When radiative transfer theory is applied for understanding lidar measurements, it is usually assumed that light interacts with a spatially uncorrelated medium. In situ measurements suggest that most clouds are positively auto-correlated spatially. When light travels within a positively auto-correlated cloud system, the chance of a cloudy parcel hidden behind another cloud parcel is higher than the one for an uncorrelated system. For the same amount of cloud particles, the effective extinction optical depth of the spatially auto-correlated system is equivalent to the extinction optical depth of the correspondent spatially uncorrelated system minus the extra chance of a cloud parcel hiding behind another one. This equivalent extinction adjustment is normally made, intentionally or unintentionally, when applying radiative transfer theory while assuming no spatial auto-correlation of the medium. The radiative transfer theory works fine with this equivalent extinction adjustment if multiple scattering is unimportant in a measurement. But this equivalent uncorrelated medium adjustment introduces under-estimation of multiple scattering. The impact of the spatial auto-correlation on lidar depolarization measurement data analysis and multiple scattering assessments will be presented. This study is based on simulations made with a Monte-Carlo model of lidar measurements with full Stokes vector as well as Cloud Physics Lidar (CPL) measurements. The model calculations are accelerated with FPGA-based reconfigurable computation.

U14A-03 1605h

Influence of Small-Scale Drop Size Variability on the Estimation of Cloud Optical Properties

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Most of the existing cloud radiation models and conventional techniques of data processing assume that the mean number of drops with a given radius varies proportionally to volume. The analysis of microphysical data on liquid water drop sizes acquired during the First International Satellite Cloud Climatology Project (ISCCP) Regional Experiment (FIRE), July 1987, and the Atmosphere Radiation Measurements (ARM) Cloud Intensive Operational Period (IOP), March, 2000, shows that, for sufficiently small volumes, the number is proportional to the drop size dependent power of the volume. The drop size dependent coefficient of proportionality, or a generalized drop concentration, and the exponent are determined solely by the smallest sampling volume; they are independent of the volume drops occupy and differentiate spatial distributions of drops with different sizes. For abundant small drops ($r \leq 14\mu m$) present, the exponent is 1 as assumed in the conventional approach. However, for rarer large drops ($r > 14\mu m$), the exponents fall below unity for scales between the smallest sampling volume and a "saturation" scale. At these scales, therefore, the mean number of large drops decreases with volume at a slower rate than the conventional approach assumes, suggesting more large drops at small scales than conventional models account for; their impact is consequently underestimated. The analysis presented here indicates that depending on cloud size, the neglect of small-scale drop size variability can result in a systematic underestimation of cloud horizontal optical path.

URL: http://cybele.bu.edu/download/ms.html

U14A-04 1620h

Unbiased High Resolution 3D Aerosol Retrievals from Landsat

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Satellite monitoring of the man-made pollutants in urban/ industrial regions is important to understand the climate forcing of anthropogenic aerosols. Our ability to accurately study aerosols from space over land is generally limited to dark dense vegetation (DDV) targets. The urban regions of interest are notoriously difficult because of high inhomogeneity and contrast of surface, combined with the small size of sparsely located DDV targets. Such conditions enhance the atmospheric blurring of satellite images otherwise known as 3D adjacency effect. Importantly, blurring systematically increases the apparent brightness of the dark pixels resulting in the systematic overestimation of the aerosol optical thickness over land by conventional 1D methods. The small size of the DDV targets in the urban regions defines a unique niche for Landsat-like measurements for the aerosol studies. We developed a new dark target method for unbiased simultaneous retrieval of the aerosol model and optical thickness over land, based on 3-D radiative transfer theory. We will demonstrate an application of this method for a set of ETM+ images of the Washington-Baltimore area, and its initial validation with AERONET measurements.

U14A-05 1635h

Lidar Investigation of Atmospheric Stratification: Del=2, 7/3, 23/9 or 3?

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Practically all theories of turbulence assume isotropy or at least local isotropy. In buoyancy driven flows the justification is not obvious because gravity breaks the isotropy yet acts at all scales. The classical assumption is that gravity leads to a basic stably stratified state while simultaneously postulating that the perturbations are nevertheless statistically isotropic. In the atmosphere, the scale height (about 10 km) presents a further challenge: isotropic three dimensional turbulence cannot extend to very large scales. The standard model postulates an intermediate "meso-scale gap" followed at larger scales by two dimensional horizontally isotropic turbulence. Today, although we still lack consensus about the full horizontal atmospheric statistics, the meso-scale gap separating the these D=3, D=2 regimes has not been observed and there is wide consensus that the horizontal wind is scaling in the horizontal with spectral exponent β_h =5/3 out to at least several hundred km. In the vertical direction, the spectral exponent $\beta_v > \beta_h$ implying scaling stratification with the volume of structures growing at a rate Del= $2 + (\beta_h - 1)/(\beta_v - 1)$. The two main contending proposals being $\beta_v = 11/5$ (buoyancy driven, Bolgiano-Obhukov) and $\beta_v = 3$ (gravity waves, Lumley-Shur) implying Del=7/3, 23/9 respectively. In this talk we describe some recent results using state of the art lidar data of passive scalars, over the range 3m to 120km, we directly estimate Del=2.56 ± 0.05 supporting the 23/9 dimensional "unified scaling" model . We discuss this in relation to other measurement campaigns, and also the implications for modelling the atmosphere. Finally, we show how to make multifractal models of vertical cross-sections which are very close to the data.

U14A-06 1650h

Fractal Analysis Challenges for Remote Sensing of Clouds and Other Geophysical Phenomena

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Clouds are the primary source of uncertainty in models of the weather and climate. Thus it is crucial that our overall understanding of clouds be improved, especially the radiative effects of clouds. Fractal cloud models are commonly used to investigate radiative effects caused by the spatial heterogeneity of real clouds. These complex distributions exhibit variability across a range of scales, suggesting the utility of fractal modeling as a means of simulating and exploring cloud properties. Estimation of fractal dimension, the principle parameter of fractal models, has been shown to exhibit sensitive dependence on which estimator is used, suggesting a variety of estimators must be studied to determine which gives the most accurate results. This presentation will demonstrate that fractal dimension estimation is unreliable and depends upon many factors including instrument resolution, sun-view geometry, spectral channel, averaging techniques, number of data points, and estimation algorithm used. The primary conclusion drawn from this study is that the measurement of fractal dimension cannot be achieved with confidence for clouds and other geophysical phenomena and an alternative approach must be developed in order to acquire scale invariant (fractal) properties from clouds that are input into fractal models. Thus it is necessary to develop more sophisticated fitness criteria for selecting appropriate fractal models and their corresponding parameter values.

U15A CC: 517 A Monday 1715h

Union Frontier Lectures I

Presiding: **S King,** Purdue University; **W R Peltier,** University of Toronto

U15A-01 1715h INVITED

Cold Regions Hydrology: Its State and Future

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The major hydrological events in cold regions are related to storage and melt of snow and ice and the related energetics of phase change. Cold regions hydrology therefore is subject to a relatively unique assemblage of hydrological processes and parameters that produce a very distinctive hydrological response. Observational networks of snowfall, snow depth, ice extent, soil frost and streamflow have never been dense in cold regions, which due to their large size and remoteness adds the particular challenges of information scarcity and large scale of application to this branch of hydrology. The difficulties of field observations of snow accumulation, interception, redistribution, frozen soil moisture content, and ice-covered streamflow in remote cold regions environments mean that even routinely-gauged basins represent subjects of high uncertainty in hydrological calibration and estimation. Uncertainty in model operation is exacerbated by the temperate-environment bias of many hydrological models, in which their underlying approach, assumptions and structure may not be suited to the dynamics of cold regions hydrology. This paper reviews recent progress in defining and describing the relevant land-based hydrological cycle in cold regions, the scaling behaviour of some cold regions processes and the observational challenges provoked by cold, remote environments. It then discusses the appropriate modelling strategy for such environments and how this might be addressed in the next generation of hydrological research in high latitudes and altitudes.

U15A-02 1800h

Scientific Results from the Mars Exploration Rover Mission

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U21A CC: 220 C-E Tuesday 0830h

Remote Observation of the Earth's Surface and Atmosphere: The Challenges of Spatial Complexity Posters

Presiding: **S Lovejoy,** McGill University; **A B Davis,** Los Alamos National Laboratory

U21A-01 0830h POSTER

Optical and Radar Remote Sensing Measurements of the Extreme Flood of 2003, Indus River, Pakistan and NW India

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Major flooding (36 on a globally-applicable flood magnitude scale) occurred over a large area of Pakistan and northwestern India between July 15 and September 1, 2003. During this flooding, 285 fatalities occurred and over 900,000 people were displaced. This monsoon-related flood (DFO-2003-165) was extensively measured by orbital remote sensing. Multispectral classification of optical data from the MODIS sensors aboard Terra and Aqua allow multi-temporal mapping of the progress of several flood waves down the Indus Valley, and intersection of MODIS inundation limits with the newly released SRTM topographic data allows repeat measurements of flood stages along an array of flood gaging reaches. High spatial resolution (15 m pixels) data from the ASTER sensor aboard Terra is sparse but provides locally detailed imaging of the event and calibration of the time series of MODIS water surface areas. At favorable locations, flood discharge can also be estimated and a series of such estimates provides an entirely remote-sensing based flood hydrograph at a 20 km long reach near , Pakistan. Finally, backscatter polarimetry from the SeaWinds radar aboard NASA's QuikSCAT satellite records the flood by a decrease of 7 day running mean VV/HH ratios retrieved over the gaging reaches; from the pre-flood average of -2.5 and dropping to -3.3 coincident with arrival of the flood wave. The record of lands inundated by this event is accessible to an international public at:

URL: http://www.dartmouth.edu/~floods/2003165.html

U21A-02 0830h POSTER

Multiangular studies on light scattering from snow

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The new satellite and aerial sensors provide high resolution multiangular data from northern environments. For the correction and utilisation of the directional properties, both physical study and field measurements of snow BRDF (bi-directional reflectance distribution function) are applied, aiming at more accurate snow mapping techniques in, e.g., forest covered areas. For this purpose, a large spectrogoniometric database is being collected at the Finnish Geodetic Institute. We present examples of snow BRDF at different geometries and wavelengths in search for the best measurement geometries for both data correction and signature studies. We are extending our BRDF database into backscattering direction (i.e. small source-target-detector angles). Results from an extended snow backscattering campaign in Lapland are presented, and the characteristics that mostly affect snow/ice backscattering are discussed. To construct a more effective method, a scenario for combining the backscatter data with multiangle goniometric measurements is presented. The fundamental physics of light scattering from snow are still under study. Large spatial and temporal variations in snow cover present a great challenge to its experimental investigation. These results provide more information on how to apply the snow intensity effects at backscattering and other geometries in remote detection of the structural properties of the snow cover. A large database and further physical studies are needed to establish and validate such methods.

U21A-03 0830h POSTER

Characterisation of Land Surface Structure Using MISR/Terra Multiangle Observations

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Recent studies have highlighted the importance of vegetation structure, both in the context of landscape dynamics and with regard to ecosystem productivity. Quasi-simultaneous multi-spectral and multi-directional remote sensing measurements from space, as provided by the Multi-angle Imaging SpectroRadiometer (MISR), offer new and unique opportunities to document the angular variations of land surface reflectances. The geophysical interpretation of such reflectance anisotropy patterns over terrestrial surfaces has only recently permitted to relate these signatures in a quantified manner to the structure and heterogeneity of the underlying surface. This contribution shows that the joint analysis of the shape of the reflectance anisotropy together with statistics derived from canopy height field datasets - functioning as a proxy for the structural characteristics of the underlying surface - yields a remarkable pattern of organization. Furthermore, new sets of ecology-oriented parameters that are conceptually easy to grasp and relatively simple to obtain through field measurementse have been identified, permitting a geophysical interpretation of the directional signature of the surface leaving radiation.

U21A-04 0830h POSTER

Vegetation Canopy as a Boundary Condition to Atmospheric Radiative Transfer

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In spite of the different physics behind radiation transfer in clouds and vegetation, these media have certain macro and micro-scale features in common. First, both are characterized by strong horizontal and vertical variations, and thus their three-dimensionality is important to correctly describe the photon transport. Second, the radiation regime is substantially influenced by the sizes of scattering centers that constitute the medium. Third, the independent scattering concept underlies the derivation of the extinction coefficient and scattering phase function in both theories. This allows the transport equation to relate micro-scale properties of the medium to the photon distribution in the entire medium. From a mathematical point of view, these three features determine common properties of radiative transfer in clouds and vegetation. However, the governing radiative transfer equation for leaf canopies has certain unique features. The extinction coefficient is a function of the direction of photon travel. Also, the differential scattering cross-section is not, as a rule, rotationally invariant. Finally, the single scattering albedo is also a function of spatial and directional variables. From the other side, in contrast to radiative transfer in clouds, the extinction coefficient in vegetation canopies is wavelength independent. Although the scattering and absorption processes are different at different wavelengths, the optical distance between two arbitrary points within the vegetation canopy does not depend on the wavelength. This spectral invariance results in various unique relationships which compensate for the above mentioned difficulties. Because of their radiative interactions, the vegetation canopy and the atmosphere are coupled together; each serves as a boundary condition to the radiative transfer equations in the adjacent medium. To better understand radiative processes in these media we need an accurate description of their interactions. This presentation outlines a technique needed to describe interactions between vegetation and clouds and exploits it to retrieve cloud optical depth from ground-based radiance measurements.

U21A-05 0830h POSTER

Does Surface Albedo Inhomogeneity Affect Cloud Absorption Estimates?

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The enhanced shortwave cloud absorption, known as the discrepancy between measured and model-calculated cloud absorptions, has been one of the major concerns in the atmospheric community. The reason is that this excess absorption is always a bias rather than a random error, and as a result, may have significant impact on climate modeling and remote sensing applications. Among various explanations for this bias, it has been suggested that accounting for surface albedo inhomogeneity may reduce the discrepancy. Yet, to date there is a lack of analysis quantifying how surface albedo variability affects cloud absorption estimates. This study, using 3D radiative transfer modeling with checkerboard surface albedo, aims to better understand the radiative interactions between the surface and clouds, and to examine whether the anomalous shortwave cloud absorption can be explained solely by surface albedo inhomogeneity.

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U21A-06 0830h POSTER

"3D Radiative Transfer in Cloudy Atmospheres" - a new Book for Springer-Verlag

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3D cloud radiative community has matured enough to prepare a volume on 3D radiative transfer in cloudy atmosphere that will be published by Springer-Verlag this year. Many leading 3D radiative transfer scientists are amongst the coauthors of the book. The book starts with the basic 3D radiative transfer problem, describes its solutions and models, discusses the effects of cloud inhomogeneity for remote sensing, addresses climate problems in realistic atmosphere and studies cloud-vegetation interactions. In our presentation we will highlight the outline of the book, give examples from different chapter mostly focusing on broken clouds and cloud-vegetation interactions.

U21A-07 0830h POSTER

Aspects of Cloud Horizontal Variability From Higher-Level MODIS Products

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We have analyzed two full months (July 2003 and January 2004) of MODIS Atmosphere Level-3 data from the Terra and Aqua satellites in order to characterize the apparent horizontal heterogeneity in cloud optical properties at global scales. We have layed the foundation of a global cloud inhomogeneity climatology from 1 km retrievals sampled every 5 km by determining statistics of cloud variability at spatial scales of 1°x1° and at daily and monthly time scales. Specifically, we have studied geographical, diurnal and seasonal changes of various measures of cloud optical thickness variability both over land and ocean as well as its dependence on cloud type and cloud phase. Some of the highlights of the findings are that cloud inhomogeneity appears to be weaker over land than over ocean (mainly for Terra), smaller for local morning (Terra) than local afternoon (Aqua), about the same for liquid and ice clouds on a global scale, but with wider PDFs and larger latitudinal variations for ice. We have also found that global values of inhomogeneity parameters are virtually identical for both January and July, while the hemispheric values are in almost perfect seasonal correspondance: northern hemisphere (NH) winter equals southern hemisphere (SH) winter and NH summer matches SH summer. Overall, clouds are more inhomogeneous during the winter. This presentation will also discuss whether Level-3 data are appropriate for examining whether any of the apparent cloud variability behaviour described above can be linked to the influence on the retrievals of well-known morphological features of particular cloud types and the geometry of the radiometric observations.

U21A-08 0830h POSTER

Three-Dimensional Radiative Effects in MODIS Cloud Property Retrievals

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An important challenge for theoreticians who check statistical hypotheses is to get enough data to avoid any biases caused by small unrepresentative samples.With the recent arrival of new high-resolution satellite remote sensing data, there are no more excuses for sampling problems.Combining millions of pixels selected by appropriate criteria can eliminate random factors that affect cloud properties at a given location, season, illumination or observational conditions. This implies that if one divides all cloudy pixels into two nonoverlapping categories using a criterion independent on cloud properties–say, "illuminated" vs. "shadowed" or "forward-viewed" vs. "backward-viewed" pixels–the average cloud properties can be expected to be statistically equal in the two categories.If, however, 1D algorithms are applied to 3D clouds, the cloud properties retrieved for the two categories can diverge.The bias or "asymmetry" between two categories can reveal the complexity of 3D cloud structure and indicate when 3D inhomogeneity affects the accuracy of the operational 1D retrievals. We have developed two new techniques to analyze asymmetries caused by 3D radiative effects.The first technique examines the retrieved cloud properties' dependence on the solar azimuth angle. This technique uses the MODIS brightness temperature field to identify each pixel as "illuminated" or "shadowed."The second technique compares the cloud properties retrieved at different viewing directions (that is, at different cross-track positions). In the presentation we will discuss the two techniques' results obtained for large amounts of MODIS cloud data.Based on these analyses we estimate the errors that horizontal cloud variability introduces into cloud property retrievals under various climatological conditions.

U21A-09 0830h POSTER

Wide Angle Imaging Lidar (WAIL): Theory of Operation and Results from Cross-Platform Validation at the ARM Southern Great Plains Site

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WAIL was designed to determine physical and geometrical characteristics of optically thick clouds using the off-beam component of the lidar return that can be accurately modeled within the 3D photon diffusion approximation. The theory shows that the WAIL signal depends not only on the cloud optical characteristics (phase function, extinction and scattering coefficients) but also on the outer thickness of the cloud layer. This makes it possible to estimate the mean optical *and* geometrical thicknesses of the cloud. The comparison with Monte Carlo simulation demonstrates the high accuracy of the diffusion approximation for moderately to very dense clouds. During operation WAIL is able to collect a complete data set from a cloud every few minutes, with averaging over horizontal scale of a kilometer or so. In order to validate WAIL's ability to deliver cloud properties, the LANL instrument was deployed as a part of the THickness from Off-beam Returns (THOR) validation IOP. The goal was to probe clouds above the SGP CART site at night in March 2002 from below (WAIL and ARM instruments) and from NASA's P3 aircraft (carrying THOR, the GSFC counterpart of WAIL) flying above the clouds. The permanent cloud instruments we used to compare with the results obtained from WAIL were ARM's laser ceilometer, micro-pulse lidar (MPL), millimeter-wavelength cloud radar (MMCR), and micro-wave radiometer (MWR). The comparison shows that, in spite of an unusually low cloud ceiling, an unfavorable observation condition for WAIL's present configuration, cloud properties obtained from the new instrument are in good agreement with their counterparts obtained by other instruments. So WAIL can duplicate, at least for single-layer clouds, the cloud products of the MWR and MMCR together. But WAIL does this with green laser light, which is far more representative than microwaves of photon transport processes at work in the climate system.

URL: http://nis-www.lanl.gov/~love/clouds.html

U21A-10 0830h POSTER

Height, Thickness and Roughness From of Clouds and Volcano Plumes From a Systematic Analysis of Solar Photon Paths

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Clouds have a major yet poorly understood impact on climate while volcano plumes have proven to be a significant hazard, in particular for public health and air traffic. We propose a quite comprehensive characterization of their instantaneous structure from satellite remote sensing in the near IR. Cloud top height is obtained (1) from the geometry of solar illumination and how shadows are cast and (2) from a standard retrieval of column water vapor (WV) and the local atmospheric profile according to the Global Data Assimilation System (GDAS). There is a systematic bias between these two estimates due to the multiple scattering of the solar photons through the WV field inside the clouds. A diffusion theoretical model for the multiple scattering process shows that the bias is primarily a function of cloud thickness. Finally, if fine spatial resolution is available, a height-height correlation analysis tells us about the convectively-driven turbulence in the cloud by way of its outer boundary roughness. We illustrate this whole procedure with Multispectral Thermal Imager (MTI) data for clouds of opportunity and for an extensive plume from Mount Etna.

URL: http://nis-www.lanl.gov/nis-projects/mti/

U21A-11 0830h POSTER

Large Averaging Thermal Radiative Fluxes Through Inhomogeneous Cloud Fields: A Sensitivity Study Using the tdMAP Cloud Generator

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We analyze the effects of flat and bumpy top, fractional and internally inhomogeneous cloud layers on large area-averaged thermal radiative fluxes. Inhomogeneous clouds are generated by a new stochastic model: the tree-driven Mass Accumulation Process (tdMAP). tdMAP model is related to wavelet decomposition. But this analogy is too limited to be really usefull. Indeed, in wavelet analysis, we need to use specific wavelet (Haar, Lemarié-Meyer, etc.) in an orthogonal basis. Instead of this, tdMAP uses arbitrary function F shifted and scaled in the physical space as dictated by the tree-structure. This model is able to provide stratocumulus and cumulus cloud fields with properties close to those observed in real clouds. A sensitivity study of cloud parameters is done by analyzing differences between 3D fluxes simulated by the Spherical Harmonic Discrete Ordinate Method and three standard models likely to be used in General Circulation Models: Plane-Parallel Homogeneous cloud model (PPH), PPH with Fractional Cloud coverage model (FCPPH) and Independent Pixel Approximation model (IPA). We show that thermal fluxes are strong functions of fractional cloud coverage, mean optical depth, mean geometrical thickness, and cloud base altitude. Fluctuations of in-cloud horizontal variability in optical depth and cloud-top bumps have negligible effects in the whole. We also showed that PPH, FCPPH and IPA models are not suitable to compute thermal fluxes of flat top fractional inhomogeneous cloud layer, except for completely overcast cloud. This implies that horizontal transport of photon at thermal wavelengths is important when cloudy cells are separated by optically thin regions.

U21A-12 0830h POSTER

The radiative properties of ice clouds in the far-infrared spectrum: a sensitivity study from remote sensing perspective

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In recent years, there has been increasing interest in the far-infrared radiation spectrum (from 100-667 cm-1, or 15 to 100 m) in atmospheric research. For example, it has been confirmed that the radiation balance in the troposphere is influenced by radiative cooling caused by water vapor at far-infrared wavelengths. The present study explores the potential advantages of using the far-infrared spectral signature for investigating the microphysical and radiative properties of ice clouds (cirrus clouds, in particular). These clouds have a significant impact on the terrestrial climate system through their radiative effect. It is quite challenging to reliably derive the microphysical and radiative properties of these clouds. The spectral signature of ice clouds in the far-infrared (far-IR) spectral region is investigated in detail. Several state-of-the-art scattering computational methods are used in this study. Furthermore, the bulk scattering properties of ice clouds at far-IR wavenumbers are developed from scattering computations and in-situ measured microphysical properties, as well as a parameterization of the bulk scattering properties. Extensive sensitivity studies are carried out to understand the effect of ice cloud effective particle size and optical thickness on far-infrared radiance. It is found that the brightness temperature difference (BTD) between 250 and 559.5 cm-1 is quite sensitive to optical thickness for optically thin clouds (visible optical thickness t< 2). At the other extreme, for optically thick ice clouds (t> 8), the BTD between 250 and 410.2 cm-1 is shown to be sensitive to the effective particle size up to a limit of 100 m. The conclusion of this study is that the use of the far-IR spectral signature may provide complementary information to what may be inferred by current methods using satellite imagery such as MODIS, and will be useful in gaining a better understanding of the role of ice clouds in the Earth's radiation budget.

U21A-13 0830h POSTER

Optical properties of cirrus clouds retrieved from the visible and water vapor absorption bands of the Moderate Resolution Imaging Spectroradiometer

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In this paper, we introduce a method to retrieve the optical thickness of tropical cirrus clouds using the "true" 0.66 μm cirrus reflectance (without atmospheric and surface effects). The "true" cirrus reflectance is inferred from level 1b calibrated 0.66 and 1.375 μm Moderate Resolution Imaging Spectroradiometer (MODIS) data. We created an optical properties database and optical thickness look-up library using previously calculated single scattering data in conjunction with the Discrete Ordinates Radiative Transfer (DISORT) code. An algorithm was constructed based on this look-up library to infer the optical thickness of tropical cirrus clouds for each pixel in a MODIS image. We demonstrate the applicability of this algorithm using several independent MODIS images from NASA's Terra satellite. The method described here is complimentary to the MODIS operational cloud retrieval algorithm for the case of cirrus clouds.

U21A-14 0830h POSTER

Retrieval of the optical thickness of ice clouds from spaceborne high-spectral-resolution radiance measurements

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One of the primary goals of the Atmospheric Infrared Sounder (AIRS) is to retrieve atmospheric profiles. Beyond the clear sky sounding capability, the high spectral resolution infrared radiance contains useful information about clouds, particularly for high-level, optically thin cirrus. In the present research, we present methodology for the retrieval of cirrus optical thickness from AIRS high spectral resolution infrared radiances. A fast cloudy radiative transfer model is developed to simulate AIRS radiances when clouds are present. Calculations show that the brightness temperature difference between this fast cloudy radiative transfer model developed specifically to simulate clouds and a discrete ordinates (DISORT) radiative transfer model is within 0.5K for most cloud cases. However, the computing speed of the fast model is 1000 times faster than DISORT. The fast model for cloudy radiance simulations was merged subsequently with the clear-sky fast model for AIRS sounding purpose developed at the University of Maryland-Baltimore County. Various cirrus cloud studies have been conducted, which include: (1). the sensitivity of AIRS brightness temperatures to optical thickness and effective particle size, and (2) the sensitivity of simulated brightness temperatures to the microphysical properties of ice clouds for a range of wavenumbers in the IR region. Based on the sensitivity studies, methodology is suggested to retrieve the optical thickness of cirrus clouds from AIRS measurements. For the implemention of the retrieval algorithm, ECMWF atmospheric profiles and collocated MODIS cloud altitude data are used for forward modeling calculations. The applicability of the retrieval algorithm is demonstrated by a case study. The ice cloud optical thicknesses derived from the AIRS measurements are compared with those retrieved from the Moderate Resolution Imaging Spectroradiometer (MODIS) 1.38 μm and 0.66 μm bands. The optical thicknesses inferred from the MODIS measurements are collocated and degraded to the AIRS spatial resolution. Results from the MODIS and AIRS retrievals are quite similar over a wide range of optical thicknesses.

U21A-15 0830h POSTER

Microphysical and optical properties of ice clouds derived from the Airborne Visible/Infrared Imaging Spectrometer measurements

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In this paper, we introduce a method to simultaneously retrieve ice crystal effective size and cirrus cloud optical thickness using 1.38- and 1.88-μm cirrus reflectance from Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data. Atmospheric and surface effects are removed from this data to obtain isolated cirrus reflectance. An effective size and optical thickness look-up table has been produced for each case presented here using the Discrete Ordinates Radiative Transfer (DISORT) code and previously calculated single-scattering data. An algorithm has been developed based on the look-up tables to derive the effective size and optical thickness of cirrus clouds on a pixel-by-pixel basis. The applicability of this method is demonstrated using several independent AVIRIS images.

U21B CC: 517 A Tuesday 0830h

Extreme Environments of the Precambrian Earth I

Presiding: **G S Jenkins,** Howard University**; C Poulsen,** University of Michigan**; P McCausland,** University of Michigan

U21B-01 0835h INVITED

HOW STRONG IS THE CASE FOR PROTEROZOIC LOW-LATITUDE GLACIATION?

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The most recent global compilations of paleomagnetic depositional latitudes for Proterozoic glaciogenic formations indicate a dominant mode near the paleoequator (Evans 2000 AJS; Evans 2003 Tectonophysics). This result would therefore support either the snowball Earth or the large-obliquity hypotheses for Precambrian ice ages, but would reject the uniformitarian comparison to polar-temperate-restricted Phanerozoic glaciogenic deposits. The most reliable low-latitude results come from the Australian Marinoan succession, but a recent summary of these units has suggested that a glaciogenic origin is not yet demonstrated (Eyles and Januszczak 2004 Earth-Sci Reviews). It becomes useful, then, to review the global evidence for Proterozoic low-latitude glaciation. Eyles and Januszczak (ibid.) identified 13 Neoproterozoic deposits with "demonstrated" glacial influence. Among these, poor age constraints and lack of paleomagnetic data prohibit estimation of depositional paleolatitudes for the Fiq, Sturtian, Vreeland, Taoudeni, East Greenland, Port Askaig, and Zhengmuguan units. Moderate paleolatitudes are reasonably well supported for the South China, Gaskiers, Smalfjord, and Moelv units. Among the three remaining units, the Rapitan Group can be assigned a near-equatorial paleolatitude indirectly through use of the Galeros and Franklin-Natkusiak paleomagnetic results, as long as the Rapitan age lies within 750-720 Ma as generally expected. The Moonlight Valley Formation in northern Australia may be assigned a tropical paleolatitude according to high-quality paleomagnetic results from compellingly correlated Marinoan strata in southern Australia. Those strata, including the famous Elatina Formation, have yielded a robust paleomagnetic signature that is commonly interpreted to imply frigid climate (manifest in part by frost-wedge polygons) at near-equatorial latitudes. Concerns that the Neoproterozoic geomagnetic field was either nonaxial or nondipolar are valid in principle, but it should be noted that the degree of nonactualistic features required to produce polar or temperate glacial paleolatitudes is as shockingly nonuniformitarian to geophysicists as equatorial glaciation is to paleoclimatologists. Similarly, hypotheses invoking rapid paleolatitude shifts of continents to generate erroneous paleomagnetic latitudes due to lax age constraints require such motions at rates beyond what is normally considered reasonable for plate tectonics. Snowball Earth thus remains an attractive model to explain numerous anomalous features of the Neoproterozoic rock record.

U21B-02 0855h

On the Syn-glacial Sedimentary Record of Snowball Earth: Tales of Three Ice-mass Types

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We sketch a conceptual model of the glacial history of a snowball Earth, based on new field studies of Marinoan (c640 Ma), Sturtian (c710 Ma) and Huronian (c2.4 Ga) syn-glacial deposits, and informed by sea-ice dynamics modeling. If the oceans froze over from pole to pole, sea ice would thicken and flow glacially towards the Equator, maintained in dynamic steady state by sublimation-precipitation and melting-freezing (Goodman & Pierrehumbert, 2003). Flowage thickens tropical sea ice (and thins extratropical sea ice) relative to adjacent landfast sea ice, where ice thickness is set by one-dimensional thermal diffusion. The latter, called 'sikussak' on Greenland fjords, would occur on rimmed shelves, silled basins and inland seas that are physically protected from invasion by sea glaciers. Such areas have high preservation potential in the geological record and their stratigraphic development through a snowball cycle (CO2 hysteresis loop) ought to reflect an interplay between three distinct ice-mass types: (1) sea glaciers, (2) sikussak, and (3) grounded ice domes. The snowball stage begins when sea glaciers invade the tropics and sikussak prevents calving from outlet glaciers and associated shelf ice. The snowball onset might easily be mistaken for a glacial termination in the sedimentary record. Suspended sediment discharged from wet-base grounded ice may accumulate beneath the sikussak, producing deposits previously interpreted as interstadial or non-glacial. Despite tropical sea ice c450 m thick (GP2003), sea glacier movement ensures a perpetual habitat for photoautotrophy in grounding-line crack systems. After greenhouse forcing raises tropical sea-surface temperature to the melting point, sikussak is replaced by 'oases' of open water, but the tropical ocean remains ice covered due to sea glacial inflow from higher latitudes. If evolved snowball seawater is anoxic and charged with dissolved iron, banded iron-formation will precipitate in snowball oases due to air-sea exchange and oxygenic photosynthesis. Snowball oases that formed over carbonate rock or debris may become critically oversaturated upon warming, and the isotopic composition of precipitated carbonate may be dominated by the large atmospheric carbon reservoir. Snowball oases would cover only a few percent of global surface area, but glacier accumulation rates will be enhanced in their vicinity, leading to progradation of ice-proximal deposits (diamictite) over oasis and sub-sikussak formations. Very high tropical melting rates are required to beat back the sea glaciers, giving rise to an active hydrologic cycle and an erosive, wet-base, glacial regime. Ultimate collapse of the sea glaciers triggers terrestrial deglaciation, recorded by 'cap' dolostones that track the post-glacial transgression. Sections of the Polarisbreen Group (c640 Ma) in Svalbard, the Rapitan Group (c710 Ma) in the northern Canadian Cordillera, and the Gowganda Formation (c2.4 Ga) in central Canada exemplify the conceptual model described here.

U21B-03 0915h INVITED

Neoproterozoic Glacial Extremes: How Plausible is the

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The suggestion that the glaciation events of the Neoproterozoic could have been global in extent, so-called "snowball" glaciations, during which the oceans were entirely covered by sea ice and the continents by massive continental ice sheets, is an idea tha is recurrent in the geological and climate dynamics literature. It is an idea that haa both critics and defenders but concensus concerning it's plausiblity has yet to emerge. Previous work on this problem has led to the suggestion that a more likely scenario than the "hard snowball" is one in which open water continues to persist at the equator, thus enabling biological evolution into the Cambrian to proceed, perhaps stimulated by the transition from the cold conditions of the Neoproterozoic to the warm condition of the Cambrian, thus leading to the Cambrian "explosion of life". We will discuss recent extensions of our previous efforts to model the extreme climate of the Neoproterozoic, using both the University of Toronto Glacial Systems Model and the NCAR Community Climate System Model. With an appropriate choice for the albedo of sea ice, the former model conntinues to deliver hysteresis in the surface temperature vs. CO2 concentration space when solar luminosity is reduced by 6% below modern, and thus continues to suggest the existence of the previously hypothesized "CO2 attractor". We argue here that the system could be locked onto this attractor by the strong "out of equilibrium" effects of the carbon cycle recently discussed by Rothman et al. (PNAS, 2003). The open water solution is confirmed as the preferred mode of the system by the detailed CCSM integrations that we have performed.