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A case study of the evolution of a thunderstorm cirrus anvil measured during the Cirrus Regional Study of Tropical Anvils and Cirrus Layers-Florida Area Cirrus Experiment (CRYSTAL-FACE) is presented. In situ measurements of cloud bulk properties and size spectra were obtained using the NASA WB-57F and the University of North Dakota Citation aircraft. The cirrus anvil contained bulk ice water contents up to 0.30 g m^{-3} at one hour age, diminishing to 0.018 g m^{-3} at 2.5 hours of age. Ice crystal size distributions were bi-modal, with the largest crystals and effective radii near the base of the anvil. At one hour age, the optical depth calculated from in situ bulk visible extinction coefficient measurements was ~ 21.7 . Ice water content, total ice crystal concentration, relative humidity with respect to ice, and effective radius all decreased with increasing distance from the upwind edge of the anvil. The effective radius was dominated primarily by small ice crystals with a mode size of $25 \mu\text{m}$. The anvil's microphysical evolution depended primarily on dilution by entrainment, and to a lesser degree on sedimentation of large ice crystals. A second, thinner cloud, with an optical depth of 0.4, existed about 1.5 km above the anvil at the tropopause at an altitude of about 13.0 to 14.5 km and at temperatures as cold as -70°C . The cloud appears to be a remnant of the initial convective impulse of the anvil, which then maintained itself through internal circulations as the anvil dissipated beneath it. Size distributions in this cloud were monomodal with bulk ice water content values generally below 0.0015 g m^{-3} . The stability of this cloud suggests a possible production mechanism for the subvisible cirrus widespread over tropical regions.

A11B-07 0930h

Relationship Between Cirrus Anvil Ice Crystal Properties and Aerosol Concentration, Ambient Relative Humidity and Vertical Velocity During CRYSTAL FACE

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The coverage of cirrus in the tropics and their radiative effects depend on anvil lifetimes and spreading in the upper troposphere (UT). One of the goals of the CRYSTAL FACE (CF) experiment is to understand the cirrus anvil evolution processes. Cirrus anvil properties can be linked to intensity of convection in the generating cumulonimbus and on UT ambient conditions. This work uses CF measurements to document the dependence of cirrus anvil ice crystal concentration and effective size on aerosol concentration, ambient relative humidity and vertical velocity. It is shown that the presence of significant ice crystal concentration (diameter larger than 50 micrometers) in cirrus anvil is linked to ambient water vapor supersaturated with respect to ice, predominant mesoscale updraft motion and large number concentration of aerosol particles (with diameter less than 1 micrometer). The study presents cases with time evolution of anvil characteristics and a discussion of factors that affect aerosol and ice crystal concentration during cirrus anvil aging. With the aim of diagnosing the dependence of ice crystal concentration on vertical motion in the cumulonimbus core, and possible dependence on atmospheric aerosol loading, an explicit microphysical model is applied.

A11B-08 0945h

Retrieval of Cirrus Properties from Solar Spectral Irradiance During CRYSTAL-FACE

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We examine spectrally resolved solar irradiance measured from above (NASA ER-2) and below (CIRPAS Twin Otter) tropical anvils during CRYSTAL-FACE in order to derive relationships between the scattered (reflected and transmitted) radiation and cirrus microphysical properties. Retrieved parameters are interpreted with respect to other remote sensing methods and to microphysical quantities obtained in situ. In particular we compare with simultaneous MODIS Airborne Simulator (MAS) and MODIS retrievals, which provide a directional inference of cloud properties, compared to the hemispherically integrated spectral irradiance. For both the spectral irradiance and MAS/MODIS retrievals identical ice crystal single-scattering models (twelve size distributions, four crystal habits) are used. This analysis is useful to determine if a directional bias exists between the directly measured spectral irradiance and the computed irradiance using cloud parameters derived from MAS/MODIS. We also show the relationship between infrared forcing and visible optical thickness for thin cirrus over the CRYSTAL-FACE domain.

A11C MCC: 3010 Monday 0800h

Effects of Biomass Burning Plumes on the Troposphere and Stratosphere I (joint with B, AE)

Presiding: K Drdla, NASA Ames

Research Center; D Jaffe, University of Washington, Bothell

A11C-01 0800h

Layers with biomass burning signature observed at 15.8 km in the stratosphere

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We present evidence that boreal forest fires represent a major source of soot in the stratosphere, affecting stratospheric temperature and chemistry and global radiative forcing. Polluted air unambiguously attributable to forest fires in North America was observed at altitudes up to 15.8 km, demonstrating direct transport of heavy smoke from the surface deep into the stratosphere which is not captured by atmospheric transport models. Stratospheric soot may not be due primarily to aircraft exhaust, as currently believed, but may be sensitive to changes in forest burning associated with climatic warming.

A11C-02 0815h

The Physical Mechanism of Injecting Biomass Burning Materials into the Stratosphere During Fire-induced Thunderstorms

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Recent satellite observations indicate that biomass burning debris can be injected into the lower stratosphere due to the fire-caused thunderstorms. This study uses a 3-D non-hydrostatic thunderstorm model to investigate the mechanism responsible for the injection. A typical thunderstorm occurred in the US High Plains is chosen as the model storm for the study. An inert tracer is assumed to be uniformly distributed in the lowest two kilometers initially and is carried upward by the storm circulation. The simulated storm is then analyzed in detail to reveal its thermodynamic and dynamic structure and the mechanism responsible for the cross-tropopause is identified. It will be shown that the diabatic process of cloud top gravity wave breaking is the mechanism of such transport. Local Richardson numbers (LRN) are computed and the animation of the LRN field indicates that the wave breaking is intimately related to the high convective instability at the cloud top region. Implications of such injections will also be discussed.

A11C-03 0830h

Pyro-Cumulonimbus: Strongly suppressed precipitation by smoke-induced extremely small cloud drops up to the homogeneous freezing level

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Pyro-cumulonimbus (Pyro-CB) is defined here as a convective cloud that feeds directly on the heat and smoke of a major fire, with its top exceeding the -40C isotherm level. The microstructure and precipitation of Pyro-CBs that were formed over large forest fires were observed by in situ measurements at the Amazon, by

radar in Canada and the USA, and by satellite multispectral retrievals in all of these locations and several others. The satellite measurements of cloud microstructure show that the cloud drop effective radius is extremely small, and at the mid and high latitudes it does not exceed the precipitation threshold of 14 micrometer even near the cloud top. This implies that the smoke provides sufficiently large activated cloud condensation nuclei that create large number of small droplets to the extent that they do not coalesce with each other or rime with ice particles up to the homogeneous freezing level, which is slightly below the -40C isotherm level. The lack of significant precipitation forming processes is manifested as very weak radar echo intensities reflected from the Pyro-CBs in spite of their vigor and depth, often penetrating the tropopause. This is especially conspicuous when compared with neighboring normal microphysically continental cumulonimbus clouds, which are composed of much larger particles and produce strong precipitation radar echoes. In situ measurements in tropical Pyro-CBs at the Amazon validated the remote sensing inferences, and showed that the large ash particles are incapable of producing fast-growing precipitation particles in the Pyro-CBs. Some of the implications of these observations are: 1. Pyro-CBs have little precipitation in spite of their vigor and extent, so that they do not help to mitigate the fire that created them. 2. Furthermore, "dry" lightning that do form with little precipitation in the Pyro-CB can ignite the forest downwind and so enhance the spreading of the forest fires by jumping forward 3. The lack of precipitation means also lack of washout of the smoke from the cloud, so that much of the smoke is detrained with the anvil at the upper troposphere and even the low stratosphere.

A11C-04 0845h

Modeling of Fire-Induced Supercell Convection and Transport of Biomass Burning Aerosol Into the Stratosphere: The Chisholm Fire of 28 May, 2001

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Several recent observations provide evidence of the presence of aerosol particles in the lower stratosphere that originate from biomass burning emissions. The long lifetime of particles within the stratosphere enables these emissions to be distributed over a large area. The vertical transport mechanism, which deposits the smoke aerosol into the lower stratosphere, is still uncertain. Direct injection of the fire emissions due to fire-induced convection is one possible transport pathway. Here, we present observations and model results of a wildfire, which took place on 28 May, 2001, near Chisholm, Alberta, Canada. Satellite and radar observations showed the development of a supercell convection above the fire reaching up to the UT/LS as a frontal system approached the fire site. Using the three-dimensional Active Tracer High-Resolution Atmospheric Model (ATHAM) we investigate the importance of the fire-induced convection for the vertical transport of the fire emissions. ATHAM takes into account the heat and aerosol flux from the Chisholm fire, based on available data of the burned fuel and the area burned. The initial meteorological conditions were taken from radiosonde data. To assess the quality of the simulations, we used the model to reproduce the observed dynamical and microphysical features of the convective cloud. Furthermore, the influence of the meteorological conditions and microphysical cloud properties on the injection height are examined.

A11C-05 0900h

Stratospheric Smoke Down Under: Injection From Australian Fires/Convection in January 2003

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In January 2003, the Australian Capital Territory suffered prolonged, extreme, and devastating bush and forest fires. On at least three distinct occasions, some of these fires erupted into convectively driven/aided firestorms producing plumes that traveled several thousand km. One in particular, a January 18 blowup, resulted in an aerosol plume tracked by TOMS aerosol index across South America, into the South Atlantic (fully one half way around the Earth) in one week. Soon after these blowups, SAGE III aerosol extinction profiles (at approximately 35 deg. S) recorded layers of enhanced aerosol at potential temperatures as high as 400 K, well into the lower stratosphere. POAM III also recorded stratospheric aerosol layers in mid-February at its measurement latitude near 70 deg. S. We explore the Australian blowups with meteorological data and an assemblage of satellite views, including the above mentioned, MODIS, SeaWiFS, MISR, and AVHRR, and GMS. We find that the setup conditions, forcing, and extreme pyro-cumulonimbus (pyro-Cb) eruption leading to stratospheric intrusion are quite similar to boreal forest fire blowups described by Fromm et al. [GRL, 2000] and Fromm and Servranckx [GRL, 2003]. Our report will include a cloud analysis, comparing an Australian pyro-Cb to a volcanic convective plume. Our monitoring of the summer 2003 Australian fires and smoke also revealed a high-altitude plume of aerosol (highlighted by TOMS aerosol index) ejected/detrained from a convective tower in northern Queensland (18 deg. S) on February 4, perhaps a direct observation of UTLS-level aerosol transport through a specific convective cell at low latitude.

A11C-06 0915h

Seasonal And Interannual Variations Of Biomass Burning Aerosol Sources As Observed With Satellite

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With the objective of improving the representation of biomass burning contribution in aerosol transport models, we have used satellite observations to constrain the emission seasonal and inter-annual variations in current inventories. Our primary dataset for the seasonal and inter-annual distribution of biomass burning is the ATSR fire count, derived from night-time observations of this instrument. This dataset provides a near global coverage over an extended time period (1996-2002). A comparison to other datasets that cover a more limited area (tropics in the case of TRMM), or are available over a limited time period (one year for GBA and GLOBSCAR) shows a consistent picture. Atmospheric transport simulations of the aerosol load, using both the original and the satellite-derived inventories, compared to optical thickness sunphotometer measurement, allows a quantitative analysis of the method impact. With the satellite-corrected emission inventories, there is a clear improvement of the seasonal distribution of aerosol load in the models. In addition, we have selected 3 specific biomass burning event with

a long-range transport that is observed by the spaceborne POLDER for a period of up to 10 days. These episodes are analyzed and demonstrate the forces and deficiencies of long-range transport in the model.

A11C-07 0930h

A Global Survey of the CO Emissions of Boreal Fires From MOPITT Data

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Retrievals of radiances obtained by the Measurements Of Pollution In The Troposphere (MOPITT) instrument on the Terra spacecraft have yielded determinations of the global distribution of CO from March 2000 to the present. These data have been used to evaluate the contributions of Boreal fires to the CO background in the Northern Hemisphere. Time series of the CO concentrations in the lower and upper troposphere over the latitude band from 40°-70°N are used to show the seasonal cycle in CO mixing ratios, and the cycle in short-term variability, off the east coasts of Asia and North America. These show the largest CO concentrations in spring, as well as the strong variability of CO concentrations during episodic production from fires. The resulting CO is transported over intercontinental distances in timescales ranging upward from a week (in spring). The inter-annual variation of CO can be quantified for the 2000-2003 period. For March 2000-April 2001 the data will be compared with the results of assimilating CO retrievals into a chemistry-transport model. This illustrates the additional information that the assimilation can add at high latitudes, where the retrieved results are depend more strongly on the a priori information.

A11C-08 0945h

Influence Of Tropospheric OH On The Stratospheric Humidity And The Background Sulphuric Aerosol Layer: Impact Of Tropical Biomass Burning?

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We propose a mechanism that couples stratospheric humidity and total sulphur levels in the stratosphere to the concentration of OH in the upper tropical troposphere. Our considerations are based on a 2-D sulphate aerosol model to calculate the number, surface and volume of particles formed in the atmosphere. The precursor gases considered are SO₂, OCS, DMS, H₂S and CS₂. The microphysical processes simulated are homogeneous nucleation, condensation and evaporation, coagulation, and sedimentation. Recent observations and modelling studies indicate that HO_x concentrations (OH + HO₂) in the upper tropical troposphere are higher by a factor of two than previously assumed. Our model studies have been performed for two different OH-fields which differ by a factor of two in the upper tropical troposphere. The results show that the increase of OH significantly increases the formation of H₂SO₄ containing condensation nuclei in the upper tropical troposphere. Upon cooling to temperatures below the frost point the larger number of condensation

nuclei leads to a slightly enhanced ice crystal number densities and, thus, to a slight reduction in the average ice particle size and sedimentation speed in the upper tropical troposphere. Therefore, on the average a larger fraction of these particles may be carried through the cold point tropopause by the rising motion of air, increasing the overall transport of water into the stratosphere. At the same time, an enhanced particle formation in the troposphere followed by some sedimentation decreases also to some extent the overall input of sulphur into the stratosphere. Since biomass burning is known to be a source of HO_x, the long-term increase in the tropical burning activity could lead to increasing stratospheric humidity and a decreasing level of sulphur in the stratosphere.

A11D MCC: 3020 Monday 0800h

Climate I: Models (joint with GC)

Presiding: M Herzog, University of Michigan; M J Prather, University of California, Irvine

A11D-01 0800h

Adaptive Grids in Climate Modeling: Concept and First Results

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One of the most important advances needed in global climate models is the development of models that can reliably treat convection. This project will result in a climate model that self-adjusts the grid resolution and the complexity of the physics model to the atmospheric flow conditions. Adaptive grid techniques are being applied to a parallel version of NASA's next generation climate model, the NASA/NCAR Finite-Volume Community Climate Model, which has been developed at the NASA Goddard Space Flight Center (GSFC, Data Assimilation Office). This global hydrostatic model is based on NCAR physics and the so-called Lin-Rood finite volume dynamical core that provides highly efficient algorithms for high performance computing. The non-hydrostatic model will be based on an extension of the Lin-Rood finite volume dynamical core. It will keep the concept of a Langrangian vertical coordinate. Special considerations are made to ensure conservation of total mass and heat. The adaptive model design utilizes a spherical grid library that is based on a computationally efficient block-structured data layout. This communication library for parallel processors will also enable a reduced grid design near polar regions. We will discuss the basic model concept with the focus on the adaptive grid design and the formulation of the non-hydrostatic model. We will present first results from runs with the block-structured code.

A11D-02 0815h

Adaptive Grids in Climate Modeling: Tests of the Dynamical Core

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Adaptive grids in climate modeling offer unique opportunities for future climate model predictions. They allow the use of static and dynamic refinements depending on terrain features or flow characteristics. For the first time, an adaptive hydrostatic dynamical core for global atmospheric General Circulation Models has been built. It is based on the NASA/NCAR finite volume dynamical core and utilizes a parallel, spherical adaptive grid library with a block-structured data layout. The model can adapt its resolution statically and dynamically during a model run. Static adaptations resolve predetermined regions of interests, like mountain ranges, at high resolutions and allow the efficient use of reduced grids in polar regions. Dynamic adaptations are guided by user defined refinement/coarsening criteria and are capable of tracking a wide variety of features of interest. Examples include vorticity and

pressure-based adaptation criteria that track a cyclone path. The presentation shows the highlights of the adaptive dynamical core experiments using both 2D shallow water tests and idealized 3D test cases. The results emphasize the pros and cons of different refinement criteria and suggest that adaptive grids can be considered an alternative to today's nested grid approaches.

A11D-03 0830h

Impacts of numerical approximation in atmospheric tracer transport: examples from the Global Modeling Initiative

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Improved numerical methods for transport of trace species in the atmosphere and ocean continue to be developed. Typically, these algorithms are evaluated against existing methods using analytic or idealized test cases, but the NASA Global Modeling Initiative now provides a realistic framework for evaluating their accuracy in full chemistry-transport models (CTM). GMI's modular approach is combined with parallel simulations in the UCI CTM to quantify the differences between two relatively accurate tracer transport algorithms (Lin-Rood, Prather 2nd-order moments), including the impact of forcing a positive-definite, ripple-free tracer abundance. We use a range of simplified atmospheric chemical tracers (radon-lead, fossil-fuel CO₂, industrial and biomass CO) with the meteorology from the Goddard Institute for Space Studies global climate model (4 deg by 5 deg with 23 layers) that includes three-hourly integrated winds, boundary-layer physics, entraining and non-entraining convection, large-scale and convective precipitation, updrafts and downdrafts. The relative accuracy of the different methods is considered in terms of forward and inverse calculations. We thank the entire GMI team, especially the researchers at LLNL and GSFC who have built and maintained the GMI modeling capability.

A11D-04 0845h

Effect of Convective Parameterization Closure on Climate Simulation in the NCAR Model

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This paper investigates the role of convective parameterization closures in the NCAR CCM3 climate simulation. Several recent observational studies using both tropical and midlatitude data suggest that the conventional convective instability-based closures for convective parameterization can deviate considerably from reality, particularly at sub-daily timescales. Based on these studies, a new closure for convective parameterization is devised. It is implemented and tested in the NCAR GCM. Results from the test simulations show that there is significant improvement in the simulated model climate. For example, the seasonal variation of tropical precipitation is in better agreement with the observations. Many GCMs including the NCAR model and the ECMWF model have difficulties in simulating the diurnal cycle of convection correctly. Particularly over land, the simulated convection occurs too early compared to observations. We will show that with the new closure, the simulated diurnal cycle of convection over land is much closer to what is observed.

A11D-05 0900h

Modeling Intra-seasonal to Interannual Variability of Precipitation Over Central America

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A devastating Central American drought occurred during the summer of 2001. This drought ravaged much of northern Central America (C.A.) but was not

predicted or anticipated; nor is a cause for it immediately apparent. The catastrophe caused by this drought points out how little is known about precipitation and its variability over this region. Some of the seasonal controls are qualitatively known (e.g., trade winds, orographic effects, seasonal march of the ITCZ) but much less is known about intraseasonal to interannual variability. For example, on intraseasonal time-scales, the midsummer drought (MSD) on the Pacific side of C.A. is well known and documented, but little is known about why it occurs. Almost nothing is known about the interactions between precipitation in C.A. and the rest of the Americas. Because of its location, C.A. is key in linking monsoon variability in both North and South America. C.A. is affected by monsoonal processes, large-scale ocean circulation and related cold tongue-ITCZ (CTIC) features, and quasi-cyclical ENSO events. Because of the importance of small-scale orography and land use issues, large-scale models and reanalyses by themselves are insufficient to fully understand and model precipitation variability over C.A. Regional modeling capabilities are critical as a means to examine how large-scale forcing gets down-scaled by orographic effects, and to explore the impact of land surface state. We are making runs with the regional climate version of MM5 with the OSU (NOAH) land surface scheme. We have focused on three key interrelated issues regarding high resolution mesoscale modeling: (i) improving the simulated distribution of precipitation and cloudiness through high resolution simulation of topographical forcing acting on anomalous large scale flows, (ii) evaluating the relative roles of C.A. land surface / east Pacific Warm Pool in controlling convective triggering; and (iii) determining if the ensemble effect of these processes on the diurnal cycle of cloudiness.

A11D-06 0915h

A less dusty future?

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Atmospheric desert dust is potentially highly sensitive to changes in climate, carbon dioxide and human land use. In this study we use 6 different scenarios of the processes responsible for changes in source areas and explore changes in desert dust loading in pre-industrial and future climates, although all the scenario results are likely to be sensitive to the climate model simulations used for this study. Comparisons between model results and available pre-industrial ice cores are not able to constrain which scenario is most likely to be correct. Simulations suggest that future dust may be 20 to 60 percent lower than current dust loadings. The anthropogenic portion of the current dust loading may be as large as 60 percent, or humans may have caused a 24 percent decrease in desert dust, depending on the relative importance of land use, carbon dioxide and human induced climate change. These results suggest there may be a high sensitivity of natural aerosols⁷ to human intervention, which has enormous implications for climate and biogeochemistry in the future.

A11D-07 0930h

A new Type of Idealized Global Climate Model and its Application to Dust-Climate Interactions

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Paleoclimatic evidence suggests that airborne mineral dust can be a climatically important atmospheric aerosol, but little is known quantitatively about the mechanisms of dust-climate interactions. We have developed an idealized global model with which to study processes and feedbacks within the dust-climate system. The model is a generalization of the energy balance approach to climate modeling. We solve numerically for equilibrium climate states defined by zonal average temperature as a function of latitude for both an atmosphere and a surface. We parameterize the effects of radiative, latent, and sensible heating, ocean heat transport, the Hadley circulation, and midlatitude atmospheric eddies. The model reproduces the mean variation of temperature with latitude and the global average heat budget within the uncertainty of observations. Dust concentrations can influence the climate system by altering the radiative properties of the atmosphere. We determine the longwave and shortwave forcing due to dust based on specified dust distribution