RETRIEVAL OF CLOUD PROPERTIES USING SURFACE METEOROLOGICAL AND BROADBAND IRRADIANCE MEASUREMENTS

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Introduction

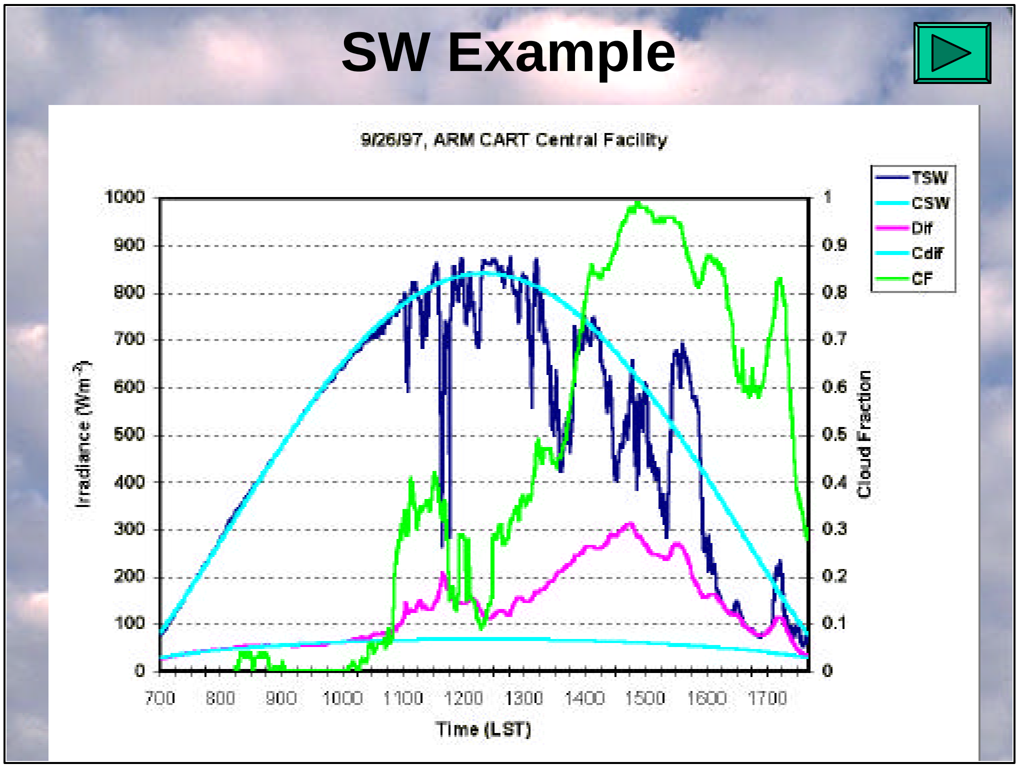
- **We have some sophisticated surface cloud and radiation sites**
  - Retrieval of cloud properties, especially microphysical
  - Used for developing, improving, & testing models & satellite retrievals
  - Costly, thus only a few
- **Many surface radiative energy budget and meteorological sites**
  - Have made progress toward more accurate measurements (BSRN) through deployment of SW direct and diffuse measurement capability

Intent of research

- **Idea: glean all possible cloud info of reasonable and useful certainty from typical surface rad. & met. meas. For use:**
  - **in climatological studies**
  - **as ground truth for model/satellite comparisons**

Clear-sky detection and SW irradiance

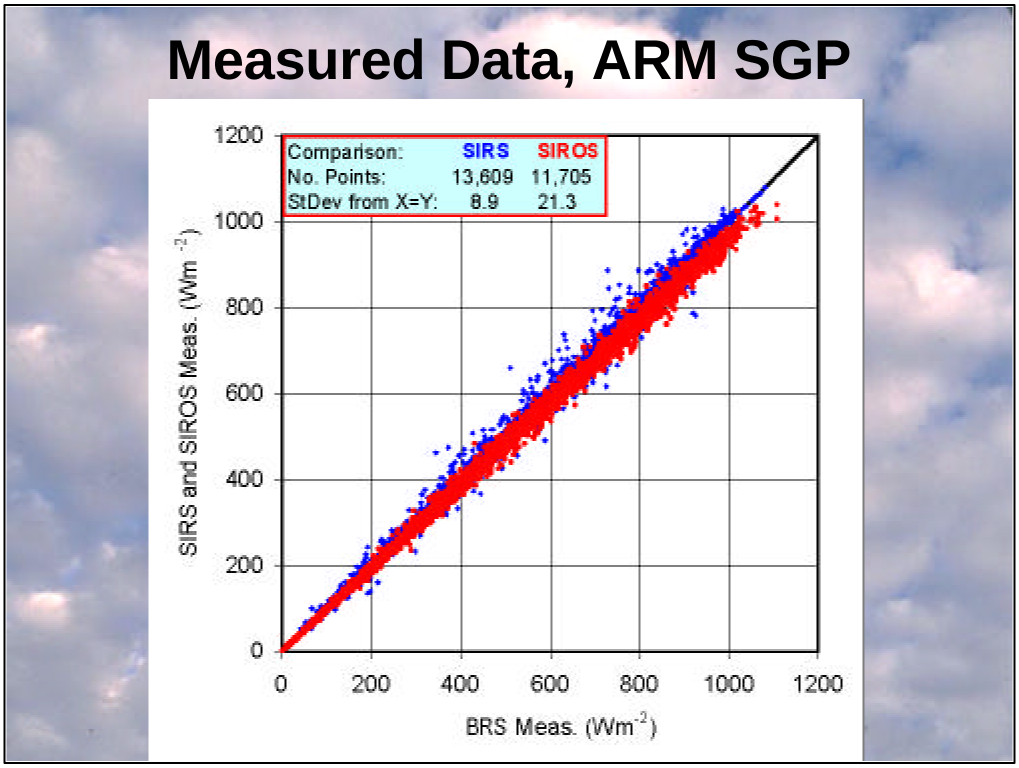
- Long & Ackerman, JGR, 2000
- Use time series of total and diffuse SW
- Identify daylight periods of clear skies for effective 160^{O} FOV
- Use these periods to determine clear-sky function coefficients, interpolate for cloudy periods, produce continuous clear-sky SW estimates
- Has RMS uncertainty of about accuracy of pyranometer measurements



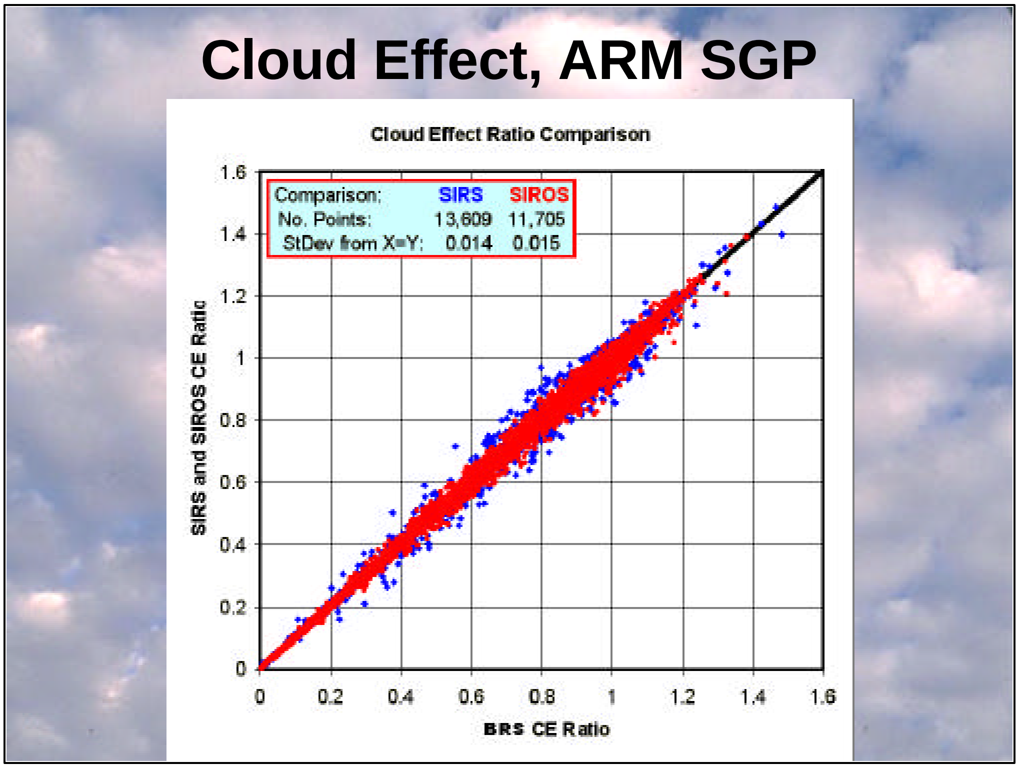
Plot showing total and diffuse SW clear sky fits, and measured irradiance. Note the high degree of correlation between the enhancement of the diffuse SW irradiance over the clear sky amount, and the fractional sky cover measured by a sky imager (green line). This is especially true with the removal of the solar zenith angle effect (not shown).

Downwelling Cloud Effect

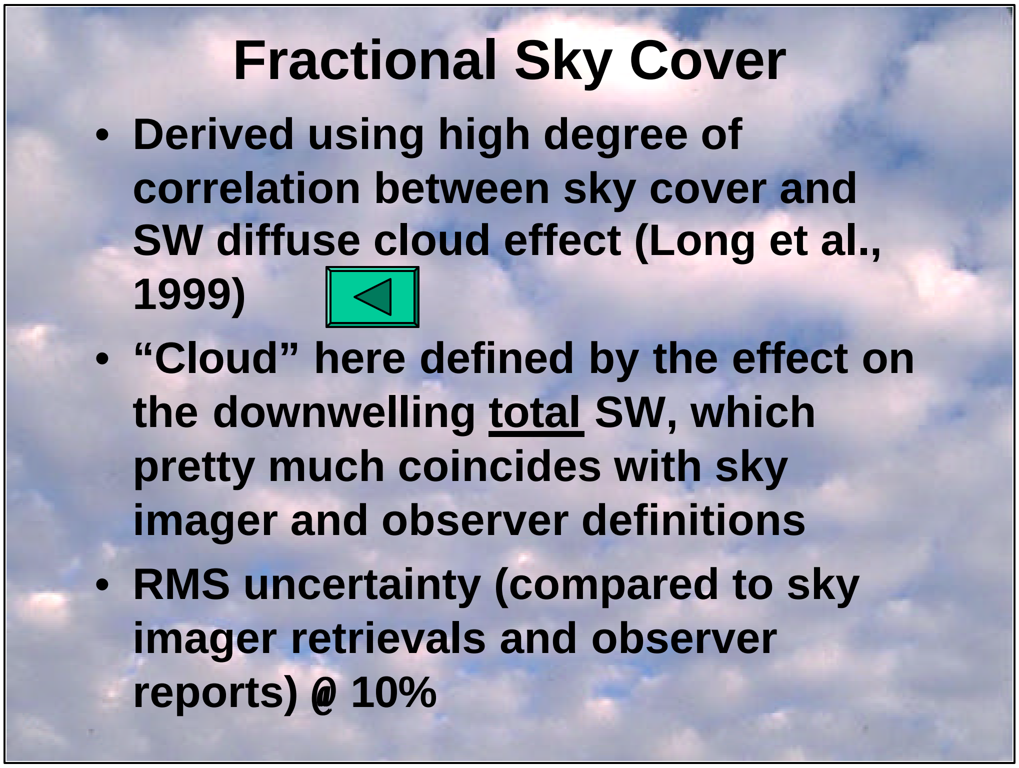
- This method of estimating clear-sky downwelling irradiance includes instrument characteristics
- Thus, effect of clouds represented as either difference or ratio of measured and clear irradiances have less uncertainty than might be present in absolute model-meas. comparisons, or due to unknown features (trends) of instrument characteristics (Long and Ackerman, 2000).



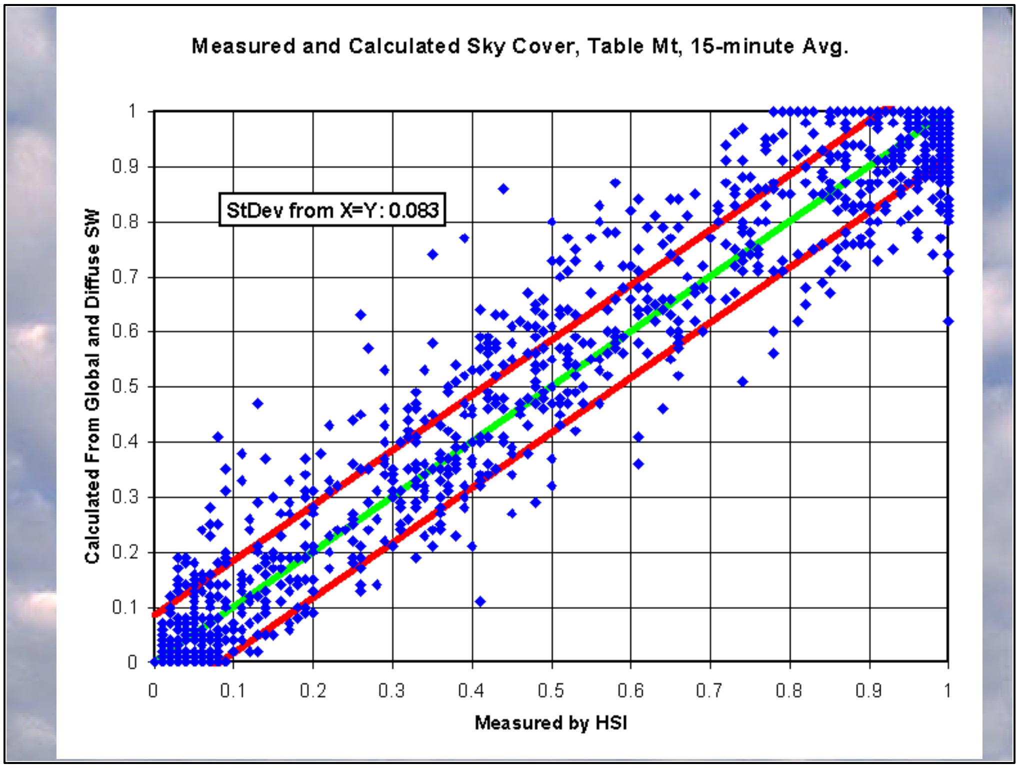
Comparison of 15-minute averages of downwelling total SW from 3 co-located systems at the ARM SGP Central Facility in Oklahoma. Note that one system (SIROS) has an apparent calibration offset compared to the other two, resulting in larger disagreement from X=Y.



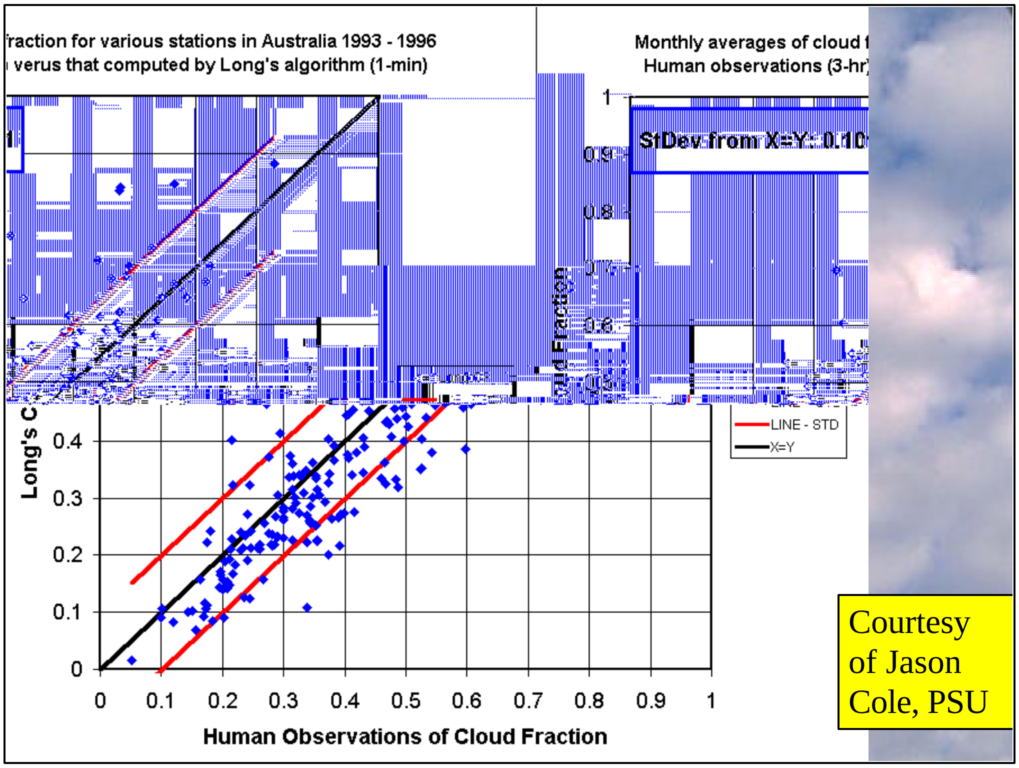
Despite the calibration offset shown in the previous plot, all systems show excellent agreement in the calculated measured/clear SW ratio, i.e. very small standard deviation from X=Y. This is due to the instrument characteristics, such as the calibration, being removed from the ratio due to the fitting to actual clear sky measurements.



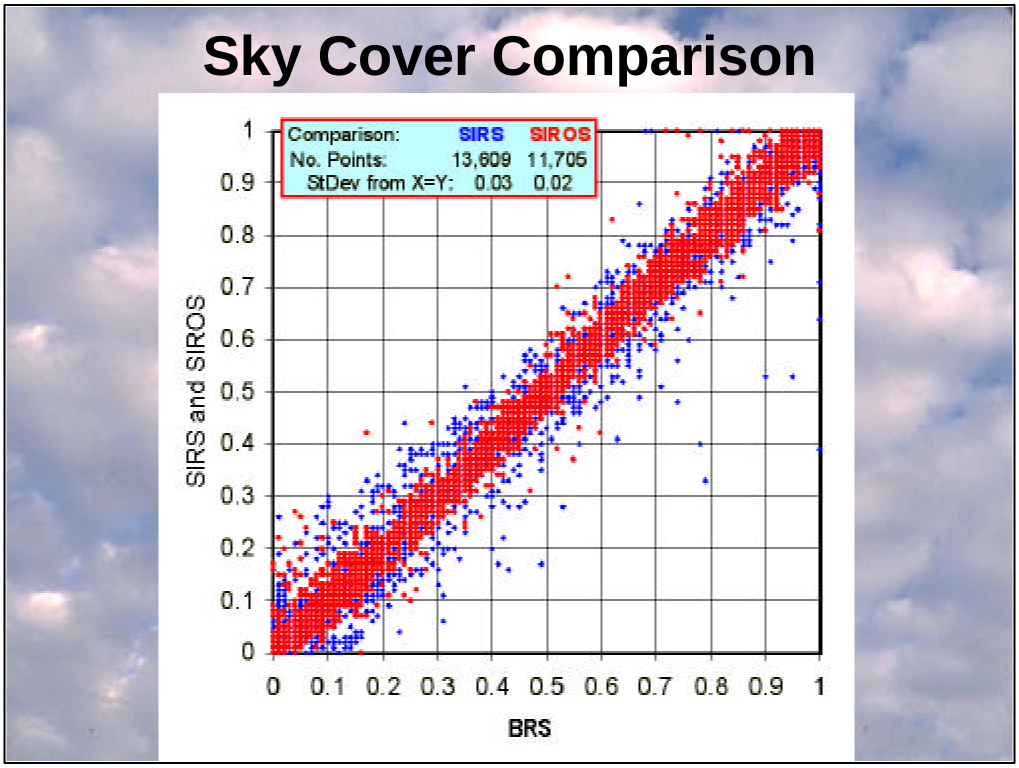
The "action button" links to panel 5, the "SW Example" plot.



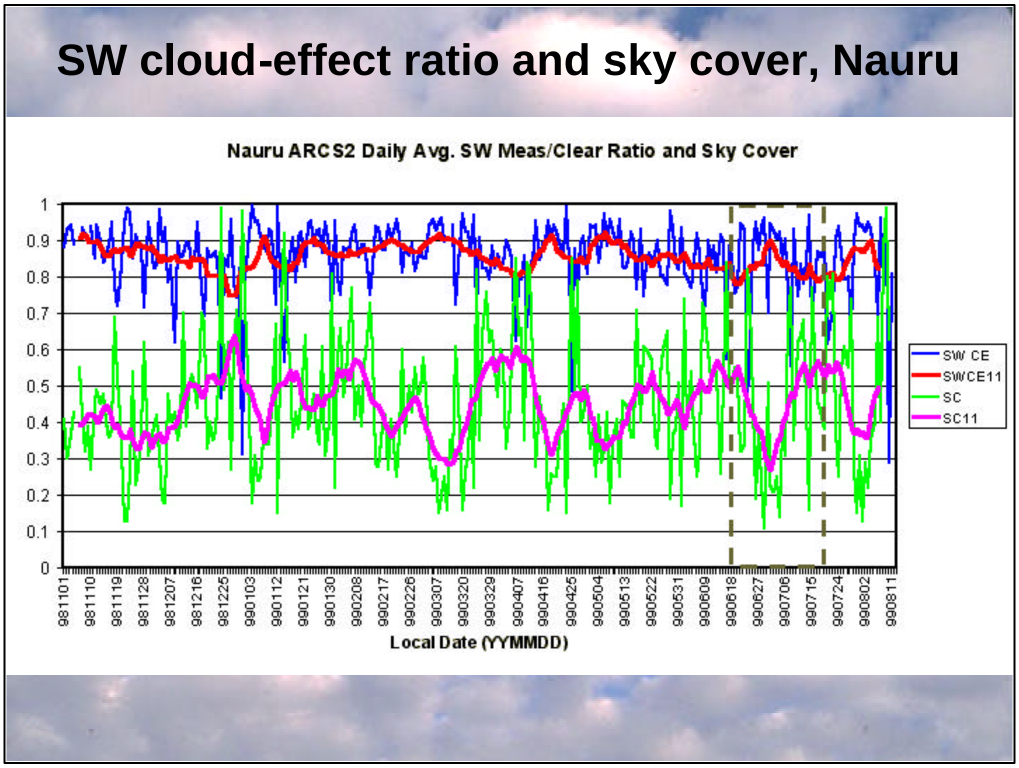
Comparison of sky imager retrieved fractional sky cover, and that estimated from SW irradiance measurements, produces an RMS uncertainty of only about 8%.



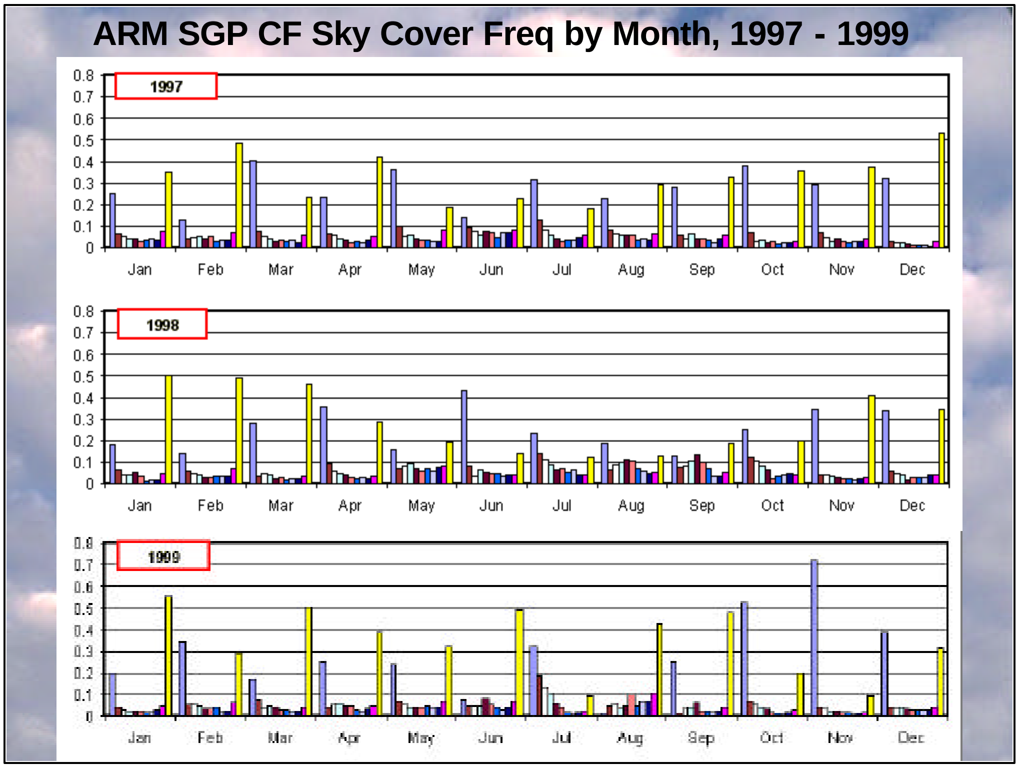
Comparison of monthly averages of co-located observer reports with that estimated from SW irradiance measurements. Monthly averages are used to decrease the effect of the sampling disparity (3-hr for observations versus 1-second sampling for the SW). Despite the sampling disparity, and uncertainty associated with human observations, the RMS uncertainty is still on the order of 10% between the two.



Same as panels 7 and 8, but for estimated sky cover. Note the high degree of repeatability, on the order of 2-3%, despite system differences shown in panel 7.



Plot of daily average, and 11 day running means. These techniques allow the study of long-term records not only for surface radiative energy budget, but for sky cover (green and pink lines), and SW cloud effect (blue and red lines). Here, 9 months worth of data from the ARM site on Nauru in the tropical western Pacific show not only the Madden-Julian oscillation, but oscillations on other time scales as well.



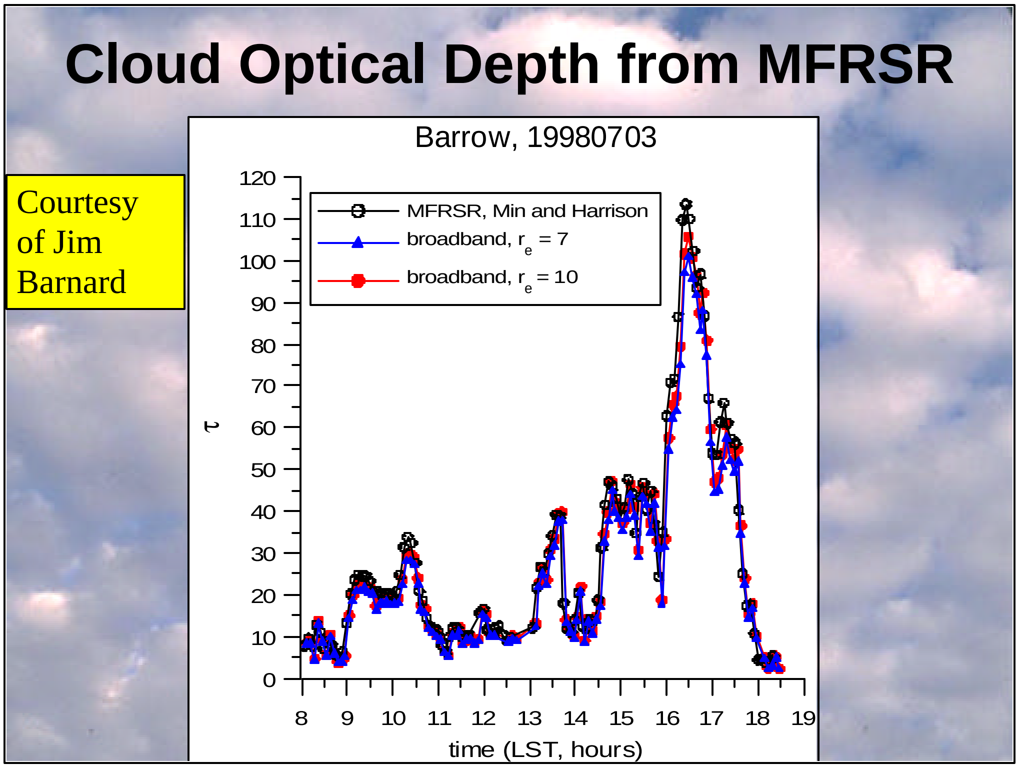
This is an example of 3 years worth of frequency histograms of fractional sky cover by month for the ARM SGP Central Facility. It is statistics such as these that can be used in model and satellite comparisons to alleviate the difficulties inherent in "point-to-point" comparisons.

SW Flux Analysis Code

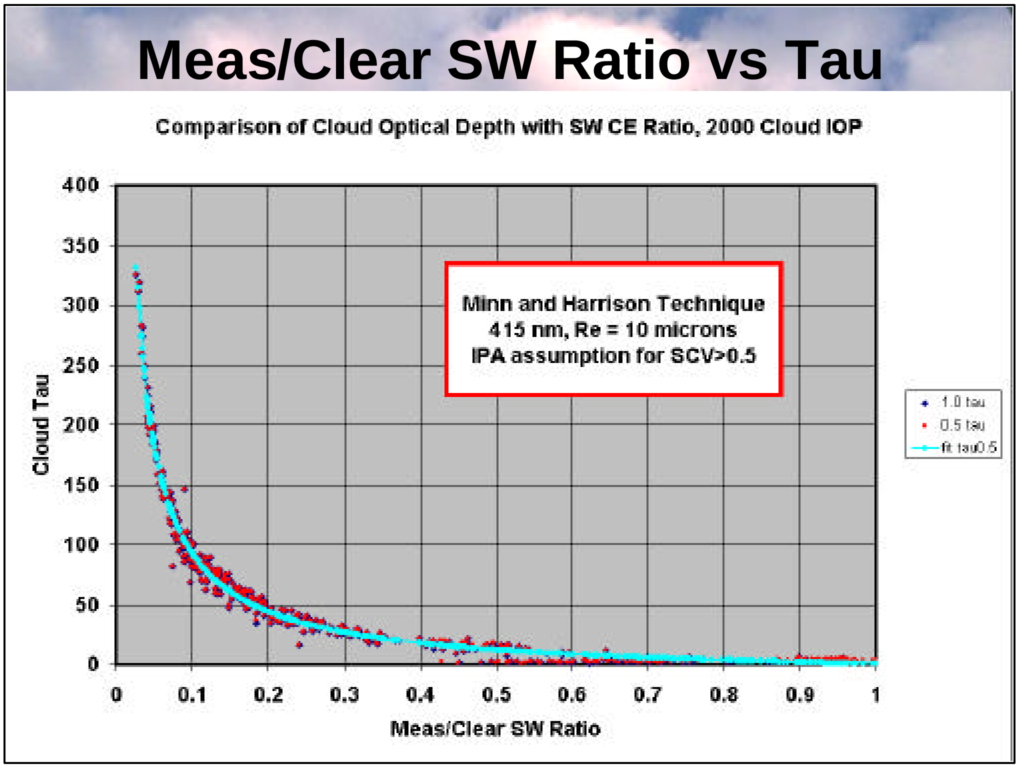
- Currently operational for all ARM SGP Central and Extended Facilities
- Modified version for ARM TWP should be online early next year
- Currently operational for all SURFRAD sites
- Will be installed at BSRN Archive this spring

Cloud Optical Depth

- Technique by Min and Harrison (1996)
  - Uses MFRSR data
  - 415 nm channel (minimum impact by albedo)
  - Assume reasonable r_e (not very sensitive)
- Combining technique of M. & H. with BB SW gives good results (~ 10% agreement)
- Assume single-layer overcast
- We are investigating using IPA-type assumptions to deal with broken cloud



Example comparing the retrieval of cloud optical depths from MFRSR data, and SW data, using the Min and Harrison technique. Both methods agree well, and are insensitive to small differences in effective radius assumed for the calculations.



Plot showing a comparison with MFRSR cloud optical depths using the Min and Harrison technique, and the corresponding measured/clear total SW ratio. This plot shows that indeed the SW ratio does “bring out” the effect of clouds on the downwelling SW, to the point where this ratio can be used to make a ball-park estimate of cloud optical depth for those sites where other means of inferring the cloud optical depths are not available.

LW clear-sky irradiance

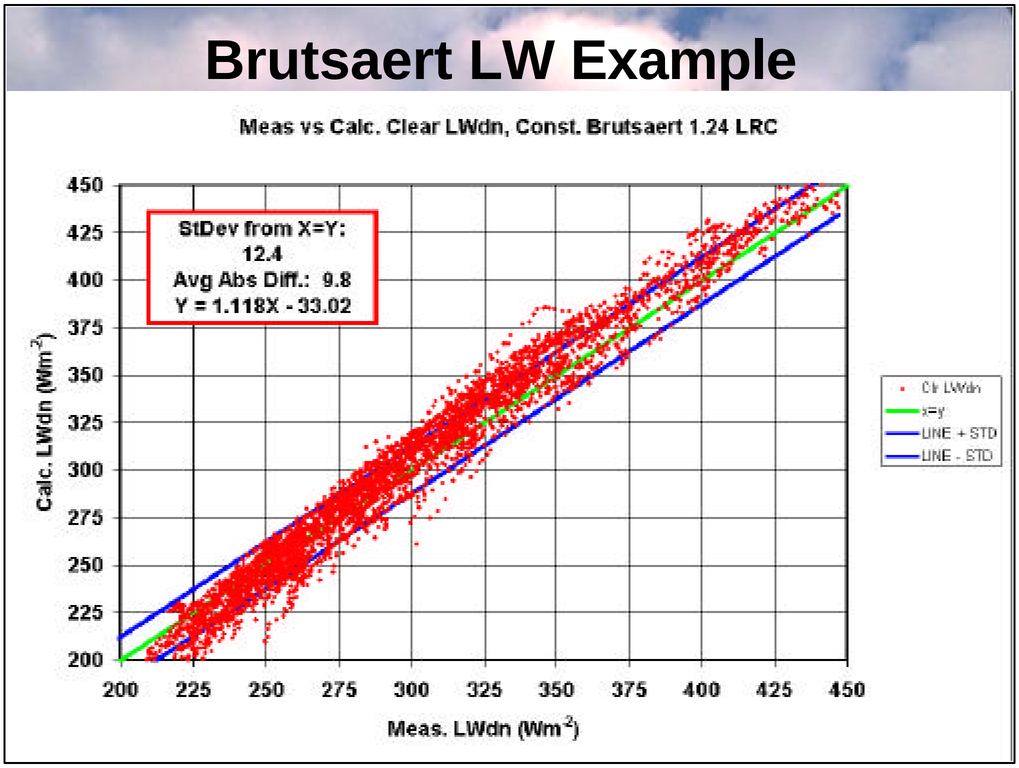
- **Use Brutsaert (1975) “effective emmisivity”**

$$\epsilon_c \cong 1.24 * (e/T_a)^{1/7}$$

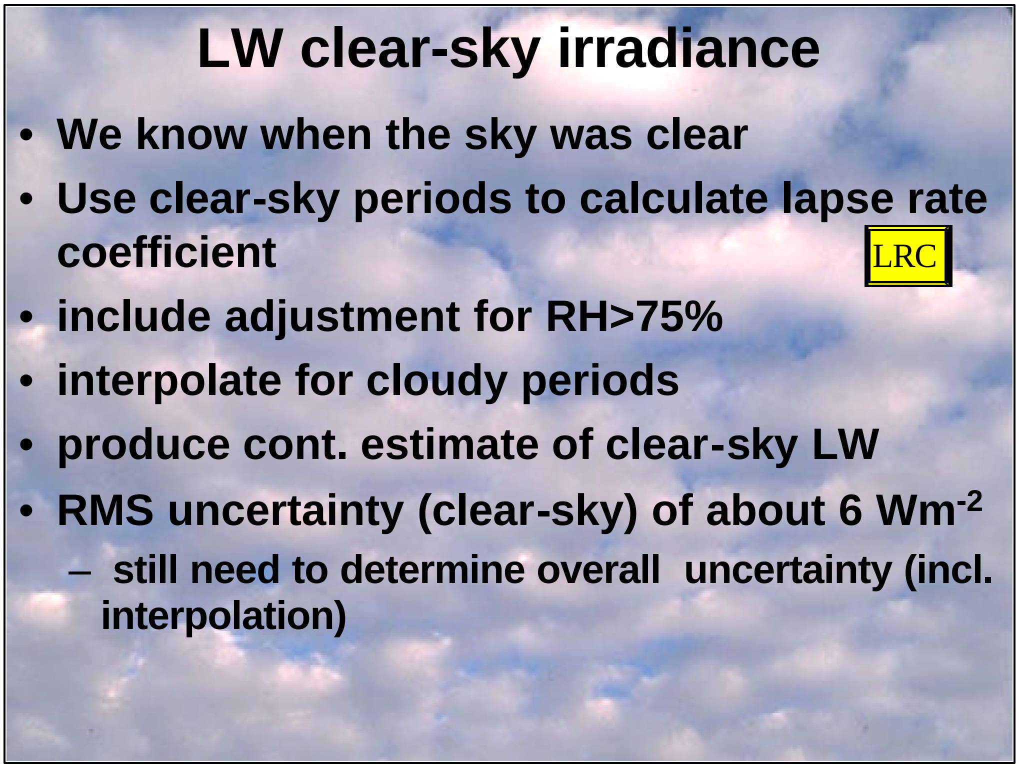
$$LW_c \cong \epsilon_c * \sigma * T_a^4$$

  - **based on Schwarzschild’s equation**
  - **1.24 from lapse rate coefficient of T and e from Std. Atmos.**
  - **RMS uncertainty of about 12 Wm^{-2}**

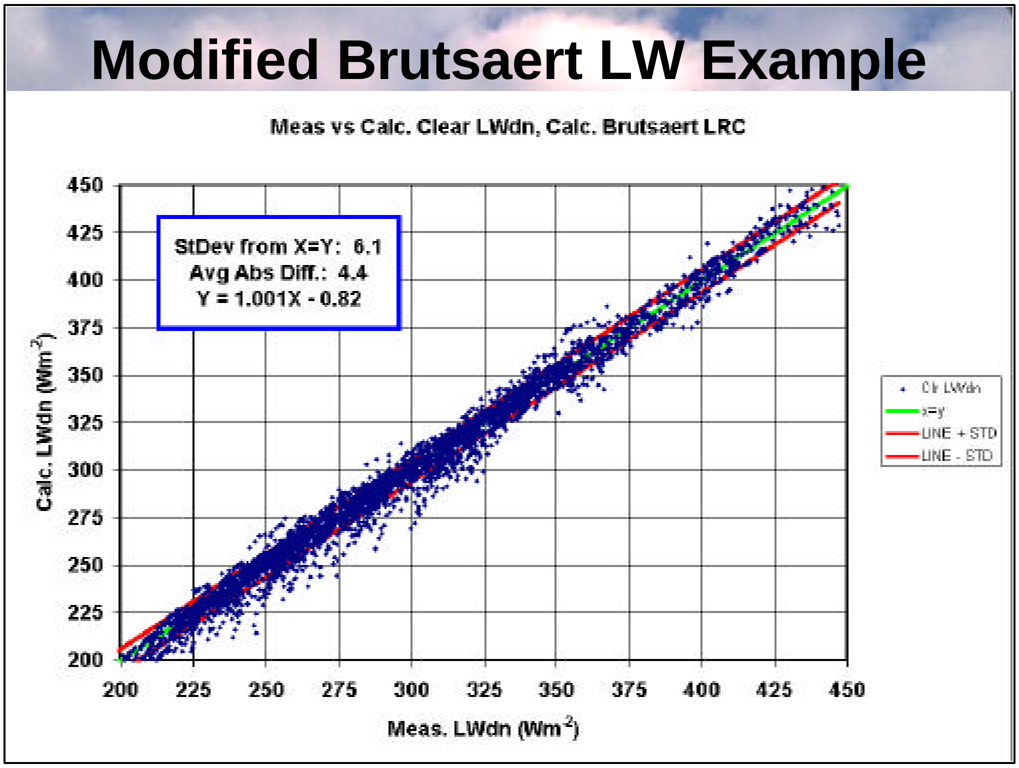
Brutsaert formulation of estimating clear-sky downwelling LW “effective emmisivity”, based on Schwarzschild’s equation of radiative transfer. “1.24” related to lapse rates of temperature and moisture, and was derived from analysis of the “standard atmosphere”.



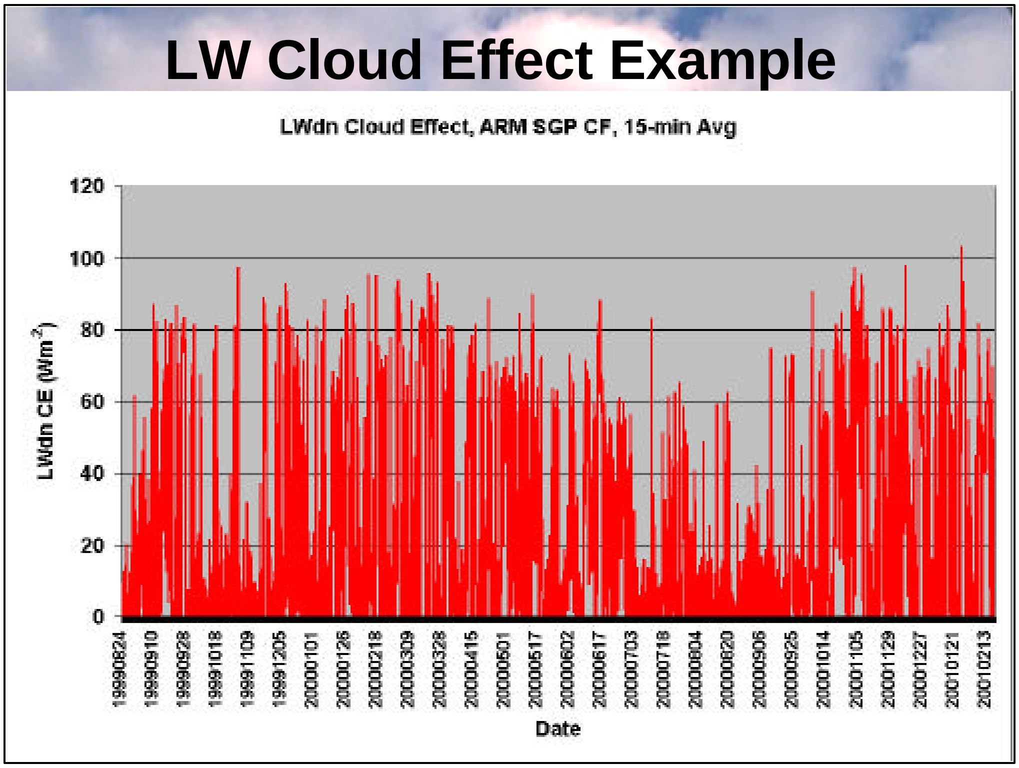
Plot showing a comparison of measured downwelling LW during periods detected as clear-sky by the SW Flux Analysis methodology, and the corresponding amounts calculated via the Brutsaert formulation using surface temperature and humidity measurements. The RMS uncertainty between the two is about 12-13 W/m^2, and the linear fit exhibits both a bias and offset.



For the Brutsaert methodology, we know when it is clear, thus have the corresponding clear-sky downwelling LW, surface temperature, and humidity measurements. Thus we can invert the Brutsaert equation for these periods, and calculate the lapse rate coefficient, instead of depending on the generic value of “1.24” (action button links to panel 35 showing time series of retrieved lapse rate coefficient for the ARM SGP Central Facility). In addition, we adjust the clear sky “effective emmisivity” to include the effect of haze development for RH greater than 75%. We then interpolate the lapse rate coefficient for cloudy periods, similar to the SW Flux Analysis methodology, and produce a continuous estimate of clear-sky downwelling LW.



Same as panel 20, but for the modified Brutsaert method described in the panel 19. This improved method has decreased the RMS uncertainty by a factor of 2 over the original. In addition, the linear fit now shows no significant bias or offset.



Measured minus clear-sky downwelling LW cloud effect example for the ARM SGP Central Facility, as derived by the modified Brutsaert method.

Cloud Base Height

$LW_{clr} \approx \varepsilon_{clr} * \sigma * T_a^4$ (from panel 19)

For Overcast Skies:

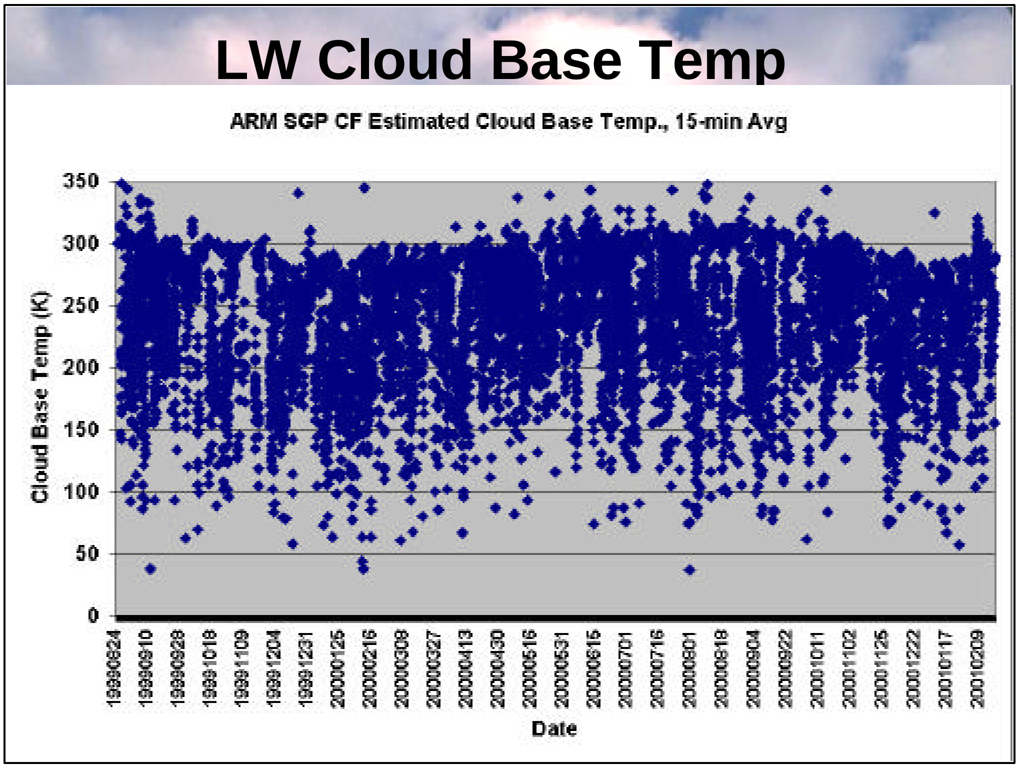
$LW_{cld} = \varepsilon_{cld} * \sigma * T_{cld}^4 \approx (1- \varepsilon_{clr}) * \sigma * T_{cld}^4$

For All-Sky:

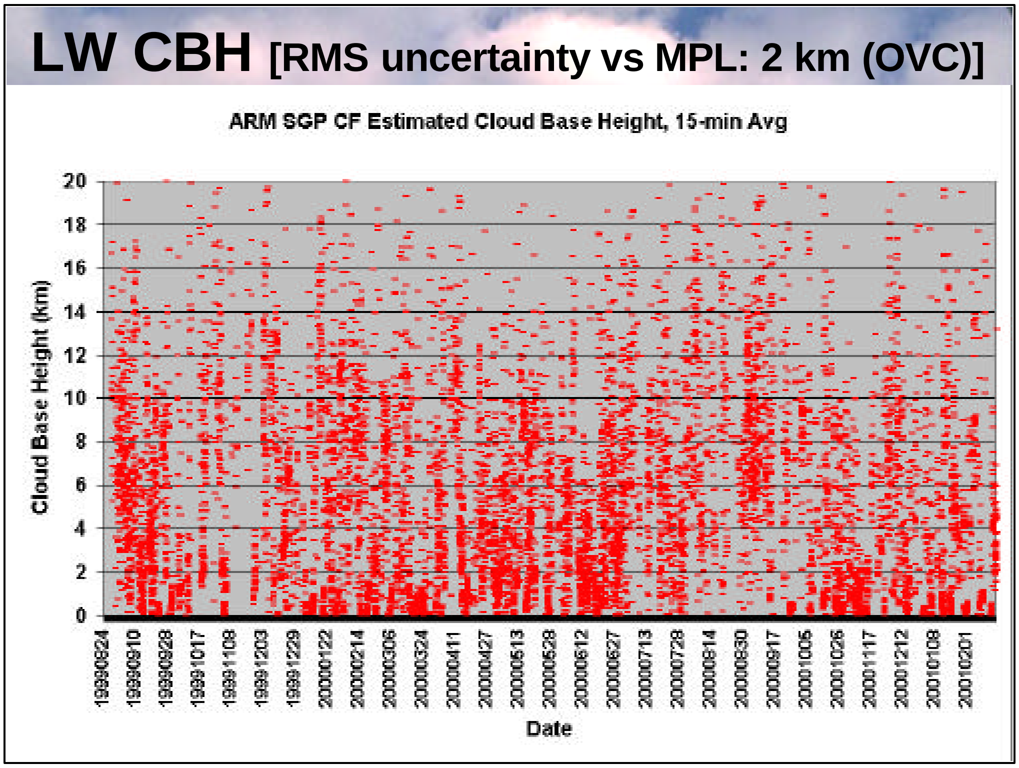
$$LW_{dn} = LW_{clr} + (Ac * LW_{cld})$$
$$\approx LW_{clr} + Ac * (1- \varepsilon_{clr}) * \sigma * T_{cld}^4$$

- Solve for cloud base temperature
- Use dry adiabatic lapse rate and $T_a - T_{cld}$ difference to infer cloud base height

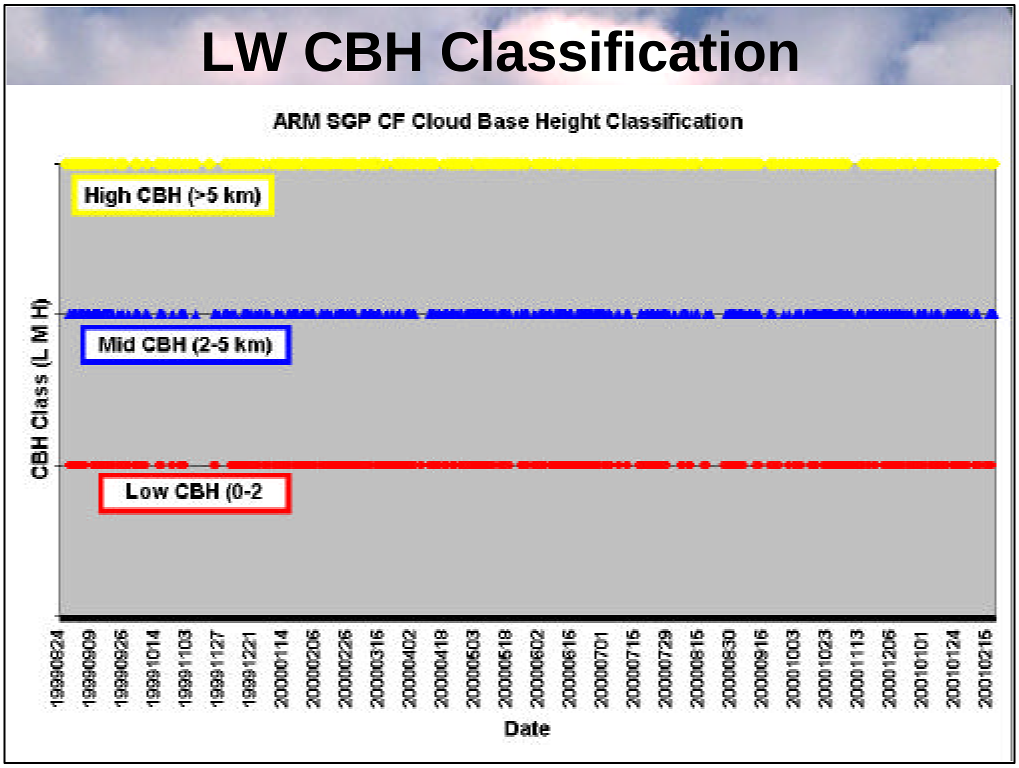
Our interest in determining an estimate in clear-sky downwelling LW, and the LW cloud effect, is not a end in itself. What we are striving for is a means to estimate cloud base heights from BSRN-type data. Using the assumptions shown above (clouds are opaque in the LW, and they can only affect the surface LW measurements to the extent that the atmosphere above is not opaque, i.e. in the IR 8-12 micron window), we end up with the final equation wherein we know all variables but the cloud base temperature. We solve for the cloud base temperature, then use the dry adiabatic lapse rate of 10 K per km to estimate cloud base height from the difference between the surface air temperature and the estimated cloud base temperature.



Same as panel 23, but for estimated cloud base temperature.



Same as previous panel, but here for estimated cloud base height. We are currently working to establish "truth" with which we can compare these retrievals. However, we are struggling to overcome differences in sensitivity and field-of-view, etc. inherent in available co-located cloud base height data. Thus, this is all preliminary work-in-progress.



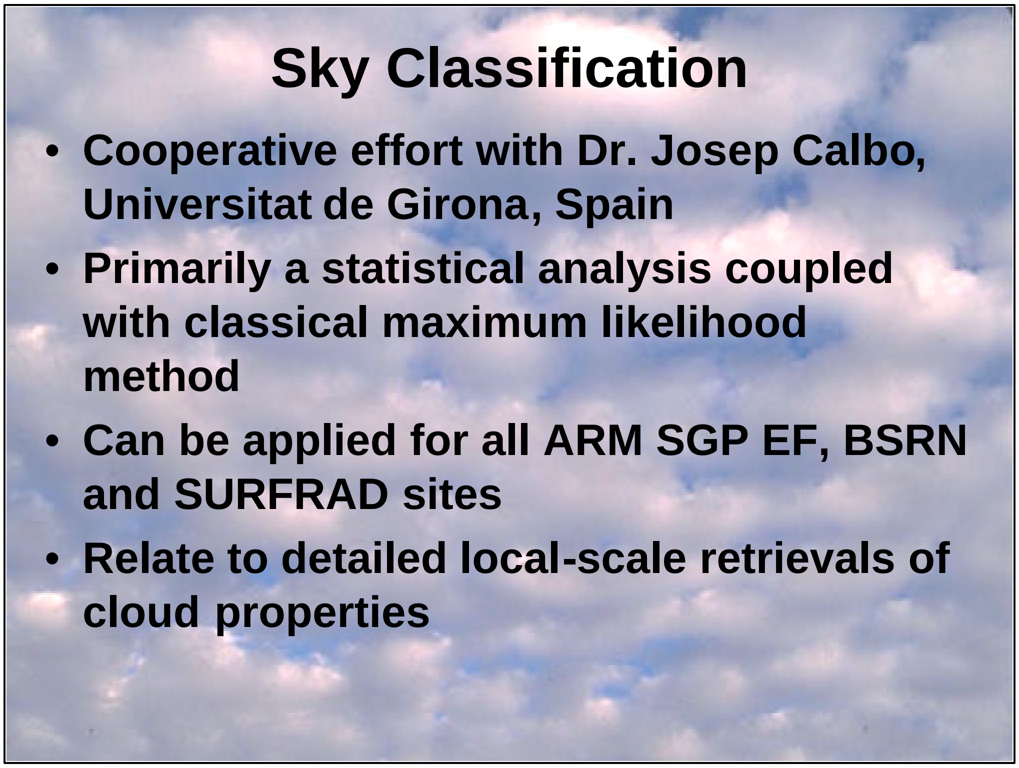
Given the current unknown uncertainty of these cloud base height retrievals, we here classify the data from the previous plot as low (0-2 km), mid (2-5 km), and high (>5 km) cloud base heights. We believe a classification using these categories will have reasonable and useful uncertainties, and thus be useful as "ground truth" for model and satellite comparisons.

Sky Classification

- Have been some attempts:
  - Duchon and O'Malley, 1999
  - Calbo et al. (in press, JAM)
- All use only measured irradiances
- Uncertainty too large or number of classes too few for practical atmospheric/radiative scientific use.
  - D. & M. ~ 50% for 6-8 classifications
  - C. et al. ~ 60%, 5 classifications
  - C. et al. recent ~ 70%, 4 classifications

We now have more information

- Known clear sky periods
- Sky cover amounts
- Cloud effect (instead of only measured irradiance) both SW & LW
  - SW includes separate components
- Cloud optical thickness
  - (SW cloud effect)
- Rudimentary cloud height (low, mid, high) from LW cloud effect



We will be applying this classification methodology to measurements at sites with more sophisticated cloud measurement instruments, such as the ARM SGP CF, TWP, and NSA sites. The intent is to relate each type of sky classification category to the corresponding retrievals of cloud properties. Thus, for less sophisticated BSRN-style sites, given a sky classification we will also then be able to say something about the expected typical properties of the clouds present.

Sky Classification Results

Category	Description	# records in class	Number of correct	% correct
A	clear sky	568	493	**87**
B1	cloudless, boundary haze	57	49	**86**
B2	cloudless, sub-visual cirrus	100	83	**83**
B3	almost cloudless, unknown cloud type	572	500	**87**
K	OVC, thin high or mid [Cs or cirrus]	148	93	**63**
H	OVC, Thick mid [Ac, As, Ns]	48	40	**83**
I	OVC, thin mid [Ac, As, Cs]	34	18	**53**
G	Fog	68	46	**68**
F1	Dark thick low clouds	103	75	**73**
F2	Thick low clouds	104	87	**84**
E	Thin stratus	50	30	**60**
C	Fair weather Cu (or stratoCu)	97	61	**63**
D	StratoCu invading sky	153	94	**61**
O	Other scattered or broken sky	150	75	**50**
		Weighted average of correct		**77**

NOTE: THIS COMPARISON USES ARM SGP OBSERVER REPORTS AS "TRUTH". THIS "TRUTH" HAS SIGNIFICANT UNCERTAINTIES.

Table showing preliminary success of sky classification work to date. Again, we are struggling to produce adequate “truth” with which we can compare these retrievals. These results are highly encouraging, and we are continuing with this research.

The Result:

- **Climatological studies of more than just surface radiative energy budget**
- **More detailed satellite/model ground truth for sites that do not have better means of determining these:**
  - – **Continuous clear sky SW and LW fluxes**
  - – **Cloud amount**
  - – **Cloud optical depth**
  - – **Cloud type (typical cloud properties)**
    - **Tied to local scale studies of typical cloud properties of each type**
  - – **SW and LW Cloud effect (cloud treatment)**

References:

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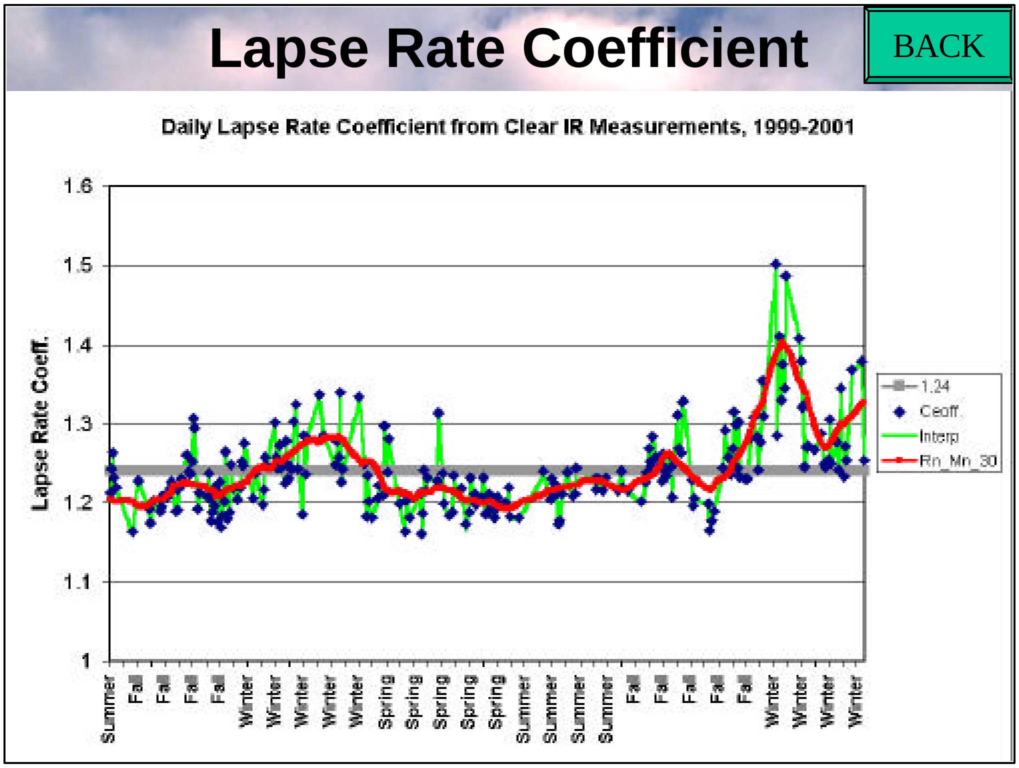
Files from here on are extra, or already linked in presentation.


Lapse Rate Coefficient
BACK
Daily Lapse Rate Coefficient from Clear IR Measurements, 1999-2001
Lapse Rate Coeff.
1.6
1.5
1.4
1.3
1.2
1.1
1
1.24
Ceoff.
Interp
Rn_Mn_30
Summer
Fall
Winter
Spring