DOE/ER/61070

FINAL REPORT

for period: 9/20/90 – 5/8/97

**Refinement, Testing, and Application of an
Integrated Data Assimilation/Sounding System (IDASS)
for the
DOE/ARM Experimental Program**

Prepared by

David B. Parsons
National Center for Atmospheric Research
Atmospheric Technology Division
Mesoscale and Microscale Meteorology Division
Boulder, Colorado 80307-3000

NCAR Proposal No. 90-35

DOE Patent Clearance Granted

Mark P. Dvorscak
Date

(630) 252-2393

E-mail: mark.dvorscak@ch.doe.gov

Office of Intellectual Property Law
DOE Chicago Operations Office

Prepared for

U.S. Department of Energy
Office of Energy Research
Acquisition and Assistance Management Division, ER-64
Washington DC 20585

DOE Interagency Award No. DE-AI05-90ER61070

April 9, 2002

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

**Portions of this document may be illegible
in electronic image products. Images are
produced from the best available original
document.**

ARM SUPPORT — 1990-1997

A. IDASS Philosophy and the ARM Program

Under our previous ARM support, we developed an Integrated Data Assimilation and Sounding System (IDASS). The IDASS system couples *in situ* and remote sensing instruments with a state-of-the-art mesoscale data assimilation system to provide a time-continuous description of three-dimensional atmospheric structure with a horizontal resolution of approximately 5 km* over a domain of 200x200 km². The observing system associated with IDASS is the Integrated Sounding System (ISS) which combines numerous remote and *in situ* sensors into a single transportable unit. Combining sensor platforms into a single unit allows us to take advantage of their positive attributes, while overcoming their singular limitations. The data assimilation system most frequently used in IDASS is Newtonian relaxation (often termed nudging) in a non-hydrostatic version of the NCAR/Pennsylvania State University mesoscale model Version 5 (MM5). The assimilation system is nested with horizontal resolution on the inner domain ranging between ~2 and 6 km. We have also developed a version of IDASS that employs the adjoint assimilation technique on coarser mesoscale grids. In a sense, IDASS couples two powerful changes in atmospheric technology as the high resolution numerical model takes advantage of recent growth in computational abilities, while the ISS maximizes the capabilities of recently developed remote and *in situ* sensors.

The IDASS system was developed to meet the ARM experimental program requirements of an accurate determination of radiative and atmospheric parameters over an area similar to that defined by the full-extent of a General Circulation Model (GCM) grid scale (i.e., the CART domain). The IDASS system, when coupled with the other measurement capabilities of ARM-CART, will provide estimates of the mean and sub-grid scale structure over the entire CART domain and boundary conditions to this domain for a wide variety of meteorological parameters, including cloud and radiative properties. While it may be philosophically more attractive to use a pure set of observations through objective analysis, recent studies have demonstrated that an objective analysis of observations taken during CART IOPs will often produce errors too large to make the data useful for testing parameterizations. The following discussion includes a brief overview of our accomplishments thus far for the

*This represents a significantly enhanced resolution when compared to ARM's original goal of 20-km resolution.

IDASS program. This brief discussion is based on the extensive list of the publications and presentations resulting from our past ARM support (Appendix A). Further details of these accomplishments can also be found in our ARM annual reports. The vitae of the IDASS development team can be found in Appendix B.

B. Development of a Data Assimilation System

One component of the IDASS system is a state-of-the-art mesoscale model with data assimilation capabilities. During our past support we have developed and tested this model and have begun data assimilation experiments with simulated and actual ARM data. The highlights of this portion of our past ARM effort includes:

- During the first funded period of our grant, a non-hydrostatic version of the NCAR/Pennsylvania State mesoscale model was developed with partial ARM support (Dudhia, 1993a). When this version of the model is used with horizontal resolutions of 5 km or less, the non-hydrostatic capabilities of the model allow many convective cloud processes to be directly resolved.
- Also during the first period of our grant we coupled the non-hydrostatic model to a data assimilation based on nudging. While most previous data assimilation systems on the mesoscale only assimilate data from rawinsondes and profilers, IDASS allows for the incorporation of modern remote sensing measurements. For example, it was found that the assimilation of *vertically integrated* water vapor estimates from microwave radiometers greatly improved the accuracy of the *vertical profiles* of water vapor within the hydrostatic model (Kuo et al. 1993). Since non-hydrostatic data assimilation is a relatively new area of research, we also addressed the general behavior of this non-hydrostatic assimilation system in regard to issues such as the frequency of data ingestions, radius of influence and values of the nudging coefficients.
- Through pilot experiments prior to the development of the CART site and a number of Observing System Simulation Experiments (OSSEs), we were able to investigate issues related to the design of the CART site. These issues include station density, instrument type, and the spatial extent of the domain. These studies show that a modest network of observing stations (station separations of ~200 km) can produce significant improvements in the accuracy of the assimilation products and that the location of the CART site within wind profiler demonstration network is well suited for data assimilation, as the model is able to derive significant improvements to the wind and to derive some benefit in the thermal field through assimilating wind measurements. The OSSEs were also used to compare the accuracy of data assimilation to estimates obtained from objective analysis. It was found that aliasing from smaller-scale motions could frequently degrade the accuracy of objective analysis based on current CART designs such that higher order terms (i.e., temperature and moisture advection and convergence) would not be suitable as input to coarse models testing cloud and radiation parameterization. (Parsons and Dudhia, 1996).

- Preliminary Tests using CART IOP data from the June 16-26 1993 Data Assimilation IOP has been used to test the effectiveness of the Newtonian nudging technique in spreading observed information to areas away from observations through comparison of two simulations against a data set that is independent of the assimilated data. The first simulation used only MAPS (60 km, 3 hr) gridded data to drive the coarsest 60-km mesh covering the contiguous US. This mesh interacts in a two-way sense with a 20-km domain which has a further nesting level at 6.67 km inside it. The 20- and 6.67-km domains therefore have no nudging in them, only being forced by information from the 60-km domain at the 20-km boundaries. The second simulation additionally uses Newtonian nudging to impose observational data in the 20- and 6.67-km domains. These observations include 19 NOAA Demonstration Network 405 MHZ profilers, an NCAR 915 MHZ profiler near the central facility of the CART site, standard NWS soundings with enhanced 6-hourly soundings at Dodge City KS, Topeka KS and Norman OK, and standard NWS surface 3-hourly reports. The independent data set of CLASS soundings was used for comparisons that comprised eight-times daily soundings from a triangle of sites (Kingfisher OK, Kingman KS, and Pawhuska OK) within the profiler hexagon and surrounding the CART central site.

Evaluation of the results has shown particularly an improvement in the wind from assimilating the extensive hourly profiler data, with little added benefit to the thermal field. The results show that the assimilated 4D data set has bias errors that are small enough to be extremely useful in determining the mean properties of the CART site's atmosphere. Furthermore r.m.s. errors are comparable to measurement error in the wind profile. Although the temperature bias error shows a diurnal trend reflecting a possible model deficiency in its boundary layer diurnal cycle, it provides temperatures within 1-2 degrees C of the independent measurements. We hope to improve the diurnal cycle through implementing a new surface/atmosphere energy budget. Detailed surface property information, particularly on land-use and soil moisture in the CART site, together with *in situ* flux measurements should be valuable tools in this next phase for improving the model.

- In order to provide a four-dimensional time-continuous data set of the wind, temperature, humidity, and cloud distributions at high resolution, we have developed an advanced data assimilation system based on the adjoint technique that we term the 4DVAR (Four-Dimensional VARIational) system. The 4DVAR system is a full physics version of the MM5 model that is capable of assimilating all of the available data collected in the Southern Great Plains CART site. The development was completed over the past two years through the support of ARM and other projects. The system includes two cumulus parameterization schemes, an explicit microphysics scheme including cloud and ice, and two planetary boundary layer (PBL) schemes including a radiation and surface energy equation. 4DVAR will afford us a wide range of research opportunities for ARM applications.
- The 4DVAR system based on the MM5 adjoint has been successfully used in observing system simulation experiments to assess the potential impact of the atmospheric radio refractivity profiles (Zou et al., 1995), in experiments assessing the impact of the precipitable water (PW) data on moisture analysis and short-term precipitation forecast (Kuo et al., 1995), in rainfall assimilation experiments (Zou and

Kuo, 1996), and most recently in the OSSE experiment of assimilating rainfall, cloud water and rain water observations (Guo et al., 1996) which will soon be extended to the ARM real data assimilation experiments.

C. Development and Deployment of an Integrated Sounding System (ISS)

During our past support we have developed an Integrated Sounding System that combines various state-of-the-art remote and *in situ* sensors into a single transportable unit. In addition special instrumentation was developed especially for this ARM prototype ISS. A number of measurement campaigns were conducted in support of the goals of the ARM program. The highlights of this development that relate to our past ARM support include:

- During the initial period of our grant, a field experiment was conducted in eastern Colorado during February and March 1991 termed ARM-WISP. Remote and *in situ* sensors from NCAR, NOAA and the University of Wisconsin were co-located in order to successfully simulate an ISS (Martin, 1991). This data set was used in the data assimilation experiments. During this project, surface fluxes were measured by NCAR's ASTER system (Businger et al., 1990). Intercomparisons were made between these measured fluxes and those predicted by the model in order to test the accuracy of the flux schemes in the model and different treatment of surface properties (Oncley and Dudhia 1995).
- During the first grant period, a prototype ISS was developed for ARM that included a 915-MHZ wind profiler with RASS, a CLASS sounding system, an enhanced surface meteorological station, and a specially developed software system. The ISS was included in two field experiments conducted at the CART site during the first grant period. The first IOP was conducted in November 1993 and included *in situ* measurements taken by the NCAR King Air. The aircraft measurements have been used to test surface and boundary layer schemes employed in the assimilation model. In addition, a data assimilation experiment was conducted in June 1993 at the CART site, using ISS, rawinsonde, and the standard CART instrumentation coupled with the non-hydrostatic model. The subsequent ARM Single Column Modeling (SCM) IOPs were similar in design to this early experiment allowing for a test of the IOP concept at the CART site.
- In addition to a number of deployments within the CART domain, six ISS were deployed during TOGA COARE through a collaboration between NCAR and NOAA's Aeronomy Laboratory (Parsons et al. 1993). As noted in the ARM science plan, the design of the ISS and its deployment greatly impacted the design of ARM's ARCS (Atmospheric Radiation and Cloud Station) measuring systems. In addition, one of the ISS deployed for TOGA COARE directly served ARM goals through providing the measurement center for the special radiation observations taken for ARM at Kavieng. The measurements taken by the ISS in the tropical western Pacific (TWP) also provided a unique application of testing the instrumentation that will be deployed in the ARM ARCs in this region. A detailed discussion of instrument performances, height coverages by remote sensors and instrument accuracies can be found in Riddle et al. (1996). This study revealed for the first time a bias in RASS measurements in the lower portions of the boundary layer.

- The prototype ISS includes the development of the NCAR/ARM Multiple Antenna Profiling Radar (MAPR). This system has motivated considerable theoretical advancement in spaced-antenna analysis techniques. Doviak et al. (1996a) and subsequent papers describe spaced antenna wind measurement ideas which implicitly correct for decorrelation due to turbulence. Without this correction, wind speed will be overestimated, but the implicit technique simplifies analysis and eliminates accumulated errors. Spaced-antenna techniques can give frequent (less than 30-second) full-vector wind profiles which are useful in techniques to measure fluxes and turbulence-induced variances. Holloway et al. (1996) describe a newly developed technique to measure turbulent parameters directly using spaced antenna data.
- Over the current grant period MAPR participated in two ARM field deployments at the CART site in June 1993 and September 1995, and one deployment at a NOAA 300m tower in Erie, CO. The primary purpose of these deployments has been instrument testing and validation, and technique development in a data-rich environment. Through these experiments MAPR average winds have been successfully compared with rawinsonde winds, and with 30-second integrated sonic anemometer winds. A turbulence parameter related to eddy dissipation rate has been measured but not validated. The field experiments also clarified shortcomings of the current hardware. Specifically, the signal-noise ratio is frequently weaker than expected and sometimes too weak to give a useful result. Also, the variance in measured winds is larger than theoretically predicted (Doviak et al. 1996b).
- Hardware and software upgrades have improved MAPR performance considerably. Changes to the data handling and storage have reduced the 'dead time' between measurements by a factor of four, effectively increasing the duty cycle of the instrument allowing shorter integration times. All the original phase switches have been replaced with more reliable switches (this has been an issue with all wind profilers of similar design). Finally, phase differences between the receiver channels have been measured and are now being corrected for in later processing. Future work is aimed at improving the signal to noise and reducing the variance.
- Two additional field deployments will be carried out during this grant period. The first experiment is the Boundary Layer IOP (BLX-96) planned to take place this summer in conjunction with aircraft measurements over the CART site. During this IOP, the ISS with the MAPR will be deployed near the CART site to test the ability of this instrument to provide vertical profiles of turbulence through comparison with the in-situ aircraft measurements. The second additional experiment is the Water Vapor IOP to be conducted during either September or October 1996. In this experiment, we will deploy six Global Positioning System (GPS) measuring systems to derive column-integrated estimates of water vapor. Combining the column integrated estimates from these six systems with other GPS systems and the radiometers already deployed within the CART domain will allow a well-designed test of the ability of data assimilation to provide vertical profiles of water vapor through using the column-integrated GPS values and GPS slant range measurements as constraints. The variational data assimilation approach is particularly well suited to working with these types of constraints.

D. Testing Parameterization Schemes and Other Scientific Applications

Our ARM activities have also concentrated on using observations to test and improve the parameterizations in the data assimilation model. In this regard, IDASS reflects the basic strategy of the ARM program where data is used to improve model physics. The improvements in model physics are expected to result in corresponding improvements in the accuracy of the data assimilation products. The highlights of these activities and other related scientific applications include:

- As a result of testing against ARM IOP data and other modeling projects, MM5 undergoes continuous improvements and refinements to its physics. Surface flux observations from our pilot experiment prior to the creation of the CART site and aircraft data from the November 1993 IOP at the CART site were used to test surface and boundary layer parameterizations at the CART site. These results describe the importance of accurate determinations of soil moisture to the diurnal cycle, and this is primarily a limitation of data initialization rather than the model physics. However, it is now recognized that there may be some gains in using a multi-layer soil model as opposed to the current slab model, particularly in improving the phase and amplitude of the diurnal ground temperature wave, which will in turn feed back to the atmospheric boundary layer. Another area of improvement has been in the model's solar radiation treatment. The long-term data set from FIFE has been used to tune the model's clear-air scattering coefficient to give surface shortwave radiation fluxes in agreement with observations over the annual cycle.
- Currently MM5 is being run in a real-time forecast mode centered on Colorado, but with the CART site within the 27-km grid domain, and this is a valuable testbed for continuous model improvement. Continual evaluation of real-time forecasts is an important part of identifying model biases and errors. We have used this platform to evaluate cumulus schemes, soil and radiation treatments in the model. The short-wave radiative interaction with precipitation has been modified based on comparisons of these forecasts with observed surface temperatures, particularly east of the Rockies where ice clouds appeared to produce too much blocking of solar radiation, and this parameter has been re-evaluated based upon expected particle size distributions in such clouds. For another example, from the June 16-26 1993 IOP data assimilation tests, a model deficiency was identified in the treatment of ice crystal fall speeds as the sedimentation of cirrus cloud lead to unrealistically long-lived cirrus outflow affecting the next day's diurnal cycle. Addition of ice sedimentation improved the surface temperature prediction over the CART site by allowing cirrus generated the previous day over the Rockies to dissipate at a realistic rate. This model improvement has also been demonstrated by verifying model cloud cover against satellite images for selected winter-time cases over the US. The results concerning ice sedimentation are directly applicable to GCMs.
- Simulations in the Tropical Western Pacific - Month-long and multi-day regional climate simulations (Wang et al. 1996, ARM Science Team Meeting) have also been valuable in isolating model drifts and biases. These simulations cover East Asia and the West Pacific, a domain large enough for model drifts to show despite the control

of the analyses used for lateral boundary conditions. The primary lessons from these tests have come from comparisons of model biases with the NMC analyses. One bias is a coolness of the model boundary layer relative to the observed. This reflects a possible deficiency of the boundary/surface scheme or the cumulus parameterization downdrafts and is being investigated. The other bias in upper-level mean temperature is sensitive to the radiation/cloud interaction due to widespread cirrus in the region. Certain adjustments of parameters related to this physics can eliminate this bias, but the primary uncertainty at these coarse grid scales (appr. 100 km) is how to represent cloud fraction and this is also an area for research.

- Testing of model physics and parameterizations has also been undertaken through a one-dimensional version of MM5 that is primarily of use in evaluating soil, boundary layer and radiative parameterizations in the absence of mean vertical motion and advection. This simple SCM is a valuable testbed for these parameterizations when used in meteorologically quiescent periods and gives results close to those of the full 3D model under these conditions. It has been found that to properly represent the wind evolution over a day, which is crucial to representing surface fluxes, the large scale pressure gradient needs to be specified to maintain the momentum against frictional forces at the ground. So far this model has helped in the development of soil and radiation parameterizations.
- Our non-hydrostatic simulations over the CART site were used to directly test parameterizations for deep convection through using identical simulations with coarse grids. Preliminary results include the finding that some convective schemes have trouble triggering convection in the capped environments that are frequently found over the CART domain (Dudhia and Parsons 1994). To further investigate the behavior of convective parameterization schemes, we also used idealized simulations with reduced model physics and initialized convection on both coarse and cloud resolving grids. This research clearly shows how many of the difficulties inherent in GCM style convective parameterizations can be overcome with a mesoscale approach that resolves the circulations associated with mesoscale convective systems. Some preliminary aspects of this work are described in Kuo et al. (1996).
- Through analysis of ISS data from TOGA COARE and resolved cloud modeling studies we have also been involved in a number of fundamental studies of clouds and the link between clouds and the ocean surface in the TWP. These studies include studies of the diurnal cycle during suppressed conditions showing how the radiation cycle and surface fluxes lead to an evening maximum in convective activity during suppressed conditions. The work also shows how dry intrusions of middle latitude and subtropical air mass are advected into the lower troposphere over the TWP accounting for very low relative humidities that change the radiation balance at the surface through modifying down-welling long wave radiation. Finally, resolved cloud modeling was undertaken with a simple surface flux scheme to show how convection modifies the ocean surface and how the surface fluxes feedback on the convection. This work is also partly supported by TOGA COARE and can be found in Parsons and Yoneyama (1996) and Trier et al. (1996).

Publications and Presentations Resulting from ARM Support

Refereed papers

1. Carter, D.A., W.L. Ecklund, K.S. Gate, M. Spowart, H.L. Cole, E.F. Chamberlain, W.F. Dabberdt, and J. Wilson, 1992: First test of a shipboard wind profiler. *Bull. Amer. Meteor. Soc.*, **73**, 1587-1592.
2. Cohn, S.A., 1994: Investigations of the wavelength dependence of radar reflection from atmospheric turbulence, *J. Atmos. and Oceanic Tech.*, **11**, 225-238.
3. Cohn, S.A., 1995: Radar measurements of turbulent eddy dissipation rate in the troposphere: a comparison of techniques, *J. Atmos. and Oceanic Tech.*, **12**, 85-95.
4. Cohn, S. A., and P. B. Chilson, 1995: NCAR workshop on spaced antenna and frequency domain interferometry techniques for wind profiling, *Bull. Amer. Meteor. Soc.*, **76**, 2474-2480.
5. Cohn, S.A., J.R. Gyakum, R.R. Rogers, W.L. Ecklund, D.A. Carter, and J.S. Wilson, 1996: Wind profiler/RASS observations of complex synoptic events, *Contributions to Atmos. Physics* (accepted May 1995)
6. Doviak, R.J., 1994: Recent Developments in Atmospheric Radar. *Alta Frequenza Rivista di Elettronica*, Suppl. al n.6, *Aspetti teorici ed applicativi della radarmeteorologia*, 1-36.
7. Doviak, R.J., R. J., Lataitis, and C. L. Holloway, 1996: Cross-correlations and cross spectra for spaced antenna wind profilers, Part 1: Theoretical analysis. *Radio Science*, **31**(1), 157-180.
8. Dudhia, J., 1993: A nonhydrostatic version of the Penn State / NCAR mesoscale model: Validation tests and simulations of an Atlantic cyclone and cold front. *Mon. Wea. Rev.*, **121**, 1493-1513.
9. Dudhia, J., 1995: Reply to comment on "A nonhydrostatic version of the Penn State / NCAR mesoscale model: Validation tests and simulations of an Atlantic cyclone and cold front" by J. Steppeler. *Mon. Wea. Rev.*, **123**, 2573-2575.
10. Holloway, C.L., R. J. Doviak, S. A. Cohn, R. J. Lataitis, and J. S. Van Baelen, 1996: Cross correlations and cross spectra for spaced antenna wind profilers, Part 2: Algorithms to estimate wind and turbulence. Submitted to *Radio Science*, April, 1996.
11. Kuo, Y.-H., X. Zou, and Y.-R. Guo, 1996: Variational Assimilation of Precipitable Water Using a Nonhydrostatic Mesoscale Adjoint Model. Part I: Moisture retrieval and sensitivity experiments. *Mon. Wea. Rev.*, **124**, 122-147.
12. Kuo, Y.-H., J. Bresch, M.-D. Cheng, J. Kain, D.B. Parsons, W.-K. Tao, and D.-L. Zhang, 1996: Summary of a mini-workshop on cumulus parameterization for mesoscale models. Submitted to *Bull. Amer. Meteor. Soc.*

13. Kuo, Y.-H., X. Zou, and W. Huang, 1996: The Impact of GPS Data on the Prediction of an Extratropical Cyclone: An Observing System Simulation Experiment. Submitted to the Special issue of *J. Dyn. Atmos. Ocean*.
14. Kuo, Y.-H., Y.-R. Guo, and E.R. Westwater, 1993: Assimilation of precipitable water measurements into a mesoscale numerical model. *Mon. Wea. Rev.*, 121, 1215-1238.
15. Lataitis, R.J., S. F. Clifford, and C.L. Holloway, 1995: An alternative method for inferring winds from spaced-antenna radar measurements, *Radio Science*, 30, no. 2, pp. 463-474.
16. Lataitis, R.J., R.J. Doviak, S.A. Cohn, and C.L. Holloway, 1996: Precision of Spaced-Antenna and Doppler Beam Swinging Wind Estimates, in preparation, to be submitted to *Radio Science*.
17. Lataitis, R.J., R.J. Doviak, S.A. Cohn, and C.L. Holloway, Precision of spaced-antenna wind estimates, Submitted to the *J. of Atmospheric and Oceanic Tech.*, 1996
18. Oncley, S.P., and J. Dudhia, 1995: Evaluation of surface fluxes from MM5 using observations. *Mon. Wea. Rev.* 123, 3344-3357.
19. Parsons, D.B., and J. Dudhia, 1996: Testing of a data assimilation system in support of the goals of the Atmospheric Radiation Measurement Program. Submitted to *J. Clim.*
20. Parsons, D.B., W. Dabberdt, H. Cole, T. Hock, C. Martin, A.-L. Barrett, E. Miller, M. Spowart, M. Howard, W. Ecklund, D. Carter, K. Gage, and J. Wilson, 1994: The Integrated Sounding System: Description and Preliminary Observations from TOGA COARE. *Bull. Amer. Meteor. Soc.*, 75, 553-567.
21. Riddle, A.C., W.M. Angevine, W.L. Ecklund, E. Miller, D. Parsons, D.A. Carter, K.S. Gage, 1996: Wind-profiler and rawinsonde observations compared at ISS sites during TOGA COARE. In press *Contributions to Atmospheric Physics*.
22. Rodgers, R.R., S.G. Leblanc, S.A. Cohn, W.L. Ecklund, D.A. Carter, and J.S. Wilson, 1996: Profiler measurements of turbulence and wind shear in a snowstorm, *Contributions to Atmos. Physics* (accepted May 1995).
23. Smith, W.L., W.F. Dabberdt, et al. (19), 1991: GAPEX - A ground-based atmospheric profiling experiment. *Bull. Amer. Meteor. Soc.*, 71 (3), 310-318.
24. Trier, S.B., and D.B. Parsons, 1993: Evolution of environmental conditions preceding the development of a nocturnal mesoscale convective complex. *Mon. Wea. Rev.*, 121, 1078-1098.
25. Trier, S.B., W. Skamarock, M.A. LeMone and D.B. Parsons, 1996: A three-dimensional numerical simulation of a tropical squall line observed during TOGA COARE. In press *Mon. Wea. Rev.*

26. Zou, X., and Y.-H. Kuo, 1996: Rainfall Assimilation Through an Optimal Control of Initial and Boundary Conditions in a Limited-Area Mesoscale Model. Submitted to *Mon. Wea. Rev* [revised]
27. Zou, X., Y.-H. Kuo, and Y.-R. Guo, 1995: Assimilation of Atmospheric Radio Refractivity Using a Nonhydrostatic Adjoint Model. *Mon. Wea. Rev.*, 123, 2229-2249.

Non-refereed papers

1. Bao, J.-W., J. Dudhia, P. O. G. Persson, and G. Grell, 1995: Implementation of Burk-Thompson PBL scheme in MM5. *Fifth Annual PSU/NCAR Mesoscale Model Users' Workshop*, Boulder CO, August 1995, 115-116.
2. Cohn, S.A., R.R. Rogers, W. Ecklund, D. Carter, and J. Wilson, 1993: Horizontal convergence measurements with a 5-Beam wind profiler. *26th International Conference on Radar Meteorology*, Norman, OK, pp. 634-636.
3. Cohn, S.A., J.R. Gyakum, R.R. Rogers, W.L. Ecklund, D.A. Carter, and J.S. Wilson, 1994: RASS observations of complex synoptic events, Preprints, *Third Int. Symp. on Tropospheric Profiling*, Hamburg, Germany, pp.164-166.
4. Cohn, S. A., C. L. Holloway, R. J. Doviak, and J. Van Baelen, Wind and flux measurements with a UHF spaced antenna profiler Fifth Atmospheric Radiation Measurement (ARM) Science Team Meeting, San Diego, CA, 19-23 March, 1995.
5. Cohn, S. A., J. S. Van Baelen, R. J. Doviak, C. L. Holloway, and R. J. Latatits, 1995: Wind measurements with the NCAR UHF Spaced Antenna Profiler. Proceedings, *Ninth Symposium on Meteorological Observations and Instrumentation*. March 27-31, 1995, Charlotte, NC., pp.161-165.
6. Cohn, S. A., J. K. Smith, C. Martin, C. L. Holloway, R. J. Doviak, and J. S. Van Baelen, 1995: Spaced antenna profiler wind measurements: Implementation. *27th Conference on Radar Meteorology*, 9-13 October, 1995, Vail, CO, pp. 326-328.
7. Cohn, S. A., C. L. Holloway, R. J. Doviak, and J. Van Baelen, High time-resolution (30-second) wind profiling with the NCAR/ARM MAPR Sixth Atmospheric Radiation Measurement (ARM) Science Team Meeting, San Antonio, TX, 4-7 March, 1996.
8. Cohn, S.A., J. K. Smith, C. Martin, and C. L. Holloway, 1996: Wind measurement with the NCAR UHF spaced antenna profilers: New algorithms implementation. *HandBook for MAP*, Vol. 29, 1996.
9. Cohn, S. A., J. K. Smith, C. Martin, and C. L. Holloway: 1996, Wind measurement with the NCAR UHF spaced antenna profilers: New algorithms implementation. Seventh workshop on technical and scientific aspects of MST/ST radar, 7-11 November 1995, Hilton Head Island, SC.

10. Dabberdt, W.F., 1993: Advances in the development of an integrated data assimilation and sounding system (IDASS). Proceedings, Third Atmospheric Radiation Measurement (ARM) Science Team Meeting, Norman, OK, March 1993.
11. Dabberdt, W.F., C.L. Martin, H.L. Cole, et al., 1991: An integrated data assimilation and hybrid sounding system. Proceedings, *International Conf. on Mesoscale Meteorology and TAMEX*, December 1991, Taipei, Taiwan.
12. Dabberdt, W.F., H.L. Cole, et al., 1991: An integrated data assimilation and sounding system. Proceedings, *25th Int. Conf. on Radar Meteor.*, June 1991, Paris, France.
13. Dabberdt, W., D. Parsons, Y.H. Kuo, J. Dudhia, C. Martin, S. Oncley, J Van Baelen, 1992: Preliminary results from an Integrated Data Assimilation and Sounding System. *Symposium for Global Change*, Anaheim, CA, Jan. 1993, 163-168.
14. Doviak, R.J., 1994: Recent Developments in Doppler Analysis for Weather Radars and Wind Profilers. Proceedings of RADME 94: Aspetti teorici, sperimentali ed applicativi della radarmeteorologia. June 14-15, 1994, Universita' di Roma Tor Vergata, Rome, Italy.
15. Doviak, R.J., C.L. Holloway, and R. J. Latatits, 1994: A generalized theoretical analysis of cross-correlation and -spectra in spaced-antenna wind profilers. Proceedings, *Third International Symposium on Tropospheric Profiling*. Aug.30-Sept.2, 1994, Geomatikum Universitat, Hamburg, Germany, pp. 274-276.
16. Doviak, R.J., R.J. Latatits, and C.L. Holloway, 1995: A generalized theoretical analysis and application of cross-correlation and cross-spectra to spaced-antenna wind profilers. *International Geoscience and Remote Sensing Symposium*, Firenze, Italy, 10-14 July, 1995. [Invited Paper]
17. Doviak, R.J., R.J. Latatits, C. L. Holloway, and J. Van Baelen, 1994: A generalized theoretical analysis of cross-correlation and cross-spectra for spaced-antenna wind profilers. *NCAR Technical Note 407+STR*, National Center for Atmospheric Research, Boulder, CO, October, 1994.
18. Doviak, R.J., R.J. Latatits, C.L. Holloway, J. Van Baelen, and S.A. Cohn, 1995: A generalized theoretical analysis and application of cross-correlation to spaced-antenna wind profilers. *International Geoscience and Remote Sensing Symposium*, 10-14 July, 1995, Firenze, Italy. [Invited Paper]
19. Doviak, R. J., S. A. Cohn, C. L. Holloway, and R. J. Latatits, 1996: Recent Developments in Doppler Radar and Related Processing. Third Italian Symposium on Meteorological Radar, RADME96, Tor Vergata Univ., Roma, Italy, 11-12 June, 1996. [Invited Paper]
20. Dudhia, J., 1993: A nonhydrostatic version of the Penn State/NCAR mesoscale model: Validation tests and simulation of an Atlantic cyclone and cold front. *Mon. Wea. Rev.*, **121**, 1493-1513.
21. Dudhia, J., 1992: A simulation of a cold front associated with a marine cyclone. Preprints, *Fifth Conference on Mesoscale Processes*, January 1992, Atlanta, GA, 170-173.

22. Dudhia, J., 1992: A simple ice phase and radiation scheme. Preprints, *The Second Annual Penn State/NCAR Mesoscale Model Users' Workshop*, October 1992, Boulder, CO, 16.
23. Dudhia, J., G. Grell and D. Stauffer, 1992: MM5 model development, Preprints, *The Second annual Penn State/NCAR Mesoscale Model Users' Workshop*, October 1992, Boulder, CO, 12-15.
24. Dudhia, J., Y.-H. Kuo and Z. Guo, 1991: Data assimilation using hydrostatic and non hydrostatic models with WISP data. Preprints, *Second Symposium on Tropospheric Profiling: Needs and Technologies*, Sept. 10-13, 1991, Boulder, CO.
25. Dudhia, J., 1993: The importance of an upper radiative boundary condition in real-data nonhydrostatic mesoscale modeling. Proceedings, *Ninth Conference on Atmospheric and Oceanic Waves and Stability*, San Antonio TX, May 1993, 226-229.
26. Dudhia, J., 1993: New options in version 1 of MM5. Third Annual PSU/NCAR Mesoscale Model Users' Workshop, Boulder CO, October 1993, 5.
27. Dudhia, J., 1993: Radiation studies with a high-resolution mesoscale model. Third Annual PSU/NCAR Mesoscale Model Users' Workshop, Boulder CO, October 1993, 13.
28. Dudhia, J., 1993: The importance of an upper radiative boundary condition in real-data nonhydrostatic mesoscale modeling. Third Annual PSU/NCAR Mesoscale Model Users' Workshop, Boulder CO, October 1993, 11.
29. Dudhia, J., 1994: Mesoscale simulations of convective systems with data assimilation during June 1993 in the Southern Great Plains. Fourth Annual ARM Science Team Meeting, Charleston, SC, February 1994, 127-130.
30. Dudhia, J. and S. P. Oncley, 1994: Surface flux intercomparison between the MM5 model and observations during STORM-FEST 1992, 131-135. Fourth Annual ARM Science Team Meeting, Charleston, SC, February 1994.
31. Dudhia, J., 1994: Mesoscale simulations of convective systems in Oklahoma/Kansas in June 1993. Preprints, *Tenth Conference on Numerical Weather Prediction*, Portland, OR, July 1994, 632-634.
32. Dudhia, J. and S. P. Oncley, 1994: Surface flux intercomparison between the MM5 model and observations during STORM-FEST 1992. Proceedings, *Fourth Annual PSU/NCAR Mesoscale Model Users' Workshop*, Boulder CO, August 1994, 39-42.
33. Dudhia, J. and D. B. Parsons, 1995: Mean properties of mesoscale convective systems in Oklahoma/Kansas in June 1993. Preprints, *Fourth Conference on Global Change Studies*, Dallas TX, January 1995, 152-156.
34. Dudhia, J., and D. B. Parsons, 1995: Comparison of mean properties of simulated convection in a cloud-resolving model with those produced by cumulus parameterization. Fifth Annual ARM Science Team Meeting, San Diego CA, March 1995.

35. Dudhia, J., and Y.-R. Guo, 1995: Data assimilation of a ten-day period during June 1993 over the Southern Great Plains site using a nested mesoscale model. Fifth Annual ARM Science Team Meeting, San Diego CA, March 1995.
36. Dudhia, J., 1995: Initial plans for MM6. *Fifth Annual PSU/NCAR Mesoscale Model Users' Workshop*, Boulder CO, August 1995, 126.
37. Dudhia, J., 1996: Data assimilation for the June 1993 IOP in the Southern Great Plains Site. Sixth Annual ARM Science Team Meeting, San Antonio TX, March 1996.
38. Dudhia, J., and D. B. Parsons, 1996: Cloud-resolving model simulations conducted over the SGP CART Site. Sixth Annual ARM Science Team Meeting, San Antonio TX, March 1996.
39. Dudhia, J., 1996: Data assimilation of a ten-day period during June 1993 over the Southern Great Plains Site using a nested mesoscale model. *Seventh Conference on Mesoscale Processes*, Reading, UK, September 1996.
40. Gage, K., D. Carter, W. Ecklund, J. Wilson, W. Dabberdt, D. Parsons, C. Martin and H. Cole, 1994: Use of an Integrated Sounding System (ISS) during TOGA COARE--An overview. TOGA 95, Melbourne, Australia, 2-7 April 1995, 217.
41. Gage, K.S., D.A. Carter, W.L. Ecklund, J.L. Wilson, W. Dabberdt, D. Parsons, C. Martin, and H. Cole, 1994: Use of the Integrated Sounding System in TOGA COARE-an overview. Preprints, *Third International Symposium on Tropospheric Profiling: Needs and Technology*, Hamburg, Germany, Aug.-Sept. 1993, 178-181.
42. Grell, G. A., J. Dudhia and D. R. Stauffer, 1994: A Description of the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5). *NCAR Technical Note, NCAR/TN-398+STR*, 138pp.
43. Guo, Y.-R., X. Zou, and Y.-H. Kuo, 1996: Development of MM5 4DVAR system and its preliminary applications. Proceedings of the Sixth Atmospheric Radiation Measurement (ARM) Science Team Meeting.
44. Haagenson, P. L., J. Dudhia, G. A. Grell, and D. R. Stauffer, 1994: The Penn State / NCAR mesoscale model (MM5) source code documentation. *NCAR Technical Note, NCAR/TN-392+STR*, 200pp.
45. Holloway, C. L., J. Van Baelen, and S. B. Copeland, 1994: UHF profiling radar wind estimation techniques, Preprints, *Third International Symposium on Tropospheric Profiling: Needs and Technologies*, Hamburg, Germany, August 30-September 2, 1994, 280-282.
46. Holloway, C. L., D. Parsons, and J. Van Baelen, Boundary layer wind estimations with a UHF Doppler/interferometric wind profiler, Fourth Atmospheric Radiation Measurement (ARM) Science Team Meeting, March, 1994.
47. Holloway, C.L., R. J. Doviak, S. A. Cohn, and R. J. Latatits, 1995: Algorithms to retrieve wind from spaced-antenna wind profilers. *27th International Conference on Radar Meteorology*, October 9-13, 1995, 323-325.

48. Holloway, C. L., R. J. Doviak, S. A. Cohn, R. J. Lataitis, and J. Van Baelen, 1995: Techniques to retrieve wind from spaced antenna wind profilers. Preprints, *27th International Conference on Radar Meteorology*, 9-13 October, 1995, Vail, CO, 323-325.
49. Holloway, C. L., R. J. Doviak, S. A. Cohn, R. J. Lataitis, and J. Van Baelen, 1995: Algorithms to retrieve wind from spaced-antenna wind profilers. Seventh Workshop on Technical and Scientific Aspects of MST/ST radar. 7-11 November, 1995, Hilton Head Island, SC.
50. Holloway, C. L., R. J. Doviak, S. A. Cohn, and R. J. Lataitis, Spaced antenna profiler estimates of wind and turbulence in the boundary layer, Sixth Atmospheric Radiation Measurement (ARM) Science Team Meeting, San Antonio, TX, 4-7 March, 1996.
51. Holloway, C. L., R. J. Doviak, S. A. Cohn, and R. J. Lataitis, 1996: Retrieval of boundary-layer turbulence using spaced-antenna wind profilers. IGARSS 1996 *International Geoscience and Remote Sensing Symposium*, 27-31 May 1996, Lincoln, Nebraska. [Invited Paper]
52. Holloway, C. L., R. J. Doviak, S. A. Cohn, and R. J. Lataitis, 1996: Time-domain algorithms to retrieve wind from space-antenna wind profilers. *Handbook for MAP*, Volume 29, 1996.
53. Koracin, D., M.M. Cairns, N. Ahmad, S. Del Soldato, V. Isakov, J. Hallett, and S.A. Cohn, 1996: Predictability of local wind shear and turbulence and comparison with observations in complex terrain, AIAA 96-0509 (American Institute of Aeronautics and Astronautics), 34th Aerospace Sciences Meeting, Reno, Nevada.
54. Kuo, Y.-H., J. Dudhia, Z. Guo, and Y.-R. Guo, 1991: Preliminary data assimilation experiments during ARM/WISP 1991. Preprints, *Second Symposium on Tropospheric Profiling: Needs and Technologies*, Sept. 10-13, 1991, Boulder, CO.
55. Kuo, Y.-H., A. Wang, A. Lau, and J. Dudhia, 1996: Sensitivity of regional climate simulation to radiation parameterization. Sixth Annual ARM Science Team Meeting, San Antonio TX, March 1996.
56. Lataitis, R. J., S. F. Clifford, and C. L. Holloway, 1994: An alternative method for inferring winds from spaced-antenna measurements. Preprints, *Third International Symposium on Tropospheric Profiling: Needs and Technologies*, Hamburg, Germany, August 30-September 2, 1994, pp. 277-279.
57. Lataitis, R. J., R. J. Doviak, 1995: Precision of spaced-antenna wind estimates. Preprints, *27th Radar Conference on Radar Meteorology*, 9-13 October, 1995, Vail, CO, pp. 717-719.
58. Martin, C.L., 1991: Summary of observations made during the WISP/ARM 1991 field program in support of the integrated data assimilation and sounding system development.
59. Martner, E.E., D.P. Wuertz, B.B. Stankey, R.G. Strauch, E.R. Westwater, K.S. Gate, W.L. Ecklund, C.L. Martin, and W.F. Dabberdt, 1993: An evaluation of wind profiler, RASS, and microwave radiometer performance. *Bull. Amer. Meteor. Soc.*, **74**, 599-613.

60. Parsons, D.B., 1996: The behavior of the cloud and radiative system over the Tropical Western Pacific during suppressed conditions. Abstracts from the ARM Science Team Meeting, 4-7 March 1996, 63.
61. Parsons, D.B., 1994: Impacts of convective outflows on the air-sea interface during TOGA COARE. Joint proceedings *6th Conf. on Climate Variations and 5th Symposium on Global Change Studies*, Nashville, TN, Jan. 1994, J76-J80.
62. Parsons, D.B., 1993: Some preliminary results from deployment of integrated sounding system for TOGA COARE. Preprints, *20th Conf. on Hurricanes and Tropical Meteorology*, San Antonio, TX, May 1993, 620-623.
63. Parsons, D.B., and J. Dudhia, 1996: Cloud resolving model simulations conducted over the CART site, Abstracts from the ARM Science Team Meeting, 4-7 March 1996, 62.
64. Parsons, D., H. Cole and P. Hildebrand, 1992: ATD gears up for TOGA COARE field study. *ATD Observer*, Summer 1992 issue, 1-4.
65. Parsons, D.B., W. Dabberdt, H. Cole, K. Gage, A. Riddle, and W. Ecklund, 1995: Development of Integrated Sounding Systems and examples of scientific advances. *Progress In Electromagnetics Research Symposium (PIERS)*, Seattle, WA., July, 1995 (invited talk) 1018.
66. Parsons, D. B., J. Dudhia, W. F. Dabberdt, and Y.-H. Kuo, 1995: Development of an Integrated Data Assimilation and Sounding System. Preprints, *Ninth Symposium on Meteorological Observations and Instrumentation*. Charlotte, N.C., March 27-31, 1995, pp. 1-5.
67. Parsons, D., W. Dabberdt and K. Gage, 1994, Development of an Integrated Sounding System for TOGA COARE. Preprints, National Weather Service and Associated Restructuring Workshop as part of the *11th conference on Interactive Information and Processing systems*, AMS annual meeting, (Invited talk), Dallas, Texas, 15-20 Jan. 1994.
68. Parsons, D.B., J. Dudhia, and W.F. Dabberdt, 1994: Data assimilation studies using a non-hydrostatic model. Preprints, *Third International Symposium on Tropospheric Profiling: Needs and Technology*, Hamburg, Germany, Aug.-Sept. 1993, 7-9.
69. Parsons, D.B., Trier, S.B., and M.A. LeMone, 1995: Studies of atmospheric processes over the tropical western Pacific. Abstracts from the ARM Science Team Meeting, March 1995.
70. Parsons, D.B., and S.B. Trier, 1992: The initiation and structure of a nocturnal mesoscale convective complex. Preprints, *5th Conference on Mesoscale Meteorology*, Atlanta, GA, 327-332.
71. Riddle, A.C., E. Miller, D. Parsons, and K. Gage, 1995: Intercomparison of profiler and Omega rawinsonde observations taken by the Integrated Sounding System during TOGA COARE, TOGA 95, Melbourne, Australia, 2-7 April, 1995, 203.

72. Riddle, A.C., W.M. Angevine, H.L. Cole, E.R. Miller,, C.L. Martin, D. B. Parsons, C. Morel, P.E. Ciesielski, and D. A. Carter, 1994: Intercomparison of profiler and balloon observations during TOGA COARE. Preprints, *Third International Symposium on Tropospheric Profiling: Needs and Technology*, Hamburg, Germany, Aug.-Sept. 1993, 286-288.
73. Rogers, R.R., S.A. Cohn, S.G. Leblanc, W.L. Ecklund, D.A. Carter, and J.S Wilson, 1994: Profiler measurements of shear-induced turbulence in a snowstorm, Preprints, *Third Int. Symp. on Tropospheric Profiling: Needs and Technologies*, Hamburg, pp. 98-100.
74. Trier, S.B., D.B. Parsons, and M.A. LeMone, 1994: A three-dimensional numerical simulation of a tropical squall line observed during TOGA-COARE. Preprint volume, *6th Conf. on Mesoscale Processes*, Portland, Oregon, 18-22 July. A.M.S., Boston, MA, 45-48.
75. Trier, S.B., and D.B. Parsons, 1993: Long-lived convective cells in a three-dimensional simulation of a tropical rainband, Preprints, *17th Conf. on Severe Local Storms*, St. Louis, MO., Oct. 1993, 470-475.
76. Trier, S., W. Skamarock, M.A. LeMone, and D. Parsons, 1995: Numerical Simulations of the 22 February 1993 TOGA COARE Squall Line. Preprints, *21st Conf. on Hurricanes and Tropical Meteorology*, Miami, FL, 24-28 April, 576-578.
77. Van Baelen, J.S., 1993: A UHF boundary-layer Doppler/interferometric profiler. Preprints, *8th Symposium on Meteorological Observations and Instrumentation*, Jan. 17-22, 1993, Anaheim, CA.
78. Van Baelen, J.S., 1993: UHF Doppler and interferometric profiling and RASS applications in the atmospheric boundary layer: Preliminary investigations. Preprints, *8th Symposium on Meteorological Observations and Instrumentation*, Jan. 17-22, 1993, Anaheim, CA.
79. Van Baelen, J.S., 1993: A UHF Doppler/interferometric boundary-layer profiler: Description and preliminary investigations. Preprints, *26th Conference on Radar Meteorology*, May 24-28, Norman, OK, American Meteorological Society, Boston, MA.
80. Van Baelen, J.S., 1993: A UHF boundary-layer Doppler/interferometric profiler: Part I: Motivation and description. Preprints, *6th Workshop on Technical and Scientific Aspects of MST Radar*, August 17-20, 1993, Chung-Li, Taiwan, Republic of China.
81. Van Baelen, J.S., 1993: A UHF boundary-layer Doppler/interferometric profiler: Part II: Projected research and preliminary results. Preprints, *6th Workshop on Technical and Scientific Aspects of MST Radar*, August 17-20, 1993, Chung-Li, Taiwan, Republic of China.
82. Van Baelen, J.S., 1992: Simultaneous accurate measurements of 3-D wind and virtual temperature profiles. Preprints, *URSI Commission F Symposium*, June 8-11, 1992, Ravenscar, U.K.

83. Van Baelen, J.S., D.A. Carter, W.L. Ecklund, and W.M. Angevine, 1991: UHF Radar interferometry and RASS for boundary-layer wind and temperature profiling. *Summary Volume of the 5th Workshop on Technical and Scientific Aspects of MST Radar*, August 6-9, 1991, Aberystwyth, Wales.
84. Van Baelen, J.S., D.A. Carter, W.L. Ecklund, and W.M. Angevine, 1991: Radar interferometry at UHF for boundary-layer wind profiling. Preprints, *Second Symposium on Lower Tropospheric Profiling: Needs and Technologies*, Sept. 10-13, 1991, Boulder, CO.
85. Van Baelen, J.S., D.A. Carter, W.L. Ecklund, and W.M. Angevine, 1991: RASS applications with UHF interferometry. Preprints, *Second Symposium on Lower Tropospheric Profiling: Needs and Technologies*, Sept. 10-13, 1991, Boulder, CO.
86. Van Baelen, J.S., C.L. Martin, S. Peytier, W.L. Ecklund, and D.A. Carter, 1991: Operation of a Doppler SODAR system to provide high resolution wind profiles in the boundary layer between ground level measurements and UHF wind profilers. Preprints, *Second Symposium on Lower Tropospheric Profiling: Needs and Technologies*, Sept. 10-13, 1991, Boulder, CO.
87. Van Baelen, J., C. L. Holloway and S. B. Copeland, 1994: Atmospheric boundary layer investigations with a UHF doppler/interferometric wind profiler. *1994 International Geoscience and Remote Sensing Symposium (IGARSS)*, Pasadena, CA, August 8-12, 1994. pp. 2248-2450.
88. Van Baelen, J., S. B. Copeland, and C. L. Holloway, 1994: A UHF doppler/interferometric profiler for boundary layer studies: First results. Preprints, *Third International Symposium on Tropospheric Profiling: Needs and Technologies*, Hamburg, Germany, August 30-September 2, 1994, pp. 306-309.
89. Van Baelen, J.S., 1994: A UHF doppler/interferometric boundary layer profiler: description and preliminary investigations, Preprints, *26th International Conference on Radar Meteorology*, Norman, OK, pp. 490-491.
90. Van Baelen, J. S., L. Hirsch, C. Prada-Julia, and H. Steinhagen, Radar interferometry and correlation analysis with the Lindenberg UHF wind profiler: first results, *Seventh workshop on technical and scientific aspects of MST/ST radar*, 7-11 November 1995, Hilton Head Island, SC.
91. Warner, T.T., Y.-H. Kuo, J.D. Doyle, J. Dudhia, D.R. Stauffer and N.L. Seaman, 1992: Nonhydrostatic meso-beta scale, real-data simulations with the Penn State University/National Center for Atmospheric Research mesoscale model. *Meteor. and Atmos. Physics*, 49, 209-227.
92. Yoneyama, K, D. Parsons, and E.K. Miller, 1995: Dry Air Intrusions from the subtropics. *Amer. Geophysical Soc.*, Published as a supplemental to EOS, November 7, 1995, F124.

Presentations

1. Cohn, S. A., 1994: Research with the NCAR Integrated Sounding System, AMS Meeting Reno Chapter, November 1994. [Invited Talk]
2. Cohn, S. A., NCAR's spaced antenna profiler: current developments and future plans, 1st Annual NCAR Spaced Antenna Workshop, 7-8 November, Boulder, CO, 1994.
3. Cohn, S. A., 1995: Basin studies with an NCAR ISS, Workshop on inter-mountain meteorology, September, 1995.
4. Doviak, R. J., Cross-correlation and cross spectra in spaced-antenna wind profilers: theoretical analysis, 1st Annual NCAR Spaced Antenna Workshop, 7-8 November, Boulder, CO, 1994.
5. Doviak, R. J., Scattering Theory, Second international school of atmospheric radar, Hilton Head, SC, 5-6 November 1995 [Invited Talk]
6. Doviak, R. J., C. L. Holloway, and R. J. Latatits, 1996: The cross-correlation of fields scattered by anisotropic refractive index irregularities, *URSI National Radio Science Meeting*, Baltimore, Maryland, 21-26 July, 1996.
7. Dudhia, J., 1993: A numerical study of data assimilation requirements for simulating mesoscale systems. NCAR MMM Seminar, June, 1993.
8. Dudhia, J., 1994: Simulation of convection and a nocturnal jet in Oklahoma/Kansas in June 1993. | Dudhia, J., 1993: A numerical study of data assimilation requirements for simulating mesoscale systems. NCAR MMM Seminar, June, 1993.
9. Dudhia, J., 1994: Simulation of convection and a nocturnal jet in Oklahoma/Kansas in June 1993. Invited Seminar, Max-Planck Institut, Max-Planck Institut, Hamburg, August, 1994. [Invited Seminar.]
10. Dudhia, J., 1993: A numerical study of data assimilation requirements for simulating mesoscale systems. NCAR MMM Seminar, June, 1993.
11. Dudhia, J., 1995: Simulation of convection and a nocturnal jet in Oklahoma/Kansas in June 1993. CAPS, Norman, OK, April 1995. [Invited Seminar.]
12. Dudhia, J., 1995: Comparison of mean properties of simulated convection in a cloud-resolving model with those produced by cumulus parameterization. Invited Seminar, NASA Goddard, Greenbelt, MD, July 1995.
13. Dudhia, J., 1996: The nonhydrostatic version of MM5. First SRNWP Workshop on Nonhydrostatic Modelling, Frankfurt, Germany, March 1996. [Invited Talk.]
14. Dudhia, J., 1996: Applications and results of MM5. First SRNWP Workshop on Nonhydrostatic Modelling, Frankfurt, Germany, March 1996. [Invited Talk.]

15. Dudhia, J., and D. B. Parsons, 1996: 4D Data Assimilation and Single-Column Modeling. Talk at ARM SCM Workshop, Livermore CA, April 1996.
16. Holloway, C.L., 1995: Techniques to analyze signals from spaced antenna wind profilers. *URSI National Radio Science Meeting*, Boulder, CO, January, 1995.
17. Holloway, C. L., Spaced antenna systems: The Big Picture. *3rd International symposium on Tropospheric Profiling: Needs and Technologies*, Hamburg, Germany, August 30-September 2, 1994. [Invited Talk]
18. Holloway, C. L., 1994: Introduction to new techniques estimating winds from spaced antenna radars, *1st Annual NCAR Spaced Antenna Workshop*, Boulder, CO, 7-8 November, 1994.
19. Holloway, C.L., R. J. Doviak, S. A. Cohn, and R. J. Latatits, 1995: Algorithms to retrieve turbulence and wind from space-antenna wind profilers. *7th International Workshop on MST/ST Atmospheric Radars*, Hilton Head, SC, November 5-11, 1995.
20. Holloway, C. L., R. J. Doviak, R. J. Latatits, S. A. Cohn, and J. Van Baelen, 1995: Techniques to analyze signals from spaced antenna wind profilers. *National Radio Science Meeting*, Boulder CO, 3-7 Jan. 1995.
21. Holloway, C.L., D. Parsons, and J. Van Baelen, 1994: Boundary layer wind estimations with a UHF Doppler/interferometric wind profiler. *Fourth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, Charleston, SC, March, 1994.
22. Latatits, R. J., Space-time correlation function for horizontally isotropic scatterers, *1st Annual NCAR Spaced Antenna Workshop*, 7-8 November, Boulder, CO, 1994.
23. Latatits, R. J., R. J. Doviak, 1995: A general expression for the space-time correlation function for spaced-antenna radars. *National Radio Science Meeting*, Boulder CO, 3-7 Jan. 1995.
24. Parsons, D.B., 1993. Recent results from the Integrated Sounding Systems deployed in TOGA COARE. *NCAR/MMM Seminar*, October 1992.
25. Parsons, D.B., 1994. An Overview of the IDASS program. Invited keynote speaker (one of six) for the ARM Science Team Meeting held in April 1994.
26. Parsons, D.B., 1995: The Integrated Data Assimilation and Sounding System Program. *NCAR/ATD Seminar*, September 1995.
27. Parsons, D.B., 1995: Dry intrusions over the tropical western Pacific warm pool. *CSIRO*, Aspendale, Australia, December, 1995

28. Parsons, D.B., and J. Dudhia, 1996: Recent results using data assimilation at the Southern Great Plains CART Site. Invited oral presentation selected from the ARM posters. ARM Science Team Meeting held in March 1996.
29. Smith, J.K., and C.L. Martin, 1995: Spaced Antenna Profiler Wind Derivation Techniques. ARM Science Team meeting, San Diego, CA, March 20-23, 1995.
30. Van Baelen, J. S., Design and early results from NCAR's UHF multi-receiver wind profiler, 1st Annual NCAR Spaced Antenna Workshop, 7-8 November, Boulder, CO, 1994.