Department of Energy

Bonneville Power Administration
P.O. Box 3621
Portland, Oregon 97208-3621

FREEDOM OF INFORMATION ACT/PRIVACY PROGRAM

September 14, 2021

In reply refer to: FOIA #BPA-2021-00092-F

Jeremy Hainsworth
Glacier Media
303 West 5th Ave
Vancouver, BC V5Y1J6
Email: jhainsworth@glaciermedia.ca

Dear Mr. Hainsworth,

This communication concerns your agency records request submitted to the Bonneville Power Administration (BPA), made via the Freedom of Information Act, 5 U.S.C. § 552 (FOIA). BPA received your request on October 28, 2020. BPA formally acknowledged your request on November 18, 2020 and provided you a first partial response of records on June 25, 2021.

Request
"All reports, memos and briefing notes regarding the effects on US water supply and power supply as a result of the effects of climate change on watersheds in the Canadian province of British Columbia. All communications regarding the effects of climate change from the government of British Columbia regarding water and power supply to the United States. This is a media request."

Agreement to Re-scope Responsive Records
On February 23, 2021, after communicating with the agency, you agreed to re-scope your request to: "All reports and briefing notes regarding the effects on US water supply and power supply as a result of the effects of climate change on watersheds in the Canadian province of British Columbia."

Second Partial Response
This partial response comprises records that BPA was required by 5 U.S.C. § 552(b)(4) (Exemption 4) to solicit objections from third parties prior to their release. The records contain information created by:

- BC Hydro
- University of Victoria
- University of British Columbia
- University of Northern British Columbia
- Environment and Climate Change Canada

- University of Washington
- Oregon State University
- University of Idaho

Those outreaches to third parties have been made. We are releasing 426 pages of records with one page containing minor redactions under Exemption 4.

We are also providing a link to one responsive record that is publicly available at:
Gao_et_al_VIC_2014.pdf (lancs.ac.uk)

Please note, several records provided to BC Hydro, the University of Washington, and Oregon State University were jointly authored with the U.S Army Corps of Engineers (the Corps) and the U.S. Bureaus of Reclamation (the Bureau); those records continue to be reviewed as described below at 'Ongoing Processing – Corps and Bureau.'

Explanation of Exemption
Exemption 4 permits withholding third party confidential commercial information found in agency records. BPA here relies on Exemption 4 to protect commercial and financial information belonging to BC Hydro. In this instance, Exemption 4 protects file paths to confidential BC Hydro resources that explain how the agency conducts their business.

Certification
Pursuant to 10 C.F.R. § 1004.7(b)(2), I am the individual responsible for the second partial FOIA response described above.

Ongoing Processing – Corps and Bureau
Prior to publicly releasing agency records, BPA is required to review responsive records for possible exemptions under 5 U.S.C. § 552(b)(5) (Exemption 5). Exemption 5 protects agency records showing the deliberative or decision-making processes of the agency. The majority of records collected for your request were jointly created by the River Management Joint Operating Committee, which consists of the Corps and the Bureau. BPA sent approximately 30,000 pages of records to the Corps and the Bureau for their examination. Those agencies will notify us as soon as they have completed their reviews. Please note, BPA does not control their processing time.

Target Date
In light of the required consultation with the Corps and the Bureau BPA currently estimates the completion of a response to your FOIA request by December 9, 2021. BPA invites you to contact us to discuss this estimated completion date.

Lastly, you may contact the Office of Government Information Services (OGIS) at the National Archives and Records Administration to inquire about the FOIA mediation services they offer. The contact information for OGIS is as follows:

Office of Government Information Services
National Archives and Records Administration
8601 Adelphi Road-OGIS
College Park, Maryland 20740-6001
E-mail: ogis@nara.gov
Phone: 202-741-5770
Toll-free: 1-877-684-6448
Fax: 202-741-5769

Questions about this communication or the status of your FOIA request may be directed to FOIA Public Liaison Jason Taylor at jetaylor@bpa.gov.

Sincerely,

Candice D. Palen
Freedom of Information/Privacy Act Officer

Responsive agency information accompanies this communication.

COLUMBIA RIVER TREATY
HYDROMETEOROLOGICAL COMMITTEE

2009 ANNUAL REPORT

January 15, 2010
Prepared by S.Smith BCH

Climate and River Level Monitoring Station, Elk River ***(Source: BCH)***

JANUARY 2010

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COLUMBIA RIVER TREATY
HYDROMETEOROLOGICAL COMMITTEE

2009 ANNUAL REPORT

Introduction

The Columbia River Treaty Hydrometeorological Committee (CRTHC) was established in September 1968 by the Entities. The Committee is responsible for planning and monitoring the operation of the hydrometeorological data collection network in accord with the Columbia River Treaty (CRT). It also assists the Entities in matters related to hydrometeorological and water supply forecasting.

This report summarizes Committee activities during the 2009 operating year (October 1, 2008 – September 30, 2009). The Annual Report focuses on:

- action taken on proposed changes to the hydrometeorological monitoring network
- updates to CRT communications and data storage systems
- updates to data exchange requirements
- updates to forecasting procedures
- review of the 2009 CRT water supply forecasts
- other activities of the Committee

The Committee began issuing regular Annual Reports in 2001. General background information on Committee activities contained in the 2001 and 2002 annual reports is now presented in a separate supplemental document. The supplement contains general information that does not typically change from year to year. Appendices in the 2009 supplemental document include:

- Appendix A – Introduction to the Committee terms of reference
- Appendix B – Terms of reference for the CRTHC
- Appendix C – Process for reviewing hydrometeorological data networks
- Appendix D – List of contributors of hydrometeorological data
- Appendix E – Data communication and storage systems
- Appendix F – Data exchange reports
- Appendix G – Treaty studies, models, and forecast requirements

C O L U M B I A   R I V E R   T R E A T Y
H Y D R O M E T E O R O L O G I C A L   C O M M I T T E E

2 0 0 9   A N N U A L   R E P O R T

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(Note: Italics indicates new sections for 2009)

See 2009 Supplemental Report for a list of Acronyms used in this report

COLUMBIA RIVER TREATY
HYDROMETEOROLOGICAL COMMITTEE

2009 ANNUAL REPORT

2009 Annual Summary

The Columbia River Treaty Hydrometeorological Committee (CRTHC) was established in September 1968 by the Entities and is responsible for planning and monitoring the operation of hydrometeorological data collection network in accord with the Treaty and otherwise assisting the Entities as needed. The Committee consists of four members as follows:

UNITED STATES SECTION	CANADIAN SECTION
David Bright*, BPA Co-Chair	Stephanie Smith, B.C. Hydro, Chair
Peter Brooks, USACE Co-Chair	Frank Weber*, B.C. Hydro, Member

* There were two changes in the Committee Membership in 2009. Frank Weber replaced Doug Smith as the Canadian Member on November 1, 2008. David Bright replaced Brian Kuepper as the BPA co-chair for the US on August 3, 2009.

The CRTHC met twice in the 2008-2009 water year: on November 3, 2008 in Vancouver and on June 10, 2009 in Portland.

The CRTHC 2007-2008 Annual Report was completed and submitted to the Columbia River Operating Committee (CRTOC) in February 2009.

Stations

The Committee process for reviewing proposed changes to the operation of stations within the hydrometeorological network is described in Appendix C of the 2009 Supplemental Report. The process is intended to ensure that changes made to the network do not negatively affect the monitoring, planning, and operations of Treaty facilities. Schedule 1 summarizes the Committee's response to changes to stations of the CRT hydrometeorological network in 2009.

The CRTHC responded to a notice sent in 2008 from the NRCS in the U.S. about a review of the SNOTEL monitoring network and the identification of 9 potential station closures in the network. The CRTHC reviewed the list and responded to the NRCS, and is still awaiting their reply.

The observers at Porthill and Bonners Ferry in Idaho both quit over the summer, and the NWRFC informed CRTHC that they were seeking new observers. Both stations are used by Canada in the Kootenay Lake water supply forecasts, and are considered important to forecasting for the Columbia region. Until the replacement observers are hired, NWRFC is providing their estimated monthly precipitation for the sites to BCH. Temperature estimates for the Porthill station, required for water supply forecasting, are currently not being provided.

The Seattle District office of USACE, BPA and BCH coordinated to install two new water temperature sensors in the Kootenay River at Fort Steele and Elk River at Fernie hydrometric gauging stations to aid in water temperature modeling for Koocanusa reservoir. USACE provided the sensors, BC Hydro arranged for installation and maintenance by Water Survey of Canada at the sites, and BPA will pay for the annual operating costs. The probes were installed in the Fall of 2009.

Station Network Review for Improved Forecasting

The CRTHC developed a strategy and began drafting a work plan to investigate enhancing the hydrometeorological monitoring network in the Columbia basin, specifically for monitoring real-time snow monitoring. The investigation is currently focused on the relatively data sparse regions in the headwater regions of the Columbia above Mica and Kootenay River above Libby. The Committee is investigating the addition of new monitoring stations along with other options such as upgrading existing sites by converting manual snow courses into automated sites, re-establishing sites that have closed, and/or upgrading satellite communications to permit more frequent data transmission rates. The CRTHC recognizes that establishing more and/or more automated snow monitoring sites does not necessarily result in an automatic improvement in forecasting. Forecasting volumes and streamflows is a complex process involving qualitative as well as quantitative analysis. Furthermore, data demands are driven by the type of forecast model employed currently and in the foreseeable future. The CRTHC is pursuing a network review and will evaluate possible forecasting improvements including a cost-benefit. BCH is a partner in a new provincial climate network coordination effort to better integrate the monitoring networks across BC which could provide access to data from stations already operating in the desired regions by other agencies. The CRTHC will also explore possible funding mechanisms including a partnership in funding between the U.S and BC Hydro.

Communication and data storage systems

The Columbia Basin Telecommunications (CBT), other communication systems, and the Columbia River Operational Hydromet System (CROHMS) are described in Appendix E of the 2009 Supplemental Report. The CBT system, operated by USACE in Portland, is the primary communications system for transmitting data from the Columbia River Treaty hydrometeorological network. Agencies, including the Northwest River Forecast Center (NWRFC), USACE, and BCH, also use other communication systems to exchange data. CROHMS is the central system for collecting and re-distributing hydrometeorological data used to support the operations of Treaty projects.

The USACE new Regional Water Control Data System (RWCDS) is on track for deployment in 2010. It will use agency standard hardware and software (Corps Water Management System 2.0). The RWCDS will be a tri-node system for redundancy and continuity of operations. All support operations will be managed at the regional level, pooling resources from three USACE districts and the Columbia Basin Water Management Division. A Steering Committee has been established to oversee the RWCDS. The permanent program manager, Troy Fox, has been selected to lead implementation and manage the system as laid out by the Steering Committee.

Data exchange

Appendix F of the 2009 Supplemental Report describes current data exchange procedures. Data exchanged among operational projects and entity agencies may be categorized according to the type of data and the frequency of transmission. Types of data include project data, weather and streamflow data, inflow forecasts, as well as reports and messages. The frequencies of transmission may be hourly, daily, or monthly.

In addition to the standard reporting, there were additional actions and issues during 2009. These are summarized as follows:

- A BCH CROHMS program which sends data to CROHMS has become unsupportable by their IT department. BCH updated the coding of their program to a more supportable programming structure in 2009, and will investigate incorporating the whole functionality into a new data management system in 2010.

- In accordance with Section 3.1C(1) of the 2003 POP, the Entities participated in studies to update the estimated irrigation depletions in the historic streamflow record used for Assured Operating Plan studies. This effort, entitled the "2010 Modified Flows" formally began in August 2009 and is expected to be completed by August 2011. Most of the work will be conducted by staff of the Northwestern Division of USACE, BPA and USBR, with data input from BCH and others. The contractors that produced the 2000 Modified Flows were hired to train agency staff.

Forecasting

There were no changes to any of the forecasting procedures in 2009. The Committee is involved with various Treaty planning studies and models from time to time. These studies and models and associated forecasting requirements are described in Appendix G of the 2009 Supplement Report.

Walla Walla District USACE is considering a modification to the Dworshak volume forecast procedure to include mid-month adaptive management.

KOOTENAY LAKE FRESHET DECLARATION FORECAST PROCEDURE

The declaration of the spring freshet on Kootenay Lake by the IJC Kootenay Board of Control has operational impacts to both Libby and Duncan operations upstream. The CRTHC prepared and submitted to the CRTOC an objective procedure tool to assist determining the onset of the Kootenay Lake spring freshet. The procedure is not intended to replace human decision making, but would provide addition guidance and some limited predictive capability on when to expect the freshet to begin.

CRTOC chairs presented the methodology to the IJC Kootenay Board of Control, and the IJC Kootenay Board of Control rejected the proposal due to a difference in interpretation of the term 'commencement of the spring rise' on Kootenay Lake. Thereby the methodology proposed by the CRTHC is based on a definition that assumes that the term 'spring rise' is synonymous with the term 'spring freshet' and, as such, refers to the periodic, annual increase in natural, unregulated Kootenay Lake inflows due to snowmelt. It was learned that, in contrast, the IJC Kootenay Board of Control bases the declaration on the rise in the Kootenay Lake level.

As a result the IJC Kootenay Board of Control prefers their own experts' advice to make the declaration of the freshet. CRTOC and CRTHC will follow up with the Kootenay Board of Control about the deficiencies in the methodology and whether it can be modified into something they will accept.

Forecast Verification

BC Hydro presented a 2009 forecast verification report for the Columbia River Treaty forecasts at a meeting of the Columbia River Forecast Group on December 15, 2009 in Portland. The presentation included a summary of 2009 climate, hydrology and water supply forecasts. The water supply forecasts and information on the hydrometeorology for the year are presented in the 2009 Annual Report of the Columbia River Treaty by the Entities (p.55 Tables 1M and 1), and will not be repeated here. This section gives a brief overview of the forecasts and focuses on the results of the verification of the Treaty project forecasts and any lessons learned.

The Arrow local drainage is defined as the sum of the Arrow, Revelstoke, and Whatshan basins, while the Arrow total drainage is defined as the sum of the Arrow, Revelstoke, Whatshan, and Mica basins. Arrow local and total forecasts are aggregates of sub-basin forecasts.

For early-season (December) forecasts, total Feb-Jul forecast volumes are disaggregated into monthly volumes using the monthly runoff distribution from the 71-year mean. For consecutive forecast dates, total Feb-Jul volumes, or the residual thereof, are calculated by aggregating BC Hydro's monthly forecast volumes and disaggregated using the monthly runoff distribution from the 71-year mean. January forecasts are naïve (climatology, 71-year mean) forecasts. August forecasts are the difference between Apr-Aug forecasts and the Apr-Jul volume of the disaggregated Feb-Jul forecasts.

2009 Highlights

- Columbia and Kootenay River projects' inflow for the Feb-Jul and Apr-Aug periods were well-below normal (74-80 % of 71-yr Avg.).
- Seasonal runoff for all projects and forecast dates were over-forecast throughout the season, but with the forecast volume generally declining over time and asymptotically approaching what was to become the true value.
- For most forecast dates and projects, the final observations fell outside the - 1 standard error prediction confidence bounds and for many of the forecast dates and projects even outside the - 2 standard error prediction confidence bounds.

- There was a progressive and very strong drying trend through much of the water year. Weather (especially precipitation) between the forecast date and the end of the forecast horizon forms the major source of uncertainty in seasonal water supply forecasts. With the partial exception of some modest and inconsistent prediction skill derived from climate indices (see below), it is necessarily assumed in such water supply models that future precipitation will follow seasonal normals. Hence, if actual precipitation comes in below- (above-) normal, the water supply prognosis will turn out to be an over- (under-) estimate.
- The role played by ENSO climate data in the forecast equations contributed slightly to the over-forecasts. The most accessible and perhaps reliable means for providing intelligence on long-term weather between the forecast issue date and the end of the forecast season is the incorporation of seasonal climate information into the forecast system. Jun-Sep mean values of the Southern Oscillation Index (SOI) and Multivariate ENSO Index (MEI) are employed in the Treaty statistical forecast equations. In Water Year 2009, these values pointed to slightly cold-phase (La Niña) conditions. On average, cool-phase ENSO conditions tend to give higher-than-normal precipitation and lower-than-normal temperatures over winter and spring; the temperature signal is the more consistent of the two. Thus, the climate state information entered into the early-season quantitative statistical forecast process brought the Feb-Sep volume forecasts up slightly. Later in the season, however, it became apparent that although the cool temperatures generally seen in southern BC were consistent with La Niña conditions, very dry conditions also materialized, and these were less consistent with a cool-phase tropical Pacific climate state. It thus appeared at that time that the climate state data entered into the Treaty statistical forecast equations might slightly overestimate Feb-Sep flow volumes. Finally, following the end of the water year, the official verdict from the Climate Prediction Center was that WY2009 was not, in fact, a La Niña year. Particularly, early-season (i.e., December and January) forecasts were adversely

affected by using the climate signal. However, the impact was generally small, being generally on the order 4% of the residual forecast volume (for example, Arrow Dec forecasts) or less.

Climate Change

While not under the mandate of the CRTHC, the agencies that make up CRTHC are all involved in research into the potential impacts of climate change on the water resources in the Pacific Northwest, and are working together to provide a coordinated set of studies across the Columbia River Basin. These studies will be input into water resource management planning across the region, including potentially the CRT 2014/2014 studies. The three main studies will be completed in 2010 and are outlined here for reference.

COLUMBIA RIVER MANAGEMENT JOINT OPERATING COMMITTEE COLUMBIA BASIN STUDY

The River Management Joint Operating Committee (RMJOC) members are coordinating on studying climate change impacts to water resources across the whole of the Columbia basin with the goal of providing consistent incorporation of climate projection information into RMJOC longer-term water management planning studies. The need for a coordinated effort was recognized by the agencies to:

- adopt common dataset (climate and hydrology),
- establish consensus methods for data use, and

- efficiently use limited resources through coordinated development of data and methods.

The project leads include Nancy Stephan from BPA, Seshu Vaddey from USACE Portland District and Levi Brekke from USBR. BCH is an external reviewer of this study. The study began in spring of 2009 and is on schedule to be completed in the summer of 2010.

PACIFIC CLIMATE IMPACTS CONSORTIUM STUDIES

The Pacific Climate Impacts Consortium (PCIC) formed in 2005 with seed funding from the province of British Columbia, BCH and others to create a local centre of excellence in assessing the potential impacts of climate change in the unique geographic and hydroclimatic conditions in B.C. BCH is sponsoring studies to assess changes to the future hydrologic regime in its reservoirs under climate change. Currently in the third year of a four-year research program, the studies examining potential changes to inflows in the Williston, the Columbia and Campbell River watersheds are on schedule to be completed in late 2010.

WESTERN CANADIAN CRYOSPHERIC NETWORK MICA GLACIER STUDY

The Western Canadian Cryospheric Network (WC2N) is a consortium of six Canadian universities, two American universities and government and private scientists who are examining the links between climatic change and glacier fluctuations in western Canada. WC2N is undertaking a study to model changes in glacier extent and glacier runoff in the Mica watershed based on possible future climates. This study was commissioned by BCH to specifically address the deficiencies of the two studies above in capturing the changes to the glaciers in the Columbia basin and to provide a quasi-independent study to compare to the other study results. Results from this study are expected in mid-2010.

Schedule 1 Changes to the hydrometeorological network in 2009

- Porthill, Idaho and Bonners Ferry, Idaho lost their observers. NWRFC is seeking replacement observers and in meantime providing estimates of precipitation data for the sites to BCH for input into the Kootenay Lake water supply forecast. Temperature data, or estimates, for the Porthill station are currently missing.

- Status of 9 potential SNOTEL station closures proposed by NRCS in 2008 undetermined.

Snow Course Site	Period of Record
Dead Horse Grade	1950 – present
Government Corrals	1981 – present
Meacham	1929 - present
New Dutchman #3	1990 – present
Park H.Q. Rev	1943 – present
Hungry Flat	1952 – present
Grayback Peak	1936 – present
Tollgate	1931 – present
Annie Spring REV	1929 - present

- 2 new water temperature sensors were installed at Kootenay River at Fort Steele and Elk River at Fernie in BC at request of USACE Seattle District to support water temperature modelling of Koocanusa Reservoir.

Schedule 2 CRTHC Action Items

Table 1 Outstanding Action Items 2009

Meeting Source	Description	Notes/Updates	Assigned To
OUTSTANDING ACTION ITEMS			
57.2.c.2	Explore options to clarify HGH storage tables used for various uses and modeling.	Peter to follow up. **USBR trying to consolidate and standardize to single table (with and without storage) for TSR**	~~Cindy Henriksen~~ Peter Brooks
58.5.c	Peter to pursue putting electronic versions of forecast reports on FTP site	Mtg 59.1.a: Peter to assign someone to give access details to BPA / BCH	Peter Brooks
59.4.a	Stephanie to provide updated list of Environment Canada reference climate stations and core temperature and precip. Stations. Will cross-reference with Treaty station list. Will also include indication if stations are potentially vulnerable		Stephanie Smith
60.4.b	Establish a data working group to address ongoing data issues, document and improve data transfer protocols, and coordinate communication around changes and updates to data management systems.	NWS reps will be Harold Opitz and Kevin Berghoff	All - with Corps as lead agency.
60.4.c	Disaster Recovery plans - Stephanie to determine what, if anything, BC Hydro will do about data recovery in the event of a major system interruption	BCH working on in 2010.	Stephanie Smith
61.4.b	Potential SNOTEL closures in Pac NW. Follow up with RFC. Keep updated by NRCS (Jon Lea)	BCH has no issue with potential station closures	Peter Brooks & David Bright
63.1.a	Investigate monitoring station coverage of upper Columbia by investigating station density vs. hydrologic response		David Bright
63.1.b	Pull together documentation on how suitable monitoring sites have historically been identified by BCH, Env Canada and BC	64: BC MoE has no documentation on site selection criteria	Stephanie Smith

Table 2 Completed Action Items 2009

Meeting Source	Description	Notes/Updates	Assigned To
COMPLETED ACTION ITEMS			
57.3.a	Set up meeting with RFC, COE, BPA and USGS to discuss USGS rating table issue	Meeting delayed due to the fact the USGS to continue providing data through 2006. Still need to meet on this issue. Mtg 59: Deferred to Fall 2006 **Mtg 60: USGS Ratings Depot Live. Still a few issues to resolve around timing of updates.**	Nancy Stephan
61.2	Streamflow workshop for Fall 2008. Peter has draft requirements for BiOp	changed to Volume forecast workshop in 09	Nancy & Randy
62.7.b	Kootenay Lake Freshet declaration methodology - form technical committee to make a recommendation of method prior to Spring 09 Freshet. Present draft recommendation at the PEB meeting Feb 25.	Frank Weber from BCH developed forecasting methodology and CRTOC presented to IJC/ Kootenay board of control.	Frank Weber, Randy Wortman
62.7.c	Pacific NW RFC briefing on changes to forecast procedures. BPA to keep BCH informed		Brian Kuepper
62.7.f	CRTHMC to collaberate on respective climate change studies. Identify gaps and overlap between methodologies. Inform CRTOC of collaberation.	change to regular agenda item in CRTHC meeting	Doug Smith / Doug McCollor (?) and Nancy Stephan
62.8.c	Include action items in annual reports starting with 2008. Consider adding station performance stats and forecest verification to 2009 report		Stephanie Smith to send completed 2008 actions to Brian
63.1.c	Conduct literature search on monitoring site identification techniques	Paper: Mishra & Coulibaly. "Developments in Hydrometric network design: A review" Reviews of Geophysics, Vol 47, 2009	Frank Weber

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Columbia River Treaty Operating Committee meeting

HYDROLOGIC CLIMATE CHANGE IMPACT

PART 3: MULTIAGENCY PREDICTIONS - SYNTHESIS

Teleconference: Burnaby, BC, Canada – Portland, OR, USA
August 10, 2011

Frank Weber, Lead, Runoff Forecasting

BC hydro
FOR GENERATIONS

hydrology & technical services

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CONTENT

PART 3: MULTIAGENCY PREDICTIONS - SYNTHESIS

- Comparison of multi-agency projections of hydroclimate conditions
- Comparison of multi-agency projections of annual and monthly Mica inflow
- Action Plan

COMPARISON OF MULTI-AGENCY PROJECTIONS OF HYDROCLIMATE CONDITIONS

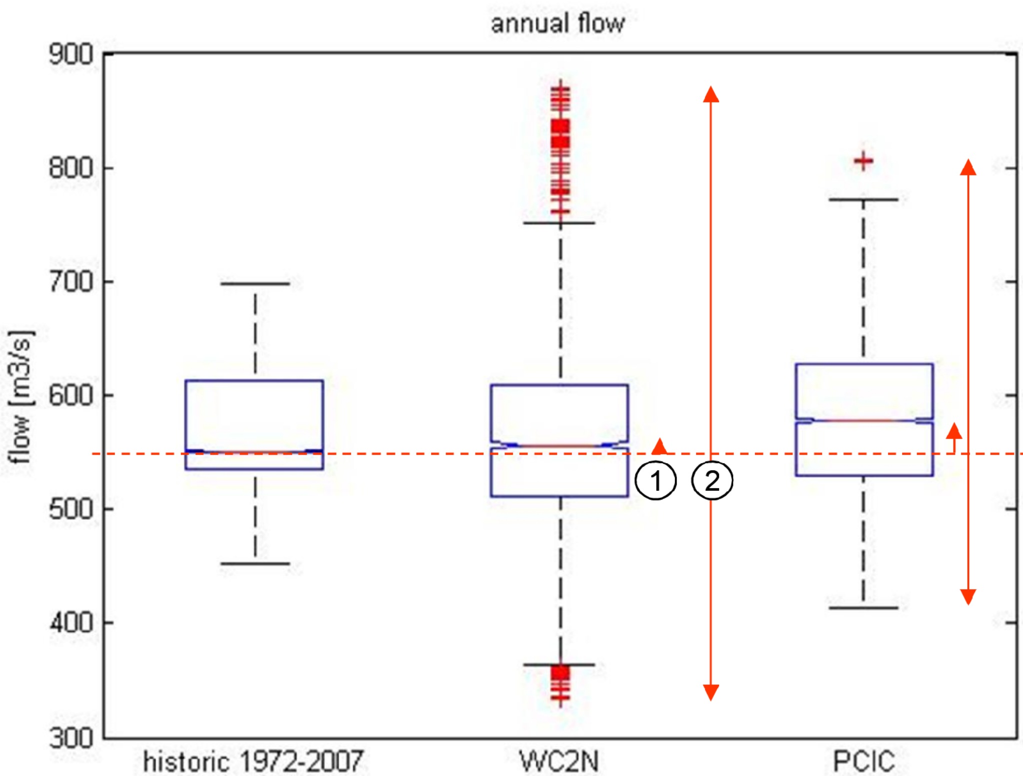
- Project: Mica

	median annual precipitation (%)		median annual temperature (ºC)		median annual flow (%)	
	PCIC*	WC2N**	PCIC*	WC2N**	PCIC*	WC2N**
B1	+9	+6	+2.0	+1.9	+16	+4.2
A1B	+10	+11	+2.7	+2.2	+22	+10.0
A2	+7	+10	+2.2	+2.2	+17	+7.7
mean	+7.3	+9.2	+2.3	+2.1	+18	+7.3

* Relative to 1961-1990
** Relative to 1985-2000

COMPARISON OF ANNUAL FLOW PROJECTIONS

- Project: Mica
- Projections for 2050-2065 period generated with agency specific ensembles

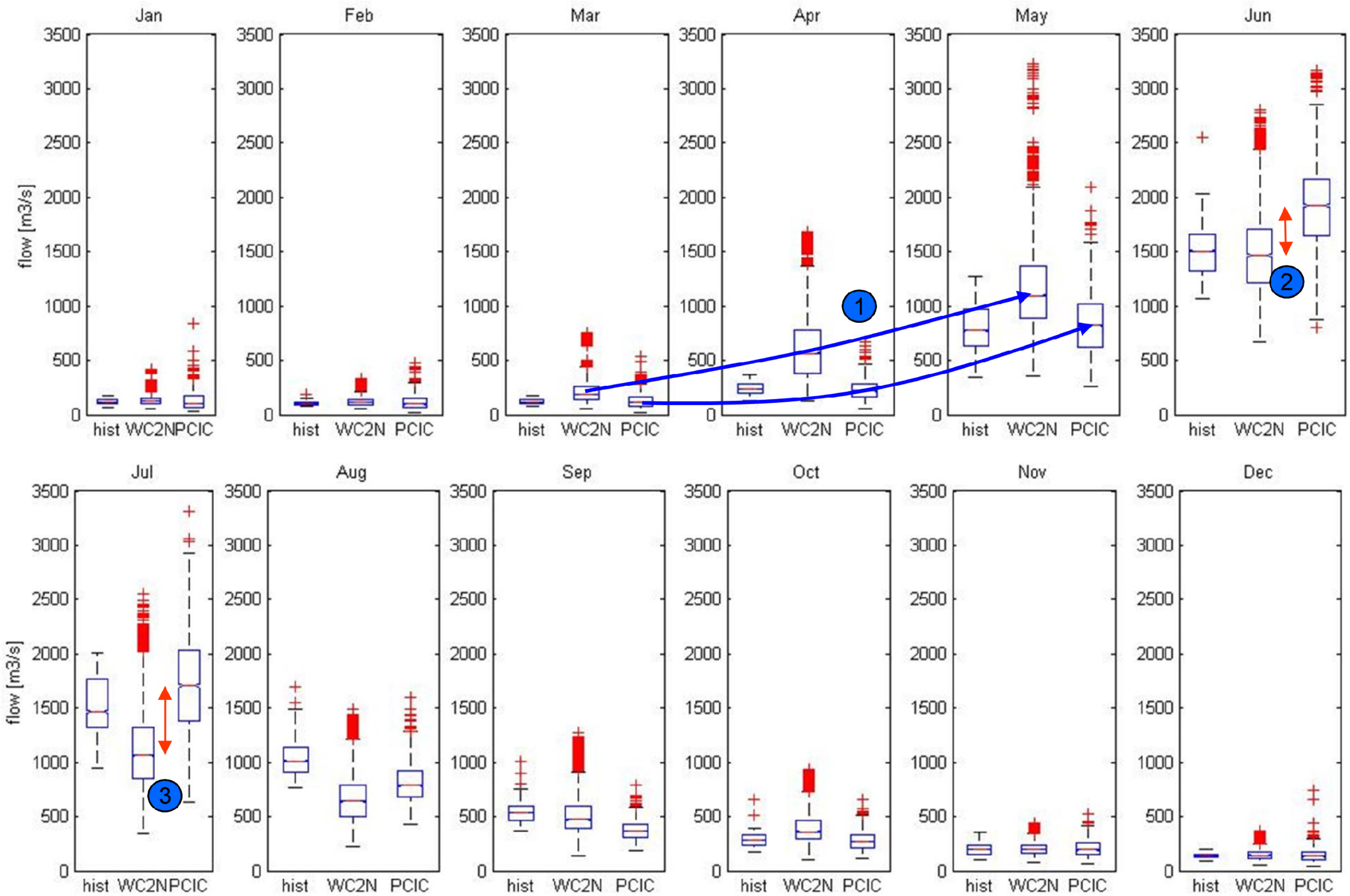


COMPARISON OF ANNUAL FLOW PROJECTIONS

KEY DIFFERENCES

1. Annual inflow increase: PCIC forcings are marginally wetter than WC2N forcings
2. Uncertainty: (i) WC2N TreeGen downscaling includes a stochastic component and (ii) WC2N modeling incorporates hydrologic modeling uncertainty

COMPARISON OF MONTHLY FLOW PROJECTIONS



COMPARISON OF MONTHLY FLOW PROJECTIONS

KEY DIFFERENCES

1. Freshet onset: PCIC projections are for smaller changes in freshet onset timing
2. June (and – although to a lesser degree) July flows:PCIC flows are substatially higher than WC2N flows
3. July flows: agency projections go into opposite direction

Overall hydrologic modeling uncertainty is masking the differences in glacier modeling approaches!

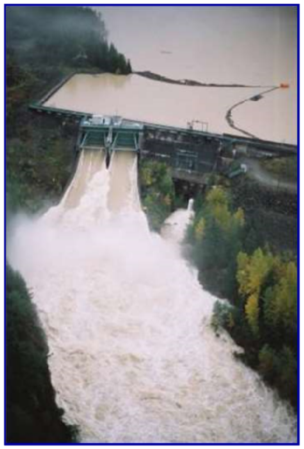
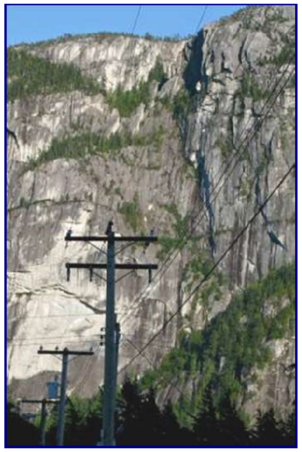
ACTION PLAN

- Add UW-CIG/RMJOC results into the ensemble
- Compare monthly hydrologic model biases and further analyze quality of the hydrologic models
- Compare seasonal basin-specific forcings
- Investigate the disproportional flow increase projected by the PCIC study
- Define system modeling requirements for hydrologic flow projections

THANKS FOR LISTENING





Columbia River Treaty Operating Committee meeting

HYDROLOGIC CLIMATE CHANGE IMPACT

PART 2a: PREDICTIONS – STATE OF SCIENCE
PART 2b: PREDICTIONS – WC2N STUDY

Teleconference: Burnaby, BC, Canada – Portland, OR, USA
August 10, 2011

Frank Weber, Lead, Runoff Forecasting
Georg Jost, Senior Hydrologic Modeler

BC hydro
FOR GENERATIONS

hydrology & technical services

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CONTENT

PART 2a: PREDICTIONS – STATE OF SCIENCE

- Key science questions
- Emission scenarios & Global Climate Models
- Hydroclimatic projections for BC
- Glaciers and Climate Change
- Hydrologic Climate Change impact studies – the modeling chain
- What do the results mean?

PART 2b: PREDICTIONS – WC^{2}N STUDY

- Overall modeling approach
- Multi-criteria based GCM/scenario selection
- GCM downscaling
- Watershed modeling
- Glacier mass balance & dynamics modeling
- Projected climate trends
- Projected glacier trends
- Projected inflow trends

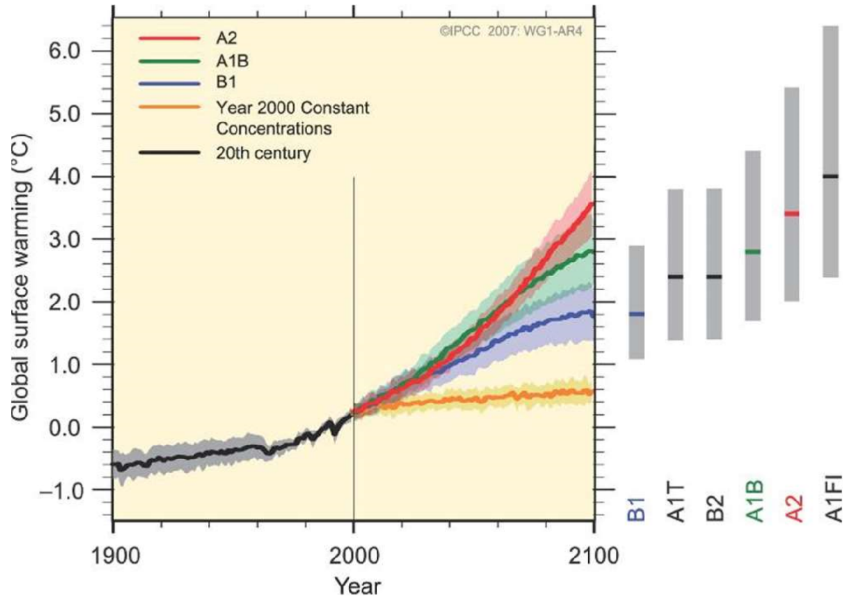
INTRODUCTION

KEY SCIENCE QUESTIONS

- What future water supply can we expect for individual projects & collectively for the system?
- What is the direction and magnitude of change?
- How will the seasonal timing of inflows change?
- Can we expect changes in reliability, i.e., year-to-year variability, of water supply?
- What is the largest source of uncertainty in the modeling chain?
- How sensitive is hydroelectric power generation to the hydrologic impacts of climate change?

EMISSION SCENARIOS

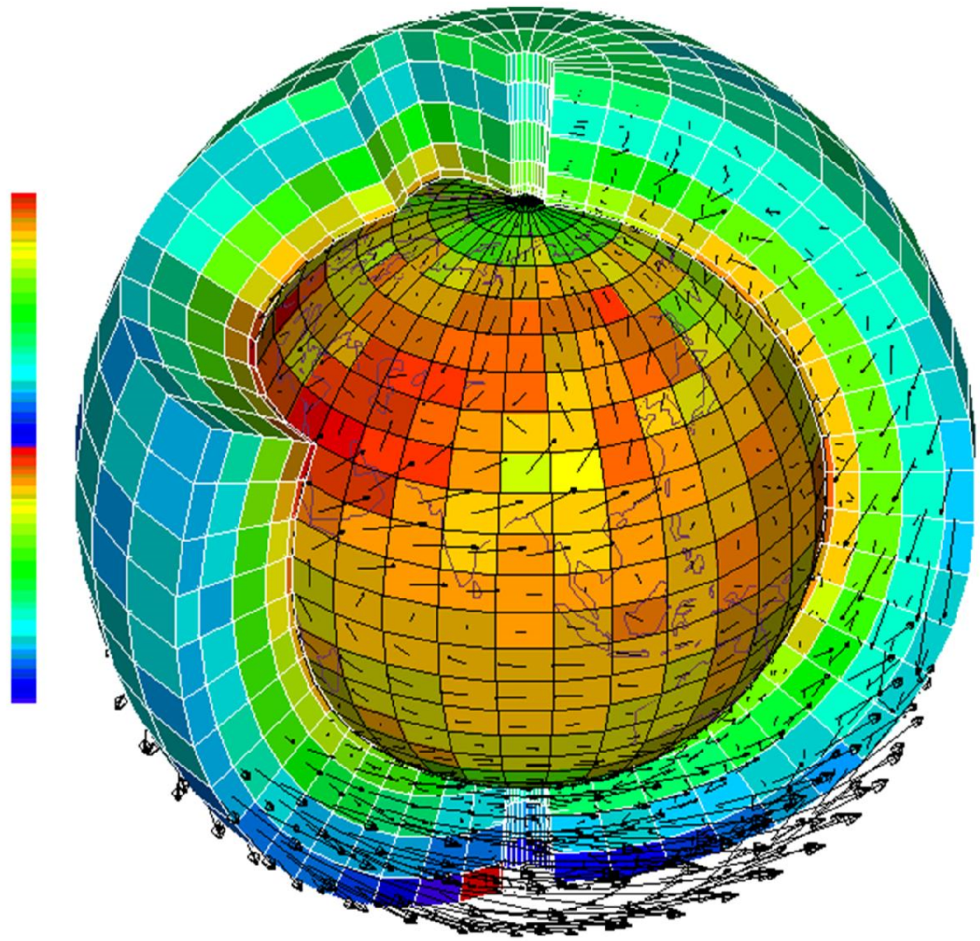
- Scenarios only deal with anthropogenic forcings and are based on demographic, social, economic, technological and environmental developments
- Scenarios do not take, e.g., volcanic eruptions into consideration
- Primary scenarios:
  - High forcings from 2000 to 2100: A2 (CO_2 concentration about 820 ppm by 2100)
  - Medium forcings from 2000 to 2100: A1B (CO_2 concentration about 700 ppm by 2100)
  - Low forcings from 2000 to 2100: B1 (CO_2 concentration about 550 ppm by 2100)
- Note that the emissions trajectories for A2 and A1B are such that the projected climate response to A1B is generally larger than for the A2 by the mid-21st century
- Recent 21st century emissions have been more pessimistic than the worst case SRES scenario; the A1B trajectory is the most likely scenario for the 2050s



Source: IPCC AR4

GLOBAL CLIMATE MODELS (GCMs)

- GCMs are numerical models representing physical processes in the atmosphere, ocean, cryosphere and land surface ('earth simulators')
- GCM model output used from the World Climate Research Program (WCRP) through its Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset
  - Note: CMIP5 for AR5 to be published in late 2013
- 22 GCMs from 17 modelling groups from 12 countries
- In some cases multiple model runs per GCM/SRES scenario
- Due to the chaotic nature (i.e., high non-linearity) of the climate system, GCMs typically do not replicate historically observed weather, but its climate



Source : Jean-Philippe Piedelievre, Météo-France

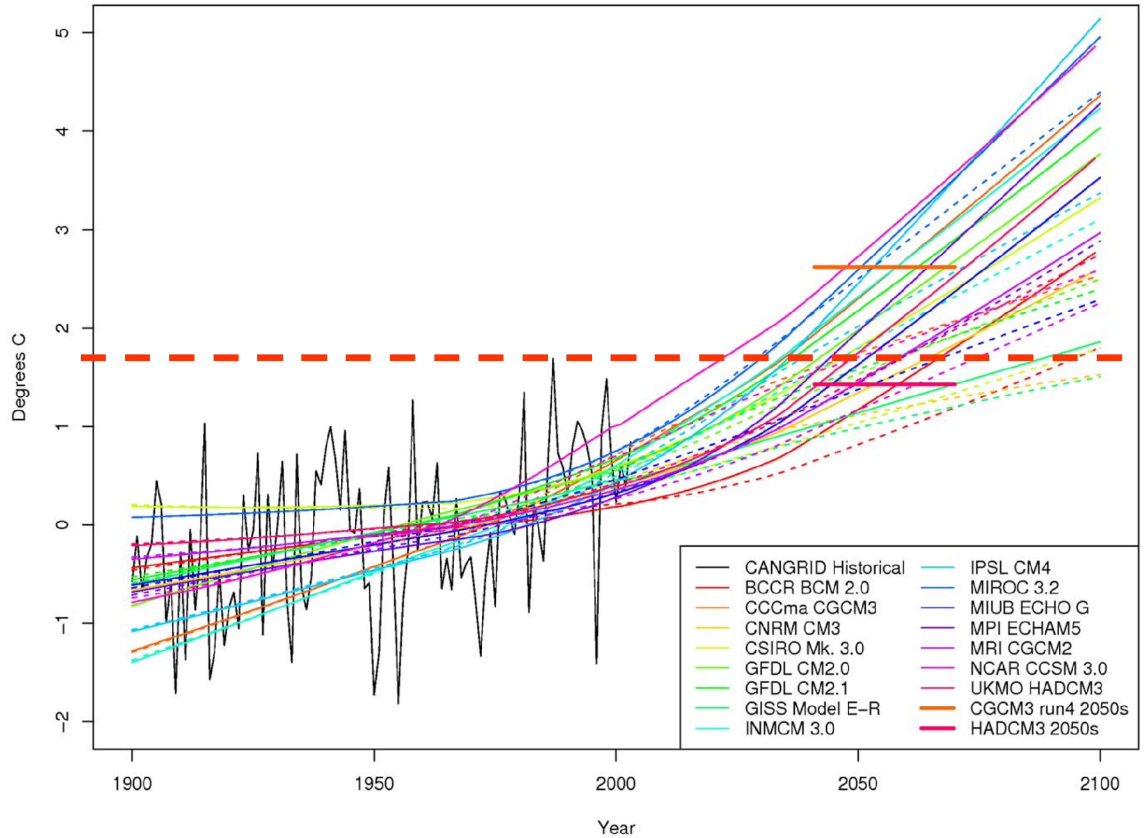
TEMPERATURE PROJECTIONS FOR BRITISH COLUMBIA

- 15 GCMs
- Solid lines: A2 scenarios
- Dashed lines: B1 scenarios

- Continued temperature increase
- Temperature projections for 2050s and beyond are largely outside the range of natural variability

Relative to 1961-1990

Source: PCIC



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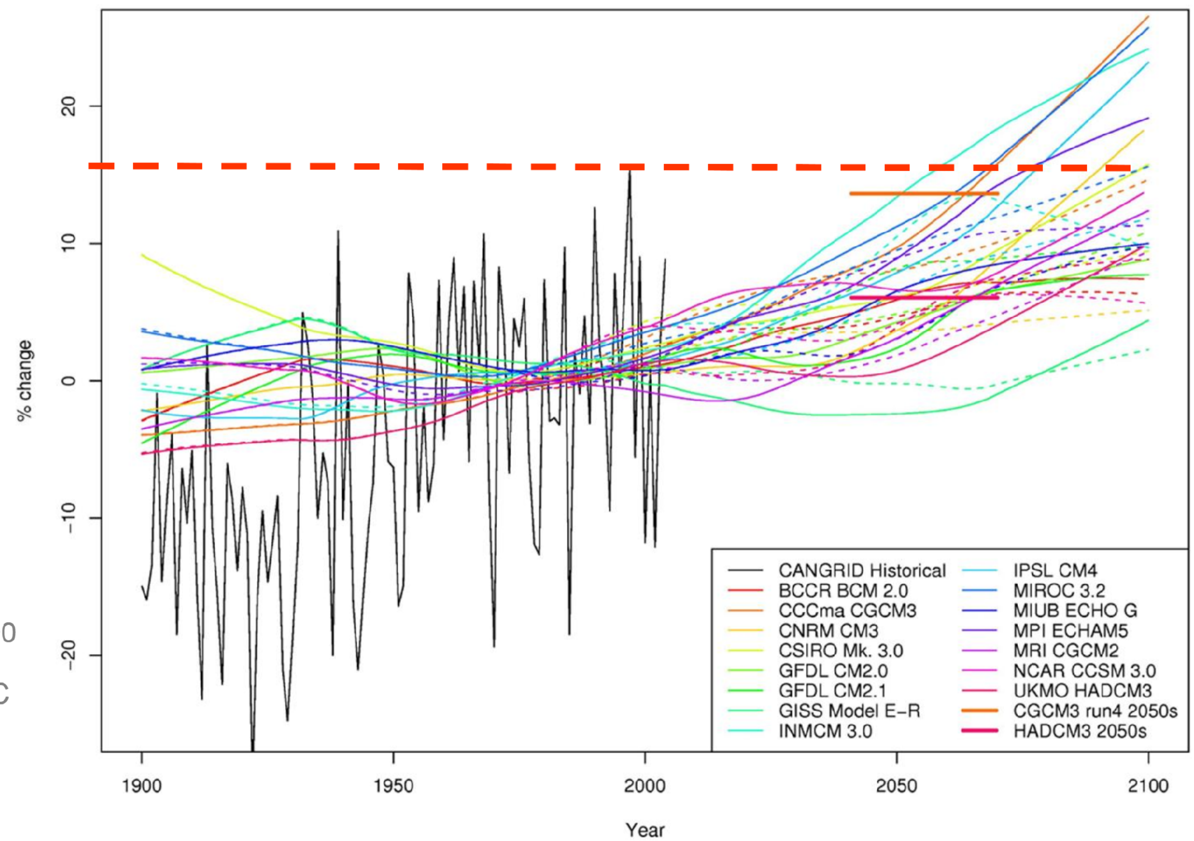
PRECIPITATION PROJECTIONS FOR BRITISH COLUMBIA

- 15 GCMs
- Solid lines: A2 scenarios
- Dashed lines: B1 scenarios

- Continued precipitation increase
- Precipitation projections for 2050s mostly not outside the range of historical variability



Relative to 1961-1990

Source: PCIC

GLACIERS AND CLIMATE CHANGE

- Wrinkle in the story: apart from the usual precipitation & temperature signals, in BC we also have glacier recession
- The additional ensuing water input to the system cannot be relied upon indefinitely
- Summertime glacier melt production is noticable in some reservoir inflows, including parts of the Columbia, Kootenay and Bridge River basins and some south coastal basins
- Several practical implications
  - Glacial melt = additional source of water
  - Impact most pronounced in late summer (when other water sources scarce)
  - Glaciers buffer year-to-year flow variability and modulate climate variability (e.g., ENSO) responses

BC-SPECIFIC SCIENCE QUESTIONS

- What will be the net impact of climate and glacier change be on river flows?
- How do we develop and apply computational tools to generate projections of future glacier coverage & streamflow given a large range of future climate scenarios?
- How important is it to model these processes interactions in detail?

From Moore et al., *Hydrological Processes*, 2009

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HYDROLOGIC CLIMATE CHANGE IMPACT STUDIES:

THE MODELING CHAIN

CARBON CYCLE AND CHEMISTRY MODELS

- Projections of GHG inputs to atmosphere (emission scenarios)
- Scenarios of 21st century global socioeconomic activity
- Many different trajectories possible

GLOBAL CLIMATE MODELS (GCMs)

- Process-based models of planetary climate
- Run on massively parallel supercomputers
- Many models; multiple runs (different ICs) for each

DOWNSCALING

- GCMs on too coarse a grid for most watershed studies
- Must “downscale” GCM output to local scales
- Many methods, both empirical & dynamical

WATERSHED MODELLING

- Feed altered climate into watershed model
- Produce corresponding streamflows
- Many models available each with uncertain parameters
- Model requires glacial melt module

ECOSYSTEM MODELLING

GLACIER MASS BALANCE & DYNAMICS MODELLING

WATER RESOURCES IMPACTS MODELLING

- Feed ensemble of flow scenarios into operations models
- Produce corresponding generation

HYDROLOGIC CLIMATE CHANGE IMPACT STUDIES: WHAT DO THE RESULTS MEAN?

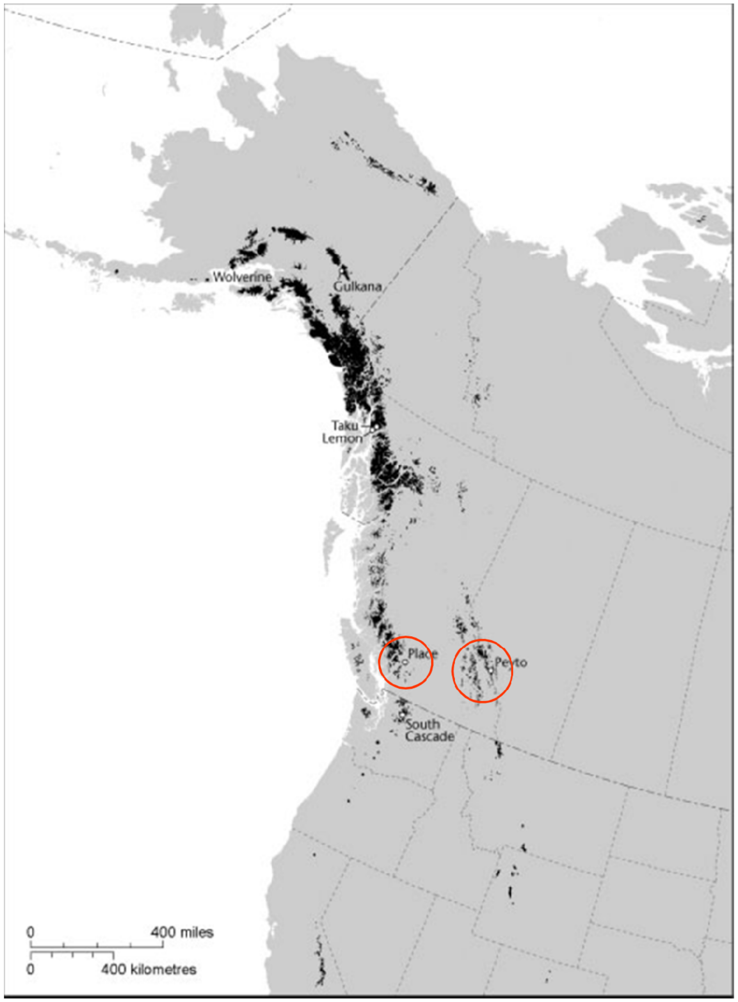
- Many social & physical modelling uncertainties
  - Inherent to physical system (e.g., extreme nonlinearity of climate system)
  - Incomplete physical knowledge (e.g., model process & parameterization uncertainties)
  - Limitations on available computing power (e.g., limits to spatial resolution)
  - Entire procedure predicated on emissions scenarios (conjectured possible social futures)
- Important to consider many different scenarios and models to quantify & constrain uncertainties
- Result
  - Ensemble of physically plausible future hydrologic realities
  - Hopefully bracketing the envelope of what might reasonably be encountered
  - Computationally & process-wise similar to a prediction, but the modeling outcome is profoundly different from a prediction
- Modelling component of uncertainty is amplified by presence of glaciers, as climate-glacier-streamflow interactions have not been extensively modelled previously in this context

WC²N MICA CLIMATE-GLACIER-STREAMFLOW STUDY

MOTIVATION & OBJECTIVES

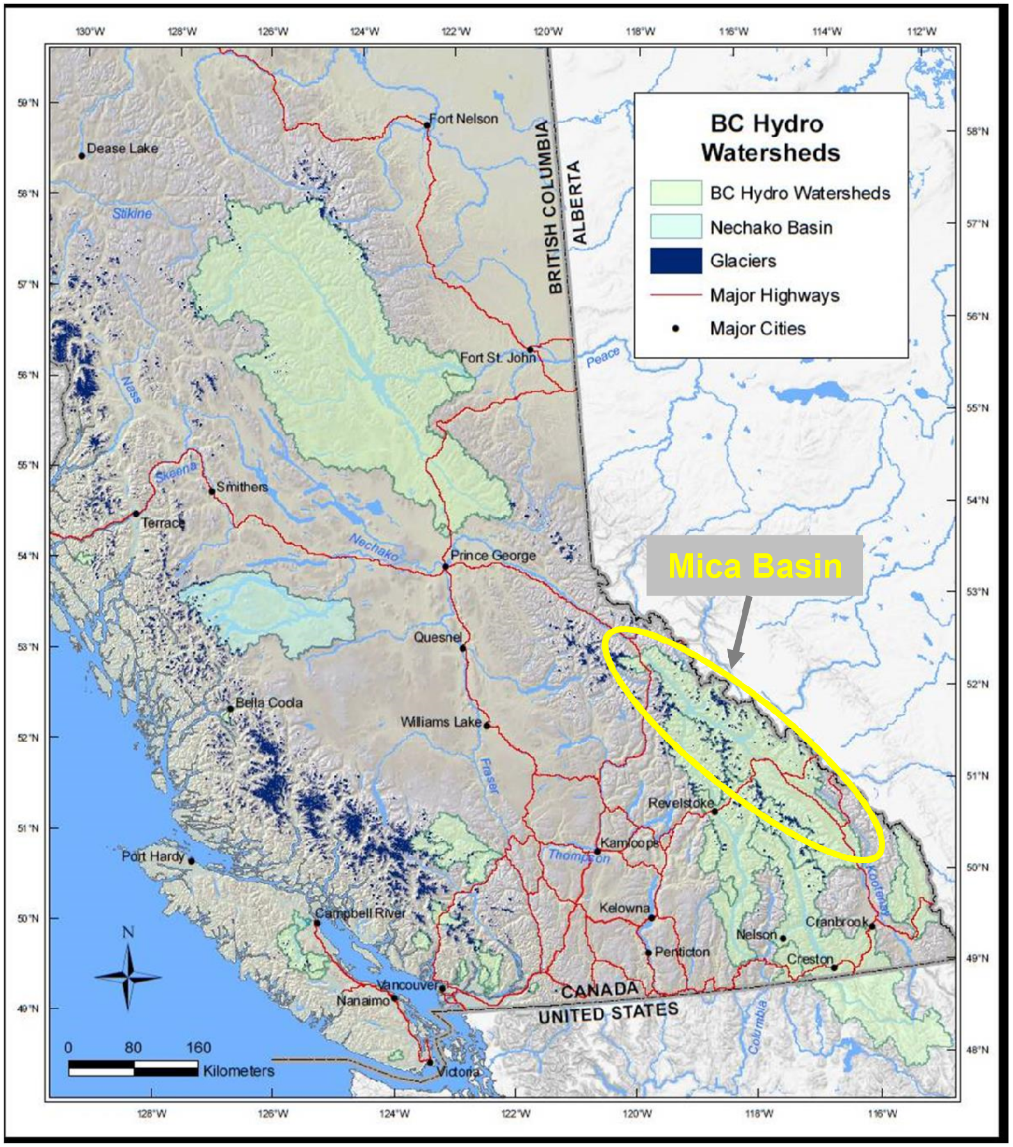
- Glaciers impact local hydrology at some reservoirs
- In BC Hydro's Bridge, Columbia, Kootenay and south coastal hydro generation regions
- Determine the net impact of climate change and glacier change on reservoir inflows in the Mica basin
- Determine how important it is to model these processes interactions in detail
- Provide an ensemble of physically plausible future hydrologic realities that bracket uncertainties
- Provide future projections of reservoir inflows for the 2050s at a daily time-scale

Adapted from Moore et al., *Hydrological Processes*, 2009



WC²N MICA CLIMATE-GLACIER-STREAMFLOW STUDY

Geographic scope: Mica basin



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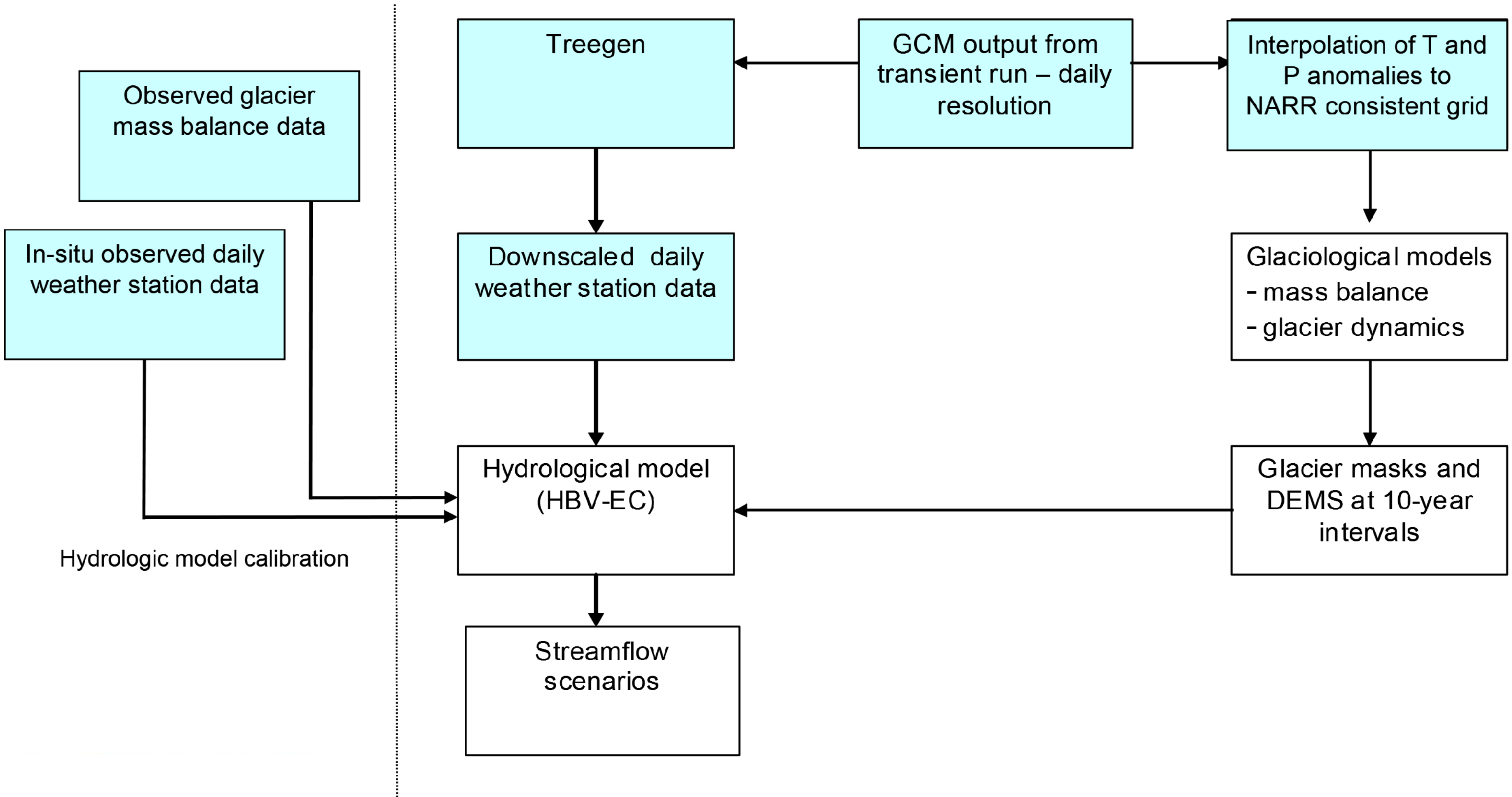
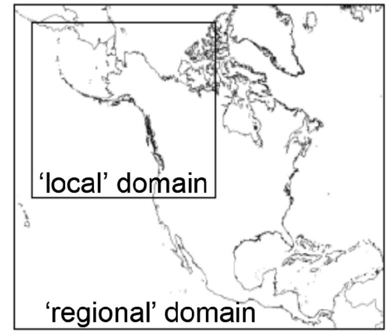
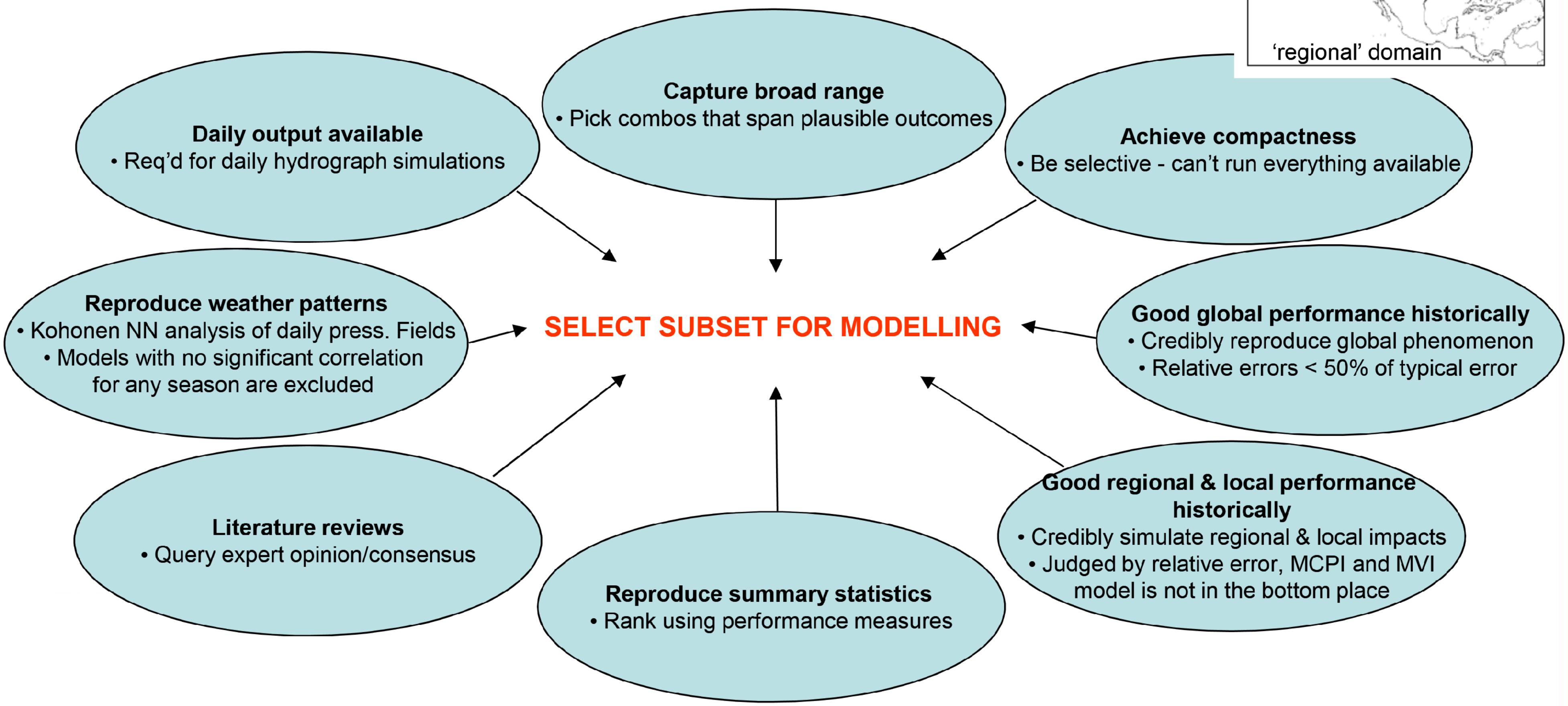
OVERALL MODELING APPROACH



MULTI-CRITERIA BASED GCM-SCENARIO SELECTION

The selection of GCMs depends on the intended application – i.e., there is no universal set of performance metrics that are optimally suited for all applications





MULTI-CRITERIA BASED GCM-SCENARIO-RUN SELECTION

FINAL SELECTION OF 6 GCMs

	Emission Scenario		
GCM	**B1**	**A1B**	**A2**
CGCM3.1 (T47)	(WC^2N)	(WC^2N)	(WC^2N)
CGCM3.1 (T63)	(WC^2N)	(WC^2N)	(WC^2N)
CSIRO-Mk3.0	(WC^2N)	(WC^2N)	NA
CCSM3	---	---	---
GFDL-CM2.0	(WC^2N)	(WC^2N)	(WC^2N)
GFDL-CM2.1	---	---	---
MIROC3.2 (hires)	(WC^2N)	(WC^2N)	NA
MIROC3.2 (medres)	---	---	---
ECHAM5/MPI-OM	(WC^2N run 1)	(WC^2N run 4)	(WC^2N run 1)
UKMO-HadCM3	---	---	---
UKMO-HadGem1	---	---	---

GCM DOWNSCALING FOR WATERSHED MODELING

- Hydrology model (HBV-EC) requires daily input at specific surface meteorological stations
- Downscaled weather traces must be temporally & spatially consistent
- TreeGen method developed by Alex Cannon at Environment Canada
- Statistical downscaling technique previously used in BC climate change studies
- Hybrid method, which includes regression modelling and analogue resampling, and employs stochastic weather generator to reproduce temporal & spatial covariances at the daily timestep
- Preserves the sequencing of daily weather patterns as predicted by GCMs

GCM DOWNSCALING FOR GLACIOLOGY

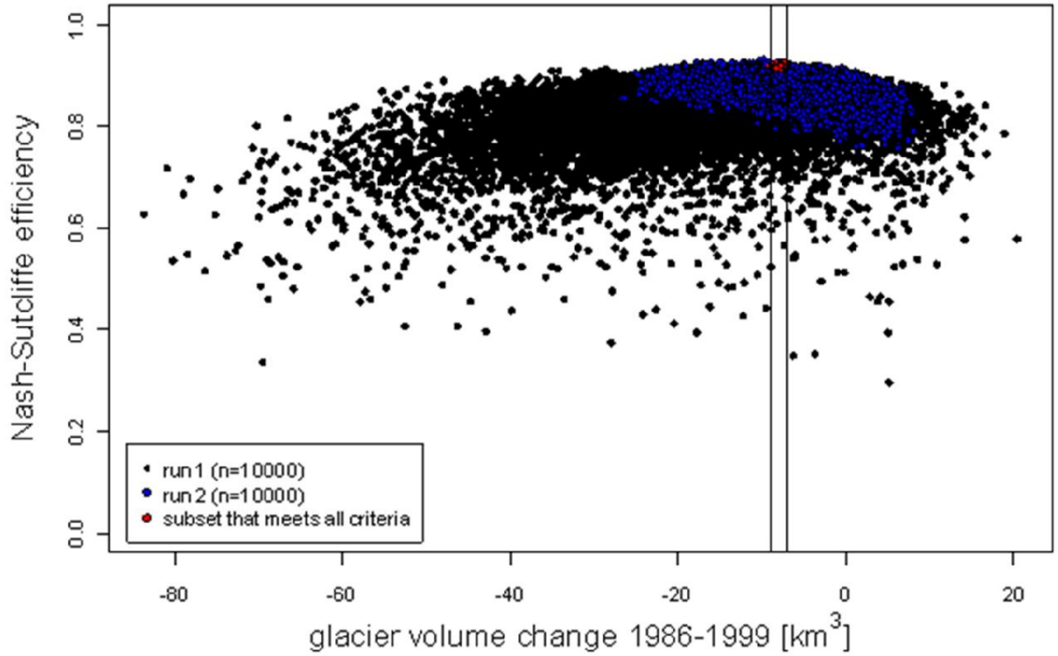
- Glacier mass balance model (in UBC-RGM) requires monthly, gridded, meteorological input fields of very high spatial resolution
- Used modification of classical delta-method downscaling
- NARR grids employed to ensure spatial relationships across model domain are preserved

WATERSHED MODELING

- HBV-EC: good track record for flow/climate change simulations in mountainous/nordic regions w/ glaciers
- 1985-1999 calibration period (1985-1992 w/ 1985 glacier cover, 1993-1999 w/ 2000 glacier cover)
- Generalized Likelihood Uncertainty Estimation (GLUE) type calibration procedure with benchmark parameter set derived via evolutionary & steepest gradient descent algorithm; Monte Carlo simulations for calibration under parameter uncertainty
- Calibration criteria render 23 “behavioural” parameter sets:
  - Nash-Sutcliffe efficiency > 0.915
  - Mean annual & August streamflow errors < 5%
  - -9 km^3 < cumulative net balance 1985-1999 < -7 km^3 (external constraint from Schiefer et al. 2007); necessary particularly for watersheds with relatively low glacier coverage
- Excellent models: Best parameter set Nash-Sutcliffe Effiiceny of 0.93/0.95 (calibration/validation)
- Validate calibration against historical records of streamflow & glacier mass balance (2000-2007 validation w/2005 glacier cover)
- Force model forward under downscaled (TreeGEN) climate & projected future glacier masks
- Process-oriented watershed model to convert future climates + future glacier covers into flow realizations for 2008-2099 or 2050-2065 period

WATERSHED MODELING

Nash-Sutcliffe efficiency (E) plotted against simulated glacier volume change for 10,000 model runs in the initial Latin Hypercube Search (black) and for 10,000 model runs in a Latin Hypercube Search with adjusted prior parameter distributions (blue). Red dots indicate acceptable parameter combinations.



- A wide range of (incorrectly) modeled glacier volume changes that can lead to acceptable E's (and models commonly deemed acceptable)
- E does not peak at the observed glacier volume loss

GLACIER MASS BALANCE & DYNAMICS MODELING

- Major step forward in projecting climate change impacts upon contemporary glaciers for practical purposes
- The University of British Columbia Regional Glaciation Model (UBC-RGM) employs a sophisticated, physically-based approach – some basic ideas are as follows:
- Temperature & solar radiation-indexed mass balance model over reference topography (SRTM)
  - Winter accumulation & summer ablation
  - Simple algorithms for redistribution by wind and avalanche
- Finite-difference ice dynamics model distributes this mass according to ice deformation & bed sliding
  - Mass balance adjusted as topography varies
  - Ice dynamics results allow comparison to field measurements (volume, area, velocity changes)

PROJECTED CLIMATE TRENDS

- Clearer change direction signal for temperature, than for precipitation
- Very likely future increases in temperature (consistent signal across emission scenarios, GCM runs and seasons)
  - Warming is greatest in summer
- Likely modest future increases in precipitation
  - Fall, winter and spring will likely get wetter
  - Summers will likely become drier

Mica	**mean annual precipitation change* (%)**				**mean annual temperature change* (ºC)**			
SRES	2050-2065		2085-2100		2050-2065		2085-2100	
B1	**+6.3**	-3 to +15	**+10.8**	+7 to +19	**+1.9**	+1 to +3	**+2.6**	+1 to +5
A1B	**+10.8**	+2 to +16	**+14.5**	+6 to +25	**+2.2**	+1 to +4	**+3.4**	+2 to +6
A2	**+10.4**	+7 to +19	**+15.3**	+4 to +25	**+2.2**	+2 to +3	**+4.1**	+3.8 to +4.4
mean	**+9.2**	---	**+13.5**	---	**+2.1**	---	**+3.4**	---

* relative to 1985-2000 baseline

HOW IMPORTANT ARE GLACIER PROCESSES?

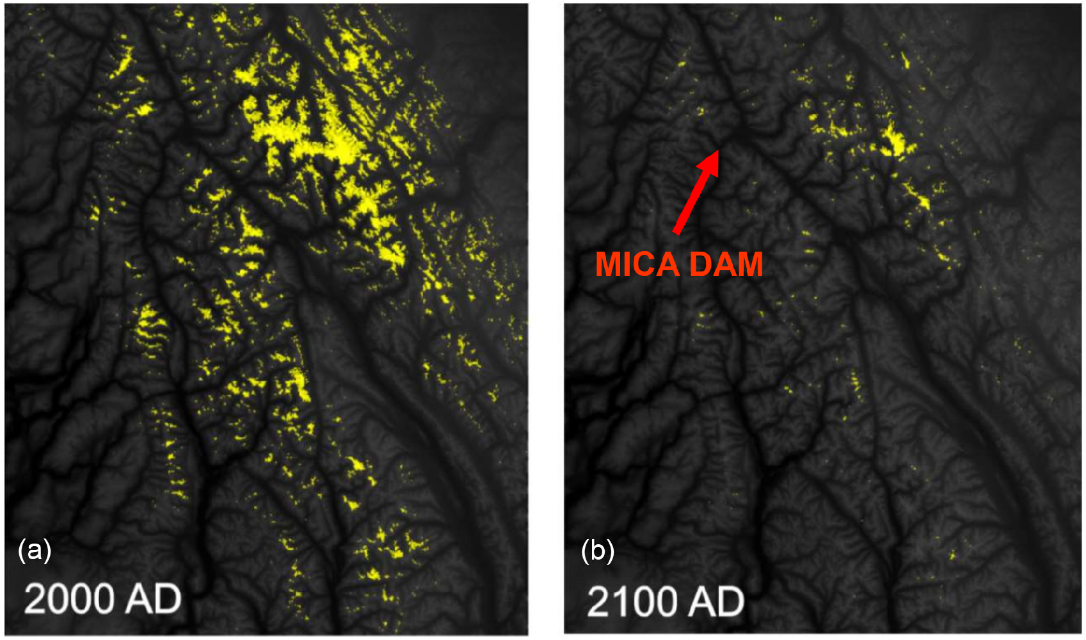
- Mica basin: historic variations in glacier area

Year	Glacier area (km^2)	% change relative to 1985	% of Mica basin
1985	1268.8		6.1
2000	1168.0	-7.9	5.6
2005	1088.6	-14.2	5.2

- Ice melt contribution to total streamflow: 6% (range: 3-9%, for 1972-2007 period)
  - This corresponds to ~10-30M$ in revenue annually or ~1-2 days of system generation
- August and September ice melt contributions: up to 25% and 35% of total flow, respectively
- The results imply that (for Mica) the total water input from ice melt is relatively small compared to that from precipitation; however, for a large basin (like Mica) with high runoff this water amounts to a substantial value.
- Further, late summer ice melt contributions are high, both in relative and absolute terms, with potential implications for reservoir management
- Results of this study are likely to be broadly representative of the practical downstream water resource impacts of glacier recession in large basins in the Columbia & Kootenay region

PROJECTED GLACIER AREA TRENDS

- Extreme ice loss
- Best case: reduction of 44% of 2000 ice cover by 2100 (w/ CSIRO-B1)
- Worst case: reduction of 100% of 2000 ice cover by 2100 (w/ several scenarios)
- Mid-range scenario: reduction of 83% of 2000 ice cover by 2100 (w/ ECHAM A1B); only larger ice caps remaining

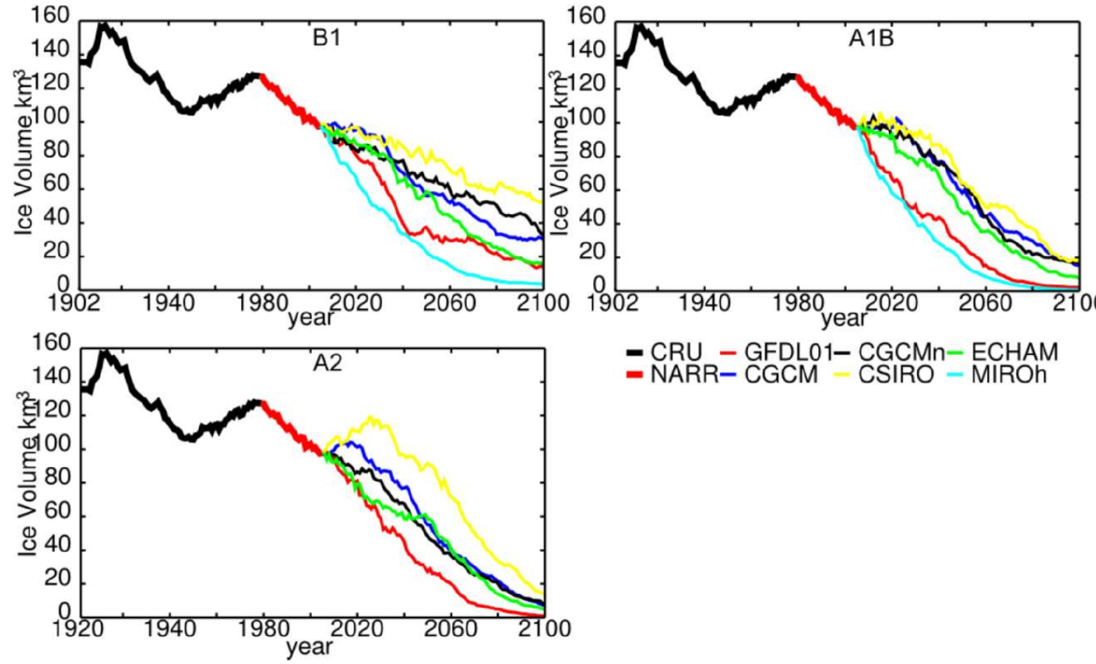


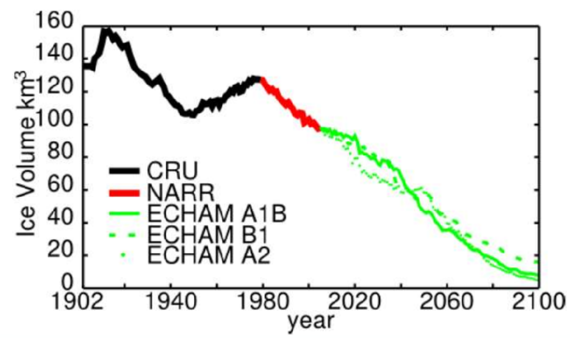
For example: simulated ice masks for the Mica basin region. (a) Mask for 2000 AD using NARR and CRU climate forcing for 1900-2000 AD. (b) Mask for 2100 AD derived from ECHAM-A1B scenario.

PROJECTED GLACIER VOLUME TRENDS

- Generally convergence by 2100 due to ice loss
- No substantial decadal variability in the prediction period
- Conditional statistics for each emission scenario and 2100:
  B1 -76%, A1B -90%, A2 -93%
  - Best case: reduction of 49% of 2000 ice cover by 2100 (w/ CSIRO-B1)
  - Worst case: reduction of 100% of 2000 ice cover by 2100 (w/ several scenarios)
  - Mid-range scenario: reduction of 85% of 2000 ice cover by 2100 (w/ ECHAM A1B);
- Conditional statistics for each emission scenario and 2050:
  B1 -49%, A1B -55%, A2 -45%

- Between-scenario difference in the projections is relatively small, compared to the between-GCM differences





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PROJECTED CHANGES IN GLACIER AREA, VOLUME & DYNAMICS

- Example for one Columbia headwater location at 2 time slices