for liquid CO_2 flow. Calculated zeta potentials are -3.4 mV using water as the pore fluid and -1.7 x 10-6 mV for liquid CO_2. We propose that the lower coupling coefficient for CO_2 flow is primarily a result of changes in zeta potential, since changes in pore fluid resistivity and viscosity would act to increase the coupling coefficient. Zeta potential for the liquid CO_2 / mineral interface is a function of the low polarity and lack of mobile ions associated with liquid CO_2. We find no anomalous 2-phase liquid/gas effects, which may have augmented single-phase streaming potentials by many times. We propose that although CO_2 gas may have been present for some of the higher pressure drop events, the low gas fraction (or quality) of the two-phase mixture did not lead to any significant anomalous or augmented observations. Implications of this work include spatial and temporal monitoring of CO_2 injectate in subsurface reservoirs and the identification of flow paths, with the recommendation being to attempt to image the advancing CO_2/water front, where the coupling coefficient is higher.

GC32A-0205 1330h POSTER

CIRF.B Reaction-Transport-Mechanical Simulator: Applications to CO2 Injection and Reservoir Integrity Prediction

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An important component of CO_2 sequestration in geologic formations is the reactions between the injected fluid and the resident geologic material. In particular, carbonate mineral reaction rates are several orders of magnitude faster than those of siliciclastic minerals. The reactions between resident and injected components can create complex flow regime modifications, and potentially undermine the reservoir integrity by changing their mineralogic and textural compositions on engineering time scale. This process can be further enhanced due to differences in pH and temperature of the injectant from the resident sediments and fluids. CIRF.B is a multi-process simulator originally developed for basin simulations. Implemented processes include kinetic and thermodynamic reactions between minerals and fluid, fluid flow, mass-transfer, composite-media approach to sediment textural description and dynamics, elasto-visco-plastic rheology, and fracturing dynamics. To test the feasibility of applying CIRF.B to CO_2 sequestration, a number of engineering scale simulations are carried out to delineate the effects of changing injectant chemistry and injection rates on both carbonate and siliciclastic sediments. Initial findings indicate that even moderate amounts of CO_2 introduced into sediments can create low pH environments, which affects feldspar-clay interactions. While the amount of feldspars reacting in engineering time scale may be small, its consequence to clay alteration and permeability modfication can be significant. Results also demonstrate that diffusion-imported H^+ can affect sealing properties of both siliciclastic and carbonate formations. In carbonate systems significant mass transfer can occur due to dissolution and reprecipitation. The resulting shifts in in-situ stresses can be sufficient to initiate fracturing. These simulations allow characterization of injectant fluids, thus assisting in the implementation of effective sequestration procedures.

GC32A-0206 1330h POSTER

Identification of bottom-simulating reflectors related to gas hydrates, silicate diagenesis, and other P/T dependent sediment processes

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Large quantities of the green-house gas methane exist in the form of gas hydrate within continental margin sediments. Bottom-simulating reflectors (BSR) are the most prominent geophysical indication for such gas hydrate reservoirs, but there are other geological processes that create similar seismic phenomena. It is therefore important to analyse the seismic character of different BSR in order to be able to distinguish between them. Three classes of BSR cross-cut the post-breakup sediments of the mid-Norwegian margin. The first class is caused by gas hydrates, which trap free gas at the base of their pressure- and temperature-dependent stability zone. The second class of BSR is caused by the diagenetic transition from opal A to opal CT. The third class is always observed underneath the opal A / opal CT transition but heat flow data and the amplitude characteristics of this event exclude one of the known silicate diagenetic transitions or gas hydrates as the explanation for this arrival. ODP Site 643 drilling results suggest two possible processes as the reason for this BSR: (a) smectite dewatering, or (b) a sudden increase in the abundance of authigenic carbonates. The genesis of both is pressure- and temperature-dependent and could potentially result in a cross-cutting seismic reflector. The data are not conclusive as to which process is causing the observed third class of BSR. Comparison of the seismic characteristics of the different types of BSR shows that apparent polarity without previously applied automatic gain control is the best way to distinguish between them, as gas hydrate related BSR have reverse polarity and the diagenetic transitions cause normal polarity BSR. On the other hand, seismic amplitude variations can be very similar for all classes of BSR.

GC32A-0207 1330h POSTER

CO_2 Extraction from Ambient Air Using Alkali-Metal Hydroxide Solutions Derived from Concrete Waste and Steel Slag

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To mitigate global climate change, deep reductions in CO_2 emissions are required in the coming decades. Carbon sequestration will play a crucial role in this reduction. Early adoption of carbon sequestration in low-cost niche markets will help develop the technology and experience required for large-scale deployment. One such niche may be the use of alkali metals from industrial waste streams to form carbonate minerals, a safe and stable means of sequestering carbon. In this research, the potential of using two industrial waste streams—concrete and steel slag—for sequestering carbon is assessed. The scheme is outlined as follows: Ca and Mg are leached with water from a finely ground bed of steel slag or concrete. The resulting solution is sprayed through air, capturing CO_2 and forming solid carbonates, and collected. The feasibility of this scheme is explored with a combination of experiments, theoretical calculations, cost accounting, and literature review. The dissolution kinetics of steel slag and concrete as a function of particle size and pH is examined. In stirred batch reactors, the majority of Ca which dissolved did so within the first hour, yielding between 50 and 250 $\frac{mg\ Ca}{g\ slag}$ and between 10 and 30 $\frac{mg\ Ca}{g\ concrete}$. The kinetics of dissolution are thus taken to be sufficiently fast to support the type of scheme described above. As proof-of-concept, further experiments were performed where water was dripped slowly through a stagnant column of slag or concrete and collected at the bottom. Leachate Ca concentrations in the range of 15 mM were achieved — sufficient to support the scheme. Using basic physical principles and numerical methods, the quantity of CO_2 captured by falling droplets is estimated. Proportion of water loss and required pumping energy is similarly estimated. The results indicate that sprays are capable of capturing CO_2 from the air and that the water and energy requirements are tractable. An example system for enacting the scheme is presented, along with capital and operational cost estimates. The system is found to be profitable for carbon credits above \$5/$ton\ C$. Many findings in this research apply to a more general set of systems which capture CO_2 from the air for sequestration. The metal-hydroxide solution in these systems is regenerated on site, allowing application of this scheme on as large a scale as needed. Implications of this study's findings for these more general carbon-capture systems is discussed.

GC52A MCC: 3010 Friday 1340h

Reconstructing Hydroclimatic Variability in North America: Progress, Methods, and Uncertainties I *(joint with H, PP)*

Presiding: **C Woodhouse,** NOAA Paleoclimatology Branch**; R Webb,** NOAA/OAR Climate Diagnostics Center

GC52A-01 1340h INVITED

The North American Drought Atlas

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A large part of the western US has been experiencing unusually severe and persistent drought over the past 5 years. This drought highlights both the vulnerability of this semi-arid region to shortfalls in rainfall and the need to better understand long-term drought variability and its causes in North America. To this end, centuries long, annually-resolved tree-ring records have been used to reconstruct annual changes in both drought and wetness over large portions of North America. The drought metric used for this purpose is the summer-season Palmer Drought Severity Index (PDSI). The PDSI reconstructions have been produced on a 297-point $2.5x2.5^\circ$ regular grid that covers most of North America. This new generation of North American drought reconstructions was made possible through support from the NOAA Office of Global Programs. These drought reconstructions, some of which extend back almost 2,000 years into the past, have been used to create a North American Drought Atlas that provides a detailed spatial and temporal history of drought and wetness. This effort has been supported by the NSF Paleoclimatology Program. The North American Drought Atlas, which will be available on a CD-ROM and can be accessed inter-actively using standard web browsers, has been created to make the drought reconstructions easily accessible. Each of the 297-point summer PDSI reconstructions, with their estimated uncertainties, can be displayed in PDF format. There are also 1,992 annual PDSI maps also in PDF format that can be selected and displayed by year. The annual maps have also been linked together into an animation to provide a dynamic look at patterns of drought and wetness as they develop across parts of North America where tree-ring estimates exist back in time. The numerical values of the PDSI reconstructions will also be available on the CD-ROM for independent analyses. Some properties of past reconstructed drought over North America will also be described in context with that which is currently afflicting the western US. In particular, an examination of the area affected by drought conditions of at least incipient severity (i.e., $PDSI < -1$ or worse) reveals the occurrence of a prolonged period of elevated aridity over the western US during the AD 850-1300 interval. This dry epoch, which is arguably a hydrologic expression of the Medieval Warm Period, is unprecedented over the past 1,200 years. If this is an indication of how warmer conditions in the past have affected the incidence of drought in the western US, it cannot be viewed as good news as we enter into a warmer world increasingly forced by greenhouse gases.

GC52A-02 1400h

The Atlantic Basin as a Source for North American Drought: New Perspectives from Proxy Climate Networks

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Investigations into the causes of severe, persistent droughts in North America have focused primarily on interannual (ENSO) to decadal-scale (PDO) variability in Pacific sea surface temperatures (SST). This, in turn, has justified rapid development of high-resolution proxies to extend Pacific SST fields beyond the instrumental record. However, recent studies show that low-frequency (30-70 yr) modes in North Atlantic ($0 - 70^\circ$

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N) SST, the so-called Atlantic Multidecadal Oscillation (AMO), may influence long-term summer moisture trends and modulate Pacific teleconnections over North America. To examine this linkage, we compare a new, tree-ring based proxy for the AMO (A.D. 1567-1991) with gridded reconstructions of drought (1700-1978) and hydroclimatic variability (late 1500s-Present) across North America. Our AMO reconstruction, which includes 13 tree-ring chronologies from Eastern North America, Western Europe, Scandinavia and the Middle East, captures both interannual (r = 0.78) and decadal-scale (10 yr) variability (r = 0.94) in observed SST over the North Atlantic Basin. Reconstructed AMO is significantly correlated with reconstructed drought frequency and intensity throughout North America, particularly in the central and southern Rockies and western Great Plains. This is not only true for the interval of the gridded PDSI reconstructions (1700-1978), but also for a suite of proxy records from the Western US that overlap with the complete AMO reconstruction. Specifically, the late-16th and mid-20th Century (1930s and 1950s) "megadroughts", as well as current drought in the Western US, occurred during strong, persistent warm phases of the AMO. In addition, wet spells in the early 17th, 19th and 20th centuries correspond with cool regimes in North Atlantic SST. The coherency of drought events across major river basins and climatic regions of the Western US also increases when warm phases of the AMO coincide with cool phases of the PDO. Overall, these analyses demonstrate the potential for using Atlantic SSTs to understand drought variability throughout North America, and the need to reevaluate Pacific-North American teleconnections in light of larger-scale SST fluctuations.

GC52A-03 1415h

Melting Arctic Sea Ice Dries the American West

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Over the last century, Arctic sea ice cover has decreased dramatically and many researchers expect that future greenhouse warming will exacerbate this trend. The prospect of a warmer Arctic with less ice raises many environmental and economic questions, one of which is: How will reduced Arctic ice cover effect extrapolar climates? Using the fully coupled NCAR CCSM we completed a multi-century simulation of global climate responses to reduced Arctic sea ice cover. While the global average climate response is muted, regional responses to the imposed forcing are significant. One of the more striking regional responses is a shift in storm tracks that drives a 50-100% increase in annual evaporation minus precipitation over the American West, a region where limited water resources are already a significant problem. This result highlights two well-known aspects of climate change: (1) relatively small global changes can be composed of significant regional changes and (2) changes in one region can have a large impact on distant locations. Both of these facts will become increasingly important as researchers and policy makers attempt to untangle the looming thicket of climate change impacts and feedbacks.

GC52A-04 1430h

A Widespread Trend Towards Earlier Streamflow Timing Across North America Over the Past 5 Decades

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This study examined the year-to-year variations in the timing of streamflow since the late 1940's for a network of gauges across North America from the United States and Canada. Within this network, a predominant fraction of streams exhibit a trend towards earlier occurrence of the major seasonal flows. Advances in seasonal flows ranged from one to four weeks earlier. This result is seen from inspection of monthly and seasonal fractional flow, the date of the center of mass for flow (CT), and for snowmelt-dominated streams, the start of snowmelt streamflow pulse. There is considerable spatial coherence of streamflow timing changes in regions including much of western North America, the Midwestern United States, and the Atlantic region. Both snowmelt and non-snowmelt dominated streams exhibited earlier streamflow timing, although non-snowmelt streams in the far western United States tended to display later timing. The earlier timing of snowmelt-derived streamflow in the western United States and western Canada was most strongly connected with warmer winter and spring temperatures. Surprisingly though, significant trends towards earlier timing of streamflow are not only observed throughout the West, but also in three eastern and southern regions of North America, where precipitation and streamflow are more evenly distributed throughout the water year. Correlations of streamflow timing with Pacific Decadal Oscillation (PDO) and the Southern Oscillation Index (SOI) indicate that a significant fraction of the variability is related to interannual and decadal climatic modes.

GC52A-05 1445h

Continental Summer Dryness in the New GFDL Climate Model

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In this work, we revisit the question of continental summer drying in a doubled-CO2 environment using the latest version of the Geophysical Fluid Dynamics Labs (GFDL) model of the atmosphere and land surface coupled to a mixed layer (slab) ocean. Two highly significant differences between this new model and earlier GFDL models are the increased resolution (2.5° longitude x 2.0° latitude and 17 vertical levels vs. 3.75° longitude x 2.25° latitude and 14 vertical levels for the previous model), and the inclusion of both a diurnal cycle and a seasonal cycle (the earlier models only had the latter). Results from these earlier models showed, among other things, an increase in wintertime rainfall over most mid-latitude continental regions when CO2 is doubled, an earlier snowmelt season and onset of springtime evaporation, and a higher ratio of evaporation to precipitation in summer. These factors led to large-scale increases in soil moisture in winter and decreases in summer in mid-latitudes in the doubled-CO2 experiment. The new model shows similar results, and the processes discussed above are important in this model as well. In addition, we find that changes in atmospheric circulation are playing an important role in regional hydrologic changes, particularly in Western Europe. Additional experiments have been run to isolate the feedback from the land surface from the role of the atmospheric changes caused by the doubling of CO2. These simulations show that the CO2 impacts alone explain the majority of the results, while the land surface feedbacks serve to strengthen the observed signals. Experiments to isolate the role of the CO2-induced changes to the sea surface temperature on the atmospheric circulation are currently underway.

GC52A-06 1500h INVITED

Columbia River Flow And Drought Since 1750

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A network of drought sensitive tree-ring chronologies is used to reconstruct flow on the Columbia River at The Dalles, Oregon, since 1750. The reconstruction explains 30 percent of the variability in mean water-year flow, with a moderate fraction of unexplained variance caused by underestimates of the most severe low-flow events. Residual statistics from the tree-ring reconstruction, as well as an identically specified reconstruction using instrumental records, exhibit a positive trend over the twentieth century. This finding suggests that the relationship between drought and streamflow has changed, consistent with results from hydrologic models. Both the reconstructed streamflow and the models suggest that changes in land cover over the 20th century have led to increases in runoff relative to precipitation. Lowpass filtering the reconstructed flow record suggests that persistent low flows during the 1840s were probably the most severe of the past 250 years, but that flows during the 1930s were nearly as extreme. The period from 1950 to 1987 is anomalous in the context of this record for having no notable multiyear drought events. A comparison of the flow reconstruction to paleoproxy records of the Pacific Decadal Oscillation (PDO) and El Niño / Southern Oscillation (ENSO) supports a strong 20th century link between large-scale circulation and streamflow, but suggests that this link is very weak prior to 1900.

GC52A-07 1520h INVITED

Quantifying Hydrologic Drought in the Sierra Nevada With Tree Rings: A Frequency-dependent Approach

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Tree-ring reconstructions for the Sierra Nevada suggest that extended droughts uncharacteristic of the instrumental period occurred more than 500 years ago. Were comparable droughts to occur today, they would likely stress water supplies in even those large basins where reservoir storage serves as a buffer against climate fluctuations. The reconstructed severity and duration of such droughts depends critically on the low-frequency runoff signal in tree rings. Yet in the Sierra Nevada, the low-frequency component of tree growth is sometimes disparate in different species, and even in different chronologies of the same species. Moreover, a sharp increase in tree-ring index over the last 100 years is present in many chronologies yet absent from the observed streamflow records. To address these discrepancies, a frequency-dependent approach to reconstruction is proposed. The main difference from the conventional reconstruction approach is filtering to separate the high-frequency and low-frequency components prior to reconstruction. Different subsets of chronologies may be selected as predictors for the two components, depending on their correlation with streamflow at the high and low frequencies. PCA is incorporated to condense the frequency-dependent variance common to multiple chronologies. The method is illustrated in a reconstruction of annual flow of the San Joaquin River, California, and results are compared with those of a more conventional reconstruction. Ranking of tree-ring chronologies by relative strength of runoff signal was found to differ markedly in the high and low frequencies. Reconstructions by the two methods are similar for the 20th century calibration period, but differ greatly at times in the distant past. For example, the frequency-dependent approach accentuates the severity of a drought in the early 1300s and the magnitude of a shift from dry to wet conditions near A.D. 1600. The method may be useful in posing alternative scenarios of severe sustained drought consistent with variations in tree growth.

GC52B MCC: 3010 Friday 1600h

Reconstructing Hydroclimatic Variability in North America: Progress, Methods, and Uncertainties II *(joint with H, PP)*

Presiding: **C Woodhouse,** NOAA Paleoclimatology Branch**; R Webb,** NOAA/OAR Climate Diagnostics Center

GC52B-01 1600h

Colorado Streamflow Reconstruction Network: A Basis for New Dendrohydrologic Techniques, Analyses, and Applications

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We have developed a dense network across Colorado of 60 moisture-sensitive tree-ring chronologies, 300-800 years long, creating a unique resource for hydroclimatic reconstructions. This network is the basis for collaborative work with major Colorado water providers to develop high-quality streamflow reconstructions for gages critical to water management in the Upper Colorado, Gunnison, and South Platte River basins. The