Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)
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# 2007 DRI Progress Report

## Project Title: Atmospheric Moisture and Thunderstorm Drought

**Investigator: G.S. Strong**

## 1.0 Progress (beginning January 2007 to end December 2007)

**1.1 Describe progress towards meeting the project objectives for those theme areas where you have received funding for 2006-2007. How are the original milestones being met (be specific)? List the key objectives and results achieved to date as well as any relevant application(s) of the results.**

### *1.1.1 Objectives*

The overall objective of the Drought Network Initiative (DRI) is *to better understand the physical characteristics of and processes influencing Canadian Prairie droughts, and to contribute to their better prediction, through a focus on the recent severe drought that began in* 1999.

To address this overall objective, the Network is focussed on complementary and cross-cutting research objectives that correspond to the following themes:

1. **Theme 1: Quantify the physical features of this recent drought:**
   **a)spatial and temporal features;**
   **b) flows of atmospheric and terrestrial water and energy into and through the region, and their storage and redistribution within the region.**
   - **Boundary Layer Moisture Cycling:** Results on moisture cycling suggest that prior to reaching the *wilting point*, that is, when plants can draw no more water from the soil, the diurnal evaporation cycle is interrupted such that moisture cycling stops. This may be crucial to the early detection of drought initiation in particular. Some cases have demonstrated that this shows up time series of surface mixing ratio (e.g., case shown for Saskatoon last reporting period); however, even in extremely dry-soil situations such as July 2002 near Calgary (Fig. 1)[1], this does not always show up (Fig. 2), so that other possible factors need to be isolated; e.g., the Calgary surface data may be reflecting some atmospheric moisture (and cycling) from the foothills region to the west, where orographic storms and precipitation occur, even during otherwise drought conditions. More cases will be investigated in the coming year.

[1] Figures/tables are attached to the end of this report.

- **Free Atmosphere Layer Moisture Cycling:** 30 years of radiosonde data and software were assimilated this year for investigating short-term cycles and longer-term trends in (above-surface) atmospheric temperatures and humidity. No results are ready to report on this aspect yet.
- **Diurnal Cycle of Moisture from Varying Land Cover:** An important step was taken towards quantifying (i) the diurnal cycle of moisture availability to convective processes from regional evapotranspiration, and (ii) distinguishing moisture sources from varying land coverage. This was demonstrated to some degree in the 1991 Regional Evaporation Study reported in Strong (1997), but needs quantifying down at the microscale. Data from a brief field experiment carried out in St. Denis in 1992 (reported by Hrynkiw, 1992) were resurrected this year to re-visit this question. Early results (Figures 3 and 4) show that for normal soil moisture conditions, the average diurnal increase in mixing ratio was 4 g $kg^{-1}$ (over a 17-day period), a very significant input to the boundary layer. Furthermore, using a 180-m transect with three mesonet stations, a very clear gradient of mixing ration exceeding 1 g kg-1 between a wheat field and adjacent prairie grass was observed. It would be desirable to also measure the vertical gradient over the crop itself, but that would require substantial more instrumentation. Some estimates of total evaporated water for such wheat crops would be useful in quantifying the overall soil water budget for normal and drought situations. Estimates of same will be carried out this year.
- **Convective Processes across Strong Moisture Gradients:** Drought initiation and cessation are often coincident with a 'thunderstorm drought' and return of an outbreak of storms respectively. Severe thunderstorms will also sometimes occur on the periphery of a region under severe drought conditions, skirting its edge. Also, severe storms in the lee of the Rockies are often associated with the interaction of a *dryline* moving off the mountains (essentially a summer Chinook – Strong, 1982, in Chinook Magazine) with a region of converging moisture over the foothills capped by a *capping lid*. These three types of scenario all seem to be related. I have been conducting summertime mobile transects of temperature and humidity over the foothills since 2003, associated with the A-GAME study (also funded by CFCAS through the University of Calgary). Figure 5 and Table 1 document one such *dryline* documented on 19 July 2007, and associated with storms that day. In this case, I encountered the *dryline* in three segments as indicated, with an average mixing ratio gradient of 0.3 g kg-1 per km; that is, the mixing ratio dropped about 1 g kg-1 every kilometre into the dry air, a significant observation that cannot be documented through regular synoptic network stations spaced some 100 km apart. Note that this is very distinct from a synoptic scale cold front, since the temperature varies very little across the *dryline*, but the effect on storms is quite similar to cold fronts because of the input of latent heat. **The importance to DRI** here is that similar processes are occurring when storms brush along the edge of a drought region. Such was the case for the infamous *Pine Lake Tornado* storm, which skirted the edge of fairly severe drought conditions south of its eastward track through central Alberta on 14 July 2000. This will be documented in greater detail later. More dryline information will be collected in 2008 in conjunction with an intensive convective initiation field research program planned by Environment Canada, called UNSTABLE.
- **GPS Moisture in Drought Studies:** Moisture (precipitable water – PW) data from 8-15 GPS receiver sites over central Alberta and operated by University of Calgary

Geomatics Engineering have been assimilated for 2003-2005. These data are being used in my *dryline* study above, but I am also evaluating the data with the view to estimating the diurnal change in local evapotranspiration. I will have some analysis results to report next year. A secondary objective is to use these data as a potential means of detecting early onset (and cessation) of drought, since the data can be made available continuously at 10-60-minute resolution. For example, to date I have shown that GPS data can detect signatures of impending storms up to *three hours prior to first radar echoes*, while the diurnal signature shows up equally well. Meanwhile, we also plan to operate 8-10 of these sites during the upcoming UNSTABLE field program.

2. **Theme 2: Improve the understanding of the processes and feedbacks governing the formation, evolution, cessation and structure of the drought.**

- **Boundary Layer Moisture Cycling:** see notes for Theme 1 above.
- **Free Atmosphere Layer Moisture Cycling:** see notes for Theme 1 above.
- **Diurnal Cycle of Moisture from Varying Land Cover:** see notes for Theme 1 above.
- **Convective Processes across Strong Moisture Gradients:** see notes for Theme 1 above.
- **GPS Moisture in Drought Studies:** see notes for Theme 1 above.

3. **Theme 3: Assess and reduce uncertainties in the prediction of drought and its structure.**

- **Diurnal Cycle of Moisture from Varying Land Cover:** The quantification of moisture gradients across varying land cover such as between a wheat crop and prairie grass (as reported in notes for Theme 1 above) should be important input for the parameterization of numerical models.

1.2. **What contributions have you made, if any, to the unfunded themes of DRI through support in kind.**

*Theme 4: Compare the similarities and differences of the recent drought to previous droughts over this region and those in other regions, in the context of climate variability and change.*

- **Boundary Layer Moisture Cycling:** The results on short-term cycles in moisture reported earlier for the Saskatoon cases of 1988 and 1991 (see notes for Theme 1 above) compare recent and previous drought situations.
- **Diurnal Cycle of Moisture from Varying Land Cover:** this is also a contribution to the goal of comparing the recent and previous drought scenarios (see notes for Theme 1 above).

*Theme 5: Apply our progress to address critical issues of importance to society.*

- Nothing specific to report here.

1.3 **Describe your plans for research during the coming year and the following year and outline how the expected results will support the deliverables and goals of DRI.**

1) **Processing of Climatological Database of Temperature and Moisture:**
   a) Part-time technical help will be hired to help process data as indicated below; in addition, I will hire a short-term student programmer for short software tasks.

2) **Short-term Cycles and Long-Term Trends in Atmospheric Temperature and Moisture:**
   a) Continue to process several case studies from the focus drought period to determine the degree of significance of the effective shutdown of moisture cycling during drought.
   b) Carry out analysis of short-term cycles and long-term trends in the radiosonde (upper air) data now assimilated for Stony Plain and The pas.
   c) If part-time help and funding are available (or collaboration with other DRI investigators), I will attempt to carry out a more thorough analysis of upper air trends using archived GEM model output for Run-0 (initialization) data.

3) **The role of Thunderstorms during drought and non-drought situations, including initiation and cessation of drought:**
   a) Will attempt to milk more from the St. Denis dataset, as well as look for an enhanced dataset which might provide vertical as well as horizontal temperature/moisture gradients across a crop-grass transect. This might be accomplished with three dataloggers on a similar (180-m) transect again, with the two ends dataloggers employing three sets of T/RH sensors at 0.5 to 1-meter height intervals. One pressure sensor would suffice for all three dataloggers. It may be possible to carry this out during the UNSTABLE field project in July.

## 2.0 <u>Impact</u>

### 2.1 What short and medium term objectives have been achieved, or are anticipated;

**Short-term goals during this calendar year and progress achieved are as follows:**

1) **Processing of Climatological Database of Temperature and Moisture:**
   **a)** The DRI Data Management facility and our data manager were absolutely essential to me last winter in filling in data gaps in my surface and radiosonde data inventory, including primary prairie surface stations plus the two upper air sites at Stony Plain (Alberta) and The pas (Manitoba).
   **b)** I required also several simple software routines for the data processing, plus assistance in the actual data processing. Two computing students were hired for approximately one month each, one in January and the other in August. Further software development may require another computing student for 1-2 months. SUGGESTION: Developed routines and user documentation could easily be made

available on our web site for use by other DRI investigators, preferably with password protection.

**c)** A third assistant was hired in April and May to carry out data processing. Those results are being reported in this document. My intention is to hire that person again for a period of 1-3 months in the coming year.

**2) Short-term Cycles and Long-Term Trends in Atmospheric Temperature and Moisture:**

Last year I reported on a climatological case study (1991 wet- and 1988 dry- soil cases for Saskatoon) which clearly showed active moisture cycling for the non-drought year with a period of 15 days, and no cycling during the drought year. This year I was able to collect some examples from the current (1999-2004) drought period of DRI focus. The purpose of this is to relate the frequency and intensity of moisture cycling to convective weather outbreak periods of from 5-15 days. The hypothesis is that when the cycling stops or slows down, or its intensity drops, that this will be related to the initiation (or near-start, depending on available soil moisture) of drought (THEME 2). Access to areal soil moisture data for the prairies is crucial to this part of my study, so that I am collaborating with Hanesiak and Brimelow to use their soil moisture estimates.

**a)** A preliminary comparison of summer trends in mixing ratio for dry-soil (1988) and wet-soil (1991) years at Saskatoon (reported last year) exhibited moisture cycling during the wet year with an average period of 15 days. The moisture cycling appears to be necessary for convective weather outbreaks. During the dry-soil drought year this cycling terminated early in the summer when the soil moisture was depleted, with no significant convection during the period. A severe thunderstorm came through Saskatoon in early-August, and this seemed to prelude the end of the drought, with continued storms during August, and a return to surface moisture cycling with periods near 15 days. These results represent a contribution to DRI THEME 4.

**b)** Comparable cases for Calgary in southern Alberta were processed, focussing on the extremely low soil moisture summer of 2002, and comparing it with a wet-soil summer of 1999 (Figure 1). The accompanying Figure 2 shows the average July soil moisture computations (by Brimelow) for both years. The results for this case are inconclusive at this stage in that surface moisture cycling did not shut down during 2002 (dry-soil case), and in fact, the amplitude of the cycles appeared to increase. The average period of the cycles were comparable to the Saskatoon case, being 12.8 days for the wet 1999 and 14.3 days for the dry 2002 cycle. This may have resulted because of the proximity to the foothills and mountains where storms were more active, and atmospheric moisture may have been spilling over from that, rather than cycling from the local soil moisture. This contributes directly to THEMES 1/2, and the investigation is being expanded to include other surface stations within or on the periphery of the drought region, including Red Deer, Edmonton, and Saskatoon for the same case (July 2002).

**c)** Other cases from the 1999-2004 drought period of interest will be included in the coming year before making any judgement as to the validity of my hypothesis (THEMES 1/2).

**d)** This coming year I also intend to look closer at such short-term cycles and long-term trends in the radiosonde data (Stony Plain and The pas) (THEMES 1/2). It may also be possible to use a larger dataset such as the GEM Run-0 initialized model output, if a suitable student can be found to carry out the processing.

3) **The role of Thunderstorms during drought and non-drought situations, including initiation and cessation of drought:**

Thunderstorms are tied to the daily diurnal temperature/evapotranspiration cycle. The primary diurnal source of boundary layer moisture for storms on the prairies, and especially in Alberta, is hypothesized to be local evapotranspiration from grain crops. Storm and radar data information will be compiled by an assistant to be hired this winter, and these will be analyzed with the objective of relating same to the moisture cycling above. Progress to date include:

**a)** I have carried out reanalysis of an extensive hourly temperature and humidity data collected over a 180-m transect of wheat crop to prairie grass at St. Denis, Saskatchewan during the summer of 1992 (FIGURE 3), a year of normal soil moisture. [Earlier results on this study were reported by Hrynkiw, 1992 – *St. Denis Humidity Sensor Field and Laboratory Tests*.) These data show a strong diurnal trend in moisture (mixing ratio) with an average diurnal increase of 4 g $kg^{-1}$ (from 8 to 12 min/max) over an 18-day period (FIGURE 4), which one might interpret as withdrawing an average of 4 mm of water per day during that period. This is important corroboration for THEMES 1-4.

**b)** In addition, the average horizontal gradient in moisture from wheat to grass exceeded 1 g $kg^{-1}$ across 180 m. This was a relatively small field of wheat, so that this gradient may even be conservative. Such temporal/spatial gradients are very significant in terms of convective initiation. It is also significant in terms of quantifying the physical features of the focus drought (THEME 1), and for parameterizing numerical models (THEME 3), especially given that it is difficult to quantify variations in changing land cover across the prairies. This revitalized and rare dataset is extremely valuable to these purposes, and further analysis is on-going.

**c)** During the past summer (2007), I continued my surface transect field work focussed on Alberta *drylines* associated with thunderstorm initiation over the foothills. These *dryline* storms are somewhat analogous to those storms that often traverse the edge of a drought region (THEME 1), but also in considering processes controlling the initiation and cessation of drought (THEME 2). One excellent case study has been documented for 19 July 2007 where the dryline was encountered in three stages as indicated in Figure 5 and Table 1. There were storms involved in this sharp dryline, but I have yet to collect and assimilate those data (to be completed this coming year).

4) **The use of GPS Moisture Data in Drought Studies:**

I am applying results from my work in the CFCAS-funded UofC A-GAME network (2003-05) towards the DRI objectives of quantifying drought (THEME 1). As the acronym suggests, the primary goal of A-GAME (Alberta GPS Moisture Evaluation), was to evaluate the validity of moisture data (precipitable water, PW) retrieved from GPS receivers. Secondary goals were to use these data (i) as an early signal of convective initiation, and (ii) as potential means to estimating regional evapotranspiration. I have added a new objective for DRI, which is (iii) to evaluate its potential use in drought monitoring. A continuous record of daily evapotranspiration such as is possible with GPS moisture, would also provide adequate signalling a drop in moisture cycling when the *wilting point* in soil moisture is reached, that is, when a severe drought is initiated. The following tasks, which relate directly to THEMES 1/3, have been commenced and results will be available in the coming year:

**a)**GPS PW data have been processed and several storm cases have been investigated where PW showed significant increases up to three hours prior to initial radar echoes of the storms.

**b)**I plan to carry out post-processing of the GPS data to evaluate preliminary estimates of daily evapotranspiration.

**c)**A full network of GPS receivers and surface mesostations is planned for operation during the 2008 UNSTABLE field program, along with several radiosonde systems and other field data equipment. This will allow a more thorough investigation of the above sub-goals.

**2.2 Describe the significance / impact of the results achieved to date and how this new knowledge has influenced research policy, enhanced research collaboration or competitiveness, or helped attract or train skilled personnel.**

**Address the following items, as appropriate:**

- **The impact of the project on government policy development (federal, provincial or municipal); - N/A**
- **How the project has expanded contacts in partner organizations, or increased cross-disciplinary cooperation; -** N/A
- **Whether and how it has improved the reliability of predictive methods; - N/A**
- **The impact of the project on your own institution; - N/A**
- **Whether and how the project has helped increase funding from other agencies, or led to new partnerships; -** not to date, mostly due my lack of formal attachment to any one institution (other than adjunct status at UofA where it has no impact at all).
- **Any current (or potential) commercial or social applications, which the results may have;** - nil
- **Links with international initiatives and the potential impact of these;** - nil
- **Anticipated benefits of the work for Canadians.** – too far in the distance to judge.

## 3.0 Dissemination

**3.1 Provide information on dissemination of the research results (publications, including journal names and whether refereed), conference contributions, seminars, workshops or videos, websites or other methods of transferring the results.**

- Paper presented at CMOS Congress, St. John’s, May 2007: *Atmospheric Moisture and Thunderstorm Drought*.
- I’ve also presented some of my DRI results to students in my physical geography course given each fall at The King’s University College.

# FIGURES

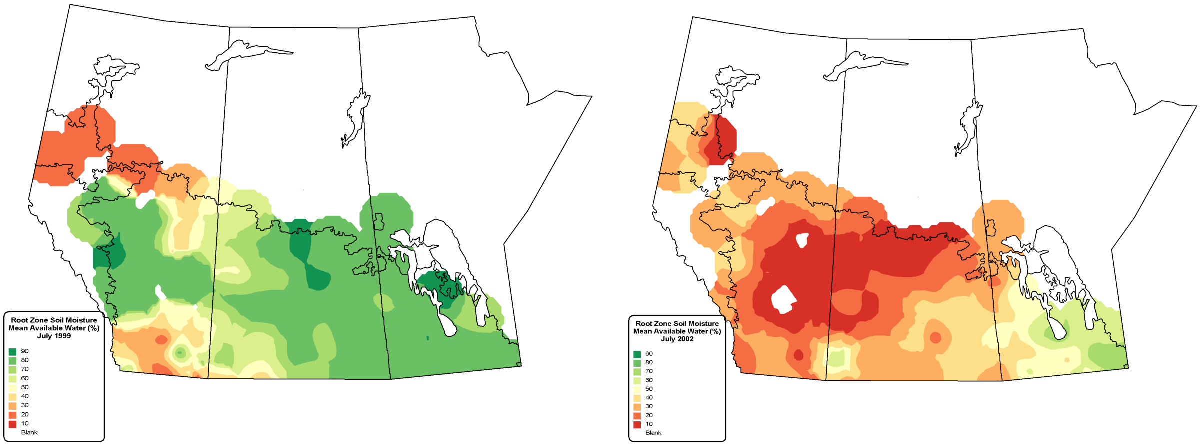


FIGURE 1: Estimated monthly average soil moisture for July 1999 and July 2002 (after Brimelow, 2007)

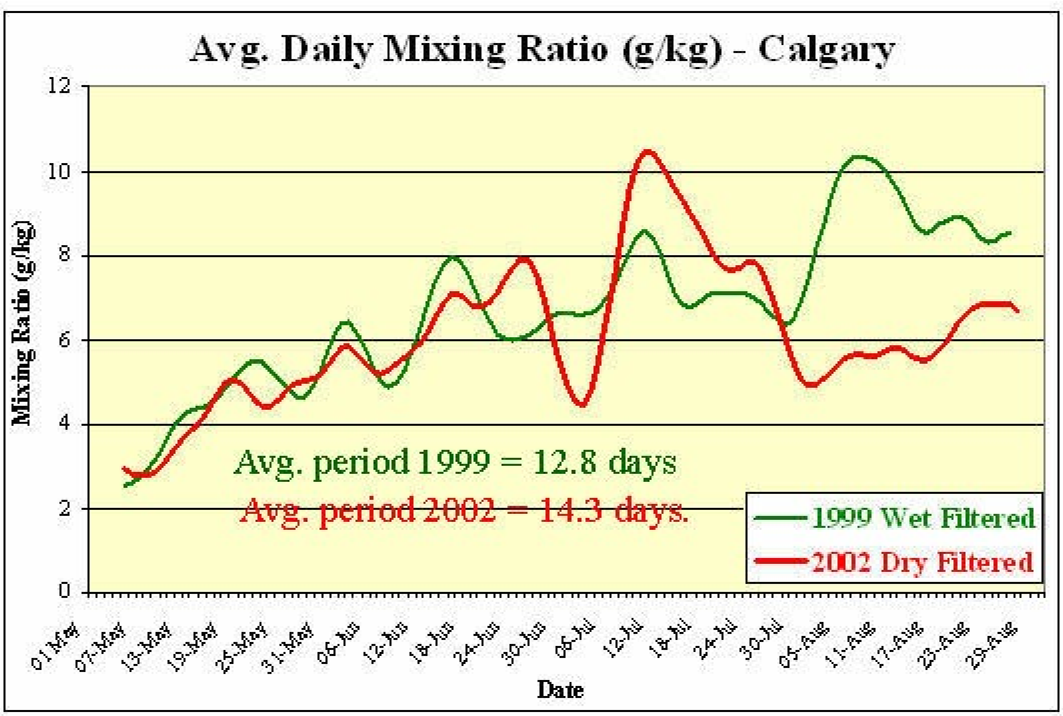


FIGURE 2: Average daily mixing ratios for Calgary for (a) wet-soil summer, 1999, and (b) dry-soil 2002. Trends were smoothed using a 9-point weighted filter.

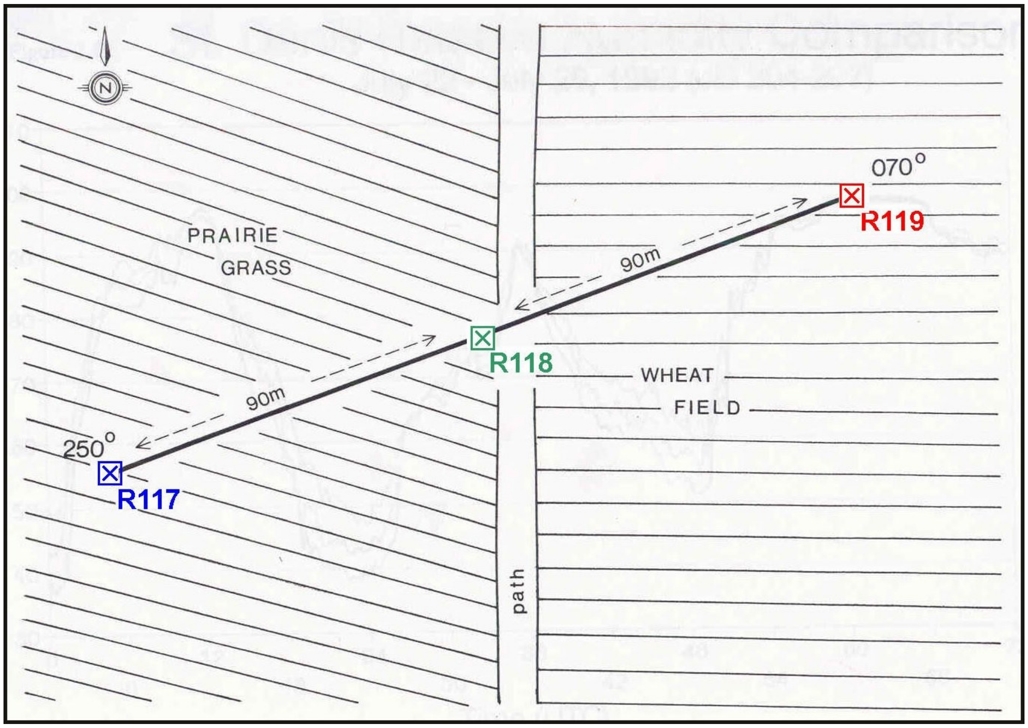


FIGURE 3: Field siting of datalogger transect across wheat and prairie grass at St. Denis, Sask. July-August, 1992.

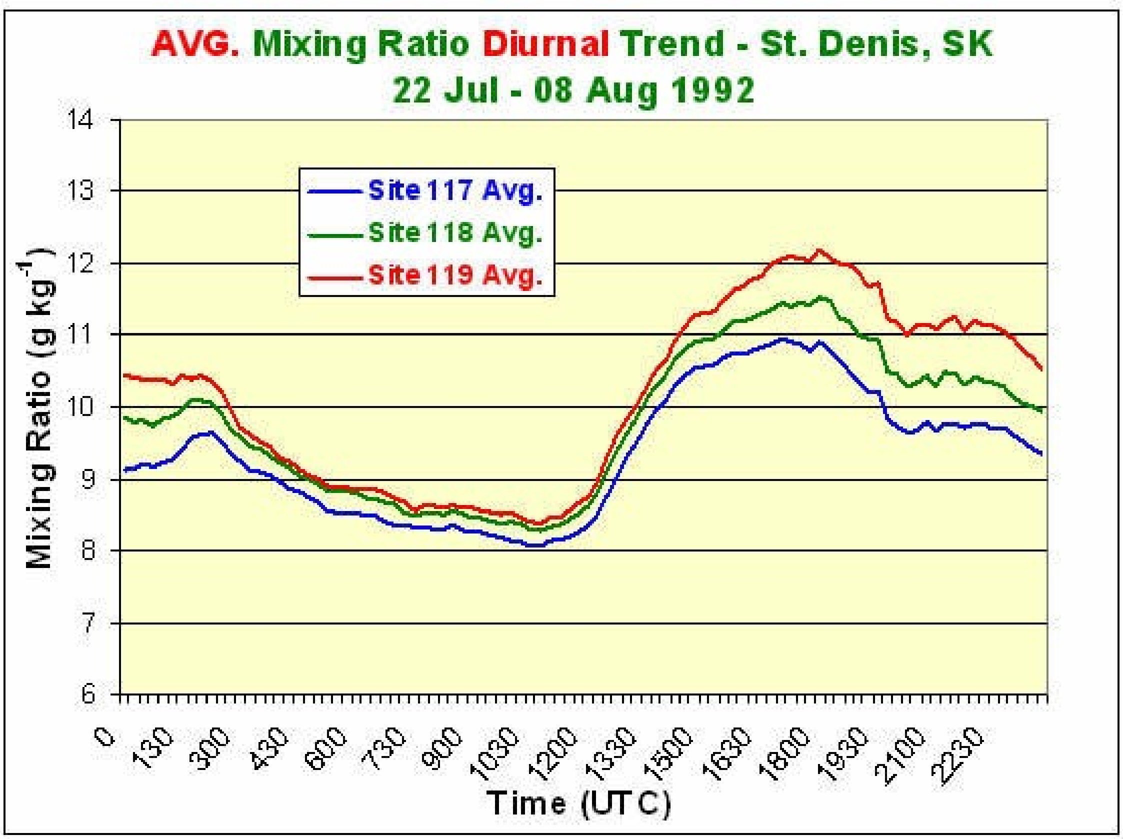


FIGURE 4: Diurnal trend in daily mixing ratio and gradient of mixing ratio across the 180-m wheat-grass transect. Data were averaged for each half-hour over the period 22 July through 08 August, 1992.

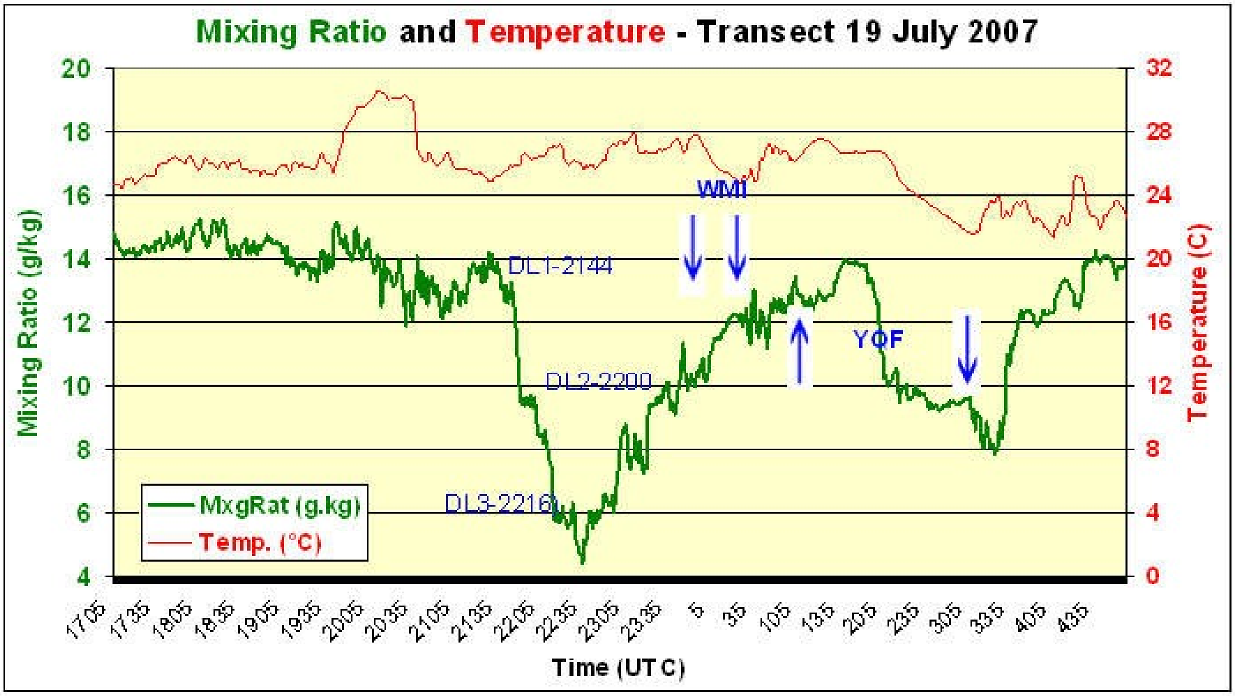


FIGURE 5: Transect across a dryline over Alberta foothills in three stages, beginning at 21:44, 22:00, and 22:16 on 19 July 2007. Accompanying table shows gradients of temperature and mixing ratio.

TABLE 1: Three stages of a dryline transect (shown in Fig. 5) with mixing ratio gradients of up to 0.4 g kg-1 km-1.

| Dryline Ref. | Variable | Start | End | Change | | Gradient ($m^{-1}$) | | Gradient ($km^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| **DL1A** | Time (mins.) | 21:44 | 21:50 | 6 | | | | |
| | Distance (km) | | | 9.3 | | | | |
| | Avg. Spd (km $hr^{-1}$) | | | 92.7 | | | | |
| | Elev. (m) | 1114 | 1109 | -5.0 | | -0.54 | m/km | |
| | Temp.(ºC) | 25.7 | 26.2 | 0.5 | | 0.05 | ºC/km | |
| | MxgRat (g $kg^{-1}$) | 13.3 | 9.4 | -3.9 | | -0.42 | g $kg^{-1}$/km | |
| **DL1B** | Time (mins.) | 22:00 | 22:14 | 14.0 | | | | |
| | Distance (km) | | | 16.9 | | | | |
| | Avg. Spd (km $hr^{-1}$) | | | 72.4 | | | | |
| | Elev. (m) | 1175 | 1281 | 106.0 | | 6.28 | m/km | |
| | Temp.(ºC) | 26.4 | 27.1 | 0.7 | | 0.04 | ºC/km | |
| | MxgRat (g $kg^{-1}$) | 9.6 | 5.8 | -3.8 | | -0.22 | g $kg^{-1}$/km | |
| **DL1C** | Time (mins.) | 22:26 | 22:33 | 7.0 | | | | |
| | Distance (km) | | | 6.7 | | | | |
| | Avg. Spd (km $hr^{-1}$) | | | 57.6 | | | | |
| | Elev. (m) | 1347 | 1377 | 30.0 | | 4.46 | m/km | |
| | Temp.(ºC) | 26.2 | 25.8 | -0.4 | | -0.06 | ºC/km | |
| | MxgRat (g $kg^{-1}$) | 6.3 | 4.4 | -1.9 | | -0.28 | g $kg^{-1}$/km | |