NIAC
NASA Institute for Advanced Concepts

GLOBAL CONSTELLATIONS OF STRATOSPHERIC SATELLITES

Presentation to the NASA Institute for Advanced Concepts (NIAC) 3rd Annual Meeting: Visions of the Future in Aeronautics and Space

by

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TOPICS

CONSTELLATION CONCEPT
STRATOSAT SYSTEMS
EARTH SCIENCE AND OBSERVATIONS
DEMONSTRATION MISSIONS
SUMMARY

CONSTELLATIONS OF STRATOSPHERIC SATELLITES

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CONCEPT

- Tens to hundreds of small, long-life (3-10 years) 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

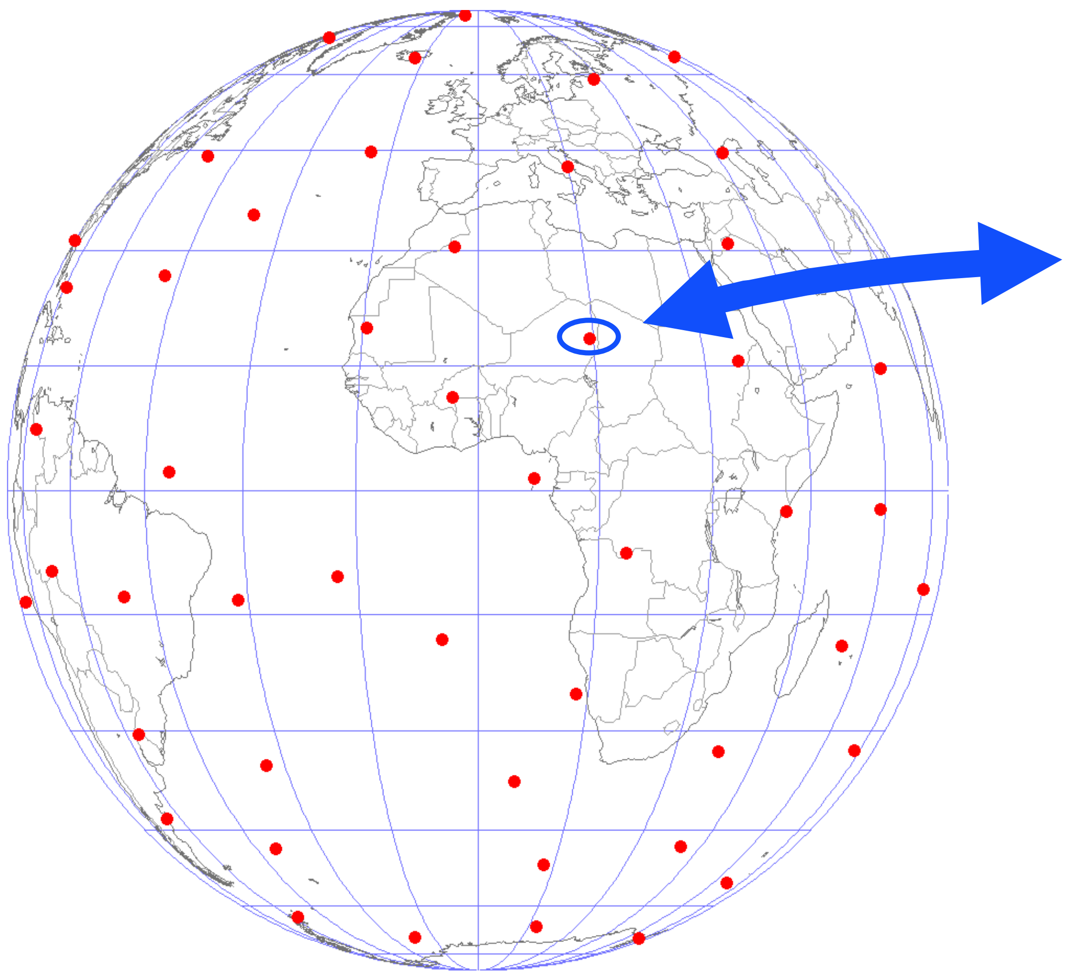
BENEFITS

- Provide low-cost, continuous, simultaneous, global and regional earth observations
- Provides in situ and remote sensing from very low earth "orbit"

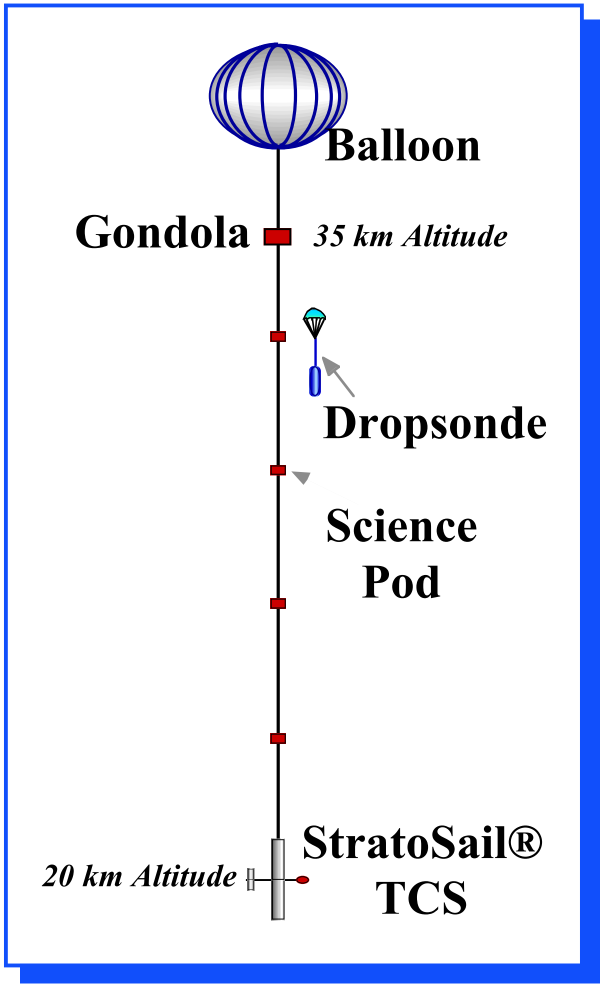
Global Constellations of Stratospheric Satellites

CONCEPT SCHEMATIC

Global Constellation



StratoSat Flight System



BENEFITS 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
- Provide frequent to continuous measurements
- Provide horizontal gradients in addition to vertical profiles
- Extended duration and low-cost potentially provide a cost-effective method for earth science and/or satellite calibration and validation

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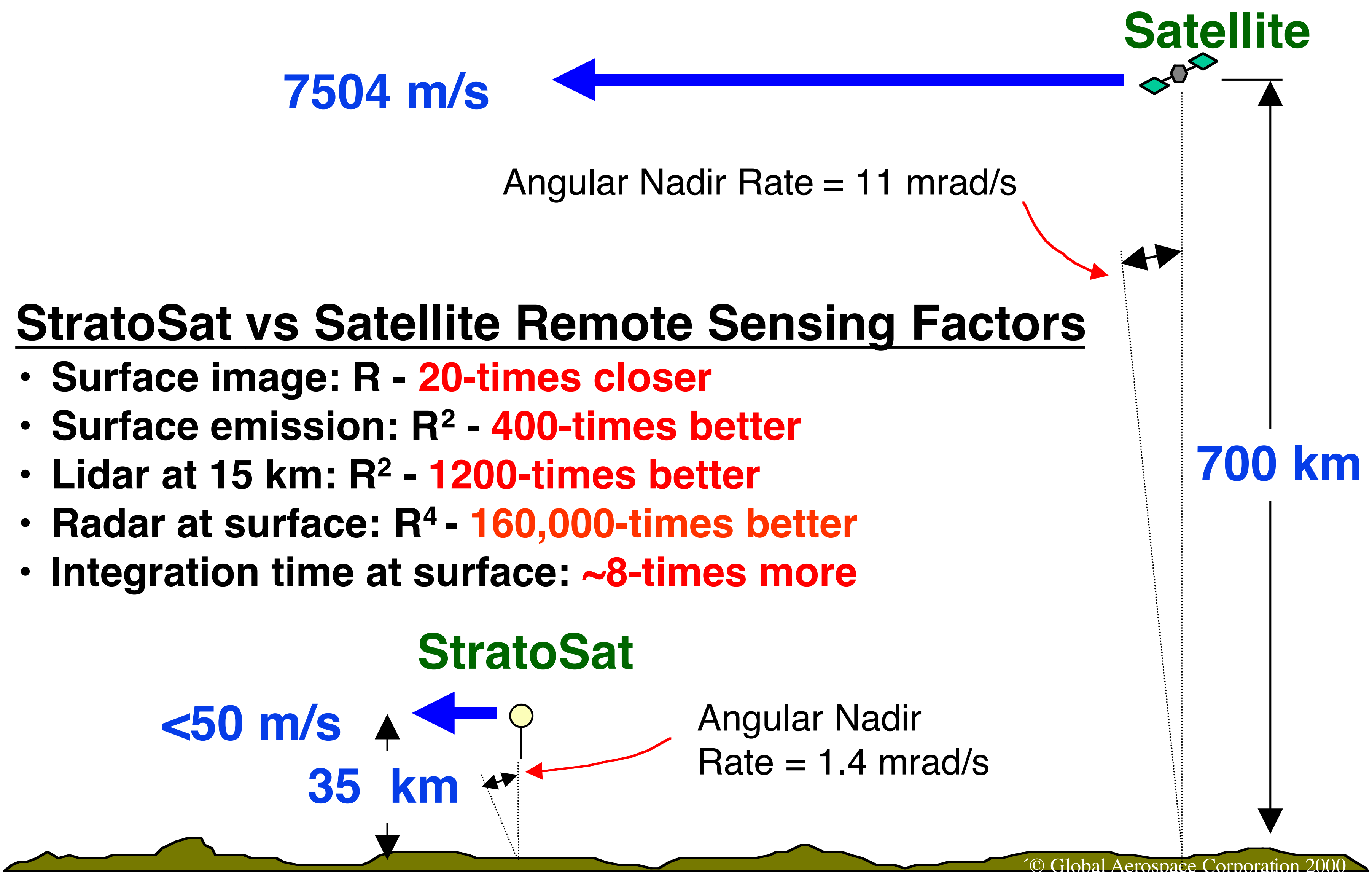
REMOTE SENSING



StratoSat vs Satellite Remote Sensing Factors

- **Surface image: R - 20-times closer**
- **Surface emission: R^2 - 400-times better**
- **Lidar at 15 km: R^2 - 1200-times better**
- **Radar at surface: R^4 - 160,000-times better**
- **Integration time at surface: ~8-times more**


STRATOSAT™ BALLOON DESIGN
• Euler Elastica Pumpkin Design
• Volume ~ 70,000 m³
• Advanced Composite Film, 15 g/m²
• 140 Gores ~1.3 m Wide
• Zylon® Load Tendons
• Balloon Mass ~ 250 kg
NASA ULDB
Scale Model Tests

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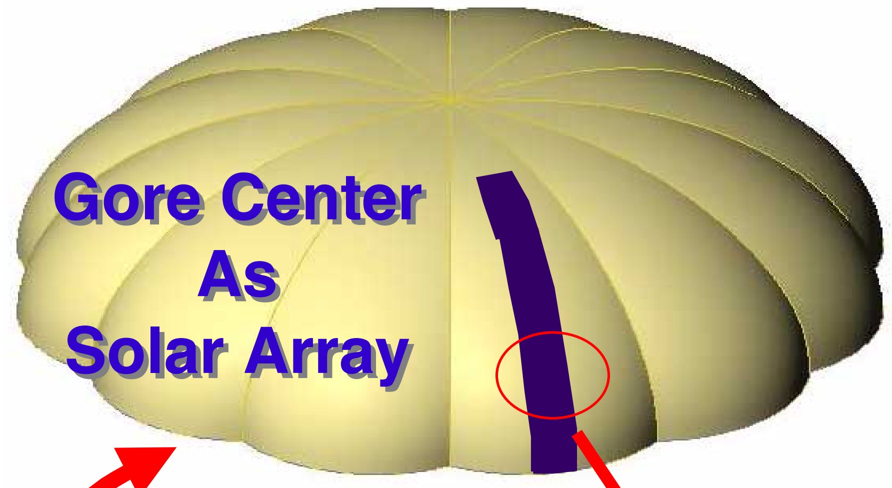
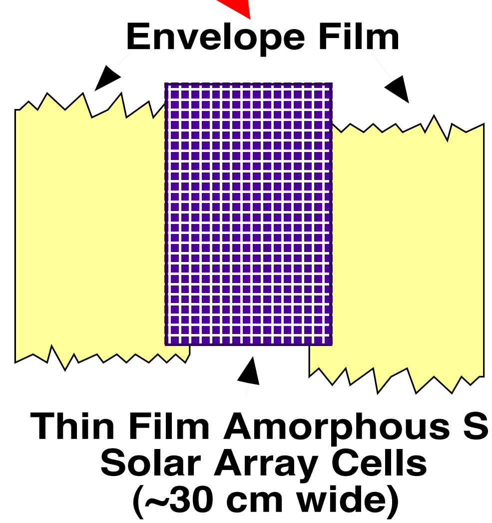
INTEGRATED SOLAR ARRAY & BALLOON ENVELOPE



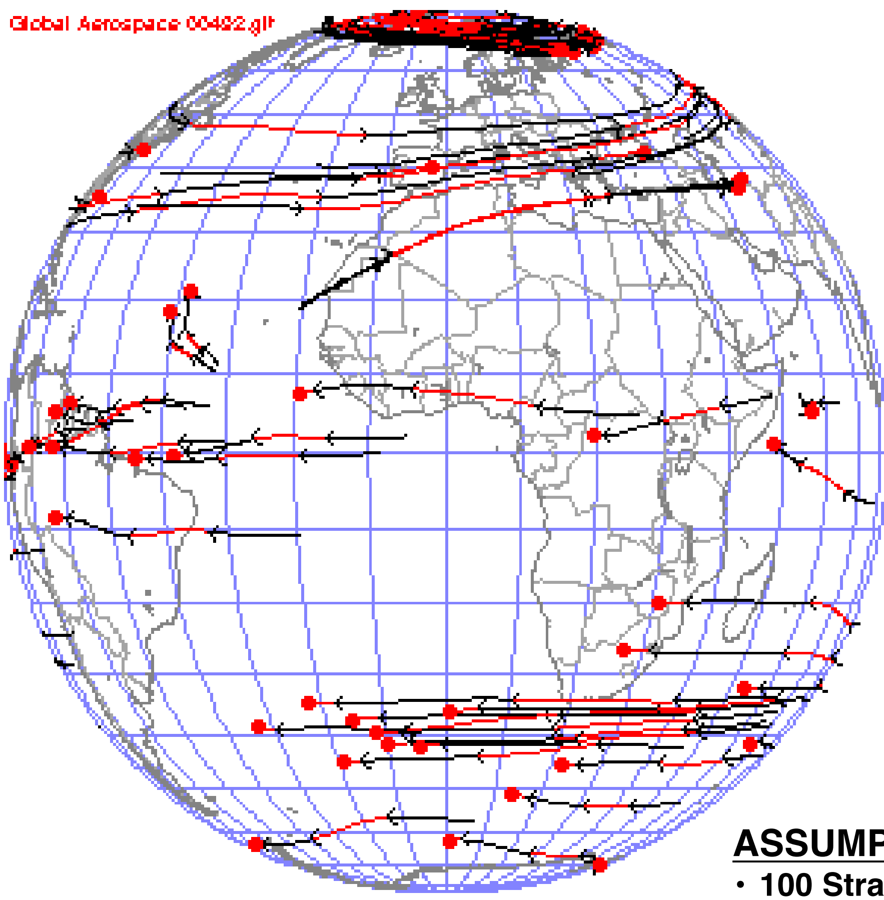
Example Power

- 48 m dia
- 100 Gores/Seams
- 30 cm Wide Solar Array
- 10 % Efficiency
- ~45 kW

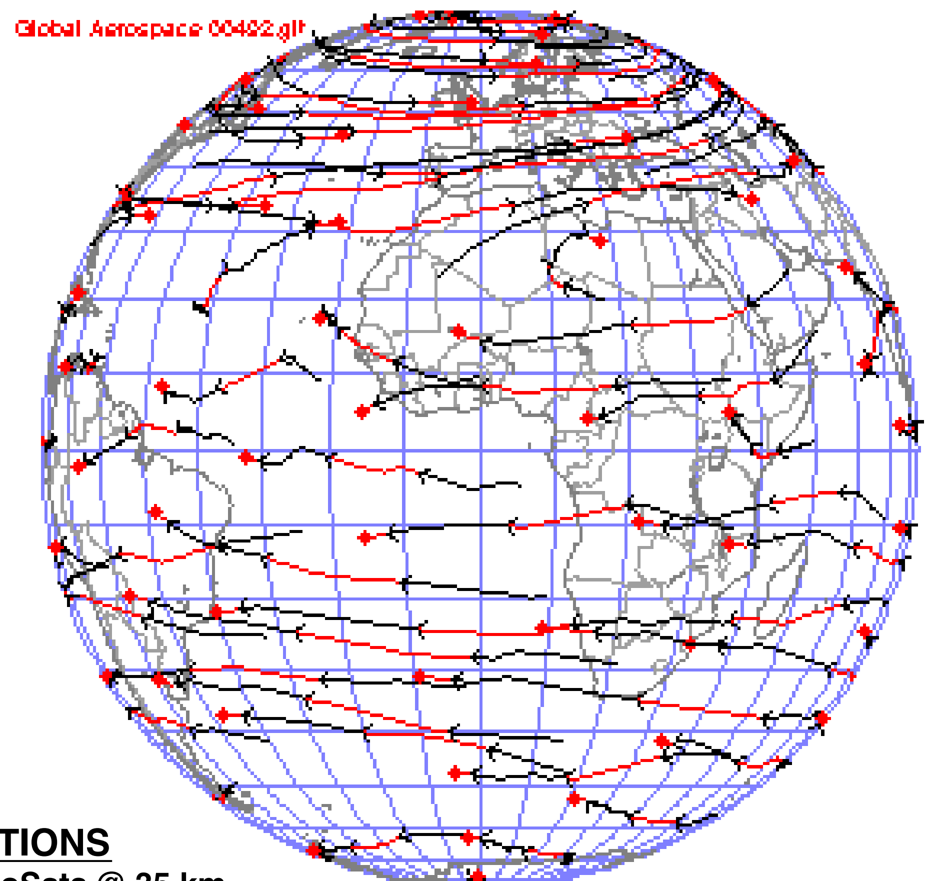


THE NEED FOR GLOBAL CONSTELLATION MANAGEMENT

FREE FLIGHT



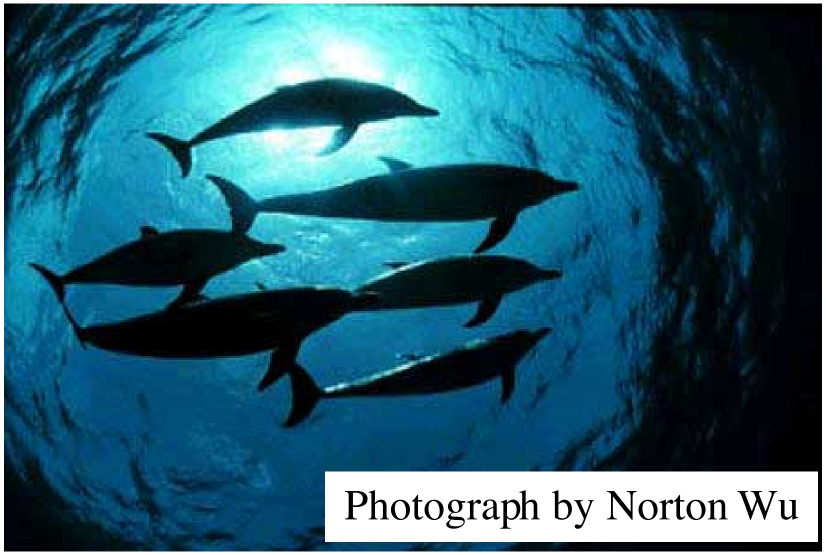
SIMPLE CONTROL



ASSUMPTIONS
- 100 StratoSats @ 35 km
- 82 day Simulation
- 5 m/s Control

CONSTELLATION MANAGEMENT

- Constellation management is the process of maintaining a desired spatial distribution of balloons in constellation
- Constellation management DOF
  - Environment information used
  - Fidelity of balloon model
  - Coordinate system
  - Constellation control method
    - Nearest neighbor (molecular)
    - Biological analogs (flocks, pods, schools, herds)
    - Weak Stability Boundary (WSB) theory
- Constellation management objectives
  - Uniform global and regional distributions
  - Targeted overflight



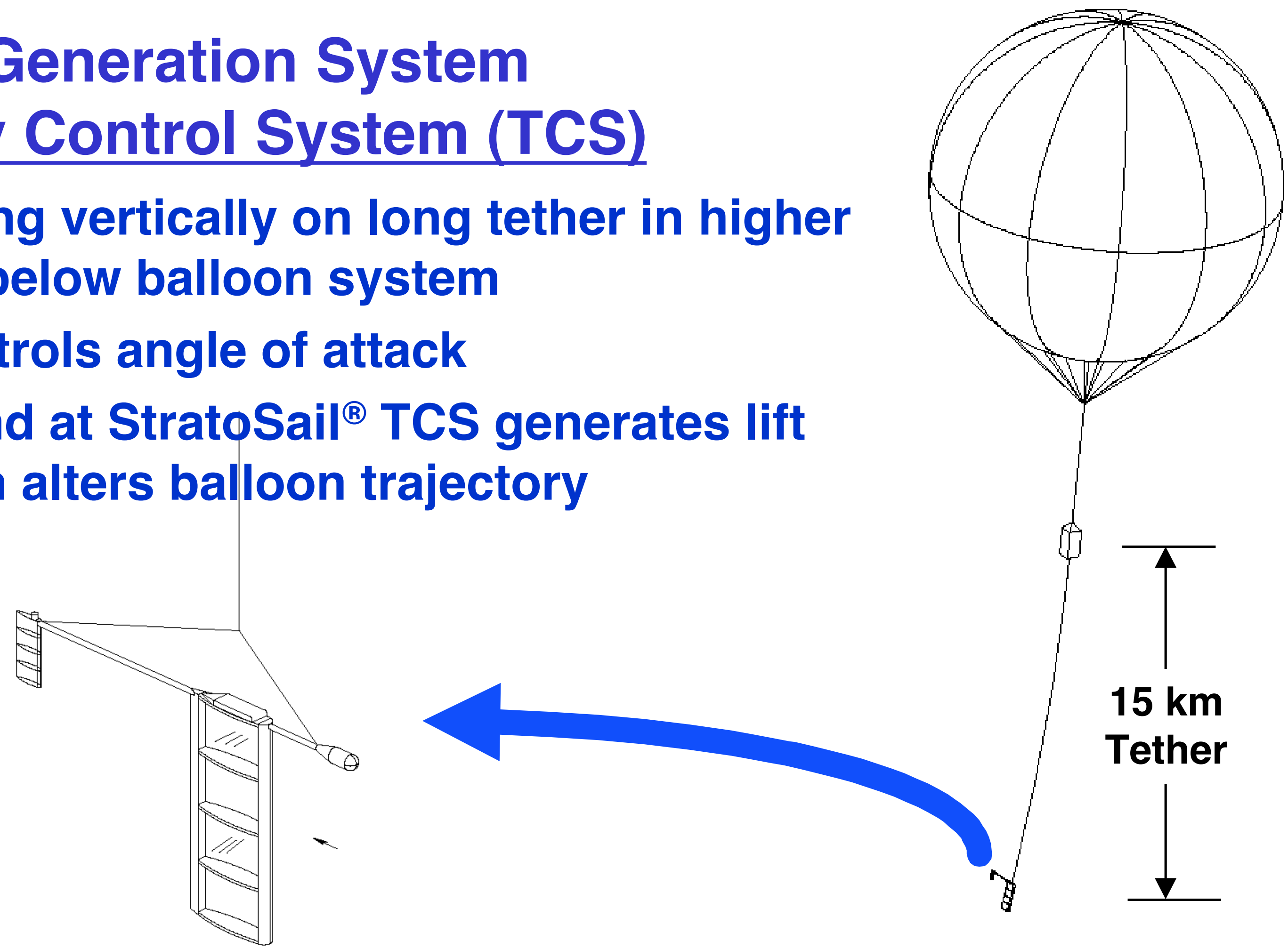
Photograph by Norton Wu

BALLOON TRAJECTORY CONTROL

First Generation System

Trajectory Control System (TCS)

- Wing hanging vertically on long tether in higher density air below balloon system
- Rudder controls angle of attack
- Relative wind at StratoSail® TCS generates lift force, which alters balloon trajectory

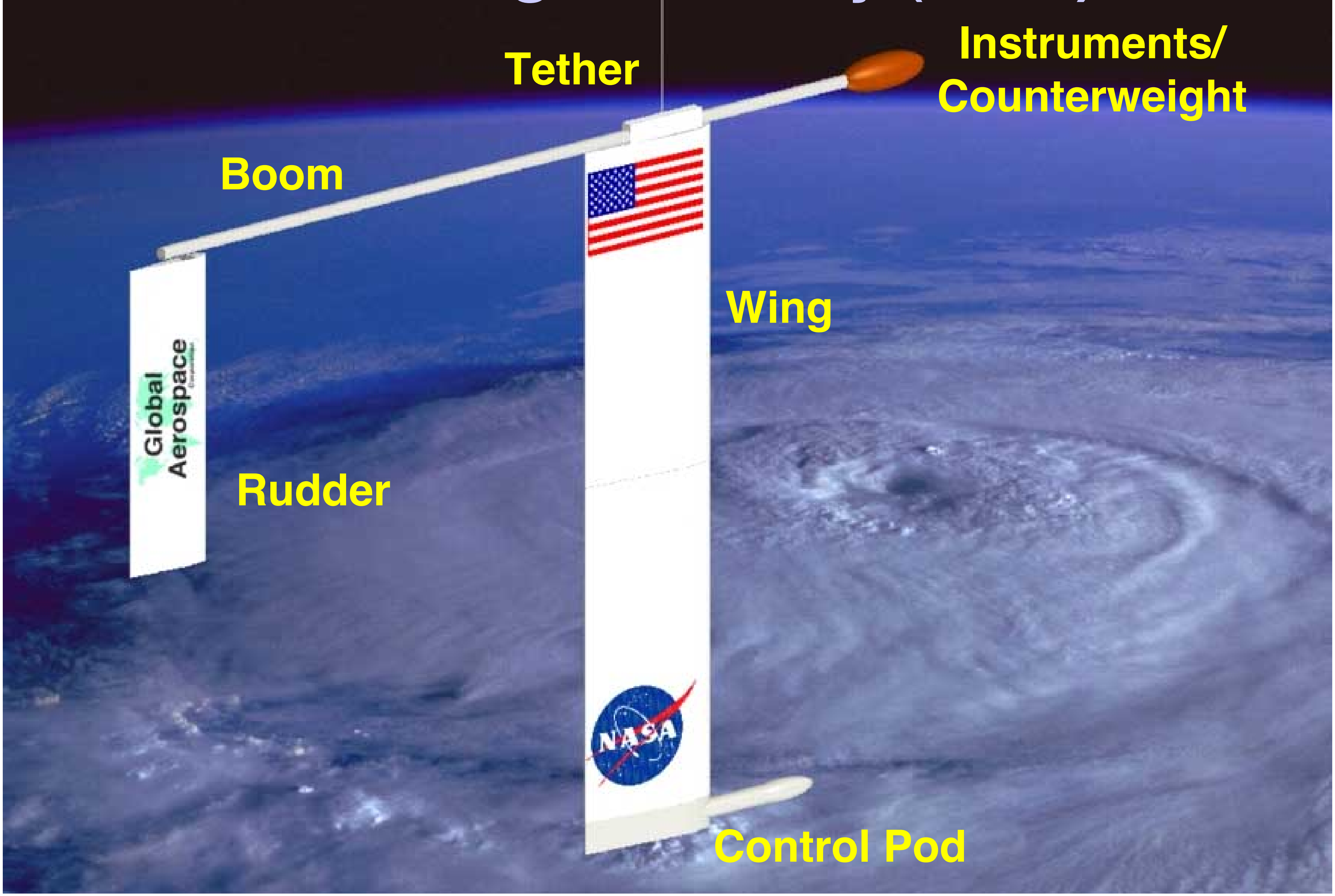


TCS FEATURES

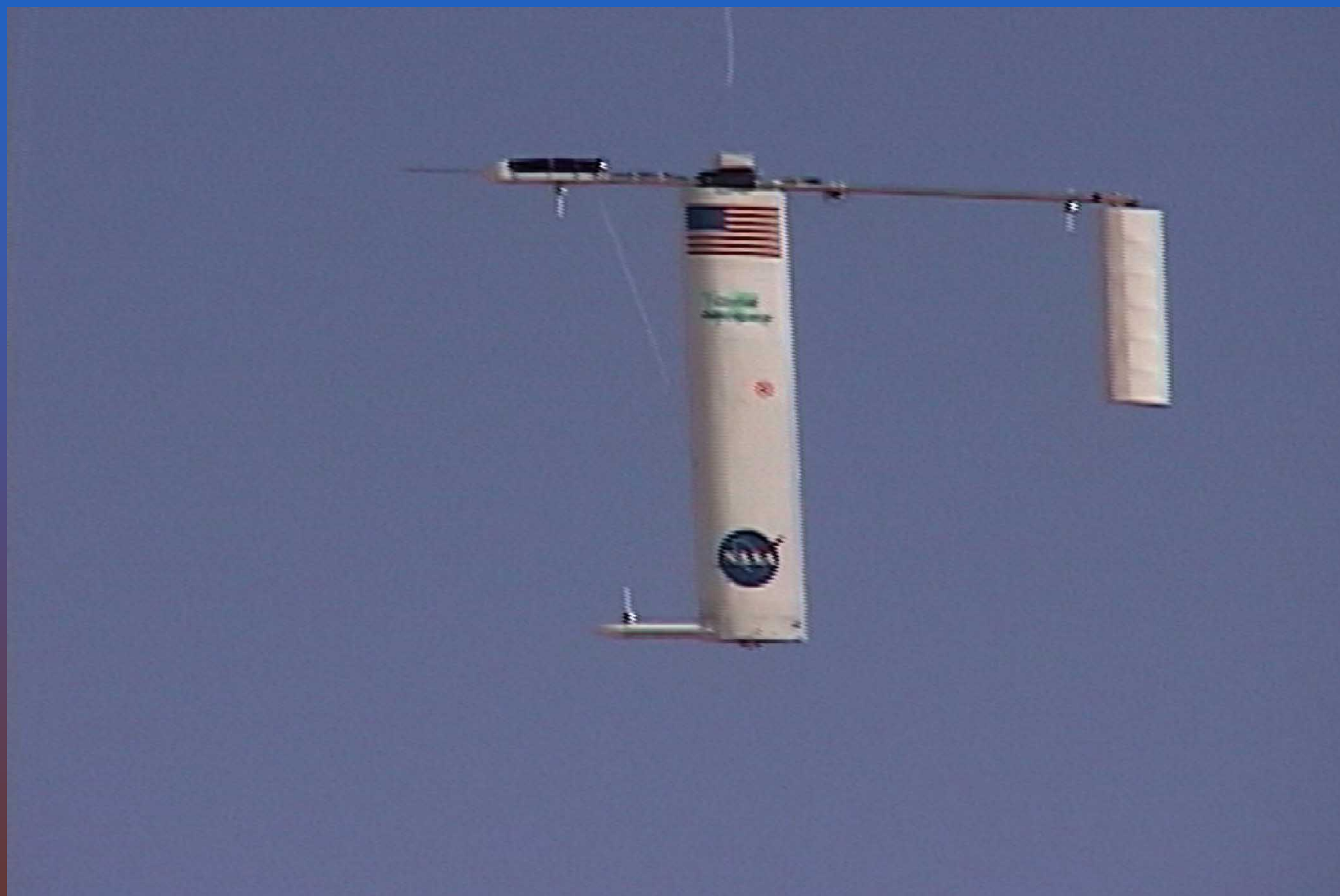
- Passively exploits natural wind conditions
- Operates day and night
- Offers a wide range of control directions regardless of wind conditions
- Can be made of lightweight materials, mass <100 kg
- Does not require consumables
- Requires very little electrical power

Radio-Controlled Dynamically-scaled Model (1:4) Tested in Natural Winds Suspended From Tethered Blimp, April 2001

TCS Wing Assembly (TWA)



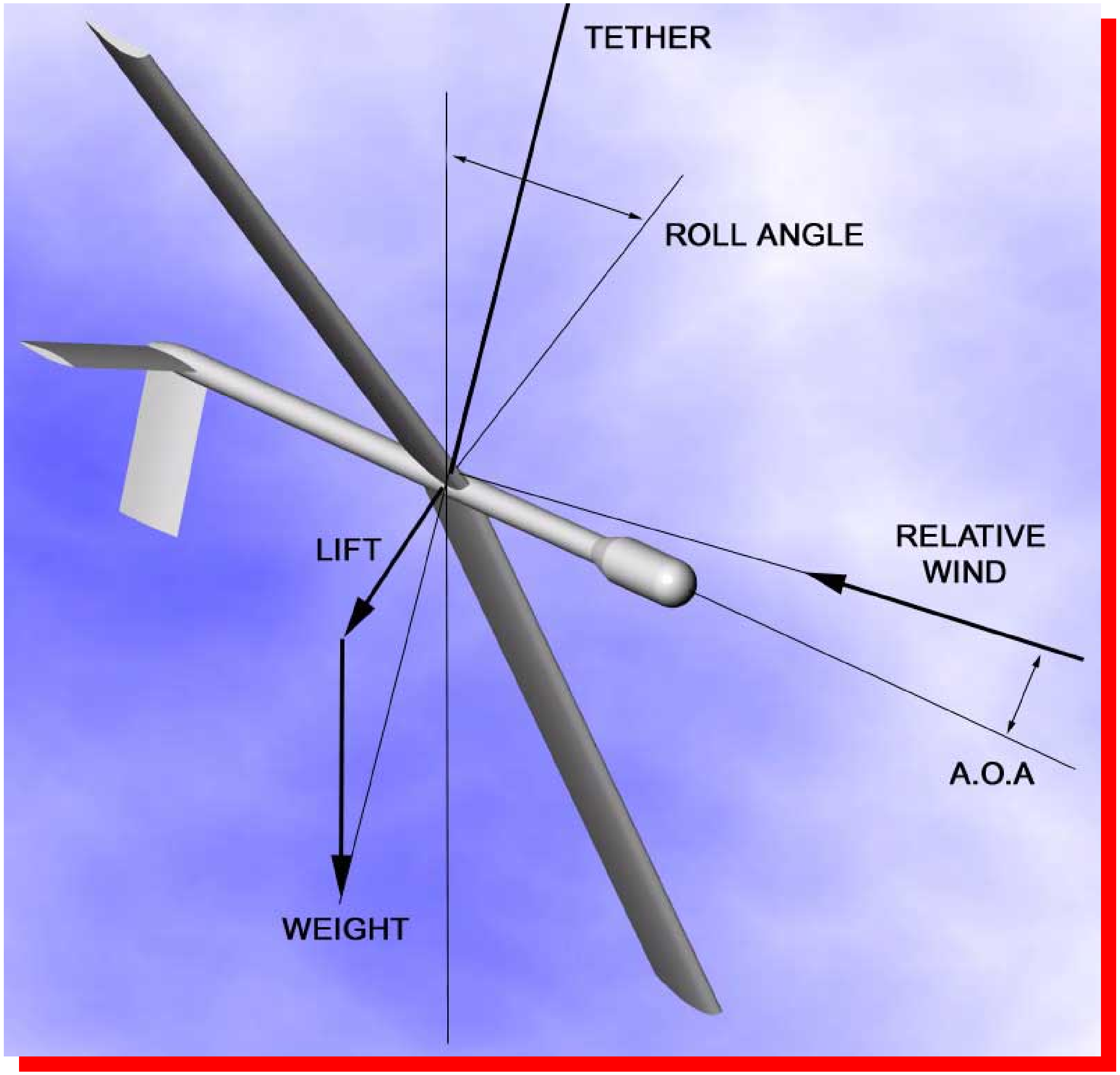
SCALE MODEL TEST



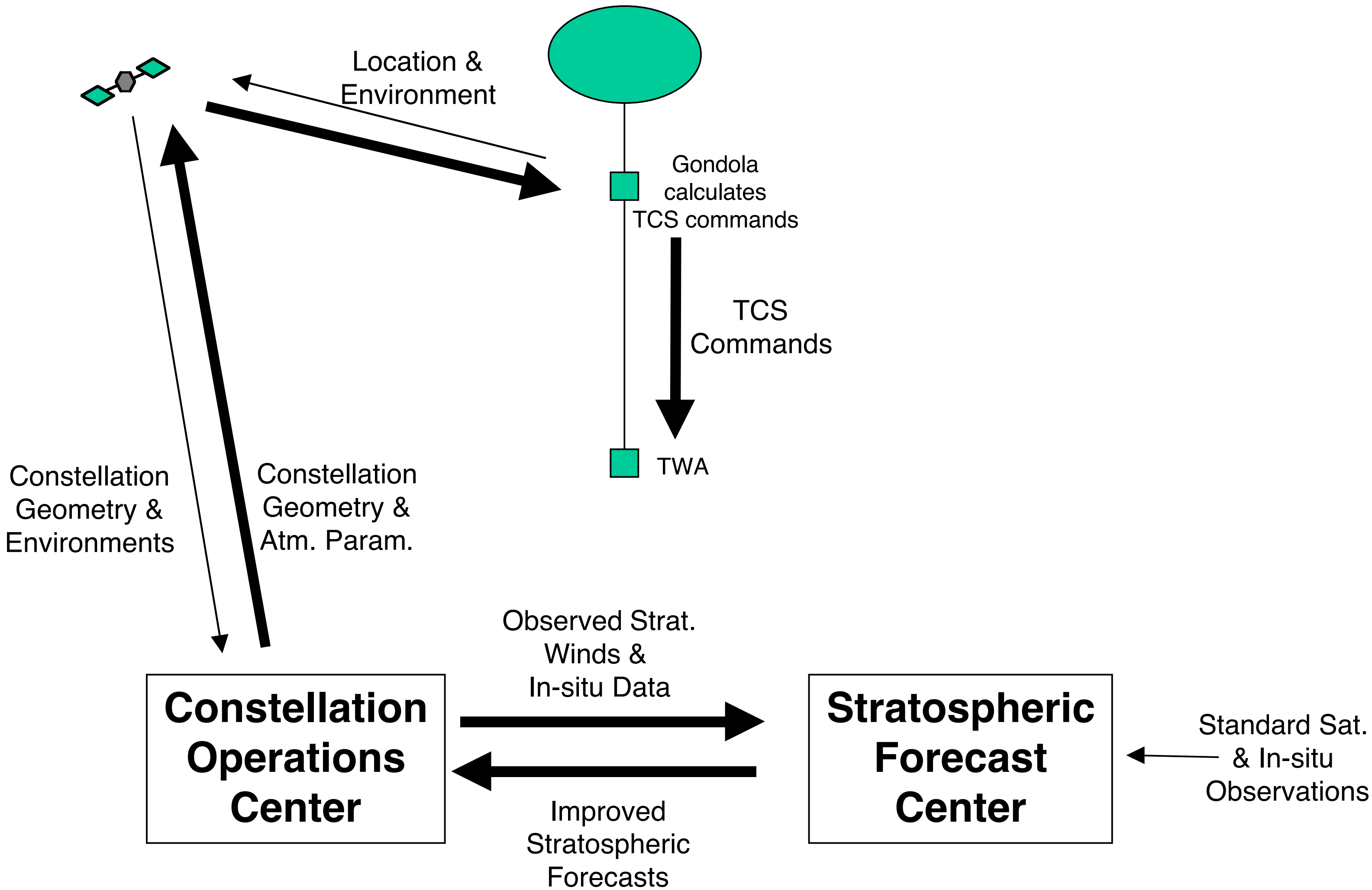
ADVANCED TCS CONCEPT

Advanced StratoSail® TCS Design Features

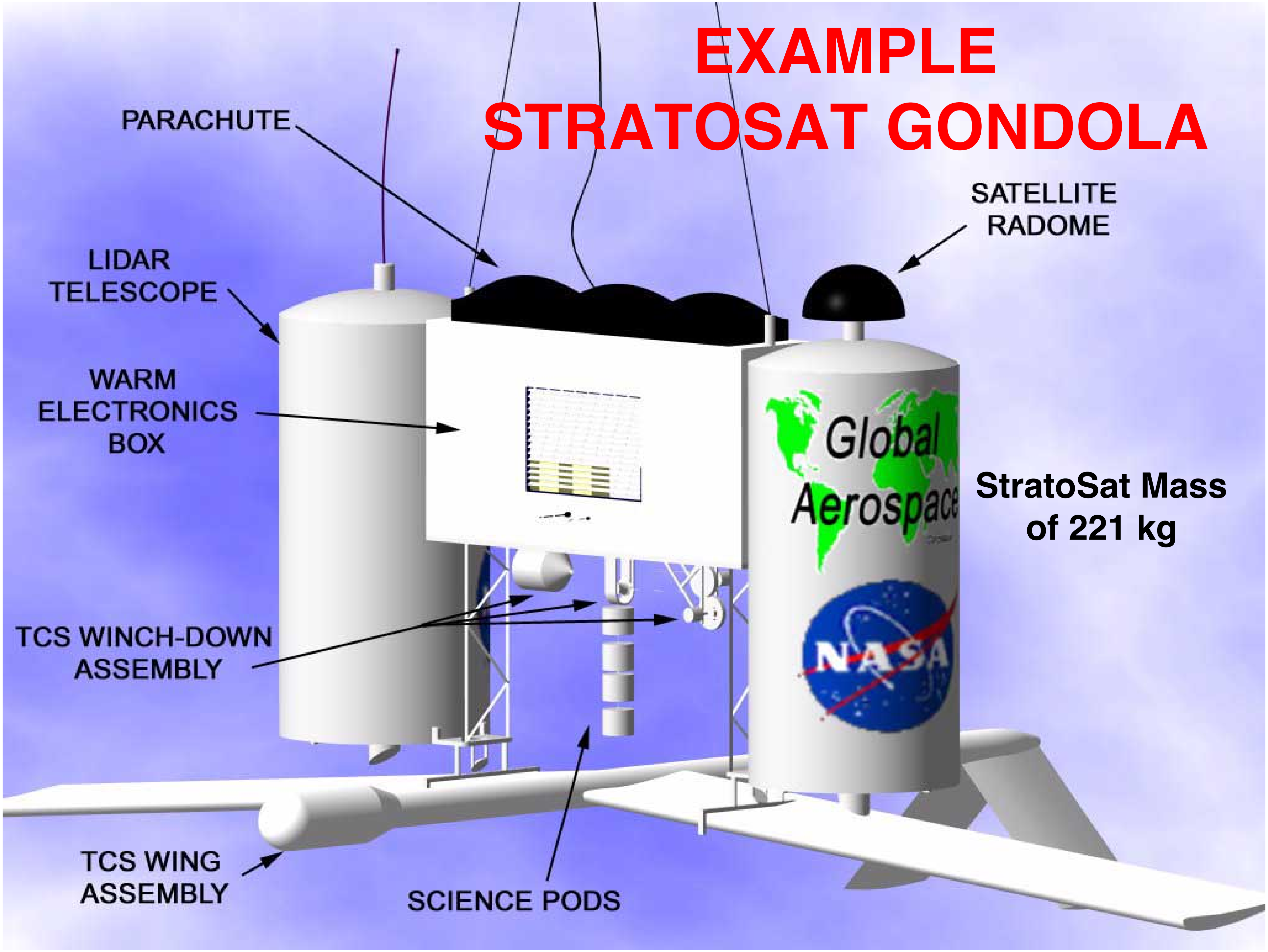
- Lift force can be greater than weight
- Will stay down in denser air
- Less roll response in gusts
- Employs high lift cambered airfoil
- Greater operational flexibility
- Possible Dynamic Power Generation



CENTRALIZED STRATOSAT OPERATIONS



EXAMPLE STRATOSAT GONDOLA



StratoSat Mass of 221 kg

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
- Global Circulation and Age of Air
- Global Ocean Productivity
- Weather and Adaptive Sampling
  - Hurricane forecasting and tracking
  - Tropospheric winds
  - Forecasting weather from ocean basins & remote areas
- Hazard Detection and Monitoring

ADVANTAGES OF STRATOSATS TO ERB

- Radiative flux measured directly at 35 km
  - Commonly accepted TOA to which ERBE/ERBS products are extrapolated; no extrapolation required from 800 km down to 35 km
  - High spatial resolution measurements
  - No angular modeling needed
- Complete diurnal coverage (no diurnal model required, the leading source of uncertainty in daily and monthly regional flux averages)
- No sun angle bias (Sun synchronous orbits, except ERBE/ERBS and CERES/TRMM)
- Global synoptic coverage allows actual dynamics of ERB to be seen (including horizontal fluxes); never before possible

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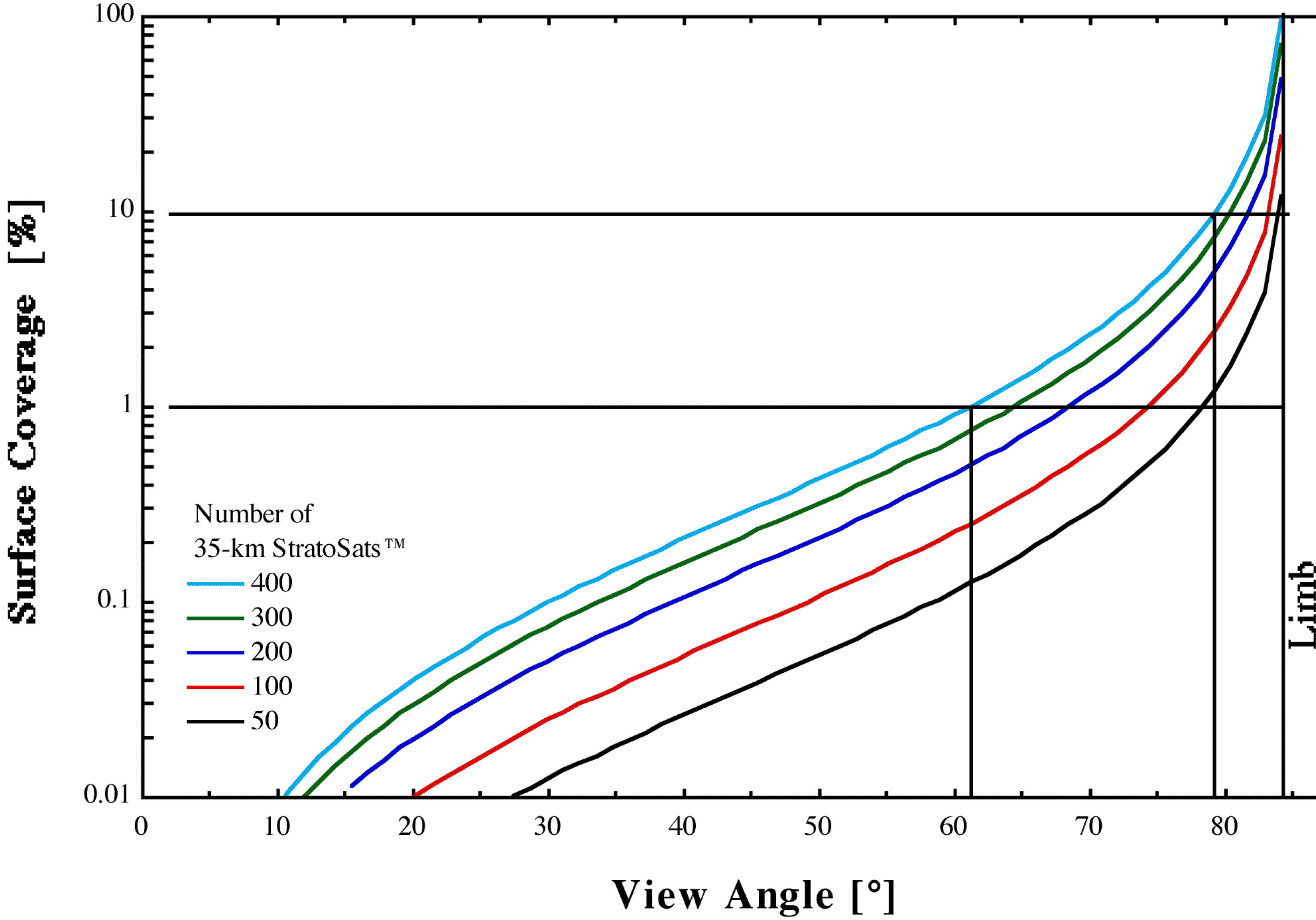
ERB COVERAGE



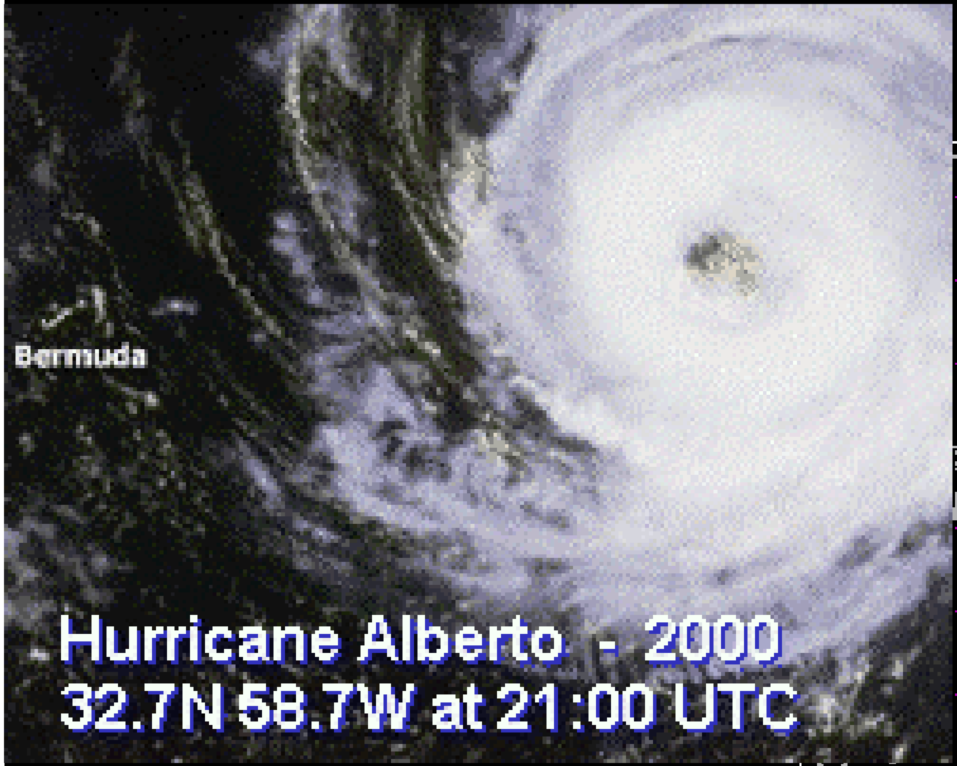
HURRICANE PREDICTION

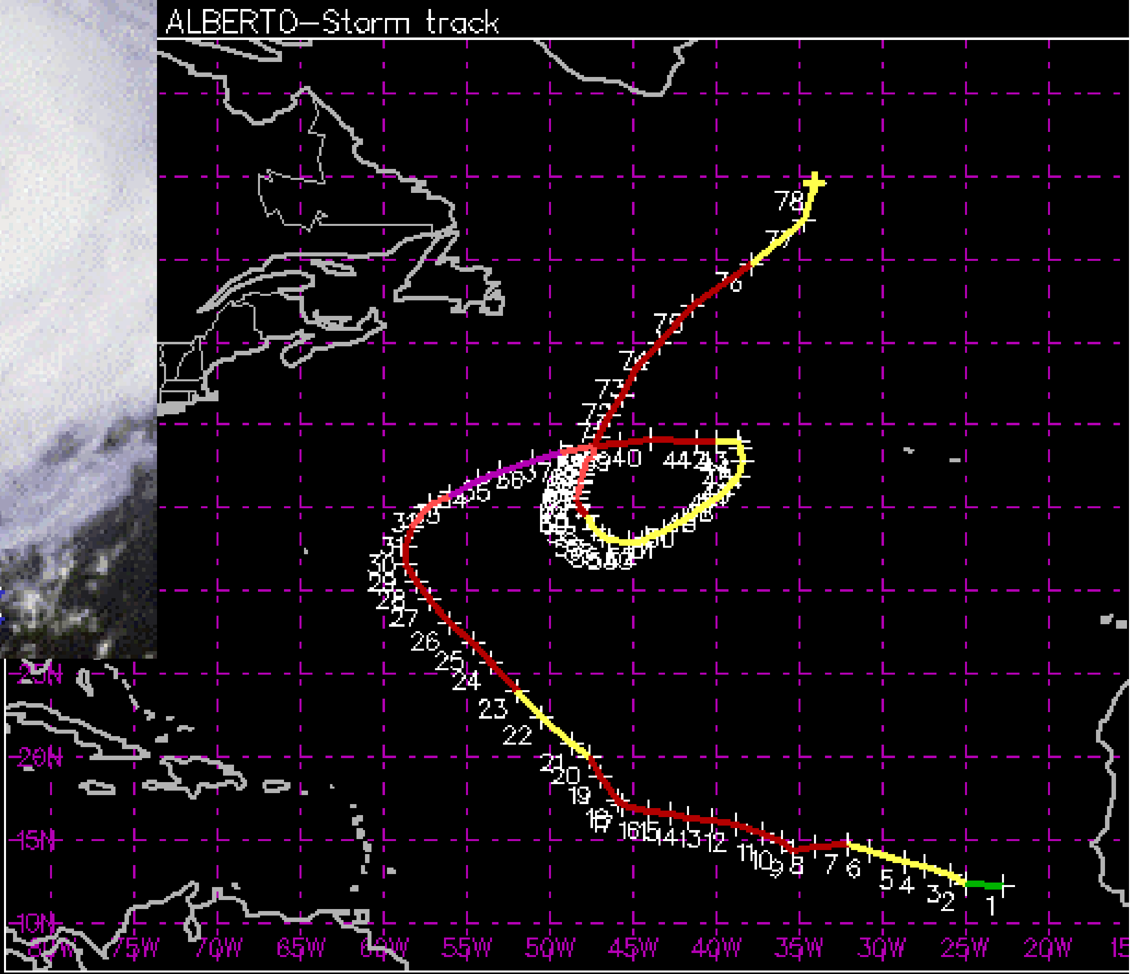
- More accurate prediction of a hurricane track and its intensity can avoid economic disruption and save lives
- Current data sources
  - Satellites provide low resolution atmospheric data,
  - Buoys provide surface wind, pressure, air and ocean temperature, and
  - Crewed aircraft fly into the storm to supplement the wind, pressure and temperature data around the storm.
- While this data and better models have continued to improve hurricane forecasting, more high quality, high resolution in situ data is needed
- For example, more accurate wind data is needed
  - The winds in the vicinity of the hurricane are important for predicting the hurricane’s path
  - The winds inside the hurricane are important to estimating its eventual intensity

ECONOMIC BENEFITS TO IMPROVED PREDICTION

- In a 72 hour forecast the current average hurricane landfall error is 200 miles
- When a hurricane is predicted to hit a coast, up to 300 miles of a coastal zone is placed under a warning, which is 4-times the area actually seriously effected
- The estimated financial impact on US of a hurricane warning is between $1-50 M per mile of coast, depending on economic sectors along that stretch of coast
- If landfall prediction could be improved by 50% a potential savings of at least $150 M per hurricane landfall could be achieved

HURRICANE ALBERTO



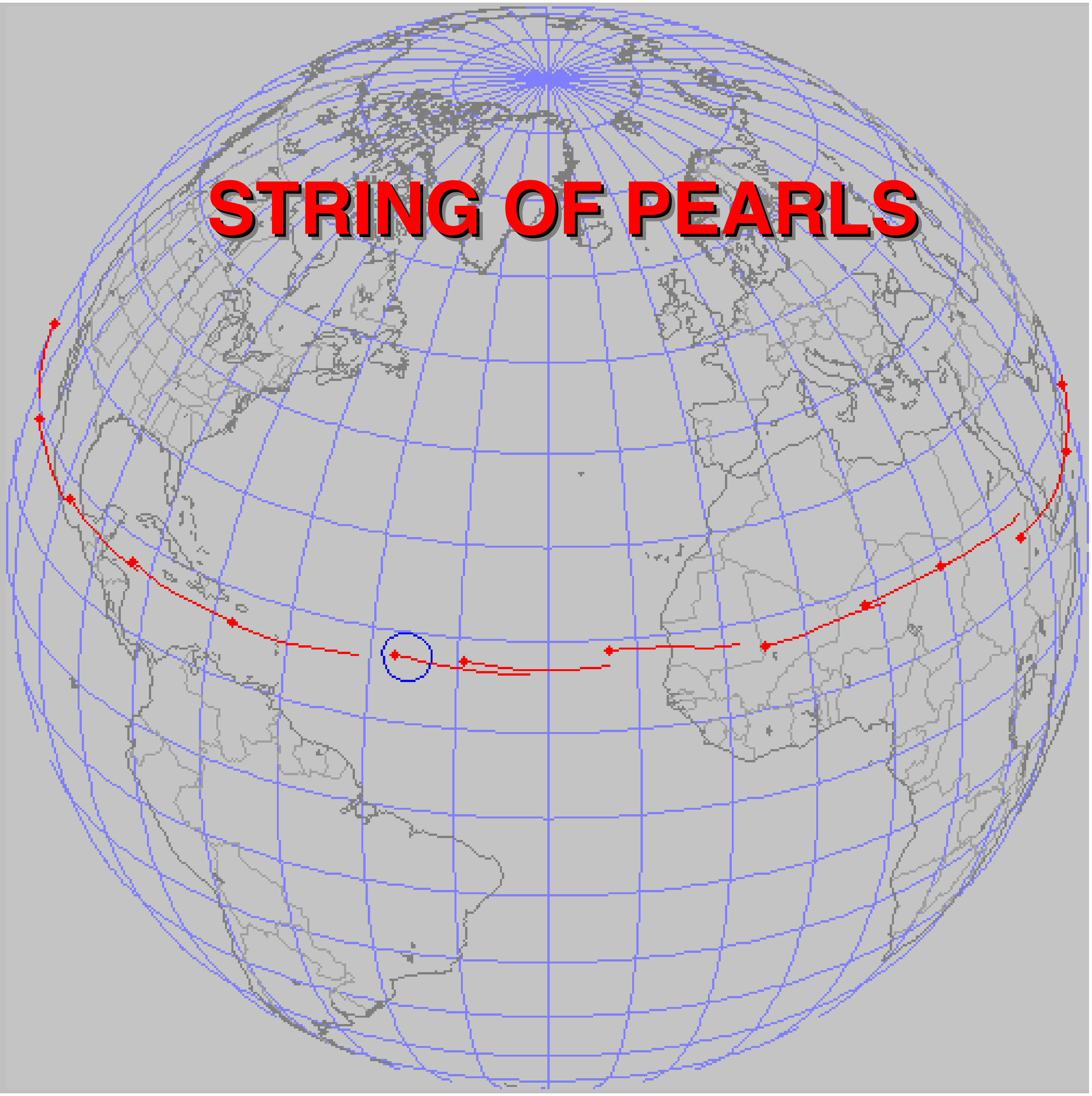


POSSIBLE HURRICANE TRACKING NETWORK

- Track a moving target (hurricane) with multiple balloons
- As one balloon moves beyond the horizon, new balloon enters the scene for observations
- Deploy one or more StratoSat "string-of-pearls" around the World near the latitude of hurricanes
- Example constellation management strategy
  - When > 90° longitude from hurricane, maintain hurricane's latitude
  - When < 90° longitude from hurricane, aim directly for the eye
- After Northern Hemisphere hurricane season the network could move to the Southern Hemisphere

STRING OF PEARLS

- Hurricane Alberto
- 20 balloons
- 1-day look-ahead
- 4 hrs/frame
- 31 days
- Actual easterly winds at 35 km
- Advanced TCS (0.5-5 m/s)
- Lat control strategy
  - >90° track lat
  - <90° aim eye



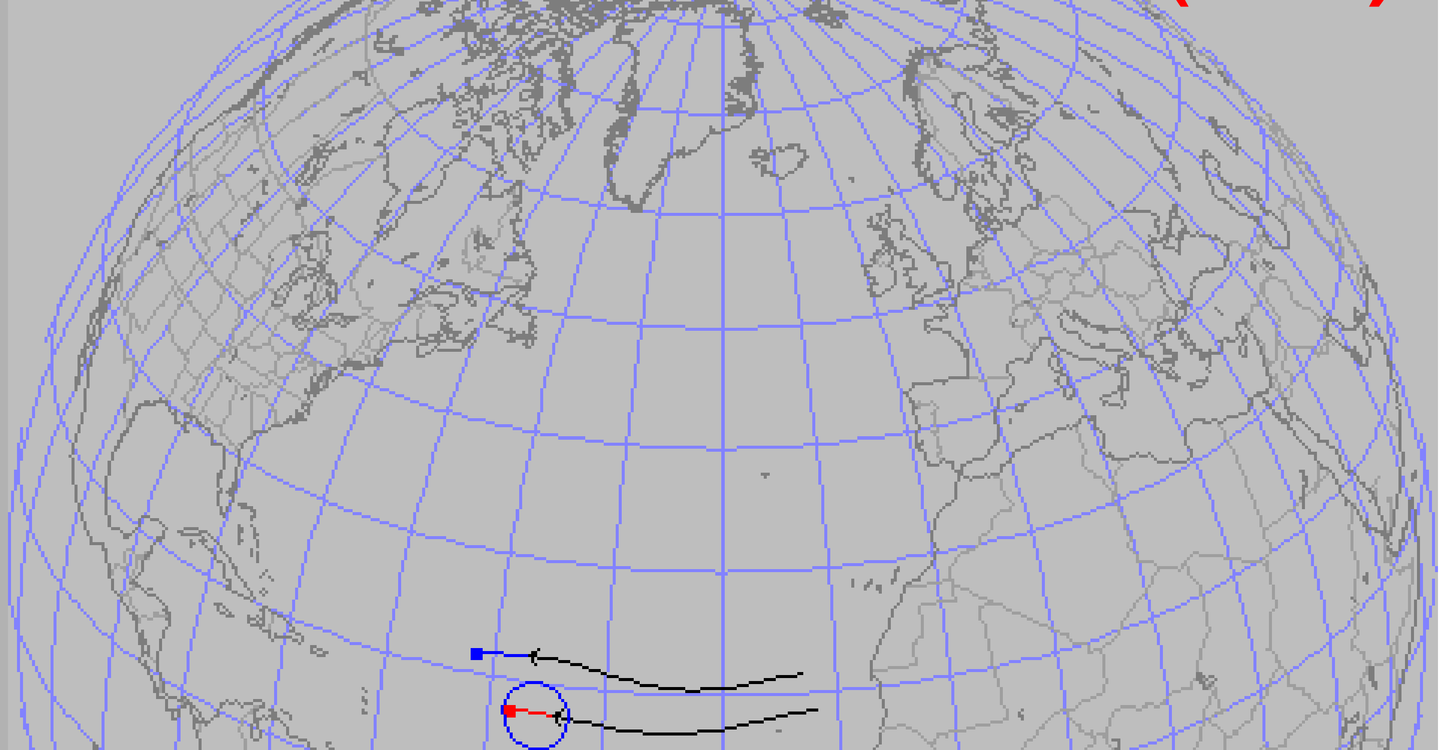
DEMONSTRATION MISSIONS

EXAMPLE DEMONSTRATION MISSION OPTIONS

- Hurricane Intercept Mission
- Satellite Radiometry Calibration and Validation
- Wind Lidar Measurements
- Demonstration Earth Radiation Budget Experiment (DERBE)
- Or a Combination of Mission Objectives

HURRICANE INTERCEPT MISSION (HIM)

- Hurricane Alberto
- UKMO winds at 35 & 20 km
- Red
  - Aerodynamic TCS model
  - ~ 2 m/s control authority
  - Maintains lat.
- Blue
  - Uncontrolled
  - Floats with winds
- 4 hrs/frame
- 4.25 days



- Potential Primary Objectives
  - Intercept and Possibly Follow Hurricane
  - Obtain High Resolution Meteorological Measurements
  - Demonstrate Hurricane Intercept Trajectory Control Capability
- Possible Science Experiments
  - Meteorological Dropsondes
  - High Resolution Wind Lidar
  - GPS Reflection Sea-state
  - Precipitation Radar
  - Low Resolution Imager

EXAMPLE DERBE MISSION PROFILE

- Radiative flux measurements of the Earth
- Float altitude of 35 km
- Generally “orbit” Earth at +15° latitude
- ~5 overflights of SGP CART at +35° latitude
- 100 day mission

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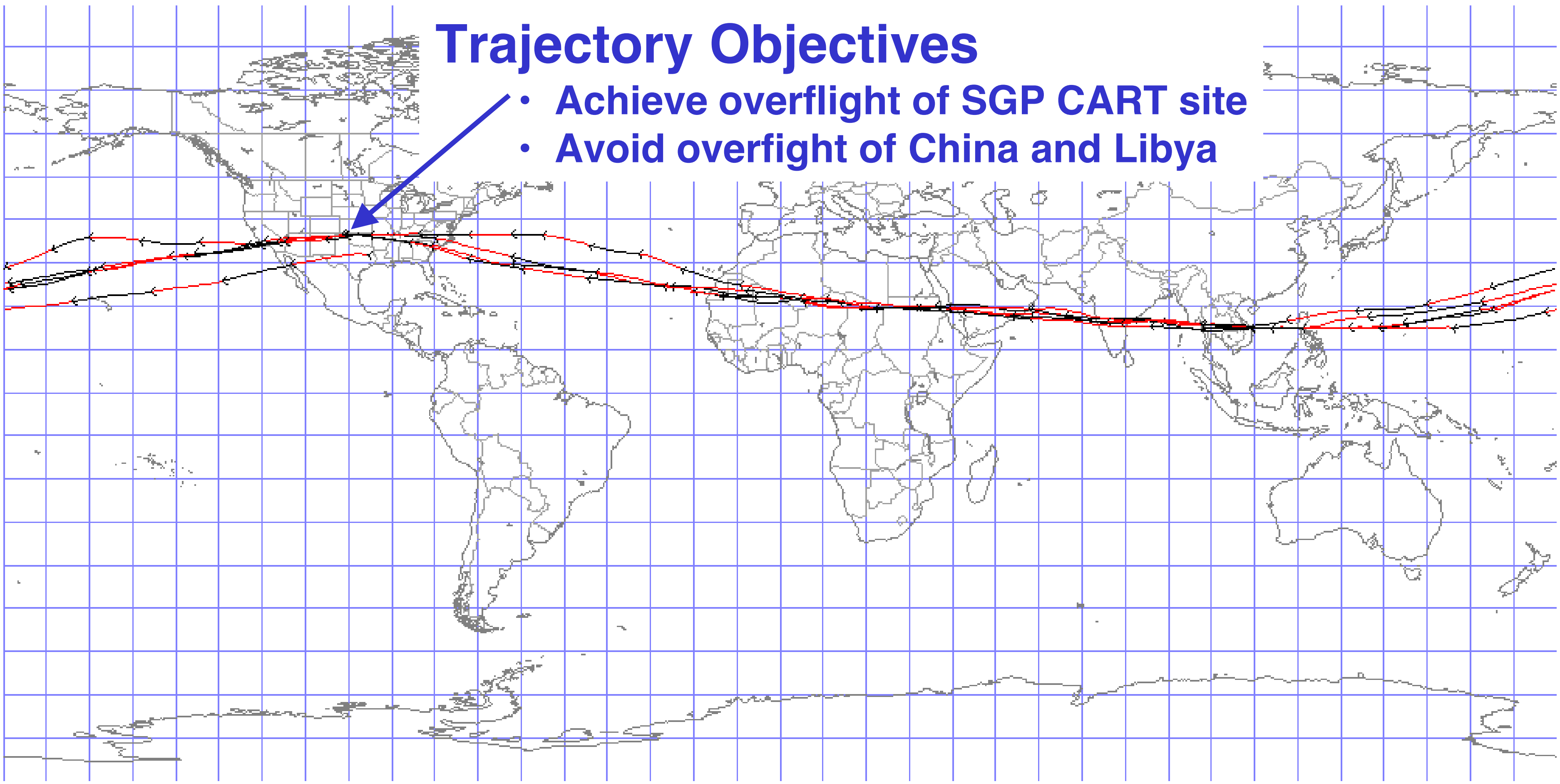
EXAMPLE DERBE TRAJECTORY SIMULATION



Trajectory Objectives

- Achieve overflight of SGP CART site
- Avoid overfight of China and Libya

EXAMPLE DERBE SCIENCE PAYLOAD

- Pyranometers
  - Four instruments of different types
  - Hemispherical FOV
  - Short-wave (0.3-3 μm)
- Pyrgeometers
  - Two instruments of different types
  - Hemispherical FOV
  - Long-wave (4-40 μm)
- Radiometers are modified Earth science instruments
- Instruments located on an optical benches
- Calibration system

CALIBRATION SYSTEM

- Pyranometers
  - Periodically view Sun to provide known input source
  - Issues
    - Reflections off balloon will contaminate solar signal
    - Cosine response of instrument may necessitate corrections
    - 0.1° pointing knowledge with respect to the Sun required
  - Collimator tube to eliminate all other signal sources
- Pyrgeometers
  - Rotate to a “black body” to cover field of view of pyrgeometer
  - Black body temperature must be known to ± TBD (0.1) K
  - Emissivity of black body must be known to ± TBD (0.5) %

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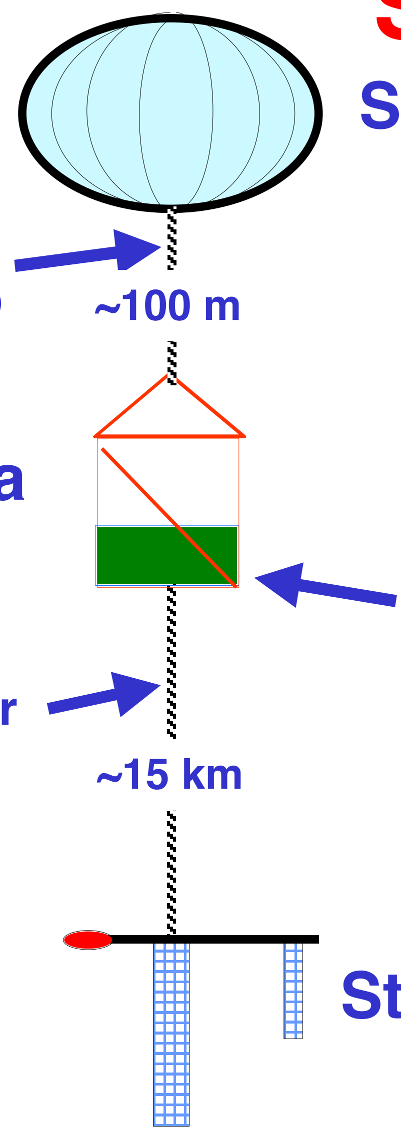
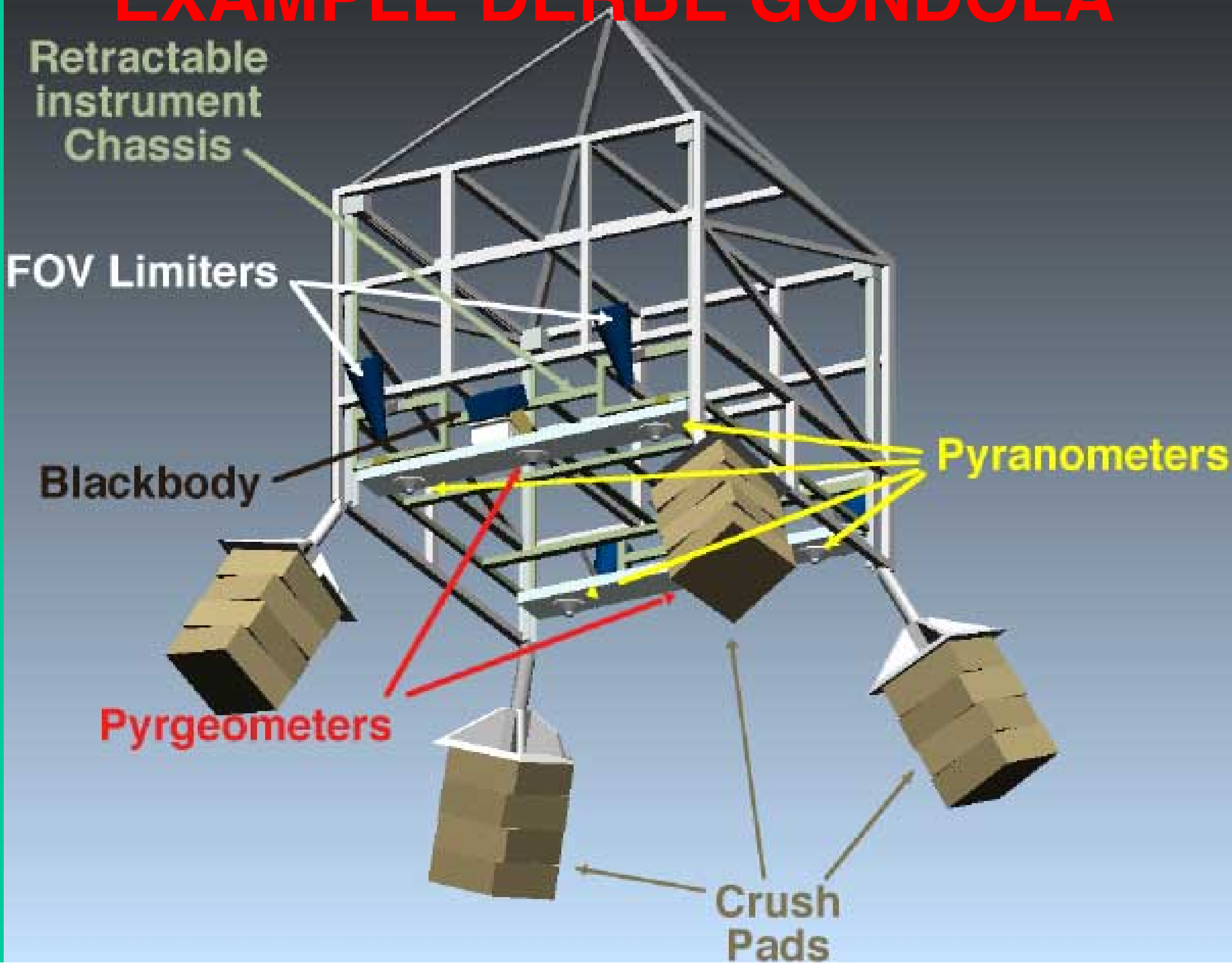
EXAMPLE DERBE BALLOON SYSTEM CONCEPT



EXAMPLE DERBE GONDOLA



INTERNATIONAL PATHWAYS TO OVERFLIGHT

INTERNATIONAL OVERFLIGHT OPTIONS

- Free flight in upper stratosphere
- Expand on the 1992 Treaty on Open Skies
- Exploit World Meteorological Organization (WMO) cooperation
- Seek new treaties
  - Committee on Space Research (COSPAR) study
  - World pollution issues
  - Growing interest in providing method for all countries of the world to participate in global observations

COSPAR RESOLUTION

- 33rd COSPAR Scientific Assembly in Warsaw, Poland in 2000
- Scientific Balloon Panel formulated a resolution to the COSPAR Executive Council
- Resolution requested a task group be formed to study and report to the bureau on the technical aspects of overflight of scientific balloons including:
  - altitudes,
  - balloon sizes and payload masses,
  - characteristics and features of payloads, and
  - safety requirements) and
  - possible international actions to enable the geographically-unrestrained and the peaceful free flight of such apparatus over all countries.
- This resolution was accepted as COSPAR Internal Decision No. 1/2000.

PROPOSED OVERFLIGHT REQUIREMENTS

- Airworthiness certificates from appropriate organization, perhaps ICAO, indicating the craft meets equipment and safety requirements
- A means of identification
- Evidence of liability insurance
- Payloads must not compromise any State's national security
- Launch and payload oversight
- Any nation free to operate stratospheric platforms if they meet all requirements

SUMMARY

SUMMARY

- The StratoSat™ platform is a stratospheric satellite that can provide:
  - 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
- A demonstration mission is essential first step toward regional and global measurements from 35 km
- Mission definition has progressed on two demonstration missions,
  - Demonstration Earth Radiation Budget Experiment (DERBE)
  - Hurricane Intercept Mission (HIM)