The ICNet REU Freeze-Thaw Research Project:
Literature Review on the Use and Source of Climate Model Output

Summer 2015

Overall Synopsis of Reviews

The literature review included ten studies examining climate change affects in various disciplines. The goal of this review was to examine the source and use of climate model output. All of the studies had similarities with the ICNet REU Freeze-Thaw research, either in topic, methods, or both. The differences among the studies were primarily the source and usage of data, the existence of a baseline comparison, and the timeline. Data sources refer to the global climate models used to produce future climate and weather output. The majority of the studies used temperature and/or precipitation information.

Half of the studies used data from the Coupled Model Intercomparison Project (CMIP). Of those, 80% used version three and 20% used version five. This is most likely because CMIP5 is fairly new. Some other sources of model output included NARCCAP, the VIC hydrologic model, and the PRISM model, as well as other sources from outside of the United States. 70% of the studies used downscaled climate model output, either dynamically or statistically. All of the studies bias corrected their model output.

Only one of the ten papers, Sooraj, K. P., et al. (2015), conducted a thorough comparison between the baseline output of the models and the observed data. While they found that only seven of the CMIP5 models were "good", their final results used an ensemble, which included all of the models. Although the remaining nine papers did not document their baseline analysis, they did include a bias correction step, which might be considered to be a baseline comparison.

80% of the studies used the climate model output as input to a sector model or equations to calculate a secondary variable of interest. The majority of the studies analyzed the output for a 20 to 30 year period. One study used output from only two years and used a method referred to as "point-to-point," to interpolate to the intervening years.

References

Andreasson, J., et al. (2004). "Hydrological change - Climate change impact simulations for Sweden." Ambio 33(4-5): 228-234.

Cai, S., et al. (2014). "Statistical modeling and forecasting of fruit crop phenology under climate change." Environmetrics 25(8): 621-629.

Cayan, D. R., et al. (2010). "Future dryness in the southwest US and the hydrology of the early 21st century drought." Proceedings of the National Academy of Sciences of the United States of America 107(50): 21271-21276.

Gill, S. E., et al. (2007). "Adapting Cities for Climate Change: The Role of the Green Infrastructure." Built Environment (1978-) 33(1): 115-133.

Jaczewski, A., et al. (2015). "Comparison of temperature indices for three IPCC SRES scenarios based on RegCM simulations for Poland in 2011-2030 period." Meteorologische Zeitschrift 24(1): 99-106.

Larsen, P. H., et al. (2008). "Estimating future costs for Alaska public infrastructure at risk from climate change." Global Environmental Change-Human and Policy Dimensions 18(3): 442-457.

Lau, K. K. L., et al. (2015). "The effect of urban geometry on mean radiant temperature under future climate change: a study of three European cities." International Journal of Biometeorology 59(7): 799-814.

Miller, H., et al. (2013). Comparative Analyses of Methods for Posting Spring Load Restrictions. Proceedings of the 10th International Symposium on Cold Regions Development, Anchorage, Alaska June.

Miller, H. J., et al. (2015). "Modification of the U.S. Army Corps of Engineers Model 158 for Prediction of Frost–Thaw Profiles in Northern New England." Transportation Research Record: Journal of the Transportation Research Board 2474: 135-142.

Schlenker, W., et al. (2007). "Water availability, degree days, and the potential impact of climate change on irrigated agriculture in California." Climatic Change 81(1): 19-38.

Sooraj, K. P., et al. (2015). "Global warming and the weakening of the Asian summer monsoon circulation: assessments from the CMIP5 models." Climate Dynamics 45(1-2): 233-252.

Stewart, I. T., et al. (2004). "Changes in snowmelt runoff timing in western North America under a 'business as usual' climate change scenario." Climatic Change 62(1-3): 217-232.

Notes on the Articles Reviewed

Andreasson, J., et al. (2004). "Hydrological change - Climate change impact simulations for Sweden." Ambio 33(4-5): 228-234.

- Data sources:
  - Regional Climate Model from Swedish Regional Climate Modeling Programme (SWECLIM) (calibrated for 1985-1999)
  - Statistical downscaling with delta change approach
  - Global General Circulation Models
    - Rossby Centre Regional Atmospheric Model
    - Rossby Centre Regional Atmosphere-Ocean Model
  - General Circulation Models → boundary conditions → RCA models
  - Conceptual hydrological model HBV (calibrated for 1967-1997)
    - Input = precip., temp., and potential evapotranspiration
  - Avg. output over larger region before transfer to hydrological model via interface
  - Bias corrected
- Output = temperature, precipitation, and evapotranspiration
- Baseline = 1961-1990
- Future = 2071-2100
- Process:
  - Analysis looks at runoff volume, seasonal distribution, and frequency of peak values

    - Plot peaks per location w/lines for each model and present climate table of mean annual runoff change
    - Problems with model = need better special coverage compared to single location
    - % or degree increases per model presented – avg. of scenarios
- Information display:
    - Analysis chain
    - Maps
    - Tables
    - Line graphs

Cai, S., et al. (2014). "Statistical modeling and forecasting of fruit crop phenology under climate change." Environmetrics 25(8): 621-629.

- Data sources:
    - Canadian Coupled Global Climate Model version 3
    - Hadley Centre Coupled Model version 3
    - North American Regional Climate Change Assessment Program (NARCCAP)
- Output = downscaled temperature data
- Baseline = 1937-1964
- Future = 2020-2100
- Emission Scenario = A2
- Process:
    - Created own model to predict bloom dates compared to growing degree-days (Stochastic model).
    - Compare temp. from past bloom dates/GDD to future.
- Information display:
    - Tables

Cayan, D. R., et al. (2010). "Future dryness in the southwest US and the hydrology of the early 21st century drought." Proceedings of the National Academy of Sciences of the United States of America 107(50): 21271-21276.

- Data sources:
    - CMIP3
    - Geophysical Fluid Dynamics Lab. (GFDL) CM 2.1
    - Centre National de Recherches Meteorologiques (CNRM) CM3
- Baseline = 1951-1999
- Future = 2000-2100
- Emission scenarios = SRES A2 and B1
- Output = temperature, precipitation, and soil moisture
- Process:
    - Model selection:
        - Models fell within larger ensemble
        - Provide continuous daily output
        - Statistically downscaled to 1/8" x 1/8" through the constructed analysis method
- Data Presentation:
    - Timelines
    - Maps
    - Bar charts
    - Scatter plots

Gill, S. E., et al. (2007). "Adapting Cities for Climate Change: The Role of the Green Infrastructure." Built Environment (1978-) 33(1): 115-133.

- Urban Morphology Types (UMTs)

- Baseline = 1961 – 1990
- Future = 2020s, 2050s, 2080s
    - Results are for 2080s
- Data sources
    - UKCIP02
    - Energy Exchange Model
        - Output = max surface temp
    - Surface Runoff Model
        - Input = proportional area cover, building mass per unit land, air temp
    - Curve number approach (US Soil Conservation Service)
- Emission Scenario = Low and High
- Output = Daily temp. and precip.
- Used 99th percentiles from each timespan in the winter for comparison
- Process = plugged daily temp. and precip. into surface runoff and energy exchange models.
- Information display:
    - Color divided maps
    - Bar charts
    - Line graphs

Jaczewski, A., et al. (2015). "Comparison of temperature indices for three IPCC SRES scenarios based on RegCM simulations for Poland in 2011-2030 period." Meteorologische Zeitschrift 24(1): 99-106.

- Baseline = 1970-1990
- Future = 2010-2030
- Emission Scenarios = SRES Bi, A1B, A2
- Data sources:
    - Comparison = gridded observed vs modeled for past
    - Bias correction strategy = model output statistics (MOS)
    - RegCM(CMIP3)
    - ECHAM5/MPI-OM
    - Biosphere-Atmospheric Transfer Scheme (BATS)
    - USGS elevation data at 10-min res.
    - 75 km radius
    - 0.25^{o} x 0.25^{o} grid
- Output = mean daily temperature
- Process:
    - Calculated max/min daily temp. from mean daily temp. using 10th and 90th percentiles
    - Lapse rate of 0.6^{o}C/100m
    - Compared results yearly and seasonally
    - Calculate frost, ice, summer, and hot days based off temperature
        - Frost days Tmin < 0^{o}C
        - Ice days Tmax < 0^{o}C
        - Summer days Tmax > 25^{o}C
        - Hot days Tmax > 30^{o}C
    - Results:
        - Yearly: decrease of frost days, general decrease of ice days, general increase of summer days, general increase of hot days
        - Seasonally: only decrease of frost days in autumn, increase of ice days in spring, decrease of ice days in winter and autumn, mostly decrease of summer days in spring and autumn, general increase of hot days in summer
- Information display:
    - Tables

    - Color divided maps

Larsen, P. H., et al. (2008). "Estimating future costs for Alaska public infrastructure at risk from climate change." Global Environmental Change-Human and Policy Dimensions 18(3): 442-457.

- Data sources:
    - ICICLE = ISER Comprehensive Infrastructure Climate Life-Cycle Estimator
    - CMIP3
    - Warm Model: CSIRO Atmospheric Research, Australia, CSIRO Mk3.0
    - Warmer Model: US Department of Commerce, NOAA, Geophysical Fluid Dynamics Lab, GFDL-CM2.0
    - Warmest Model: Center for Climate System Research (University of Tokyo); National Institute for Environmental Studies; and Frontier Research Center for Global Change, Japan, MIROC3.2(hires).
- Emission Scenario = A1B
- Baseline = 2006
- Future = 2030, 2080
- Process:
    - Interpolated mean temp. and precip. values for intervening years
    - Spatially joined 6 locations w/ public infrastructure ("points to points")
    - Account for uncertainties in projections (bias correct)
    - How do temp. and precip. change over time? How will this affect infrastructure (and costs) in Alaska?
- Information display:
    - Tables
    - Distribution graphs
    - Maps
    - Line graphs
    - Bar charts
    - Pie tables

Lau, K. K. L., et al. (2015). "The effect of urban geometry on mean radiant temperature under future climate change: a study of three European cities." International Journal of Biometeorology 59(7): 799-814.

- Data sources:
    - Bias corrected RCM output
    - European Centre for Medium-Range Weather Forecasts
    - Hamburg (ECHAM) 5/max Planck Institute Ocean Model (MPI-OM)
    - GCM- CMIP3
    - 25 km resolution (downscaled)
    - Rossby Centre Regional Atmospheric Climate Model (RCA)
    - SOLWEIG Model:
        - Inputs = hourly time series for air temp., relative humidity, and global and diffuse solar radiation
        - 1-m resolution digital surface model (DSM) and geographical location
- Output = air temperature, solar radiation (3 components = global, diffuse, and direct), and relative humidity
- Emission Scenario = RCP4.5
- Baseline = 1998-2005 (Gothenberg), 2003-2010 (Frankfurt and Porto)
- Future = 2070-2098
- Locations:
    - Gothenburg, Sweden; 400x400m
    - Frankfurt, Germany; 370x400m
    - Porto, Portugal; 370x400m

- Process:
  - Interpolated hourly max and mins and 3-components of radiation through statistical downscaling
  - Increasing thresholds of danger of mortality based on T_{mrt} (mean radiant temperature
  - Analysis = find when
    - $T_{mrt} > 55^{o}C$ (moderate heat stress)
    - $T_{mrt} > 60^{o}C$ (severe heat stress)
    - # of days per year when T_{mrt} exceeds both thresholds (overheating degree hours ODH)
- Data presentation:
  - Tables
  - Line graphs

Miller, H., et al. (2013). Comparative Analyses of Methods for Posting Spring Load Restrictions. Proceedings of the 10th International Symposium on Cold Regions Development, Anchorage, Alaska June.

Main Points/Topics:
  - Background on freeze-thaw process
  - Background on SLR
  - FWD<atmospheric data because it's cheaper and more readily available
  - Types of frost-depth prediction models
    - Based on atmospheric data from each site
    - Based on software (Enhanced Integrated Climatic Module or TEMP/W)(EICM)
  - Modifications in equations of FD
  - Description of model testing in NH
    - Showed promise for use at most NH sites

Miller, H. J., et al. (2015). "Modification of the U.S. Army Corps of Engineers Model 158 for Prediction of Frost–Thaw Profiles in Northern New England." Transportation Research Record: Journal of the Transportation Research Board 2474: 135-142.

Main Points/Topics
  - Overview of spring load restrictions
  - Methods of analysis/data collection
    - Temp./climate data
    - FWD data (falling weight deflectometer)
  - SLR posting approaches
    - Mahoney et. al. (2006) – includes removal of SLR
    - Berg/USFS Method (Berg et. al, 2006)
    - Minnesota DOT (Mn DOT, 2009) – includes removal of SLR
    - Manitoba Department of Infrastructure & Transportation (MIT) & FPInnovations (Bradley et. al, 2012) – includes removal of SLR
  - Test sites and instrumentation
  - Applications of SLR methods in NH
    - Tested all approaches except Manitoba (very similar to MnDOT)
    - Berg/USFS and/or MnDOT best for SLR start dates
    - MnDOT(2009) and/or Bradley et. al. (2012) for removal dates (more conservative results)

Schlenker, W., et al. (2007). "Water availability, degree days, and the potential impact of climate change on irrigated agriculture in California." Climatic Change 81(1): 19-38.

- Degree Days = sum of degrees above a lower baseline and below an upper threshold during the growing season (8^{o}C – 32^{o}C)
- Data sources:
    - June Agricultural Survey – stratified sample of farms based on geographic location (value of land)
    - PRISM
    - 103-yr high resolution small scale data set developed by the Spatial Climate Analysis Service at Oregon State
        - "one of the most reliable interpolation procedures for climatic data on a small scale."
- Output = temperature and precipitation (April to September)
- Baseline = 1960-1989 (30 year temp. averages)
- Process:
    - Plug temperature output into growing degree day calculations
    - Base value of farm land off growing degree days ("ability to produce")
- Information display:
    - Maps
    - Tables

Sooraj, K. P., et al. (2015). "Global warming and the weakening of the Asian summer monsoon circulation: assessments from the CMIP5 models." Climate Dynamics 45(1-2): 233-252.

- Data sources:
    - CMIP5 models
        - **CCSM4**
        - **CNRM-CM5**
        - **GFDL-CM3**
        - **GFDL-ESM-2G**
        - **GISS-E2-R**
        - **IPSL-CM5A-LR**
        - **NorESM1-M**

          DEEMED "GOOD MODELS"
        - BCC-CSM1.1
        - CSIRO-Mk3.6.0
        - GFDL-ESM-2M
        - GISS-E2-H
        - HadGEM2-ES
        - INM-CM4
        - IPSL-CM5A-MR
        - MIROC5
        - MIROC-ESM
        - MIROC-ESM-CHEM
        - MRI-CGCM3
- Output = visibility, rainfall, circulation, monsoon seasonality, MGT, water vapour budget (June to September)
- Emission scenarios: all 4 CMIP scenarios
- Baseline = 1980-1999
- Future = 2080-2099
- Process:
    - CMIP3 or CMIP5? → CMIP5
    - Downscaled statistically to a 2.5^{o} x 2.5^{o} grid
    - Observed data vs. Model Output model selection
        - 2 Taylor diagrams → spatial pattern correlation, root-mean-square, and ratio of standard deviations
        - Rainfall climatology and variability over broad region

            - Strategy:
                - Pattern correlation in climatological mean field above 0.65
                - Pattern correlation in inter-annual std. dev. Field above 0.6
                - Spatial inter-annual std. dev. of 1.0 ± 0.2
    - Created an ensemble w/ good models and extended ensemble w/ all models
    - Had difficulties w/ precipitation data
- Data presentation:
    - Tables
    - Taylor diagrams
    - Line graphs
    - Maps

Stewart, I. T., et al. (2004). "Changes in snowmelt runoff timing in western North America under a 'business as usual' climate change scenario." Climatic Change 62(1-3): 217-232.

- CT = center of mass of streamflow
- Output = daily/monthly flow volumes
- Data sources:
    - USGS Hydro-Climatic Data Network
    - The Reference Hydrometric Basin Network of Environment Canada
    - PCM simulations 5^{o} lat-long grid
    - Statistically downscaled
    - Variable Infiltration Capacity (VIC 4.0.3)
        - ¼^{0} resolution
    - USGS Precipitation-Runoff Modeling System PRMS
- Emission Scenarios: BAU
- Baseline = 1951-1980
- Future = 1995-2099
- Process:
    - Comparison = statistical models vs. hydrologic models
    - 3 linear regressions of CT based on PI and TI (TI dominates)
        - Average CT for each gage = absolute CT projections
- Information display:
    - Graphs w/varying degrees of future change
    - Scatter plots
    - Line graphs