Measurement of flux divergences from small AUAVs

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ARM Radiative Heating Profile workshop
January 08, 2007

The Maldives Autonomous Unmanned Aerial Vehicle Campaign (MAC)

06 March - 01 April, 2006

Science Team: Scripps Institution of Oceanography

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C. Corrigan *(Aerosols)*
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Flight Team: Advanced Ceramic Research

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L. Wardell *(Project Leader)*
P. Corcoran *(Pilot-in-Command)*
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R .A.G. Pineda *(Pilot)*

NSF/NOAA/NASA/Vetlesen/Alderson

The Maldives Autonomous Unmanned Aerial Vehicle Campaign (MAC)

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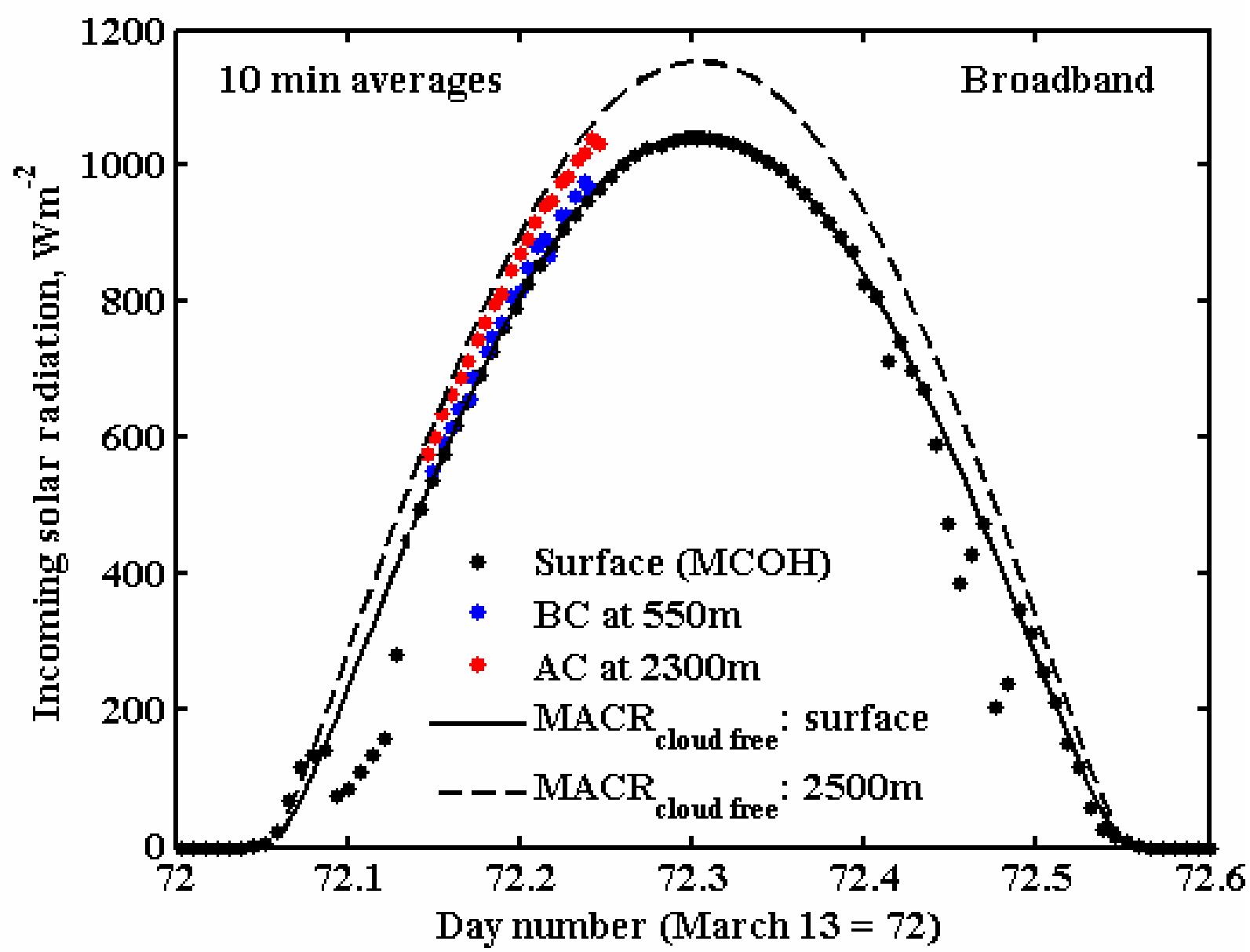
The MAC Observing System

MAC Lightweight Instrumentation

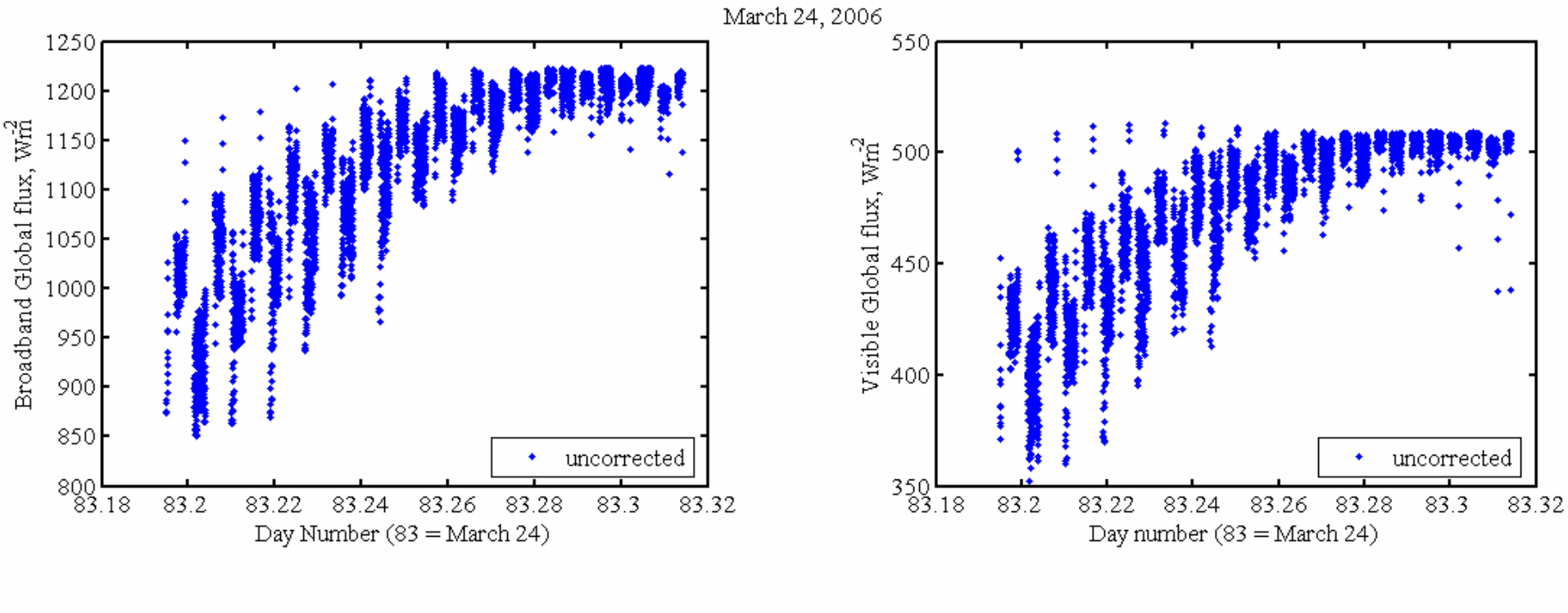
Instruments	Above Cloud (AC)	In-Cloud (IC)	Below Cloud (BC)
Aerosol			
Total CN (CPC; >0.01 µm)	√		√
Size distribution (OPC; 0.3-3.0µm)	√		√
Black Carbon (Aethalometer; 370, 520, and 880nm)	√		√
Radiation			
Up/Down Pyranometer (0.3-2.8 µm)	√		√
UP/Down PAR (0.4-0.7µm)	√		√
Clouds			
Cloud droplet probe (1-50 µm)		√	
Liquid water content probe		√	
Turbulence			
Gust probe		√	
Met. Parameters (T, RH, P)	√	√	√
Aerosol inlet + flow splitter + cyclone	√		√
Data Acquisition system	√	√	√
Video Camera + Downlink		√	
Miscellaneous + Batteries	√	√	√
Total weight	**5.4 kg**	**5.3 kg**	**3.9 kg**

Validation with Ground Observations

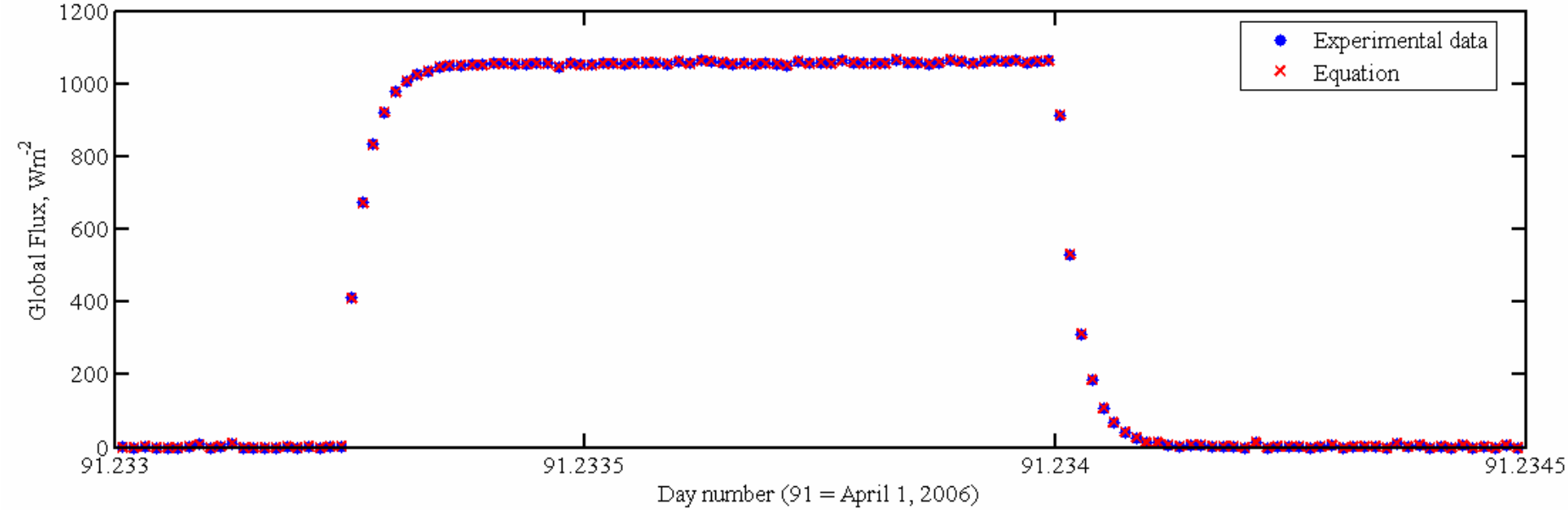
Comparison with MCOH data & MACR calculations



Measured fluxes at 3km altitude on March 24



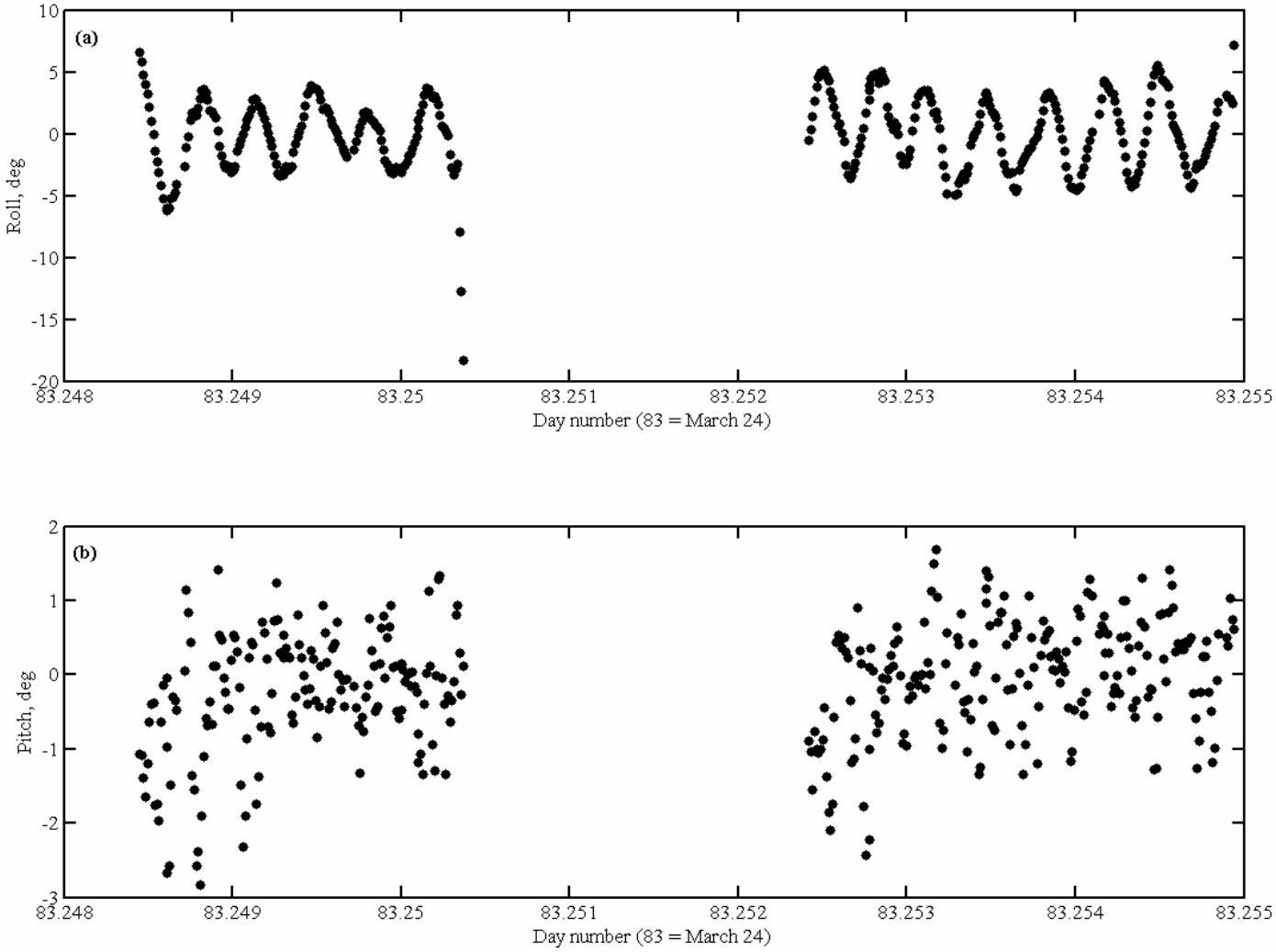
Pyranometer response curve



$$Pyranometer\ response = f(t) + [f(t-1) - f(t)]\, e^{\left(\frac{-(t-1)}{3}\right)} + [f(t-2) - f(t)] e^{\left(\frac{-(t-2)}{3}\right)}$$

$$PAR\ response = v(t) + [v(t-1) - v(t)] e^{\left(\frac{-(t-1)}{2}\right)}$$

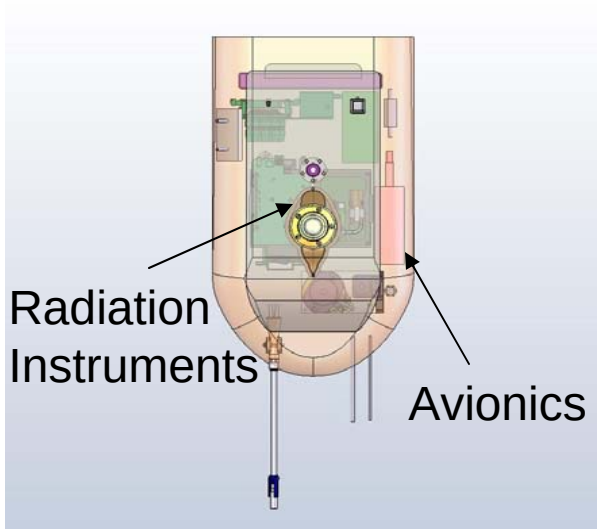
UAV roll & pitch



Corrections to direct flux: UAV Attitude & Offset corrections

$$Global(G_{z,\theta}) = Direct(D_{z,\theta}) + Difuse(F_{z,\theta})$$

Offsets



$$Direct(D_{z,\theta}) = Global(G_{z,\theta}) * R_{z,\theta}$$

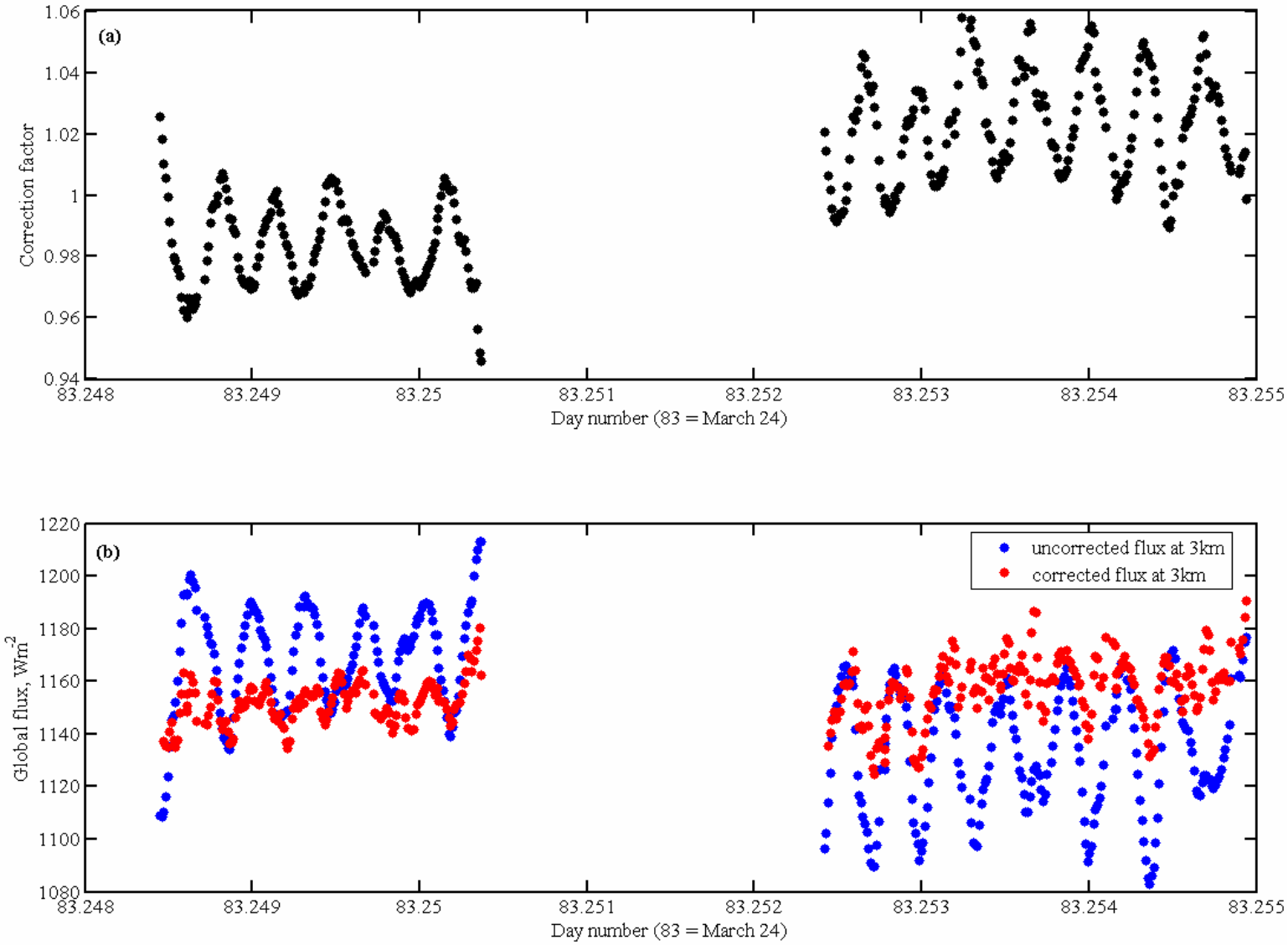
$$Cf_{z,\theta} = \frac{\sin(\theta_s)}{\cos(\theta_s)\sin(r)\sin(\varphi - h) - \cos(\theta_s)\sin(p)\cos(r)\cos(\varphi - h) + \sin(\theta_s)\cos(p)\cos(r)}$$

(*Bannehr and Glover, 1991: NACR report*)

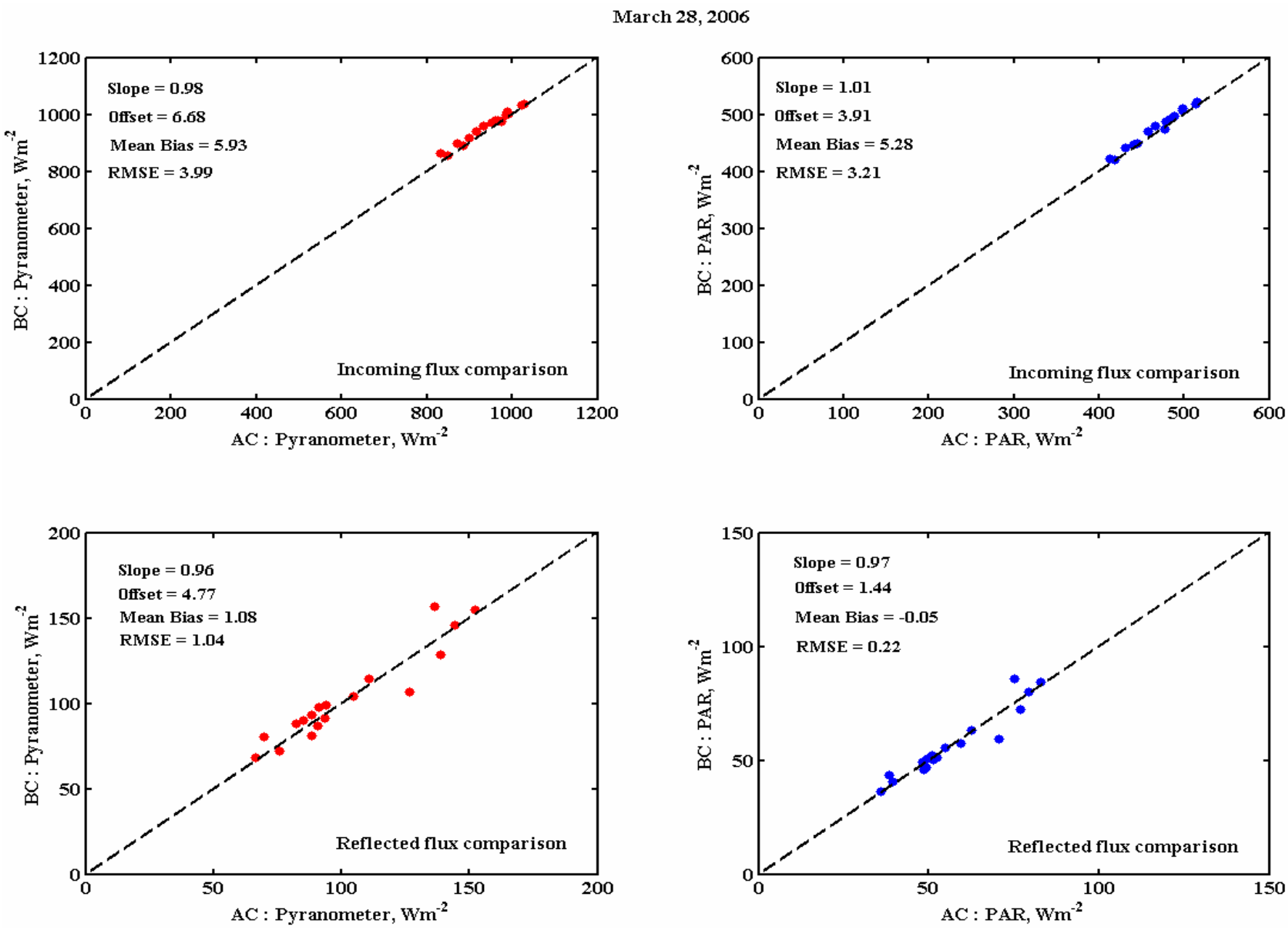
$$Corr_direct(CD_{z,\theta}) = Direct(D_{z,\theta}) * Cf_{z,\theta}$$

$$Corr_global(CG_{z,\theta}) = Corr_direct(NCD_{z,\theta}) + Diffuse(F_{z,\theta})$$

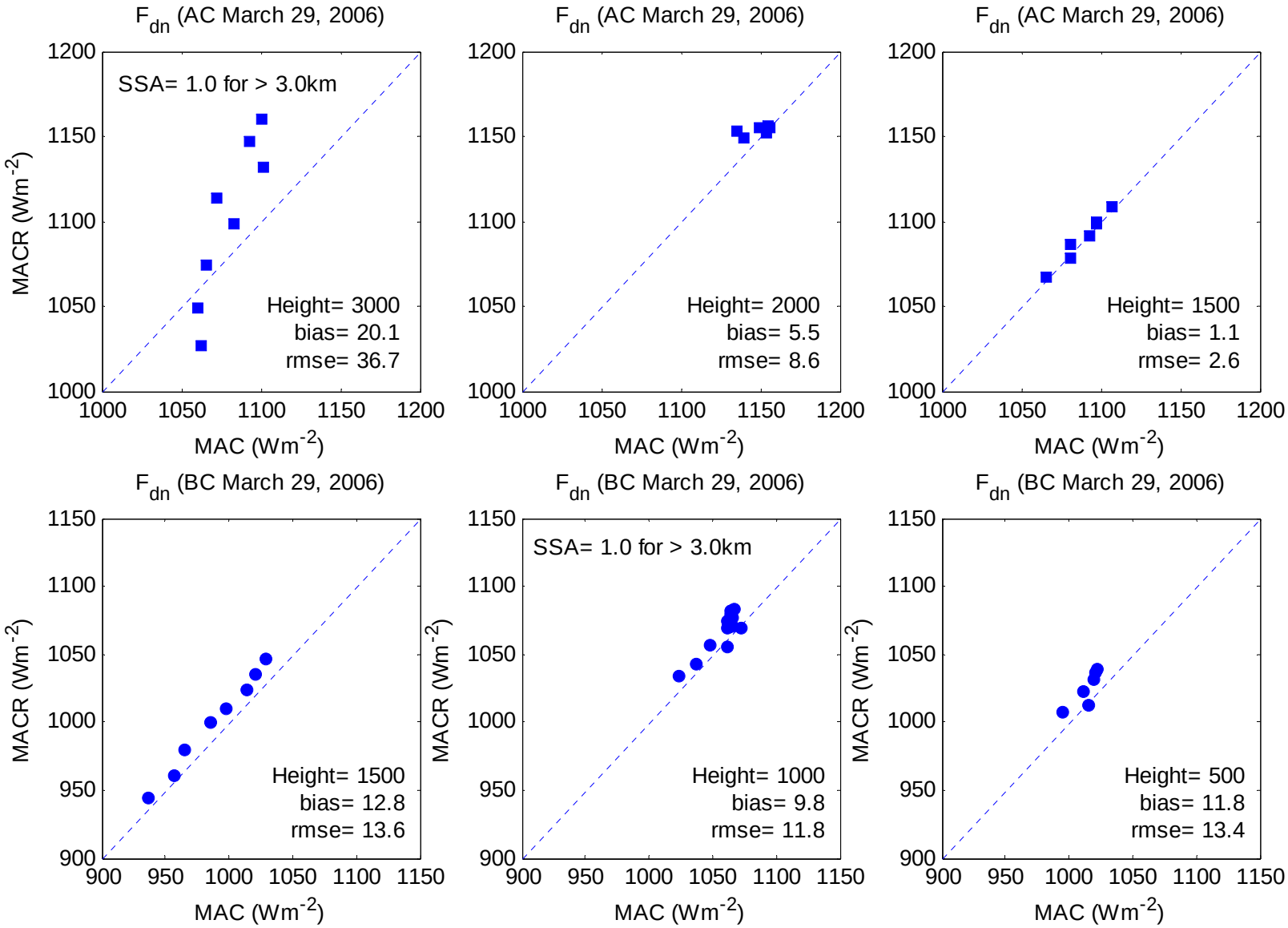
Corrected fluxes after applying the correction factor



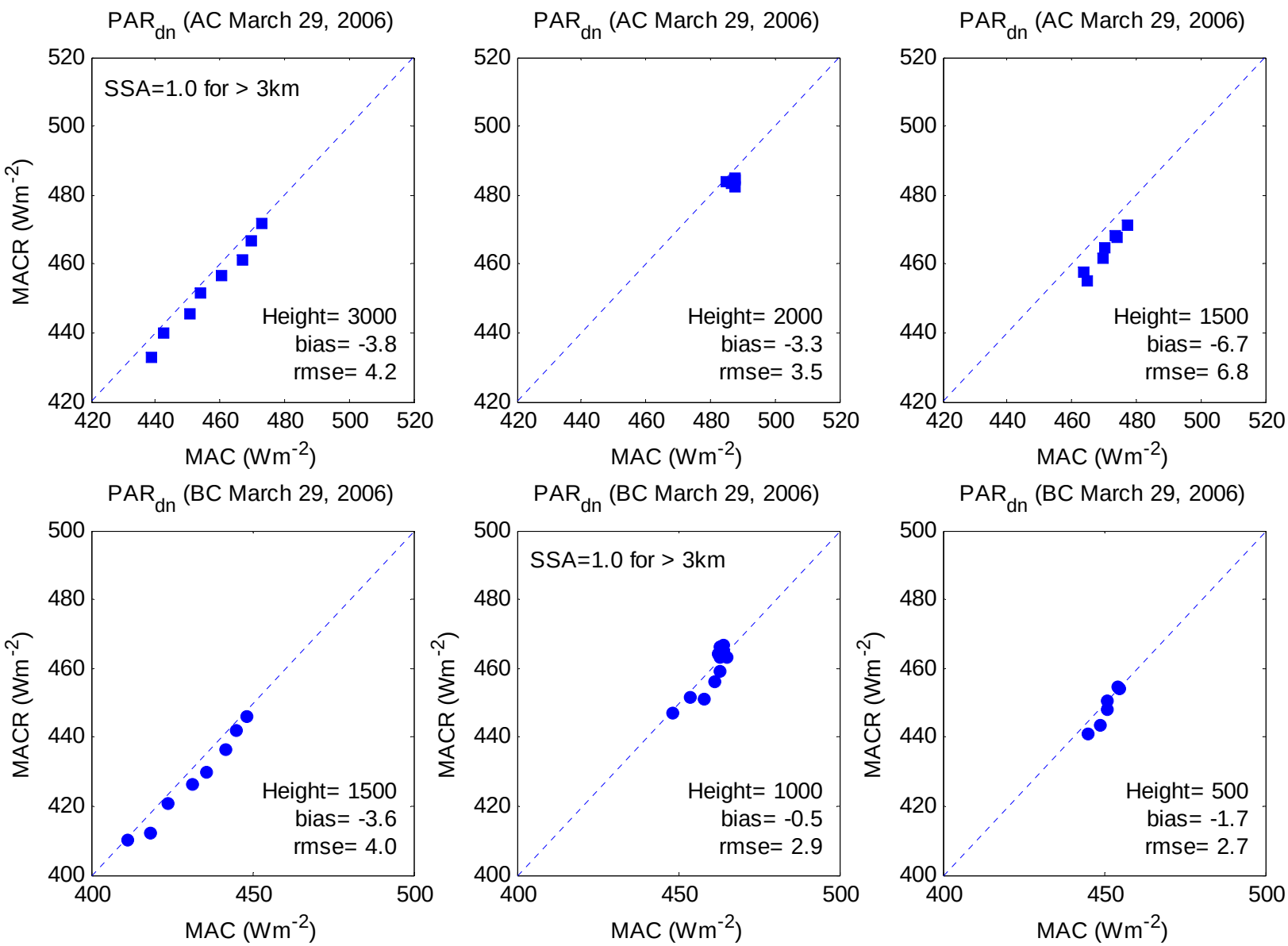
Wingtip to wingtip comparison



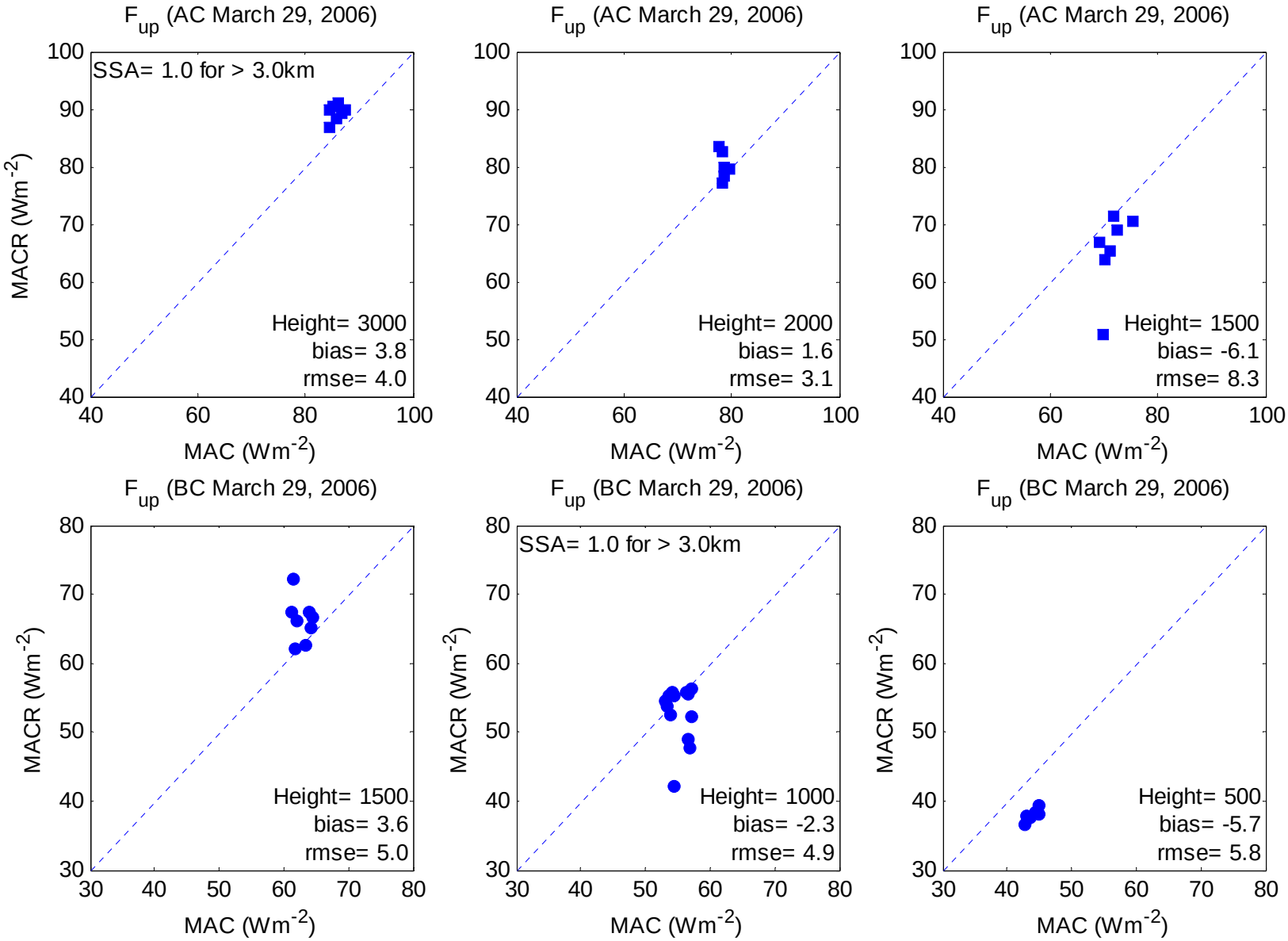
Measured vs MACR on March 29: Comparison of Broadband incoming fluxes



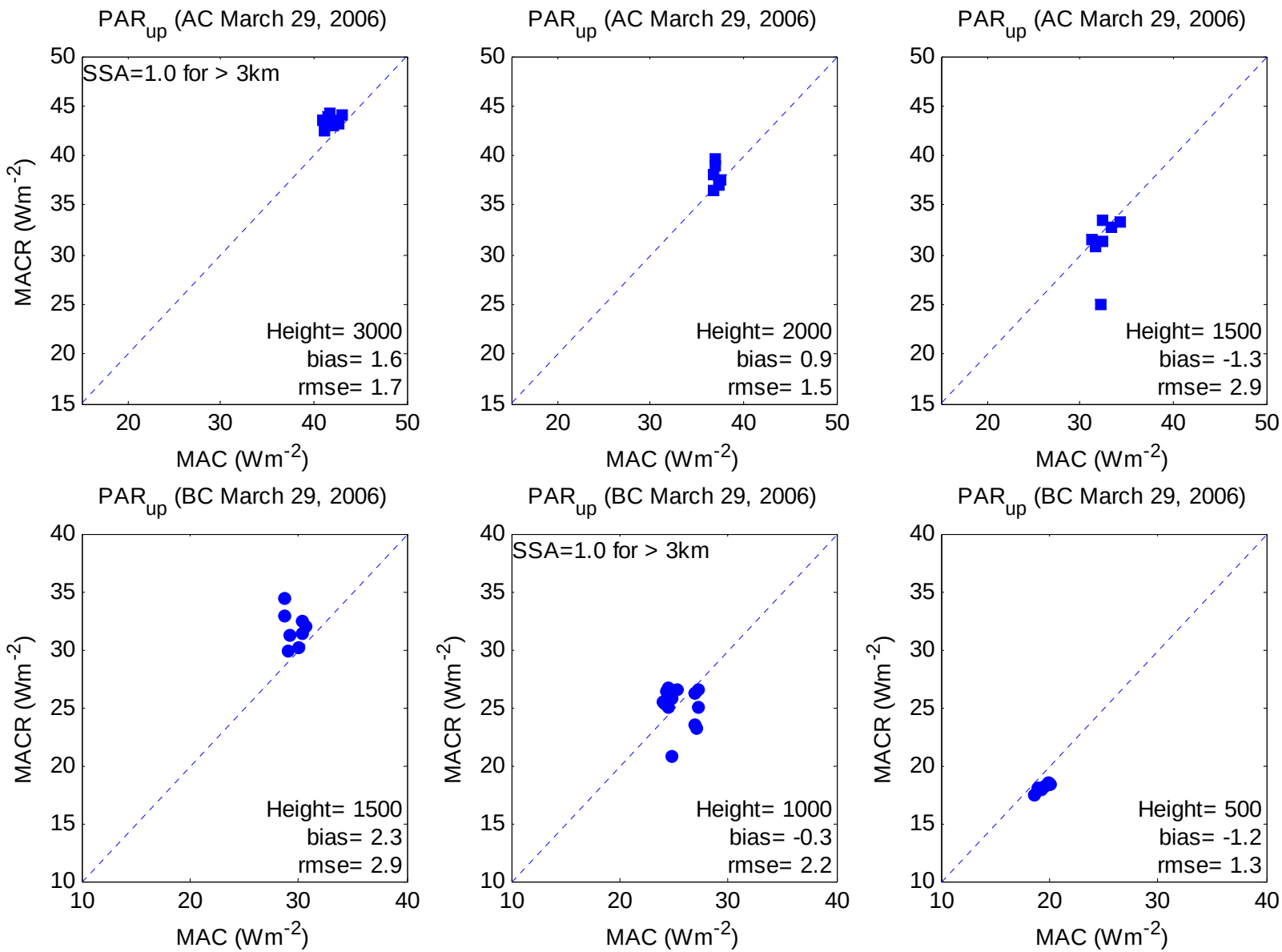
Measured vs MACR on March 29: Comparison of Visible incoming fluxes



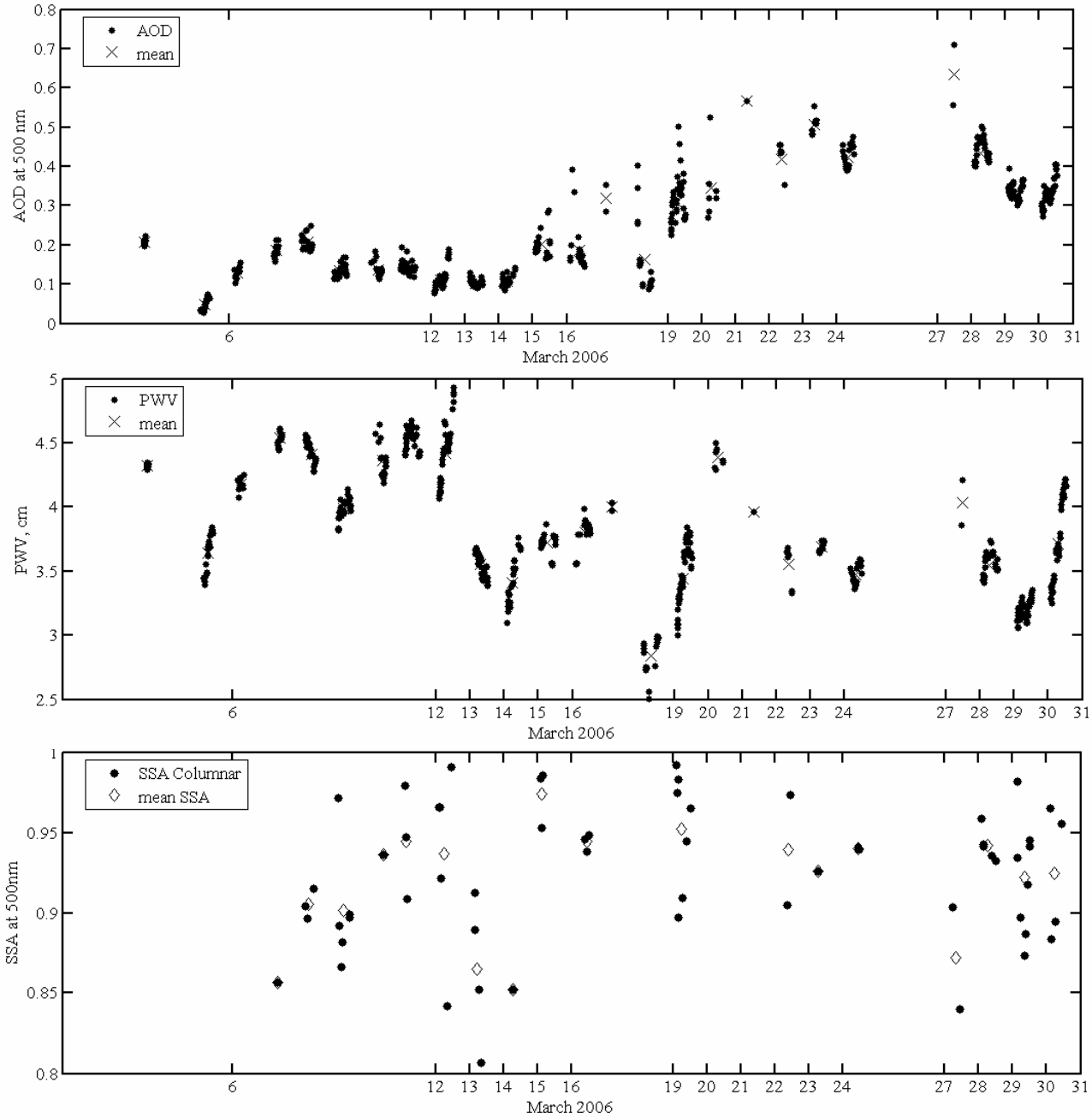
Measured vs MACR on March 29: Comparison of Broadband reflected fluxes



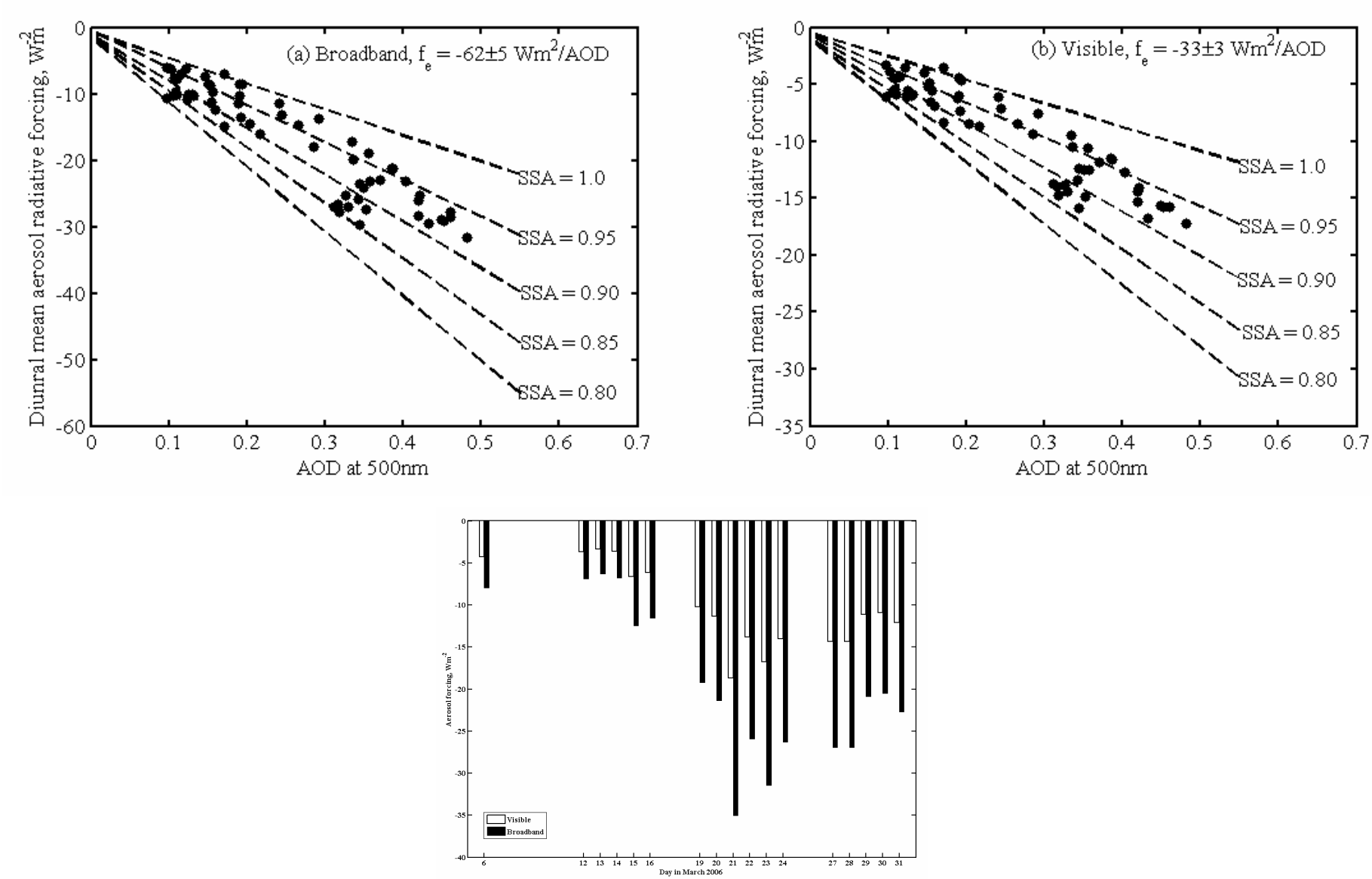
Measured vs MACR on March 29: Comparison of Visible reflected fluxes

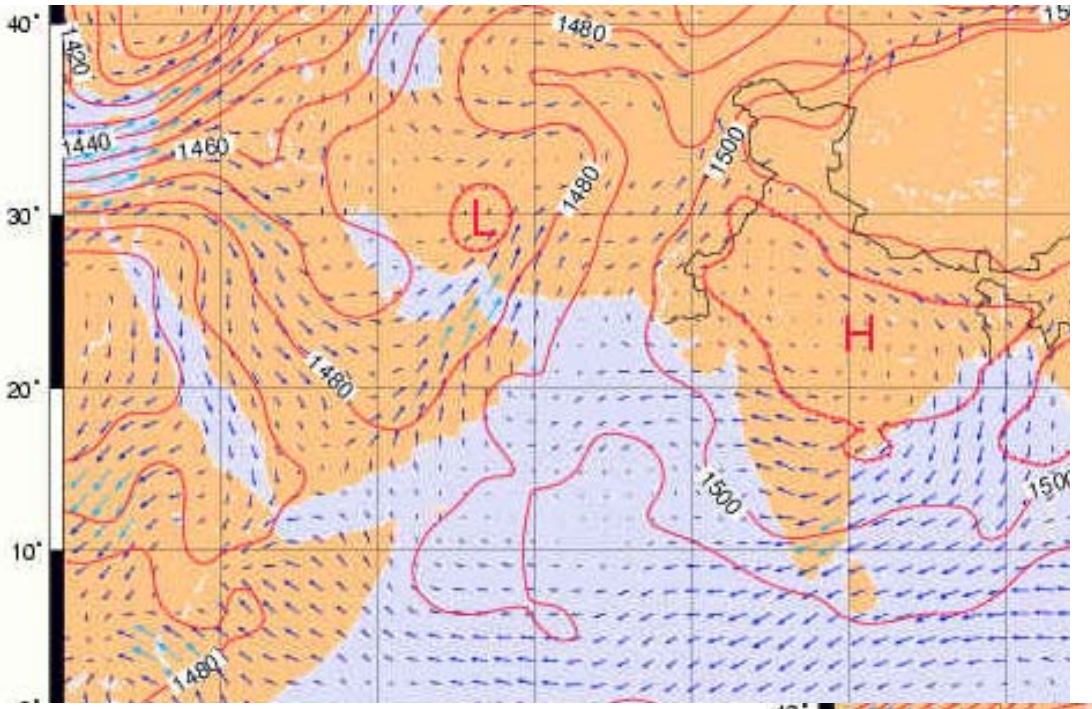


AOD, PWV and SSA during March 2006 : AERONET



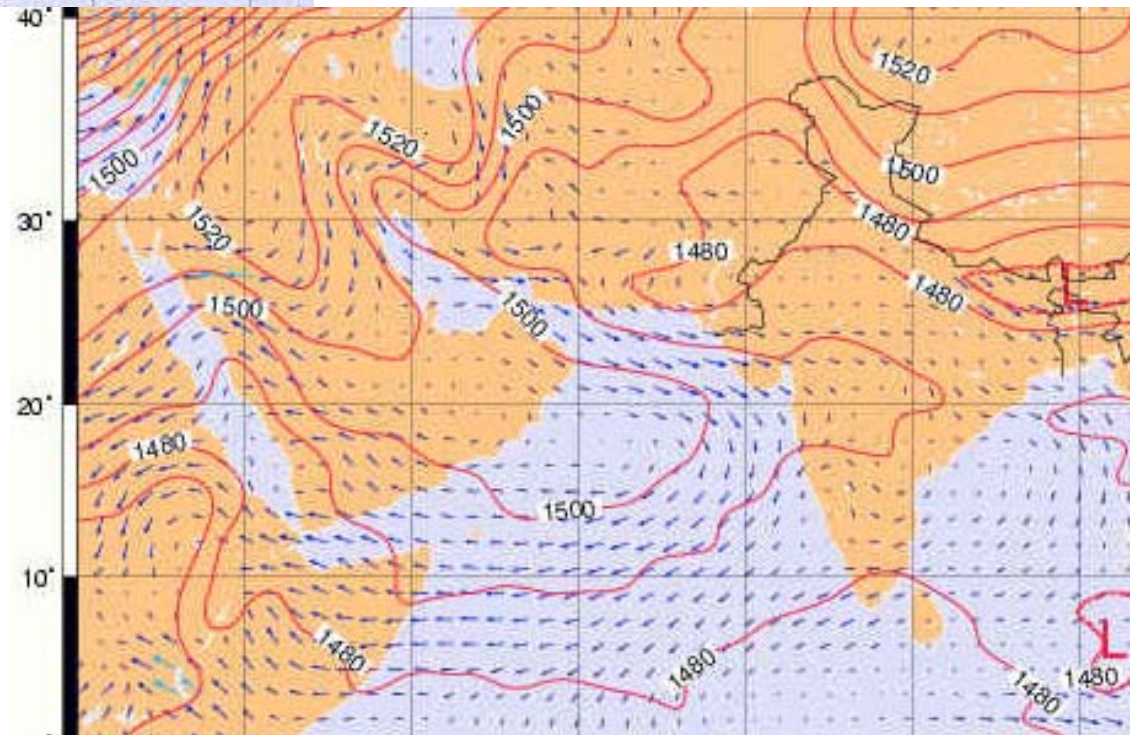
Aerosol radiative forcing at the surface during MAC





March 19 2006
850 mb winds

Termination of S Asian Pollution Few days later

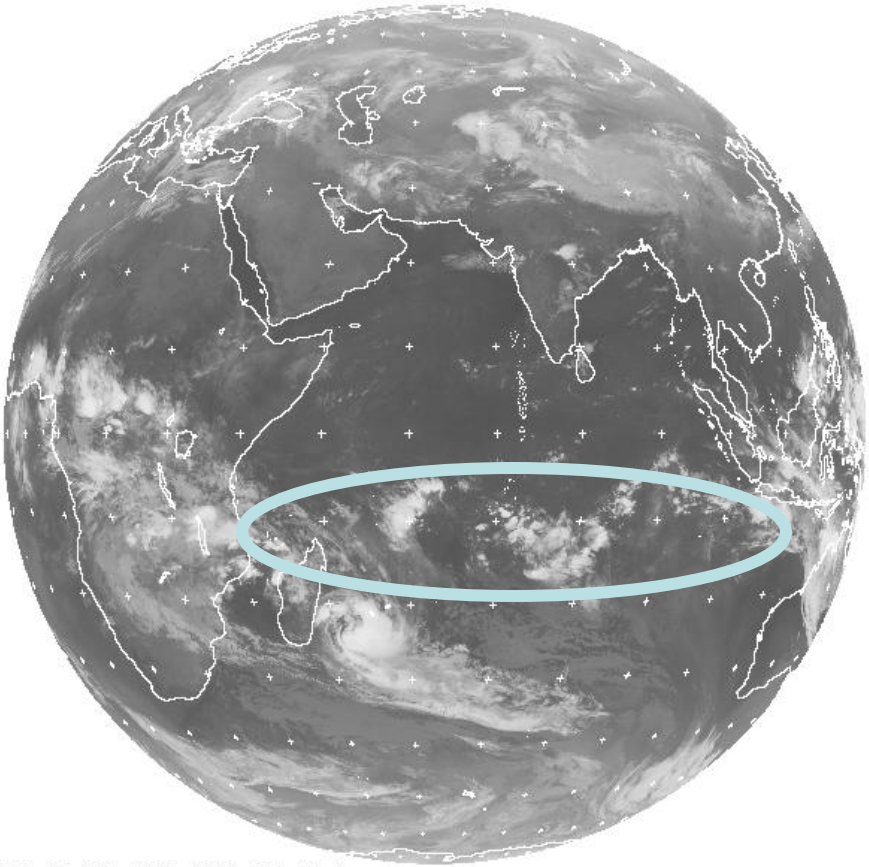


Beginning of Dust Events

March 23 2006
850 mb winds

March 7 2006

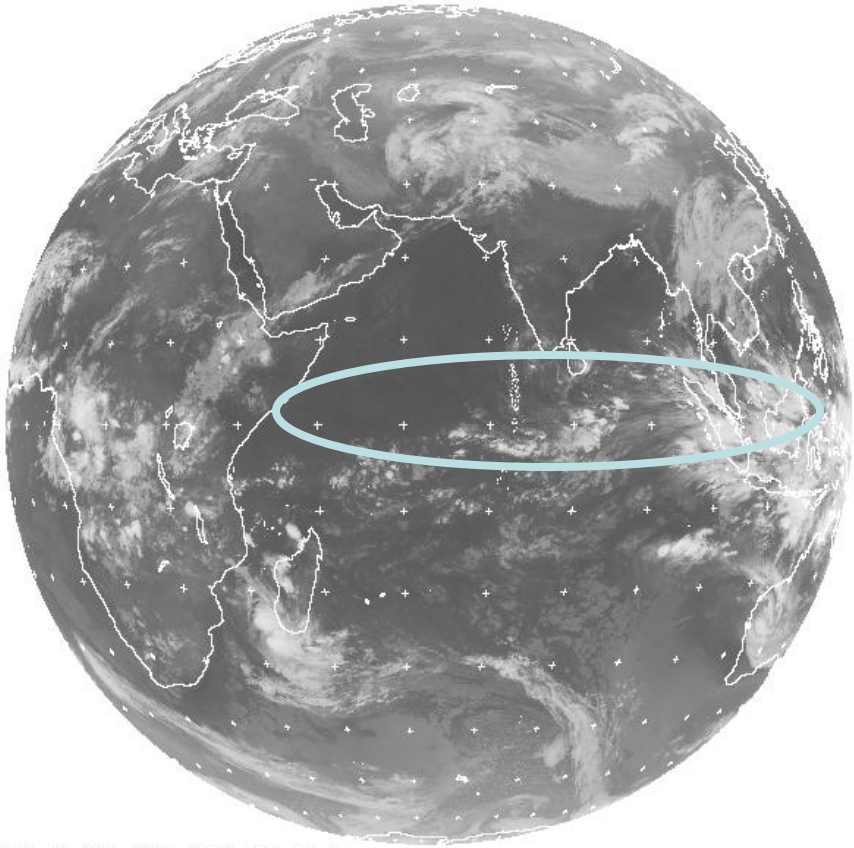
ITCZ was south of Equator



MET5 07 MAR 2006 0000 BNW IR 0

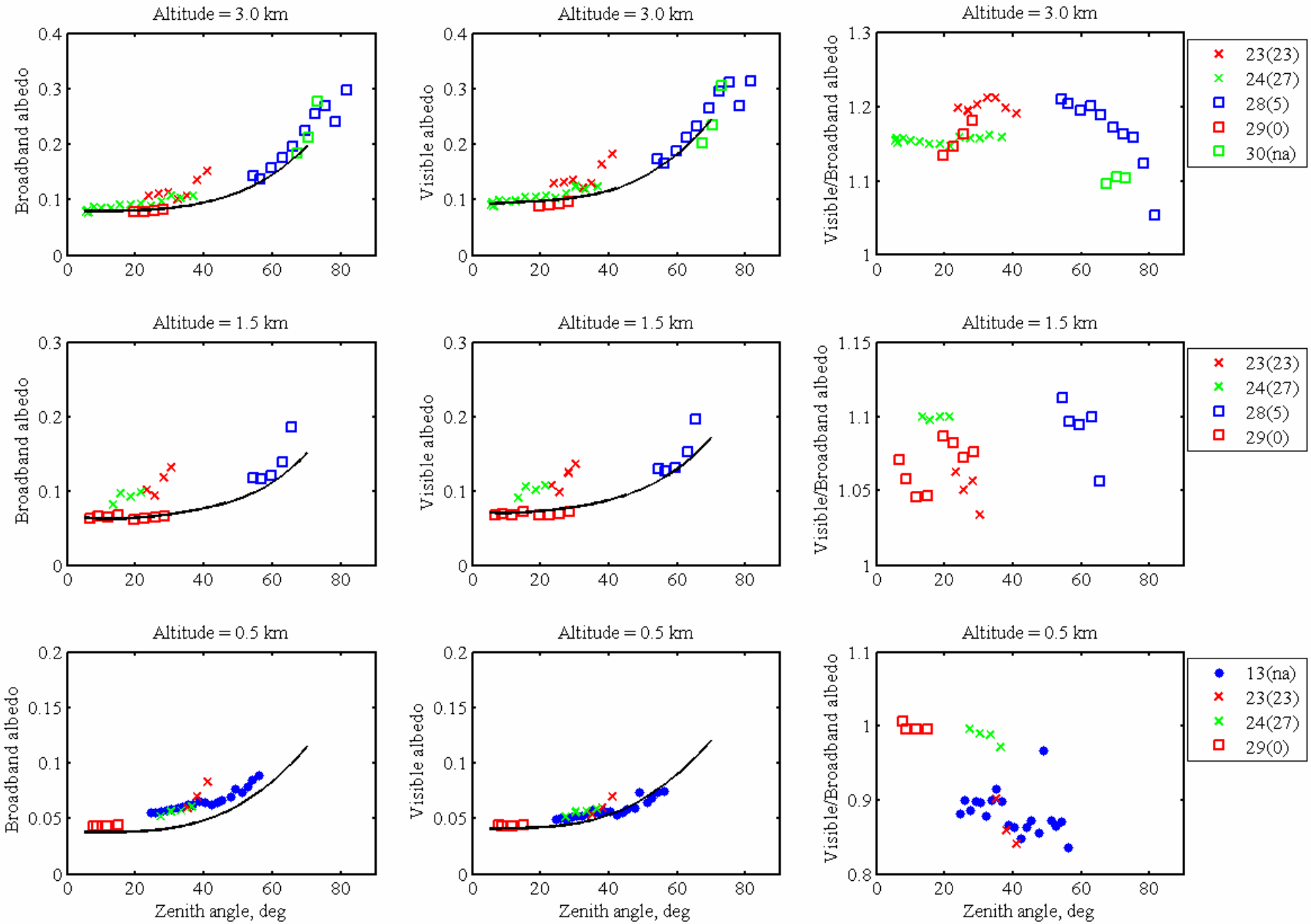
March 31 2006

Northward shift started

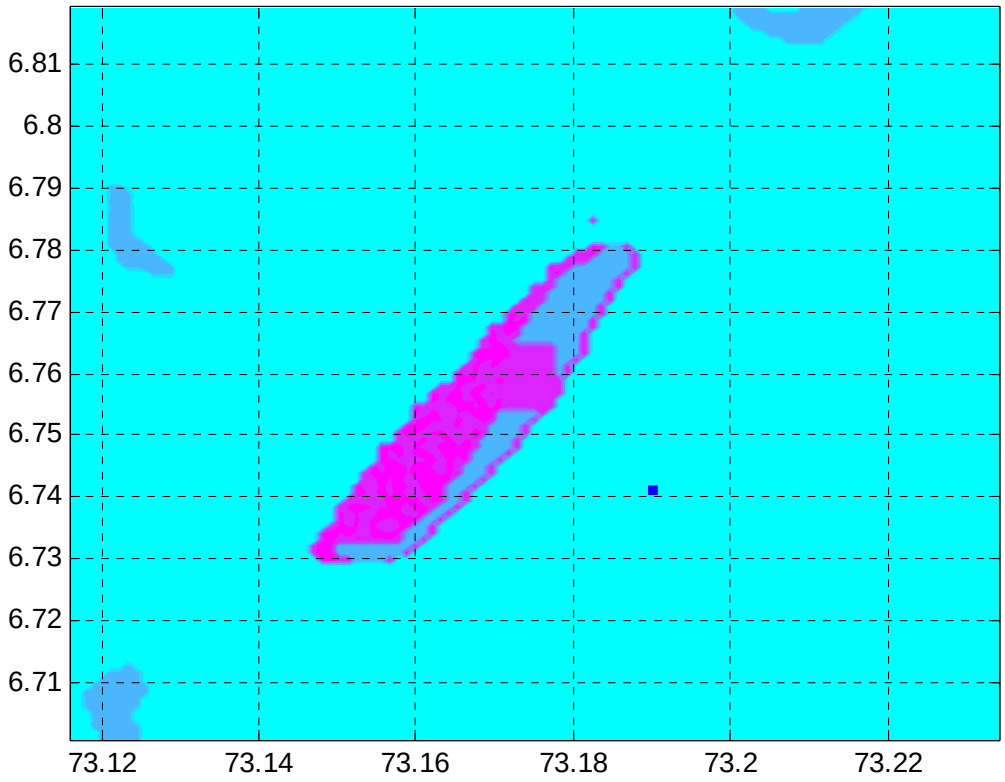


MET5 30 MAR 2006 2100 BNW IR 0

Broadband & Visible albedo's at 3.0, 1.5, & 0.5 altitudes: Near Cloud-free cases

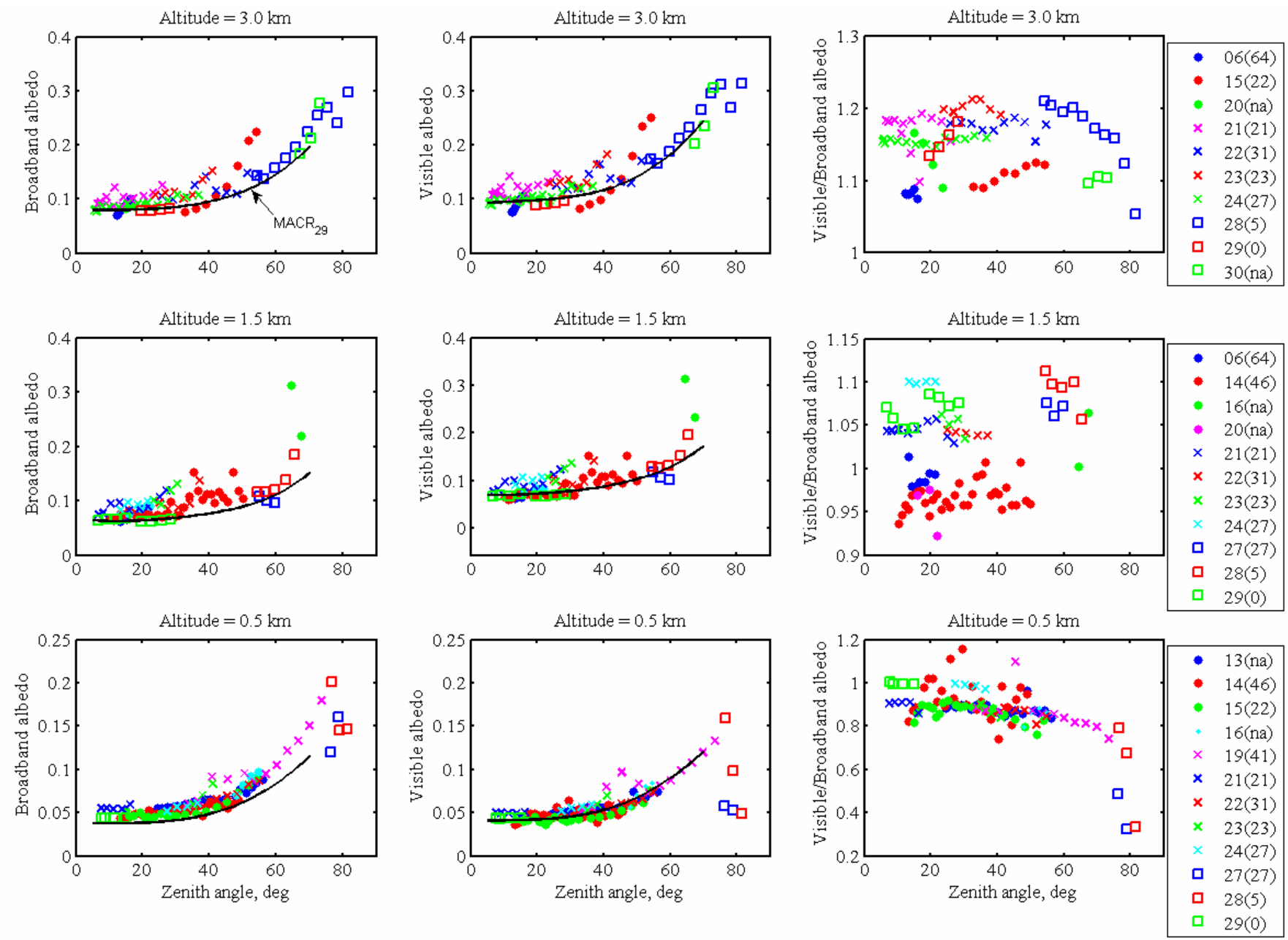


MACR calculations of Albedo's are carried at 6.741N, 73.19E

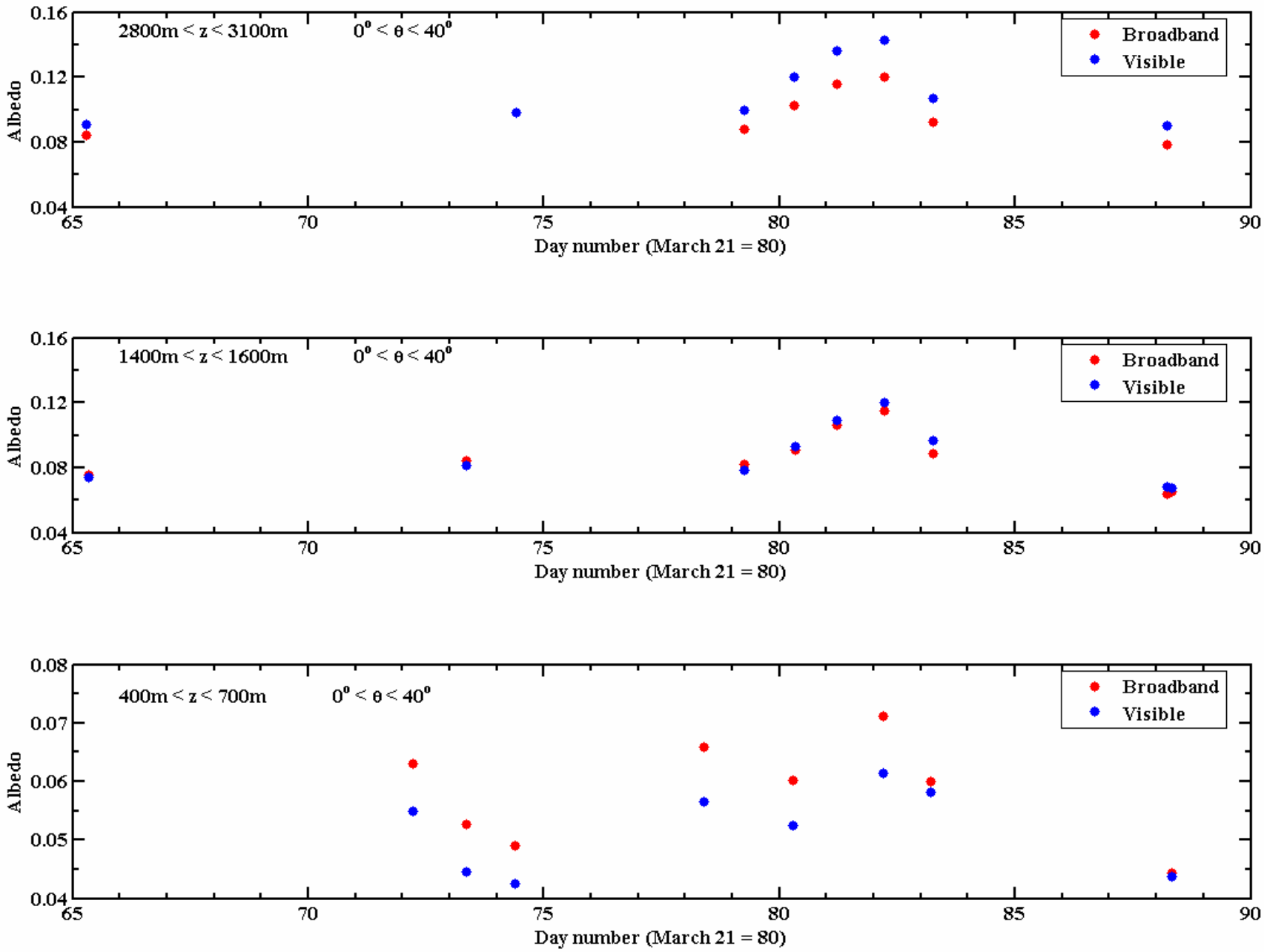


Theoretical line shown in above slide is obtained at the blue dot.
The blue dot is the mean position of the track.

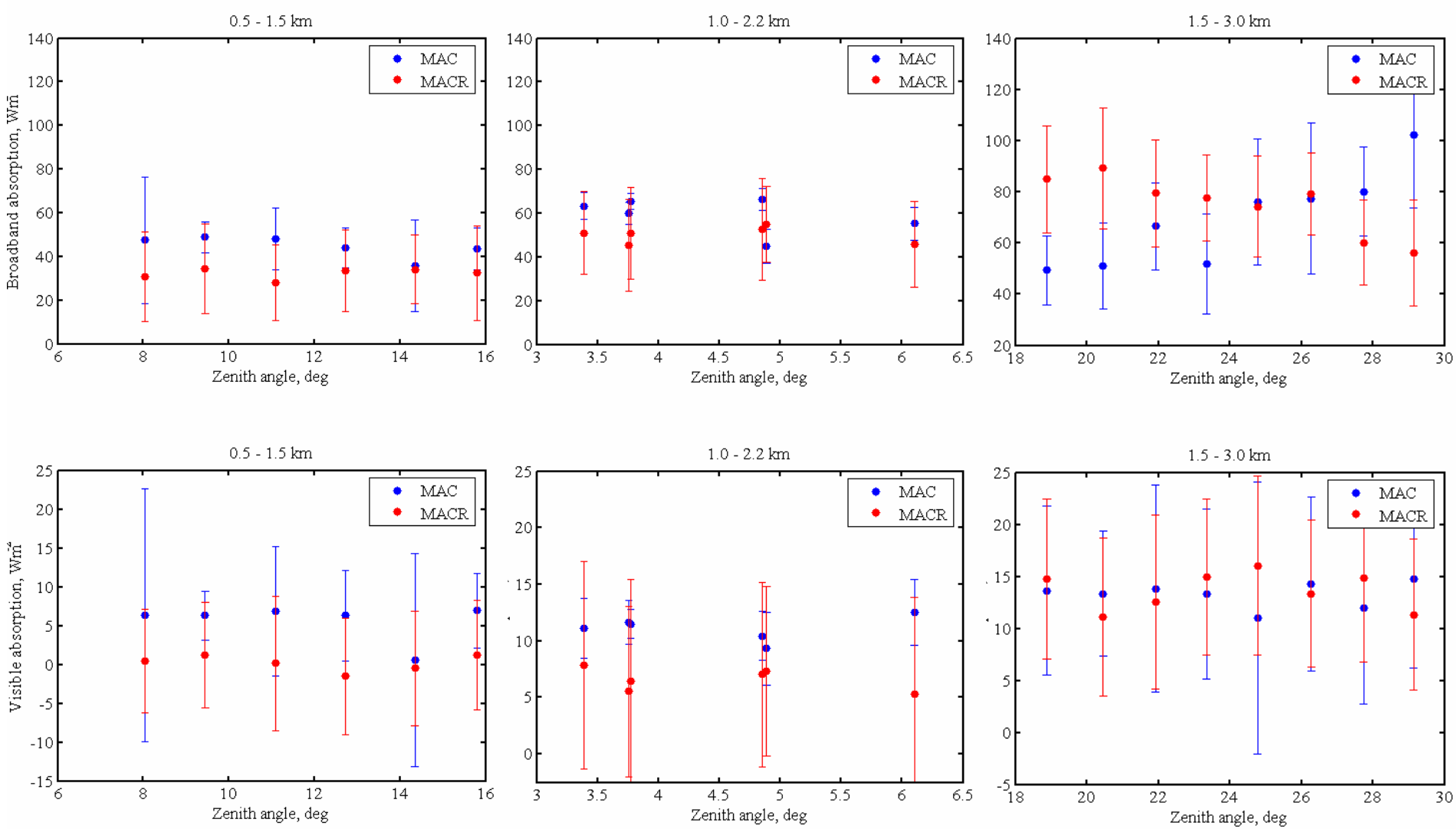
Broadband & Visible albedo's at 3.0, 1.5, & 0.5 altitudes: All sky data



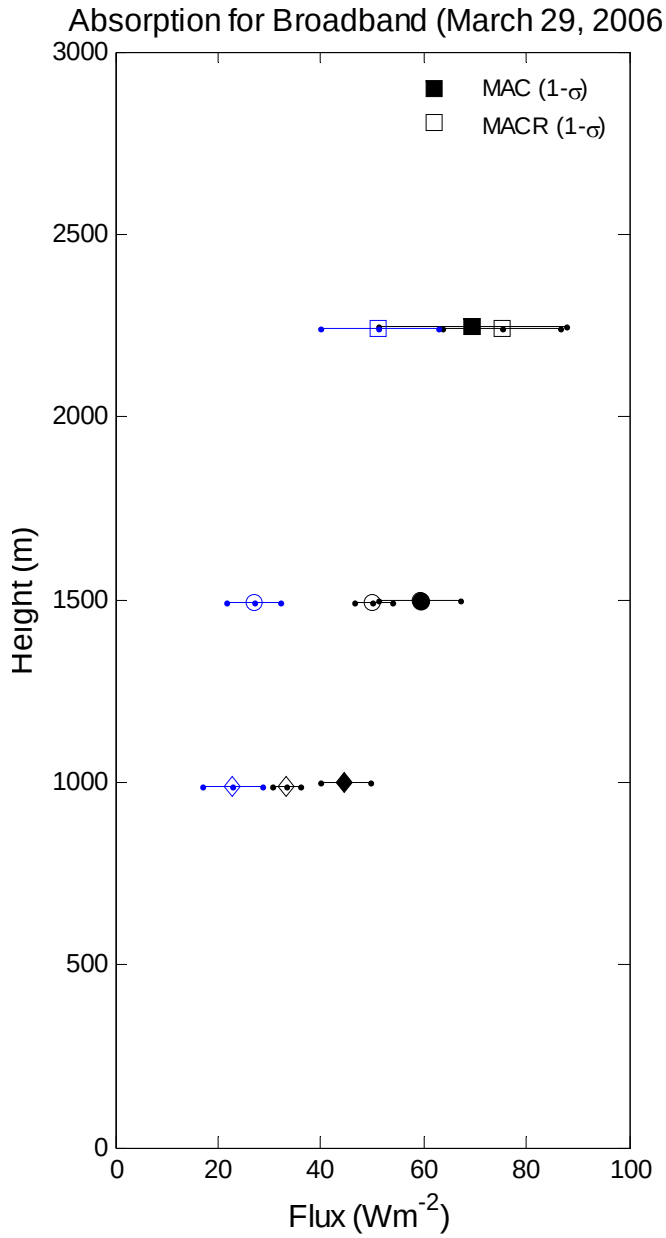
Temporal variation of Broadband & Visible albedo's



Atmospheric Solar Absorption: March 29 (Cloud-free day)

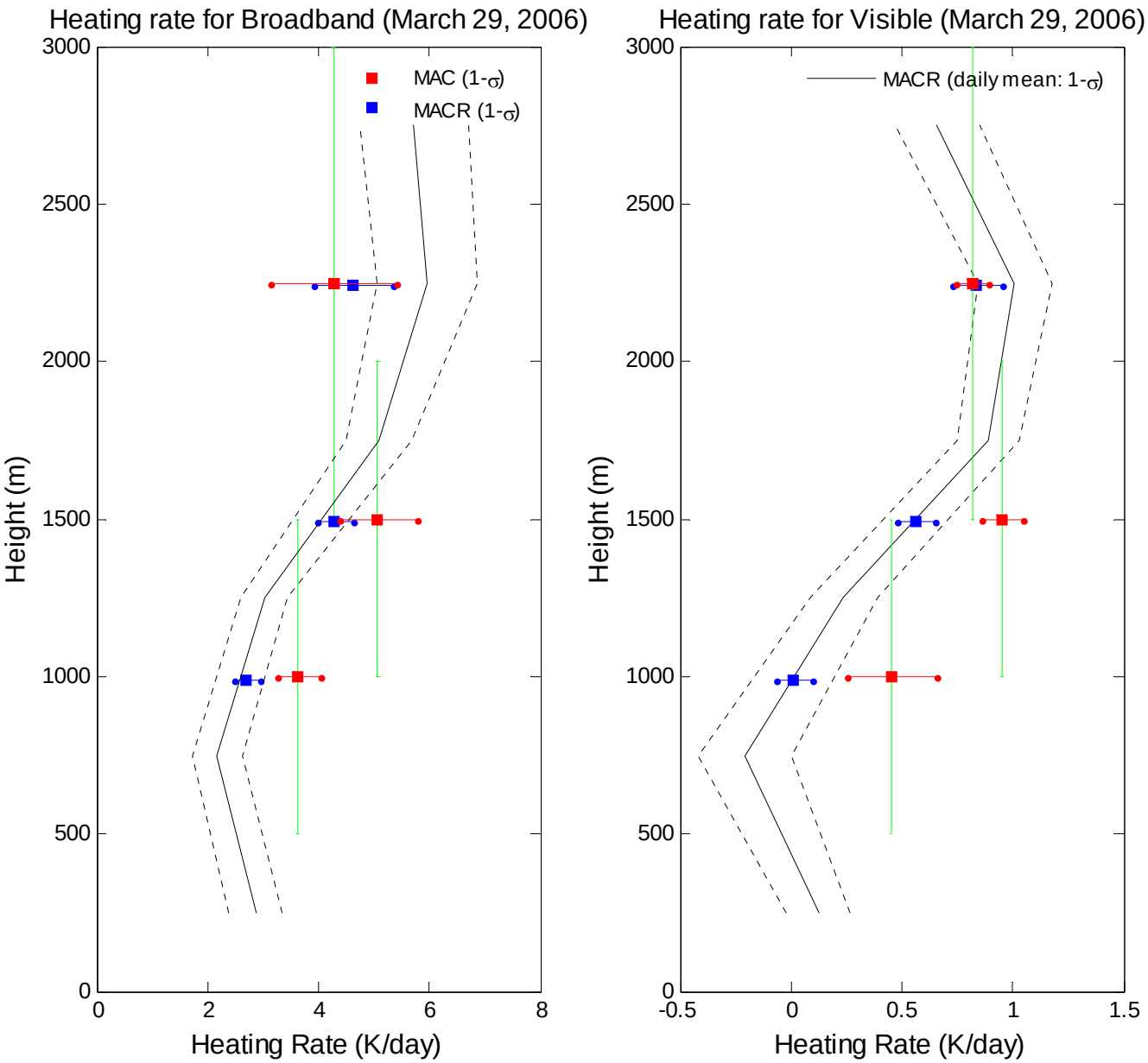


Vertical profiles of Atmospheric Absorption on March 29



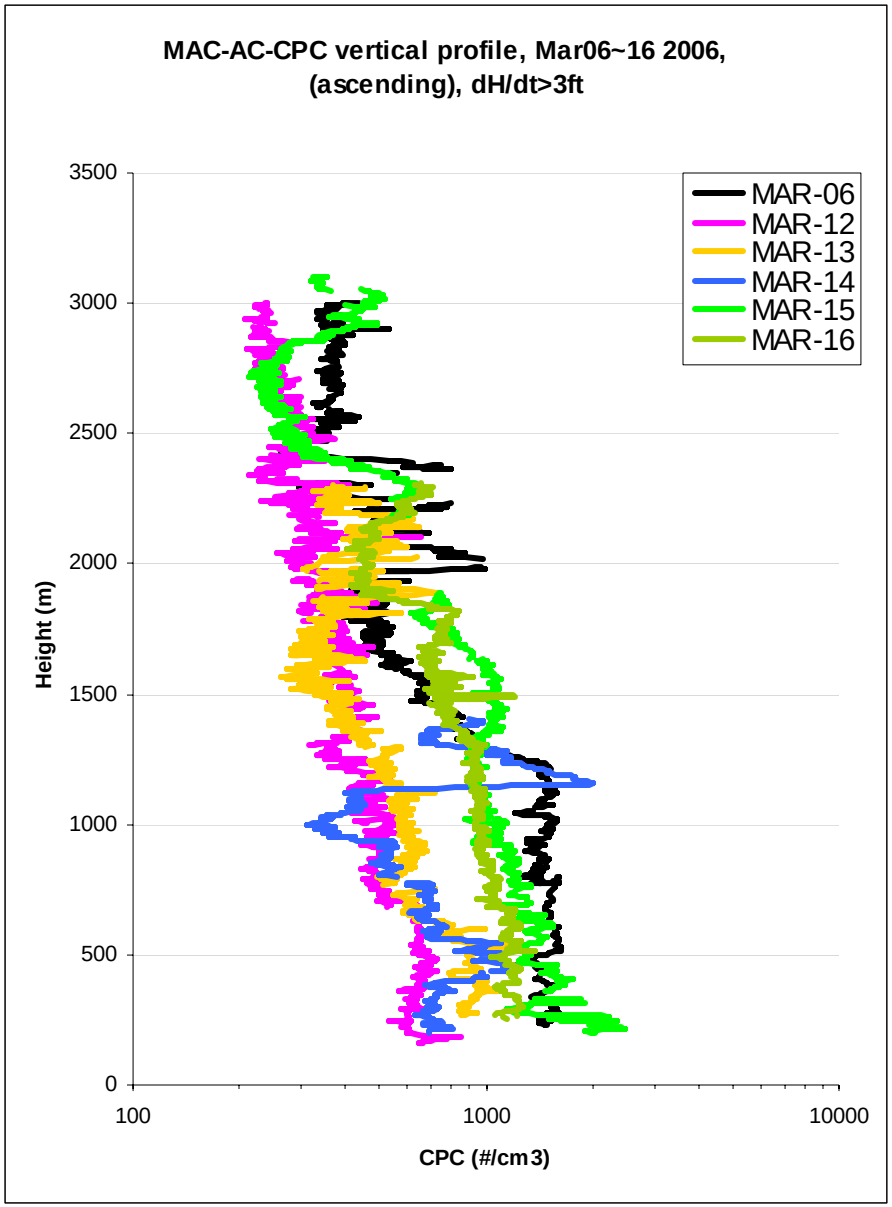
The blue points represents aerosol-free atmospheric absorption.

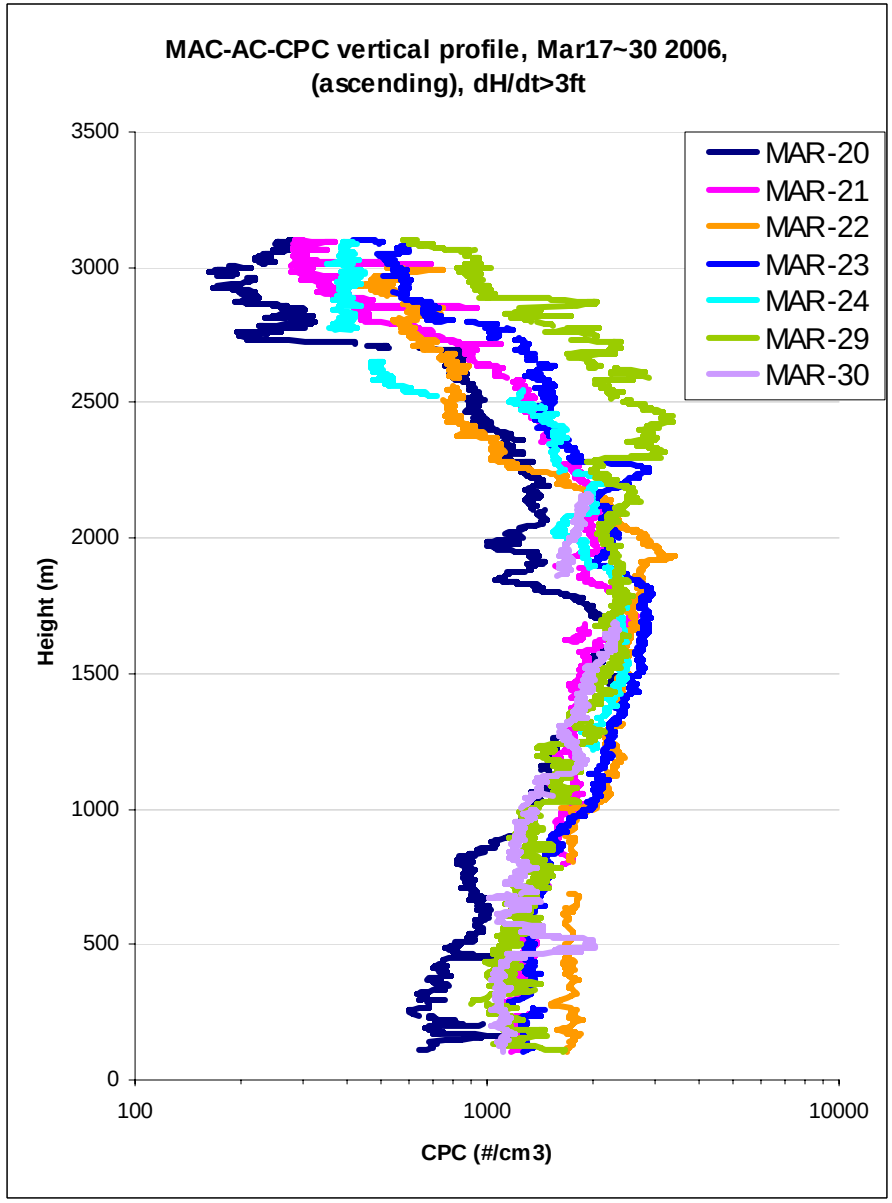
Atmospheric Heating rates:



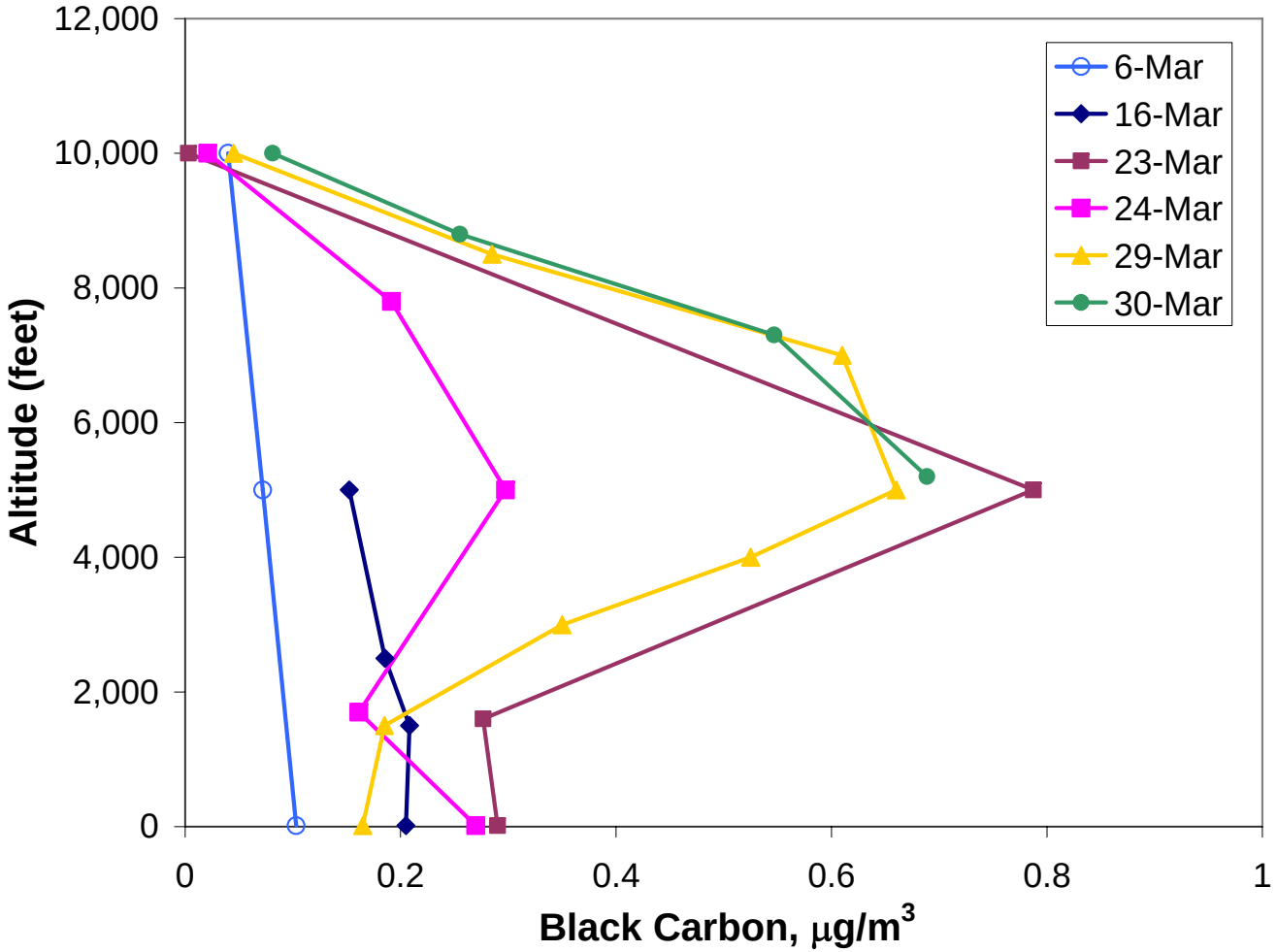
The green line represents the altitudes between which the absorption values are calculated.

Vertical Profiles of Aerosol concentrations





Vertical Profiles of Black Carbon during MAC



Conclusions:

An in-flight comparison (wingtip to wingtip) showed agreement between the two aircraft of within 2% for both the upwelling and downwelling broadband and visible radiation fluxes.

The measured visible albedo's are slightly higher than broadband albedo's at 3.0 km altitude whereas the broadband albedo's are observed to be slightly higher at 0.5 km. Low altitude visible albedo's could have been affected by nearby island vegetation absorption.

The presence of black carbon in between 1.5 and 3.0km haze layer resulted in a relatively large atmospheric absorption of 70 Wm-2 in the broadband region and 15 Wm-2 in the visible region.

The region of maximum heating closely followed the boundaries of the black carbon and instantaneous heating rates on cloud-free day between 1.5 and 3.0km observed to be 5 K/day in the broadband region and 1 K/day in the visible region.

Acknowledgements:

1) NSF/ NOAA/NASA/Vetlesen/Alderson

2) Maldives Govt

3) Fahey/Fein/Koblinky/Kuettner/Maring/Yuhas

4) NASA-Dryden (Curry/Jennison)

5)ACR Team: Patterson/Mulligan/ Maldives Crew