GLOBAL CONSTELLATION OF STRATOSPHERIC SCIENTIFIC PLATFORMS

Presentation to the NASA Institute of Advanced Concepts (NIAC)

by

Kerry T. Nock

Global Aerospace Corporation

November 9, 1999

TOPICS

- **CONCEPT OVERVIEW**
- **EARTH SCIENCE OVERVIEW**
- **CONSTELLATION MANAGEMENT**
- **TRAJECTORY CONTROL**
- **BALLOON**
- **GONDOLA**
- **INTERNATIONAL CONSIDERATIONS**
- **PHASE 2 PLAN**
- **SUMMARY**

CONCEPT OVERVIEW

BENEFITS OF STRATOSPHERIC CONSTELLATIONS TO NASA

- **Provide low-cost, continuous, simultaneous, global Earth observations options**

- **Provides in situ and remote sensing from very low Earth "orbit"**

CONCEPT DESCRIPTION

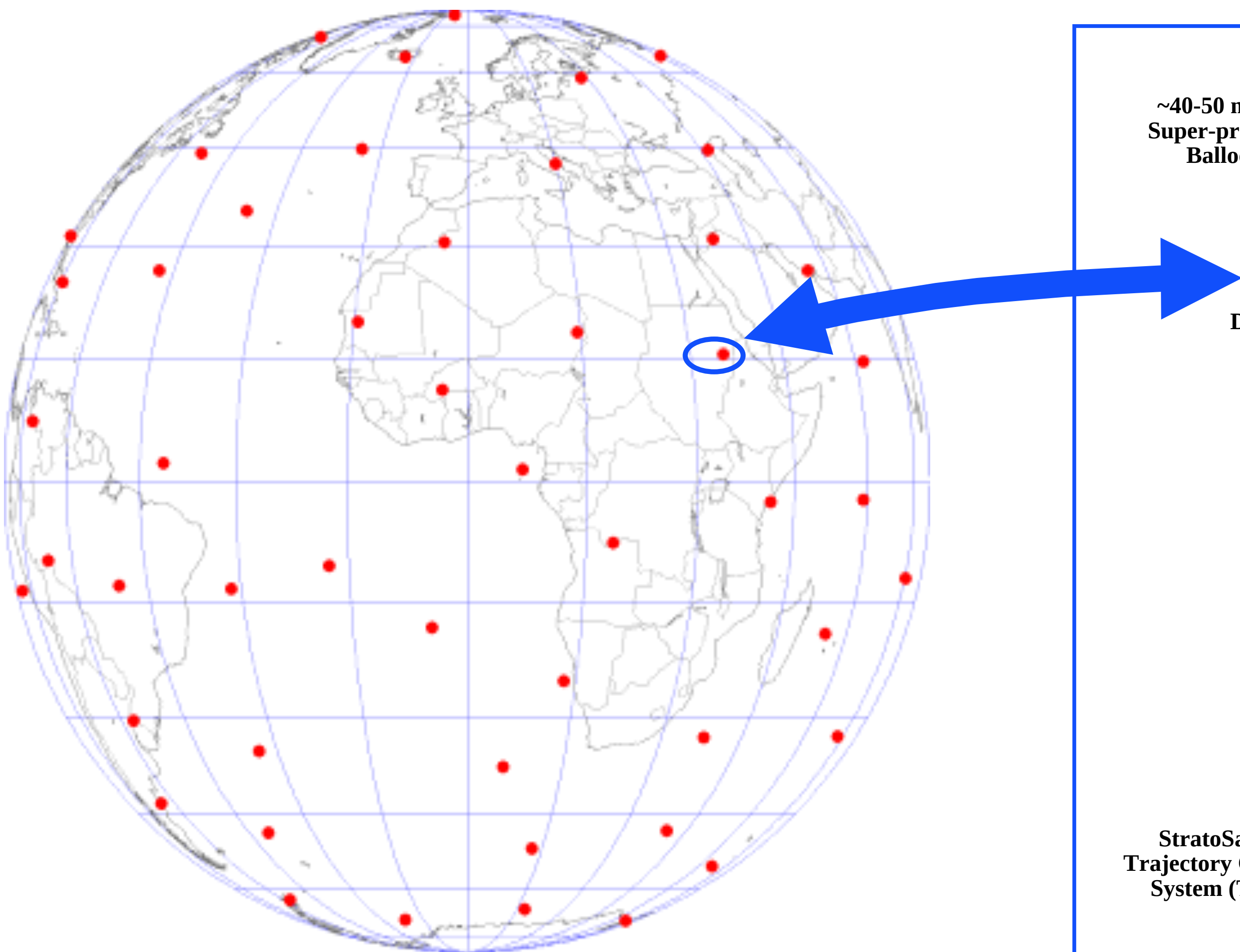
- **Tens to Hundreds of Small, Long-life Stratospheric Balloons or *StratoSats***
- **Uniform Global Constellation Maintained by Trajectory Control Systems (TCS)**
- **Flight Altitudes of 30-35 km Achievable With Advanced, Lightweight, Superpressure Balloon Technology**
- **Gondola and TCS Mass of 235 kg at 35 km Altitude**
- **Goal of ~50% Science Instrument Payload of Gondola**

Global Aerospace Corporation

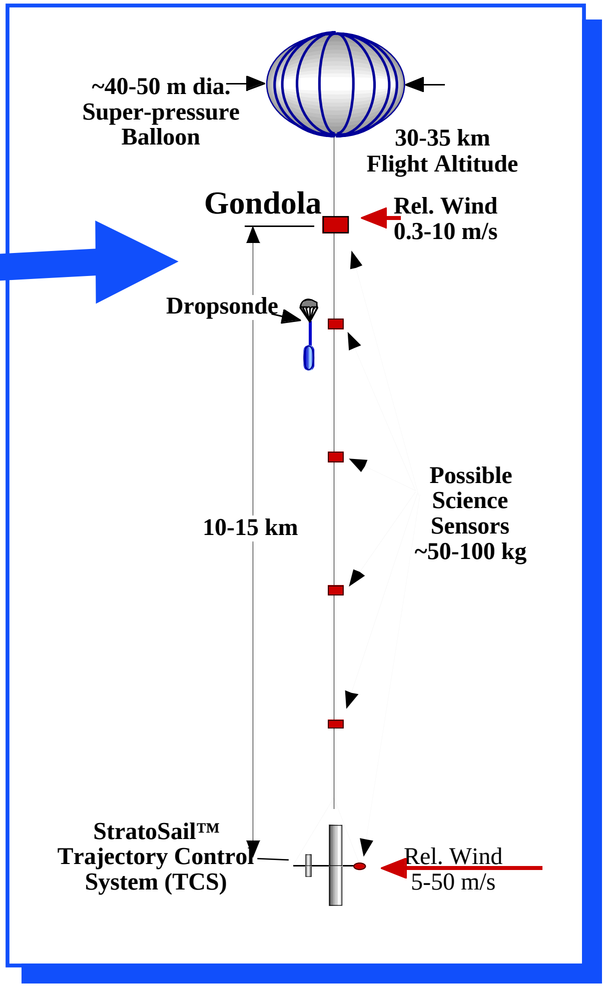
Global Stratospheric Constellation

CONCEPT SCHEMATIC

Global Constellation



StratoSat Flight System



RATIONALE FOR STRATOSATS

- **High Cost of Space Operations (Spacecraft and Launchers) Relative to Balloon Platforms**
- **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

EARTH SCIENCE OVERVIEW

ESE STRATEGIC PLAN GOALS

Expand scientific knowledge of the Earth system . . . from the vantage points of space, aircraft, and in situ platforms

- **Understand the causes and consequences of land-cover/land-use change**
- **Predict seasonal-to-interannual climate variations**
- **Identify natural hazards, processes, and mitigation strategies**
- **Detect long-term climate change, causes, and impacts**
- **Understand the causes of variation in atmospheric ozone concentration and distribution**

Global Aerospace Corporation

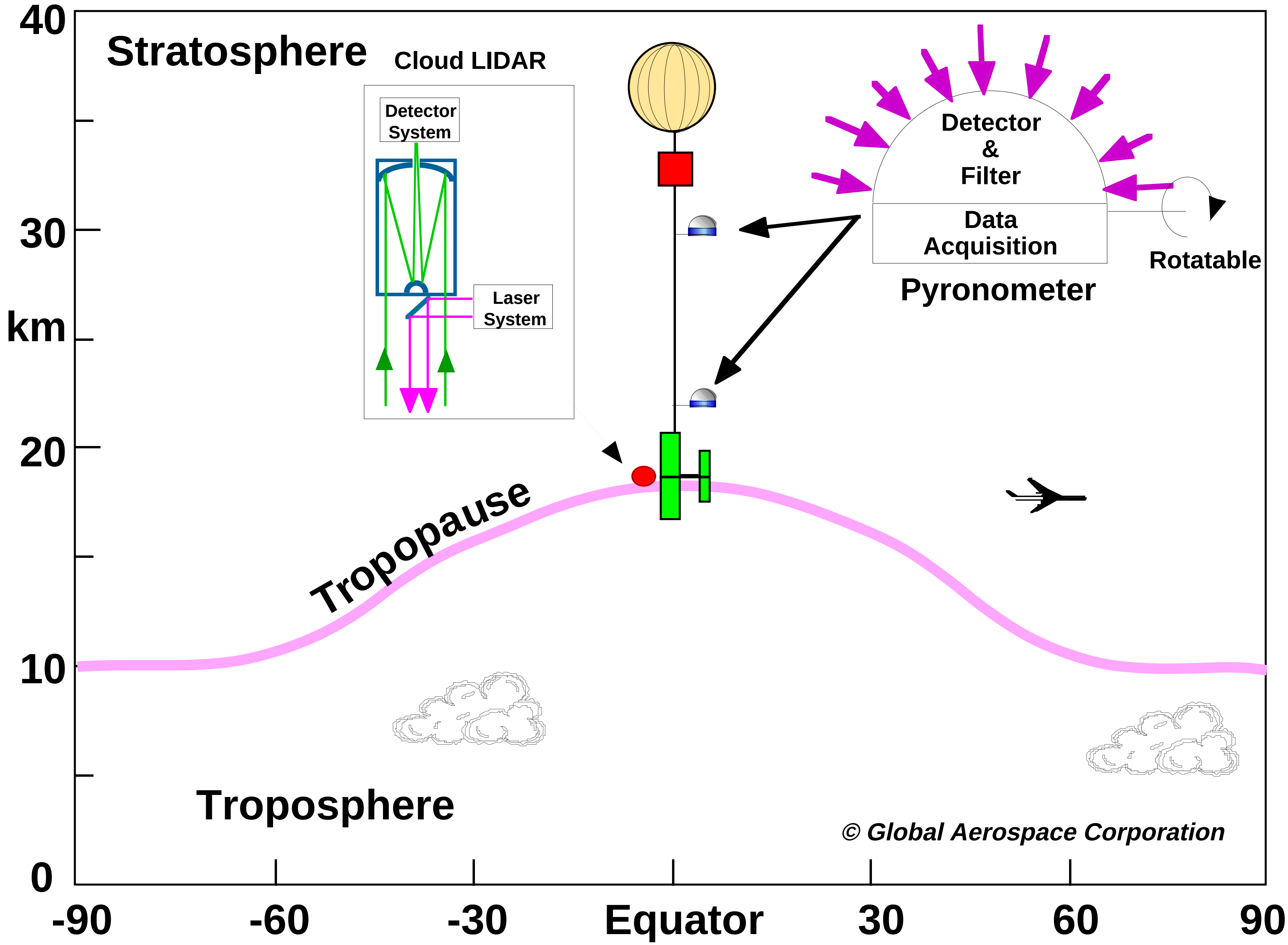
Global Stratospheric Constellation

PROMISING EARTH SCIENCE THEMES

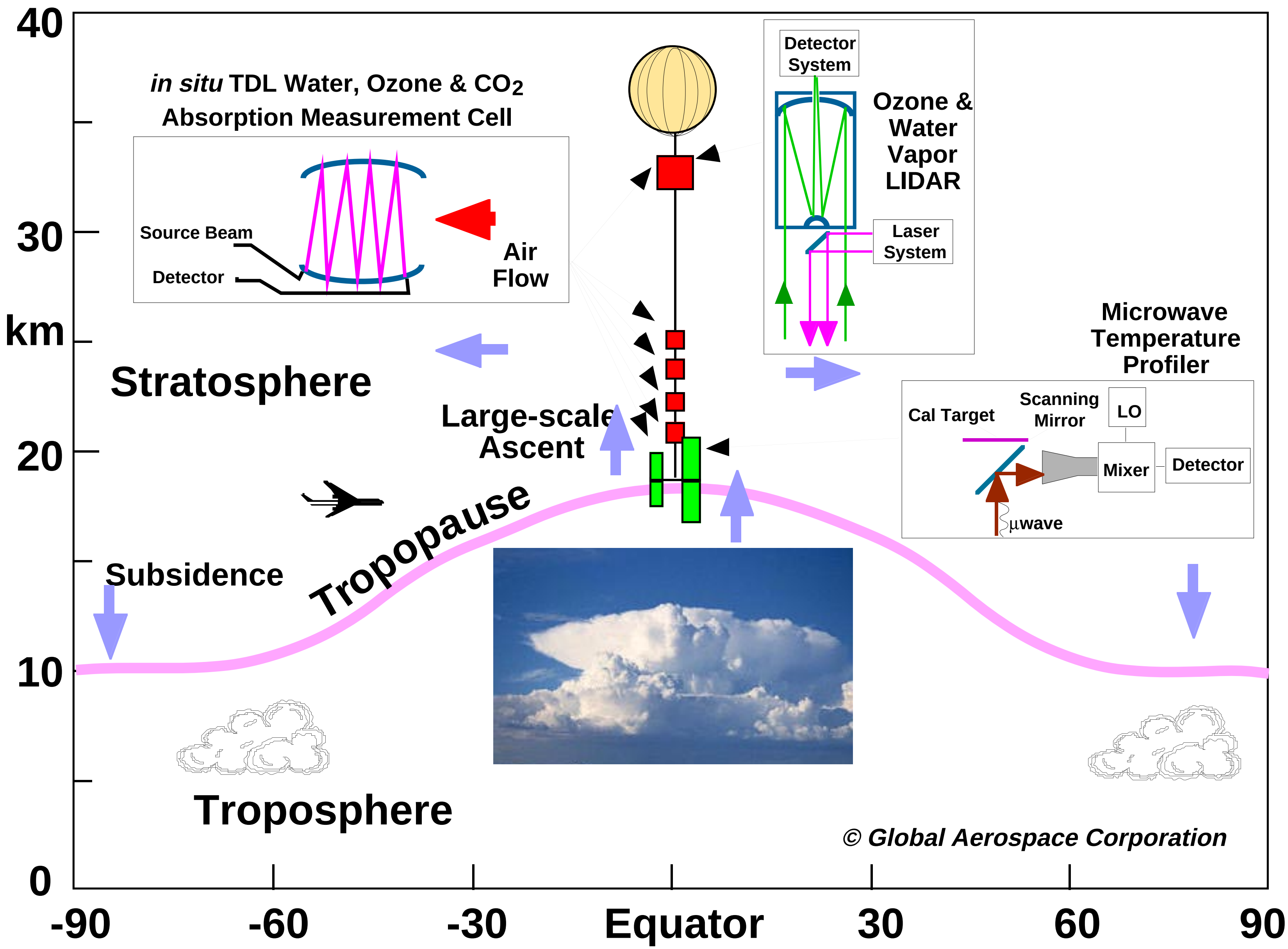
- Climate Change Studies
  - **Water Vapor and Global Circulation in the Tropics***
  - **Radiative Studies in the Tropics:**
  - **Global Radiation Balance***
- Ozone Studies
  - **Mid-latitude Ozone Loss**
  - **Arctic Ozone Loss***
  - **Global Distribution of Ozone***
- Weather Forecasting
  - **Hurricane 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*

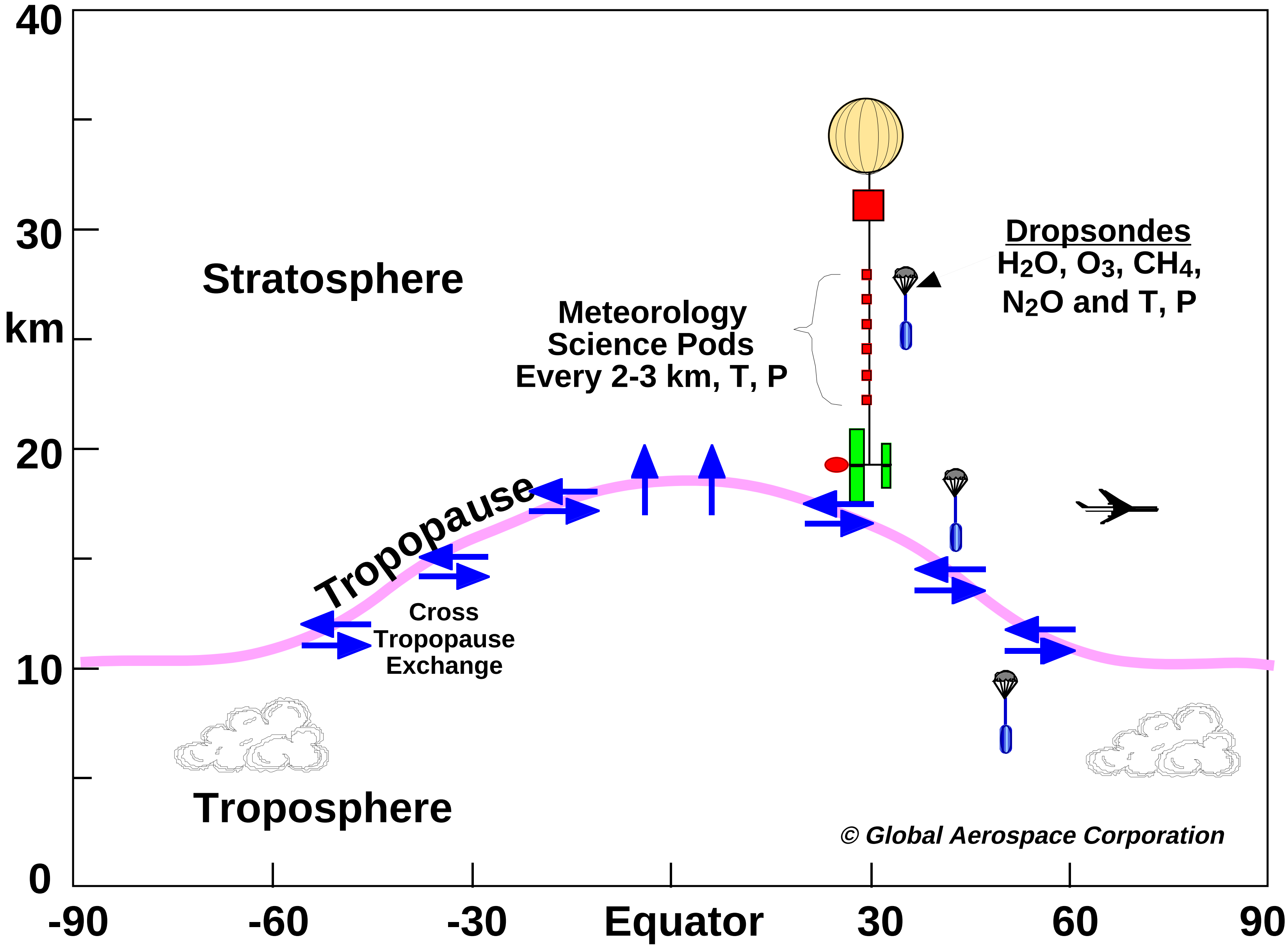
CLIMATE CHANGE: GLOBAL RADIATION BALANCE



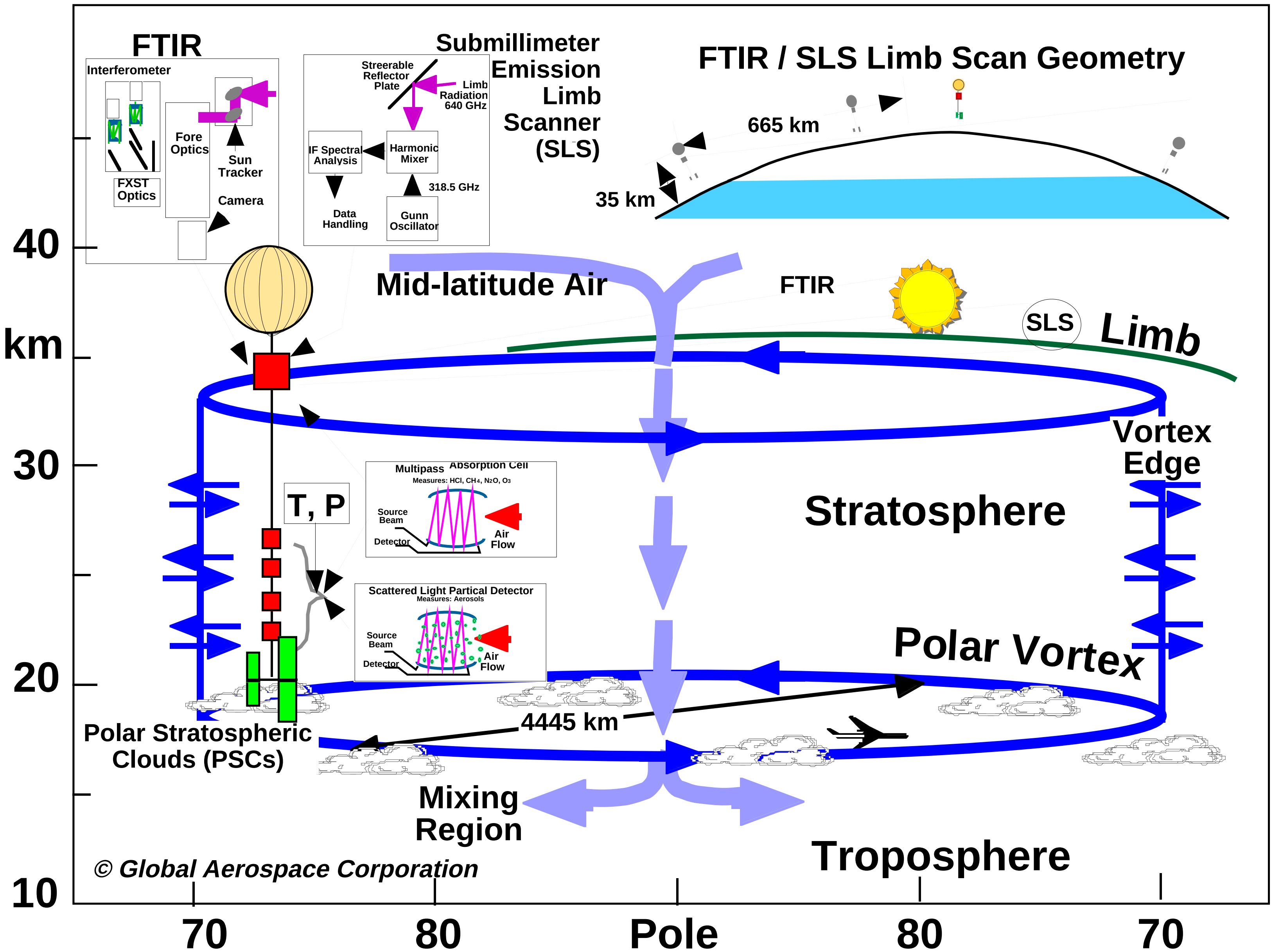
CLIMATE CHANGE: DYNAMICAL PROCESSES IN TROPICS



OZONE STUDIES: GLOBAL DISTRIBUTION OF OZONE



OZONE STUDIES: POLAR OZONE LOSS



Global Aerospace Corporation

Global Stratospheric Constellation

SURFACE REMOTE SENSING

7200 m/s

- **At 30 km a StratoSat Platform Is >30 times Closer to the Earth's Surface Than Sun-synchronous LEO Satellites**
- **The Ground Speed of a 30 km StratoSat Is a Factor of >140 times Slower Than LEO Satellites (angular rates over nadir are >2 times less)**
- **A Constellation of Stratospheric Balloons Can Observe the Entire Earth at the Same Time**

1000 km

<50 m/s

30-45 km

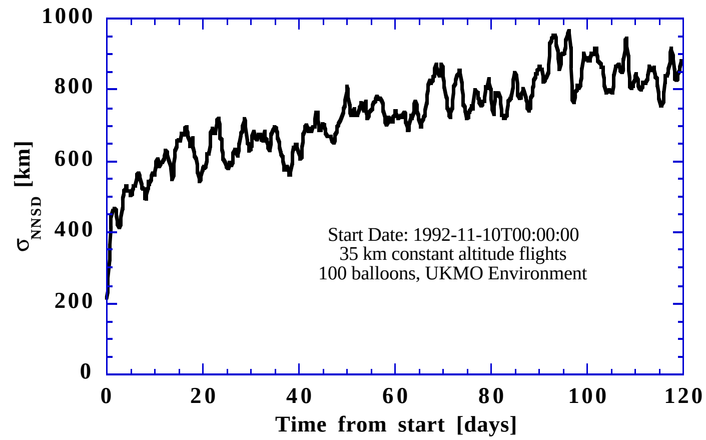
CONSTELLATION MANAGEMENT

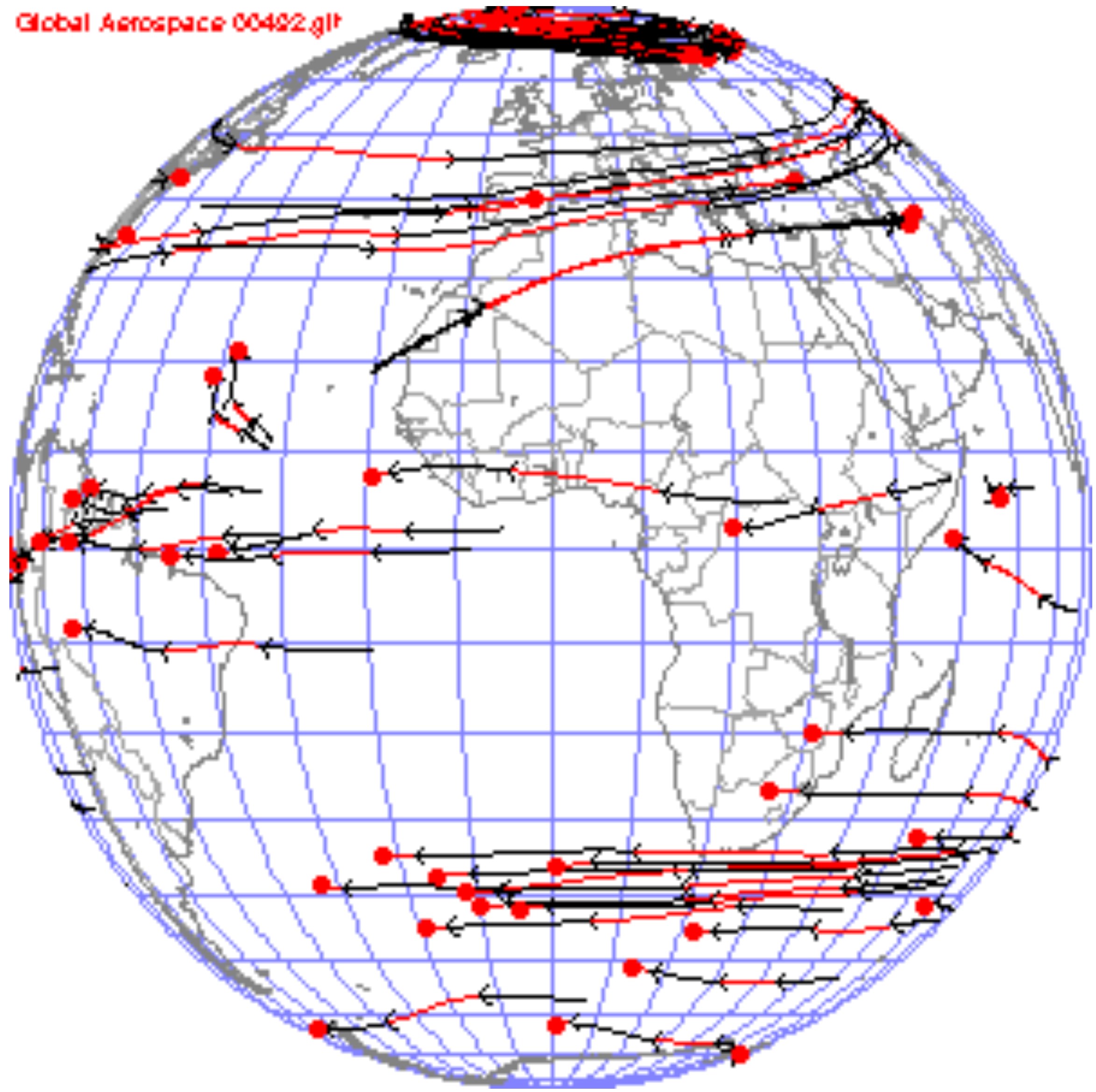
GLOBAL CONSTELLATION WITHOUT TRAJECTORY CONTROL

ASSUMPTIONS

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

STATISTICS

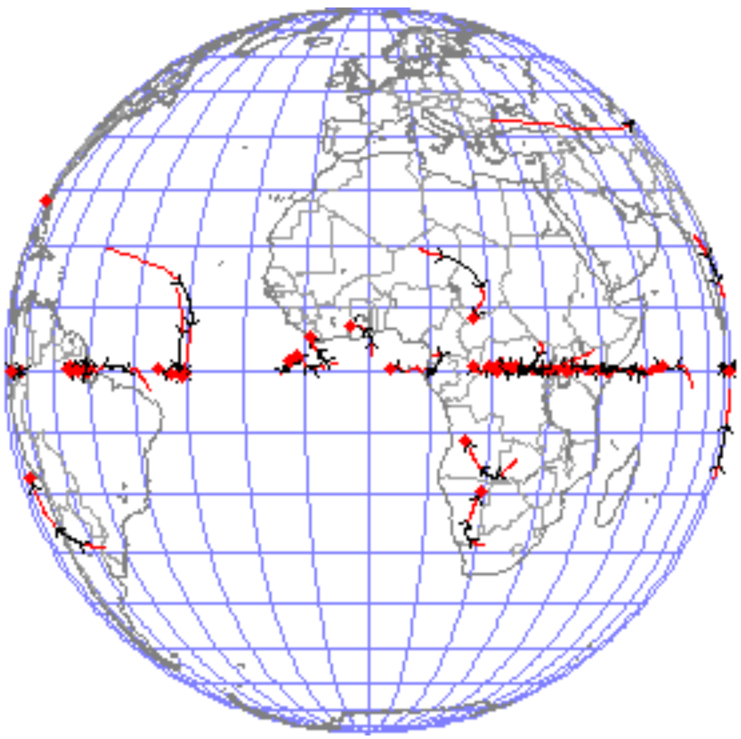




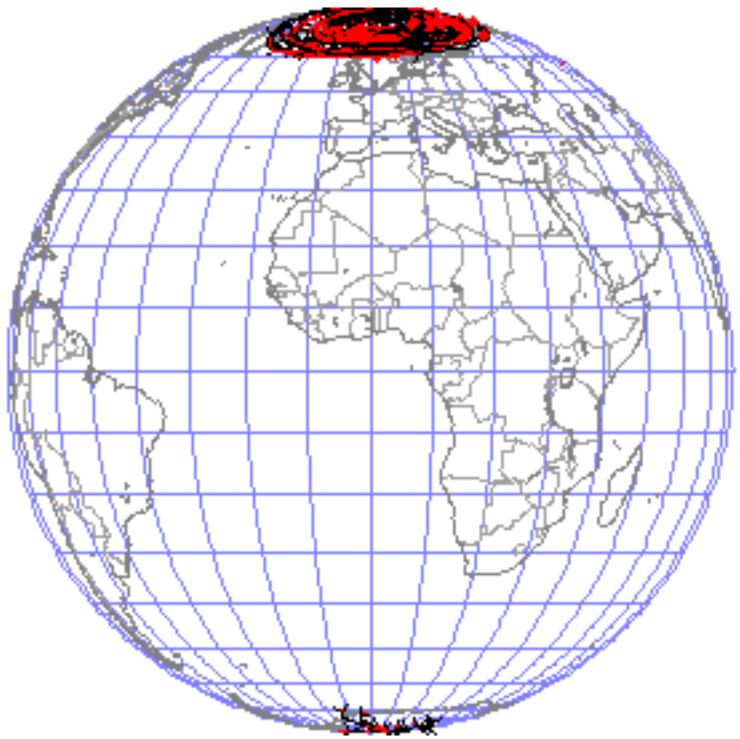
CONSTELLATION GEOMETRY MAINTENANCE

- **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 Stratospheric Constellation

MAINTENANCE STRATEGIES

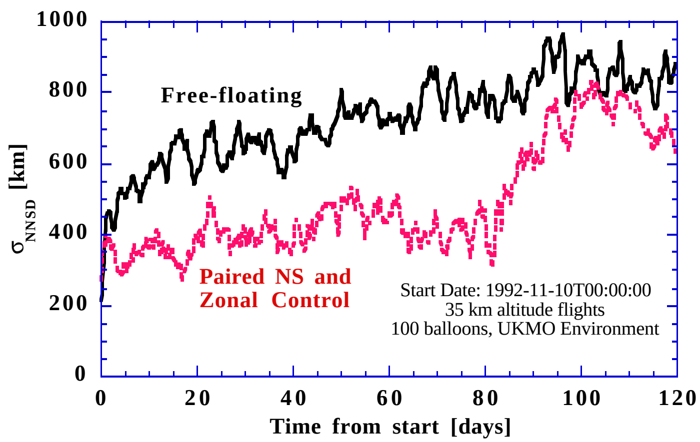
- **Environment Information Used**
  - Successive Correction Data (Interpolated Measurements)
  - Assimilations (Atmospheric Model Tuned by Actual Measurements)
  - Forecasts (Can Be Used for "Look-ahead" Decision-making)
- **Level of TCS Model Fidelity**
  1. Omni-directional Delta-v of Fixed Amount Applied at StratoSat
  2. Delta-v Proportional to True Relative Wind at TCS
  3. Actual TCS Aerodynamic Model and Sophisticated TCS Control Algorithms
- **Network Control Algorithms**
  - Randomization: Move StratoSats North or South Randomly
  - "Molecular" Control: Each Balloon Responds Only To Its Neighbor
  - Macro Control: Entire Network Is Managed, Balloons Are Moved Between Zones
- **Cyclone Scale Coordinates for Control Algorithms**

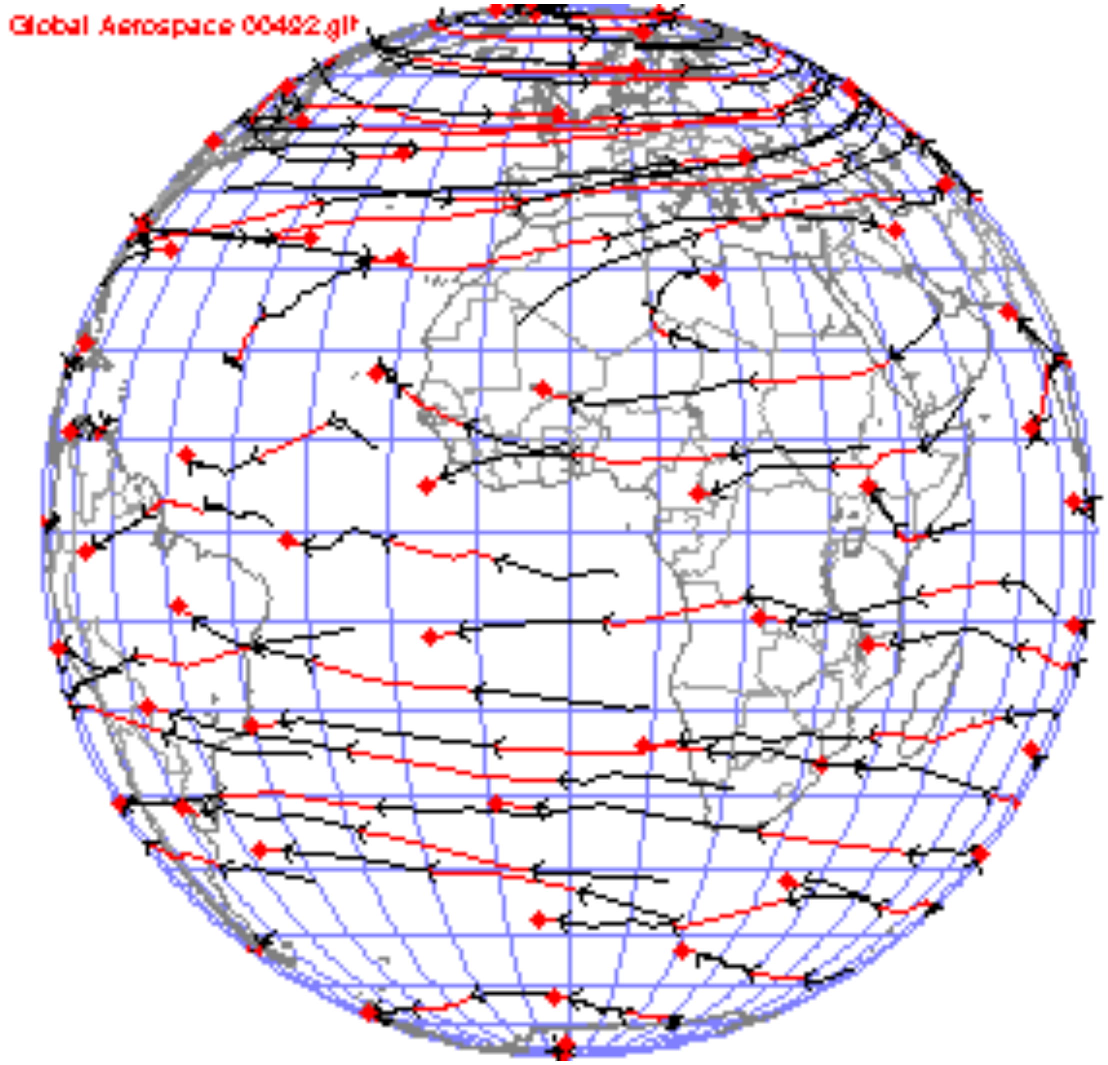
GLOBAL CONSTELLATION WITH SIMPLE, INTELLIGENT CONTROL

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

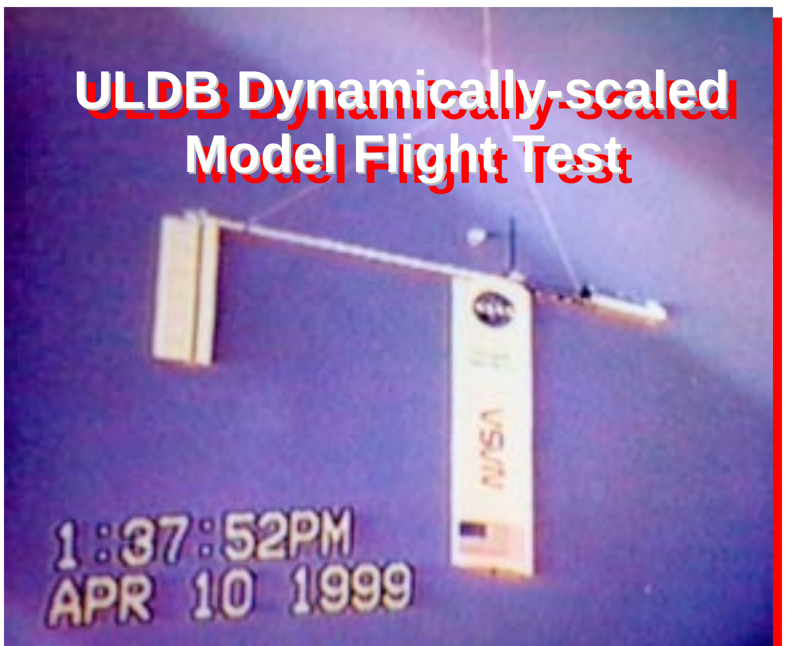
- **Passively Exploits Natural Wind Conditions**
- **Operates Day and Night**
- **Offers a Wide Range of Control Directions Regardless of Wind Conditions**
- **Can Be Made of Lightweight Materials, Mass <100 kg**
- **Does Not Require Consumables**
- **Requires Very Little Electrical Power**
- **Relative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

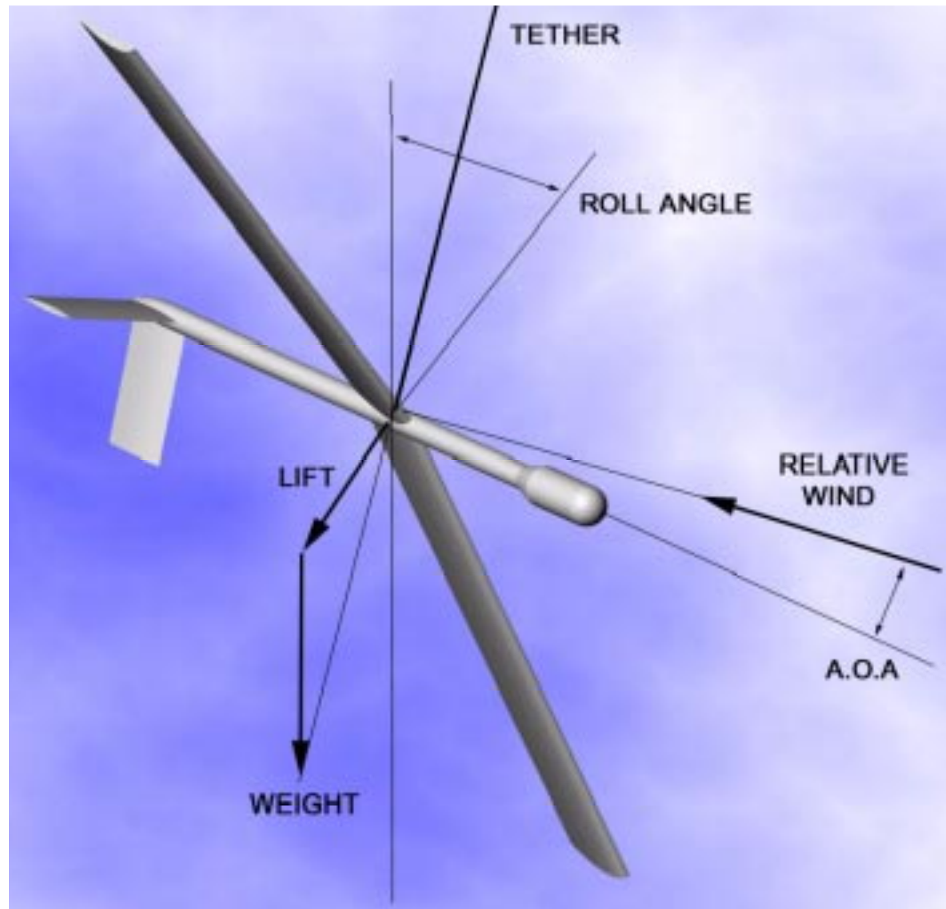
Global Stratospheric Constellation

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

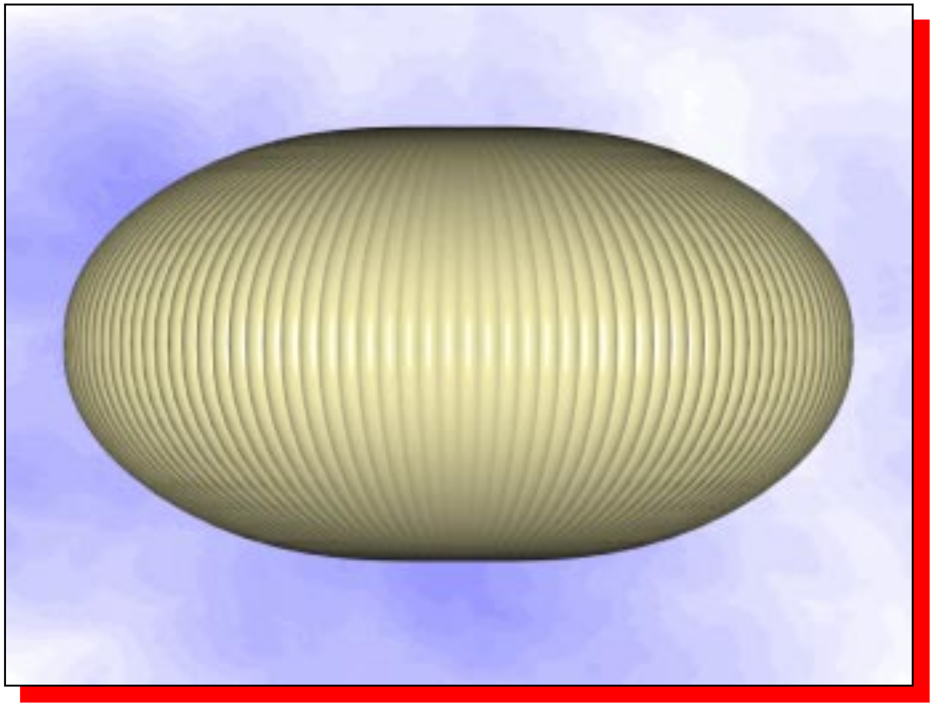
- Euler Elastica Design
- Medium Envelope Stress
- Lightweight, Medium Strength Films
- Lobbed Gores With Very High Strength PBO Load-bearing Tendons Along Seams

Global Stratospheric Constellation

BALLOON VEHICLE DESIGN

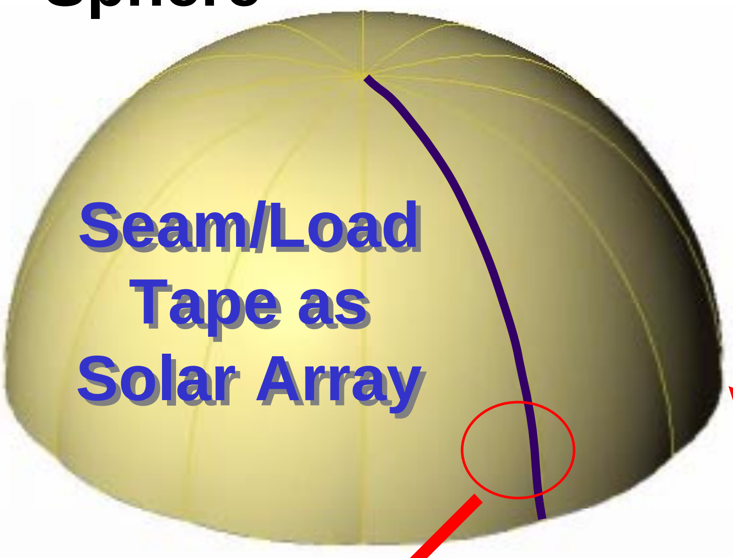
Baseline Balloon Design

- 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

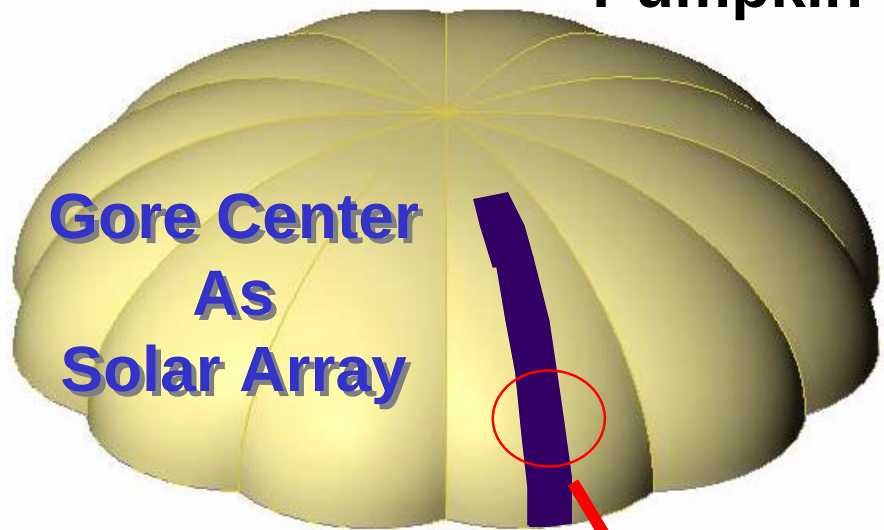


SOLAR ARRAY / BALLOON INTEGRATION

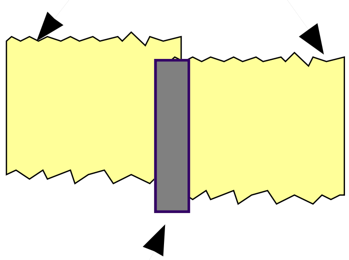
Sphere



Pumpkin

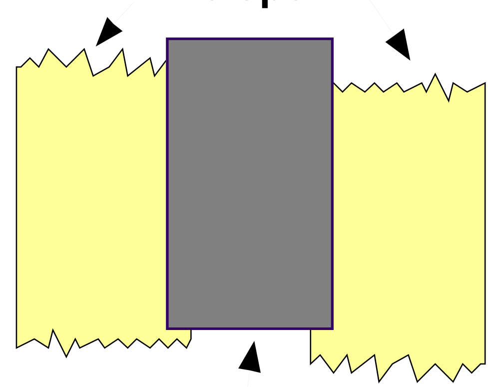


Envelope Film



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

Envelope Film



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

Example Power

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

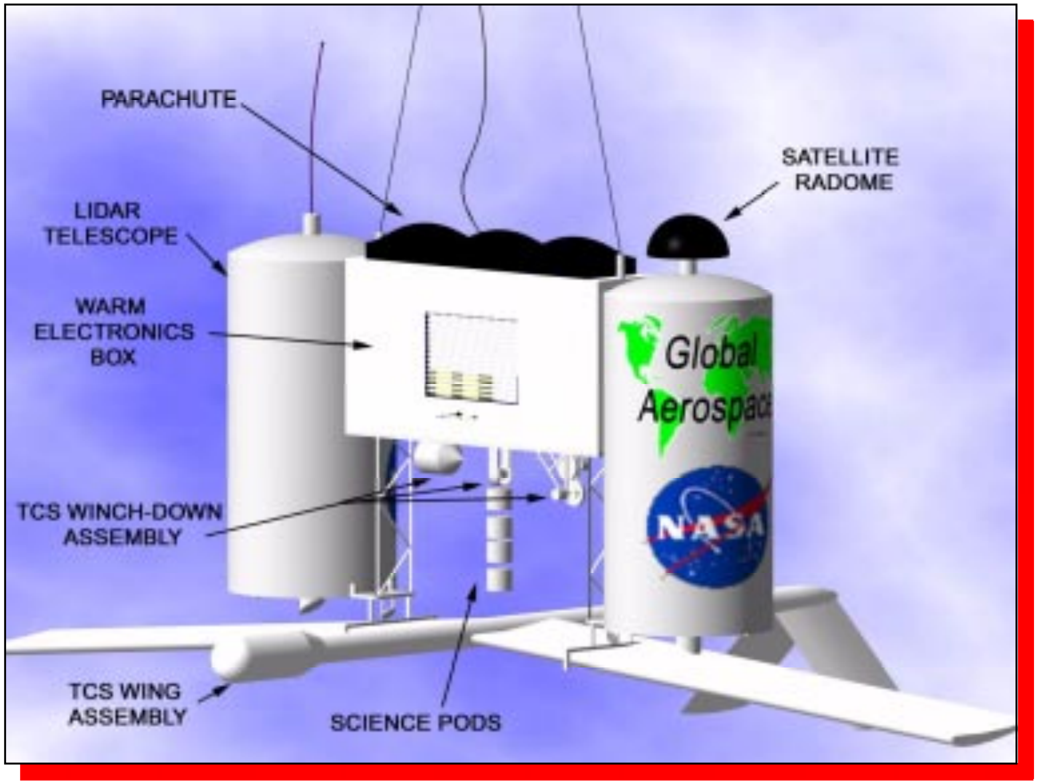
GONDOLA

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

Global Aerospace Corporation

Global Stratospheric Constellation

INTERNATIONAL OVERFLIGHT

- **Current 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 - 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

PHASE II PLAN

Global Aerospace Corporation

Global Stratospheric Constellation

PHASE II PLAN

- **Constellation Management**
  - Control of Distributed Systems in Chaotic Environments Research
  - Develop Advanced Constellation Geometry Control Algorithms
  - Integrate Balloon Model, Environment and Advanced TCS Models and Control Algorithms in Constellation Simulations and Analysis
- **Advanced Trajectory Control**
  - Develop Control Models and Design Concepts
- **Advanced Balloon Design**
  - Materials Research
  - Structural and Thermal Design
  - Envelope Design and Fabrication Technology
- **Science Applications Development**
  - Proof-of-Concept Flight Definition - A Logical Next Step
  - Broaden Search for New Earth Science Concepts

SUMMARY

Global Aerospace Corporation

Global Stratospheric Constellation

SUMMARY

- **The StratoSat Is a New Class of *in Situ* Platform Providing:**
  - **Low-cost, Continuous, Simultaneous, Global Observations Options**
  - ***In Situ* and Remote Sensing From Very Low Earth "Orbit"**
- **Global Stratospheric Constellations Will Expand Scientific Knowledge of the Earth System**
- **Broader Involvement of the Earth Science Community Is Encouraged and Sought in the Definition of Constellation Mission and Instrument Concepts**
- **A Proof-of Concept Science Mission Is One Essential First Step on the Path Toward Global Stratospheric Constellations**

APPENDIX

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

Measurements 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

Global Aerospace Corporation

Global Stratospheric Constellation

STRATOSAT FLIGHT SYSTEM DESCRIPTION

Flight System Design Features

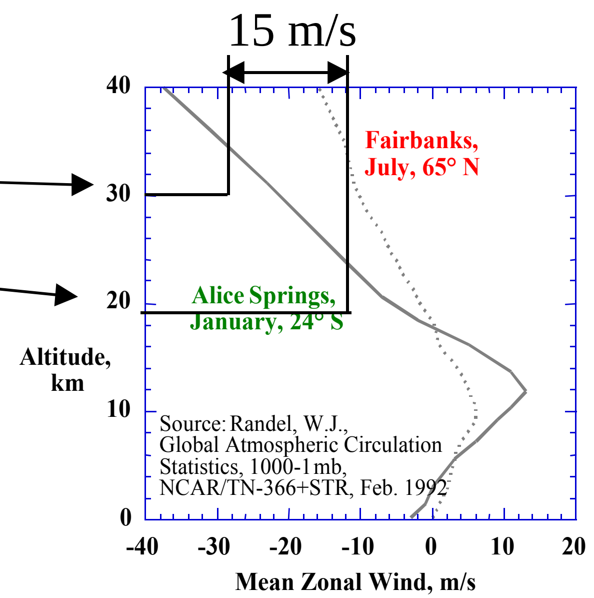
- Sample Payload for Climate Change Studies in Tropics
- 68,800 m^3 Pumpkin balloon
- 5 kW capable integrated solar array
- Telecom capable of 6 Mb/s
- Advanced TCS
- Tethered science pods

Mass Summary

Subsystem	Mass, kg
Balloon	236
Helium	87
Power	19
Telecomm	5
Mechanical	30
Guidance & Control	1
Robotic Controller	1
Trajectory Control	81
Science	56
Science Reserve	44
Total	560

HOW THE TCS WORKS

- **Winds vary with altitude**
  - Balloon at 30 km
  - Wing at 20 km
  - Relative wind velocity ~15 m/s



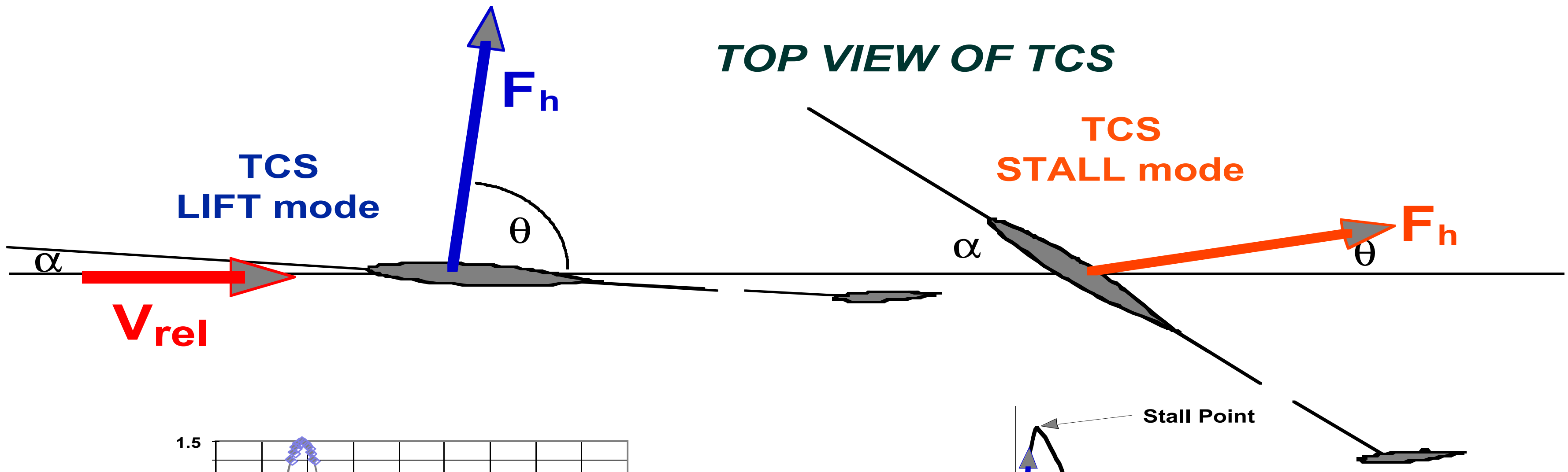
- **Wing generates lift force**
  - "Lift" force is horizontal
  - force is transmitted by tether to balloon
  - balloon drifts relative to local air mass
  - balloon drag ≈ wing lift
- **Wing is in much denser air than balloon**
  - 25km : 35km (5x); 20km : 35km (10x)
  - equivalent wing area increased relative to balloon

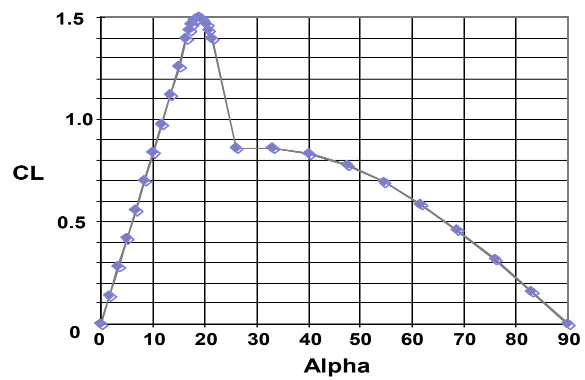
Global Aerospace Corporation

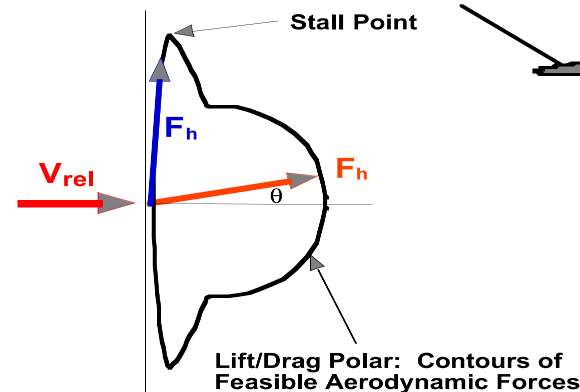
Global Stratospheric Constellation

HOW THE TCS WORKS, CONTINUED

TOP VIEW OF TCS





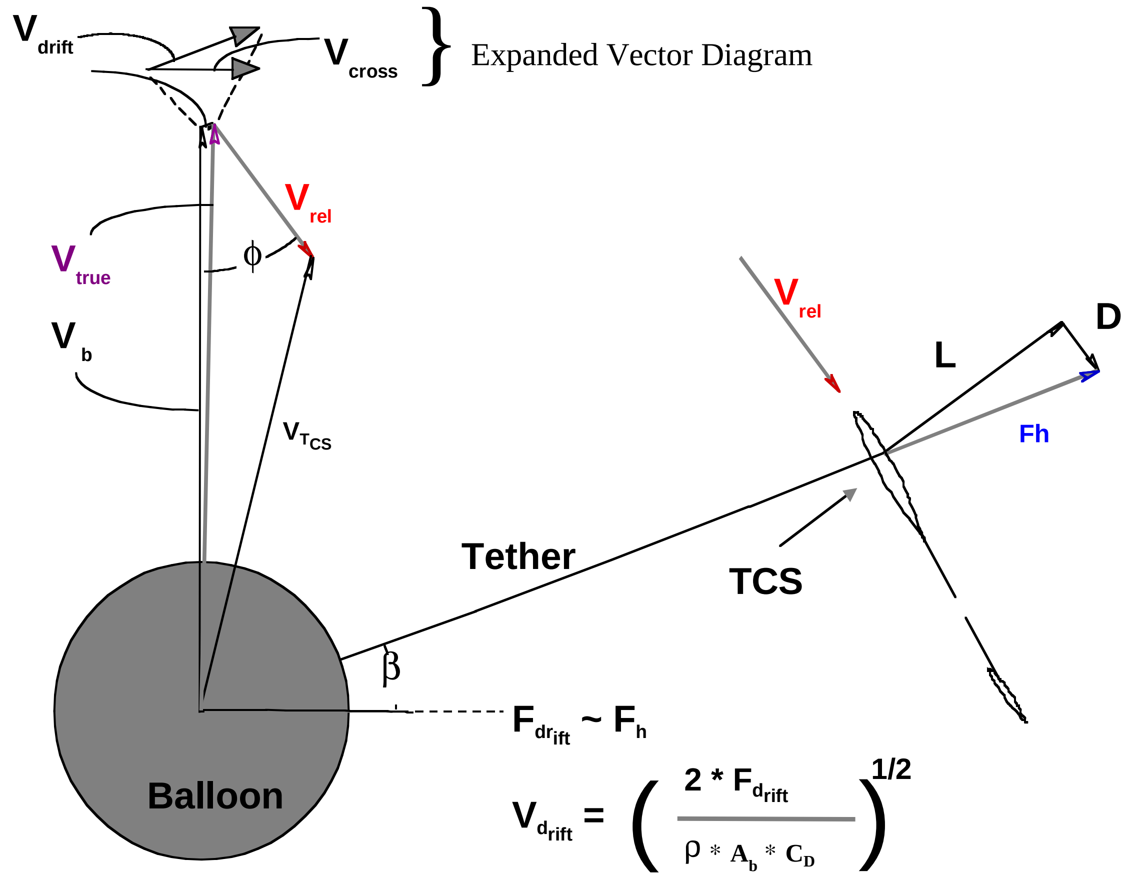


LIFT vs ANGLE OF ATTACK

LIFT / DRAG FORCE POLAR

Global Stratospheric Constellation

HOW THE TCS WORKS, CONTINUED



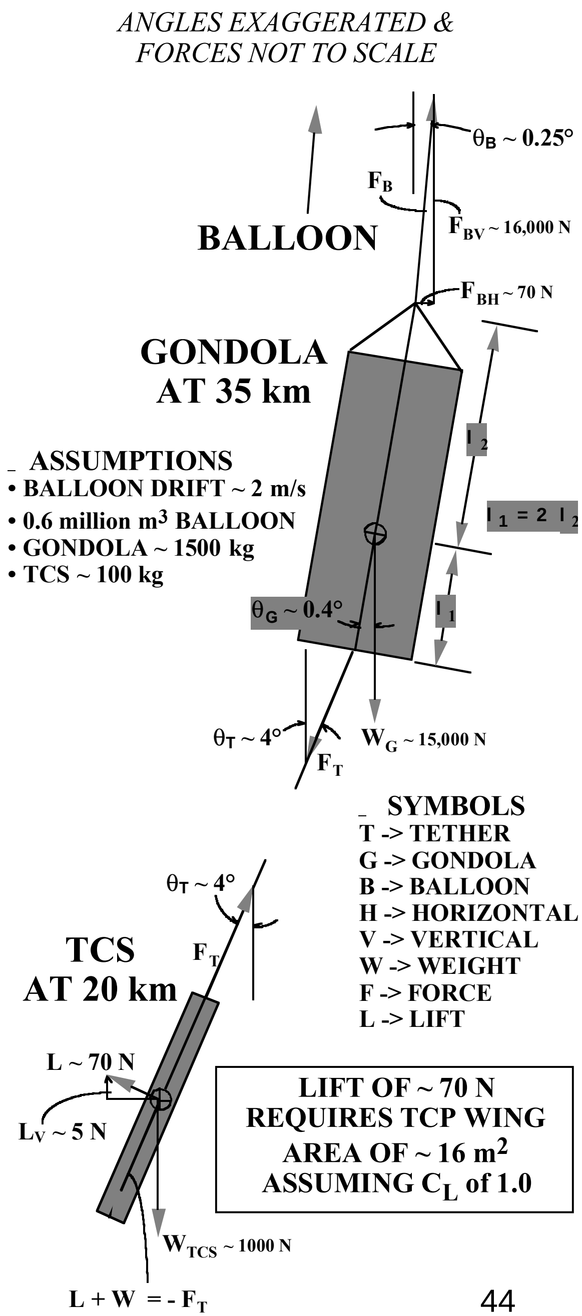
$$V_{drift} = \left(\frac{2 * F_{drift}}{\rho * A_b * C_D} \right)^{1/2}$$

$$\beta = \phi - \tan^{-1}(D/L)$$

$$V_{cross} = V_{drift} * \cos \beta$$

Top View

Global Stratospheric Constellation



ULDB TCS FORCE DIAGRAM