An Abbreviated History of the IRF Working Group: 1992 -2005

R. G. Ellingson
Department of Meteorology
Florida State University
October 2006

Outline

- Where did the IRF originate?
- Birth of the IRF – first workshop information
- Summary of workshop locations and developments
- Some major thrusts – LBL- QME, Water Vapor IOP, Anomalous Absorption – ARESE, Diffuse SW problems, BBHRP, CLOWD –Instrumentation, IOPs, and extensive analyses – New parameterizations
- Some offshoots as well – I3RC
- Reports along the way – 97, 2000, 2001, 2003 and 2006
- Current make up and primary thrusts – Surface and atmospheric properties, 3-D clouds, Instrumentation

IRF Predecessor - ICRCCM Intercomparison of Radiation Codes in Climate Models

- Initiated and funded by the U.S. DOE
- Sponsored by the International Radiation Commission (IRC) and the World Climate Research Programme (WCRP)
- Began in 1983 as a series of short- and long-wave radiation model comparisons
- International workshops in 1984 and 1988
- JGR Special edition in 1990 summarized the results
- Recommended a major field experiment to test models (SPECTRE 1991), the plan for which evolved into the ARM Program Plan

State of the Science 1990 - ICRCCM Conclusions - Longwave

- **There is a clustering of many models in the ±2% flux range relative to line-by-line models. This is in the marginal range to meet the accuracy (relative) requirements of major climate programs.**
- **Uncertainties in the physics of line wings and in the proper treatment of the water vapor continuum make it impossible for line-by-line models to provide an absolute reference.**
- **The large discrepancies revealed by the model comparisons can only be resolved by well calibrated *spectral* observations because *the uncertainties associated with broadband observations are the same magnitude or larger of the discrepancies between models (5% or 20 W m^{-2}).***

State of the Science 1990 - ICRCCM Conclusions - Shortwave

- Different parameterizations for H2O absorption may lead to significant differences between band model results.
- If the discrepancies attributable to various water vapor transmittances are removed, flux calculations at the surface generally agree to within 1%.
- Provided that the Rayleigh optical thickness is adequately parameterized, climate model codes appear to simulate clear-sky fluxes in reasonable correspondence with results from the high-resolution codes.
- More definitive recommendations will emerge only from comparisons of high resolution calculations with high precision observations.

IRF Info from the First Science Plan

- **Programmatic Objective**: ***Develop and test radiation parameterizations at the accuracy required for climate studies***
- **Scientific problems presented as a series of *"Grand Hypotheses"* covering a variety of *important* clear-and-cloudy sky radiation problems that might be solved through comparison of observations with calculations**
- **Example:**

Common Assumption	Current Understanding
H2O absorption inside clouds is well understood	H2O absorption has never been measured in the laboratory at relative humidities above about 70% ...

Evolution of the IRF - Workshop Dates, Venues and Important Developments

Year	Host/Location
1992	PNNL, Richland, WA
1994	UM, College Park, MD
1996	UM, College Park, MD
1997	UM, College Park, MD
1998	LLNL, Pleasanton, CA Joint with Cloud and SCM
1999	SUNY Albany, NY
2001	PNNL, Richland, WA
2002	SUNY Albany, NY
2003	SUNY Albany, NY
2004	UC Santa Barbara, CA
2005	Annapolis, MD (with Cloud)
2006	Washington, DC

↔ H2O IOP group

↔ IRF SOS Report for Science Plan

↔ IRF White Paper

↔ IRF reorganization

↔ BBHRP initiated

↔ Input to Science Plan

↔ CLOWD initiated

↔ Nuggets

First IRF Workshop - November 4-6, 1992, Richland, WA

General Goals For The First IRF Workshop

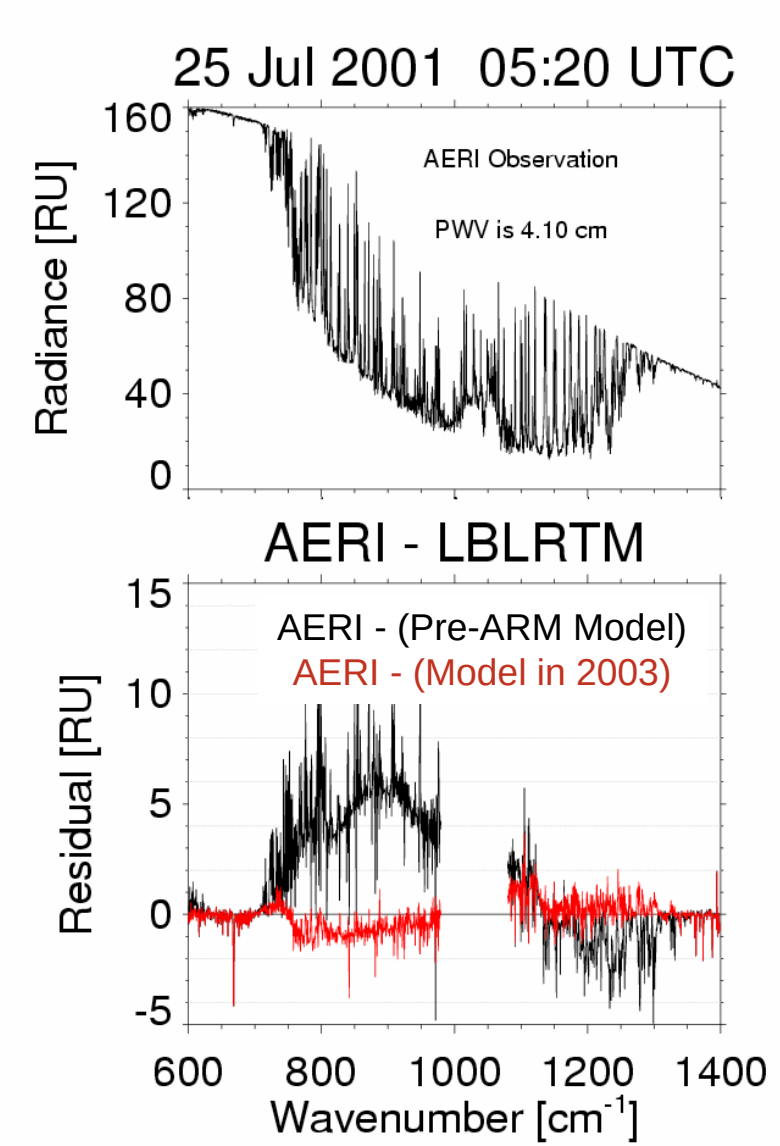
- To discuss the status of the Southern Great Plains CART site, currently and in the near term.
- To ascertain the extent to which the measurements available from CART are sufficient to support the research goals of the Science Team projects.
- To foster communication between IRF projects concerning research issues of joint interest, and to develop plans to acquire the measurements necessary to address these issues.

IRF focus through 1996 Was on the 'Clear-sky Longwave Problem'

- ICRCCM identified problems associated with errors in flux measurements, lack of spectral detail, and the H2O continuum
- Instrumentation was relatively mature - particularly the Wisconsin interferometer - AERI
- Could build on initial efforts from SPECTRE
- Necessary step prior to major advancement on cloudy-sky problems

From 1997 State of Science Report

AERI Observations at Southern Great Plains Improve Infrared Radiative Transfer Models

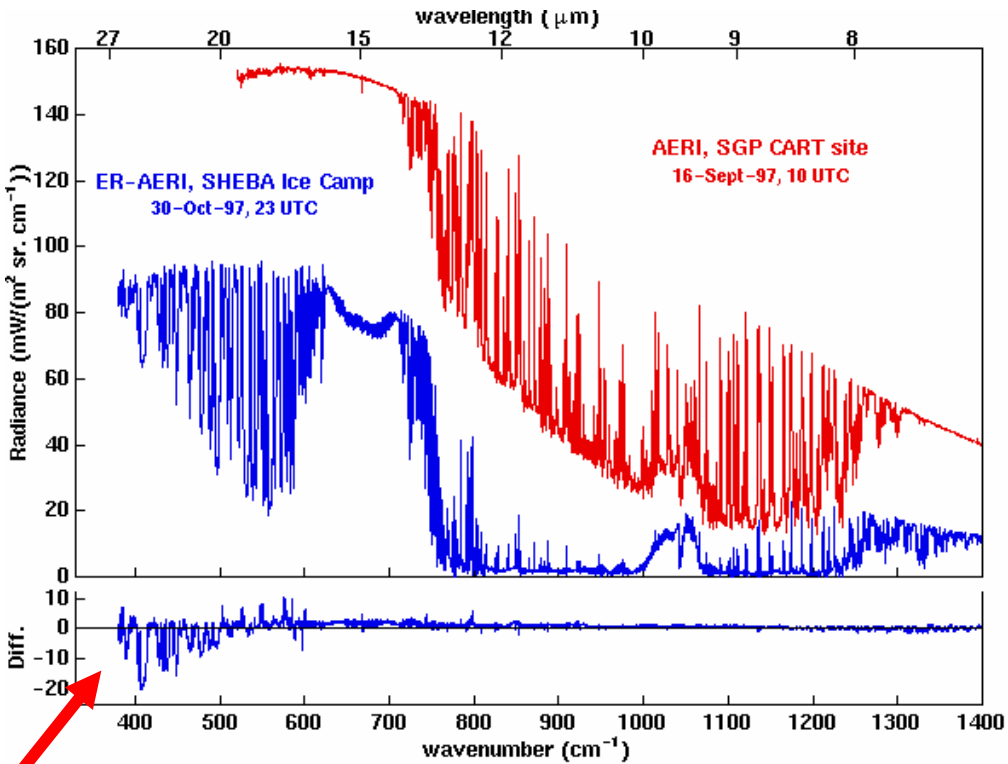


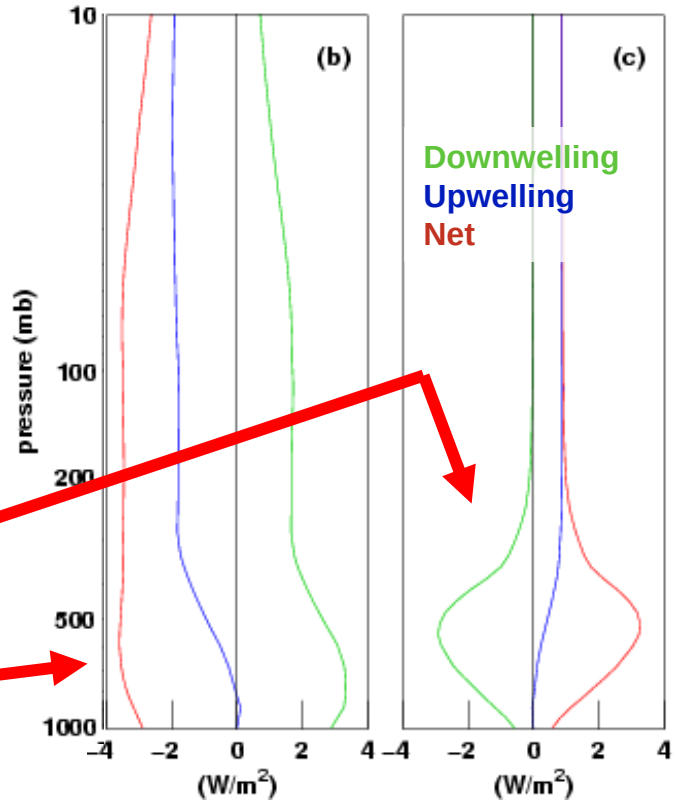
- AERI observations used to evaluate clear sky IR radiative transfer models
- Long-term comparisons have improved
  - Spectral line database parameters
  - Water vapor continuum absorption models
- Reduced errors in computation of downwelling radiative IR flux by approx 4; current uncertainty is on the order of 1.5 W/m^2

1 RU = 1 mW / (m^2 sr cm^{-1})

Turner et al., JAS, 2004

AERI Observations During SHEBA Improve Far-Infrared Radiative Transfer Models





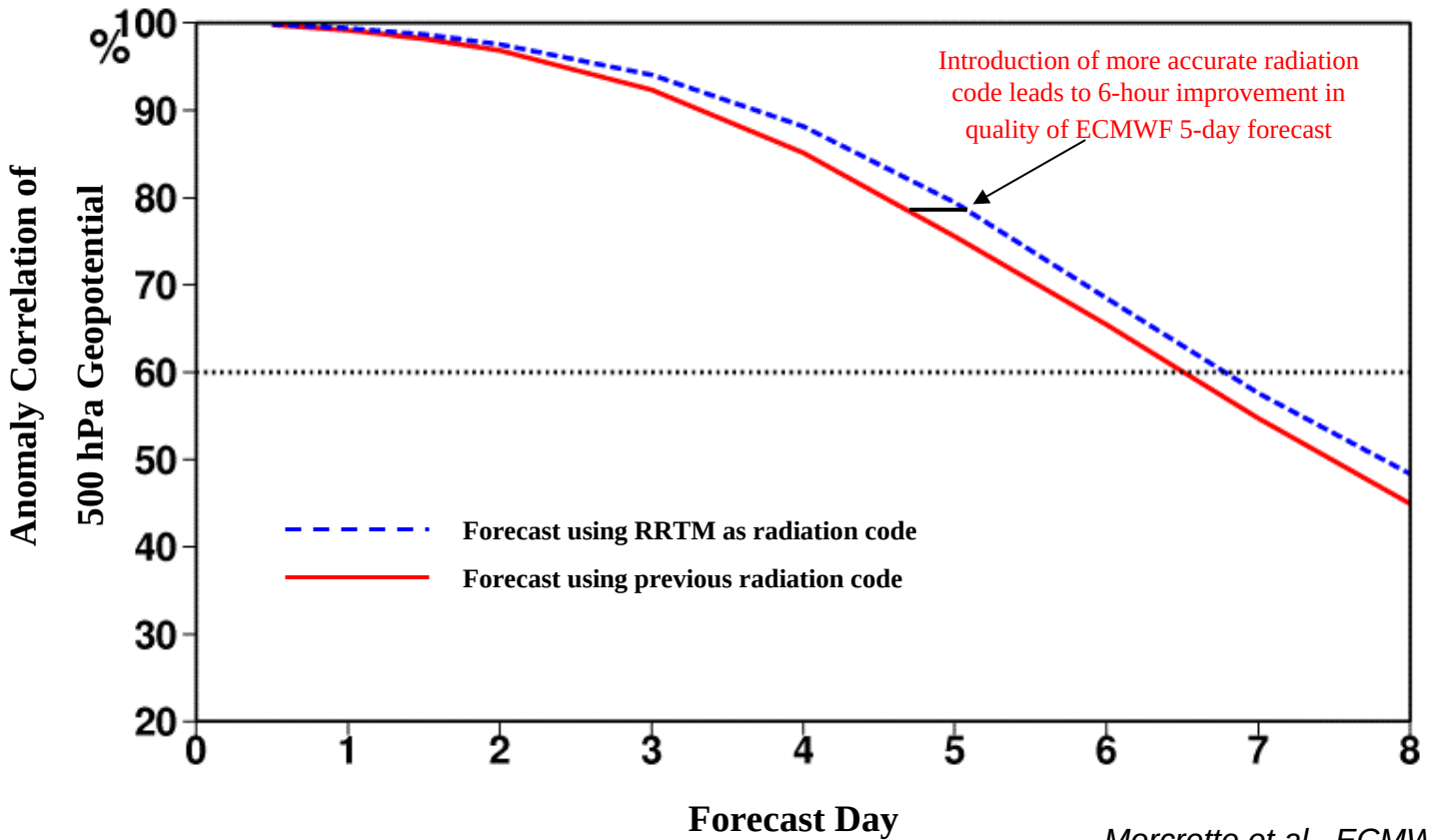
300% error in water vapor continuum absorption model in far infrared (18-25 µm)

Impact on radiative flux profile (c) is the same magnitude as CO_2 doubling (b)

Tobin et al., JGR, 1999

ARM-Developed Radiation Code Improves Weather and Climate Prediction

- Radiation code 'RRTM' developed at AER, Inc., *with ARM funding and using ARM data*, has been implemented in a number of forecast models, including:
  - NCEP Global Forecast System (GFS)
  - ECMWF Forecast Model
  - PSU/NCAR Mesoscale Model (MM5)



Morcrette et al., ECMWF Memo, 1998

ARM IRF-related Observational Accomplishments

- **Implementation of the 'Super Satellite on the Ground' with instrument accuracy and precision at or approaching the level required for many IRF studies**
- **Operationally infer downwelling longwave fluxes with the AERI for homogeneous scenes to better than 5 W m^{-2} - a reduction of observational uncertainty by about a factor of 4.**
- **Simultaneous operation of the AERI and pyrgeometers allows an accurate check of the pyrgeometer data for homogeneous conditions, thereby assuring accurate flux estimates for all scenes.**
- **The SGP CART site has become a satellite validation location and is being used by many different agencies (NASA, NOAA, DOD, and groups using GPS)**

From 1997 State of Science Report

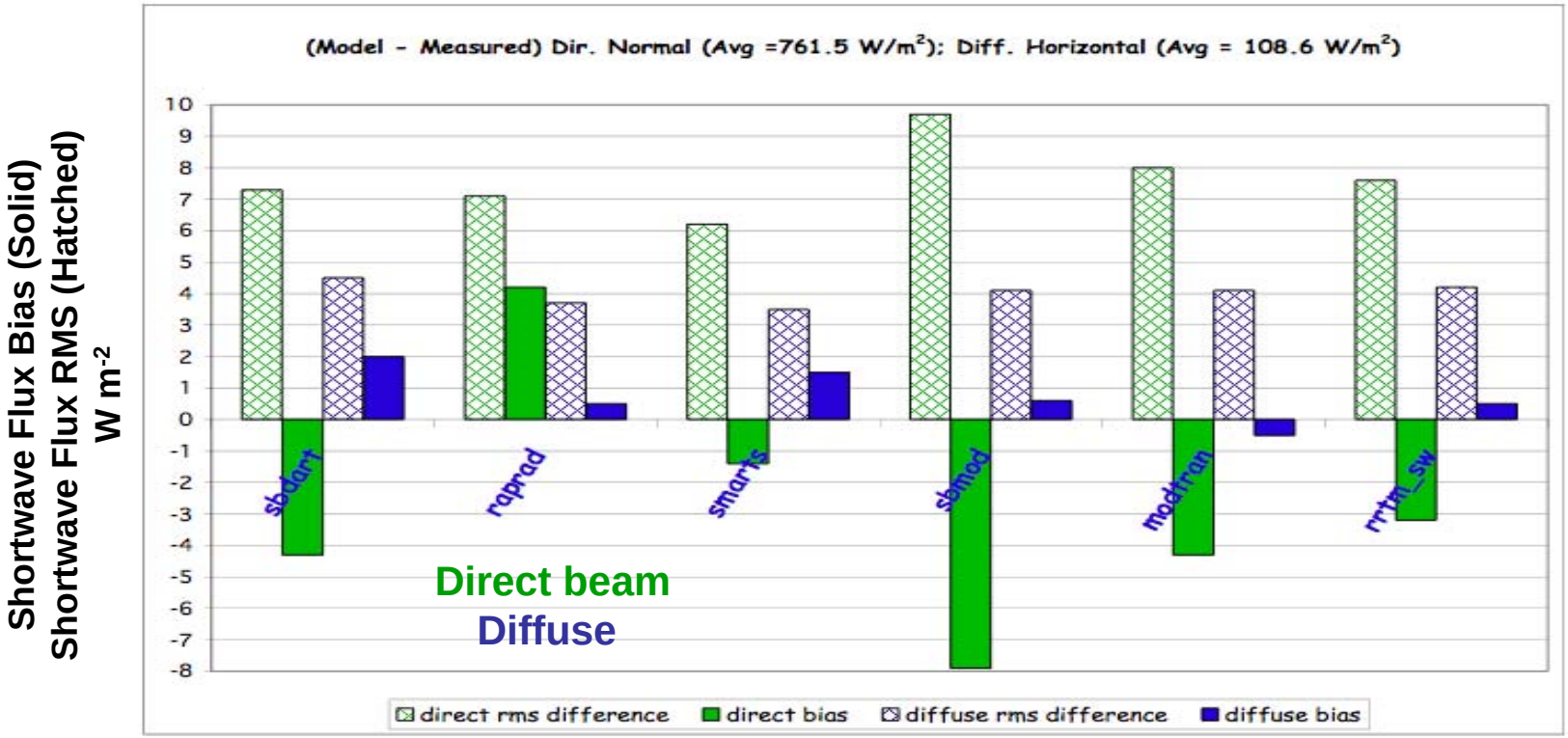
1997 - 2000 Period

- Foci shifted more to Shortwave Radiation, particularly the diffuse field, cloud-radiation problems and the development of GCM parameterizations
- Led to development of an IRF White Paper in 2000 (available from the ARM website) which highlighted the views of where the IRF should focus its activities
- Led to a reorganization of the IRF into a set of focus groups, ones that very much remain the same today

1997- 1999 Workshops

1997	UM, College Park, MD	H2O WV_IOP Summary Shortwave Radiation Status of instrumentation Microwave measurement PWV at the NSA Longwave Clear-and-Cloudy Radiative Transfer
1998	Pleasanton, CA Joint with Cloud and SCM	Recent Issues Regarding Measurement and Calculation of Diffuse Radiation Development of a strategy for parameterization of radiation for climate models Results from Recent Analyses/IOPs ARESE Follow-on - A call for ideas
1999	SUNY Albany	Shortwave Radiation - Measurement and modeling activities Atmospheric State - T, q and clouds ARESE revisited Shortwave Spectral radiation Longwave Radiation Spectral Modeling Discussion and Formulation of New IRF Activities Use of models in discovery

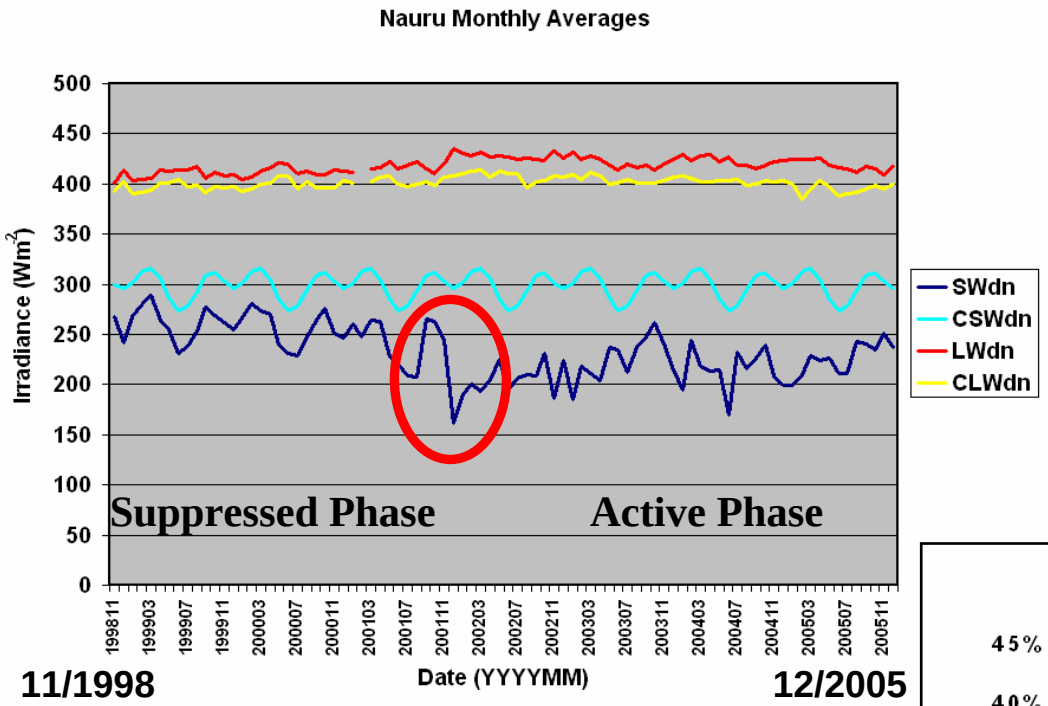
Excellent Agreement in Clear Sky Shortwave Radiative Transfer Between Obs and Calcs



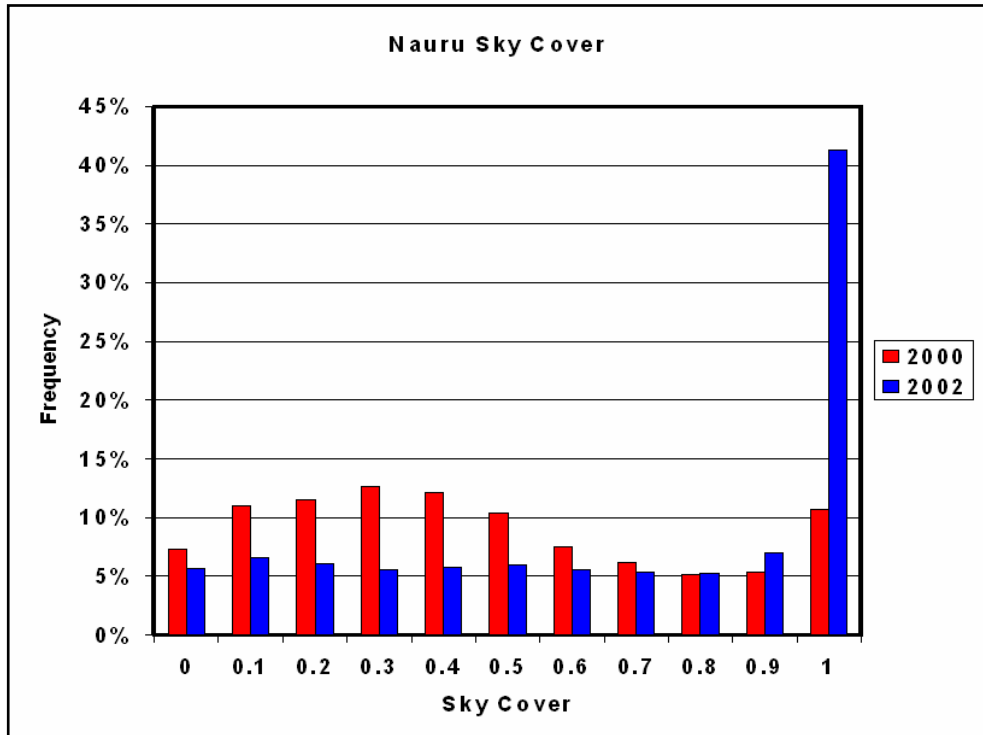
- Comparison of shortwave radiative flux at the surface during 2003 aerosol IOP with 6 different models
- Better specification of input parameters (esp. aerosol) yield excellent agreement, with the bias < 1% in direct beam, bias < 2% in diffuse

Michalsky et al., JGR, 2006

Shortwave Flux Analysis



ARM Value Added Product (VAP) -Produces continuous estimates of daylight clear-sky downwelling total, direct and diffuse SW, plus fractional sky cover. These quantities allow assessment of radiative impact of clouds at the surface.



Analyses show a decrease in all-sky downwelling SW (above) is associated with a transition from less to more convectively active phase at Nauru in December of 2001 and a distinct shift in sky cover frequency distribution (right).

Long et al., JGR, 2006

IRF Science Philosophy/Vision and Foci

- **Fix the focus and process of implementation within ARM on a very, very short list of high profile science questions**
- **Focus more attention on the direct and indirect effects of aerosols**
- **Focus more attention on cloudy sky work – 3–dimensional clouds**
- **Focus more attention on cloudy sky work – ice and mixed phase clouds**
- **Focus more attention on cloudy sky work**

Recommendations from the 2000 white paper

Revised ARM IRF Working Group

Major Components

- **Steering Committee** (Bob Ellingson, Bill O'Hirok, Chuck Long, Joe Michalsky, and Andy Vogelmann)
  - Arbitrates priorities from subgroups and makes recommendations to STEC & ARM management
- **IRF Focus Groups**

Overarching goal - the solution of major ARM-related problems - not the solution of individual PI projects

  - make recommendations for ARM acquisitions to meet programmatic goals
  - subgroups determine the major ARM subgroup problems to be studied and set the priorities for their solution

2001 -2006 Period

Focus shifted to

- 3-D radiative transfer
- Cooperative work with other working groups leading to new focus groups, namely
  - BBHRP (Broad Band Heating Rate Profile) - overarching with aerosol, CPM and CP WGs
  - CLOWD - Clouds with Low Optical Water Depth - overarching with CP WG

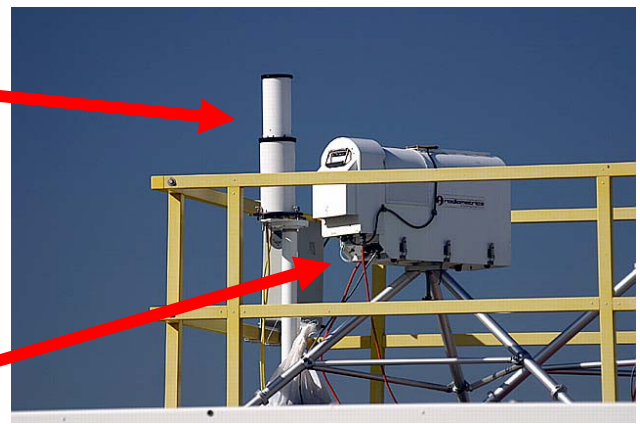
Remote Sensing of Cloud Properties Using Measurements of Zenith Radiance

Cloud optical thickness is the most fundamental optical variable in any cloud-resolving model, including the ones used in super-parameterization. If we cannot confidently and unambiguously measure it, we will never be able to validate such models.

ARM accomplishment:
We have recently pioneered in the development of a new cloud optical thickness retrieval algorithm that accounts for a fully 3D cloud structure including broken clouds. This method uses the new ARM ground-based passive two-channel narrow-field-of-view (2NFOV) measurements. In addition to cloud optical thickness, an *effective* cloud fraction is also provided.

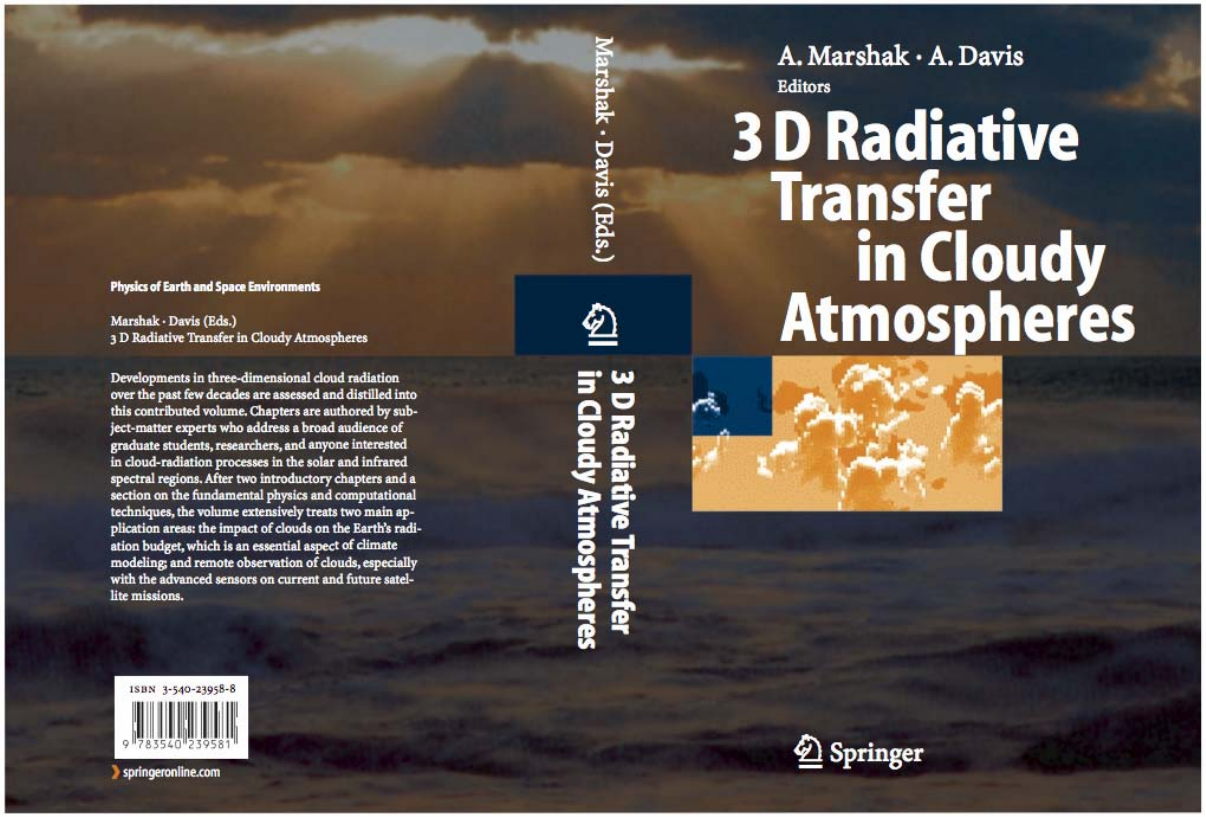
2NFOV

Microwave radiometer (MWR)



Marshak et al., JAS, 2004
Chiu et al., JGR, in press 2006

New book has been published by Springer

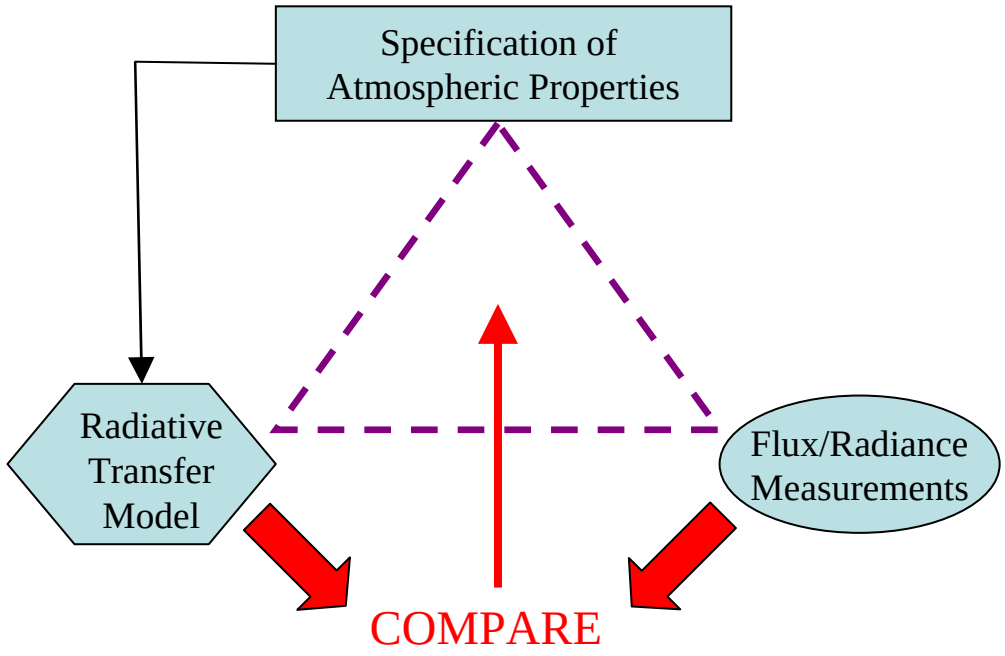


3D cloud radiative community has matured enough to prepare a volume on 3D radiative transfer in cloudy atmosphere. More than half of the authors of the book chapters are from ARM science team

The objective of the book was to capture and preserve much of the best ARM 3D cloud radiation work, and bring it to better maturity as authors took special care to explain their discoveries and advances to a larger audience. The book starts with the basic 3D radiative transfer problem, describes its solutions and models, discusses the effects of cloud inhomogeneity for remote sensing, addresses climate problems in realistic atmosphere and studies cloud-vegetation interactions.

Major Expansion of ARM Radiative Closure Studies: Broadband Heating Rate Profile Project (BBHRP)

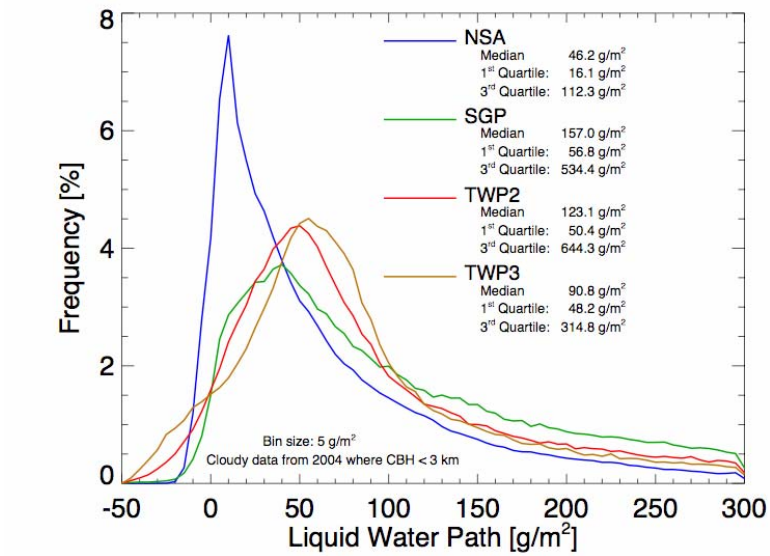
Since the beginning of ARM, *radiative closure studies* have been instrumental in the evaluation and improvement of radiation codes and ARM measurements.

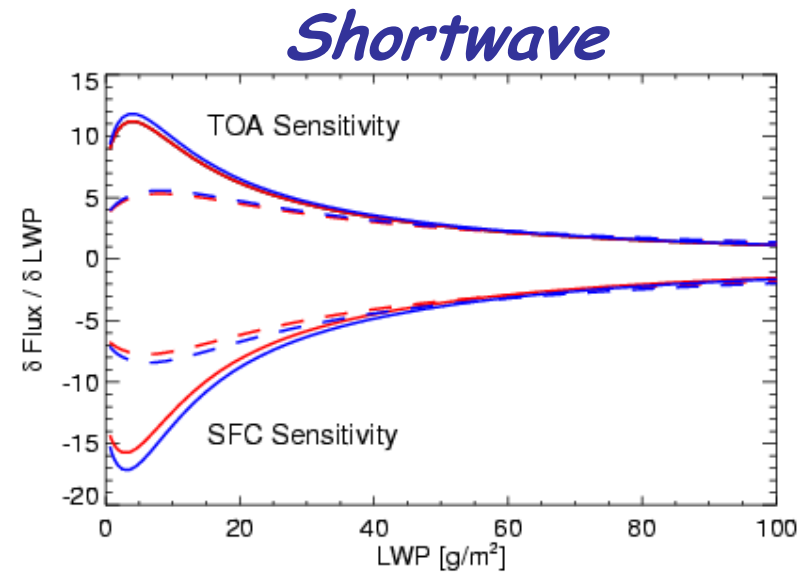


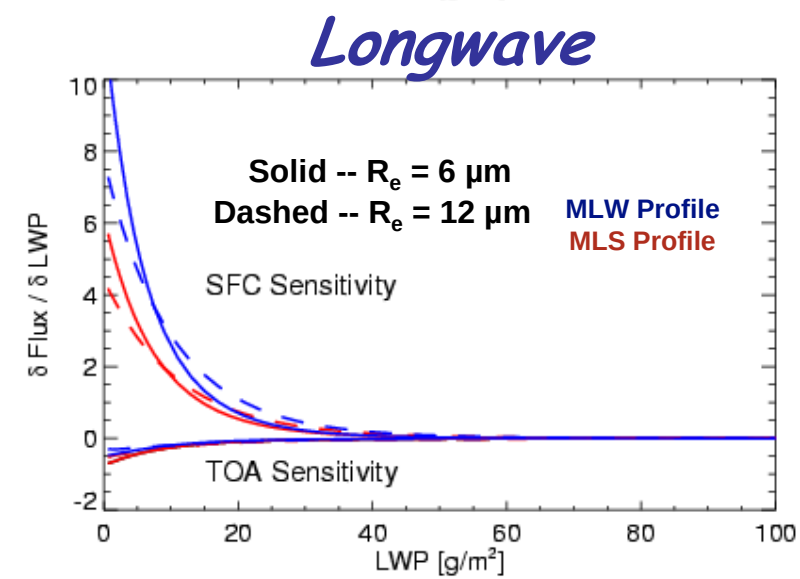
Main objective of BBHRP - Generation of long-term dataset of radiative heating rate profiles at all ARM Climate Research Facilities:

- accomplished for SGP and NSA
- in progress for TWP and ARM mobile facility deployments

Radiative Importance of "Thin" Liquid Water Clouds



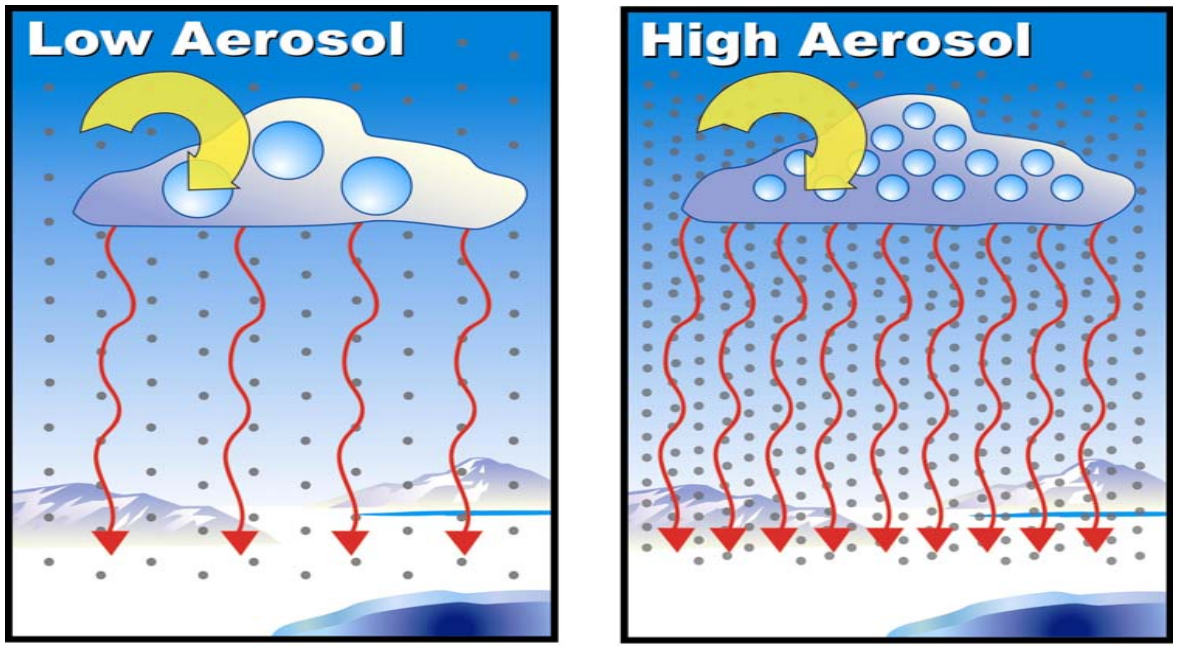




- **Thin clouds occur very frequently in Arctic, mid-latitudes, and tropics**
- **Radiative fluxes are very sensitive to small changes in liquid water path (LWP) when LWP <100 g/m²**

Turner et al., BAMS, 2006 (accepted), Sengupta et al., J Climate, 2003

Indirect Effect of Arctic Aerosols in the Infrared



- In a process known as the first aerosol indirect effect, enhanced aerosol concentrations cause the droplets in a cloud to be smaller and more numerous within a cloud of fixed water amount.
- 6-yr analysis at NSA found that this process can make clouds more opaque and emit more thermal energy to the surface.
- Significant for the Arctic energy balance

Lubin and Vogelmann, Nature, 2006

IRF Structure

Three Primary IRF Focus Groups

Instrumentation

Chuck Long

Atmospheric/Surface Properties and Modeling

Bob Ellingson
&
Dave Turner

3-D RT

Andy Vogelmann

Overarching Groups

BBHRP
Eli Mlawer &
Many Others

CLOWD
Dave Turner &
Andy Vogelmann

Measurement of Radiation Quantities and the Atmospheric State - 1

- Learn to do continuous 24/7 shortwave radiometry under any conditions in the field
- Nail down the extraterrestrial solar spectrum
- Move to trap detectors to maintain the irradiance scale
- Find a replacement for the Eppley PSP for diffuse flux measurements
- Develop an instrument that can act as a reference for standard pyranometers
- Reprocess past ARM broadband shortwave data to remove thermal offsets by an IRF-consensus algorithm (rather than having this algorithm decided off-line from the IRF)

Recommendations from the 2000 white paper

Measurement of Radiation Quantities and the Atmospheric State - 2

- Produce a weekly surface albedo product for the ARM sites, especially when surrounded by vegetation
- Measure O3 column multiple times a day with the Microtops instrument
- Convert the SWS to radiance mode
- Purchase and/or develop fast AERIs, ASTIs and or spectral radiometers
- Create a position of ARM instrument czar
- Develop direct links from the ARM website to instrument mentors
- Put some resources in

Recommendations from the 2000 white paper

ARM IRF Longwave Accomplishments

- **Line-by-line model calculations of downwelling longwave fluxes show agreement with AERI data to within 2 W m^{-2} RMS for clear-sky conditions. Uncertainties in the routine water vapor observations provide the current limitation on these comparisons.**
- **Refinements made in line-by-line radiative transfer models, particularly the water vapor continuum (e.g., LBLRTM). *SHEBA providing very exciting new information.***
- **Development of a rapid radiative transfer model for use in climate models (agrees with LBLRTM to 1 W m^{-2}).**
- **The GCM modeling community has begun incorporating the modeling developments supported by the ARM measurements in their radiation models. (GFDL, GSFC to some extent, British Met Office, ECMWF, and others)**

From 1997 State of Science Report

ARM IRF Shortwave Accomplishments

- ARESE highlighted difficulties in making absorption measurements, uncertainties in model calculations in the presence of clouds, lack of standards for making SW spectral and total flux comparisons.
- Clear-sky closure studies have bounded calculation errors of direct beam solar irradiance for a limited set of cases.
  - • MODTRAN Comparisons with active cavity radiometers data show agreement to within (-0.18 ± 0.94)% (~ -1.5 ± 7.9 W m^{-2}). <u>Uncertainty in the aerosol optical depth is the major source of error in the calculations.</u>
  - • LBLRTM comparisons with ASTI indicate flux errors of < 1 W m^{-2} in the 500 to 10000 cm^{-1} region (no evidence for Gas X, water vapor dimers, or water vapor clusters).
- Several extensive case-study data sets collected during the First ARM Shortwave IOP - September 1997.

From 1997 State of Science Report