The ARM Instantaneous Radiative Flux (IRF) Working Group in 2000: A Summary of Accomplishments, Strengths, Weaknesses, and Ideas for Future Activities

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1. Introduction

This report is in response to a request by Dr Patrick Crowley, ARM Science Director, for help in assessing ARM's present status and planning its future course. The material that follows below is a compilation and editing of my opinions and material furnished by members of the ARM Science Team in response to my request that they provide me with input for the report. 36 team members were contacted, and 14 responses were received.

*This report has **not** been reviewed by the IRF*, nor have any recommendations been prioritized. Instead, I have tried to accurately report all of the responses to give a true flavor of the range of thought within the group. Nonetheless, many of them have been edited to remove inappropriate references, to follow a consistent writing style, and to combine redundant or overlapping comments. Furthermore, some responses contained too much detail to be included, but I do plan to use some of that material, where appropriate, in different ARM committee meetings.

Particular thanks go to the respondents - Gail Anderson, Tony Clough, Anthony Davis, Lee Harrison, Jeffrey Kiehl, Andy Lacis, Zhanqing Li, Kuo-Nan Liou, Joe Michalsky, Martin Platt, Bill O'Hirok, V. Ramanathan, Knut Stamnes, and Warren Wiscombe - for without their help, little progress would be made. It is quite possible that some of their input is not reported in the intended fashion. If so, I extend my apologies in advance to the respondents and to ARM.

The material that follows below covers each of the areas noted in Dr. Crowley's request, namely:

- An assessment of the present state of the ARM program in terms of its scientific objectives from the perspective of the IRF Working Group
- Strengths and weaknesses in the present program and suggestions for improvements
- Views as to what the program should be planning for the next few (three to five) years and what this would produce for the ARM
- Ideas on how ARM can assess whether it is realizing appropriate goals intermediate to the state expected in three to five years from now

2. An assessment of the present state of the ARM program in terms of its scientific objectives from the perspective of the IRF Working Group

The ARM Science Plan delineates the interwoven nature of the ARM programmatic and scientific foci. The ARM programmatic objectives are:

- Relate observed radiative fluxes and radiances in the atmosphere, spectrally resolved and as a function of position and time, to the temperature and composition of the atmosphere, specifically including water vapor and clouds, and to surface properties, and sample sufficient variety of situations so as to span a wide range of climatologically relevant possibilities.
- Develop and test parameterizations that can be used to accurately predict the radiative properties and to model the radiative interactions involving water vapor and clouds within the atmosphere, with the objective of incorporating these parameterizations into general circulation models.

The Instantaneous Radiative Flux (IRF) Working Group has been contributing to both of these objectives by addressing a series of Grand Hypotheses delineated in Chapter 3 of the ARM Science Plan. It is important to remember that the overall programmatic objective of the IRF scientific studies may be simply stated as: *Develop and test radiation parameterizations at the accuracy required for climate studies.*

Most of the first decade of ARM witnessed the IRF concentrating its activity on clear-sky longwave radiation problems, primarily because the instrumentation to attack these problems were readily available and because routine observations of clouds and shortwave radiation were not yet at the level of sophistication necessary for significant advances on shortwave and the more general cloud-radiation objectives. During the last few years there has been a steady migration from the longwave to the shortwave and from clear to cloudy-sky problems as new instrumentation has become available and as unexplained, climatically significant anomalies between observed and model calculated quantities have been reported.

IRF investigator opinion on the success of ARM and the IRF ranges from very rosy conclusions to statements such as “I cannot think of one problem that ARM has solved in the area of understanding the radiative budget.” Clearly, there is not unanimity, and in many cases, no consensus. Nonetheless, there have been incremental advances that have attained some of the ARM objectives. The material that follows below is the author’s best attempt at summarizing these accomplishments from the input provided by the science team.

The IRF achievements (consensus, but not unanimous opinion) during the 1990’s in the longwave portion of the spectrum are:

- 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. <u>Uncertainties in the routine water vapor observations provide the current limitation on these comparisons.</u>
- Refinements have been made in line-by-line radiative transfer models, particularly the water vapor continuum (e.g., LBLRTM).
- Development of a rapid radiative transfer model (RRTM) for use in climate models (agrees with LBLRTM to 1 W m^{-2}). RRTM has been officially adopted in the ECMWF short-range and long range forecast models.

- 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).

In short, the clear-sky longwave problem appears to have been pushed to its limit with the data available from the SGP and TWP sites. Further advances are likely at wavelengths greater than 20 µm with NSA data, provided accurate water vapor data become available. Nonetheless, comparisons of spectral model calculations with reliable laboratory, aircraft and satellites observations should be pursued in order to confirm the model accuracy, particularly for vertical heating rate calculations. This, however, should be viewed as a cleanup operation rather than the central objective at this time.

The ARM IRF became particularly focussed on a variety of shortwave problems stemming from the 1995 ARM Enhanced Shortwave Experiment (ARESE), as ARESE highlighted difficulties in making absorption measurements, uncertainties in model calculations in the presence of clouds, and the lack of standards for making shortwave spectral and total flux comparisons. Nonetheless, IRF advances in the shortwave portion of the spectrum have been much more modest than in the longwave. The most promising achievements regarding model calculations include (individual claims, but not consensus opinion):

- Bounding of calculation errors of clear-sky, direct beam solar irradiance in comparison to active cavity radiometer observations to -1.5 ± 7.9 W m^{-2} for a limited set of cases. <u>Uncertainty in the aerosol optical depth is the major source of error in the calculations</u> (Halthore and Schwartz).
- Indications from recent LBLRTM comparisons with ASTI and the RSS that molecular absorption is adequately described for energy balance issues with the current spectral line parameters (this includes water lines and the continuum, oxygen lines and collision induced oxygen, and ozone) (Clough and Mlawer).
- Discovery that the extraterrestrial solar flux differs by about 5% in the mid-visible from nominally accepted values (Harrison).

Further achievements in the shortwave have been slowed, almost to a snail’s pace, due to:

- Lack of routine, <u>accurate</u> measurements of shortwave radiation and cloud/aerosol parameters with which to adequately test models, and
- Lack of a consensus/accepted vision/philosophy as to the important problems and the path forward.

Despite this cacophonous milieu, discussed in more detail below, several additional positive steps have been taken in which ARM should take pride that have strong IRF connections. These include:

- The start of an intercomparison of three-dimensional radiation codes (ICRCCM and I3RC) led by ARM IRF investigators under the auspices of the WCRP GEWEX Radiation Panel and the International Radiation Commission. These are model studies now, but they will ultimately use ARM data. Eventually, these studies will help interpret observations under broken cloud conditions and will provide means for testing GCM parameterizations.
- The deployment of and now routine observations from cloud sensing instruments (MMCR, WSI, BLC, MPL, Raman lidar, etc.). Besides being the food for IRF and CWG consumption,

data from these instruments are now talked about, used and relied upon by the national and international remote sensing community.

- The deployment and routine use of the largest array of spectral and broad band solar radiation measuring devices. While there may be disagreement as to how to interpret and use the data for different problems, there is a consensus that ARM has made a giant leap forward in deploying instrumentation that will eventually lead to meeting the ARM objectives.

3. Strengths and Weaknesses in the Present Program and Suggestions for Improvements

IRF scientists have identified several different strengths and weakness in the program that are most easily categorized under the headings of;

- Measurement of radiation quantities and the atmospheric state
- Data reduction and distribution
- IRF science philosophy/vision and foci
- Inter-science team vision/coordination

Overall, the IRF respondents found high praise for ARM, particularly with the problems under study, the instrumentation deployed, and the people participating in the research. Nonetheless, most respondents expanded upon the weaknesses rather than the strengths, in part because it is often easier to criticize than to praise, but in large part because *there is a strong desire by the science team to make a good program even better*. This section follows this overall tone and concentrates on the weakness. Some of the weaknesses have obvious paths for solutions, whereas others either do not or the respondents did not offer suggestions.

3.1 Measurement of radiation quantities and the atmospheric state

3.1.1 Strengths

- *Long-term continuity, high accuracy and precision of observations, and use of state-of-art technologies*
- *MMCR and all-sky imager are tremendous advances in instrumentation that have already challenged the experimental community's ability to ingest the data*. In response to this challenge, the ARM community has devised instrument combinations to more fully exploit MMCR and all-sky imaging.
- *Multi-site deployment and long-term maintenance of more traditional instrumentation by ARM is an invaluable asset for the community*

3.1.2 Weaknesses

- *Unreliable measurements of the broadband downwelling solar flux at the surface (direct + diffuse) have slowed progress*

  It appears as if persistent 15 W m^{-2} differences between observed and model calculated clear-sky downwelling irradiance for low aerosol conditions is due primarily to errors in the measurement of the diffuse component. The differences among the various instruments have led to unfortunate acrimony within the community, and beyond that, they preclude some scientists from using the data in a worthwhile fashion.

  A technique for accounting for the effects of dome-base temperature differences has apparently been under study for two years, but it has not been implemented for unknown reasons. This state of affairs can not continue, since poor data quality of this basic quantity undermines the credibility of *all* ARM measurements, as ARM is *the* Atmospheric *Radiation*

Measurements program. At this stage it is imperative to have state-of-the-art-calibrated instruments at the core sites of the SGP, NSA and TWP *as soon as possible* (preferably yesterday).

- *Lack of physical AND CHEMICAL determination of the aerosols over the ARM sites limits claims that we understand the energy budget*

  Note that recent, routine airborne measurement of some aerosol properties over the SGP partly meets some of this criticism. Nonetheless, the expanding casebook of "clear sky anomaly" events at SGP - events where the spectral diffuse/direct ratios from the RSS are not easily explained with standard models – begs for more information on aerosols and trace gas abundance. Deployment of active cavity radiometer measurements during clear-sky days will also help reduce the uncertainties. Furthermore, coordination with the DOE Air Chemistry program might find common ground for inter-program synergy and shared costs.

- *Theory lags with respect to measurement or is otherwise disconnected (wanting/using other data).*

  For example, although we have excellent MMCR data, we do not yet know how to interpret these data in terms of clouds seen by other instruments, such as the WSI or other vertically pointing instruments. This perhaps can be addressed by model studies using Monte Carlo simulations with the output from cloud resolving models. This is an area that can be attacked through coordinated IRF and CWG activities.

- *Frequency that the extended sites get attention is not adequate*

  Radiation measurements are always going to be uncertain if the instruments are not clean. One solution to the cleaning problem would be to hire a local attendant(s) to clean the instruments at a reduced set of sites 3-5 days per week.

- *Lack of routine measurement of cloud optical and microphysical properties precludes accurate modeling of clouds in radiation models*

  This is not a new criticism, but it is one that will continue to haunt the program until an acceptable solution is found (noted that the respondents highlighting this weakness did not offer possible solutions). As a surface based observational program, routine cloud optical and microphysical properties must be inferred from observations. Members of the CWG have been working on this problem, although the algorithms must yet be considered experimental. One instrument that will provide additional information about cloud properties, but whose SGP installation has been long delayed for unspecified reasons is the SSP (spectrally scanning polarimeter). Completion and implementation of algorithms for routine estimates of cloud properties, including optical depth must be a priority for the IRF and CWG.

3.2 Data reduction and distribution

3.2.1 Strengths

- *ARM data are easily accessible.*

3.2.2 Weaknesses

- *Difficulty in identifying measurement problems with some instruments*

  On different occasions, the appearance of unphysical spectral extinction has clearly pointed to filter degradation; the retrieval of column ozone less than 100 Dobson Units has pointed to instrument misalignment problems; and the re-appearance of aerosol optical depth features at the same time of day has identified improper cosine corrections that were part of the original MFRSR calibration. These problems often took too long to be identified, and, as such, help undermine the credibility of the entire ARM data stream. Clearly, closer routine scrutiny of the various solar radiation data as well as integration of measurements from the suite of spectral observations can help alleviate these problems.

- *Uneven dissemination of difficulties with different instruments*

There should be more of an effort in ARM to highlight the difficulties in some of the instrumentation in plain form so that modelers have a better idea on the quality of the data. It is unfortunate that one sometimes only becomes aware of difficulties when they become connected with those knowing the "lore" surrounding a particular instrument. A good example on how instrument difficulties should be disseminated is found on the ARM MFRSR web page. Unfortunately, there does not seem to be any reports (or at least not obvious to the respondent) of such MFRSR problems in ARM quality assurance reports. Such problems need to be centralized and made very clear within the archive. Additionally, a discussion on the design and operational nuances of the various instruments should be included.

3.3 IRF Science Philosophy/Vision and Foci

3.3.1 Strengths

- *ARM has built a good group of scientists to study these problems*

3.3.2 Weaknesses

- *Except for SHEBA and to some extent the NSA, there has been relatively little focus on cold clouds*

This perceived weakness is perhaps but part of the overall, poorly defined focus of the IRF as discussed below.

- *Lack of a consensus/accepted vision/philosophy as to the important problems and the path forward*

Overall, the IRF has suffered from conflicting philosophies and the lack of prioritization of specific problems. One contributor suggested that we have but two philosophies. One assumes that good radiative transfer models are basically correct and merely need to have their continuums re-tuned when small discrepancies with measurement arise; the cloud problem is of secondary interest compared to molecular absorption problems. The second proposed philosophy assumes there are no correct radiative transfer models, they are all merely approximations to the truth; models should not be tuned, neither with aerosol single-scatter albedo nor empirical continua, merely to match measurements; discrepancies with measurements should be regarded as achievements, not embarrassments to be eliminated at any cost; and finally, clouds should be the primary focus of the group, with molecular absorption somewhat sidelined for the time being.

In actuality, there are as many IRF philosophies as there are IRF PIs! In general, these philosophies fall somewhere between the two extremes suggested above, because it is almost always necessary to make *some* approximation due to lack of important data. Nonetheless, each PI has a goal that fits within the IRF programmatic objective, but *there is not a common IRF philosophy, approach or eventual group product*. Instead, there is but a hope that eventually the various improvements to radiation modeling will eventually find their way into improved parameterizations.

Clearly, some prioritization must be made to help focus the activity of this group. The opinions on how to do this ranged from no opinion to assigning this task to the youngest PIs. The planned formation of a more active IRF Steering committee encompassing the important components of ARM IRF activities will help. Moreover, **a refocus on the IRF programmatic objective** - *Develop and test radiation parameterizations at the accuracy required for climate studies* - **is imperative.** Although there is a natural tendency to solve every radiation problem, it is important to focus on the solution of the major problems that have potential climate repercussions. This focus will be helped immensely by frank discussions with the CWG and SCM concerning scientific problems *and* the physics we can realistically expect to be able to parameterize in climate models at periodic intervals over the next ten years (see below).

3.4 Inter-Science Team Vision/Coordination

3.4.1 Strengths

- *There is a modest amount of coordination between the IRF and the CWG that is leading to progress on cloud-radiation problems*

3.4.2 Weaknesses

- *There is almost **no** coordination between the IRF and the working group formerly known as the SCM*

As noted by one IRF contributor, a cursory examination of radiative parameterizations in the single column models (SCMs) participating in ARM show most dated from the mid 1980's to early 90's - obviously these are not exploiting ARM data. It would be interesting to survey the climate modelers to determine why their radiation codes have not been modified. The delay may be a result of the confusion in the climate community about the discrepancies between observations and detailed “first principle” 1-D radiative transfer computations. It could be due to the lack of any real parameterizations of the sub-grid processes that influence the radiative field. Alternatively, it may be that the parameterization of radiative fluxes is not a priority issue for the spatial and time scales associated with these models. The IRF needs an open, frank, and responsive discussion with the SCM working group to establish the radiation model needs for current and future generation(s) of climate codes, particularly as concerns cloud-radiation properties. This will help prioritize IRF, SCM and CWG objectives.

- *ARM has focused more on "point specific" measurements than on spatial coverage*

To improve the cloud-radiation parameterization schemes for use in the coarse resolution of GCM grids, spatial coherent observation is crucial to first gain knowledge of "grid-mean" values and then to develop/test parameterizations that can be used to reproduce these values. One contributor pointed out that ARM's deployment towards spatial coherent observation lies mainly in a network of radiometers. While these radiometers may be useful to interpolate and extend radiometric measurements, they suffer from numerous limitations in using them to cope with parameterization issues. There has been very little discussion in ARM as to how these data are being used or their value to the parameterization/validation effort. Without that discussion, these observations become obvious targets for curtailment.

- *Given the nil increase of overall program budget over the years, the burden to maintain the operation of ARM infrastructure may be somewhat overweighed, relative to the deployment of more science-driven IOPs*

ARM's flat budget provides much less now than it did at the start of the program due to the combined effects of inflation and the professional growth of the various participants over the 10-year lifetime of the program. These effects will only get worse over the next ten years without new funds, alliances with other programs, a re-start of the program, or a de-scoping of the current program. ARM management must ***soon*** examine these alternatives and make plans for the future if ARM is to continue to exist as a viable science-based program.

4. Views as to what the program should be planning for the next few (three to five) years and what this would produce for the ARM

Some suggestions for program activities are contained in the discussions of possible solutions to various perceived program weaknesses. The material that follows below is a compilation of suggestions by the IRF for new activities. The headings closely follow those of Section 3, namely:

- Measurement of radiation quantities and the atmospheric state
- Data reduction and distribution
- IRF science philosophy/vision and foci
- Inter-science team vision/coordination

4.1 Measurement of radiation quantities and the atmospheric state

- *Learn to do continuous 24/7 shortwave radiometry under any conditions in the field*

  Doing this in the longwave took a decade, give or take a couple of years, and it was unreasonable to expect that we would achieve this in the shortwave in only a few years.

- *Nail down the extraterrestrial solar spectrum*

  The recent result from Lee Harrison about discrepancies at the 5% level in the mid-visible (compared to the WMO standard spectrum or the Kurucz spectrum) were as big a shock as the Giver corrections, especially to those who believed clear sky shortwave was "a solved problem." As an action item, ARM should consider deploying an RSS at Mauna Loa to do continuous Langley plots for many months to really nail down the extraterrestrial solar spectrum.

- *Move to trap detectors to maintain the irradiance scale*

  This suggestion is closely tied to the preceding one. A first question to be answered is whether the trap-detector results are consistent with the ARM/NIST pool, or possibly demonstrate that our NIST lamps are in error. Secondly, confirming/smaller-error-bar Langley extrapolations should be made with trap-detector calibrations from a favorable high-altitude site.

- *Find a replacement for the Eppley PSP for diffuse flux measurements*

  The suggested approach is to field a suite of broadband shortwave radiometers from various makers at SGP with the goal of finding an instrument that is less subject to thermal offsets. This might be done with a prolonged IOP, perhaps in conjunction with the BSRN, since they suffer from the same problem. Eventually the PSP's at all ARM sites will require replacement with instruments not so subject to thermal offsets.

- *Develop an instrument that can act as a reference for standard pyranometers*

  We need to get a better estimate on the diffuse field. Should corrections to the standard instrumentation discussed in Section 3 prove impossible or if we can not find a suitable replacement as proposed above, ARM should develop an alternative to the commercially available instrumentation. One suggestion was to combine modern CCD's and fiber optics to get simultaneous measurements of discrete hemispheric radiance (albeit with a likely sacrifice on spectral range), and thereby measure the angular distribution of the radiation field.

- *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)*
- *Produce a weekly surface albedo product for the ARM sites, especially when surrounded by vegetation*

It has become impossible to test shortwave spectral models in the presence of highly-reflecting vegetation except by using the surface albedo as a tuning parameter, which diminishes the incisiveness of the test considerably; we may need a separate aircraft to do this since the aerosol aircraft apparently can't accommodate radiometers. Such flights could also provide regular vertical profile information applicable to satellite and surface-based remote sensing activities applicable to ARM problems.

- *Measure O3 column multiple times a day with the Microtops instrument*

TOMS gives us 100-km resolution O3 column once a day, but O3 can change a lot during the day as was shown at the 97 IOP (O3 has “weather systems” too) and shortwave modelers can't nail down this needed input variable using TOMS alone. Maybe the Microtops absolute calibration isn't perfect and maybe it drifts, but as a relative measurement normalized to the TOMS value once a day, it is probably excellent.

- *Convert the SWS to radiance mode*

The FOV should be variable to match the MWR or MMCR, as needed; this will allow the SWS to be independently calibrated from the RSS, which is not now possible because of the huge glass dome on the SWS which doesn't fit into any available integrating sphere. Note that this was recommended at the shortwave steering committee meeting at the ARM ST meeting last March.

- *Purchase and/or develop fast AERIs, ASTIs and or spectral radiometers*

Fast response radiometers are required to study cloud inhomogeneity from point measurements, and the time response of current instruments is not sufficient for application to this problem.

- *Create a position of ARM instrument czar*

ARM may need an instrument czar - someone to oversee development of standardization in instrument (operational and environmental) testing, calibration procedure, deployment and data format. It would be a much-hated position, but necessary evil.

- *Develop direct links from the ARM website to instrument mentors*

A status report and a discussion forum for each instrument would be extremely helpful. AERI has an excellent link, for example.

- *Put some resources into laboratory experiments*

Monitoring the scattering properties of droplets during phase changes could be conducted in environmental chambers, for instance.

4.2 Data reduction and distribution

· *Establish the type of environmental testing procedures as used, for example, in the aerospace industry before full deployment in the field*

Modelers may be more amenable to parameterization development if they had more confidence in the data being supplied by ARM. In retrospect, it may have been wiser to devote more resources in the beginning to instrument development, calibration and environmental testing.

· *Review the rationale for each data set being collected*

ARESE is/was successful because specific data were collected to answer a particular question, and it seems that ARM has some instruments collecting data without a particular mission. On the other hand, some of this data may become quite valuable to an investigator for a purpose that was never envisioned in the first place.

· *CDF data files from the archive should be accompanied by GIF or other type images of sample data plots to insure that the data are being extracted and interpreted correctly*

· *Establish a web-accessible repository for PI developed data handling software (shareware)*

One IRF respondent wrote: "An extremely useful programming job would be for ARM to employ someone to write IDL scripts for reading and extracting data from the CDF files and for converting the various time and spatial coordinates." Many PIs and infrastructure folks have already written such codes, but the ARM community does not know of their existence. Establishing a repository for such software might lessen the spinup time associated with using ARM CDF data.

· *Develop quicklooks of data through a map interface*

The Surface Meteorological Observation System (SMOS) interface is a very good example for other data sets to emulate.

4.3 IRF Science Philosophy/Vision and Foci

There are many suggestions that fall under this category, and portions of the discussion of this item were covered in the previous section. Perhaps the dominant theme can be stated as - *develop a focus on specific objectives*. Most of the suggestions for an IRF focus were for cloud-radiation studies – particularly for three-dimensional cloud effects. However, some suggested additional research on aerosol-related problems. The aerosol proposals may be more appropriate for the aerosol working group, but they are included herein for completeness. Nonetheless, ARM must decide the balance on cloud versus aerosol research, since there are likely not enough resources in ARM to do justice to both problems. Input from the SCM working group will be crucial to this discussion as well.

There are also a number of suggestions that might be considered parochial or ones that had a detailed description for particular experiments. Some of the details have been purposely filtered, because to do otherwise would be to make this document more diffuse than it already is. Bulleted suggestions and respondent comments follow below.

· *Fix the focus and process of implementation within ARM*

ARM needs to focus on a very, very short list of high profile science questions. We need to insure the most economical and best scientific plan of implementation to answer these questions. To make this work will mean that ARM needs to become more flexible. For example, should we always carry out every ARM experiment over the SGP? There may be other locations (that are still logistically favorable) that are more appropriate for the science question you are trying to answer, to name one: excess cloud absorption. There may be reasons to cut back in some areas in order to add more comprehensive aerosol measurements.

· *Focus more attention on the direct and indirect effects of aerosols*

The aerosol issue is known to be notoriously complex. It involves not only radiation and remote sensing, but also atmospheric chemistry and dynamic transport. It appears that the ARM's IRF could focus on a specific radiation issue with respect to the interpretation of spectral and broadband solar fluxes at the surface and the validation of solar radiative transfer models for clear/aerosol conditions. The surface radiometric observations at the CART site and the analyses that followed have provided the data sets for us to question the accuracy of radiative transfer models, on the one hand, and the uncertainty in broadband solar radiometric measurements, on the other. We may close the gap in aerosol/radiation uncertainty if a coordinated effort is made in this area. Collocated measurements of aerosol size distribution and composition and their uncertainties could be conducted for input to light scattering and radiative transfer models in association with radiometric observations that are available at the CART site.

Aerosols, and their indirect effect on clouds, will no doubt continue to be the principal source of uncertainty in defining the radiative forcing effects that drive climate change. To get the aerosol story right, we need to know not just the aerosol optical depth, size, and single scattering albedo, but also its composition and CNN characteristics, and simultaneously cloud droplet distributions. This information is not likely to be obtained with the current suite of instruments. To help address this issue, the respondent would like to see ARM support polarization measurements and analysis.

· *Focus more attention on cloudy sky research – 3-dimensional clouds*

Certainly, a number of aspects of clouds have been tackled for a number of years, including ‘anomalous absorption’ in clouds, plus several cloud IOPs. Some observations of ice crystal habit have also been made. However, more attention needs to be paid to basic modeling of 3-D transfer in clouds, including the effects of scattering by various ice crystal habits on the solar albedo. Future experiments could then be based on such models.

To understand the subgrid radiative fluxes, ARM has funded many successful 3-D radiative modeling efforts. While the consistency among the various models is remarkable, it now seems that 3-D modeling effort has reached something of an impasse. There is only so much that can be learned from intercomparison, and we should be looking at means for comparing 3-D computations with observations. This is a very difficult proposition since 3-D fields of atmospheric constituents are required as input.

The future requires fresh approaches. Some may be feasible, most will not. To collect 3-D data, methods such as scanning radar or lidar, balloon borne arrays of small inexpensive instruments (e.g. hot wire), or something akin to optical tomography may require seed money for prototype development. To account for subgrid variability in climate models, we may find that model-predicted variables for a particular gridcell will not be sufficient for describing the PDF in that cell. It may be necessary to have knowledge about surrounding spatial distribution of the model-predicted variables. To understand and quantify subgrid variability as related to scaling, ARM may consider collecting data using a nested grid approach rather than the irregular spacing now employed at SGP. For this type of 3-D study, spatial coverage would be paramount over absolute accuracy. This approach would require the development of inexpensive (analogous to the cost structure implied with typical radiosondes) autonomously operated systems capable of collecting basic meteorological and radiometric data.

- *Focus more attention on cloudy sky research –ice and mixed phase clouds*

  A challenging problem for ARM to address in the next 3-5 years would be how to treat ice and mixed-phase clouds, as this is probably one of the most vexing obstacles to progress in climate research. Some scientific questions that ARM could focus on here are:

  - To what extent will the shape of ice particles in the atmosphere influence their optical properties and the radiation transmitted through, absorbed by and reflected from the earth-atmosphere system?
  - What is the effect of ice particle shape on atmospheric warming/cooling rates?
  - How will particle shape influence our ability to retrieve accurate information about ice clouds by remote sensing techniques?

- *Focus more attention on cloudy sky research – but change the measurement paradigm to mega-IOPs to tackle several major interrelated issues/hypotheses*

  Some of the remaining ARM problems may not be fully resolved with the current observation strategy and infrastructure. The respondent believes that these require the deployment of more comprehensive and intensive observation campaigns emphasizing synergetic observations from ground-based, air-borne and space-borne platforms. The respondent's experience with past ARM data is that there seems always to be some key-piece of information missing which prevents unraveling a problem completely. In future IOPs, we should strive to characterize more completely and accurately the state of the atmosphere, clouds, surface, together with spectral radiative fluxes at the TOA (taking advantage of multiple EOS and other new space sensors that were not available before), inside the atmosphere (simultaneous probing of clouds, aerosol, H2O, fluxes, etc by several aircraft), and at the surface. Furthermore, special IOPs should be conducted aiming at validation and improvement of remote sensing products that are essential to the development and testing of cloud-radiation parameterization used in GCMs.

- *Focus more attention on cloudy sky research – use routine surface observations coupled occasionally with a well-designed IOP*

  Cloud IOPs have been found to be very useful for some purposes (e. g., obtaining data on cloud microphysics, ice crystal habit, etc.) However, more use should be made of the regular ARM observations, and IOPs should be more tailored to these observations. To test the IRF Grand Hypotheses, it will be necessary to develop more suitable instrumentation for point observations at the CART sites. Thus, the program should concentrate once more on this aspect. These type studies require a fast AERI and/or a fast multi-filter radiometer carrying relevant wavelength bands. A fast spectral IR narrow-beam radiometer will be coming on line shortly. The SSP is another spectral instrument that could usefully be used. The variation in spectral radiance can then be tied to the MMCR reflectivity and lidar backscatter profiles. The respondent provided specific details on how this could be done, and these will be available to the STEC when necessary.

- *Encourage a free market for radiation models, and more of the previously tried intercomparison of radiation model results*

  From past experience, our current research models evolve faster than the model documentation, so they are probably not good candidates for model archive development. There are, however, sections of these models that tend to operate as black boxes, such as Mie scattering codes, doubling/adding, vector doubling, line-by-line codes that might be good candidates for detailed intercomparisons and eventual archiving. In the past, we have seen where different Mie codes give different results for supposedly the same aerosol size and refractive index. Since Mie scattering is "exact", this should never be the case. Somebody has to be getting the wrong answer if the Mie computation results are different.

4.4 Inter-Science Team Vision/Coordination

Some suggestions for ARM science team coordination are discussed in Section 3 in relation to program weaknesses. The comments that follow below are additional suggestions that might enhance ARM over the next five years.

- *Develop inter-working group projects focussed on the intercomparison and testing of GCM cloud and cloud-radiation parameterizations*

  Improvements to climate models require the integration of knowledge from the various ARM Working groups. One way to do this would be to have intercomparisons of the various parameterizations used in the models and comparisons to ARM observations. The IRF has initiated a longwave GCM model QME, but it is not clear that all ARM SCM PIs will participate. Finding the mechanism to ease the participation in such intercomparisons and enforcing the expectations that PIs will participate in inter-model studies will be a good start to the development of new climate cloud-radiation codes.

- *Develop an ARM cloud resolving model with a Monte Carlo radiation package*

  Studies of many ARM cloud-related problems would be enhanced with the use of realistic, but simulated, cloud and radiation fields (e.g., interpretation of point cloud observations, parameterization of subgrid scale cloud effects, planning of cloud IOPs, and parameterization of 3-dimensional cloud effects). The components of such models are likely available, and ARM might consider developing and/or making one such model available for the science team to use as a resource when necessary.

- *Refocus the ARM cloud formation activity to address ice formation*

  Specific questions that should be addressed include:

  - How do ice crystals grow in different thermodynamic/dynamic regimes?
  - Is it sufficient for climate modeling purposes to describe ice crystals as either disc-like or rod-like depending on the conditions?
  - If so, is it sufficient to mimic crystal shape simply as spheroids (disc-like oblate or rod-like prolate spheroids) to obtain a reasonable first approximation to its departure from spherical shape?
  - Can we assign a size-shape distribution of spheroids (oblate and/or prolate) to the crystals from the thermodynamic and dynamic situation?

- *Link with other DOE atmospheric observation programs*

  Such links might include nonproliferation monitoring projects at LANL and elsewhere: FORTE at LANL/NIS-1 for lightning and infra-sound propagation, MTI satellite at LANL/NIS-2, the DOE Air Chemistry Program and the DOE Aerosol Program,

- *Encourage connections with expert data-analysis communities*

  For example, the NOAA ozone “tiger team” might be able to help measure progress towards ARM goals and make decisions on future investments in instrumentation and process studies.

- *Introduce a small-investment/high-risk component into the ARM research portfolio*

  Such a program might rake in high returns as in NASA's New-Millennium program. Some of the new starts in last year's proposal awards are a step in this direction, but it could be made more formal.

- *Establish a mechanism for regular, peer reviewed publications on ARM working Group accomplishments*

  It is important for ARM that the various working groups publish summary papers describing the findings at regular intervals – say on the average of every two years. Perhaps we can encourage special issues of AMS, AGU, and/or Elsevier journals for this purpose. Note that the time required to prepare such review papers is not trivial, and it is unlikely that these can or should be the purview of the ARM Chief Scientist.

- *Establish science-specific ARM leadership positions*

  Science is done best when there is a personal ownership of the process. With the reorganization of the infrastructure to be more science driven, the science team leadership should likewise change from site to science-driven leadership. These scientists would chair the various working groups, and they would provide an extended cadre of scientific leadership to the program which would help insure progress and reporting of ARM’s accomplishments. These positions would replace the current site scientists. Funds for the positions should be provided through a competitive review process for a three to five year term with fixed periods of performance review.

- *Establish sabbatical-type appointments to DOE and/or University research groups*

  One technique to encourage reporting of working group activities is for ARM to offer sabbatical-type appointments to ARM researchers to lead the various working groups for extended periods – say, one to two years – and part of their responsibilities would be to document the progress of the working groups through a formal publication.

5. Ideas on how ARM can assess whether it is realizing appropriate goals intermediate to the state expected in three to five years from now

A time-honored technique is to have external reviews by an appropriate body. During the early stages of ARM, the Jasons reviewed the program on a near yearly basis. The Jason reviews were very useful, but there was always a steep recognition curve to overcome by both sides, since most of the Jasons are not atmospheric scientists and most of the ARM scientists are not traditional physicists. More recently, ARM has been reviewed by other groups (e.g., TWAG), although at less frequent intervals. All of the reviews were useful in making sure that we had the right goals and were on track, but the frequency was either too large or too short to use as a base to address the problem posed here.

One approach might be to commission a standing ARM Advisory Panel comprised of non-ARM funded scientists chosen by the ARM Chief Scientist and DOE management. This panel would review the program on a biennial basis and would provide advice to the ARM Chief Scientist and DOE as to their opinion on the progress of ARM towards well-articulated five-year goals. The review might be done in conjunction with the annual ARM Science Team Meeting since most, if not all, of the relevant participants would be present. Review materials for the panel should include a Chief Scientist report, PI annual progress reports, PI project renewal reports, and working group reports. If the review was held in conjunction with the annual science team meeting, the Advisory Panel would be able to hear oral presentations by the various working groups, and they would gain a first-hand flavor of the ongoing research.

Note that a review of the type noted above would require the program to make very clear, not too numerous, and very well known, 3 to 5 year goals. Likewise, PIs would be requested to map their achievements to these goals in yearly reports and at renewal. Implicit in the above is an attempt to steer away from the standard measure of achievement by *number of publications alone*. Sometimes, fewer but more far-reaching publications and milestones (e.g., theoretical models, elements of instruments) in longer-term efforts can be more significant achievements. Such publications are best measured on a five, rather than a two-year interval. Nonetheless, PIs need to be encouraged of the importance of such publications to the program and to their professional standing. Any reputable review committee will want to see publications!