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モニレ・ファラマーズィ博士は、カナダのアルバータ大学地球大気科学部の准教授です。
彼女は2010年にスイス連邦工科大学チューリッヒ校で博士号を取得しました。
彼女は現在、気候変動の文脈で水と食料の課題を研究する目的で、水循環、農業、気候モデルなどのような物理的及びプロセスベースのツールの開発及び応用に関与した流域科学及びモデル研究所を率いています。彼女の研究は、取引の評価、水と土地の相互作用、作物生産、環境に基づいた管理計画の社会経済的推進力に焦点をあてたものです。現在まで、彼女の研究は、気候変動と管理要員が作物の収穫量、河川の流れ、洪水、干ばつに及ぼす影響に関連するテーマ、そしてごく最近では、カナダの草原の農地における栄養素と化学物質の負荷と輸送に関連する研究について詳しく掘り下げてきました。彼女の研究目標は、人類の不確実な未来の下で「水ー食ーエネルギーと環境」の結びつきの科学に貢献することです。

Dr. Monireh Faramarzi is an Associate Professor in the Department of Earth and Atmospheric Sciences, University of Alberta, Canada. She received her PhD from the Swiss Federal Institute of Technology ETHZ in 2010. She is currently leading the Watershed Science and Modelling Laboratory that involves developing and applying physical and process-based tools such as hydrological, agricultural, and climate models to study water and food challenges in the context of climate change. Her research focuses on assessing trade-offs and interactions between water and land resources, crop production, and socio-economic drivers for an environmnetaly-informed management plans. To date, her research has elaborated on subjects related to the impacts of climate change and management factors on crop yields, streamflow, floods, droughts, and more recently, on nutrients and chemical loads and transport in agricultural lands of Canadian Praries. Her research goal is to contributes to the science of “water-food-energy and environment” nexus under an uncertain future in the Anthropocene.

気候変動下で小麦・大麦の収穫量はどう変化するか？
～カナダにおける収量変化を予測する～

概要

持続可能な農業は、水(の利用性)の確保、食料の安全保障、自然保護という切羽詰まった三重の課題に直面しています。しかし、生物地球化学的および水循環気候変数の変化に対する作物成長の非定常的応答は、作物収量の予測を不確実にし、その結果持続可能な農業のための適応戦略の実施における曖昧さをもたらします。カナディアンプレイリーズの生産性の高い農地は、国民経済にだけではなく、世界 100 か国以上に食糧を供給することに貢献しています。ただし、気候変動やその他の新たな環境問題（水や土壌の劣化など）により、作物の収穫量が変化し、これらの土地の現在の生産レベルが制限される可能性があります。この研究は、カナディアンプレイリーズの農地におけるさまざまな気候変動と窒素施用シナリオの下での小麦と大麦の収穫量の経時変化をシミュレートしたものです。この結果は、将来の気候変動シナリオの下で、より大きな成長度合とより大きな土壌水分によって作物収量が増加すると予想される一方で、土壌栄養分の利用可能性と土壌窒素を取り込む作物の能力が収量向上のレベルを大きく左右することを示唆しています。このモデルの結果は、将来的に大気中の二酸化炭素が飽和状態になると、気孔の閉鎖が早まり、それによって栄養素の取り込みと作物の収穫量を制限する可能性があることを示しました。窒素肥料を多く施用した場合の作物収量の増加が予測されることから、施肥は気候変動下で収量を増加させるための適応策となり得ることが示唆されました。しかし、肥料の使用率が高いことによる土地、生物多様性、水質への懸念は、環境問題を引き起こし、この地域の農業実践の持続可能性の目標を制限する可能性があります。この研究は、土壌の健康とその養分利用性を促進することの重要性を明らかにし、地域の将来の気候変動の下での潜在的な管理オプションとしての再生農業実践の検討の基礎を提供するものです。

Response of wheat and barley crop yields to climate change using process-based modeling in agricultural lands of Canadian Prairies

Abstract

Sustainable agriculture is confronted by an intimidating triple challenge of ensuring water availability, meeting food security, and conserving nature. However, the non-stationary response of crop growth to changes in biogeochemical and hydro-climatic variables makes crop yield projection uncertain and thus ambiguity in the implementation of adaptation strategies for sustainable agriculture. The productive agricultural lands of the Canadian Prairies not only contribute to the national economy but also supply food to over a hundred countries worldwide. However, climate change and other emerging environmental concerns (e.g., water and soil degradation) may alter crop yields and limit current production levels in these lands. This study simulated the time-varying behavior of wheat and barley crop yields under various climate change and nitrogen application scenarios in the agricultural lands of the Canadian Prairies. The results suggest that while crop yields are expected to increase due to larger growing degree days and greater soil moisture under future climate change scenarios, the soil nutrient availability and the ability of crops to uptake soil nitrogen can highly regulate the level of yield enhancements. The model results showed that saturated atmospheric CO2 in the future can induce earlier stomatal clousure, thus limiting nutrient uptake and crop yields. The predicted increases in crop yields under a higher nitrogen fertilizer application suggests that fertilizer application can be considred as a potential adaptation measure to enhance yields under a changing climate. However, land, biodiversity, and water quality concerns due to a higher rate of fertilizer use can raise environmental issues and limit the sustainability goals of agricultural practices in the region. This study highlights the importance of promoting soil health and its nutrient availability, and it provides the basis for examination of the regenerative farming practices as a potential management option under future climatic changes in the region.

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Modeling crop yields in response to climate change in Alberta, Canada

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February 2022; 2021 Overseas Agricultural Science Seminar
Rakuno Gakuen University, Ebetsu city, Hokkaido, Japan

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Content

- Introduction: Canadian agriculture
- Introduction: Climate change and crop growth
- Methods: hydrology and crop growth simulator
- Results: barley, wheat

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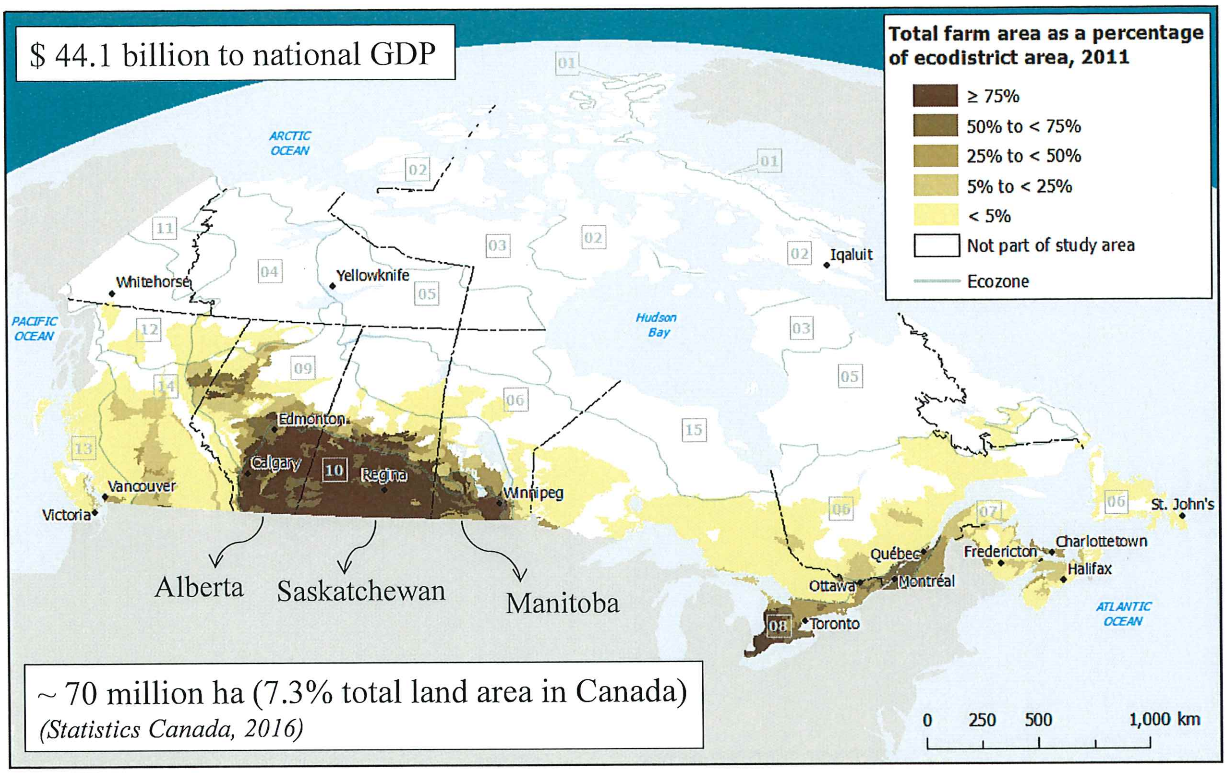
Agricultural lands

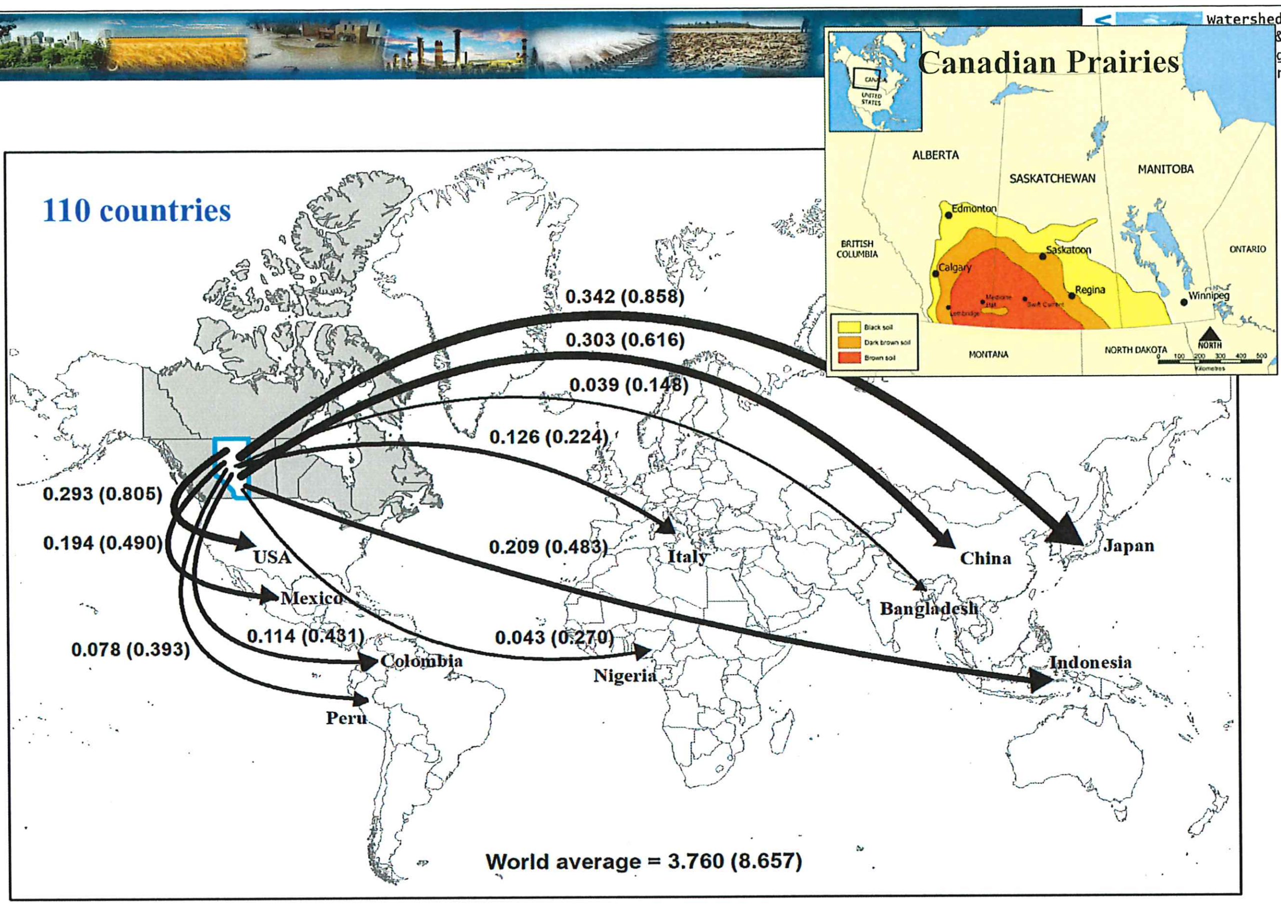
$ 44.1 billion to national GDP



~ 70 million ha (7.3% total land area in Canada)
(Statistics Canada, 2016)

https://www150.statcan.gc.ca/n1/daily-quotidien/141113/dq141113a-eng.htm

$200 billion from agriculture and petroleum in Canada



2019 — Masud, M.B., Wada, Y., Goss, G., Faramarzi, M., Global implications of regional grain production through virtual water trade, Science of the total environment 659: 807-820. DOI: 10.1016/j.scitotenv.2018.12.392.

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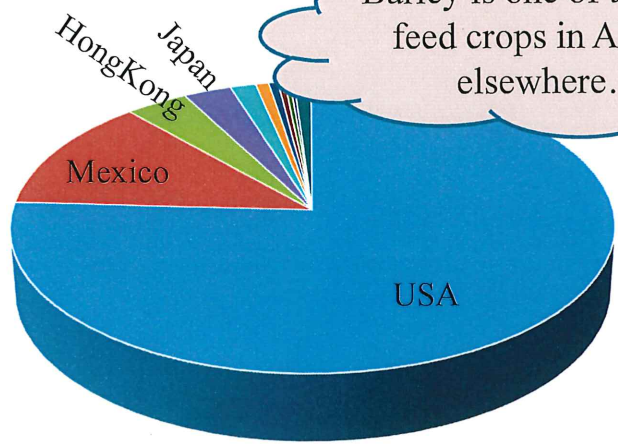
Economy and development

Canada is home to ~12 million head of cattle with majority of beef production occurring in Alberta.

Barley is one of the main feed crops in AB and elsewhere…



Country	Export (*1000) ton
USA	218.504
Mexico	35.873
HongKong	10.79
Japan	8.276
Russian Federation	4.378
Macao	2.271
Taiwan	1.576
Philippines	1.178
Indonesia	0.929
Egypt	0.619
Other countries	2.937

Source: Stat Canada, 2011

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Campus Alberta Innovates Program Chair Funding

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Alberta Agriculture and Forestry

NSERC CRSNG
Discovery Grant Program

Water quantity

- Predicting Water Related Risks and Opportunities for Albert's Beef Industry (**AAF**, 3 years, completed)
- Adapting to Changing Water in Alberta (**AI**, 3 years, completed)
- Predicting Alberta's Water Future (**AI**, 3 years, completed)

Water quality, soil health, and climate change mitigation (NbS)

- Predicting Water Related Risks and Opportunities for Albert's Beef Industry
- Adapting to Changing Water in Alberta
- Predicting Alberta's Water Future

(**Caip Chair**, 7 years, on-going; NSERC DG, 5 years on-going)

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Climate change impacts on crop yields

2021 — Khalili, P., Masud, B., Qian, B., Mezbahuddin, S., Dyck, M., Faramarzi, M. Non-stationary response of rain-fed spring wheat yield to future climate change in northern latitudes. *Science of the Total Environment*. DOI: https://doi.org/10.1016/j.scitotenv.2021.145474

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2018 — Masud, M.B., McAllister, T., Cordeiro, M.R.C., Faramarzi, M., Modeling future water footprint of barley production in Alberta, Canada: Implications for water use and yields to 2064, *Science of the Total Environment* 616-617: 208-222. DOI: 10.1016/j.scitotenv.2017.11.004.

Climate change impacts on crop yields

Direct impacts:

- Increased heat stress *(Yang et al., 2017a, 2017b)*
- Frequent extreme temperatures *(Zhang et al., 2016)*
- Intermittent heavy rainfall and waterlogging of soils *(Li et al., 2019)*
- Changes in atmospheric composition and CO_2 *(Swann et al., 2016)*

Indirect impacts:

- Changes in ice and snowmelt dynamics
- Hydrologic cycle *(Wang et al., 2017)*
- Pests and diseases *(Jabran et al., 2020)*

Climate change impacts on crop yields

Magnitude of impacts:

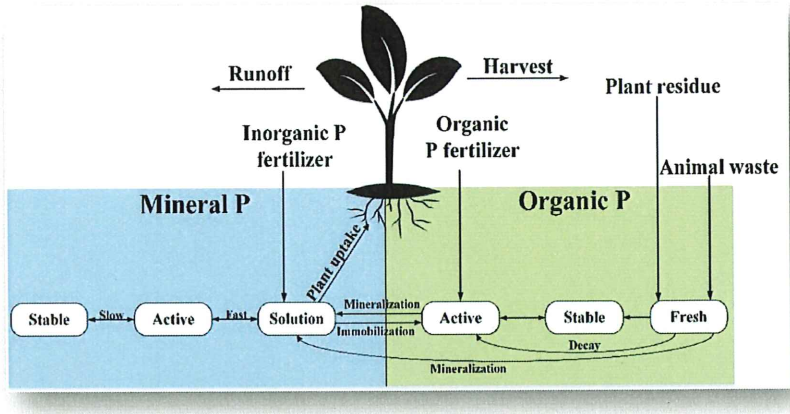
- Crop type
- Stage of growing season
- Geographic location

- Numerous biogeochemical and hydro-climate factors
- Spatiotemporal variability

Question: is crop response to changes in future climate change stationary?

Nutrient cycle

- Nutrient supplement by **fertilizer** or **manure** application to the cropping systems may form insoluble minerals and may be transported out from lands and loaded into water bodies *(Hansen et al., 2001)*.



Nutrient cycle and transport in Canadian Prairies

- Runoff-soil interface is primarily affected by frozen soil and the amount and rate of snowmelt → erosion and export of nutrients

Processes involved:

- Long non-growing seasons,
- Release of nutrients from soils and crop residue after freeze–thaw cycles
- Slower biogeochemical reaction rates by low temperature
- Snowmelt runoff and variability
- Restricted nutrient retention and infiltration to the frozen soil

https://goodineverygrain.ca/2021/12/06/facts-for-teachers-winter-and-farming/

https://www.producer.com/news/weather-network-predicts-abrupt-mid-march-shift-into-spring/

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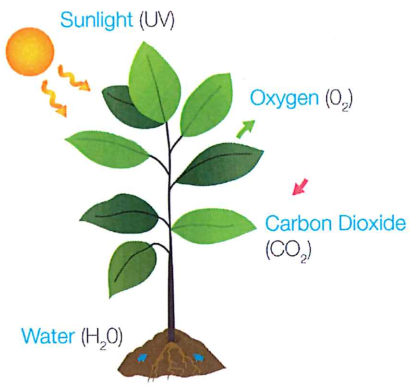
Factors affecting crop yield under future climate change scenarios

- Water (snow-ice)
- Temperature
- Solar radiation
- Air humidity
- CO2
- Soil type

Management factors:

- Soil nutrients, tillage operation
- Planting
- Harvesting
- Irrigation
- etc.



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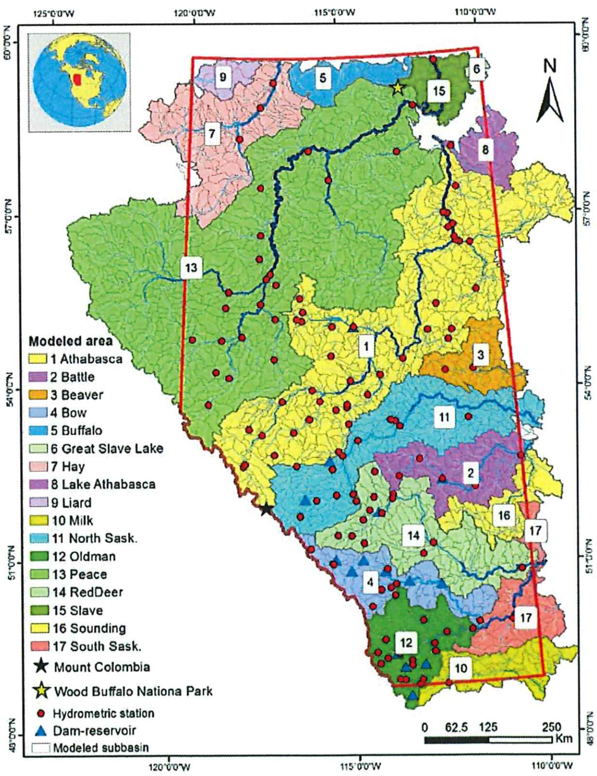
Alberta's watersheds

- **Total land area:** ~700,000 km^2
- **Study area:** 2255 sub-basins were delineated using SWAT with a 200 km^2 drainage area
- **Model calibration-validation (1983-2007):** at 129 hydrometric stations

Reference:

Faramarzi et al., *Environmental Modelling & Software, 2015.*



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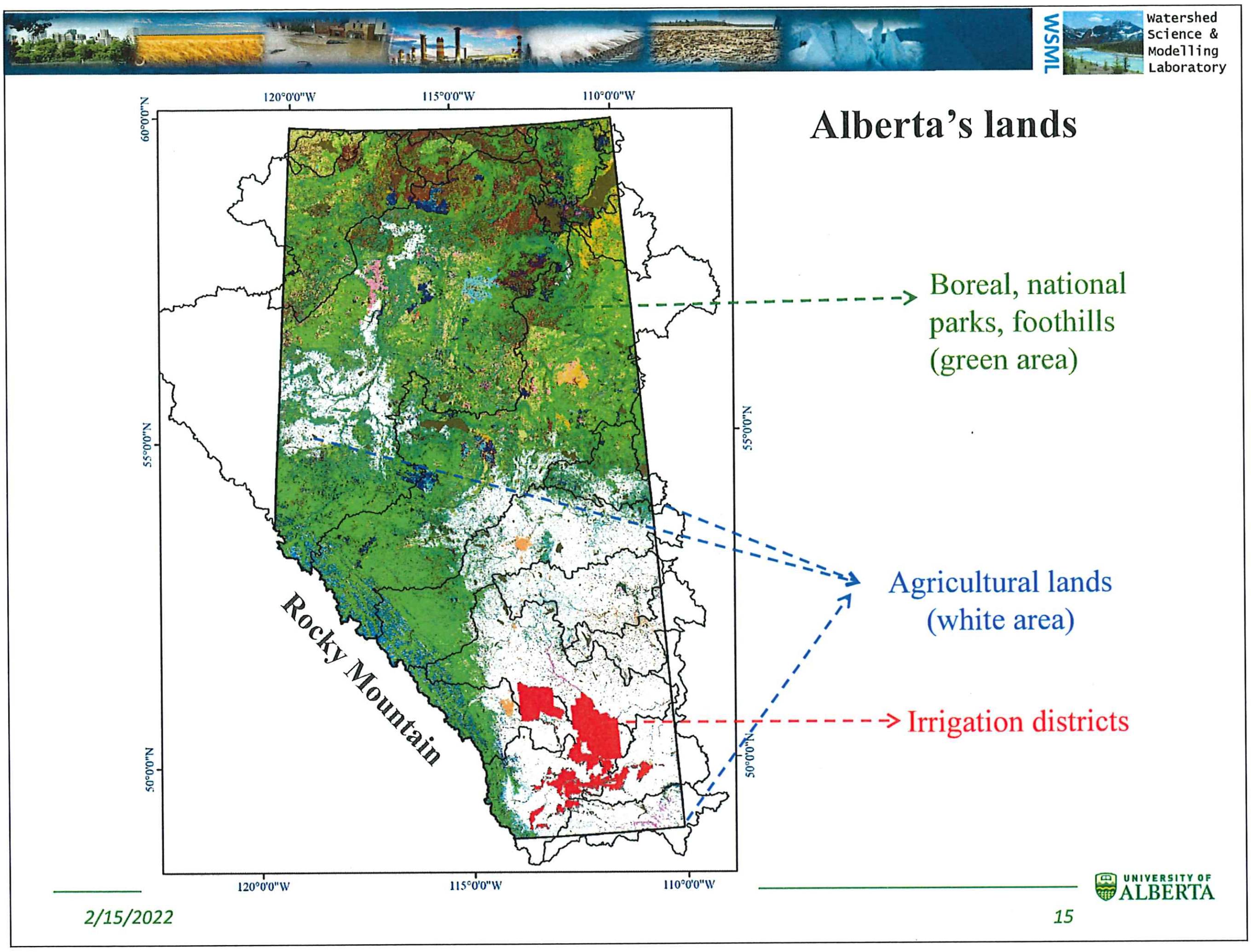
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Alberta's lands
120°0'0"W
115°0'0"W
110°0'0"W
60°0'0"N
55°0'0"N
50°0'0"N
Boreal, national parks, foothills (green area)
Agricultural lands (white area)
Irrigation districts
Rocky Mountain
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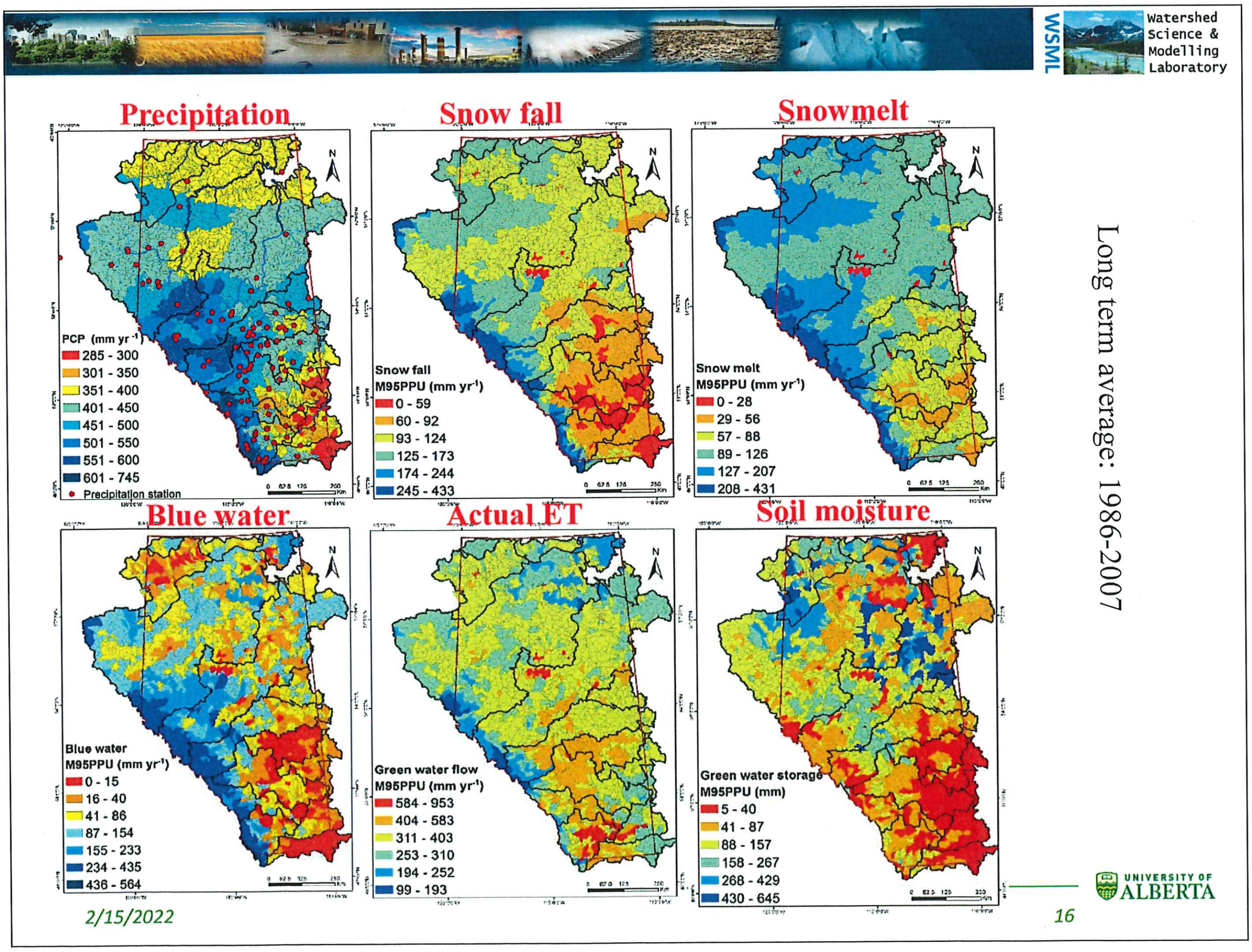
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Precipitation
Snow fall
Snowmelt
PCP (mm yr^{-1})
285 - 300
301 - 350
351 - 400
401 - 450
451 - 500
501 - 550
551 - 600
601 - 745
Precipitation station
Snow fall M95PPU (mm yr^{-1})
0 - 59
60 - 92
93 - 124
125 - 173
174 - 244
245 - 433
Snow melt M95PPU (mm yr^{-1})
0 - 28
29 - 56
57 - 88
89 - 126
127 - 207
208 - 431
Long term average: 1986-2007
Blue water
Actual ET
Soil moisture
Blue water M95PPU (mm yr^{-1})
0 - 15
16 - 40
41 - 86
87 - 154
155 - 233
234 - 435
436 - 564
Green water flow M95PPU (mm yr^{-1})
584 - 953
404 - 583
311 - 403
253 - 310
194 - 252
99 - 193
Green water storage M95PPU (mm)
5 - 40
41 - 87
88 - 157
158 - 267
268 - 429
430 - 645
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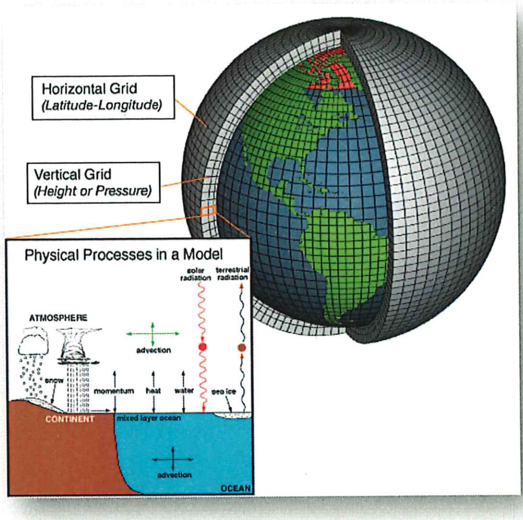
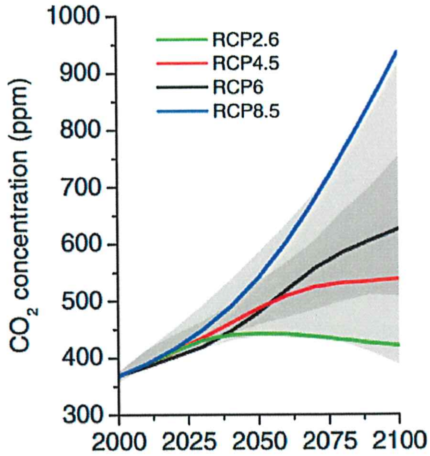
CO_2 driven climate change (anthropogenic)

IPCC global climate models





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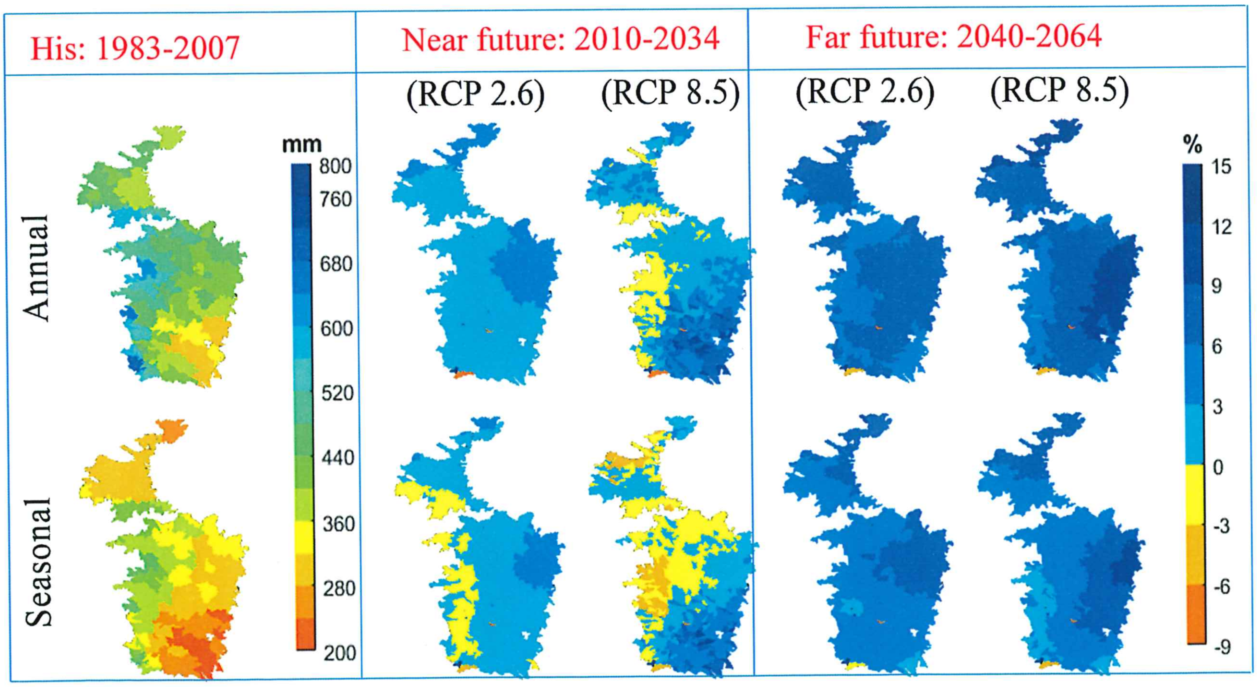
Mean seasonal and annual **precipitation** and their projected changes (%)



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2018 — Masud, M.B., Ferdous, J., Faramarzi, M., Projected changes in hydrological variables in the agricultural region of Alberta, Canada, *Water* 1–20. DOI: 10.3390/w10121810.

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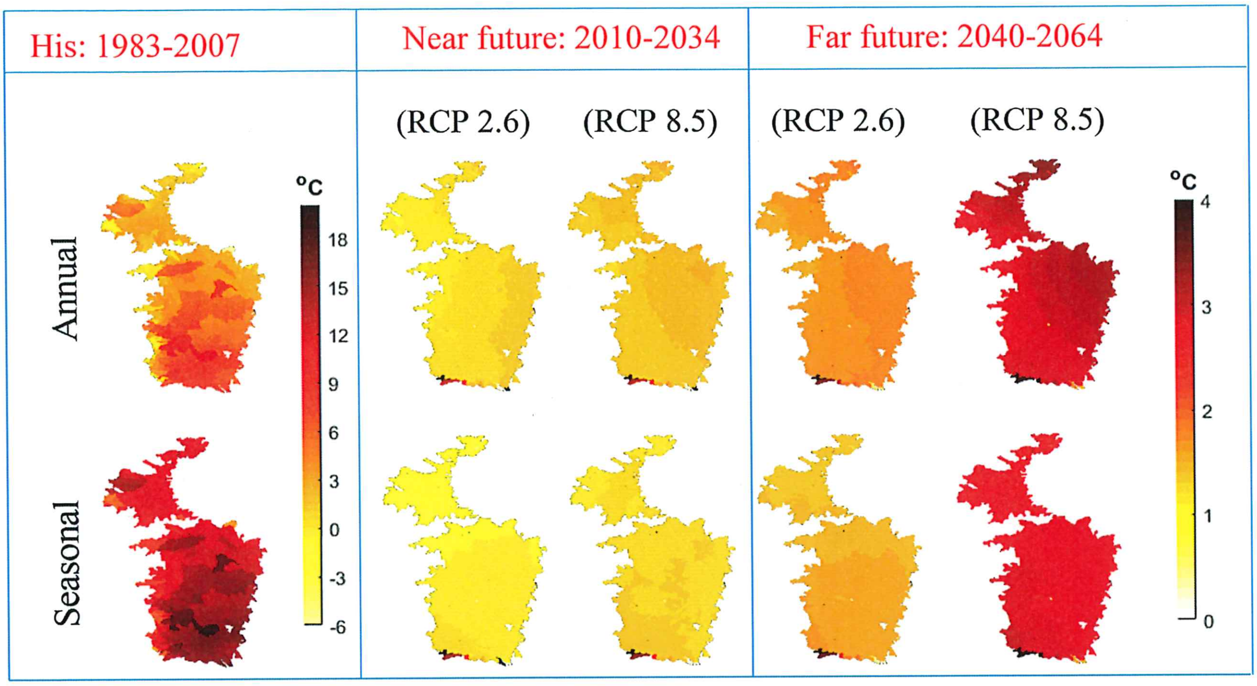
Seasonal and annual **temperature** and their projected changes (°C)



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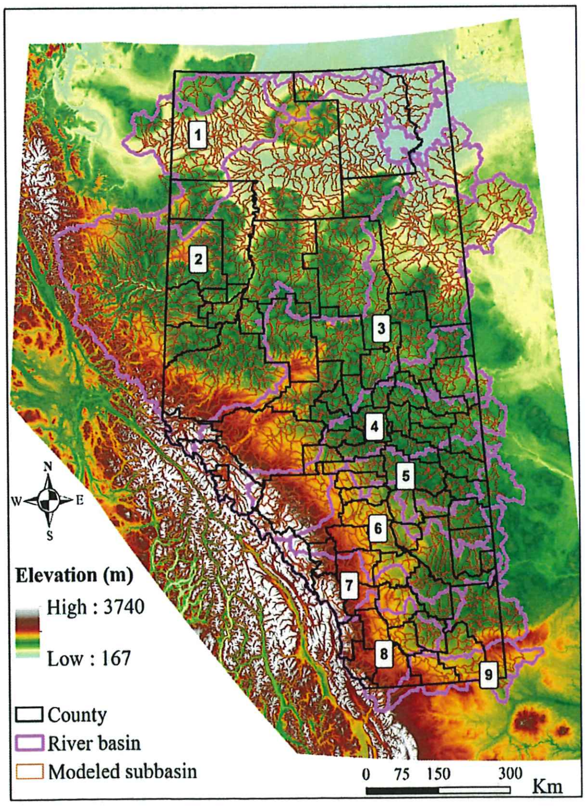
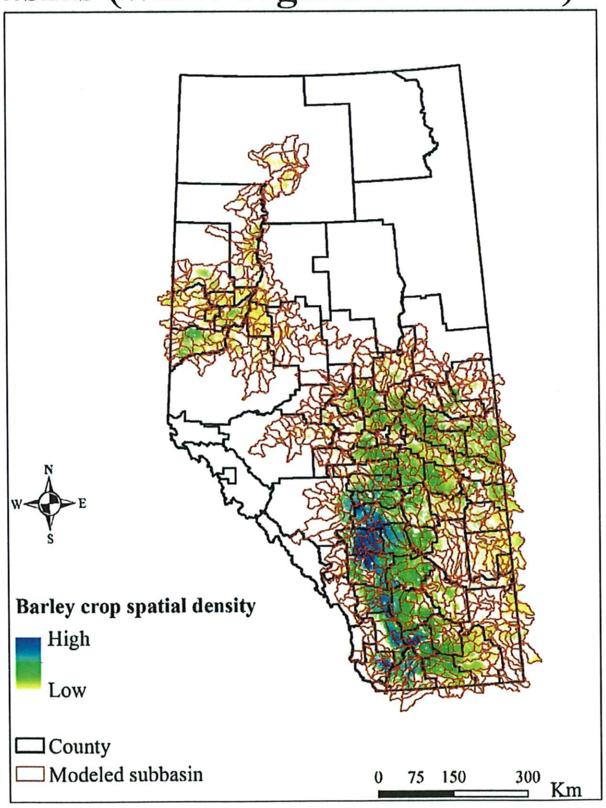
Yield simulation: over 900 sub-basins (white region of Alberta)





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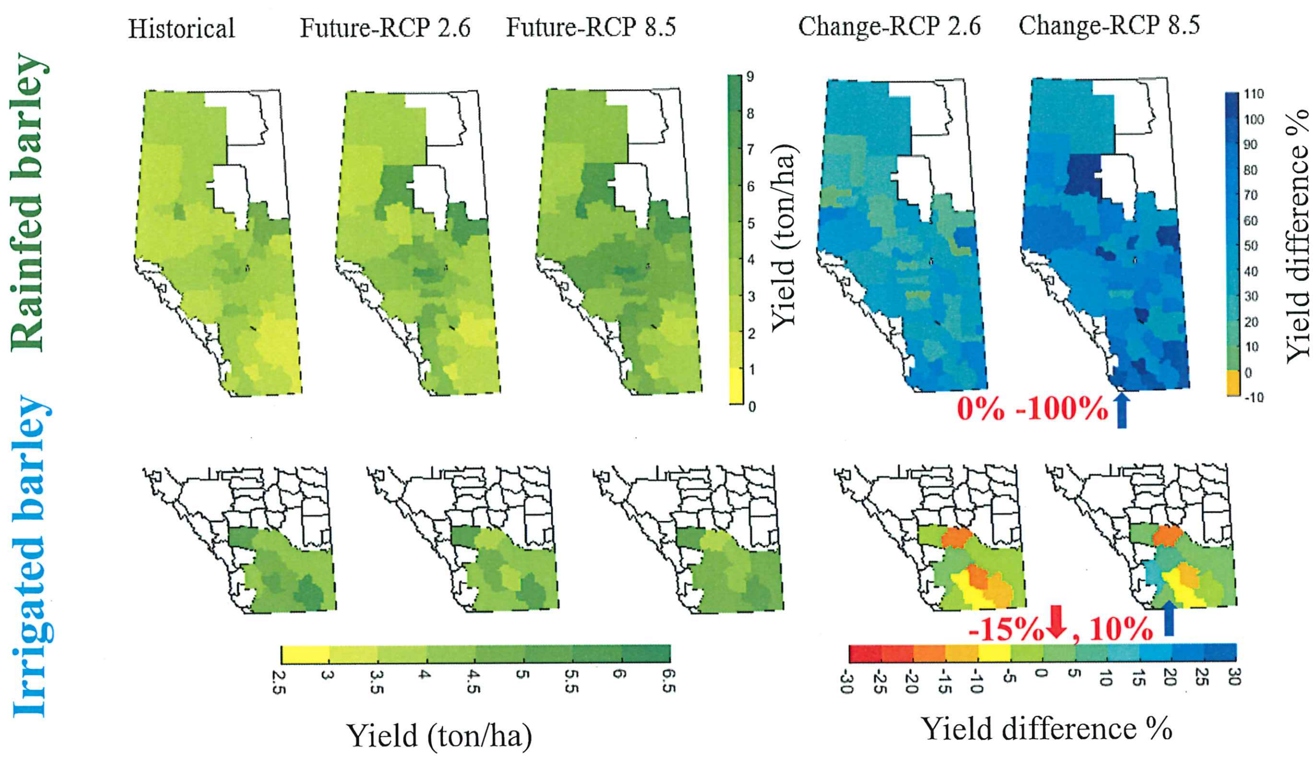
Projected changes in rainfed barley yield (2040-2064)



Source: *Masud, M.B., McAllister, T., Cordeiro, M.R.C., Faramarzi, M., Modeling future water footprint of barley production in Alberta, Canada: Implications for water use and yields to 2064, Science of the Total Environment 616-617: 208-222. DOI: 10.1016/j.scitotenv.2017.11.004.*

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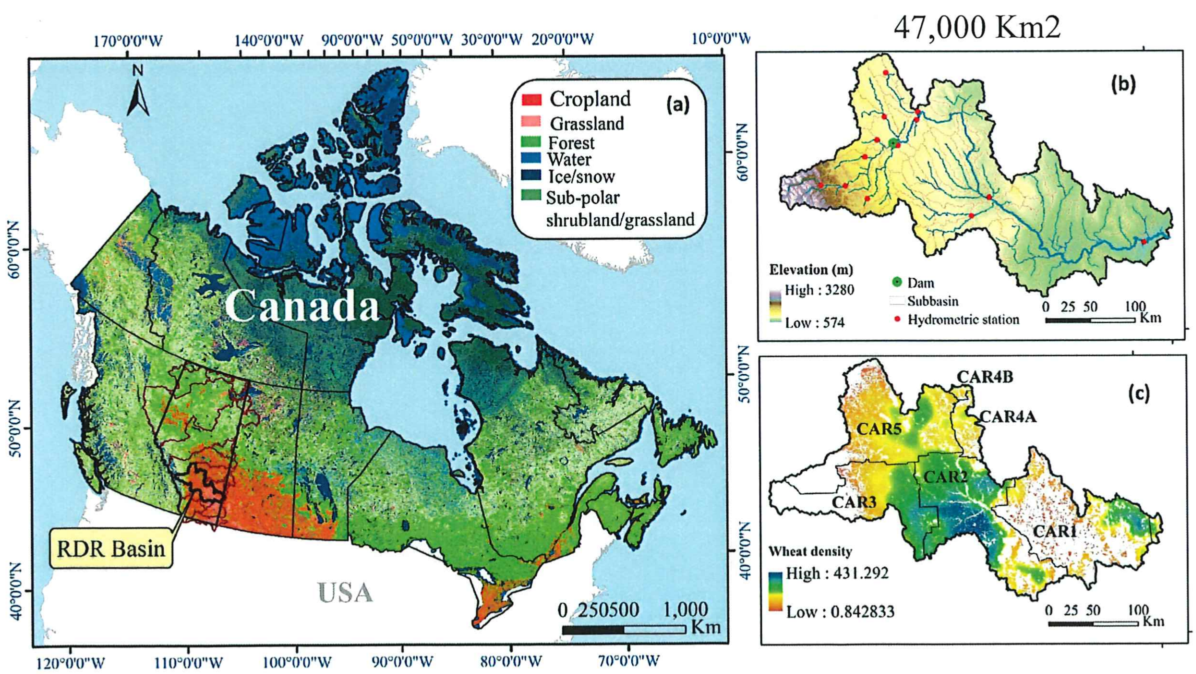
Red Deer River Basin: case study to assess future wheat yields



2021 — Khalili, P., Masud, B., Qian, B., Mezbahuddin, S., Dyck, M., Faramarzi, M. Non-stationary response of rain-fed spring wheat yield to future climate change in northern latitudes. *STOTEN*. DOI: https://doi.org/10.1016/j.scitotenv.2021.145474

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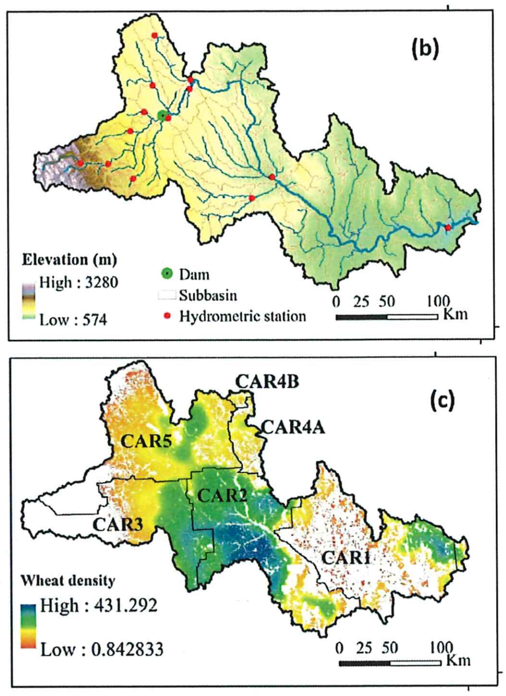
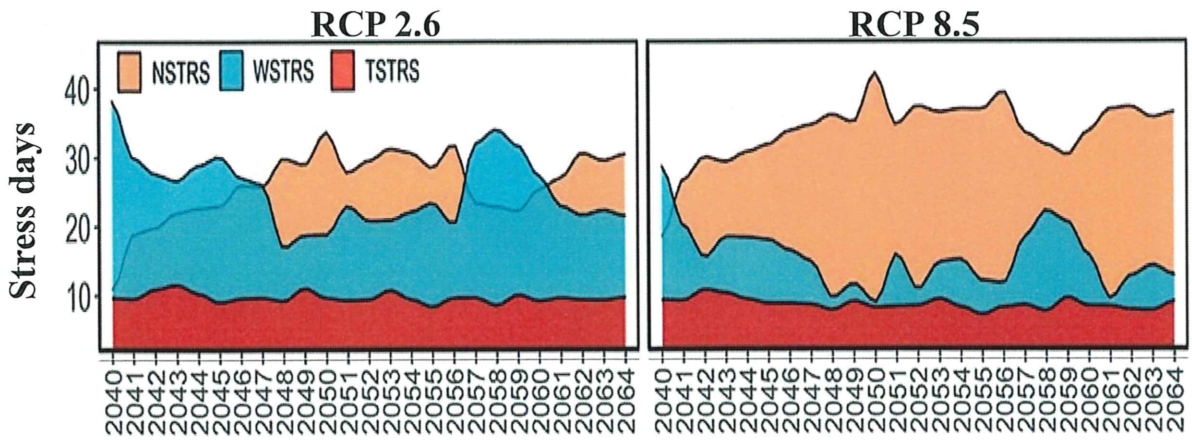
- **Watershed area:** 47,000 km^2
- **Elevation:** 574 -1700 in the croplands, up to 3280 m in the mountain
- **Temperature:** –25 - 35 °C year-round; 2 - 34 °C growing season
- **Precipitation:** 400 mm year-round; 250 mm growing season
- **Snowmelt:** plays a vital role in supplying water needs early in the growing season in RDR
- **Soils:** black soils, the most productive soils

- **Climate:** precipitation, temperature (max-min), solar radiation, wind speed, air humidity
- **Fertilizer and crop calendar:** Alberta Agricultural and Rural Development (AARD)
- **Crop yields:** Alberta Financial Service Corporation (AFSC); AARD, and for Census Agricultural Region
- **Heat units and other phonological parameters:** Literature review

Red Deer River Basin



CO_2 driven climate change impact on wheat yields stress factors (2040-2064)



(1) reduced evapotranspiration and earlier stomatal closure in response to saturated atmospheric CO2
(2) insufficient N availability in the soil
(3) insufficient moisture in the soil to produce soluble N for plants to uptake.

Summary and Conclusion

- Barley yields may increase under rainfed agriculture with the expense of more water consumption in some areas and less in some others.

- Barley yield increases are not identical in all regions.

- Irrigated barley yields may increase by up to 10% in some districts and may decrease by 15% in some other districts.

Summary and Conclusion

- Nitrogen (N) stress may dominate other stress factors in producing rainfed wheat yields in the future as compared to the current conditions that water-stress is a dominant factor.

- The future N stress might be due to **(1)** reduced evapotranspiration and earlier stomatal closure in response to saturated atmospheric CO2, **(2)** insufficient N availability in the soil, and **(3)** insufficient moisture in the soil to produce soluble N for plants to uptake.

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Summary and Conclusion

- Higher N application with supplement irrigation might be a potential measure to enhance yields under a changing climate. However, land, biodiversity, and water quality concerns due to a higher rate of fertilizer use can raise environmental issues and limit the sustainability goals of agricultural practices in the region.
- This study highlights the importance of promoting soil health and nutrient availability, and it provides the basis for the examination of regenerative farming practices as a potential management option under future climatic changes in the region.
- More studies need to include effects of large-scale modes of natural climate variabilities such as PDO.

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Acknowledgements

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