Quality Measurement Experiments Within the Atmospheric Radiation Measurement Program

N. E. Miller, J. C. Liljegren, and T. R. Shippert
Pacific Northwest Laboratory
Richland, Washington

S. A. Clough and P. D. Brown
Atmospheric and Environmental Research
Cambridge, Massachusetts

Introduction

The general goal of the Atmospheric Radiation Measurement (ARM) Program is to improve general circulation and related models of the atmosphere for global and regional prediction (DOE 1990). To achieve this goal, ARM is collecting a prodigious volume of data at its first Cloud and Radiation Testbed (CART) facility in the Southern Great Plains. Because data must be of "known and reasonable" quality, quality measurement experiments (QMEs) are a critical part of the ARM quality assessment program. In this paper, we describe the general theory behind the QMEs, explain how they are implemented in the CART data environment, and give a brief synopsis of those implemented to date.

Definition of QME

Two conceptually distinct approaches are used to check the quality of the CART data at several points along the route to the user. The first approach focuses on self-consistency: through automated and manual methods, an individual data stream is checked against itself for anomalies (Blough 1992).

In contrast, a QME compares multiple data streams against a set of expectations as to the outcome of the comparison (i.e., the hypothesis of the experiment). The multiple data streams that are inputs to a QME may include 1) *direct observations* from instruments, 2) *measurements* derived from multiple instrument observations and the subsequent application of algorithms, and 3) *model output*. Multiple data stream comparisons reveal more than do single data stream checks.

A QME is the opposite of a case study. In a QME the defined comparisons are typically made for the input dataset for the entire data record and in as near to real-time as possible.

Clearly, all QME processing must be automated because of the large amounts of data that will be collected during the anticipated 10 years of the ARM Program. The output from the QME is treated as a measurement and becomes part of the ARM data archive. These data are available for distribution to the scientific community. As of this writing, two QMEs have been implemented in the ARM Experiment Center, a computing facility for creating value-added data products (ARM measurements) and distributing them (with accompanying observations) to members of the ARM Science Team.

How QMEs Are Used

A major function of the QME is the identification of data anomalies, such as inconsistent data across instruments and incorrectly implemented or inconsistent measurements. In addition, QMEs will provide information needed to identify the root cause of the exceptional behavior.

These experiments will add value to the CART data by providing additional information describing the original data streams. These value-added data will help analysts select from the voluminous ARM archive a window of data for their particular analysis.

Selection and Methodology

Anyone who uses the CART data (members of the ARM Science Team as well as members of the infrastructure) can suggest a QME. Criteria for selecting a set of data streams for comparison from the universe of possibilities are as follows:

- the importance of the data streams to the Science Team experiments that use them
- the comparability of the data streams (how well defined is the expected result of the comparison)
- the interpretability of the experiment (can the comparison and interpretation of the result be automated).

These criteria lead to the topics of methodology and interpretation. With regard to methodology, two types of QMEs are possible: those based on purely statistical comparisons (in the temporal/spatial or the frequency/wavenumber domains, for example) and those based on physical models of atmospheric or instrument behavior.

Because the purpose of a QME is to provide a useful evaluation or estimate of data quality, the interpretation of the result is critically important. A key ingredient is the ability to detect anticipated anomalies; if one understands how anomalies can arise in a particular data stream, one can develop a QME to detect them.

QME Categories

A hierarchy of QMEs exists, distinguished by comparability and interpretability:

1. Same observed quantity, similar source, e.g., downwelling hemispheric solar irradiance from a network of pyranometers.
2. Same observed quantity, different sources, e.g., vertical profile of temperature from a balloon-borne sounding system (BBSS) and from a radio-acoustic sounding system (RASS); total-column water vapor from integration of balloon-borne vapor profiles and from statistical retrievals of microwave observations.
3. Different, correlated observations, e.g., maximum altitude coverage of RASS correlated with total-column water vapor and column-averaged wind speed.
4. Different observations related by a physical model, e.g., brightness temperature observed with microwave radiometer and calculated from radiosonde profiles of temperature and moisture; downwelling longwave radiance at the ground observed by a spectrometer and calculated using a line-by-line model and instrument performance model from input profiles of temperature, moisture, trace gas concentrations and aerosols.

Comparisons of Integrated Vapor

The first QME to be implemented in the ARM Experiment Center compares data obtained from a two-channel microwave radiometer (MWR) with the output of a MWR instrument performance model (IPM) (Schroeder and Westwater 1991). The IPM uses thermodynamic profiles from a BBSS to drive the model. The results of the QME are used to evaluate and update the MWR tuning function, as well as to check on the calibration of the MWR.

Statement of the Problem

The MWR observes two brightness temperatures that are used along with retrieval coefficients, derived from historical balloon soundings, to estimate integrated column amounts of water vapor and liquid water. The retrieval coefficients, which relate brightness temperatures to total water vapor and total liquid water in the column directly overhead, are derived from *model-calculated* brightness temperatures. The instrument uses a tuning function to convert the *observed* brightness temperatures to *model-calculated* brightness temperatures upon which the retrieval coefficients can then be applied. (The Liebe absorption model which uses the Van Vleck-Weisskopf line shape is not an exact representation of the microwave absorption/emission line at 22.235.) This tuning function needs to be updated after the instrument has been operated in the field.

Experiment Design

Sonde profiles of temperature, pressure, and relative humidity are inputs to the instrument model. The model calculates integrated column amounts for liquid water and vapor and brightness temperatures for the same two microwave frequencies at which the MWR operates. The actual MWR instrument supplies to the ARM data system 1-second averages of brightness temperatures and retrieved quantities every 20 seconds. The MWR brightness temperatures and retrieved quantities are averaged over a 40-minute window centered on the balloon launches. Figure 1 illustrates the sequence of steps for this QME.

The standard deviations of these averages are used to select soundings for which it appears that the MWR and BBSS are sensing the same atmosphere. A threshold is used on the mean integrated liquid water from the MWR as a rough indicator of cloud presence or absence. After MWR-BBSS comparisons during which the sky was apparently not adequately homogeneous (i.e., not cloud free) are eliminated, the performance of the existing tuning function may be evaluated and a new tuning function can be developed. The new tuning function reduces the errors in total vapor. An evaluation of the MWR performance which uses the output of this QME may be found in Liljegren (1994).

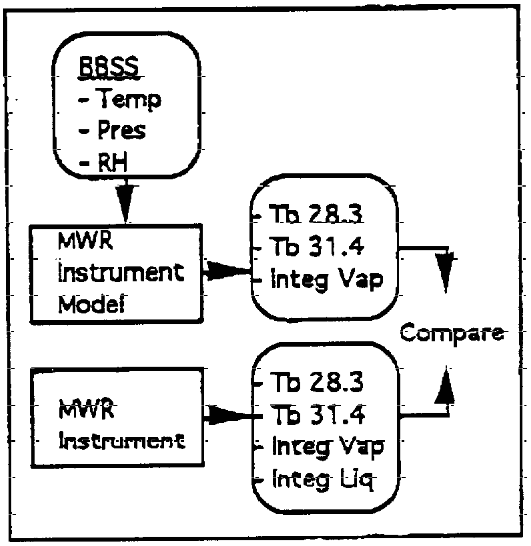

Figure 1. Schematic representation of an MWR/BBSS quality measurement experiment.

Implementation Details

These comparisons are automatically performed in the ARM Experiment Center when the balloon soundings and the MWR data are both available from the CART central facility. As the extended and boundary facilities come on line, the QME will be extended to those data streams. A data management and visualization tool called Zeb (Corbet and Mueller 1991) is used to access the CART data, run the QME processing module, and package the results of the QME comparison.

Comparisons of Observed and Modeled Spectral Radiances

The second QME, under development, makes hourly comparisons of infrared spectral radiances observed by a Fourier-transform infrared (FTIR) radiometer with the output of a line-by-line radiation transfer model (LBLRTM). (See Clough et al. [1994] for details on this model.) The definition of the atmospheric column in the model is specified by CART data to the extent possible. The observed spectra are available approximately every 10 minutes and span the region from 520 to 3020 cm-1. By analyzing the spectral residuals, this QME allows near real-time comparison between observation and model prediction.

Statement of the Problem

The general objective of this comparison is to improve the modeling of surface spectral radiances and ultimately to improve the performance of the radiative transfer modules used in general circulation models. This QME condenses large amounts of data and highlights periods and spectral regions where instrument observations and model calculation disagree. For the clear sky case (the initial focus), errors in the spectral radiance observations, errors in the radiative transfer models, and errors associated with the characterization of the radiating atmosphere are of approximately the same magnitude. This analysis provides an important quantitative evaluation on all three aspects of this problem.

Experiment Design

The temperature and moisture profiles of choice for the LBLRTM calculations are those derived from RASS and Raman LIDAR, respectively. As soon as these "instantaneous" measurements become available from CART, they will be substituted for the soundings profiles currently being used as inputs. The monochromatic radiance spectrum from the LBLRTM calculation is scanned with the appropriate instrument function to match the wavenumber intervals the FTIR instrument produces. For each set of thermo-dynamic inputs a "nearly" temporally coincident representative FTIR radiance spectrum is selected. The radiance residuals are produced for each wavenumber by subtracting the model-generated radiances from the FTIR radiances. When the "instantaneous" measurement inputs become available, this residual radiance spectrum will be created each hour. Currently the processing begins when a balloon sounding becomes available. This process is displayed schematically in the top half of Figure 2.

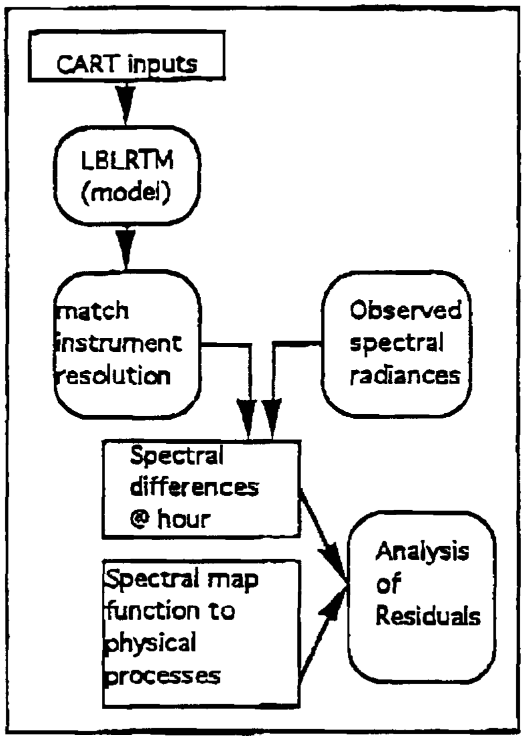

Figure 2. Schematic representation of an FTIR/LBLRTM quality measurement experiment.

A spectral mapping function, created previously, associates each spectral element with a particular physical process, such as water vapor, carbon dioxide, foreign water vapor continuum, and a sensitivity index. Simple statistical analyses are performed on the residuals within specific wavenumber bands and within the physical processes categories. This process is summarized in the bottom half of Figure 2. A detailed discussion of this experiment design and results may be found in Clough et al. (1994).

Implementation Details

The input decks for the LBLRTM runs are created automatically in the ARM Experiment Center as CART data become available. Zeb is used to access and create the rundecks, which are used as inputs for the LBLRTM. A UNIX shell script transfers these rundecks to an HP9000 model 735 where the model calculations are actually performed. Upon completion, the output files are transferred back to the Experiment Center and ingested into the database using Zeb. Once the model-calculated radiances are available, spectral residuals are obtained. Finally, this procedure accesses the previously created spectral mapping function and performs the statistical summaries. Both the statistical summaries and the residuals are ingested into the database using Zeb.

Conclusion

Now that the ARM data are becoming available, QME activity is projected to be an area of concentrated effort for the years ahead. The volume of the ARM dataset necessitates the use of automated techniques to understand the quality of the data and to provide analytic summaries of the data that can be used to help index and categorize the ARM datasets. QMEs are essential tools for both activities.

Acknowledgments

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