**NCAR CSL Annual Report (March 1, 2000 – April 30, 2001)**

Project title: Evaluating regional climate change in contrast to biases
Project No : 93300155
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## Abstract

Analysis of our decadal RCM simulations shows the following results: (1) While simulated climate change is consistent throughout the U.S., confidence in the simulations shows noticeable regionality, seasonality, and inter-model variability, with higher confidence over the western U.S. in winter for RegCM2. (2) Growing season depletion of soil water in the agricultural Midwest is simulated well, but recharge after the growing season is slower than observed due partly to underprediction of precipitation in fall, implying the need for improvements in simulating precipitation in order to produce accurate soil moisture. (3) For most of the U.S. the enhanced $CO_2$ scenario simulation showed decreased wind power availability in the range of 0-30%, however, in limited areas a 20-30% increase in wind power was simulated. (4) The future climate tends to have high streamflow during the wet season and loss of reservoir storage for the dry season in the western U.S.

## 1. Scientific accomplishments

The previous-year CSL project allowed us to complete a suite of 10-year regional climate simulations, the longest regional climate model (RCM) simulations to date in the continental U.S. As the first part of the current-year project, we have completed several studies by analyzing these runs. The second part of the project prepares for a new set of long-term regional climate simulations.

### *(1). Climate change uncertainties (Pan et al. 2001a)*

To quantitatively evaluate uncertainties associated with regional climate change, a climate confidence ratio ($R$), defined as the simulated climate change divided by maximum RCM bias, is evaluated for the RCM simulations. Four RCM biases are evaluated based on the suite of 10-year simulations, in addition to comparisons with the GCM (general circulation model) simulation: (1) RCM (performance) bias - difference between reanalysis-driven RCM simulation and corresponding observations, (2) forcing bias - difference between the GCM control climate driven and reanalysis driven runs, (3) inter-model bias - difference between runs from different RCMs (HIRHAM minus RegCM2), both driven by reanalysis, and (4) GCM-RCM upscaling bias – difference between the GCM run and RCM run driven by the GCM output, both for current climate.

While the simulated climate change is consistent throughout the domain and seasons, the confidence ratio showed considerable seasonality, regionality, and inter-model variability. The climate warming is significantly stronger in the western than eastern U.S. and in winter than summer, due possibly to decreasing snow cover in the high-elevation mountain regions in the cold season and a strengthened monsoon ridge in summer. Based on RegCM2 simulation, $R$ is > 1 in several region/seasons. The winter $R$ is larger than summer and minimum temperature change is larger than the maximum. On the other hand, $R$ for HIRHAM is almost always < 1, ranging mostly 0.2-0.5. This inter-model difference implies the need for multi-model ensemble simulations to enhance our confidence in climate change.

*(2). Soil moisture simulation and changes (Pan et al. 2001b)*

Modeled soil moisture is evaluated over Illinois and Iowa where soil water observations are available. Simulated soil moisture content does not show noticeable drift during the 10-year simulations. Simulated upper soil moisture compares reasonably well with observations while deep soil moisture has consistent low bias. Growing season depletion of soil water is simulated well, but recharge after growing season is slower than observed due to underprediction of precipitation in autumn. This suggests that improvements in simulating soil moisture depend greatly on improvements in simulating precipitation. The climate change scenario produces drier upper soil in winter but wetter soil in warm seasons because of greater precipitation, while deep soil is wetter in all seasons.

*(3). Snowpack simulation and changes (Bryant et al. 2001)*

We have evaluated snow-water equivalent along with daily max/min temperatures in 10-year climate simulations for the continental U.S. Monthly distributions of these variables compared with measurements from SNOTEL stations in the mountainous western US demonstrate that a regional model is capable of simulating seasonally changing patterns quite well but with some notable biases. Different seasonal distributions of total precipitation in different mountain ranges are accurately simulated. Snow-water equivalent, by contrast, is uniformly low in the simulations compared with measurements. It appears that snow depth in RCMs is closely related to the model's performance on temperature. It is not surprising that HIRHAM has underprediction of snow cover given that the model had a constant warm bias.

Both models simulated a considerable snowmelt increase in the future climate scenario, both in terms of snowpack depth and snow cover. The latter is even more important, because of the snow-albedo feedback. The relation between snow cover decrease and warming is most evident in winter, when snow cover is present more frequently. In the high-elevation western U.S. snow cover exists in all four seasons. The number of snow cover is reduced substantially for scenario climate in winter and spring. The snow cover decrease reaches 40-50 days during winter months. The stronger summer warming in the western U.S. probably is related to dynamic factors, in addition to more snowmelt compared to the eastern U.S. For example, HadCM2 predicts that the North American Monsoon ridge will be stronger in the future scenario climate, making the surface warmer.

*(4). Climate change effects on winder energy (Segal et al. 2001)*

Wind power (WP) is a likely source of renewable energy to reduce fossil $CO_2$ atmospheric emissions. However, WP availability might be affected by climate changes induced by such emissions. RCM simulations resolving near surface flows were used to generate WP climatologies for the U.S. consistent with present and mid 21st century enhanced atmospheric $CO_2$ levels. The simulated present WP showed reasonable general agreement with observed patterns in most locations. In most of the U.S. the enhanced $CO_2$ simulation showed a trend of decreased daily average WP availability in the range of 0-30%. However, in limited areas in the southern and northern U.S. an increase in WP, peaking at 30%, was simulated. Under the enhanced $CO_2$ climate scenario, the present relatively high WP availability in northern Texas and western Oklahoma as well as in the northwest U.S. is almost unaffected. Decline in WP is simulated in the north-central U.S. and the western mountainous region.

*(5). Stream flow change based on RCM simulations (Meller et al 2001, Hay et al. 2001)*

Forced by RCM simulated precipitation and temperature under both current and future climate, hydrological models were run to simulate streamflow changes associated with climate changes. Results from such an application (Miller et al, 2001) have indicated that the GCM global warming signal can be carried through the RCM dynamics to the streamflow. The degree of change in streamflow in a number of river basins in California is significant. The future climate tends to have high streamflow during wet season and loss of reservoir storage for the dry season. These concerns will become more prominent as California population and industrial growth continues to strain the current weather resources supply. The models indicated significant relative increase in Sierra Nevada winter and earlier streamflow based on the simulated increase in wet season precipitation and temperature. This increase may likely cause streamflow events resulting in floods. Water resource managers may need to release reservoir storage water in anticipation of major flow events, thus reducing the supply for the dry season. The warm wet season indicates a decrease in snowpack and a significant decrease in streamflow during the dry season, further reducing water availability.

In a related study (Hay et al. 2001) we found that the RCM simulations captured the gross aspects of the seasonal cycles of precipitation and temperature. However, in all four basins studied, large systemic biases in RCM simulations of temperature and precipitation were evident, which translated into unrealistic simulations of mean-monthly hydrograph. Pronounced cold biases in springtime daily maximum temperatures in the Animas and Carson River basins caused delayed melt of snowpack and delay in spring runoff. In order to reproduce realistic mean-monthly hydrograph in each of the four basins studied, the RCM output required adjustments in rain-day frequency as well as a bias correction in precipitation amounts and temperature. After RCM output was corrected for systematic biases, the accuracy of the runoff simulations is improved in the snowmelt dominated basins.

*(6). Model sensitivity to lowest model height (Wei et al. 2001)*

As part of model component coupling in the parallel modeling system, we extensively tested land surface schemes. We particularly tested the vertical location of lowest model level in RCMs. Under strong thermally stable conditions the height of the lowest model level may be well above the surface layer depth, and thus outside the range of applicability of the surface similarity theory on which the model's surface thermal flux computation is based. This can strongly affect the magnitude of simulated surface and snowmelt and thus feedback on the climate system. To explore this issue we have investigated the impact of selected heights of the model's lowest level. Setting the lowest model level to 3 m or 10 m, which typically is within the surface layer, yields nearly the same simulated turbulent thermal fluxes. However, when the model level height was set at 40 m, as used in many RCMs, exceeding the depth of the stable surface layer, especially over the snow cover, the surface turbulent thermal flux in this case can be smaller by 40%.

## 2. Experiments completed

(1) We have made some additional runs to help explain model biases or confirm climate change hypotheses. Some other runs were also made to fill missing gaps left from previous experiments.

(2) We have generated several years of initial and boundary conditions that will be used to drive regional climate models. These multiple-year (1986-1989) forcing data sets will be extended to cover the whole 20-year period as planned in the original proposal.

(3) Some test runs have been completed for a couple of months for the long-term (20 year) simulations. These tests confirmed that our modeling systems works well in the parallel environment. Preliminary results are quite promising.

## 3. Experiment remain to be completed

Partly because of our slower modeling system preparations and unexpected personnel shortage, we have not completed our intended 20-year long-term simulations. Now we have both modeling tools and human resources for the 20-year long-term runs.

## 4. Computing resource usage

In the previous 12 months ending April 2001, we have used about 3,200 eCHr (GAUs), excluding MSS storage charges. The reasons for not fully using our CSL allocations are because (1) our parallelization of new land surface schemes and input/out data stream took longer than expected, (2) some of our models (the project involves multi-models/groups) require larger memory size than normally provided, and (3) we experienced manpower shortfall due to unexpected funding cuts. Now (1) and (3) above have been resolved.

## 4. Partial list of publications used the CSL results

*(1). Peer reviewed journal papers*

Giorgi, F., B. Hewitson, and multiple co-authors (59 contributing authors including W. J. Gutowski), 2001: Chapter 10. Regional Climate Change Simulation: Evaluations and Projections**.** *Climate Change 2000: Third Assessment Report of the Intergovernmental Panel on Climate Change* (in press).

Pan Z., J.H. Christensen, R.W. Arritt, W.J. Gutowski, Jr., E.S. Takle, F. Otieno, 2001a: Evaluation of uncertainty in regional climate change simulations *J. Geophy. Res*. (in press).

Pan, Z, R.W. Arritt, W.J. Gutowski, E.S. Takle, 2001b: Soil moisture in regional climate models: simulation and projection, *Geophys. Res. Lttr* (in revision).

Segal, M., Z. Pan, R.W. Arritt, and E.S. Takle, 2001: On potential change over the U.S. due to increase of atmospheric greenhouse gases, *Renewable Energy*, **24**, 235-243.

Wei. H., W.J. Gutowski, M. Sega, Z. Pan, W.A. Gallus, and R.W. Arritt, 2001: Sensitivity of simulated regional surface thermal fluxes during warm advection snowmelt to selection of the lowest model level height, *J. Hydrometeor*. (in press).

*(2). Selected conference paper and presentation*

Arritt, R. W., R. Wilby, L. E. Hay, W. J. Gutowski, Jr., C. J. Anderson, M. P. Clark, G. H. Leavesley, Z. Pan, R. Silva, and E. S. Takle, 2000: Comparison of statistical and dynamical downscaling for evaluating climate change impacts on water resources. International Workshop on Climatic Change: Implications for the Hydrological Cycle and for Water Management. Wengen Switzerland.

Bryant, S. E., E. S. Takle, Z. Pan, C. J. Anderson, W. J. Gutowski, Jr., and R. W. Arritt, 2001: Evaluation of precipitation, snow-water equivalent, daily max/min temperatures and climate feedback in a regional climate model. European Geophysical Society XXVI General Assembly. Nice France, 25 - 30 March 2001.

Gutowski, W.J., R.W. Arritt, E.S. Takle, Z. Pan, and co-authors, 2001: Project to Intercompare Regional Climate Simulations (PIRCS): Advancing the CLIVAR Agenda, *CLIVAR Newsletter*, 5, 13-15.

Gutowski, W. J., Pan, Z., C. J. Anderson, R. W. Arritt, F. Otieno, E. S. Takle, J. H. Christensen, and O. B. Christensen, 2000: What RCM Data Are Available for California Impacts Modeling? (How Good Are They?). California Energy Commission Workshop on Climate Change Scenarios for California, California Energy Commission, Sacramento, California, 12 - 13 June 2000.

Pan, Z., J. Christensen, R. Arritt, W. Gutowski, and E. Takle, 2001: Evaluation of extreme precipitation in regional climate models, *European Geophy. Soc. XXXVI Assembly, Nice, France*, March 25-30, 2001.

Takle, E., Z. Pan, R. Arritt, and W. Gutowski, 2001: Changes in snow depth and soil moisture from regional climate model simulations of future scenario climates. *12th Symposium on Global Change Studies, Amer. Meteor. Soc.,* Albuquerque, NM., 2001.

*(3). Paper to be submitted*

Hay, L.E., P.P. Clark, W.J. Gutowski, R.W, Arritt, E.S. Takle, and Z. Pan, 2001: Use of regional climate model output for hydrologic simulations.

Miller, N.L., W.J. Gutowski, T.-K. Kim, E. Strem, Z. Pan, R.W. Arritt, and E.S. Takle, 2001: Impacts of increased CO2 on the hydroclimate of the western United States: Part 2: California basin-mean precipitation and temperature on streamflow responses.