SENSITIVITIES IN WET DEPOSITION MODELLING APPLIED TO THE FUKUSHIMA NUCLEAR ACCIDENT

HARMO21

sck cen
Belgian Nuclear Research Centre

GHENT UNIVERSITY

RMI

STIJN VAN LEUVEN

Pieter De Meutter, Johan Camps, Andy Delcloo & Piet Termonia

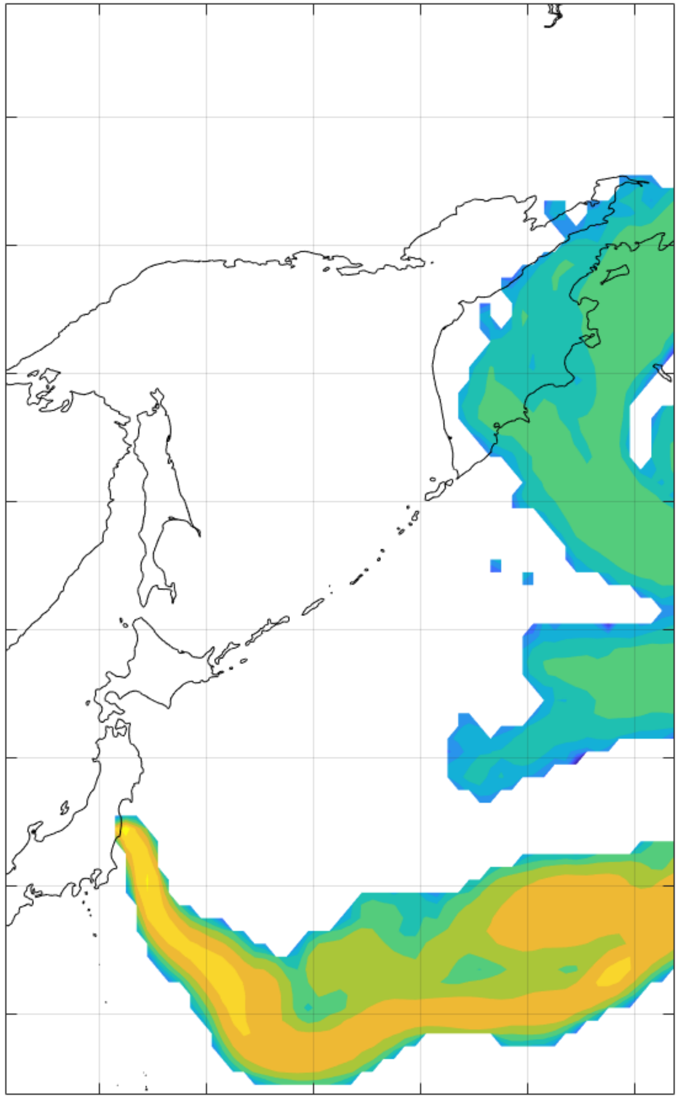
Introduction

Wet deposition is main contributor to radioactive contamination

- Atmospheric transport modelling (ATM) = important for
  - emergency preparedness
  - emergency response

  } nuclear releases
- **Wet deposition** reduces air concentration by depositing radionuclides on the ground

  → contamination
- **BUT** difficult to model



Introduction

We propose a novel method to improve wet deposition modelling

- Wet deposition is difficult to model
  - Physical properties difficult to measure
  - Simulation parameters are possibly case-dependent
- **Solutions**
  - Brute force: simulate whole parameter space (possibly 1000's of simulations)
  - **This presentation**: novel method to improve wet deposition simulations through optimisation scheme

Introduction

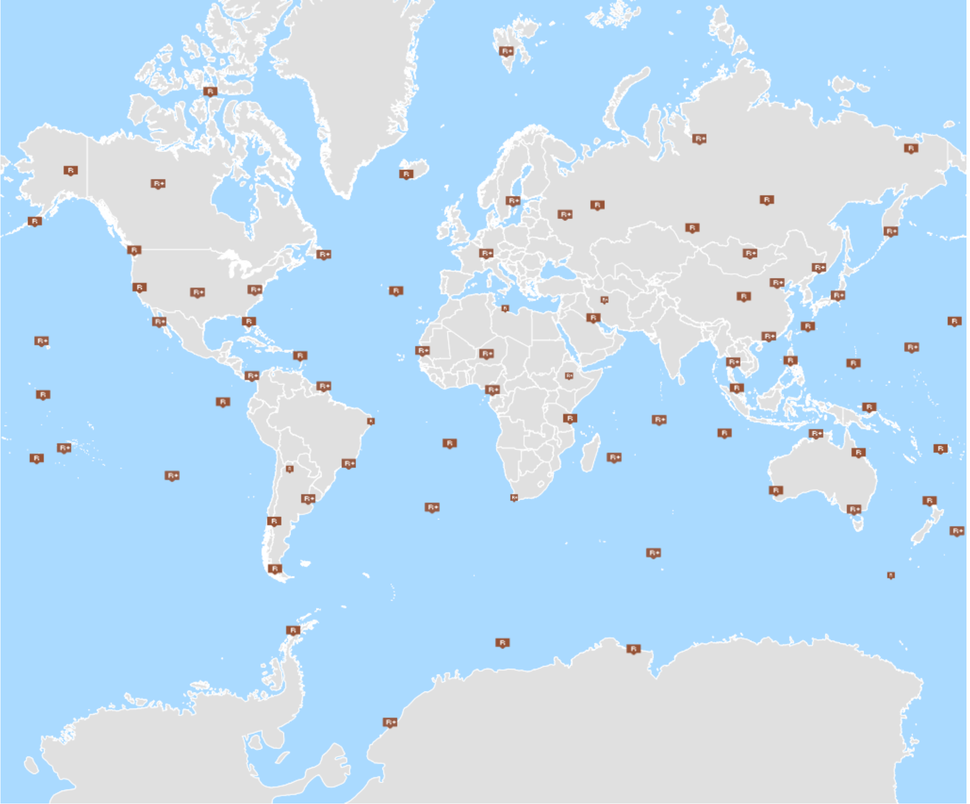
Fukushima as case study with Flexpart

- **Case study**
  - ^{137}Cs transport + deposition following **Fukushima** incident (2011)
- **Flexpart**
  - Stochastic **Lagrangian particle** model
  - Meteodata from ECMWF

Introduction

Concentration measurements provided by CTBTO

- **IMS** radionuclide stations from **CTBTO**
  - **I**nternational **M**onitoring **S**ystem
  - **C**omprehensive Nuclear-**T**est-**B**an **T**reaty **O**rganization
- 80 stations worldwide
  - 20 with highest measurements as ‘receptors’ in Flexpart



www.ctbto.org/map

Introduction

How is wet deposition modelled?

- **Scavenging**: exponential decay process
  - $c(t + \Delta t) = c(t)\exp(-\Lambda\Delta t)$
    - c : concentration $[\mathrm{Bq\ m^{-3}}]$
    - Λ : scavenging coefficient $[\mathrm{s^{-1}}]$
    - Δt : timestep $[\mathrm{s}]$

$\Lambda = \Lambda(I, d_\mathrm{p})$

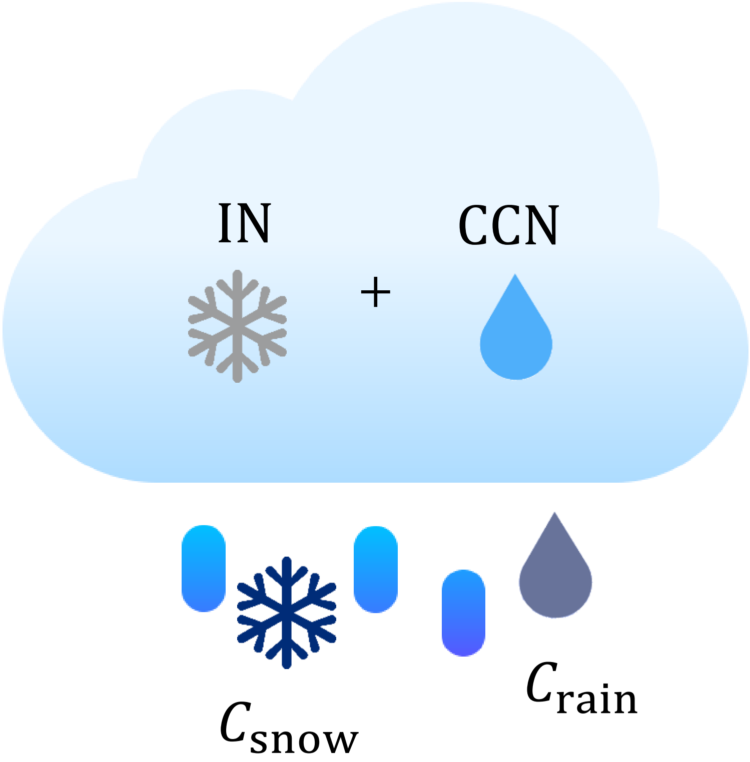
- I : rain intensity $[\mathrm{mm\ h^{-1}}]$
- d_p : particle diameter (distribution) $[\mathrm{\mu m}]$

- **Deposition**:
  - $F = \int \mathrm{d}z\, \Delta c\ [\mathrm{Bq\ m^{-2}}]$

Introduction

Different processes are represented in Flexpart 10.4 (aerosols)

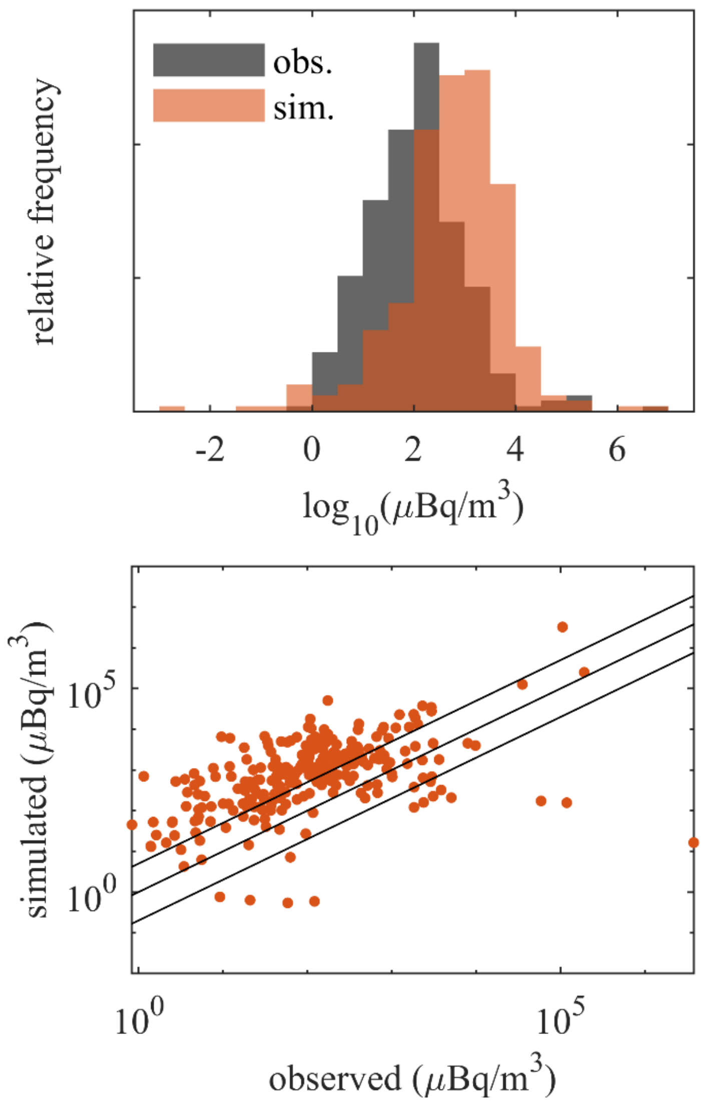
- **In-cloud** scavenging by
  - **c**loud **c**ondensation **n**ucleation (CCN)
  - **i**ce **n**ucleation (IN)
- **Below-cloud** scavenging by
  - **rain** collision (C_{rain})
  - **snow** collision (C_{snow})
- **Total** scavenging: $\Lambda = \sum_i \Lambda_i$



Introduction

Default simulations show overestimation of concentration

- Default (CCN, IN, C_{rain}, C_{snow}) values
- Concentrations **too high** (x10)
  1. Source term? ❌
     - Literature: only factor x2-4 uncertainty
  2. Wind fields? ❌
     - Xe simulations show no bias
     - Xe: noble gas → no deposition
  3. Wet scavenging too weak ❓



Methodology

We propose a 2-step method to improve wet deposition modelling

1. **Extract** scavenging contribution of each process from single Flexpart simulation

$$(\mathrm{CCN}, \mathrm{IN}, C_{\mathrm{rain}}, C_{\mathrm{snow}})$$

2. **Optimisation scheme**: scale individual scavenging contributions and fit remaining concentration to observations

Methodology

STEP 1 – extract scavenging contributions

- Concentration left over at location $\vec{x}$ & after time T since release

$$c(\vec{x},T) = c_0(\vec{x},T) - \sum_i \Delta c_i(\vec{x},T)$$

- c_0 : concentration without scavenging
- $\Delta c_i = \int_0^T \Lambda_i c \mathrm{d}t$: contribution of each scavenging process (CCN, IN, C_{rain}, C_{snow}) between release and time T

→ extract from Flexpart: altering source code

Methodology

$$c = c_0 - \sum_i \Delta c_i$$

STEP 2 – optimise scavenging: scaling

- How to scale Δc_i's?
  - Simply scaling $x_i \Delta c_i$ can produce negative c
    → **not physical**!

- **Solution**: introduce scaling factor A_i for every Λ_i so that
  - $\Delta c_i = (c + \Delta c_i) A_i$
  - A_i acts on part of the concentration that is 'available' to process i

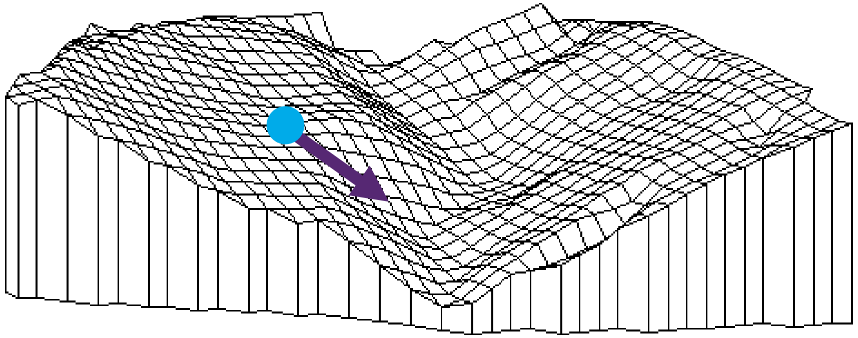
Methodology

STEP 2 – optimise scavenging: fitting

$$c = c_0 - \sum_i \Delta c_i$$
$$\Delta c_i = (c + \Delta c_i)A_i$$

- Minimising cost function by varying A_i's
  - $F(c, c_{\text{obs}}; A_i) = (\log_{10} c(A_i) - \log_{10} c_{\text{obs}})^2$

- Minimisation in 4-dimensional parameter space
  - $(\text{CCN}, \text{IN}, C_{\text{rain}}, C_{\text{snow}})$



Results

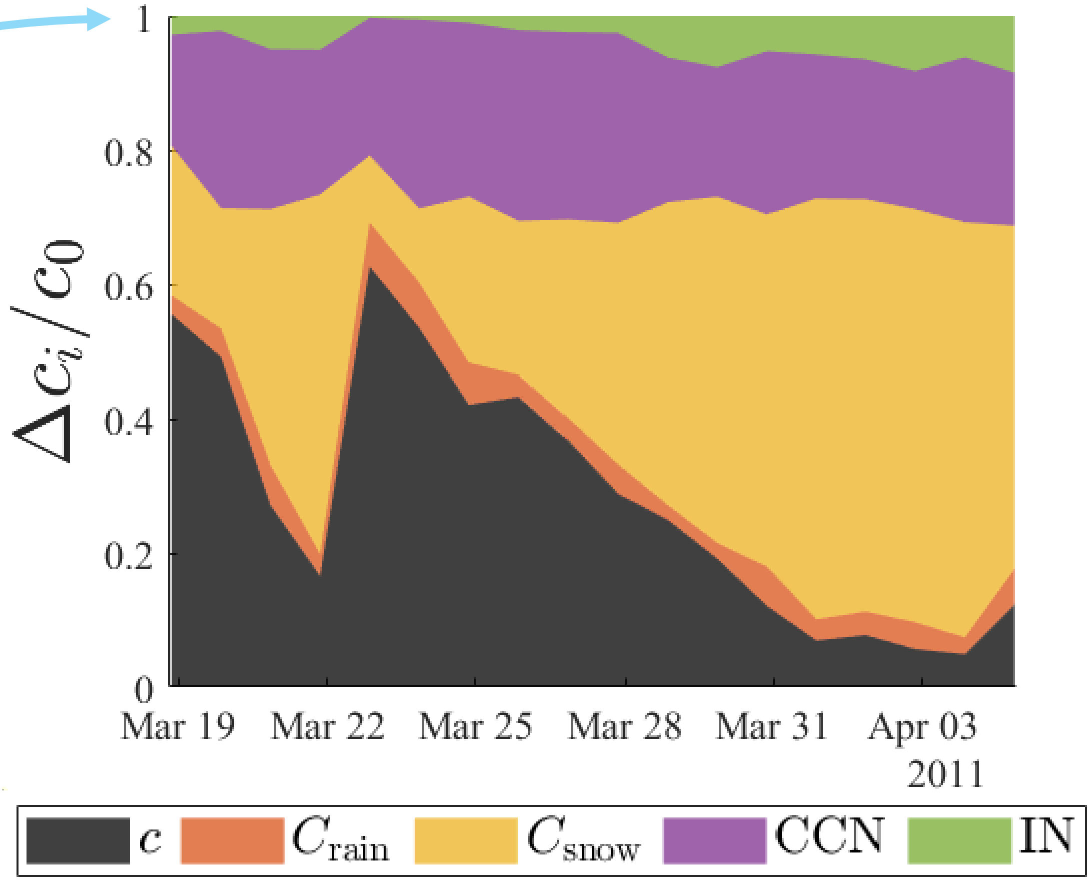
Sanity check: step 1 works!

- $c = c_0 - \sum_i \Delta c_i$

  $$\rightarrow \frac{c}{c_0} + \sum_i \frac{\Delta c_i}{c_0} = 1$$

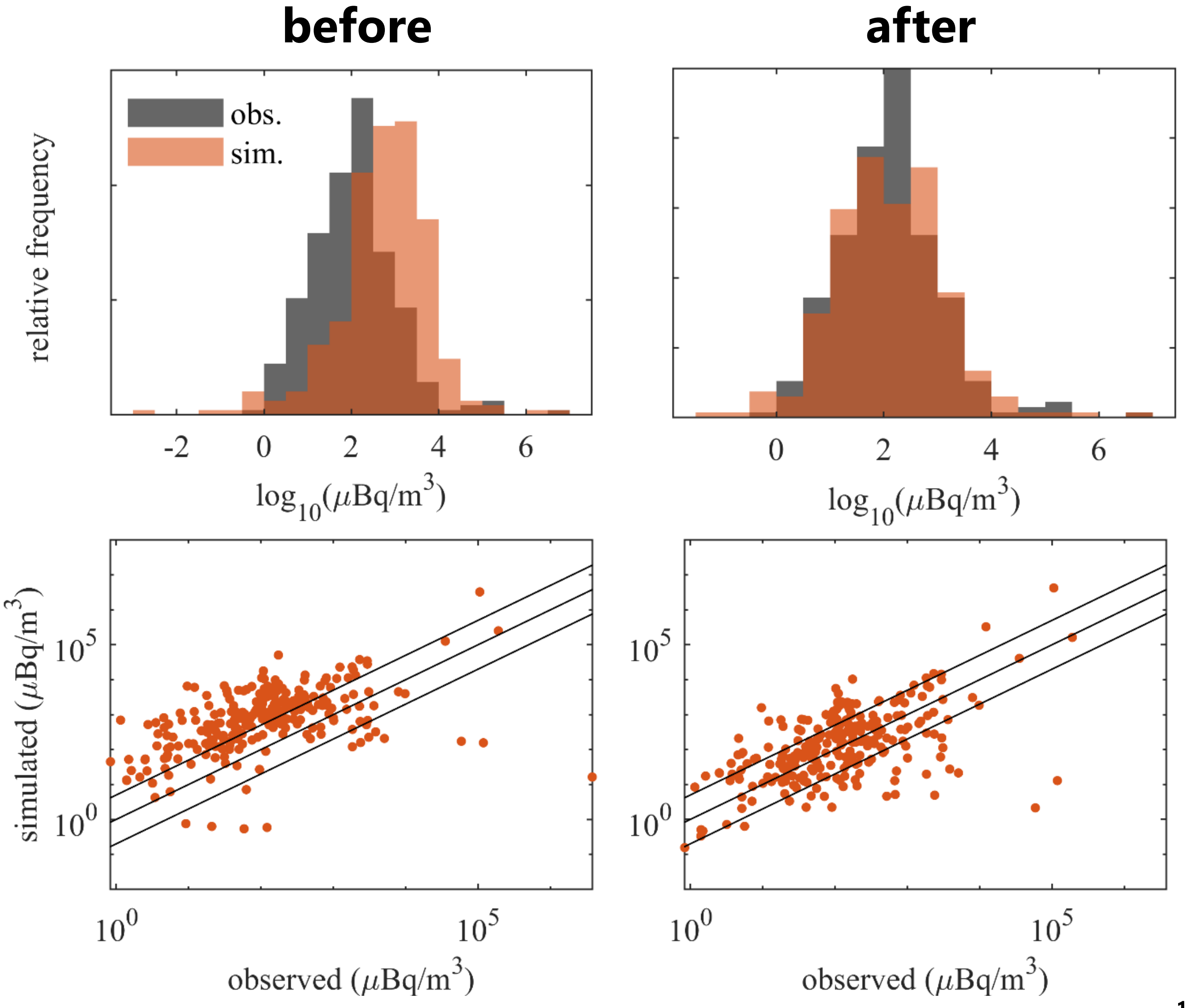
- Default (CCN, IN, C_{rain}, C_{snow}) values in Flexpart

IMS station RN71



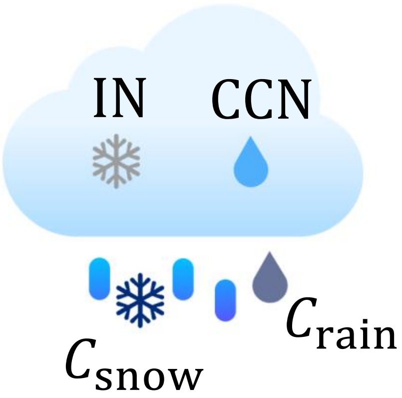
Results

After step 2: optimisation process makes big improvement

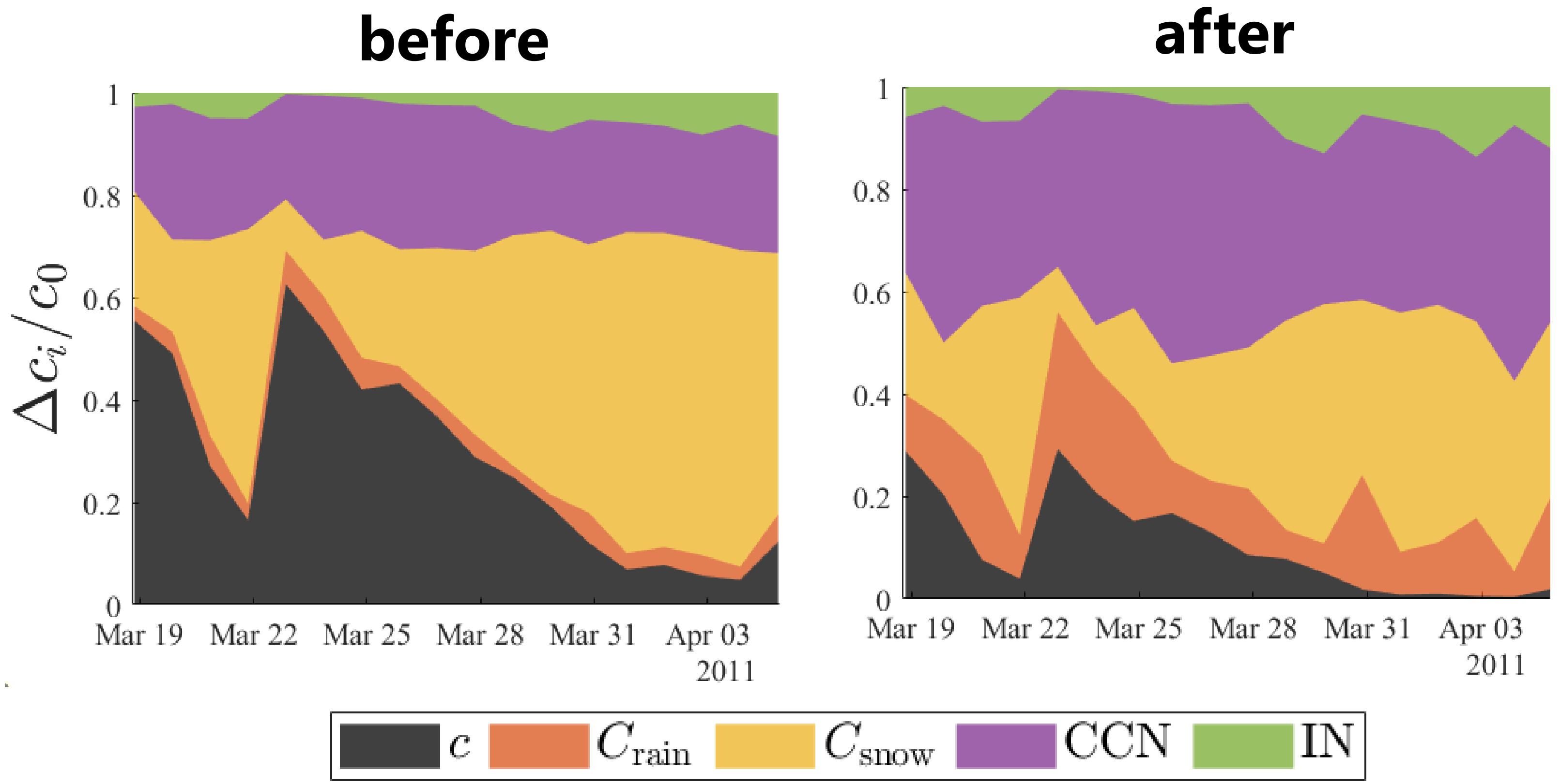


Results

What happened behind the scenes...



- Scaling factor of all scavenging processes increased
- Greatest increase for CCN and C_{rain}
- Due to compensating effects, relative contribution of some processes can decrease (e.g. C_{snow})



Conclusions

✓ The proposed optimisation scheme is able to improve simulation-observation correspondence by scaling the wet scavenging contributions of different scavenging processes

✓ This method is more efficient than a brute force method, as it in principle only requires 1 simulation

Questions?