ASR Instrument Team Meeting

AGENDA

1. INSTRUMENT UNCERTAINTY: THE ONE MINUTE MADNESS

The uncertainty estimates of your instrument. This is the one Power Point slide for each instrument that you are responsible for. The slide must have: 1) the "simple" expression of uncertainty, and 2) the expression of uncertainty in your Handbooks. I want to use the one-minute madness format for each of you to provide your slide to the others. (Doug Sisterson)

2. NEW INSTRUMENT HANDOFF

Review the handoff of ARRA (or new) instruments (IRR) and acceptance by Operations (ORR). The process is being tweaked to make it less ambiguous. (Doug Sisterson, Jim Mather, Jimmy Voyles)

ASR Instrument Team Meeting

3. THE SARS AND YOU

Cyber Security is as real an issue as ESH. We need to do better! (Cory Stuart)

4. INSTRUMENTS FOR THE NEW FIXED SITE AND MOBILE FACILITY

The challenges for building the Eastern North Atlantic (ENA) fixed site in the Azores and the third Mobile Facility for longer-term deployment in the the North Slope of Alaska (NSA) at Oliktok. How's that going to affect you! (Jimmy Voyles)

5. UNMET MEASUREMENT NEEDS

We need to think about unmet measurement needs and what new instrumentation we would need to obtain those measurements. ARM has certainly had a barrage of new ARRA instruments, but they really aren't new: we simply had the funds to buy them. What we need to think about is the next generation of observations. (Doug Sisterson)

Let's Get Started!

Uncertainties Associated with MFRSR Measurements (95%) Hodges

- **Silicon-based broadband solar irradiance components**
  - Clear skies total horizontal irradiance ±2.1%
  - Clear skies direct normal irradiance ±2.3%
  - Clear skies diffuse horizontal irradiance ±5.2%

  {Based on Michalsky et al., Solar Energy (2009) 83: 2144-2156; Michalsky et al., JGR (2007) 112: doi:10.1029/2007JD008651; Michalsky et al., JAOT (2011) 28: 752-766}

- **Spectral irradiances**
  - Lamp calibrations ±5% (typical)

  (Based on NREL & NOAA LI-COR lamp calibrations, unpublished)
  - Langley calibrations ±2.5% (415, 500, 615, 673, 870)

  (Based on World Radiation Center FRC-III results and estimated extraterrestrial spectral irradiance uncertainty of 2%; not yet published)

- **Aerosol optical depth ±0.005 + 0.01/m**

  (Based on World Radiation Center FRC-III results; not yet published)

Soil Water and Temperature System (SWATS) Hartsock

Data File Variable	Variable Name	Units	Uncertainty
tref	Reference Temperature	C	0.5°C
tsoil	Soil Temperature	C	0.5°C
trise	Temperature Difference	C	0.5°C
soilwatpot	Soil-Water Potential	kPa	4 – 20 kPa
watcont	Water Content	m^3/m^3	0.05 m^3/m^3

Uncertainty = 2 x RMSE

$$RMSE = \sqrt{(B^2 + \sigma^2)}$$

(B - bias mean error)
(σ^2 - variance)
~ 95% confidence interval

Manufacturer Uncertainty Analysis For Met Sensors (Ritsche)

Systems included:

AMF1 MET, AMF2 MET, SGP MET, TWP MET, NSA MET, SurTHRef, THWAPS

Sensors:

T/RH: Vaisala HMP337, HMP45D, HMP155, HMP233, Rotronic MP100H

Present Weather: Vaisala PWD-22

Wind Speed and Direction: Vaisala WS425, RM Young 05103/05106

Barometers: Vaisala PTB201, PTB220, PTB330,

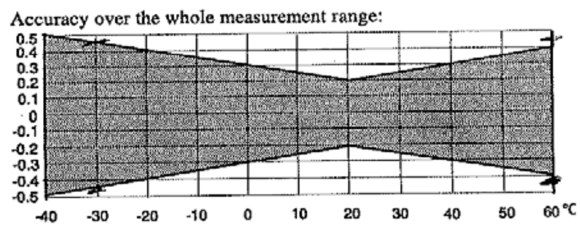
Precipitation: Optical Scientific ORG 815, NovaLynx 260-2500E Rain Gage, RIMCO 7499 Rain Gage

Loggers: Campbell Scientific CR10/10X, CR23X, CR3000

Ritsche: T/RH Probes

- Only used currently installed sensors. We did not include historically used probes although that information is included in the Handbooks.

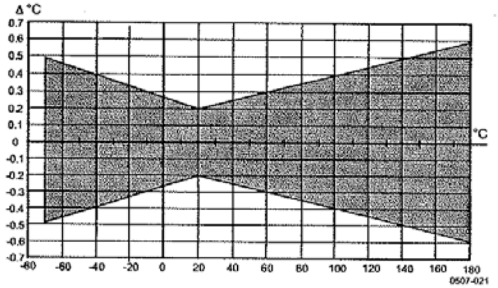
- Vaisala HMP45D
  - Temp: +/- 0.2°C @ 20°C
  - RH: +/- 2% for 0-90%
    +/- 3% for 90 – 100%
    - Temperature dependence of +/- 0.05% RH/°C
    - No Factory Calibration uncertainty reported



- Vaisala HMP155
  - Temp: +/- (0.1 + 0.00167 x temp)°C
  - RH: Depends on ambient temperatures
    - -60 to -40°C Rh is (1.4 + 0.032 x reading)%
    - -40 to -20°C Rh is (1.2 + 0.012 x reading)%
    - -20 to +40°C Rh is (1.0 + 0.008 x reading)%
  - Addition calibration uncertainty
    - +/- 0.6% for (0-40%)
    - +/- 1.0% for (40 – 97%)

Ritsche: T/RH Probes, Cont'd

- Vaisala HMT 337
  - Temp: +/- 0.2°C @ 20°C
  - RH: -40 to +180°C +/- (1.5 + 0.015 x reading)%
  - Additional calibration uncertainty
    - +/- 0.6% for (0 to 40%)
    - +/- 1.0% for (40 to 97%)



- Vaisala HMP 233
  - Temp: +/- 0.1°C @ 20°C
  - Temperature dependence of electronics: 0.005°C/°C
  - RH: +/- 2% (0-90)%
    +/- 3% (90 – 100)%

- Rotronic MP100H
  - Temp: +/-0.2°C @ 20 – 25°C
  - RH: +/-1.5% (0-100)%

Ritsche: Wind Speed & Direction

- R.M. Young Wind Monitor Models 05103/05106
  - Speed: +/- 2% for 2.5m/s to 30m/s
  - Direction: +/- 3°

- Vaisala WS425/425 F/G 2-d Ultrasonic
  - +/- 0.135 m/s or 3% of reading. Whichever is the greater of the two.
  - +/- 2° for wind speeds > 1.0 m/s

Barometer

- Vaisala PTB 201
  - Total Accuracy: +/- 0.3 hPa
  - Long Term Stability: +/- 0.2 hPa/yr

- Vaisala PTB 220
  - Total Accuracy: +/- 0.15 hPa
  - Long Term Stability: +/- 0.1 hPa/yr

Ritsche: Barometers Cont’d

- Vaisala PTB 330
  - +/- 0.10 hPa
  - Long Term Stability +/- 0.01 hPa/yr

Precipitation

- Novalynx Model 2600-250 12” Tipping Bucket Rain Gage, heated
  - +/- 0.254 mm
  - Unknown during heavy winds or snow

- RIMCO 7499 Series Tipping Bucket Rain Gage
  - +/- 1% up to 250 mm/hr rain rate
  - +0 to -7% for 250 mm/hr to 500 mm/hr rain rate

- Optical Scientific Model 815 Optical Rain Gage
  - +/- 5% of accumulation
  - Snow: used to be listed as +/- 10%, but now the website states it should not be used for snow.

Ritsche: Present Weather & Visibility

- Vaisala PWD-22 Present Weather Detector
  - Visibility: +/- 10% for 10m to 20000m
    - Consistency: +5%
  - Precipitation: None given.
    - Detection: 0.05 mm/h or less, within 10 minutes

Chilled Mirror Hygrometer

- Technical Services Laboratory Model 1088
  - Temp: +/-0.5°F (-58 to 122°F), +/- 1° through remainder of range.
  - Dew Point:
    - +/- 2°F RMSE (30 to 86°F)
    - +/-3°F RMSE (-10 to 30°F)
    - +/-4°F RMSE (-30 to -10°F)

- General Eastern Hygro M4/E4
  - Dew/Frost Point: +/- 0.2°C

Ritsche: Dataloggers

- Campbell Scientific Model CR10/10X
  - Voltage measurements: +/-0.1% Full Scale Range
  - Excitation accuracy: +/- 5mV (-25 to 50°C)
  - Resistance measurement: +/-0.02% Full Scale Input

- Campbell Scientific Model CR23X
  - Voltage measurements: +/-0.075% Full Scale Range
  - Excitation accuracy: +/- 5mV (-25 to 50°C)
  - Resistance measurement: +/-0.02% Full Scale Input

- Campbell Scientific Model CR3000
  - Voltage measurement: +/-0.09 Full Scale Range (-40 to 85°C)
  - Voltage output (Vx): +/- 0.09% + .5mV (-40 to 85°C)
  - Resistance output (Ix): +/- 0.15% + .5µA (-40 to 85°C)
  - Resistance measurement: +/-0.03% + offset/Vx or Ix) (-40 to 85°C)

Ritsche: Additional Uncertainty Analysis Mentor Provided

- This information is included in the handbooks. (We have found some errors and omissions and are working to correct them)
- For Temperature and RH probes:
  - There is a radiation error associated with the solar shields used:
    - For a Gill non-aspirated shield
      - +/- 0.2°C for winds greater than 6 m/s (assume aspirated shield error)
      - +/- 0.4°C when the wind speed is 3 m/s
      - +/- 0.7°C when the wind speed is 2 m/s
      - +/- 1.5°C when the wind speed is 1 m/s
    - For a Gill aspirated shield
      - +/- 0.2°C
- Using Root Sum of Squares for independent sources of error = $(\varepsilon^2 + \varepsilon^2 + \varepsilon^2 \ldots)^{1/2}$
  - HMP45D, HMT337 and Rotronic MP100H uncertainty @ 20°C
    - Temperature uncertainty in an non-aspirated gill shield
      - +/- .28°C for winds greater 6 m/s
      - +/- .45°C when the wind speed is 3 m/s
      - +/- .73°C when the wind speed is 2 m/s
      - +/- 1.51°C when the wind speed is 1 m/s

Ritsche: Additional Uncertainty Analysis Mentor Provided, cont'd

- Temperature uncertainty in a Gill aspirated shield
  - +/- 0.28°C
- HMP 155 uncertainty at 20°C
  - For a Gill non-aspirated shield
    - +/- 0.24°C for winds greater than 6 m/s
    - +/- 0.42°C when the wind speed is 3 m/s
    - +/- 0.71°C when the wind speed is 2 m/s
    - +/- 1.51°C when the wind speed is 1 m/s
  - For a Gill aspirated shield
    - +/- 0.24°C
- HMP 233 uncertianty at 20°C
  - For a Gill non-aspirated shield
    - +/- 0.22°C for winds greater than 6 m/s
    - +/- 0.41°C when the wind speed is 3 m/s
    - +/- 0.71°C when the wind speed is 2 m/s
    - +/- 1.51°C when the wind speed is 1 m/s
  - For a Gill aspirated shield
    - +/- 0.22°C

Ritsche: Additional Uncertainty Analysis
Mentor Provided, cont'd

– RM Young Wind Monitor Model 05103/05106 Wind Speed Threshold calculation.
  - a 1m/s threshold and assuming normal distribution of the wind speeds about the mean.
  - Uncertainty
    - +/- 2% for wind speeds from 2.5 to 30 m/s
    - -0.12 to +0.02 m/s for a wind speed of 2.0 m/s
    - -0.22 to +0.00 m/s for a wind speed of 1.5 m/s
    - -0.31 to -0.20 m/s for a wind speed of 1.0 m/s
    - -0.51 to -0.49 m/s for a wind speed of 0.5 m/s

EBBR System Uncertainties

David R. Cook <drcook@anl.gov>

- Primary variables include Sensible Heat flux (H), Latent Heat Flux (LE), Net Radiation (Rn), and Soil Surface Heat Flux (SSHF)
- Secondary variables include Air Temperature (TA), Relative Humidity (RH), Atmospheric Pressure (P), Soil Heat Flow (SHF), Soil Moisture (SM), and Soil Temperature (ST)
- Uncertainties in ½ hr means of the primary and secondary variables dominate errors due to instrument precision (~1 %) and calibration uncertainties (TA 1%, RH 3%, P 2%, Rn 5%, SHF 3%, SM 5%, ST 1%)
- Use RMS technique
- Soil Heat Flux uncertainty is therefore ~6%
- Sensible and Latent Heat Flux uncertainty is therefore ~10%

SEBS System Uncertainties

David R. Cook <drcook@anl.gov>

- Primary variables include Net Radiation (Rn), Surface Soil Heat Flux (SSHF from Soil Heat Flow (SHF), Soil Moisture (SM), and Soil Temperature (ST)), and the resultant Surface Energy Balance (SEB)
- Uncertainties in ½ hr means of Rn and SSHF dominate errors due to instrument precision (~1 %) and calibration uncertainties (Rn 3%, SHF 3%, SM 5%, ST 1%)
- Use RMS technique
- Surface Soil Heat Flux uncertainty is therefore ~6%
- Surface Energy Balance uncertainty is therefore ~ 7%

SGP Tower T and RH Uncertainties

David R. Cook <drcook@anl.gov>

- Primary variables include Air Temperature (TA), Relative Humidity (RH), and Vapor Pressure (VP)
- Uncertainties in ½ hr means of the primary variables are solely due to instrument precision (~1 %) and calibration uncertainties (TA 1%, RH 3%)
- Use RMS technique
- TA uncertainty is therefore ~1%
- RH uncertainty is therefore ~ 3%
- Vapor Pressure uncertainty is therefore ~3%

Eddy Covariance Flux System Uncertainties (ECOR, CO2FLX, PFLX, CH4FLX)

Marc L. Fischer <MLFischer@lbl.gov>, David P. Billesbach <dbillesbach1@unl.edu>, David R. Cook <drcook@anl.gov>

- Primary variables include turbulent fluxes of momentum, sensible and latent heat, CO_2, and CH_4
- Approximately 10% random (turbulence) uncertainties in ½ hr mean fluxes of primary variables dominate errors due to instrument precision (~ 1 %) and calibration uncertainties (~ 1-3%)
- Long-term (e.g., seasonal-annual) mean fluxes require gap-filling for periods with low turbulence and instrument failure which can increase uncertainties
- Uncertainties in secondary variables, including meteorological and soil physical measurements, are dominated by spatial heterogeneity or instrument calibration

MWR (Cadeddu)

- Measurements:

Estimated brightness temperature uncertainty (propagated from calibration equation) ~ 0.3 K

- Estimated statistical retrieval uncertainty expressed as monthly RMSE is provided in the data files. Varies with month/locations:

PWV RMSE ~ 0.5-0.7 mm
LWP RMSE ~ 0.020-0.030 mm

MWR3C (Cadeddu)

- Measurements uncertainty propagated from calibration equation:

  23.834 and 30 GHz: 0.5-0.6 K

  89 GHz: 1.5 K

- Estimated NN retrieval uncertainty expressed as individual error bars in the data files varies with time/location:

$\varepsilon^2=\varepsilon^2_T+\varepsilon^2_N$

PWV ~0.5-0.7 mm

LWP ~0.010-0.020 mm

ε_T = target noise,

ε_N= instrument noise

MWRHF (Cadeddu)

- Measurements uncertainty propagated from calibration equation:

90 and 150 GHz ~1.5 K

GVR (NSA only) (Cadeddu)

- GVR measurement uncertainty is ~1.5-2 K (hot/cold targets)

- Estimated PWV NN retrieval uncertainty expressed as individual error bars in the data files. It varies with the PWV amount

$\varepsilon^2=\varepsilon^2_T+\varepsilon^2_N$

PWV ~ 3%-10%

ε_T = target noise,

ε_N= instrument noise

LWP ~ 0.010-0.015 mm (LWP retrievals not yet available)

GVRP (NSA only) Cadeddu

- GVRP measurement uncertainty is estimated ~1.5 K (LN2 calibration + frequent gain calibration)

MWRP (Cadeddu)

MWRP measurement uncertainty:
20-30 GHz ~0.5 K (tip curves calibration)
50-60 GHz ~ 1.5 K (cryogenic calibration)

- Estimated statistical retrieval uncertainty expressed as monthly RMSE is provided in the data files. It varies with season/locations/height

PWV ~ 0.5-0.7 mm
LWP: 0.025-0.030 mm

Temperature profile 1-2 K (0-2km) to 3-4 K (10 km)
Vapor density profile 0.5-1 g/m^3 (0-1km) to 0.01-0.05 g/m^3 at 10 km

Bartholomew: Instrument Uncertainty Reference Precipitation Systems

Rain Gauges

Belfort Insruments model AEPG 600 Weighing Bucket Rain Gauge

High Accuracy:+/- 0.01 inches (0.25mm) or 0.1% FS

High Resolution: +/- 0.01 inches (0.25mm)

Precipitation Rate: 0.01 in (0.25 mm)/hr. to 120 in. (304 cm)/hr.

Capacity:24 inches (609 mm) or 40 inches (1016 mm)

Optical Scientific model 815-DA Optical Rain Gauge

Rain Dynamic Range 0.1 to 3000 mm/hr

Rain Measurement Accuracy 5% accumulation

Disdrometers (Bartholomew)

Distromet Impact Disdrometer, model RD-80

Accuracy +/- 5% of measured drop diameter

Joanneum Research 2 Dimensional Video Disdrometer, Compact model

horizontal resolution better than 0.19 mm

vertical resolution better than 0.19 mm (vert. vel. < 10 m/s)

vertical velocity accuracy better than 4% (vert. vel. < 10 m/s)

Video Disdrometer Intercomparison*

Dm Fractional Bias 2 to 4.8% depending upon rain rate

Dm mass weighted mean diameter

log10(Nw) Fractional Bias 1.4 to 2.9% depending upon rain rate

Nw normalized intercept parameter

OTT Present Weather Sensor, model Parsivel^2

+- 1 size class up to diameter 2mm

+- 0.5 size class for diameter >2mm

Precipitation Amount +-5% (liquid)/+-20% (solid)

*Final Report for NASA Grant NNX09Ad72G

Bringi, V.N., M. Thurai and W. Petersen, 2011

Gregory: Cimel Sunphotometer (CSPHOT) Uncertainty Estimates

AERONET's Estimations:

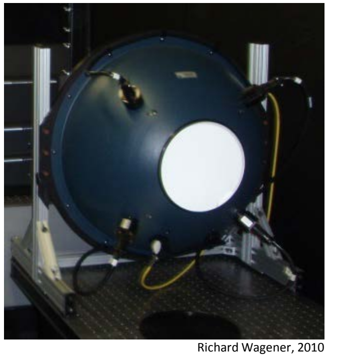
AOD accuracy: 0.01 - 0.02 for field operated Cimels.

Sky radiance : +/- 5%.

Based on one sigma combined variance determined by Mauna Loa Langley calibrations (Holben, 1998).

No uncertainty estimates for VAP quantities retrieved from almucantar, principal plane, and zenith radiances.

Richard Wagener, 2010



Richard Wagener, 2010

AERONET GSFC roof top calibrations and integrating sphere.

Detail

- Field instruments intercalibrated at GSFC against Mauna Loa (MLO) reference instruments annually. MLO reference instruments are calibrated using Langley technique approx. every 3 months. AOD uncertainty for MLO reference instruments is better than 0.002-0.005 (Holben, 1998)
- Linear rate of change in time (between pre and post deployment) of the zero air mass voltage is assumed in calibration of field instruments - Analysis shows 0.01-0.02 AOD uncertainty.
- For normal field deployments, zero air-mass voltage change is from ~0%-2% . Usually larger changes are due to degradation of filters.
- General factors affecting quality/accuracy – obstructions in tube (webs, lizards), corroded terminals (especially in tropics), extreme cold + temperature differences (Storm Peak). These are documented in DQR's and DQPRs.
- Sky radiance: done at GSFC using calibrated integrating sphere (est. +/- 5%)

References

Holben, B.N., T.F.Eck, I.Slutsker, D.Tanre, J.P.Buis, A.Setzer, E.Vermote, J.A.Reagan,Y.J.Kaufman, T.Nakajima, F.Lavenu, I.Jankowiak, and A.Smirnov, AERONET -A federated instrument network and data archive for aerosol characterization,*Rem.Sens.Env., 66(1), 1-16, 1998.*

Holdridge: Vaisala RS92-SGP Radiosonde Sensor Uncertainty

Total Uncertainty in Sounding as reported by manufacturer

Sensor	Uncertainty
Temperature	±0.5°C
Humidity	±5%
Pressure: 1080-100 hPA 100-3 hPa	±1 hPa ±0.6 hPa
Wind Speed	±0.15 m/s
Wind Direction	±2 degrees
GC25 Temperature	±0.1°C
Combined RMSE – Temperature	±0.5°C

*Surface value for T, RH, P, WS, WD are input from various surface system at each site (THWAPS, SurTHRef, MET, Autosonde AWS)

2-sigma (k=2) confidence level (95.5 %), cumulative uncertainty including:

- Repeatability
- Long-term stability
- Effects due to measurement conditions
- Dynamic effect (such as response time)
- Effects due to measurement electronics

For humidity T > -60 °C
For pressure T < 35 °C

Morris: ARM Instrument Uncertainty

- Infrared Thermometer (IRT)
  - Heitronics KT19.85 II Infrared Radiation Pyrometer
    - Sky brightness temperature, T_{sky}
      - resolution = ±1.20 K at T_{sky} = 223 K, ε = 1.0, and t_r = 0.3 s
      - uncertainty = greater value of ±0.5 K + 0.007(T_{sky}- T_{ref}) or resolution
    - Ground surface temperature, T_{sfc}
      - resolution = ±0.10 K at T_{gnd} = 293 K, ε = 1.0, and t_r = 3.0 s
      - uncertainty = greater value of ±0.5 K + 0.007(T_{gnd}- T_{ref}) or resolution

      where ε is emissivity, t_r is time resolution, and T_{ref} is internal reference temperature

Morris: ARM Instrument Uncertainty

- Laser Ceilometer (VCEIL)
  - Vaisala CL31 Ceilometer
    - Cloud base height
      - uncertainty = ±10 m
    - Vertical visibility
      - uncertainty = ±10 m
    - Backscatter profile, range and sensitivity normalized
      - resolution = ±10 m
      - uncertainty = ±0.1 $(10000*srad*km)^{-1}$

Morris: ARM Instrument Uncertainty

- Total Sky Imager (TSI)
  - Yankee Environmental Systems TSI-660
    - Cloud fraction
      - uncertainty = < 10%
      - determined by comparison of cloud fraction retrievals from both short-wave flux analysis and trained human weather observers
      - TSI sky filter thresholds used in image processing are set subjectively by human observation of color and contrast
      - Long CN. 2010. "Correcting for circumsolar and near-horizon errors in sky cover retrievals from sky images." *The Open Atmospheric Science Journal*, 4, doi:10.2174/1874282301004010045.

Total Precipitation Sensor (TPS)

Yankee Environmental Systems

Mentor: Jessica Cherry

- No quantitative error data provided by vendor or existing publications.
- Error is largely a function of the precipitation particle size. Small particles are ignored by algorithm, especially in high winds (signal smaller than noise). In Barrow, this is relatively common. From comparison with a nearby gauge, cumulative seasonal undercatch of the TPS caused by this algorithm problem was in the ballpark of 30%. So consider this a precision bias. Accuracy is not known because of biases in the gauge used for comparison.
- Errors in the TPS are likely much lower in any other location.

Aerosol Observing System (AOS) measurement uncertainties

(Jefferson)

TSI nephelometer aerosol scattering measurements

The measurement uncertainty associated with the TSI 3563 nephelometer has five known sources: noise, calibration drift, calibration error, truncation of forward scattered light and STP corrections.

$$du_{total}^2 = du_{noise}^2 + du_{drift}^2 + du_{cal}^2 + du_{trunc}^2 + du_{stp}^2.$$

Particle Soot Absorption Photometer (PSAP) aerosol absorption measurements

The PSAP uncertainty stems from 3 variables: instrument precision (includes flow uncertainty), noise, and filter spot size area.

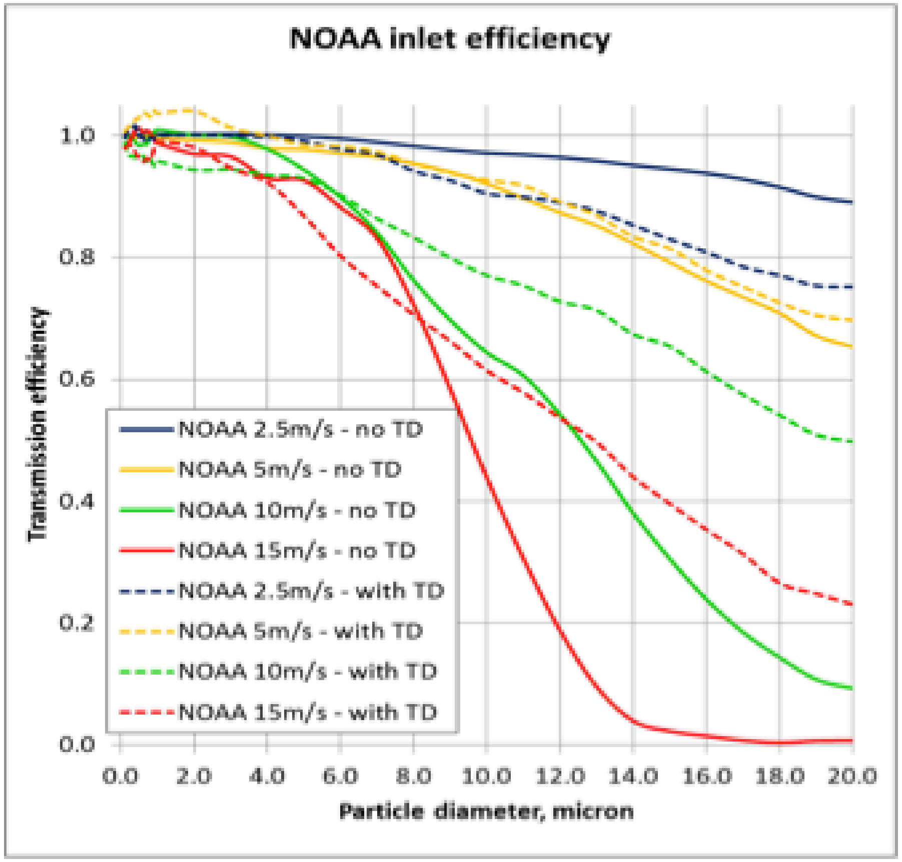
$$du_{total}^2 = du_{precision}^2 + du_{noise}^2 + du_{spot}^2$$

TSI condensation particle counter (CPC)

CPC uncertainty is difficult to ascertain without comparison to a reference. Known sources of uncertainty are from the flow calibration, coincidence corrections at high concentrations and instrument malfunction. A qualitative check is to daily compare the CPC signal to the CCN signal for any abnormalities.

Aerosol sample line losses: (Jefferson)

NOAA and DRI hired a computational fluid dynamic (CFD) firm to model of their aerosol inlets and manifold. The results of that model are shown in the graph below for the inlet used on the SGP, AMF1 and NSA AOS systems. From the model few particle losses were observed for particles below 3 *um* in diameter with and without turbulent dispersion (TD). Inlet transmission efficiency decreased at higher wind speeds.



Detailed analysis of uncertainty for TSI nephelometer scattering corrections

(Jefferson)

Noise:

$\delta\sigma_{sp,noise}(\sigma_{sp},\tau)=2*\delta(\sigma_{m,air}(\tau_0))*(\tau_0/\tau)^{1/2}*((\sigma_{sp}+\sigma_{air}+W)/(\sigma_{air}+W))^{1/2}$

Drift (calibration drift in terms of offset (O) and slope (S) of the weekly calibration checks):

$\delta_{drift}=((2*\delta O)^2+(2*\delta S*\sigma_{sp})^2)^{1/2}$

Calibration (error in calibration constants, photon counting, T and P):

$\delta\sigma_{sp,drift}=0.07*\sigma_{sp}$

STP:

$((2*\delta T/273.15)^2+(2*\delta T\delta P/(273.15*1013.2)^2)^{1/2}$

Truncation:

Table 1 Mean (max) values for uncertainty in the nephelometer truncation correction as a function of wavelength and measurement size cut. Max uncertainty values are at the smaller Angstrom exponents with higher forward scattering (from Table 4 in Anderson and Ogren (1998)).

	σ_{sp}(450 nm)	σ_{sp}(550 nm)	σ_{sp}(700 nm)
No cut	0.05 (0.22)	0.05 (0.21)	0.04 (0.17)
Sub-um	0.01 (0.03)	0.01 (0.02)	0.004 (0.01)

TSI Nephelometer instrument uncertainty with sub *um* scattering coefficient at 550nm (Bsp) for 1 min average time.

Table 4. Instrument noise, drift, and uncertainty factors.

Bsp	Noise	Drift	Calibration	Truncation	STP	**Total**
1	1.25	0.44	0.08	0.02	0.003	**1.33**
10	1.56	0.80	0.75	0.22	0.03	**1.92**
20	1.84	1.20	1.50	0.44	0.07	**1.70**
50	2.50	2.40	3.75	1.10	0.17	**5.23**
100	3.32	4.40	7.51	2.10	0.34	**9.58**

Detailed analysis of PSAP uncertainty

(Jefferson)

Precision: (Müller et al., 2011, comparison of 6 psaps)

$du_{precision} = 0.08*\sigma_{ap}$

Noise: (Virkkula et al., 2005)
Calculated from tests of filtered air at 1 min average time
$du_{noise} = 0.5\ Mm^{-1}$

Spot: (std dev of area calculation from pixal counting of 3 digital photos)

$du_{spot} = 0.018*\sigma_{ap}$

Flow:
Uncertainty in flow calibration is included in the instrument precision, which was determined from a comparison of 6 psap instruments (Müller et al., 2011.)

Additional uncertainty:
PSAP noise and uncertainty was found to increase in high RH environments and in air with high concentrations of semi-volatile organics (Lack et al. 2008). This increase in the instrument uncertainty is attributed to water or organics being absorbed into the filter substrate and changing the filter transmission properties. Instrument accuracy may vary with the aerosol type, whether brown or black carbon, and needs to be studied further.

VAPS and other instruments (Jefferson)

The uncertainty many of the VAPS and newer instruments have yet to be evaluated.

Cloud Condensation Nuclei Counter

Uncertainty in this instrument stems from the instrument flow, temperature, pressure, column thermal resistance, system leaks, inlet losses and counting efficiency. A qualitative check is to compare the CCN at the highest %SS to the CPC counts. The instrument is still in the evaluation stage and a detailed analysis of the calibration drifts and thermal resistance is forth coming. Rose et al., *ACP,* 2008 give a detailed study of instrument uncertainty.

AOS VAPS

The uncertainty in all AOS VAPS will increase at low signal counts and for large particles with low Angstrom exponents. The aerosol hygroscopic growth, *fRH,* is especially sensitive to the sensor RH calibration as it involves a power law fit of (wet scattering/dry scattering) to RH. Many of the AOS VAPs are semi-qualitative. When using them it’s good to look at relative changes and regard data with smaller particles and higher scattering and absorption coefficients as being more robust.

Table of uncertainty in %SS in CCN from Rose et al., *acp,* 2008 (Jefferson)

Table 4. Overview of characteristic calibration and measurement uncertainties affecting %SS in the CCNC (for SS>0.1%): statistical uncertainties are characterized by observed relative standard deviations (preceded by "±"); systematic errors are characterized by observed/calculated maximum relative deviations (preceded by a sign indicating the direction of bias, if known).

source of uncertainty	deviation of ss (%)
Measurement precision (hours)	±1
Condition variability (weeks)	±5
Changes of instrument properties (months)	–10
CCNC flow model extrapolations	10
Doubly charged particles	+3
DMA transfer function	<1
Effective temperature of CCN activation	–5
Solution density approximation	-1
Surface tension approximation	-2
Water activity representation for NaCl	–5 to +9
Particle shape correction for NaCl	up to 18

Coulter: UNCERTAINTIES ASSOCIATED WITH SIGMA SPACE MICRO PULSE LIDARS

<u>MANUFACTURER'S ESTIMATES</u>:

UNKNOWN

<u>MENTOR'S ESTIMATE</u>:

DETECTED SIGNAL: 1 photon/μs

HEIGHT: 0.5*Range_gate (15, 30, 75 m)

Coulter: UNCERTAINTIES ASSOCIATED WITH 915/1290 MHZ RADAR WIND PROFILERS

MANUFACTURER'S ESTIMATES:

WIND SPEED: < 1 m/s

WIND DIRECTION: < 10 deg

HEIGHT: ~6 m + 0.5*Range_gate

MENTOR'S ESTIMATE:

RADIAL WIND SPEED: < 0.5 m/s

Coulter: UNCERTAINTIES ASSOCIATED WITH SCINTEC SODARS

MANUFACTURER'S ESTIMATES:
UNKNOWN
MENTOR'S ESTIMATE:
WIND SPEED: < 0.6 m/s
WIND DIRECTION: < 4 deg
HEIGHT: 0.5*Range_gate
RADIAL WIND SPEED: < 0.25 m/s

AERI Instrument Uncertainty

(Gero)

Simple statement of uncertainty

- The absolute radiometric calibration error shall be < 1% (3σ) of ambient blackbody radiance
- The absolute knowledge of the spectral calibration shall be known to < 5 ppm (3σ)

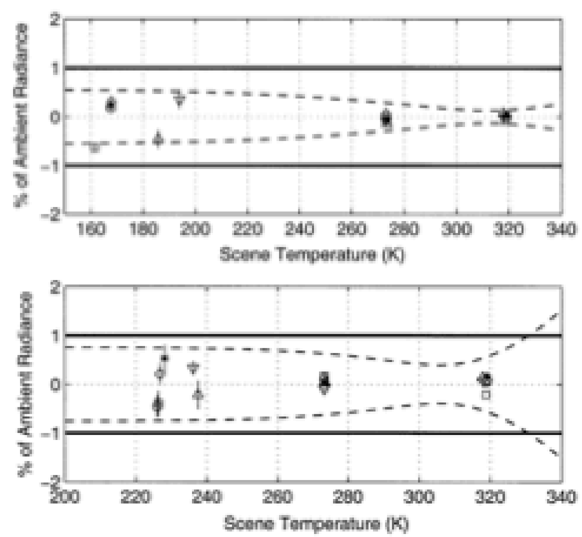
Complete expression of uncertainty

Radiometric Calibration:

- The absolute radiometric calibration error shall be < 1% (3σ) of ambient blackbody radiance
- The radiometric calibration reproducibility shall be < 0.1% (3σ) of ambient blackbody radiance

Spectral Calibration:

- The absolute knowledge of the spectral calibration shall be known to < 5 ppm (3σ)
- The stability of the spectral calibration shall be < 1 ppm (3σ)



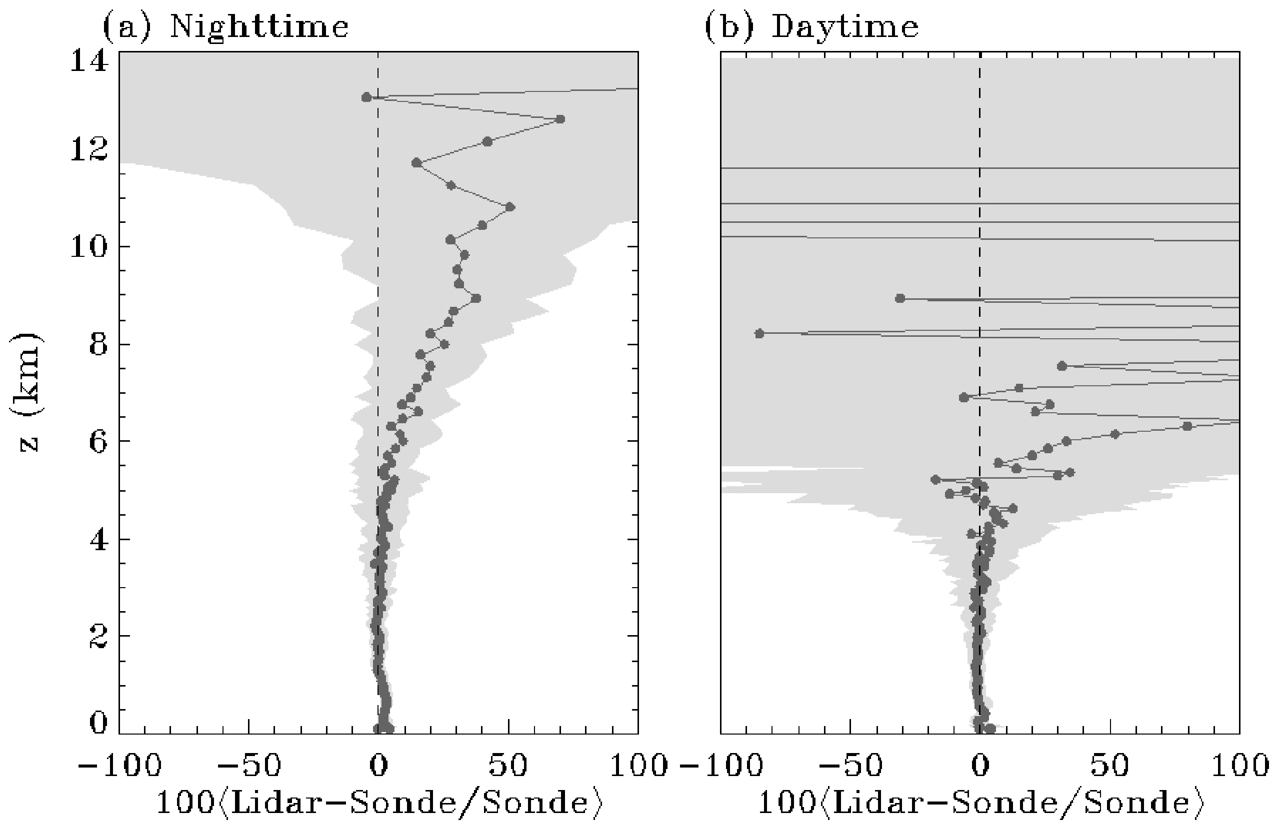
Knuteson et al., *J. Atmos. Oceanic Technol.* 2004.

Noise (RMS for 2 min. ambient blackbody view):

- The NESR shall be < 0.2 mW/(m^2 sr cm^{-1}) for 670–1400 cm^{-1} (Standard AERI)
- The NESR shall be < 0.4 mW/(m^2 sr cm^{-1}) for 420–1400 cm^{-1} (Extended Range AERI)
- The NESR shall be < 0.0015 mW/(m^2 sr cm^{-1}) for 2000–2600 cm^{-1} (except 2300–2400 cm^{-1} where CO_2 absorption reduces responsivity)

Newsom: ARM Raman Lidar Water Vapor Mixing Ratio Error Estimates

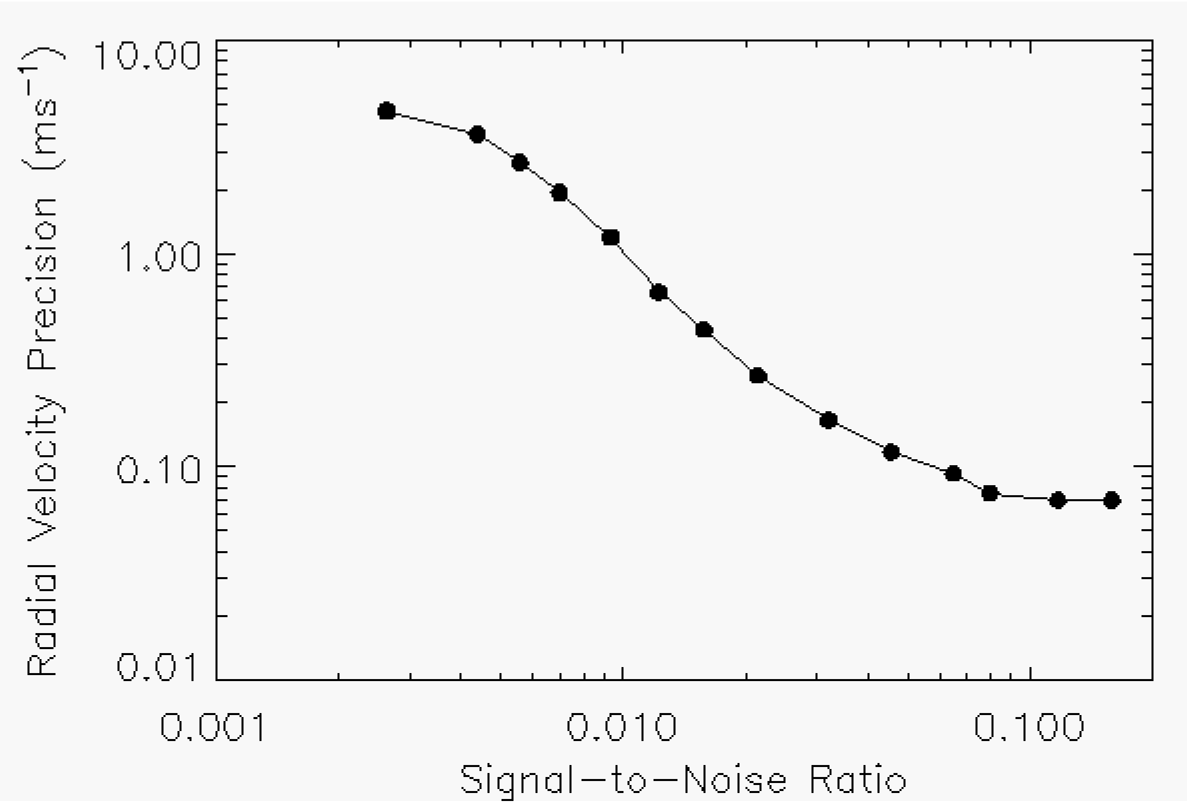
Based on comparison to radiosondes



- Night time (N2 background < 0.01 MHz) soundings = 120
- Daytime soundings (N2 background > 1.0 MHz) = 140
- Analysis period covers 1 April 2007 to 30 Sept 2007

ARM
CLIMATE RESEARCH FACILITY

Newsom: ARM Doppler Lidar Radial Velocity Error Estimates



SNR	Radial Velocity Error (ms^{-1})
0.0026	4.6416
0.0044	3.6169
0.0056	2.6607
0.0070	1.9201
0.0094	1.1885
0.0123	0.6556
0.0159	0.4382
0.0215	0.2661
0.0321	0.1647
0.0457	0.1166
0.0651	0.0926
0.0802	0.0750
0.1598	0.0694

- Error < 10 cm s^{-1} for SNR>0.05 (-13dB)
- Radial velocity error is parameterized in terms of the return signal strength or SNR
- DL datastreams include both radial velocity and signal intensity (SNR+1)

ARM CLIMATE RESEARCH FACILITY

ARM Carbon group Instrument Precision

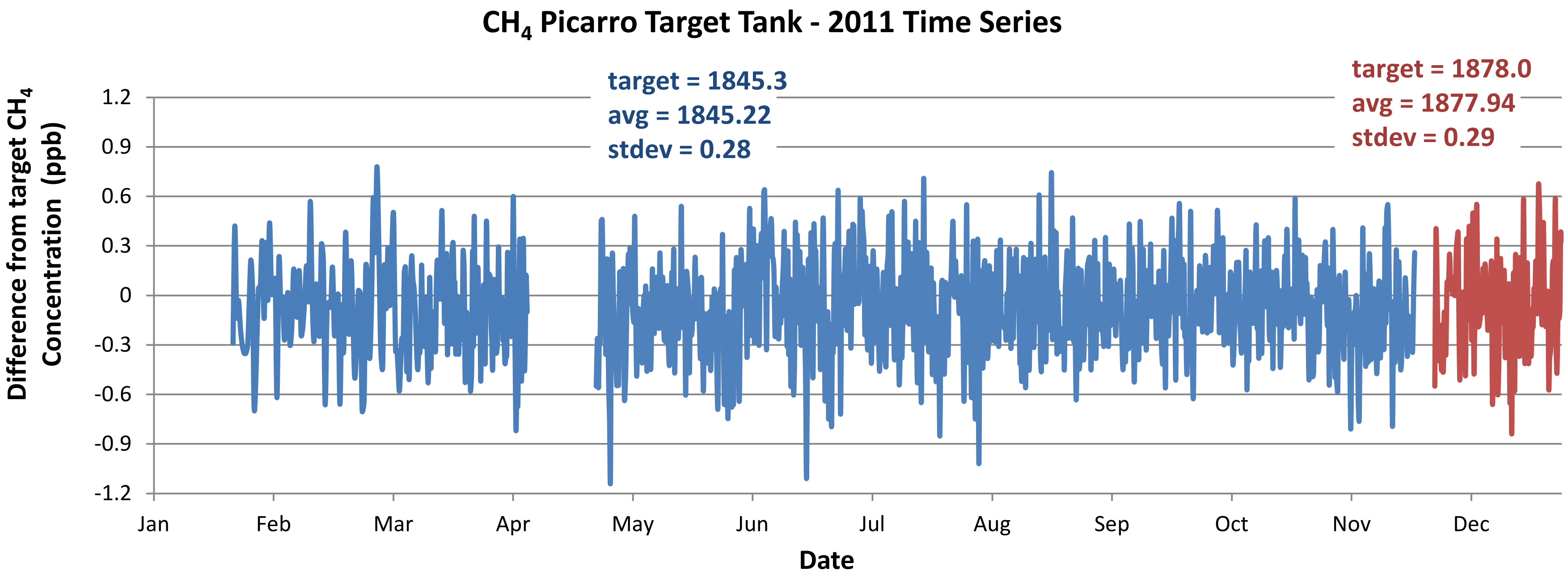
CO_2, CH_4, CO, isotope flasks, trace gas flasks

Margaret Torn
Sébastien Biraud
Marc Fischer
Joe Berry

Picarro for atmospheric CO_2 and CH_4 (sgppgsC1)

Species	Field Precision	Field Accuracy	Factory-Certified Precision	WMO Goal for Network compatibility
CO_2 (ppm)	0.06	-0.02	0.04	0.1
CH_4 (ppb)	0.28	0.08	0.40	2.0

Note: Field precision and accuracy calculated from target cylinder measured in the field.

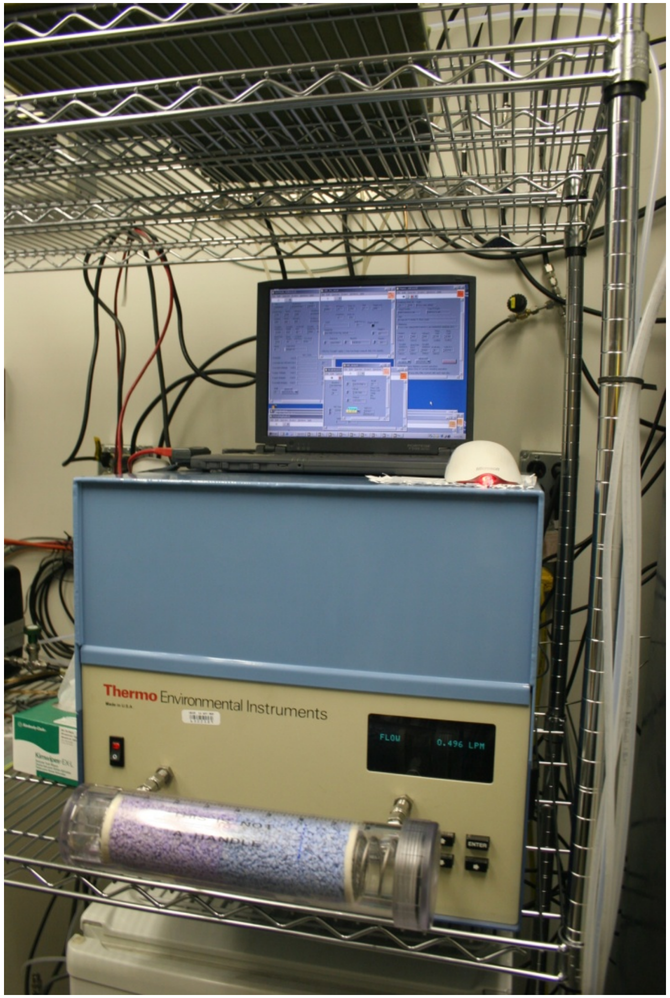


Rev: 2012-03-01

Thermo Scientific: Carbon monoxide (sgpcoC1)

Field Precision	10.0 ppb
Field Accuracy	5.0 ppb
Factory-Certified Precision	100 ppb
WMO Goal for Network compatibility	2.0 ppb

Note: Field precision and accuracy calculated from target cylinder measured in the field.



Isotopes from flask analysis (sgpcarbonflasksC1, sgpco2)

Species	Lab Precision	Lab Accuracy	WMO Goal for Network compatibility
^{13}COO	0.03 ‰	0.01 ‰	0.01 ‰
$CO^{18}O$	0.03 ‰	0.00 ‰	0.05 ‰

Ribas-Carbo, M., Still, C. and Berry, J. 2002. Automated system for simultaneous analysis of $\delta^{13}C$, $\delta^{18}O$ and CO_2 concentrations in small air samples. *Rapid Communications in Mass Spectrometry* **16**, 339-345

Rev: 2012-03-01

Trace gases from flask analysis (sgpcarbonflasksC1, sgpnoaasurface)

Species	Field Precision	WMO Goal for Network compatibility
CO_2	0.03 ppm	± 0.1 ppm
CH_4	1.2 ppb	± 2.0 ppb
CO	0.3 ppb	± 2.0 ppb
N_2O	0.4 ppb	± 0.1 ppb

http://www.esrl.noaa.gov/gmd/outreach/behind_the_scenes/measurementlab.html

Kiedron: Rotating Shadowband Spectroradiometer (RSS) Uncertainty Estimates

Products: I_{tot} -Total Horizontal Irradiance, I_{dir} -Direct Normal Irradiance, I_{dif} -Diffuse Horizontal Irradiance spectra

File Data Structure: (seven columns ×1040 pixels tall): λ, I_{tot}, I_{dir}, I_{dif}, nsr_{tot} , nsr_{dir}, nsr_{dif}; where λ – wavelength [nm], $I_x(\lambda)$ is irradiance in [$Wm^{-2}\,nm^{-1}$] and $nsr_x(\lambda)$ is unitless1-standard deviation noise-to-signal-ratio of photon noise and CCD read noise in units of irradiance. Standard deviations are nonegative truncated so $nsr_x \leq 2$. They are not statistically independent among tot, dir and dif components; however the covariance can be neglected when calculating ratios, e.g. of DDR= I_{dif} /[I_{dir} cos(SZA)].

Wavelength Calibration: Each scan (1/60s) has wavelengths λ(pixel) corrected to within 1/20 pixel (1-sigma) with respect to reference spectrum that has λ_{ref}(pixel) (with 1/15 pixel uncertainty).

Irradiance Calibration: Traceable to NIST FEL lamp scale via Licor Calibrator and ASRC Portable Calibrator with 2-sigma uncertainty $u_{Lamp}(\lambda)$ that includes both (Type A and B uncertainties) with respect to SI values. For RSS wavelengths $u_{Lamp}(\lambda)$ is interpolated from the following NIST table:

350nm	654.6nm	900nm	1300nm
1.09%	0.91%	1.08%	1.13%

Irradiance uncertainty (2-sigma) formula for a given wavelength λ for x=tot,dir,dif

$$u_x(\lambda) = I_x(\lambda)\cdot\sqrt{[2\cdot nsr_x(\lambda)]^2 + [u_{Lamp}(\lambda)/100]^2 + [u_{STS}(\lambda)]^2 + [u_{LTS}(\lambda)]^2} \quad [W\cdot m^{-2}\cdot nm^{-1}]$$

Short and long term stability uncertainties $u_{STS}(\lambda)$ and $u_{LTS}(\lambda)$ are determined from lamp calibrations and Langley calibrations, respectively. The former has not been determined, yet while the latter can be determined from Langley process or virtually eliminated by it. The Langley data are available and posted but are not an official data stream product.

Wavelength uncertainty (2-sigma) formula for a given wavelength λ

$$u_\lambda(\lambda) = \gamma\cdot\frac{d\lambda(p)}{dp} \quad [nm] \quad \text{where} \quad \gamma = \sqrt{(2/20)^2 + (2/15)^2} = 0.17\,\text{pixel}$$

Diffuse-to-Direct uncertainty (2-sigma) formula for a given wavelength λ

$$u_{DDR}(\lambda) = 2\frac{I_{dif}(\lambda)}{I_{dif}(\lambda)\cos(SZA)}\sqrt{[nsr_{dif}(\lambda)]^2 + [nsr_{dir}(\lambda)]^2}$$

Collins: SGP HTDMA / APS uncertainty estimates

	Simple		*Probable range*		*Sources*	
	Size	**Conc.**	**Size**	**Conc.**	**Size**	**Conc.**
DMA (SMPS)	5%	10%	15% @ 20 nm 3% @ 100 nm 10% @ 500 nm	20% @ 20 nm 5% @ 100 nm 20% @ 500 nm	• HV error ↘ • Flow error ↗ • Count rate ↘↗ • Evaporation ↘	• Charging probability ↘↗ • Count rate ↘↗ • Inlet/tubing losses ↘ • CPC η ↘
APS	10%	20%	20% @ 500 nm 10% @ 1 μm 10% @ 5 μm	10% @ 500 nm 10% @ 1 μm 20% @ 5 μm	• Particle density → • Count rate ↗	• Inlet/tubing losses ↗ • Laser power → • Optics alignment →
HTDMA	3%	3%	10% @ 13 nm 2% @ 100 nm 10% @ 600 nm	10% @ 13 nm 2% @ 100 nm 10% @ 600 nm	• Shape factor ↘ • Cal. correction ↘↗ • Count rate ↘↗ • RH error → • Cal. source →	• Count rate ↘↗ • CPC η ↘

→ Uncertainty independent of particle size

↘ Uncertainty largest towards small particle end of size distribution

↗ Uncertainty largest towards large particle end of size distribution

↘↗ Uncertainty has a minimum in middle of measured size range

Aerosol Observing Systems Uncertainty Analysis

Springston, Kuang, Senum, Sedlacek, Manvendra, Mei, Lee, and Coulter

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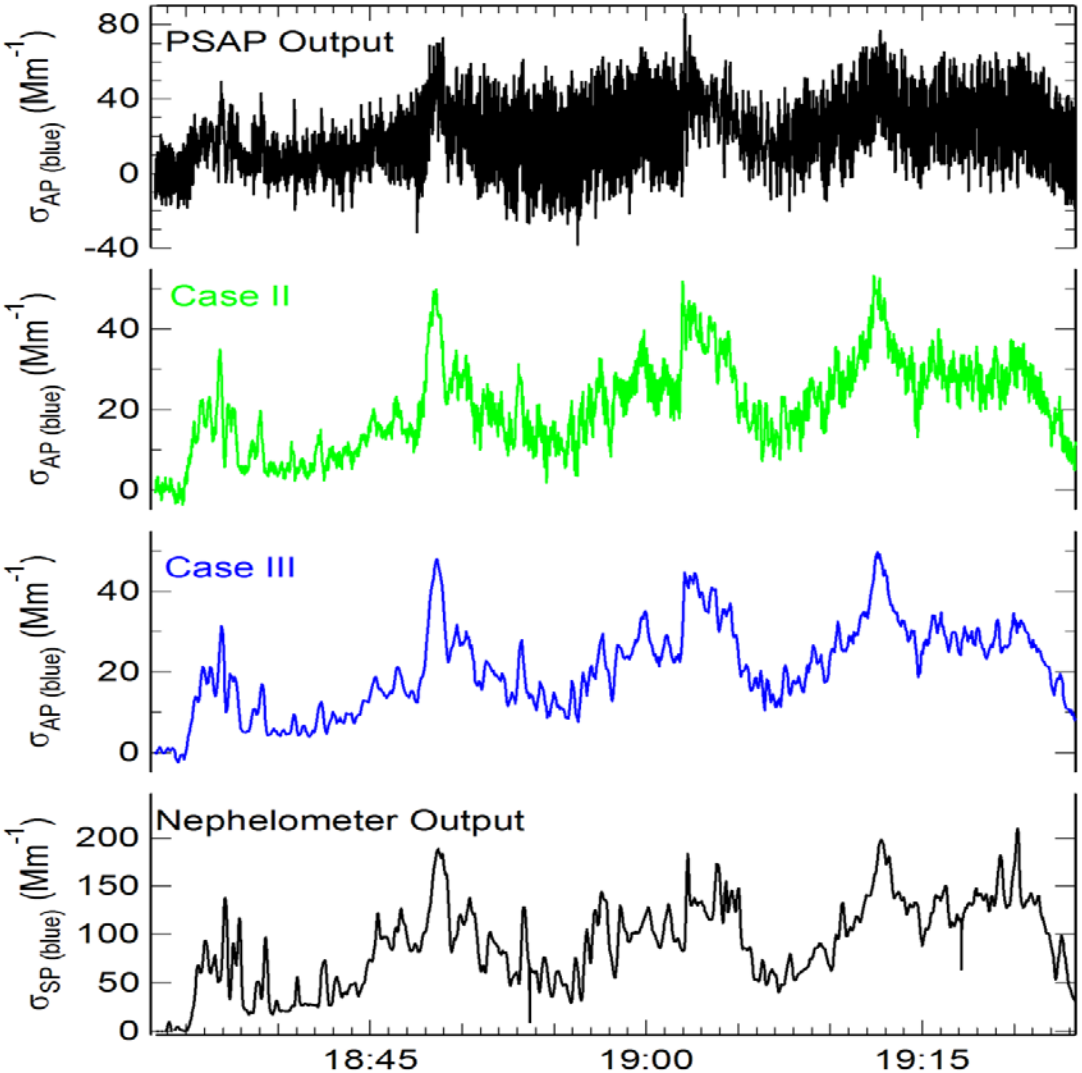
Instrument Uncertainty Analysis

General comments:

- Most ARRA instruments do not yet have sufficient operational history under real-world conditions to robustly assess uncertainties
- $\sigma_{vendor} \neq \sigma_{laboratory} \neq \sigma_{field}$ (in most cases substitute < for ≠)
- σ = f(operator, calibration history, local matrix, time . . .)
- σ meaningless with τ !!
- Only god knows the true accuracy
- What is most valuable varies depends on the data application
- **Practically,** the best measure is the Mentor's assessment of campaign data results

Therefore:

Application to Ambient Measurements



Aircraft-based sampling (Δt = 2-sec)

Raw data averaged (t_{avg}= 12-sec)

Case II (moving boxcar w/ascii stream)

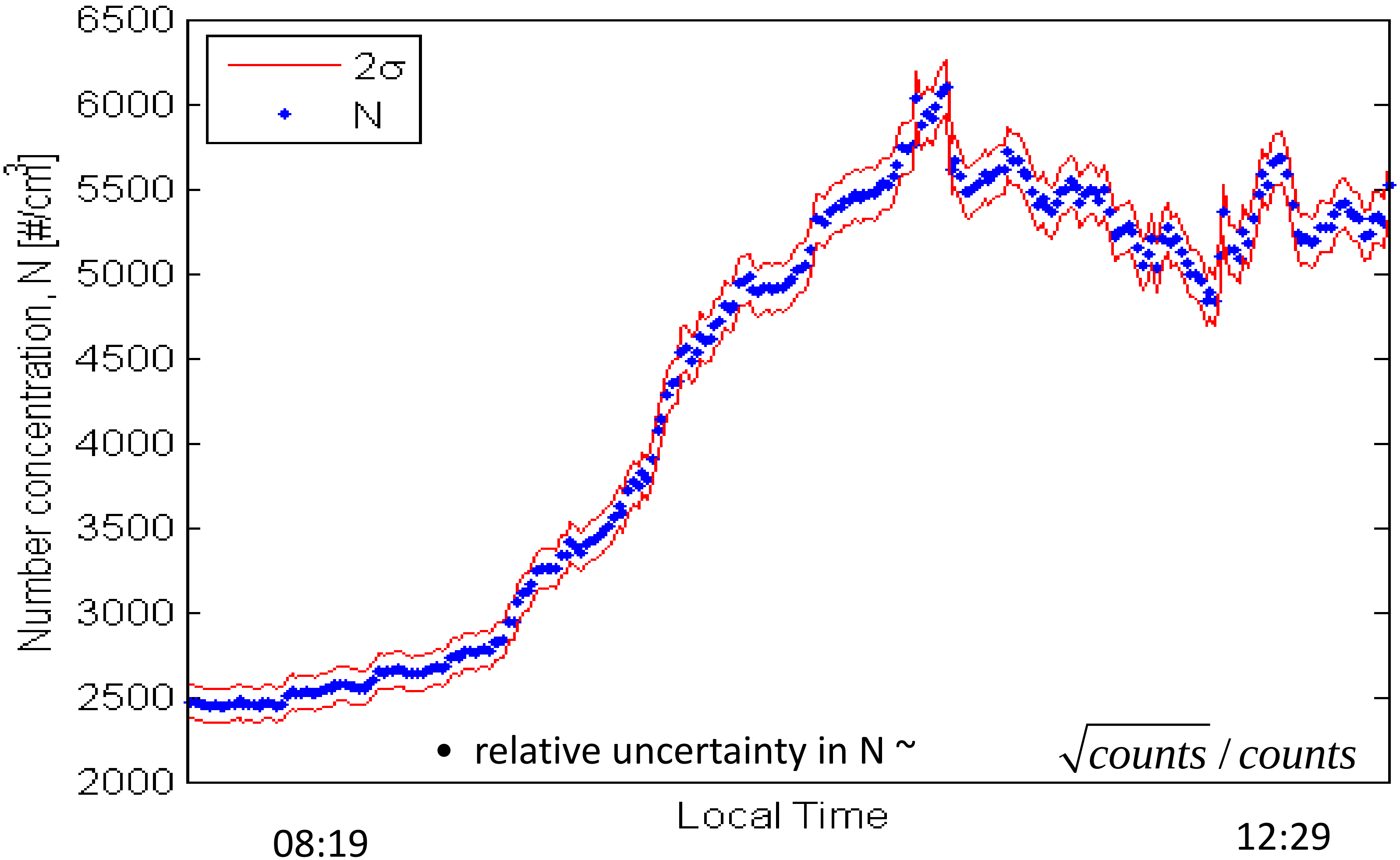
Case III (using Hex stream)

MILAGRO

Aerosol Counters I	
Instrument (Acronym)	Condensation Particle Counter (CPC)
Make/Model	TSI 3772
Mentor/Affiliation	Kuang/BNL
Platform(s)	AMF2, MAOS A, TWP-D, NSA-O, Azores
Species	N > 10 nm
Precision	~5-10% (resolution @ 1 s)
Accuracy	±10% @ < 1 x 10^4 part/cm^3 Manufacturer's data
Notes	Units have variable dilution system accurate to ±10% for a combined accuracy of ±14%

Aerosol Counters II	
Instrument (Acronym)	Ultra Fine Condensation Particle Counter (UCPC)
Make/Model	TSI 3776
Mentor/Affiliation	Kuang/BNL
Platform(s)	MAOS A
Species	N > 2.5 nm
Precision	~5-10% (resolution @ 1 s)
Accuracy	±10% @ < 3 x 10^5 part/cm^3 Manufacturer's data
Notes	

Condensation Particle Counter [3772 and 3776 CPC]
Instrument Uncertainty



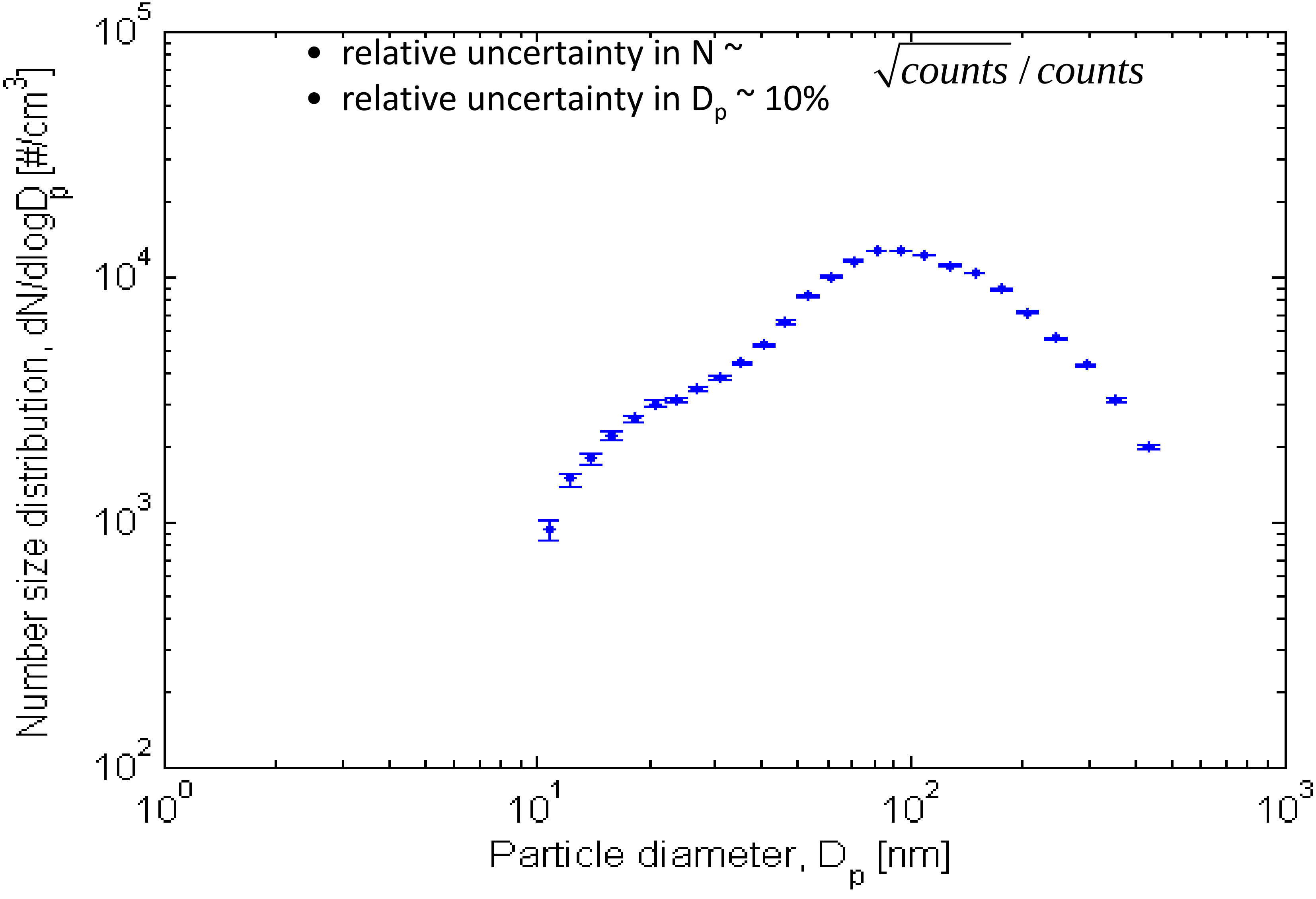
- relative uncertainty in N ~ $\sqrt{counts} / counts$

Aerosol Size Distribution I

Instrument (Acronym)	Ultra-High Sensitivity Aerosol Spectrometer (UHSAS)
Make/Model	DMT UHSAS
Mentor/Affiliation	Senum/BNL
Platform(s)	MAOS A, NSA-O, Azores
Species	N 0.06 – 1µm N count/sec
Precision	3% per abs (1.53 RI) Larger of 100*Sqrt(N)/N or 3%
Accuracy	
Notes	Mie theory, Counting Statistics, Calib.

Aerosol Size Distribution II	
Instrument (Acronym)	Scanning Mobility Particle Sizer (SMPS)
Make/Model	TSI 3080/3772
Mentor/Affiliation	Kuang/BNL
Platform(s)	MAOS A
Species	dN/dlogDp for Dp: 10 – 500 nm
Precision	±5%
Accuracy	±15%
Notes	Uncertainties for 5-min measurement time

Scanning Mobility Particle Spectrometer [SMPS]
Instrument Uncertainty



Aerosol Optical Properties I

Instrument (Acronym)	Particle Soot Absorption Photometer (PSAP)
Make/Model	Radiance PSAP
Mentor/Affiliation	Sedlacek/BNL
Platform(s)	AMF2, MAOS A, TWP-D, NSA-O, Azores
Species	Particle absorbance
Precision	2σ=0.2 Mm^{-1} (@ 60 s)
Accuracy	
Notes	~10% uncertainty in filter area + 10% uncertainty in flow implies 14% additional uncertainty

Aerosol Optical Properties II

Instrument (Acronym)	Ambient Nephelometer (Neph)
Make/Model	TSI 3563
Mentor/Affiliation	Senum/BNL
Platform(s)	AMF2, MAOS A, TWP-D, NSA-O, Azores
Species	Particle scattering
Precision	0.25 Mm^{-1} (95% CI @ 5 min)
Accuracy	
Notes	Literature value

Aerosol Optical Properties III

Instrument (Acronym)	Single Particle Soot Photometer (SP2)
Make/Model	DMT SP2
Mentor/Affiliation	Sedlacek/BNL
Platform(s)	MAOS A
Species	Individual particle incandescence
Precision	5-10%
Accuracy	30%
Notes	Accuracy due to uncertainties associated with OC/EC content of calibration standards

Aerosol Optical Properties IV

Instrument (Acronym)	Photo Acoustic Soot Spectrometer (PASS-3)
Make/Model	DMT PASS-3
Mentor/Affiliation	Manvendra/LANL
Platform(s)	MAOS A
Species	Particle absorbance
Precision	Not reported by mentor
Accuracy	Not reported by mentor
Notes	

Aerosol Optical Properties V

Instrument (Acronym)	Aethalometer
Make/Model	Magee Sci. Aethalometer
Mentor/Affiliation	Sedlacek/BNL
Platform(s)	MAOS A
Species	Particle absorbance
Precision	16% LOD 100 ng/m^3 (@ 5 min)
Accuracy	
Notes	Prec. (Chow et al., J Air & Waste Manage. Assoc. 58:141-163, 2008) LOD. (Lim et al., JGR 108, 2003)

Aerosol Composition I

Instrument (Acronym)	Aerosol Chemical Speciation Monitor (ACSM)
Make/Model	Aerodyne ACSM
Mentor/Affiliation	Mei/BNL
Platform(s)	MAOS A, TWP-D
Species	PM1
Precision	~15-30% (resolution @ 30 min)
Accuracy	±10%, depending on the accuracy of DMA/CPC used to calibrate ACSM
Notes	LOD (μg/m^3): Organic: 0.3 Sulfate: 0.4 Nitrate: 0.2 Ammonium: 0.5 Chloride: 0.2

Aerosol Composition II

Instrument (Acronym)	Particle-Into-Liquid Sampler – Ion Chromatograph – Total Organic Carbon (PILS-IC-TOC)
Make/Model	Assembled from Components
Mentor/Affiliation	Lee/BNL
Platform(s)	MAOS C
Species	NH_4, Na, K, Ca, Mg, Cl, NO_3, SO_4, Oxalate, Br and PO_4 or TOC
Precision	15% (15-min integration for ions/ 5-min integration of TOC)
Accuracy	15%
Notes	LOD (µg/m^3): anions: 0.01 cations: 0.03 TOC: 0.5

Aerosol Hygroscopicity I

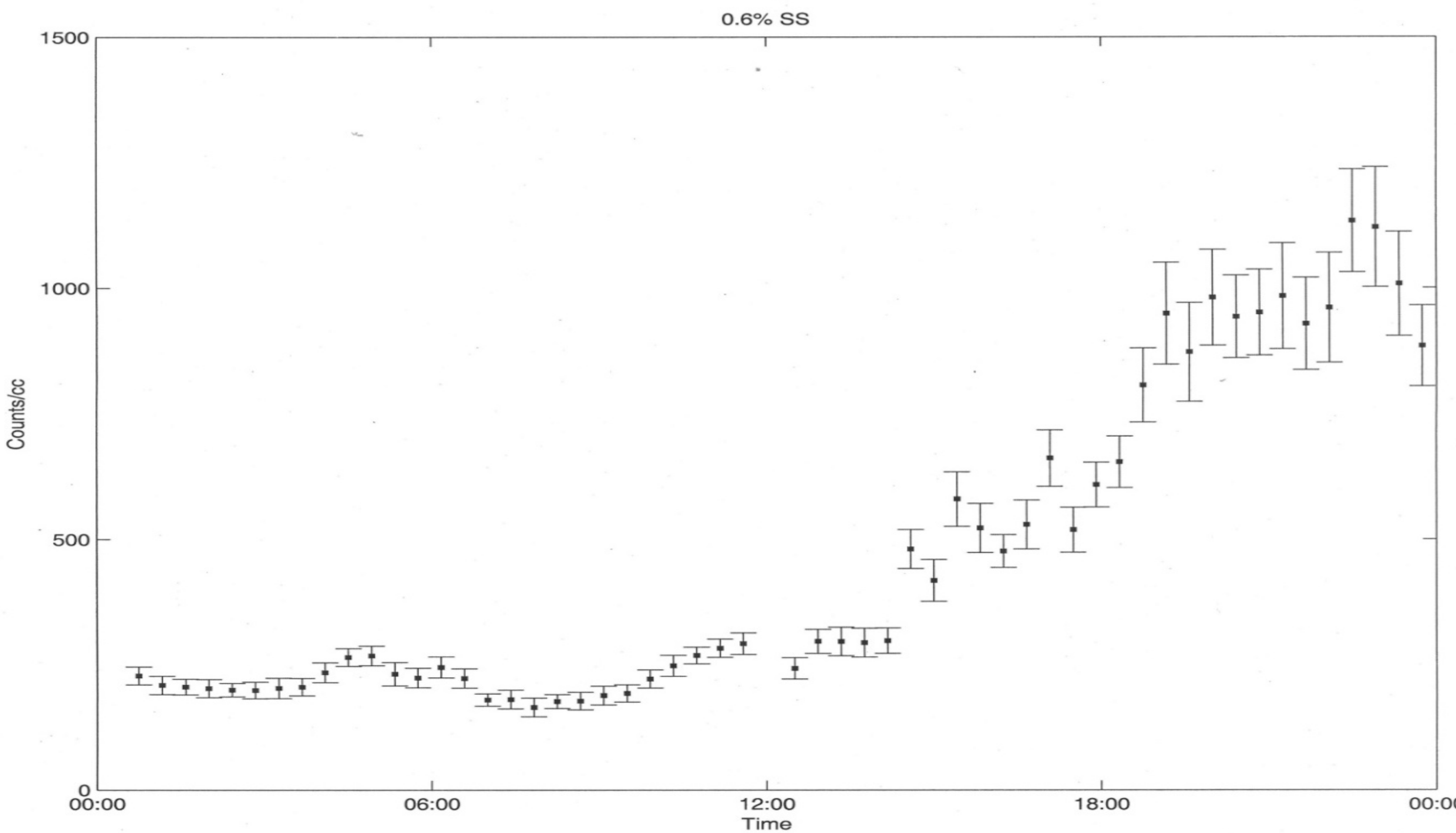
Instrument (Acronym)	Hygroscopic Tandem Differential Mobility Analyzer (HTDMA)
Make/Model	BMI HTDMA
Mentor/Affiliation	Senum/BNL
Platform(s)	AMF2, MAOS A, TWP-D, NSA-O, Azores
Species	Size, growth, f(RH)
Precision	Size: 100*Sqrt(N)/N or 7% (greater) RH: 10%
Accuracy	
Notes	Size based on CPC comparison RH based on calibration

Aerosol Hygroscopicity II

Instrument (Acronym)	f(RH)/"Wet" Nephelometer (f(RH))
Make/Model	RH control/TSI 3563
Mentor/Affiliation	Senum/BNL
Platform(s)	AMF2, MAOS A, TWP-D, NSA-O, Azores
Species	Particle scatter. growth, f(RH)
Precision	Total scatter: 0.25 Mm^{-1} (95% CI @ 5 min), RH: 10%
Accuracy	
Notes	Scatter precision from literature RH based on calibration

Aerosol Cloud Precursors	
Instrument (Acronym)	Cloud Condensation Nuclei Counter
Make/Model	DMT CCN-100, CCN-200 (MAOS only)
Mentor/Affiliation	Senum/BNL
Platform(s)	AMF2, MAOS A, TWP-D, NSA-O, Azores
Species	CCN counts, Saturations
Precision	100*Sqrt(N)/N or 7% (greater) Saturation: 6%
Accuracy	
Notes	Based on theory and delta P

CCN Uncertainities



Trace Gases I

Instrument (Acronym)	Proton Transfer Reaction Mass Spectrometer (PTRMS)
Make/Model	Ionicon Hi-Res PTRMS
Mentor/Affiliation	Lee/BNL
Platform(s)	MAOS C
Species	benzene, toluene, xylenes, isoprene, methylvinylketone/methacrolein, pinene, sesquiterpenes, formic acid, acetic acid, methanol, acetonitrile, and species requested by users
Precision	20% (@ 1 min for surface meas.)
Accuracy	30-60%
Notes	Accuracy depends on reaction rate constants which are known to 50%, and ion transmission efficiencies, known to 25%

Trace Gases II

Instrument (Acronym)	Off-Axis ICOS (CO)
Make/Model	Los Gatos CO/N_2O/H_2O
Mentor/Affiliation	Springston/BNL
Platform(s)	MAOS C, NSA-O, Azores
Species	CO
Precision	2σ=2 ppbv (precision @ 1s)
Accuracy	greater of 2 ppbv or ±5 %
Notes	Mentor assessed from program data

Trace Gases III	
Instrument (Acronym)	Ozone Analyzer (O_3)
Make/Model	TEI 49i
Mentor/Affiliation	Springston/BNL
Platform(s)	AMF2, MAOS C, TWP-D, NSA-O, Azores
Species	O_3
Precision	2σ=2 ppbv (precision @ 4s)
Accuracy	greater of 2 ppbv or ±5 %
Notes	Mentor assessed from program data

Trace Gases IV

Instrument (Acronym)	Oxides of Nitrogen Analyzer ($NO/NO_2/NO_y$)
Make/Model	AQD Ground NO_x
Mentor/Affiliation	Springston/BNL
Platform(s)	MAOS C
Species	$NO/NO_2/NO_y$
Precision	NO: 2σ=0.01 ppbv (precision @ 15s) NO_2: 2σ=0.03 ppbv (precision @ 15s) NO_y: 2σ=0.05 ppbv (precision @ 15s)
Accuracy	NO: greater of 0.01 ppbv or ±5 % NO_2: greater of 0.03 ppbv or ±5 % NO_y: greater of 0.05 ppbv or ±5 %
Notes	Mentor assessed from program data

Trace Gases V

Instrument (Acronym)	Sulfur Dioxide Analyzer (SO_2)
Make/Model	TEI 43i-TLE
Mentor/Affiliation	Springston/BNL
Platform(s)	MAOS C
Species	SO_2
Precision	2σ=0.5 ppbv (precision @ 10s)
Accuracy	greater of 0.5 ppbv or ±10 %
Notes	Mentor assessed from program data

Local Meteorology I

Instrument (Acronym)	Meteorology Sensor (Met)
Make/Model	Vaisala WXT520
Mentor/Affiliation	Springston/BNL
Platform(s)	AMF2, MAOS A, TWP-D, NSA-O, Azores
Species	Wind Speed/Dir Temperature Barometric P RH Precipitation
Precision	Wind Speed/Dir: 0.1 m/s E/N (resolution @ 1s) Temperature: 0.1ºC (resolution @ 1s) Barometric P:0.1 hPa (resolution @ 1s) RH: 0.1% RH (resolution @ 1s) Precipitation: 0.01 mm
Accuracy	Wind Speed/Dir: greater of ±0.3 m/s or ±3% Temperature: ±0.2 to ±0.7ºC @ -50..60ºC Barometric P: ±0.5 hPa @ 0..30oC, ±1 hPa @ -52..60oC RH: ±3% @ 0..90%RH, ±5% @ 90..100%RH Precipitation: ±5% weather dependent
Notes	Manufacturer

Local Meteorology II

Instrument (Acronym)	SODAR
Make/Model	Scintec MFAS-MFASHX
Mentor/Affiliation	Coulter/ANL
Platform(s)	MAOS C
Species	Wind Speed/Dir Radial Wind Speed
Precision	Wind Speed/Dir: 0.1 m/s; 1 Deg (τ not reported) Radial Wind Speed: 0.1 m/s; (τ not reported)
Accuracy	Wind Speed/Dir: 0.5 m/s; 3 Deg (τ not reported) Radial Wind Speed: 0.3 m/s; (τ not reported)
Notes	Wind Speed/Dir: Manufacturer plus publications Radial Wind Speed: Mentor assessed from data

Local Meteorology III	
Instrument (Acronym)	915 MHz Radar Wind Profiler (RWP)
Make/Model	Vaisala LAP6000
Mentor/Affiliation	Coulter/ANL
Platform(s)	MAOS C
Species	Wind Speed/Dir
Precision	Wind Speed/Dir: 0.01 m/s; 1 Deg (τ not reported)
Accuracy	Wind Speed/Dir: 0.4 m/s; 3 Deg (τ not reported)
Notes	Mentor assessed from data

Flynn: HSRL Slide #1

Primary measurements:

- Particulate backscatter profile, β(z)
- Particulate extinction profile, σ(z)
- Particulate depol ratio, δ(z)

Actual standard deviations for a quasi-stable aerosol layer 3-4 km, no underlying clouds:

Quantity	30m x 30s	60m x 60s	120m x 120s	Dominant
β(z)	6e-3 sr/Mm	4e-3 sr/Mm	3e-3 sr/Mm	Atmos. Stability
σ(z)	60 1/Mm	15 1/Mm	4 1/Mm	Signal levels
dpr(z)	8%	5%	3%	Atmos. stabiliyt

Flynn: HSRL Slide #2

Uncertainties related to:

1. Instrument sensitivity (signal levels, counting statistics)
2. Calibration (instrument stability, signal identification)
3. Atmospheric variability (measured quantity changes…)
4. Atmospheric attenuation (obscuration by opaque/semi-opaque cloud)

Flynn: HSRL slide #3: particulate backscatter coefficients

The calibration uncertainty, atmospheric variability, and counting statistics are presumed to be uncorrelated error sources, and so add in quadrature as:

$$(\partial\beta_{total}(z))^2 = (\partial\beta_{cal}(z))^2 + (\partial\beta_{atmos}(z))^2 + (\partial\beta_{counting}(z))^2$$

Even for averaging intervals as short as 30 s, the instrument sensitivity is sufficient for atmospheric variability to dominate the uncertainty.

Calibration uncertainty is more difficult to quantify as it depends on the system health and the ability to separately identify molecular and total backscatter signals.

Flynn: HSRL Slide #4: Particulate extinction coefficients

The extinction is essentially a derivative of the backscatter quantity so is highly sensitive to the uncertainty in the backscatter profile. Thus to first order calibration issues cancel leaving the counting statistics and underlying atmospheric stability as the dominant error terms.

$$(\partial\sigma_{total}(z))^2 = (\partial\sigma_{atmos}(z))^2 + (\partial\sigma_{counting}(z))^2$$

Flynn: HSRL Slide #5: Depolarization ratio uncertainties

Despite the fact that the HSRL measures circular depolarization ratios, linear depol ratios are directly obtainable and the error analysis is more straightforward so this is what is provided here.

Case 1: low depol ratio.

$$\lim_{P_\perp \to 0} (\partial\Delta)^2 < {NSR_{P_\parallel}}^2 < {NSR_{P_\perp}}^2$$

Case 2: high depol ratio. The linear polarization components are essentially equal but still strongly correlated.

$$\lim_{\Delta \to 1} (\partial\Delta)^2 = 2\left(\frac{\partial P_\parallel}{P_\parallel}\right)^2 [1 - \rho_{\perp\parallel}]$$

Where $0 \le \rho_{\perp\parallel} \le 1$ *is the correlation between* polarization components

Flynn: ASSIST uncertainties Slide #1

Primary measurement:

- Spectral zenith radiance from two channels, ch A & ch B.

Measurement specifications:

- Noise ch A (MCT) < 0.2 mW/(m^2 sr cm^{-1}) for 670 to 1400 cm^{-1}
- Noise ch B (InSb) < 0.015 mW/(m^2 sr cm^{-1}) for 2000 to 2600 cm^{-1}
- Wavenumber determination 5 ppm (< 0.01 1/;cm)
- Wavenumber stability 0.5 ppm (<0.001 1/cm over measurement cycle)

Flynn: ASSIST uncertainties: slide #2

- The uncertainties depend on the BB calibration stability and confidence, on individual detector sensitivity, and on atmospheric transmittance variability. Each of which depends on wavenumber.
- The variability of the calibration radiances is indicative of underlying uncertainty. It can be estimated as:
  – HBB_NEN1 (in summary file)
- Or
  – HBB_NEN2 (in summary file)
- The imaginary component of the calibration is another indication of measurement uncertainty.
  – Sky_NEN (in summary file)

Flynn: SWS uncertainties: slide 1

- Primary measurements: zenith spectra radiance.
- Calibrated from a 30” NIST traceable integrating sphere at NASA Ames having a primary calibration of 2% at 400 nm, ~1% from 500-900 nm, 2-3% 900-1700 nm, 5% 1700-2100 nm.
- This is upper theoretical limit based on calibration source.

Flynn: SWS uncertainties, slide 2

- Comparisons between SWS, SAS-Ze, and Cimel zenith sky radiance yield agreement to within +/- 10% over the visible. This exceeds the quoted accuracy of the integrating sphere but has not been resolved yet.

Flynn: SAS-Ze

- Primary measurement: zenith spectral radiance 350 nm – 1000 nm and 970 nm – 1700 nm.
- In principle this is the same measurements as the SWS. For equivalent spectral resolution these instruments have comparable sensitivity but exhibit an unexplained discrepancy of +/- 10% or more throughout the day. This is unresolved.

Flynn: SAS-He

- Has shown stability versus the NIMFR of ~1-2% over most of the Si CCD spectral range.
- Calibration of the SAS-He Si and InGaAs detectors will be via Langley regression. This is underway. Anticipated to show variability < 1% per month.

ARM Radar Uncertainty

Kevin Widener and Nitin Bharadwaj
Pacific Northwest National Laboratory
March 12, 2012

Uncertainty Definitions

- **Accuracy** – is the closeness of agreement between an measured value and its true value.
- **Repeatability** – is the closeness of agreement between successive measurements of the same thing measured under the same conditions.
- **Reproducibility** - is the closeness of agreement between successive measurements of the same thing measured under the changing conditions.
- **Error** – is the difference between the measured value and the true value.
- **Uncertainty** – is an estimate of error at a 95-percent confidence level.

Radar Probability Definitions

- Minimum Detectable Reflectivity (SNR=0)
- Probability of False Alarm
- Probability of Detection
- False Alarm Rate (FAR)
- Constant False Alarm Rate (CFAR)

What do our radars measure?

- Reflectivity
- Doppler Velocity
- Spectral width
- Spectra
- Dual-polarization parameters
  - Z_{DR} – differential reflectivity
  - ρ_{HV} – correlation coefficient
  - Φ_{DP} – differential phase
  - K_{DP} – specific differential phase

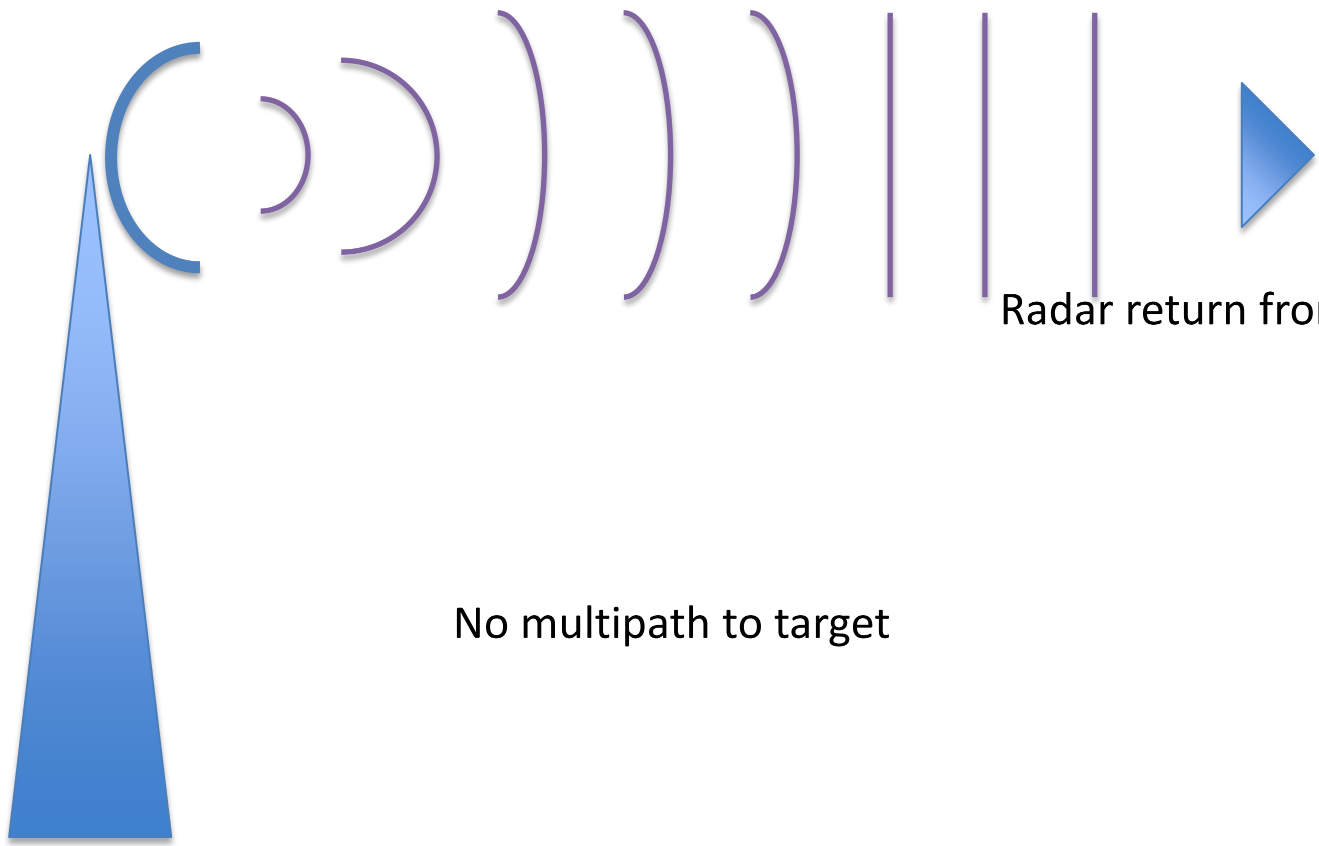
Radar Range Equation

$$Z = 10\log\left(\frac{1024\ln(2)\lambda^2 R^2 P_r L_a L_{sys}}{10^{-18} c\tau\pi^3 G_0^2 |K_w|^2 \theta_{3dB}^2 P_t}\right) \qquad dBZ$$

where:

- Z = *reflectivity (dBZ)*
- λ = *wavelength (m)*
- R = *range (m)*
- P_r = *received power (watts)*
- L_a = *two-way atmospheric loss*
- L_{sys} = *radar system losses*
- c = *speed of light (m/s)*
- τ = *pulse width (s)*
- G_o = *antenna gain*
- $|K_w|^2$ = *index of refraction factor for liquid water at 0 C*
- θ_{3dB} = *antenna beamwidth*
- P_t = *transmit power (watts)*

Uncertainty in an ideal world



Radar Uncertainty Estimates

Radar	Absolute Reflectivity	Doppler Velocity	Spectral Width	Dual-Pol
C-SAPR	4 dB	1.0 m/s	TBD	TBD
X-SAPR	4 dB	1.0 m/s	TBD	TBD
X-SACR	3 dB	1.0 m/s	TBD	TBD
Ka-SACR	3 dB	0.1 m/s	TBD	TBD
KAZR	4 dB	0.1 m/s	TBD	TBD
W-SACR	3 dB	0.1 m/s	TBD	TBD
WACR	4 dB	0.1 m/s	TBD	TBD
SWACR/MWACR	3 dB	0.1 m/s	TBD	TBD

Assumption: SNR > 10 dB, liquid water, unattenuated

Uncertainty Estimates for SIRS, SKYRAD, & GNDRAD Data

ASR Science Team Meeting
2012

Ibrahim Reda, Tom Stoffel, and
Aron Habte

The Guide to the Expression of Uncertainty in Measurement (GUM)*

Basic Steps:

1. ***Determine the measurement equation.***
2. ***Estimate the standard uncertainty*** **(u_i)** associated with each variable in the measurement equation and for each component that might introduce uncertainty to the measurement process (e.g. interpolation, environmental conditions).
3. ***Calculate the combined standard uncertainty*** **(u_c)** by summing in quadrature the standard uncertainties in step 2.
4. ***Calculate the expanded uncertainty*** **(U)** by multiplying the combined standard uncertainty by the coverage factor, k (typically known as Student's "t"), or prescribed coverage factors for known distributions of measurements representing the single value of the quantity to be measured (e.g. Gaussian, triangular, rectangular).

*BIPM; IEC; IFCC; ISO; IUPAP; OIML. (1995).
Guide to the Expression of Uncertainty in Measurement, ISO TAG4, Geneva.

http://www.nrel.gov/docs/fy11osti/52194.pdf

Uncertainty Estimates for SIRS, SKYRAD, & GNDRAD

Simple Expression:

1. ***Determine the measurement equation:***

   Pyrheliometers: $W = V / Rs$

   Pyranometers: $W = (V - Rnet * Wnet) / Rs$

   W = Flux (Wm^{-2})
   V = Thermopile Voltage (μV)
   Rs = Shortwave Responsivity ($\mu V/Wm^{-2}$)
   Rnet = Longwave Responsity
   Wnet = Longwave Irradiance (Pyrgeometer)

2. ***Estimate the standard uncertainty*** **(u_i)** based on Type A and Type B error sources

   e.g., Std Dev; Calibration; Responses: Temperature, Spectral, Angular; Linearity, Stability, etc.

3. ***Calculate the combined standard uncertainty*** **(u_c):**

$$u_c = \sqrt{u_A^2 + u_B^2}$$

4. ***Calculate the expanded uncertainty*** **(U)**

   $U = k * u_c$ (k = 1.96 for large degrees of freedom)

http://www.nrel.gov/docs/fy11osti/52194.pdf

Calibration Uncertainty Estimates

Traceable to SI Units

Radiometer	Expanded Uncertainty $U95 = U_c * 1.96$
Pyranometer	±3%
Pyrheliometer	±2%
Pyrgeometer	± 5 Wm^{-2}*

*@ 300 Wm^{-2} + interim World Infrared Standard Group (WISG) Type B Uncertainty of ±4 Wm^{-2}

http://www.nrel.gov/docs/fy11osti/52194.pdf

Uncertainty Estimates for SIRS, SKYRAD & GNDRAD

Measurement	Abbreviation	Eppley Radiometer Model	Typical Responsivity ($\mu V/Wm^{-2}$)	Estimated Measurement Uncertainty	Value Added (correction for zenith, thermal offset, etc.)
Direct Normal (Beam)	DNI	NIP	8	±3.0% (>700 Wm^{-2})	±2.0% (>700 Wm^{-2})
Diffuse Horizontal (Sky)	DD	PSP	9	+4.0% to -(4%+20 Wm^{-2})	+2.0% to -(2%+4 Wm^{-2})
Diffuse Horizontal (Sky)	DD	8-48	8	+4.0% to -(4%+2Wm^{-2})	+4.0% to -(4%+2Wm^{-2})
Downwelling Shortwave (Global)	DS	PSP	9	+4.0% to -(4%+20 Wm^{-2}) zenith < 80°	+2.0% to -(2%+4 Wm^{-2}) zenith < 80°
Downwelling Longwave (Atmospheric)	DIR	PIR	4	±(5%+4* Wm^{-2}) ±16 Wm^{-2}	±(1%+4* Wm^{-2}) ±5 Wm^{-2}
Upwelling Shortwave (Reflected SW)	US	PSP	9	±3.0%	±2.0%
Upwelling Longwave (Reflected/Emitted LW)	UIR	PIR	4	± 2 Wm^{-2}	±2 Wm^{-2}

*** WISG uncertainty**

All uncertainties are estimated with respect to the Système international d'unités (SI) and represent optimal maintenance and installation.

References:

- Reda, I. (2011). "Method to Calculate Uncertainty Estimate of Measuring Shortwave Solar Irradiance using Thermopile and Semiconductor Solar Radiometers". 20 pp.; NREL Report No. TP-3B10-52194

- Reda, I.; Zeng, J.; Scheuch, J.; Hanssen, L.; Wilthan, B.; Myers, D.; Stoffel, T., 2012. "An absolute cavity pyrgeometer to measure the absolute outdoor longwave irradiance with traceability to International System of Units, SI". Journal of Atmospheric and Solar-Terrestrial Physics 77 (2012) 132-143. http://dx.doi.org/10.1016/j.jastp.2011.12.011

ASR Instrument Team Meeting

AGENDA

1. INSTRUMENT UNCERTAINTY: THE ONE MINUTE MADNESS

The uncertainty estimates of your instrument. This is the one Power Point slide for each instrument that you are responsible for. The slide must have: 1) the "simple" expression of uncertainty, and 2) the expression of uncertainty in your Handbooks. I want to use the one-minute madness format for each of you to provide your slide to the others. (Doug Sisterson)

2. NEW INSTRUMENT HANDOFF

Review the handoff of ARRA (or new) instruments (IRR) and acceptance by Operations (ORR). The process is being tweaked to make it less ambiguous. (Doug Sisterson, Jim Mather, Jimmy Voyles)

2. NEW INSTRUMENT HANDOFF

Currently, the Instrument Readiness Review (IRR) is just one step of multiple processes. It's not the end game.

The SGP has a companion document called the Operational Readiness Review (ORR), but it has not been adopted by the other sites. The ORR is intended to address issues from a site operations perspective (safety issues, documentation, training, parts list, calibrations, etc.).

The ORR does not include the DMF, the DQ Office, or the Archive perspectives. (Oh no, another form…)

2. NEW INSTRUMENT HANDOFF (cont'd)

So, Doug will be assigned an ECR to address the issue but (perhaps) simply modifying the IRR with an additional section that is essentially a checklist for all sites and mobile facilities:

- Have you submitted the updated or new ARM Instrument Handbook,
- Have you conducted training,
- Have you entered in all the spares and components into the OSS,
- Have you provide the DQ Office with data quality algorithms for their weekly data checks,
- Have you provided the Archive with the data release statement,
- Have you approved ingests, etc.

ASR Instrument Team Meeting

3. THE SARS AND YOU

Cyber Security is as real an issue as ESH. We need to do better! (Cory Stuart)

4. INSTRUMENTS FOR THE NEW FIXED SITE AND MOBILE FACILITY

The challenges for building the Eastern North Atlantic (ENA) fixed site in the Azores and the third Mobile Facility for longer-term deployment in the the North Slope of Alaska (NSA) at Oliktok. How's that going to affect you! (Jimmy Voyles)

5. UNMET MEASUREMENT NEEDS

We need to think about unmet measurement needs and what new instrumentation we would need to obtain those measurements. ARM has certainly had a barrage of new ARRA instruments, but they really aren't new: we simply had the funds to buy them. What we need to think about is the next generation of observations. (Doug Sisterson)

Roses are red,
Violets are blue,
We are now finished,
But never really through….