NSPO's Microsatellite Program

Y. S. Chen and Bill Wu
National Space Organization, Taiwan

UNIVERSAT-2006, Moscow State University, Russia
26~30 June 2006

NSPO
NATIONAL SPACE ORGANIZATION

Outline

- Introduction
- University Projects
- FORMOSAT-3/COSMIC Mission
- Related Science Researches in Taiwan
- Intense Observation Period
- Conclusion

Introduction

- Major Part of NSPO's Mission is for Meteorological Research – Typhoon, Flood, Earthquakes, etc., that concerns the General Population on Taiwan
- Ionosphere Research has Generated Some Interests in the Science Community
- Microsatellite Development for Low-cost and Timely Launch of Experiments
- Constellation Deployment Strategy – a Future Trend in Microsatellite Applications
- University Teams for Strengthening the Education in Science and Engineering

University Projects

NCKU Microsatellite

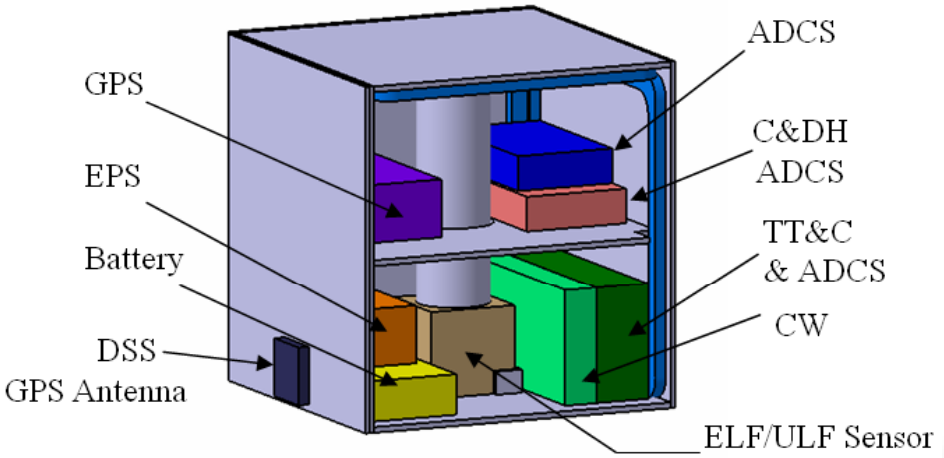
Name: PACESAT^2

Orbit: 500 km, 22° Inclination

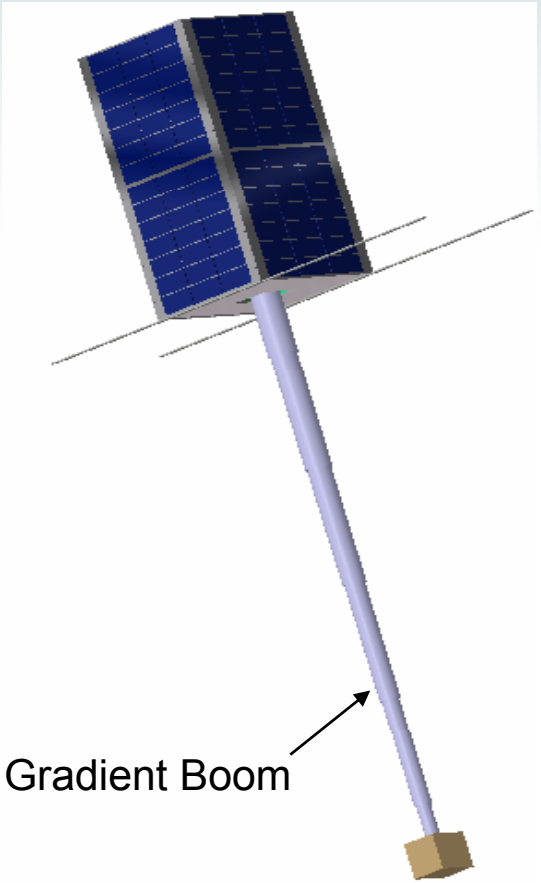
Mass: 30 kg

Communication: UHF/VHF

Mission: Earth ELF/ULF Observations



System Layout

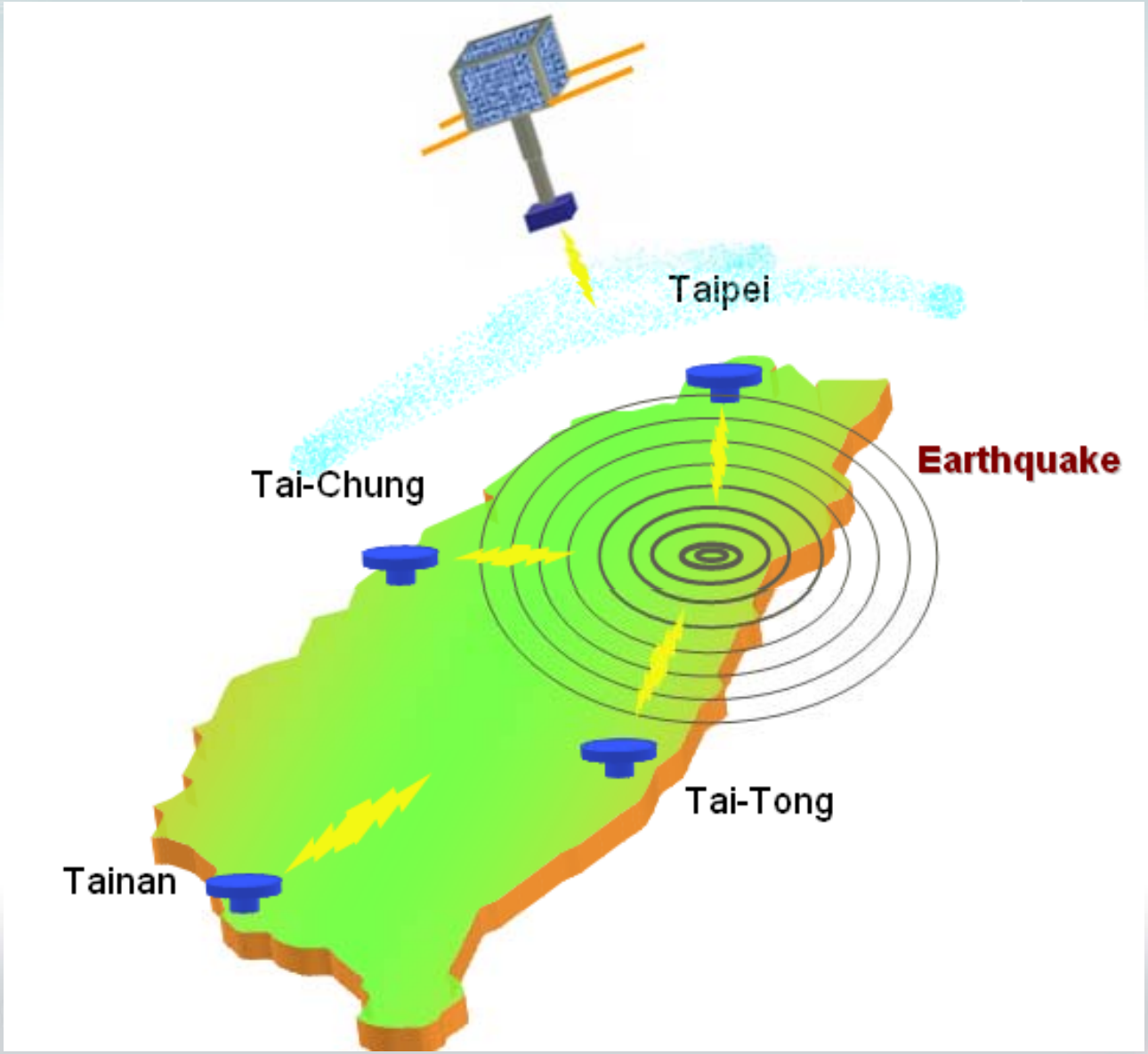


NSPO

NATIONAL SPACE ORGANIZATION

University Projects

NCKU Microsatellite



NSPO

University Projects

TKU Microsatellite

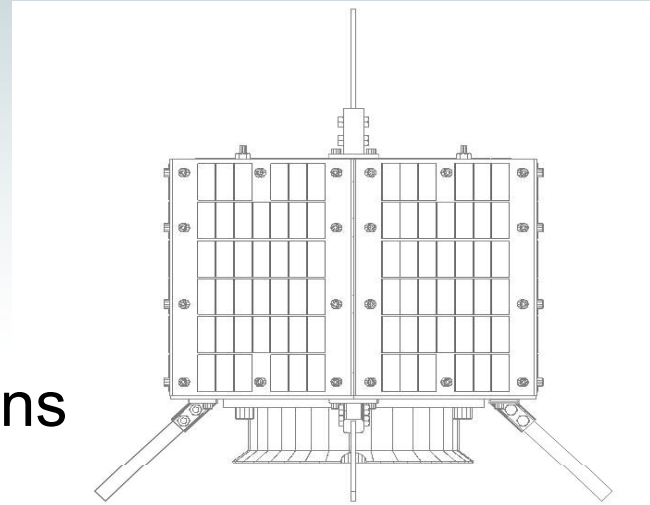
Name: TUUSAT

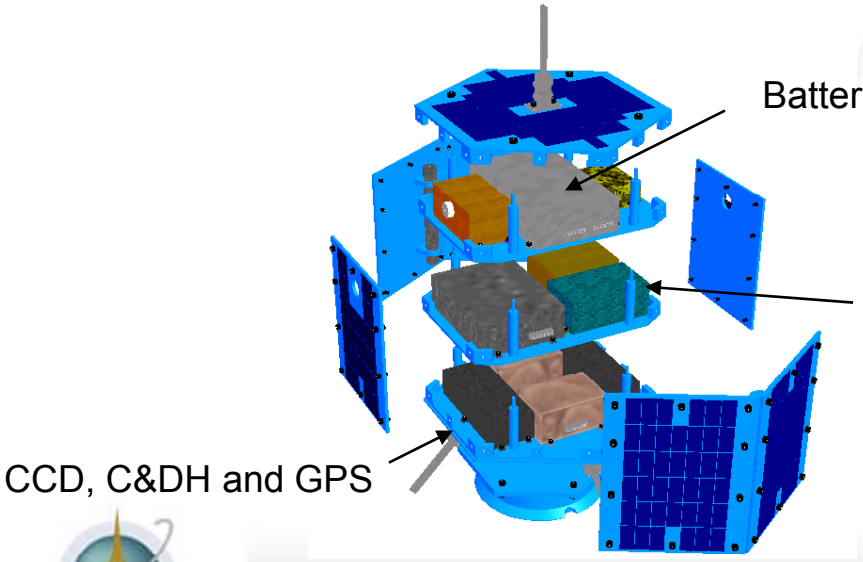
Orbit: 500 km, 22° Inclination

Mass: 22 kg

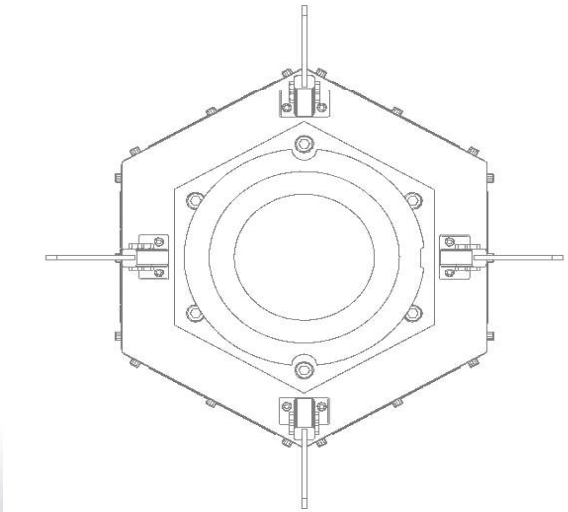
Communication: UHF/VHF

Mission: CCD Meteorology Observations





System Layout

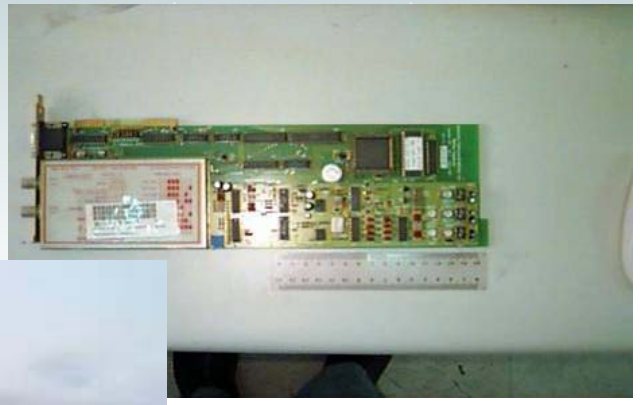


NSPO

NATIONAL SPACE ORGANIZATION

University Projects

TKU Microsatellite

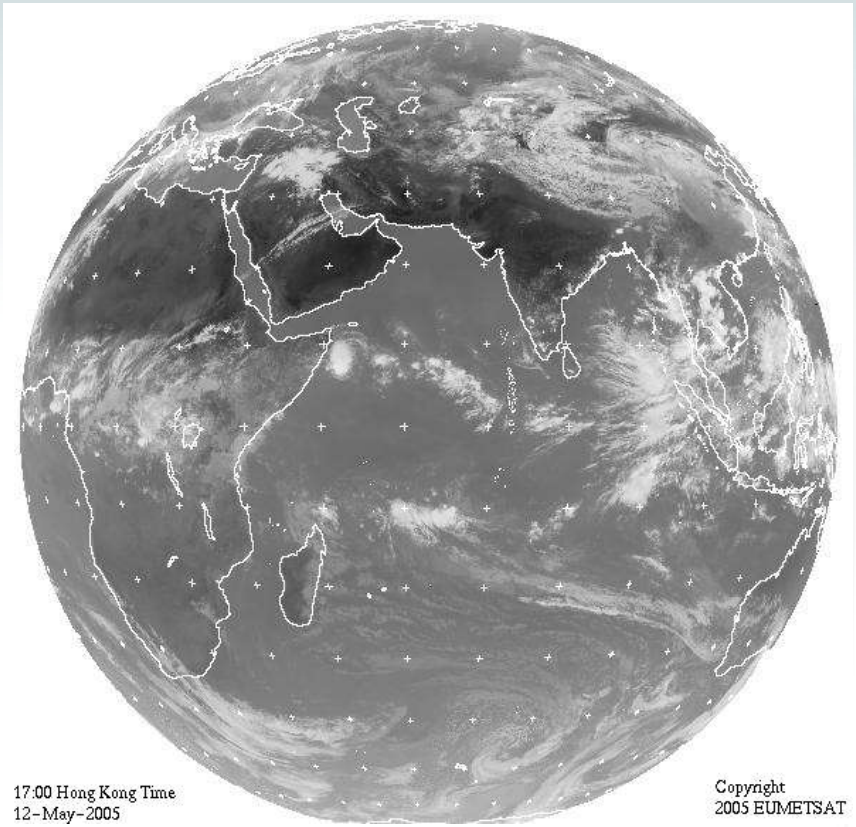


NSPO

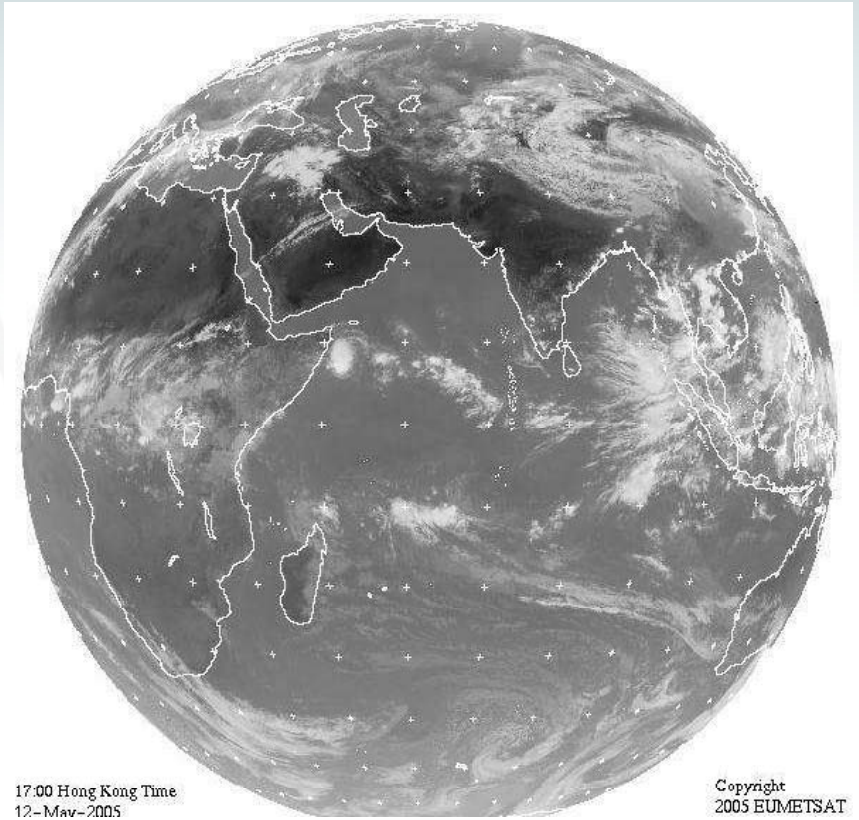
NATIONAL SPACE ORGANIZATION

University Projects

TKU Microsatellite



Before Compression: 340KBbytes



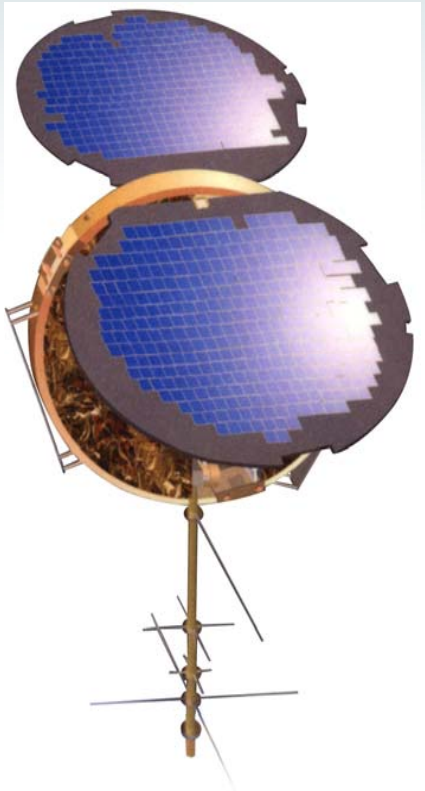
After Compression: 53KBbytes

Adjustable Image Data Compression Ratio

FORMOSAT-3/COSMIC Mission

FORMOSAT-3/COSMIC Satellite

- Mission Life：2 years minimum.
- Design Life : 5 years.
- Constellation：consist of 6 satellites.
- Weight：62 Kg/each (including propellant).
- Dimension：diameter 103 cm，height 16 cm；with two circular solar panels deployed at 121 degrees and 59 degrees.
- Orbit period：~100 minutes.
- Mission Orbit：circular orbit，altitude 700-800 Km，inclination 72 degree.
- Payloads: GPS Occultation Experiment (GOX), Tiny Ionosphere Photometer (TIP) and Tri-Band Beacon (TBB)

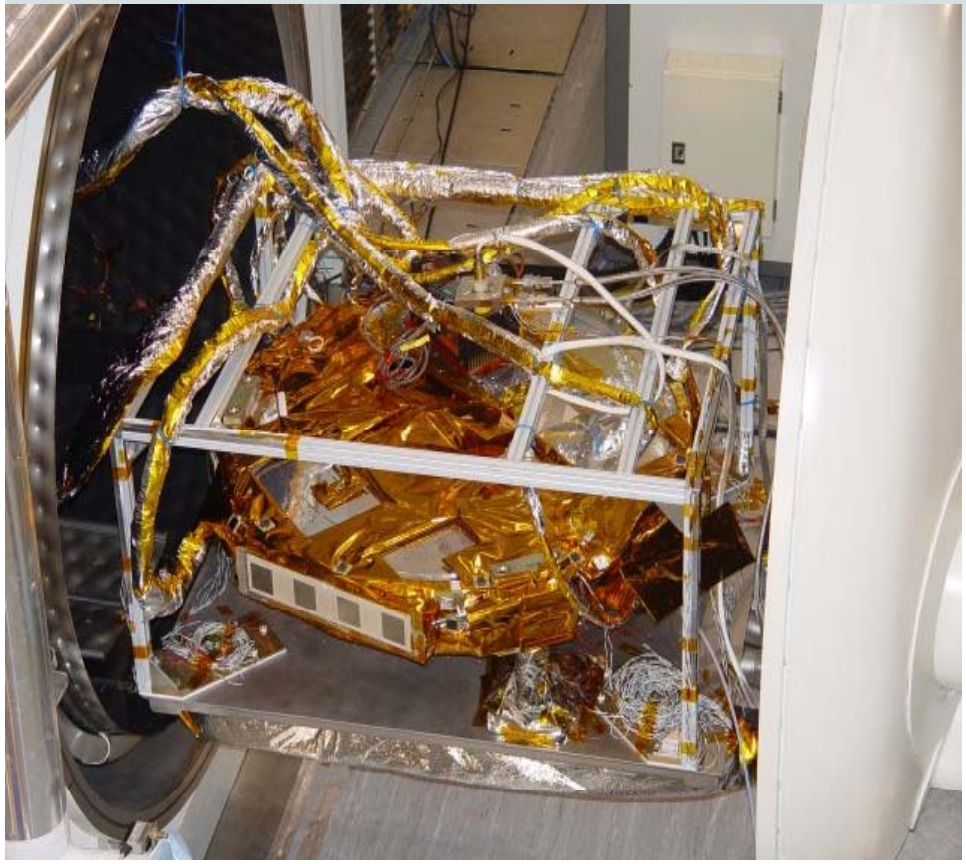


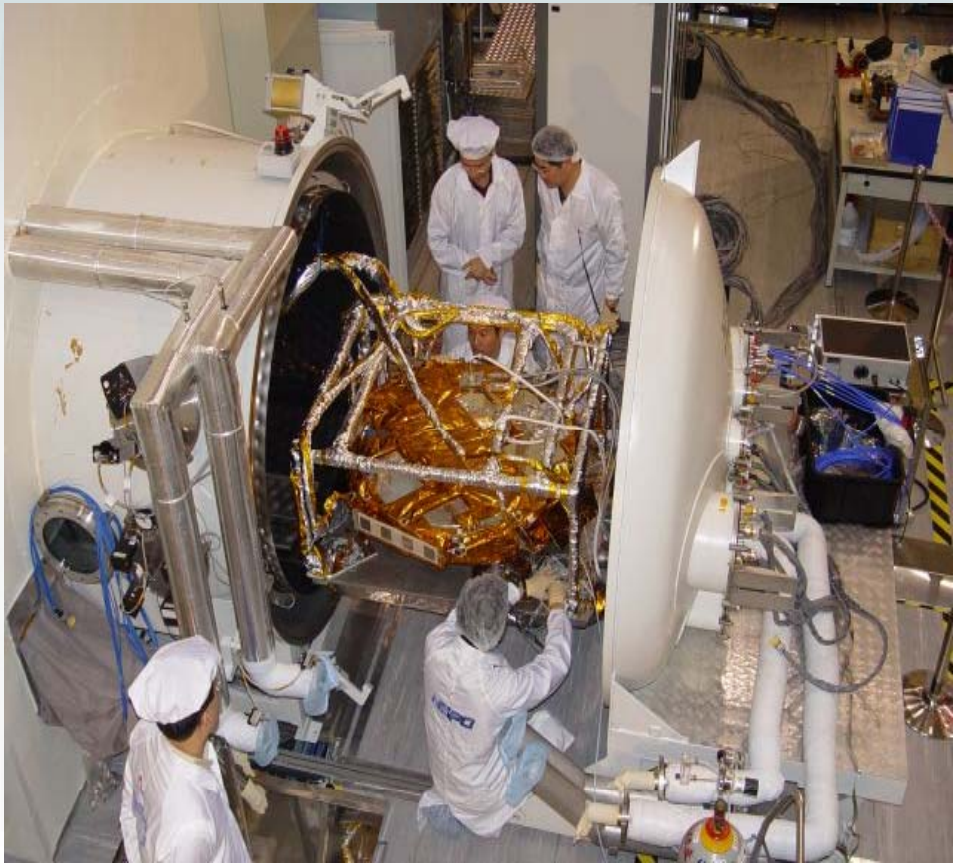
FORMOSAT-3/COSMIC Payloads

- **GPS Occultation Experiment (GOX)**
  - Function:
    - Track L1/L2 signals to collect occultation data and to determine precise orbit.
  - Mission:
    - Retrieve the vertical profile of atmosphere/ionosphere, for
      - Weather and space weather forecasts
      - Climate and ionospheric research
    - Determine the precise orbit for geodetic research
- **Tiny Ionosphere Photometer (TIP)**
  - Function:
    - Measure 135.6nm photon emission at satellite's nadir direction.
  - Mission:
    - Retrieve nighttime electron number density for ionospheric research
    - Map aurora boundaries
- **Tri-Band Beacon (TBB)**
  - Function:
    - Transmit phase coherent signals in 150, 400, 1066.7 MHz.
  - Mission: (TBB signals will be received on ground receivers)
    - Compute the satellite to ground linked TEC, for
      - 3-D maps of Ionosphere tomography
      - Scintillation monitoring

FORMOSAT-3 Assembly at NSPO

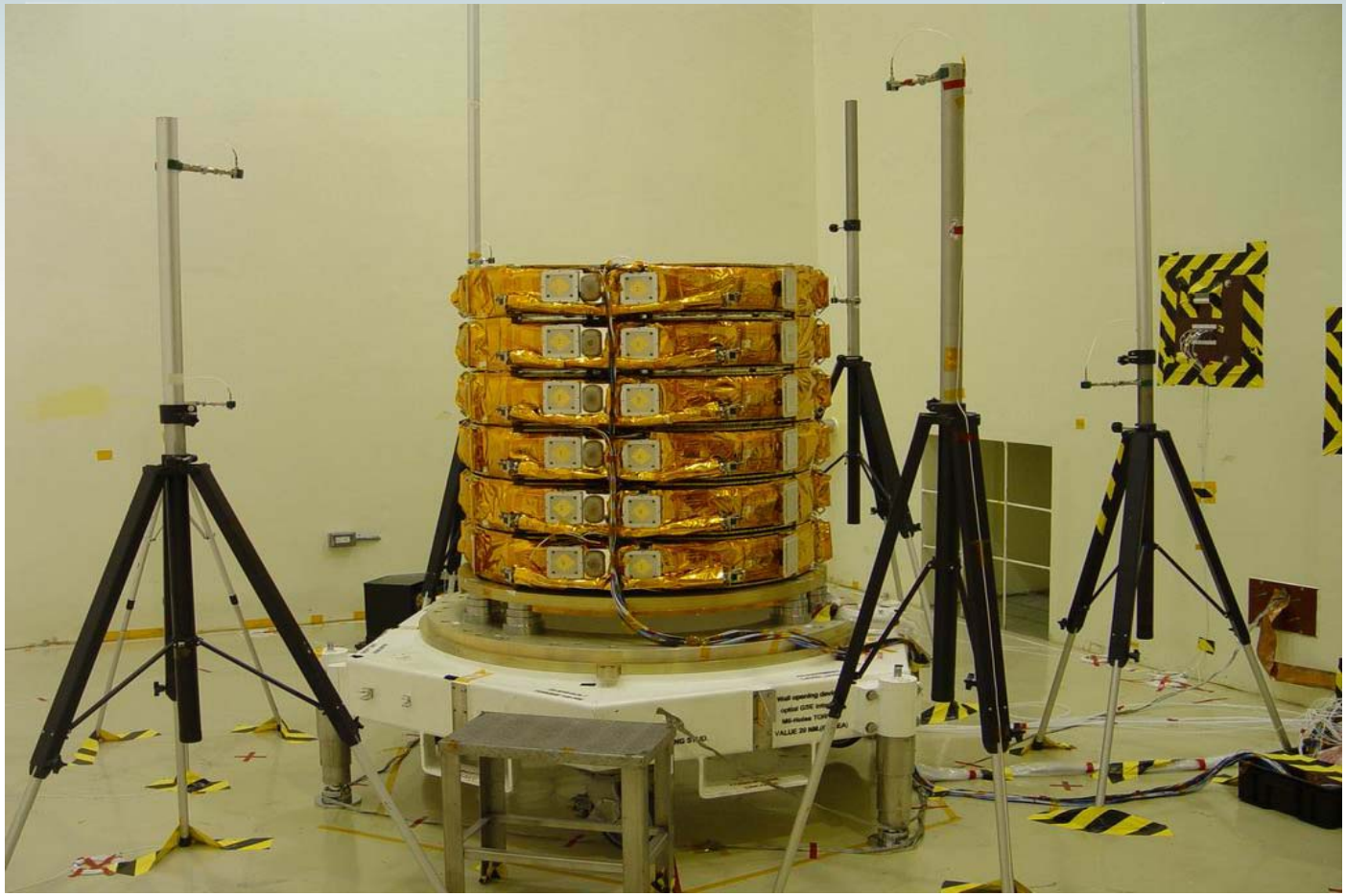
FORMOSAT-3 Thermal Vacuum I&T



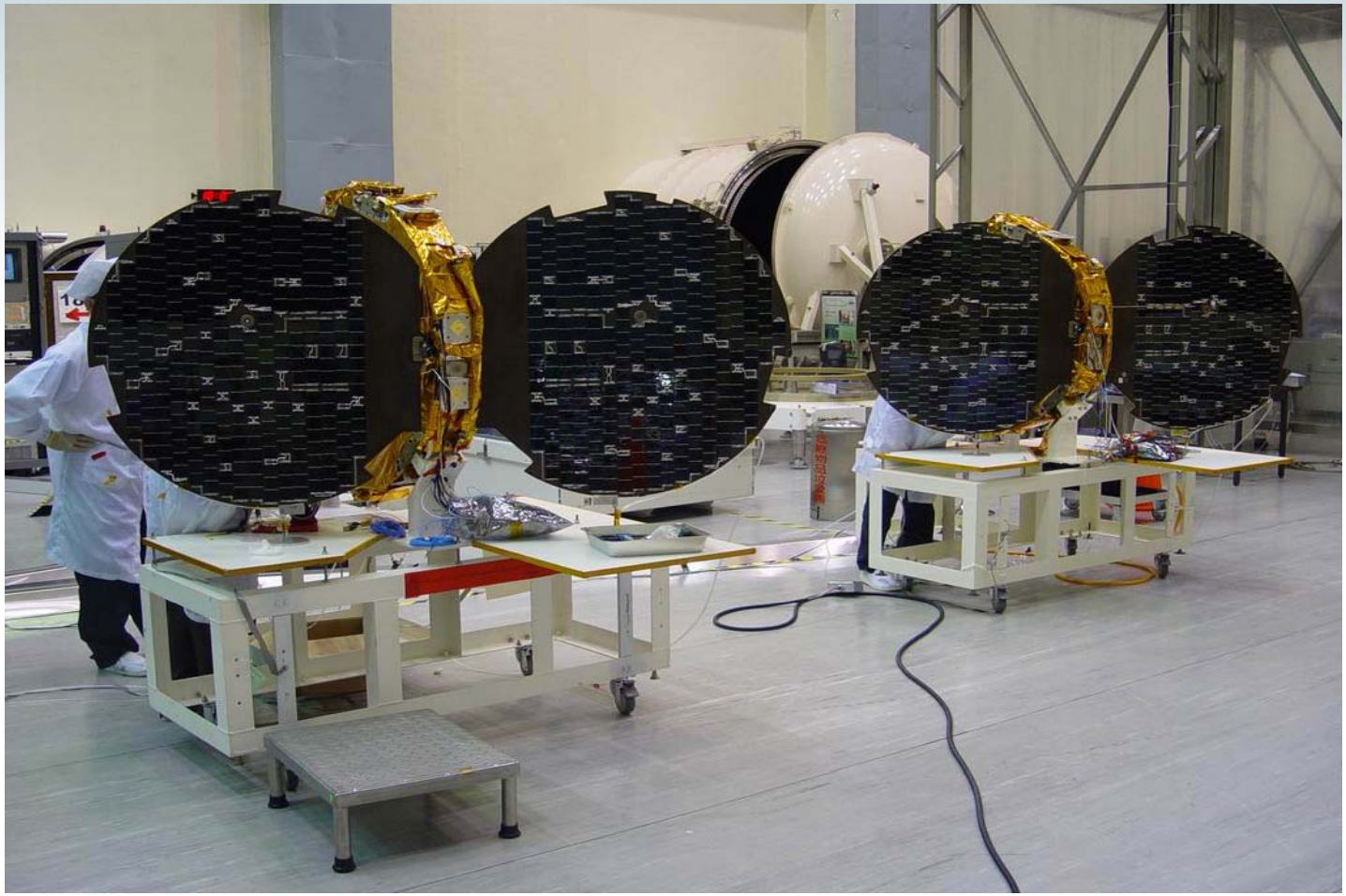


10~12 Days Continuous Tests for each Satellite

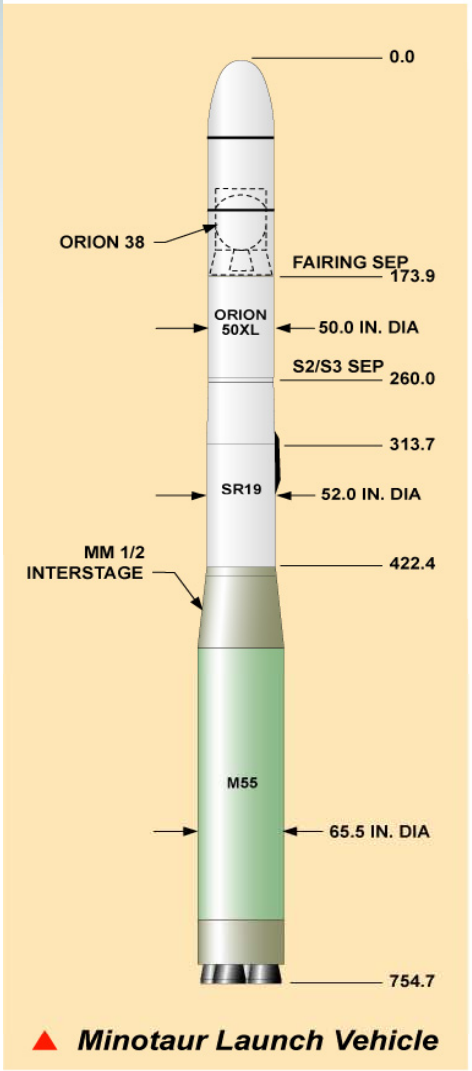
FORMOSAT-3 Acoustic/Vibration I&T



FORMOSAT-3 Solar Panel Tests



FORMOSAT-3 on Minotaur LV



▲ *Minotaur Launch Vehicle*

- Inaugural JAWSAT Launch, 26 January 2000, successfully deployed 11 satellites into targeted orbits
  - Launched from California Spaceport (SSI Commercial Launch Facility)
  - Demonstrated ability to launch with minimal infrastructure support
- Successful MightySat II Launch, 19 July 2000
  - Successfully delivered DoD Space Test Program/AFRL MightySat II Payload to targeted orbit
- Successful XSS-11 Launch, 11 April 2005
  - Successfully delivered DoD Space Test Program XSS-11 Payload to orbit
- Successful STP-R1 Launch, 22 September 2005
  - Sucessfully delivered DoD Space Test Program STP-R1 Payload to orbit

▲ *JAWSAT*

▲ *MightySat II*

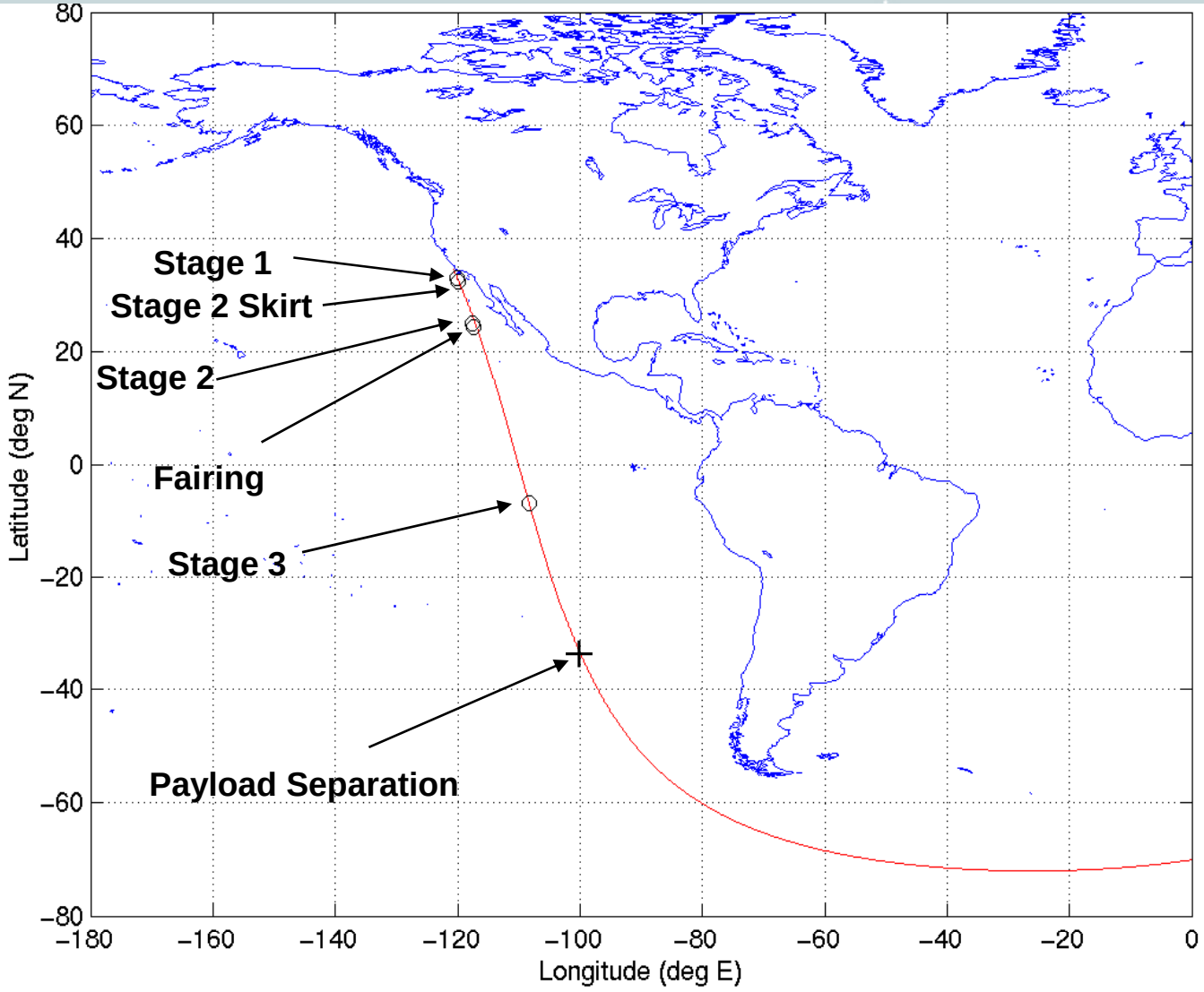
▲ *XSS-11*

▲ *STP-R1*

PR00033_004d

NSPO

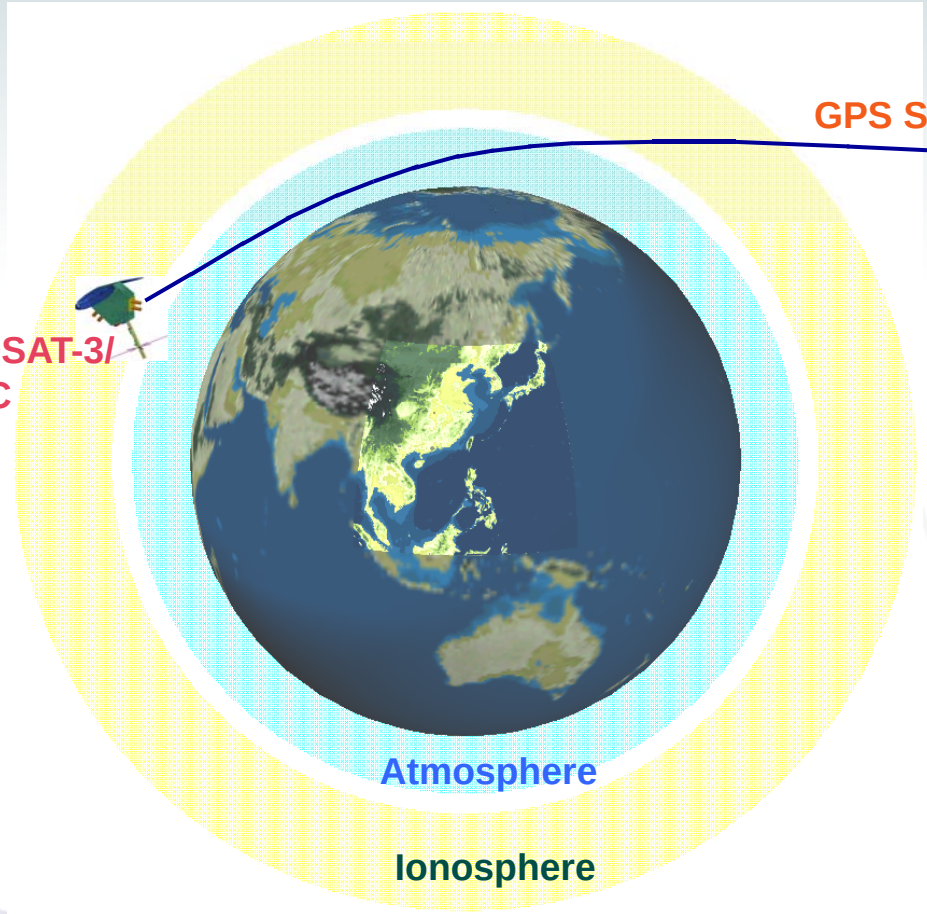
FORMOSAT-3 Launch Trajectory



NSPO

FORMOSAT-3 Mission Operation

GPS Occultation Sounding

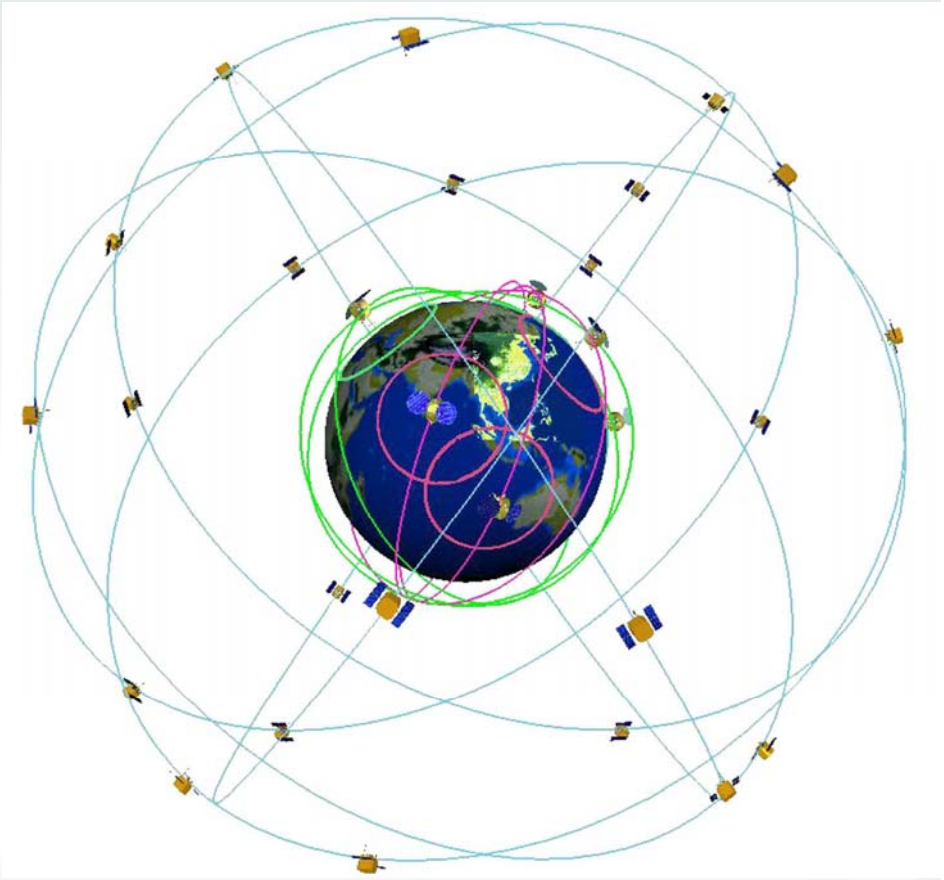


- To obtain the temperature, pressure, and water vapor pressure
- To provide TEC and electron density profiles

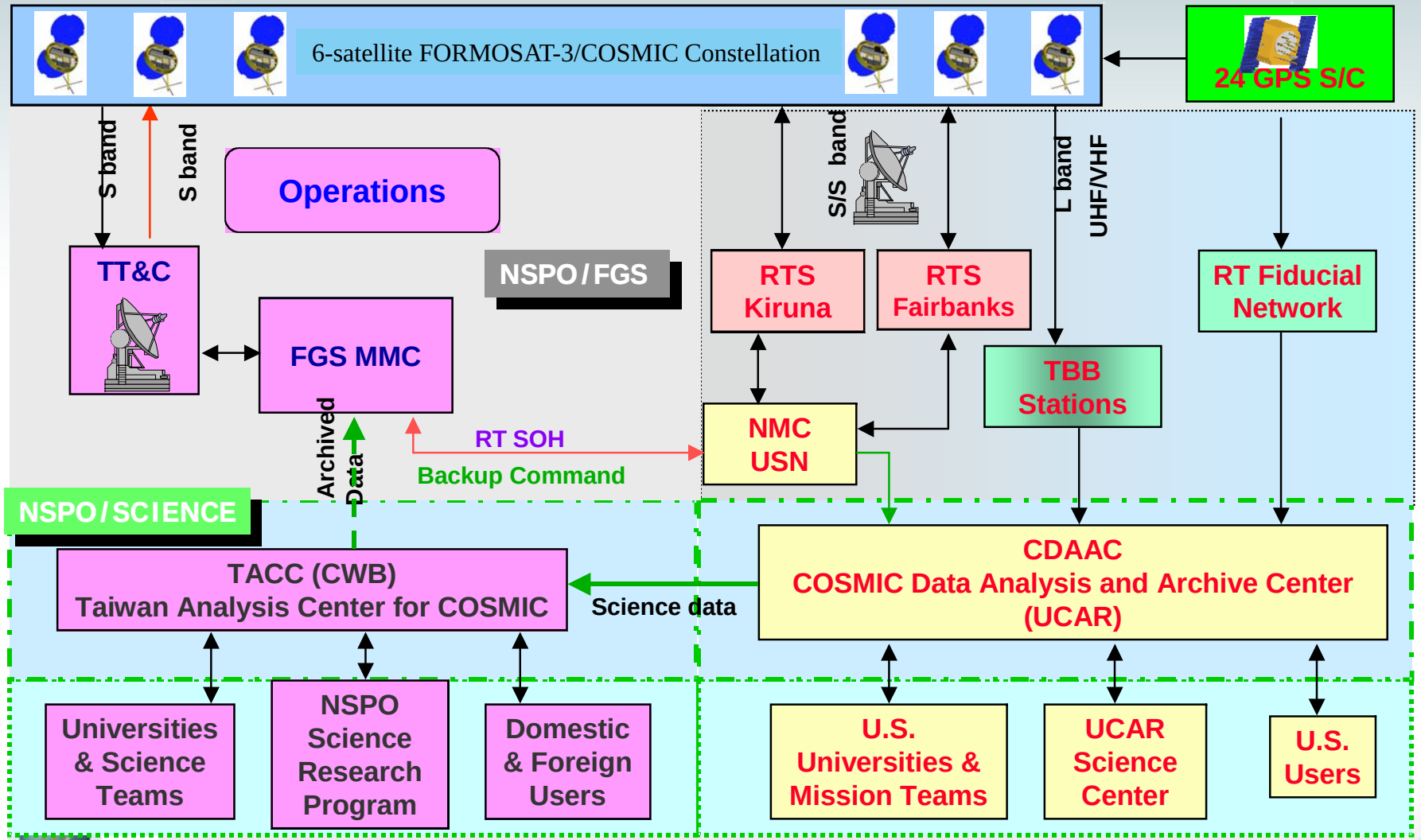
FORMOSAT-3 & GPS Constellations

- **GPS constellation**
  - 24-30 satellites in 6 orbit planes (55□ inclination)
  - ~3.8km/s at 20,200km altitude
  - Orbit period ~12hr

- **FORMOSAT-3 Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC)**
  - 6 satellites in 6 orbit planes (72□ inclination)
  - ~7km/s at 700-800km altitude
  - Orbit period ~100min

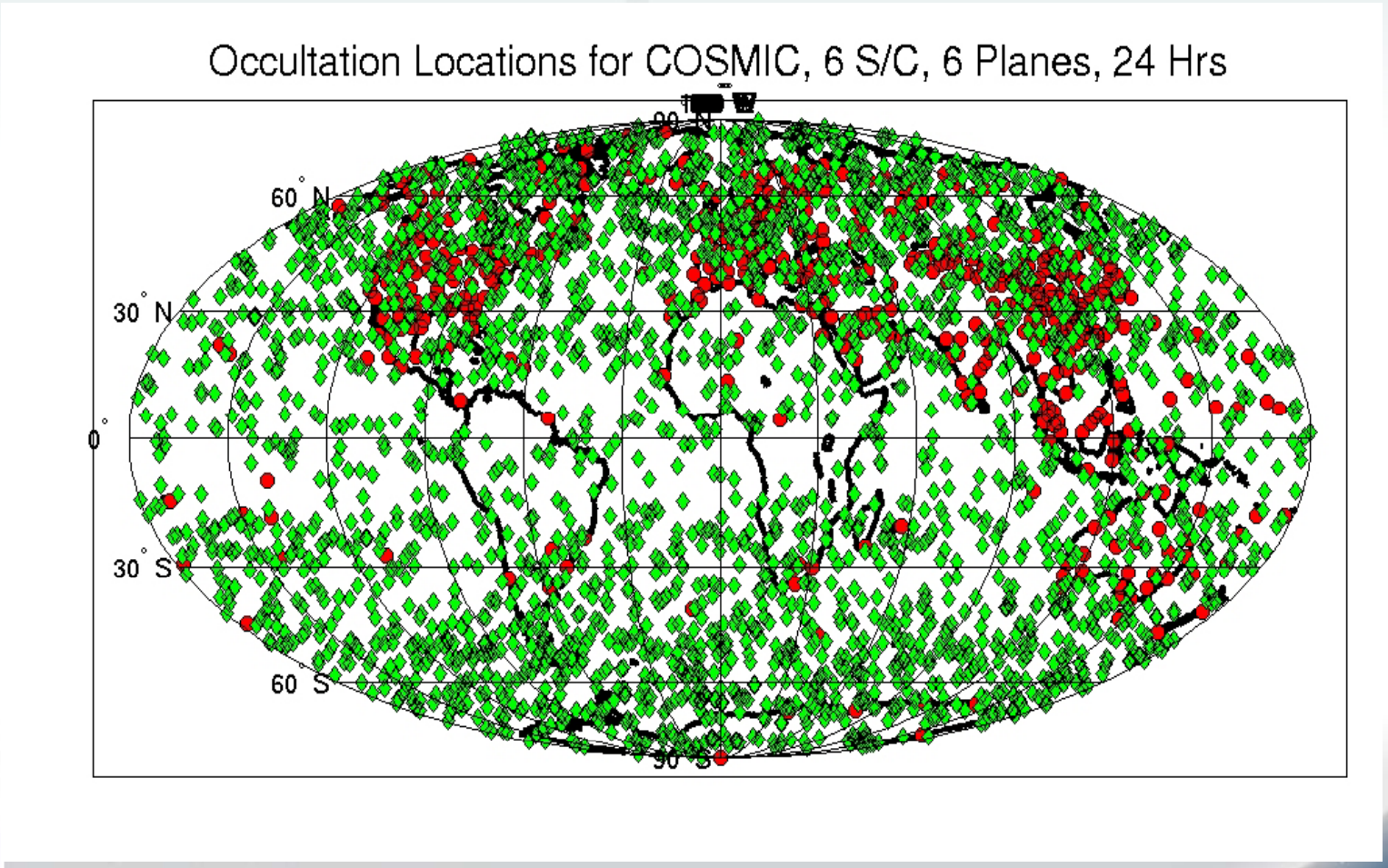


System Architecture



GOX Measurements: 2500 Soundings Per Day

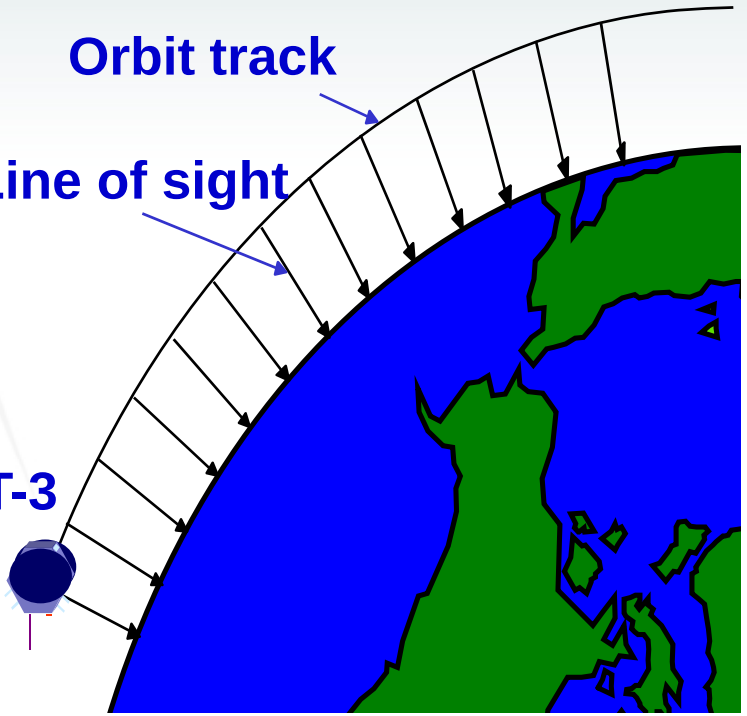
- An average of 2500 globally distributed atmospheric soundings will be obtained each day.



NSPO

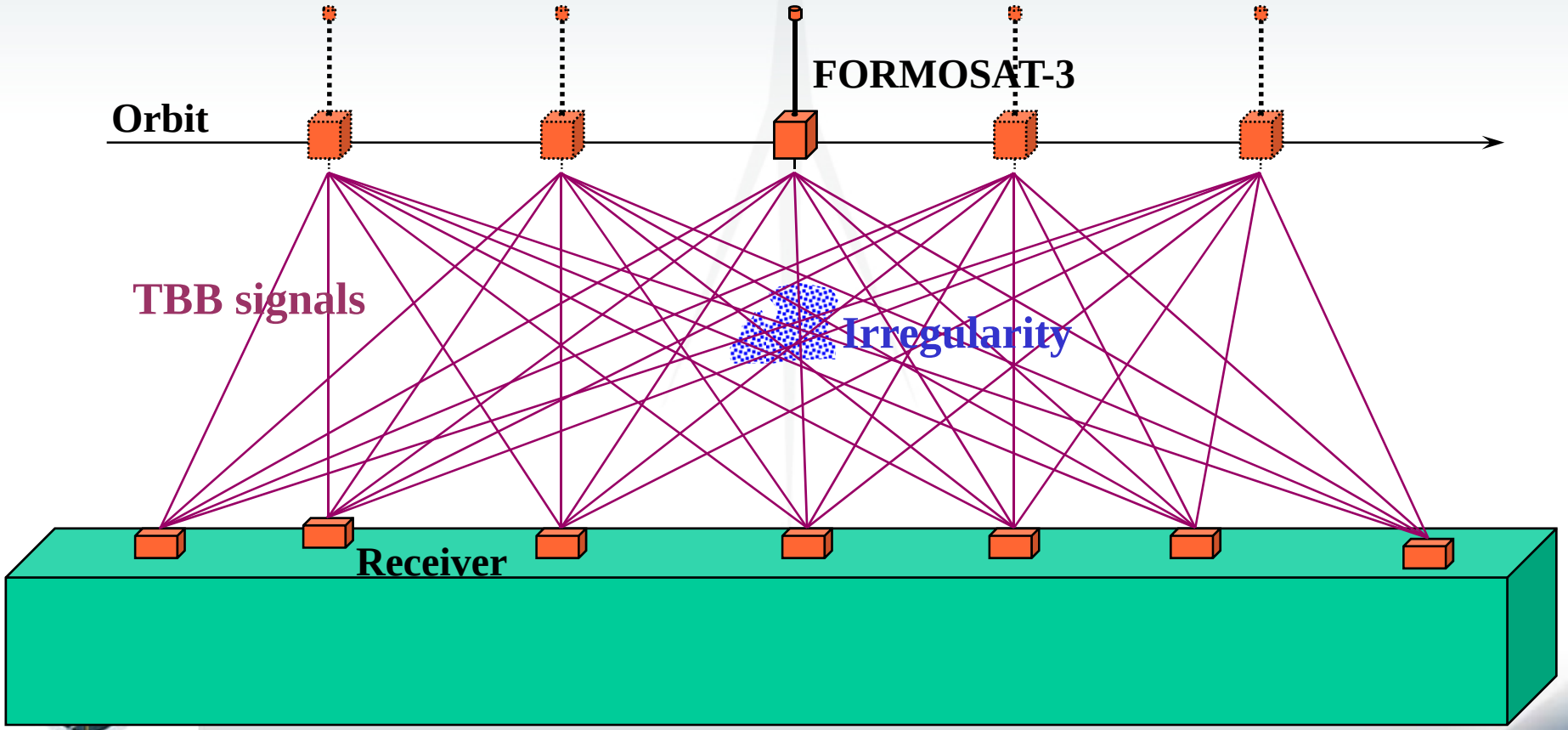
TIP Measurements

- **Nighttime ionospheric TEC measurements (e^-)**
  - *radiative recombination*
  - $O^+ + e^- \rightarrow O + h\nu\,(135.6nm)$
- **Map aurora boundaries (O)**
  - *electron impact excitation*
  - $O + e^- \rightarrow O + e^- + h\nu$
- **With the BaF2 filter, TIP can detect the molecular N_2 LBH emissions. (N_2)**
- **O, N_2 & e^- number densities are all retrieved from measured FUV radiance intensity (or photon counts, #/sec).**

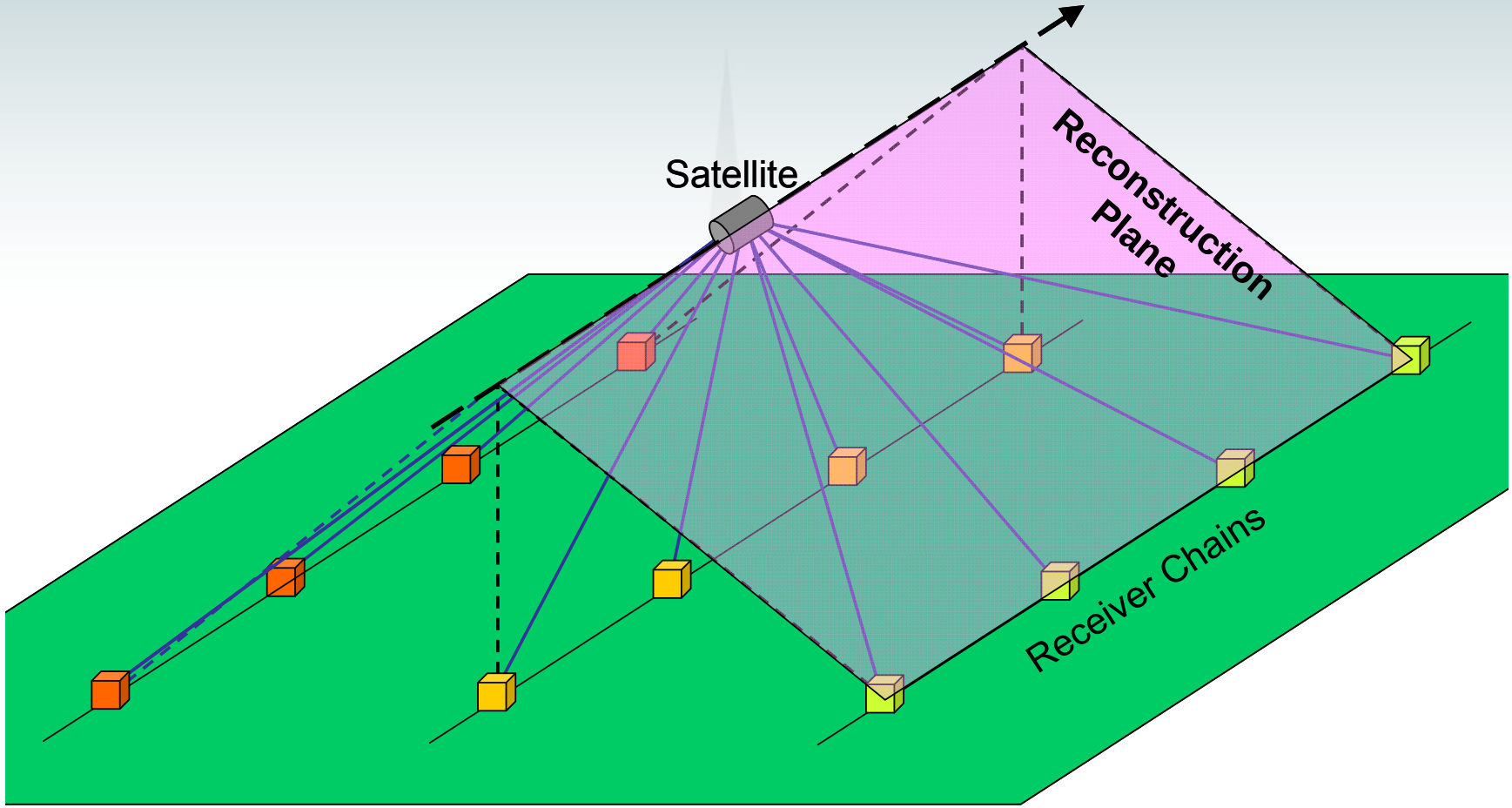


TBB Measurements

- Signals measured by a chain of ground receivers will be used to
  - *Retrieve electron density & 2-D Tomography*



3-D Tomography if Multiple Chains



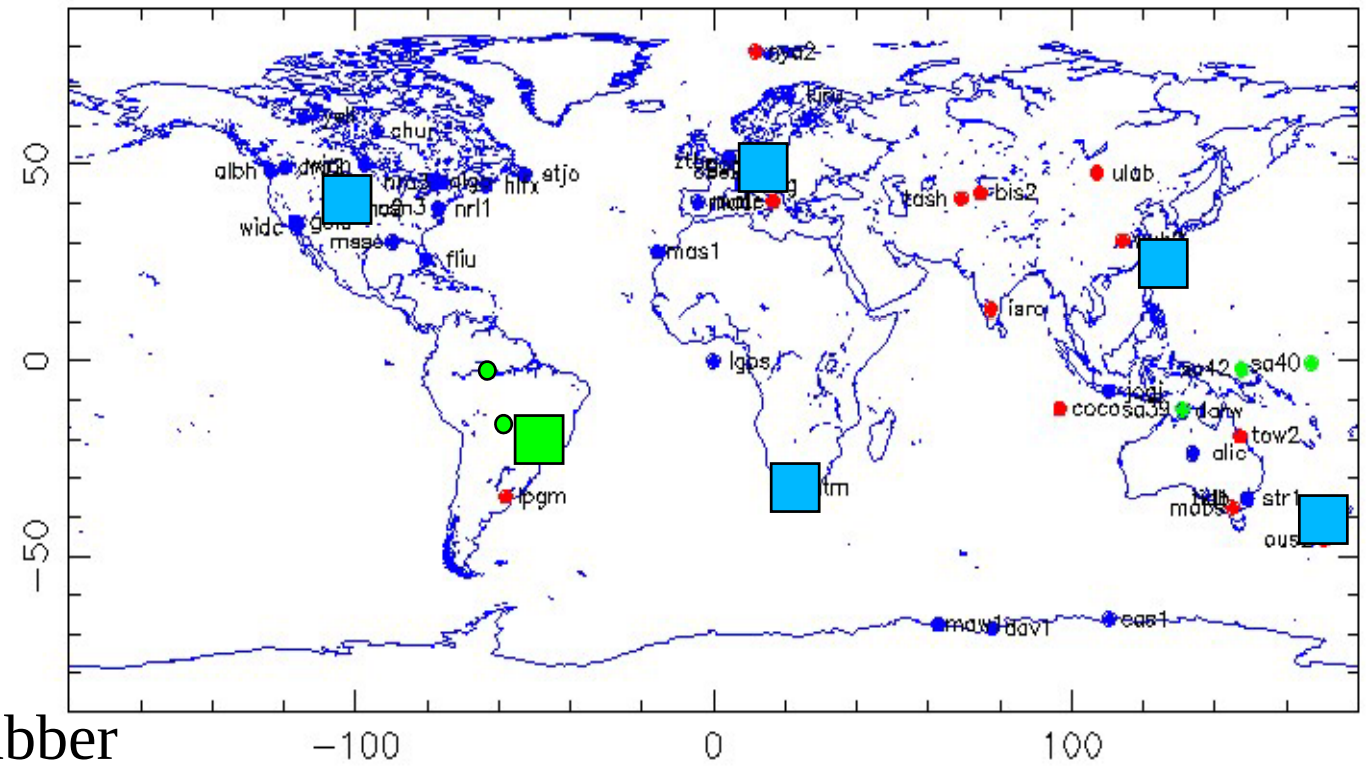
Data Processing in CDAAC

- **Real-time processing (RT)**
  - Run automatically, as data are received, on one or more cluster nodes.
    - Currently processing CHAMP results are generated on ~15 min. after receipt of CHAMP raw data
    - Expect to complete data processing from one orbit in 10-15 min after reception of FORMOSAT-3 occultation raw data
  - Uses predicted GPS orbits and forecast weather grids (NCEP/AVN)
- **Post-Processing (PP)**
  - Done 1-2 months behind real-time, in batches of one month
  - Done with more fiducial sites, precise GPS orbits and better fiducial troposphere values than those used in RT

CDAAC Development

- **Develop software, database, and web system**
  - Improve and speed up for the orbit, atmosphere inversion, data validation, and constellation data simulation
    - open loop tracking
    - Single difference for excess phase computation
    - non-local observational operator
  - Ionospheric profiling and tomography
- **Fiducial network**
  - ~20 IGS stations (igsHrf)
  - ~30 Natural Resources of Canada (NRCan) stations (canHrf)
  - 5 netRS GPS receivers (cosHrf)
    - 3 in South Pacific + 2 in Brazil
  - Global Bit Grabber network (under plan)
    - To assist with open loop tracking

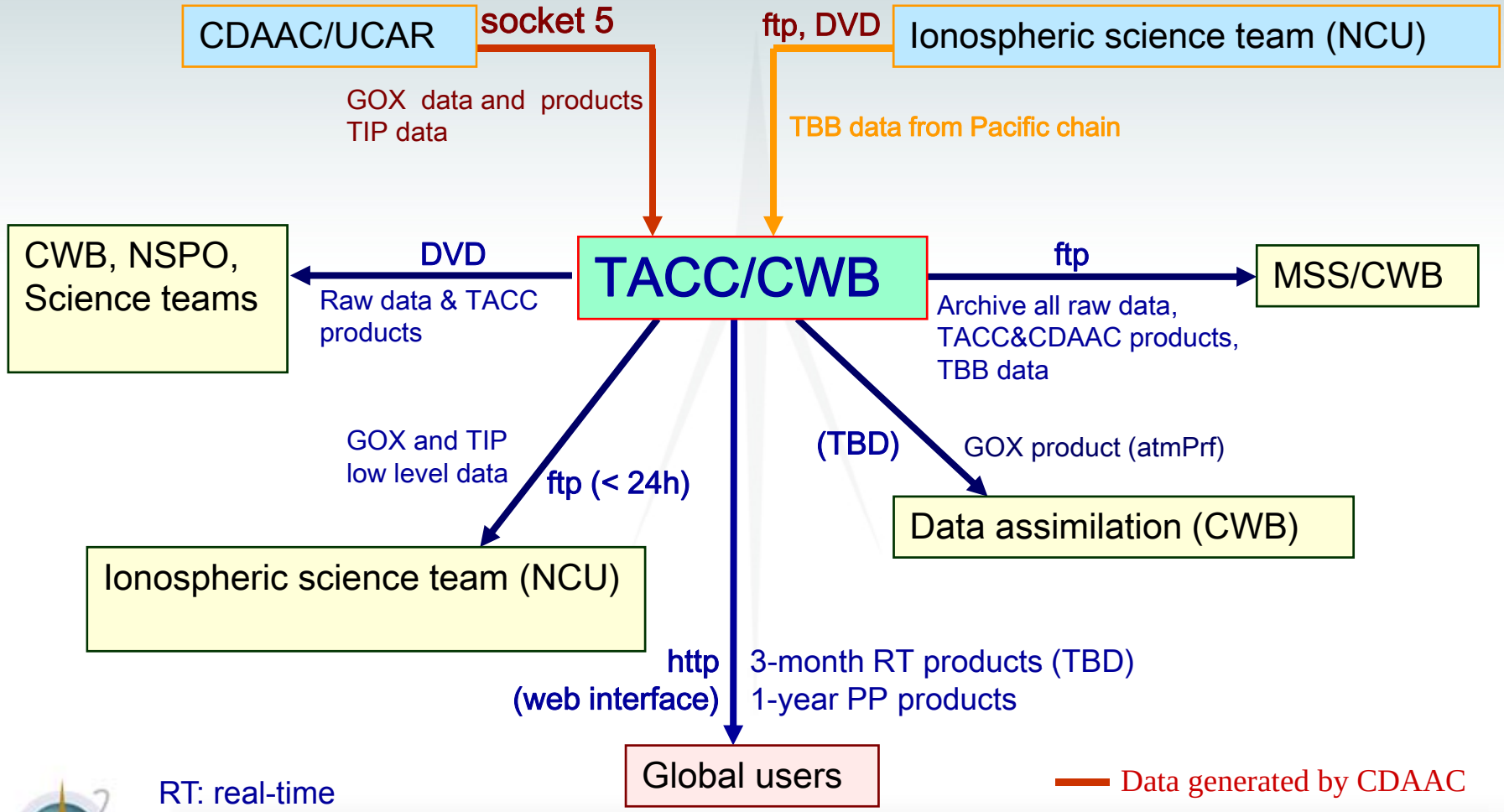
Fiducial Network



Bit Grabber

- Host agreed
- Host needed

TACC Data Flow



Related Science Research in Taiwan

Application of FORMOSAT-3/COSMIC Data

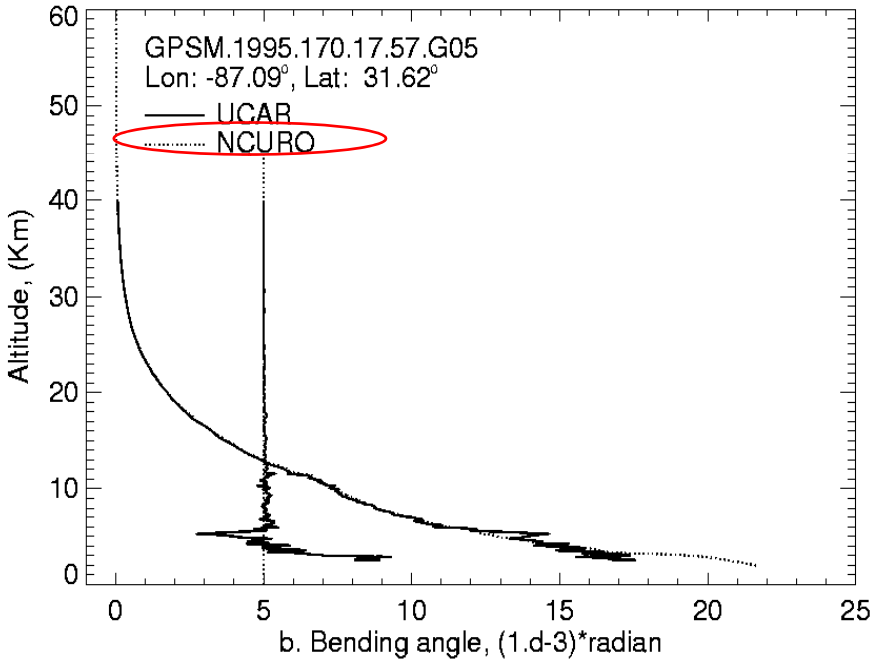
- **Improve global/regional scale weather and space weather forecasting**
- **Provide data sets for the research of climate change, global warming detecting, scintillation, ionospheric structure, and Earth gravity field.**
  - Meteorology: global weather analysis, interaction between low- and mid- latitudes weather system…
  - Climate: long-term observation record, global climate variability
  - Ionosphere: TEC, electron density distribution, scintillation, sporadic E (E_S) layer…
  - Geodesy: gravitational field, precise satellite orbit…

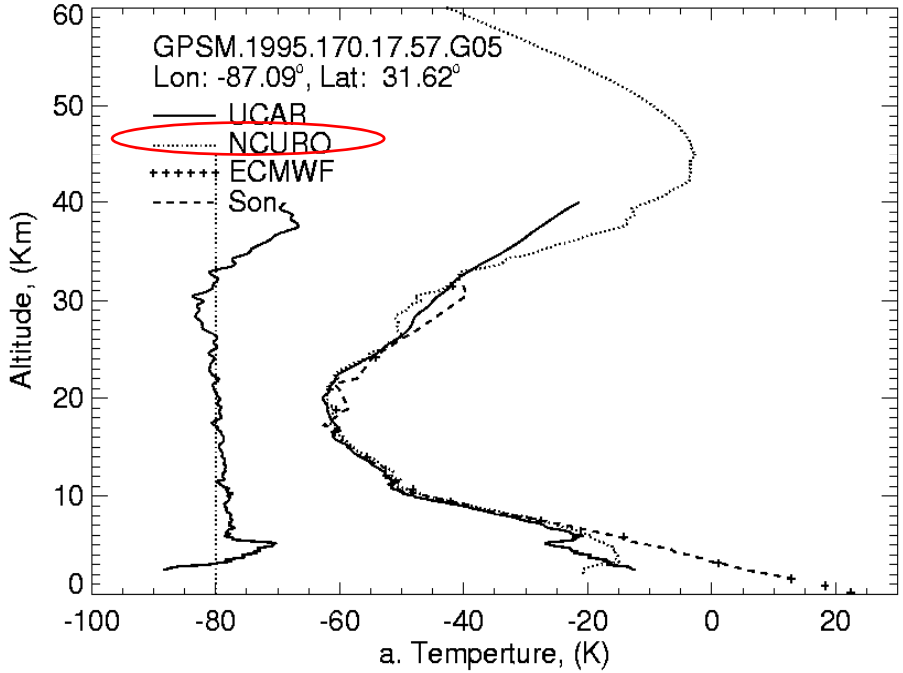
Atmospheric Research in Taiwan

- **Typhoon study by 3D-VAR assimilations**
  - Using CHAMP and SAC-C data to study the route and rainfall of typhoons passing Taiwan.
- **Implementation of ray-tracing operator and bending angle (and/or local refractivity) assimilation system into the CWB forecast model.**
- **Occultation inversion technique**
  - Occultation retrieval scheme by 3D vector analysis
  - New ionospheric correction method
  - Effects of multipath and diffraction on retrieved parameters
  - Ground-based GPS observations
    - sensing precipitable water vapor and its dynamics during the passage of typhoon

Development of Occultation Inversion Technique

- **Comparison of retrieved profiles for bending angle and temperature**
  - NCURO is developed by Dr. Huang (2004)



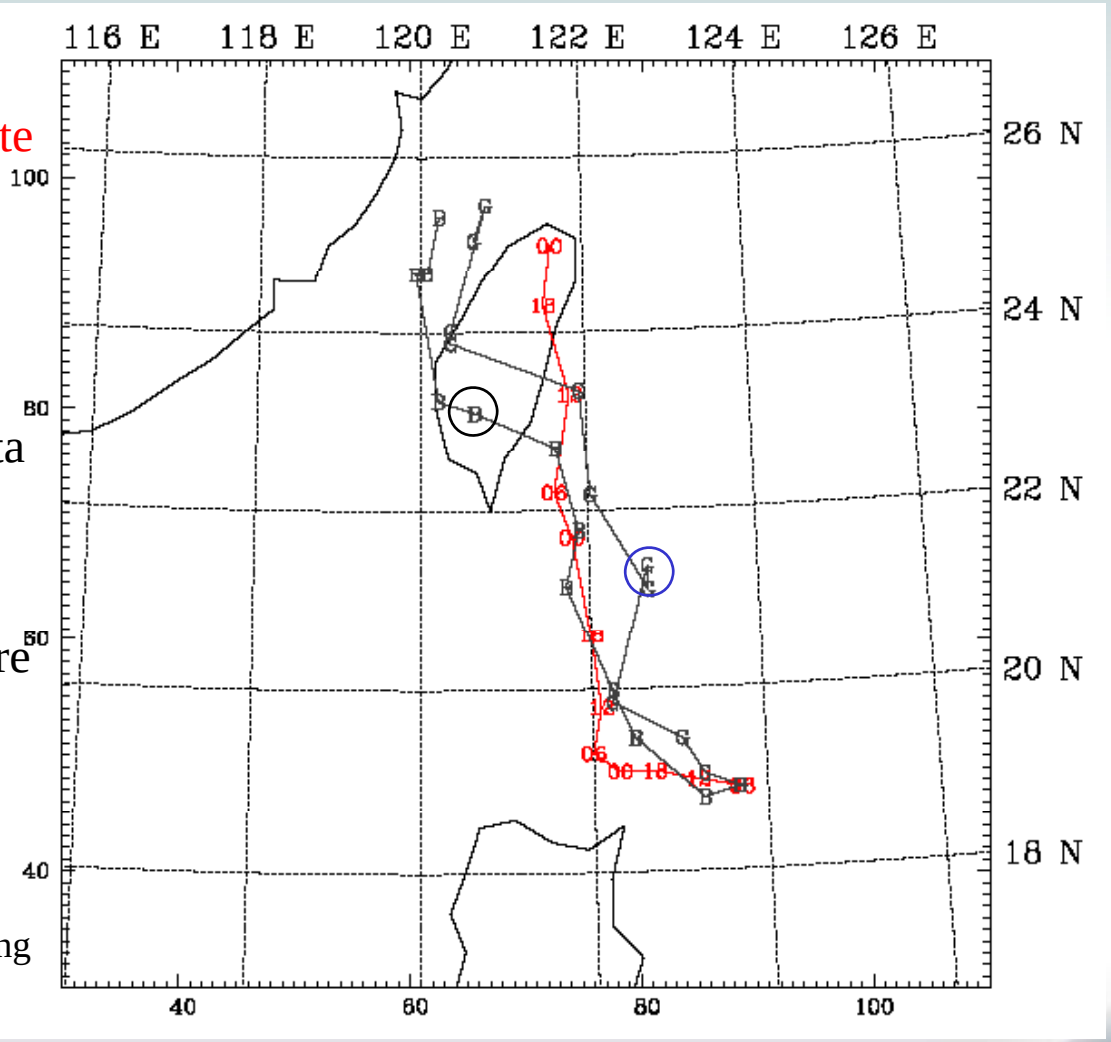


Identical with UCAR result

Difference above 25km is due to the different background models

Assimilated Typhoon Route By Adding CHAMP Occultation Data

- **Mindulle typhoon in June, 2004**
  - Red: CWB's optimized route
  - "G": assimilated route by using traditional measurements
  - "B": assimilated result by traditional and CHAMP data
- **Agree with the optimized route?**
  - "B" is better than "G" before Mindulle landed Taiwan.
  - Both "G" and "B" are bad after landing.
    - Due to the complexity of topographic model and the long time computation error.



Ionospheric Research in Taiwan

- **Setup of four transmitter/receiver pairs of 30 MHz bistatic coherent radar system in Taiwan:**
  - Measuring the ionospheric E region irregularity to determine the possibility of the TBB or GPS signal scintillations
    - For TBB operation in the Pacific chain, the bistatic radar observations will provide a referenced index for the UHF&L-band mode to be turned on.
- **More vertical data with Sounding Rocket Experiments**
- **Ionospheric global modeling and space weather forecast**
- **3D/4D Computerized ionospheric tomography (CIT)**
- **Retrieval/validation of electron density through occultation data**

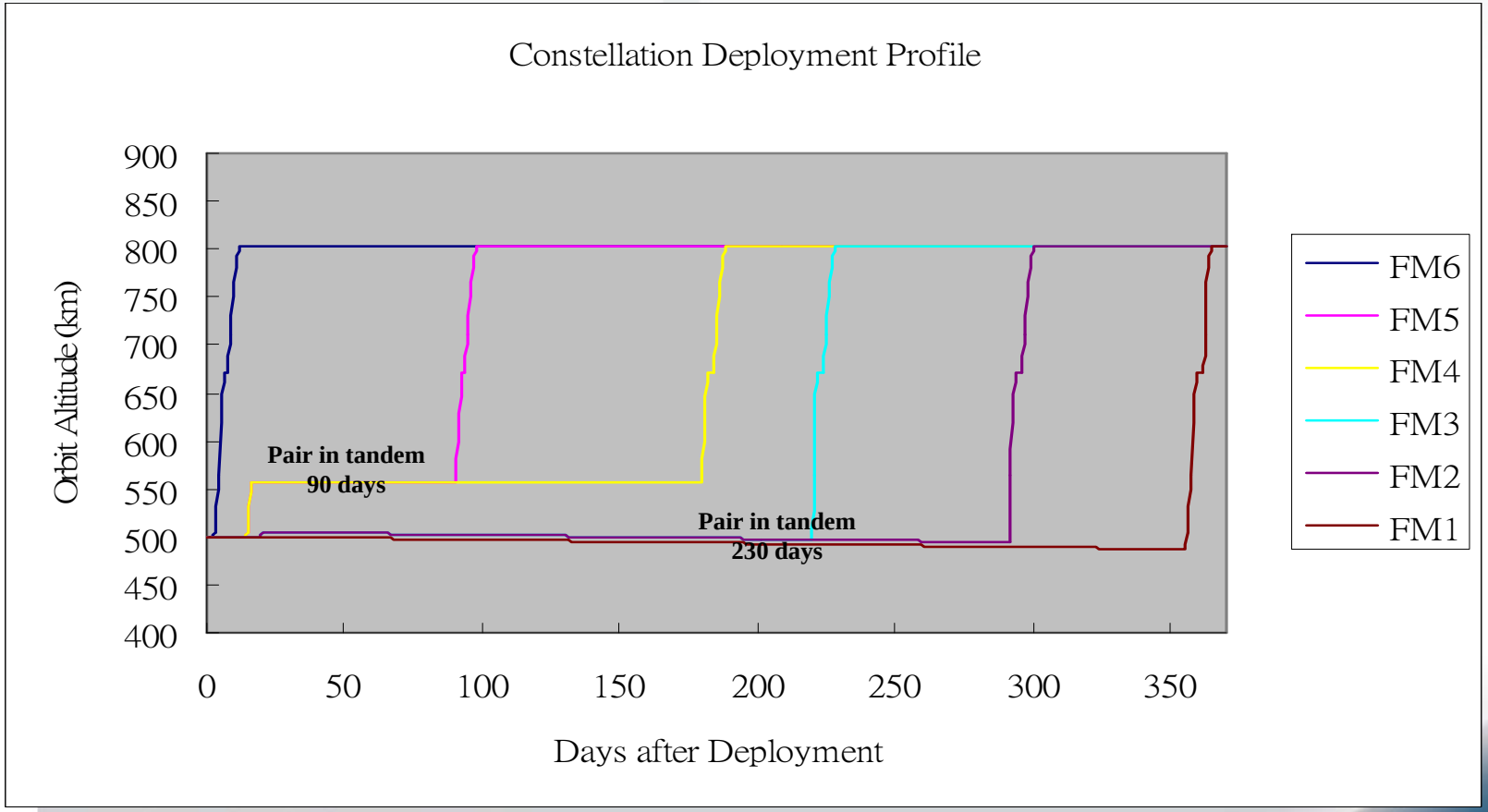
Geodetic Research in Taiwan

- **POD techniques**
  - A CTODS (reduced-dynamic orbit) package was developed for precise orbit and gravity determination from spaceborn GPS data.
  - Kinetic orbit procedures were developed to support the near-real time processing of occultation inversion.
- **Earth's mantle discontinuity in 3D**
  - The 3D inversion of the Earth's underground structures was studied by comparing the recent gravity model with the perturbation of satellite orbit from POD data.
    - Two major boundary layers in the Earth's mantle are at depth of 400 km and 670 km within the mantle, respectively.

Intensive Observation Period

FORMOSAT-3 Constellation Orbits Deployment

- Launch and early orbit (L&EO): 1st month
- Constellation deployment: 1 ~ 12th month
- Final orbit: after the 13th month



NSPO

Intense Observation Period (IOP) Campaign

- **Taking advantage of very dense observation points due to localized (in longitude) FORMOSAT-3 satellite orbits during the earlier deployment phase to conduct IOP campaign.**
  - Allows most complete comparison and validation of FORMOSAT-3 GPS occultation observations with ground-based observations and dropsonde experiments and other space-based observations in East Asia longitude region.
  - Improve weather forecast capability, typhoon prediction, and monsoon rainfall in East Asia region.
  - Improve global space weather monitoring capability and earthquake application.

IOP Items

- **IOP campaign provides a platform for Taiwan to play a major role in international collaboration on research in atmosphere, ionosphere and geodesy.**
  - Period: 2006/05 - 2006/11
  - Hold an IOP Campaign workshop/conference in November or December, 2006 in Taiwan

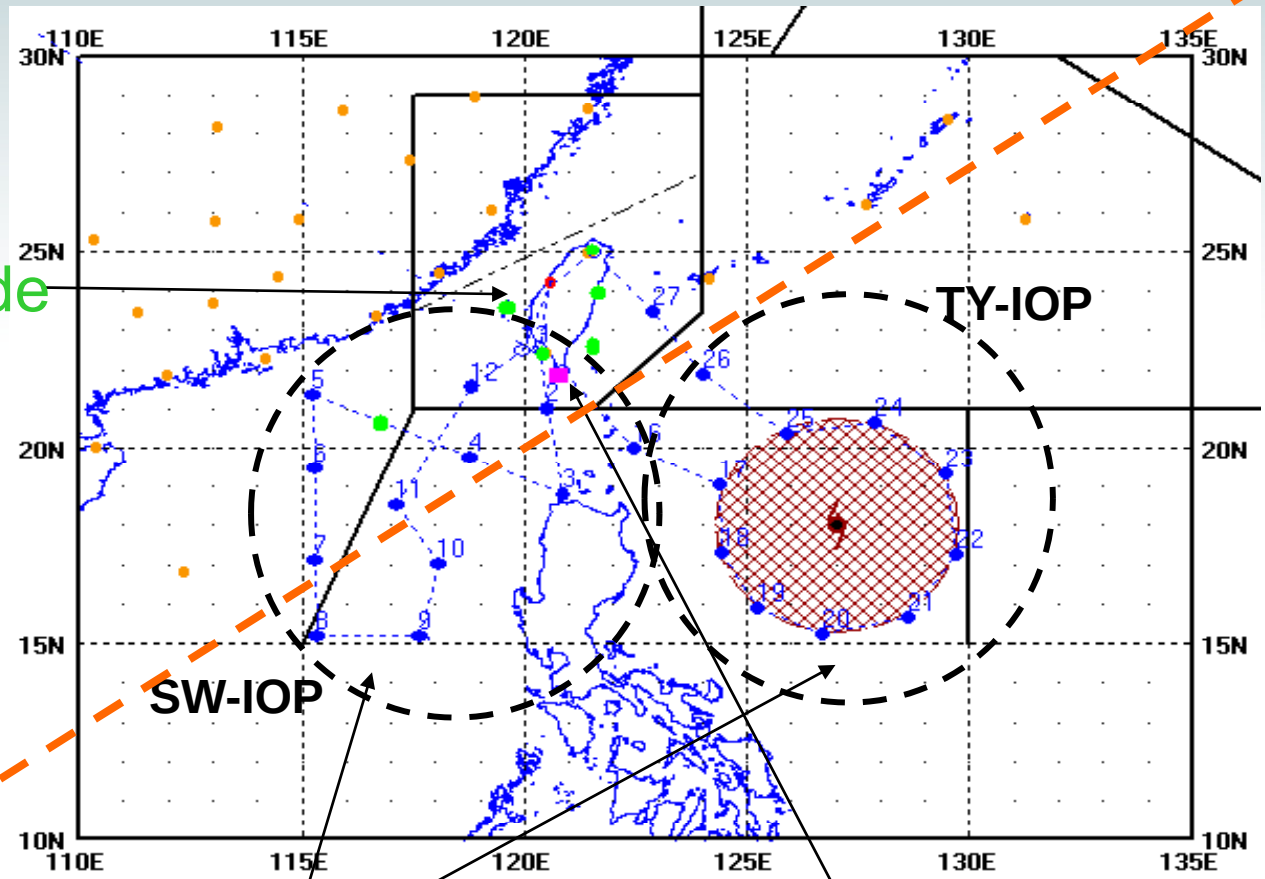
- **IOP Campaign for atmospheric study in East Asia Region**
  - Taiwan: 2006/05 - 2006/11
  - Southwesterly flow: 2006/05 – 2006/06
  - Typhoon: 2006/05 – 2006/10
  - Instruments: radiosonde, GPS receiver, dropsonde, satellites, etc.

- **IOP Campaign for global ionospheric study**
  - Observation comparison between GOX, TIP, ground GPS and ionospheric radars: 2006/05-2006/11

2006 South China sea Southwesterly flow/Typhoon path forecast experiment

GPS

Radiosonde



FORMOSAT

Dropsonde

UAV sonde +
Microwave Radiometric profiler

NSPO

NATIONAL SPACE ORGANIZATION

Conclusion

- University microsatellite projects are on going.
- FORMOSAT-3/COSMIC has been launched on April 14 2006.
- With the real-time operations, FORMOSAT-3/COSMIC results will complement other Earth observing systems and improve global weather analyses and Numerical Weather Prediction (NWP) forecasts.
- The science teams in Taiwan are actively pursuing FORMOSAT-3/COSMIC researches in the areas of GPS occultation for weather forecasting, climate prediction, ionospheric monitoring, and a suite of related earth science studies.
- The period during the orbit deployment provides a very unique opportunity for special studies. Many researches are being planned for this Intensive Operation Period.