California Energy Security Project

Progress Report, Q3

Period: 8 Jan 2004 – 8 April 2004

1. Introduction and Overview

The California Energy Security project is a NOAA-funded effort to determine the economic benefit of climate and weather forecasts to California's energy sector. The work is headed by P.I. Tim Barnett of the Scripps Institution of Oceanography (SIO), with additional contributors from SIO, Georgia Tech, Science Applications International Corporation (SAIC), and the University of Washington (UW).

During Q3, work focused on executing the scenarios associated with the California ISO: the delta breeze prediction project, and the ensemble forecasting project. Work was also started on the SDG&E tariff day (load-demand management) scenario.

The climate and economic work for the delta breeze is essentially complete (it remains to write the results up for journal publication). The main outcomes of the work were as follows. 1) The AVN-MOS temperature forecasts for the Bay Area in particular (and, to a lesser extent, the inland non-Bay Area) consistently underestimate maximum temperatures. This was a surprise to us, as we anticipated that the MOS corrected forecast should have no systematic errors. Be that as it may, we developed a medianbased MOS corrector for the 6 stations the CalISO uses for the Bay Area forecast, and gave these correctors to the CalISO, where they will be used in the upcoming summer. 2) We found that AVN and MRF forecasts of the delta breeze were of quite poor quality. Based on suggestions of the stakeholder, we devised a statistical sub-daily prediction scheme that gives the likelihood that the upcoming day will be a delta breeze day, based on meteorological observations at 7 AM. The 7 AM time was chosen because the CalISO does a final adjustment to the load forecast at that time. If, for example, the traditional weather forecast calls for a delta breeze event but the statistical forecast indicates it is highly unlikely to have one develop, then the temperature forecast can be adjusted accordingly. The economic value of these forecast changes (and, in fact, of any arbitrary forecast) can be evaluated using the cost curves the stakeholder developed. The benefits of these improvements are about \$X M/yr.

The ensemble forecasting scenario for CallSO was also completed. The main result is that the asymmetric cost curve biases the "minimum cost" forecast away from the median forecast. This is because underforecast temperature errors cost more than overforecast errors. The exact compensation needed to minimize costs was shown to be the 55th isopleth of the multi-model ensemble forecast. The reduction in costs possible by using this methodology would be up to \$X M/yr if the CallSO operators currently chose the median value of the AVN-MOS forecast for their decisions.

The SDG&E tariff day scenario is mostly complete. A perfect prediction study has been carried out that quantifies the reduction in electrical load possible under various predication strategies. The strategies were evaluated over the period 1990-2003 so that the expected range of benefits attainable, given the historical record, could be quantified. Part of this process was showing the effect that the PUC's constraints on the program have on the shed electrical load. As part of this process, a practical way of attaining a reasonable fraction of the total attainable benefits was devised. This consists of the so-called "super simple scheme," which calls a tariff day based on the current day's temperature and the increase in temperature over the previous day. The skill of the super simple scheme was evaluated over the verification period, and shown to be a reasonable approach to gaining benefit from the program, and also yielded results distinctly better than what the stakeholder managed in 2003. The value of this forecast is at least \$X M/yr, based on the costs of avoided electricity during called tariff days. The ultimate value of the program ranges up to \$X M/yr if construction of peaker plants can be avoided by using this forecast.

Unfortunately, the SDG&E seasonal prediction scenario had to be dropped. Despite numerous meetings with SDG&E, we could not work out the exact details for a scenario that fit both the stakeholder's requirements and the realities of climate forecasting. I.e., for those forecast products that climate science can produce with skill, there was no decision process in place for using those forecasts that could be used to perform an economic valuation of the forecast. For those decision processes that were in place and able to be economically valued, the lead time required for the climate forecast was not one at which the climate system is predictable. Our overall assessment was that there is scope for seasonal climate predictions in operations and planning at SDG&E, but the exact way such forecasts would actually be used is still not well defined. This may be an area for future work, if the project is extended.

During the upcoming quarter, our attention will be focused on finishing the tariff day scenario, and starting the PacifiCorp scenario (irrigation pump load forecasting in the Pacific Northwest).

2. Progress Towards Objectives and Tasks

The progress made in Q3 towards the objectives and tasks set forth in the original proposal will now be described. An estimate of the percent of work for that task that has been completed to date will also be given. For reference, the progress made during the previous quarters (Q1 and Q2) is also included, after the progress made during the current quarter is described.

Objective 1. Produce weather and climate forecasts tailored for energy producers

Task 1. Assess weather-related issues of importance to the energy industry

Work accomplished Q3:

- Met again with SDG&E on March 24, 2004 to deliver and explain forecast products for the tariff days application, and to explore an additional application involving capacity expansion decisions.
- Met with SDG&E on April 12, 2004 to further define the capacity expansion decisions, e.g., whether to defer or accelerate the next year's project(s), and to estimate the economic value of the tariff days forecast improvement. For the capacity expansion project, the decision-makers would like to know, ideally, twelve months in advance of June, but it still would be useful to know six to nine months in advance (September-December). The forecast information would be the seasonal tercile probabilities for the following summer. The decision to go ahead with or to defer construction would be made by January 1st of the following year.

Work accomplished Q2:

- Iterated several times with CaISO to identify the specifics of the weather/climate issues of importance to them. Of primary importance is the issue of poor delta breeze forecasting. Delta Breeze effects may suddenly lower or increase temperature due to cooler, fast moving air masses moving inland. Cal ISO load error can be as much as X MW or X percent of total summer peak lead due to uncaptured Delta Breeze events in the forecast. This is a most expensive error that has to be covered with supplemental power purchases. Cal ISO would like to determine the cause of the NOAA ETA-MOS model error in predicting Delta Breeze events. The lead time on identifying delta breeze events is about 1.5 to 3 days. *The CalISO delta breeze issue will be one of the scenarios*.
- Of great interest to CalISO is whether they can make use of new techniques of ensemble weather forecasts in their planning. Current forecasts have no indication of how reliable the upcoming temperature forecasts are, or what their expected spread is. CalISO understands this is a problem, and would like to make use of emerging ensemble forecasts if they can be shown to be reliable, and add useful information. *Exploring the use of ensemble forecasts by CalISO will be one of the scenarios*.
- Met with SDG&E several times to clarify exactly what issues were top priority for them, out of the many identified ones. Converged to the following two issues:
 - 1. Scheduling of tariff days (i.e., pricing and load control incentives). The purpose here is to forecast what are the optimal days for calling tariff events, given the constraints of the imposed rules (for example, only 2 events may be called per week). The lead time on this is about 3 days. *Scheduling of tariff days for SDG&E will be one of the scenarios*.
 - Extending seasonal forecasts of seasonal averaged temperature and precipitation so that these forecasts can be used in resource planning. Currently, only summer forecasts are used, and only to a limited degree. This will be extended to winter forecast as well, and along with SDG&E, we will explore the possibility of using these forecasts for a wider range of planning

uses. Seasonal temperature and precipitation forecasting for SDG&E will be one of the scenarios.

- Discussed with SoCal Gas their seasonal forecasting needs to better manage pipeline storage withdrawals. Weather sensitive peak use of gas demand and impacts on the transmission system are of great concern for scheduling pipeline deliveries. A variety of operational alternatives that potentially balance gas demand and peak sendout were investigated. Unfortunately, SoCal Gas was not able to participate in the project due to work load and time constraint issues. The SoCal Gas project will be dropped.
- Iterated with PacifiCorp to identify their top issues, from the selection identified during Q1. The problem of predicting irrigation pump loads emerged as one of the top issues that is related to climate. This deals with anticipating when the pumps will be turned on in the spring/early summer. The time when the pump load ramps up can change by several weeks, year to year. Right now, there is no forecast of when the pump load will happen. The useful lead time on this forecast is 1 to 3 months. *Forecasting the onset of irrigation pump loads for PacifiCorp will be one of the scenarios.*

Work accomplished Q1:

- Organized three meetings with the California Energy Commission (CEC) (6/13/03; 7/14/03; 9/9/03) and one with DWR/CERS (7/14/03). First meeting identified critical scenarios, forecast needs, current uses, and potential applications of new forecast information. Second meeting explored and defined forecast products desired, candidate applications, and economic benefits assessments. Third meeting discussed in greater detail the proposed forecast products, and additional products that could benefit the energy sector.
- The CEC currently uses ~13 "California climate zones" to characterize the state, as it would be unwieldy to apply their load forecasting methodology to every community in California. Analyzed appropriateness of these zones based on the Groisman data set. From this, found that the Blythe data set used by the CEC isn't correct. Gave a better set of data back to Glen Sharp at the CEC.
- An issue in forming the climatological "average" year to use for load forecasts is the strong trend in many climate records. Examined CEC's use of a "12-year/30year mean" correction to climatological HDD and CDD data. Found that it tends to be systematically different from the best fit trend, since there is pronounced warming in the station records. Many stations show strong decadal climate signals -- there is obviously a big climate component there.
- Conducted in-depth interviews and established relationships with more than 30 stakeholders among 10 public agencies and private firms involved with energy planning and decision-making in California; specifically, the California Energy Commission (CEC), Department of Water Resources (DWR), Public Utilities

Commission (PUC), Independent System Operator (ISO), California Energy Resources Scheduling (CERS), Sierra Energy, DSI Power, SoCal Gas, Sempra Utilities, and San Diego Gas and Electric.

- Results and impressions: Stakeholders committed and generally enthusiastic about applications and potential net benefits of forecast products. Climate forecasts not really used currently, despite indications of usefulness and high potential value. Weather forecasts widely and regularly used, however. Identified critical needs and uses of forecast information. For electricity applications: generally weather forecasts, for summer temperatures, in "swing regions," for strings of hot days, and for heat storms across California. For gas applications: generally climate forecasts, for winter temperatures, in all regions, but also seasonal precipitation forecasts for California and Pacific Northwest.
- Had 6 sessions with the Cal-ISO load forecasting group in Sacramento. Not only are they a willing participant in this study, but they have assigned internal resources for participation in this project. Their key weather and climate related issues include:
 - 1. Anticipated seasonal heat wave (5-10 days in duration particularly during May-October)
 - 2. Relationships between temperature extremes and system and regional demand for electricity
 - 3. High temperatures in swing regions (San Jose, LA, San Diego, San Francisco)
 - 4. "If it's greater than 95 degrees in Sacramento, what's the probability that it will be greater than 95 degrees in San Jose?"
 - 5. Sequential days of hot weather (3, 4, 5 days in a row)
 - 6. "Clear statement of indicators of El Niño and La Niña conditions"
 - 7. Improved accuracy of day-ahead temperature forecasts, especially for inland weather stations used by CA ISO.
- Convened several sessions with San Diego Gas and Electric. Participants have been from several of the major operational centers. SDG&E's key weather/climate related issues include:
 - 1. Improved short and mid- term forecasts of gas and electric energy consumption and load levels for procurement, pricing and transaction scheduling. Need reliable sub regional forecasts for better prediction of temperature swings and events.
 - 2. Econometric forecasting of electric and gas consumption and load levels which are used in annual forecasts that span three-to-five years, and sometimes ten years out. These forecasts are usually done for regulatory purposes that relate to filings with the California Public Utility Commission. These filings have to do with setting rates to charge customers for gas and electricity and for estimating future load levels use in resource planning exercises. These forecasts are medium to long-term (3-5 years and 5-10

years). In addition revenue forecasts are used by the officers of the company for revenue planning on the monthly and annual basis. The needs here are for improved regional weather and climate forecasts at lead times from day ahead to several years ahead.

- 3. Transmission planning particularly of long term infrastructure requirements relies on the accurate estimates of demand. Any forecast improvement in the year ahead to 30 year ahead seasonal temperature extremes will allow them to optimize the design of the system as well as of the components. Regional forecasts are of particular interest.
- 4. Workload planning is a function of the Electric Distribution Department. Tim Barnett has already built a long-term weather prediction model that is used to forecast summer and winter weather conditions over the service territory. This seasonal temperature outlook has been most useful.
- 5. Transaction scheduling operation for the energy procurement department runs a model that forecasts very short-term electric load. This model (ANNSTLLF) forecast hour-by-hour demand over one-to-seven days out. The model is highly dependent on a forecast of hourly weather data. The business decisions made relate to making spot market buy/sell decisions for electric power or for short-term contracts for purchased power. Improved sub-day-11 day ahead forecasting in service zones is desirable.
- 6. Statewide pricing and load control incentives are in need of accurate forecasts on a 3-7 day ahead basis (7 day for loads, 3-5 day ahead prediction of warm weather). This information is used to schedule and dispatch load tariff events and develop elasticity in the system. Presently using temperature alone. In many cases, it is the humidity that contributes to the error.
- Convened two productive sessions with PacifiCorp. Our major contact is with the Senior Vice President of sales planning whose group will participate in the project as a case study. He has presented the potential project before his weekly staff meeting. This group does the company wide monthly and annual load forecasting. His group needs the information for better seasonal and year ahead planning of revenue and coverage of assets. PacifiCorp is the third largest utility in the West. The company exports power into California -- also has markets Oregon, WA, Idaho, Montana, Utah and Wyoming. Key PacifiCorp issues include:
 - 1. Their operations have two overarching demand drivers: The Western service territory is driven by winter heating requirements; for the Eastern region, from about 40 miles inland to Utah and Wyoming, the summer cooling requirements drives summer peak load.
 - 2. The key issues pertinent to the Scripps production of forecasts are scheduling of the wind output, longer-term scheduling of hydro, both short term as well as long term.

3. PacifiCorp's actual output of wind power from turbines is far less than the potential output. This is due to significant variability of the winds, and hence output, on a diurnal, monthly, and seasonal basis.

Summary: 100% done. The weather-related issues of importance to the energy industry that we will be addressing in this program have been identified and characterized. (In fact, our efforts on this task during the last two quarters has identified many interesting issues that we simply do not have time to address.)

Task 2. Identify the weather/climate information needed to address these issues

Work accomplished during Q3:

• The discussed SDG&E seasonal project (regarding capacity expansion decisions) would involve year-ahead estimates of seasonal average temperature and prevelance of temperature extremes, for summer. There was also discussion of season-ahead wind gust information for management of repair crew staffing.

Work accomplished during Q2:

- For the *issue* of the delta breeze, the weather/climate *information* needed to address the issue was identified as follows.
 - 1. Surface wind vectors, particularly at Fairfield station. CalISO has already found that winds at Fairfield are an excellent indicator of the state of the delta breeze. Hourly data at Fairfield, and approximately 140 other stations in California, was obtained and analyzed to pick out the delta breeze signal.
 - 2. The structure of the atmosphere at the Oakland radiosonde station. It is fortunate that a major radiosonde station is located in a key spot for understanding the delta breeze. The radiosonde observations over the past 14 years were obtained (twice daily), and analyzed to show the typical structure of the atmosphere during days when the delta breeze is present, as compared to when it is absent.
 - 3. Surface temperature records. A similar set of stations as used in the wind analysis was used to obtain hourly surface temperature records. It should be noted that temperature is the key driving variable for the electrical load, so temperature is the aspect of weather/climate that links the large-scale phenomenon of the delta breeze to the electrical load patterns that are of interest to this project.
 - 4. Global atmospheric reanalysis data was obtained to show the state of the larger-scale atmosphere during breeze events, and to compare it to non-breeze days. The data is 6-hourly, has global coverage, and is on 17 vertical pressure levels in the atmosphere. The data cover the period 1979 to 2002. This will allow us to chart the evolution of the delta breeze in time, which is necessary to understand the predictability of the phenomenon.
- For the *issue* of the use of ensemble weather forecasts by CalISO, the *information* needed to address the issue is a historical set of ensemble forecasts, along with a verification (what was actually observed) so that the skill of the ensembles can be

evaluated. During Q2, a set of medium range forecasts from NCEP was assembled to address this question. Additional data sets will be obtained as well during Q3.

- For the *issue* of scheduling tariff days by SDG&E, the weather/climate *information* needed is a historical record of weather observed at stations over their service region (together with the non-weather/climate information of the historical electrical loads experienced at the same time). This information was obtained. Additionally, another set of (non-weather/climate) information is needed to complete the analysis; this is the set of rules (or constraints) under which the program operates. These rules were obtained. Together, this information will allow a so-called "perfect predictability" study to be made, i.e., we will be able to calculate the benefit of having perfect weather forecasts to the program. This will set an upper limit to the potential benefit of actual weather forecasts, which will be evaluated in Q3.
- For the *issue* of seasonal temperature and precipitation forecasting for SDG&E, the weather/climate *information* needed is a historical record of seasonal weather over their service region. This is merely the seasonally averaged version of the information obtained for the SDG&E tariff scheduling scenario, and so the same data set can be used for this issue as well.
- For the *issue* of irrigation pump forecasting for PacifiCorp, the weather/climate *information* needed is historical records of precipitation, temperatures, and hydrological indicators (possibly including soil moisture and reservoir levels) during the period of record. The precipitation and temperature variables were assembled (using U.S. divisional climate records). The hydrological indicators are underway and should be finished during Q3.

Work accomplished Q1:

- The seasonal forecasters met with the people interacting with the energy industry participants to discuss reasonable forecasting capabilities, variables and climate timescales important for energy applications. These meetings helped to define feasible and relevant seasonal forecast products for energy applications.
- Met with the California Energy Commission to show them results of analysis relating North Pacific Oscillation to seasonally averaged HDD, CDD, and energy use in California. Discussed the usefulness of long timescale (decadal) temperature predictions for the planners, in the context of placing and planning for transmission lines.
- Generated a list of ten specific potential forecast products to explore and develop:
 - Summer temperatures: Frequency of strings of hot days (3 or more days in a row); statistically based definitions of "strings" and "hot" (starting with 3 days and 95 F, respectively); spatial patterns of variability; effect of NPO and ENSO on CDD. This will also include "CA Tmax," a weighted average (60% today, 30% yesterday, 10% day before that; weighted by number of air conditioners). Average temperature over season; CDD for season; frequency of hot days (e.g., >95F in San Jose).

[Note in particular we do not yet have demonstrated skill for predicting summer temperatures.]

- 2. Conditional probabilities of joint summer high temperatures in "swing regions" (Burbank, San Jose, San Francisco). How much (if any) having hot temperatures in place X affects the likelihood of hot temperatures at place Y; effects of NPO and ENSO on this.
- 3. Probabilities of "critical scenarios": winter conditions of dry in the PNW (and/or cold in CA) followed by hot summers, followed by cold winters. Are conditional probabilities skewed by large-scale climate effects?
- 4. Winter temperatures: average temperature for season; HDD for season; chance of extreme cold days over the season; chance of runs of extreme cold days over the season; effect of NPO and ENSO on HDD.
- 5. Winter precipitation: seasonal anomaly; location dependence (spatial patterns of variability); relationship to NPO and ENSO.
- 6. Wind. Historical climatology, by season, of wind speeds (i.e. frequencies of extreme daily winds); dependence on ENSO and PDO; spatial patterns of variability and predictability.
- 7. Structure of model errors of predicted Tmax for <14 day forecasts. How this varies by season, location, large scale climate conditions.
- 8. Tmax/sequence skill: Model skill in predicting strings of hot days in swing regions at <14 day lead times.
- 9. A complete set of historical <14 day forecasts and observations of what actually happened should allow different forecast-based strategies to be evaluated to show which are the best.
- 10. Wind predictability in <14 day forecasts. Model skill for different lead times, seasons, locations, large scale climate conditions.
- Weather/climate information identified by Cal-ISO as being important to address their weather/climate issues:
 - 1. An appropriate temperature weight to develop a daily system wide temperature vector.
 - 2. Dry bulb daily temperatures stratified by monthly variation and climatic conditions in southern and northern California.
 - 3. Effects of climatic conditions and wind velocity on seasonal temperatures by southern and southern California.
 - 4. Forecasting the wind speed and direction (wind vector) for key geographical areas (delta breeze, Catalina eddy) in order to improve temperature forecasts. The time of onset of the sea breeze is particularly important.

- Weather/climate information important to PacifiCorp's issues:
 - Accurate precipitation forecasts are needed for hydro plant scheduling. Hydropower is scheduled on a 30 day basis, and must be optimized for several competing uses: power output during peak times, natural resource and fish and wildlife management, water use, and for exports into California. This requires careful reservoir management. PacifiCorp will usually hold back power if they are uncertain about future precipitation levels. This results in more costly power requirements.
 - 2. Better prediction of the winds on the day ahead to 11 day ahead is valuable. They produce hourly load forecasts out to 11 days. Also, as they schedule the wind output on a 30 day basis, estimates of seasonal variability in the wind production will be of use.

Summary: 100% done. We believe we now have all the data we need to address all the chosen scenarios. (Note that the SDG&E seasonal scenario was not ultimately chosen, as there were persistent difficulties identifying specific problem areas with the SDG&E personnel.)

Task 3. Produce operational 0-7 day weather forecasts for the energy industry

Work accomplished during Q3:

- Generated a statistical "confidence of forecast" measure for the CallSO delta breeze problem at a sub-daily lead time. This essentially uses observed and forecast information in the early hours of a day (7 AM) to determine the likelihood of a delta breeze event developing during the upcoming afternoon. This will allow CallSO to adjust the temperature forecast in circumstances where there is a delta breeze being forecast, but climate analysis shows that there is little chance of one actually occurring. These are the worst misses from CallSO's point of view, because they result in hotter than forecast days.
- Along with Dennis Gaushell of CalISO, generated a MOS corrector for the Bay Area that fixes systematically to low forecasts of warm days by the AVN-MOS model. This was targeted at the 1-day lead time problem.
- Constructed probability models based on each of 5 individual weather forecast products, weighted for optimum prediction skill in the CalISO service region. Found AVN ranked highest, while the NCEP ensembles were rather low. The multi-model combination (with appropriate weighting) scores higher than any single model. This result was checked using out-of-sample data from 2002, and the results found to generally hold up. Skill was found primarily for the 1- and 2-day lead time forecasts.
- Devised a "super simple scheme" for SDG&E tariff day determination at a 3-day lead time. This exploits the characteristic temporal evolution in temperature leading up to a tariff day. Also evaluated a perfect prediction scenario for tariff day determination, with the results as follows. If electrical load is known perfectly in advance and in the absence of PUC regulatory constraints on when tariff events can be called, 12 tariff days per summer result in an average

afternoon weekday (10am – 4 pm) load of X MW, versus X MW for an average summer day. Including the PUC constraints (2 events/week max; 5 events/month max) drops this to X MW. Picking based on temperature rather than load, and no constraints, results in X MW. Picking based on temperature, with constraints, results in X MW. The actual value of the picked days in 2003 was X MW. Based on an analysis of historical temperatures and loads (1990-2003), the super simple scheme would have picked days with an average of X MW. This is substantially higher than actually picked in 2003, and usefully approaches the actual maximum that could have been obtained in 2003 using perfect forecasts of temperature.

Work accomplished during Q2:

- In looking at 'Delta Breeze' events, we decided that higher resolution RSM forecast data might be more useful than coarser scale reanalysis data. RSM forecasts made previously for the summer of 2003 are therefore being analyzed to determine whether additional value is provided by the RSM, which is available in an operational setting via the ECPC (Experimental Climate Prediction Center).
- Another avenue of attack on the delta breeze issue is via statistical models. The idea here is to relate the forecasts of global-scale numerical weather models to the details of the delta breeze. This work was started, by analyzing the expression of delta breeze in the global model (NCEP), and tracking antecedent conditions that set up the delta breeze in the global model.

Work accomplished during Q1:

- Received request for daily 2-week forecasts from the current global to regional forecast system, which previously had made 7-day forecasts once a day and 16 week forecasts once a week.
- The global forecast was then extended to 2 weeks every day.
- The CA regional forecast was subsequently extended to 2 weeks every day.
 - Daily average 2-m temperature, as well as the corresponding diurnal maximum and minimum, are now being provided from our CA RSM96 forecast for the San Jose "swing region" area on our ECPC web site.
 - Additional variables and locations are available from our experimental forecasts upon request.
- We are now attempting to upgrade our current global to regional near real time experimental forecast system to a newer model (GSM/RSM CVS) that is already being used for our current monthly 7-month forecasts.
 - As part of this upgrade, we will make similar forecasts for comparison to the CA RSM96 version, as well as historical runs in order to better evaluate the model biases, which need to be taken into account in order to develop the most accurate forecast possible.
- Efforts to get the compute cluster to support the forecasts (on all timescales) is coming along but more slowly than hoped. The room modification plans are in place and currently the A/C equipment is being ordered. We are waiting for the ship date of the A/C units to send out the request for quotes, as no sense having the equipment get here before the location is ready.

Summary: 100% done. The delta breeze MOS correctors and confidence forecast, along with the CalISO multi-model ensemble and the SDG&E tariff day scheduling, constitute all of the short lead time scenarios selected for the project. The remaining scenario is a seasonal application.

Task 4. Produce 0-14 day hindcasts for the energy industry

Work accomplished during Q3:

• The multi-model ensemble work described above was also extended to weekly and bi-weekly lead times. However it was found that there is no evidence of relevant skill beyond day 10. Although disappointing, it is worthwhile for the stakeholders (CalISO in this case) to know the limitations of the forecasts.

Work accomplished during Q2:

- The cluster computer funded under this initiative to (among other things) finish construcing the archive of 0-14 day hindcasts arrived and was installed at the end of Q2. Several of the principals met to discuss migration of the historical mrf production runs to the new platform. We have obtained the assistance of Dr. Kanamitsu in this effort; as he was one of the principal architects of the NCEP prediction model, this help will be invaluable.
- The archive of NCEP reanalysis data is now essentially complete, and has already been used in the delta breeze study to characterize the phenomenon. The archive of runs on hetchy has been made available to the climate scientists, and is starting to get more heavily used.

Work accomplished during Q1:

- Acquired 4 TByte storage system for Historical Medium-Range Forecast Archive:
 - 1. requested quotes from several vendors
 - 2. chose system from SDCOM that includes:
 - 2) External 4TB Raid Subsystem

G1600 Titan 16bay Enclosure Redundant P/S Raid 5 16x 250GB 7200RPM MAXTOR 8mb ATA-133 IDE

3) External Exabyte VXA 2 80/160 Tape Backup

Host PC Intel Pentium 4 1.8Ghz 512K CPU 512mb DDR PC2100 Memory 40Gb Maxtor HDD 7200 rpm ATA133 52x LiteOn CDROM 1.44 Floppy Drive

3. UCSD index number available on August 4 so Purchase Order was submitted on August 4

4. Machine arrived at UCSD on August 25th

5. On September 5-7 noticed errors reading data on disks of the RAID system; diagnosed as cable problem and rectified

- 6. Machine up and ready as hetchy.ucsd.edu
- Hired UCSD undergraduate student worker Belinda Lu to assist in reading historical medium-range forecast (MRF) data. Data is from a set of hindcast model runs using the NCEP MRF global spectral model, Reanalysis II version. The data extracted is stored on tape archives, but in order to access it efficiently for the necessary diagnostic studies that will be performed it must be transferred from tape to the new RAID archive (hetchy.ucsd.edu). Each month of historical MRF data is on one 20 GByte tape. Tapes exist for September 1982 thru September 1990. It takes approximately one hour to read a tape. To read existing archive will take approximately 120 hours. While tapes are being read, Belinda is working on retrieving historical MRF data for January 1996 to the present from MRF archive at the Climate Diagnostics Center. Belinda is also working on organizing the data on the new archive hetchy.
- Status of MRF archive on hetchy (October 8, 2003): data for January 1984 thru April 1988. Data is organized by subdirectories of year and month. Each variable has a unique file in wgrib format that runs for a 15-day forecast with data written every 12 hours.
- In progress: archive of NCEP reanalysis data to use as verification and comparison with MRF archive.
- In progress: web site describing data available and tools to extract select regions and variables from archive. Current website describing archive can be found at: http://meteora.ucsd.edu/cap/hindcast.html
- Computer Platform issue: The Cray J-916, that we have used for running MRFs was damaged and irrevocably lost during power outage on 21 August 2003. As a replacement, we will continue historical MRF production on existing cluster. This requires use of a slightly different version of the global climate model (will move from the NCEP Reanalysis II model to Kanamitsu's global climate model). Previous comparison of the NCEP Reanalysis II model, Kanamitsu's Global Climate Model and the (2001) NCEP Operational MRF model for a 6-month period (January 1998 to June 1998) found the models to be almost identical during the 0-7 day forecast and only slightly different (in ensemble mode) during the 8-14 day forecast.
- In progress: Extracting maximum and minimum 2-meter air temperature over greater California region for search of multi-day "spells" periods with 3 or more hot/cold days. Goal is to examine model skill (in 2-14 day forecasts).

Summary: 100% done. It is unfortunate that the forecast skill seems to be so poor in this time frame, as the stakeholders have repeatedly expressed that skillful forecasts with 10 or 2-week lead times would be very valuable to them. However, the models simply do not seem to have skill on these lead times, at least in the areas of interest to this project

(California bay area, central valley, southern California). As the stakeholders have repeatedly expressed interest in this leadtime, fundamental research over the next several years focused on this leadtime would be quite valuable.

Task 5. Produce seasonal forecasts for the energy industry

Work accomplished during Q3:

- The work developed during Q3 supposes a continuity of the previous seasonal prediction experiments done during Q2, incorporating also the feedbacks and some suggestions made during the meetings with the stakeholders during Q3.
- To adopt and develop statistical thresholds for hot and cold days in every station, based on the previous Q2 results, the extreme warm events were defined as those values greater or equal to the 90th percentile during the summer, T90, and the extreme cold events were defined as those values lower or equal to the 10th percentile during the winter, T10. Then, annual time series, expressed as the percentage of days with extreme values for the season, were calculated. The definition based on the same threshold for all stations in a particular season (e.g. 95 °F for all cities during summer) was inconvenient because some stations presented temperature values above (below) the threshold almost during the whole summer (winter) and some of them hardly ever. This problem was also identified for different days in a row.
- Summer prediction and diagnostic experiments. Two new experiments were done with the canonical correlation-based prediction models using different time series as predictands: (1) seasonal mean temperature (Tmean) and (2) Cooling Degree Days (CDD). CCA models were used in two ways. In the specification experiment, contemporaneous JJA and June-SST were used in a diagnostic relationship with the JJA-Temperature variables. These kinds of relationships are useful to define the upper limit of predictability given a perfect SST forecast for the period 1950-2001. The climate prediction experiment was used in the classical forecast scheme for different lead times, in which previous SST from Jan to May were used to predict JJA-Temperature variables.
- Winter prediction and diagnostic experiments. As for summer, two new experiments were done with the CCA models using as predictands: (1) Tmean and (2) Heating Degree Days (HDD). In the specification experiment, contemporaneous DJF and Dec-SST were used in a diagnostic relationship with the DJF-Temperature variables for the period 1951-2001. For the climate prediction experiment previous lead SST times from Jul to Nov were used to predict DJF-Temperature variables.
- A persistent climate feature that was identified by the Canonical Correlation Analysis influencing the climate variability of temperature in California was a SST contrast between the North West-Central and East Pacific, suggesting the influence of the North Pacific Oscillation (NPO). Contingency analysis using empirical conditional probabilities between the observed MAM-NPO and JJA-Tmean and CDD was done for summer and observed SON-NPO and DJF-Tmean

and HDD for winter. For this purpose were used the stations that California Energy Commission has already defined as representative of the different California Climate zones (Pierce, 2004), 8 of these 12 stations are very close to the coast providing a bias analysis for coastal regions of the state.

Work accomplished during Q2:

- Using the Groisman data set, time series for winter and summer seasons were calculated for every station. Those series include mean Tmax, Tmin and Tmean and the frequency of extreme events (expressed as a percentage) of warm events for the summer and cold events for the winter. Some important spatial distributions (summarized in maps) were calculated for California in the 1950-2001 period that include:
 - a. The probability of having hot days (> 95F as maximum temperature) in several days in a row, e.g. 1 day or 3 days in a row.
 - b. The 90 percentile for Tmax during summer and the 10 percentile for Tmin and Tmean during the winter.
 - c. Taken the 90th percentile as a threshold for warm extremes events during summer and the 10th percentile for the cold ones during winter, the monthly distribution of that events were calculated for that particular seasons.
- These spatial distributions are important to establish the climate background and also the study of the distribution of extreme events allows us to identify particular years that are to be taken as case studies in order to understand the climate scenarios in which that particular situation occurs.
- In order to explore the potential use of the NPO and ENSO as predictors for summer and winter mean temperature in different regions of California, contingency analysis was used to calculate the probability of having a Below Normal (BN), Neutral (N) or Above Normal (AN) season in Burbank and San Jose stations given a BN, N and AN winter scenario for NPO and ENSO.
- The statistical Canonical Correlation Analysis (CCA) diagnostic and prediction methodology of Gershunov and Cayan (2003) was applied to several seasonal temperature variables derived from the Groisman data set. Some of the experiments include extreme warm events during the summer for Tmax and extreme cold events during the winter for Tmin and Tmean. Diagnostic results, allowed us to identify seasonal relationships between temperature variables and spatial structure in contemporaneous Pacific sea surface temperature (SST) and antecedent relationships to study predictability of temperature variables of interest.
- Described the relationship between the delta breeze and preceeding seasonaltimescale temperature patterns in the North Pacific. Interestingly, the North Pacific Oscillation (NPO) pattern becomes evident in this analysis. We will work this into the CalISO delta breeze project.

Work accomplished during Q1:

- Obtained the new, expanded and improved daily station temperature (max/min) and precipitation data from Dr. Pavel Groisman at the NCDC. This is the highest quality daily data available and will be the working observational data set for our studies.
- Hired a visiting researcher, Dr. Eric Alfaro, who has broad experience in statistical climatology and climate studies with societal applications. Dr. Alfaro will start working with us on October 10.
- Getting ready to, together with Dr. Alfaro, start applying the statistical diagnostic and prediction methodology (Gershunov and Cayan 2003) to several seasonal temperature variables derived from the Groisman data set. These variables will include summer and winter season's frequencies of cold and warm daily extremes, respectively, and frequencies of consecutive extreme days as well as HDD and CDD. Diagnostic results will include seasonal relationships between temperature variables and spatial structure in contemporaneous and antecedent Pacific sea surface temperature (SST). Antecedent relationships will be used in a prognostic context to study predictability of temperature variables of interest, paying particular attention to the optimization of forecasting skill.
- Broke out California HDD and CDD distributions, by station, depending on the phase of the NPO. Used simultaneous winter NPO for HDD (winter), and preceding winter NPO for summer (CDD). There is a strong correlation between the NPO and winter temperatures; HDDs differ by about 150 (out of a mean of 3000 or so) depending on the phase of the NPO. I.e., it's about a 5% effect. CDDs differ less, but it is still statistically significant at some stations.
- Used the Sailor and Munoz paper to relate the NPO's changes in HDD to expected changes in natural gas consumption. Factored in marginal gas costs provided by the CEC to calculate that the phase of the NPO makes about a \$220M difference in California natural gas consumption. Made a publicity graphic for this for Kathleen Ritzman.

Summary: 80% done. The remaining scenario is a seasonal one: predicting the onset of irrigation pump loads for PacifiCorp in the Pacific Northwest. The work for this scenario has just begun. However, the work for the California temperature/precipitation outlooks is nearly complete. The SDG&E seasonal project had to be dropped, unfortunately, as repeated meetings with the SDG&E people involved failed to uncover an application where there was an overlap between the desired lead time and forecast information on the part of the stakeholder, and the availability of skillful seasonal climate forecasts.

Task 6. Iterate to produce the optimal weather/climate forecasts

Work accomplished during Q3:

• Repeated iterations with the CalISO have progressively refined the station MOS corrector, and the statistical confidence forecast for the upcoming (sub-daily)

delta breeze. The basic tradeoff involved is between greater skill of the forecast, and a reduced number of times during the year during which the forecast can be made.

- An iteration of the SDG&E tariff day scheduling project indicated that they were actually fairly pleased with the super-simple scheme. The only issues that came up were a) tuning the exact temperatures and rates of change involved; b) looking into incorporating humidity as well. These efforts are underway.
- SIO again met with CEC staff on March 2, 2004, to deliver, explain, and receive • feedback on SIO forecast products, following the iterative process detailed earlier. The following forecast products were provided, all for the state of California: Relationships between NPO (SON) and winter temperatures (Tmean, DJF); Tercile distributions for Tmean (BN, N, AN) given NPO phase (BN, AN); Contingency Tables (tercile probabilities and boundaries) for 12 zones (Eureka, Ukiah, Sacramento, Fresno, San Francisco, Long Beach, Los Angeles, San Diego, Burbank-Glendale-Pasadena, Blythe, San Bernadino, San Jose, 1951-2001); Relationships between NPO (SON) and heating degree days (HDD, DJF); Tercile distributions for HDD (BN, N, AN) given NPO phase (BN, AN); Contingency Tables (tercile probabilities and boundaries) for the 12 zones, 1951-2001; Relationships between NPO (MAM) and summer temperatures (Tmean, JJA); Tercile distributions for Tmean (BN, N, AN) given NPO phase (BN, AN); Contingency Tables (tercile probabilities and boundaries) for the 12 zones, 1950-2001; Relationships between NPO (MAM) and cooling degree days (CDD, JJA); Tercile distributions for CDD (BN, N, AN) given NPO phase (BN, AN); Contingency Tables (tercile probabilities and boundaries) for the 12 zones, 1950-2001; NPO contingency table, terciles (BN, N, AN); NPO (DJF) vs. NPO (JAS, ASO, SON), 1900-2003; NPO contingency table, terciles (BN, N, AN); NPO (JJA) vs. NPO (DJF, JFM, FMA, MAM), 1900-2003; Correlations and significance levels for #1-6, 1950(1)-2001.
- Feedback on the CEC products included the following: desire for more forecast information pertaining to Tmax (rather than Tmean) for summer months, need for explanation of confidence levels for correlations (SIO provided a follow-up explanation to CEC staff the following week).
- Met with CEC economist and energy planners to estimate the types of economic benefits and costs associated with this forecast information, and to quantify those benefits and costs. Findings were that electricity costs could actually be higher if purchased on the year-ahead or season-ahead market (i.e., based on using climate forecasts) rather than three months ahead. Yet the climate forecasts would have particular value regarding hydropower, both in the Pacific Northwest and in California, as it affects electricity supplies.

Work accomplished during Q2:

• SIO met with CEC staff on September 9, 2003, to deliver, communicate, and receive feedback on SIO forecast products. This was the first of several rounds of

an iterative process consisting of the following steps: (a) providing and explaining forecast information to stakeholders, (b) obtaining feedback on forecast products from stakeholders, (c) discussing stakeholder feedback with forecasters, (d) revising products and developing new forecast products, and (e) delivering next set of forecast products to stakeholders. Results of this process are provided in this section.

• In this meeting, SIO went through each forecast product (listed below), detailing and explaining each one. CEC staff asked questions, suggested revisions, and generated ideas for additional forecast products. SIO answered questions and recorded the suggestions for revisions and additions. For this first round, the following forecast products were provided, all for the state of California:

1) Temperatures at 10th percentile (P10), using daily Tmin (degrees F), DJF, 1950-2001. 2) Percentage of P10, DJF, in each of the three months, Dec, Jan, Feb. 3) Temperatures at 90th percentile (P90), using daily Tmax (degrees F), JJA, 1950-2001. 4) Percentage of P90, JJA, in each of the three months, June, July, Aug. 5) Probability of Tmax \geq 95 degrees F for three or more consecutive days. 6) Contingency tables: Tercile distribution (below-normal, near-normal, abovenormal) of mean DJF temperature by ENSO (DJF) and NPO (DJF), for Burbank (1940-2001) and San Jose (1934-2001). 7) Correlation between the winter (DJF) NPO Index and seasonally averaged temperature anomalies for contemporaneous winter (DJF) and following summer (JJA), 1960-2001. 8) Composite HDD/CDD anomaly for NPO highest tercile (DJF, HDD anomaly; JJA, CDD anomaly) and NPO lowest tercile (DJF, HDD anomaly; JJA, CDD anomaly). 9) Composite temperature anomaly (degrees C) for NPO highest tercile (DJF, JJA) and NPO lowest tercile (DJF, JJA). 10) Locations where distribution of daily average temperature anomalies is significantly different depending on the state of the NPO, for contemporaneous winter (DJF) and following summer (JJA). 11) Correlation between the winter (DJF) Niño 3.4 Index and seasonally averaged temperature anomalies for contemporaneous winter (DJF) and following summer (JJA), 1960-2001, 12) Composite HDD/CDD anomaly for El Niño (DJF, HDD anomaly; JJA, CDD anomaly) and La Niña (DJF, HDD anomaly; JJA, CDD anomaly). 13) Composite temperature anomaly (degrees C) for El Niño (DJF, HDD anomaly; JJA, CDD anomaly) and La Niño (DJF, HDD anomaly; JJA, CDD anomaly). 14) Primer on the effects of the NPO and ENSO on seasonally averaged temperatures in California.

• Feedback from CEC staff on the forecast products included the following: provide more specificity for coastal regions of state, develop statistical thresholds for hot days (rather than 95 degrees for all cities), display distributions of temperatures and precipitation in addition to anomalies, develop finer gradation of color scale and add more numbers, create map of apparent heat and humidity in addition to temperature, provide confidence intervals for skill, develop map of peak demands to enable correlation with temperatures, provide information on predictive ability of NPO and ENSO (i.e., how well does JJA Niño 3.4 predict DJF Niño 3.4), examine different lead times for ENSO and NPO, develop contingency tables for more cities and more forecast variables, examine precipitation distribution shifts in addition to temperature shifts, provide same maps but for entire western U.S. (11 states), provide typical ENSO and NPO patterns for entire U.S.

• SIO forecast team then convened to discuss results from CEC meeting and to develop a second round of forecast products. The products that will be the focus of the second round include the following:

1. Summer temperatures: a. T90, JJA. b.Tmean, JJA. c. CDD, JJA. d. Effect of NPO and ENSO on CDD. e. Probability of "hot days" and "strings of hot days" (3 or more days in a row) in JJA; statistically based definitions of "strings" and "hot" (starting with 3 days and 95F).

2. Winter temperatures: a. T10, DJF. b.Tmean, DJF. c. HDD, DJF. d. Effect of NPO and ENSO on HDD. e. Probability of "cold days" and "strings of cold days" in DJF; statistically based definitions of "strings" and "cold."

3. Winter precipitation: a. Pmean, October-March. b. Effect of NPO and ENSO on Pmean; spatial and temporal patterns of variability.

4. Conditional Probabilities: a. Joint summer high temperatures between Burbank and San Jose (over 95F in both places). Effects of NPO and ENSO on this. b. "Critical scenarios": dry winter in the PNW (and/or cold winter in CA), followed by hot summer, followed by cold winter. Effects of NPO and ENSO on this.

• Forecast contingency tables (proportion in each tercile category) will also be provided for (a) SST₀ vs. forecast variable, and (b) SST_t vs. SST₀ (lead time = t).

Summary: 80% done. We have iterated on the CalISO delta breeze scenario and on the SDG&E tariff day scenario to come to a product that is both useful for the stakeholder and possible to forecast (from a climate sciences point of view). The PacifiCorp scenario remains to be addressed.

Task 7. Evaluate the skill of the climate forecasts

Work accomplished during Q3:

• For the CalISO ensemble forecasting scenario, we have been constructing multimodel ensembles (AVN, ETA, NGM, ...) also using the NCEP ensemble statistics; combining all sources of information available, concentrating on short range. After considering each model individually and various methods for combining them, we focused on two probability models: one based exclusively on AVN products, the other containing all models (even at day one). Obviously the NCEP IC ensembles contribute more at later lead times, but they appear to contribute (just barely significantly) even on shortest time scales. Note also the we use both AVN and AVN-mos in union (this seems to imply that there is information not extracted by the current mos, the same is true for NCEP ensembles. to avoid over fitting we use drop-some-out cross validation (building about 80 versions of the same model using different pieces of the data set), this effect appears robust. Ourmajor concern in terms of deployment of only of these model analysis is the fact the the properties of the models (and the MOSs) can change significantly between consecutive summers. i have aimed for careful cross validation within 2003, but cross validation within a summer cannot account for this effect. We are now contrasting summer 2003 inferences with summer 2002 data to produce some consistency checking.

- For the CalISO delta breeze project, an extensive evaluation of the newly constructed MOS corrector, and the confidence forecast for the delta breeze, has been performend. As above, our main limitation is the short data set available for this work, being only 2 years. However, it is at least demonstrable that the techniques work for both years in the record.For the SDG&E tariff day project, a complete perfect prediction study has been finished, which details the expected skill using various tariff day selection techniques. The period of evaluation was 1990-2003. Additionally, the "super simple" tariff day selection scheme was evaluated over the same time period.
- For every experiment described in the point 3), *task 5*, Q3, and those developed during Q2 with extreme events (summer T90 and winter T10), cross validation was done between the observed and predicted values for all the stations. The information was summarized in correlation maps. The statistical models used showed prediction capability during summer and winter for the different temperature variables used. The maximum average skill for every experiment was used to determine the best lead time for the prediction of the different temperature variables in California. As it is expected, in general the skill values tend to decrease as the time lag increases between the predictors and the predictands.
- Contingency analysis between the observed values and the predicted ones was calculated for the stations representative of the different California climate zones. For summer the analyses were done for the results of the CCA models that used May-SST as predictors and JJA-Tmean and T90 as predictans. For winter were done for the models that used Nov-SST as predictors and DJF-Tmean and T10 as predictans. The significance levels for all the contingency tables were calculated using Monte Carlo (Pierce, per. com.). The advantage of using this kind of approach is that non linear relationship is supposed a-priori and allows to identify significant relationships for some scenarios (e.g. Below Normal) even if other ones don't have significant skills (e.g. Above Normal).
- Similar analyses of point 3), *task* 7, were done but for the nearest 10 stations of those representative of the California climate zones. This step compared the model's results for single points and area averages.

Work accomplished during Q2:

• The evaluation of the forecasting skill for the CEC products is in the preliminary phase and has been done using cross validation. Some of the tools used are skill maps and contingency analysis for the different "climate zones".

Summary: 80% done. The skill of the MOS corrector and sub-daily forecasts of delta breeze have been evaluated, as have the skills of the multi-model ensembles for the CalISO ensemble forecasting project. A perfect prediction evaluation has been done for the tariff day project, and the skill of the super-simple scheme as been quantified. The skill of the PacifiCorp scenario remains to be completed.

Objective 2. Quantify the economic benefit of weather and climate forecasts

Task 1. Identify key weather/energy "scenarios"

Work accomplished during Q3:

Met several times with SDG&E to pin down the details of a seasonal timescale scenario that could be accommodated within this project. Unfortunately, despite the active support and interest of the SDG&E manager, we could not find a scenario that would fit our requirements: 1) economically valuable to SDG&E; 2) have a value that can be estimated; 3) be based on a skillful climate forecast. As a result, the seasonal SDG&E scenario had to be dropped. The main problems were a) SDG&E did not have set procedures in place to incorporate seasonal climate predictions, with the result that there were no clearly identifiable, and economically evaluatable, decisions made using such data; b) in cases where specific, identifiable decisions could be identified (such as capital improvement projects) the desired lead time of >1 year is longer than current climate forecasts can give useful skill.

Work accomplished during Q2:

• Finished selecting the key weather energy scenarios. In brief, the five scenarios are as follows. 1) Cal-ISO delta breeze project. Purpose: evaluate predicatibility of the delta breeze that influences electricity loads in the California central valley. Target timescale: 1 to 3 days. 2) Cal-ISO ensemble forecasting. Purpose: evaluate the benefit of using new ensemble weather forecasts, rather than the current practice of using a single forecast, to Cal-ISO's load forecast. Target timescale: 1-7 days. 3) SDG&E tariff day scheduling. Purpose: characterize the predictable effect of temperatures on scheduling load-demand management ("tariff") days scheduled by SDG&E. Target timescale: 3-5 days. 4) SDG&E seasonal resource management. Purpose: develop seasonal (winter and summer) temperature and precipitation outlooks for SDG&E to use in resource planning. Target timescale: 2-6 months. 5) PacifiCorp irrigation pump loads. Purpose: predict onset time of irrigation pump loads in the Northwest. Target timescale: 2-6 months.

Work accomplished during Q1:

• Identified and investigated six potential applications for the economic valuation of forecast information; three using climate forecasts and three using weather forecasts. Detailed potential applications according to decision context, forecast type and calculation, current use of forecast information, proposed types of new

forecast information, models involved, temporal scale, spatial scale, intended users, and methods for net benefits estimation.

- Key scenarios for Cal-ISO:
 - 1. Probability of worst-case scenarios for their operations (dry winter Pacific North West, followed by hot summer in California, followed by a cold winter in California)

2. Probability of hot/dry summers, two or more years in a row Summary: 100% done.

Task 2. Evaluate climate connections between California and the Pacific Northwest

Work accomplished during Q3:

- We have used the forcing data developed as part of this project to run our Variable Infiltration Capacity (VIC) model over the PNW and California regions for the period 1915-2002. Simulations were conducted in water balance mode using a daily time step. Results have been obtained for streamflows at 23 locations (Figure 1) in California and 16 over the PNW. This allows for comparison of the VIC simulations and naturalized observed streamflows, for the periods 1921-1994 for the San Joaquin-Sacramento and 1915-1997 for the Columbia.
- We have developed techniques to correct streamflow simulations for model bias prior to using them as drivers for our Columbia River and California reservoir simulation models (see Hamlet and Lettenmaier 1999). These methods have been applied to all locations used in our ColSim reservoir simulation model of the Columbia basin (Hamlet and Lettenmaier, 1999), and similarly at all locations over California in use in CVmod, the Central Valley reservoir model developed by the Alphaus group at the University of Washington (Van Rheenen et al, 2004). The bias correction of daily streamflows is based on the full period when naturalized observed streamflows are available, i.e. from 1921-1994 for the San Joaquin-Sacramento and 1915-1997 for the Columbia.
- Two 86 year VIC simulations have been performed over the California and the Columbia River Basin for the October 1915 to September 2002 period. Prior to running the routed streamflow through the reservoir model, we performed a bias correction, as the reservoir models tend to be sensitive to small differences in streamflow. The simulation of hydropower generation is sensitive to the accuracy of streamflow. Two hydropower generation simulations have been performed with and without the bias corrected streamflows in California. As an average over the full period (1917-2002), the CVmod simulation with uncorrected streamflows outputs a yearly total hydropower generation that is 4% larger than with the simulation driven by bias corrected streamflow, but it is 10% larger 18 times over the 86 year simulation and reaches 17% in 1977.

• Results suggest that in addition to the ENSO pattern, a broader pattern exists when there might be years when the whole Western US is either wet or dry. Similar analyses have been performed on streamflows, and on annual and seasonal scales.

Work accomplished during Q2:

- We have completed updating our retrospective hydrologic forcing data set (consisting of daily precipitation, temperature maxima/minima, and various derived variables like solar and downward longwave radiation), as well as hydrologic derived variables (daily runoff, soil moisture, snow water equivalent, and various other variables) over the Pacific North West (PNW) and California for the period 1915-1997 (extension to 2003 in progress) using our Variable Infiltration Capacity (VIC) model. At this point our runs have used daily time step in what we term water balance mode (no iteration on surface temperature to close the surface water balance). We have routed the model-derived runoff to produce simulated daily streamflow at 15 locations in California and 16 in the PNW. We have compared the VIC simulations and naturalized observed stream flows, for the periods 1921-1994 for the Sacramento-San Joaquin basin and 1915-1997 for the Columbia.
- We have developed and implemented techniques to correcting streamflow simulations for model bias prior to using them as drivers for our Columbia River and California reservoir simulation modes. Although the biases are modest (the model predicts slightly too much runoff in spring), these biases can be important for prediction of hydropower production. The bias correction methods, which are based on distribution mapping methods, have been applied to all locations used in our ColSim reservoir simulation model of the Columbia basin, and similarly at all locations over California in use in CVmod, the Central Valley reservoir model. CVmod and ColSim both operate at a monthly time step, to which the VIC daily simulated values are aggregated. Both represent the physical properties of the water resources systems and their performance under current operational policies. The bias correction is based on entire period for which naturalized observed streamflows are available, i.e. from 1921-1994 for the San Joaquin-Sacramento and 1915-1997 for the Columbia.
- As a first step an assessing the covariability of the energy production and the energy demand between California and the Columbia, two preliminary 43 year CVmod runs (1952-1994) have been performed. The simulation period is currently limited by water demand data, which are available only for the period 1951-1994, although we intend to implement assumptions that will allow us to simulated power generation for the entire period for which model-simulated streamflow data can be derived at the two sites. The current demand scenario is based on water rights, level of hydrologic development, streamflows, temperatures, precipitation, and carryover storage. Similarly, the demand scenario in COLSIM will have to be extended in the Columbia River Basin; COLSIM is driven by flood control and power demand, with an interannual power demand that is relatively constant.

Work accomplished during Q1:

During the reporting period our work has focused on extension of our 50-year retrospective derived hydrologic data set for the continental U.S., originally for the period 1950-2000 (Maurer et al, 2002) back to 1916 and forward to 2002, specifically for the Pacific Northwest and California regions as defined by Maurer et al. Specifically, we have:

- Gridded NCDC Cooperative Observer data which as now available from the beginning of the period of historic record through 1950. NCDC has just completed a major project which has converted the pre-1950 data to electronic form. We have used procedures described in Maurer et al to create the gridded forcing data sets for the PNW and California at the same 1/8 degree spatial resolution used by Maurer et al. We use the Maurer et al procedures that adjust the gridded data for orographic effects based on the PRISM approach developed by Daly and colleagues at Oregon State University. We have developed a technique, too be reported in a paper in process, to adjust the gridded data to reflect long-term trends that are present in the carefully quality controlled Hydroclimatic Network (HCN) and a similar network for the Canadian portion of the PNW region.
- We have used the forcing data developed as reported above to run our Variable Infiltration Capacity (VIC) model over the PNW and California regions for the period 1915-1997 at daily time step in water balance mode as a test of the driving data. Water balance mode essentially assumes that surface skin and air temperatures are equal, and hence ground heat flux is zero, assumptions that are relaxed in energy balance mode to be run later (at subdaily time step). Preliminary results have been obtained for stream flow at two locations, comparing the VIC simulations and naturalized observed stream flows, for the periods 1921 – 1994 for the San Joaquin-Sacramento and 1915-1997 for the Columbia.
- We have developed techniques to correcting stream flow simulations for model bias prior to using them as drivers for our Columbia River and California reservoir simulation modes. These methods have been applied to all locations used in our ColSim reservoir simulation model of the Columbia basin, and similar work for California is in progress.

Summary: 90% done. For the remainder of the project, we will further analyze the covariability between California and the Pacific Northwest. We will also develop a simple model that simulates the total monthly electricity demand as a function of daily temperature for different regions in the Pacific Northwest and in California. The methodology will be to subtract the energy demand from the available energy (hydroelectricity and conventional resources) and deduce the surplus of energy that could potentially be transferred between California and the Pacific Northwest. We will then perform an investigation of extra hydropower forecasting potential based on ENSO and PDO indicators.

Task 3. Calculate the economic effect of various strategies used during the scenarios

Work accomplished during Q3:

- Using the cost curves generated by the CalISO stakeholder (Dennis Gaushell), we have completed an analysis of the economic costs of the delta breeze and the benefits of using forecast information to CalISO's weather-generated errors. Bottom line, weather forecast errors cost CalISO approximately \$X /year. Combining the cost curves with the forecast model error curves allowed us to calculate the contribution of various weather forecast errors to total cost. Interestingly, mildly over-forecast days contribute more total cost to the CalISO than severely under-forecast days, as the far greater number of the former more than compensate for the significantly greater costs of the latter. Additionally, this methodology allows us to estimate the cost savings from any improvement in weather forecasts of the delta breeze phenomenon.
- The multi-model ensemble forecasting approach was developed in such a way as to ultimately be able to identify how to best use the forecast information for minimizing costs to CalISO. It was found that, on average, the 55th percentile isopleth of the forecast probability was optimal for minimizing weather-related costs. It is not the median (50th percentile) because of the non-symmetry of the cost curve (underforecast days cost the CalIso more than overforecast days). The economic benefit of using the optimal isopleth from the optimal combination of models was in the range of X dollars per year.
- The economic valuation of the SDG&E tariff day scheduling scenario has been completed. There are two parts to this valuation. The first part concerns the avoided cost of building peaker generation plants, given that selecting tariff days reduces peak demand over the summer. In this context, the forecasting of tariff days by climate sciences is a preliminary first step to the ultimate goal of having real-time electricity meters in consumers' homes that would transmit real-time electricity pricing data. Real-time meters, if and when they achieve full market penetration, have the potential to truly truncate peaks in electricity demand. Climate forecasts do not have this potential, as 1) they are not 100% skillful, and 2) PUC regulations prevent the actual peak days from being called as tariff days anyway (i.e., hot days tend to run in spells, but PUC regulations only allow 2 events to be called in a week). Notwithstanding, the value of avoided peaker plant generation is \$X/MW, according to our stakeholder in this scenario (SDG&E). Therefore, the ultimate benefit realizable by full market penetration of real-time meters is about \$X/year in the SDG&E service region, assuming that peaks are truncated by 5% (SDG&E's goal). This is an upper limit to the benefit of the climate forecasting effort for the reasons noted above. There is also a lower limit of the benefit of the climate effort, consisting of the avoided cost of energy purchased on the hot summer days called as tariff days by the climate forecast. We have calculated this to be on the order of \$X/year.

Work accomplished during Q2:

• At our request, the CalISO stakeholder has done a very useful preliminary analysis of the costs involved with over- or under-forecasting the daily temperature maximum in the central valley. This data will be crucial for evaluating the economic benefit of weather forecasts in the California delta breeze project and in the ensemble forecasting project.

Work accomplished during Q1:

• We have gathered and analyzed data that will be critical to the economic evaluation, including statewide prices for gas and electricity supplies, by sector, retail/wholesale, and the total expenditures on energy according to type, sectors, and year. We also obtained cost data from CERS/DWR on energy purchases for the State's long-term power contracts, and for the State Water Project.

Summary: 80% done. The economic valuation has been performed for the CalISO delta breeze and ensemble scenarios, and for the SDG&E tariff day scenario. It remains to be done for the PacifiCorp seasonal prediction scenario.

Task 4. Evaluate the sensitivity of the business forecast to the weather forecast

Work accomplished during Q3:

- Met again with SDG&E to further understand how the seasonal climate forecasts actually affect their workflow. The main difference that the forecasts made to the operations manager we are dealing with is to add surety in her mind that the number of work crews she has hired for the season is appropriate to the expected number of outages. Other business decisions she quoted as potentially being affected by such forecasts are: 1) Timing of capital improvement projects; if she knew the next summer was not going to be especially hot, she would postpone construction intended to address the peak summer gaps. 2) Retention of line repair crews in winter; if she knew that the upcoming winter was likely to have more or less than the usual number of wind storms, she could adjust the number of repair crews accordingly.
- Estimated economic impact of a 24/7 (year-round) temperature increase in California, for example, as expected from a climate chance scenario. For June-September electricity demand, using the estimates (provided by PG&E) of 550-600 average MW per degree F (for the entire state), 8,000 Btu per kWhr (for supplies on the margin), and an average electricity retail rate of \$0.13/kWhr, the cost of a 1-degree C (1.8-degree F) rise in temperature for the summer months (June-Sept) would be between \$373 million and \$407 million per year.

Work accomplished during Q2:

• Met with SDG&E to query them on what decisions they would have made differently given knowledge of the seasonal temperature and precipitation beforehand. This is a kind of "perfect prediction" scenario, and so represents only an upper bound to the changes in action that could be accomplished with accurate climate forecasts, but nevertheless will serve to frame the issues.

Summary: 70% done. Work remains on the tariff day scenario, and also the PacifiCorp irrigation pump scenario.

Task 5. Evaluate the economic benefits of the weather-enhanced business forecasts Work accomplished during Q3:

- Did a fairly extensive analysis of the economic implications of the tariff day scenario (i.e., the SDG&E load-demand management scenario). A perfect forecast based on known loads could clip, on average, X% of the load experienced on the average summer day (with yearly values ranging from X% to X% over the analyzed period of 1990-2003). Adding in the PUC's constraints of no more than 2 events/week and 5/month gives an average of X% (range: X% to X%). If temperature is used instead of load, the average is X% (range: X% to X%). The super simple prediction scheme we devised averages X% (range: X% to X%). By comparison, the stakeholder's picks in 2003 were X% greater than the average summer day. Using a cost of \$X/MW for peaker plants, the maximum benefit attainable is about \$X/year to SDG&E. Given that forecasts based on temperature are not perfect, and that the PUC rules make it impossible to achieve 100% efficiency, this entire value will not be attained using climate forecasts. Note that a minimum attainable value is the cost of avoided electricity, which is about \$X/yr with the super simple scheme.
- Evaluated the ensemble of forecasts to identify the most cost-effective operating regime for CallSO given the known spread and skill of the various forecasts. Showed that the cost-minimizing forecast is determinable, and somewhat higher than the actual forecast for the day. Demonstrated that the ensemble spread contains information that can be used to weight the guardband put on the anticipated temperature for the upcoming day. The cost savings expected from this approach is on the order of \$X/yr.

Work accomplished during Q2:

• Did analysis similar to that described below (which examined the NPO), but for the California delta breeze. Based on CalISO's load figures, the delta breeze can make typically make a difference in peak load on the order of X MW or so. "Big" breeze days can be twice this. The direct cost of this change in electricity is fairly modest, on the order of \$X per event. The indirect costs are likely higher, and are associated with false positives; i.e., days when a delta breeze was forecast but one did not actually develop. In such event, the electricity load can be significantly higher than anticipated, possibly resulting in price spikes or realiability issues.

Work accomplished during Q1:

• Evaluated economic impact of weather and climate fluctuations on energy consumption in California, using CEC analyses and data. Quantified changes in electricity and gas consumption due to temperature variations, given CEC assumptions about load distributions and marginal demand, and available data. Estimates of economic impact ranged from \$0.6 to \$1 billion per year for gas and electricity combined. Concern about assumptions and lack of data. Used alternative approaches (e.g., the Sailor and Munoz equation; Dave's regression analyses) to calculate economic impact. Estimates ranged from \$0.22 to \$0.55 billion for changes in natural gas consumption due to NPO phase.

Summary: 80% done. The economic implications of the delta breeze scenario, the ensemble prediction scenario, and the tariff day scenario are done. The PacifiCorp (irrigation pump load) scenario remains.

Task 6. Complete draft and final report

Summary: 60% done. As the final report will contain information from the quarterly reports, the information herein represents a good start to this task.

Task 7. Complete project workshop

Work accomplished during Q2:

• We discussed this idea with the CalISO stakeholder. Various ways this could be accomplished were considered, along with the appropriate format and audience.

Summary: 10% done. It is not clear when we should schedule the workshop, given the change in dates associated with the no cost extension to the project.

Date of report: 19 May 2004