Progress Report for the
GEWEX Global Aerosol Climatology Project
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Proposal Title: Characterizing Clear-Sky Direct Radiative Forcing of Aerosols From Surface Broadband Solar Observations: A Long-Term Globally Distributed Validation Data Set.

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Proposal Abstract (includes objectives and goals as italicized for FORM A):

One strategy for assessing the radiative forcing of aerosols on the global climate during the last 20 years is to investigate relationships between aerosol variability and subsequent radiative forcing over a long time period. Concurrently, with the past 20 years of satellite observations, are a large number of globally distributed surface solar insolation measurements. *The purpose of this proposal is to derive a multi-year data set using these insolation measurements and a gridded meteorological product (e.g., European Centre for Mid-Range Weather Forecasting Reanalyses) to provide a measure of the variability in the clear-sky direct aerosol radiative forcing (ARF) and identify possible mechanisms for the observed trends and perturbations.* This data set will provide a first-order global validation for future aerosol satellite retrieval algorithms and aerosol climate models.

Thus, we propose to produce a multi-year monthly averaged climatology of a clear-sky broad-band total (direct + diffuse) solar residual flux (SRF). The monthly SRF is the average of the difference between the daily averaged observed clear-sky (no clouds) solar insolation and the solar insolation predicted by a radiative transfer model with no clouds and no aerosols (clean-sky flux). The variability of this residual flux is strongly related to the variability of the direct ARF in clear-skies within certain error bounds over a given location and/or region. To complement this data set, we also propose to characterize statistically, on a monthly basis at several different atmospheric levels, the sources of air masses that are likely to advect over the given surface site during the month using a transport model. The air masses will be classified according to the surface type of their origin and the likelihood that the air mass contains smoke particles. *The most valuable contributions of this research toward the goal of assessing the radiative forcing of atmospheric aerosols are that the proposed data set will:*

1. *provide an approximate measure of the variability including long-term trends and perturbations in clear-sky SRF for a large number of locations in climactically diverse areas where there is no other validation;*
2. *provide physical insight into the mechanisms responsible for the observed SRF variability, not only from biomass burning but from other sources like dust that can be advected over large distances; and*
3. *use/improve the derivation of biomass burning source maps to identify areas affected by smoke where satellite retrievals are problematic.*

A complete error analysis of the measurements, atmospheric inputs, and radiative transfer sensitivities will be performed by considering various case studies and newly developed surface sites that contain multiple measurements of the solar insolation (e.g., Baseline Surface Radiation

Network) and aerosol measurements (e.g., Atmospheric Radiative Measurement/Clouds and Radiation Testbed, Surface Radiation Budget Network). The transport modeling will be also be tested by selecting case studies of large fire events, using AVHRR imagery and surface radiometry.

Approach (required for FORM A):

A three-fold approach is being used to conduct the investigations above. The first, involves the analysis of surface radiometric observations. Minute, hourly, and daily surface radiometric measurements will be analyzed in conjunction with satellite and trajectory modeling to study the effects of smoke on these measurements and to develop a longer term climatology at certain selected sites. These sites are contained in data bases from the World Radiation Data Centre (WRDC), the National Oceanic and Atmospheric Administration Climate Monitoring Diagnostics Laboratory (NOAA CMDL), the Baseline Surface Radiation Network (BSRN) and from the Canadian Meteorological Centre (CMC). The analysis will lead to the development of the Solar Residual Flux (SRF) for clear-sky days as described above. Methods for determining clear-sky days will be evaluated for a set of case studies, one of which using the backbone processing from the GEWEX Surface Radiation Budget Experiment to process ISCCP DX data to a 1 degree grid.

The second approach is to identify areas of large biomass burning smoke aerosols using a combination of data from both AVHRR and DMSP satellite observations. Satellite analysis of AVHRR data will be used to find smoke particles from large fires over dark surfaces like boreal forests. Where AVHRR fire/smoke detection algorithms are problematic (such as over Savannah regions in Africa), DMSP observations of night-time fire locations will be used to develop monthly smoke pattern maps over the tropical land areas.

The third approach is to use the NASA Langley Trajectory Model (LTM) to construct a climatology of air mass origin for a selected set of surface radiometer sites as noted above. This involves;

1. computing daily clustered back-trajectory calculations over a range of altitudes to determine the latitude, longitude, and altitude history of air masses which are advected over each site,
2. identifying which of these trajectories was recently within the Planetary Boundary Layer (PBL), and
3. classifying the air masses with a surface type from the International Geosphere-Biosphere Project (IGBP) ecosystem data base.

Air masses which are likely to contain smoke, will be determined from AVHRR imagery and biomass source maps. Once the air masses have been classified, a statistical estimate of the altitude profile of source regions and air mass type is constructed for each surface radiometric site by averaging the daily clustered back-trajectory results over the period of a month. These daily and monthly time series will be compared with the SRF climatology at those surface sites

To develop and validate these analysis techniques, we will first select for several different case studies comprising at least the 1989 Canadian fires, the 1986 African fires and the 1992 South American fires. Once validated, we will complete the calculations for all the selected radiometer surface sites for two years, 1986 and 1992.

Tasks Completed (required for FORM A):

1. Surface radiometric data was collected and analyzed in terms of hourly, daily, and monthly data from the data bases noted above. Quality control and averaging techniques were developed and tested during the processing, particularly for the data sets containing minute or hourly data. The data for the selected sites (except from CMC) will be made available.
2. Continued the case study analysis of the July 1989 Manitoba, Canada boreal forest outbreak. This analysis required processing of AVHRR LAC images over the site to identify fire locations. The NASA Langley Trajectory Model (LTM) was used to predict the large-scale transport of smoke aerosols associated with forest fires. Air parcels containing smoke aerosols were traced globally for a period of 10 days. These trajectories were used to identify

periods during which smoke may have advected over surface radiometer sites in Canada and the northern United States. Surface broadband solar insolation predictions from the Advanced ECMWF Reanalysis (ERA-15) were then compared to radiometric observations for a number of sites which were; a) predicted to be influenced by smoke and, b) identified as cloud free during the smoke periods based on the ERA-15 cloud distributions.

3. The DMSP-OLS instrument has been used to develop detailed fire maps within the entire tropical belt for Africa and South America for the years 1986 and 1987. The areas of southeast Asia and Australia are nearly complete and all the tropics will be completed by the beginning of next month. The OLS imagery has been selected as the primary source of data for developing the fire maps since this instrument is considerably better then AVHRR at detecting small fires (Cahoon et al., 1999).

Future Plans for 1999-2000 (FORM A or FORM C):

1. The remaining analysis and preliminary processing of the surface radiometric data shall be completed with an error analysis investigating the areas associated with the SRF quantities. The completion of a ISCCP DX processing backbone by the GEWEX Surface Radiation Budget project will allow for the processing of this cloud data for case studies and the years 1986 and 1992. The SRF climatologies for these years will be developed.
2. The AVHRR LAC processing will be extended for 1989 Manitoba case study to include a longer time period of fire and smoke locations. The fire locations will be used to demonstrated the ability of the LTM to predict the advection of smoke from the area. The smoke pixel identification will be used to validate this advection relatively close to the fires sites. The fire/smoke mask algorithm will also be extended to the GAC resolution data to identify mainly smoke containing pixels.
3. We have recently acquired the ECMWF re-analysis data set and will begin constructing the isentropic data base required for the trajectory calculations within the next month. The air mass origin calculations require the specification of the global PBL depth. This will be determined from the ECMWF re-analysis using the surface buoyancy relative to the profile of equivalent potential temperature plus a small entrainment layer similar to Zhang and Anthes, [1982]. We are currently testing the feasibility of incorporating turbulent mixing within the PBL using a modified version of the Asymmetrical Convective Model (ACM) [Pleim and Chang, 1992] which was developed for application in regional or mesoscale atmospheric chemistry models. Initial testing of the PBL depth and ACM turbulent mixing parameterization constrained with equivalent potential temperature from the ERA-15 re-analysis shows promising results in representing the diurnal variation in PBL height and turbulent mixing over a wide range of boundary layer types.
4. The LTM will be used within the context of the 1989 Manitoba case study to construct a climatology of air mass origin for selected Canadian surface radiometer sites. This involves; a) computing daily clustered back-trajectory calculations over a range of altitudes to determine the latitude, longitude, and altitude history of air masses which are advected over each site, b) identifying which of these trajectories was recently within the Planetary Boundary Layer (PBL), and c) classifying the air masses with a surface type from the International Geosphere-Biosphere Project (IGBP) ecosystem data base. Air masses which are likely to contain smoke, will be determined from AVHRR imagery and biomass source maps. Once the air masses have been classified, a statistical estimate of the altitude profile of source regions and air mass type is constructed for each SRB site by averaging the daily clustered back-trajectory results over the period of a month. These daily and monthly time series will be compared with the SRF for a set of surface sites for several different case studies comprising at least the 1989 Canadian fires, and extended to the 1986 African fires and the 1992 South American fires.
5. Finish the analysis of the OLS data to provide tropical maps of fire distributions. The entire extent and spatial weighting of tropical fire activity will be established. ESA's ATSR fire maps, even though not as detailed, will be used to fill in fire patterns in any regions in which gaps exist. The result will be a detailed multi-year fire map which will document the entire spatial extent of fire in the tropics. This map, when gridded into a 1x1 degree map, with serve as the

foundation for an annual tropical combustion aerosol source region map. Meteorological models will be developed to model the monthly fire patterns for each year. There are currently several concepts that need to be tested and evaluated against the known fire patterns documented in the imagery.

Results (FORM A or FORM B):

The case study of the Manitoba fires has given promising results in combining satellite analysis, trajectory modeling and surface radiometer analysis. As noted above the NASA LTM was used o simulate the advection of smoke containing parcels using the ECMWF reanalysis. Since this reanalysis has no information regarding the smoke aerosols, differences between the predicted surface fluxes and the observed fluxes could provide information regarding the radiative influence of smoke aerosols at those sites (assuming that the reanalysis are able to reproduce the observed surface fluxes during periods which are not influenced by smoke aerosols). Periods of clear-skies and smoke influence where found for two sites: Madison, Wisconsin, and St. Pierre & Miquelon Island. During periods without smoke influence, the ERA-15 predictions and the observed surface fluxes were in remarkable agreement (within 20 W m^{-2}), even during overcast periods. This lends support to the use of the observed minus analyzed surface flux predictions for determining the radiative impact of smoke aerosols. For the limited number of sites considered, we found significant reductions (up to 130 W m^{-2}) in the observed surface shortwave fluxes during periods which were predicted to be influenced by smoke aerosols. More analysis will be performed for this particular case study using other radiometric sites and more satellite analysis. This work was presented as a poster at the 10th Atmospheric Radiation Conference in Madison, Wisconsin in June, 1999. The figures from that poster are appended to this report as postscript files.

GACP Bibliography (or FORM D):

a. Publications

Baum, B. A., and Q. Trepte, 1999: A grouped threshold approach for scene identification in AVHRR Imagery. *J. Atmos. and Ocean. Tech.,* **16**, 793-800.

D. R. Cahoon, Jr., Stocks B. J., Alexander, B. A., Baum, B. A., Goldammer, J. G., Wildland Fire Detection from Space: Theory and Application, Biomass Burning and its Inter-Relationships with the Climate System, Advances in Global Change Research series, Innes, J.L., Verstraete, M.M., and Beniston, M. (Eds.), Series Editor: M. Beniston, Kluwer Academic Publishers, Dordrecht and Boston, in press, 1999.

Stackhouse, P.W., Jr., R.B. Pierce, and B.A. Baum, 1999: The radiative effect of the 1989 Manitoba Canada boreal forest fires from satellite observations, surface radiometric observations and trajectory modeling calculations. (in preparation for JGR)

c. Conference

Stackhouse, P.W., Jr., R.B. Pierce, B.A. Baum, and R.C. Dipasquale, 1999: Combining satellite trajectory modeling and surface insolation measurements to deduce the direct radiative effect of smoke aerosol. 10th Conference on Atmospheric Radiation: A Symposium with tributes to the works of Verner E. Suomi. American Meteorological Society. Madison, Wisconsin, 28 June-2 July.