Retrieval scheme from MAX-DOAS O_4 observations

MAX-PLANCK-GESELLSCHAFT

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- Retrieval without a-priori assumptions?
- Observational results and radiative transfer simulations

Information content of MAX-DOAS O_4 observations is limited

-e.g. for O_4 MAX-DOAS observations in the UV (360nm) there are less pieces of information than elevation angles (because the absorptions at different angles are correlated). Typical value for the UV: ~2 (?)

=> Aerosol profile information is limited, e.g.

-total aerosol optical depth

-aerosol layer height

-often in such cases, a-priori information is used (for example in optimal estimation retrieval schemes, see e.g. Rogers)

=> how much is final result influenced by the a-priori assumption?

-our aerosol retrieval scheme uses no a-priori assumptions.

=> we use a least squares approach

Information content of MAX-DOAS O_4 observations is limited

How can the information content be increased?

-use of other wavelengths

-analysis of other species (O_2, H_2O)

-analysis of the Ring effect

-analysis of the (relative) radiance (=> single scattering albedo)

-analysis of polarisation

-analysis of other azimuth angles (=> phase function)

Radiative transfer modelling

-Backward Monte-Carlo RTM McArTim (Deutschmann, 2009)

-Surface albedo: 5%

-surface altitude of measurement site

-pressure and temperature profiles from US stdandard atmosphere

-Greenblatt et al. O_4 cross section corrected by +15%

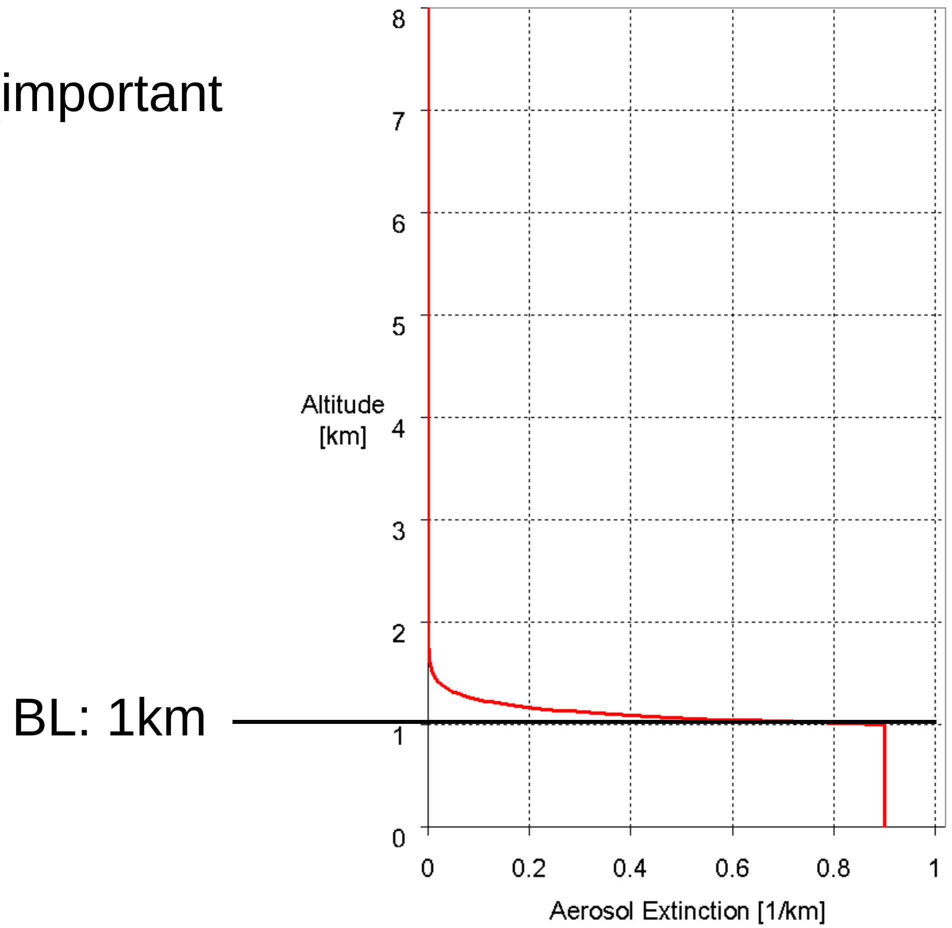
(Wagner et a., 2009)

Aerosol profiles are parametrised by 3 parameters:

(following the ideas of

Li, X., Brauers, T., Shao, M., Garland, R. M., Wagner, T., Deutschmann, T., and Wahner, A.: MAX-DOAS measurements in southern China: 1. automated aerosol profile retrieval using oxygen dimers absorptions, Atmos. Chem. Phys. Discuss., 8, 17661-17690, 2008)

A) boundary layer height (important atmospheric parameter)



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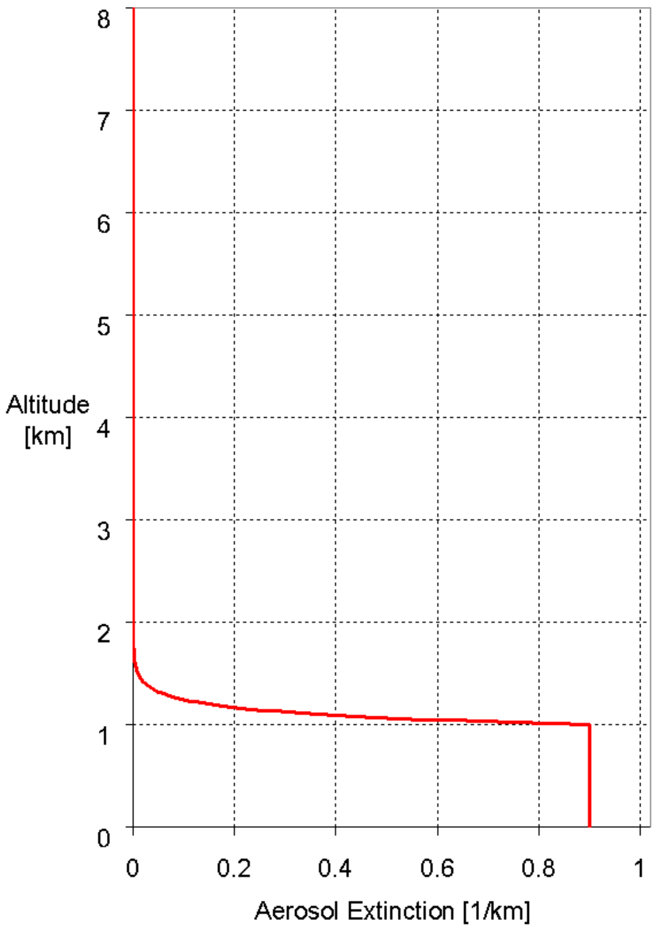
A) boundary layer height (important atmospheric parameter)

B) vertical optical depth (related to total aerosol amount) OD: 1.0



Aerosol profiles are parametrised by 3 parameters:

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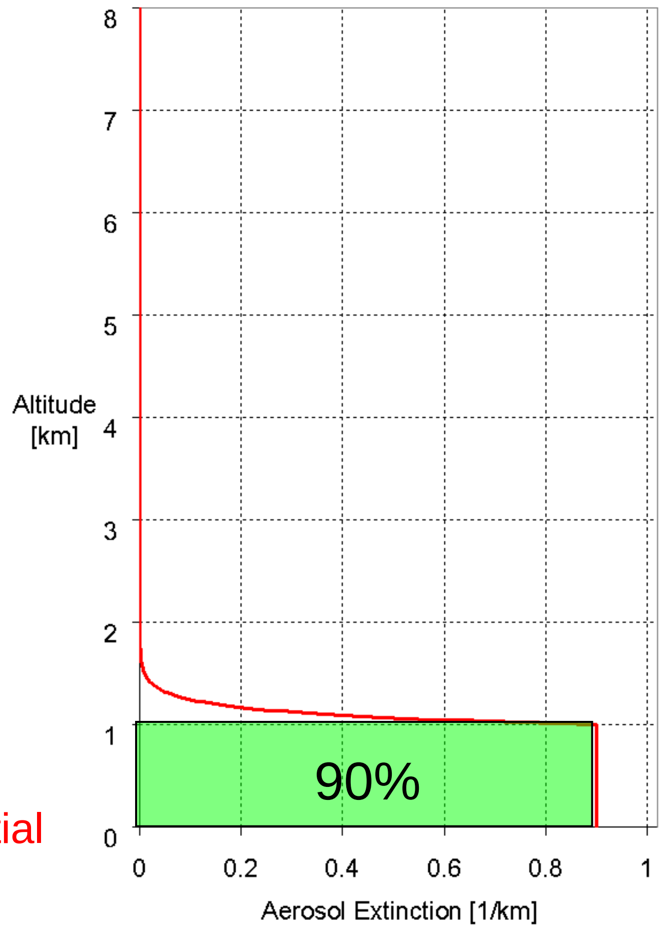
A) boundary layer height (important atmospheric parameter)

B) vertical optical depth (related to total aerosol amount)

C) fraction of total optical depth in boundary layer (allows to adjust vertical profile, depending e.g. on vertical mixing into free troposphere) f = 0.9



Extinction constant in BL, exponential above, partial profiles have similar values at top of BL height

Several parameters are fixed:

-single scattering albedo: 0.95

-asymmetry parameter: 0.68

-extinction profiles: constant in BL, exponential above, partial profiles have similar values at BL height

These parameters might also be fitted in the future if more quantities are measured:

-O4 at other wavelengths

-O4 at other azimuth angles

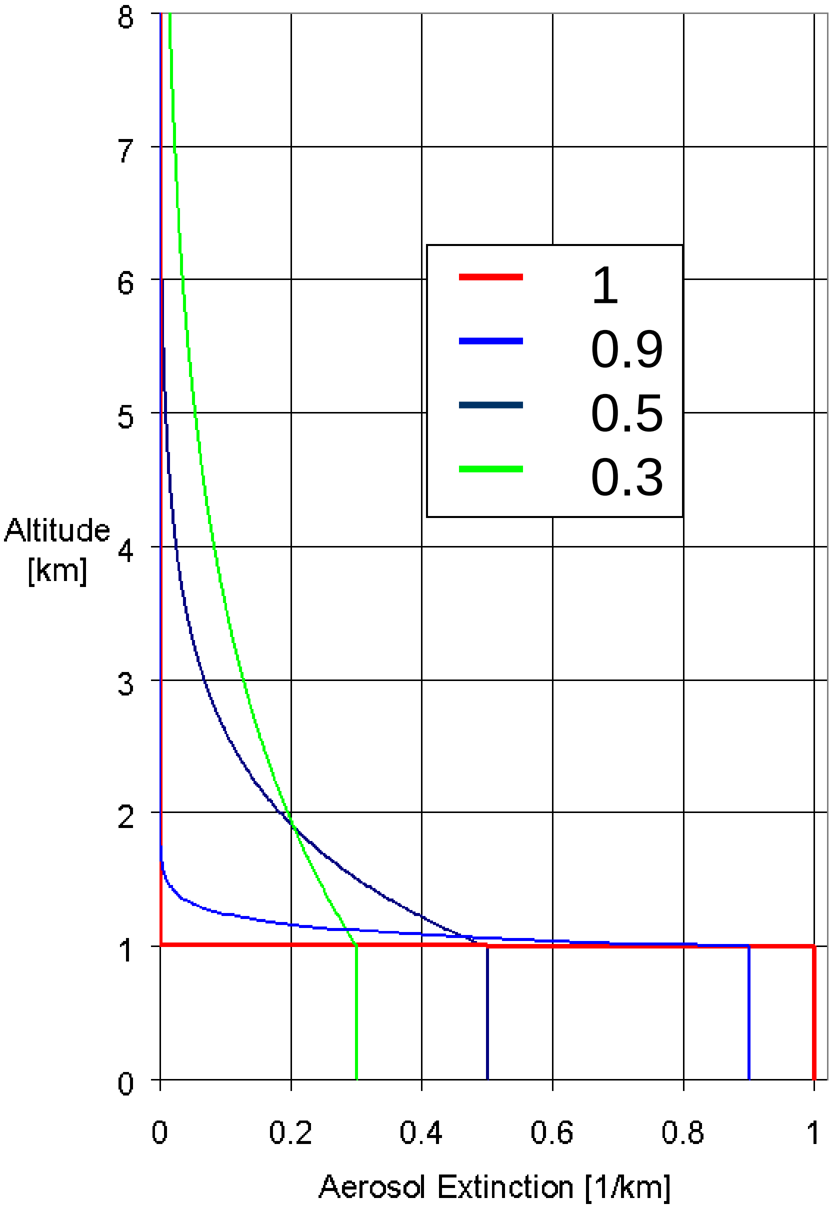
-(normalised) radiance

-Ring effect

constant τ: 1

constant BL: 1km

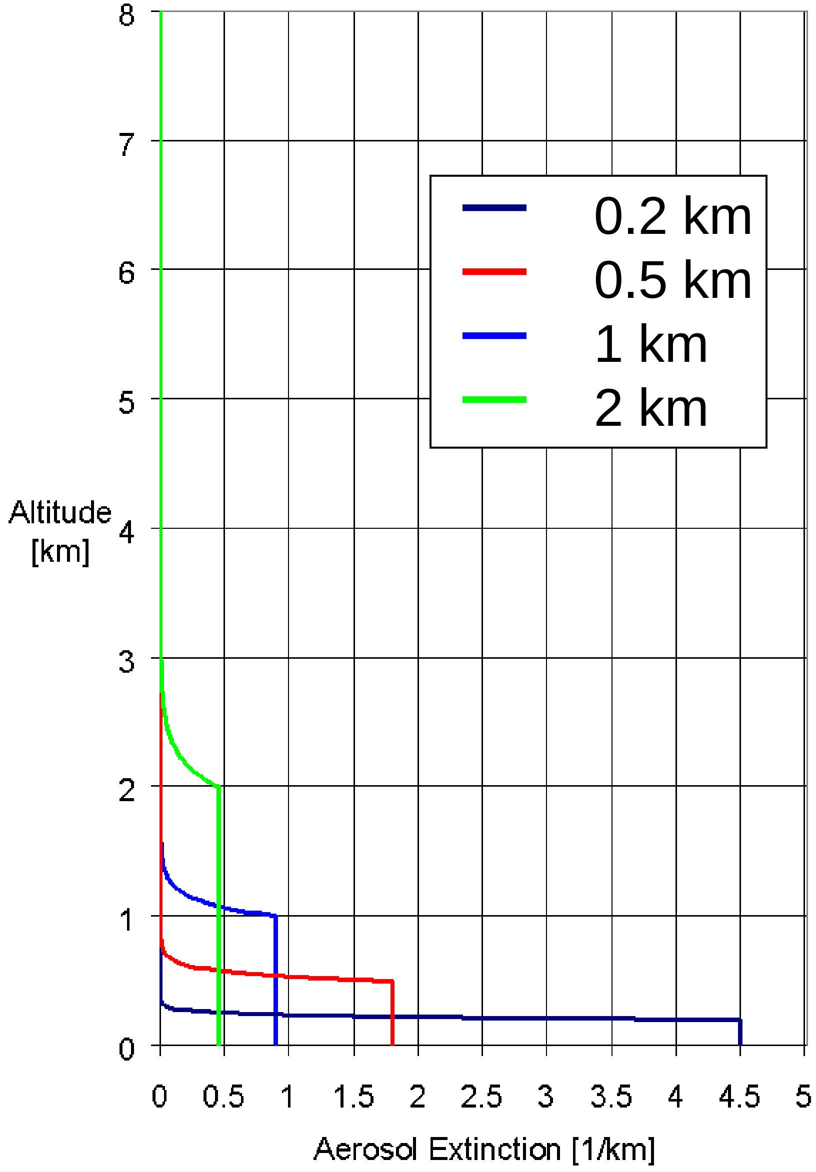
variable fraction f



constant τ: 1

variable BL

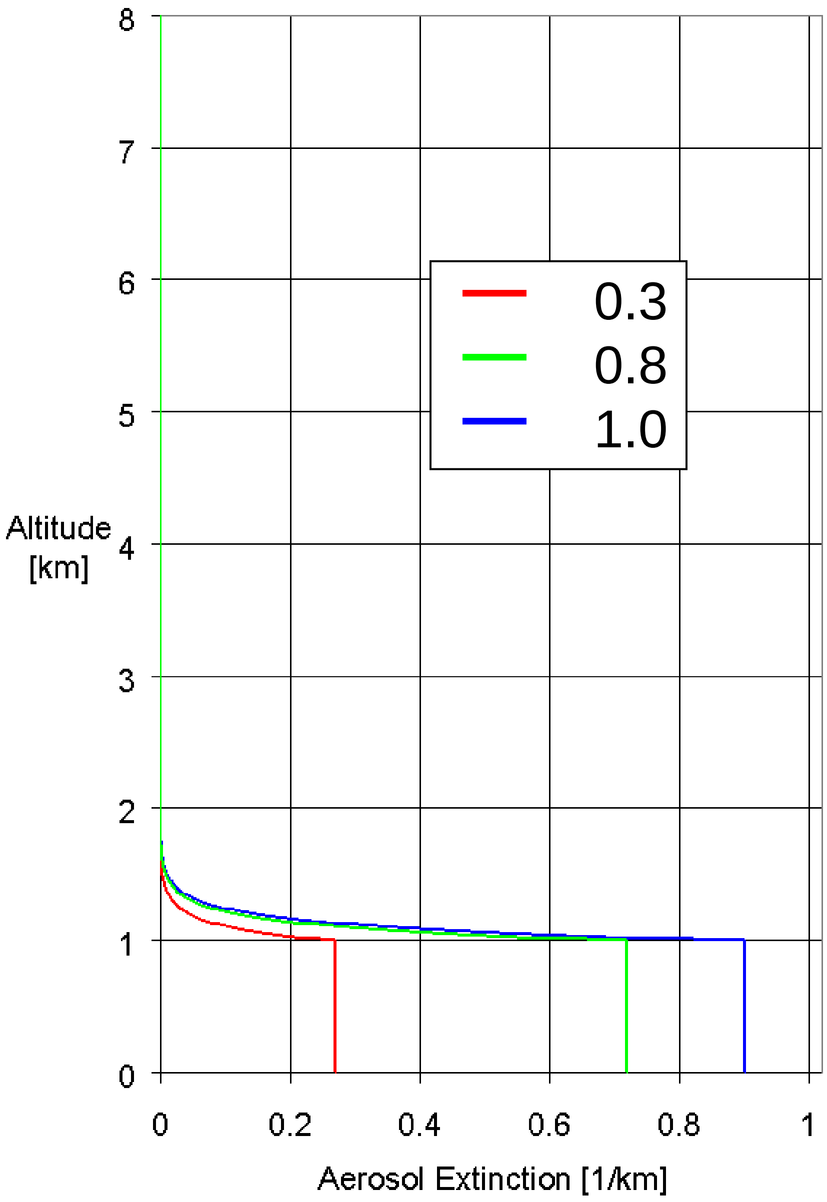
constant fraction f: 0.9



variable τ:

constant BL: 1km

constant fraction f: 0.9



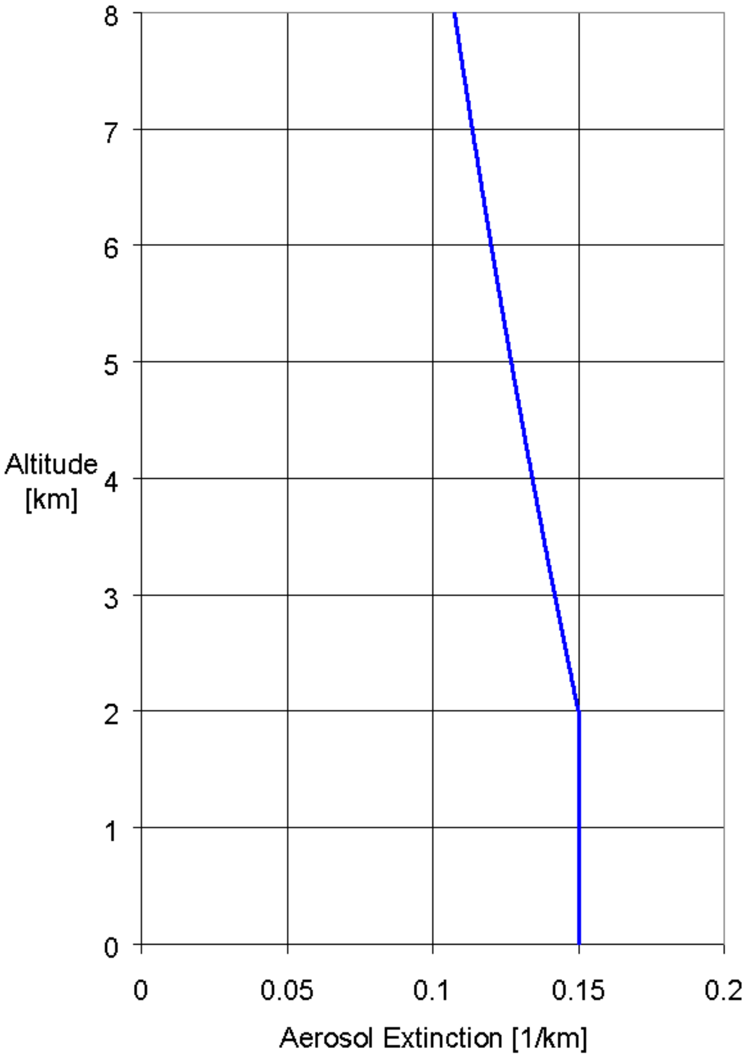
Some combination of parameters make (probably) no sense….

τ: 3

BL: 2km

fraction f: 0.1

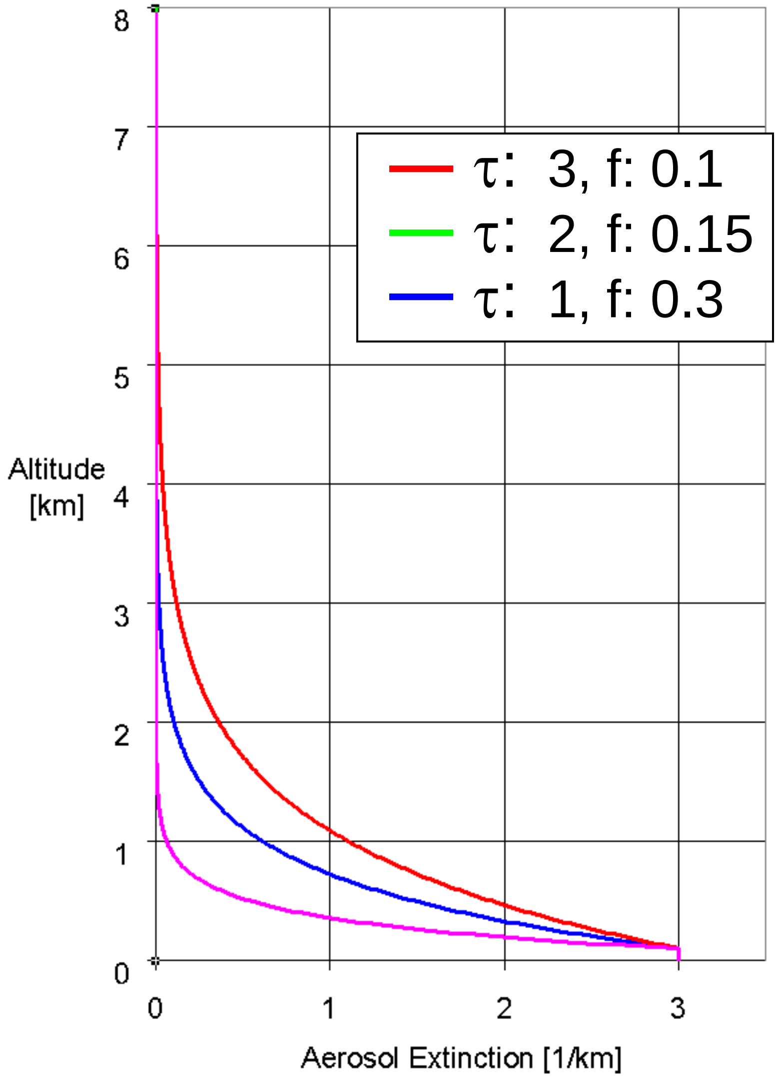
Especially high
BL and low f



Also quasi exponential BL extinction profiles can be described:

BL: 0.1 km

exponential decrease above 100m



In current version:

elevated layers or multi-layer aerosols can not be described by this parametrisation

Number of calculations:

BL (x 13): 100, 200, 300, 500, 700, 1000, 1200, 1500, 1750, 2000, 2500, 3000, 5000m

OD (x 10): 0.05, 0.1, 0.2, 0.3, 0.5, 0.7, 1.0, 1.5, 2.0, 3.0

f (x 7): 0.1, 0.2, 0.3, 0.4, 0.5, 0.7, 1.0

=> 13 x 10 x 7 = 910

=> 101 920 (for 8 elevation angles + 14 SZA / rel. Azimuth angles)

Parametrisation of NO_2 profiles in a similar way:

BL, f

However, no absolute tropospheric VCD is varied, because NO_2 AMF depends only on relative profile

Modelled AMF are compared (fitted) to the measured data in the following way:

measurements:

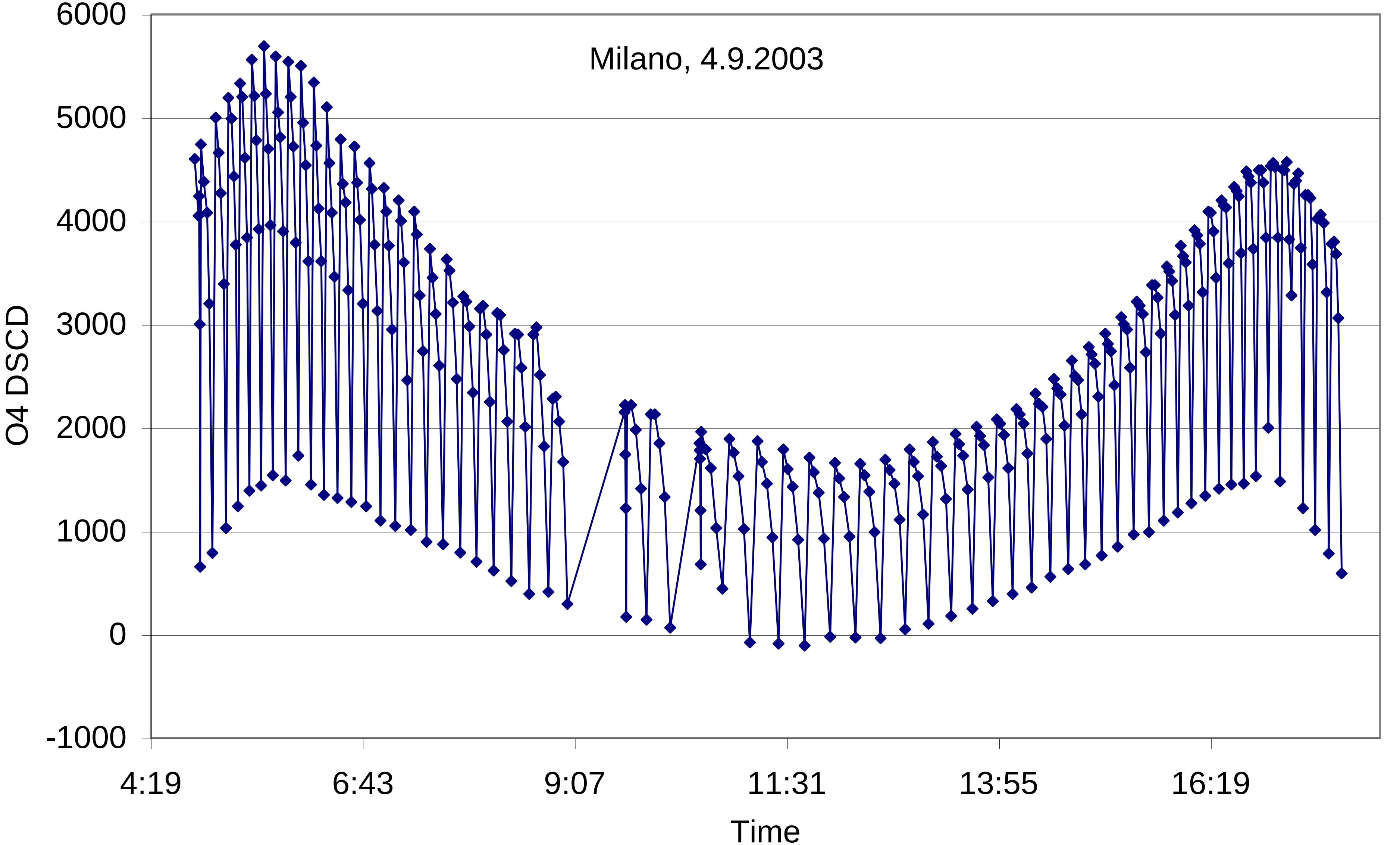
-O_4 DSCD for 90°is subtracted from values of each elevation sequence

-O_4 DSCDs are divided by O_4 VCD => O_4 DAMF

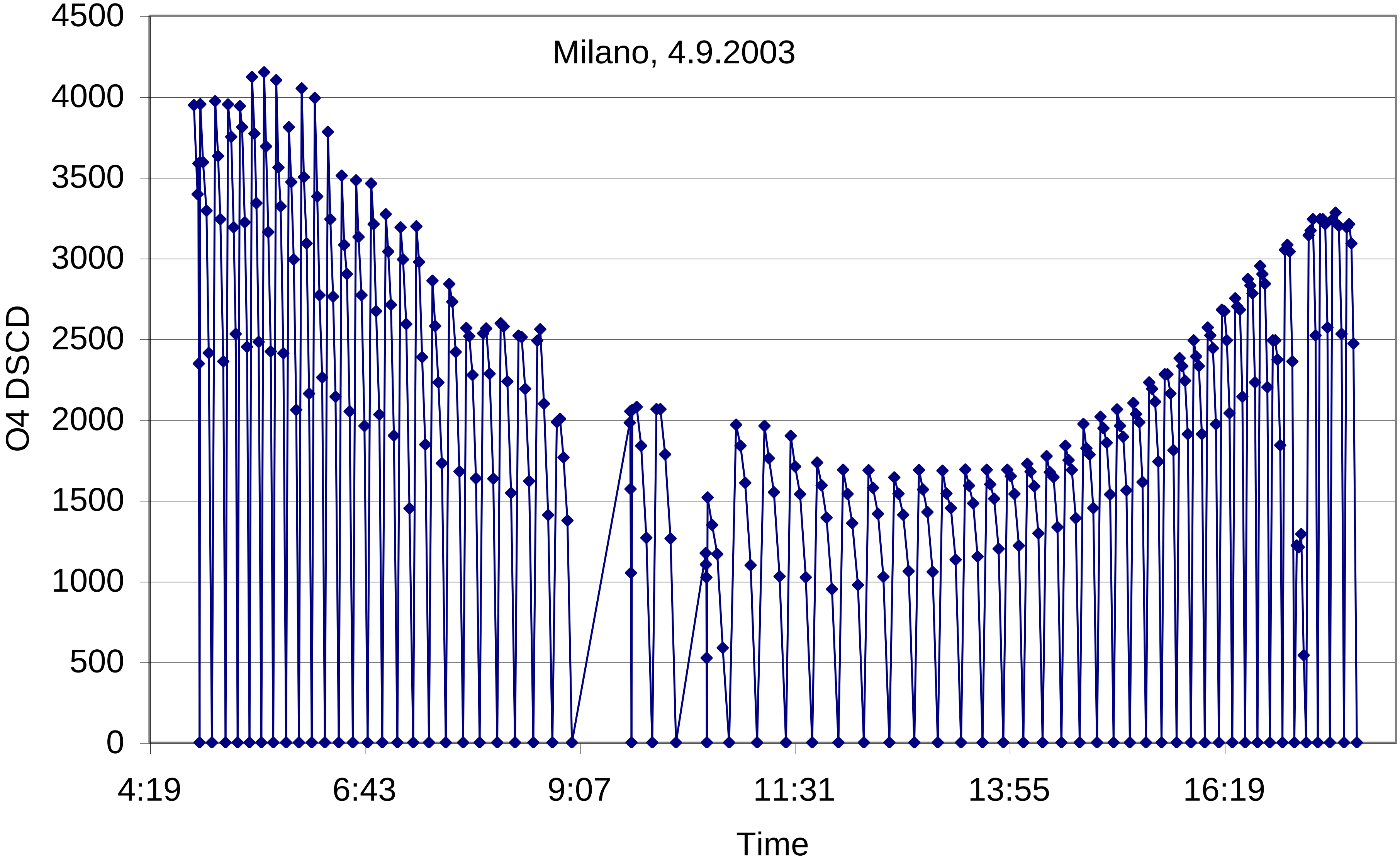
Model results:

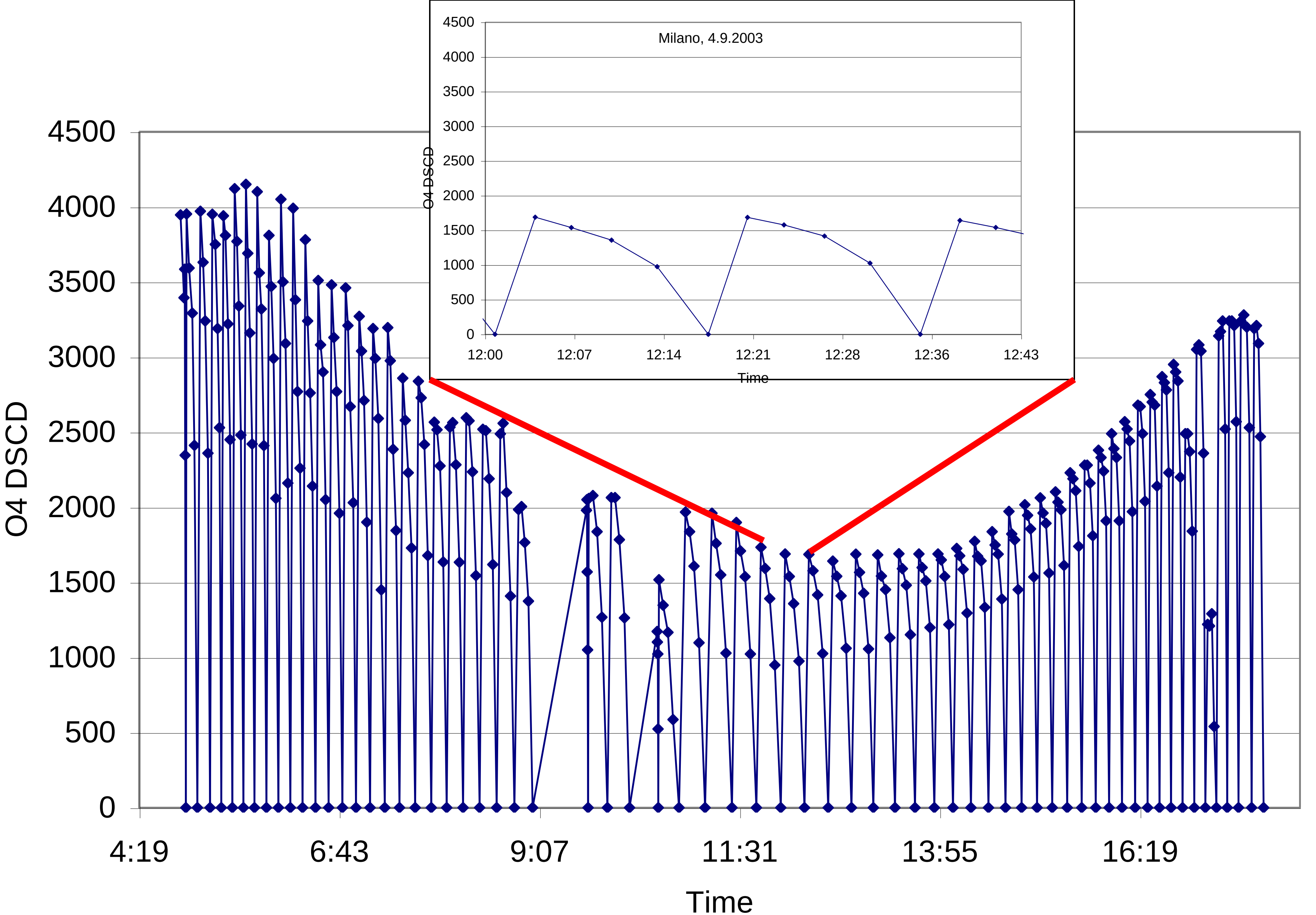
-O_4 AMF for 90°is subtracted from values of each elevation sequence => O_4 DAMF

Data are compared by least squares fit



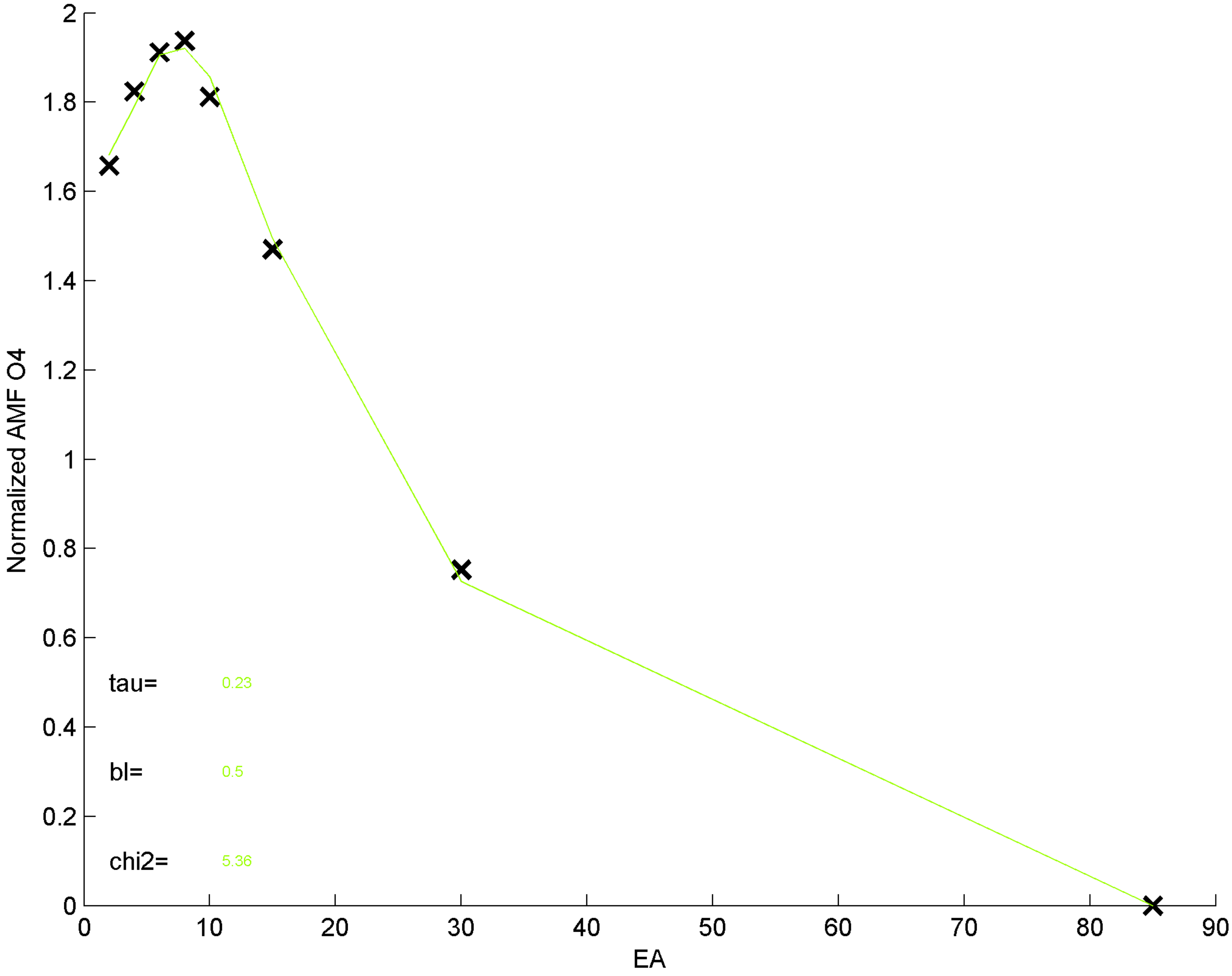
Milano, 4.9.2003
O4 DSCD
6000
5000
4000
3000
2000
1000
0
-1000
4:19
6:43
9:07
11:31
13:55
16:19
Time


Milano, 4.9.2003
O4 DSCD
Time
0
500
1000
1500
2000
2500
3000
3500
4000
4500
4:19
6:43
9:07
11:31
13:55
16:19

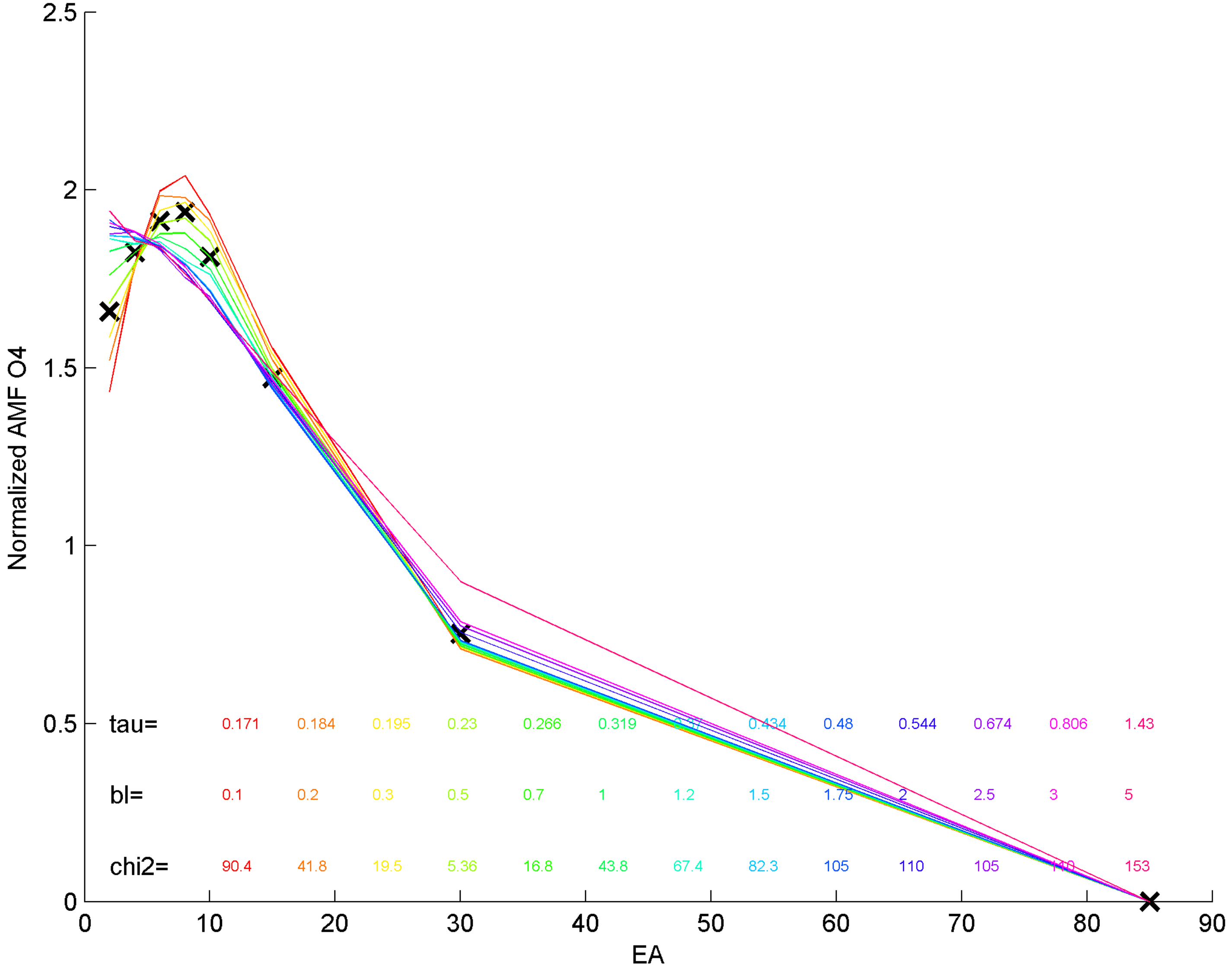


Milano, 4.9.2003
O4 DSCD
Time
4500
4000
3500
3000
2500
2000
1500
1000
500
0
12:00
12:07
12:14
12:21
12:28
12:36
12:43
4:19
6:43
9:07
11:31
13:55
16:19

Result of aerosol fit, Cabauw, 26.6. Sequence 6



Result of aerosol fit, Cabauw, 26.6. Sequence 6



Modelled AMF are compared (fitted) to the measured data in the following way:

Measurements:

- NO_2 DSCD for 90° subtracted from individual values of each elevation sequence

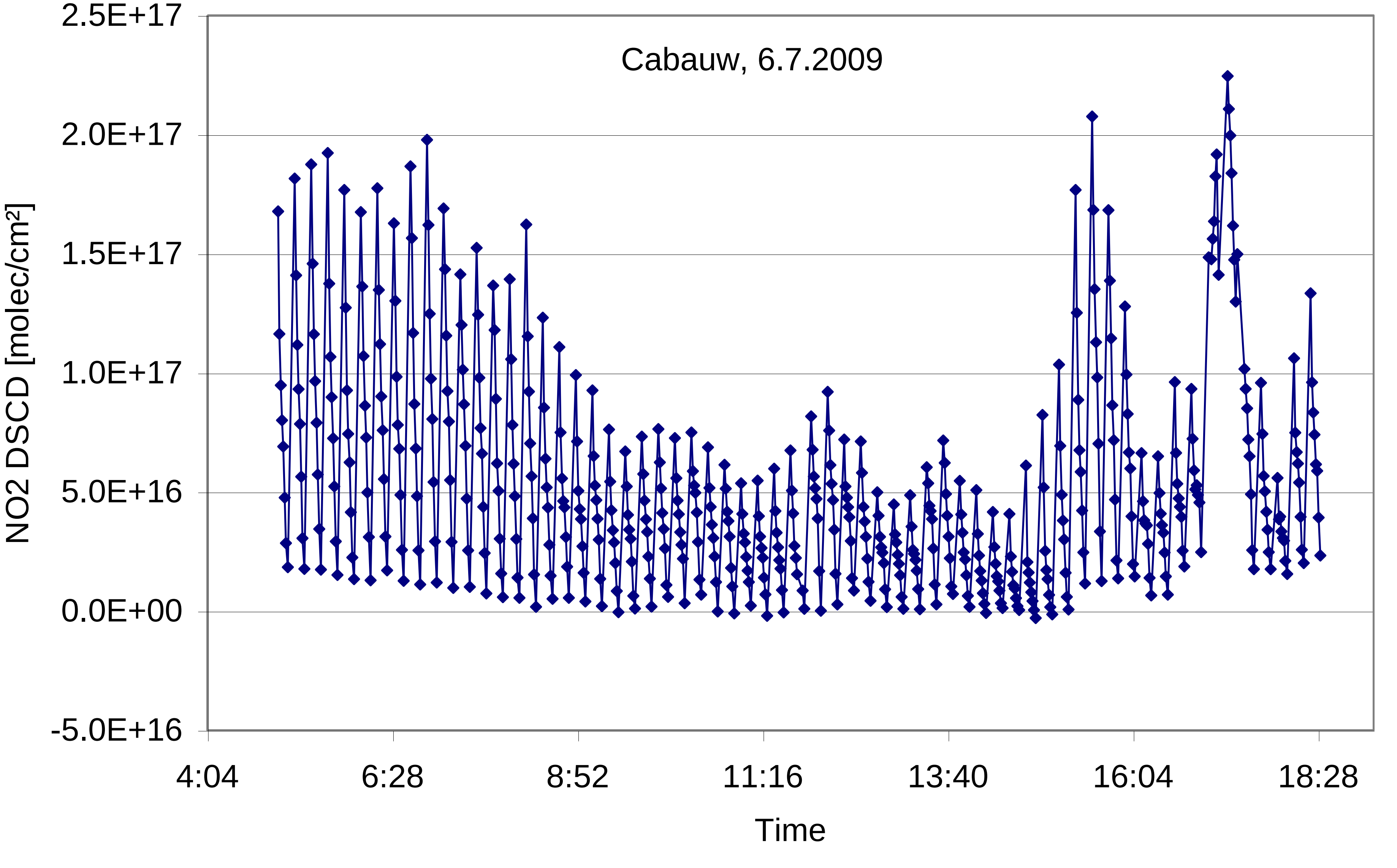
-DSCDs are divided by DSCD for 10°

Model results (calculated for specific aerosol scenario):

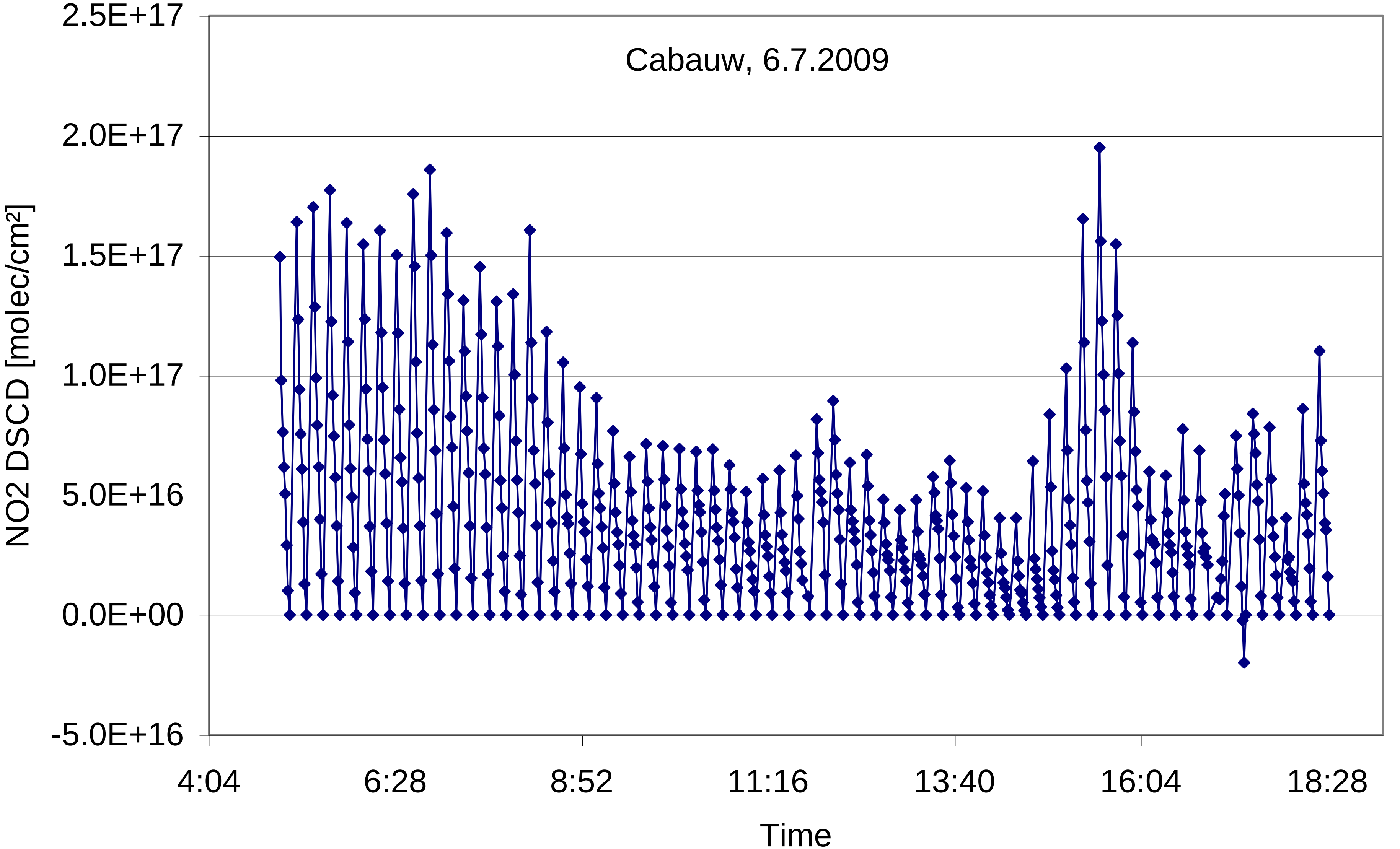
-NO_2 AMF for 90°is subtracted from values of each elevation sequence => NO_2 DAMF

-DAMFs are divided by DAMF for 10°

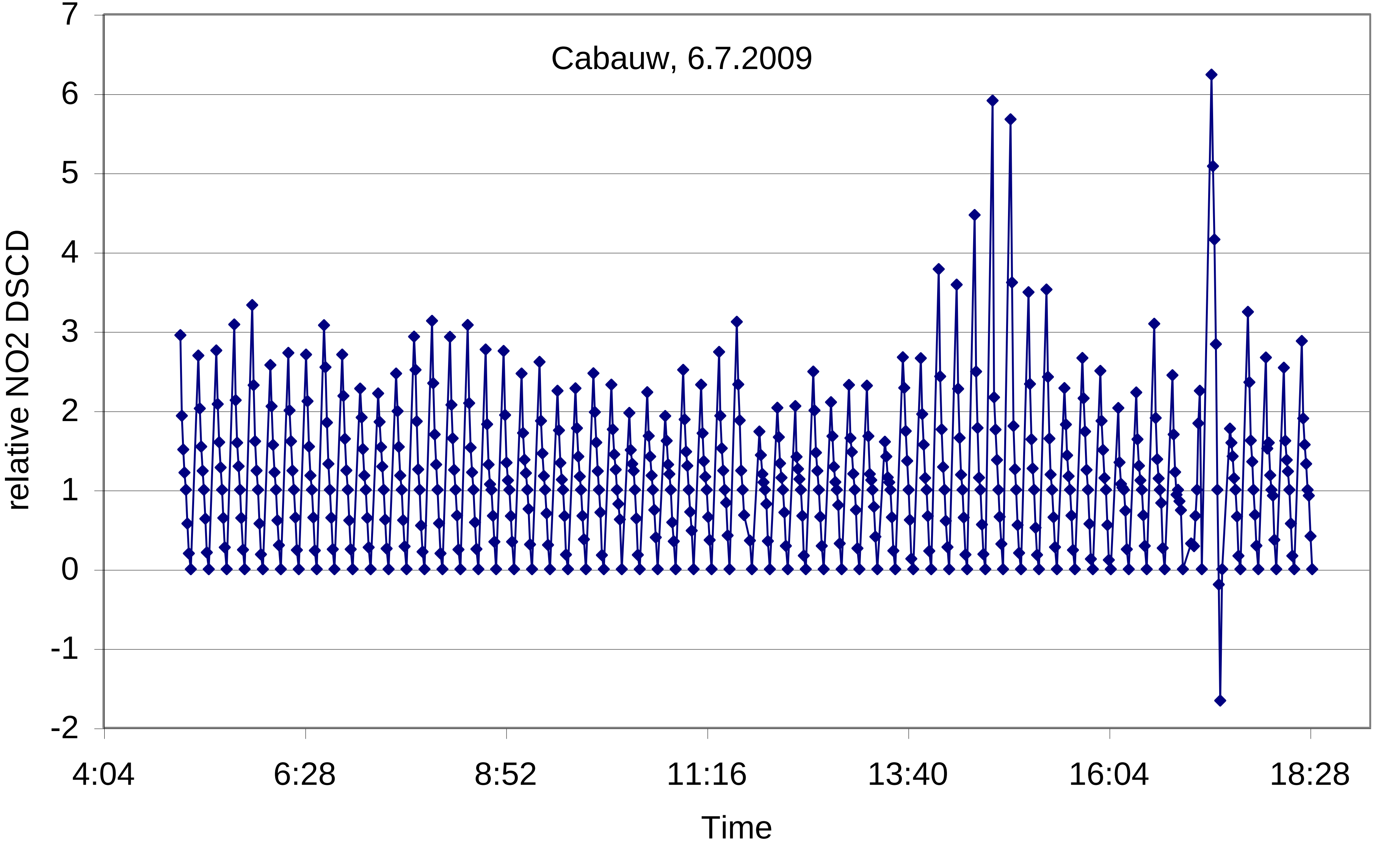
Data are compared by least squares fit



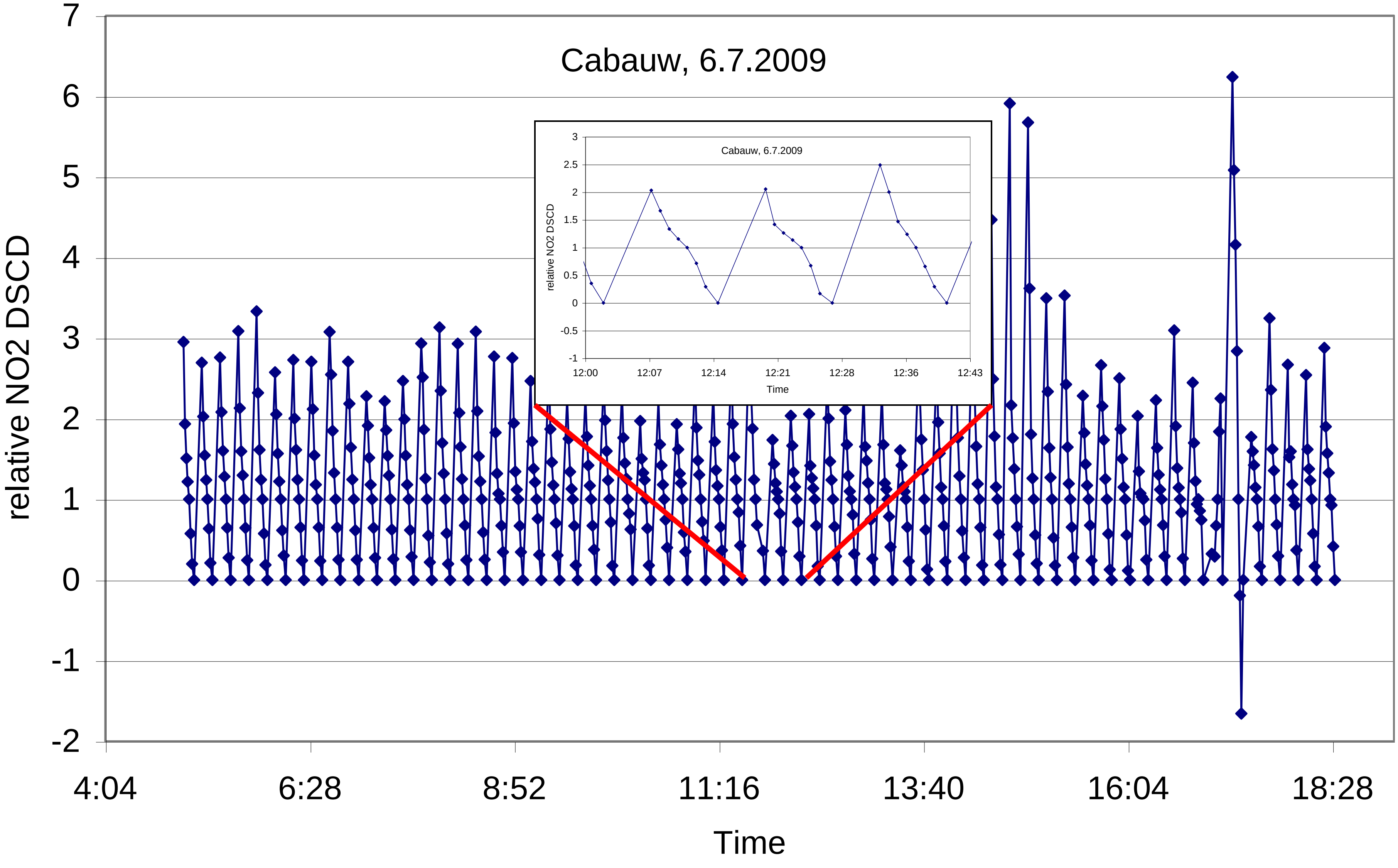
Cabauw, 6.7.2009
NO2 DSCD [molec/cm²]
2.5E+17
2.0E+17
1.5E+17
1.0E+17
5.0E+16
0.0E+00
-5.0E+16
4:04
6:28
8:52
11:16
13:40
16:04
18:28
Time



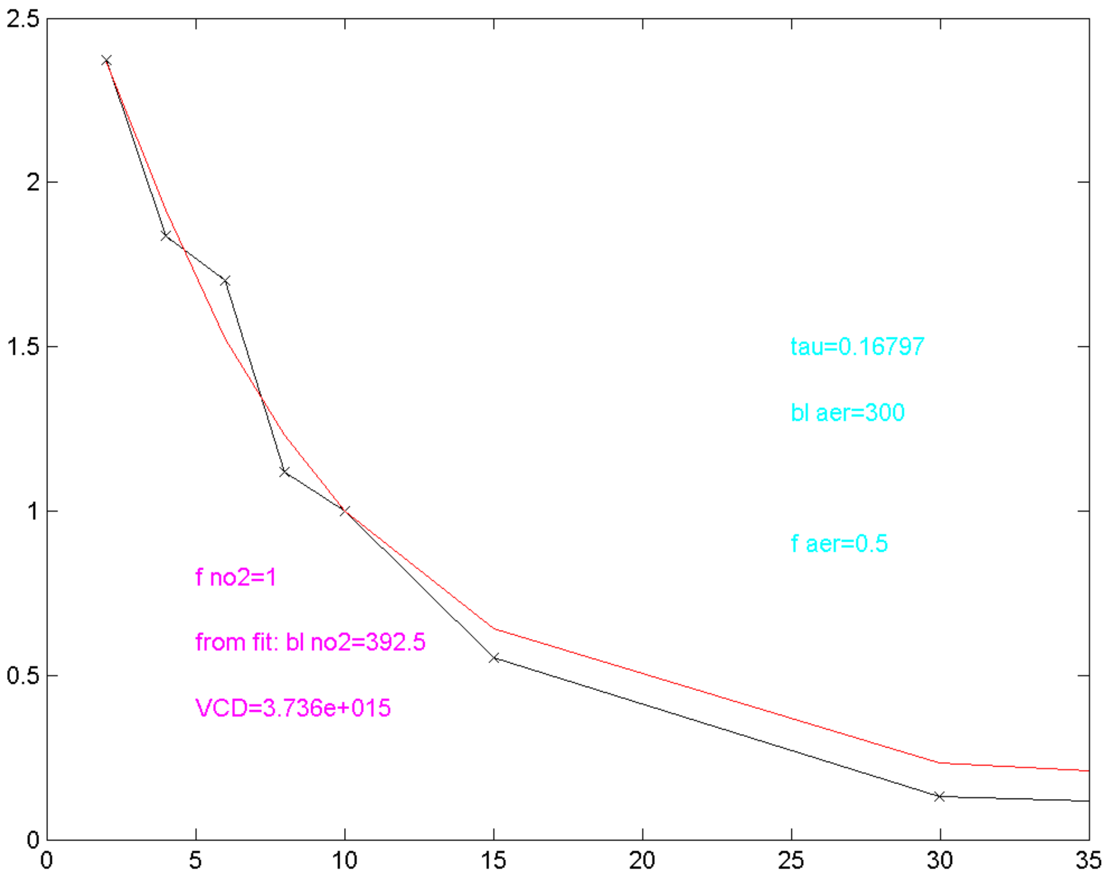
Cabauw, 6.7.2009
NO2 DSCD [molec/cm²]
2.5E+17
2.0E+17
1.5E+17
1.0E+17
5.0E+16
0.0E+00
-5.0E+16
4:04
6:28
8:52
11:16
13:40
16:04
18:28
Time



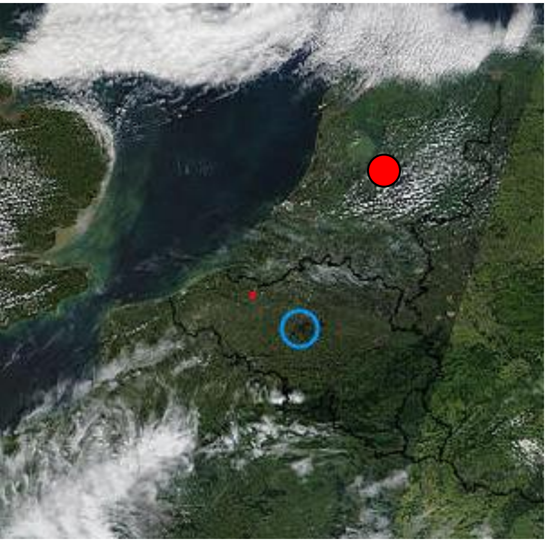
Cabauw, 6.7.2009
relative NO2 DSCD
7
6
5
4
3
2
1
0
-1
-2
4:04
6:28
8:52
11:16
13:40
16:04
18:28
Time

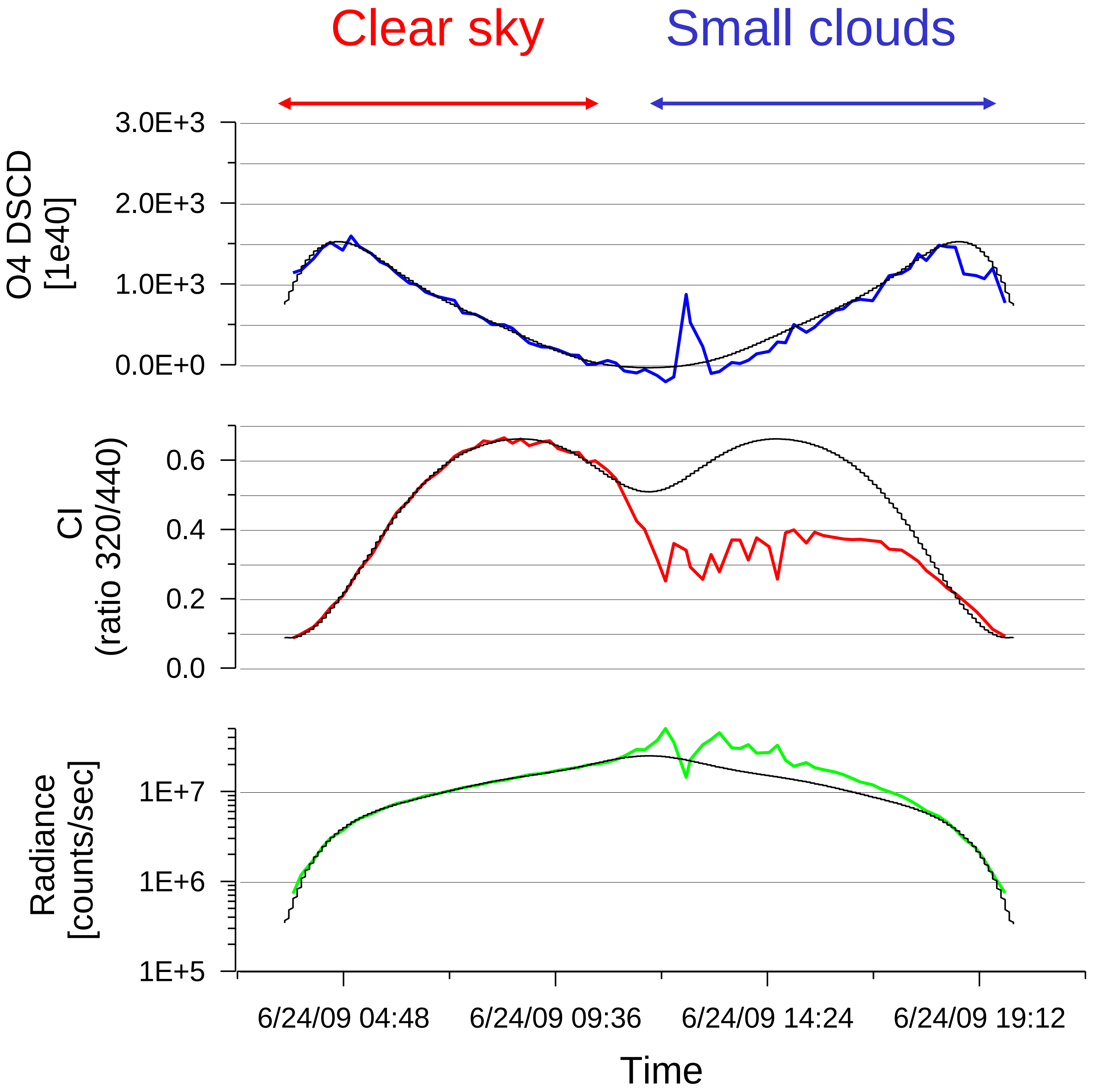

Cabauw, 6.7.2009
relative NO2 DSCD
Time
7
6
5
4
3
2
1
0
-1
-2
4:04
6:28
8:52
11:16
13:40
16:04
18:28
Cabauw, 6.7.2009
relative NO2 DSCD
Time
3
2.5
2
1.5
1
0.5
0
-0.5
-1
12:00
12:07
12:14
12:21
12:28
12:36
12:43

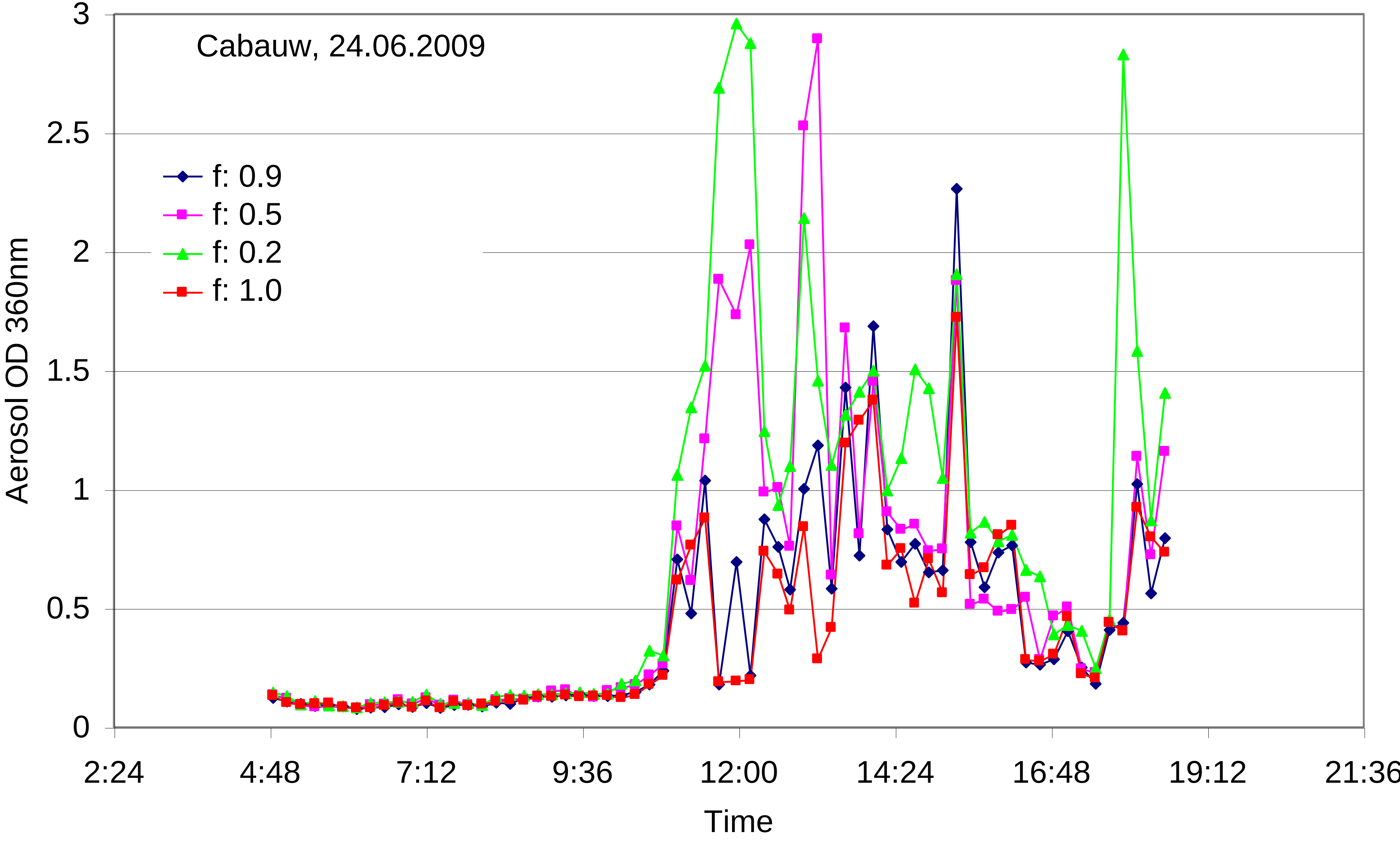
Result of NO2 fit, Cabauw, 26.6. Sequence 6



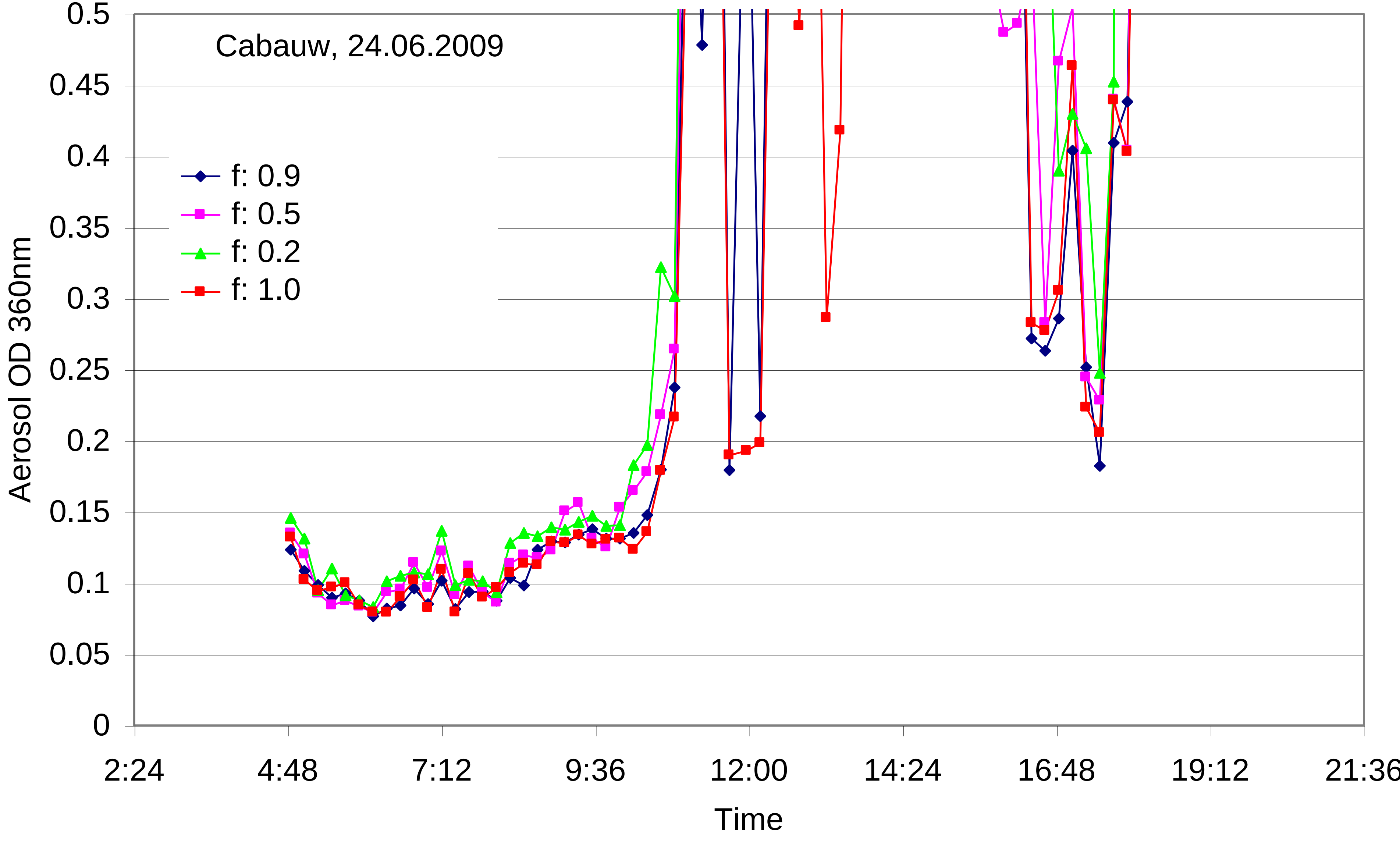
Cabauw, 24.06.2009



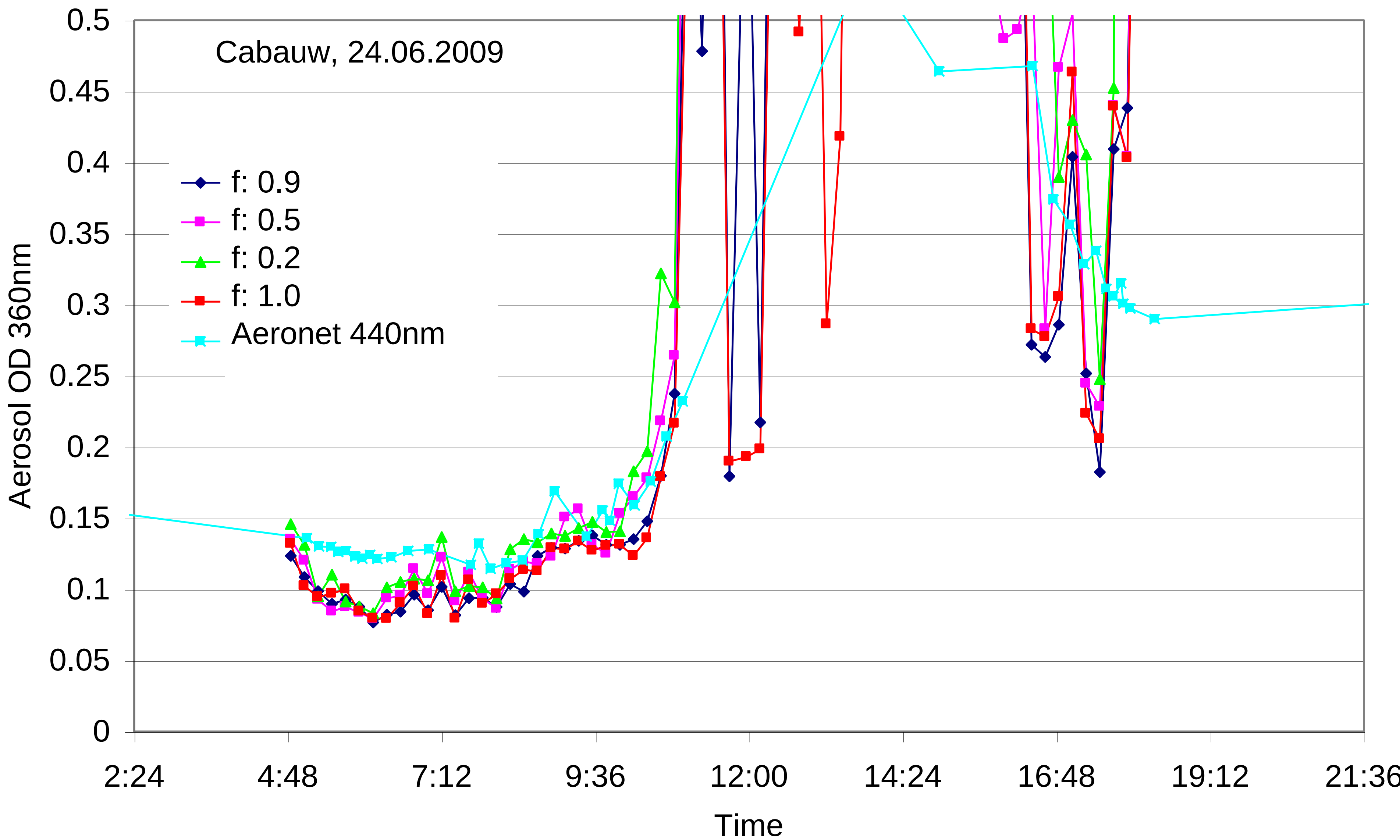


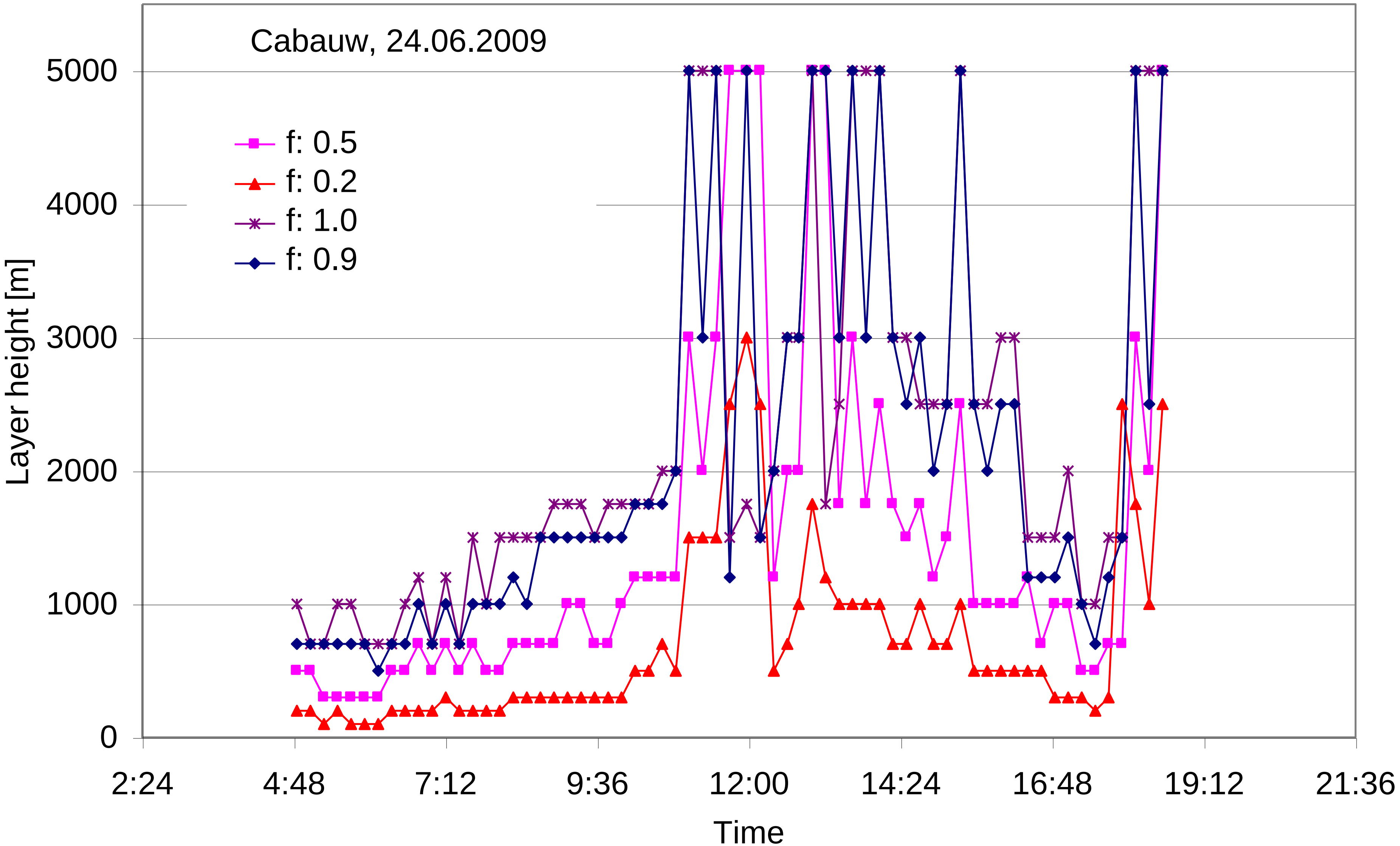


Cabauw, 24.06.2009
f: 0.9
f: 0.5
f: 0.2
f: 1.0
Aerosol OD 360nm
Time
0
0.5
1
1.5
2
2.5
3
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36

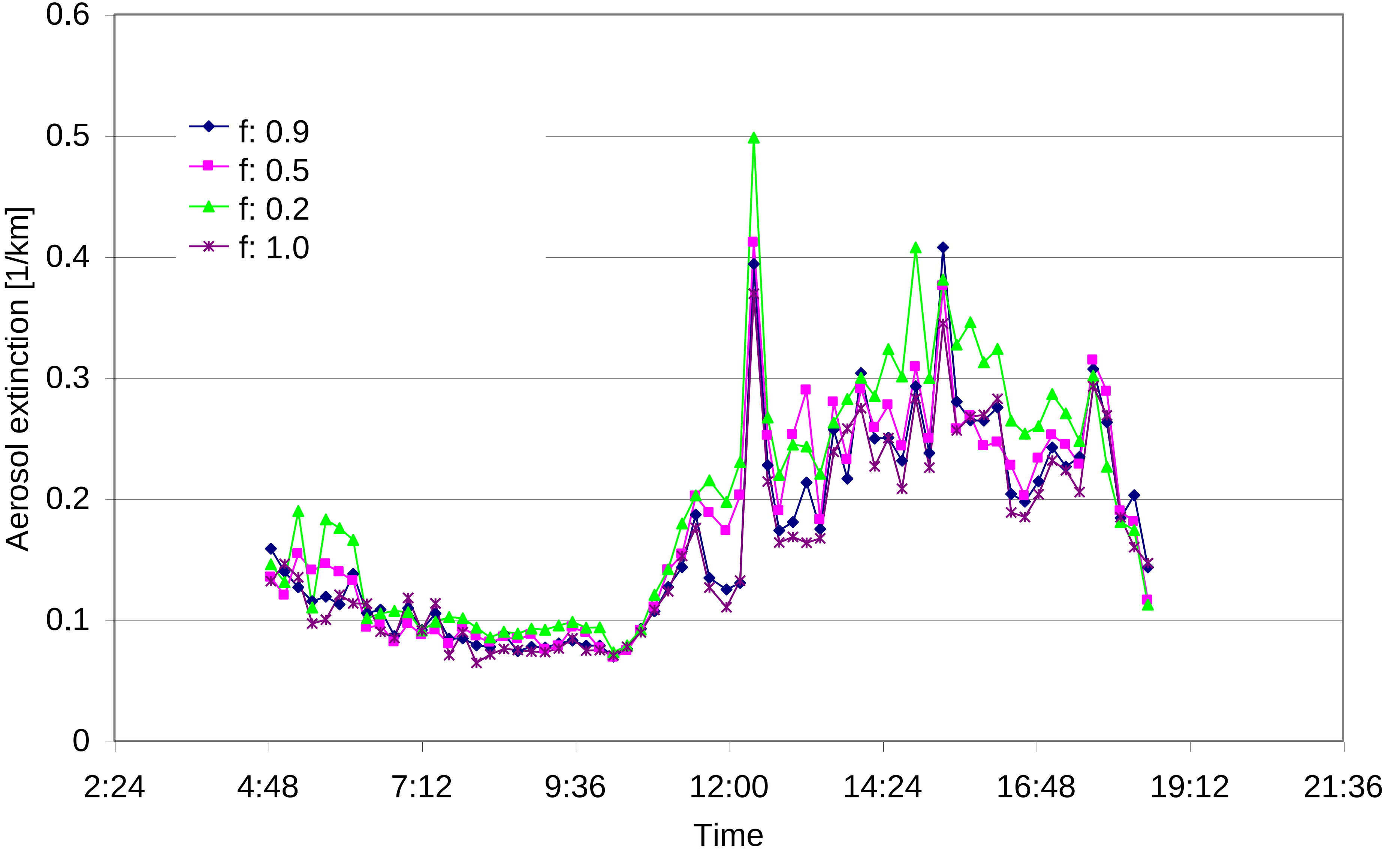


Cabauw, 24.06.2009
Aerosol OD 360nm
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
f: 0.9
f: 0.5
f: 0.2
f: 1.0
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time

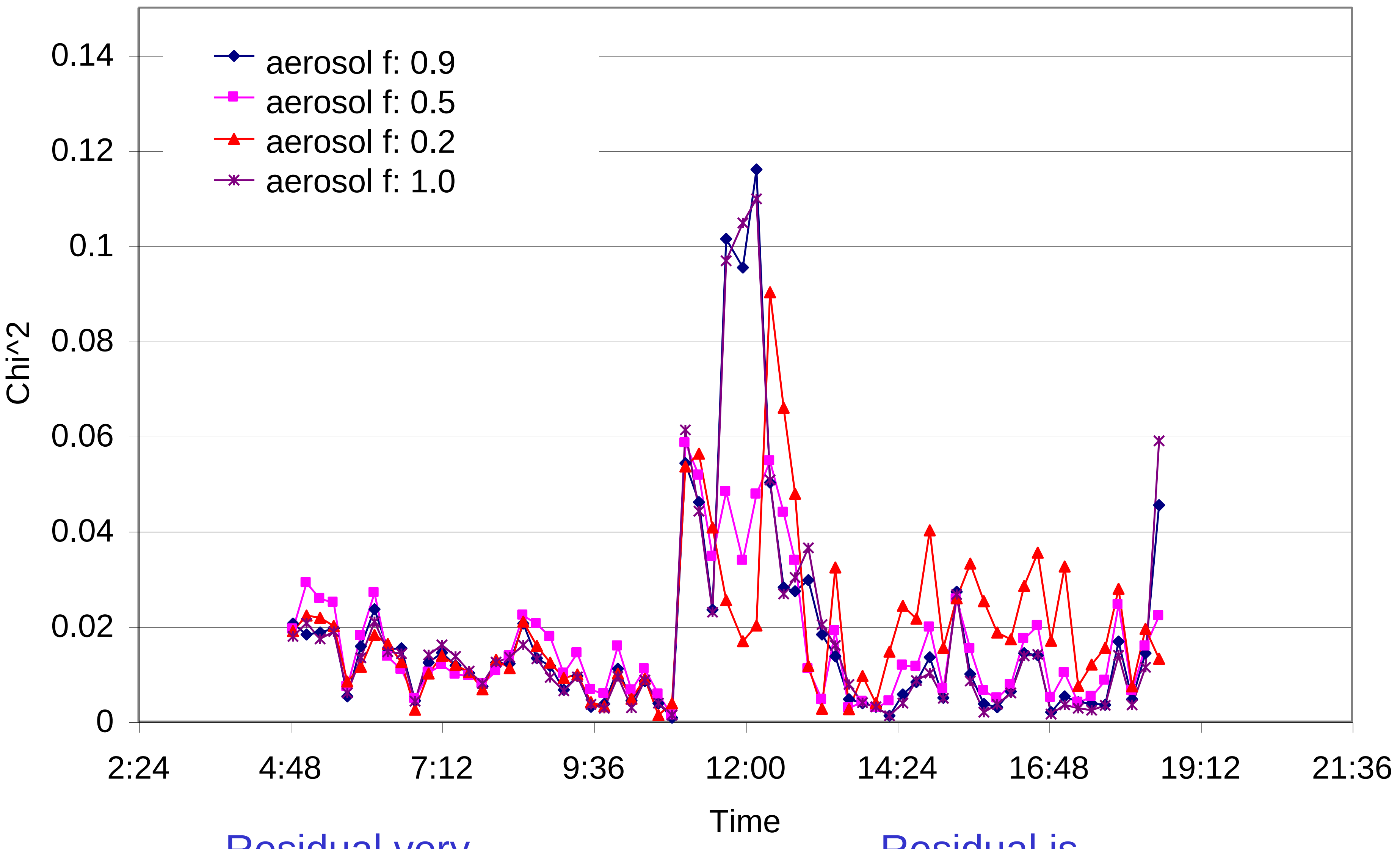

Cabauw, 24.06.2009
f: 0.9
f: 0.5
f: 0.2
f: 1.0
Aeronet 440nm
Aerosol OD 360nm
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time



Cabauw, 24.06.2009
f: 0.5
f: 0.2
f: 1.0
f: 0.9
Layer height [m]
0
1000
2000
3000
4000
5000
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time

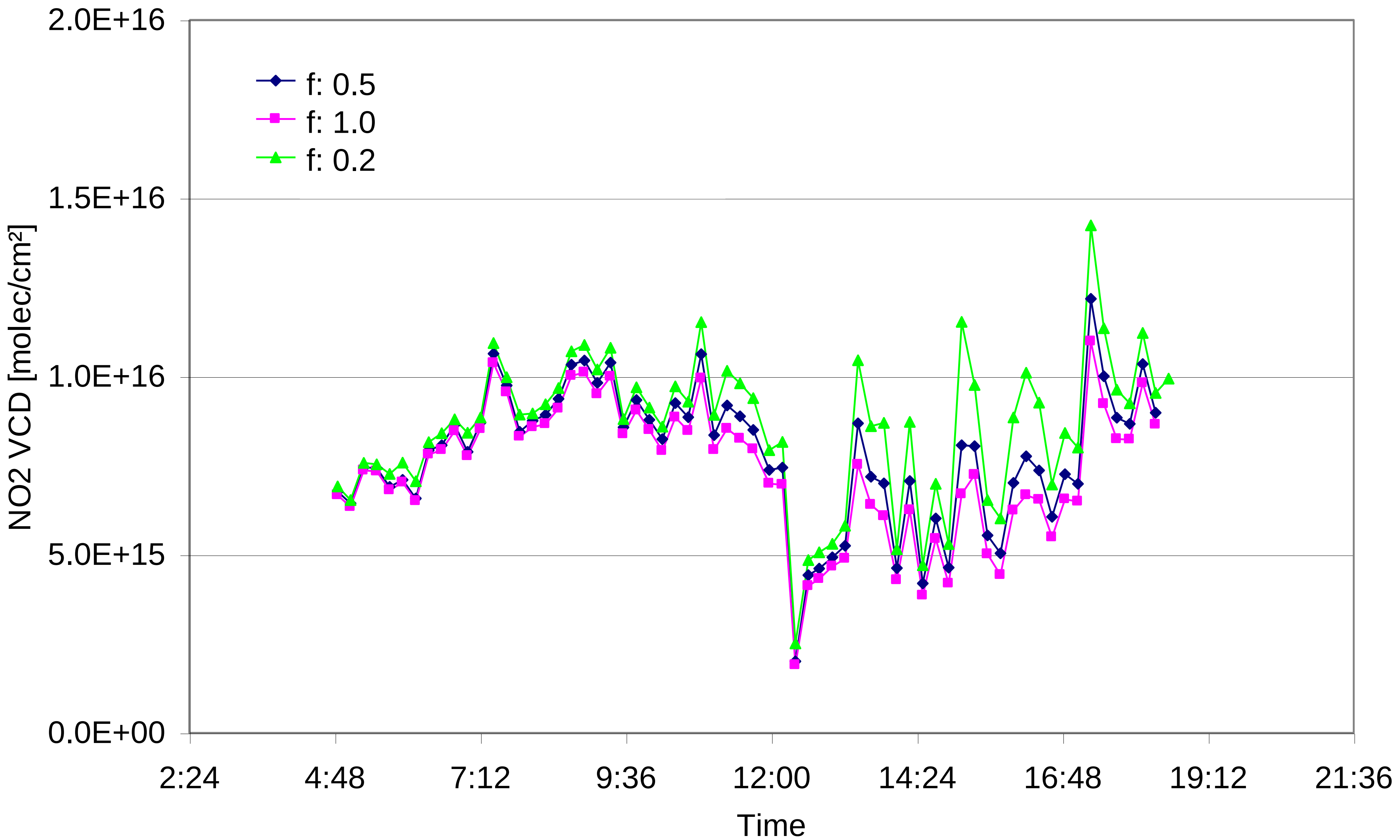


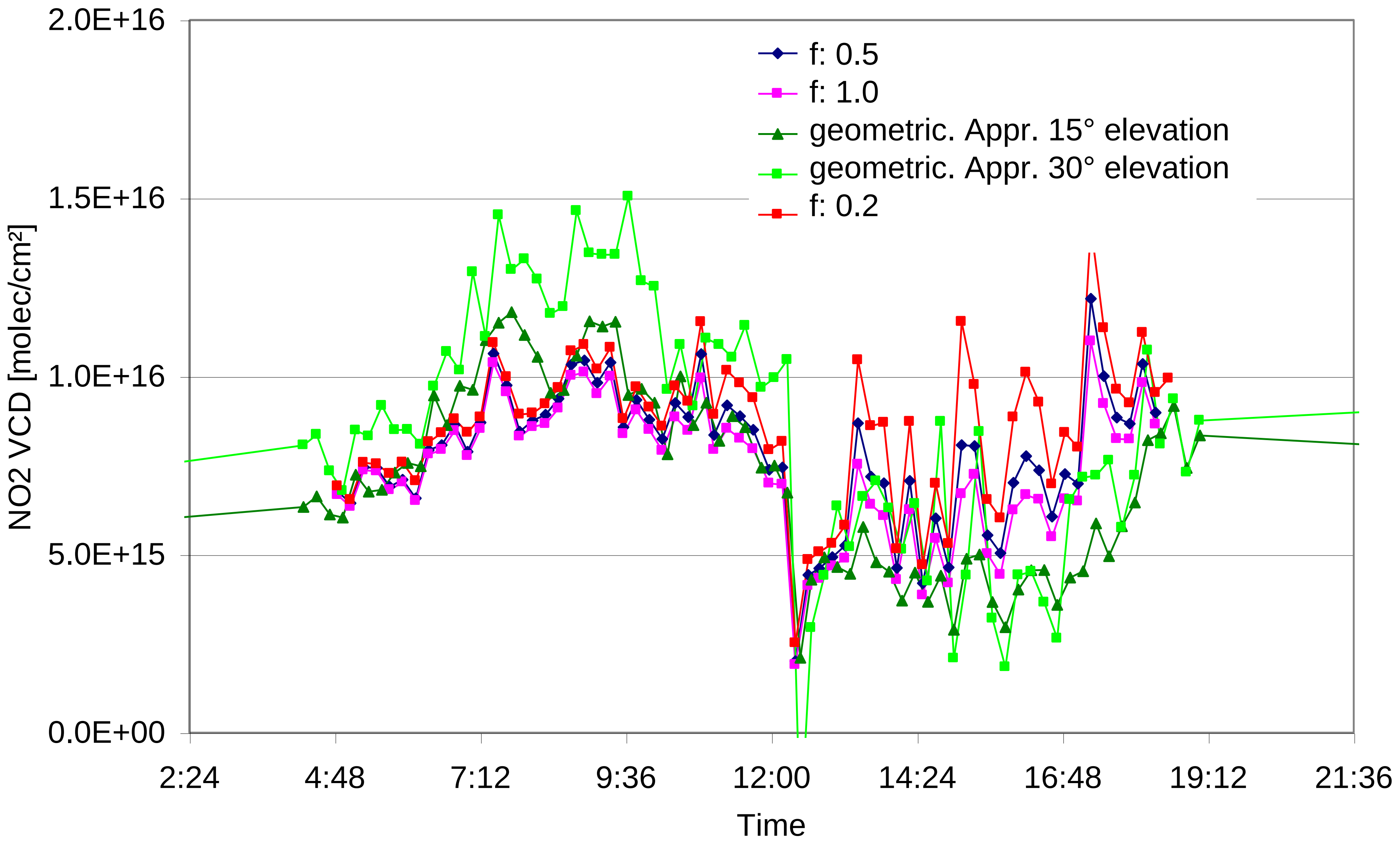
0.6
0.5
0.4
0.3
0.2
0.1
0
Aerosol extinction [1/km]
f: 0.9
f: 0.5
f: 0.2
f: 1.0
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time



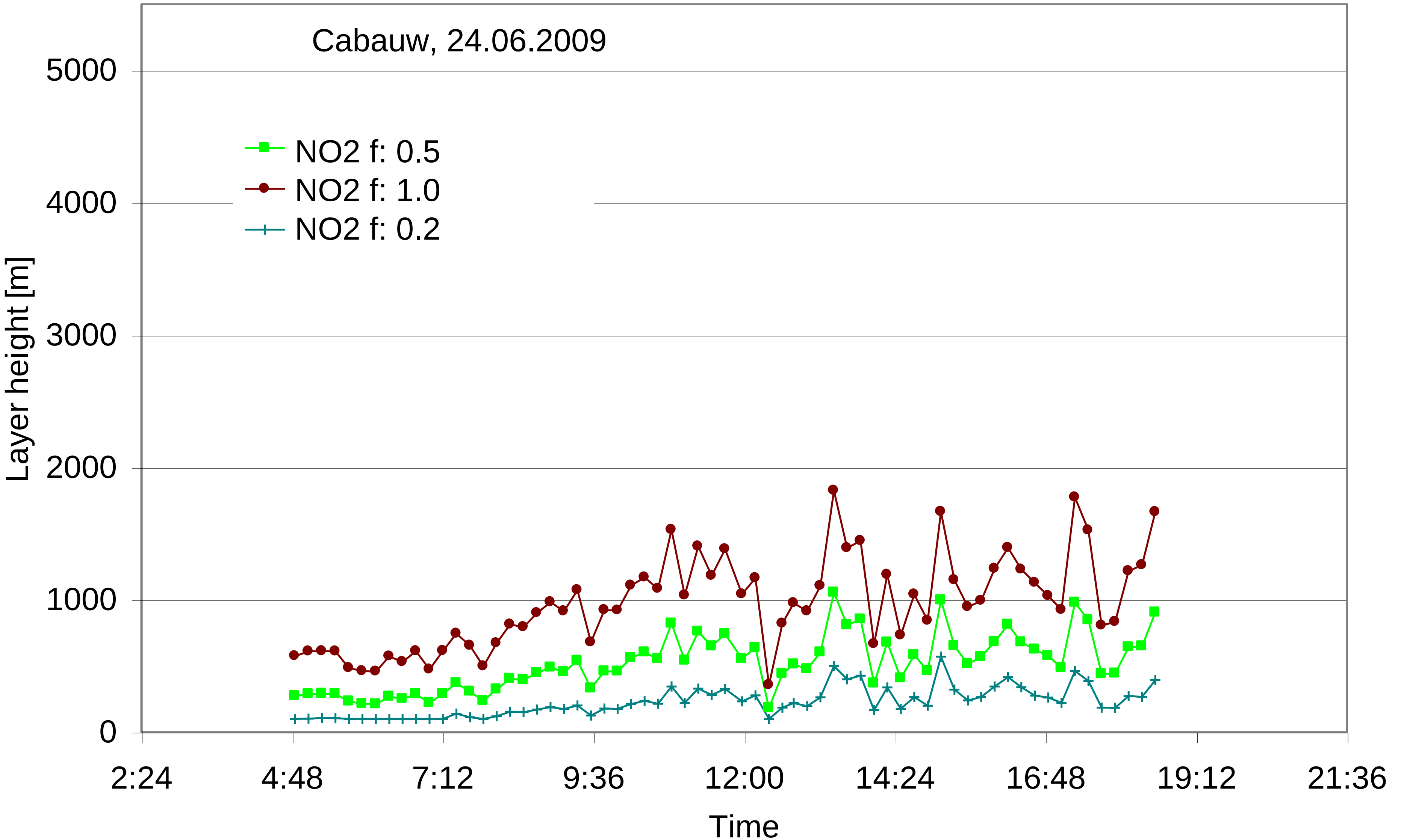
Residual very similar for different f

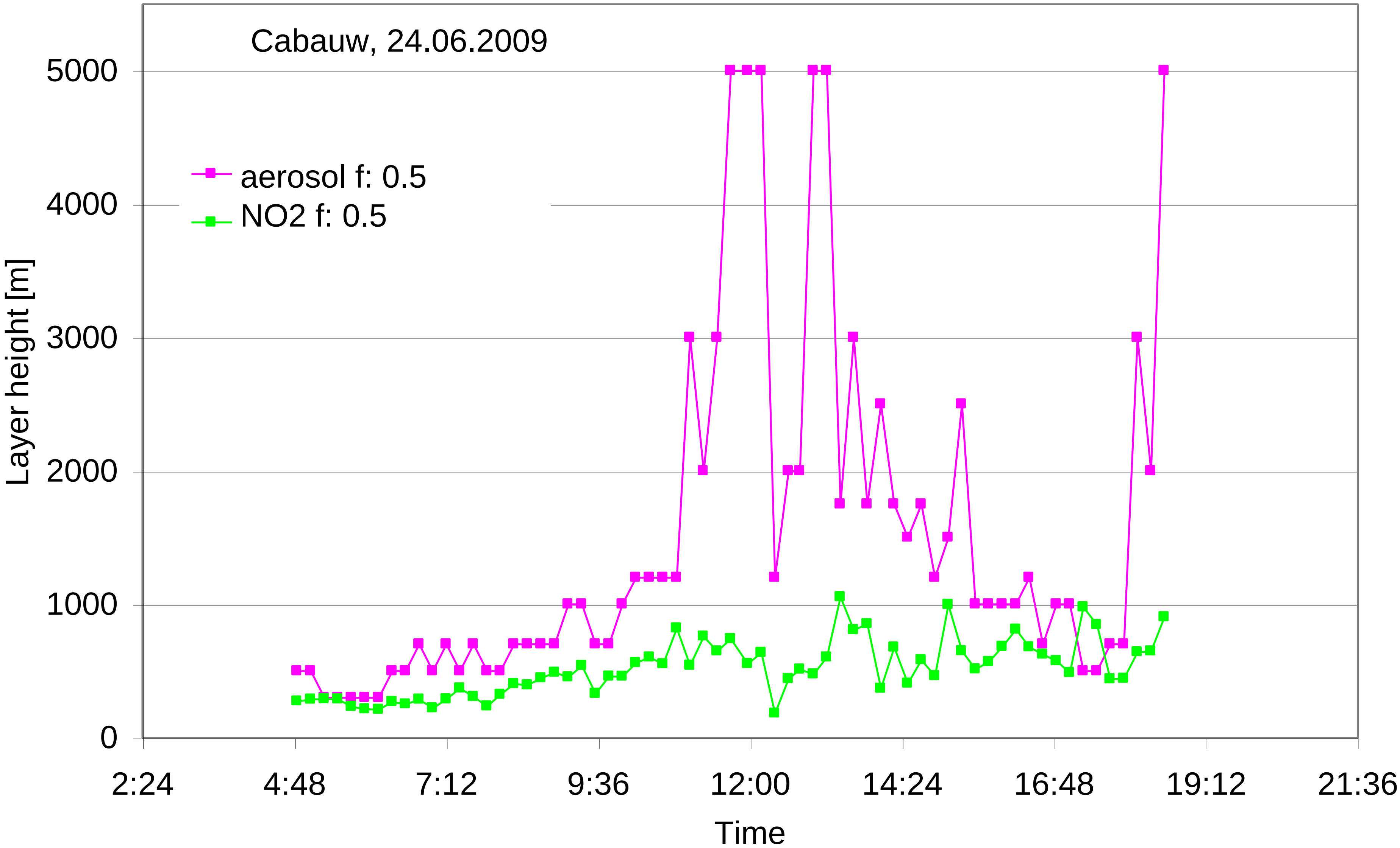
Residual is smallest for large f

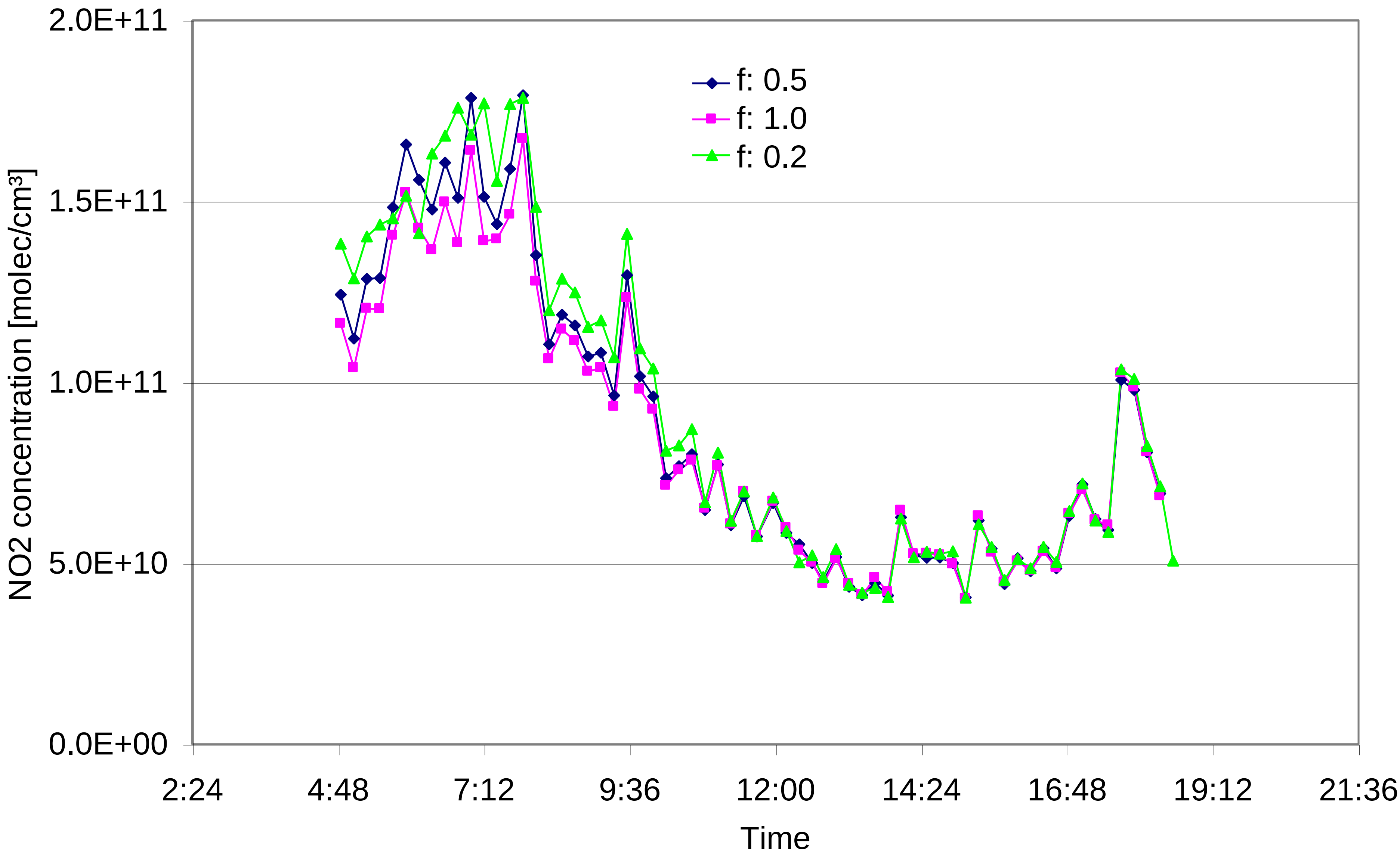

2.0E+16
1.5E+16
1.0E+16
5.0E+15
0.0E+00
NO2 VCD [molec/cm²]
f: 0.5
f: 1.0
f: 0.2
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time



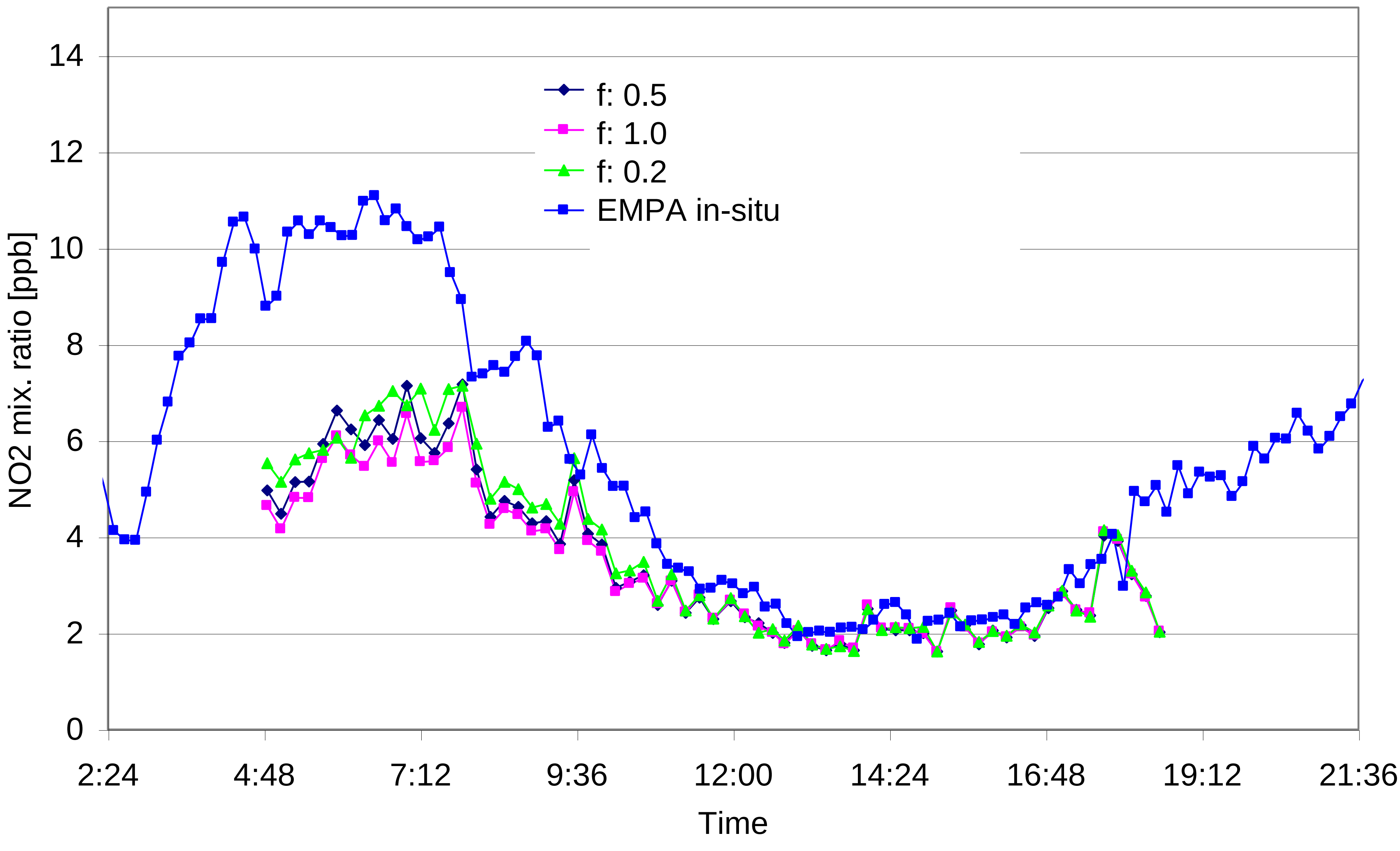
2.0E+16
1.5E+16
1.0E+16
5.0E+15
0.0E+00
NO2 VCD [molec/cm²]
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time
f: 0.5
f: 1.0
geometric. Appr. 15° elevation
geometric. Appr. 30° elevation
f: 0.2


Cabauw, 24.06.2009
NO2 f: 0.5
NO2 f: 1.0
NO2 f: 0.2
Layer height [m]
5000
4000
3000
2000
1000
0
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time

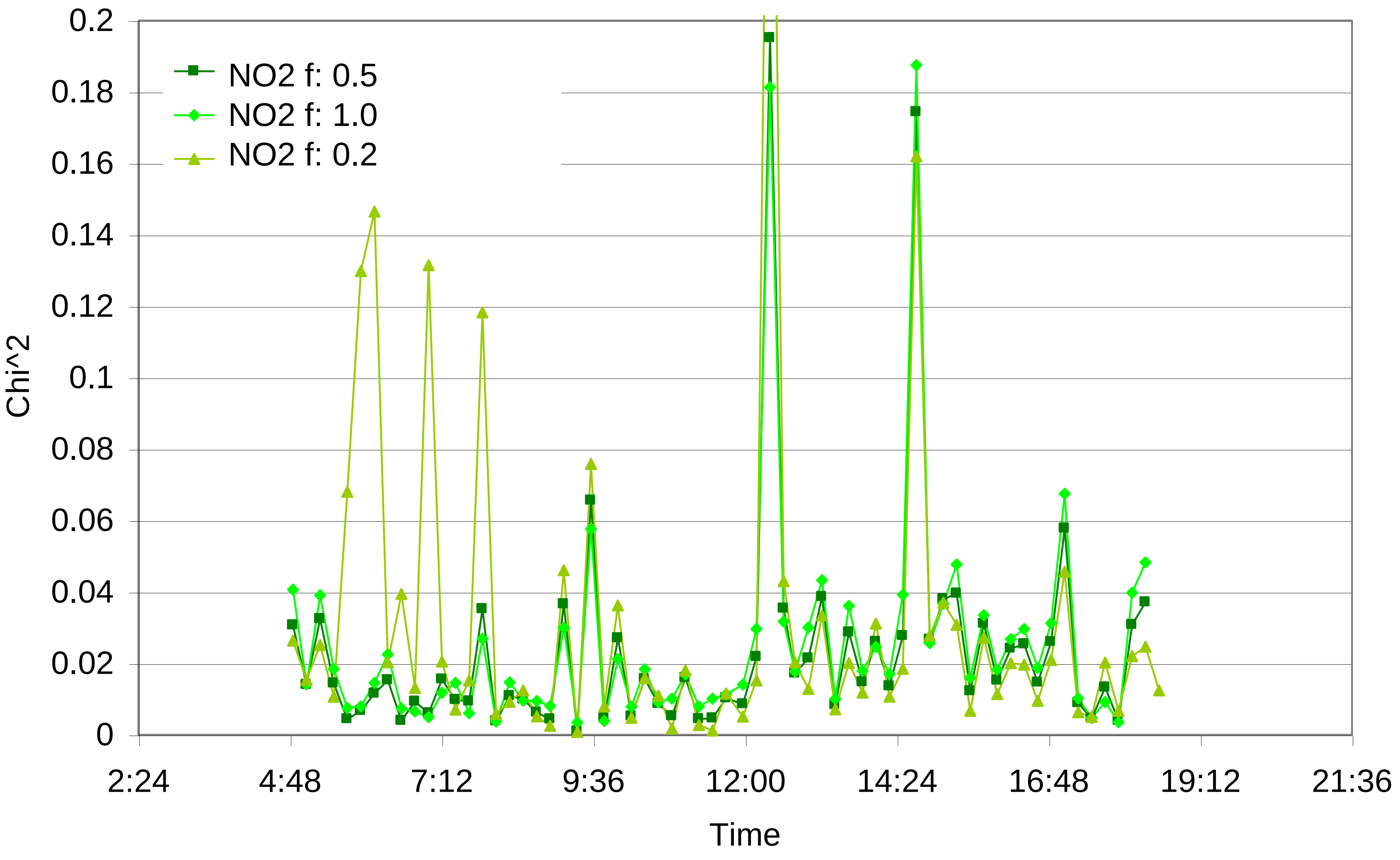

Cabauw, 24.06.2009
aerosol f: 0.5
NO2 f: 0.5
Layer height [m]
5000
4000
3000
2000
1000
0
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time



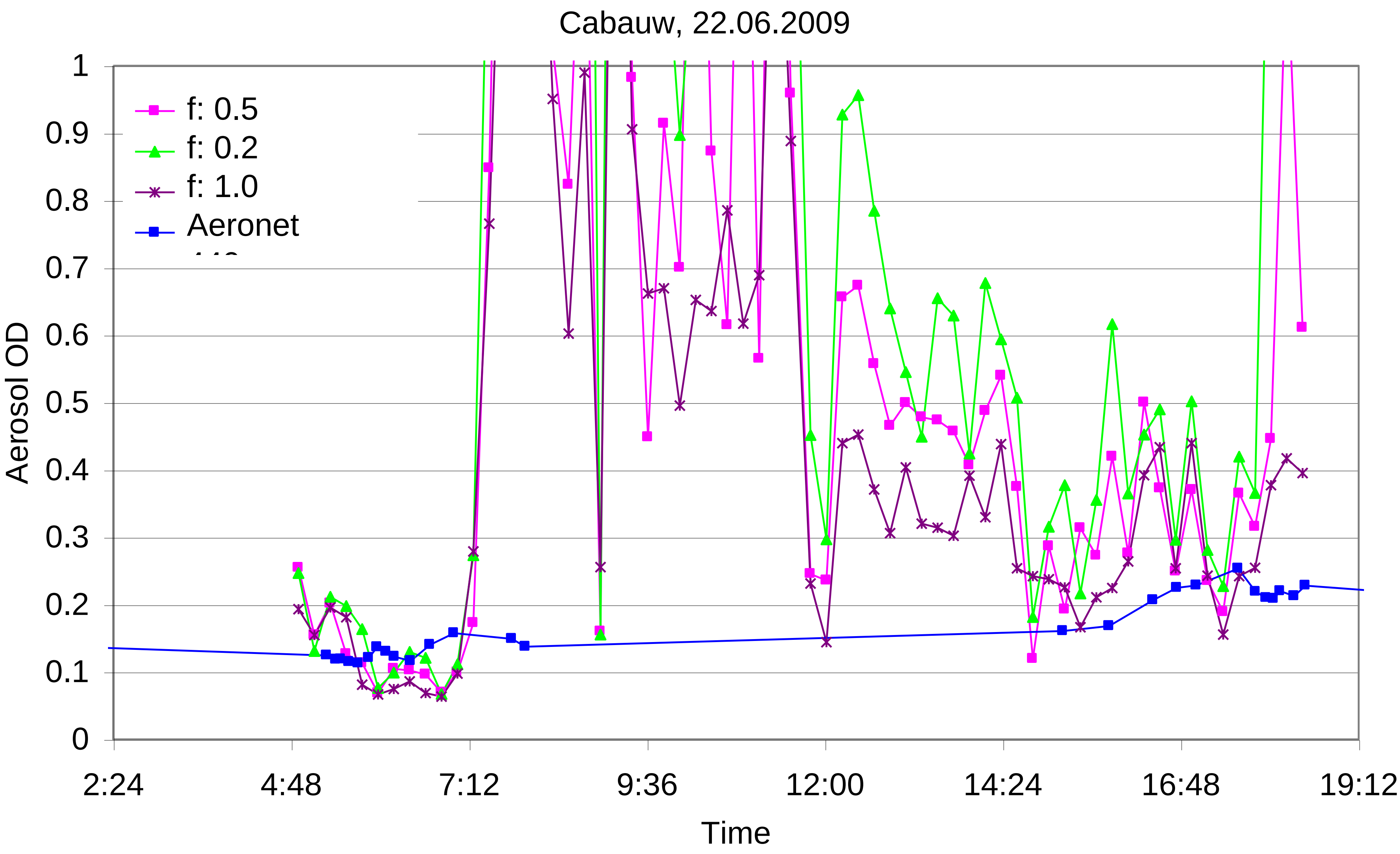
2.0E+11
1.5E+11
1.0E+11
5.0E+10
0.0E+00
NO2 concentration [molec/cm³]
f: 0.5
f: 1.0
f: 0.2
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time



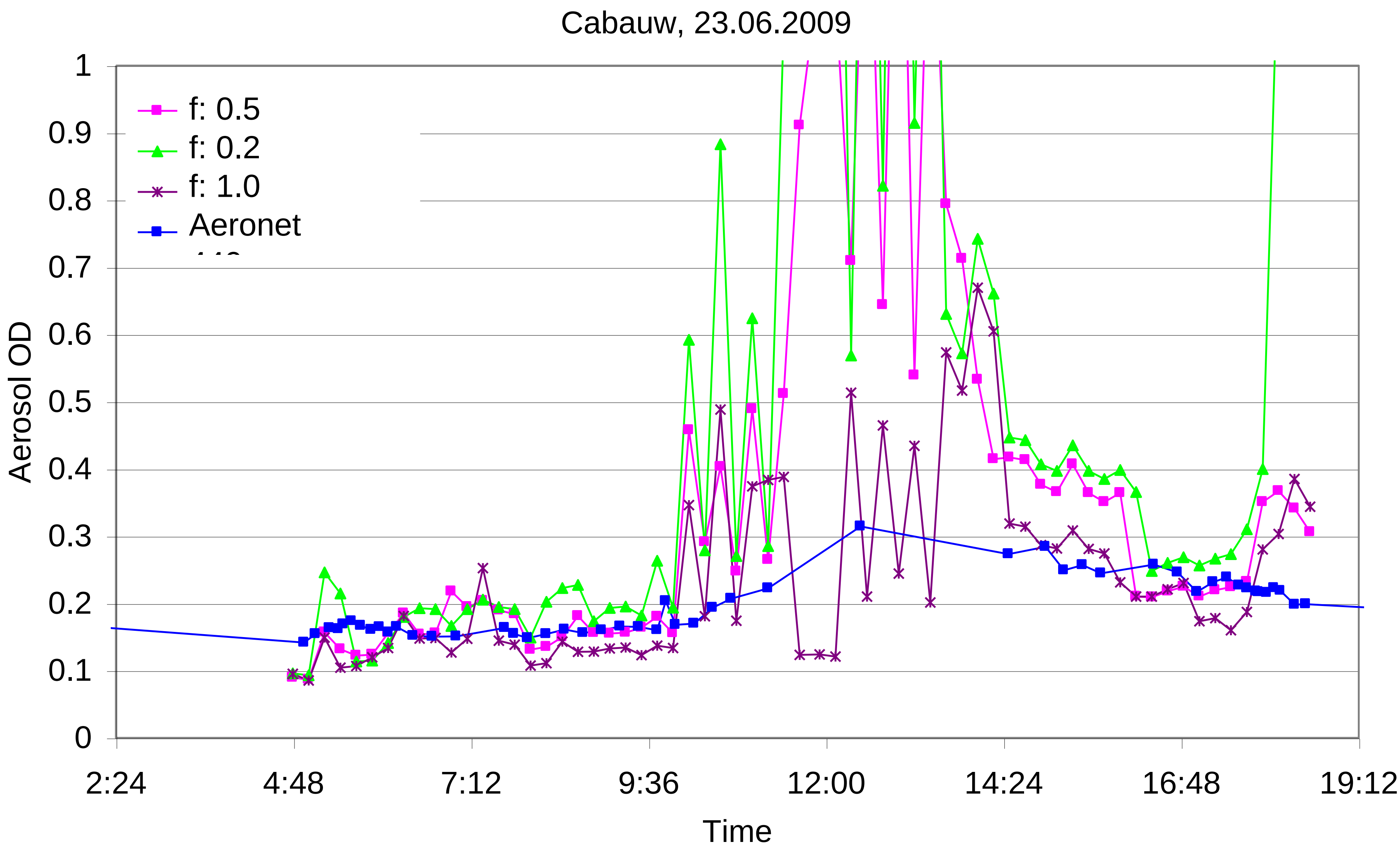
f: 0.5
f: 1.0
f: 0.2
EMPA in-situ
NO2 mix. ratio [ppb]
0
2
4
6
8
10
12
14
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time

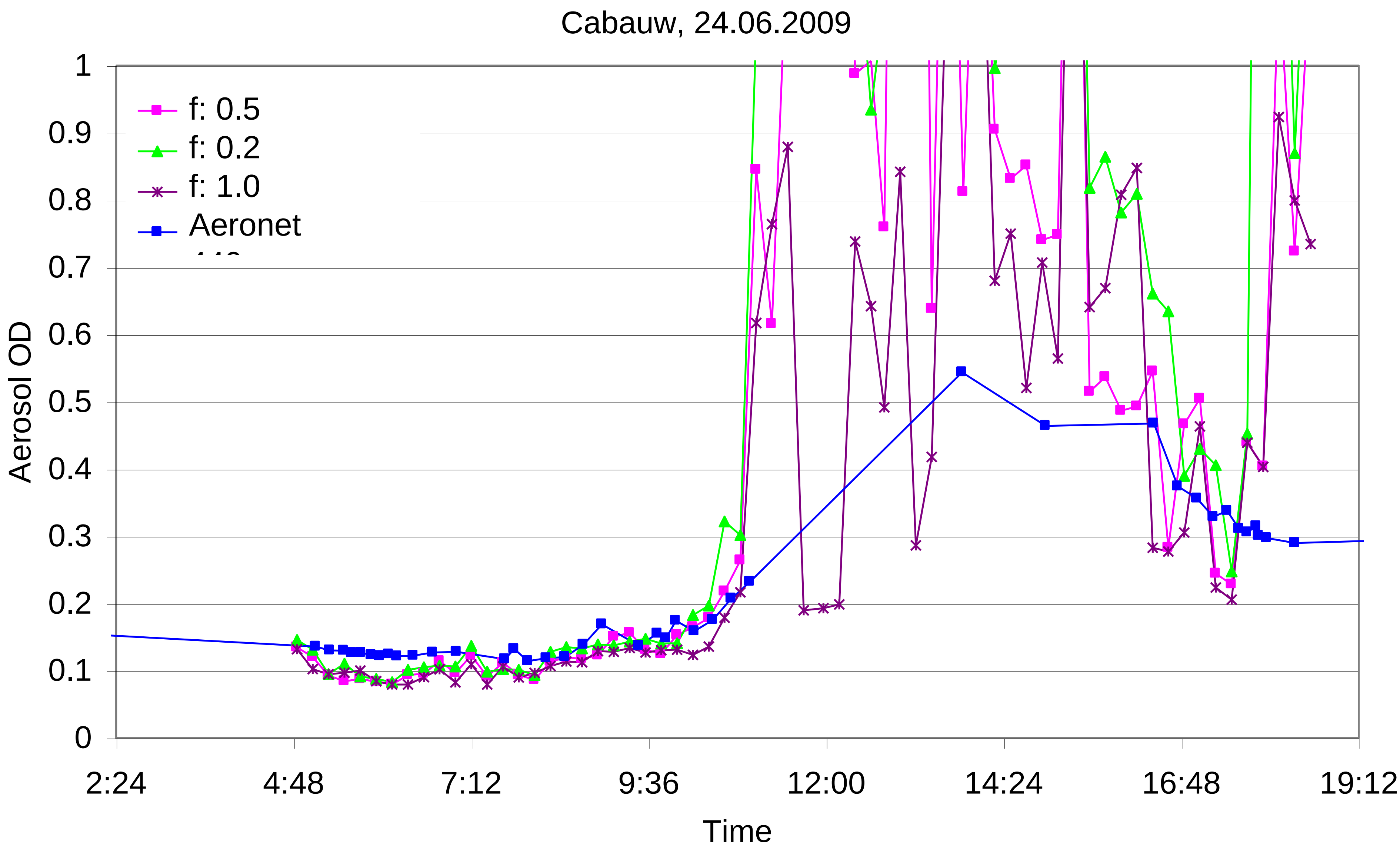


NO2 f: 0.5
NO2 f: 1.0
NO2 f: 0.2
Chi^2
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time

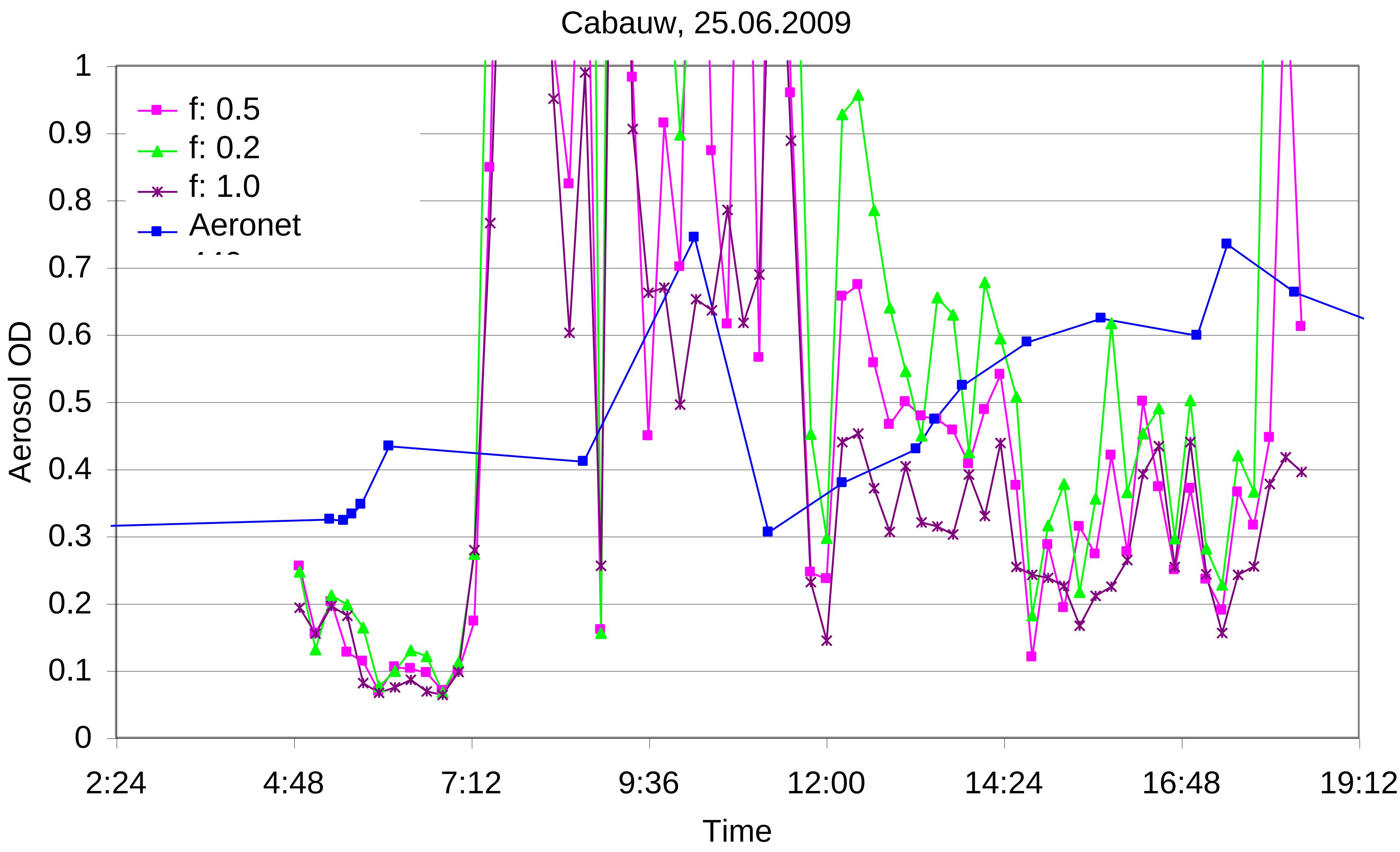


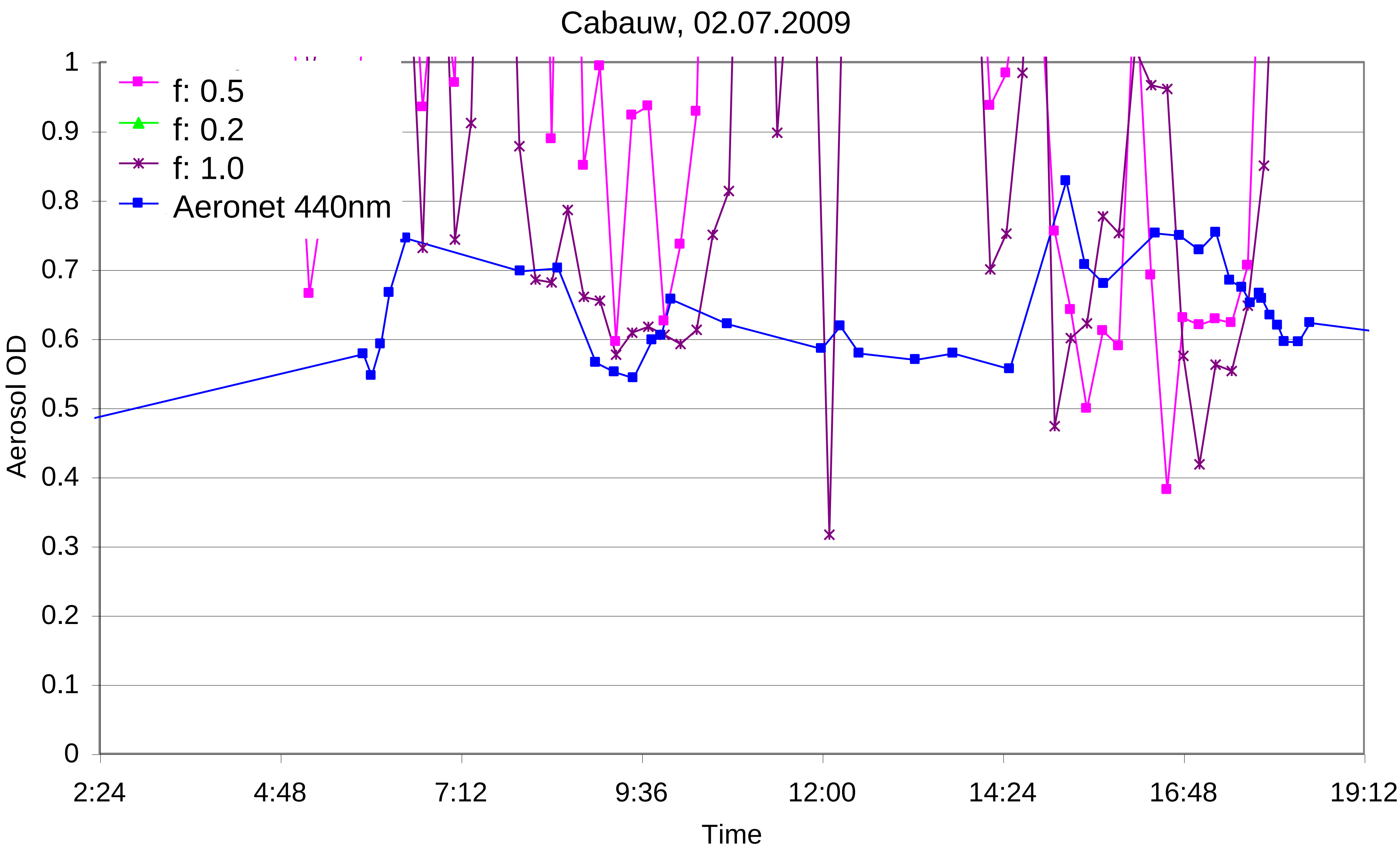
Cabauw, 22.06.2009
Aerosol OD
Time
f: 0.5
f: 0.2
f: 1.0
Aeronet
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12


Cabauw, 23.06.2009
f: 0.5
f: 0.2
f: 1.0
Aeronet
Aerosol OD
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
Time

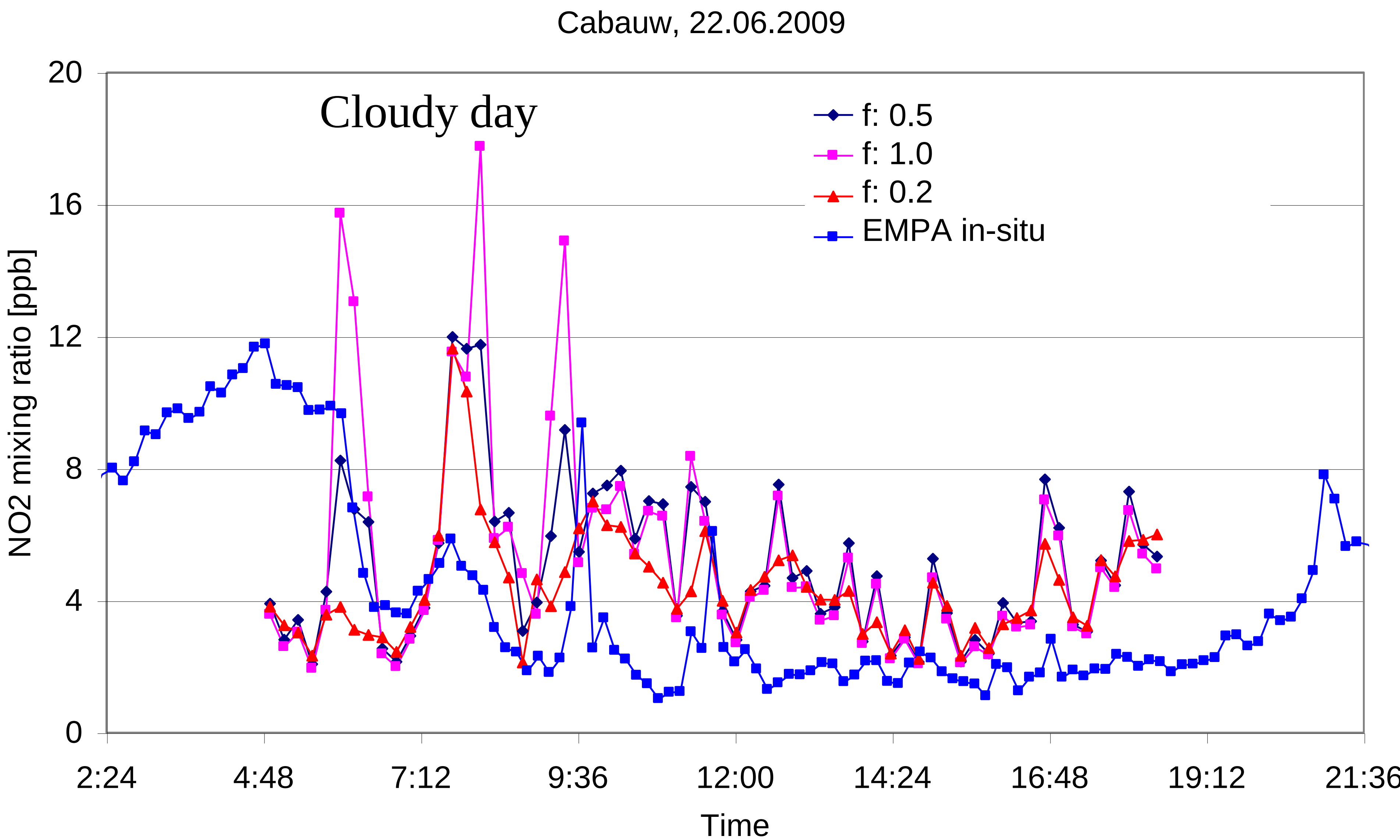


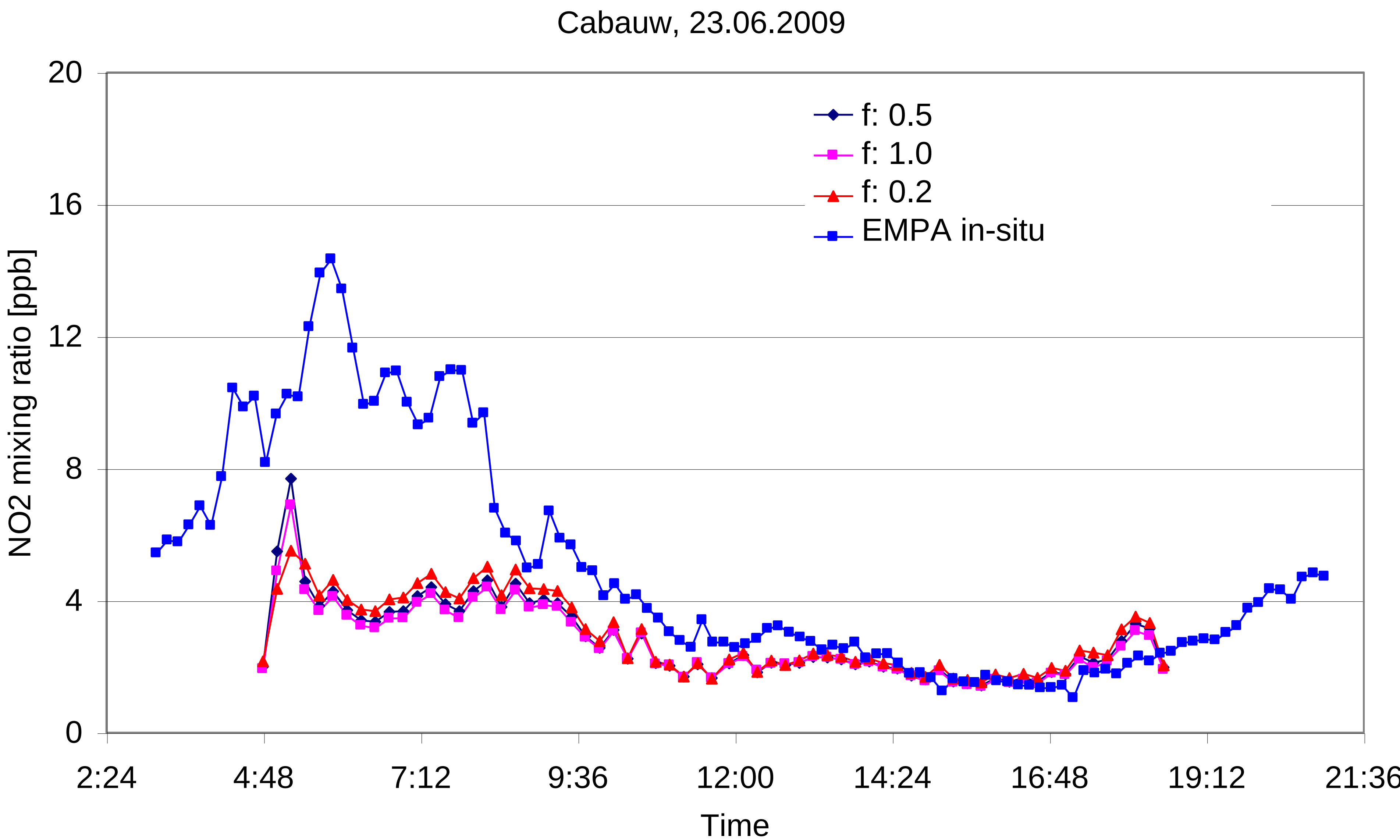
Cabauw, 24.06.2009
Aerosol OD
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
f: 0.5
f: 0.2
f: 1.0
Aeronet
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
Time

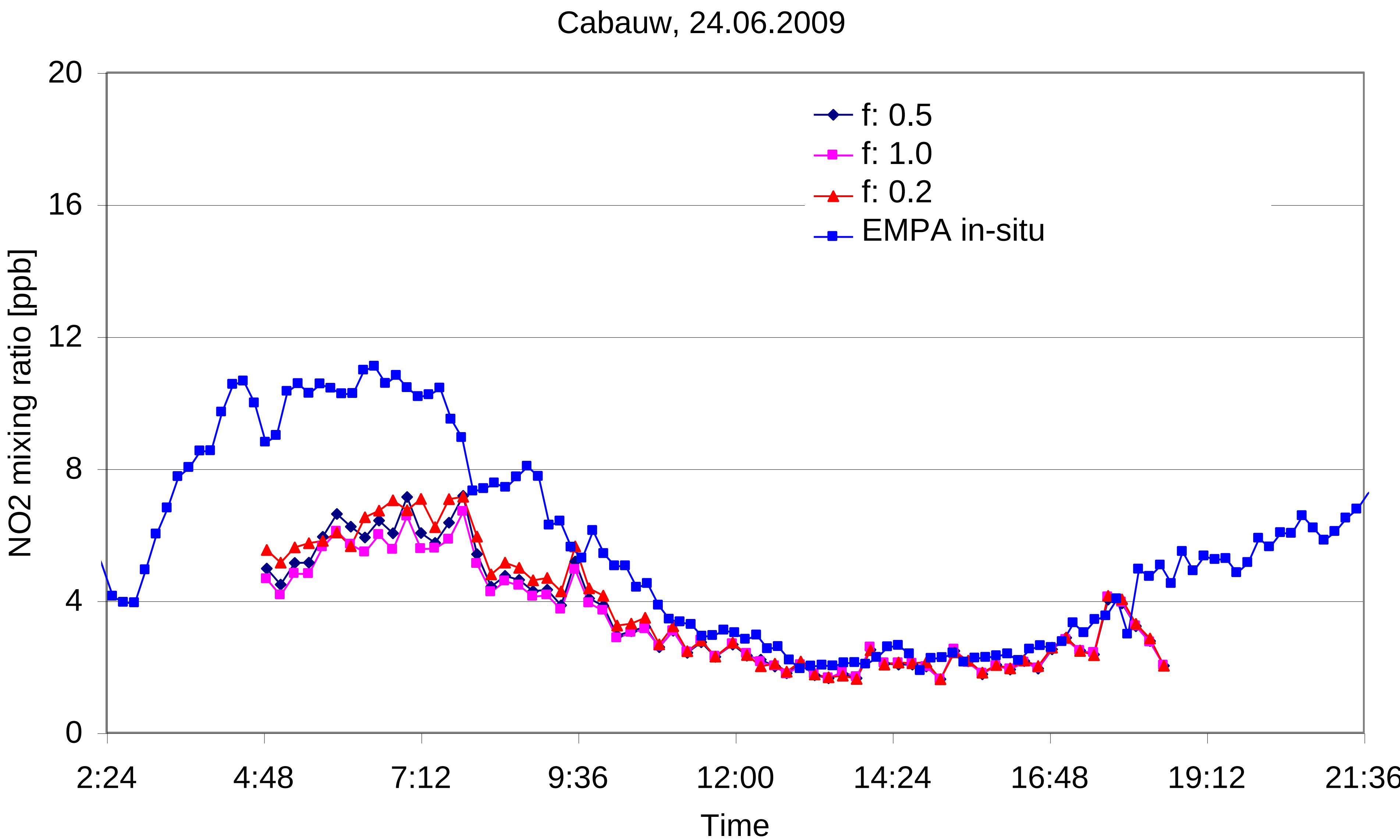

Cabauw, 25.06.2009
Aerosol OD
Time
f: 0.5
f: 0.2
f: 1.0
Aeronet
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12

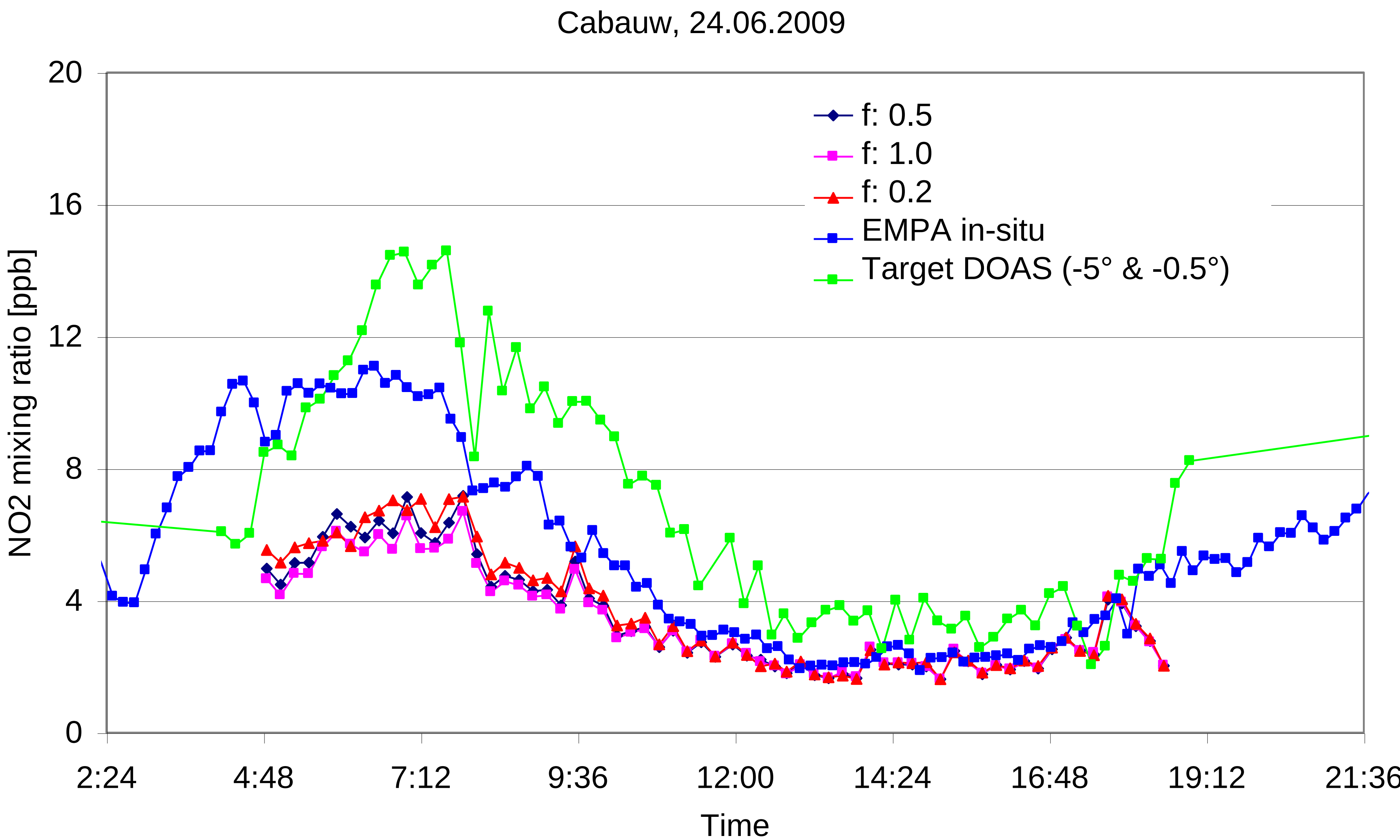


Cabauw, 02.07.2009
f: 0.5
f: 0.2
f: 1.0
Aeronet 440nm
Aerosol OD
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
Time

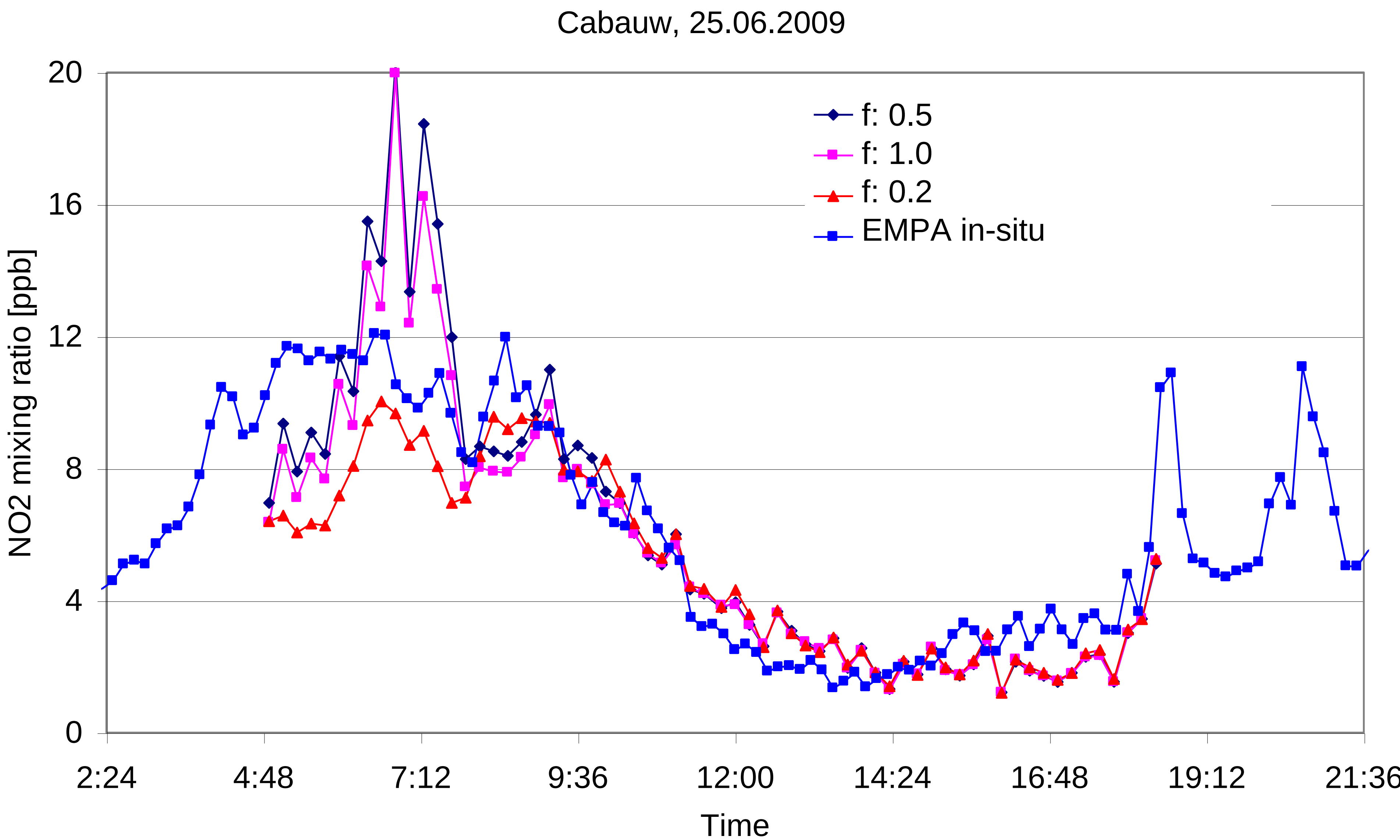

Cabauw, 22.06.2009
Cloudy day
f: 0.5
f: 1.0
f: 0.2
EMPA in-situ
NO2 mixing ratio [ppb]
0
4
8
12
16
20
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time

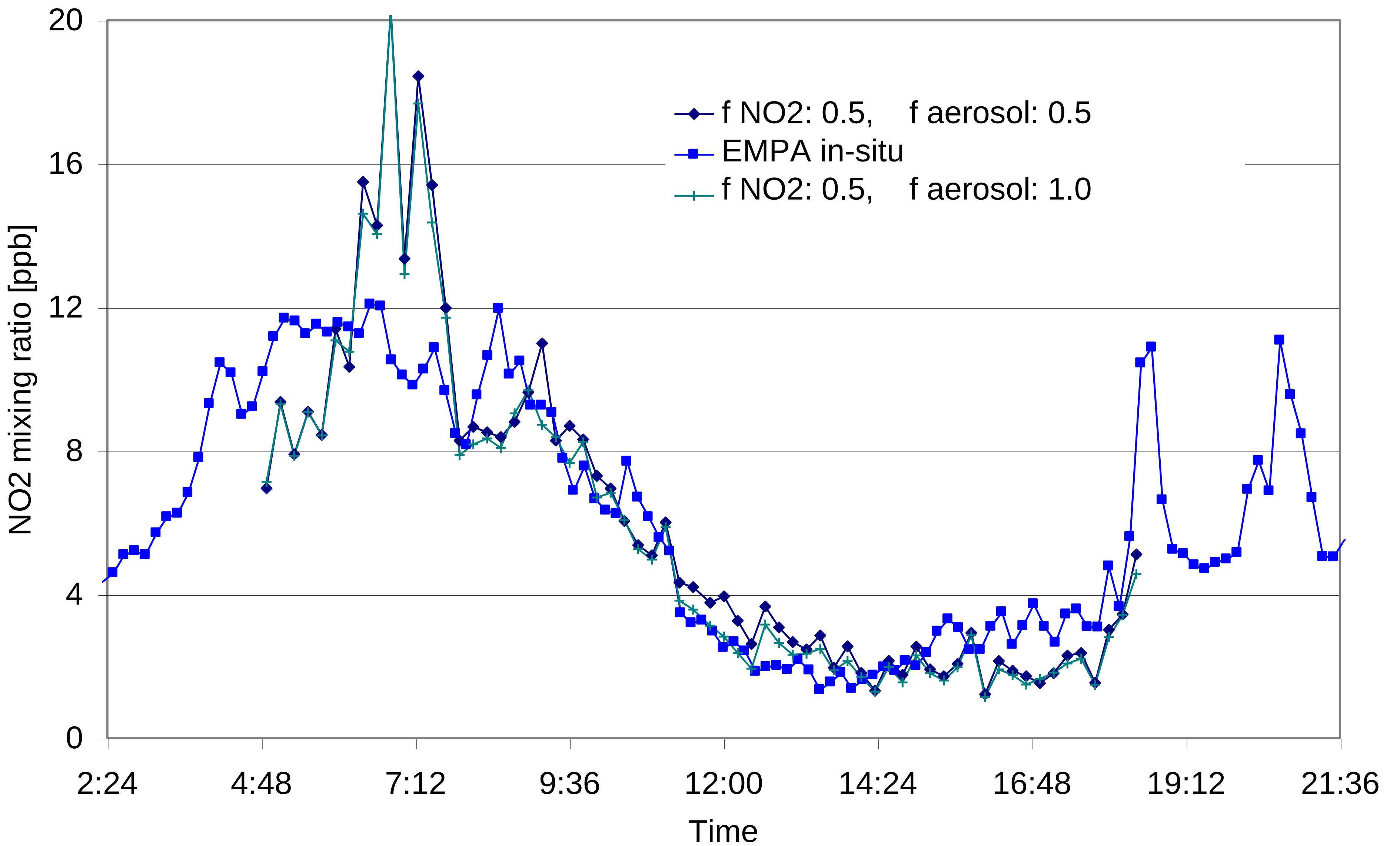

Cabauw, 23.06.2009
NO2 mixing ratio [ppb]
20
16
12
8
4
0
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time
f: 0.5
f: 1.0
f: 0.2
EMPA in-situ


Cabauw, 24.06.2009
f: 0.5
f: 1.0
f: 0.2
EMPA in-situ
NO2 mixing ratio [ppb]
0
4
8
12
16
20
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time

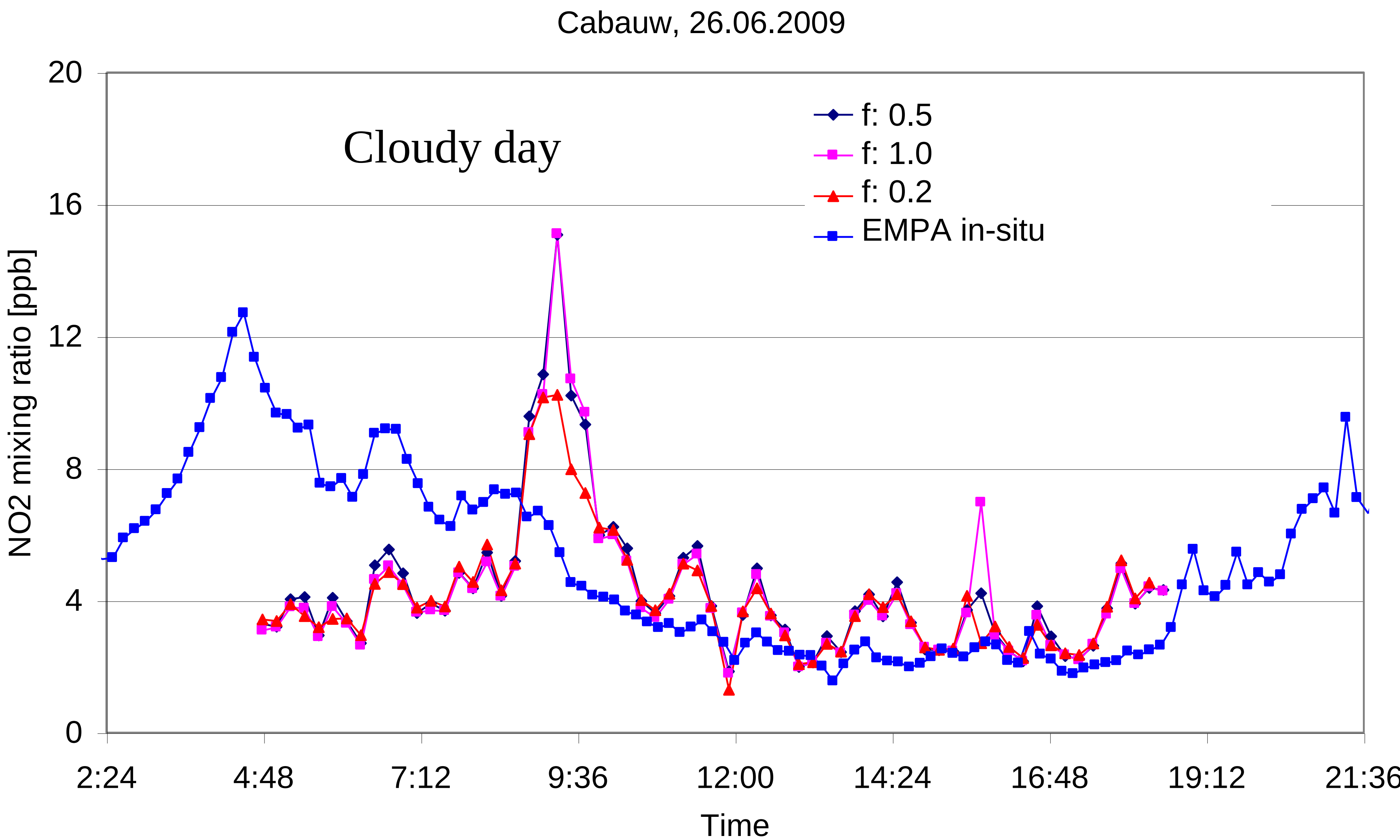


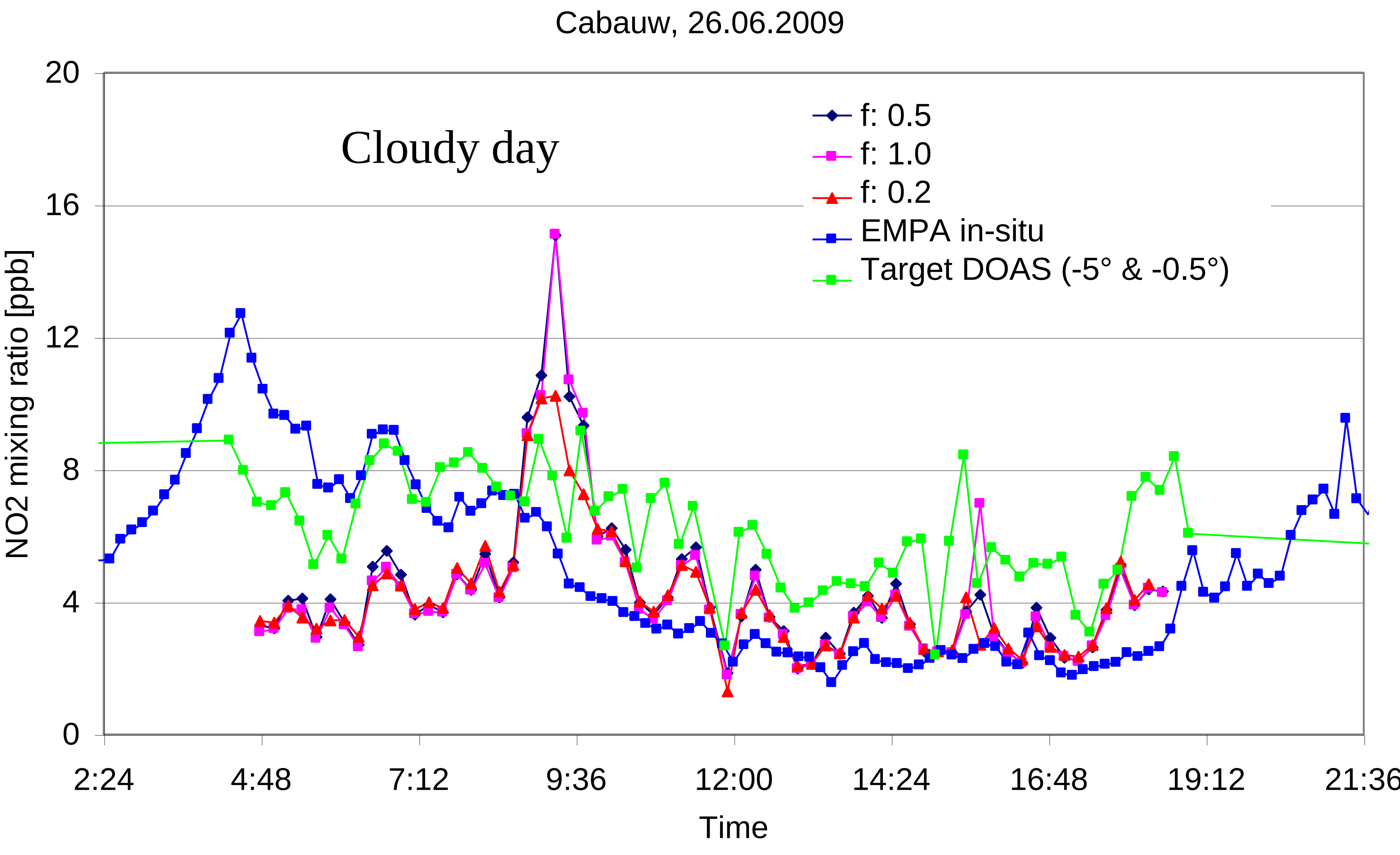
Cabauw, 24.06.2009
NO2 mixing ratio [ppb]
0
4
8
12
16
20
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time
f: 0.5
f: 1.0
f: 0.2
EMPA in-situ
Target DOAS (-5° & -0.5°)

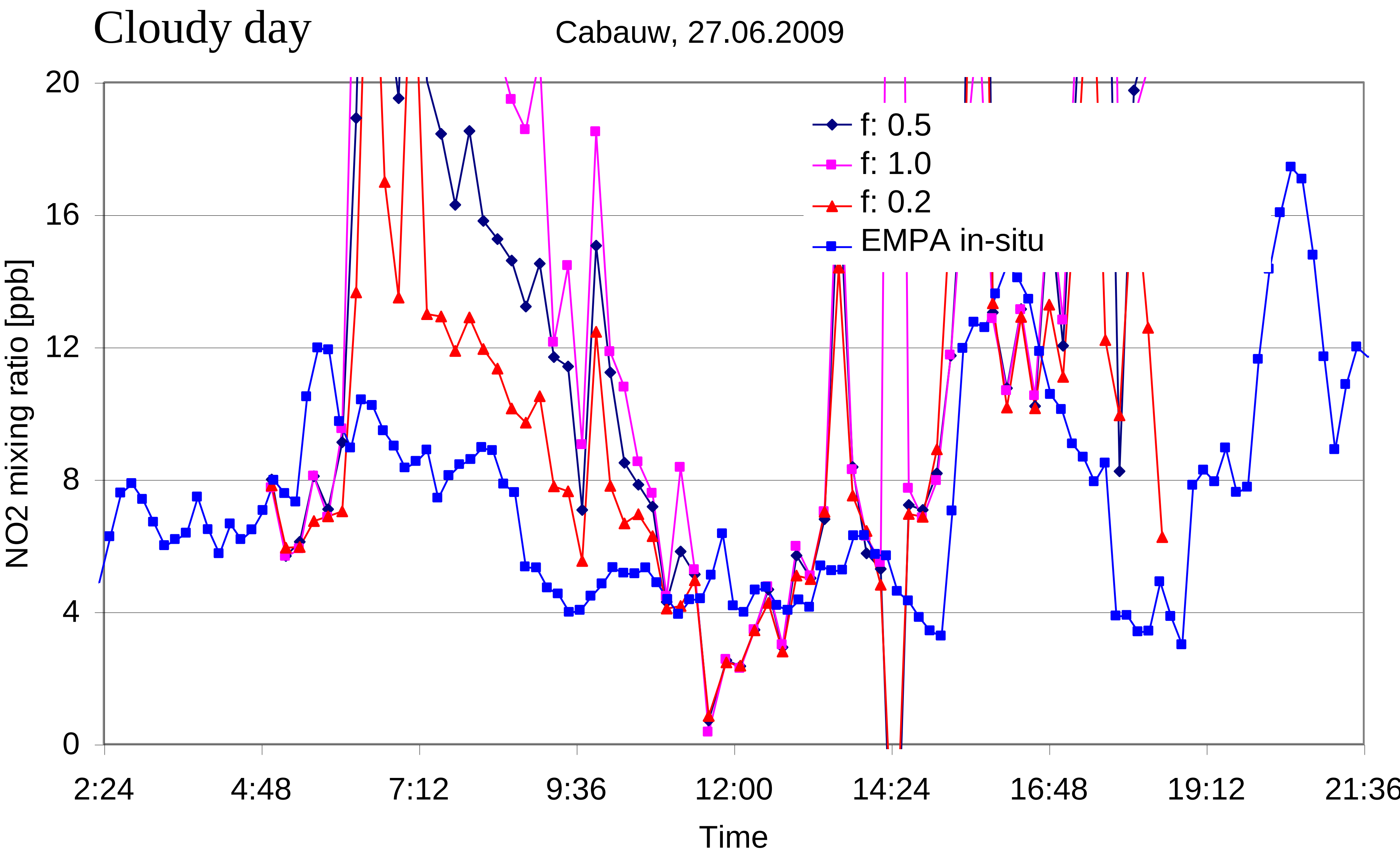

Cabauw, 25.06.2009
NO2 mixing ratio [ppb]
Time
0
4
8
12
16
20
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
f: 0.5
f: 1.0
f: 0.2
EMPA in-situ



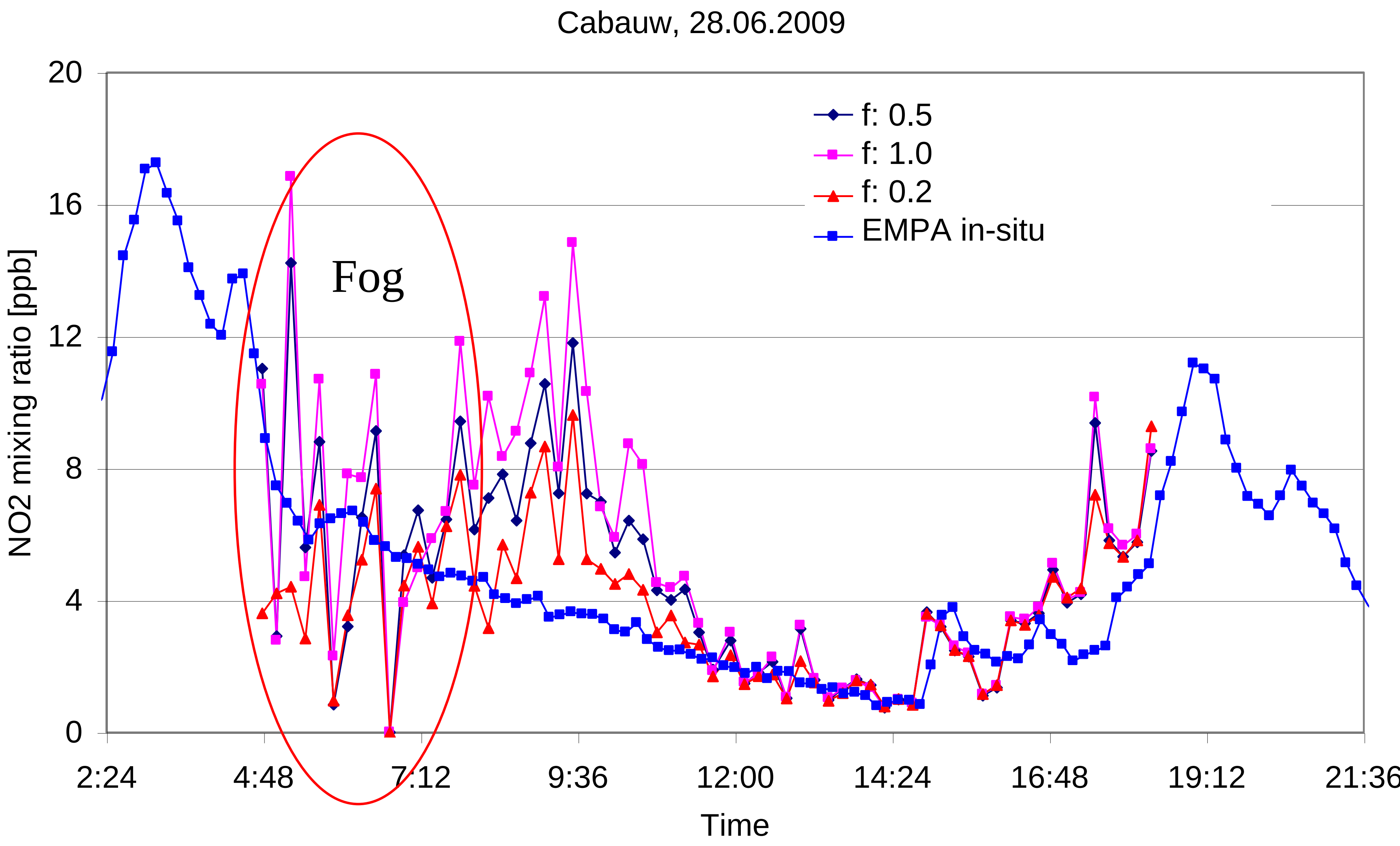
20
16
12
8
4
0
NO2 mixing ratio [ppb]
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time
f NO2: 0.5, f aerosol: 0.5
EMPA in-situ
f NO2: 0.5, f aerosol: 1.0

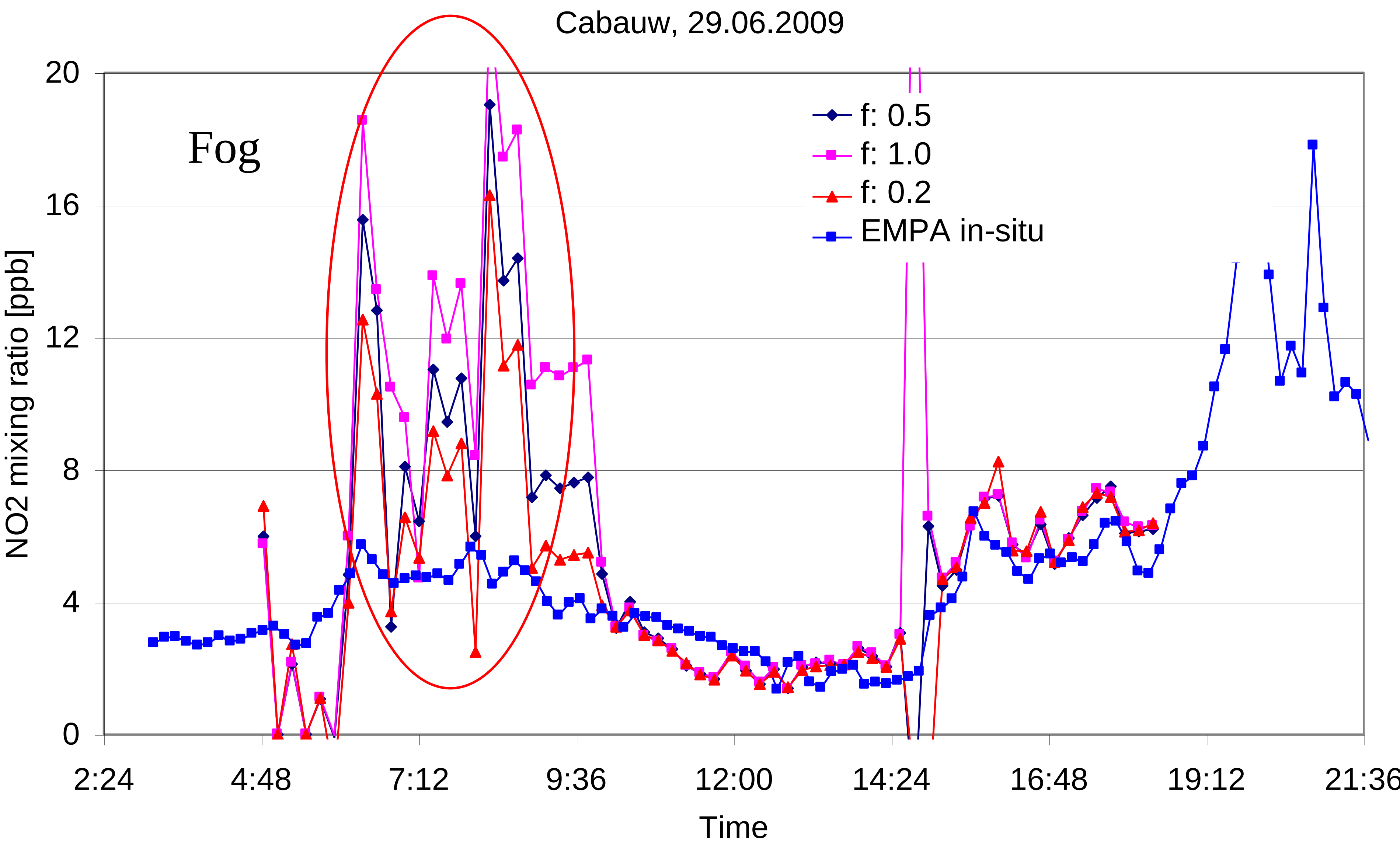

Cabauw, 26.06.2009
Cloudy day
f: 0.5
f: 1.0
f: 0.2
EMPA in-situ
NO2 mixing ratio [ppb]
0
4
8
12
16
20
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time

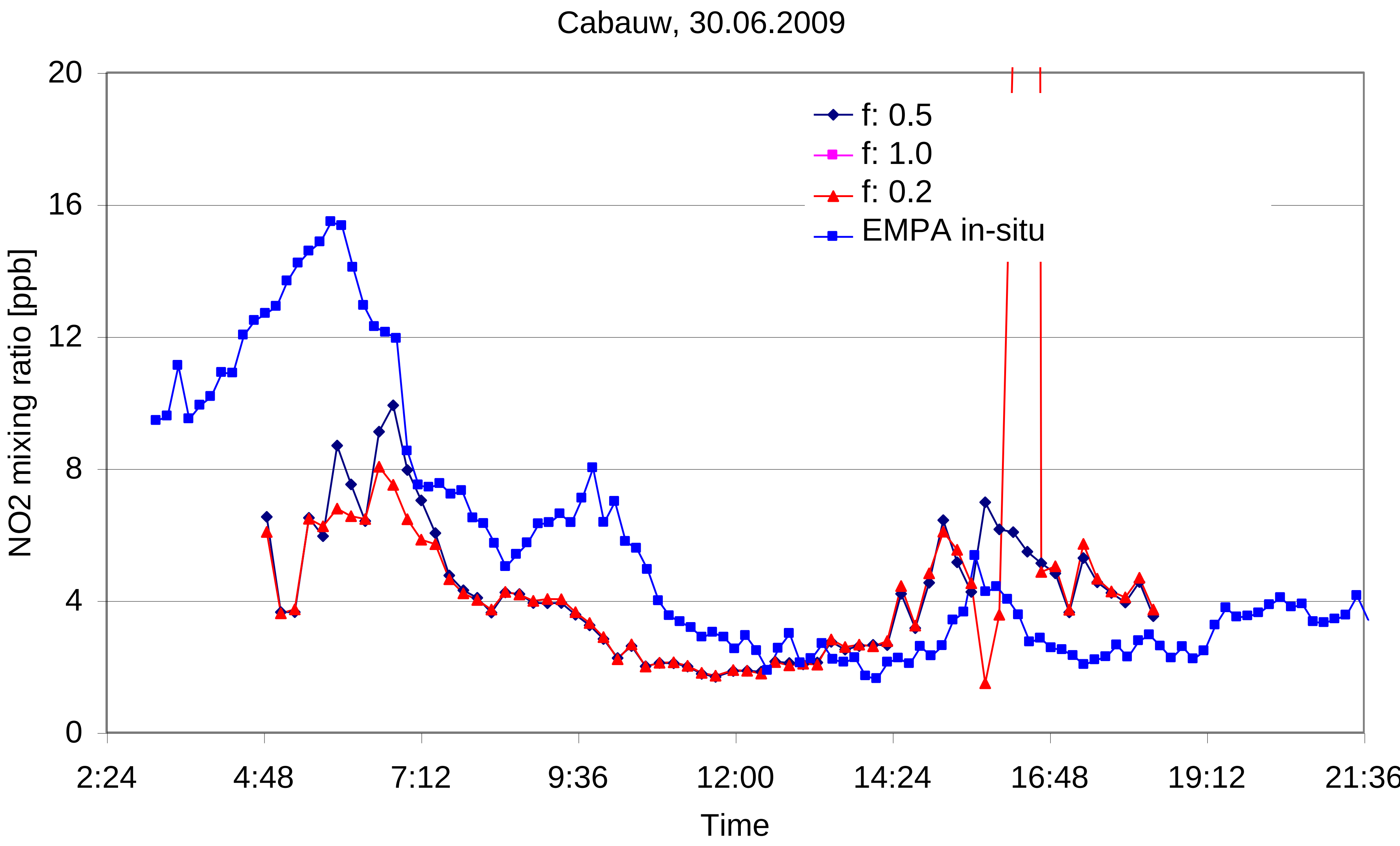

Cabauw, 26.06.2009
Cloudy day
f: 0.5
f: 1.0
f: 0.2
EMPA in-situ
Target DOAS (-5° & -0.5°)
NO2 mixing ratio [ppb]
20
16
12
8
4
0
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time



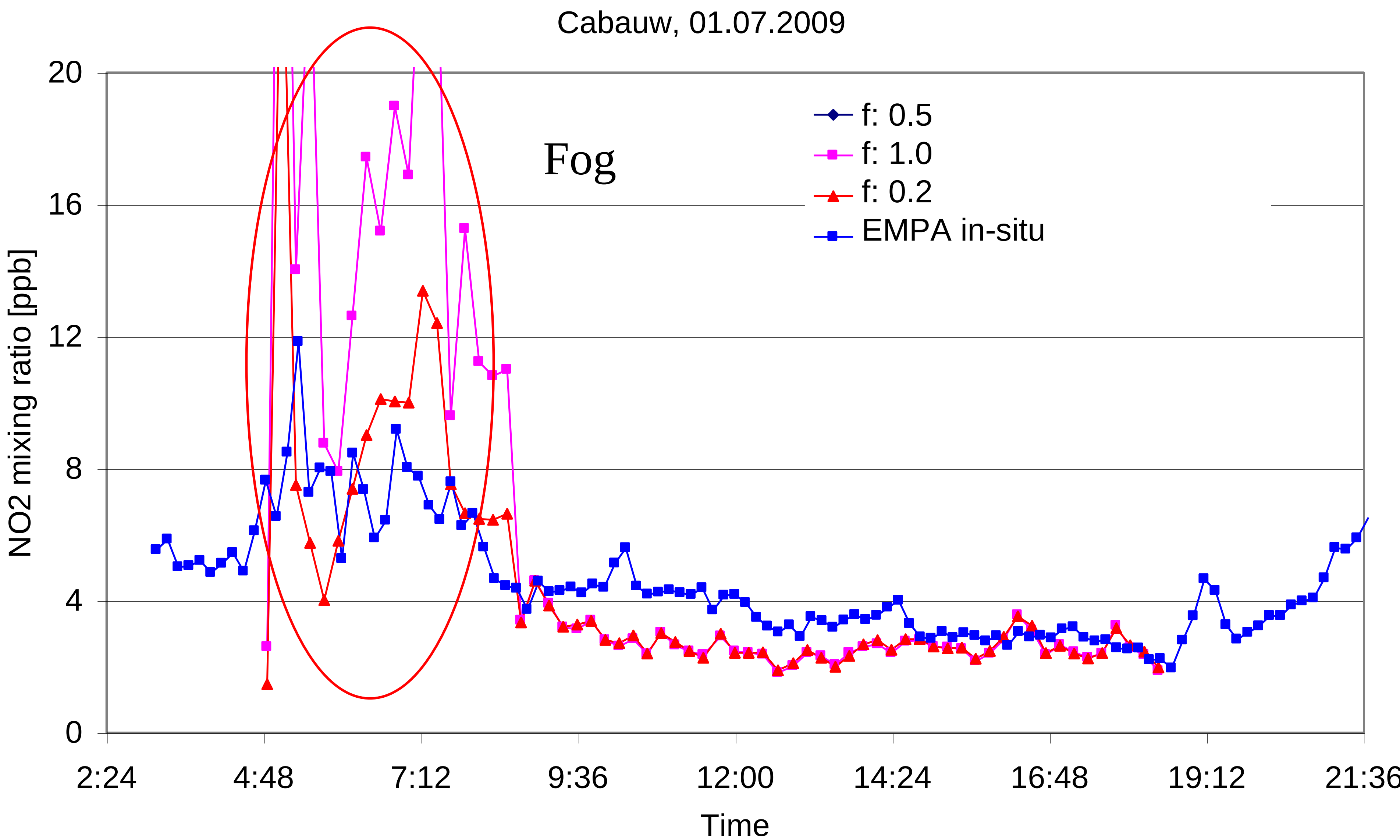
Cloudy day
Cabauw, 27.06.2009
NO2 mixing ratio [ppb]
0
4
8
12
16
20
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time
f: 0.5
f: 1.0
f: 0.2
EMPA in-situ

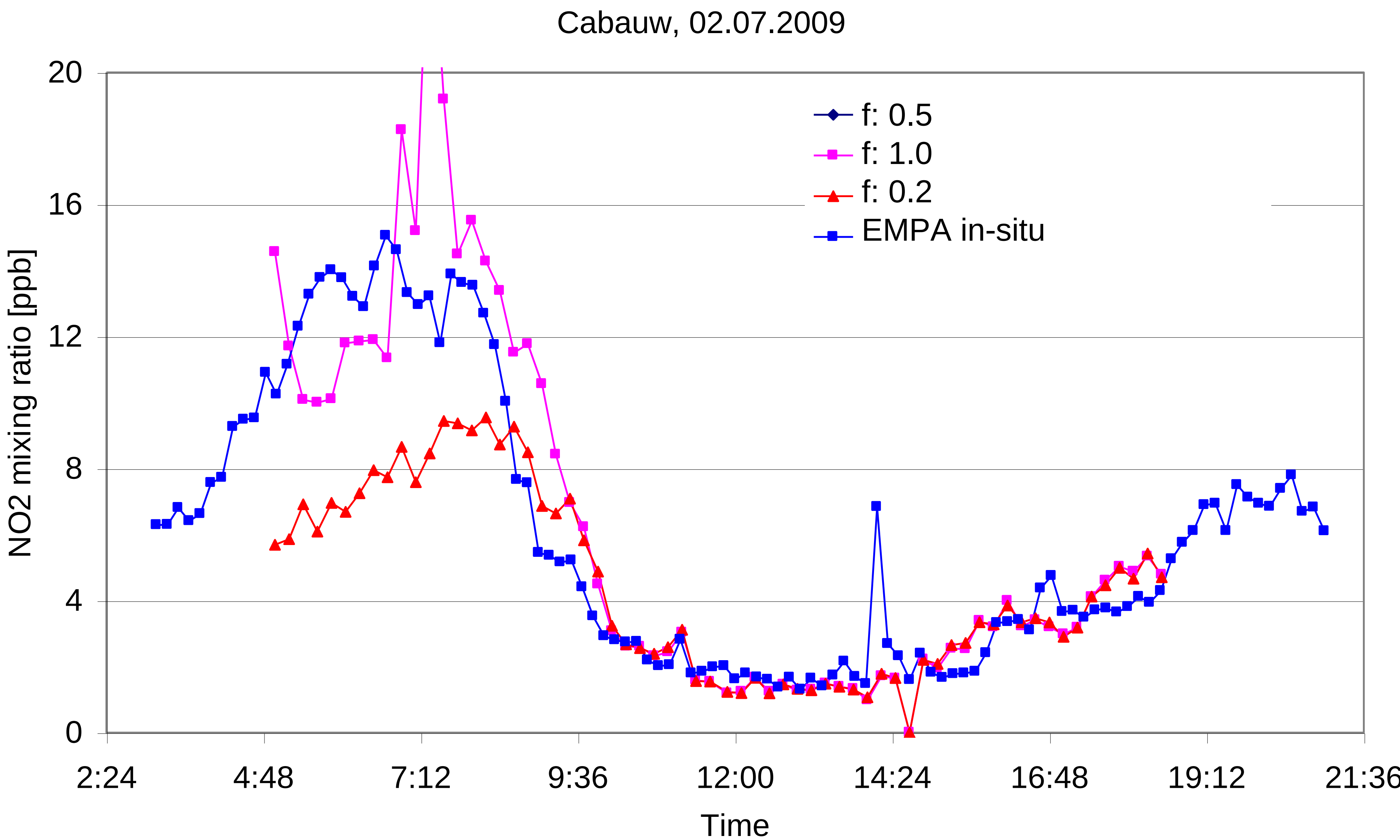

Cabauw, 28.06.2009
NO2 mixing ratio [ppb]
0
4
8
12
16
20
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time
Fog
f: 0.5
f: 1.0
f: 0.2
EMPA in-situ


Cabauw, 29.06.2009
Fog
f: 0.5
f: 1.0
f: 0.2
EMPA in-situ
NO2 mixing ratio [ppb]
20
16
12
8
4
0
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time

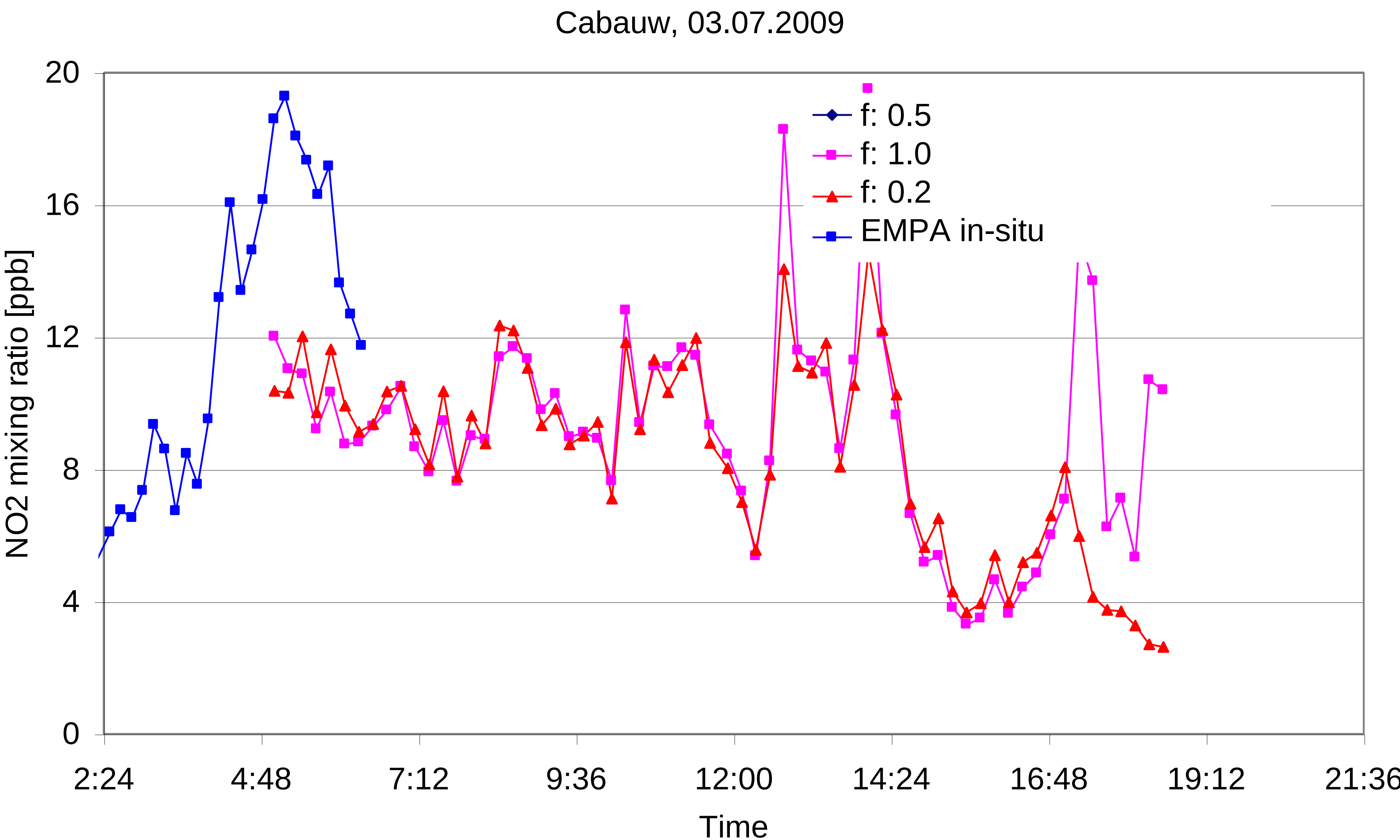


Cabauw, 30.06.2009
NO2 mixing ratio [ppb]
0
4
8
12
16
20
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time
f: 0.5
f: 1.0
f: 0.2
EMPA in-situ

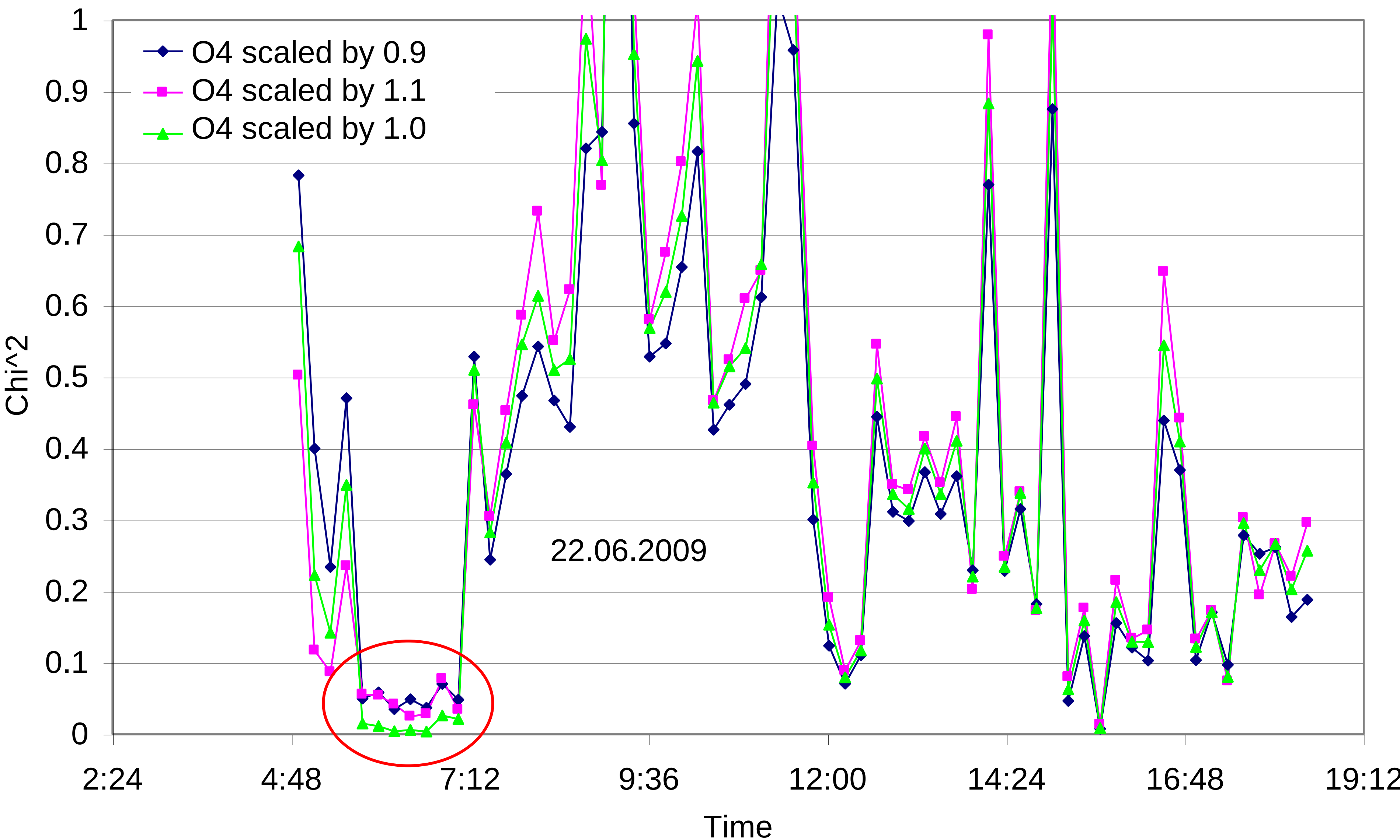

Cabauw, 01.07.2009
Fog
f: 0.5
f: 1.0
f: 0.2
EMPA in-situ
NO2 mixing ratio [ppb]
20
16
12
8
4
0
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time



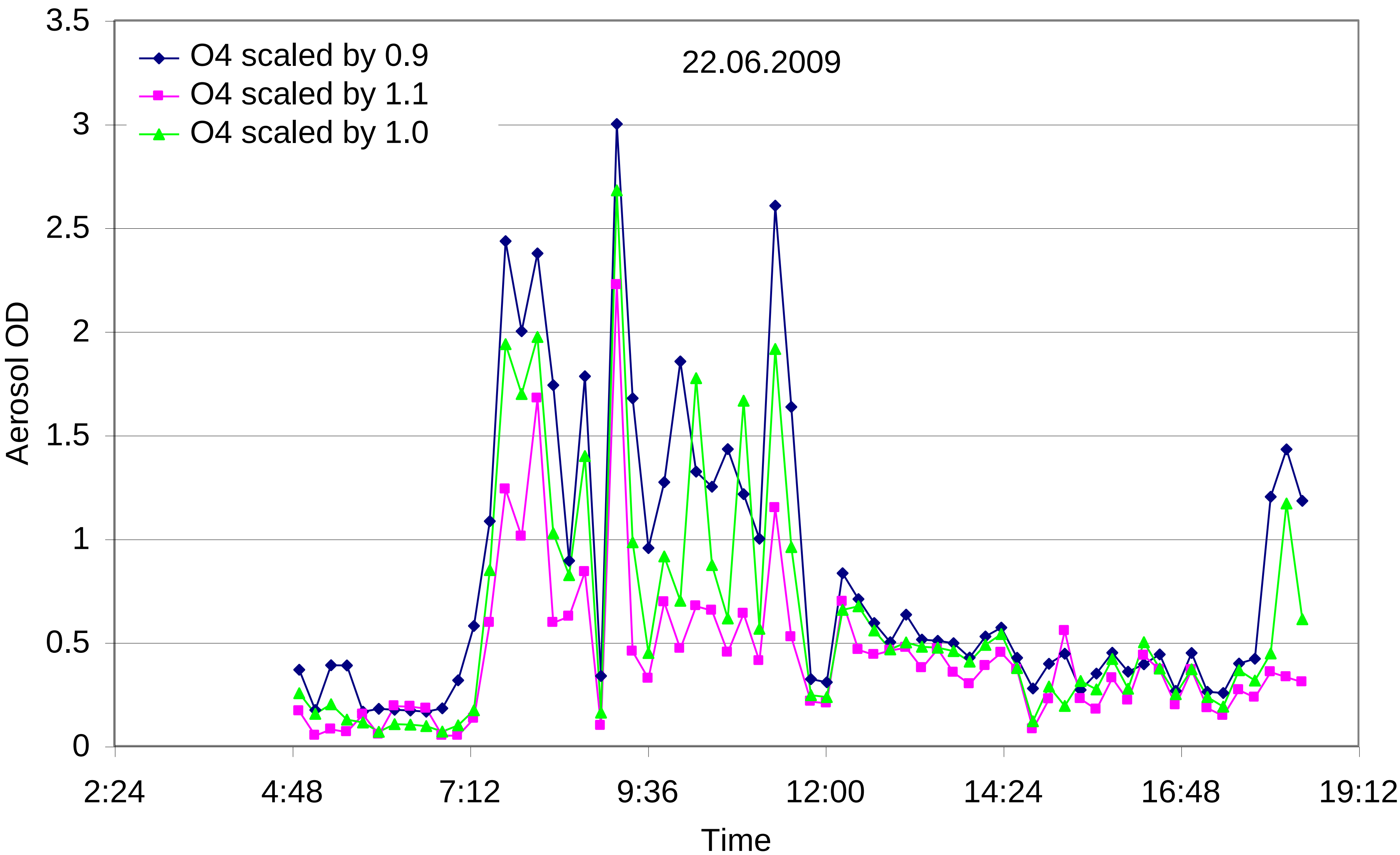
Cabauw, 02.07.2009
NO2 mixing ratio [ppb]
0
4
8
12
16
20
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time
f: 0.5
f: 1.0
f: 0.2
EMPA in-situ



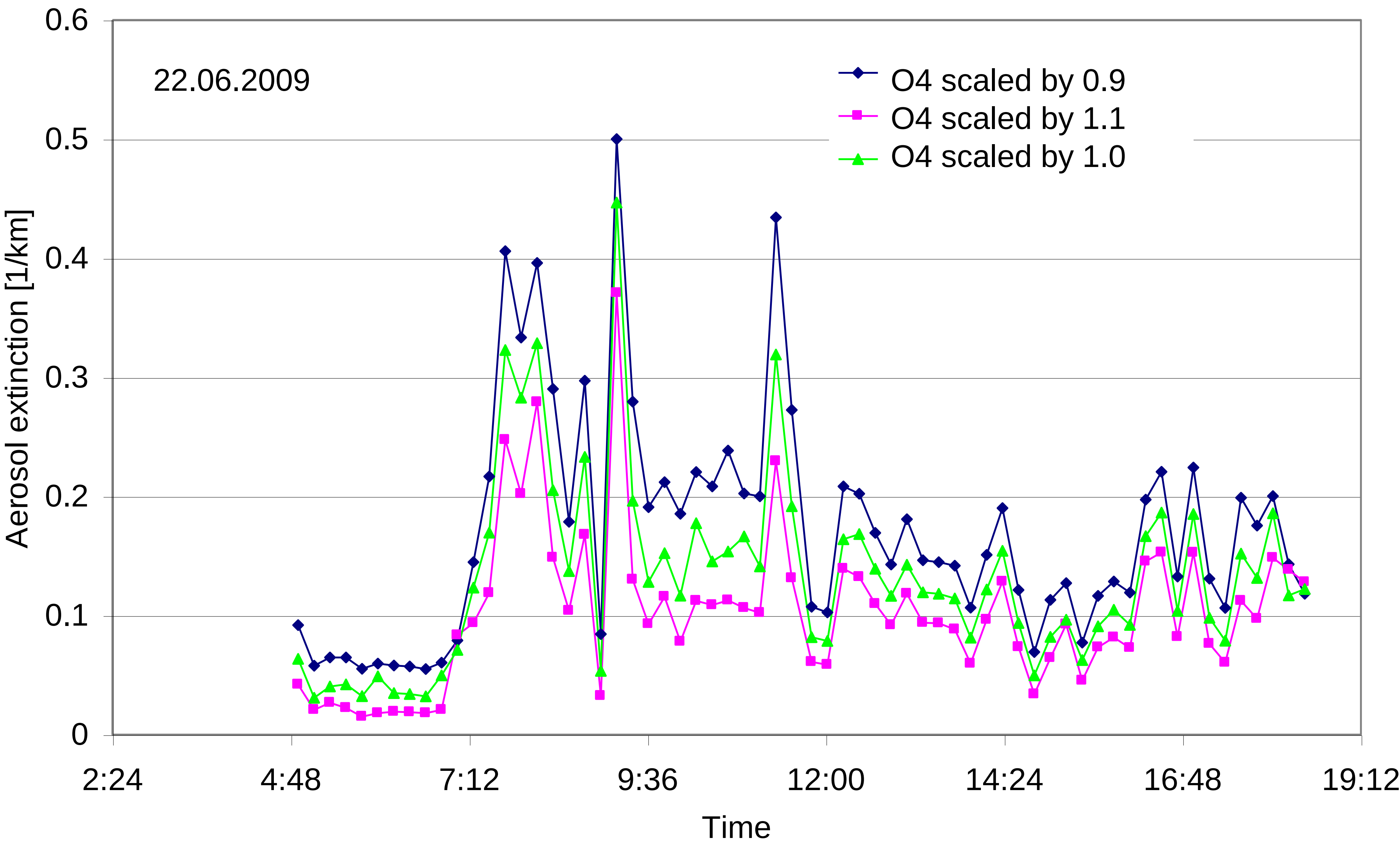
Cabauw, 03.07.2009
NO2 mixing ratio [ppb]
20
16
12
8
4
0
f: 0.5
f: 1.0
f: 0.2
EMPA in-situ
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time



O4 scaled by 0.9
O4 scaled by 1.1
O4 scaled by 1.0
22.06.2009
Chi^2
Time
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12



O4 scaled by 0.9
O4 scaled by 1.1
O4 scaled by 1.0
22.06.2009
Aerosol OD
3.5
3
2.5
2
1.5
1
0.5
0
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
Time



22.06.2009
O4 scaled by 0.9
O4 scaled by 1.1
O4 scaled by 1.0
Aerosol extinction [1/km]
0
0.1
0.2
0.3
0.4
0.5
0.6
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
Time

Conclusions

-simple inversion schemes for aerosols and NO_2

-in general good agreement with aeronet OD and in-situ NO_2

-NO_2 VCD agrees well with geometric approximation (30°)

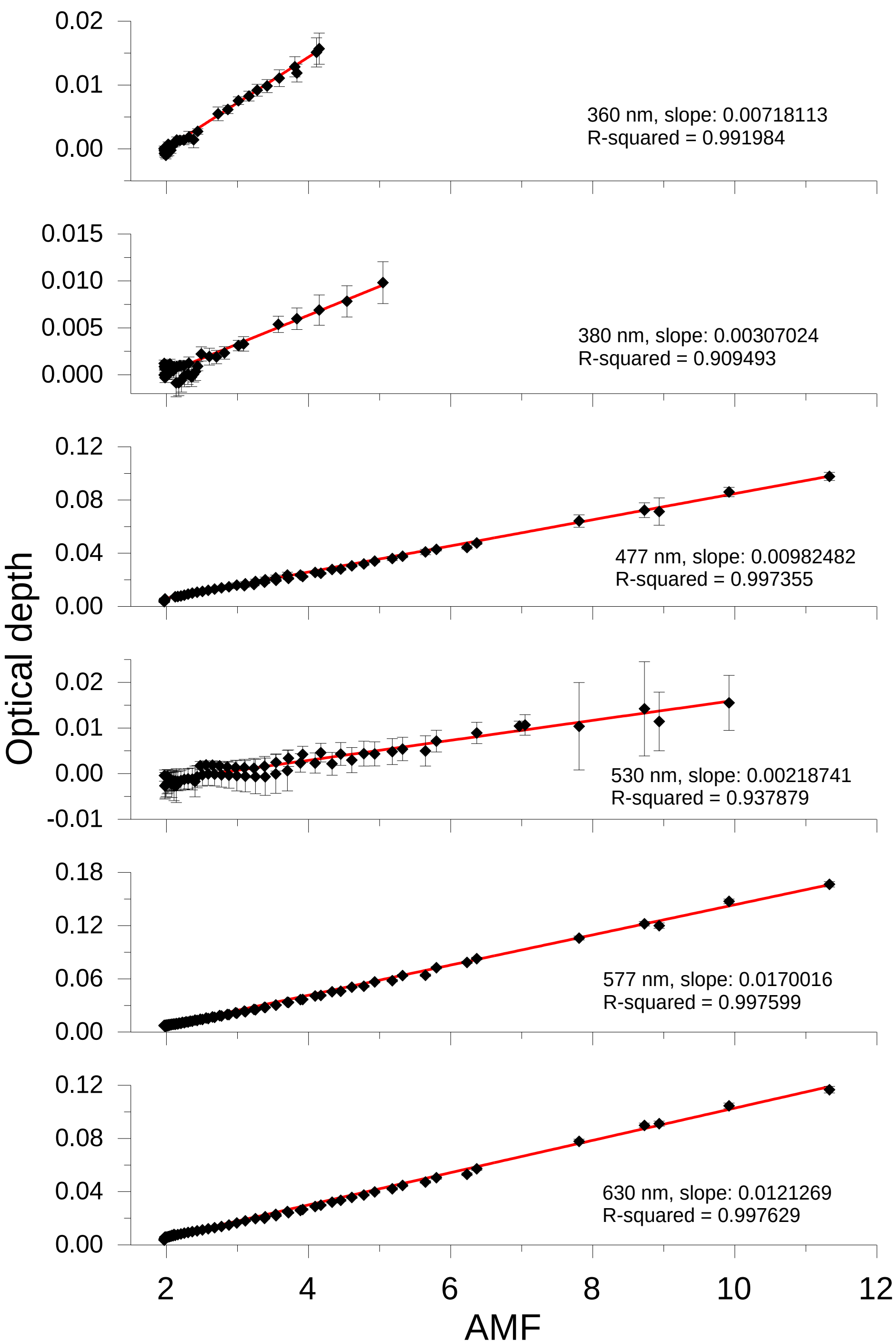
-profile information is limited

-retrievals are possible for many cloudy situations (except very thick clouds and rapidly varying clouds

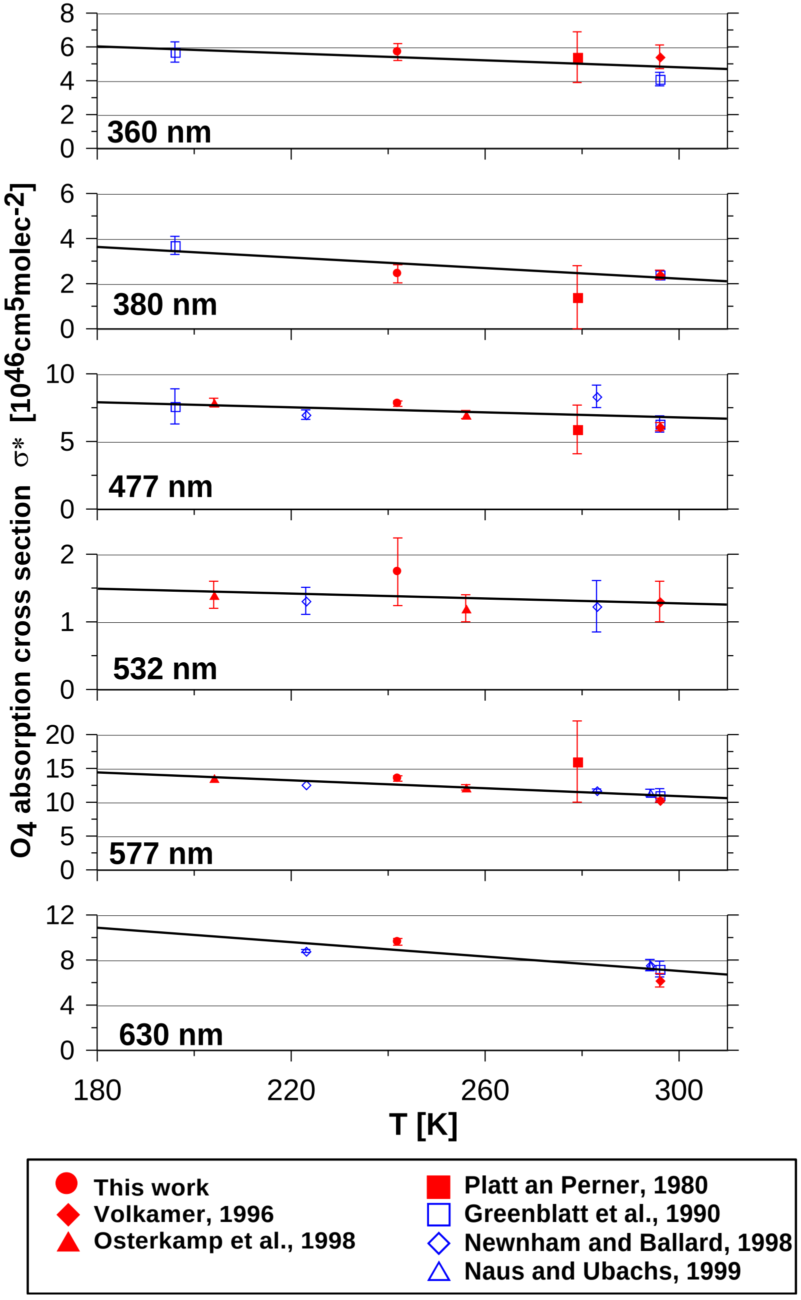
-especially for cloudy sky, aerosol extinction seems to be more reliable than aerosol OD

-in some cases (especially during morning) NO_2 mixing ratio depends on profile assumption

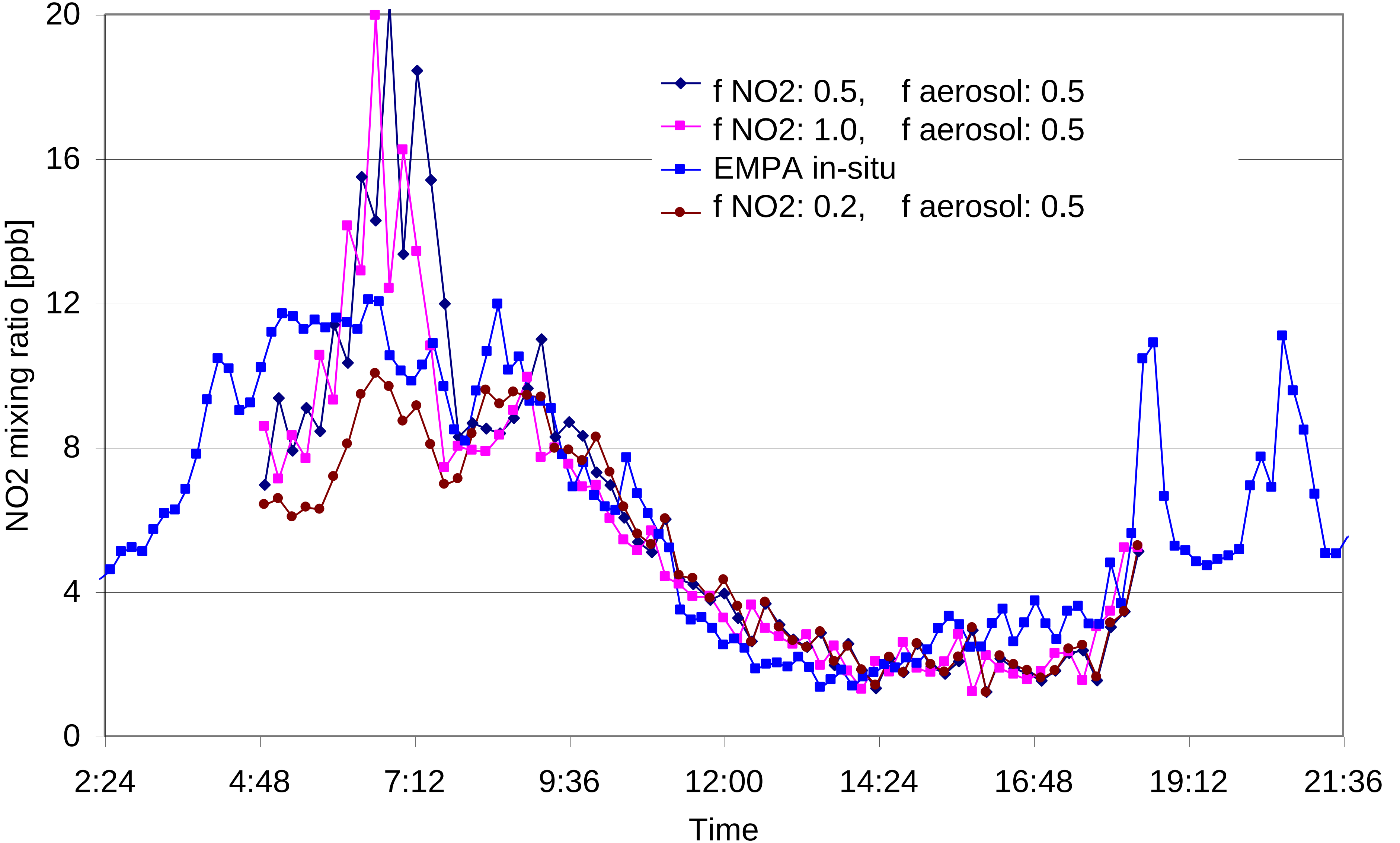
-for small aerosol OD the absolute value of the O_4 cross section (or O_4 VCD) becomes important



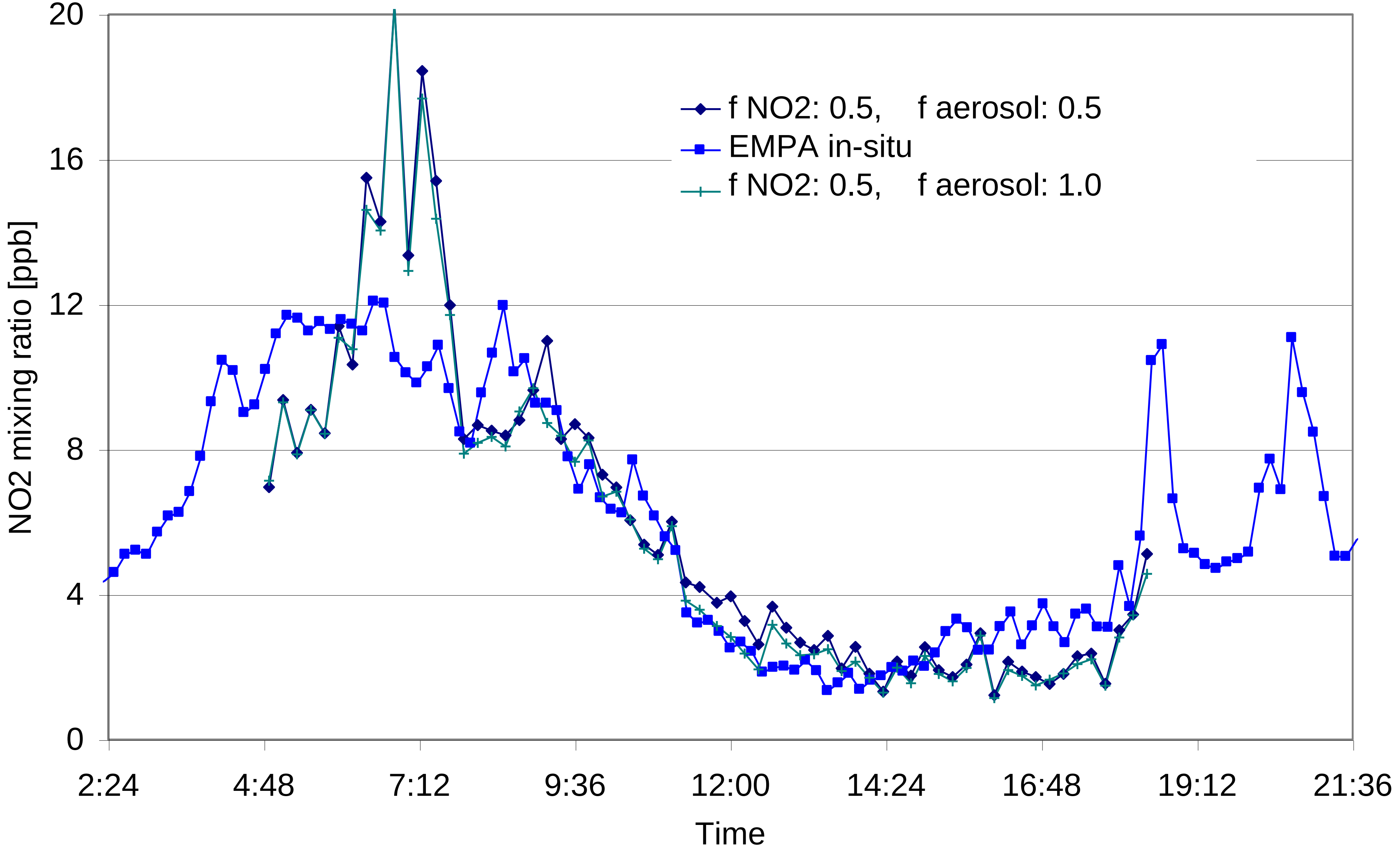
Optical depth
AMF
360 nm, slope: 0.00718113
R-squared = 0.991984
380 nm, slope: 0.00307024
R-squared = 0.909493
477 nm, slope: 0.00982482
R-squared = 0.997355
530 nm, slope: 0.00218741
R-squared = 0.937879
577 nm, slope: 0.0170016
R-squared = 0.997599
630 nm, slope: 0.0121269
R-squared = 0.997629



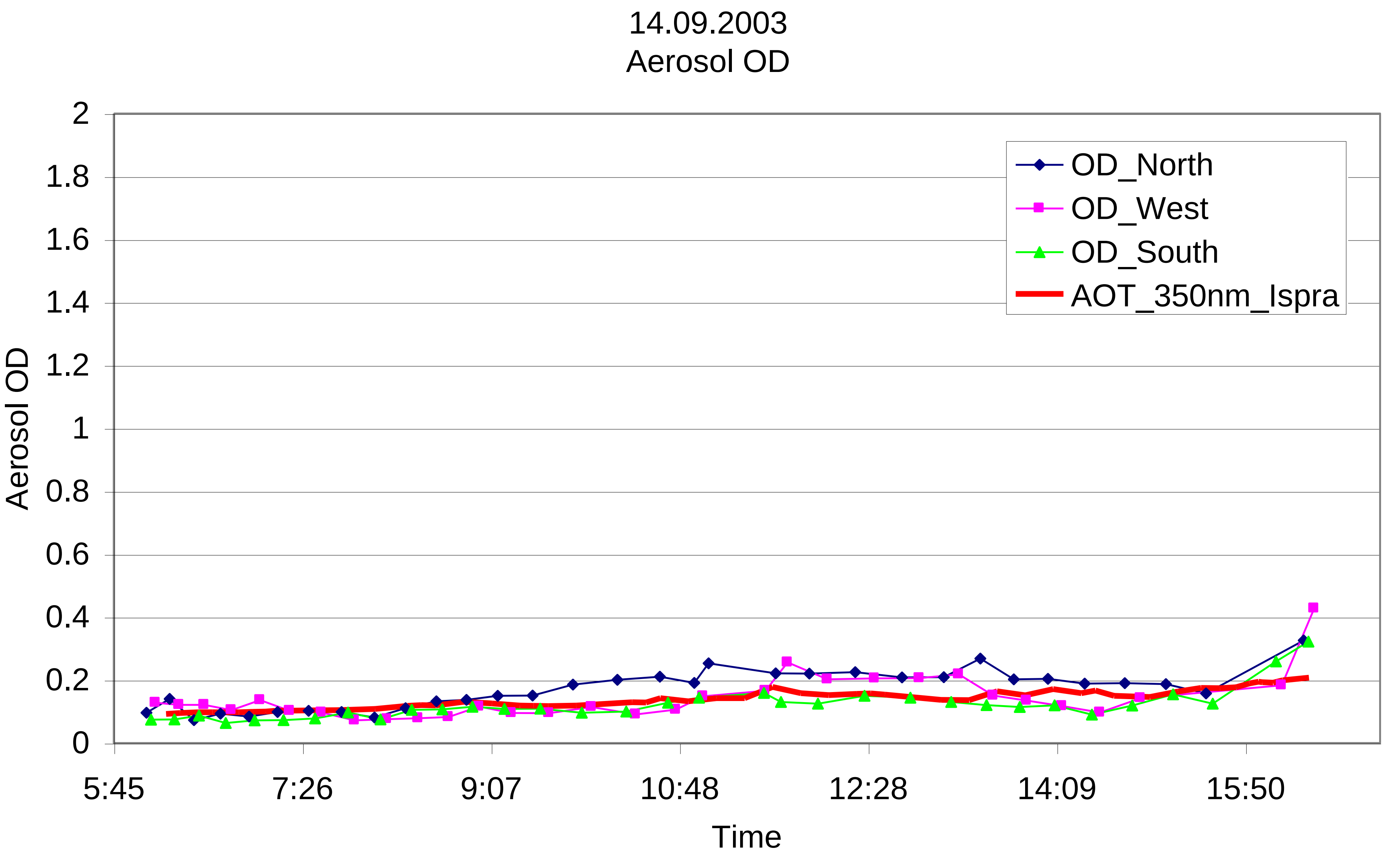
O4 absorption cross section σ* [10^46cm^5molec^-2]
360 nm
380 nm
477 nm
532 nm
577 nm
630 nm
T [K]
This work
Volkamer, 1996
Osterkamp et al., 1998
Platt an Perner, 1980
Greenblatt et al., 1990
Newnham and Ballard, 1998
Naus and Ubachs, 1999



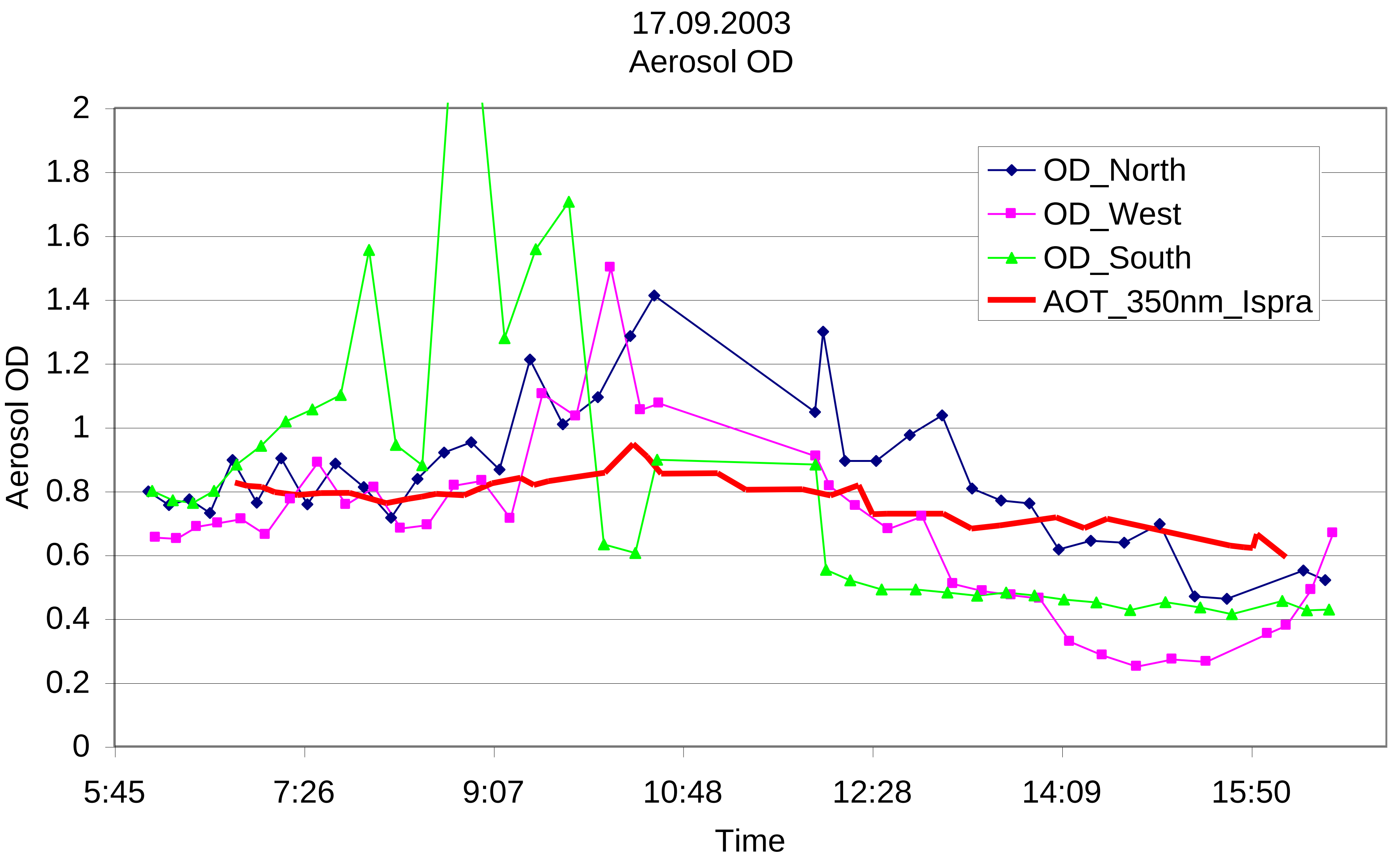
f NO2: 0.5, f aerosol: 0.5
f NO2: 1.0, f aerosol: 0.5
EMPA in-situ
f NO2: 0.2, f aerosol: 0.5
NO2 mixing ratio [ppb]
0
4
8
12
16
20
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time

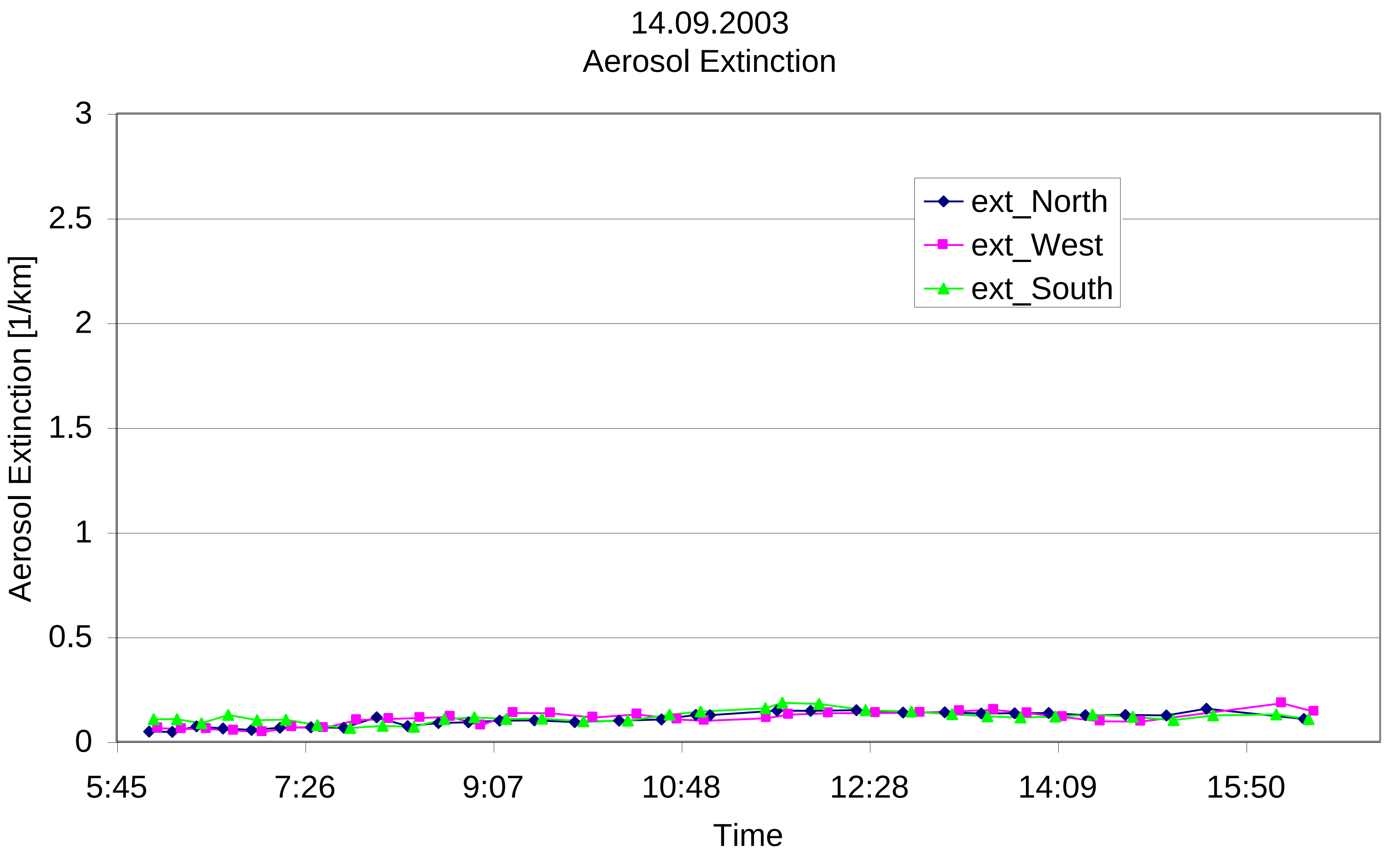


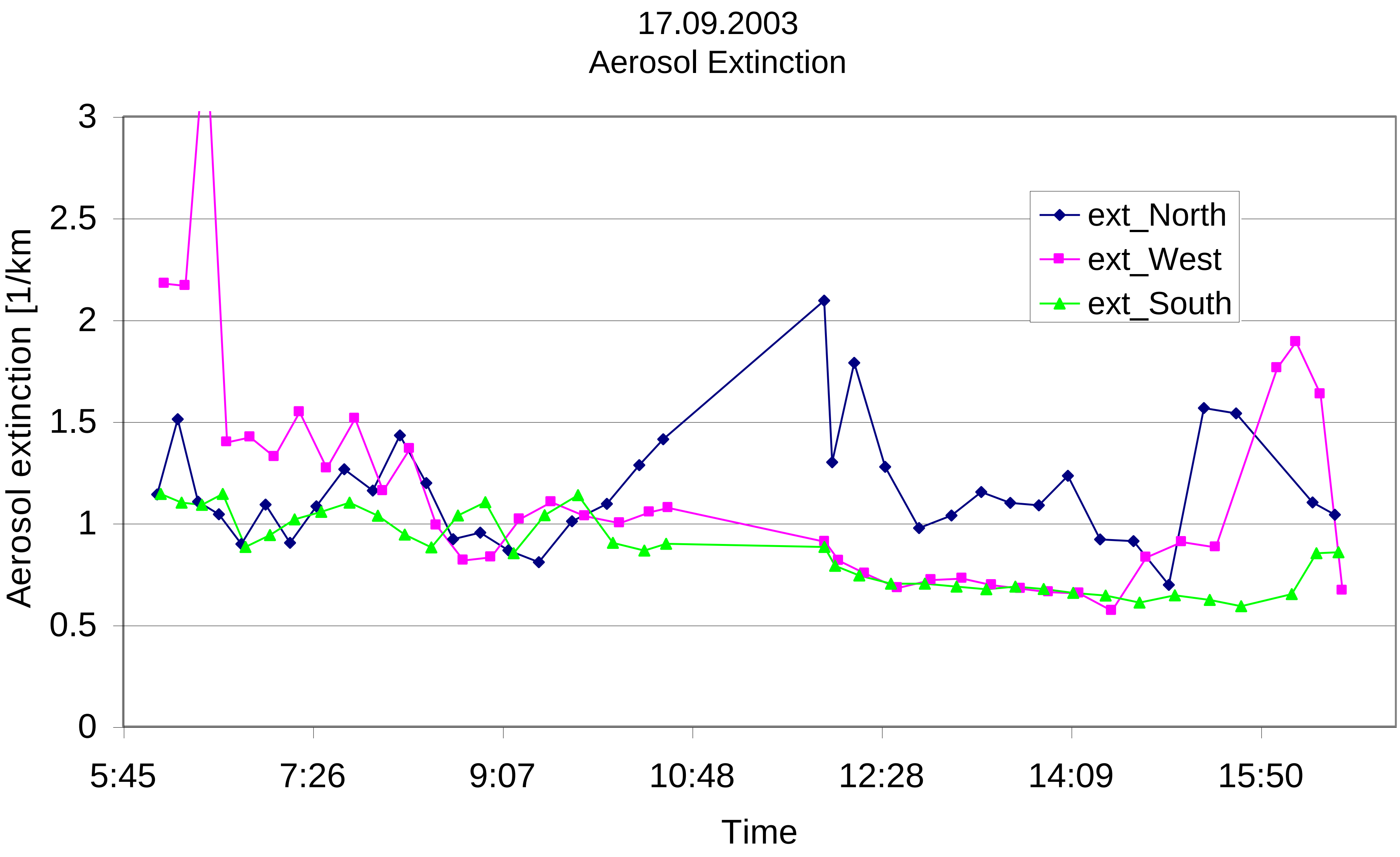
20
16
12
8
4
0
NO2 mixing ratio [ppb]
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time
f NO2: 0.5, f aerosol: 0.5
EMPA in-situ
f NO2: 0.5, f aerosol: 1.0

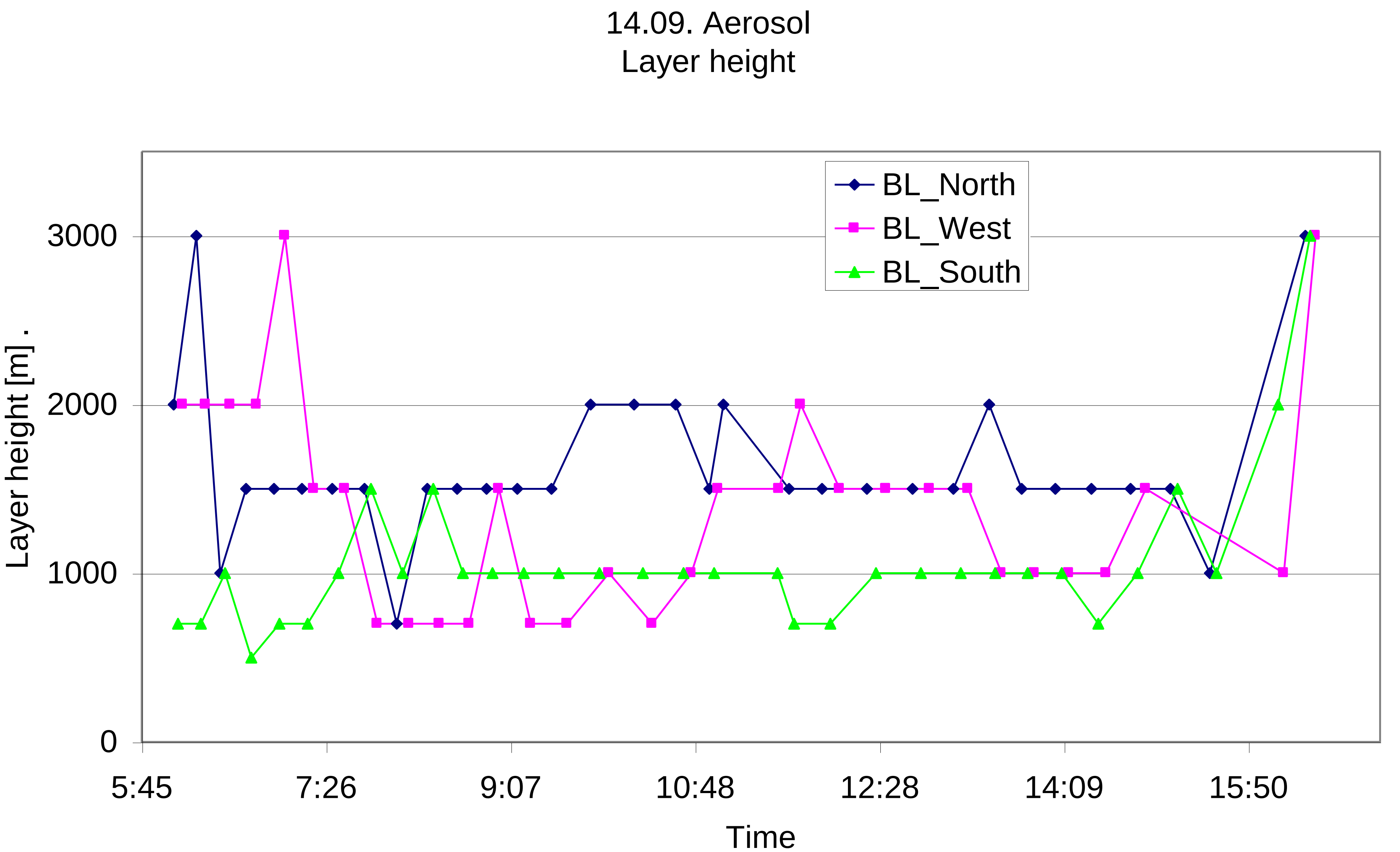


14.09.2003
Aerosol OD
Aerosol OD
Time
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
5:45
7:26
9:07
10:48
12:28
14:09
15:50
OD_North
OD_West
OD_South
AOT_350nm_Ispra

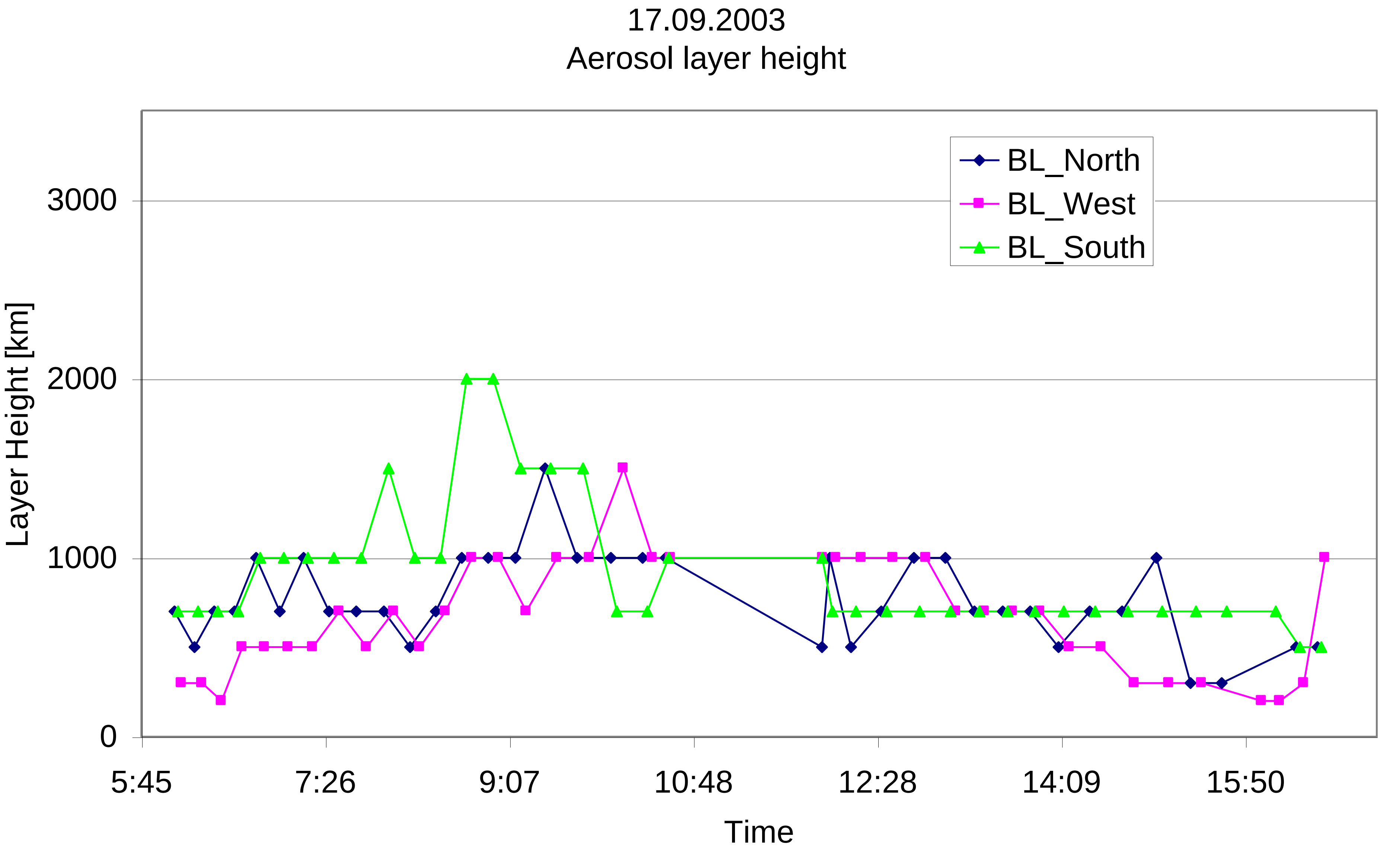

17.09.2003
Aerosol OD
Aerosol OD
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
5:45
7:26
9:07
10:48
12:28
14:09
15:50
Time
OD_North
OD_West
OD_South
AOT_350nm_Ispra

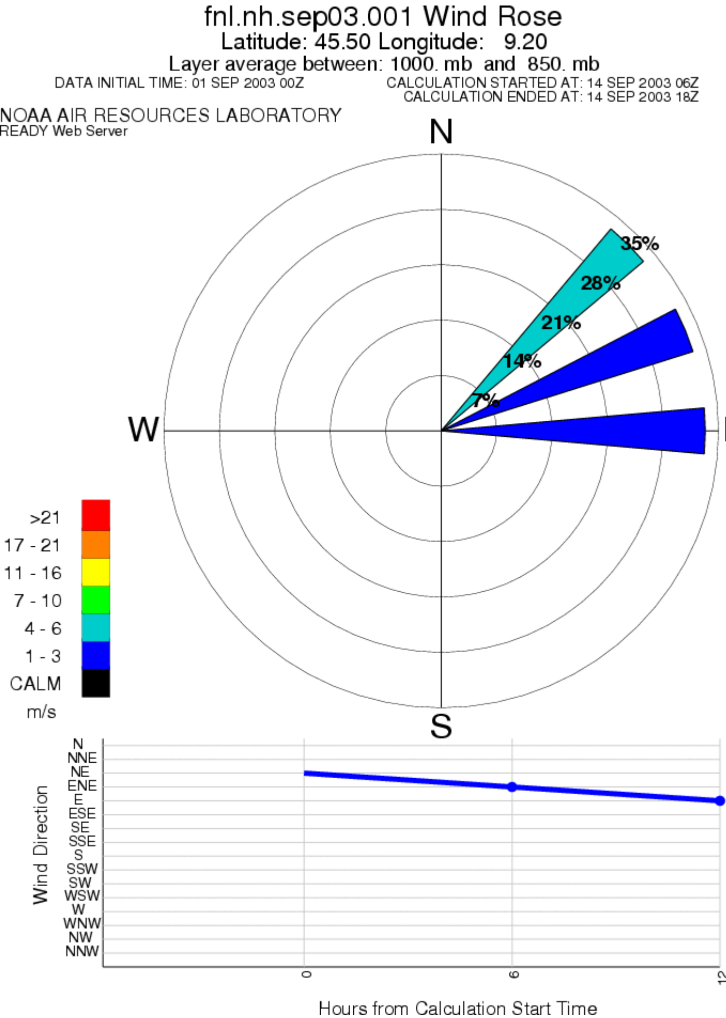

14.09.2003
Aerosol Extinction
ext_North
ext_West
ext_South
Aerosol Extinction [1/km]
3
2.5
2
1.5
1
0.5
0
5:45
7:26
9:07
10:48
12:28
14:09
15:50
Time

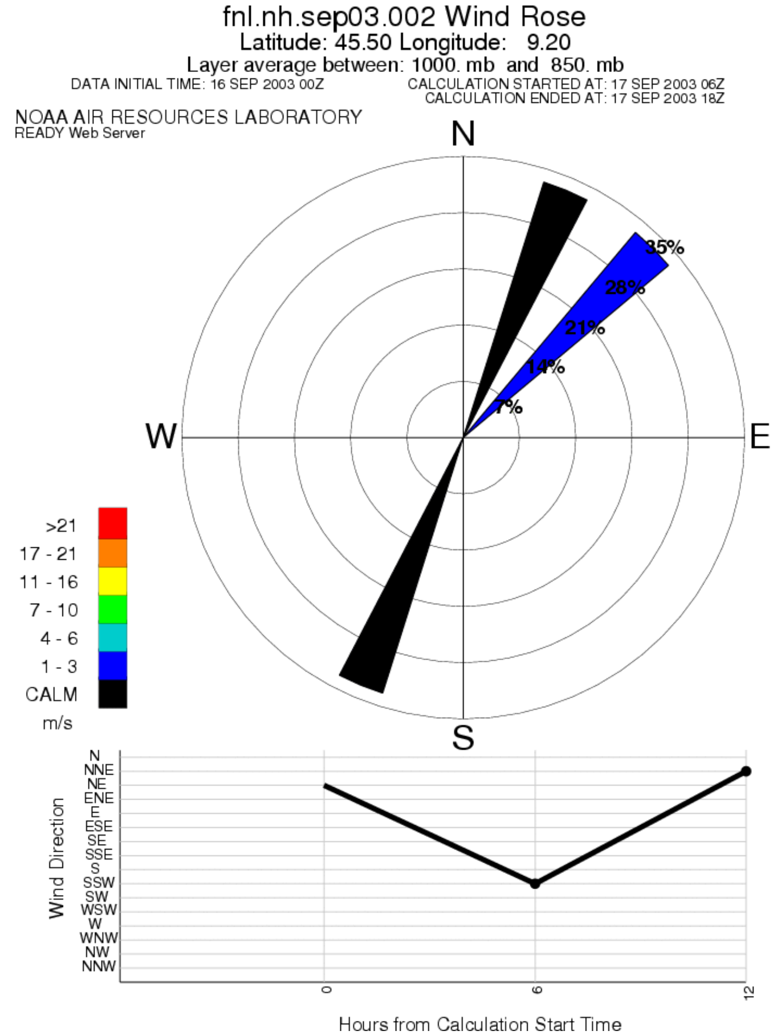

17.09.2003
Aerosol Extinction
Aerosol extinction [1/km
Time
0
0.5
1
1.5
2
2.5
3
5:45
7:26
9:07
10:48
12:28
14:09
15:50
ext_North
ext_West
ext_South



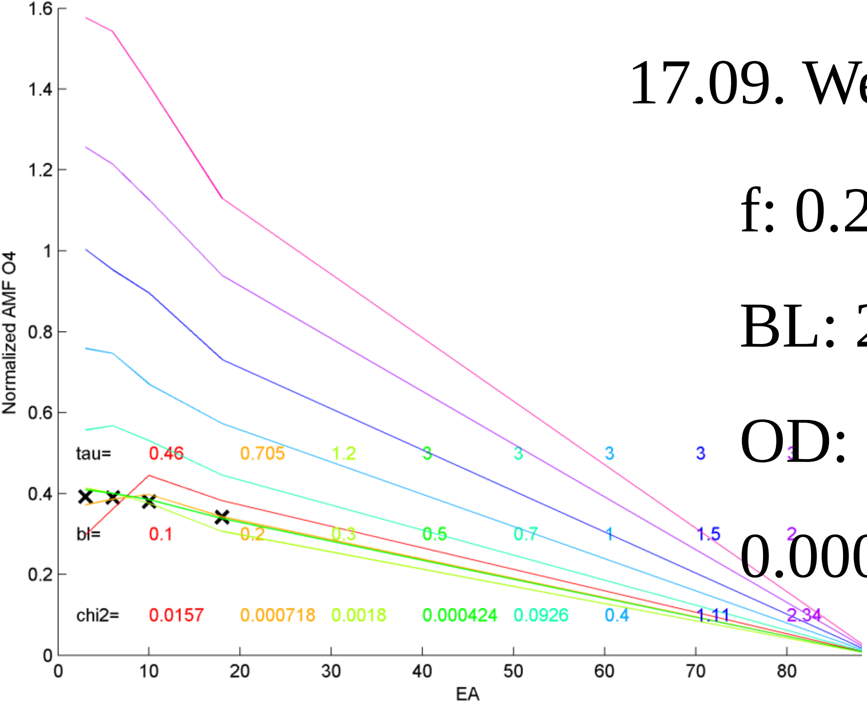
14.09. Aerosol
Layer height
BL_North
BL_West
BL_South
Layer height [m] .
3000
2000
1000
0
5:45
7:26
9:07
10:48
12:28
14:09
15:50
Time


17.09.2003
Aerosol layer height
BL_North
BL_West
BL_South
Layer Height [km]
3000
2000
1000
0
5:45
7:26
9:07
10:48
12:28
14:09
15:50
Time


fnl.nh.sep03.001 Wind Rose
Latitude: 45.50 Longitude: 9.20
Layer average between: 1000. mb and 850. mb
DATA INITIAL TIME: 01 SEP 2003 00Z
CALCULATION STARTED AT: 14 SEP 2003 06Z
CALCULATION ENDED AT: 14 SEP 2003 18Z
NOAA AIR RESOURCES LABORATORY
READY Web Server
N
E
S
W
7%
14%
21%
28%
35%
>21
17 - 21
11 - 16
7 - 10
4 - 6
1 - 3
CALM
m/s
Wind Direction
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
0
6
12
Hours from Calculation Start Time


fnl.nh.sep03.002 Wind Rose
Latitude: 45.50 Longitude: 9.20
Layer average between: 1000. mb and 850. mb
DATA INITIAL TIME: 16 SEP 2003 00Z
CALCULATION STARTED AT: 17 SEP 2003 06Z
CALCULATION ENDED AT: 17 SEP 2003 18Z
NOAA AIR RESOURCES LABORATORY
READY Web Server
N
E
S
W
7%
14%
21%
28%
35%
>21
17 - 21
11 - 16
7 - 10
4 - 6
1 - 3
CALM
m/s
Wind Direction
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
0
6
12
Hours from Calculation Start Time

17.09. West, seq. 32

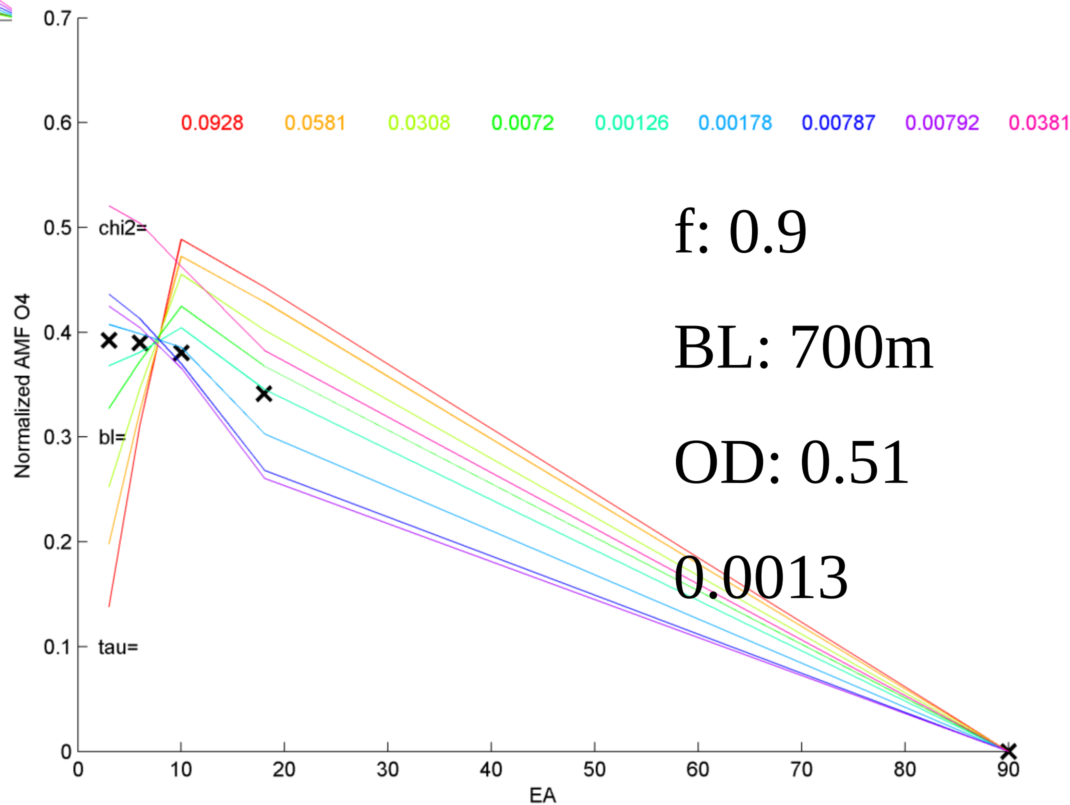


f: 0.2

BL: 200m

OD: 0.71

0.0007



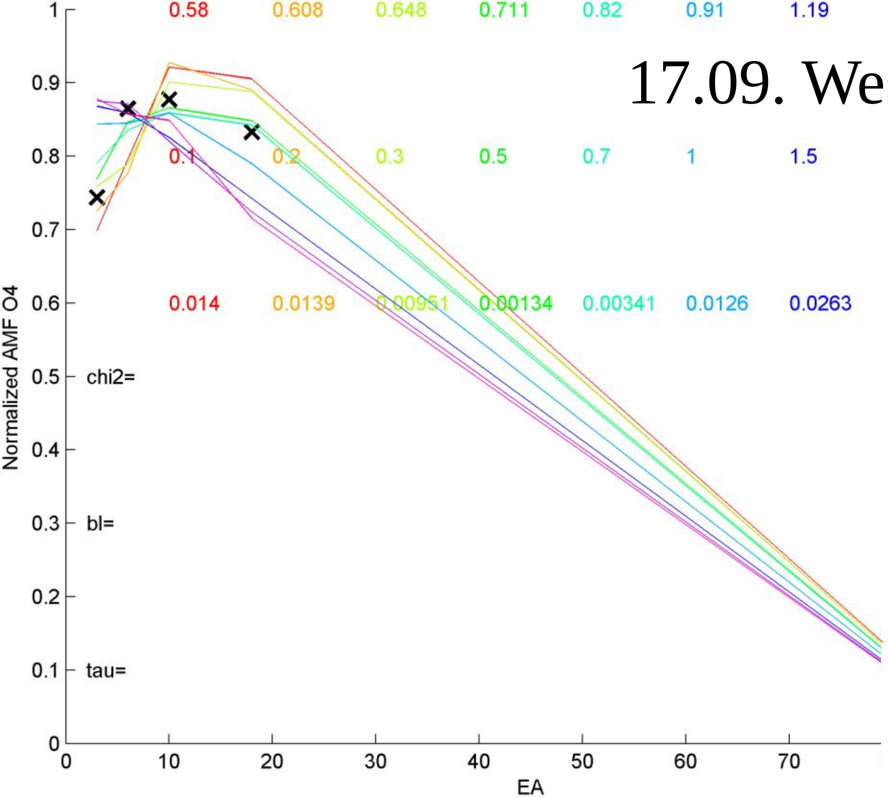
f: 0.9

BL: 700m

OD: 0.51

0.0013

17.09. West, seq. 11

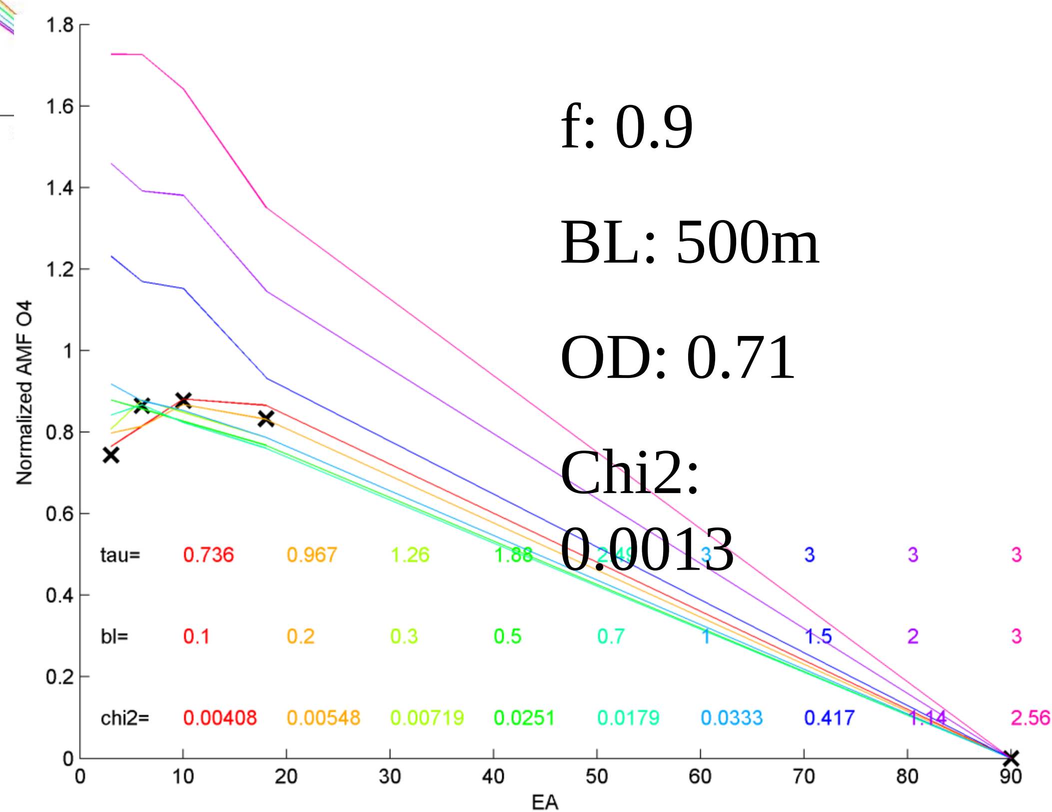


f: 0.2

BL: 100m

OD: 0.74

0.0041

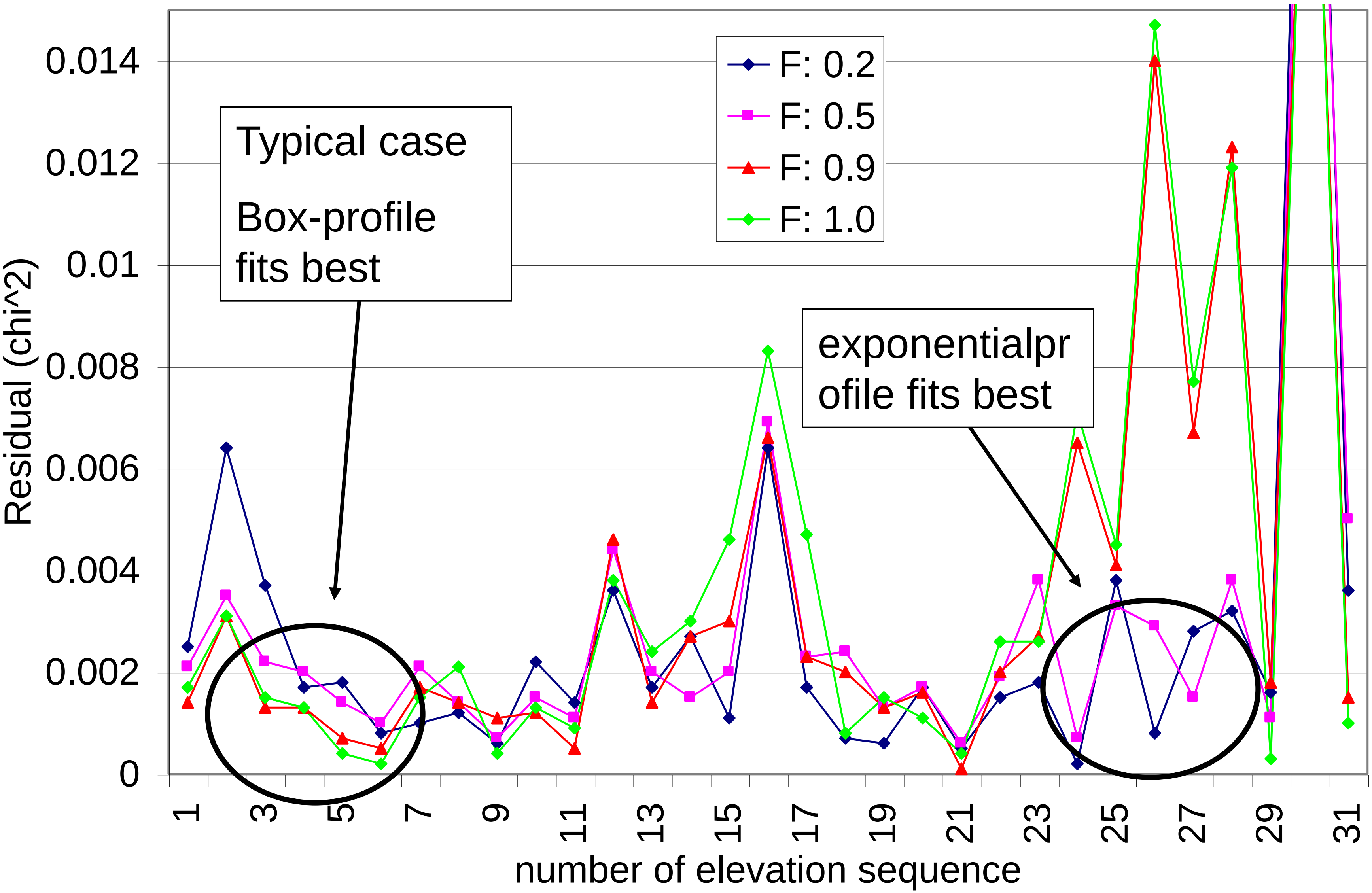


f: 0.9

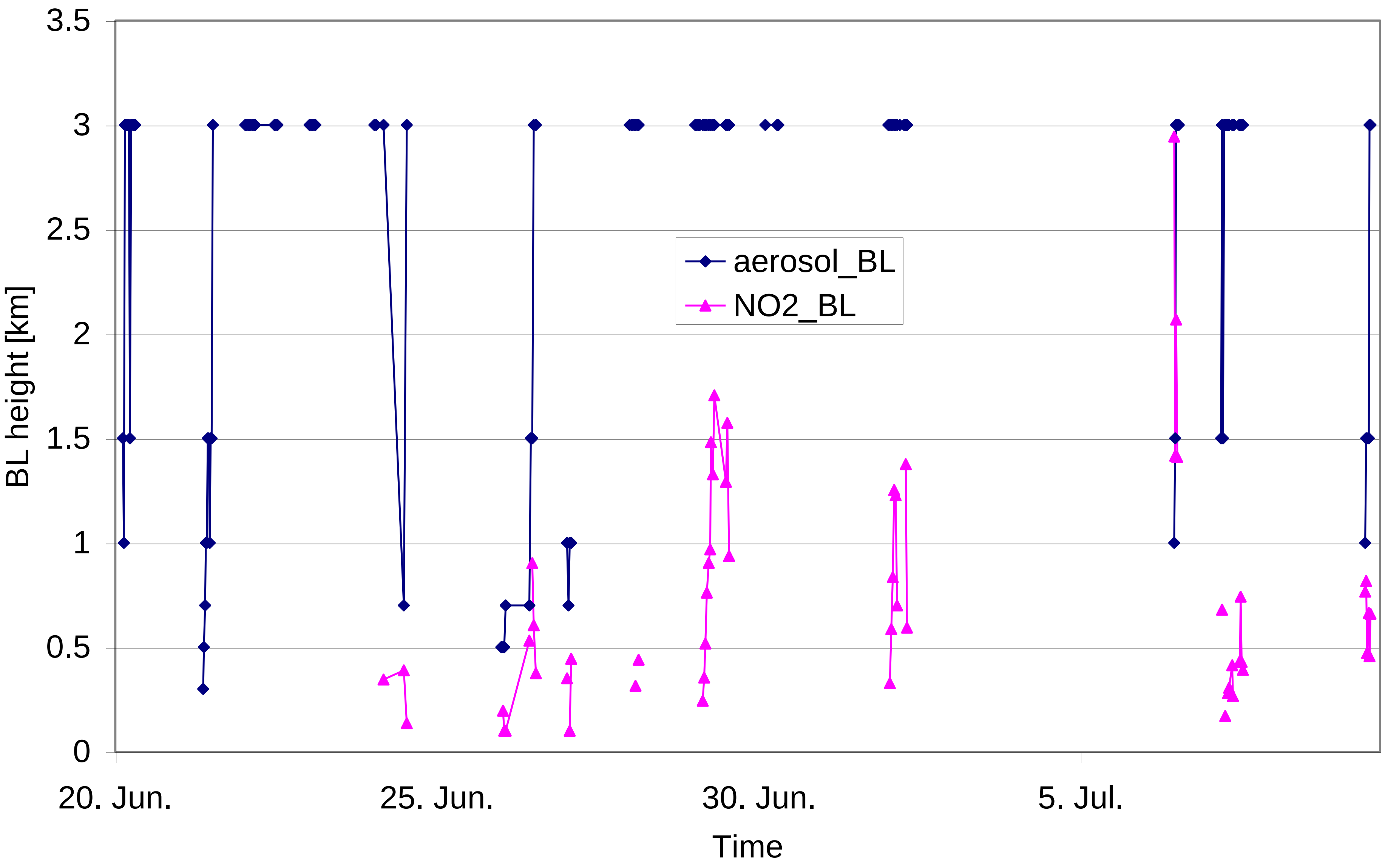
BL: 500m

OD: 0.71

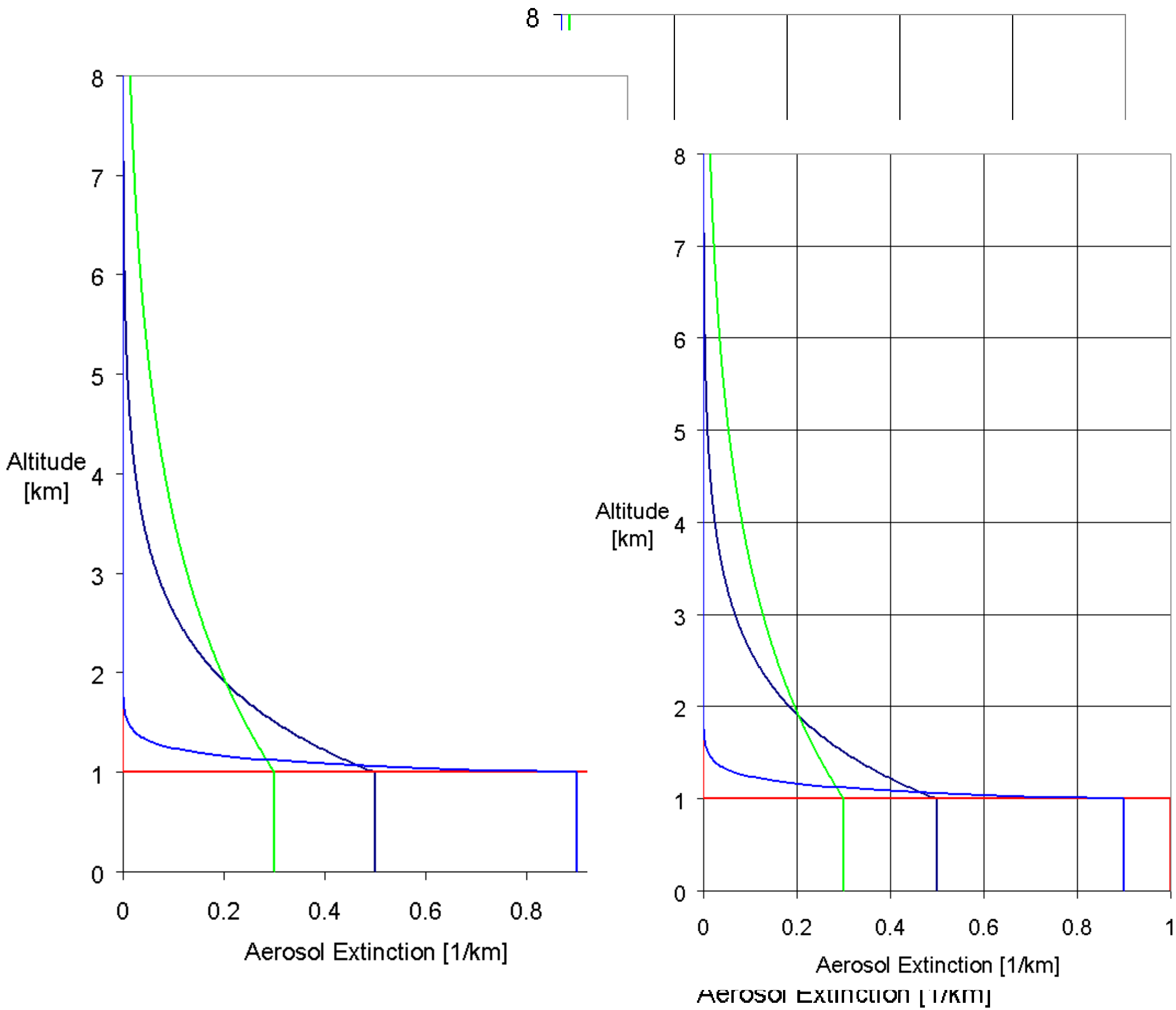
Chi2:
0.0013

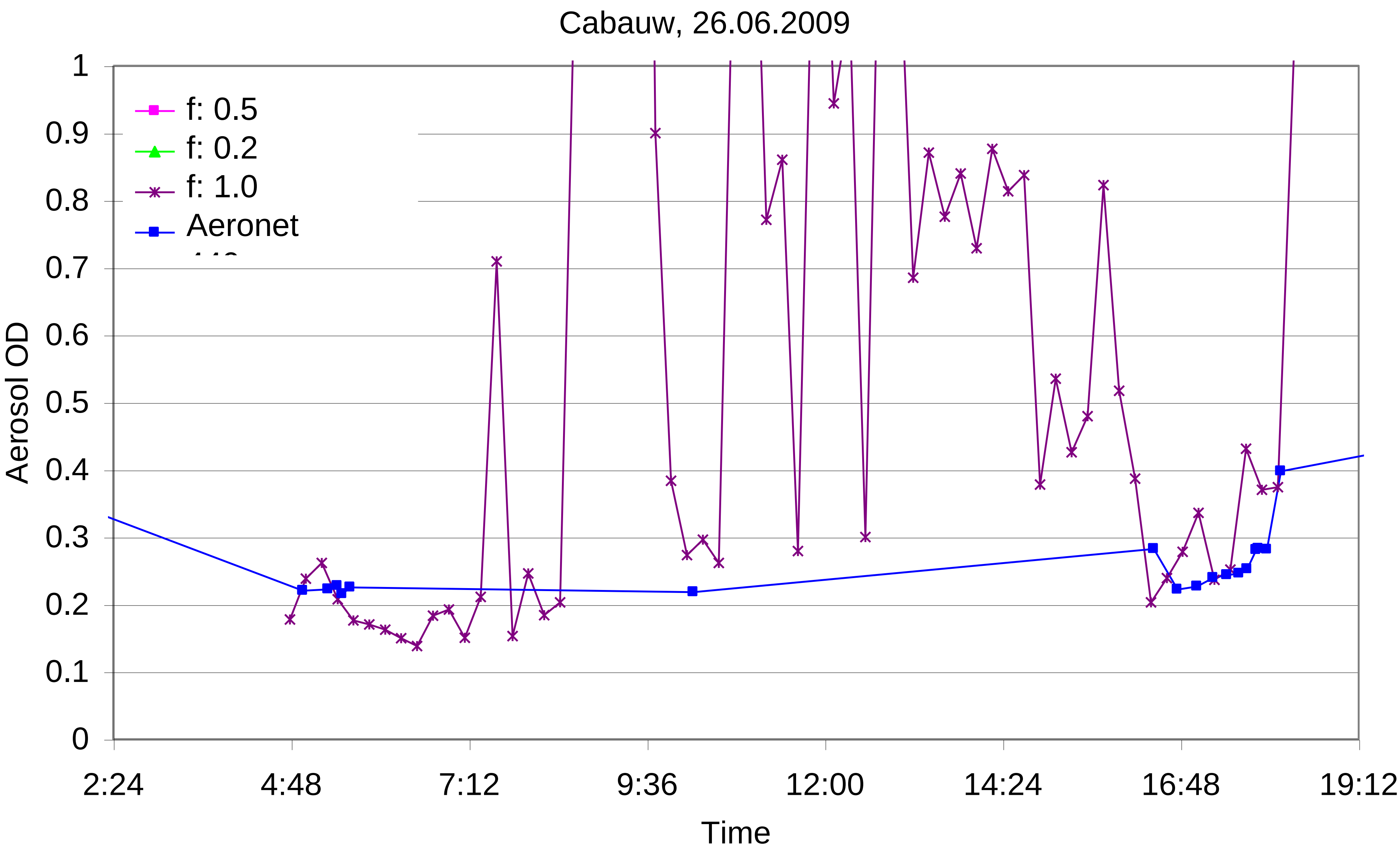


F: 0.2
F: 0.5
F: 0.9
F: 1.0
Typical case
Box-profile fits best
exponentialpr ofile fits best
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
Residual (chi^2)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
number of elevation sequence

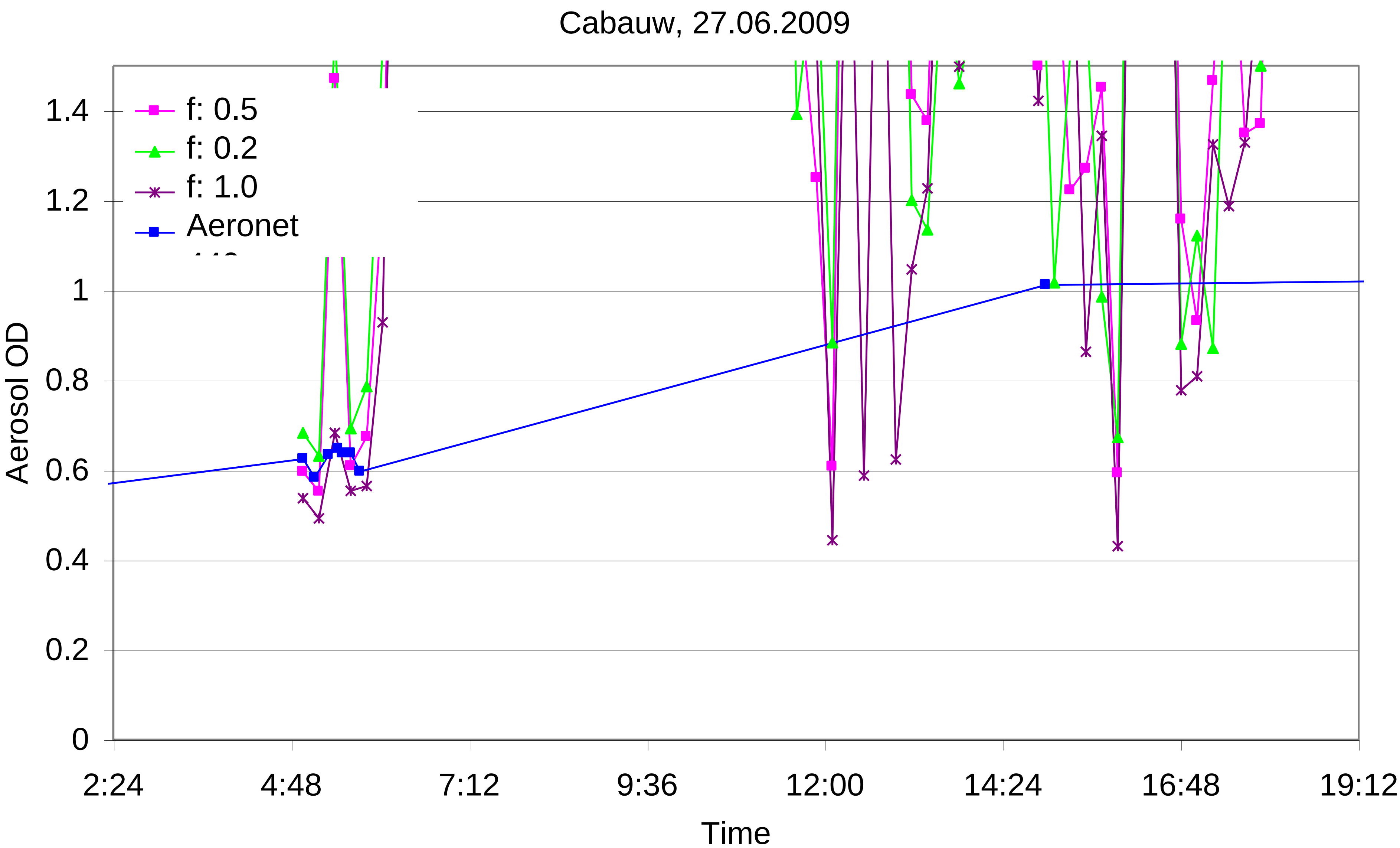


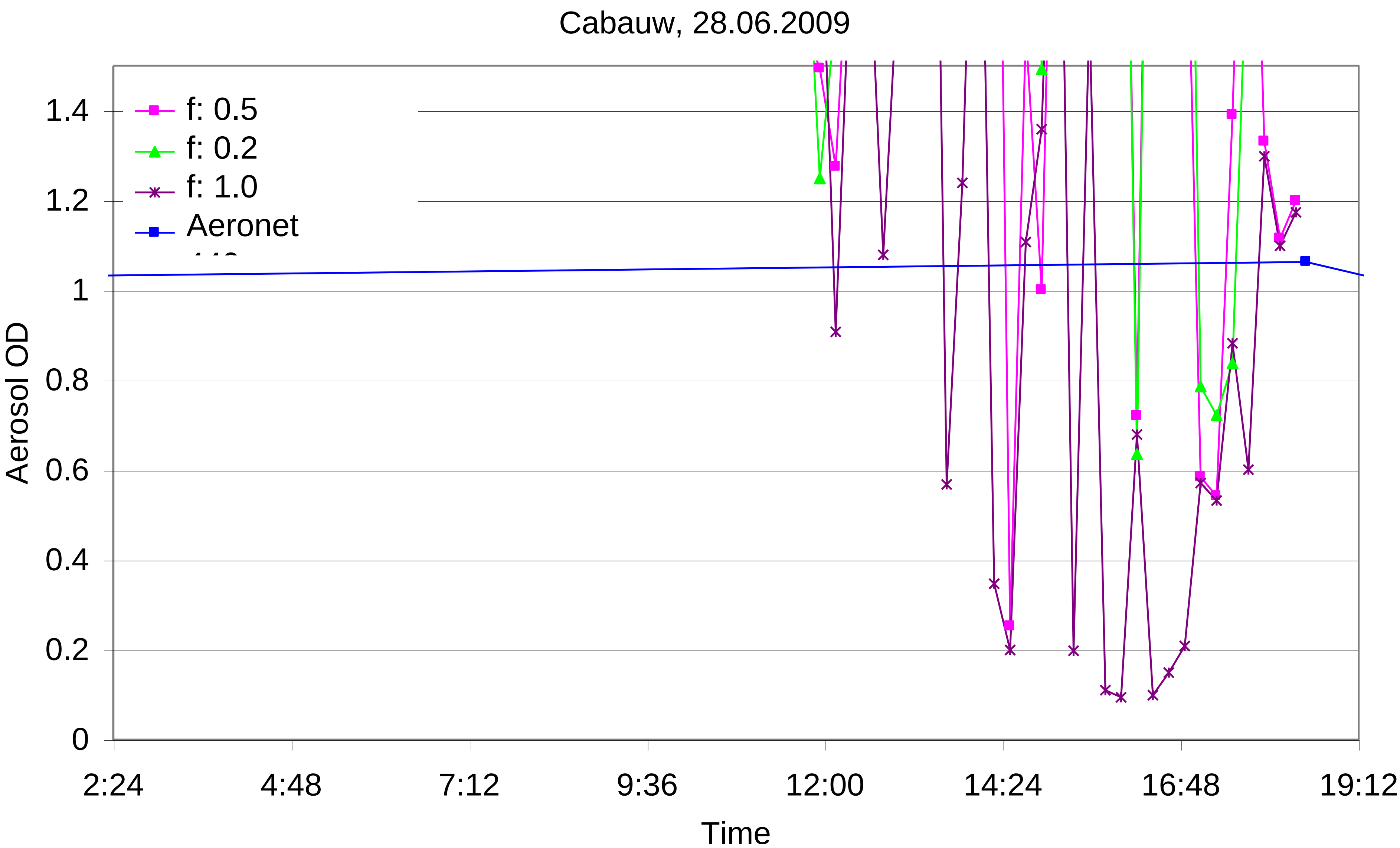
3.5
3
2.5
2
1.5
1
0.5
0
BL height [km]
aerosol_BL
NO2_BL
20. Jun.
25. Jun.
30. Jun.
5. Jul.
Time


Altitude [km]
Aerosol Extinction [1/km]
Altitude [km]
Aerosol Extinction [1/km]

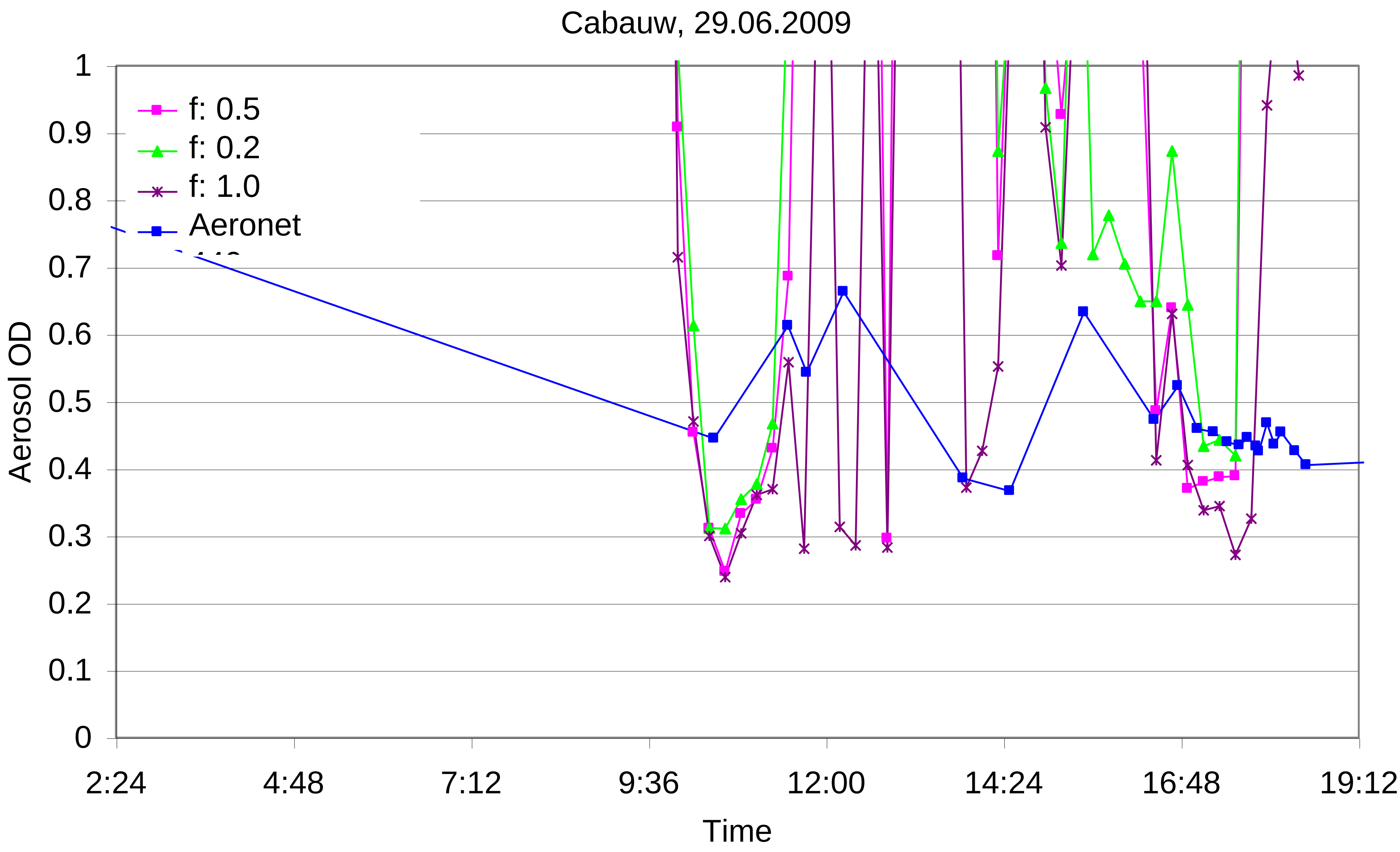


Cabauw, 26.06.2009
Aerosol OD
Time
f: 0.5
f: 0.2
f: 1.0
Aeronet
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12

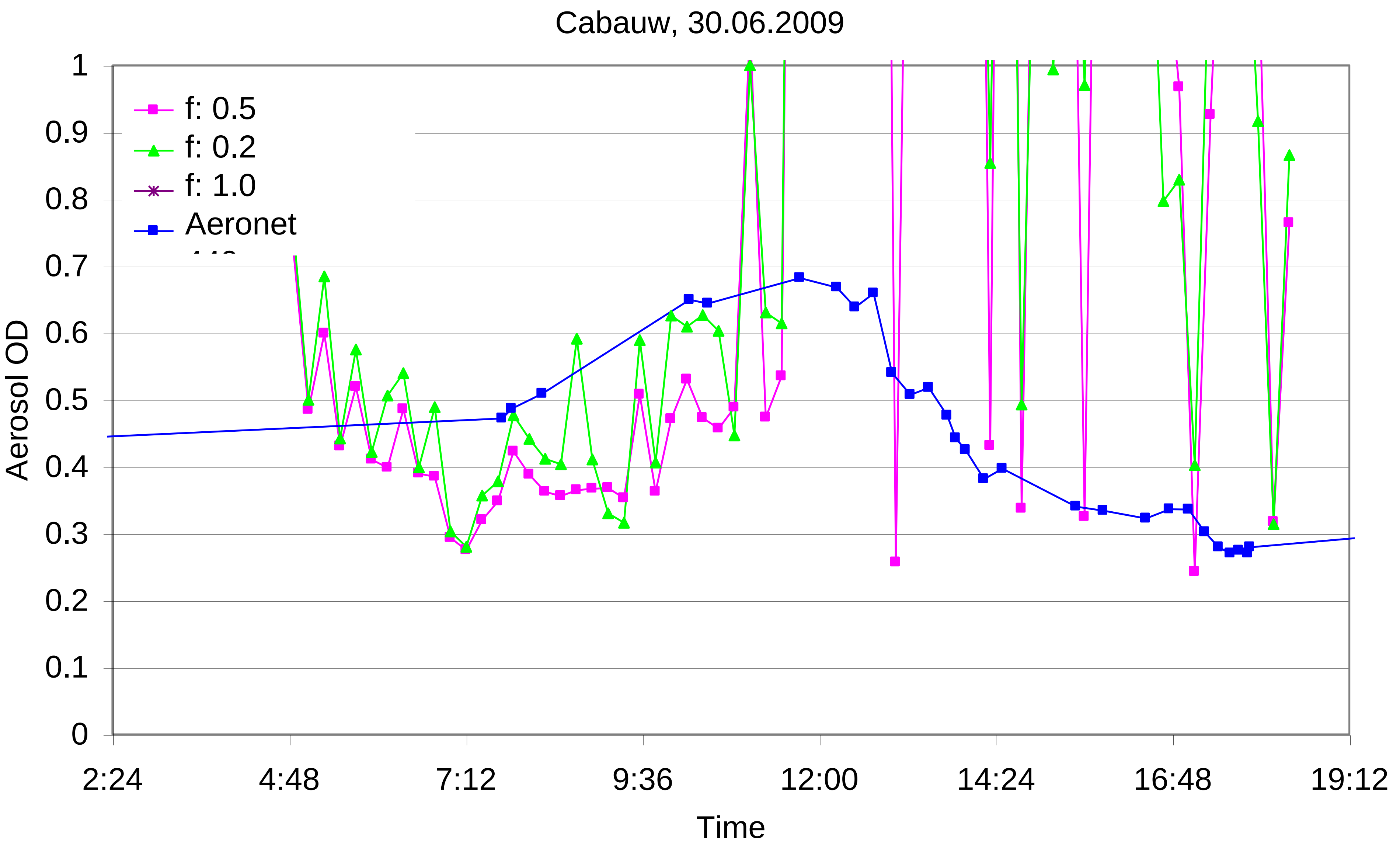

Cabauw, 27.06.2009
f: 0.5
f: 0.2
f: 1.0
Aeronet
Aerosol OD
0
0.2
0.4
0.6
0.8
1
1.2
1.4
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
Time

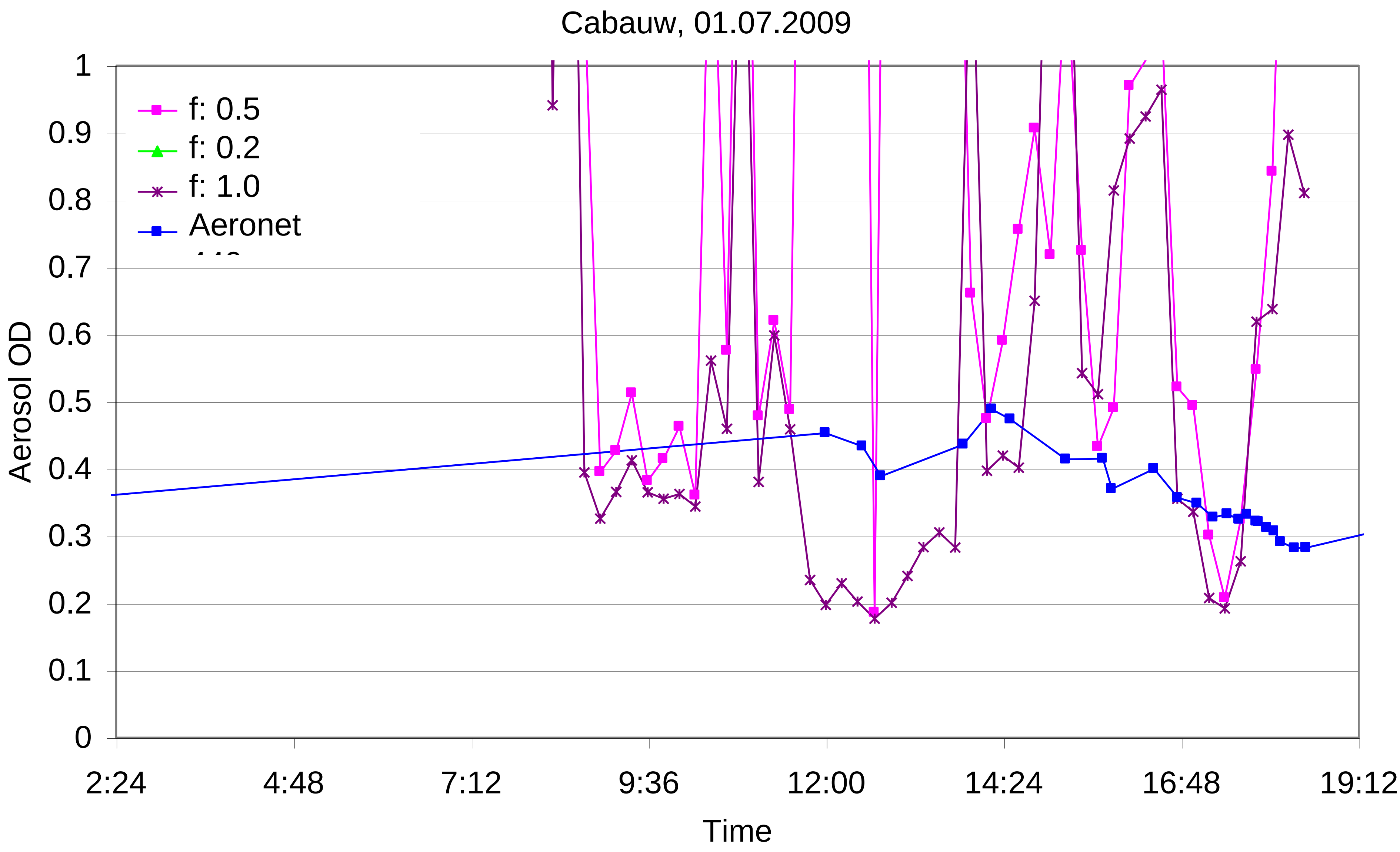


Cabauw, 28.06.2009
Aerosol OD
1.4
1.2
1
0.8
0.6
0.4
0.2
0
f: 0.5
f: 0.2
f: 1.0
Aeronet
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
Time

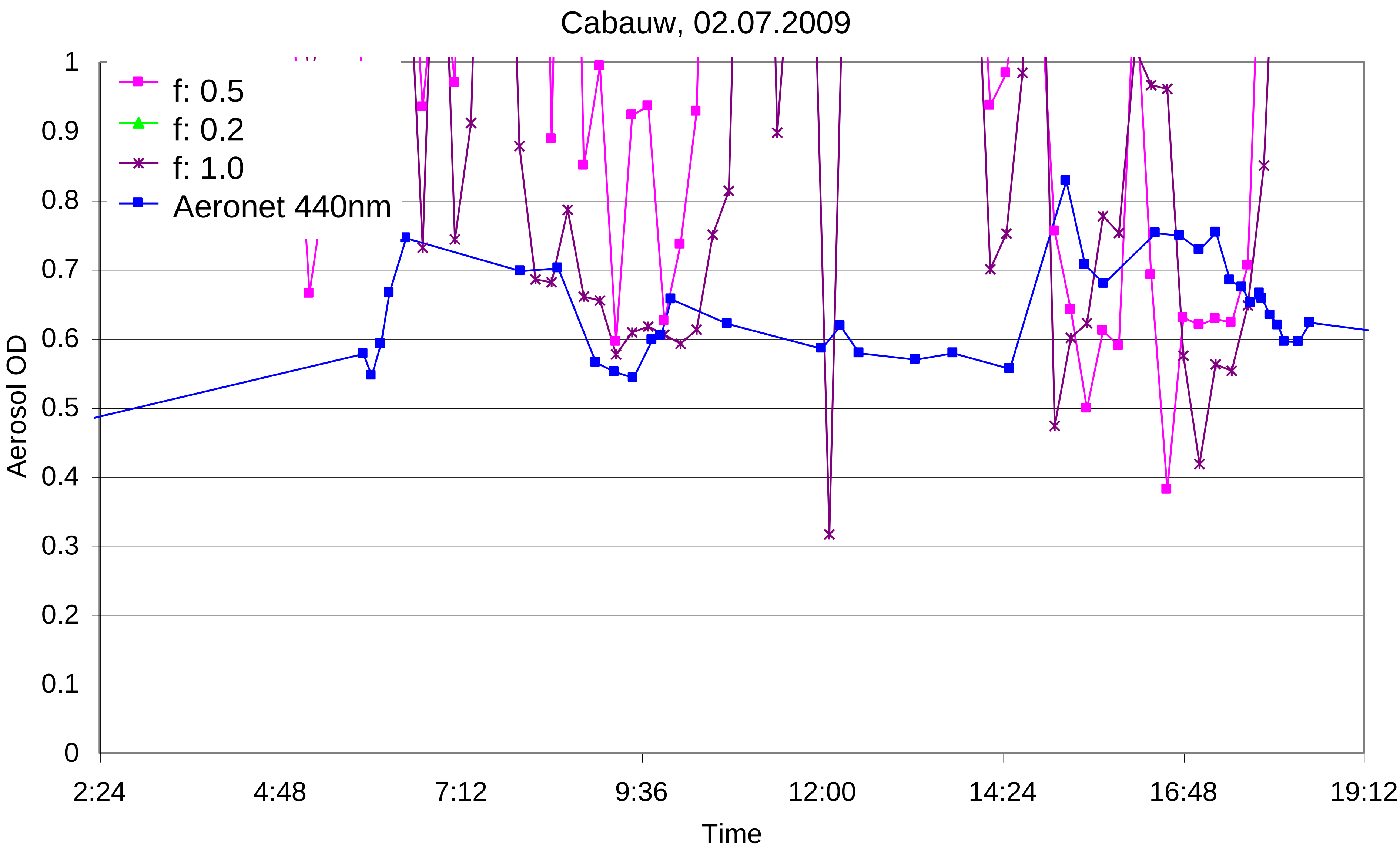


Cabauw, 29.06.2009
Aerosol OD
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
f: 0.5
f: 0.2
f: 1.0
Aeronet
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
Time

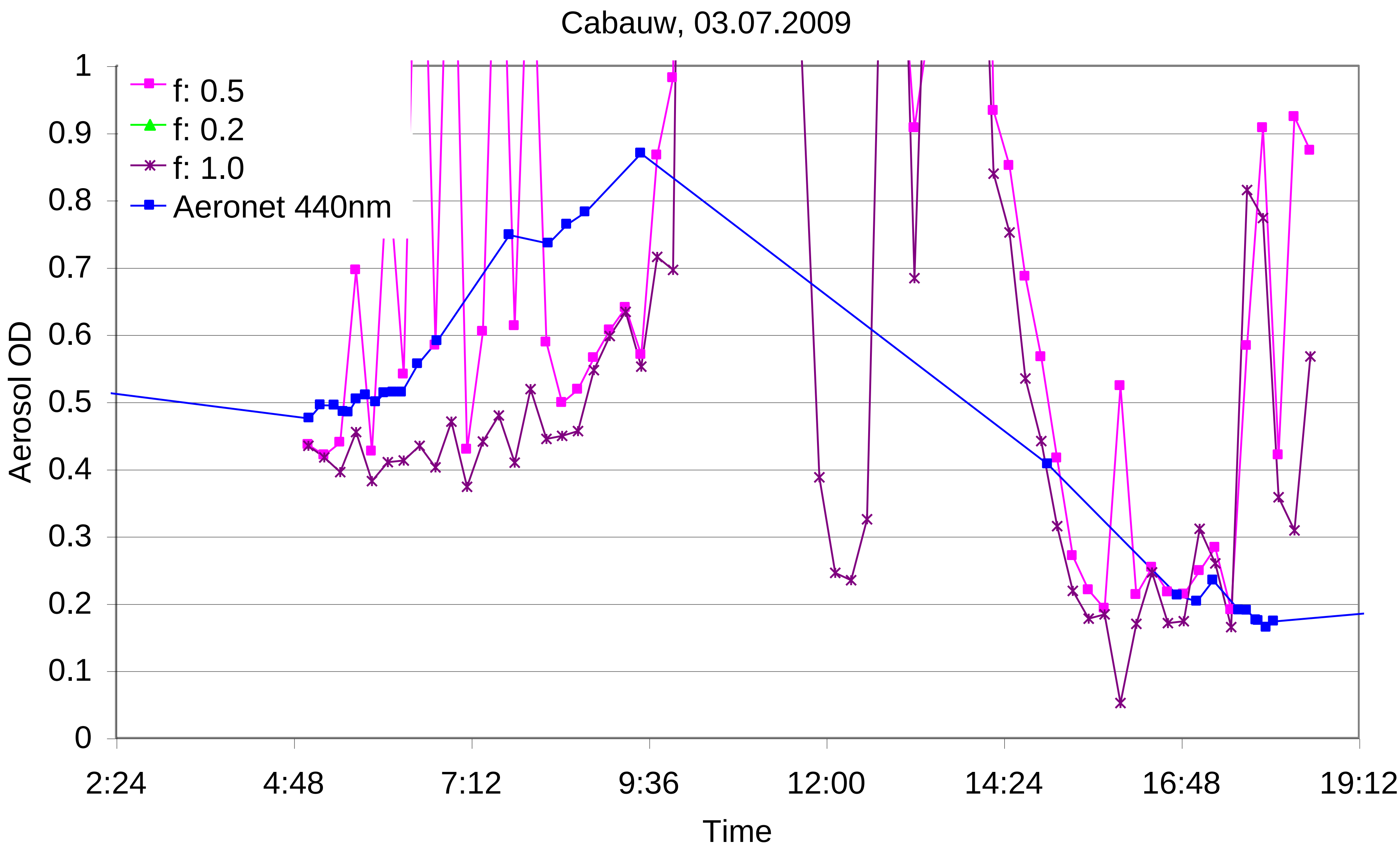

Cabauw, 30.06.2009
Aerosol OD
Time
f: 0.5
f: 0.2
f: 1.0
Aeronet
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12



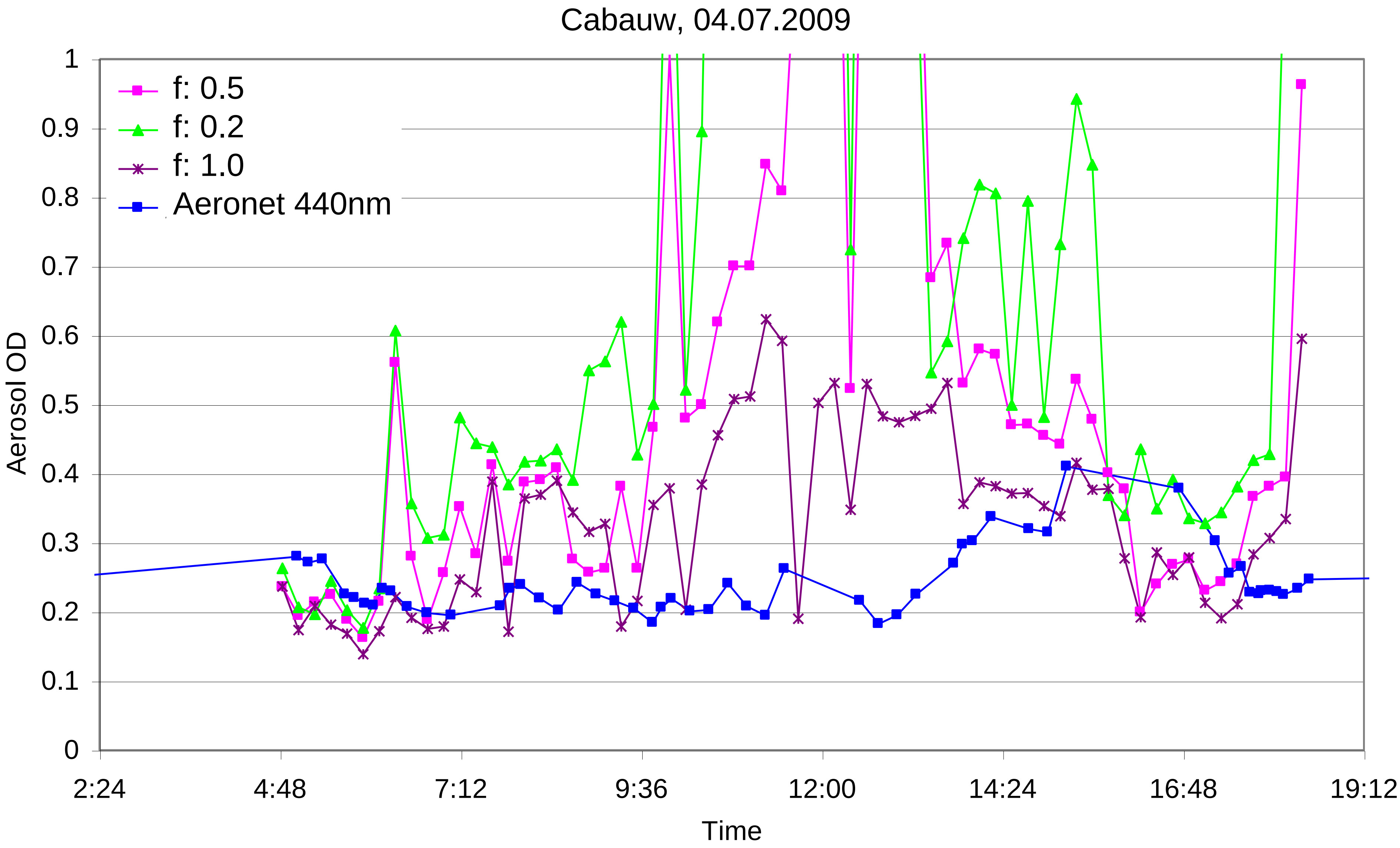
Cabauw, 01.07.2009
Aerosol OD
Time
f: 0.5
f: 0.2
f: 1.0
Aeronet
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12



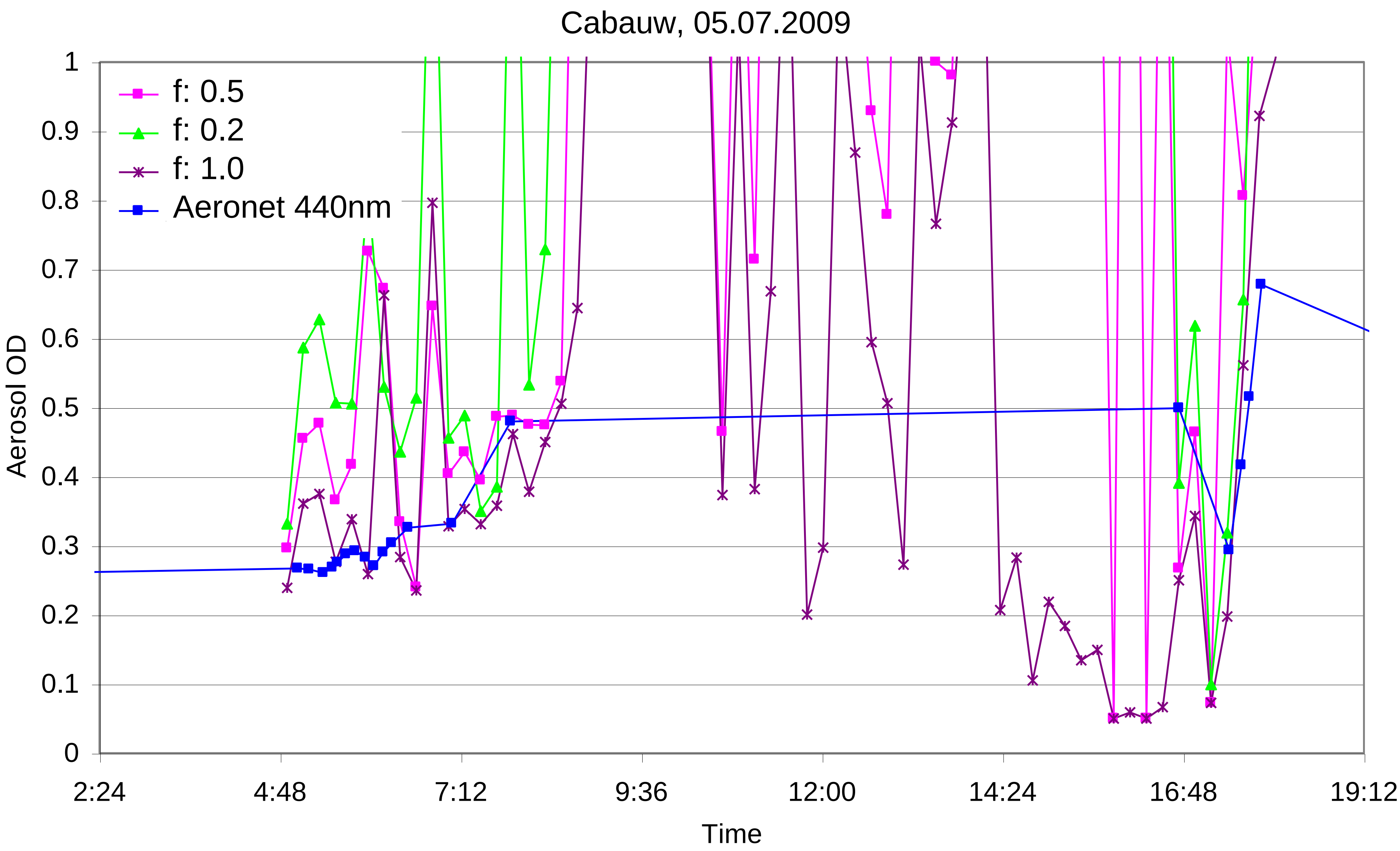
Cabauw, 02.07.2009
f: 0.5
f: 0.2
f: 1.0
Aeronet 440nm
Aerosol OD
Time
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12

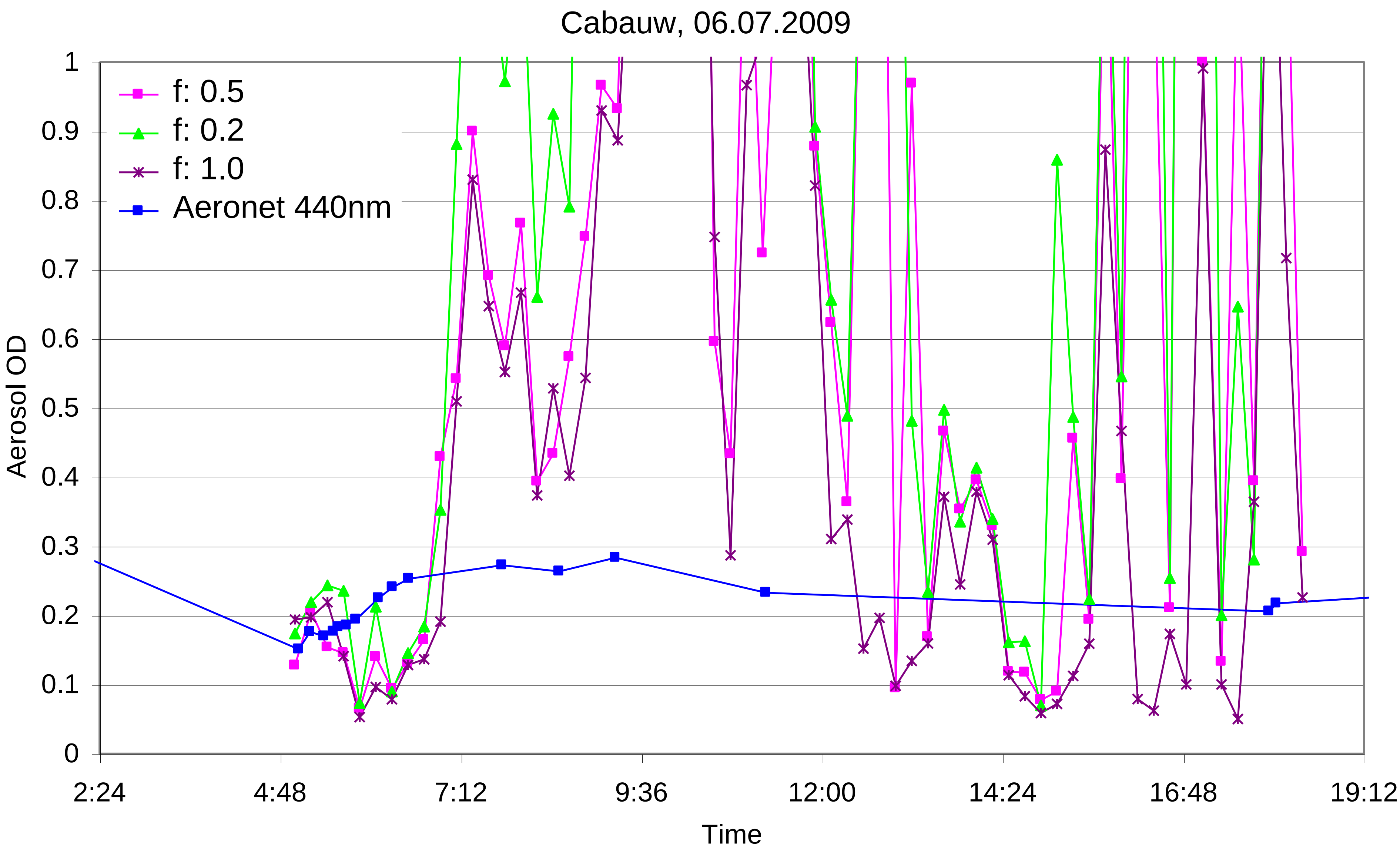


Cabauw, 03.07.2009
Aerosol OD
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
f: 0.5
f: 0.2
f: 1.0
Aeronet 440nm
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
Time

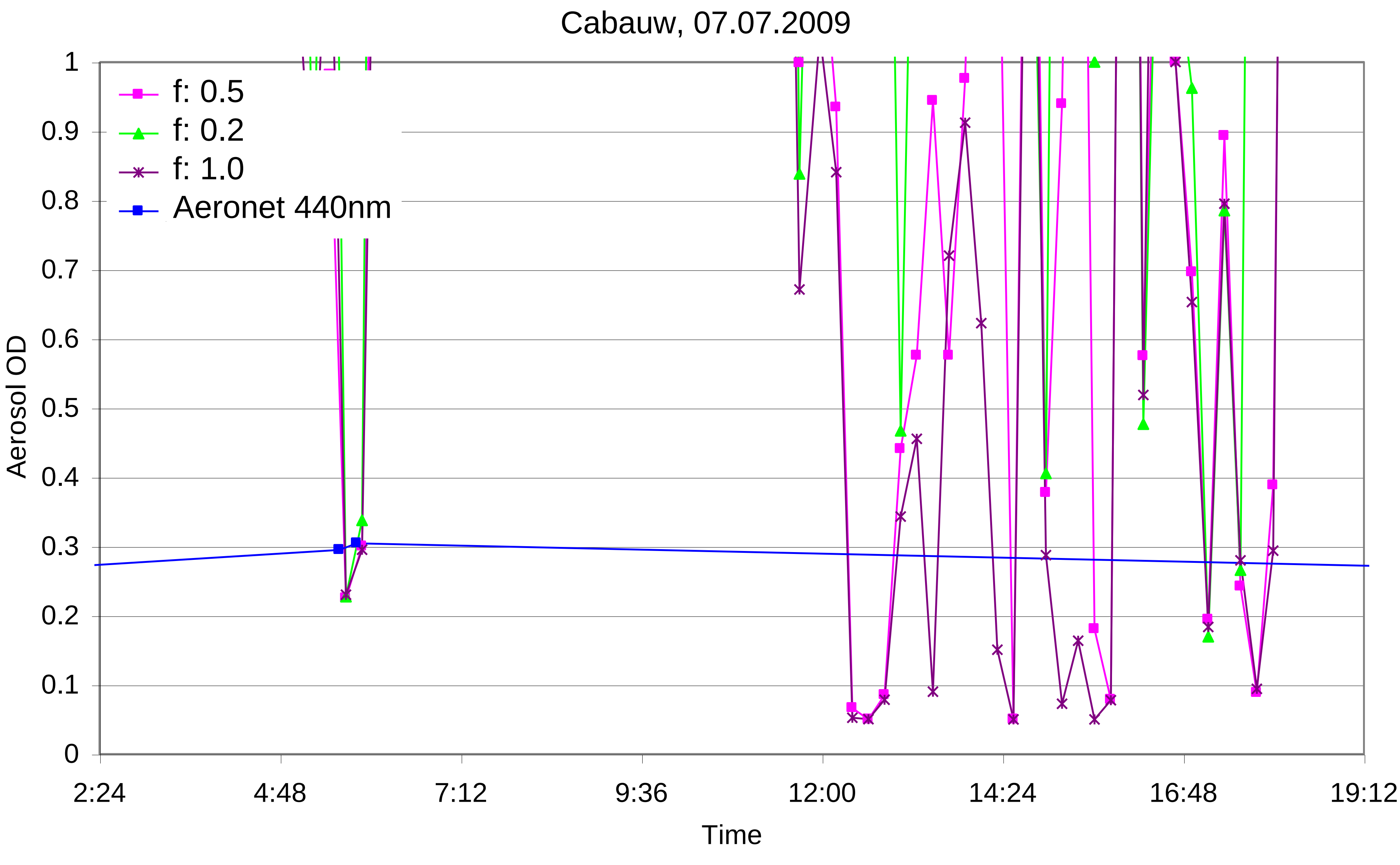


Cabauw, 04.07.2009
f: 0.5
f: 0.2
f: 1.0
Aeronet 440nm
Aerosol OD
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
Time

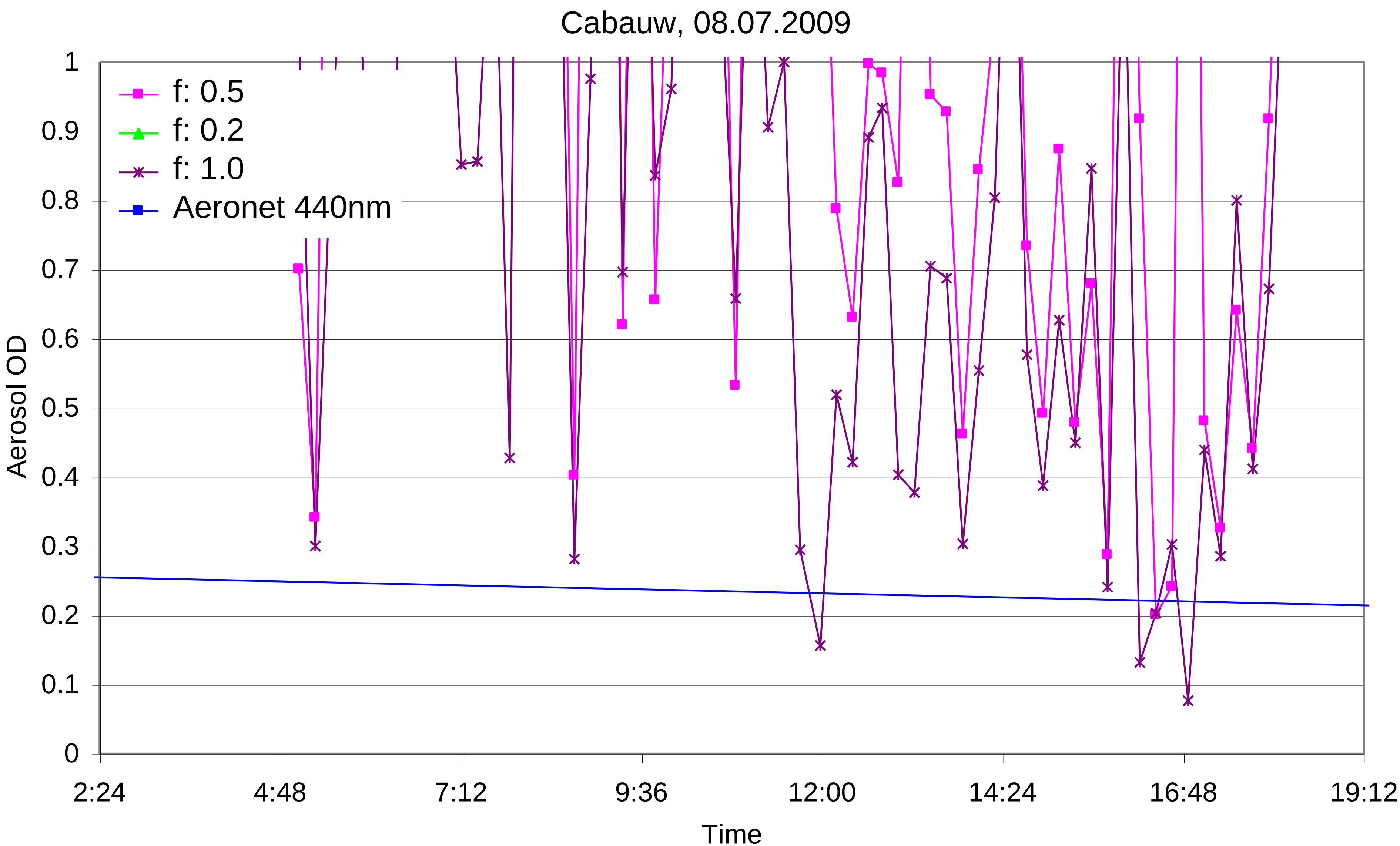

Cabauw, 05.07.2009
f: 0.5
f: 0.2
f: 1.0
Aeronet 440nm
Aerosol OD
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
Time

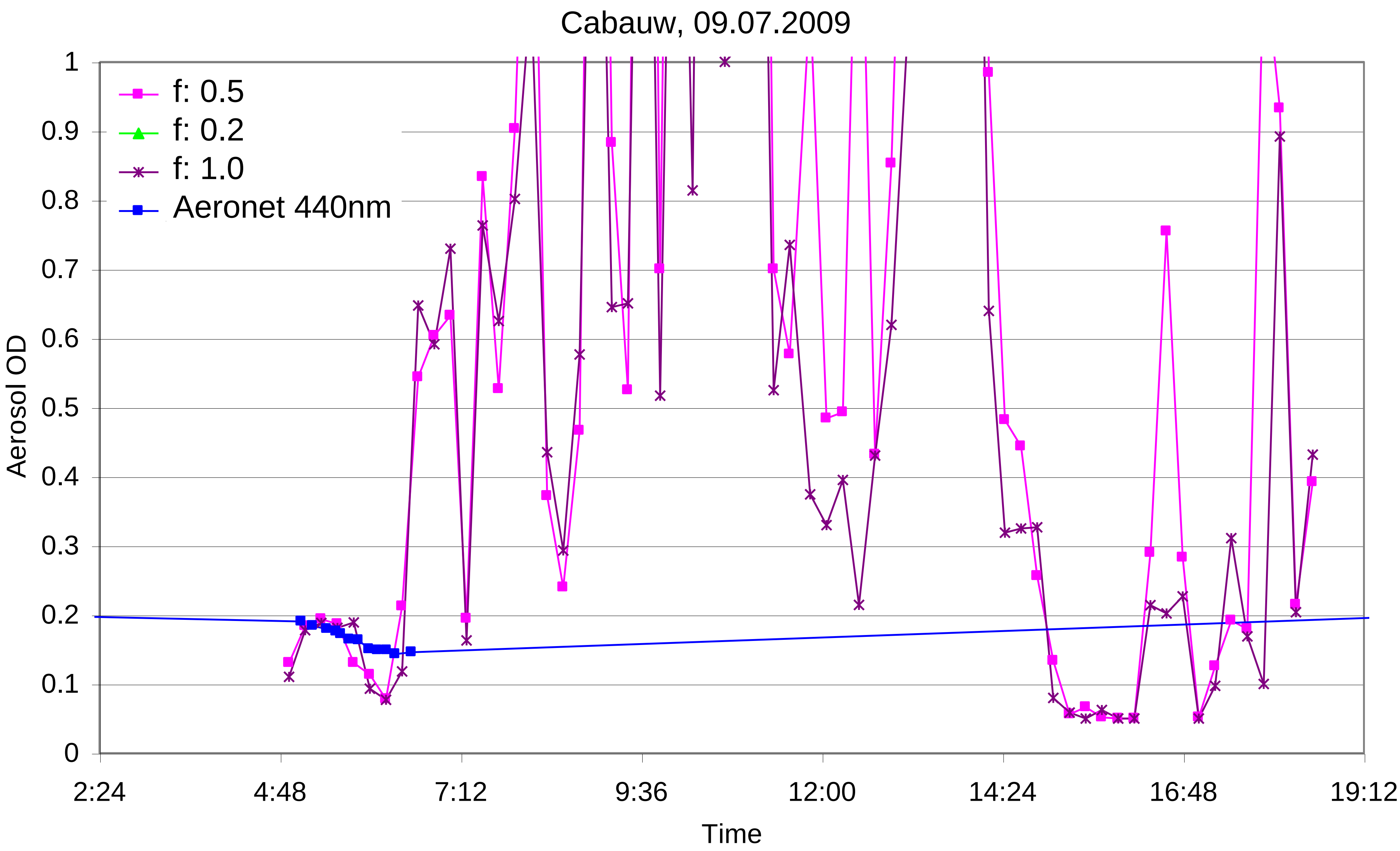


Cabauw, 06.07.2009
f: 0.5
f: 0.2
f: 1.0
Aeronet 440nm
Aerosol OD
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
Time

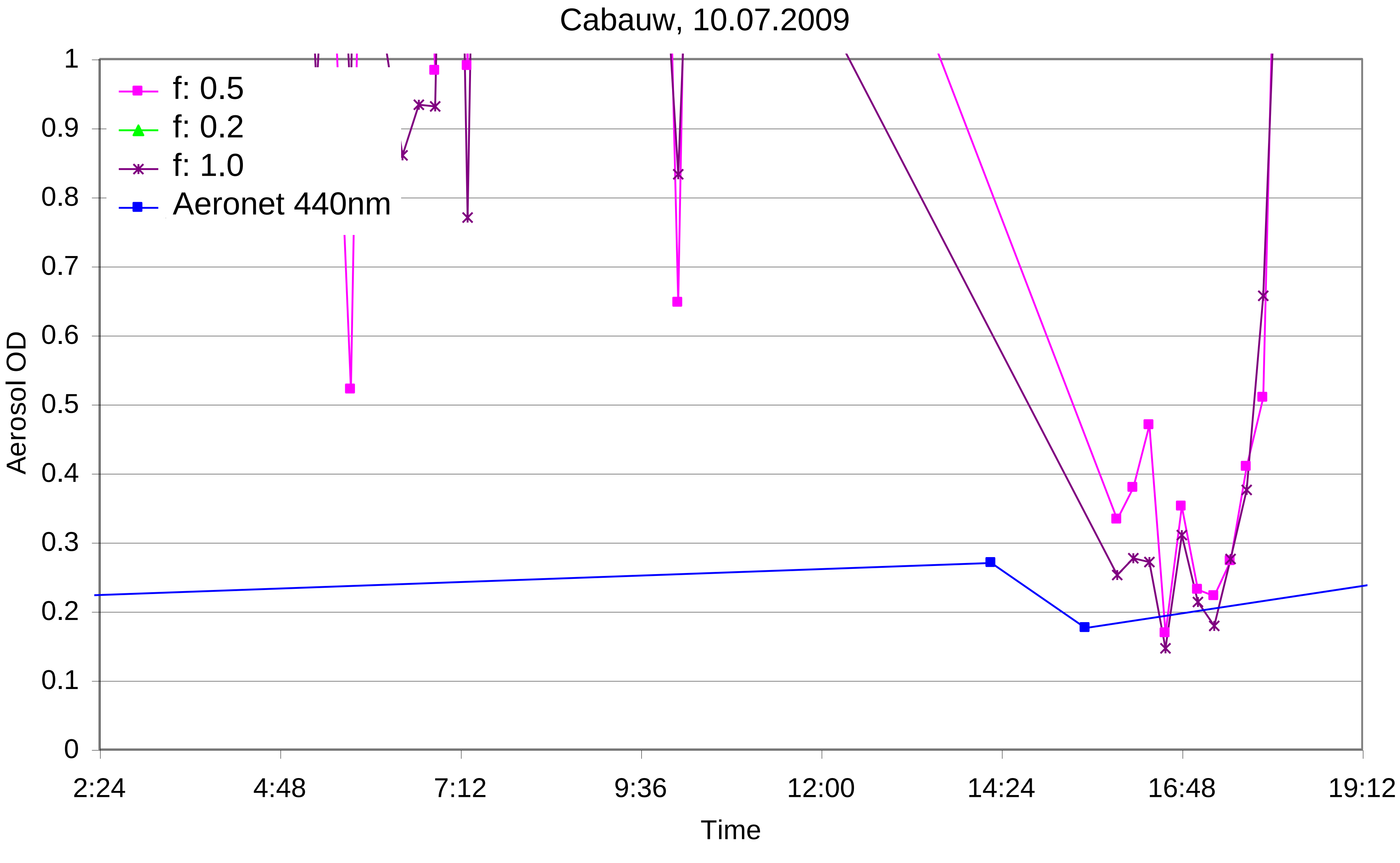


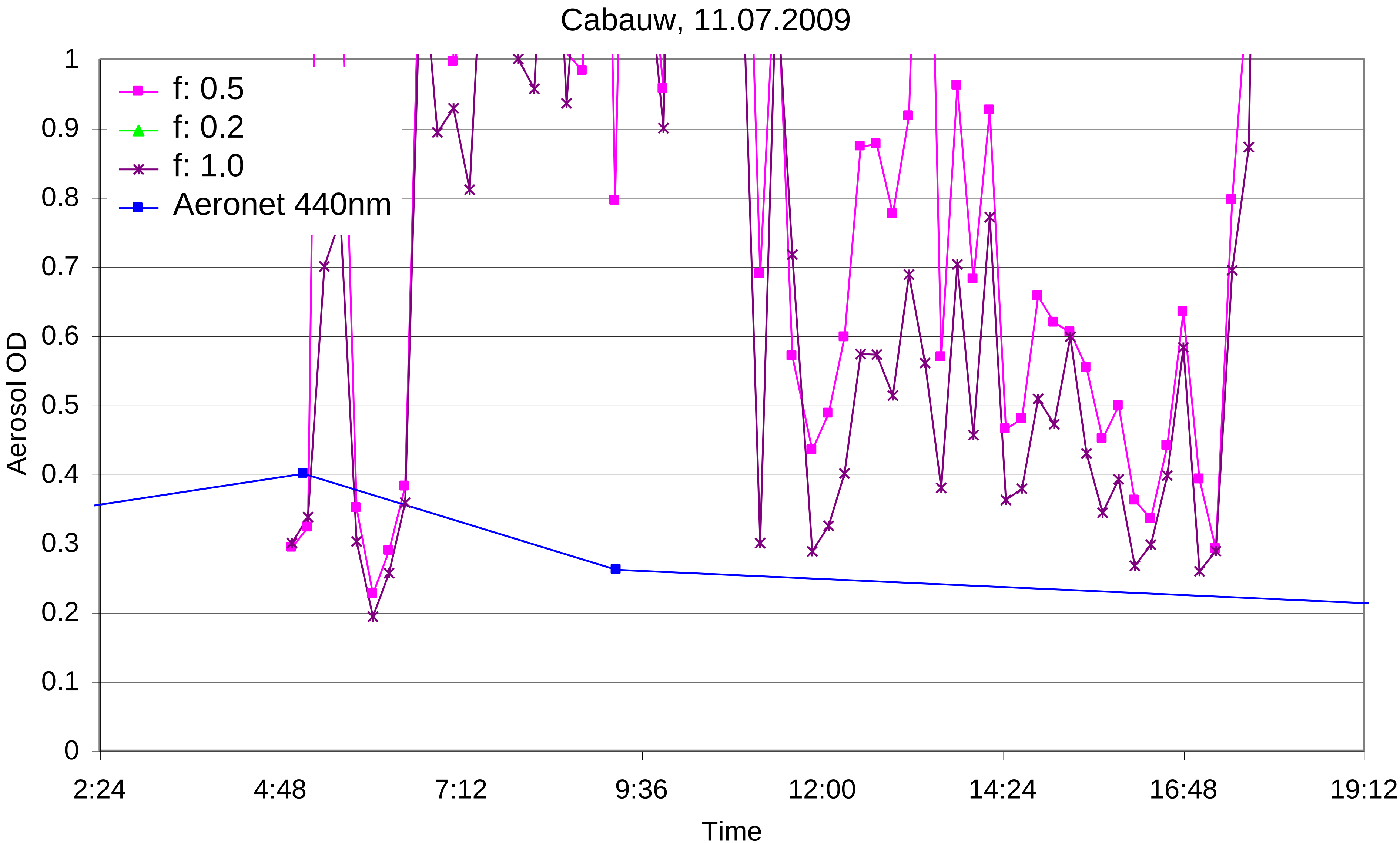
Cabauw, 07.07.2009
Aerosol OD
Time
f: 0.5
f: 0.2
f: 1.0
Aeronet 440nm
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12

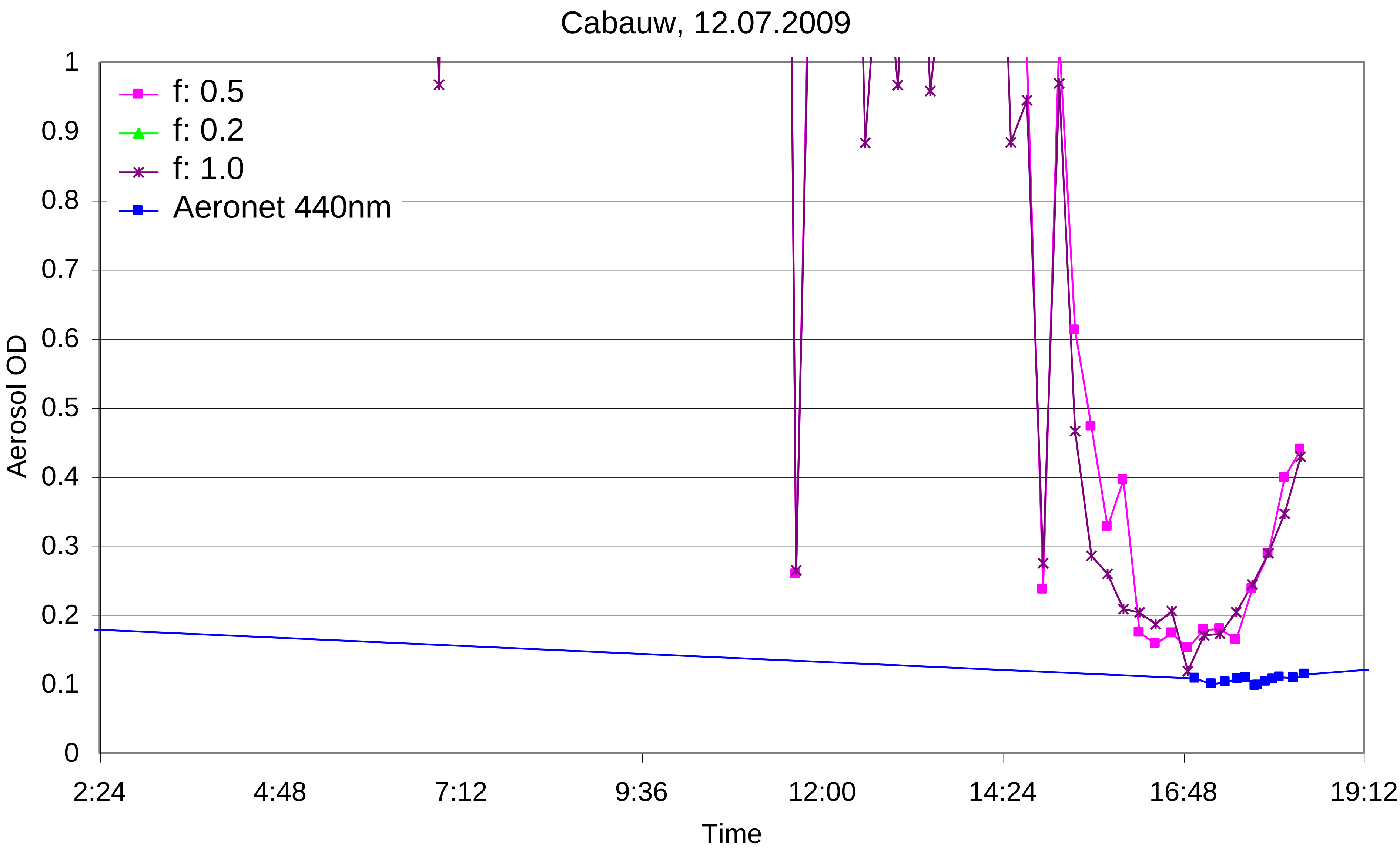

Cabauw, 08.07.2009
f: 0.5
f: 0.2
f: 1.0
Aeronet 440nm
Aerosol OD
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
Time



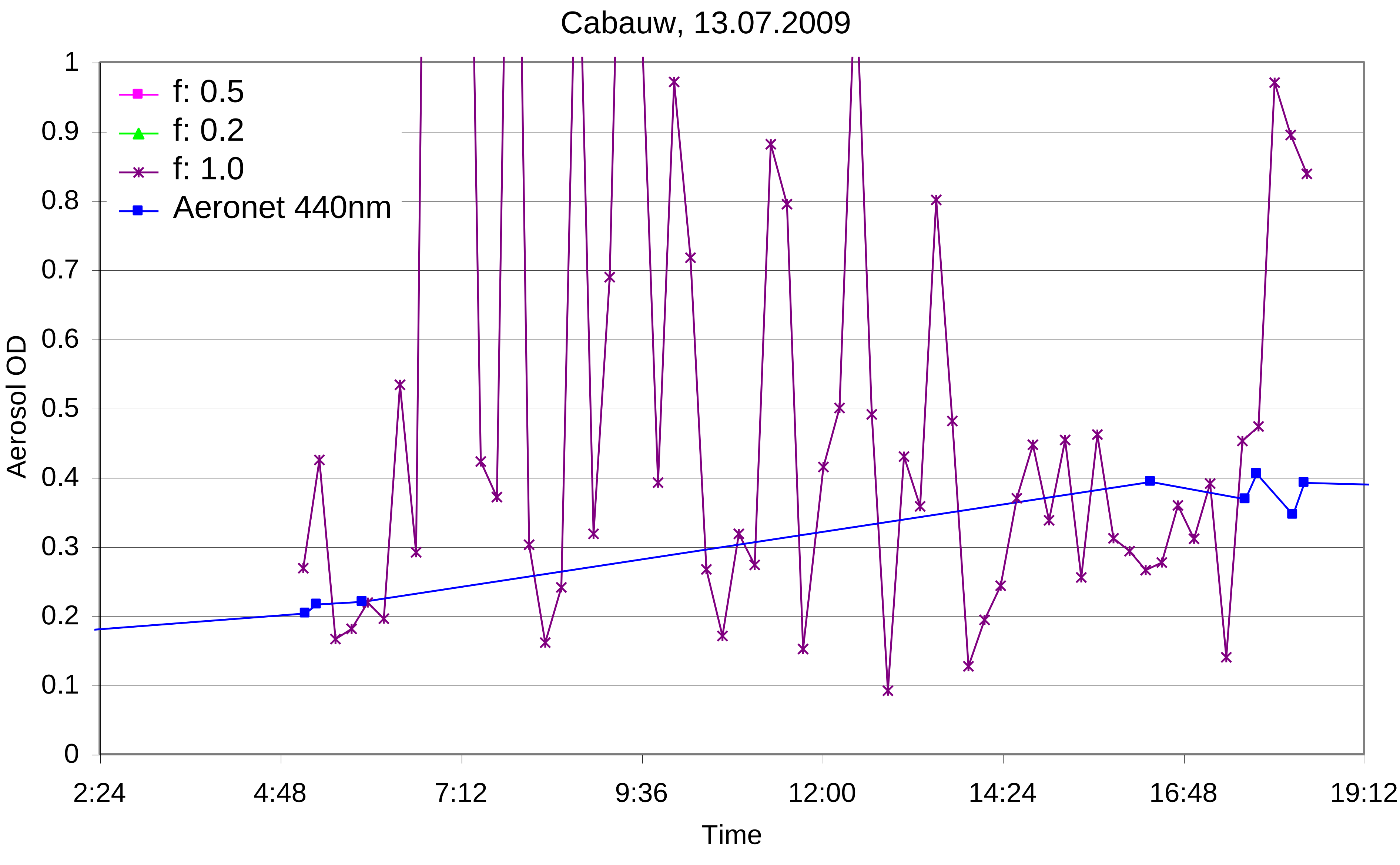
Cabauw, 09.07.2009
f: 0.5
f: 0.2
f: 1.0
Aeronet 440nm
Aerosol OD
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
Time


Cabauw, 10.07.2009
f: 0.5
f: 0.2
f: 1.0
Aeronet 440nm
Aerosol OD
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
Time

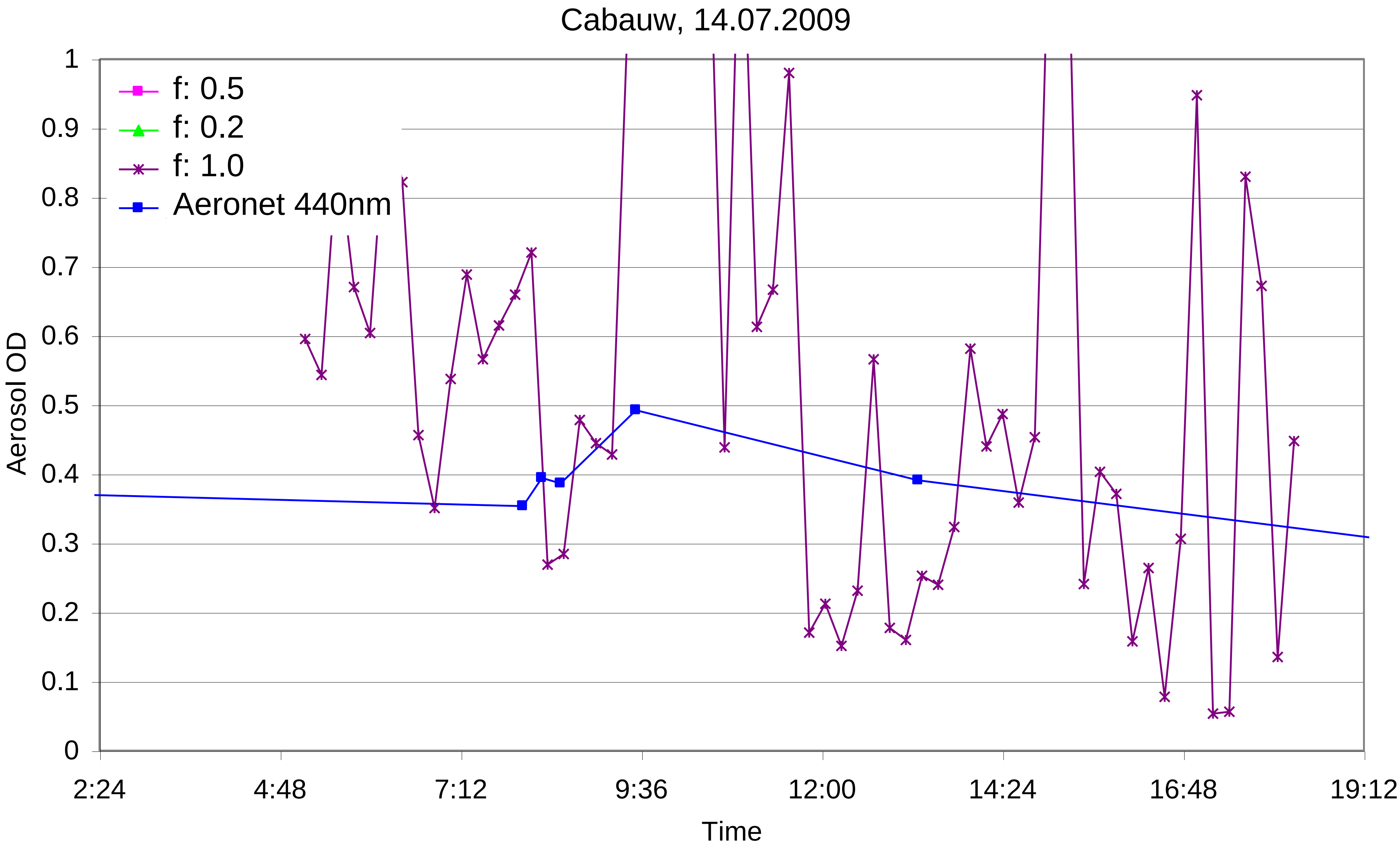

Cabauw, 11.07.2009
f: 0.5
f: 0.2
f: 1.0
Aeronet 440nm
Aerosol OD
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
Time



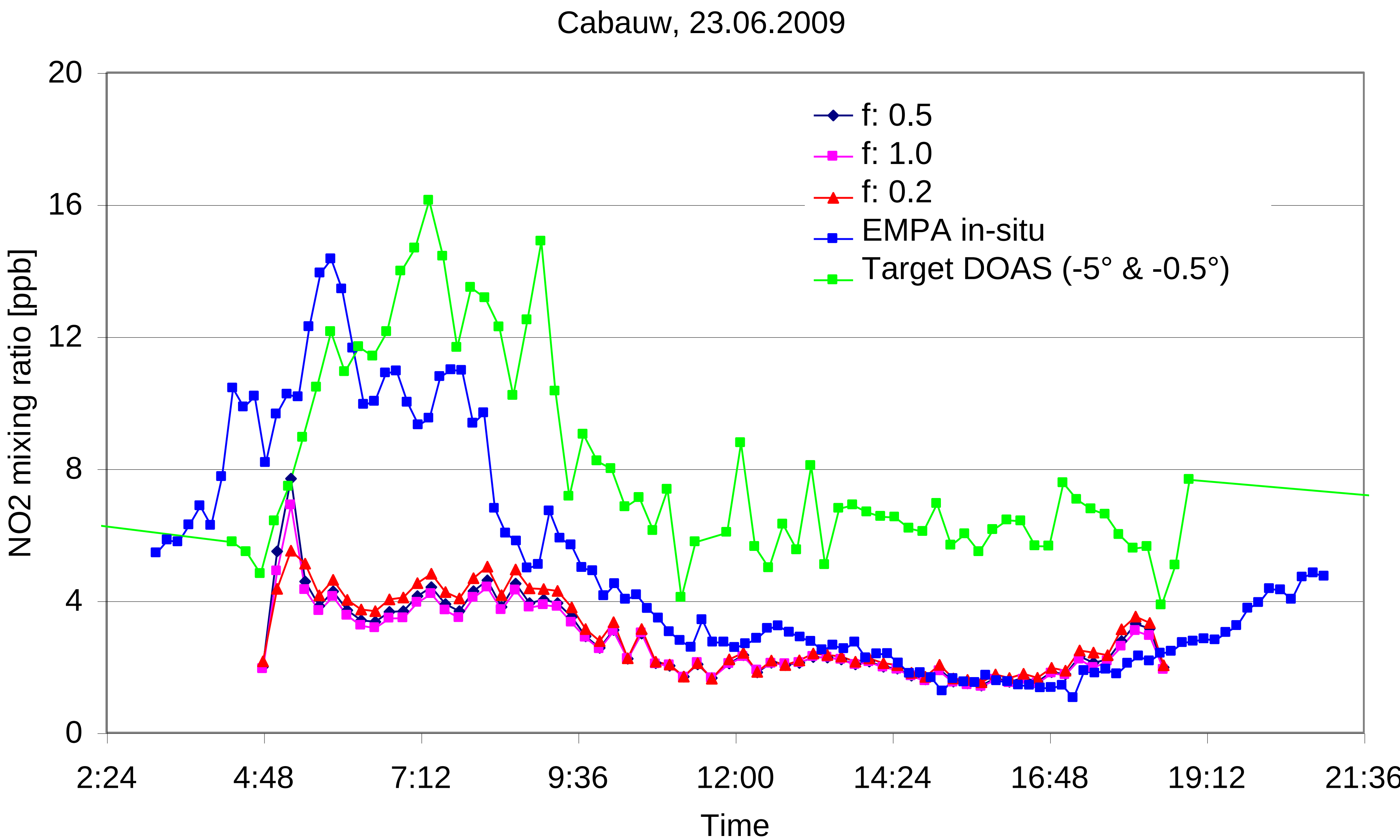
Cabauw, 12.07.2009
f: 0.5
f: 0.2
f: 1.0
Aeronet 440nm
Aerosol OD
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
Time



Cabauw, 13.07.2009
f: 0.5
f: 0.2
f: 1.0
Aeronet 440nm
Aerosol OD
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
Time



Cabauw, 14.07.2009
f: 0.5
f: 0.2
f: 1.0
Aeronet 440nm
Aerosol OD
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
Time


Cabauw, 23.06.2009
NO2 mixing ratio [ppb]
0
4
8
12
16
20
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time
f: 0.5
f: 1.0
f: 0.2
EMPA in-situ
Target DOAS (-5° & -0.5°)