GLOBAL CONSTELLATION OF STRATOSPHERIC SCIENTIFIC PLATFORMS

Presentation to the NASA Institute of Advanced Concepts (NIAC) 2000 Annual Meeting

by

Kerry T. Nock

Global Aerospace Corporation

June 7, 2000

TOPICS

- **CONCEPT OVERVIEW**
- **PHASE II OBJECTIVES**
- **SUPPORT FOR EXPANSION OF EARTH SCIENCE**
- **POTENTIAL BENEFITS TO EARTH SCIENCE**
- **CONSTELLATION MANAGEMENT**
- **TRAJECTORY CONTROL**
- **BALLOON**
- **GONDOLA**
- **INTERNATIONAL CONSIDERATIONS**
- **SUMMARY**

CONCEPT OVERVIEW

BENEFITS OF STRATOSPHERIC CONSTELLATIONS TO NASA

- **Provide Low-cost, Continuous, Simultaneous, Global and Regional Earth Observations Options**

- **Provides *in situ* and Remote Sensing From Very Low Earth "Orbit"**

CONCEPT DESCRIPTION

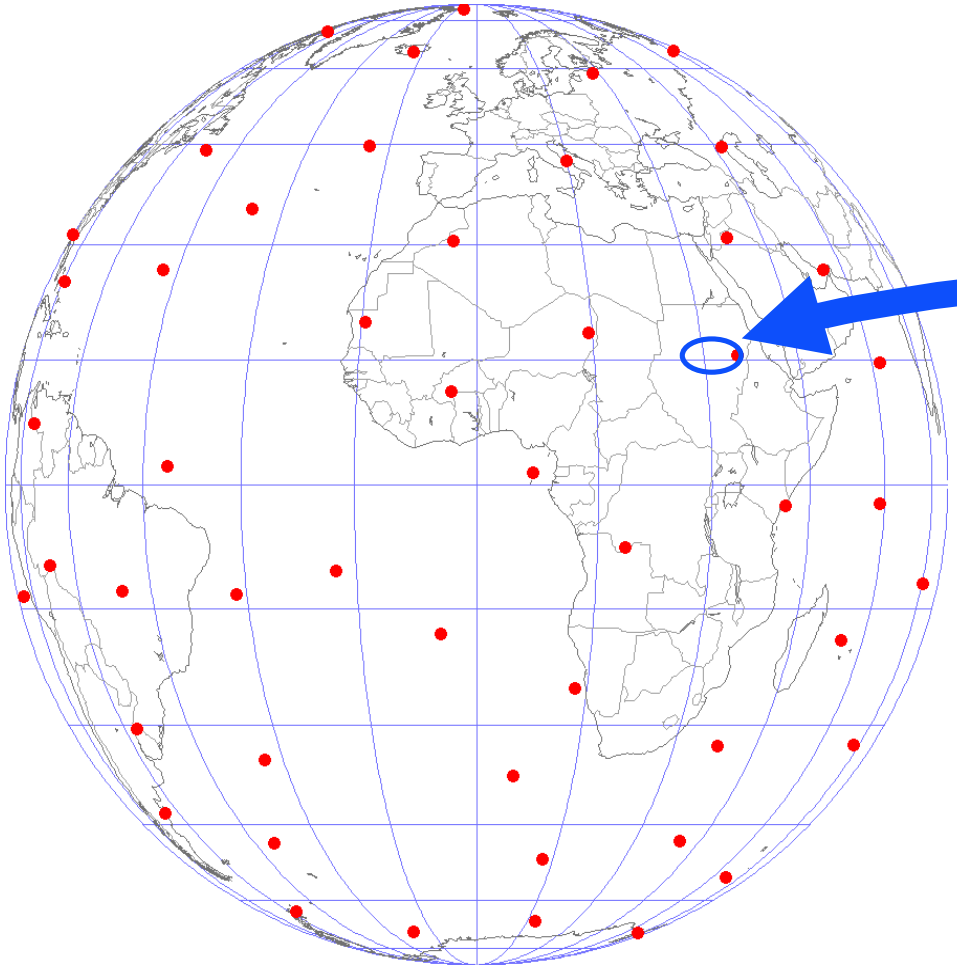
- **Tens to Hundreds of Small, Long-life Stratospheric Balloons or *StratoSats***
- **Uniform Global and Regional Constellations Maintained by Trajectory Control Systems (TCS)**
- **Flight Altitudes of 35 km Achievable With Advanced, Lightweight, Superpressure Balloon Technology**
- **Gondola and TCS Mass of 235 kg at 35 km Altitude**
- **Goal of ~50% Science Instrument Payload of Gondola**

Global Aerospace Corporation

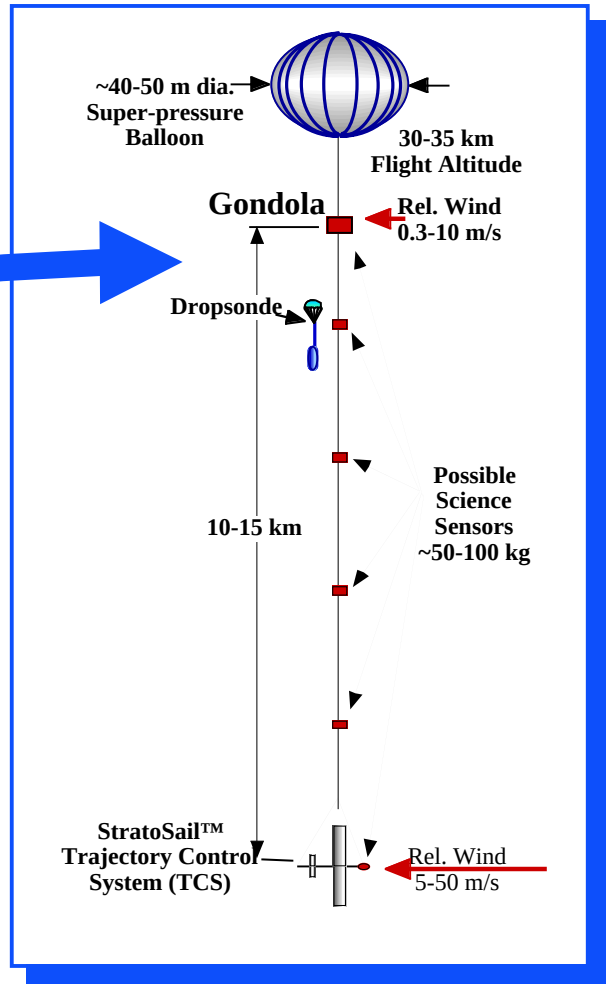
Global Stratospheric Constellation

CONCEPT SCHEMATIC

Global Constellation



StratoSat Flight System



RATIONALE FOR STRATOSATS

- **Low Cost of Stratospheric Operations Relative to Spaceflight (Spacecraft and Launchers)**
- **Advanced Balloons Are Capable and Desirable High Altitude Science Platforms**
- **In Situ Measurement Costs Are Reducing With the Advance of Technology (Electronics Miniaturization, Sensor Advances)**
- **There is an Emerging and Widely Accessible Global Communications Infrastructure**
- **Balloons Fly *Close* to the Earth and Are *Slow*, Both Positive Characteristics for Making Remote Sensing Measurements**
- **A Constellation of Balloon Platforms May Be More Cost Effective Than Satellites for Some Measurements**

KEYS TO THE CONCEPT

Affordable, Long-duration Stratospheric Balloon and Payload Systems

Lightweight, Low Power Balloon Trajectory Control Technology

Global Communications Infrastructure

PHASE II OBJECTIVES

PHASE II OBJECTIVES

- **Explore and Develop New Earth Science Constellation Applications and Define a Low-cost Proof-of-concept Mission**
- **Develop Optimized Control Strategies and Techniques for Constellation Geometry Management**
- **Extend and Expand the Systems Design Definition and Technology Requirements of StratoSats**
- **Understand International Overflight Issues for Stratospheric Constellations and Identify Approaches That Would Facilitate Their Operation**

SCIENTIFIC AND PROGRAMMATIC SUPPORT FOR EXPANSION OF EARTH SCIENCE

Global Aerospace Corporation

Global Stratospheric Constellation

SUPPORT FOR EXPANSION OF EARTH SCIENCE

Significant scientific and programmatic support exists for new approaches and more complete observations necessary to understand our global environment and global change.

- **NASA Earth Science Enterprise (ESE):**
  - **Develop *Advanced* Technologies to *Reduce Cost* and *Expand* Earth Science Observation Capability**
  - **Partner With Other Agencies to Develop and Implement *Better Methods* for Using Remotely Sensed Observations in Earth System Monitoring and Prediction**

- **National Research Council -** *Atmospheric Sciences, Entering the 21st Century (1998):* **Highest Priorities**
  - **Optimize *Global* Observations of the Atmosphere**
  - **Develop *New* Capabilities for Observing Critical Variables in the Atmosphere**

Global Aerospace Corporation

Global Stratospheric Constellation

SUPPORT FOR EXPANSION OF EARTH SCIENCE

- **National Research Council -** *Global Environmental Change: Research Pathways for the Next Decade (1999)*
  Recommendations:
  - **Both Space-based and *in-situ* Focused Observations to Test Scientific Hypotheses and Document Change**
  - **Characterize Climate Change; Elucidate Links Among Radiation, Dynamics, Chemistry and Climate; Understand Earth's Carbon and Water Cycles**
  - **Priority for *Accurate* Long-term Observations**
  - **More Aggressive Use of *Technical Innovation***

ESE STRATEGIC PLAN GOALS

POTENTIAL BENEFITS TO EARTH SCIENCE

SCIENTIFIC ADVANTAGES OF GLOBAL BALLOON PLATFORMS

- **Good Diurnal Coverage of Entire Globe**
- **Low Altitude Observations That Can Improve Resolution and/or Signal-to-Noise Ratios of Measurements**
- **Slow Moving Balloon Platforms Can Enable New Observation Techniques**
- **Weaknesses Associated With Traditional Atmospheric Balloon-borne Systems Are Overcome by the Concept of a Long-duration, Stratospheric Constellation of Platforms**
  - Provide Frequent to Continuous Measurements
  - Provide Horizontal Gradients in Addition to Vertical Profiles
  - Concept of Extended Duration Provides a Cost Effective Method for Science and Satellite Validation.

POTENTIAL EARTH SCIENCE BENEFITS

Balloon-borne Measurements Have Unique Validation and Science Capabilities. Their Strengths Include*:

- **Stratospheric and Tropospheric Measurements (40 to 10 Km), (Much of This Above Aircraft Altitudes)**
- **Simultaneous Measurements of Multiple Atmospheric Species**
- **High Resolution Vertical Profiling Across a Large Pressure Range**
- **Simulation of Remote Sensing Footprint of Limb Sounding Satellites**

** Professor William Brune, Pennsylvania State University, Workshop for Integrated Satellite Calibration/Validation and Research Oriented Field Missions in the Next Decade (Fall, 1999, Snowmass, CO)*

PHASE I EARTH SCIENCE CONTACTS - 1

NASA Goddard Space Flight Center

Data Assimilation Office Meetings

Dave Lamich *Stratospheric data assimilation production, Use of stratospheric wind data in assimilation process*

Guang-Ping Lou "

Richard Swinbank ***(United Kingdom Meteorological Office)***

- Interested in dropsondes in data-sparse regions
- **Suggested working with WMO to develop support for the concept**

Laurie Rokke *Stratospheric data assimilation production, Use of stratospheric wind data in assimilation process*

- Interested in dropsondes when satellites are overflying
- **Interested in getting more balloons near a stratwarm event and near volcanos prior to erup**

Steve Pawson *Stratospheric modeling, middle atmosphere, observational data base*

- In-situ wind measurements needed to validate any predictions above 10 hPa

Ricky Rood *Atmospheric Researcher*

- **Global balloon network could evaluate and validate GPS temperature profiles measuremen**

PHASE I EARTH SCIENCE CONTACTS - 2

NASA Goddard Space Flight Center

General Science Discussions

Jim Garvin *ESSP Scientist and Visioneer*

- Interested in hyperspectral data looking at landcover change - DOD constraints
- **Excited about oceanic ice monitoring - sats not doing a good enough job**

Mark Schoeberl *EOS-CHEM Proj. Scientist, Earth Sciences Visioneer*

- Appeared very interested in near-term application of balloons/trajectory control systems
- Use ULDB in "campaign" mode for particular targets
- **Interested in aerosol LIDARs, 1/r^2 problem better on balloon vs satellite**
- Angle of radiance isssue important since sats don't do flux.
- Proposed "Leonardo" sat constellation to measure radiance vs angle.
- Sat sees rad. From one direct., to understand flux need to integrate over all angles.
- A constellation of balloons could check this integration
- Some satellites could be replaced by cheaper balloon formations
- Interested in science and applications which can make a better world

Paul Newman *Atm. Chemistry*

- Advocated complex, expensive instrumentation which he felt was too heavy for StratCon
- Initially wasn't sure about usefulness of constellation, was more interested in ULDB as a platform
- Reality of UAVs have not matched their promise. Major concern about altitude and payload capability

Global Aerospace Corporation

Global Stratospheric Constellation

PHASE I EARTH SCIENCE CONTACTS - 3

NASA Goddard Space Flight Center

General Science Discussions

P. K. Bhartia *Tropospheric Chemistry, Remote sensing*
Jim Gleason "

- **Very interested in LIDAR both active & passive**
- Initially worried about flying on balloon due to mass (100 kg) & power (10 kW)
- Like stationkeeping systems - even looking at GEO Sat ideas
- Interested in UV Lasers - lots of power required
- Very interested in dropsondes - ozone systems - require chem calibration before launch
- **Unknown when sats could make LIDAR measurements due to power issue.**
- Interested in limb scanning in microwave & laser - absorbtion meas.
- Balloon limb meas. Would be much higher resolution because range to limb shorter

Yorum Kaufman *Troposphere, clouds, chemistry & spectral radiometry*
Warren Wiscombe "

- Currently fly airplane multispectral mapping instrumentation
- Issue of overflight of countries - even difficulties w/Brazil
- **VERY excited about global radiation measurements. Sats only measure radian**
- Sats convert radiances to fluxes at 35 km! - Balloon could measure directly!
- Wiscombe might be interested in taking the radiation balance idea further.

Global Aerospace Corporation

Global Stratospheric Constellation

PHASE I EARTH SCIENCE CONTACTS - 4

NASA Ames Research Center

Katja Drdla *Researcher on Polar Region Ozone Loss*
- Cont. meas. on air masses as they travel polar regions great help in modeling ozone loss

Bob Chatfield *Tropospheric Chemistry Researcher*

Jet Propulsion Laboratory

Geoff Toon *Atm. Scientist, flys FTIR from balloons*
- Interested in putting payloads on ULDB.
- Would like to fly in tropics to obtain multiple sunrises and sunsets
- **Very interested in balloon-borne instrument concept, esp. long flights at mid**

Bob Stachnik *Atm. Scientist in sub-millimeter limb sounding*
- Very interested in balloon-borne instrument concept
- **Equatorial regions are important; balloons could provide diurnal coverage.**

Pennsyvania State University

William Brune *Project Scientist on recent balloon missions for polar and tropical studies*

Global Aerospace Corporation

Global Stratospheric Constellation

PHASE I EARTH SCIENCE CONTACTS - 5

Massachusetts Institute of Technology

Kerry Emanuel *Atmospheric Researcher*
- Steer balloons of a network over hurricanes to deploy dropsondes

Harvard Smithsonian Institution

Wes Traub *Balloon experimenter, Far-IR Emission Spectrocopy*
- Discussed issues of flying a few weeks including detector cooling requirements

Harvard University

Daniel Jacob *Co-chair on Workshop on Tropospheric Chemistry*
- Outlined critical issues in global & regional air pollution and need for quantifying problem
- Asian pollution a specific goal
- **Being able to monitor specfic pollutants would be extremely helpful**

Jennifer Logan *Atmospheric Scientist*
- Monitoring ozone variations in remote regions, e.g. tropics, could provide critical information for understanding global pollution.

David Keith *Atmospheric Scientist*
- Any way that would accurately measure tropospheric water, especially in tropics, would be invaluable
- **Currently no good/accurate global coverage measurements of tropospheric water**
- Measurements could be made on StratoSat from tether or dropsondes
- Required accuracy would be >10%

SUMMARY OF SCIENCE CONTACTS

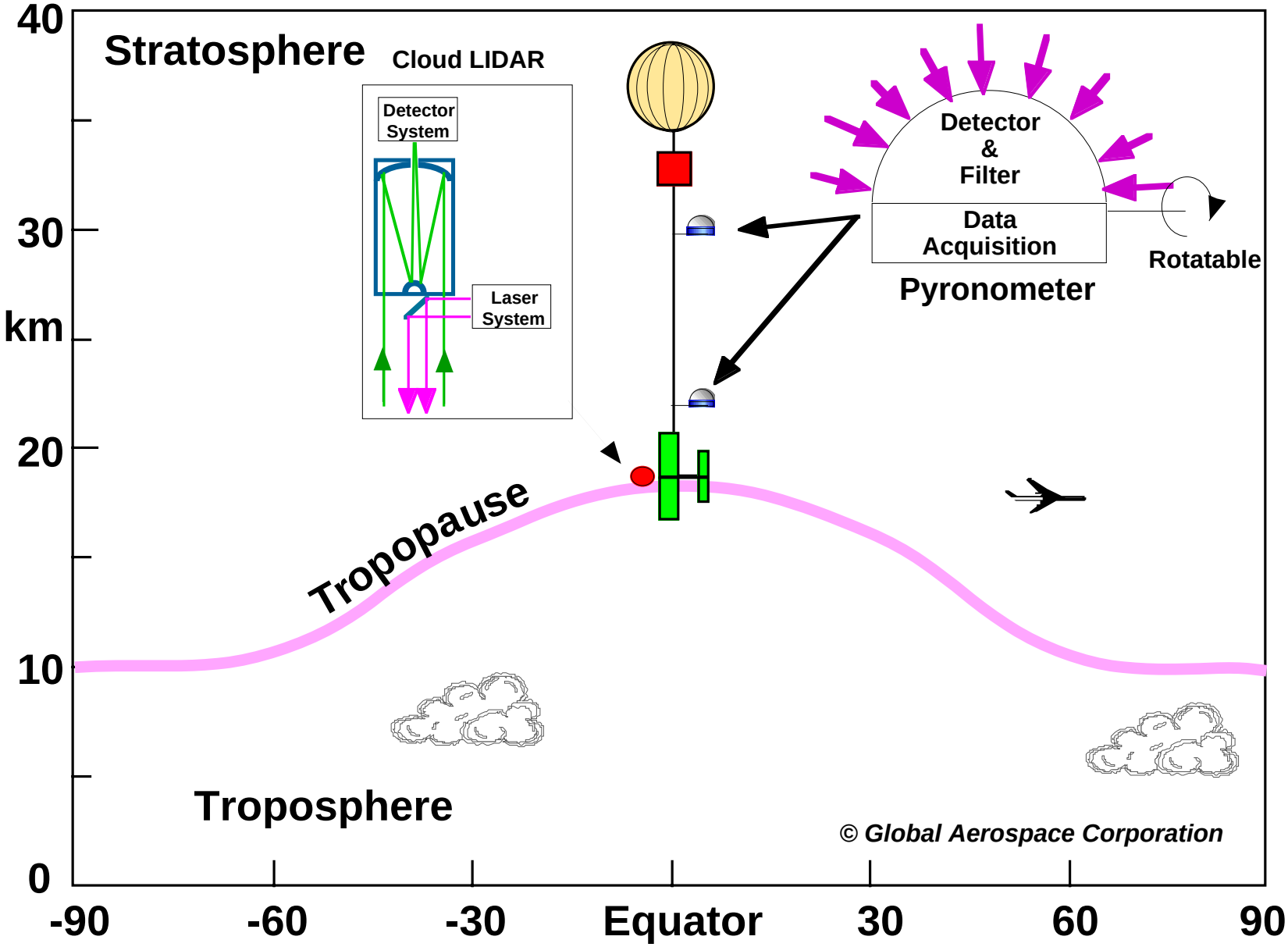
- **In Phase I, More Than 25 NASA and University Earth Science Researchers Were Briefed on the Global Stratospheric Constellation Concept**
- **Many Were Enthusiastic About the Potential Benefit of Global Constellations to Contributing to Earth Science**
- **Several Researchers Provided the Ideas for the Constellation Science Concepts Discussed Later**
- **In Phase II, the Strong Involvement of NASA and University Earth Science Researchers Is Being Continued and Expanded**

PROMISING EARTH SCIENCE THEMES

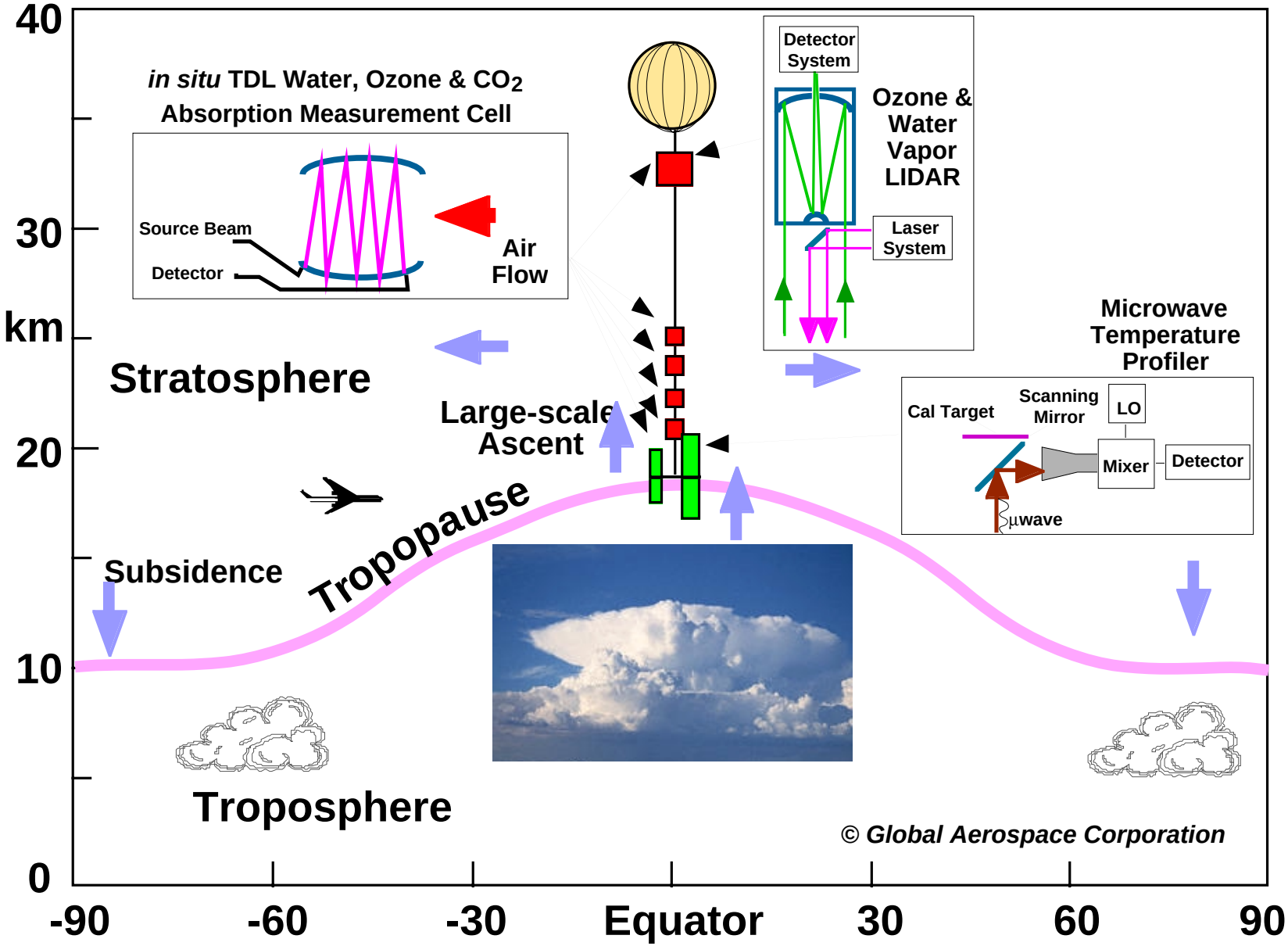
- **Climate Change Studies**
  - **Water Vapor and Global Circulation in the Tropics***
  - **Radiative Studies in the Tropics**
  - **Global Radiation Balance***
- **Ozone Studies**
  - **Mid-latitude Ozone Loss**
  - **Arctic Ozone Loss***
  - **Global Distribution of Ozone***
- **Weather Forecasting**
  - **Hurricane Forecasting and Tracking**
  - **Forecasting Weather from Ocean Basins & Remote Areas**
- **Global Circulation and Age of Air**
- **Global Ocean Productivity**
- **Hazard Detection and Monitoring**
- **Communications for Low Cost, Remote Surface Science**

** Discussed further in later charts*

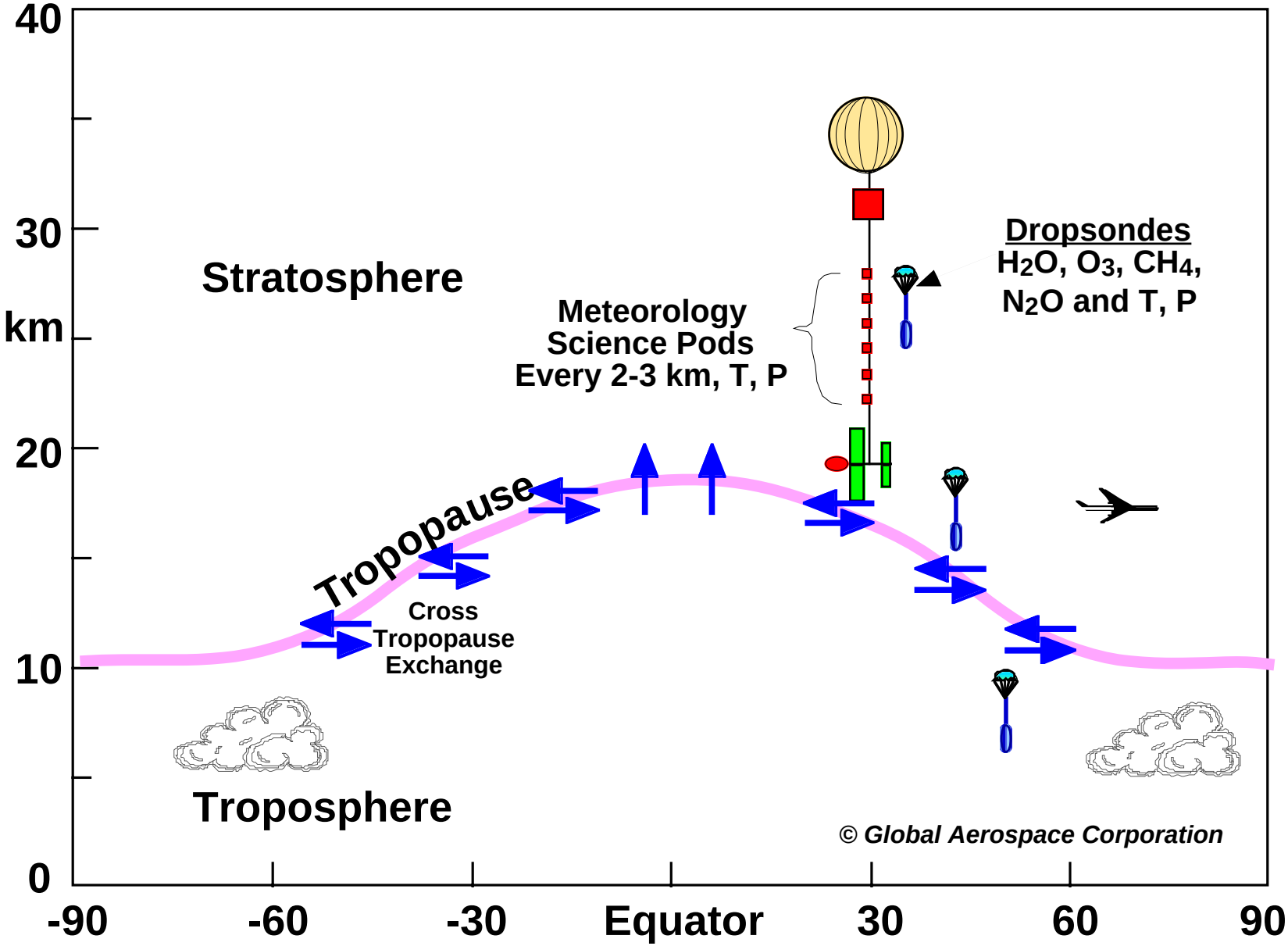
CLIMATE CHANGE: GLOBAL RADIATION BALANCE



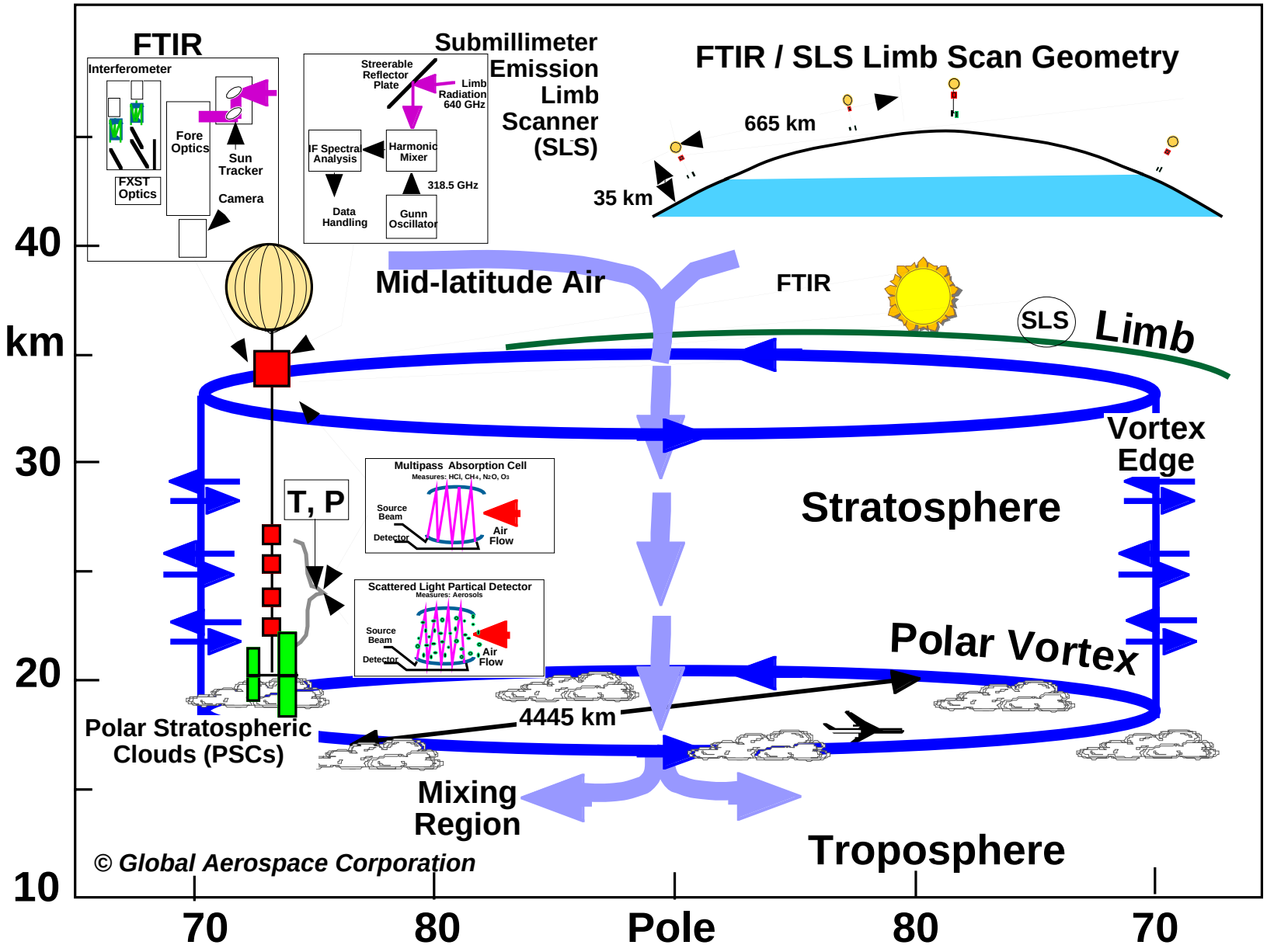
CLIMATE CHANGE: DYNAMICAL PROCESSES IN TROPICS



OZONE STUDIES: GLOBAL DISTRIBUTION OF OZONE



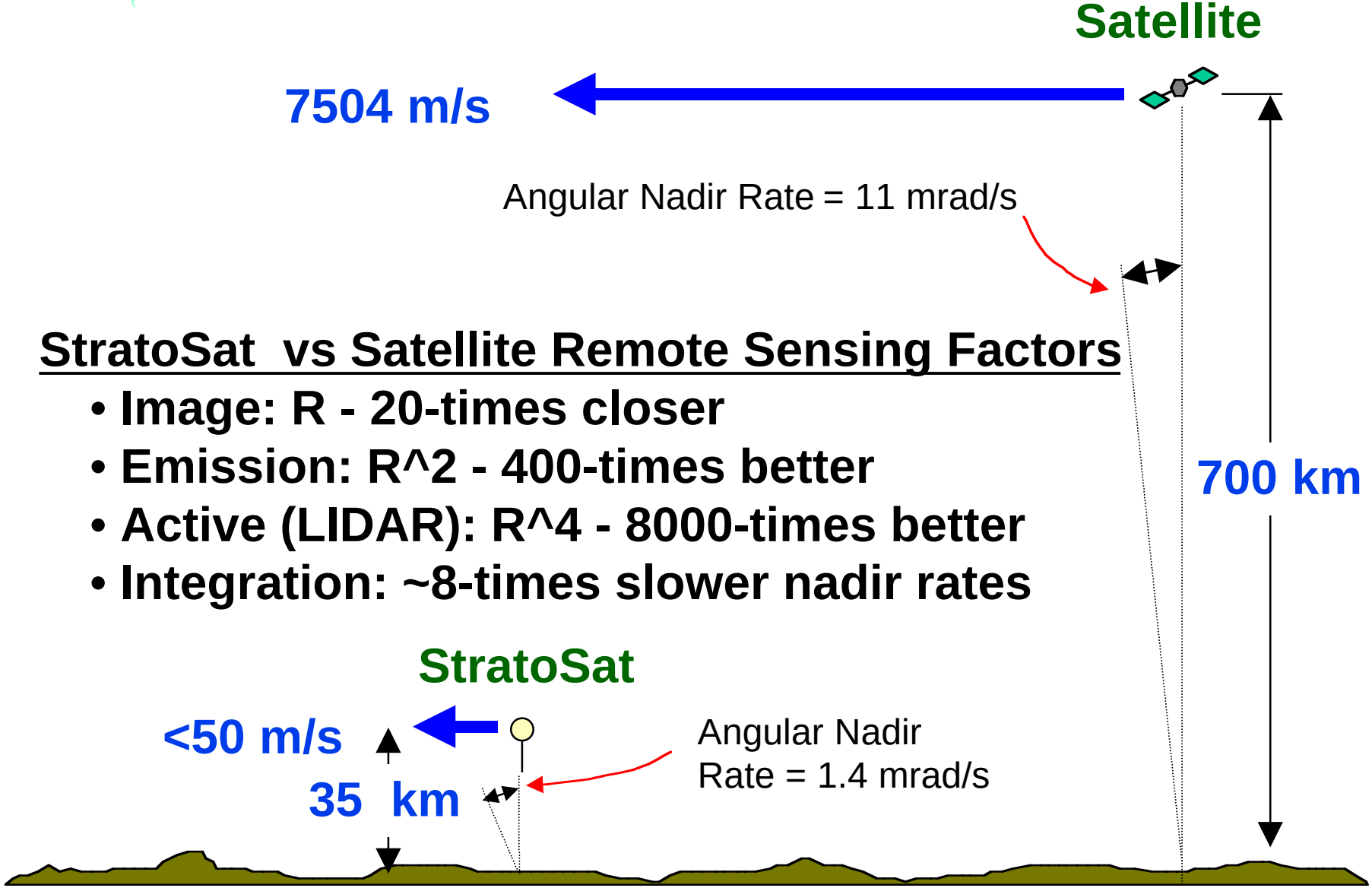
OZONE STUDIES: POLAR OZONE LOSS



Global Aerospace Corporation

Global Stratospheric Constellation

SURFACE REMOTE SENSING



StratoSat vs Satellite Remote Sensing Factors

- **Image: R - 20-times closer**
- **Emission: R^2 - 400-times better**
- **Active (LIDAR): R^4 - 8000-times better**
- **Integration: ~8-times slower nadir rates**

STEPS TO GLOBAL STRATO-SPHERIC CONSTELLATIONS

Constellation Types/Locale

- Regional
  - South Polar
  - Tropics
  - North Polar
- Southern Hemisphere
- Global
  - Sparse Networks for Wide Representative Coverage
  - Dense Networks for Global Surface Accessibility

Measurement Types

- In Situ & Remote Sensing of Atmospheric Trace Gases
- Atmospheric Circulation
- Remote Sensing of Clouds
- Atmospheric State (T, P, U, Winds)
- Radiation Flux
- Low Resolution Visible & IR Surface and Ocean Monitoring
- High Resolution Surface Imaging and Monitoring

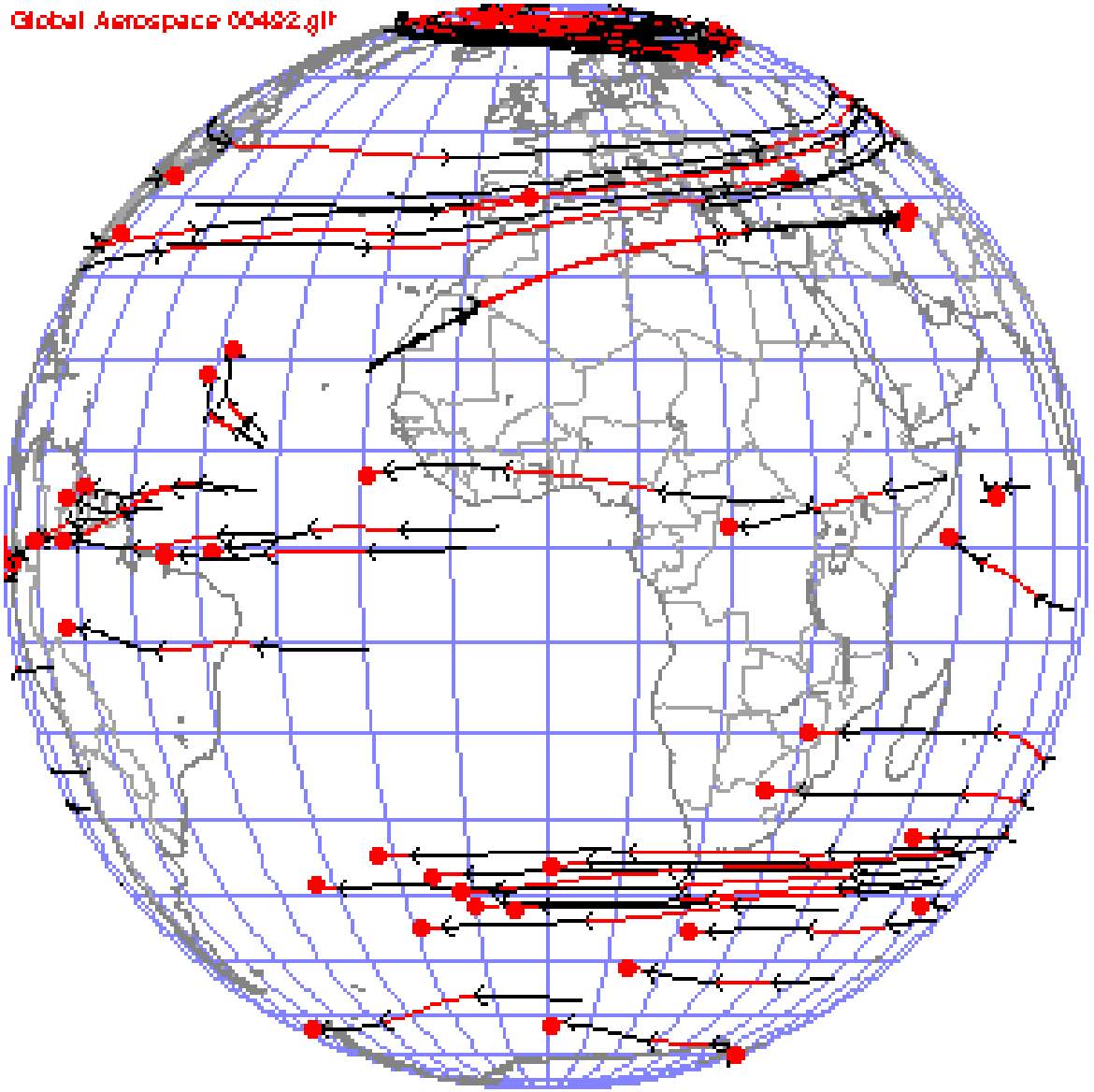
A First Step Is a Proof-of-concept Science Experiment Using Soon to Be Available ULDB Technology

CONSTELLATION MANAGEMENT

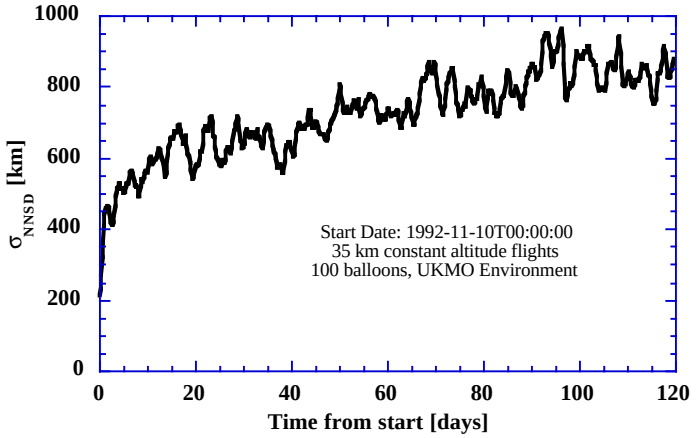
GLOBAL CONSTELLATION WITHOUT TRAJECTORY CONTROL

ASSUMPTIONS

- 100 StratoSats @ 35 km
- Simulation Start: 1992-11-10
- UK Met Office Assimilation
- 4 hrs per frame
- 4 month duration



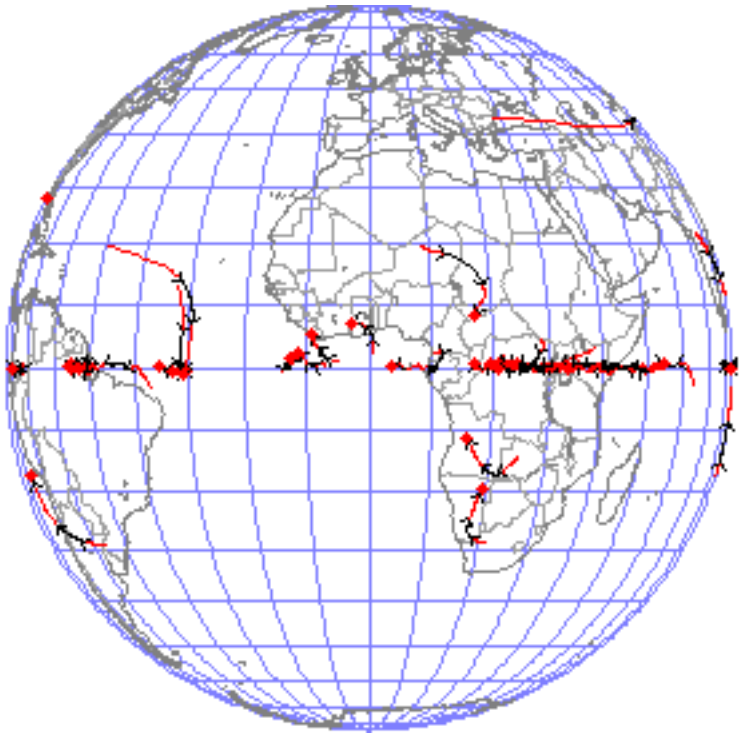
STATISTICS



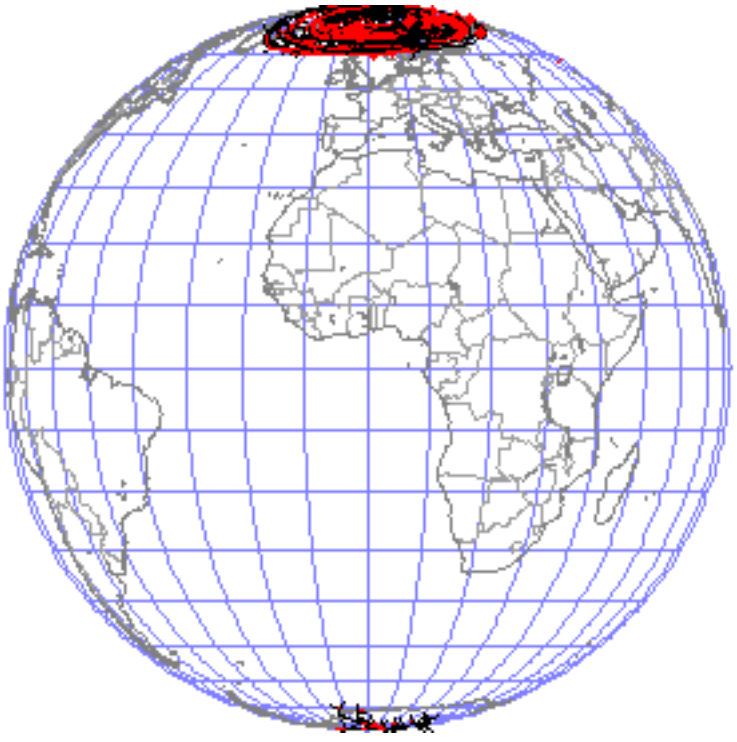
CONSTELLATION GEOMETRY MAINTENANCE

- **Balloons Drift in the Typical and Pervasive Zonal Stratospheric Flow Pattern**
- **Trajectory Control System Applies a Small, Continuous Force to Nudge the Balloon in Desired Direction**
- **Balloons Are in Constant Communications With a Central Operations Facility**
- **Stratospheric Wind Assimilations and Forecasts Are Combined With Balloon Models to Predict Balloon Trajectories**
- **Balloon TCS Are Periodically Commanded to Adjust Trajectory Control Steering to Maintain Overall Constellation Geometry**

ILLUSTRATION OF CONTROL EFFECTIVENESS



5 m/s Toward Equator



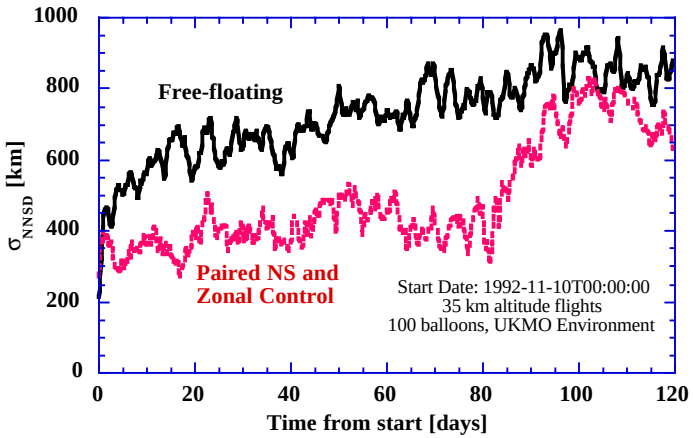
5 m/s Toward Poles

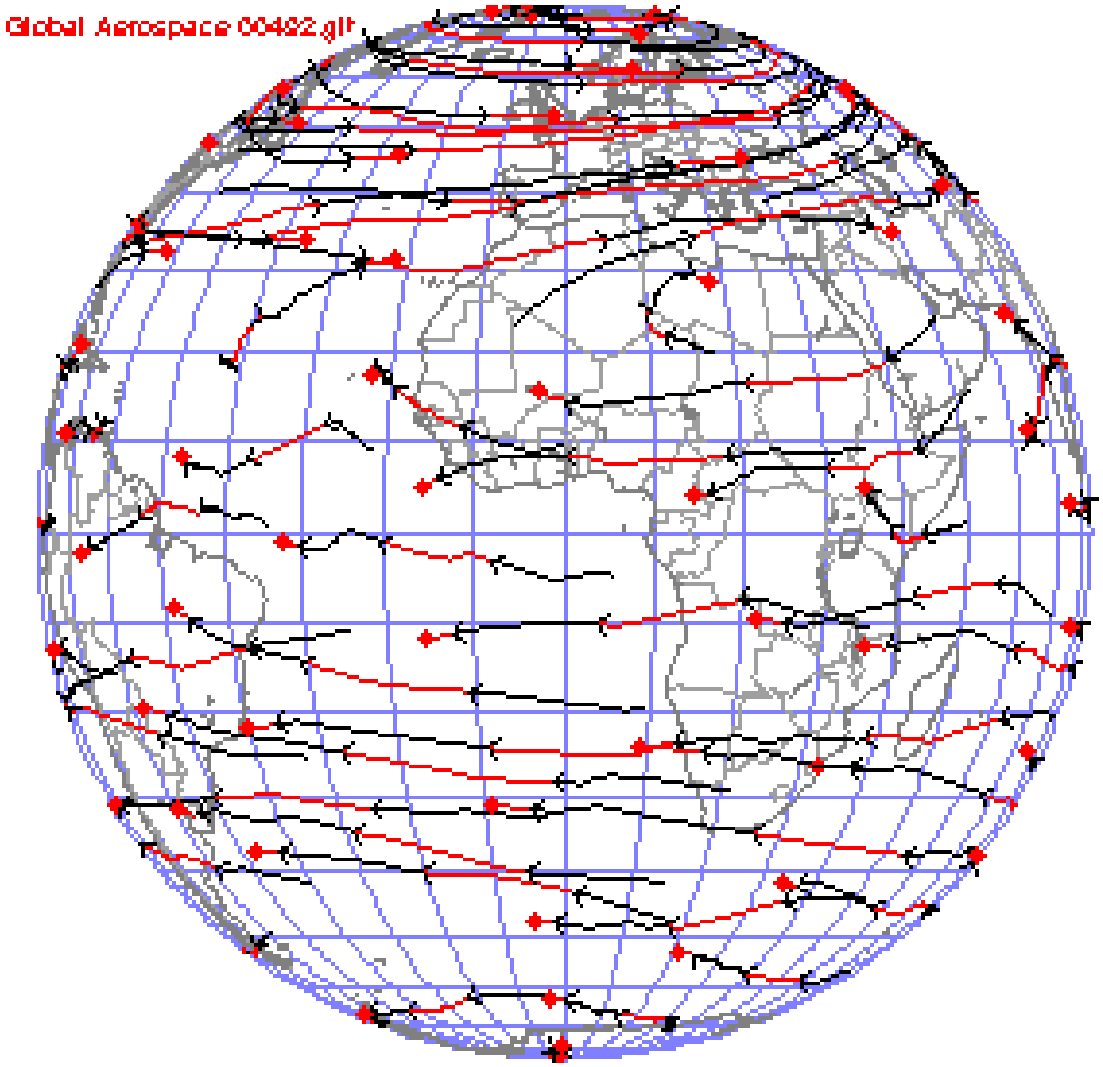
GLOBAL CONSTELLATION WITH SIMPLE, INTELLIGENT CONTROL

ASSUMPTIONS

- 100 StratoSats @ 35 km
- Simulation Start: 1992-11-10
- UK Met Office Assimilation
- 4 hrs per frame
- 4 month duration
- 5 m/s control when separation is < 2000 km
- Same initial conditions

STATISTICS





TRAJECTORY CONTROL

FEATURES OF STRATOSAIL® TCS

- Passively Exploits Natural Wind Conditions
- Operates Day and Night
- Offers a Wide Range of Control Directions Regardless of Wind Conditions
- Can Be Made of Lightweight Materials, Mass <100 kg
- Does Not Require Consumables
- Requires Very Little Electrical Power
- Relative Wind at Gondola Sweeps Away Contaminants

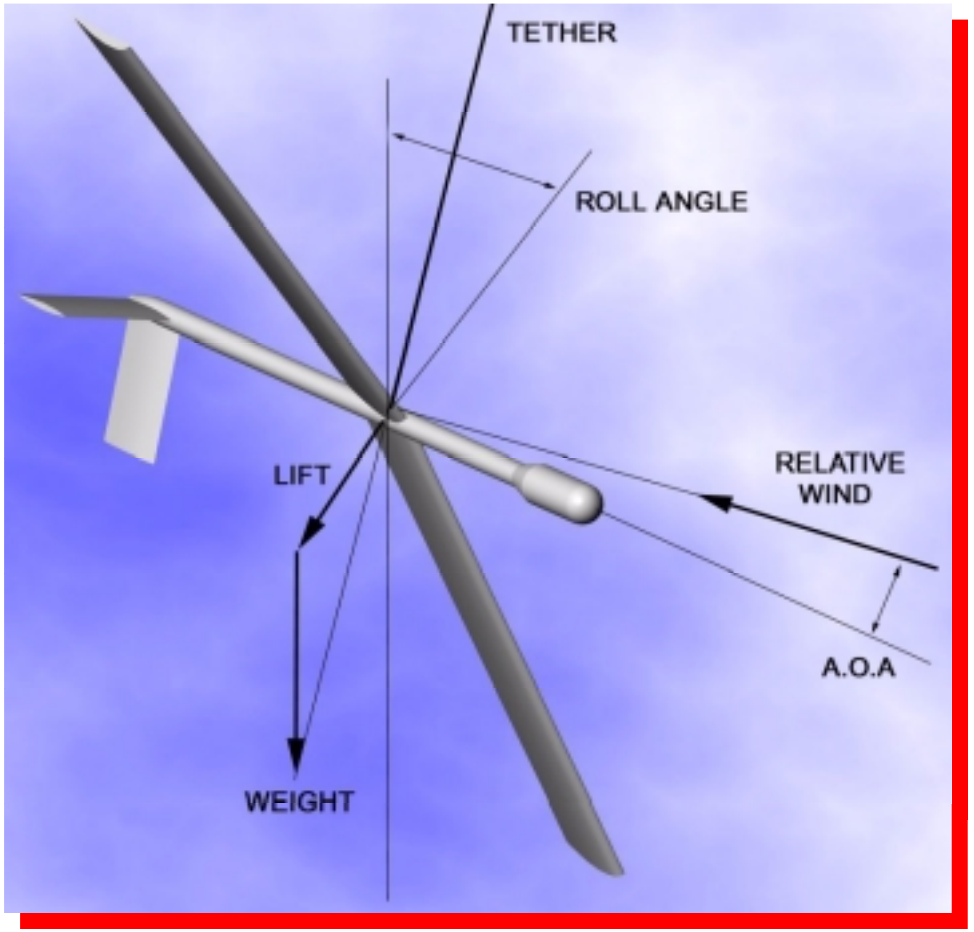
Global Aerospace Corporation

Global Stratospheric Constellation

ADVANCED TRAJECTORY CONTROL SYSTEM

Advanced Design Features

- Lift force can be greater than weight
- Will stay down in dense air
- Less roll response in gusts
- Employs high lift cambered airfoil
- Greater operational flexibility



BALLOON

BALLOON DESIGN OPTIONS

Spherical Envelope

- **Spherical Structural Design**
- **High Envelope Stress**
- **High Strength, Lightweight Laminate Made of Gas Barrier Films and Imbedded High Strength Scrims**
- **Multi-gore, Load / Seam Tapes**

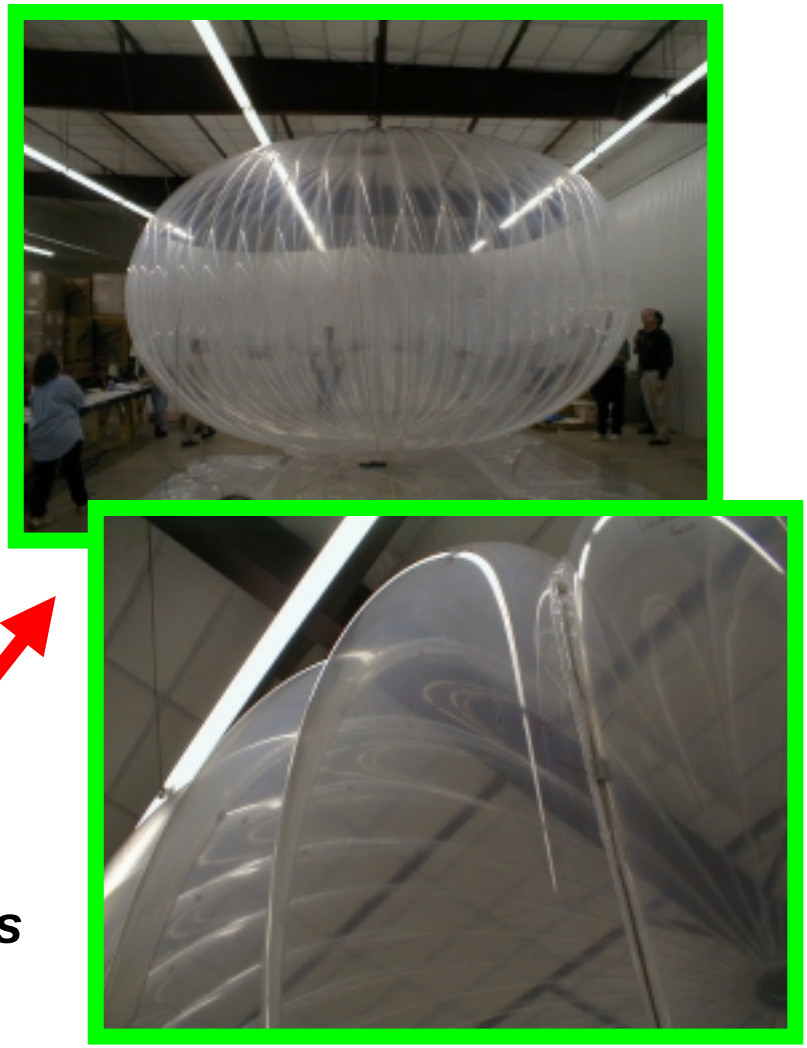
Pumpkin Envelope

- **Euler Elastica Design**
- **Medium Envelope Stress**
- **Lightweight, Medium Strength Films**
- **Lobbed Gores With Very High Strength PBO Load-bearing Tendons Along Seams**

BALLOON VEHICLE DESIGN

Baseline Balloon Design

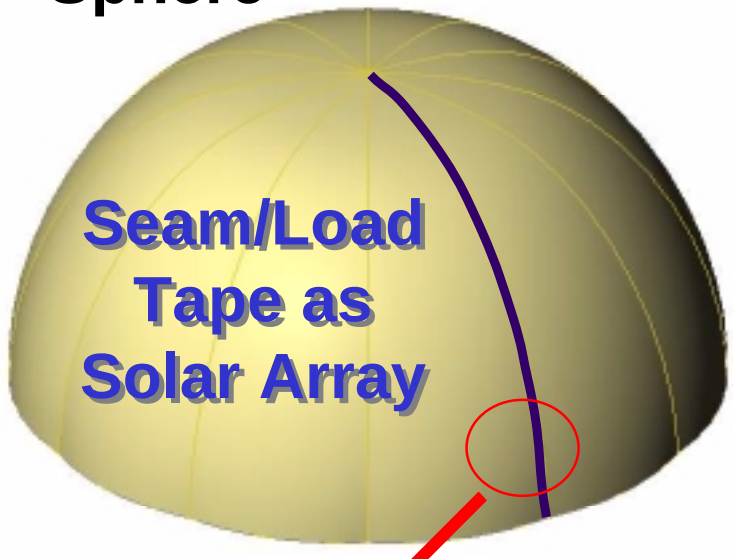
- Euler Elastica Pumpkin Design
- 68,765 m^3, 59/35 m Eq/Pole Dia., Equivalent to 51 m dia. Sphere
- Advanced Composite Film, 15 μm thick, 15 g/m^2 Areal Density
- 140 gores each 1.34 m Max Width
- Polybenzoxazole (PBO) Load Tendons At Gore Seams
- Balloon Mass of 236 kg



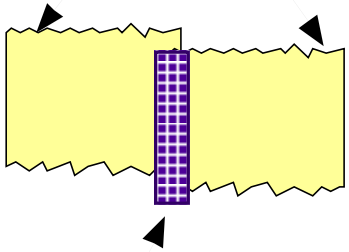
NASA ULDB Scale Model Tests

SOLAR ARRAY / BALLOON INTEGRATION

Sphere



Envelope Film

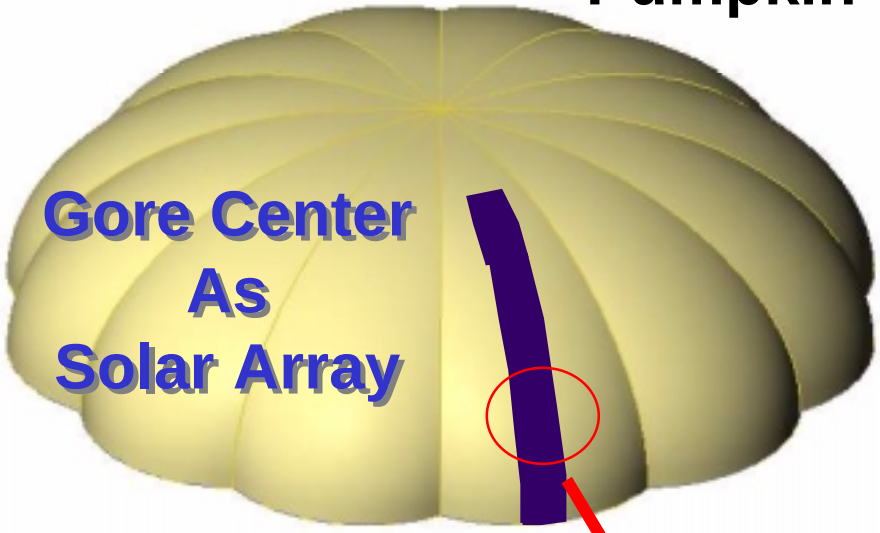


Seam/Load Tape / Solar Cells
(~ 3 cm wide)

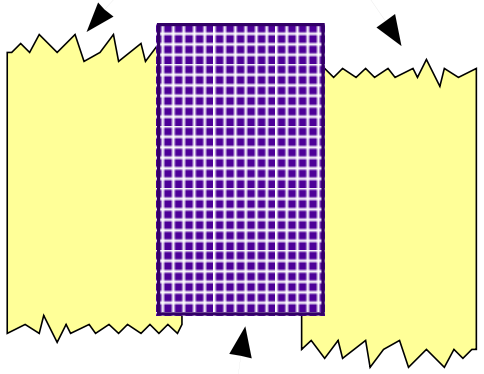
Example Power

- 48 m dia Spherical Design
- 100 Gores/Seams
- 3 cm Wide Solar Array
- 10 % Efficiency
- 4.7 kW

Pumpkin



Envelope Film



Thin Film Amorphous Si
Solar Array Cells
(~30 cm wide)

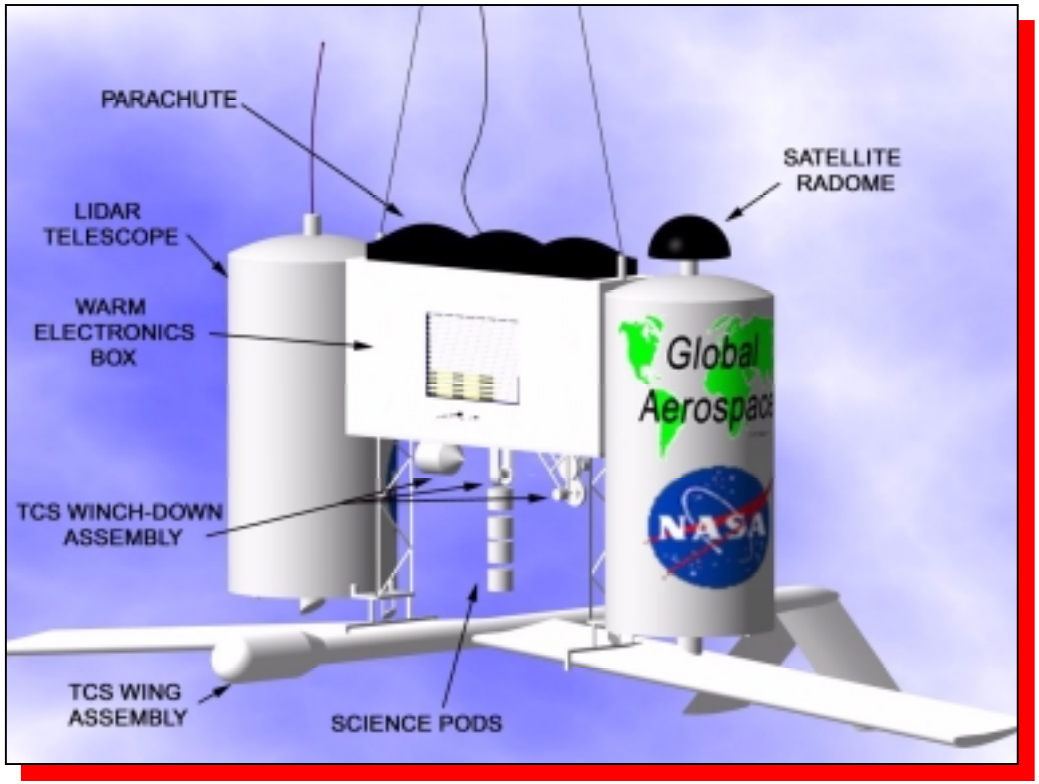
GONDOLA

STRATOSAT GONDOLA

StratoSat Gondola

- Example Climate Change Science Payload
- 2x1x0.5 m warm electronic box (WEB) with louvers for daytime cooling
- Electronics attached to single vertical plate
- LIDAR telescopes externally attached to WEB
- TCS wing assembly (TWA) stowed below gondola at launch before winch-down
- Science pods on tether

Stowed Gondola



INTERNATIONAL OVERFLIGHT CONSIDERATIONS

INTERNATIONAL OVERFLIGHT

- **Current NASA Scientific Balloon Program**
  - **Overflight Often Allowed Especially If No Imaging and If Scientists of Concerned Countries Are Involved**
  - **Not All Countries Allow Overflight and This List Changes Depending on World Political Conditions**
- **Treaty on Open Skies (TOS) - Signed By 25 Nations in 1992**
  - **Establishes a Regime of Unarmed Military Observation Flights Over the Entire Territory of Its Signatory Nations**
  - **First Step of Confidence Building Security Measures (CBSM)**
- **Future Political Climate**
  - **Global Networks Can Build on World Meteorological Cooperation**
  - **World Pollution Is a Global Problem Which Will Demand Global Monitoring Capability**
  - **First Steps Need to Be Important Global Science That Does Not Require Surface Imaging**

INTERNATIONAL ISSUES: CONTACTS TO DATE

- **Department of State (DOS)**
  - **Office of Space and Advanced Technology**
    - **Very Interested in Potential of Global Constellations for Monitoring International Environmental Agreements**
    - **Invited GAC to Participate in Planning International Workshops - Seville & Sustainable Development**
    - **Interested in Supporting GAC in Analysis of Foreign Policy Issues**
- **Defense Threat Reduction Agency (DTRA)**
  - **Key Agency for Treaty on Open Skies (TOS), Referred to by DOS**
  - **DTRA Mission**

    Reduce the Threat From Nuclear, Biological, Chemical (NBC), Conventional and Special Weapons Through Technology Security Activities, Cooperative Programs, Treaty Monitoring and On-site Inspection, and Counterproliferation
  - **Interested in Mixed Platform Systems For TOS**
  - **Global Balloon Networks Potentially Offer Low Cost, High Technology Solutions**
- **World Meteorology Organization (WMO) - Dieter Schiessl, Director, Basic Systems**
  - **WMO is potential vehicle for establishing global constellations**
  - **Need to Think in Terms of a Long-term Strategy**
  - **Global Balloon Networks Enable All Countries to Contribute and to Benefit**
  - **WMO Charter Goes Well Beyond Meteorology**

SUMMARY

SUMMARY

- **The StratoSat Is a New Class of *in situ* Platform Providing:**
  - **Low-cost, Continuous, Simultaneous, Global and Regional Observations Options**
  - ***In Situ* and Remote Sensing From Very Low Earth "Orbit"**
- **Global and Regional Stratospheric Constellations Will Expand Scientific Knowledge of the Earth System**
- **There Has Been Strong Involvement of NASA's Earth Science Community During Phase I and This is Being Expanded in Phase II.**
- **International Pathways Toward Concept Appear to Exist**
- **A Proof-of Concept Science Mission Is One Essential First Step on the Path Toward Global Stratospheric Constellations**