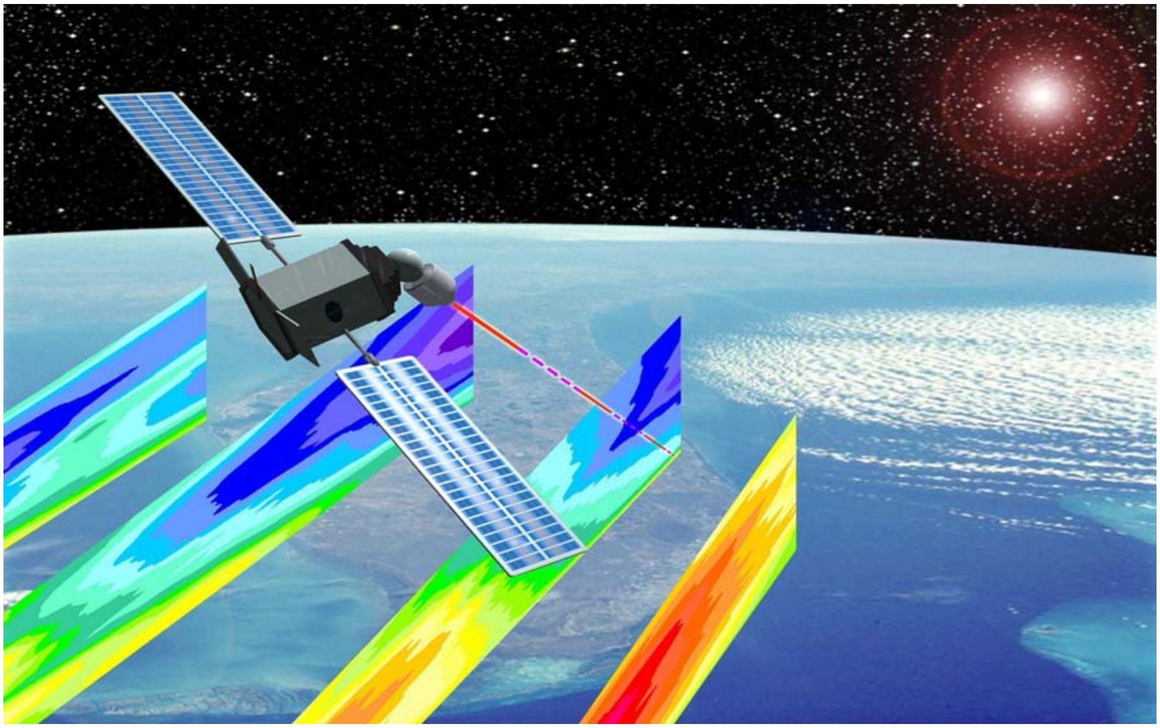
Meeting of the Working Group on Space-Based Lidar Winds
Wintergreen, VA
July 8-11, 2008
<u>Minutes</u>



Background. Beginning in 1994, the Lidar Working Group (LWG) has met twice yearly to bring together Doppler Wind Lidar (DWL) technologists and potential users from government, industry, academia, and international organizations to exchange information, review technology developments, and build consensus for missions to measure the global wind field from space.

The importance of global wind profile measurement is well established.

- It is the number one unaccommodated Environmental Data Record (EDR) and the single most important measurement still needed in the Global Observing System.
  - The Numerical Weather Prediction (NWP) community unanimously identifies global wind profiles as the most important missing observations.
  - Independent modeling studies at the National Centers for Environmental Prediction (NCEP), NOAA Earth System Research Laboratory (ESRL), NOAA Atlantic Oceanographic and Meteorological Laboratory

(AOML), NASA and the European Centre for Medium-range Weather Forecasts (ECMWF) show tropospheric wind profiles to be the single most beneficial measurement missing from the Global Observing System.

- More than 25 years of development have led to a viable space-based Hybrid Doppler Wind Lidar (HDWL) concept. Recent conceptual instrument designs include:
  - Global Wind Observing Sounder (GWOS) for space demonstration in a 400 km orbit as early as 2016. This was a NASA-sponsored design at the Goddard Space Flight Center (GSFC) Instrument Synthesis and Analysis Laboratory (ISAL) in 2006.
  - NPOESS Wind Observing Sounder (NWOS) for operation in the National Polar-Orbiting Environmental Satellite System (NPOESS) NexGen series in an 824 km orbit as early as 2022. This was sponsored by the NPOESS Program Executive Office (PEO) at GSFC Instrument Design Laboratory (IDL) in 2008.
- The National Research Council (NRC) decadal survey recommended HDWL as a priority for implementation as a NASA demonstration mission followed by an operational mission.
- GWOS and NWOS design teams at NASA concluded that HDWL is viable for space missions.
- Cost benefit studies show major societal benefits.
- The European Space Agency (ESA) plans to launch the first space-borne Doppler Wind Lidar (DWL) instrument in 2010 in the Atmospheric Dynamics Mission (ADM) to provide global line of sight wind profiles.
- A joint NASA/NOAA/DoD HDWL mission offers the best opportunity for the U.S. to demonstrate a wind lidar in space in the coming decade.
- The GWOS and NWOS instruments are designed to measure 3-D global horizontal wind vector profiles for the first time, using bi-perspective views of target volumes.

NASA and NOAA briefed several agencies and organizations recently on lidar winds mission opportunities, including:

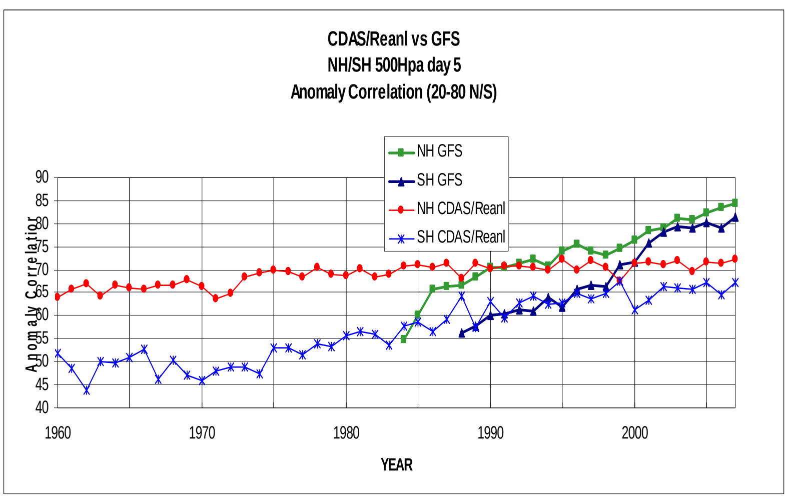
- USAF (March 20, 2007). The USAF Director of Weather sent a letter on August 1, 2007 to NASA HQ stating support for tropospheric wind measurements
- USAF Space Command - May 8, 2007
- US Army - May 10, 2007
- NOAA Observing Systems Council (NOSC) – June 8, 2007; June 18, 2008
- Navy (June 11, 2007); supporting letter from Navy on August 8, 2007
- Joint Planning and Development Office (JPDO) and Federal Aviation Administration (FAA) - June 18, 2007
- FAA Director of Weather - May 16, 2008
- NOAA Research Council - May 19, 2008
- PEO Director – July 30, 2008

Progress continues in laser and optics technologies, instrument architectures, mission concepts, field demonstrations, and applications of wind data to numerical weather forecasting. Interagency support for airborne and space demonstrations of a hybrid DWL continues to build. The NRC decadal survey report, a NASA Earth-Sun System Technology Office (ESTO) study report, the U.S. Integrated Earth Observing System Strategic Plan, and the NPOESS Integrated Program Office (IPO) assign high priority to global observations of winds at all levels. The USAF, Navy, Army, and FAA have interest in improved wind data and weather forecasts in support of their respective missions. A US space demonstration of HDWL is anticipated following ESA's ADM mission.

Technology readiness continues to advance. The GSFC ISAL and IDL have developed GWOS and NWOS instrument reference designs for space. HDWL uses two lidar subsystems, one direct detection ultraviolet and the other coherent detection infrared, to meet data requirements while optimizing mass, power, and volume requirements. These reference designs were determined to be feasible with no technological "tall poles." NASA continues to advance the capabilities and space qualification of lasers and lidars.

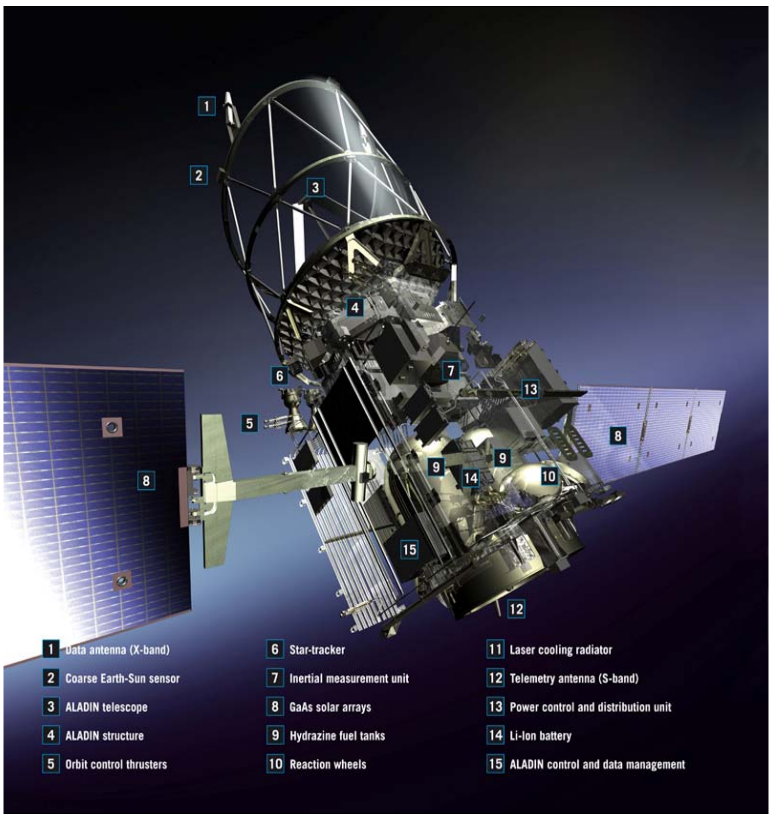
Tuesday, July 8

Wayman Baker opened the 30th meeting of the Working Group on Space-Based Lidar Winds (LWG) with introductory remarks. He led a discussion of Action Items from previous meetings (see LWG website http://space.hsv.usra.edu/LWG/Index.html). Wayman reviewed a graph showing steady progress in forecast skill (Anomaly Correlation) from 1960 through 2007. In discussion of the chart, it was concluded that it would be helpful if the anomaly correlation metric could be related to dollar values of societal benefits.



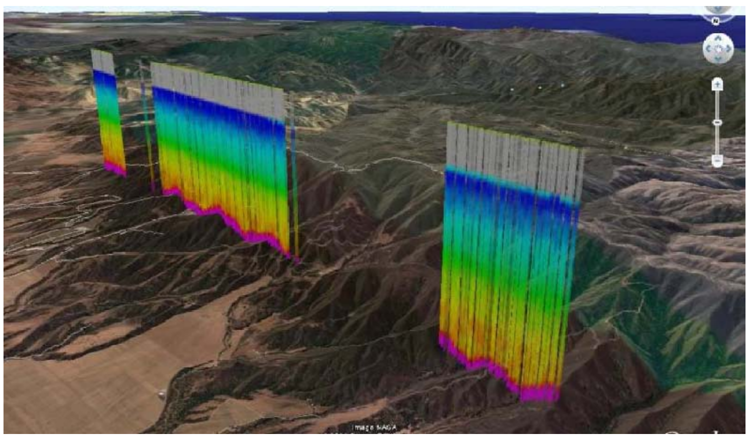
Ramesh Kakar presented "NASA Headquarters Perspective." Ramesh reviewed recent NASA wind lidar support and activities, including seven proposals selected for funding as a result of the Research Opportunities in Space and Earth Sciences 2007 (ROSES 07) Wind Lidar Science Announcement and two Instrument Incubator Programs (IIP) proposals selected in April 2008. NASA plans to support a Hurricane Genesis field experiment during the 2010 hurricane season. The GSFC Tropospheric Wind Lidar Technology Experiment (TWiLiTE) direct detection and the LaRC Doppler Aerosol Wind Lidar (DAWN) coherent detection airborne wind lidars will be the primary instruments in the Hurricane Genesis 2010 mission. NASA plans to make TWiLiTE and DAWN autonomous. He reviewed the ROSES Wind Lidar Science selections. The selected IIP programs included a High Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP). Ramesh announced that Dr. Ed Weller replaced Dr. Alan Stern as SMD Associate Administrator in March 2008. Ramesh reviewed the NRC Decadal Survey recommendations to NASA, in which wind lidar was included in the 15th place on the list. NASA is currently following the order of the NRC sequence. It is possible that NRC could revisit rankings at some point, considering the importance of societal benefits and the advances in risk reduction. He noted that NRC placed a scatterometer instrument on NOAA's list of recommendations.

David Tan presented "Data Processing for ESA's Doppler Wind Lidar Mission ADM-Aeolus." David described ECMWF activities for ADM, including preparing for assimilation of Level-2B horizontal line-of-sight (HLOS) winds, developing the Level-2B processor, and related work. Other work included Mission Advisory Group, Cal/Val, in-orbit commissioning, operational L2B/L2C products, monitoring and assimilating Aeolus mission data, and assessing impact on numerical weather prediction (NWP). ECMWF will maintain, develop and distribute an L2B processor on behalf of ESA. The Day-1 system will support L2B HLOS winds, the primary product for assimilation. The main algorithm components are developed, validated and available. They are tested on Linux platforms. Work is continuing on sensitivity, quality control, and weighting options. Contacts may be made at ESA or ECMWF. David reviewed mission requirements. ADM is a single payload mission, carrying the Atmospheric Laser Doppler Instrument (ALADIN). The ultraviolet lidar will provide 3200 wind profiles per day, about 3 times as many as the radiosonde network. It has two receivers, one optimized for Mie aerosol sensitivity and the other for Rayleigh molecular backscatter. Instrument mass is 470 kg, bus mass is 1100 kg dry plus 116 to 266 kg of fuel. Instrument average power is 840 W, and total average power is 1.4 kW. Volume is 4.3 m x 2 m x 1.9 m. Telescope diameter is 1.5 m. The launch vehicle is not yet selected. The ALADIN optical layout was described. Data availability will be 3 hours after observation. The current plan is for a May 2010 launch and a 39 month lifetime. David compared Power-Aperture Products of several space lidars, showing that ALADIN will have 45 times the Power-Aperture Product of the Cloud-Aerosol Lidar



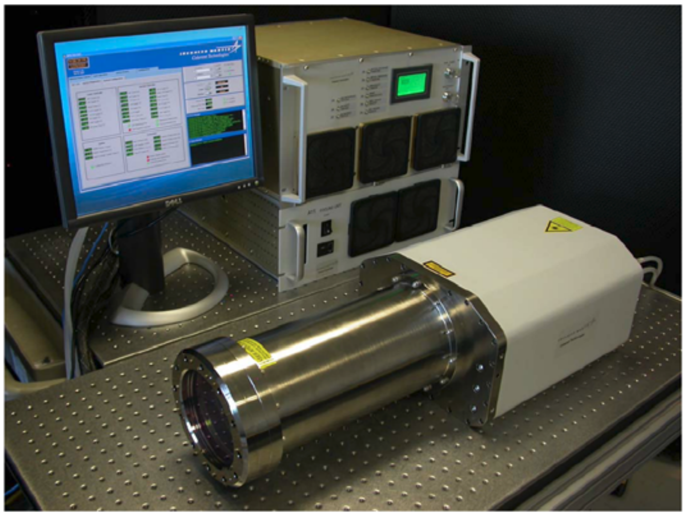
with Orthogonal Polarization (CALIOP) and 56 times that of ESA's Atmospheric Lidar (ATLID). The ground segment and data products were reviewed. On-going scientific studies and teams were described, including consolidation of ground processing, development of wind data products, campaigns, sampling optimization, tropical dynamics and equatorial waves, and a Rayleigh-Brillouin Scattering experiment. An ESA Announcement of Opportunity (AO) is planned for late 2008 for scientific uses of the data. The product for assimilation is the L2B HLOS wind profile. Simulation of L2B data and positive impact study results were discussed. L2B HLOS was introduced as new observations into 4D-Var. L1B data and L2B processers were introduced at NWP centers. Data processing structures, organizations, and products were discussed. Expectations are high for Aeolus, with advanced implementation, and extensive supporting studies, simulations, and airborne campaigns.

Dave Emmitt and Scott Shipley presented "Airborne Doppler Wind Lidar: Recent Results and In-flight Visualization Using Google Earth," coauthored with S. Greco, and S. Wood. The presentation provided an update on flight programs with the Twin Otter DWL (TODWL) data processing, discussed issues related to SkyWalker autonomous Unmanned Aerial Vehicle (UAV) glider studies and space-based data interpretation, and showed animated projections of wind profiles from TODWL flight paths onto Google Earth maps and displays. These displays showed profiles of u, v, w, and signal-to-noise ratio (SNR).



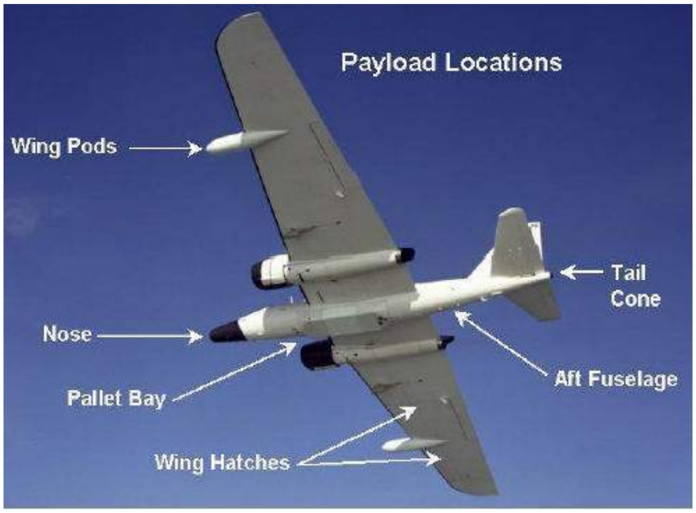
April and November 2007 TODWL flights addressed nocturnal energy studies, SkyWalker, and application of onboard DWL. Studies with Airborne Doppler Lidar Analyses and Adaptive Targeting System (ADLAATS) for the Army Research Office (ARO) and In-flight Lidar Integrated Mission Management System (I-LIMMS) for the Office of Naval Research (ONR) were also conducted (see also http://www.swa.com/ald/ILIMMS), comparing models with airborne DWL observations and testing autonomous scan mode changes based on comparisons of models with observations. The Google Earth displays provided real time 4D analysis and visualization from various perspectives to optimize in-flight data collection and processing. They enhance ability to relate wind patterns to terrain and location using extensive geographic display capabilities. Google Earth data structures and airborne lidar in Google Earth were described. Visualization methods that projected onto Google 3D images were shown, including scan animation, radial wind speed, backscatter, location and height, wind speed as cross section, and wind speed and direction. Comparison with 4 km MM5 was shown. Real time processing was described.

Yucheng Song presented "Update on Winter T-PARC," coauthored with Zoltan Toth. Winter T-PARC will take place in January through March 2009. Yucheng described the planned platforms, deployment decision processes, and real-time parallel processing at NCEP. Proposed observing platforms include NASA and NOAA satellites, a NOAA G-IV aircraft with dropsondes (out of Japan) capable of 45,000 foot altitude, a USAF C-130 (35,000 feet) covering the mid Pacific, an ONR P-3 in the east Pacific or western US with a DWL (see picture) and an Electra Doppler Radar (ELDORA), and enhanced Siberian network (contributions from Russian Roshydromet, NOAA, Naval Research Laboratories (NRL), and Japan to provide about 600 additional soundings). Other possible platforms may include satellite data from Japan and Asian Hemispheric Observing system Research and Predictability Experiment (THORPEX) data on the Tibetan Plateau. The proposed observing platforms cover the north Pacific region to allow tracking potential storms. Communications among participants will include a webpage and emails. High impact weather events will be identified in advance using information from US, Canada, Mexico, and research groups. Sensitive area identification will use capabilities of the NCEP Ensemble Transform Kalman Filter (ETKF), ECMWF Data Targeting System, and NRL targeting. A targeting example was described. NCEP will conduct real time parallel data denial experiments to measure and verify impacts of T-PARC observations. There is a possibility that a Global Hawk high altitude Unmanned Aerial System will be available in time for T-PARC.



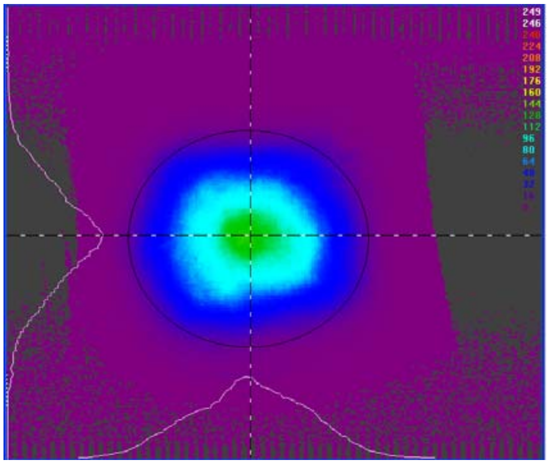
Dave Emmitt presented "Status of P3DWL for T-PARC and TSC-08." The P3DWL (see picture) will feature a 1.6 micron coherent wind lidar provided by the Army Research Laboratory (ARL) and Lockheed Martin Coherent Technologies (LMCT), a 10 cm bi-axis scanner provided by NASA, and analysis software provided by Simpson Weather Associates and the Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS). The mission will study tropical cyclogenesis, intensification, transmission and demise from a base on Guam, along with AF C130 and German Aerospace Center (DLR) Falcon aircraft. Other instruments include dropsondes and ELDORA. P3 data will be collected on the ferry flights from Patuxent River MD to Guam as well as flights out of Guam. The DWL is now installed in the P3. Some problems encountered in the ferry flight to National Center for Atmospheric Research (NCAR) in Boulder are being corrected. The next test flight was scheduled for July 11, 2008. Flights are scheduled from late July through early October.

Bruce Gentry presented "Status of the Tropospheric Wind Lidar Technology Experiment (TWiLiTE) Instrument Incubator Program," coauthored with M. McGill, G. Schwemmer, M. Hardesty, A. Brewer, T. Wilkerson, R. Atlas, M. Sirota, S. Lindemann, F. Hovis. The primary objective of TWiLiTE is to advance the readiness of key component technologies as a stepping stone to space. TWiLiTE is a Direct Detection DWL that will measure wind profiles from a high altitude aircraft. Bruce discussed the 2007 NRC Decadal Survey recommendations for tropospheric winds, including a space demonstration mission followed by an operational mission. An HDWL technology maturity roadmap was discussed and TWiLiTE's place in the roadmap (Autonomous Operational Technology / Direct Detection) was described.

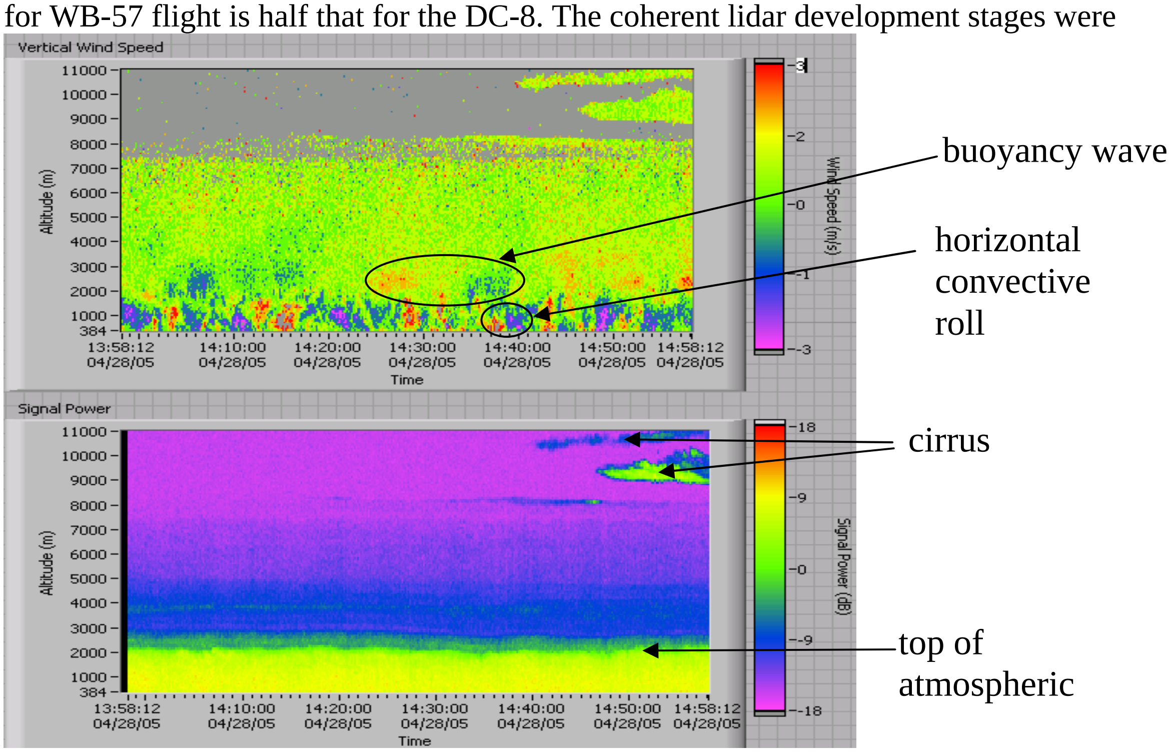


TWiLiTE will demonstrate downward looking wind profiles from 18 km with a scanning DWL. It is designed for autonomous operation on the NASA WB57 or ER2 aircraft (flight up to about 20 km), possibly transitioning to a UAV with flight up to about 25 km. Bruce discussed measurement requirements and predicted error. Key TWiLiTE Technology Readiness Levels (TRLs) of 5 will be targeted exiting this activity. The scanning holographic telescope was delivered to GSFC in December 2007, the laser in May 2008. The Doppler receiver has advanced over the ground based receiver, with volume reduced 90%, optical path minimized, throughput increased by 80%, and signal dynamic range increased by 2 orders of magnitude. Mechanical integration onto the WB57 pallet was illustrated. Highlights of the timeline include ground tests in August 2008, first engineering test flight on the ER2 November 2008, DC8 test flight September 2009, and HDWL (with the DAWN instrument) March 2010.

Floyd Hovis presented "Update on Single Frequency Laser Developments for the TWiLiTE and High Spectral Resolution Lidar (HSRL)/Ozone Differential Absorption Lidar (DIAL) Instrument Incubator Programs," coauthored with J. Edelman, T. Schum, K. Andes, B. Gentry, M. McGill, T. Cook, J. Hair, C, Hostetler, D. Harper. This program develops laser transmitters for NASA IIPs, TWiLiTE and HSRL / Ozone DIAL. The goal is a design to meet requirements of both. Floyd reviewed performance specifications and measured performance. BalloonWinds, Space Winds, and Air Force lasers provided the basis for the design. The design, models, and implementation were described. The laser has completed acceptance and environmental testing. TWiLiTE and HSRL laser optical performance, mass, volume, power, and thermal characteristics were provided. The TWiLiTE and HSRL laser subsystems were delivered in May and February 2008, respectively.

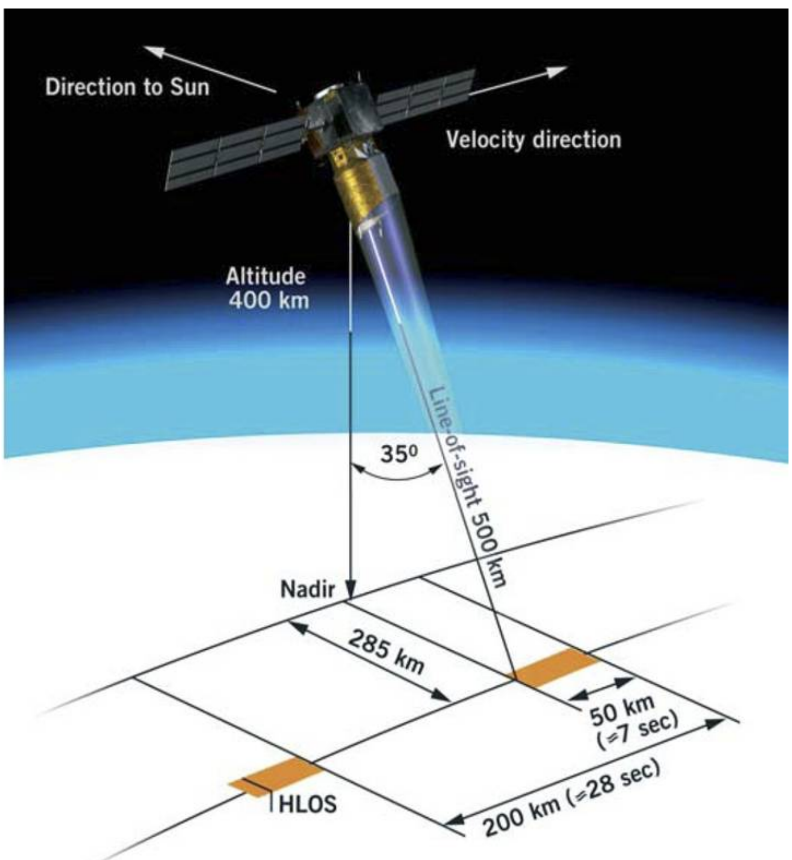


Michael Kavaya presented "Preparing Coherent Doppler Lidars for the DC-8 and WB-57," coauthored with G. Koch, U. Singh, B. Trieu, and J. Yu. Target aircraft for the LaRC DAWN are the DC-8 and WB-57. The DC-8 supports a heavier payload and on-board experimenters with flight up to 13 km and 12 hours duration. The WB-57 flies up to 18 km with 6.5 hour duration, but does not support on-board experimenters. Per-hour cost for WB-57 flight is half that for the DC-8. The coherent lidar development stages were described, including Validation Lidar Facility (VALIDAR), Laser Risk Reduction Program



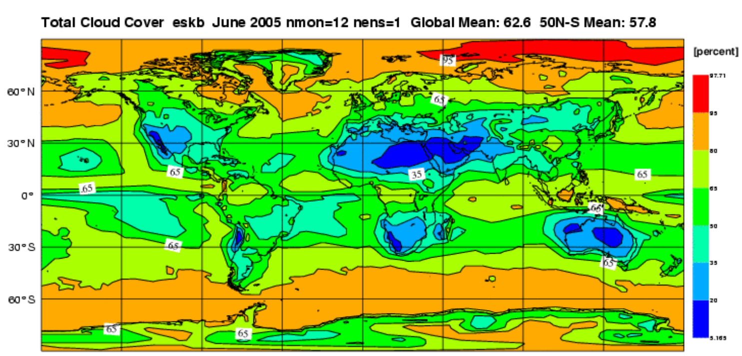
(LRRP), DAWN, DAWN-AIR1 DC-8, AND DAWN AIR2-WB-57. Highlighted areas of advancement from DAWN to DC-8 are compactness of Transceiver and Laser Control Electronics, high energy telescope, wedge scanner from Space Readiness Coherent Lidar Experiment (SPARCLE), compactness and high velocity adaptation of data acquisition, telescope diameter, down-looking geometry, and lidar sensitivity gain. Advancement from the DC-8 to WB-57 adds autonomous operation for Laser Control Electronics and Data Acquisition. A 1-hour plot of vertical wind speed and signal power from VALIDAR was shown, illustrating altitude variation of signal power for the coherent lidar. A timeline of coherent DWL activities at LaRC was discussed. Ongoing activities include DWL Intercomparison, Risk Reduction Laser, Intercomparison Facility, VALIDAR Ground Measurements, DAWN and LRRP development. These will be followed by DAWN DC-8 and WB-57 development. Work has been proposed on Optics Aberration Tools and DC-8 Hurricane Science Mission. Laser life testing and space qualification testing are not funded.

David Tan presented "The Data Assimilation Ensemble Technique for Assessing Observing System Impact Applied to Simulated ADM-Aeolus Data." David discussed ADM-Aeolus data simulations and the technique for impact assessments. The Assimilation Ensemble Technique for impact assessment provides an alternative to Observing System Simulation Experiments (OSSEs). Results from previous data simulations were summarized for 10 km, 5 km, and 1 km altitudes. The data simulations were compared to radiosondes and mission specifications. Aeolus HLOS observations were expected to receive appreciable weight in assimilation. Rayleigh and Mie HLOS observational error vs. altitude were plotted with and without representativeness, and compared with mission specifications and with radiosondes. Model cloud cover percentages and effects of model cloud cover were plotted. The data simulations were performed with the Lidar Performance Analysis Simulator (LIPAS). The assimilation of ADM-Aeolus simulated data via 4D-Var at ECMWF was described. Ensemble spreads were used to estimate short range forecast errors, and reduction in ensemble spreads with use of DWL was employed as a measure of DWL impact. Information content measures (entropy reduction and signal degrees of freedom) were applied. David discussed functional block diagrams



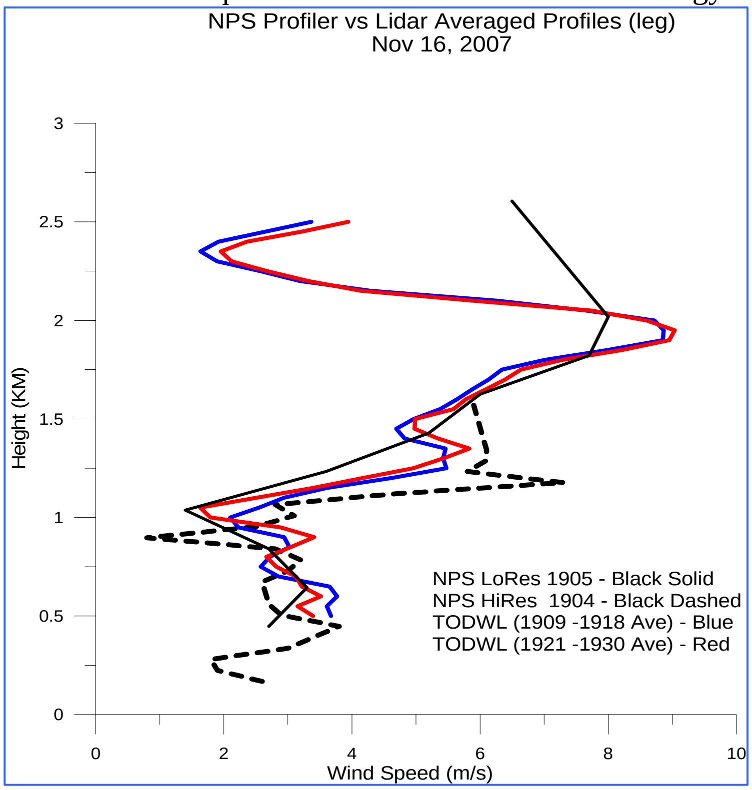
of OSEs, OSSEs, and Assimilation Ensemble methods for impact assessment. Plots of global impact on ensemble forecasts (zonal wind spread) were shown at 500 hPa and 200 hPa for Control, Control plus Sondes, and Control plus Sondes plus ADM Aeolus data. Radiosondes and wind profilers were active over Japan, Australia, North America and Europe. DWL was active over oceans and tropics. Findings included: (1) similar effects for tropics, northern and southern hemispheres, simulated DWL adds value at all altitudes and in longer-range forecasts. Information content metrics were shown to support these findings.

Yucheng Song presented "Recent Results from WSR 2008," coauthored with Z. Toth, S. Majumdar, and M. Shirley. The objective of this program is to improve forecasts of significant winter weather events through targeted observations in the data-sparse northeast Pacific Ocean. The activity took place from January 17 thru March 15, 2008. An adaptive approach is used to collect data before significant weather events and in areas that influence the events. In the past, more than 70% of targeted numerical weather predictions were improved by the data, with 10 to 20% error reduction for high impact event forecasts. There was an average 12 hour improvement in high impact event prediction. A Valentine's Day storm had a large societal impact, and forecasts were improved over a large area using adaptive data. ETKF targeting methods were used to plan approximately 35 flights with dropwindsonde observations using NOAA's P-3 and Air Force C-130s. Experiments were run with NCEP Global Forecast System with and without Winter Storm Reconnaissance (WSR) data assimilated. Differences between paired runs were analyzed. A WSR analysis was described, along with dropsonde impacts on signal propagation and forecasts, ETKF and NCEP signals were comparable in identifying target areas. The 2007 and 2008 overall impacts were shown for temperature, vector wind, surface pressure, and humidity. Results for 2007 were more favorable than for 2008. The 2008 results did not show major impact from the targeted observations. This was partially attributed to the lack of the G-IV, which flies higher than the C-130, and partially to the fact that P-3 tracks were close to land where they may have had less impact. It was suggested that upper level winds may be important, especially in the Jet Stream regions. Summary statistics for WSR from 2004 through 2007 showed more improved forecasts than degraded forecasts.



Michiko Masutani presented "Update on Joint OSSEs: Simulation of DWL and Radiance Data." Michiko identified the joint OSSE team and described OSSEs, their roles, and needs. She described the role of a national OSSE capability. Full OSSEs will use a Nature Run produced from a free forecast from the highest resolution operational model. It will be used to estimate impact of data scenarios on forecasts. One objective is to have this Nature Run shared by researchers so that results can be compared effectively. Michiko described Nature Runs, archive and distribution, calibration and validation. Simulation of DWL and radiance observations was discussed. Royal Netherlands Meteorological Institute (KNMI) will simulate ESA lidar and Simpson Weather Associates (SWA) will simulate NASA lidar. Planned OSSEs and past results for DWL impact studies were presented.

Steve Greco presented "More on Shear Statistics for DWL Data Processing," coauthored with Dave Emmitt. DWL from space or aircraft can directly measure wind shear with high resolution, a primary objective. Shear is a source of bias and possible error in estimating average wind over a layer. Steve discussed quantitative definitions and climatology of wind shear. Wind shear is currently measured by the global radiosonde network and the NOAA Profiler Network (35 unmanned Doppler Radar sites in 18 central US states and Alaska), and cooperative agency profilers. Histograms showed characteristics of wind speed shear categories and shear altitudes at various locations. The TODWL instrument and recent flights were described. Plots of November 12, 2007 wind speed profiles and intercomparisons between TODWL and microwave sounder data were shown, with the DWL showing more resolution of wind shear. Intercomparisons between TODWL and balloon rawinsonde soundings appeared to show more agreement. Plots from November 16, 2007 calibration flights were presented and contemporary average profiles overlaid onto profiles from NPS and Fort Ord Profilers, showing apparent better agreement with DWL profiles.



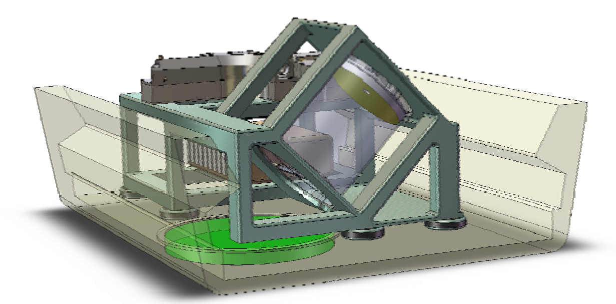
Bruce Gentry presented "Ground-Based Measurements and Intercomparison Program," coauthored with B. Demoz, D. Venable, G. Koch, and U. Singh. Bruce discussed a multi-year DWL experiment to assess instrument performance in a wide variety of atmospheric conditions. This is a joint effort of GSFC, LaRC, and Howard University, with student training as one of its goals. Bruce described the Howard University-Beltsville Research Campus, wind experiment goals, instruments, collaborations, and work at the site. The site is semi-urban and in a major pollution corridor. It integrates science and education resources and offers extensive instrumentation. Opportunities for Federal and State collaborations were discussed for NASA, National Weather Service (NWS), NOAA, EPA, and Maryland Department of Environment. DWL experiments will analyze performance for the Goddard Lidar Observatory for Winds (GLOW) direct detection and LaRC VALIDAR coherent detection instruments. A database archive for wind observations will be developed. Intercomparisons of coherent and direct detection DWLs will be conducted, as well as intercomparisons with other sensors. The Howard University Raman Lidar (HURL) will measure water vapor and aerosol backscatter. Sonde, radio acoustic sounding, and other capabilities are available.

<u>**Wednesday, July 9**</u>

Bruce Gentry presented "Error Characteristics of Lidar Wind Measurements with GLOW," coauthored with Z. Pu and B. Demoz. This presentation described progress and plans for assessing DWL requirements for seasonal climate studies and high impact weather forecasting. This project is investigating climatology of global wind profiles and uncertainty of current wind analysis, investigating error characteristics of future DWL measurements, and comparing climatology with expected observations. The project is also determining minimum requirements for resolution and error tolerance to improve high impact weather forecasting. As a measure of global wind speed uncertainty, plots of mean wind speed and vector differences between two reanalyses were shown for 850 mb and 500 mb. Mean and vector wind speed from NCEP reanalysis were plotted. Plots of seasonal variability in global wind analysis and variation of monthly mean wind speed with altitude were shown. It was suggested that DWL requirements should support detection of monthly and seasonal variations. Wind measurements and uncertainties from the International H_2O Project (IHOP) 2002 were discussed. A scatter plot of sonde vs. lidar wind speed measurements illustrated the nature of the uncertainty of IHOP wind measurement (mean difference 0.13407 m/s, standard deviation 4.0535). Plots of wind vs. time for a low level jet were compared for the GLOW lidar and sonde data, showing good agreement below 4 km. GLOW data included more detail. Work is continuing with GLOW data. Coherent lidar data, profiler, and sonde data are planned for future studies. OSSE activities are planned for hurricane and winter storm cases.

Farzin Amzajerdian presented "Long Lifetime Operation of Coherent Doppler Wind Lidar in Space." Farzin reported on extensive work and major advances at LaRC on Laser Diode Arrays (LDAs). LDAs are now the major factor in long lifetime space operations and require long shelf life, long operational life, and robustness in the harsh environments. NASA has pursued conductively cooled 2 micron Th/Ho lasers for coherent DWL measurements from space. Farzin showed sample lifetime test results for LDAs operating in long pulse mode, up to 900 million shot counts, and discussed the amount of improvement needed for viable space missions. Plots of lifetime as a function of pulse width were presented. The LaRC approach to advancing laser diode arrays included a characterization/lifetime test facility, evaluation of different designs, identification of failure causes, defining optimum operational parameters, and lifetime testing. A performance model was developed to predict lifetime using measured characteristics. A NASA Diode Laser Working Group was established in 2004 to exchange data and findings. Over 30 papers were published in conference proceedings. Farzin discussed key elements and findings in improving lifetime and reliability, selection, and specification of LDAs. The new generation of LDAs is characterized by use of hard solder, higher quality material and coating, higher power, improved packaging, increasing number of suppliers, and decreasing costs. The LaRC LDA Characterization Facility is being expanded.

Chris Grund presented "OAWL Progress and Plans," coauthored with B. Pierce, J. Howell, and C. Weimer. Chris discussed the Optical Autocovariance Wind Lidar (OAWL), an instrument under development at Ball Aerospace Internal Research and Development (IRAD) for measuring wind profiles from Low Earth Orbit (LEO) or Geostationary Orbit (GEO). NASA recently awarded Ball an IIP project to build OAWL into a robust lidar to fly on the WB-57 and exit at TRL-5. IRAD objectives include (1) fabricating a prototype receiver for high altitude aircraft demonstration, HSRL, and depolarization measurements, (2) developing optical assembly and alignment techniques for autonomous interferometry on flight systems, and (3) developing an integrated model for risk reduction for space. Chris described the receiver design and its use of polarization multiplexing, and showed illustrations of the solid model of the receiver. He reviewed the integrated model process and some model design results. OAWL IIP objectives include (1) Demonstrate wind profiling, (2) advance the TRL to 5 through high altitude aircraft flight, (3) validate radiometric performance model, (4) demonstrate robust receiver, (5) validate integrated system model, and (6) provide a technology roadmap to TRL 7. Chris reviewed the IIP project plan, system concept for WB-57 tests, test plans, milestones, and milestone dates. The IRAD receiver is scheduled for test in September 2008, and flight testing and TRL 5



capability for 2010. The IIP science advisory board includes Mike Hardesty and Bruce Gentry.

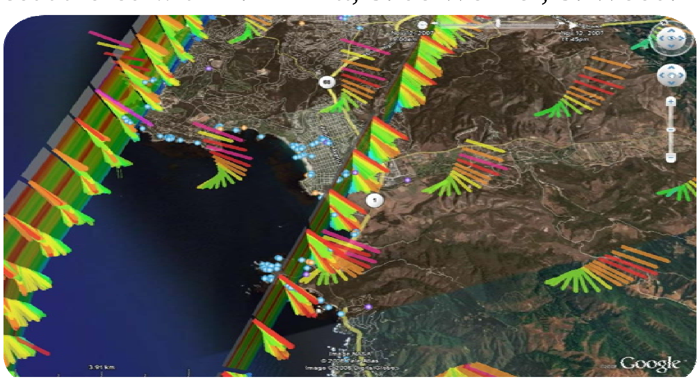
A. Shelekov presented "Short-Term Prediction of Measurement Precision of the Radial Wind Velocity in the Turbulent Atmosphere," coauthored with E. A. Shelekhova, A.V. Starchenko, and D. A. Belikov. This presentation addressed classical solutions to atmospheric differential equations for Doppler shift estimate, spectrum estimation, and Doppler lidar signal for estimation of radial wind velocity, standard deviation of random error, and turbulence. Comparisons of theory with experiments and simulation results were presented.

Mike Hardesty presented "Update on the Cal/Val Proposal Submitted to ESA." A consolidated US proposal was submitted and accepted by ESA to support calibration and validation for the ESA Aeolus mission and ALADIN DWL. The next step is to locate funding for the proposed activities sinceESA does not fund these activities directly. ESA received proposals from 9 countries. Areas proposed were (1) validation using other satellite, airborne, or ground experiments, (2) experiments to assess accuracy, resolution, and stability of ALADIN, and (3) assessment and validation of retrieval and data processing. Proposed investigators and institutions, including many in the LWG community, were identified. The US proposal offers to obtain and analyze aircraft measurements under the Aeolus flight track using remote sensors and dropsondes, to maintain a data set coinciding with Aeolus measurements over the life of the mission from surface and in situ sensors, investigate correlations between Aeolus and Atmospheric Motion Vector winds, and investigate Aeolus data quality based on data assimilation. Mike described proposed airborne wind studies including: lower tropospheric (Hardesty and Emmitt), full tropospheric (Gentry and Kavaya), aerosol comparisons (Hostetler, Hair, Ferrare), and NASA Cloud Physics lidar (McGill). Surface instrument studies included long term wind comparisons (Hardesty, Bowdle, Kavaya), comparison to mesoscale models (Bowdle), aerosol comparisons with visible HSRL in far northern latitudes (Eloranta), aerosol comparisons with a 355 nm lidar and sun photometer (Gimmestad). Dropsonde and satellite comparisons were proposed by Dunion and Etherton and by Genkova and Velden. Data assimilation was proposed by the Joint Center for Satellite Data Assimilation (JCSDA). Proposals are being reviewed now.

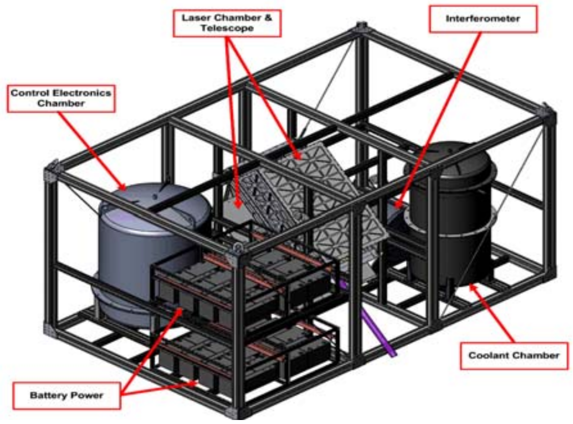
Bob Brown presented "The History of the SeaSat Sensor Follow-On Missions." Bob reviewed progress since SeaSat towards getting winds from space. He addressed theory for winds measurements, SeaSat instruments, the lidar challenge, results of winds from space, and political influences. Winds are the basic parameter in the equations of motion for weather and climate. Bob reviewed his work in Planetary Boundary Layer (PBL) theory, PBL modeling, and scatterometers. He pointed out that satellite observations begin with a measurement, often of a non-geophysical parameter, followed by curve fit and parameterization with a geophysical measurement. Ground truth data to use in parameterizing satellite instruments are inevitably flawed, for example, ship winds, buoy winds, and model winds all have significant limitations. The scatterometer principle, using a radar signal bounced off the sea surface to estimate wind speed, was summarized and followed by a history of scatterometers and scatterometer products (including sea surface wind and pressure fields, pack ice properties, vegetation, fronts, storms, mean PBL temperature, etc.) since SeaSat was launched in 1978. Scatterometer data led to several significant revelations, including its value in forecasting weather, data on storms and fronts, incorrectness of ship and buoy winds and hence the climate record, and problems with the physics of PBL models. The principles of the radiometer, which observes solar reflections from the sea surface, and the synthetic aperture radar (SAR) were addressed. This was followed by a discussion of lidar winds, beginning with the Laser Atmospheric Wind Sounder (LAWS) in 1989. Lidar has the potential to measure the full wind profile from the satellite to the surface, with value in weather and climate modeling, roll and shear details, aerosol statistics, and other areas. Satellite observations since SeaSat have led to new understanding of the atmosphere, (e.g., General Circulation Models (GCMs) and climate records are often inaccurate, that there are unknown regions of high winds, raised new concepts of fronts, and improved forecasts). Histories of scatterometer, radiometer, SAR, lidar, and data availability were discussed.

Michael Kavaya presented "Laser Reliability and the 3-D Winds Mission." Michael addressed the framework for understanding and quantifying reliability from the individual component to the system and mission levels. He described the effects on reliability of using hot spares (always on) vs. cold spares (off until needed) for emitters, diode bars, diode arrays, heads, and lasers and showed example failure density functions and reliability curves. He concluded that laser lifetime requirements can be found given overall requirements for lifetime, reliability, number of cold spares, and failure density function. Lifetime of the individual laser will be achieved by overdesigning laser diode arrays, bars, and emitters and derating laser diode array current and pulse duration.

Steve Greco presented "Airborne Doppler Lidar Analyses and Adaptive Targeting System (ADLAATS): Integrating Mesoscale Models with DWL Data in Realtime," coauthored with D. Emmitt, S. de Wekker, S. Wood. Airborne DWL provides targeted and adaptive wind measurement with high resolution and precision. ADLAATS provides autonomous on-board observation management and processing for an airborne DWL, comparisons between observations and model predictions (validation), switching observation modes, and transmission of selected data. ADLAATS interfaces with data acquisition system and numerical models and executes the numerical model on-board the aircraft. Possible models include WRF, MM5, 3DWF, NOAA LAPS, and COAMPS. Validations of of the MM5 model were discussed. Wind speed and direction comparisons between MM5 model predictions and DWL-observed wind profiles showed that model outputs differed from the DWL observations.

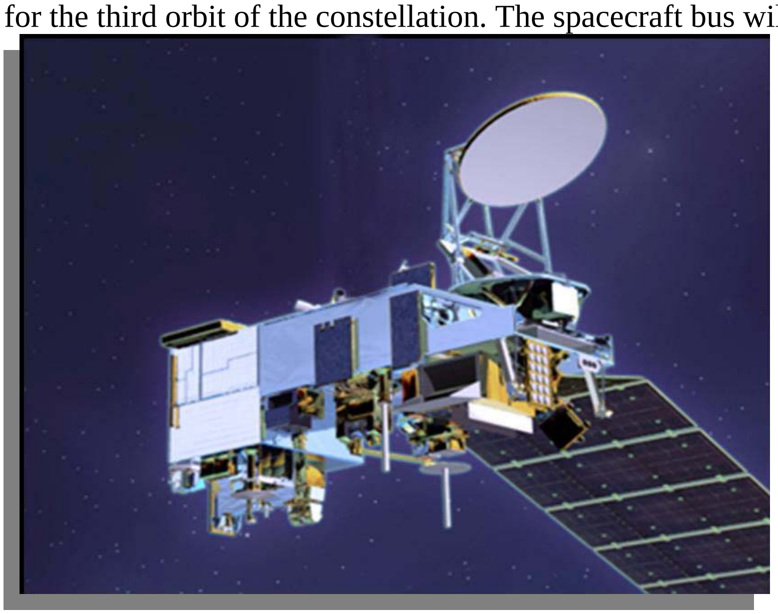


James Ryan presented "BalloonWinds Update--Straight to Launch." Jim reviewed the current configuration of the BalloonWinds direct detection DWL, controls, and gondola,



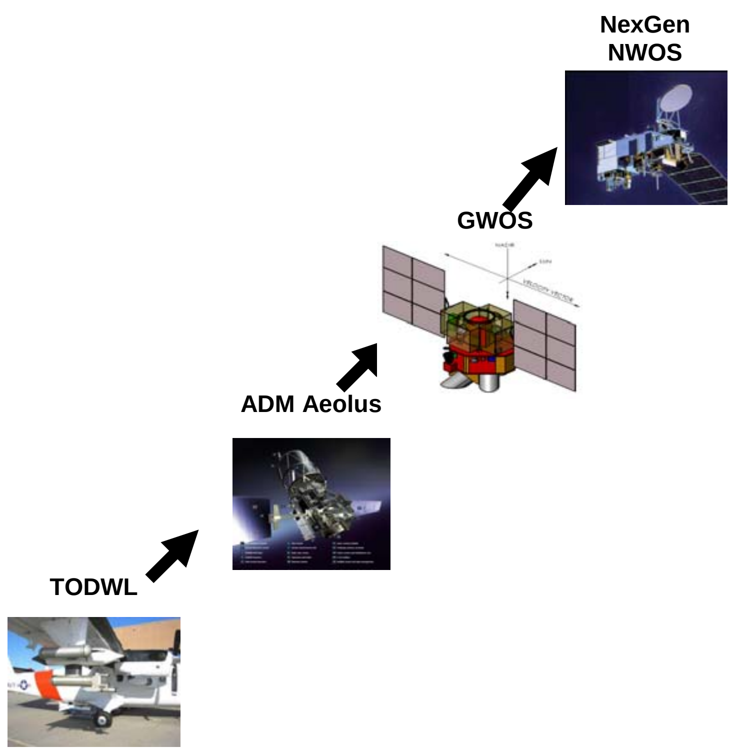
packaged for balloon flight. A 2007 thermal vacuum test failure necessitated a redesign and recovery effort, recently completed. Air Force Research Laboratory (AFRL) environmental tests will not be repeated prior to flight, largely because the upgraded AFRL thermal vacuum facility has new cleanliness requirements that are out of scope for the BalloonWinds project budget. Environmental test objectives were rolled into flight objectives. Flights are scheduled for October and November 2008.

Steve Mango presented "NPOESS/NPP Status and A Perspective for a Wind LIDAR on the NPOESS 2nd Generation - NexGen." NPOESS was restructured and certified in 2006-2007. There will be two polar sun-synchronous orbits instead of three, using MetOp for the third orbit of the constellation. The spacecraft bus will carry multiple sensors, with



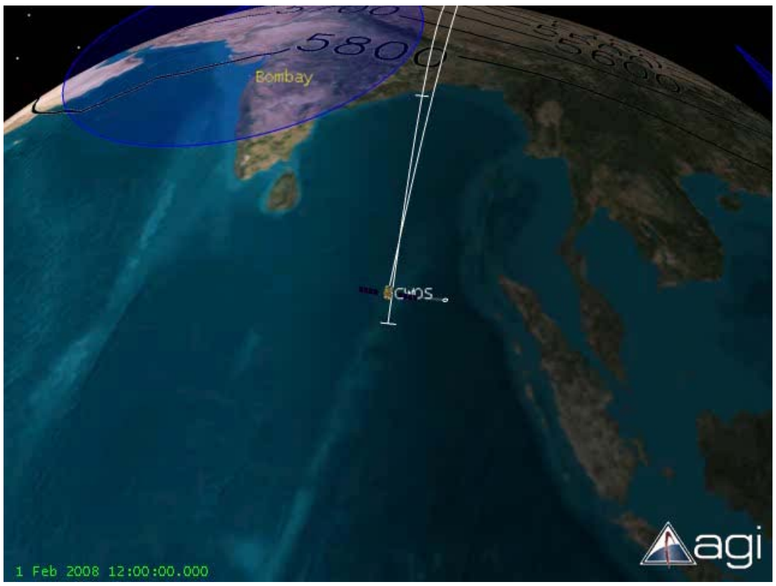
some of the original sensor suite de-manifested. The NPOESS Preparatory Project (NPP) satellite, a bridge from EOS to NPOESS, is scheduled for a June 2010 launch. Planned Environmental Data Records (EDRs) were identified for NPP, and NPOES C1 through C4. Notional time scales for several climate and weather satellite programs were shown, with NPOESS NPP launch estimated in 2010, C1 in 2013, C2 in 2016, C3 in 2020, and C4 in 2022. Notional NPOESS NexGen launch dates are shown in 2025, 2027, 2031, and 2033. The NRC Earth Science and Applications Decadal Survey recommendations of the National Research Council were reviewed, including "Providing Global Wind Profiles: The Missing Link in Today's Observing System," an input to the Decadal Survey describing the need and approach for obtaining lidar winds from space. The Decadal Survey recommendations included a 3D Tropospheric Winds mission, called "transformational" for weather forecasting and pollution transport in the 2016 to 2020 time frame. This mission was ranked number 1 by the Weather Panel and was also give high priority by the Water Cycle Panel. An aggressive program was recommended early on to address high risk components, flight tests, and prototype space tests of a Hybrid DWL. A space demonstration mission could take place as early as 2016 and an operational mission as early as 2022. Increasingly capable flight tests are taking place now and in the near future. Conceptually, we anticipate the ESA ADM space mission to demonstrate a direct detection lidar in space capable of line of sight wind measurements, followed by a US prototype demonstration space mission (GWOS) in 2016, and a US operational mission (NWOS) on NexGen in 2027. Steve compared capabilities of ADM, GWOS, and NWOS. The PEO for Environmental Satellites is considering NexGen, and planning conceptual and exploratory studies and advanced sensor development studies, especially leveraging other space sensors including ADM and NASA Laser Technology and IIPs. Steve identified Study 1 as NexGen Instrument/Mission Study (accommodation of HDWL on NPOESS NexGen), and Study 2 as NexGen Wind Profiles using ADM Aeolus product validation and product utilization.

Wayman Baker and Bruce Gentry presented "NexGen NPOESS Wind Observing Sounder: NASA/GSFC Instrument Development Laboratory Study and Findings." This briefing was prepared for Mr. Dan Stockton, PEO for Environmental Satellites. A joint NASA/NOAA/DoD global wind mission offers the best opportunity for the US to demonstrate wind lidar from space in the coming decade, measuring profiles of horizontal vector wind for the first time. Since May 2007, briefings have been presented to offices of the Air Force, Army, Navy, Joint Planning and Development Office, FAA, NASA and NOAA. NRC wind lidar recommendations were reviewed, and cost benefits study results summarized. NWP will be a primary beneficiary of a DWL mission, and improved weather forecasts in turn benefit many civilian and military interests. Benefits of more than $800 M per year have been estimated across six areas. NOAA programs requiring atmospheric winds were identified. The path to space includes 4 steps: Airborne campaigns, ESA ADM mission, a US demonstration in about 2016, and NexGen NPOESS operational mission in about 2026. Requirements for the three space missions were compared. The GSFC ISAL and IDL advanced conceptual designs for GWOS and NWOS were reviewed. The NWOS study was sponsored by the PEO for Environmental Satellites with the objective of defining an instrument concept that can be accommodated with the NexGen NPOESS spacecraft and orbit parameters. Both instruments were determined to be technically feasible in their respective time frames. A technology roadmap was reviewed, showing status and future planning. The NWOS conceptual design was presented. Next



steps include NPOESS evaluation of data from the ESA ADM mission and further development of the NWOS conceptual design.

Sid Wood presented "DWL Operations within a Sensor Web Modeling and Data Assimilation System: Recent Results," coauthored with M. Seabloom, S. Talabac, G. McConaughy, J. Ardizzone, G. Brin, B. Womak, R. Burns, S. Wood, and D. Emmitt. A model-driven sensor web is defined as an Earth observing system that uses information derived from assimilation systems and NWP models to drive targeted observations. This project team included NASA GSFC, NASA JCSDA, SAIC, Northrup Grumman, SWA, and the University of Maryland. Project goals included demonstrating the value for meteorology, quantifying cost savings to missions, quantifying improvement in meeting science goals, and building a simulator. The simulator would include sensors, networks, models, analysis systems, and targeting techniques to be tested. An anomaly correlation plot showed gradual improvements in predictive skill since 1984 for several models and it was conjectured that the sensor web provides an opportunity for a revolutionary impact. As an example of societal impact from improved weather prediction, errors in temperature forecasts were discussed. In the example, a 5 degree C forecast error led to $10 M extra costs for San Francisco electrical power purchases on the spot market on May 28, 2003. A simulation case addressed extending space mission life by modulating instrument power demand. In this case, DWL duty cycle was reduced when observed winds agreed closely to model predictions. The model results suggest that nearly 30% of lidar duty cycle can be reduced without impacting skill. A second case addressed whether better science data could be acquired with targeted observations of sensitive regions of the atmosphere, considering spacecraft slewing and choices between multiple targets. Differences between two forecasts taken at different times were the basis for calculating sensitive regions, using an adjoint technique. Future testing is planned in coordination with NASA's Global Modeling and Assimilation Office (GMAO). Illustrations of adaptive targeting and slewing were shown. The NASA Software Integration and Visualization Office (SIVO) Workflow Tool and the SWA Doppler Lidar Simulation Model (DLSM) were integrated and used in the experiment design. Future plans include building a Line of Sight wind operator, integrating Satellite Toolkit, getting T511 and T799 nature runs into DLSM, building a slewing capability into the scanner model, integrating a cloud motion wind model, and global OSSEs.



John Theon presented "Comments on the Progress in Wind Lidar Technology." John has had a long association with wind lidar, and he provided a perspective of status and progress. John's remarks follow

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> *"In my experience, there are two kinds of research: that conducted by specialists who are experts in a given research area and generalists who have become*

managers of research programs: the specialist who learns more and more about less and less until he or she knows everything about nothing, and the generalist who learns less and less about more and more until he or she knows nothing about everything. I am a generalist who knows very little, but during the past two days, I have learned of the significant progress that has been made in developing the Doppler Winds Lidar (DWL) satellite mission since I retired from NASA Headquarters in 1995.

The justification for a DWL is very strong. Winds are clearly the missing link in our ability to observe the state of the atmosphere as we attempt to forecast its future behavior. Improvements in forecast skill will benefit many aspects of modern life: transportation, construction, agriculture, and military operations to name a few. The Observing System Simulation Experiments (OSSEs) have became far more realistic as advances in computer models of the atmosphere have incorporated improved physics, greater spatial resolution, and improved observations of cloud, aerosol, and sea surface wind observations than were available 13 years ago. These improved OSSEs confirm the significant value of global scale wind observations for increasing forecast skill, and the only practical and affordable means of obtaining such data is from a Doppler Wind Lidar in space. In addition, the World Meteorological Organization (WMO) has ranked global wind profile observations as very important because of the positive impact they would have on Numerical Weather Prediction.

We now have the benefit of experience with a number of lasers that have been successfully flown in space: the Mars Orbiter Laser Altimeter (MOLA), the Near Earth Asteroid Rendezvous (NEAR), the ICESAT and CALIPSO missions to name several.

All of these missions have used lasers to measure distances to their intended targets from the satellite which is a far less complicated application than that of measuring wind profiles as in the DWL approach.

Early DWL studies such as the Laser Atmospheric Wind Sounder (LAWS) used powerful coherent infrared lidars that required aerosol or cloud particle targets. Later, the idea of using atmospheric molecules as targets and a shorter ultraviolet wavelength lidar was proposed for the direct detection approach where coherent lidars fail. Combining these two distinct techniques as a hybrid system was a brilliant idea, permitting the two techniques to complement each other. This combined the best capabilities of each kind of lidar to obtain maximum accuracy and coverage and has the advantage of saving system weight and power since each lidar can be made smaller, requiring lower power by focusing on the targets to which it is most sensitive and efficient.

The introduction of Fabry-Perot etalons, Fizeau interferometers, and double edge and fringe techniques to enhance the resolution of the Doppler shifts is also a significant advance that early systems did not utilize. This certainly improves *accuracy and sensitivity of the observations. Although lasers have become more rugged, more reliable, and more durable than was previously possible, there must still be more development to improve the efficiency, weight, power requirements, and lifetime of lasers to assure the success of a space mission, NASA has funded a sizeable program, the Laser Risk Reduction Program, to do just that, and significant progress has been reported at this meeting. Detectors, including photomultiplier tubes (PMTs), Avalanche Photo Diodes (APDs), and Charge Coupled Devices (CCDs) can also be improved to enhance sensitivity.*

Clearly, obtaining both orthogonal components of the horizontal wind requires that a space borne lidar be scanned. This represents a set of problems of compensating for the rotating mass inherent in the scanning element. Not only must the rotation be compensated, but the changes in angular momentum resulting from the accelerations involved in stopping, dwelling, and restarting the scanning mechanism as rapidly as possible without affecting the pointing accuracy must be neutralized. While a holographic approach is promising to alleviate this problem, further development and refinement are required before a holographic system is ready for space deployment.

Dissipating waste spacecraft heat is a concern. Improvements in laser efficiency will certainly help with this problem, but reducing laser duty cycle will also help. An intelligent approach has been proposed, that of utilizing ensemble NWP model forecasts to identify the areas where wind observations will be most beneficial in advance to maximize the effectiveness of the DWL while conserving power and extending mission lifetime.

The European Space Agency (ESA) has decided to go forward with a simplified line-of-sight, horizontal-only component observation space mission using a direct detection lidar system. This is called the Aeolus instrument aboard the ADM mission. The fact that the mission launch date has slipped several times is testament to the fact that even a simplified, non-scanning Doppler wind measurement is not an easy problem to solve.

In conclusion, I am truly astonished and encouraged by the considerable progress that has been made in addressing the problems that must be solved before a scanning Doppler Wind Lidar system can be flown in space. Thus, I wish to commend this working group for your ingenuity, perseverance, and dedication, and I especially wish to recognize the leadership that Dr. Wayman Baker has shown in making such impressive progress. I also wish to recognize the enduring support and encouragement provided by Dr. Ramesh Kakar. Everyone at this meeting deserves kudos for the contributions you have made in going forward with this enterprise. I believe that the potential benefits certainly justify the effort and resources you have invested in this project. "

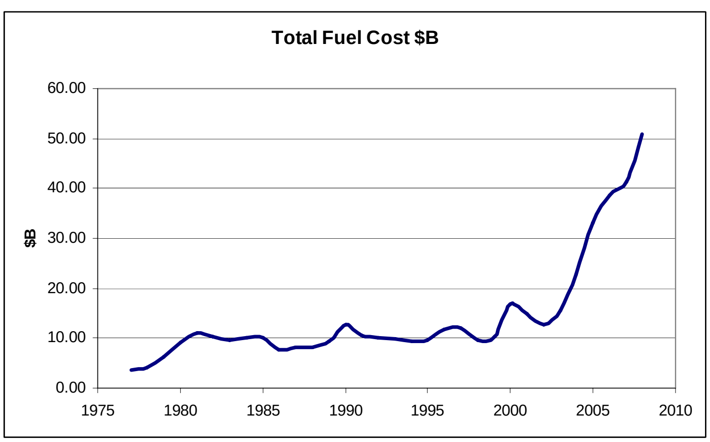
Award Presentation– The Lidar Working Group presented Dr. Wayman Baker with a plaque with the following message: *"In recognition of your dedication, vigorous support and perseverance in leading the Working Group for Space-Based Lidar Winds, we the Members wish to thank you for serving as the Working Group Chair since 1994."*

A cake, commemorating the 30th meeting of the LWG, was served.

Open Discussion – The afternoon session concluded with a general discussion followed by subgroup meetings.

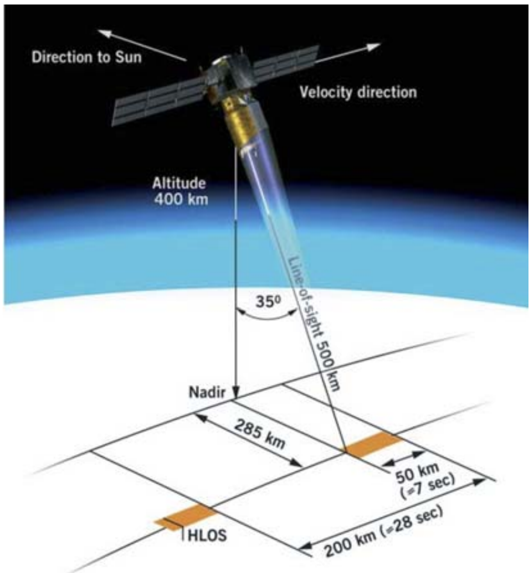
Thursday, July 10

Ken Miller presented "Aviation Fuel Benefits Update." In the February 2007 Lidar Working Group meeting, Ken presented estimates of societal benefits from forecast improvements in six areas totaling $807 M per year. The areas were: hurricane over-warning, hurricane damage reduction through increased lead time for preparation, offshore drilling, general forecasting, commercial aviation fuel, and military aviation fuel. The largest component of estimated benefit was aviation fuel, which alone totaled $344 M per year in the 2006 analysis. This presentation updated the aviation fuel estimates, using the recent dramatic increases in cost of fuel, and accounted for inflation in the other categories. While commercial aviation fuel usage has declined since year 2000, unit costs and total costs have risen rapidly. Commercial aviation fuel savings estimates rose from



$243 M to $320 M per year, and military aviation savings estimates rose from $101 M to $133 M. The total benefits estimate for the six areas rose to $940 M per year in 2007-08. In discussions, it was suggested that additional societal benefits areas, including the insurance industry, be explored.

Discussion of the ADM Cal/Val Proposal Efforts, led by Mike Hardesty (see above presentation "Update on the Cal/Val Proposal Submitted to ESA"). Calibration and validation are intended to find out if data is good, how good, and if not then why not. The first topic was a strategy for funding the proposed activities, beginning in 2010. NOAA, NASA, NPOESS, DOD, and NSF interest areas were discussed. Steve Mango discussed cross-satellite verification and the use of resources from other programs. Ramesh Kakar discussed the possibility of competitive funding opportunities from NASA, and suggested that the Lidar Working Group consider making a proposal based on priorities and rankings of critical issues, similar to those of the NRC Decadal Survey. It was suggested that we determine ESA's priorities for criticality of our proposal elements. If FY 2010 funding is not available for all the elements, it is important to present priorities based on critical issues and potential resources. Possible NPOESS-related areas include:



- Cross-calibration with other instruments
- Demonstration of NPOESS instruments' values
- Reduction of future NPOESS calibration costs
- Cross-calibration opportunities using instruments on the same platform
- Other additional values of wind lidar in cross-calibration

Efforts should be coupled to US mission requirements, risk reduction, and measurement issues. Aircraft programs were discussed. Mike Hardesty will talk to the proposers to clarify what data are needed for their proposed activities.

Discussion of the Next NWOS Study Phase. The NWOS Mission Definition Team held a planning session for the next study phase. Topics included evaluation of ADM data, further NWOS concept development, instrument cost studies, mission conceptual design, and accommodation on NPOESS. Steve Mango pointed out that future DWL impact studies must consider that the platform will be NexGen NPOESS, not the current NPOESS. Current OSSEs do not include future (NexGen) instruments in the control suite. Steve suggested that it is too soon to develop a mission conceptual design, because it would require too many assumptions about the NexGen configuration. Discussion followed on a concept of operations, orbits, adaptive targeting, and the possibility and the potential advantages of spacecraft maneuvering. Steve described the early NexGen orbits (1330 then 1730 dawn/dusk). Impact of orbit on power, signal to noise ratios, and time of day that observations are made were discussed. A question was raised regarding impact of a non-dawn/dusk orbit. Next steps were identified as:

- NPOESS evaluation of ADM data (Cal/Val and study of utility and impact of NWOS using ADM data)
- NWOS concept development including cost and mission concept study

Subcommittee Discussions.

The general session was followed by subcommittee discussions.

Bruce Gentry, Wayman Baker and others met to complete preparation of the briefing to the Program Executive Office, presented earlier as a dry run, for Dan Stockton of the NPOESS PEO.

Friday, July 11

Presentation of Short Subjects – There was a brief discussion of forecast benefits from a space-based DWL.

Subcommittee Reports and Recommendations - Yesterday's meetings of the Cal/Val subgroup and the Mission Definition Team subgroup were discussed.

Action Items- New action items were formulated and discussed.

Next Meeting- Destin FL was selected for the winter 2009 meeting, to be held January 27-30, 2009. The next summer meeting will be held at Wintergreen VA, June 23-26.

Adjourn

These minutes were prepared by Kenneth Miller.

Glossary

A2D	ALADIN Airborne Demonstrator
ADJ	Adjoint method of analysis
ADLAATS	Airborne Doppler Lidar Analyses and Adaptive Targeting System
ADM	ESA’s Atmospheric Dynamics Mission
ADMAG	ADM Advisory Group
AIRS	Atmospheric Infrared Sounder
ALADIN	Atmospheric Laser Doppler Instrument
AMSR-E	Advanced Microwave Scanning Radiometer-EOS
AMSU	Advanced Microwave Sounding Unit
AO	Announcement of Opportunity
AOML	NOAA Atlantic Oceanographic and Meteorological Laboratory
ARL	Army Research Laboratory
ARMOR	Advanced Radar for Meteorological and Operational Research
ARO	Army Research Office
ASCAT	Advanced Scatterometer on MetOp
ATLID	ESA Atmospheric Lidar
ATMS	Asynchronous Transfer Mode Satellite
ATP	Advanced Technology and Plans
ATReC	Atlantic THORPEX Regional Campaign
AVHRR	Advanced Very High Resolution Radiometer
BAMS	Bulletin of the American Meteorological Society
BUFR	WMO BUFR format used for weather observations
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarization
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation Satellite
Cal/Val	Calibration and validation
CAMEX	Convection and Moisture Experiment
CCD	Charge Coupled Device
CFLOS	Cloud-Free Line of Sight
CIRPAS	Center for Inter-Disciplinary Remotely Piloted Aircraft Studies
CLARREO	Climate Absolute Radiance and Refractivity Observatory
CLIO	Circle to Line Optic
CNR	Carrier to Noise Ratio
CrIS	Coordinate Registration Improvement System
Cv2	Velocity Variance Constant
DARPA	Defense Advanced Research Projects Administration
DAWN	Doppler Aerosol Wind Lidar
DESDYNI	Deformation, Ecosystem Structure and Dynamics of Ice mission
DIAL	Differential Absorption Lidar
DMI	Doppler Michelson Interferometer
DOD	Department of Defense
DLR	German Aerospace Centre
DLSM	Doppler Lidar Simulation Model

DMSP	Defense Meteorological Satellite Program
DWL	Doppler Wind Lidar
ECMWF	European Centre for Medium-range Weather Forecasts
EDR	Environmental Data Record
ELDORA	Electra Doppler Radar
EnKF	Ensemble Kalman Filtering
EOS	Earth Observing System
EPS	EUMETSAT Polar System
ESA	European Space Agency
ESRL	NOAA Earth System Research Laboratory
ESSP	Earth System Science Pathfinder (ESSP) program
ESTEC	European Space Research and Technology Center
ESTO	Earth-Sun System Technology Office
ETKF	Ensemble Transform Kalman Filter
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FAA	Federal Aviation Administration
FEA	Finite Element Analysis
fvGCM	finite volume General Circulation Model
GCM	General Circulation Model
GEO	Geosynchronous Earth Orbit
GEOSAT	Geodetic Satellite
GEOSS	Global Earth Observation System of Systems
GFS	Global Forecast System
GLAS	Geoscience Laser Altimeter System
GLOBE	Global Backscatter Experiment
GLOW	Goddard Lidar Observatory for Winds
GMAO	Global Modeling and Assimilation Office
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
GTS	Global Telecommunications System network
GTWS	Global Tropospheric Wind Sounder
GWHI	GroundWinds Hawaii
GWNH	GroundWinds New Hampshire
GWOLF	Ground-based Wind Observing Lidar Facility
GWOS	Global Wind Observing Sounder
HDWL	Hybrid DWL
HFIP	Hurricane Forecast Improvement Project
HIRAD	Hurricane Imaging Radiometer
HIWRAP	High Altitude Imaging Wind and Rain Airborne Profiler
HIRS	High Resolution Infrared Sounder
HLOS	Horizontal Line of Sight
HOE	Holographic Optical Element
HPMT	Hybrid Photomultiplier Tube
HQ	Headquarters
HRDL	High Resolution Doppler Lidar

HRDI	High Resolution Doppler Imager
HSRL	High Spectral Resolution Lidar
HURL	Howard University Raman Lidar
ICESat	Ice, Cloud, and land Elevation Satellite
IDD	Integrated Direct Detection
IDL	GSFC Instrument Design Laboratory
IHOP	International H2O Project
IIP	Instrument Incubator Program
I-LIMMS	In-flight Lidar Integrated Mission Management System
IMDC	GSFC Integrated Mission Design Center
INS	Inertial Navigation System
IORD	Integrated Operational Requirements Document
IPC/OAWL	Imaging Photon Counting Optical Autocorrelation Wind Lidar
IPO	Integrated Program Office that manages NPOESS
IPY	International Polar Year
IRAD	Internal Research and Development
ISAL	GSFC Instrument Synthesis and Analysis Lab
ISCCP	International Satellite Cloud Climatology Project
ISS	International Space Station
JCIDS	Joint Capabilities Integration and Development System
JCSDA	Joint Center for Satellite Data Assimilation
JPDO	Joint Planning and Development Office
KNMI	Royal Netherlands Meteorological Institute
LaRC	Langley Research Center
LAWS	Laser Atmospheric Wind Sounder
LDA	Laser Diode Array
LEO	Low Earth Orbit
LETKF	Local Ensemble Transform Kalman Filter
LIPAS	Lidar Performance Analysis Simulator
LITE	Lidar In-space Technology Experiment, 3 wavelength lidar
LMCT	Lockheed Martin Coherent Technologies
LOS	Line of Sight
LRRP	Laser Risk Reduction Program
LWG	Working Group on Space-Based Lidar Winds, or Lidar Working Group
MACAWS	Multi-Center Airborne Coherent Atmospheric Wind Sensor
MAX	Mobile Alabama X-band radar
MBL	Marine Boundary Layer
MDT	Mission Definition Team
METOC	Meteorological and Oceanographic
METOP	ESA Meteorological Operational Satellite
MODIS	Moderate-resolution Imaging Spectroradiometer
MOLA	Mares Orbiter Laser Altimeter
MOPA	Master Oscillator Power Amplifier Lidar
MSFC	Marshall Space Flight Center
MSU/GRI	Mississippi State University GeoResources Institute
NAAPS	Navy Aerosol Analysis and Prediction System

NAMMA	NASA African Monsoon Multidisciplinary Analyses
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NAST	NPOESS Airborne Sounder Testbed
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NEAQS	New England Air Quality Study
NEAR	Near Earth Asteroid Rendezvous
NESDIS	National Environmental Satellite, Data, and Information Service
NexRad	Next Generation Radar
NIR	Near infrared region of the electromagnetic spectrum
NOGAPS	Navy Operational Global Atmospheric Prediction System
NOSC	NOAA Observing Systems Council
NPOESS	National Polar-orbiting Observing Environmental Satellite System
NPP	NPOESS Preparatory Project
NPS	Naval Postgraduate School
NRC	National Research Council
NRL	Naval Research Laboratory
NSF	National Science Foundation
NWOS	NPOESS Wind Observing System
NWP	Numerical Weather Prediction
NWS	National Weather Service
OA	Optical Autocovariance
OAWL	Optical Autocovariance Wind Lidar
OES	Office of Earth Sciences
OLE	Organized Large Eddy
OLR	Outgoing longwave radiation
OMI	Ozone Monitoring Instrument
OPAL	Ozone Profiling Lidar
OPC	Ocean Prediction Center
OSE	Observation System Experiments
OSSE	Observing System Simulation Experiment
P3DWL	DWL Instrument on a P3 Aircraft
PARC	Pacific Asia Regional Campaign (THORPEX)
P^3I	Pre-Planned Product Improvement program (NPOESS)
PBL	Planetary Boundary Layer
PDE	Photon Detection Efficiency
PE	Primitive Equations Model
PEO	Program Executive Office
PIEW	Prediction Improvement for Extreme Weather
PMT	Photomultiplier Tube
Prf	Pulse Repetition Frequency
QBO	Quasi Biennial Oscillation
QRT	Quasi-Real Time
QuikSCAT	Quick Scatterometer polar orbiting satellite
RICO	Rain In Cumulus Over Oceans

ROSES	Research Opportunities in Space and Earth Sciences
SAIC	Science Applications International Corporation
SALLJEX	South America Low Level jet Experiment
SAR	Synthetic Aperture Radar
SBIR	Small Business Innovation Research
SiSPAD	Silicon Single Photon Avalanche Detector
SIVO	GSFC Software Integration and Visualization Office
SMAP	Soil Moisture Active/Passive mission
SMD	Science Mission Directorate
SNR	Signal to Noise Ratio
SOSE	Sensitivity Observing System Experiment
SPARCLE	Space Readiness Coherent Lidar Experiment
SPCM	Single Photon Counting Module
SSMI	Special Sensor Microwave Imager
STP	Space Test Program
SW	Solar shortwave radiation
SWA	Simpson Weather Associates
SWS	Sensor Web Simulator
TC	Tropical Cyclone
TCS-08	Tropical Cyclone Structure Field Experiment
TCSP	Tropical Cloud Systems and Processes
TE	Transfer Electron
TexAQS	Texas Air Quality Study
THORPEX	The Hemispheric Observing system Research and Predictability Experiment
TKE	Turbulent Kinetic Energy
TODWL	Twin Otter DWL
TOVS	TIROS Operational Vertical Sounder
T-PARC	THORPEX Pacifica Area Regional Campaign
TRL	Technology Readiness Level
TTL	Tropical Tropopause Layer
TWiLiTE	Tropospheric Wind Lidar Technology Experiment
UAH	University of Alabama in Huntsville
UARS	Upper Atmosphere Research Satellite
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
UNH	University of New Hampshire
UV	Ultraviolet
UWPBL	University of Washington Planetary Boundary Layer model
VALIDAR	LaRC Validation Lidar Facility
VIIRS	Visible Infrared Imager / Radiometer Suite
WINDII	Wind Imaging Interferometer
WMO	World Meteorological Organization
WRF	Weather Research and Forecasting model
WSR	Winter Storm Reconnaissance Program
WWMCA	World Wide Merged Cloud Analysis