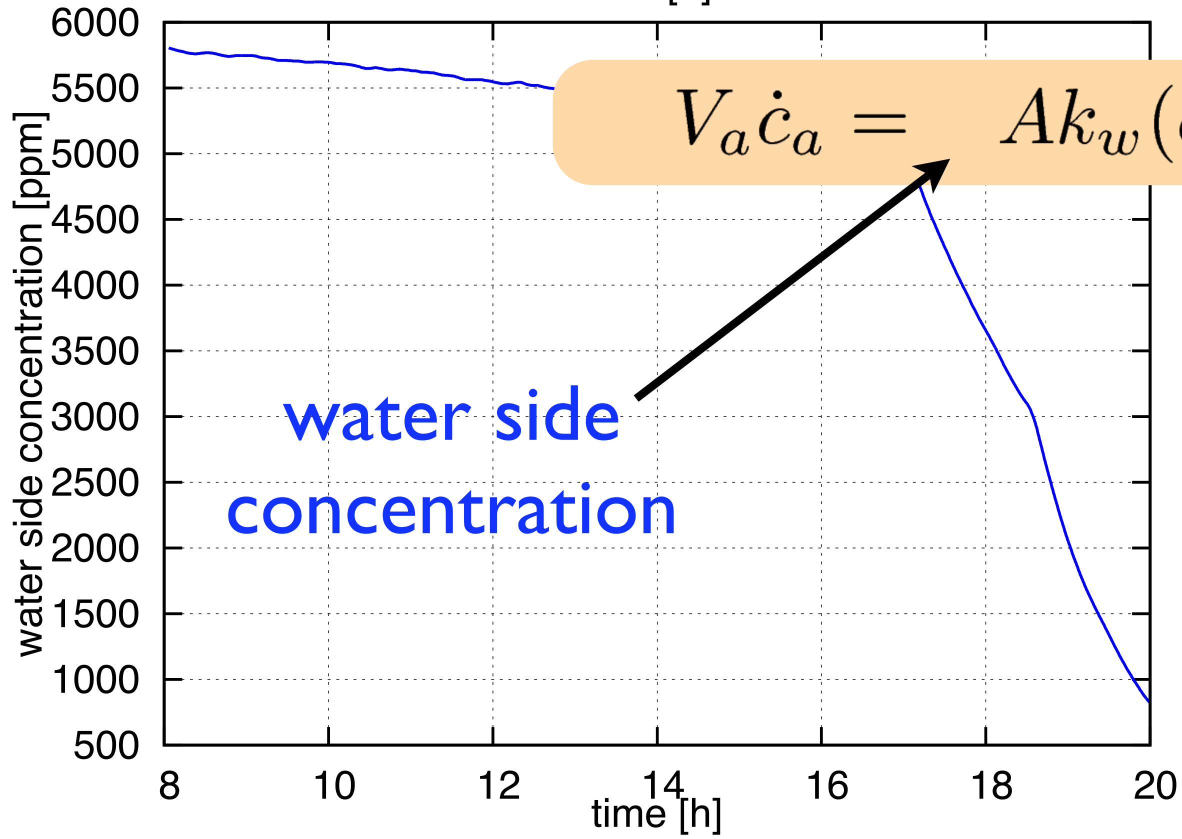

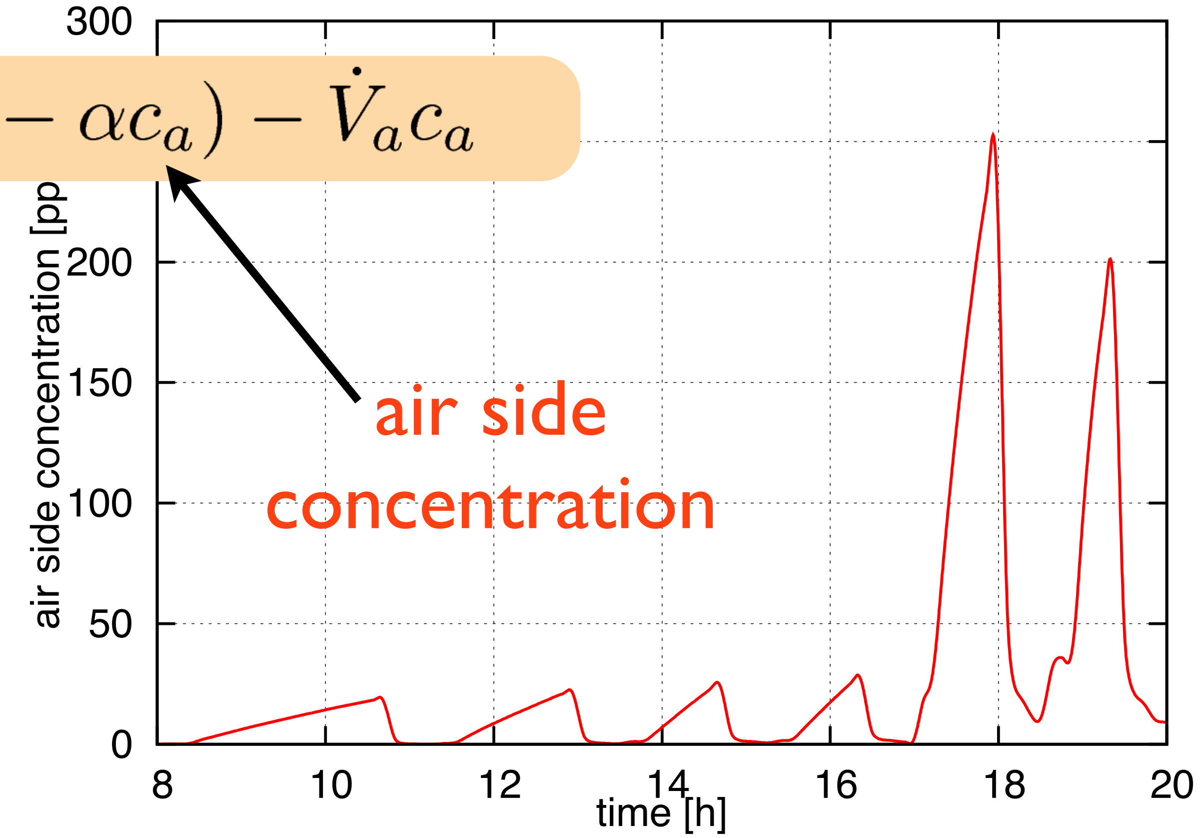

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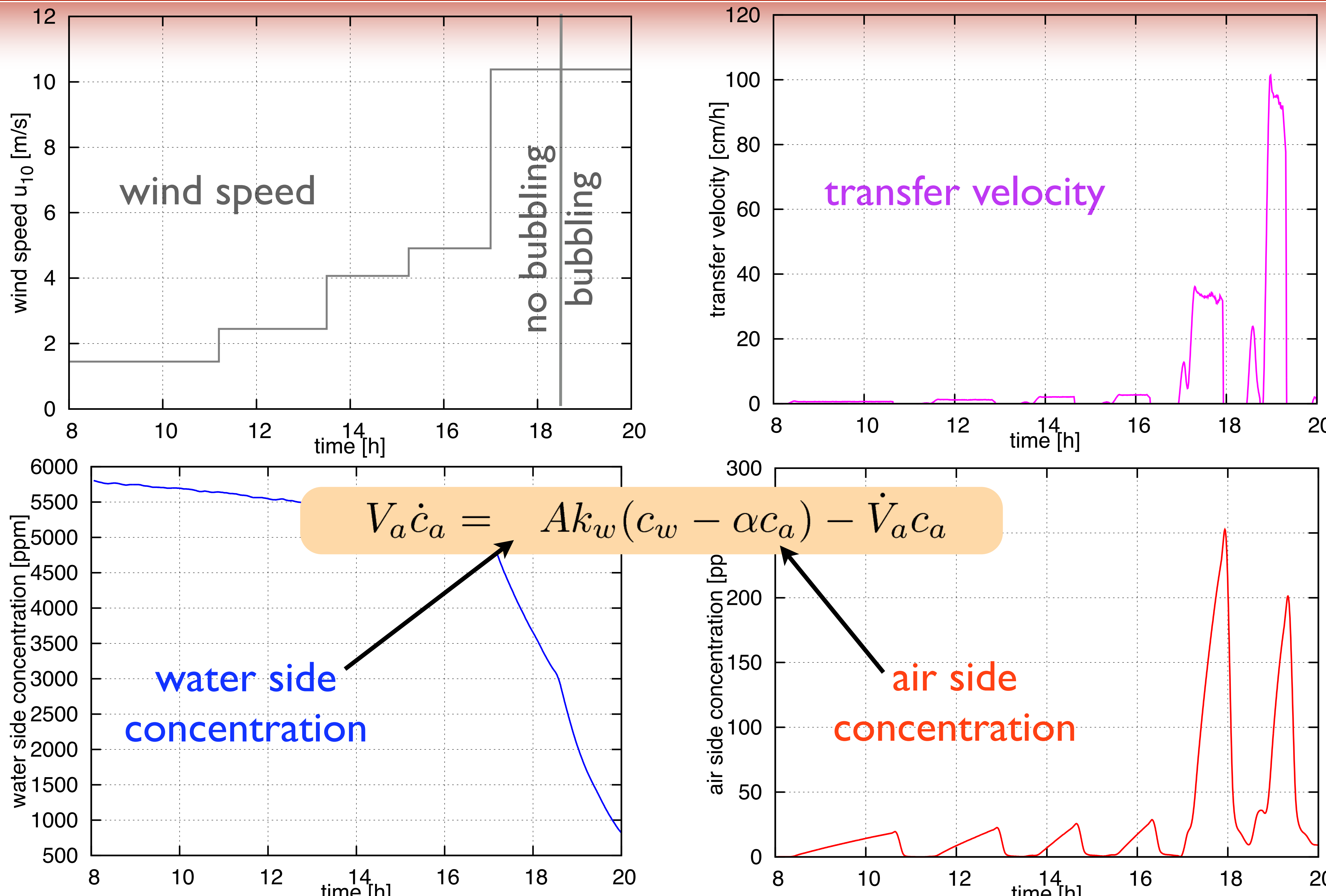

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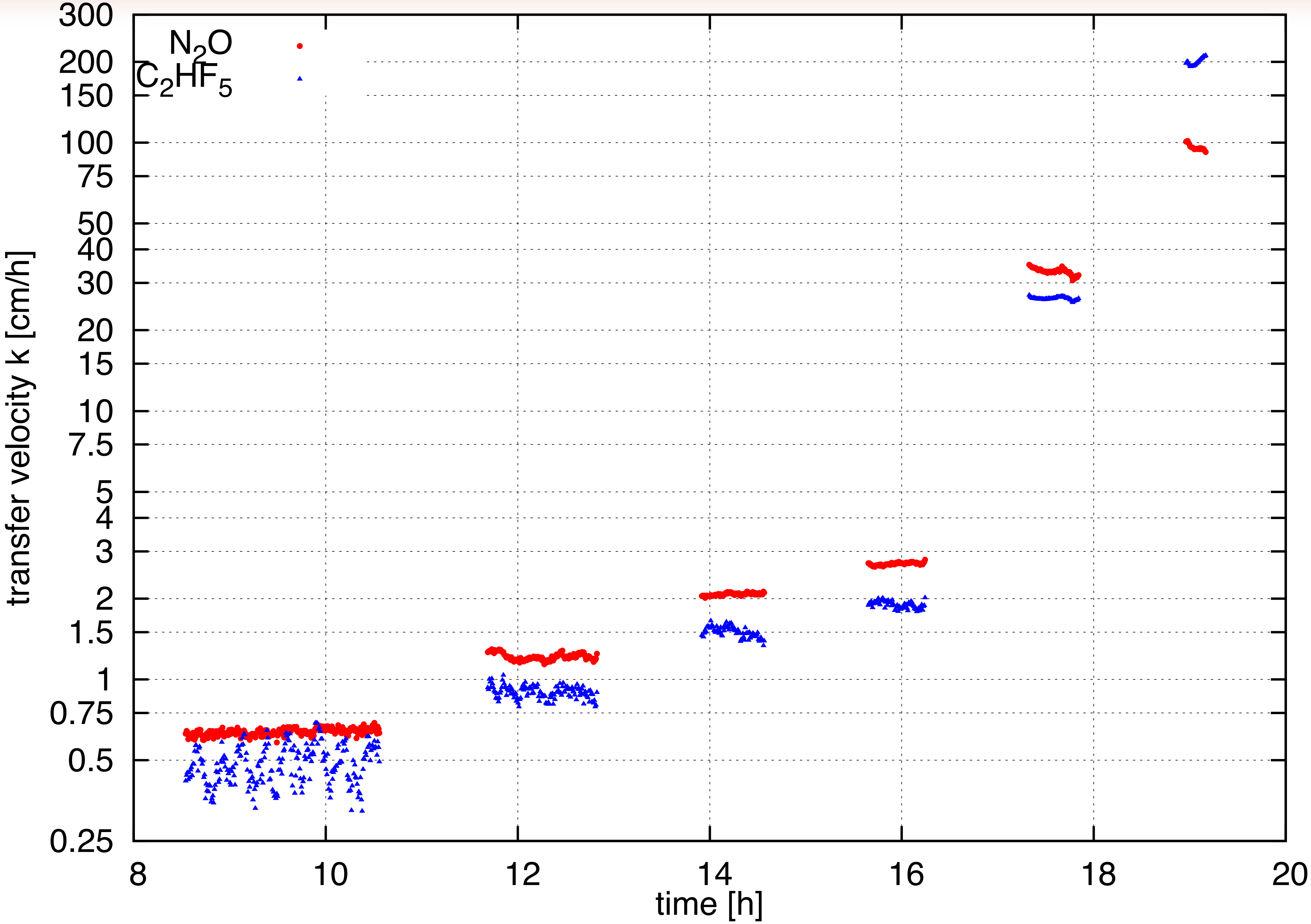
Transfer Velocities

of N_2O and C_2HF_5 - Schmidt number scaling



Schmidt number scaling:

$$\frac{k_A}{k_B} = \left(\frac{Sc_A}{Sc_B}\right)^{-n}$$

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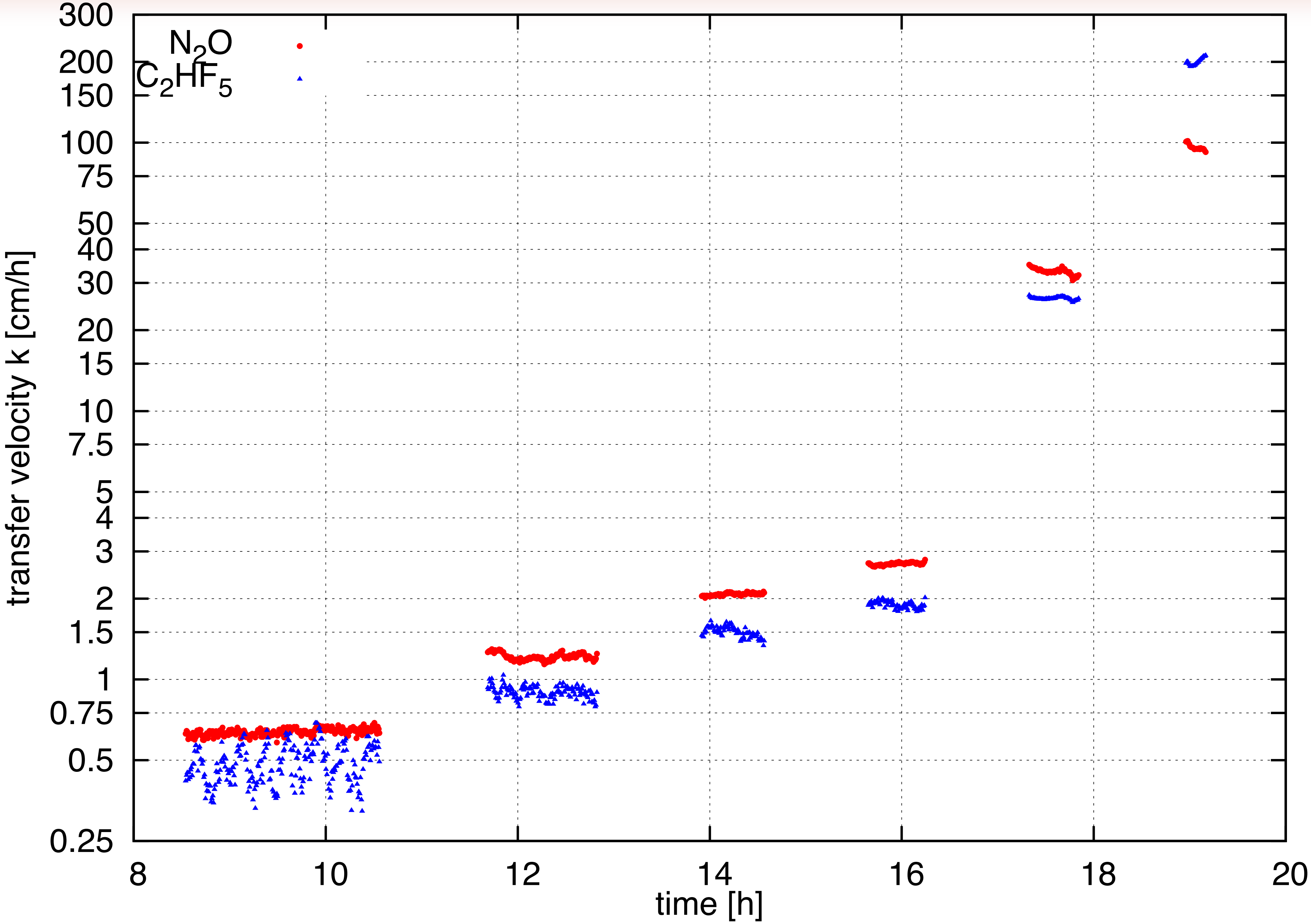

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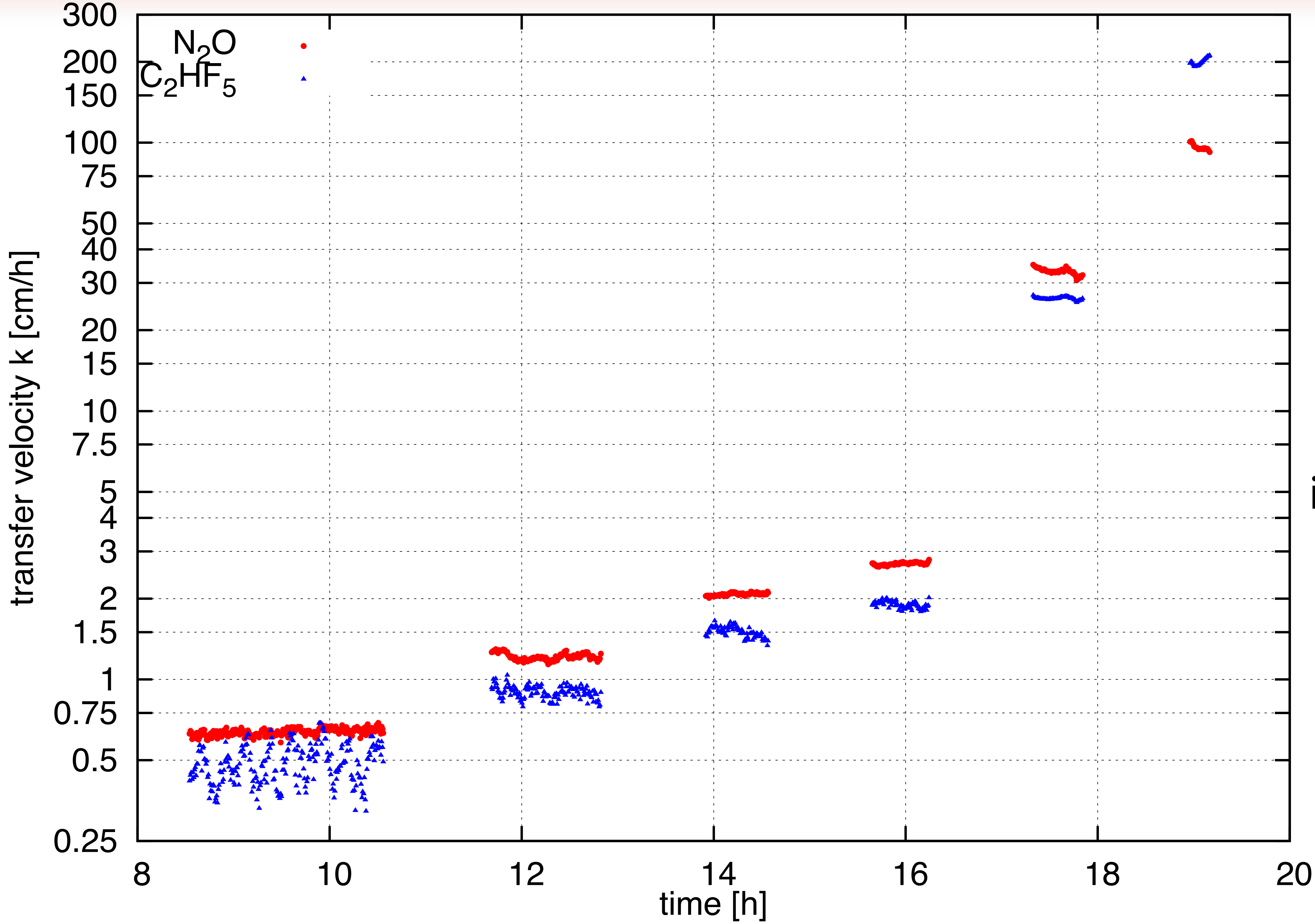


Schmidt number scaling:

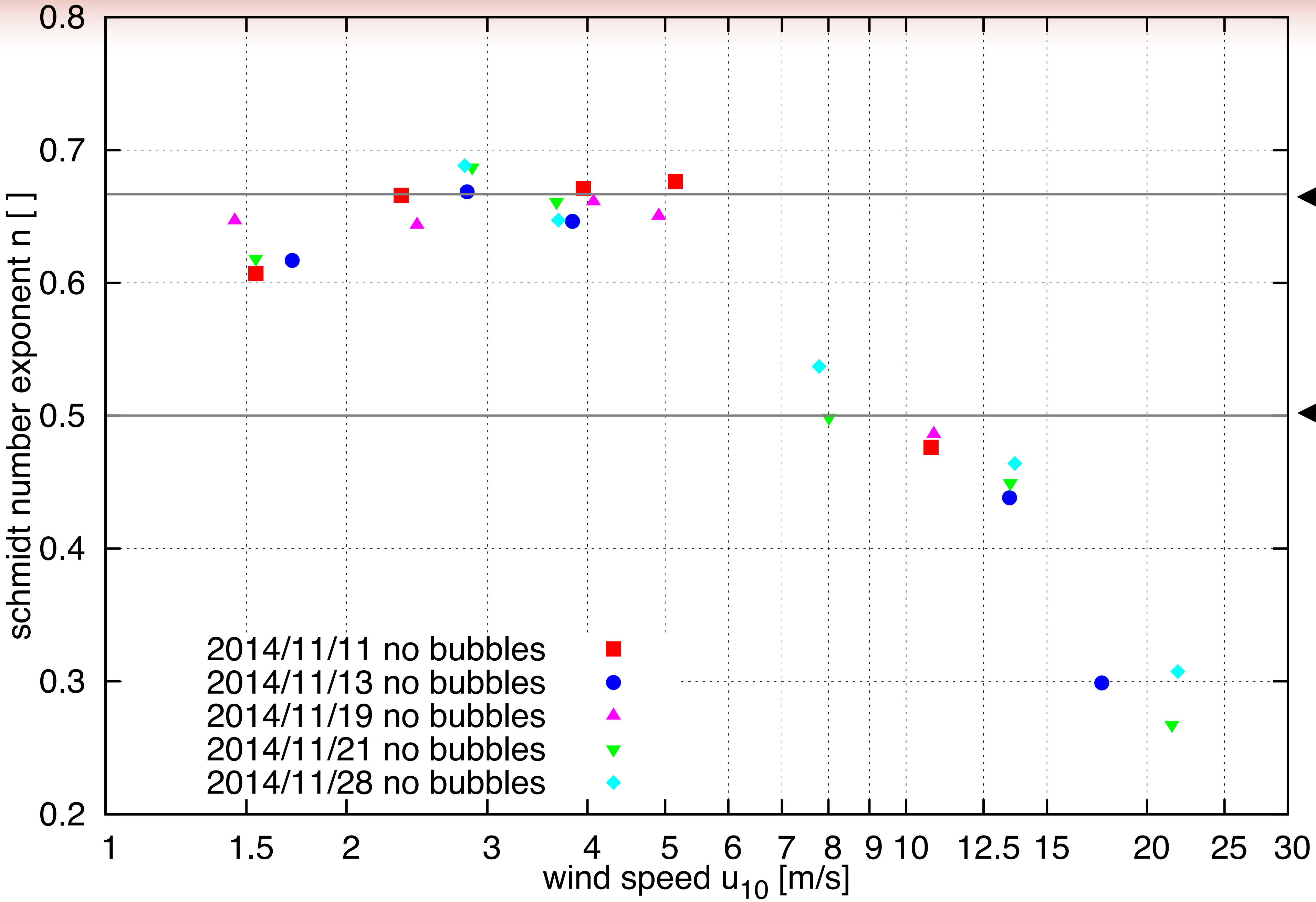
$$\frac{k_A}{k_B} = \left(\frac{Sc_A}{Sc_B}\right)^{-n}$$

is used to calculate the Schmidt number exponent n

use this n to scale to k_{660}

Schmidt number exponents

calculated using the tracer combination N_2O and C_2HF_5



expected:

n=2/3
smooth water surface

n=1/2
wavy water surface

Schmidt number exponents

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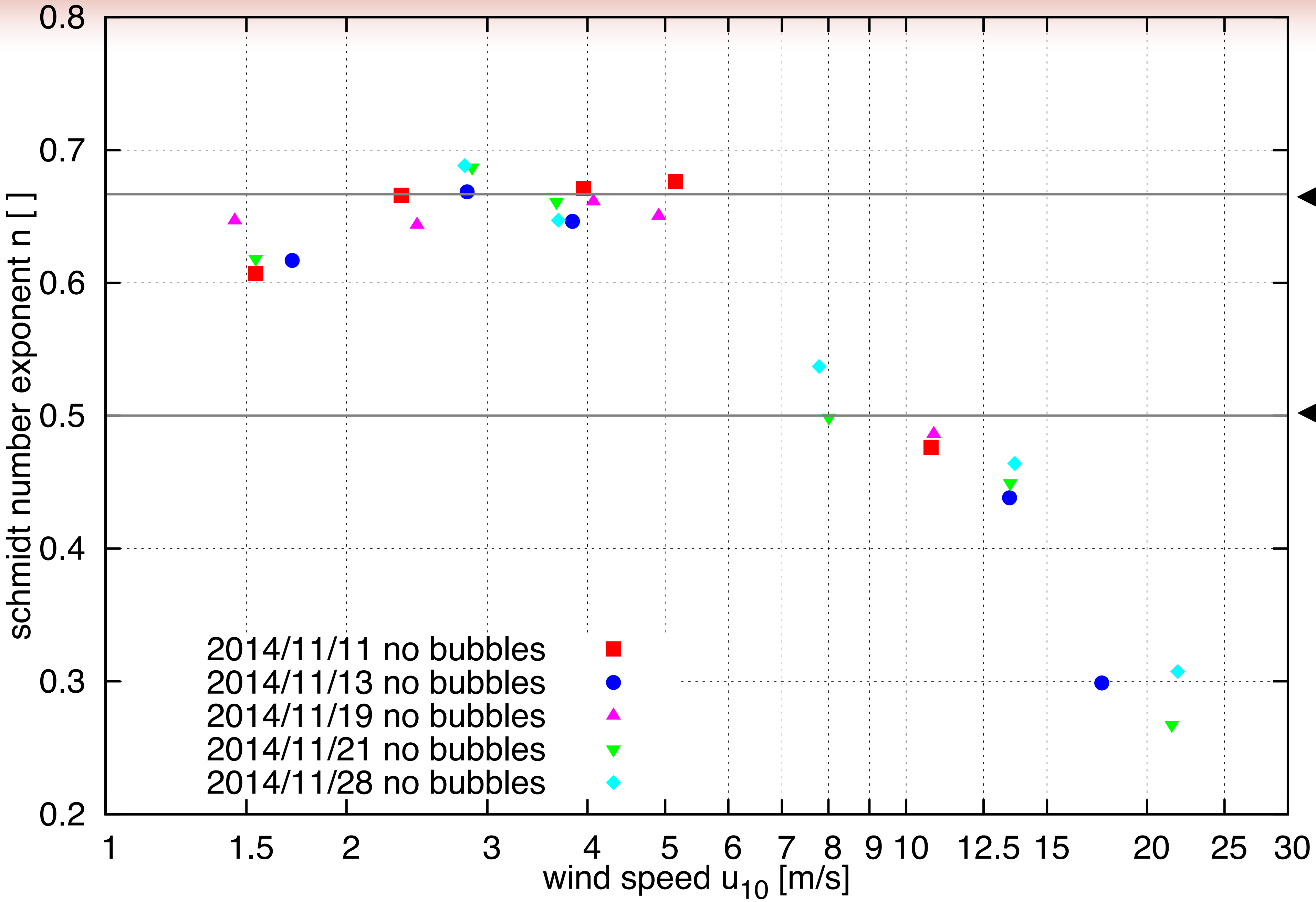

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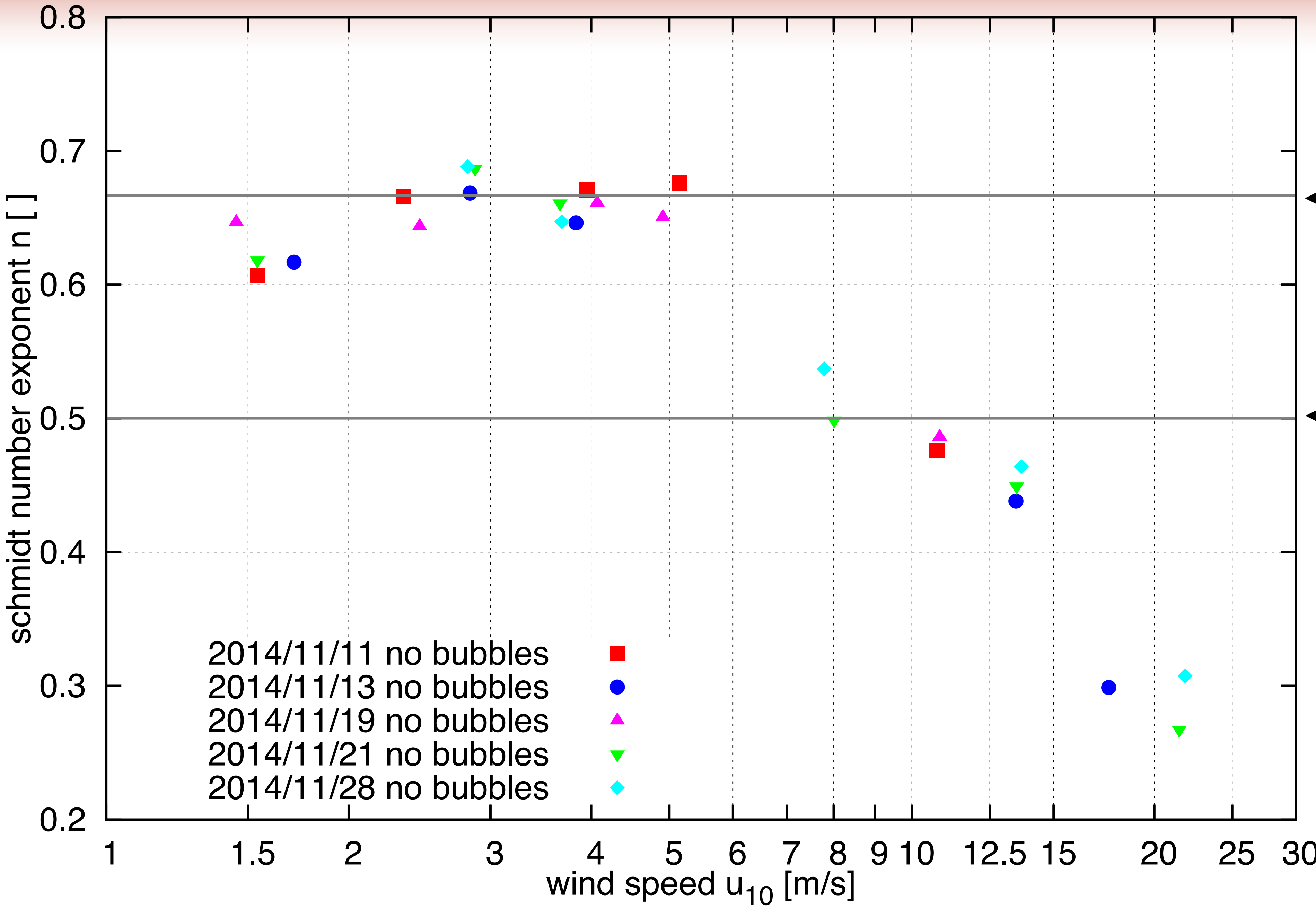
$$k_{\text{meas}} = k_{\text{interface}} + k_b$$

$$k_{\text{interface}} \propto u_* Sc^{-n}$$

k_b depends on Sc and solubility

Schmidt number exponents

calculated using the tracer combination N_2O and C_2HF_5



expected:

n=2/3
smooth water surface

n=1/2
wavy water surface

the Schmidt number exponent n transitions from 2/3 to 1/2

$$k_{\text{meas}} = k_{\text{interface}} + k_b$$

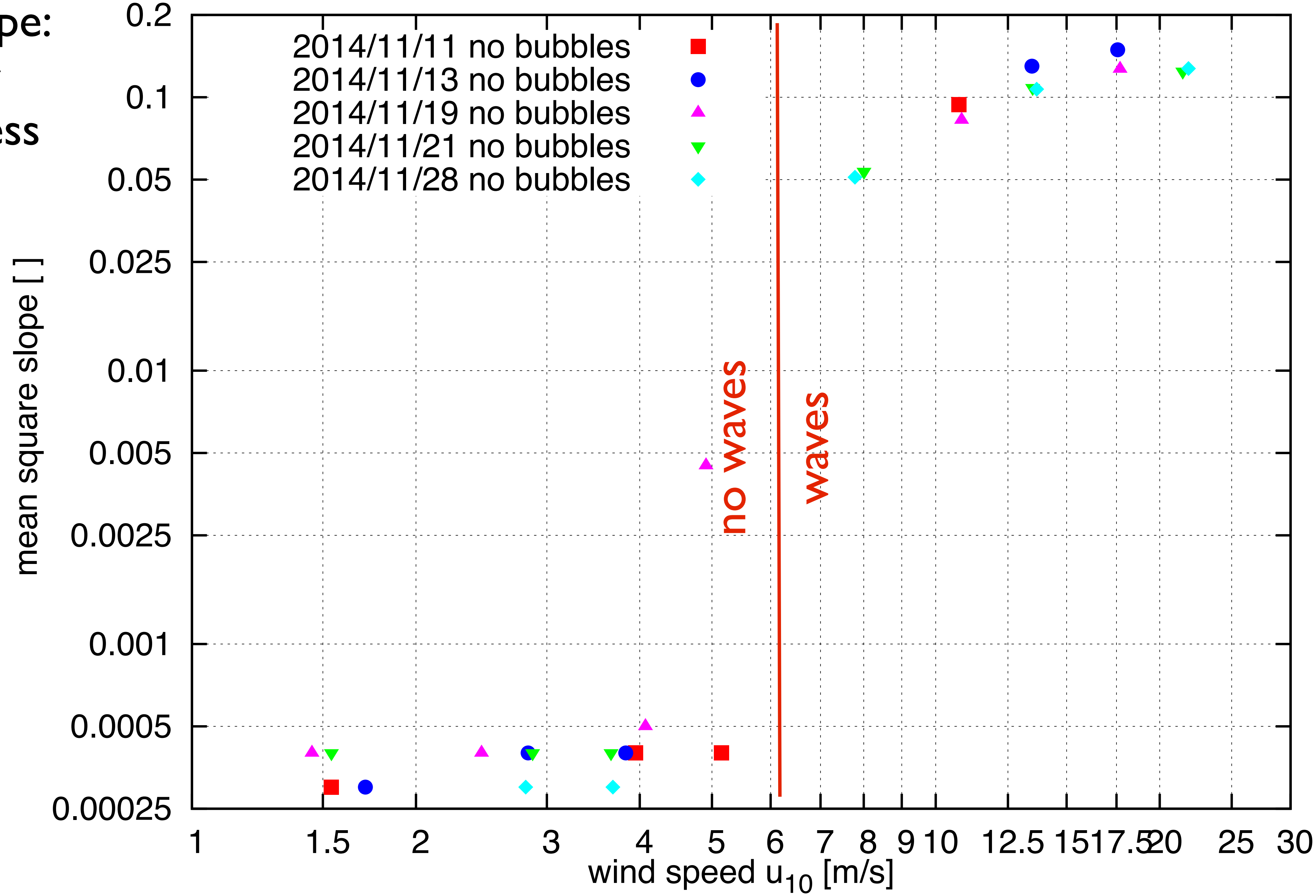
$$k_{\text{interface}} \propto u_* Sc^{-n}$$

k_b depends on Sc and solubility

Water surface roughness

mean square slope

mean square slope: a measure for surface roughness

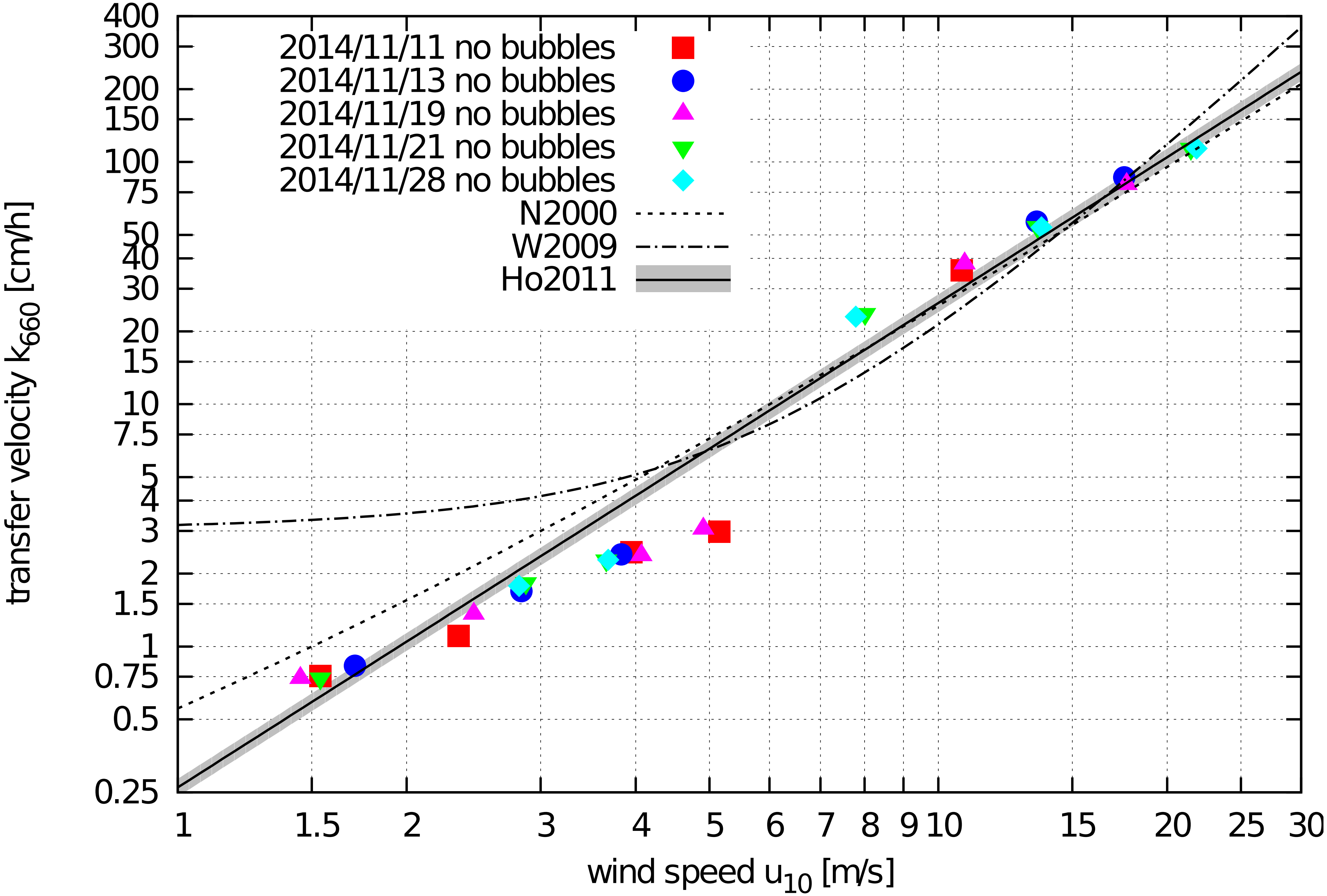


k_{660} from measured k of N_2O

comparison with previous studies

$$k_{660} = k_{N_2O} \cdot \left(\frac{660}{Sc_{N_2O}}\right)^{-n}$$

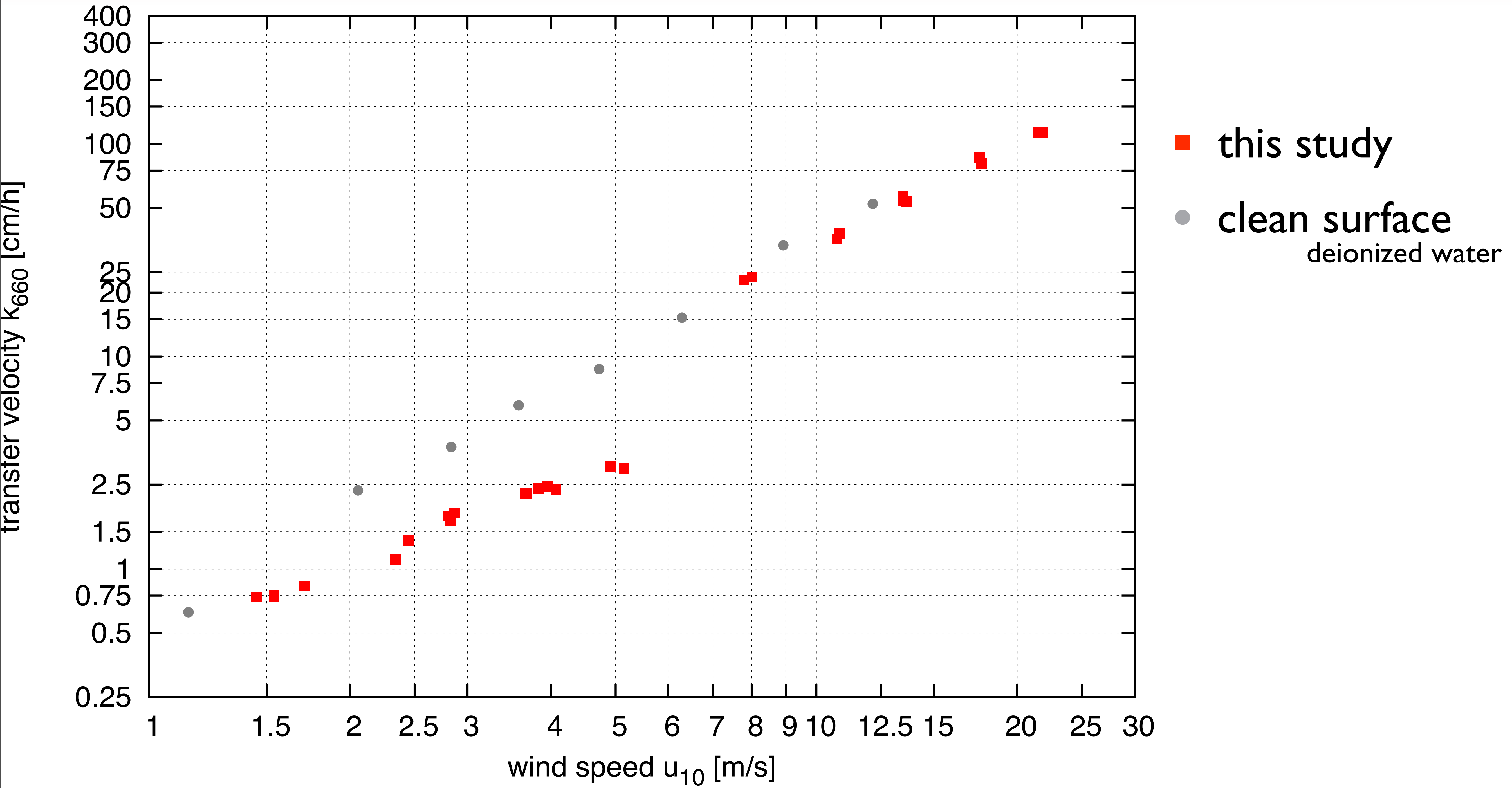
with: measured n for u_{10} <10m/s
n=1/2 for u_{10} >10m/s



N2000: Nightingale et al., In situ evaluation of air-sea gas exchange parameterization using novel conservation and volatile tracers, 2000; W2009: Wanninkhof et al. Advances in quantifying air-sea gas exchange and environmental forcing, 2009; Ho2011: Ho et al., Toward a universal relationship between wind speed and gas exchange: Gas transfer velocities measured with 3He/SF6 during the Southern Ocean Gas Exchange Experiment, 2011

k_{660} from measured k of N_2O

comparison to a study with artificial surfactants



K. Krall, Laboratory Investigations of Air-Sea Gas Transfer under a Wide Range of Water Surface Conditions, 2013

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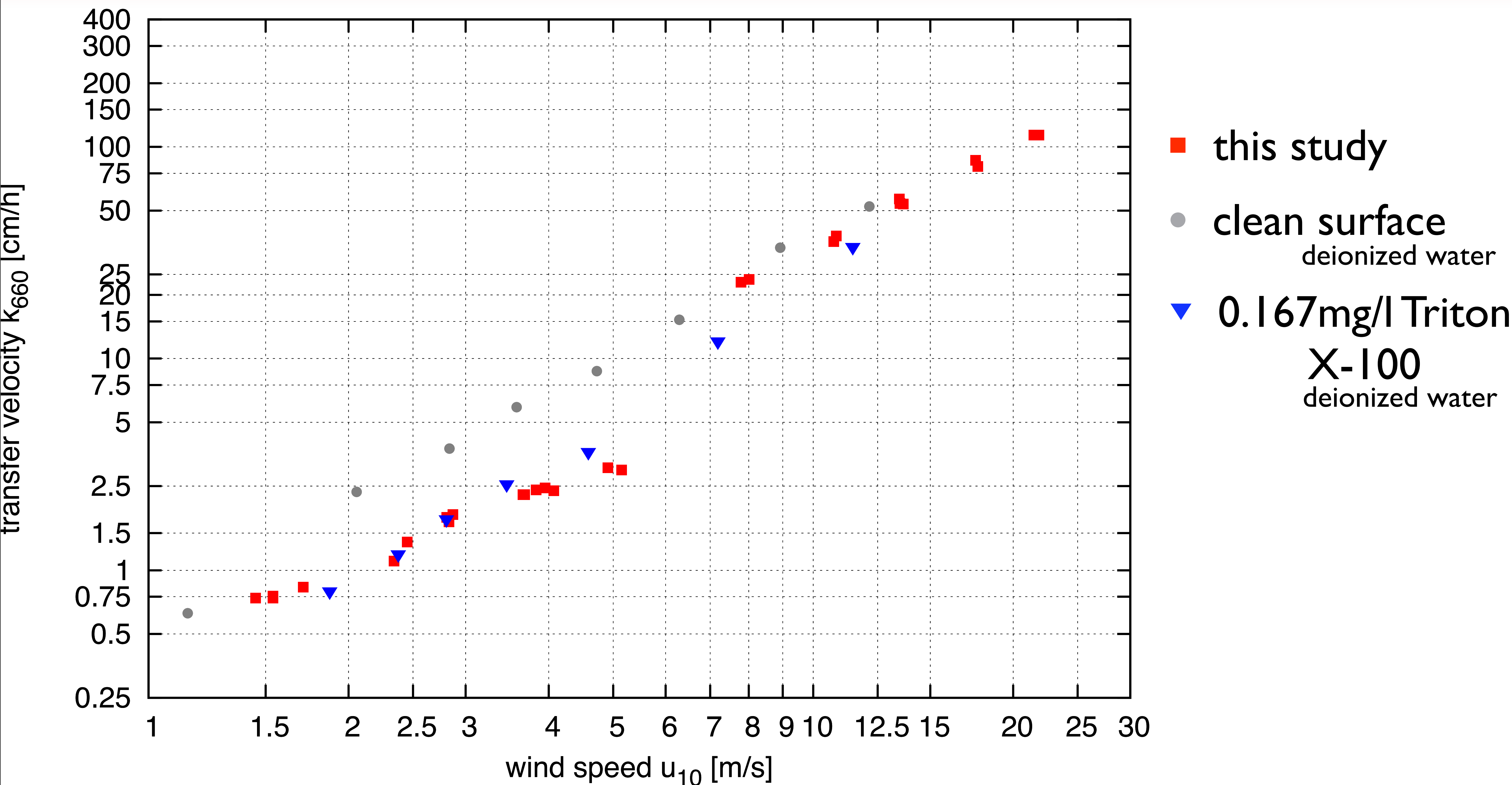

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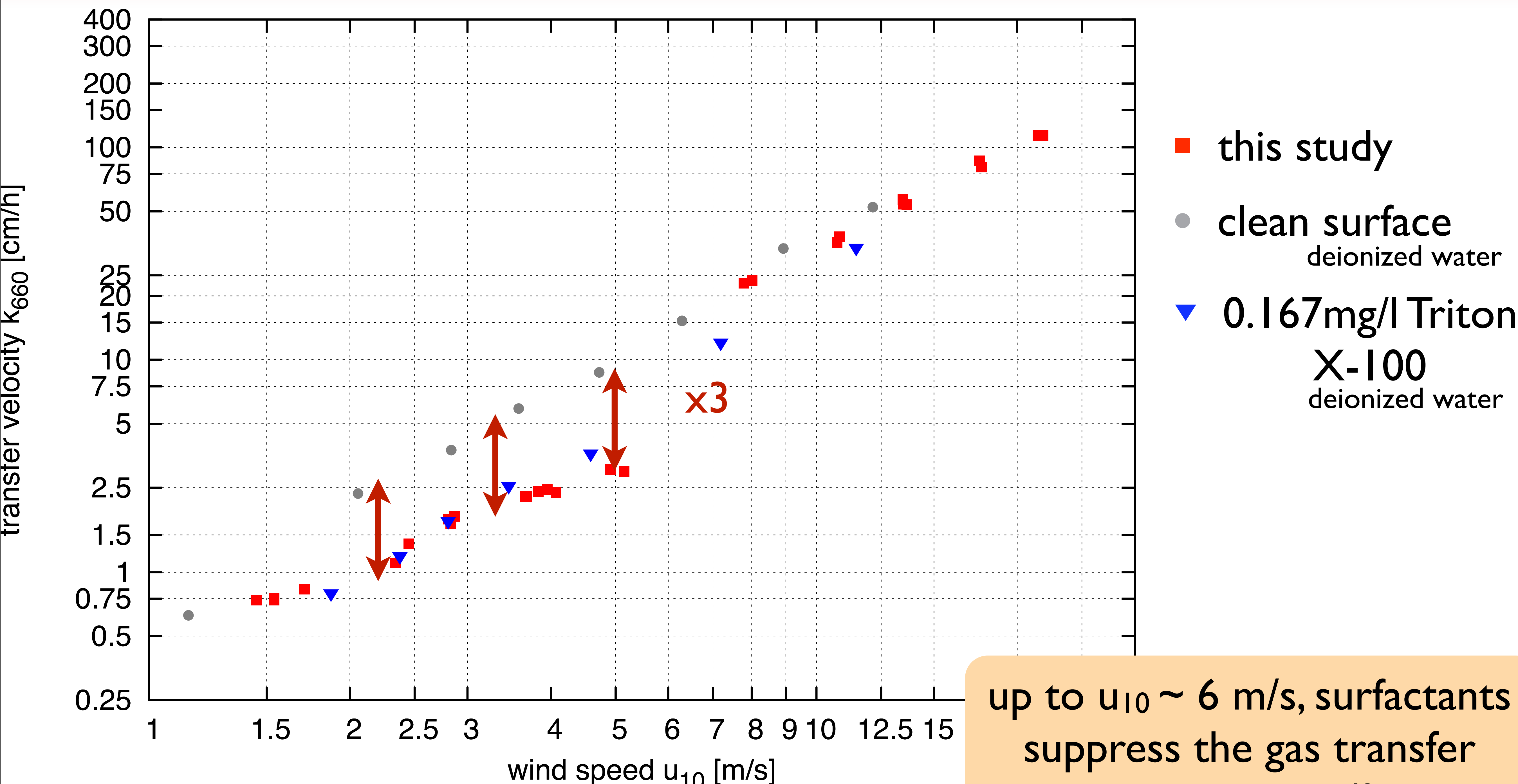

up to u_{10} ~ 6 m/s, surfactants suppress the gas transfer velocity to 1/3

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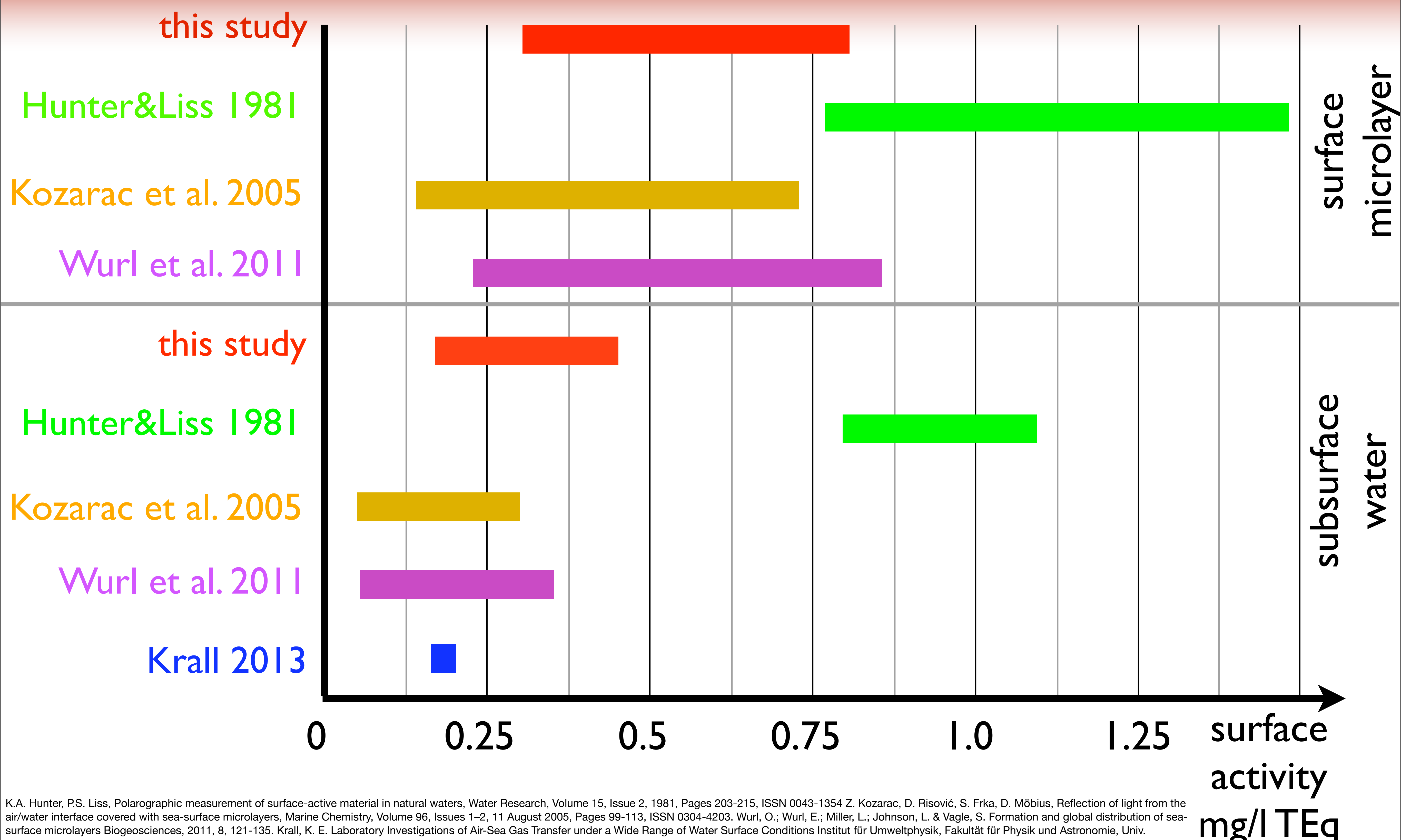
Surface activity

compared to field studies



K.A. Hunter, P.S. Liss, Polarographic measurement of surface-active material in natural waters, Water Research, Volume 15, Issue 2, 1981, Pages 203-215, ISSN 0043-1354 Z. Kozarac, D. Risović, S. Frka, D. Möbius, Reflection of light from the air/water interface covered with sea-surface microlayers, Marine Chemistry, Volume 96, Issues 1–2, 11 August 2005, Pages 99-113, ISSN 0304-4203. Wurl, O.; Wurl, E.; Miller, L.; Johnson, L. & Vagle, S. Formation and global distribution of sea-surface microlayers Biogeosciences, 2011, 8, 121-135. Krall, K. E. Laboratory Investigations of Air-Sea Gas Transfer under a Wide Range of Water Surface Conditions Institut für Umweltphysik, Fakultät für Physik und Astronomie, Univ. Heidelberg, 2013

Bubble enhancement

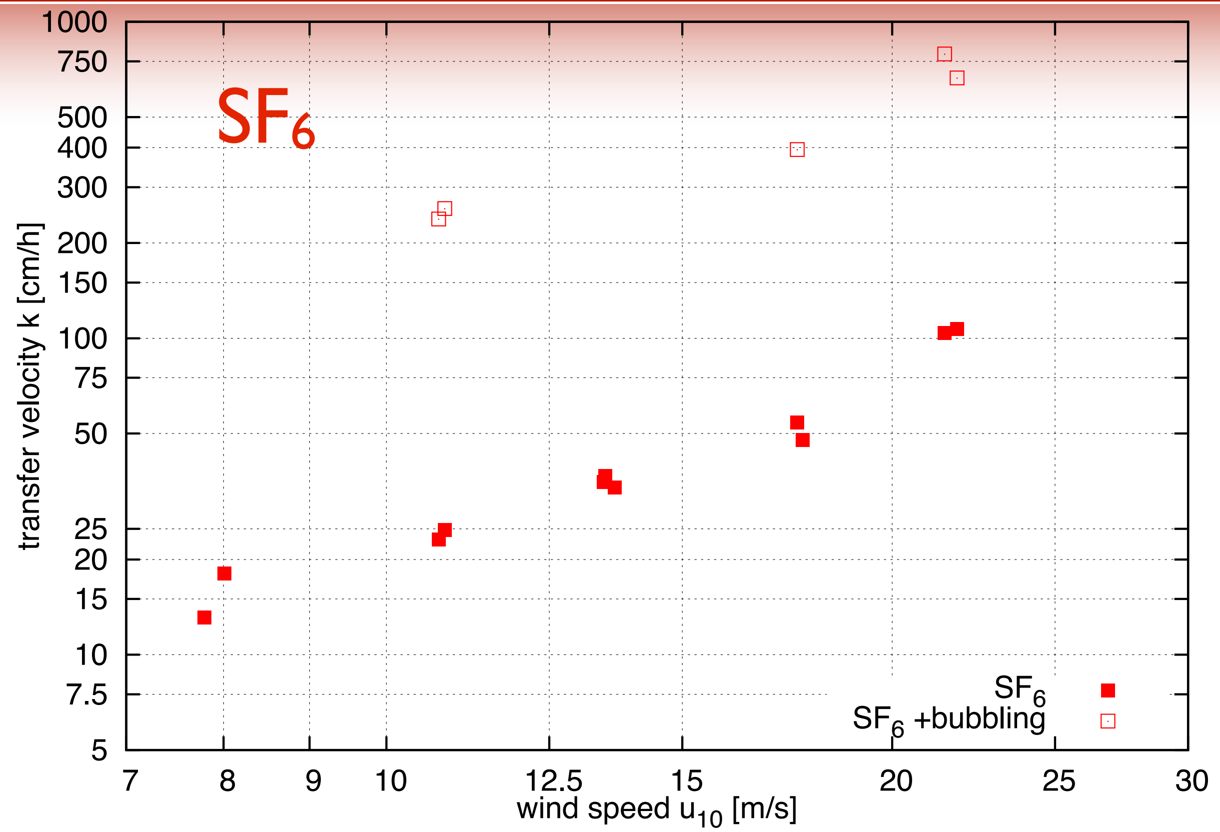
SF_6, Krypton, N_2O, CH_3Cl

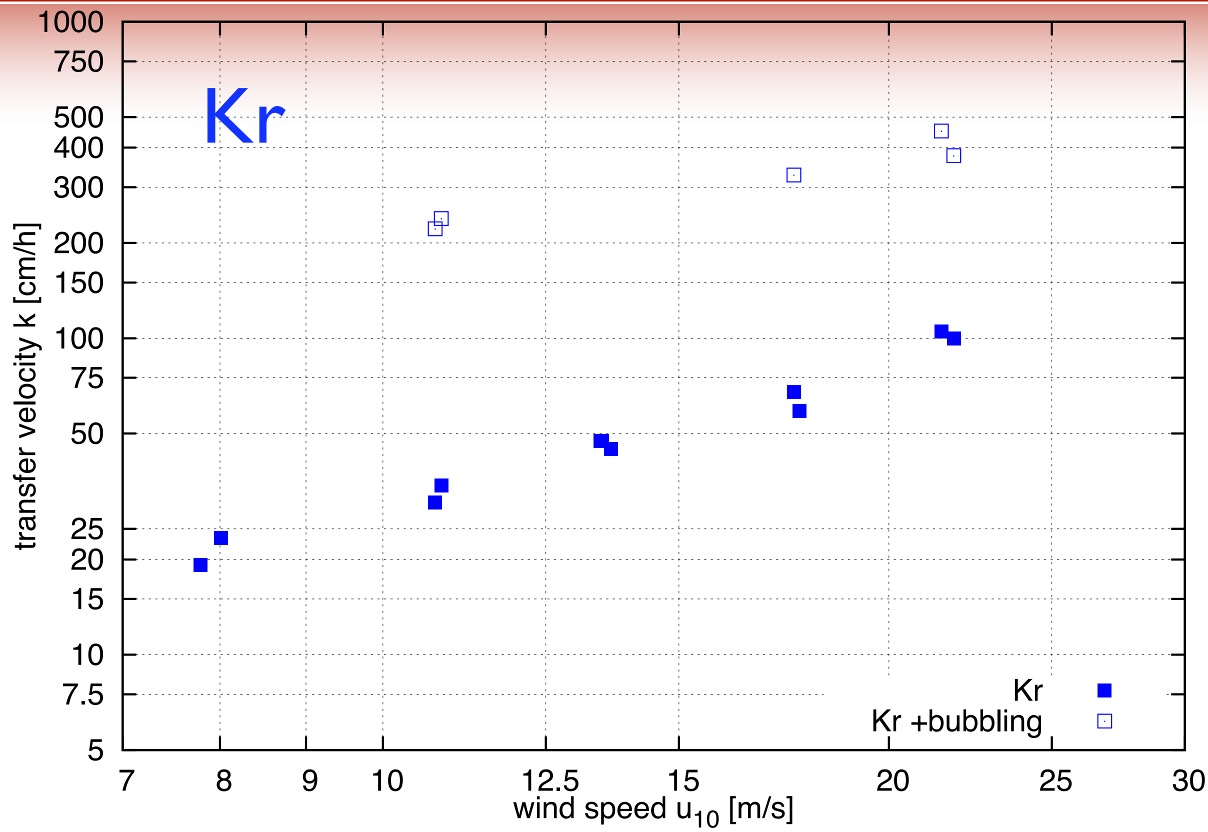
additional gases: only water side concentration measured

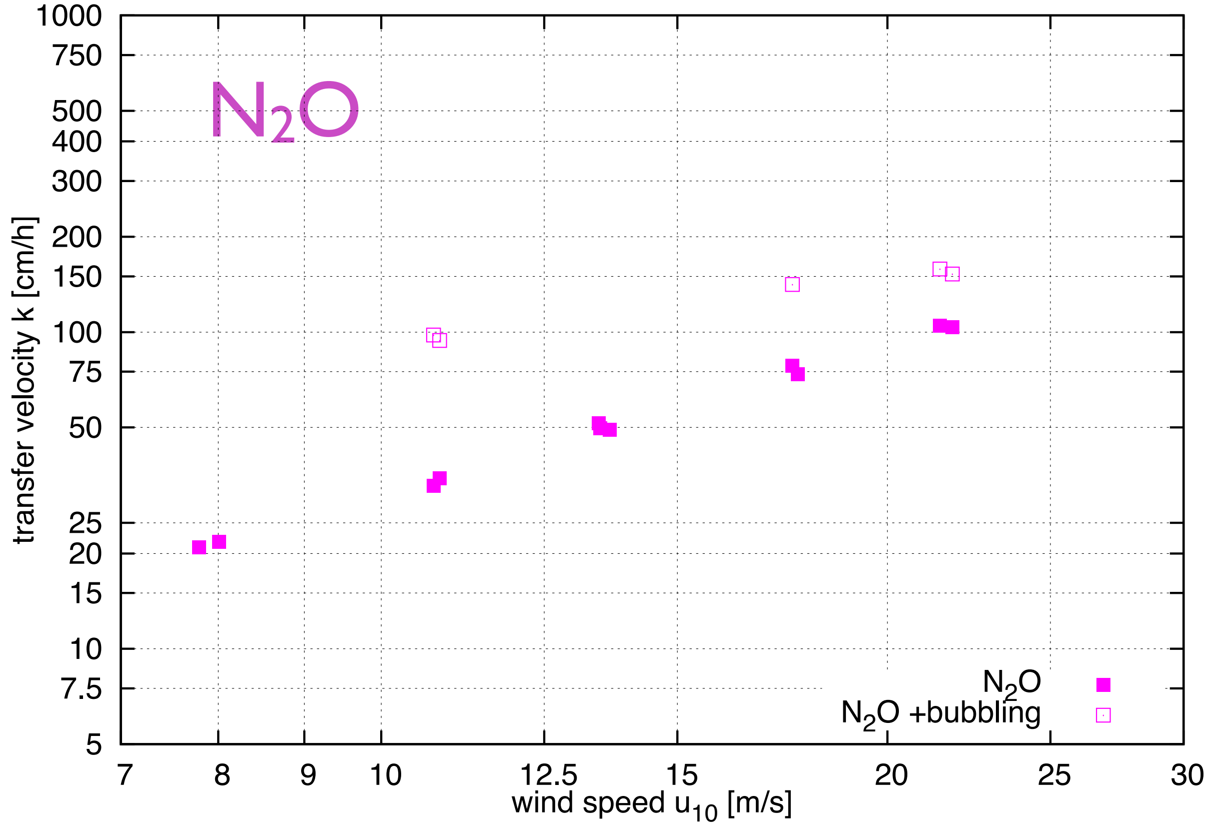
use exponential decrease of water side concentration to calculate k

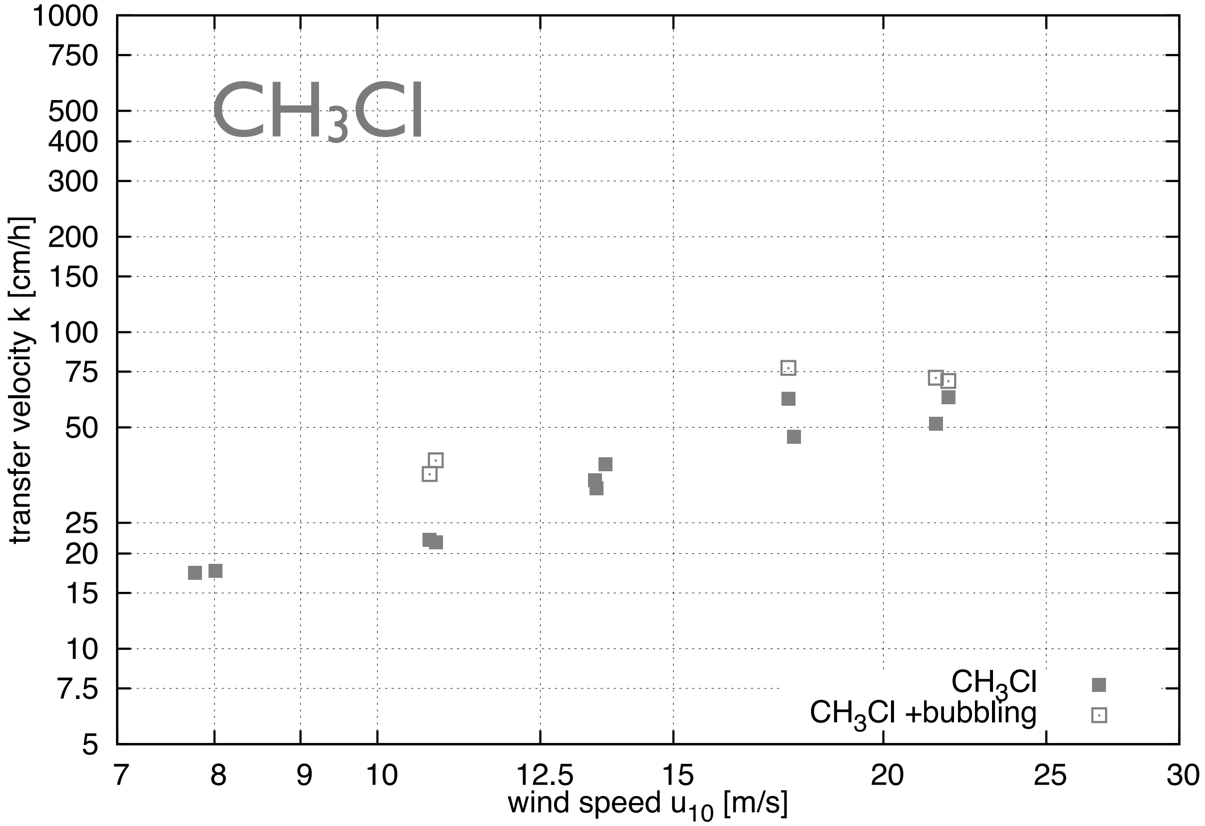
Bubble enhancement

SF_6, Krypton, N_2O, CH_3Cl



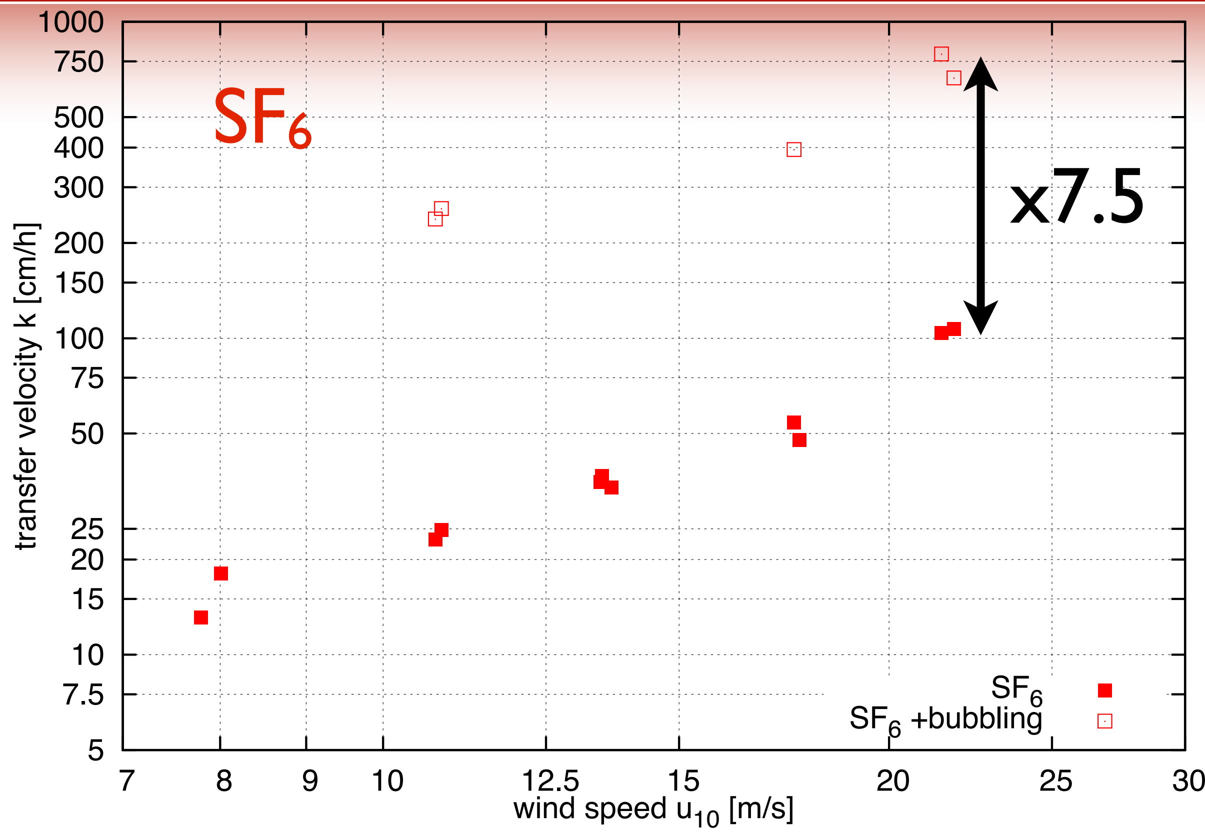


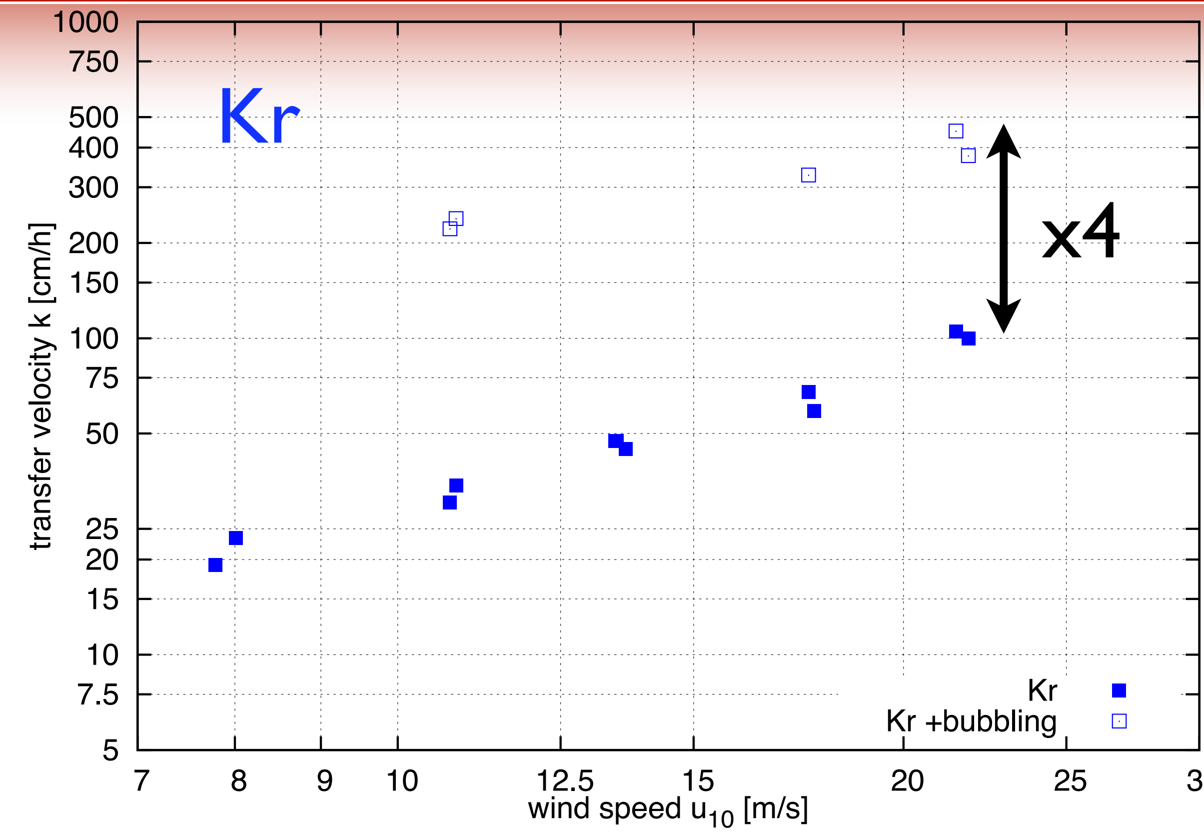


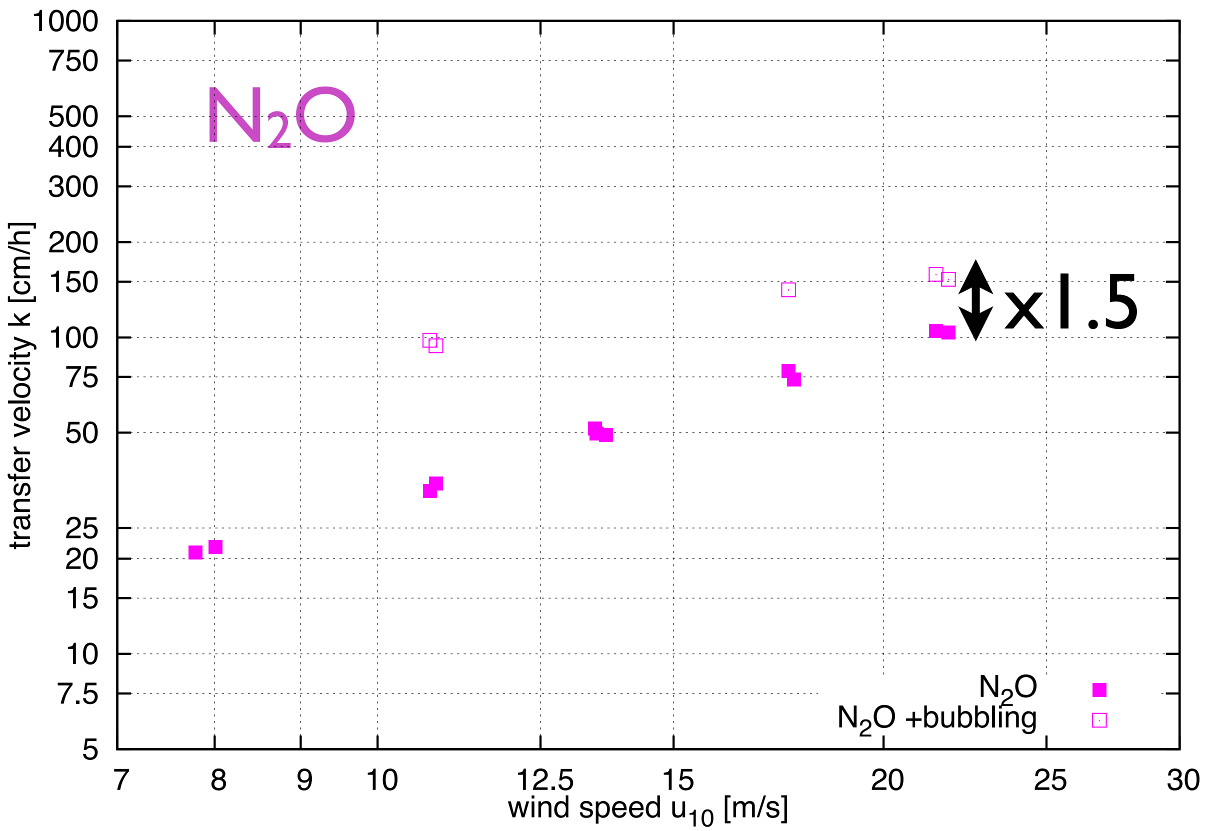


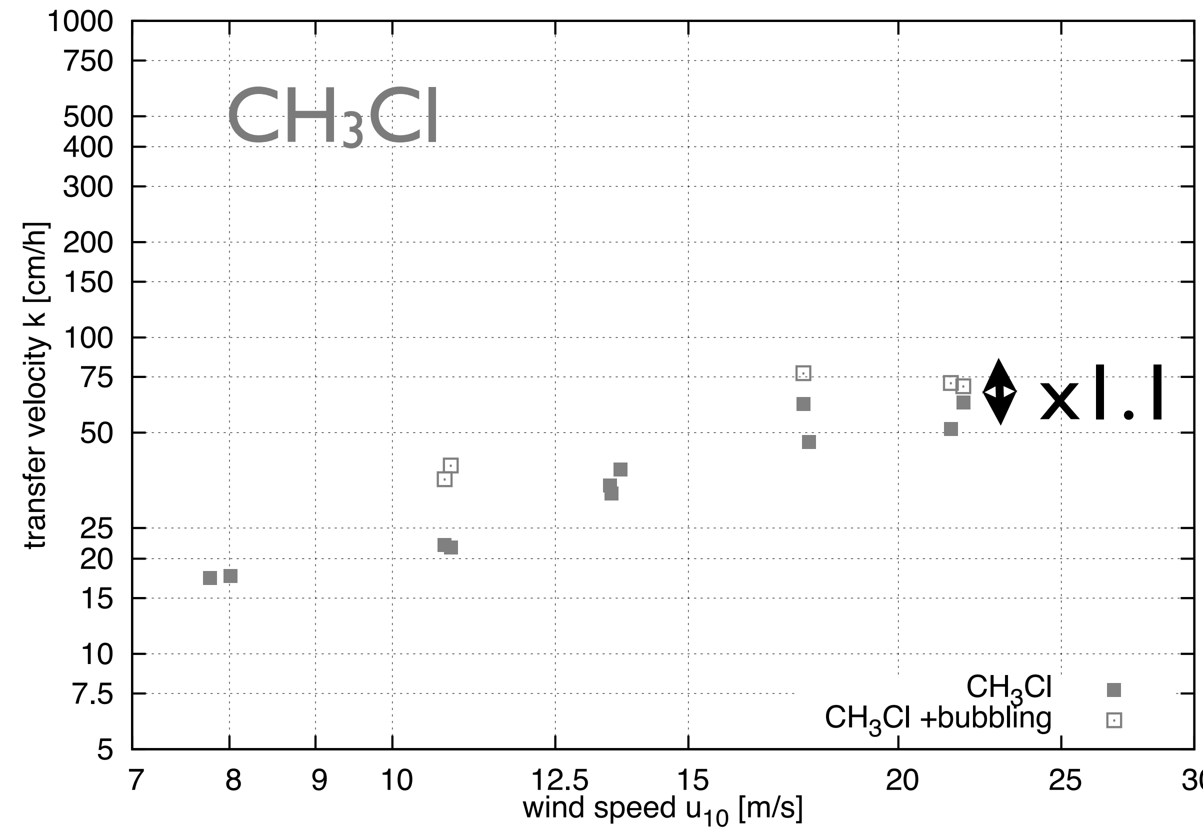
Bubble enhancement

SF_6, Krypton, N_2O, CH_3Cl



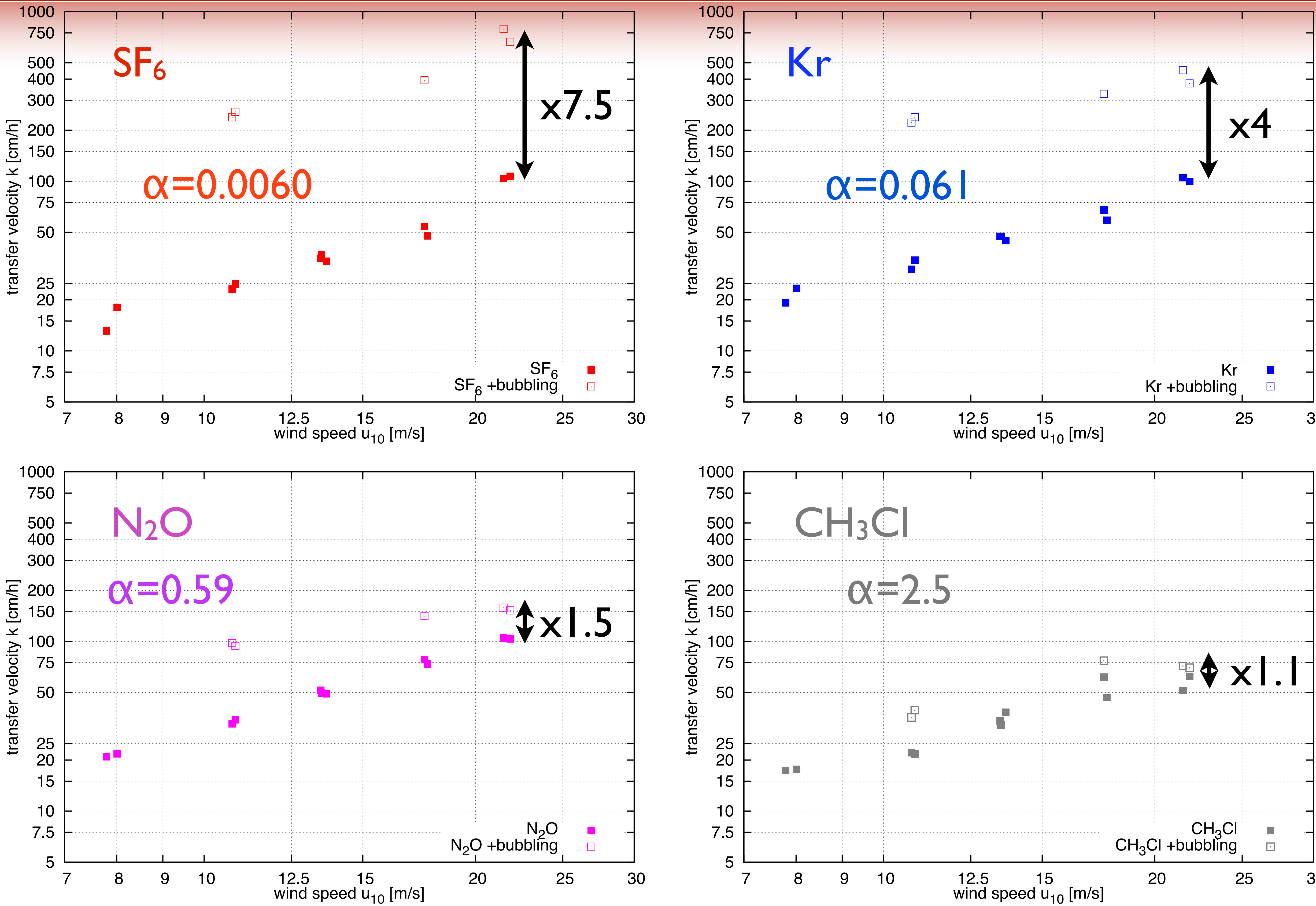






Bubble enhancement

SF_6, Krypton, N_2O, CH_3Cl



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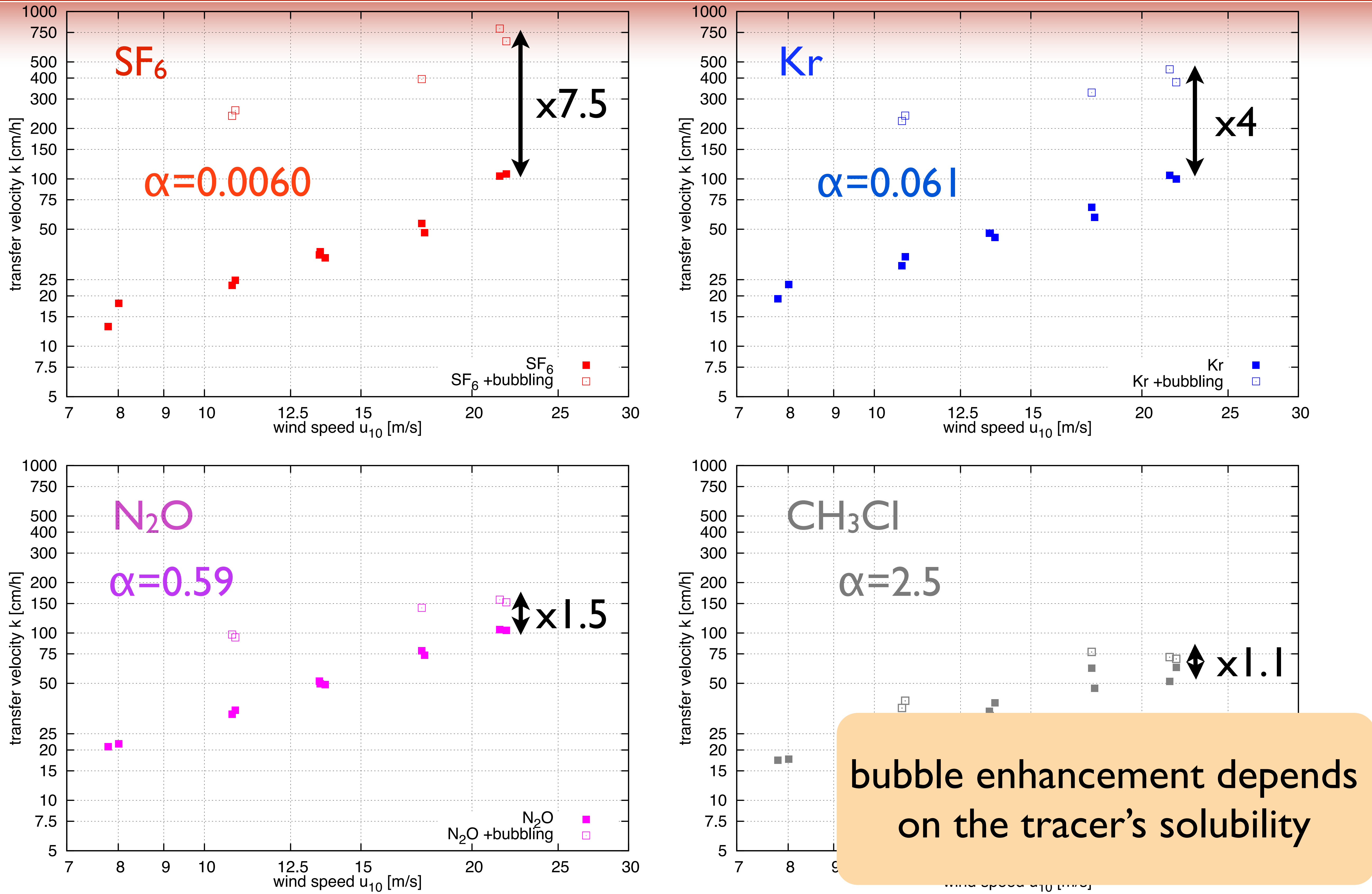

bubble enhancement depends on the tracer's solubility

Summary

transfer velocities of a large number of gases were measured in parallel in a controlled lab setting at wind speeds between 1.5 and 21 m/s using sea water taken from the North Atlantic

the Schmidt number exponent n transitions from 2/3 (smooth surface) to 1/2 (wavy surface)

up to u_{10} ~ 6 m/s, the gas transfer velocity is suppressed to 1/3 compared to a clean water surface

surface active material hinders wave formation up to u_{10} ~ 6 m/s

additional bubbling enhances the gas transfer velocity depending on the tracer's solubility

to do: in depth analysis of the underlying physics, model comparisons as well as synthesis with surface microlayer characteristics measurements