

Tammy M. Weckwerth* and David B. Parsons
National Center for Atmospheric Research
Atmospheric Technology Division
Boulder, CO USA

1. INTRODUCTION

The International H₂O Project (IHOP_2002) was one of the largest North American weather field experiments in history (Weckwerth et al. 2003). From 13 May to 25 June 2002, over 250 researchers from the U.S., France, Germany and Canada converged on the Southern Great Plains (SGP) to measure water vapor and other atmospheric parameters. The principle objective of IHOP_2002 is obtaining an improved characterization of the time-varying three-dimensional water vapor field and evaluating its utility in improving the understanding and prediction of convective processes. Toward this goal, IHOP_2002 brought together many of the existing operational and state-of-the-art research water vapor sensors and numerical models.

The focus of IHOP_2002 is on four coordinated and overlapping research components: i) The Quantitative Precipitation Forecasting (QPF) research component seeks to determine the degree of improvement in forecast skill that occurs through improved characterization of the water vapor field. This work includes a variety of research and operational numerical modeling, data assimilation and expert systems. ii) The Convection Initiation (CI) research component seeks to further understand and eventually predict the processes that determine where and when convection forms. iii) The Atmospheric Boundary Layer (ABL) Processes research component seeks to improve understanding of the relationship between atmospheric water vapor and surface and boundary layer processes and their impact on convective development; and iv) The Instrumentation research component seeks to determine the optimal mix of future operational water vapor measurement strategies to better predict warm season rainfall. This group will also work toward better quantification of measurement accuracy, precision and performance limitations as they relate to using water vapor measurements in warm season forecasts and data assimilation systems.

This paper presents a brief summary of IHOP_2002 and shows some preliminary data analyses which illustrate the value of integrated measurements.

2. MOTIVATION

An accurate prediction of warm season precipitation amounts has remained an elusive goal for the atmospheric sciences despite steady advances in the

forecast many other atmospheric variables (e.g., Emanuel et al. 1995; Dabberdt and Schlatter 1996). One necessary condition for an accurate prediction of convective rainfall is a good forecast of where and when convection will initially develop. Currently both the prediction and understanding of convection initiation processes are impeded by a lack of high-resolution, high-accuracy water vapor measurements.

Radiosondes, the traditional means of obtaining water vapor measurements, are insufficient because they provide only vertical profile information, are only available twice a day at most locations and have significant errors and biases (Guichard et al. 2000; Wang et al. 2002). Additionally, there is a general absence of operational ground-based water vapor remote sensing systems and many satellite techniques have relative difficulty in obtaining high-resolution and high-accuracy water vapor measurements in the lower troposphere. Thus, while water vapor measurements are critically linked to convective processes, measurements are simply not available to derive high quality initial conditions for the next generation of numerical weather prediction models or to provide guidance for forecasters seeking to nowcast convective development and evolution. Adequate means for measuring water vapor are only now beginning to emerge.

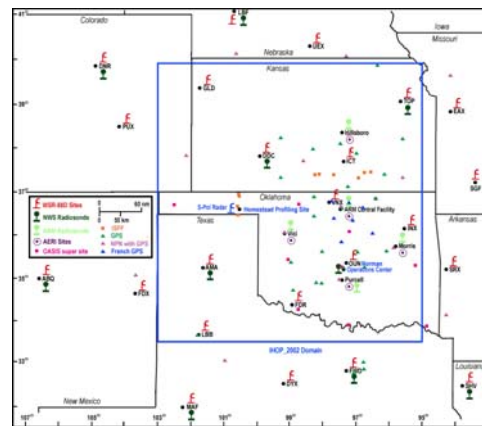


Fig. 1. Map of IHOP_2002 domain with subset of operational instruments, including NEXRAD radars, NWS and ARM sounding sites and AERI locations.

3. IHOP_2002

The U.S. SGP was chosen for IHOP_2002 due to the extensive array of operational and experimental instruments. An overview map of the IHOP_2002 domain is shown in Fig. 1.

* Corresponding author address: Tammy M. Weckwerth, NCAR, P.O. Box 3000, Boulder, CO 80307-3000, USA. E-mail: tammy@ucar.edu

A concentration of IHOP_2002 research instruments was placed in the Oklahoma panhandle. This extensive array of instruments included NCAR's S-Pol radar, numerous surface stations, some of which measure surface fluxes, a tethered sonde and a multitude of instruments based at the Homestead Profiling Site.

The densely-instrumented Homestead site included the NASA Scanning Raman Lidar (SRL) providing water vapor profiles, the NASA Goddard Lidar Observatory for Winds (GLOW) lidar providing Doppler wind measurements, the NASA Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE) lidar providing backscatter profiles, the U-Mass FMCW radar, UW-Madison AERIBAGO, which is an AERI in a Winnebago and an NCAR Integrated Sounding System (ISS) with an advanced wind profiler called MAPR, sodar, RASS and soundings.

The project also had a wealth of mobile systems. Mobile instruments based in the Liberal, KS area included 2 University of Oklahoma/NCAR Doppler on Wheels (DOW) radars, 2 NCAR mobile GLASS sounding systems, University of Connecticut's X-Pol radar, University of Alabama-Huntsville Mobile Integrated Profiling System (MIPS) and DRI's Mobile Microwave Radiometer. An NSSL mobile armada of instruments based in Norman, OK was directed from a mobile Field Control (FC) van with wireless data links to the NSSL mobile instruments, including a Shared Mobile Atmospheric Research and Teaching Radar (SMART-R), 9 mobile mesonets, a field camera vehicle and a mobile CLASS sounding system.

Six research aircraft participated in IHOP_2002, many of them with unique instrumentation. The NRL P-3 had an unprecedented combination of sensors, including NCAR's airborne Doppler radar (ELDORA) and Leandre II (CNRS/France's airborne water vapor DIAL). Leandre II was pointed downward for ABL and QPF missions and in a horizontal-pointing mode during CI missions. This combination of sensors during CI flights allowed for the horizontal mapping of the moisture field in the context of clear-air dual-Doppler winds from ELDORA. The DC-8 with downward-pointing LASE water vapor DIAL was used to map out the large-scale moisture distribution. The Falcon had downward-pointing water vapor DIAL which also provided curtains of water vapor measurements from the aircraft down to the ground. Additionally the Falcon launched numerous dropsondes and housed NOAA's High-Resolution Doppler Lidar (HRDL) providing high-resolution wind measurements. The Flight International Learjet was utilized as a dedicated dropsonde aircraft for IHOP_2002. The University of Wyoming King Air (UWKA) was a critical platform for both ABL and CI missions. The UWKA housed the Wyoming Cloud Radar (WCR) which obtained high-resolution Doppler and backscatter measurements of boundary layer motions in clear air and within clouds.

Numerous numerical models were run in real-time during IHOP_2002. Some of these were used to assist

in forecasting decisions (e.g., LAPS, local ETA, ARPS) while others were run to evaluate the impact of new data assimilation products (e.g., MM5 with AERI data). A multitude of models will be run in research and analysis mode to evaluate the impact of various datasets on improving the models' QPF performance (e.g., WRF, MM5, ARPS).

4. PRELIMINARY HIGHLIGHTS

4.1 Convection Initiation

Several CI events were successfully documented during the experiment. One case, 24 May 2002, is shown in Fig. 2 with the visible satellite imagery providing the background for the OK mesonet data, the composite radar display with the flight tracks and locations of mobile vehicles prior to CI. The mobile vehicles and aircraft all intercepted and collected data on a couple of boundaries prior to CI.

The focus was Shamrock, TX where there was an intersection (i.e., triple point) between a nearly north-south dryline and nearly east-west cold front. The ground-based instruments included two DOWs, SMART-R, X-Pol, eight mobile mesonets, three mobile sounding systems, the NSSL field camera and MIPS. The intensive operation region (IOR) was set up around the developing dryline. During the operations, which included quad-Doppler data collection, the triple point propagated through the center of the IOR. This was the first DC-8/LASE IHOP_2002 mission and they performed a large-scale racetrack-pattern mapping of the region. The Falcon with the DLR water vapor DIAL covered a smaller racetrack pattern. The Learjet dropped nine sondes every ~30 km from 4700 m MSL along a leg which was coordinated with the Falcon. The NRL P-3 flew a rectangular-pattern straddling the dryline at 305 m AGL and crossing the triple point several times. The UWKA flew multiple legs from 150 m AGL up to 2440 m AGL crossing the dryline. Additionally they flew multiple legs penetrating the cold front and a few legs through the triple point. When the UWKA flew above 700 m AGL, the WCR was operated in vertical plane dual-Doppler mode. The WCR was operated in simultaneous up and down mode on flight legs below 700 m AGL, providing single-Doppler data. The UWKA WCR and in situ measurements (not shown) showed a dramatic difference in depth of enhanced reflectivity of the cold frontal zone (<500 m AGL) and the dryline (~1600 m AGL). This may be attributed to the enhanced low-level stability associated with a cold front. Deep convection initiated near the intensive data collection region by 2100 UTC.

Please see sessions 11A and 12A and poster session 5A (this conference) for more on CI observations during IHOP_2002.

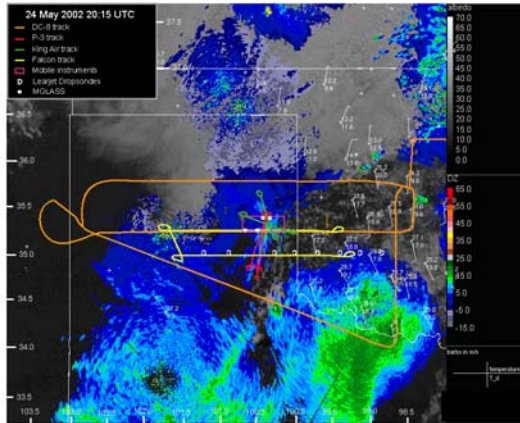


Fig. 2. Visible satellite and radar composite image on 24 May 2002 20:15 UTC prior to CI. Shown are the flight tracks of the various aircraft, the locations of the mobile ground-based systems and the available surface station data, plotted with temperature (deg C) on top, dew-point temperature (deg C) on bottom and wind barbs with a full barb of 5 m s^{-1} .

4.2 Reference radiosonde

Some preliminary results which will have significant impact on both operational and research sounding datasets were obtained from the reference radiosonde system (Wang et al. 2003). This state-of-the-art sounding package can be flown on the same balloon as traditional sounding packages. An intercomparison of the Snow White (SW) moisture sensor, which is the reference value, with the carbon hygistor and the Vaisala sensor is shown in Fig. 3. It is apparent that substantial variations exist between the reference and the standard sounding packages. At extremely cold temperatures (i.e., high levels), in particular, there is alarmingly little response in the hygistor and Vaisala sensors.

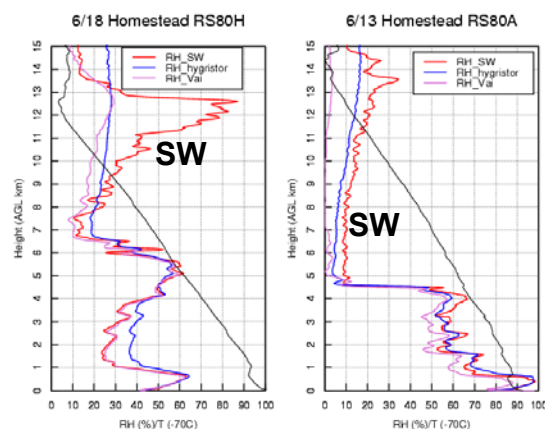


Fig. 3. Relative humidity intercomparisons between Snow White reference sensor (red), carbon hygistor (blue) and Vaisala RS80 (pink) on 18 June (left) and 13 June (right). The temperature profile (+70 deg C; black) is also shown. Figure courtesy Junhong Wang (NCAR/ATD).

4.3 Radar refractivity retrieval

An excellent example of a new product with a great deal of potential is the radar refractivity retrieval. It has been implemented on McGill's radar for some time (Fabry et al. 1997) but has only recently been utilized on NCAR's S-Pol radar. Fabry et al. (1997) use an ingenious technique to retrieve surface-layer refractivity measurements (closely related to moisture measurements) from ground targets. The technique takes advantage of the stationarity of the ground targets and therefore relates variations in Doppler signal delay to variations in the intervening atmospheric refractivity field. The refractivity field often identifies boundaries corresponding to the traditional reflectivity fine lines and velocity convergence zones (Figs. 4 and 5). At times, the refractivity field illustrated boundaries prior to the appearance of boundaries in the other more-traditional radar fields. Additionally the refractivity field sometimes showed blobs of moisture or pockets of dry air approaching and receding from S-Pol. These boundaries and other features apparent from the refractivity field will be examined to evaluate their impact on better understanding boundary layer evolution, boundary layer heterogeneity and convection initiation processes.

Please see Pettet et al. (2003) and Fabry and Park (2003) for more on IHOP_2002 refractivity measurements.

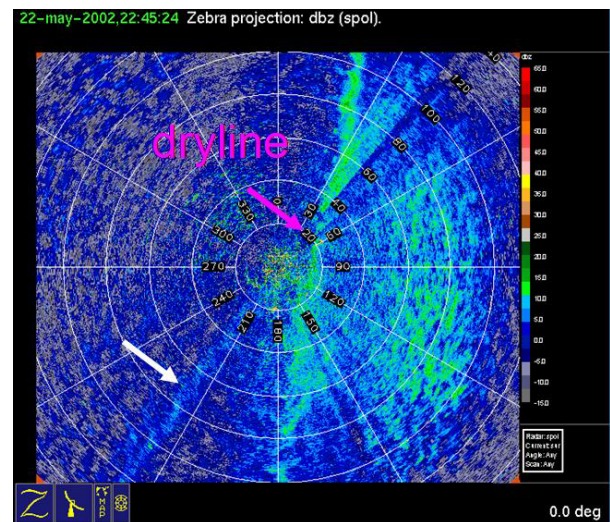


Fig. 4. S-Pol radar reflectivity field at 2245 UTC on 22 May 2002 with arrows showing two well-defined boundaries: a dryline and an unidentified boundary.

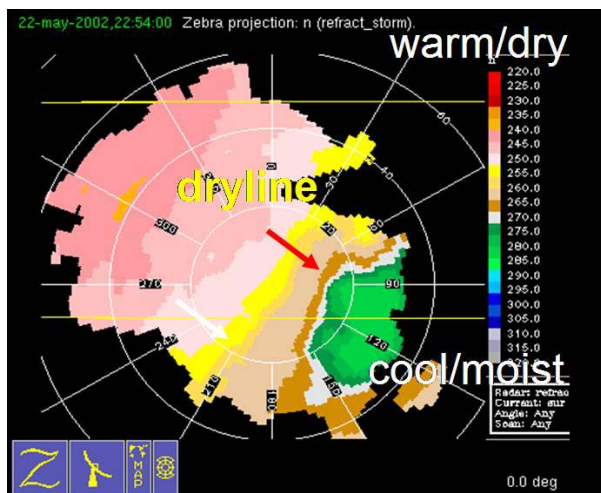


Fig. 5. S-Pol radar refractivity retrieval at 2254 UTC on 22 May 2002 corresponding to Fig. 4. Note the strong refractivity gradients at the locations of the arrows indicative of boundary features.

4.4 Bores

One of the exciting surprises during IHOP_2002 was the multitude of bore events in the region. Bores may be produced when a cold front or outflow boundary impinge upon a stable surface layer in the presence of sufficient wind curvature. Bores cause a “permanent” displacement of a layer aloft while atmospheric solitary waves occur when a layer is displaced upward and then returns back to its original height. Such events occurred numerous evenings in association with cold fronts, outflow boundaries and low-level jets. The downward-pointing Leandre II water vapor DIAL onboard the P-3 aircraft obtained an impressive image of the water vapor structure in association with an undular bore on 20 June 2002 (Fig. 6). Their impact on convection initiation and the maintenance of convection will be studied. Please see Parsons et al. (2003) for more on IHOP_2002 bores.

6. REFERENCES

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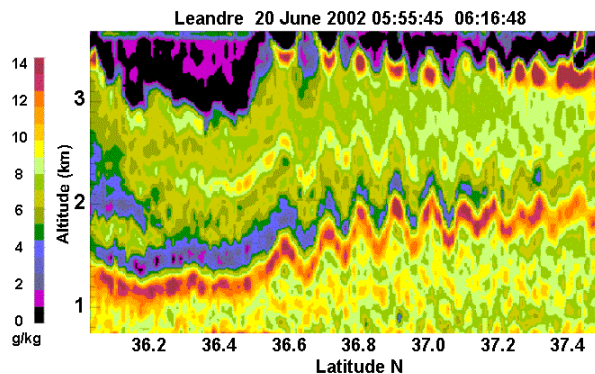


Fig. 6. Leandre II downward-pointing water vapor DIAL field from NRL P-3 at 0616 UTC on 20 June 2002. The wave-like structure in the moisture field depicts an undular bore propagating beneath the aircraft. Figure courtesy Cyrille Flamant (CNRS/France).

5. SUMMARY

The wealth of data collected during IHOP_2002 will be studied by teams of international investigators for years to come. These datasets will allow for detailed comprehensive studies of the moisture fields along with temperature and wind fields with the aim of i) assimilating these data into numerical models to ascertain the level of improvement in QPF; ii) better understanding and pinpointing exactly why and when storms form; iii) evaluating the relationship between land surface heterogeneities and boundary layer moisture distribution and iv) determining the future optimal mix of operational ground-based and satellite-borne moisture sensing instruments for forecasting convective rainfall.

Further examples of datasets collected during IHOP_2002 may be viewed at: <http://www.joss.ucar.edu/ihop/catalog/>. Additionally please see various papers at this conference in sessions 11A, 12A and poster session 5A for more on IHOP_2002.

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