Evaluating Global Aerosol Models and Aerosol and Water Vapor Properties Near Clouds

Dr. Richard A. Ferrare, Principal Investigator
Science Directorate
NASA Langley Research Center, MS 401A
Hampton, Virginia 23681
757-864-9443; 757-864-7790 (fax)
richard.a.ferrare@nasa.gov

Dr. David D. Turner, Co-Principal Investigator
Space Science and Engineering Center
University of Wisconsin – Madison
1225 West Dayton Street
Madison, WI 53706
608-263-1061, 608-262-5974
dturner@ssec.wisc.edu

DOE Program Manager: Dr. Ashley Williamson

KEYWORDS: Raman lidar, MPL, aerosol extinction, aerosol scattering, relative humidity, water vapor

OBJECTIVE: Project goals:

- Use the routine surface and airborne measurements at the ARM SGP site, and the routine surface measurements at the NSA site, to continue our evaluations of model aerosol simulations.
- Determine the degree to which the Raman lidar measurements of water vapor and aerosol scattering and extinction can be used to remotely characterize the aerosol humidification factor.
- Use the high temporal resolution CARL data to examine how aerosol properties vary near clouds
- Use the high temporal resolution CARL and Atmospheric Emitted Radiance Interferometer (AERI) data to quantify entrainment in optically thin continental cumulus clouds

Analysis of model aerosol simulations

Dr. Ferrare attended the 8th AEROCOM Workshop that was held in Princeton, New Jersey in October, 2009. At this meeting, he gave a presentation describing the use of lidar measurements to evaluate the NASA GEOS-5 model. These comparisons indicated good overall agreement between the lidar and GOES_5 aerosol extinction profiles over the Arctic region during spring 2008. The GEOS-5 dust fraction was generally higher than those inferred by the lidar measurements.

The lidar measurements suggest that there may be significant periods when passive sun photometer measurements that have been cloud-screened (e.g. AERONET, NIMFR) may report aerosol optical thickness values that actually contain significant amounts of ice. These cases suggest that, in the Arctic, it may be problematic for using such measurements from these passive sensors to validate and interpret aerosol transport models, since what may be interpreted to be aerosol (e.g. sulfate, smoke) may actually be ice.

Raman Lidar Upgrades

Drs. Ferrare and Turner are co-authors on the paper “The use of simultaneous analog and photon counting detection for Raman Lidar” that was published in Applied Optics. The lead author is Dr. Rob Newsom (PNNL). This article discusses the development and use of a new algorithm to merge the photon counting and analog signals collected by the ARM Raman lidar system and the evaluation of the use of this algorithm via comparisons of water vapor profiles.

Water Vapor and Aerosol Retrieval Results from ALIVE

Drs. Ferrare and Turner are co-authors on the paper “Validation of aerosol extinction and water vapor profiles from routine ARM Climate Research Facility measurements”; Beat Schmid (PNNL) is the lead author. This study used measurements from the DOE ARM Aerosol Lidar Validation Experiment (ALIVE), which was conducted during September 2005, to evaluate the aerosol and water vapor measurements of the refurbished Raman lidar. The ALIVE results show that the refurbishment of the lidar, along with the upgraded algorithm to merge the photon counting and analog signals, brought the Raman lidar aerosol extinction profiles into excellent agreement with the corresponding extinction profiles measured by the AATS-14 airborne Sun photometer. These results indicate that the routine aerosol extinction profiles measured by the Raman lidar agree with the AATS-14 within the state-of-the-art uncertainty.

Examination of aerosol properties near clouds

We have been using the new, high temporal resolution measurement capability of the Raman lidar to examine how aerosol backscattering and extinction changes in proximity to clouds. The upgraded Raman lidar can provide 10 sec profiles of aerosol backscattering, water vapor mixing ratio, and relative humidity, and 1 minute profiles of aerosol extinction. In our work this past year, we have been focusing heavily on the use of these data in conjunction with the airborne High Spectral Resolution Lidar (HSRL) measurements from CHAPS/CLASIC mission to examine the behavior of aerosols near clouds. We have focused on developing algorithms that take advantage of camera imagery to help determine how far the lidar beam is from the cloud under a variety of situations. Most recently, we have developed algorithms to use the camera imagery in conjunction with the lidar data to determine the appropriate distance to clouds. This work has been developed to use both the Total Sky Imager (TSI) when used in conjunction with the Raman lidar data as well as the camera imagery available on the NASA B200 during the CHAPS/CLASIC and RACORO missions. In the latter case, considerable effort was expended to account for the difficulty in distinguishing clouds from variable surface background images.

These analyses were conducted for Raman lidar and airborne HSRL data acquired during the CHAPS/CLASIC (June 2007) and RACORO (June 2009) field missions. We found that that there were significant changes in aerosol properties within 1 to 2 km from clouds. The Raman lidar data indicated that there was a 5-10% increase in relative humidity within a few kilometers of clouds. The Raman lidar and HSRL data showed increases in aerosol extensive parameters (backscatter (20-40%); aerosol optical thickness (5-10%) within a few kilometers of clouds. The HSRL data show 10-20% decreases in aerosol depolarization within a few kilometers of clouds. This is consistent with aerosols becoming more spherical with higher relative humidity near clouds (i.e., hygroscopically growing aerosols). The HSRL measurements show a general increase in the aerosol backscatter wavelength dependence within a few kilometers of clouds indicating that a larger fraction of scattering comes from accumulation mode aerosols in this region.

The aerosol humidification factor (f(RH)) was computed from Raman lidar measurements of aerosol backscatter and relative humidity during the CHAPS/CLASIC and RACORO missions. Raman lidar data from these missions were chosen to isolate easily identifiable cases of aerosol humidification at the top of the boundary layer. The humidification factor (e.g. ratio of scattering at RH=85% to RH=60%) derived from the Raman lidar measurements generally varied between 1.2-1.8 during these observations. The aerosol humidification factor derived from Raman lidar data 1-2 km above the surface was consistent with that derived from surface SGP AOS in situ measurements. The Raman lidar measurements showed that the variations in aerosol properties and relative humidity are largest at or within about 200 meters below cloud base.

Inferring boundary layer turbulence structure

After the significant upgrade to the Raman lidar in September 2004, the lidar was able to measure water vapor mixing ratio (WVMR) profiles with 10-s temporal resolution. These high time resolution profiles showed significant variability during the afternoons in well-developed convective boundary layers (CBLs), especially near the top of the CBL. Since WVMR is conserved in the absence of condensation and precipitation, WVMR can be as a tracer of atmospheric motion. Together with Dr. Volker Wulfmeyer, we analyzed the Raman lidar WVMR observations, and especially the instrument noise contribution to these profiles, to see if the lidar is able to provide profiles of turbulent statistics (e.g., variance, skewness, kurtosis). Our analysis suggests that the lidar's noise level is low enough and its sensitivity high enough to measure WVMR variance and skewness in the CBL; this was published in an article entitled "Can water vapor Raman lidar resolve profiles of turbulent variables in the convective boundary layer?" This analysis has continued to include nearly 100 cases over a multi-year period; these results have been shown at the International Symposium for the Advancement of Boundary Layer Remote Sensing as an invited talk, and is currently being written up for peer-review.

Retrieving entrainment rate in cumulus

Measurements of cumulus entrainment rate are very sparse, because the only currently accepted way to observe this variable is via aircraft observations. However, variations in the entrainment rate greatly affect the lifetime and radiative impact of the cumulus, and virtually all models parameterize this process due to its sub-gridscale nature. Tim Wagner developed an algorithm that retrieves cumulus entrainment rate from the ground-based remote sensors (including the Raman lidar) at the ARM SGP site as his Ph.D. research topic. Dr. Wagner performed an intensive error analysis to understand how uncertainties in the input observations and his assumptions impacted the uncertainty of the retrieved entrainment rate. His analysis showed that, in general, the uncertainty in entrainment rate from his ground-based remote sensing approach is about one-third the size of the uncertainty of aircraft-measured entrainment rate. Dr. Wagner is currently expanding upon the dataset processed for his dissertation and is writing a manuscript that will be submitted for peer-review soon.

Participation in RACORO

The RACORO field experiment, which occurred over the SGP domain from Jan-Jun 2009, was designed to make regular, routine measurements of the properties of clouds in the boundary layer and to characterize the aerosol and water vapor in the boundary layer. Dr. Turner was a co-investigator of this experiment, and participated heavily during the planning stages and when the experiment was underway. Dr. Turner and Dr. Wagner used RACORO observations to help validate Dr. Wagner's cumulus entrainment rate retrieval algorithm, and Dr. Turner used the water vapor measurements to evaluate the accuracy of the turbulent profiles computed from the Raman lidar WVMR observations. Importantly, boundary layer height analysis by Dr. Ferrare using HSRL observations on the NASA King Air, which was flown in a coordinated manner with the RACORO aircraft in Jun 2009, was a key step in the analysis of the turbulent profiles. An article summarizing the RACORO experiment is currently being written.

Collaborations

-We collaborated with Yang Liu (Emory Univ.) in using Raman lidar measurements to assess the impact of the vertical distribution of aerosol on satellite estimates of surface sulfate particle concentrations.

- During much of this work, Dr. Ferrare was a member of the NASA Earth Observing System (EOS) Moderate Resolution Imaging Spectroradiometer (MODIS) science team. He has been working on the combined use of MODIS and lidar data to characterize aerosol properties

- Dr. Ferrare is a member the NASA Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) science team and working on several projects associated with CALIPSO data. These include:

  - development and analyses of combined active+passive retrievals to derive aerosol properties
  - evaluation and enhancement of CALIPSO aerosol products and
  - investigation of continuum in cloud and aerosol properties
  - improvements in the Goddard Chemistry Aerosol Radiation and Transport (GOCART) model

- Dr. Ferrare is a member of the NASA Langley airborne High Spectral Resolution Lidar (HSRL) team. This instrument has participated in several major field missions including MILAGRO/INTEX B (Mexico, March 2006), TexAQS/GoMACCS (August-September, 2006), CALIPSO Validation (eastern U.S., 2006-2007), San Joaquin Valley (California, February 2007), CLASIC/CHAPS (Oklahoma, June 2007) , NASA ARCTAS/DOE ISDAC (April, 2008), the DOE ARM RACORO mission (June 2009), the NOAA CALNEX mission (2010), and the DOE CARES (2010) mission. The HSRL has been used to measure multiwavelength profiles of aerosol backscatter, extinction, and depolarization for use in studying radiative transfer and air quality.

- Dr. Ferrare is also a member of the NASA Lidar Atmospheric Sensing Experiment (LASE) team. This instrument, which measures water vapor and aerosols profiles, has participated (August-September 2006) in the NASA African Monsoon Multidisplinary Activities (NAMMA) to studying the impact of the Saharan Air Layer (SAL) of tropical storm cyclogenesis, the Tropical Composition, Cloud, and Climate Coupling (TC^4) field experiment, to improve our understanding of the Tropical Tropopause Layer (TTL) over tropical regions, characterize the upper troposphere relative humidity in the tropics and sub-tropics; and measure aerosol and cloud distributions for use in evaluating CALIPSO/CloudSat measurements, and the NASA Genesis and Rapid Intensification Processes (GRIP) experiment (2010) to better understand how tropical storms form and develop into hurricanes.
- Dr. Ferrare is a member of the GEWEX Aerosol Working Group. This group will be working to assess satellite measurements of aerosol properties.
- Dr. Turner is the chairperson of the ASR Cloud Aerosol Interactions Working Group .
- Dr. Turner is a member of the International Scientific Steering Committee (ISSC) for the Convective and Orographic Precipitation Study (COPS), which is being conducted in the Black Forest region of Southwestern Germany. The ARM Mobile Facility was deployed as part of the COPS campaign. Dr. Turner is one of the primary contacts between the international COPS principal investigators and the ARM program.
- Dr. Turner is the PI (together with Dr. Eli Mlawer) of the recently completed Radiative Heating in Underexplored Bands Campaign (RHUBC), an ARM experiment to look at radiation in the far-infrared.
- Dr. Turner is the co-chair (with Dr. Andrew Vogelmann) of the Clouds with Low Liquid Water Optical Depth (CLOWD) focus group.
- Dr. Turner is a co-investigator of the RACORO field campaign that was conducted over the SGP site in Jan-Jun 2009.
- Dr. Turner is a co-investigator of the Indirect and Semi-Direct Effect Campaign (ISDAC) and the Routine In-situ Cloud and Aerosol Measurement (RISCAM) experiments, both of which will focus on aerosol/cloud interactions at the ARM North Slope of Alaska site in 2008. Dr. Ferrare is a PI on a project funded through the NASA ARCTAS mission that coincided with the ISDAC mission. Dr. Ferrare is working with ISDAC investigators to study aerosol properties over the Barrow region during ISDAC.
- Dr. Turner is collaborating with Dr. David Whiteman and Dr. Felicita Russo on deriving liquid water content profiles from the ARM Raman lidar. The data, together with the lidar's aerosol backscatter observations, are being used to look at the aerosol indirect effect in optically thin, nighttime clouds.
- Dr. Turner is working with Dr. Graham Feingold, Dr. Mark Miller, and colleagues to look at the aerosol indirect effect on marine stratocumulus clouds observed by the ARM Mobile Facility when it was at Pt. Reyes, CA.

Presentations:

1. Ferrare, R.A., M. Clayton, W. Su, D. Turner, C. Hostetler, J. Hair, A. Cook, D. Harper, R. Rogers, M. Obland, G. Schuster, N. Loeb, R. Newsom, C. Sivaraman, H. Jonsson, L. Berg, Lidar observations of aerosols near clouds during CHAPS/CLASIC, Fall AGU Meeting, December, 2008, San Francisco, CA.
2. Ferrare, R.A., M. Clayton, W. Su, D. Turner, C. Hostetler, J. Hair, A. Cook, D. Harper, R. Rogers, M. Obland, G. Schuster, N. Loeb, R. Newsom, C. Sivaraman, H. Jonsson, L. Berg, Lidar observations of aerosols near clouds, AMS Special Symposium on Aerosol-Cloud-Climate Interactions, January, 2009, Phoenix, AZ., http://ams.confex.com/ams/89annual/techprogram/paper_149050.htm
3. Ferrare, R., M. Clayton, D. Turner, R. Newsom, C. Sivaraman, C. Hostetler, J. Hair, A. Cook, D. Harper, M. Obland, R. Rogers, S. Burton, W. Su, G. Schuster, L. Berg, H. Jonsson, J. Ogren, E. Andrews, Aerosol Variability Near Clouds During CLASIC/CHAPS, 19th ARM Science Team Meeting, Louisville, Kentucky, March, 2009, http://www.arm.gov/publications/proceedings/conf19/poster/P00051.pdf
4. R. A. Ferrare, C. Hostetler, J. Hair, A. Cook, D. Harper, S. Burton, M. Clayton, M. Obland, R. Rogers, Amy Jo Swanson, Karl Froyd, Peter Colarco, Norm O'Neill, Airborne High Spectral Resolution Lidar (HSRL) Measurements and Comparisons with GEOS-5 Model, Eighth AEROCOM Workshop, October 2009, Princeton, New Jersey, http://nansen.ipsl.jussieu.fr/AEROCOM/DATA/AEROCOM_WORK/princeton/pdf_tue/ferrare.pdf
5. R. Ferrare, C. Hostetler, J. Hair, A. Cook, D. Harper, S. Burton, M. Obland, R. Rogers, A.J. Swanson, D. Turner, N. O'Neill, P. Colarco, M. Shupe, Airborne High Spectral Resolution Lidar Aerosol/Ice/Cloud Observations during ARCTAS/ISDAC, DOE ASR Science Team Meeting, March 2010. http://asr.science.energy.gov/meetings/stm/posters/poster_pdf/2010/P000205.pdf
6. R. Ferrare, C. Hostetler, J. Hair, M. Obland, R. Rogers, C. Butler, A. Cook, D. Harper, S. Burton, A.J. Swanson, M. Clayton, M. Wusk, Airborne Remote Sensing Measurements during CARES, DOE Aerosol Life Cycle Working Group Meeting, October, 2010.
7. R. Ferrare, M. Clayton, D. Turner, C. Hostetler, J. Hair, M. Obland, R. Rogers, A.J. Swanson, A. Jefferson, H. Jonsson, Raman Lidar and HSRL Measurements of Aerosol and Water Vapor Variability, DOE ASR Meeting, March 2011. http://asr.science.energy.gov/meetings/stm/posters/poster_pdf/2011/P000347.pdf
8. T.J. Wagner, D.D. Turner, and L.K. Berg, Investigations of cumulus entrainment rates through remotely-sensed observations, Fall AGU Meeting, December 2010, San Francisco, CA.
9. T.J. Wagner, D.D. Turner, and S.A. Ackerman, Remote retrieval of cumulus entrainment rates, Annual American Meteorological Society Meeting, Phoenix, AZ, Jan 2009
10. E. Wagner and D.D. Turner, Boundary layer turbulence measurements via Raman lidar water vapor detection, Annual American Meteorological Society Meeting, Phoenix, AZ, Jan 2009
11. T.J. Wagner, D.D. Turner, and L.K. Berg, A remote sensing approach to retrieve fair weather cumulus entrainment rates, International Symposium for the Advancement of Boundary Layer Remote Sensing, Paris, France May 2010.

12. D.D. Turner, E. Wagner, V Wulfmeyer, S. Pal, and L Berg, Raman lidar observations of water vapor turbulence profiles in the convective boundary layer, International Symposium for the Advancement of Boundary Layer Remote Sensing, Paris, France May 2010.

Publications:

Liu, Y., Z. Wang, J. Wang, R. Ferrare, R. Newsom, E.J. Welton, The effect of aerosol vertical profiles on satellite-estimated surface particle sulfate concentrations, Remote Sensing Environment, 115, 508-513, 2011.

McComiskey, A., G. Feingold, A.S. Frisch, D.D. Turner, M. Miller, J.C. Chiu, Q. Min, and J. Ogren, 2009: An assessment of aerosol-cloud interactions in marine stratus clouds based on surface remote sensing. *J. Geophys. Res.*, 114, D09203, doi:10.1029/2008JD011006.

Newsom, R.K., D.D. Turner, B. Mielke, M. Clayton, R. Ferrare, and C. Sivaraman, 2009: The use of simultaneous analog and photon counting detection for Raman lidar. *Appl. Opt.*, 48, 3903-3914.

Schmid, B., C.J. Flynn, R.K. Newsom, D.D. Turner, R.A. Ferrare, M.B. Clayton, E. Andrews, J.A. Ogren, R.R. Johnson, P.B. Russell, W.J. Gore, and R. Dominguez, 2009: Validation of aerosol extinction profiles from routine ARM climate research facility measurements. *J. Geophys. Res.*, 144, D22207, doi:10.1029/2009JD012682.

McMillan, W.W., R. Pierce, L. Sparling, G. Osterman, K. McCann, M.L. Fischer, B. Rappengluech, R. Newsom, D. Turner, C. Kittaka, K. Evans, S. Biraud, B. Lefer, A. Andrews, and S. Oltmans, 2010: An observational and modeling strategy to investigate the impact of remote sources on local air quality: A Houston, Texas, case study from the second Texas air quality study (TexAQS II). *J. Geophys. Res.*, 115, D01301, doi:10.1029/2009JD011973.

Hartung, D.C., J.A. Otkin, J.E. Martin, and D.D. Turner, 2010: The life cycle of an undular bore and its interaction with a shallow intense cold front. *Monthly Wea. Rev.*, 138, 886-908, doi:10.1175/2009MWR3028.1.

Naud, C.M., A.D. Del Genio, M. Haeffelin, Y. Morille, V. Noel, J.-C. Dupont, D.D. Turner, C. Lo, and J. Comstock, 2010: Thermodynamic phase profiles of optically thin midlatitude clouds and their relation to temperature. *J. Geophys. Res.*, 115, D11202, doi:10.1029/2009JD012889.

Wulfmeyer, V., S. Pal, D.D. Turner, and E. Wagner, 2010: Can water vapour Raman lidar resolve profiles of turbulent variables in the convective boundary layer? *Boundary Layer Meteor.*, 136, 253-284, doi:10.1007/s10546-010-9494-z

Wulfmeyer, V., A. Behrendt, C. Kottmeier, U. Corsmeier, C. Barthlott, G.C. Craig, M. Hagen, D. Althausen, F. Aoshima, M. Arpagaus, H.-S. Bauer, L. Bennett, A. Blyth, C. Brandau, C. Champollion, S. Crewell, G. Dick, P. DiGirolamo, M. Dorninger, Y. Dufournet, R. Eigenmann, R. Engelmann, C. Flamant, T. Foken, T. Gorgas, M. Grzeschik, J. Handwerker, C. Hauck, H. Hoeller, W. Junkermann, N. Kalthoff, C. Kiemle, S. Klink, M. Koenig, L. Krauss, C.N. Long, F. Madonna, S. Mobbs, B. Neiniger, S. Pal, G. Peters, G. Pigeon, E. Richard, M.W. Rotach, H. Russchenberg, T. Schwitalla, V. Smith, R. Steinacker, J. Trentmann, D.D. Turner, J. van Baelen, S. Vogt, H. Volkert, T. Weckwerth, H. Wernli, A. Wieser, and M. Wirth, 2011: The convective and orographically induced precipitation study (COPS): The scientific strategy, the field phase, and first highlights. *Quart. J. Roy. Meteor. Soc.*, 137, 3-30, doi:10.1002/qj.752.

Borg, L.A., R.E. Holz, and D.D. Turner, 2011: Investigating cloud radar sensitivity to optically thin cirrus using collocated Raman lidar observations. *Geophys. Res. Lett.*, 38, L05807, doi:10.1029/2010GL046365

Wagner, T.J., 2011: A method for retrieving cumulus entrainment rate from ground-based remote sensors. Ph.D. Dissertation, Atmospheric and Oceanic Sciences Department, University of Wisconsin-Madison.