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The Southern Ocean produces much of the deep and bottom waters of the global ocean, hence is a major conduit by which the abyssal ocean communicates with global climate. Given the vast heat content and area of the ocean around the Antarctic continent, along with recent paleoceanographic evidence that the Southern Ocean dominated bottom water production during the last glacial maximum, it is plausible that deep convection there is at least as important for climate change as its better known counterpart in the North Atlantic. Understanding ocean dynamics in the Antarctic thus represents an important missing component in the quest for realistic climate simulation and prediction. A special session of the 2002 Spring Polar Research Board meeting addressed several aspects of the connection between Southern Ocean dynamics and climate, including: (i) the critical role of remote sensing for observing the system (Comiso); (ii) the intricate coupling between the ocean and vast floating shelves of continental ice (Holland); (iii) sea-ice variability and teleconnections with well known atmospheric indices (Martinson); (iv) wintertime stability of the upper ocean and possible triggers for a mode change in deep convection (McPhee); (v) pathways by which cold, dense water formed in the Antarctic finds its way to the rest of the abyssal world ocean (Padman); and (vi) recent atmospheric circulation trends and possible connections with the stratosphere (Thompson). A recurrent theme was the paucity of data from this remote part of the globe, particularly during winter. A brief review of the PRB session and other recent findings will suggest that programs designed to significantly expand our knowledge of the Southern Ocean should be a major thrust in the upcoming International Polar Year.

C32C-05 1715h

Antarctic Array: A vision for seismology on an ice-bound continent

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Antarctic Array is an emerging initiative designed to improve the understanding of the structure and evolution of the Antarctic continent by advancing seismic instrumentation on Antarctica. A long list of scientific questions motivate the development of Antarctic Array. Some of these questions are common to all continents; such as, How has Antarctica grown and evolved and what are the processes that have shaped the lithosphere? Others questions relate to Antarctica's unique position as the keystone in the paleo-history of supercontinent formation and break-up throughout Earth's history, as well as its present unique tectonics and geochemistry. In this context, the scale and nature of rifting as a process that has shaped the continent and dominated its evolution is of primary importance. Still other questions are unique to the Earth's single ice-bound continent; for example, How do lithospheric processes drive and how may they be driven by global environmental change (sea level, climate)? Also, how does the tectonic and thermal structure of the Antarctic lithosphere affect current ice sheet dynamics? A workshop to discuss Antarctic Array was held in Boulder, CO USA in March, 2003, entitled "Structure and Evolution of the Antarctic Plate 2003". A preliminary science plan for Antarctic Array is currently being developed by the Science Team. Antarctic Array is envisioned to encompass four components, with significant similarities to the rapidly developing Earthscope USARRAY technology: (1) process-oriented experiments along the line of PASSCAL experiments, (2) an active source system, (3) a set of evolving regional arrays with a "pinwheel" geometry, and (4) an enhanced permanent "backbone" network. Antarctic Array is currently scheduled to initiate as part of the International Polar Year. Developments can be followed at the Antarctic Array web site (www.antarcticarray.org).

URL: http://www.antarcticarray.org

C32C-06 1730h

Opportunities and Challenges for Arctic Geoscience in the IPY (International Polar Year)

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Anyone who has seen a weather map of the northern hemisphere understands that the Arctic Ocean has a climatic and oceanographic influence far beyond its limited geographic extent. This influence is not matched by our understanding of the basin history. For example, we do not know when sea ice first covered the Arctic Basin. The detailed geologic composition and history of major morphologic features, ridges, plateaus and margins is unknown. We could learn the coupled histories of the ocean basin and high latitude climate from the record preserved beneath the Arctic seafloor. Capturing this buried history requires a coordinated program of site surveying and drilling in the Arctic. The IPY is an opportune time to concentrate on this program. Over the past fifty years, we have learned the history of the continents from understanding the histories of the adjacent ocean basins. In the Arctic, we have inferred the history of the Amerasian basin from the limited stratigraphic record exposed on the Canadian and American continental margins. Large tectonic features, such as Lomonosov Ridge, the Alpha-Mendeleev Ridge, Makarov Basin, the Canada Basin and a number of continental margin features are virtually unknown. Reconstructions of the paleogeography of the northern hemisphere prior to Cenozoic times are hypothetical and can only be solved by deciphering the plate tectonic puzzle of the Mesozoic Arctic. Continental margins and sedimentary basins of polar and sub-polar areas contain large quantities of natural resources. The geological history of the northern hemisphere and the framework for the formation of such resources cannot be reconstructed properly if the nature and evolution of the basement of the Arctic Ocean is not determined by directly sampling basement rocks. The IPY offers an opportunity for a coordinated assault on the unsolved problems of the Arctic Ocean. The primary scientific goals during the IPY would be to understand: A) the climatic and paleo-oceanographic evolution of the Arctic region and its effects on global climate, the biosphere and the dynamics of the world ocean and atmosphere; and B) the nature and evolution of the major structural features of the Arctic Ocean Basin and circum-Arctic continental margins. NAD (Nansen Arctic Drilling Program) has suggested that the primary target areas in a first phase of drilling in the Arctic Ocean are the rises and plateaus. Here, the sediments are primarily biogenic fallout from the water masses and hemipelagic/pelagic clays. A later phase of drilling would give priority to the deep ocean basins where the water depth is 4000 m or greater and the sediment thicknesses are greater than 1 km. A major part of all plateaus and ridges would be accessible with a water depth capability of 1500 m except for Alpha Ridge. While the logistics of this work would be quite difficult, the drilling itself would present few challenges. From the available seismic reflection records it appears that 500m of penetration would reach basement on all plateaus and ridges as well as the major unconformity on the Lomonosov Ridge, which overlies a Mesozoic-aged passive margin, the European edge of the Mesozoic Arctic Ocean. This could be the most scientifically productive drilling ever undertaken (per meter).

C32C-07 1745h

Study of Environmental Arctic Change (SEARCH) and the IPY

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Recent studies of the arctic environment have revealed unexpected changes including lower sea-level atmospheric pressure, increased air temperature over most of the Arctic, but lower temperatures over eastern North America and Greenland, changed ocean circulation and rising coastal sea level, warmer Atlantic waters penetrating farther in the Arctic Ocean, reduced sea ice cover, and thawing permafrost. These changes are affecting every part of the arctic environment and are having repercussions on society. To understand the recent observations and put them into the context of natural variability and anthropogenic forcing, a multidisciplinary, multi-agency program, has recently been developed. This program, SEARCH (Study of Environmental Arctic Change), has the potential to significantly contribute to the IPY by creating a framework for extensive new observations and placing the results into the context of a changing physical, biological, and social environment. Our contribution will outline SEARCH and explore its possible connectivity with the IPY.

C41A MCC: 3002 Thursday 0800h

Ice-Ocean Interactions and the Cryosphere II *(joint with OS, GC)*

Presiding: **M A Lange,** University of Muenster**; D MacAyeal,** University of Chicago

C41A-01 0800h

STABILITY OF ANTARCTIC ICE SHELVES AND THEIR ROLE IN THE GLOBAL CLIMATE SYSTEM

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The Earth's radiation budget, a key determinant of global climate, depends critically on the spatial distribution of surface albedos of our planet. Climate is also driven by major oceanic transport and exchange processes. In that regard, the polar regions play a particularly decisive role. While attention has so far mainly been paid to the annual and inter-annual variability of polar sea ice covers, a number of recent dramatic changes, i.e., the disintegration of the Larsen A- and parts of Larsen B Ice Shelves as well as the major calving events of Filchner-Ronne- and Ross Ice Shelves have led to renewed interest in the role of ice shelves for the global climate system. In this regard, it is not only the disintegration of ice shelves itself that is of particular concern. Ice shelves are known to play a distinct role in the overall stability of the (West-) Antarctic Ice Sheet. Thus, ice shelf disintegration could lead to instability of (parts of) the Antarctic ice cover, with corresponding consequences for the global albedo. Furthermore, the disintegration of major ice shelves will ultimately lead to a significant change of Antarctic Bottom Water (AABW) formation with widespread implications for the world ocean and ultimately global climate. In this paper we will, firstly based on a conceptual model, elucidate the possible impact chain leading from initial regional climate warming, over surface processes on the ice shelves and an increase in calving events to their possible disintegration. We will strive to consider possible feedback between reduced ice shelf surface area and sub-ice shelf exchange processes and their role for global climate and AABW formation. The more qualitative conjectures will be compared with first results from coupled ice shelf-ocean models under varying climate conditions.

URL: http://earth.uni-muenster.de/projekte/clivar.html

C41A-02 0815h

Coupled Ice Shelf – Ocean System Simulations for Different Climate Scenarios

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Based on a new approach for coupled applications of an ice shelf model and an ocean general circulation model, we investigate the evolution of an ice shelf - ocean system and its sensitivity to changed climatic boundary conditions. Combining established 3-d models into a coupled model system enables the investigation of reactions and feedbacks of each component to changes at their interface, the ice shelf base. After calculating the dynamics for prescribed initial ice shelf and bathymetric geometries, the basal mass balance determines the system evolution. In order to explore possible developments for given boundary conditions, an idealized geometry has been chosen, reflecting principle features of the Filchner-Ronne Ice Shelf, Antarctica. The model system is found to be especially sensitive in regions, where high ablation or accretion rates occur. Ice Shelf Water formation as well as the built up of a marine ice body, resulting from accretion of marine ice, is simulated, indicating strong interaction processes. Experiments under different climatic conditions (ocean warming of 0.2°C and 0.5°C and doubled surface accumulation rates) show the coupled model system to be sensitive especially to ocean warming. Increased basal melt rates of 100 % for the 0.5°C ocean warming scenario and an asymmetric development of ice shelf thicknesses suggest a high vulnerability of ice shelf regions, which represent pivotal areas between the Antarctic Ice Sheet and the Southern Ocean.

C41A-03 0830h INVITED

Melting and Freezing Under the Ross Ice Shelf: Lessons From an Impacted Cavity

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The dimensions of ice shelves are strongly influenced by the temperature and circulation of the underlying ocean. Inflow temperatures vary by about three degrees, with most ice shelves floating in seawater near the in situ freezing point. Circulation under the ice depends on modifications of the thermohaline field by melting, freezing and tidal mixing, which determine the vertical stratification and heat flux. Observations near ice fronts have previously been used to estimate the amount of meltwater present in outflows from ice shelf cavities. While limited by the seasonality and dynamic range of the measurements, along with discrete sampling methods and uncertain source water assumptions, geochemical data add valuable information to the more commonly utilized temperature and salinity fields. Here we evaluate repeat chlorofluorocarbon and thermohaline sections in a region that has experienced a multidecadal decline in shelf water salinity. Inferences about net basal melting are compared with results from numerical models and bottom-moored instruments. Ice shelf cavities are sinks for much of the high salinity shelf water produced by sea ice formation. Outflows from those cavities reflect the properties of shelf water inflows, and affect the salinity and density of downstream bottom water production. We suggest future work that could help to better understand ocean forcing of ice shelf change in an evolving climate.

C41A-04 0845h INVITED

Seasonal Ventilation of the Cavity Beneath Filchner-Ronne Ice Shelf Simulated With an Isopycnic Coordinate Ocean Model

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The ocean cavity beneath Filchner-Ronne Ice Shelf is observed to respond to the seasonal cycle of water mass production on the continental shelf of the southern Weddell Sea. Here we use a numerical model to investigate the propagation of newly-formed shelf waters into the cavity. We find that the model reproduces the most distinctive features of the observed seasonality and offers a plausible explanation for those features. The most saline shelf waters are produced in the far west, where the inflow to the cavity peaks twice each year. The major peak occurs during the short period around mid-winter when convection reaches full-depth and the densest waters are generated. Once the surface density starts to decline, dynamic adjustment of the restratified water column leads to a gradual fall in the salinity at depth and a secondary peak in the inflow that occurs in summer at the western coast. Beneath the ice shelf, the arrival of the wintertime inflow at the instrumented sites is accompanied by a rapid warming, while the slower decline in the inflow leads to a more gradual cooling. Water brought in by the secondary summer peak flows mainly to the eastern parts of the cavity. Here the seasonality is suppressed because the new inflows mix with older waters that recirculate within a topographic depression. This pooling of waters in the east, where the primary outflow of Ice Shelf Water is generated, dampens the impact of seasonality on the local production of Weddell Sea Bottom Water.

C41A-05 0900h

The Ice Shelf - Ocean Model Intercomparison Project (ISOMIP)

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The Ice Shelf - Ocean Model Intercomparison Project (ISOMIP) is currently being proposed as an open, international effort to identify systematic errors in sub-ice shelf cavity ocean models. ISOMIP intends to bring together the international modeling community for a comprehensive evaluation and validation of current sub ice shelf cavity ocean models. In the preliminary stages of the project, idealized forcing and geometry are to be used (including physical laboratory data); latter stages will involve realistic forcing and geometry. Model results will be contrasted and compared so as to understand model strengths and weaknesses. This process will be assisted by use of a Live Access Server (LAS) dedicated to ISOMIP. In this presentation, the first intercomparison results from the project are presented and discussed. The intercomparison activity is expected to provide valuable information on improving such models as well as likely result in a better understanding of the processes that control the exchange of waters between the sub ice shelf cavity and the open ocean, and hence the role such cavities play in climate and climate change. Further information on the project may be found at URL http://fish.cims.nyu.edu/project_oisi/isomip/overview.html.

URL: http://fish.cims.nyu.edu/project_oisi/isomip/overview.html

C41A-06 0915h

Glacial Meltwater Fractions in Ice Shelf Water Derived From Stable Isotopes and Noble Gases: Comparison of the Filchner Ronne and Ross Ice Shelves

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Stable isotopes of water ($H_2{}^{18}O/H_2{}^{16}O$ ratio) and noble gases (helium and neon) can be used to study the interaction of shelf water and glacial ice underneath the floating ice shelves around Antarctica. These isotopes can further be used to investigate the role of shelf waters that have been modified by glacial meltwater in formation of intermediate and deep waters on the Antarctic continent. Typical fractions of pure glacial meltwater observed in the cores of ISW flowing out from underneath the ice shelves are about 3 to 5 per mil. The resulting melt rates of glacial ice are of the order of several 10 cm for the Filchner/Ronne Ice Shelf. The glacial meltwater signal in ISW can be traced into the deep waters of the Southern Ocean and the low-salinity ISW contributes significantly to the formation of Weddell Sea Bottom Water (WSBW). In this contribution we summarize early and recent results from tracer studies of glacial meltwater fractions and the impact of glacial ice/shelf water interaction on the formation of deep waters around Antarctic. The sites include the Filchner/Ronne Ice Shelf, the Ross Ice Shelf and the ice shelves in the Amundsen/Bellingshausen seas.

C41A-07 0930h

Velocity change and ice discharge from Antarctic Peninsula Glaciers

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Satellite radar interferometry data from ERS-1/2 acquired in 1996 were employed to map the ice velocity

of the outlet glaciers discharging ice along the eastern flank of the Peninsula from 64 south to 71 south, and along the former Wordie Ice Shelf in the west. Differential radar interferometry was employed to map the position of the glacier grounding lines. Estimates of ice thickness at the grounding line were obtained from hydrostatic equilibrium using existing topographic maps, or from direct measurement from radio echo sounding by BAS in 1994-2000 and CECS/NASA in 2002. The resulting glacier fluxes were compared to snow accumulation compiled by Turner et al. (2002) to deduce first-order estimates of the glacier mass balance. In places where ice shelves are known to have been retreating, we compared the 1996 velocities with older measurements as well as more recent estimates from ERS-1/2 (2000), Radarsat (2000-2003) and Aster (2002). On Fleming Glacier, we find a large increase in flow speed from 1972 to 1996, with no further increase after 1996, which suggests that the glacier did respond to the collapse of Wordie Ice Shelf several decades ago. On Drygakski glacier in the east, we confirm a large acceleration of the glacier following the collapse of Larsen B, as revealed by Rott et al. (2002), which is continuing to this date. We conclude on the effect of retreating ice shelves on the evolution of inland ice in this sector of Antarctica and on its impact on sea level rise.

C41A-08 0945h

The sea ice Thickness Distribution and Iceberg Size Distribution From AUV Measurements in the Northern Weddell and Eastern Amundsen Seas

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The AUV AUTOSUB 2 has been used on two campaigns in Antarctica. The first was in February 2000 at the northern edge of the Weddell Sea (63S, 50W), the second in March 2003 at the shelf break region of Pine Island Bay (71S, 102W). The aim in both cases for this project was to determine the sea ice thickness distribution on scales of 10's of km. In the first campaign the AUV was sent on missions of up to 80 km length at depths in the range 150-250 m. It was equipped with an upward looking scientific echo sounder operating at two frequencies as well as a full suite of oceanographic sensors including 2 CTD's, and both upward and downward looking ADCP's. The data allow derivation of the sea ice distribution and iceberg size distribution as well as recording under ice hydrographic data at very high spatial scales. We will show examples of the thickness data and give an example of the hydrographic data from a close approach to a small iceberg. In the second campaign the vehicle was substantially different and thickness data were obtained from upward looking ADCP data with shorter missions (30 km) but at shallower depths. In total the AUV has collected over 500 km of data for this project and is part of the Autosub Under Ice programme. The AUV will be sent to the Greenland Sea in 2003 and then back to Antarctica in 2004/5 for missions beneath the Filchner Ronne ice shelf.

C41B MCC: Level 2 Thursday 0830h

Monitoring, Measuring, and Modeling Snow Processes Posters *(joint with H)*

Presiding: **K Elder,** Rocky Mountain Research Station, U.S. Forest Service**; D Marks,** USDA Agricultural Research Service

C41B-0947 0830h INVITED POSTER

Snow Processes: Current Understanding and Future Prospects

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Snow processes are the key to understanding and describing the hydrology and climatology of cold regions and seasons. Snow is not simply a solid precipitation that can be treated like other hydrological inputs, but is redistributed, sublimated, and metamorphosed after snowfall and undergoes complex and rapid changes during melt. In open landscapes blowing snow erodes and transport surface snow from exposed surfaces through two-phase flow and redistributes the snow to more sheltered surfaces. During transport, significant sublimation loss may occur, making the process not just one of redistribution but ablation. Rapid changes to snow density, crystal size and spatial statistical properties occur during this phenomenon. In forested regions, snow interception by the canopy can store the majority of a mid-winter snowfall, and intercepted snow is exposed to high energy inputs, driving enhanced sublimation and melt. All snowpacks are subject to complex radiative, turbulent and conductive energy transfers which couple with snow mass transfer in manners that are not fully understood. It is increasingly realised however that simple flat plane assumptions in calculating coupled heat and mass transfer are not adequate for describing snow dynamics. Further, the non-linear aspects of most snow processes make their larger scale description highly dependant on the spatial distribution of boundary conditions and how these in turn are affected by the evolving snowpack state. The upcoming challenges in the study of snow processes still include improving the basic descriptions of these processes, yet new challenges have arisen in understanding and describing snow processes and their space-time dynamics over highly heterogeneous landscapes. The remarkable consistency of larger scale descriptions of snowcover evolution and spatial variation suggests that there are relevant principles of spatial organisation whose importance to snow phenomena has not been identified or explained.

C41B-0948 0830h POSTER

Estimation of snow water equivalent from sparse field measurements in Italian Alps

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The estimation of Snow Water Equivalent (SWE) is a far reaching matter in the hydrology of alpine rivers. SWE at the beginning of the melting season is often adopted as a boundary condition for snow melt models, low flows simulation and spring floods. Here, SWE snow measurements from alpine areas in central-northern Italy are analysed. Using 10-years snow depth registrations from a network of 28 stations, SWE is estimated and mapped on the observed area at the beginning of the melting season, set at April 1th. Because no systematic snow density measurements are provided at the given stations, sparse density measurements (about 200 over 5 years of observation) are used to find a relation between snow density, geo-morphologic features and the season, so as to provide SWE estimation at sites where only depth measurements are available. To enlighten regional features in SWE distribution, a Principal Component Analysis (PCA) is carried and two different regions are found. The covariance structure of the SWE field is assessed and an analysis is carried, to incorporate spatial and geomorphic attributes. A Kriging procedure is then carried and validated, showing proper estimation of SWE at ungauged sites. The Kriging methodology is then compared to other different, straightforward approaches used in the related bibliography, showing interesting performances. Then, areal estimation of SWE is provided, showing the Kriging procedure enhances systematic error in estimation from the other methodologies and also provides remedies for their correct application.

C41B-0949 0830h INVITED POSTER

Methods to Identify and Correct Snow Water Equivalent Pressure Sensor Measurement Errors to Improve Estimates of Water Stored as Snow

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Snow water equivalent (SWE) pressure sensor measurement errors significantly reduce the ability of water resource managers to accurately predict the amount of available SWE or snowmelt water runoff. SWE errors may occur when the snow/soil interface is at the melting temperature and the differential snowmelt rate between a SWE sensor and the soil exceeds the snow creep rate. A cold, dry snow cover overlying frozen soil will not exhibit SWE sensor errors because the snow and soil temperatures are both below the melting temperature. A delayed SWE sensor response may occur when the SWE accumulation rate exceeds the snow creep rate. Cold snow covers with many ice layers will have a relatively low creep rate while isothermal wet snow will have a relatively high creep rate. This is why a SWE sensor that exhibits a large error just before the onset of wet isothermal conditions will suddenly start to accurately measure SWE. By understanding the physical mechanisms that affect SWE sensor performance the occurrence of SWE errors can be identified and a variety of approaches to correcting them are possible. When only SWE sensor data are available, the occurrence of SWE errors can be identified by excursions in SWE, which can be corrected by interpolating from data on either side of the excursion. A delayed SWE sensor response to a snowstorm is related to the snow creep rate and can be corrected by shifting the SWE record to ensure that the start of the SWE increase and the storm agree. The SWE accumulation rate midway between the beginning and end of the storm should provide a good approximation of the storm's accumulation rate. When additional information on precipitation, snow depth, and snow core SWE are available then relatively simple comparison and interpolation methods can be used to correct errors. Ground temperature or heat flux data can be used to predict SWE sensor performance and correct SWE errors. Air temperature data and a heat flux model of snow and soil may be used to estimate data needed to correct SWE errors.

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Snow Water Equivalent Predictions for Hydrologic Model Input and Simulation

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A multiple regression equation was developed to describe temporal and spatial variability of daily snow water equivalent (SWE) in Lake Tahoe's Incline Creek watershed. SWE maps of the basin are needed for parameterization of the physically-based Alpine Hydrochemical Model (AHM) to simulate basin hydrology and solute transport. SWE maps allow for calculation of snow covered area, snowfall, and potential snowmelt needed for AHM input. SWE data collected during 2002's peak snow accumulation were used in conjunction with data from three local SNOTEL stations to calibrate the regression equation. Calibration was conducted during a dry and average water year using the sum of least squares. The multiple-regression is dependent on elevation, aspect, slope, vegetation density and solar radiation and is normalized by the average SWE measured at the three SNOTEL sites. Basin-wide computations were done at 30 m resolution in ArcView to generate daily SWE maps. Normalized error was added to predictions from the regression equation to mimic the variability in the observed data. Verification was performed at the three SNOTEL sites for a wet year and another average year. Stream response is highly dependent on SWE distribution and associated melt rates such that hydrologic model results allow evaluation of the SWE interpolation technique.

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Distribution of Soil Dynamics in a Small Mountain Catchment

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Soil moisture in semi-arid regions dominated by winter precipitation is recharged as a bulk influx during spring melt and dries down quickly during the ensuing months. This timing in combination with various spatially distributed landscape properties produces distinct spatial soil moisture patterns. The patterns