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Calcium (Ca) and iron (Fe) are common major constituents of soils in watersheds and are essential nutrients for plants. Ca is potentially a limiting ecosystem nutrient due to its depletion from soil and biomass pools as a result of both anthropogenically-induced and natural leaching processes. In contrast, Fe is rarely limiting due to its typically greater abundance in soils as a result of the immobility of its oxidized weathering products. Although both Ca and Fe play critical roles in the biogeochemical dynamics of forest ecosystems, their differing chemical affinities provide little reason to expect similarities in biogeochemical behavior at the ecosystem level. However, initial assessments of the isotopic systematics of Ca at a watershed developed on granitoid glacial till in New Hampshire (USA) and of Fe at a watershed developed on marine sediments in northern California (USA) have revealed similar patterns of isotopic distribution and thus a potential linkage between their respective biogeochemical cycles. In each case, easily extractable Ca or Fe in the forest floor is isotopically heavier than residual Ca or Fe; in contrast, easily-extractable Ca or Fe in the deepest mineral soils is isotopically lighter than residual Ca or Fe. The development of these depth distributions of isotopic composition is consistent with either transport of relatively light, easily extractable Ca and Fe from deep mineral soils to shallow soils via plant root networks and/or soil water migration, or retention of relatively light Ca and Fe internally by plants with subsequent redistribution to and concentration in the shallow soils. An important role for the latter process is suggested at the New Hampshire site, where detailed analysis of red spruce tissues reveals that relatively light Ca is retained by foliage and bark, probably as a result of Ca-oxalate formation, and subsequently concentrated in the forest floor through litter deposition. We are currently determining the Fe isotope distribution in the soils at the New Hampshire site, the Ca isotope distribution in the soils and plants at the California site, and the Fe isotope distribution in the plants at both sites in order to understand potential linkages between the Ca and Fe biogeochemical cycles at these watersheds.

H21E CC: 520 A Tuesday 0830h

Advanced Methods for Probabilistic Hydrometeorologic Forecasting I

Presiding: **A Pietroniro,** National Hydrology Research Center**; L Hay,** U.S. Geological Survey

H21E-01 0830h INVITED

The Hydrological Ensemble Prediction Experiment (HEPEX)

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Ensemble forecast techniques are beginning to be used for hydrological prediction by operational hydrological services throughout the world. These techniques are attractive because they allow effects of a wide range of sources of uncertainty on hydrological forecasts to be accounted for. Forecasting should not only offer an estimate of the most probable future state of a system, but also provide an estimate of the range of possible outcomes. Indeed, users are often more concerned with having a quantitative estimate of the probability that catastrophic effects may occur, than with knowing the most probable future state. Not only does ensemble prediction in hydrology offer a general approach to probabilistic prediction; it offers an approach to improve hydrological forecast accuracy as well. The main objective of HEPEX is to bring the international hydrological community together with the meteorological community to demonstrate how to produce reliable "engineering quality" hydrological ensemble forecasts that can be used with confidence to assist the water resources sector to make decisions that have important consequences for the economy and for public health and safety. Representatives of operational hydrological services and operational water resources agencies are expected to participate in helping to define and execute the project. This objective can be achieved if the meteorological, hydrological and water resources communities understand the key challenges they face and work together both to couple currently available forecasts tools and to improve the current quality of available systems. This paper reports on a workshop held at ECMWF to initiate the project and explains project plans for the near future.

H21E-02 0845h

Ensemble Prediction at the Canadian Meteorological Centre

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A global ensemble prediction system (EPS) is running operationally at the Canadian Meteorological Centre (CMC) since February 1998. The number of members was increased from 8 to 16 members in august 1999 and the resolution was increased from 250km to 150km in June 2001. A multi-model approach is used to produce 10 day forecasts once a day. The Spectral Finite Element model (SEF) is used at TL149 and the Global Environment Multi-scale (GEM) model is used at the equivalent 1.2 degree resolution. The initial analyses are produced from an Optimal Interpolation (OI) technique developed at CMC in the early seventies is currently being replaced by an Ensemble Kalman Filter approach developed by Houtekamer and Mitchell. We will describe the new method to obtain the perturbed analyses using the Ensemble Kalman Filter and the verifications obtained to phase out the old OI technique. The ensemble approach is a natural tool to forecast the probability of precipitation (POP). Classes can be defined for different thresholds of 2, 5, 10 and 25 mm of precipitation of 24 hour periods. Improving the resolution of the EPS models has resulted in improvement of the POP over Canadian stations. Results of this evaluation as compared to the operational deterministic model will be shown.

H21E-03 0900h

Probabilistic Runoff Forecasting using a Limited-Area Ensemble Prediction System

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A high-resolution atmospheric ensemble forecasting system, based on 51 runs of a Limited Area Model (LAM) has been used to make probabilistic runoff forecasts for the Alpine Rhine basin. The operational European Centre for Medium-Range Weather Forecasts Ensemble Prediction System (ECMWF EPS) provides the initial and boundary conditions for the LAM integrations with the Local Model (LM) for a 5 day forecasting period. The LM runs in a horizontal resolution of 0.0625 degree (7 km) and provides output with a three hour interval. Output from this model is used to drive a distributed hydrological model with a resolution of 500 m and a time-step of one hour. Runoff generation in the Precipitation Runoff EVApotranspiration Hydrotope (PREVAH) model is based on the HBV-model. The model further contains modules, which calculate snow and glacier melt, after a combined radiation and temperature index approach. The case-study investigated is the November 2002 flood event, in which a deep trough over Europe caused heavy precipitation in northern Italy and south-eastern Switzerland. The area investigated is the Alpine Rhine catchment (6119 km^2) in eastern Switzerland. This river catchment, characterized by highly complex topography, has an altitude range from 410 m up to 3500 m a.s.l. The hydrological model component has been calibrated for the period 1997-1998 using ground observations, and validated for 1999-2002. This study focuses on the feasibility of ensemble prediction data for runoff forecasting and addresses the predictability of this flood event. Forecast uncertainties are investigated and runoff predictions from the deterministic forecast are compared with those obtained from probabilistic atmospheric forecasts. keywords: Ensemble Prediction System (EPS), runoff prediction, forecast uncertainties, coupled meteorological / hydrological models

H21E-04 0915h

Producing and Assessing Short-Term Temperature Ensembles for Ensemble Streamflow Prediction

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An ensemble pre-processor has been developed to generate the short-term precipitation and temperature ensemble forecasts needed for the National Weather Service (NWS) Ensemble Streamflow Prediction (ESP) system that produces probabilistic streamflow forecasts. The meteorological ensemble forecasts are constructed to incorporate the skill of the current single-value forecasts and to account for the forecast uncertainty. The statistical pre-processing estimates the conditional distribution for the future events given the current forecast, from historical pairs of forecasts and observations. A distribution mapping process is then used to re-scale the original ensembles according to this conditional distribution. Finally the resulting synthetic ensembles are ingested by ESP in place of the historical data to produce streamflow ensembles that reflect the meteorological uncertainty. In support of the Advanced Hydrologic Prediction Service, the method has been developed in an operational forecasting environment integrating the existing forecasts used at the River Forecast Centers (RFCs) and is being tested in pilot projects at four RFCs. Verification results are presented for temperature ensembles for the Juniata River basins (Pennsylvania) at Middle-Atlantic RFC and the American River basins (California) at California-Nevada RFC where temperature drives the winter snow hydrology operations. Temperature forecasts are the single-value daily maximum and minimum Model Output Statistics (MOS) temperature forecasts from the Global Forecast System for lead times of one to five days with three to five years of data. The corresponding daily maximum and minimum temperature observed values are generated from the mean areal temperature time series using a fixed diurnal cycle. Daily maximum and minimum temperature ensembles are then generated for lead days one to five and merged to produce a 6-hour mean temperature ensembles based on a user-defined diurnal cycle. Retrospective forecast verification procedures have been developed to compute the Nash-Sutcliffe efficiency, the Heidke and Brier skill scores among other statistics.

H21E-05 0930h

Ensemble streamflow predictions: from climate scenarios to probabilistic weather predictions

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Ensemble streamflow predictions (ESP) are obtained by processing an ensemble of meteorological scenarios through a rainfall-runoff hydrological model to obtain hydrological scenarios. Until recently, these scenarios were typically taken from the climatology. Now that more accurate medium- and long-term numerical weather predictions (NWP) are available, it is tempting to replace climatology by numerical weather forecasts. At least two approaches are possible to take into account the uncerta1000 inty on the meteorological forecast: (1) let a meteorologist propose a subjective

probabilistic forecast based on one or more deterministic NWPs, or (2) take advantage of ensemble meteorological forecasts, which are built precisely to assess the level of uncertainty on the deterministic forecast. Practical solutions to problems encountered with both types of meteorological forecasts are discussed, and the methodology used by Hydro-Québec to score the resulting streamflow forecasts is presented.

H21E-06 0945h

Practical use of ensemble meteorological forecast for streamflow prediction : Examining and correcting the bias in the ensemble meteorological forecast.

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The main source of uncertainty when predicting streamflows using a hydrologic model is meteorological forecasts. It is therefore of great importance to take into account uncertainty due to meteorological events. For this purpose, Hydro-Quebec intends to use ensemble meteorological forecasts. After some preliminary analysis, several problems persist concerning the practical use of ensemble meteorological forecasts for streamflow prediction. For instance :

1. The Canadian meteorological forecasts are given on a coarse grid (1.2 deg in latitude and longitude). Therefore, at best only a few grid points fall within the limits of a typical watershed.
2. There is an obvious bias in temperature and precipitation ensemble forecasts.
3. The ensemble meteorological forecasts are not equiprobable. Therefore, we should eventually assign unequal weights to each member of the ensemble.

In this talk we will first propose several statistical methods to analyse and correct the bias in the meteorological ensemble forecasts. These approaches will be applied and compared on real data on a basin managed by Hydro-Quebec. Then the problem of dowscaling will be discussed. In this work, we consider both classical and Bayesian methods.

H22A CC: 520 C Tuesday 1030h

Linked Biogeochemical Cycles in Forested Watersheds: Details, Dynamics, and Impacts II

Presiding: **T Bullen,** U.S. Geological Survey**; I Creed,** University of Western Ontario

H22A-01 1030h

Contrasting Stream Water Nitrate Concentration in two Nearly Adjacent Catchments Located in the Adirondacks, NY: Investigating the Role of Hydrology

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Recently there has been considerable interest in exploring how hydrologic flowpaths influence the export of solutes such as NO_3^- during hydrological events. We evaluated the mechanisms explaining the marked differences in stream water chemistry during hydrologic events between two nearly adjacent subcatchments in the Archer Creek Catchment in the Adirondack Mountains of New York State. During three fall storms, NO_3^- followed a characteristic dilution curve in Subcatchment 14 (S14) while NO_3^- peaked with peak discharge in Subcatchment 15 (S15). During snowmelt, NO_3^- concentrations remained relatively constant for both S14 and S15. Baseflow NO_3^- concentrations during fall storms and spring snowmelt were as much as three times higher in S14 versus S15. Both hydrometric data and End Member Mixing (EMMA) analysis (a tracer-based analysis) suggested that there were no differences in sources of flow or hydrology during fall and winter events between S14 and S15. The variability in stream water chemistry between the subcatchments was explained by differences in vegetation and soil characteristics. S14 had a higher abundance of sugar maple ($p = 0.04$) associated with greater internal sources of Ca ($p = 0.014$) while S15 had a greater abundance of American beech ($p= 0.006$). Areas with a high abundance of sugar maple are often associated with high rates of nitrification. During the winter, when there was less biotic demand for N, the accumulation of soil NO_3^- was much greater in S14 versus S15. Much of this elevated soil NO_3^- was leached to the groundwater, as evidenced by S14 having much greater groundwater NO_3^- concentrations than S15. Hence, S14 had high baseflow NO_3^- concentrations that were diluted during fall storms in marked contrast to S15 where stream water NO3- concentrations increased during the same storms. These results show that surface water NO_3^- response to storms was a function of the amount of soil NO_3^- generated within the subcatchments.

H22A-02 1045h

The Influence of Soil Calcium Availability on Forest Vegetation and Nitrate Concentrations in Surface Waters.

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Recently there has been a growing interest in the role of calcium (Ca^{2+}) availability affecting nitrate production and export in forested watersheds. The relative abundance of calcium can affect soil pH, vegetation communities, litter quality, and consequently nutrient cycling rates. We evaluated two nearly adjacent subcatchments, S14 and S15, in the Archer Creek Catchment in the Adirondack Mountains of New York State with significant differences in stream water calcium (851 and 427 μmolc L^{-1}, respectively) and nitrate (73 and 26 μmolc L^{-1}, respectively). These differences in stream chemistry could not be attributed to variations in physiographic or hydrological characteristics, land use history, or atmospheric deposition. Soil analyses, however, indicate that S14 had significantly higher concentrations of Ca^{2+} and higher pH in both organic and mineral (0-10 cm) horizons. Additionally, nitrification rates in the organic horizon of S14 were also significantly higher relative to S15. Vegetation surveys show significantly greater stocking of sugar maple (Acer saccharum), American basswood (Tilia americana), and hophornbeam (Ostrya virginiana) in S14, and significantly greater American beech (Fagus grandifolia) and white pine (Pinus strobus) in S15. We are currently using calcium isotopes ($^{44}Ca/^{40}Ca$) to identify sources and pathways in the two catchments to determine if Ca^{2+} in the mineral soil (15-100 cm) is principally from mineralized organic matter or from weathered sources not fractionated by biological uptake.

H22A-03 1100h INVITED

Coupled Nitrogen and Calcium Cycling in Forests across a Gradient of Soil Nitrogen Availability

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Nitrogen (N) is a critical limiting nutrient that regulates plant productivity and the cycling of essential base cations in forests. Increases in N availability beyond the threshold of plant and ecosystem needs may drive non-linear biogeochemical changes that include excess nitrate leaching and base cation depletion from soils. While such variations in N cycling are typically associated with polluted regions, comparable changes may also occur in unpolluted forests of the Pacific Northwest due to legacies of soil N enrichment from biological N fixation in red alder. We sampled 22 young Douglas-fir stands in the Oregon Coast Range, and found that surface soil calcium (Ca) and magnesium (Mg) concentrations were inversely related to N across a gradient from 0.15 to 1.1 soil %N. Strontium isotope ratios indicate that N-rich forests are decoupled from weathering, and obtain $> 97\%$ of base cation nutrition from marine sea-salt aerosols. However, high Ca:Mg ratios of plant demands relative to aerosol inputs selectively fosters Ca deficiency at high soil N. Plant and soil patterns were similar for sandstone versus basalt derived soils, indicating that biological N availability - not bedrock - can be the primary control of coupled N and base cation cycling across areas of high N enrichment.

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H22A-04 1115h

Untangling the tales of red spruce growth decline in Great Smoky Mountains National Park

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Concern exists as to the status of red spruce (Picea rubens Sarg.) in the Great Smoky Mountains, with evidence both for and against an unprecedented decline in radial growth during the past century. Based on a dendrological record from 1850 to 1998, our analyses support a decline in radial growth starting as early as the 1940s through to the 1970s; in the 1970s there was a reversal of this decline. In comparing trees near ridges (2000 m) versus in draws (1500 m), we found differences in the (a) timing of the decline, (b) rate of decline, and (c) homogeneity of the decline, with trees near ridges showing earlier, faster, and more homogeneous declines that trees in draws. We hypothesized that changes in climatic conditions and/or atmospheric pollutants, both of which changed beyond ranges of natural variability, were related to the observed decline in radial growth. In trees near ridges, up to 67.1% of changes in radial growth could be explained by a combination of climatic conditions (7.6%) and annual emissions of nitrous oxides (NOx) and sulfur dioxide (SO2) (an additional 59.5%). In trees from draws, up to 38.3% of the changes in radial growth could be explained by climatic conditions only. A conceptual model is presented where trees in naturally acidic soils with low base saturation provide a sensitive signal for the changing nature of acidic pollutants, but trees in anthropogenically acidifying soils with an initially higher baser saturation provide a signal that is confounded by a transient increase of calcium (Ca) and magnesium (Mg) in the soil that results in a transient increase in radial growth.