Climatology of Aerosol Radiative Properties in the Free Troposphere

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Motivation

The combined observatory measurements of free tropospheric (FT) aerosol radiative properties have the potential to contribute to aerosol-climate research in a way that far exceeds the contribution from individual sites.

For example, this type of analysis may help:

→constrain chemical transport models

→validate satellite measurements

→quantify the influence of smoke and dust episodes on free troposphere aerosol properties

Scientific Questions

1. What is the climatology of FT aerosol measurements at a range of sites?

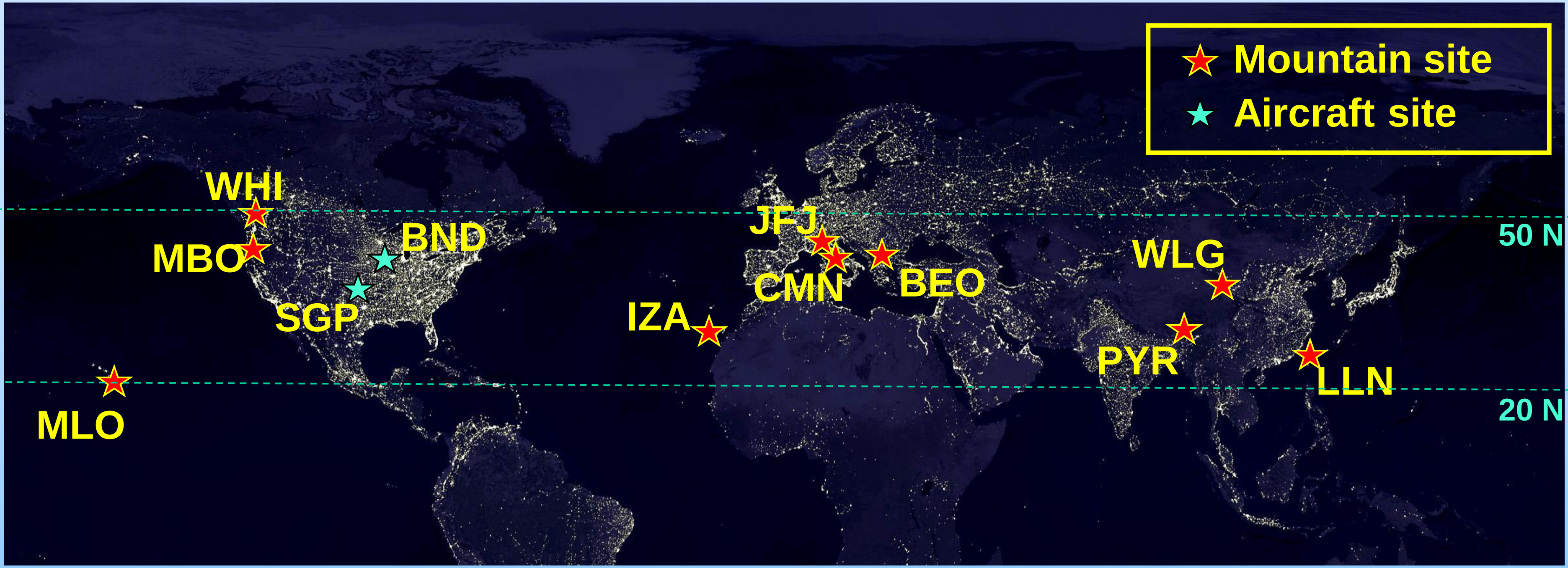
2. Do FT aerosol properties vary systematically?

3. How do in-situ climatologies of FT aerosol loading compare to the satellite-derived climatology presented by Kent et al., 1998?

4. Do aerosol events have a significant influence on FT climatological values?

And many more…

Location of Free Troposphere Sites

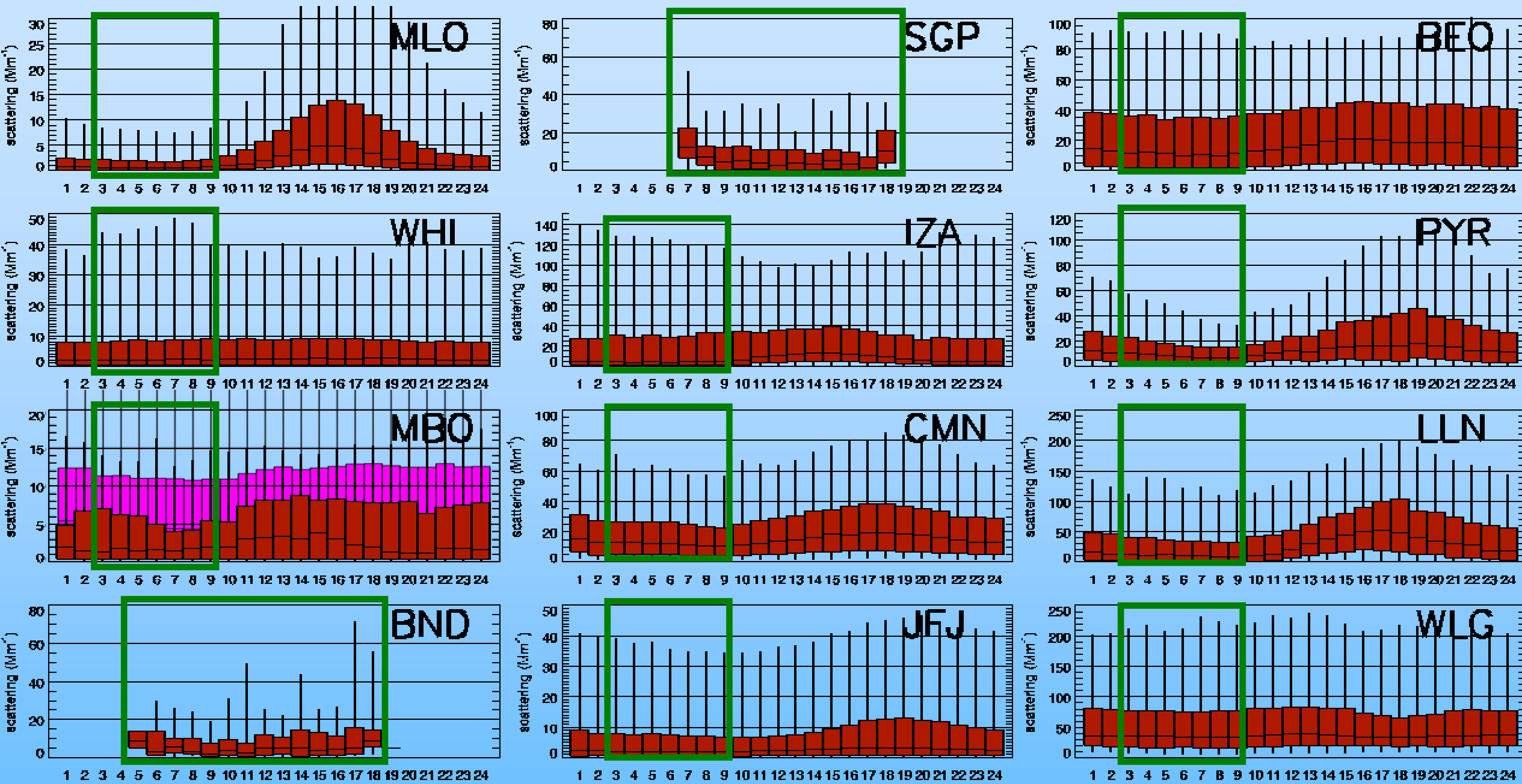


MLO – Mauna Loa, USA (3.4 km)
MBO – Mt Bachelor, USA (2.4 km)
WHI – Whistler, Canada (2.2 km)
SGP – Oklahoma, USA (3-5 km)
BND – Illinois, USA (3-5 km)
IZA – Izana, Spain (2.4 km)

JFJ – Jungfraujoch, Switzerland (3.6 km)
CMN – Monte Cimone, Italy (2.2 km)
BEO – Beo Moussala, Bulgaria (2.4 km)
PYR – Pyramid, Nepal (5.1 km)
WLG – Mt Waliguan, China (3.8 km)
LLN – Mt Lulin, Taiwan (2.9 km)

All sites have scattering and absorption data (except BEO).
Results adjusted to and presented at STP and 550 nm (where possible)

Diurnal cycle of light scattering – all data

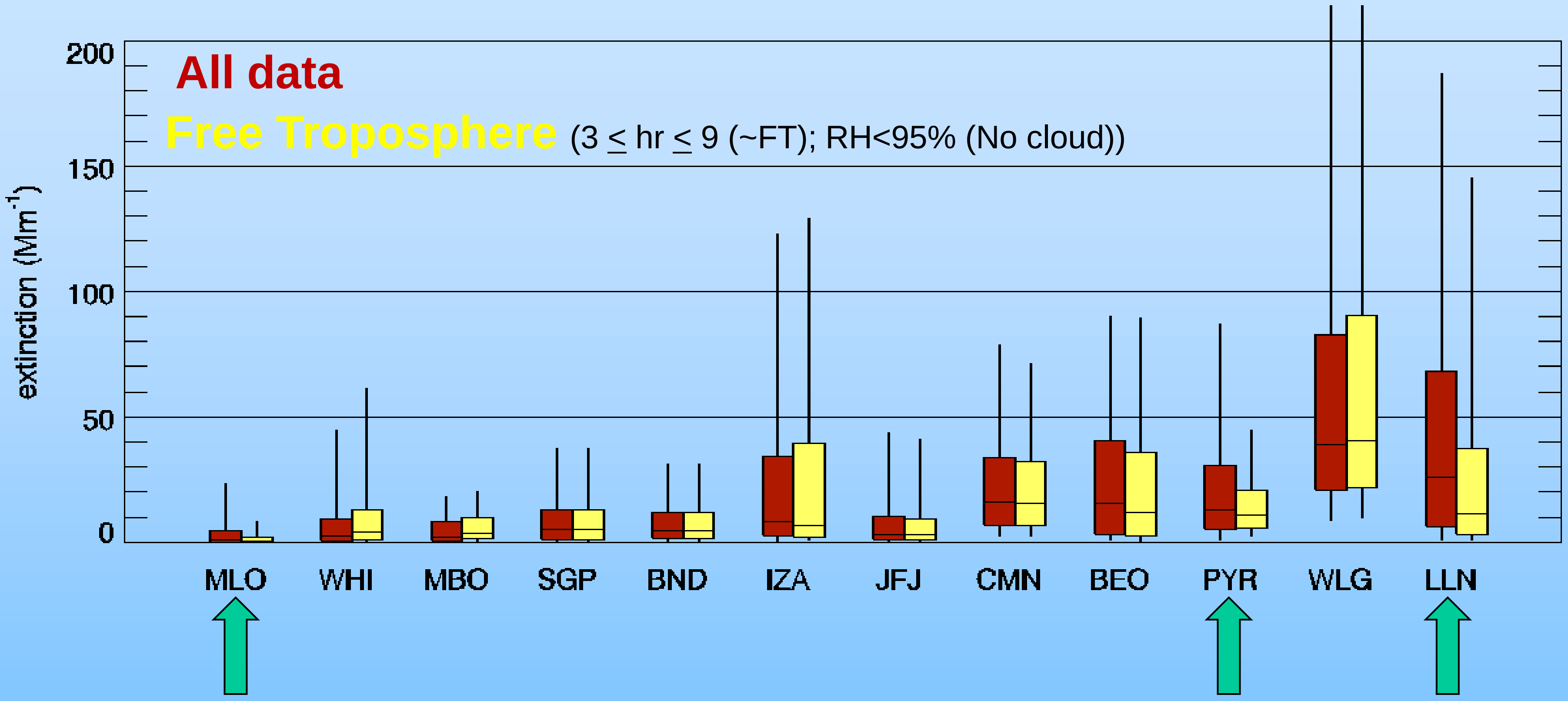


Data presented in local time

Green boxes indicate FT time period.

MBO April-June (1um, 550 nm) All year (1um, 530 nm)
CMN (520 nm)

Extinction (all data vs. ~ free troposphere)

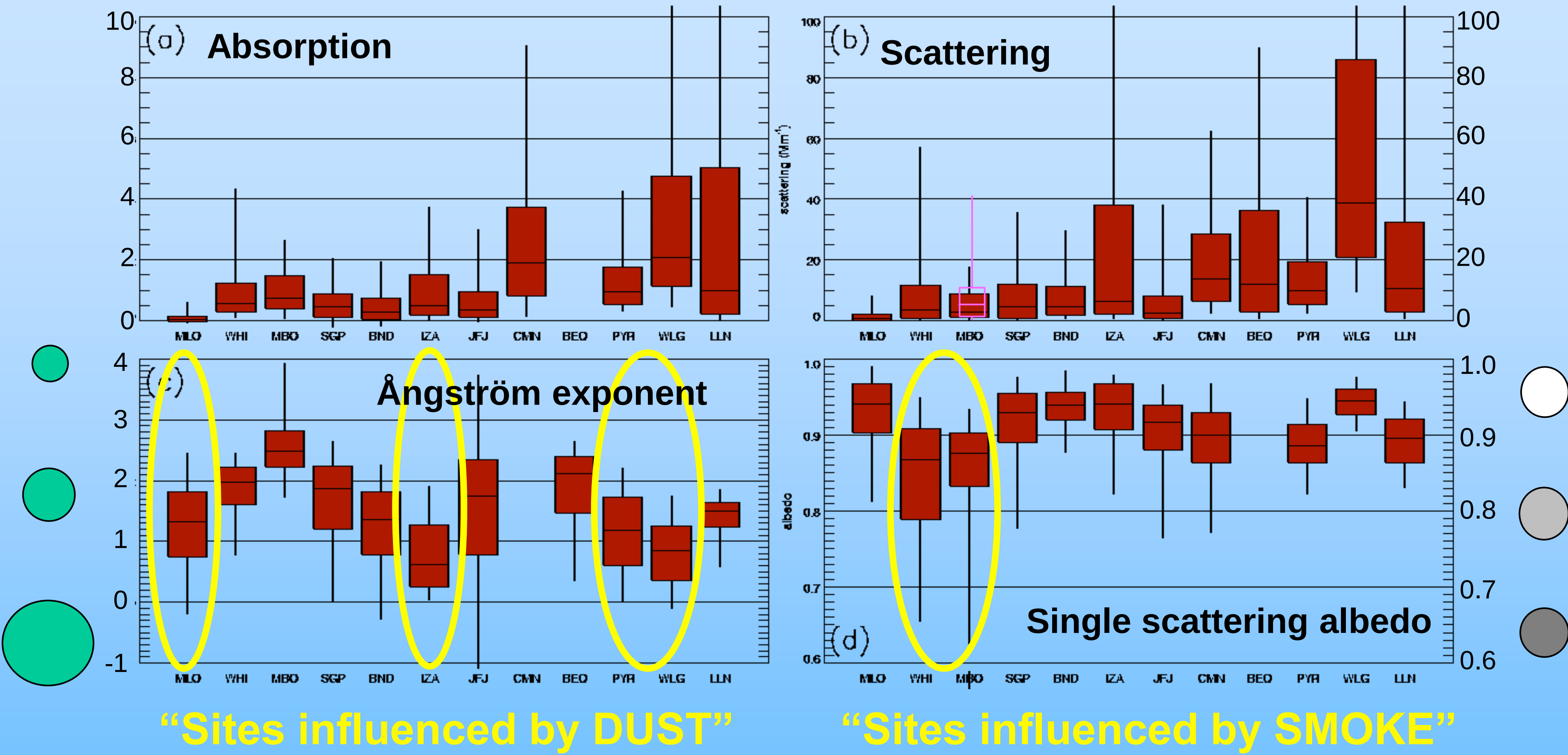


Increase in aerosol loading from west to east (almost split by hemisphere)

Difference between ‘all data’ and ‘FT’ data largest for sites with strongest diurnal cycle (MLO, PYR, LLN).

BEO →scattering

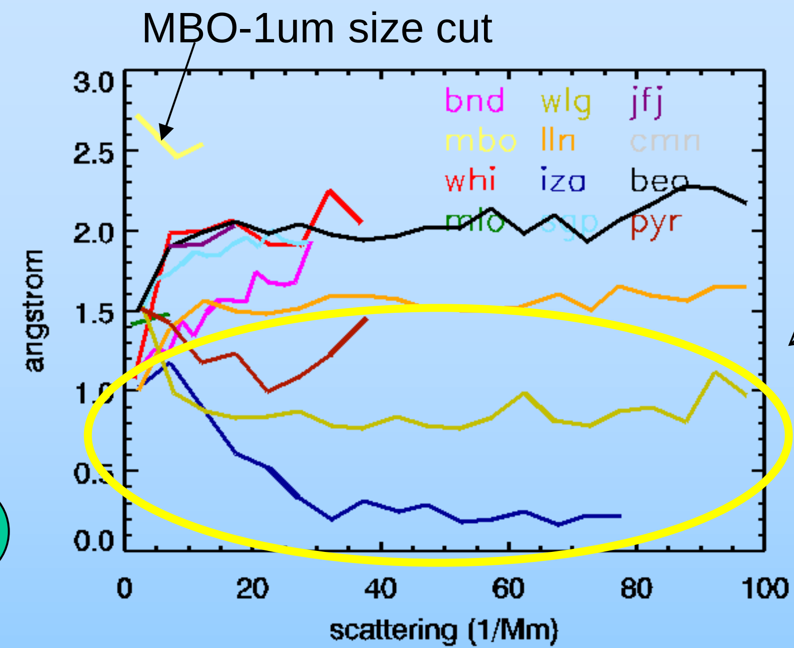
Comparison of FT aerosol optical properties



Ovals indicate sites known to be influenced by specific sources – the source signature can be seen in the value of the parameter

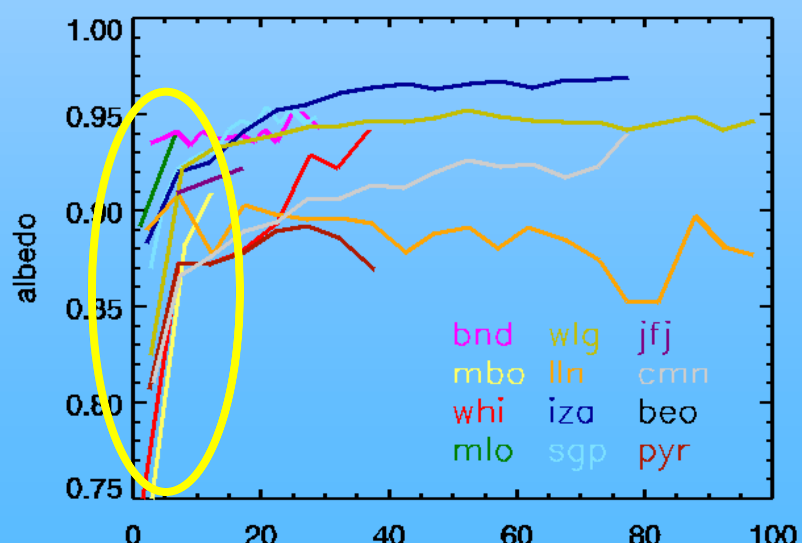
MBO-size cut=1um (hence higher Ångström exponent!); CMN – at 520 nm

Systematic variation of aerosol properties with loading



→atmospheric processing/sources
→aerosol parameterizations

Ångström exponent
These three sites (**IZA**, **WLG**, **PYR**) impacted by dust. Note: **MLO** is also experiences dust events, but is more distant from source of dust (gives larger particles more time to deposit out?)

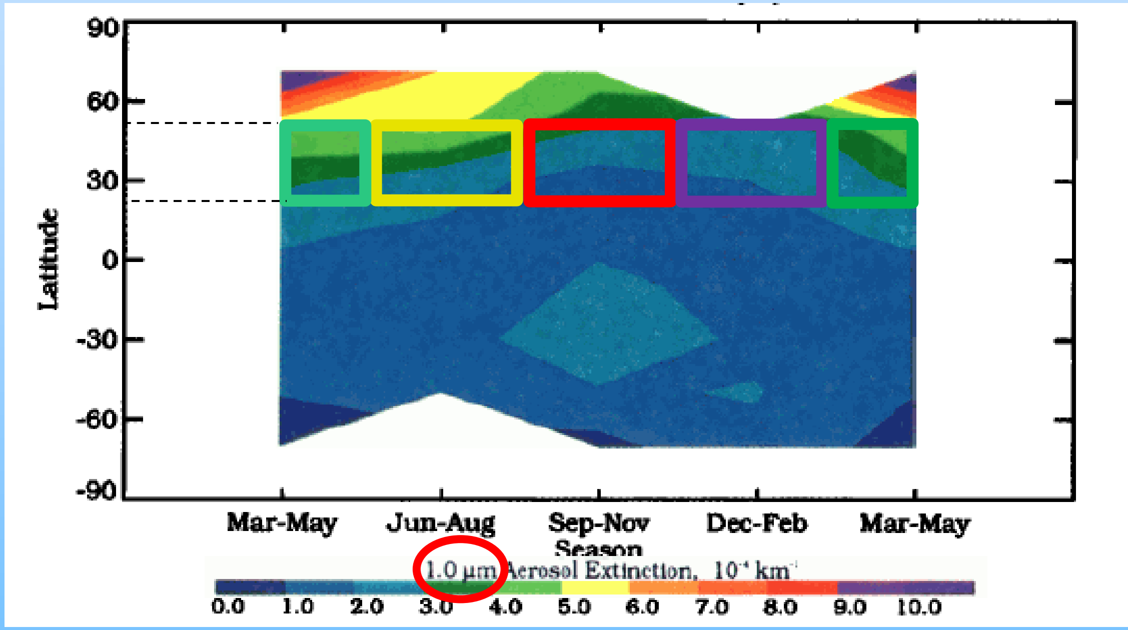


Single scattering albedo
Most sites show lower single scattering albedo values for clean air (low scattering).
→cloud processing? Preferential removal of more hygroscopic scattering aerosol?

LLN and BND do not show this behavior.
→Why!?!

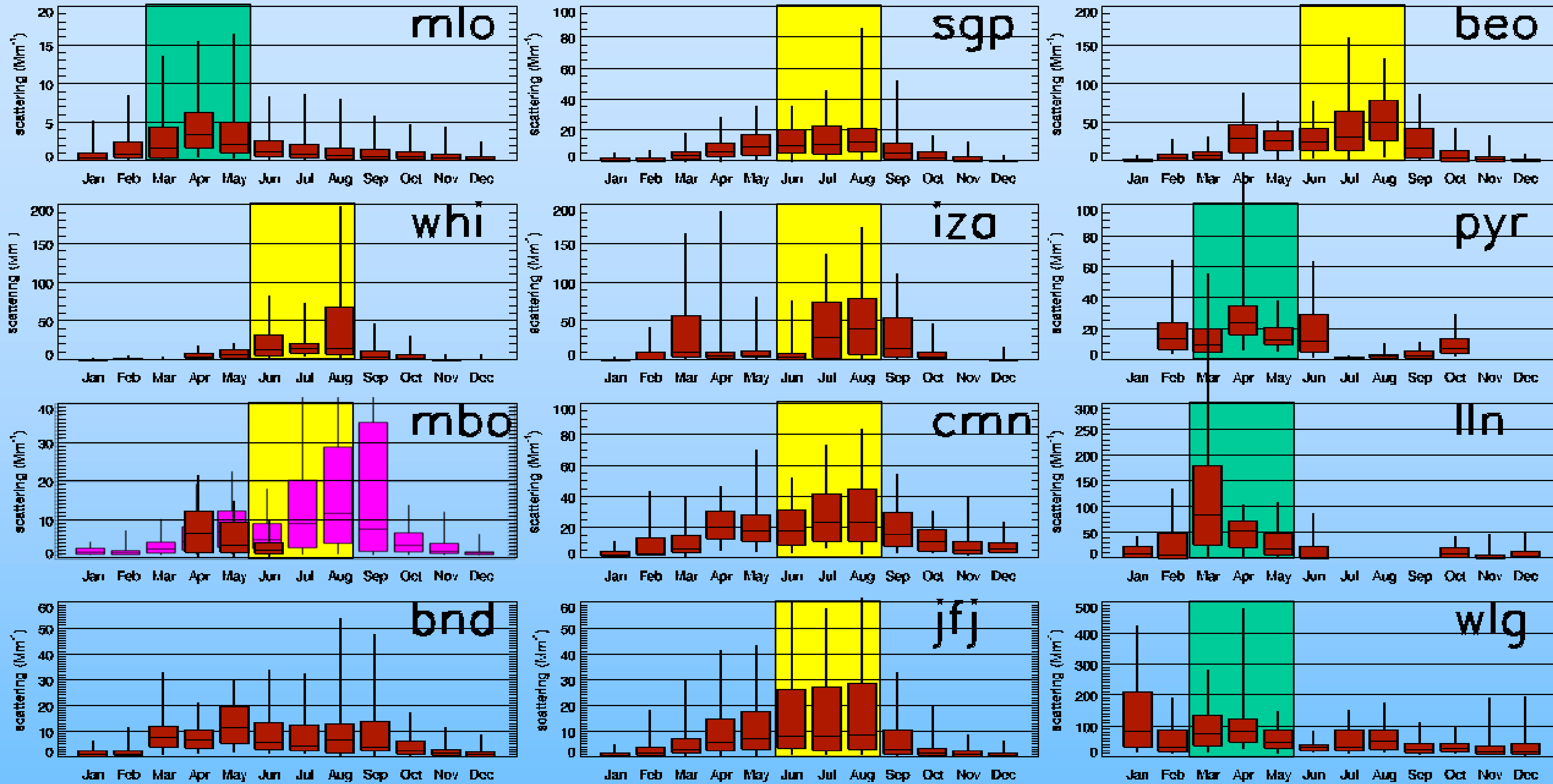
Comparison with satellite climatology

A zonally-averaged climatology of free troposphere aerosol extinction based on satellite measurements (Kent et al., 1998) shows: Extinction is highest in spring (MAM); Extinction is lowest in winter (DJF).



- Measurement wavelength is 1000 nm.
- Extinction scale is 0 to 1 Mm^{-1}.
- Measurements above 6km.
- Daytime measurements only.
- Ambient RH conditions.
- Measurements made pre-1998.

Monthly in-situ FT climatologies (scattering)



Peaks in summer months (JJA)

Peaks in spring months (MAM)

Most sites with springtime maxima are dust-impacted sites (bigger aerosol)

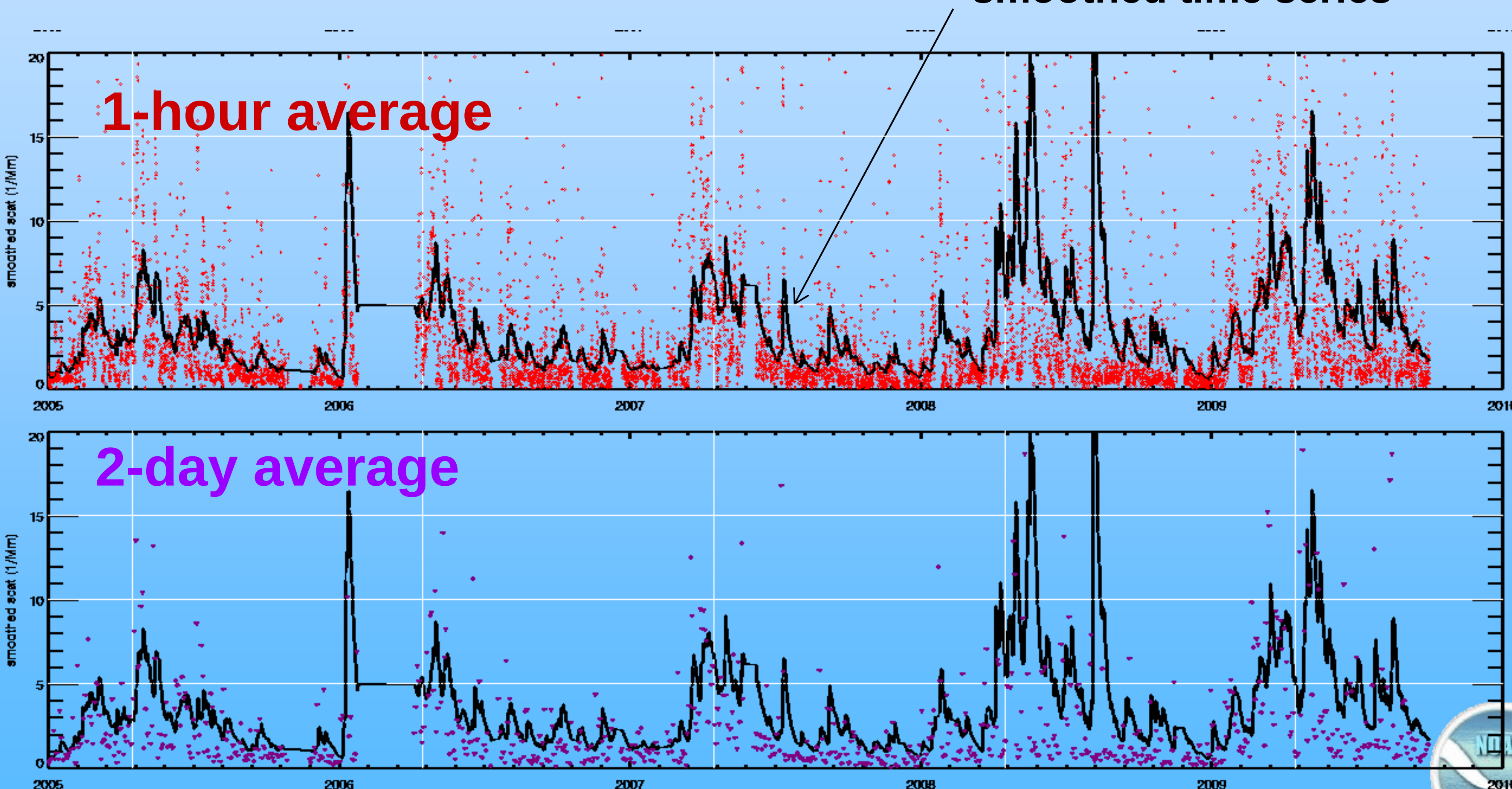
Springtime scattering values range from ~1 Mm^{-1} to ~100 Mm^{-1}.

Identification of ‘events’ in climatologies

How we did this:

1. Identify ‘events’ – Use 48 hr low pass filter to smooth data
2. Remove events
3. Recalculate ‘event-free’ climatology

smoothed time series



Example showing 5 years of MLO data

Importance of events on FT climatologies

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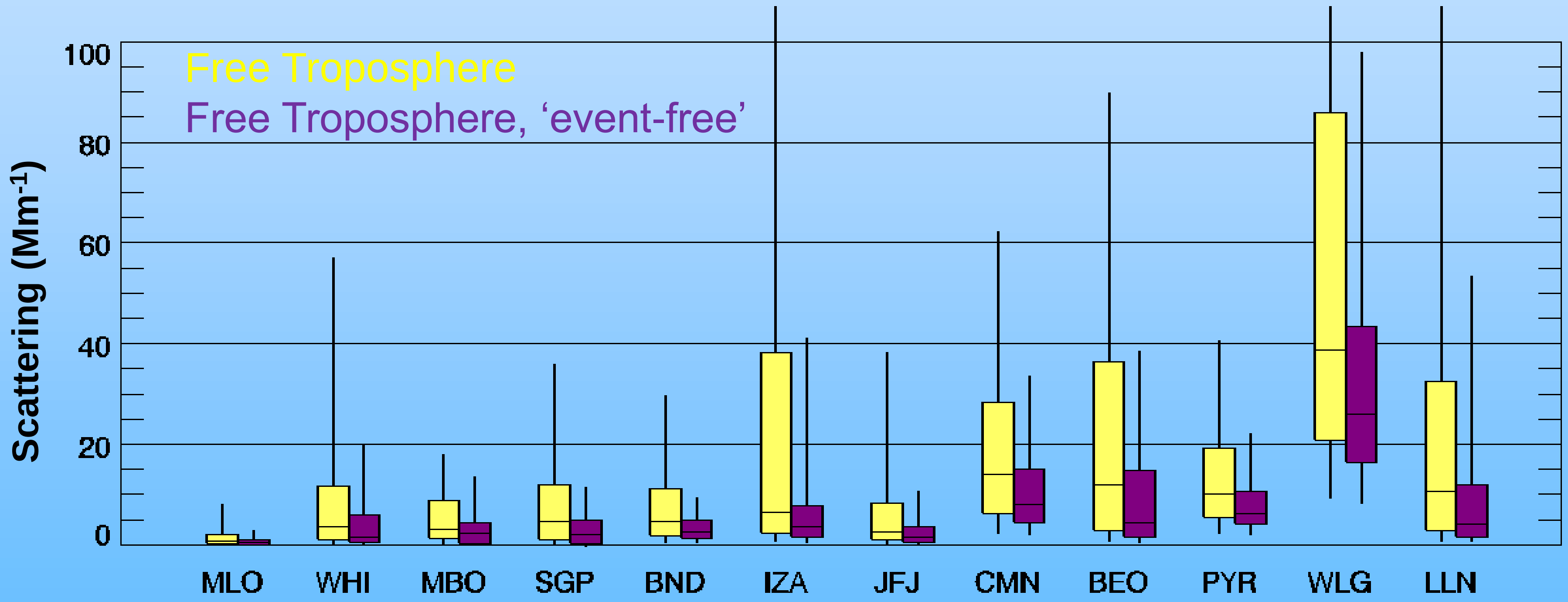


→Significant decrease in FT scattering when 'events' removed
→(Obviously) choice of event identification method will change results
→Different event identification method may be needed for each site

Conclusions

- What is climatology of FT aerosol at a range of sites?
- →Order of magnitude difference in amount of aerosol among sites
- →See influence of sources (e.g., dust) on aerosol optical properties
- →Values increase from west to east – appear to be 2 groups of sites

- Do FT aerosol properties vary systematically?
- →Dust-influenced sites Ångström exponent decreases with loading
- →Most sites have low SSA for low loading (cloud processing?)

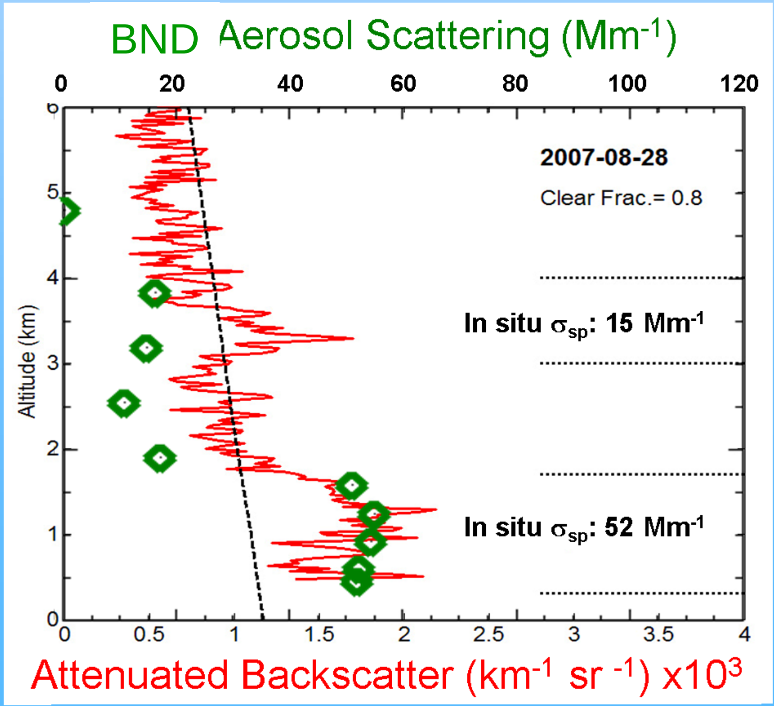
- How do in-situ climatologies of free tropospheric light extinction compare to the satellite-derived climatology presented by Kent et al.?
- →Sites 'in-phase' with satellite are strongly dust-influenced.

- Do aerosol events (e.g., smoke transport) have a significant influence on free troposphere climatological values?
- →Yes! By our simple method, factor of 2 difference in scattering at many sites.

Future Work

- Add more sites to analysis
- Try other FT identification options (e.g., gases, RH, wind)
- Try other 'event' identification options and look at event influence on additional aerosol property variables
- Effect of clouds on aerosol properties (RH surrogate)
- Model comparisons
- Compare lidar (surface/spaced based) with in-situ FT climatologies

We are beginning to do comparisons of our in-situ aircraft profiles with CALIPSO measurements. CALIPSO derives aerosol extinction at 532 nm →wavelength means more similar comparison than SAGE. →CALIPSO may not be as sensitive at low aerosol loadings



T. Anderson provided CALIPSO data

Thanks!!

☺

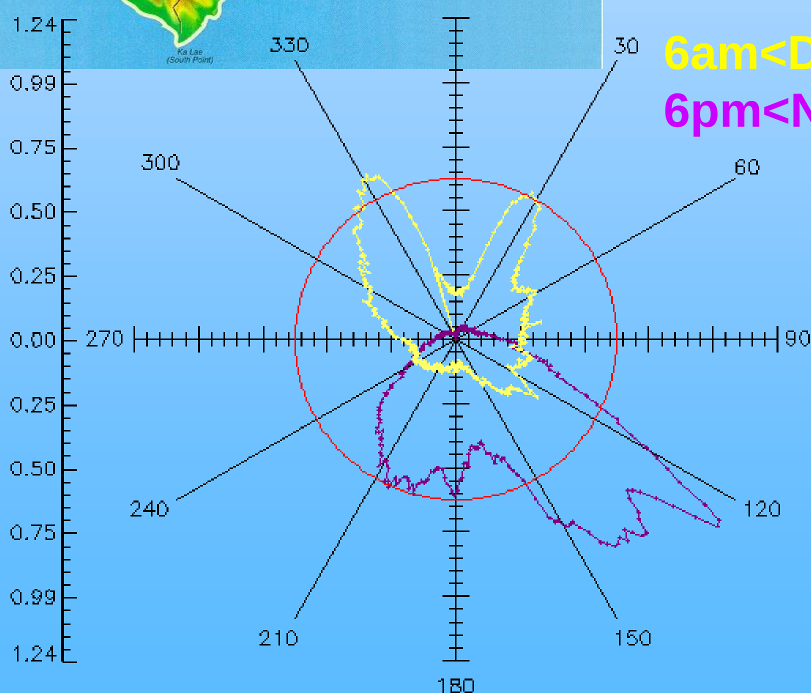
Upslope/downslope

Methods:

--wind direction

--time of day

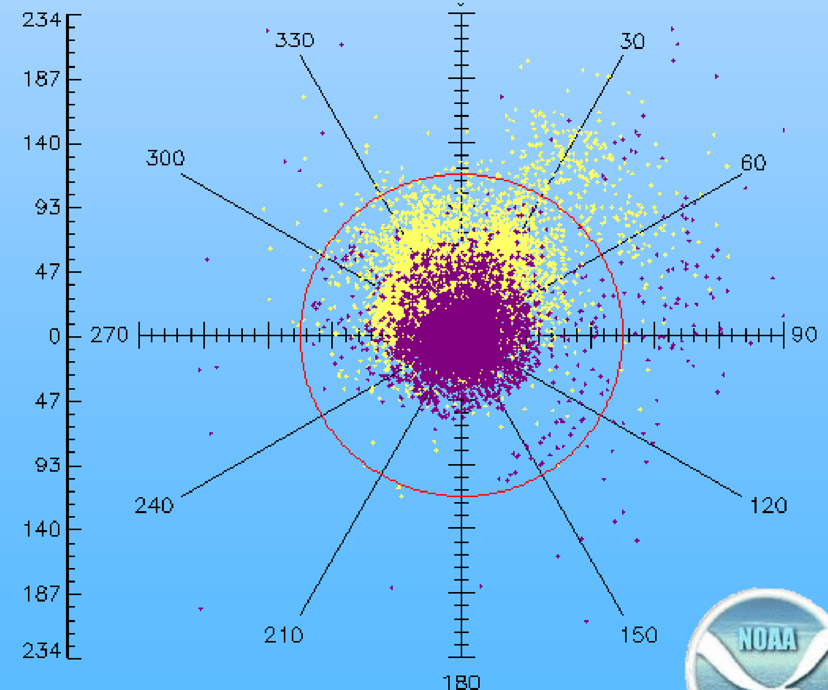
--gas concentrations (CO, RH, …)



Frequency of wind direction

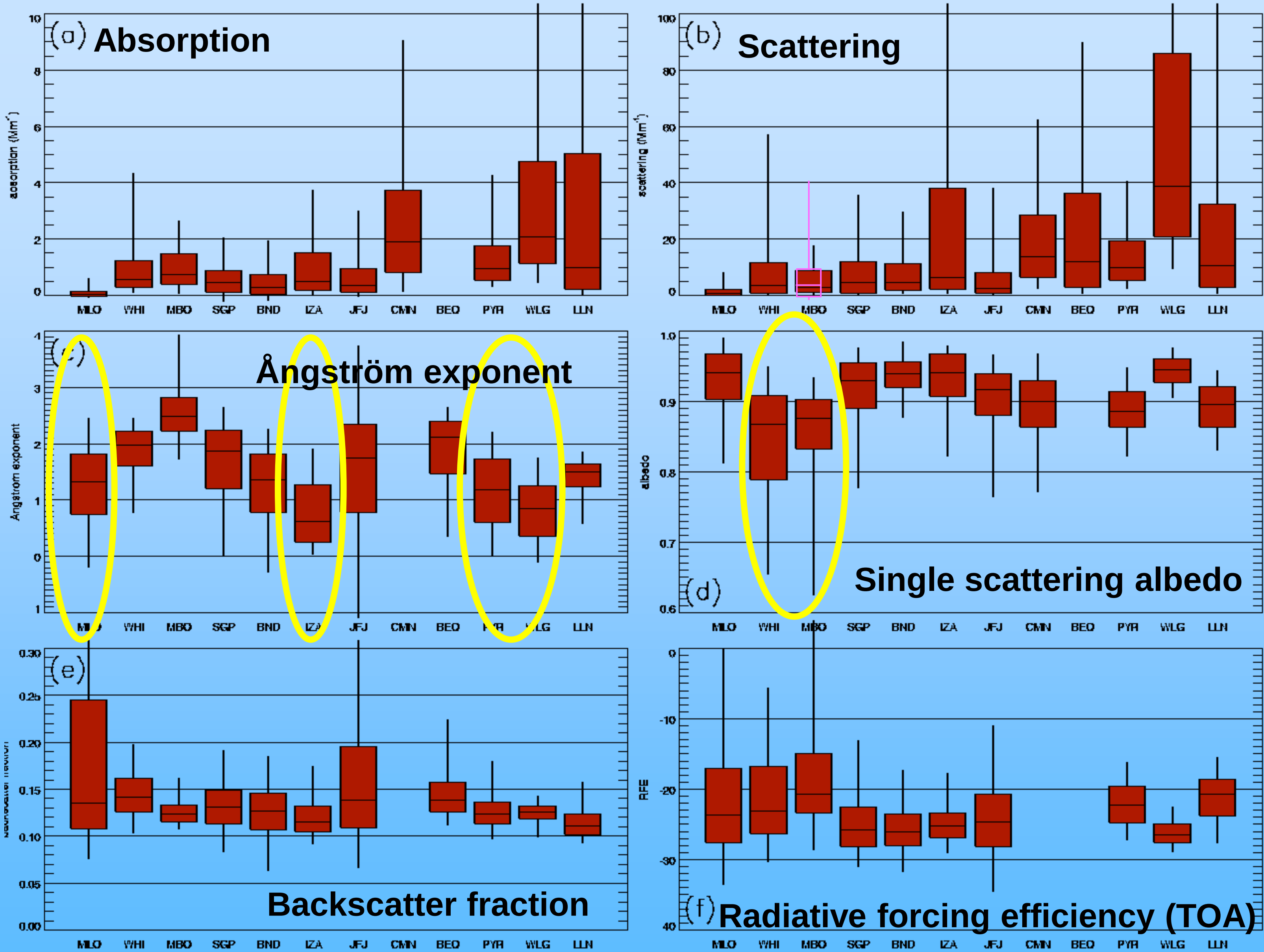
6am<Day<6pm

6pm<Night<6am



Scattering as f(WD)

Comparison of FT aerosol optical properties



MBO-size cut=1um (hence higher angstrom exponent!);CMN – at 520 nm

Parameters controlling aerosol forcing

$$\Delta F \approx -DS_0 T_{at}^2 (1-A_c)(1-R_s)^2 \tilde{\omega}_0 \bar{\beta} \delta \left[1 - \frac{2R_s}{(1-R_s)^2} \left(\frac{1-\tilde{\omega}_0}{\tilde{\omega}_0 \bar{\beta}} \right) \right]$$

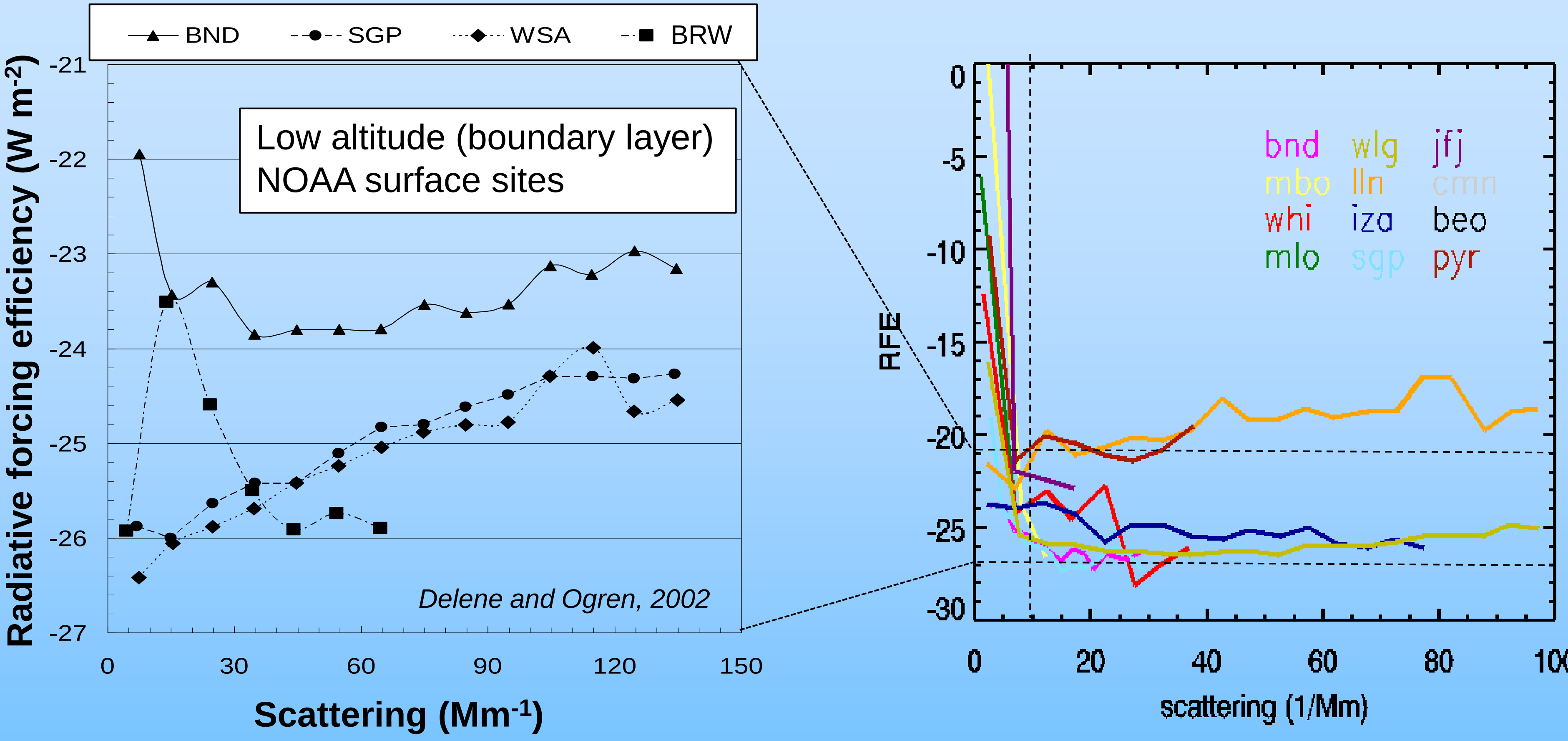
ΔF	average aerosol forcing at top of atmosphere (TOA)
δ	aerosol optical depth
$\tilde{\omega}_0$	aerosol single-scattering albedo
$\bar{\beta}$	average aerosol up-scatter fraction

D	daylight fraction
S_0	solar constant
T_{at}	atmospheric transmission
A_c	cloud fraction
R_s	surface albedo

$\Delta F/\delta$ = Radiative Forcing Efficiency

Source: Haywood and Shine (1995)

Importance of aerosol amount versus type for RFE

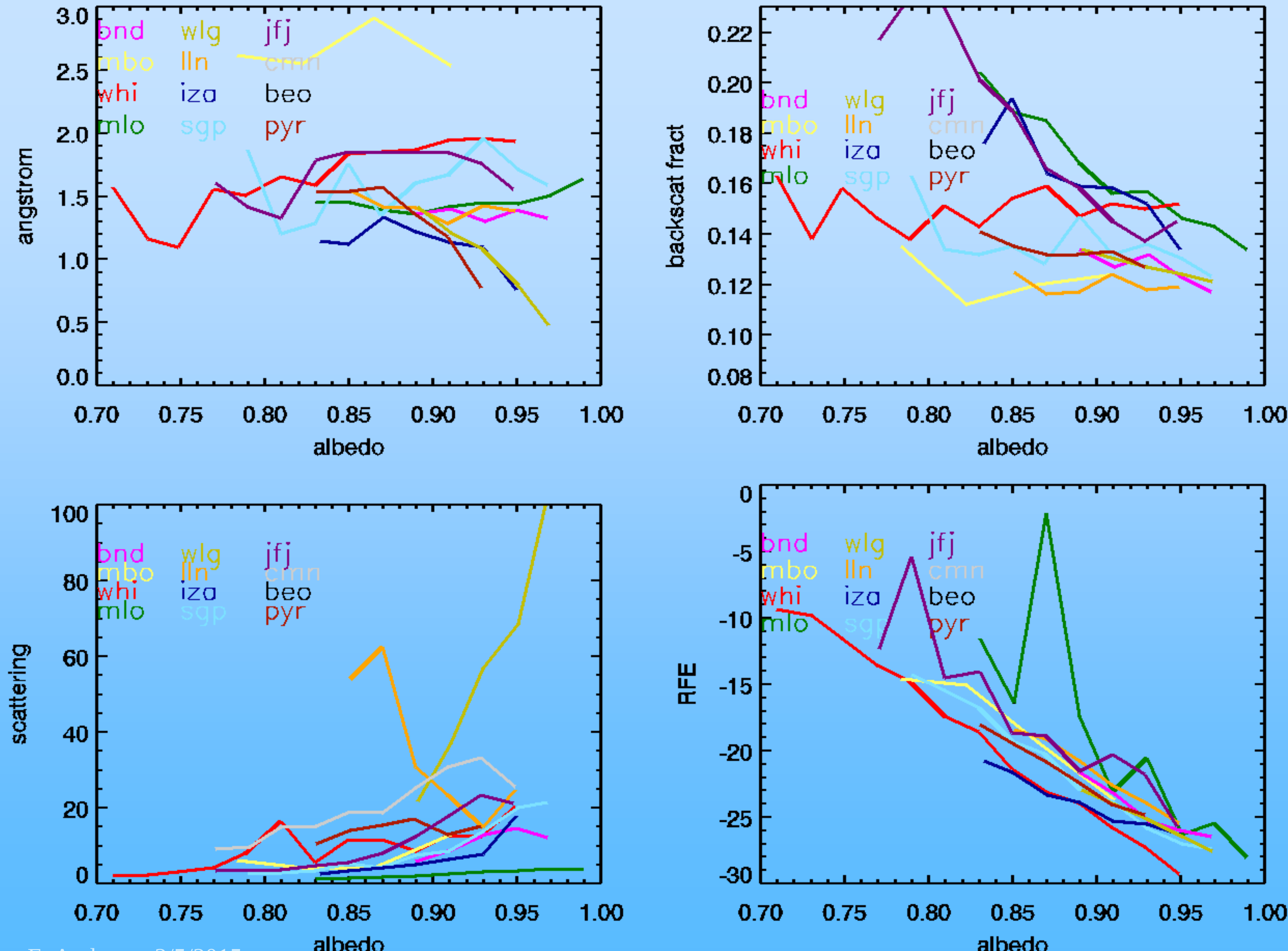


Delene and Ogren (2002): The small variation in RFE with scattering suggests the nature of aerosol controls RFE, independent of aerosol amount.

FT sites show high variability in RFE below ~10 Mm^{-1}

→nature of aerosol and thus, RFE, depends on amount of aerosol

→*How much of variability at low scattering is due to noise in measurements?*



angstrom
albedo
backscat fract
albedo
scattering
albedo
RFE
albedo
bnd wlg jfj
mbo lln cmn
whi iza beo
mlo sgp pyr

Identification of 'events' in climatologies

How we did this:

1. Identify 'events' – Used fast Fourier transform smoother
2. Remove events
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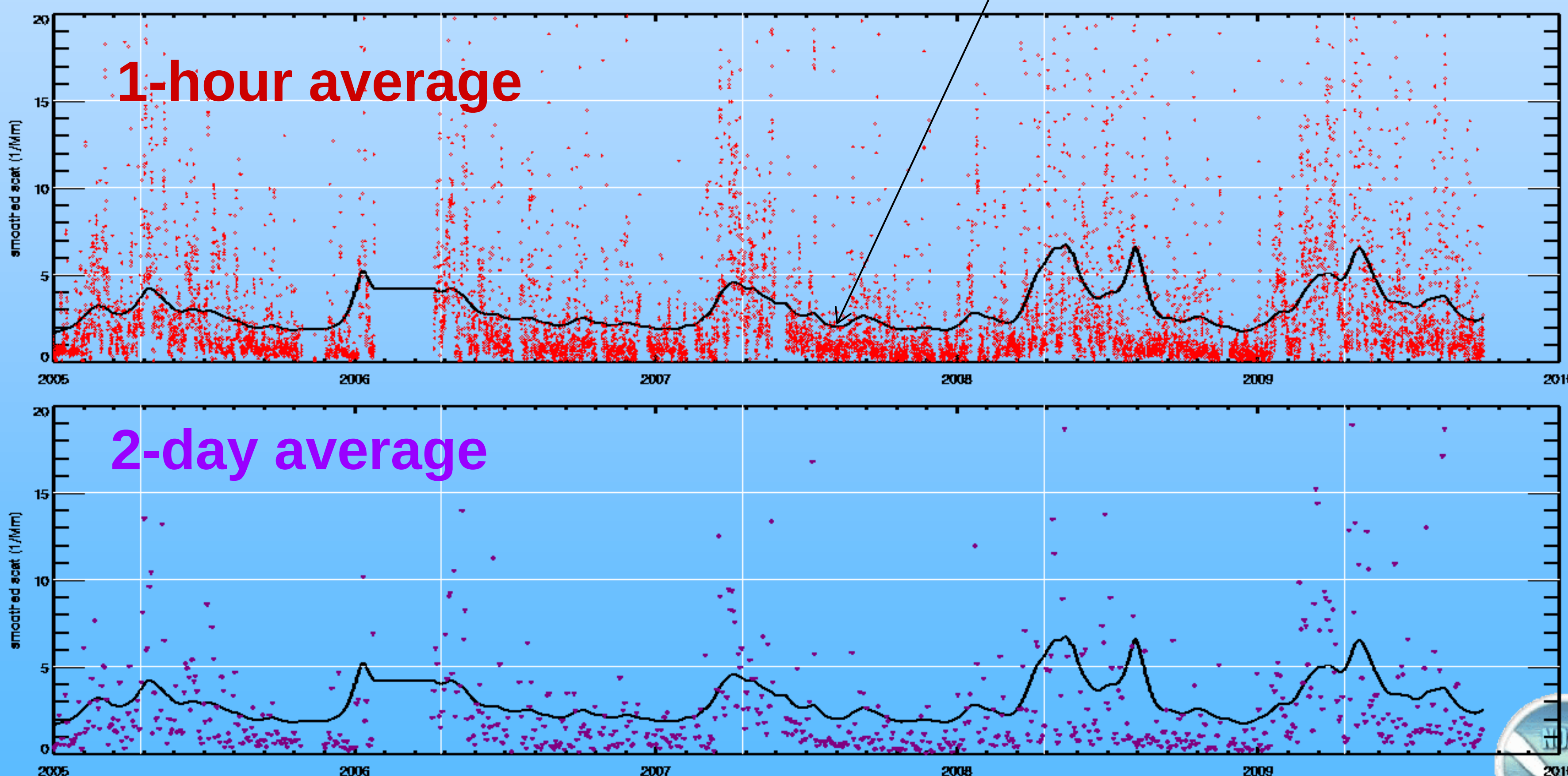
smoothed time series



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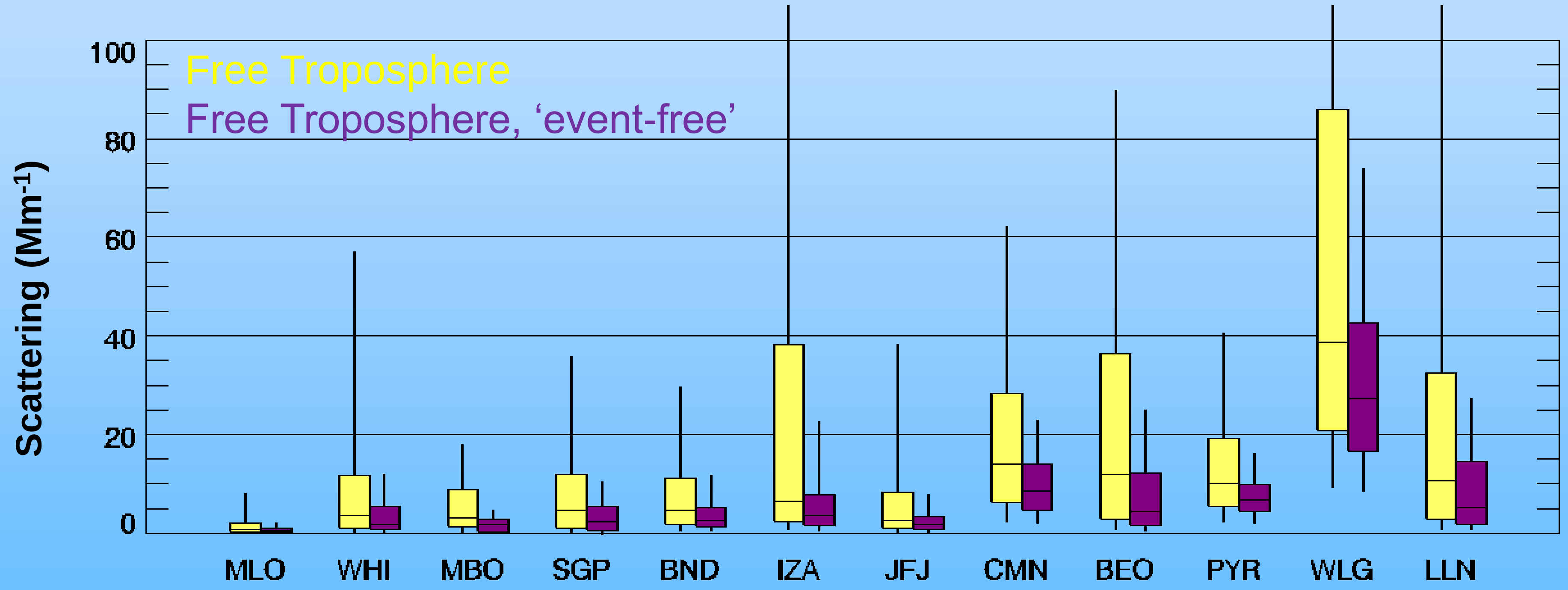

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