DRAFT OPEN FILE: A Mini Manual for Running OpenQuake Canada

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Abstract

As part of the national Canadian Seismic Risk Model, a collection of scenario earthquakes have been created and will be expanded. All files will be accessed through the OpenDRR GitHub project page as they become available: <https://github.com/OpenDRR>.

1 Introduction

Earthquake scenarios can provide insights into what and who will be impacted by a particular fault rupture. They can illuminate startling susceptibilities and gaps in our preparedness, or highlight our community successes in mitigating risk and strengthening our resilience. Most importantly, scenarios create a narrative that people can place themselves within. It helps us digest abstract or difficult ideas by imagining how they interact with our own reality. In fact, Lok et al. (2019) found that Vancouverites are more likely to take risk-reducing actions if presented with imagery of earthquake damage than with statistics. Thus, scenarios are an invaluable tool for communicating risk to practitioners and the public.

Unfortunately, scenario models are typically created for a single event or a limited region of interest. Without open access to scenario results calculated using large, uniform datasets, municipalities, provinces, or other stakeholders must pay to conduct individual analyses. For these reason, the Geological Survey of Canada (GSC) has created a catalogue of earthquake scenarios. Scenarios are freely available online. The datasets and functions used in the modelling are national and uniformly implemented, so risks may be compared between regions and ruptures.

It is important to note that these scenarios are not predictions. They represent a selection of plausible events which could occur similarly in the future, or which may have occurred in the pre-instrumental past. All of the fault rupture scenarios are based on our best scientific understanding of the tectonic landscape of Canada, historical seismicity, prehistoric earthquakes, and the quickly-advancing field of active fault study. Much is left to be learned, but the hope is that these scenarios can be used by planners, emergency managers, policy makers, financial analysts, academics, engineers, and even the public to keep our communities safe as we learn.

This guide is not meant to replace the OpenQuake User Manual, but will provide a concise overview of the commands needed to generate scenario Hazard, Damage, Consequence, and Risk outputs using the Canadian datasets and functions, produced by Natural Resources Canada (NRCan) and partners. In future, if needed, a similar document could be created for the probabilistic use case.

2 Setting Up Your System

Note that this tutorial is written for OpenQuake (OQ) 3.11, QGIS 3.4, and OQ QGIS Plugin 3.9 on MacOS Catalina version 10.15.3. Other operating systems such as Windows, Linux, or other versions of MacOS are permitted by OQ, though the specifications of installation will differ slightly.

OpenQuake Developed by the Global Earthquake Model (GEM) Foundation (Pinho, 2012; Crowley et al., 2013), OQ is a free, open-source, community-developed code to assess seismic hazard and risk globally (see Monelli et al., 2012; Pagani et al., 2014; Silva et al., 2014). Natural Resources Canada has been a proud public partner of GEM since 2017.

An average user can visit the OQ 'Getting Started' Page to download the latest stable version of the engine, created and maintained by the GEM. Currently, however, the developer version is required to use the Consequence functions implemented here — instructions are provided here. As you follow the installation instructions, you'll be required to install Python 3 and some miscellaneous tools. While it is an excellent resource for managing dependencies, the Anaconda installation of Python conflicts with OQ. Therefore, it is recommended to use Pip or Homebrew. When finished you can use OQ from the command line (terminal) or the web-based user interface. This tutorial will utilize the command line and the developer version, accessed through the 'oqenv' python environment:

```
> source $HOME/openquake/oqenv/bin/activate
```

You can ensure that you have installed OQ by typing:

```
> oq engine --version
```

and making sure it reports OQ 3.11 (or whatever version you installed). You should also see an openquake environment listed at the start of your command prompt, such as '(openquake)' or '(oqenv)'.

QGIS Outputs of the OQ engine can be easily viewed in the open source Geographic Information System (GIS) software, *QGIS*. Download from the QGIS website and then install the OQ plugin under 'Plugins' and then 'Manage and Install Plugins'. In the popup window, search for 'openquake' and click the 'OpenQuake Integrated Risk Modelling Toolkit'. At the bottom of the window you will then see an 'Install Plugin' button, which you must click. Once installed, you will see a toolbar on your main QGIS project page for OQ functions. Clicking the first button (a triangular 'play' button in side a circle) will forge a connection to the OQ engine, allowing you to see your runs and load your outputs. Note that this step is not necessary, though you may find it helpful especially while learning OQ.

GitHub All datasets used by NRCan are on the OpenDRR *GitHub* page. As new data or models are available, they will be continuously integrated onto this account so users can access the most up-to-date versions. Install the GitHub desktop and then fork a new branch of the openquake-inputs, CanadaSHM6 and earthquake-scenarios repositories. The former contains the models (functions) and datasets needed as inputs to OQ. CanSHM6 is the seismic hazard model for Canada, including GMPE's and their weighting. The earthquake-scenarios repo contains scripts and initialization files needed for scenario runs, including rupture files. Clone your forked repos to the desktop, so you can access the contents from within your command line and push your changes back up to the origin as needed. Note that if you are an NRCan employee or internal collaborator you may be able to clone the repo directly without forking.

3 Types of Calculations and Data Requirements

This section will describe the kinds of calculations that are performed and the data files needed to run them. Those who are already familiar with risk modelling and OQ may wish to skip to Section 4.

3.1 Types of Runs

Hazard The most straightforward thing you might want to do when running a scenario is to estimate the shaking caused by the earthquake. This is called the Hazard. You calculate Hazard at a series of points, which may be assets of concern or just an evenly-spaced grid of points in a region of interest. In addition to a grid of points, you also need the earthquake rupture information and at least one Ground Motion Prediction Equation (GMPE). This calculation is referred to as a 'Scenario Hazard' calculation and requires:

- a rupture file (.xml)
- a single GMPE or a logic tree with multiple weighted GMPEs (.xml)
- a site model file describing the soil conditions at the points where you want to calculate the shaking (.csv)

Damage After you know how much the ground will shake during the scenario earthquake, you might like to know how damaged buildings will be. The term Damage is used for specifically this calculation. The term Risk, as we will see in the next section, refers to the calculation of capital and human losses. For a Damage assessment you need the same files as for the Hazard, as well as information about your buildings (Exposure) and some function to describe how they respond to shaking (Fragility).

- a rupture file (.xml)
- a single GMPE or a logic tree with multiple weighted GMPEs (.xml)
- a site model file describing the soil conditions at the points where you want to calculate the shaking (.csv)
- an Exposure file with building location, type, seismic design level, and occupancy (.xml)
- a Fragility model file relating shaking to damage, by building type (.xml)
- *Optional: a taxonomy mapping file that allows you to change the building type, occupancy, or seismic design level of groups of buildings without editing your Exposure file. (.csv)*

Consequence The impacts of building damage can be assessed using the methodology implemented in the *HAZUS* software released by Federal Emergency Management Agency (FEMA). The equations therein have been reworked by GEM into a Python script with accompanying parameter file. It will take outputs from an OQ damage run as input.

- the consequence script (.py)
- the parameter file with values needed to run the consequence script (.xml)

Note that neither of these files changes for each iteration.

Risk You can determine the potential Loss from the event by performing a Risk assessment, which will estimate the dollar value of the building Damage and the number of fatalities. You require the same inputs as for a Damage calculation, only instead of a Fragility function you use a Vulnerability function. This file will relate losses to building type and shaking, rather than Damage state.

- a rupture file (.xml)
- a single GMPE or a logic tree with multiple weighted GMPEs (.xml)
- a site model file describing the soil conditions at the points where you want to calculate the shaking (.csv)
- an Exposure file with building location, type, seismic design level, and occupancy (.xml)
- a Vulnerability model file relating shaking to loss, by building type (.xml)
- *Optional: a taxonomy mapping file that allows you to change the building type, occupancy, or seismic design level of groups of buildings without editing your exposure file. (.csv)*

3.2 Datasets

For a sample run, we will use a Moment Magnitude (M_w) 9.0 Cascadia Interface event. This scenario event is called 'SIM9p0_CascadiaInterfaceBestFault' because it is a subduction interface (SI) earthquake with magnitude M_w 9.0 using the full 'best' geometry from the 6th Generation Canadian Seismic Hazard Model. The full list of tectonic environments is available in Table 2 of Hobbs et al. (2021b).

The complete list of files needed to run this scenario is available in Table 1. A full technical description of the input datasets and methodology is described in Hobbs et al. (2022), but generally speaking the GMPEs are from the 6th generation national seismic hazard model (Adams and Halchuk, 2019; Kolaj et al., 2019, 2020a,b), exposure is from a national compilation (Journeay et al., 2022), fragility/vulnerability functions are developed by GEM for Canada (Rao and Silva, 2017; Martins and Silva, 2020; Hobbs et al., 2022) and site conditions (v_{s30}) are from the topographic slope proxy of Wald and Allen (2007); Allen and Wald (2009).

Table 1: An example set of the files used to run OpenQuake.

In earthquake-scenarios/	
Run Script	scripts/run_OQStandard.sh
Hazard Initialization	initializations/s_Hazard_SIM9p0_CascadiaInterfaceBestFault.ini
Damage Initialization	initializations/s_Damage_SIM9p0_CascadiaInterfaceBestFault_b0.ini initializations/s_Damage_SIM9p0_CascadiaInterfaceBestFault_r1.ini
Risk Initialization	initializations/s_Risk_SIM9p0_CascadiaInterfaceBestFault_b0.ini initializations/s_Risk_SIM9p0_CascadiaInterfaceBestFault_r1.ini
Rupture	ruptures/rupture_SIM9p0_CascadiaInterfaceBestFault.xml
Consequence	scripts/consequences-v3.10.0.py scripts/Hazus_Consequence_Parameters.xlsx
In openquake-inputs	
Sites	earthquake/sites/regions/site-vgrid_BC.csv
Fragility	earthquake/vulnerability/structural_fragility_CAN.xml
Vulnerability	earthquake/vulnerability/vulnerability_contents_CAN.xml earthquake/vulnerability/vulnerability_nonstructural_CAN.xml earthquake/vulnerability/vulnerability_occupants_CAN.xml earthquake/vulnerability/vulnerability_structural_CAN.xml
Mapping	earthquake/vulnerability/CanSRM1_TaxMap_b0.csv earthquake/vulnerability/CanSRM1_TaxMap_r1.csv
Exposure	exposure/general-building-stock/oqBldgExp_BC.xml exposure/general-building-stock/oqBldgExp_BC.csv
In CanadaSHM6/	
GMPE	OpenQuake_model_files/gmms/LogicTree/... OQ_classes_NGASa0p3weights_interface.xml

4 Running OpenQuake Canada

4.1 Initialization Scripts

Openquake uses initialization files (.ini) for each type of run: hazard, damage, and risk. They specify the parameters and locations of relevant data files. For consequence models, our python script uses the OQ damage output directly so no initialization file is needed. Typically we consider one level of retrofit above current conditions, entitled baseline/current ('b0') and retrofit level 1 ('r1'). The retrofit is achieved by bumping everything up either 1 or 2 levels of seismic code, depending on their intended post-earthquake usage, with limitations on the highest possible code level for Unreinforced Masonry (URM) and concrete building types. The retrofit assignment strategy is outlined in Hobbs et al. (2021a). For each retrofit level, we require additional initialization files.

Therefore, a 'full' OpenQuake scenario analysis would include the following runs:

1. hazard
2. damage - baseline
3. consequence - baseline
4. damage - retrofit
5. consequence - retrofit
6. risk - baseline
7. risk - retrofit

4.2 Run Script

To combine hazard, damage, consequence, and risk calculations, we have written one central 'run' wrapper script (.sh). If desired, that wrapper script can also handle different initializations for varying seismic retrofit levels. To run this calculation, using the files outlined in Table 3.2 in the specified directory locations, execute the 'run_OQStandard.sh' script from the top of the 'earthquake-scenarios' repository. Use the command line, for example:

```
> sh run_OQStandard.sh
```

You'll notice it gives a usage statement when run without arguments. The arguments include the scenario name ('SIM9p0_CascadiaInterfaceBestFault') and flags for the calculations to be run. For a full run we want to calculate the hazard ('-h'), damage/consequence ('-d'), and risk ('-r') for baseline plus one level of retrofit ('-o'). Here we are specifying the name of the scenario so the script knows what name to look for in the initializations folder.

```
> sh run_OQStandard.sh SIM9p0_CascadiaInterfaceBestFault -h -d -r -o
```

The script will first look for the suite of initialization files: 1 hazard file, 2 damage files, and 2 risk files. If all the initialization files are present it will start running. It will also call some scripts to perform a weighted average of the results, and move them into your output folder.

Jeremy: *For your test, let's make copies of the ini files with a slightly different name so you won't replace the existing Cascadia results. I would copy all 'SIM9p0_CascadiaInterfaceBestFault' ini files in the initializations folder, and then append 'JEREMY' to the end of 'CascadiaInterfaceBestFault' in the names. Then your call to run_OQStandard.sh will look like:*

```
> sh run_OQStandard.sh SIM9p0_CascadiaInterfaceBestFaultJEREMY -h -d -r -o
```

I suspect we will run into issues with windows vs. unix-based operating systems. If so, we'll get a conversation going with Anthony and maybe Drew, who have some experience with generalizing code to handle either more seamlessly.

4.3 Outputs

A directory will be created or appended, called 'outputs'. For a full run of the Hazard, Damage, Consequence, and Risk, output files will be created and named according to the name of the scenario specified while calling the run script. A full list of the output files can be found in Hobbs et al. (2021b). Log files will also be created, with naming similar to 's_Damage_SIM9p0_CascadiaInterfaceBestFault_b0.log', recording the command line output from running the OQ Damage calculations.

Jeremy: *Now you can compare your results against mine. The easiest way would be to use the command line tool 'diff' to print out the difference between two files. Ex:*

```
> diff outputs/s_s_dmgbyasset_SIM9p0_CascadiaInterfaceBestFault_b0_317_b.csv
    outputs/s_dmgbyasset_SIM9p0_CascadiaInterfaceBestFaultJEREMY_b0_*_b.csv
```

You can also use python or other programs to inspect the results and check that your answers match the high level results displayed at ***https://github.com/OpenDRR/earthquake-scenarios/blob/master/FINISHED/SIM9p0_CascadiaInterfaceBestFault.md****.*

Glossary

Consequence An estimation of the tangible impacts from a scenario earthquake. For example, the number of displaced persons or the volume of debris generated. 1, 2, 7

Damage The damage state of a building, or collection of buildings, following an earthquake. Example: complete damage refers to a collapse.. 1, 3, 4, 7

Exposure The assets and people in harms way. 3, 4

Fragility A function relating earthquake shaking (Hazard) to probable building Damage states, by building typology. 3, 4

Hazard A measure of the expected ground shaking or the probability of a certain level of ground shaking for an earthquake or an earthquake source region/fault. 1, 3, 7

Loss The financial losses and human fatalities caused by a scenario earthquake or, probabilistically, from a collection of earthquakes within a source region. 4, 7

Risk The probability of Damage and Loss of exposed assets, from an earthquake, or from an earthquake source region. Note that OQ defines a 'risk' calculation as one which estimates Loss. 1, 3, 4, 7

Vulnerability A function relating earthquake shaking (Hazard) to probable financial losses or fatalities (collectively Loss), by building typology. 4

Acronyms

FEMA Federal Emergency Management Agency. 4

GEM Global Earthquake Model. 1, 2, 4

GIS Geographic Information System. 2

GMPE Ground Motion Prediction Equation. 3, 4

GSC Geological Survey of Canada. 1

$\mathbf{M_w}$ Moment Magnitude. 4

NRCan Natural Resources Canada. 1, 2

OQ OpenQuake. 1, 2, 3, 4, 7

URM Unreinforced Masonry. 5

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