Advancing Solar Irradiance Measurements for Climate-related Studies:

Accurate Constraint on Direct Aerosol Radiative Effect (DARE)

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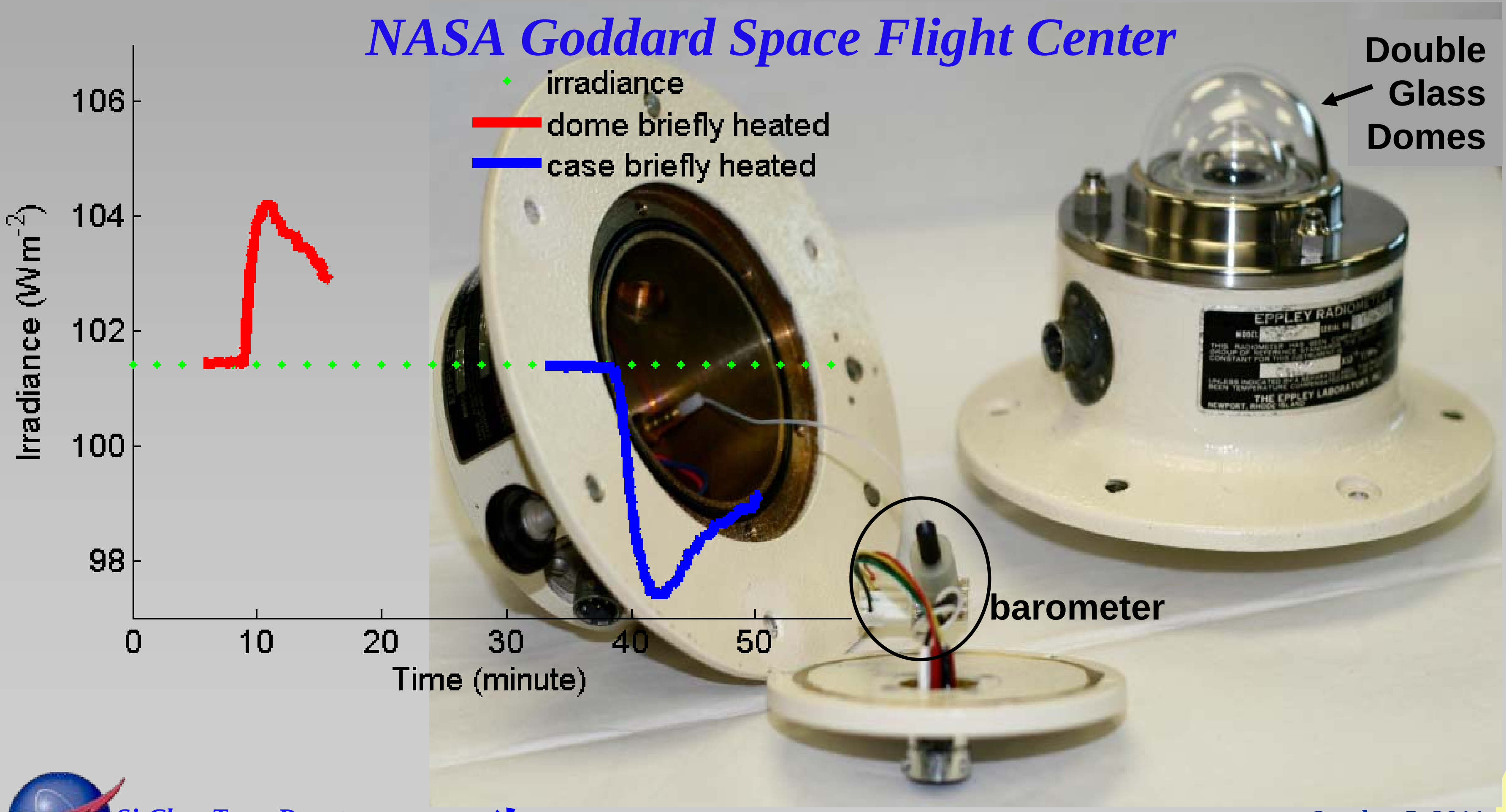
NASA Goddard Space Flight Center



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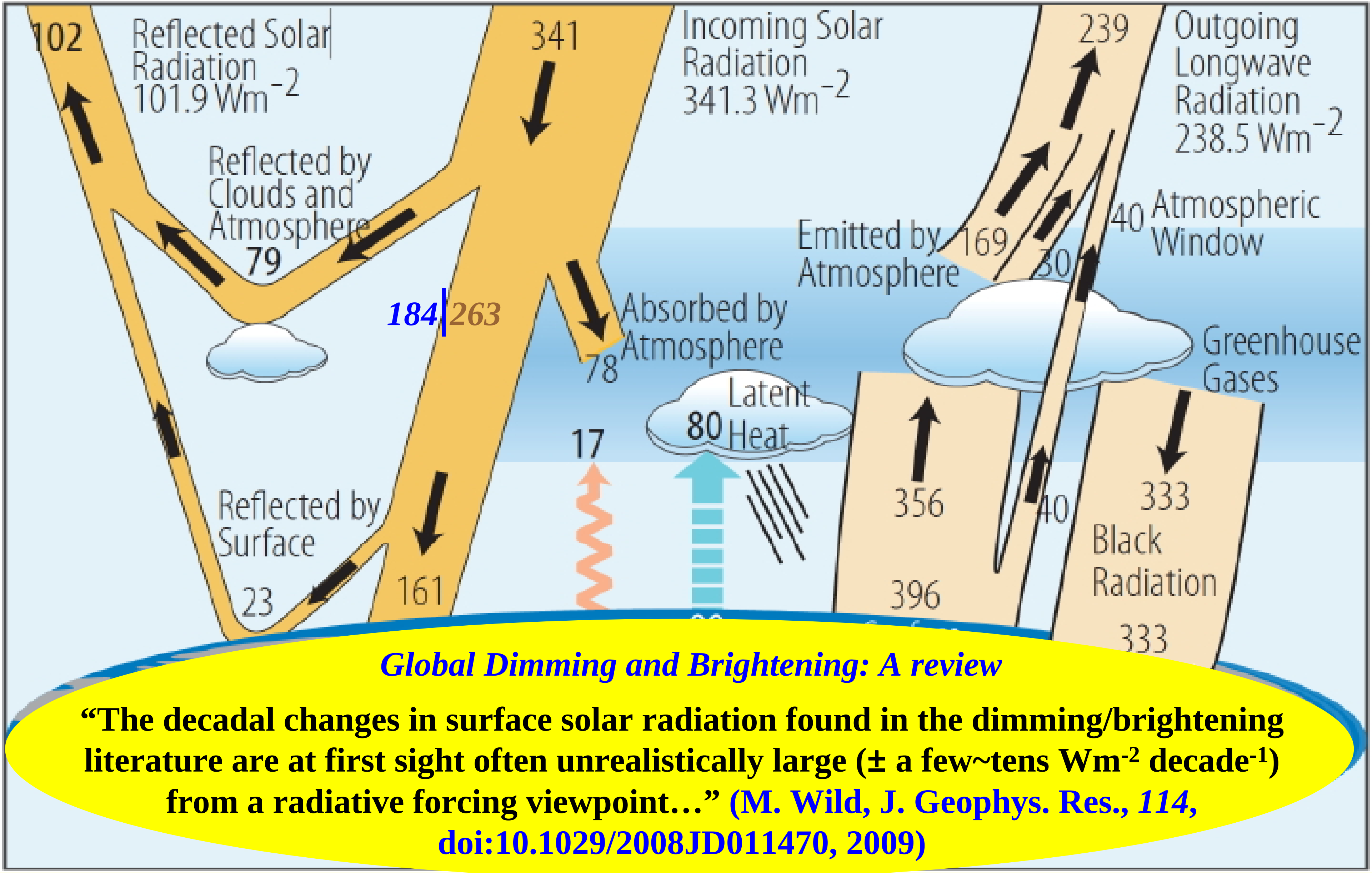
****http://smartlabs.gsfc.nasa.gov/***

October 5, 2011
NASA/GSFC

Pyranometer Specifications: Guide to Meteorological Instruments and Methods of Observation (7th edition), WMO-No 8.

		Secondary Standard	First Class
Response time	to 95% of final value	< 15 s	< 30 s
Zero off-set response:	to 200 W/m^2 net radiant loss to sky (ventilated)	7 W/m^2	15 W/m^2
Zero off-set response:	to 5°C/hr change in ambient temperature	±2 W/m^2	±4 W/m^2
Resolution	(smallest detectable change)	±1 W/m^2	±5 W/m^2
Non-stability	(change in sensitivity per year)	±0.8%	±1.5%
Non-linearity	(deviation from sensitivity at 500 W/m^2 over 100 to 1000 W/m^2 range)	±0.5%	±1%
Directional response for beam radiation	(error due to assuming that the normal incidence response at 1000 W/m^2 is valid for all directions)	±10 W/m^2	±20 W/m^2
Spectral selectivity	(deviation of the product of spectral absorptance and transmittance from the mean)	±2%	±5%
Temperature response	(error due to 50°C ambient temperature change)	±2%	±4%
Tilt response	(deviation from horizontal responsivity due to tilt from horizontal to vertical at 1000 W/m^2)	±0.5%	±2%
Achievable uncertainty	95% confidence level	WMO hourly totals 3% WMO daily totals 2%	8% 5%
Suitable applications		Working standard	Low-cost operations



Global Dimming and Brightening: A review

"The decadal changes in surface solar radiation found in the dimming/brightening literature are at first sight often unrealistically large (± a few~tens Wm^{-2} decade^{-1}) from a radiative forcing viewpoint…" (M. Wild, J. Geophys. Res., *114*, doi:10.1029/2008JD011470, 2009)

Global annual mean of Earth's energy budget (Trenberth et al. 2009)

Brief History

Eppley Pyranometer
(180° Pyrheliometer)

1930s
to
1970s

→

Continuity

Precision Spectral Pyranometer (PSP)

~1965 to date

Precision Infrared Radiometer (PIR)

~1975 to date

Moll-Gorczynski
Pyranometer:
Kipp and Zonen
(Solarimeter)

1930s
to
date

→

Evolution

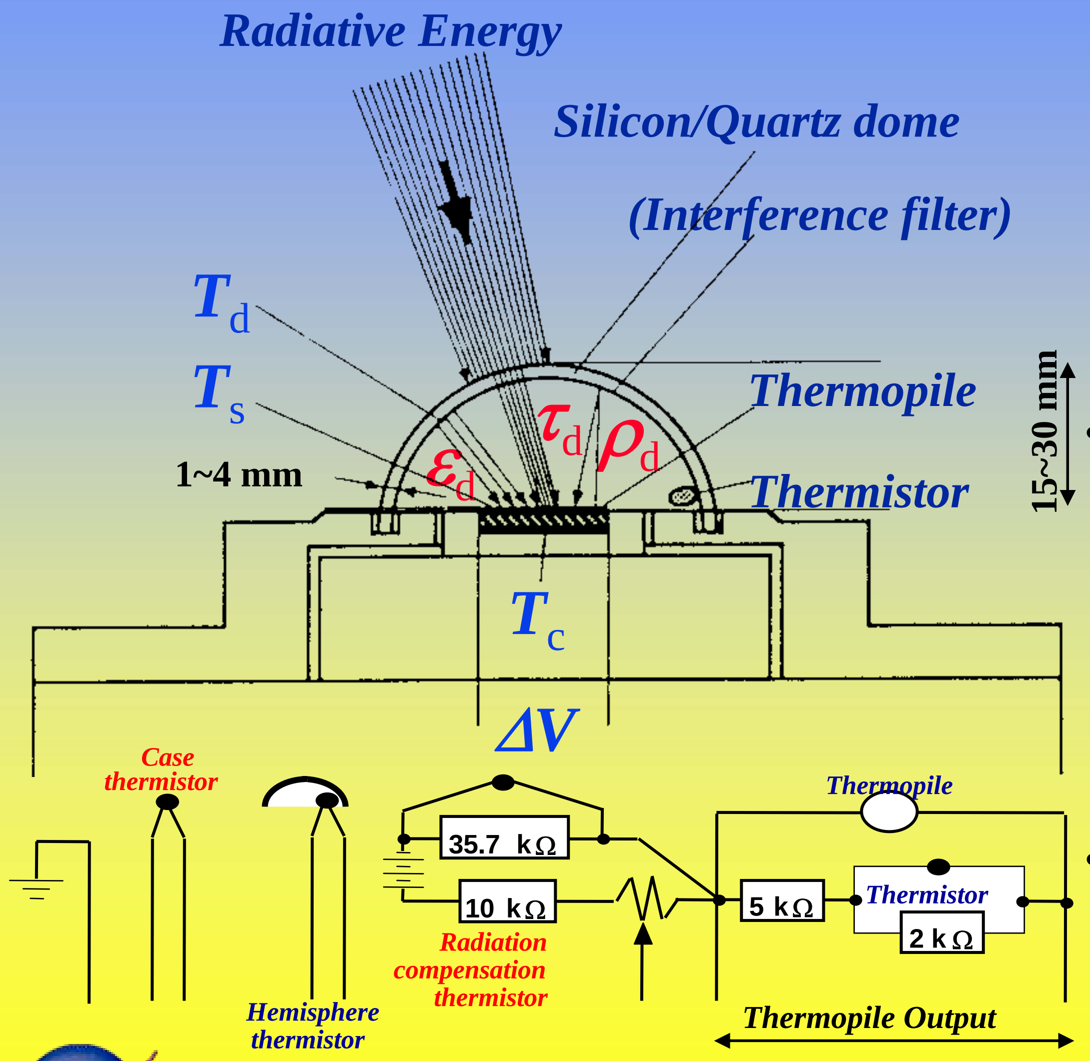
CM Pyranometer (CM3-CM22)

~1965 to date

CG Pyrgeometer (CG1-CG4)

~1990 to date

Thermopile Technology*



*Drummond, et al., 1965
Albrecht, et al., 1974
Philipona, et al., 1995
Bush, et al., 2000

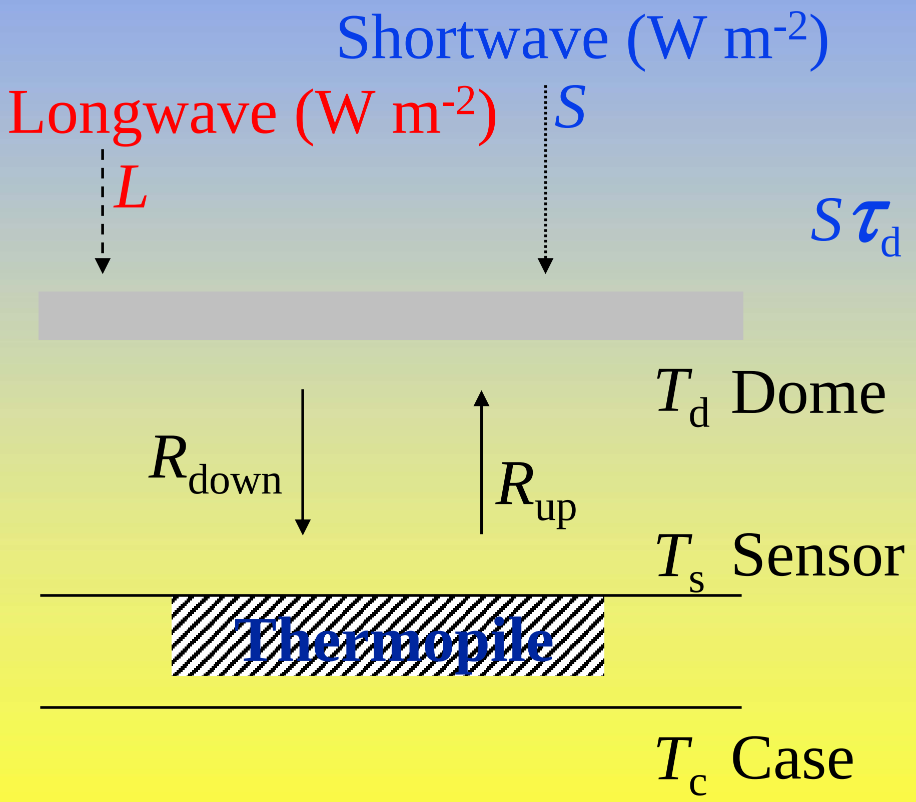
Statistics+

- Market share for past 2-3 decades:
  - Shortwave radiometers
    - » Eppley PSP's -- ≈40%
    - » Kipp & Zonen CM's -- ≈55%
  - Longwave radiometers
    - » Eppley PIR's -- ≈90%
- Total: ≈10,000 units distributed globally

+Kirk, EPLAB president, 1999 personal communication

Radiative Energy Balance

Built on Fairall et al. (1998, J. Atmos. Oceanic Tech., 15, 1229-1242) IR work:



Shortwave (W m^{-2})

Longwave (W m^{-2})

S

L

R_{down}

R_{up}

T_d Dome

T_s Sensor

Thermopile

T_c Case

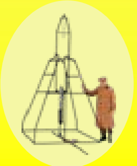
$$R_{down} - R_{up} = \kappa\alpha V$$

$$\varepsilon_s \sigma T_s^4 + \rho_s R_{down} = R_{up}$$

$$S\tau_d + L\tau_d + \varepsilon_d \sigma T_d^4 + \rho_d R_{up} = R_{down}$$

where κ: thermal conductivity
α: thermoelectric coefficient (K/V)
V: voltage output

$$\begin{cases} \varepsilon_s + \rho_s = 1 \\ \varepsilon_d + \tau_d + \rho_d = 1 \\ T_c + \alpha V = T_s \end{cases}$$



Solutions:

$$^{*}S_{2000} = \kappa\alpha V + \varepsilon_d \sigma (T_s^4 - T_d^4) + \tau_d (\sigma T_s^4 - L)$$

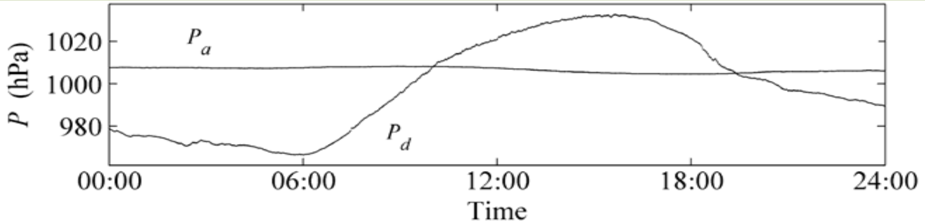
$\kappa\alpha V$ **: *Output from common Pyranometers***

$\varepsilon_d \sigma (T_s^4 - T_d^4)$**: *Thermal effect from the dome***

$\tau_d (\sigma T_s^4 - L)$**: *Thermal leakage of the dome***

***Ji and Tsay, 2000, *On the Dome Effect of Eppley Pyrgeometers and Pyranometers*, Geophys. Res. Lett., 27, 971-974.**

$$^{\#}S_{2010} = cV + f\sigma[(T_c + \alpha V)^4 - (P_d / r)^4]$$



Ideal gas law: $P_d = r\,T_d$

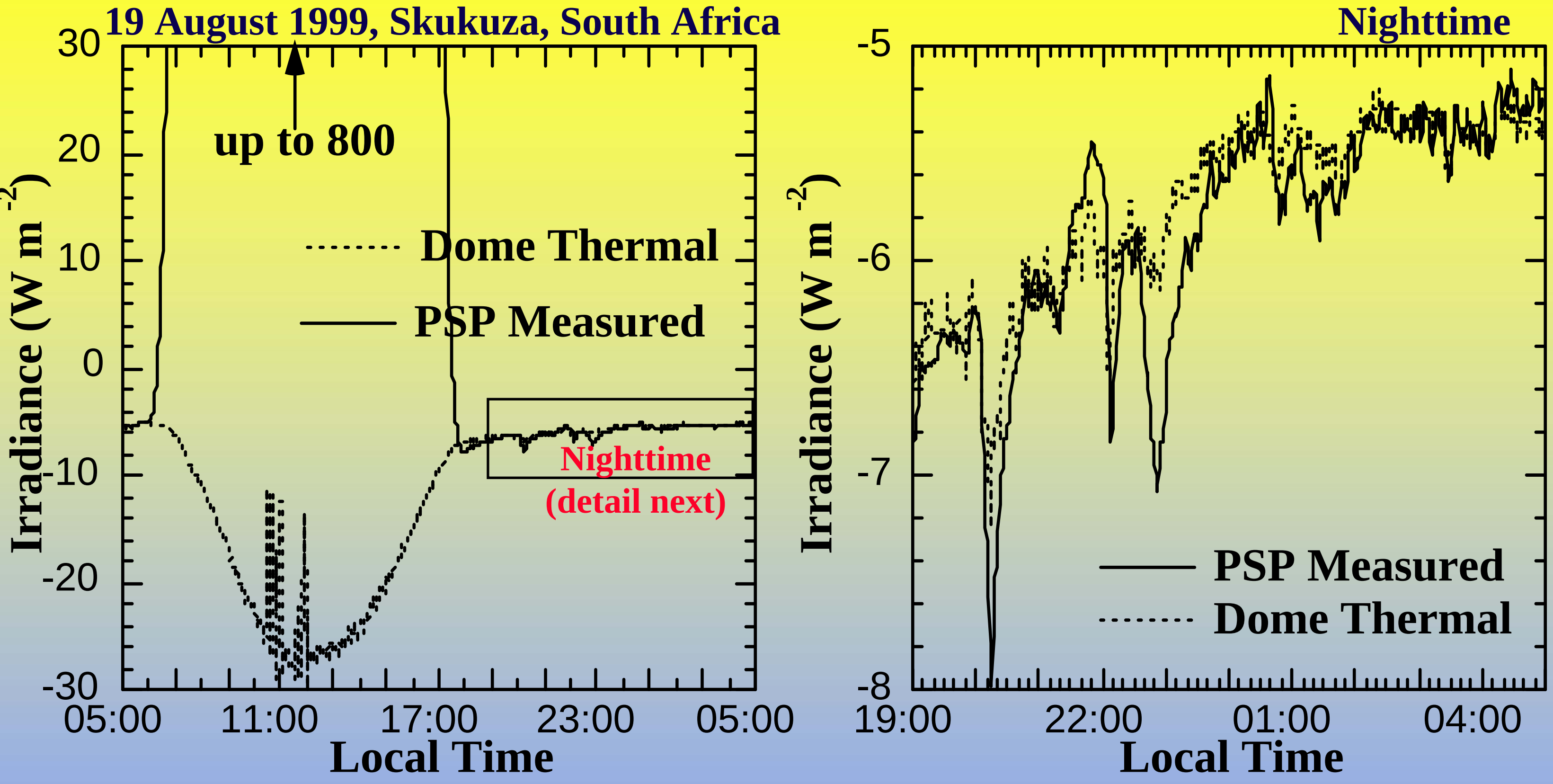
Measurements: V, T_c and P_d

Constants: σ, α, r, c and f, rooted in stable physical properties.

(σ, Stefan-Boltzmann constant; α, thermoelectric coefficient; *r*, ideal gas coefficient; *c*, intrinsic calibration constant; and *f*, dome factor)

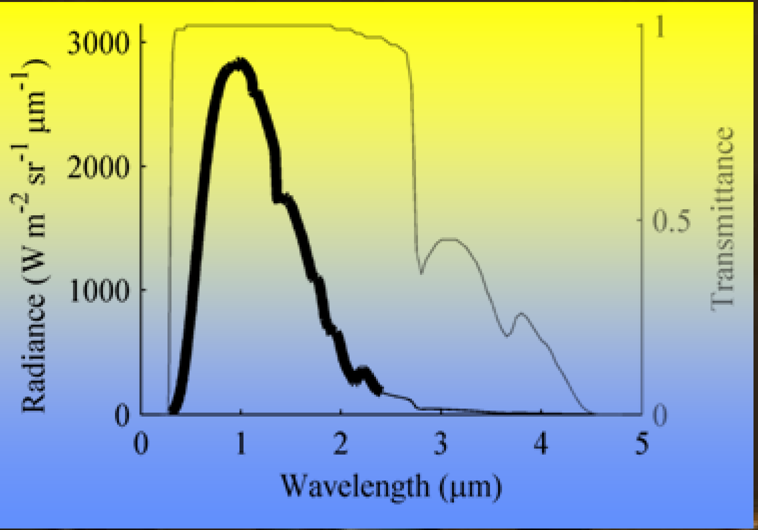
#Ji and Tsay, 2010, *A Novel Non-Intrusive Method to Resolve the Thermal-Dome-Effect of Pyranometers. Part I: Instrumentation and Observational Basis*, J. Geophys. Res., 115, D00K21, doi:10.1029/2009JD013483.

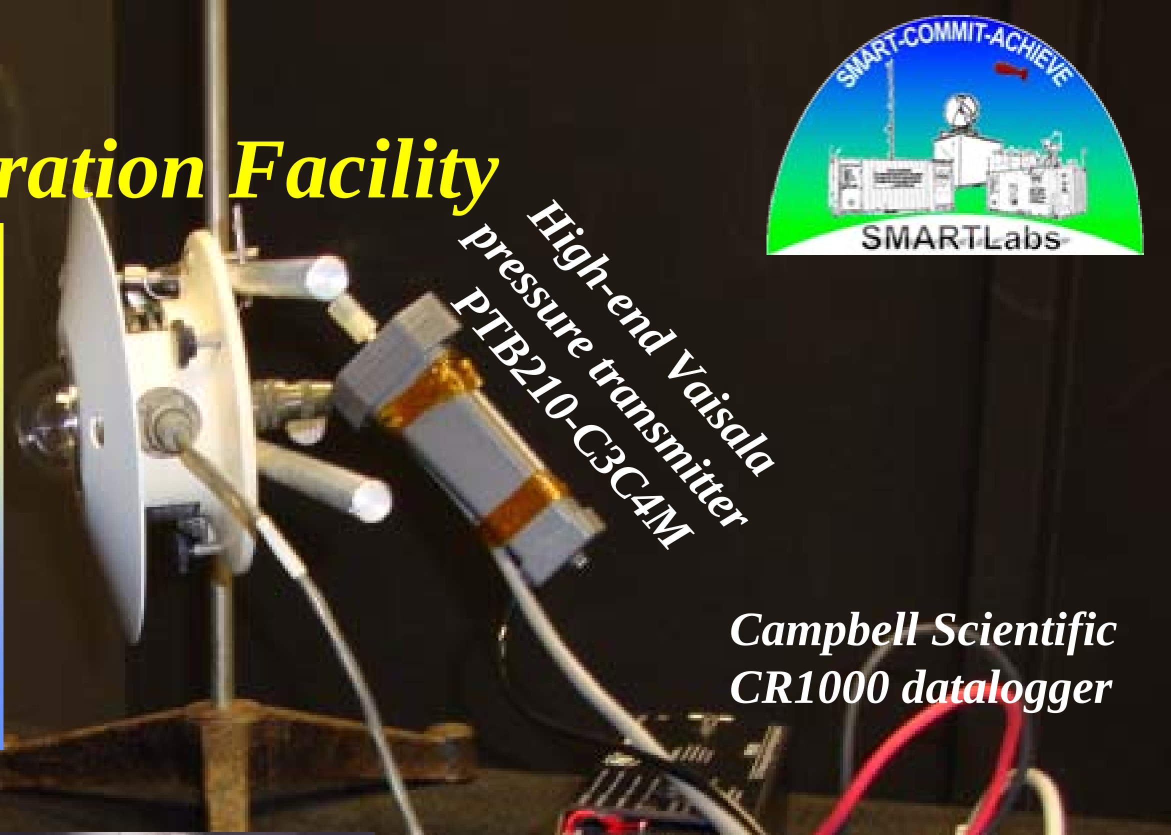
Aerosol Recirculation and Rainfall Experiment (ARREX)



- **Using collocated PSP/PIR measurements to correct thermal dome effect:**
  - **approximate** $\varepsilon_d = 0.71, (T_c)_{PSP} = (T_c)_{PIR}, and\ (T_d)_{PSP} = 0.996(T_d)_{PIR}$
  - **Nighttime (near thermal equilibrium) off-set can be explained well.**
  - **Daytime data involving solar heating and other effects are very complex.**

NASA/GSFC: Radiometric Calibration Facility

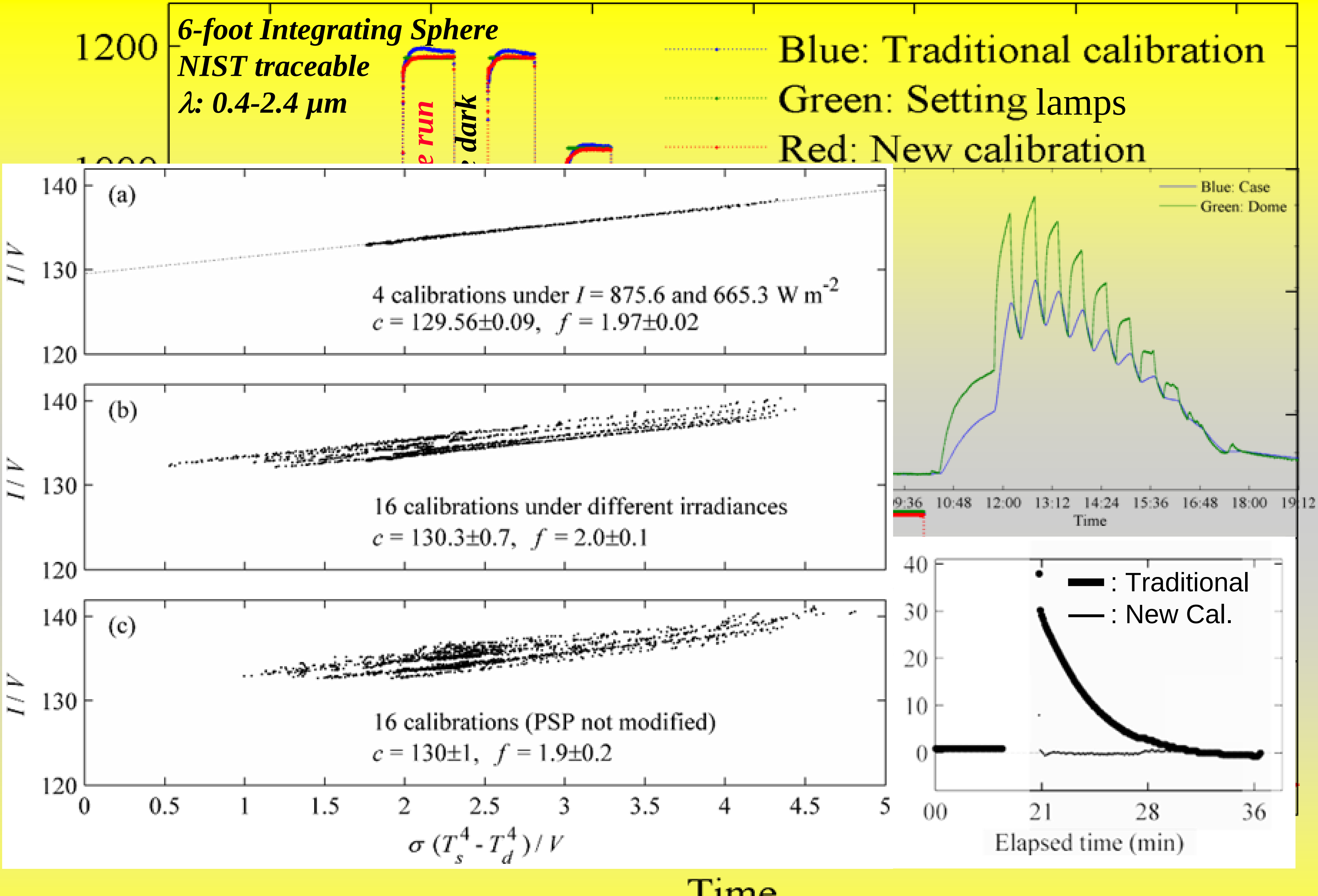




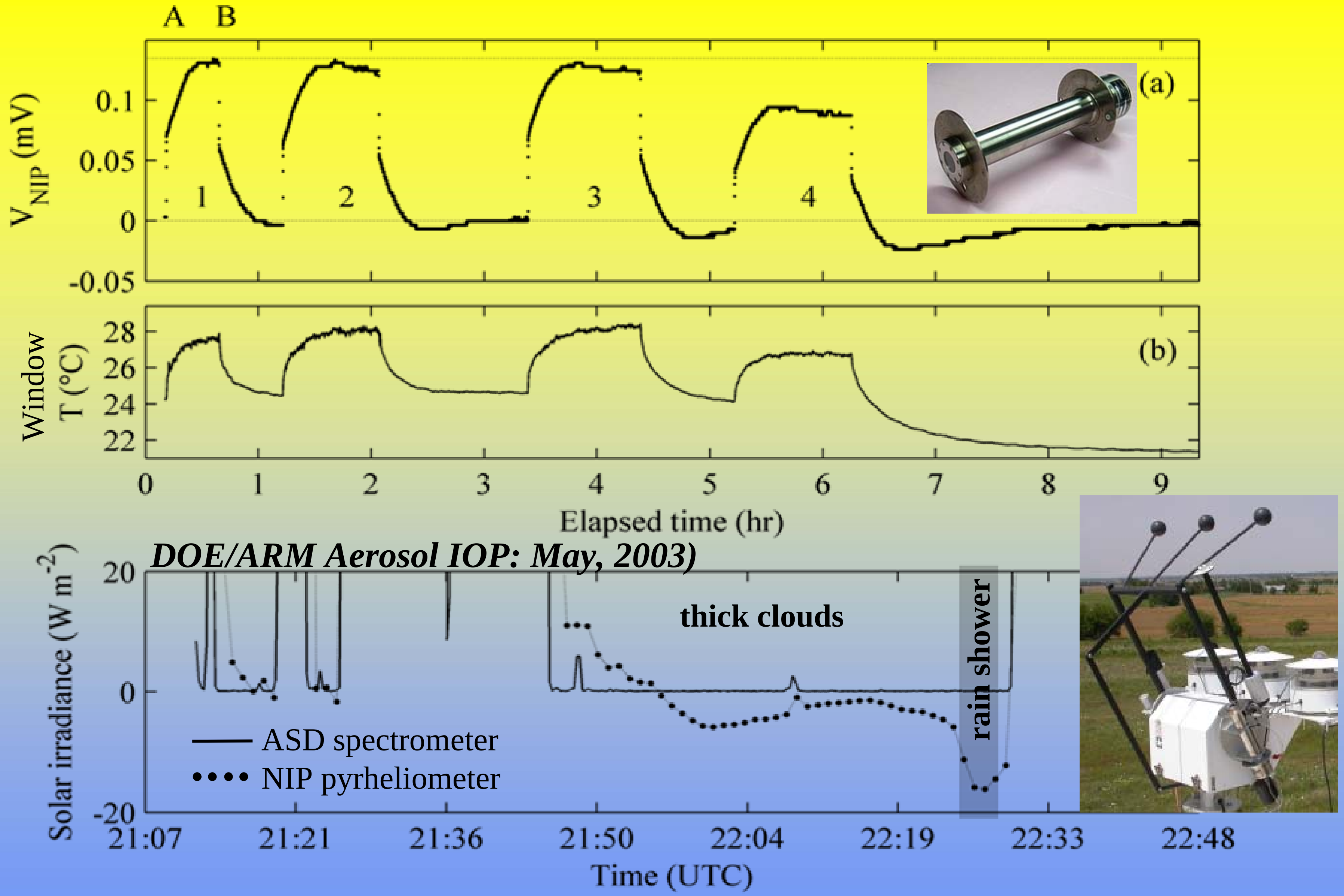
High-end Vaisala pressure transmitter PTB210-C3C4M

Campbell Scientific CR1000 datalogger

6-foot Integrating Sphere
16-lamp, NIST traceable



Ji, Tsay, *et al.*, 2011, *Part-II: Radiometric Calibration and Implications*, J. Geophys. Res., in revision (Intellectual Property Disclosure, PS-2011-055).



DOE/ARM Aerosol IOP: May, 2003)

WCRP/BSRN: shortwave irradiance = direct normal × cosθ_0 + shaded diffuse horizontal (Michalsky et al. 1999)

CHINA^2-AMY08: Cloud, Humidity Interacting Natural/ Anthropogenic Aerosols in AMY-2008 (Asian Monsoon Years)

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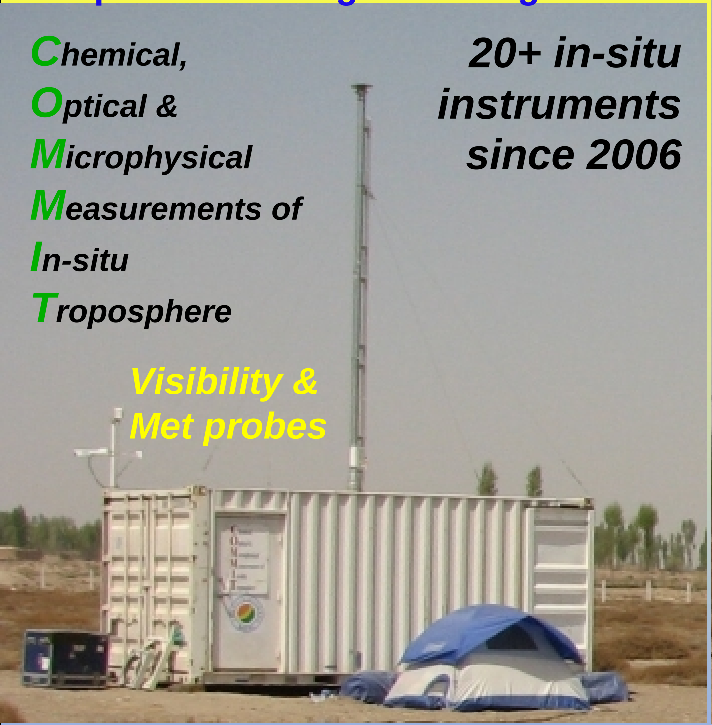
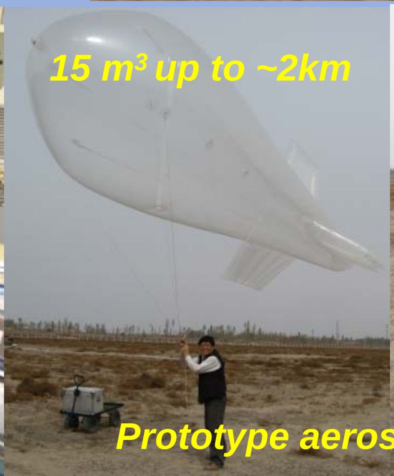
Chemical,
Optical &
Microphysical
Measurements of
In-situ
Troposphere

20+ in-situ instruments since 2006



Surface-sensing
Measurements for
Atmospheric
Radiative
Transfer

30+ remote sensing instruments since 2002



Prototype aerosol sampler

ACHIEVE: *Aerosol-Cloud-Humidity Interaction Exploring & Validating Enterprise*

***Successive-Derivatives* approach to build up information metrics**

Simulations: *Method and Constraint*

- *Over two months (April–June 2008) of data (i.e., aerosol, cloud, surface, state parameters) collected in a remote region frequented by dust outbreaks in northwest China are used to constrain a radiative transfer model (RTM, i.e., Fu-Liou code, 1993).*
- ***Atmospheric profiles:*** *mid-latitude summer as a template, updated with the available sounding data, and scaled to measured column ozone & precipitable water vapor amounts at elevated sfc height.*
- ***Aerosol properties:*** *aerosol optical thickness measured by sun-photometer, vertical distribution derived from MPL backscatter profile, and built-in RTM aerosol models used but modified accordingly with dust/soot mixture (Li et al., 2010).*
- ***Surface properties:*** *spectral albedo derived from the BRDF measurements by ASD spectrometer (Tsay et al., 2011).*
- ***Model simulations:*** *tuned to agree with downward solar irradiance measurements, by adjusting aerosol optical properties.*

Summary: Impact on Direct Aerosol Radiative Effect

- ***Without** TDE corrections, the measurements can be **well matched** using a **pure dust** aerosol optical model (AOM) in the RTM.*
- ***With** TDE corrections applied, the measurements **decreased ~3 Wm^{-2}** on average thus requiring an addition of **soot** to the AOM, simulating ~1.7% of the total aerosol optical thickness (modeled single scattering albedo at $\lambda = 0.55$ μm changes from **0.871** to **0.860** using the OPAC database).*
- ***A** … **to** -5 …) i … -2*