NPOESS REVIEW

REMOTE SENSING DIVISION

CLIMATE SUITE STUDY

OZONE/AEROSOL PROFILE SENSORS

Optical Occultation Sensors

Millimeter-Wave Scanning Sensor

December 19, 1996

Presenter: Dr. R. L. Lucke, NRL code 7227

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M. 14

NPOESS Profiling Sensors

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IORD Requirements Include Vertical Profiles of

Ozone, Aerosols, Water Vapor

Temperature, Pressure, Density

Study Objective: Evaluate Optical Occultation Sensors and Scanning Millimeter-Wave Sensor for These Requirements

Study Objectives

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Optical Occultation Sensors

- Solar, Lunar, Stellar
  - Utility to NPOESS: Mostly the Stratosphere
  - Ozone, Aerosols, Water Vapor, Temperature, Pressure
  - Do Not Expect Global Water Vapor Coverage

Improvements to POAM

Scanning Millimeter-Wave Sensor

- Stratospheric Ozone, Water Vapor, Temp., Press.
  - Doesn't Do Aerosols

Requirements Completely or Partially Addressed by Ozone Sensors
(More numbers in parentheses indicates greater deficiency)

Sensor Type:	SBUV	Microwave & IR	Solar Occultation	Stellar Occultation
Parameter				
Key				
4.1.6.1.1 Vertical moisture profile*		P(1,2)	P(1,2,3)	
4.1.6.1.2 Vertical temperature profile		P(1,2)	P(1,2,3)	P(1,2)
Other				
4.1.6.2.1.1 Aerosol partical size			P(1,2,3)	P(1,2)
4.1.6.2.1.2 Aerosol optical thickness			P(1,2,3)	P(1,2)
4.1.6.2.28 Ozone column	C	S(1)	S(1,3)	S(1)
4.1.6.2.28 Ozone profile	P(4)	S(1)	S(1,3)	S(1)
4.1.6.2.31 Pressure profile		P(1,2)	P(1,2,3)	P(1,2)
4.1.6.2.41 Total water content*		P(1,2)	P(1,2,3)	

* Usually, but not always, measured by ozone profile sensors

C = Complete satisfaction of requirement
S = Significant satisfaction of requirement
P = Partial satisfaction of requirement

1 = Measures upper troposphere and above only
2 = Inadequate horizontal resolution
3 = Inadequate refresh time
4 = Inadequate vertical resolution

Viewing Geometry

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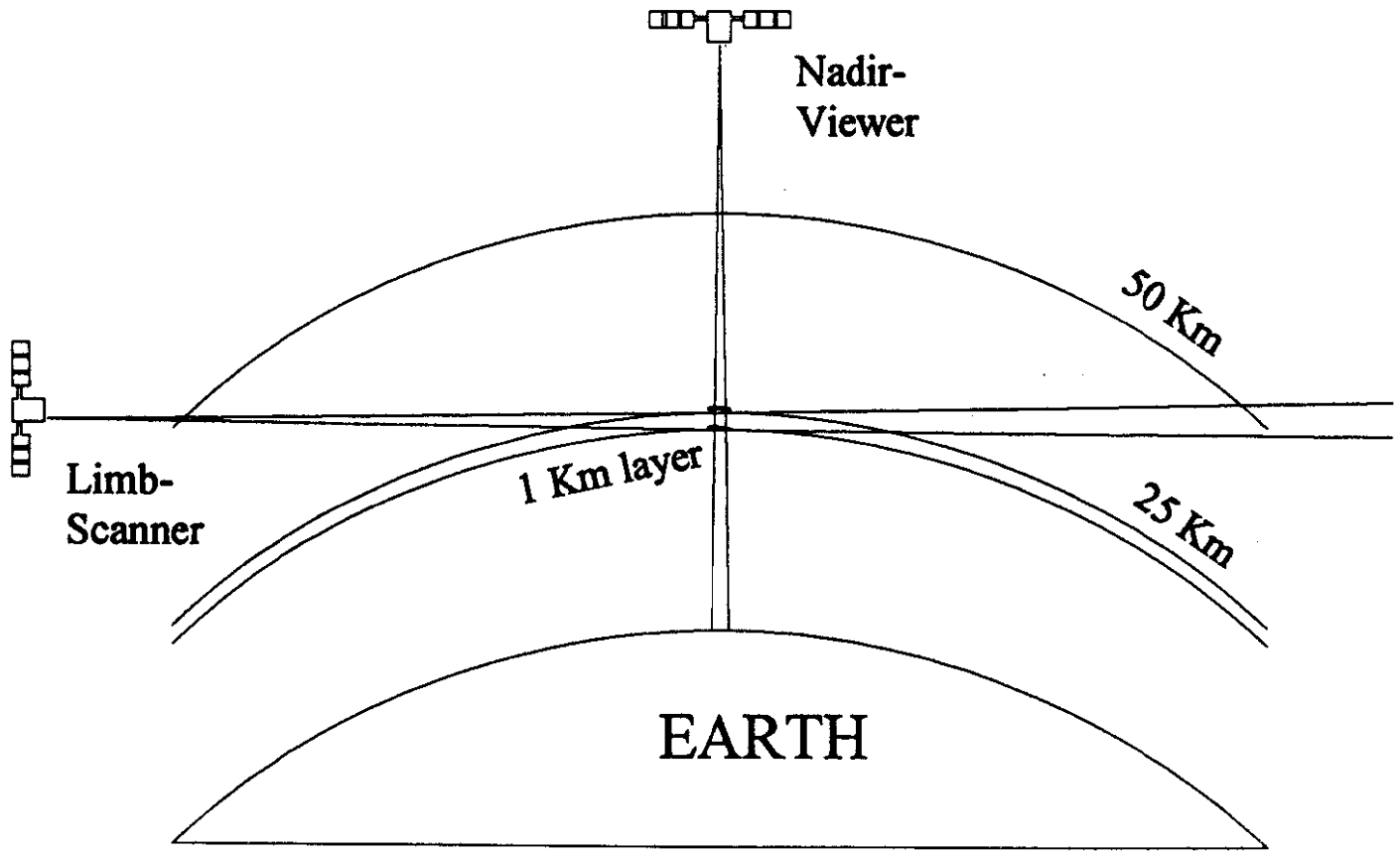

Optical Occultation Sensors

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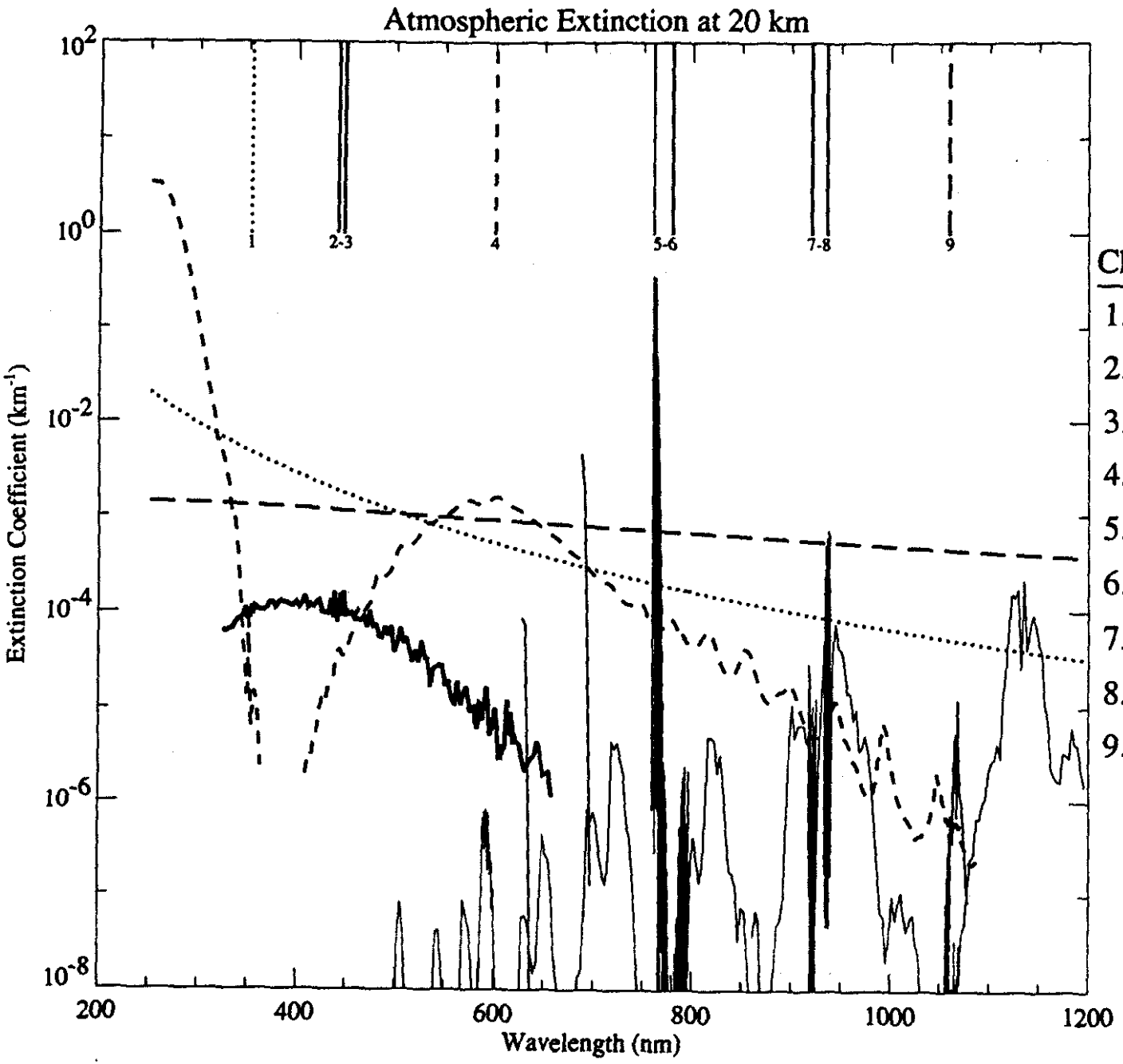
- Spectral Signatures of Absorption/Scattering
  - Ozone, Aerosols, Minor Constituents (Water Vapor)
  - Temperature, Pressure from O_2 and/or Rayleigh Scattering
- High Vertical Resolution & Accuracy
- No Long-Term Calibration Problem
- Low Altitudes are Hard to Reach
  - Need Long Cloud-Free Line of Sight
  - Atmospheric Attenuation over Long Path



Channel	Purpose
1. 353.0	Rayleigh
2. 442.0	NO_2 off
3. 448.3	NO_2 on
4. 600.0	O_3
5. 760.8	O_2 on
6. 780.0	O_2 off
7. 920.0	H_2O off
8. 935.5	H_2O on
9. 1059.0	aerosol

Occultation Sensors

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- Solar Occultations
  - Proven On Orbit: POAM and SAGE (for Stratospheric measurements only).
  - Very High Resolution (1 km)
  - Low Altitudes (5 km or below) Achievable if No Clouds
    - SAGE: Sees Below 6 km 50% of Time; to Surface, 10%
  - Poor Global Coverage
    - Only Two Observation Points per Orbit
    - In Polar Orbit, Measure Only Polar Regions
- Lunar Occultations
  - Adds Some Coverage
  - Non-Uniformity of Source Causes Trouble (Especially for Aerosol Measurements)

Profile Sensors

REMOTE SENSING DIVISION

- Solar, Lunar Occultation Sensors Meet NPOESS Requirements for Profile Accuracy, but not for Global Coverage
  - Also Gives Calibration Check for Column Density Sensors
  - Adding Satellites in Lower-Inclination Orbits Would Help
- Stellar Occultation Sensor (StOS) for NPOESS?
  - Cover Globe, Maintain Good Vertical Resolution (2-3 km)
  - GOMOS (Global Ozone Monitoring by Occultation of Stars)
    - European Experiment, Research Instrument, Weighs 300 lb
- Preliminary Design for Small Version (25 lb)
  - Operational: Ozone, Aerosols, Perhaps Temp., Press.

→ PDR @ GOMAS-lite done by NRL.

Occultation of Stars

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- Many Stars in the Sky: Good Global Coverage
- Very Weak Sources (1 - 100 Trillionths of Sun)
  - Vertical Resolution Degraded (2-3 km)
  - Low Altitudes Difficult
- Requires Photon-Limited Detection System
  - Need SNR = 100 in 10 nm BW for 3rd Magnitude Star
- Many Spectral Types
  - "Early" Types (O, A, B) Have Bluer Spectrum Than Sun
  - "Late" Types (K, M) Have Redder Spectrum
  - Affects Sensitivity to Different Species/Properties
  - Algorithm Must Recognize and Adapt

Stellar Occultation Sensor

REMOTE SENSING DIVISION

- Observe Starsets from Satellite
  - Control Line of Sight with External Steering Mirror
    - ± 25° LOS Motion (± 12.5° Mirror Motion)
  - Acquire Star 2 - 3 degrees above Horizon
  - Track Descent Through Atmosphere
  - Nighttime Measurements Only (No Sunlit Atmosphere)

1/3 ORBIT

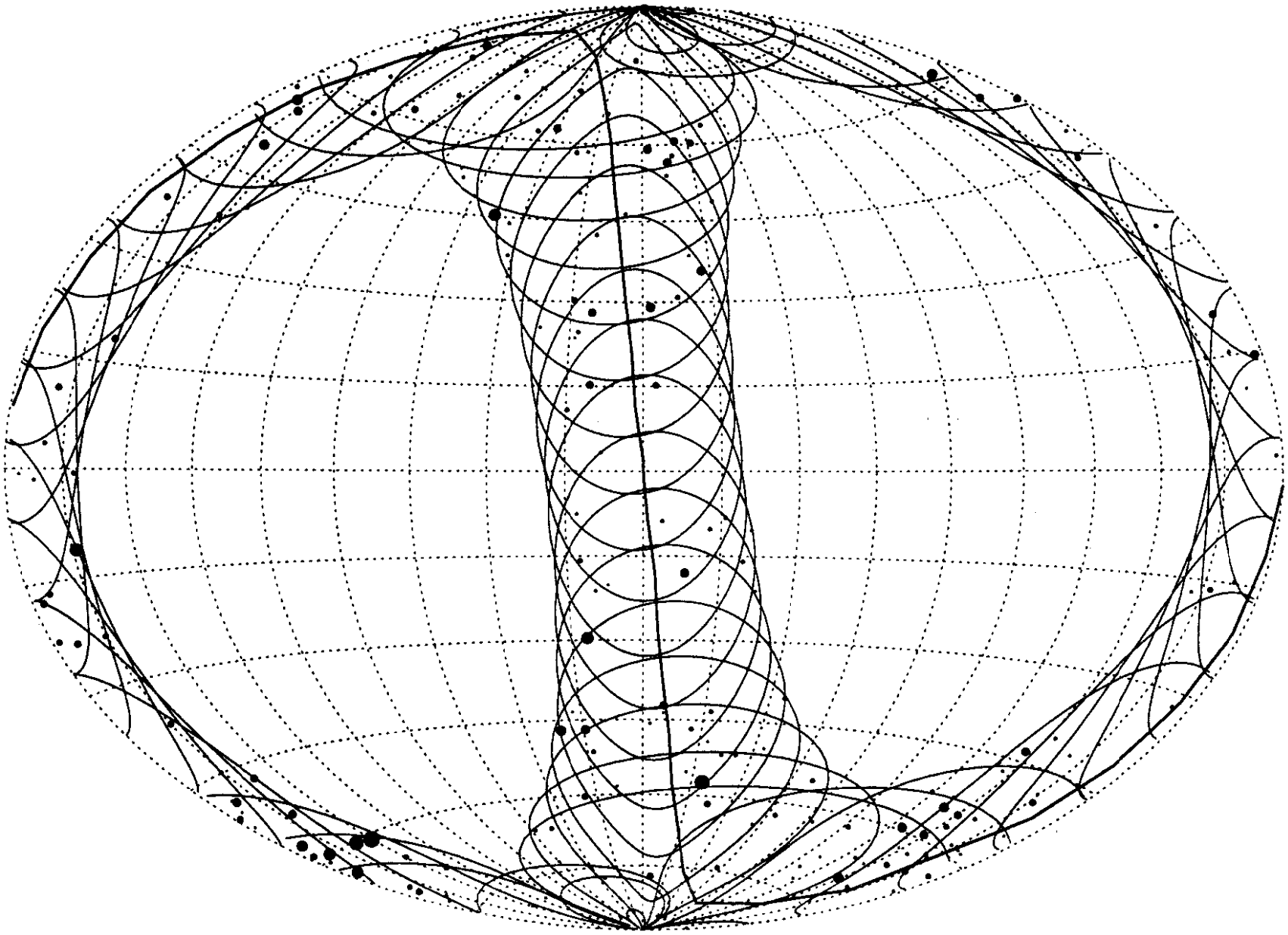
- Tracking Accuracy, LOS Stability
  - Need About 0.03 deg (Not a Stringent Requirement)
  - Use Sensor's Own Output for Tracking, Low Frequency Jitter Control (Closed-Loop Feedback Control)
  - Tap into Satellite IMU for High Frequency Jitter Control (Open-Loop Control)
- Do Sun, Moon Also (Attenuate Signal Drastically)

Earth Coverage

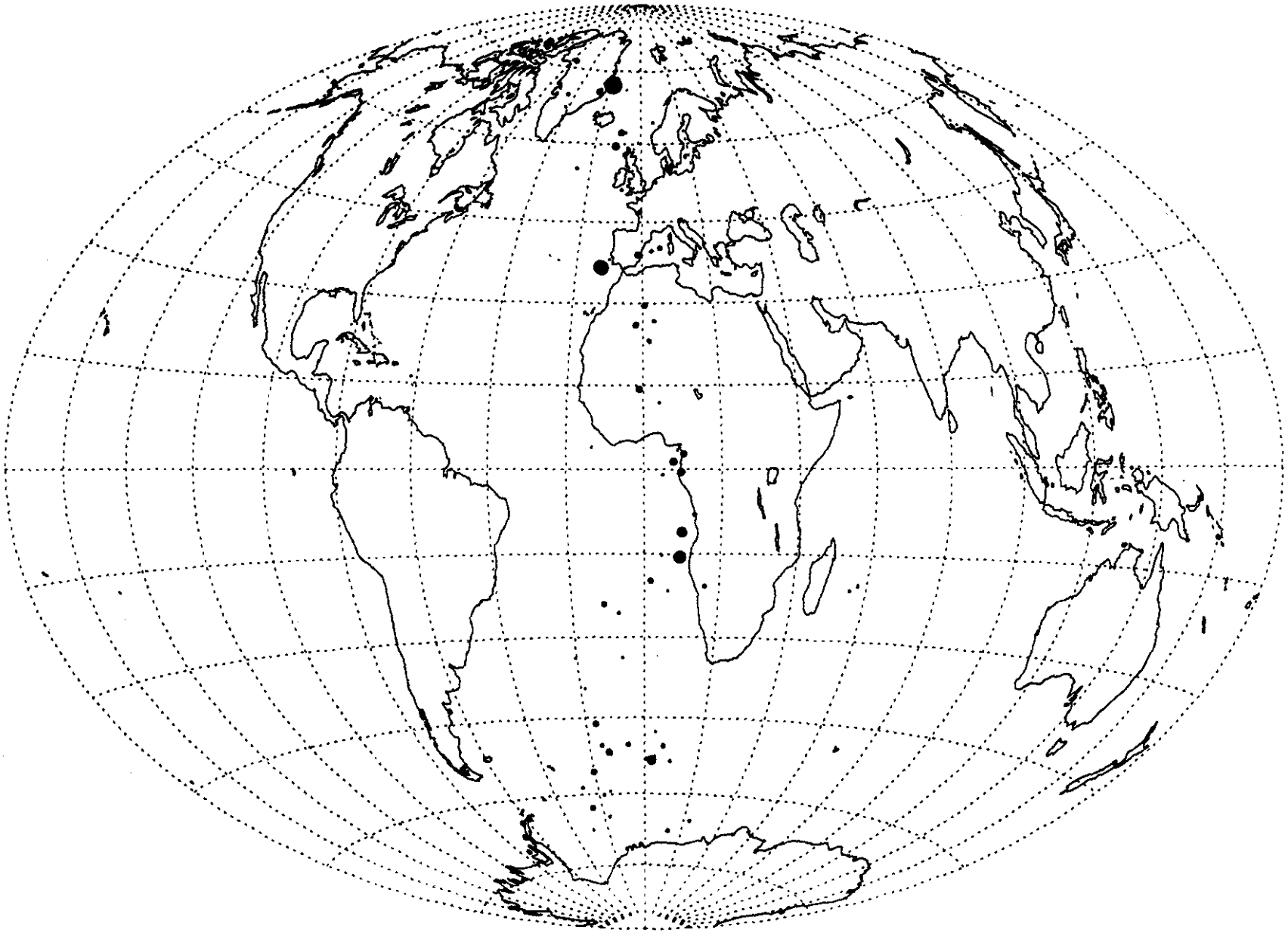
REMOTE SENSING DIVISION

- Make Measurements Only in Dark Atmosphere
  - 40 - 45 Minutes per Orbit (check number)
  - One Star per Minute (Occultation Takes About 30 Sec.)
  - About 600 Earth Observation Points per Day
  - Moonlight, Nightglow Interfere Slightly
- Store a Set of Bright Stars Positions
  - Yale Bright Star Catalog
  - Select Stars for Year-Round Global Coverage
  - Use Spacecraft IMU for Absolute Pointing to Acquire

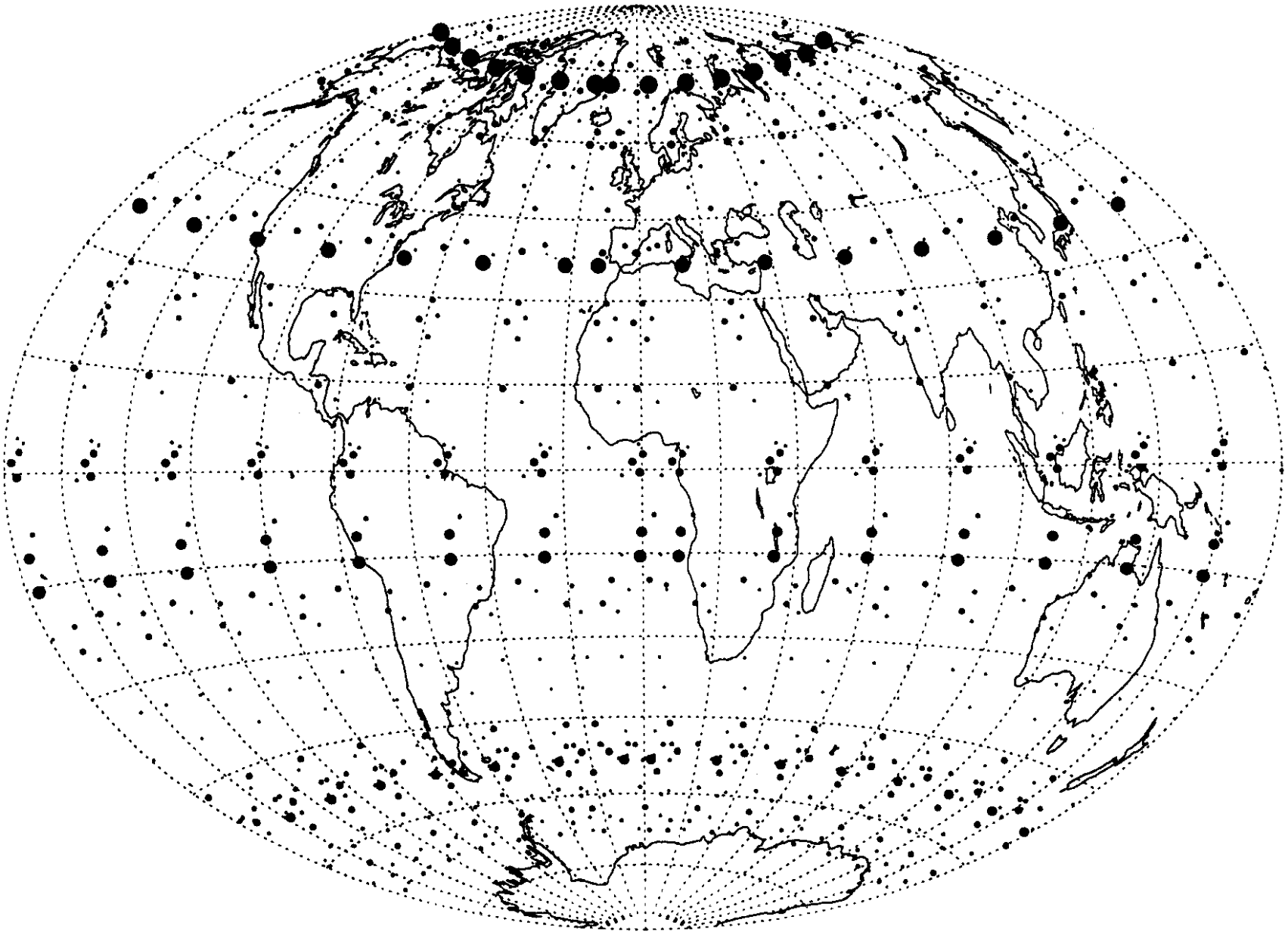
Observed Starset Positions on Sky



Location of Starset Tangent Points (Single Orbit)



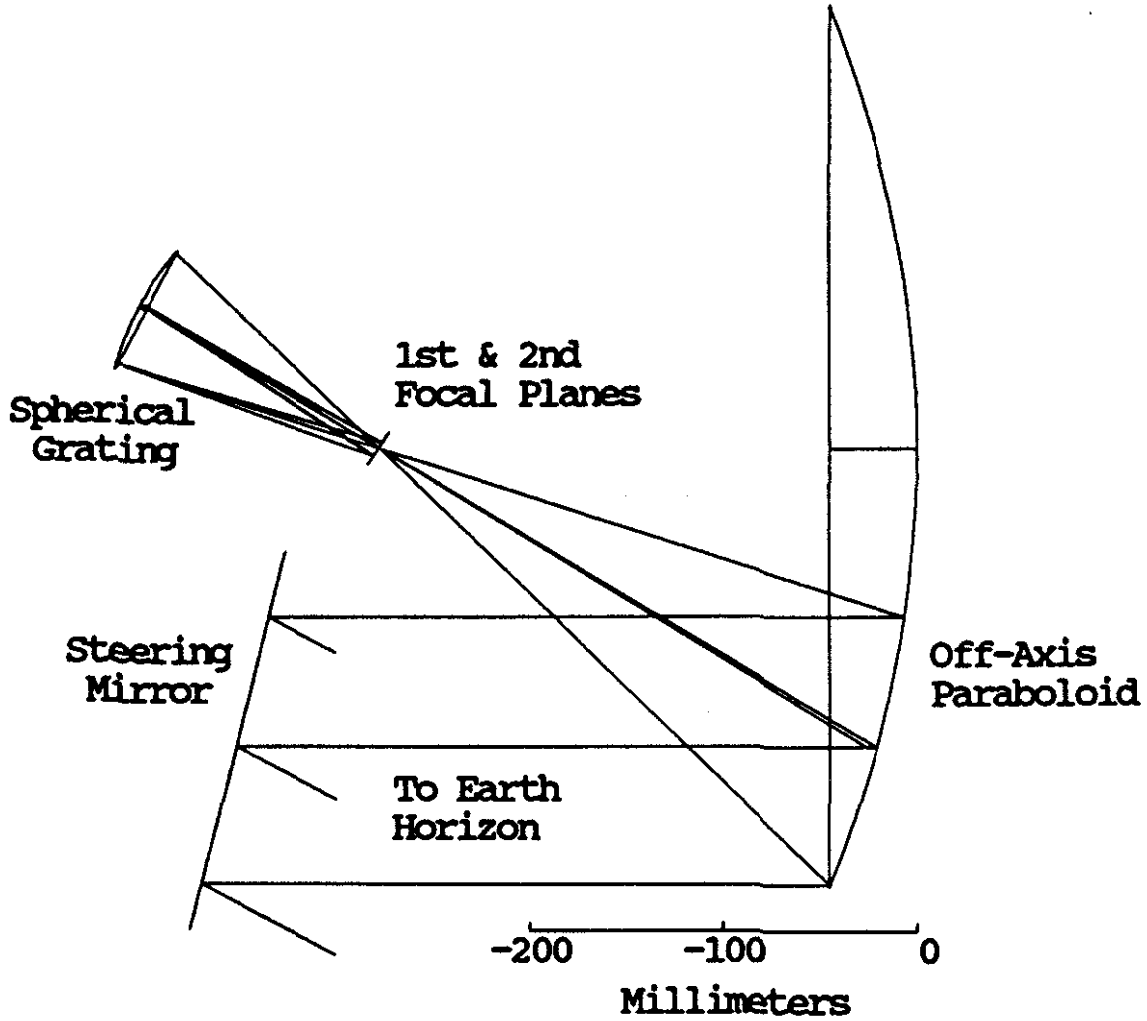
Location of Starset Tangent Points (1 Day, Nov-Dec)



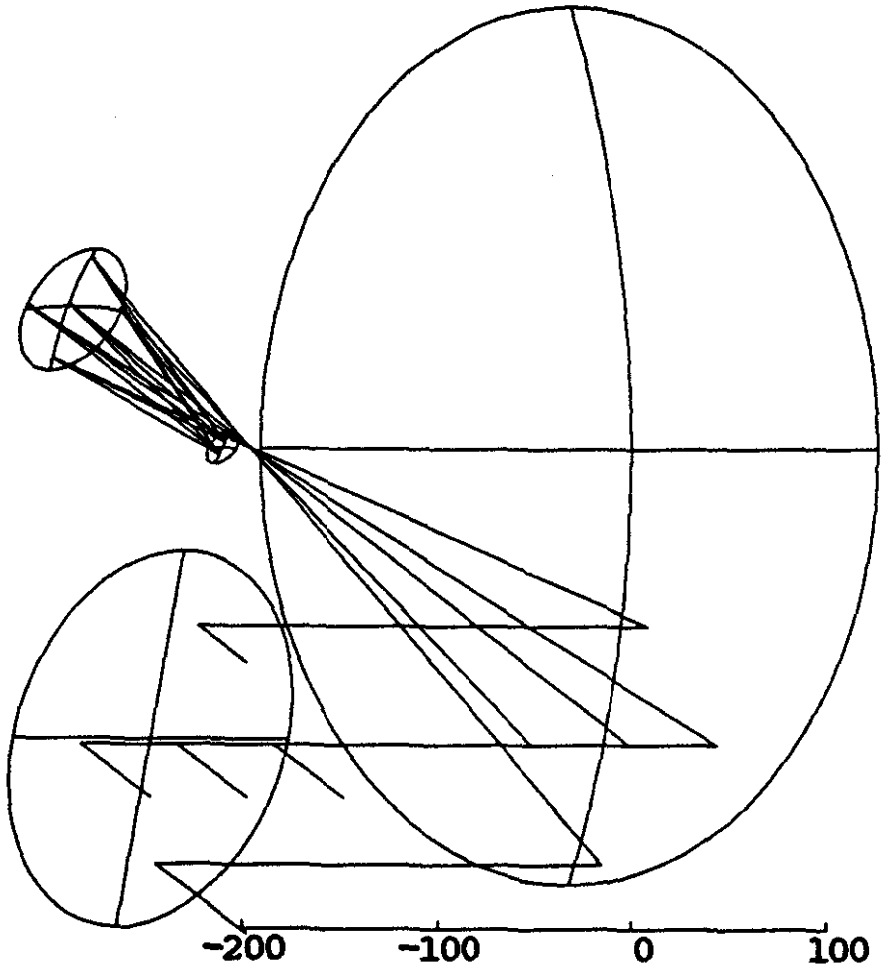
Design of StOC

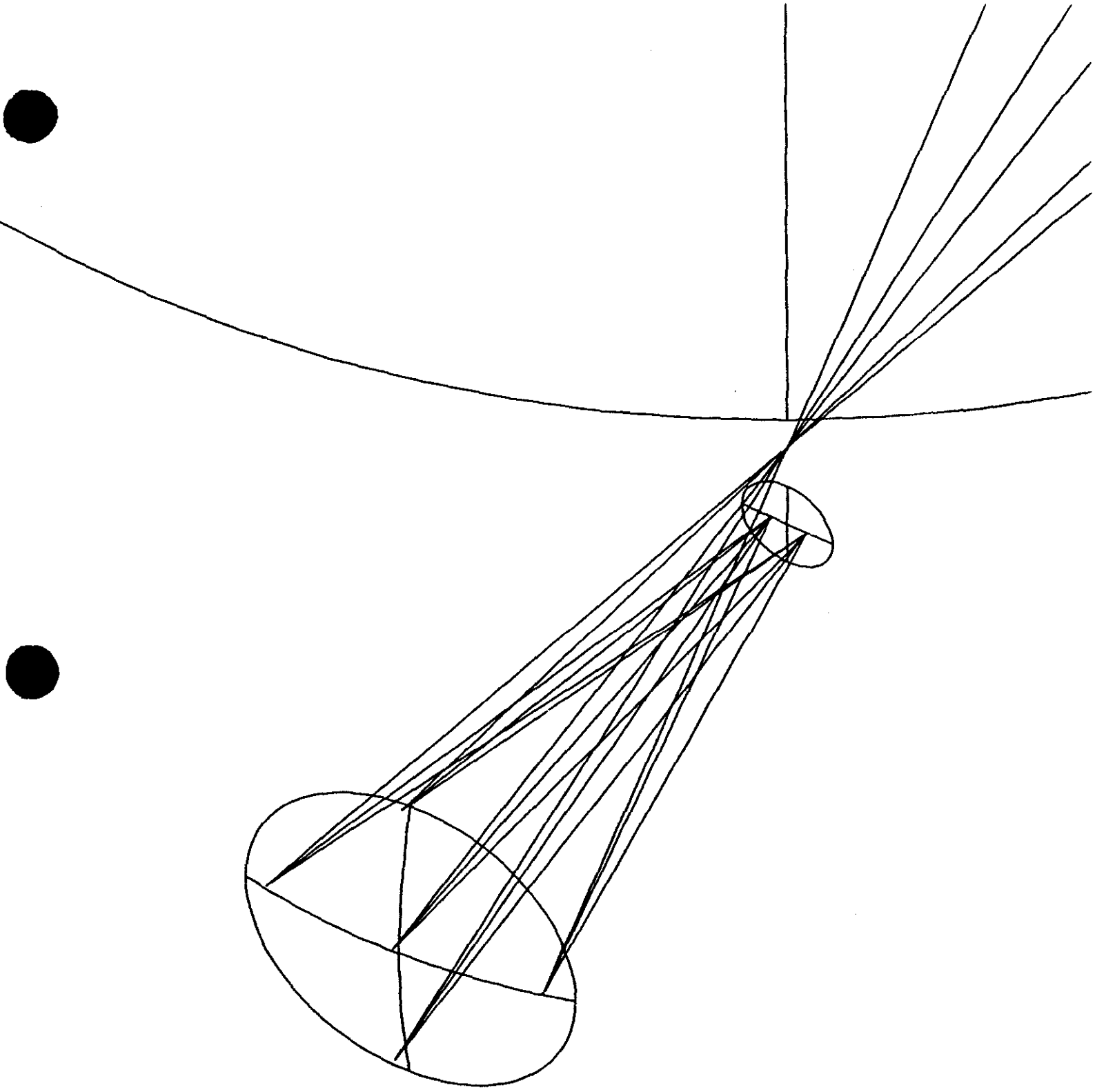
REMOTE SENSING DIVISION

- Reasonable Aperture Size (10 - 15 cm)
- High Through-put Optics
- Cover 350 - 900 nm with 10 nm Resolution
  - Spherical Grating
  - Order-Sorting Filter Near Focal Plane
- Record Full Spectrum
- Cooled CCD Detector Approaches Photon Limit
  - Mild Cooling Sufficient (250° K Probably OK)
  - Less Than 20 w for TE (ThermoElectric) Cooler
  - Square Array Records Scattered Moonlight, Nightglow Above & Below Star Spectrum, Subtract Out



LOS ≡ 2(MIRROR SCAN ∡)
= 2(12.5°) = 25°


-200
-100
0
100



Stellar Occultation Sensor

REMOTE SENSING DIVISION

- Collecting Mirror is Off-Axis Paraboloid
  - Maintains High Contrast
- First Image Plane
  - Suppress Stray Light with Field Stop
    - Large Aperture for Acquisition, Small for Tracking
  - Insert Notch- or Edge-Filter for Wavelength Calibration, Tracking in Dispersion Direction
- Spherical Grating
  - Blazed Toroidal or Holographic
  - Optimize for Efficiency, Spot Size on CCD

Size, Weight, Power

REMOTE SENSING DIVISION

- Optics Package
  - 45×25×20 cm
  - 25 lb in Aluminum
  - 15 lb in SiC (Silicon Carbide)
    - SSG, Inc., is Developing SiC Optical Structures for Space
- Electronics Package
  - 25×20×15 cm
  - 10 lb
- Power: Estimate Less Than 50 w Total

Simulated Data Processing

REMOTE SENSING DIVISION

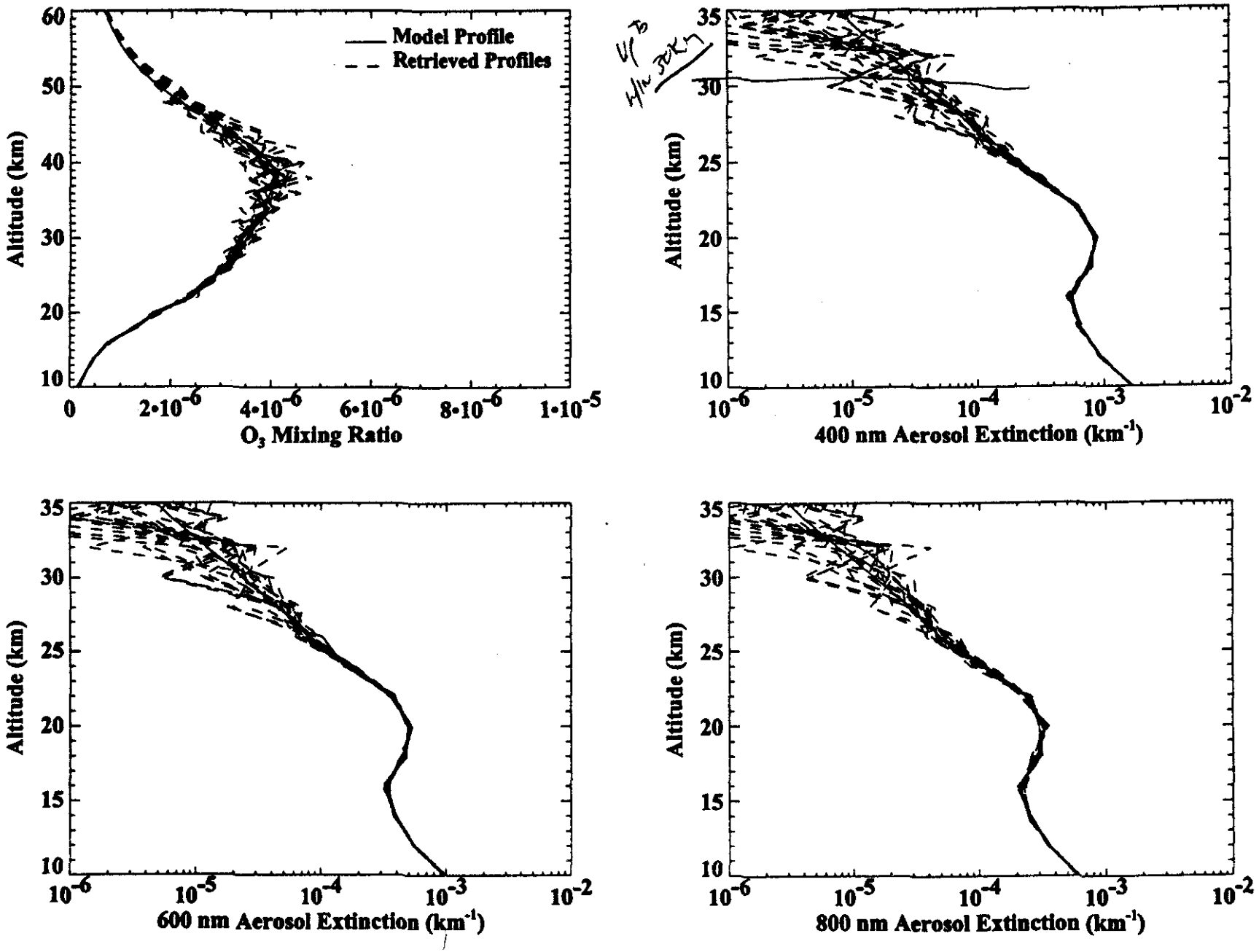
- Simulated Data Based on Preliminary Design
- Spectral Range and Resolution
- Wavelength Dependence of SNR: Star Type
- Atmospheric Effects (Refractive Attenuation)
- Random Error: Effect of SNR (SNR typ Ranges from 100 → 1000)

Data Retrieval Algorithm

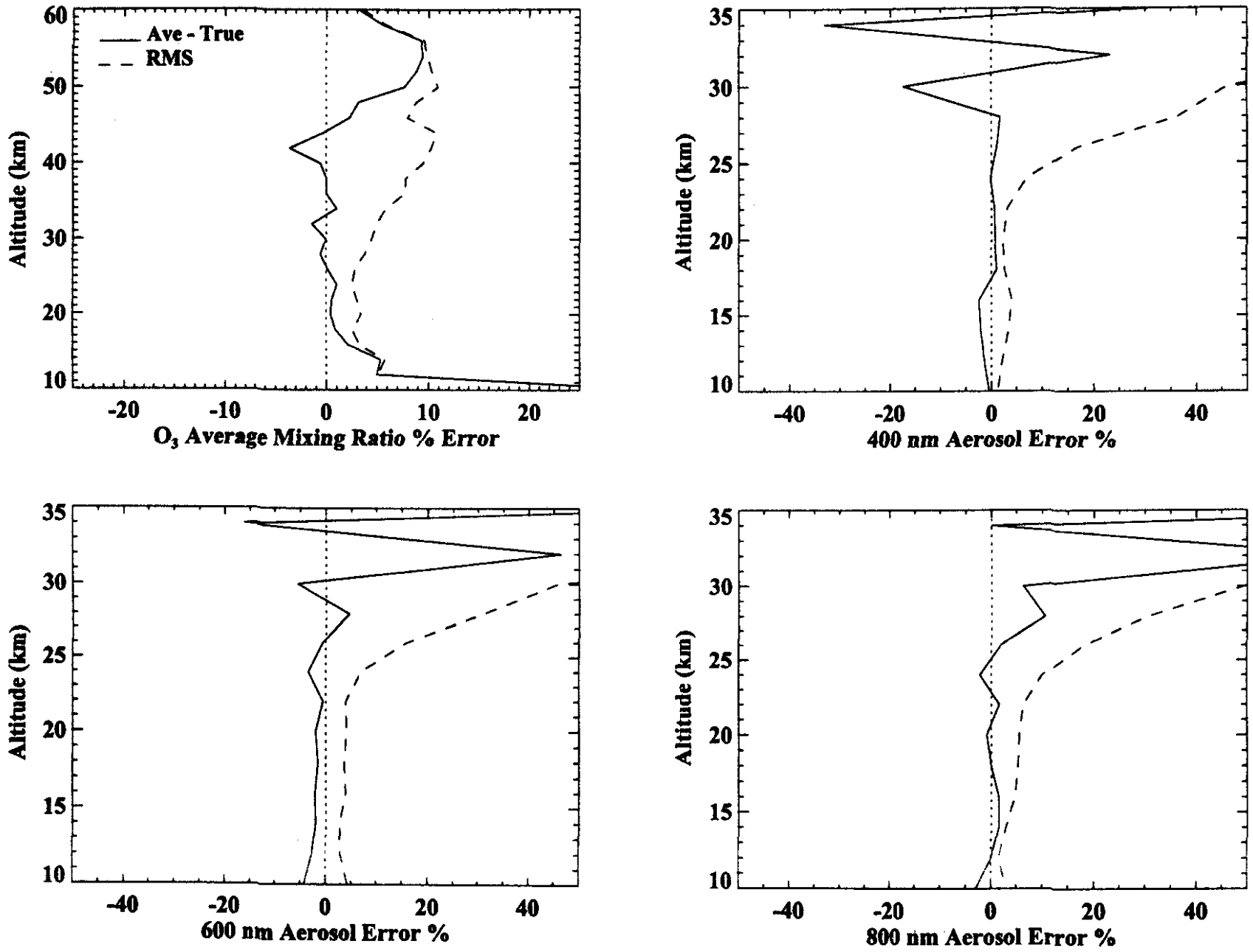
REMOTE SENSING DIVISION

- In Common with Other Occultation Sensors:
  - Measure Source Above and Through the Atmosphere
  - Division Gives Self-Calibrated Transmission
  - Species, Properties of Atmosphere Measured by Attenuation of Light at Particular Wavelengths
- Necessary to Stellar Occultation Sensors:
  - Measure Full Spectrum, Not Just Parts of It
  - Algorithm Must Accommodate to Spectral Type of Star
    - Types Have Different Blue/Red Light Ratios
  - Atmospheric Scintillation(?) & "Refractive Attenuation"
    - Problem for Point Sources (Stars)
    - Not for Extended Sources (Sun, Moon)
  - Subtract Moonlight, Nightglow Contribution

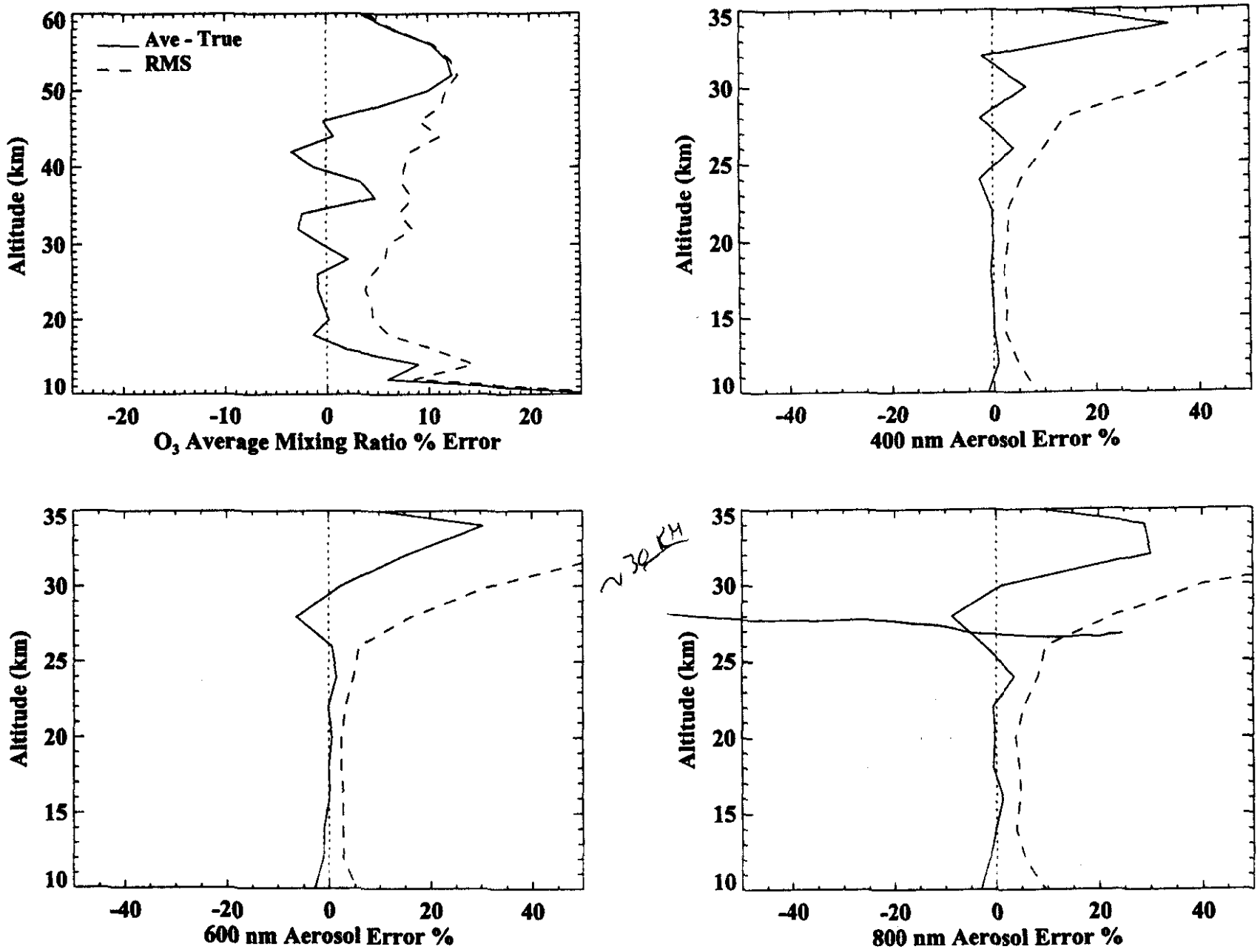
Sun-type Stars, Non-Volcanic Aerosols, 10nm resolution, 400-800nm



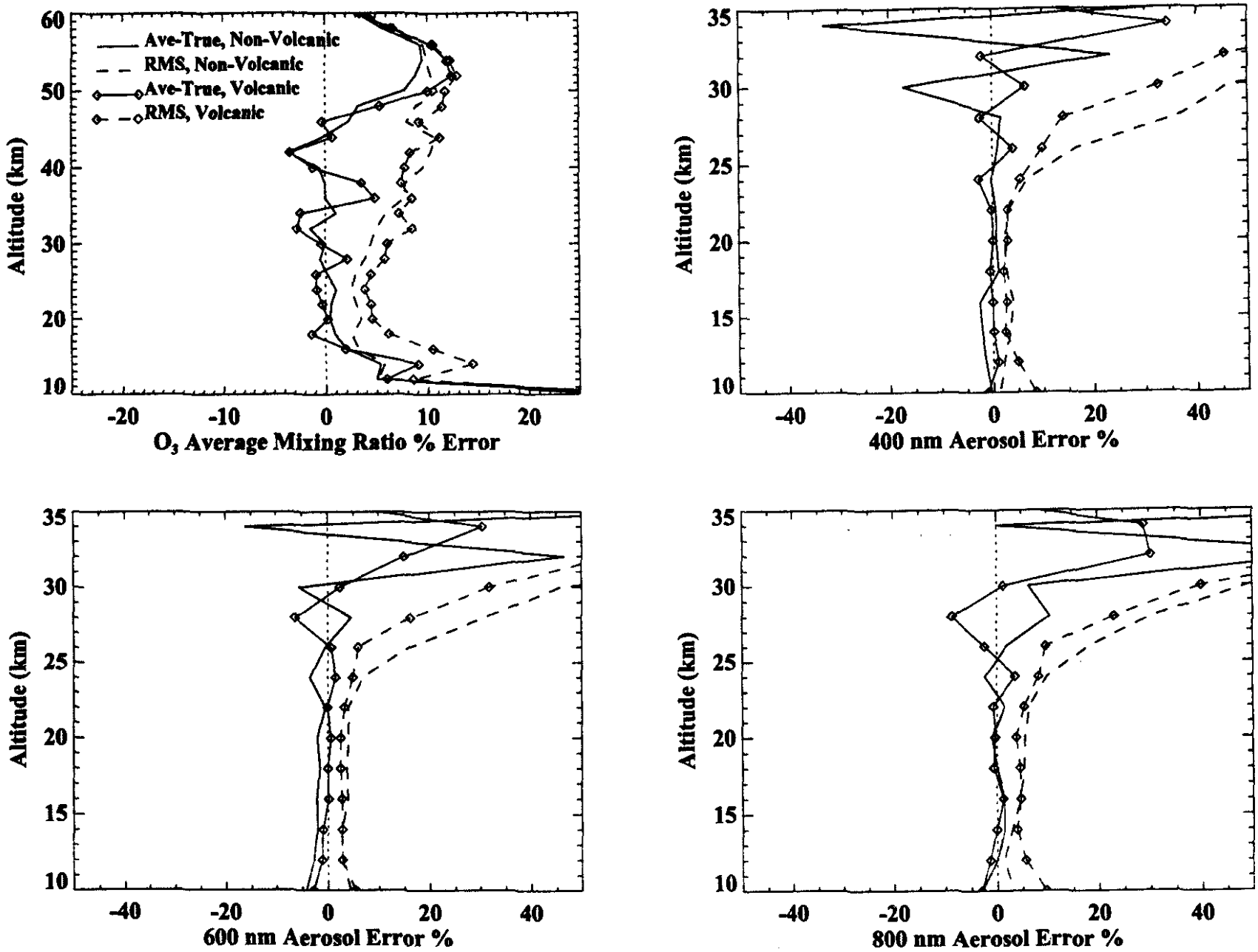
Sun-type Stars, Non-Volcanic Aerosols, 10nm resolution, 400-800nm



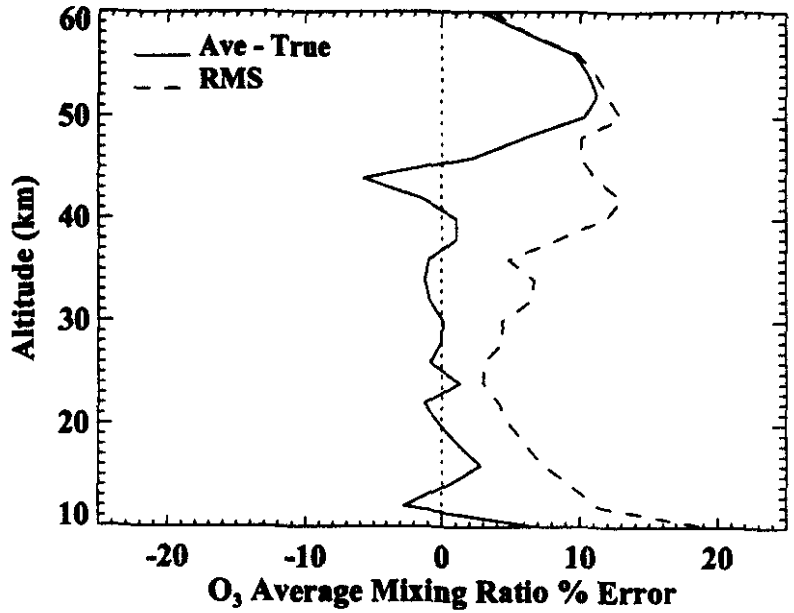
Sun-type Stars, Volcanic Aerosols, 10nm resolution, 400-800nm

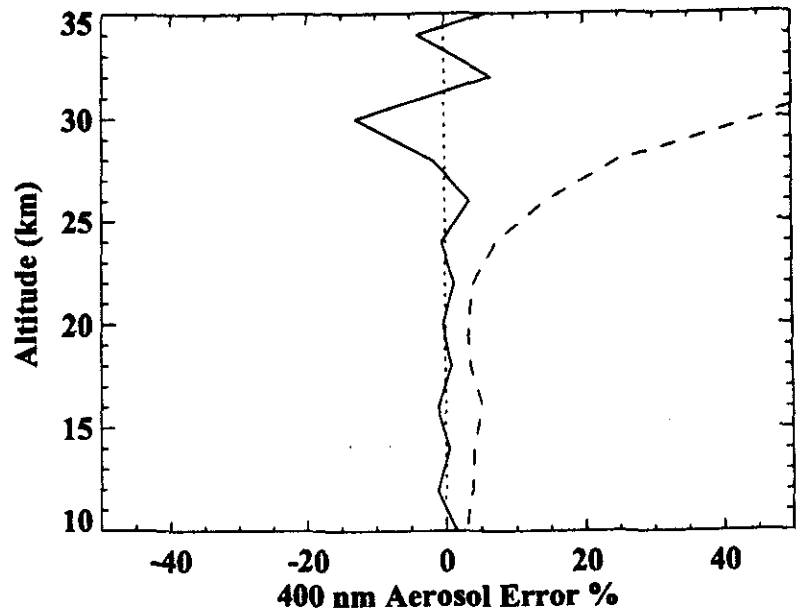


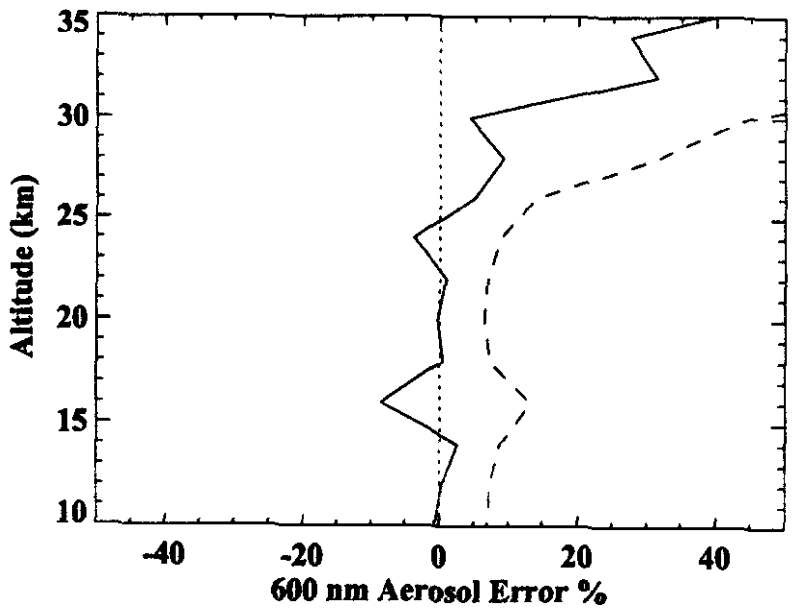
Sun-type Stars, Volcanic vs Non-Volcanic Aerosols

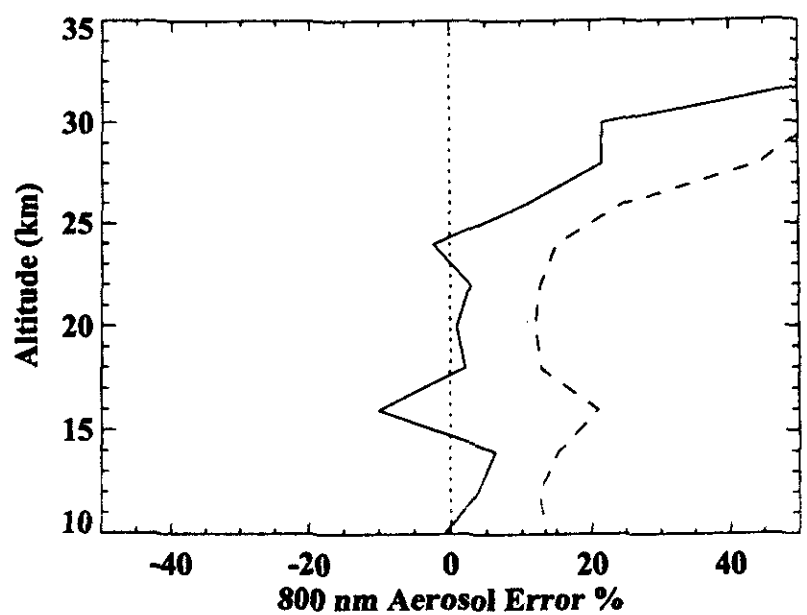


Blue Stars, Non-Volcanic Aerosols, 10nm resolution, 400-800nm

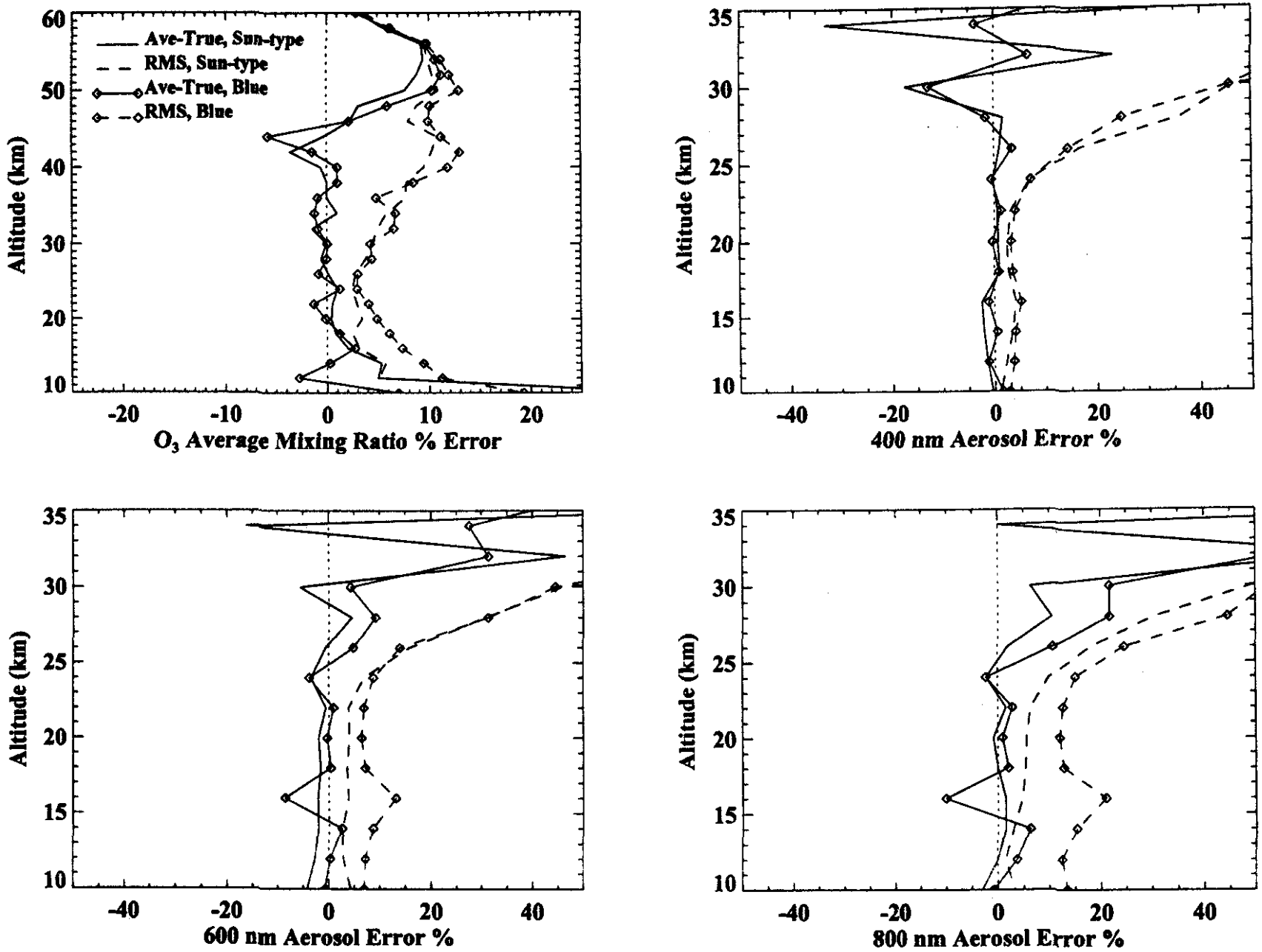




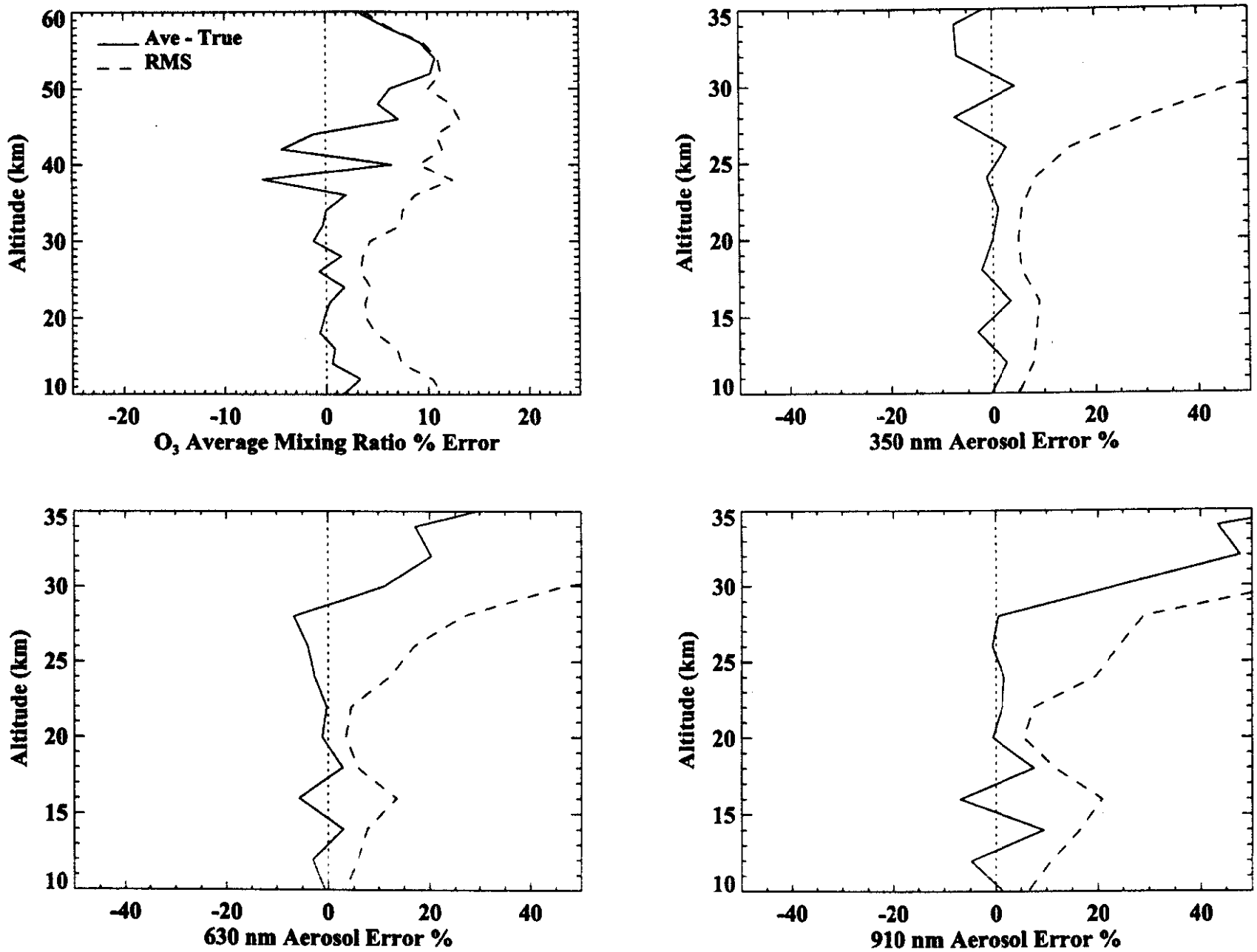




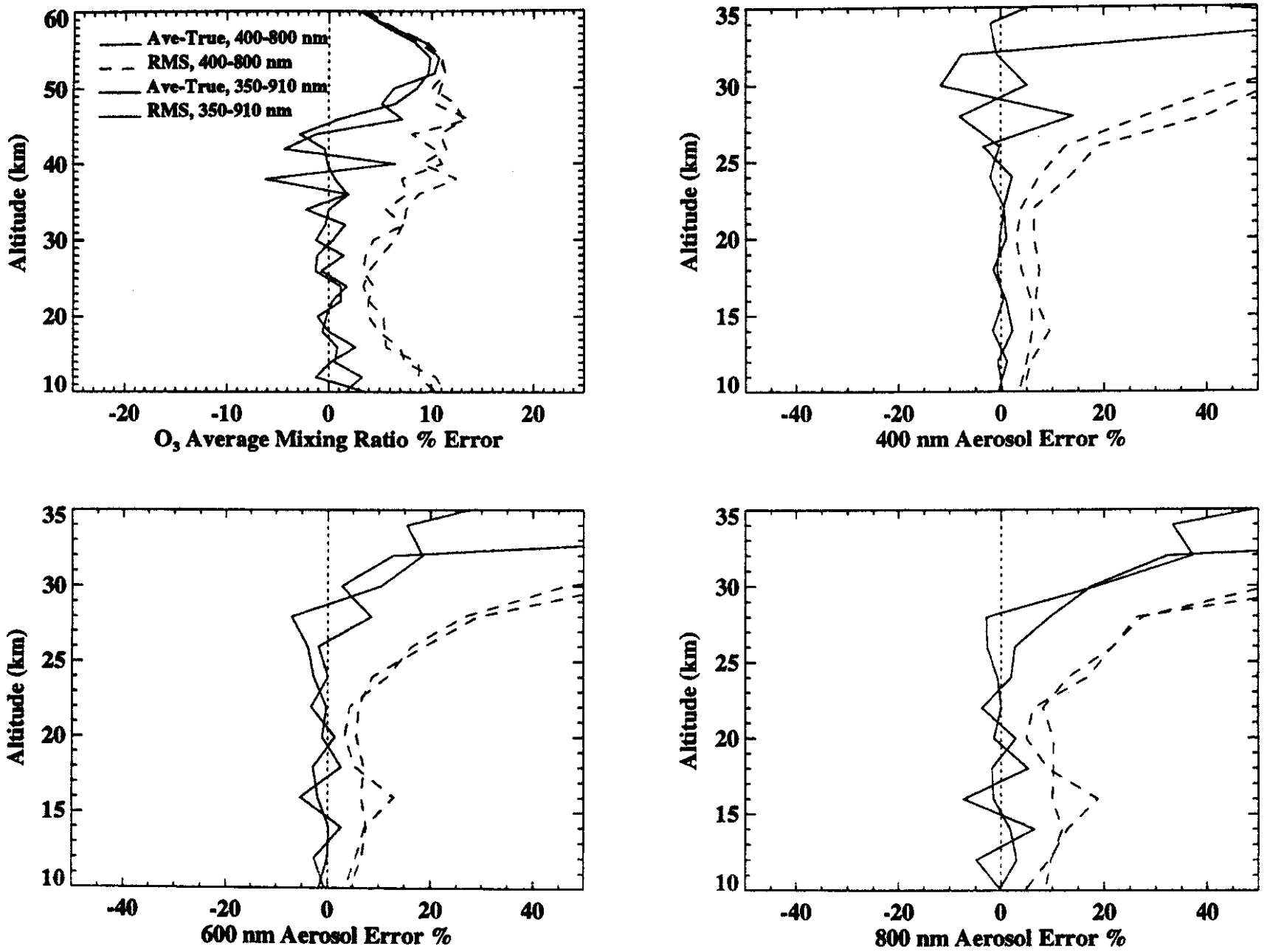
Sun-type vs Blue Stars, Non-Volcanic Aerosols



Sun-type Stars, Non-Volcanic Aerosols, 10nm resolution, 350-910nm



Sun-type, Non-Volcanic, 400-800nm vs 350-910nm



Simulated Data Results

REMOTE SENSING DIVISION

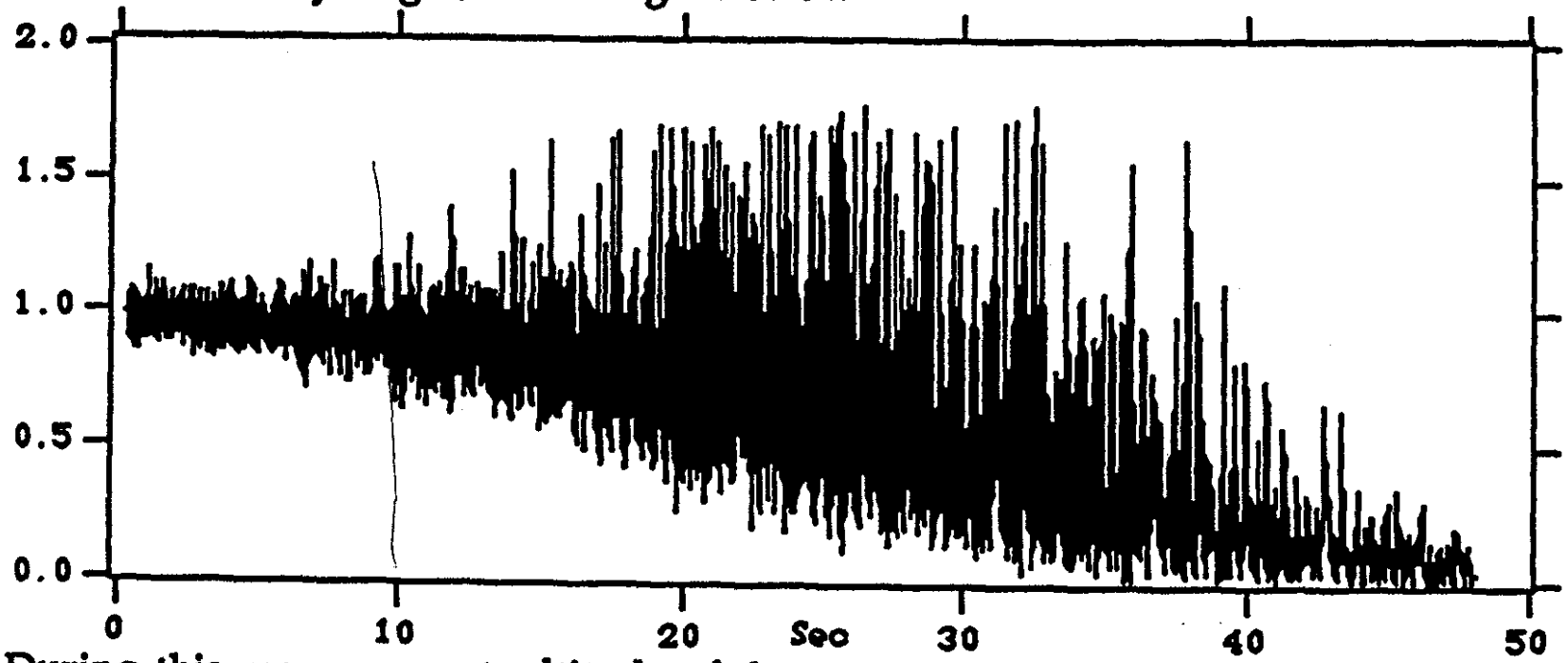
- Ozone
  - 10% Accuracy over 15 - 60 km
  - 20% Accuracy over 12 - 15 km
- Aerosol
  - 10% Accuracy over 10 - 25 km
  - 20% Accuracy over 25 - 30 km
- Temperature, Pressure
  - Evaluating Measurement via Oxygen A-band, Rayleigh Scattering

Scintillation Question

REMOTE SENSING DIVISION

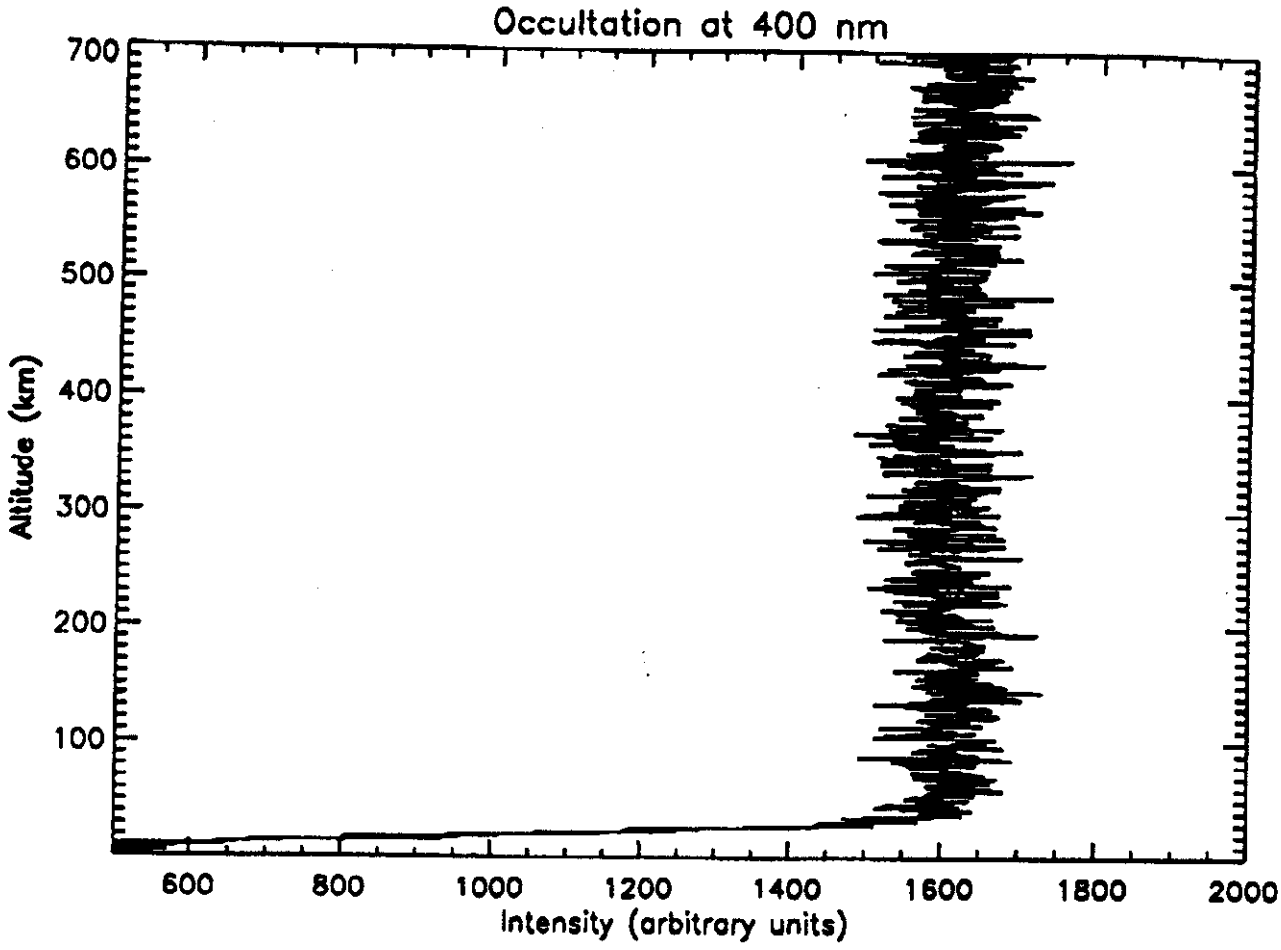
- Atmospheric Scintillation (Twinkling of Starlight)
  but in alg. to correct.
  - Visible Observations from Russian Mir Show Large Effect
  - Little or No Effect Seen by MSX UVISI
  - If Substantial, Makes Retrieval Harder
  - Issue Must Be Resolved

0.11 μm was used. The dark current was removed from the raw data and the signal was normalized using 8 seconds of measurement obtained above the atmosphere (not shown here). The normalized intensity is plotted as a function of time (in seconds from an arbitrary origin) on the figure below.



During this measurement, altitude of the tangent point varied (non linearly) between 43.8 and 16.7 km. This measurement contains noise (mainly from photon statistics) as well as the effect of absorption and Mie and Rayleigh diffusion (however, the optical filter was chosen in order to limit these non refractive effects). These effects will not be discussed further and we will concentrate on refractive effects.

During the occultation, the mean (normalized) intensity, calculated by averaging data over 0.5 s for example, decrease when the tangent altitude decrease. Because of the large intensity fluctuations observed during the occultation, this decrease is not guaranteed to be strictly monotonic. This effect, independent of absorption or diffusion is called "refractive attenuation", but it would be better to call it "refractive dilution". It is a consequence of the global (large scale) divergence of the light rays after


Occultation at 400 nm
Altitude (km)
700
600
500
400
300
200
100
600
800
1000
1200
1400
1600
1800
2000
Intensity (arbitrary units)

StOC FY97

REMOTE SENSING DIVISION

- Finish Design
  - Choose Collecting Aperture Size, Grating, CCD
- Assemble Laboratory Prototype
  - Prove Low-Noise CCD Operation, Tracking Capability
  - Measure Ozone, Aerosol Column Densities with Real Stars
- Extend and Improve Retrieval Algorithms
  - Some Aspects are Star-Specific

perhaps need to include scintillation effects 'TWINKLING' of stars.

Improvements to POAM

POAM II

REMOTE SENSING DIVISION

- Polar Ozone and Aerosol Measurement
  - Solar Occultation Sensor
  - Ozone, Aerosols in Polar Regions
- POAM II Launched on SPOT-3, Sept. of 1993
  - SPOT-3 Malfunctioned November, 1996
- Three Years of Space Operation
  - Polar Ozone Phenomena, esp. Ozone Hole
- Continuing Program
  - POAM III for SPOT-4: Deliver Jan. 6, 1997
  - OOAM for STP Mission: Deliver Jan. 6, 1997
    - Non-Polar Orbit (45° Inclination)

POAM Improvements

REMOTE SENSING DIVISION

- Better Elevation Pointing Knowledge Needed
  - Improves In-Atmosphere Altitude Determination
  - Replace Potentiometer Readout with Optical Shaft Encoder
- Better Knowledge of Location on Sun Needed
  - Tracks Sun's Center of Brightness, which Varies with Depth of LOS in the Atmosphere
  - Replace Existing Sun Sensor with 1-D "Camera", Image Sun in Vertical Direction
- Use Above to Improve Retrieval Algorithms

Millimeter-Wave Spectrometer (MWS)

MWS FY96

REMOTE SENSING DIVISION

- Ozone, Water Vapor Lines Near 600 GHz → characterizing of stratosphere
  - 623.688 for Ozone, 620.701 for Water Vapor
  - First Local Oscillator Freq: 623.2, 621.7 Respectively
  - IF: 500 Mhz, 1 GHz Respectively
  - Image Freq: 622.7 for Both, in Clean Spectral Region
    - Minimize Interference from Image Region
    - Two Looks Will Help Characterize Image Region
- Temperature, Pressure from 118 GHz
  - Conventional Observation of O_2
  - New Technology HEMT Amplifiers
    - High SNR
    - Improve Super-Resolution for Good Vertical Profiles

MWS FY97

REMOTE SENSING DIVISION

- Millimeter-Wave Spectrometer Design
  - Light-Weight Scanning Antenna
  - 600 GHz Operation for Ozone, Water Vapor
  - Acousto-Optic Crystal Spectrometer
- Assemble Prototype for Aircraft Operation
  - Have 600 GHz Receiver
  - Other Parts are Commercially Available
- Improve Retrieval Algorithms
  - Must Work in Operational System

Algorithm Development

Algorithms FY97

REMOTE SENSING DIVISION

- Construct Robust, Efficient, General-Purpose Algorithm for Operational Profile Sensors
- Instrument-Specific Model of Atmospheric Transmission, Emission, Attenuation
- Optimal Estimation Retrieval as Mathematical Analysis Package: Performs Retrieval
- Information Content and Error Analysis to Characterize Retrieval Fully (Rodgers 1990)
- Specifically, Examine Ozone Errors as Function of Aerosol Loading of Atmosphere