Feedbacks in Enviro-HIRLAM

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Definition: aerosol feedback

Interaction mechanism between aerosols and meteorological fields, when a change in an initial aerosol process affects meteorological fields, which in turn affects the aerosol process.

If the initial process intensifies the feedback is positive and if it is reduced the feedback is negative

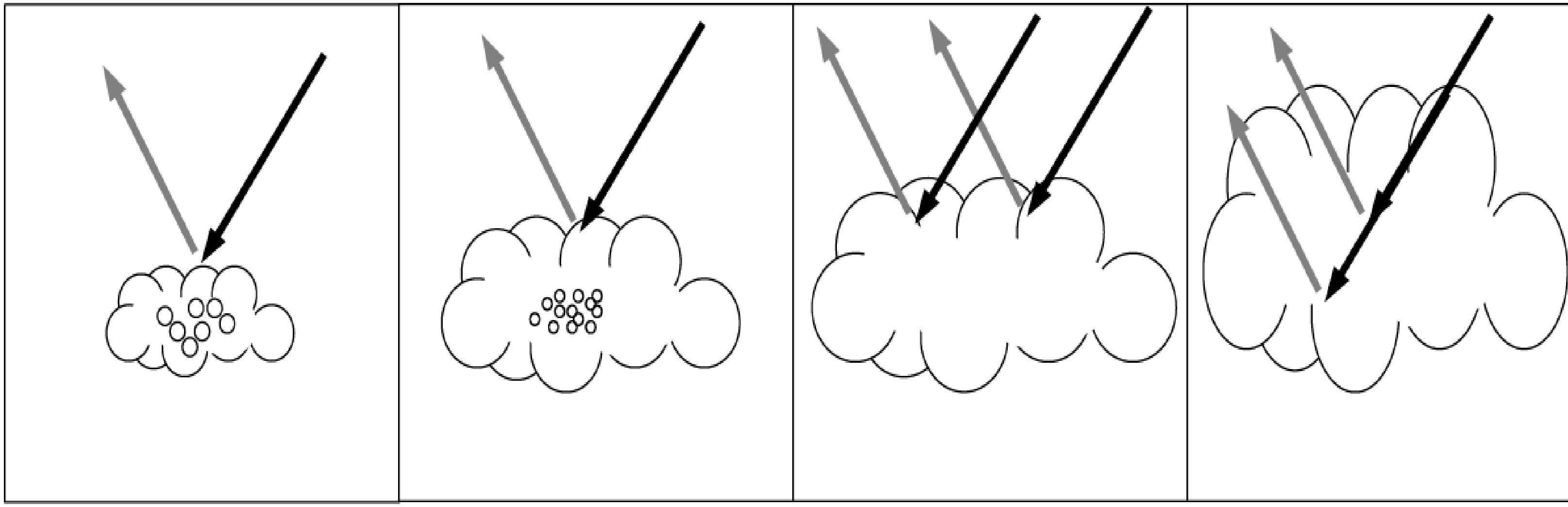
There are many feedbacks in the atmosphere: which ones are important ?

Note: Even small changes in meteorological fields may be of importance in chemistry.

Examples of feedbacks: Photochemistry effect, daytime stability effect, indirect effect, semi-direct effect, smudge-pot effect, self-feedback effect all related to the direct aerosol effect
Jacobson, Science and History of Air Pollution

Gas-radiation feedbacks, cloud feedbacks, direct effect, semi-direct effect

DMI's main focus have been on aerosol-cloud interactions



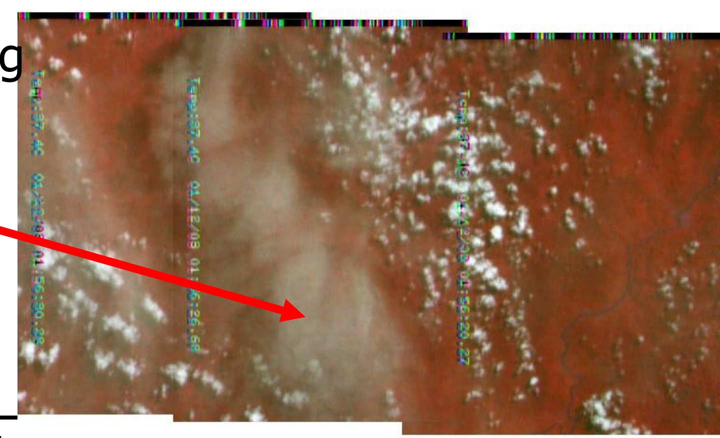
Direct aerosol effect

1st aerosol indirect effect

2nd aerosol indirect effect

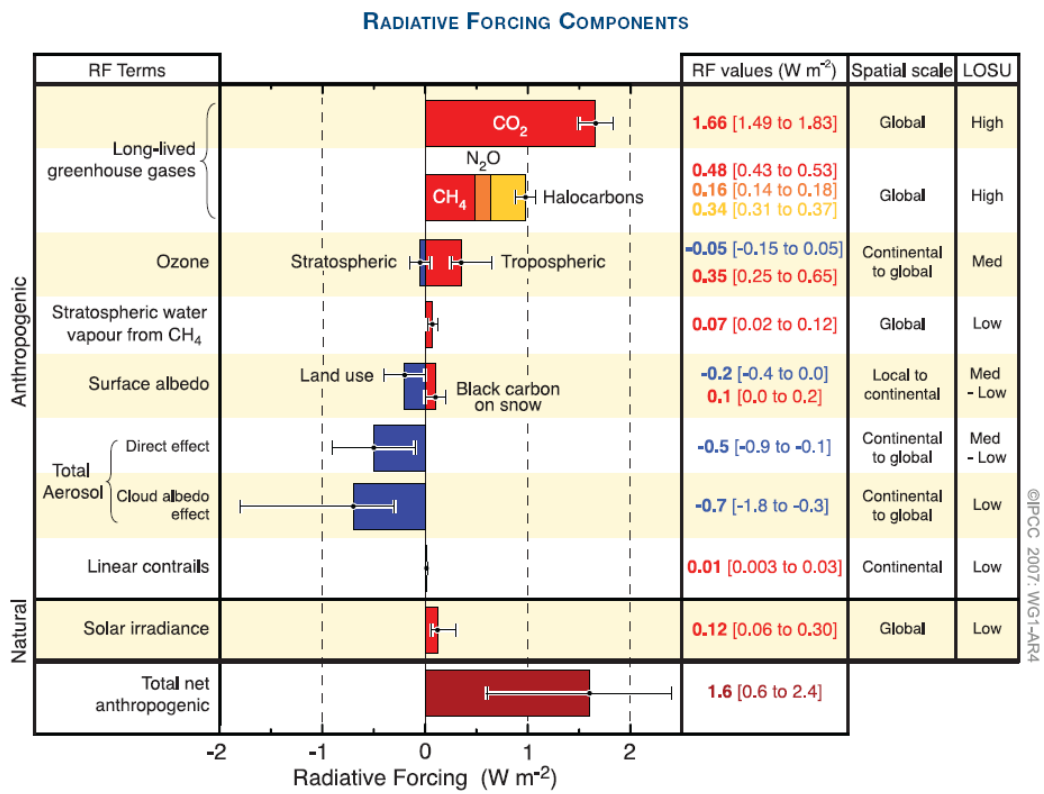
Semi-direct aerosol effect

Semi-direct effect: Aerosols from biomass burning
Absorbing in the short wave and heat the air
-> evaporation of clouds

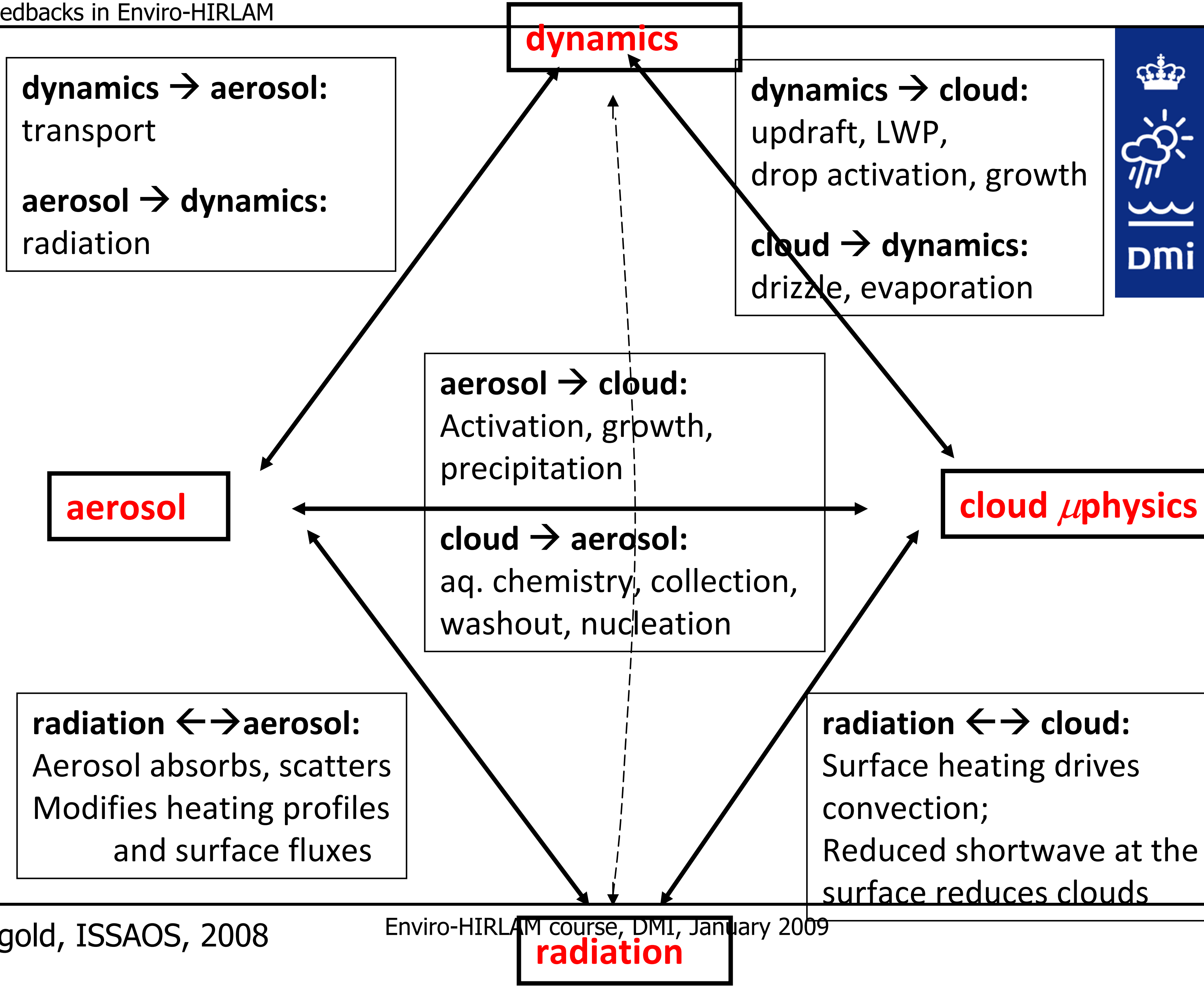


Columbia shuttle image (Brazil) Jan 12th 2003

Large uncertainties in quantification of these effects



How does anthropogenic aerosols affect clouds ?



Feingold, ISSAOS, 2008

How does anthropogenic aerosols affect clouds ?

Overview of cloud and precipitation formation

Clouds form when air supersaturates in unstable/stable conditions:
Convection, isobaric cooling, orographic lifting, …
-> vapor condense on natural and anthropogenic hygroscopic aerosols
-> decrease in supersaturation
-> growth by condensation untill r ~ 10 μm
-> collision/coalescence takes over
-> rain produced by collision/coalescence not condensation
-> rain initiated by statistical effects: droplets fall through region of higher conc. and is then controlled by collision/coalescence

Orographic cloud formation

How does anthropogenic aerosols affect clouds ?

Clouds are formed by dynamics, which controlles supersaturation

Aerosols do not form clouds, but they are a neccessary component of cloud droplet formation

Without aerosols it would be very difficult to form clouds

Aerosols affect cloud microphysical and optical properties

How does anthropogenic aerosols affect clouds ?

Kelvin effect (surface tension)

Solute effect (composition)

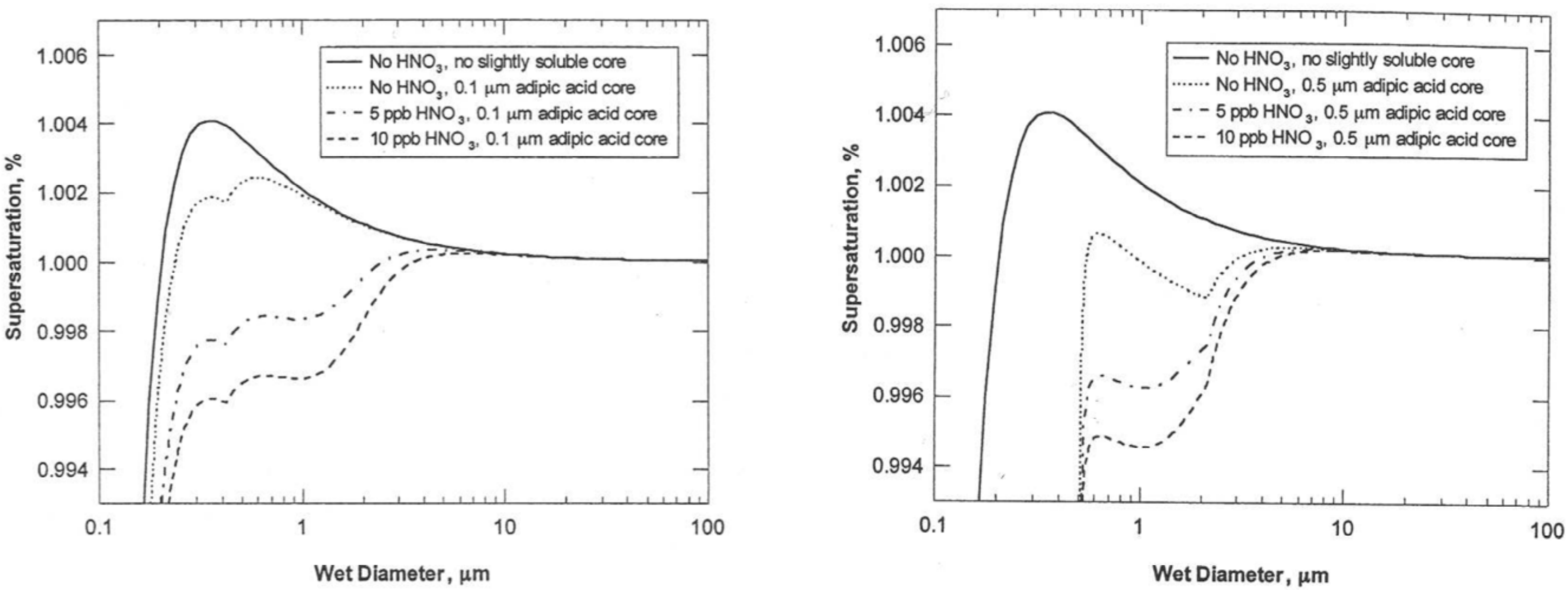
$$\ln\left(\frac{p_w(D_p)}{p^\circ}\right) = \frac{A_w}{D_p} - \frac{B_s}{D_p^3},$$

Classical Kohler theory

$$S_w = 1 + \frac{A_w}{D_p} - \frac{B_s}{\left(D_p^3 - D_{ss}^3\right)} - \frac{B_a}{\left(D_p^3 - D_{ss}^3\right)} - c_{ss}$$

Modified Kohler theory

Accounting for slightly soluble substances and trace gases



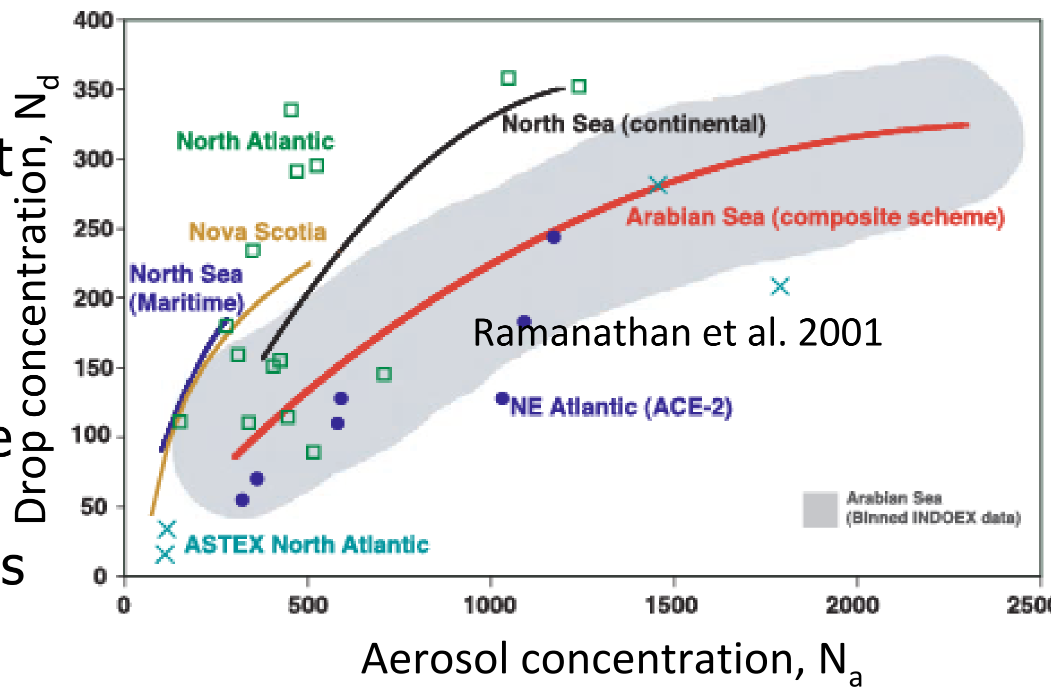
How does anthropogenic aerosols affect clouds ?

- The activated fraction is a neccessary component of cloud formation
- From theory and observations an increase in aerosol concentration always lead to an increase in cloud droplet concentration

Cloud droplet effective radius:
Ratio of second and third moments of the droplet distribution, i.e droplet volume to droplet surface area ratio

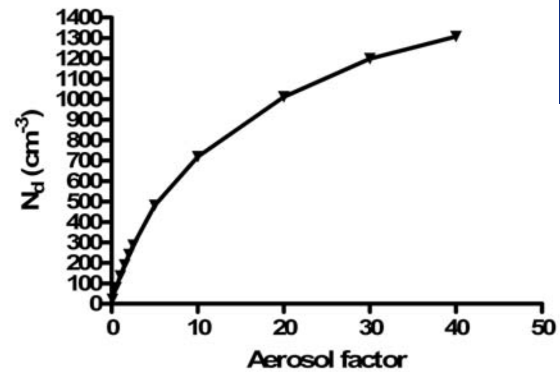
$r_{eff} = [3L_c/(4\pi\rho_w kN)]^{1/3}$

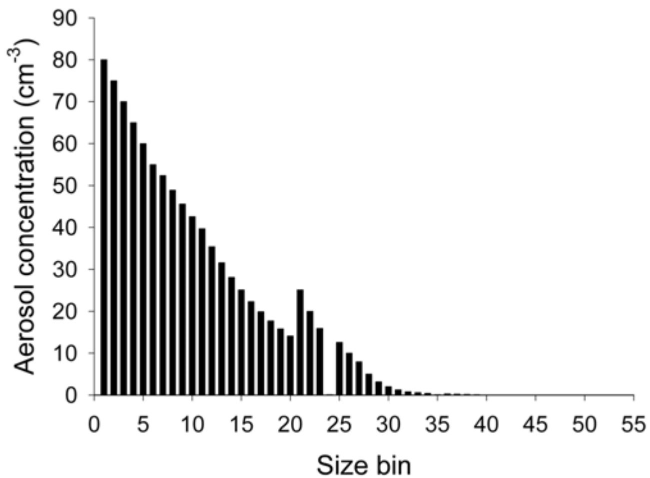
Keeping all else constant an increase
In droplet number concentration will
Lead to a decrease in effective radius

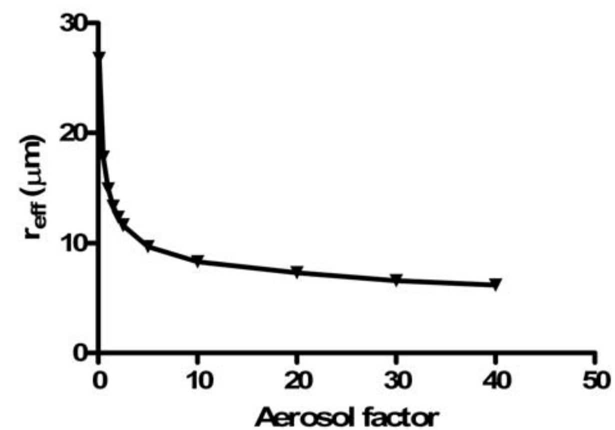


How does anthropogenic aerosols affect clouds ?

1D cloud model
Lifting air parcel
Detailed size resolved microphysics
Aerosol growth, activation, condensation
55 size classes; 1 – 25 μm
Steady updraught 1 m/s



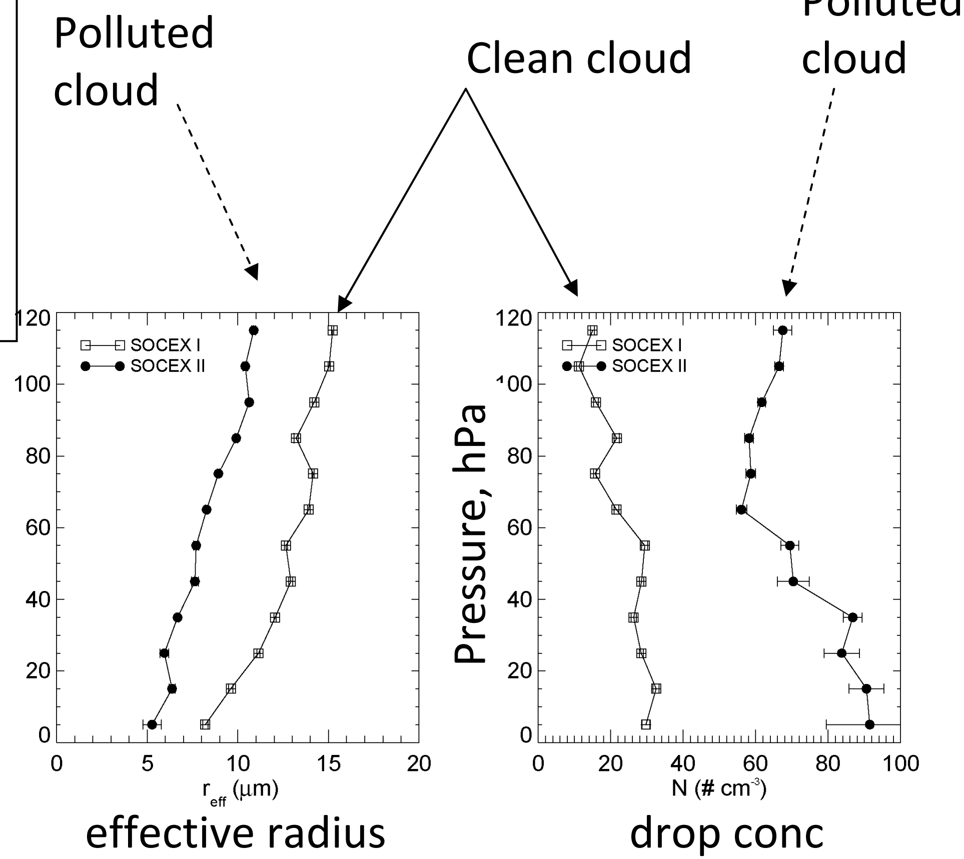




How does anthropogenic aerosols affect clouds ?

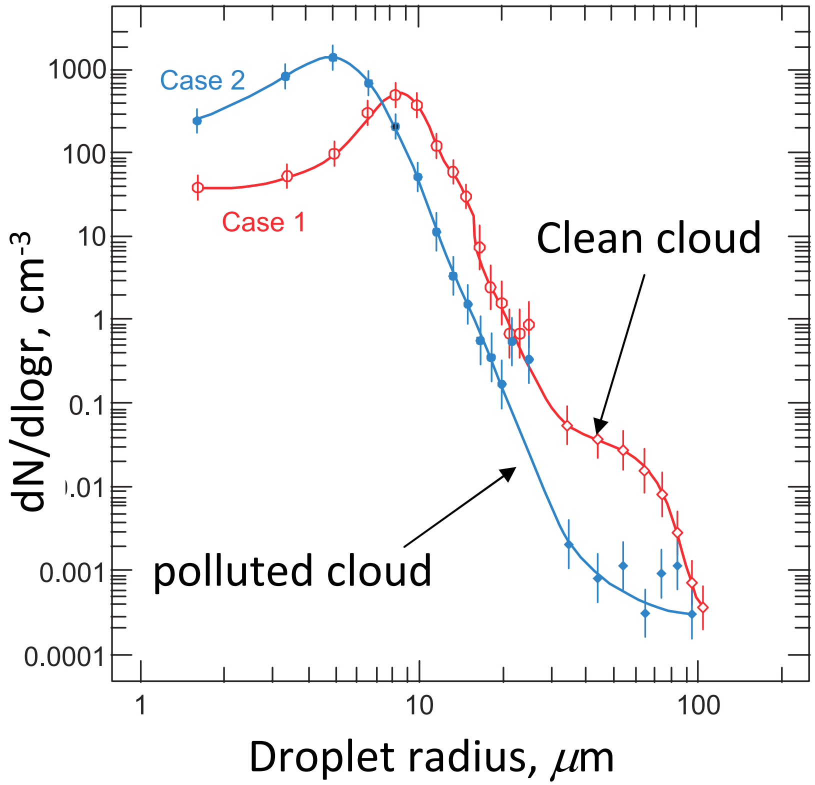
Warm clouds:

- Drop size increases with height
- Drop conc ~ constant with height
- Polluted clouds: more numerous smaller drops



Feingold, ISSAOS, 2008

How does anthropogenic aerosols affect clouds ?



Garrett and Hobbs (1996)

The 1st aerosol indirect effect *(Twomey, 1974)*

Cloud albedo: $A_{cloud} = \tau/(\tau+7.7)$ for Droplet radii >> incomming wavelength (*Seinfeld and Pandis, 1998*)

If τ is the cloud optical thickness, cloud depth is h and extinction coefficient is b_{ext}: $\tau = b_{ext}\, h$

$b_{ext}(\lambda) = \pi/4 \int D^2\, Q_{ext}\, n(D)dD$

Size distribution

Extinction cross section

For droplets around 20 μm $Q_{ext} \sim 2$ and for a mono disperse cloud:

$$\tau = 3LWP/(2r_{eff}\rho_w)$$

The 1st aerosol indirect effect

For warm phase clouds an increase in anthropogenic aerosol load
-> activation and increase in CCN concentration
-> decrease in r_{eff}
-> increase in A_{cloud}, assuming everything else stays constant

Can be observed directly in ship tracks

Ship tracks embedded in stratocumulus layer

Ship tracks

- On the microphysical level this effect is well understood
- It has been observed in several campaigns
- The radiative impact is less understood

The 1st aerosol indirect effect

Which clouds are most important

Low clouds provide strong shortwave forcing

Strong contrast with underlying dark ocean

Radiate at ~ same T_o as ocean therefore no longwave effect

High clouds (cirrus) provide longwave forcing by trapping outgoing longwave radiation

Feingold, ISSAOS, 2008

The 1st aerosol indirect effect

Implementation in Enviro-HIRLAM

Cloud radiative properties dependent bulk cloud properties
Cloud radiation parameterization mainly dependent on r_{eff}

$r^3_{eff} = 3L/(4\pi\rho_{wat}kN)$
(*Wyser et al. 1999*)

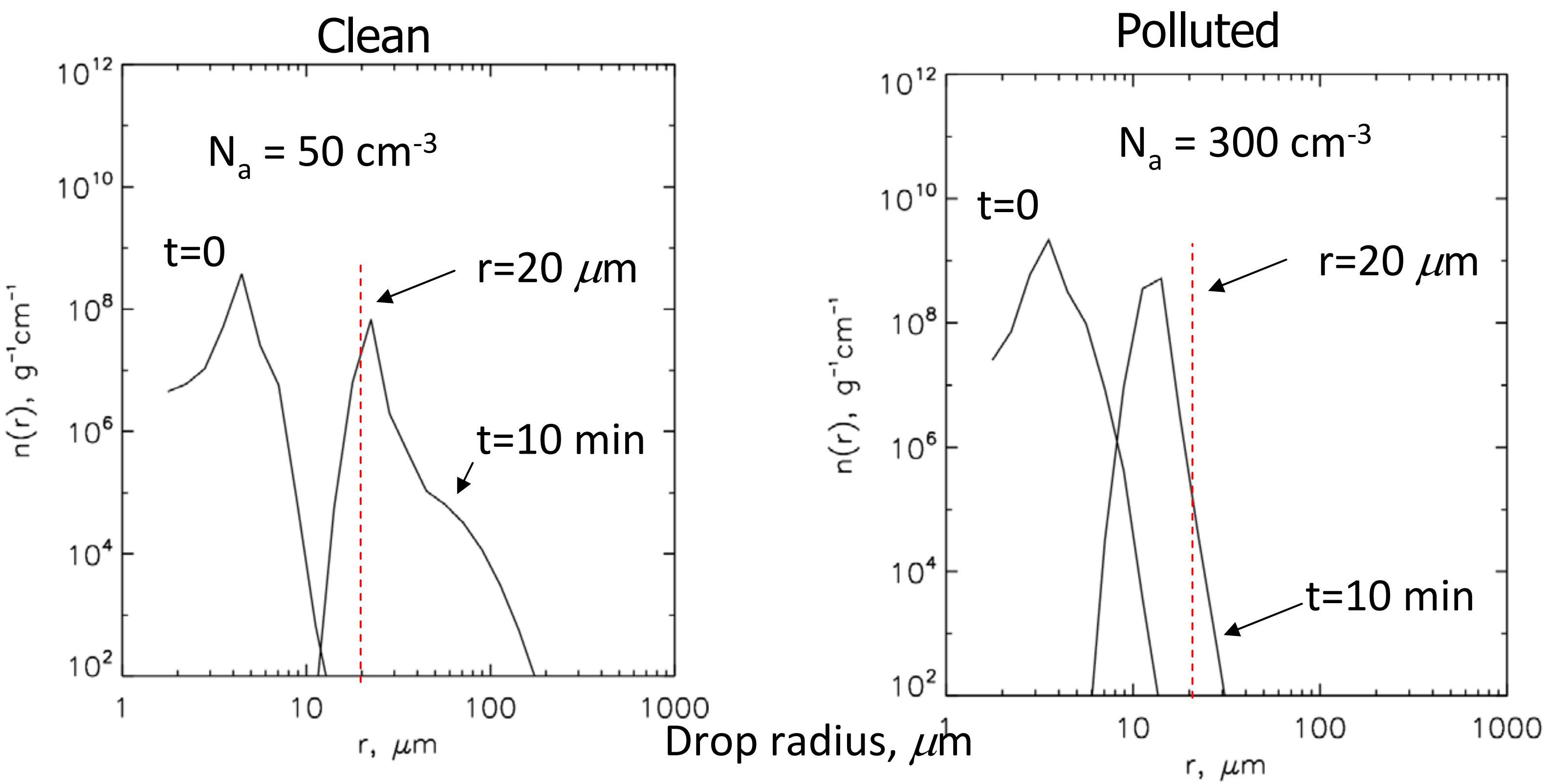
L : Cloud condensate content
N: Number concentration of cloud droplets
ρwat : water density

Activated fraction:
$\Delta N_{cont} = 10^{8.06}\ conc^{0.48}$
$\Delta N_{sea} = 10^{2.24}\ conc^{0.26}$
(*Boucher & Lohmann, 1995*)

	k	N [m^{-3}]
Marine	0.81	10^8
Cont.	0.69	$4\ 10^8$

The 2nd aerosol indirect effect (*Albecht, 1989*)

Aerosol significantly reduces the ability of warm clouds to generate precipitation (all else equal)
(Gunn and Phillips 1957; Warner 1967)



The 2nd aerosol indirect effect (*Albecht, 1989*)

Originally defined for stratocumulus clouds, although used
In general: As r_{eff} decrease less droplets grow into the collision/coalesence regime and drizzle is surpressed
-> increase in LWP
-> increased cloud cover
-> increased cloud lifetime

Also denoted the lifetime effect

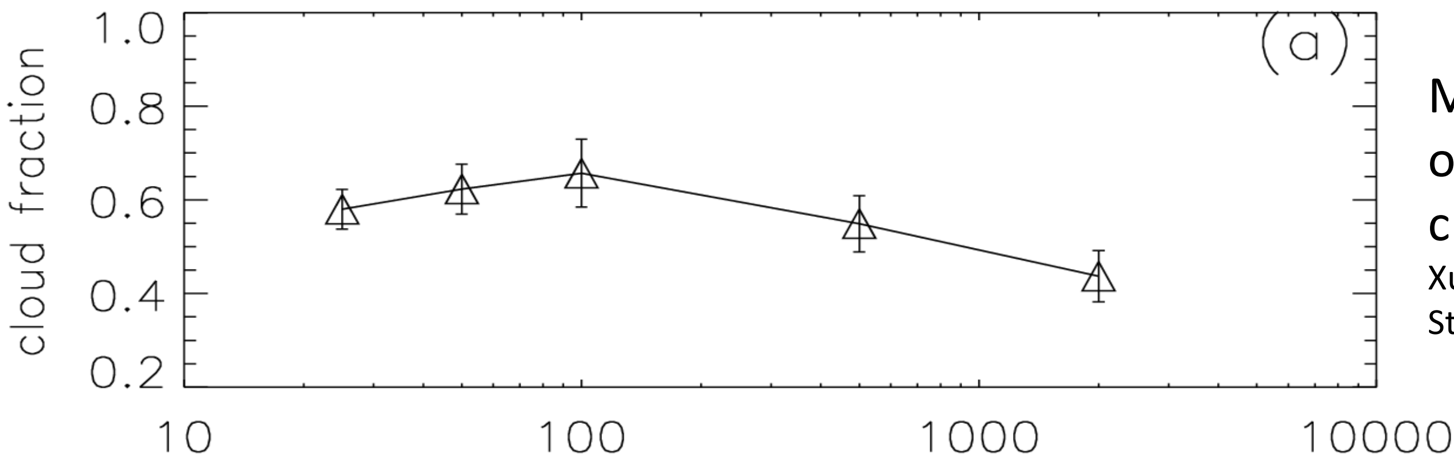
Turns out that things are not that simple, even in stratocumulus clouds

The 2nd aerosol indirect effect (*Albecht, 1989*)

Cloud microphysics-dynamics feedbacks complicates the simple picture

Using LES models it is found that for stratocumulus two regimes exist

Condensation: $\partial r/\partial t = S_w/r$ -> small droplets evaporate easier than large



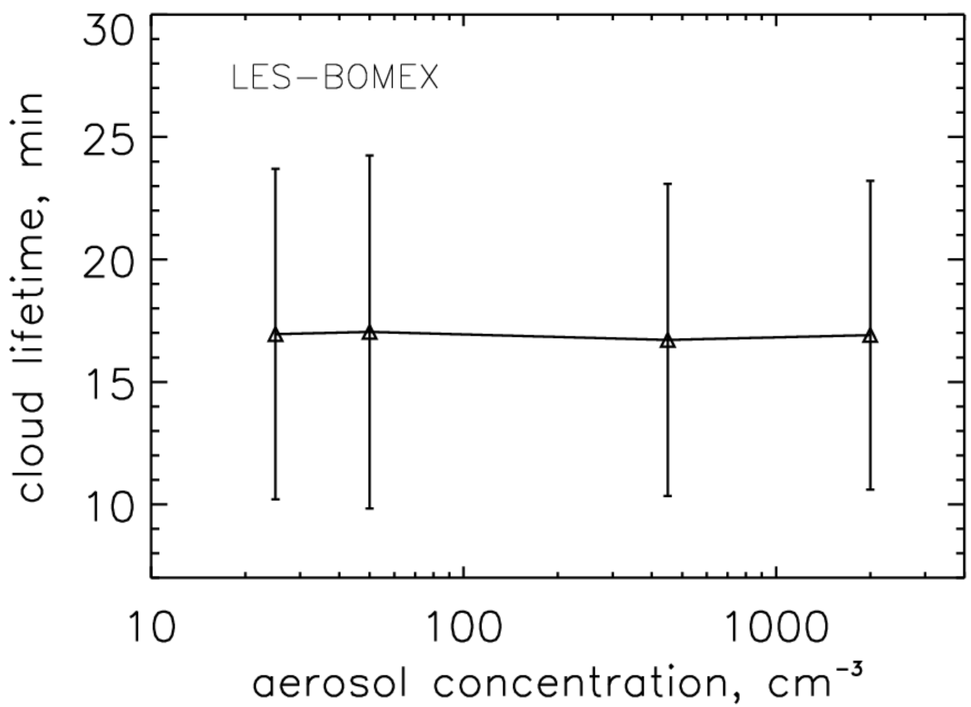
Modeling of warm clouds

Xue, Feingold, Stevens, 2008

The 2nd aerosol indirect effect (*Albecht, 1989*)

- There are no observations of aerosol effects on cloud lifetime!

- Modeling: No statistical signal for aerosol effect on cloud lifetime



Jiang, Xue, Teller, Feingold, Levin: GRL 2006

The 2nd aerosol indirect effect (*Albecht, 1989*)

Implementation of the second aerosol indirect effect

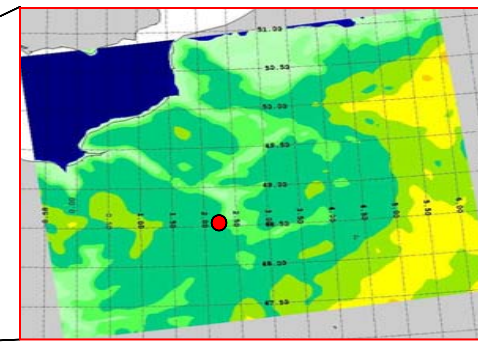
Rasch - Kristjansson condensation scheme in STRACO
Auto-conversion: $F(q_l, \rho_{air}/ \rho_{wat})N^{1/3}$ $H(r - r_c)$
r : droplet volume radius; $r = r^3_{eff} * \rho_{air}$
r_c : critical value below which no auto-conversion takes place; 5 µm
ρ_{air} : air density
q_l : in-cloud liquid water mixing ratio

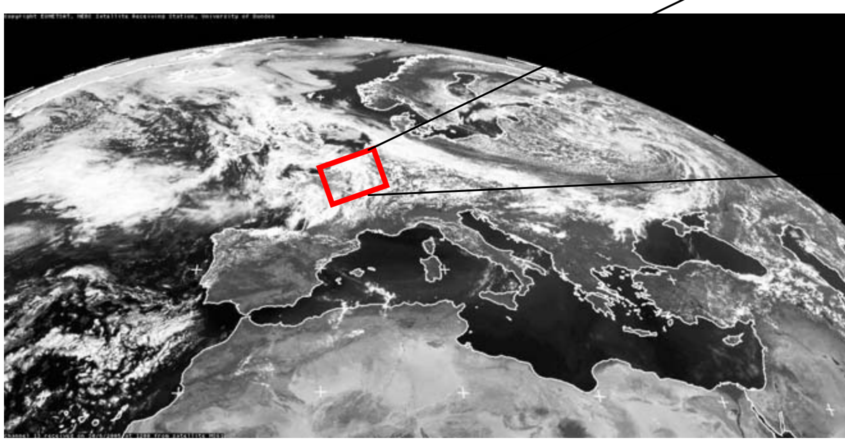
Importance of aerosol indirect effects for pollutant distribution and transformation

- Case chosen to optimize the effect

665 km

445 km



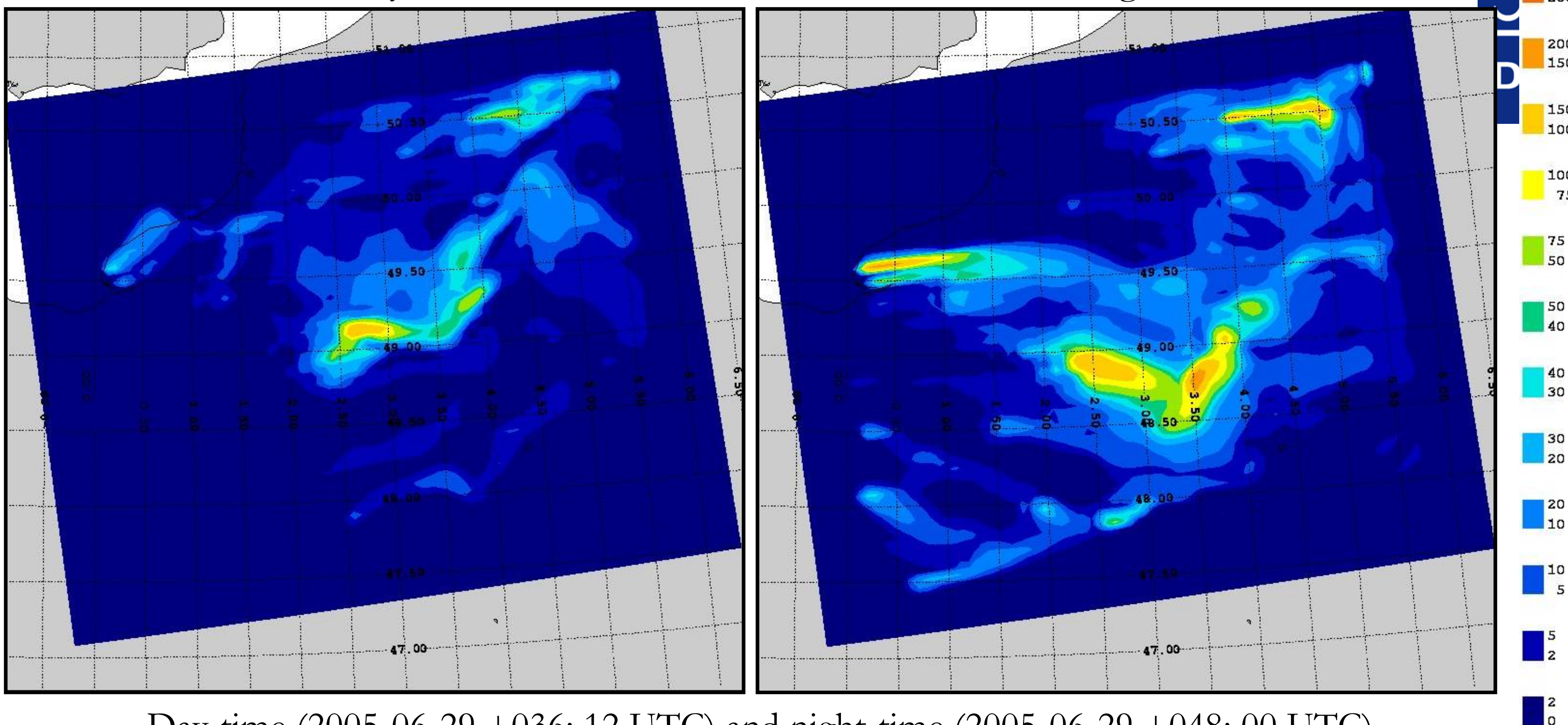


Horizontal resolution: 0.05º x 0.05º
Vertical resolution: 40 levels
Model top: 10 hPa

MSG1 satellite image 2005-06-30, 12 UTC

Importance of aerosol indirect effects for pollutant distribution and transformation

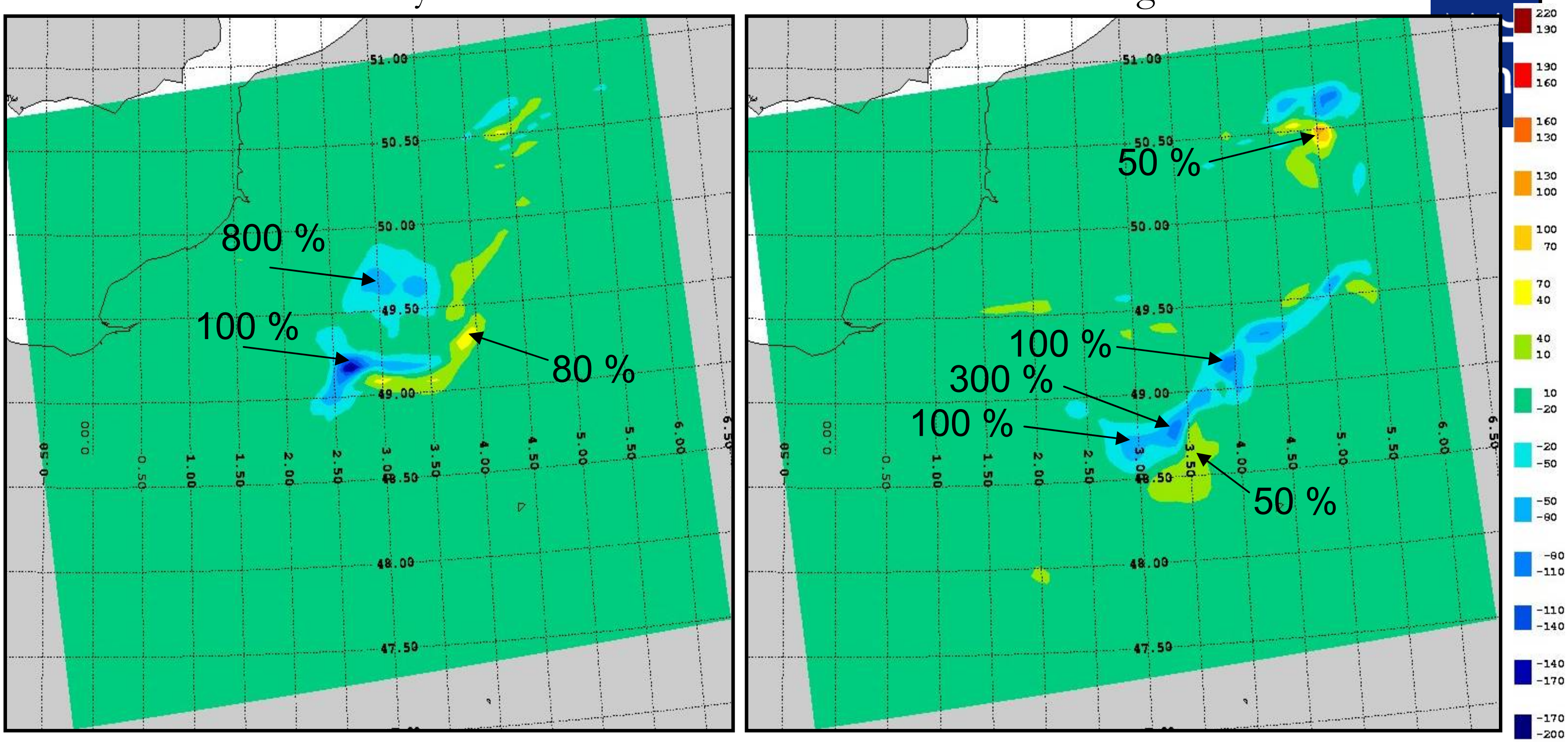
Day   Night



Day-time (2005-06-29 +036; 12 UTC) and night-time (2005-06-29 +048; 00 UTC) reference NO_2 concentration (μg m^{-3})

Importance of aerosol indirect effects for pollutant distribution and transformation

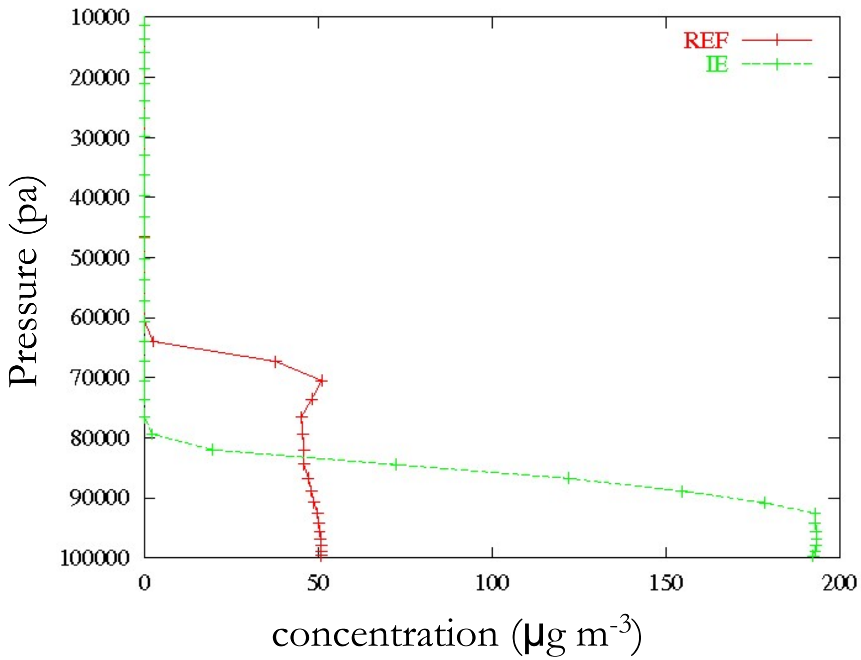
Day Night



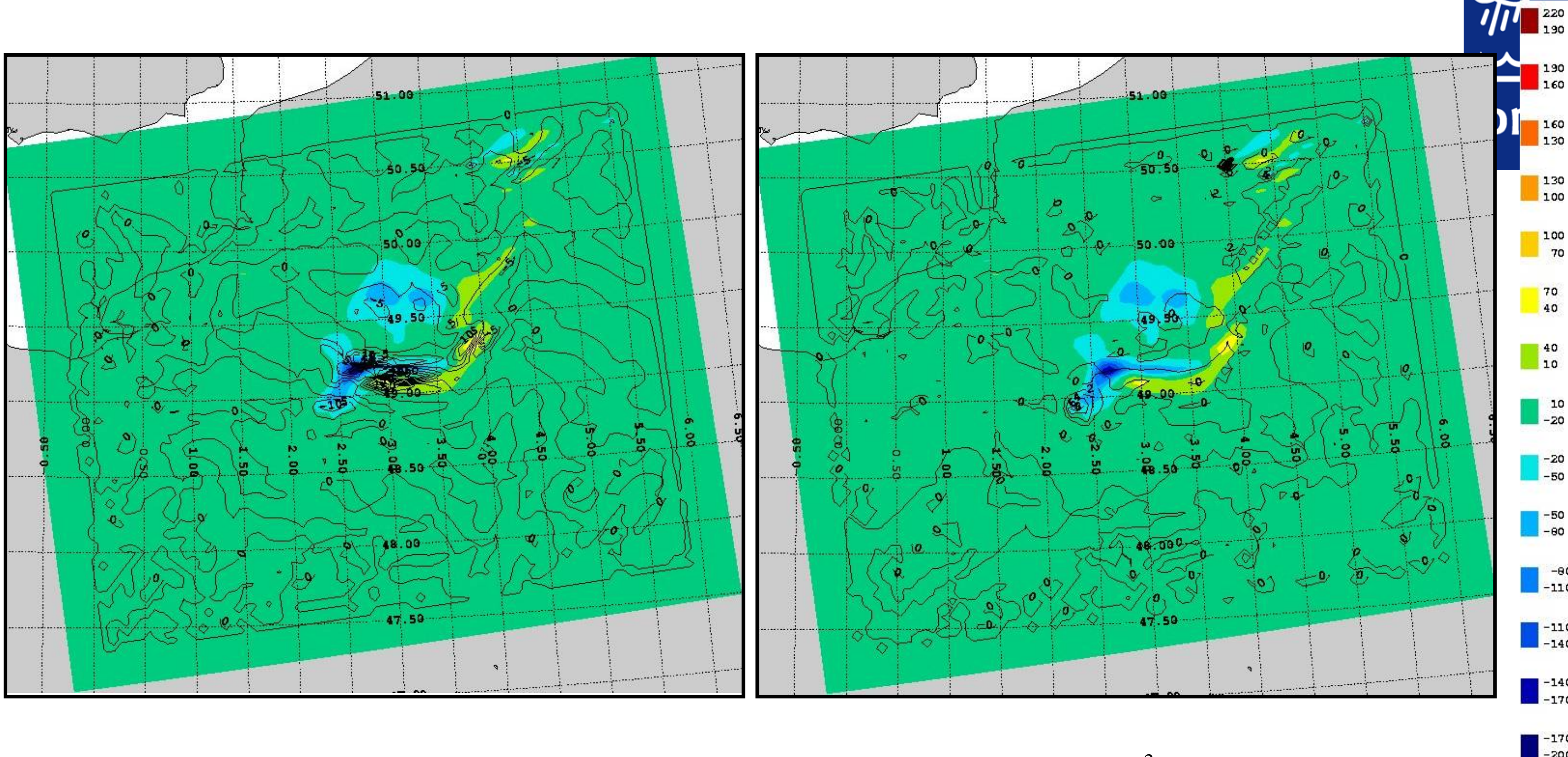
Day-time (2005-06-29 +036; 12 UTC) and night-time (2005-06-29 +048; 00 UTC) reference - perturbation NO_2 concentration (μg m^{-3})

Importance of aerosol indirect effects for pollutant distribution and transformation

Vertical NO_2 profile in point of maximum increase (49.2N;2.7E) during daytime 2005-06-29 +036; 12 UTC for the reference simulation (red) and the simulation including the indirect effects (green)



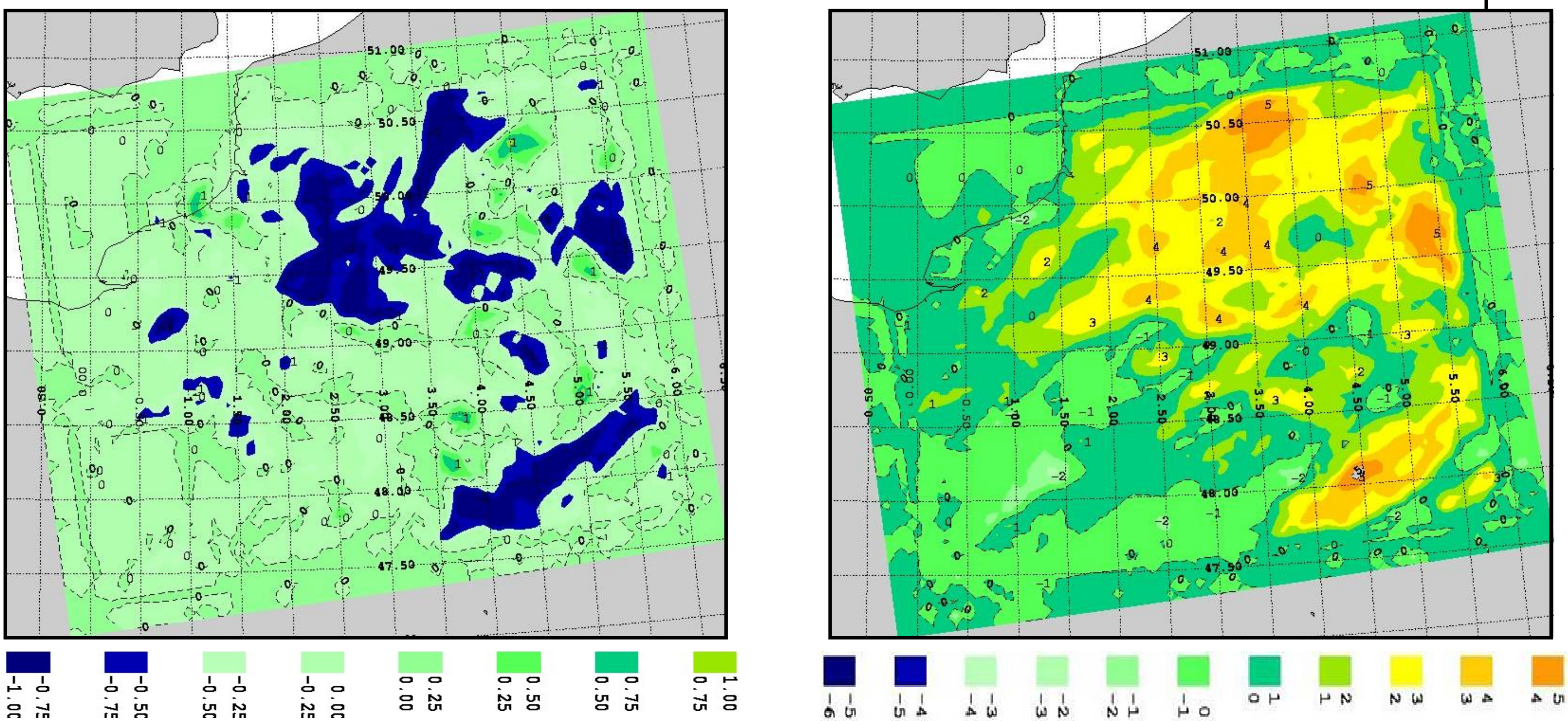
Importance of aerosol indirect effects for pollutant distribution and transformation



Day-time (2005-06-29 +036; 12 UTC) NO_2 concentration (μg m^{-3}) difference (reference-perturbation) with dynamical (right) and chemical (left) tendencies (μg m^{-3} s^{-1}) overlain.

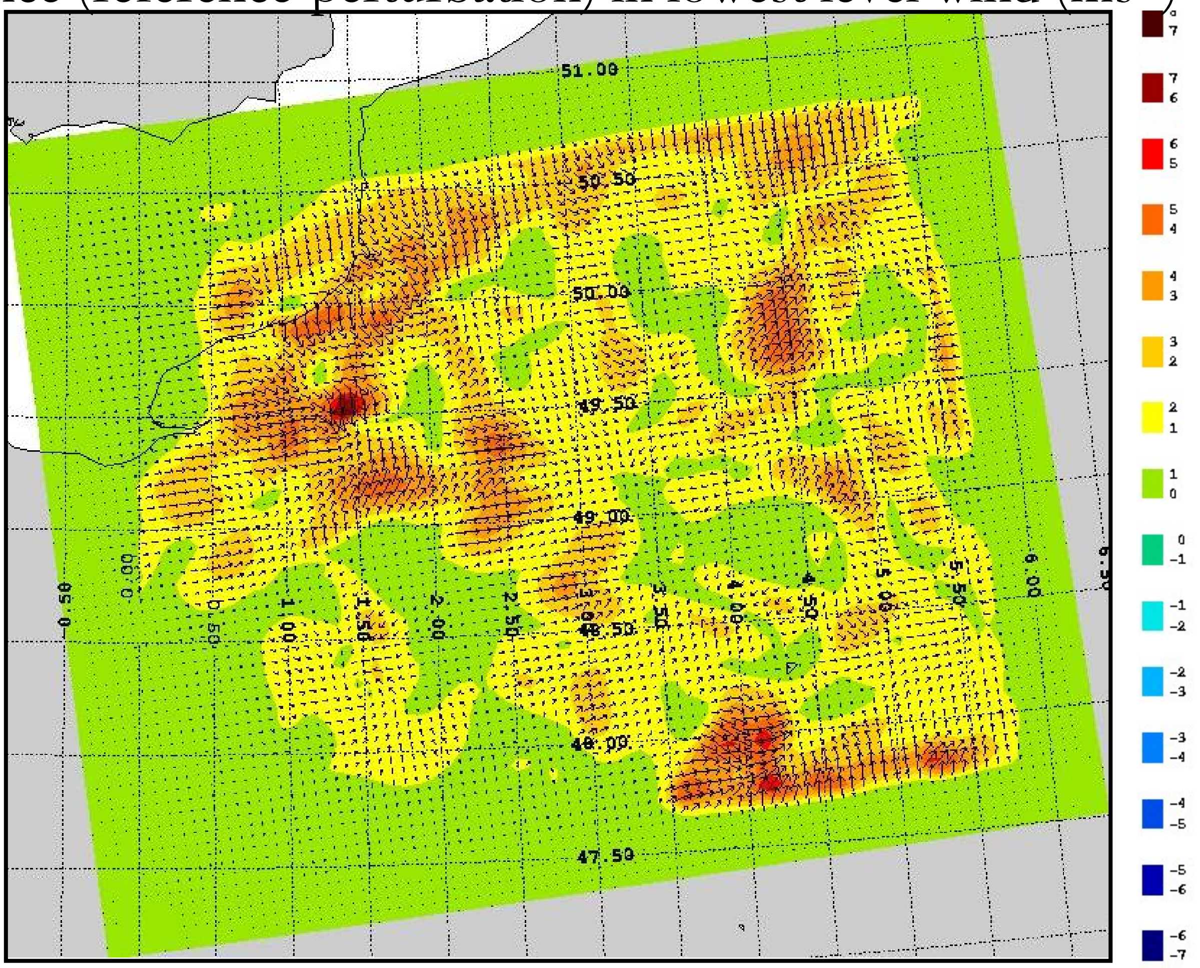
Importance of aerosol indirect effects for pollutant distribution and transformation

Day-time (2005-06-29 +036; 12 UTC) low cloud cover (left) and T2m (right) difference (reference - perturbation) with T2m in C.

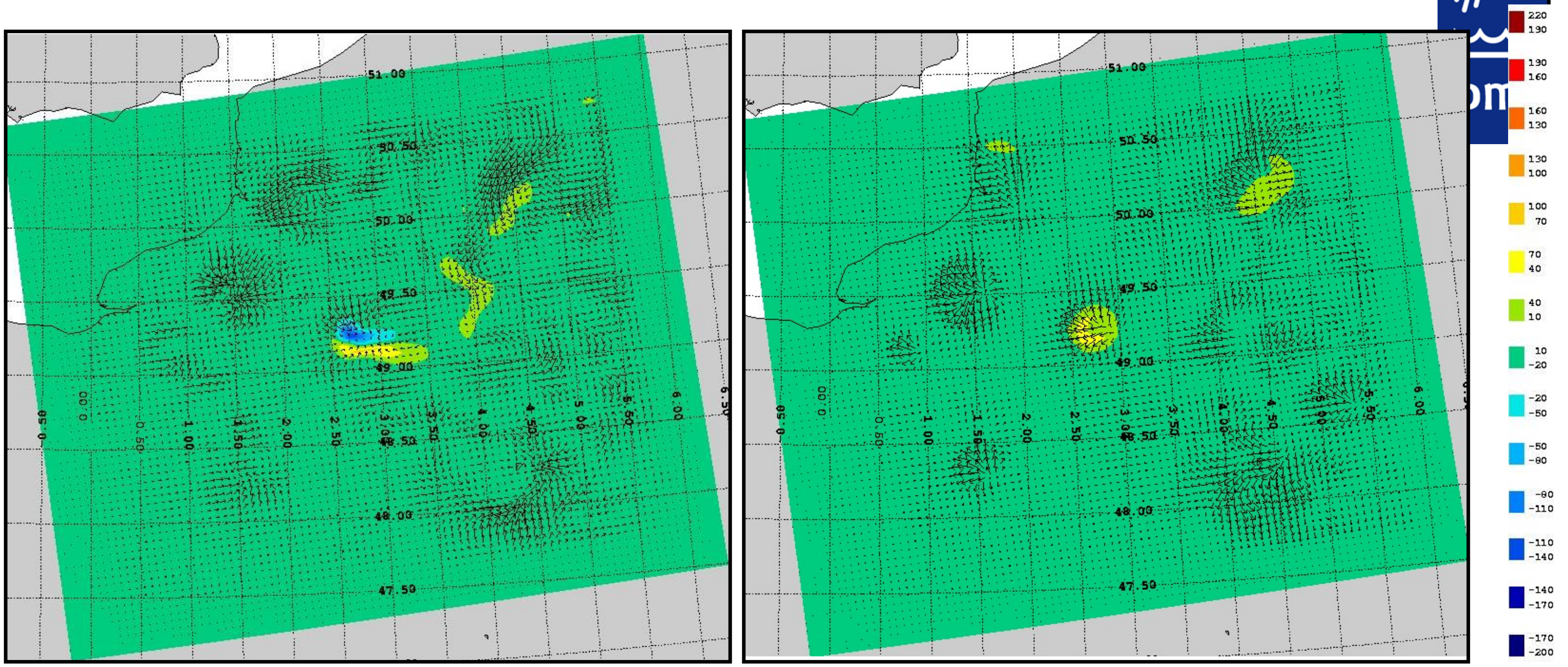


Importance of aerosol indirect effects for pollutant distribution and transformation

Difference (reference-perturbation) in lowest level wind (ms^{-1})



Importance of aerosol indirect effects for pollutant distribution and transformation



Daytime (2005-06-29 +036; 12 UTC) difference (reference-perturbation) in 850 hPa winds (ms^{-1}) (left) and 710 hPa wind (ms^{-1}) (right).

Importance of aerosol indirect effects for pollutant distribution and transformation

In this particular case:

- Indirect effects induce large changes in NO_2
- Changes dynamics dominates changes in chemistry
- Residual circulation induced by temperature changes
- Redistribution both vertically and horizontally
- Also applies for night-time conditions