The Sensitivity of Shortwave Radiative Forcing and Heating Rates to the Aerosol Vertical Profile

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Aerosol Radiative Forcing

$$F_{net} = F_{\downarrow} - F_{\uparrow}$$

$$ARF = F_{net}(with\ aerosol) - F_{net}(without\ aerosol)$$

- **Altitude:**
  - **Top of Atmosphere**
  - **Surface**
  - **Profile**
- **Averaging (or not)**
  - **Spectral or Broadband**
  - **Instantaneous or 24 hours**

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Heating Rate

$$HR = \frac{\partial T}{\partial t} = -\frac{1}{\rho c_p}\frac{\partial F_{net}}{\partial z}$$

$$AHR = HR(with\ aerosol) - HR(without\ aerosol)$$

$F : Flux$

$ARF : Aerosol\ Radiative\ Forcing$

$AHR : Aerosol\ Heating\ Rate$

$T : Temperature$

$t : time, \quad z : Altitude$

$\rho : air\ density, \quad c_p : specific\ heat\ capacity$

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INPUTS needed to calculate ARF or AHR profiles:

Profiles of:
Extinction, $\sigma(\lambda)$
Single Scattering Albedo, $\omega(\lambda)$
Asymmetry Parameter, $g(\lambda)$
H_2O, O_3, p, T, other gases

Surface Albedo, R (λ)
Solar Zenith Angle

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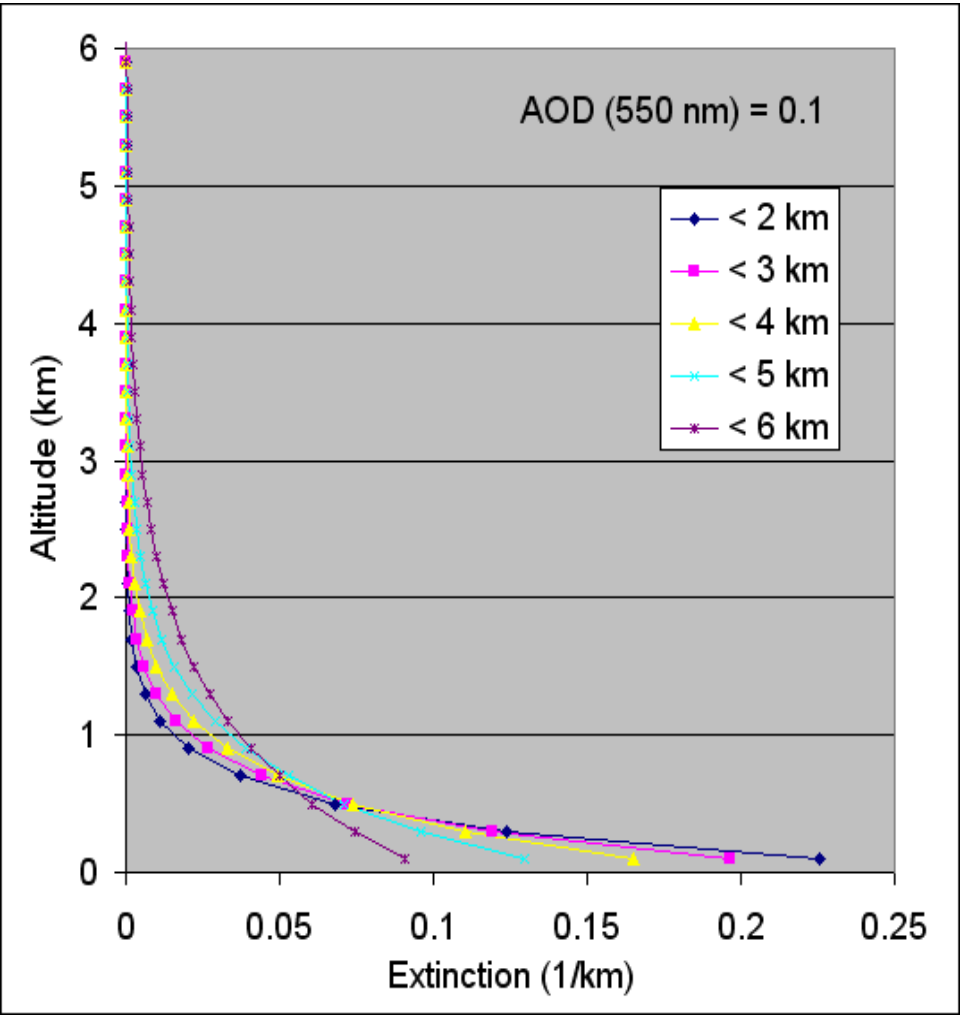
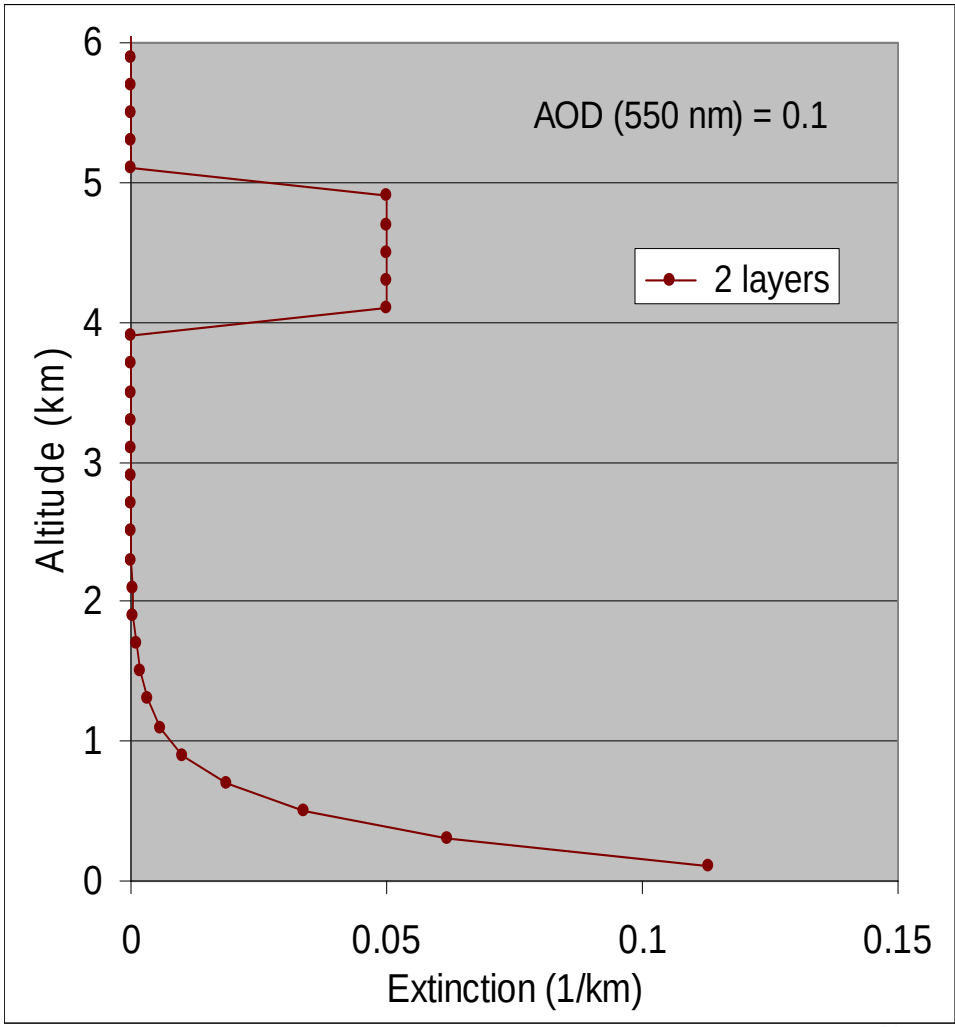
Does the vertical profile of aerosol properties matter for the radiation budget?





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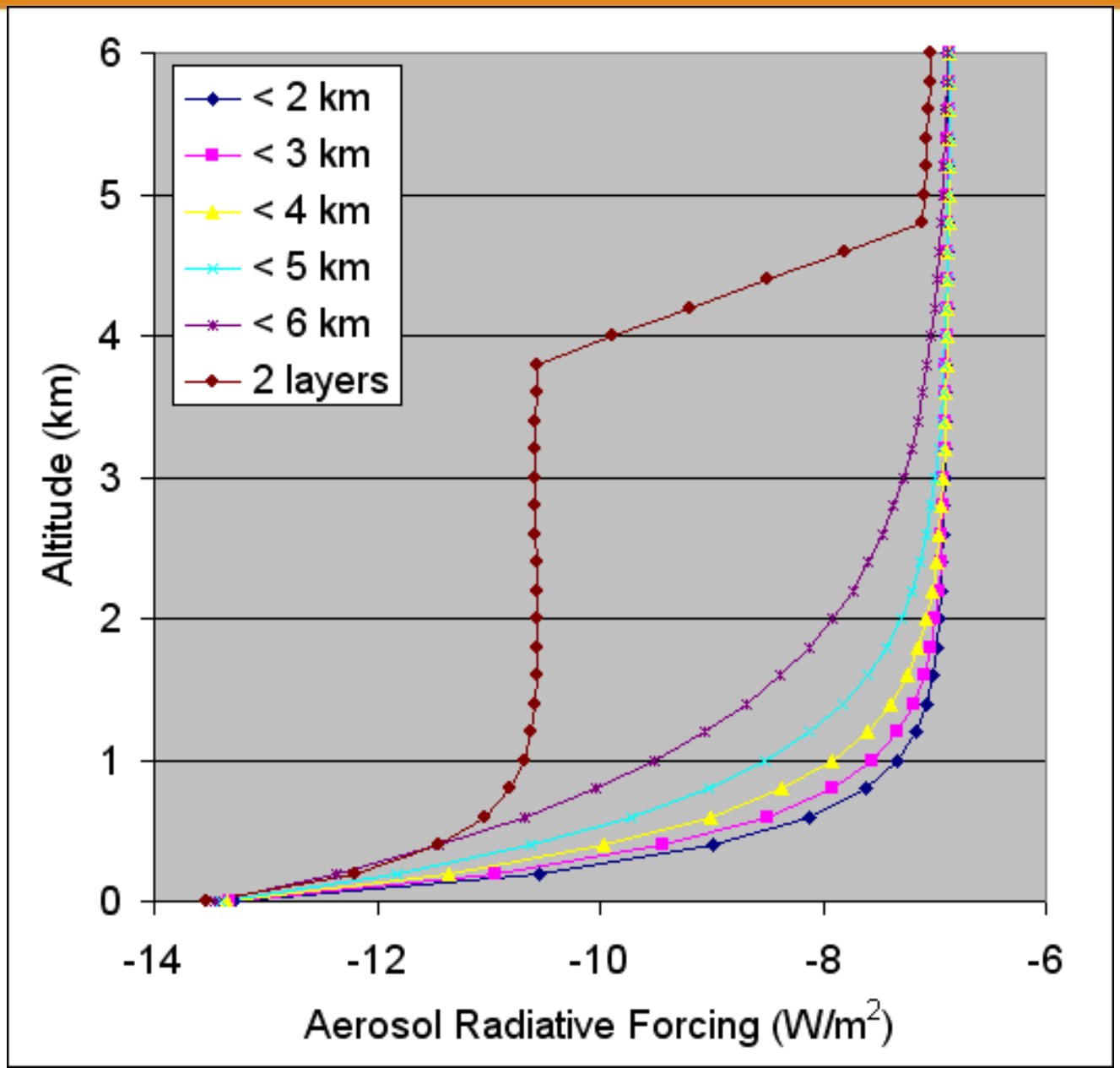
It depends on where in the profile you look!



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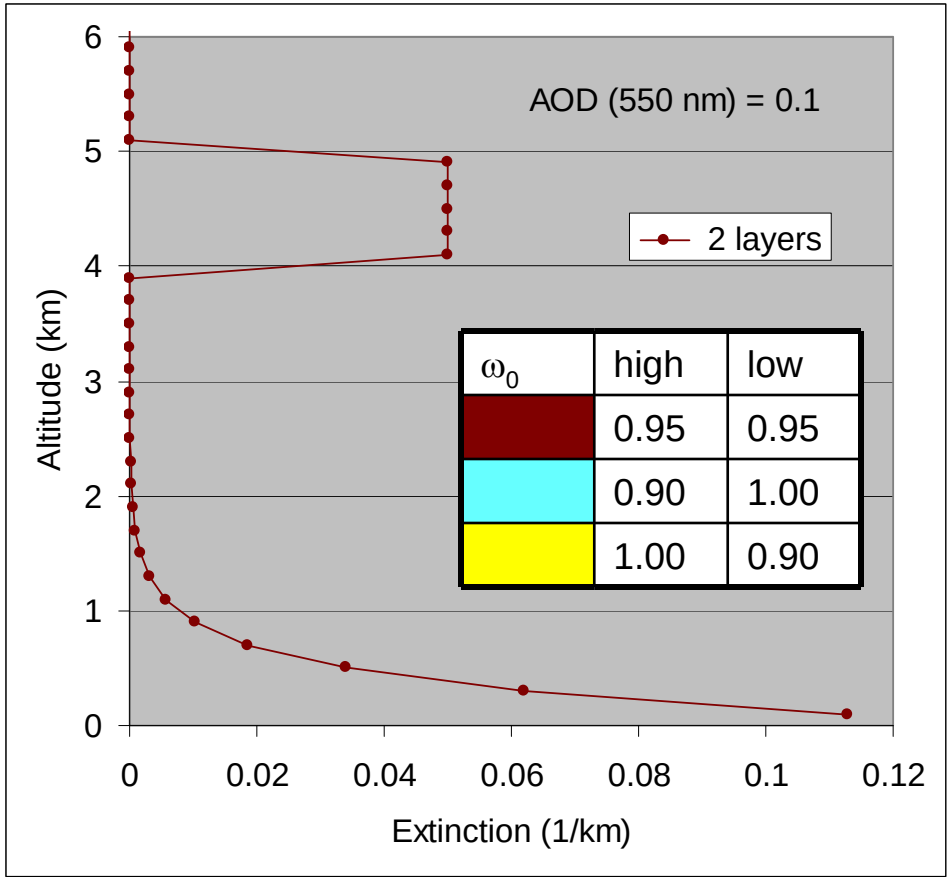
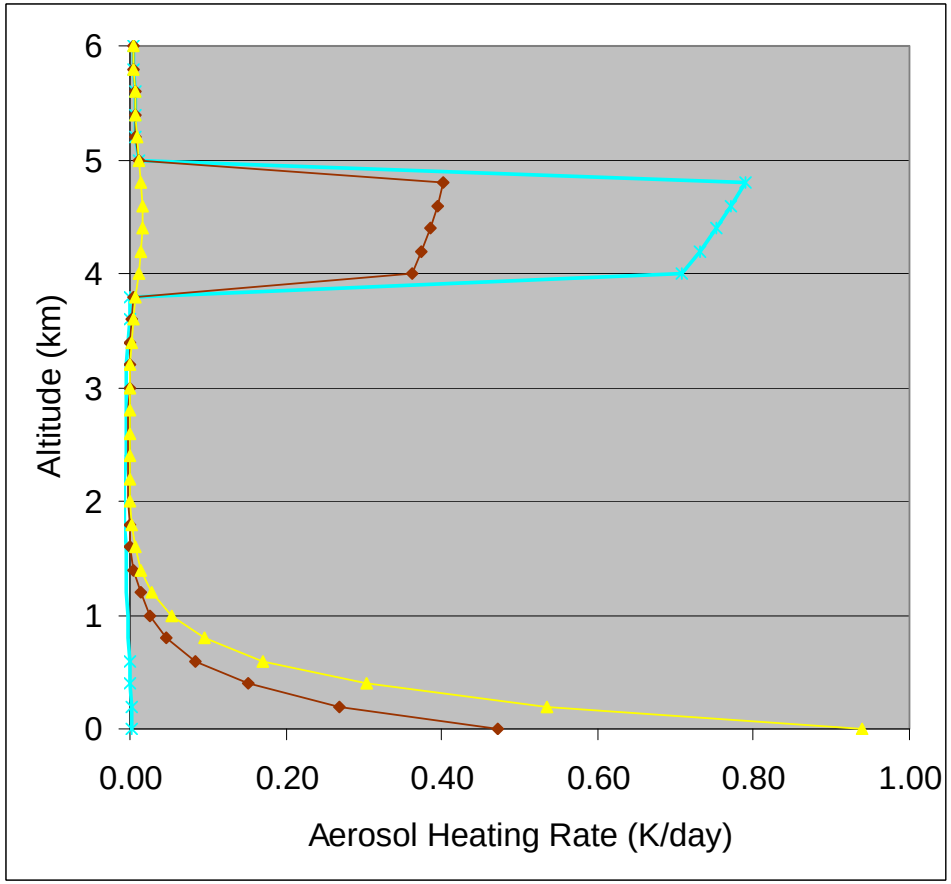
Does the vertical profile of aerosol properties matter for the radiation budget?



ω_0	high	low
	0.95	0.95
	0.90	1.00
	1.00	0.90



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Can we use radiation measurements to determine the heating rate profile?

"The holy grail of radiation measurements"
(W. Wiscombe)

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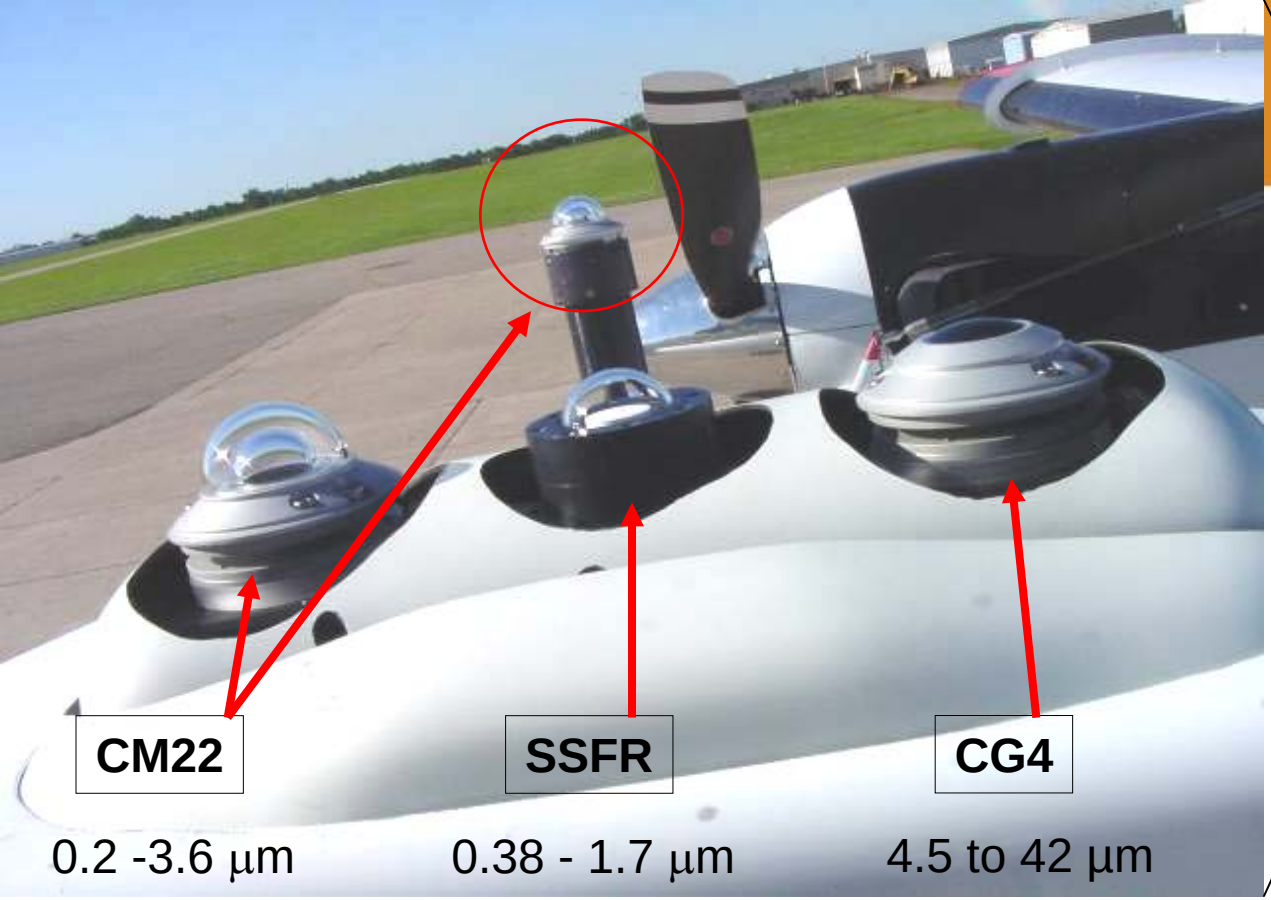
ARM Aerosol IOP
Oklahoma, May 2003

CIRPAS Twin Otter

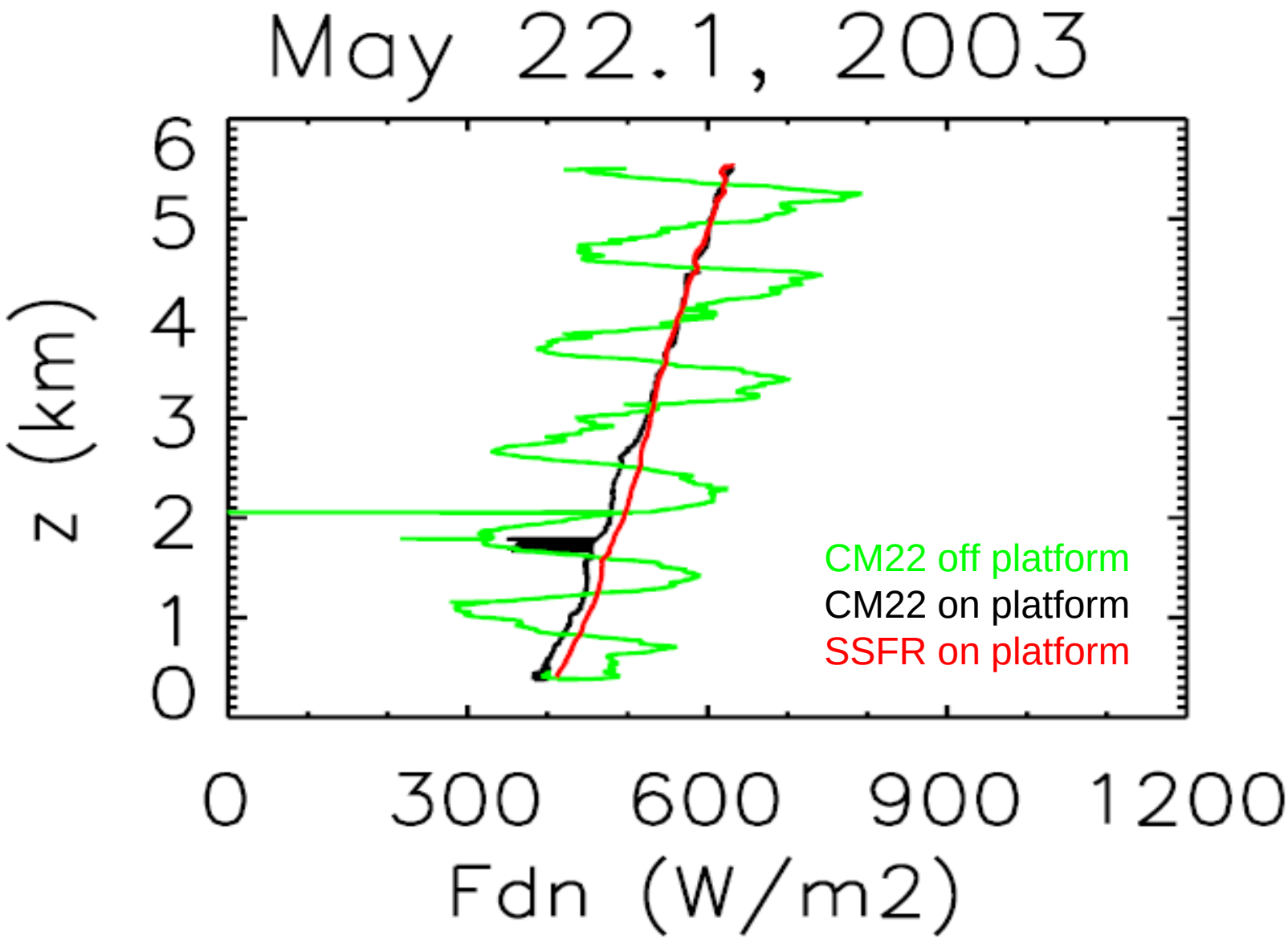
2006 JGR special issue with 18 papers + new papers



Down-welling flux

Up-welling flux

Stabilized platform is essential!

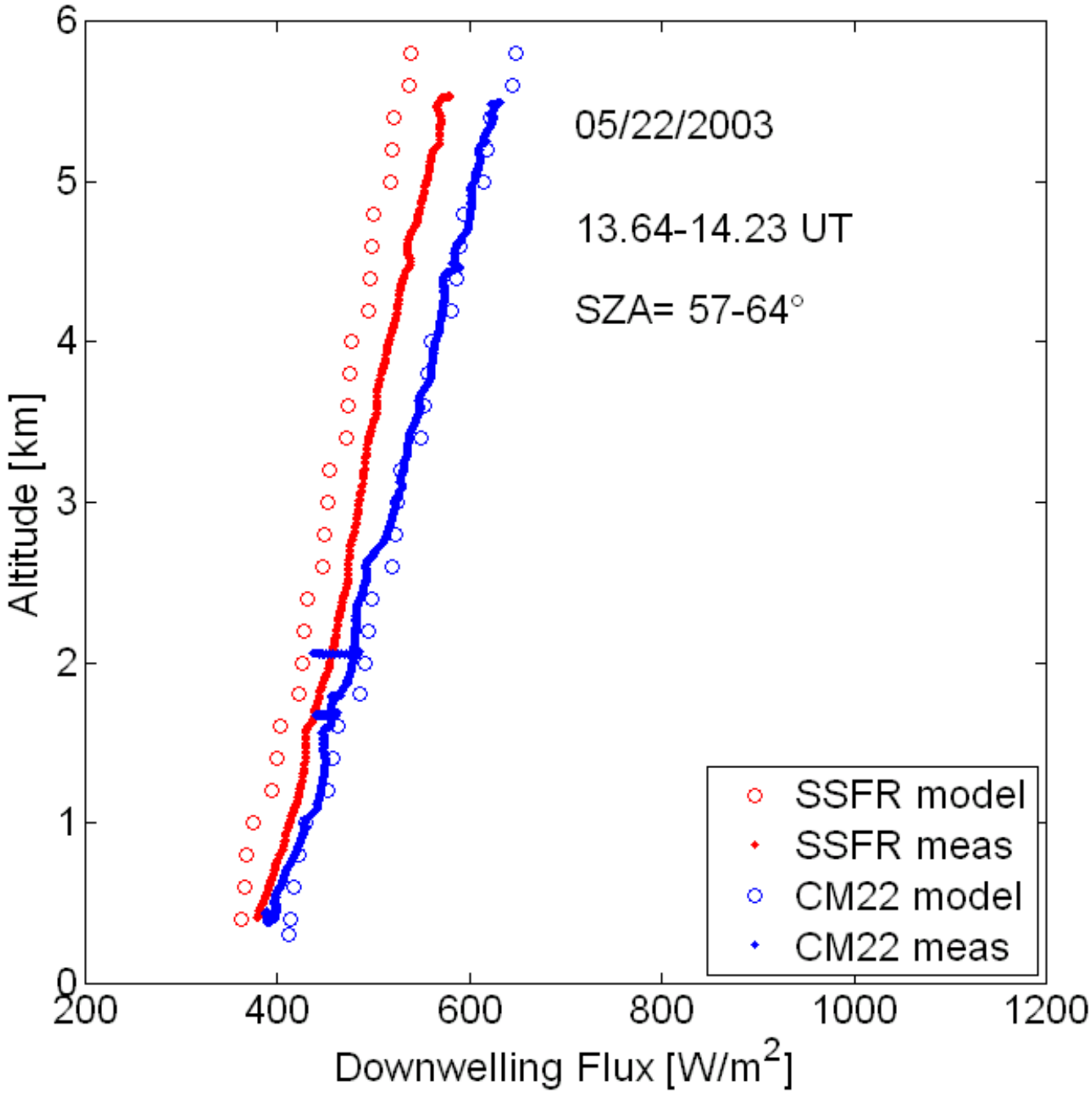


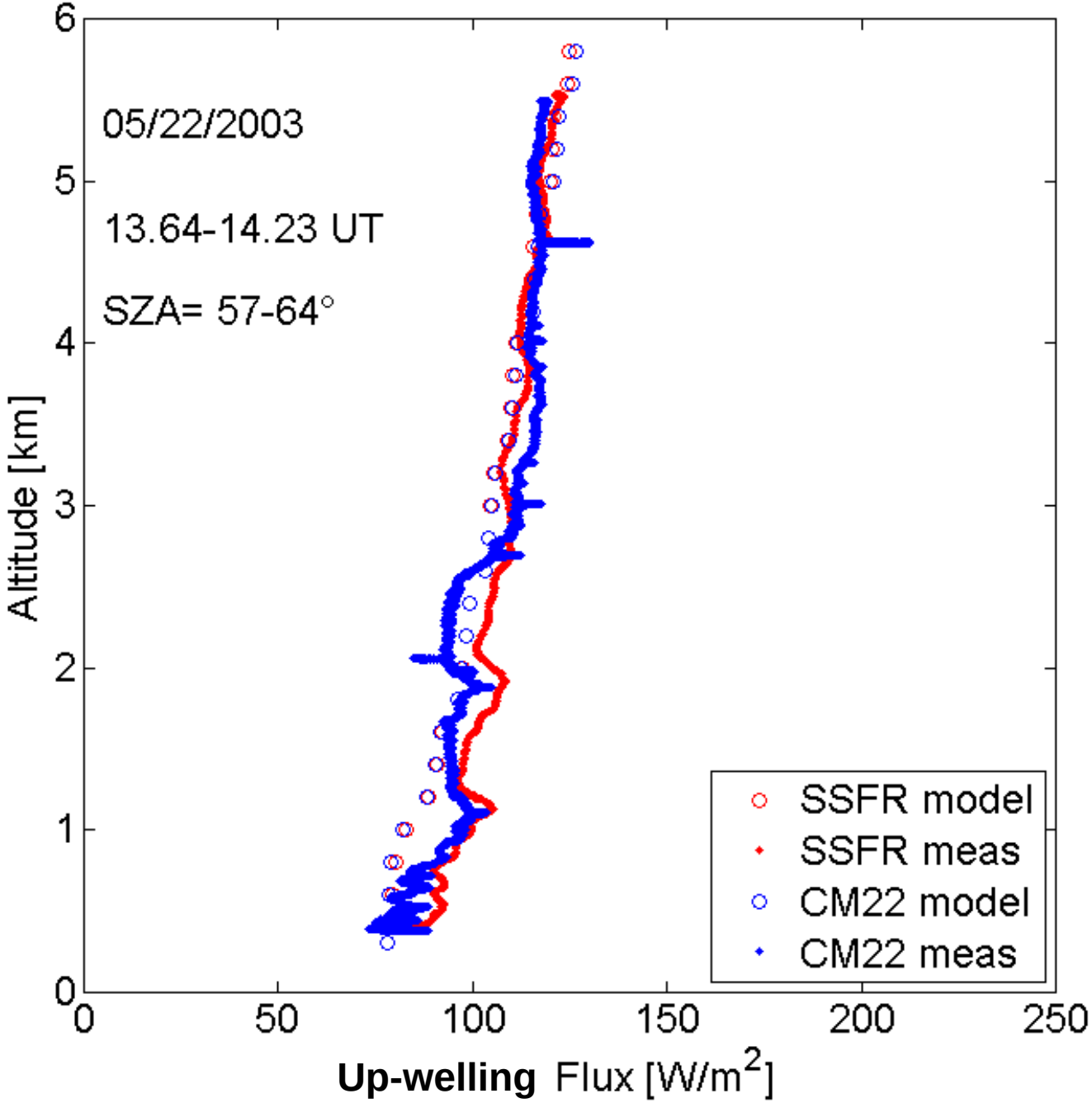
Modeling the measured fluxes

INPUTS into RRTM_SW 2.5:

Profiles of:	
Extinction, σ (λ)	AATS-14
Single Scattering Albedo, ω (λ)	0.95 (550 nm)
Asymmetry Parameter, *g* (λ)	0.6 (550 nm)
H_2O, p, T, O_3, other gases	Aircraft & Sondes Climatology

Surface Albedo, R (λ)	F↑/F↓ lowest legs
Solar Zenith Angle	calculated


05/22/2003
13.64-14.23 UT
SZA= 57-64°
SSFR model
SSFR meas
CM22 model
CM22 meas
Altitude [km]
Downwelling Flux [W/m2]
0
1
2
3
4
5
6
200
400
600
800
1000
1200


05/22/2003
13.64-14.23 UT
SZA= 57-64°
SSFR model
SSFR meas
CM22 model
CM22 meas
Altitude [km]
Up-welling Flux [W/m2]
0
1
2
3
4
5
6
0
50
100
150
200
250

Statistics for 19 Vertical Profiles

- ☑ Direct Beam not obstructed by clouds
- ☑ Stabilized Platform fully functional
- ☑ Data and measurements → 200m bins

ARM Aerosol IOP May 2003, Oklahoma.

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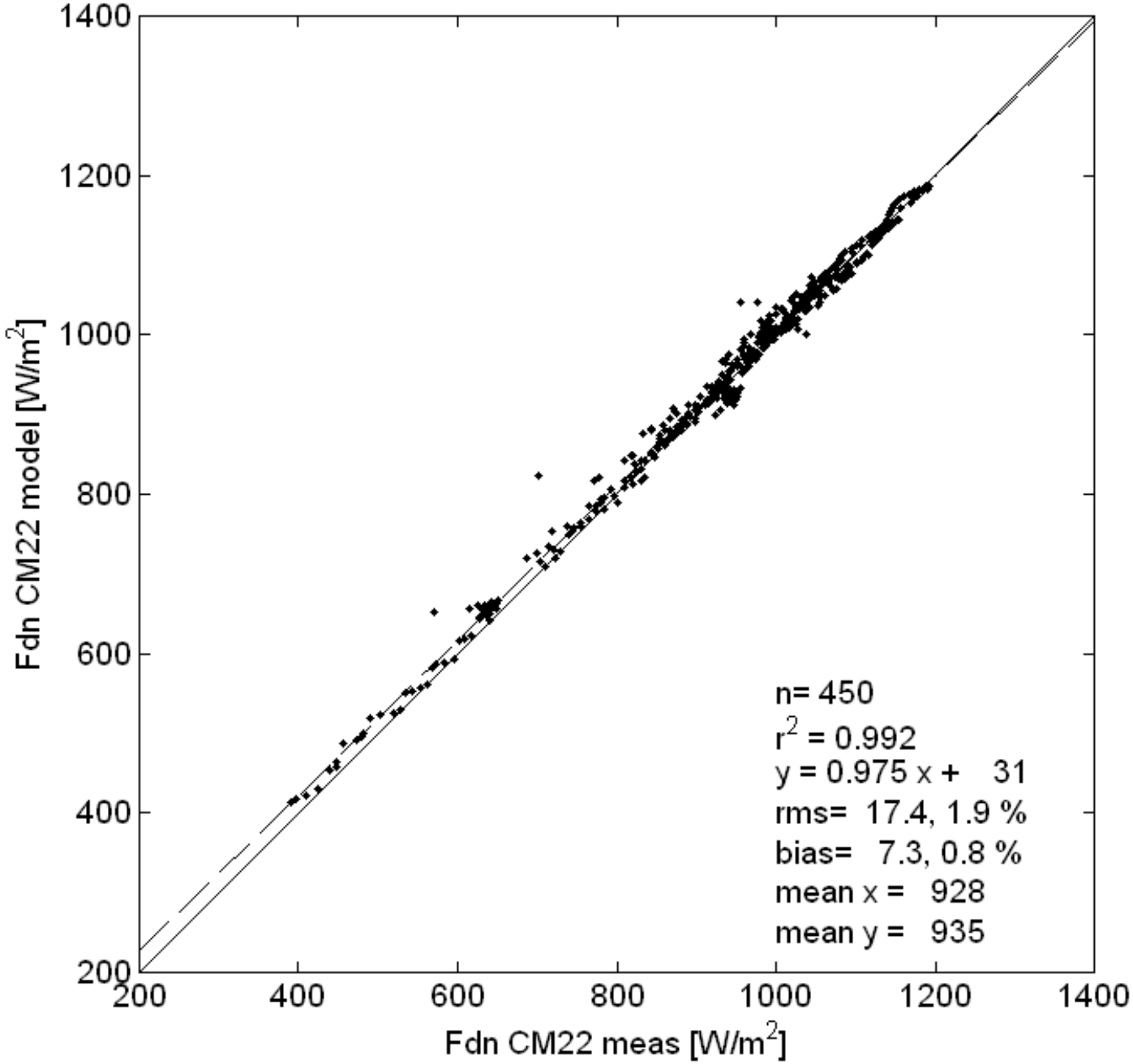
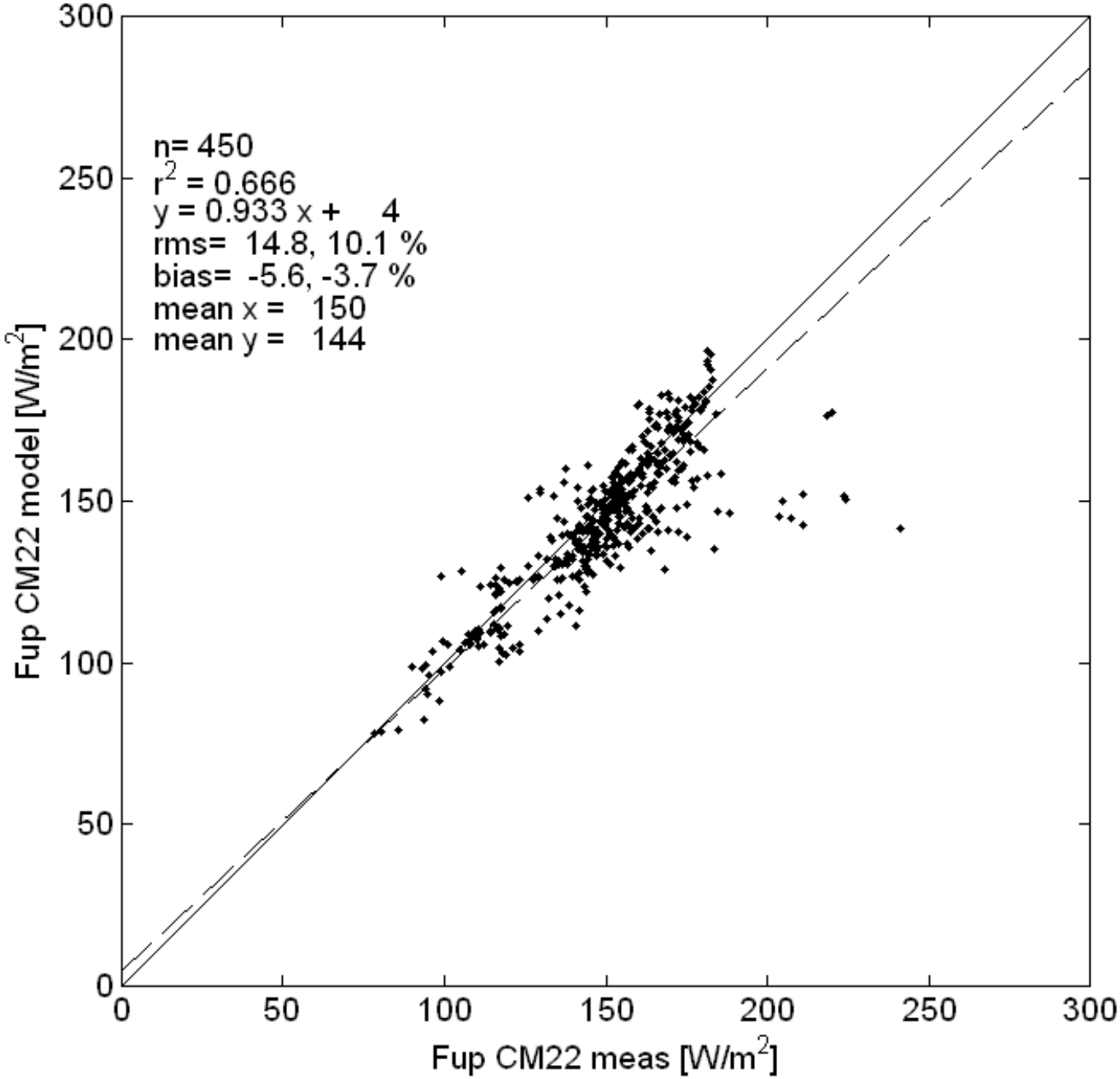

1400
1200
1000
800
600
400
200
200
400
600
800
1000
1200
1400
Fdn CM22 model [W/m2]
Fdn CM22 meas [W/m2]
n= 450
r2 = 0.992
y = 0.975 x + 31
rms= 17.4, 1.9 %
bias= 7.3, 0.8 %
mean x = 928
mean y = 935


n= 450
r2 = 0.666
y = 0.933 x + 4
rms= 14.8, 10.1 %
bias= -5.6, -3.7 %
mean x = 150
mean y = 144
Fup CM22 model [W/m2]
Fup CM22 meas [W/m2]
0
50
100
150
200
250
300

Can we see the effect of aerosols in the flux profiles?

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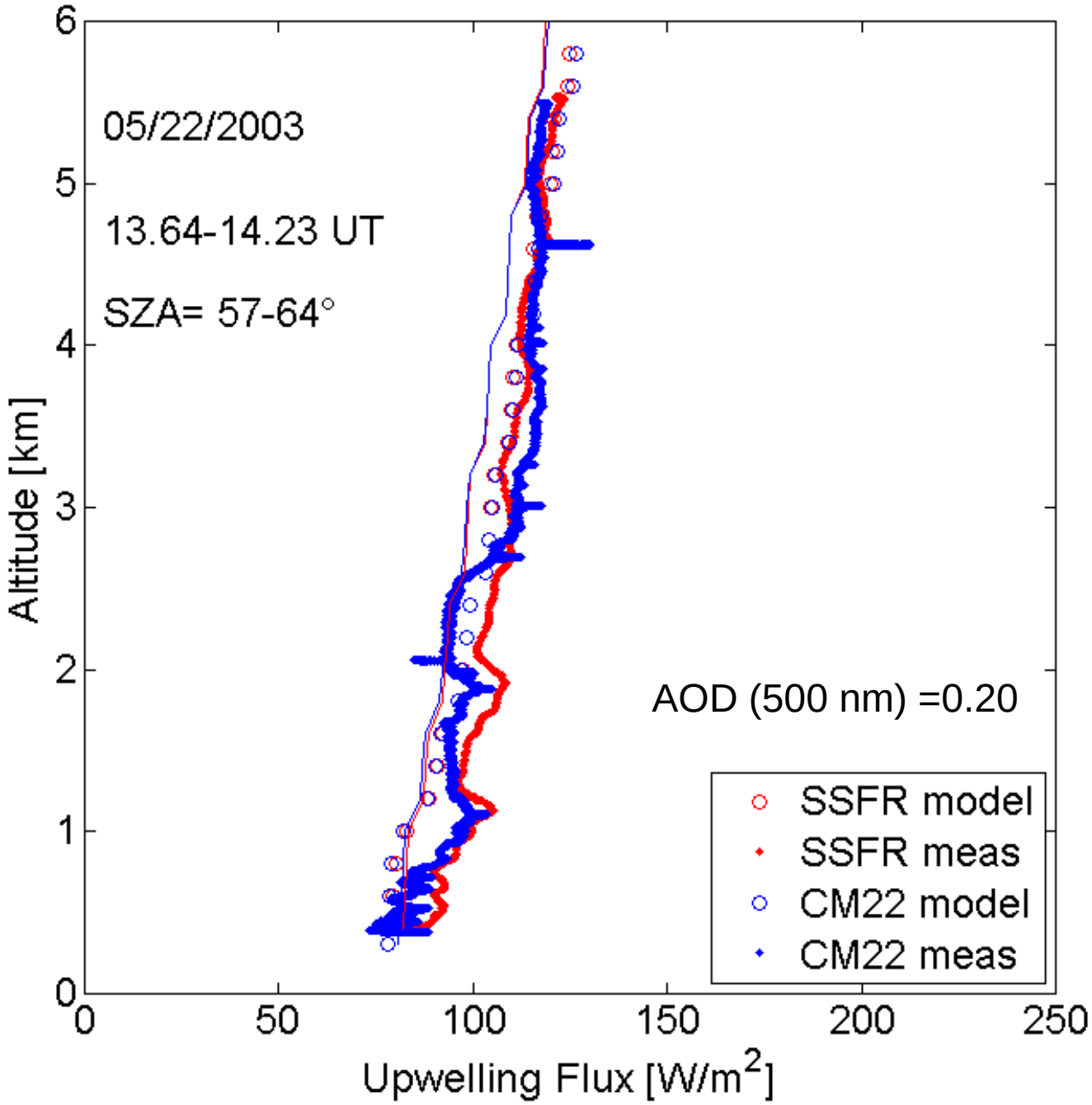
05/22/2003
13.64-14.23 UT
SZA= 57-64°
AOD (500 nm) =0.20
SSFR model
SSFR meas
CM22 model
CM22 meas
Altitude [km]
Upwelling Flux [W/m2]
0
1
2
3
4
5
6
0
50
100
150
200
250

Adding aerosol information helps the statistics!

19 profiles

$\overline{AOD}$ (500 nm) = 0.22 ± 0.09

	Up-welling				Down-welling			
	CM22		SSFR		CM22		SSFR	
Scenario	**std**	**r^2**	**std**	**r^2**	**std**	**r^2**	**std**	**r^2**
no aerosols	14.7	0.613	14.7	0.614	19.6	0.986	17.0	0.983
column AOD only, fixed ssa	14.3	0.637	14.4	0.628	17.8	0.989	15.9	0.986
measured extinction prof, fixed ssa	13.7	0.666	14.1	0.640	15.7	0.992	16.0	0.985
measured extinction and ssa profile	14.2	0.642	14.7	0.609	16.8	0.990	15.7	0.986
std= stdev (meas-model) in Wm^{-2}								

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How about heating rate profiles?

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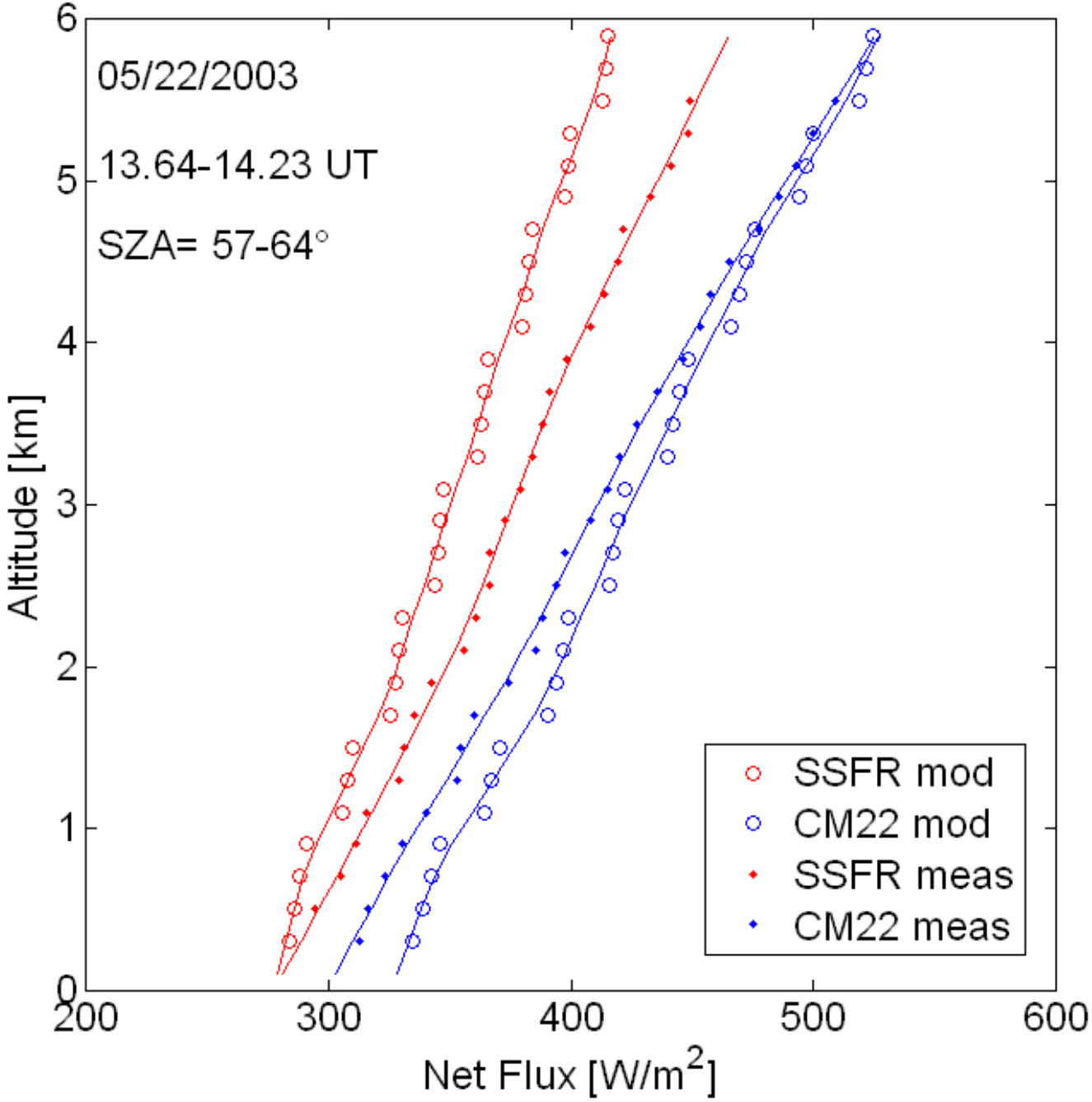
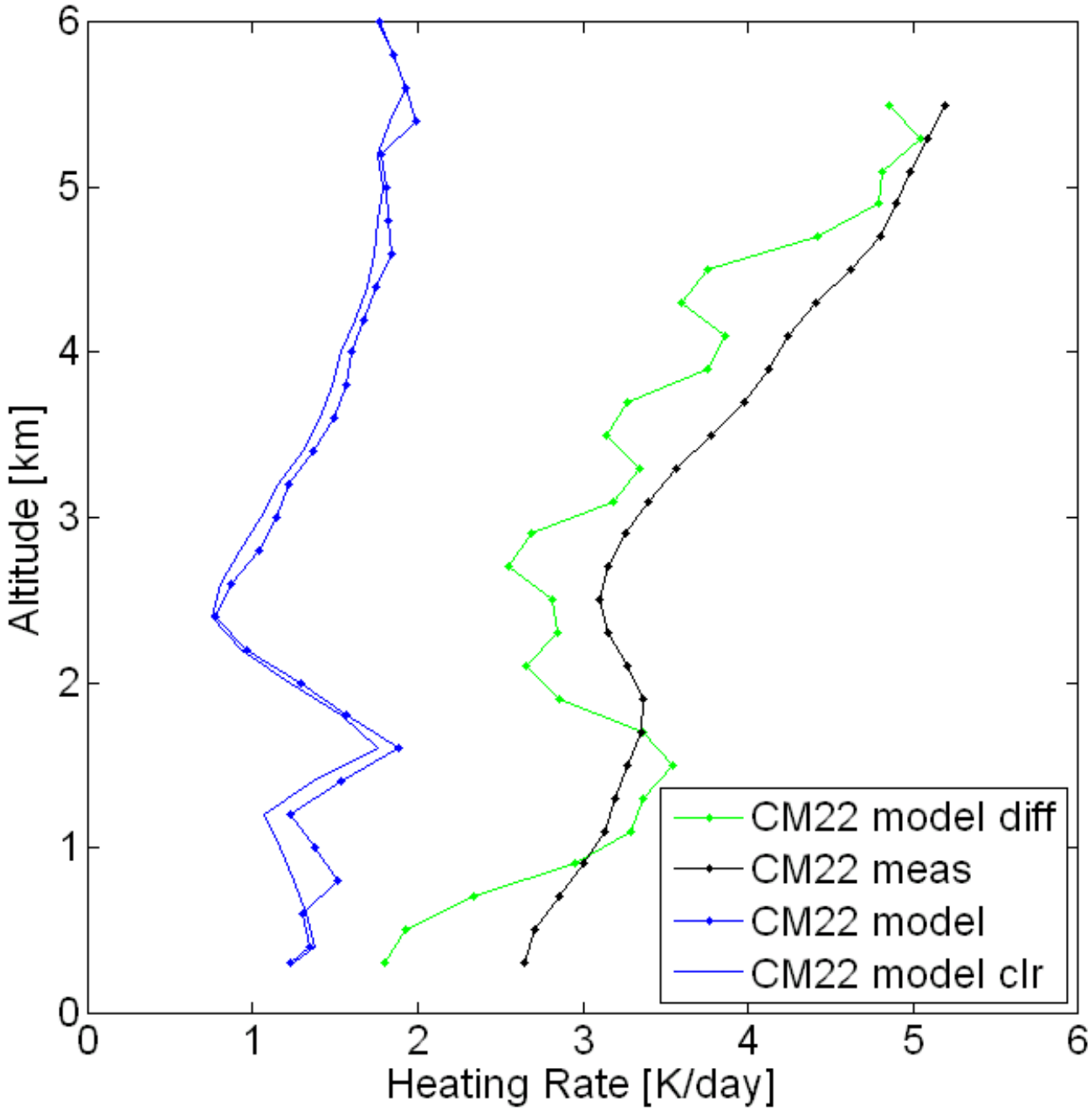
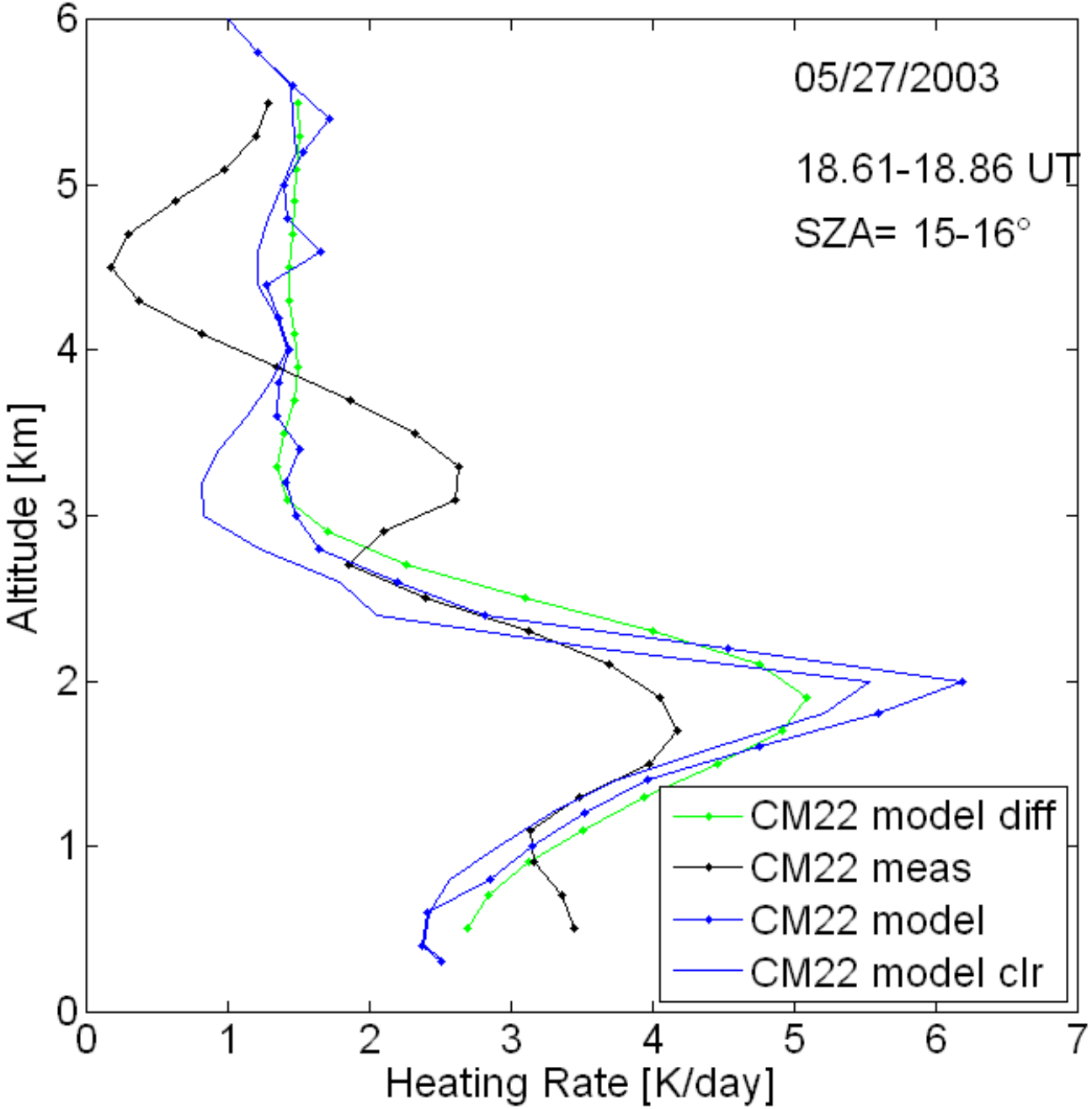

05/22/2003
13.64-14.23 UT
SZA= 57-64°
Altitude [km]
Net Flux [W/m2]
0
1
2
3
4
5
6
200
300
400
500
600
SSFR mod
CM22 mod
SSFR meas
CM22 meas



5/22/03
SZA 57º-64º


05/27/2003
18.61-18.86 UT
SZA= 15-16°
CM22 model diff
CM22 meas
CM22 model
CM22 model clr
Altitude [km]
Heating Rate [K/day]
0
1
2
3
4
5
6
7

Conclusions (1)

- Shape of the aerosol extinction profile has very little impact on TOA and surface forcing.
- If aerosol is not purely scattering, the shape of extinction profile is important for the vertical profiles of forcing (and heating rates).
- Identical extinction profiles with different absorption profiles drastically influence the forcing and of heating rate profiles.
  - Problem: Aerosol absorption profile difficult to measure

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Conclusions (2)

- **Using real aerosol extinction profiles helps flux closure**
  - **Expect to tighten flux closure (SZA → 1 min)**

- **Can aircraft flux measurements be used to determine heating rate profiles?**
  - **Yes, for thick (absorbing) aerosol layers**
    - **Pilewskie et al. 2003, Ramanathan et al. 2007**
  - **Vertically resolved?**
    - **This study →No .**
    - **Profiles not instantaneous (or need Sun near zenith)**
    - **Not enough (absorbing) aerosol at SGP**
    - **Look at bands w/o H_2O absorption**
    - **Measurements pushed to their limit?**

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