A Comparison of Statistical and Dynamical Downscaling for Surface Temperature in North America

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How can we test if a downscaled climate projection is skillful?

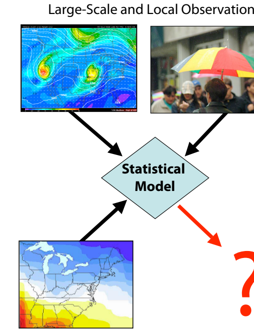
- **Two general classes of methods to estimate climate variables at higher resolution**
  - Dynamical: regional climate model (RCM) → dynamically-consistent suite of regional climate variables
    - State-of-the-science, physically sound
    - Equivalent to operational weather forecasting
    - Computationally expensive
    - Parameterizations uncertain in future climate states
  - Statistical (SD): observed correlations → statistically-consistent single variables (region or point)
    - Low-cost, off-the-shelf tools available
    - Seconds to calculate 100-year time series
    - Multiple methods suitable for means, extremes, all temporal scales
    - Statistical relationships uncertain for future climate states
- **New York Climate and Health Project (NYCHP)**
  - Assesses heat- and ozone-related mortality & morbidity in NYC from projected climate, land use change
  - Publications have highlighted uncertainty in the RCM-derived regional temperature scenario and emphasized effects of regional temperature change dominate projected changes, outweighing emissions
  - Regional ozone [Hogrefe et al., 2004] • Health impacts [Knowlton et al., 2004]
- **Statistical Downscaling to Complement the NYCHP**
  - Identify the elements of an SD model that contribute most to potential agreement with RCM
  - Understand the physical reasons behind any apparent agreement
  - Provide more comprehensive understanding of uncertainty in the NYCHP downscaled scenario
  - Template for model sensitivity analysis by the impacts analyst using SD to develop regional scenarios
  - Flexible, globally-applicable protocol for downscaling radiative forcing changes from ambient concentrations, independent of chemistry or thermodynamics

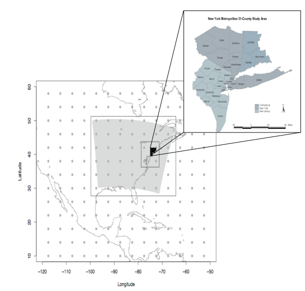
Downscaling Methods

- **June, July and August monthly mean surface temperature (T_{SFC})**
- **Predictor: NASA GISS 4° x 5° Global Atmosphere-Ocean Model (GISS-GCM)**
  Model years 1990 - 2087, IPCC 'A2' scenario
- **RCM**: PSU/NCAR mesoscale regional climate model (MM5) coupled to GISS-GCM one-way by Lynn et al. [2005]
- **Statistical Downscaling**
  - University of Delaware Air Temperature and Precipitation 0.5° x 0.5°
  - Multiple linear regression statistical downscaling on predictor empirical orthogonal functions (EOFs); 8 Leading EOFs explain >99% of variance
  - Extensive sensitivity testing
    - Predictors: T_{SFC} alone or with MSLP (TP)
    - Predictor domains, training, resolution
  - Skillful Model for present-day conditions
    - SD for the period 1997-2004 using NCEP Reanalysis: RMS error ~ 0.7 ºC
    - Predictor domain, resolution, and variables played negligible roles in present-day simulation

Statistical Downscaling

Large-Scale and Local Observations





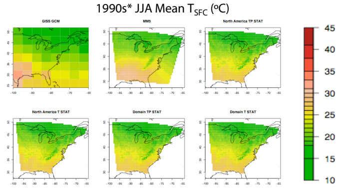
The regional modeling domain is shaded in light grey. Boxes (including the axes) represent boundaries of the three scales of predictor domain. Gridcells of the NYC area are shown in black. GISS-GCM gridcell centers are shown as grey points.

Results

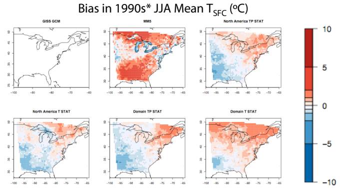
In projection, all models yielded warming greater than the host GCM, (in excess of twice as much); temperature increases in GISS-CGM, as well as those in the downscaled results from SD and MM5, were within the range of temperature changes predicted by other global climate models for the A2 scenario for the same region. We assessed model agreement for future simulation with downscaled results adjusted at each point to compensate for bias found during the summers of the 1990s. When MM5 was adjusted for model bias from 1992-1997, MM5 mean warming was still 28% greater than the GCM. Bias-corrected monthly mean TSFC and departure from 1990s averages for the 2050s and 2080s from MM5 and SD consistently agree closely in spatial patterns and magnitudes of warming. While the MM5 simulations were sporadic, the continuous monthly time series from SD put them into perspective and show that, with the exception of two years in the 2080s, MM5 is never an outlier over the entire domain or NYC. As statistical estimates diverged, MM5 agreed most with the domain-scale predictors. Since the domain-scale predictors' boundaries are nearly identical to the lateral boundaries of the MM5 simulation, this relationship is logical and likely not a chance feature of the region or training data.

Current Skill

1990s* JJA Mean T_{SFC} (ºC)

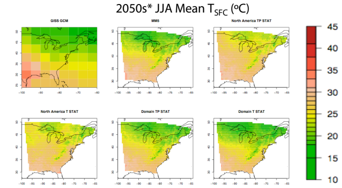


Bias in 1990s* JJA Mean T_{SFC} (ºC)

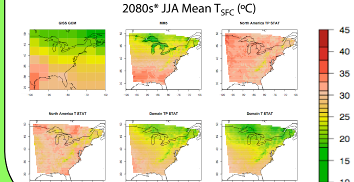


Projections

2050s* JJA Mean T_{SFC} (ºC)



2080s* JJA Mean T_{SFC} (ºC)



Predictor-Predictand Relationships

The relationship between the time-series at a single observation station or surface gridpoint and large-scale patterns, from which the SD method derives its predictions, may remain perfectly constant even while the collective relationship between the regional field of projections and the large-scale patterns vary greatly, whether in training or projection. Rather than merely an indication of error, these changes can be an indicator of the relative contributions of the strength of the predictor forcing and the codified relationship between large-scale and local features built into the RCM or SD algorithms.

This evolution over time then highlights discrete periods when uncertainty in the downscaled scenario is more likely due to the downscaling process's inappropriate training or parameterization for a particular large-scale pattern, as opposed to times when stationarity is evident and uncertainty is concentrated more heavily in the choice of downscaling method, domain location and size.

In this study, the observed correlation between predictand T_{SFC} and NCEP reanalyzed T_{SFC} was 0.92 for the periods 1950-1996 and 1990-1996. By contrast, correlation with GISS-GCM was only 0.55. None of the regional correlations between downscaled results from GISS-GCM and GCM predictors were invariate over the quasi-decades chosen for comparison. In fact, neither MM5 for 1993-1997 nor any of the SD predictions from GISS-GCM for 1997-1999 even maintained the same relationship with GISS-GCM as the training of the previous 7 years.

Predictor/predictand field relationships generally weakened over time, and mostly remained weaker than observed historical patterns. The MM5 and the Domain T_{SFC} SD scenarios, whose spatial patterns were found similar, also share a limited influence by GISS-GCM that weakened significantly over time — even becoming negative. This peculiar feature suggests that for this particular domain size and location, the strength of the training relationship in SD and model formulation in MM5 overwhelmed GCM variability, such that the GCM served more as a mean warming trend upon which to overlay statistical constaints or dynamical calculations than as the driving force behind spatial patterns of variance. This similarity may, then, be a reason for the apparent agreement between these two downscaled scenarios.

**Quasi-decadal averages calculated to accommodate the intermittency of MM5 simulatios and limited SD prediction period in the 1990s. MM5 quasi-decadal average was calculated for 1993-1997; for SD, 1997-1999. For all models, 2053-2057 and 2083-2087.*

What Does This Imply for Impacts Assessment?

- One global scenario, multiple plausible regional scenarios
- SD a flexible tool for regional effects of radiative forcing (black carbon & aerosols)
- De-biased projections from regional climate model and statistical methods agree
- Continuous time-series of regional effects identify outlying models and intervals

These results highlights the advantage and relative ease for integrated assessments to take into account multiple sources of information, at all available scales, at every step of the process, in order to quantify uncertainty and reduce the assessment's reliance on arbitrary, *a priori* linkages. Regional surface temperature scenarios, and the assessments to which they contribute, can be improved by assessing multiple downscaling methods for the same GCM, ranging from state-of-the-science dynamical models to relatively simple statistical predictions; by deriving climate change predictors from a weighted ensemble average of multiple GCMs; and by using multiple downscaling methods with an ensemble of GCMs. Ideally, multiple GCMs driving statistical downscaling can quickly generate long-term, continuous time series to illustrate a range of likely regional effects; select GCMs best-suited for the region, downscaled variable, and scenario; and identify periods of regional change to then downscale dynamically. Such analysis will allow climate downscaling to yield the most plausible projections for impacts assessments and develop a comprehensive understanding of reasons the regional downscaling yielded plausible projections, increasing confidence in the downscaling procedure and the assessment results.

References

Results were obtained using clim.pact v2.12 by RE Benestad (The Norwegian Meteorological Institute and the Norwegian Research Council's RegClim programme) in R v2.

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