ARM Atmospheric Radiation Measurement Program

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

Flux Analysis Code: Basic Cloud Properties and Cloud Effects Derived from Surface Radiation Measurements

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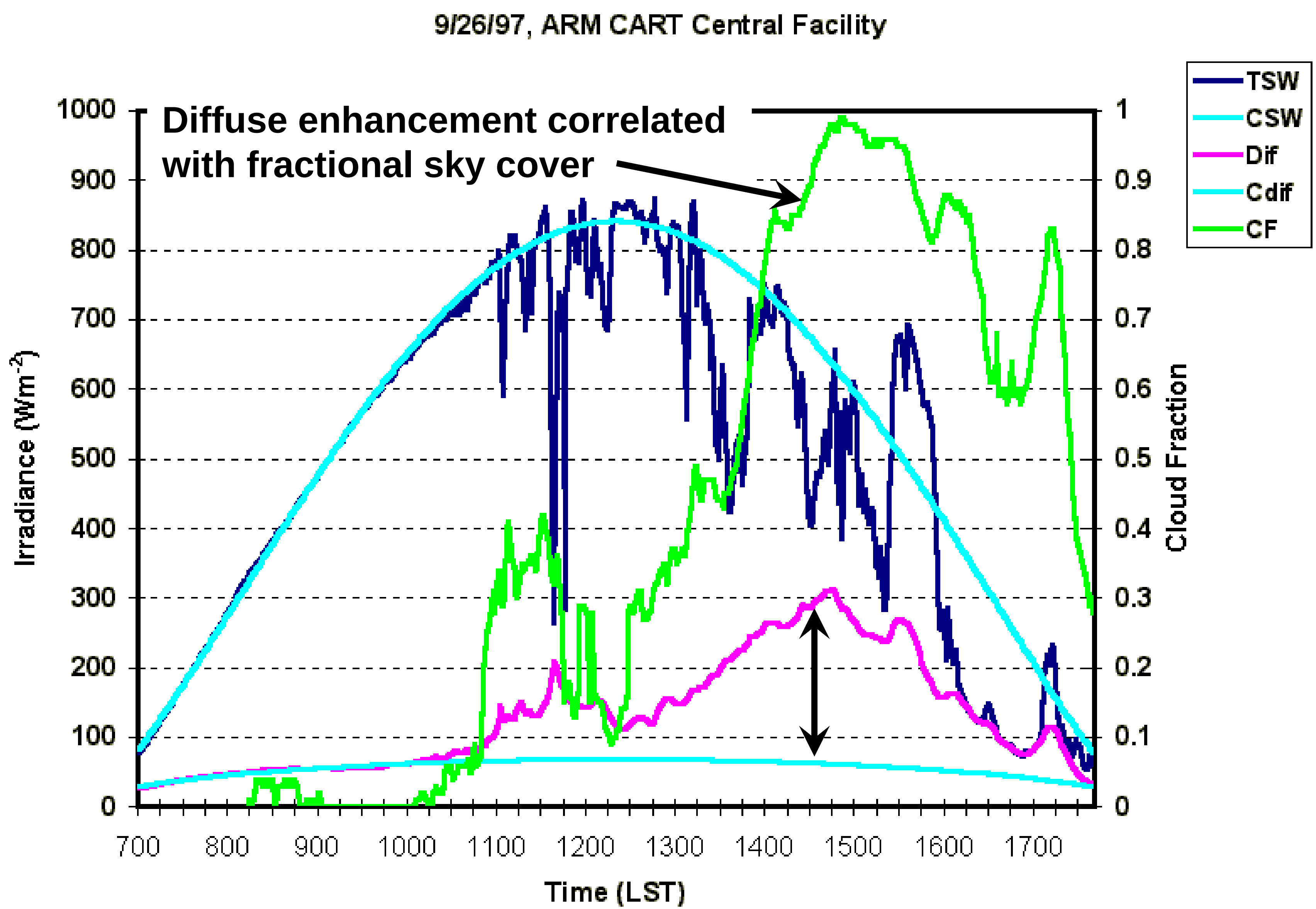
SW Flux Analysis

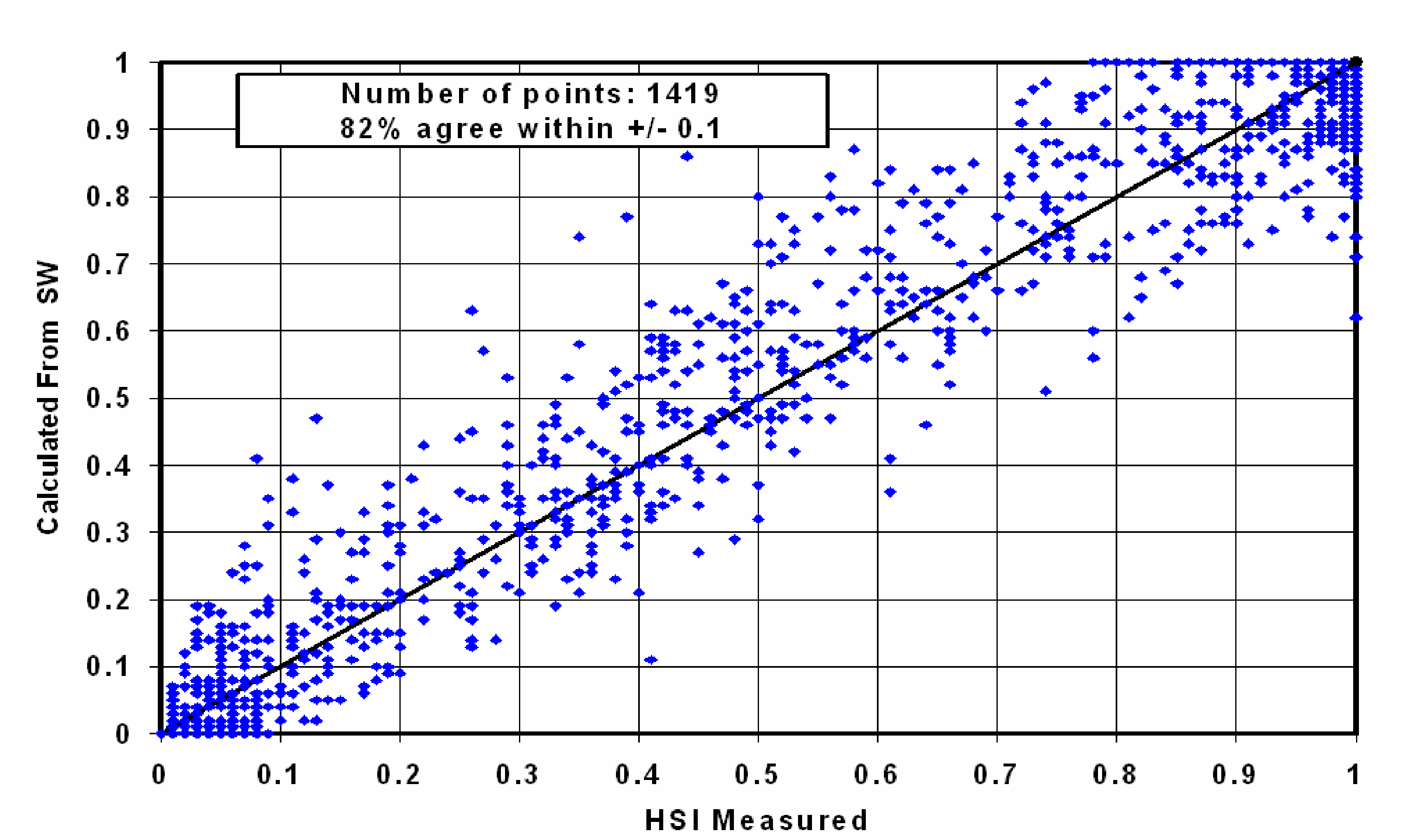
- Long and Ackerman (JGR, 2000)
- Detection of clear (i.e. cloudless) sky periods
- Empirically fit functions to clear-sky data, interpolate for cloudy periods
- Produce continuous estimates of clear-sky global, direct, and diffuse SW
- Infer fractional sky cover for solar elevations of 10^{O} and greater (Long et al., 1999)
- Current ARM VAP, 15-min. Sky Cover

Example



9/26/97, ARM CART Central Facility
Diffuse enhancement correlated with fractional sky cover
TSW
CSW
Dif
Cdif
CF
Irradiance (Wm-2)
Cloud Fraction
Time (LST)
1000
900
800
700
600
500
400
300
200
100
0
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700

Fractional Sky Cover, 1-min



Long, C. N., T. P. Ackerman, K. L. Gaustad, and J. N. S. Cole, (2006): *Estimation of Fractional Sky Cover from Broadband Shortwave Radiometer Measurements*, JGR, 111, D11204, doi:10.1029/2005JD006475.

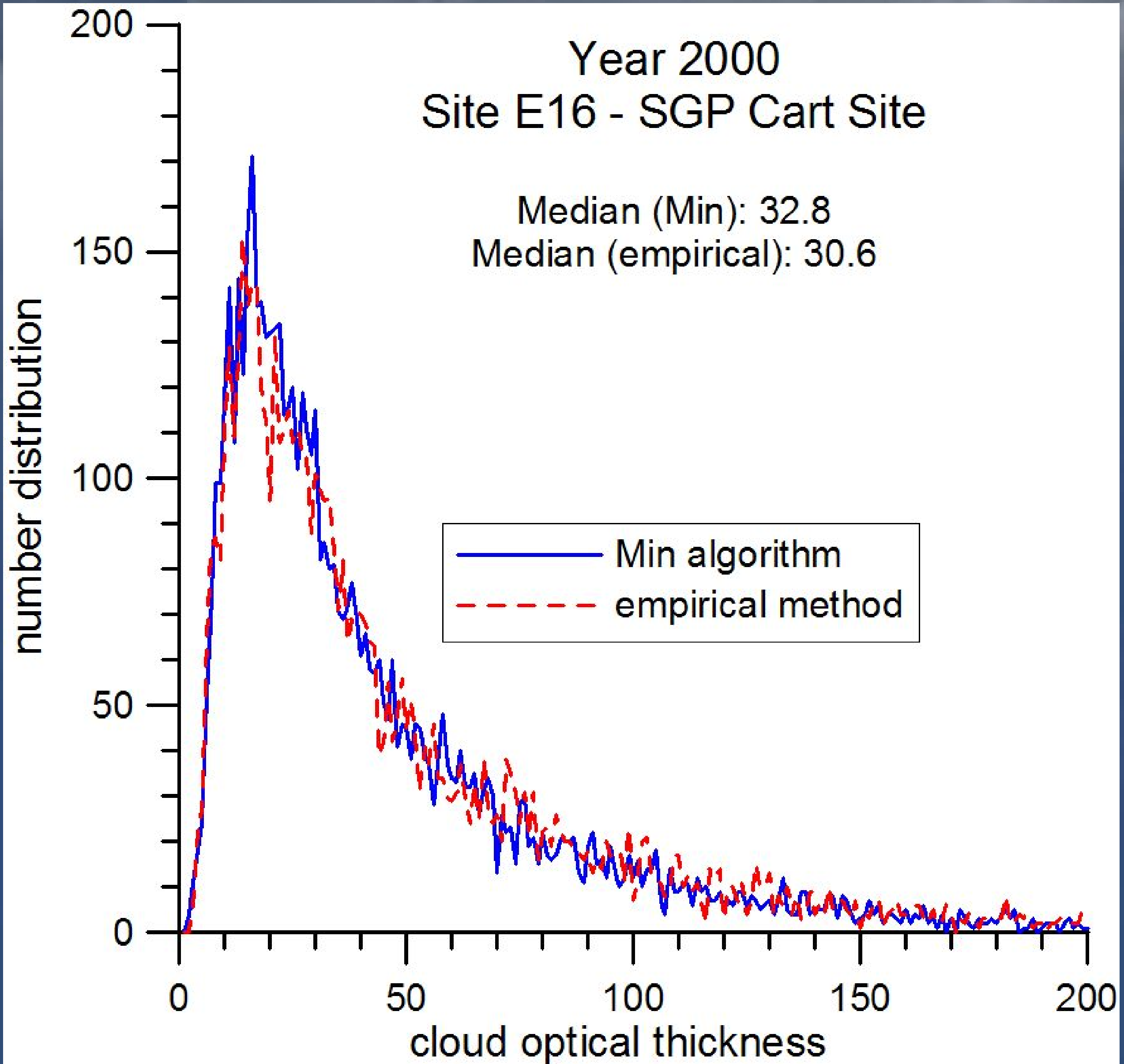
Work since SW Flux Analysis

- Barnard, J. C., and C. N. Long, (2003): A Simple Empirical Equation to Calculate Cloud Optical Thickness from Shortwave Broadband Measurements, 13th ARM Science Team Meeting Proceedings, Broomfield, Colorado, March 31-April 4, 2003.
- Long, C. N. and K. L. Gaustad, (2004): The Shortwave (SW) Clear-Sky Detection and Fitting Algorithm: Algorithm Operational Details and Explanations, Atmospheric Radiation Measurement Program Technical Report, ARM TR-004, 26 pp., Available via http://www.arm.gov/publications/techreports.stm.
- Long, C. N., (2004): The Next Generation Flux Analysis: Adding Clear-sky LW and LW Cloud Effects, Cloud Optical Depths, and Improved Sky Cover Estimates, 14th ARM Science Team Meeting Proceedings, Albuquerque, New Mexico, March 22-26, 2004.
- Long, C. N., J. C. Barnard, J. Calbo, and T. P. Ackerman, (2005):Using Integrated Surface Radiation Measurements to Infer Cloud Properties, AMS Ninth Symposium on Integrated Observing and Assimilation Systems for Atmosphere, Oceans, and Land Surface (IOAS-AOLS), 9–13 January 2005, San Diego, California.
- Long, C. N., (2005): On the Estimation of Clear-Sky Upwelling SW and LW, 15th ARM Science Team Meeting Proceedings, Daytona Beach, Florida, March 14-18, 2005.
- Long, C. N., J. C. Barnard, K. L. Gaustad, D. D. Turner, and T. P. Ackerman, (2006): Basic Cloud Properties and Cloud Effects Derived from Surface Radiation Measurements, Proceedings 2006 International Geoscience and Remote Sensing Symposium, July 31 - Aug.4, 2006, Denver, CO.

Cloud Visible Optical Depth

- Effective plane-parallel cloud visible optical depth for overcast skies
  - Based on Min and Harrison, 1996, GRL.
  - Barnard and Long, 2004, JAM, empirical formulation
    - Agreement within 10%
  - New formulation including surface albedo and asymmetry parameter

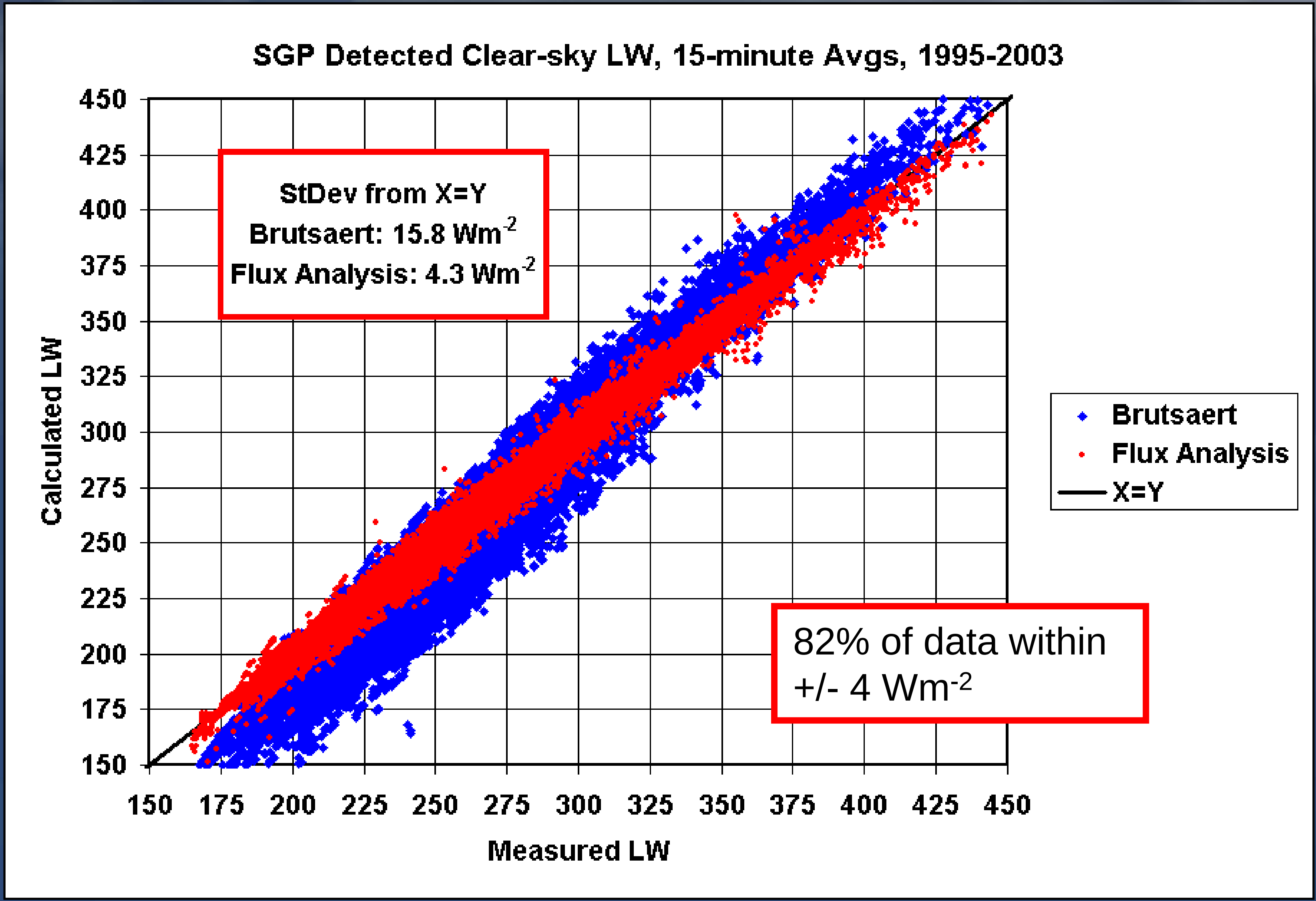
Comparison to MFRSR



Clear-Sky Downwelling LW

- Related work by Marty and Philopona (2000), Duerr and Philipona (2004), Sutter at al. (2004)
- Use SWFA detected clear-sky periods,
- Additionally detect "LW effective clear-sky" periods
  - Variability of LW time series
  - Use $T_a - T_e$ difference
- Use clear-sky measurements to calculate Brutsaert lapse rate coefficients
  - include adjustment for RH>75%
- Interpolate coefficients for cloudy periods similar to SWFA

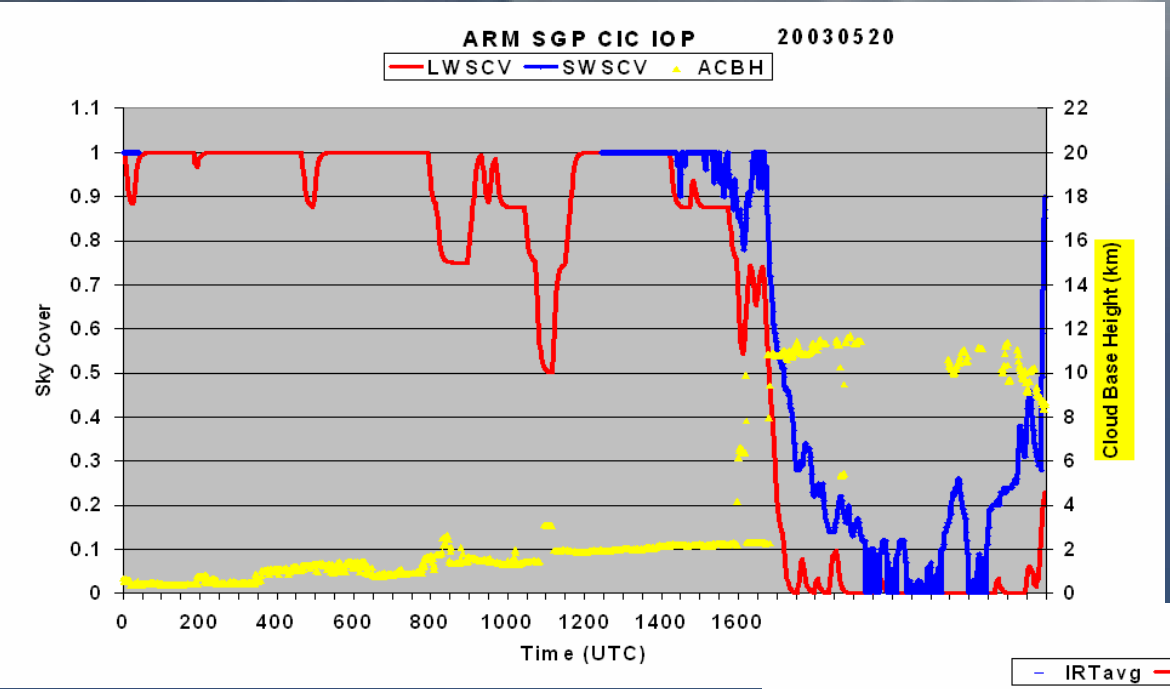
Estimated Clear-Sky LW

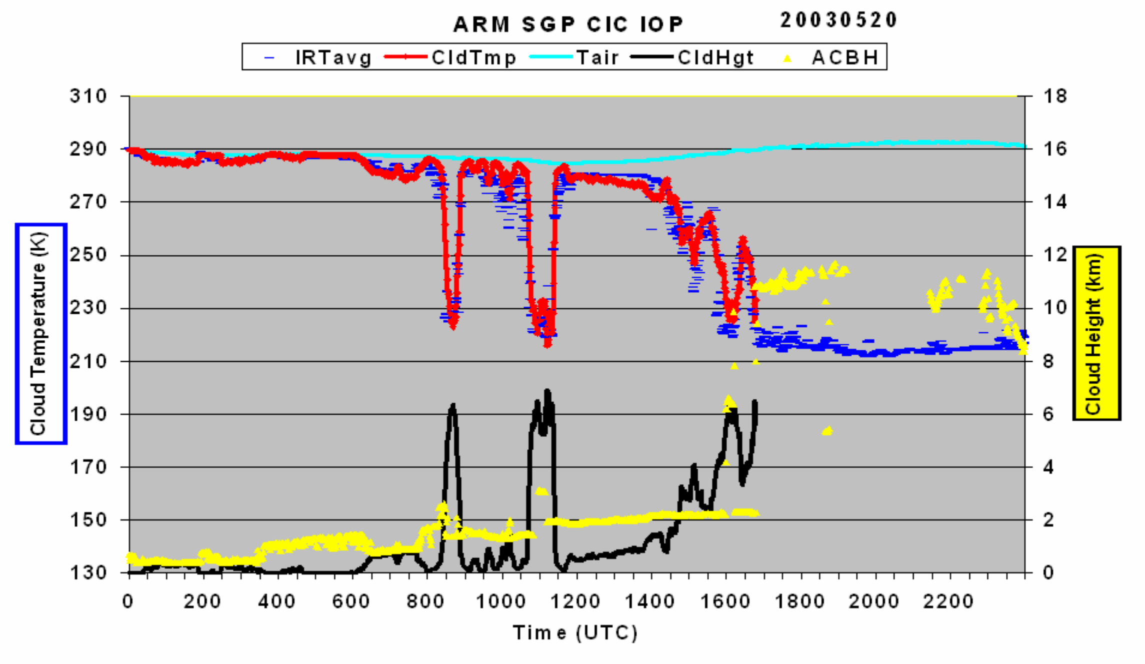


LW Effective Sky Cover and Radiating Temperature

- LW effective sky cover
  - Durr and Philipona (2004, JGR)
  - Low and middle clouds
  - Technique adapted for Flux Analysis
- Cloud effective radiating temperature
  - use independent pixel approximation arguments, the LW effective cloud amount, and the clear-sky and measured LW
  - "effective" - assumes single uniform layer
  - Results for low and middle clouds, when LW Scv > 50%

LW Estimated Cloud Properties

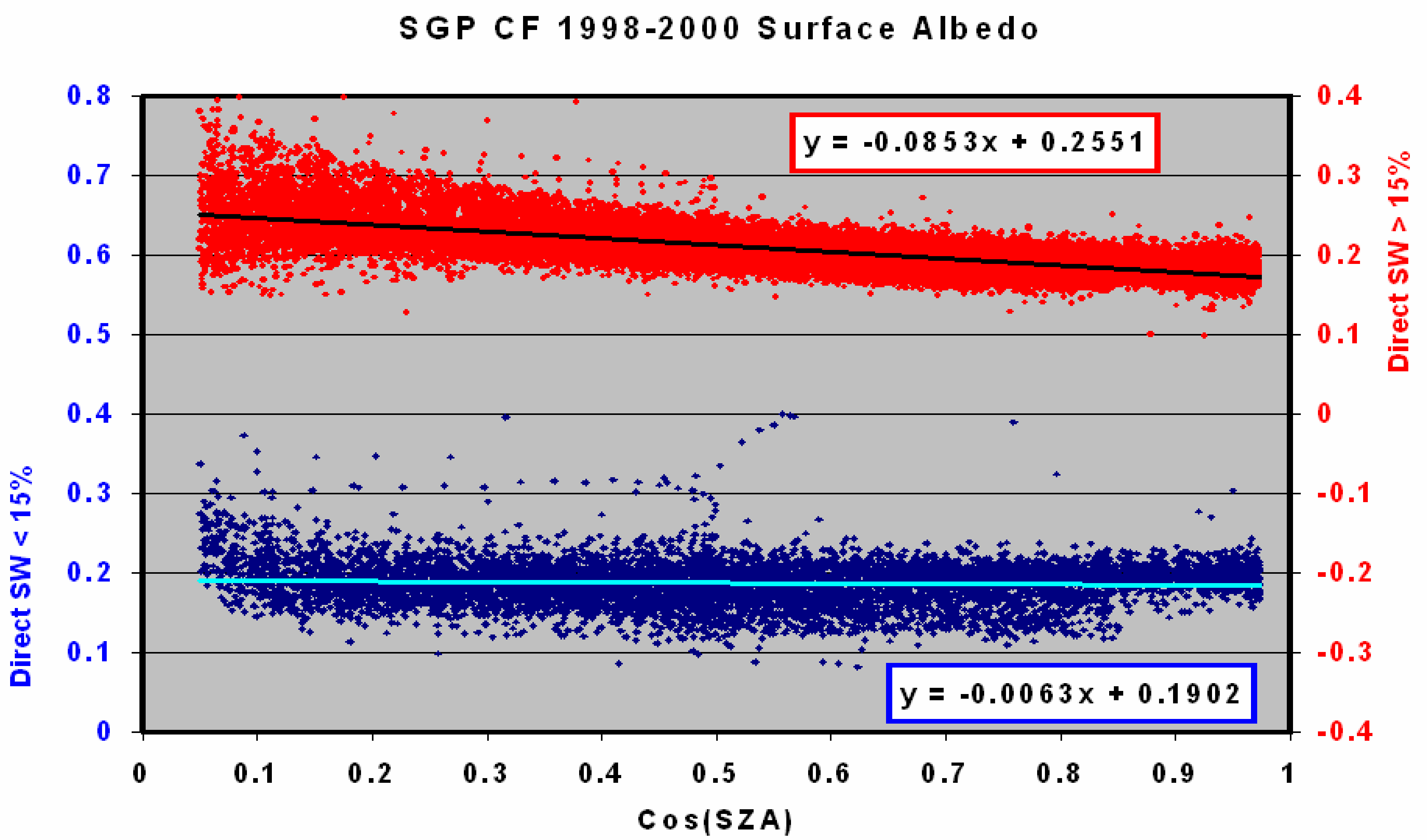




SW Surface Albedo (surface reflectivity)

- Daily diffuse SW albedo fairly constant
- Direct SW component introduces solar elevation dependence

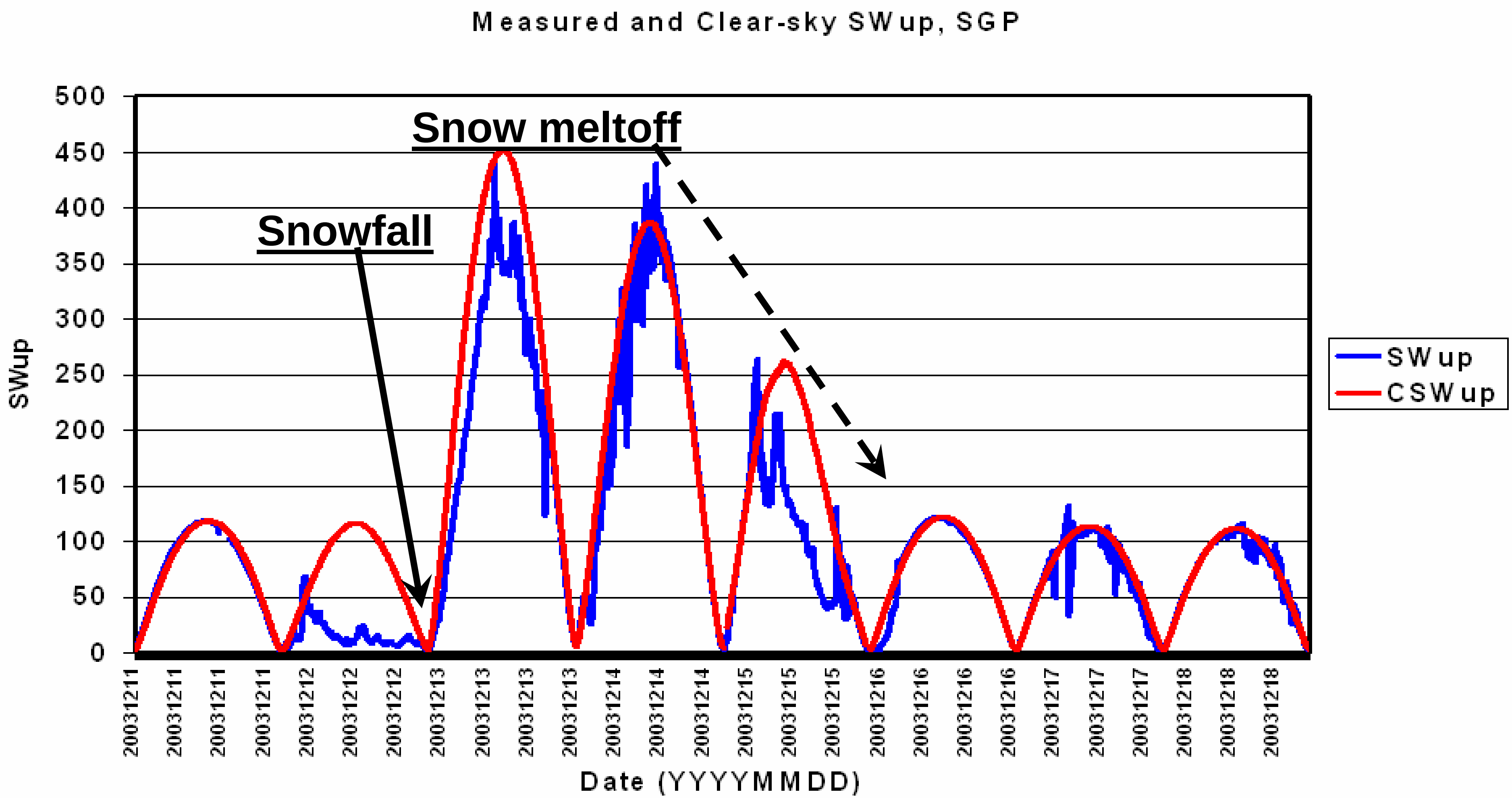
Surface Albedo SZA Dependence



Clear-Sky Upwelling SW

- Use daily sampling of near-noon albedo and running analysis of solar zenith angle dependence of "direct" albedo
  - Needed for significant albedo changes under cloudy skies: SNOW
  - Recall that high sun albedos nearly same
- $Alb_{clr} = Alb_{noon} + [a + b*Cos(SZA)]$
- Interpolate for days not fitted

Measured and Clear-Sky SWup

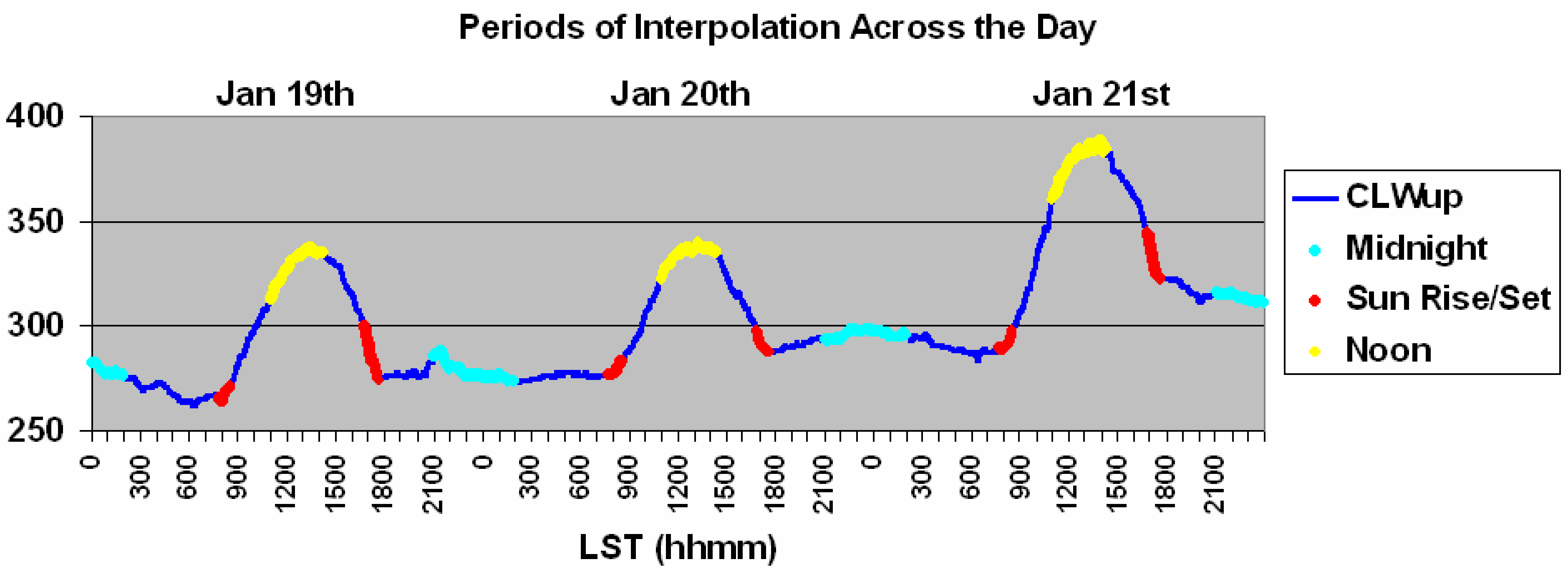


Clear-Sky Upwelling LW

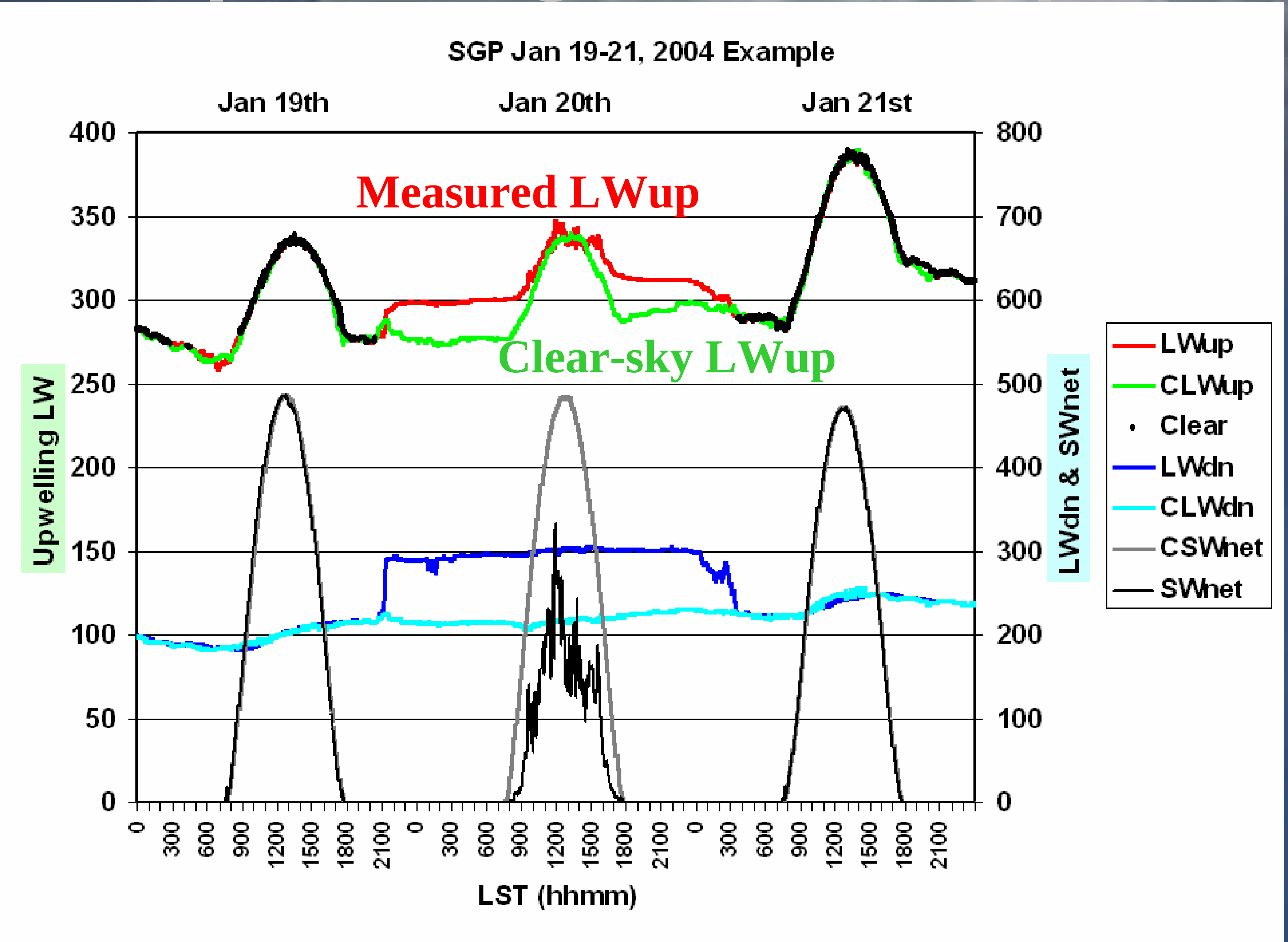
- Upwelling LW
  - Product of total surface energy exchange
    - Including latent and sensible heat
  - Sequential fitting and interpolation
    - Using LWdn, SWnet, RH, Wspd
    - Primary driver is LWdn
    - Some SWnet for vegetated surface converted to plant energy, not heat; not so for bare soil or snow
    - RH & Wspd surrogates for relative changes in surface latent and sensible exchange

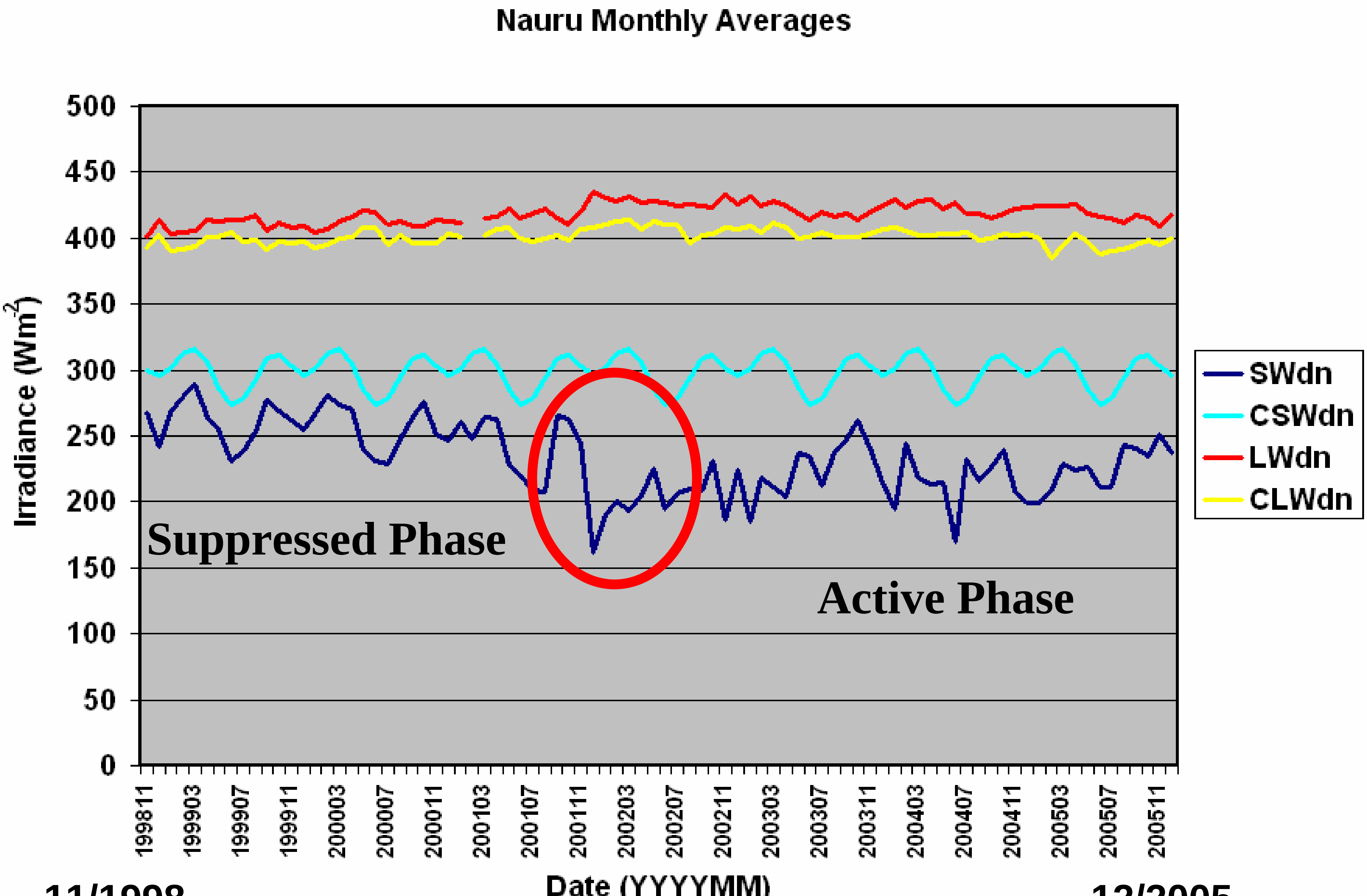
Methodology

- The surface properties can and do change on shorter than daily time scales
- For fitting, divide 24-hour day into 4 parts
  - 1st and 2nd half of night, morning, afternoon



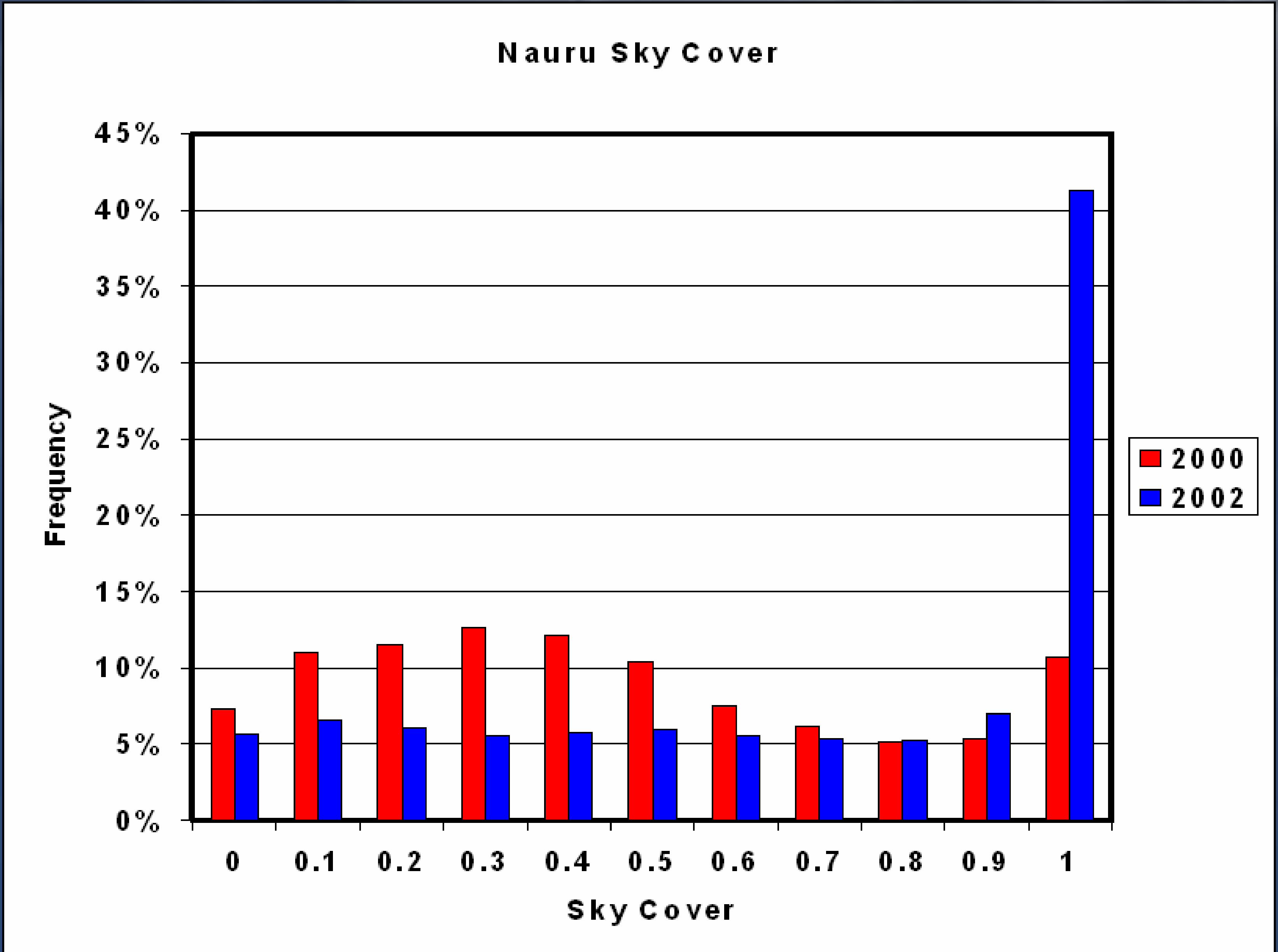
Upwelling LW Example



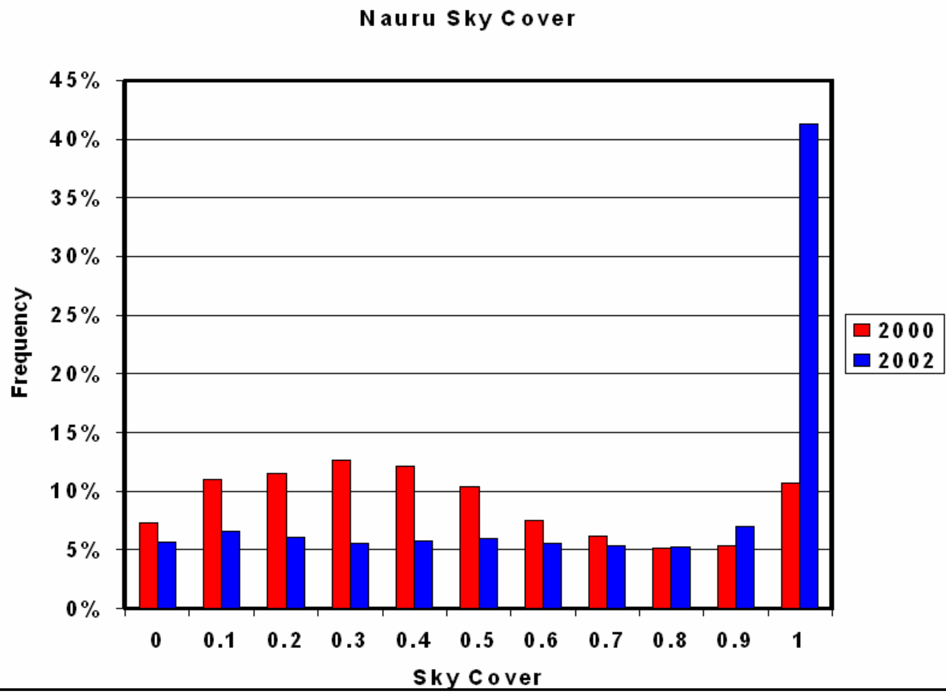


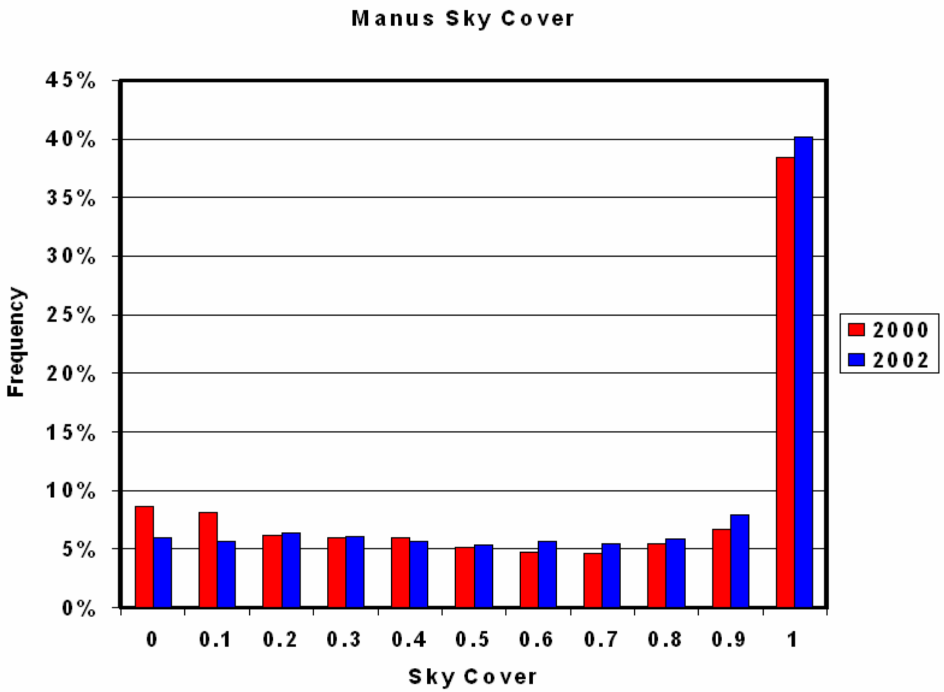
11/1998 **12/2005**

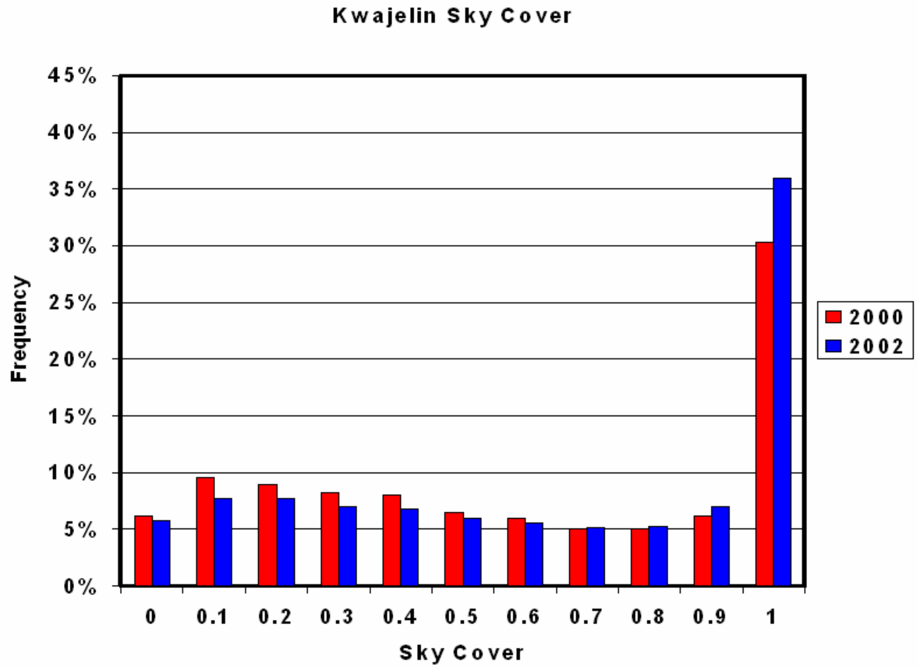
Nauru Sky Cover Frequency



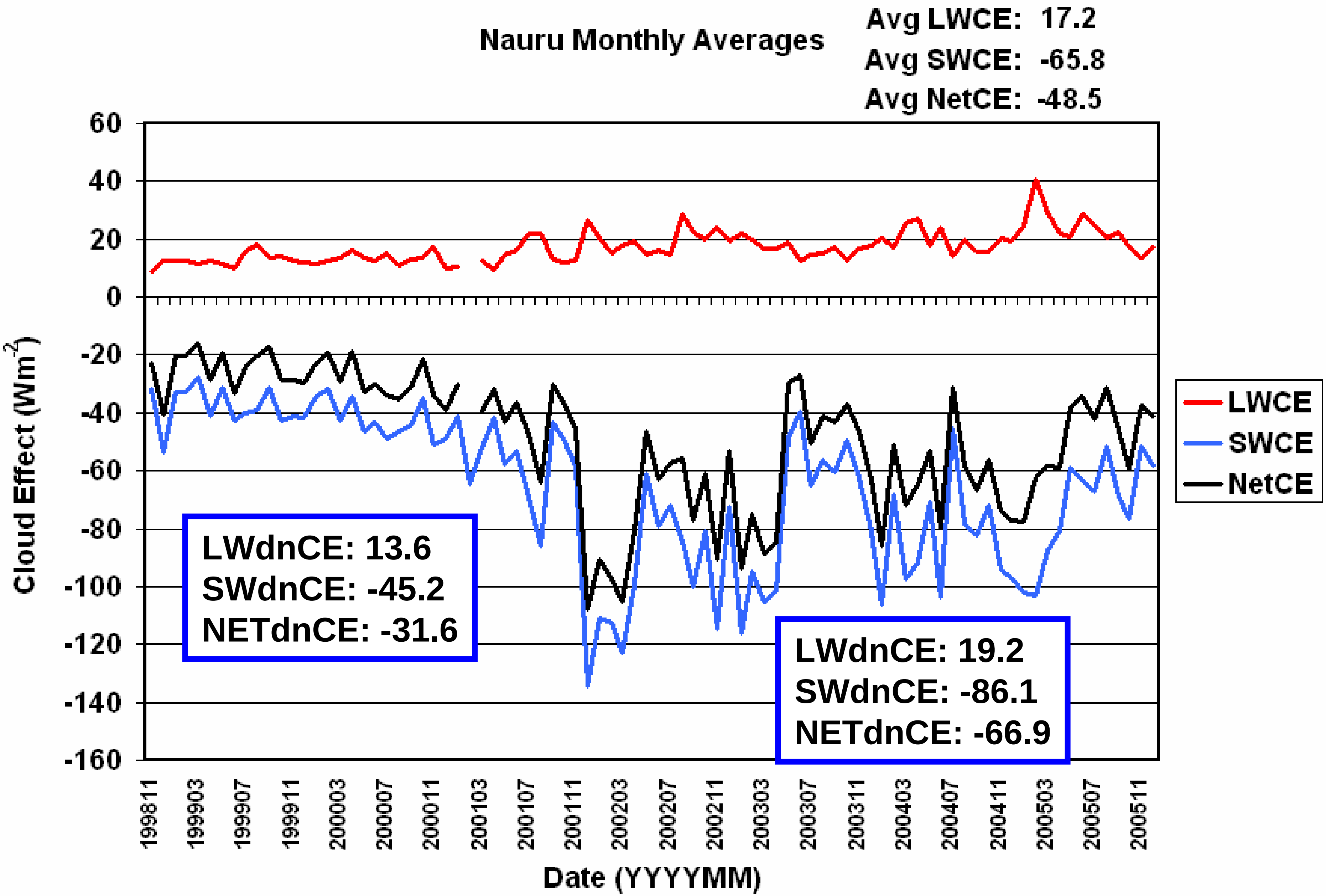
Sky Cover Frequency





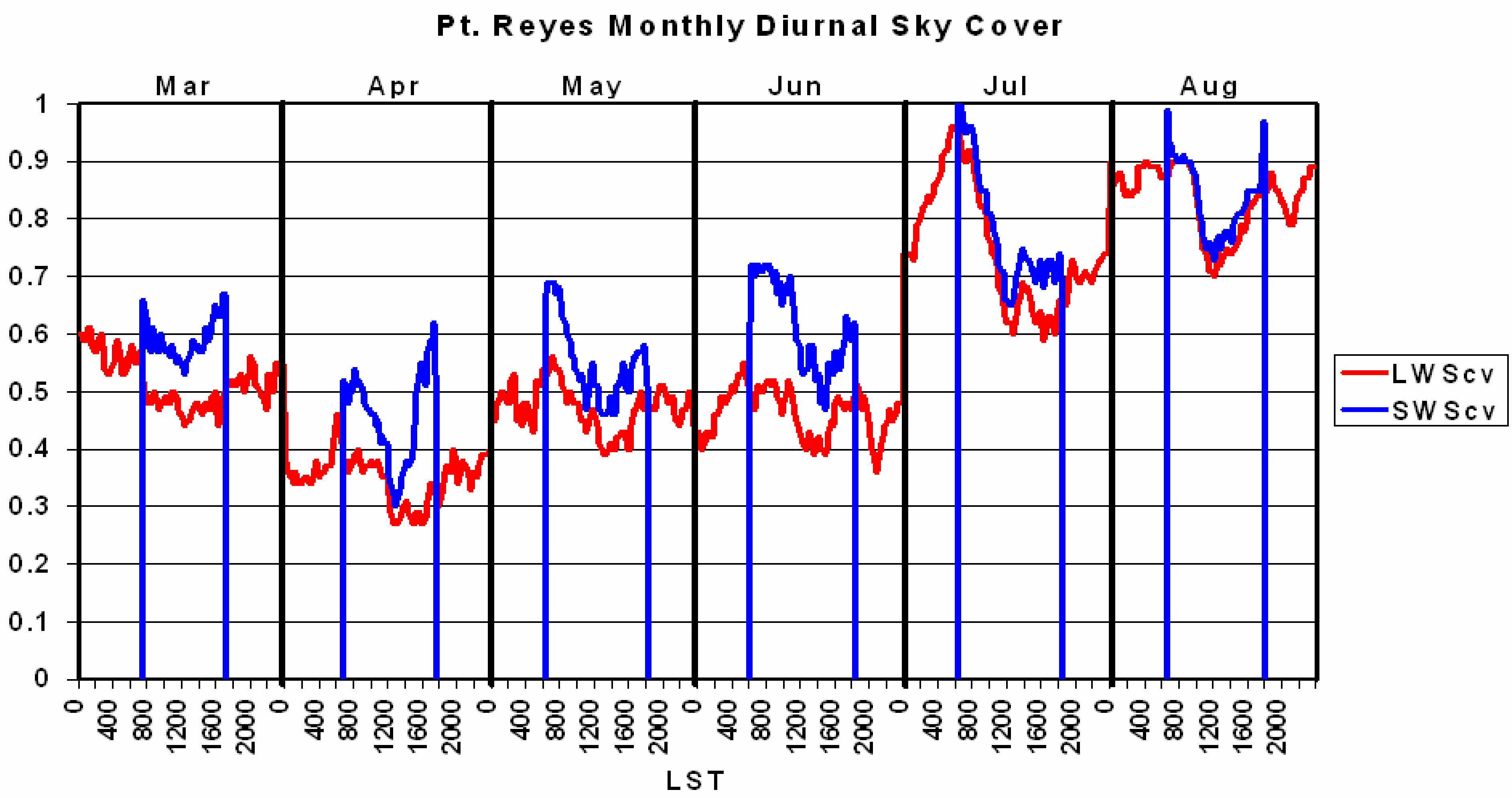


8.7N, 167.7E

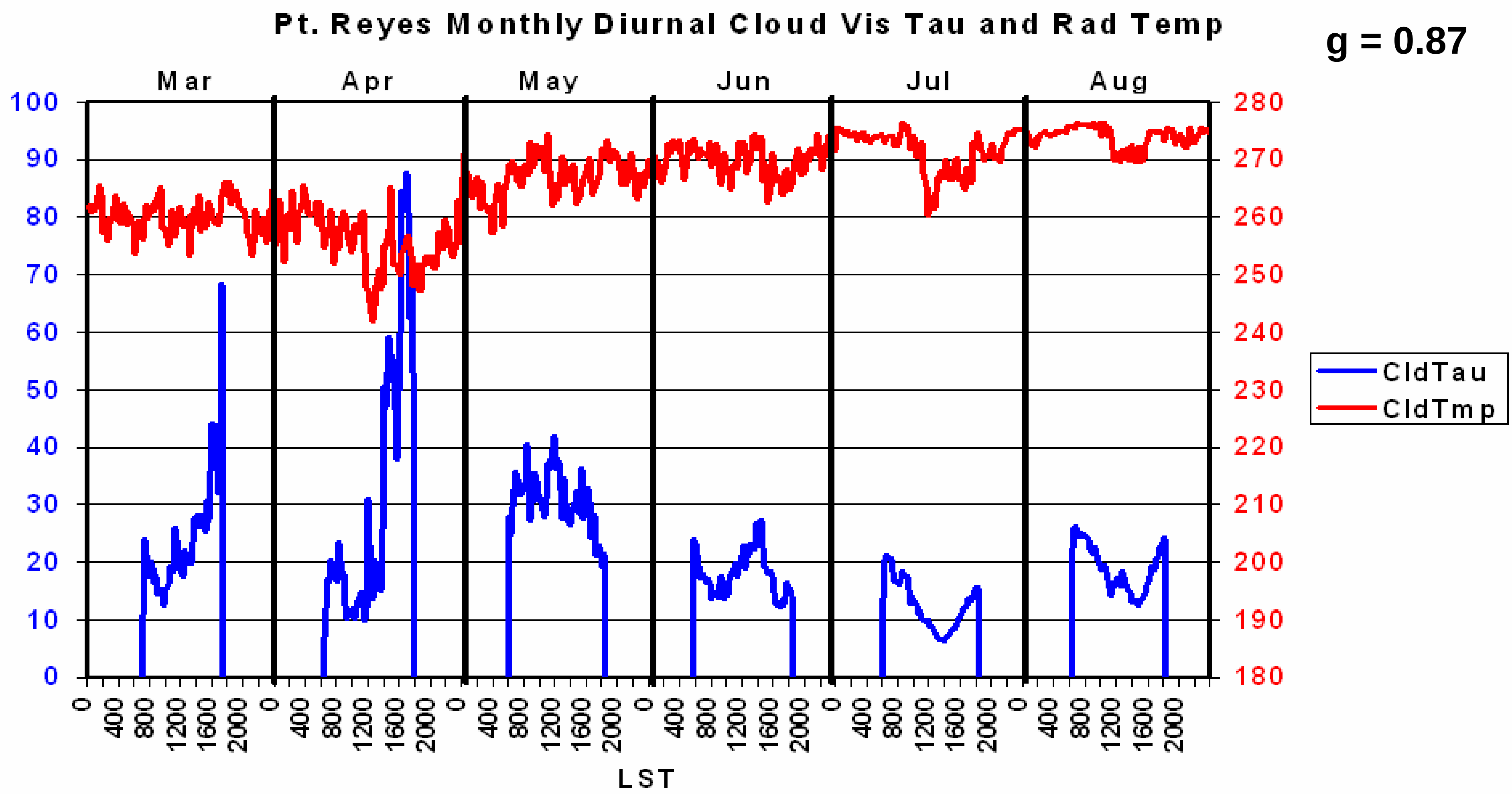


Nauru Monthly Averages
Avg LWCE: 17.2
Avg SWCE: -65.8
Avg NetCE: -48.5
Cloud Effect (Wm-2)
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
LWdnCE: 13.6
SWdnCE: -45.2
NETdnCE: -31.6
LWdnCE: 19.2
SWdnCE: -86.1
NETdnCE: -66.9
LWCE
SWCE
NetCE
199811
199903
199907
199911
200003
200007
200011
200103
200107
200111
200203
200207
200211
200303
200307
200311
200403
200407
200411
200503
200507
200511
Date (YYYYMM)

Pt. Reyes Monthly Diurnal

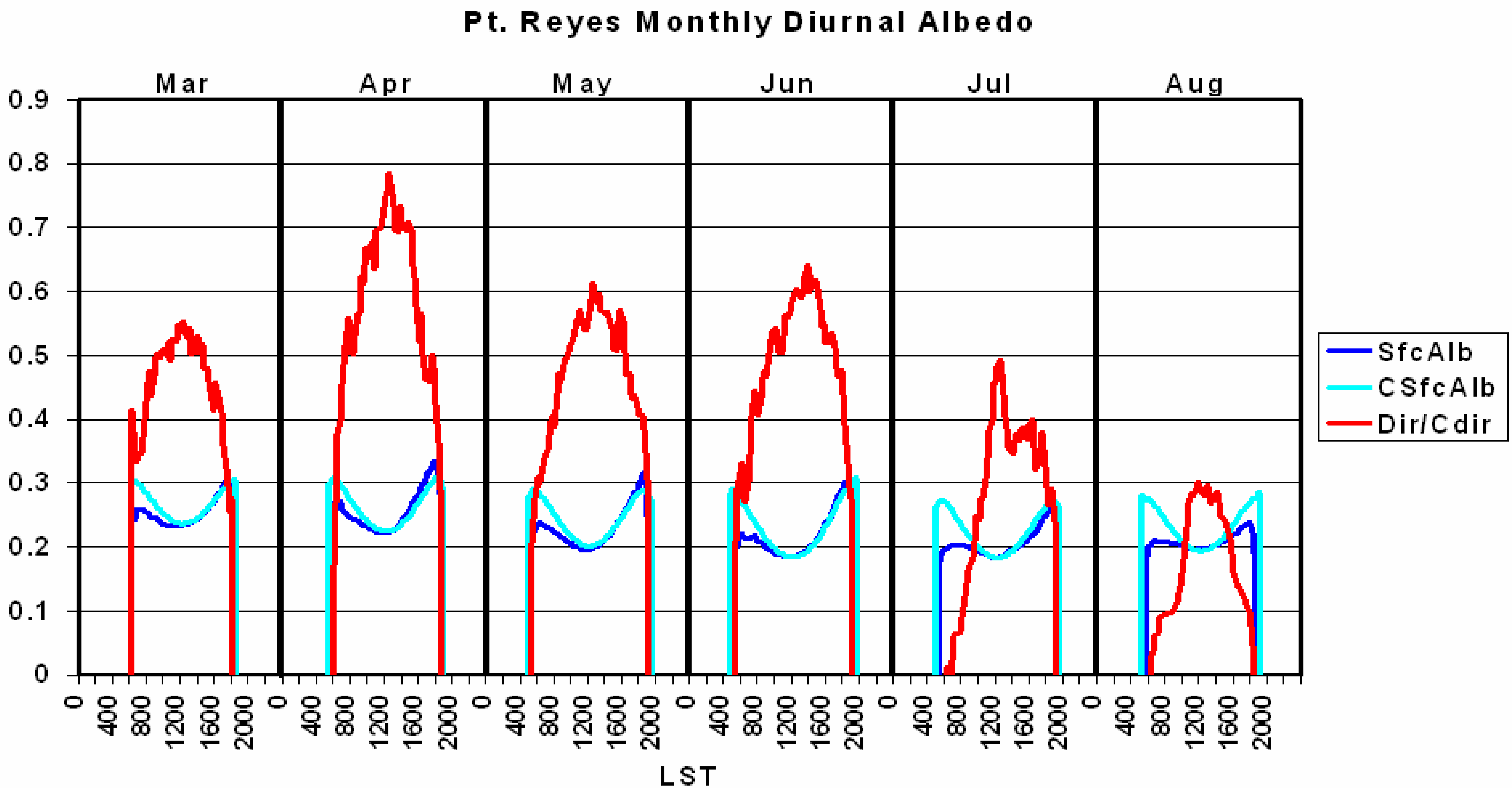


Pt. Reyes Monthly Diurnal



g = 0.87

Pt. Reyes Monthly Diurnal



Flux Analysis Summary

- More than just surface radiation measurements
  - Detected clear-sky periods
  - Clear-sky upwelling and downwelling SW and LW
    - for cloud effect/forcing
  - SW total and LW effective fractional sky cover
  - Clear-sky effective LW emissivity
  - Effective cloud transmissivity
  - Cloud visible optical depths (OVC)
  - Cloud effective radiating temperature
    - (LW Scv > 50%)
  - Crude effective cloud height

VAP Question:

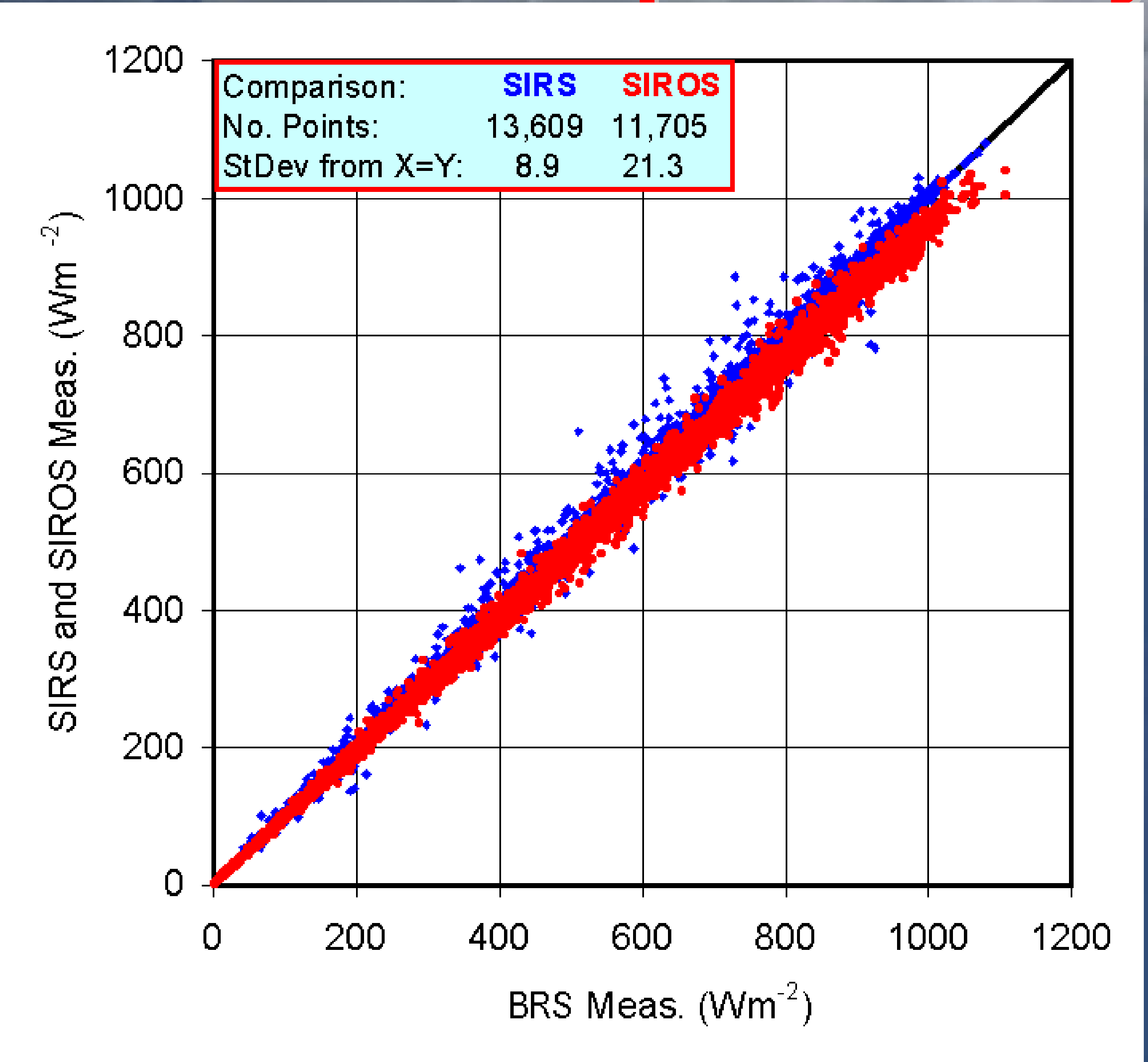
- Is it time to upgrade from the SW Flux Analysis to the full Flux Analysis as a VAP?
- Alternately, just upgrade current SW Flux Analysis to 1-minute sky cover and add visible optical depths?
  - No separation between water/ice clouds

Proposal for new VAP

- <u>Local Cloud Field QME</u>
  - combine data/retrievals to produce best estimate of local cloud field macrophysical properties
  - Inputs:
    - <u>TSI</u> (100 Deg FOV, cld aspect ratio) [also IRSI]
    - <u>ARSCL</u> (temporal cloud fraction, heights, aspect ratio)
    - <u>IRT</u> (cloud temp)
    - <u>AERI</u> (cloud temp, thin opt depth)
    - <u>MFRSR CLDOD</u> (optical depth and effective radius)
    - <u>CLD VIS</u> (MPL cloud visible optical depth)
    - <u>Flux Analysis</u> (listed variables)
  - use for MicroBase --> BBHRP P-i, fodder for CRM comparisons

Thank You

Excellent Repeatability



Excellent Repeatability