Climate Change for the Engineer: Standardized Procedure for Climate Change Integration into Engineering Design

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Abstract. There is agreement within the engineering community that climate change is occurring, and there is a responsibility to integrate climate change into engineering design. However, there are few best practices and no common standards of practice that provide a prescribed and/or consistent process for incorporating climate change into engineering design. This is a barrier in the ability to address the impacts of climate change to mining infrastructure. This paper describes a Standardized Procedure for Climate Change Integration into Engineering Design (SPCCIED), specifically developed to provide a practical, transparent, and consistent approach to the problem. This makes decisions easy to defend to both technical reviewers as well as non-technical interested parties, as subjectivity is removed.

Key words: climate change, engineering design, integration, mining

1. Introduction

Consensus among scientists and engineers is global climate change (GCC) is occurring. As identified by the Canadian Standards Association [1], the lack of consistent processes to integrate GCC into engineering design acts as a barrier in the ability to address the effects of GCC.

This paper describes a Standardized Procedure for Climate Change Integration for Engineering Design (SPCCIED) developed by SRK Consulting (Canada), Inc. This procedure was specifically developed to provide a practical, transparent, and consistent approach for establishing defensible climate change design criteria for integration into engineering design. The process recognizes that engineering judgement is required and ensures those judgements are properly documented.

The four-phase procedure includes select elements from EARG [2] and PIEVC [3], but is essentially a completely new fit-for-purpose process (see Fig.1.). The analysis uses computer programming to analyse GCC models and baseline climate data in parallel. Results are then statistically compared to produce unique GCC design values.
FIG. 1. Standardized procedure for climate change integration for engineering design.
2. Establishing Climate Dependency

Climate change need to be considered in engineering design; however, as with most engineering decisions, appropriate judgement should be used as to how rigorous the consideration should be. Phase 1 and 2 (see Fig. 1.) is intended to provide a transparent basis to determine exactly when climate change should be considered, and if so for which climate variables and to what extent.

For each identified infrastructure component, consideration is given whether the design analysis is dependent on specific climate variables (e.g. temperature, precipitation, etc.). A dependency is assumed to exist if the climate variable is determined to potentially have a measureable impact on infrastructure performance within the expected design life of the component. If no dependency is identified, climate change need not be considered in the design. If a dependency does exist, the relative sensitivity of each climate variable is evaluated through risk assessment.

For low risk relationships, there is no need for inclusion of climate change in the engineering design. For high risk infrastructures, rigorous integration of climate change is required and Phase 3 is initiated (see Fig. 1.).

3. Conducting Climate Change Analysis

3.1 Approach

Different GCC software packages are available through research institutions (e.g. the Pacific Climate Impacts Consortium). In some cases, GCC modelling provides highly detailed climate change predictions, but these are only applied to specific regions. The majority of GCC modelling methods also do not forecast historical trends as a comparison against available models. The benefit of the procedure described in this paper is that it is not regionally bound, and it takes into consideration forecasting methods.

To complete the analysis described herein, all GCC models from the five International Panel for Climate Change (IPCC) assessment reports (ARs) [4, 5, 6, 7, 8] are accessed through EC [9].

To apply the GCC models, a substantive dataset of baseline climate date is required. Since this level of information is seldom available for most remote mining project locations, the baseline climate data can be supplemented with reanalysis data. Such reanalysis data are sourced from ERA-Interim, produced by the European Centre for Medium-Range Weather Forecast [10].

All this data is subsequently processed using a purpose-built script developed with R software [11]. This facilitates automated data retrieval, calculations, and presentation of graphical results.

The proposed methodology produces more conservative GCC values for locations where historical trends show GCC is occurring more rapidly than predicted by GCC models (see Fig. 2.). For locations where GCC is predicted to exceed historical trend forecasting (see Fig. 3.), the results from this procedure favors similar results as other GCC models.
3.2 Assessment Reports

The five IPCC ARs contain monthly GCC modelling predictions for any location in the world. The GCC models and scenarios presented in these ARs assume application of radiative forces (energy fluxes) through different anthropogenic sources that result in discharge of varying concentrations of atmospheric greenhouse gases. These radiative forces are not constant through time because they depend on global anthropogenic behavior, such as environmental policies, population growth, economic growth, energy sources, land use, and hydrocarbon usage. Each GCC model presented in the ARs represents these radiative forces differently and thus each presents a different GCC scenario underscored by its own model assumptions and boundary conditions.
None of these GCC models are inherently superior or inferior to others. Likewise, the newer generation of ARs are not necessarily more reliable than older versions. Instead, they represent more detailed consideration of global anthropogenic forces. Typically, the user must apply professional judgment when choosing the most suitable model or generation of models for design, which invariably leads to bias. The procedure herein aims to eliminate this bias by weighting the available models equally [12].

The AR1 to AR4 data cover the years 1960–2100, and the AR5 data cover the years 1900–2100 in NetCDF format [13]. Significant data gaps exist in each of the ARs depending on the report, scenario evaluated, and assessed climate variable.

Although the meteorological variables in AR1 to AR5 are used for most analyses, some GCC design values need to be calculated through application of empirical models (e.g., snowpack thickness using snowmelt energy models [14]).

3.3 Reanalysis Data

To best represent trends, a GCC model reanalysis approach was used because the availability and timespan of records tends to be more consistent than regional meteorological stations. Reanalysis extends for several decades and covers the entire planet. Publicly available reanalysis data from ERA-Interim [10] comprise six-hour time interval data from 1979 to 2016 based on a 0.75° latitude by 0.75° longitude grid. Whenever possible, data from regional meteorological stations are compared with the reanalysis data to validate the reanalysis data for a specific site.

The reanalysis models generally use 3DVar and 4DVar for data assimilation of the measured meteorological information when compared with short-term forecast information [15]. 4DVar assimilation is more representative of measured values because forecast information is corrected within the respective time step. ERA-Interim is one of few available and reanalysis models with 4DVar data assimilation for a small grid size [16]. These characteristics support the use of ERA-Interim in this procedure.

3.4 Baseline Analysis

Using every model in the five ARs, GCC is projected with respect to a set baseline condition spanning a minimum of 30 years (1975–2005) per AR5. This is generally accepted as the minimum time period deemed statistically significant [17]. Three projection periods, 2011–2040, 2041–2070, and 2071–2100, represent the future for which GCC models are applied.

The projected change associated with a given climate variable for each time period is automatically calculated using the R script. By way of example, the resulting graphical summary (see Fig. 4.) represents the variety of predicted changes in mean air temperature a specific location.
Figure 4: Example outcome showing projected air temperature relative to baseline conditions for individual climate change models associated with each of the five ARs for the projection period of 2011 to 2040.

The same data can be presented as a box-whisker plot (see Fig. 5.). The centerline of the box represents the median value, while the upper and lower borders represent the third and first quartiles, respectively. The whiskers span the maximum and minimum values, and the span is less than 1.5 times the total range of the box (i.e., the third quartile minus the first quartile). If values exist outside the whisker limits, they are presented as dots.

FIG. 5. Combined box-whisker plot showing projected air temperature relative to baseline conditions for climate change models in the individual and combined assessment reports.
To best understand these results, they are presented in the form of a cumulative probabilistic curve (see Fig. 6.). For the purpose of this procedure, only the overall cumulative probabilistic curve associated with data from all the available ARs combined is needed because all GCC models are equally weighted [8]. The spread of results presented in the box-whisker plot (see Fig. 5.) illustrates why this is deemed appropriate.

FIG. 6. Summary of baseline and trend analyses including the cumulative probabilistic curve based on climate change models and statistically significant historical trends. The design value represents the change in air temperature expected for 2011 to 2040.

3.5 Trend Analysis

Reanalysis data are assessed by first identifying the trend and secondly estimating the trend’s statistical significance. Five trend analysis methods were used: ordinary least square [18], quantile regression [19], Mann-Kendall and Theil Sen [20, 21], Zhang [22], and Yue and Pilon [23].

The outcome of the trend analysis (see Fig. 7.) shows the different trends and the statistical significance of each regression method. Significant trends (i.e., trends > 95%) are displayed on the cumulative probabilistic curve (see Fig. 6.).
FIG. 8. Trend analysis outcome based on reanalysis of air temperature data.

4. Climate Change Design Value

Following completion of the baseline and trend analyses, a design recommendation is presented for the identified meteorological variable and time period. This design value, which constitutes Phase 4 of the procedure, is shown on the cumulative probabilistic curve (see Fig. 6). The value depends on which analysis outcome is deemed to be more representative of the location based on a simple calculation. If the previous trend analysis showed no historical statistical significance, then the design variable would be the percent change associated with 50% cumulative probability based on the GCC models. However, if there were statistically significant historical trends, then the design variable would be calculated based the maximum value between the 50% cumulative probability number or the mean of any statically significant regression analysis numbers.

5. Discussion

The procedure presented facilitates incorporation of GCC into engineering design in a practical way and is to be applied in addition to normal engineering best practices that are already implemented during engineering design. Such practices include the consideration of site-specific and engineering investigations, design codes, and the use of safety factors, risk management, and professional judgment.
GCC models inherently contain several assumptions and there is no clear way to assess the accuracy of a given model. The procedure statistically analyses all climate predictions included in the IPCC ARs and identifies trends in historical data to produce the most representative GCC design variable for a given location and time period. The method eliminates the bias introduced by selecting a single model and compares GCC models with historical data.

The limitations of this procedure are inherent in GCC analysis. The source data are publically available, and the software and methods that use these data share flaws associated with the data. Another limitation is the maximum time horizon over which the GCC models are projected. EC provides data access for models up to the year 2100. There are few GCC projections beyond 2100, and the uncertainty and variability in these models tends to be high [8]. Therefore, it is considered appropriate to limit the use of models projecting beyond the year 2100 in engineering applications.

6. References


