CONTENTS

1. Introduction

This is the progress report for the first year (4/1/02-3/31/03) of the Center for Science in the Earth System (CSES) and Budget Request for the second year (4/1/03-3/31/03) of the five year CSES project.

According to its Charter "The CSES researches the impacts of climate on the Pacific Northwest in as integrated a sense as possible. It does this by combining and integrating expertise in climate dynamics, ecological dynamics, hydrologic dynamics and institutional and policy analysis, all concentrated on climate variability and change in the Pacific Northwest. The CSES also researches the methodologies for accomplishing the above. It also researches the applications of climate information by servicing stakeholders in the Pacific Northwest in support of the regional aspects of an eventual Climate Service. Since its prime mission is research, it cannot and does not provide services on a regular and systematic basis".

The report is organized in the same way as the Proposal so that what was promised and what is being delivered can be directly compared.

2. Climate Variability

- **Daily PNA Indices and Extreme Events** (Brown, Battisti, Mantua)

Based on work of Thomson and Wallace on the daily values of the AO and its climatic implications, especially for extreme events, Craig Brown completed a Master's thesis (Brown, 2003) on the daily values of the PNA Pattern and its implications for extreme events in the nodes of the PNA pattern, in particular the Pacific Northwest and the Southeast.

It was found that:

When the winter daily value of PNA was more than one standard deviation positive, (i.e. Aleutian low deeper)

- There were more heavy precipitation events along the Southeastern Alaska coast
- It never snowed in the Pacific Northwest
- The number of snowfall events for the snow belt regions of the Great Lakes increased
- The probability of freeze events in the southeastern US increased.

When the winter daily value of PNA was more than one standard deviation negative,

- Precipitation events increased in Hawaii
- Extreme precipitation increased in the Pacific Northwest
- Snowfall events became more frequent and more severe in Seattle
- Low temperature extreme events increased along the entire west coast of the US.

The value of these correlations is that the PNA is predictable as much as a week in advance (its autocorrelation time is of order a week). Skillful predictions are routinely made a week in advance (http://www.cdc.noaa.gov/~gtb/tele/pna.gif) so that some information for extreme event risk assessment becomes possible.

- **The PDO in The CSIRO Coupled Model**

The PDO has been thoroughly investigated in one coupled climate model: the Australian CSIRO model (Vimont, Battisti and Hirst, 2002). Both ENSO and the PDO lack a spectral peak and the general conclusion is that, although each is prominent in the model climate record, they are both forced by stochastic forcing by the atmosphere. The relationship between the PDO and ENSO is complex and can be expressed by the "seasonal footprinting" mechanism wherein stochastic forcing by the atmosphere in mid-latitudes imprints itself on the tropical ocean in winter, the imprint lasts till summer and the summer imprint affects the rainfall and subsequent evolution of ENSO into the next winter(Vimont, Hirst, and Battisti, 2003). In particular, this communication through the atmospheric bridge affects ENSO and symmetrizes the PDO about the equator. This mechanism has been verified in the observations (Vimont, Wallace, and Battisti, 2003) and forms the substance of a thesis by Vimont, 2002.

- **Extreme Events in the Pacific Northwest** (Mitchell, Wallace, and Shabbar)

A collaborative study with Dr. Amir Shabbar of Environment Canada is documenting the occurrence of extreme daily temperature, precipitation, and wind events in the Alaska, western Canada, and the Pacific Northwest. This study builds on the work of Brown and Mantua by analyzing a much larger number of stations to document the strong effect that topography plays in extreme weather of this region.

A key part of the preceding study is the development of regional data sets of high-spatial resolution daily, 5-day, and monthly average statistics of weather variables.

- **Aquaplanet Climate Model for Global** Warming (Li and Battisti)

In recent years, there has been much effort devoted to predicting the response of the climate system to external forcings such as global warming and ozone depletion. Of particular interest are the deep, zonally-symmetric modes of variability, represented in the zonal-mean wind field by a meridional shift of the jet, that dominate the extratropical atmosphere. These "annular" modes are free modes of variability arising from internal interactions between the mean flow and the eddies embedded therein, and hence may exhibit a relatively dramatic response to modest external forcing.

Observed trends in these modes over the past 30 years are seemingly larger than the natural background variability, and have been linked to warming in regions such as northern Eurasia, Alaska and western Canada (1). The causes of these trends are uncertain although there are a number of candidates. Modeling studies suggest that an overall warming of the ocean

surface alone tends to drive the annular modes toward a high-index state (2). A similar outcome results from radiative forcing through anthropogenic increases in greenhouse gases and aerosols (3). The stratosphere has also been fingered as an important factor due to the strong dynamical linkages that allow forcing from ozone depletion and volcanic eruptions to influence the troposphere (4). To date, determining the relative importance of the various mechanisms and establishing the feedbacks that exist between them remain open research issues.

In this context, we are currently running a series of idealised experiments using the NCAR CCM3.6 to investigate the effects of increased greenhouse gases on the atmospheric circulation of a land-free aquaplanet model with a slab ocean. We plan to investigate the adequacy of the model's stratospheric resolution in representing the dynamical linkage discussed above and the factors that control the strength and position of the storm tracks and jets. Through such experiments, we hope to gain an improved dynamical understanding of the climate system's response to global warming. The insight gained by studying this idealised situation may then be applied to tackle more realistic scenarios in which zonal asymmetries and stationary waves caused by land-sea heating contrasts and orography are considered.

- **Coupled Climate Model for Global Warming** (Kamenkovich)

We describe a coupled climate model of intermediate complexity that has a two-dimensional (zonally-averaged) statistical-dynamical model that includes full representation of the hydrological and momentum cycles; and a coarse resolution ocean GCM with simplified global geometry (Kamenkovich, Sokolov, and Stone, 2002).

i) Long-term present-day climate simulations are carried out with and without flux adjustments. Deep ocean temperatures systematically decrease in the runs without flux adjustment. We demonstrate that the mismatch between heat transports in the uncoupled states of two models is the main cause for this systematic drift.

ii) To evaluate the model's response to transient external forcing global warming simulations are also carried out with the flux-adjusted version of the coupled model. The coupled model reproduces reasonably well the behavior of more sophisticated coupled GCMs for both current climate and for the global warming scenarios.

This model is then used to simulate the response of the thermohaline circulation to increasing CO_2 concentration in the atmosphere (Kamenkovich, Sokolov, and Stone, 2003). The relative roles of different factors in the slowing down and recovery of the thermohaline circulation were studied by performing simulations with ocean only and partially coupled models.

i) The evolution of the atmosphere-to-ocean surface heat fluxes is shown to be the dominant factor in causing the weakening of the circulation in response to an increasing external forcing as well as in controlling the subsequent recovery.

ii) The feedback between heat flux and the sea surface temperature is necessary for the ocean circulation to recover.

iii) The rate of the recovery, however, is not sensitive to the magnitude of the feedback, and changes in the atmosphere, while contributing to the recovery, play a secondary role.

iv) Subsurface changes in the density structure accompany recovery despite nearly fixed SST in one of the uncoupled experiments.

v) The secondary role of the moisture fluxes is explained by a smaller magnitude of their contribution to the surface buoyancy flux. Imposing amplified changes in the moisture fluxes leads to a significant slow down of the circulation, accompanied, however, by changes in the heat flux.

- **Ocean Thermohaline Circulation Processes** (Kamenkovich, Sarachik)

The deep-ocean heat uptake (DOHU) in transient climate changes is studied using an ocean general circulation model and its adjoint (Huang, Stone, Sokolov, and Kamenkovich, 2003). The model is forced with the anomalies of surface heat and freshwater fluxes from a global warming scenario with a coupled model using the same ocean configuration.

i) After 70 years, the ocean heat uptake is almost evenly distributed within the layers above 200m, 200m-700m, and below 700m.

ii) The effect of anomalous surface fresh water flux on DOHU is negligible.

iii) The penetration of surface heat to the deep layers occurs mainly in the North Atlantic and Southern Ocean.

iv) The DOHU relies on the reduction of convection and eddy mixing.

In another study (Kamenkovich, and Sarachik, 2003a) we identify an important dynamical mechanism that explains strong sensitivity of the Atlantic thermohaline circulation in numerical models to parameterization of the heat and salt transports by mesoscale eddies. In order to analyze the dynamical reasons for the differences between the control runs, we carry out a number of numerical experiments with regionally varying diffusion coefficients emphasizing the effects of different schemes in key regions. We demonstrate that:

i) The eddies in the Southern Ocean strongly influence the meridional density structure in the Atlantic and therefore effectively control the rate of formation of North Atlantic Deep Water (NADW) by affecting density of the intermediate water that enters the Atlantic from the south.

ii) The eddy transports in the western boundary current in the Northern Hemisphere also influence density and horizontal flow structure at the low and mid latitudes. These processes,

however, are complex and the combined effect of the Northern Hemisphere eddy transports on the strength of the NADW formation is limited in our model.

iii) The Northern Hemisphere upwelling is controlled by the local eddy transports, and the outflow of the NADW is very sensitive to the Northern Hemisphere eddy transports as a result.

iv) The eddy transports also affect the properties of the Antarctic Bottom Water, which influences the vertical penetration of the NADW overturning cell as well as the density of the deep ocean.

Finally, in a technical study, (Kamenkovich, and Sarachik, 2003b) we introduce a simple but effective method of modifying conventional restoring boundary conditions designed to keep the calculated values of surface temperature and salinity as close to observations as possible. The technique involves changing the target fields in the restoring boundary conditions iteratively.

i) The method implicitly accounts for oceanic processes, such as advection and eddy mixing in the derivation of the new boundary conditions.

ii) The simplicity of the method is particularly attractive in idealized studies, which often employ restoring surface boundary conditions.

iii) The success of the new method is, however, limited by several factors, which cannot be easily compensated by the adjustment of the target profiles: inaccurate model dynamics, errors in the observations, and simplified form of restoring surface boundary conditions themselves.

iv) The application of the method in our study with a coarse resolution model leads to significant improvements of the simulation of sea surface temperature and sea surface salinity.

v) The subsurface values of temperature also improve significantly, proving that a large part errors in the subsurface temperature distribution can be corrected by reducing errors at the surface.

- **Paleo Records of PDO** (Gedalof, Mantua, Peterson)

We identified the covariability in 5 previously published PDO reconstructions based on annually resolved proxies (tree-rings and corals) to develop a "consensus" paleo-record back to 1840. A comparison of these records suggests that the spatial pattern of the PDO may have been relatively unimportant for Pacific and western American climate in the mid-to-late 1800's (Gedalof et al, 2002)

- **ENSO and the Arctic Oscillation** (Wallace)

The structure of the Northern Hemisphere annular mode (NAM) is shown to be significantly different during warm and cold winters of the ENSO cycle (Quadrelli and Wallace, 2002) During warm winters the Arctic center of action of the annular mode is more prominent

and extends deeper into Siberia, its related surface air temperature signal is stronger, and the compensating outer ring in the sea-level pressure field is much broader, encompassing the entire tropics. During cold winters the NAM signature is much more pronounced over the Pacific sector: the sea-level pressure pattern exhibits a North Pacific center of action, positively correlated with the Atlantic center, and pronounced deflections of the storm track are also evident. It is suggested that the former features are associated with the equatorward displacement of the jet stream and the storm tracks during warm winters of the ENSO cycle and the latter is related to the more pronounced break in the subtropical jet stream over the Pacific sector during cold winters.

- **ENSO, AO, and Weather over US** (Bond, Harrison, and Vecchi)

The atmospheric circulation and US weather anomalies during the winter of 2002-03 are shown to be similar to those during previous winters when there was both El Nino and negative Arctic Oscillation (AO) index. When both climate factors are present, the anomalous middle tropospheric flow over North American features a ridge in the west and a trough in the east, which tends to bring colder than normal temperatures to the eastern U.S. The joint effect of these factors is different than would be expected from them individually. (Bond and Harrison, 2003).

We have also preliminary results indicating a surprisingly strong relationship between anomalously warm Alaska winter weekly temperatures and particular phases of the MJO. These results are being examined further and will be prepared for publication during 2003.

- **ENSO Indices** (Mitchell and Wallace)

We are studying, the historical record of Darwin Australia and Tahiti sea-level pressure (SLP), which are commonly used as indices of the El Nino / Southern Oscillation (ENSO). Darwin pressure has exhibited a significant upward trend in the 20th century, which has been interpreted as indicative of enhanced and more frequent warm ENSO episodes, possibly due to Greenhouse warming. Our calculations show, however, that Tahiti SLP exhibits a negligible trend over the same period, such that the trend in the Southern Oscillation Index (normalized Tahiti minus normalized Darwin SLP anomalies) is only 60% as large as the trend in Darwin itself.

- **Orographic Precipitation** (Smull)

Work during the past year have focused on combined observational and numerical studies of orographic precipitation processes of importance to regional climate and severe weather in mountainous regions (including but not limited to the Pacific Northwest) and associated technical advances in processing of large observational datasets over regions of complex terrain (Bousquet and smull, 2003a,b: Steiner et al, 2003).

We have been working to engineer major advances in the processing of remotely sensed three-dimensional wind and precipitation reflectivity fields from NOAA's airborne (P-3) research

platforms and to exploit these data to describe not only direct but remote (i.e. upstream) influences of orography upon airflow and ensuing precipitation processes adjacent to the Swiss Alps.

Smull is Co-PI (with Prof. Robert Houze) of a new three-year/830k NSF-sponsored effort entitled "Orographic Enhancement of Precipitation in Midlatitude Baroclinic Waves" that is exploiting an extensive dataset on orographic precipitation processes collected over the Oregon Cascades during November-December 2001. This work, which commenced in September 2002 under the auspices of the IMPROVE project (http://improve.atmos.washington.edu/) is designed to provide unique four-dimensional observational validation of simulated mesoscale wind and precipitation fields over a relatively two-dimensional orographic barrier during the passage of baroclinically-modulated flows.

3. Predictability and Prediction Research

- **Markov Modeling** (Roberts and Battisti)

We analyse the principal oscillation patterns (POPs) of various empirical linear models of the tropical pacific sea surface temperature (SST) using different datasets and different spatial domains and periods within the datasets. The period of the mode most closely resembling ENSO is fairly constant, at around 45 months, for all models, but the decay time of the mode varies significantly. We find that in the COADS the decay time of the ENSO mode is dependent upon the time segment of the dataset we use but pretty much insensitive to the spatial domain used. Models derived from later in the COADS record have a longer decay time than those from earlier. Thus the ENSO mode of Penland and Sardeshmukh (1995), which uses COADS SST from 1950-1990, has a shorter decay time than does that of Johnson, Battisti and Sarachik (2000), which uses the period 1965-1993. Using NOAA/NCEP Optimally Interpolated (OI) SST data from 1981-2002 gives yet longer decay times despite the shorter length of the data record. We find that the skill of cross validated forecasts is enhanced for longer decay times so the best forecast model is made using the OI data. The inclusion of subsurface data in the model is not found to lengthen the decay time of the mode.

Using different spatial domains of SST to derive the empirical models demonstrates that the optimal forecast of SST is made if we use a domain of the tropical Pacific and Atlantic oceans. Adding the Atlantic increases the skill at long lead times. For the OI data, cross validated correlations between the forecast and observed Niño 3 index exceed .6 until 13 months whereas for a pacific only domain the correlation falls below .6 at 11 months. Similar increased skill is also seen in normalized root mean squared error. Preliminary modeling studies suggest that this may be due to a cooling (warming) in the Atlantic forcing a warming (cooling) in the eastern pacific and thus acting as a stochastic forcing of ENSO.

The resulting prediction system can be viewed at
http://www.atmos.washington.edu/~wroberts/ENSO/LIM.html

- **Optimizing the ENSO Observing System** (Battisti)

A detailed series of predictions, using a simplified linear prediction and assimilation model (which has proved to be reasonably accurate), in which the TAO array is moved, added to, and thinned, has been conducted in order to understand what is the most cost effective observing array that still gives reasonable ENSO predictive skill. Generally it was found that a thinner array in the tropics but observations extended to higher latitudes is optimal (Morss and Battisti).

4. Downscaling Research and Interfaces

- **Downscaling** (Miles and Salathé)

This component was done was part of CDEP flexible funding.

In the first year of this project, we have concentrated on verification and development of tools for downscaling in the Pacific Northwest: Two statistical methods have been developed within the Climate Impacts Group (Widmann et al, Wood et al), and we are evaluating these against each other and against a regional climate model (RCM, Leung and Ghan, 1998). These statistical methods are being used to downscaling a suite of climate-change scenarios for application to hydrologic studies. We are beginning work on implementing a high-resolution mesoscale weather model, MM5, for climate studies.

1. Comparison of Statistical Methods and RCM

Statistical methods are efficient and currently the most practical tool for downscaling long time series and many climate scenarios. There is the possibility, however, that certain processes are not correctly accounted for. A mesoscale model, since it is physically based, may capture essential weather or climate processes that influence the impacts of climate in hydrologic or other modeling applications. In order to assess the merits of mesoscale models relative to statistical methods, we are collaborating with the "Experimental West-wide Ensemble Hydrologic Prediction System" project headed by Dennis Lettenmaier. This study makes a systematic comparison among two statistical methods and a regional climate model.

We are using these three methods to downscale the NCEP reanalyses in order to reduce uncertainties from a free-running GCM and to ground the results to observations. Two statistical methods are used, the "dynamical scaling" of Widmann, Bretherton, and Salathé (2003), developed for the Climate Impacts Group, and the "bias correction" of Wood et al. (2002), which is the basis of the west-wide hydrologic prediction system. These are compared against dynamical downscaling using the Regional Climate Model (RCM, Leung and Ghan, 1998). An example of monthly-mean precipitation for January 1990 simulated by RCM, downscaled from the NCEP reanalysis, and gridded observations are shown in Figure 1. Since the RCM is a fairly coarse-resolution model (80-km), in order to fairly compare with the statistical methods, output from RCM will be processed according to the same statistical methods. The essential question we seek to answer is whether the RCM can detect temporal variability that is missing in the statistical methods despite their high special resolution.

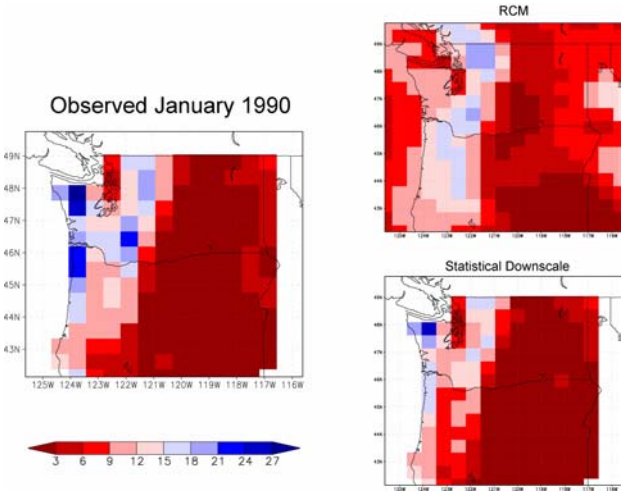

Figure 1. Comparison of observed precipitation with RCM and statistical downscaling at 50km resolution. Shown are monthly-means for January 1990.

2. Statistical Methods

We have applied statistical downscaling methods to produce high-resolution maps of temperature and precipitation from various climate change simulations in the IPCC collection of models and scenarios, and are in the process of creating an extensive database of downscaled scenarios. These results are directly applicable to studies where high spatial resolution, multiple

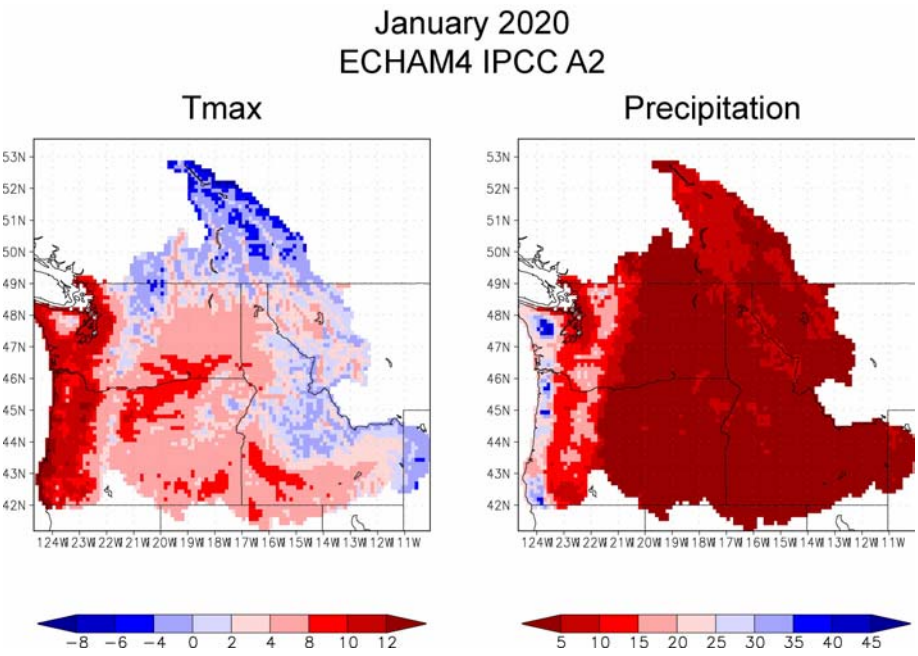

Figure 2 Downscaled Temperature and Precipitation for the ECHAM4 GCM and A2 SRES Scenario. Shown are monthly-means for January 2020.

scenarios, and a long time span are desired. Currently, we are applying these results to several water resource management studies (Seattle Public Utilities, Climate Impacts Group regional workshop). In the example in Figure 2, the ECHAM4 model is downscaled at 1/8-degree resolution over the Pacific Northwest using the method in Salathé, 2003. Daily data from 1990 to 2060, three models (ECHAM4, HADCM3, NCAR-PCM), and two IPCC scenarios (A2 and B2) have been produced with this method. The method in Wood, *et al.* has been applied to an ensemble of runs with the NCAR-PCM model.

3. MM5

The MM5 mesoscale forecast model has been extensively applied in the region for weather prediction by researchers in the Atmospheric Sciences department, and we are collaborating with that group and supporting a graduate student to undertake implementing this model for downscaling climate simulations. The model will be nested within the NCAR CSM and be run at 12-km resolution. We have already performed a number of climate-change simulations with the NCAR GCM in order to establish the best procedure and scenario for forcing the mesoscale model. A graduate student has just begun working on the project and is being trained in using mm5.

There are several research problems that we hope to address with this model:

- Mesoscale circulation effects of climate change that alter precipitation and temperature patters from what climate models indicate
- The intensity of extreme events associated with climate change
- The temperature relationship with the intensity of orographic precipitation

4. Future work

Current work has focused on developing and refining tools for climate downscaling. The statistical methods are well-proven tools and are being applied to hydrologic studies. We will be exploring further applications in ecological studies within the Climate Impacts Group. The mesoscale model technique will require up to a year of development, but should yield results of immediate importance to application studies, particularly information regarding extreme events.

5. References

Leung, L. R., and S. J. Ghan, 1998: Parameterizing subgrid orographic precipitation and land surface cover in climate models. *Mon. Wea. Rev.*, **126**, 3271-3291.

Salathé, E. P., 2002:Comparison of Various Precipitation Downscaling Methods for the Simulation of Streamflow in a Rainshadow River Basin. Accepted at *International Journal of Climatology*.

Widmann, M., C. S. Bretherton, and E. P. Salathé, 2002: Statistical precipitation downscaling over the Northwestern United States using numerically simulated precipitation as a predictor", *Journal of Climate*. **16**, 799-816
http://www.atmos.washington.edu/~salathe/papers/downscale/

Westrick, K. J., P. Storck, and C. F. Mass, 2002, Description and evaluation of a hydrometeorological forecast system for mountainous watersheds. *Weather and Forecasting,* **17,** 250–262.

Wood, A.W., Maurer, E.P., Kumar, A. and D.P. Lettenmaier, 2002. Long range experimental hydrologic forecasting for the eastern U.S.S, in press, *Journal of Geophysical Research*.
http://www.ce.washington.edu/pub/HYDRO/aww/east_fcast/aww_jgr2002.pdf

5. Regional Impacts-Sectors

- **Pacific Climate Variability and Impacts** (Gedalov)

This dissertation (Gedalov 2002) include separate chapters focused on

1. paleo-proxy climate reconstructions of the Pacific Decadal Oscillation back to 1850
2. An EOF analysis of annual area burned in US National forests in the Pacific Northwest, and an investigation into the climate and weather patterns associated with extremely active and inactive fire years for the different regional fire patterns
3. a paleoproxy reconstruction for annual water year streamflows in the Columbia River basin back to 1750

a. Hydrology and Water Resources

- **Experimental Western U.S. Hydrologic Forecasting Systems** (Lettenmaier and Wood)

This section is a report on the CDEP flexible funding proposal.

Efforts to establish a real-time monthly to seasonal hydrologic forecasting system for the western U.S. have begun. A dry autumn of 2002 delayed snowpack formation and raised concerns about a potential Pacific Northwest drought, leading to an initial focus of build-out efforts on Columbia River basin streamflow. Our first forecast was made on December 28, 2002 (http://www.ce.washington.edu/pub/HYDRO/aww/arcs/arcs.htm) and forecasts been updated every 2 weeks since. The forecast system has evolved to include the following elements:

1) Ensemble Streamflow Prediction (ESP) method based forecasts are composited to give two additional forecasts, one based on ENSO-state and one based on ENSO-PDO state. These typically are of length 8-9 months, and statistics on April-September flow anomalies are calculated for comparison with forecasts issued monthly by the NRCS National Water and Climate Center (NWCC).

2) NCEP Global Spectral Model (GSM) based forecasts, of length 6 months, are issued for comparison with the others. A retrospective analysis comparing the skill of GSM and ESP based forecasts is nearly complete and a journal article on the results is in preparation.

3) Improvements in the estimation of initial snow state have come through the development of an assimilation of NRCS SNOTEL snow water equivalent (SWE) and Environment Canada Automatic Snow Pillow (ASP) observations at the forecast initiation date. This routine blends simulated SWE with observed SWE for over 300 stations in the Pacific Northwest Domain. In support of this operation, automated access and processing of real-time SWE observations was developed.

4) Alternatives for improving the quality of recent meteorological data (particularly during the 2 months prior to the forecast start date) are being explored. A method of applying index station anomalies at 20-30 real-time reporting stations to a climatology based on a much more comprehensive dataset is the alternative that is currently implemented.

We have also begun a retrospective comparison of our forecasts with NWCC official statistical forecasts for 30 streamflow locations. Discussions have also begun on the development of experimental forecast products which could be linked to the official NWCC web pages, in addition to other potential collaborative efforts.

- **Streamflow Forecasting Research** (Hamlet and Lettenmaier)

An extended routing network for the 1/8 degree resolution VIC model has been constructed, and bias correction software has been implemented that will permit the production of more accurate streamflow forecasts at roughly 85 locations in the Columbia basin. Explicit linkages to the well-known GENESYS model for hydropower planning (Northwest Power Planning Council) are nearing completion (see below for more details), and linkages to UW and IDWR reservoir models for the Snake will follow by early April.

Retrospective streamflow forecasts for the Columbia River basin are being produced for the period from 1950-1999 for Oct1, Nov 1, Dec 1, and Jan 1 to facilitate analysis of various sources of hydrologic predictability and error in the forecasts. Specifically, we are interested in the relative importance of hydrologic (soil moisture and snow) persistence, and climate predictability at S/I time scales. Preliminary results for the Oct 1 and Jan 1 forecasts have been presented at several conferences (Hamlet 2002c d, 2003b). A journal article covering these results is in progress and will be submitted in spring or early summer.

A paper describing this work is in process, and preliminary work was presented in posters at the Fall 2002 AGU meeting and 2003 AMS annual meeting.

- **Extend Water Management Modeling Capability to Snake River basin** (Lettenmaier and Hamlet)

Nathan Van Rheenan (PhD student in Rick Palmer's group) was funded to move the Snake modeling effort forward. Currently the surface water components of the model are

essentially complete and are undergoing testing and validation. Alan Hamlet is generating climate change streamflow scenarios (see below) to drive this model, and we are anticipating preliminary results on sensitivity to surface water changes for the April 30, 2003 climate change workshop. Work is currently underway to construct an appropriate modeling framework encompassing the complex interaction between climate, irrigation technology, aquifer recharge, and the interconnected groundwater and surface water systems. The Idaho Department of Water Resources (IDWR) has provided a groundwater model and related data bases of water application and recharge that will be used in the research. This portion of the work will be ongoing in the coming year.

Ultimately the new Snake River model will be incorporated in the ColSim model to allow an integrated investigation of the role of the Snake in the context of the entire Columbia basin. Due to other ongoing commitments this portion of the project probably will not be complete until 2004-2005, however.

- **Climate Change Streamflow Scenarios for Critical Period Planning Studies** (Hamlet and Lettenmaier)

Climate change streamflow scenarios to support two large scale planning efforts in the PNW are being constructed. Preliminary results were presented at our water resources workshops in Olympia and Boise in fall, 2002, and a more recent version is the target of our planned April 30 climate change workshop in Seattle. A web-based data distribution system has been implemented for the pilot study and will be updated periodically. Ongoing work is extending the number of scenarios available (with Eric Salathe and Andy Wood) and the length of streamflow records available.

- **Construction of Long-Term Climate Data Set for the PNW** (Hamlet and Lettenmaier)

Our gridded temperature and precipitation data set for the PNW, currently for the period 1950-2000, has been extended back to 1915 using newly digitized NCDC records for Washington, Oregon, Idaho, and Montana. The National Climatic Data Center (NCDC) has recently digitized daily temperature and precipitation records from co-op stations back to the beginning of the written records. Data for Oregon, Washington, Idaho, and Montana (with previously available records available for BC) were processed to produce a driving data set at 1/8 degree resolution for the VIC hydrologic model for the period from 1915-1999 (Park et al. 2002). An additional data set was also constructed using only high-quality HCN station records for use in trend analysis. Ongoing work will remove temporal inhomogeneities from the more spatially dense data set, facilitating analysis of long-term trends in hydrologic variables such as soil moisture, snowpack, spatially distributed runoff, and streamflow for the PNW. This data set will also benefit the streamflow forecasting effort by providing extended driving data and greater sample size.

- **Intraseasonal Variability in the Tropics and Precipitation in the PNW** (Bond and Vecchi)

The Madden-Julian Oscillation (MJO) is the primary mode of large-scale intraseasonal variability in the tropics. Previous work has explored the influences of the MJO on atmospheric circulation anomalies over the North Pacific, and precipitation in California, among other effects. The present study (Bond and Vecchi, 2003) focuses on the relationship between the MJO and mean precipitation in Oregon and Washington states, and between the MJO and the occurrence of flooding in western Washington state. The MJO is diagnosed using principal component analysis based on 850 mb zonal winds from the NCEP/NCAR Reanalysis for 1979 to 2000. The data set for precipitation is daily rain gauge data gridded on a scale of 50 km and was available for the period 1979–1994. The occurrence of flooding is based on streamflow records from the Sauk, Snoqualmie, and Chehalis Rivers for 1979–2001. The results indicate that the phase of the MJO has a substantial systematic effect on intraseasonal variability in precipitation in Oregon and Washington in both early winter (October–December) and late winter (January–March). The MJO is also associated with a statistically significant modulation of floods in early winter. The phases of the MJO that promote enhanced precipitation in the mean and increased incidence of western Washington floods are substantially different during early winter than during late winter. We suggest that this result is attributable to the difference in the atmospheric circulation of the North Pacific in early versus late winter.

- **Snow Trend Study** (Hamlet and Lettenmaier)

This project involves analysis of historic data and model output to evaluate long-term trends in snowpack, the role of climate variability and climate change. This represents an extension of the recently submitted GRL paper by Mote based on a shorter period of snow course observations. Inclusion of model output allows us to include reconstructed records of snow water equivalent that nearly double the length of the observation record and to investigate the roles of temperature and precipitation explicitly.

- **Ski Study Update** (Hamlet and Lettenmaier)

Our previous work examining the effects of climate change on the PNW ski industry are being extended to a larger number of sites throughout the PNW. A draft paper describing the earlier results is being modified to include the updated results.

- **Climate Change Outreach Program and Water Resources Screening Model** (Hamlet and Lettenmaier)

A simple water resources screening model has been built to support climate change outreach efforts by Lara Whitely Binder in partnership with the WA Dept. of Ecology watershed planning program. The model will be supported by additional work to produce snow and runoff maps for a number of small watersheds in Washington.

- **Other Climate Change Related Research** (Hamlet and Lettenmaier)

In conjunction with the ACPI funded water management investigations for the western US, a study of adaptive management in the Columbia River basin in response to climate change was carried out using the ColSim model (Payne et al., 2003). These investigations were some of the first attempts to look explicitly at the transient variability of the climate model simulations for the PNW, and to attempt to mitigate the impacts of these changes in streamflow variability using conventional water resources engineering techniques. The study also made several improvements to the ColSim model with regard to recent changes to the reservoir operating system. [The basic climate model bias-correction and downscaling methods used in this ACPI study are also used in the seasonal to interannual forecasting system for the Columbia in making the linkage to GCM climate forecasts (Wood et al. 2002).]

- **Outreach Program Support** (Hamlet and Lettenmaier)

We produce, on an as-needed basis, technical information and presentations to support the annual CIG fall water workshops and other outreach related efforts such as press releases, regional climate change workshops, outreach to water planning studies through the Dept. of Ecology, etc.

b. Aquatic Ecosystems

- **GLOBEC** (Mantua)

A review paper describing the large-scale climate influences on US GLOBEC study regions; specifically, the marine ecosystem associations with AO/NAO influences on the Georges Bank, ENSO and PDO influences on the California Current System and Coastal Gulf of Alaska, and ENSO influences on the West Antarctic Peninsula coastal zone (Mantua et al, 2002).

- **Salmon** (Francis and Mantua)

An empirical model is developed to relate changes in coastal ocean SST, winds and sea level to observed Oregon coho salmon marine survival rates; the simple environmental model explains 75% of the variance in the model training period (1969-1998), and offers a means for making skillful preseason run-size forecasts that can inform salmon resources managers and fishers up to 6 months prior to the harvest season (Logerwell, et al, 2003).

We review the methods currently used to incorporate forecast information into salmon management, and the potential for reducing fishery forecast errors with climate information; we focus on the past linkages between "command-and-control" management and how that compares with the results of recent research into climate impacts on salmon production, and conclude that monitoring offers many more immediate benefits to managing for sustainable fisheries than does a narrow focus on prediction (even with careful consideration of climate information) (Mantua and Francis, 2003)

- **Climate Uncertainty and Fisheries** (Mantua and Mote)

We describe the probabilistic nature of climate forecasts and the key uncertainties associated with longer-term climate change scenarios that may be of interest to fishery scientists; specifically, we provide a few examples of the model-based uncertainties and emissions scenario uncertainties in term of model outputs for selected variables in productive ocean regions (.Mantua and Mote, 2002).

- **River Ecosystems** (Francis, Mantua, Peterson)

We describe the state of the art in seasonal to interannual climate forecasting and the state of the art in developing longer term climate change scenarios, with the aim of informing stakeholders about climate variability and uncertainty and how it influences river ecosystems. River restoration needs to be addressed in the context of climatic variability in order to ensure that structure, function, and processes are achieved in the long term. The importance of climatic variability is illustrated with examples from major river ecosystems of the United States (Edmonds et al., 2003.)

c. Coasts

- **Coastal Upwelling and Global Warming** (Mote and Mantua)

We examine selected outputs from two state of the art climate system model simulations for the next century and find only very small changes in simulated upwelling winds for important coastal upwelling systems around the world; because the natural variability of the models is much weaker than that in the observations, we suspect that the models examined in this study are not adequate to the task of simulating potential changes in wind-driven upwelling as a response to anthropogenic climate forcing (Mote and Mantua, 2002).

- **PACJET** (Smull)

In his role as Chief Scientist aboard the NOAA P-3 research aircraft, Smull continues to serve as a key contact for operations related to PACJET (the Pacific Landfalling Jets experiment), especially as they may be focused over and offshore of the Pacific Northwest. Owing to aircraft allocation constraints, PACJET-related P-3 operations planned for winter 2002-03 were sharply curtailed with respect to those planned. While the concept of a dual-base operation (viz. Monterey, California & Seattle, Washington) providing comprehensive west coast coverage remains viable for upcoming winters, a more limited set of flights (based out of Portland, Oregon) was employed during February 2002 and focused on assessment of QuickScat satellite-derived winds in the offshore low-level jet. Data collected in PACJET-2002, which was characterized by a near-neutral phase of ENSO, will complement those gathered under strong El Niño conditions during 1997/98 and the weak La Niña of 2001. Additional efforts in Jan-Feb. 2003 focused on data collection using systems other than aircraft along rugged coastline north of

San Francisco, an area that has particularly poor coverage by NOAA's operational network of WSR-88D radars. PACJET observations in this zone included a network of wind profilers, a ground-based polarimetric X-band scanning radar, a pair of S-band precipitation profiling radars, raindrop disdrometers, and special high-resolution rain gauges. The focus of Smull's activity over this period has been on advancing means to process large volumes of P-3 airborne-Doppler radar data in conjunction with other specialized datasets collected along and immediately off the California coast during PACJET-2001, and publication of results derived from these data.

d. Forests

- **Forest Regeneration** (Peterson)

High-elevation forests in the North Cascade Range of Washington generally are less resilient to disturbance such as forest harvest. Despite the long time lag in regeneration, forests clearcut 30 years ago appear to be achieving species composition similar to that of pre-harvest stands.

- **Forest Response to Climate Variability** (Fagre, Peterson and Peterson)

An ecosystem modeling framework is being used to address the effects of climatic variability and change on the Olympic, North Cascades, and Northern Rocky Mountains. Combined with ongoing monitoring of atmospheric, productivity, and water supply parameters, a regional-scale perspective is being developed on climate-ecosystem relationships in mountain environments (Fagre and Peterson, 2002).

The Pacific Decadal Oscillation is a dominant mode of climatic variability that affects ecosystem parameters across northwestern North America. Studies on tree growth and hydrological components (glaciers, snow, streamflow) demonstrate that the effects of deterministic climatic change need to be inferred in the context of long-term climatic variability (Fagre, Peterson, and Hessl, 2003). Subalpine fir, one of the most common high-elevation trees in western North America, responds strongly to the Pacific Decadal Oscillation in mountains of the Pacific Northwest. Growth of this species is positively correlated with PDO index at snowy, treeline sites; growth is negatively correlated with PDO index at lower elevation and drier sites (Peterson, Peterson and Ettl, 2003).

An ecosystem modeling framework is being used to address the effects of climatic variability and change on the Olympic, North Cascades, and Northern Rocky Mountains. Combined with ongoing monitoring of atmospheric, productivity, and water supply parameters, a regional-scale perspective is being developed on climate-ecosystem relationships in mountain environments (Fagre, Running, Keane, and Peterson, 2003).

- **Predicting Forest species Distributions** (Peterson and Peterson)

A biophysical environmental analysis of distribution of dominant tree species in northern Washington was conducted on >10,000 vegetation plots on federal lands. The ecological niche of most species was limited by one and occasionally two environmental parameters with relatively

simple quantitative relationships. This information provides accurate algorithms for modeling the response of vegetation to climatic change (McKenzie, Peterson, and Peterson).

- **Wildland Fire** (Peterson)

A variety of analytical approaches at different spatial scales were used to infer the effects of fire on forest ecosystems n the Pacific Northwest. By using large empirical databases and statistical techniques appropriate at regional to watershed scales, the effects of fire can be interpreted at multiple spatial and temporal scales (McKenzie, Prichard, Hessl, and Peterson, 2003).

- **Forest Carbon Storage** (Peterson)

Carbon distribution in subalpine forest ecosystems is highly variable at small spatial scales, with much larger carbon storage in tree islands than in adjacent meadows. Carbon stored in subalpine forests likely has a long residence time in cold conditions. (Sanscrainte, and Peterson, 2003a).

Clearcut logging in high-elevation forests of the Cascade Range has a significant effect on the distribution of soil carbon, depending on the post-harvest treatment (burning versus no burning). In general, leaving logging slash and minimizing burning will encourage long-term storage of carbon in soils (Sanscrainte, and Peterson, 2003b).

6. Integration and Assessments Research

- **PNW Assessment**

We review key results from the ongoing NOAA-funded *Integrated assessment of climate impacts on the Pacific Northwest;* highlighting the regions sensitivity and vulnerability to temperature changes as they propagate through the hydrologic cycle to impact ecosystems and water resources in the region (Mote et al., 2003).
We review key results from the ongoing *Integrated assessment of climate impacts on the Pacific Northwest;* highlighting the regions sensitivity and vulnerability to temperature changes as they propagate through the hydrologic cycle to impact ecosystems and water resources in the region

- **Rhythms of Change (Ed Miles and Climate Impacts Group)**

We are nearing completion of the substantial revision of a book length manuscript prepared for MIT Press. The book is now in eleven rather than nine chapters.

The book presents a comprehensive treatment of the Climate Impact Group's integrated assessment of climate impacts across all sectors of the Pacific Northwest on the basis of work completed up to 2002. We have added a new chapter on the human rhythms of the Pacific Northwest and integrated human dimensions more completely in each sectorial chapter as recommended by the reviewers. We will revise the analysis of patterns in the use of climate

forecasts to take account of recent trends and re-write the concluding chapters putting heavier emphasis on horizontal connections across sectors. Completion is due June 15, 2003.

7. Human Dimensions Research

- **Mitigation (Slaughter)**

Since the empirical evidence available shows that some of the biggest barriers to adapting to climate variability and change in the Pacific Northwest are basically institutional in nature, we have chosen to emphasize explorations in institutional design and performance as the major theme of our human dimensions research.

Slaughter (2003) begins at the global level with respect to the strategies available for mitigation. This work applies micro economic theory to the question of what characteristics an effective institutional structure is likely to exhibit. It then applies that analysis to the structure of the obligations of the Kyoto Protocol. The analysis finds that the standard model of human economic behavior, adding consideration of transaction costs, provides powerful insights into how institutions might be more effectively designed for the purpose of reducing human emission of greenhouse gases.

- **Regional Adaptation** (Slaughter, Hamlet, Huppert, Mote and Reading)

The paper Slaughter et al. (2003) examines adaptation at the regional level. The dialogue between three economists and a hydrologist seeks to understand in some detail the drawbacks to the current institutional arrangements for managing water in the Pacific Northwest and how it might be possible to move from this current unsatisfactory situation to a more appropriate specification of rights under an arrangement determining allocations through water markets.

Current work (Slaughter and Reading, 2003) explores the nature of institutional adaptation in the Snake River basin over the past 100 years in response to climate variability and to changes in demand. It attempts to empirically identify the degree of external stresses needed to prompt a change in institutional structures.

8. Service, leadership, and Outreach

- **A Pacific Decadal Variability Program** (Mantua and Sarachik)

As promised in the original CSES proposal, we proposed for, convened, and chaired a workshop on Pacific Decadal variability for the purpose of producing a program prospectus of a rather unique program on Pacific Decadal Variability.

The unique aspect of this proposed program is the coordination of the needs of various applications community, especially fisheries and hydrology, with the production of knowledge of

the climate system over the pacific, directly relevant to pacific CLIVAR. This therefore involves getting the various communities together to agree on a common agenda and the funding agencies together to agree to fund the program.

The meeting convened in Alexandria VA on Feb. 25-26 [http://www.usclivar.org/PDV_0203.html}produced lively discussion and a beginning to the process of building the community. The writing group (Cayan, Cook, Hollowed, Mantua, Nigam, Sarachik, Suarez) met the next day, Feb. 27 to revise the Prospectus which should be ready by the end of March.

- **Water Stakeholder Meetings** (Miles, Whitely-Binder and CIG)

Two water stakeholder meetings were held during this period:

1. Outlook for Climate and Water Resources in the Northwest - Olympia, Washington (September 25, 2002)

2. Forecasting Climate and Water Resources in Idaho: Past experience and outlook for 2002-03 - Boise, Idaho (October 16, 2002)

- **Outreach Coordinator** (Mote)

Dr. Phil Mote is the main outreach coordinator and media resource for both climate impacts and climate variability. During the period April 2002 to March 2003, Dr Mote has given approximately 53 presentations. These include seminars and classes at UW, talks at meetings of professional societies like the American Meteorological Society, briefings for congressional staff, workshops organized by the Climate Impacts Group for water resources managers, and invited lectures for various civic and religious groups. Dr Mote and Professor Richard Palmer produced a special session on climate change for the annual meeting of the American Water Works Association.

- **Outreach Program Support** (Hamlet and Lettenmaier)

On an as needed basis we provided information, streamflow forecasts, and other technical support for the CIG Fall Water Workshops (Olympia and Boise, Oct, 2002), other climate related workshops (e.g. Hamlet 2003), as well as the climate change outreach being spearheaded by Lara Whitely Binder in partnership with WA Department of Ecology's (DOE) watershed planning initiative. Efforts include long-range streamflow forecasts for The Dalles and various subbasins in the Columbia River basin (Hamlet 2002a b). A simple water management screening model was built to help facilitate education and training of regional stakeholders in smaller watersheds in Washington with regard to climate change impacts (see Whitely Binder, 2002). The snowpack and runoff maps described above will also be used in the outreach program, particularly in the context of the smaller watershed planning efforts with the DOE.

- **Streamflow Data Server** (Hamlet, Lettenmaier and Snover)

Developed online server tool to make climate change streamflow scenarios available to PNW water resources managers for use in long-range planning. www.ce.washington.edu/~hamleaf/climate_change_streamflows/CR_cc.htm

- **GIS Decision Support Tool for the Pacific Northwest** (Snover)

We have hired Robert Norheim, a GIS-specialist with a M.S. in GIS and 5.5 years of experience who is responsible for developing the GIS relational databases and relevant meta-data to support research on integrated assessment, aid communication within CIG, enhance external communication, and undergird decision-support tools for regional stakeholders. He is currently constructing the "physical template," a GIS-based quantitative virtual reality, of the Pacific Northwest to combine fine-scale information not only about climate impacts, but the regulatory, socioeconomic, and ecological environments in which they will occur.

- **International Workshop on Regional Integrated Assessment of Climate Impacts** (Miles, Mote, Snover)

Convened the (first) International Workshop on Regional Integrated Assessment of Climate Impacts, Castelvecchio Pascoli, Italy (September 2002). This 5-day workshop brought together practitioners and theorists of regional assessment to discuss methods and approaches, to share successes and failures, and to discuss the blending of academic research with policy influence. Participants included 45 attendees from 22 countries, including 15 people from 12 developing countries. http://jisao.washington.edu/PNWimpacts/RIAworkshop/index.html .

- **Course on Science and Decision Making** (Snover and Cullen)

In collaboration with the Alison Cullen (University of Washington Evans School of Public Affairs), developed and taught a new graduate course on "The Role of Science in Environmental Decisions." This course examines how science contributes to decisions that involve the natural environment: how science and scientists help frame debates and decisions; how scientific findings are incorporated into decision-making processes; and how scientists and nonscientists deal with uncertainty about scientific questions.

- **Seminar Series on Decision Making** (Snover, Whitely Binder and Cullen)

Developed and organized a new university-wide seminar on risk-based decision-making in public sector natural resources management entitled "Decision Making in the Face of Uncertainty: Practitioner Views on Environmental Resource Management Challenges." Speakers from a variety of natural resource sectors will discuss how their agencies approach decisions affected by uncertainty.

- **AGU Session on Pacific Decadal Variability** (Mantua and Sarachik)

Convened a session on Pacific Decadal Variability with only invited talks for the purpose of seeing if there was interest in a PDV program. Washington DC, Spring 2002.

- **ASLO/Ocean Sciences Session on Regime Shifts in Marine Ecosystems** (Greene and Mantua)

Convened Session at Honolulu meeting of ASLO. Winter 2002.

- **Memberships and Other Positions**

- Battisti served as co-Chair of the US CLIVAR Scientific Steering Committee until 12/30/02.

- Mantua continues to serve on US GLOBEC scientific steering committee, executive committee member

- Mantua served as Panel Member on the National Research Council study of the Alaska Groundfish Fishery and Stellar Sea Lions, study completed November 2002

- Miles continues to serve as a member of the Board of Trustees of the Heinz Center.

- Miles serves as a member of the Scientific Advisory Board pf the President's National Ocean Commission.

- Sarachik continues to serve as Co-Chair of the IRI International Science and Technology Advisory Committee with Miles continuing as a member.

- Sarachik continues to serve as Chair of the UCAR/NSF Community Climate Systems Model (CCSM) Advisory Board.

- Sarachik serves on the NOAA Climate observing Systems Council.

- Miles and Sarachik serve on the NOAA Climate and Global Change Working Group

- Sarachik serves on the NASA Earth Systems Model Framework Advisory Board.

9. Infrastructure Development

- **Data Archives** (Hamlet and Lettenmaier)

We will provide misc. climate and hydrologic data for proposed CIG live access server data distribution system.

- **Live Access Server for PNW Climate Data** (Mitchell and Snover)

Developing integrated data management and service capabilities. Working with all of CSES to specify requirements for a Live Access Server node, which would provide web-based access to CSES unique spatial datasets of parameters relevant to the regional manifestations and impacts of climate variability and change for studies of the Pacific Northwest climate and its impacts Access to the data is being provided by Live Access Server (LAS) software, which also requires the installation of Distributed Oceanographic Data System (DODS) and Ferret software. David Warren, a systems programmer in the UW Atmospheric Sciences department, is installing the software, and Todd Mitchell are overseeing this activity. LAS will provide users access to both digital values and to simple user-specified maps. LAS should be running in the next few months, and a variety of data sets and their updates will be added in the next 5 years. The data system could also distribute weather statistics of various simulated climate change scenarios, which would be very useful to planners.

- **CSES Website** (Snover)

Managing the development of CSES new website. Overseeing the design and construction of a new website oriented towards the needs and interests of stakeholders, the media and interested public, in addition to the academic audience. The new site will provide greatly streamlined access to information about CSES, our products and forecasts, outreach events, research results and current projects, datasets, and publications. It will demonstrate how CSES is creating the foundation for a regional climate service.

10. Publications during this period (4/1/02-3/31/03)

1. Climate Variability

Biasutti, M., D.S. Battisti, and E.S. Sarachik, 2002: On the annual cycle over the tropical Atlantic, South America, and Africa. *J. Climate,* in press.

Bond, N.A. and D.E. Harrison, 2003: U.S. Winter Weather Anomalies with El Nino and negative Arctic Oscillation: 2002-03 and before. *Geophys. Res. Lett.,* Submitted.

Bousquet, O., and B.F. Smull, 2003: Airflow and Precipitation Fields within Deep Alpine Valleys observed by airborne Doppler radar. *J. Appl. Meteor*. (In Press).

Bousquet, O., and B.F. Smull, 2003: Observations and impacts of upstream orographic blocking during a widespread orographic precipitation event. *Quart. J. Royal Met. Soc.*, **129**, 391-410.

Brown, C.A., 2003: The impact of daily changes in the Pacific North American pattern on the occurrence of extreme weather events. MA Thesis, University of Washington, 127pp.

Gedalof, Z., NJ Mantua, and DL Peterson, 2002: A multi-century perspective of variability in the Pacific Decadal Oscillation: new insights from tree rings and corals. *Geophys. Res. Lett.,* **29**, doi: 10.1029/2002GL015824, 2002.

Goodman, P.J. and E.S. Sarachik, 2003: Forced variability of North Atlantic Deep Water Production in an Ocean GCM. *J. Marine Res.*, in revision.

Huang, B., P.H. Stone, A.P. Sokolov, and I.V. Kamenkovich, 2003: The deep-ocean heat uptake of transient climate change, *J. Climate*, in press.

Kamenkovich, I. V., and E. S. Sarachik, 2003a: Mechanisms controlling the sensitivity of the Atlantic thermohaline circulation to the parameterization of eddy transports in an ocean GCM. *J. Phys. Ocean*. Submitted.

Kamenkovich, I. V., and , E. S. Sarachik, 2003b: On reducing errors in temperature and salinity in an ocean model forced by restoring boundary conditions. *J. Phys. Ocean*. Submitted.

Kamenkovich, I.V., A. Sokolov, and P.H. Stone, 2002: An efficient climate model with a 3D ocean and statistical-dynamical atmosphere. *Climate Dyn.,* **19**, 585-598.

Kamenkovich, I.V., A. Sokolov, and P.H. Stone, 2003: Feedbacks affecting the response of the thermohaline circulation to increasing CO2. A study with a model of intermediate complexity, *Climate Dyn. ,*in press.

Mantua, N.J., and S.R. Hare, 2002: The Pacific Decadal Oscillation. *J. Oceanography* (Japan), **58,** 35-44.

Mitchell, T.P., and J.M. Wallace, 2003: Recent trends in the Southern Oscillation. *J. Climate*, submitted.

Mantua, N.J., and P.W. Mote, 2003: Uncertainty in scenarios of human-caused climate change, *Amer. Fish. Soc. Symp.,* 32, 263-272. Published August 2002.

Morss, R. and D.S. Battisti, 2003: ENSO Observing simulation experiments. *J. Climate,* submitted.

Mote, P.W., 2003: How and why is Northwest climate changing? in *Climate Change, Carbon, and Forestry in Northwestern North America,* edited by David L Peterson and John L. Innes. Pacific Northwest research station general technical report, in press.

Mote, P.W., 2003: Trends in temperature and precipitation in the Pacific Northwest, Mote, *Northwest Science*, submitted

Quadrelli, R. and J. M. Wallace, 2003: Dependence of the structure of the Northern Hemisphere annular mode on the polarity of ENSO. *Geophys. Res. Letts.*, 29, doi:10.1029/2002GL015807.

Sarachik, E.S., and D.J. Vimont, 2003: Pacific Decadal Variability. In *Chaos in Geophysical Flows*. Kluwer, submitted.

Sarachik, E.S. 2003: The Ocean in Climate. *Handbook of Weather, Climate, and Water*. John Wiley, in press.

Seager, R., D.S. Battisti, J. Yin, N. Gordon, N. Naik, A.C. Clement and M. Cane, 2002: Is the Gulf Stream responsible for Europe's mild winters? *Q. J. R. Meteor. Soc.,* **128**, 2563-2586.

Steiner, M., O. Bousquet, R.A. Houze, B.F. Smull and M. Mancini, 2003: Airflow within major Alpine river valleys under heavy rainfall. *Quart. J. Royal Met. Soc.*, **129**, 411-432.

Vecchi, G.A. and D.E. Harrison, 2002: Monsoon breaks and subseasonal sea surface temperature variability in the Bay of Bengal. *J. Clim.,* **15,** 1485–1493.

Vimont, D. , D.S. Battisti, and A.C. Hirst, 2002: Pacific Interannual and Interdecadal Equatorial Variability in a 1000 year simulation of the CSIRO coupled General Circulation Model. *J. Climate*, **15**, 160-78.

Vimont, D. J., A.C. Hirst, and D. S. Battisti, 2003: Seasonal footprinting mechanism in the CSIRO general circulation model. *J. Climate* in press

Vimont, D. J., J. M. Wallace, and D. S. Battisti, 2003: The Seasonal Footprinting Mechanism in the Pacific: Implications for ENSO. *J. Climate,* in press.

Vimont, D.J., 2002: The Seasonal Footprinting Mechanism in the CSIRO Coupled General Circulation Models and in Observations. Ph.D. Thesis, Atmospheric Sciences, University of Washington, 113pp.

2. Predictability and Prediction Research

Wallace, J.M., and D.W.J. Thompson 2002: Annular Modes and Climate Prediction. *Physics Today*, **55**, 28-33

3. Downscaling Research and interfaces

Salathé, E. P., 2002:Comparison of Various Precipitation Downscaling Methods for the Simulation of Streamflow in a Rainshadow River Basin. Accepted at *International Journal of Climatology*. http://www.atmos.washington.edu/~salathe/papers/downscale/

Widmann, M., C. S. Bretherton, and E. P. Salathé, 2002: Statistical precipitation downscaling over the Northwestern United States using numerically simulated precipitation as a predictor", *Journal of Climate*. **16**, 799-816

4. Regional Impacts-Sectors

Gedalof, Ze'ev, 2002: Ph D, College of Forest Resources. Dissertation title: *Links between Pacific Basin Climatic Variability and Natural Systems of the Pacific Northwest.*

a. Hydrology and Water Resources

Bond, N.A., and G.A. Vecchi, 2003: On the Madden Julian Oscillation and Precipitation in Oregon and Washington. *Weather and Forecasting*, *in press.*

Cohen, S. and co-authors, 2003, Threats to Fresh Water Availability in Canada, Chapter 15, Integration, Environment Canada.

Hamlet A.F., Lettenmaier, D.P., 2002d, Retrospective Evaluation of the Performance of Experimental Long-Lead Columbia River Streamflow Forecasts, AMS Conference on Applied Climatology, Portland, OR, May (poster)

Hamlet, A.F., Lettenmaier, D.P., 2003b, *Evaluation of skill and error characteristics for alternative seasonal streamflow forecast methods*, Poster, AMS Annual Meeting, Long Beach, CA, Feb

Hamlet A.F., Snover, A.K., Lettenmaier, D.P., 2003c, *Climate Change Streamflow Scenarios for Critical Period Water Planning Studies: A Technical Methodology*, (Draft in internal review, to be submitted to ASCE J. Water Resources or JAWRA this month)

Lettenmaier, D. P., Hamlet, A. F., 2003, Opportunities for Improving Water Resource System Performance through Long-Range Climate Forecasts: The Pacific Northwest Experience, UC Boulder Monograph, (in press)

Mote, P.W., 2003: Trends in snow water equivalent in the Pacific Northwest and their climatic causes, *Geophysical Research Letters,* submitted March

Payne, J.T., A.W. Wood, A.F. Hamlet, R.N. Palmer, and D.P. Lettenmaier, 2003: Mitigating the effects of climate change on the water resources of the Columbia River basin. *Climatic Change* submitted.

Snover, A.K., Hamlet A.F., Lettenmaier, D.P., 2003: Climate Change Scenarios for Water Planning Studies: Pilot applications in the Pacific Northwest., *Bull. Am. Met. Soc.*, submitted.

Wood, A.W., Maurer, E.P., Kumar, A. and D.P. Lettenmaier, 2002, *Long Range Experimental Hydrologic Forecasting for the Eastern U.S.* J. Geophys. Res., 107(D20), 4429, doi:10.1029/2001JD000659

Wood, A.W., Leung, L. R., V. Sridhar and D.P. Lettenmaier, 2003, Hydrologic implications of dynamical and statistical approaches to downscaling climate model outputs. *Climatic Change,* submitted

Wood, A.W., Maurer, E.P., Kumar, A. and D.P. Lettenmaier, 2002, Long Range Experimental Hydrologic Forecasting for the Eastern U.S., *J. Geophys. Res.*, 107(D20), 4429, doi:10.1029/2001JD000659

b. Aquatic Ecosystems

Edmonds, R.L., R.C. Francis, N.J. Mantua, and D.L. Peterson. (in press). Chapter 2. Sources of climate variability in river ecosystems. Pages 000-000 in R.C. Wissmar and P.A. Bisson, editors. *Strategies for restoring river ecosystems: sources of variability and uncertainty in natural and managed systems*. American Fisheries Society, Bethesda, Maryland.

Logerwell, EA, N.J. Mantua, P. Lawson, RC Francis, and V Agostini, 2003: Tracking environmental bottlenecks in the coastal zone for understanding and predicting Oregon coho (Oncorhynchus kisutch) marine survival. *Fisheries Oceanography*, in press.

Mantua, N.J., D. Haidvogal, Y. Kushnir, and N. Bond, 2002: Making the Climate connections: bridging scales of space and time in the US GLOBEC program. *Oceanography*, 15, 75-86.

Mantua, NJ, and P Mote, 2002: Uncertainty in scenarios of human-caused climate change. American Fisheries Society *Special symposium on Fisheries in a Changing Climate,* **32**, 263-272.

Mantua, NJ, and RC Francis, 2003: Natural climate insurance for Pacific Northwest Salmon and Salmon fisheries: finding our way through the entangled bank (in review):

c. Coasts

Mote, P.W. and N.J. Mantua. 2002. Coastal upwelling in a warming future. *Geophy. Res. Lett*., doi: 10.1029/2002GL016086.

d. Forests

Elman, E. and D.L. Peterson. 2003. Post-harvest regeneration of high-elevation forests in northern Washington, USA. *Forestry Chronicle*. In press.

Fagre, D.B. and D.L. Peterson. 2002. Modeling and monitoring ecosystem responses to climate change in three North American mountain ranges. Pages 249-259 in C. Körner and E. Spehn (eds.), *Global Mountain Biodiversity: Changes and Threats*. Springer-Verlag, Berlin.

Fagre, D.B., D.L. Peterson, and A.E. Hessl. 2003. Taking the pulse of mountains: ecosystem responses to climatic variability. *Climatic Change*. In press.

Fagre, D.B., S.W. Running, R.E. Keane, and D.L. Peterson. 2003. Assessing climate change effects on mountain ecosystems using integrated models: a case study. In H. Bugmann and U. Huber (eds.), *Global Change and Mountain Regions*. Kluwer Academic Publishing, Dordrecht, The Netherlands. In press.

McKenzie, D., D.W. Peterson, and D.L. Peterson. 2003. Predicting conifer species distribution in mountain forests of Washington state, USA. *Forestry Chronicle*. In press.

McKenzie, D., S.J. Prichard, A.E. Hessl, and D.L. Peterson. 2003. Empirical approaches to modeling wildland fire in the Pacific Northwest region of the United States: methods and application to landscape simulation. In A. Perera and L. Buse (eds.), *Emulating Natural Forest Landscape Disturbances*. Columbia University Press, New York. In press.

Peterson, D.W., D.L. Peterson, and G.J. Ettl. 2002. Growth responses of subalpine fir (*Abies lasiocarpa*) to climatic variability in the Pacific Northwest. *Canadian J.Forest Research* **32**, 1503-1517.

Sanscrainte, C.L. and D.L. Peterson. 2003a. Carbon storage and soil properties in subalpine parklands of the North Cascade Range, Washington. *Northwest Science*. In press.

Sanscrainte, C.L. and D.L. Peterson. 2003b. Carbon storage and soil properties in late-successional subalpine forests and adjacent clearcuts in the North Cascade Range, Washington. *Northwest Science*. In press.

5. Integration and Assessments Research

Snover, A. K. and P. Mote, 2002. Climate Impacts on the Natural Resources of the Pacific Northwest, *The Climate Report* 3(2): 7-11.

Gamble, J. L., J. Furlow, A. K. Snover, A. F. Hamlet, B. J. Morehouse, H. Hartmann, and T. Pagano, 2003: Assessing Regional Water Resources: The Implications for Stakeholders of Climate Variability and Change, Chapter 14, in *Science and Water Resources: Challenges and Opportunities,* AGU Monograph, in press.

Huppert, D., J. Kaje, A. F. Hamlet, E. L. Miles, and A. K. Snover, 2002. Applications of climate forecasts in natural resources management: Implications for industry, *The Climate Report* 3(2): 12-22.

Miles, E.M., et al, 2003: *Rhythms of Change*. MIT Press, in press.

Mote, P.W., E.A. Parson, A.F. Hamlet, K.G. Ideker, W.S. Keeton, D.P.,Lettenmaier, N.J. Mantua, E.L. Miles, D.W. Peterson, D.L. Peterson, R., Slaughter, and A.K. Snover, 2003:

Preparing for climate change: the water, salmon, and forests of the Pacific Northwest. *Climatic Change,* in press.

Peterson, D. L., N. J. Mantua, P. W. Mote, A. K. Snover, Z. M. Gedalof, and S. R. Hare. The Pacific Decadal Oscillation and natural resources in northwestern North America. *Bioscience*, submitted

Snover, A. K., and the Climate Impacts Group (CIG), 2002. The Climate Impacts Group: Piloting climate services for the Pacific Northwest. *Proceedings of the NOAA Climate Prediction Assessment Workshop: Research and Applications on Use and Impacts*, Alexandria, Virginia, October.

6. Human Dimensions Research

Slaughter, R. A., 2003: Institutions, Institutional Change, and Climate: Considerations for Policy. *Policy Sciences*, submitted

Slaughter, R. A., A. Hamlet, D. Huppert, J. Hamilton, and P. Mote, 2003: Regulation vs. Markets: A Dialogue on Over-Allocation of Pacific Northwest River Basins. *Policy Sciences*, Submitted .

Slaughter, R.A., and Reading, 2003: Institutional Adaptation to climate variability and demand change: The Snake River Basin 1850-2000.

7. Service, Leadership, and Outreach

Bender, M., S. Doney, R.A. Feely, I. Fung, N. Gruber, D.E. Harrison, R. Keeling, J.K. Moore, J. Sarmiento, E. Sarachik, B. Stephens, T. Takahashi, P. Tans, and R. Wanninkhof, 2002: A large-scale CO_2 observing plan: In situ oceans and atmosphere (LSCOP). NOAA OAR Special Report, 201 pp.

Mantua, N., and E.S. Sarachik, 2003: Draft Prospectus for a program on Pacific Decadal Variability. 21pp. http://www.usclivar.org/Meeting_Files/PDVStrawman.pdf

11. Presentations during this Period

The Climate Impacts Group, 2002: Evaluating the Impacts of Climate Variability and Change on the U.S. Pacific Northwest (poster), International Workshop on Regional Integrated Assessment of Climate Impacts, Il Ciocco, Italy, September.

The Climate Impacts Group, 2002: A pilot project providing climate services for the Pacific Northwest, NOAA Climate Prediction Assessments Workshop, Alexandria, VA, October.

Hamlet, A.F., Wood, A., Lettenmaier, D.P. , 2002a, Long-Lead Streamflow Forecast for the Columbia River Basin for 2002-2003, 2003, CIG Water Workshops, Olympia, WA and Boise, ID, Oct

Hamlet, A.F., Snover, A.K., Lettenmaier, D.P., 2002b, *Climate Change Streamflow Scenarios for Pacific Northwest Water Planning Studies*, CIG Water Workshops, Olympia, WA and Boise, ID, Oct

Hamlet, A.F., Lettenmaier, D.P., 2003a, *Effects of Climate Change on Pacific Northwest Rivers*, Columbia Mountain Institutes Climate Change Workshop, Cranbrook, B.C. Jan

Hamlet A.F., Andrew W. Wood, and Dennis P. Lettenmaier, 2002c, Quantifying the effects of initial soil moisture on seasonal streamflow forecasts in the Columbia River basin, Meeting of the European Geophysical Society, Nice, France, March (Poster)

Hamlet A.F., Lettenmaier, D.P., 2002d: Retrospective Evaluation of the Performance of Experimental Long-Lead Columbia River Streamflow Forecasts, AMS Conference on Applied Climatology, Portland, OR, May (poster)

Hamlet, A.F., Lettenmaier, D.P., 2003b: Evaluation of skill and error characteristics for alternative seasonal streamflow forecast methods, Poster, AMS Annual Meeting, Long Beach, CA, Feb

Miles, E.M., P.M. Mote, and R.A. Slaughter, 2002: Briefing for PNW Congressional staff, April 26, Washington, D.C.

Mote, P.M., and A. Snover, 2003: Climate Change Streamflow Scenarios for Water Managers: Responding to regional stakeholders," American Meteorological Society annual meeting, Long Beach, CA, February 2003

Park, H.S., Hamlet, A.F., Lettenmaier, D.P., 2002, Use of extended daily hydroclimatalogical records to assess hydrologic variability in the Pacific Northwest, Poster, AGU Annual Meeting, San Francisco, CA, Dec.

Peterson, D.L., 2002: Restoring the role of fire in Western ecosystems: will the smoke get in our eyes? North American Forest Biology Workshop, Pullman, WA, July (invited keynote speaker)

Peterson, D.L., 2002: Rocky 2002: Climatic variability and natural resources in mountain ecosystems. Mountain Summit, Whitefish, MT, September (invited keynote speaker)

Sarachik, E.S., 2002: Atmospheric Aspects of ENSO (3 lectures) . Principle lecturer at the International Center for Theoretical Physics, Trieste, Italy, June 3-14.

Sarachik, E.S., 2002: Interaction of Data, Observations and Models. Invited talk at the CCSP meeting, Washington, DC., December.

Slaughter, R.A., 2002: Mitigation: Controlling GHG Emissions (Energy Economics), Presentation to SMA 521, Governmental Responses to Global Climate Change, E.L. Miles, instructor, November 20.

Snover, A., 2002: Integrated assessment of climate impacts on the Columbia Basin (US): The sensitivity, adaptability and vulnerability of regional water resources. International Workshop on Regional Integrated Assessment of Climate Impacts, Il Ciocco, Italy, September.

Snover, A. K., E. L. Miles, A. F. Hamlet, and D. P. Lettenmaier, 2002. "Integrating Natural and Social Science for Regional Assessment of Climate Impacts on the Pacific Northwest." Mississippi River Climate and Hydrology Conference special science session on Regional Integrated Sciences and Assessments, New Orleans, May.

Snover, A., 2003: The impacts of climate change on the PNW," University of Washington seminar Civil Engineering, 30 January 2003.

Snover, A., and Ed Miles 2002: "The Importance of Climate Change to National Ocean Policy: Lessons from the Pacific Northwest" University of Washington seminar, SMA 550L: "Ocean Governance for the 21st Century: In search of sustainability," 9 May

Snover, A., 2002: Impacts of climate change on the Pacific Northwest. Training session for high school teachers at Washington State University's Summer Workshop on The Science of Global Climate Change. Vancouver, Washington. July 25.

Snover, A., 2002: Washington State University seminar: "Impacts of climate change on the Pacific Northwest," Washington State University Science Program seminar series, 8 April.

Snover, A., 2003: Planning for climate change in the Pacific Northwest. Briefing to King County Council, Council of the Whole, Seattle, January..

Whitely Binder, L. 2002. *Assessing watershed vulnerability to climate impacts: Developing alternative approaches*, presented at the Watershed Management Council Biennial Meeting, Skamania Lodge, Stevenson, Washington. November 4, 2002.

Wood, A.W. and D. P. Lettenmaier, D.P., 2003, Retrospective Assessment of Seasonal Hydrologic Forecasts in the Western U.S., AMS Annual Meeting, Long Beach, CA, Feb (Poster)

Wood, A.W. and D. P. Lettenmaier, 2002, Experimental Real-time Seasonal Hydrologic Forecasting, AMS Conference on Applied Climatology, Portland, OR, May (poster)

Wood, A.W. and D. P. Lettenmaier, 2003, Comparing hydrologic forecast uncertainty due to initial condition error versus climate forecast error, Meeting of the European Geophysical Society, Nice, France, to be given in April (Poster)

Wood, A.W. and D. P. Lettenmaier, 2002, Experimental Real-time Seasonal Hydrologic Forecasting, Meeting of the European Geophysical Society, Nice, France, April

12. The Next Four Years

In the area of global climate dynamics, we intend to continue our concentration on the climate processes and variations that contribute to climate variability over the US and in particular, the Pacific Northwest. This includes the mechanisms for the variability and predictability of ENSO and for the variability, impacts, and predictability of Pacific Decadal Variability. In support of the latter, we will continue our development for a program on Pacific Decadal Variability. We are also generally examining the problem of the role of the tropics in global climate variability since it is gradually becoming clearer that past global changes would have been impossible without the active participation of the tropics and future climate change depends essentially on the tropics changing.

For climate impacts, our overall objective for next four years is moving to a higher level of integration. The purpose is to develop capability to answer questions relative to impacts & policies at different time and space scales at which climate, natural ecosystems, and human social systems interact in the original 4 sectors-hydrology and water resources, forests, coasts, and marine ecosystems. (Later hope to add agriculture and human health if funding permits).

Problems of Incomplete Vertical Integration:

1). Most complete existing work is on effects of climate variability and projected climate change on regional hydrological impacts and impacts on water resources and management. Substantial progress on forests and wildfire, Coho life cycle, and coastal hazards (although the policy research is yet incomplete).

2). Need much tighter vertical linkages in each sector: climate variability to impacts to policies and in particular detailing the response capacity in view of the sensitivity and vulnerability of each sector taken separately and in interaction.

3). Need explicit links on different time/space scales. In particular, need more detailed systematic analysis at watershed level.

Problems of Horizontal Integration

1).Need to focus on linkages across sectors starting with climate variability pattern that shows small changes in temperature and precipitation may have quite large effects. Impacts mediated through ENSO and PDO, but PDO the more powerful integrator, especially when in-phase with ENSO.

2). Need as much as possible quantitative analysis of impacts across sectors and across scales. Need also much tighterlinkage between climate variability dynamics and impacts re terrestrial hydrology/forest ecology/coastal watersheds and estuarine and coastal ecosystems
.

3). Existing work to date on Coho, forest wildfire, and hake & sardines in California current showing critical importance of local winds & patchiness of space scale effects. Also links to PDO structural effects in winter up to year before actual impacts generated.

4).Advances in cross-sectoral analyses will raise issues of multiple purpose or coordinated management possibilities based on more detailed understanding of cross-sectoral linkages.

5). Need construction of alternative scenarios taking account of variability as well as means.

13. Budget Request for 4/1/03-3/31/04

CENTER FOR SCIENCE IN THE EARTH SYSTEM

REQUESTED BUDGET: April 1, 2003- March 31, 2004

SALARIES	**MO/Yr**	**CY/AC/Summer**	**Base $**		**Budget**
PERSONNEL: FACULTY					
David Fluharty	1	AY	$6,117	$6,117	
Robert Francis	1	Summer	$8,762	$8,762	
Edward Miles	2	Summer	$15,405	$30,810	
Battisti, 2 mos.	2	Summer	$9,882	$19,764	
Kamenkovich, 10.5 mos.	10.5	CY/AC/Summer	$ 5,646	$59,285	
Sarachik, 7.5 mos.	7.5	CY/AC/Summer	$10,078	$75,582	
Rick Palmer	1.5	Summer	$ 10,441	$15,662	
Sub-Total:					**$215,981**
PERSONNEL: RESEARCH SCIENTISTS					
Alan Hamlet - Research Scientist	11	CY	$4,460	$49,060	
Nathan Mantua - Research Scientist	12	CY	$4,748	$56,976	
Todd Mitchell - Research Scientist	12	CY	$4,994	$59,929	
Philip Mote (shared w/ UW Provost)	6	CY	$4,352	$26,112	
Eric Salathe	12	CY	$3,872	$46,464	
Amy Snover (Synthesis)	12	CY	$3,858	$46,296	
Robert Norheim (shared with Dave Peterson)	12	CY	$3,808	$22,848	
Lara Whitely Binder: Policy/Outreach	12	CY	$3,500	$42,000	
Sub-Total:					**$349,685**
PERSONNEL: ADMINISTRATIVE STAFF					
Professional Staff (@23.2% benefit rate)					
Adrienne Karpov Mgr., Program Operations	6	CY	$3,623	$21,738	
					$21,738
Classified Staff (@26.2% benefit rate):					

Secretary Sr. @ 50% rate	5	CY $2,586	$6,465	
Sub-Total:				**$6,465**
GRAD. STUDENTS: RA-SHIPS (through March 31, 2003)				
Forestry- Littell	12 mos. @ .50 FTE		$17,460	
Fisheries - Agostini	9 reg. + 3 sum.		$21,825	
AtSci - Takahashi	9 reg. + 3 sum.		$22,807	
AtSci - Li	9 reg. + 3 sum.		$22,807	
AtSci - Graduate student	9 reg. + 3 sum.		$24,570	
AtSci - Roberts	9 reg. + 3 sum.		$22,807	
Human Dimensions-Liz Petras	3 reg. + 2 sum.		$8,820	
Human Dimensions- new in fall	6.5 mos.		$8,190	
Hydrology- Nate van Rheenan	9 reg. + 2 sum.		$20,150	
Sub-Total:				**$169,437**
Total UW Salaries:				**$763,306**
BENEFITS				
Faculty and Post-Docs, 22.3%			$48,164	
Professional Staff, 24.5%			$90,999	
Classified Staff, 26.2%			$1,694	
Graduate Students, 11.7%			$19,824	
Total:				**$160,680**
SERVICES (all figures are based upon last year's actual costs)				
Computing Services ($250 X 12 mos.)			$3,000	
Long-distance tolls			$1,200	
Computer maintenance, services			$6,120	
Duplicating ($330 x12mos.)			$3,960	
Publications Charges (per-page charges for research pub.)			$8,000	
Postage, express services			$540	
Registration/Conference fees (10 X $200)			$2,000	
Subscriptions/Membership Fees (5 X $50)			$250	
	Total:			**$25,070**
SUPPLIES (all figures are based upon last year's actual costs)				
Software (3 x $200 average)			$600	
Books and Journals (15 x $50)			$750	
	Total:			**$1350**
TRAVEL				
Domestic Travel			$15,000	
3 trips to scientific meetings for AtSci				

faculty, grad students, research professional				
(Hypothetical destination: New York City)				
Airfare, 3 trips			$600	
Per diem, 5 days per trip @ $240/day			$3,600	
	Total Travel:			**$19,200**
EQUIPMENT				
Computer			$2,726	
1 workstation upgrade			$3,000	
	Total:			**$5,726**
GRADUATE OPERATING FEES				
9 grad students			$52,295	
	Total:			**$52,295**
TOTAL DIRECT COSTS			$1,027,627	
INDIRECT COSTS, 51.6% of MTDC			$500,317	
	TOTAL REQUEST (UW)			**$1,527,944**
SUB-CONTRACTS:				
UNIV. OF IDAHO Sub-Contract #1				
IMPACTS ON ENERGY SECTOR-Year 5				
University of Idaho-Joel Hamilton/Richard Slaughter				
Richard Slaughter		:CY $9,085	$27,256	
Contract with Ben Johnson Assoc. (for expertise in PNW electricity regulation & power systems)			$25,350	
Travel: 6 Seattle Meetings @$300			$1,800	
2 trips to Portland for data/model consultation @$250			$500	
Other Expenses:				
Phone & Long Distance			$250	
Software to support special comm. and modelling needs			$400	
UI Direct Costs			$55,556	
UI Indirect Costs @20.7% (off-campus rate)			$11,500	
	TOTAL ENERGY IMPACTS:			
	TOTAL DIR. COSTS (Core & Sub-Contr.)			**$1,094,683**
	TOTAL INDIR.COSTS (Core & Sub-Contr.)			**$500,317**
	TOTAL: (Direct and Indirect Costs)			**$1,595,000**
	TOTAL BUDGET:			**$1,595,000**

14. Budget Comments

All items in the budget are standard University of Washington salaries, graduate student support, benefits, and overhead.

The subcontracts have all continuations of subcontracts in previous CIG proposals and conforms to all the UW rules for overhead.

Overhead is on Modified Total Direct Costs which does not include equipment over $2500 and graduate student fees.