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A PROGRAM TO OPERATE AND UPGRADE THE GL LOW ALTITUDE LIDAR SYSTEMS

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This report describes work performed under a four year program to operate, upgrade, and maintain the GL/OP low altitude slant-path extinction mobile lidar system and the high altitude mobile and fixed lidar systems. In addition, certain instruments associated with the Mobile Atmospheric Optical Laboratory were to be operated, maintained, and upgraded. During the latter part of the program the responsibility to assist in development and operation of the GL/OP CO_2 low altitude lidar system was added.

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TABLE OF CONTENTS

1 PROGRAM OBJECTIVES

The objectives of this four year contractual effort initially included operating, maintaining and upgrading the capabilities of both the GL/OP low altitude slant-path extinction mobile lidar system and the more energetic high altitude mobile and fixed systems. In addition certain instruments associated with measurements made from the Mobile Atmospheric Optical Laboratory (MOAL) were to be operated, maintained and upgraded. After the first year of the program the high altitude systems were administratively shifted to GL/LI and the effort associated with those systems was continued under a separate contract. The award date of this contract was 13 June 1986.

The low altitude lidar system was to be upgraded in a variety of ways including addition of polarization/depolarization measurement capability to discriminate between ice and water in atmospheric clouds. The capability to detect the 1.06 micron laser radiation was to be added to the system. The data acquisition system was to be upgraded to include two-channel capability with control, data manipulation, and storage being done by a PC/AT computer. The possibility of conversion to an eyesafe system was to be investigated. Methods of improving the lidar data inversion algorithm were also to be investigated and implemented.

An improved data-logger system for the MOAL was to be developed using PC/AT computers. Other equipment on the MOAL to be operated and improved included the standard meteorological instruments, the Broadband IR Transmissometer, the Spectral IR Transmissometer, the Visible Transmissometer/Nephelometer, and the Laser Nephelometer.

In June of 1989 the responsibility to assist in the development and operation of the ground-based CO_2 low altitude lidar system was formally added to the contract.

2 TECHNICAL PROGRESS

2.1 First Year

During the first year of the program polarization and 1.06 micron detection capabilities were added to the low altitude Nd:YAG system. Work was started on enhancement of the data-logger capabilities. The data acquisition system for the low altitude Nd:YAG system was redesigned to incorporate a CAMAC system composed of DSP Technology fast A/D units, signal averagers, and crate controller. The system was interfaced to a Zenith ZW-241 computer.

Operation and maintenance of the high altitude fixed and mobile systems continued through the first year of the program. Also during the first year, through a Task Requirement Notice, work was started on the upgrade of the Thermosonde electronics.

2.2 Second Year

2.2.1 LOW ALTITUDE Nd:YAG LIDAR

Early in the second year the improved low altitude Nd:YAG lidar was installed on the trailer at the Sudbury test site and testing was initiated. Test data was acquired under a variety of meteorological conditions for diagnostic purposes. Considerable snow data was taken to *demonstrate the polarization measurement* capability of the system. Work on the Thermosonde improved electronics was completed.

During the year additional snow data was taken. Techniques for analysis of the polarization data were developed based on measurement of the Stokes parameters of the backscattered radiation. A Monte Carlo code was written to determine the probability density function for the degree of polarization given the probability density functions for the amplitude and relative phase of the two polarization directions.

In June of 1988 the lidar trailer was moved to an area 20 miles south of Belen, NM for approximately one month. Data was acquired there to determine cloud heights and the atmospheric extinction coefficient below the clouds. Extensive data analysis was performed.

A paper entitled "Polarization Studies of Backscattered 532 nm Radiation From Snow Using a Nd:YAG Based Lidar" was presented by R. Garner at the 14th International Laser Radar Conference in San Candido, Italy in July 1988. The paper was based on research aimed at understanding multiple scattering and its effects on extinction in the atmosphere.

Progress was made on several upgrades to the lidar system. A new motor and motor control system were evaluated for use for near-simultaneous polarization measurements of backscattered 532 nm radiation using only one PMT. This allows accurate polarization measurements on clouds, which had not been possible with the previous motor and motor control system due to the relatively rapid movement of clouds. The new motor rotates a wheel holding polarizers in between pulses of the laser during a single lidar run. A single lidar run may contain hundreds to thousands of laser pulses which occur at a 20 Hz rate. The movement of the wheel is coordinated with a clock that controls the transient recorders acquiring data so that data corresponding to the different polarizers are placed in different portions of the averaging memories connected to the transient recorders.

In order to extend the range of the lidar system, development of a photon counting capability was initiated. An approach which was evaluated is the use of one PMT in both current mode and pulse count mode. A 170 MHz bandwidth LeCroy amplifier capable of driving two 50 ohm loads was acquired for this purpose. In addition, a DSP Technology multichannel scaling averager was purchased for acquiring the data.

Design of a new 12 inch diameter aperture receiver was initiated to replace the existing 6 inch refractor. The new receiver will use a Dall-Kirkham type telescope with an effective focal length of 120 inches. The upgrades mentioned above along with the new receiver are to be packaged in a new housing.

2.2.2 RVAN

At mid-year work was initiated on repair and calibration of the Solar Transmissometer on the RVAN. The main effort during this period was spent on the range related data transfer problems. We breadboarded and tested (on a spare unit) circuit modifications to the EG&G 580-13 indicator unit to enable CPU range selection. We also made the necessary software modifications to the LOGGER.

2.2.3 CO_2 LIDAR

Our initial efforts included the cleaning, leak checking/sealing, and testing of the laser cavity in the GE TEA laser system. Diagnostics performed indicated that an electron-attaching contaminant -- produced or released by the sustainer discharge -- was reducing the discharge excitation rate below the lasing threshold. The source of the contaminant was unknown. An Applied Photonics catalytic purifier/recirculator was installed to allow a greatly increased gas flow rate (10 x) which would assist in cleaning the cavity of contaminants.

Work on all the necessary components for the HgCdTe detector preamp and bias supply were completed. The final wiring and testing of the preamp was done and preliminary work was started on a second preamp unit which utilized an ANZAC AM110.

We proceeded with the construction of the heterodyne receiver unit, including mechanical mounting of the RF modules, power supply, gain controls, and the fast switching circuitry. We assisted in the design of the optical layout for the CO_2 lidar transceiver and in the specification of the telescope and the "small" IR optical components: beam splitter, polarizer, attenuator, lenses,and quarter wave retarder. In addition we determined that a 4:1 beam expander for the LO was required to match the LO and backscattered wave fronts before mixing on the detector surface.

2.3 Third Year

2.3.1 LOW ALTITUDE Nd:YAG LIDAR

In the early part of the third year data analysis for the June field trip to New Mexico was completed. Our primary conclusion from these data was that Rayleigh scattering dominated over other scattering during fair weather conditions. Deviations from almost pure Rayleigh scattering were only significant in clouds and during times of precipitation.

The extinction coefficient of a Rayleigh atmosphere is smaller than that which can be calculated using the data acquired with the lidar system. Instead the scattering ratio, the ratio of actual backscattered power to backscattered power from a Rayleigh atmosphere, was calculated for each lidar run. The Rayleigh backscattered power as a function of altitude was calculated using a standard atmospheric model that takes temperature, humidity, and pressure (all at a base altitude) as inputs. Outputs included the Rayleigh extinction and backscatter coefficients from which backscattered power as a function of range was deduced.

Upgrades to the lidar system continued. Design of the new 12 inch diameter aperture, f/10 Dall-Kirkham telescope to be used as a new receiver was completed and construction started. The two mirrors forming the telescope were recoated. A major design problem was in imaging the 12 inch diameter primary to the 3 mm active area of the silicon avalanche photodiode (1.06 micron detector) over a distance greater than 120 inches. The problem was solved by using a Plossl eyepiece as the transfer optical element and by reducing the field of view of the telescope from the original design of 10 mrad to 5 mrad. The reduction of the field of view had the added advantage of reducing background noise. A variable diameter iris would be used as a field stop so that the field of view of the telescope can be changed continuously up to approximately 10 mrad. However, only 532 nm data would be valid for fields of view greater than 5 mrad because of the small 1.06 micron detector. Such experiments will test for multiple scattering.

The proposed scheme of making nearly simultaneous polarization measurements of the backscattered 532 nm radiation with one photomultiplier tube was tested in the lab and shown to be feasible. A 4 inch diameter plexiglass wheel can be rotated 60 degrees in 40 msec at a repeat rate of 50 msec. Such a wheel with polarizers is incorporated into the design of the new telescope. Every 60 degree rotation of the wheel places either one of four polarizers, an opening, or a block in front of the field stop of the telescope. The 60 degree rotation of the wheel occurs at the 20 Hz laser pulse rate. Data corresponding to each wheel position is placed in one of six regions of digitizer memory by starting and stopping an external digitizer clock at the same rate. A CAMAC clock module (LeCroy model 8501) is used for this purpose. A motor controller card for the PC family of computers (Oregon Micro Systems, Inc) is used to control the wheel motion. The card can be downloaded with a program to run the motor (in a closed loop fashion with a shaft encoder) independently of the host computer.

A new Hamamatsu photomultiplier tube (model R268) was purchased for use with the new receiver. We anticipate using this tube simultaneously in current mode and photon counting mode. We also anticipate using a trigger circuit, similar to the one currently in use with the EMI photomultiplier tube, which gates the tube on in several microseconds. Calibration of the gate turn-on response gives us a known variable gain function for the tube which allows for a greater dynamic range. Hamamatsu does not supply gated photomultipliers which are suitable for our use. A trigger circuit has been breadboarded and preliminary tests show that it will work with some modification.

An Oregon Micro Systems stepper motor controller card was purchased and tested for its anticipated operation. The card allows for software control of the polarizer wheel in the new receiver. The card sends pulses from the computer to a stepper motor translator (Bodine, 5 Amps), which moves the stepper motor on which the polarizer wheel is mounted. The card also accepts pulses from a shaft encoder, allowing for closed loop motion control.

Additional data analysis was done for the June, 1988 field trip to Dripping Spring, New Mexico. It was realized that small extinction coefficients (less than approximately 0.015 km^{-1}) at short ranges cannot be calculated from the lidar data because the extinction effect cannot be distinguished from the R squared effect. This is especially severe at short ranges, although at far ranges the lidar return is too low anyway. The limit is set by the resolution of the detection system. Allowing the lidar return signal to saturate the detection system at near ranges alleviates the problem somewhat.

At mid year the YAG doubling crystal was sent to Litton Laser Systems for repair. During an attempted lidar operation in February we found an abnormally low 0.53 micron energy level, and an output laser beam quivering in the transverse direction. Inspection of the doubling crystal revealed a bubble in the matching fluid surrounding the crystal. The repair consisted of repolishing the crystal, replacement of a damaged window, and replacement of the matching fluid. In addition, a hairline crack in the crystal was discovered, but found not to greatly affect the crystal's operation at this time.

Additional analysis of the lidar snow data from February, 1988 was done. This was in preparation of a poster paper which was presented at the 1989 Conference on Lasers and Electro-Optics. A program was written to simulate lidar data (with Poisson statistics) which has been depolarized due to interactions with irregularly shaped, randomly oriented particles (i.e. snow). The program indicated that the degree of polarization calculated from the data should be rejected when the voltage level of the data is less than the level corresponding to 1 bit in the data acquisition system.

We used this knowledge in recalculating degrees of polarization for the data of February, 1988. We found that the data was in general valid beyond one optical depth. Our original analysis the year before concluded that the data showed evidence of multiple scattering effects after approximately one optical depth of range. The degree of polarization drops from approximately 0.3-0.5 within one optical depth to near zero after one optical depth. Our analysis indicated that this drop is dependent on the choice of baseline for the data. However, the baseline is difficult to determine because the laser power supply adds a time dependent baseline to the data.

Our analysis continued to show that the degree of polarization due to snow was insensitive to snow density or extinction coefficient. We found the depolarization (ratio of power of polarized backscattered power to total power) to be in the range 0.5 to 1.0. A geometric optics model was devised which predicted this. The model indicated that the polarized light from a single snowflake is primarily due to single external reflections and two external reflections. The unpolarized light is primarily due to light that has undergone one *transmission into the snow*, one reflection (not total internal), and one total internal reflection.

During April 1989 we attended the annual Conference on Lasers and Electro-Optics (CLEO) in Baltimore, Maryland. The conference was held jointly with the Quantum Electronics and Laser Science conference (QELS). We presented a poster entitled "Polarization studies of backscattered 532 nm radiation from snow and clouds using a Nd:YAG based lidar."

A new 200 MHz pulse amplifier (LeCroy model VV100B) was received. This amplifier was to be used with the new Hamamatsu R268 photomultiplier tube, which we had received. The pulse amplifier is capable of driving two 50 ohm cables. It can be used to direct the photomultiplier output along two paths. One path can lead to a discriminator and scalar for photon counting. The other path can lead to an integrater and analog/digital converter for current measurements. We received a new photomultiplier tube housing (Thorn EMI model B-2) with a gating circuit (Thorn EMI model G1000B) to be used with the Hamamatsu R268 photomultiplier tube. The gating circuit is an updated version of the gating circuit being used with the existing photomultiplier tube.

A 400 MHz voltage comparator (LeCroy model MVL407) was procured to be used as a discriminator for the photon counting pathway of the PMT output. The comparator output is ECL-based logic while the (DSP model 2090) scaler input can be either TTL or NIM logic. We discovered that the scaler input is converted to ECL logic internally. Therefore, we planned to connect the discriminator output to the ECL input inside the scaler. We tested the new PMT/amplifier in its intended mode of operation. The gating circuit turns the tube fully on in approximately 2 microseconds. The turn-on effectively gives the PMT a variable gain which is used to reduce the relatively large initial lidar return. Both during and after this turn-on period the current measured along the current measurement pathway is linear with respect to light intensity incident at the photocathode. When the current is too low to be accurately measured the photon counting pathway has well-defined, 10 nsec wide photon pulses which can be easily countable by a discriminator/scaler. The new PMT/amplifier/discriminator can be mounted on the existing lidar receiver.

We updated the lidar control program for the photon counting channel. The program is now capable of communicating with the averaging scaler CAMAC module (DSP model 2190) and its CAMAC clock (LeCroy model 8501). While this was being done additional improvements to the lidar control program were made which facilitate lidar operation.

2.3.2 RVAN

We completed the refurbishing of the Solar Transmissometer and demonstrated its operation. In addition to modifications discussed earlier, we chose the best functioning *detector cooler housing for the* transmissometer, redesigned the PMT mount to improve thermal insulation, and reinstalled temperature regulation circuitry. (The latter had been removed at some time in the past.) We wrote software to calculate absolute calibration curves for the transmissometer based on the available calibration lamp data and the solar spectral irradiance as contained in LOWTRAN. Data obtained in trial runs have been so calibrated and agree qualitatively with expected atmospheric transmission at wavelengths below about 900 nm. We believe that the observed discrepancies at wavelengths above 900 nm are due to the degradation (due to age) of the order sorting filter employed by the monochromator above 700 nm.

We completed modifications of the EG&G 580-13 indicator unit (solar transmissometer) which enable CPU selection of (current) range. The unit's internal auto-ranging facility (apparently used heretofore) results in intermittent errors in data/range readouts due to: (a) range looping on up-conversions arising from finite input RC times, and (b) incorrect timing of the range change enable signal. The available EG&G 580-13 documentation was updated to reflect the installed modifications. (Similar changes to the indicators used by other RVAN units could be done as they are made operational). In addition, we made changes in the interrupt timing circuitry in the solar transmissometer controller.

Prior to the SABLE 89 mission we transferred the Solar Transmissometer to the CO_2 trailer to enable direct path solar transmission measurements. In addition, we confirmed that--given the geometry constraints--it would be possible to operate the transmissometer in its equatorial tracking mode. To do so would require modification of the instrument base plate and reversal of the synchronous clock motor (to operate in the southern hemisphere). After shipment it was necessary to realign the tracking and detector optics. In addition, the grating change circuitry malfunctioned, requiring an IC card to be replaced and the power supply for the calibration lamp failed. A substitute current-regulated supply was obtained.

2.3.3 CO_2 LIDAR

The 3-channel/Gated Heterodyne Receiver Amplifier was completed and delivered. We calibrated the manual gain controls (at AFGL) and generated the final documentation and operation manual for this unit. Work was initiated on the setting up and testing of the LSI CO_2 laser and, in consultation with GL personnel work was started on the transmitter/receiver construction and installation.

We started modeling of the system optics to determine ideal range/sensitivity characteristics and effects due to component wave front distortion and displacements. These results were necessary to properly plan and evaluate system calibration tests.

Work continued on establishing alignment procedures and measurements of the operating parameters for the LSI laser. Tests on the Gated Heterodyne Receiver Amplifier revealed a need for enhanced mixer LO-IF isolation as well as low pass filtering of the linear amplifier video output. The required components were specified and ordered. In addition, we began looking into the possibility of gain ramping/switching: in particular whether the MGC of the RHG-ICEVT amplifiers can be reproducibly swept on a time scale comparable to backscatter return durations. This allows for a larger dynamic range of coverage by a single linear amplifier and is similar to gated PMT techniques employed in incoherent detection of backscatter.

At mid-year we continued to assist with construction and testing of the CO_2 lidar system with the aim of deployment on Sable 89. Work done in this time period included: (a) testing and modification of the LSI laser, (b) consulting on the optical components and mounting for the transmit/receive system, (c) assisting with trailer installation of the lidar components, (d) selection of a calibration target material, (e) and design of modifications to the electronic receiver.

Concerning the laser and AFC System, we corrected the power supply wiring for fast and slow preamps used in the AFC and alignment systems; redesigned fast preamp housing and rearranged other AFC system components to improve RF noise immunity; traced a laser output frequency offset (~ 1-2 Mhz) to an improperly zeroed amplifier stage in the AFC EMT-driver (LSI); identified improper installation and insufficient vibration isolation/damping as cause of laser frequency jitter in excess (~ ±5 MHz) of supplied specification (± 2 MHz); to reduce this frequency jitter we redesigned the shipping mount accessories, readjusted the invar rod supports and Brewster window mounts, constructed a clamp for the rear Brewster window mount, and drilled additional holes in the laser base plate for secure mounting to the optical table; (this latter was also required for mounting to the smaller table in the trailer).

In addition, we constructed a clean N_2 flow tube for the laser output coupler and front and rear intracavity aperture mounts. These steps were taken to avoid the output coupler laser damage encountered with the two output couplers supplied by LSI. The cause of this damage was thought to be due to either contamination of the reflection coating or "hot spots" arising from diffraction at the intracavity near aperture. We purchased two spare couplers for the SABLE 89 mission and investigated the availability of reflection coatings with higher pulse damage thresholds.

Constraints due to the trailer geometry required a redesign of the transmit/receive optical component train between the laser/detector and telescope. We assisted in this redesign ensuring sufficient adjustability of beam alignments and proper polarization geometry. We also assisted with planning for the installation in the trailer of the optical table, laser, telescope, and electronics and obtained for them necessary hardware.

We investigated materials presently used for CO_2 targets. Availability and prices were obtained for a 6'x6'x½" flame sprayed Aluminum target. Due to time, portability, and price constraints the suitability of other target materials (especially polystyrene foam) were also researched for use as a secondary field deployable target.

The receiver/amplifier unit was modified to increase high pass filtering in the log branch and in the linear amplifier video output. In addition, the modifications to enable gain ramping were designed, tested and fabricated. Calibration of the unit indicated that the video detecting circuitry of the RHG-ICEVT amplifiers operated in a near square-law mode. For future applications we looked into the availability of separate linear and/or square-law detectors.

We communicated the requirements for the data acquisition software, especially operating repetition rate. We tested the Analogic DATA-6000 and determined two possible operating modes which could provide sufficient rates (~ 10 Hz): (1) single shot digitizing with inter-shot dumping of the data to the computer and (2) use of the 620 plug-in averaging procedure.

Thorough system testing was performed prior to departure for SABLE 89 on Ascension Island. Testing of the laser indicated improved frequency stability over that previously obtained due to the mounting and EMT-driver modifications discussed earlier. The air-float vibration isolation system was found to give no significant improvement in frequency stability. Tests just prior to departure showed the output coupler to be damaged despite previously reported efforts to ensure cleanliness and avoid diffraction pattern hotspots. As in prior cases, this damage occurred over a short period of time and appeared to be caused by certain operational conditions rather than cumulative damage. We believe that this damage resulted from the excitation of a superposition of transverse and longitudinal modes with anomalously large on-axis peak powers. Such excitation was possible since the injection laser was not spatially matched to the TEA cavity TEM(00) mode. This also explained other anomalous behavior (beating) observed under certain injection laser alignment conditions.

Concerning the receiver electronics, we constructed a spare preamp and detector test components, and time delay circuitry to vary system triggering times. We completed modifications to enable gain ramping (50 dB) and obtained two low-barrier Schottky diode RF detectors for conversion of the amplified IF signal to video.

Blue polystyrene foam was chosen as the target material due to its portability. The foam was purchased and delivered to GL for treatment (planing, sanding, and sun exposure). We constructed a stand to hold a 6'x6' square of the foam.

During-operational testing of the system prior to departure for Ascension procedures were developed for the difficult alignments of LO and Backscatter wave fronts on the detector and transmit and receive optic axes. System sensitivities with the provisional system were found to be sufficient to give a S/N of 5-10 for 100 shot averages of returns off clouds at a slant range of 11 km. Preliminary measurements indicated that the detector was not being operated in an LO shot noise limited regime. However, insufficient variability of detector bias voltage and LO power prevented optimizing detector parameters as well as heterodyne efficiency.

2.3.4 MULTICHANNEL TRANSMISSOMETER

The capability to control and acquire data from the multichannel transmissometer was added to the data logger. Additional RS-232 communication ports were added to the computer to control PAR Lock-In Amplifiers and a small patch panel constructed to interface the remaining digital and analog signals from the transmissometer to the computer.

Task files stored on computer disk are used to direct positioning of the Circular Variable Filters to monitor transmission at different infrared wavelengths. Reduction of the raw data to transmission and display of the data have been added to the logger data reduction program, however the nature of the data (many wavelengths) makes display of transmission versus time and wavelength cumbersome. Different methods of display were investigated.

The frequency and duration of calibration sequences and computer controlled calibration were also examined.

2.4 FOURTH YEAR

2.4.1 LOW ALTITUDE Nd:YAG LIDAR

Early in the fourth year we completed construction of a new discriminator to be used with the photon counting channel. The discriminator uses the LeCroy MVL400 chip, a 400 MHz, 2 nsec response time voltage comparator. The discriminator is mounted onto the side of the CAMAC scalar module in the CAMAC crate.

With the completion of the discriminator the photon counting channel was complete. We tested the photon counting channel both on the bench with a simulated lidar and during standard operation of the lidar. The lidar return was simulated with an LED pulser built at the Physics and Electronics Laboratory at The Hague, Netherlands. With the pulser, an LED is pulsed on for several microseconds and then allowed to decay. The decay is approximately exponential over several (at least 4 to 5) orders of magnitude. Using the pulser, we showed that we can use a single PMT simultaneously in photon counting mode and current mode, which extends considerably the range over which the system is sensitive compared to running the PMT in current mode only. The amount of extension is dependent on the number of pulses that are averaged over.

Simultaneous current mode and photon counting mode was successfully demonstrated during normal lidar operation as well. Some preliminary nighttime data was taken. (The photon counting channel can only be used at night when the background light level is low.) We had to solve some additional problems during actual lidar operation that did not exist during simulated lidar operation. Careful cabling between the PMT/amplifier, discriminator/scaler, and their power supplies must be observed to prevent ground loops. The lidar is especially vulnerable to ground loops when the laser power supply is operating.

We investigated a problem with the new Hamamatsu PMT. The PMT, with its dynode chain and gating circuit supplied by Thorn/EMI, has a linear response for anode currents up to approximately 100 microamps. Our goal was to extend this to 3 mA. We successfully extended the linear regime by rewiring the dynode chain. However, it failed to operate properly when the gating circuit is used.

We added a new lidar inversion technique to the lidar control program. The technique still uses the Klett routine to invert the data from some final range inward. The way in which the extinction value at this final range is chosen is new. In the former method the extinction was assumed to be constant over several range points near the final range. In the new method the extinction is assumed to be linear over several range points near the final range. This method requires finding two parameters (the slope and intercept of the linearly varying extinction) by doing a nonlinear least squares fit to a section of the data.

During the winter period two snow data sets were acquired with the mobile Nd:YAG lidar system in Sudbury. For each data set depolarization measurements were made by measuring the perpendicular and parallel polarized components of the 0.53 micron backscattered radiation. For snow we assumed that the backscattered radiation acquires a randomly polarized component upon scattering. That is, it does not simply change its polarization state to a different completely polarized state. Thus, the two additional polarization measurements that would be required to determine the complete polarization state are not necessary.

The first data set was acquired during the relatively light snow of January 15,1990. The second data set was acquired on January 29 when conditions varied from light to heavy snow. The second data set also consisted of measurements taken with supporting ground instruments such as visibility meters, rain depth gauge, and meteorological data. We analyzed the lidar data of each set. The results were consistent with our previous conclusions concerning snow: The depolarization is relatively constant (approximately 0.4), independent of snowflake density.

We developed a new and improved algorithm to analyze the snow polarization data. The algorithm predicts a smaller spread (than that calculated with the old algorithm) in the depolarization value as a function of snow density. The snow density here is considered to be proportional to the extinction coefficient, which is determined by a Klett inversion of the lidar data.

We calibrated the beam steering optics which controls the direction of the laser beam propagation path with respect to the receiver field of view. This was done in anticipation of experiments (discussed below) whereby we would measure the lidar return as a function of angle between laser transmitter axis and receiver optical axis. The presence of such "off axis" scattering would be due to multiple scattering.

The calibration was performed in the laboratory. A HeNe laser beam was focussed through the beam steering optics to a spot on a wall approximately 3 meters away. The vertical and horizontal displacement of the spot was measured as a function of the position of the knobs which control vertical and horizontal displacement respectively. We found 3 milliradians of vertical motion and 3.3 milliradians of horizontal motion for one revolution of the vertical and horizontal knobs respectively. Each knob is resolved to within 0.01 times one revolution, with an estimated accuracy of 0.02 to 0.03 times one revolution. Therefore, the beam can be steered with resolution of tens of microradians. This is to be compared with the 2.5 milliradian laser beam spread and the 10 milliradian receiver field of view.

We performed atmospheric backscatter experiments steering the beam relative to the receiver. The lidar data was taken for conditions in which there was "clear air" up to approximately four kilometers, followed by a cloud layer. This enabled us to compare the return in clear air, where we expect little off axis backscatter (very little multiple scattering), to the return from a cloud, where we expect much off axis backscatter. Our conclusion from this experiment was that the aberrations of the receiver optics will not permit us to study the off axis scattering. The ratio of off axis radiation to on axis radiation is the same for both cloud and clear air. The power at an angle difference of 7.5 milliradians (the expected cutoff of single scattered radiation) is approximately 0.05 times the power for an angle difference of zero. Presumably, off axis radiation is imaged to the detector because of the severe aberrations we expect from the single-element aperture of the f/1 receiver. We expect that these experiments will be possible with the new f/10 Dall-Kirkham receiver that is currently being fabricated for the mobile Nd:YAG lidar at the Geophysics Laboratory.

We performed ray tracing calculations for the six inch diameter, six inch focal length lens which constitutes the aperture of the lidar receiver. The calculations predict even worse results than our experiments show. The power at an angle difference of 7.5 milliradians is approximately 0.5 times the power for an angle difference of zero. This is explained by the fact that the analytical case did not consider the additional optics between aperture and detector, which further stops down the light. The ray tracing calculations also show that only 10% of the light in the receiver field of view can get to the detector. Again, we expect the new receiver to have much better behavior.

We began modeling of multiple scattering of the lidar beam. Our objective was to determine the effects of multiple scattering in our technique of interpreting lidar data. A survey of the literature for techniques of incorporating multiple scattering effects was done. We decided to take the radiative transfer approach. For simplicity, we only considered large particles, for which the scattering phase function can be assumed to be nonzero only in a small cone about the forward scattering direction. We did not include time in our analysis; thus only small angle forward scatters were considered. There is one large angle (180 degree) scatter. We did not consider polarization effects. We reduced the 24 dimensional radiative transfer integro-differential equation to a 3 dimensional integration. We programmed a numerical procedure to perform these integrations for an MS-DOS based computer.

2.4.2 RVAN

As noted earlier, the transmissometer--with minor repairs-- was operated throughout the SABLE mission with data acquired from 25 June to 7 July 1989. The software was written to have the unit alternate between monitoring the solar brightness at a fixed wavelength (for about 40 minutes) and taking a spectral scan. During operation it was found that, at about 1600 UT (about 3 PM LST near the summer solstice) the telescope assembly, in seeking to track the sun, would hit the base of the transmissometer and lock up. Late in the TDY a few continuous scans through this time were obtained by mis-setting the unit's heading with a compensatory decrease in its declination setting. We had previously modified the unit's tracking clock to enable CCW motion in order to operate in the southern hemisphere. Accounting for this, this lockup condition can be expected to occur in the northern hemisphere for a several week period near the winter solstice and at about 9 AM LST.

We converted the solar transmissometer data into absolute atmospheric transmission using previously written software. The reduced transmissions showed an increasingly significant deviation from expected values for wavelengths below about 550 nm. We traced this to an effect on the calibration data of a reentrant spectrum in the monochromator. The reduced data was corrected semi-quantitatively for this effect.

A report was submitted describing the method of calibration employed for the solar transmissometer data. This report pointed out two problems with past methods: incorrect handling of the limb darkening effect and ignoring of the reentrant spectrum contamination. In the former case, we detailed an adequately precise way to correct for the limb darkening effect.

2.4.3 CO_2 LIDAR

During the SABLE experiment backscatter data was taken over the time period 30 June to 6 July 1989. Generally the lidar operation was coordinated with aircraft measurements and occurred during late morning/early afternoon and late evening flights. Due to an ABLE system computer failure and transfer of the CO_2 LIDAR computer, the data was collected by operating the Data Precision D6000 in a manual mode and employing its built-in floppy drives for data storage. This technique had been previously developed as a backup in case of computer failure.

Prior to operational data acquisition, we attempted to optimize the SNR by varying LO power and the detector bias voltage. Although improvements were made, shot noise limited operation was not achieved. Possible reasons for this were greater than expected added preamplifier noise or an insufficient dynamic range of the detector. In the latter case it may be that the detector was being driven into saturation before sufficient LO powers were achieved for the shot noise to dominate the detector/preamplifier noise. Detector/preamplifier specifications were reviewed and systematic tests of detection sensitivity were performed.

Test firing of the lidar at hard targets at distances up to 2-2.5 km showed that the return was sufficient to saturate the detector system. As the suspected saturating component was the high gain amplifier, calibration against such hard targets will have to incorporate a calibrated electronic attenuation of the signal.

We obtained the binary-packed coding of the data format used by the D6000 to write to floppy disc. Using this, we wrote software for PC compatibles to read, display, plot and make simple manipulations of the SABLE data. We also wrote into the package a capability to fit stratified data (horizontal scans) to modeled heterodyne lidar sensitivities and aerosol extinctions. This can be used together with aircraft data to provide an absolute calibration of the lidar data.

The layout of the CO_2 laser was redesigned to eliminate the base plate and provide for a more convenient optical layout. This necessitated drilling and tapping a number of holes in the optical table and customization of several mounts in order to fasten the laser components directly to the table.

Our tests of the high voltage modulator electronics showed two failures: the HY-6 thyratron in the preionizing circuitry and an over voltage protection diode in the bias supply for the ITT thyratron employed by the main discharge circuitry. Evidently the former was responsible for failure experienced on Ascension Island. The latter fault may have been pre-existing as thyratrons can operate nominally with low bias voltage (especially at the low repetition rates employed--10 Hz). We corrected both conditions.

We assisted with redesign of the transmit/receive optics necessary for the planned new system configuration and aided with testing and modifications of the TEA laser. Frequency jitter due to the 400 Hz fan vibration was found to be greatly reduced by the installation of new fans and the improved isolation provided by the elimination of the magnesium base plate. Frequency jitter due to the cw laser's locking dither is now apparent at dither modulations above about 15%. The present dominant source of uncontrollable jitter was been traced to the gas delivery system.

In the present design, fresh gas flows into the Brewster window assembly and across the inner surface of the windows in order to prevent contamination and consequential burning of these surfaces. Turning off this flow was found to drastically reduce the shot-to-shot frequency jitter. (Note: the TEA laser can operate with no gas flow and a 10-20 Hz rep rate for about 5-10 minutes without noticeable power droop.) We also observed in the flow-off condition a significant improvement in the frequency stability (to better than 1 MHz) when the rep rate was increased from 10 to 20 Hz. This indicated that the remaining cavity instabilities have low frequency (~10 Hz) components.

We replaced the horizontally polarized cw laser used for injection locking with a vertically polarized laser of the same make. The latter has a longer expected tube lifetime and a spare is available for field replacement. Due to the differing polarization, the geometry of the various pick-off's from this beam (e.g., AFC LO, injection beam,...) and their delivery optics were modified. Several new optical mounts were made and installed for this purpose. In addition, we constructed an attenuator using two available wire grid polarizers. This can be used to provide a continuously variable attenuation of the receiver LO so that optimum levels can be ascertained.

We assisted with redesign of the transmit/receive optics and the necessary modifications to the trailer optical table and support structure. In addition, we designed and tested modifications to the TEA laser pick-off and injection scheme. The new configuration eliminates the beam splitter which was used to pick-off a fraction of the TEA laser output for the AFC system. The zero order diffracted beam from the cavity grating is now employed. This modification increased the transmitted power by about 10% and made the laser more compact.

During the spring and early summer of 1990 work was centered around preparations for and execution of the GABLE field measurement program at the Azore Islands, to be held during August. The final preparation included completion and installation of the new transmit/receive optics as well as a manual drive system and readout for the scanner. Atmospheric backscatter measurements were taken from the Cinco Pico site on August 14, 15, 17, 18, 19, 20, and 21. These measurements were made in concert with the airborne CO_2 lidar, ground based 532 nm lidar, and balloon radiosonde and thermosonde measurements. Preliminary reduction of the calibration data was performed on return from the field trip.

The scanner drive system was found to have sufficient resolution to acquire the calibration target at 3.5 km. One problem which was noted with the target alignment procedure was the "parallax" between the camera FOV and the laser direction if the laser was not accurately aligned to the scanner. This resulted in a wander of the apparent laser direction in the camera FOV as the scanner was rotated and increased the search time required to align the lidar to the target.

Two problems associated with the laser AFC system were encountered. The pulse frequency counter (PFC) ceased working after an initial test run of the laser. This box was opened and examined with no apparent evidence as to the cause of its failure. On reassembly and for the rest of the field trip it functioned properly. We believe that an electrical short may have developed on the signal input line which was repositioned on reassembly. The other problem was that the AFC system occasionally tried to lock the TEA laser at a 35 MHz offset from the cw laser instead of the nominal 40 MHz. We had observed this behavior before this field trip, but only intermittently. It appeared to be dependent on the alignment of the injection seed laser to the TEA cavity. Tedious readjustment of this alignment on a trial and error basis did return the proper functioning of the AFC system. Identifying the source of this behavior is a high priority for future routine performance of the lidar.

2.4.4 MULTICHANNEL TRANSMISSOMETER

Data logger software which controls the PAR Lock-in Amplifiers was modified to ensure adequate dwell time (at least 3 times the averaging time constant of the Lock-in) at each position of the Circular Variable Filters. Additional changes reduced the time the logger requires to alter the gain of the Lock-in Amplifiers. The patch panel was modified to provide data logger control of the operational mode of the transmissometer (Calibration or path measurement). The transmissometer can now, in principle, run unattended for long periods, alternately performing calibration and transmission measurements.

Voltage dividers were added between the Lock-in output and the input to the computer analog-digital converter to reduce the input voltage. Over-range condition of the Lock-in produces approximately 16.5 volt output, while interchannel interference in the A-D converter starts at 15 volts. Calibration of the computer analog-digital converter with and without the dividers was done to provide the data reduction programs with a look-up table for conversion of measured digital values to engineering units.

Data which provide support for transmission modeling (pressure, temperature and relative humidity) are logged. Independent point measurements of extinction from two visibility meters (at approximately 0.9 μm) are also recorded. Two computers were reinstalled in the TOADS trailer in preparation for winter time snow operations. These computers control and collect data from the visible transmissometer/ nephelometer, visibility meters, weather system and rain distrometer.

Data acquired using the multichannel transmissometer were analyzed to determine optimum modes of operation for the computer control, to assess results of changes made to the alignment of the instrument, test instrumental stability from day to day, and estimate the precision of the transmission measurements. Changes were made to the initial data reduction program (which generates data in engineering units) to speed the process. Computer programs to perform calibration and change the data to physical units were developed. Calibration technique using the Lowtran model and "clear day" transmissometer measurements to determine the instrument response were also developed.

Installation of the data loggers on the MOAL was completed with calibration of the A/D converters and recording calibration data for the visibility meters. Data from the visible transmissometer, visibility meters, rain distrometer and met equipment taken during the snowstorm on 29 January 1990 were reduced to physical units and turned over to GL for further analysis.

In July 1990 the MOAL was moved to Brunswick Naval Air Station, Maine for participation by the multichannel transmissometer and associated met equipment in the FLAPIR program. Measurements were made of transmission in various types of fogs at selected wavelengths in the visible and infrared. During fourteen days of operation seventy-three hours of measurements were taken. The detailed transmissometer results of this field measurement program are presented in a separate Phillips Laboratory report (PL-TR-91-2012).