NASA's Geoscience Laser Altimeter System Mission

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The Geoscience Laser Altimeter System (GLAS) of the NASA Earth Observing System (EOS) is currently scheduled to be deployed in the 2002 time frame. GLAS is both a surface altitude laser ranging system and an atmospheric lidar. The most important surface ranging application is the measurement of the altitude of the polar ice sheets. The scientific importance of this application is easily understood. A precise and repeated altitude measurements by GLAS will monitor the change in the thickness of the polar ice caps of Greenland and Antarctica. The possible effect on polar ice caps from global change is of significant interest. The required surface altitude accuracy for GLAS is better than 10 cm. The surface accuracy requirement leads to system parameters for the instrument of a 0.9 m telescope reciever and a 150 mJ, 40 Hz laser. These parameters are compatible with atmospheric measurement applications.

There are significant applications for atmospheric lidar measurements from space for cloud and aerosol observation. The GLAS atmospheric measurements will both provide important global observations that are fundamentally unique to active sounding and observations that are an important adjunct and validation to EOS passive sensors.

Active cloud profiling is needed to validate and to supplement the limitations of passive cloud retrievals. A main deficiency for parameterization of clouds is our lack of knowledge on the vertical distribution of clouds. Existing and planned passive measurements, while providing top of the atmosphere radiation information, do not adequately provide the essential vertical profiles of cloud and the resultant heating. The prospect of adding active measurements will significantly add to progress on determining the 4-D distribution of cloud optical properties and the relationships between these properties and cloud liquid water, ice mass, and water vapor. Optically thin, or sub-visual, cirrus is potentially a significant greenhouse component of the atmosphere. In particular aircraft and solar occultation measurements indicate that typically over half of the west Pacific warm pool region is covered by a sub-visible layer of cirrus at the tropopause. The optical thickness of this persistent layer is small. However the net radiative impact over the entire region is estimated to be potentially significant. Such optically thin cirrus is not reliably detected by passive sensing other than limited sampling by solar occultation observations. Laser measurements provide a very sensitive measure of the presence, height and thickness of tenuous cirrus layers. GLAS cloud observations will have significant value for polar cloud studies. The interpretation of satellite-based cloud imaging and retrievals in polar regions have major problems due to factors such as darkness and extreme low temperatures. Satellite radiometers operate at or beyond the limit of their response. Current polar cloud retrievals are considered in large part unreliable. GLAS would obtain a very good coverage at the poles and would unambiguously define cloud type and fraction. Typical cloud structure is multiple layered and broken. Observations of the structure multiply layered clouds is problematic for passive remote sensing techniques. The data set of laser measurements of cloud multiple layering will be unique and important for understanding the interpretation of passive cloud observations and will directly relate to all applications for cloud vertical profiling. For a significant fraction of cloud cover, laser measurements will determine cloud base height. The measurements are direct and unambiguous. Surface radiation budget is a critical factor for climate. Cloud effects on surface warming are related to the cloud component of the downward atmospheric flux. The determining factor of the cloud flux component is largely the distribution of cloud base height. Cloud base height measurements are generally not possible from passive satellite measurements.

Aerosol profiles provided by the GLAS instrument will provide information on episodic aerosol events such as volcanic emissions, ablated dessert soils, continental particulates and arctic haze. Vertically elevated layers of particulates are transported over long ranges and have been linked to air quality degradation and ocean nutrients. The laser measurements uniquely define the vertical aerosol structure throughout the troposphere. The laser measurements will give full diurnal coverage. When coupled with wind direction and speed information, the vertical distribution of aerosol trace materials also provides information on aerosol mass transport. Long range transport of trace gases and aerosols is a dominating factor in the global chemical balance. Accurate aerosol vertical profile information is necessary. In many cases the GLAS observations will determine the height of the mixed layer from the aerosol scattering structure and in all cases, at high accuracy, the height for a cloud capped boundary layer. The planetary boundary layer height is a basic parameter linking the surface to atmosphere dynamics, especially over oceans. Measurement of the PBL height is unique to the active laser measurements.

It is very technically compatible, scientifically benificial and programatically efficient to do atmospheric lidar observations with the same laser based instrument that can be used for surface altimetery measurements. Combined applications from a single instrument is observationally advantageous. The surface return signal for laser ranging will be effected by the intervening atmosphere. Filtering will be required in the case of surface signals that have been affected by cloud attenuation, or potentially, pulse spreading. Also the acquired surface return signal is a boundary condition that can aid the interpretation of atmospheric signals. The most significant use of GLAS is to measure ice sheet mass change. Ice sheet mass change is related to crystal precipitation and polar clouds. Lidar measurements are required for clould observations in Arctic winters.

The GLAS instrument will be a highly photon efficient design based on advanced solid state lasers and detectors. Overall planned instrument parameters for the GLAS channels are given in Table 1. The laser 1.06 μm wavelength is used for the surface signal and a 0.532 μm channel is needed for the atmospheric measurement.

Table 1 GLAS instrument Parameters

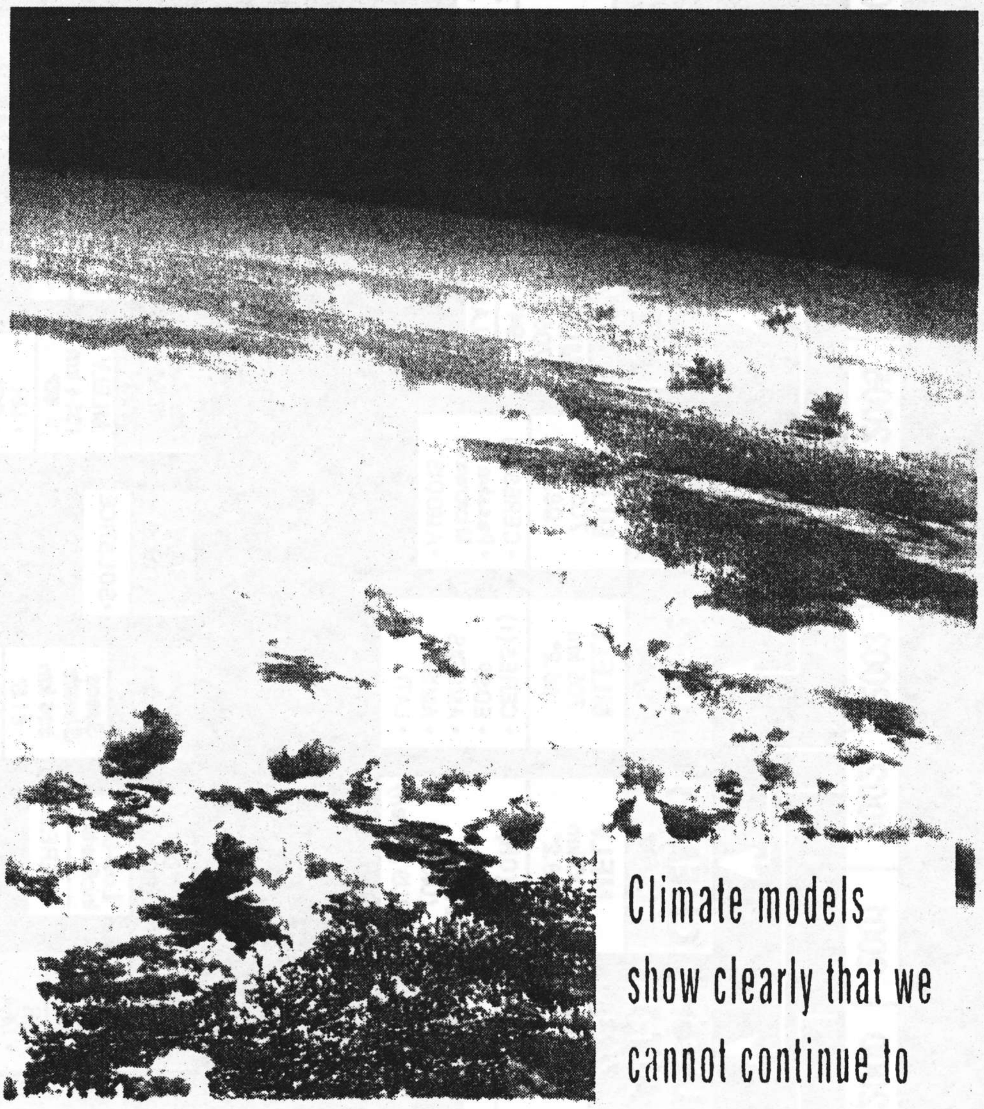
Parameter	523 nm channel	1064 nm channel
Telescope diameter	0.9 m	0.9
Telescope field-of-view	0.14 mrad	0.2 mrad
Laser PRF	40 Hz	40 Hz
Laser pulse energy	50 mJ	100 mJ
Optical filter bandwidth	0.013 nm	0.05 nm
Detector quantum efficency	0.6	0.3
Detection scheme	Photon counting	Analog

Whether useful atmospheric signals would be obtained GLAS measurements has been studied extensively. The results are that atmospheric signals can be more than adequate for significant cloud and aerosol applications. Lidar data from the NASA ER-2 aircraft has been used as the basis to model the expected signals for the GLAS instrument. This and other results indicate GLAS will adequately observe atmospheric scattering structure including optically thin cirrus, near surface aerosols and volcanic plumes.

The high quantum efficiency of the silicon Geiger mode APD detectors is a major advantage for space borne lidar. These detectors are now planned to be used for the GLAS atmospheric signal. The 60% quantum efficiency we have measured at the 532 nm wavelength is over four times what would be expected with previous detectors. To obtain the same increase in signal by doubling the reciever aperture of the lidar instrument would mean an increase of the instrument size and weight, launch vehicle requirements and of course total mission cost. Radiation damage of the GAPD detectors has been studied, and it now seems within acceptable limits. Another factor for an efficient space borne lidar is the optical transmission efficiency of the narrow band filter that is required to limit background radiation. A holographic filter design is being considered as an alternative to an etalon filter.

More important than the detector and optics improvements described above, the fundament development that makes lidar instruments in space practical is of course the advent of efficient, diode pumped solid state lasers. GLAS will use a diode pumped Nd:YAG laser. These lasers are demonstrating the long lifetime and high efficiency necessary for spacecraft. Power efficiencies greater than 6% have been shown. The lidar work at Goddard Space Flight Center has included the use of a diode pumped Nd:YAG laser for lidar remote sensing from the NASA high altitude ER-2 aircraft. The laser has been used in six major field programs with over 600 flight hours flown. The operational efficiencies and reliability have been outstanding.

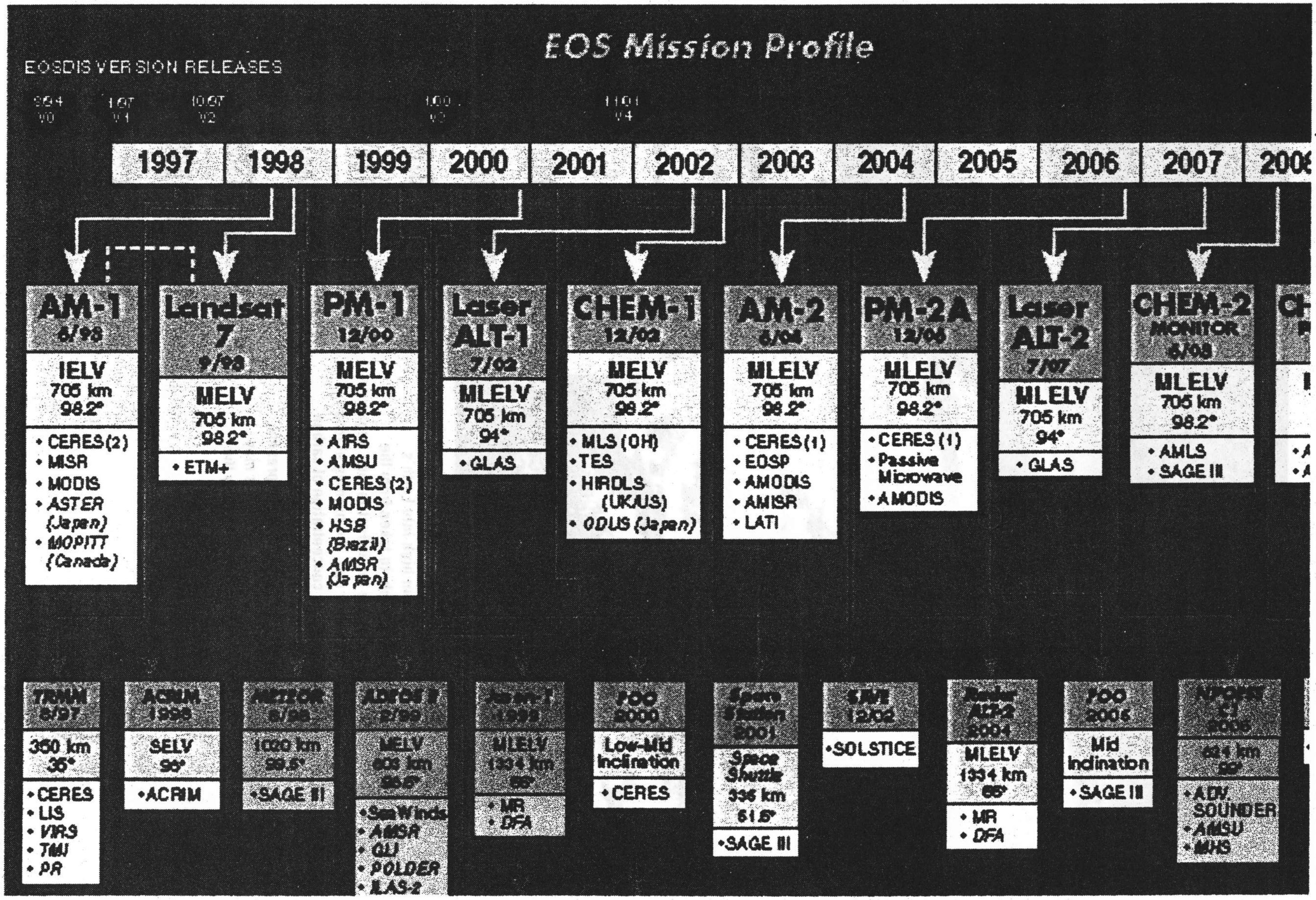
In summary GLAS is a mission that is designed for a very significant application for ice sheet and atmospheric science. The design involves the application of recently available technology for solid state lasers and detectors. The three years of observations to be obtained from the GLAS mission will be of large importance for NASA's EOS program and the study and prediction of possible global warming from anthropogenic atmospheric modification.

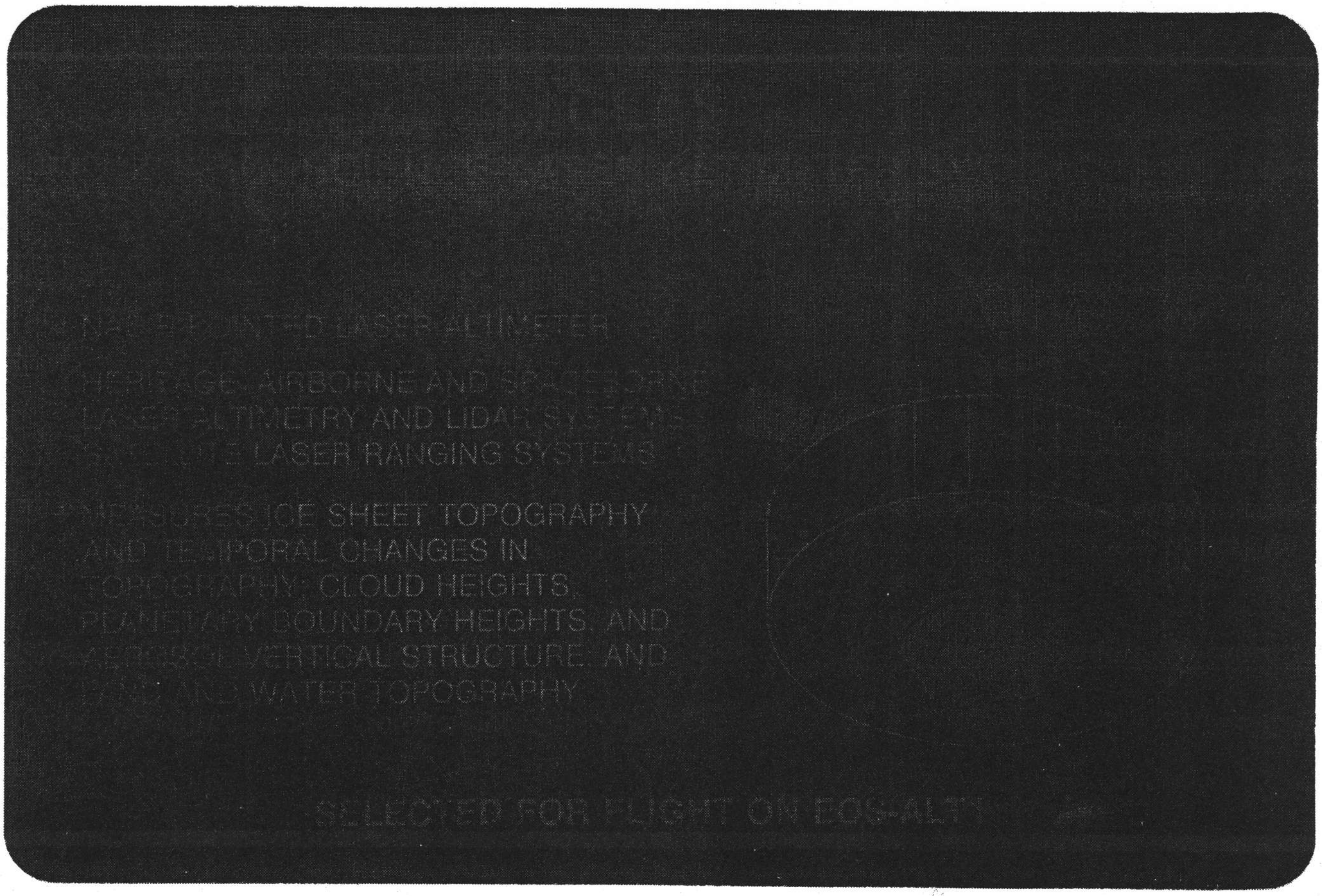


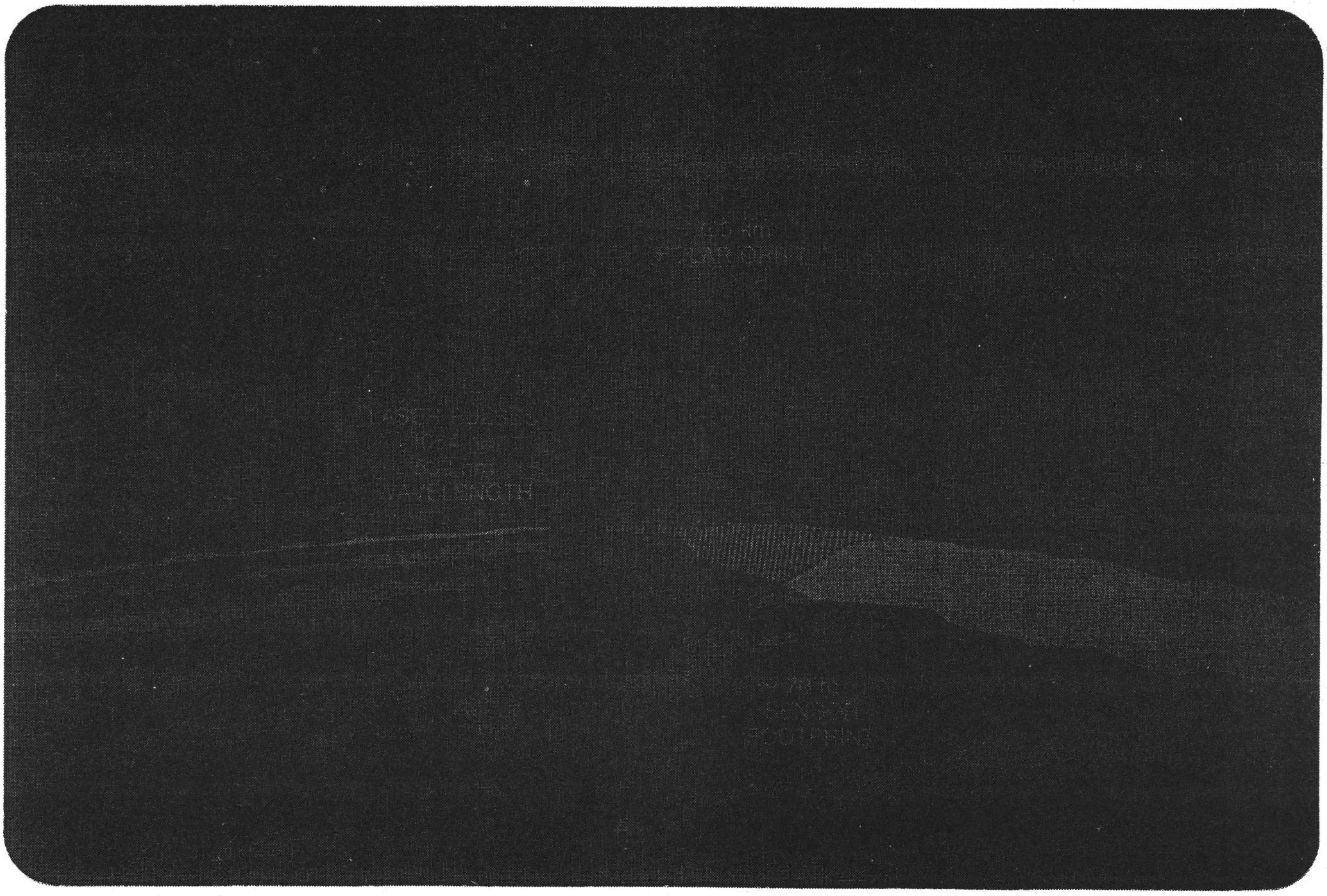
Thunderstorms bloom high into Earth's atmosphere in this photo taken from the space shuttle. Since the industrial age began more than a century ago, the burning of fossil fuels has raised the concentration of carbon dioxide — the most important greenhouse gas — by about 27 percent. At the present rate, carbon dioxide concentrations may double over pre-industrial levels by the middle of the next century.

Climate models show clearly that we cannot continue to pump such a large amount of carbon dioxide and other greenhouse gases into the atmosphere without having some effect.

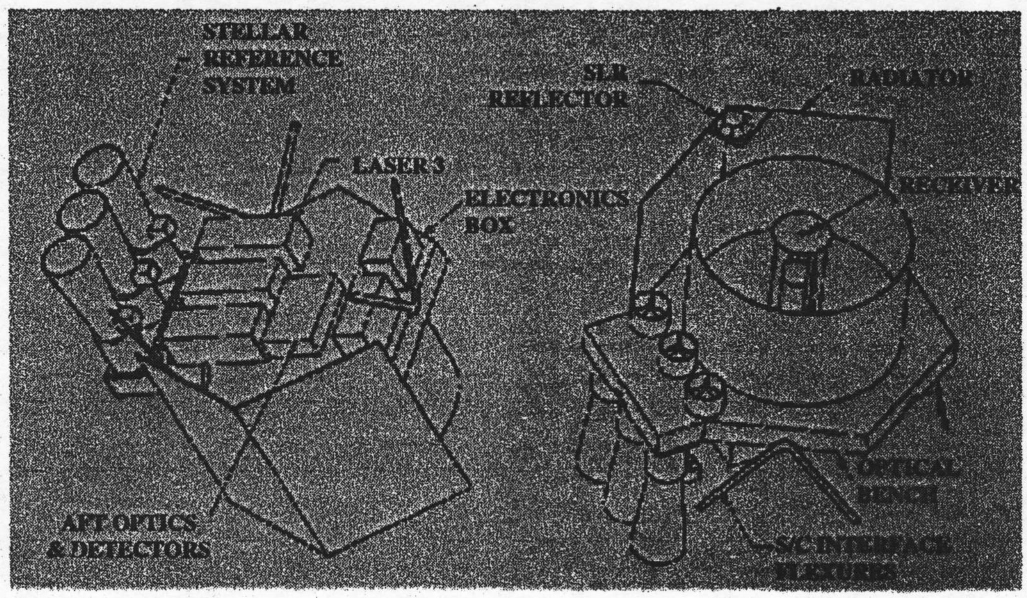
NASA


EOS Mission Profile
EOSDIS VERSION RELEASES
V0
V1
V2
V3
V4
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
AM-1
6/98
IELV
705 km
98.2°
• CERES (2)
• MISR
• MODIS
• ASTER (Japan)
• MOPITT (Canada)
Landsat 7
9/98
MELV
705 km
98.2°
• ETM+
PM-1
12/00
MELV
705 km
98.2°
• AIRS
• AMSU
• CERES (2)
• MODIS
• HSB (Brazil)
• AMSR (Japan)
Laser ALT-1
7/02
MLELV
705 km
94°
• GLAS
CHEM-1
12/02
MELV
705 km
98.2°
• MLS (OH)
• TES
• HIRDLS (UK/US)
• ODUS (Japan)
AM-2
6/03
MLELV
705 km
98.2°
• CERES (1)
• EOSP
• AMODIS
• AMISR
• LATI
PM-2A
12/05
MLELV
705 km
98.2°
• CERES (1)
• Passive Microwave
• AMODIS
Laser ALT-2
7/07
MLELV
705 km
94°
• GLAS
CHEM-2 MONITOR
6/08
MLELV
705 km
98.2°
• AMLS
• SAGE III
TRMM
8/97
350 km
35°
• CERES
• LIS
• VIRS
• TMI
• PR
ACRIM
1998
SELV
98°
• ACRIM
METEOR
8/98
1020 km
• SAGE III
MELV
• SeaWinds
• AMSR
• GLI
• POLDER
• ILAS-2
MLELV
1334 km
• MR
• DFA
FOO
2000
Low-Mid Inclination
• CERES
Space Station
Space Shuttle
336 km
51.6°
• SAGE III
12/02
• SOLSTICE
MLELV
1334 km
66°
• MR
• DFA
FOO
2005
Mid Inclination
• SAGE III
• ADV SOUNDER
• AMSU
• MHS


LASER ALTIMETER
AIRBORNE AND
LIDAR
LASER RANGING SYSTEMS
ICE SHEET TOPOGRAPHY
CHANGES IN
CLOUD HEIGHTS,
BOUNDARY HEIGHTS, AND
VERTICAL STRUCTURE, AND
WATER TOPOGRAPHY
SELECTED FOR FLIGHT ON EOS-ALT


WAVELENGTH

Geoscience LaserAltimeter System



Blue - Atmosphere Channel
Red - Surface Channel

PARAMETERS:

	532 nm	1064 nm
Laser Pulse Energy	50 mJ	100 mJ
Laser PRF	40 Hz	40 Hz
Telescope Diameter	0.9 m	0.9 m
Receiver FOV	0.14 mrad	0.18 mrad
Optical Bandwidth	< 0.013 nm	< 0.05 nm
Detector Quantum Efficiency	0.6	0.3
Detection Scheme	Photon Counting	Analog
Surface Ranging Accuracy		10 cm
Pointing Knowledge		3 arcsec

ICE SHEETS AND SEA LEVEL CHANGE

IPCC WGI REPORT 1996, CHAPTER 7:

o SEA LEVEL IS ESTIMATED TO RISE BY 50 CM BY 2100 (15 CM FOR LOW CLIMATE AND ICE MELT SENSITIVITIES AND 95 CM FOR HIGH SENSITIVITIES)

o "OF ALL THE TERMS IN SEA-LEVEL CHANGE EQUATION, THE LARGEST UNCERTAINTIES PERTAIN TO THE EARTH'S MAJOR ICE SHEETS"

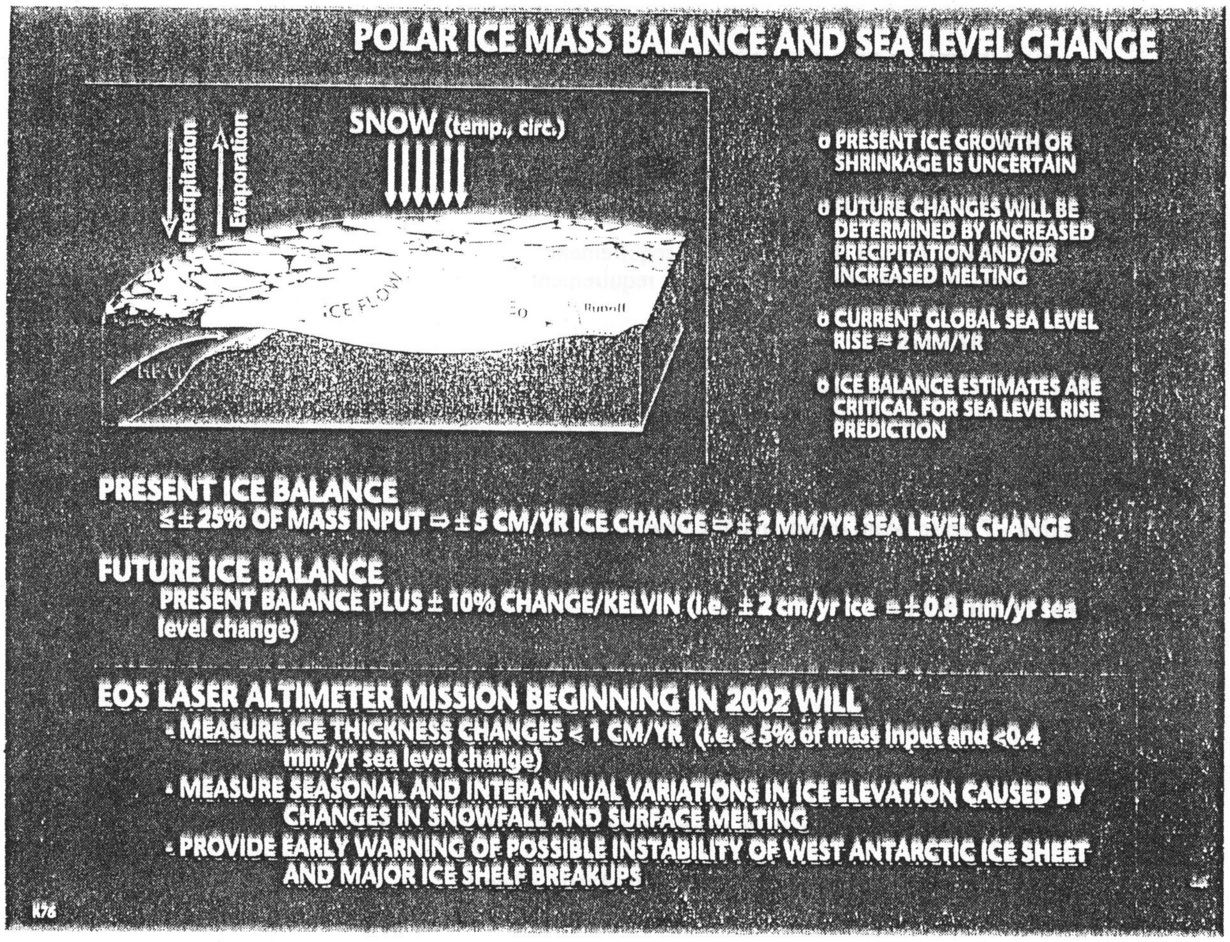
o "THE CURRENT MASS BALANCES OF THE ANTARCTIC AND GREENLAND ICE SHEETS NEED TO BE DETERMINED AND FUTURE CHANGES MONITORED. ... A LASER ALTIMETER IS URGENTLY NEEDED ON A POLAR-ORBITING SATELLITE..... THESE MEASUREMENTS SHOULD BEGIN AS SOON AS POSSIBLE IN ORDER TO PROVIDE A BASELINE FOR DETECTING GREENHOUSE-INDUCED CHANGES IN THE FUTURE".

o "THE OBSERVED SEASONAL AND INTERANNUAL VARIATIONS IN SURFACE ELEVATION WILL PROVIDE INFORMATION ON PRECIPITATION, WHICH CAN BE USED IN ENERGY BALANCE MODELS AND TO TEST ATMOSPHERIC GCM RESULTS."

US CLIMATE ACTION REPORT TO UN 1996

o A 50 CM SEA LEVEL RISE WOULD INUNDATE 1300 TO 3700 KM^2 OF US DRY LAND, 20-45% OF US COASTAL WETLANDS, AND COULD NECESSITATE SPENDING \$50-200 BILLION FOR COASTAL PROTECTION.

(UNCERTAINTY OF ICE MASS BALANCE FOR 1 TO 3.5 C WARMING IS ±30 TO ±50 CM)



Technical Compatibility of GLAS Surface and Atmosphere Measurements

SURFACE
Strong signal strength
High height resolution and signal bandwidth

ATMOSPHERE
Low signal strength
Low height resolution and signal bandwidth

\>>>>>>>> *Similar Telescope and Laser Requirements*

Special Requirement for Atmospheric Signal:

Photon counting signal acquisition channel

COMPATIBILITY OF SURFACE RANGING & ATMOSPHERIC LIDAR

TECHNICAL:

Similar Laser and Receiver Size

Surface - Strong signals, high bandwidth requirement
Atmosphere - Low signals, low bandwidth requirement

Same 100% Duty Cycle

Lidar - Global coverage requirement
Ranging - High laser stability requirement

Laser Beam Quality Advantage

Ranging - Precise beam quality requirement
Lidar - Narrow filter enabled for accurate daytime measurements

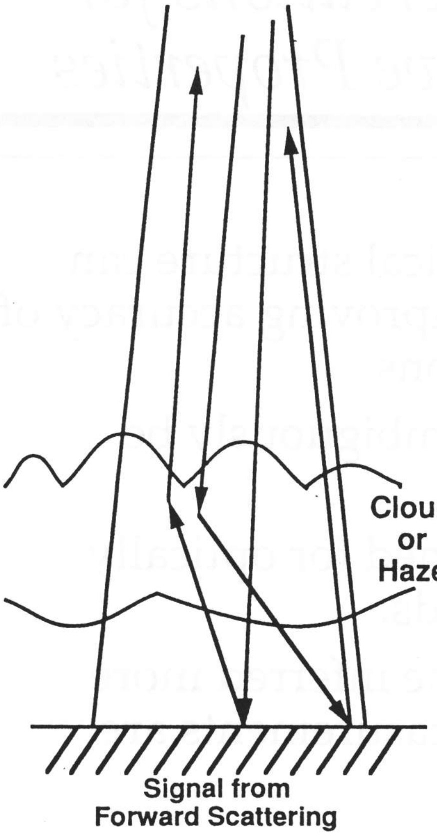
OBSERVATIONAL:

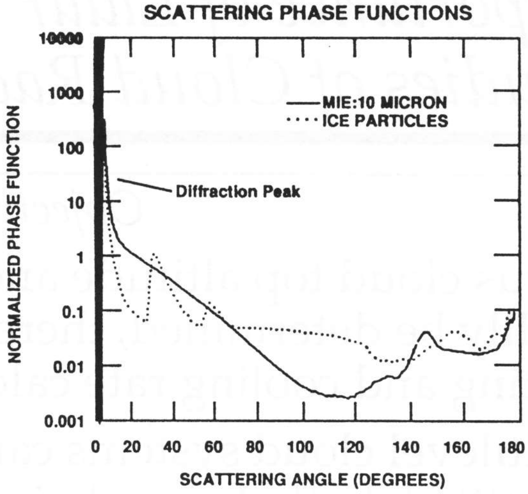
- Atmospheric structure must be known to avoid pulse stretch ranging errors
- Atmospheric optical thickness retrieval improved by surface return normalization

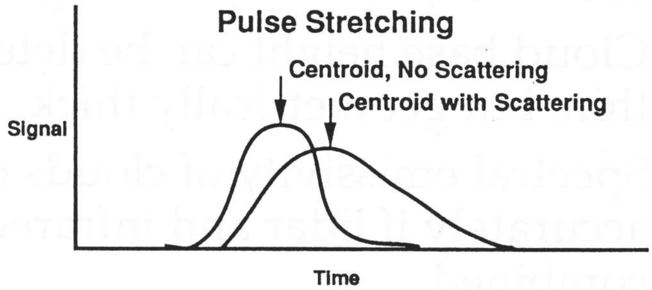
SCIENCE:

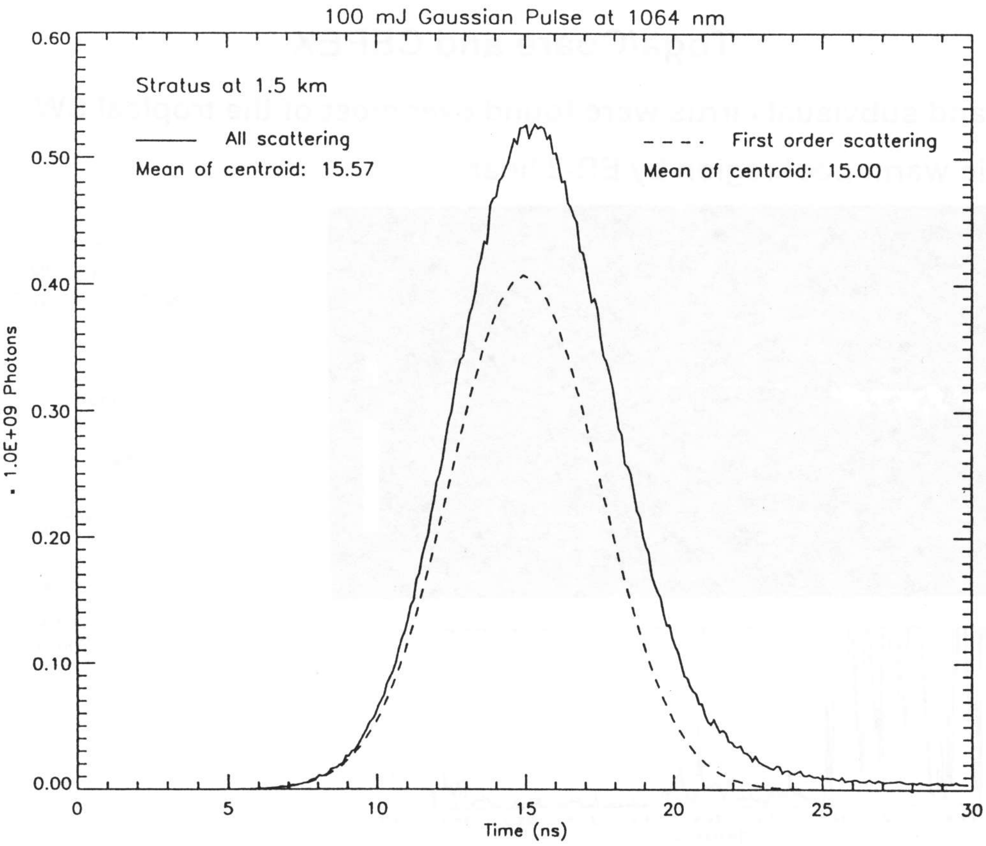
- Ice sheet mass change is related to crystal precipitation and polar clouds
- Lidar is required for cloud observations in Arctic winters

Surface Altitude Error From Atmosphere Scattering









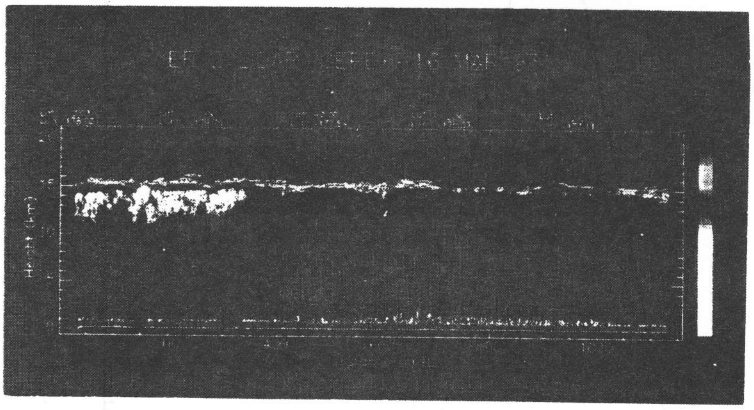
Importance of Lidar Observations for Studies of Cloud Radiative Properties

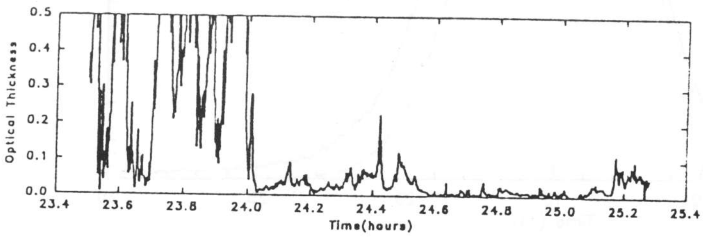
Objectives

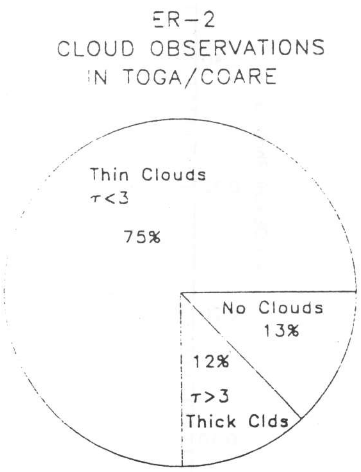
- Cirrus cloud top altitude and vertical structure can readily be determined, thereby improving accuracy of heating and cooling rate calculations.
- Multilevel cloud systems can unambiguously be identified, both day and night.
- Cloud base height can be determined for optically thin, but geometrically thick, clouds.
- Spectral emissivity of clouds can be inferred more accurately if lidar and infrared measurements are combined.

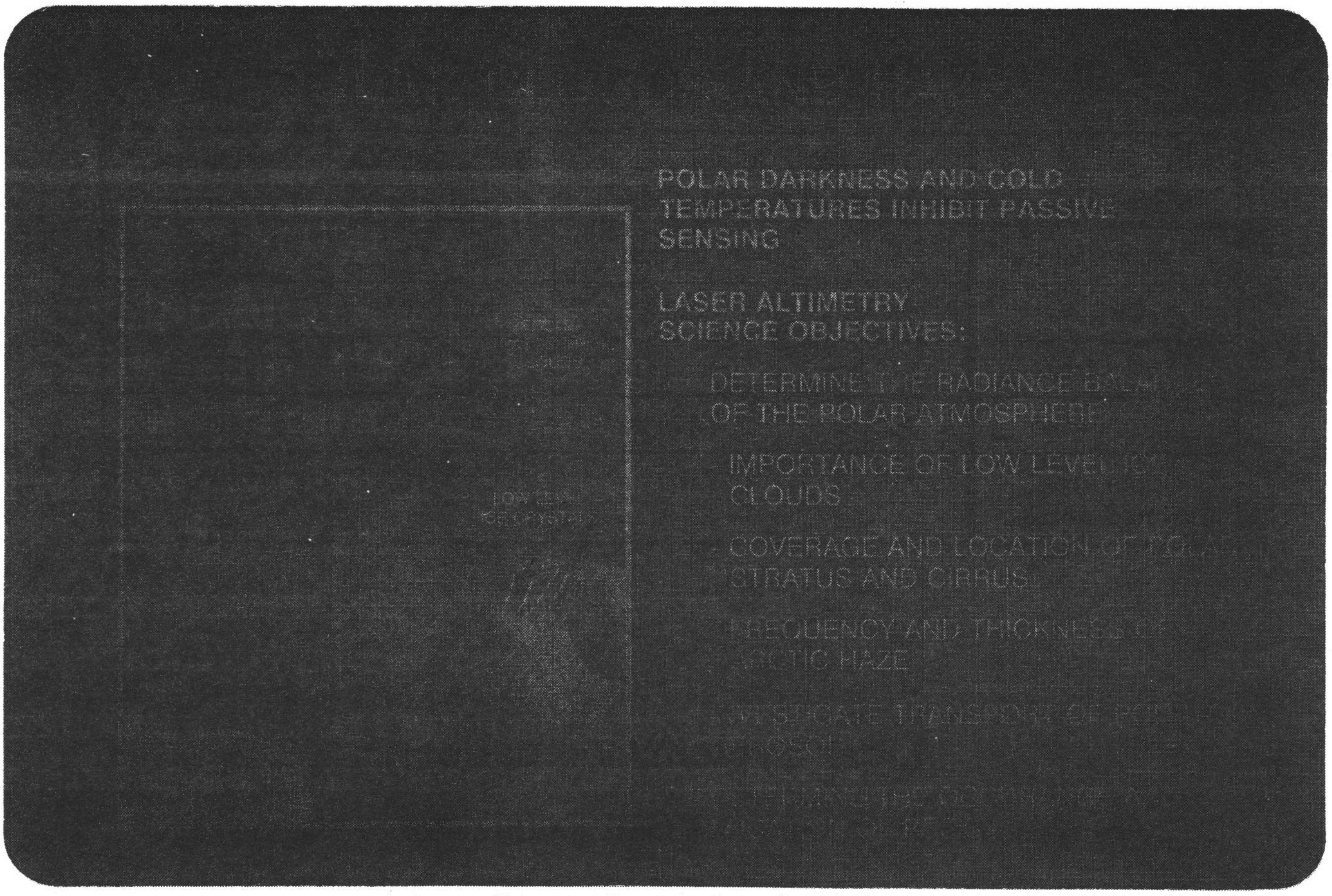
Toga/Coare and CEPEX

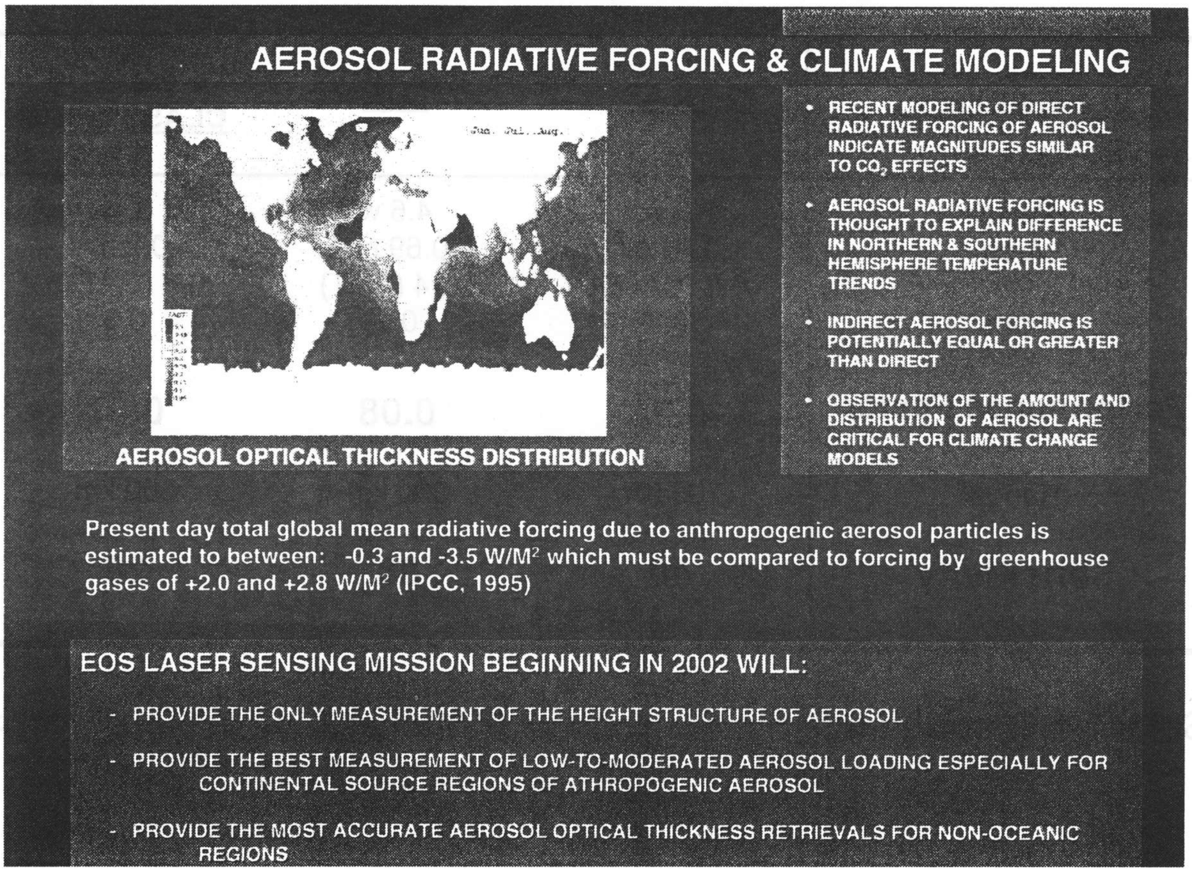
- **Thin and subvisual cirrus were found over most of the tropical SW Pacific warm pool region by ER-2 lidar**








POLAR DARKNESS AND COLD
TEMPERATURES INHIBIT PASSIVE
SENSING
LASER ALTIMETRY
SCIENCE OBJECTIVES:
OF THE POLAR ATMOSPHERE
CLOUDS
STRATUS AND CIRRUS
FREQUENCY AND THICKNESS OF


AEROSOL RADIATIVE FORCING & CLIMATE MODELING
Jun. Jul. Aug.
AEROSOL OPTICAL THICKNESS DISTRIBUTION
• RECENT MODELING OF DIRECT RADIATIVE FORCING OF AEROSOL INDICATE MAGNITUDES SIMILAR TO CO_2 EFFECTS
• AEROSOL RADIATIVE FORCING IS THOUGHT TO EXPLAIN DIFFERENCE IN NORTHERN & SOUTHERN HEMISPHERE TEMPERATURE TRENDS
• INDIRECT AEROSOL FORCING IS POTENTIALLY EQUAL OR GREATER THAN DIRECT
• OBSERVATION OF THE AMOUNT AND DISTRIBUTION OF AEROSOL ARE CRITICAL FOR CLIMATE CHANGE MODELS
Present day total global mean radiative forcing due to anthropogenic aerosol particles is estimated to between: -0.3 and -3.5 W/M^2 which must be compared to forcing by greenhouse gases of +2.0 and +2.8 W/M^2 (IPCC, 1995)
EOS LASER SENSING MISSION BEGINNING IN 2002 WILL:
- PROVIDE THE ONLY MEASUREMENT OF THE HEIGHT STRUCTURE OF AEROSOL
- PROVIDE THE BEST MEASUREMENT OF LOW-TO-MODERATED AEROSOL LOADING ESPECIALLY FOR CONTINENTAL SOURCE REGIONS OF ATHROPOGENIC AEROSOL
- PROVIDE THE MOST ACCURATE AEROSOL OPTICAL THICKNESS RETRIEVALS FOR NON-OCEANIC REGIONS

GLAS Cloud and Aerosol Measurement Requirements

Measurement	Spatial Requirement Small Scale	Requirement Large Scale	Cross Section Range $(m\text{-}sr)^{-1}$	Accuracy Requirement
Dense Clouds		0.2 km	10^{-4} - 10^{-2}	10%
Cirrus	>2 km	<20 km	10^{-6} - 10^{-4}	5%
Thin Cirrus	>10 km	<50 km	10^{-7} - 10^{-5}	10%
PBL Aerosol	>2 km	<100 km	10^{-7} - 10^{-4}	10%
Upper Trop. Elevated Aerosol	>10 km	<100 km	10^{-7} - 10^{-6}	10%

Lidar System Comparison

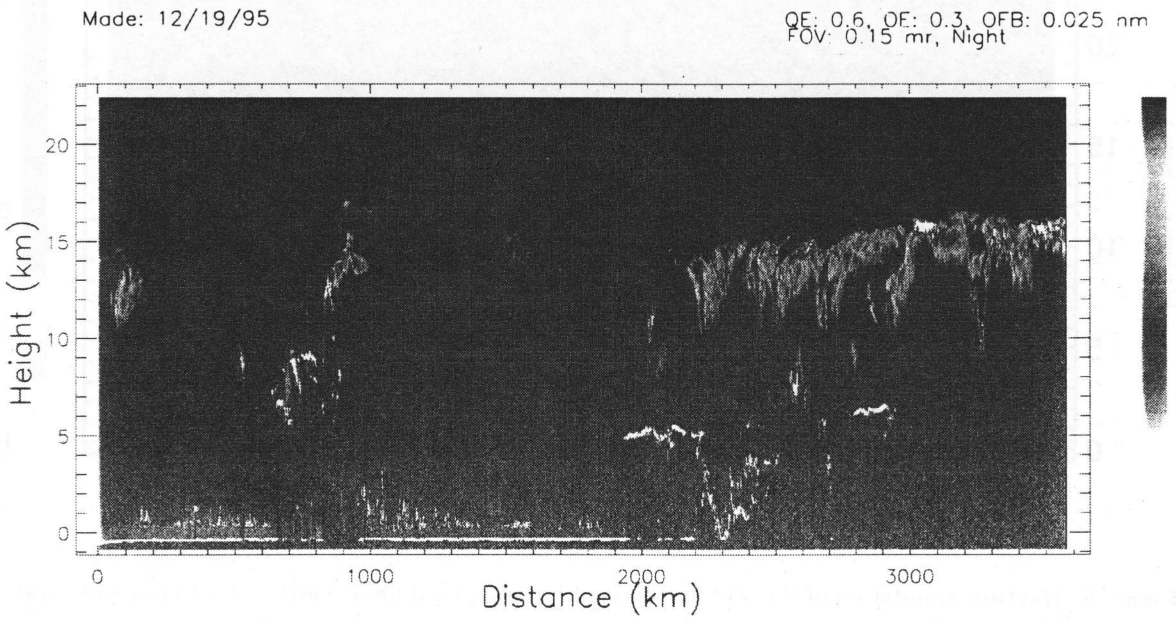
performance Factor = Power x Area reciever x Qe detector x Trans. receiver

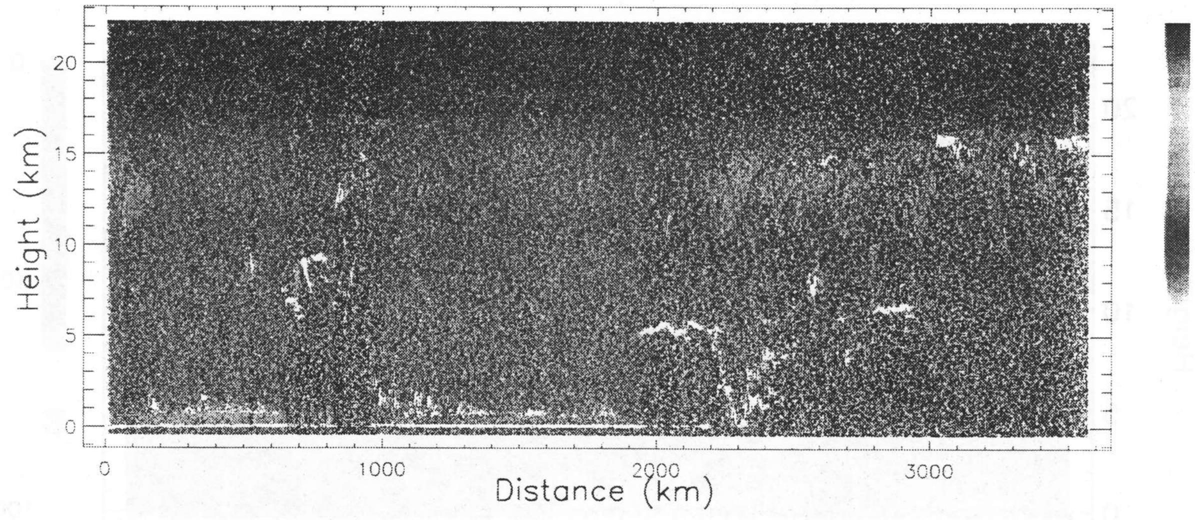
relative Sensitivity = Factor / Range^2

Parameter	GLAS	LITE	PEGASUS CLASS LIDAR
Power	2 w	4.6 w	2 w
Area	0.64 m^2	0.69 m^2	0.2 m^2
Qe	0.6 (GAPD)	0.14 (PMT)	0.6 (GAPD)
Trans.	0.3	0.2	0.3
Performance Factor	**0.23**	**0.08**	**0.07**
Range	705 Km	300 km	500 km
Sensitivity	**46**	**88**	**28**

Solar Background Influence: optical BW x solid angle x laser PRF

GLAS => 0.12 LITE => 3.0





Laser Energy: 0.050 J
Telescope Diameter: 0.80 m
Optical Efficiency: 0.30
Optical Filter Bandwidth: 0.0250 nm
Detector Quantum Efficiency: 0.20
Receiver Full Angle: 0.000200
Background Model: MAS Radiances

Made on: 6/20/95

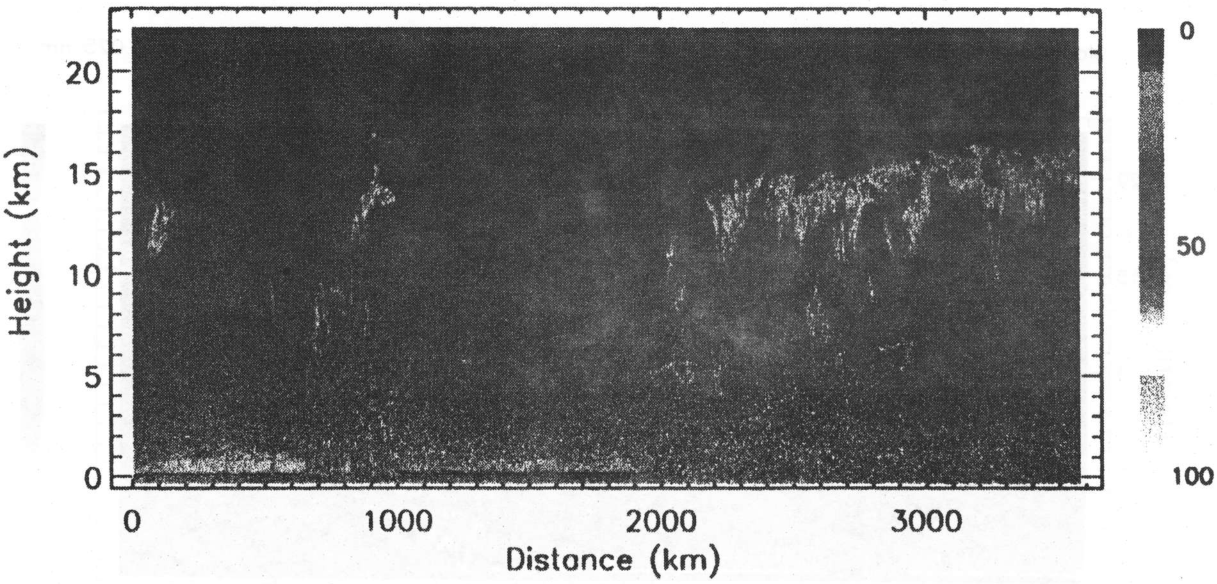


Figure 5: Daytime simulation of the 532 nm channel for an optical filter width of 0.010 nm and total optical effeciency of 0.37.

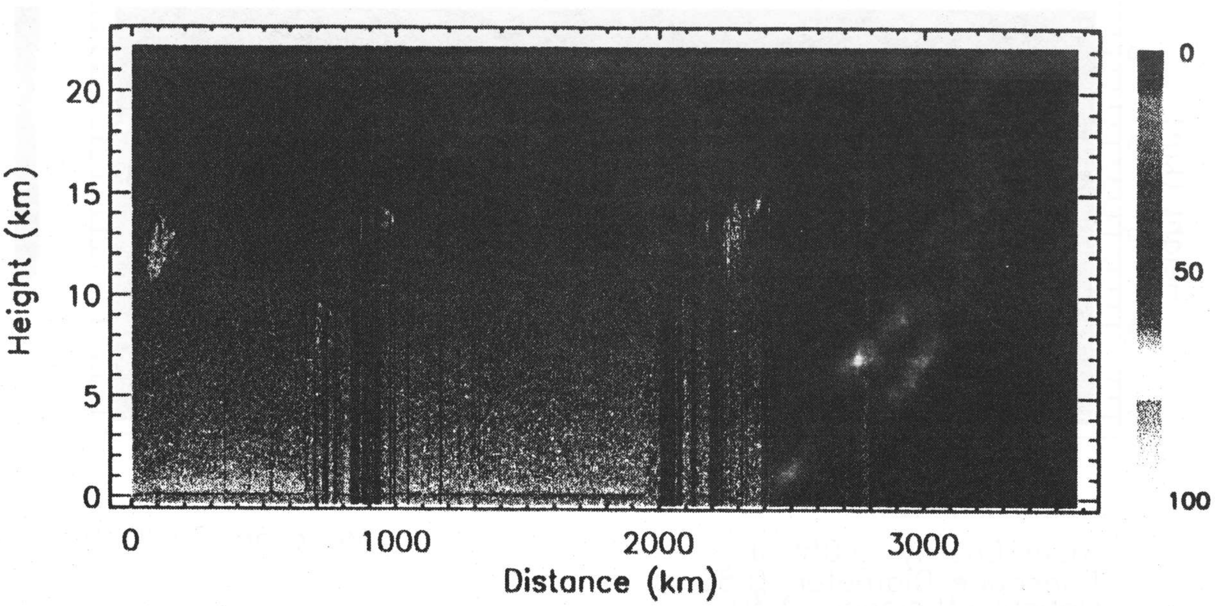
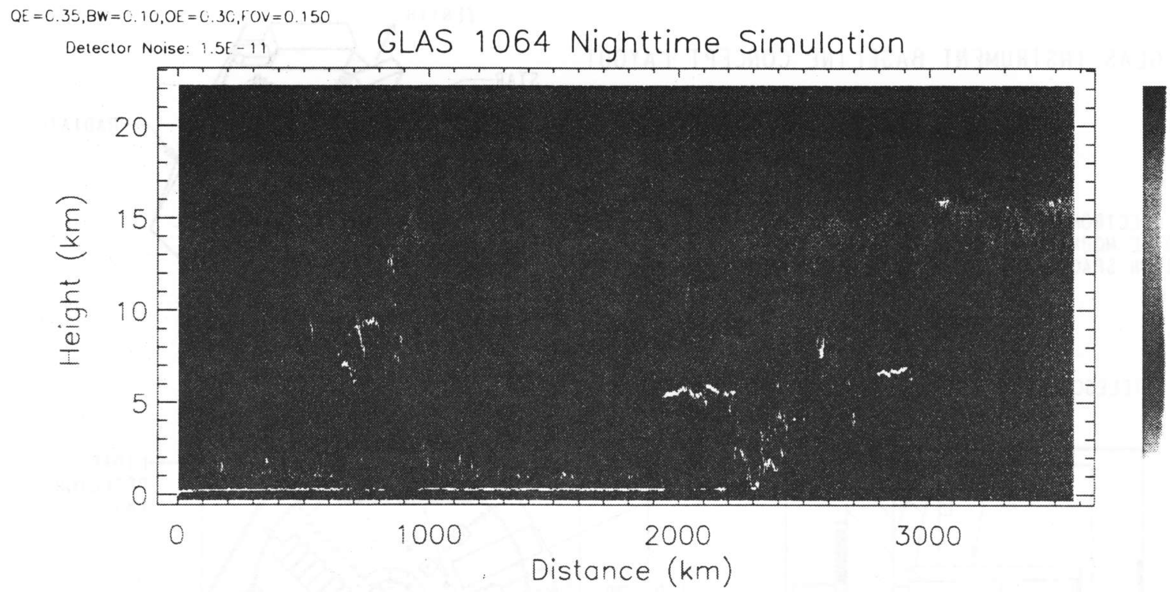
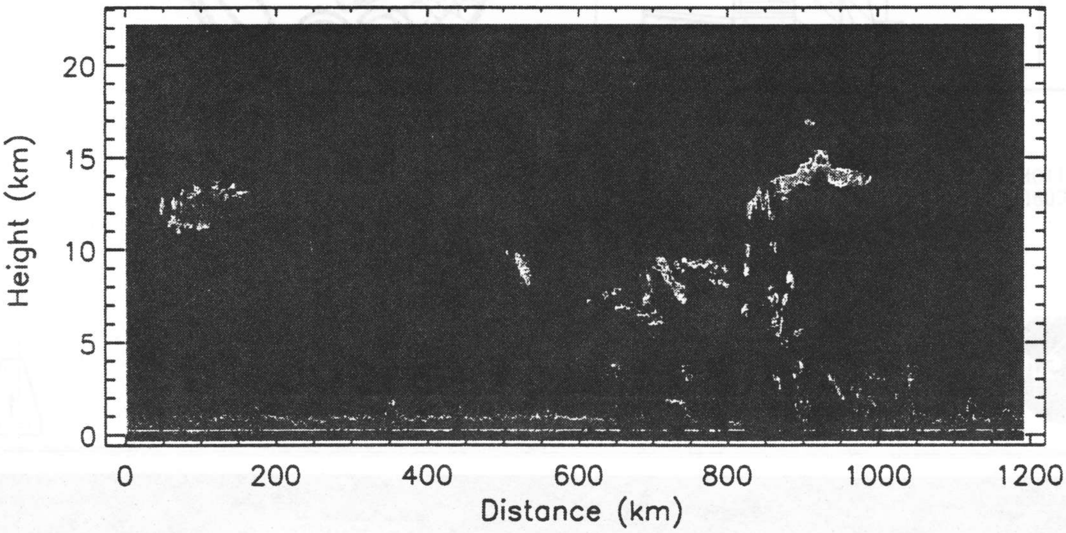
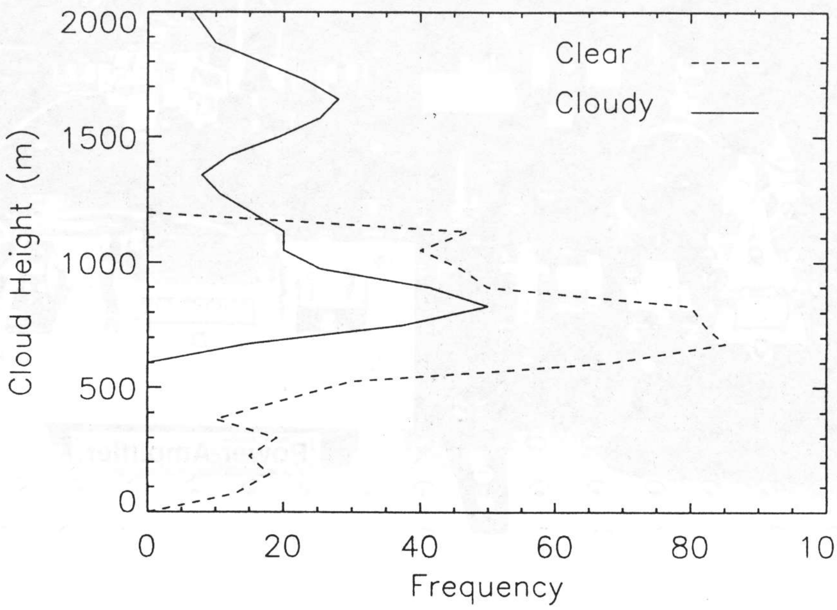


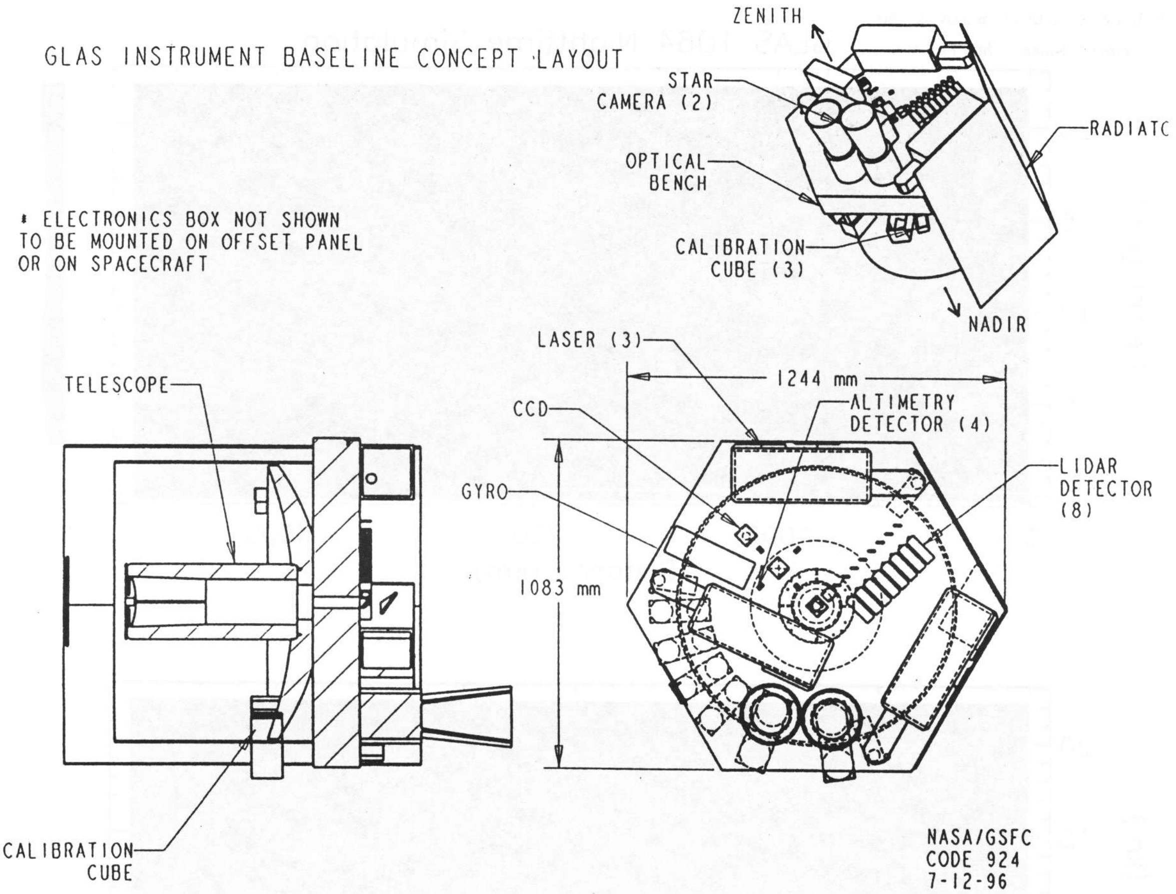
Figure 6: As for Figure 5, except for an optical filter width of 0.025 nm and total optical effeciency of 0.45.


QE=0.35,BW=0.10,OE=0.30,FOV=0.150
Detector Noise: 1.5E-11
GLAS 1064 Nighttime Simulation
Height (km)
0
5
10
15
20
0
1000
2000
3000
Distance (km)


Height (km)
0
5
10
15
20
0
200
400
600
800
1000
1200
Distance (km)


Clear
Cloudy
Cloud Height (m)
0
500
1000
1500
2000
0
20
40
60
80
100
Frequency

GLAS INSTRUMENT BASELINE CONCEPT LAYOUT



GLAS Laser Breadboard