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A Geosynchronous Lidar System for Atmospheric Winds and Moisture Measurements

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Abstract

An observing system comprised of two lidars in geosynchronous orbit would enable the synoptic and meso-scale measurement of atmospheric winds and moisture, both of which are key first-order variables of the Earth's weather equation. Simultaneous measurement of these parameters at fast revisit rates promises large advancements in our weather prediction skills. Such capabilities would be unprecedented and a) yield greatly improved and finer resolution initial conditions for models, b) make existing costly and cumbersome measurement approaches obsolete, and c) obviate the use of numerical techniques needed to correct data obtained using present observing systems. Additionally, simultaneous synoptic wind and moisture observations would lead to improvements in model parameterizations, and in our knowledge of small-scale weather processes. Technology and science data product assessments are ongoing. Results will be presented during the conference.

OBJECTIVE

To provide accurate global observations of the earth's wind and moisture fields with sufficient spatial and temporal resolution to enable significantly improved weather/climate predictions.

RATIONALE

NASA envisions a future where we can expect, on a routine basis:

- 10 year climate forecasts
- 15-20 month El Nino / La Nina predictions
- 12 month regional rainfall rate predictions
- 5 day hurricane track predictions to +/- 30 Km
- 2 day air quality notifications, and
- 30 minute tornado warnings.

In the coming decades, these data products and fundamental improvements in weather and climate measurements will be provided by an array of new sensor platforms and technologies that will include an observational web of satellite, aircraft and surface observations of the Earth surface, the atmosphere, and the ocean. New sensor technologies will assess global winds, temperatures, rainfall, pollution, chemical composition and more, all on high resolution time and space scales. The combination of global measurements, plus high spatial and temporal resolution, will

enable monitoring of quickly changing storm systems such as tornadoes and hurricanes. In addition, large changes in weather patterns that will have large energy consumption or transportation effects or serious air pollution events will also be monitored. The measurements from this sensor web will feed data assimilation engines that account for both the physics of earth science and the technology of the measurements. These assimilation approaches will enable a new generation of weather and climate models to produce forecasts for highly specific uses such as agricultural applications, transportation, traffic management, or air pollution monitoring and response, power generation, etc.

This vision can only be realized if we have multiple data sources including geostationary and low earth orbit satellites, in situ, sub-orbital systems, and micro-nets. This paper deals with one set of advanced observations from geosynchronous orbit that we believe will revolutionize weather forecasting, particularly on the short term (<48 hours).

NOTIONAL INSTRUMENT CONCEPT

The notional concept for observing winds and moisture from geosynchronous orbit involves a Doppler Wind Lidar (DWL) and a Differential Absorption Lidar (DIAL). We refer to this set of lidars as the GeoLidarObservatory (GLO). The DWL would use direct detection and could require staring at fixed locations for periods of up to several seconds. The DIAL would also require long integration periods (several seconds) to make a water vapor sounding. Both instruments would be pointed at the same target areas so that correlated wind and water vapor measurements could be made. A highly desirable capability would be the ability to steer the lidar beams in such a fashion as to enable targeted observations. Such a system would also provide basic aerosol measurement capabilities that could have an impact on Earth radiation budget measurements.

Preliminary feasibility studies suggest that GLO would require transmit optics of a few meters in diameter, a hundred meter diameter receiving telescope, fineness of both optical systems scaled to the wavelength, and scanning for the transmit system. Potential technology issues include optical quality of large transmit and receiving telescope optics, the size of the detector area needed, the transmit scanning system, signal detection (S/N ratio of detector system) for the

extremely weak return signal at Geo-orbit, and power demands in the 1-2 kilowatt range.

EXPECTED DATA PRODUCTS

The DWL would deliver LOS components of the wind based upon the averaging of numerous shots taken over a footprint of a few 100's of meters dimension. The vertical resolution would vary between .25 km in the planetary boundary layer (and near clouds) and 1-2km above. The accuracy would vary between 1 and 3 meters/second over most (50%) of the instrument's field of regard (see Figure 1).

The DIAL would provide soundings of the water vapor profile throughout most of the troposphere. The vertical resolution (~ .5 km) and accuracy (~ 1%) would be unsurpassed by any passive remote sensing system. Aerosol profiles would also be a primary product of the DIAL technique.

TECHNOLOGY ASSESSMENT (IN PROGRESS)

A feasibility study for GLO is underway and is expected to be completed by July 2001. The technology assessment is, in part, a review of the performance of some heritage instruments. For the DWL these include NASA's airborne systems and several ground-based systems operated by NOAA, NASA and the DoD. For the DIAL concept, the primary heritage system is an airborne system flown on the NASA DC-8. The Laser In space Technology Experiment (LITE) also provides technological insight to space-based lidar operations.

Currently, the focus of this technology assessment is on the following issues:

- Lasers for Doppler lidar
- Lasers for water vapor DIAL
- Optics (100 meter)
- Data volumes
- On-board processing

SCIENCE DATA ASSESSMENT (IN PROGRESS)

While the merits of the ability to measure winds and moisture from Geo-orbit are obvious, the technology requirements must be driven by the observation feasibility of requirements. In addition to assessing the technological aspects of GLO, we are also addressing the issues associated with the data product quality and quantity. Much of the data product assessment is being carried out in parallel to Observing System Simulation Experiments (OSSEs) ongoing at both National Centers for Environmental Prediction (NCEP) and the Data Assimilation Office (DAO). While Figure 1 describes the general distribution of data, the other data product issues being examined are:

- Accuracy
 - Must compete with (be better than) current observing systems
- Coverage
 - Spatial coverage must be nearly global
 - Temporal coverage must be adequate for surveillance of mesoscale weather systems such as hurricanes, meso-convective complexes, atmospheric jets, and mountain induced cyclones.
- Role of adaptive targeting
 - Given the need for reasonable dwell times by both the DWL and DIAL instruments, an adaptive targeting strategy will most likely be required. (see Figure 1)
- Cloud effects
 - Cloud avoidance strategies may be needed to optimize the likelihood of full tropospheric soundings

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Geo Lidar Observatory for Winds and Water Vapor

200 Km Surveillance Mode

20 Km Targeted Mode

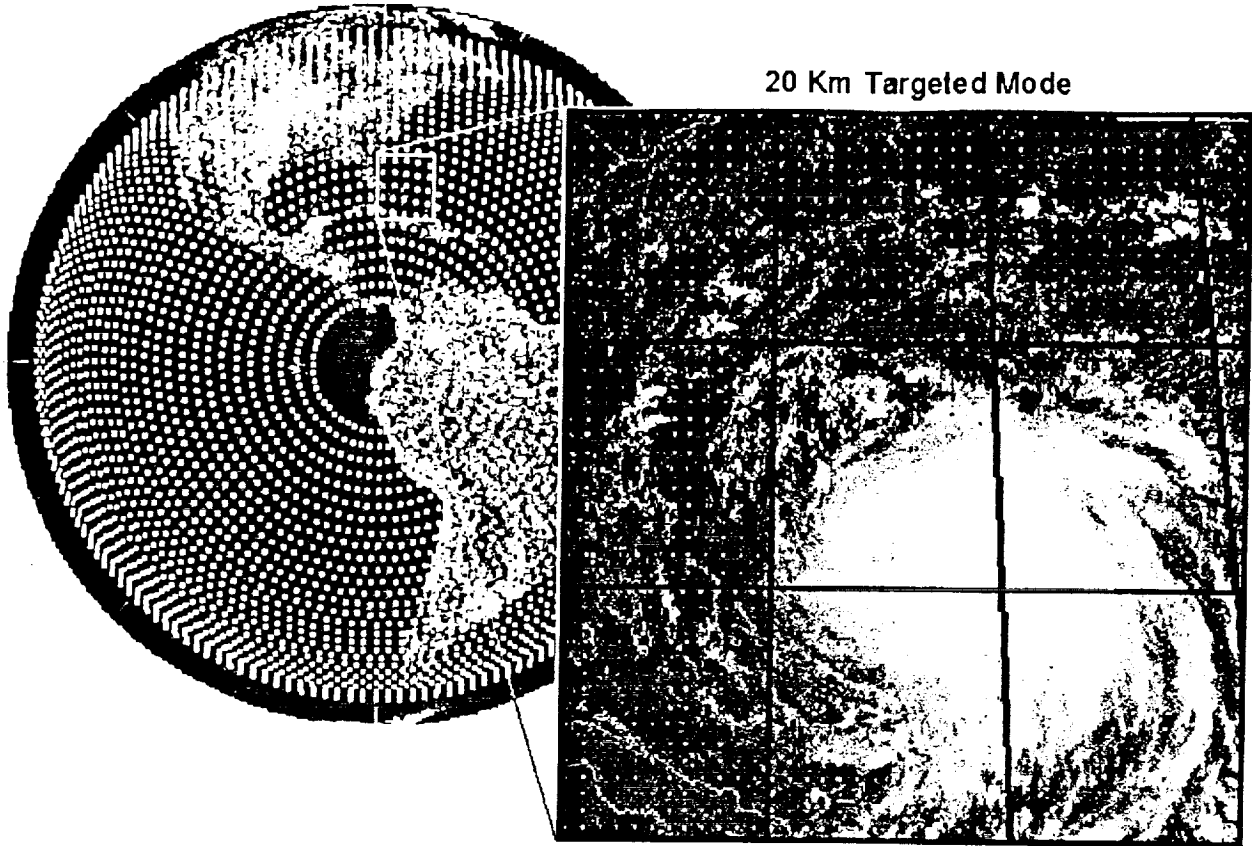


FIGURE 1

In the circular area, the distribution of lidar profiles (cloud-free potential) is shown for the case where the spacing between profiles is ~ 200 km. The data void area in the middle represents the region over which the off-nadir angle for the DWL is not sufficient to resolve the horizontal wind component. This area would not be a data void for the water vapor profiles. There are 3550 potential profile locations ($>20\times$ the number of rawinsondes in this same region). The vertical extent of a profile will be cloud dependent.

In the rectangular area, a target mode of operation is illustrated. In this case the horizontal resolution is ~ 20 km. Operation in this mode would be at the expense of global surveillance on the 200 km scale. However, this pattern (~ 2500 profiles, clouds permitting) could be repeated on the order of once per hour. The exact times required to obtain accurate observations is still being assessed.