Research questions being addressed by BioEarth Teams! (Note that all of these activities are funded directly from BioEarth, but are very much related to BioEarth activities)

Overarching Questions – from the proposal

Our *overarching goal* is to improve understanding of C, N, and H_2O interactions in the context of global change to better inform decision makers involved in natural and agricultural resource management.

Specific Objective #1: To determine the influence of atmospheric processes on surface C:N:H_2O cycles.

- *Science Question*: How do future changes in inter-annual to decadal-scale climate variability patterns (e.g., ENSO and PDO) affect regional-scale coupled C:N:H_2O cycles?

Specific Objective #2: To determine how ecosystem processes will be affected by climate change and climate variability and how these regional changes feed back to the atmosphere.

- *Science Question:* How do inter-annual to decadal-scale changes in coupled atmospheric, terrestrial and aquatic C:N:H_2O cycles affect regional meteorology, greenhouse gas fluxes, and other atmospheric trace gas cycling?

Specific Objective #3: To investigate alterations to and interactions among C:N:H_2O cycles from changes in land use within and across sectors, water use for irrigation, nutrient applications, and other production inputs under a range of climate change adaptation and mitigation policy scenarios.

- *Science Question:* How do proposed mitigation and adaptation strategies affect C:N:H_2O cycles at both the intensive (input use) and extensive (land use change) margin, and how might the impacts of these strategies feed back to regional meteorology, greenhouse gas fluxes, and ecosystem change, including both agricultural lands and managed natural landscapes?

Specific Objective #4: To produce scientific results that can support stakeholder decision-making related to agriculture, forestry, and resource management by designing, implementing, and assessing an interactive and iterative model development process between scientists, practitioners, and the public.

- *Science Question:* How does regular interaction between Bio-EaSM developers and resource stakeholders influence the perceived relevance and utility of Bio-EaSM to decision-making?

Atmospheric Group – WG Ia

Tsengel Nergui's (advised by Serena Chung) Dissertation Topics:

1. How does climate variability impact seasonal N deposition rates in the US? Are the correlations with climate indices different or the same for NH_4^+ vs NO_3^+?
   - Apply wavelet analysis on historical data
2. Does the WRF and CMAQ (uncoupled) capture the impact of ENSO on N deposition in the PNW?
   - Run offline WRF & CMAQ simulations for selected ENSO years and evaluate with results from #1. The years selected will be based on results from #1 where the signals of the observations are the highest.
   - Perform synoptic pattern analysis and detailed evaluations of how well WRF does on getting the precipitation patterns right in terms of frequency, spatial distribution, and form of preciptation (snow vs rain).
3. What is the source contribution of N deposition for sensitive ecosystems in the western US?

- Run offline WRF and CMAQ-adjoint for selected weeks and evaluate with stable isotope composition data of deposition samples (with Dave Evans and Sarah Anderson)
- Similar analysis as #2, but for several weekly periods

4. What is the projected change in N deposition rate in 2050s in the PNW (or western US) due to climate change?
    - Run CMAQ (with MEGAN) with future climate results downscaled by WRF-BioEarthLand

Sarah Anderson's (advised by Dave Evans) Dissertation Topic:

5. To better understand atmospheric deposition of nitrogen, its source-receptor relationships, and its ecological impacts by combining isotopic analyses, atmospheric modeling, and biological indicators

More Atmospheric-Relevent Science Questions for a post-doc or another student and involved coupled models:

6. How well does WRF-VIC/CropSyst simulate CO_2, CH_4, N_2O, and NH_3 emissions?
    - Add CO_2, CH_4, N_2O to CMAQ and use WRF-VIC/CropSyst (uncoupled and coupled) results to drive CMAQ (and MEGAN , offline from WRF-VIC/CropSyst) simulations
    - Hypothesis: By including a crop model, surface roughness is explicitly modeled (as crops grow and are harvest) and prediction of surface moisture is improved. This should improve meteorological results of WRF, which should then improve CropSyst's predictions
7. What is the impact of fire emissions on nitrogen deposition?
    - Run coupled WRF-BioEarthLand-CMAQ (i.e., "final" coupled model) for selected historical fire cases

Terrestrial/Aquatic Group – WG Ib

Justin Poinsatte's (advised by Dave Evans) Dissertation Topic:
Preliminary modeling with DayCent in 2011-12 analyzed the effects of atmospheric nitrogen (N) deposition on critical biogeochemical processes in subalpine ecosystems of the central Cascade Range. Field data were collected in 2012 that addresses the source of N deposition in snowpack and the biogeochemical cycling of three subalpine vegetation communities. Future objectives are to 1) Use results from the preliminary modeling and data collection to inform manipulative experimental design to measure community-specific responses to elevated N deposition and to 2) Integrate field results with DayCent and RHESSys under modeled climate change scenarios to inform BioEarth and land management decisions.

Keyvan Malek's (co-advised by Claudio Stockle and Jennifer Adam) Dissertation Questions:
By developing a fully coupled large-scale hydrology and cropping system model (VIC-CropSyst), we can address these questions:

1. What is the effect of improvement of irrigation system efficiency on water availability of Yakima River Basin?
2. What are the effects of climate change and different irrigation managements and strategies on agricultural water availability and evaporative losses in the Yakima River Basin?
3. What are the feedbacks of irrigation management on local atmospheric conditions, and how does this impact water demand and overall water resources availability? (this question utilizes the WRF-VIC/CropSyst coupled model)

Mingliang Liu's Research:

1. How do spatial scale representations in RHESSys affect simulations of regional carbon and water fluxes, e.g., for a case study over the Willamette basin (to support WISDM project);
2. How do dynamics of terrestrial ecosystems interact with the regional climate system in the Pacific Northwest (necessitates use of the WRF-VIC coupled model);
3. What are the effects of land-use and land cover change on water fluxes in the Pacific Northwest during 1973-2005.

Kirti Rajagopalan's (advised by Jennifer Adam) Dissertation Questions:

1. What are the effects of climate change (precipitation, temperature, carbon dioxide) and crop mix due to socioeconomic changes on water supply, demand and shortages in the Columbia River basin?
2. What are the effects of climate change on agricultural productivity (irrigated and non-irrigated) in the Columbia River basin? How do the relative effects of changes in precipitation, temperature, and carbon dioxide concentrations impact crop yield at multiple periods in the future; is crop yield response to climate change nonlinear?

Cody Miller's (advised by John Harrison) Research:

Adapt NEWS to run on a regional scale and integrate a spatially explicit wetland component to the regional NEWS model.

Julian Reyes's (advised by Jennifer Adam) Dissertation Research:

1. How do long-term grassland management schemes, such as grazing and cutting (i.e. haying), affect productivity, and stores of carbon and nitrogen in soils and plants?
2. How can these processes by represented in an ecohydrology model? What spatial scales are needed to represent grassland ecohydrology over a range of climatic gradients and management intensities?
3. What are the potential nonlinearities in grassland biogeochemical processes in respond to changes in climatic conditions and management intensities?

Christina Tague's Research Group:

Research questions associated with the California Critical Zone Observatory (see Figure 1 in Appendix)

1. What are the impacts of fine-(micro-meter) scale topographic, vegetation structure and snow heterogeneity on ecohydrologic predictions and their sensitivity to climate variability and change in Sierra catchments? As part of answering this question we use models to develop strategic sampling design to capture soil moisture and vegetation water use patterns in Sierra catchments?
2. How do soil and regolith patterns influence the spatial patterns of ecohydrologic variables (streamflow, transpiration, NPP) and their sensitivity to climate variability and change across an elevation gradient in the California Sierra (and other Western Mountain regions) - a related question that we are asking with geologists as part of the CZO is: how do the interactions among climate, vegetation and soil develop processes influence the evolution of these patterns over long time scales? This extends our previous work on the role of geology in mediating streamflow responses to warming (Tague and Grant, JGR 2009, Tague et al., 2012, HESS)

Cross-Site Vegetation-Streamflow Interactions

Garcia's research explores the influence of forests on streamflow in three western United States mountain watersheds located in Oregon's Western Cascades, Colorado's Rocky Mountains and the California Sierra Nevadas. It focuses on highlighting the regional differences in the influences of climate and landscape characteristics on forest evapotranspiration (ET) and their implications for changes in streamflow. The second part of her work seeks to expand our understanding of forest responses to these primary controls through use of a dynamic vegetation model, focusing on basin-scale changes in streamflow due to changes in plant allocation strategies and asking:

1. How do the timing and magnitude of water and energy inputs (snowmelt, rain/snow partitioning, temperature) change forest ET? How do vegetation characteristics and soil storage influence this relationship?
2. How does a dynamic carbon allocation cycling strategy (i.e., fixed ratio, age-based, resource-based) influence streamflow response under historic climate conditions? How do these responses change with warmer temperatures?
3. How will streamflow respond to changes in forest species at variable spatial extents? How will streamflow recovery to disturbance vary with increasing inter-annual climate variability?

As part of this work, Garcia tests the sensitivity of ET, NPP and streamflow estimates to climate forcing data (in particular inclusion of fine-scale met. features such as cold air drainage in mountain environments - Garcia et al., WRR, in press)

Role of Vegetation-Management (Thinning/Control Burn) on Semi-Arid Forest water use and streamflow

Dugger as the following questions for a semi-arid forested water supply watershed in New Mexico

1. How well does RHESSys capture streamflow, remote-sensing derived forest LAI, inter-annual growth across elevation gradients (based on tree rings) and literature based estimates of forest carbon stores in this region?
2. Based on this model, how will water supply vulnerability for Santa Fe change under different climate and land management scenarios
3. How does streamflow and water partitioning between transpiration and evaporation change under different scenarios of forest management and forest dieback? (Recent observation based literature in the Western US leads to conflicting conclusions about how moderate changes in forest structure (due to drought or thinning) influences streamflow - Here Dugger uses the model to disentangle why these conflicting results may occur)

Drought stress -response of forests

1. How does changing the timing of snow-melt influence the availability for useable water for forests? (in review JGR, Biosciences)
2. Can we capture watershed to regional scale drought-related forest mortality patterns - and the relative influences of changing precipitation magnitude and timing, temperature and forest management activities (thinning, fire-suppression) on these patterns? (Do we need to include explicit representation of insect dynamics and spread independent of drought stress estimates)
3. (first paper in review PLOS)
4. How do forest responses to drought stress influence fire extent?

Economics Group – WG II

1. How can we develop new approaches for integrating traditional equilibrium based economic models with spatially explicit grid cell based economic models? Both rely on optimization rather than simulation but their concepts of equilibrium are very different.

The traditional approach to representing economic decision making in integrated modeling is to aggregate significantly over the spatial dimension to make it possible to define relatively small number of sub-regions that result in a tractable equilibrium optimization model. While this approach does permit accounting for some spatial heterogeneity in growing conditions, through agro-ecological zones or sub-region specific production function parameterizations and resource constraints, it does not allow for spatially explicit modeling. This is a significant problem when modeling regions dominated by irrigated agriculture for a number of reasons. Adaptive responses to climate change by economic "agents" typically reverberate heterogeneously across space due to changes in consumptive use, return flows, water transfers, and cropping patterns. This approach also does not allow for direct coupling to biophysical models that are grid based. The result is that all of the detail in the biophysical model must first be aggregated to the sub-regions of the economic model, which then runs and provides output that must be disaggregated back down. This process throws out a lot of information. There is a significant potential for economic models of irrigated agricultural regions to draw from the regional science and urban economics literature that have begun to enrich grid cell based models developed in geography with a more substantial representation of human behavior. However, a number of obstacles remain that are directly related to model integration. An important science question is to develop approaches for integrating grid cell based spatially explicit economic models with traditional equilibrium models within the larger question of coupling to biophysical models.

2. How can we develop approaches that adequately represent the complex influence of policies that shape how resources are used through legal and regulatory institutions in a way that is simple and generalizable enough to make models tractable?

It is widely recognized that economic models based on mathematical programming tend to overestimate producer response to changes in conditions. Inadequate consideration of constraints on decision making like crop rotations, information costs, time constraints, and cognitive limitations are known to be important but remain difficult to model. Another important factor is the system of water law and regulation that inserts a very complicated layer that is very difficult to adequately abstract within an economic model in any way other than ad hoc restrictions. In order to develop economic models that better predict behavior it is critical to identify ways to consider how resource policy, regulation, and enforcement shape decisions over matters like irrigation intensity, crop choice, and irrigation efficiency. This is in part a question of taking the time to use all available information, but advances can also be made in terms of modeling. A movement towards grid cell based models would make it possible to embed policy related influences on production at a more disaggregate level.

Communications Group – WG III

<u>Liz Allen's Research:</u>
Analyzing perceptions of model development among researchers and stakeholders with the goal of developing effective science communication and stakeholder engagement strategies.

Appendix

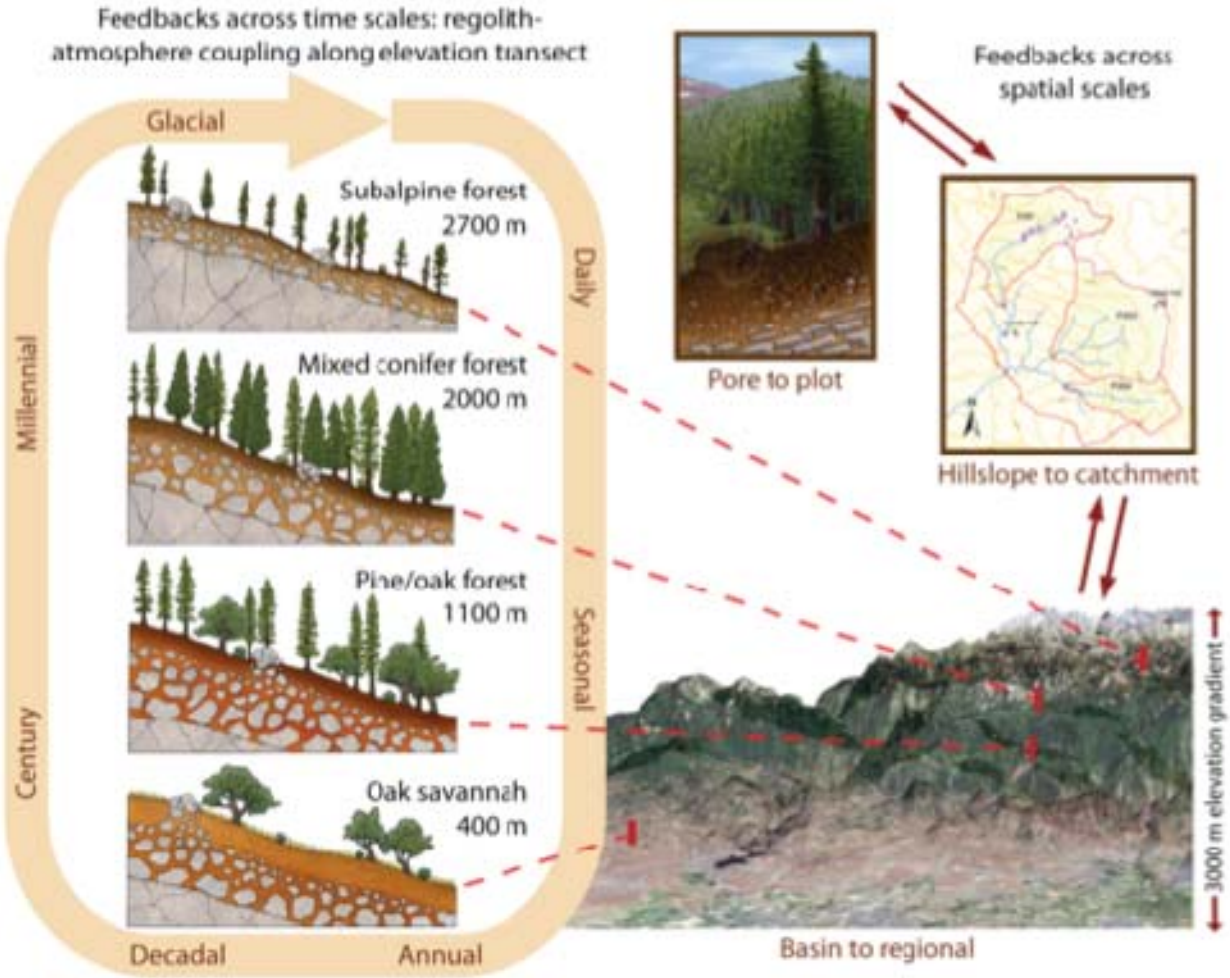

Figure 1. Sierra CZO Conceptual Model