A Geosynchronous LIDAR Observatory For Atmospheric Winds And Moisture Measurements

G. D. Emmitt

Simpson Weather Associates

G. D. Spiers

CalTech/JPL

Goal for GLO

Revolutionize our ability to monitor and predict severe atmospheric events on a routine basis

- –tropical cyclone tracks and intensity
- –tornado, hail and flooding
- –high winds including jet stream location/strength
- –severe event precursors (moisture convergence, tropospheric/stratospheric interactions,shear...)

Current and near term space-based observations of T,q & v

- Temperature:
  - –TOVS, AIRS, CrIS, ATMS in LEO
  - –GOES and GIFTS in GEO
- Moisture:
  - –AMSU, CrIS(NPOESS)
  - –GOES and GIFTS
- Winds:
  - –cloud and water vapor motion vectors
  - –ER-2, QuickScat, CMIS(NPOESS),ASCAT

GLO design target definition

- Parameters:
  - Tropospheric and stratospheric winds
  - Tropospheric moisture
- Space scales and accuracy:
  - < 20 km resolution
  - RMSE < 1 m/s
- Temporal resolution:
  - < 1 hour

GLO technology demands

- Lidars beyond current state-of-the-art
  - very large optics (order 100 meters)
  - large laser transmitters
- Pointing knowledge and control requirements are stringent
- On-board processing to process lidar signals and adaptively target observations
- Downlink bandwidths adequate to deliver data products in real-time to many users
- Rapid cycling of data through model assimilation routines at high spatial resolution (HPCs)
- Rapid dissemination of information (e.g. analyses and predictions)

Lidar technology candidates

- Winds:
  - Doppler Wind Lidars (DWL)
- Water Vapor:
  - DIfferential Absorption Lidars (DIAL)

GEO vs. LEO

•Permits observations with temporal resolution appropriate for ageostrophic phenomena

•Eliminates need to account for satellite motion and earth's rotation

•Allows off nadir DIAL observations

•Very large range to target

•Only one perspective for DWL observations

•Provides global coverage from one platform

•Distance to target is minimized

•Offers opportunity for bi-perspectives with the DWL

•Temporal resolution limited to 12 or 24 hours (maybe never) for most targets when using one platform

Airborne and LEO Experience

- **DWL**
  - Airborne
    - MACAWS, WINDS, DoD
  - Space (none)
    - LAWS,SPARCLE,Zephyr,ADM (attempts)

- **DIAL (water vapor)**
  - Airborne
    - LASE
  - Space (none)

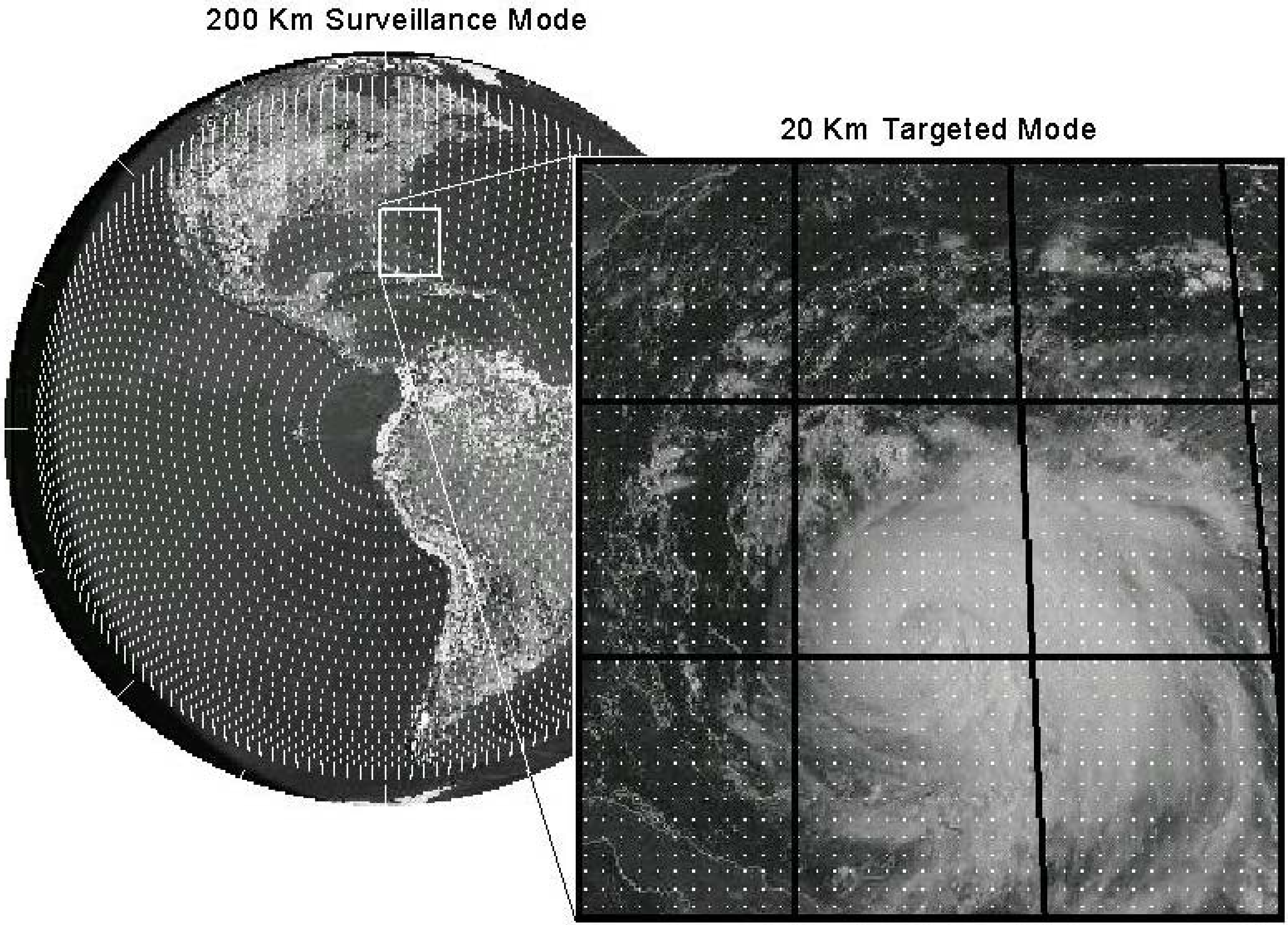
Notional concept study

- Focuses upon data products and their utility
- Assumes large receiver optics
  - 100 meter diameter
- Initially DWL is based on direct detection
- Bases water vapor DIAL on scaled LASE
- Assumes both surveillance and target modes of operation

Points of reference

- ~1.5x108 km2 = area of Earth's surface viewable (full disc) between nadir angles of 3 (70) and 8.5 (12) degrees (angles in () are LOS relative to horizon)
- ~3860 cells (200 x 200 km)
- Range to target is between 36,000 and 41,000 km
- 100 μrad pointing error can lead to > 4 km position errors

Geo Lidar Observatory for Winds and Water Vapor



Reference data product (Surveillance Modes)

- Full disc
  - Spatial resolution (clouds permitting)
    - data point spacing: 200 km (~3860 points)
  - Temporal resolution
    - ~ 5 second dwell with 6 hour revisit
- Regional (7500 x 7500 km)
  - Spatial resolution (clouds permitting)
    - data point spacing: 200 km (~1400 points)
  - Temporal resolution
    - ~ 5 second dwell with 2 hour revisit

Reference data product (Target Mode)

- The target is assumed to have meso- space and time scales
- Target region
  - 500 km x 500 km
- Spatial resolution (clouds permitting)
  - data point spacing: 20 km (625 points)
- Temporal resolution
  - 5 second dwell with 1 hour revisit

DWL system description

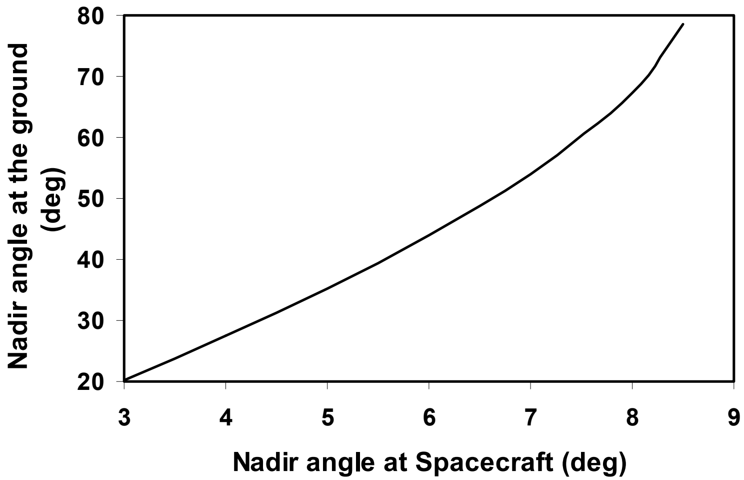
- Telescope: 100 meter
- Laser transmitter
  - 355 nm
  - 1.5 joule at 355 (~ 4 J at 1060)
  - 100 hz
- Integration time: 5 seconds (720 obs/hour)
- Unit data product: LOSP wind speed with 1 km vertical resolution and <1 m/s RMSE

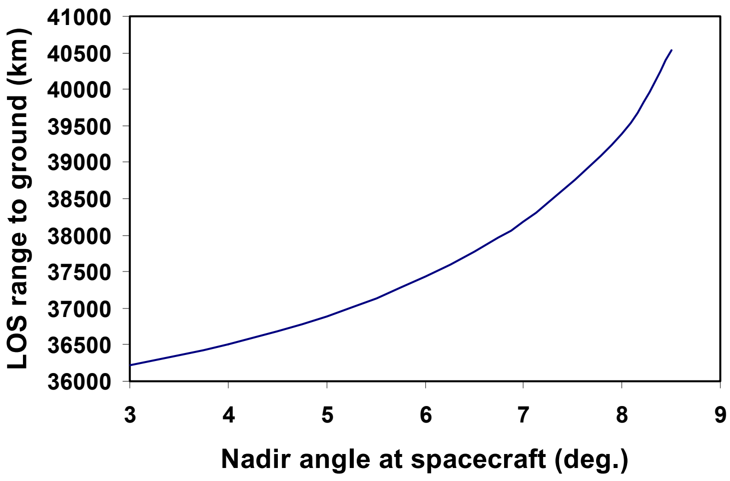
DIAL system description

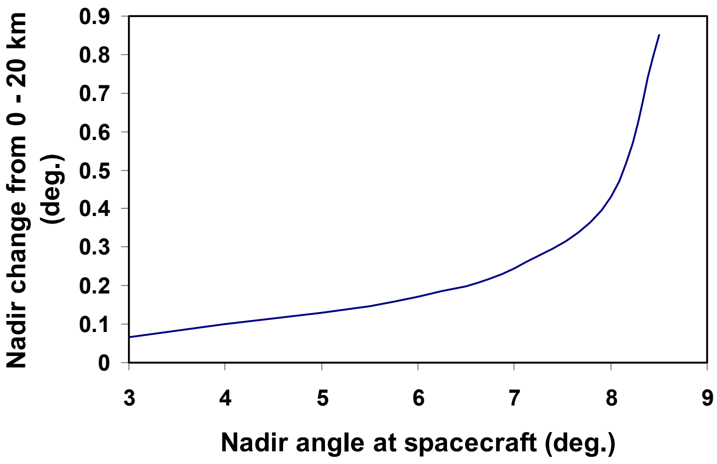
- Telescope: 100 meters
- Laser transmitter
  - 813 - 818 nm (Ti:sapphire)
  - 1 Joule
  - 30 Hz
- Integration time: 5 seconds
- Unit data product: specific humidity with 1 km vertical resolution and <10% RMSE

Nadir angle issues

As we vary the nadir angle at the spacecraft to provide coverage the nadir angle at the ground and the slant path through the atmosphere both increase. Not only does the nadir angle at the surface change but the variation in nadir angle through the atmosphere also changes with increasing slant range.



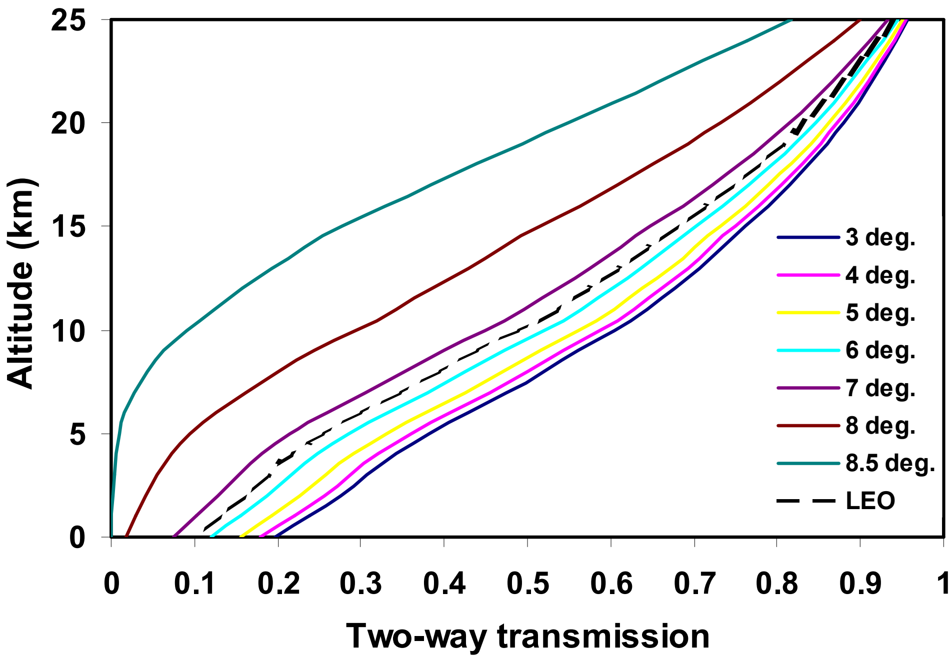




GeoLidarObservatory

Atmospheric Attenuation

Varying the nadir angle leads to a nadir angle dependent atmospheric extinction. The two way atmospheric extinction shown here is compared to that for an instrument in a 400 km orbit altitude with a 45 degree nadir angle. The initially shallow nadir angle of the geostationary system leads to an improvement in atmospheric transmission over a LEO system, however the atmospheric loss increases rapidly for nadir angles above 6-7 deg due to the increased slant path through the atmosphere.

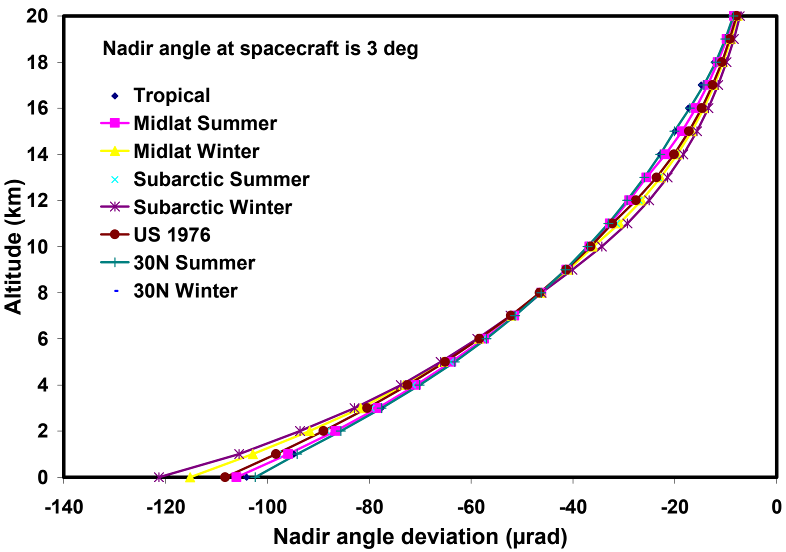


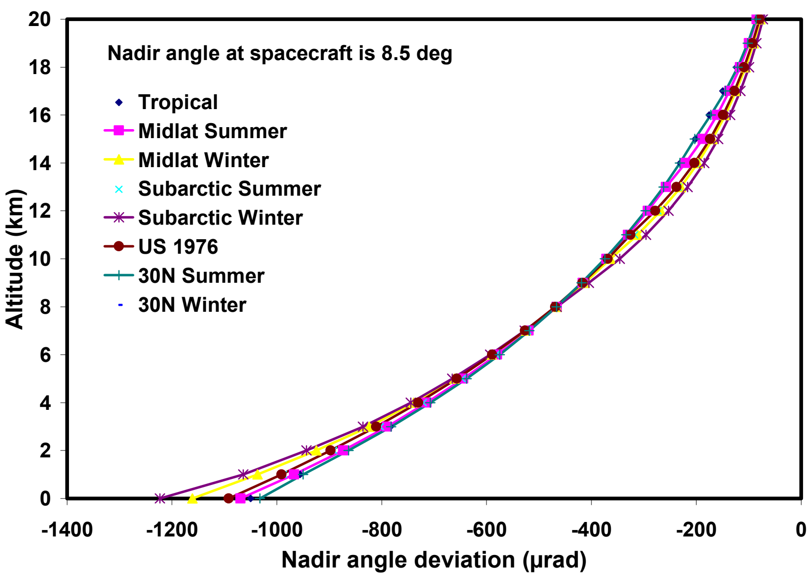
The sample plot is for a 355 nm wavelength using the NMP* reference atmospheres.

•Emmitt, Spinhirne, Menzies, Winker & Bowdle, "Target atmospheres for use in DWL Concept studies", http://www.swa.com/ALD/LidarProducts/targetAtm/

Atmospheric Refraction

As the nadir angle is varied the path through the atmosphere also varies and the amount of bending due to atmospheric refraction will also vary.Atmospheric refraction also depends on the local pressure and temperature profile. This combination of variation with nadir angle and local condition leads to considerable variability in the amount of refractive bending likely to be experienced.





The uncertainty in the nadir angle results in an uncertainty in the knowledge of the position of the measurement.

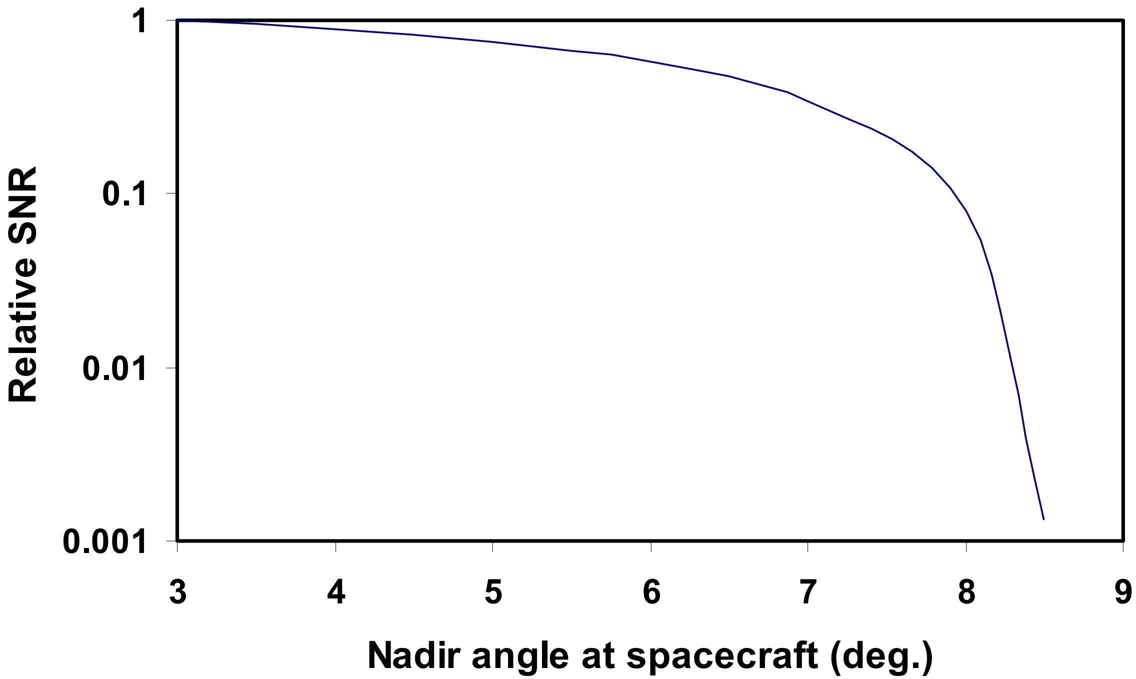
GeoLidarObservatory

Signal to Noise Ratio

The signal to noise ratio (SNR) is a function of both the atmospheric extinction and the range to the target both of which vary with nadir angle.

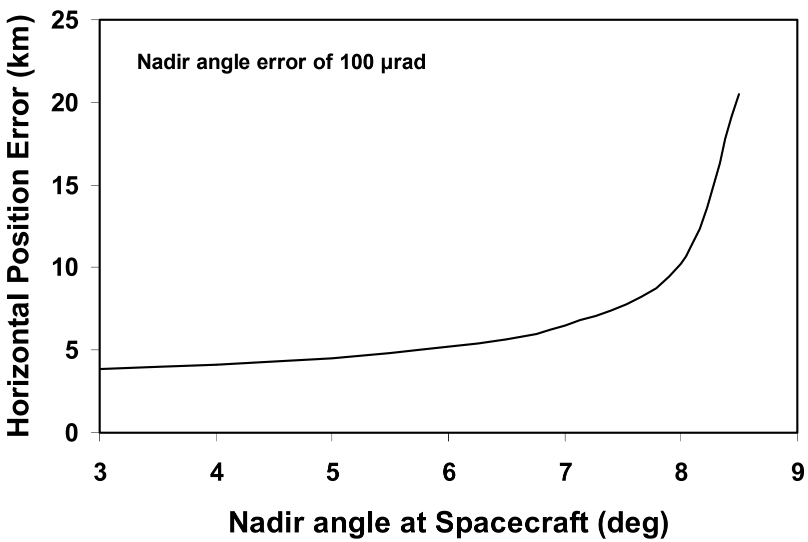
We can combine these terms to show the SNR dependence on nadir angle.

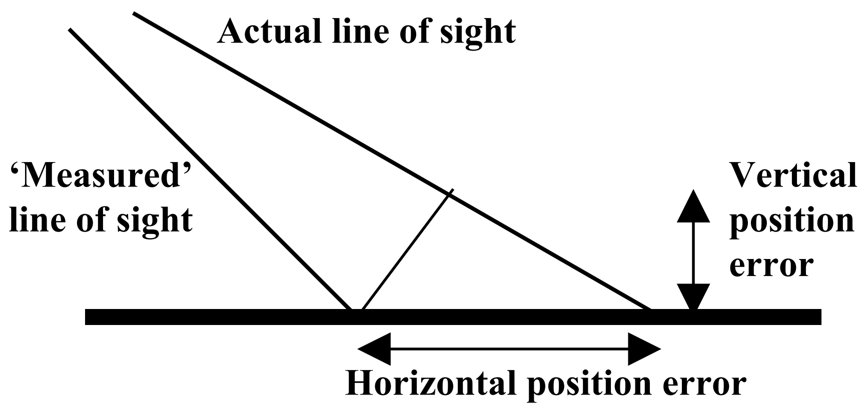
The example shown is for a 355 nm system.



Position Knowledge

Errors in the pointing angle knowledge result in an incorrect position assignment. If we wish to place the measurement to within 500m in the vertical we will require ~ 5 - 12 µrad pointing knowledge but atmospheric refraction (see previously) may prevent this level of position knowledge from being achieved even with perfect attitude knowledge systems.



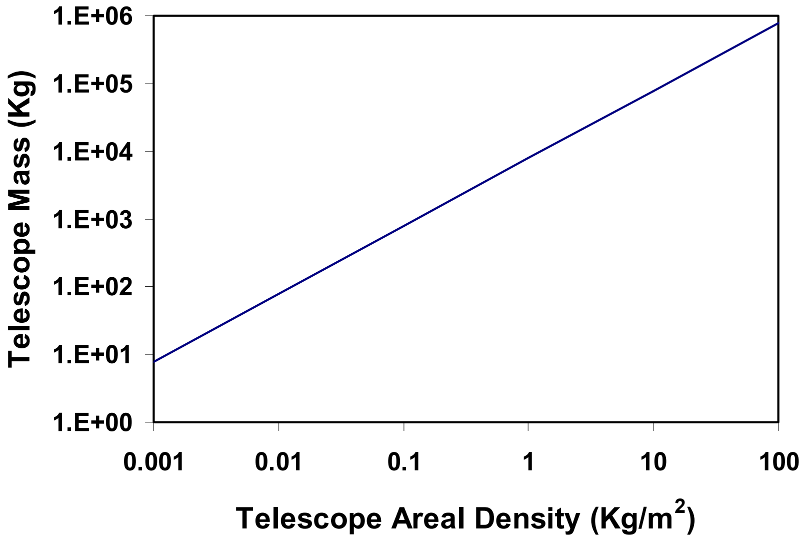


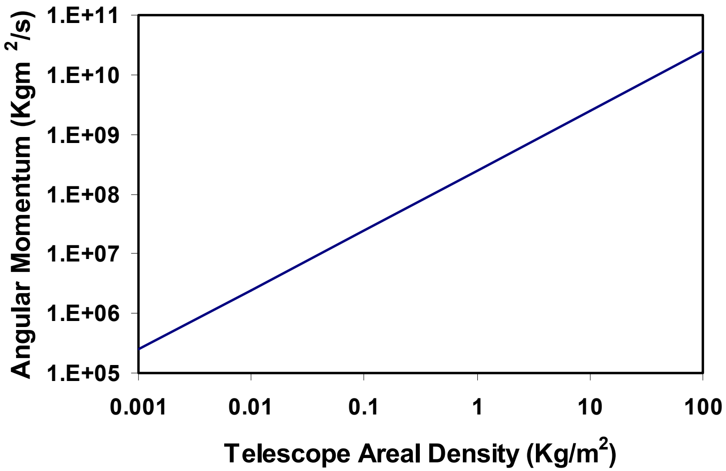
GeoLidarObservatory

Pointing a 100 m Optic

Conventional lidar design concepts have relied on a scanner or rotating telescope. A ~100m diameter telescope of any design will have considerable mass and moment of inertia.

Current space telescope development is for the realization of practical < 10 Kg/m^2 areal densities. To obtain a ‘reasonable’ mass for the geolidar telescope will require significant improvement on this. For the scan patterns discussed for the geostationary lidar, we are looking at scan rates up to ~800 µrad/sec. This is much smaller than the scan rate of a typical LEO lidar design (~0.3 rad/sec).



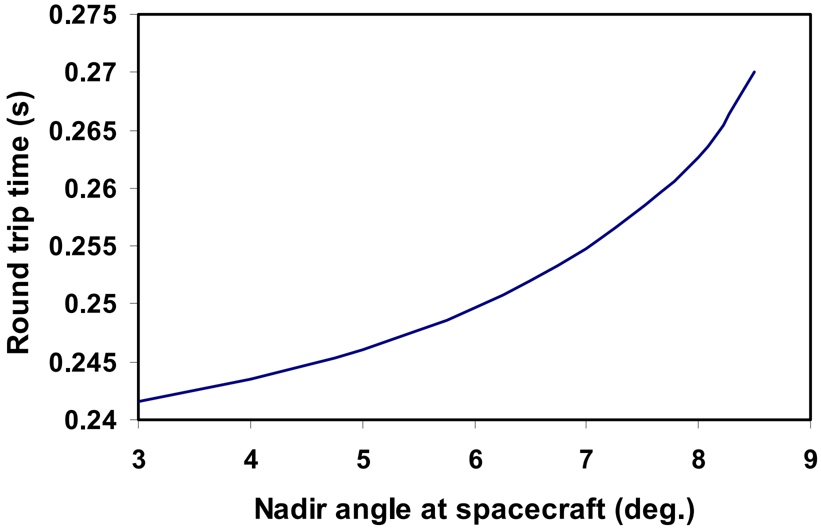


The large size of the telescope still leads to a large angular momentum making scanning of the entire telescope in the step/stare pattern required a difficult proposition. Alternate scan techniques would probably be required. (e.g. moving secondary c.f. Arecibo radio telescope & other more advanced concepts).

Pointing Stability

There are two pointing stability requirements.

The first is that during the round trip time of flight of ~0.25 seconds the alignment between the transmit and receive optical apertures must be maintained to prevent degradation in SNR. For a nominal target size of ~<20 km this requires maintaining alignment to better than 40 μrad over 0.25 seconds.



The second requirement is that during the 5s data collection time the position error for the measurement volume does not exceed the desired accuracy. For the nominal 500m height assignment discussed previously this leads to a 1 – 2 μrad/s rate requirement for the targeted mode.

GeoLidarObservatory

Pointing Knowledge and Control

Spacecraft	Pointing Control (deg)	Pointing Control (µrad)	Pointing Knowledge (deg)	Pointing Knowledge (µrad)	Rate Error (deg/sec)	Rate Error (µrad/sec)
Clementine	0.05	873	0.03	524		
Discovery/NEAR	0.1	1745	0.003	52		
Discovery/Mars Pathfinder	1	17453	N/a			
Explorer/SMEX-SWAS	0.0008	14	-			
Explorer/SMEX-TRACE	0.006	105	-			
Explorer/MIDEX-MAP	0.03	524	-			
New Millennium/Deep Space 1	0.2	3491	N/a			
New Millennium/Earth Observer 1	0.009	157	N/a			
SSTI/Lewis	-		0.004	70		
SSTI/Clark	2	34907	0.02	349		
Surveyor/ Mars Global Surveyor	0.57	9948	0.18	3142		
Surveyor/ Mars Surveyor '98 Orbiter	1.1	19199	N/a			
RADCAL	10	174533	5	87266		
STS Orbiter[2]	0.1	1745	0.1	1745	0.2 or larger	3491 or larger
NPOESS (0- 10 Hz) RMS/axis	0.01	175	0.002778	48	0.03	524
NPOESS (>10 Hz) RMS/axis			0.001389	24		

This chart shows the pointing control and knowledge capabilities of various spacecraft.

Sources:

"The Cosmos on a Shoestring: Small Spacecraft for Space and Earth Science", Liam Sarsfield, Critical Technologies Institute, RAND (1998).

"Hitchhiker Accommodations and Requirements Specifications (CARS)", HHG-730-1503-07, NASA GSFC, (December 1996).

"Interface Requirements Document (IRD) for NPOESS Spacecraft and Sensors", NPOESS Integrated Program Office, Version 3, (May 1999).

Further evaluation

- Beam directing techniques
- Bi-perspective views
- Cloud avoidance strategies
- Observing System Simulation Experiments