The SONDE Project: Dryline Structure, Dynamics and Land-surface Interaction

Bart Geerts, University of Wyoming
Margaret LeMone, National Center for Atmospheric Research

1. Introduction

1.1. Dryline characteristics

The dryline is a well-defined atmospheric boundary frequently observed over the Southern Great Plains, between hot dry air to the west, and air of maritime tropical (mT) origin to the east. To a first order, the dryline can be considered as the intersection of the top of a capped layer of this mT airmass and the sloping terrain east of the Rocky Mountains (e.g., Schaefer 1974a). The dryline has clear diurnal characteristics and generally moves eastward in the afternoon, as it becomes more defined. The large-scale convergence along the dryline is attributed to the formation of a heat trough in the lee of the Rockies (e.g., McCarthy and Koch 1982; Parsons et al. 1991; Bluestein and Crawford 1997). The mature dryline is often a remarkably fine boundary \(O(1 \text{ km})\), with a substantial jump in specific humidity, and significant convergence over the depth of the boundary layer. On account of the fine-scale convergence, radars generally see the dryline as a reflectivity ‘fine-line’ (Wilson et al. 1994; Geerts and Miao 2005a). Only in some cases is the dryline marked by a cloudy line or a cloud edge.

Thunderstorms sometimes break out along the dryline, or at some distance east of the dryline. The dryline tends to form on about 50% of the days in May, at an average longitude of 100.6°W in West Texas (Hoch and Markowski 2005). While there is considerable day-to-day variability in dryline position due to synoptic conditions, on synoptically-quiet days the dryline position remains close to its climatological mean position, presumably because it is locked to the terrain and land-surface conditions.

Indeed there is much evidence that dryline formation is strongly tied to the land surface. It has long been speculated that the regional east-west gradient in soil moisture and vegetation properties result in substantial differences in daytime surface sensible heat fluxes. As the day progresses, the higher buoyancy flux on the west side of the dryline produces a deeper convective boundary layer (CBL) and more entrainment of dry, potentially-warm air from aloft. These differences themselves (unaided by large-scale differential horizontal advection) may be sufficient to create a mesoscale gradient in humidity and temperature (e.g., Hane et al. 1997). Several modeling studies have confirmed this hypothesis (Ziegler et al. 1995; Grasso 2000). Thus the formation and evolution of the dryline, and associated convective initiation and precipitation distribution, may have been altered by agricultural activity and irrigation in West Texas (Pielke et al. 1997; Moore and Rojstaczer 2002). Soil and vegetation properties vary in a complex mosaic across West Texas, and exist at multiple scales. Given the singularity, relative straightness, and mobility of the dryline, only the larger scales of this mosaic appear to be able to elicit an atmospheric response (Avissar and Schmidt 1998). However, finer-scale land surface properties may at least in part explain the occurrence of multiple boundaries with sharp horizontal specific humidity gradients (Hane et al. 1997; Hane et al. 2002, DeMoz et al. 2006; Weiss et al. 2006; Miao and Geerts 2007).

We refer to these boundaries as ancillary drylines. A preliminary dryline climatology by C. Weiss (pers. comm., 2006) based on West Texas radar data suggests that they tend to form near horizontal gradients in land use and soil moisture and/or local ridges in the terrain. Terrain features are thought to explain geographically-locked CBL convergence zones in Oklahoma (Shaw and Doran 2001), however land use gradients are often coincident with terrain features. Whatever their origin, ancillary dryline circulations may phase constructively with the primary dryline at points of intersection to support deep convection (Atkins et al. 1998; Hane et al. 1997).

Observations and numerical studies have shown that ‘the’ dryline (be it a single boundary or an array of boundaries) becomes more defined during the course of the day, and moves eastward by vertical mixing of a shallow moist airmass (e.g. Schaefer 1974a, b). When the zonal wind increases with height, this eastward movement can be intensified through downward mixing of westerly momentum (e.g., Ziegler et al. 1995). A buoyancy gradient typically develops across the dryline, with lower \(\theta_v\) (virtual potential temperature) values on the east side (Bluestein et al. 1990; Parsons et al. 1991; Ziegler and Hane 1993; Hane et al. 1997; Atkins et al. 1998; Ziegler and Rasmussen 1998). This gradient may result in a baroclinic solenoidal circulation, which is key to fine-scale frontogenesis (Parsons et al. 1991; Ziegler et al. 1995; Grasso 2000) and the tightening of the humidity difference from a scale \(O(100 \text{ km})\) to \(O(1 \text{ km})\) (Miao and Geerts 2007). Well-defined dryline boundaries may assume characteristics of a density current (Parsons et al. 1991; Ziegler and Hane 1993; Atkins et al. 1998; Miao and Geerts 2007).
Several studies have resolved a frontogenetic solenoidal circulation in the vertical plane across the dryline, using ground-based and/or airborne radar data (e.g., Atkins et al. 1998; Weiss et al. 2002; Demoz et al. 2006; Weiss et al. 2006; Miao and Geerts 2007). The normal dryline circulation is positive (i.e., the horizontal vorticity points north for a N-S dryline), thus the dry air rides over the denser moist airmass. Exceptions may however exist (Sipprell and Geerts 2007). The normal solenoidal circulation probably explains why the dryline echo plume tends to tilt eastward (Miao and Geerts 2007), and why the dryline cumulus cloud line, if present, tends to occur on the east side of the dryline (e.g., Ziegler and Rasmussen 1998). The development of a line of towering cumulonimbi depends on the detailed vertical and horizontal circulations and mixing patterns near the dryline.

The dryline often moves westward (‘retrogrades’) in the evening. On a larger scale, this may be interpreted as a response to isallobaric advection due to lee troughing west of the dryline (Benjamin and Carlson 1986). On a smaller scale, it may be due to density current dynamics, although not all retrograding drylines assume the structure of a density current (e.g. Crawford and Bluestein 1997).

1.2. Key objectives

The two outstanding questions that arise from the above description are: (a) to what extent do differences in surface buoyancy flux and vertical mixing drive the mesoscale buoyancy gradient that leads to the formation of a dryline ‘fine-line’; and (b) how do the fine-scale horizontal and vertical circulations near a dryline lead to towering cumulus formation. These questions revolve around processes at an array of scales, ranging from ~200 km to ~200 m. They are the foundation of the following key objectives of the proposed research, listed by decreasing spatial scale:

A. to examine how observed and simulated regional heat flux variations at the surface and entrainment near the CBL top contribute to dryline formation and evolution;
B. to describe and dynamically interpret the vertical radar echo and flow structure of the dryline convergence zone and associated cumulus cloud line (if present), in terms of ambient wind profiles and buoyancy differences;
C. to examine the fine-scale horizontal structure of drylines, including the kinematic and thermodynamic properties of misovortices.

The proposed research is focused on the analysis of data collected in a field campaign described in Section 2 below. The first objective (A) will also use the High-Resolution Land Data Assimilation System (HRLDAS) output. HRLDAS (Chen et al. 2007) will be run at 4-km resolution during the campaign; model output includes soil moisture and temperature profiles, and surface sensible & latent heat fluxes. We further hope to have access to higher-resolution coupled WRF (Weather Research and Forecasting)-HRLDAS output, in order to test the ability of the model system to forecast the timing, location, and strength of drylines, the observed structure of drylines in the vertical and horizontal planes (objectives B and C), and convective initiation (CI) along drylines. Possible venues for this capability are the NCAR-NOAA Developmental Testbed Center (DTC) and NCAR MMM (Morris Weisman). Discussions are under way.

1.3. Broader significance

Many observational and numerical dryline studies have been conducted; some focused on the existence and evolution of the dryline; others explored why and how CI tends to occur along the dryline. This proposal addresses both realms, and their connections.

It is well-known that differences in soil and/or vegetation properties at a sufficiently large scale can lead to differences in CBL depth, humidity, clouds, and precipitation. Furthermore, many studies (mostly modeling studies) have addressed the hypothesis whether such differences, if occurring on appropriate scales, can lead to mesoscale circulations sufficient and maybe even necessary to trigger precipitation (e.g., Segal et al. 1988; Lyons et al. 1993; Avissar and Liu 1996; Pielke 2001). Very few measurements exist to validate this hypothesis, and the dryline environment is well suited for this purpose.

The fine-scale dynamical processes responsible for CI along a dryline, or any other radar “fine-line” (i.e., convergence line), remain poorly understood, notwithstanding several intensive field campaigns, including VORTEX-94/95 [Verification of the Origin of Rotation in Tornadoes Experiment, Rasmussen et al. (1994)] and
IHOP-02 [International H$_2$O Experiment, Weckwerth et al. (2004)]. Both VORTEX and IHOP have yielded detailed dryline case studies, but neither aimed to study the mechanisms of dryline formation. Much similarity is believed to exist between drylines and other fine-lines in terms of fine-scale processes leading to CI. Non-dryline fine-lines are more ubiquitous in the Great Plains, but generally harder to predict and shorter-lived. One advantage of targeting drylines is that they form rather frequently in a rather specific region.

It is well known that numerical weather prediction (NWP) models perform relatively poorly in terms of warm-season quantitative precipitation (e.g., Weckwerth et al. 2004). An important reason for this relates to the model representation of surface fluxes and boundary-layer processes (e.g., Chen et al. 1997, 2001). The ability of a high-resolution NWP model to accurately capture the location and timing of dryline formation and (if present) CI in synoptically-quiescent conditions critically depends on the model’s performance in terms of surface and boundary-layer processes. As far as we know, the proposed project will present the first time that a land-atmosphere model will be used in real time to predict where and when drylines will form. The combination of detailed surface and boundary-layer observations, a state-of-the-art land surface model coupled with a NWP model, and the targeting of a relatively simple atmospheric situation with strong regional gradients, promises to lead to significant progress in the area of land-atmosphere interaction and impact on precipitation.

1.4. Summary of prior relevant research

1.4.1 Dr. Geerts’ research


IHOP-02 aimed to study the variations of water vapor at all scales, in order to improve warm-season quantitative precipitation forecasting. Geerts’ team studied convergence zones in the Great Plains, resulting in 11 publications so far (Weckwerth et al. 2004; Geerts and Miao 2005a, b, c; Geerts et al. 2006a; Miao et al. 2006; Demoz et al. 2006; Weiss et al. 2006; LeMone et al. 2007a; Sipprell and Geerts 2007; Miao and Geerts 2007) and two more in preparation. We used the Wyoming Cloud Radar (WCR) aboard the University of Wyoming King Air (WKA) to study the optically clear CBL. This rather unorthodox use of a cloud radar has yielded new insights into boundary-layer convection and the vertical structure of other fine-lines. Our work supports broad evidence that fine-lines and distributed ‘echo plumes’ are regions of high concentration of small insects. Geerts and Miao (2005a) find that these high concentrations result from the insects’ tendency to oppose the updraft in which they find themselves embedded. Thus fine-lines reflect a history of sustained convergence and rising air motion. Geerts and Miao (2005b) corroborate this finding by means of a simple numerical model of CBL circulations, and Geerts and Miao (2005c) use it to describe the vertical air velocity structure of the free-weather CBL. The observed echo and updraft plumes generally represent buoyant thermals in the CBL (Miao et al. 2006). Geerts et al. (2006) use the WCR data to describe the vertical structure of a cold front in unprecedented detail. They find striking evidence of density current dynamics.

The vertical structure of a dryline and processes leading to CI on 19 June 2002 are described in Sipprell and Geerts (2007). The vertical slope of the dryline and associated solenoidal circulation are found to be consistent with the horizontal buoyancy (or $\theta$) gradient. The slope shifts from westward (with denser air on the dry side) to eastward (with denser air on the moist side) during the two hours before CI. In IHOP-02 only three more dryline cases were documented by the WKA/WCR; the slope and convergence of these drylines were consistent with the observed buoyancy difference (Miao and Geerts 2007). More details on our IHOP work can be found at [http://www.atmos.uwyo.edu/wcr/projects/ihop02/](http://www.atmos.uwyo.edu/wcr/projects/ihop02/).


During July and August 2006, Geerts’ team studied the mechanisms of thermally-forced, orographically-controlled circulations, and the interaction between these circulations and cumulus formation over Catalina Mountain in Arizona, in an experiment called CuPIDO (Cumulus Photogrammetric In-situ and Doppler Observations) (Geerts et al., 2006b; Damiani et al. 2007). Several CuPIDO investigations are under development, including anabatic flow development and resulting heat and moisture transport, using 10 continuously-operating integrated surface flux facilities around the mountain, 51 mountain circumnavigations of the University of Wyoming.
1.4.2. Dr. LeMone’s research

LeMone is base-funded by NCAR. She was co-PI on three NSF proposals with Robert Grossman to conduct the CASES-97 (Cooperative Atmosphere-Surface Exchange Study 1997) field program and to take part in IHOP-02 (LeMone et al. 2007a). CASES-97 was the inaugural field campaign of the eight-year-long CASES program, which was married to the Atmosphere Boundary Layer Experiments Facility of Argonne National Laboratory (LeMone et al. 2002; Klazura et al. 2006). LeMone, Grossman, and colleagues used CASES-97 to study the heating and moistening of the boundary layer during the day and document a clear-cut example of a 60-km scale circulation in the fair-weather CBL (LeMone et al. 2002), as a testbed for developing methods to describe horizontal heterogeneity of surface sensible and latent heat fluxes in the daytime boundary layer (Yates et al. 2001; LeMone et al. 2003a,b; Grossman et al. 2004; LeMone et al. 2007b), and for testing land surface models (Chen et al. 2003).

2. SONDE-08

2.1. Joint objectives

This proposal is linked to the Simultaneous Observation of the Near-Dryline Environment (SONDE-08) project, to be conducted in West Texas in spring 2008. The principal goals of this experiment, which combines novel observations with state-of-the-art modeling, are to advance our understanding of how the land surface controls the formation of the dryline, and what dynamical processes lead to the fine-scale dryline structure and associated CI. Specific goals are listed in Table 1. There will be considerable collaboration – e.g., several groups will be involved in simulations, which will be an integral part of the post-analysis and synthesis. The SONDE-08 PIs are: Drs. M. LeMone, F. Chen [both at the National Center of Atmospheric Research (NCAR)], K. Knupp [University of Alabama in Huntsville (UAH)], D. Niyogi (Purdue), and C. Weiss [Texas Tech University (TTU)]. The facilities listed in Table 1 are introduced in Section 2.2. The one-page Project Summaries of the proposals from UAH, TTU, and Purdue are included as supplementary documentation to this proposal.

Table 1. Goals of SONDE-08 and Lead PIs. The goals are as stated in the SONDE-08 facility requests.

<table>
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<tr>
<th>Primary Goals</th>
<th>Lead PIs</th>
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<tr>
<td>A to run HRLDAS in real time to guide field operations, to examine how it</td>
<td>Niyogi, Chen, Geerts</td>
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<td>simulates regional soil moisture and surface sensible (H) and latent (LE)</td>
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<td>heat fluxes, and how it can be used in the WRF modeling system to forecast</td>
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<td>the timing, location, and strength of dryline and resulting convective</td>
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<td>B to examine the role of surface and entrainment heat flux role (measured</td>
<td>Weiss, Knupp, Geerts (Section 3 of this</td>
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<td>by ISFF, MIPS, WKA; and simulated) in dryline formation and evolution</td>
<td>proposal), LeMone</td>
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<td>C to examine the role of vertical transport of horizontal momentum (measured</td>
<td>Weiss, Knupp, LeMone</td>
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<td>by ISFF, MIPS, WKA, possibly MAX; and simulated) in dryline formation and</td>
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<td>D to examine the role of surface heat flux (measured by ISFF, WKA; and</td>
<td>Weiss, LeMone, Geerts</td>
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<td>simulated) and terrain in the formation of ancillary boundaries</td>
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<td>E to examine the structure and dynamics of the dryline convergence zone</td>
<td>Knupp, Geerts (Section 4), Weiss</td>
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<td>(and other convergent boundaries that may occur), including the development</td>
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<td>of a solenoidal circulation, density current characteristics, and their</td>
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<td>relation to cumulus formation and CI</td>
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<td>F to examine the fine-scale horizontal structure of drylines, including the</td>
<td>Weiss, Geerts (Section 5)</td>
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<td>kinematic and thermodynamic properties of “misovortices”.</td>
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## Secondary Goals

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<th>Lead PIs</th>
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<tr>
<td>i</td>
<td>to examine the horizontal variability of H and LE as a function of number of days after rainfall using observations and HRLDAS fluxes (offline and coupled to WRF)</td>
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<td>ii</td>
<td>to assess the surface energy balance, and response of stressed savannah grassland vegetation to diverse environmental forcings; evaluate the ability of HRLDAS (offline and coupled to WRF) to simulate diffuse and direct short-wave radiation components</td>
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<tr>
<td>iii</td>
<td>to assess the effect of horizontal convective rolls (HCRs), including clouds, on the time variation of surface H and LE.</td>
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### 2.2. Facilities

The SONDE experimental design contains the following platforms: the WKA research aircraft with WCR; two Ka-band mobile Doppler radars (‘TTUKa’), to be delivered to TTU later this year; a network of 12 integrated surface flux facilities (ISFF); a TTU mobile radiosonde platform; the UAH Mobile Integrated Profiling System [MIPS, Karan and Knupp (2006)], measuring profiles of wind, vertical velocity, temperature, and humidity; five TTU vehicles with instrument racks [the ‘Mobile Mesonet’ or MM]; 20-30 rapidly-deployable “Stick-Net” instruments measuring wind, temperature, pressure, and humidity; and several mobile towers sampling at 3-10 m AGL. Data from a 200 m flux tower sampling at ten levels (at 30 Hz), and a 915 MHz wind profiler, both at Reese, will be useful, however Reese is located in the SW corner of the area of focus (Fig. 1).

We further rely on the operational West Texas Mesonet [WTM, Schroeder et al. (2005)], currently containing ~50 stations, some with flux and soil measurements, and on the Weather Surveillance Radar-88Doppler (WSR-88D) at Lubbock (LBB) and, secondarily, at Amarillo (AMA), 165 km further north. Proximity to the LBB radar is important primarily to enable us to make the fine-scale radar operations. In many cases the dryline is expected to be too far east of the LBB (or AMA) radar. Even in close proximity to a WSR-88D, a spectral gap will exist in radar coverage, from the coarse scale provided by the WSR-88D, to the very fine scale provided by Ka-and W-band radars. We are aware of this limitation, and in his request for SONDE-08 support, Kevin Knupp includes the dual-polarization Mobile Alabama X-band (MAX) radar as an option. The SONDE-08 operations center will be at the Reese Technology Center just west of LBB (Fig. 1).

### 2.3. Experimental design

The target of choice is a fair-weather, dryline, with or without ancillary boundaries. More active synoptic conditions will be targeted at a lower priority: prefrontal drylines are probably less tied to the land surface, and may propagate quickly. Boundaries moving slower than ~3 ms⁻¹ are preferred, especially for objectives A, B, C, D, and F in Table 1). Quasi-stationary boundaries allow longer data collection periods for the ground facilities that need to be accurately positioned (the TTUKa radars, MIPS). In case of a fast-moving dryline, the TTUKa radars can convert to wind profilers, using high-elevation angle VAD scans. Thus they would complement the MIPS wind profiler, and allow several cross sections of a dryline passing overhead, through time-space conversion.

All observing platforms will concurrently sample the dryline environment, mainly in a ~150 km wide region east of Lubbock, in the vicinity of the climatologically-favored dryline position (Fig. 1). The ISFF stations will be positioned in two east-west transects separated meridionally by ~30 km. The use of two transects (as opposed to a single one, longer or more detailed) is intended to quantify along-dryline variability of the cross-dryline gradient in surface fluxes. The larger scale will be covered by the WTM network, whose typical spacing is closer to 50 km (Fig. 1). The ISFF transects will be sited across the Caprock Escarpment, which is a benign terrain feature but also an approximate land use boundary (Fig. 1). According to Weiss’s preliminary climatology, radar fine-lines frequently form there. Further ISFF deployment details can be found in the ISFF request.

The two TTUKa radars will be deployed with a baseline of ~13 km normal to the dryline. This positioning will permit two dual-Doppler lobes ~18 km in diameter. The Stick-Net units will be positioned in a cluster (as shown in Fig. 1) for missions focused on the fine-scale structure of boundaries, and in an E-W line during missions focused on land-atmosphere interaction. MIPS will operate mainly on the west side of the dryline during the dryline
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formation period, to document changes in the CBL structure and wind profile, and will position such that the dryline convergence zone drifts overhead during the mature dryline stage. The mobile radiosonde platform will collect soundings on both sides and within ~20 km of the dryline. If towards the end of SONDE-08 insufficient drylines have been sampled within the ISFF transect area, then the mobile armada will be deployed elsewhere, e.g. near Amarillo (Fig. 1) or further east, especially if MAX is available.

Fig. 1 - SONDE-08 deployment strategy. The left image shows the outer domain, including the fixed facilities, the right image shows the inner domain of intensive mobile operations. In this illustration an ancillary dryline joins the main dryline just north of the TTUKa baseline. The MM and WKA tracks are shown in the inner domain only, for clarity. The WKA sampling strategies are discussed in Section 7. The green shading in the outer domain highlights the main areas of center-pivot irrigation. Because of irrigation, the prevailing soil moisture gradient in the outer domain may be the inverse of the larger-scale gradient. In the inner domain, the orange (grey) shading represents the estimated single-Doppler (dual-Doppler) coverage resulting from the two TTUKa radars.

Both VORTEX-94 & -95 and IHOP-02 benefited from a denser observation network than SONDE-08, but none of these campaigns specifically aimed to study the formation and dynamics of drylines. Also, the IHOP-02 surface sites were oriented N-S in the vicinity of expected dryline development ("Homestead" area). This orientation made the sites of little use to the study of the development of drylines, which are generally N-S oriented. The ISFF and WKA requests describe how SONDE-08 is distinct from what has already been done. The substantial heterogeneities in terrain elevation, land-use, and synoptic conditions in the Texas Panhandle will allow the sampling of a variety of dryline formation pathways, dryline fine-scale structures, and CI mechanisms.
3. Surface heat flux, BL entrainment, and dryline formation

3.1. Connection to earlier studies

Several modeling studies, with varying degrees of idealization, have confirmed the importance of surface properties to dryline formation and evolution (e.g., Ogura and Chen 1977; Benjamin 1986; Ziegler et al. 1995; Pielke et al. 1997; Grasso 2000). The actual soil moisture and vegetation properties will be captured with unprecedented detail and accuracy in SONDE-08: HRLDAS will combine a continental-scale outer domain with higher-resolution inner domains with detailed observations, enabling examination of regional variation of surface fluxes in the context horizontal advection and other factors.

SONDE-08 enables the convergence of two long-term efforts by Fei Chen and his colleagues. The first effort examines the impact of land-surface models (LSM) on the simulation of convective precipitation. Chen et al. (2001) demonstrated that replacing the older “bucket” model with the Oregon State University (OSU) LSM (Pan and Mahrt 1987; Chen et al. 1997) improved 24-28 h ETA model precipitation forecasts as much as doubling the horizontal resolution. Trier et al. (2004) illustrated two manifestations of the effect of surface processes in modulating convective precipitation, (a) through CBL growth that resulted in destabilization, and (b) through the enhancement of mesoscale circulations that favored the growth of convection in their upwelling regions.

The second effort is the development of the HRLDAS (Chen et al. 2007) to enable the running of high-resolution coupled WRF-land-surface-model runs to forecast the onset and evolution of convective precipitation. Much of the testing was done using ISFF and Oklahoma mesonet data collected during IHOP-02. Since soil moisture observations are sparse, the soil moisture in HRLDAS is initialized by running it offline for several months model time, with meteorological data as input, to allow the soil moisture profile to equilibrate. HRLDAS uses the Noah LSM, which has several similarities to the OSU LSM.

Much effort in SONDE-08 is aimed at measuring, modeling, and understanding the spatial and day-to-day variations of surface heat fluxes. This effort is lead by M. LeMone and will be guided by her experience using in CASES-97 and IHOP-02 data collected over the mostly grass- and winter-wheat covered Walnut River Watershed in SE Kansas. Using these data and idealized simulations with the Noah LSM over the same region/periods, LeMone et al. (2007b) found for days of sparse cloudiness, that H and LE (both averaged over 6 hours centered on local solar noon) followed a repeatable pattern after a rain event, namely:

1. Over lush vegetation, LE was high and H low, with little change over ~5 days (consistent with Yates et al. 2001; Alferi et al. 2007; and others); over sparse or dormant vegetation, LE was high and H low right after rainfall, but LE rapidly decreased and H rapidly increased.

2. Thus the mosaic of winter wheat, pasture, and bare ground resulted in an increase in horizontal variability in H and LE, for several days after rainfall, increasing horizontal variability in buoyancy flux and possibly increasing the likelihood of mesoscale circulations.

For this region, plots of LE as a function H, for an array of ISFF stations or locations along a flight track showed consistent behavior after rainfall events, making such plots a useful tool for summarizing horizontal variability. The points cluster around a common point right after rainfall (high LE, low H). The slope ΔLE/ΔH (once definable) is about -1.5. For uniform net radiation and flux into the soil, one would expect ΔLE/ΔH = -11. The slope steadily becomes shallower, reaching values between -1 and -0.5 after ~5 days. This behavior is due to less available energy (more flux into soil Gsfc) at the sparse-vegetation sites compared to beneath the green lush sites shortly after rainfall. Gsfc decreases with time (dry soil a poor conductor), but it decreases faster at the sparsely-vegetated sites.

In the Texas Panhandle the vegetation is sparser than in SE Kansas, although large sections are irrigated. We expect that the soil moisture contrast will be relatively more important than in SE Kansas, and that the surface flux variability will be largest right after rainfall, provided it is non-uniform. The effects of net radiation should be more detectable and the effects of irrigation should be important.

A related topic, to be examined in SONDE-08, regards the effects of rolls [horizontal convective rolls or HCRs, LeMone (1973)] on surface fluxes, and its sampling. Regarding the sampling, one question that remains unanswered is whether the “standard” 30-minute averaging time used for computing fluxes using surface stations is

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1 This follows from the surface energy budget: H+LE = Rnet – G_{sfc}, where R_{net} is the net radiation, and G_{sfc} is the soil heat flux. Under clear skies R_{net} – G_{sfc} is roughly constant, thus H+LE should vary little, and the slope ΔLE/ΔH = -1.
optimum (e.g., LeMone 1976; Mahrt 1998). Regarding the net impact, it has long been shown that roll circulations tend to increase surface fluxes, either by concentrating flux-transporting plumes in the roll upwelling regions (LeMone 1976), or by increasing the horizontal variability in surface winds, and the non-linear relation between wind speed and fluxes, at least over water (e.g., Morrison et al. 2005 and references therein). More recently, coupled HRLDAS/WRF runs by Chen and Tewari (underway) suggest an additional mechanism, shading by clouds. Cloud shading is well-recognized as a factor in the surface energy budget, but its effect is difficult to assess in half-hour averages. Hence, we propose to compute five-minute ISFF fluxes so that longer-term averages can be computed relative to phase in the roll circulation, which is easily seen as slowly-varying wind direction in the record (LeMone 1973), particularly if satellite or radar images are available to predict the expected roll advection time, which increases as rolls become more closely aligned with the mean CBL wind direction.

3.2. Specific hypotheses

The main resources needed are listed following each hypothesis, between square brackets.

Primary hypotheses:

A1. The formation of boundaries (primary or ancillary drylines) can be explained by a meso-β \( \theta_v \) gradient, caused by differences in surface sensible heat flux and/or downward heat transfer at matching scales. The frontogenetic solenoidal circulations associated with these boundaries concentrate this background \( \theta_v \) gradient to much finer scales.\(^2\) [ISFF transect; WKA/WCR stepped traverses; WTM and Stick-net; MIPS and radiosondes; WRF output]

A2. A high-resolution WRF model coupled with a state-of-the-art land-surface model is capable of replicating the observed variations in surface heat fluxes, CBL depth and correctly-oriented HCRs, and the formation and propagation of primary and ancillary drylines in synoptically-quiescent conditions with strong terrain and land surface control. [HRLDAS, WRF, ISFF, WTM, WKA, MIPS, radars]

Secondary hypotheses:

A3. The surface sensible and latent heat flux (H and LE), averaged over a given time interval, will vary horizontally in such a way that the slope \( \Delta \text{LE}/\Delta \text{H} \) is negative. They will have maximum horizontal contrast right after a rain event, and the contrast will decrease with time. This is in contrast to regions with a mix of unstressed (ample-watered) lush vegetation with dormant vegetation (harvested or mature crops), for which the horizontal contrast increases with time (LeMone et al. 2007b). [ISFF, HRLDAS, WRF/HRLDAS]

A4. HRLDAS (offline and coupled to WRF) accurately captures the horizontal variability of the sensible and latent heat fluxes as a function of number of days after rainfall. [HRLDAS, WRF, ISFF, WTM, WKA]

A5. Clouds in the upwelling regions of HCRs will have a measurable effect on surface fluxes. [ISFF, radar surveillance scans, GOES visible imagery]

4. Variations in the dryline vertical structure and cumulus development

4.1. Connection to earlier studies

The term ‘dryline’ is a reflection of the remarkably fine structure of this phenomenon; the dryline convergence zone and humidity change often are only O(1 km) wide. Several radar-based studies have documented a secondary circulation in the vertical plane across the dryline (e.g., Beebe 1958; Fujita 1958; Ziegler and Hane 1993; Hane et al. 1993; Hane et al. 1997; Weiss et al. 2002; Weiss et al. 2006). Such circulation is clearly present on 22 May 2002, one of the IHOP-02 cases (Fig. 2). The \( \theta_v \) changes 1.3 K over 10 km in the lower CBL across this convergent boundary, thus the circulation shown in Fig. 2 and its horizontal vorticity appear due to solenoidal forcing, in agreement with Ziegler et al. (1995). Miao and Geerts (2007) show that the fine-scale (~10 km) dryline confluence near four IHOP-02 dryline complexes is dynamically consistent with the horizontal \( \theta_v \) difference over matching distances, in other words that baroclinicity drives the formation of a dryline fine-line. Several studies have

\(^2\) Differential vertical transfer of westerly momentum on opposite sides of the dryline, on account of different CBL depths, may contribute to dryline formation. This will be examined mainly by C. Weiss’s group (Objective C in Table 1).
documented $\theta$, difference of 1-2 K across drylines over a 10 km distance, with the dry air being lighter [see Miao and Geerts (2007) for a review]. If the density contrast is sufficient, which is not always the case, then drylines can assume density current propagation characteristics (e.g., Parsons et al. 1991; Ziegler and Hane 1993; Atkins et al. 1998). Drylines may have the appearance of an inland sea breeze (Sun and Ogura 1979), in fact the $\theta$, difference across sea breeze fronts is of the same magnitude (Miao and Geerts 2007).

*It remains uncertain to what degree the well-known diurnal movement of the dryline (e.g., Schaefer 1974a; Sun and Wu 1992; Jones and Bannon 2002) is controlled by density current dynamics.* We believe that this process exercises some control, at least during the part of a dryline’s lifecycle when it is most defined in terms of fine-scale temperature and humidity contrast and radar signature; this is also the time that CI is most likely. Density current theory suggests that the westbound dryline velocity should decrease as the cool-air wedge thins over the sloping Great Plains, yet an increase in propagation speed occurred at least on two days in IHOP (June 18 and 19; Miao and Geerts 2007). Other factors may explain retrogression: Crawford and Bluestein (1997) note that a westward-moving dryline during the evening did not contain the horizontal pressure gradient expected from an intense density current.

Convergent flow in the vicinity of a dryline may also be the result of surplus westerly momentum transferred vertically into the CBL on the west (dry) side of the dryline, during the CBL deepening phase (e.g., Hane et al. 1993). The *differential vertical transfer of zonal momentum* is the direct result of the differences in CBL depth across the dryline (e.g., Hane et al. 1997). Miao and Geerts (2007) show some evidence that this mechanism is of little significance in their four cases, however this will be examined further in SONDE-08 (Objective C in Table 1).

The dryline, or a belt up to 15 km east of the dryline, may be marked by a line of shallow to towering cumuli (Ziegler and Rasmussen 1998). Much dryline research has been motivated by the fact that thunderstorms, sometimes severe, may break along drylines. Sipprell and Geerts (2007) documented a reversal of the solenoidal circulation and $\theta$, difference just before CI. *It is an open question whether CI is more likely if the baroclinically generated horizontal vorticity opposes the horizontal low-level vorticity on the other side of the dryline*, as has been shown for a CBL convergence zone in Colorado (Wilson et al. 1992).
Sipprell and Geerts (2007) also found that mid-CBL air very close to the dryline was buoyant over a scale of ~10 km, irrespective of the circulation direction. Detailed near-surface pressure measurements [which we plan to collect in SONDE-08 using the WKA Global Positioning System (GPS) data] should yield a trough at the dryline in this case. In the normal dryline solenoidal circulation, the warm air rising over the dryline may mix with penetrating moist-air thermals from below at the time when moisture convergence in the vicinity of the dryline has eroded most convective inhibition (Atkins et al. 1998; Ziegler et al. 2007). It remains unknown whether the undiluted cores of cumulus clouds have the conserved properties of the moist airmass. We will assess this using a Paluch diagram including in-cloud WKA data and sounding data collected in the moist and dry airmasses. A Paluch diagram is a scatterplot of two conserved variables, e.g. total water mixing ratio and wet equivalent potential temperature (Paluch 1979). If moist-air properties are encountered in the cumuli, then the cumuli either are rooted directly in the moist air, or else grow from an elevated moist layer that originates at the dryline convergence zone and is advected east of the dryline (Ziegler and Hane 1993; Ziegler et al. 1995).

4.2. Specific hypotheses

B1. A primary or ancillary dryline forms where the meso-β scale θv gradient exceeds some threshold. This gradient, usually pointing westward (lighter air to the west), triggers a frontogenetic solenoidal circulation. The convergence associated with this circulation creates and sustains the sharp dryline humidity contrast. This circulation has a width that scales with the CBL depth, is evident in the vertical slope of the dryline echo, is thermally direct, and in strength is proportional to the local (meso-γ scale) horizontal density difference. It increasingly assumes the characteristics of a propagating density current as meso-γ scale θv difference increases. [ISFF transect; WKA/WCR stepped traverses; WTM and Stick-net; MIPS and radiosondes; WRF output]

B2. Under the same stability conditions (same convective inhibition), deeper, more upright ascent along the dryline occurs if the solenoidal vorticity is roughly equal to the ambient shear vorticity, but of opposite sign [RKW theory (Rotunno et al. 1988; Weisman et al. 1988; Weisman and Rotunno 2004)]. [Key resource: all soundings]

B3. Cumulus clouds at (or usually just east of) the dryline have buoyant roots within the moist CBL. The updrafts at the cumulus base have the thermodynamic properties of the underlying moist airmass, or at least a mixture that includes the moist air. The core of towering cumuli is buoyant even at the lifting condensation level (LCL). The failure of thunderstorm development notwithstanding cumulus penetration above the LFC is attributed to the erosion of the buoyant core of growing cumuli by entrainment in the dry residual BL air lifted over the dryline. [WKA/WCR; TTUKa; MIPS and radiosondes]

5. Along-line variability of moisture and misovortices (misocyclones)

5.1. Connection to earlier studies

In recent years much knowledge has been gained about the fine-scale horizontal variability of drylines and other baroclinic boundaries in the mature CBL. Discontinuities along drylines may play an important role in the horizontal transport and mixing of moisture, as well as in the vertical transport, and thus CI.

Kingsmill (1995) reports a series of rather long-lived vertical vorticity maxima along the leading edge of a gust front. These “misocyclones” (<4 km in diameter) occurred at a spacing compatible with Helmholtz shearing instability, related to the horizontal wind shear across the boundary. Atkins et al. (1995, 1998), studying a sea-breeze and a dryline, respectively, suggest that misocyclones are associated with HCR vorticity tilting and stretching. They note deeper cumuli and even CI at the intersection points of HCRs and a dryline.

Both shearing instability and HCR intersections would explain regularly-spaced misovortices and cumulus clouds. Yet recent IHOP-based observations reveal little regularity in the spacing between misocyclones. Marquis et al. (2007) show that vertical vorticity maxima, resulting from cyclonic shear across the dryline, continuously evolve through vortex mergers and decay, and thus spectrum of sizes, strengths, and spacings results. Misocyclones may become more prominent when the dryline weakens and the continuous convergence zone and updraft region breaks down (Arnott et al. 2006).

It is well-known that superposition of updraft and vertical-vorticity maxima can generate significant vortex stretching, as in tornadoes. Such superposition suppresses turbulence dissipative processes (Lilly 1986) and thus may enhance buoyant ascent. Combining photogrammetry with Doppler radar syntheses, Pietrycha and
Rasmussen (2004) show that some cumuli are located above misovortices. Yet Murphey et al. (2006) find that updraft maxima and cumuli are most common on the north side of misocyclones along a dryline. Other studies too conclude that updrafts and vertical vorticity maxima are often not collocated, but rather displaced from each other along drylines (or other radar fine-lines) (Kingsmill 1995; Arnott et al. 2006; Markowski and Hannon 2006; Xue and Martin 2006). The radar fine-lines investigated in these studies all had small density (θ_v) contrast and occurred in a vigorous CBL. Based on close-up radar surveillance imagery of such lines, we conceive such boundaries as belts with high concentrations of thermals (plumes of buoyant, rising air) advected from either side of the boundary. The above studies then imply that misocyclones are not rotating thermals. Nevertheless they have been shown to be remarkably long-lived (Markowski and Hannon 2006; Marquis et al. 2007).

It remains unclear whether and how misovortices are significant in the vertical transport of heat and moisture leading to cumulus formation. Part of the problem is that the detailed thermodynamic properties of misocyclones and associated cumuli are unknown. Misocyclones have not been targeted by research aircraft before. Clearly aircraft observations cannot be used to study the evolution of misocyclones, but chance penetrations will reveal a spectrum of misocyclone life stages, vertical velocity and buoyancy characteristics. IHOP-02 The associated WCR horizontal-plane dual-Doppler (HPDD) scans will depict misocyclone flow patterns at a resolution one order of magnitude finer than in previous studies.

In IHOP-02 only two along-dryline legs were flown by the WKA, and on one of those a misocyclone clearly was penetrated (Fig. 3). This vortex is marked by two gust probe wind maxima in opposite direction, separated by 800 m (Fig. 3c). The vortex is buoyant (b), and carries rising air with excess moisture and θ_e (a).

5.2. Specific hypotheses

C1. Buoyant misocyclones generally contain ascending motion and excess water vapor. The spin-up is primarily due to buoyantly-driven ascent and vortex stretching. [WKA and WCR HPDD data]

C2. In non-buoyant misocyclones ascent and water vapor maxima are displaced from the vortex, especially if a large density difference exists across the dryline. Many non-buoyant misocyclones probably are ‘mature’; the cyclonic circulation may persist well after the vortex loses its buoyancy, in fact it may grow due to merger processes. Note that the ‘maturity’ of misocyclones cannot be assessed, unless the WKA observations fall within the TTUKa dual-Doppler lobes (Fig. 1).
Non-buoyant misocyclones may also result from the tilting of horizontal vorticity due to ambient vertical shear. In this case too the updraft and moisture maximum should be displaced from the vortex [WKA and WCR HPDD data, TTUKa scans].

C3. Smaller misovortices are more common near a dryline, although a peak at about 1 km may exist in the spectral decay of vorticity. [TTUKa scans and WCR HPDD data]

6. Wyoming King Air and Wyoming Cloud Radar measurements in SONDE-08

The WKA carries a state-of-the-art suite of atmospheric sensors and a gust probe. In SONDE 08 water vapor will be measured with a chilled-mirror dewpoint sensor and a Licor 6262, which measures extinction at an infrared water vapor absorption line. Of particular interest in SONDE 08 are pressure perturbations, which could not be measured accurately in IHOP-02 because of lack of precise GPS position data. These data now make pressure variations (or height variations on a constant pressure surface) measurable to 0.1 hPa (1 m) or better (Parish et al. 2007). Such variations can be measured on the scale of cumulus clouds (Geerts et al. 2006b).

The WCR (http://www-das.uwyo.edu/wcr/) is a 95 GHz (3 mm) Doppler radar with four fixed antennas on the WKA: one is oriented sideways or upward (depending on the position of a reflector-plate located in a fairing outside the cabin), a 2nd is oriented ~35º forward of the lateral beam direction in the horizontal plane, a 3rd oriented towards nadir, and a 4th oriented ~30º forward of nadir in the vertical plane. The first (last) two antennas allow dual-Doppler syntheses of the scatterers’ motion in the horizontal (vertical) plane, a configuration referred to as horizontal (vertical) plane dual-Doppler, or HPDD (VPDD) (Fig. 4) (Leon et al. 2006; Damiani et al. 2006): during straight-and-level flights, the two beams view approximately the same sample volume along two different directions within a short time interval (Δt= 6 s per km range). The great strength of these radar data is the proximity of full thermodynamic and kinematic data, collected aboard the WKA. The WCR is sensitive enough to capture towering and even shallow cumulus clouds (Damiani et al. 2006; Damiani and Vali 2007; Damiani et al. 2007), as well as clear-air echoes. The clear-air back-scatter is mostly due to insects, which are carried by, and concentrated in, updrafts and convergence regions (Geerts and Miao 2005a). A new radar (WCR-II), with low-noise amplifiers, a digital receiver, and a new data system, is being built, and should be available for SONDE-08. While WCR-II is preferred, the current radar (WCR-I) will suffice for our objectives.

Errors for single Doppler data are affected by the signal-to-noise ratio of the distributed target, by uncertainties in the beam pointing directions and in the aircraft motion correction due to GPS data errors (Damiani et al. 2006). Geometrical interpolation and regridding are additional error sources for dual-Doppler winds. Based on previous experiments such as IHOP-02 and CuPIDO, the standard deviation of aircraft attitude variations (in roll, pitch and yaw) can be kept below 3º along dual-Doppler legs in the CBL. This results in an uncertainty of the in-plane wind vector of about 1 m s⁻¹, which is not much larger than the uncertainty of gust probe wind measurements (Brown 1993). The unfiltered wind vectors appear rather smooth and regular out to 2.5 km in clear air (e.g., Geerts et al. 2006a) and out to 10 km, in a case with hydrometeor echoes (Yang and Geerts 2006). The range limitation in the optically-clear CBL is due to the relatively low signal-to-noise ratio and the shaking of the aircraft.

The usual WCR range resolution is about 30 m. Because of the narrow beamwidth (~0.7º), the across-beam resolution is better than 30 m at all ranges of interest (< 3 km). The minimum detectible signal at 1 km range is on the order of -25 dBZ, depending on the mode and antenna used. During SONDE-08 a larger pulse width and a coarser range resolution of 75 m may be used to gain about 6 dB in sensitivity, and to reduce the noise in the dual-Doppler wind fields. Two antennas are operated simultaneously, but the two other antennas can be used in a pulse-
by-pulse interleaved fashion, resulting in a quasi-simultaneous data stream from all four antennas. Again to gain sensitivity, we will mainly operate a single antenna pair. The key pairs are: up & down (allowing single Doppler profiling with sandwiched flight-level data), down/down-forward (for VPDD), and side/side-forward (for HPDD).

7. Wyoming King Air measurement strategies

Four schematic flight patterns are listed below. All flight patterns are preferably conducted in the vicinity of the TTU Ka radars, the ISFF transects, and a surveillance radar. The hypotheses listed in below refer to Sections 3.2, 4.2, and 5.2. Combined in situ and WCR data will be used to mark the precise location of the dryline(s).

7.1 Flux legs (Fig. 5)

These legs are intended to estimate sensible and latent heat fluxes and momentum fluxes, at the bottom and top of the CBL (hypothesis A1, and hypotheses D3A,B in Weiss’ proposal), and secondarily, to depict the meso-β scale environment of the dryline, in particular of mixing ratio, pressure, and $\theta_v$. These flight legs should preferably be over, or slightly downwind (north) of an ISFF transect (as in Fig. 1, with prevailing southerly winds). A single, quasi-stationary dryline in an environment without much active Cu is preferred.

Fig. 5: Flux legs. Plan view on the left, cross-section on the right.

The legs are necessarily long in order to compute momentum fluxes (Mann and Lenschow 1994). IHOP statistics by M. LeMone indicate that a roughly 300-km sample at a given level is needed to estimate the mean vertical momentum flux within this domain with 10% uncertainty. West of the dryline, the surface momentum fluxes may be estimated over shorter distances at the same accuracy because of a deeper CBL and thus larger eddies. The dryline crossings at upper levels are not needed for flux estimates, but they provide some additional WCR vertical transects and in situ data of the dryline. The WCR will be in up mode on the lower legs and in dual-down or profiling modes along the upper legs. This flight pattern will be flown mainly during the dryline development phase when surface fluxes tend to peak (between about 11 am - 3 pm local time LT).

7.2 Multiple-level stepped traverse (Fig. 6)

- Objectives: to examine dryline vertical structure, dryline formation, and vertical transport (hypotheses B1, B2; and D1A,B in Weiss’ proposal). The boundary in question can be the primary dryline or an ancillary one.
- Flight legs are stacked and the end points are geographically fixed. The end points move with the dryline only if the dryline propagates at 4 m s$^{-1}$ or more.
- In situ flight-level data from stepped traverses will be analyzed.
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objectively (gridded), if possible with sounding data, to obtain transects of gust probe velocities, moisture, and thermodynamic data, under the assumptions of uniform advection and negligible evolution.

- The traverse is ~30 km long (Fig. 1); longer if multiple humidity boundaries are present. The flight legs should be centered near the dryline.
- The stepped traverse is to be repeated in opposite direction to assess differences relative to a central time.
- The vertical separation between legs is ~500 m; the lowest flight leg is as low as possible and is flown at constant height AGL; the highest flight leg is just above the highest WCR plume or thermodynamically defined BL depth.
- The WCR operates in profiling mode, plus VPDD mode in the upper flight legs.
- This pattern focuses on the mature dryline (between about 2-6 pm LT). It can be flown later also, to examine the density current characteristics of the retrograding dryline.

7.3 **Dryline-cumulus interaction (Fig. 7)**

- Objectives: to examine the formation of (preferably towering) cumuli along or near drylines, and cumulus evolution in the context of the ambient stability and humidity (Hypothesis B3).
- The flight pattern is the same as Fig. 6, but the legs should be extended to include cumuli (usually towards the moist side), and shrunk on opposite side (usually the dry side); also, the vertical separation should be larger to constrain the duration of the stepped traverse; flight levels should include mid- and upper-CBL, cloud base (LCL), and mid- to upper-levels of Cu.
- This pattern is flown only when a cumulus cloud line is found parallel to, and over or near the dryline.
- The WCR operates in profiling mode, plus VPDD in the upper flight legs. CuPIDO-06 experience (Section 1.4.1) testifies that the WCR can see young Cu at close range when the Cu is at least ~500 m deep (Damiani et al. 2007).
- This flight pattern focuses on the mature dryline, and is terminated if/when deep convection develops.

7.4 **Dryline-parallel plus cross-dryline legs (Fig. 8)**

- Objectives: to examine the finescale kinematic and thermodynamic structure of misocyclones and HCR intersections (hypotheses C1, C2, C3, and A5; and D2A,D in Weiss’ proposal).
- This pattern is flown only when the dryline is well-defined, relatively straight, and quasi-stationary. The boundary occurs preferably within the TTUKa dual-Doppler lobes (Fig. 1), although the flight pattern can be executed using the reflectivity data from any radar within 30-50 km range.
- The along-dryline legs are 30-50 km long, the cross-dryline legs ~30 km long.
- The flight level is mainly at ~0.5 \( z_{CM} \) where ground clutter is small and the echoes rather strong (\( z_{CM} \) is the CBL depth on the moist side, typically 1-2 km AGL).
- The along-dryline legs (possibly a closed racetrack) should be level yet also keep the dryline within WCR range (3-4 km) to the right of the aircraft. If misocyclones are present, penetration should be attempted by steering closer to the boundary. If a cumulus line is present close to the dryline, an upper leg (near 1.0 \( z_{CM} \), see green line in Fig. 8) can be aimed below the cumuli.
• If HCRs are well-defined, the length of the along-dryline leg can be adjusted such that the diagonal legs are approximately normal to the HCRs (relevant to hypothesis A5).
• The WCR operates in HPDD mode on the 0.5 $z_{im}$ along-dryline flight leg and in VPDD + sideview mode on all other legs.

8. Proposed research collaboration and schedule

The SONDE-08 field phase is scheduled for 1 May – 9 June 2008. We hope to sample 16 drylines by means of coordinated surface and airborne observations (Section 2.3). We have requested that NCAR EOL Field Program Support (FPS, formerly JOSS) develops a field catalog and archives all experimental and relevant operational data. Both the field phase and the follow-up analysis are planned to involve collaboration with NCAR, TTU, UAH, and Purdue University. Clearly the TTU group will emphasize TTUKa data, the UAH group MIPS (and possibly MAX), and the University of Wyoming (UW) group will focus on WCR data. Yet we have several mutual objectives that involve composite analyses from a series of SONDE missions (Table 1). The three ‘instrument’ groups (UW, UAH, and TTU) also plan comprehensive, single-mission case studies, built on the full array of ground-based and airborne data collected in SONDE-08. The lead on such case studies will be distributed amongst the three groups. Our collaboration will involve the exchange of processed and analyzed products. This type of exchange has happened before, based on IHOP data (e.g. Weiss et al. 2006; Miao and Geerts 2006) and is more effective than simply making the raw data available. The budget of all groups includes travel for one SONDE-08 planning meeting and three post-field science meetings, either at NCAR or at a suitable conference.

This is a three-year proposal, with the 2nd and 3rd year devoted to research, presentations, and the preparation of collaborative publications. The PhD students will have completed their first year of courses upon the start of SONDE-08, and will be focused on research starting with the field phase. We plan to present at the AMS Boundary-Layer and Turbulence, Mesoscale Processes, and Radar Meteorology Conferences, and publish most likely in Monthly Weather Review, but also in the Journal of Atmospheric Sciences, and in Boundary-Layer Meteorology.

9. Educational initiatives

Several educational opportunities are planned in conjunction with SONDE-08. Three are listed below. A fourth one, ‘EXPLORE’, lead by Dr. Weiss, is described in his SONDE-08 proposal.

(a) PhD projects: two PhD students will be supported through this proposal, a first one working closely with Dr. LeMone on observed and modeled surface fluxes and entrainment into the CBL. This work primarily uses WKA data along ‘flux legs’ (Section 7.1), ISFF data, HRLDAS, and coupled WRF model output. This person’s research activities center on Section 3. The 2nd PhD student will work more directly with Dr. Geerts on the fine-scale vertical and horizontal structure of drylines (Sections 4 and 5). During the SONDE-08 field phase, the 1st PhD student will share the responsibility of running HRLDAS in real-time with a Purdue PhD student. This will involve close collaboration with Dr. Chen’s group at NCAR starting a few months before the field project. This person will be based at the Reese Operation Center, and will discuss HRLDAS-predicted surface fluxes and dryline formation at the daily planning meetings. The 2nd PhD student will be tied to aircraft operations, and will partake in most flights, initially as 4th seat communicator, and later also as flight scientist in the cockpit.

(b) Summer course: We are requesting support ($7K) from the UW for the participation of four additional junior graduate students. These students will participate in the field phase, and will be needed in the operation of the mobile armada (esp. the MM vehicles, the mobile radiosonde, and the Stick-Net deployment). All 6 UW graduate students, plus the graduate students from UAH, TTU, and Purdue, will take part in a SONDE Field Course: Boundary-Layer Measurements and Dryline Dynamics. This summer course (to be listed at 3cr at the UW) forms the basis of the $7K UW financial support. It will consist of (i) a lecture series given on down days in the field by the SONDE-08 P/Is, and dealing with both measurement techniques and atmospheric boundary-layer processes; (ii) a student-designed and student-coordinated SONDE-08 mission; and (iii) a main project involving the analysis of data and/or HRLDAS output and resulting in a written report.

(c) GLOBE link: as Chief Scientist of GLOBE, Dr. LeMone has already started to coordinate efforts with Texas representatives and will include some of her experiences in SONDE-08 in her science blog (go to www.globe.org, click on “Chief Scientist’s Blog”).