The Link between Soil Moisture and Drought as Examined in DRI

John Pomeroy
Centre for Hydrology
Department of Geography
University of Saskatchewan,
Saskatoon

THE TEAM

- **Co-leads:**
  Ron Stewart (PI, *McGill*) and John Pomeroy (*Sask*)

- **Network Manager:**
  Rick Lawford (Manitoba)

- **Information Managers:**
  Matt Regier (HAL, EC), Patrice Constance (Ouranos)

- **Investigators (13):**
  Bonsal (*Sask/NHRC*), Bullock (*Man*), Gyakum (*McGill*), Hanesiak (*Man*), Hayashi (*Calg*), Leighton (*McGill*), Lin (*McGill*), Pietroniro (*Sask/NHRC*), Snelgrove (*Memorial)*, Strong (*Alta*), van der Kamp (*Sask/NHRC*), Wheaton (*Sask/SRC*), Woodbury (*Man*)

- **Collaborators (+14):**
  Boer (*MSC*), Caya (*Ouranos*), Derome (*McGill*), Derksen (*MSC*), Donaldson (*MSC*), Granger (*NHRC*), Martz (*Sask*), Raddatz (*MSC*), Ritchie (*MSC*), Shabbar (*MSC*), Sills (*MSC*), Smith (*MSC*), Szeto (*MSC*), Walker (*MSC*), more…..

- **Research expertise covers critical areas for DRI**
- **Solid track record of working together as well as being in and leading networks**

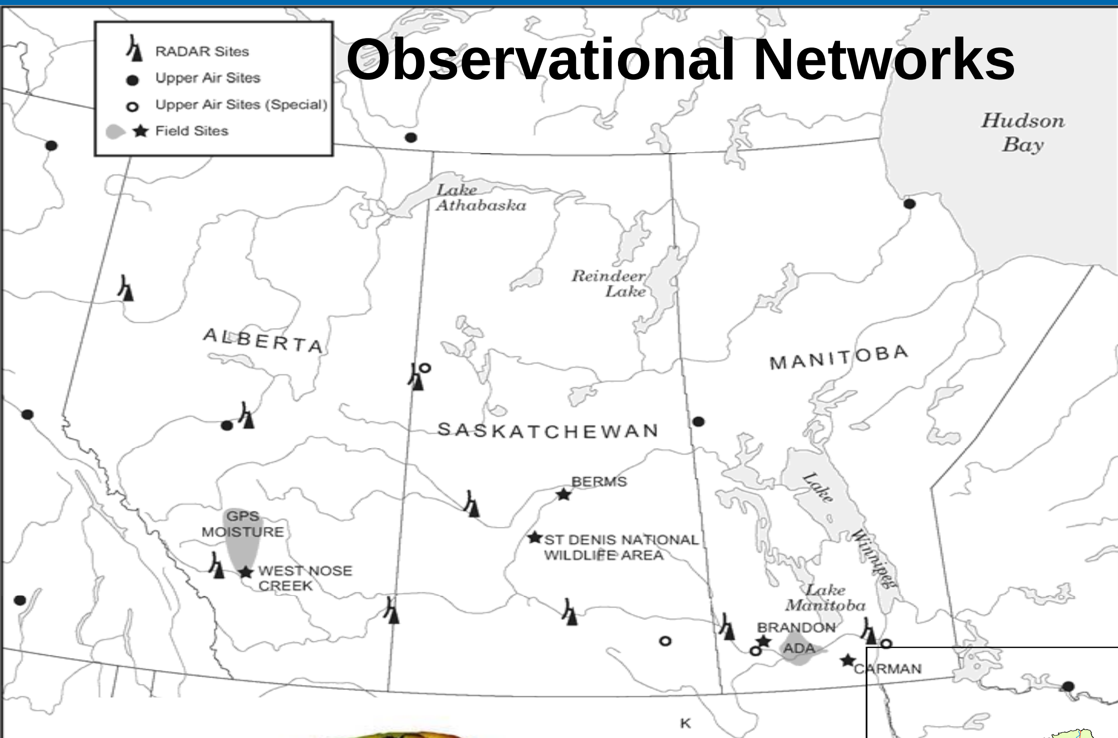
OBJECTIVE OF DRI

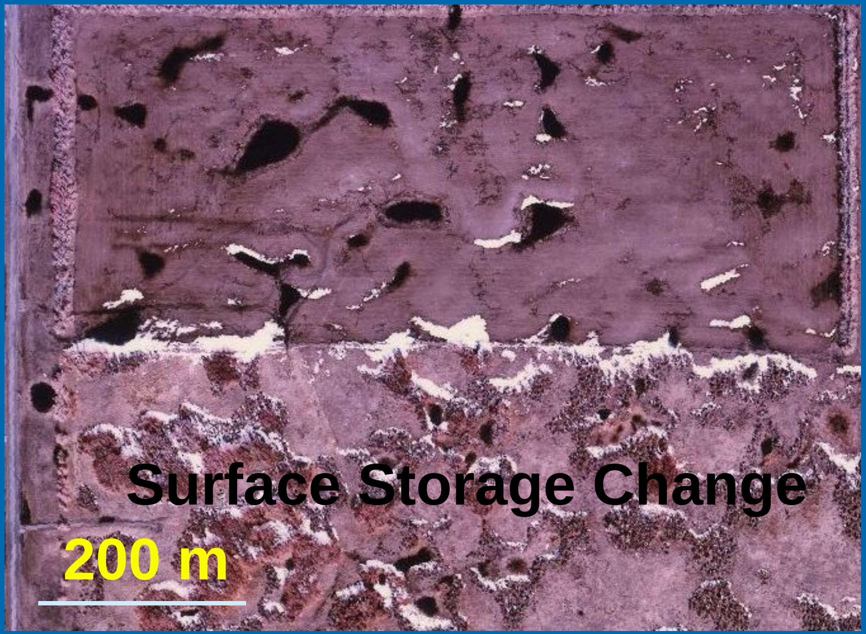
To better understand the physical characteristics of and processes influencing Canadian Prairie droughts, and to contribute to their better prediction, through a focus on the recent severe drought that began in 1999

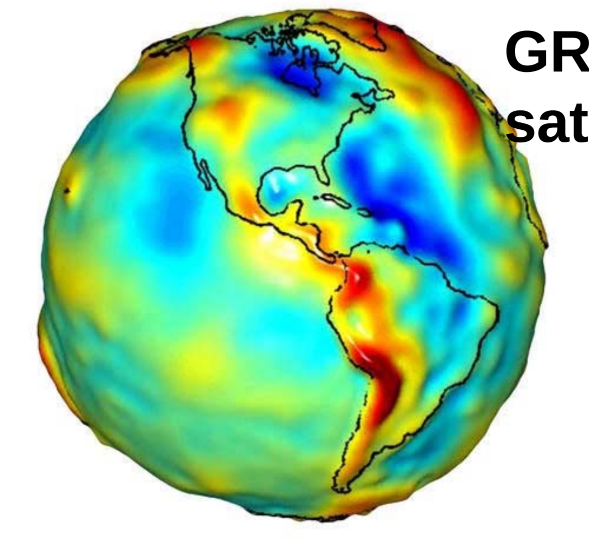
DRI THEMES

1. Quantify the physical features,
   - flows of water and energy into and out of the region, and
   - storage and redistribution within the region
2. Improve the understanding of processes and feedbacks governing the
   - formation,
   - evolution,
   - cessation and
   - structure of the drought
3. Assess and reduce uncertainties in the prediction of drought
4. Compare the similarities and differences of current drought to previous droughts and those in other regions
5. Apply our progress to address critical issues of importance to society

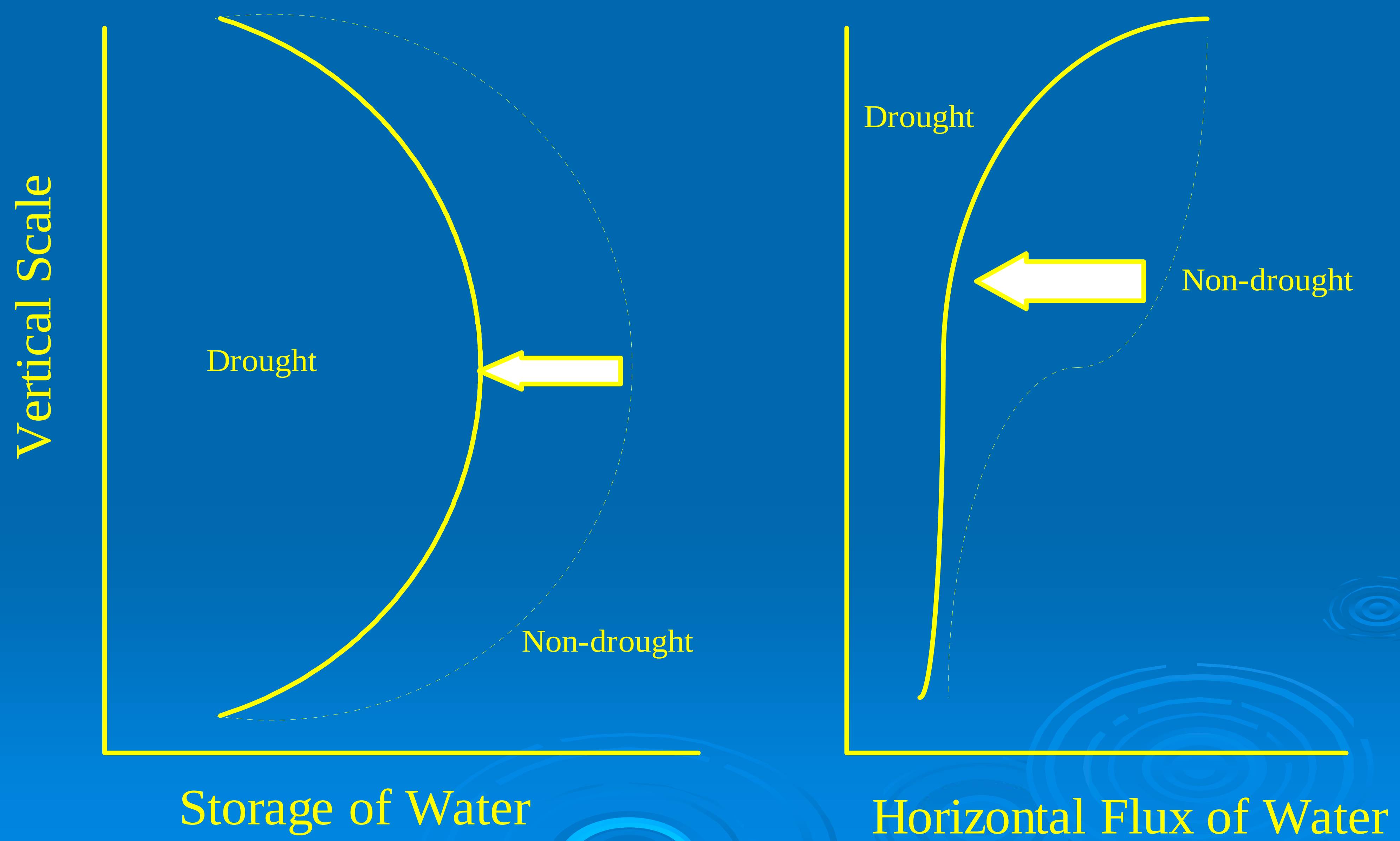
1. QUANTIFY THE DROUGHT



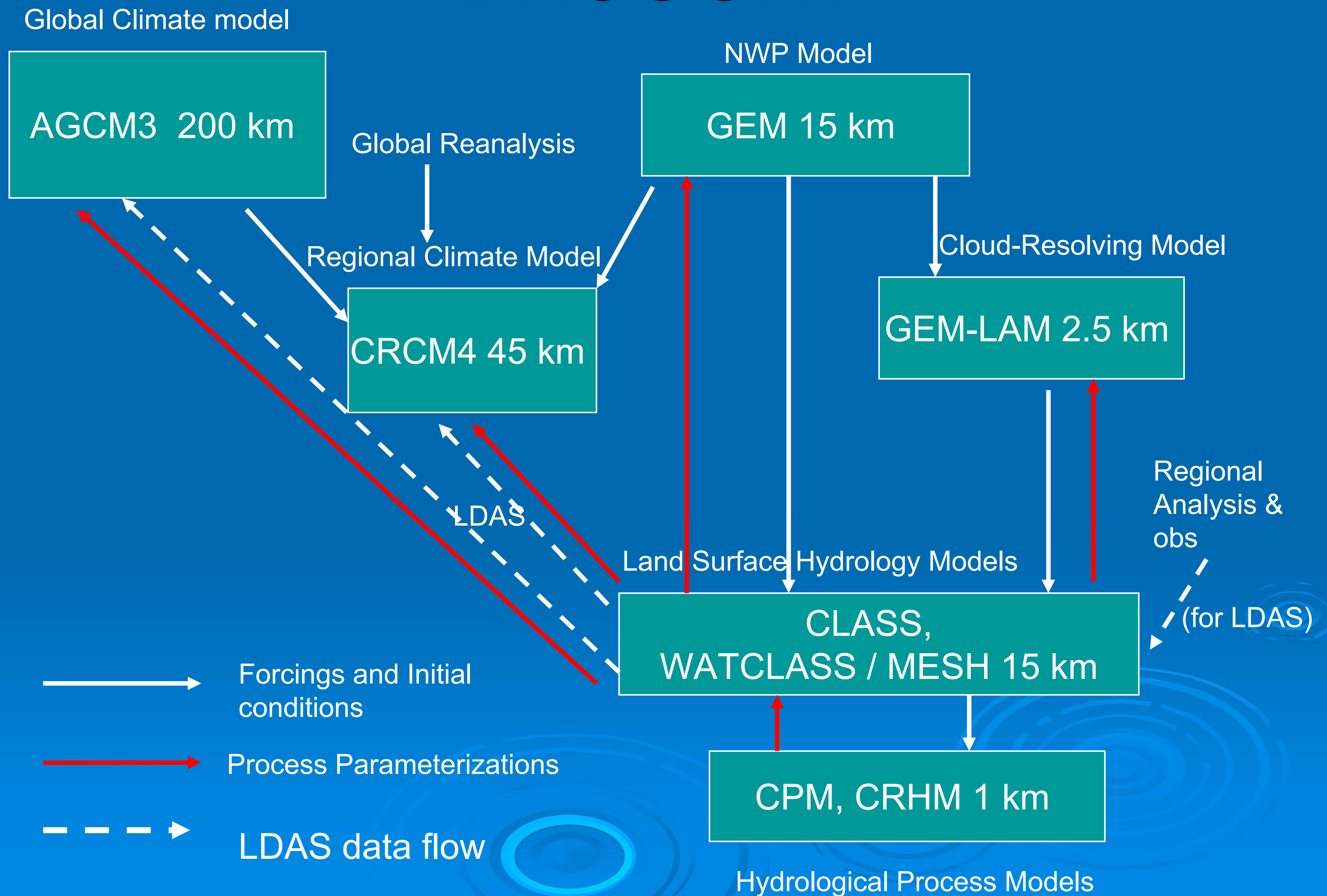




2. UNDERSTAND THE DROUGHT



3. SIMULATE AND PREDICT THE DROUGHT



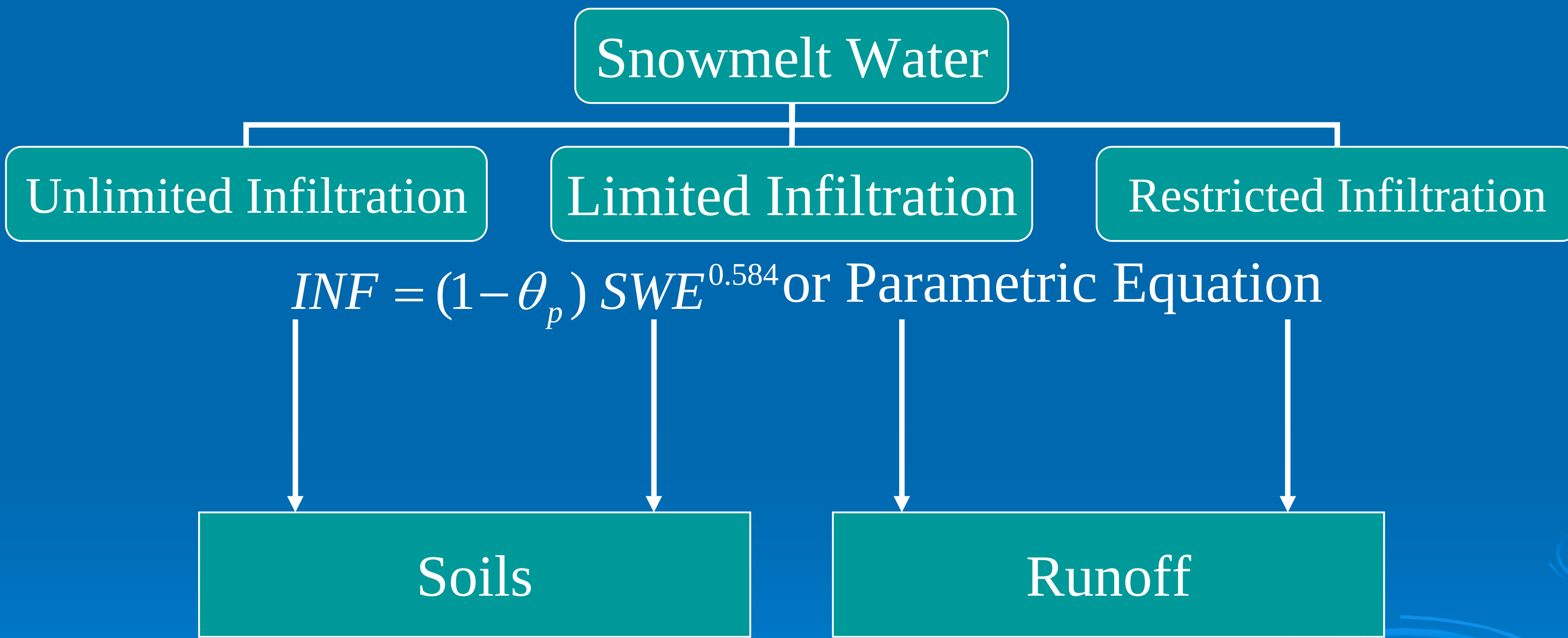
Soil Moisture and Drought

- Agricultural Drought based on soil moisture
- Atmospheric feedbacks from evaporation and sensible heat controlled by soil moisture
- Hydrological flows strongly influenced by soil moisture in drought.

Hydrological Drought and Soil Moisture

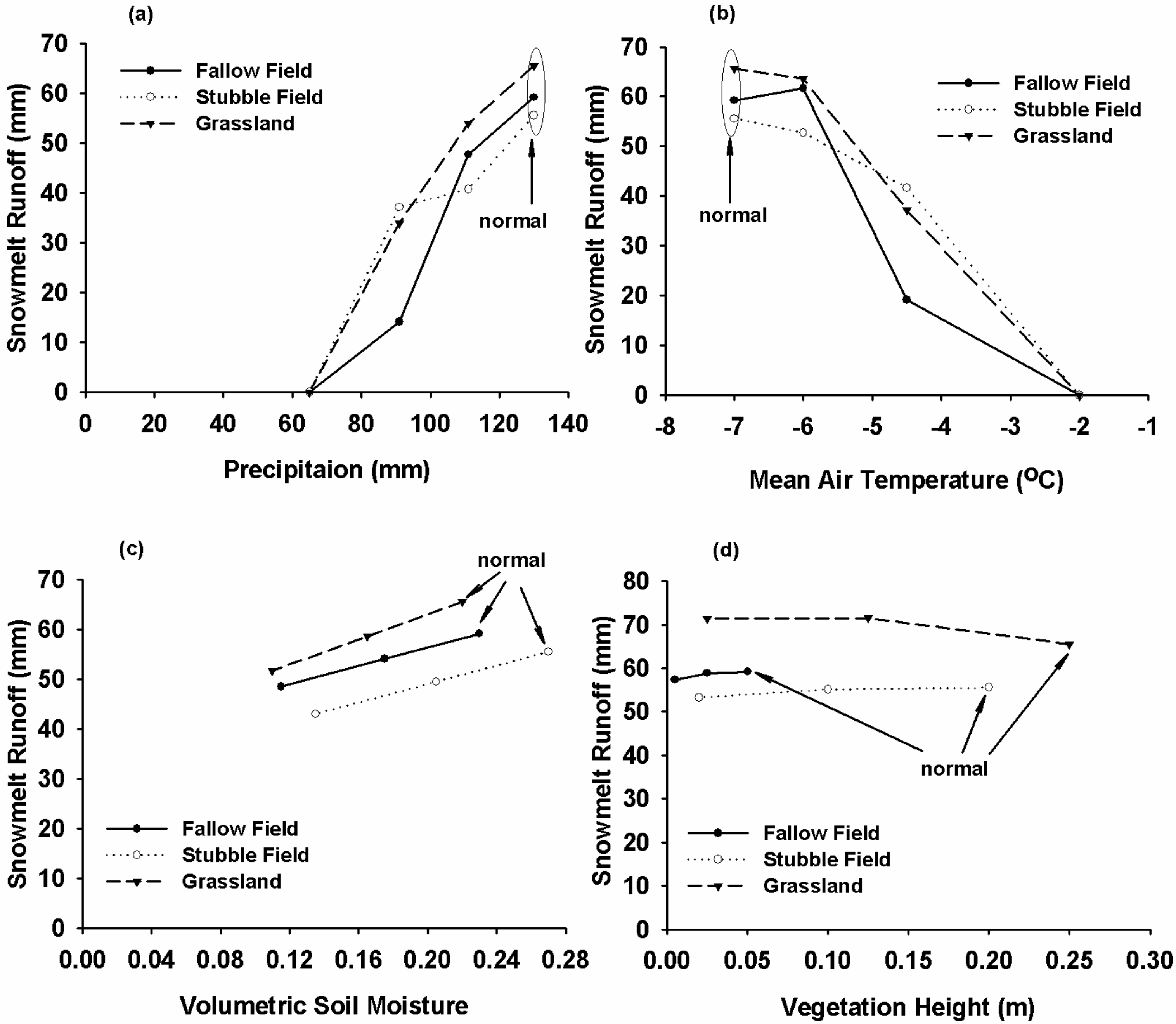
- Evaporation control
- Antecedent conditions for runoff generation
  - Unfrozen soils – some effect on streamflow generation from heavy rainfall, but not extreme rainfall or snowmelt (upper layers)
  - Frozen soils – unsaturated frozen soil moisture content (top 40 cm) can have a strong effect on runoff generation from snowmelt

Infiltration into Frozen Soils



References: Granger et al., Gray et al., Zhao & Gray

Snowmelt Runoff over Frozen Soils



Semi-arid
SW Saskatchewan

Soil moisture is
FALL soil moisture

Snowmelt runoff is
Spring

Physically based
Infiltration equations
(Zhao & Gray, 1999)

Cold Regions
Hydrological Model

Evaporation and Soil Moisture

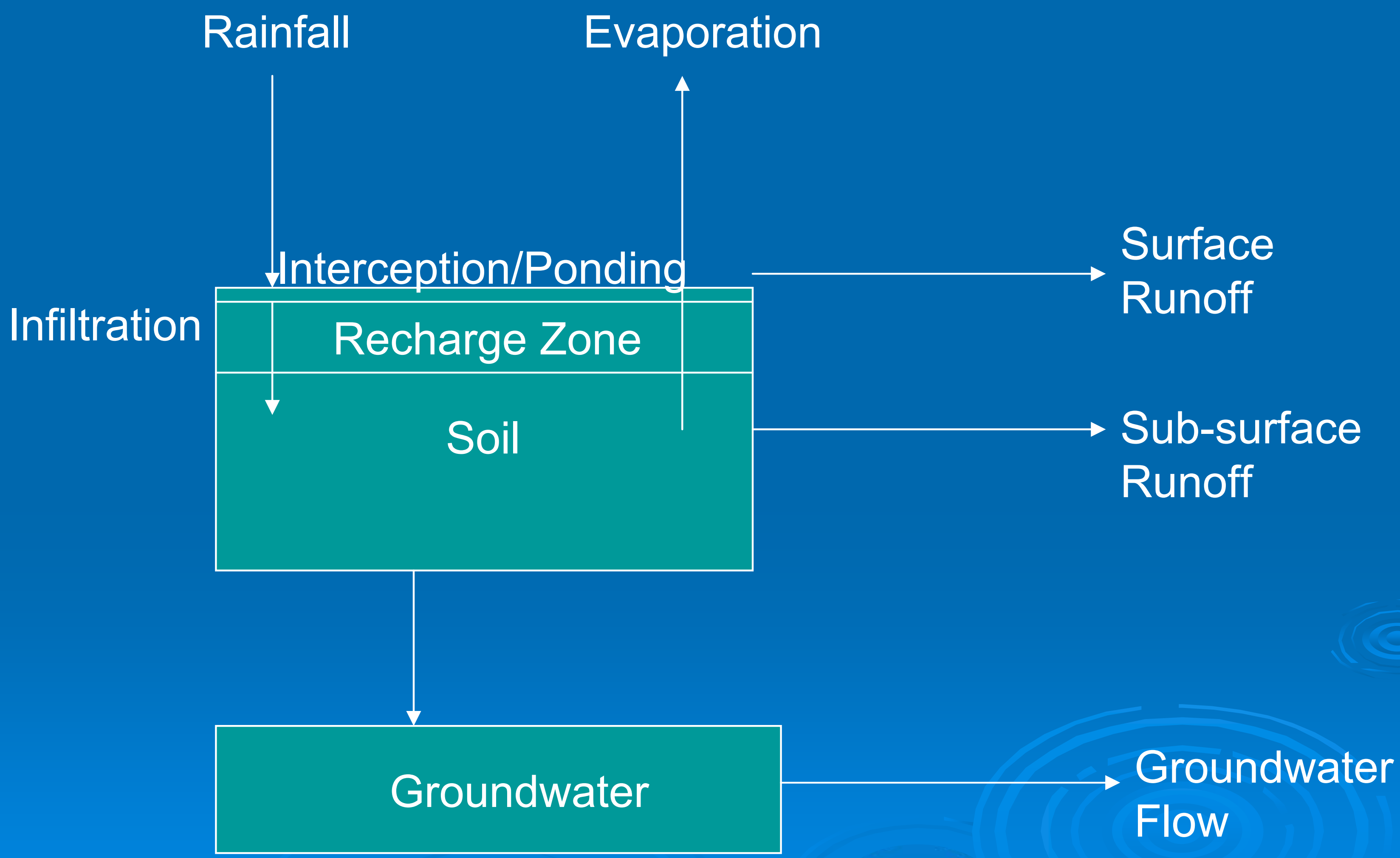
- Water vapour flux to the atmosphere from
  - Soil
  - Open Water
  - Vegetation
    - Interception water/snow
    - Stomatal release
  - Snow/ice
  - Precipitation (? depends on how defined)
- Phase change and transport provides coupling of atmosphere, land surface and sub-surface water and energy balances

Drought, Soil Moisture & Evaporation

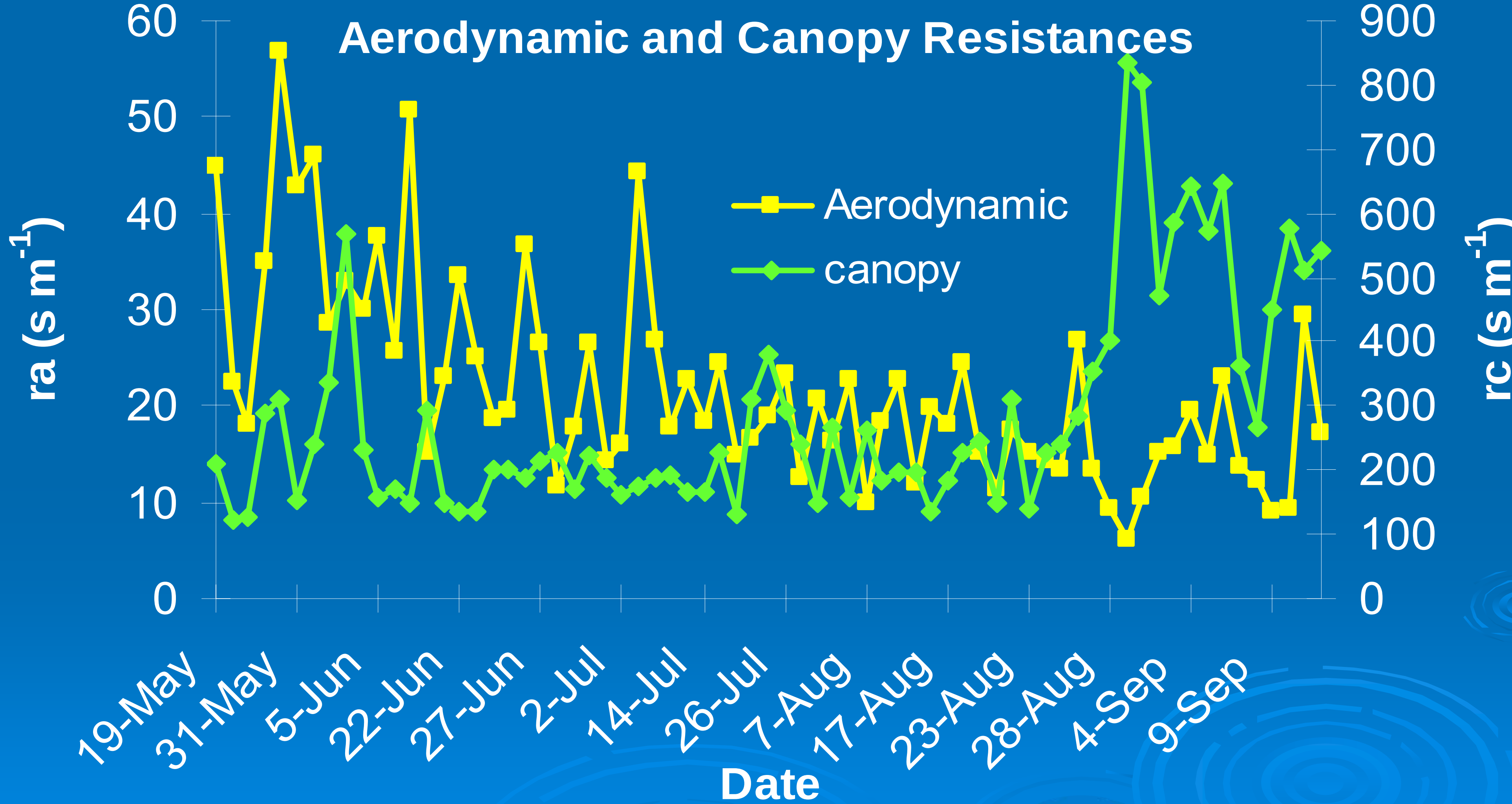
- Should be Easy! If $R = 0$, then $P = E$
- Not that easy…..
  - $E = P - \Delta S$ This is when sub-surface coupling becomes critical to the atmosphere
  - Storage is dynamic during drought. Decreasing surface area of open water, increased root depths, increased depth to water table
  - Seasonality –
    - most runoff is from snowmelt (snowfall),
    - most evaporation is from rainfall + snowmelt
    - Precipitation or melt at times of low evaporative energy goes into storage (including soil moisture) or runoff
  - Episodic Events – runoff removes water before it can infiltrate and form storage for evaporation.
    - Snowmelt over frozen soil
    - Intense rainfall rates (convective storms).

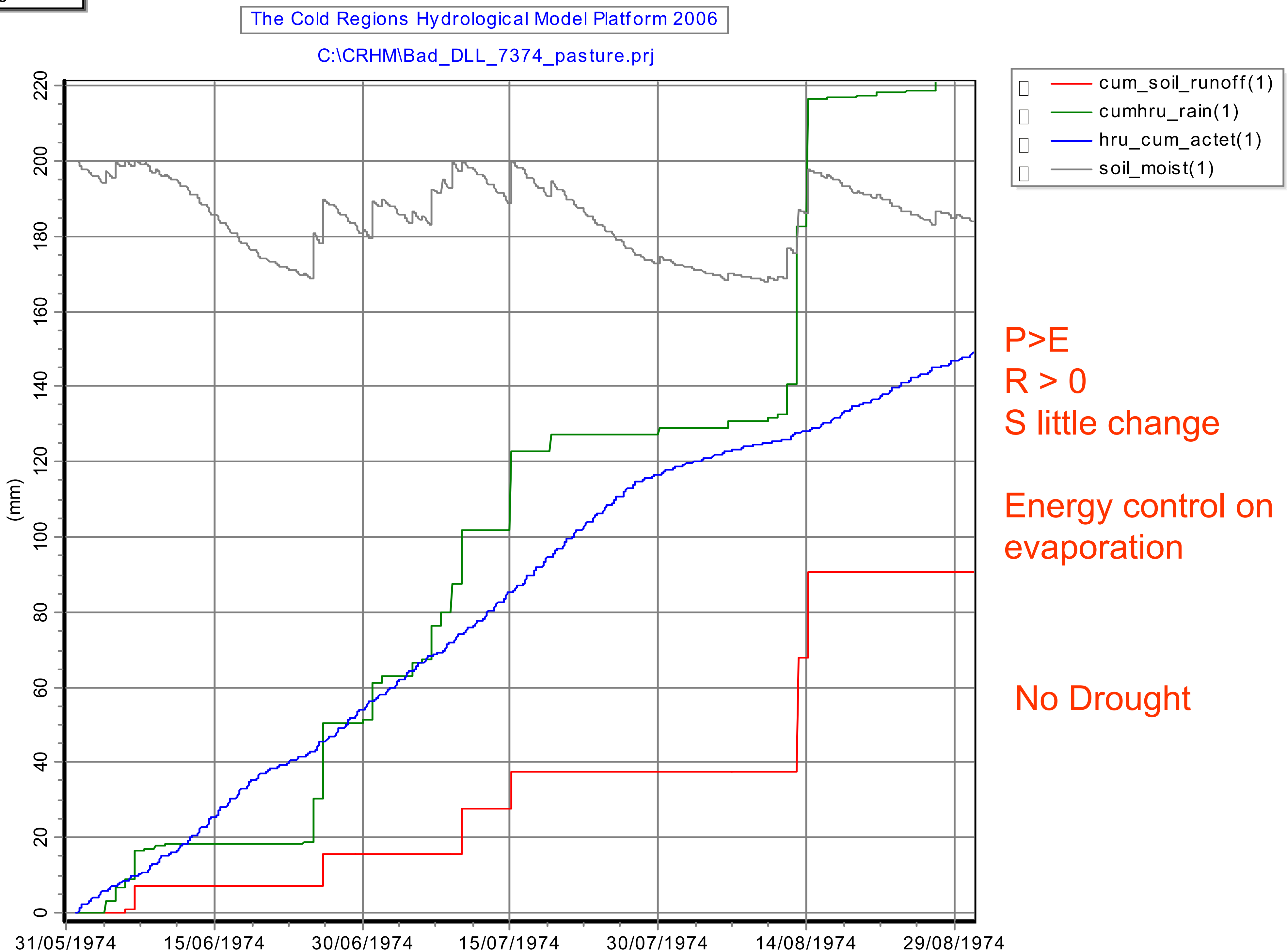
Drought Simulation

CRHM: Cold Regions Hydrological Model



Change in Resistances to Evaporation during Prairie Soil Moisture Depletion

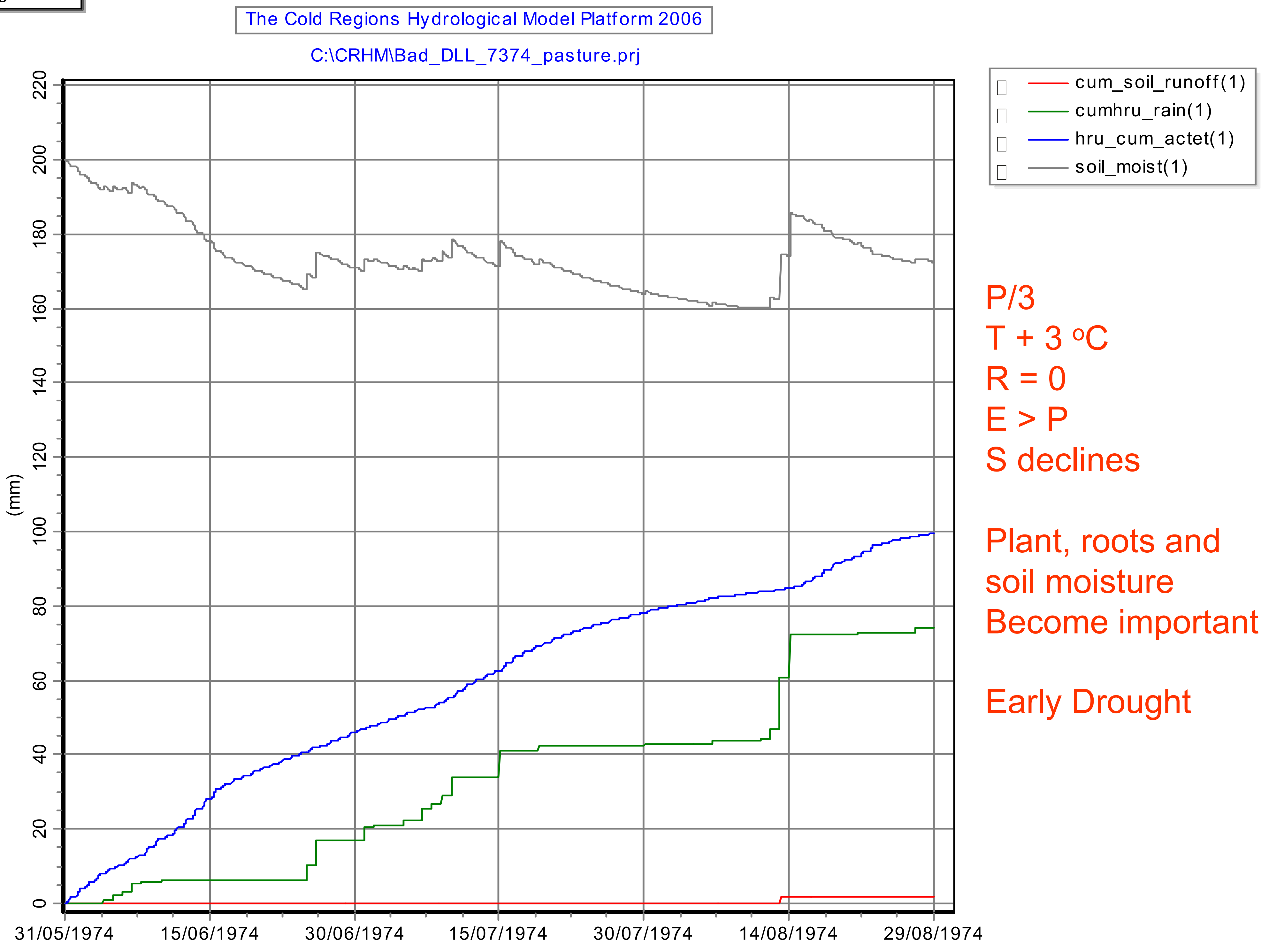




P>E
R > 0
S little change

Energy control on evaporation

No Drought



P/3

T + 3 °C

R = 0

E > P

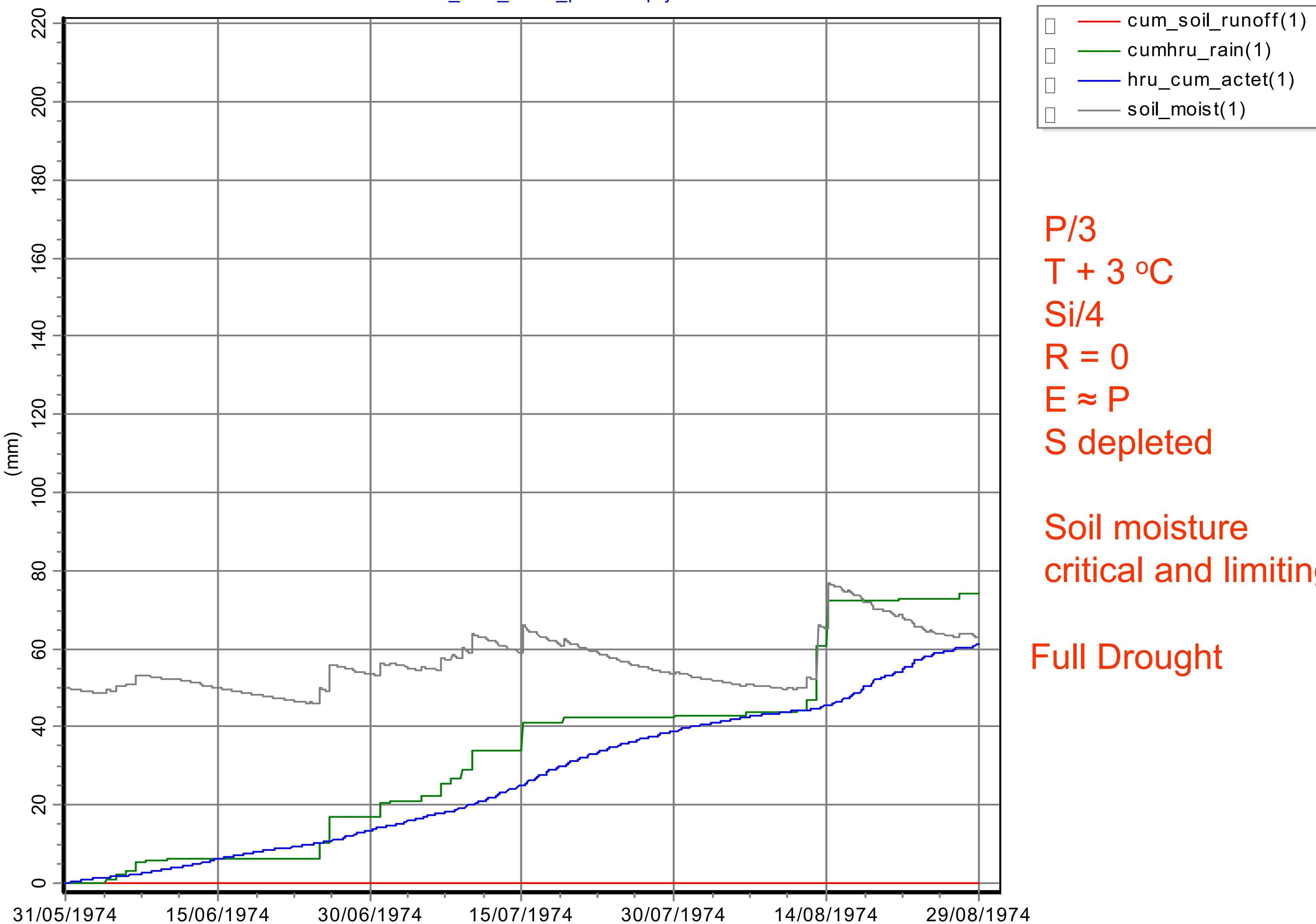
S declines

Plant, roots and soil moisture Become important

Early Drought

The Cold Regions Hydrological Model Platform 2006

C:\CRHM\Bad_DLL_7374_pasture.prj



P/3

T + 3 ^{o}C

Si/4

R = 0

E ≈ P

S depleted

Soil moisture critical and limiting

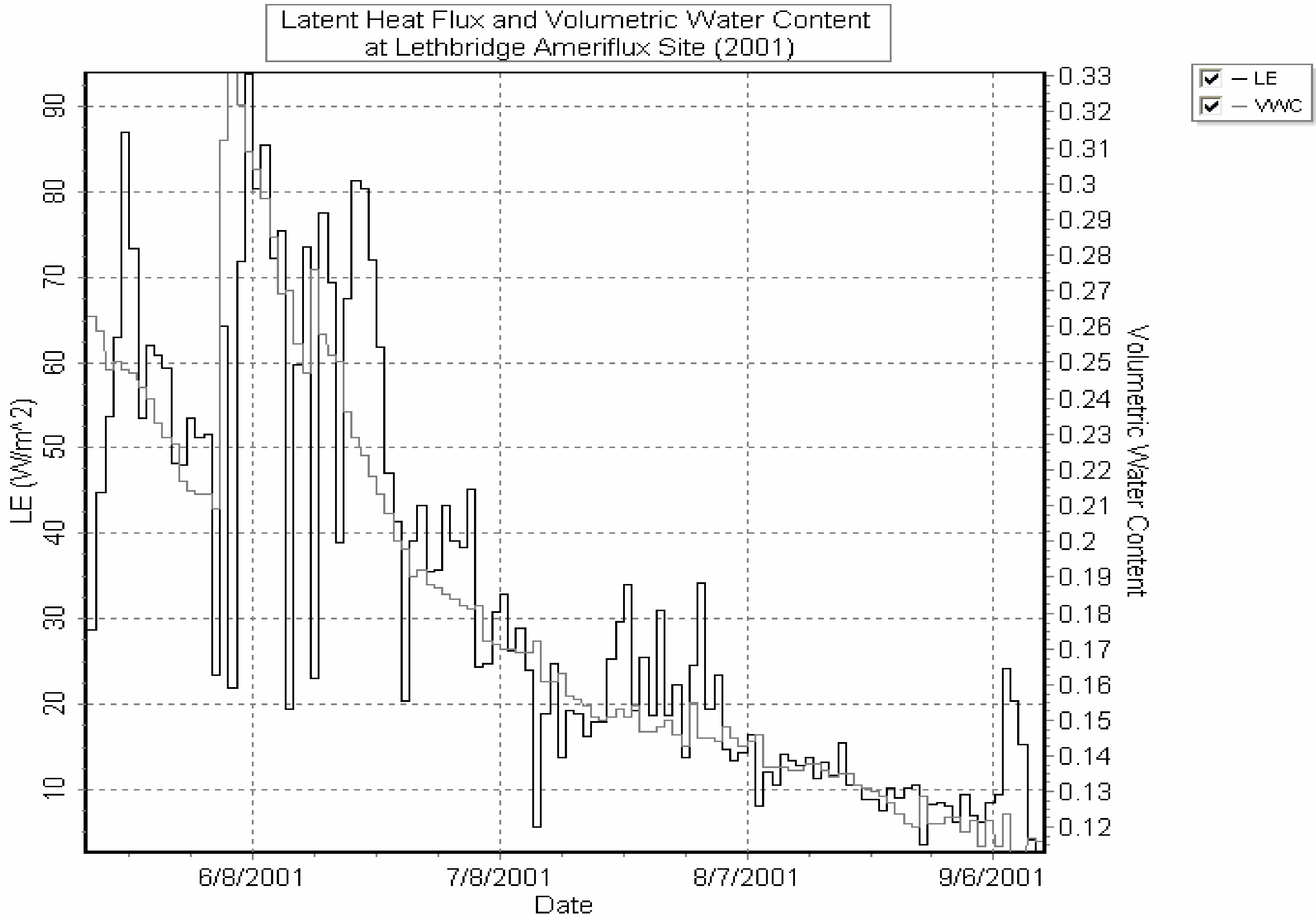
Full Drought

Synthetic Drought Progression

mm of water

	No Drought	1st Summer	Full Drought
Rainfall	222	75	75
Evaporation	150	100	61
Storage Change	-18	-28	+14
Runoff	90	3	0

Lethbridge Ameriflux Site (2001)



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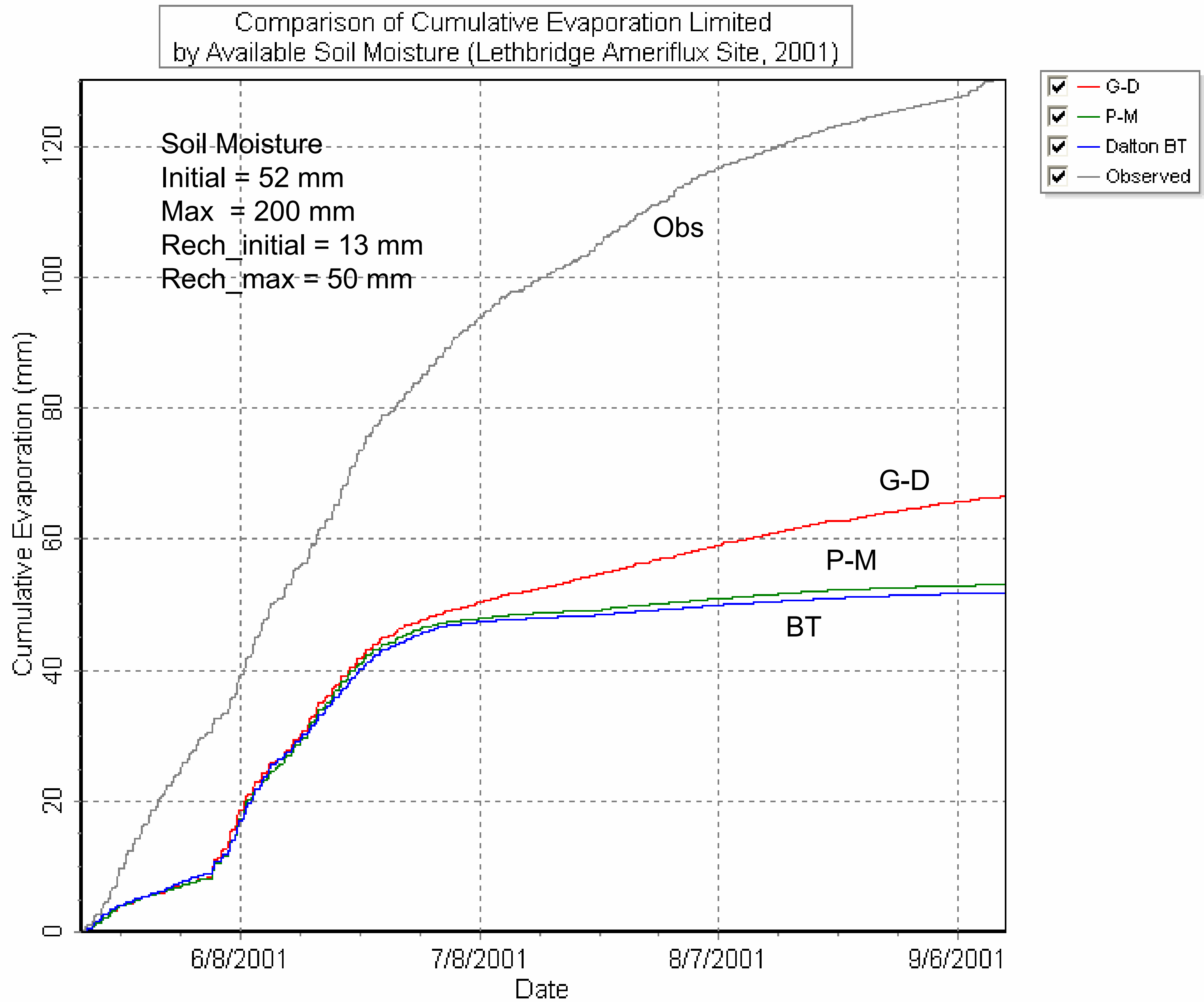
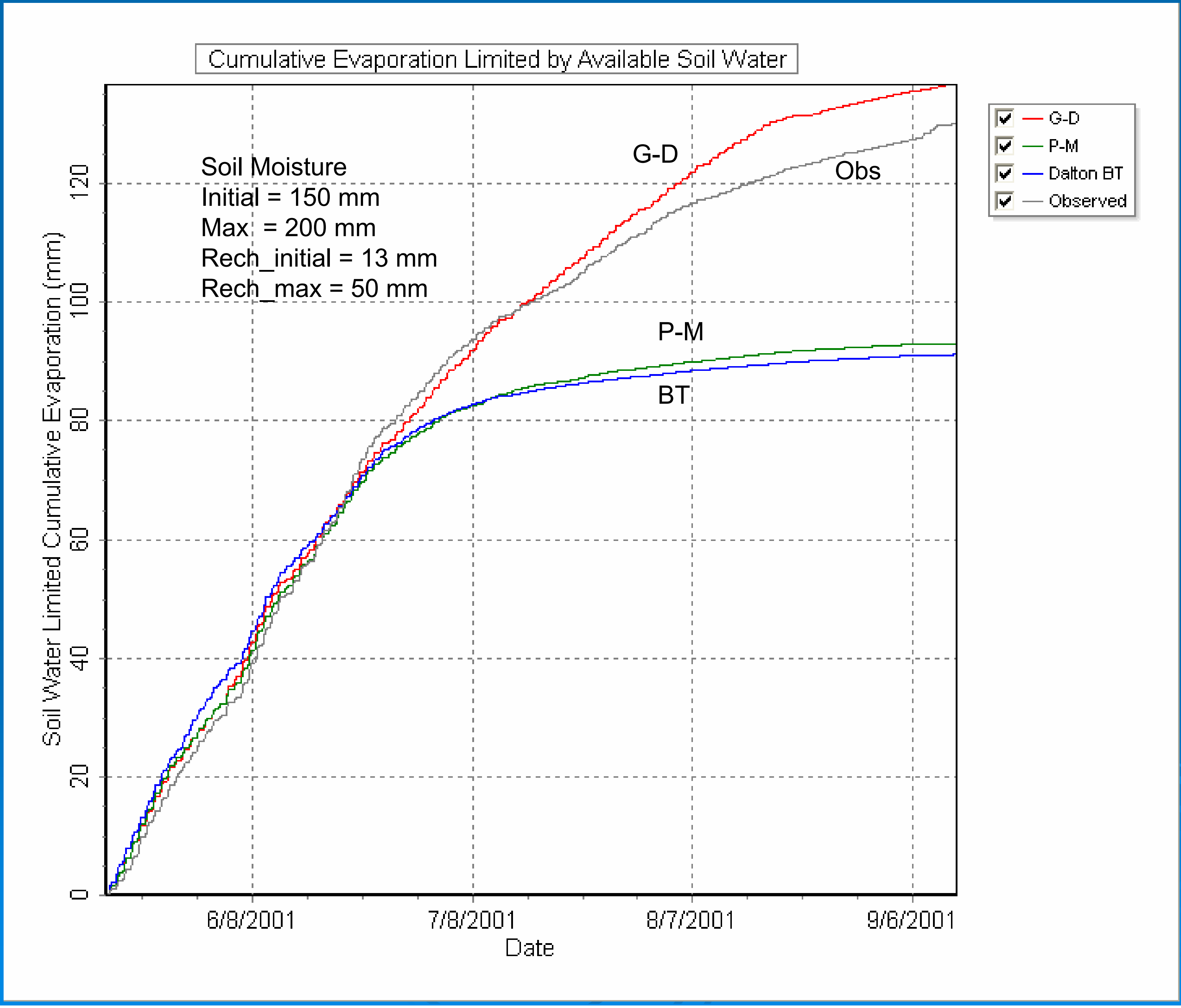


Lethbridge Ameriflux Site (2001)



DRI Evaporation Workshop

- Intensive: 19 papers and an open discussion in Saskatoon on 17 May 2007
- Presenters identified soil moisture as the greatest *unknown* in estimating evaporation during drought. Soil moisture essentially controls evaporation during drought. *Unknown* because
  - Not measured
  - Not modelled well
  - Not appropriately coupled to evaporation models (e.g. depth of rooting zone exceeds model soil depth…)
  - Not linked well to groundwater

Evaporation Workshop Summary

Presentation Summary I

- Overview, Measuring and Understanding
  - Need for improved observed data to calculate and bound evaporation (forcing variables, state variables, parameters).
  - Need for new data assimilation (earth observation) to permit more confident evaporation estimation
  - Drought indices may not capture drought evaporation well
  - Need to improve turbulent transfer formulations to account for surface coupling, heterogeneity, advection, snow surfaces
  - **Need for better links between evaporation estimation methods and the ‘true’ soil/ground water storage that is available for evaporation (roots, phenology, ecosystem water management).**

Presentation Summary II

- Modelling Evaporation
  - **Resistance networks vs. mosaic approach?**
  - **Need to improve plant phenology, root uptake, soil moisture representation.**
  - Variety of models available for evaporation. What is best application of the various strategies? Is a coordinated modelling strategy desirable?
  - Possibility of using hydrological/agricultural models to model drought evaporation, concern on
    - what information from streamflow can add during drought when contributing areas are small
    - Model parameterizations
  - **Need to address changing landscape structure – drying wetlands/lakes, changing root zone, changing land use.**
  - Snow redistribution modelling ready for LSS, hydrological models
  - Satellite data assimilation useful way to set parameters and provide inputs (surface temperature, radiation)
  - **Feedbacks to atmosphere from evaporation can be important in convection**
  - Coupled land surface hydrology models as drought indices (MESH, VIC, VSMB, CRHM, PAM2, EALCO)

Discussion Questions/Answers

- What are the requirements for data and what is the availability of data for calculating evaporation?
  - We need a soil moisture observation network…..
- Are current evaporation estimation techniques suitable for calculating evaporation (for atmosphere, soil, water resources)
  - No. Problem with short term estimates, problem with soil moisture link via continuity and resistances
- How might we better estimate evaporation in drought and use estimates to assess drought severity
  - Evaporation estimates in drought are completely controlled by moisture storage and this involves deep soil moisture and groundwater as a continuum
- How might the hydrometeorological community reduce uncertainty and improve accuracy of evaporation estimates in atmospheric, agricultural and hydrological models? WHAT CAN DRI CONTRIBUTE TO THIS?
  - Prairie parallel to BERMS – observational grid with model runs, algorithm testing, remote sensing, tests of data assimilation

Workshop Summary

- What can DRI do?
  - Show how to use available data (surface obs, soil moisture, earth observation, model outputs) for calculating evaporation
  - Suggest improvements to evaporation calculation routines
  - Show how evaporation can be used in drought indices

DRI Soil Moisture Interests

- Need to characterize soil moisture spatially and temporally for the recent drought (lack of data!!)
- Need to understand how soil moisture storage interacts with drought evolution, including feedbacks to the atmosphere.
- Need to model soil moisture storage and surface interactions in drought accurately in order to better predict drought, water supply, evaporation and atmospheric feedbacks

DRI

DROUGHT RESEARCH INITIATIVE

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