Environment and Sustainable Resource Development

Environmental Modelling Workshop 2013

Simulating Hydrological Behaviour Under Environmental Change in Alberta

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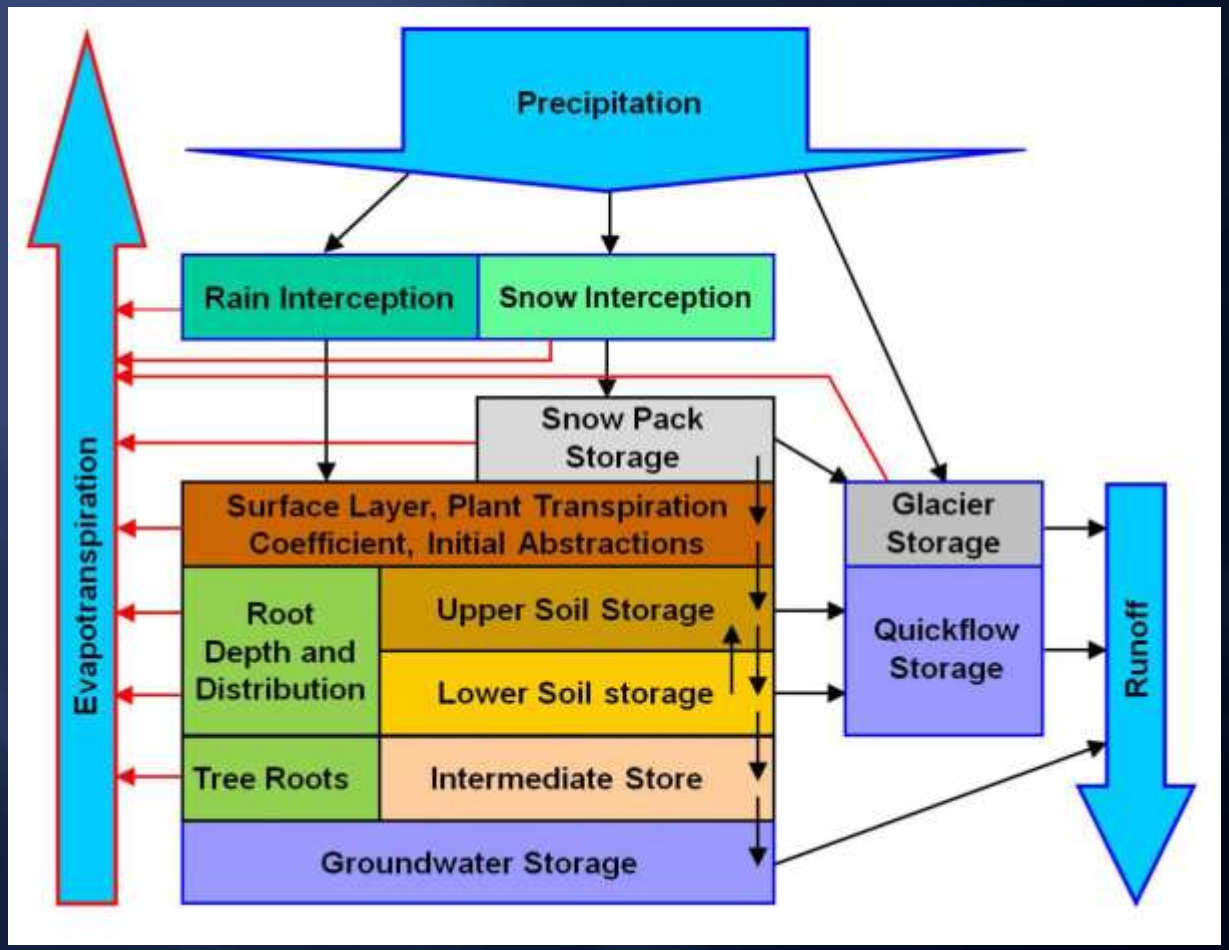
ACRU agro-hydrological modelling system

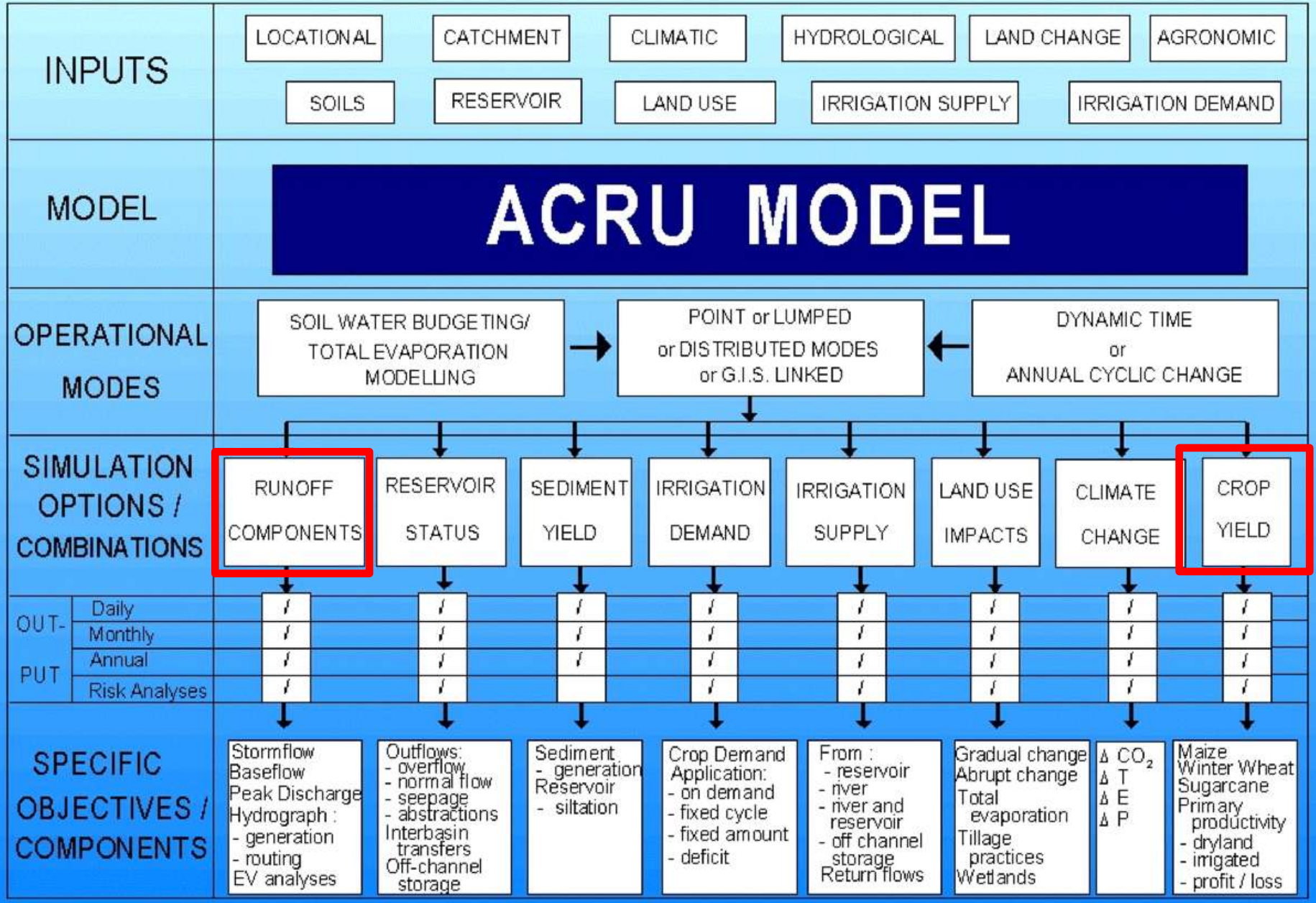


Multi-purpose

Multi-level

Integrated physical model

- Actual evaporation
- Soil water and groundwater storages
- Snow
- (Glaciers)
- Land cover and abstraction impacts on water resources
- Streamflow at a daily time step.


INPUTS
LOCATIONAL
CATCHMENT
CLIMATIC
HYDROLOGICAL
LAND CHANGE
AGRONOMIC
SOILS
RESERVOIR
LAND USE
IRRIGATION SUPPLY
IRRIGATION DEMAND
MODEL
ACRU MODEL
OPERATIONAL MODES
SOIL WATER BUDGETING/ TOTAL EVAPORATION MODELLING
POINT or LUMPED or DISTRIBUTED MODES or G.I.S. LINKED
DYNAMIC TIME or ANNUAL CYCLIC CHANGE
SIMULATION OPTIONS / COMBINATIONS
RUNOFF COMPONENTS
RESERVOIR STATUS
SEDIMENT YIELD
IRRIGATION DEMAND
IRRIGATION SUPPLY
LAND USE IMPACTS
CLIMATE CHANGE
CROP YIELD
OUT-PUT
Daily
Monthly
Annual
Risk Analyses
SPECIFIC OBJECTIVES / COMPONENTS
Stormflow
Baseflow
Peak Discharge
Hydrograph :
- generation
- routing
EV analyses
Outflows:
- overflow
- normal flow
- seepage
- abstractions
Interbasin transfers
Off-channel storage
Sediment
- generation
Reservoir
- siltation
Crop Demand
Application:
- on demand
- fixed cycle
- fixed amount
- deficit
From :
- reservoir
- river
- river and reservoir
- off channel storage
Return flows
Gradual change
Abrupt change
Total evaporation
Tillage practices
Wetlands
Δ CO2
Δ T
Δ E
Δ P
Maize
Winter Wheat
Sugarcane
Primary productivity
- dryland
- irrigated
- profit / loss

ACRU agro-hydrological modelling system

Applications in:

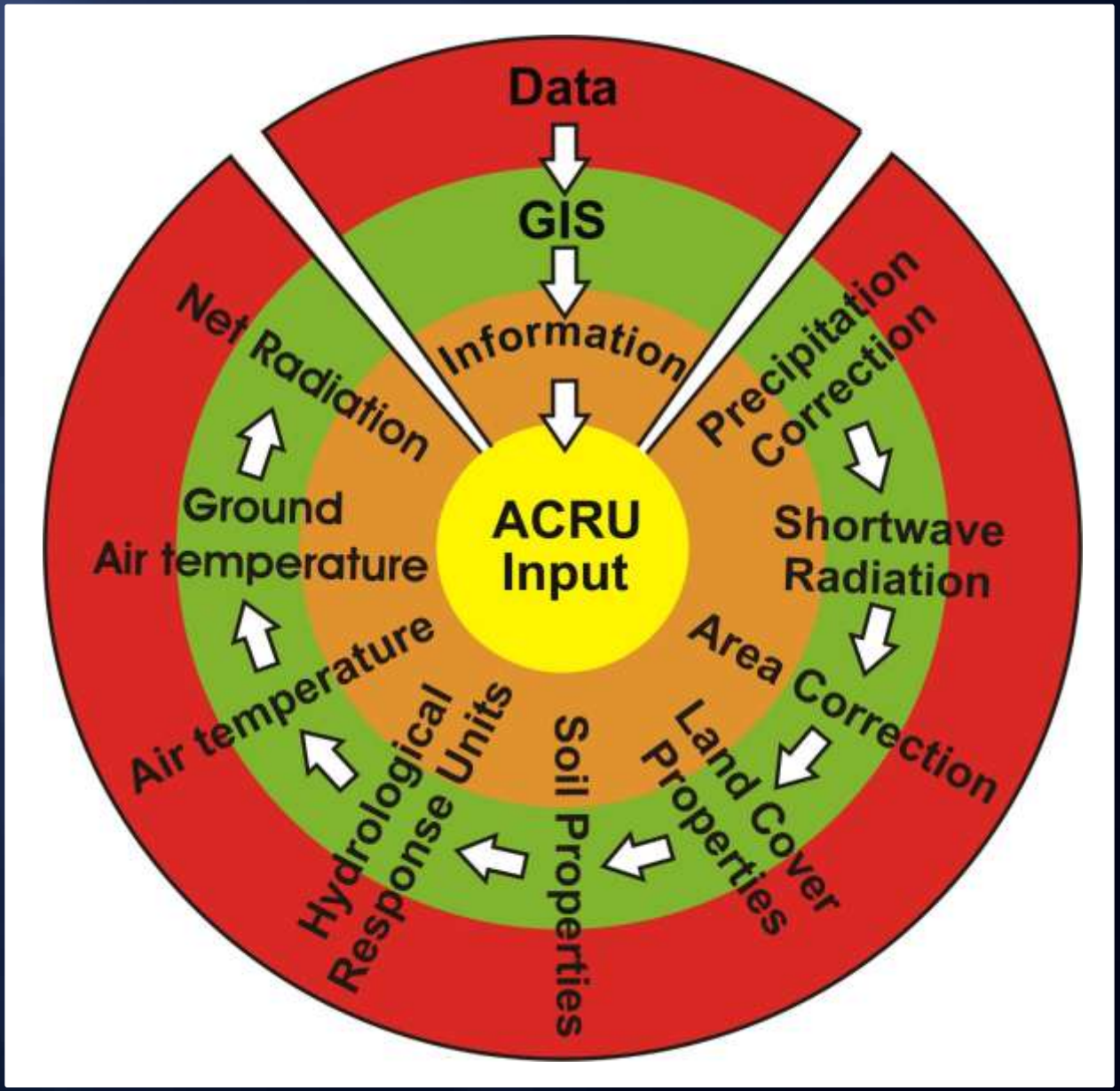
- Water resource assessments
  - (Everson, 2001; Kienzle *et al*, 1997; Schulze *et al.*, 2004)
- Flood estimation
  - (Smithers *et al.*, 1997; 2001; 2012)
- Land use impacts
  - (Kienzle and Schulze, 1991; Tarboton and Schulze, 1993, Kienzle, 2008)
- Climate change impacts
  - (New, 2003; Schulze *et al.*, 2004; Forbes *et al.*, 2011; Nemeth et al., 2012; Kienzle et al., 2012)
- Irrigation supply & demand
  - (Dent, 1988; Kienzle, 2008)

Actual Evapotranspiration

Monthly values for

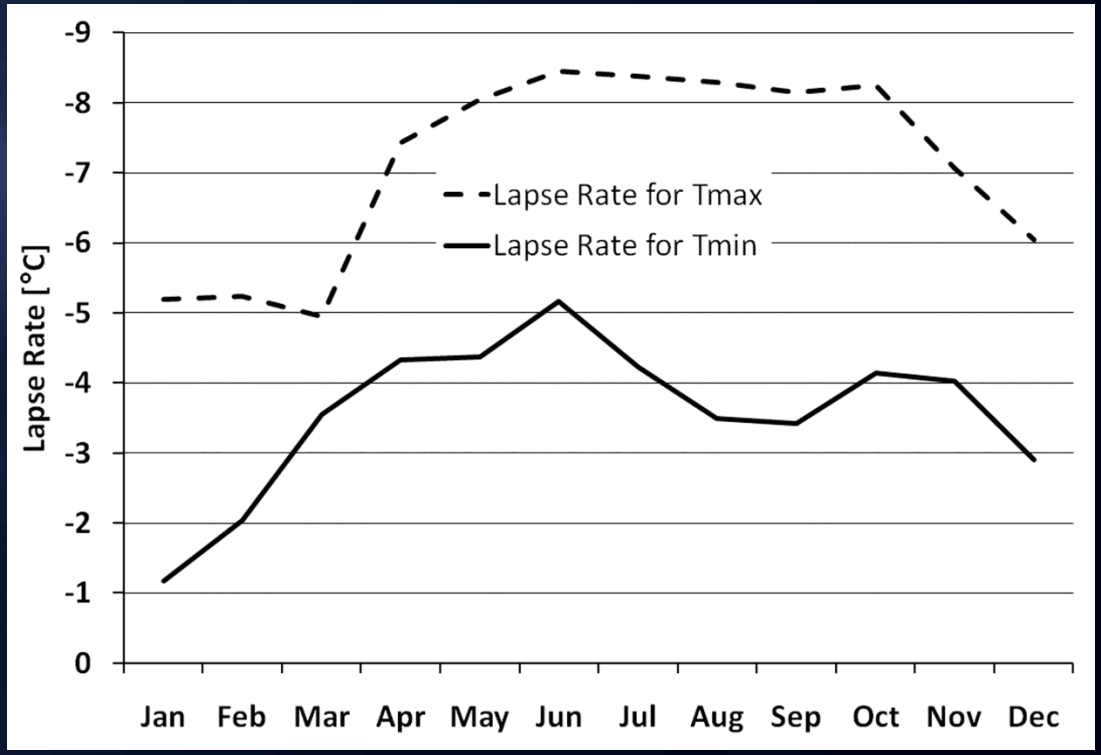
- Plant Transpiration Coefficient
  - = crop coefficient
- Stress threshold
- Interception
- Root distribution
- Initial abstractions

Extensive Data Pre-processing



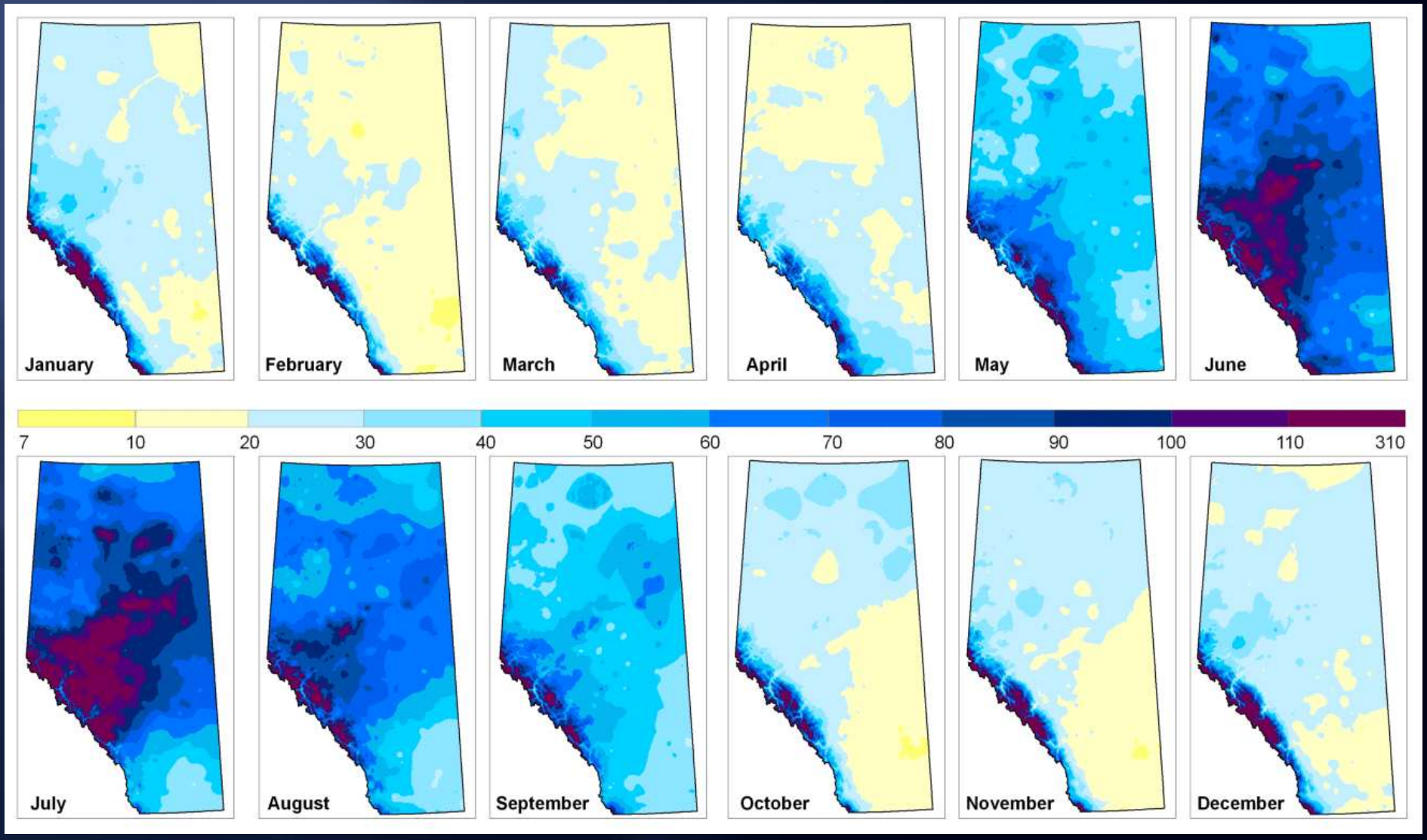
Seasonality of many variables

- Lapse rates
- Wind speed
- Relative humidity
- Albedo
- Radiation
- Sunshine hours



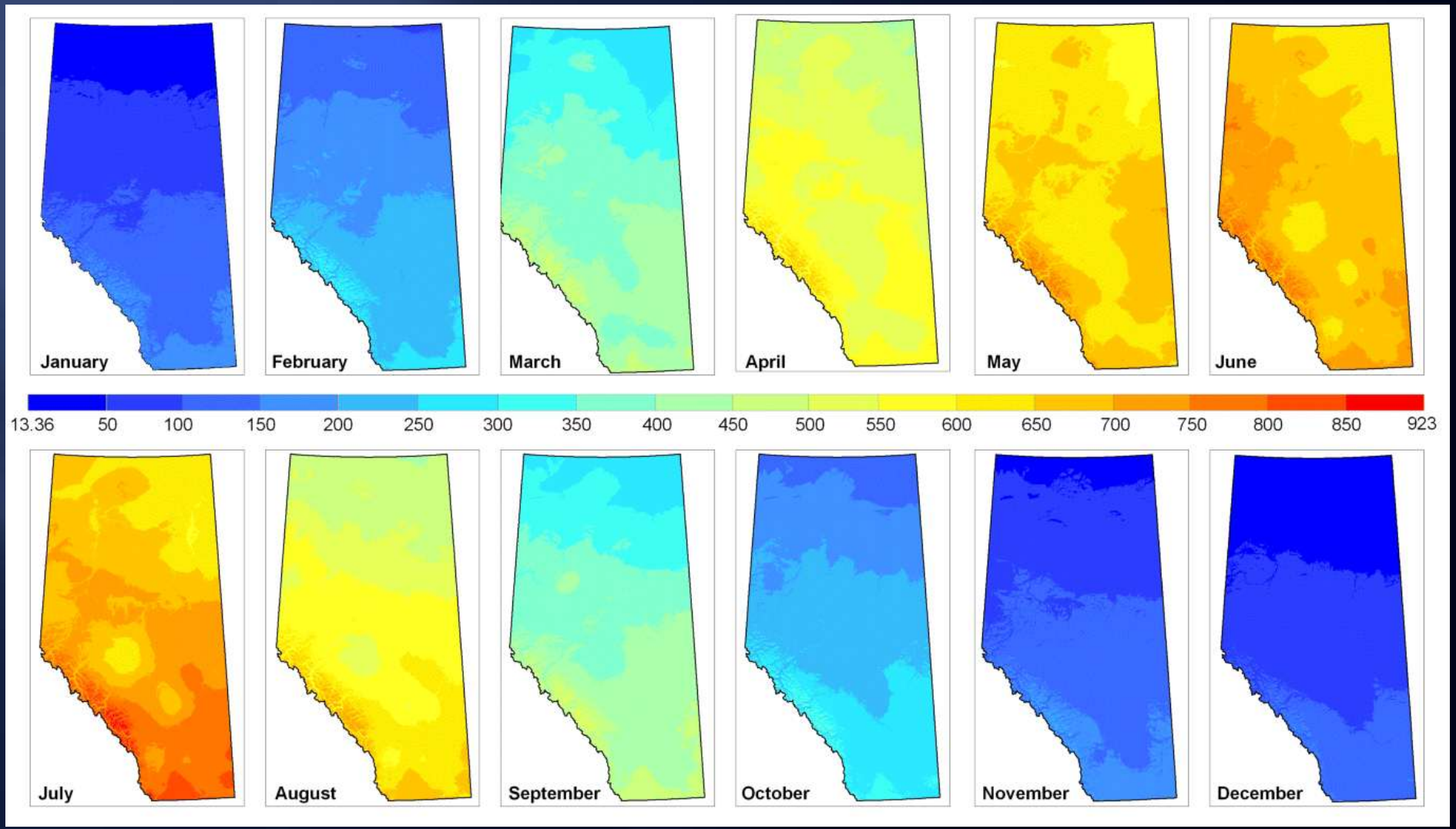
PRISM Mean Monthly Precipitation (1971-2000)

[mm month-1]

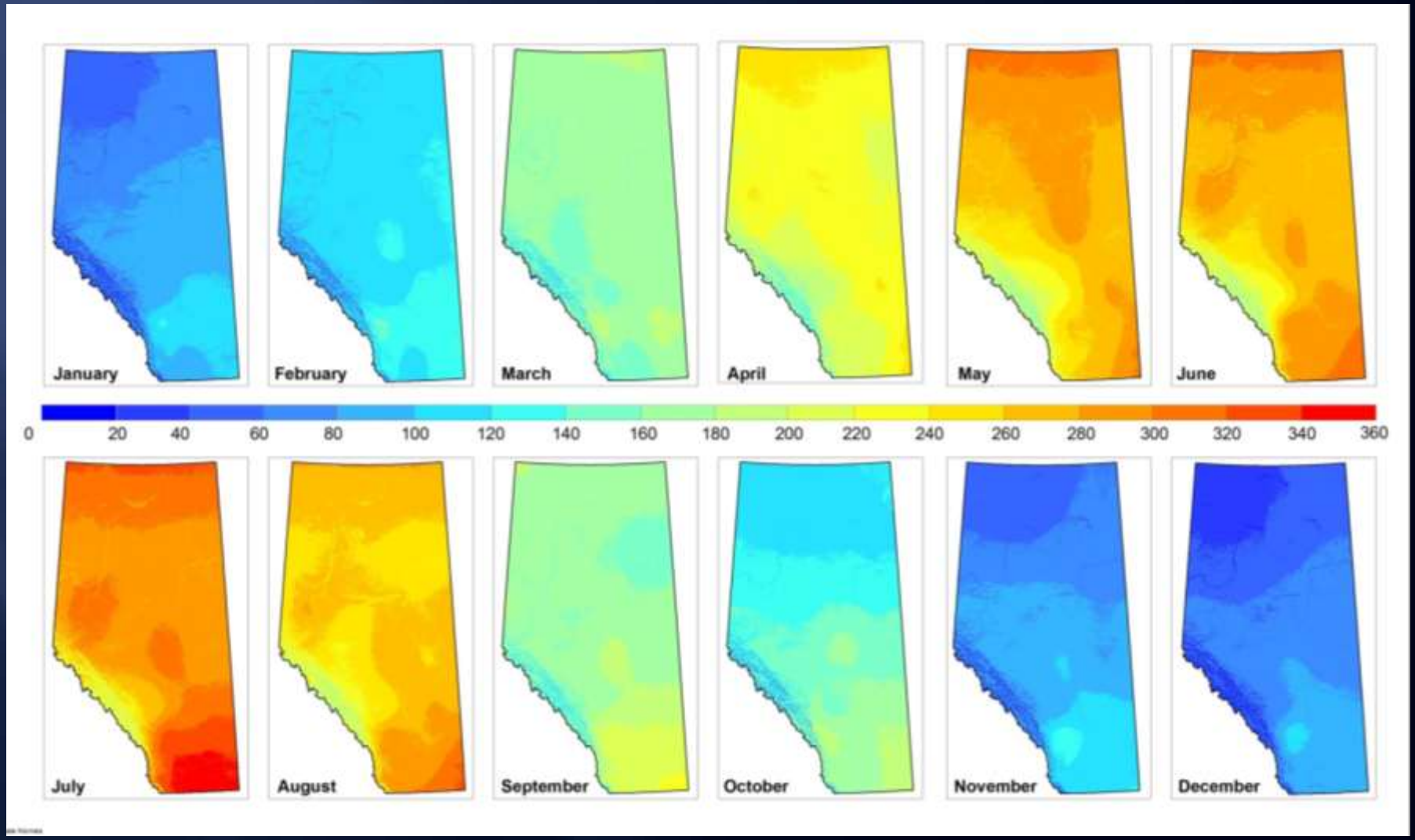


Mean Monthly Incoming Solar Radiation

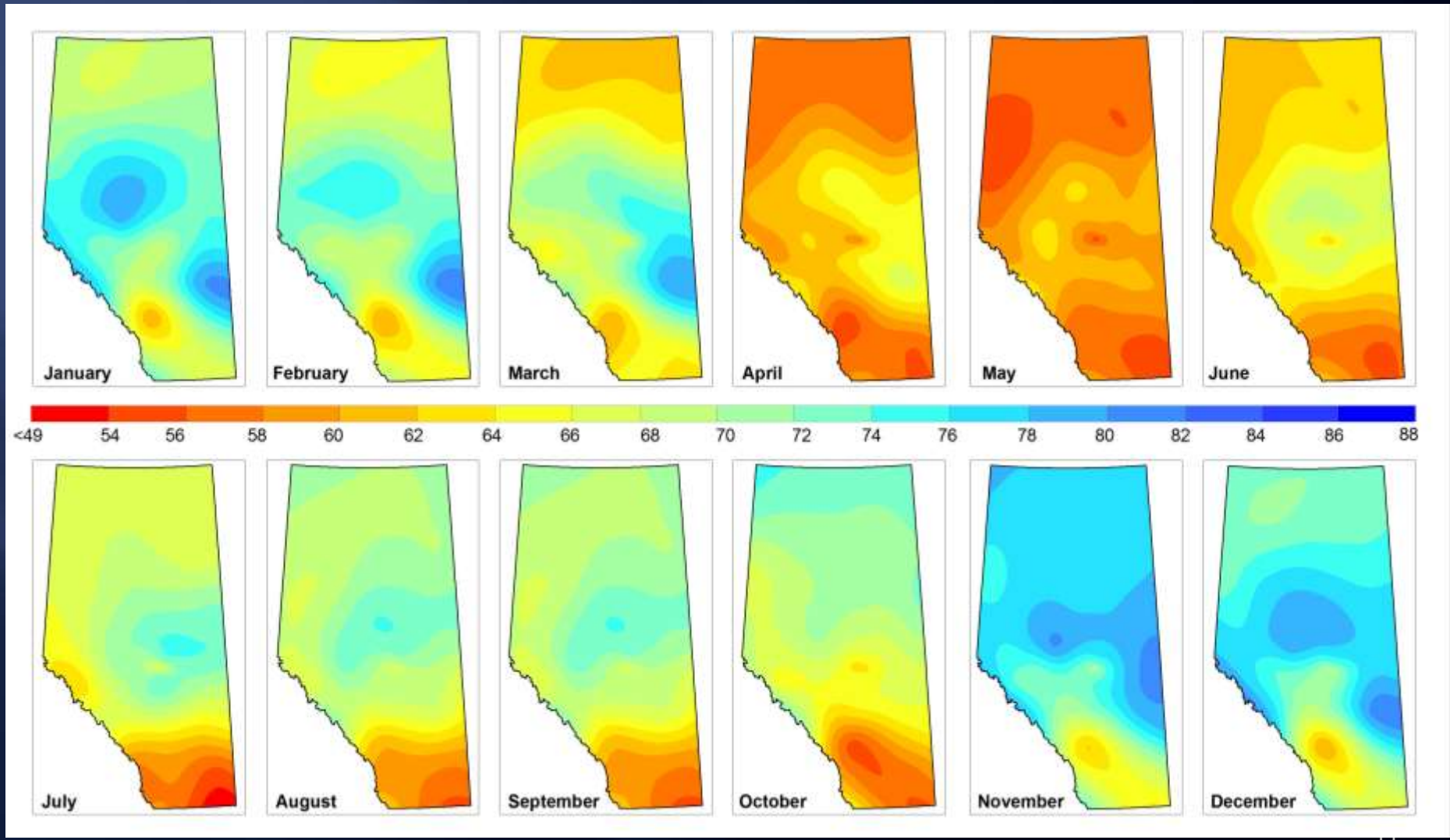
[MJ m-2 month-1]



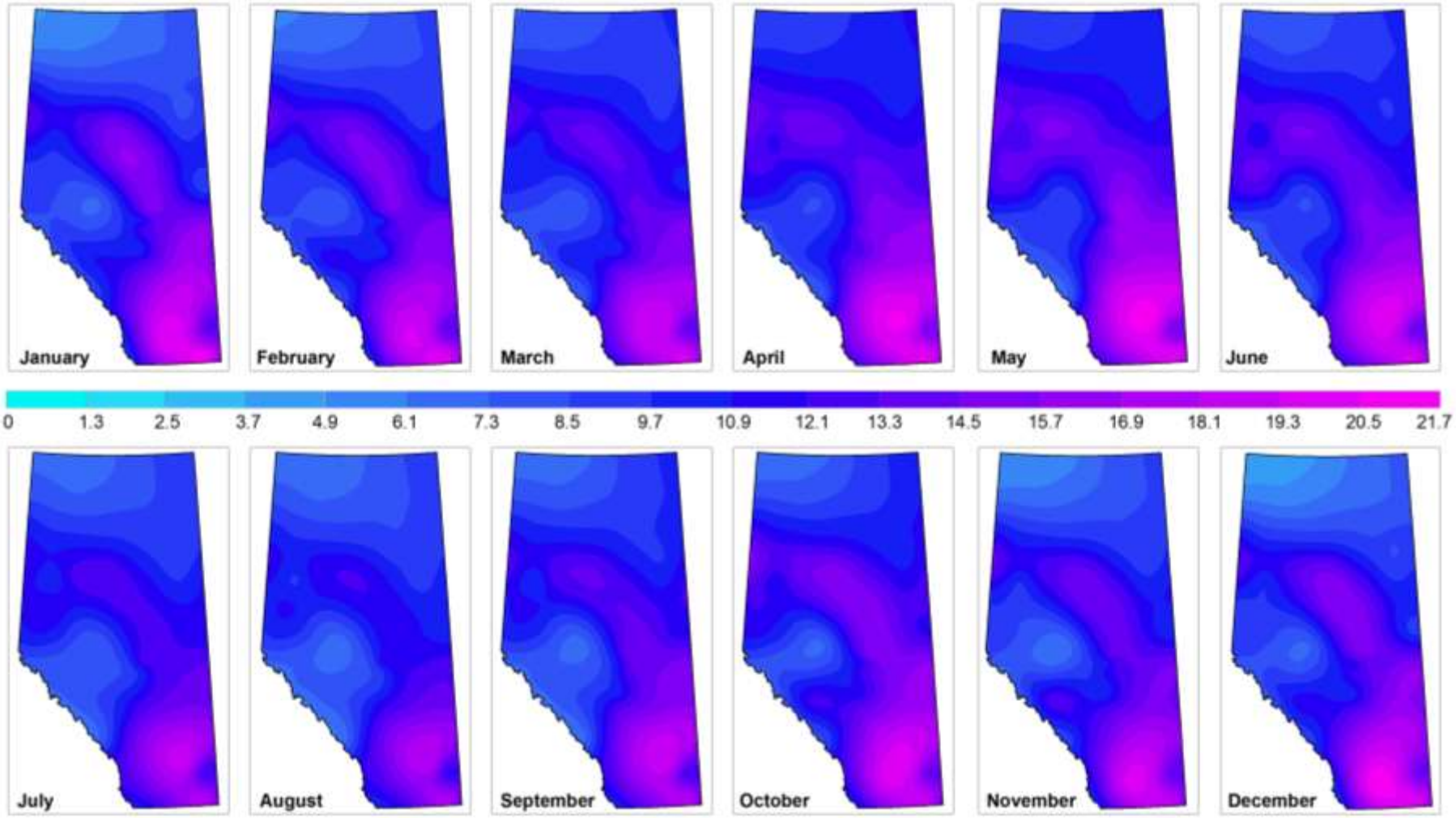
Mean Monthly Sunshine Hours



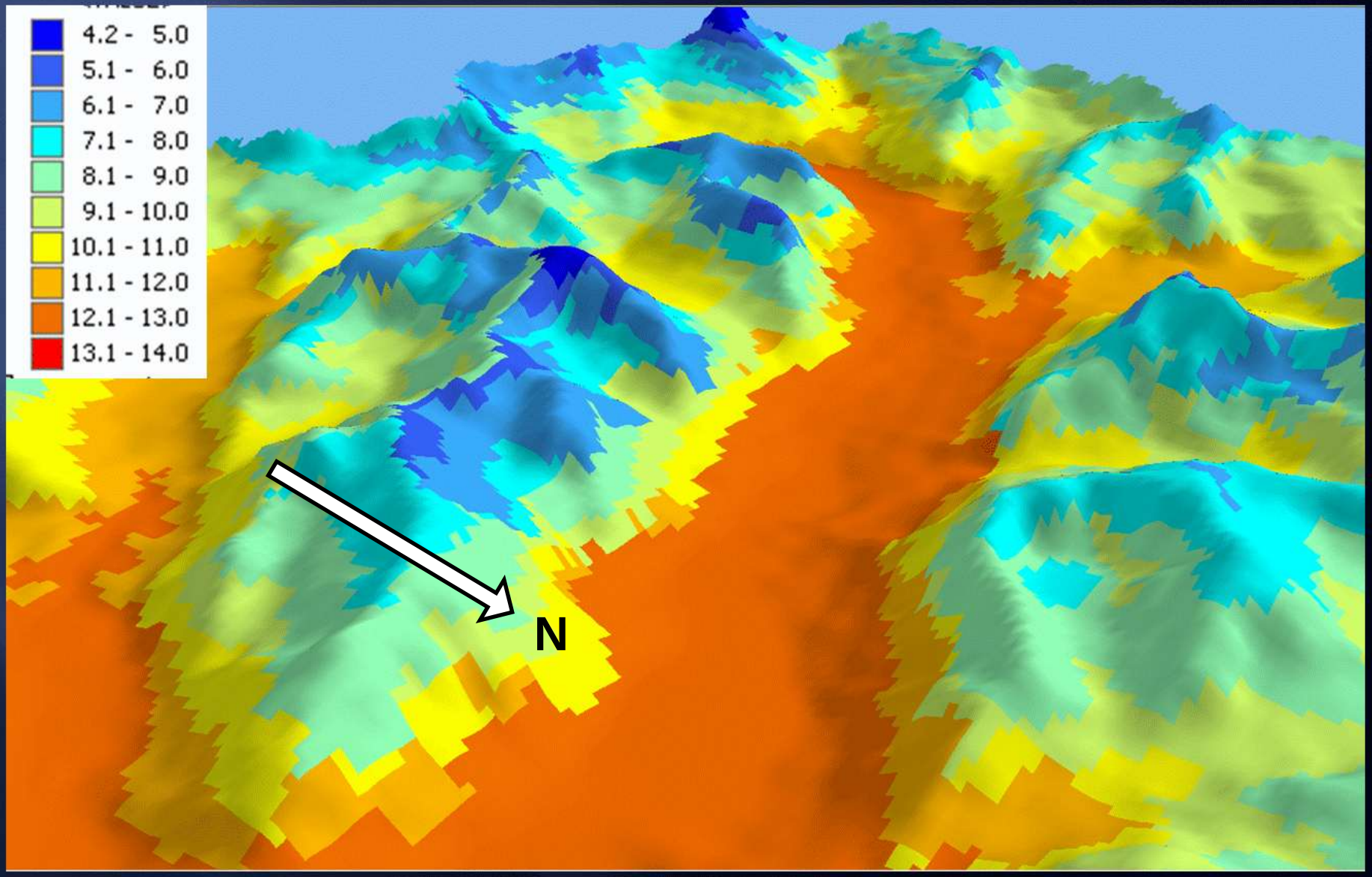
Mean Monthly Relative Humidity [%]



Mean Monthly Wind Speed [km/hr]



MEAN ANNUAL MAX. TEMPERATURE – ADJUSTED



Example Application: Impacts of Climate Change Modelling Approach

1. Setup of all input variables for the physical-based hydrological model

2. Verify baseline (1961-1990) output against observations
   - Air temperature
   - Snow pack (SWE)
   - Streamflow
     - – calibrate within physically meaningful boundaries

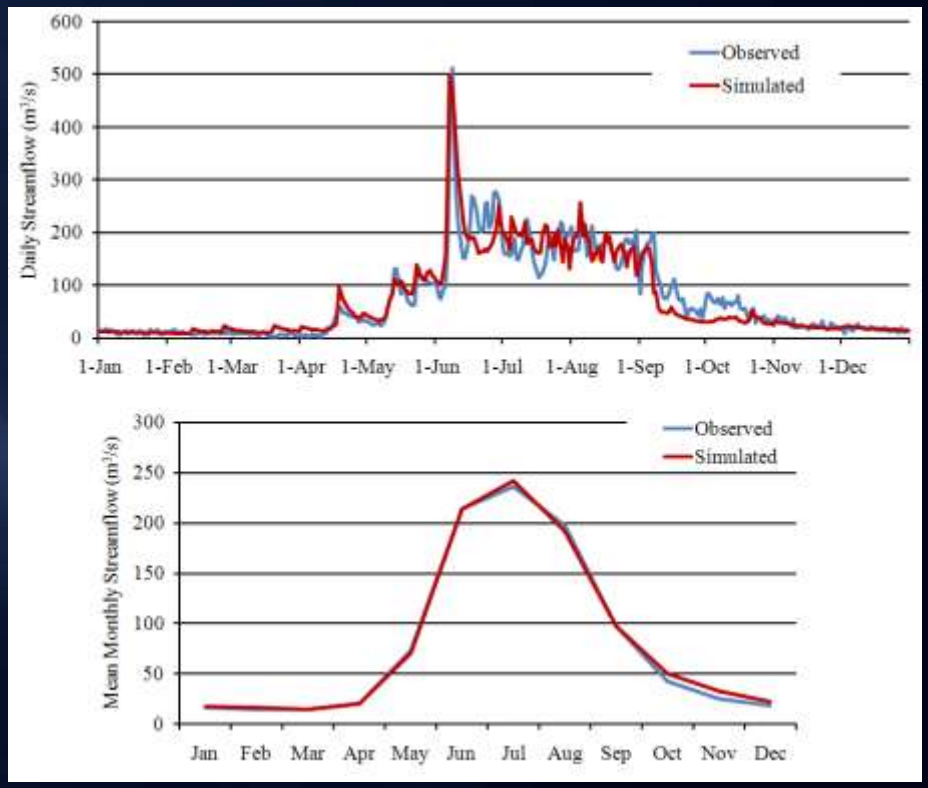
3. Simulate hydrology under environmental change

   - Risk analysis for operational hydrology

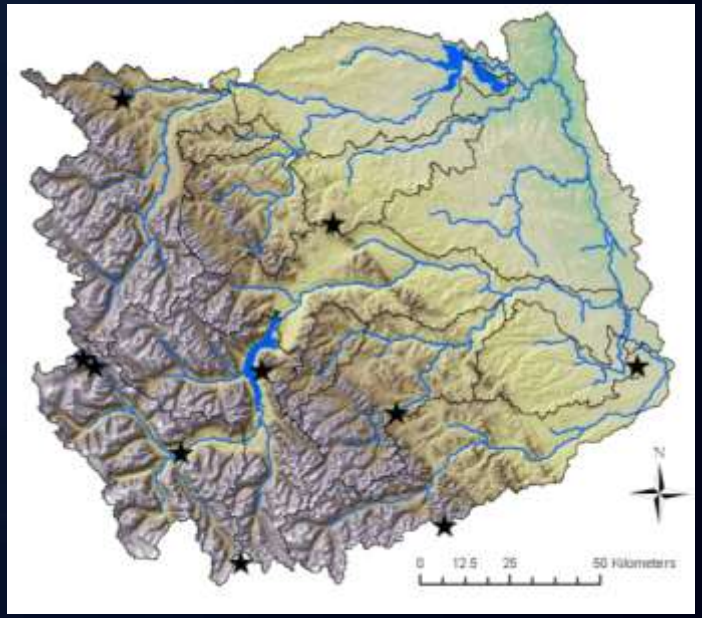
Simulation Objectives: Operational Hydrology

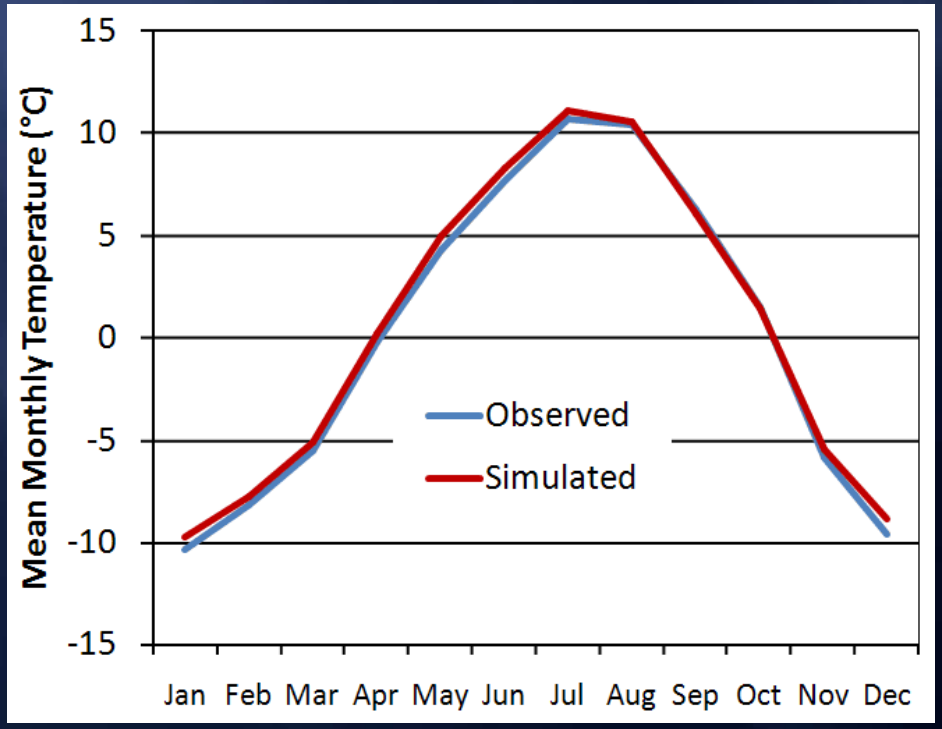
Simulate streamflow for the base period 1961-1990 to replicate these characteristics:

- Annual water yield
- Seasonality
- Shape of hydrographs
- Timing of snowmelt
- Peak flows
- Low flows
- Variance



Temperature Verification

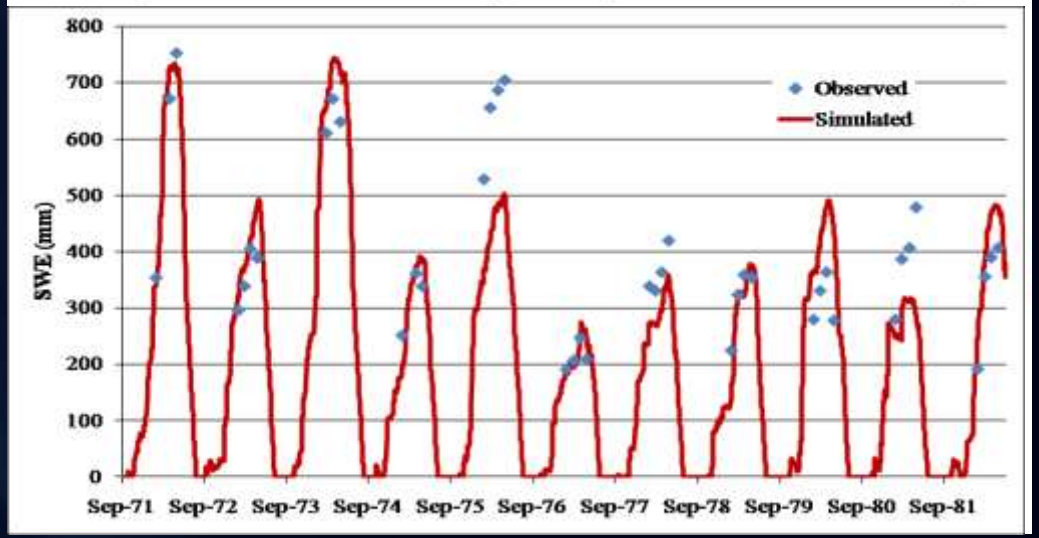




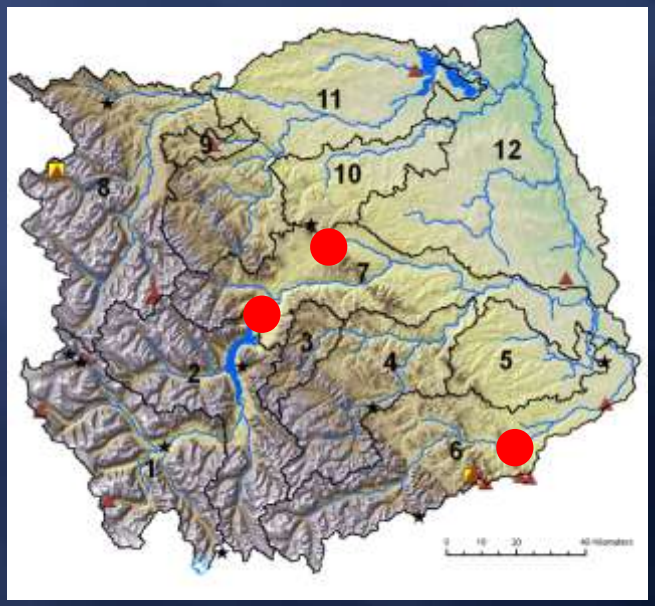
	Daily	Monthly
N	37402	499
Observed Mean (°C)	3.30	0.40
Simulated Mean (°C)	3.67	0.77
P(T<=t) two-tail	0.00	0.46
Observed Variance	78.98	67.04
Simulated Variance	75.48	64.59
% Difference	-4.64	-3.79
Coefficient of Determination (r^2)	0.88	0.98
Regression Coefficient (Slope)	0.92	0.97
Regression Intercept	0.75	0.39

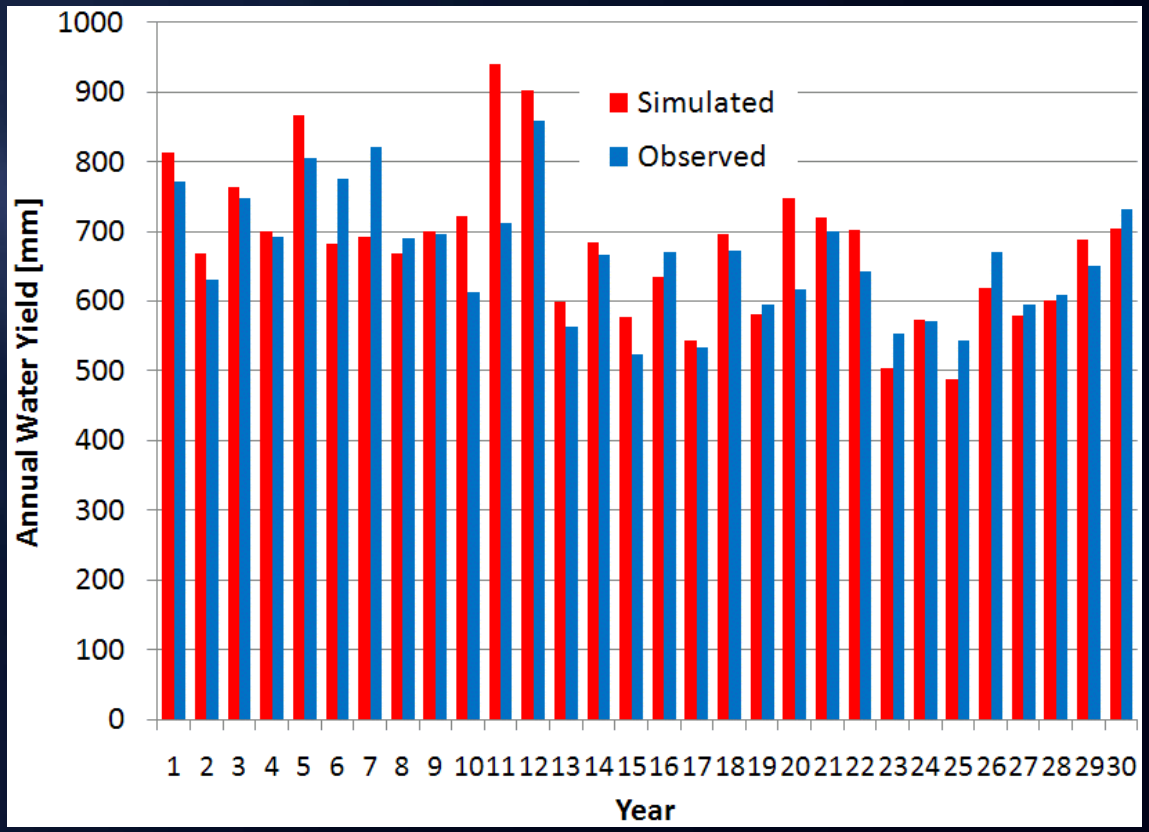
Snow Verification

- Average conditions and their variance are simulated successfully.

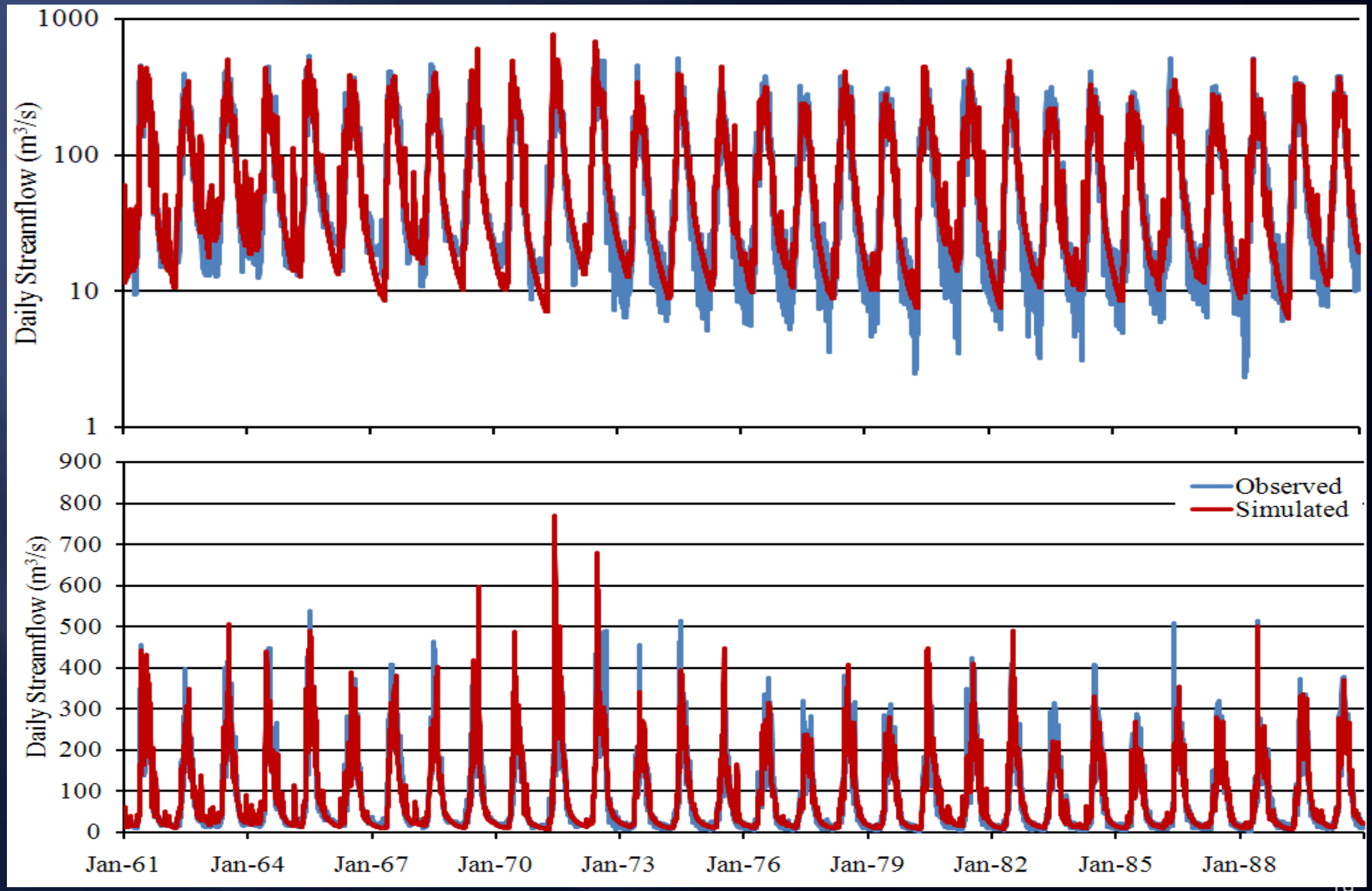


Simulated and Observed Annual Streamflow





Simulated and Observed Daily Streamflow

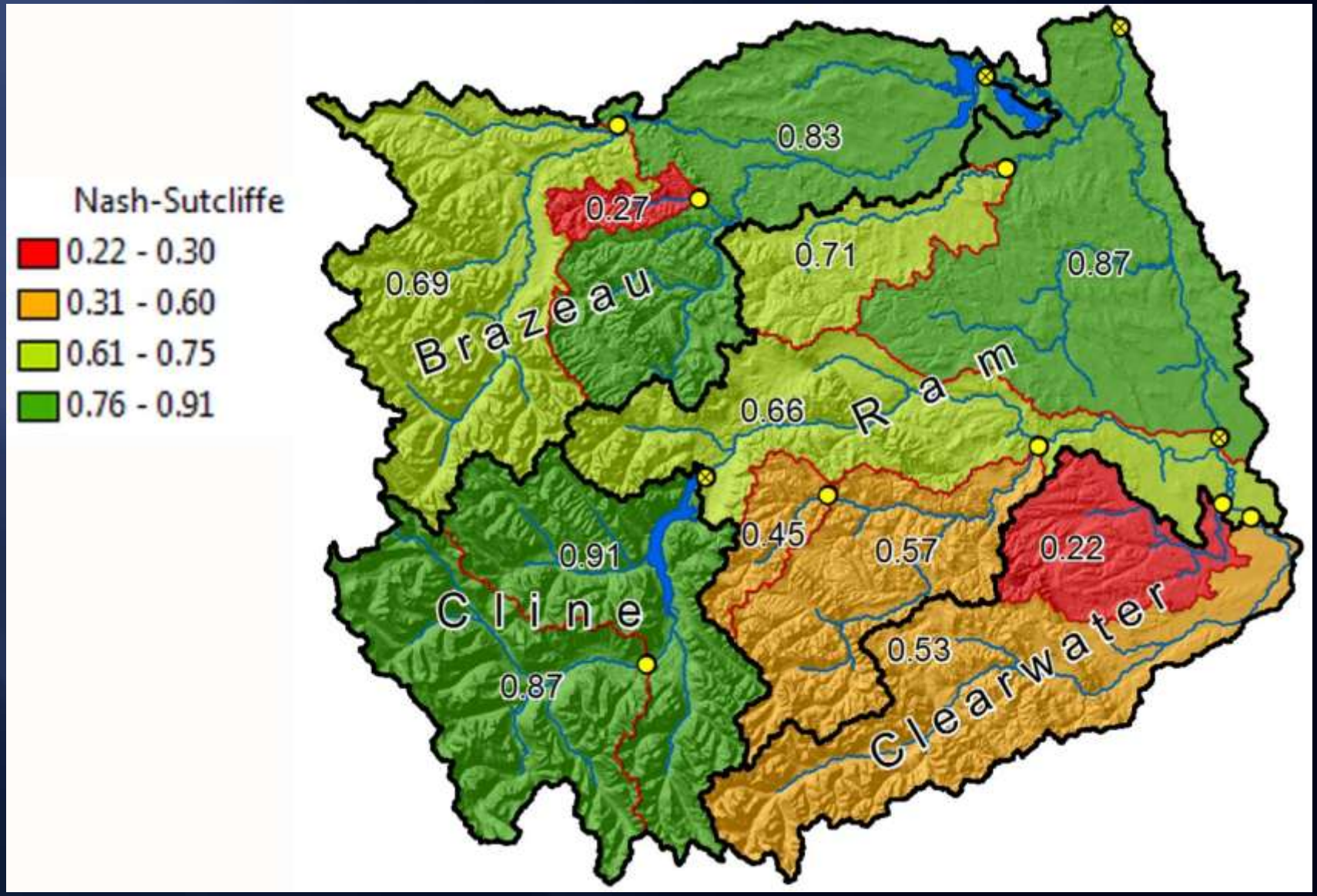


Cline River: Simulated and observed streamflow

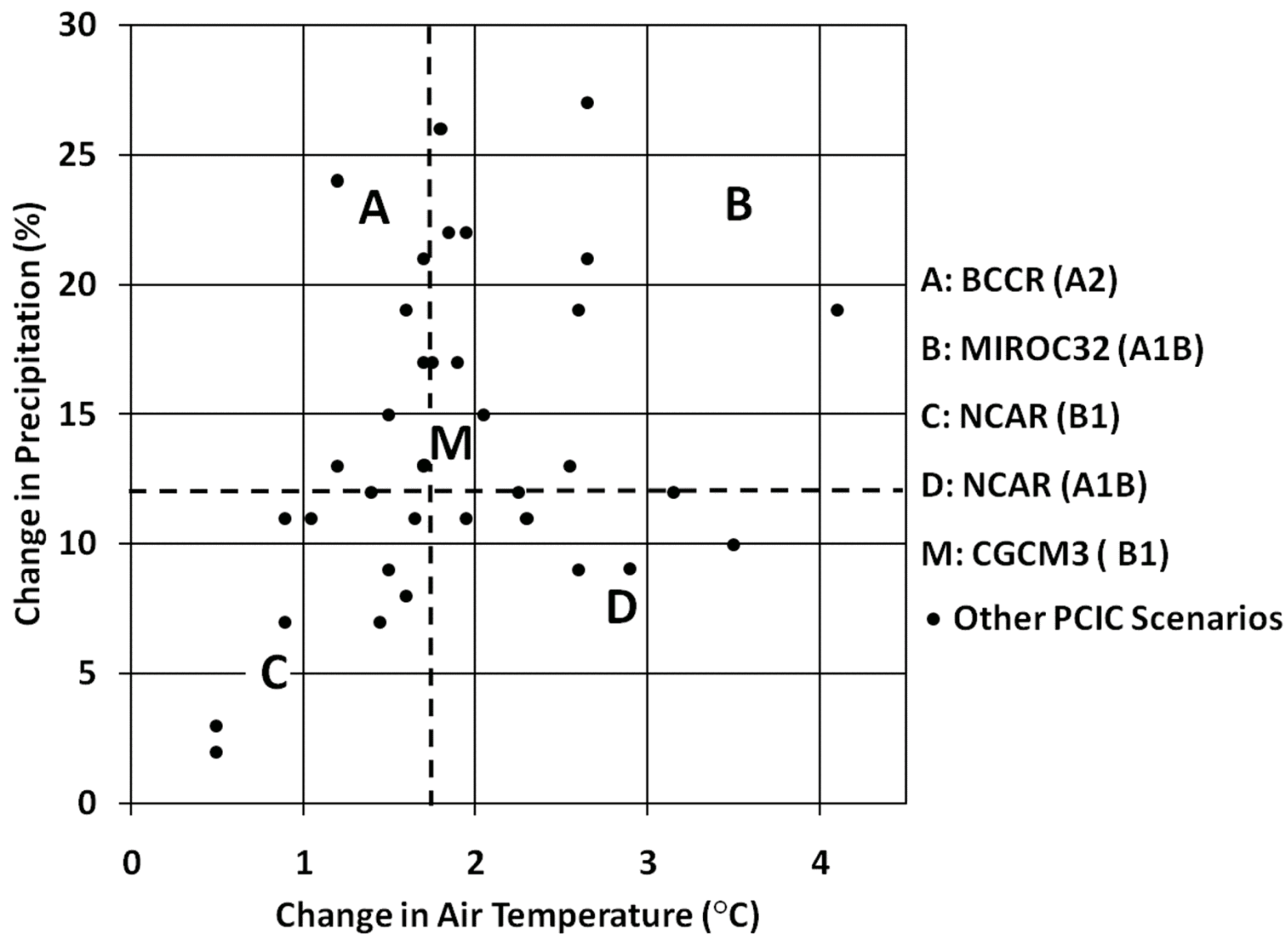
	1961-90	
	Daily	Monthly
Observed Sample Size (Days/Months)	10957	360
Simulated Sample Size (Days/Months)	10957	360
Observed Mean (m^3/s)	81.18	80.77
Simulated Mean (m^3/s)	82.95	82.54
% Difference	2.13	2.14
P(T<=t) two-tail	0.16	0.78
Observed Variance	8756.30	7419.40
Simulated Variance	8445.30	7401.60
% Difference	-3.68	-0.24
Observed Standard Deviation	93.58	86.14
Simulated Standard Deviation	91.90	86.03
% Difference	-1.82	-0.12
Coefficient of Determination (r^2)	0.83	0.92
Regression Coefficient (Slope)	0.89	0.96
Regression Intercept	0.23	0.11

Upper North Saskatchewan River Simulation

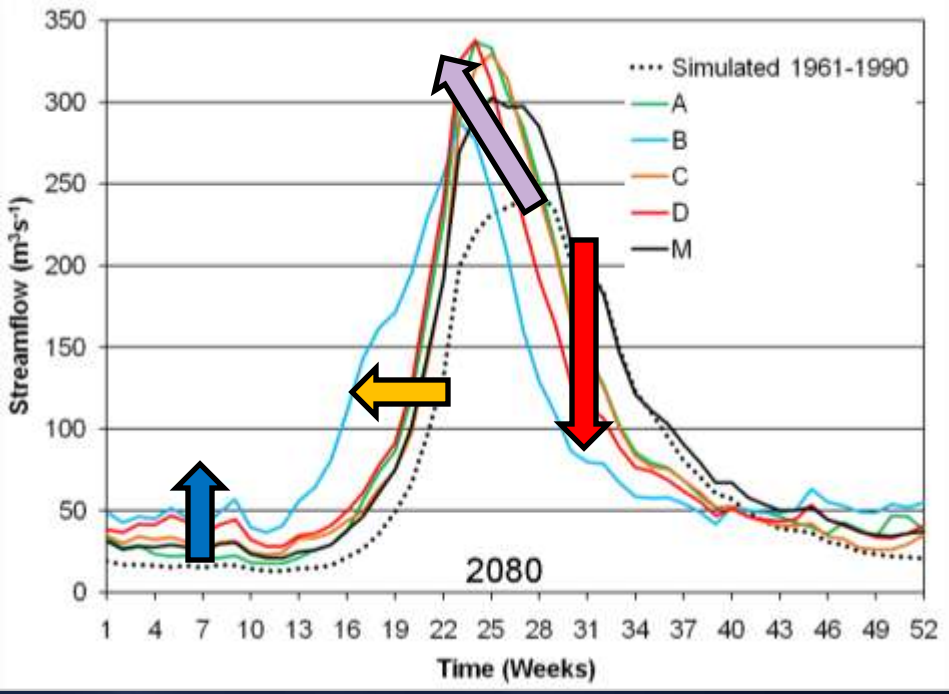
Nash-Sutcliffe Efficiency coefficients for 12 sub-watershds

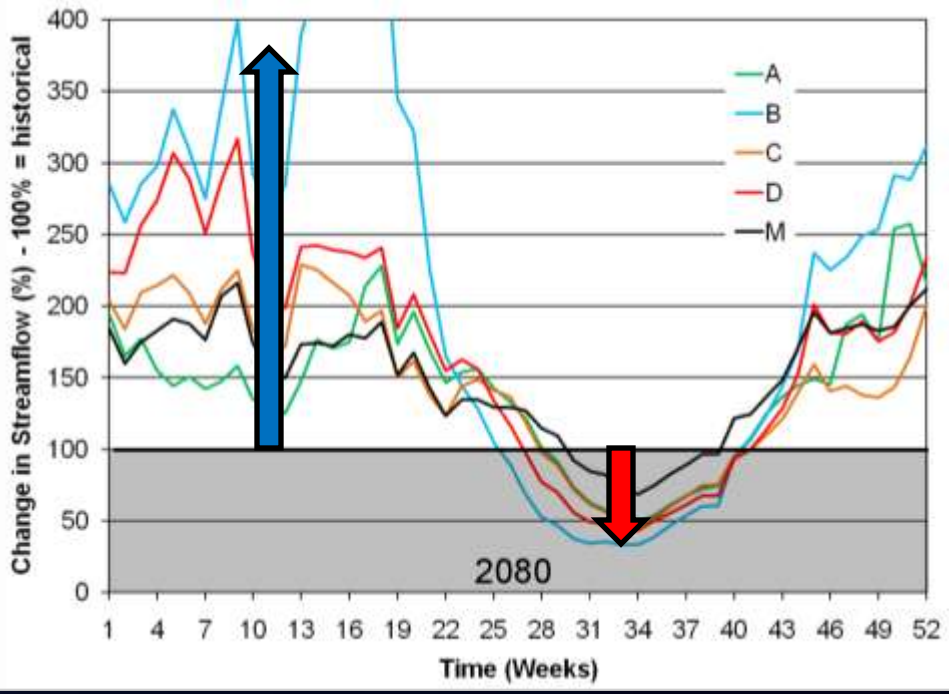


Selection of Climate Scenarios

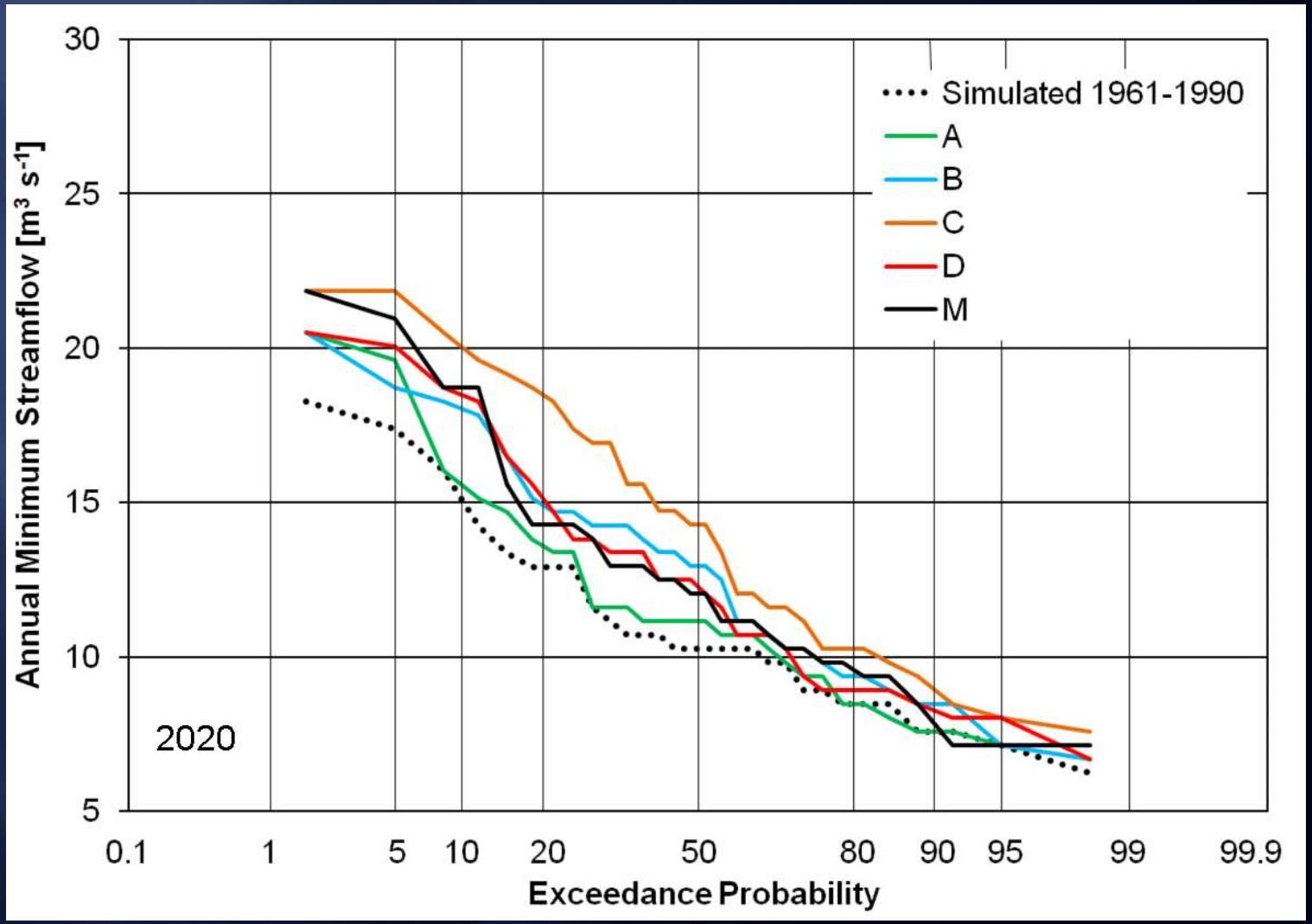


Cline River: Streamflow Impacts 2040-2069





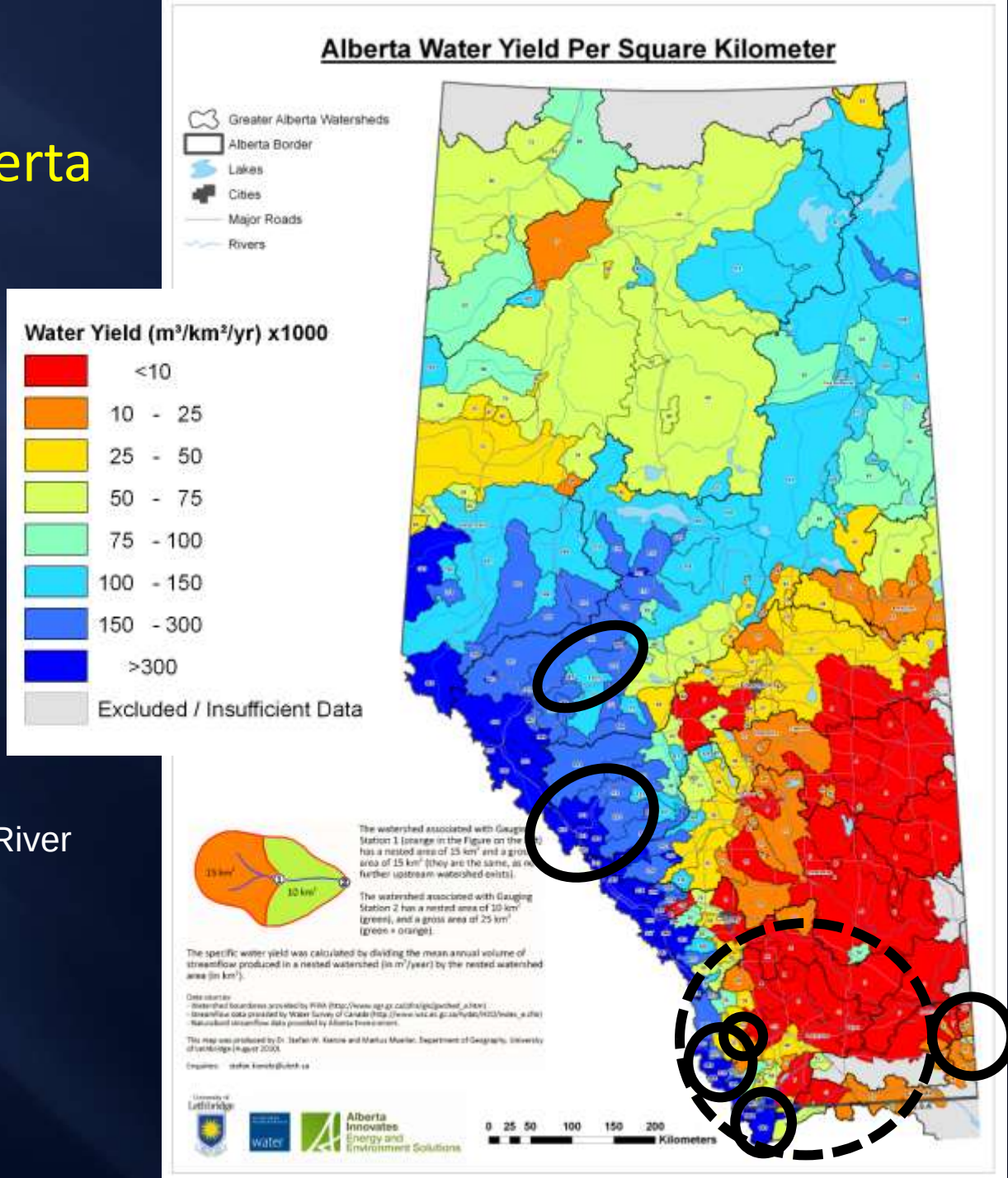
Cline River: Annual Minimum Streamflow Exceedance Probability: 2020



Many hydro-climatological variables

- Daily time series for each HRU:
  - 52 variables
    - Streamflow
    - Groundwater contribution
    - Potential evapotranspiration
    - Actual evapotranspiration
      - Evaporation
      - Transpiration
    - Soil water storage
      - Soil water deficit
      - Groundwater recharge
      - Irrigation demand
    - .....

Water Yield in Alberta



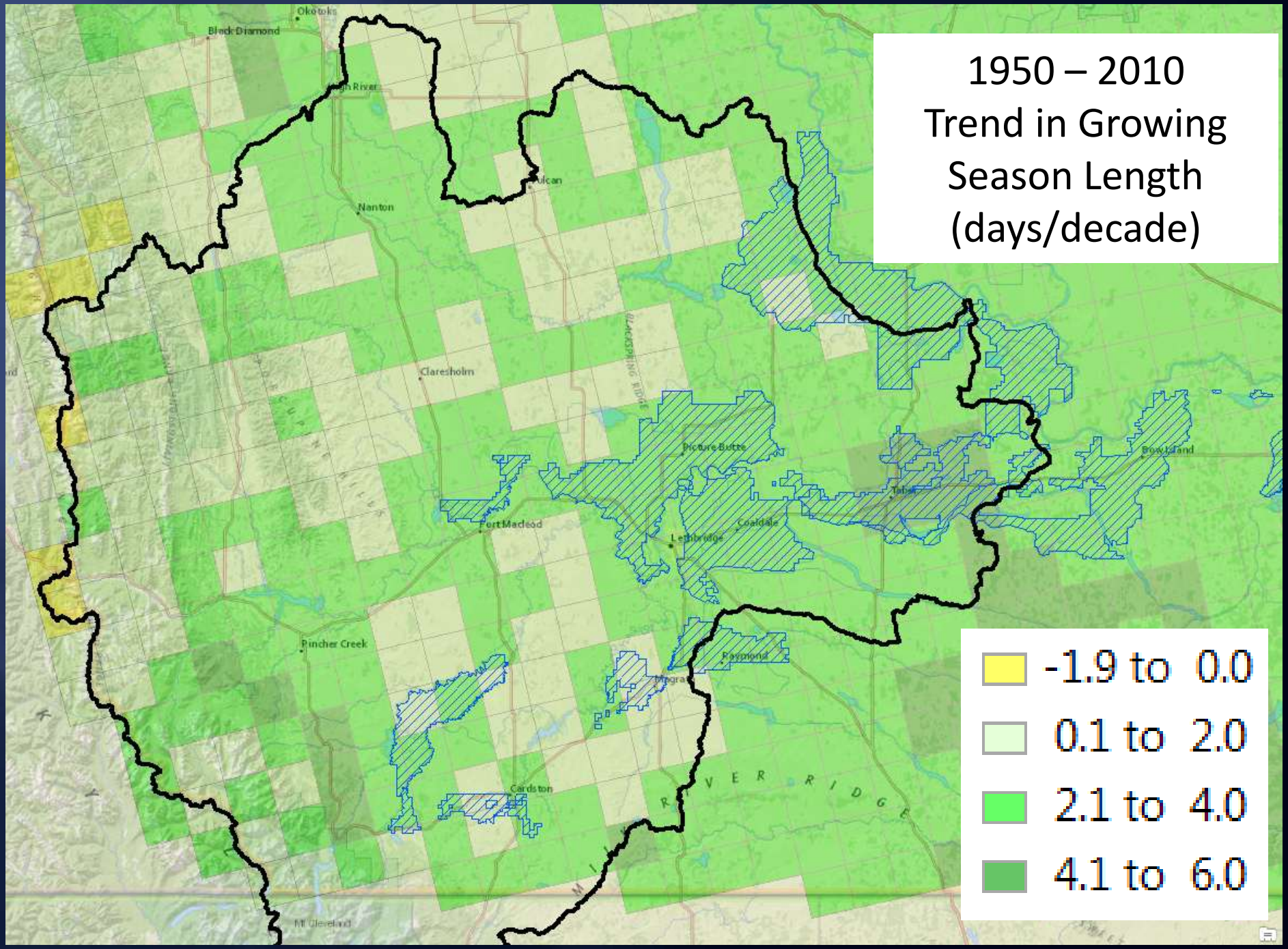
ACRU Simulations in:

- Upper North Saskatchewan River
- Castle River
- St. Mary's River
- Beaver Creek
- Swift Current Creek
- Oldman River
- McLeod River

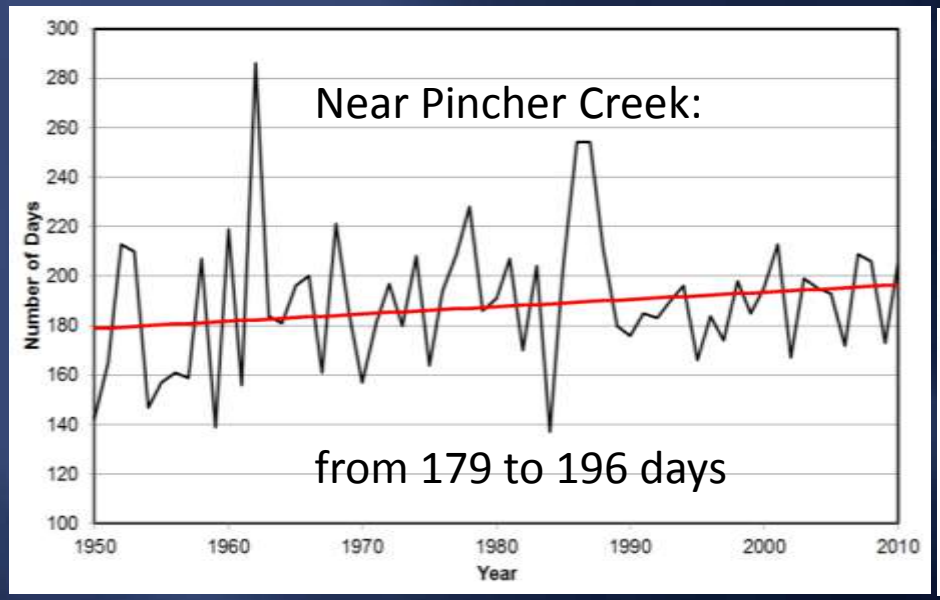
The ACRU model is used as a translator of climate change and land cover scenarios into hydrological responses.

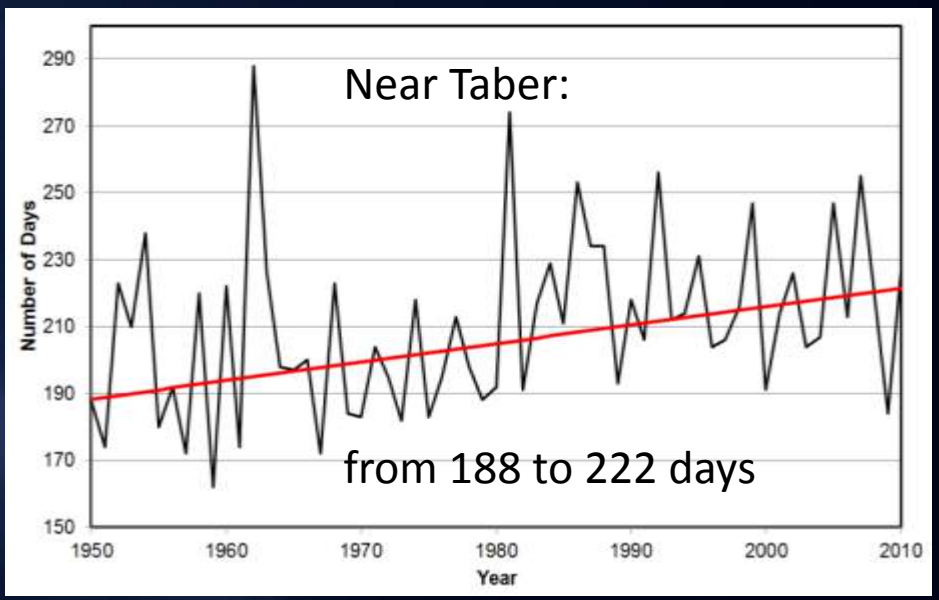
Land Use Impacts on Streamflow
Mgeni Watershed

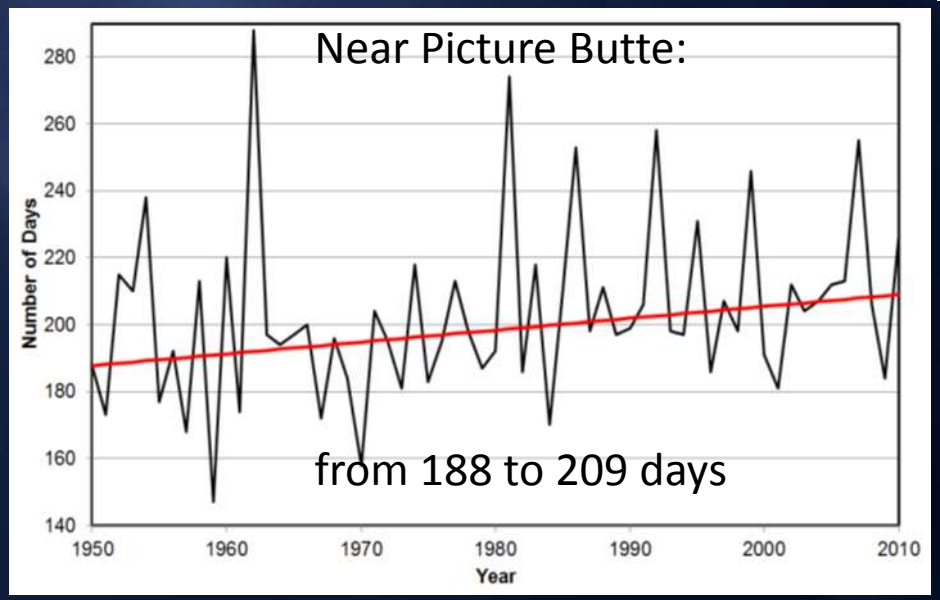
Scenario		Mean annual runoff (mm)			
		Lions MC (MAP = 979 mm)		Karkloof MC (MAP = 1 081 mm)	
A	Baseline land cover	233.4		345.6	
B	Present land use	204.5	(–12.4%)	277.6	(–19.7%)
C	Baseline + irrigation	180.2	(–22.8%)	319.7	(–7.5%)
D	Baseline + afforestation	192.9	(–17.4%)	272.0	(–21.3%)
E	Baseline + 2 × afforestation	178.4	(–23.6%)	241.6	(–30.1%)

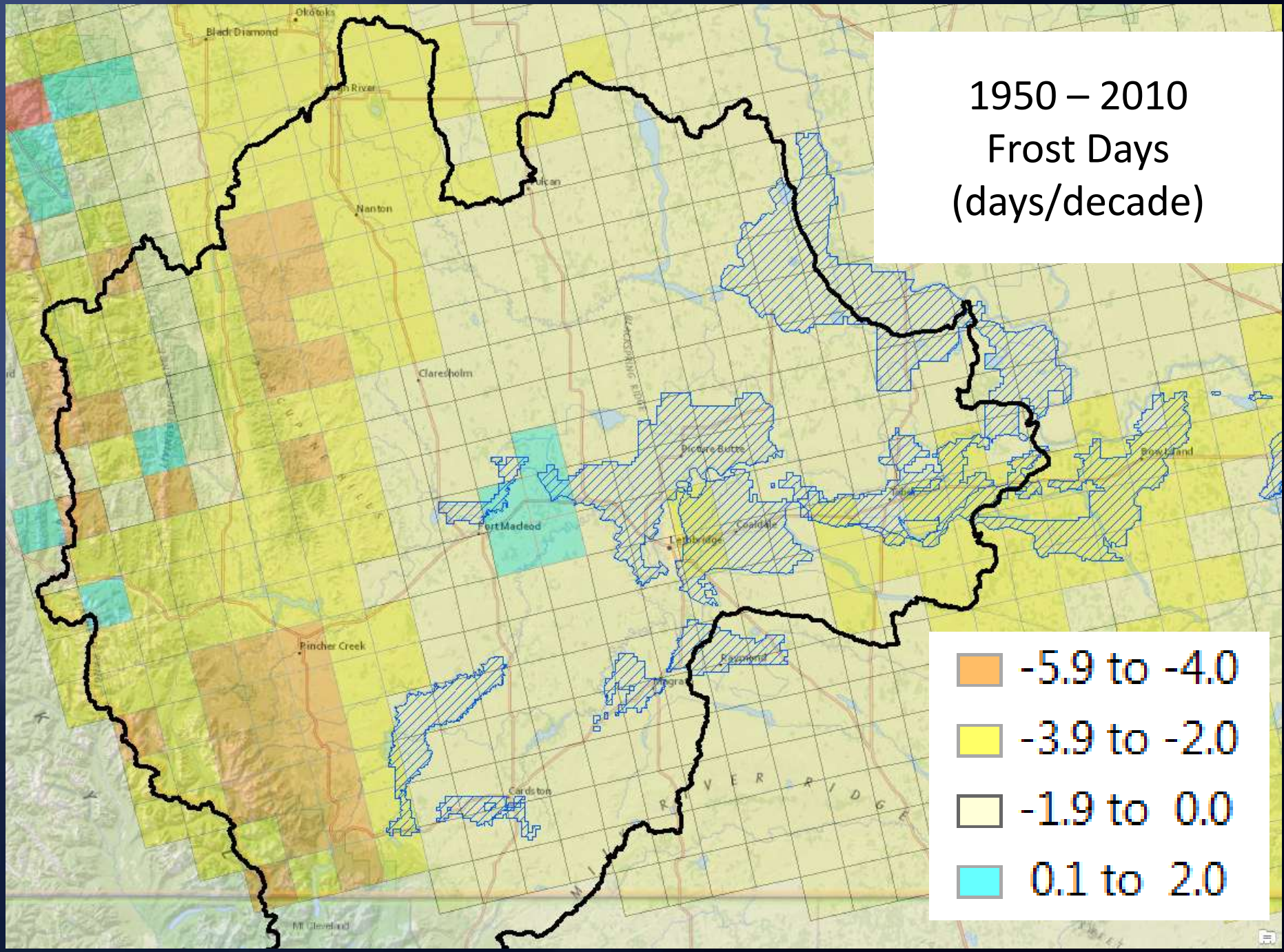

1950 – 2010
Trend in Growing
Season Length
(days/decade)
-1.9 to 0.0
0.1 to 2.0
2.1 to 4.0
4.1 to 6.0
Okotoks
Black Diamond
Nanton
Vulcan
Claresholm
Fort Macleod
Lethbridge
Coaldale
Picture Butte
Taber
Bow Island
Pincher Creek
Raymond
Cardston
BLACKSPRING RIDGE
R I V E R R I D G E

Historical Trend in Growing Season Length

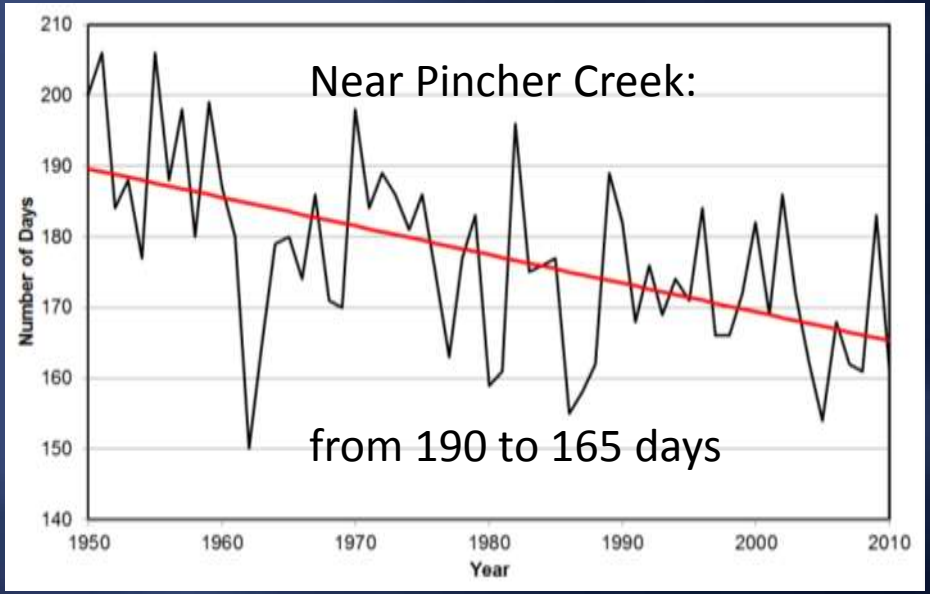


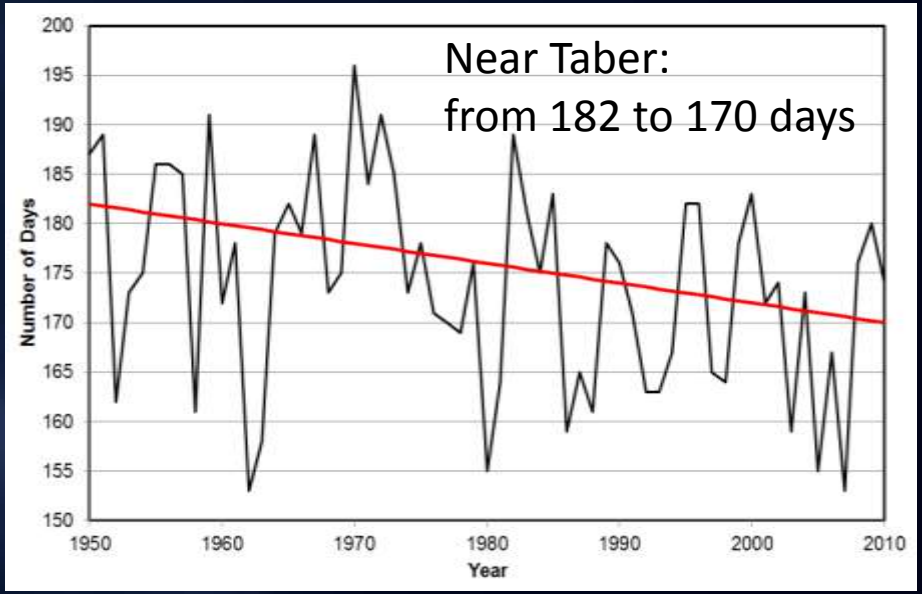


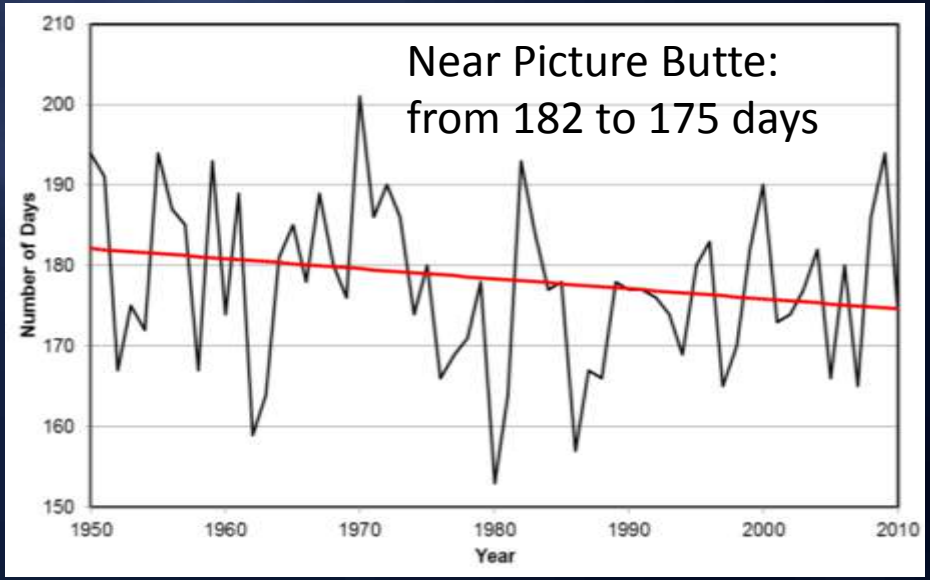



1950 – 2010
Frost Days
(days/decade)
-5.9 to -4.0
-3.9 to -2.0
-1.9 to 0.0
0.1 to 2.0
Okotoks
Black Diamond
Nanton
Claresholm
Fort Macleod
Pincher Creek
Cardston
Picture Butte
Coaldale
Raymond
Brooks
Milk River Ridge

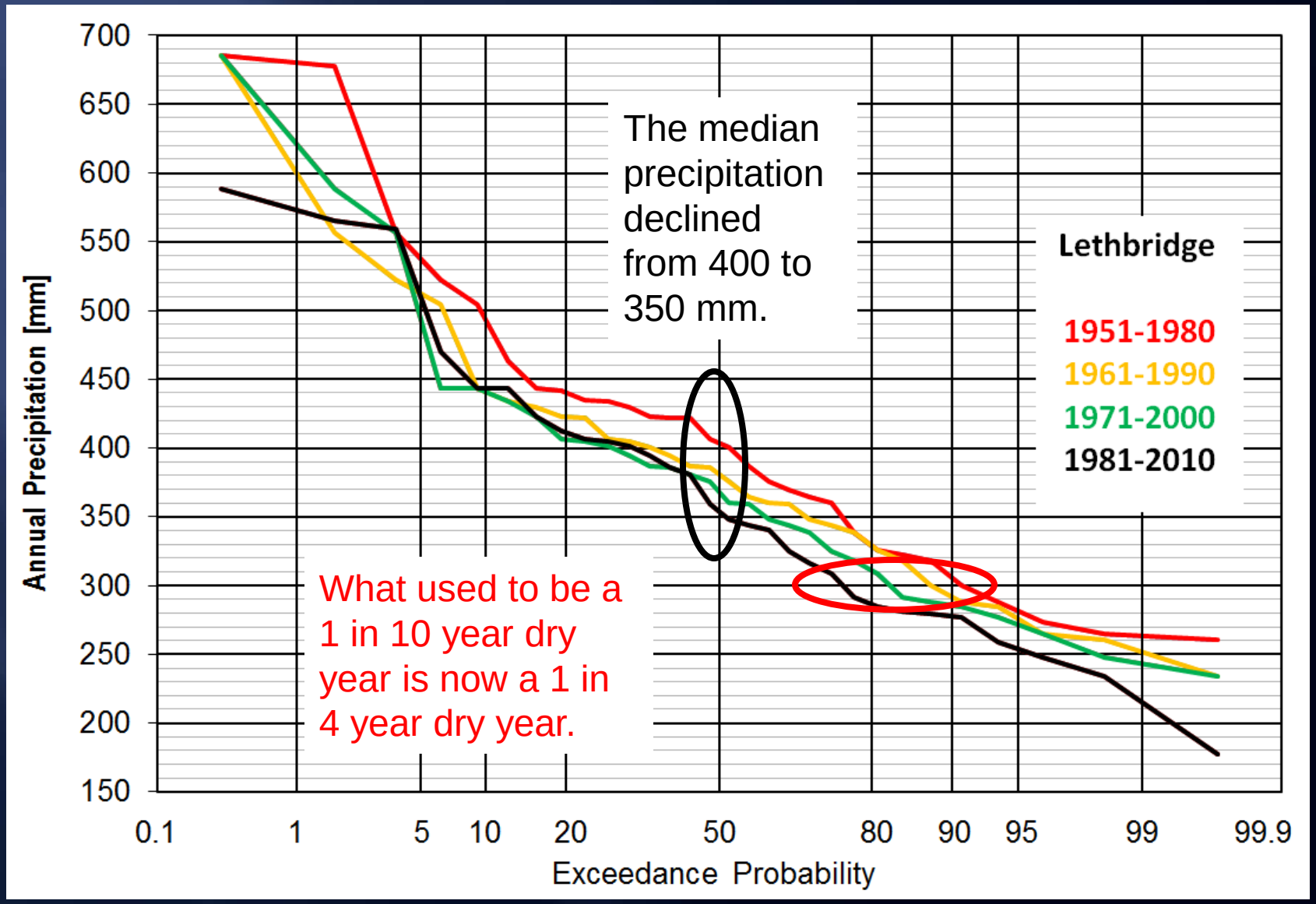
Historical Trend in Number of Frost days







What is the chance of annual precipitation being over a certain value in Lethbridge?



Alberta 1950-2010 Change in growing season length [in days]

Alberta maps will be created for:

- Many climate indices
- PET
- Future climates
- Drought indices
- Crop yields