Challenging Issues on fog forecast with a 3D fog forecast model

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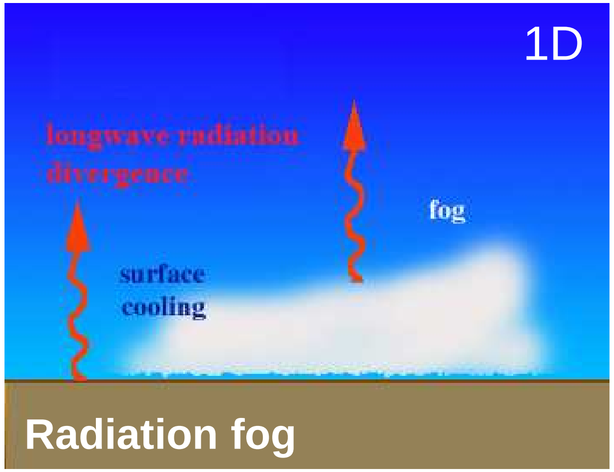
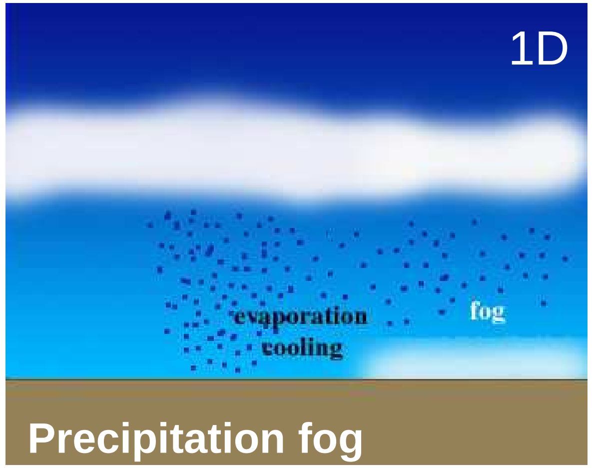
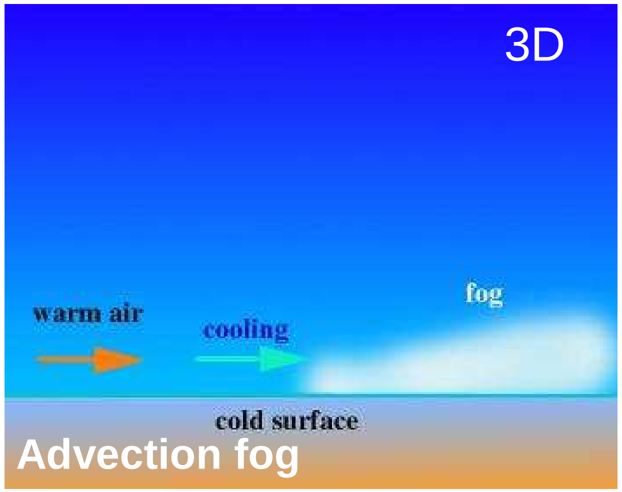
Fog Formation

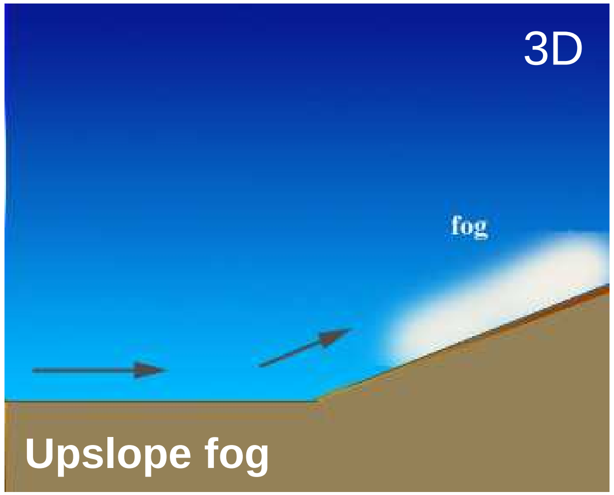
- •Cooling
- •Moistening
- •Turbulent Mixing

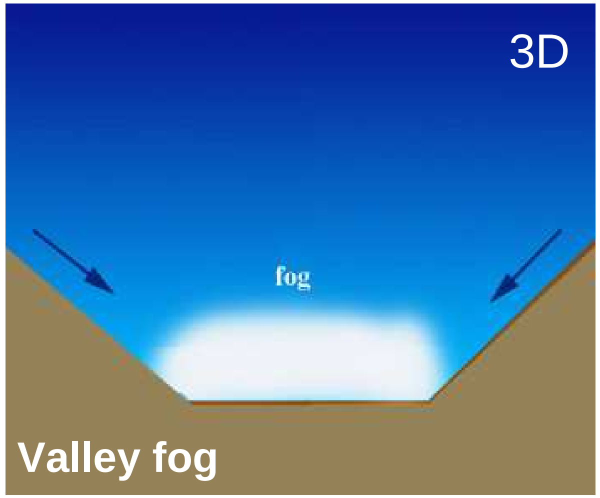
Reach saturation





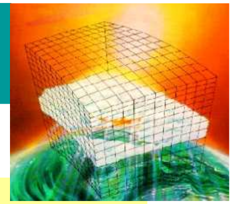






Source figures: R. Tardif's Website

3D FOG Model = COSMO + PAFOG



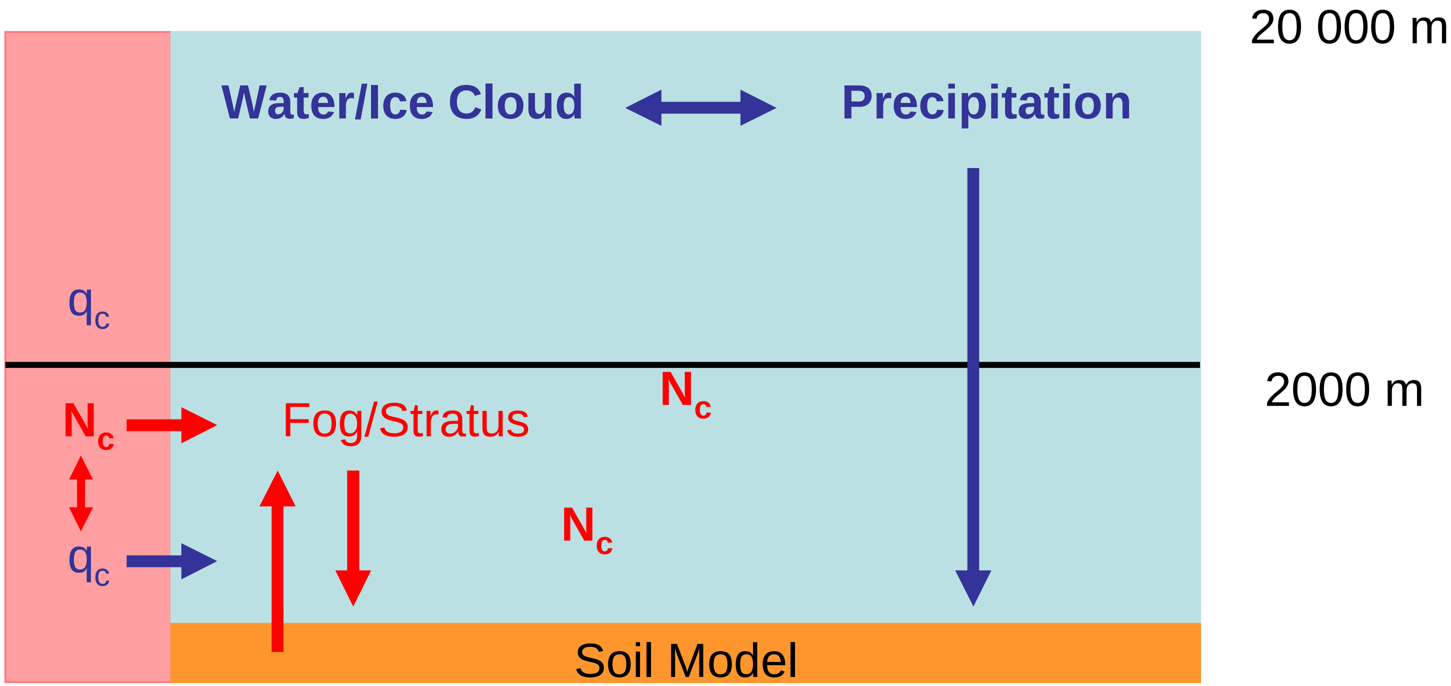
$$\frac{\partial N_c}{\partial t} = ADV(N_c) + DIF(N_c) + \left(\frac{\partial N_c}{\partial t}\right)_{sed} + \sigma(N_c)$$

Droplet number concentration

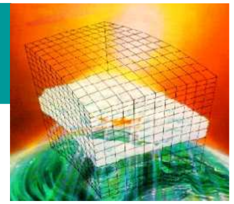
$$\frac{\partial q_c}{\partial t} = ADV(q_c) + DIF(q_c) + \left(\frac{\partial q_c}{\partial t}\right)_{sed} + \sigma(q_c)$$

Liquid Water Content

LM-Dynamics (ADV, DIF terms) **PAFOG-Microphysics** (sedimentation and σ terms)



PAFOG Microphysics



$$\frac{\partial N_c}{\partial t} = \left(\frac{\partial N_c}{\partial t}\right)_{act} + \Delta(\overline{S})\left(\frac{\partial N_c}{\partial t}\right)_{eva} + \left(\frac{\partial N_c}{\partial t}\right)_{sed}$$

$$\frac{\partial q_c}{\partial t} = \left(\frac{\partial q_c}{\partial t}\right)_{con/eva} + \left(\frac{\partial q_c}{\partial t}\right)_{sed}$$

$$\Delta(\overline{S}) = \begin{cases} 1, if\ (\overline{S}) < 0 \\ 0, if\ (\overline{S}) \geq 0 \end{cases}$$

Supersaturation **S**

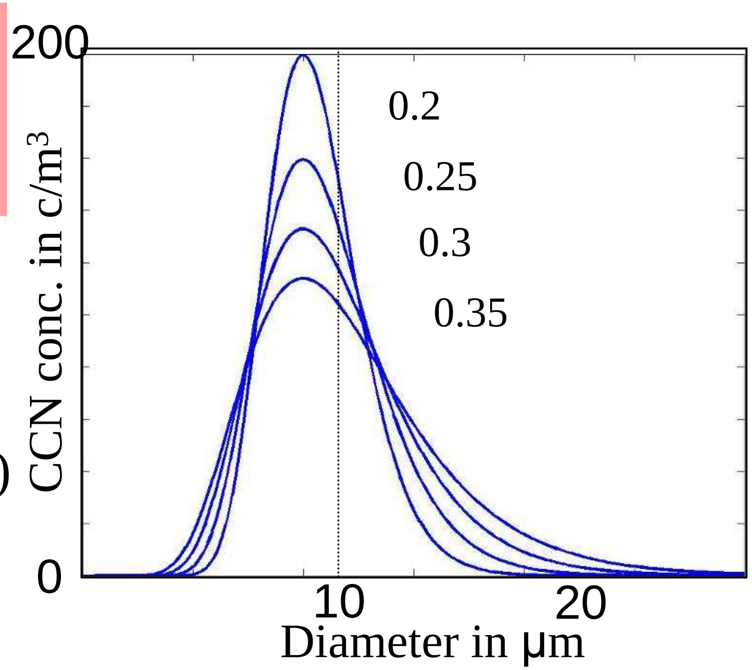
Assumption for droplet spectra : **Log-normal**

$$dN_c = \frac{N_c}{\sqrt{2\pi\sigma_c D}} \exp\left(-\frac{1}{2\sigma_c}\ln^2\left(\frac{D}{D_{c,0}}\right)\right) dD$$

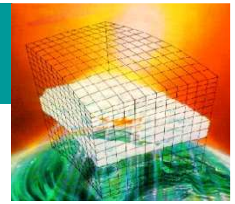
D droplet diameter

$D_{c,0}$ mean value of D

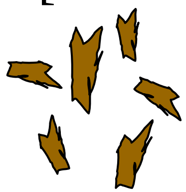
σ_c standard deviation of size distribution (σ_c=0.2)



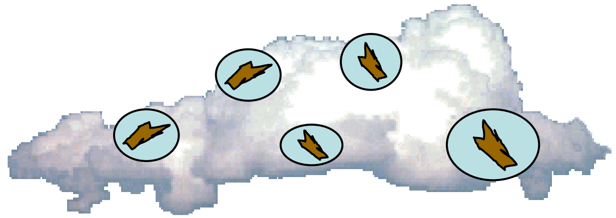
PAFOG Microphysics



1- Activation [Twomey (1954)] :



$$N_{act} = N_a S^k$$



k and N_a depend on their environment (maritime, rural, urban)

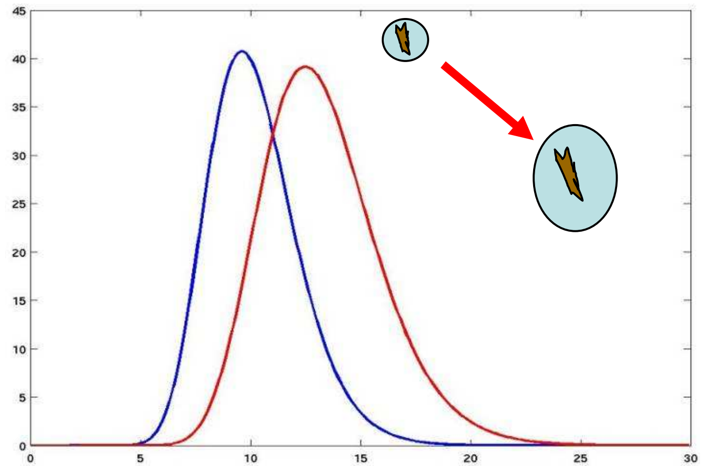
2a-Detailed Condensation/Evaporation : parametrised Köhler relation

[Chaumerliac et al. (1987) and Sakakibara (1979)]

2b-Time dependent relation between

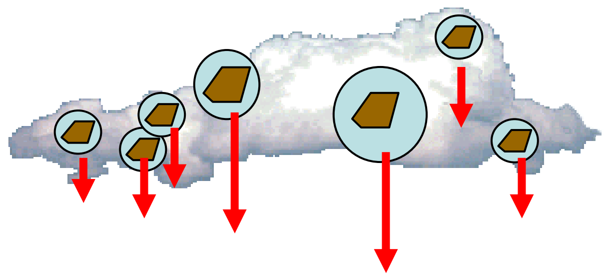
supersaturation S and diameter D

$$\frac{dD}{dt} = A\frac{S}{D}$$



3-Droplet size dependent sedimentation

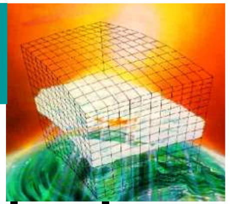
[Berry and Pranger 1974]

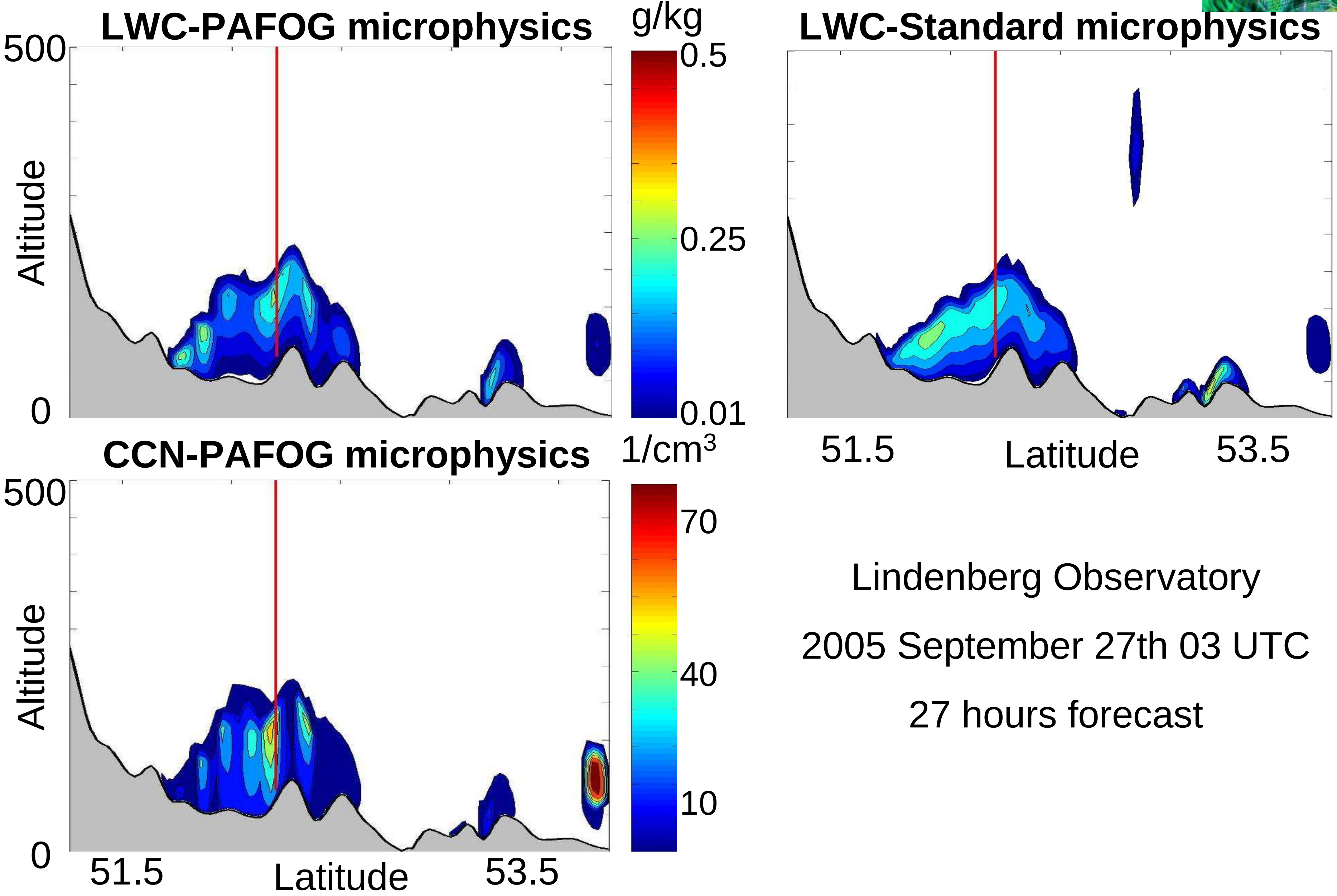


Positive Definite Advection Scheme

[Bott (1989)]

STANDARD-PAFOG Microphysics



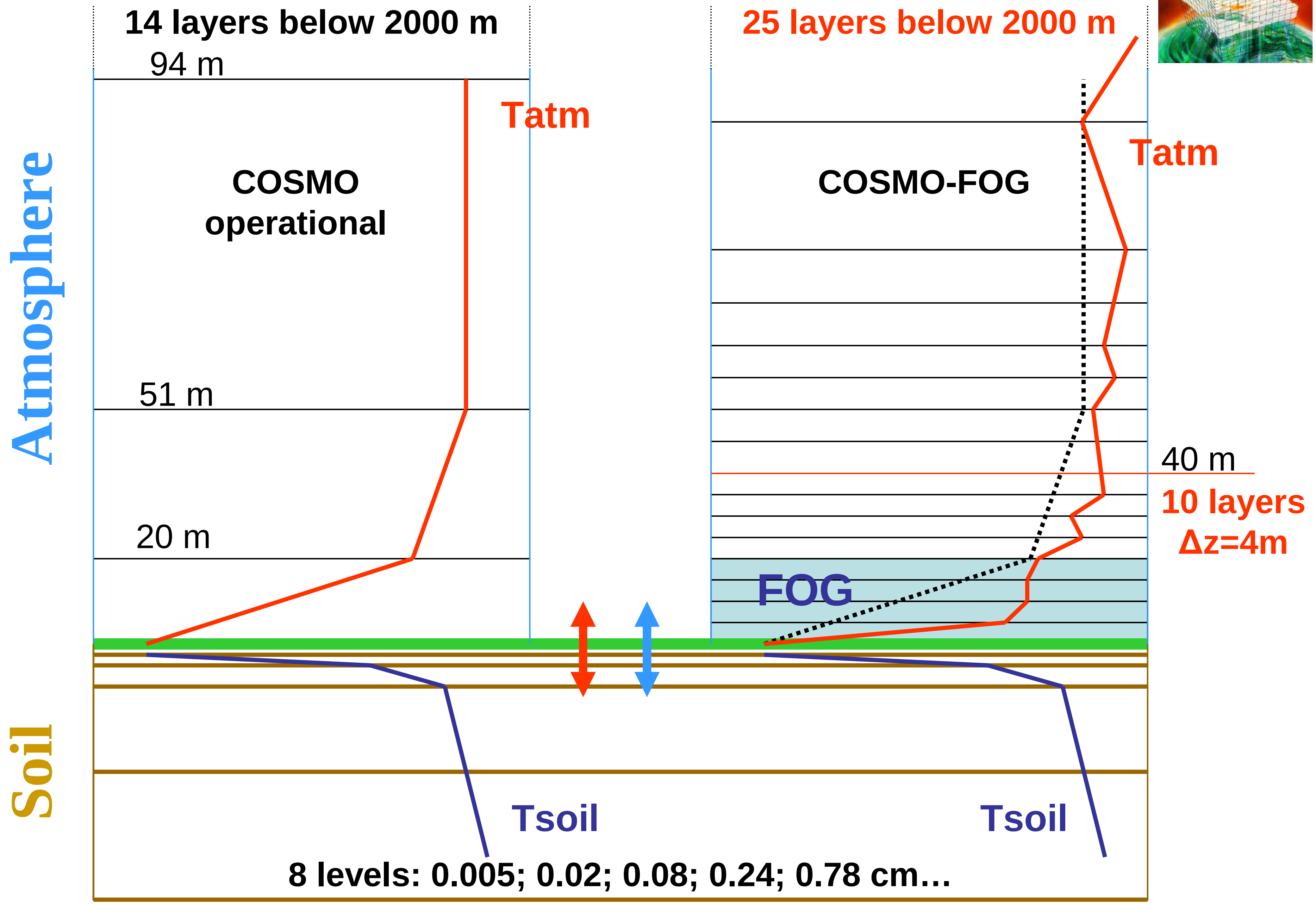


Lindenberg Observatory

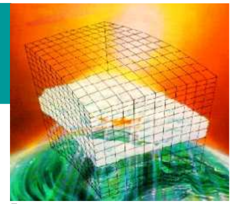
2005 September 27th 03 UTC

27 hours forecast

Vertical resolution



Turbulence Scheme



Turbulent mixing terms are given by a flux gradient relation

$$M_T = \frac{1}{\rho\sqrt{G}} \frac{\partial}{\partial \zeta} \left(\frac{\rho \pi K_H}{\sqrt{G}} \frac{\partial \theta}{\partial \zeta} \right)$$

$$M_{q^x} = \frac{1}{\rho\sqrt{G}} \frac{\partial}{\partial \zeta} \left(\frac{\rho K_H}{\sqrt{G}} \frac{\partial q^x}{\partial \zeta} \right)$$

$$M_u = \frac{1}{\rho\sqrt{G}} \frac{\partial}{\partial \zeta} \left(\frac{\rho K_M}{\sqrt{G}} \frac{\partial u}{\partial \zeta} \right)$$

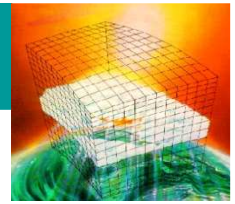
$$M_v = \frac{1}{\rho\sqrt{G}} \frac{\partial}{\partial \zeta} \left(\frac{\rho K_M}{\sqrt{G}} \frac{\partial v}{\partial \zeta} \right)$$

Parametrized following Mellor and Yamada(1982)

2.5th-Order

(Raschendorfer, 2001)

Modification of Turbulence Scheme



Step 1:

replace semi- implicit calculation of the TKE diffusion term by a implicit calculation

Step 2: Based on the work of M. Buzzy, 2008

Instability due to wind Shear term :

$$G_M \equiv \frac{\lambda^2}{q^2}\left[\left(\frac{\partial}{\partial z}u\right)^2 + \left(\frac{\partial}{\partial z}v\right)^2\right]$$

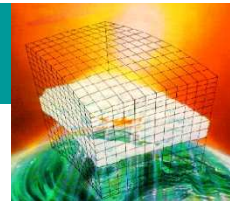
Filtering the wind gradient before evaluating the stability function

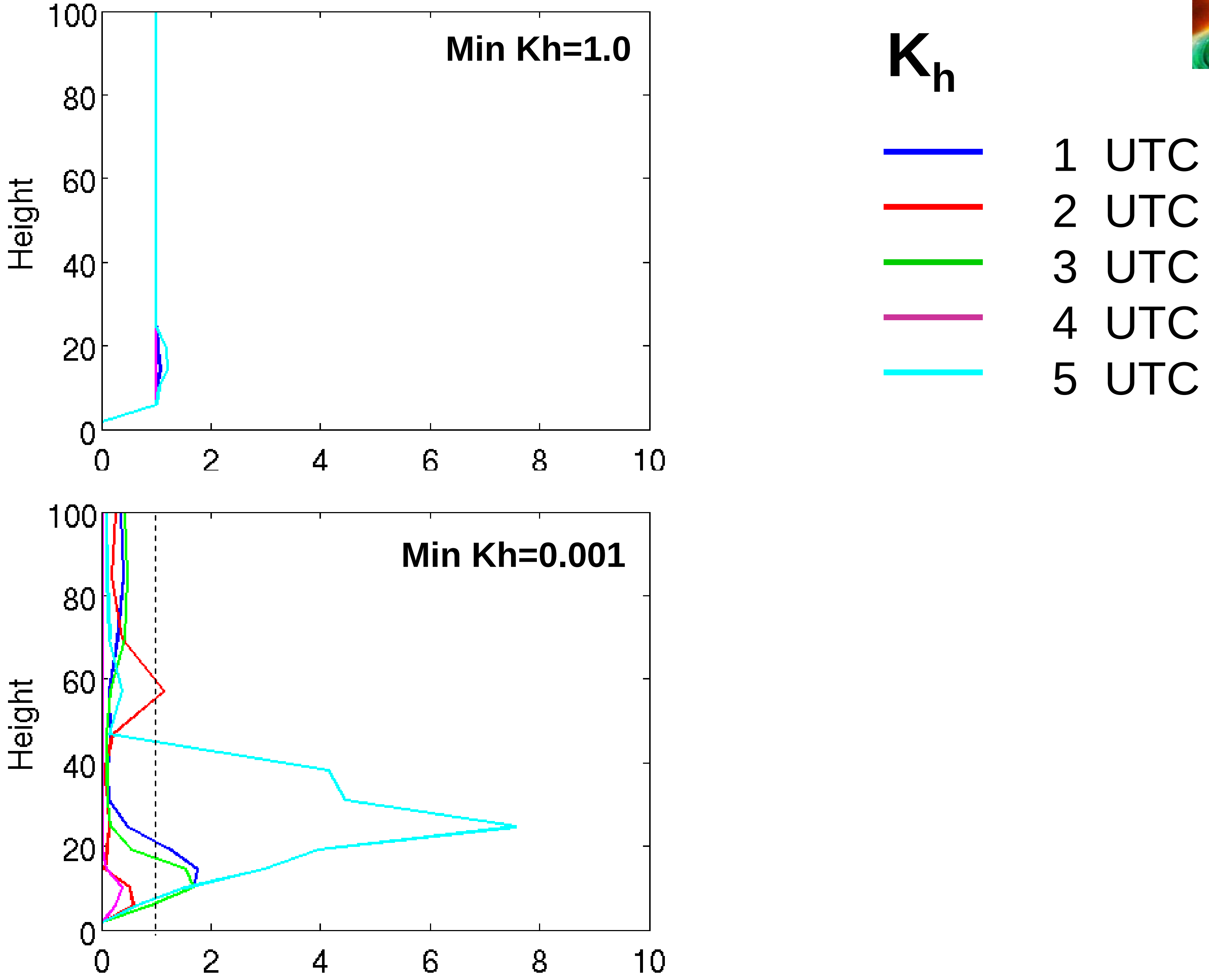
$$f_k^{new} = 0.5 f_k + 0.2\left(f_{k-1} + f_{k+1}\right) + 0.05\left(f_{k-2} + f_{k+2}\right)$$

More details about problem of the instability in stable turbulence regime.

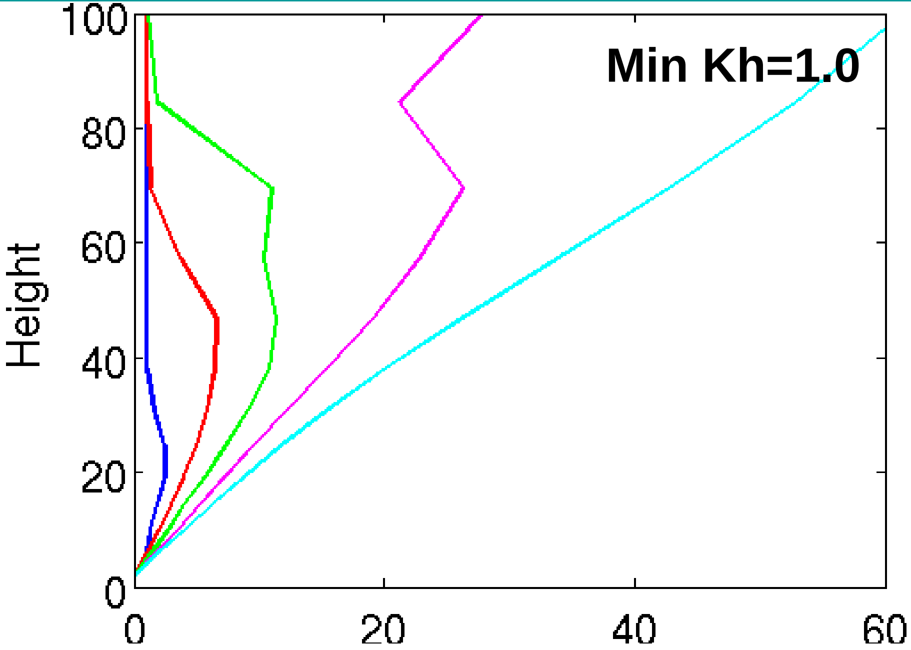
See Buchard and Deleersnijder 2001, Mellor 2003, Buzzi 2008

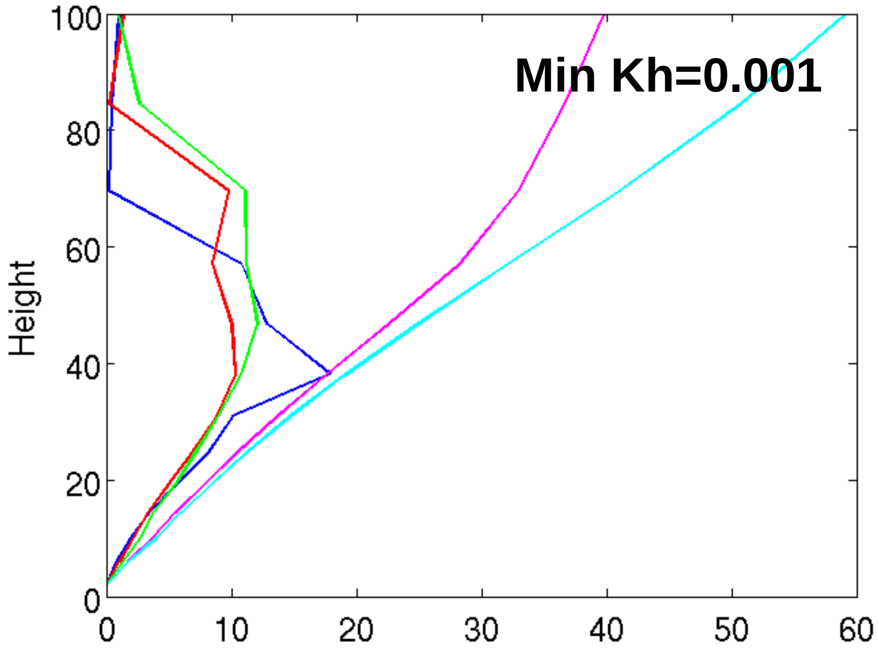
Modification of Turbulence Scheme





Modification of Turbulence Scheme

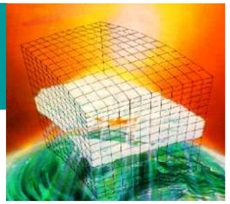




K_h

- 7 UTC
- 8 UTC
- 9 UTC
- 10UTC
- 11UTC

COSMO-FOG, Setup



COSMO V4.6:

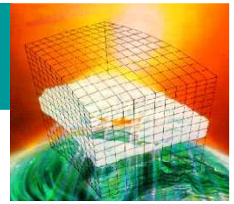
Grid
- **60 layers, dz_min = 4min**
- **dx= 2.8 km**
- **Domain 200 x 200**

Numerics
- **Standard runge-kutta numerics**
- **dt = 10 s**
- **Very smooth lateral boundary condition**

Physics
- **Itype_gscp = 4**
- **dt_rad= 1 min**
- **Implicit TKE turbulent scheme**

PAFOG
- **Na=1000 cm^{-3}**

Lindenberg, Cabauw & Zürich



3 Sites:

- **Lindenberg** (Germany), bumpy terrain, alt: 0-500 m.
- **Cabauw** (the Netherlands), flat terrain.
- **Zürich** (Switzerland), mountaineous terrain, alt: 200-3000 m.

Weather Situation:

- 1st-15th October 2005
- **High Pressure System** over Europe (Omega weather situation)
- No cloud cover

only Radiative fog & valley fog

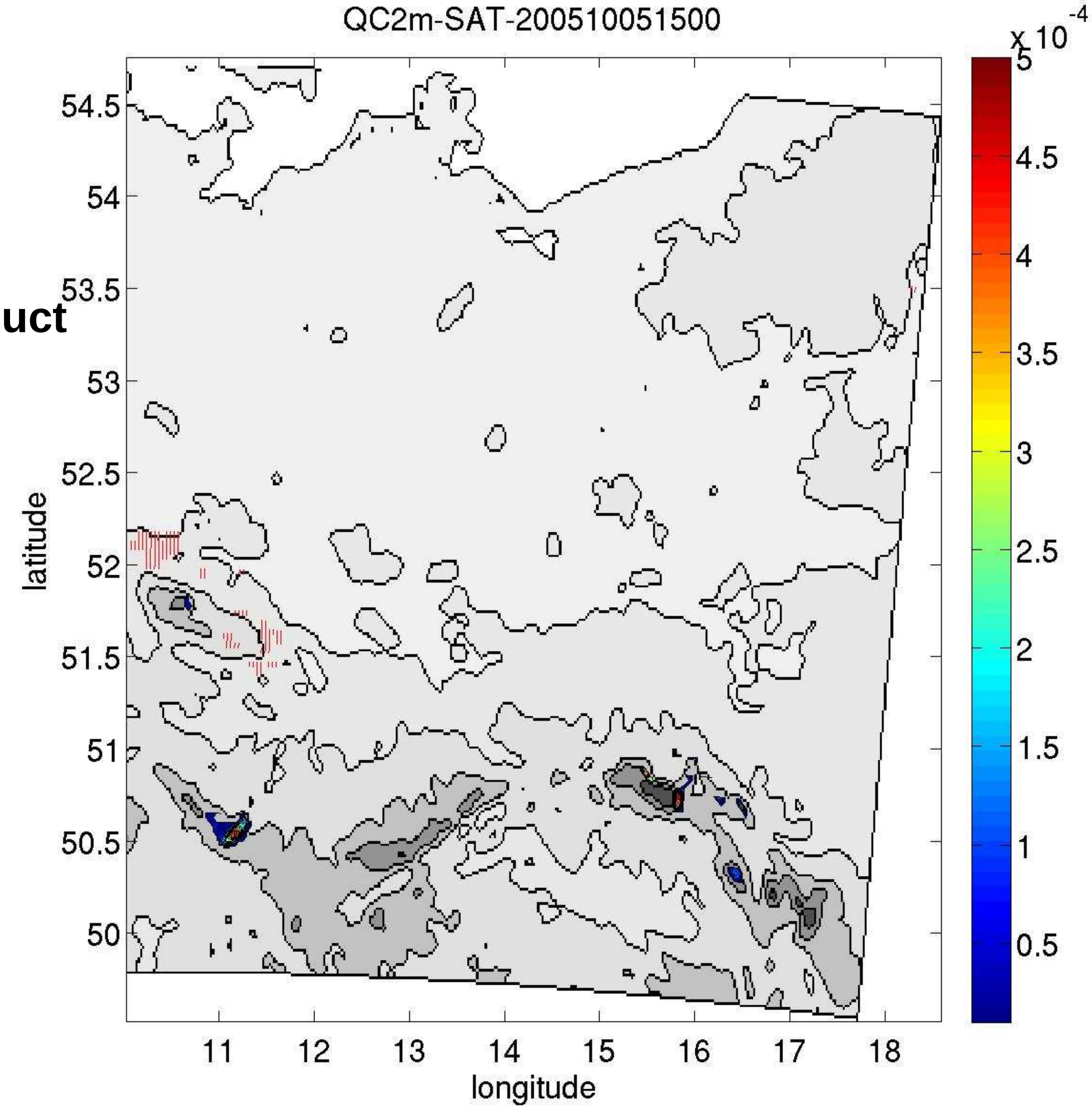
Comparison with MSG satellite product for fog and low stratus

Lindenberg- 05 October 2005- 15 UTC

15:00 UTC

Sat Product

Qc_2m (FOG)

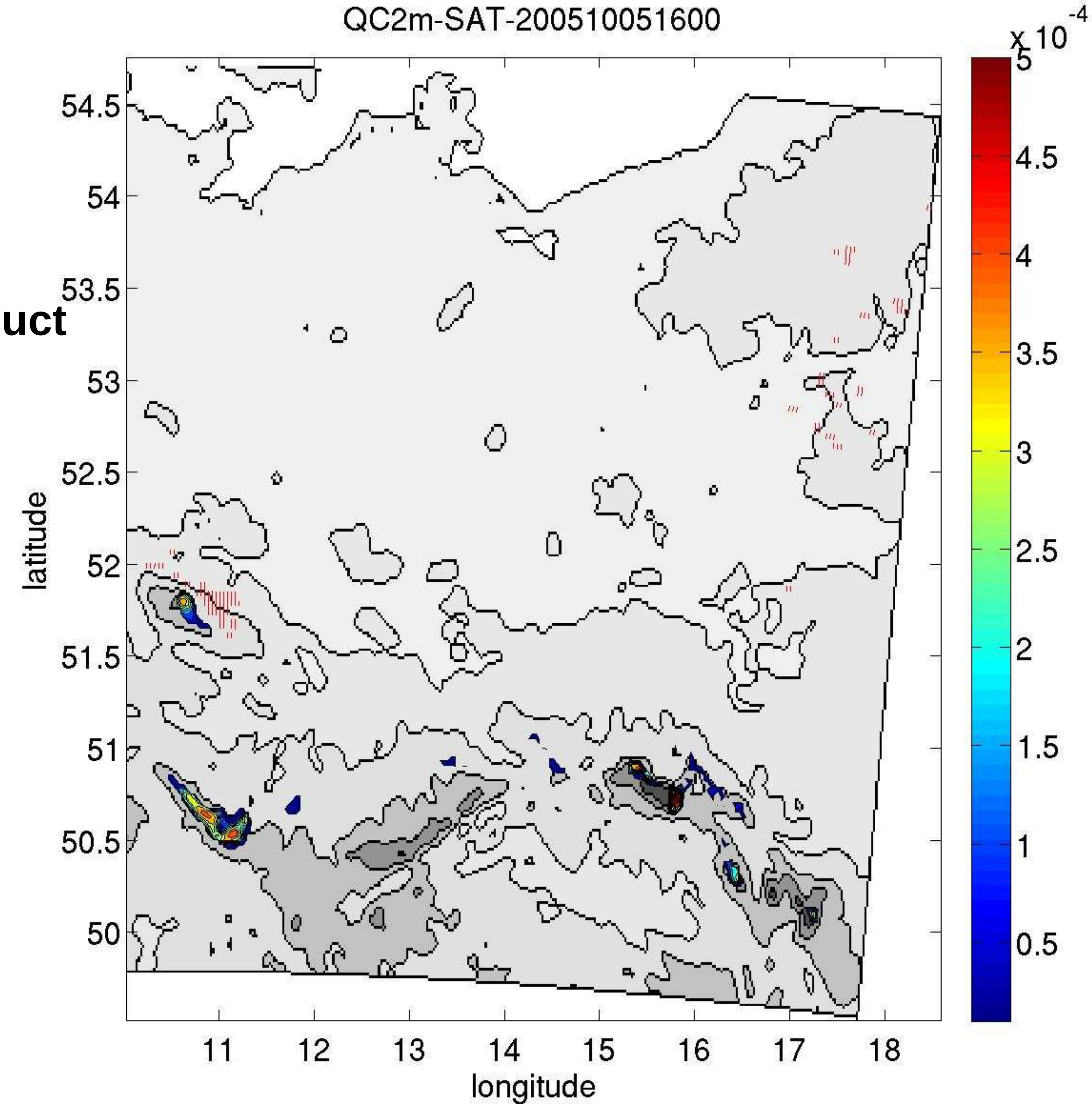


Lindenberg- 05 October 2005- 16 UTC

16:00 UTC

Sat Product

Qc_2m (FOG)

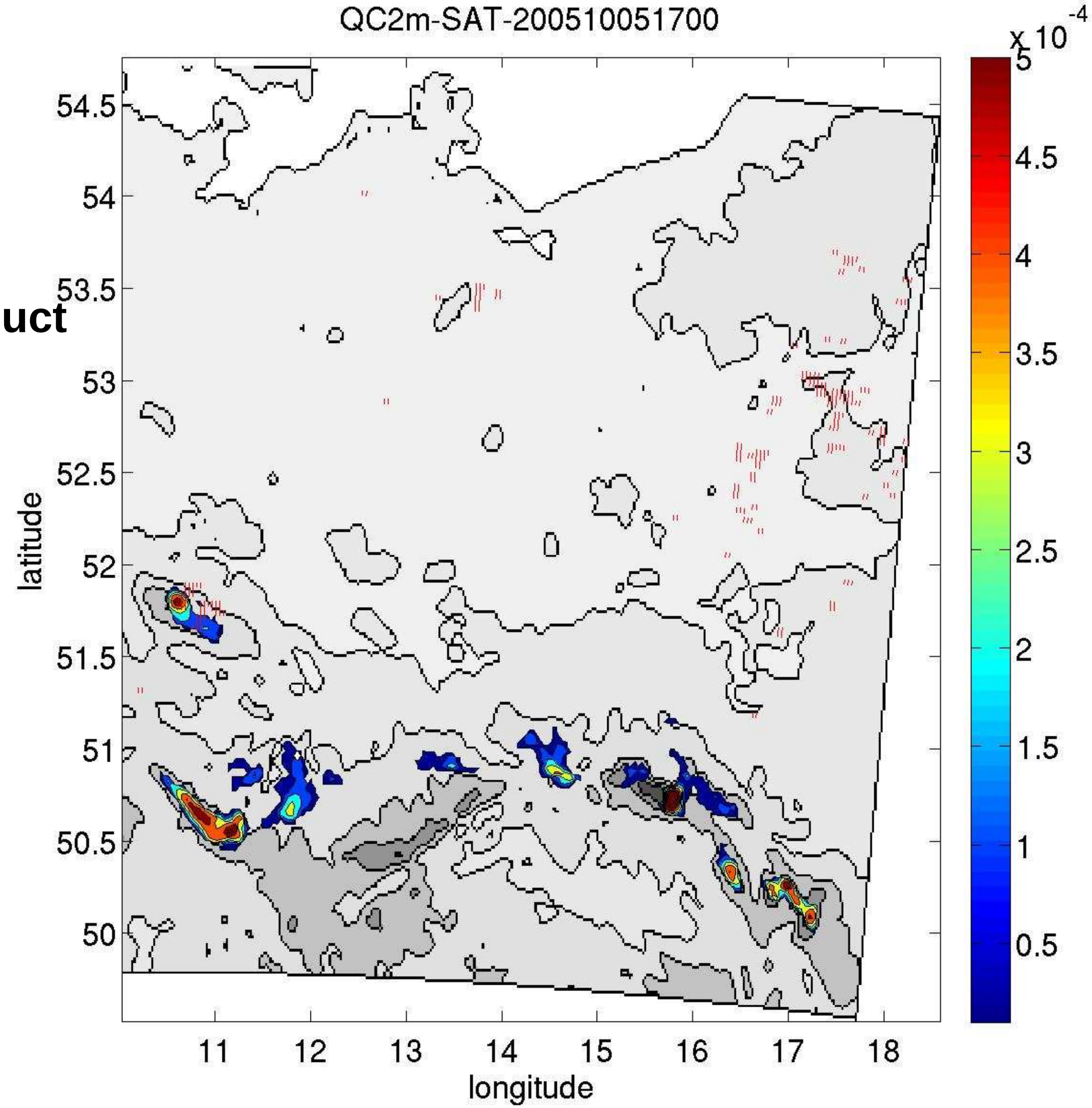


Lindenberg- 05 October 2005- 17 UTC

17:00 UTC

Sat Product

Qc_2m (FOG)

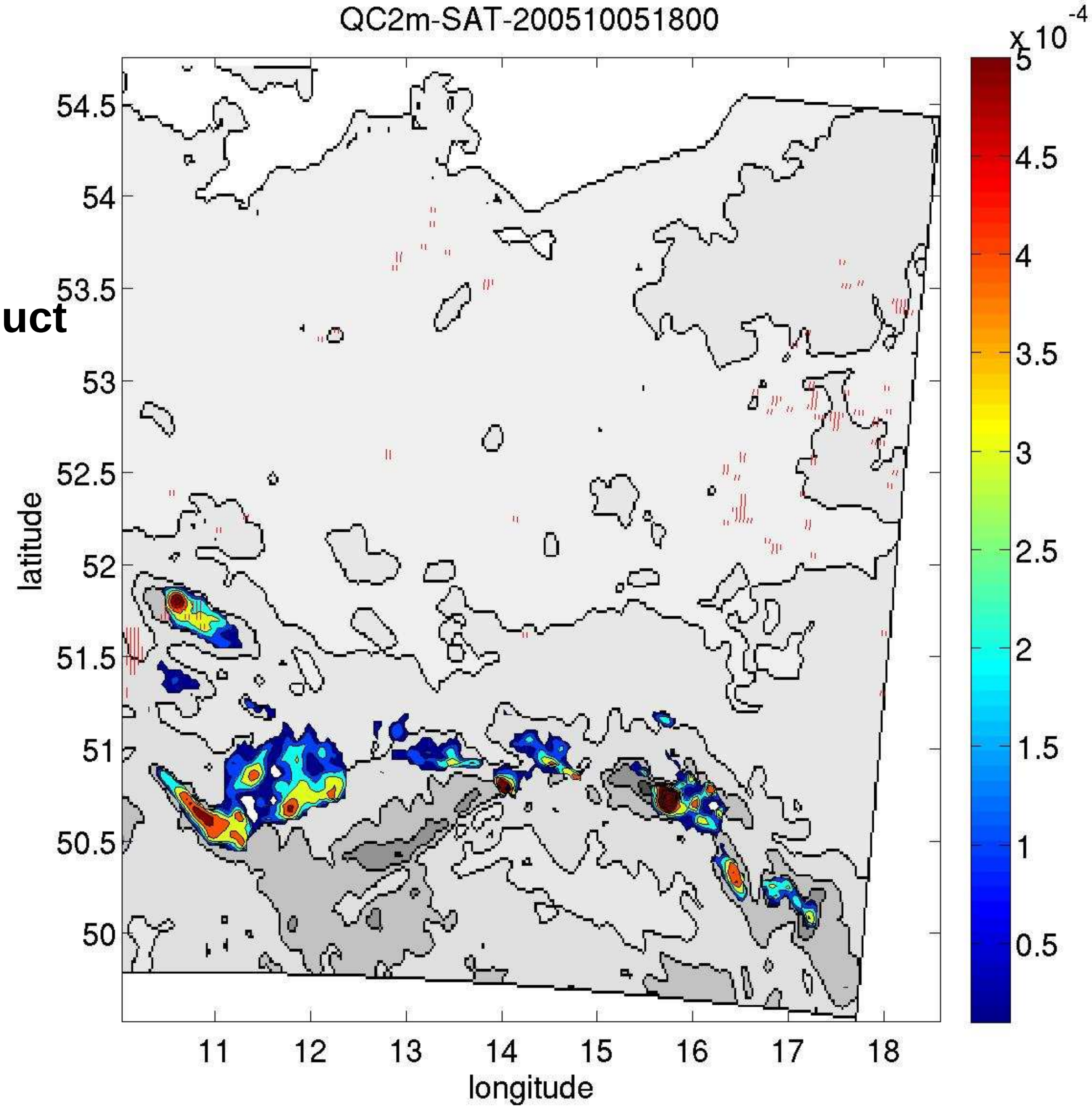


Lindenberg- 05 October 2005- 18 UTC

18:00 UTC

Sat Product

Qc_2m (FOG)

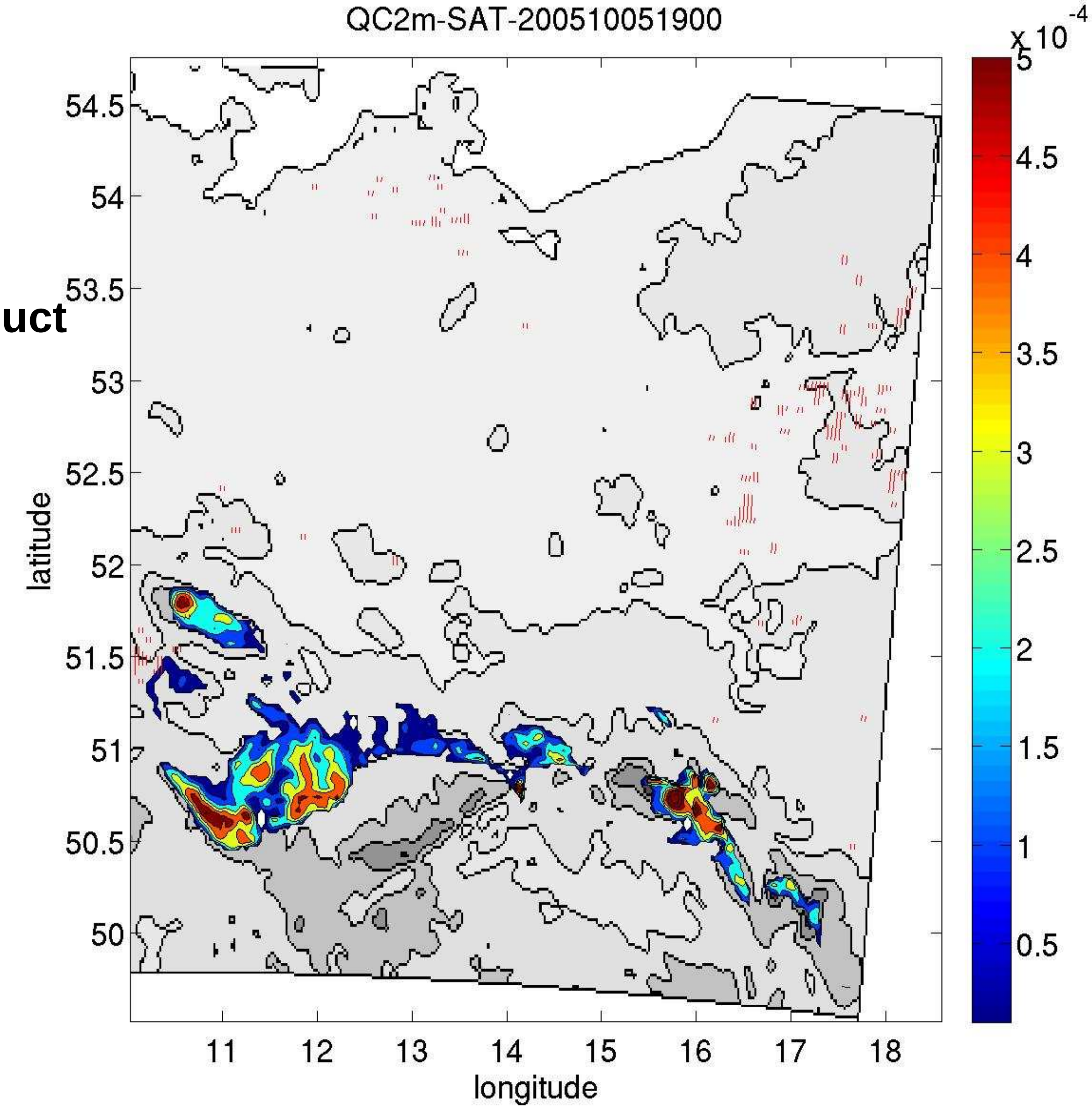


Lindenberg- 05 October 2005- 19 UTC

19:00 UTC

Sat Product

Qc_2m (FOG)

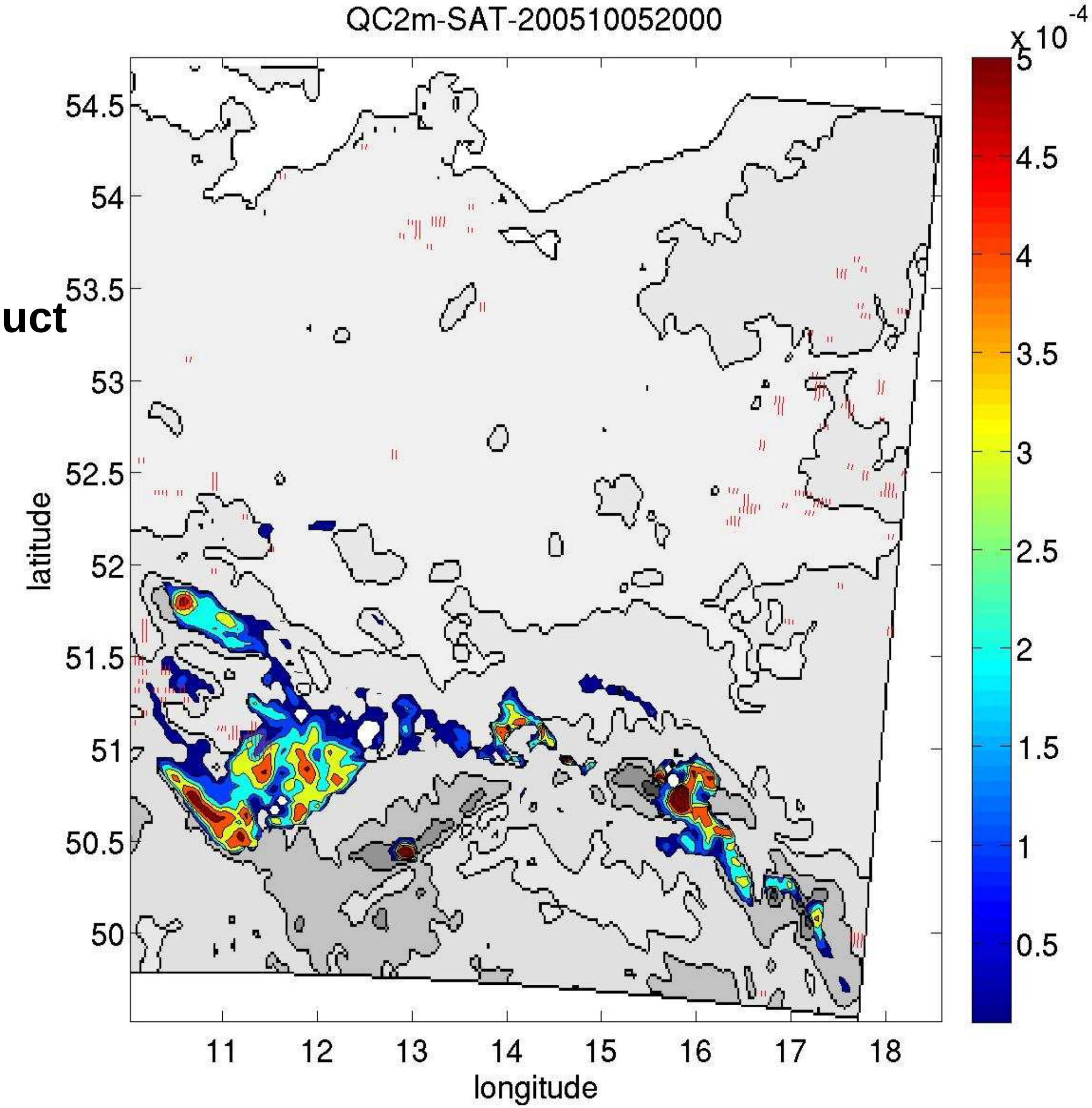


Lindenberg- 05 October 2005- 20 UTC

20:00 UTC

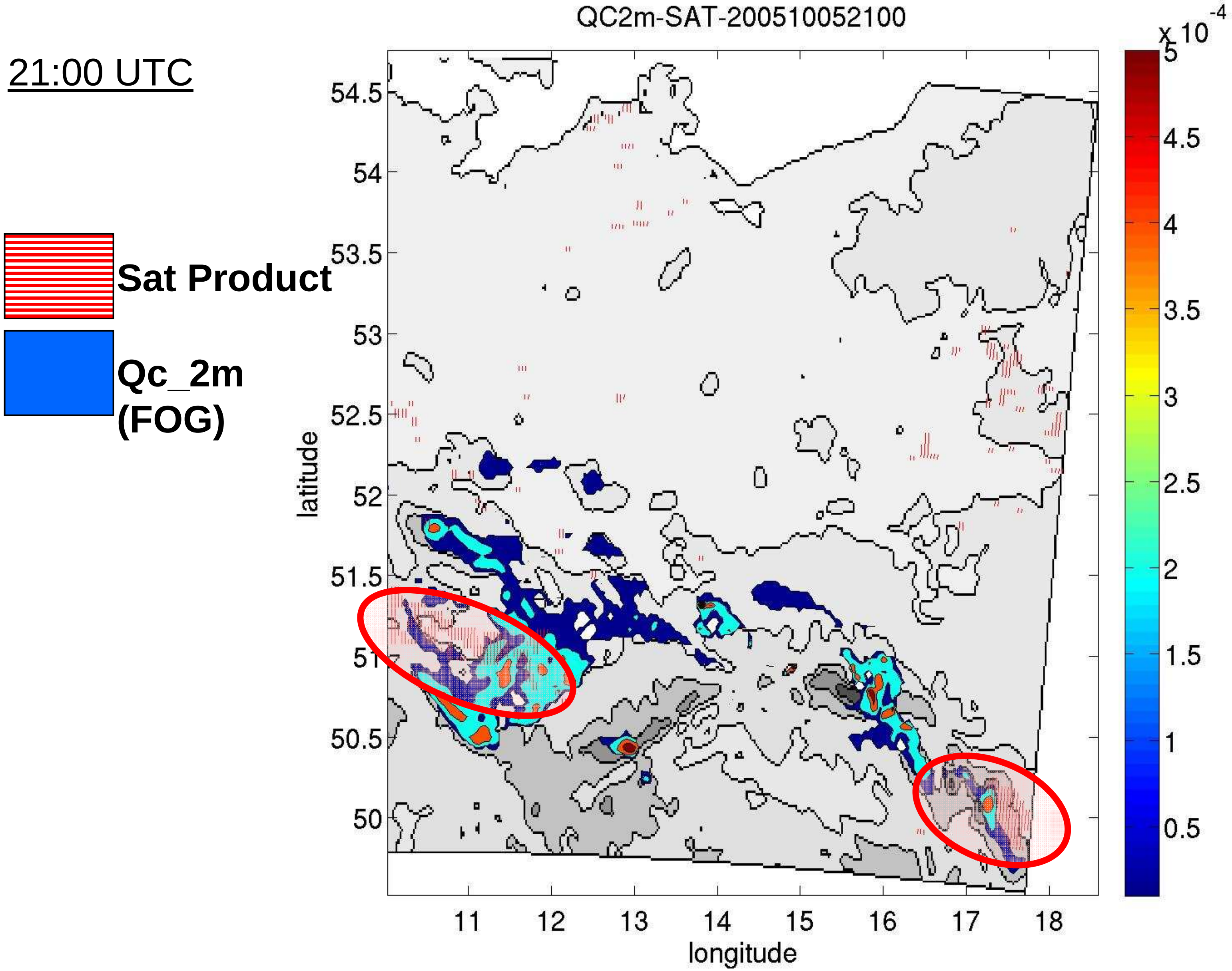
Sat Product

Qc_2m (FOG)



Lindenberg- 05 October 2005- 21 UTC

21:00 UTC

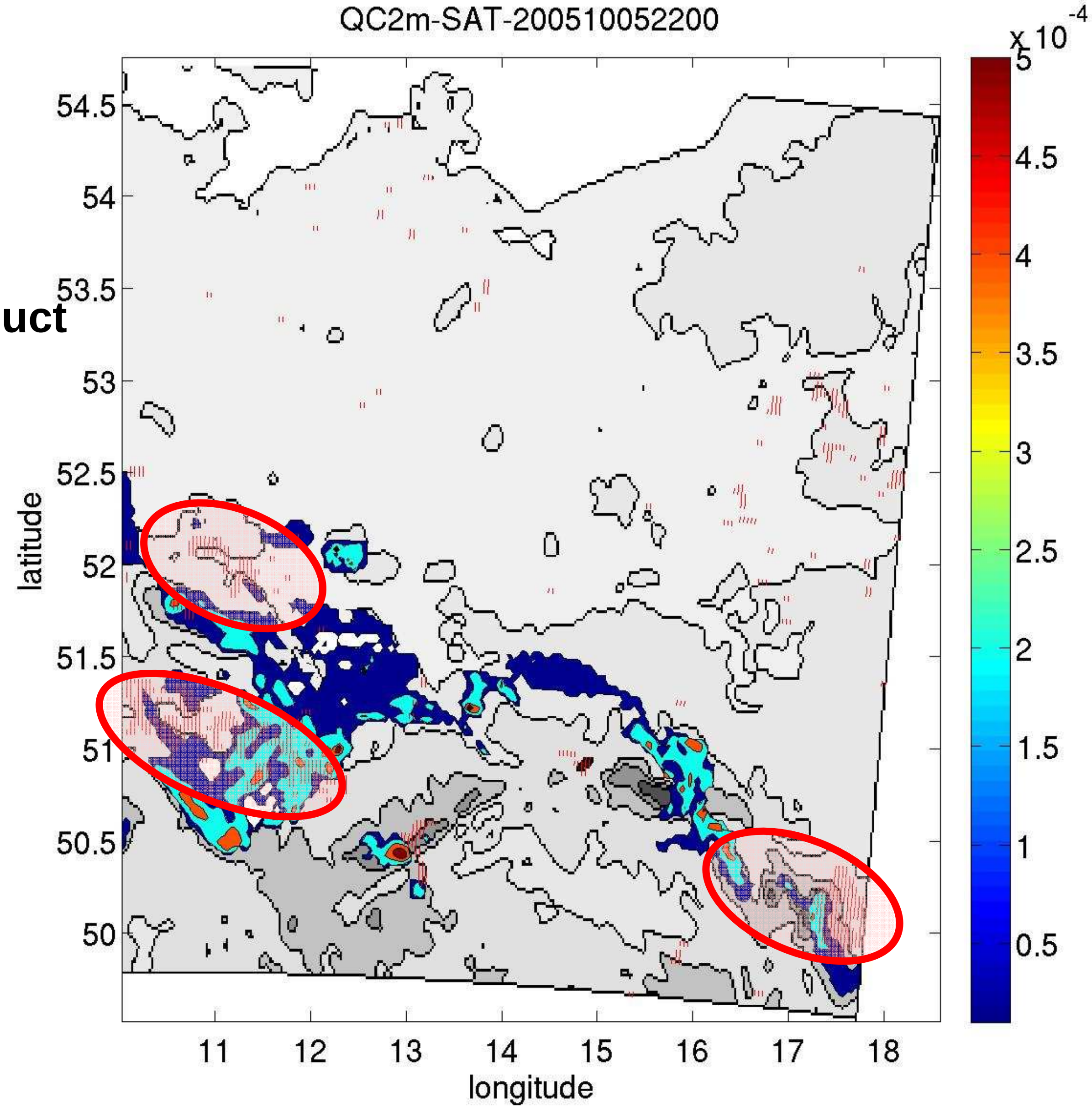


Lindenberg- 05 October 2005- 22 UTC

22:00 UTC

Sat Product

Qc_2m (FOG)

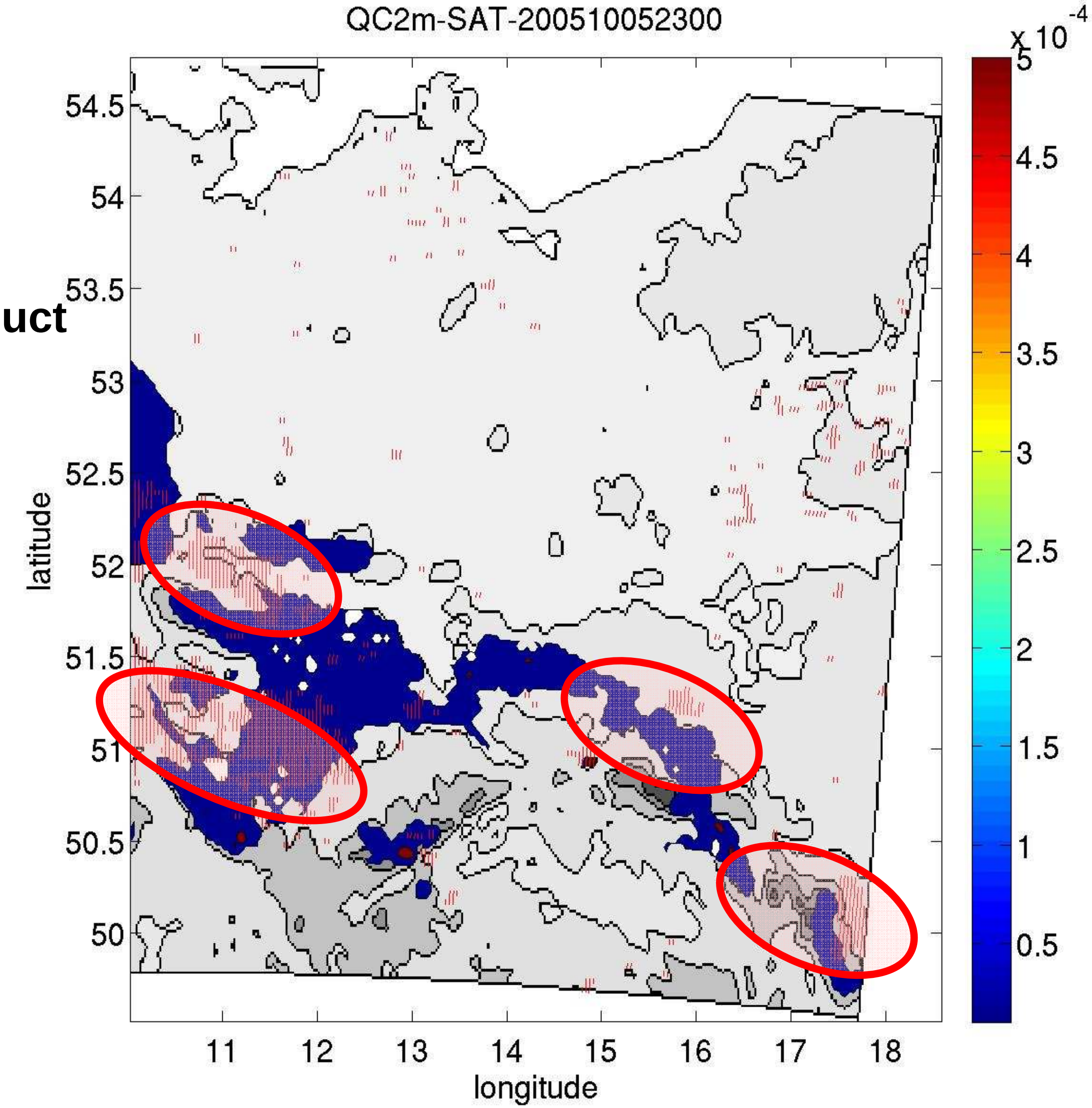


Lindenberg- 05 October 2005- 23 UTC

23:00 UTC

Sat Product

Qc_2m (FOG)

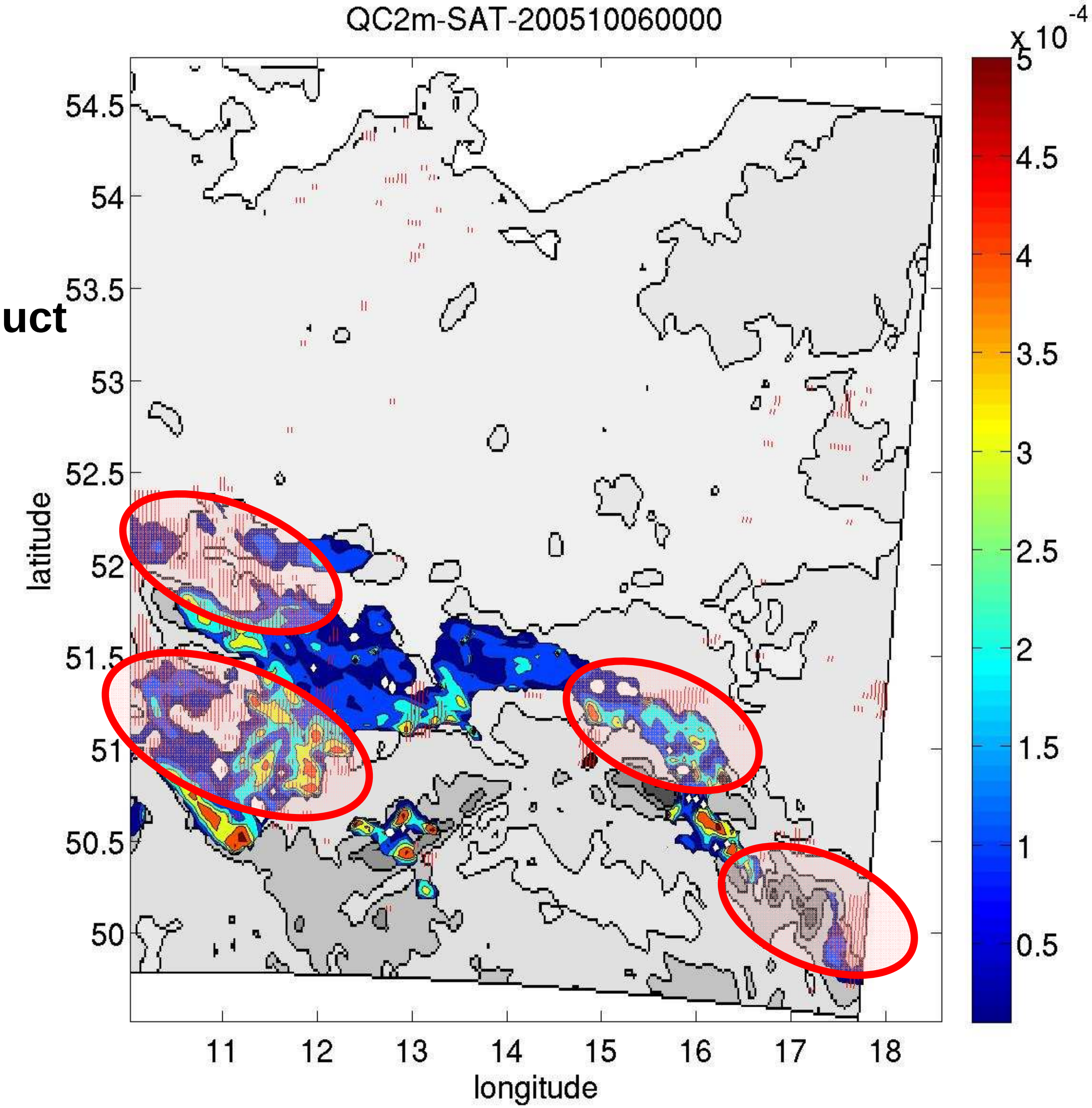


Lindenberg- 06 October 2005- 00 UTC

00:00 UTC

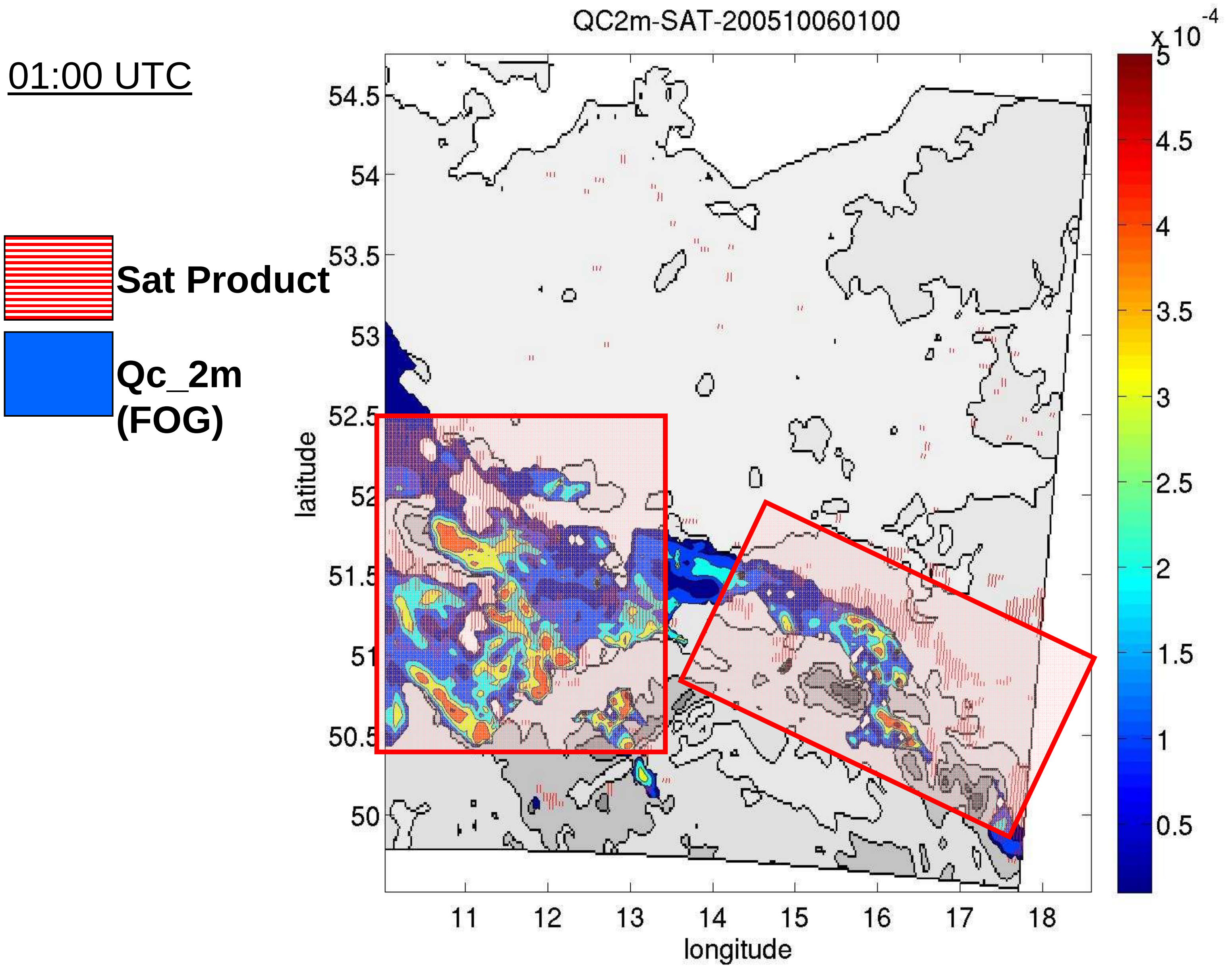
Sat Product

Qc_2m (FOG)



Lindenberg- 06 October 2005- 01 UTC

01:00 UTC

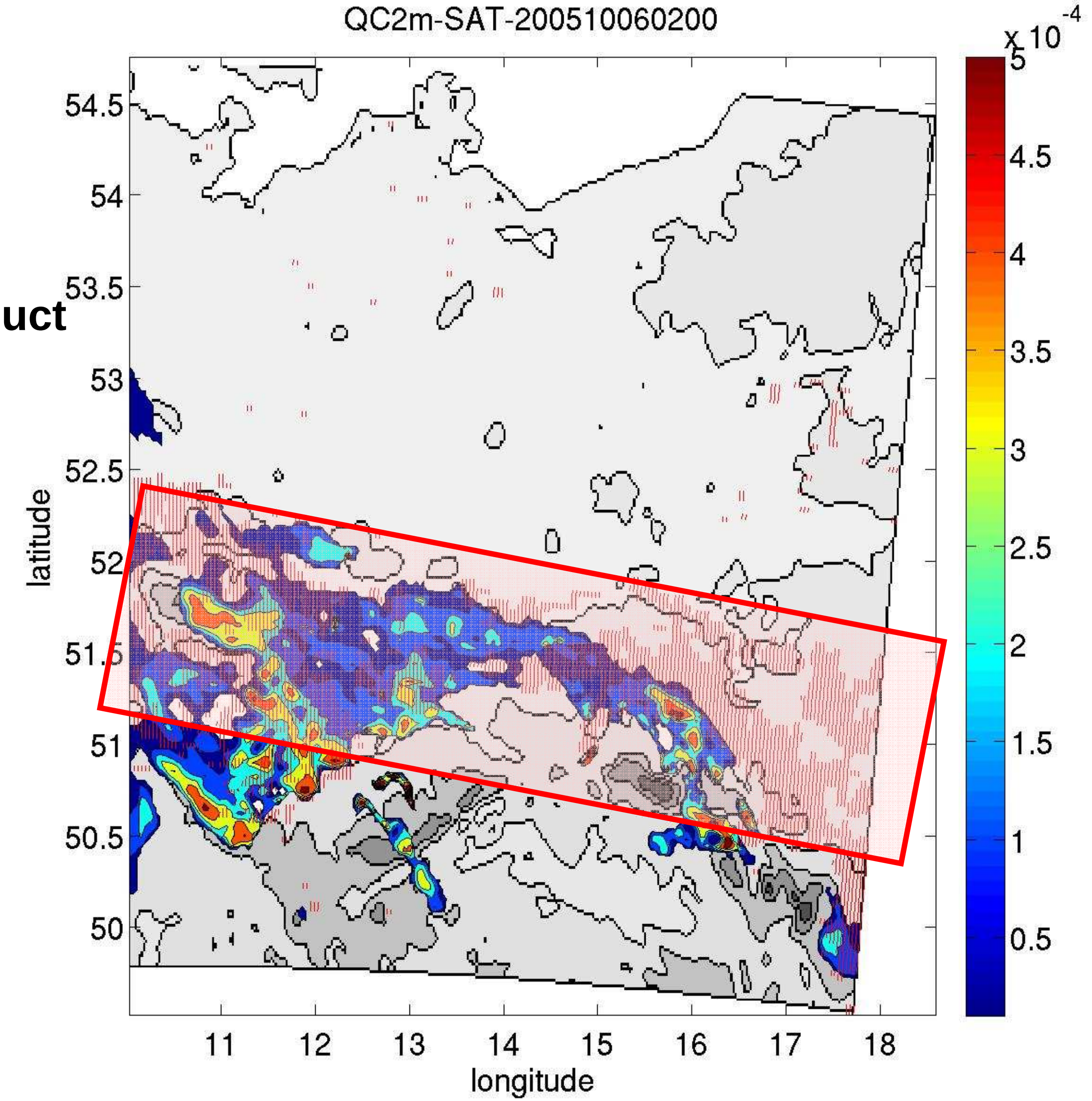


Lindenberg- 06 October 2005- 02 UTC

02:00 UTC

Sat Product

Qc_2m (FOG)

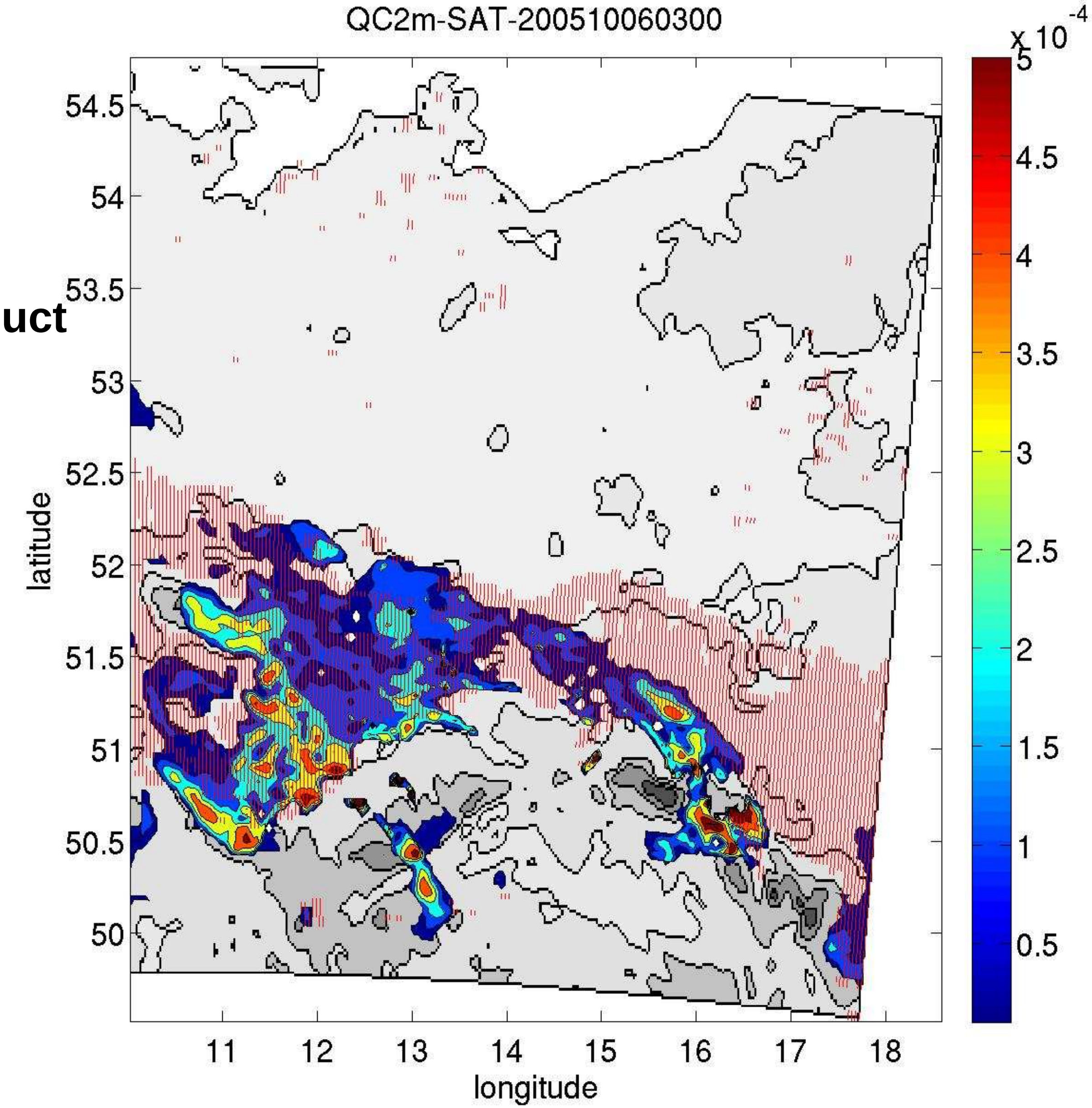


Lindenberg- 06 October 2005- 03 UTC

<u>03:00 UTC</u>

Sat Product

Qc_2m (FOG)

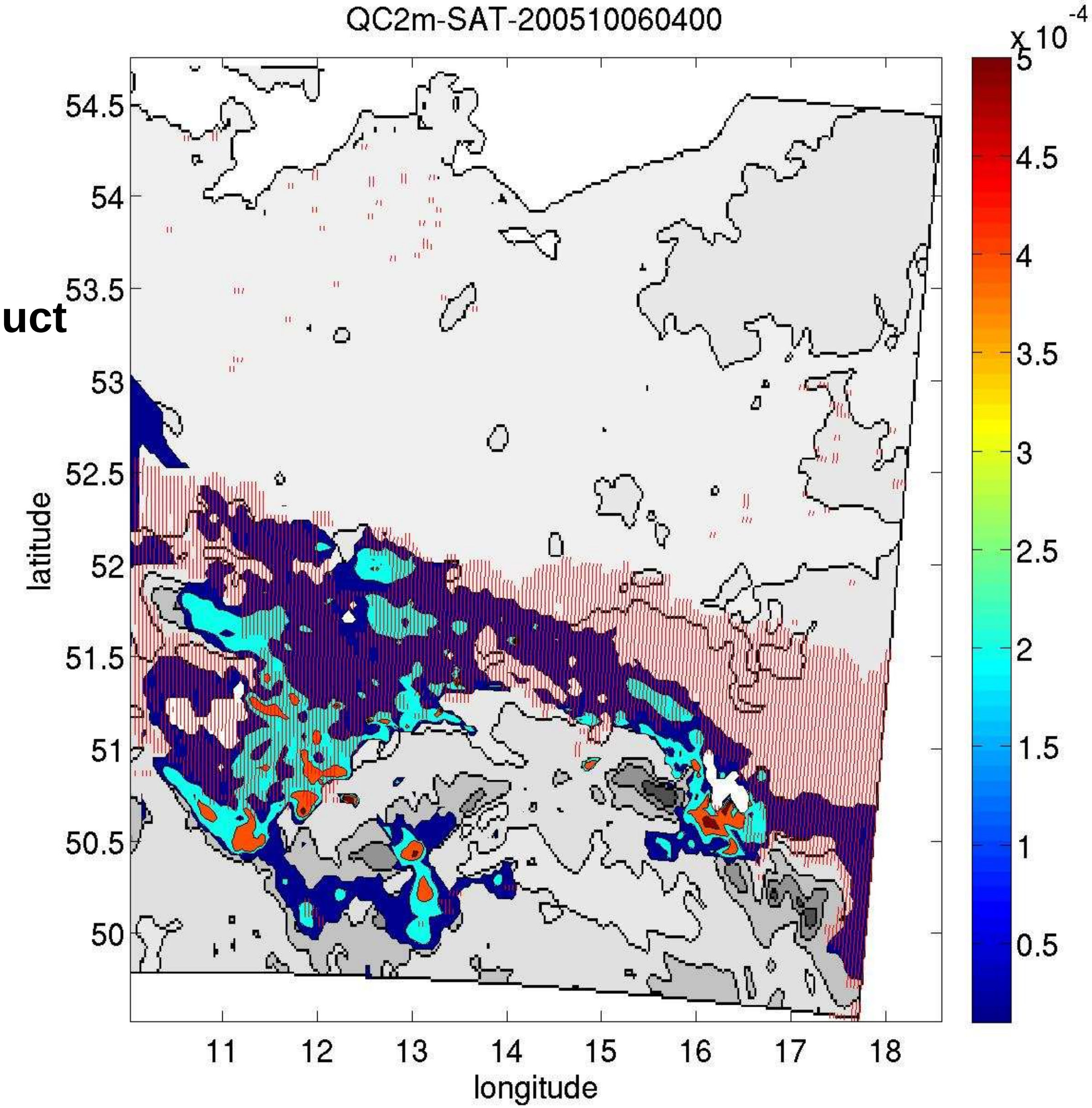


Lindenberg- 06 October 2005- 04 UTC

04:00 UTC

Sat Product

Qc_2m (FOG)

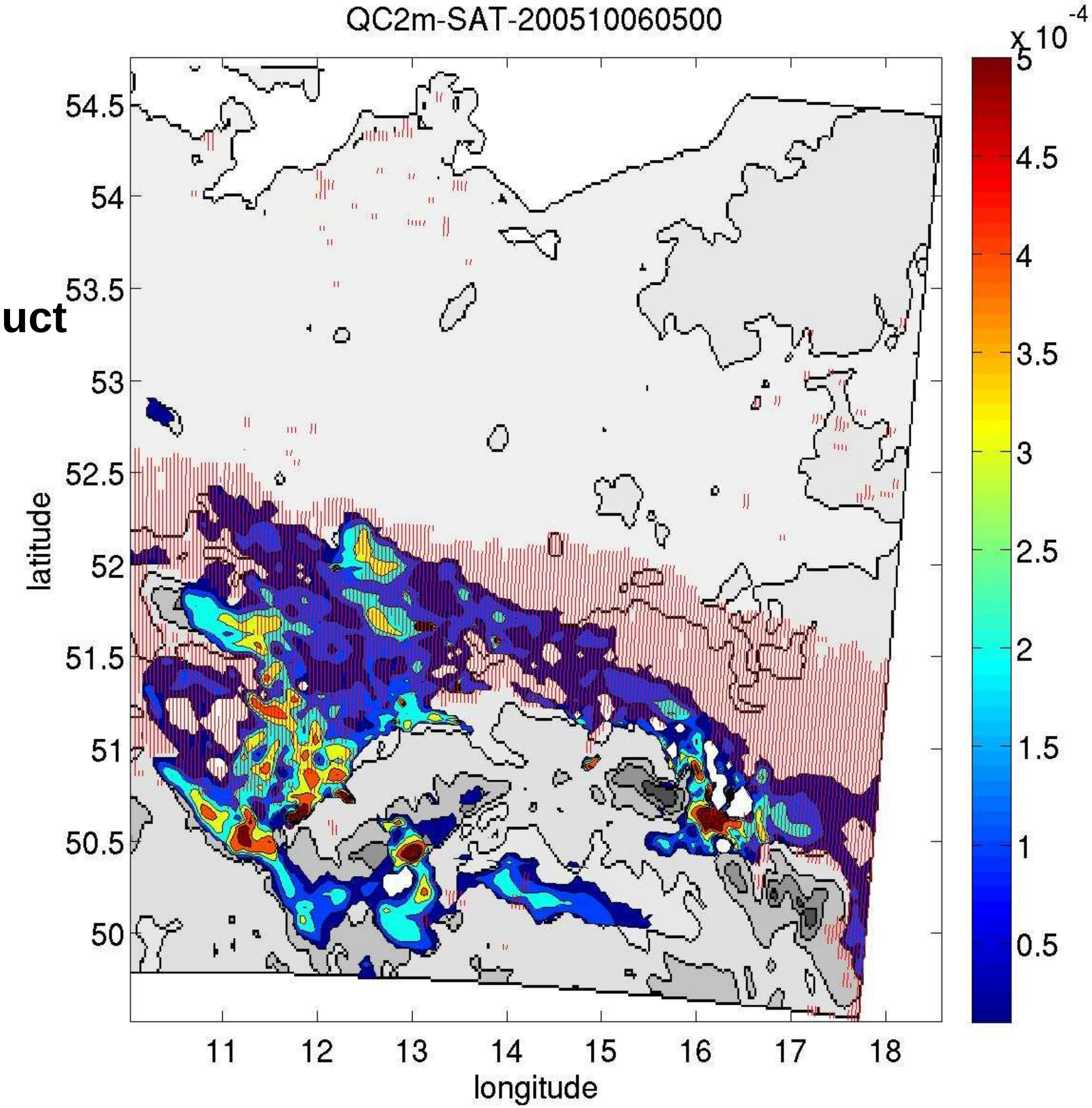


Lindenberg- 06 October 2005- 05 UTC

05:00 UTC

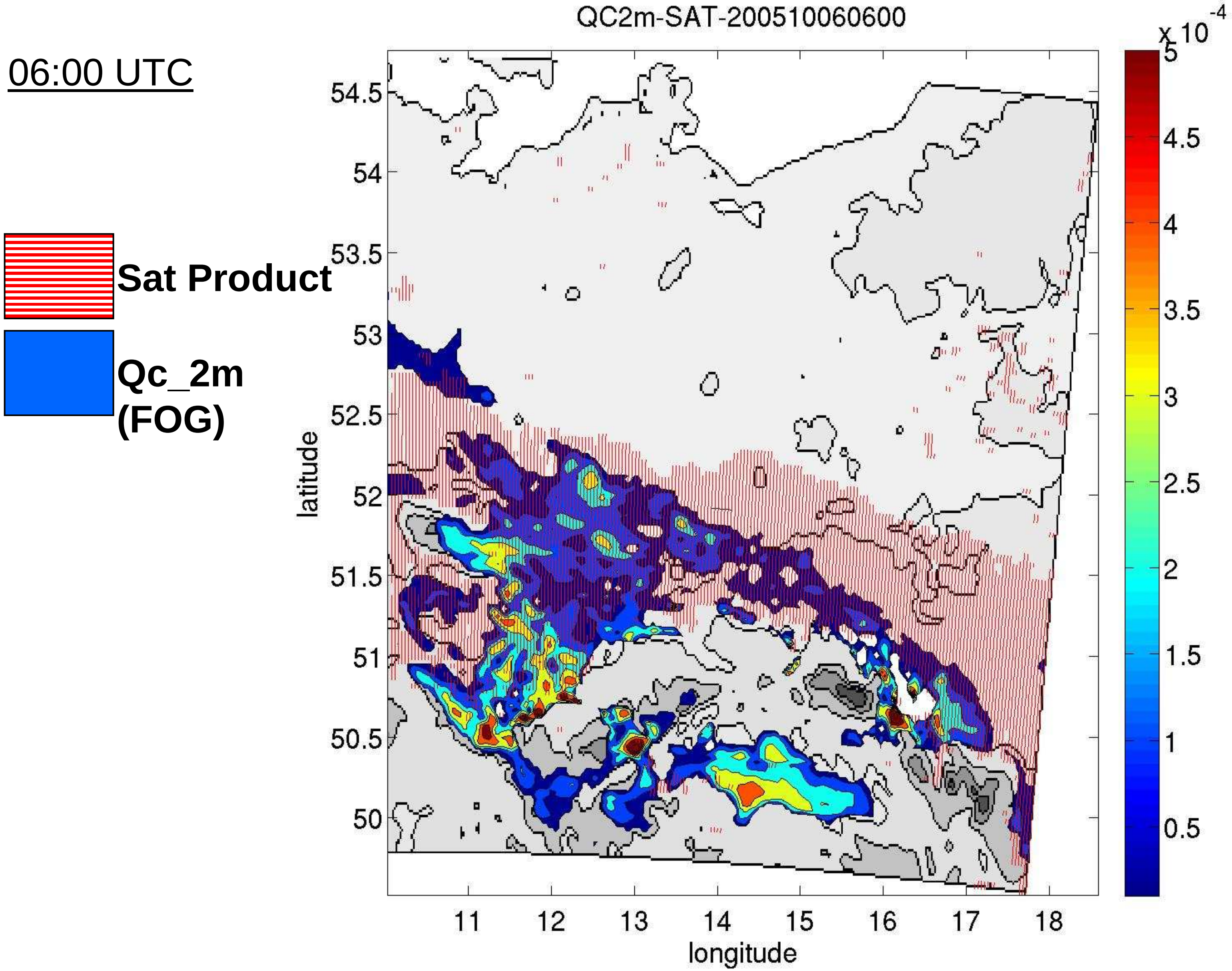
Sat Product

Qc_2m (FOG)



Lindenberg- 06 October 2005- 06 UTC

06:00 UTC

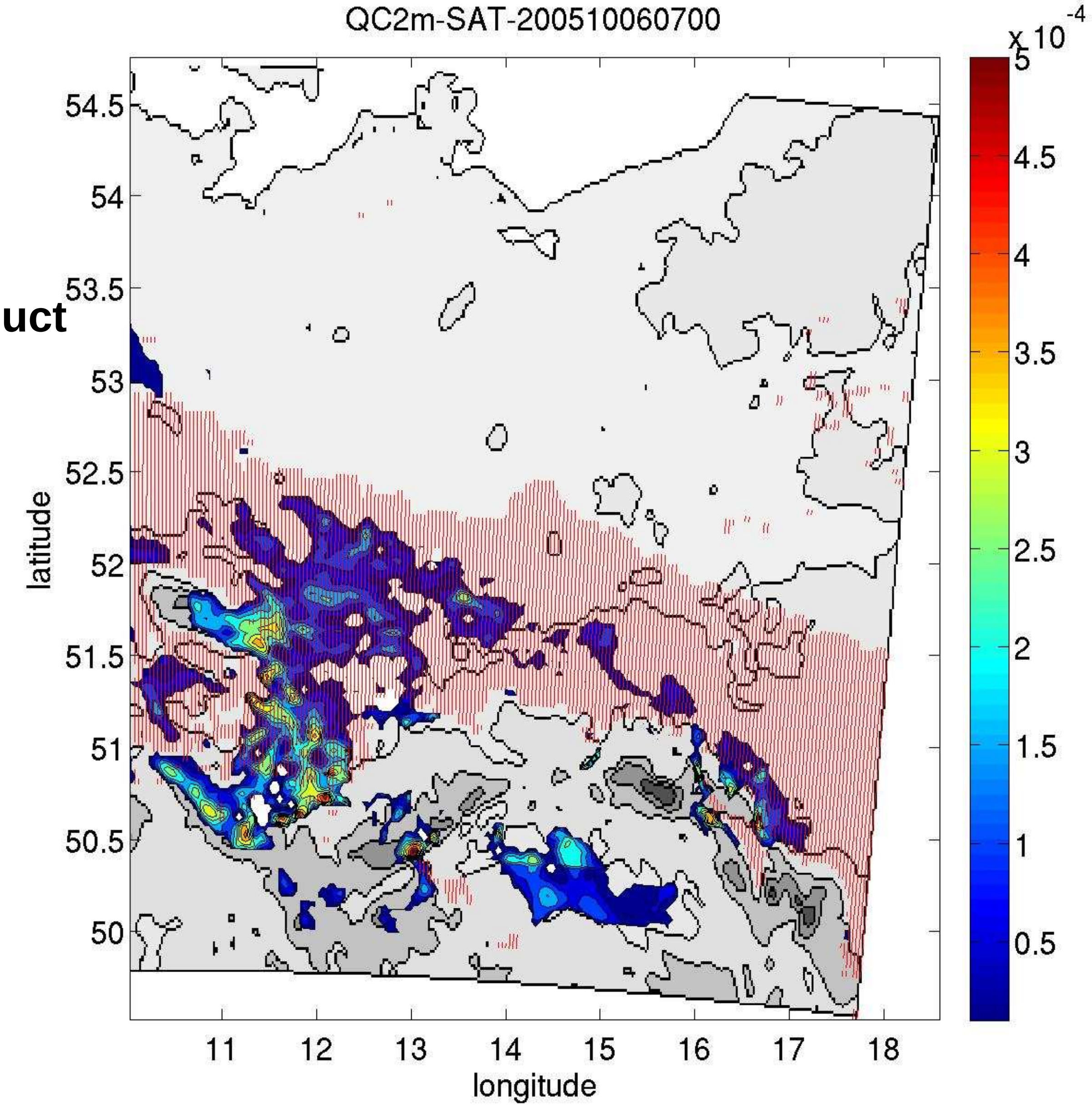


Lindenberg- 06 October 2005- 07 UTC

07:00 UTC

Sat Product

Qc_2m (FOG)

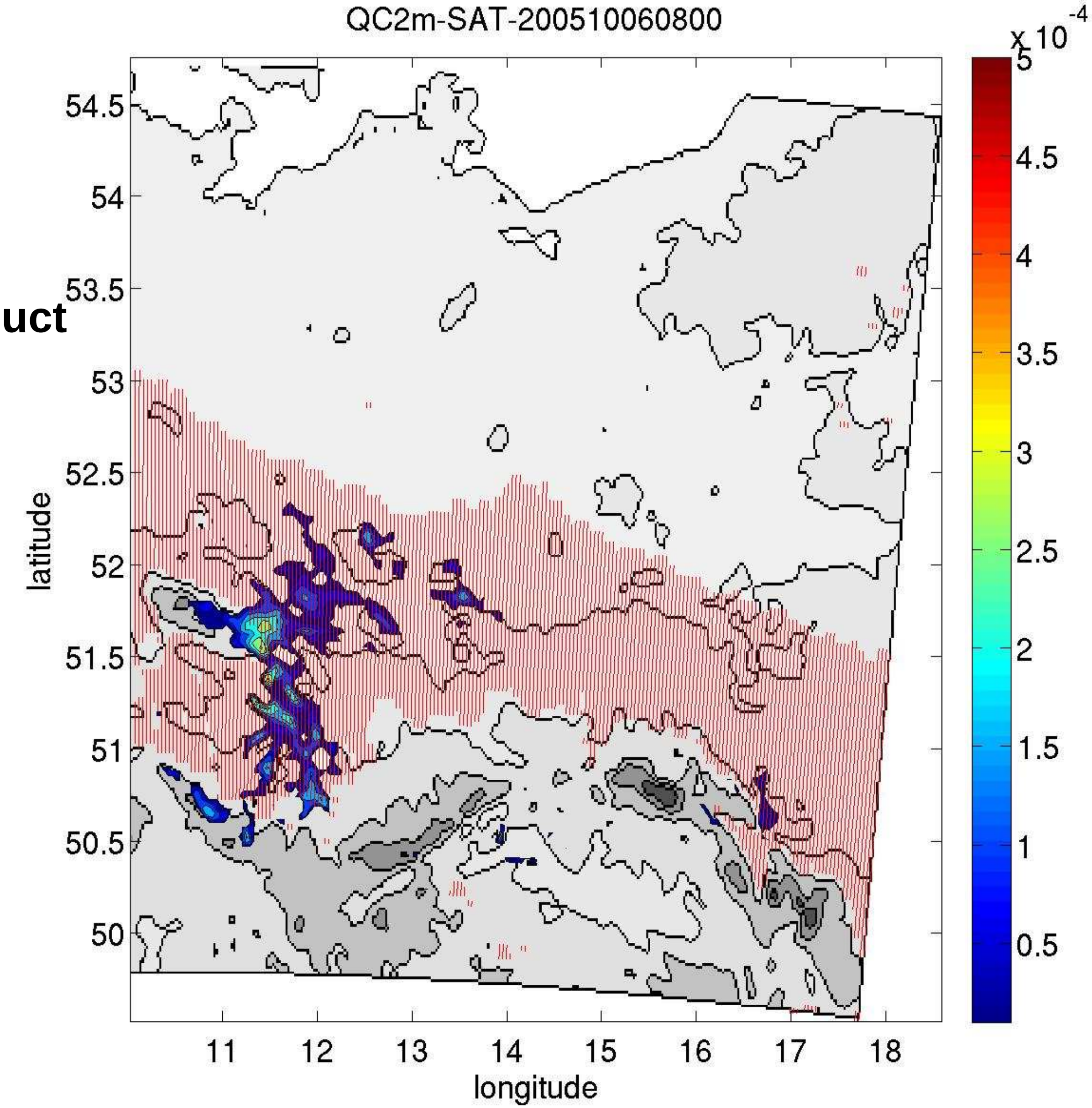


Lindenberg- 06 October 2005- 08 UTC

<u>08:00 UTC</u>

Sat Product

Qc_2m (FOG)

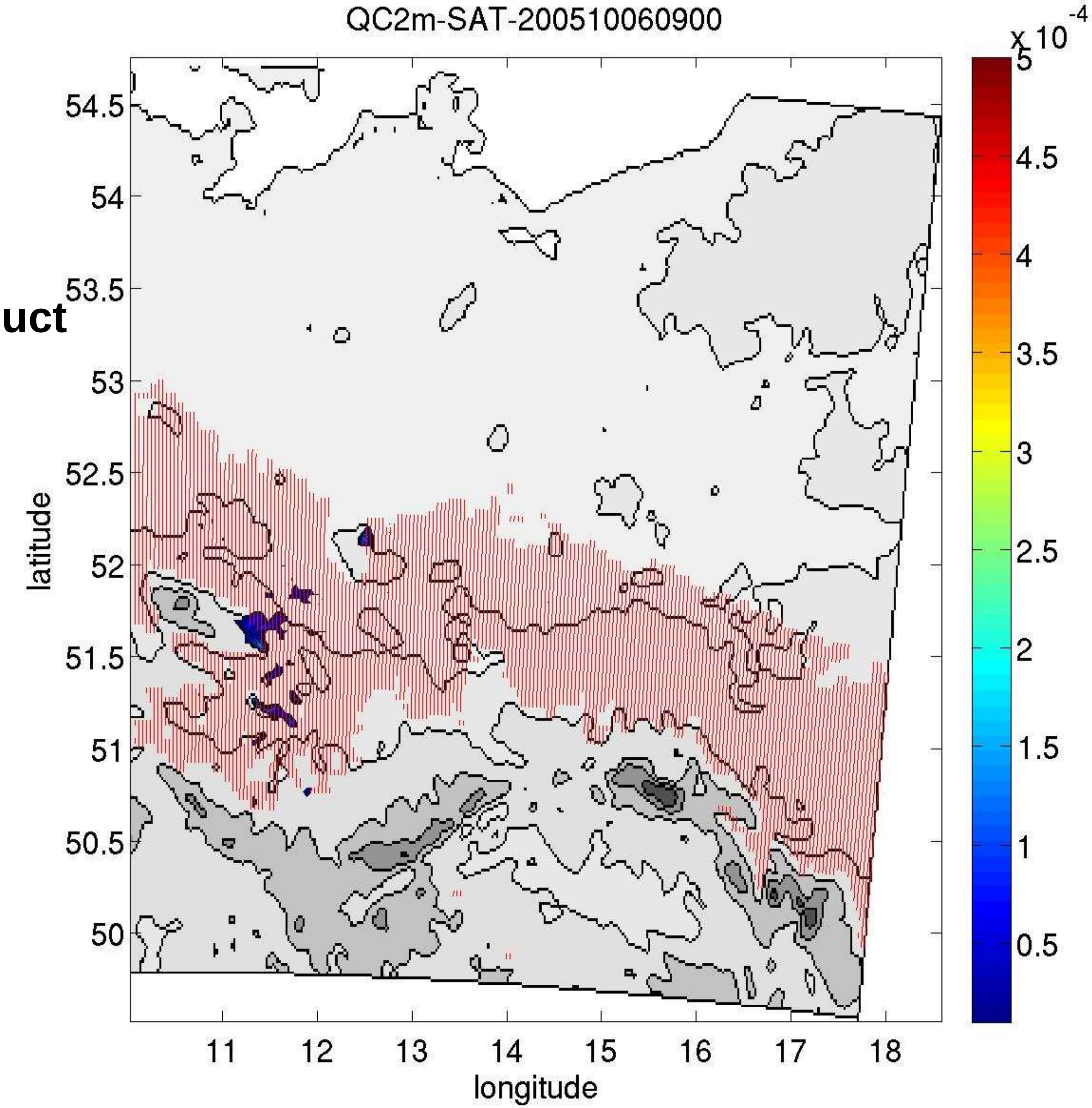


Lindenberg- 06 October 2005- 09 UTC

09:00 UTC

Sat Product

Qc_2m (FOG)

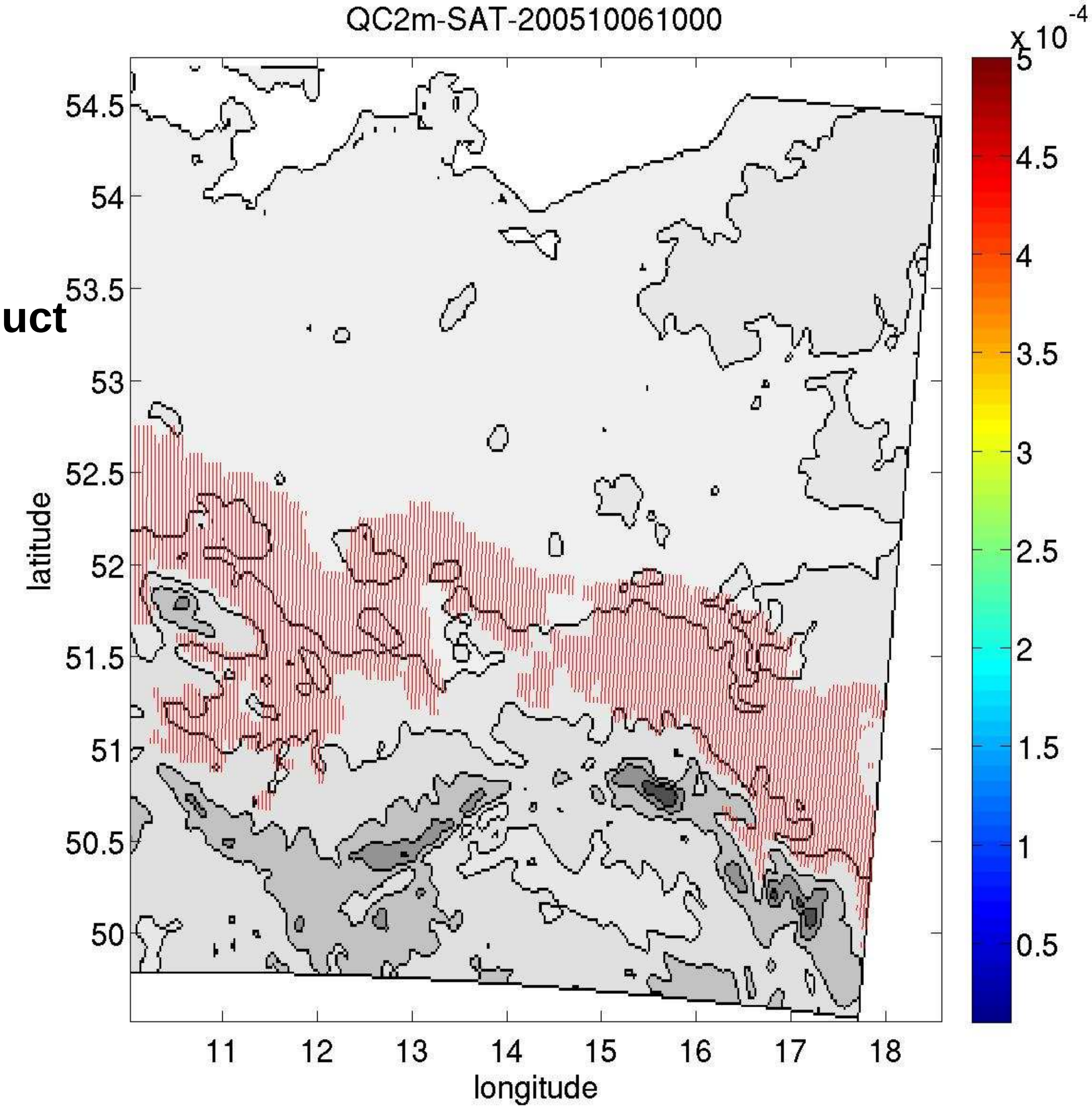


Lindenberg- 05 October 2005 48 h forecast

10:00 UTC

Sat Product

Qc_2m (FOG)



Lindenberg- Soil Moisture Sensitivity

Test influence of soil moiture on fog formation

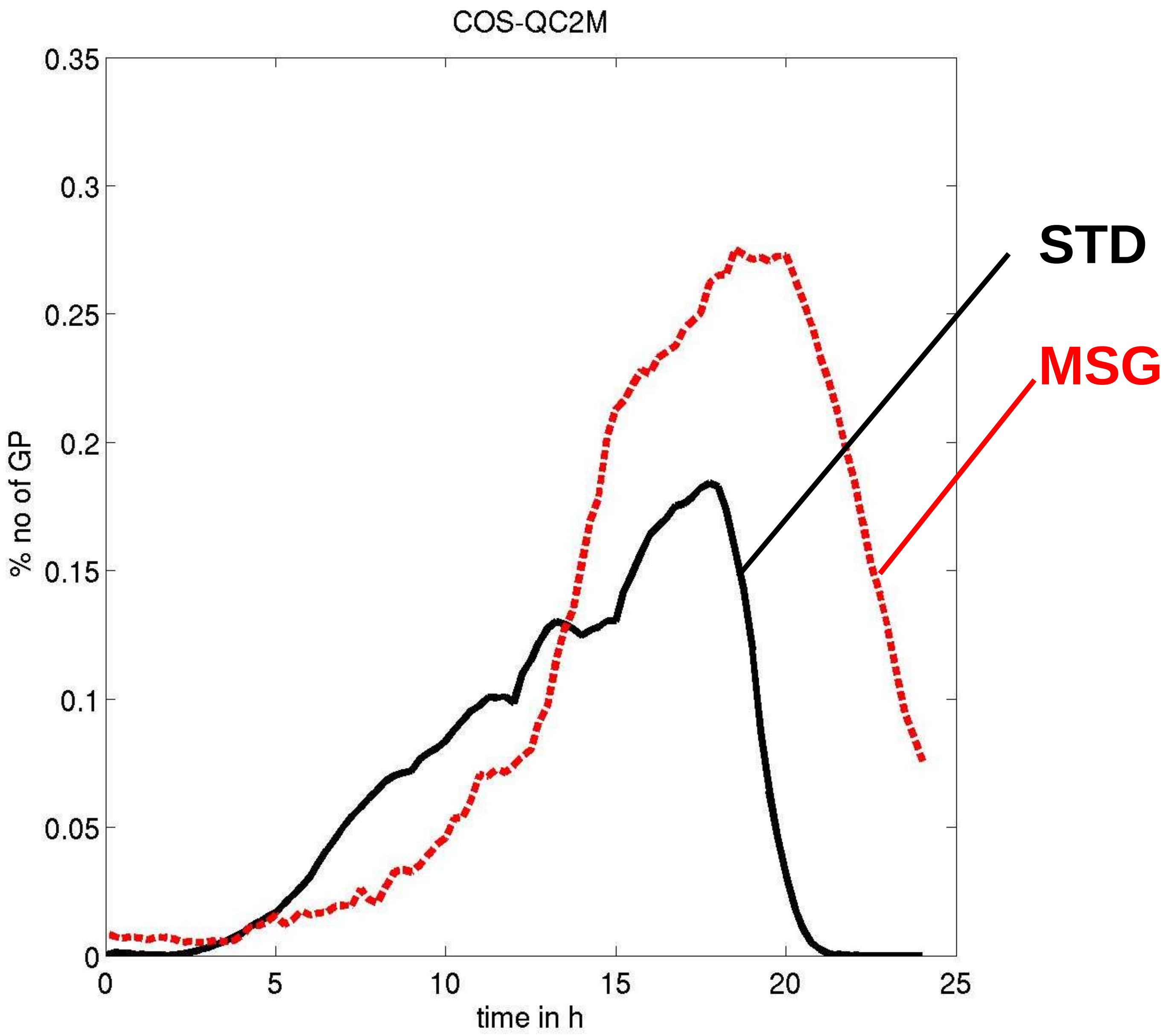
1.Standard run (original soil moisture)

2.SM = Air Dryness point at each dt

3.SM =Pore Volume at each dt

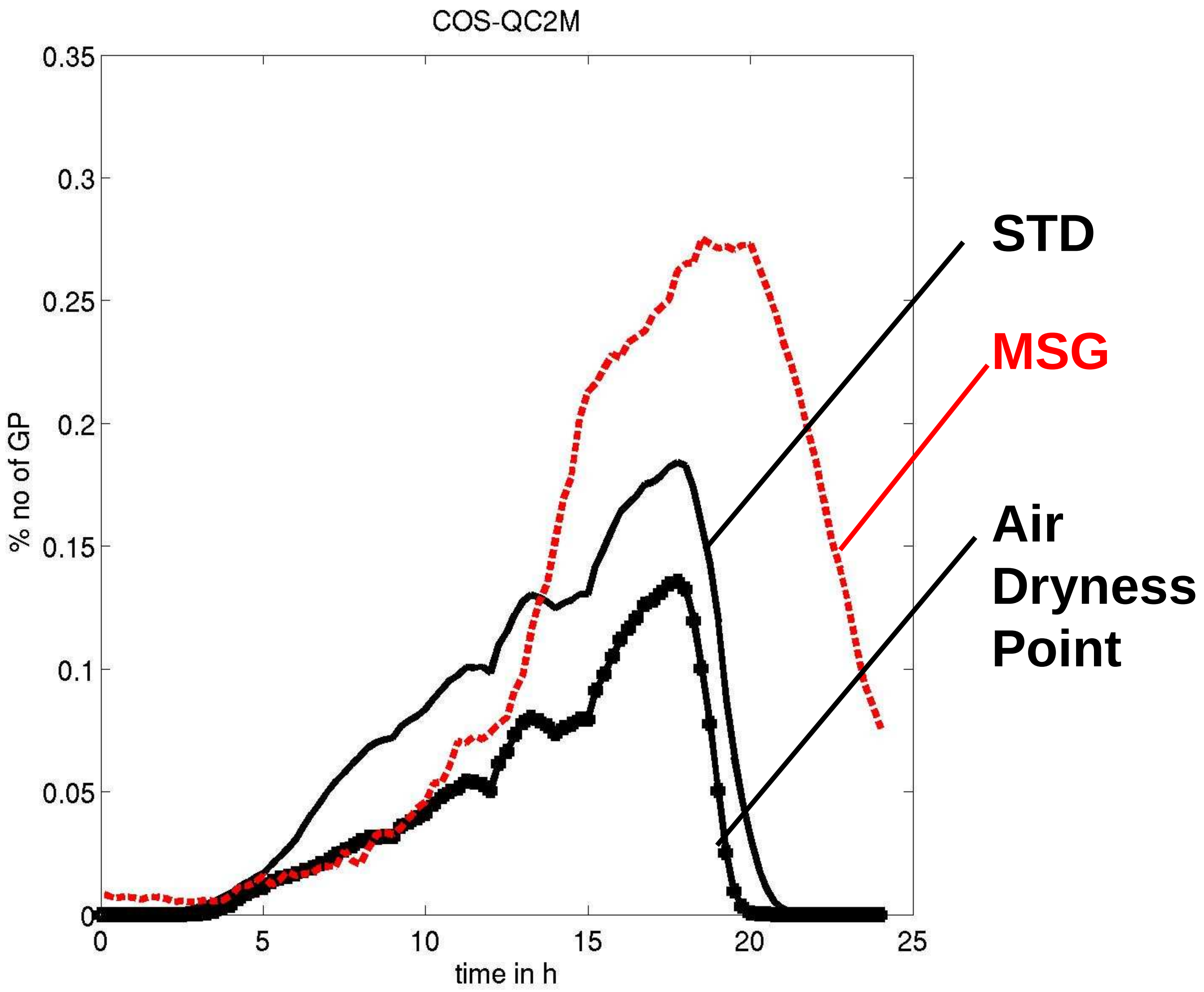
Lindenberg- Soil Moisture Sensitivity

QC–2m



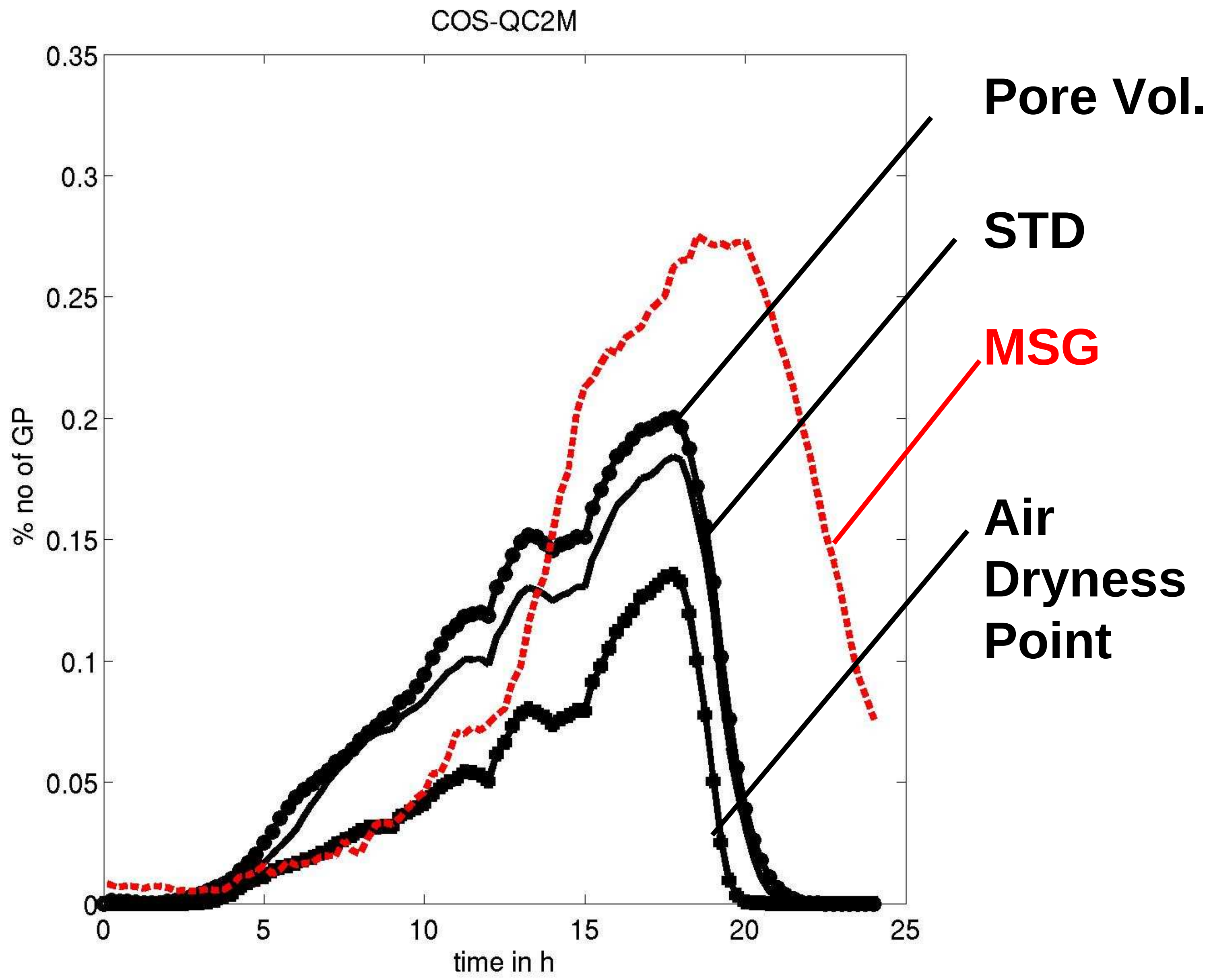
Lindenberg- Soil Moisture Sensitivity

QC–2m



Lindenberg- Soil Moisture Sensitivity

QC–2m



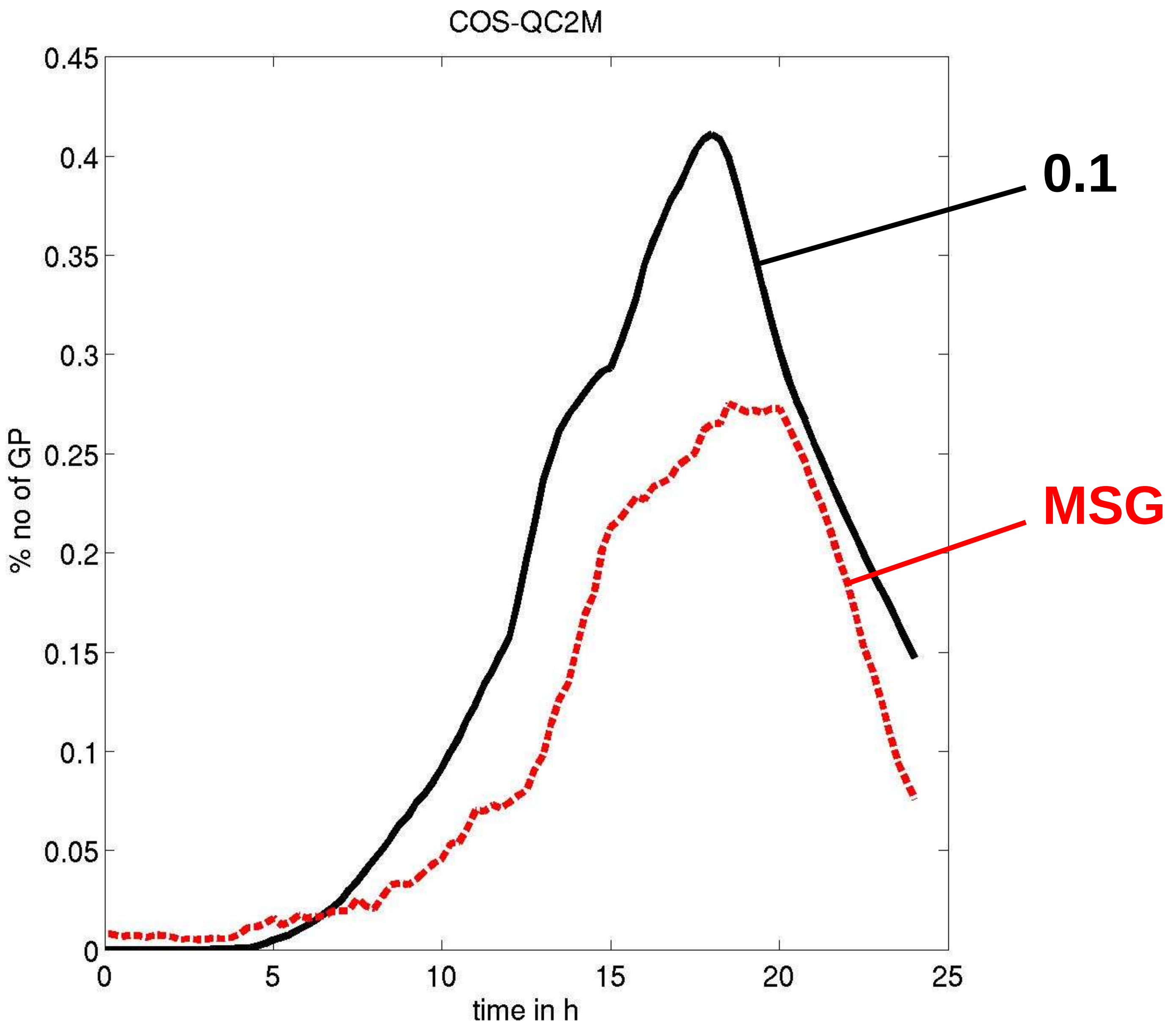
Lindenberg- Sensitivity – TKVH_MIN

Test influence of TKVH_MIN on fog formation

TKVH_MIN = 0.001, 0.1, 0.3, 0.5, 0.7, 1.0

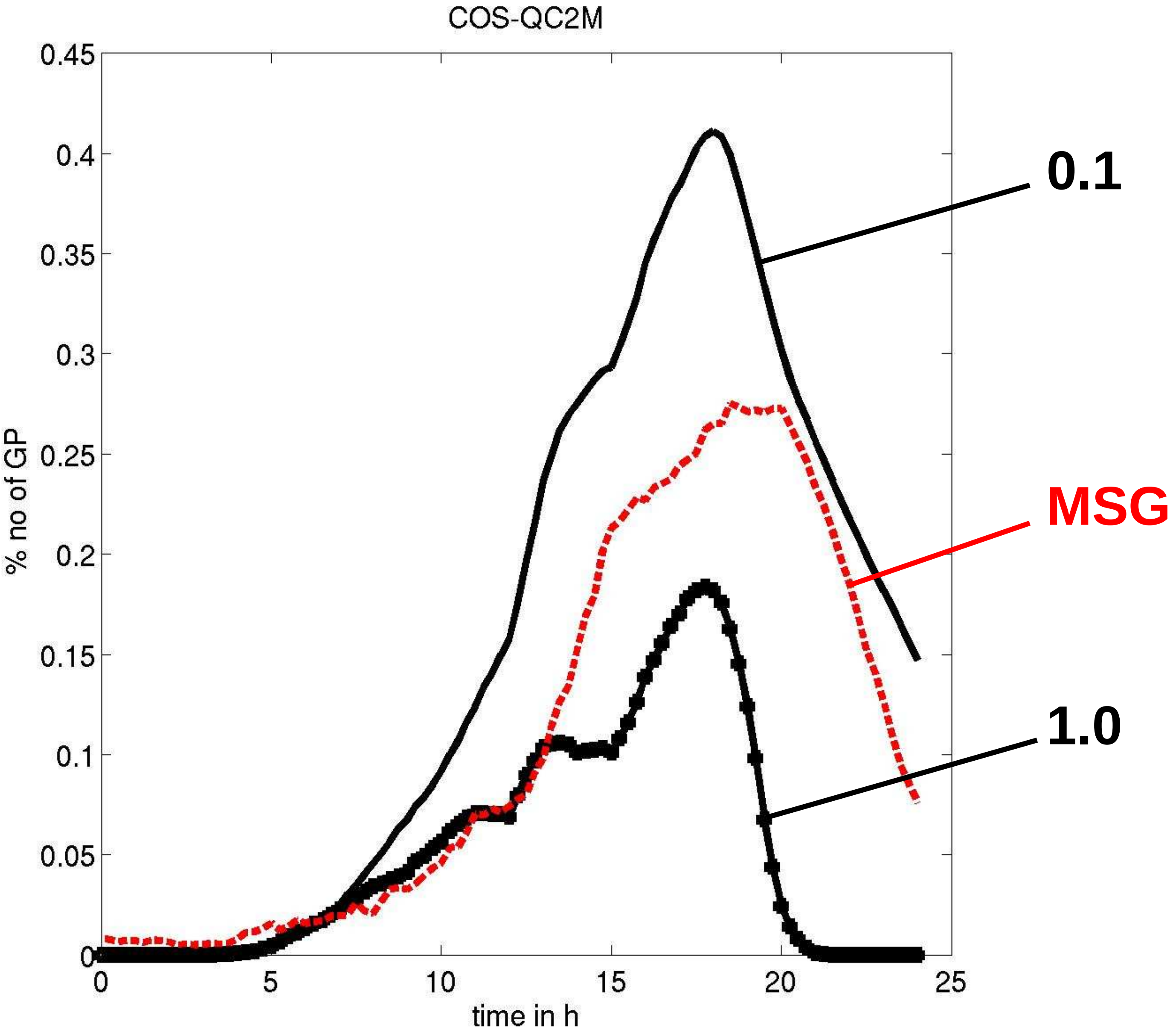
Lindenberg- Sensitivity – TKVH_MIN

QC–2m



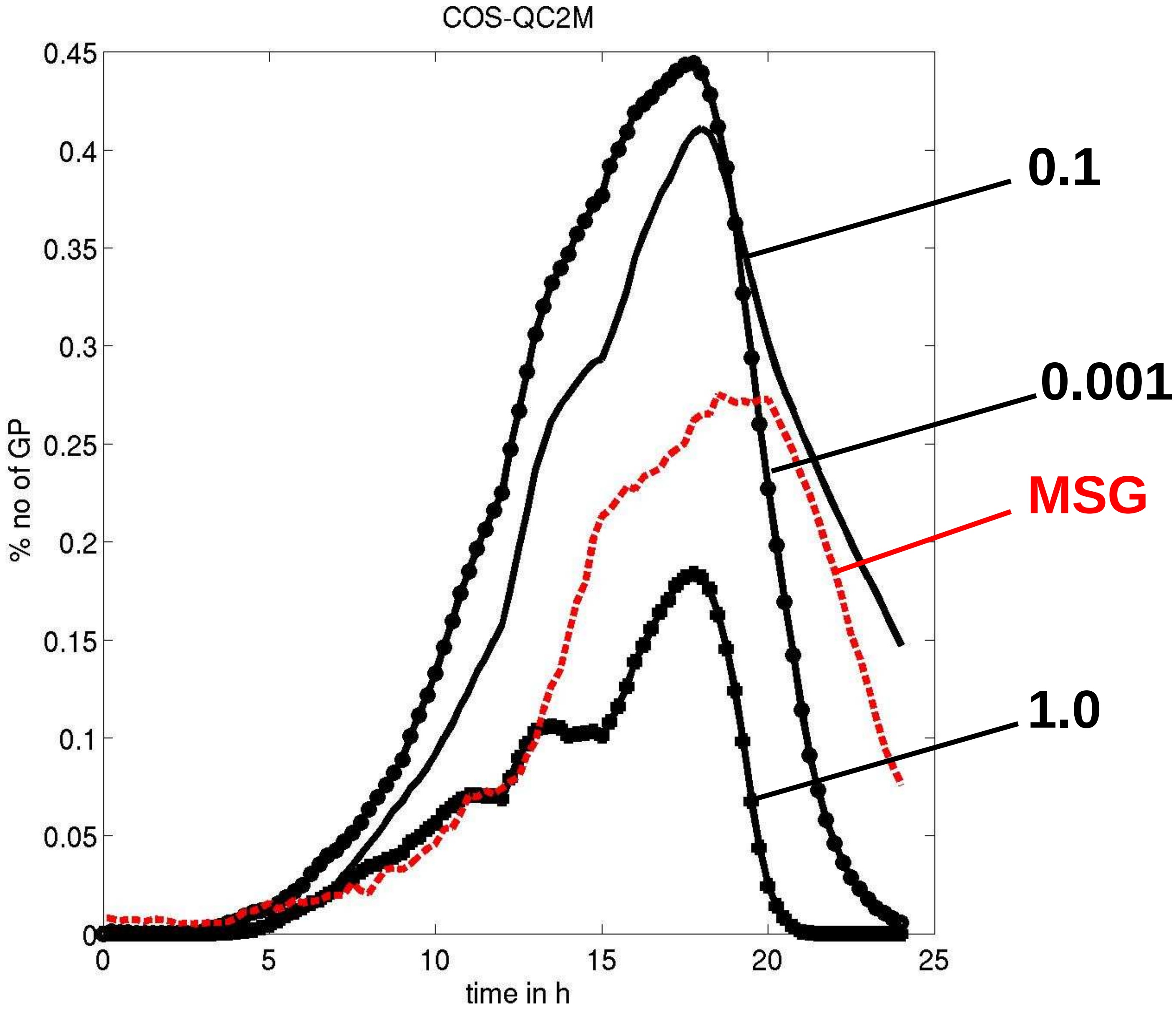
Lindenberg- Sensitivity – TKVH_MIN

QC–2m



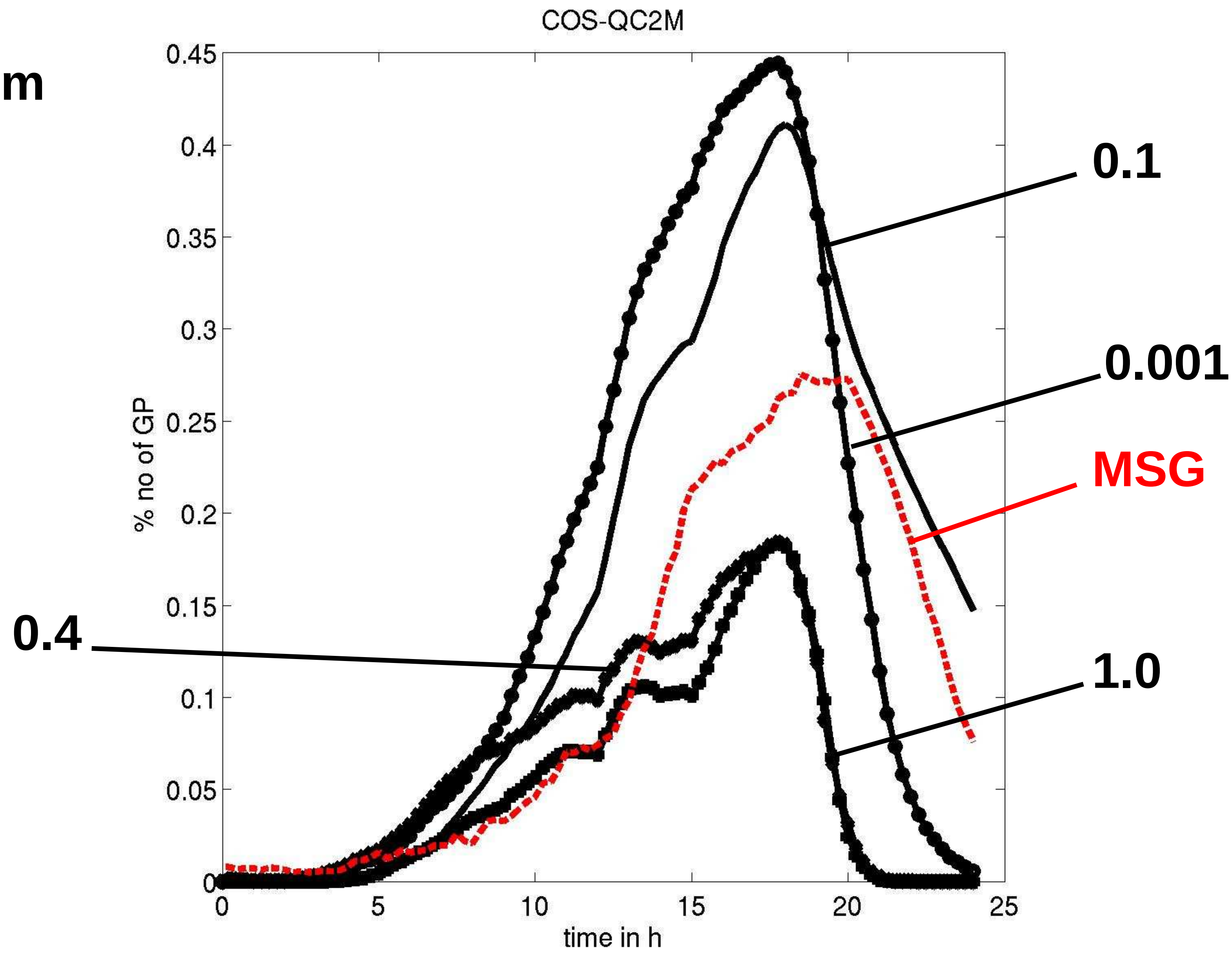
Lindenberg- Sensitivity – TKVH_MIN

QC–2m



Lindenberg- Sensitivity – TKVH_MIN

QC–2m

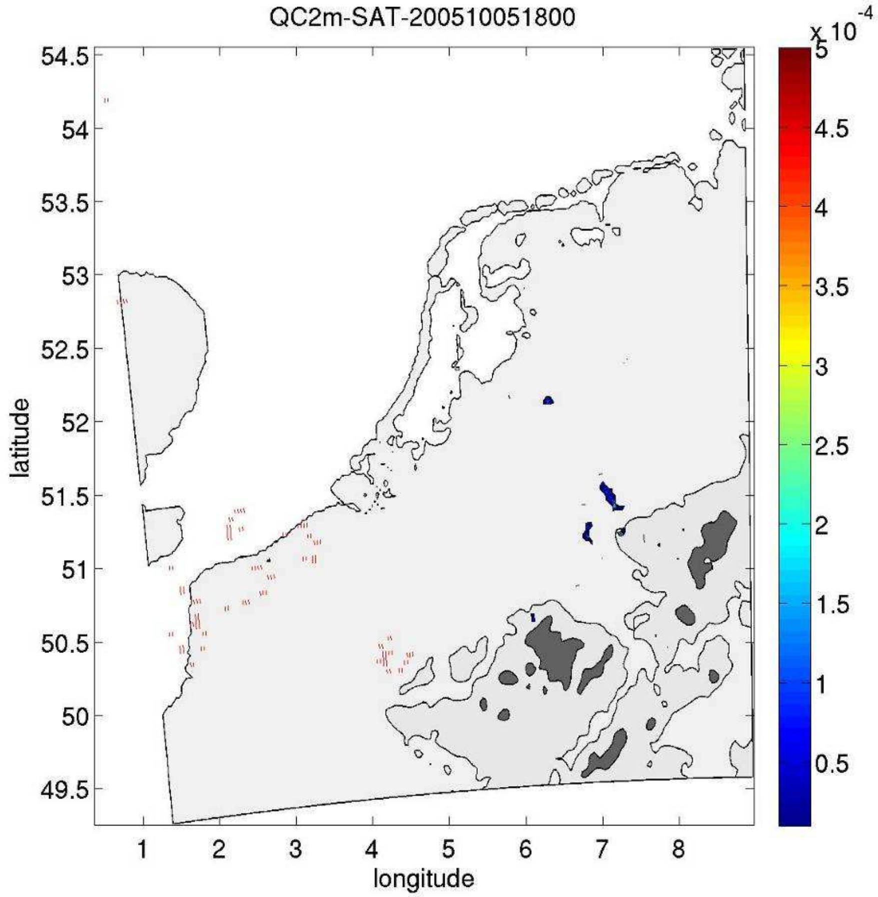


Cabauw- 05 October 2005 18:00 UTC

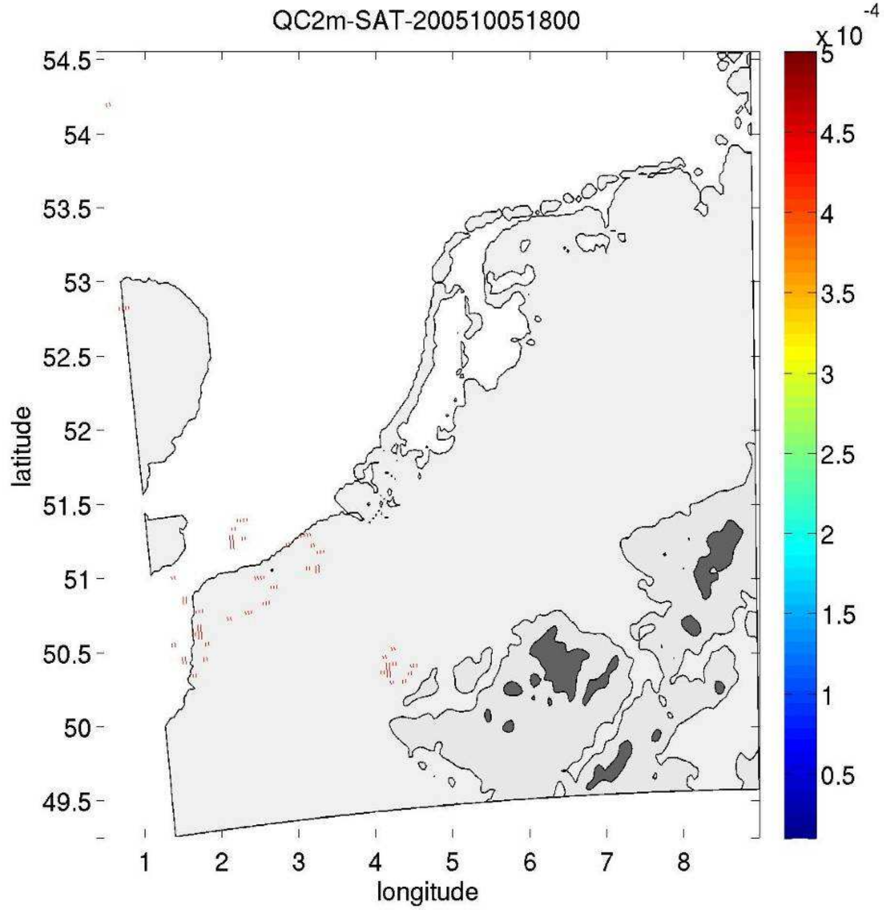
MSG-product for fog and low stratus

Specifiy water content in kg/kg (COSMO-FOG)

TKVH min = 0.001



TKVH min = 0.4

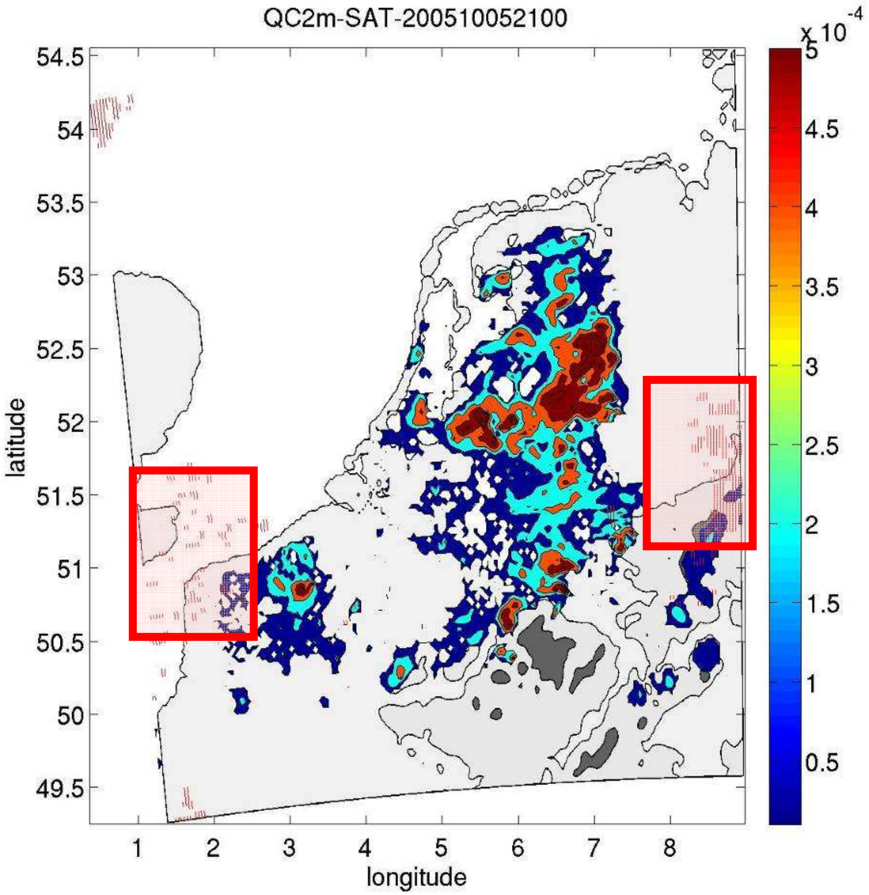


Cabauw- 05 October 2005 21:00 UTC

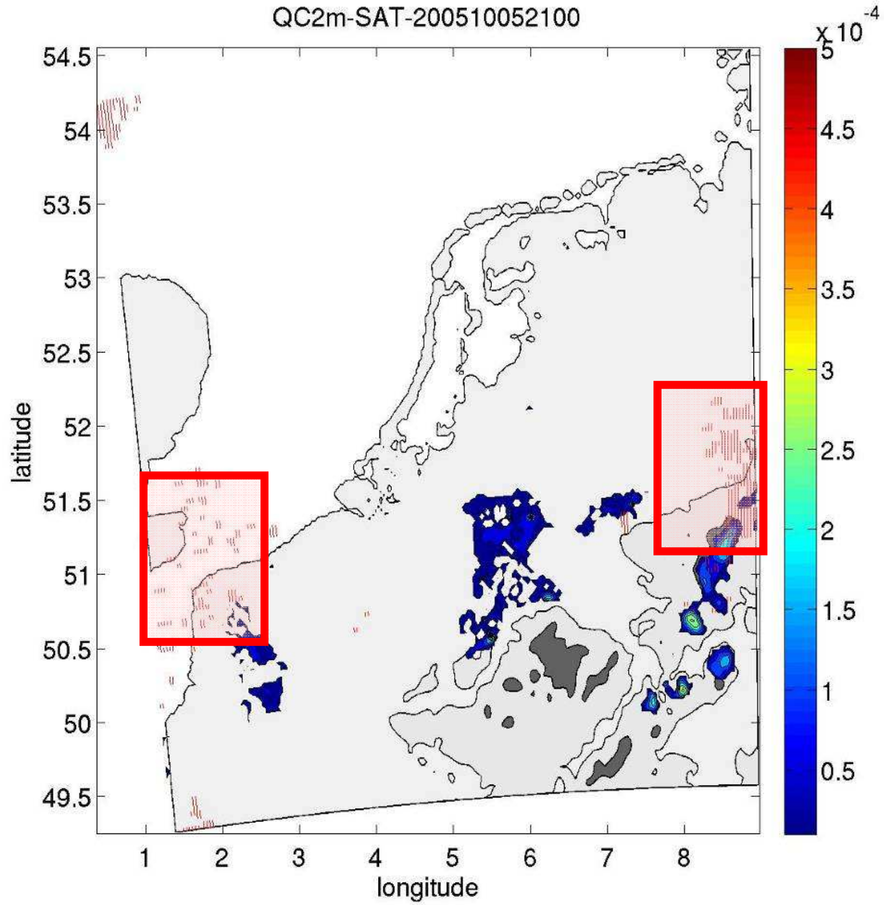
MSG-product for fog and low stratus

Specifiy water content in kg/kg (COSMO-FOG)

TKVH min = 0.001



TKVH min = 0.4

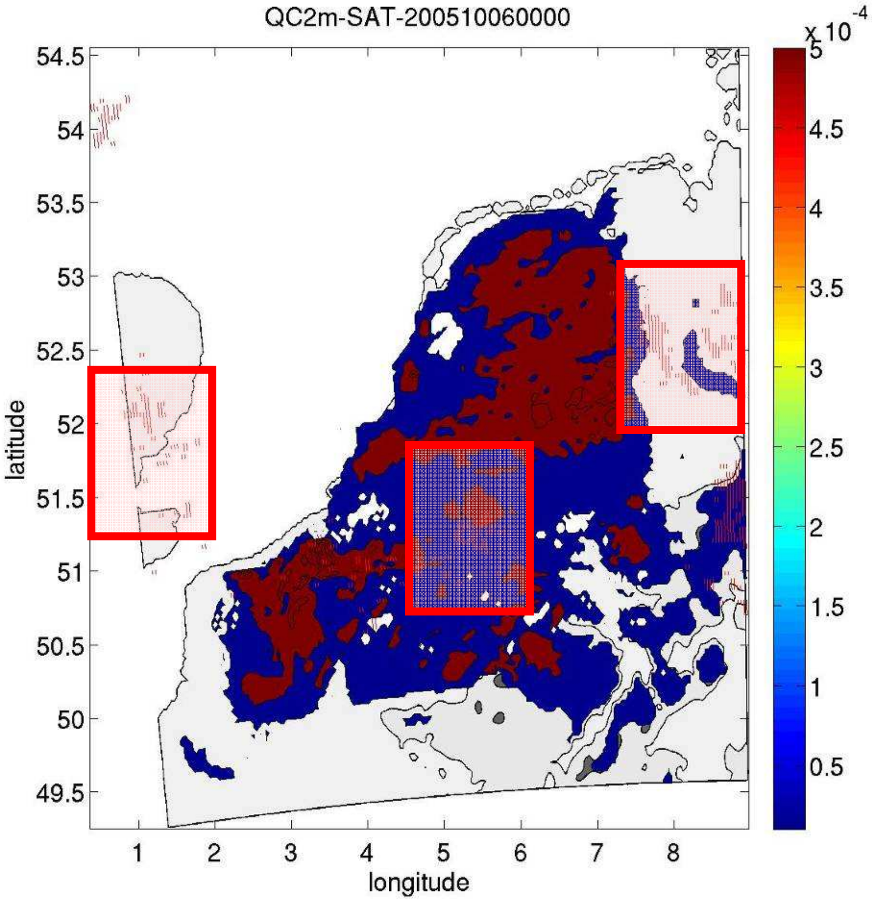


Cabauw- 06 October 2005 00:00 UTC

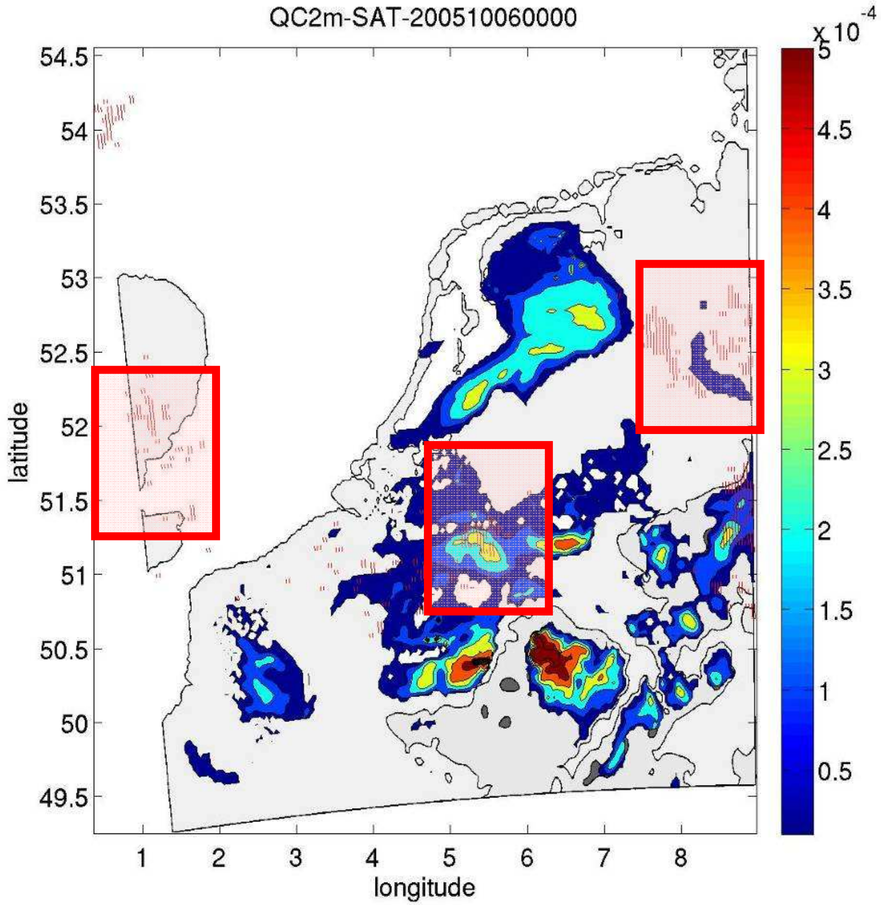
MSG-product for fog and low stratus

Specifiy water content in kg/kg (COSMO-FOG)

TKVH min = 0.001



TKVH min = 0.4

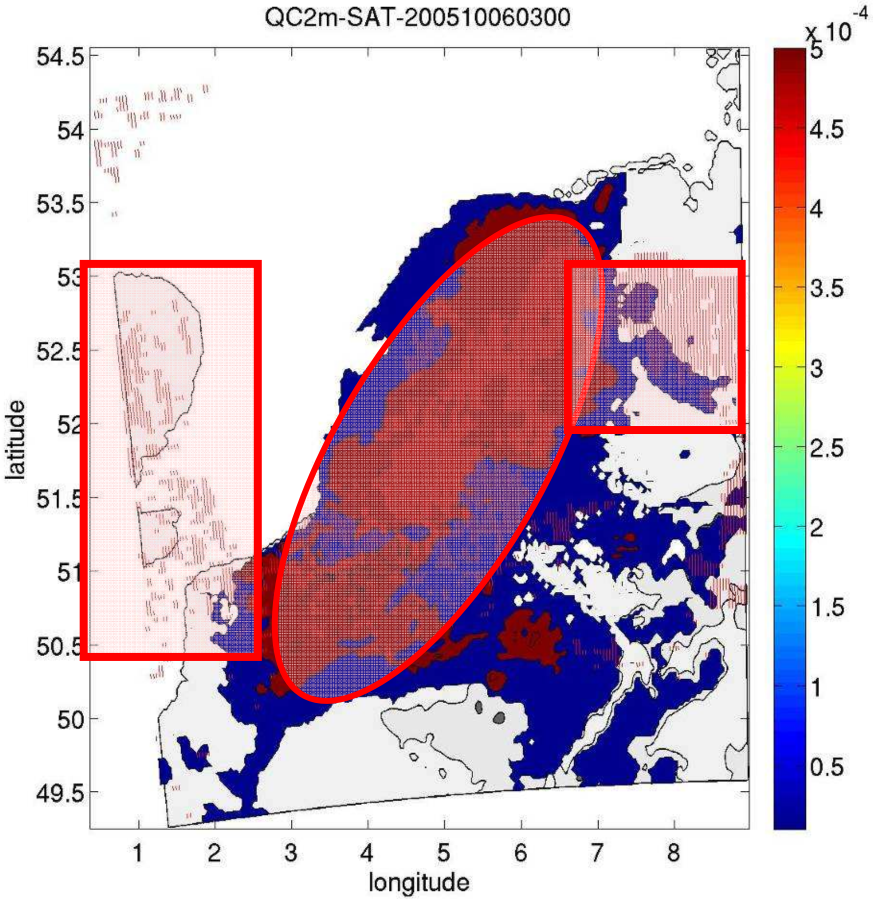


Cabauw- 06 October 2005 03:00 UTC

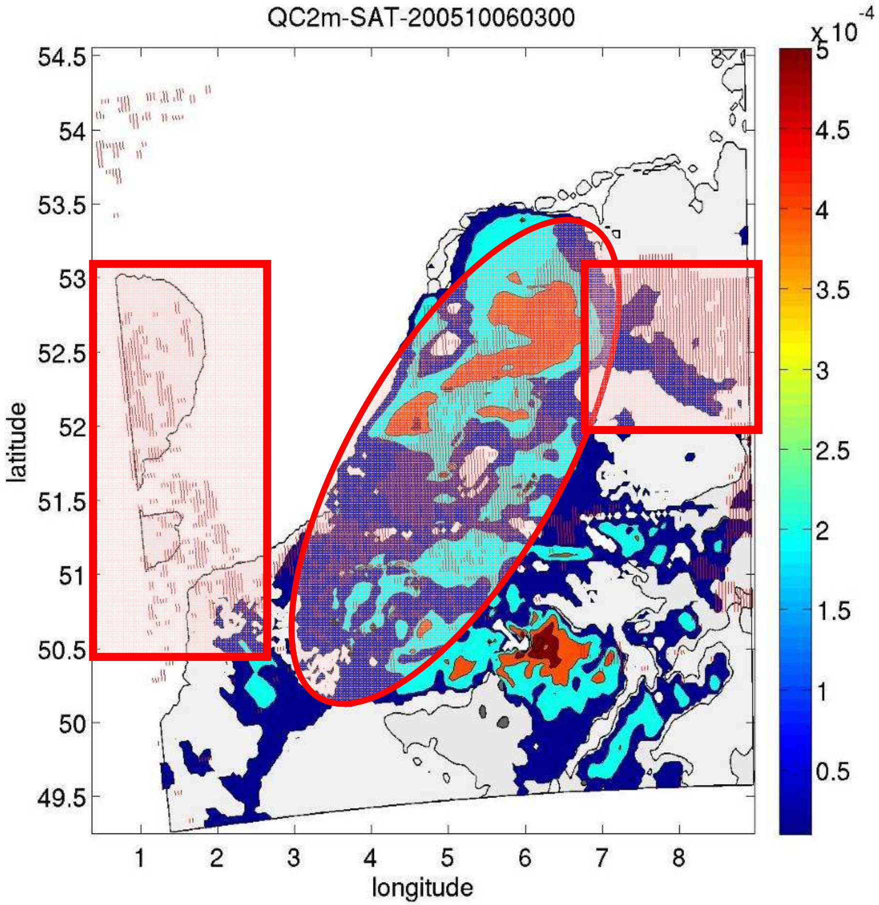
MSG-product for fog and low stratus

Specifiy water content in kg/kg (COSMO-FOG)

TKVH min = 0.001



TKVH min = 0.4

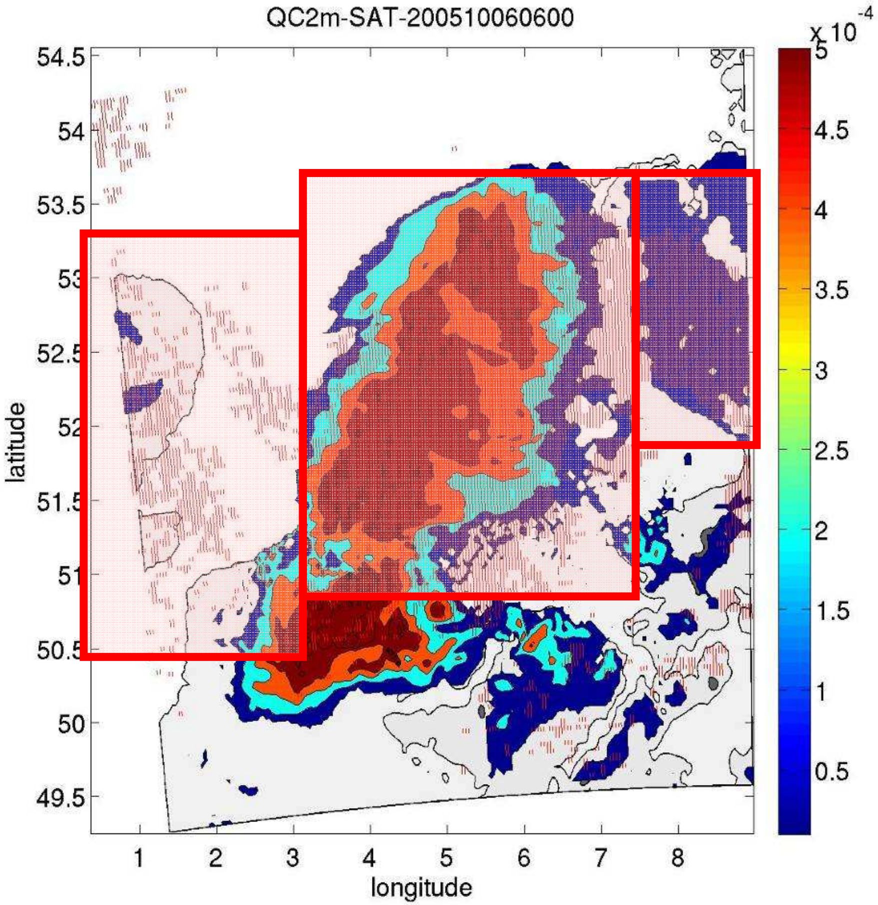


Cabauw- 06 October 2005 06:00 UTC

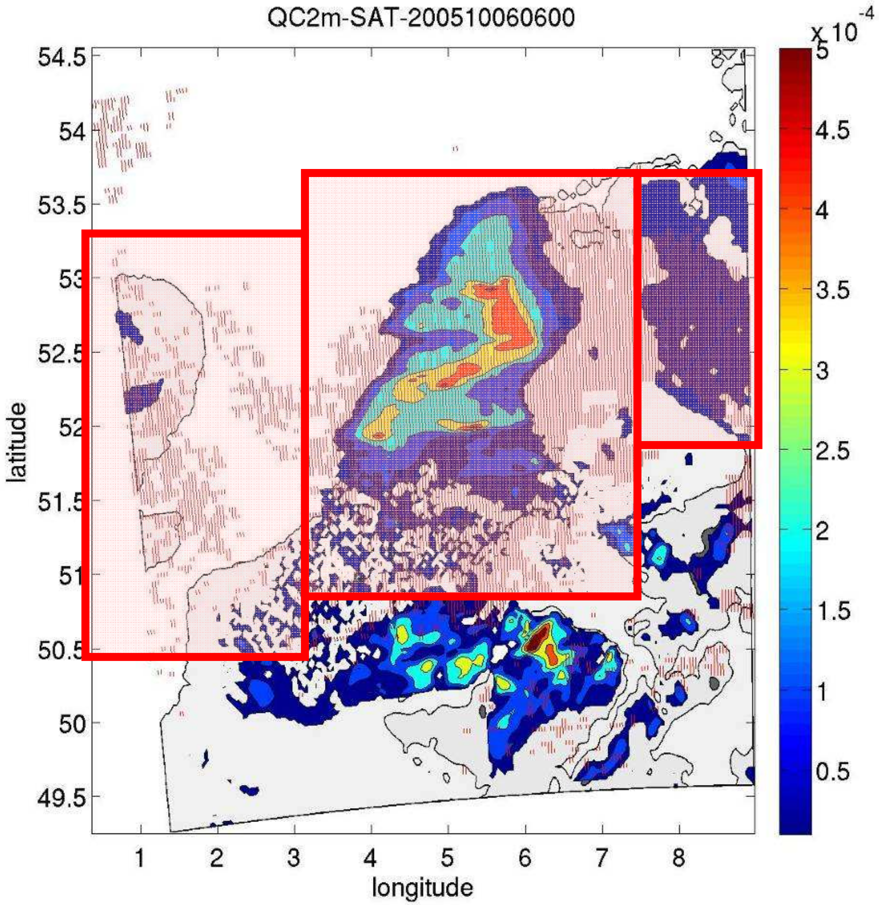
MSG-product for fog and low stratus

Specifiy water content in kg/kg (COSMO-FOG)

TKVH min = 0.001



TKVH min = 0.4

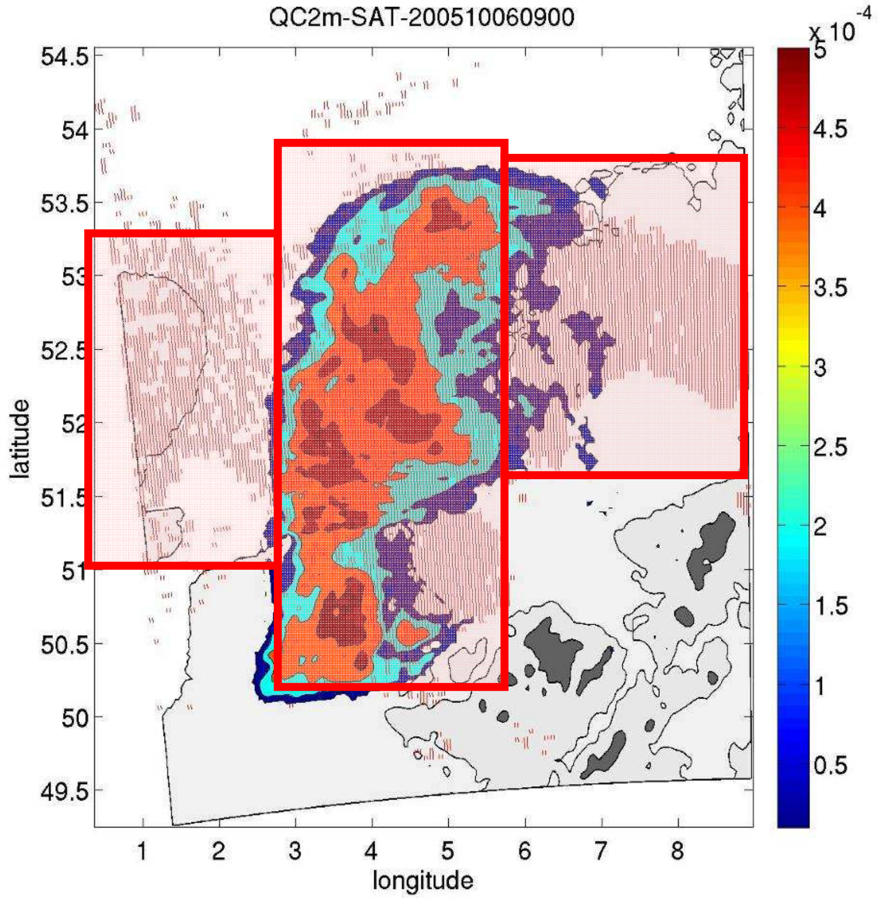


Cabauw- 06 October 2005 09:00 UTC

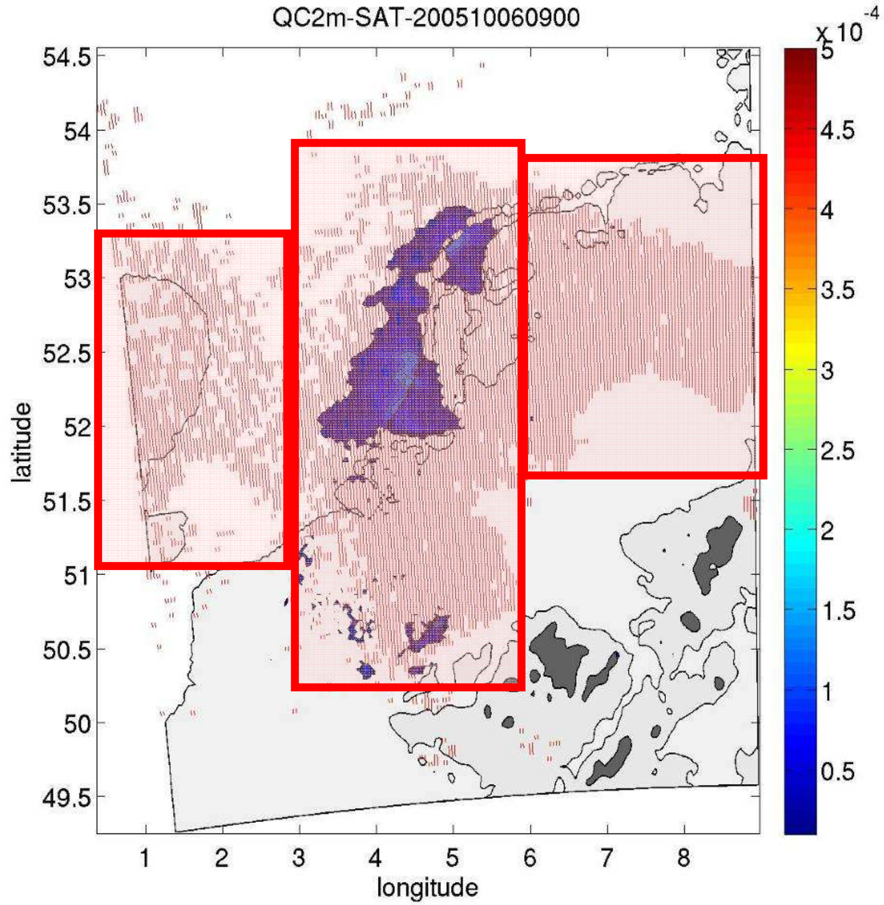
MSG-product for fog and low stratus

Specifiy water content in kg/kg (COSMO-FOG)

TKVH min = 0.001



TKVH min = 0.4

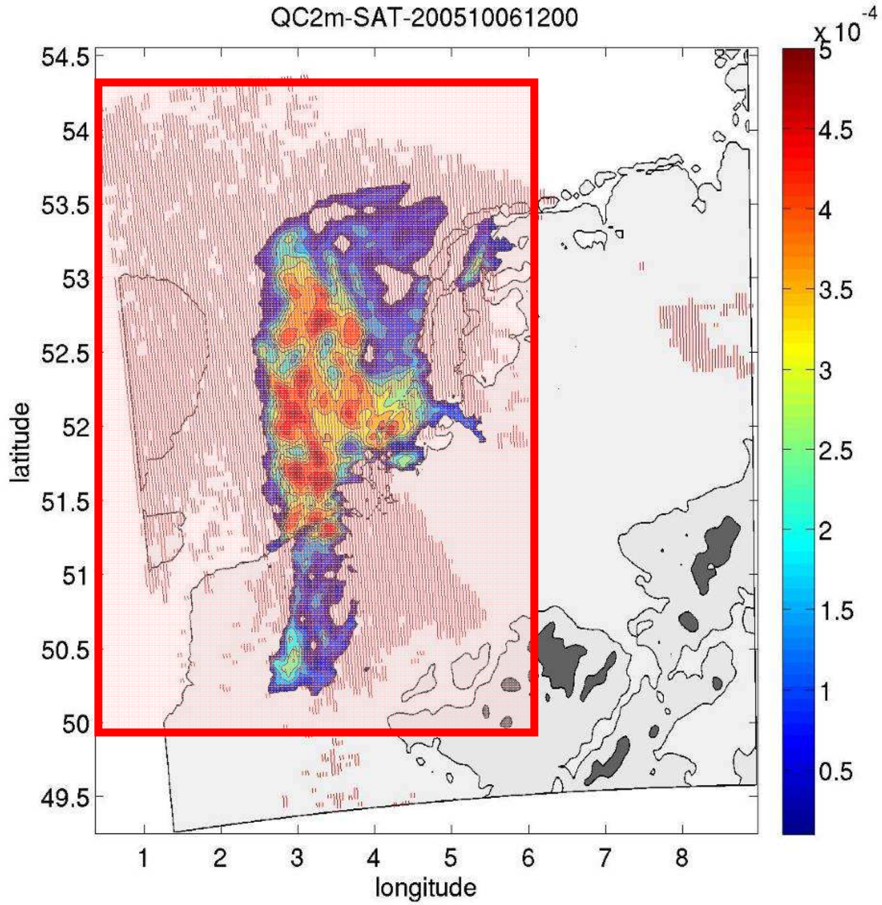


Cabauw- 06 October 2005 12:00 UTC

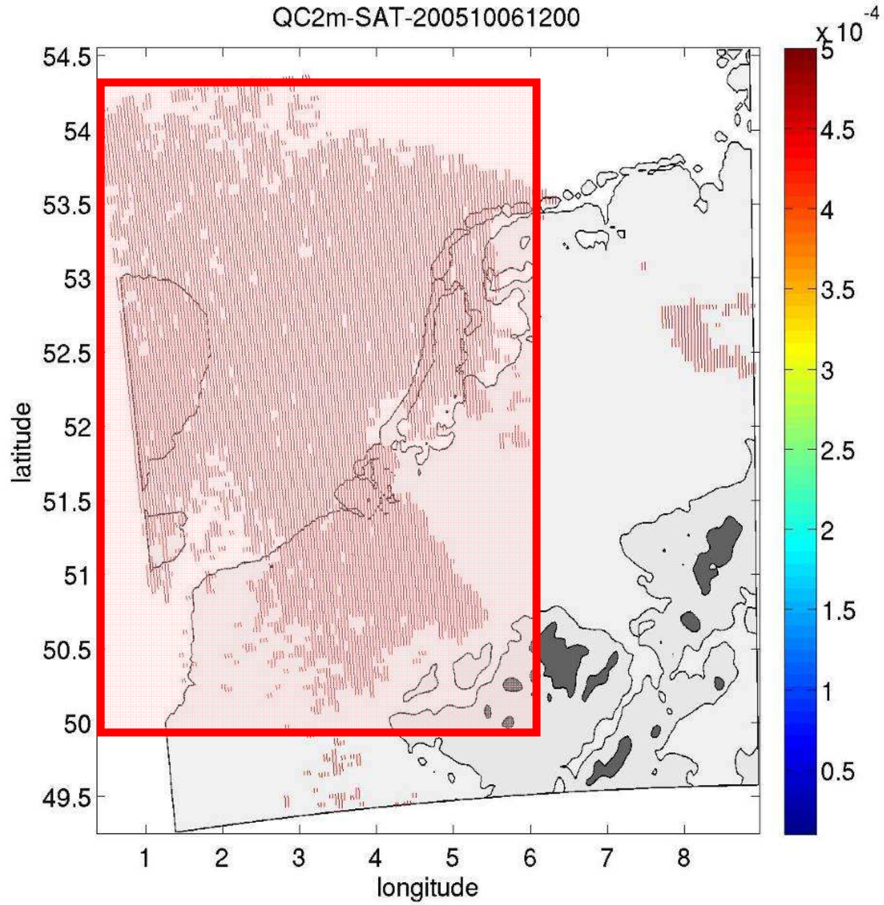
MSG-product for fog and low stratus

Specifiy water content in kg/kg (COSMO-FOG)

TKVH min = 0.001



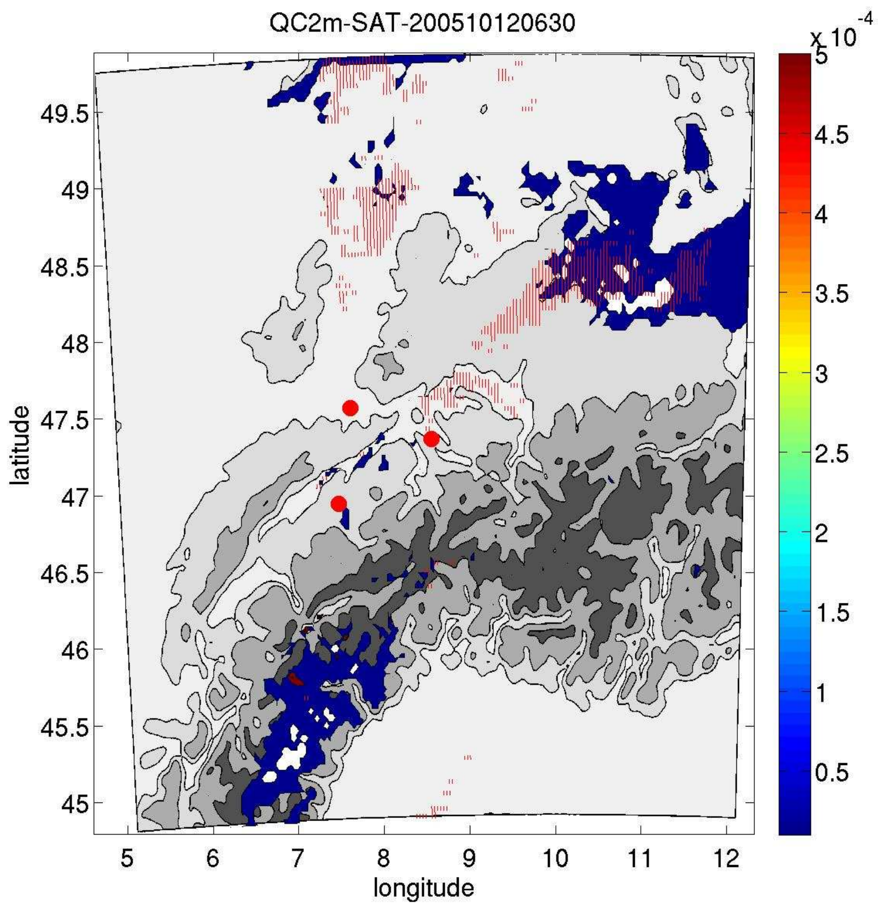
TKVH min = 0.4



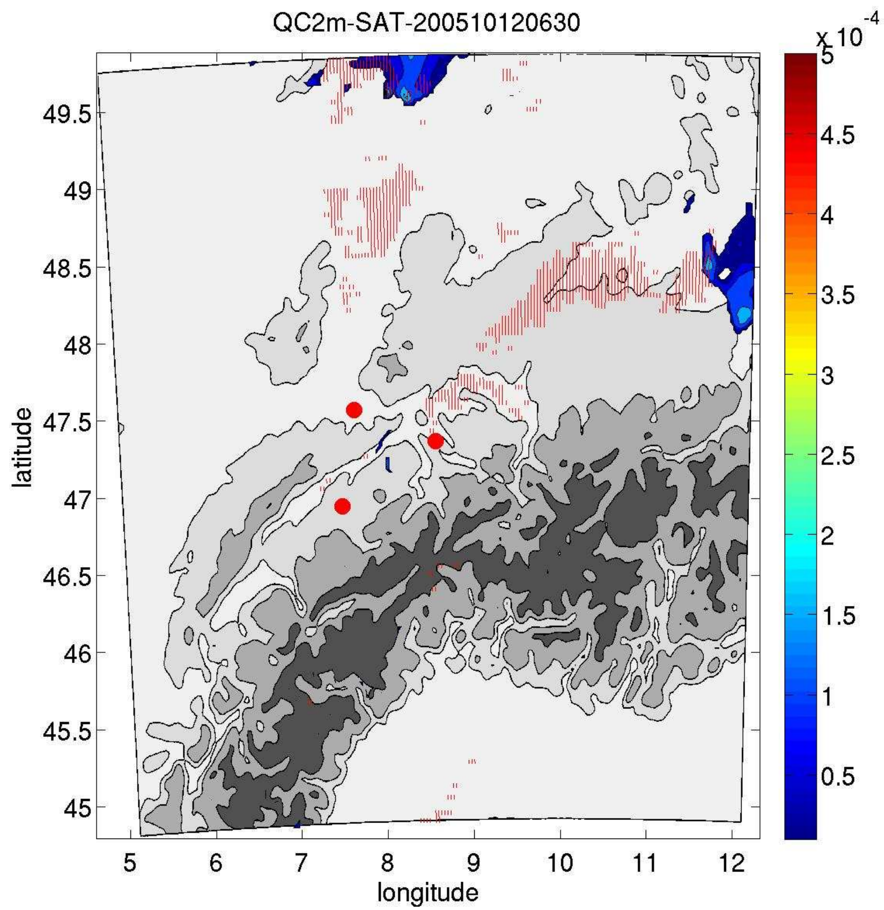
Zürich- 11 October 12UTC-24hours

12th October 2005-06:30UTC

TKVH min = 0.001



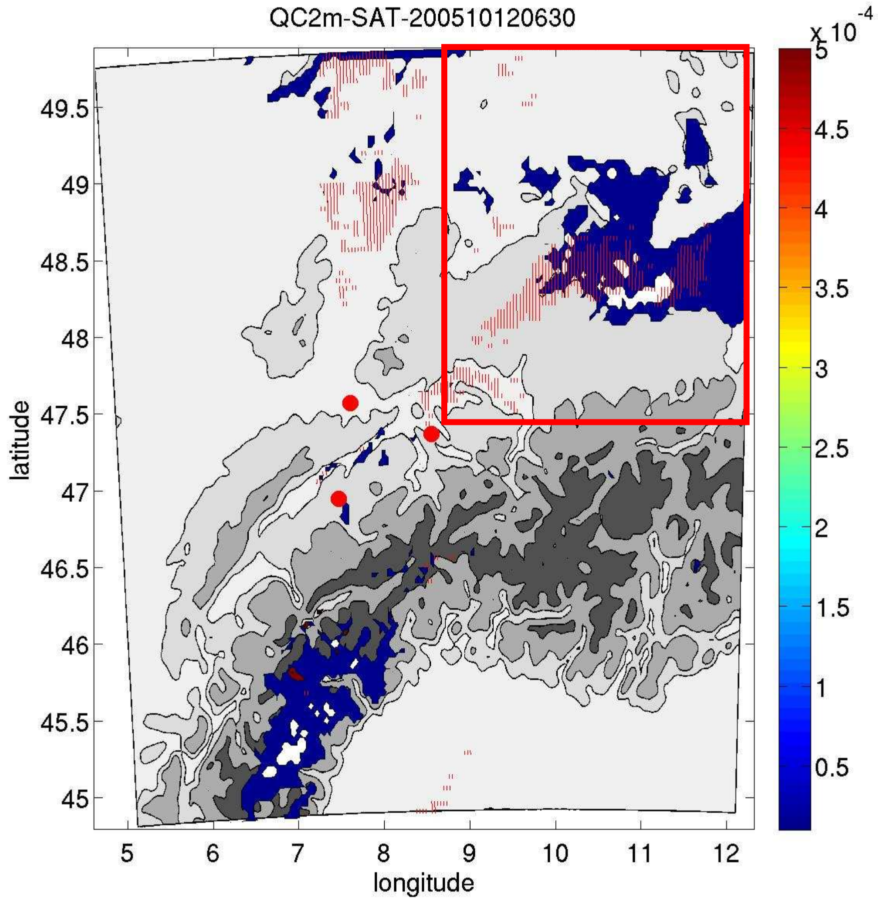
TKVH min = 0.7



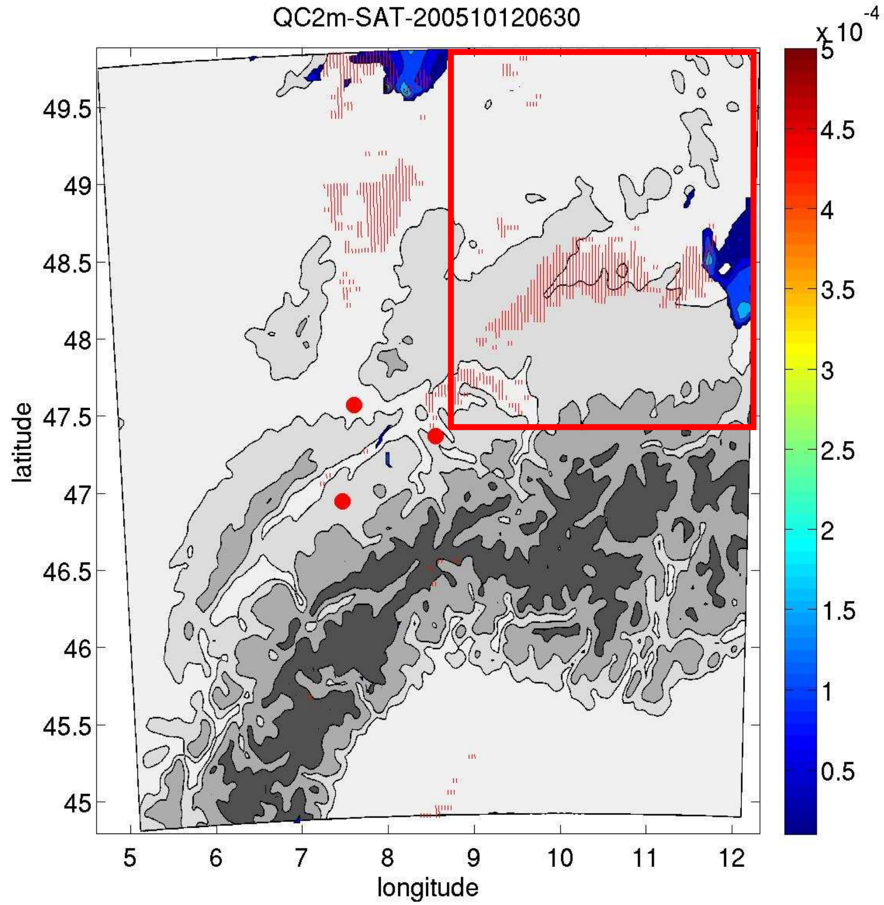
Zürich- 11 October 12UTC-24hours

12th October 2005-06:30UTC

TKVH min = 0.001



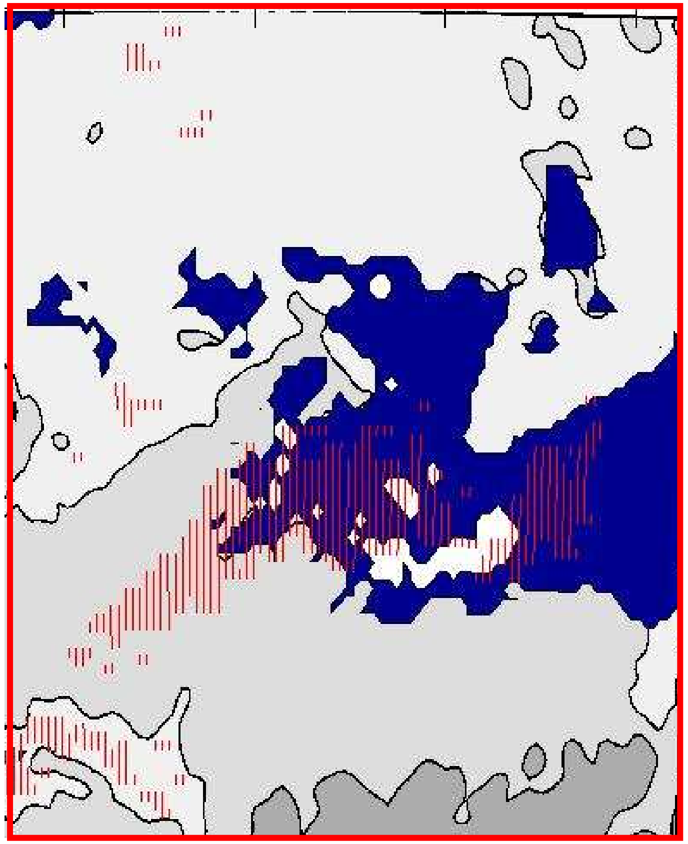
TKVH min = 0.7



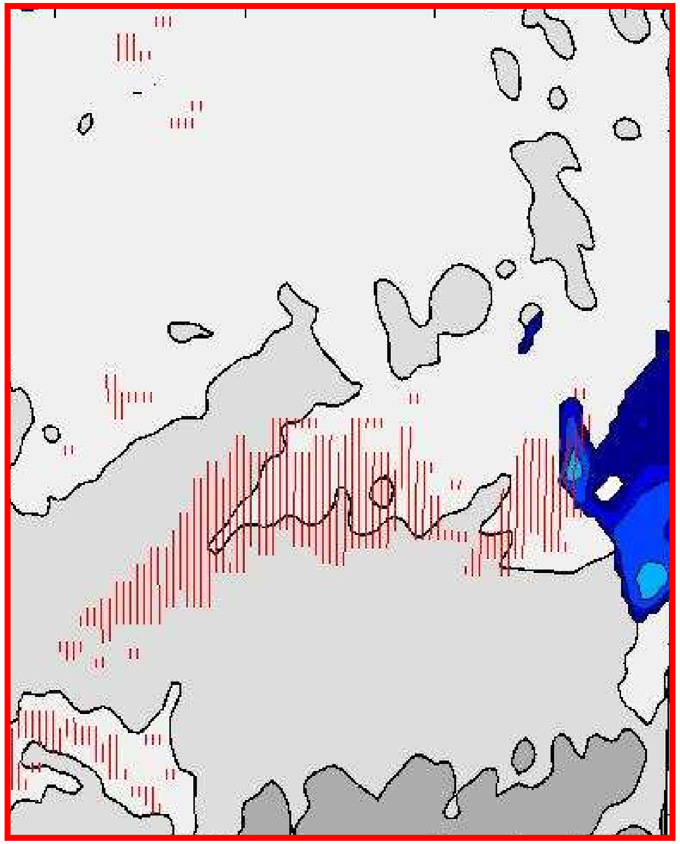
Zürich- 11 October 12UTC-24hours

12th October 2005-06:30UTC

TKVH min = 0.001



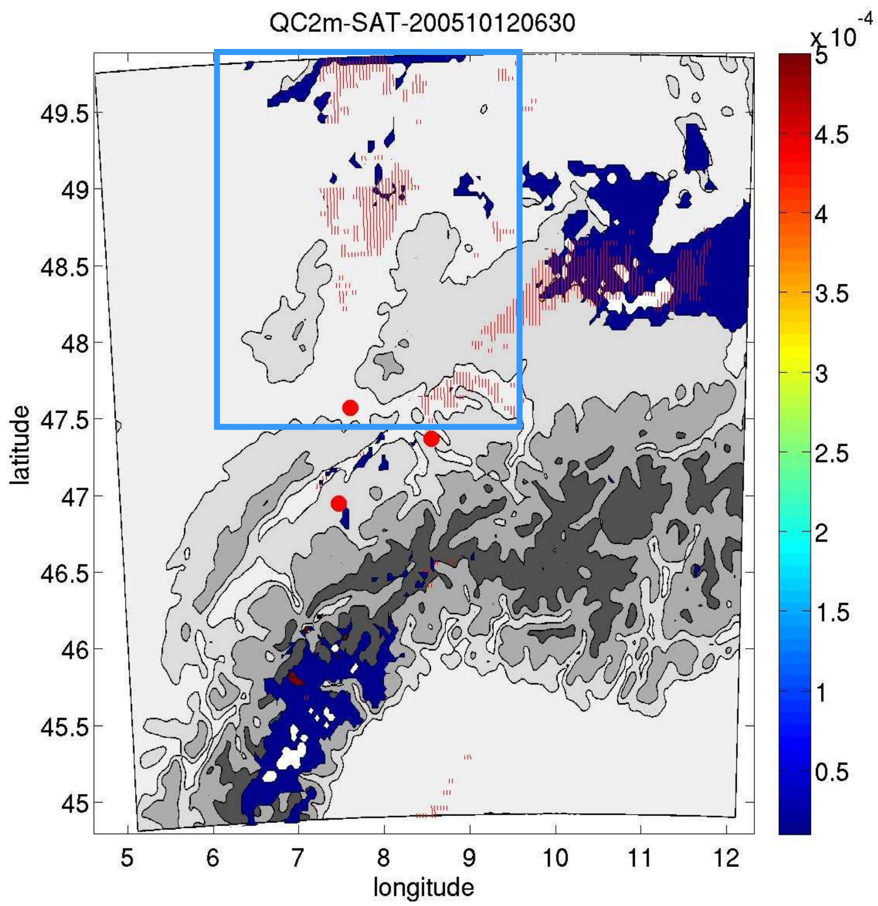
TKVH min = 0.7



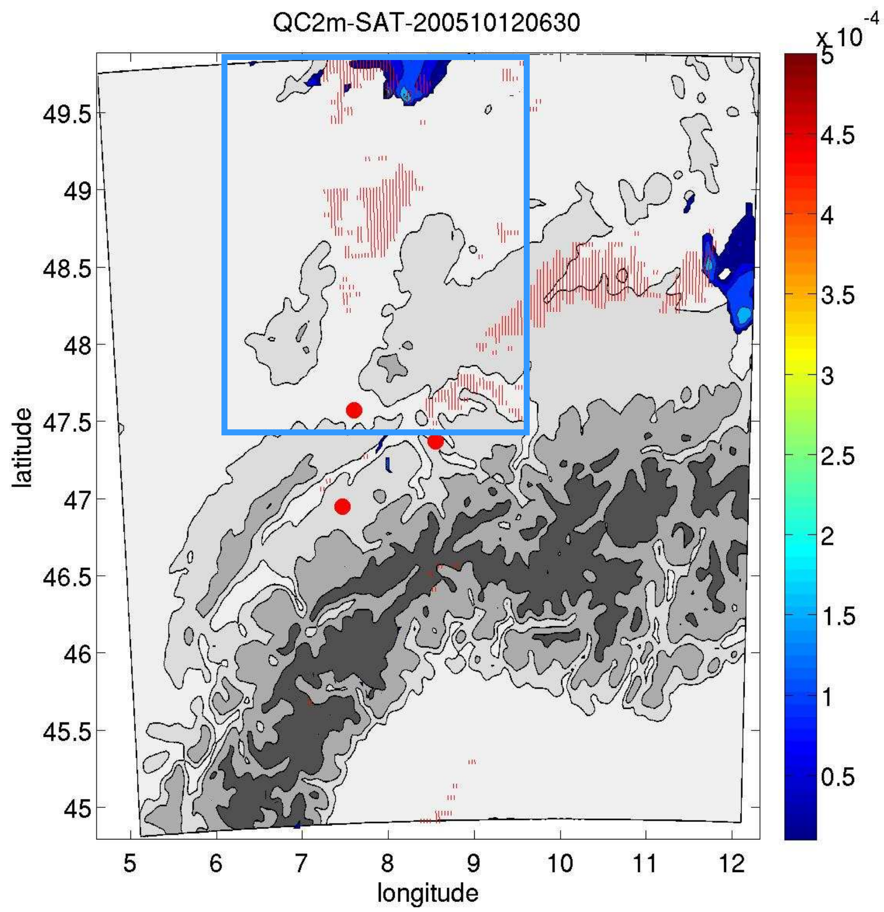
Zürich- 11 October 12UTC-24hours

12th October 2005-06:30UTC

TKVH min = 0.001



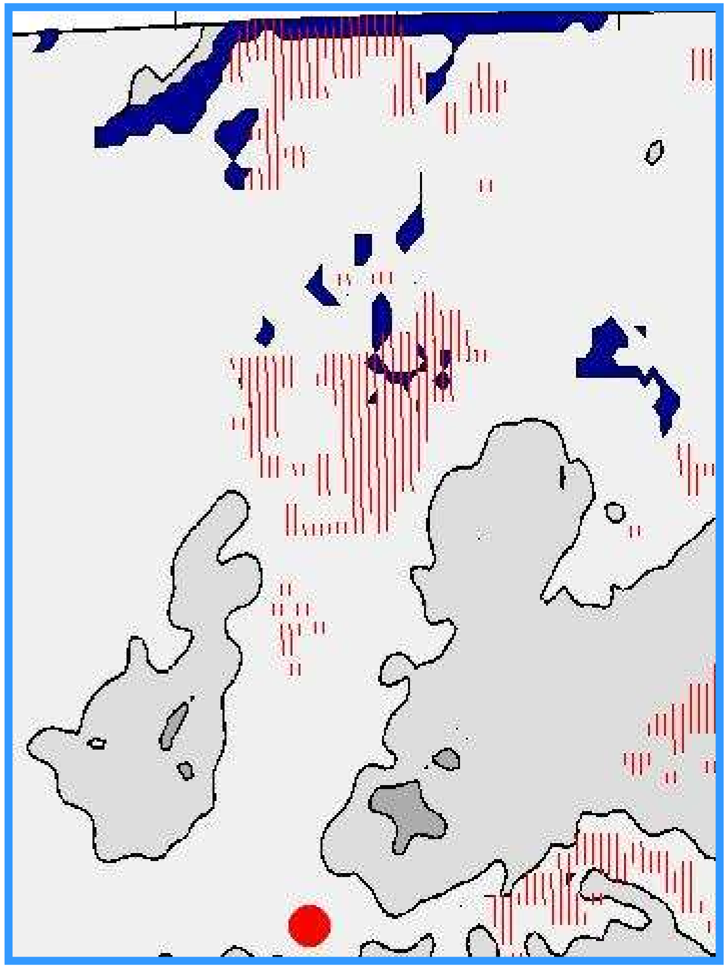
TKVH min = 0.7



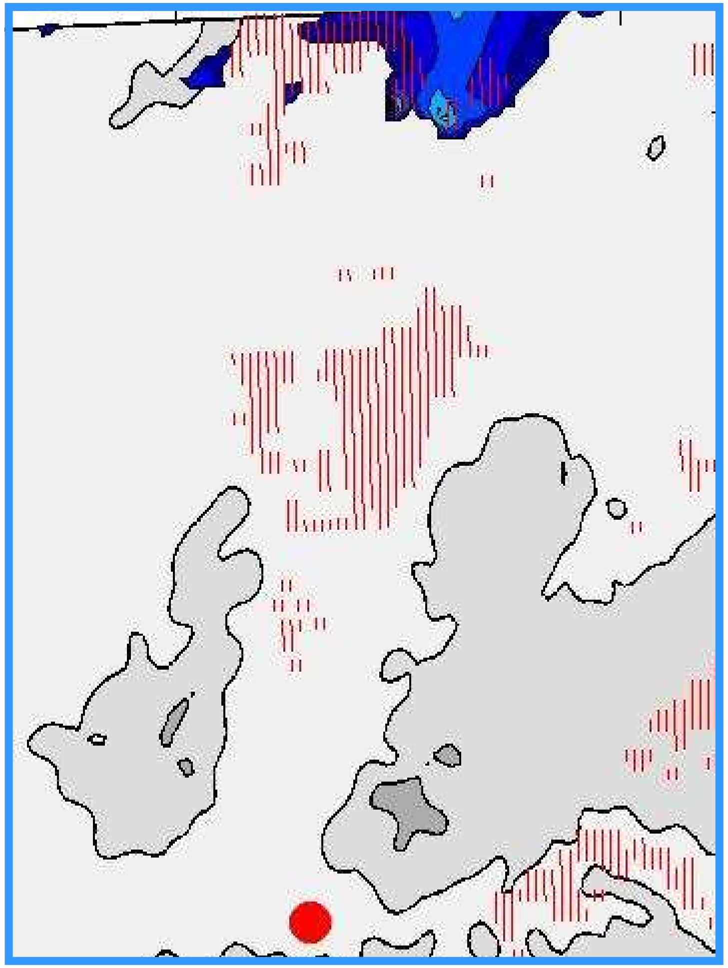
Zürich- 11 October 12UTC-24hours

12th October 2005-06:30UTC

TKVH min = 0.001



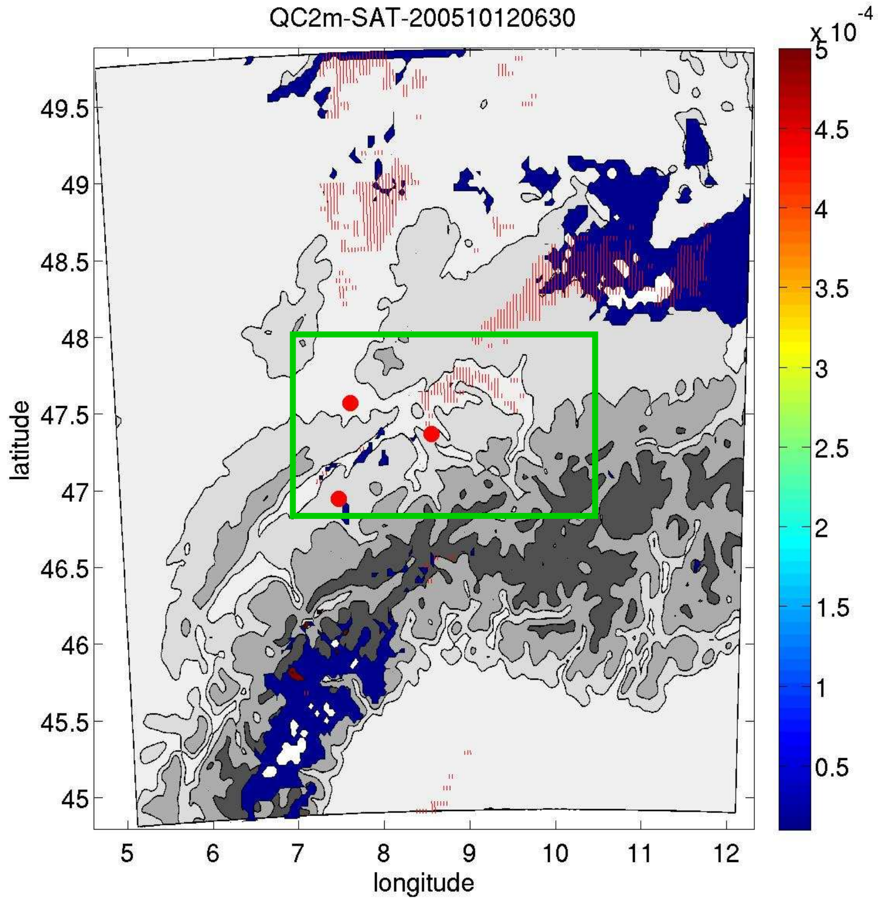
TKVH min = 0.7



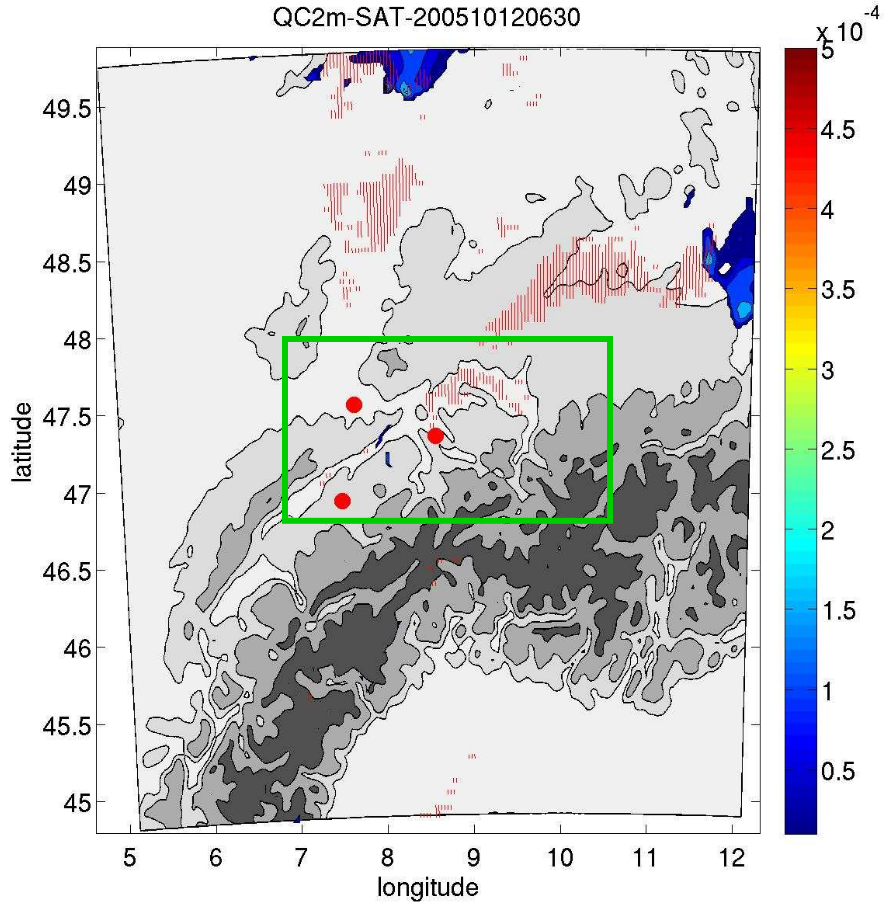
Zürich- 11 October 12UTC-24hours

12th October 2005-06:30UTC

TKVH min = 0.001



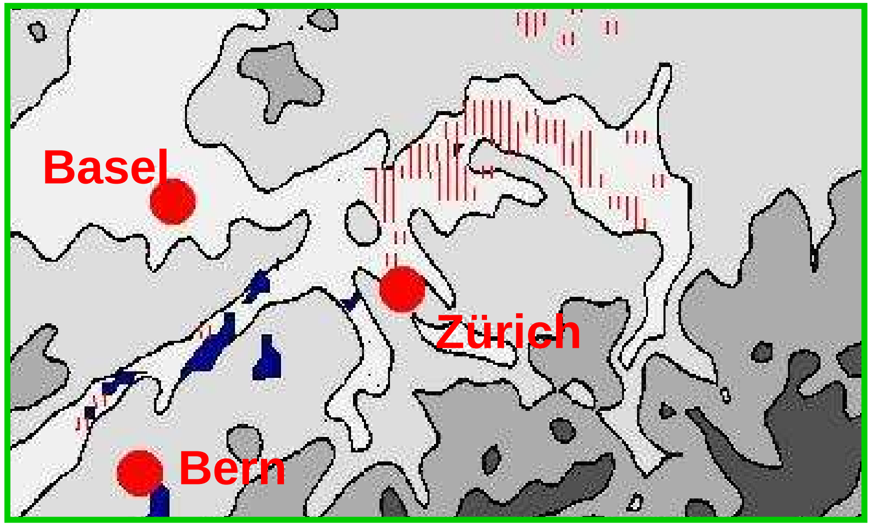
TKVH min = 0.7



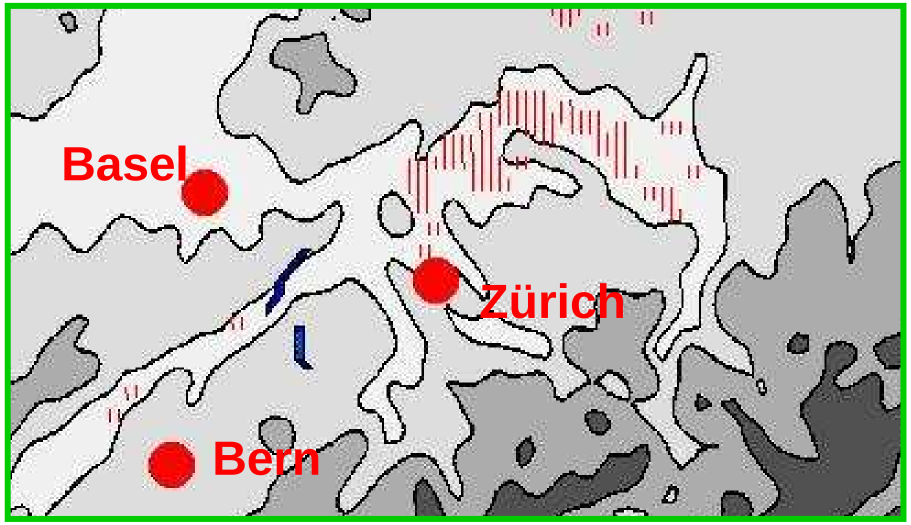
Zürich- 11 October 12UTC-24hours

12th October 2005-06:30UTC

TKVH min = 0.001



TKVH min = 0.7



CONCLUSION

- COSMO-FOG = 3D COSMO + PAFOG
- Implementation of new turbulent diffusion scheme
- Turbulent Scheme very sensitive of TKVH min value
- Low Sensitivity to the soil moisture
- Forecasted fog at 3 different terrains with same setup

Outlook

- Sensitivity study of mixing length
- Sensitivity study of microphysic parameters
- longer verification period