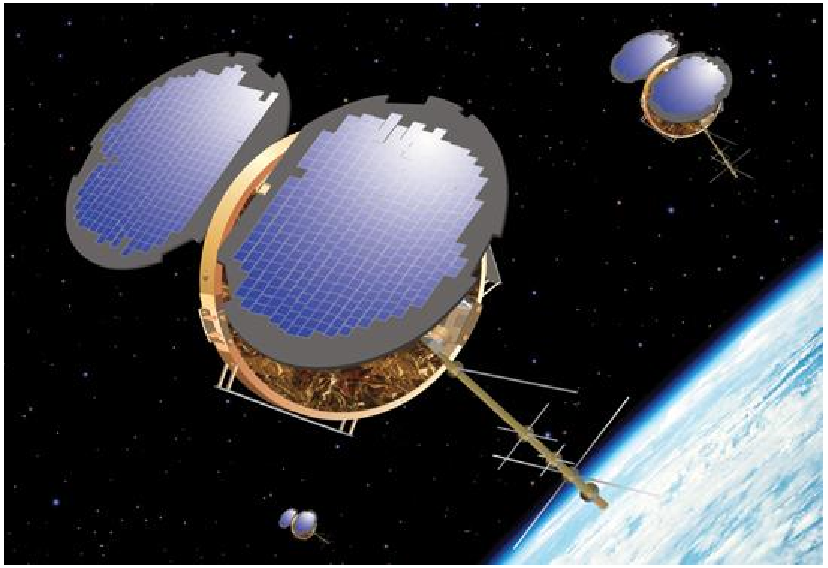
COSMIC Status and Prospects for COSMIC-2

Bill Kuo
UCAR COSMIC

COSMIC (Constellation Observing System for Meteorology, Ionosphere and Climate)

- 6 Satellites was launched:
  01:40 UTC 15 April 2006
- Three instruments:
  GPS receiver, TIP, Tri-band beacon
- Weather + Space Weather data
- Global observations of:
  Pressure, Temperature, Humidity
  Refractivity
  Ionospheric Electron Density
  Ionospheric Scintillation

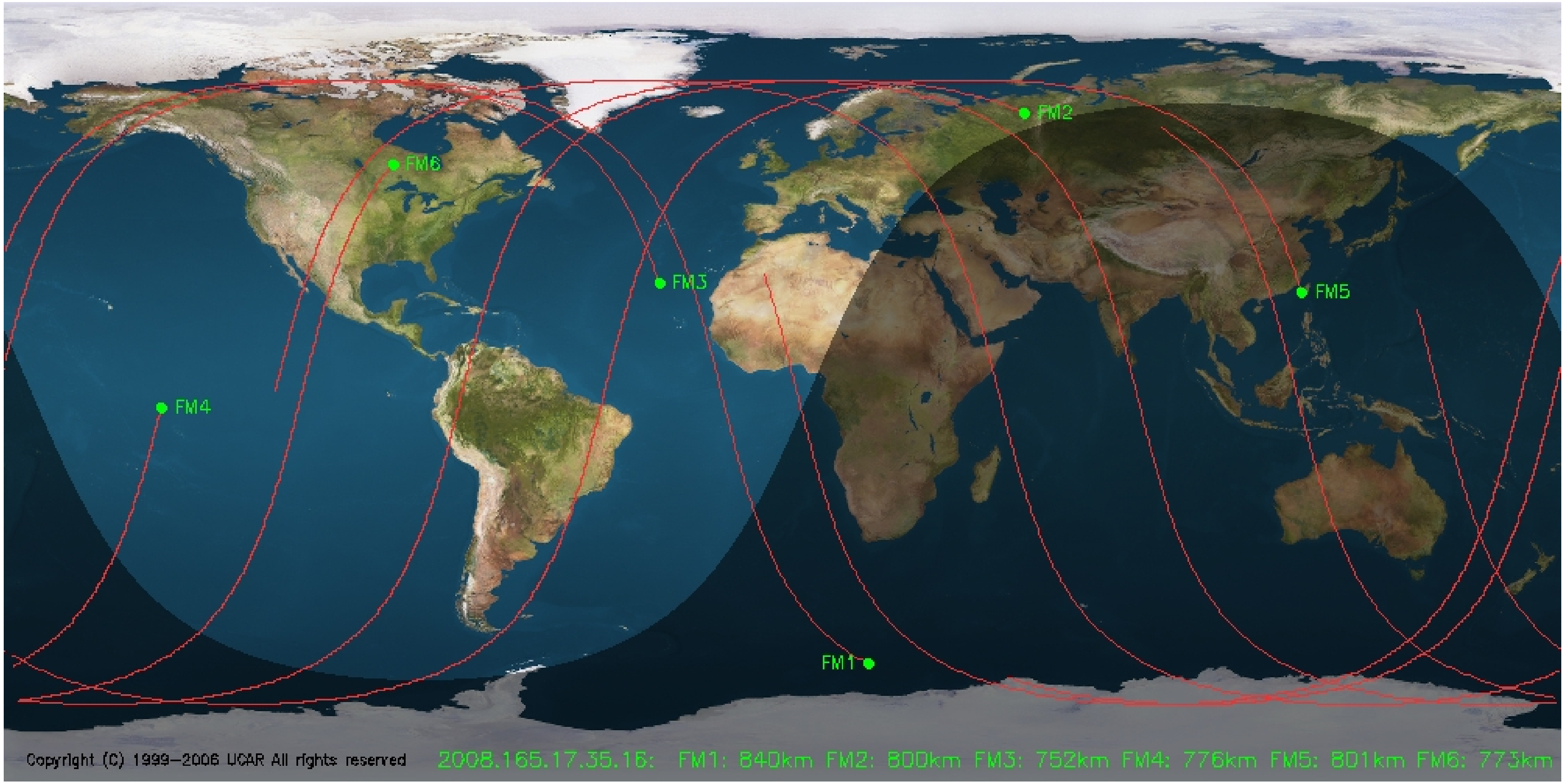


- Demonstrate quasi-operational GPS limb sounding with global coverage in near-real time
- Climate Monitoring

A Joint Taiwan-U.S. Mission

FORMOSAT-3 in Taiwan

COSMIC Constellation Status
June 13, 2008



Spacecraft State of Health
(as of 6/13/2008)

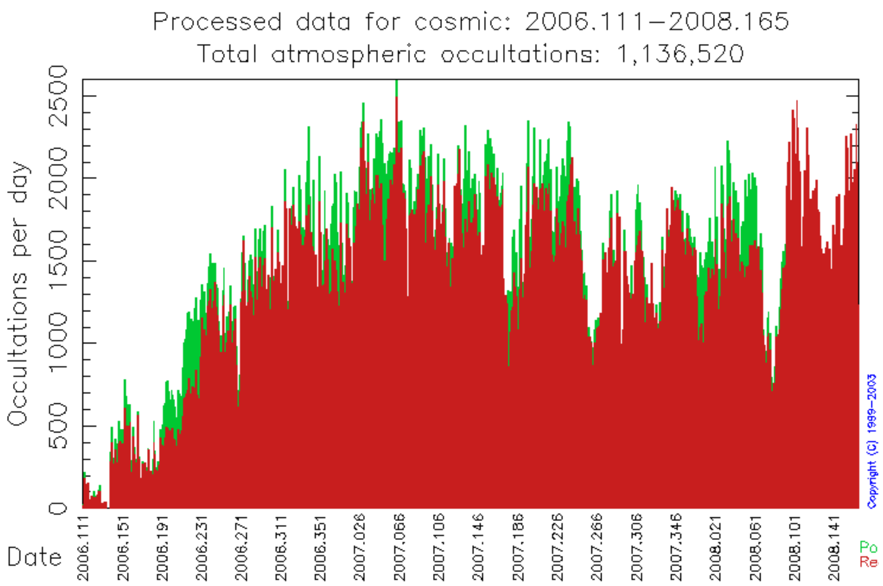
Spacecraft	Operational Mode	SC State	ACS Mode	EPS Mode	C&DH Mode	GOX	TIP	TBB
FM1	Normal	Normal	Fixed-Yaw	Normal	High Rate	Operating	Operating	Operating
FM2	Normal	Power Anomaly	Fixed-Yaw	Normal	High Rate	60~70 %	Off[1]	Off[1]
FM3	Normal	SAD Anomaly	Fixed-Yaw	Normal	High Rate	60~70%	Off[1]	Off[1]
FM4	Normal	Normal	Fixed-Yaw	Normal	High Rate	Operating	Operating	Operating
FM5	Normal	Normal	Fixed-Yaw	Normal	High Rate	Operating	Operating	Operating
FM6	Normal	Normal	Fixed-Yaw	Normal	High Rate	Operating	Operating	Operating

Note1: Secondary Payloads are power-off due to power shortage

Over 1 Million Profiles in Real Time
4/21/06 - 6/13/2008

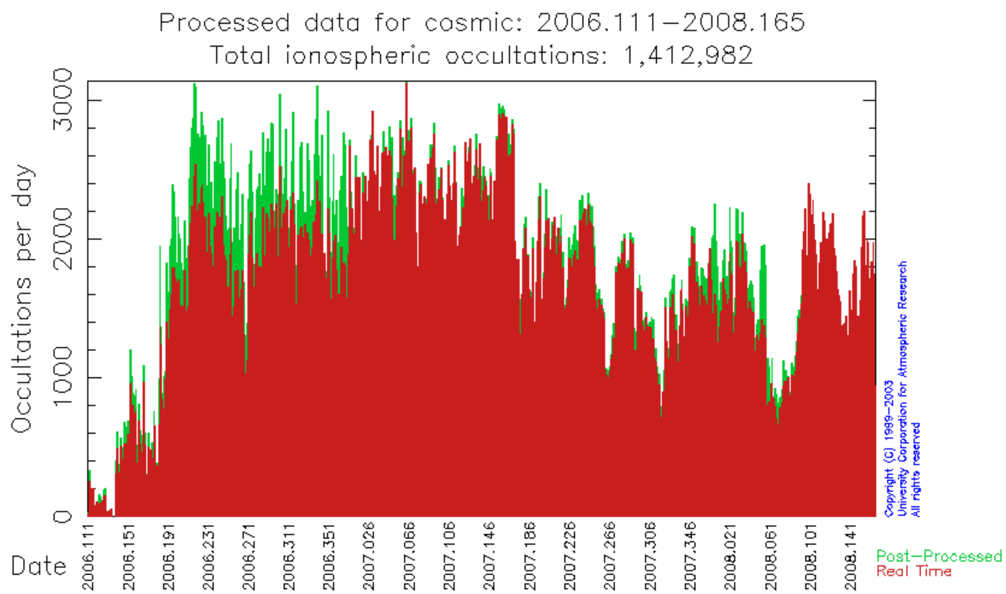
Neutral Atmosphere

1,136,520 profiles



Ionosphere

1,412,982 profiles



Global FORMOSAT-3 / COSMIC Data Users

Country	#	Country	#
Argentina	7	Denmark	2
Australia	12	New Zealand	6
Austria	10	Nigeria	2
Brasil	10	Norway	1
Bulgaria	1	Peru	1
Canada	13	Phillipines	4
Chile	2	Poland	1
China (PRC)	43	Portugal	1
Czech Republic	1	Puerto Rico	2
Egypt	1	Russia	11
Finland	1	South Africa	4
France	9	Spain	6
Germany	22	Switzerland	4
India	66	Taiwan	127
Indonesia	14	Thailand	1
Iran	1	Turkey	1
Israel	1	U.A.E.	2
Italy	13	United Kingdom	22
Japan	31	United States Am.	298
Netherlands	2	Vietnam	14
S. Korea	16		

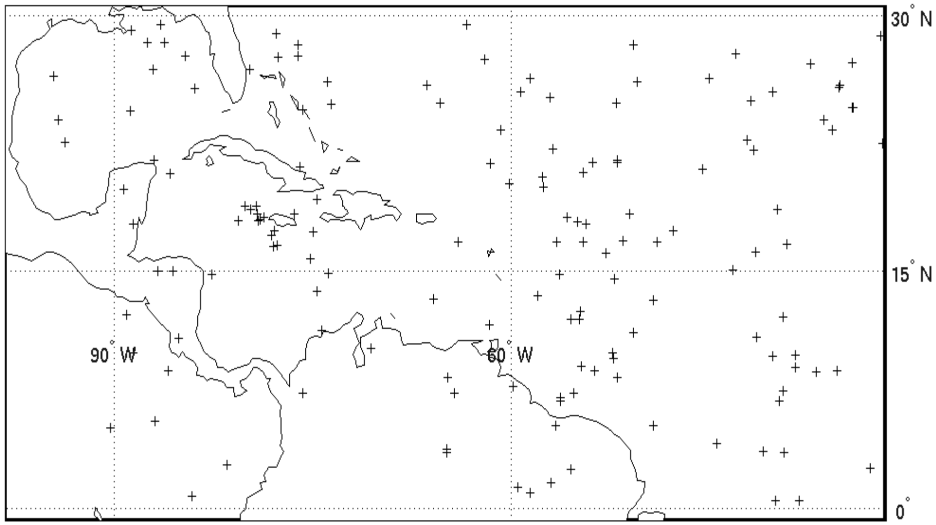
786 users
41 Countries

Presentation of first results from COSMIC/ FORMOSAT-3 to appear in Bulletin of American Meteorological Society, March 2008

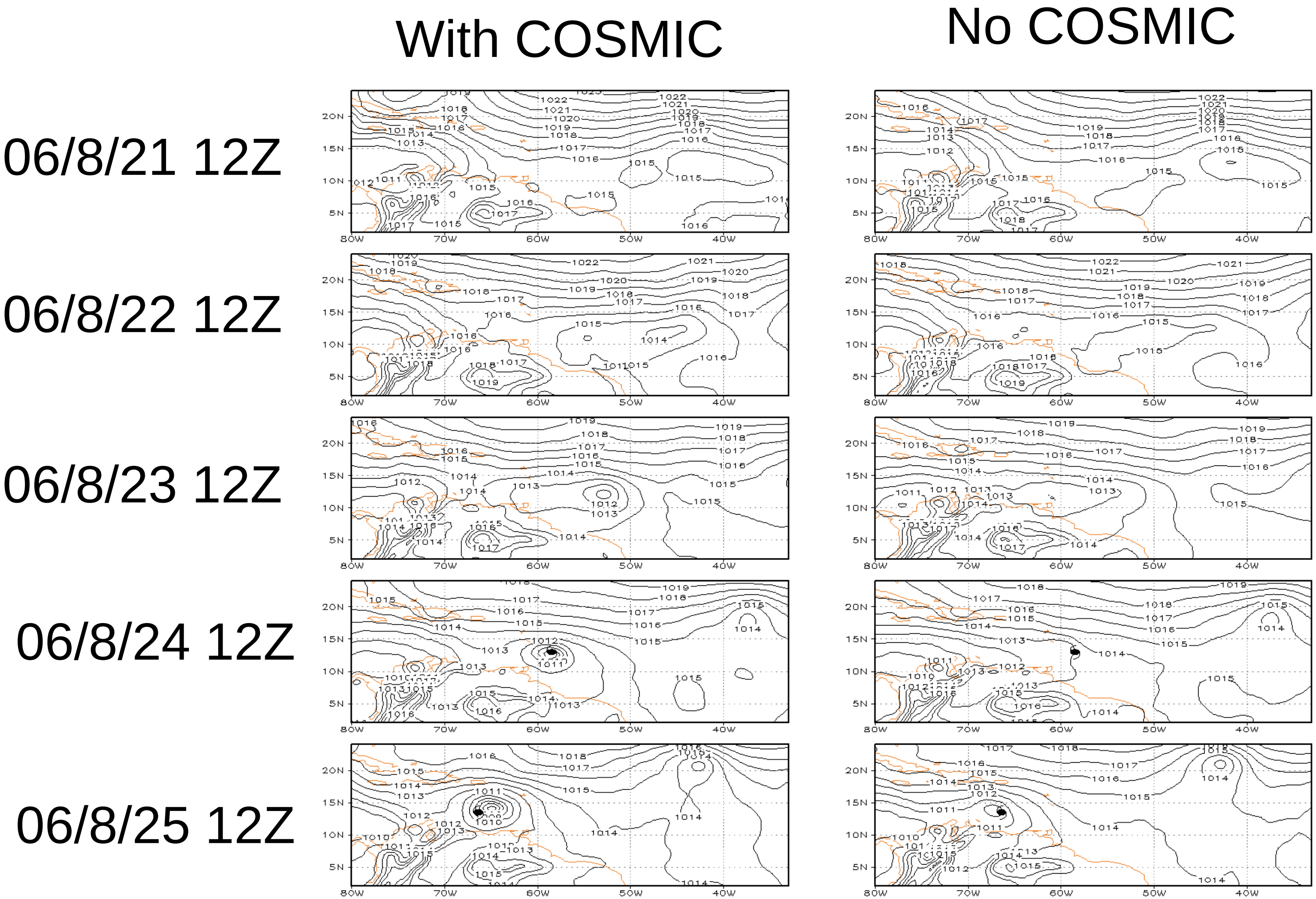
Anthes et al.

Assimilation of COSMIC GPSRO soundings during Genesis of Ernesto

- WRF/DART ensemble Kalman filter data assimilation system
- 36-km, 36-members, 5-day assimilation
- Assimilation of 171 COSMIC GPSRO soundings (with nonlocal obs operator, Sokolovskiey et al) plus satellite cloud-drift winds
- Independent verification by ~100 dropsondes.

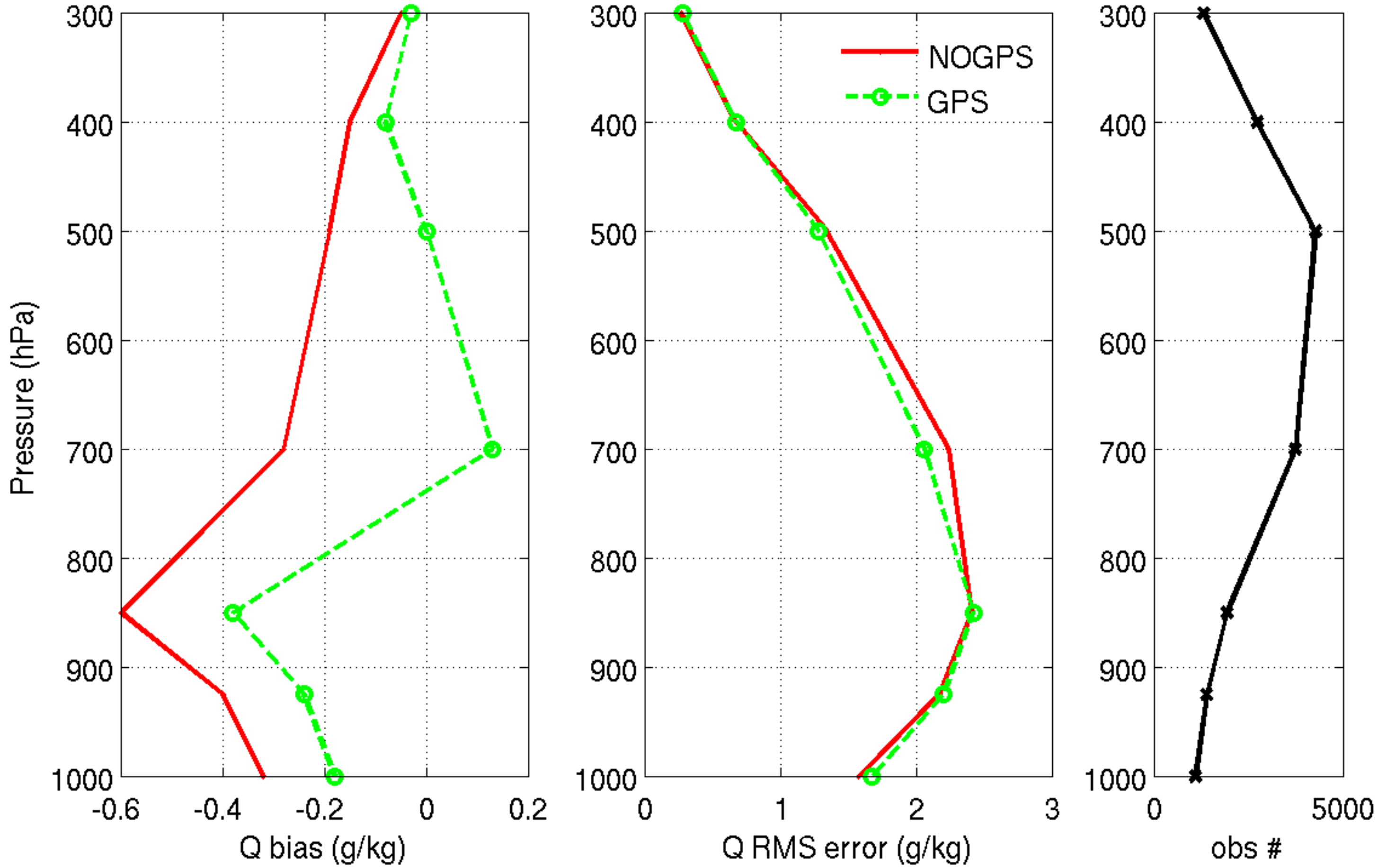


171 COSMIC GPSRO soundings during 21-25 August 2006



Genesis of Hurricane Ernesto (2006)

Continuous data assimilation during genesis stage with WRF EnKF system



Verification of WRF/DART analysis by about 100 dropsondes during the Ernesto genesis stage.

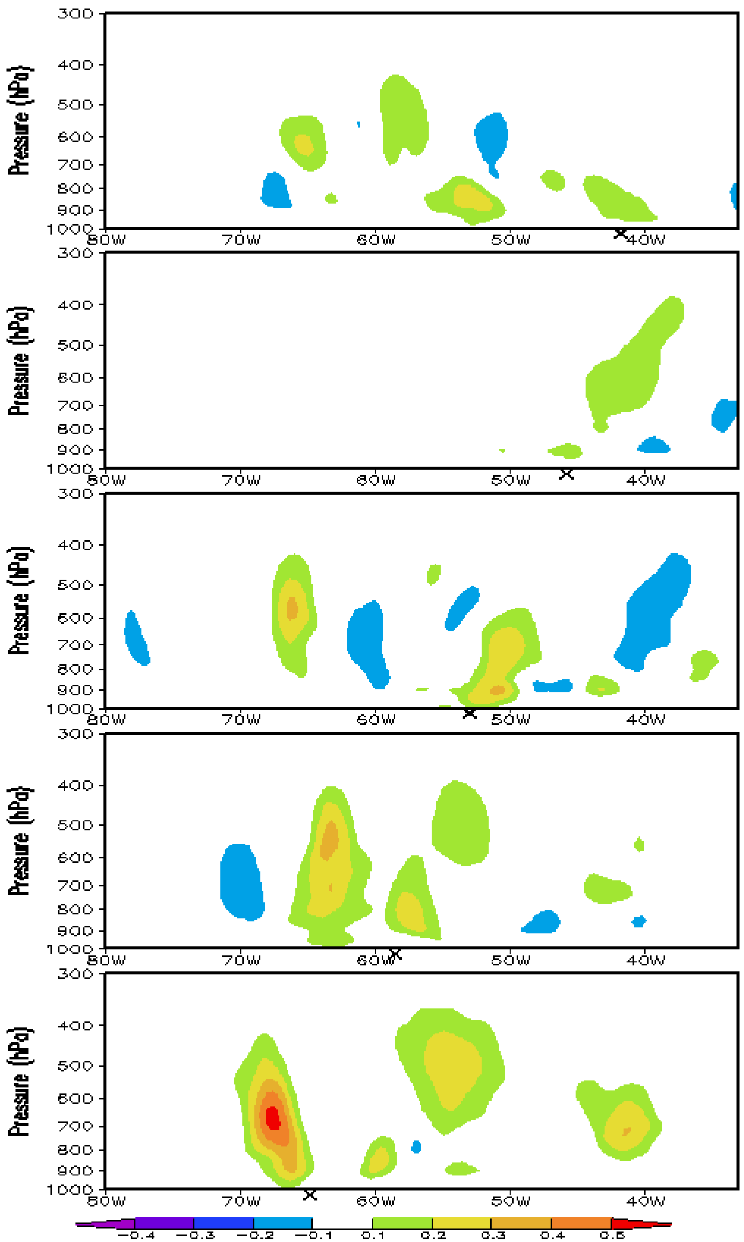
06/8/21 12Z

06/8/22 12Z

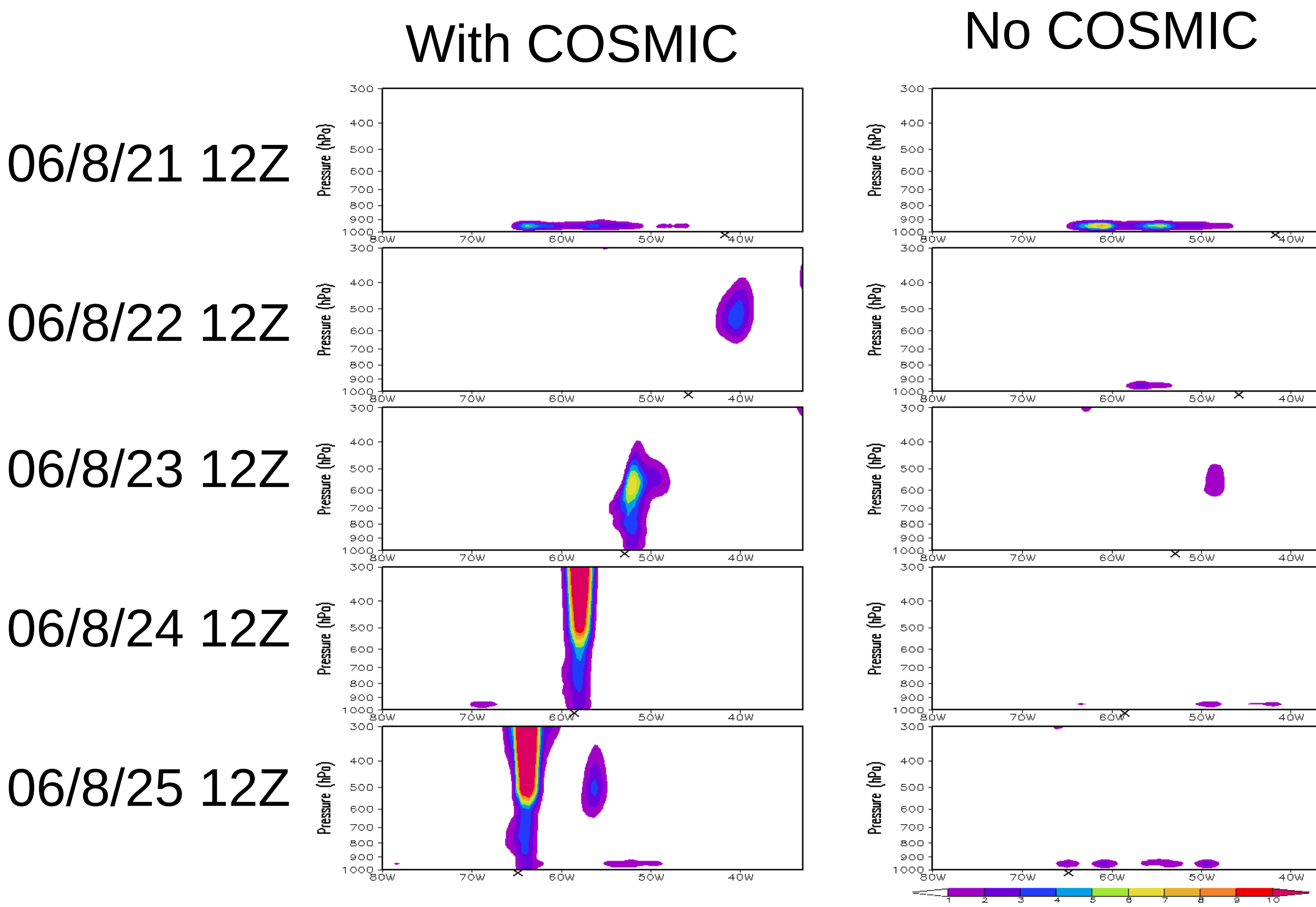
06/8/23 12Z

06/8/24 12Z

06/8/25 12Z



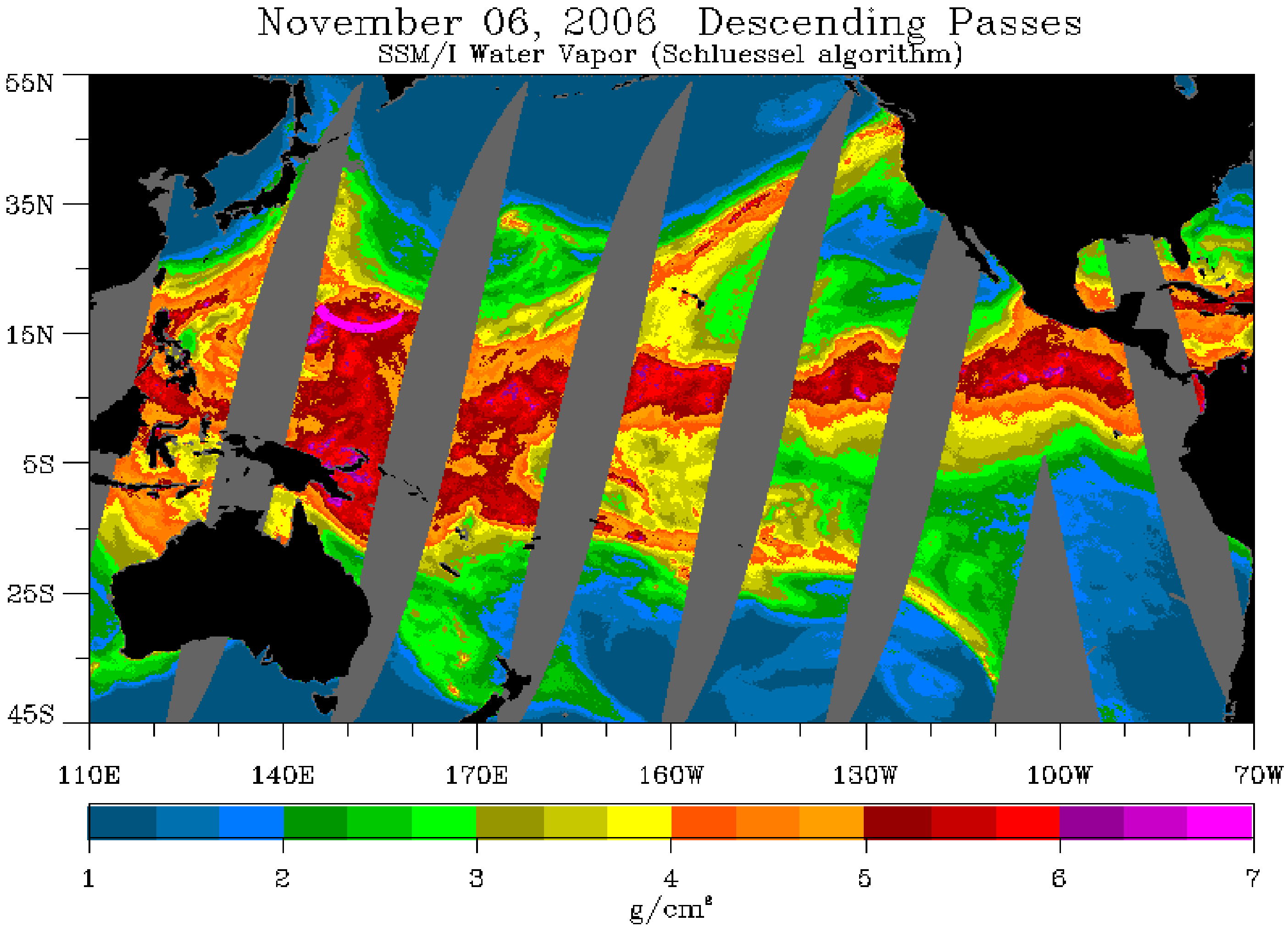
Analysis increment in Q (water vapor) due to the assimilation of COSMIC GPSRO data.



Genesis of Hurricane Ernesto (2006) Cloud and Rain water

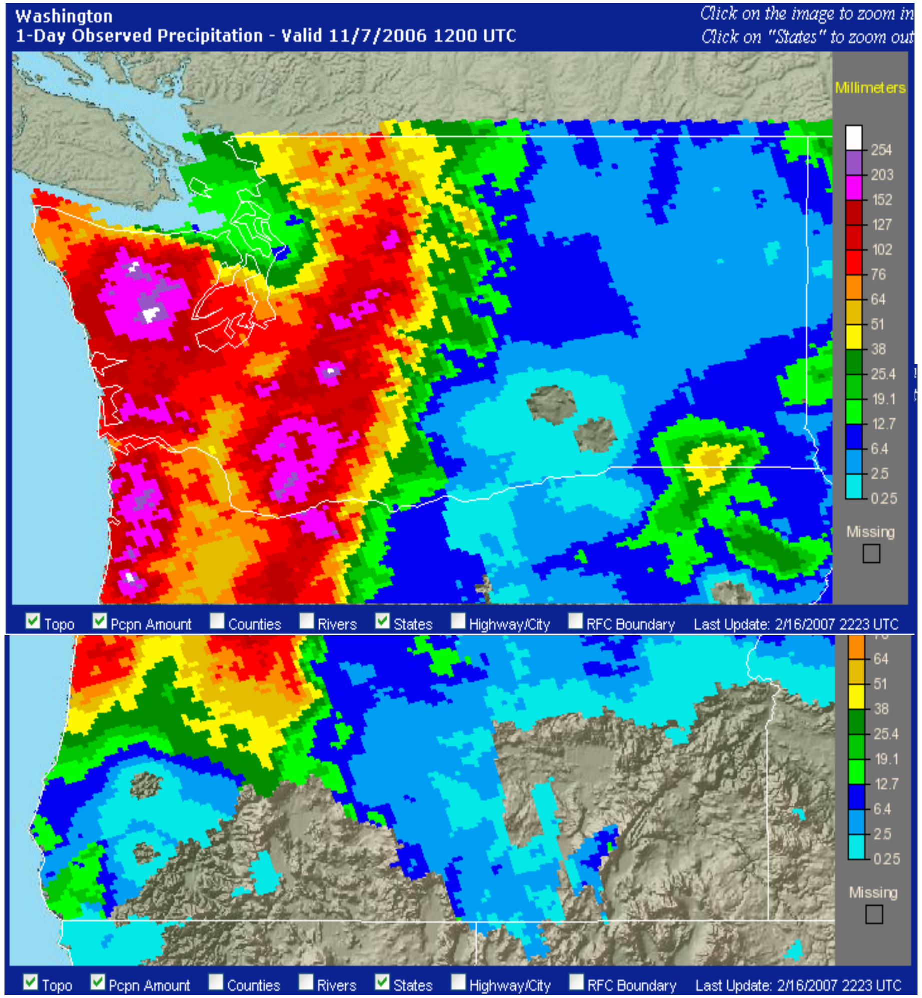
Continuous data assimilation during genesis stage with WRF EnKF system

Atmospheric River case: Nov 6-8, 2006



From Ma et al. (2008)

Observed Daily Precipitation



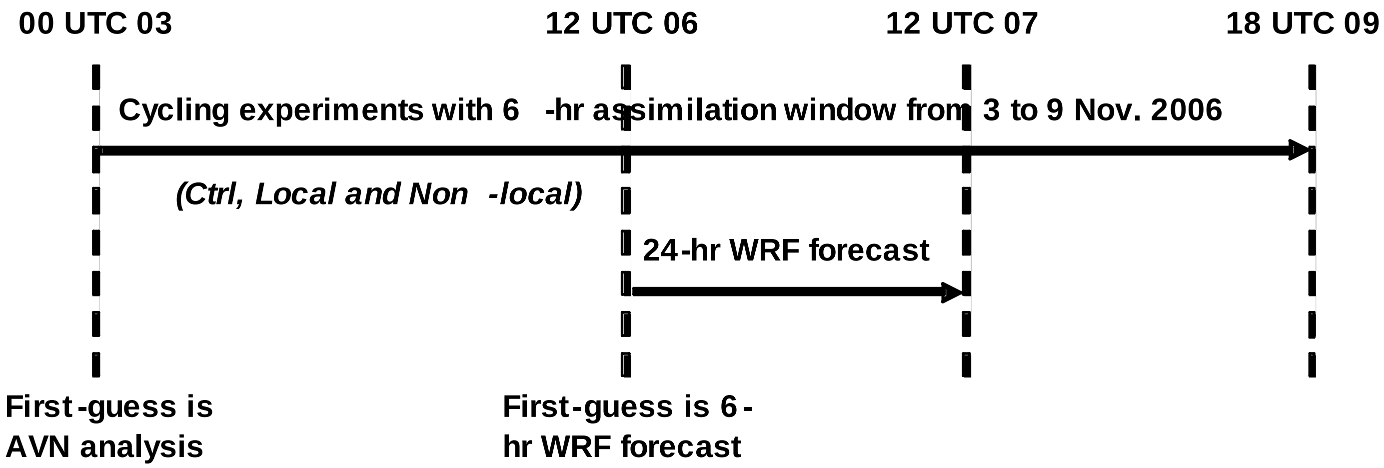
24-h precipitation ending at

1200 UTC 7 November 2006

Flooding and debris flow on White River, Oregon

Assimilation of GPS RO data for an Atmospheric River Event

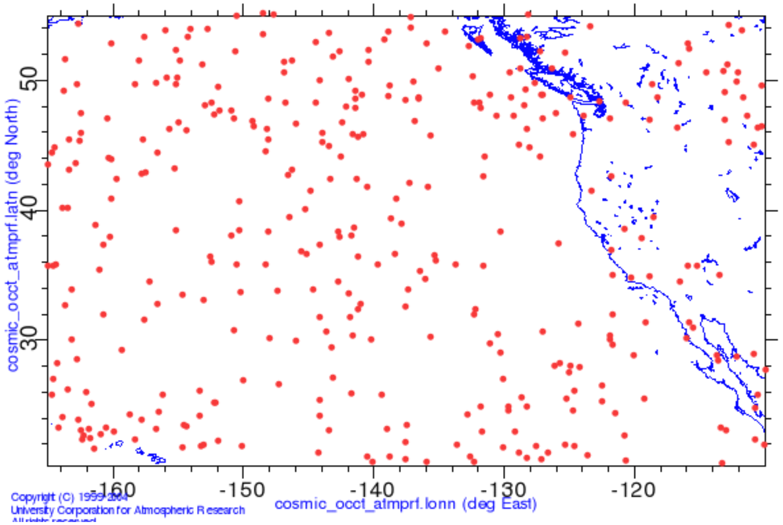
- Use NCEP Regional GSI
- 36-km resolution, with both local refractivity and nonlocal excess phase observation operator (Sokolovskiy et al. 2005).
- Continuous assimilation from 0000 UTC 3 November through 1800 UTC 9 November (with Regional GSI plus WRF-ARW).
- 24-h forecast experiments conducted based on analysis at 1200 UTC 6 November 2006.



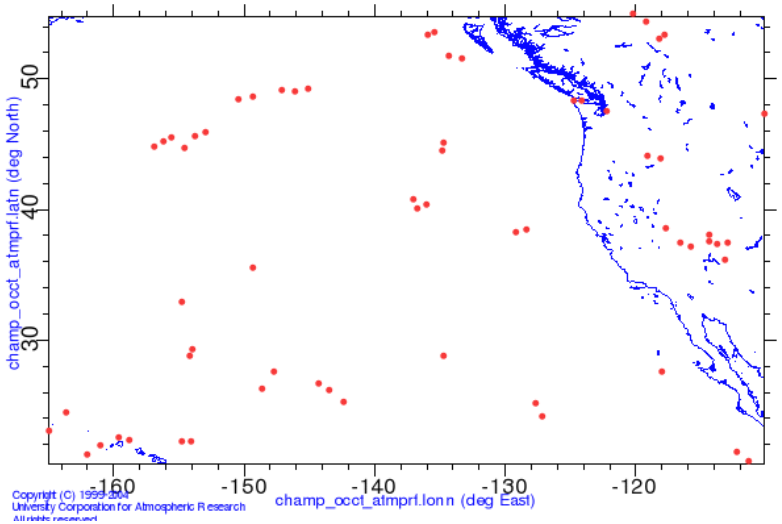
Assimilation of GPS RO data for an Atmospheric River Event

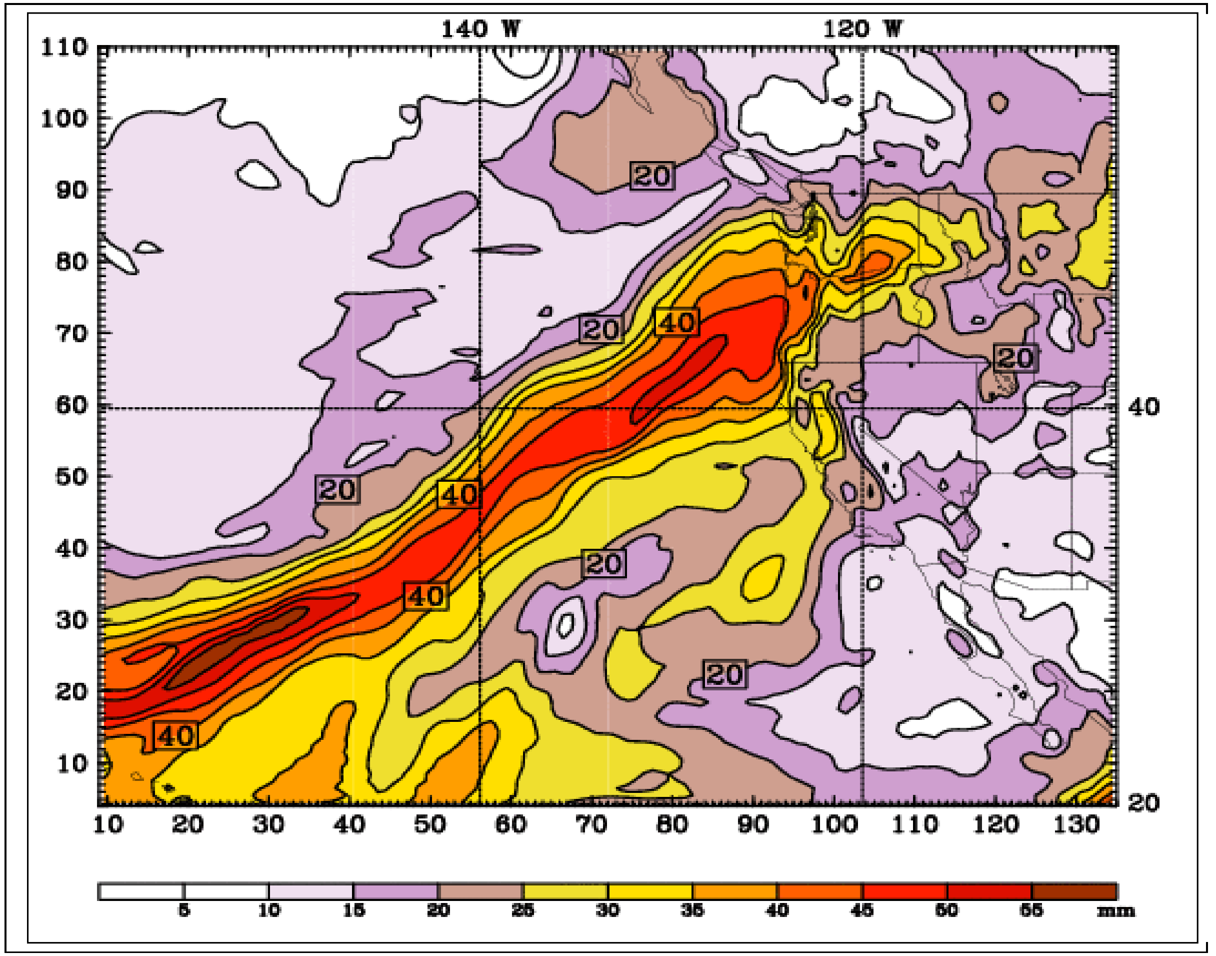
- Total of 370 COSMIC plus 63 CHAMP GPSRO soundings.
- All other operational data used by NCEP are assimilated, in additon to GPSRO data.

370 Matches



63 Matches

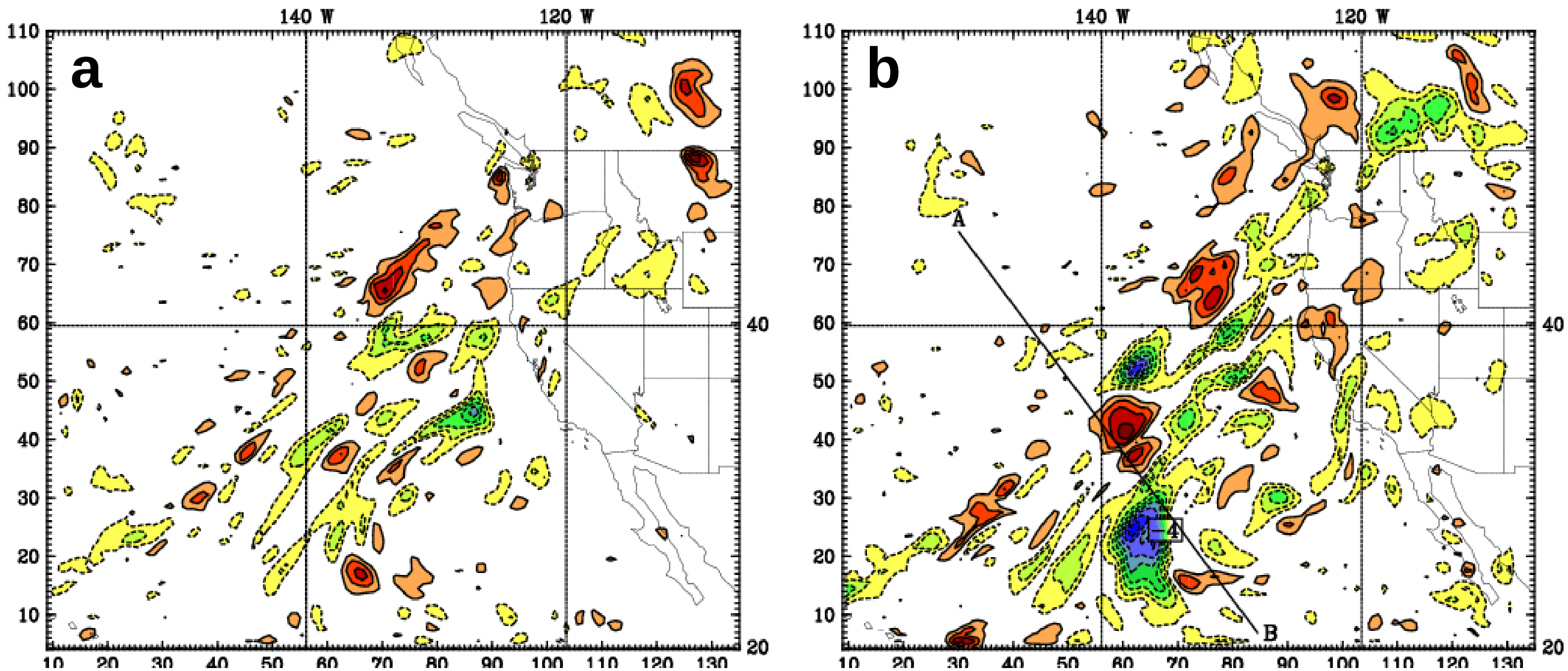




Analysis of PW from Nonlocal Experiment at 1200 UTC 7 November 2006

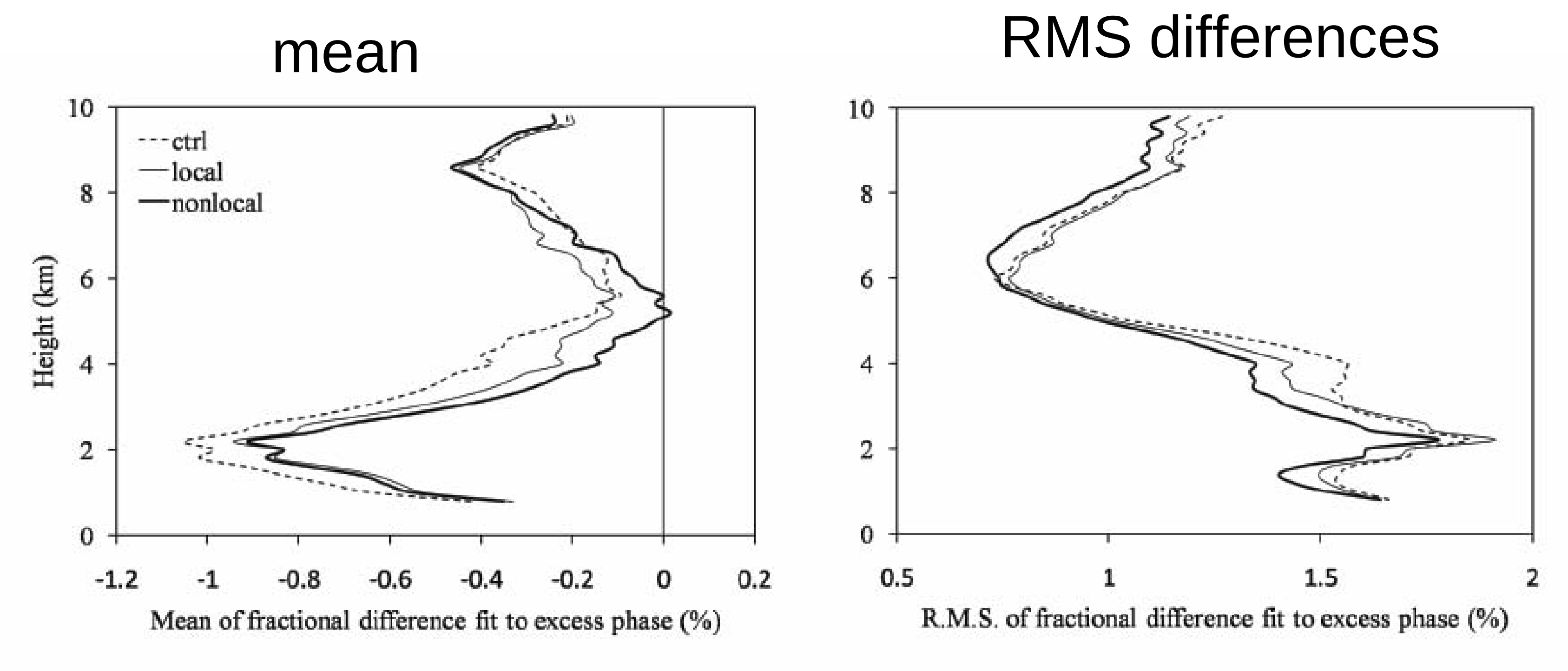
Local - CNTL

Nonlocal - CNTL



Differences in PW at 1200 UTC 7 November 2006

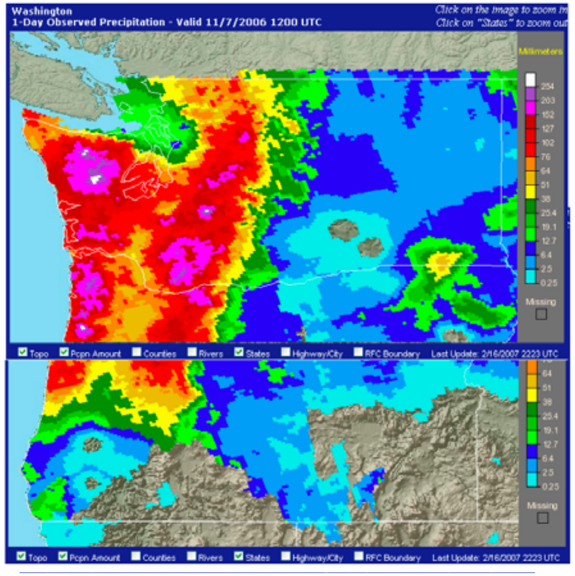
Impact of GPS RO assimilation: Use of Nonlocal excess phase operator produced more significant changes

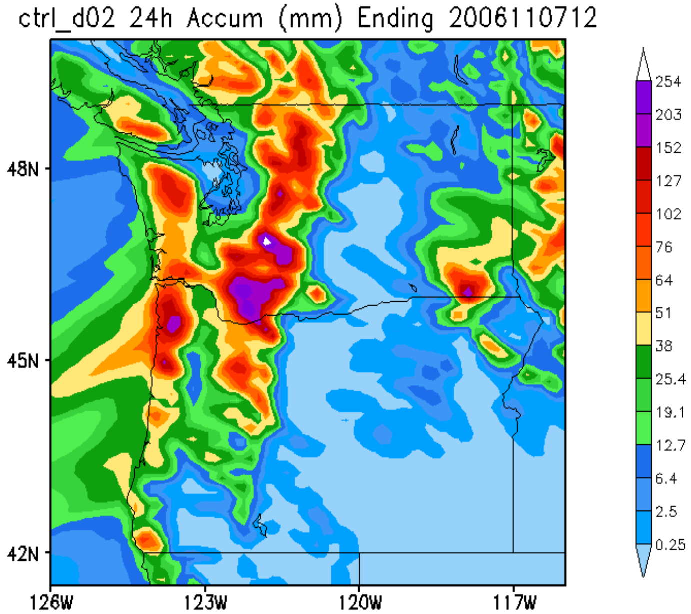


Verification of 0-24h forecast (1200 UTC 6 - 1200 UTC 7 November 2006) against GPSRO observations in terms of excess phase

24-h accumulated precipitation ending at 1200 UTC 7 November 2006

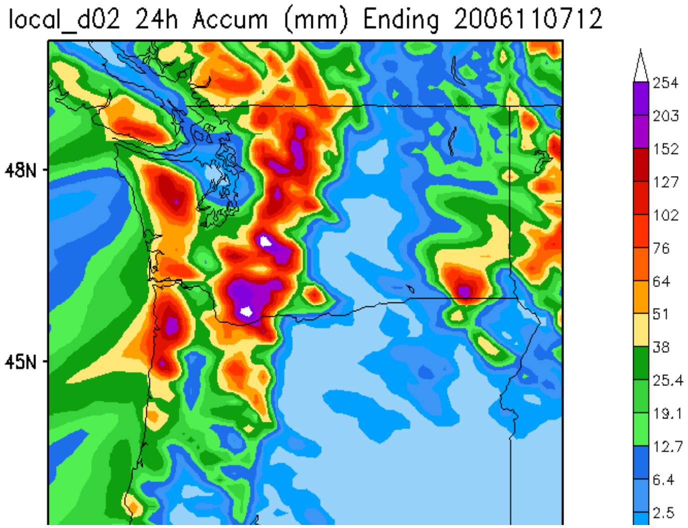
OBS

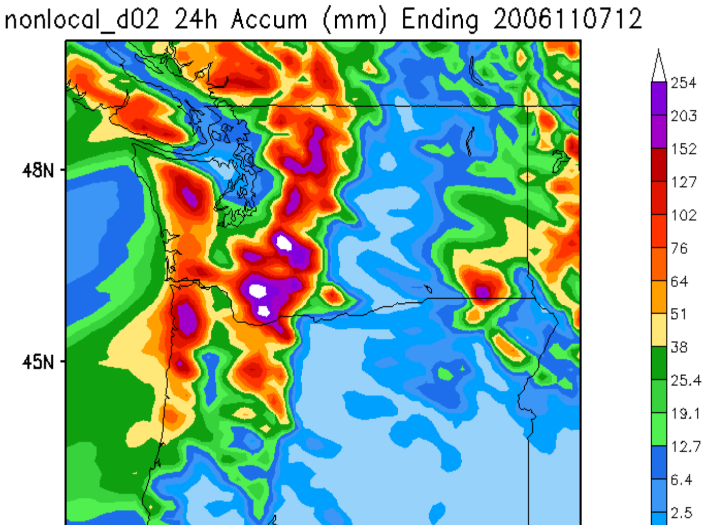




CNTL

Local





Non-Local

Use of COSMIC GPS RO soundings for atmospheric boundary layer study

Inversion layers are commonly capping layers of moist convection, e.g. cloud layers

The strongest inversion layers are most commonly observed on top of convective ABL over subtropical oceans and in some regions over continents

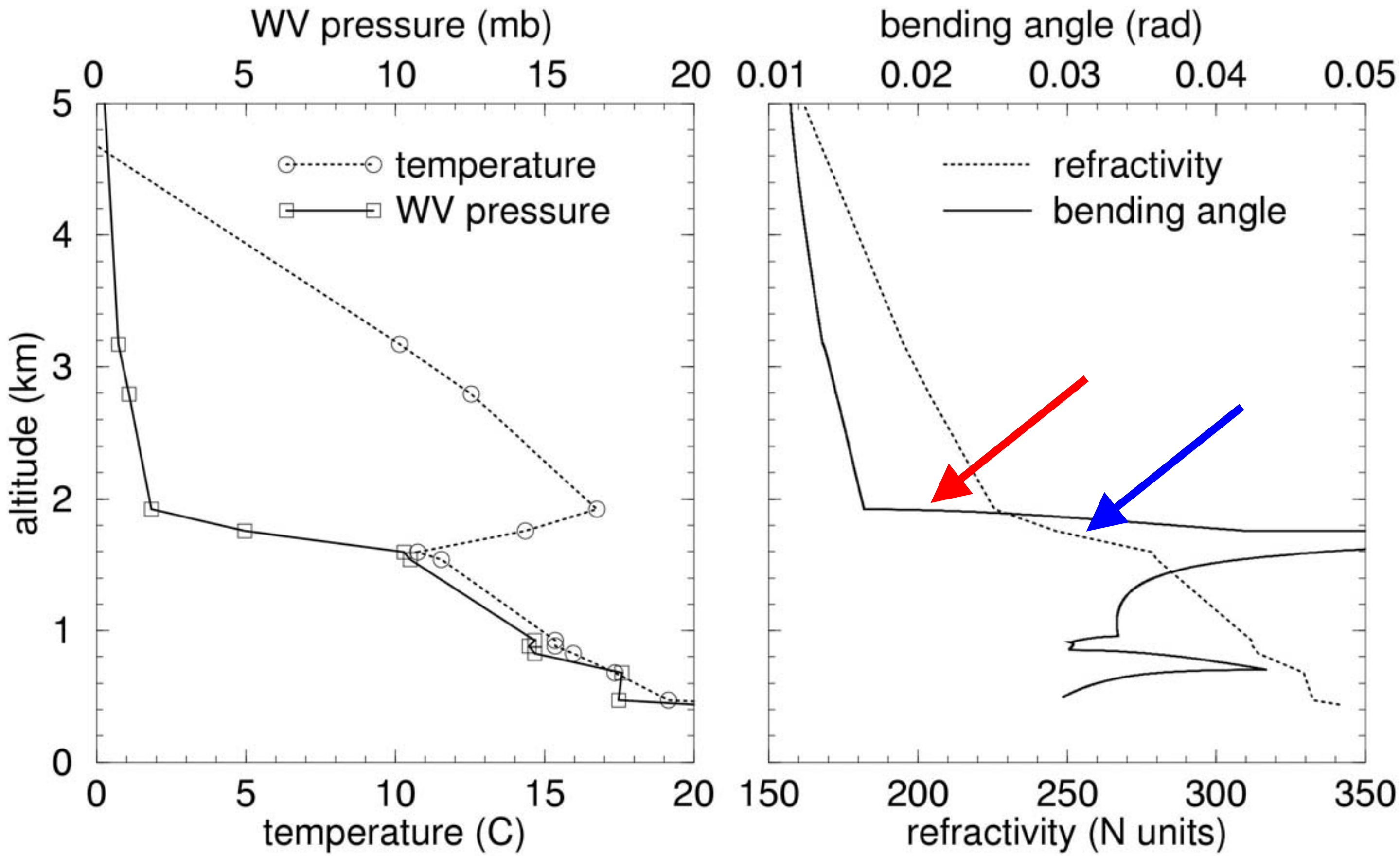
Inversion layers result in strong perturbation of the vertical gradient of refractivity

Radio occultation signals are sensitive to vertical refractivity gradients

Radio occultation – an excellent tool to monitor heights of inversion layers (depth of ABL)

From Sergey Sokolovskiy

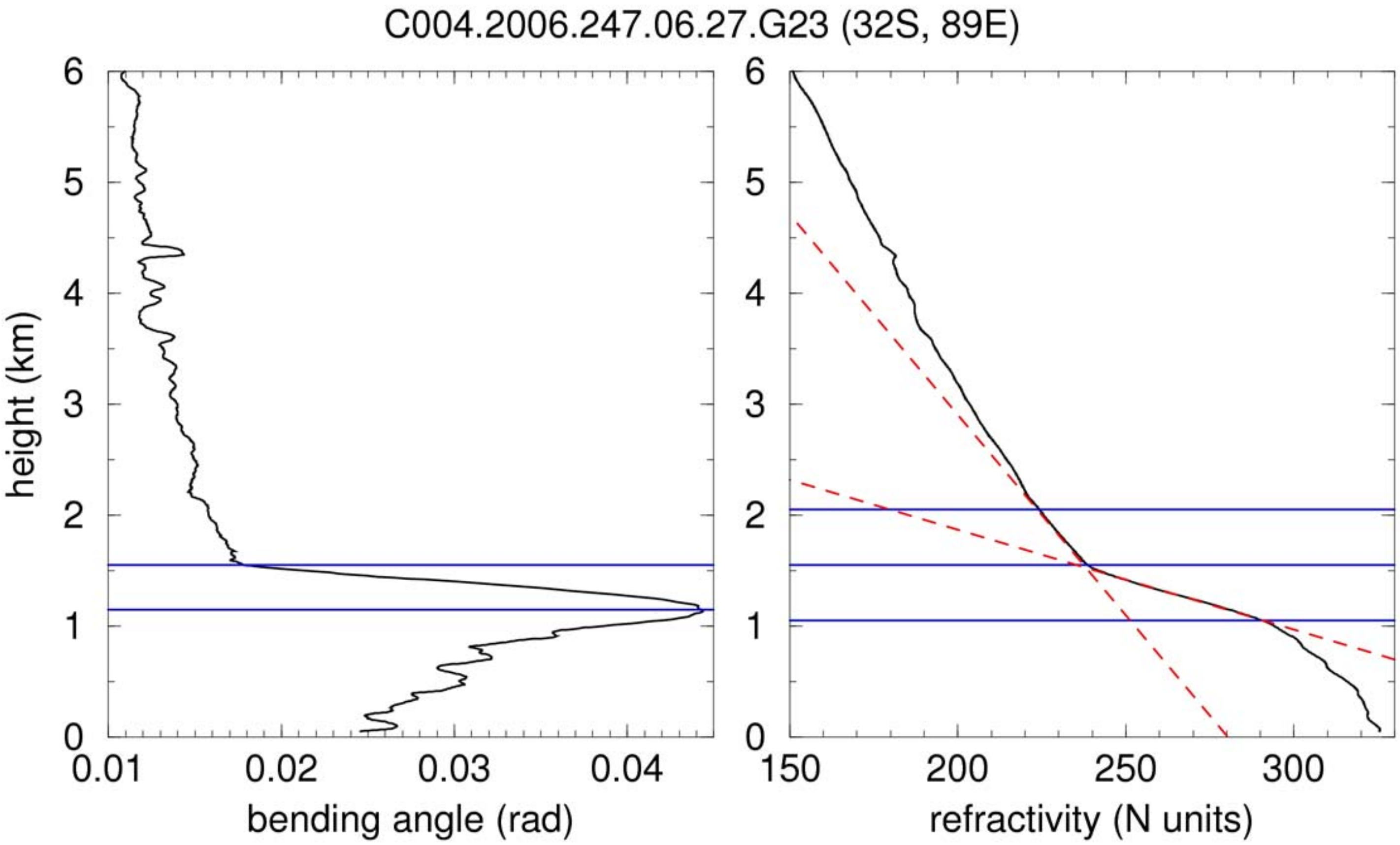
An example of strong inversion layer on top of ABL



Radiosonde data
23 January 2002
15.97S, 5.70W

RO observables modeled from the radiosonde data. The “step-like” structures in bending angle and refractivity

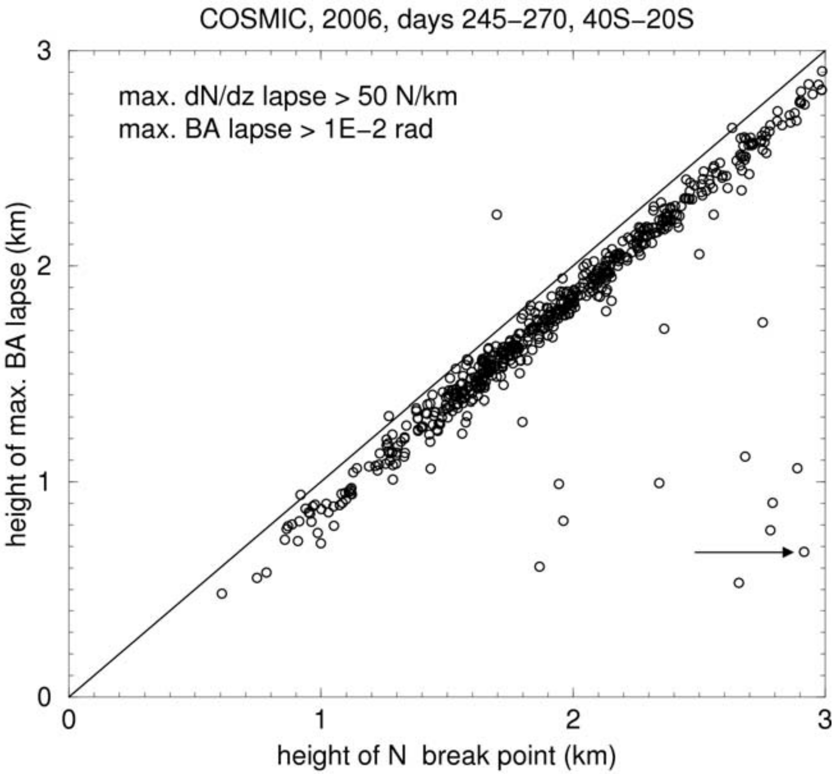
Determining height of an inversion layer from RO observables

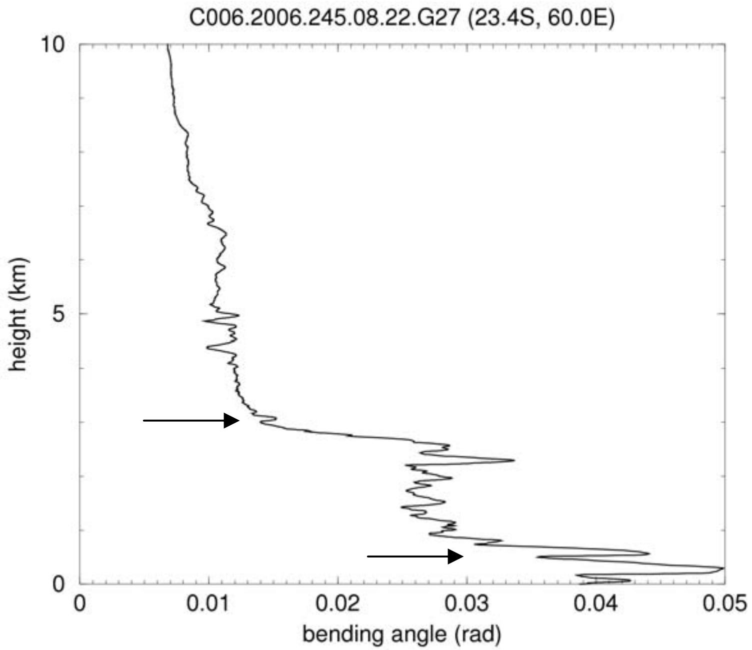


based on maximal bending angle lapse (BAL) in a sliding window of variable length:
$$\Delta\alpha(\Delta\alpha / \Delta z) = \max$$

based on maximal lapse of refractivity gradient in two sliding windows of fixed lengths (refractivity break point (NBP))

Comparison of the ABL depths obtained from bending angle and refractivity (internal validation of the method)





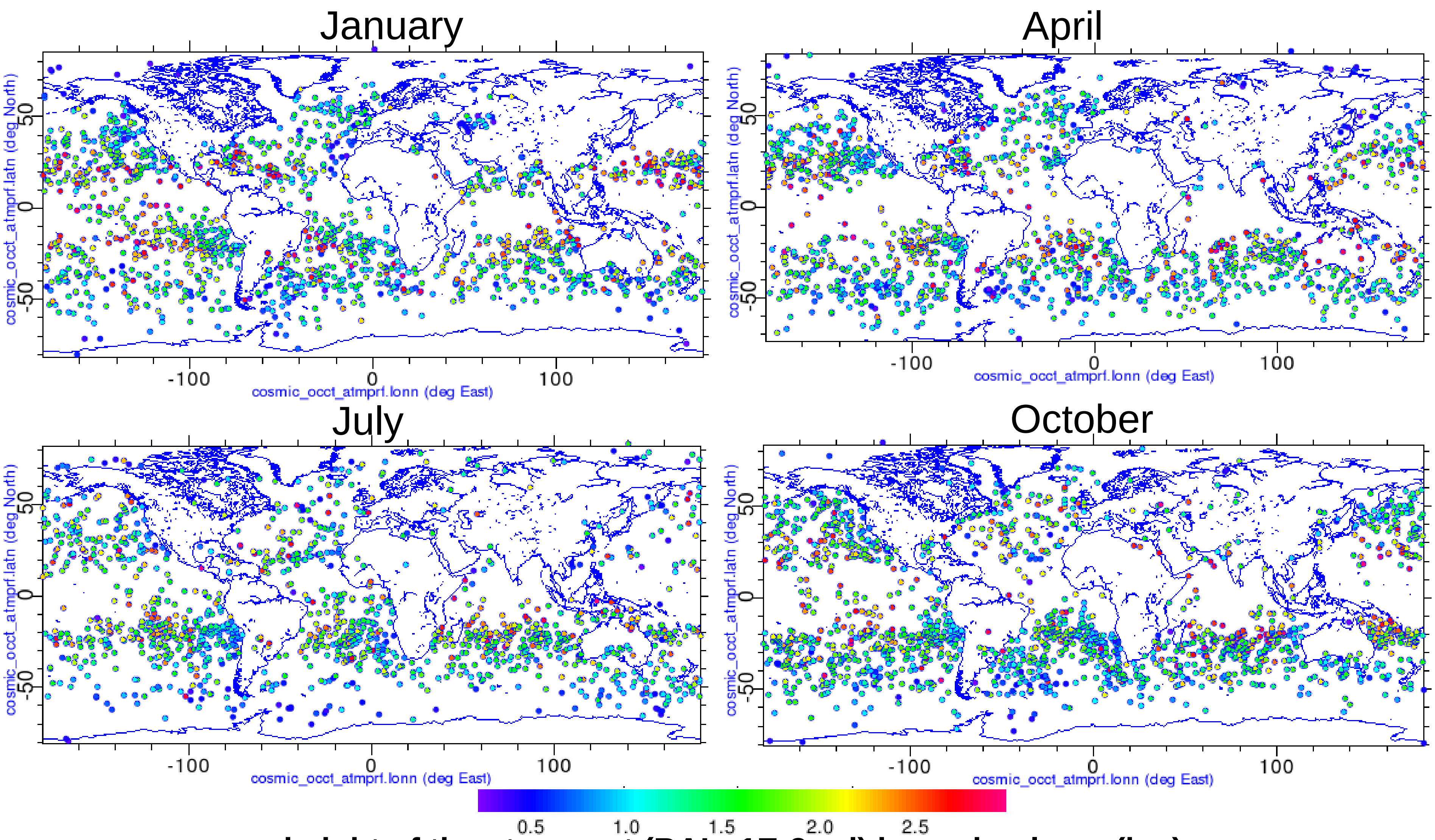
The difference is due to definitions: BA – mid height; N – top height of interfacial (inversion) layer

Large differences (outliers) are due to multiple inversion layers of about equal strength

Any approach can be used to study variability of the ABL depth

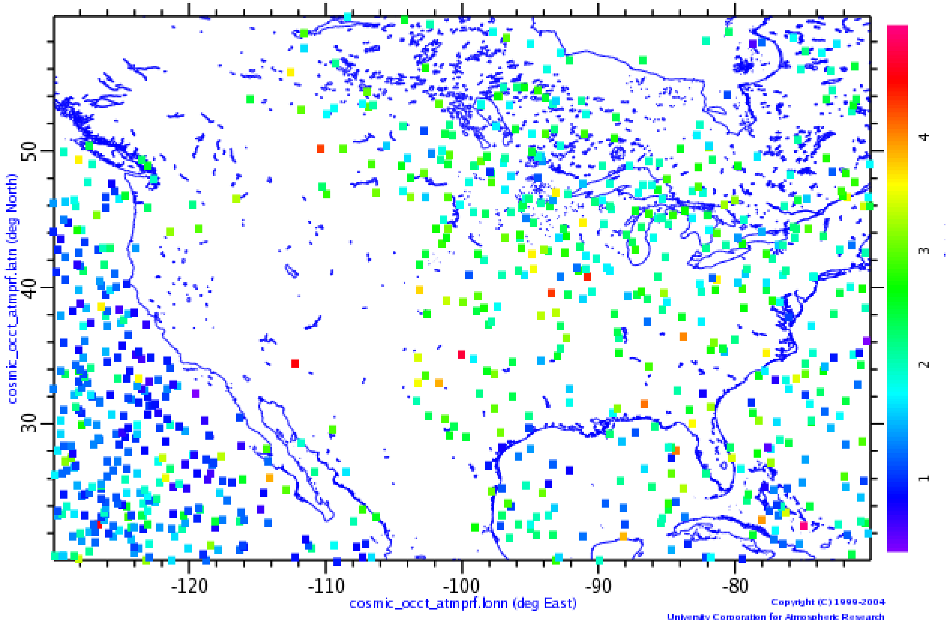
Global distribution of ABL depth over the oceans from COSMIC RO

- most sharp ABL top in sub-tropics - no pronounced ABL top in ITCZ
- decrease of ABL depth toward west coasts of continents



height of the strongest (BAL>1E-2rad) inversion layer (km)

Distribution of heights of strong inversion layers (BAL > 1E-2 rad) over North America

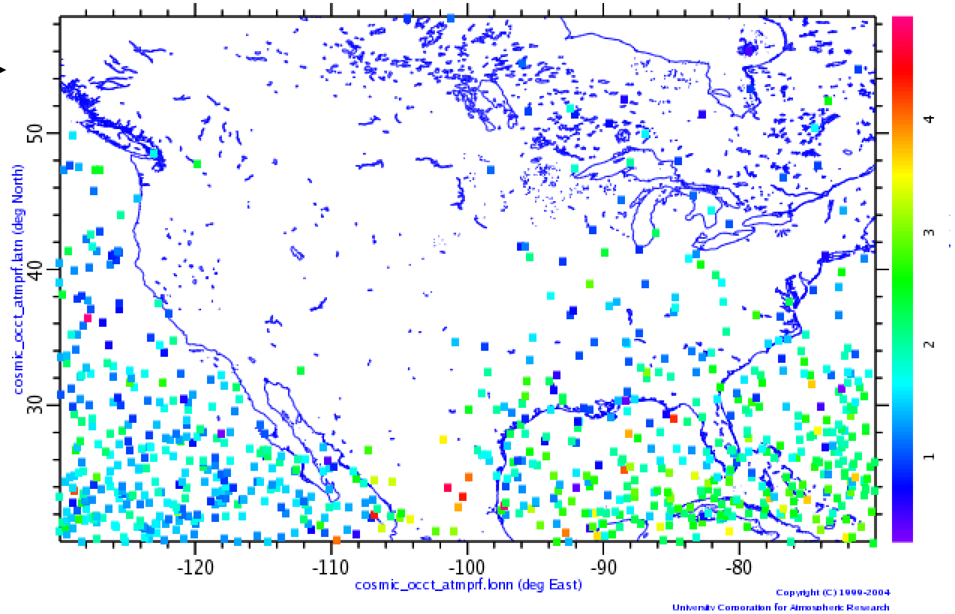


Summer:

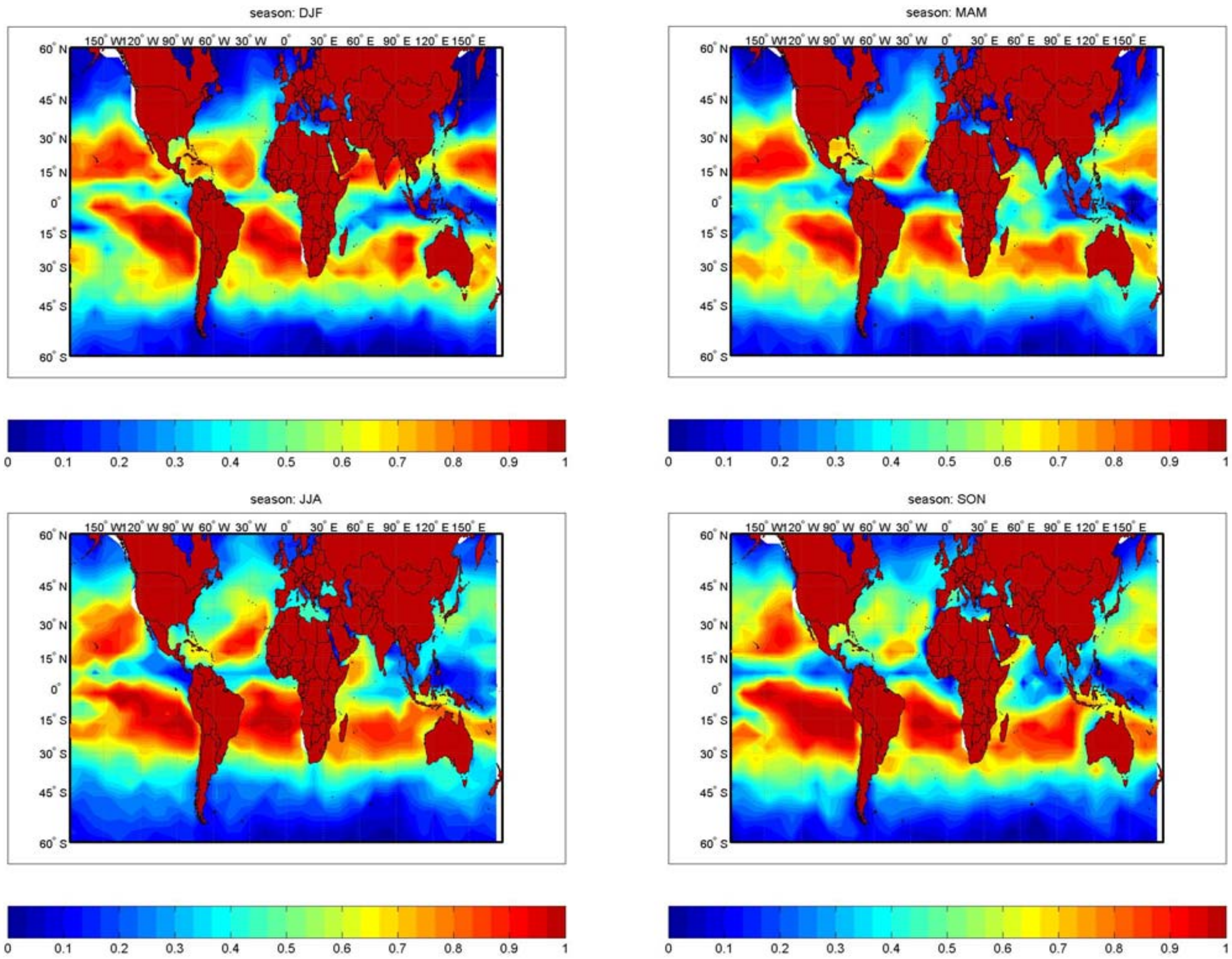
most sharp inversion layers (pronounced ABL top) over the ocean and plains; less over mountains

Winter:

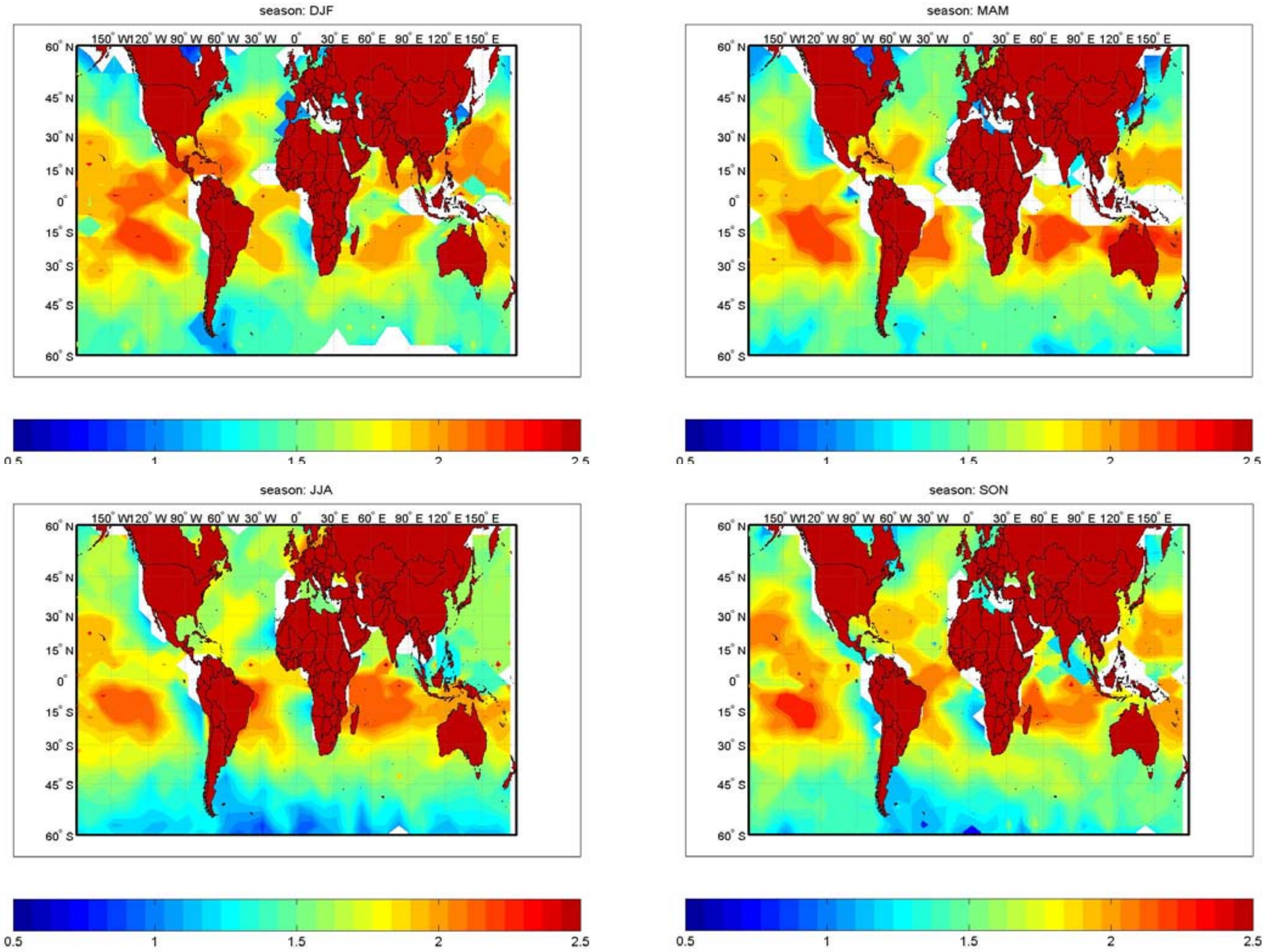
- fewer strong inversion layers over continent, more over the ocean southwards
- shallower ABL over continent
- deeper ABL over the ocean than in Summer



Seasonal variation of Frequency of ABL occurrence

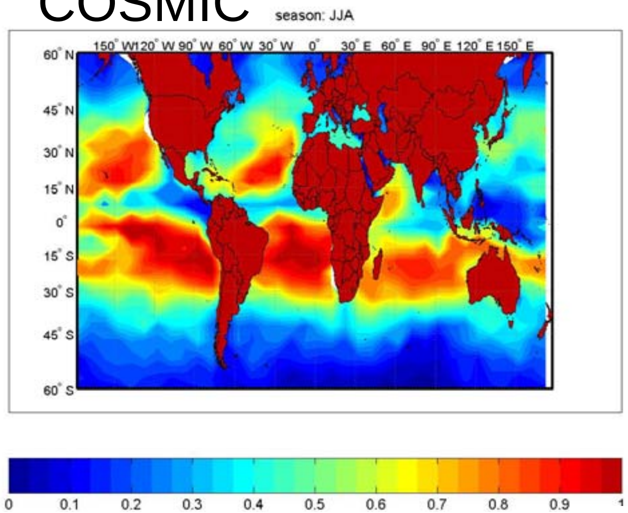


Seasonal variation of ABL height

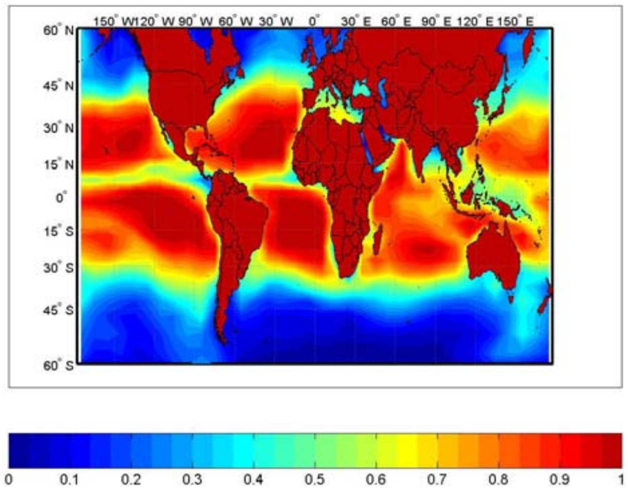


COSMIC-ECMWF Comparison

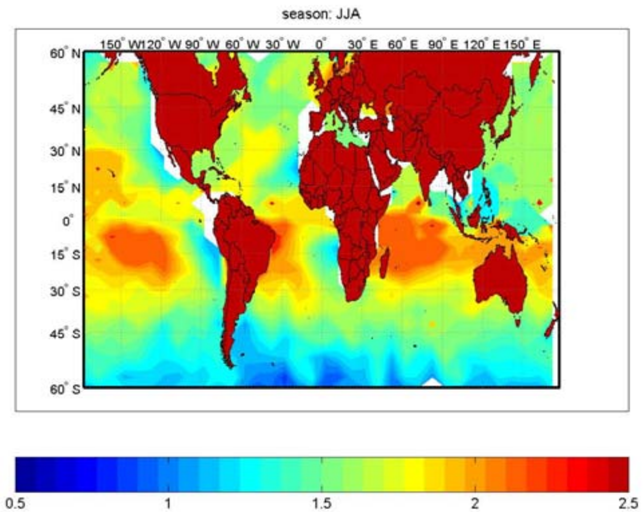
COSMIC

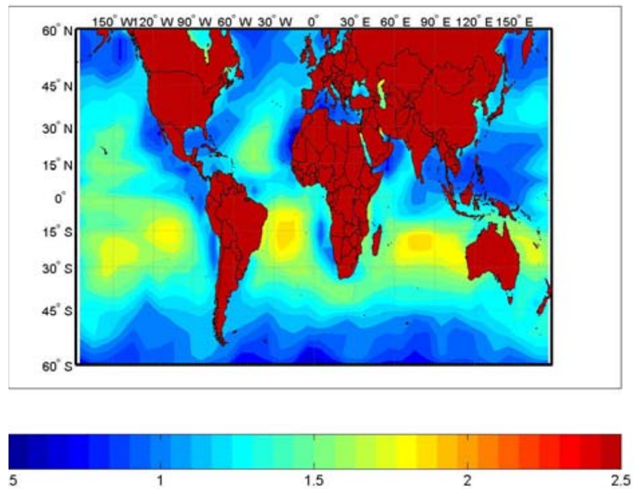


ECMWF



Frequency



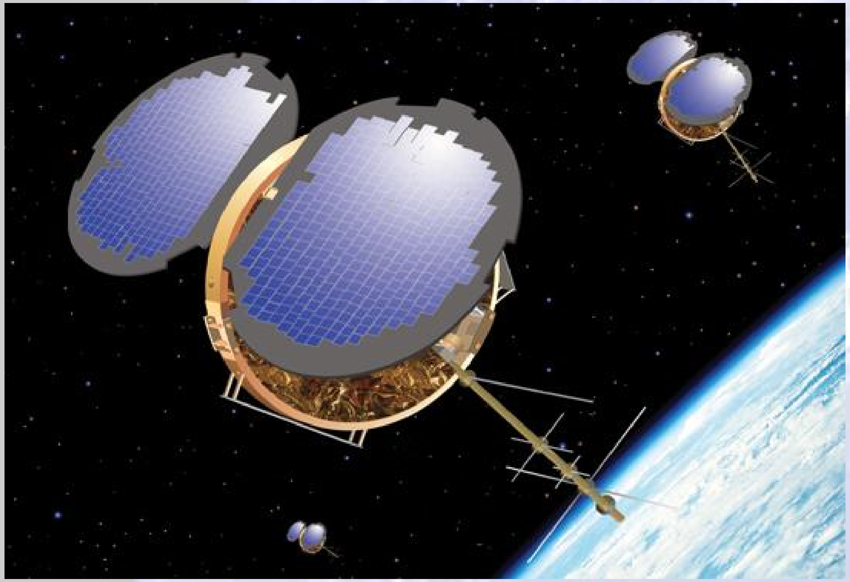


height

Future

Complete COSMIC mission (2008-2011)

Plan for next RO mission



COSMIC launch picture provided by Orbital Sciences Corporation

Operational RO Constellation

- COSMIC is a “Science Mission” for demonstrating the usefulness of RO in operational NWP, climate monitoring, and space weather forecasting
- COSMIC is not an “operational” mission (with all the redundancy and robustness)
- COSMIC constellation is expected to operate through 2011
- WMO and NRC have recommended continuing RO observations operationally
- Scientific community urges continuation of COSMIC and planning for a follow-on operational mission
- Need international standards so that future RO missions deployed by any country can be used together for operations and research

Improvements expected from “COSMIC II”

- More receivers per launch - ~20 kg micro-satellites
- More soundings per receiver - added Galileo/GLONASS tracking capability
- Higher density of profiles - more useful for global and mesoscale models, severe weather forecasting
- Lower data latency - Can be reduced from 2-3 hours to 5 minutes (especially important for Space Weather)
- Improved tracking and more antenna gain - better data in the lowest moist troposphere
- Continued, longer, stable climate record

More GNSS Transmitters for Next Mission

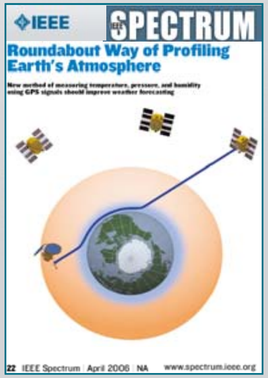
Spacecraft transmitting RO signals in 2012

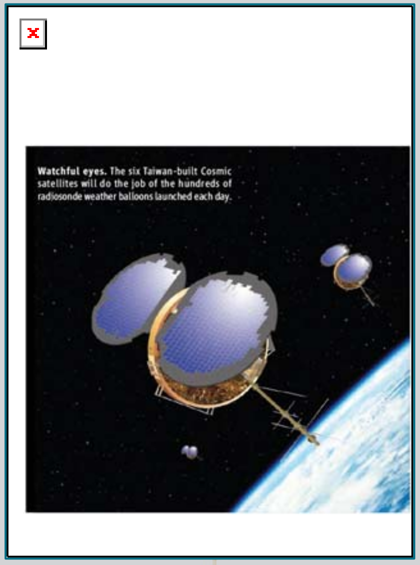
• *U.S. GPS*	*~ 30 in service*
• *Russia GLONASS*	*~ 24 in service*
• *Europe Galileo 2013*	*~ 32 will be in service*
• *China BeDou 2010 (?)*	*~ 35 will be in service*

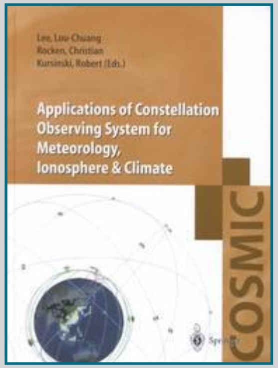
National Space Organization
&
University Corporation for Atmospheric Research

ThunderSat Program

(FORMOSAT-3 / COSMIC Follow-On)





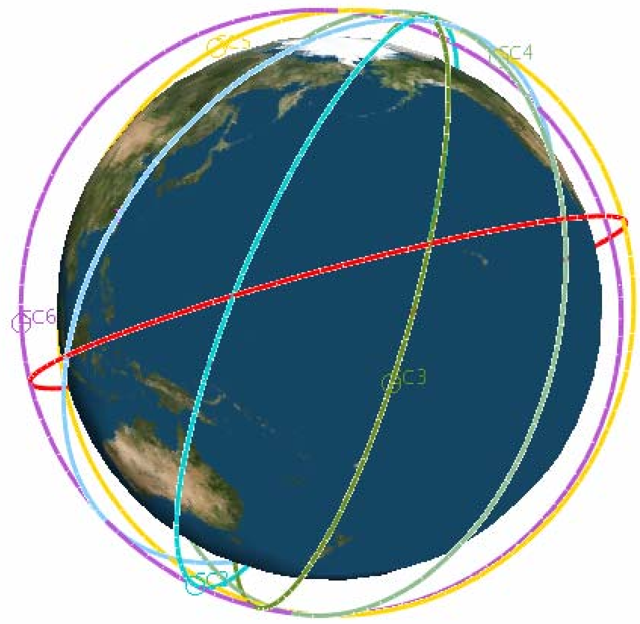


NSPO
NATIONAL SPACE ORGANIZATION

05 / 30 / 2008

ThunderSat Mission Planning
(Taiwan Sole Funding)

- *6+1 Constellation (Expected 4,000 Radio Occultation /Day)*
  - *6 satellites in high inclination angle deployed as FORMOSAT-3 / COSMIC constellation*
  - *1 satellite in low inclination in order to collect more occultation points at low and middle latitudes.*
- *The final mission planning will be through open discussion with science community and research groups.*



# Launches	Constellation Deployment
Two Launches 6+1	14 ~ 19 Months
Three Launches 3+3+1	5 ~ 7 Months

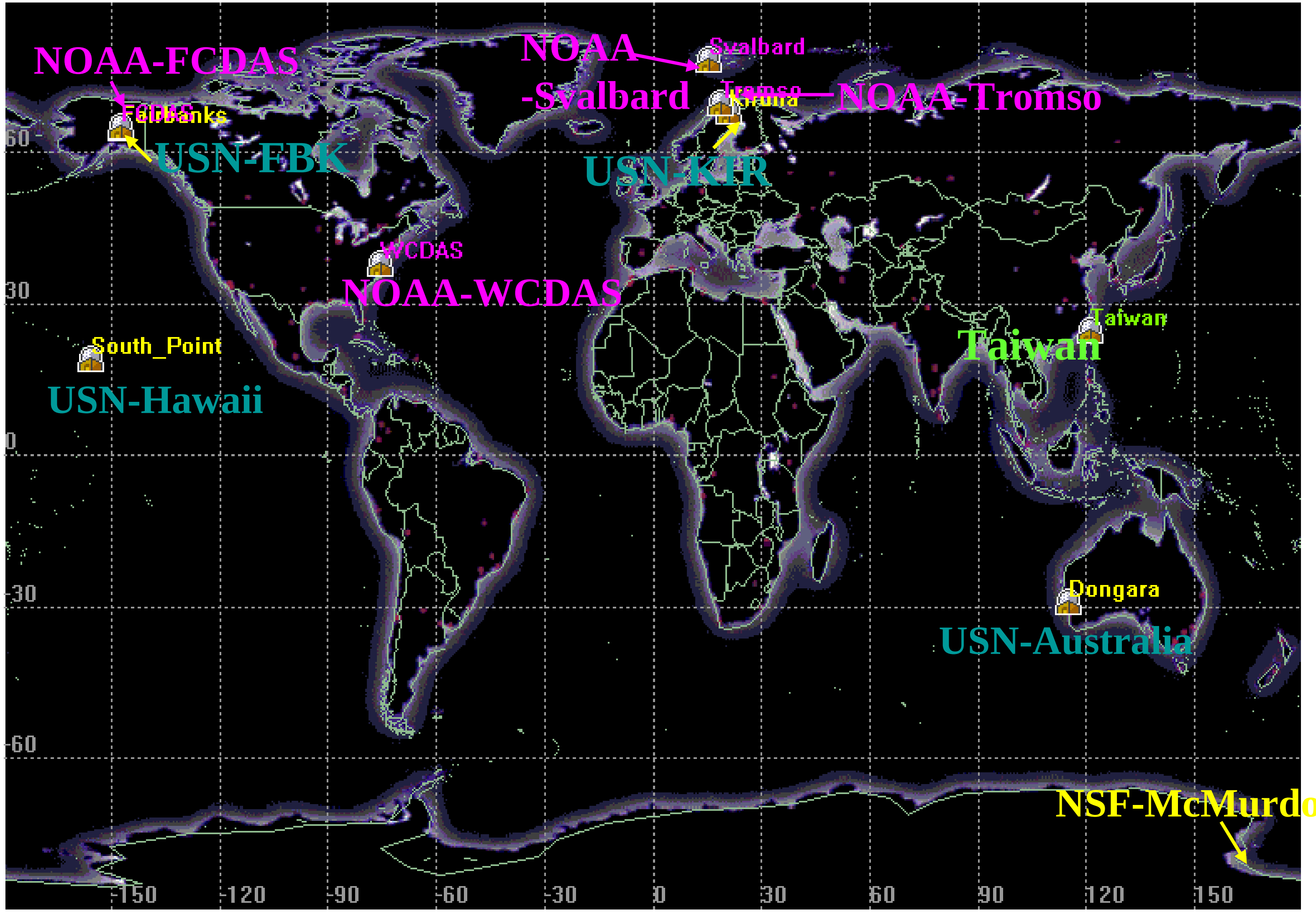
Spacecraft Bus Design

Function	Follow-on Design	FORMOSAT-3 Design	Improvement
Weight	~50 kg (Include GPS Revr) (+ 2 Additional Science P/L @ 5 Kg Each)	61 kg (w/ Propellant)	Stacked or Single Launch Piggy-Back Launch
Attitude Control Performance	3-axis linear control Roll/Yaw: +/-0.2 deg (3σ) Pitch: +/- 0.2 deg (3σ) 3-Axis Gyro, 3-axis MAG, RWA x 3, Torque x 3, GNSS PL x 1 (or Star Tracker x1 Bus GPSR x1)	3-axis nonlinear control Roll/Yaw: +/-5 deg (1σ) Pitch: +/- 2 deg (1σ) Earth Sensor x 2, CSSA x 8, RWA x 1, Torque x 3, GPS Bus Receiver PL x 1	Improved PL Performance Better Attitude Performance Simplified Operation Simplified Orbit Transfer
Science Data Storage	>1.5 G	128 M	Increased Data Storage Simplified Operations
Avionics Architecture	Centralized Architecture Radiation - Hardness	Distributed Architecture (Multiple Avionics Boxes)	Simplified Integration Harnessing & Mass Reduced
Electrical Power	Lithium Ion Battery Voltage Based Algorithm	Ni-H2 Battery dM/dC Charging Algorithm	Reduced Mass & Volume Simplified Operations
Structure	Aluminum	Metal Matrix (AlBeMet)	Cost Reduced
Payload Interface	Main PL: GNSS RO Receiver Science PL (Optional) : <2 Modular Design	Primary PL : GOX Secondary PL : TIP, TBB	Modular Design Cost Reduced

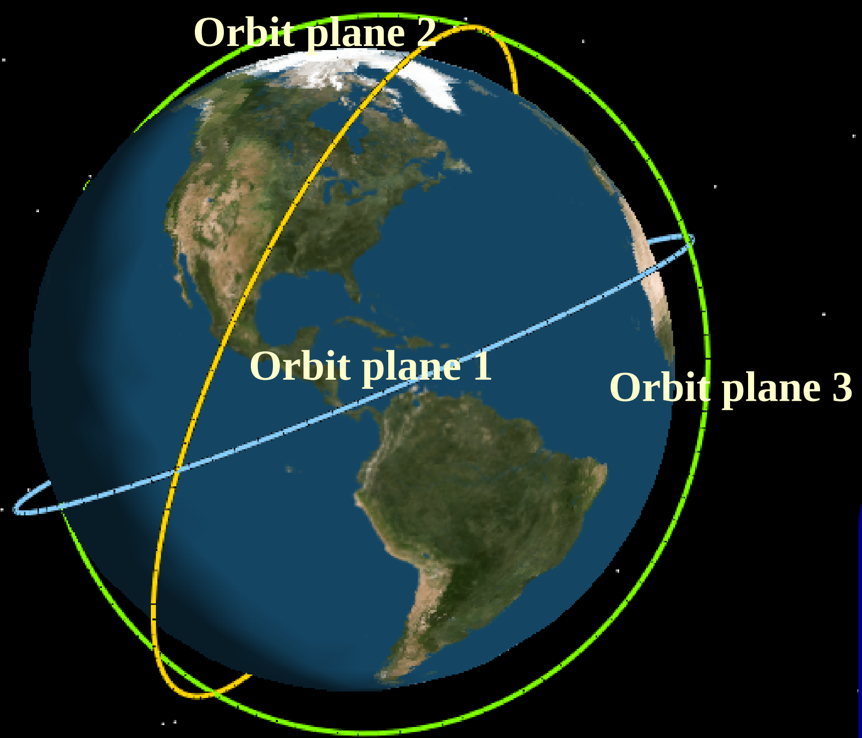
GNSS RO Payload Design

Function	Follow-on Design	FORMOSAT-3 Design	Improvements
Processor	BRE440 + GNSS ASIC/FPGA	PowerPC 603e x 2	Increased Radiation Hardness Improved Processing
Electrical Power	Average : < 25 W Peak : < 35W	Average : 16W Peak : 23W	Improved Performance
Antenna Inputs	4 to 6 Ant. Inputs	POD Ant x 2 OCC Ant x 2	Increased No. of RO profiles
Frequency	US GPS:L1/L2/L5 USSR GLONASS:L1 (Opt.) ESA GALILEO:E1/E5/E6	US GPS: L1/L2 (Dual-Frequency)	Increased RO data points Improved PVT resolution
Channels	48~128 Channel	24 Channel	Increased RO data points Improved PVT resolution

Current NOAA Ground Networks



Anticipated NOAA's Major Partnership – 12 Satellites Constellation



3 Orbit Planes

Orbit Plane 1 – inclination 72 °

Orbit Plane 2 – inclination 72 °

Orbit Plane 1 and Plane 2 separated by 90 °

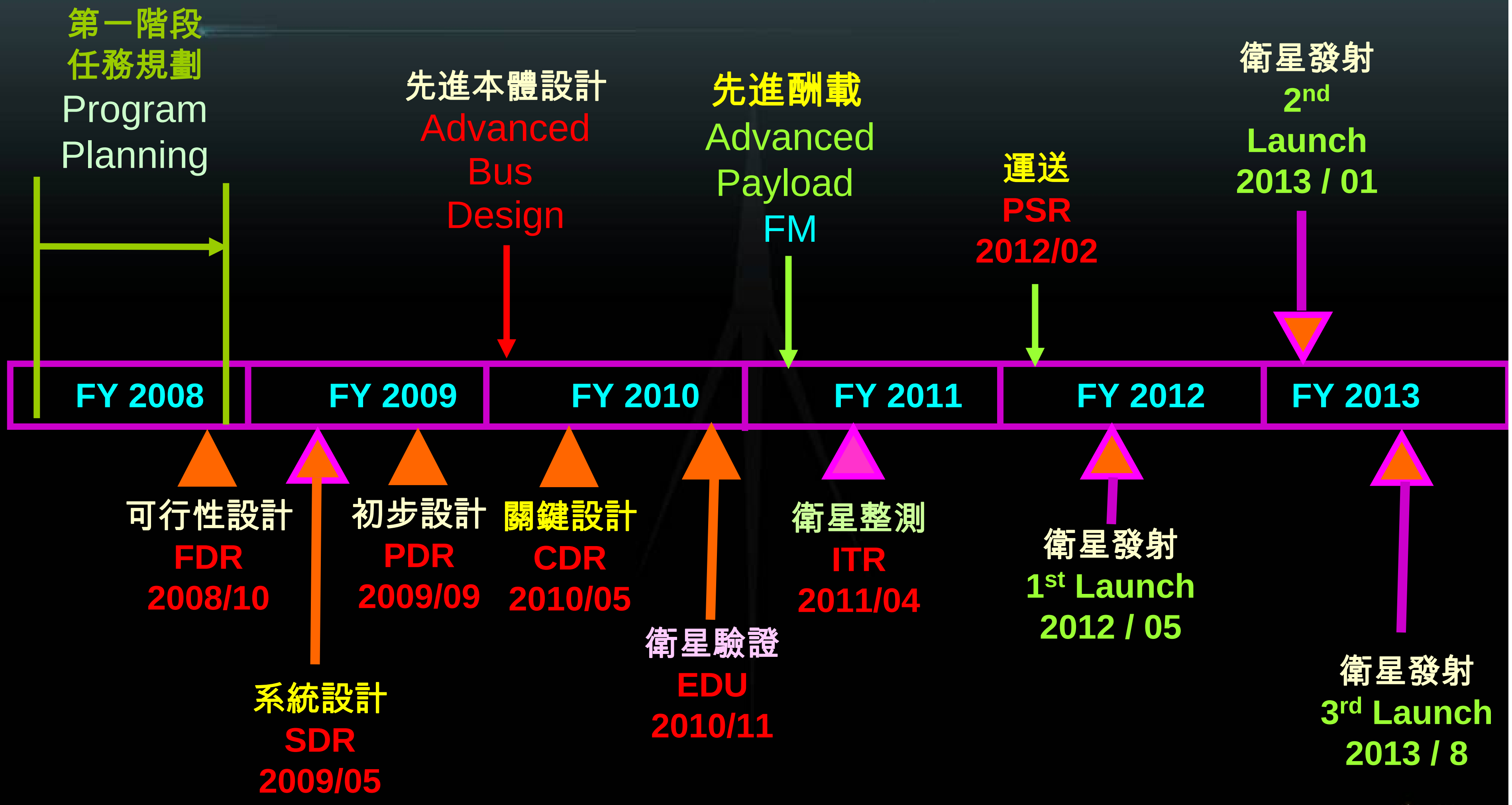
Orbit Plane 3 – inclination 24 °

2 Launches

First Launch to put 8 satellites to parking orbit to be deployed to Orbit Plane 1 and Orbit Plane 2

Second Launch to put 4 satellites to mission orbit as Orbit Plane 3

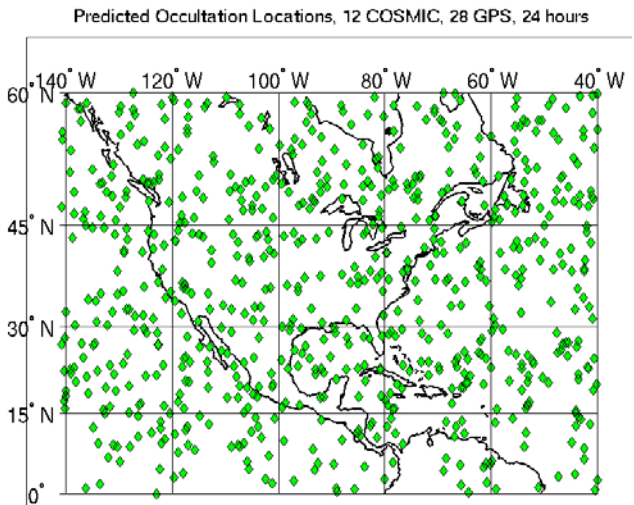
Planned ThunderSat Program Milestones



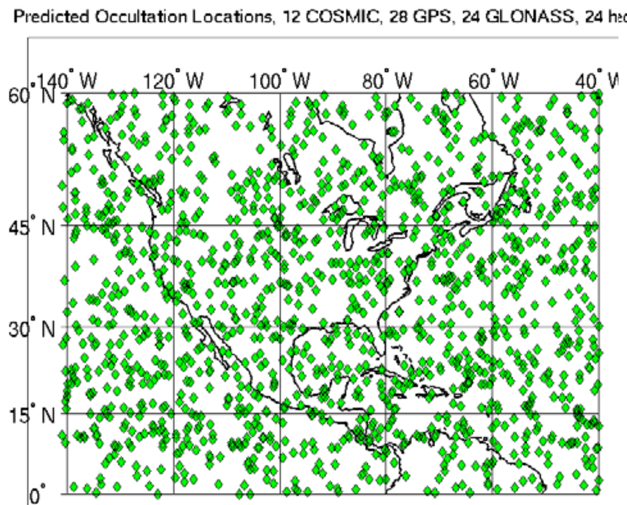
Closing Remarks

- *RO has shown positive impacts on weather prediction, climate monitoring.*
- *An opportunity exists now to begin a robust, operational RO mission.*
- *Mitigate loss of climate observing capability on NPOESS.*
- *Major contribution to operational space weather.*
- *Taiwan has proceeded with an expected funding of US $100 M for a < 6+1 > constellation to the implementation of the FORMOSAT-3 / COSMIC Follow-on Program that benefits to the global weather monitoring system.*
- *All RO major users are invited to form a greater satellite constellation.*

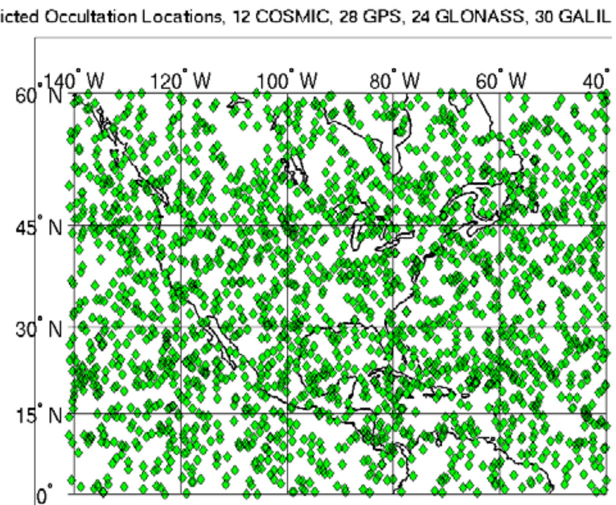
Coverage of possible future constellations
12 sat constellation-24 Hours



28 GPS



Add 24 GLONASS



Add 30 Galileo


FORMOSAT-3/COSMIC Workshop
1-3 October 2008, Taipei, Taiwan
http://www.formosat3.ncu.edu.tw/
Thank You !
NSPO
NATIONAL SPACE ORGANIZATION