Here, 3D radiative transfer is applied to the analysis of multi-angle radiance measurements by MISR on specific examples of deep convective clouds to illustrate a technique for optical depth retrievals when the side of the cloud is visible. The retrieval technique estimates the local extinction coefficient as a function of height, and combines this with the geometric cloud thickness estimated from stereo derived cloud base and top altitudes.

U12A-02 1050h INVITED

Photon path length distributions in Oxygen A-band and water vapor band

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A prototype high-resolution oxygen A-band and water vapor band spectrometer (HAWS) has been developed and demonstrated to study the applicability of photon path length statistics in the remote sensing of clouds, aerosols, and water vapor. The HAWS successfully achieves an out-of-band rejection of better than 10-5, a resolution of better than 0.5 cm-1, and high signal to noise ratio, which are crucial to retrieval of atmospheric information through high-resolution spectrometry in the A-band and water vapor band. An algorithm for retrieving the first two moments of the photon path length probability density function for both the oxygen A-band and the 0.820 mm water vapor band from measurements of HAWS and Rotating Shadowband Spectrometer (RSS) is developed and applied to data from the ARM SGP site. Results show that in the A-band thick and multiple layer clouds significantly enhance the mean and variance of the photon path length distribution, thin cirrus condition produce relatively small mean distribution and variance, and mean path lengths comparable to or smaller than the solar airmass were associated with clear sky cases at large solar zenith angles. The mean path length and variance in the water vapor band differs from that in the A-band due to the spatial inhomogeneity of water vapor amounts, particularly in association with cloud layers. Case studies illustrate that the variance of the photon path length probability density function is more sensitive than the mean of the probability density function to vertical cloud structure. Interestingly, the first two moments of the photon path length probability density function appear to exhibit sufficient sensitivity to detect cirrus that the ARM SGP millimeter-wave cloud radar failed to detect. Photon path length probability density functions from both the oxygen A-band and 0.820 mm water vapor band provide additional insights into radiative transfer through a variety of cloudy conditions, improving our understanding of water vapor absorption of solar radiation in these conditions. This work also provides a basis for the application of path length distribution in the development and validation of radiative transfer parameterizations that account for the effects of cloud inhomogeneity.

U12A-03 1110h INVITED

Wide-Angle Imaging Lidar for Probing Spatially Complex Clouds: Instrument Development and Experimental Considerations

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Understanding multiple scattering in clouds is important to both passive and lidar remote sensing, as well as to climate studies. When probing clouds using conventional lidar, where returning light is collected within a very narrow field of view about the laser beam, multiple scattering is generally regarded as a problem for which corrections must be made. But because it has thoroughly sampled the interior of the cloud, multiply-scattered light, especially high-order scattered light, carries much additional information that conventional lidar discards. The new technique of off-beam lidar seeks specifically to study this highly-scattered light, which can spread laterally as much as kilometer away from the input beam. Wide-Angle Imaging Lidar (WAIL) is the fullest realization of the off-beam lidar concept, combining high-resolution spatial imaging over a wide angular field together with high time resolution. WAIL data sets are, in essence, high-speed movies of the propagation of multiply-scattered light; mathematically, they embody the spatial and temporal Green function responses of the cloud. Here we describe the development of WAIL instrumentation at Los Alamos National Laboratory, including a WAIL implementation incorporating an ultra-high-speed (100 ps) microchannel-plate/crossed-delay-line imager and a more recent version using a gated intensified CCD capable of accommodating much higher photon rates. Strategies for performing WAIL measurements in daylight, prospects for WAIL measurements on highly complex broken cloud fields, and non-cloud applications for WAIL techniques ranging from probing sea ice to biomedical applications will also be discussed.

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

U12A-04 1130h

Neural Network Retrieval of Inhomogeneous Cloud Parameters From Multispectral and Multiscale Radiance Data. Preliminary Results From MODIS Measurements.

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Improvements of radiometric observational capabilities enable the development of new approaches for cloud parameter retrieval. In this study, we investigate the possibility of retrieving cloud parameter of inhomogeneous cloud and fractional clouds by using neural network techniques. The inverse model is defined, at the scale of retrieval, with 6 cloud parameters: the mean optical depth, the mean droplet effective radius, the fractional cloud cover, the optical thickness inhomogeneity, the effective radius inhomogeneity and the cloud top temperature. The retrieval procedure includes two separate steps: the first one is relative to the interpolation and the correction of radiance data (surface reflexion and thermal contribution effects). The second step concerns the cloud parameter retrieval. The input vector of the retrieval procedure uses multispectral information and different spatial resolution because we showed that the inclusion of sub-pixel radiance data as input vector components improved significantly the performance of the cloud parameter retrieval. The whole procedure was tested on different types of synthetic inhomogeneous and fractional clouds. All the cloud parameters of these types of clouds can be retrieved with reasonable accuracy. Following these studies, we applied this procedure to real measurements provided by MODIS on Terra.

U12A-05 1145h

Multiresolution Analysis of Radiative Transfer through Inhomogeneous Media

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In the present paper, we derive the multiresolution formulation of the radiative transfer equation through heterogeneous media, which provides an adequate theoretical framework to gain a new insight into the local scale coupling between the spatial heterogeneity of optical properties and radiative transfer process. To facilitate its physical interpretation, the multiresolution transfer equation is formally separated into two equations: the one at the pixel scale and the other at the sub-pixel scale with the contributions of local scale coupling between pixel and/or sub-pixel scale fluctuations of optical properties and radiation fields as additional internal radiation source functions. These additional source functions are expressed by the terms involving the connection coefficients of chosen multiresolution system and scaling and wavelet coefficients of heterogeneous optical properties. The multiresolution radiative transfer equations are numerically solved for the case of simple heterogeneous clouds. After validating the present approach by comparison with more traditional SHDOM and Monte Carlo radiative transfer codes, we present a preliminary analysis of the local scale coupling between the cloud heterogeneity and radiative transfer process. This shows that the contribution of sub-pixel scale cloud heterogeneity to pixel scale radiance fields varies considerably as a function of local cloud heterogeneity.

U13A CC: 517 A Monday 1330h

Remote Observation of the Earth Environment: Spatial Complexity Problems in Terrain and/or Vegetation

Presiding: **J Peltoniemi,** Finnish Geodetic Institute**; A Marshak,** NASA Goddard Space Flight Center

U13A-01 1330h

RULLI: A New Instrumental Concept for Active Characterization of Complex Terrain

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RULLI stands for "Remote Ultra-Low Light Imaging," a sustained instrument development program at LANL's Space and Remote Sensing Sciences Group that has had little exposure to the Earth science community. RULLI has been successfully used in a number of challenging applications using both active and passive modalities. Among the former, RULLI was a key component in an early realization of an off-beam (multiple-scattering) cloud lidar system developed at LANL called WAIL for "Wide-Angle Imaging Lidar." As another example of particular interest to geophysical research, we will highlight detailed mapping of complex terrain from an airborne platform. We will explain the general principles of the instrument and demonstrate its capability with an emphasis on fine laser altimetry.

URL: http://www.rulli.lanl.gov/

U13A-02 1345h

Radiometric Trouble with Rough Surfaces? ... The von Neumann Series can Help!

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Operational retrieval methods used in surface remote sensing will generally assume that the interrogated terrain is uniform as well as flat (if not outright horizontal) at least at sub-pixel scales. Both assumptions are highly questionable. There are spectral techniques (linear un-mixing, end-members, etc.) designed to address the non-uniformity issue and adjacency effects (nonlinear mixing) near large gradients in surface albedo can be unraveled with techniques using the Green function of the aerosol atmosphere. But strong deviations from local flatness define a challenging problem in three-dimensional radiative transfer; this is especially true when the terrain has a very rough fractal shape with height variability over a wide range of scales. The source of the problem is the multiple reflections between surface elements in view of each other and is mathematically akin to the problem of multiple scattering in heterogeneous turbid media like clouds. The fundamental solution to the multiple scattering/reflection problem in transport theory is called "successive orders-of-scattering/reflection" by physicists and a "von Neumann expansion" by mathematicians. I have applied this method to the analysis of two remote sensing problems that appear to be vastly different: (1) angular dependence of effective emissivity in thermal remote sensing, and (2) biases in fine laser altimetry (such as attempted by NASA's present GLAS mission which focuses on polar ice caps). The thermal problem can be reduced to a question of mean aspect ratio in the macro-roughness of the surface. The altimetry problem calls furthermore for a roughness scale. In both cases, corrections can be made to obtain the surface property of interest: actual emissivity, and actual altitude. In both cases, Monte Carlo simulation —another seminal contribution of John von Neumann, with others— was the key to first inspiring and then validating the proposed analytical models with one or two free parameters only.

URL: http://nis-www.lanl.gov/~adavis

U13A-03 1400h

A multi-scale statistical parameterization of radiative transfer in discontinuous vegetation canopies

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It has long been recognized that standard radiative transfer formulations for continuous media are not appropriate for characterizing the radiance field within and above natural vegetation. This problem is often manifested in the "hotspot effect" where the probability of an incident and exitant direction of a photon interacting with a canopy volume is correlated. The most common approach to deal with this effect is to adjust the scattering phase function. However, there are two problems with this solution: 1. Gaps exists over a range of scales so the adjustment must take into account correlations between directions due to gaps at all scales and not just the leaf scale. 2. Vegetation elements are in general non-randomly dispersed at a given scale so the parameterization of the location of vegetation elements must include clumping at potentially all scales. We present a vegetation radiative transfer model based on a multi-scale statistical parameterization of vegetation structure. The concept of the conditional gap probability function is introduced to deal with the hotspot effect. The model is compared to both measurements of below canopy gap size distributions and above canopy BRDF over BOREAS tower

U13A-04 1415h

Characterizing Woody Vegetation Spectral and Structural Parameters with a 3-D Scene Model

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Quantification of structural and biophysical parameters of woody vegetation is of great significance in understanding vegetation condition, dynamics and functionality. Such information over a landscape scale is crucial for global and regional land cover characterization, global carbon-cycle research, forest resource inventories, and fire fuel estimation. While great efforts and progress have been made in mapping general land cover types over large area, at present, the ability to quantify regional woody vegetation structural and biophysical parameters is limited. One approach to address this research issue is through an integration of physically based 3-D scene model with multiangle and multispectral remote sensing data and in-situ measurements. The first step of this work is to model woody vegetation structure and its radiation regime using a physically based 3-D scene model and field data, before a robust operational algorithm can be developed for retrieval of important woody vegetation structural/biophysical parameters. In this study, we use an advanced 3-D scene model recently developed by Qin and Gerstl (2000), based on L-systems and radiosity theories. This 3-D scene model has been successfully applied to semi-arid shrubland to study structure and radiation regime at a regional scale. We apply this 3-D scene model to a more complicated and heterogeneous forest environment dominated by deciduous and coniferous trees. The data used in this study are from a field campaign conducted by NASA in a portion of the Superior National Forest (SNF) near Ely, Minnesota during the summers of 1983 and 1984, and supplement data collected during our revisit to the same area of SNF in summer of 2003. The model is first validated with reflectance measurements at different scales (ground observations, helicopter, aircraft, and satellite). Then its ability to characterize the structural and spectral parameters of the forest scene is evaluated. Based on the results from this study and the current multi-spectral and multi-angular satellite data (MODIS, MISR), a robust retrieval system to estimate woody vegetation structural/biophysical parameters is proposed.

U13A-05 1430h

Evaluation of the Effect of Tree Shape and Density on the Correlation Between an Anisotropy Index and the Vegetation Clumping Index

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This paper presents results of model parameter testing required for the global application of a methodology that proven applicable in the Canadian environment. The Four-Scale model represents a four kernel model to simulate the anisotropy of forested environments. Its accuracy in simulating the maximum (Hotspot) and the minimum (Darkspot) of reflectance in the backscattering and forward scattering along the principal plane has allowed the formulation of the Normalised Difference of Hotspot and Darkspot (NDHD). This angular index has been shown to correlate with the vegetation clumping index, that describes the deviation of foliage distribution from a Poisson based random distribution. The clumping of vegetation significantly affects carbon budget models because it allows the correction of effective LAI observed from single angle measurements. Additional tree crown shapes have been included, and vegetation density variations within and between ecosystems are investigated. The results are evaluated in terms of model applicability to global derivation of the clumping index using POLDER data from ADEOS-1.

U13A-06 1445h

Characterization of Spatial Heterogeneity and Structure at Landscape Scale

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The monitoring of land surface dynamic processes at global scale, such as primary production, carbon and water fluxes, requires high temporal frequency remote sensing observations. Because of technological constraints, the sensors are characterized by coarse spatial resolution, i.e. a resolution from few hundred meters (MERIS/ENVISAT, MODIS/TERRA) up to one or few kilometres (VEGETATION/SPOT, SEVIRI/MSG). However, the scenes observed at this range of scales, present spatial heterogeneity which may have a great influence on land surface characteristic estimation from remotely sensed data. Therefore the characterisation of spatial heterogeneity is an important concern to scale non linear land surface processes. The aim of this study is to discuss a geostatistical approach based on two complementary tools to characterize spatial structure of remote sensing data at the landscape scale. The high spatial resolution NDVI (vegetation index) of SPOT/HRV images (20m resolution) is used to characterize the ground spatial structure of different landscapes. These NDVI images are then aggregated in order to describe the evolution of their structure with the spatial resolution. A classical method consists in describing the image spatial heterogeneity by a geostatistic tool: the variogram. The interest of the variogram is that it jointly allows to model the spatial distribution of a scene as well as to quantify the spatial heterogeneity as a function of the spatial resolution. A typology of spatial heterogeneity is derived from the variogram model parameters computed over several types of landscapes. To account for the availability of multiple wavebands, a multivariate description of the spatial heterogeneity could also be proposed. A first limit of the variogram approach is the assumption of spatial stationarity, necessary for modelling the variogram. Spatial stationarity can be checked by: - Dividing the image into local windows and adjusting the corresponding variogram model parameters for a range of window size. - Computing the variogram on increasing size of the same scene. A second limit of the variogram approach is that different models of spatial random fields can share the same variogram function. This is for example the case of the Gaussian random field with an exponential variogram and the mosaic model with Poisson random polyhedra. We show that these two models and their linear mixture are undistinguishable if the histogram and the variogram are the only tools used for characterizing the heterogeneity. In this work we propose to use the first order variogram to discriminate between these two models. Moreover, we show that it is possible to model a wide range of landscapes as a mixture of these models and to estimate their parameters and the proportion of the mixture. This new way of characterization of landscape spatial structure and heterogeneity is discussed with possible application to land surface characteristic estimation from coarse resolution observations. Key Words: remote sensing, spatial heterogeneity, landscape, scaling, spatial resolution, variogram, spatial random field simulation, non linear process

U14A CC: 517 A Monday 1530h

Remote Observation of Earth's Atmospheric Environment: The Challenge of Spatial Complexity

Presiding: **L Di Girolamo,** University of Illinois at Urbana-Champaign**; C Bostater,** Florida Institute of Technology

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U14A-01 1530h INVITED

Intercomparison of Radiation Transfer Models in Cloud Fields and Vegetation Canopies

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The communities involved in modeling radiation transfer (RT) in cloud fields and vegetation canopies have implemented, in parallel, RT model intercomparison exercises, namely the Intercomparison of 3D Radiation Codes (I3RC) and the RAdiation transfer Model Intercomparison (RAMI). These 2 projects are now being coordinated as part of the 3DRT Working Group of the International Radiation Commission. The purpose of such intercomparison is to provide benchmark cases and solutions which will be used in the development and testing of RT models. The intercomparison exercises also help to identify existing models and their ranges of applicability. Both I3RC and RAMI protocols have been designed as a series of conditions under which the various RT models should be executed. They have been selected to represent a broad set of well-defined problems for which the solutions can be easily compared. The selection of these problems are driven by the main issues faced by these two communities and, as a consequence, the proposed experiments reflect the specificity of RT problems in both cloud fields and vegetation canopy. The main goal of the first phases of the I3RC is to evaluate the performance of a wide variety of 3D RT codes on radiative experiments of varying complexity beginning with an academic "step cloud" and proceeding to more realistic cases obtained from Large Eddy Simulation models, Millimeter Cloud Radar and inferred from Landsat. In the RAMI exercise, two major series of experiments are currently scheduled: one for so-called structurally homogeneous canopies, and the other for the structurally heterogeneous ones. The main difference between these two series lies in the hierarchy of scales that may exist depending on the degree of vegetation clumpiness. This presentation will provide a general overview of the I3RC and RAMI exercises and discuss future plans of integrating clouds, vegetation, and other inhomogeneous media.

URL: http://climate.gsfc.nasa.gov/I3RC

U14A-02 1550h

Spatial auto-correlation and its impact on understanding lidar measurements of clouds

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