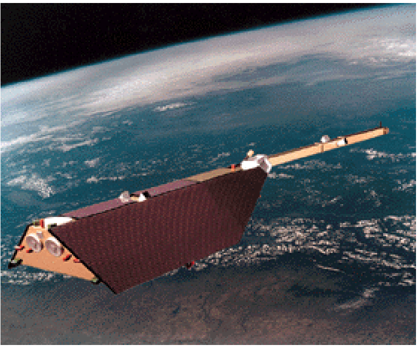
COSMIC-2: Next Generation Atmospheric Remote Sensing System using Radio Occultation Technique



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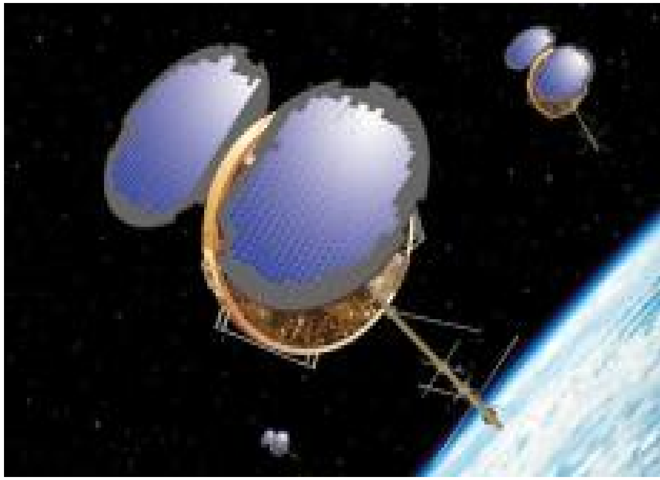
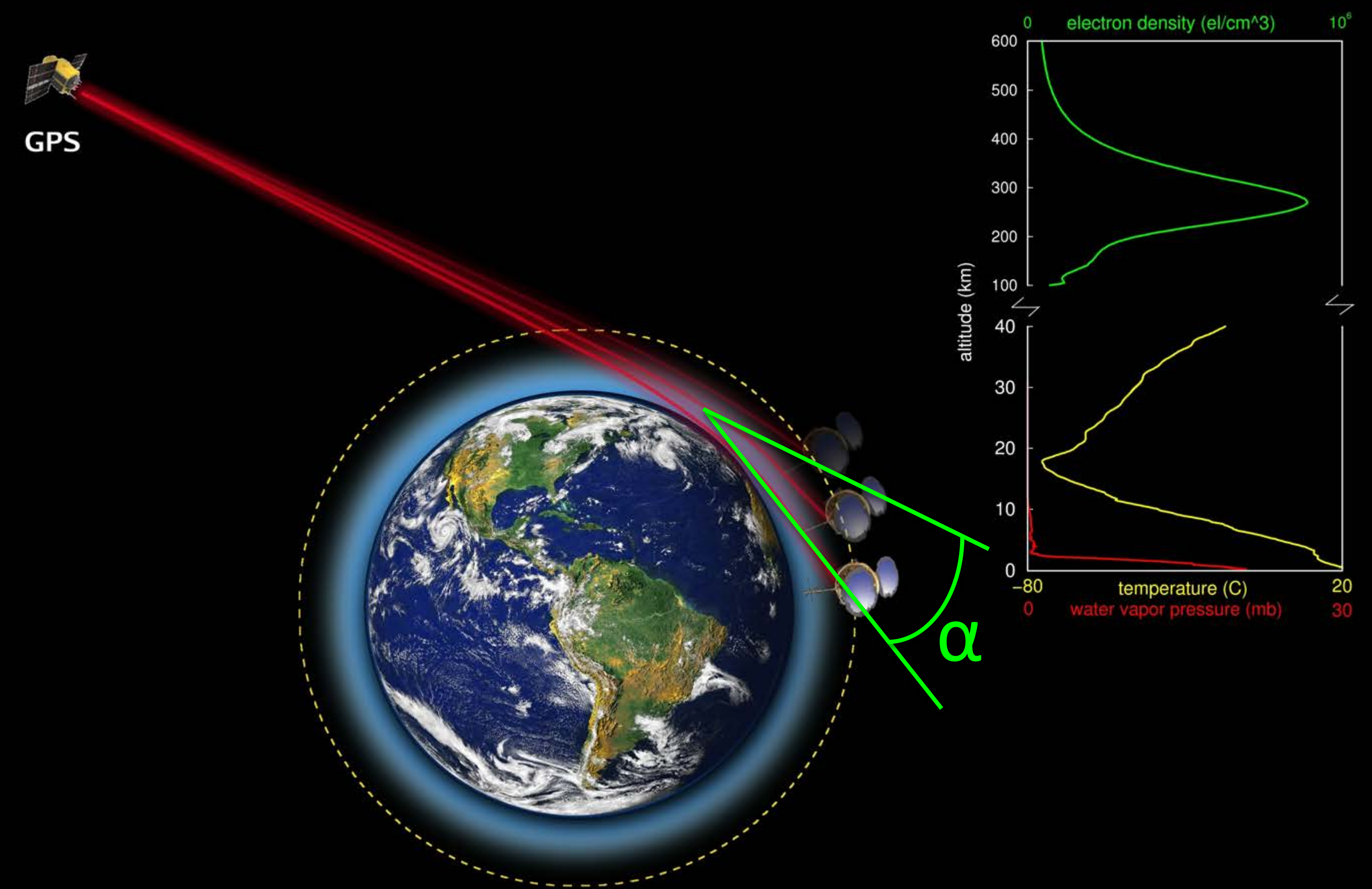
UCAR COSMIC Program Office
www.cosmic.ucar.edu



GPS Radio Occultation



COSMIC – Constellation Observing System for Meteorology, Ionosphere and Climate

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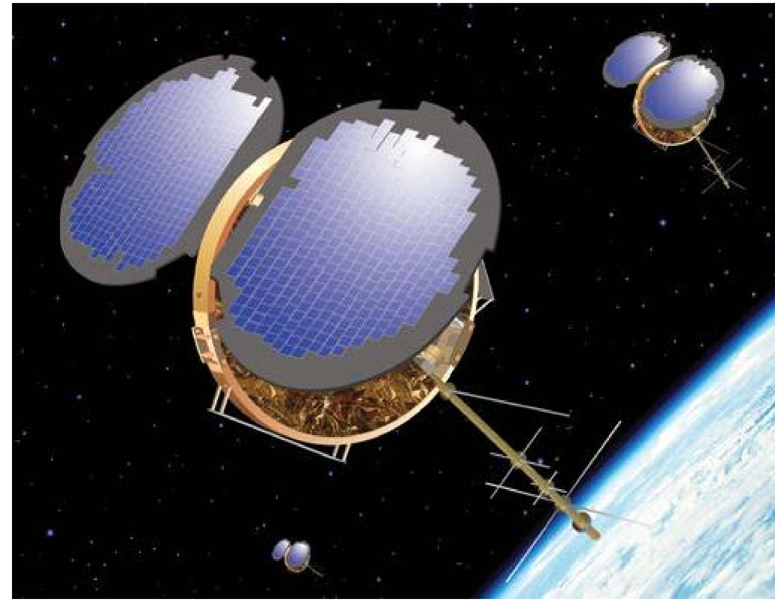
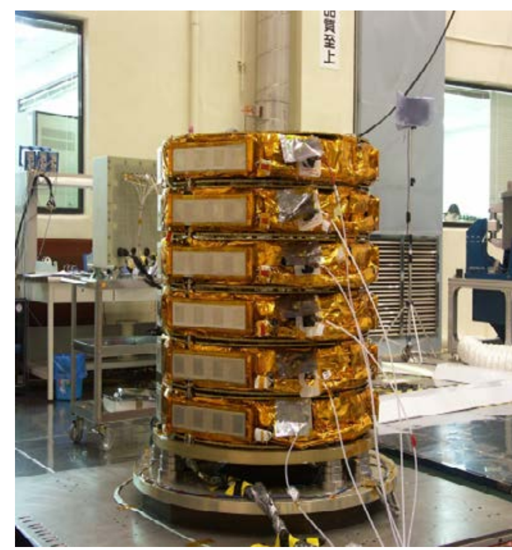


- Joint Taiwan and US project
- NSF is U.S. lead agency
  – NOAA, NASA, Air Force, Navy
- 6 Satellites launched April 14, 2006
- GPS Radio Occultation Receiver
  - Refractivity, Bending angle
  - Pressure, Temperature, Humidity
  - Absolute Total Electron Content (TEC)
  - Electron Density Profiles (EDP)
  - Ionospheric Scintillation (S4 amplitude)
- Tiny Ionospheric Photometer (TIP) – UV Radiances
- CERTO Tri-Band Beacon Transmitter
- Complete global and diurnal sampling
- Demonstrated forecast value of GPS radio occultation soundings in near-real time
- Total cost ~$100M; Taiwan paid for 80% of costs
- Mission on time, within budget, and exceeding expectations



Characteristics of RO Data

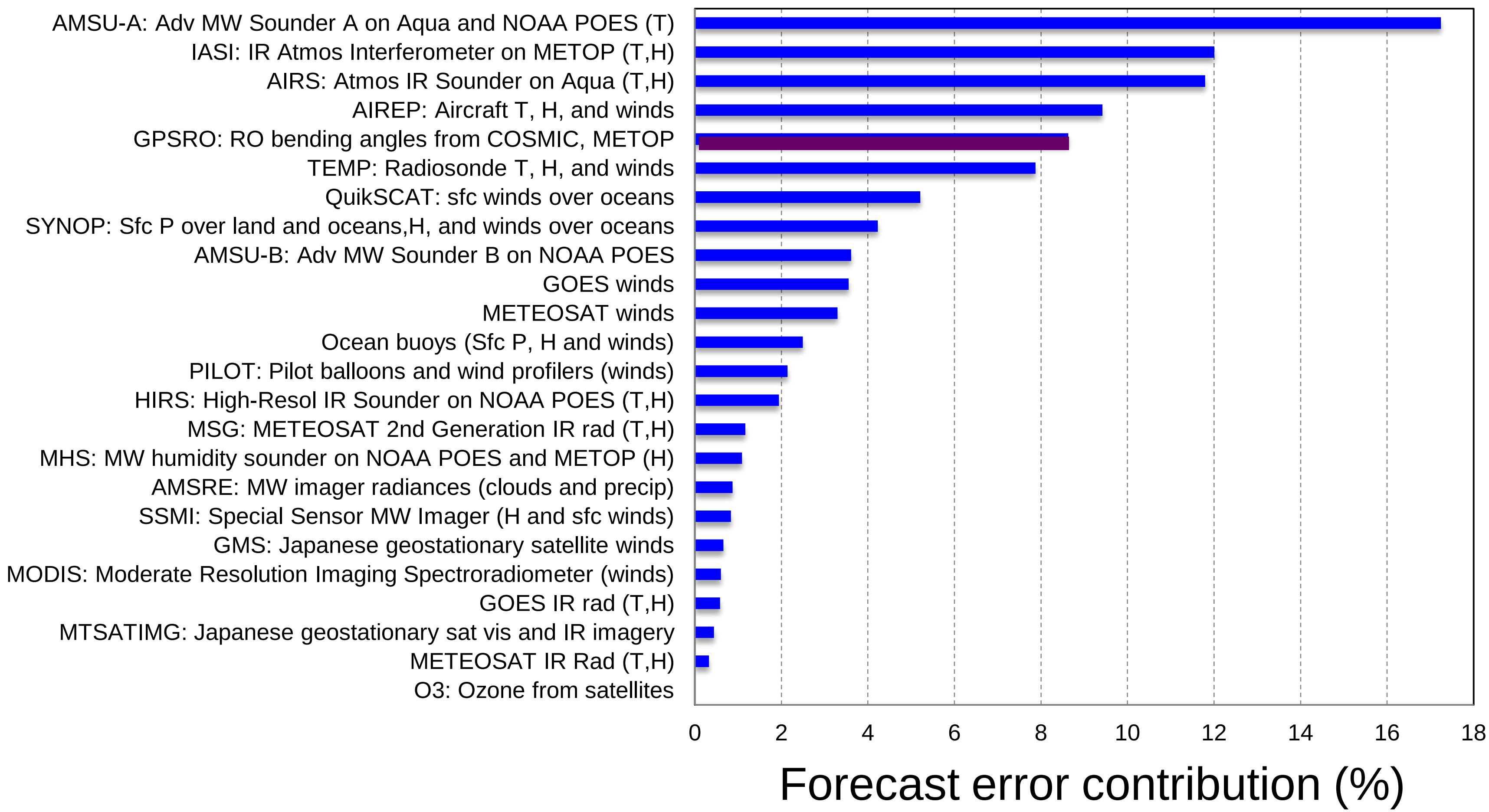
- Limb sounding geometry complementary to ground and space nadir viewing instruments
- Global coverage
- Profiles ionosphere, stratosphere and troposphere
- Only observing system from space that can profile the ABL
- High accuracy (equivalent to <1 K; average accuracy <0.1 K)
- High precision (0.02-0.05 K)
- High vertical resolution (0.1 km near surface – 1 km tropopause)
- Only system from space to observe atmospheric boundary layer
- All weather-minimally affected by aerosols, clouds or precipitation
- Independent height and pressure
- Requires no first guess sounding
- No calibration required
- Climate benchmark quality-tied to SI standards
- Independent of processing center
- Independent of mission
- No instrument drift
- No satellite-to-satellite bias
- Compact sensor, low power, low cost

All of these characteristics have been demonstrated in peer-reviewed literature.

Scientific Uses of Radio Occultation Data

- **Weather**
  - Improve global weather analyses, particularly over data void regions such as the oceans and polar regions
  - Improve skill of global and regional weather prediction models
  - Improve understanding of tropical, mid-latitude and polar weather systems and their interactions
- **Ionosphere and Space Weather**
  - Observe global electronic density distribution
  - Improve the analysis and prediction of space weather
  - Improve monitoring/prediction of scintillation (e.q., equatorial plasma bubbles, sporadic E clouds)
  - Ionospheric and lower atmospheric coupling
- **Climate**
  - Monitor climate change and variability with unprecedented accuracy-**world's most accurate, precise, and stable thermometer from space!**
  - Evaluate global climate models and analyses
  - Calibrate infrared and microwave sensors and retrieval algorithms

Operational ECMWF system September to December 2008. Averaged over all model layers and entire global atmosphere. % contribution of different observations to reduction in forecast error.



GPS RO has significant impact (ranked #5 among all observing systems) in reducing forecast errors, despite the small number of soundings.

Courtesy: Carla Cardinali and Sean Healy, ECMWF 22 Oct. 2009

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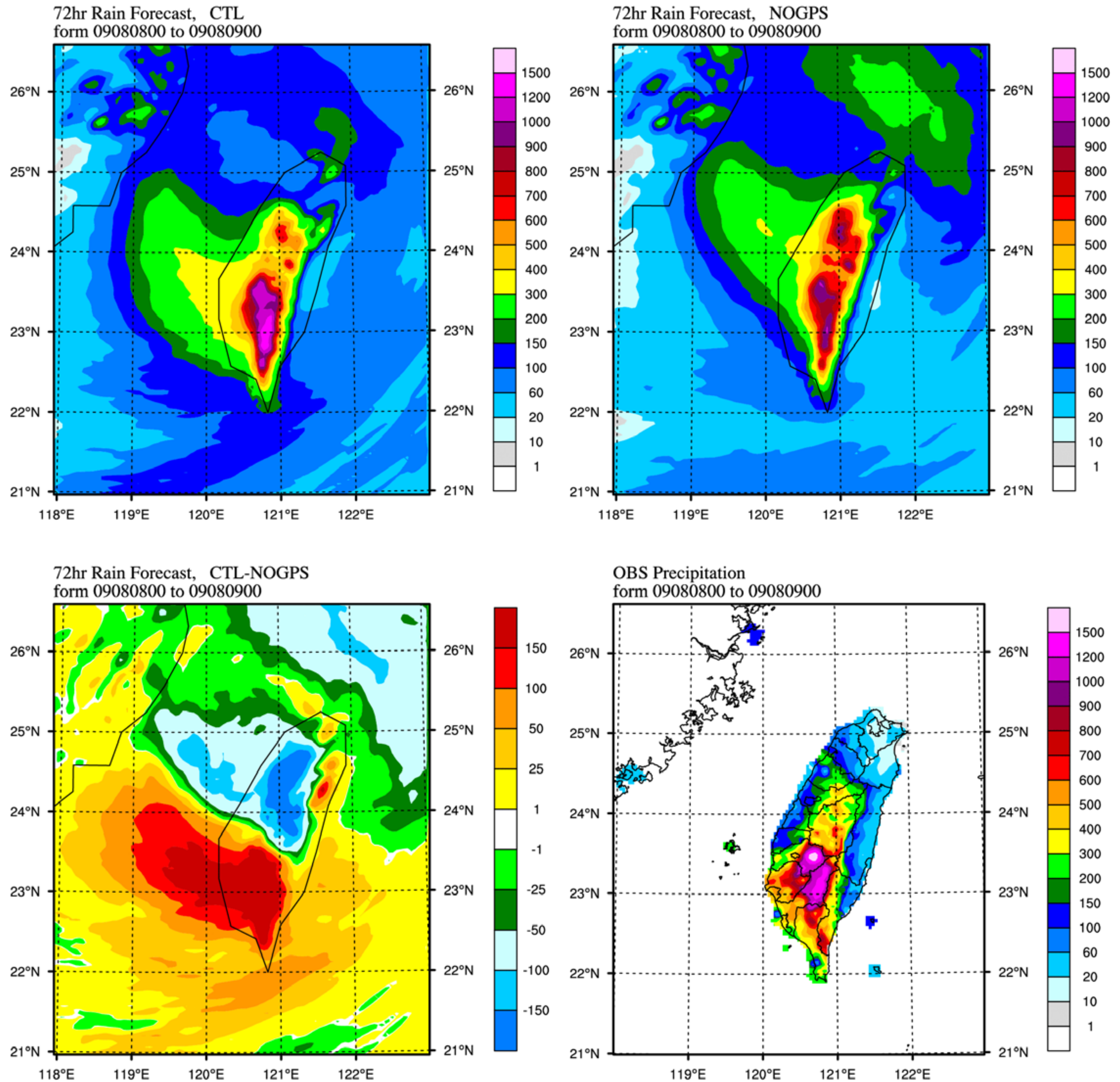
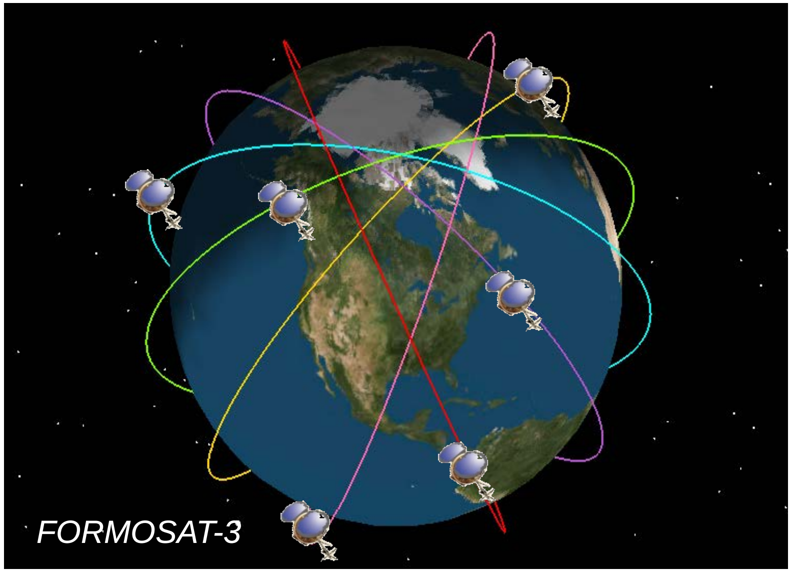
72hr Rain Forecast (August 8-9 00Z)

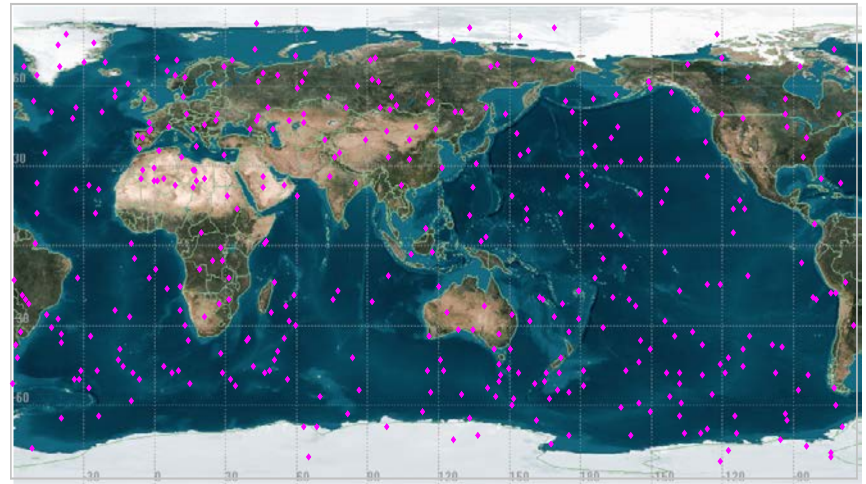


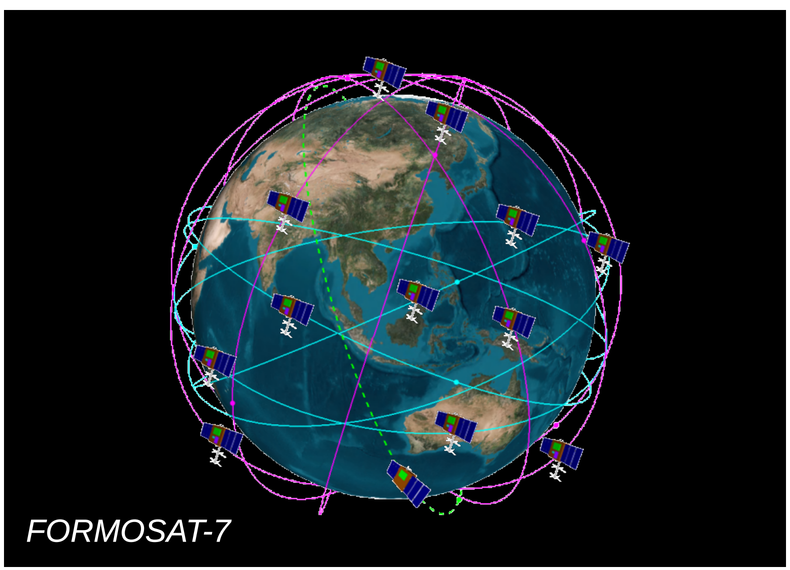
Assimilation of COSMIC RO data led to improved precipitation forecast for Typhoon Morakot (2009)

COSMIC and COSMIC-2

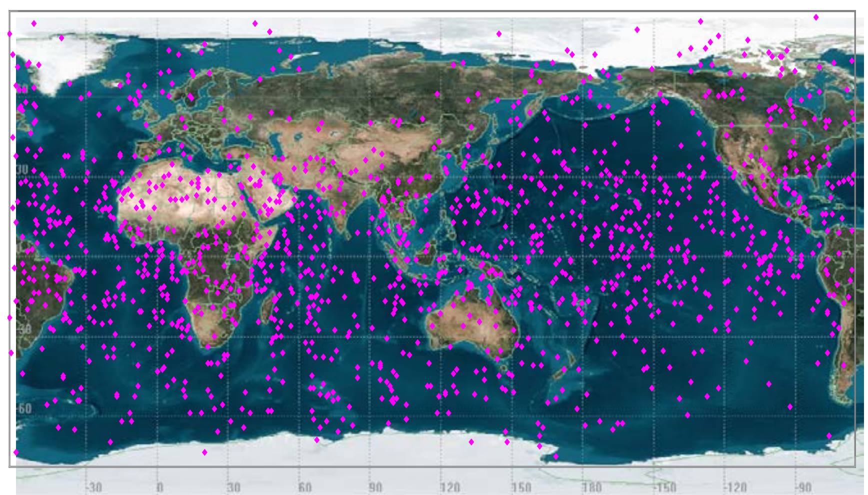


FORMOSAT-3 Occultations – 3 Hrs Coverage





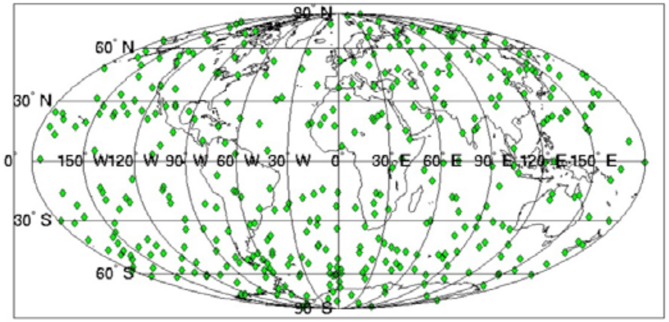
FORMOSAT-7 Occultations – 3 Hrs Coverage



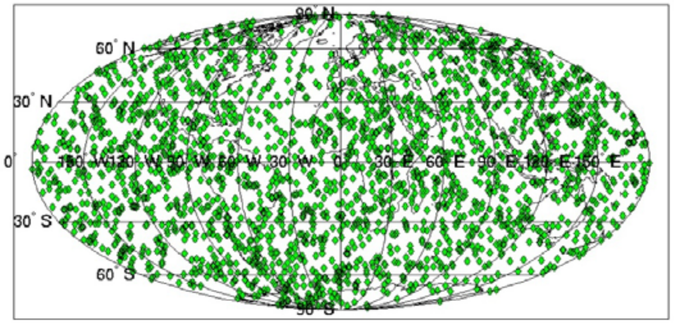
COSMIC-2 and Beyond

- Higher antenna gain will improve inversions in lower troposphere and PBL
- Tracking GPS, GALILEO, and GLONASS GNSS signals
- Many more soundings, > 10,000/day
- Improved data assimilation methods
- Monitor rapidly changing pre-tornado environment (poor man's GOES sounder)
- Greater impact on NWP forecasts
- Will significantly improve hurricane track forecasts and improve genesis and intensity forecasts
- Improve impact of infrared and microwave sounders
- Continue climate benchmark observations without gap
- Significant improvement in space weather observing and prediction

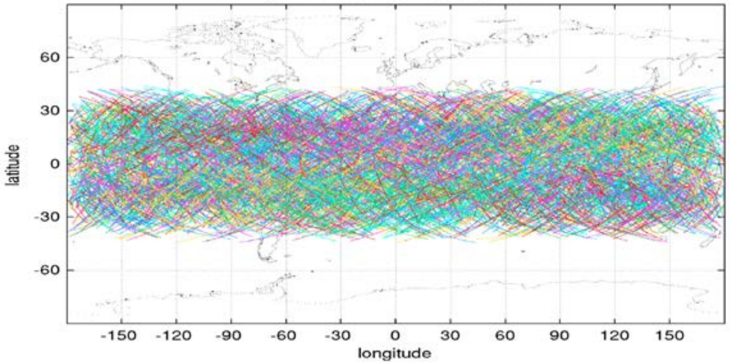
COSMIC Occultations-3 Hrs Coverage



COSMIC-2 Occultations - 3 Hrs Coverage



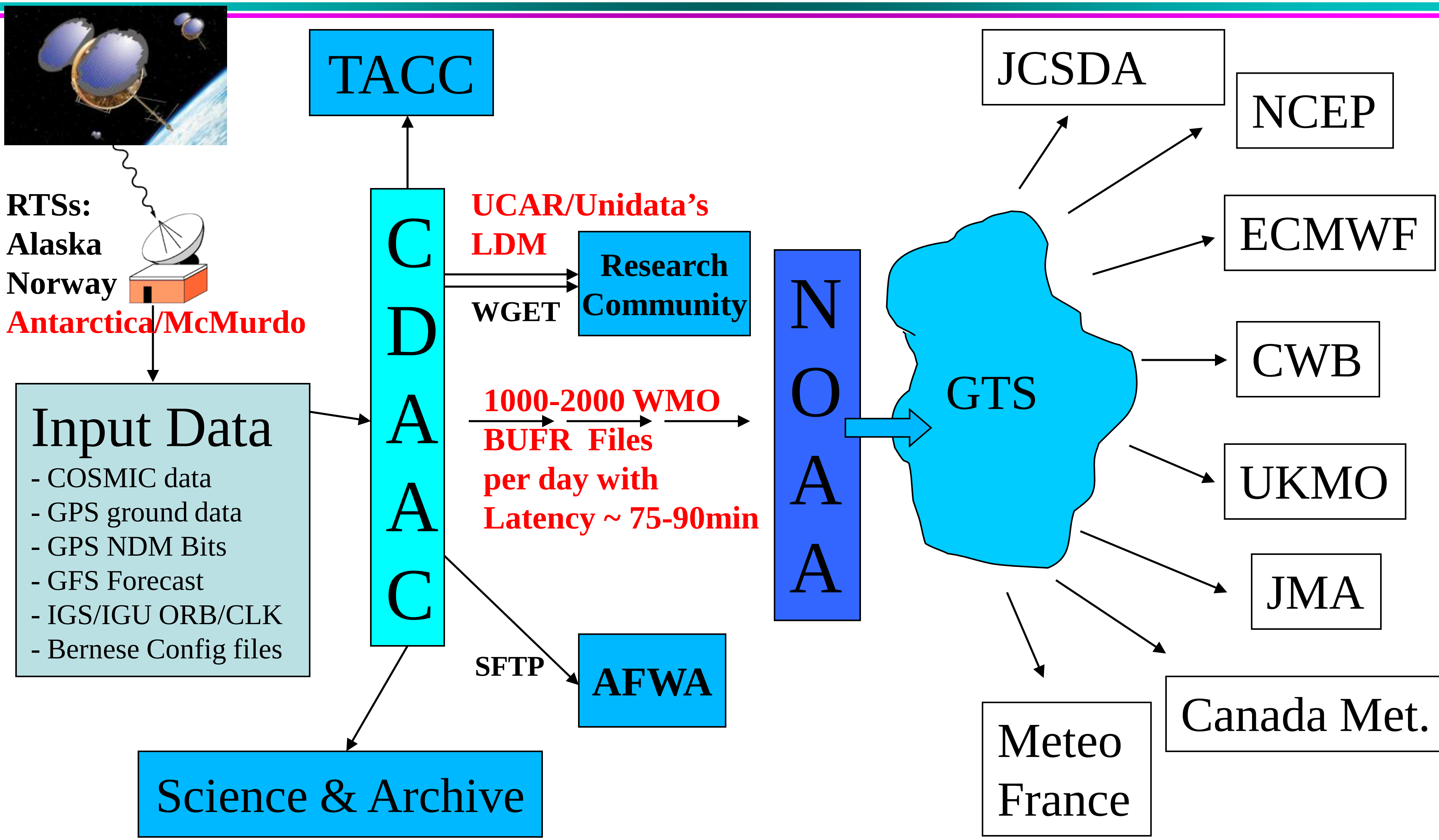
COSMIC-2 (24 deg) TEC Tracks - 24 Hrs Coverage



HURRICANE SANDY

COSMIC RADIO OCCULTATION PROFILES

COSMIC Operational Processing



Providing data to > 1900 registered users from 61 countries

CDAAC

- **COSMIC Data Archive and Analysis Center.** The data processing, distribution and archive center for COSMIC and other radio occultation satellites
- Currently houses Radio Occultation data from these satellite missions:
  - COSMIC/Formosat-3 (US/Taiwan)
  - SAC-C (Argentina)
  - CHAMP (Germany)
  - TerraSAR-X (Germany)
  - GRACE (Germany)
  - METOP-A (EUMETSAT)
  - GPS/MET (US)
- 200-1500 Gigabytes/day in web and FTP downloads
- 20 TB of data available to users in over 100 million files
- 48 TB of data archived
- Data distributed via:
  - GTS (Global Telecommunications System, used to connect weather centers)
  - Unidata LDM
  - FTP
  - HTTP for bulk download
  - Interactive database-driven web interface
- Around 100 different file types offered
- Most data in netCDF format or other standard formats (RINEX, BUFR, etc)

CDAAC Challenges

- For users who need data from just a small time period for a single mission, the current web/FTP service work well
- For users who need all data from multiple missions, the data volume and number of files is just too large for downloading in a reasonable time
- One user said it would take him ‘over a year’ to download all of his needed data via FTP. We are planning on mailing him 4 hard disks worth of data; the local copy is taking weeks.
- Newer missions, especially COSMIC-II will result in an increase in data by a factor of 10-100
- These datasets are difficult to aggregate with other geosciences data
  - Earthcube challenges

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Possible solutions

COSMIC

- Faster hardware and networks
- Parallel data servers
- Data reduction techniques (thinning oversampled data)
- Data batching techniques:
  - Creating day files
  - Allowing users to make custom subsets of data
  - Generation of gridded data products
- Use of existing supercomputer data grids. In NCAR's case, making data available via the NCAR mass storage system.
- Increase use of metadata standards in netCDF files
  - NetCDF Climate and Forecast (CF) Metadata conventions
- Use UNIDATA data aggregation and metadata tools such as RAMADDA and THREDDS
- How can EarthCube help?
  - Work to promote community tools and standards that data suppliers like CDAAC need to meet in order to get their data into the hands of researchers

Acknowledgments

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- EUMETSAT

UCAR NSF NASA USAF NOAA NSPO ONR

BROAD REACH ENGINEERING
Spaceflight Hardware, Software, Vehicle Design