Impacts of climate and forest changes to streamflow in Southern Alberta.

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Motivation

- Hydrology of Mountainous regions are most affected by the climate change as precipitation would change from snow to rain in warming climate [IPCC, 2007].
- Rivers in Southern Alberta are snow-fed river, and thus are vulnerable to climate change.
- Forest disturbances (wildfire, insects, logging, etc.) may have compounding impacts with climate change.

Objectives

- To assess the effects of potential future climate and forest change on the high water yielding headwaters of Alberta's Southern Rocky Mountain regions with the application of hydrological model.

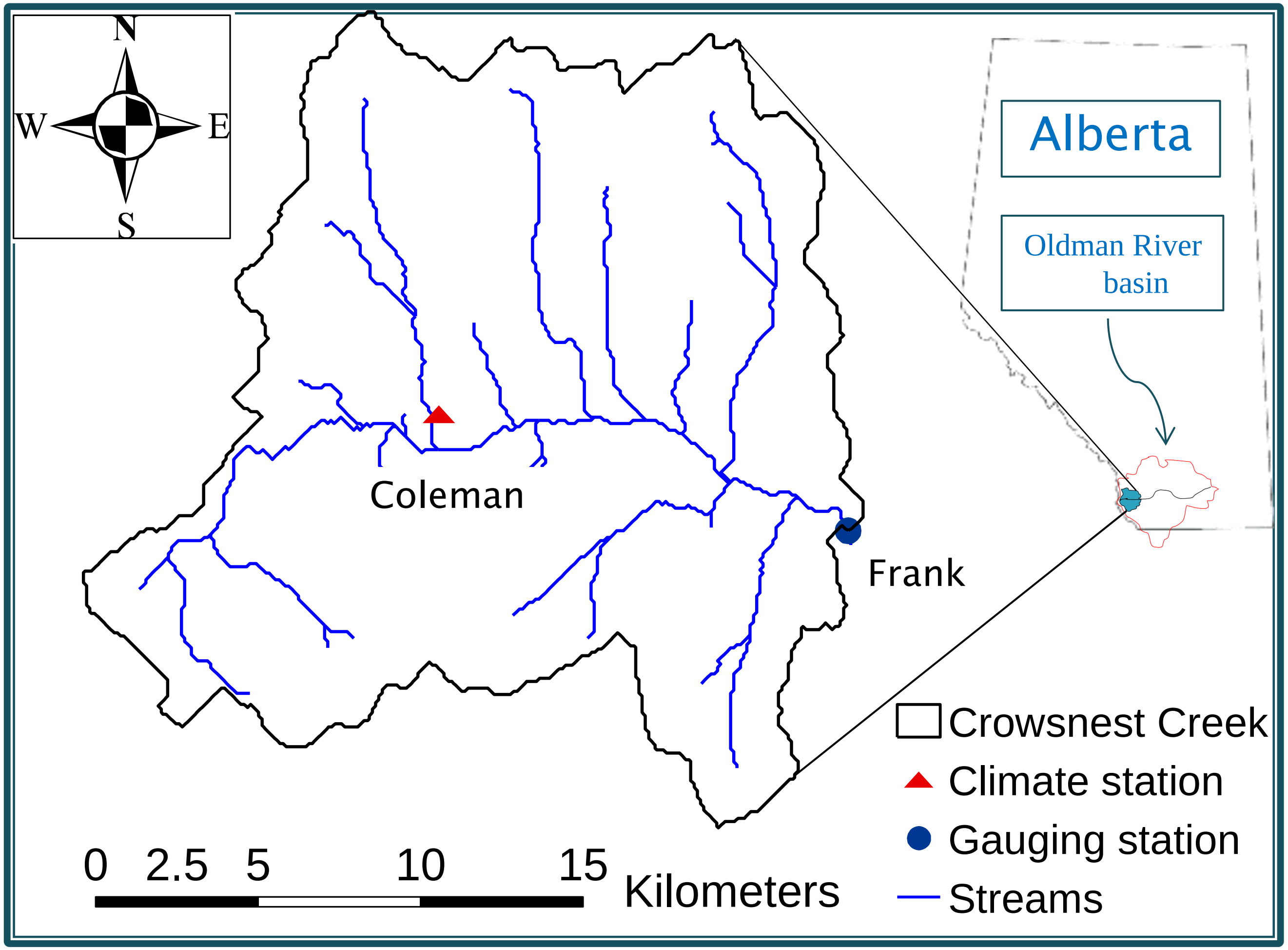
Study watershed

- Crowsnest Creek watershed
- Area:

  (384 km2)
- Elevation:

  (1236 – 2732 m)
- Forest:

  Lodgepole pine, Engelmann spruce, sub-alpile fir with alpine ecozones etc.



Method

The study methodology comprises of

- Estimates of future monthly climate means (precipitation, maximum temperature, T_{max}, and minimum temperature, T_{min}) in relation to observed climates at driver station, Coleman.
- Disaggregation (temporal downscale) of monthly climate means into daily realizations for use with hydrological model.
- Hydrological model calibration, application and parameters sensitivity

Method

Estimates of future monthly climate means in relation to observed climates at driver station

- Changes in monthly climate means observed in GCM outputs for the study watershed are calculated as

$$\Delta T_{max} = ({T_{max}}^{F} + \varepsilon) - ({T_{max}}^{R} + \varepsilon) \quad ......(1)$$

$$\Delta T_{min} = ({T_{min}}^{F} + \varepsilon) - ({T_{min}}^{R} + \varepsilon) \quad ....(2)$$

$$\Delta P = \frac{\varepsilon P^{F}}{\varepsilon P^{FR}} \quad ......(3)$$

- Daily observed climate at Coleman station is aggregated to monthly scale and monthly means of these are perturbed with ΔT_{max}, ΔT_{min} and ΔP to obtain the future monthly climate means in relation to driver station, Coleman.

Reference period	Future period			Emission Scenario
1965 – 1996 observed climate at driver station	2011-2040 (2020s)	2041-7200 (2050s)	2071-2100 (2080s)	A1B, A2, B1

Method

Disaggregation

- **Disaggregation** is done based on each month's statistical properties derived from observed daily climate data (1965-1996) at driver station using stochastic weather generator, LARS-WG.

- **LARS-WG**

    - Series of wet and dry day is determined using semi-empirical approach, fitting probability distribution to observed relative frequencies of wet and dry spell lengths [Semenov and Brooks, 1999].
    - Daily T_{max} and T_{min} are modeled separately with daily means and standard deviation conditioned on the wet or dry status of the day [Semenov and Brooks, 1999].
        - Autocorrelation values of observed T_{max} and T_{min} are also used.
        - Seasonal cycles are modeled by finite Fourier series of order 3.
    - Open source: available at Environment Canada website. (http://www.cccsn.ec.gc.ca/index.php?page=lars-wg)

Method

Hydrological model calibration, application and parameters sensitivity

Hydrological model (HBV-EC)

- Three main modules: snow, soil, runoff transfer
- Group Response Unit (GRU):
  - Elevation band , land cover (open, forest, water and glacier), different slope, aspect, elevation etc.
- Inputs: temperature, precipitation, monthly estimates of evapotranspiration
- Outputs: streamflow, SWE, evaporation, soil moisture content etc.
- Open source: available at modeling framework 'Green Kenue' developed by National Research Council Canada in collaboration with Environment Canada. (http://www.nrc-cnrc.gc.ca/eng/solutions/advisory/green_kenue/download_green_kenue.html)

Calibration

- Driven by the thirty two years (1965-1996) climate data recorded at driver station, Coleman.
- Simulated streamflow is compared the with observed values at watershed outlet, Frank.

Method

Hydrological model calibration, application and parameters sensitivity

Application

- The model is driven by the LARS-WG aggregated daily realizations to simulate the streamflows for the reference and nine different future periods.
- Climate change impacts assessment is carried out comparing the model simulated streamflows for the reference and these nine future periods.

Parameter sensitivity

- 100 most behavioral parameters giving higher Nash Sutcliffe efficiency are selected using GLUE approach.
- These 100 parameters sets are used with HBV-EC to provide results in terms of a range to capture the model parameters sensitivity.

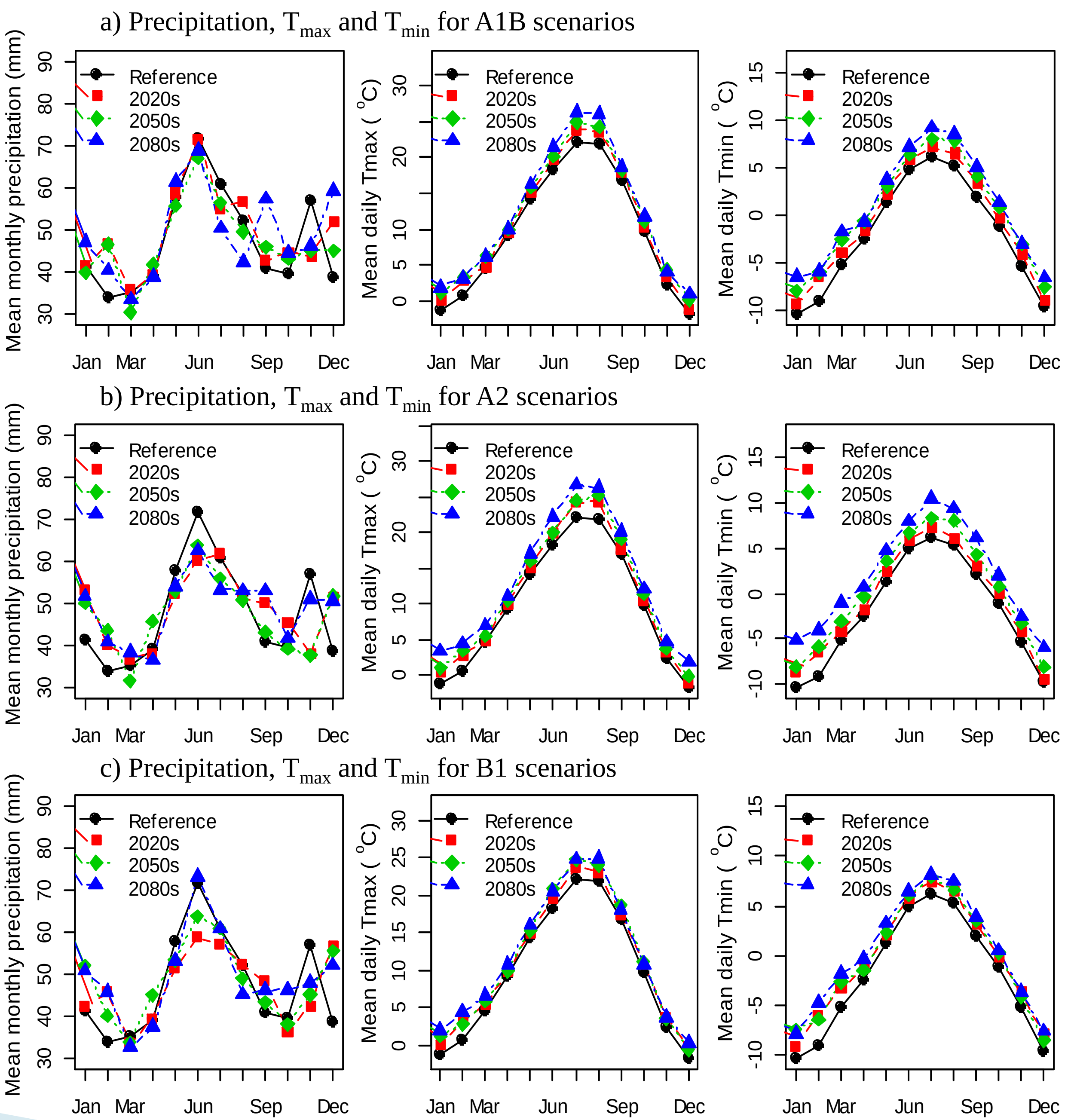
Results

Estimates of relative changes in monthly climate means observed in GCM outputs

Time period	Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann	Ann mean
Percentage change in mean monthly precipitation															
2011–2040 ("2020s")	A1B	2.6	4.1	−4.3	3.9	−7.3	−5.0	−2.4	−2.8	3.2	−2.7	−7.9	3.6	−1.6	−1.7
	A2	3.1	3.8	−4.5	3.5	−7.3	−5.2	−2.3	−3.1	2.7	−2.6	−7.7	3.6	−1.6	
	B1	2.3	3.6	−4.2	3.9	−7.8	−5.6	−2.6	−3.6	2.8	−3.5	−7.7	3.4	−1.9	
2041–2070 ("2050s")	A1B	4.2	4.7	−2.9	4.9	−6.6	−4.6	−1.6	−1.8	4.3	−1.9	−6.7	4.8	−0.6	−0.98
	A2	3.7	4.4	−3.0	5.0	−6.1	−4.5	−1.3	−1.5	4.3	−1.9	−7.0	4.5	−0.6	
	B1	3.7	2.6	−3.6	3.8	−7.9	−5.2	−2.0	−3.2	3.0	−3.4	−7.5	3.1	−1.7	
2071–2000 ("2080s")	A1B	5.3	4.4	−1.9	4.6	−6.0	−3.8	−0.6	−1.0	4.9	−1.3	−6.4	6.3	0.04	0.002
	A2	6.7	6.8	−1.2	6.1	−5.0	−3.1	0.5	−0.1	6.1	−0.6	−6.0	6.8	1.1	
	B1	3.9	4.5	−2.7	4.5	−6.9	−5.2	−2.0	−2.5	3.5	−3.2	−7.0	4.2	−1.1	
Change in mean monthly daily air temperature															
2011–2040 ("2020s")	A1b	1.6	3.1	0.9	0.7	1.0	1.6	1.5	1.7	1.5	0.8	0.9	0.7	1.3	1.4
	A2	2.0	2.8	0.6	0.4	1.2	1.7	1.8	1.8	1.1	0.9	1.0	0.8	1.3	
	B1	1.7	3.6	1.5	1.0	1.1	1.3	1.6	1.3	1.2	1.2	1.1	1.1	1.5	
2041–2070 ("2050s")	A1B	3.1	3.6	2.2	1.2	1.7	2.0	2.5	2.7	2.2	1.7	2.0	1.8	2.2	2.1
	A2	2.6	3.4	1.8	1.6	2.2	2.0	2.4	3.0	2.6	1.9	1.6	1.6	2.2	
	B1	3.0	2.7	2.0	0.9	0.9	2.4	2.5	1.9	1.9	1.3	1.4	0.8	1.8	
2071–2000 ("2080s")	A1B	3.8	3.2	2.9	1.0	2.4	3.1	3.7	3.5	2.8	2.1	2.4	3.0	2.8	3.0
	A2	5.2	5.3	3.3	2.2	3.4	3.7	4.5	4.6	4.0	2.7	2.8	3.6	3.8	
	B1	3.8	4.3	3.0	1.6	2.1	2.1	2.4	2.7	1.8	1.3	1.8	1.8	2.4	

Results

Future monthly climate means in relation to observed climates at driver station

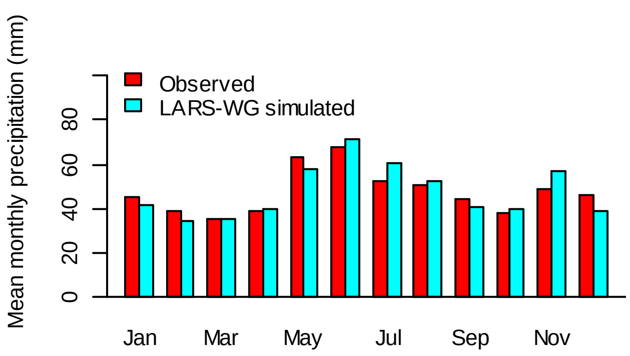


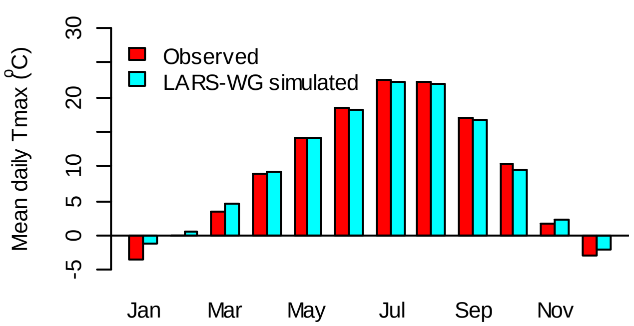
- Increase in precipitation in winter < 10%.
- Decrease in precipitation in summer < 10%.

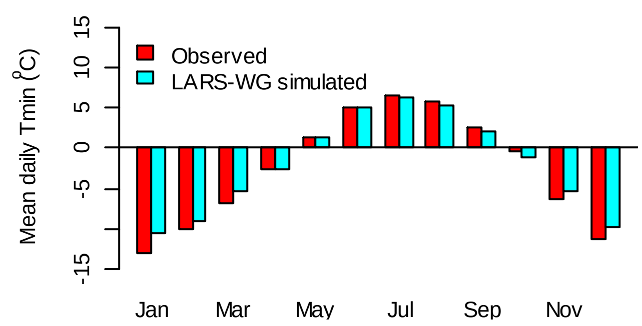
Results

Disaggregation of monthly climate means into daily realizations

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation												
Observed mean	45.10	39.13	34.98	39.03	63.24	67.58	52.56	50.98	44.42	38.19	48.70	45.91
Observed standard deviation	31.80	31.59	21.59	17.63	29.39	26.19	40.22	39.99	26.67	24.34	33.15	30.23
Disaggregated mean	41.36	33.85	35.42	39.34	57.96	71.61	60.82	52.11	41.01	39.62	56.99	38.60
Disaggregated standard deviation	21.67	17.00	20.24	17.64	25.49	25.81	23.65	20.02	22.19	21.19	32.38	22.44
P-values for T-test	0.583	0.406	0.933	0.943	0.442	0.535	0.319	0.887	0.577	0.803	0.315	0.276
P-values for F-test	0.036	0.001	0.720	0.995	0.431	0.936	0.03	0.03	0.309	0.445	0.896	0.102
Tmin												
Observed mean	-13.05	-10.09	-6.87	-2.63	1.35	4.95	6.61	5.86	2.46	-0.46	-6.39	-11.15
Observed standard deviation	4.76	4.06	2.93	1.69	0.95	1.16	1.02	1.20	1.38	1.58	3.16	4.32
Disaggregated mean	-10.41	-9.10	-5.21	-2.51	1.32	4.93	6.15	5.33	2.07	-1.13	-5.30	-9.67
Disaggregated standard deviation	1.82	1.72	1.32	0.83	0.65	0.71	0.49	0.63	0.97	1.21	1.44	1.73
P-values for T-test	0.005	0.208	0.005	0.734	0.914	0.944	0.024	0.031	0.188	0.062	0.080	0.078
Tmax												
Observed mean	-3.51	-0.02	3.55	8.91	14.22	18.38	22.37	22.36	16.90	10.41	1.66	-2.83
Observed standard deviation	4.07	3.14	2.85	2.21	1.85	1.84	2.14	2.55	3.43	2.23	2.91	3.34
Disaggregated mean	-1.25	0.64	4.64	9.21	14.24	18.30	22.12	21.84	16.85	9.66	2.33	-1.86
Disaggregated standard deviation	1.38	1.13	0.83	1.09	1.22	0.93	1.08	1.04	1.38	1.30	1.10	1.19
P-values for T-test	0.006	0.263	0.052	0.499	0.957	0.826	0.558	0.282	0.935	0.106	0.227	0.128







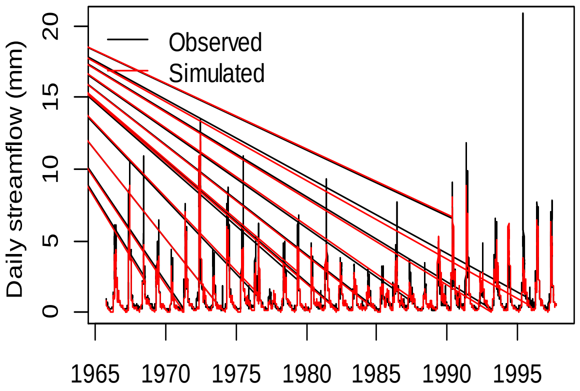
Results

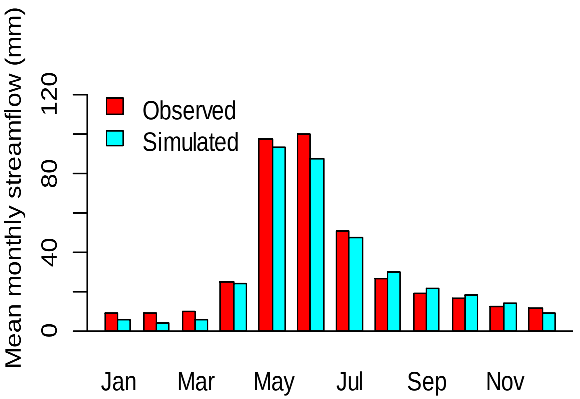
Hydrological model calibration, application and parameters sensitivity

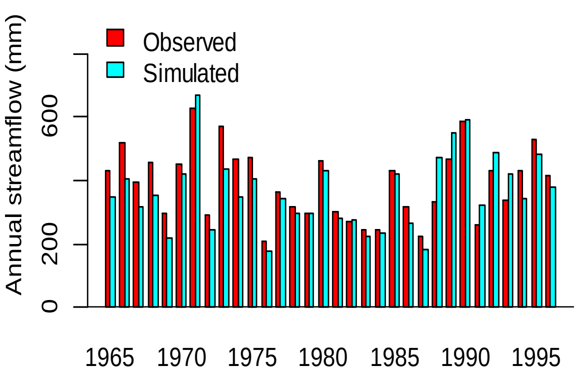
Calibration

HBV-EC is driven by the observed climate at driver station, Coleman, and model simulated streamflow is compared with observed values for calibration.

- HBV-EC reproduces the streamflow with Nash Sutcliffe efficiency 0.82.
- Some peak flows underestimated
- Large difference observed in February which is 50% (5 mm).
- Maximum 12 mm difference was observed in June.
- Difference in annual mean was less than 15% for 80% of time.
- Difference in annual mean was about 6%.







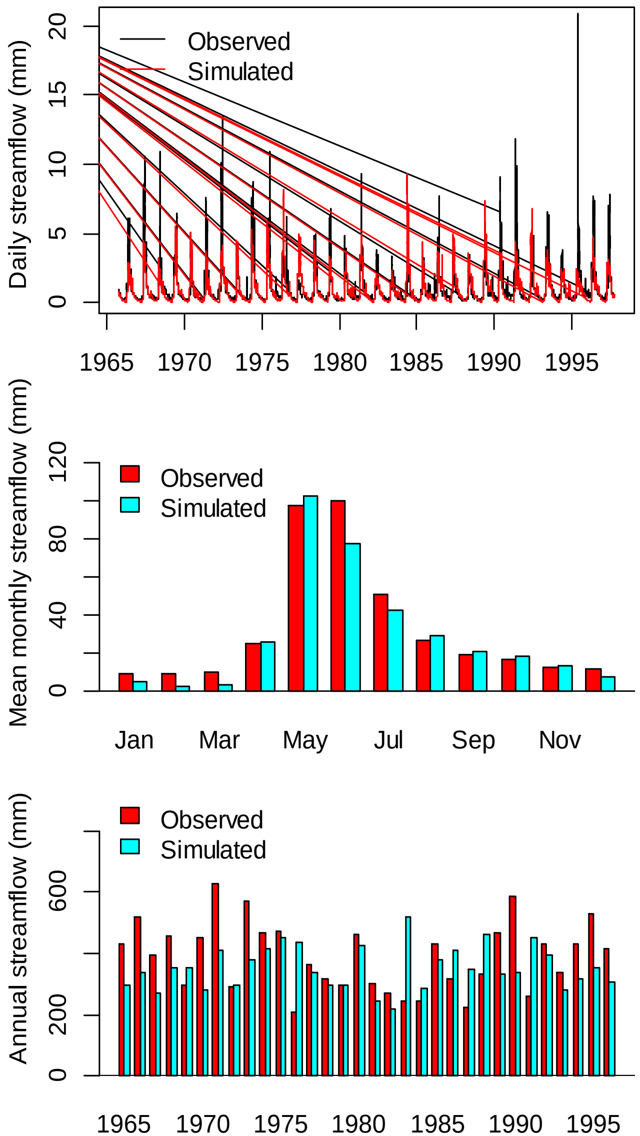
Results

Hydrological model calibration, application and parameters sensitivity

Application

HBV-EC is driven by the disaggregated climate at driver station, Coleman, and model simulated streamflow is compared with observed values.

- Similar result as in calibration was obtained though the input came from different sources.
- Difference in annual mean was about 9%.



Results

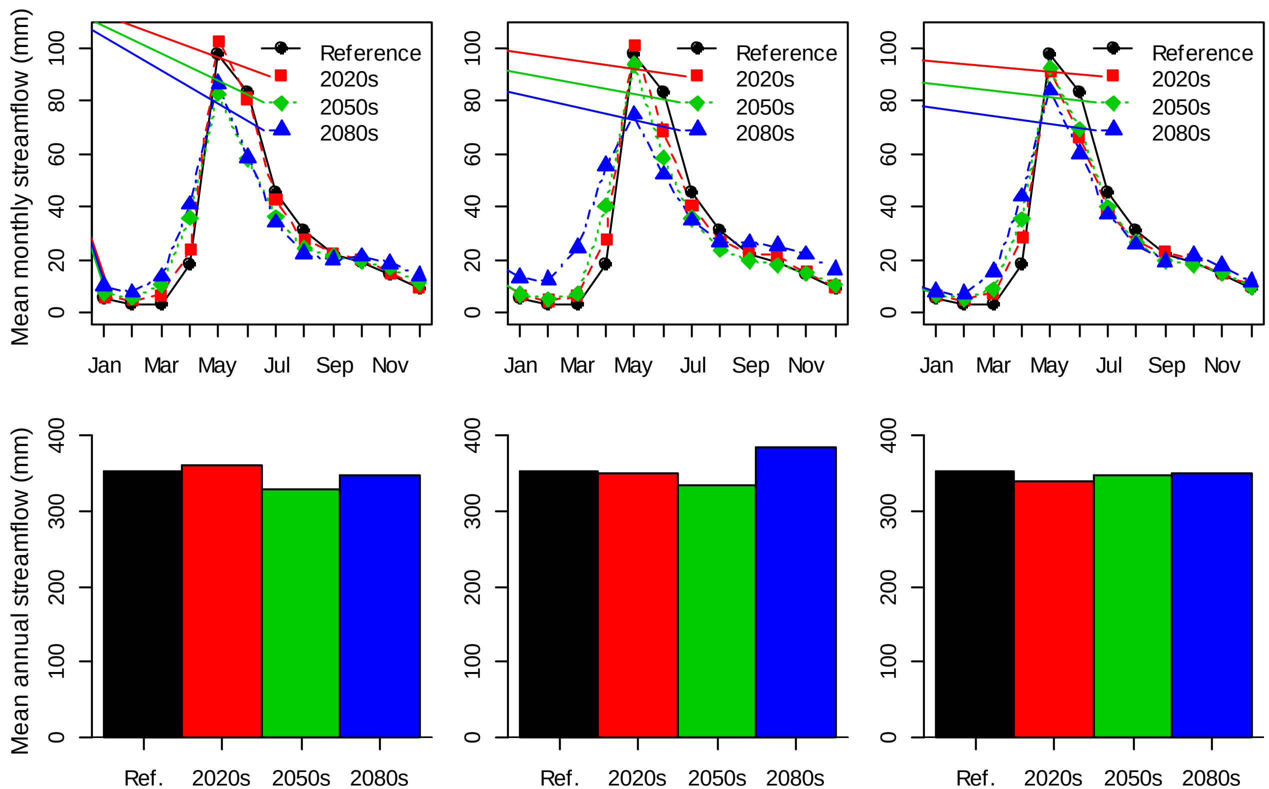
Hydrological model calibration, application and parameters sensitivity

Application

HBV-EC is driven by the disaggregated climate at driver station for reference and nine future periods, and model simulated streamflows, snow water equivalent (SWE) and evapotranspiration are compared.

Streamflow

- Winter low flows increased up to 200% (9.3 mm) in February.
- Summer high flows decreased up to 63% (31.2 mm) in June.
- Fall (September, October and November) flows were least affected and remains almost.
- Not much difference in annual water yield.

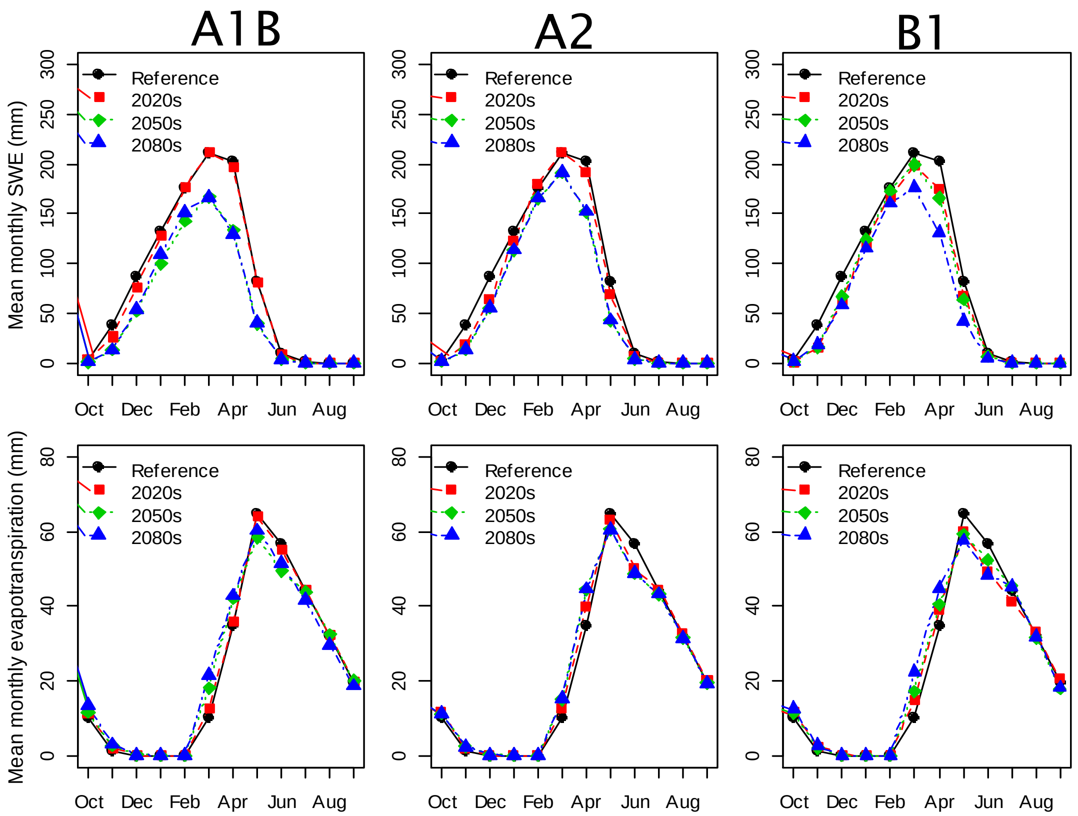


Results

Hydrological model calibration, application and parameters sensitivity

Application

- SWE
  - SWE decreased
- Evapotranspiration
  - Evapotranspiration increased in spring and decreased in summer.
  - Despite increase in temperature throughout the year, decrease in evapotranspiration during summer indicates the water limited evapotranspiration, not the energy limited.

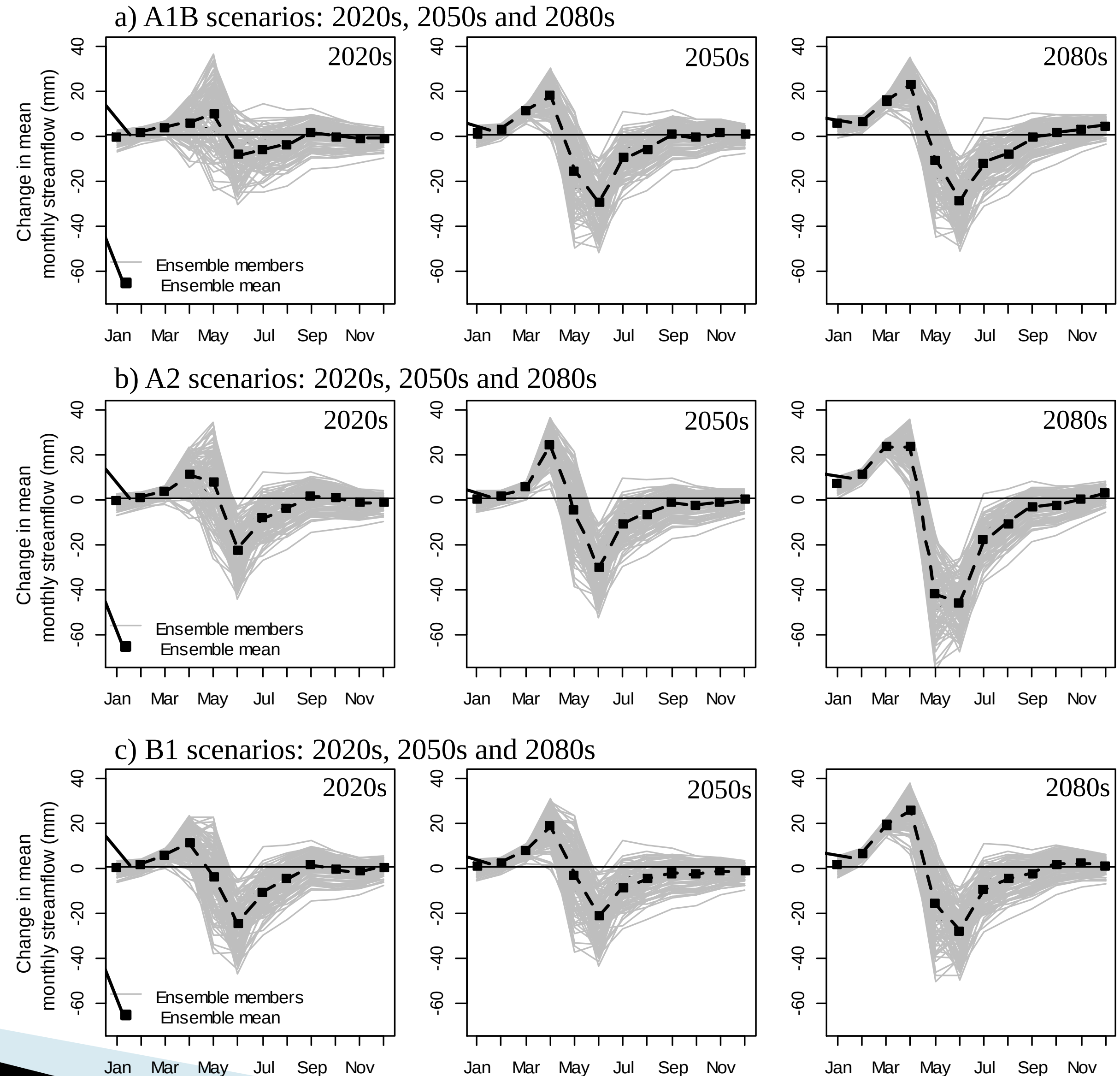


Results

Hydrological model calibration, application and parameters sensitivity

Sensitivity

- The impacts of uncertainty were higher during spring and summer.
- Chances of summer flow dropping is more.



Conclusions

- Less than 10 % increase in precipitation in winter resulted in up to 200% (9.3 mm) increase in winter streamflow.
- Less than 10 % decrease in precipitation in summer resulted in up to 63% (31.2 mm) decrease in summer flow.
- Impacts of climate change on streamflow is relatively higher for A2 scenario and this is reasonable as there is rapid economic growth but the technological changes are fragmented in A2 scenario compared to other two scenarios .
- There is more uncertainty in the prediction of summer flows, so chances of dropping summer flow is higher.

- Forest disturbances (wildfire, insects, logging, etc.) that may have compounding impacts with climate change, remains subject of further analysis.

Questions?