Investigation of Trace Gas to Aerosol Relationships over Biomass Burning Areas using Daily Satellite Observations

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- Motivation
- Selected regions and data sets
- Time series and correlation analyses
- Influence of clouds
- Conclusions

Aerosols are important

- chemistry

- radiation budget

- cloud formation

But not well characterised

- high temporal and spatial variability

- aerosol properties are difficult to quantify (optical, microphysical, etc.)

- ground based observation networkss (in-situ & remote) have large gaps

- remote sensing observations are often only possible during day and in the absence of clouds

Advantage of satellite observations

- global coverage, ‚integrative' view
- well suited for the study of aerosol - cloud relationsships (if aerosols are besides, in, or above clouds)

Which satellite observations are available?

- backscattered sunlight => AOD (MODIS, MISR, etc.)
- aerosol absorbing aerosol index (TOMS, SCIAMACHY, etc.)
- LIDAR extinction profiles (CALIOP) (very limited coverage)

What about trace gas observations?

Advantage of trace gas observations

- specific mix of trace gas abumdances can yield information on aerosol types and sources (e.g. smoldering or flaming fires)
- trace gas measurements might even serve as proxies for CCN, which can not be directly measured by remote sensing
- trace gases can be measured in the presence of clouds (also UV absorbing index)

=> important for the study of aerosol - cloud interactions

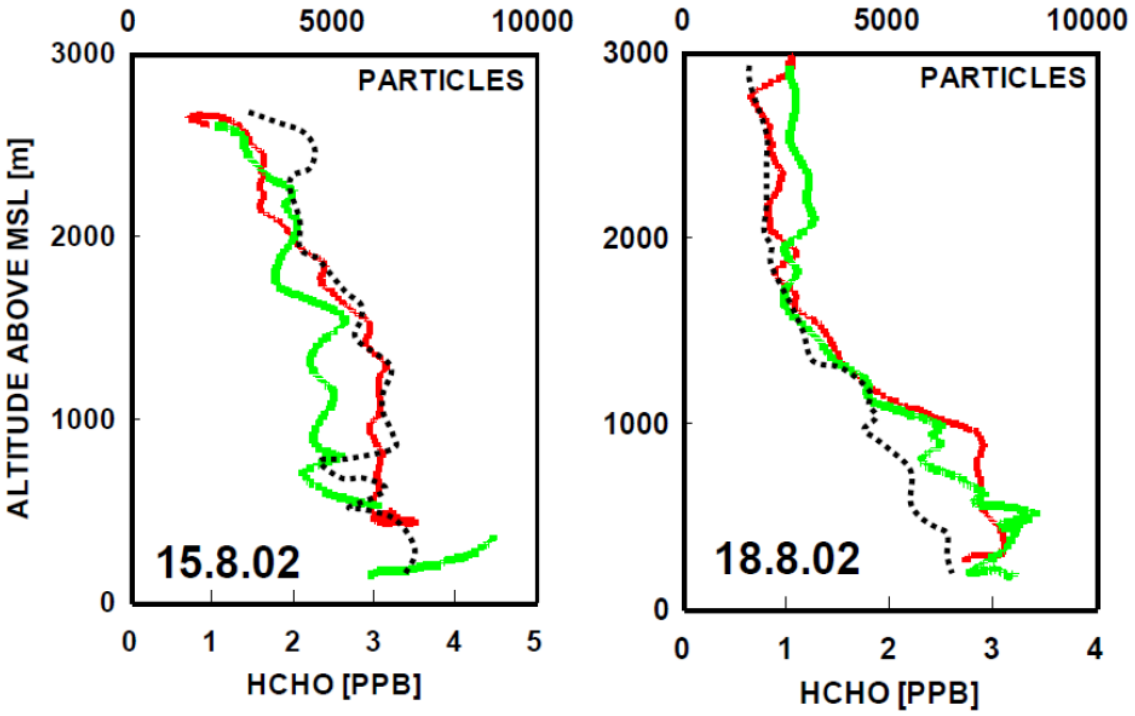
‚trace gas footprint' is much larger than for imaging instruments, typically of the order of tens of kilomters or more

Example for trace gas - aerosol relationships

Aircraft measurements in the Po valey

W. Junkermann, ACP, 2009

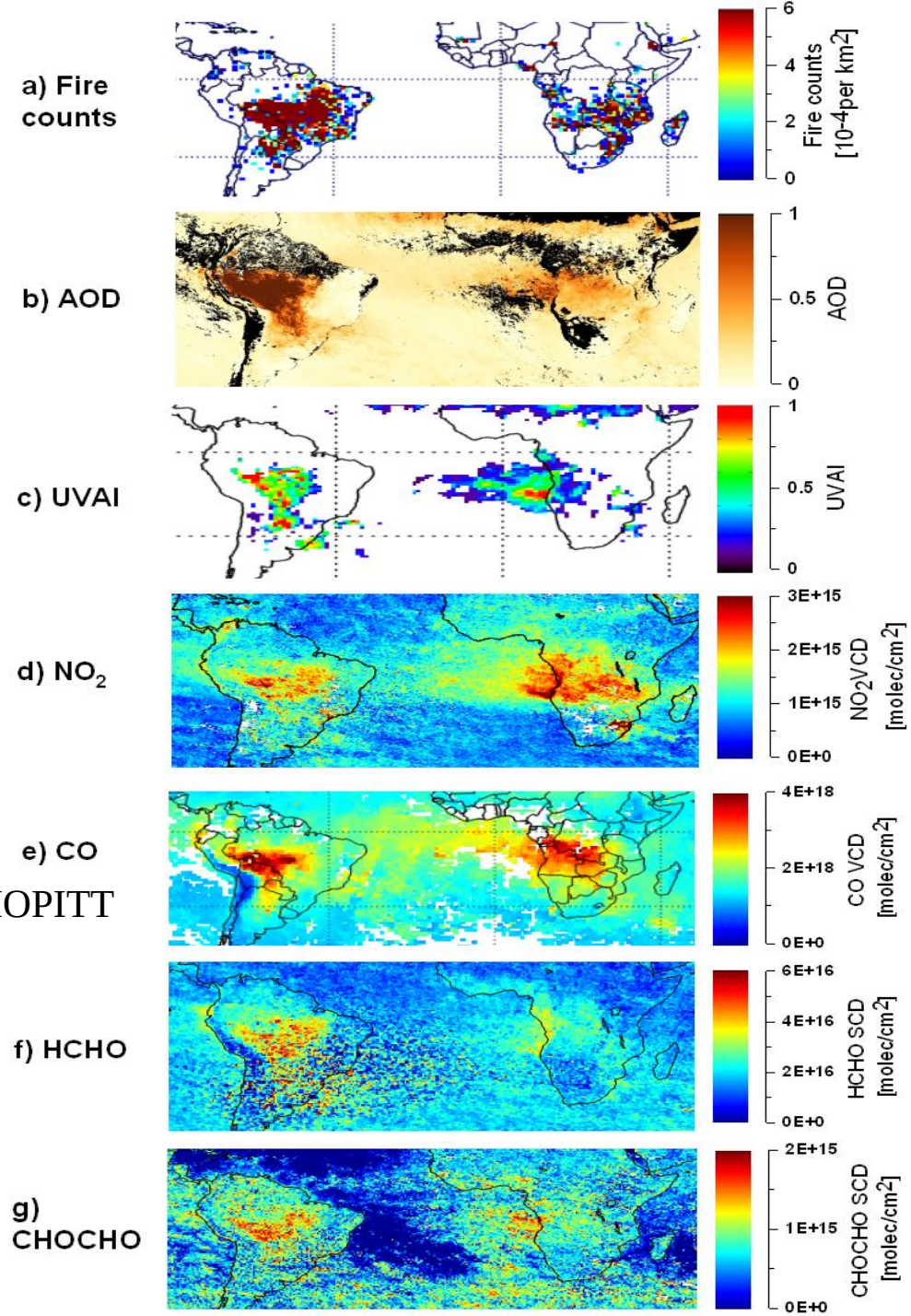
HCHO and CCN



Particles >10nm

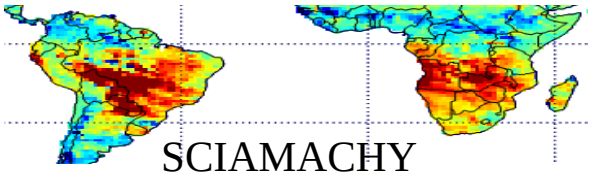
HCHO descent

HCHO ascent

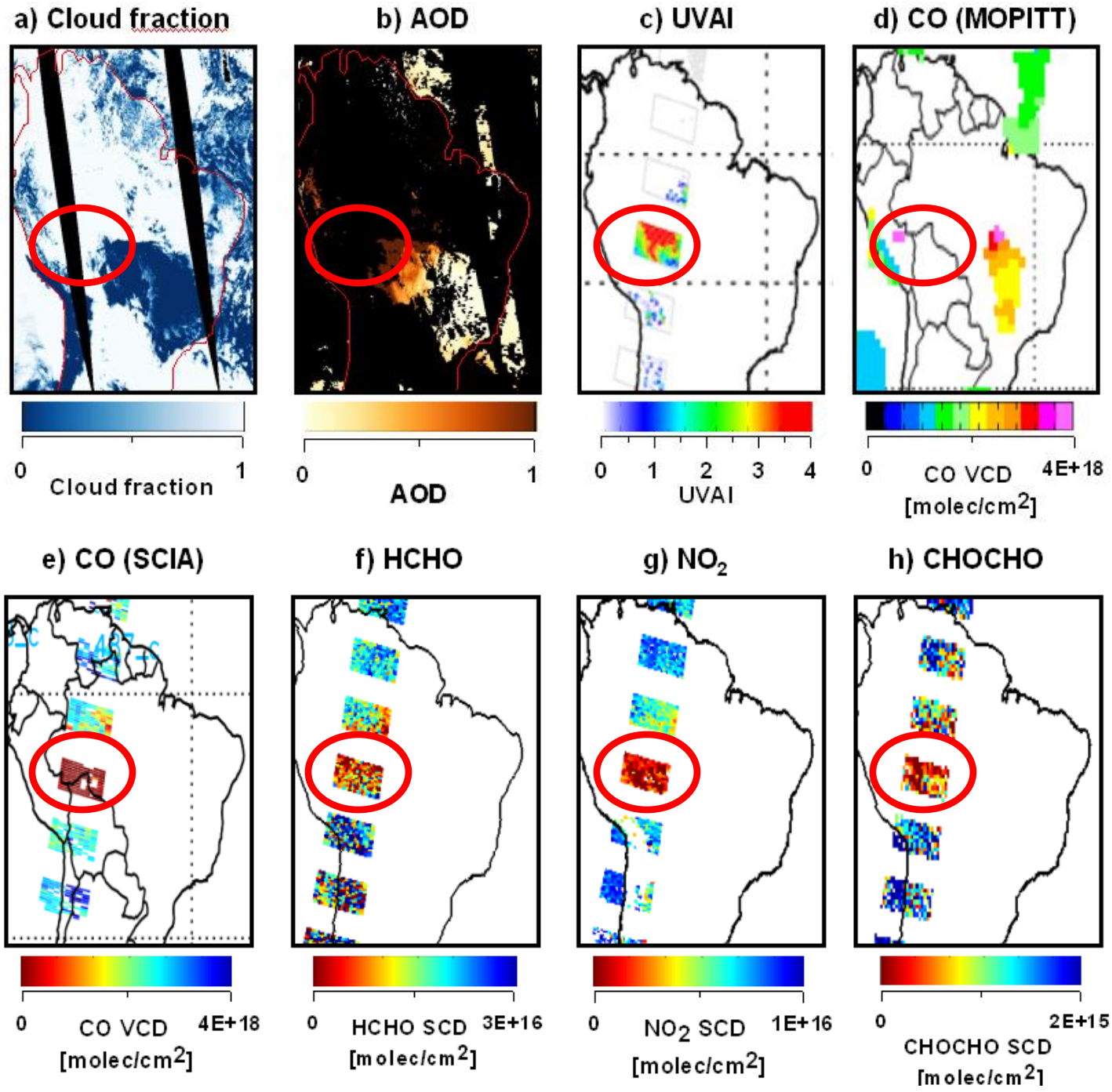


Similar patterns of aerosols and trace gases over biomass burning regions are found in monthly averages

(September 2004)



SCIAMACHY



Similar patterns are also found for selected days

(South America, 12 September 2004)

Trace gases and the UVAI can be retrieved in the presence of clouds

Specific questions addressed in this study:

- How well do satellite measurements of trace gases correlate with aerosol observations?

- Can satellite observations in the presence of clouds yield useful information?

Recent studies (e.g. Veefkind et al.) have addressed similar questions, but for monthly averages => aerosol classification

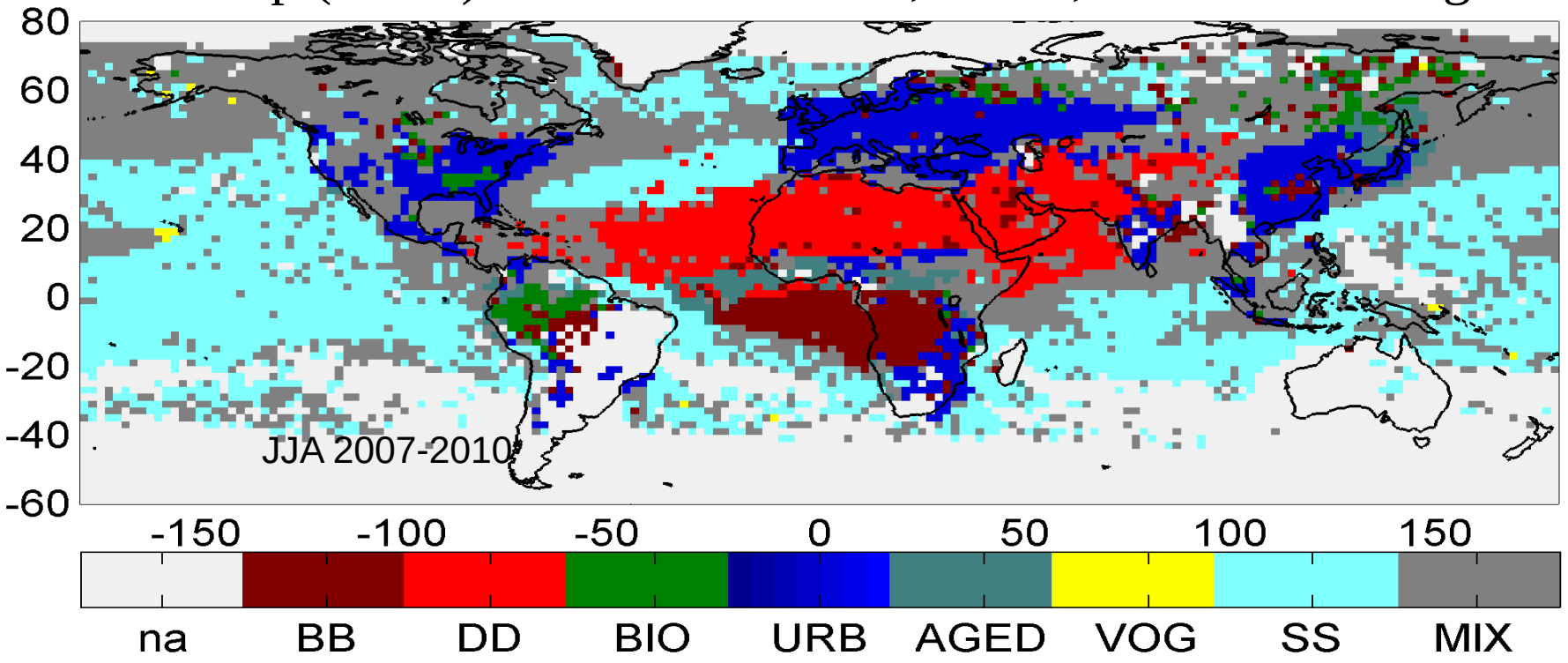
See also Poster by Penning de Vries et al.

Here we use daily observations over selected biomass burning regions for 5 years (2007 – 2011)

Towards a global aerosol type climatology from satellite observations of aerosols and trace gases

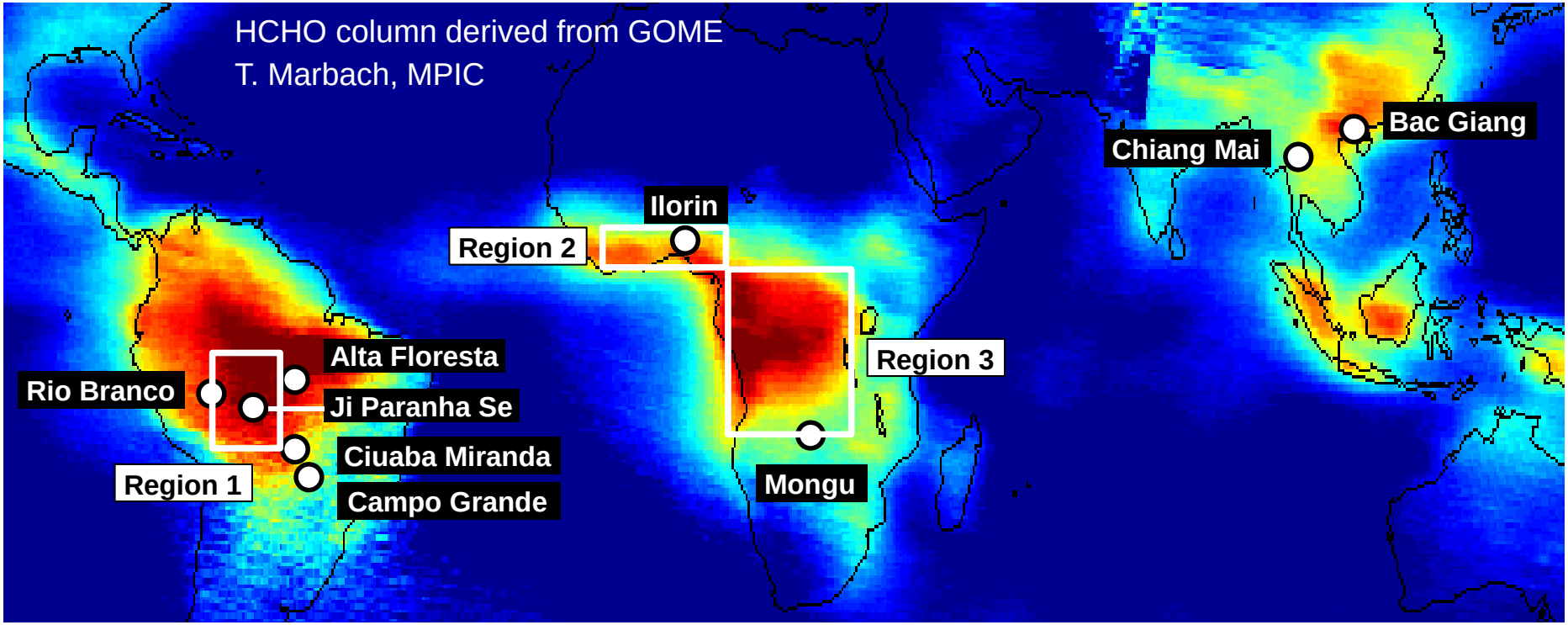
Marloes Penning de Vries[1], *Steffen Beirle*[1], *Christoph Hörmann*[1,2], *Johannes Kaiser*[1,3], *Gijsbert Tilstra*[4], *Olaf Tuinder*[4], *Piet Stammes*[4], *and Thomas Wagner*[1]

Source map (2°x2°) derived from AOT, UVAI, EAE and trace gases



Aerosol types: BB – biomass burning, DD – desert dust, BIO – (sec.) biogenic, URB – (sec.) urban, VOG – volcanic sulfate, AGED – aged or transported, SS – sea salt (na – not assessed)

Here we use daily observations over selected biomass burning regions for 5 years (2007 – 2011)

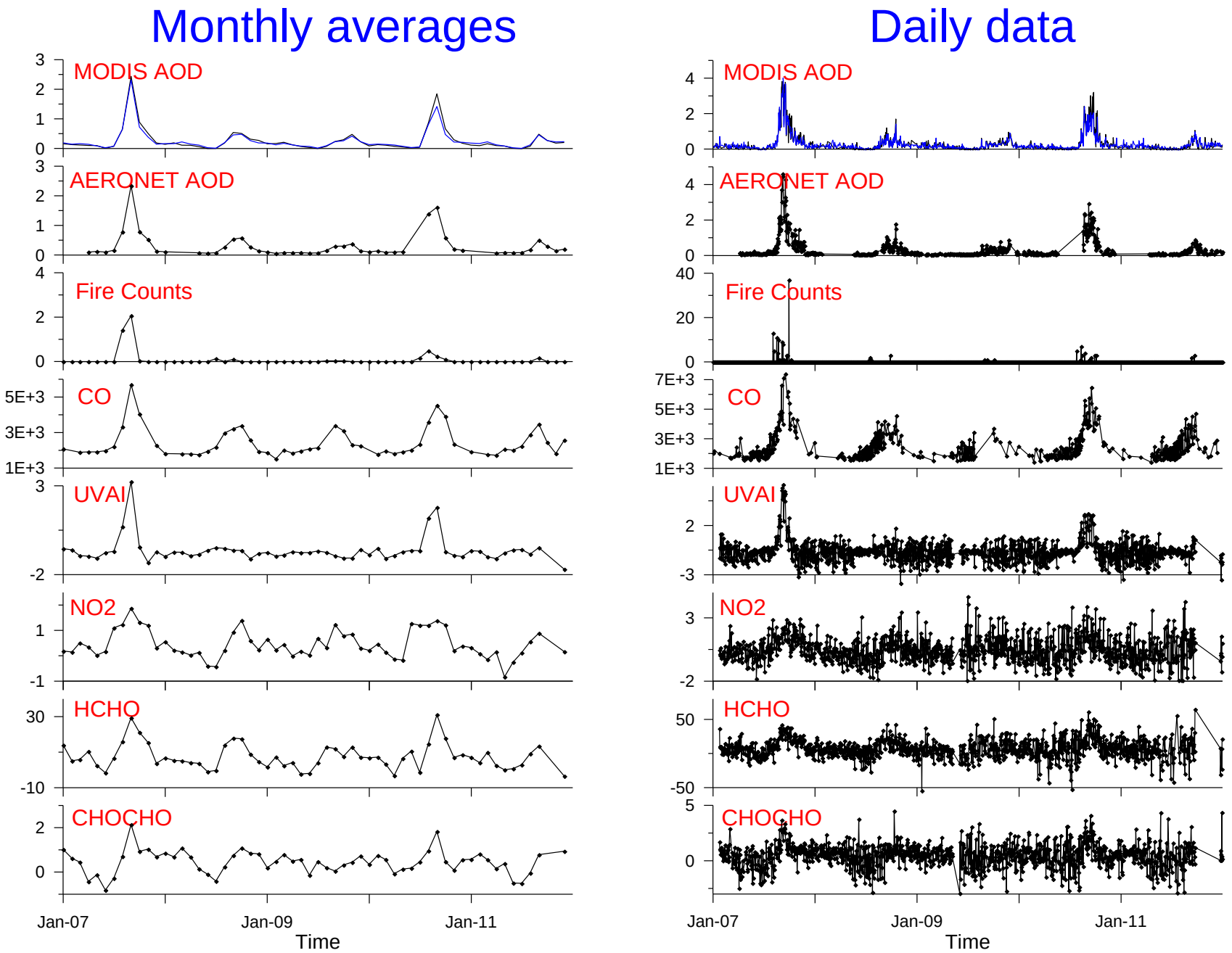


Time series for 3 regions and 8 AERONET stations (~1° x 1°)

- AERONET AOD (500 nm)
- MODIS AOD (550 nm)
- MOPITT CO (v5) (only clear sky)
- GOME-2 UVAI (KNMI), NO_2, HCHO, CHOCHO

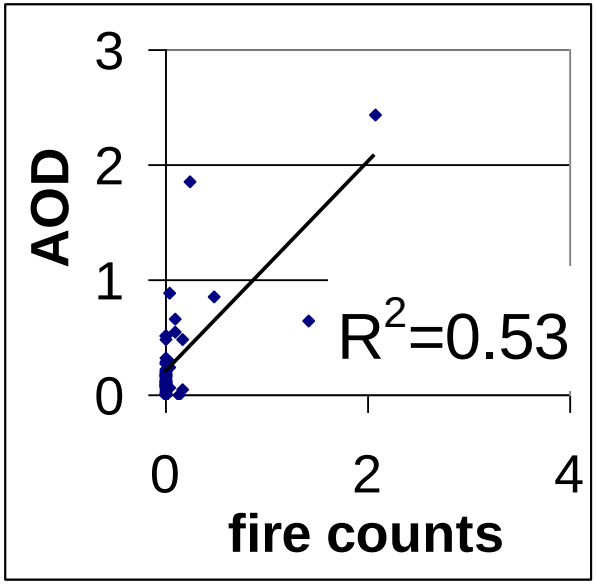
(trace gas columns are given in units of 10^{15} molec/cm²)

Time series over Alta Floresta (South America) (CF 0 – 100%)

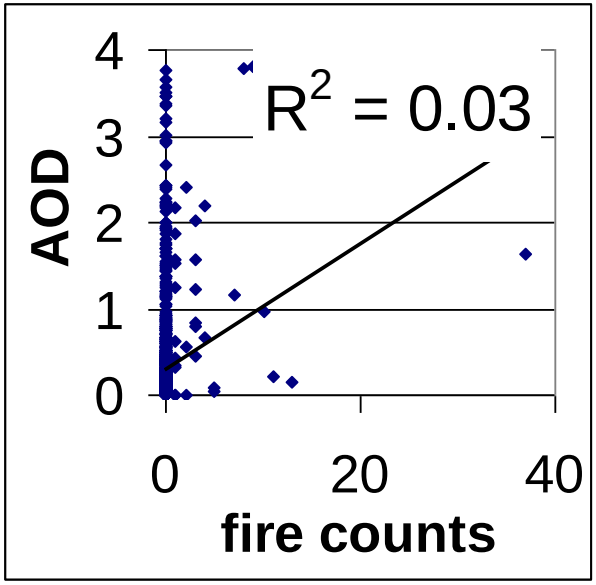


Correlation plots MODIS AOD versus fire counts

Monthly Averages

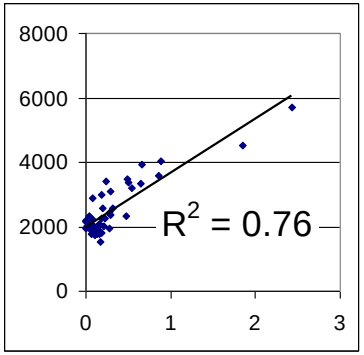


Daily Averages

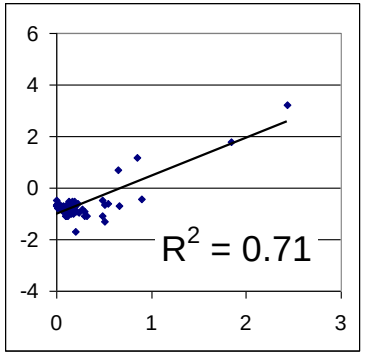


Correlation plots versus MODIS AOD

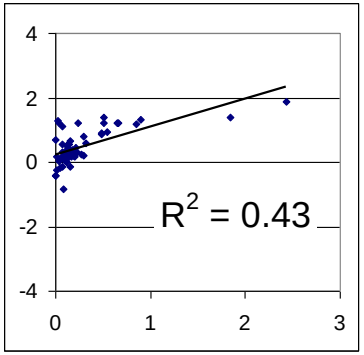
Monthly Averages



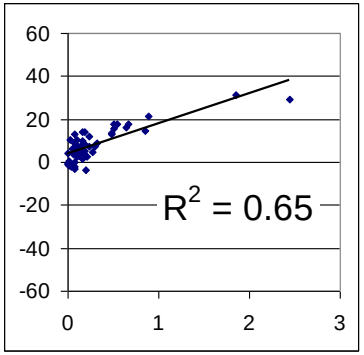
CO



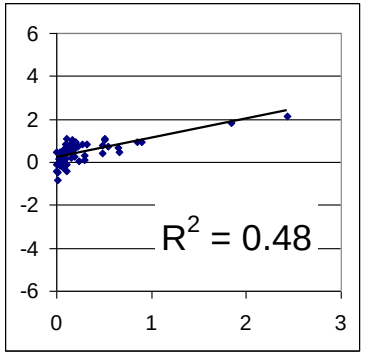
UVAI



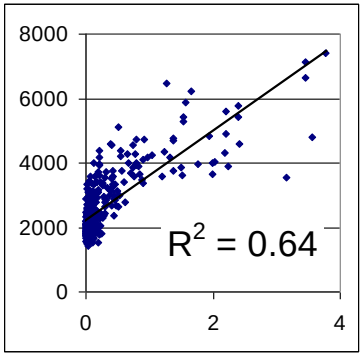
NO_2

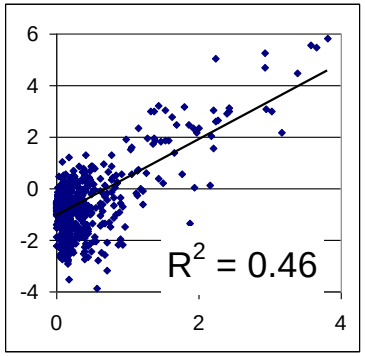


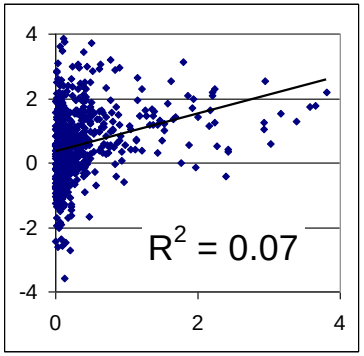
HCHO

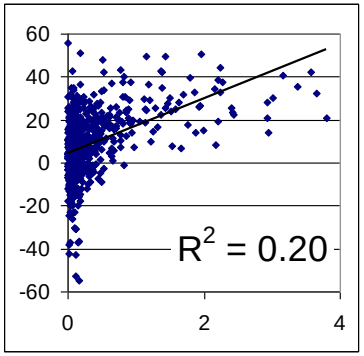


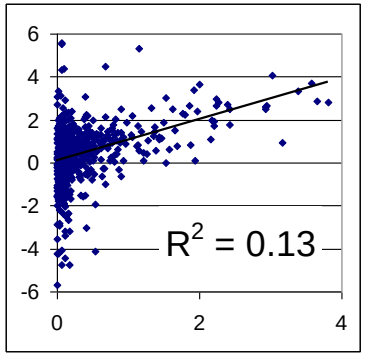
CHOCHO





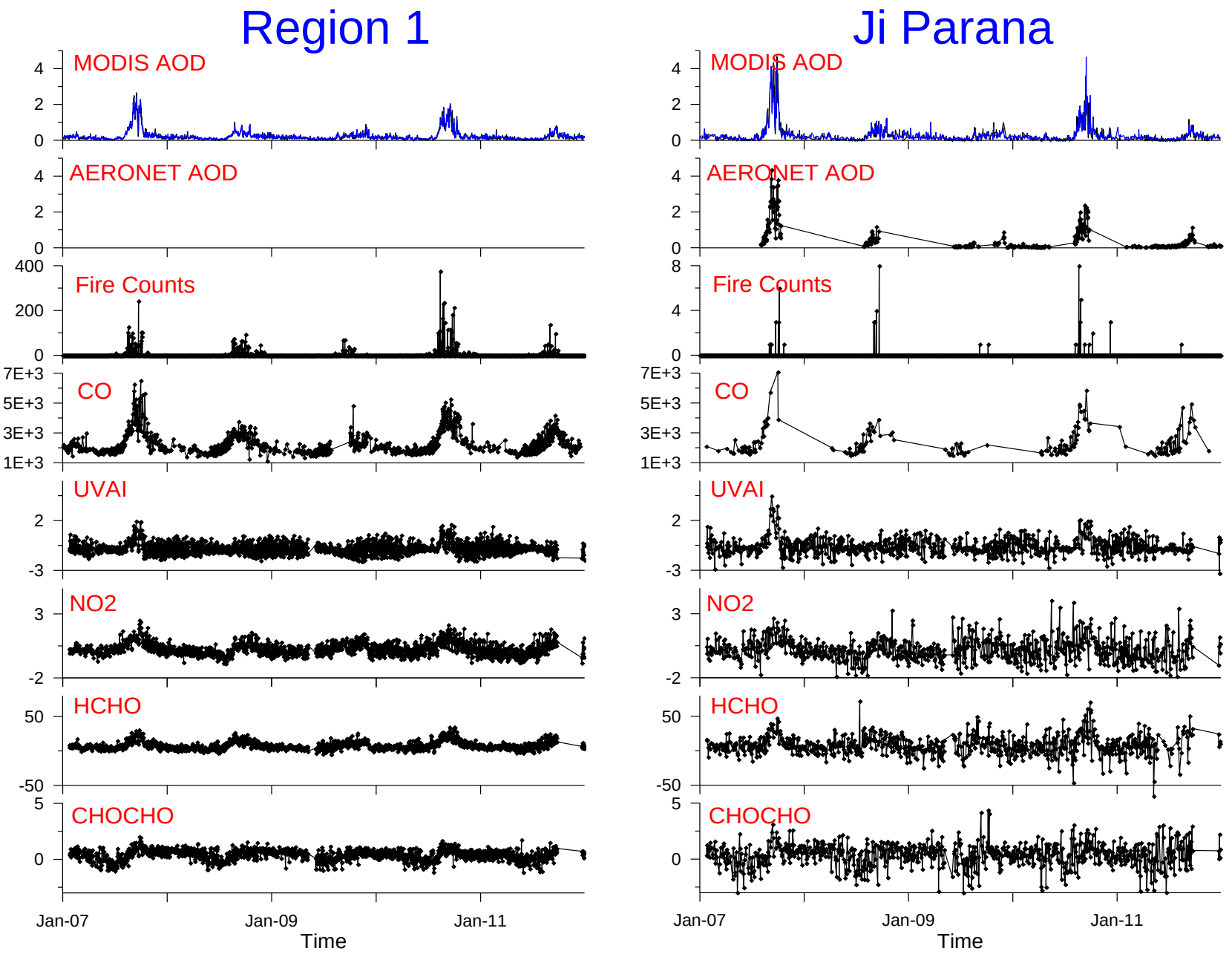






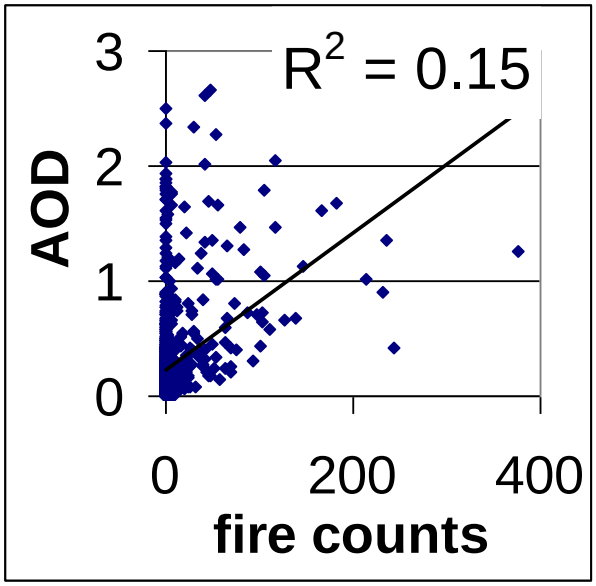
Daily Averages

Correlation plots versus MODIS AOD

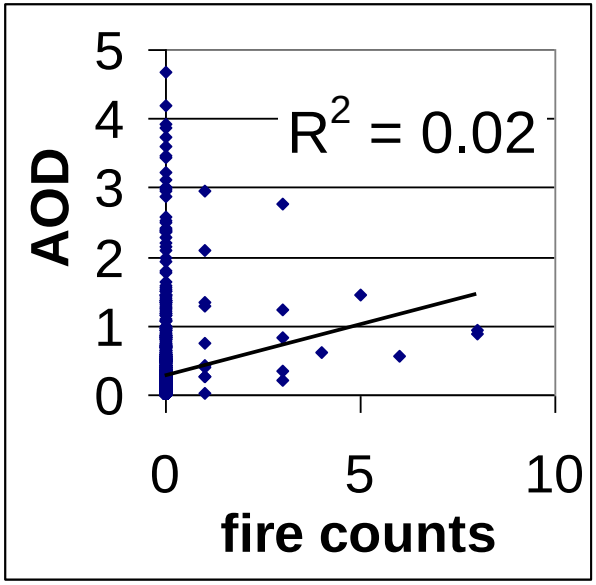


Correlation plots MODIS AOD versus fire counts

Region 1

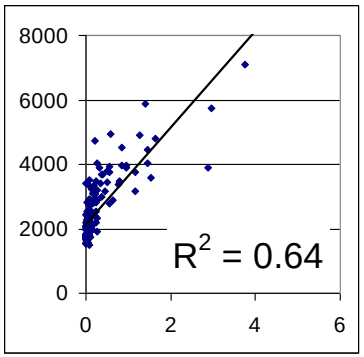


Ji Parana

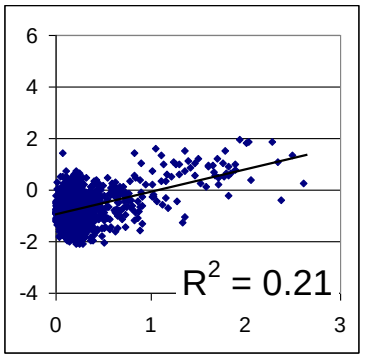


Correlation plots versus MODIS AOD

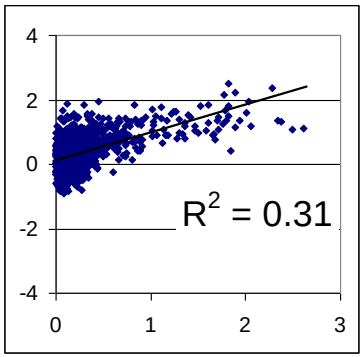
Region 1



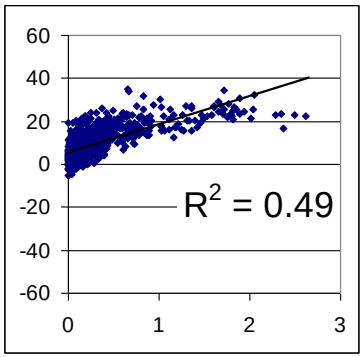
CO



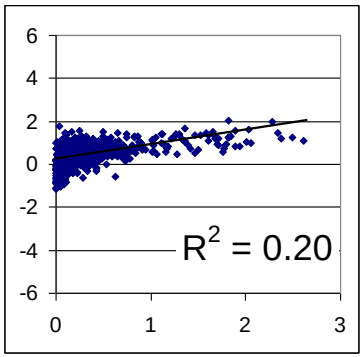
UVAI



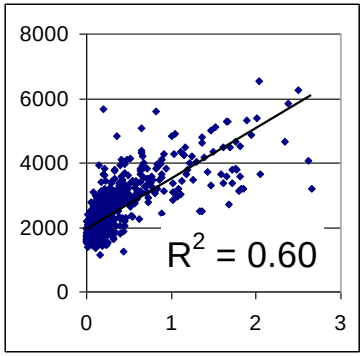
NO_2

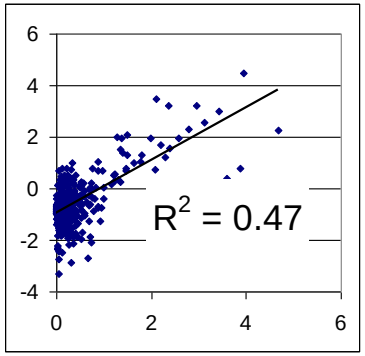


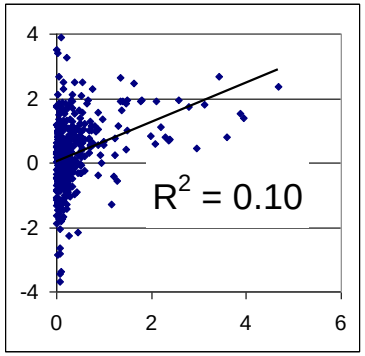
HCHO

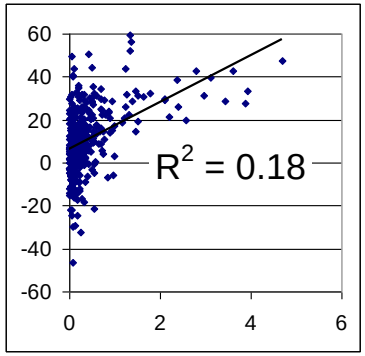


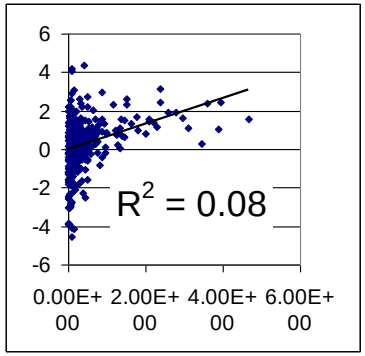
CHOCHO







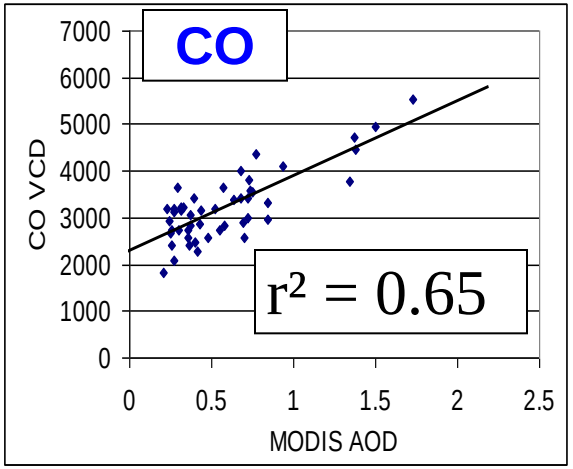




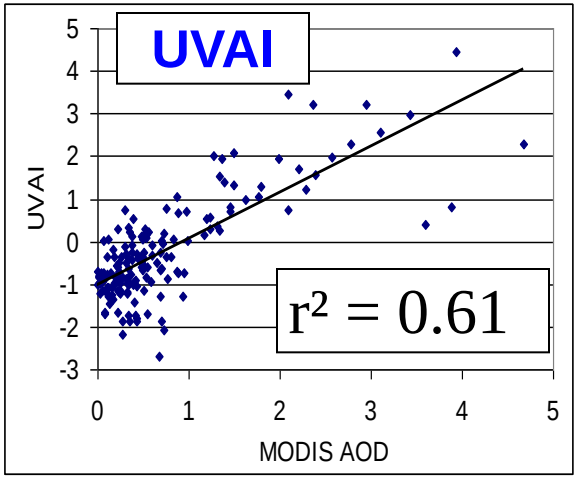
Ji Parana

Cases with best correlation for daily measurements around stations (CF: 0 – 100%)

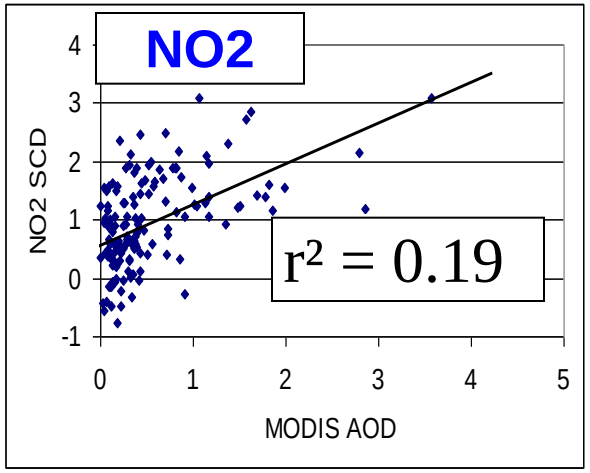
Chiang Mai



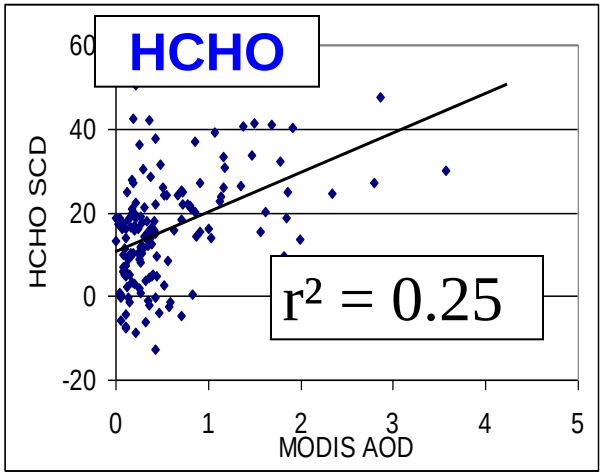
Ji Parana



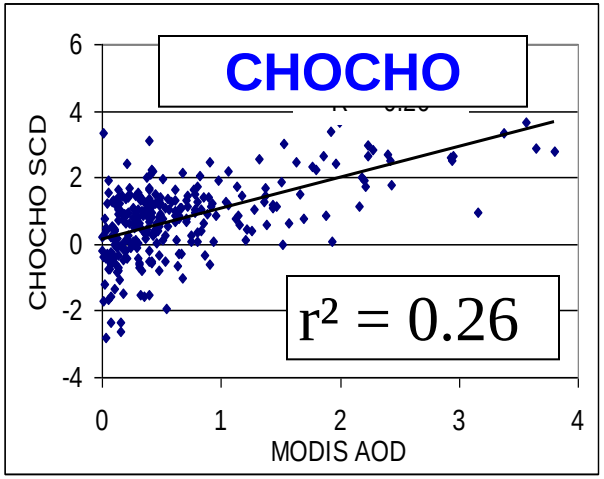
Rio Branco



Rio Branco



Alta Floresta

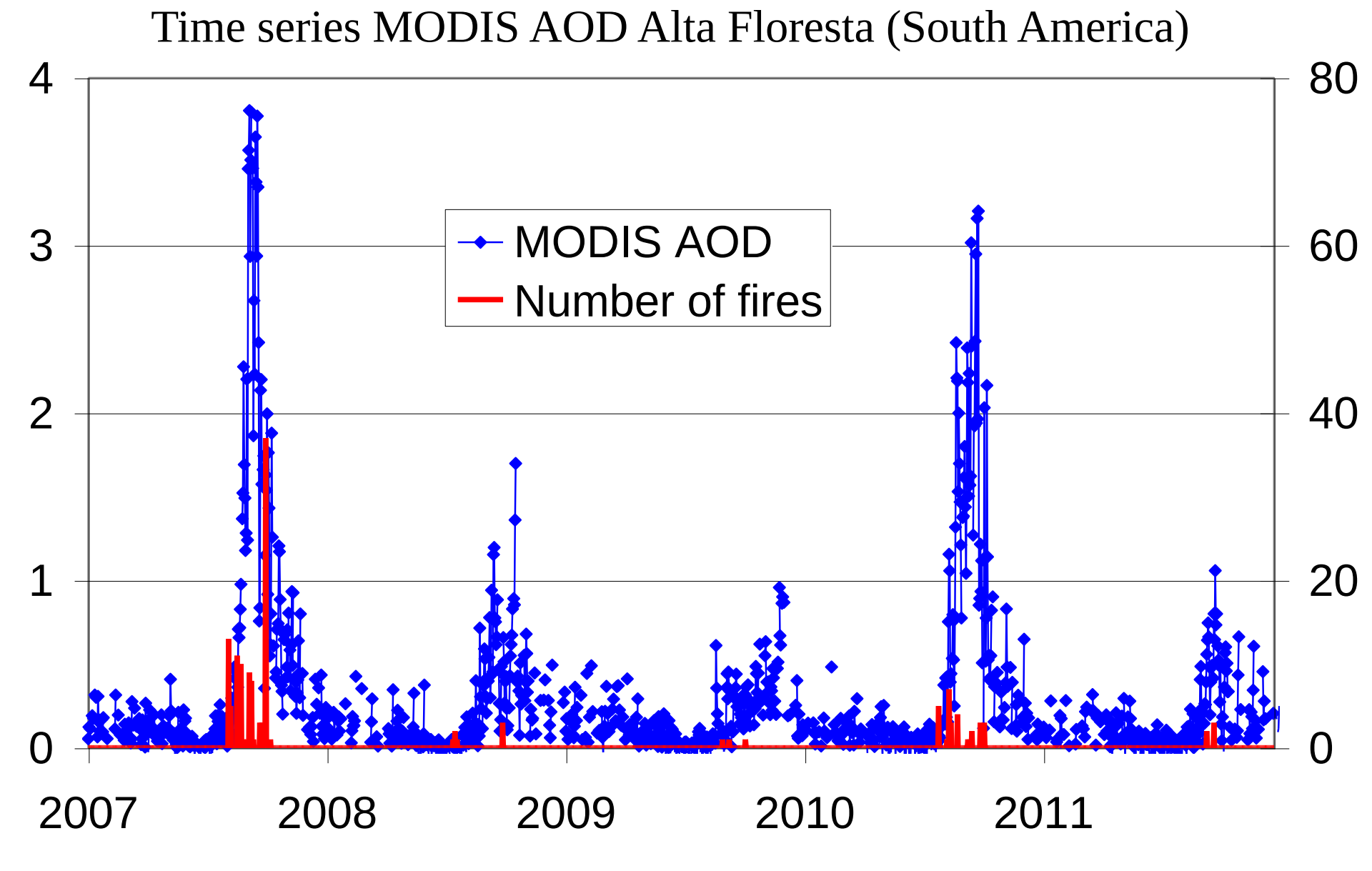


Two important questions:

a) Do we really need daily data on local / regional scale?

b) Why is the correlation so poor?

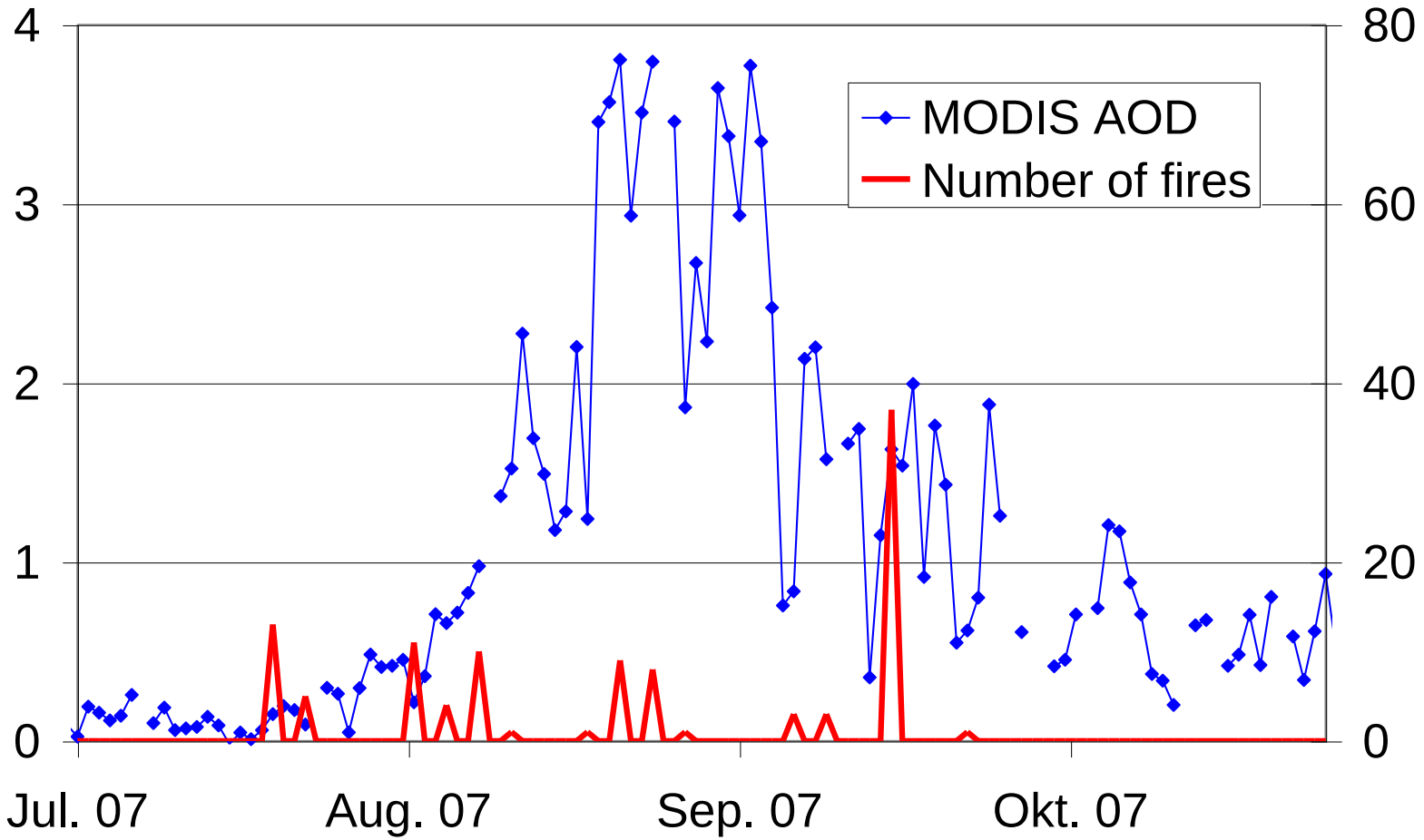
Do we need daily data on local / regional scale?



Do we need daily data on local / regional scale?

Zoom into one biomass burning region

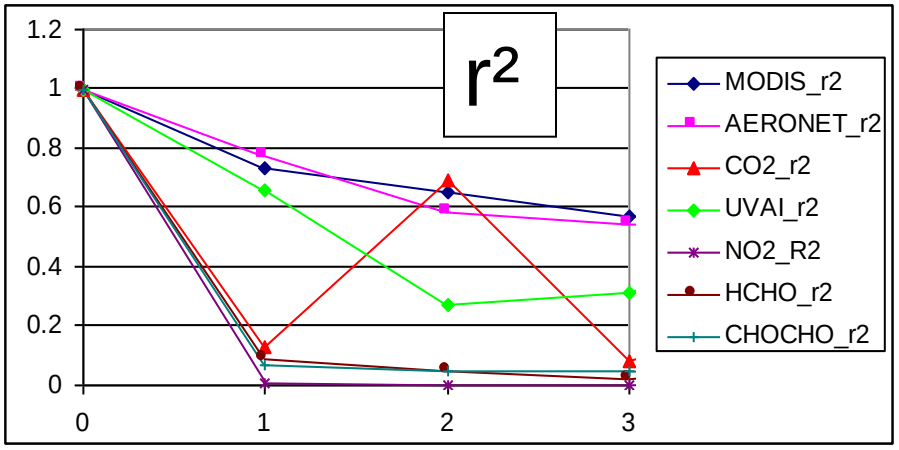
- Enhanced AOD over long time period^s, but
- also large day to day variability



Correlation analysis of shifted time series of daily observations

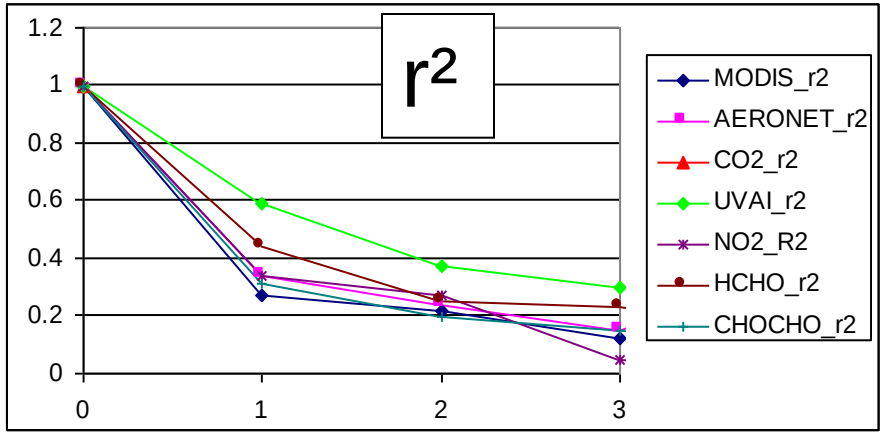
time series are shifted by 1 to 3 days

Alta Floresta



Time shift (days)

Bac Giang



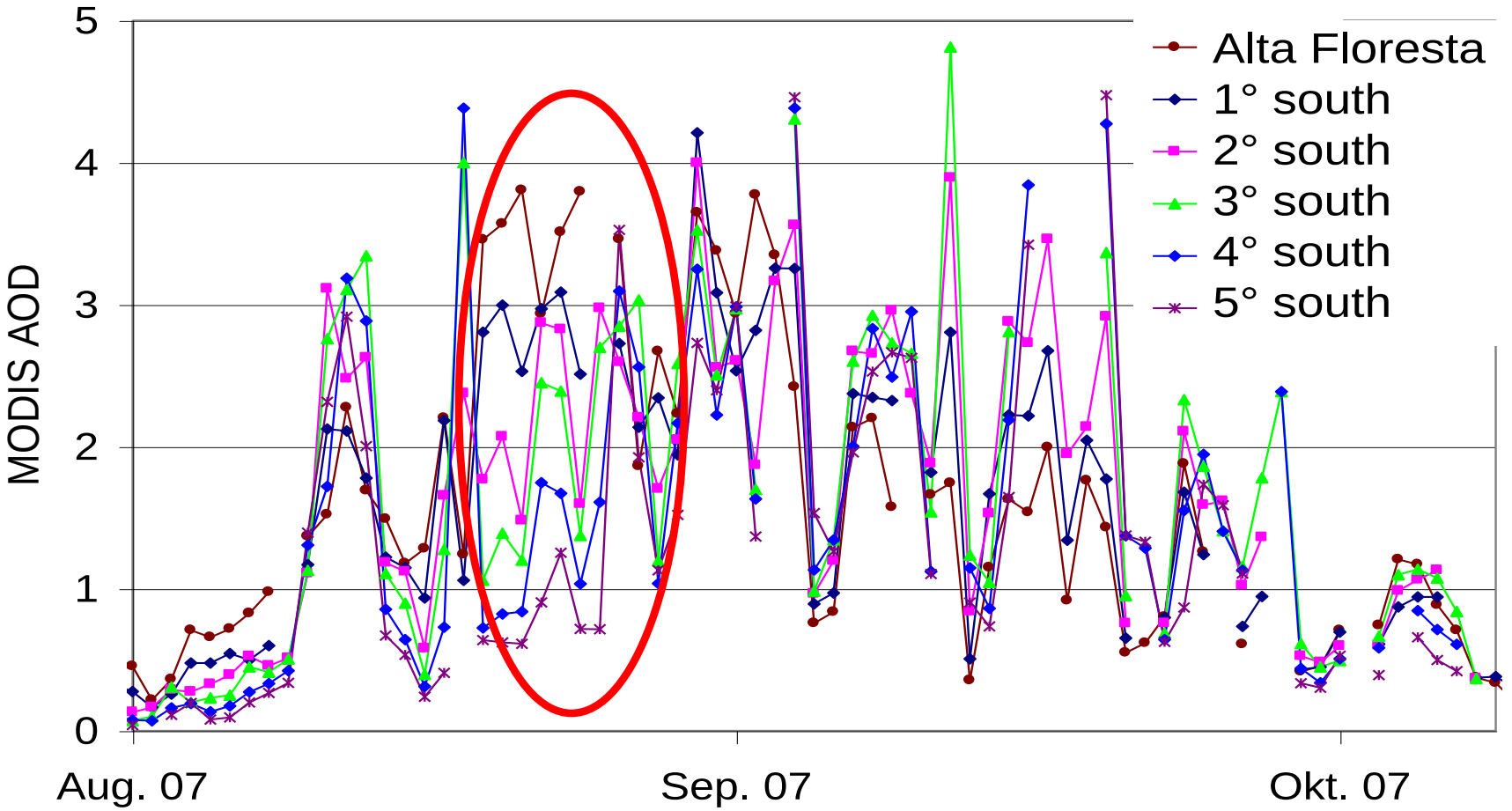
Time shift (days)

Typically the correlation coefficient for AOD, UVAI and CO decreases slowly with increasing time shift

For short-lived trace gases a much more rapid decrease is found.

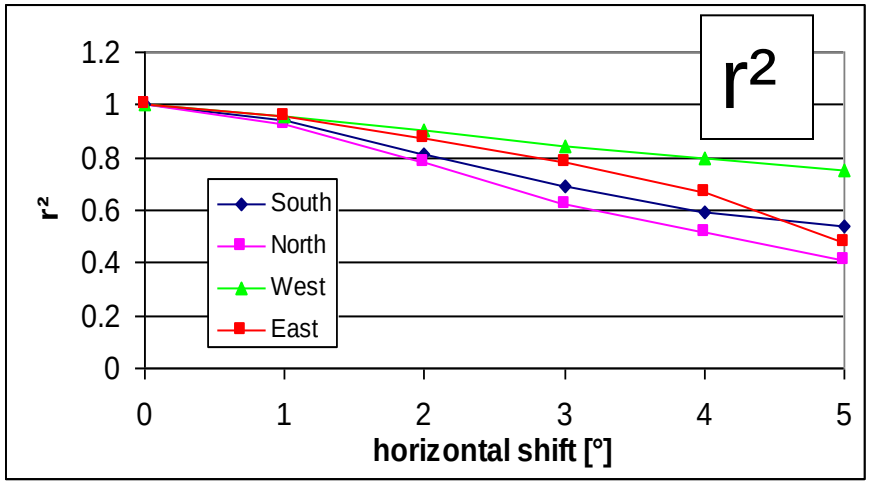
MODIS AOD at Alta Floresta & for areas shifted southwards

- Surprisingly consistent patterns, but
- also systematic differences

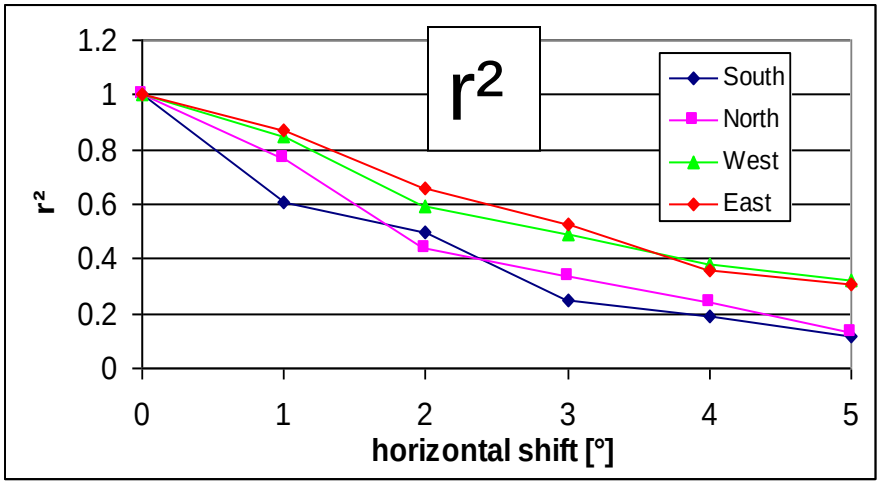


Correlation analysis of time series of daily observations time series are shifted by 1° steps in latitude or longitude

Alta Floresta



Bac Giang



The correlation coefficient for AOD decreases faster in north-south direction compared to east-west direction

For Alta Floresta high correlation is found even for large distances (> 500 km)

(Trace gas data still have to be investigated)

Why is correlation so poor?

Potential reasons:

- scatter of trace gas analysis (low S / N-ratio, viewing angle dependence, etc.)
- Different pixel size & overpass times
- different atmospheric lifetimes (AOD is also an aerosol proxy)
- cloud effects, vertical transport
- interference from other sources
- varying emission factors depending on fire properties
-

.....

How to disentangle these effects?

From the daily time series the S/N-ratio for measurements during biomss burning can be estimated:

Enhancements for NO_2, HCHO & CHOCHO are only slightly higher than the measurement noise:

species	S / N ratio
CO:	~ 8
UVAI:	~ 6
NO_2:	~ 2
HCHO:	~ 3
CHOCHO:	~ 2.5

=> Currently only the strongest biomass burning signals can be idenified

- data analysis can be improved
- S / N ratio for future instruments is probably better

Interference with other sources?

-NO_2 from lightning, soil emissions or anthropogenic emissions

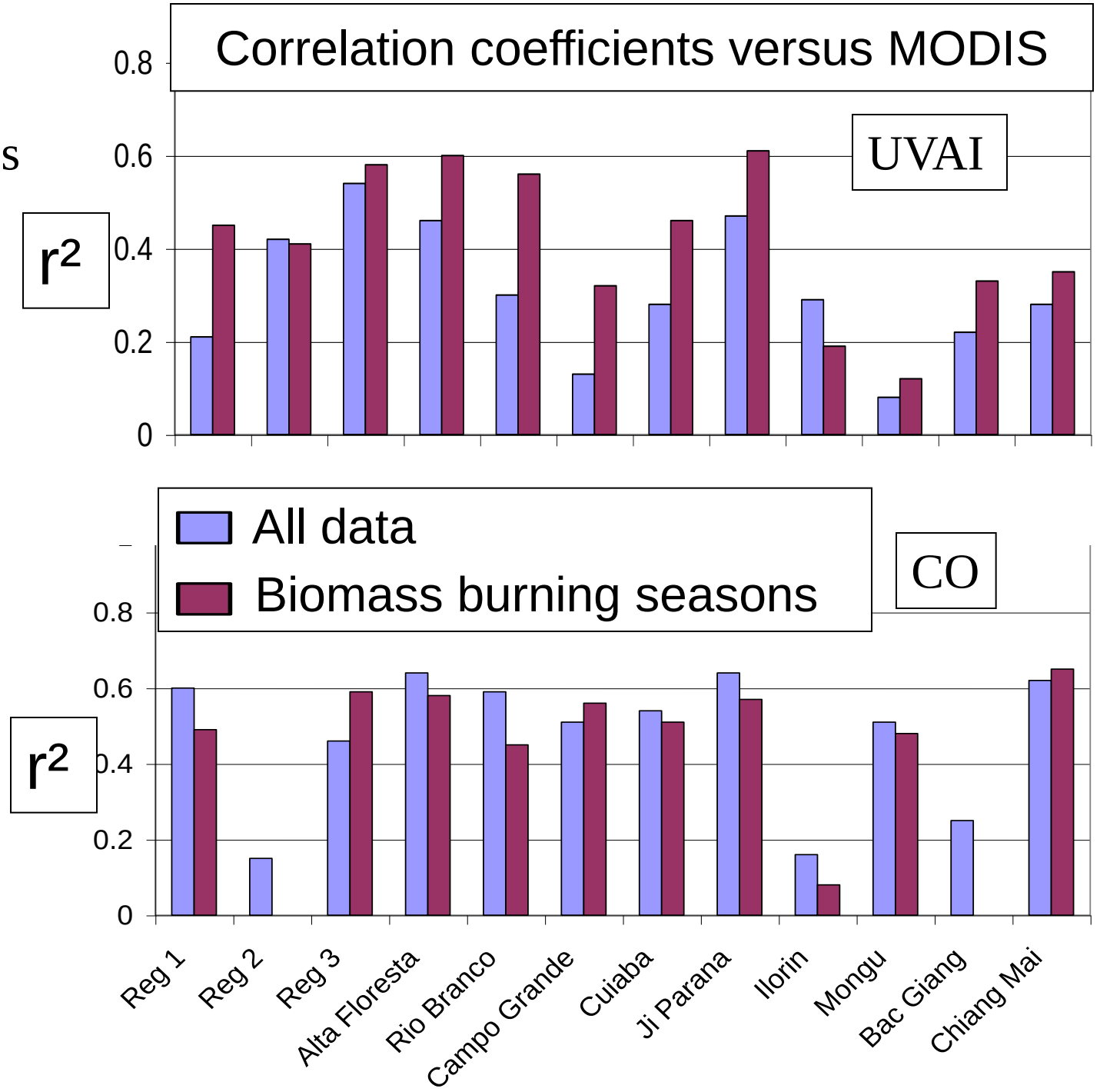
-HCHO and CHOCHO from biogenic and anthropogenic emissions?

(seasonally changing background?)

How do correlations change if only measurements during biomass burning season are considered?

For some species (UVAI & CHOCHO) systematic improvement is found

For others (CO, NO_2 and HCHO) no improvement is found

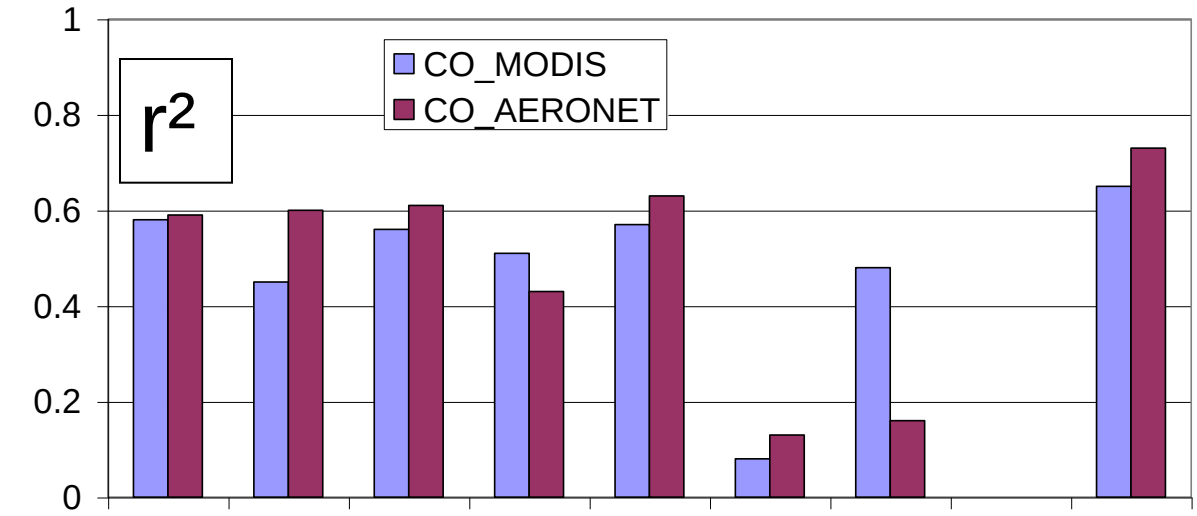


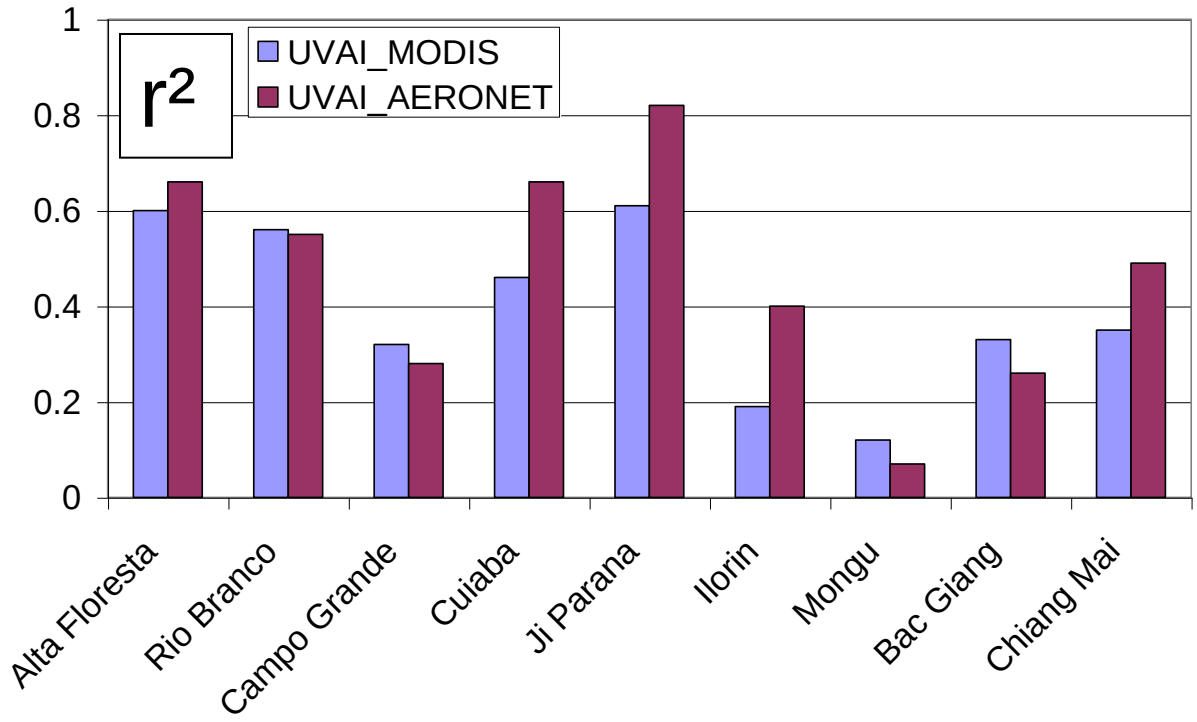
Is MODIS AOD a good proxy for aerosols?

- how good is correlation versus AERONET AOD?

- how good is correlation amongst trace gases and UVAI?

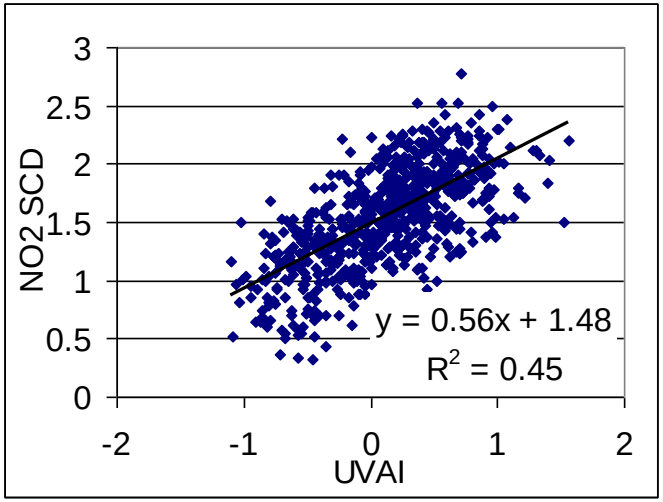
Correlation versus AERONET compared to versus MODIS



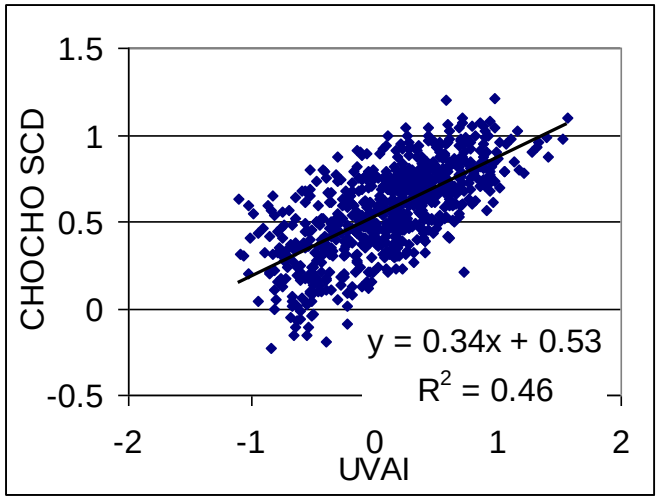


In general, better correlation with AERONET is found

NO2 versus UVAI, Region 3

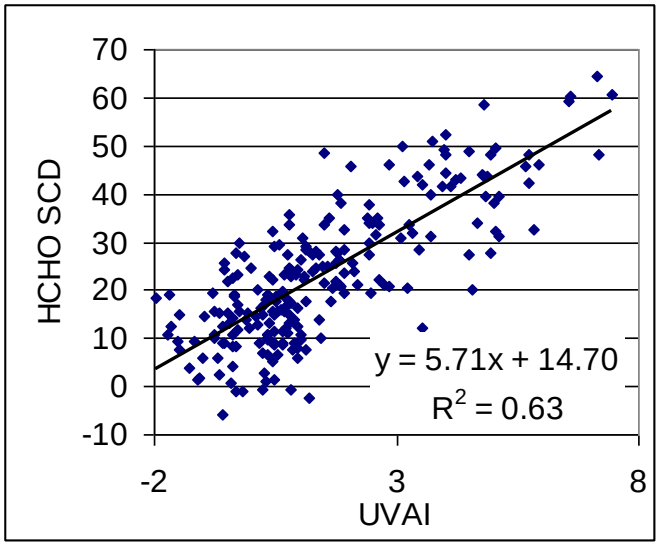


CHOCHO versus UVAI, Region 3

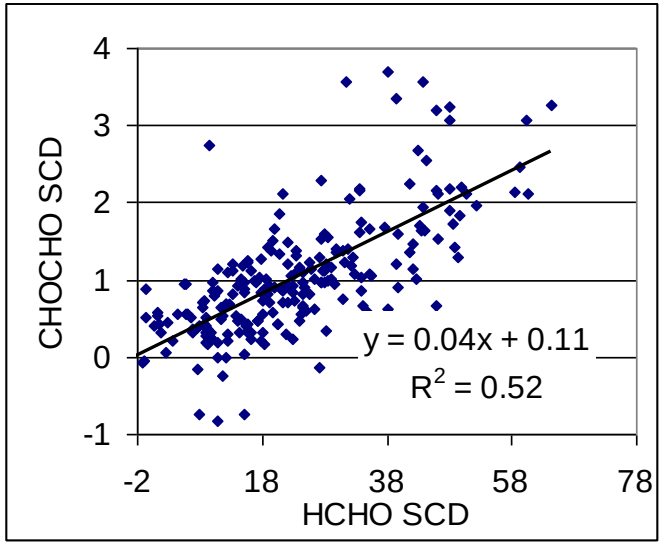


In most cases correlation versus MODIS AOD is better than correlation between trace gases and UVAI

HCHO versus UVAI, Bac Giang



CHOCHO versus HCHO, Bac Giang



But in several cases the latter is better

=> MODIS AOD is a good but not perfect proxy for aerosols

- it would be good to correlate satellite observations to in-situ aerosol observations

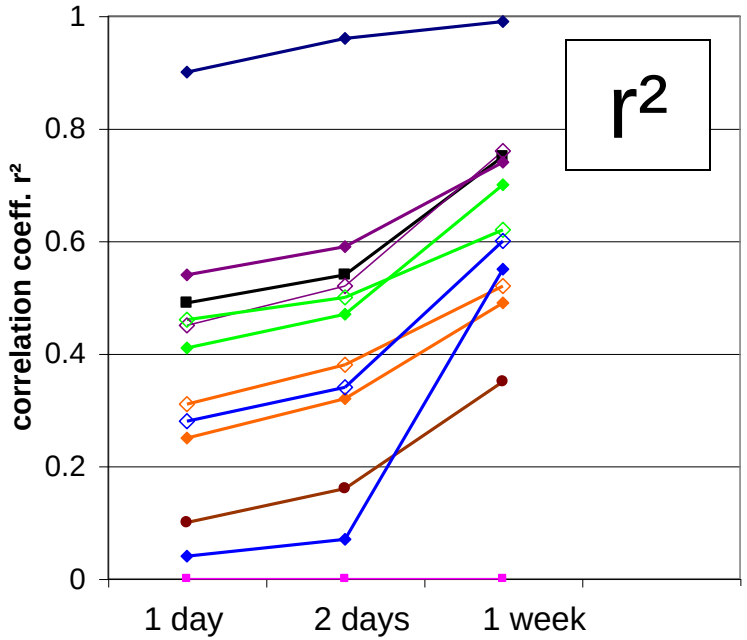
How consistent are correlation results?

- for different locations

- for different temporal averages

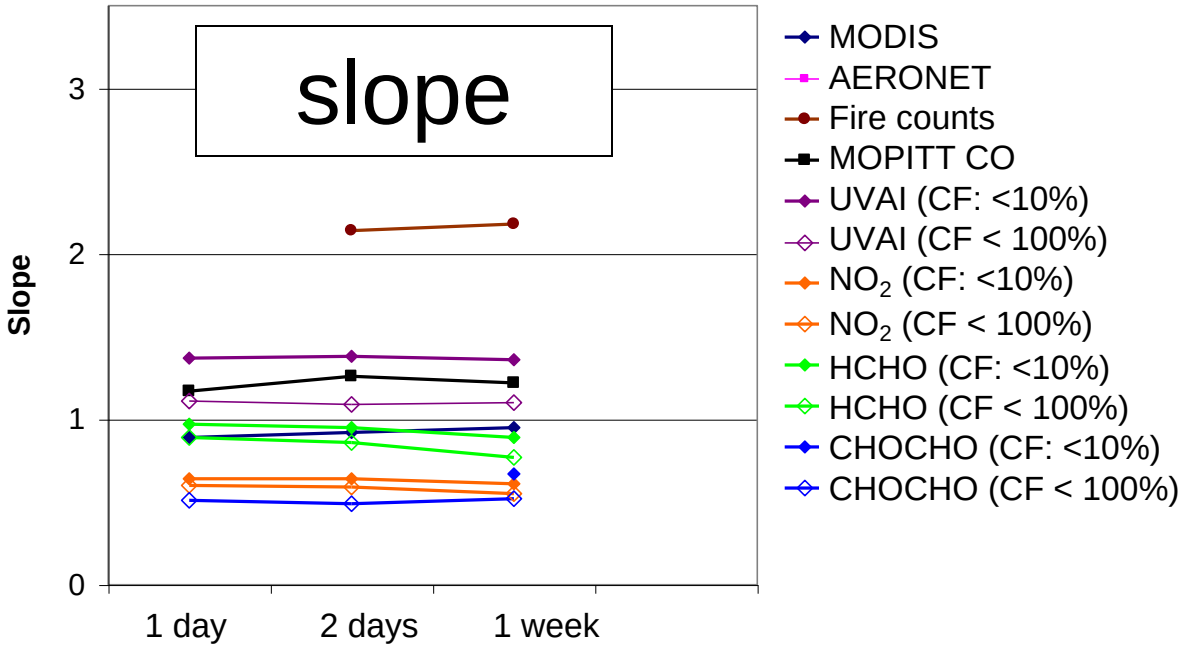
(daily, two days, weekly averages)

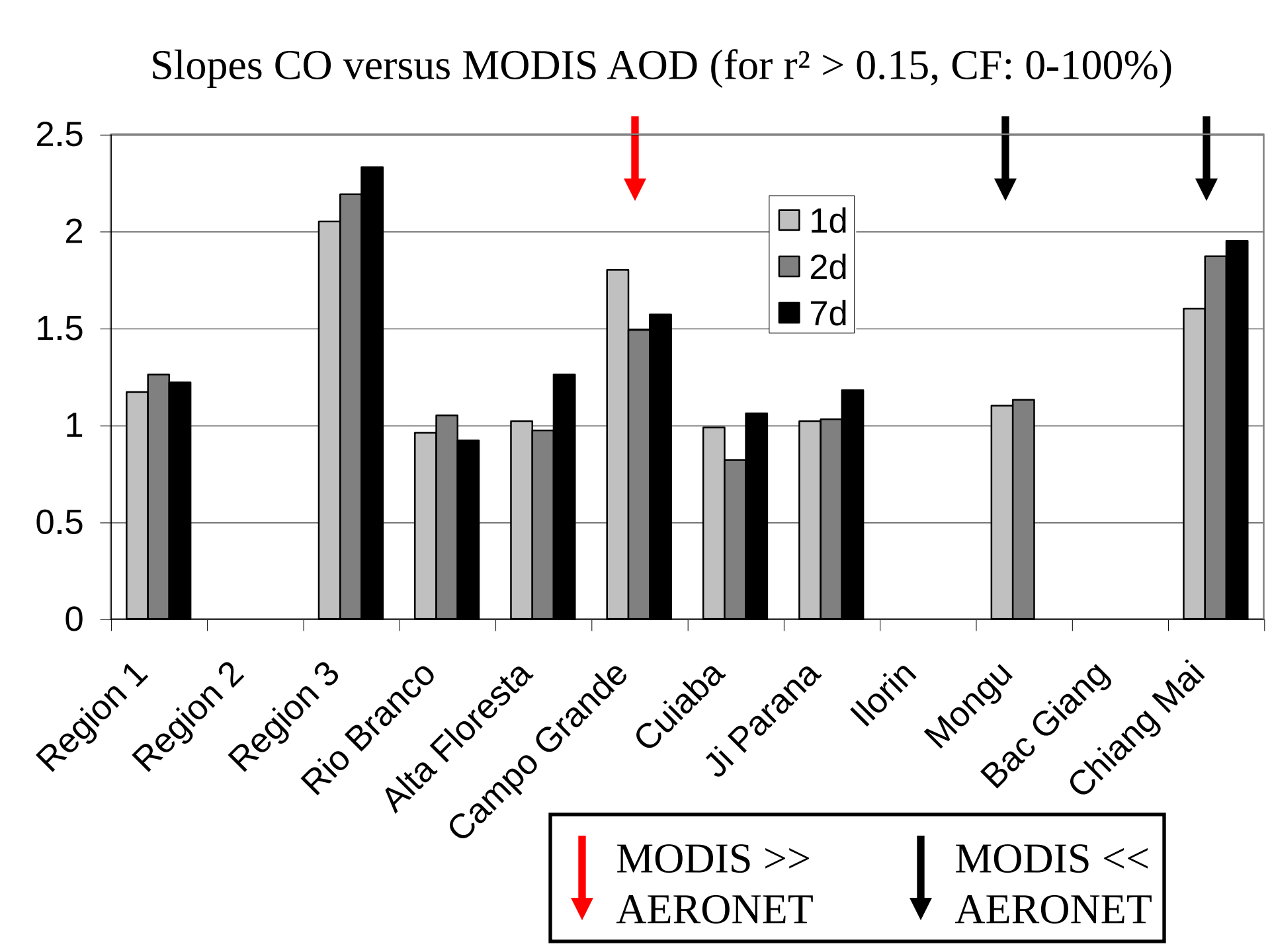
How do the correlation results depend on temporal averaging?

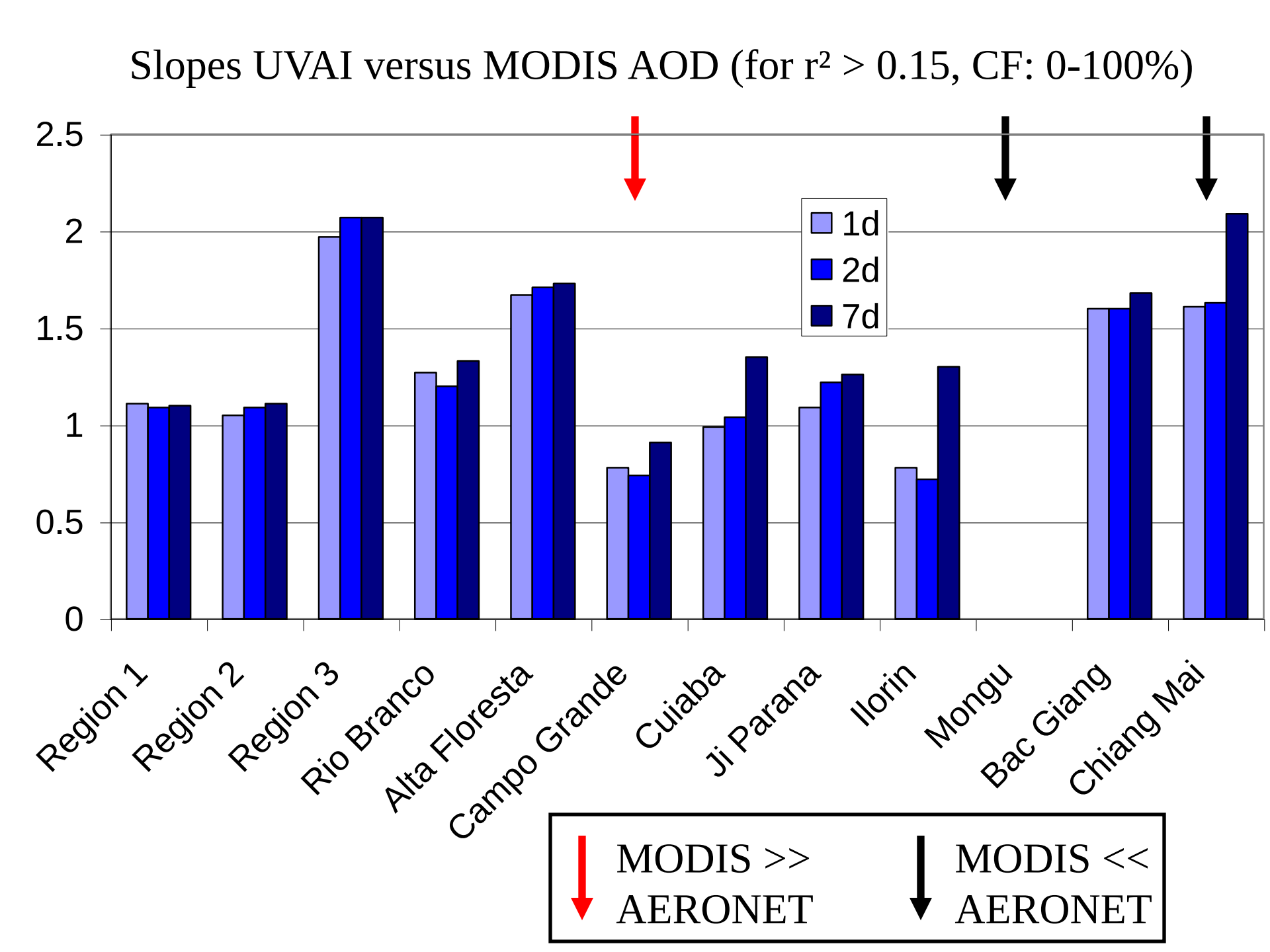


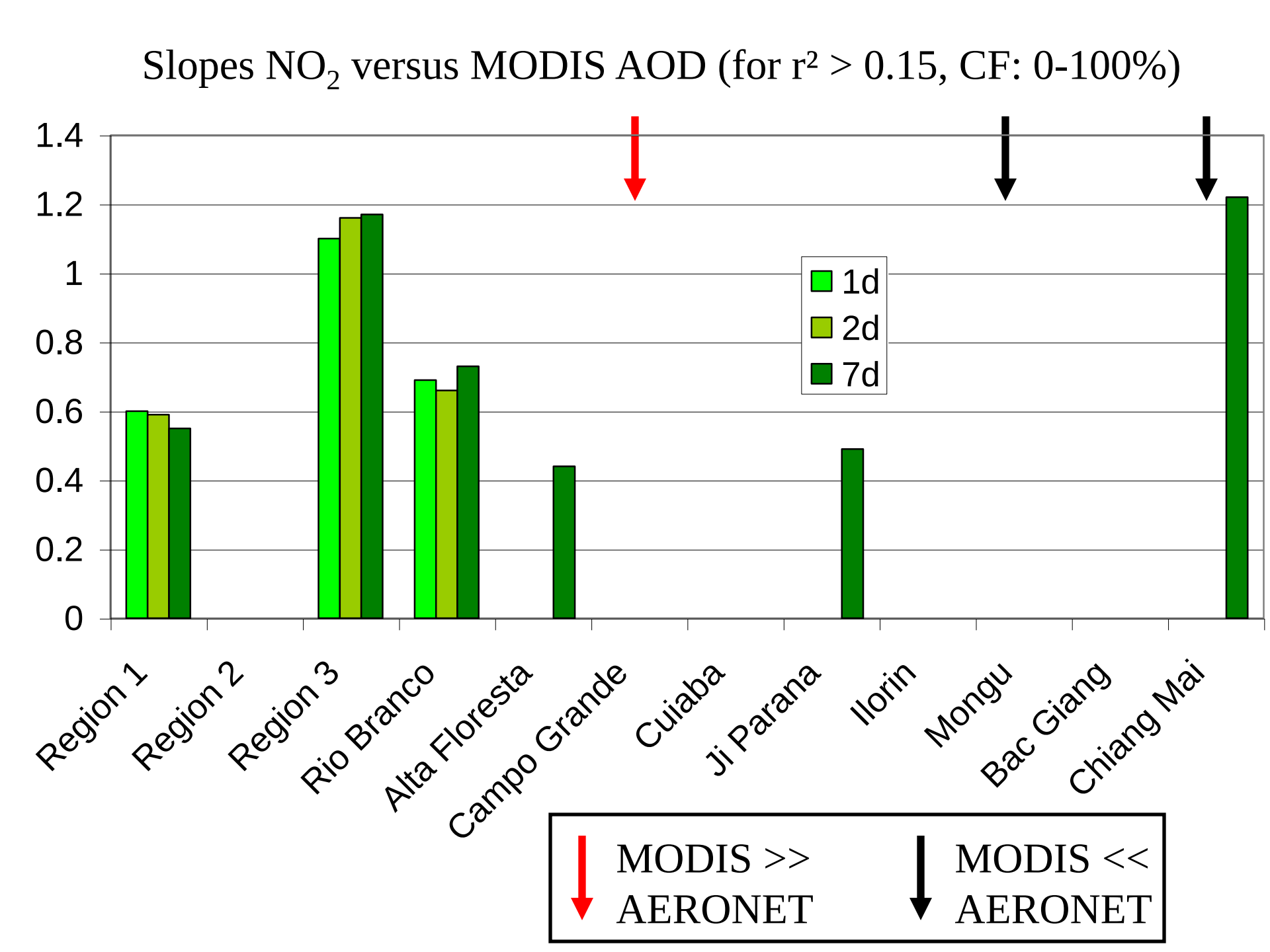
Example for Region 1 (South America)

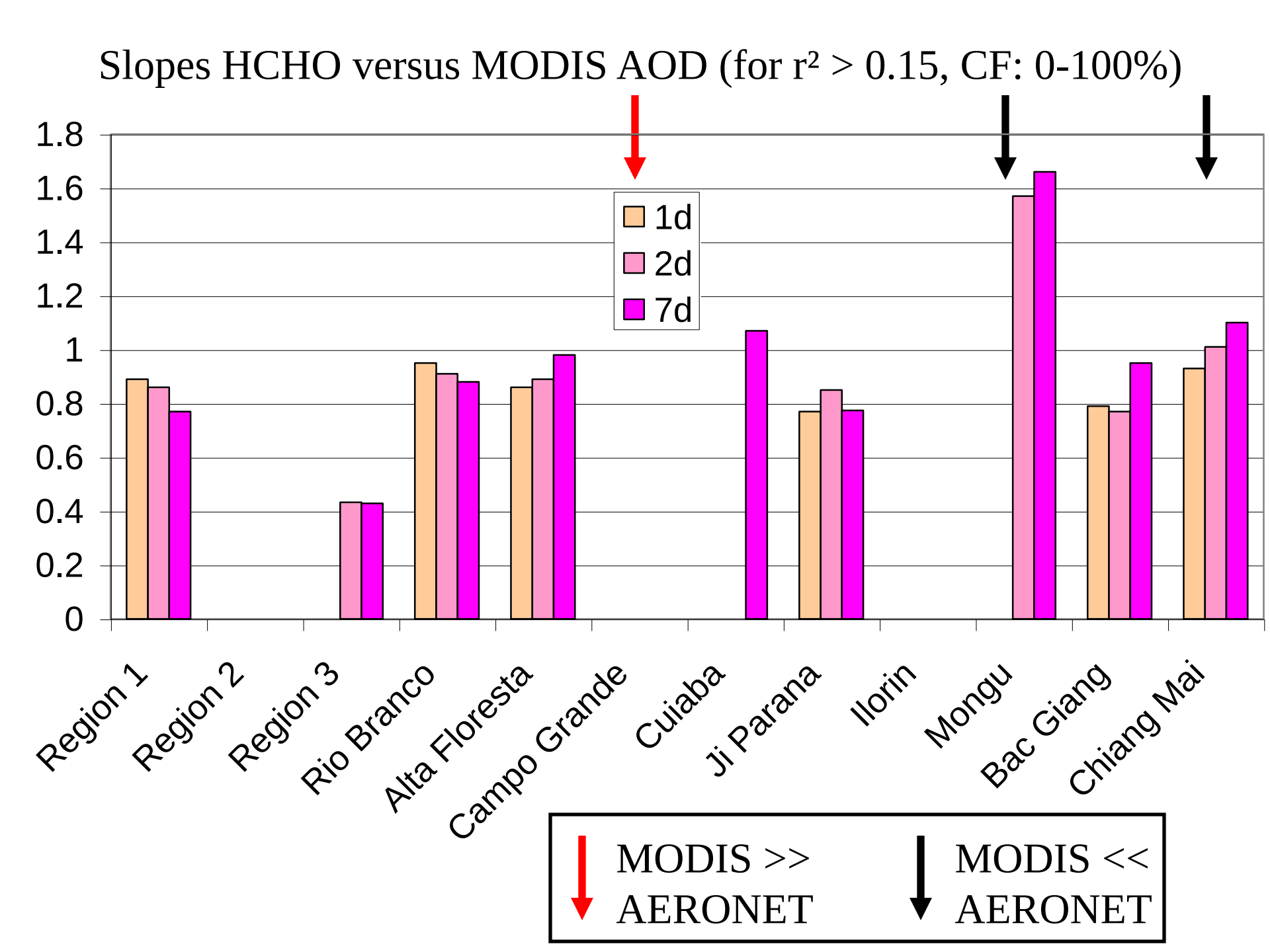
only slopes for $r^2 > 0.15$ are considered

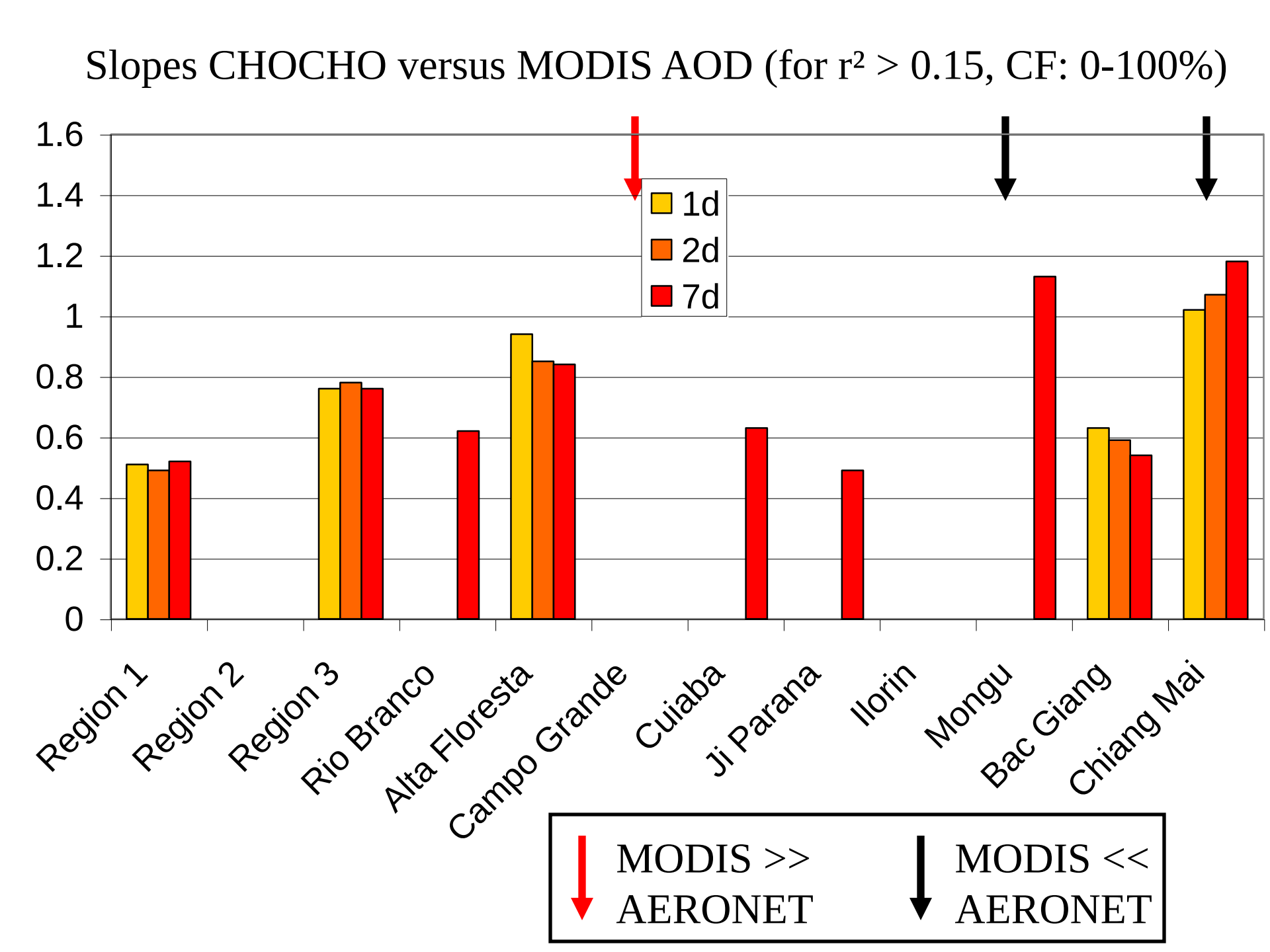



Slopes CO versus MODIS AOD (for r² > 0.15, CF: 0-100%)
2.5
2
1.5
1
0.5
0
1d
2d
7d
Region 1
Region 2
Region 3
Rio Branco
Alta Floresta
Campo Grande
Cuiaba
Ji Parana
Ilorin
Mongu
Bac Giang
Chiang Mai
MODIS >> AERONET
MODIS << AERONET


Slopes UVAI versus MODIS AOD (for r² > 0.15, CF: 0-100%)
2.5
2
1.5
1
0.5
0
1d
2d
7d
Region 1
Region 2
Region 3
Rio Branco
Alta Floresta
Campo Grande
Cuiaba
Ji Parana
Ilorin
Mongu
Bac Giang
Chiang Mai
MODIS >> AERONET
MODIS << AERONET


Slopes NO2 versus MODIS AOD (for r² > 0.15, CF: 0-100%)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1d
2d
7d
Region 1
Region 2
Region 3
Rio Branco
Alta Floresta
Campo Grande
Cuiaba
Ji Parana
Ilorin
Mongu
Bac Giang
Chiang Mai
MODIS >> AERONET
MODIS << AERONET


Slopes HCHO versus MODIS AOD (for r² > 0.15, CF: 0-100%)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1d
2d
7d
Region 1
Region 2
Region 3
Rio Branco
Alta Floresta
Campo Grande
Cuiaba
Ji Parana
Ilorin
Mongu
Bac Giang
Chiang Mai
MODIS >> AERONET
MODIS << AERONET


Slopes CHOCHO versus MODIS AOD (for r² > 0.15, CF: 0-100%)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1d
2d
7d
Region 1
Region 2
Region 3
Rio Branco
Alta Floresta
Campo Grande
Cuiaba
Ji Parana
Ilorin
Mongu
Bac Giang
Chiang Mai
MODIS >> AERONET
MODIS << AERONET

Slopes for the different species

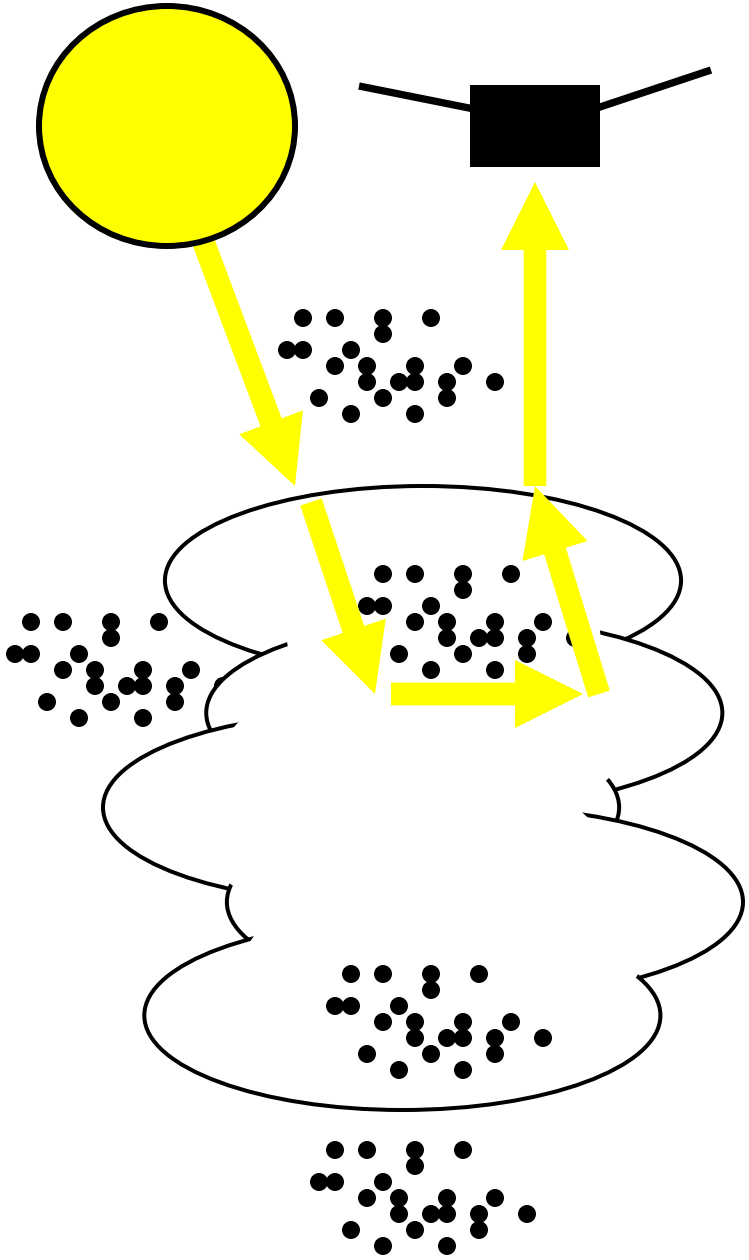
CO	$0.8 – 2.3 \cdot 10^{18}$ molec/cm²
UVAI	0.7 – 2.1
NO_2	$0.5 – 1.2 \cdot 10^{15}$ molec/cm²
HCHO	$0.4 – 1.7 \cdot 10^{16}$ molec/cm²
CHOCHO	$0.5 – 1.2 \cdot 10^{15}$ molec/cm²

– slopes are typically within 20% for individual stations

– but amongst stations within a factor of 2 to 4

=> Different emission factors & meteorological conditions

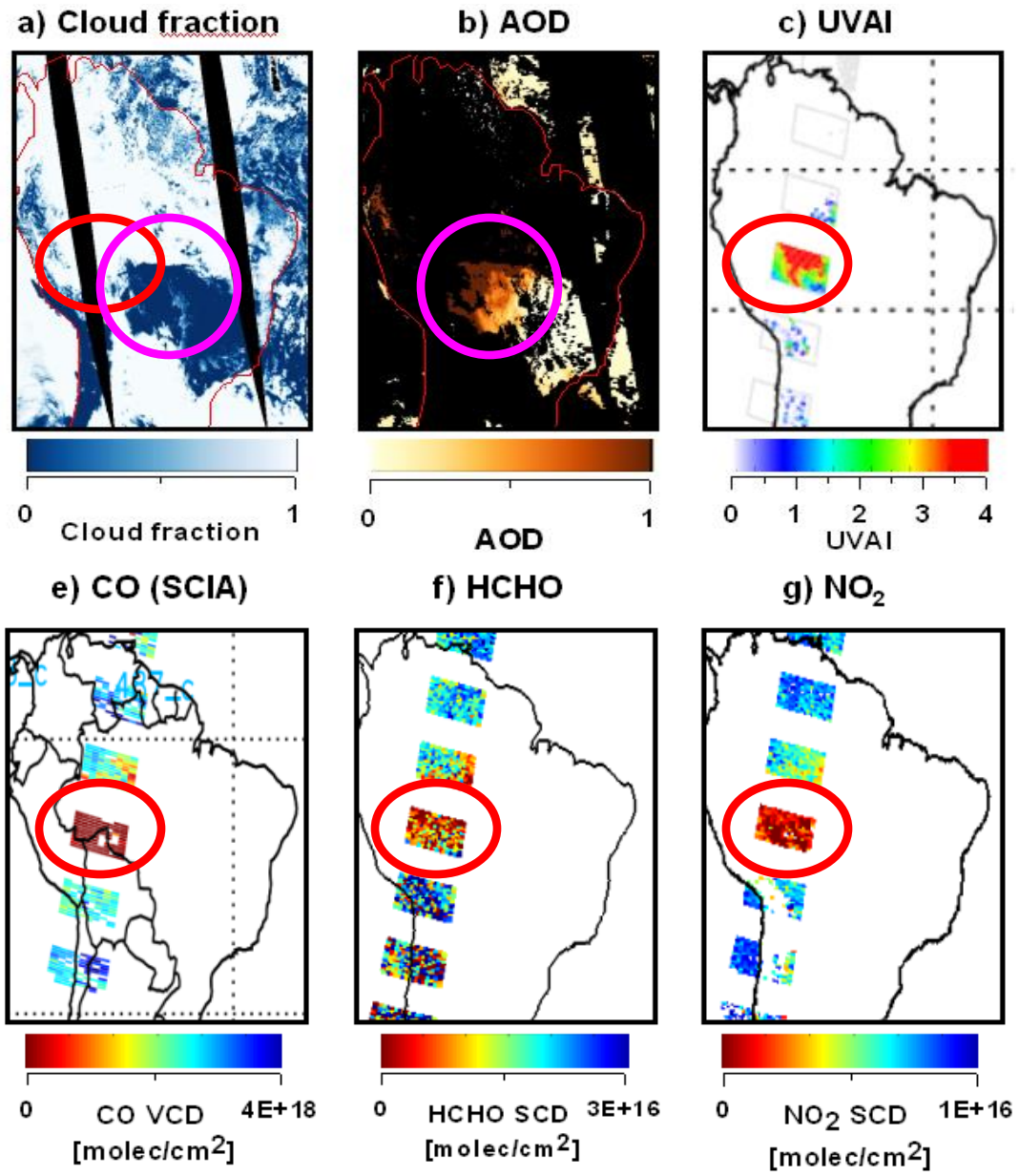
Effects of clouds



(How well) Can aerosols and trace gases be ‚seen' in the presence of clouds?

- aerosols from radiance at single wavelength – no
- aerosols from radiance at two wavelengths (aerosol indices) – yes
- trace gases from spectra – yes

Effects of clouds

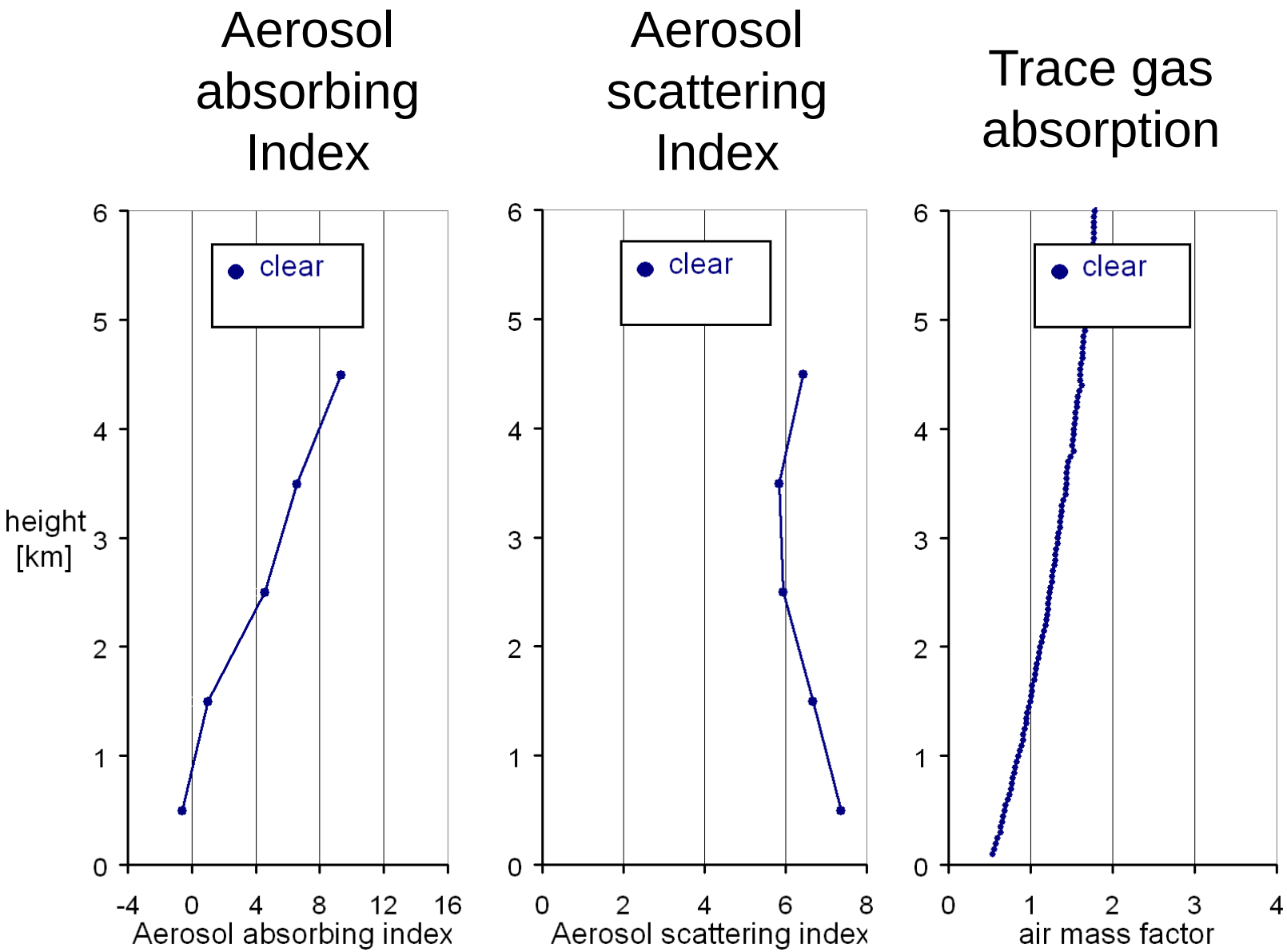


MODIS AOD can only be observed between clouds

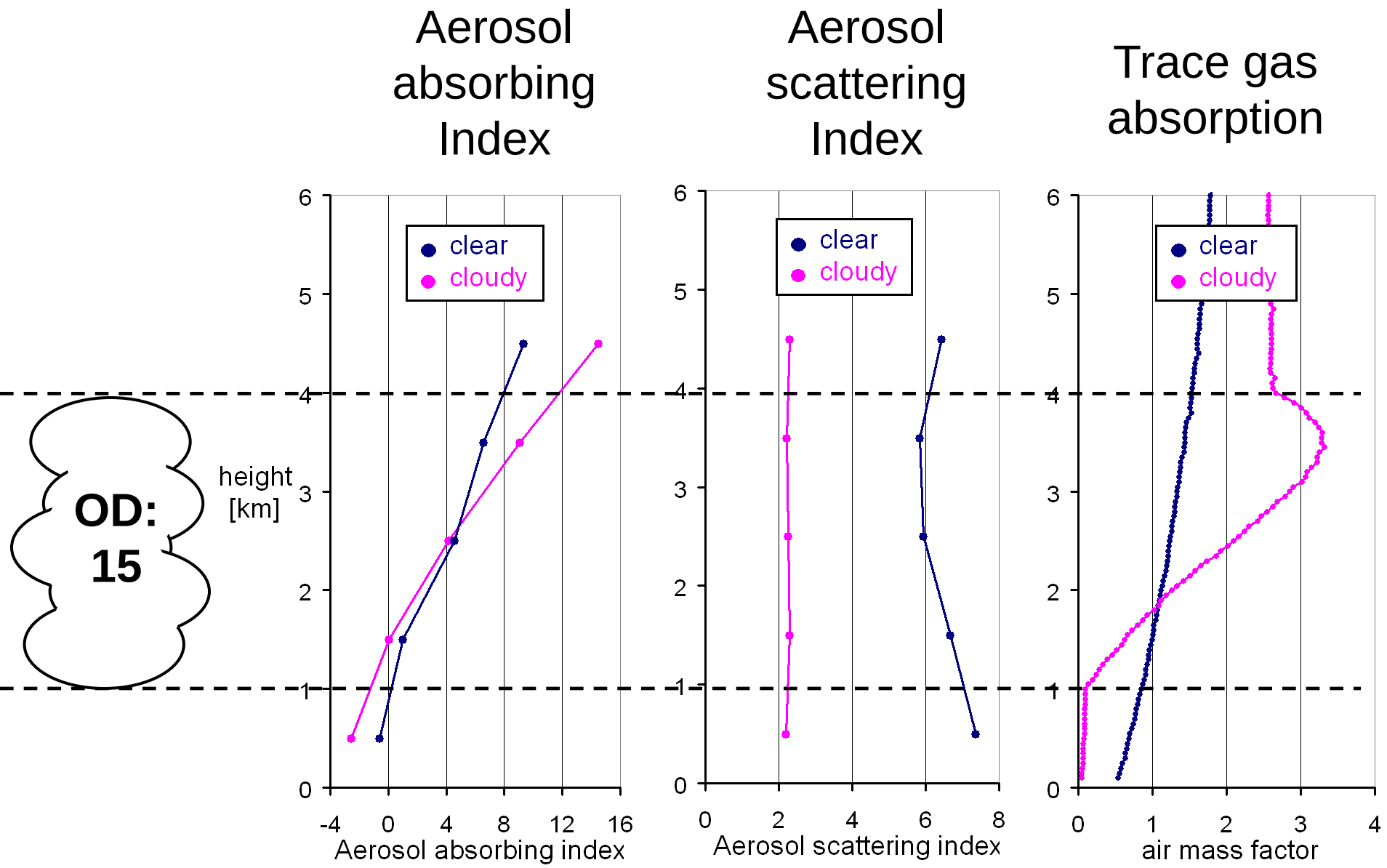
Trace gases and the UVAI can be retrieved in the presence of clouds

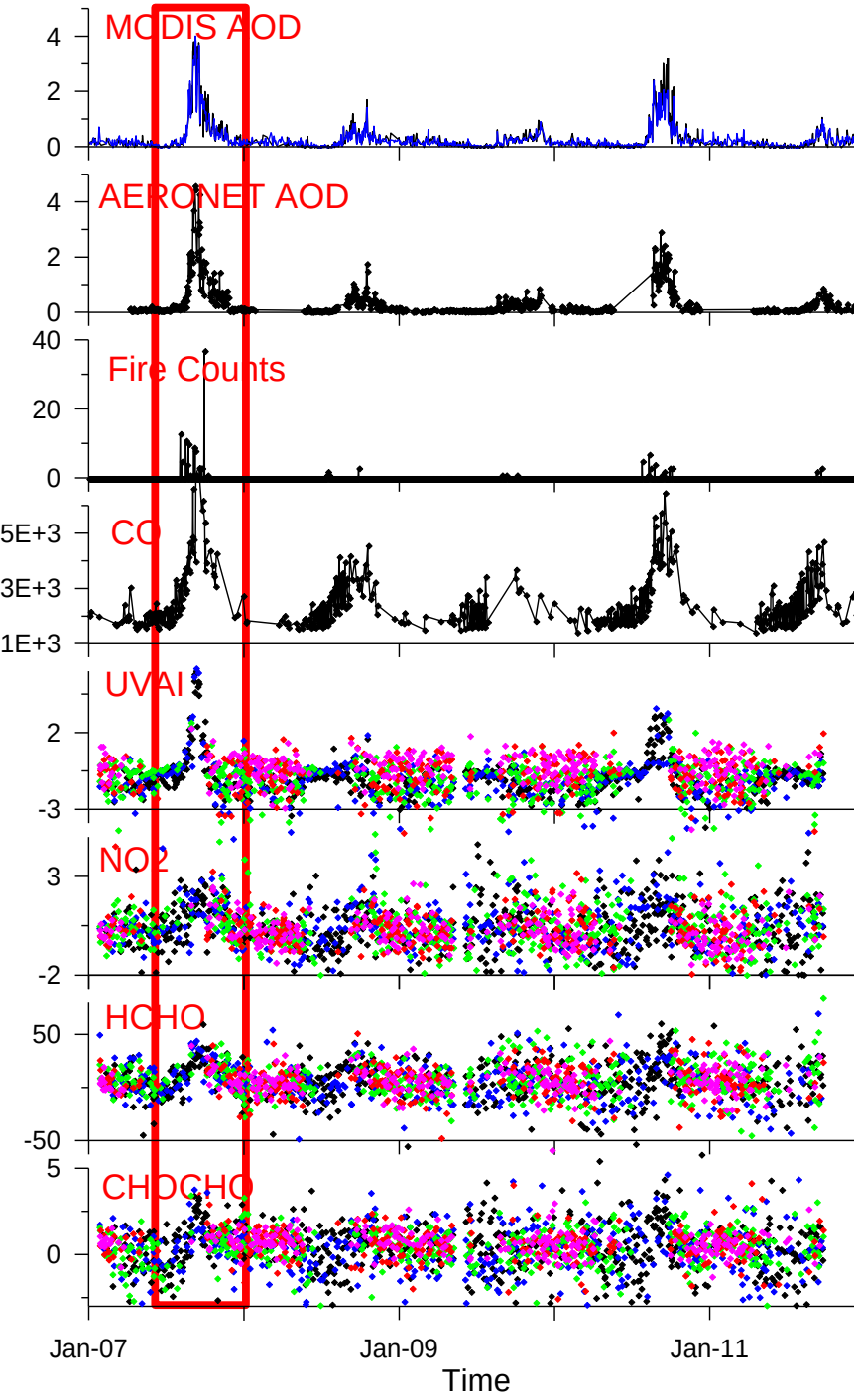
What is sensitivity for inside or below cloud?

Sensitivity for clear Sky



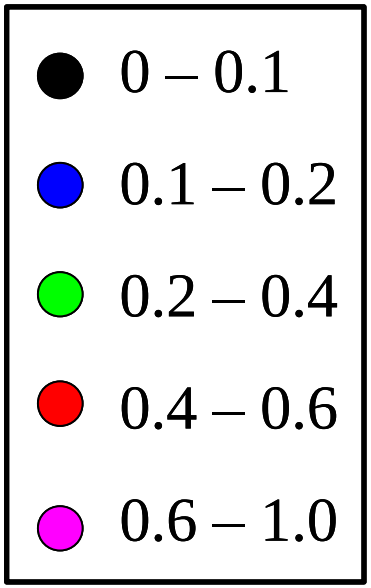
Sensitivity for cloudy Sky





Alta Floresta

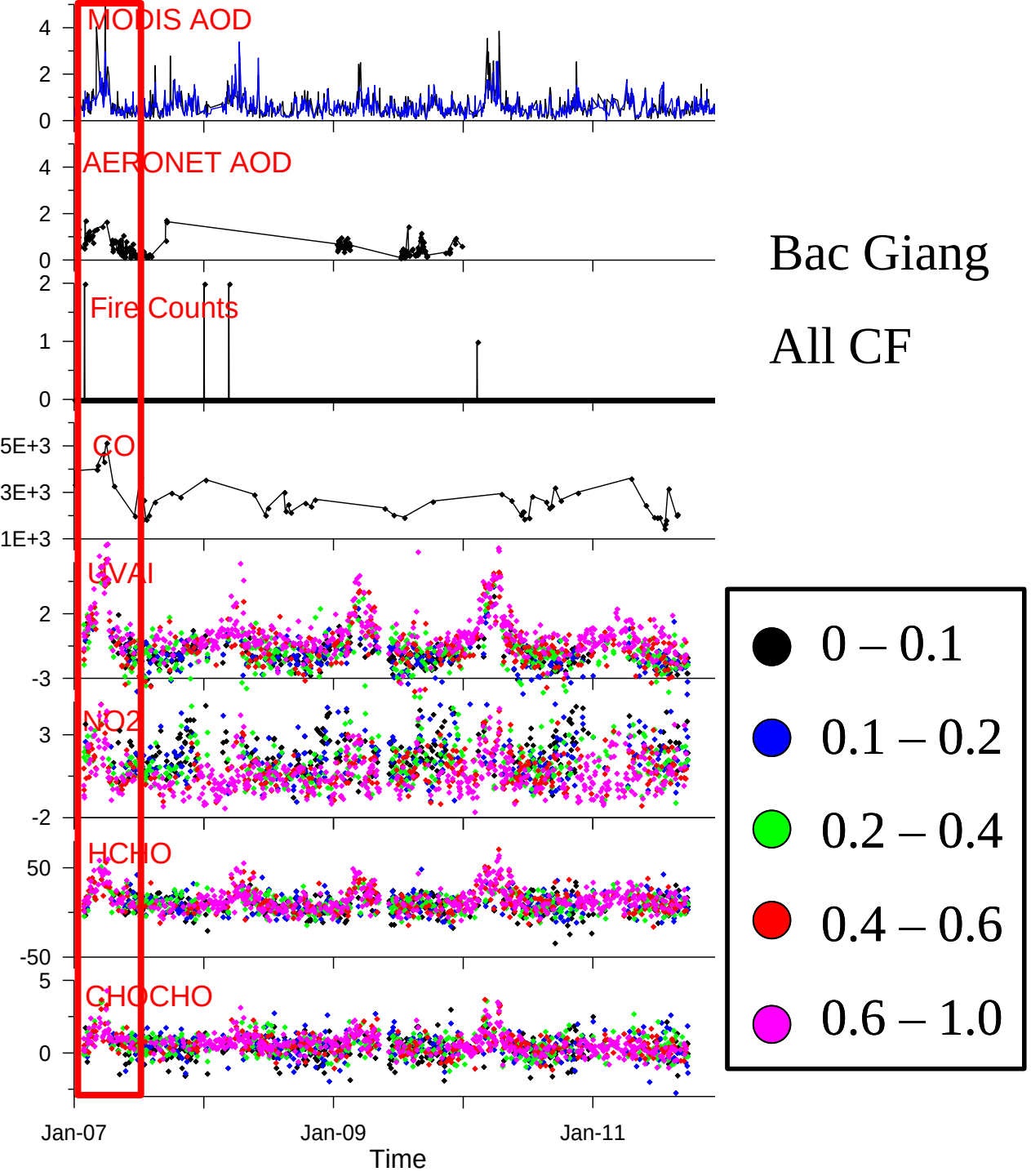
All CF



Typical case:

(e.g. Alta Floresta)

Mainly cloud free observations during phases of intense biomass burning



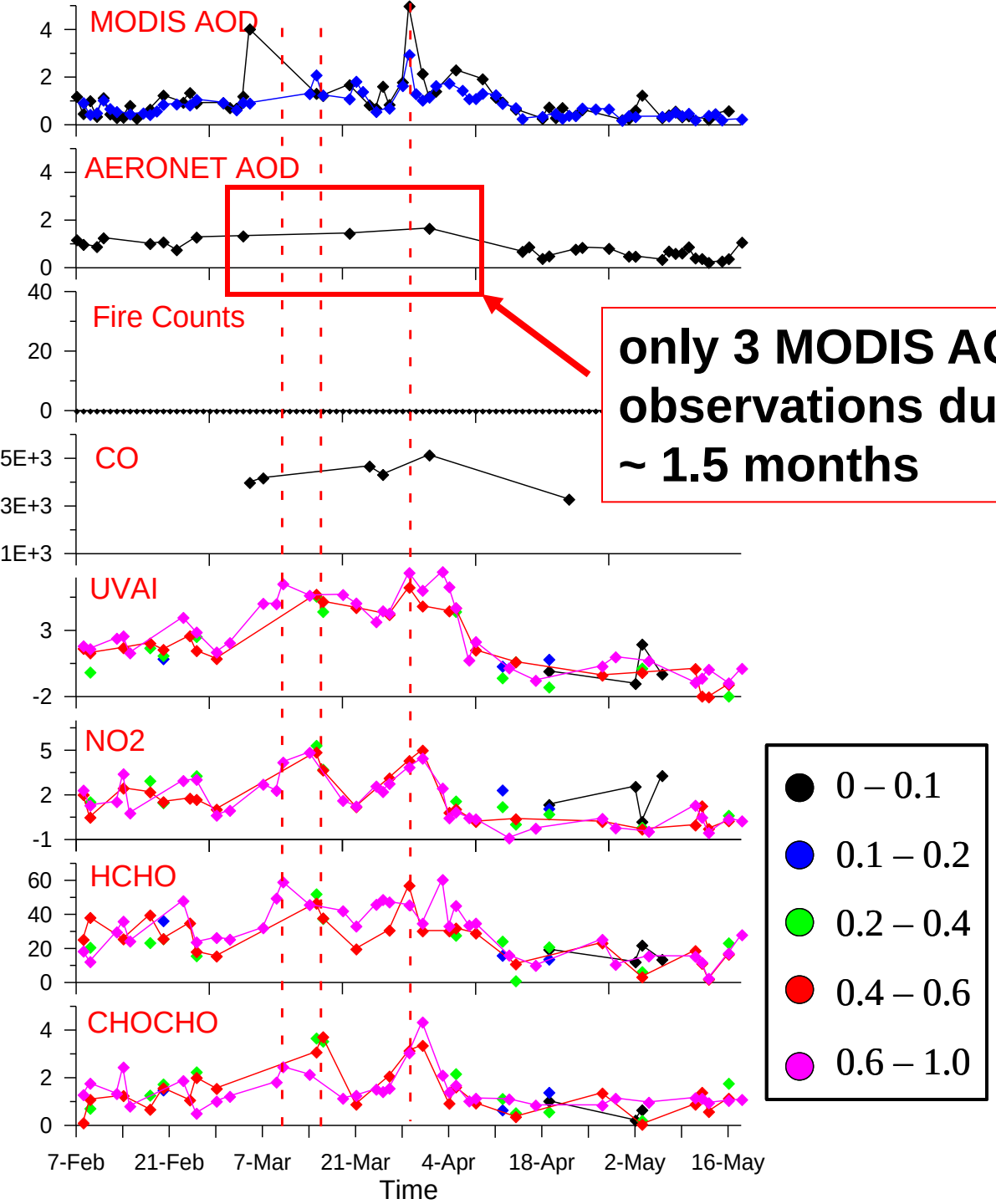
Bac Giang

All CF

Special case:

(Bac Giang)

Mainly cloudy observations during phases of intense biomass burning

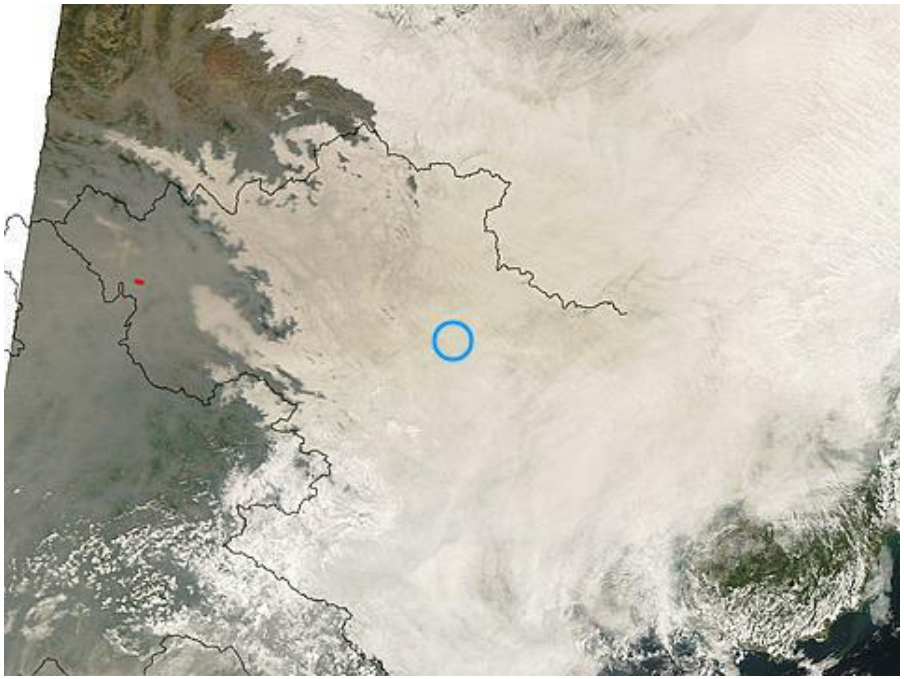


only 3 MODIS AOD observations during ~ 1.5 months

Special case:

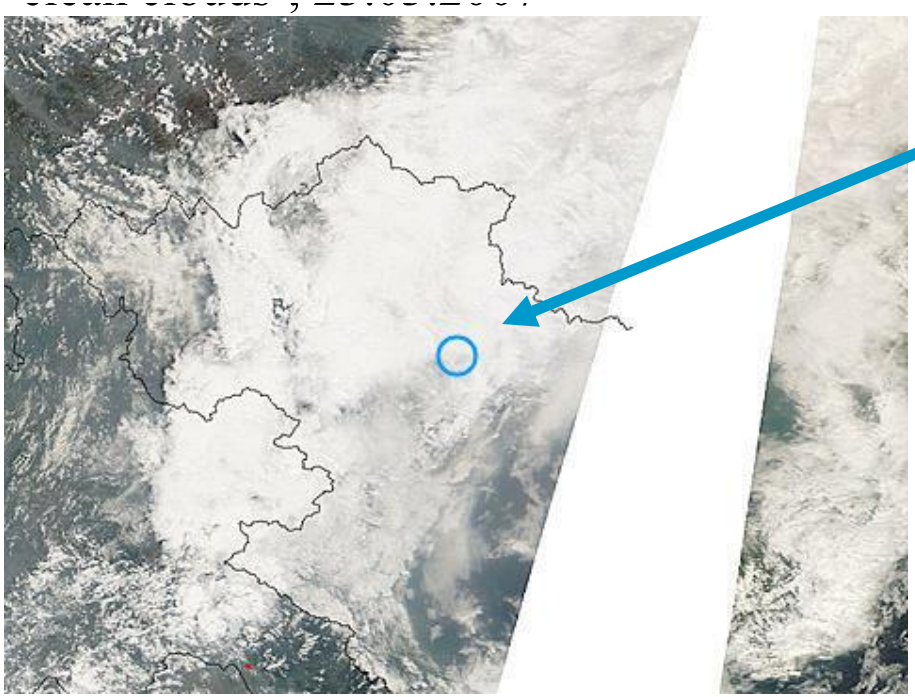
(Bac Giang)

Mainly cloudy observations during phases of intense biomass burning



Aerosol can bee seen in MODIS RGB images

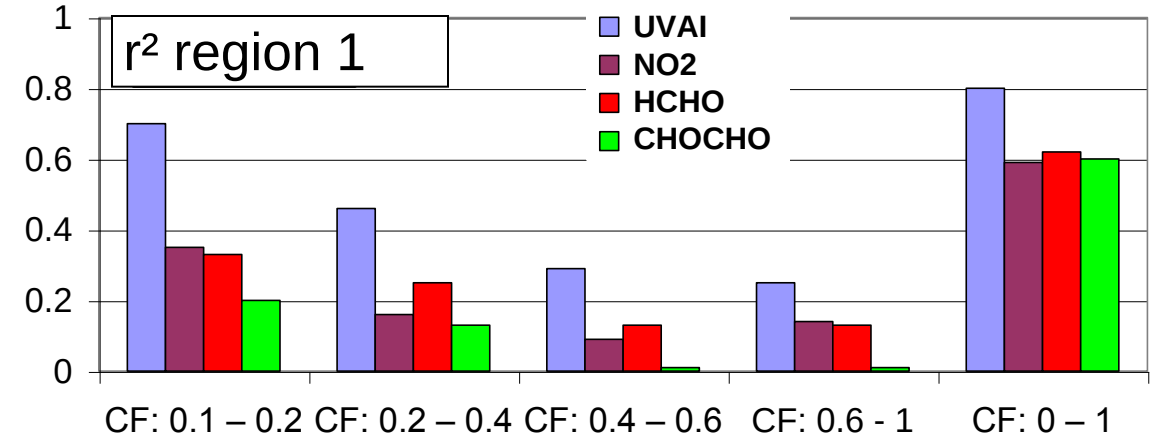
10.03.2007

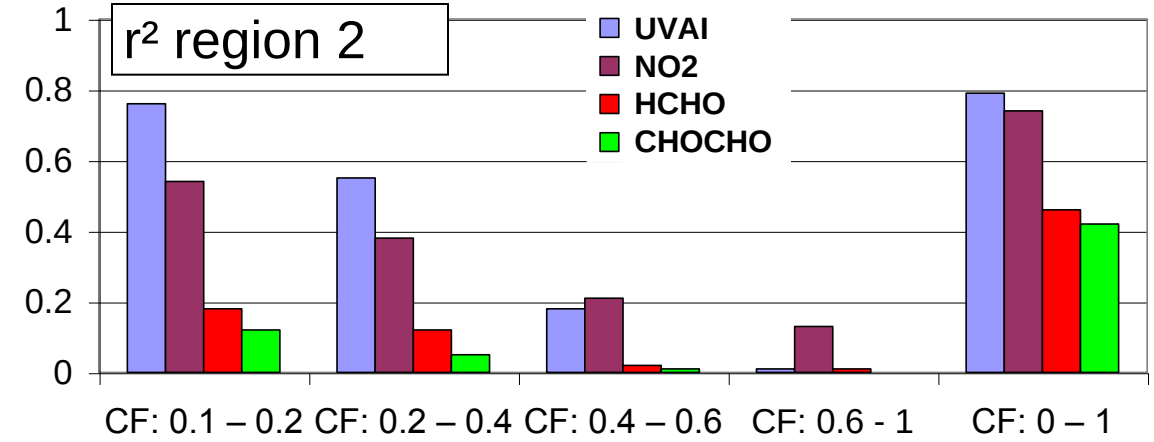


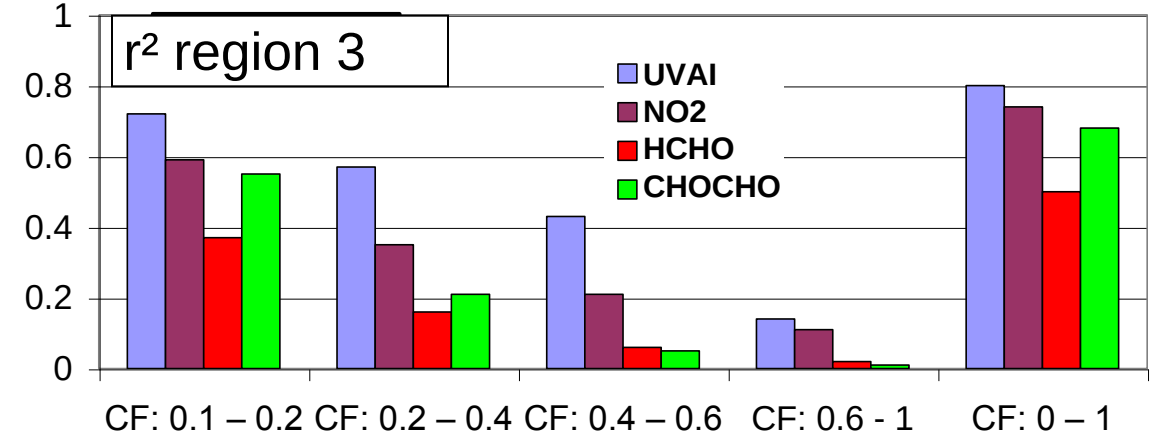
Bac Giang

Some days later, clean clouds are seen

23.03.2007



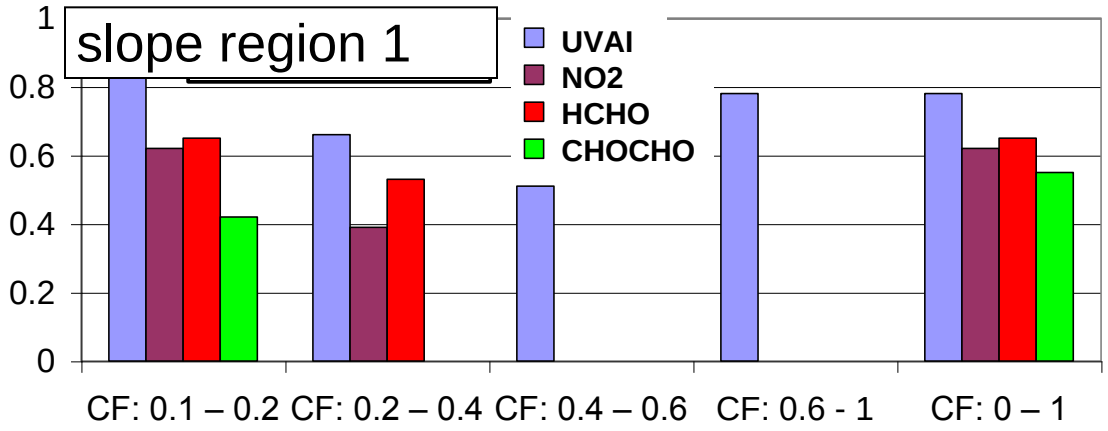


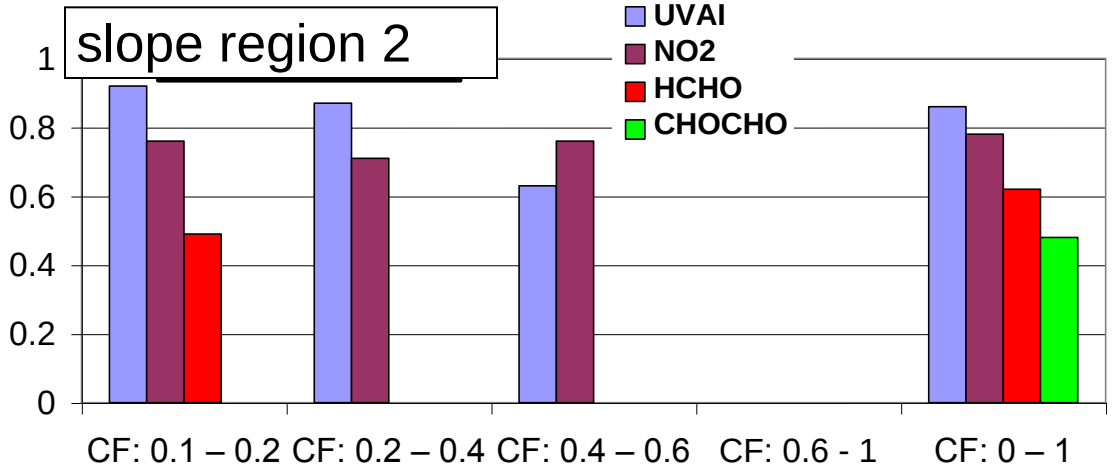


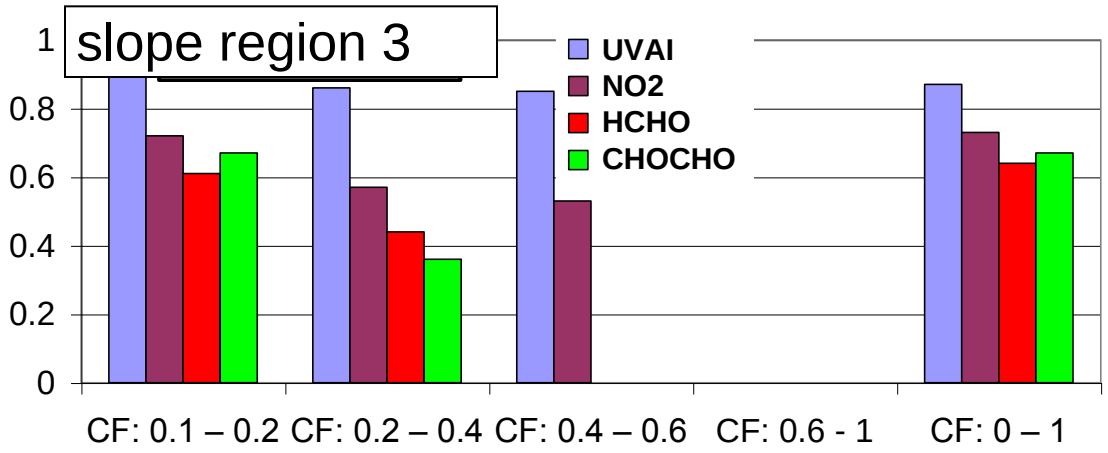
Investigate averages for different cloud fractions over extended areas

r^2

Correlation results for trace gas & UVAI observations versus respective results for CF <10%



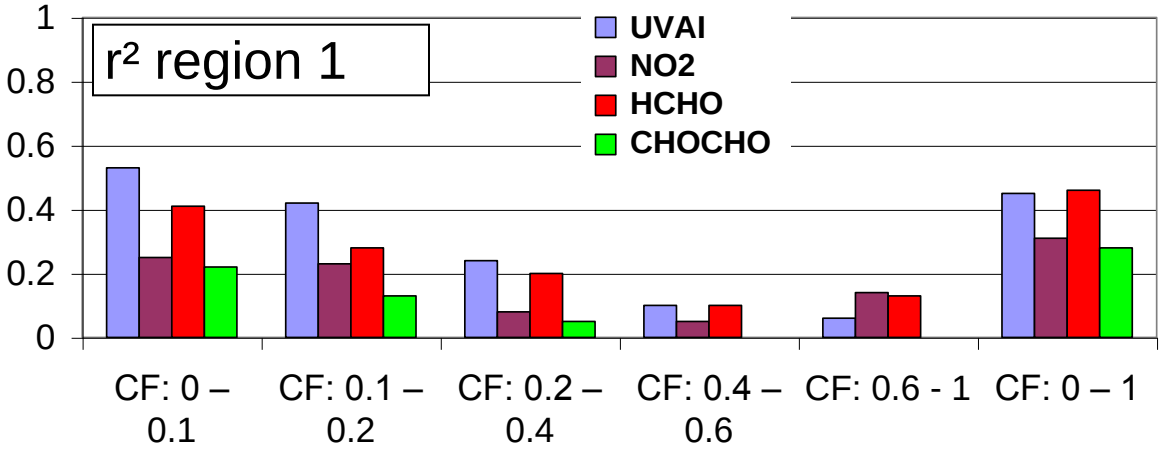


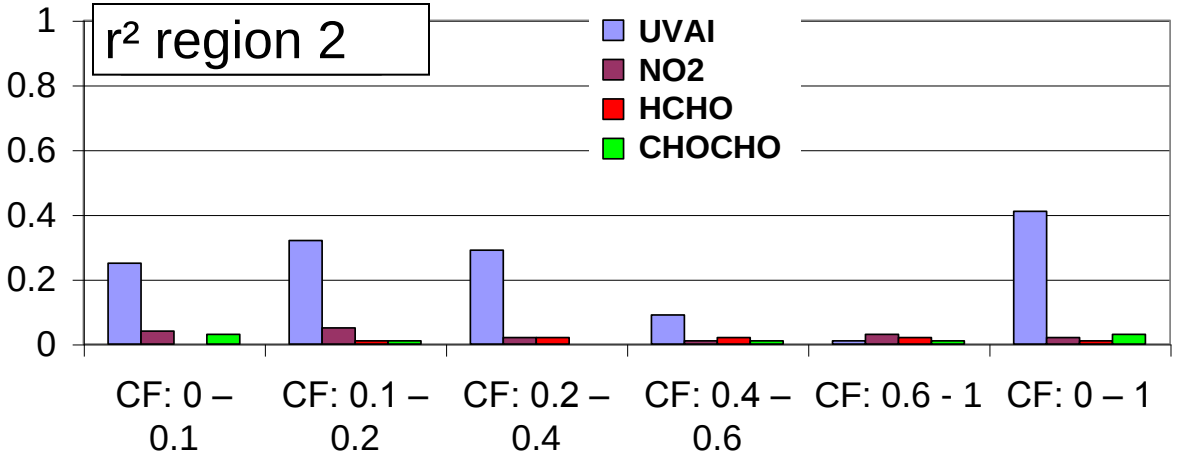


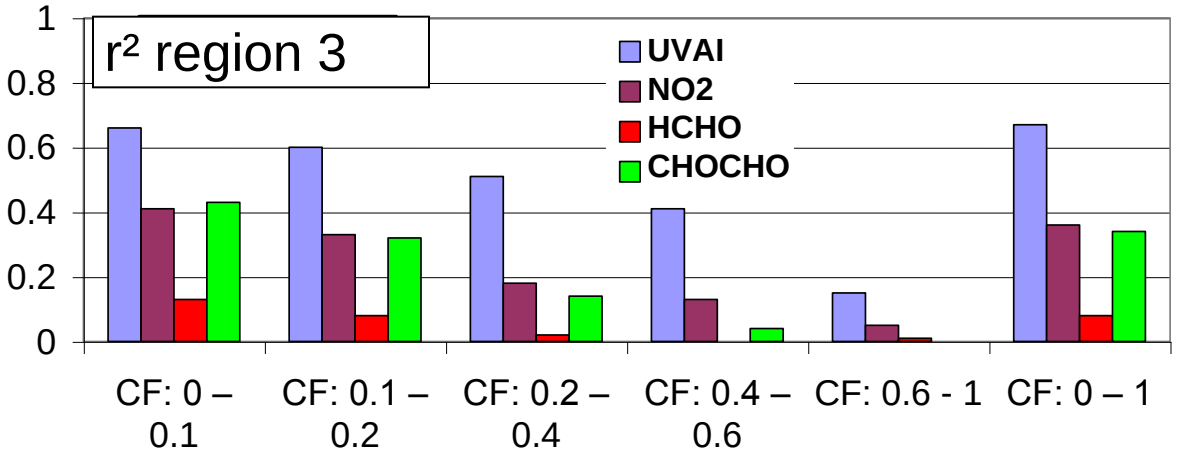
Investigate averages for different cloud fractions over extended areas

slope **($r^2 > 0.15$)**

Correlation results for trace gas & UVAI observations versus respective results for CF <10%



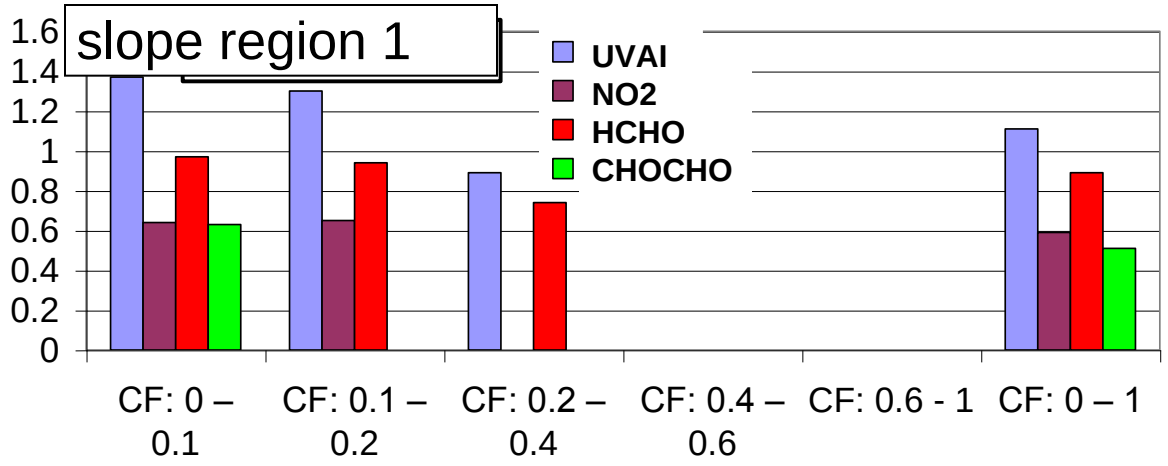


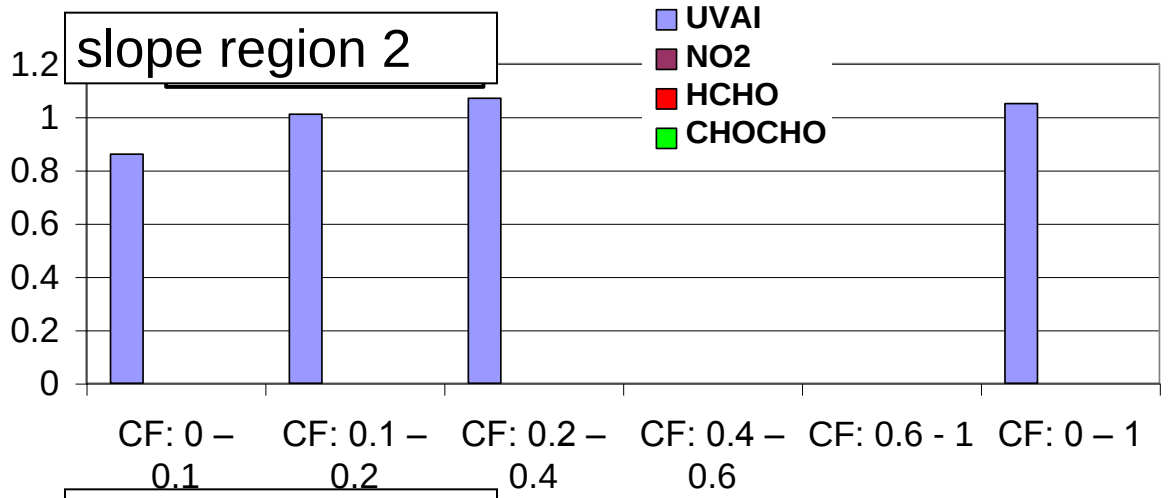


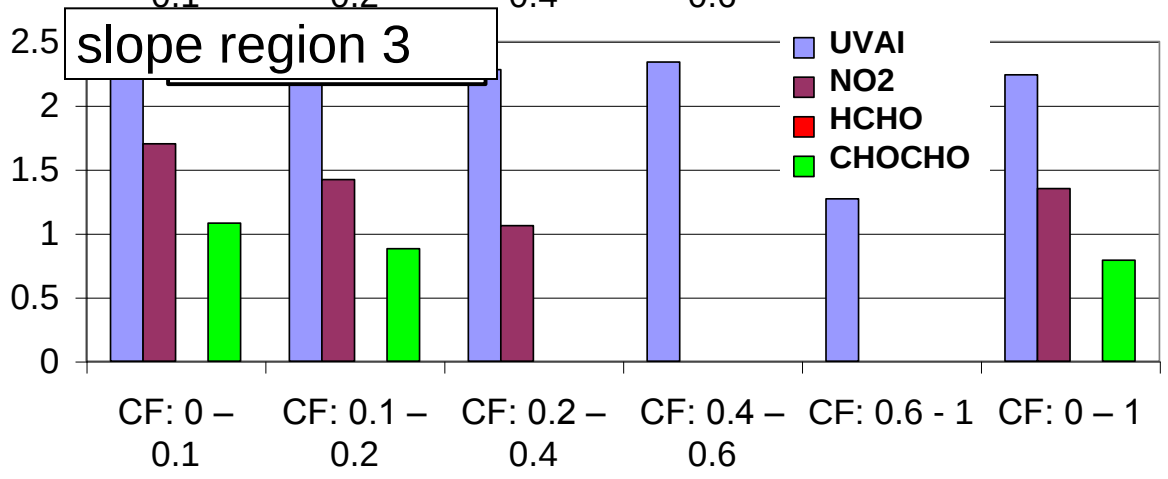
Investigate averages for different cloud fractions over extended areas

r^2

Correlation results for trace gas & UVAI observations versus MODIS AOD







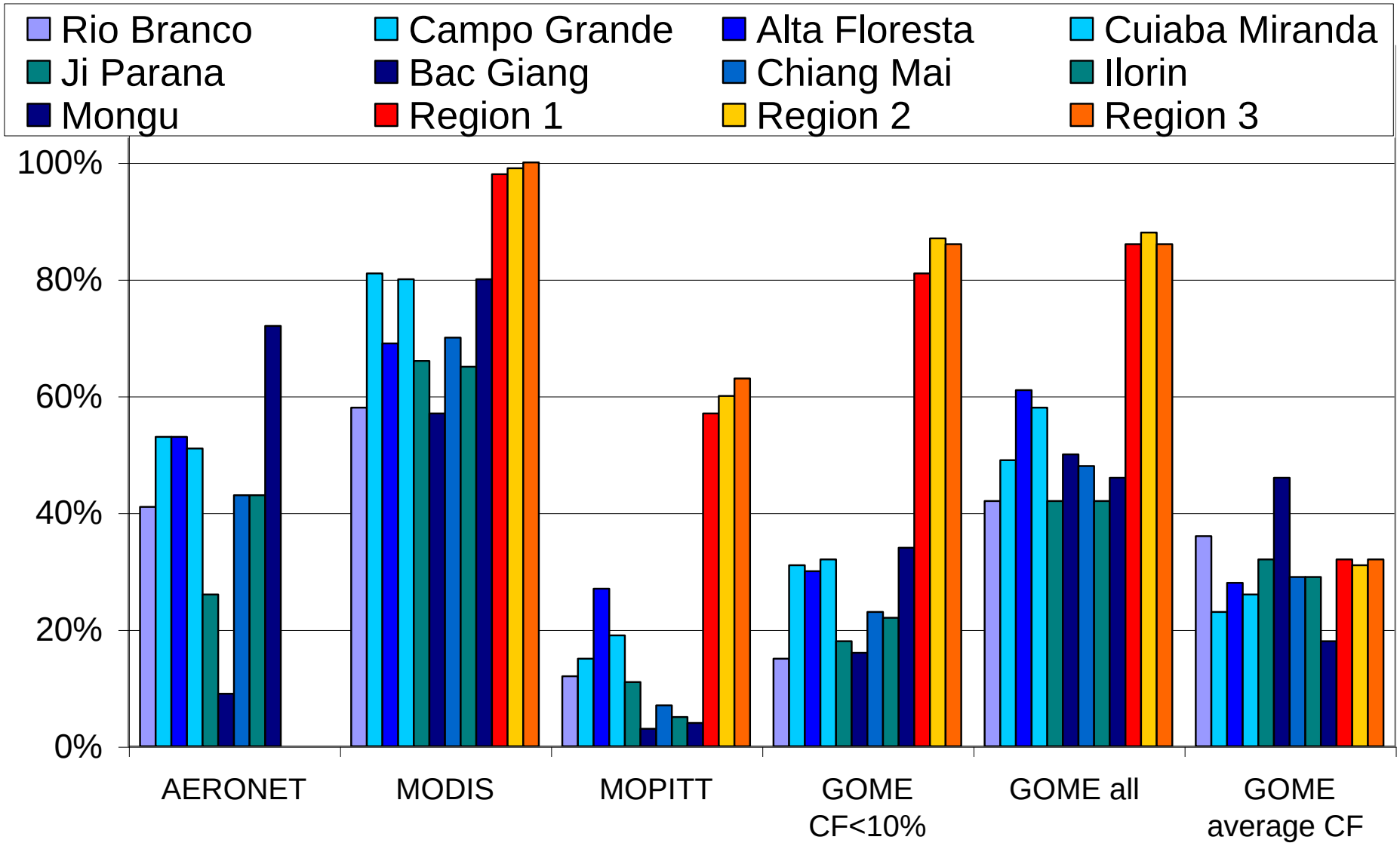
Investigate averages for different cloud fractions over extended areas

slope **($r^2 > 0.15$)**

Correlation results for trace gas & UVAI observations versus MODIS AOD

Availability of different data sets

(fraction of days with measurements)



Summary

- The selected trace gases and UVAI show low, but reasonable correlation with MODIS AOD in many cases

- Sometimes no correlation is found (=> low signal to noise, interference from other sources, different sensitivity for aerosol and trace gas observations, e.g. influence of clouds)

=> In principle aerosol UV absorbing index and trace gases (CO, HCHO, NO_2, CHOCHO) can be used as aerosol proxies and can be measured in the presence of clouds
(sometimes the correlations with AOD is even higher in the presence of clouds, e.g. in South Asia)

- This increases the number of useful measurements and might be important for the study of aerosol-cloud relationships

- Satellite observations of trace gases can close temporal and spatial gaps and can contribute to aerosol classification

Many thanks for your attention!

Many thanks to:

MOPITT team

MODIS team

TEMIS data base

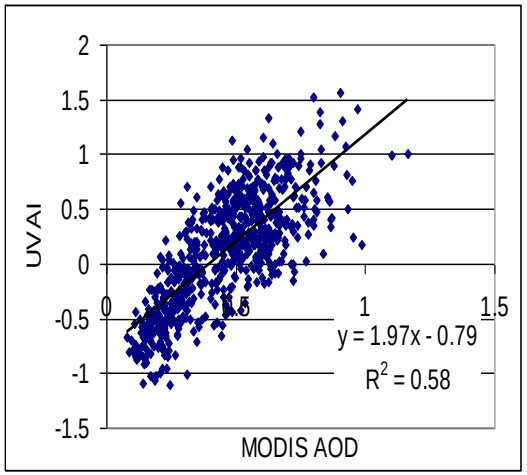
KNMI FRESCO Cloud data & UVAI

ATSR Fire counts

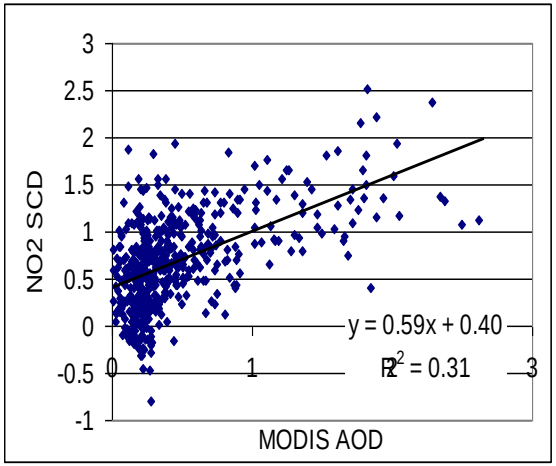
AERONET network and PIs

Cases with best correlation for daily measurements in larger areas (CF: 0 – 100%)

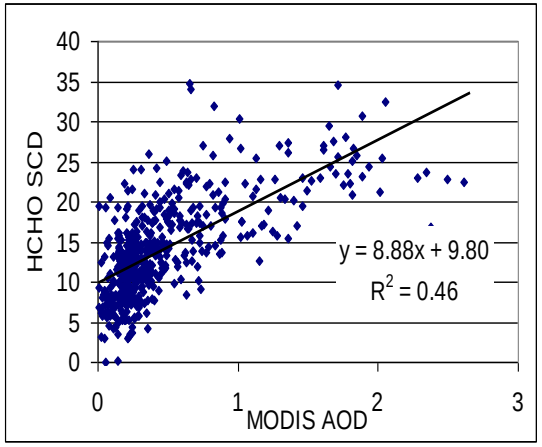
Region 4



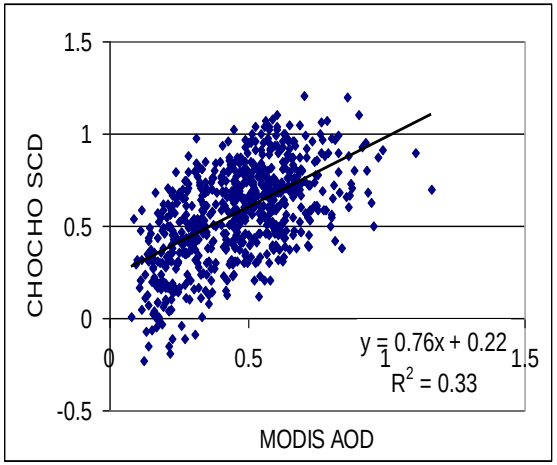
Region 2



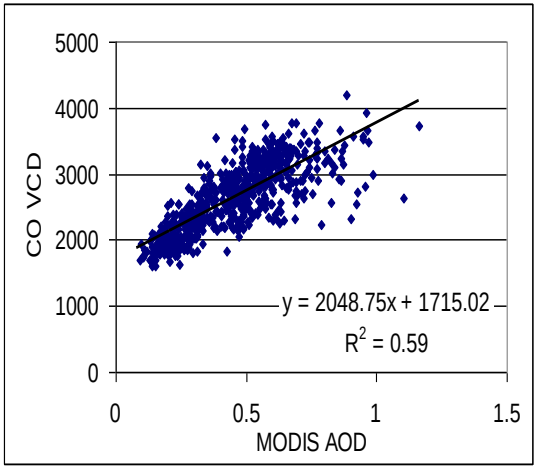
Region 2



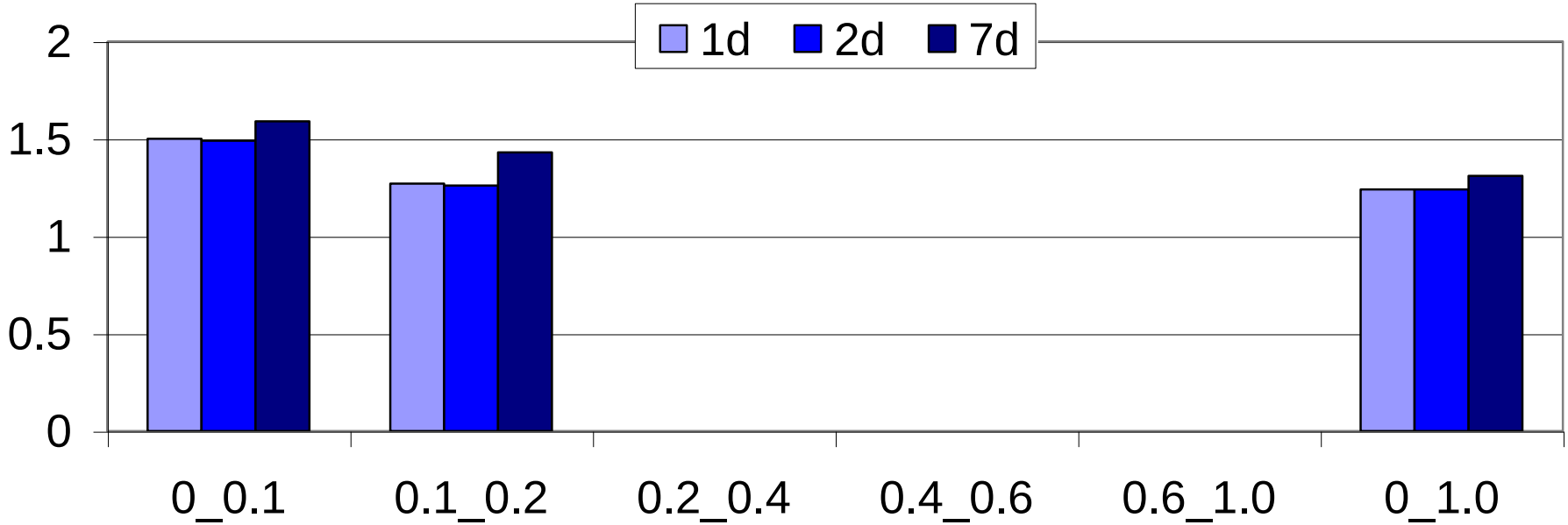
Region 4



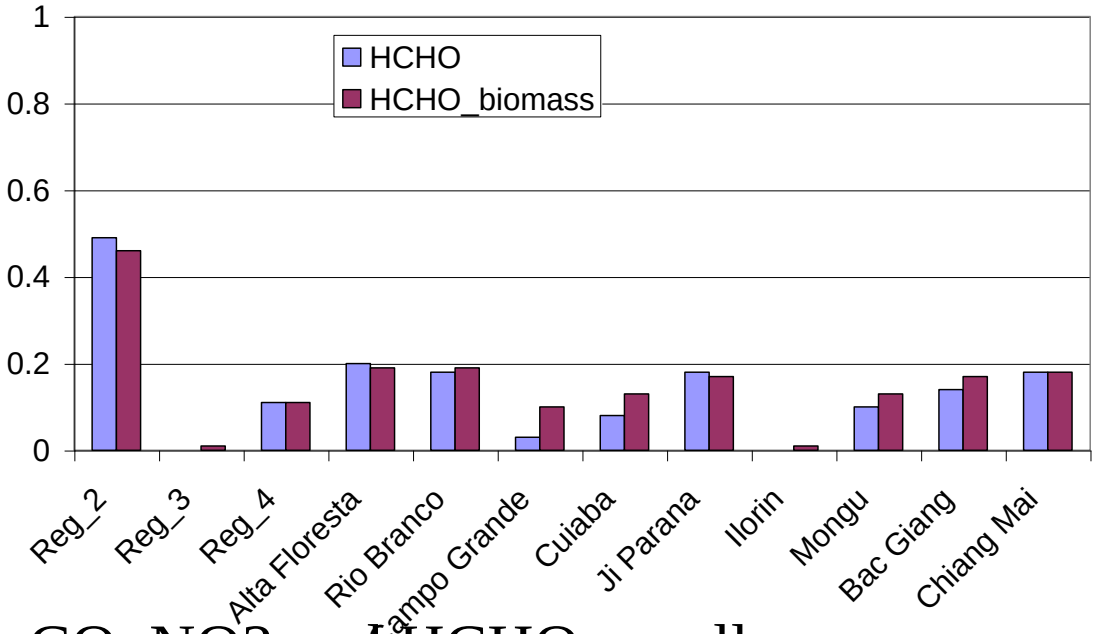
Region 4



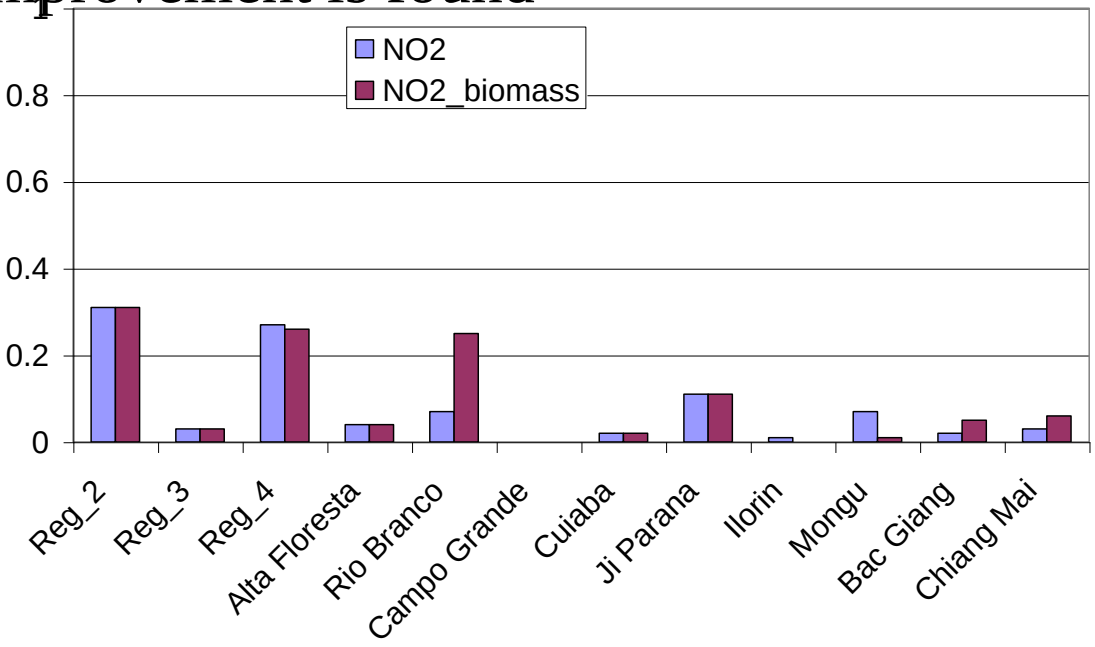
UVAI Rio Branco versus AERONET



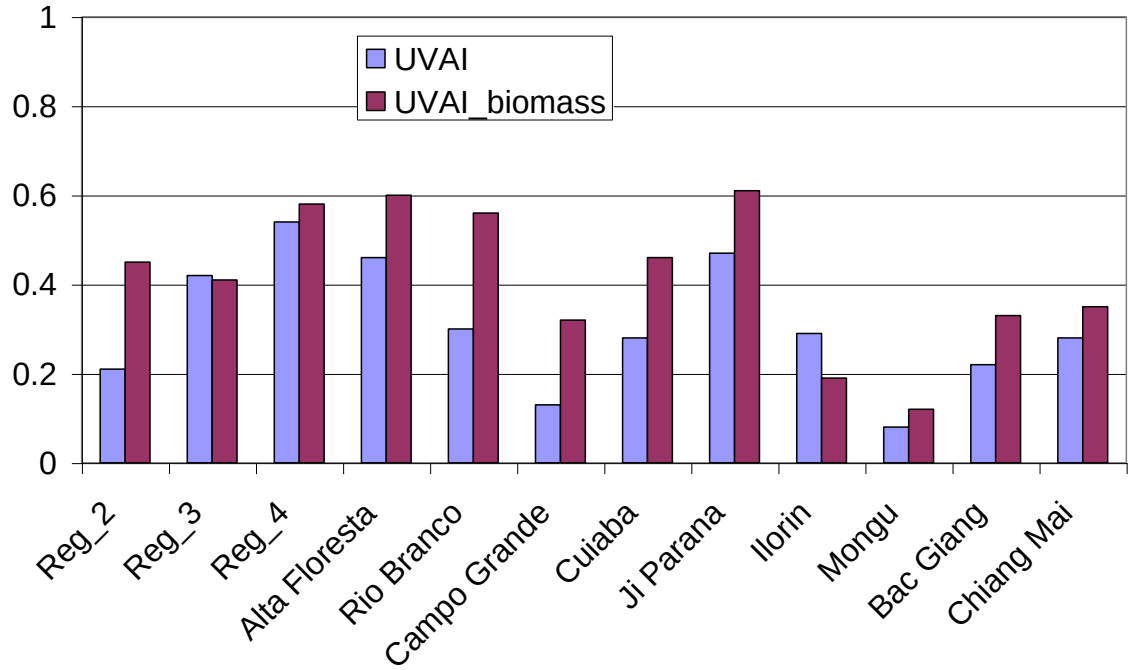
UVAI Chiang Mai

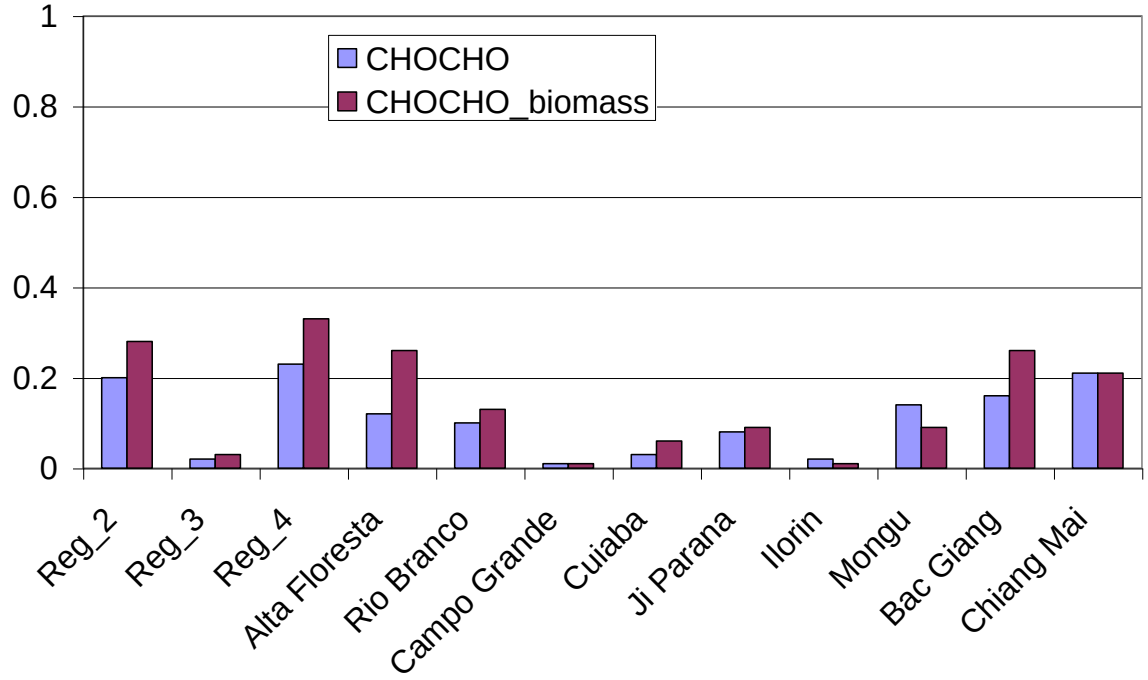


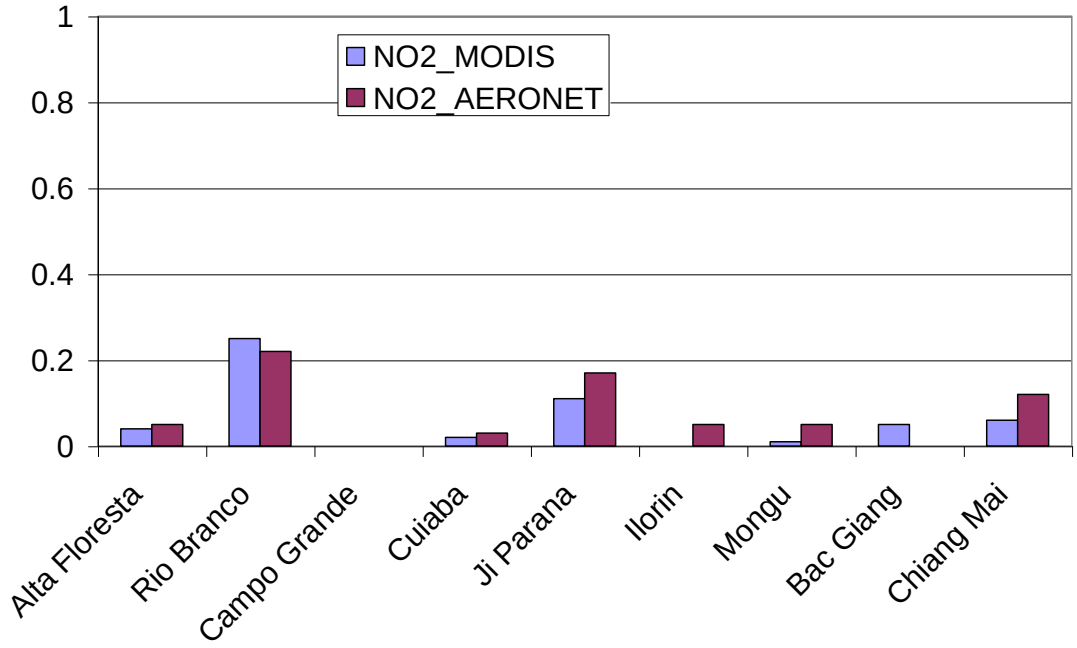
For CO, NO2 and HCHO usually no improvement is found

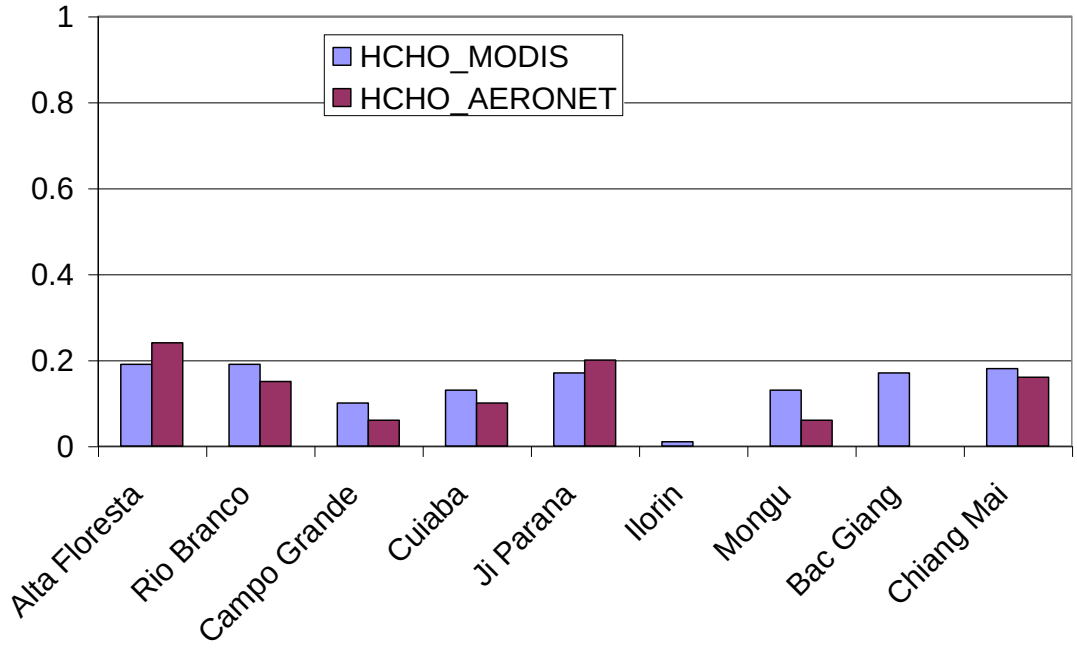


For UVAI and CHOCHO better correlation is found for biomass burning seasons

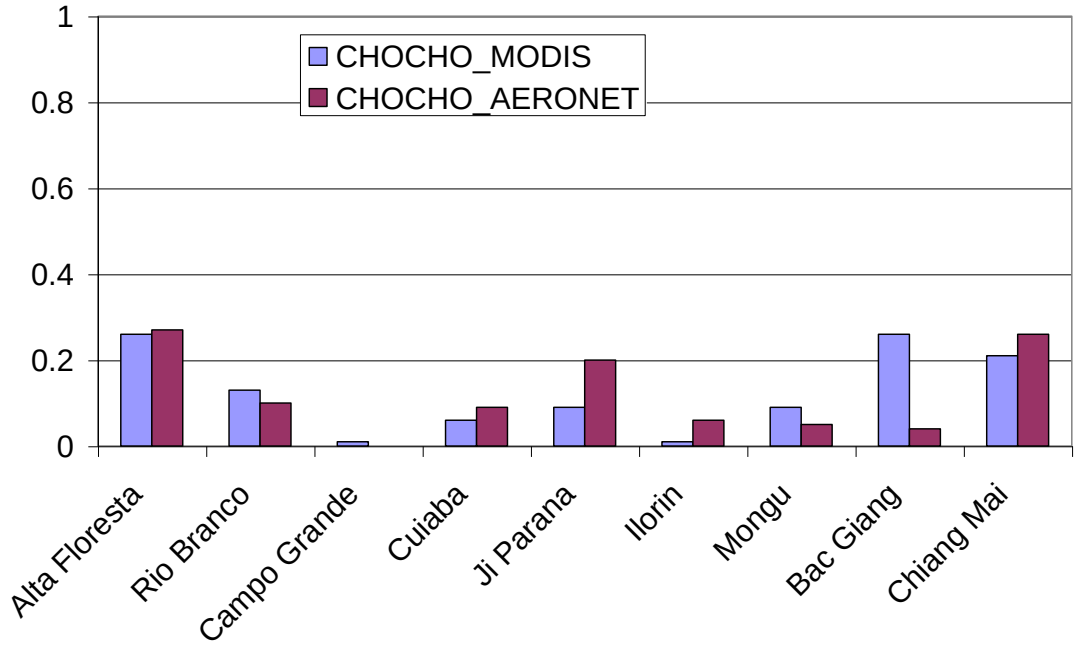






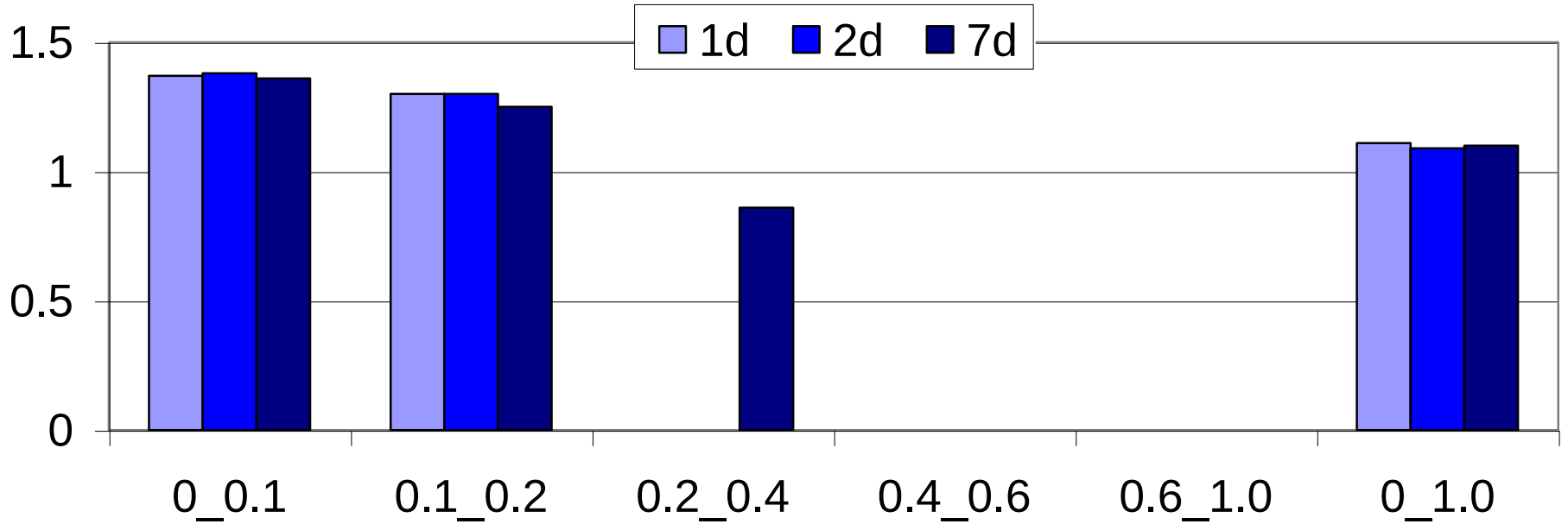


In general, better correlation with AERONET is found

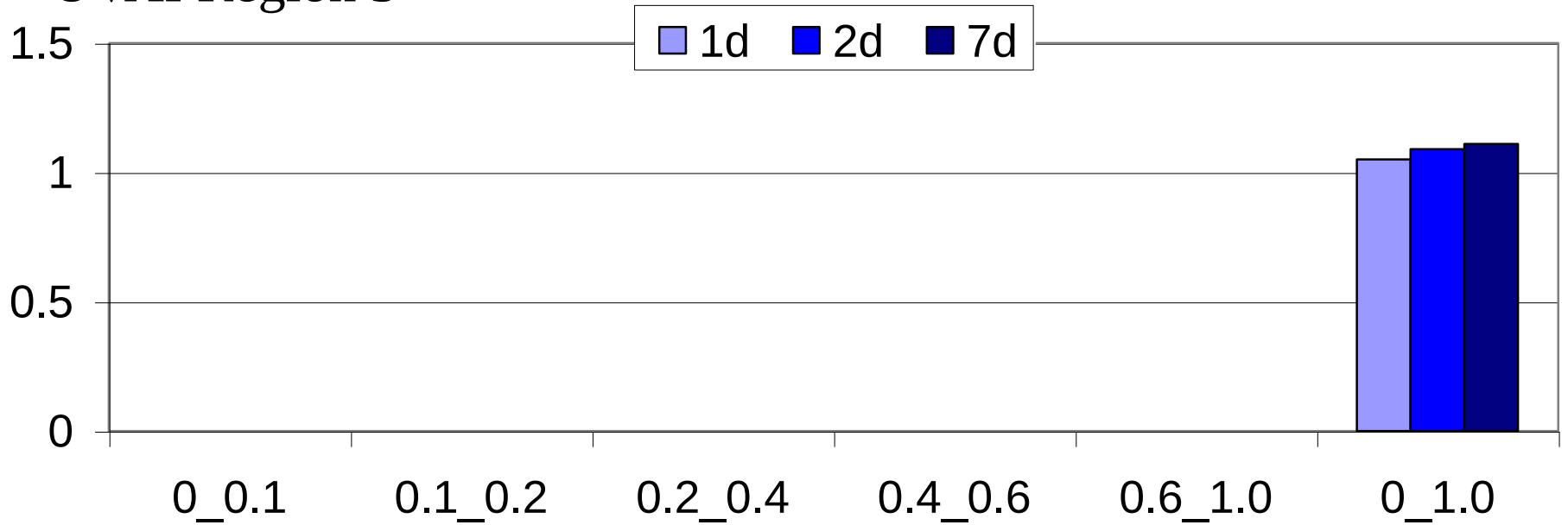


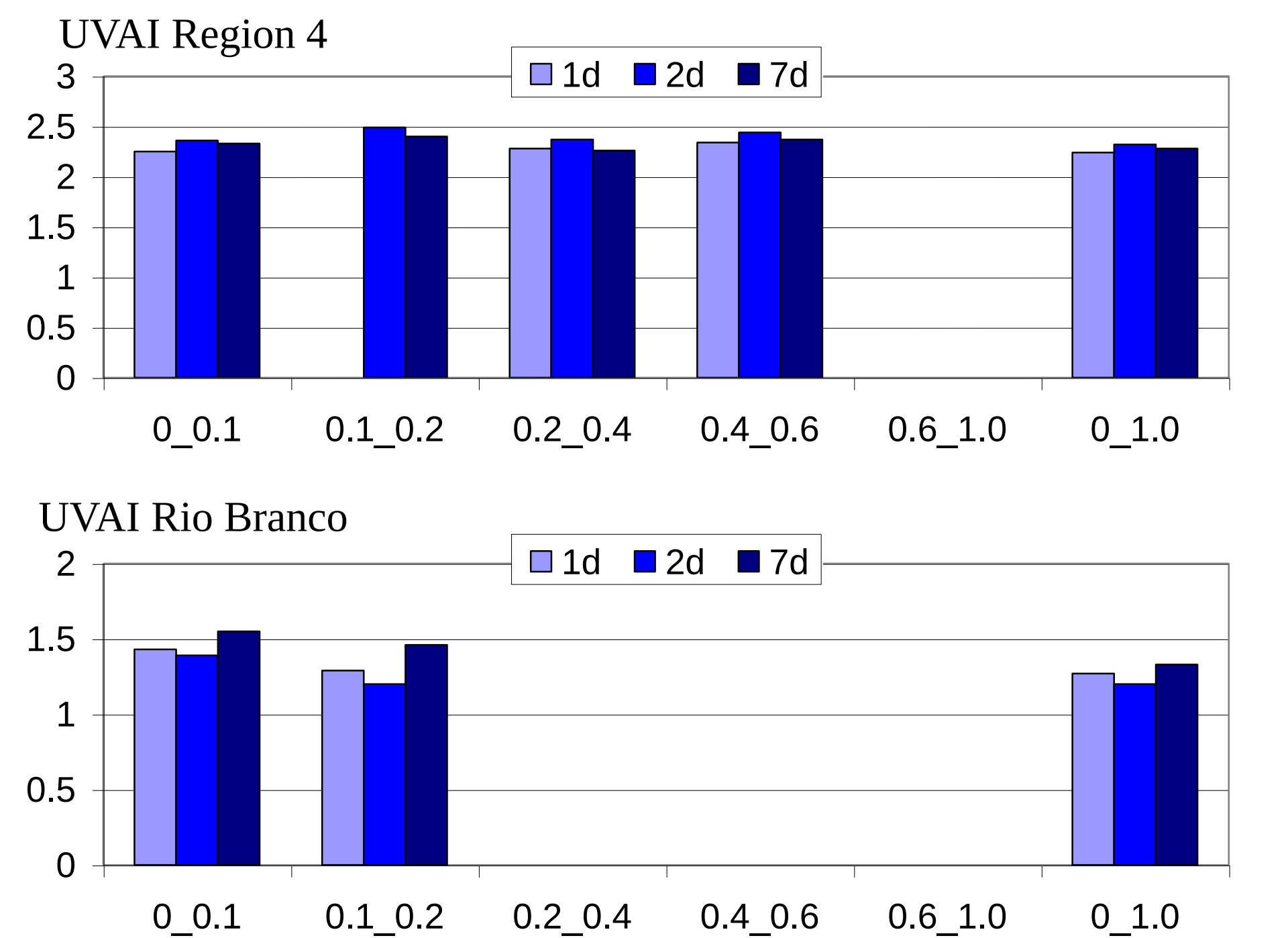
In general, better correlation with AERONET is found

UVAI Region 2

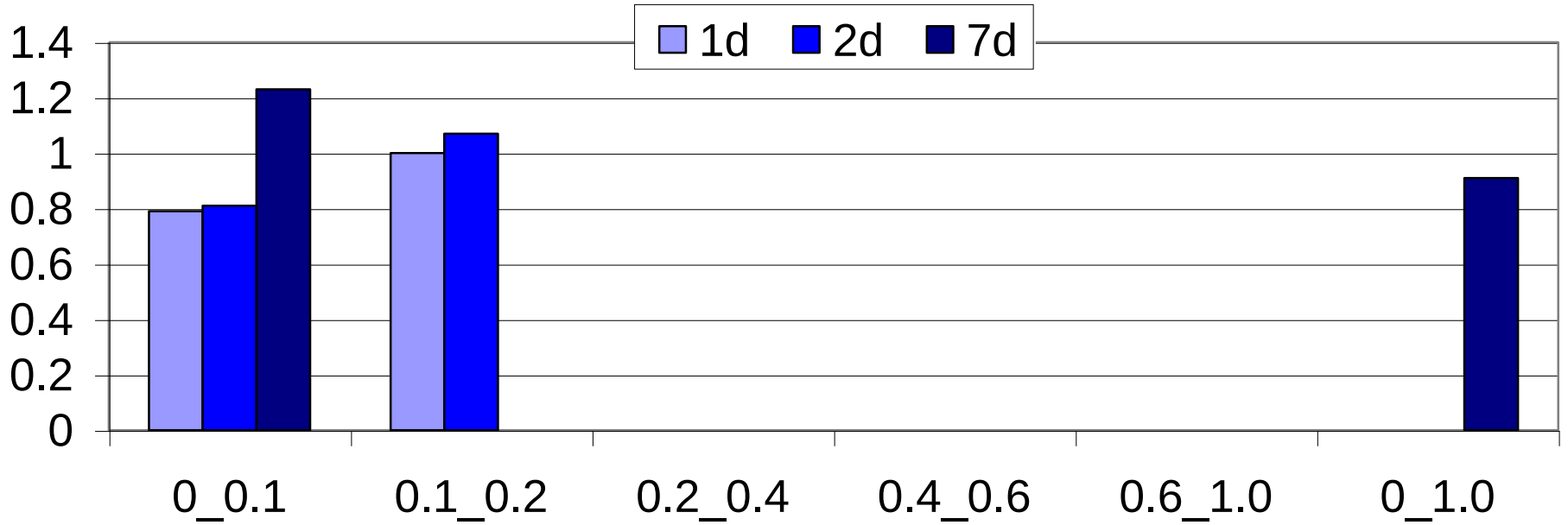


UVAI Region 3

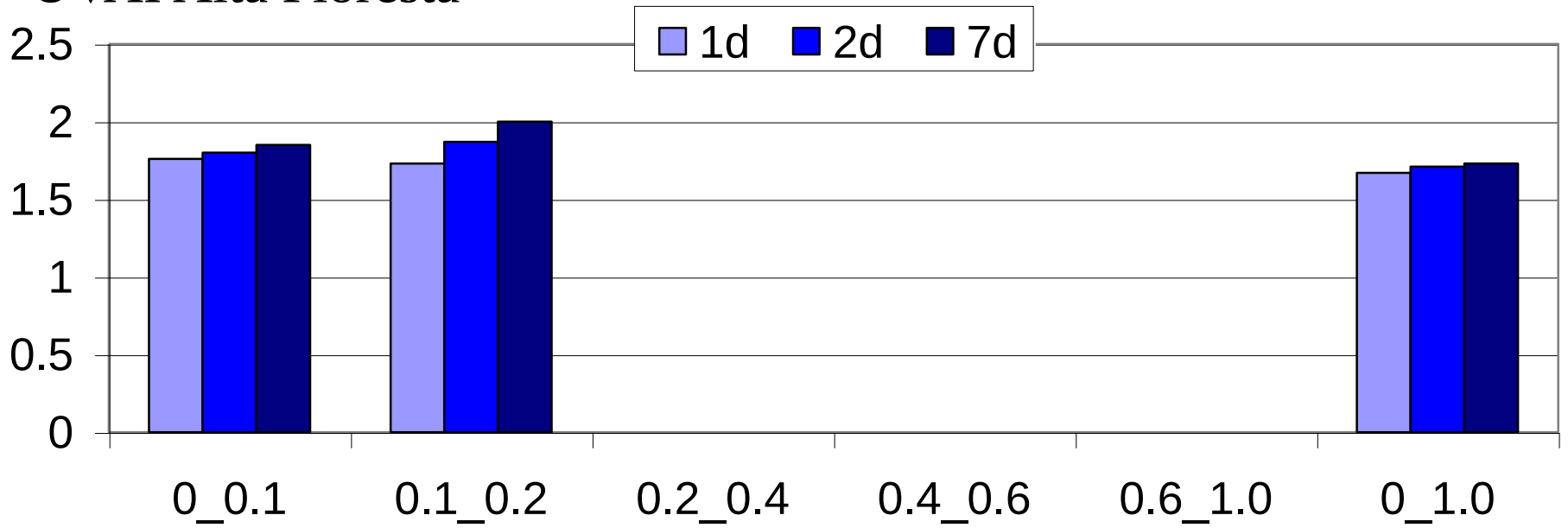


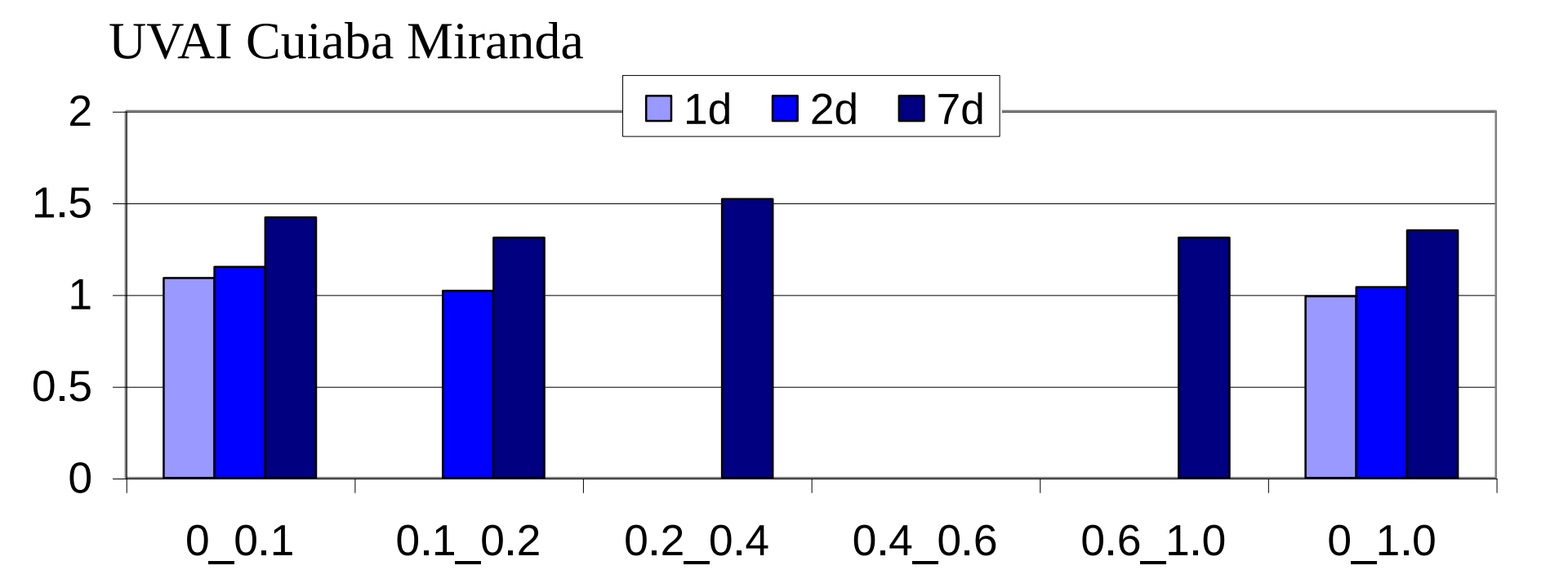

UVAI Region 4
1d
2d
7d
3
2.5
2
1.5
1
0.5
0
0_0.1
0.1_0.2
0.2_0.4
0.4_0.6
0.6_1.0
0_1.0
UVAI Rio Branco
1d
2d
7d
2
1.5
1
0.5
0
0_0.1
0.1_0.2
0.2_0.4
0.4_0.6
0.6_1.0
0_1.0

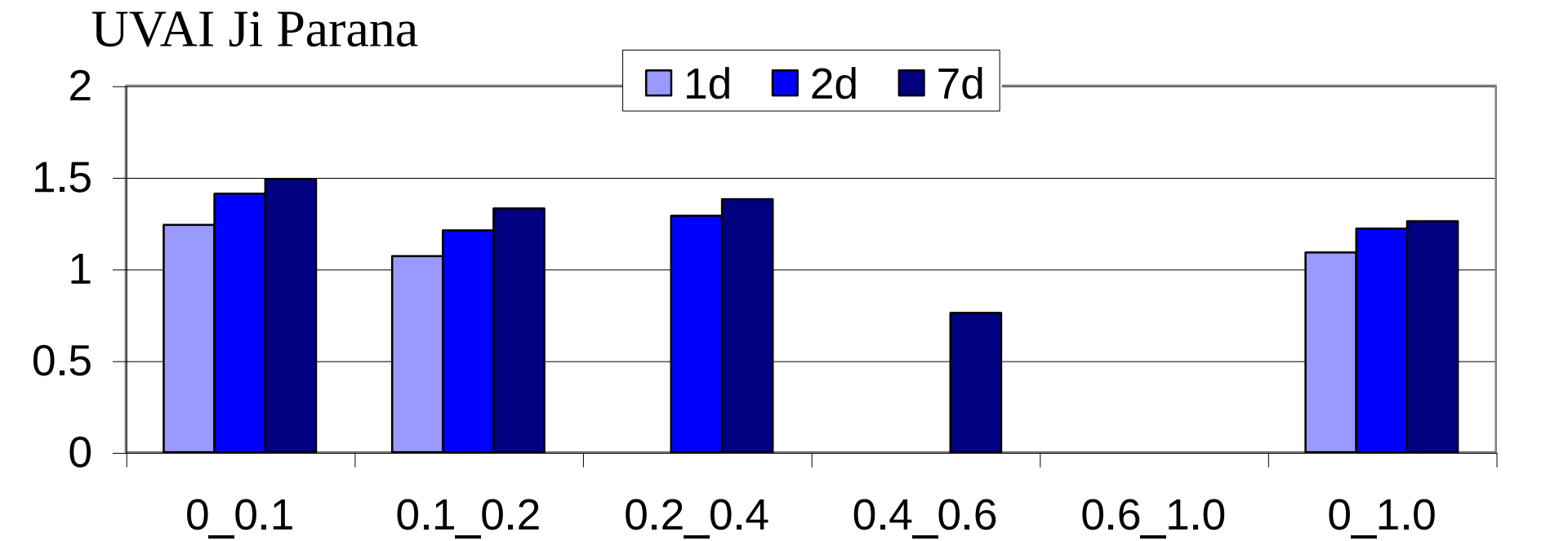
UVAI Campo Grande Sonda

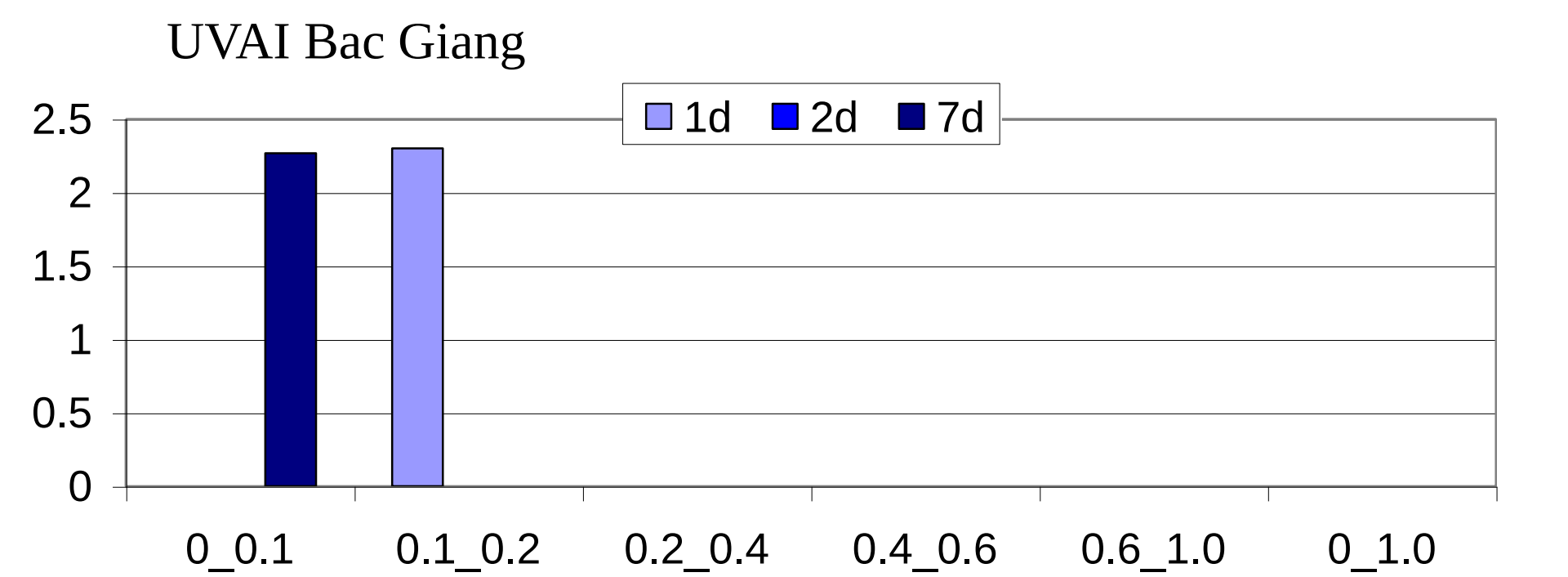


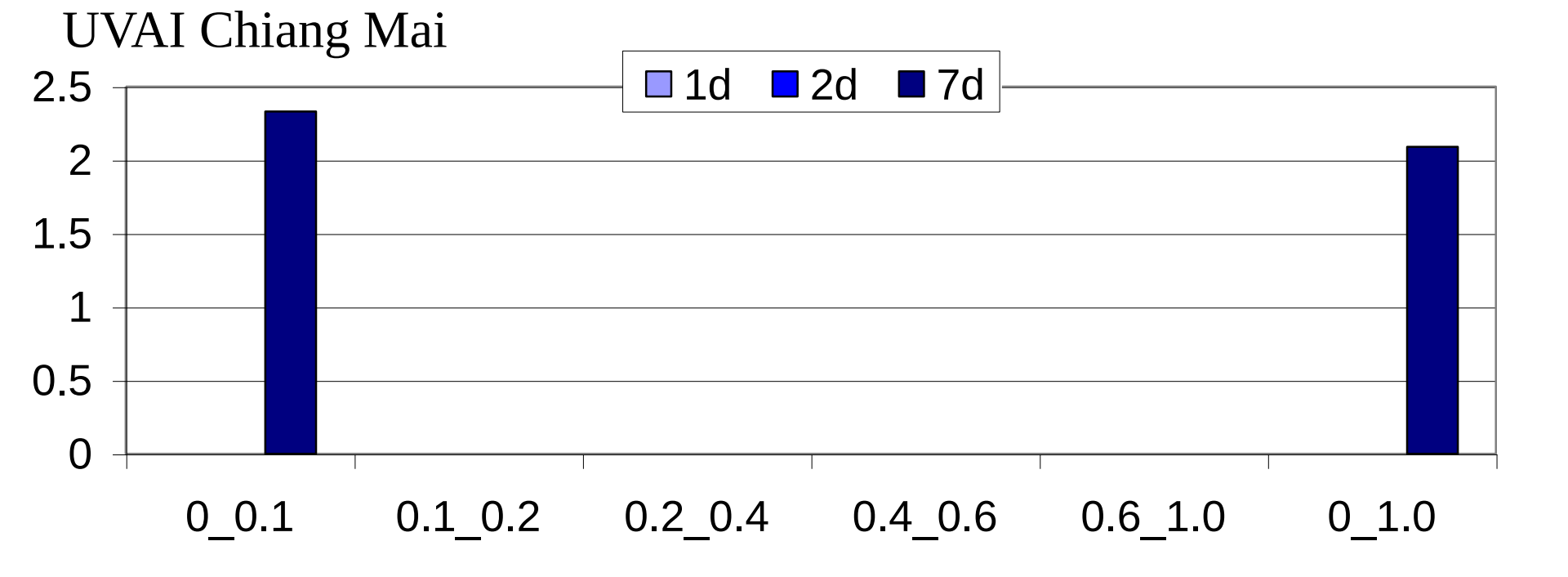
UVAI Alta Floresta

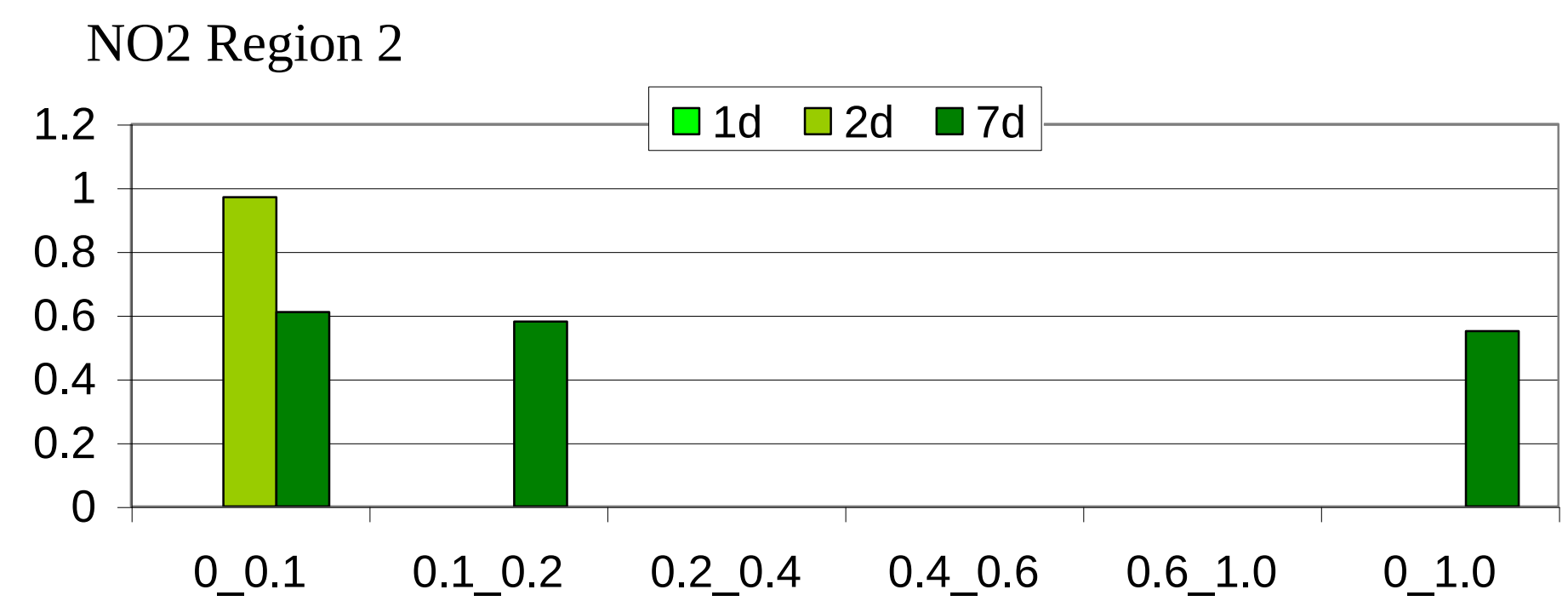


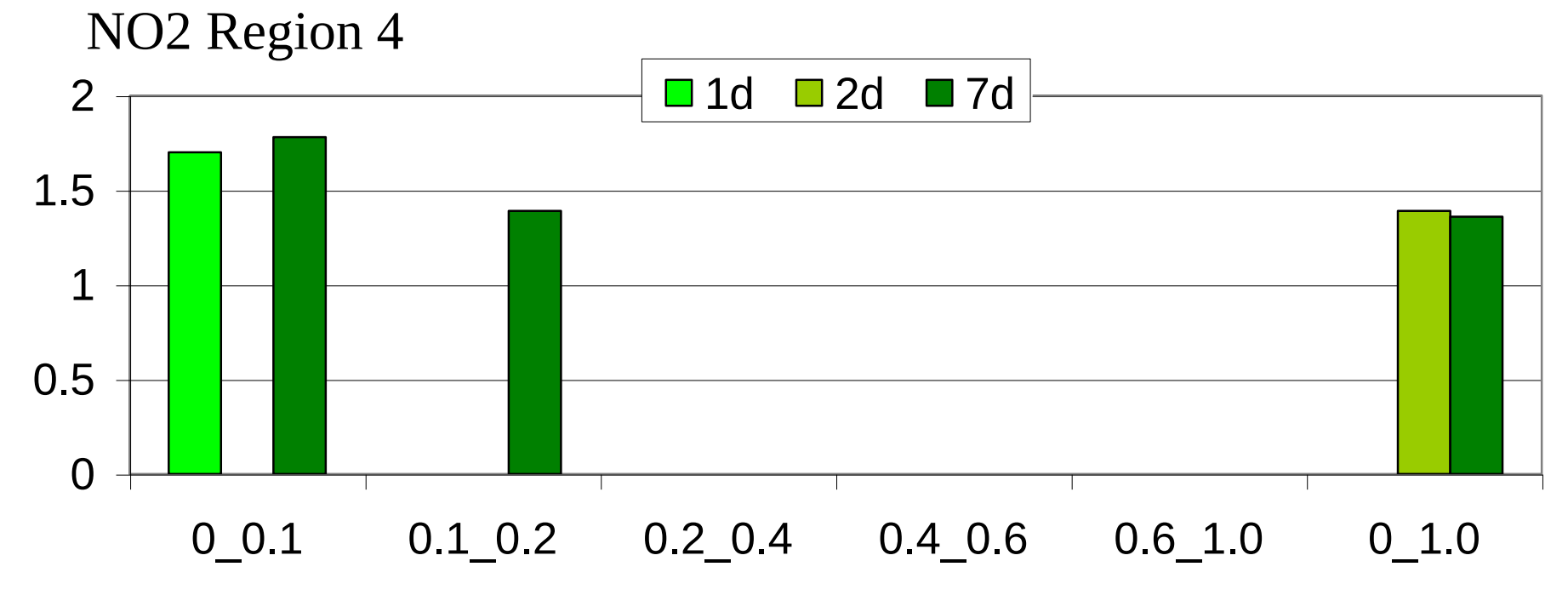

UVAI Cuiaba Miranda
1d
2d
7d
2
1.5
1
0.5
0
0_0.1
0.1_0.2
0.2_0.4
0.4_0.6
0.6_1.0
0_1.0


UVAI Ji Parana
1d
2d
7d
2
1.5
1
0.5
0
0_0.1
0.1_0.2
0.2_0.4
0.4_0.6
0.6_1.0
0_1.0

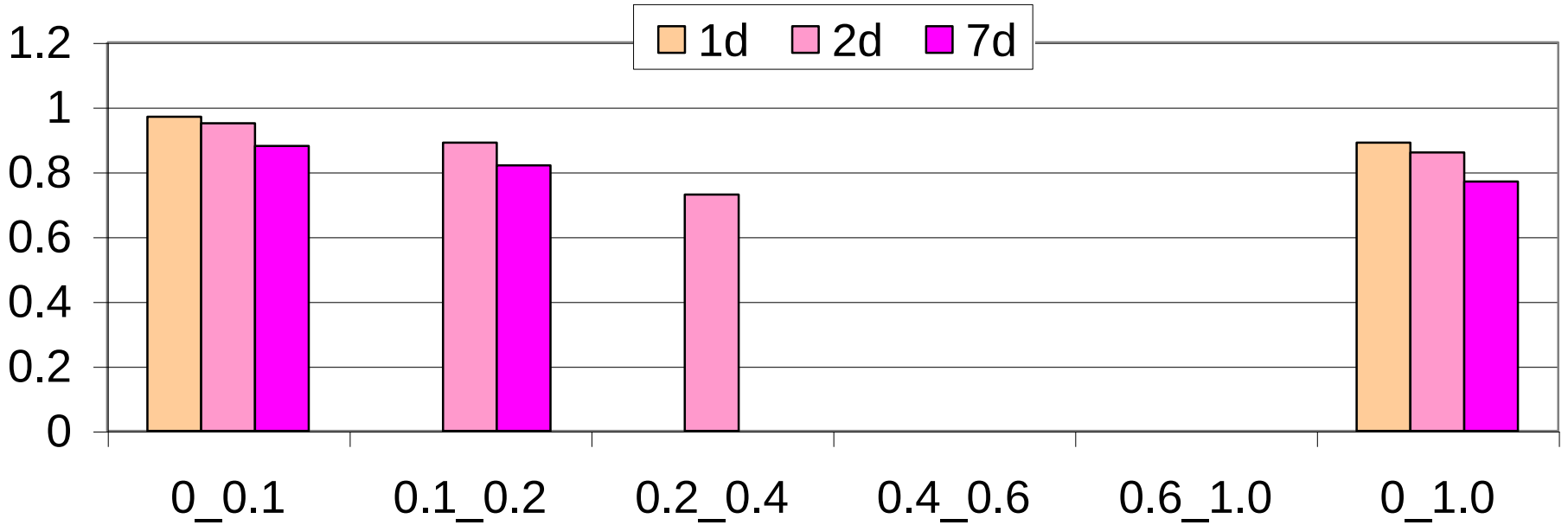

UVAI Bac Giang
1d
2d
7d
2.5
2
1.5
1
0.5
0
0_0.1
0.1_0.2
0.2_0.4
0.4_0.6
0.6_1.0
0_1.0


UVAI Chiang Mai
1d
2d
7d
2.5
2
1.5
1
0.5
0
0_0.1
0.1_0.2
0.2_0.4
0.4_0.6
0.6_1.0
0_1.0

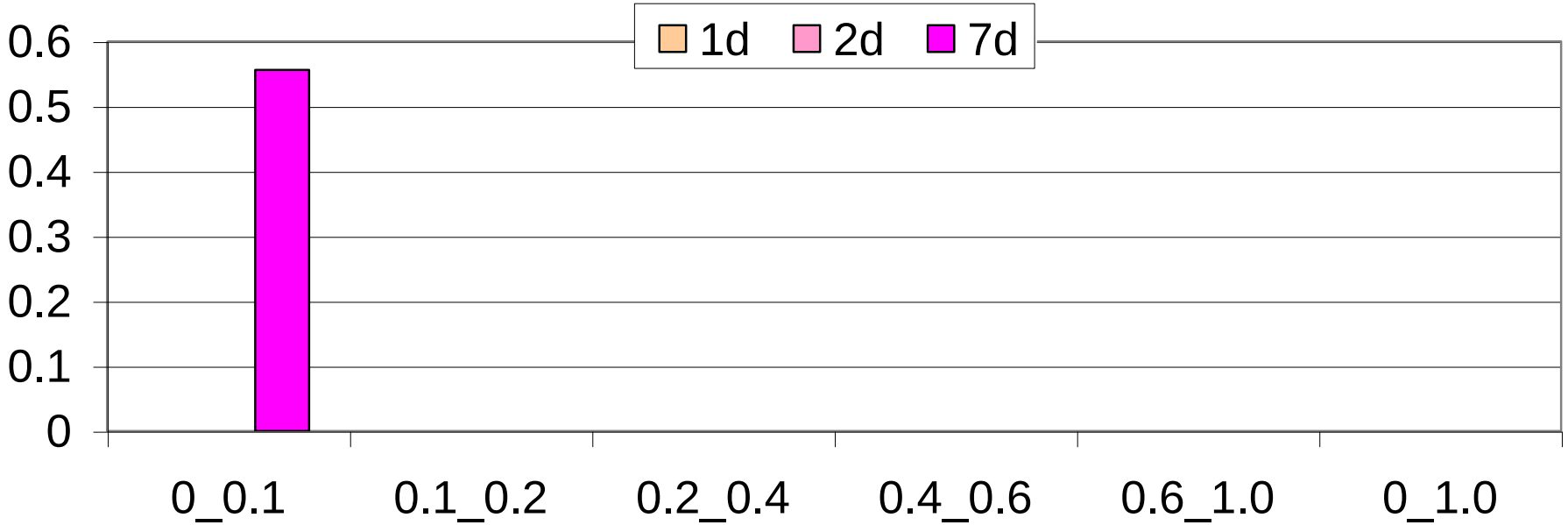

NO2 Region 2
1d
2d
7d
1.2
1
0.8
0.6
0.4
0.2
0
0_0.1
0.1_0.2
0.2_0.4
0.4_0.6
0.6_1.0
0_1.0

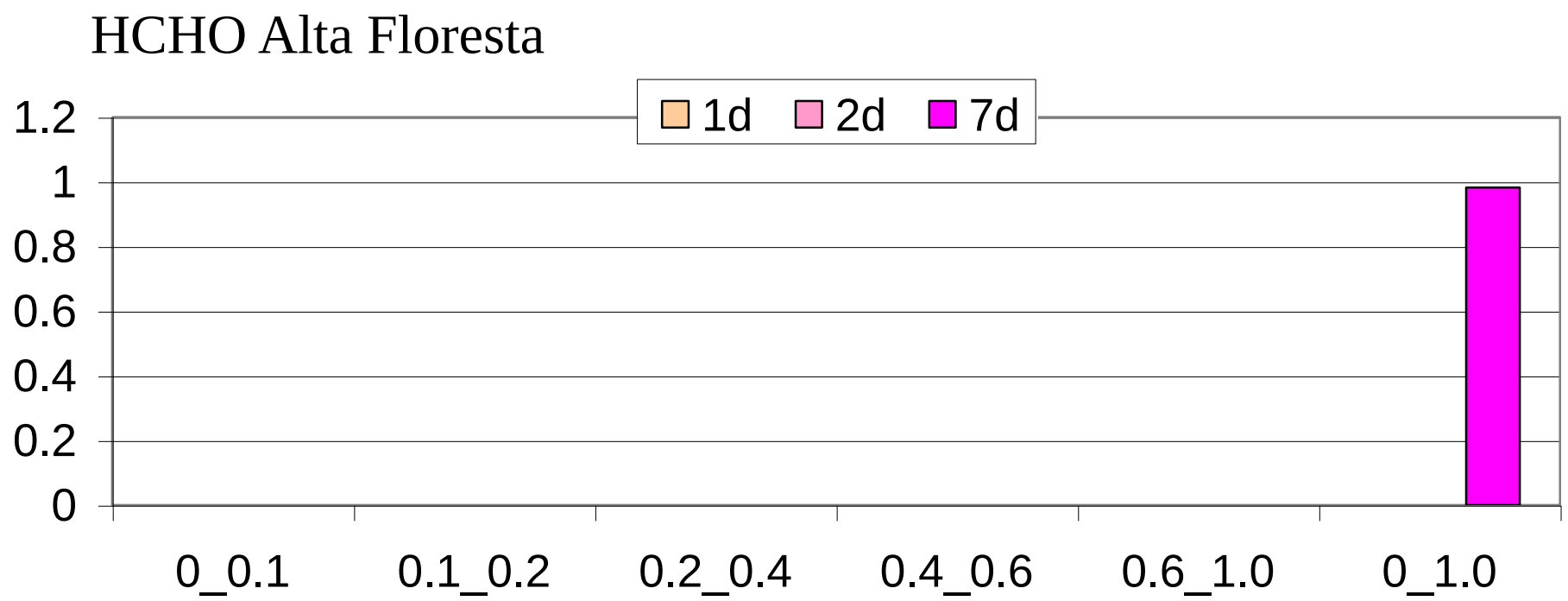

NO2 Region 4
1d
2d
7d
2
1.5
1
0.5
0
0_0.1
0.1_0.2
0.2_0.4
0.4_0.6
0.6_1.0
0_1.0

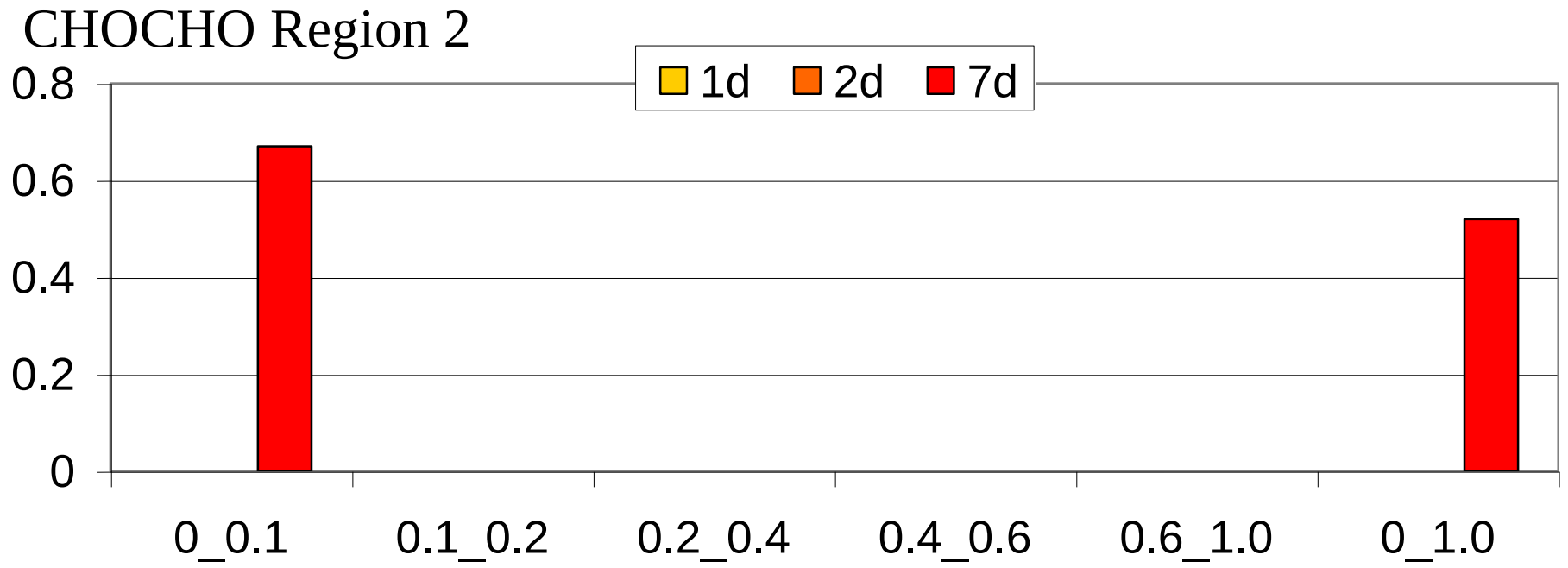
HCHO Region 2

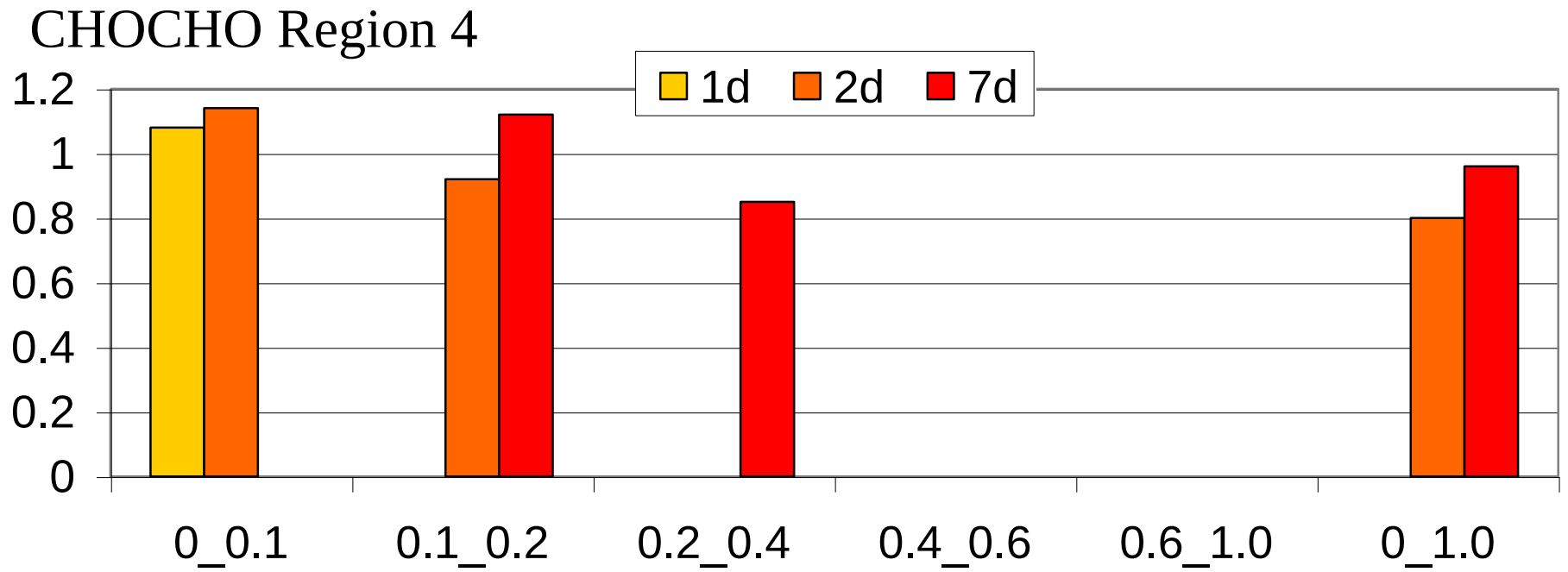


HCHO Region 4

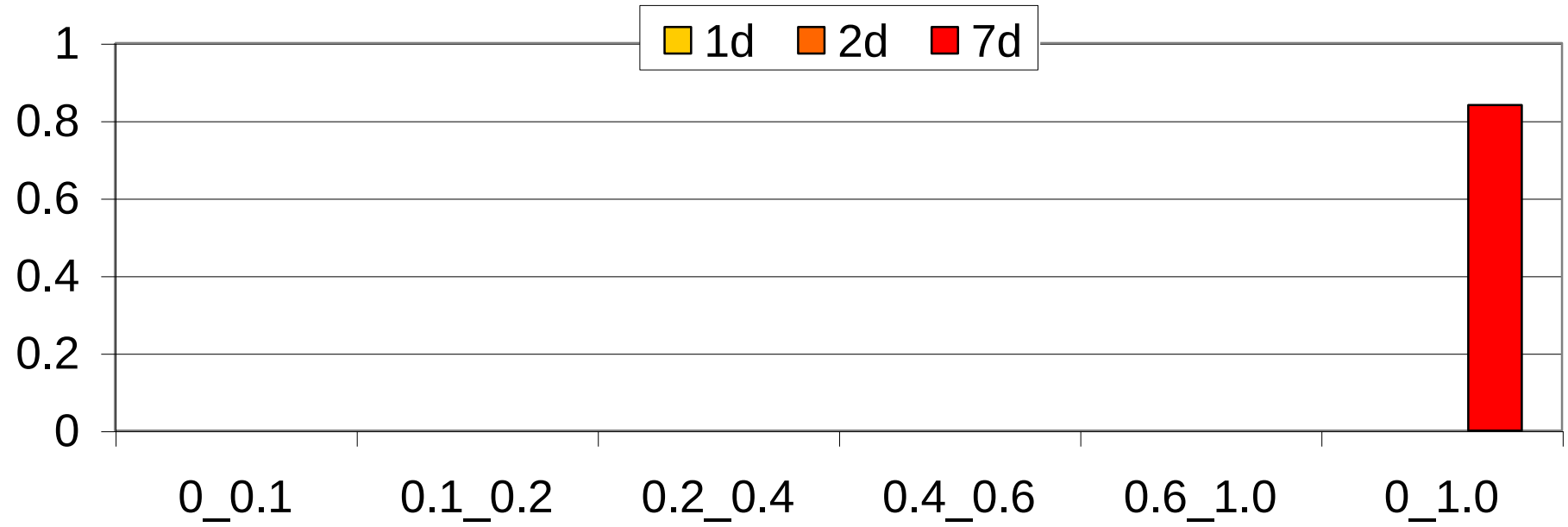



HCHO Alta Floresta
1d
2d
7d
1.2
1
0.8
0.6
0.4
0.2
0
0_0.1
0.1_0.2
0.2_0.4
0.4_0.6
0.6_1.0
0_1.0

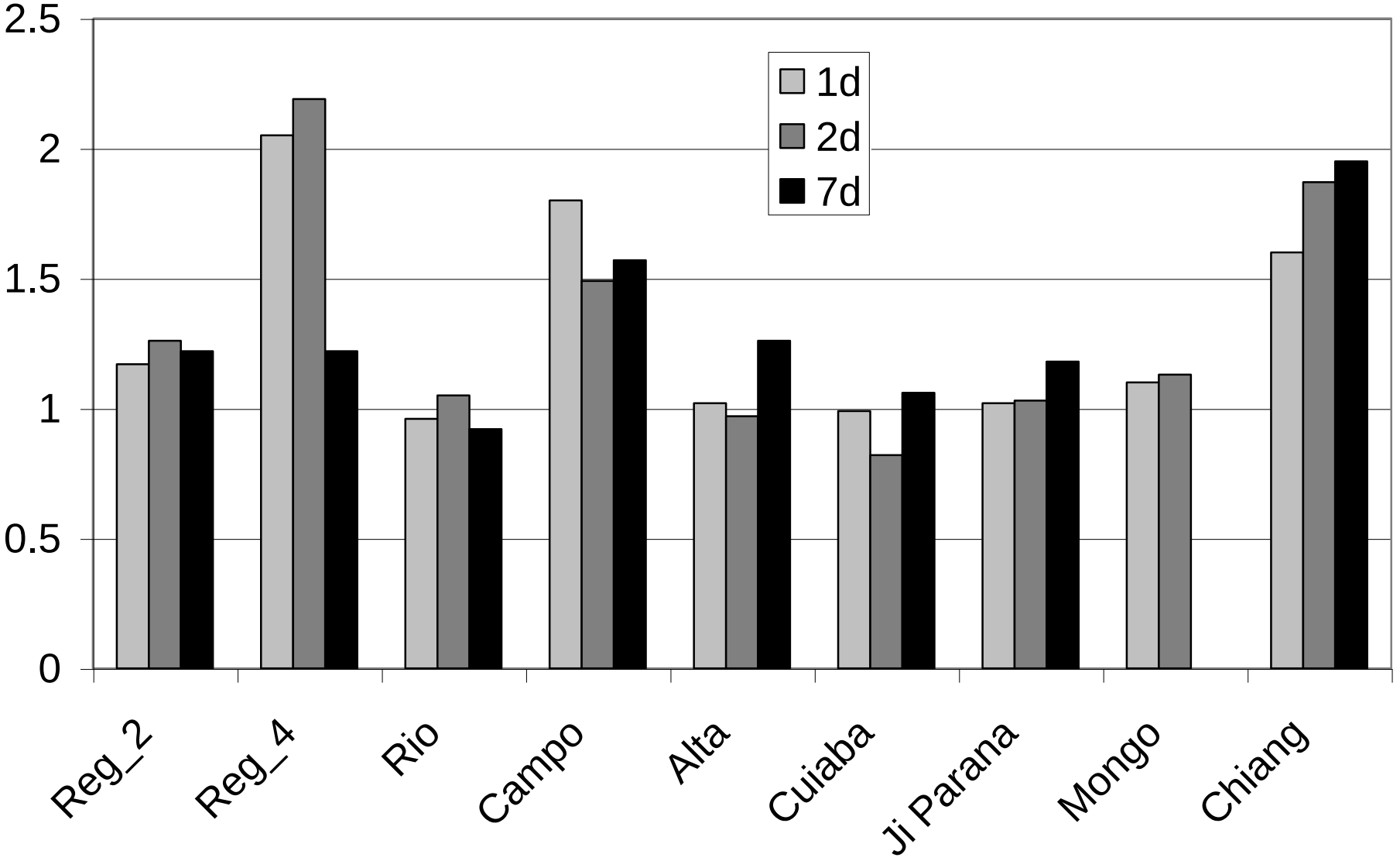

CHOCHO Region 2
1d
2d
7d
0.8
0.6
0.4
0.2
0
0_0.1
0.1_0.2
0.2_0.4
0.4_0.6
0.6_1.0
0_1.0

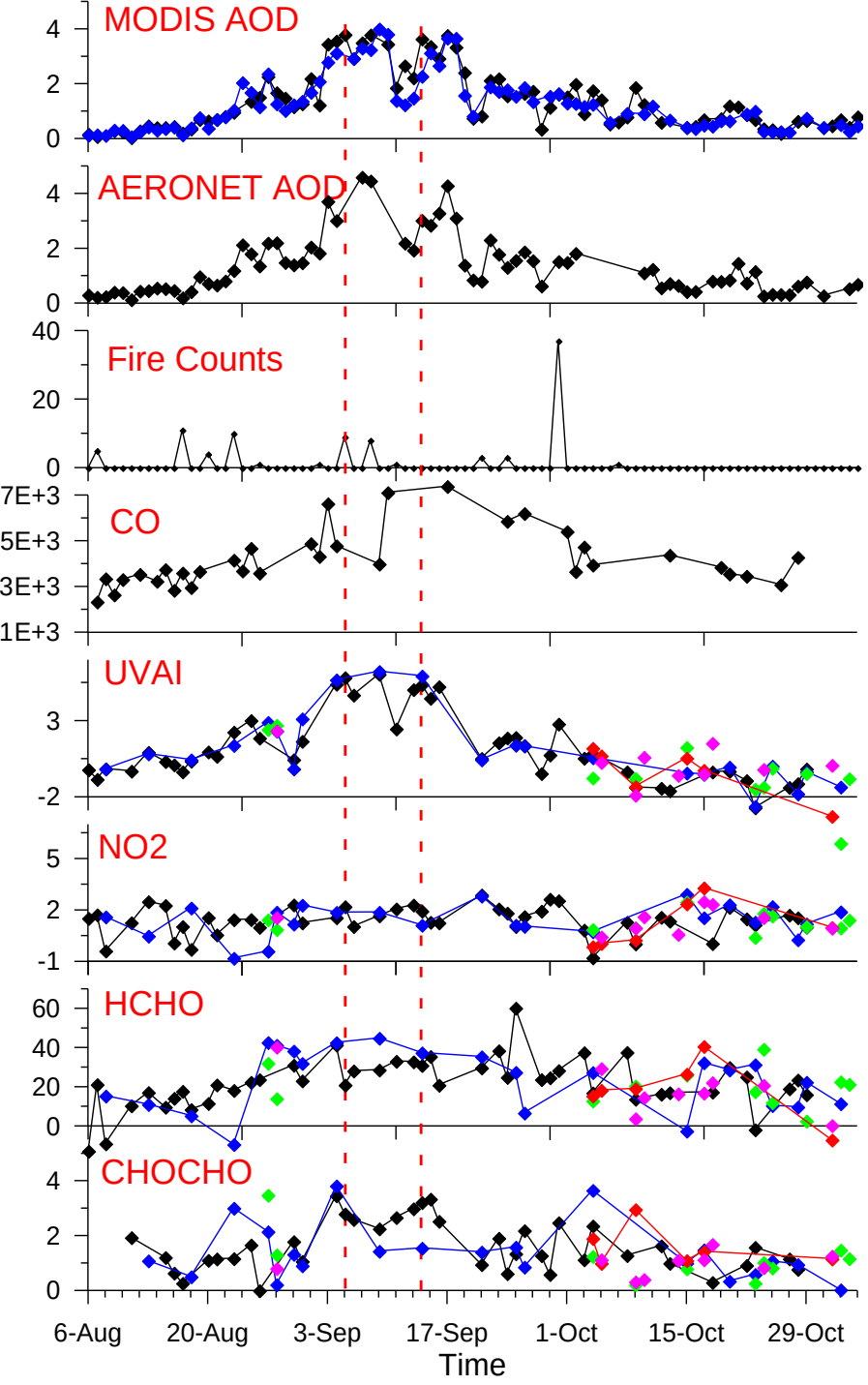

CHOCHO Region 4
1d
2d
7d
1.2
1
0.8
0.6
0.4
0.2
0
0_0.1
0.1_0.2
0.2_0.4
0.4_0.6
0.6_1.0
0_1.0

CHOCHO Alta Floresta



CO

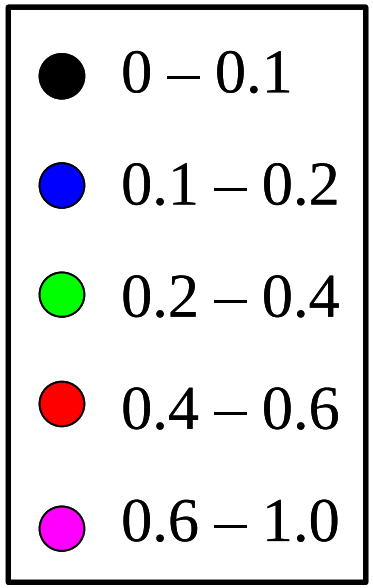

2.5
2
1.5
1
0.5
0
1d
2d
7d
Reg_2
Reg_4
Rio
Campo
Alta
Cuiaba
Ji Parana
Mongo
Chiang



Typical case:

(e.g. Alta Floresta)

Mainly cloud free observations during phases of intense biomass burning



Availability of different data sets for biomass burning seasons