Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)
Fondation canadienne pour les sciences du climat et de l'atmosphère (FCSCA)

Final Progress Report

Project Title: *Atmospheric Moisture and Thunderstorm Drought*

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1.0 Project Work

1.1 Provide a summary description of a) the objectives of the study, b) the scientific findings and c) the project work undertaken.

a) OBJECTIVES

- as specified in annual report of 23 Jan. 2007 (this study was a late addition to DRI)

General - *To investigate temperature/humidity cycles and the role of thunderstorm feedback in prairie drought situations*, particularly the 1997-2004 drought.

Specific (utilizing 1971-2000 Climatological Surface and upper air Data for selected prairie sites):

1.1 Determine *long-term* (30-year*) trends* and *cycles* in surface temperature and absolute humidity (mixing ratio) data.
1.2 Determine *short-term cycles* (of several weeks) in same data and relate to convective outbreak situations.
1.3 Identify any relationships between the short-term cycles and convective outbreak situations.
1.4 Isolate any relationships with the initiation and/or cessation of drought periods.

b) SCIENTIFIC FINDINGS

1) Climate normals (1971-2000) data indicated a 30-year upward trend in summertime moisture of ~0.1 g kg^{-1} $decade^{-1}$ (mixing ratios from surface data), and 0.2 mm $decade^{-1}$ from sounding-derived precipitable water data. These values are commensurate with climate warming trends and resulting increases in atmospheric moisture capacity, but do not necessarily translate into additional surface precipitation; in fact, all values were generally lower during the DRI focus drought period (1999-2005).
2) Surface mixing ratios are strongly correlated (>0.9) to total precipitable water in the troposphere (from soundings), supporting compelling links between surface moisture, soil moisture, and regional evapotranspiration. Links to total precipitation and to drought are less clear, as there are many other complicating factors that need to be resolved through modelling studies.
3) Dry soil (drought) conditions do not necessarily result in low surface moisture values, but there was a clear reduction in the frequency of diurnal cycling of moisture, which in turn is directly related to the frequency of thunderstorm outbreaks. During drought conditions over a region, surface mixing ratios can

appear to be near 'normal', but the mixed boundary layer tends to remain very shallow, while the larger-scale dynamics necessary to prepare the three essential conditions for thunderstorm development – namely, unstable air to high levels (through sensible heat input), a well-mixed boundary layer typically 500m or more deep (latent hear input), and the dynamics that lead to a sheared environment and provide low-level convergence (kinetic energy input) rarely exist for drought conditions.

4) Average diurnal trend in surface mixing ratio (for non-drought conditions) is 4 g kg^{-1} (determined from 1992 St. Denis and 2009-10 Kenaston data transects; these values cannot be directly translated into evapotranspiration (ET) values, but roughly correspond to ET rates of 4-10 mm day^{-1}, with a significant proportion of this from grain crops.
5) Pre-thunderstorm *drylines*, resulting from *summer chinook* effects from the mountains onto the Alberta foothills, often contribute to severe thunderstorm events, even during drought periods (e.g., the July/2000 Pine Lake tornado). Mixing ratio gradients across such drylines can be unusually high, as much as 4 g kg^{-1} over < 100 m. The dryline, behind which dry air is heated through subsidence, helps to initiate storms when it clashes with and lifts boundary layer moisture converging over the foothills (dry air is heavier than moist air at the same temperature).
6) A similar effect (to 5) occurs when very dry air over a drought region pushes up against a mass of boundary layer moisture on the periphery of the drought region. This was observed qualitatively for the Pine Lake tornadic storm of July 14 2000, but requires a more detailed modelling study for confirmation.
7) Field studies documenting drylines during 2003-07 (associated with the CFCAS GPS moisture evaluation study, AGAME) and during the 2008 UNSTABLE study, revealed *urban dry islands* over even the smallest towns (1000-5000 population) in agricultural districts; that is, urban mixing ratios of 0.5 to 1.0 g kg^{-1} less than over cropped areas outside the towns.
8) Surface transects across Edmonton (population > ¾ million) during 2009 revealed a more significant *dry island* of 2-3 g kg^{-1} below that of adjacent rural areas, along with an expected *urban heat island* of ~3°C (the latter concurred with estimates obtained from climate comparisons between the urban and rural Edmonton airports). This dry island may be significant enough to suppress convective storms as they approach Edmonton, and if true, this should produce a *rain-shadow* effect downstream from larger prairie centres such as Edmonton, Saskatoon, or Winnipeg. While such areas may be too small (Edmonton is roughly 25 km diameter) to initiate drought, it could possibly exacerbate or prolong an existing drought downstream. This part of the study is on-going (beyond DRI), as modelling studies and analysis of radar climatology only commenced during 2010. However, preliminary model results have reproduced the 'dry island' effect over Edmonton, and preliminary radar climatology shows a slight rain-shadow effect downwind (east) of Edmonton. Some case studies from the 2009 Edmonton transect data are also in progress.

c) PROJECT WORK UNDERTAKEN

1) Field studies in support of above include the 2003-04 CFCAS-funded GPS moisture evaluation study (AGAME), additional UofC-funded 2005-07 dryline field studies, 2008 UNSTABLE transect field data, 2009 Edmonton transect field data, and 2009-10 Kenaston SK fixed transect data (funded primarily by Environment Canada).
2) In addition, this project also makes use of archived data from the 1971-2000 Environment Canada climate normals data for selected prairie sites, 1985 ARC

LIMEX thunderstorm project, 1991 Regional Evaporation Study (RES) data, and 1992 St. Denis SK field data.

1.2 **Explain how the project milestones and deliverables originally proposed were met.**

Analyzed long- and short-term cycles in temperatures and humidities in climate normals data, and employed several archived field data sets to establish some findings, carried out other short field studies for remainder.

1.6 **Describe how the work of co-investigators was integrated or coordinated.**

- Coordinated with Hanesiak and graduate students in the UNSTABLE fieldwork (funding for this provided by UofC Geomatics Engineering Dept.).
- Used Brimelow's soil moisture estimates for a portion of analysis.

1.7 **Describe the participation of government (federal, provincial or local), university, industry or foreign researchers in the project.**

- Cooperated with University of Manitoba (Hanesiak), University of Calgary (Skone), and Environment Canada (Taylor, Sills), and University of Alberta (Reuter, Brown) on the UNSTABLE fieldwork.
- Cooperated with UofC (Skone) and Environment Canada (Smith, Saskatoon) on AGAME Project that yielded much of dryline data, including GPS moisture data.
- Cooperated with Environment Canada (Smith, Saskatoon) on tower and fixed transect work at Kenaston, SK.

2.0 <u>Impact</u>

2.1 Describe in broad terms how your work has contributed to the overall objectives of DRI and to our scientific understanding of drought.

- Too early to judge, but believe *dryline*/thunderstorm results and drought/thunderstorm results relevant.
- *Urban dry island* work (Edmonton and other transects) relevant to drought enhancement.

4.0 <u>Reverse Impact Statement</u>

4.1 Provide a reverse impact statement, describing what would have happened in terms of the project, the resulting science and the impacts on users/stakeholders, if the work had not been funded by CFCAS.

- Would have carried out more limited research using personal resources.

5.0 <u>Follow-on Science</u>

5.1. Based on the findings of your research identify any outstanding scientific questions that need to be addressed in future drought studies.

- Mesoscale model runs need to be carried out to simulate the role of dry air over drought regions providing lifting of moisture and thunderstorm initiation on the downwind side of the drought regions.

- Mesoscale model runs could also be used to simulate how urban dry islands downwind of larger prairie cities affect storm systems, overall precipitation (e.g., rain-shadow effect), and possibly their role in enhancing existing downwind drought regions.

6.0 Dissemination

6.1 Provide information on the 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.

- A paper on the dry island work is in preparation, with plans to submit to Atmosphere-Ocean (or other suitable journal) in the current year.
- Work on this has been slow because of the lack of institutional facilities and technical assistance (co-I is retired).

6.2 Describe data management/sharing activities including organization of the metadata. Also, are the data being archived, and how will they be made available to other researchers?

- Datasets will be provided to the DRI data archive as soon as time permits.

7.0 Training

7.1 Quantify student and PDF involvement (indicate the level of each: undergraduate, masters, doctorate or PDF). If possible and within the Federal Privacy Act rules governing the collection of personal information, provide a general indication of their subsequent employment (i.e., university, industry, government, other, etc.), and indicate whether the employment was foreign or domestic.

- Provided financial support and some scientific assistance to University of Manitoba Ph.D student Brimelow (Hanesiak, supervisor), and both data and partial supervision of University of Alberta M.Sc student Brown (Reuter, supervisor).