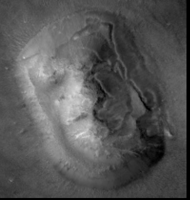
A Brisk Tour of GPS Radio Occultation

Past, Present and Future

Thomas P. Yunck

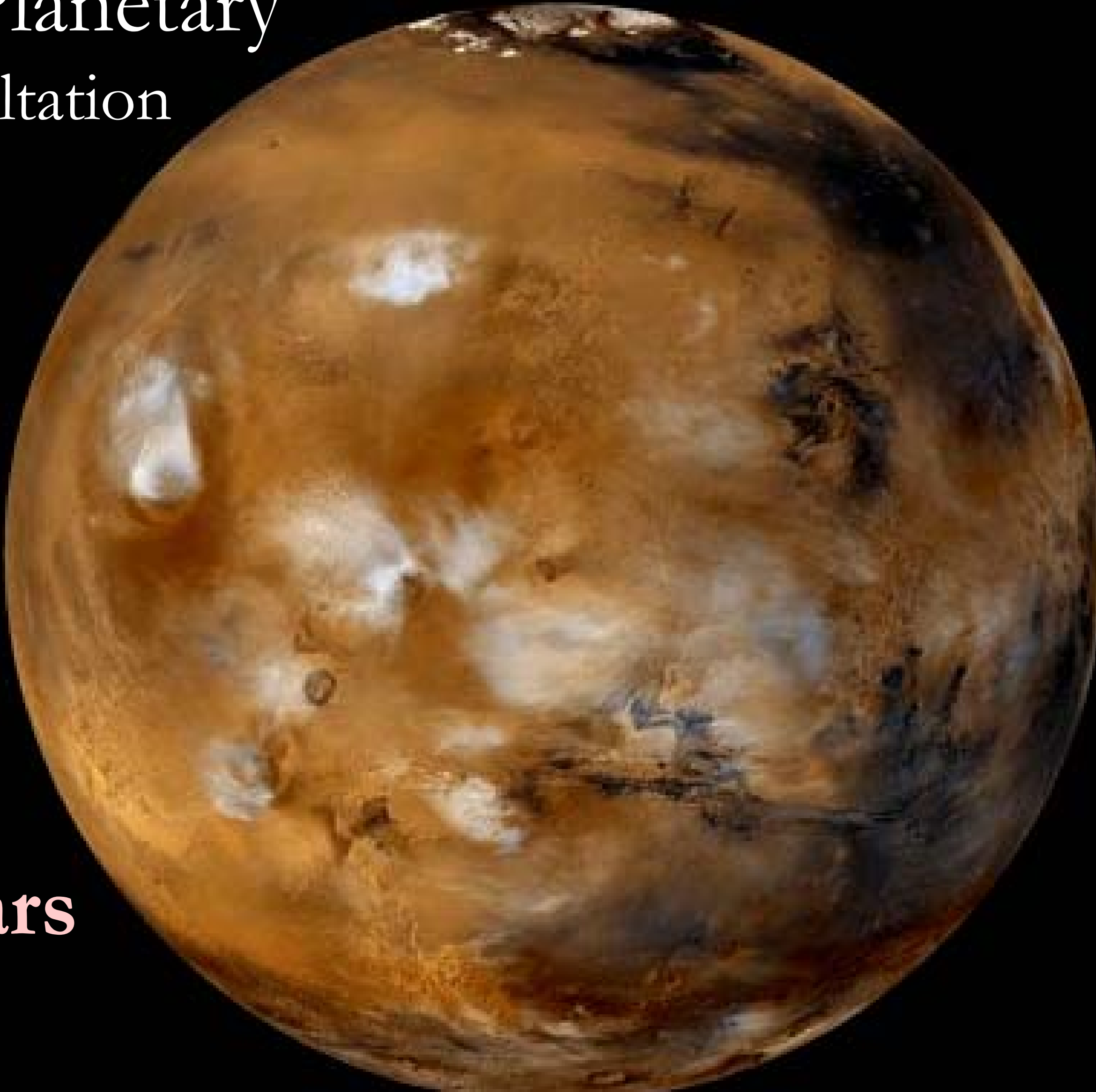
Presentation to NOAA

May 17, 2007



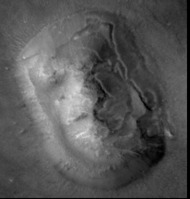
Origins-II: Planetary

Radio Occultation



Mariner IV at **Mars**

July 1965

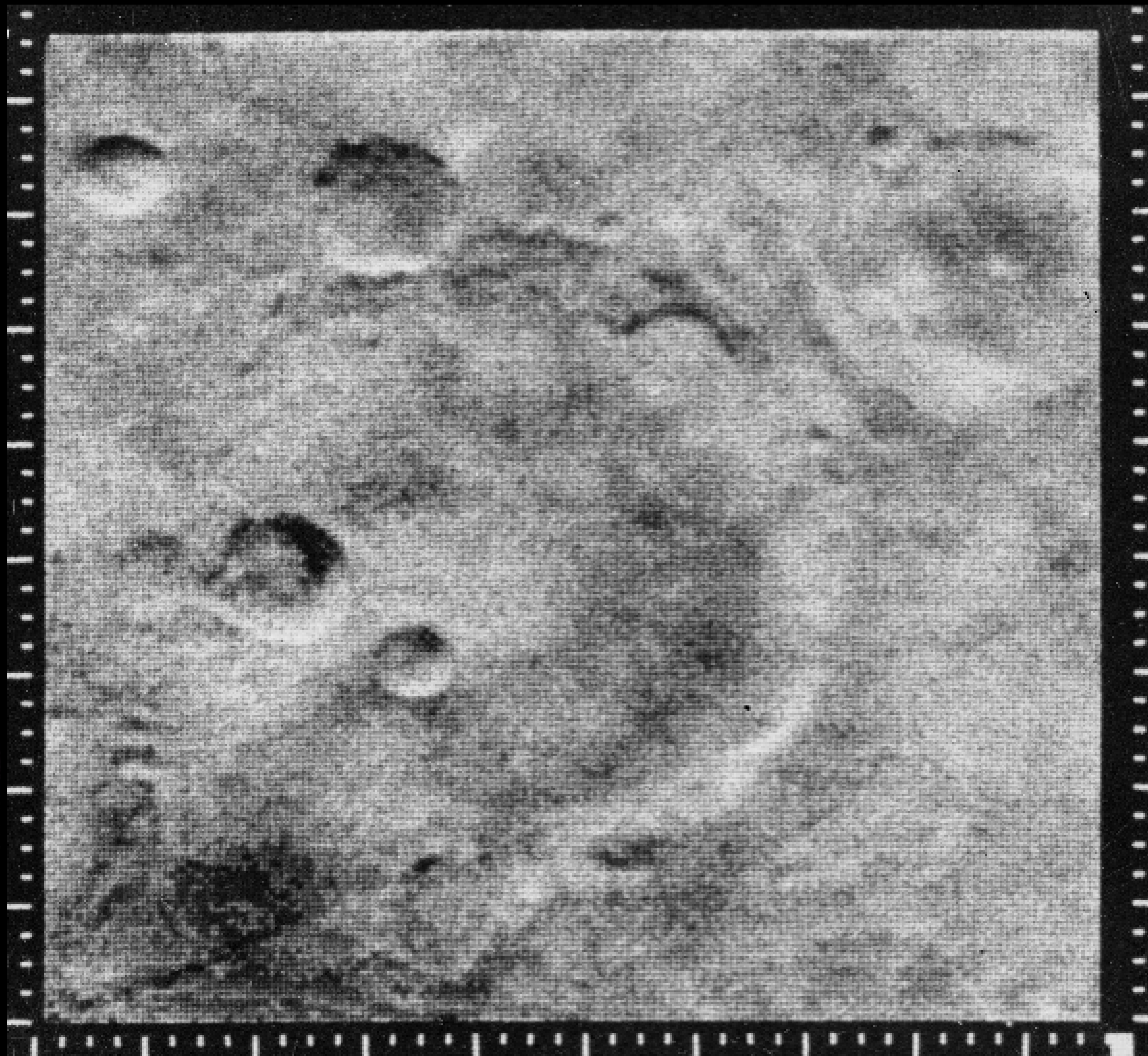


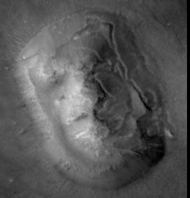
Mariner IV

Mars

15 July 1965

(JPL
wirephoto)

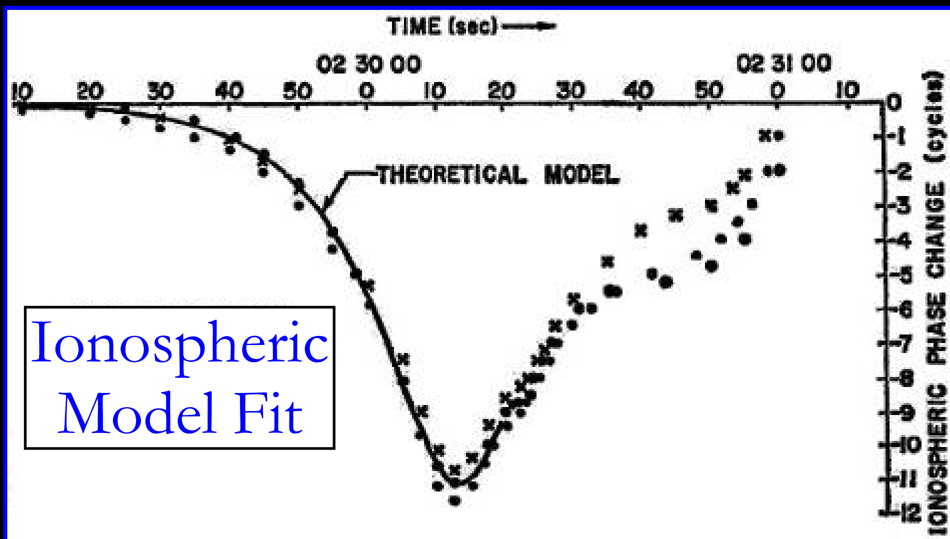


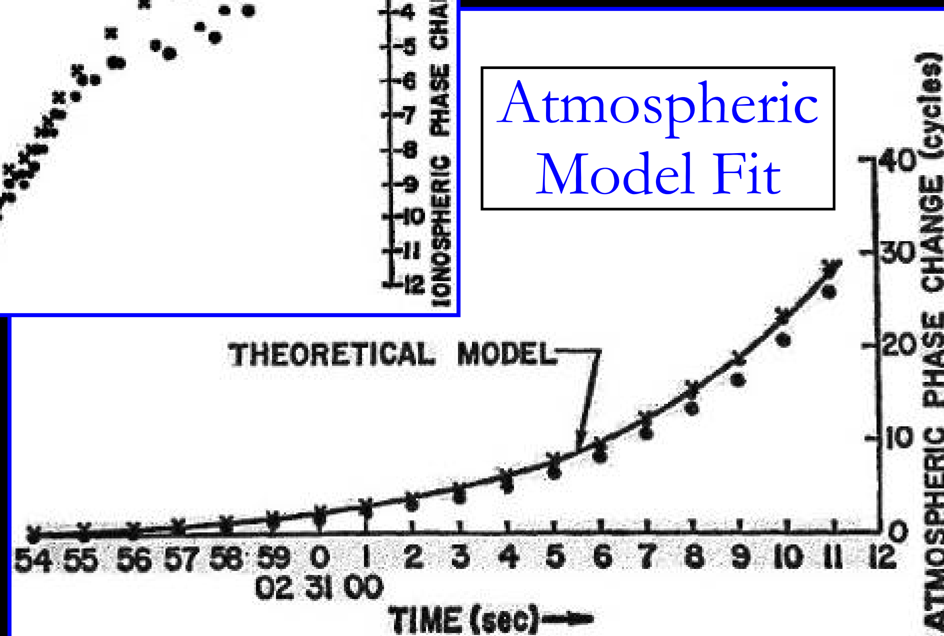


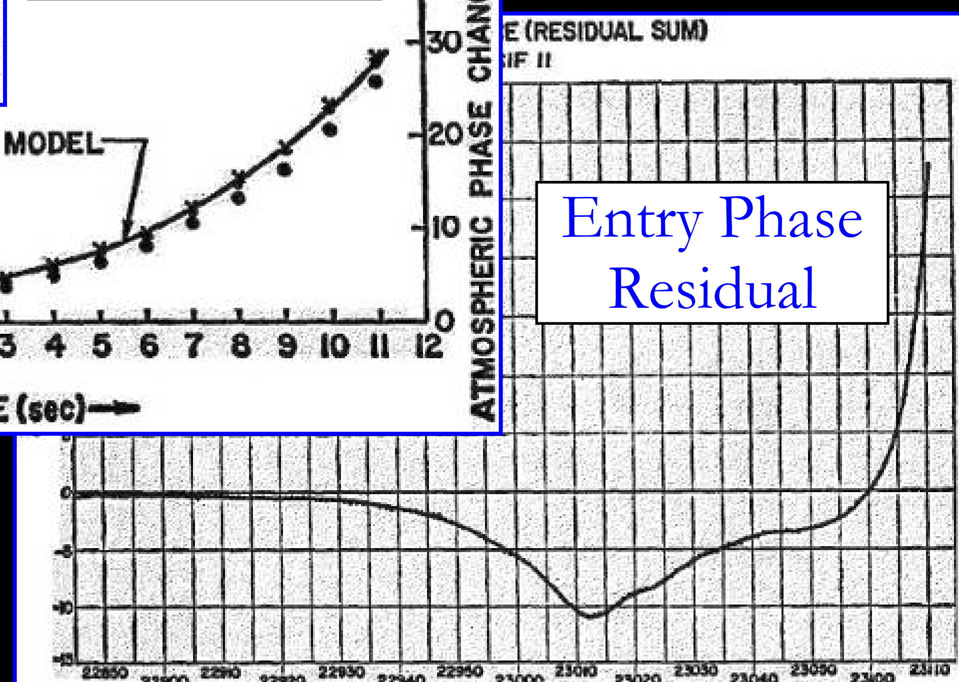
Mariner IV Occultation at Mars:

Earliest Results

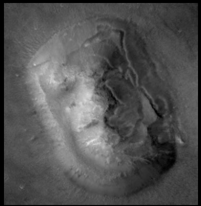
Science, 10 Sep 65







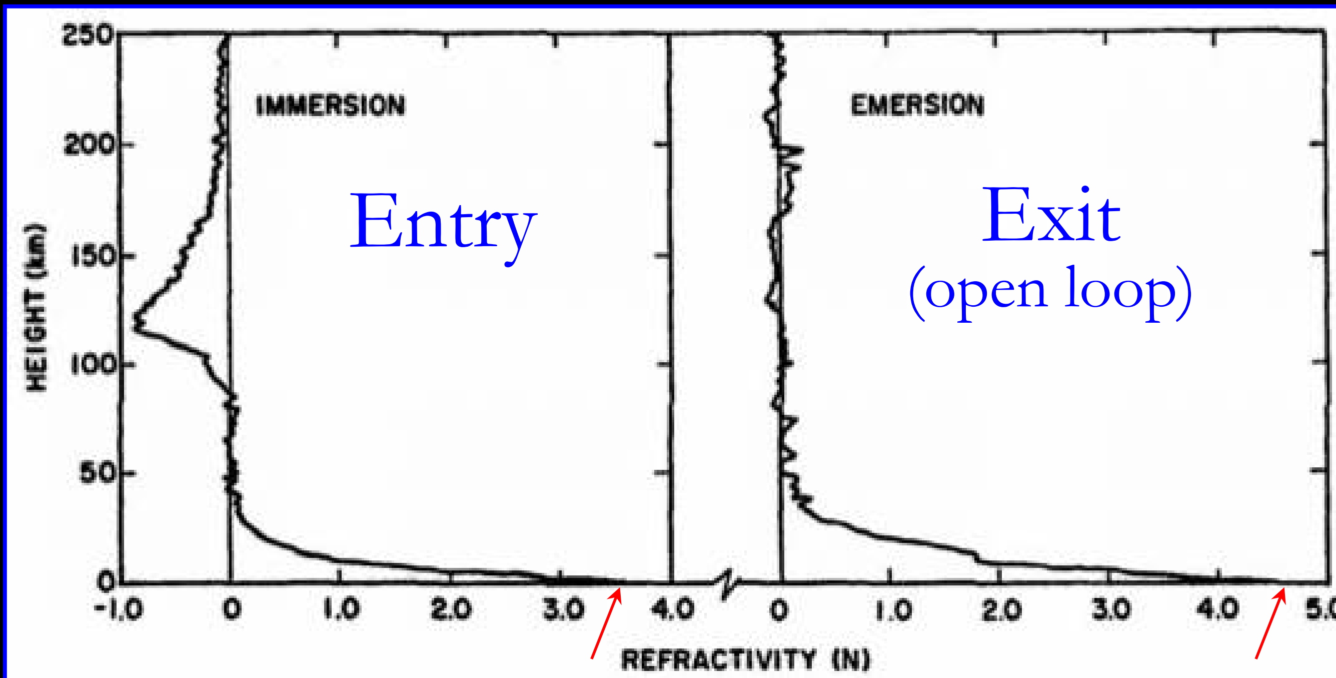
Kliore et al., 1965

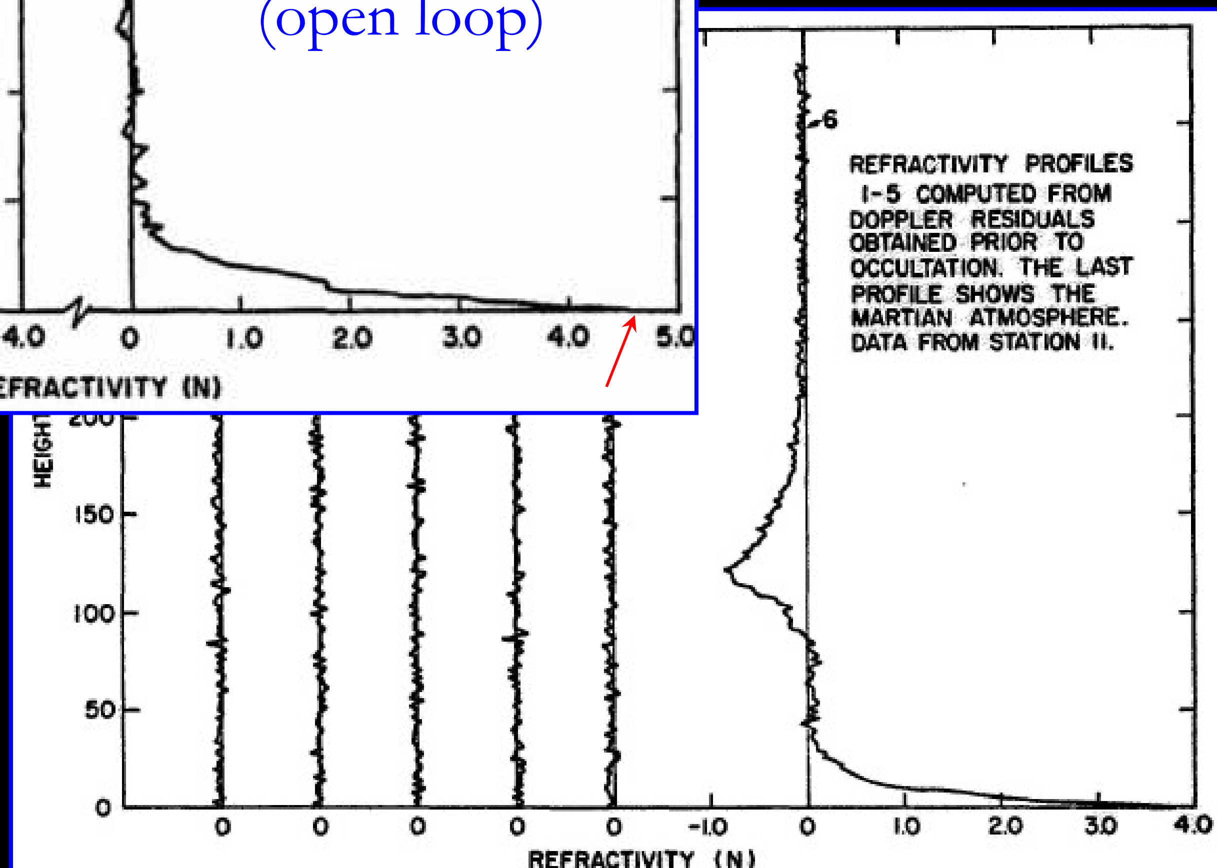


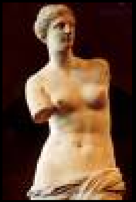
Mariner IV Occultation at Mars:

Refined Results

Fjeldbo et al., *Planet. Space Sci.* 1968

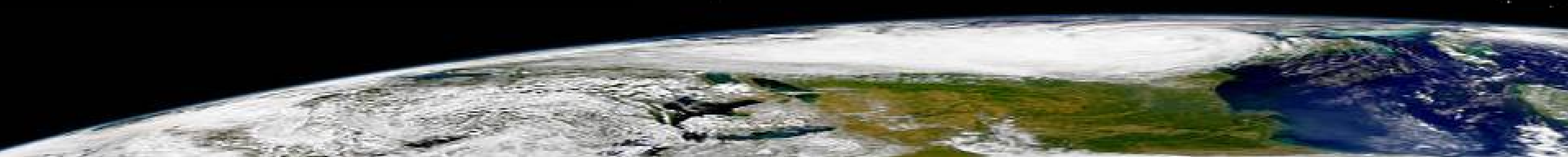


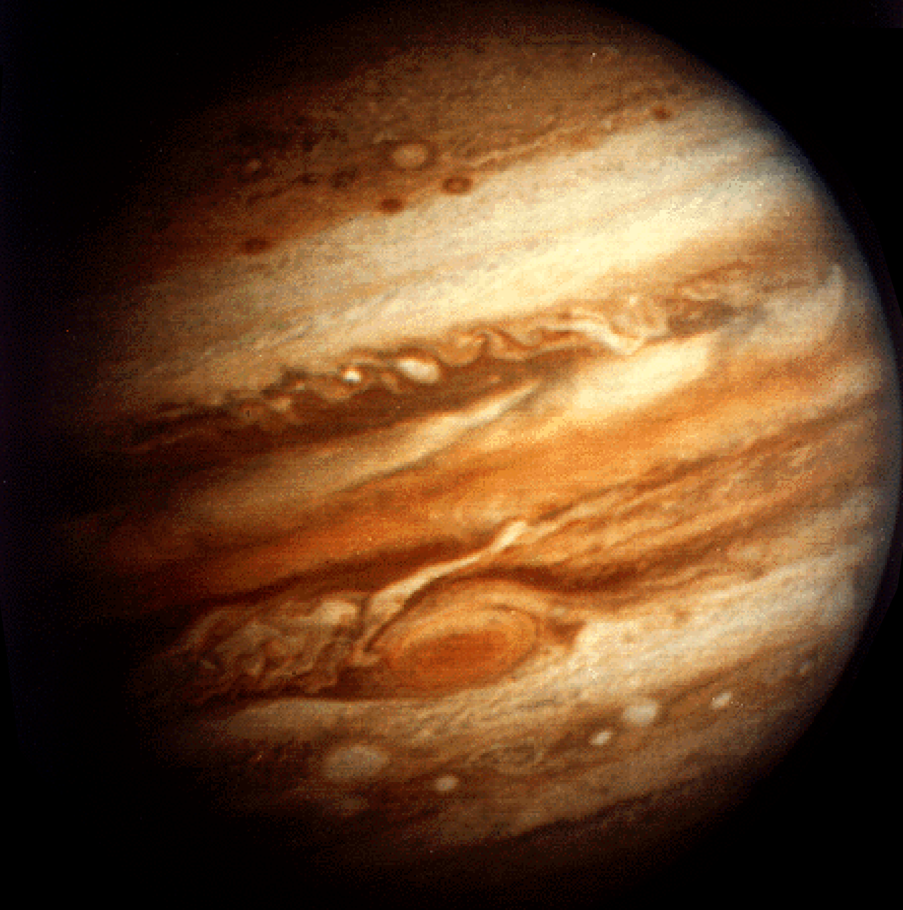




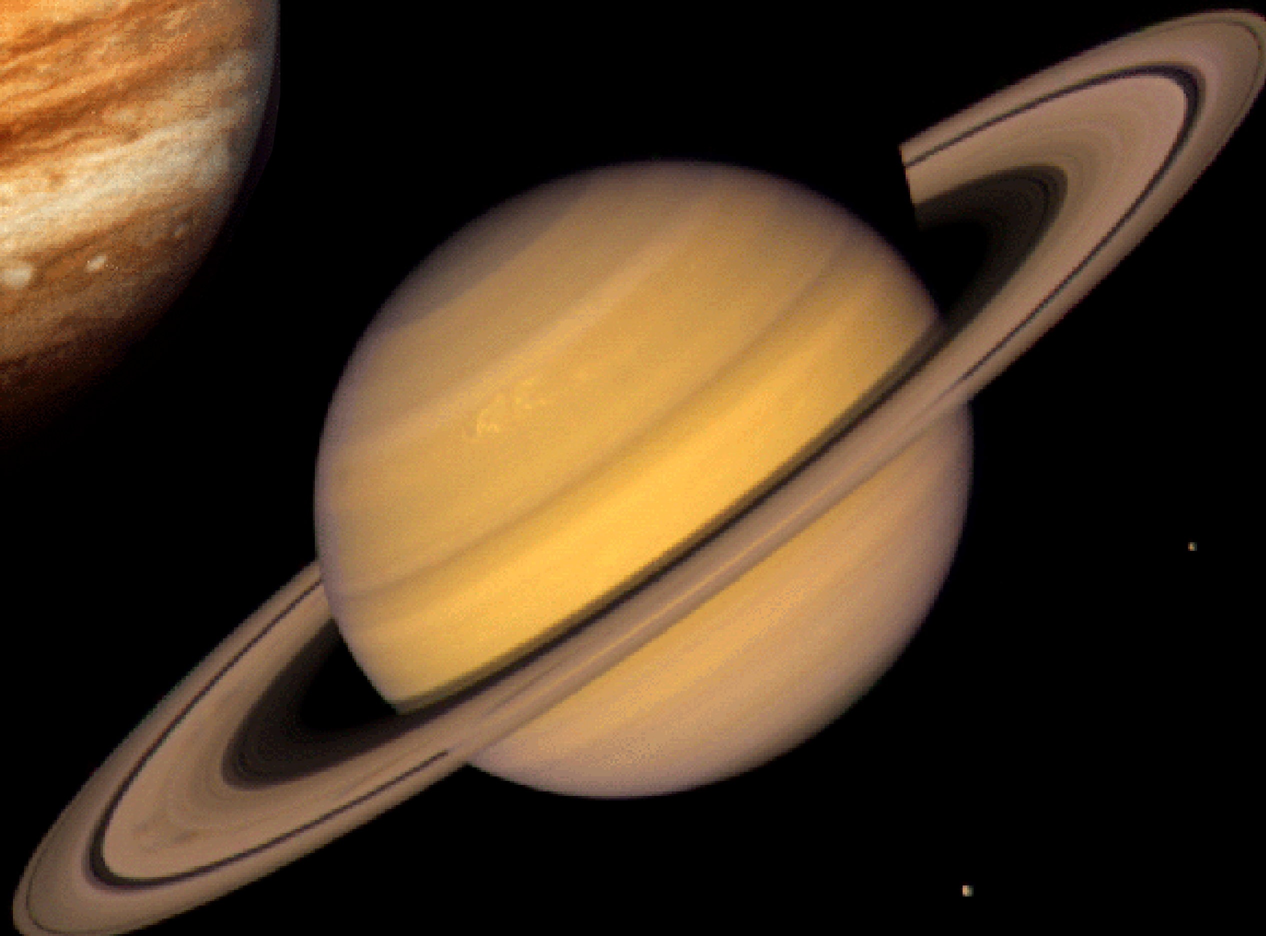
Mariner V at Venus

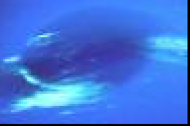
19 October 1967





Outer Planets – I
Jupiter and Saturn

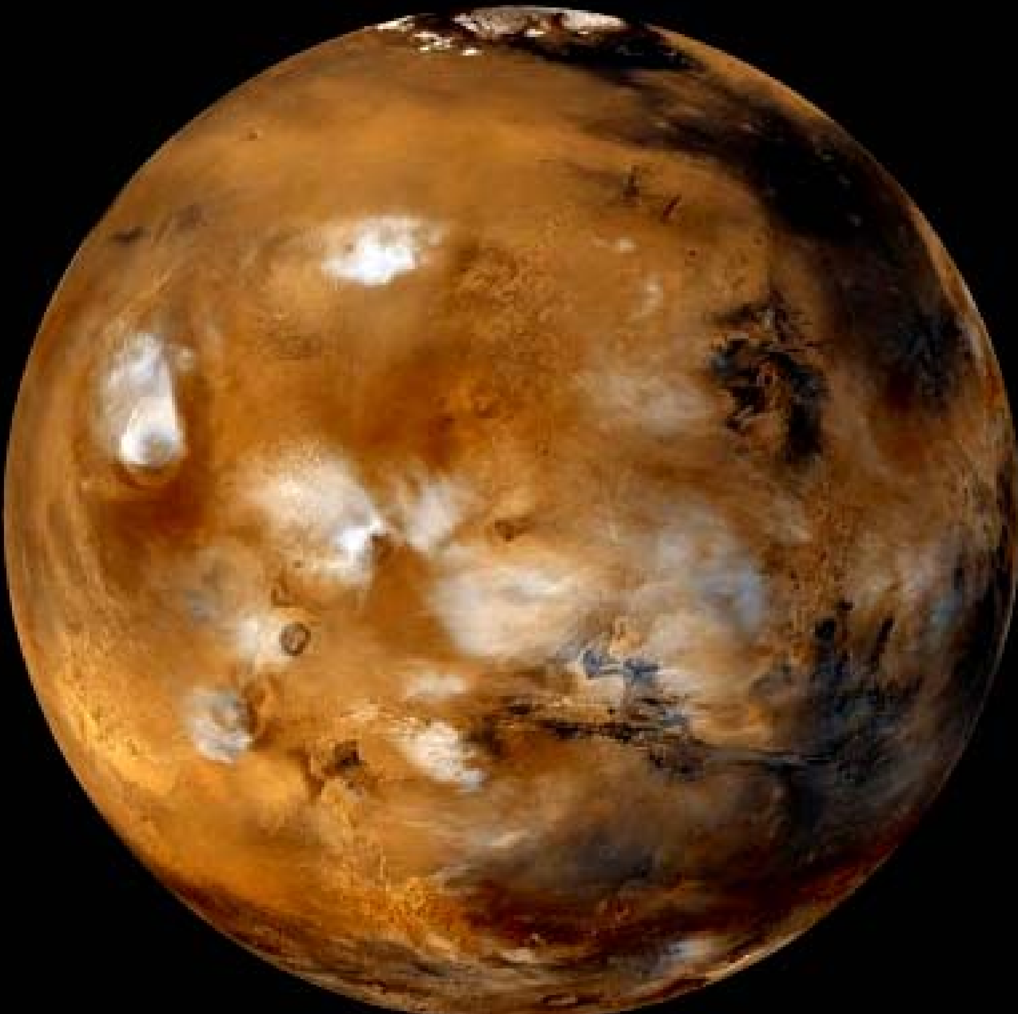




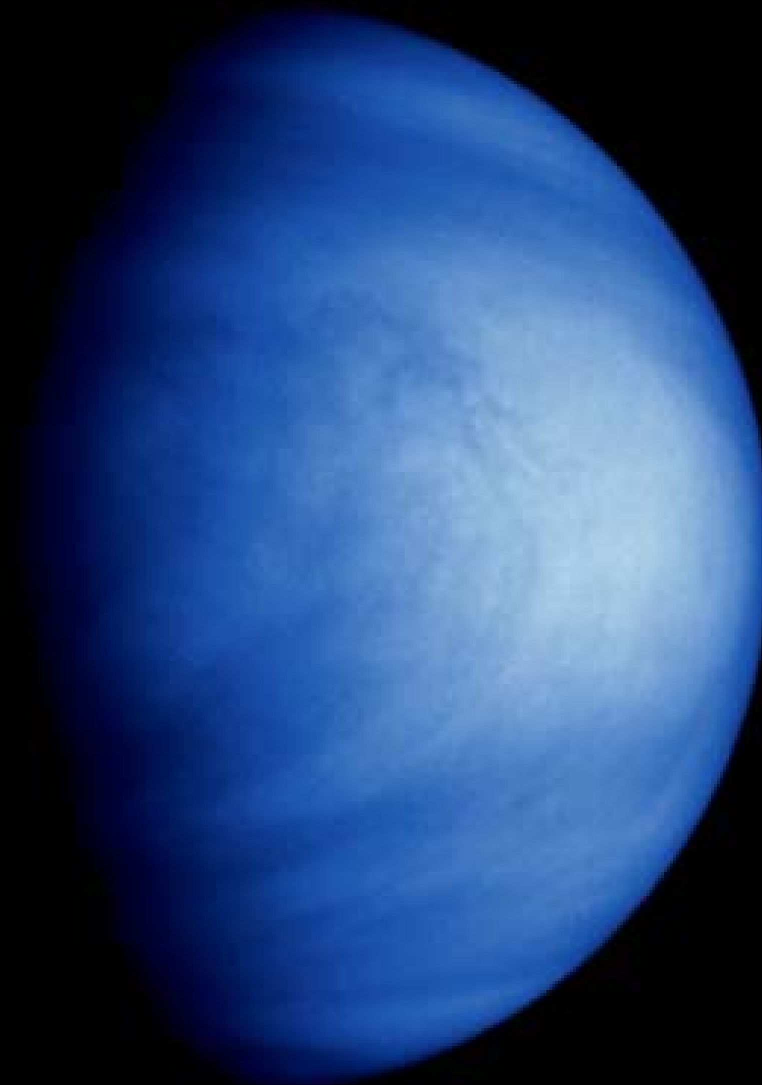
Outer Planets – II
Uranus and Neptune

Occultation Subjects: A Group Portrait

An Observation on the Terrestrial Planets



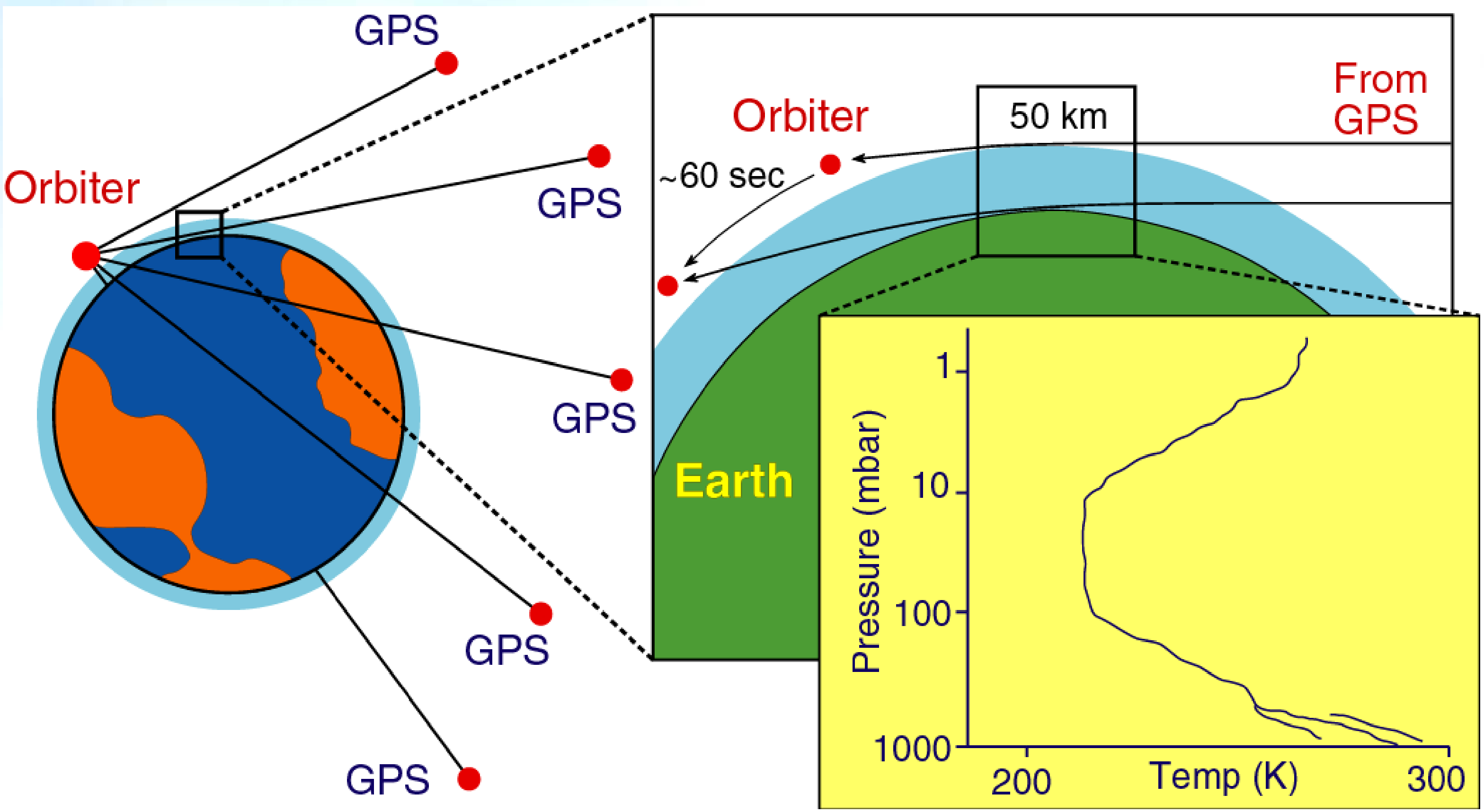
This atmosphere is too thin



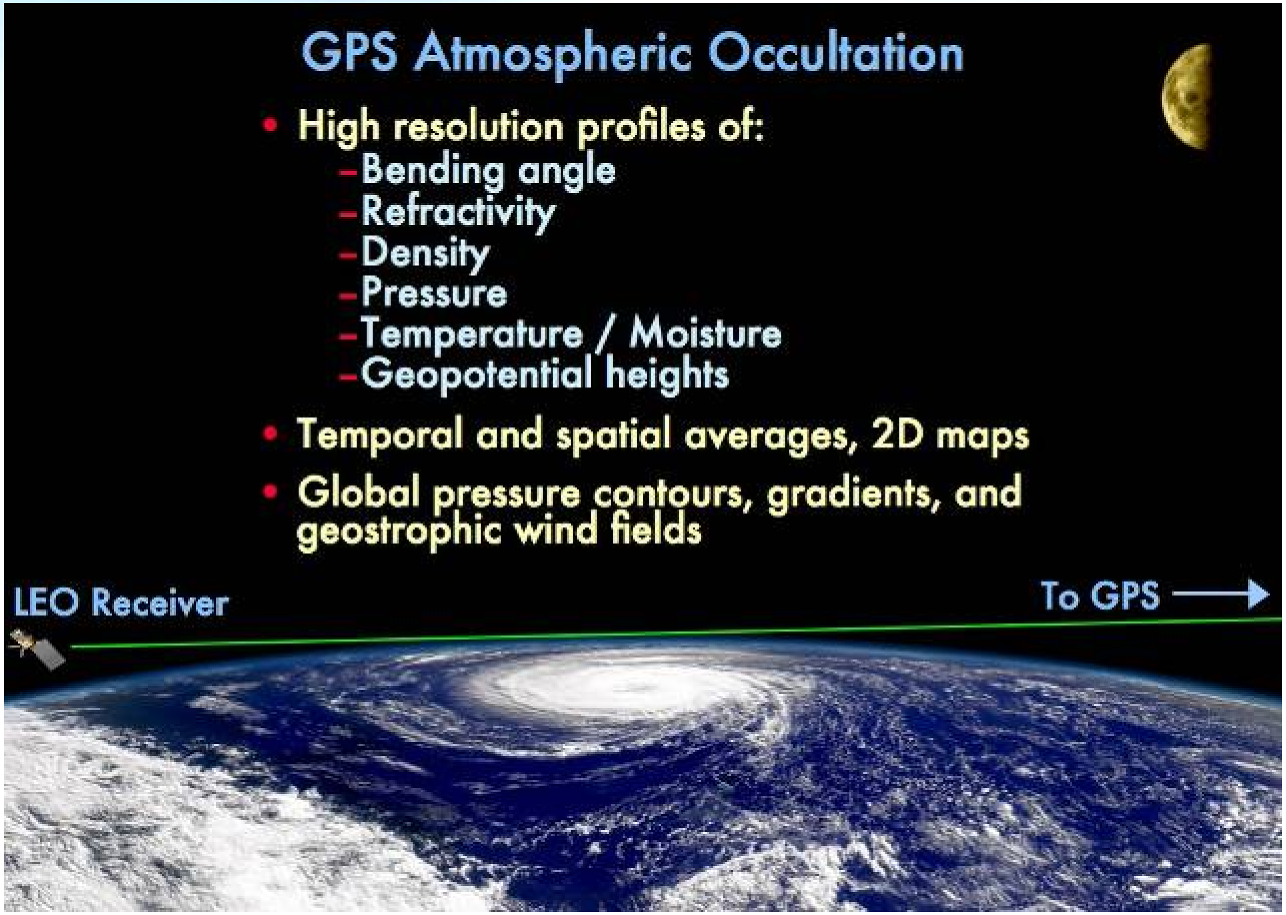
This atmosphere is too thick

Just right…

Atmospheric Limb Sounding

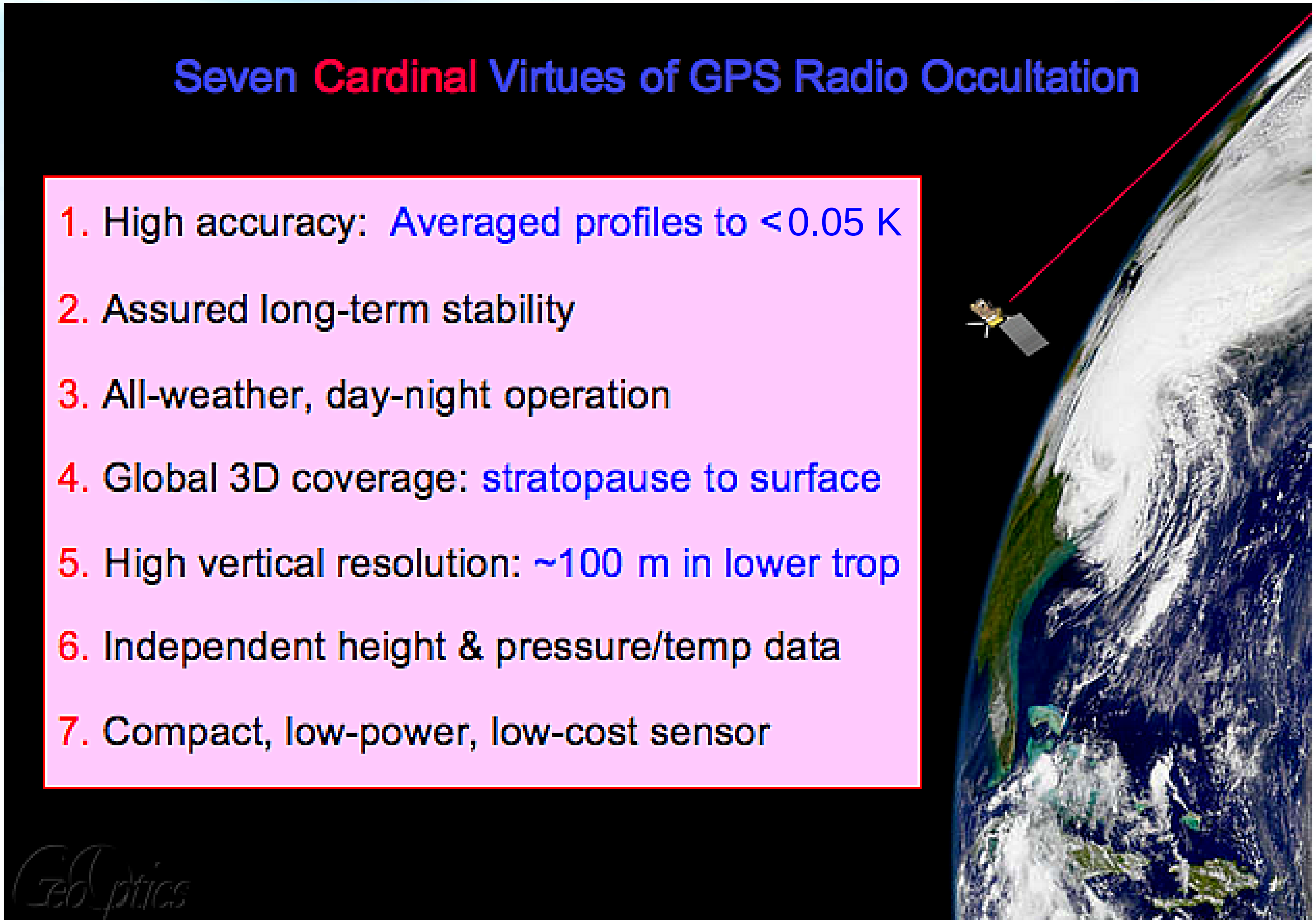


GPS RO is a breakthrough in high-accuracy, high-resolution sensing of the atmosphere

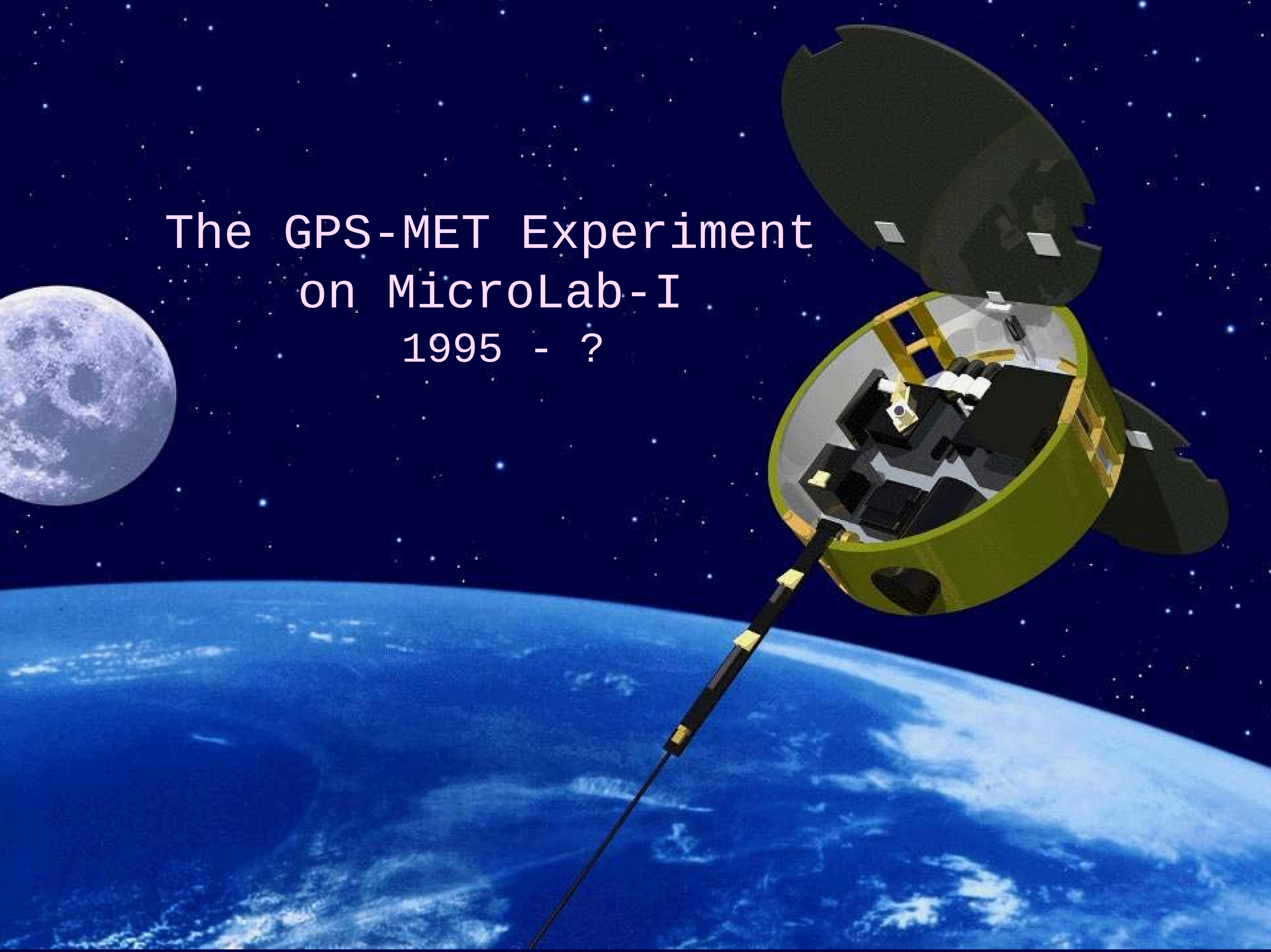


- Entirely different physical principles from radiometry
- Results directly traceable to an absolute SI standard

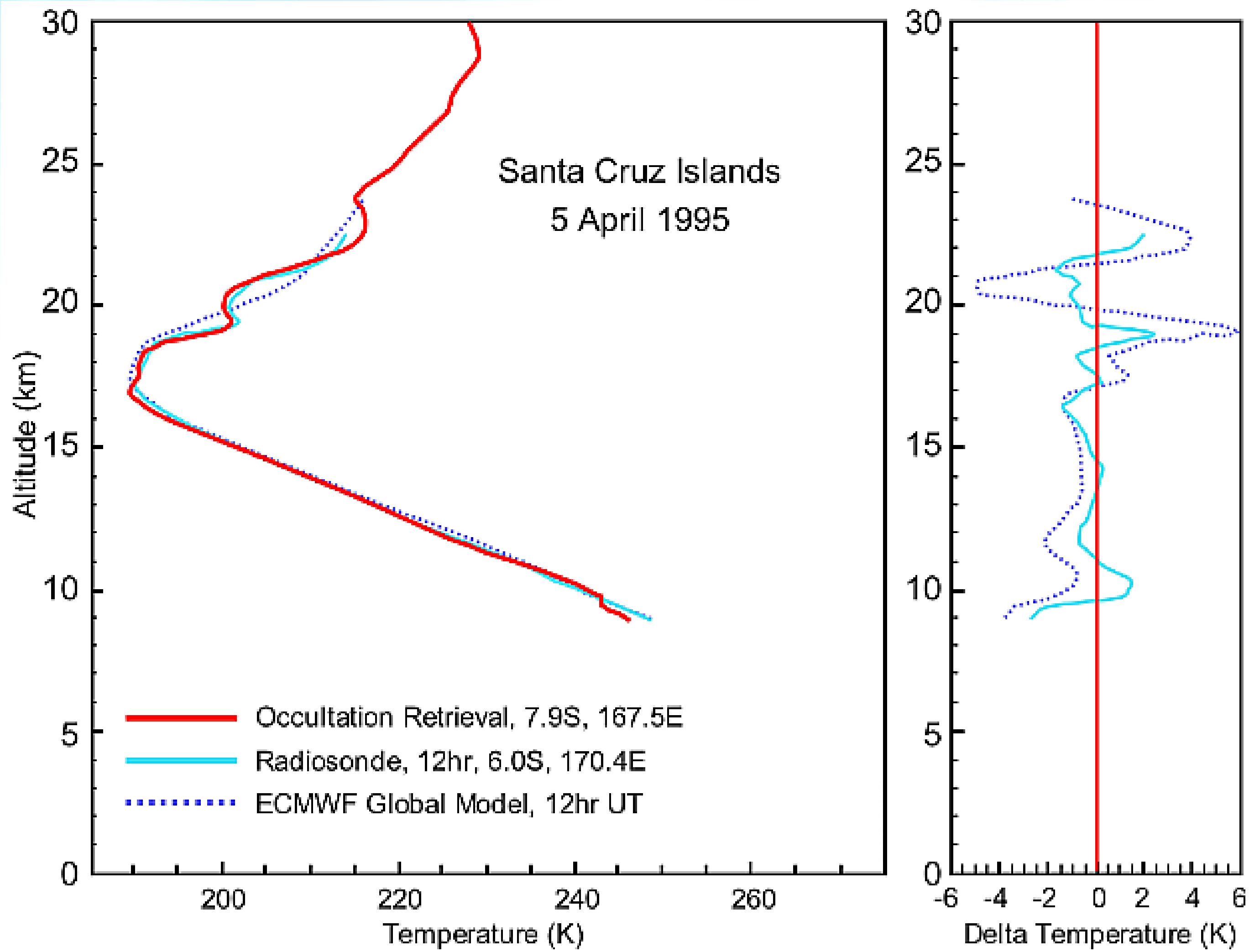
Some Key Attractions of GPS RO



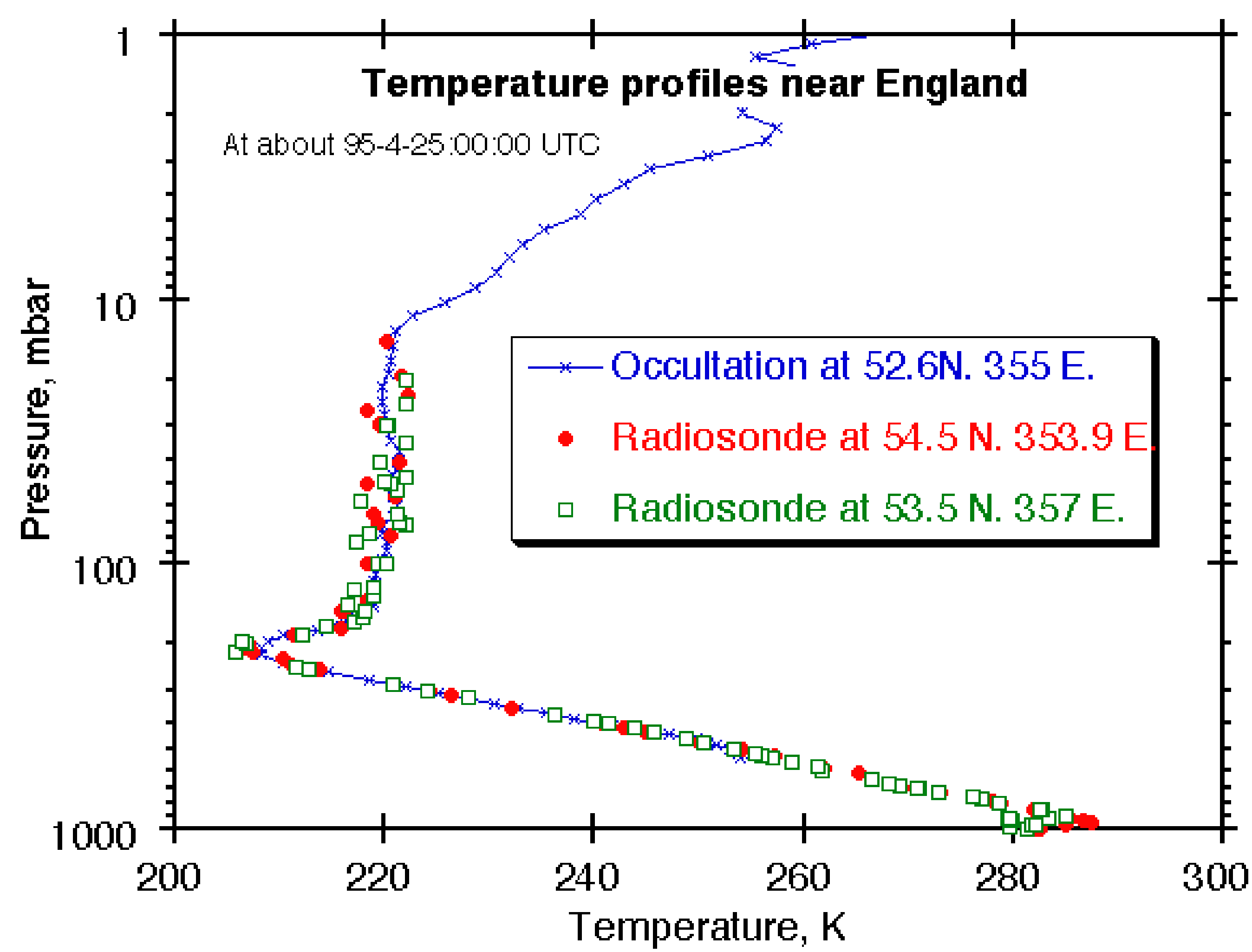
- Only technique that can monitor climate change throughout the atmosphere
- Stunning new results from NCAR in hurricane forecasting


The GPS-MET Experiment
on MicroLab-I
1995 - ?

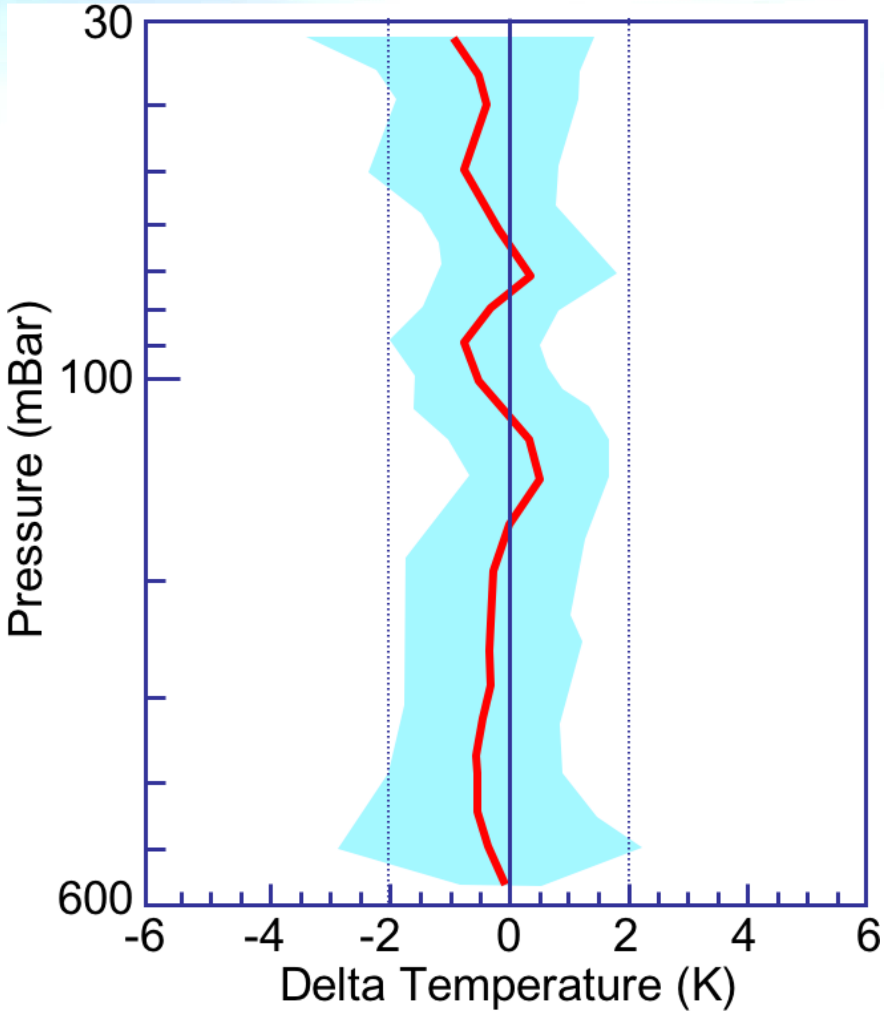
Early GPS-MET Profile (1995)

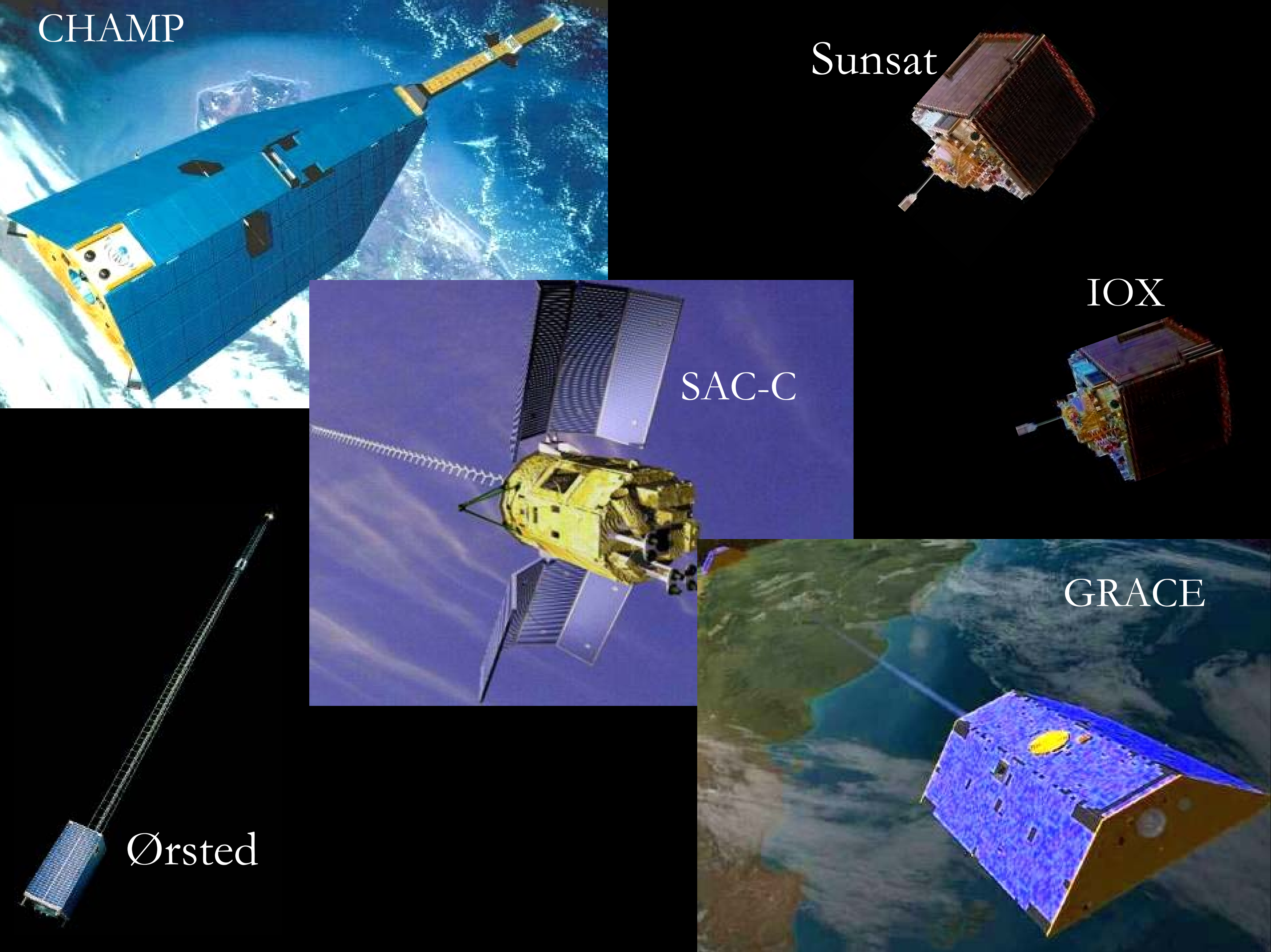


Early GPS-MET Profile (1995)

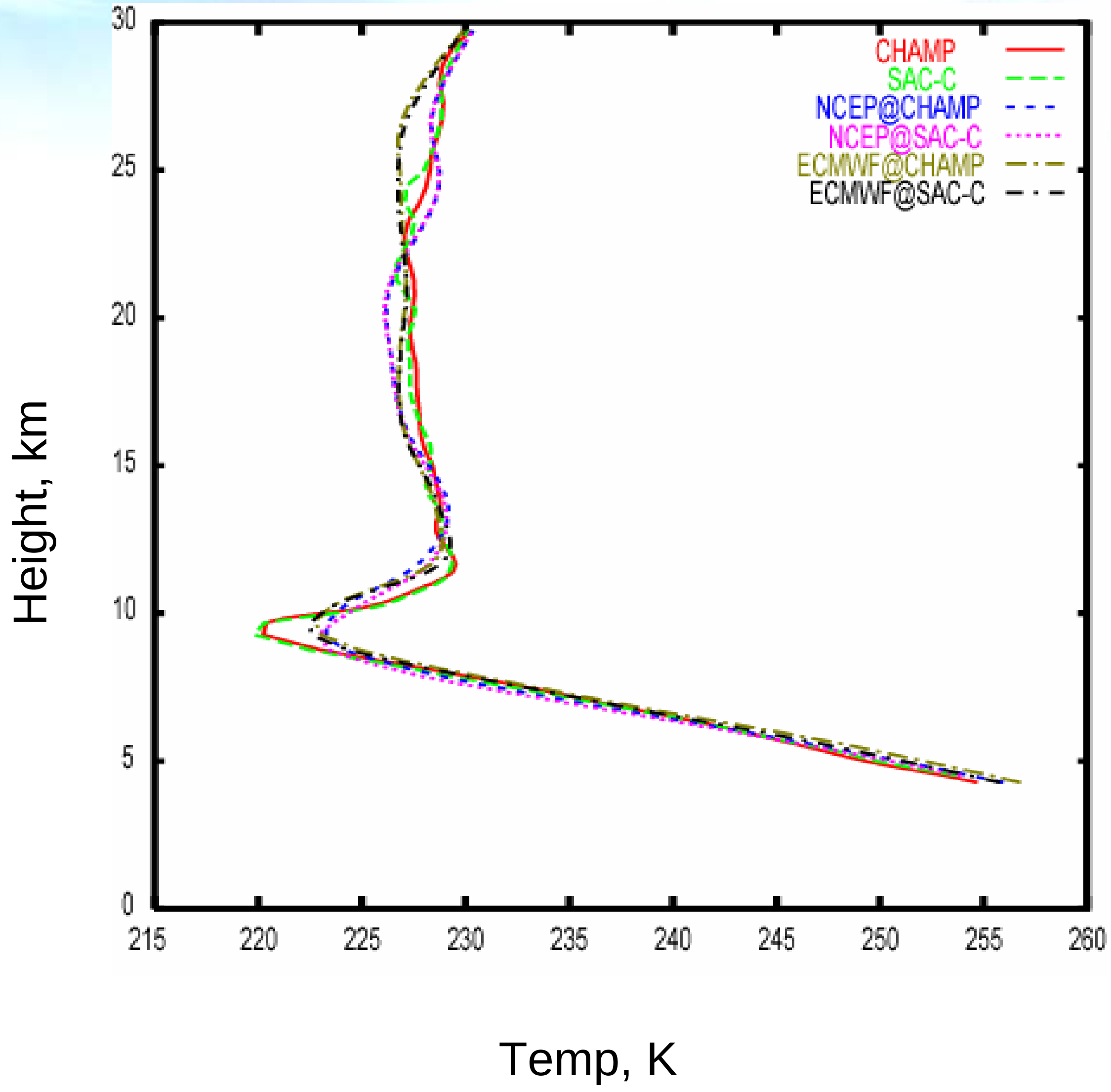


GPS-MET Agreement with Radiosondes (1995-96)

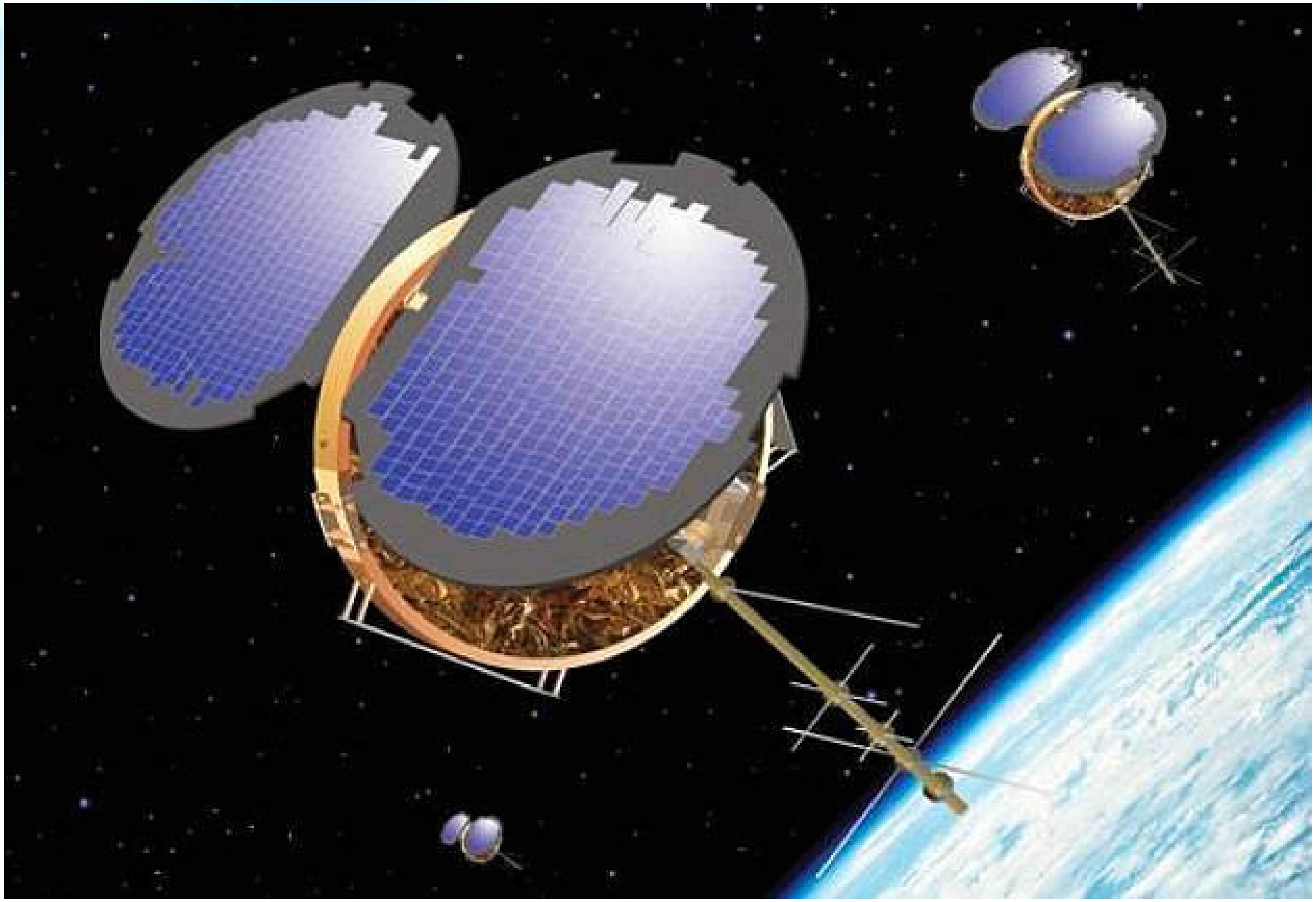



CHAMP
Sunsat
IOX
SAC-C
GRACE
Ørsted

CHAMP-SACC Profile Comparison

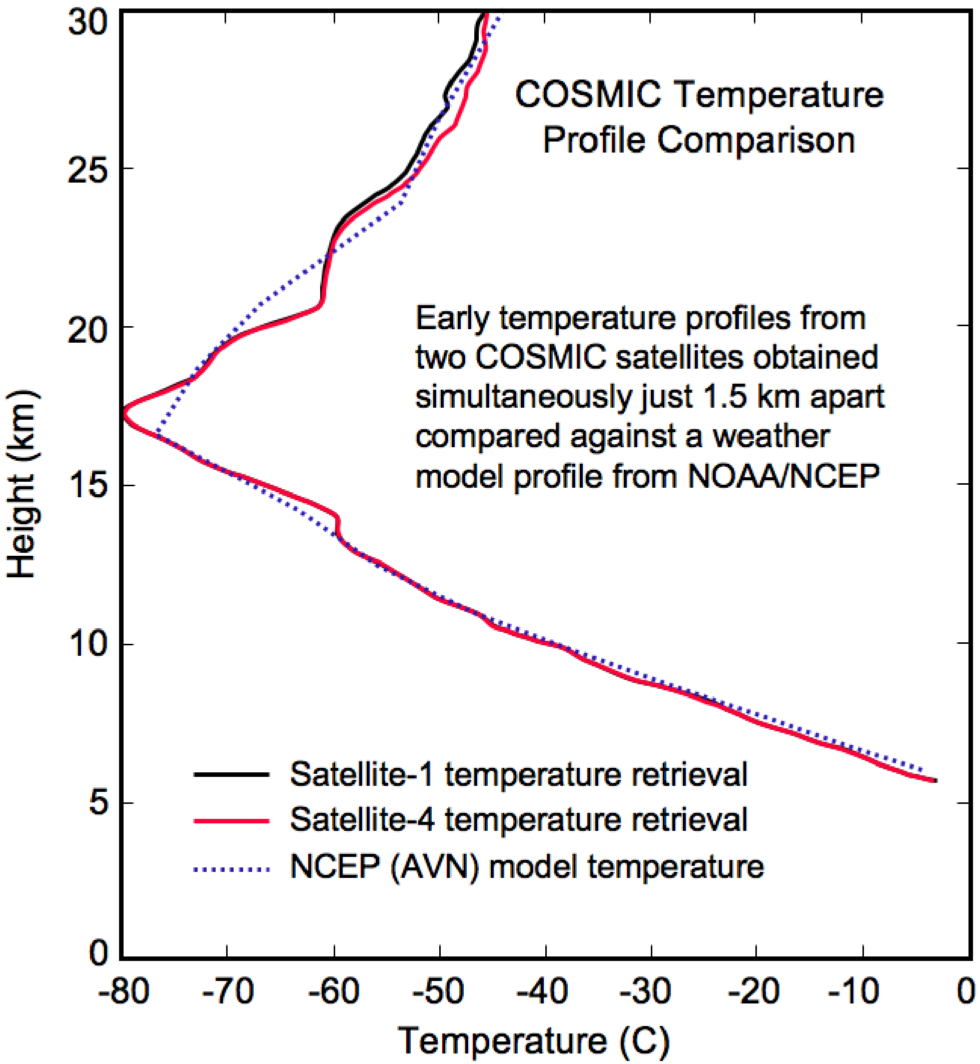


COSMIC: 2006 – ~2011

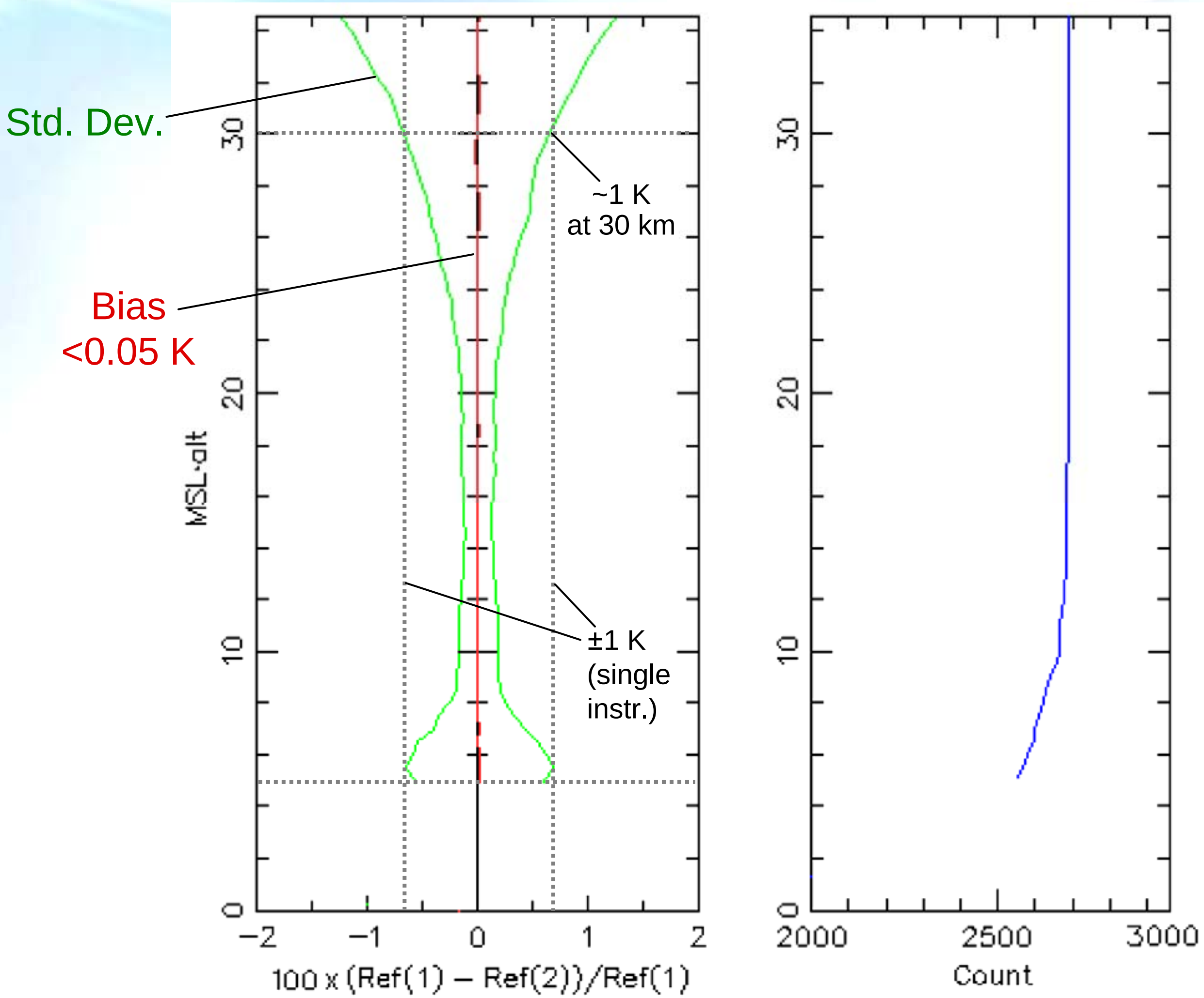


COSMIC is a 6-satellite mission funded by Taiwan and the US to demonstrate operational use of GPSRO. NCEP and other agencies around the world are now assimilating COSMIC data into their daily forecasts.

Early COSMIC Pair: <1.5 km separation



GPS-GPS Comparison Stats from COSMIC



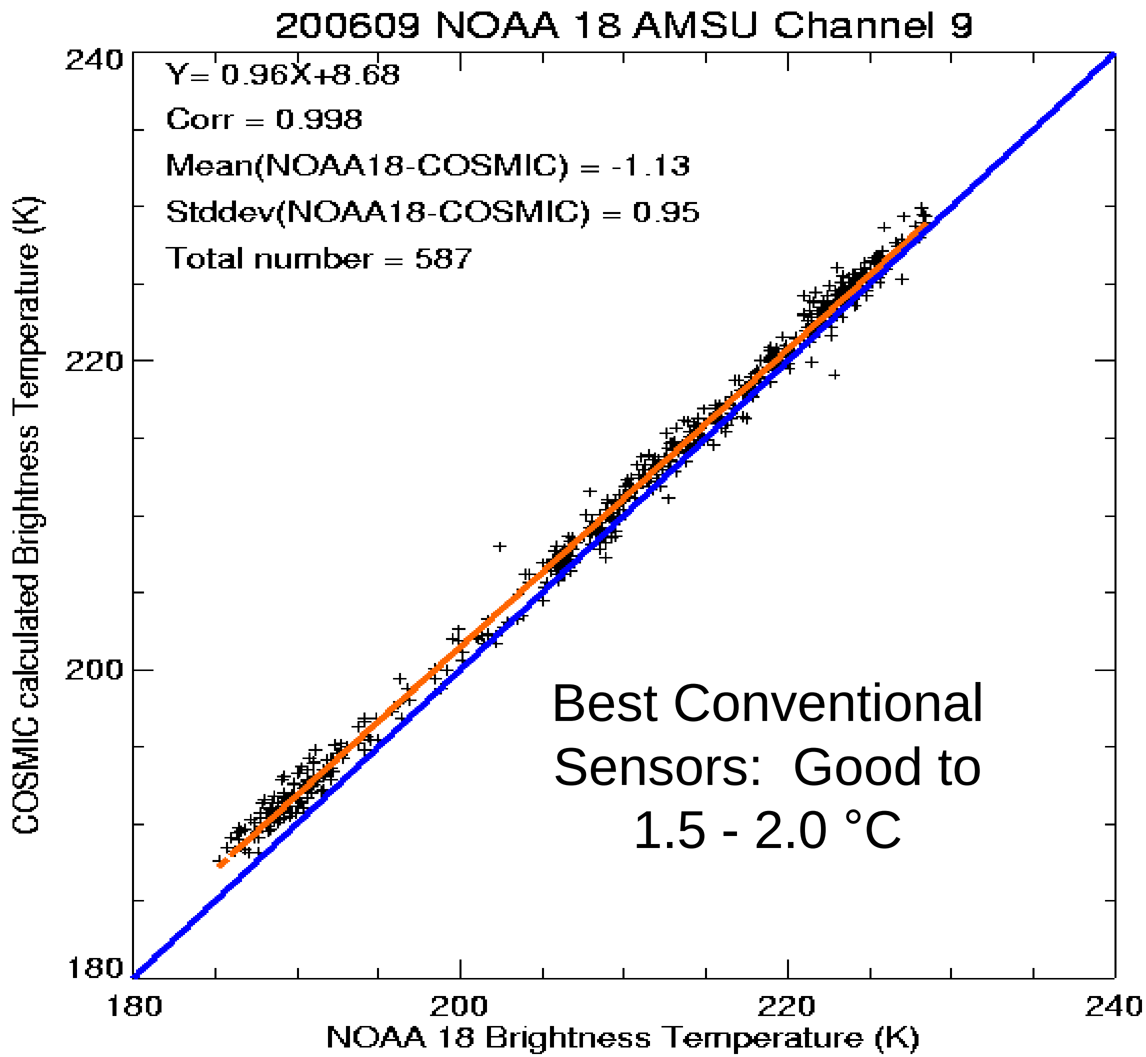
No cloud or weather sensitivity

No corrections or calibrations required

Performance traceable to an absolute SI standard

Ben Ho (UCAR), Jan 07

AMSU v. GPSRO

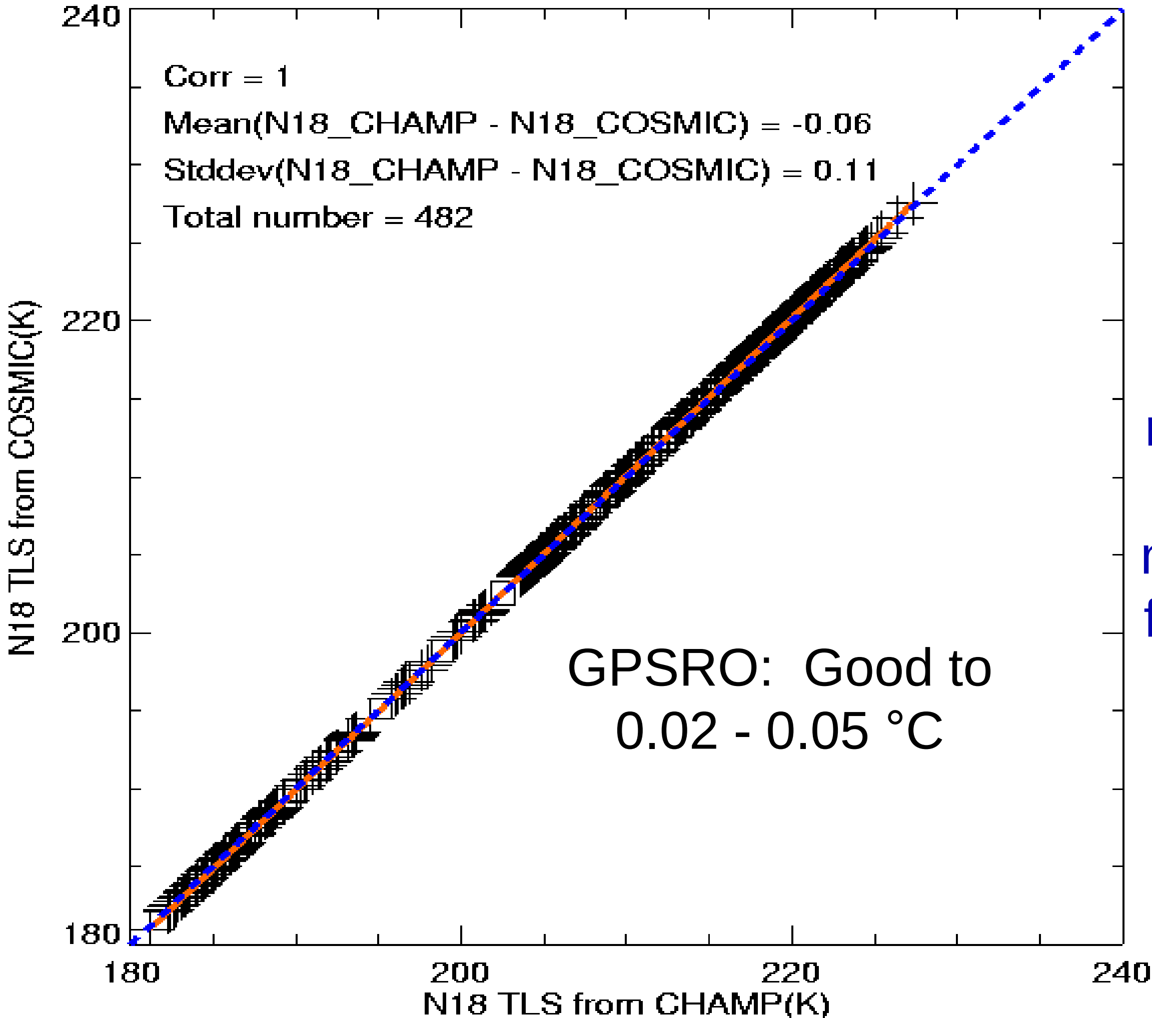


Inadequate for climate monitoring by factor of 5-10

Ben Ho (NCAR), Jan 07

AMSU v. COSMIC GPSRO

GPS v. GPS: Sensors Launched 6 yrs Apart



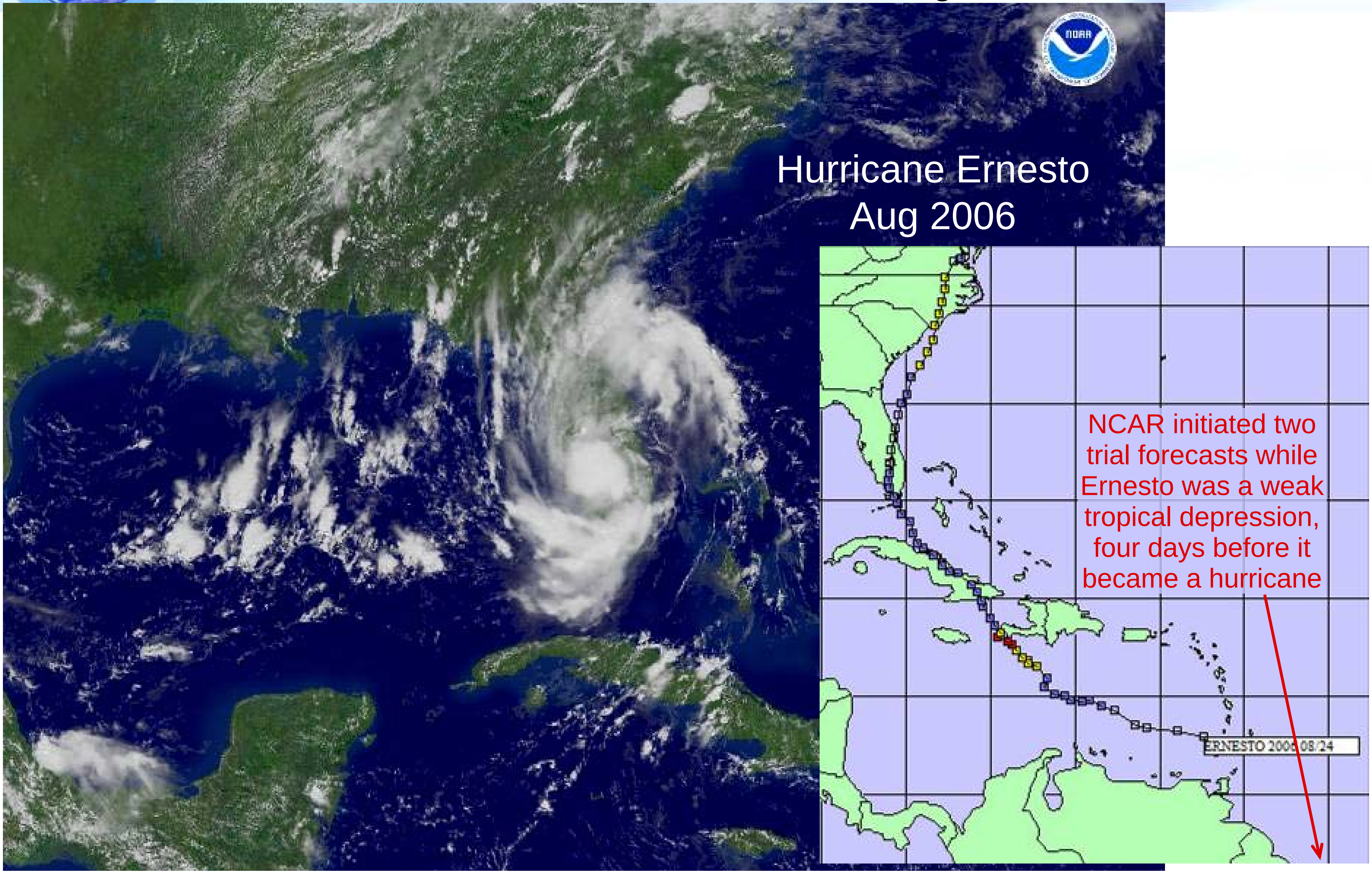
GPSRO: Good to 0.02 - 0.05 °C

Surpasses requirements for climate monitoring by factor of 5-10

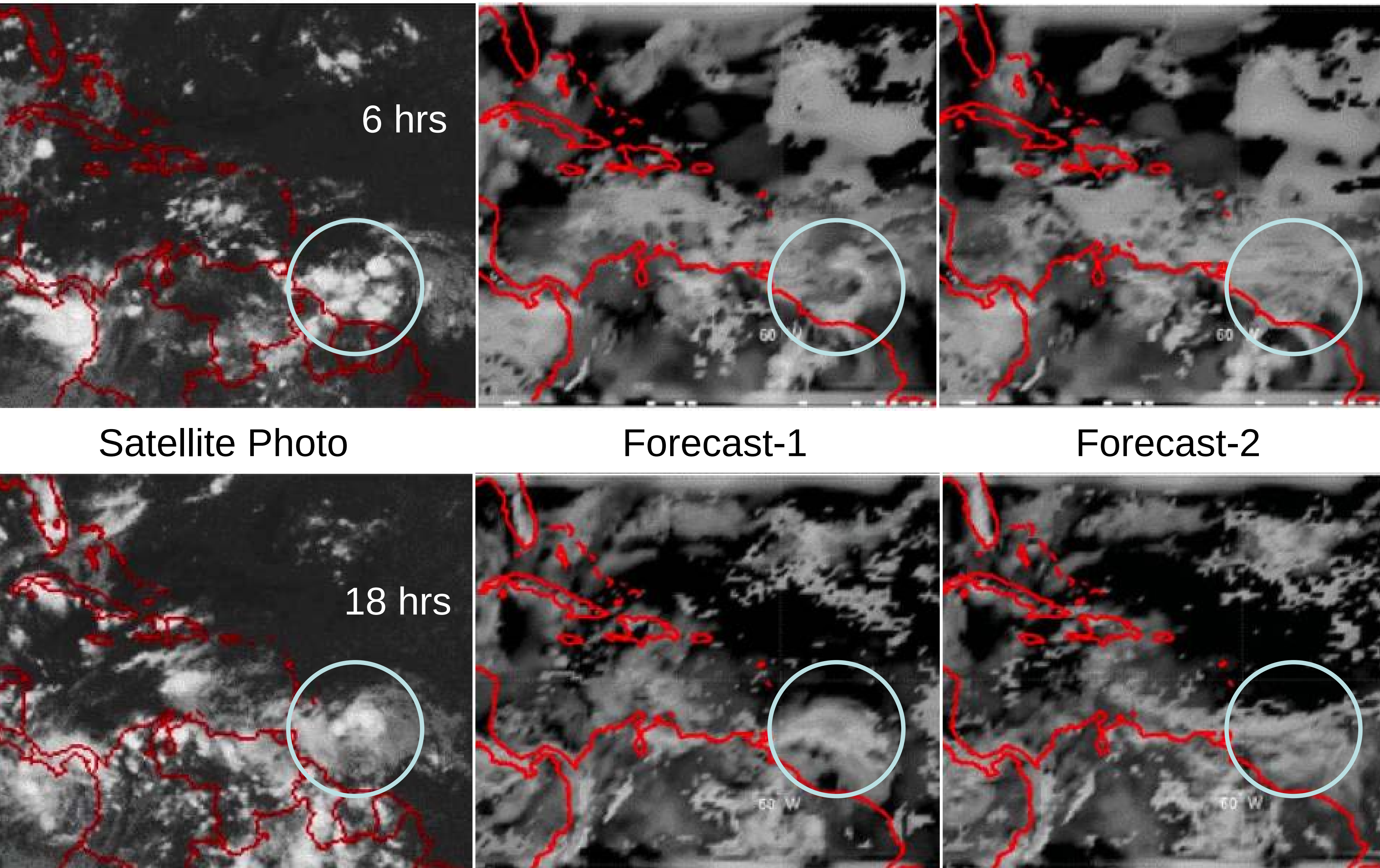
Ben Ho (NCAR), Jan 07

COSMIC GPS v. CHAMP GPS

Severe Weather Forecasting

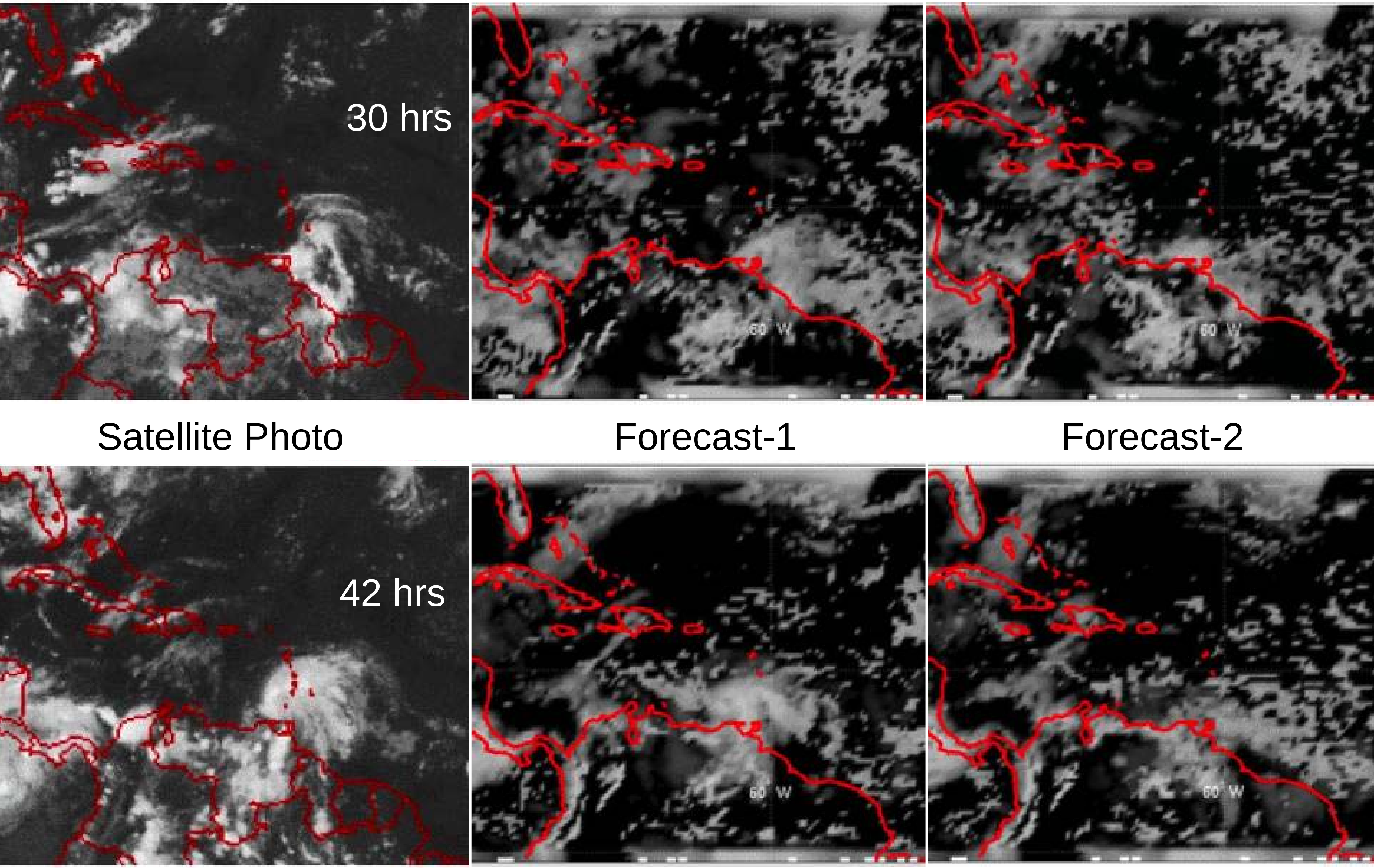


4-Day Ernesto Forecasts



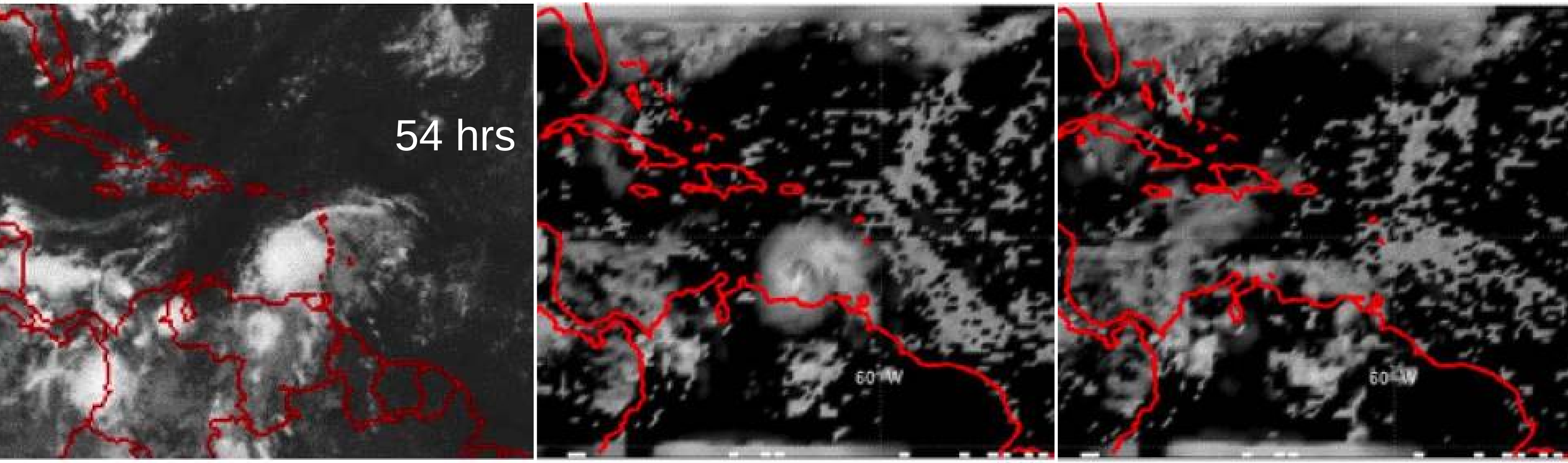
Ying-Hwa Kuo (NCAR)

4-Day Ernesto Forecast

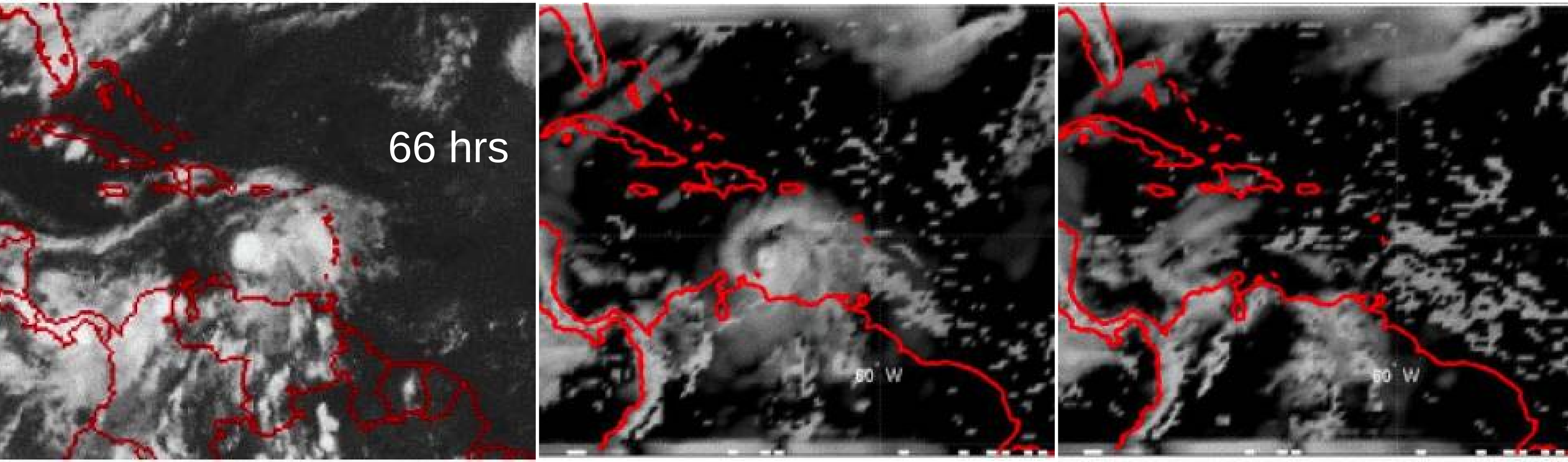


Ying-Hwa Kuo (NCAR)

4-Day Ernesto Forecast

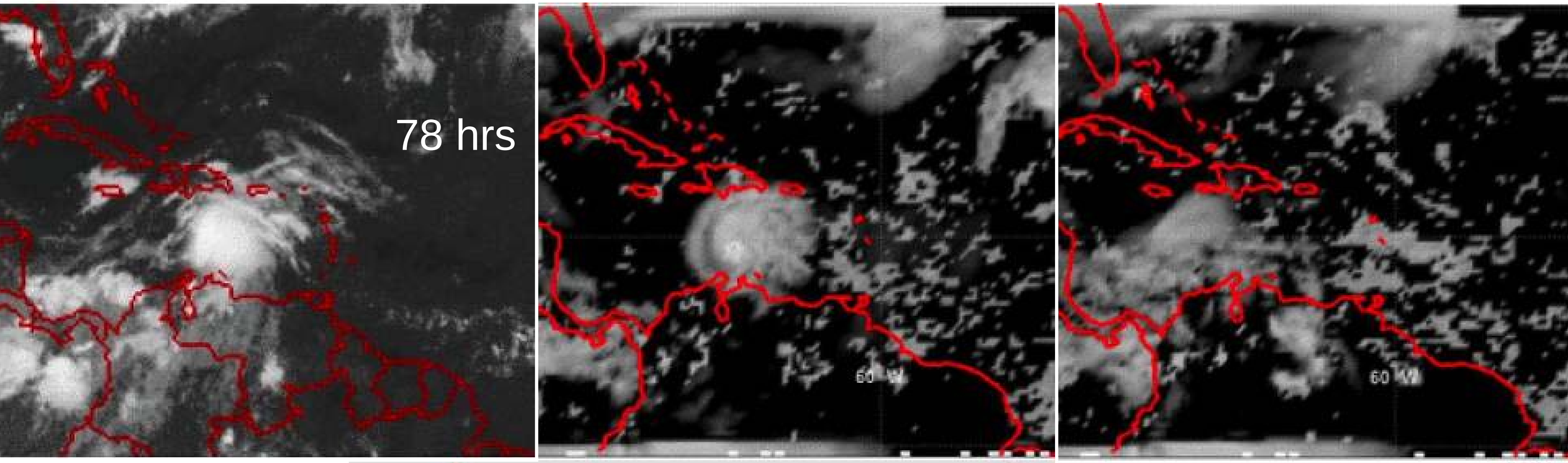


Satellite Photo | Forecast-1 | Forecast-2

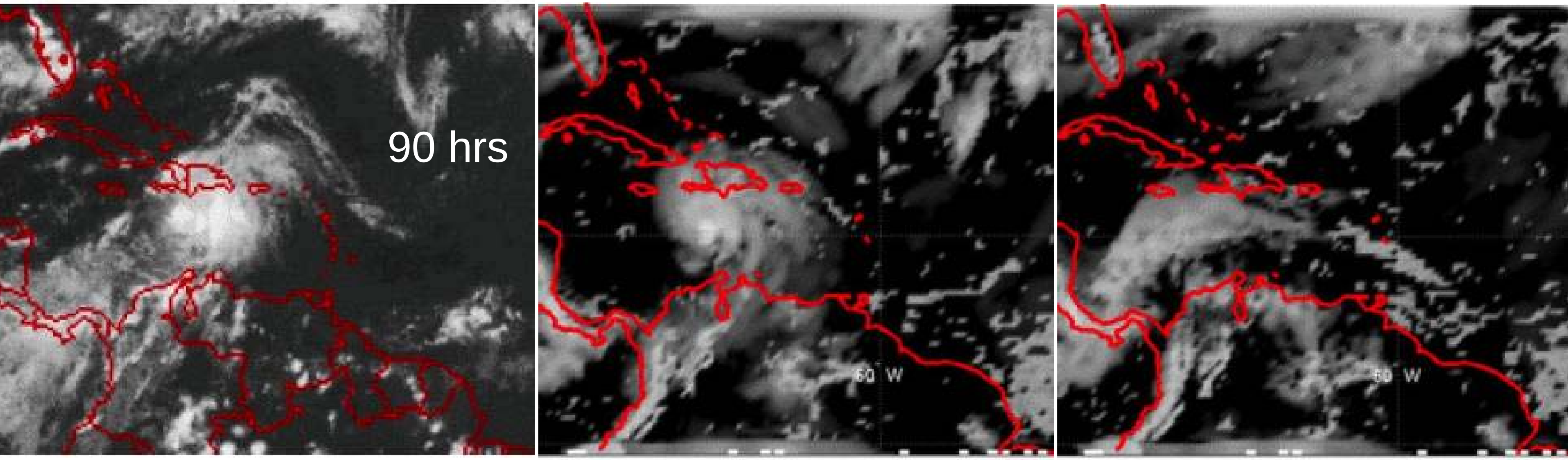


Ying-Hwa Kuo (NCAR)

4-Day Ernesto Forecast

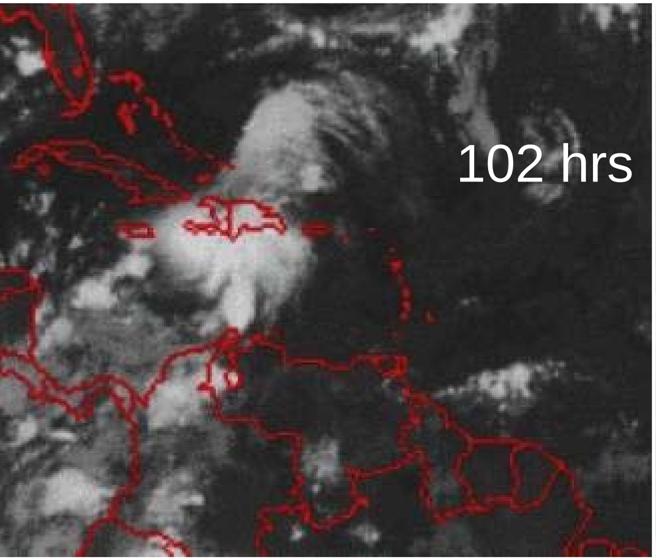


Satellite Photo | Forecast-1 | Forecast-2

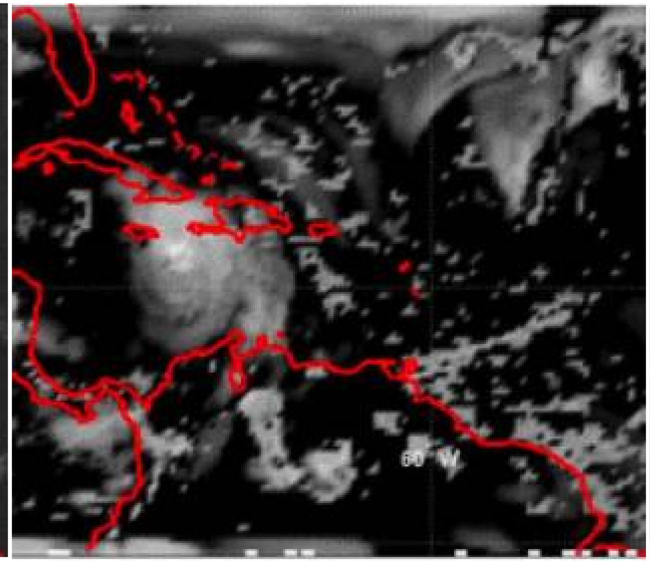


Ying-Hwa Kuo (NCAR)

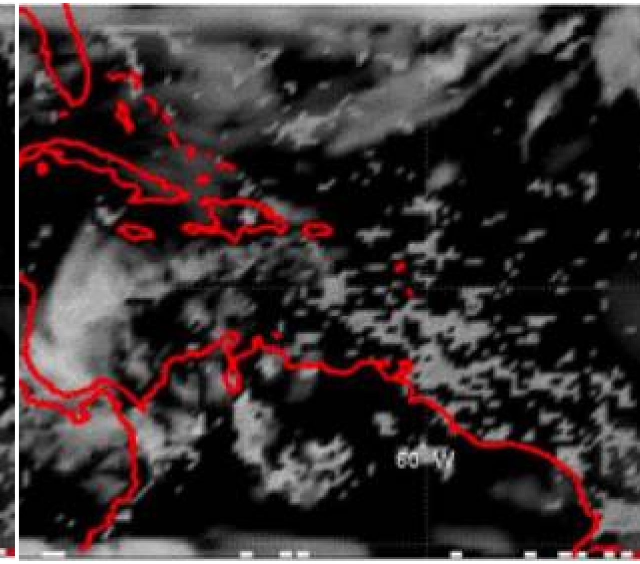
4-Day Ernesto Forecast



Satellite Photo



Forecast-1



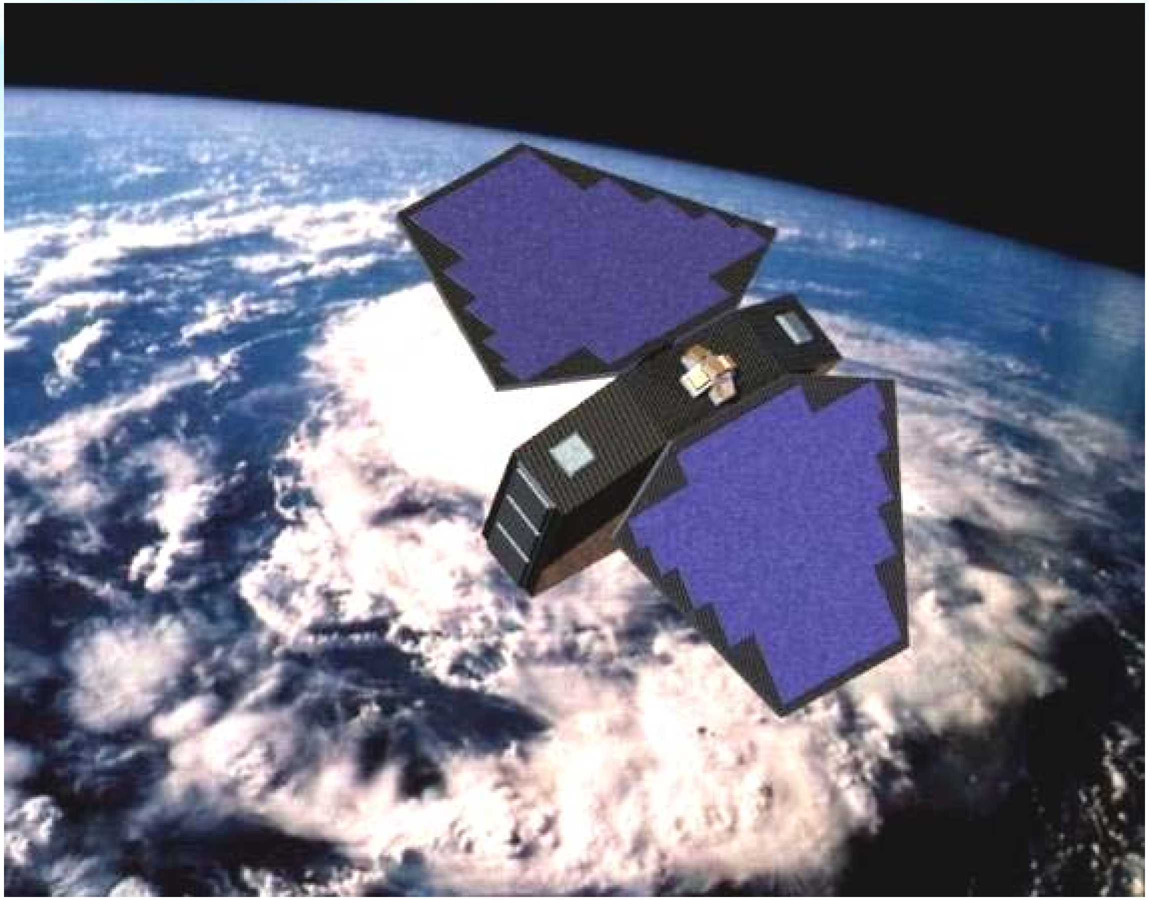
Forecast-2

Forecast-2: Best conventional forecast

Forecast-1: GPS added to Forecast-2

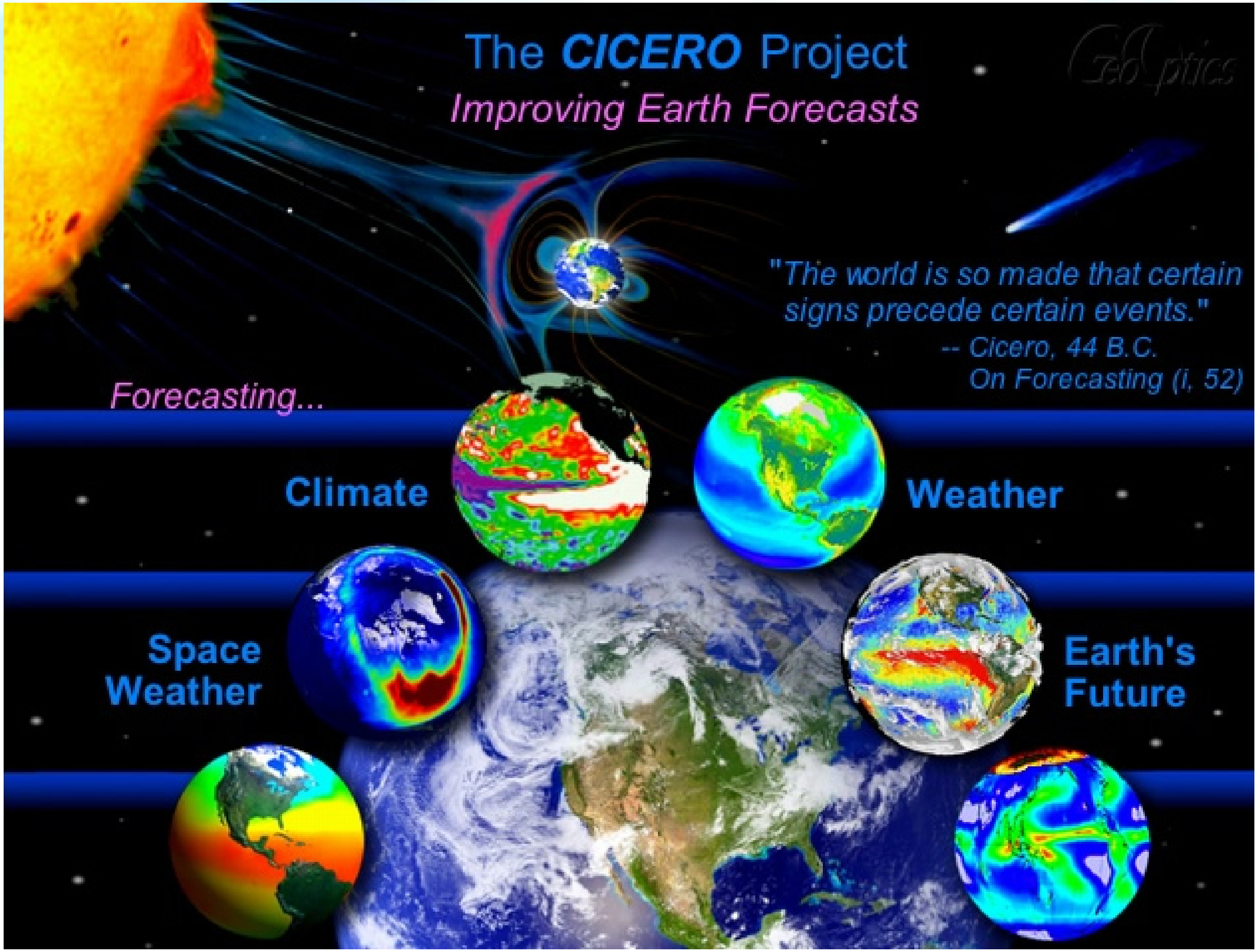
Ying-Hwa Kuo (NCAR)

COSMIC-2: 201? – ??



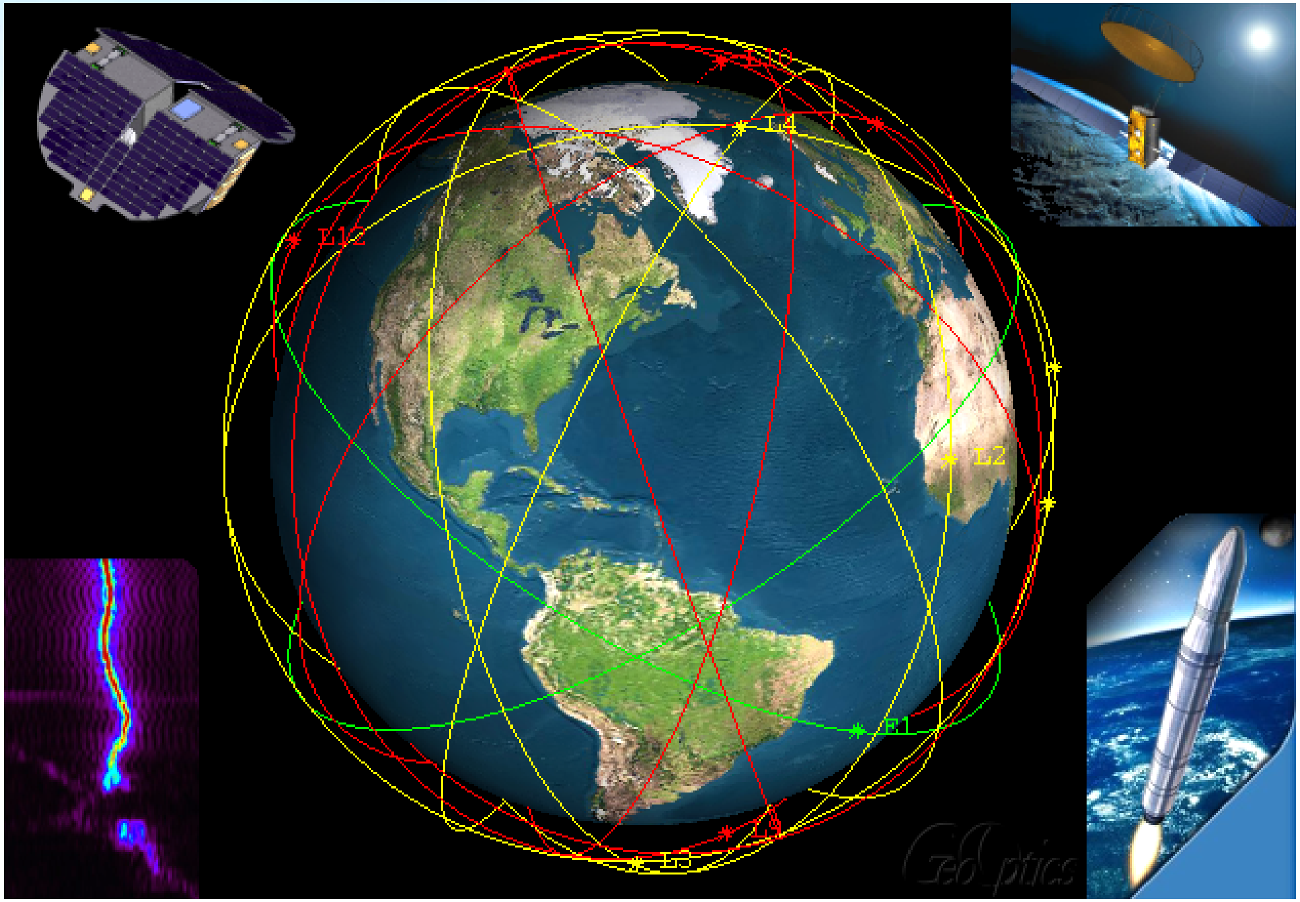
Several COSMIC-2 proposals have been floated in recent years. These tend to be baselined at 6 satellites with optional expansion to 12. This image is from a 2005 UCAR proposal to NOAA. Estimated 10-year full life-cycle costs for an operational constellation typically run from 300M$ for 6 satellites to 480M$ for 12.

Community **I**nitiative for **C**ontinuing **E**arth **R**adio **O**ccultation



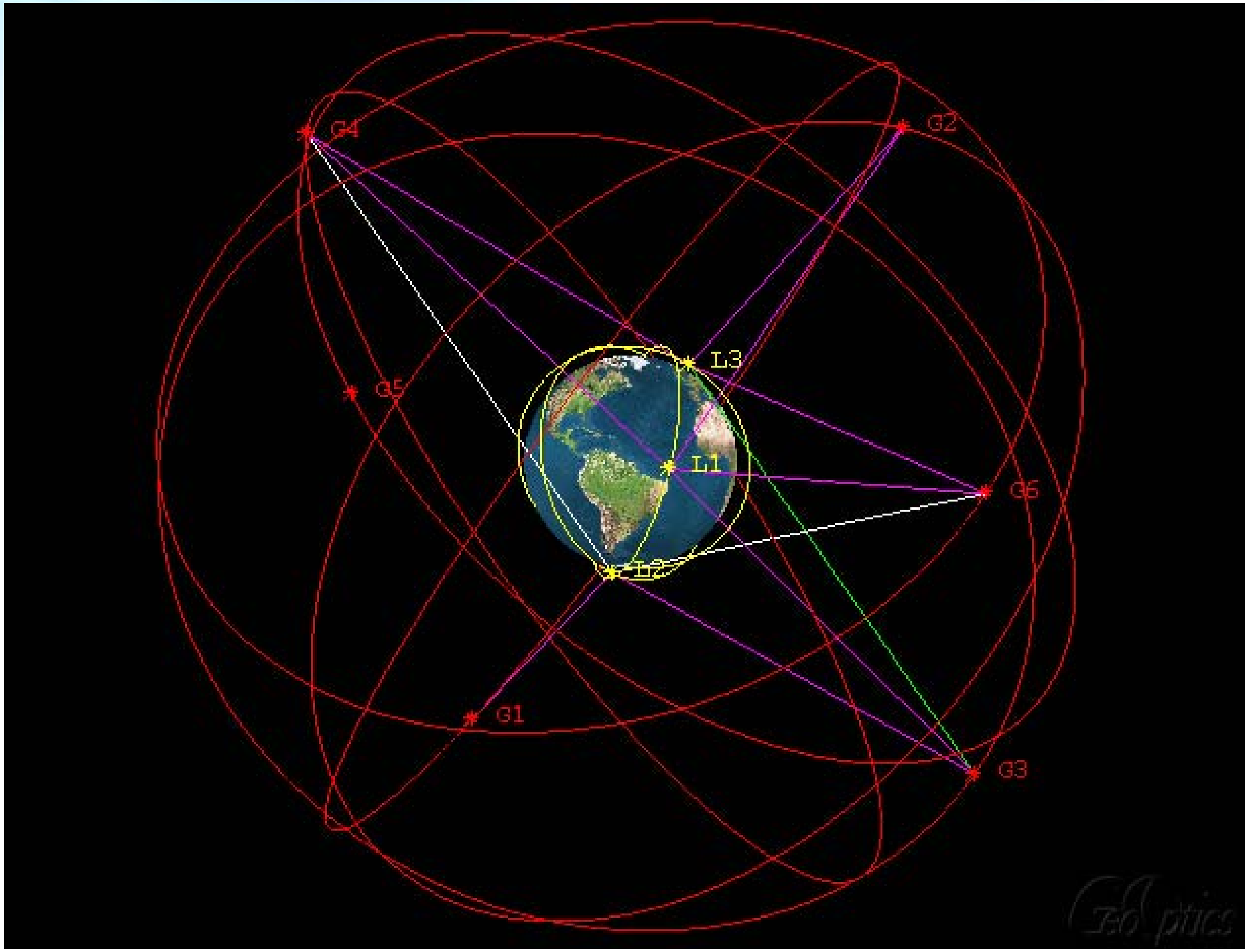
Climate • Weather • Space Weather

CICERO is a follow-on to COSMIC for performing operational GPS atmospheric radio occultation



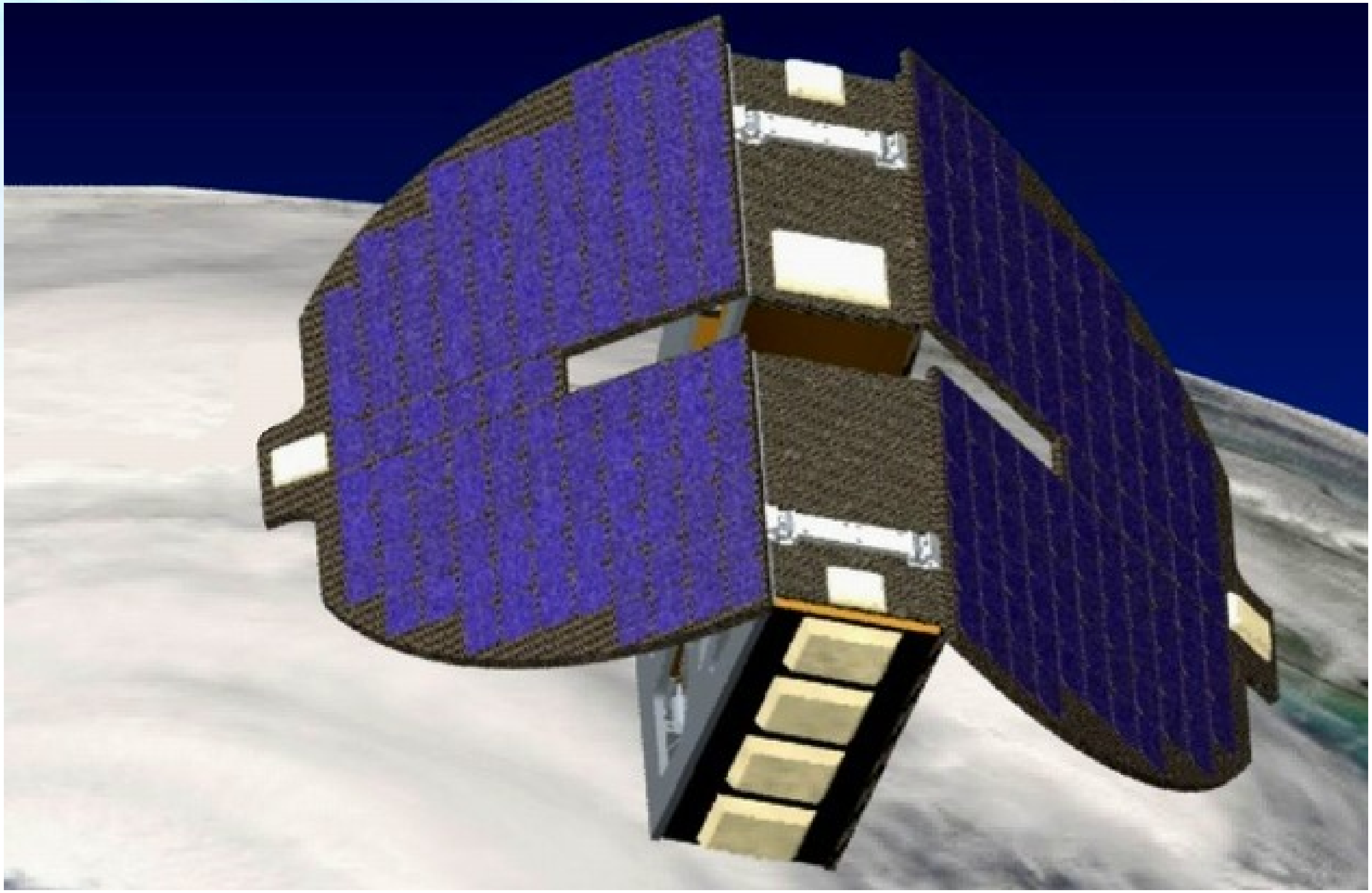
- 20 satellites by 2011
- 100 satellites by 2016

CICERO will track signals from GPS and Galileo
(and later Glonass)



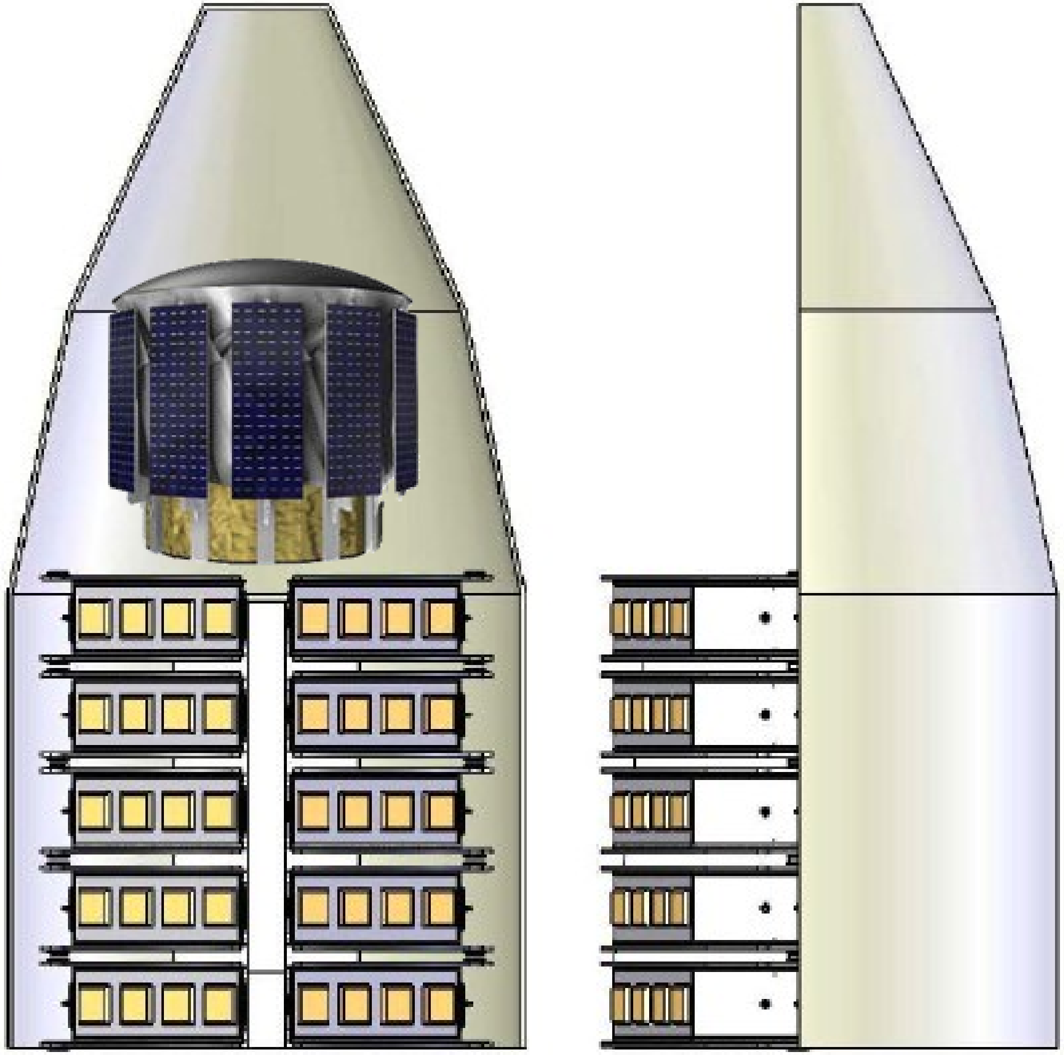
- 20,000 profiles/day by 2012
- 120,000 profiles/day by 2016

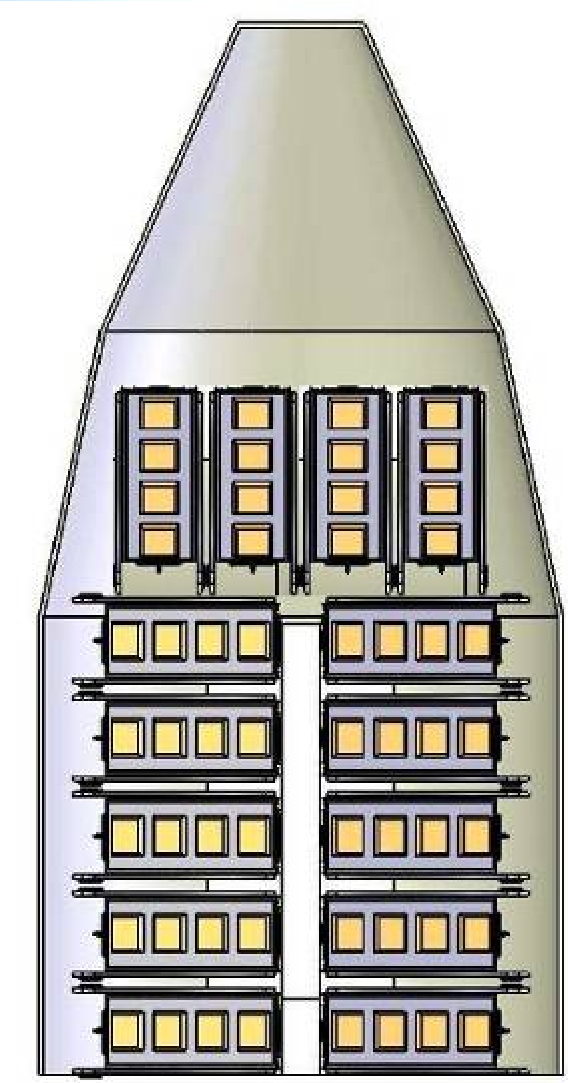
The CICERO spacecraft weighs in at ~30 kg



The instrument and spacecraft will be built by **Broad Reach Engineering** of Golden, CO

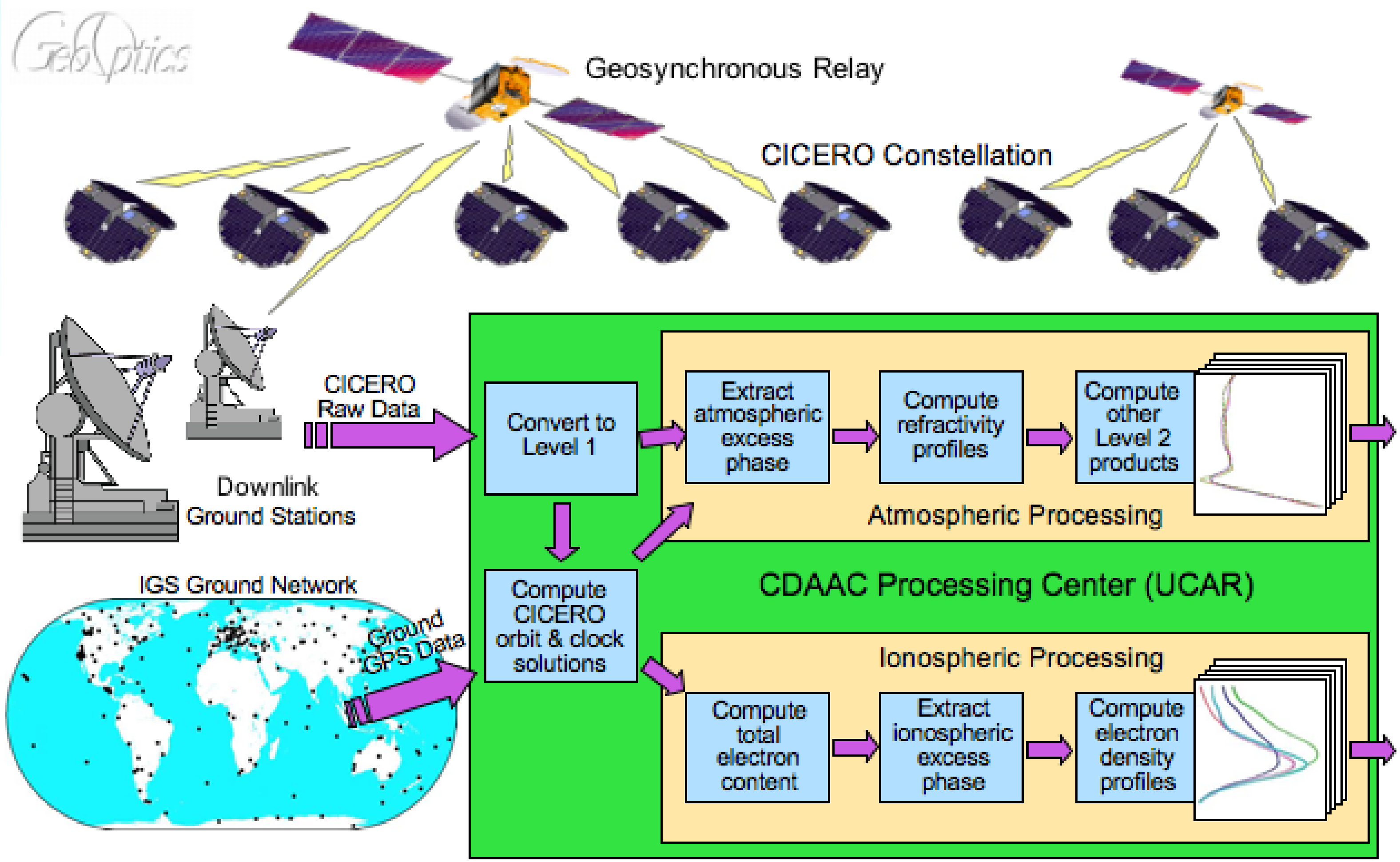
Up to 14 sats can be launched on a Falcon-1





Data Return by Geosynchronous Relay

End-to-End Data Path

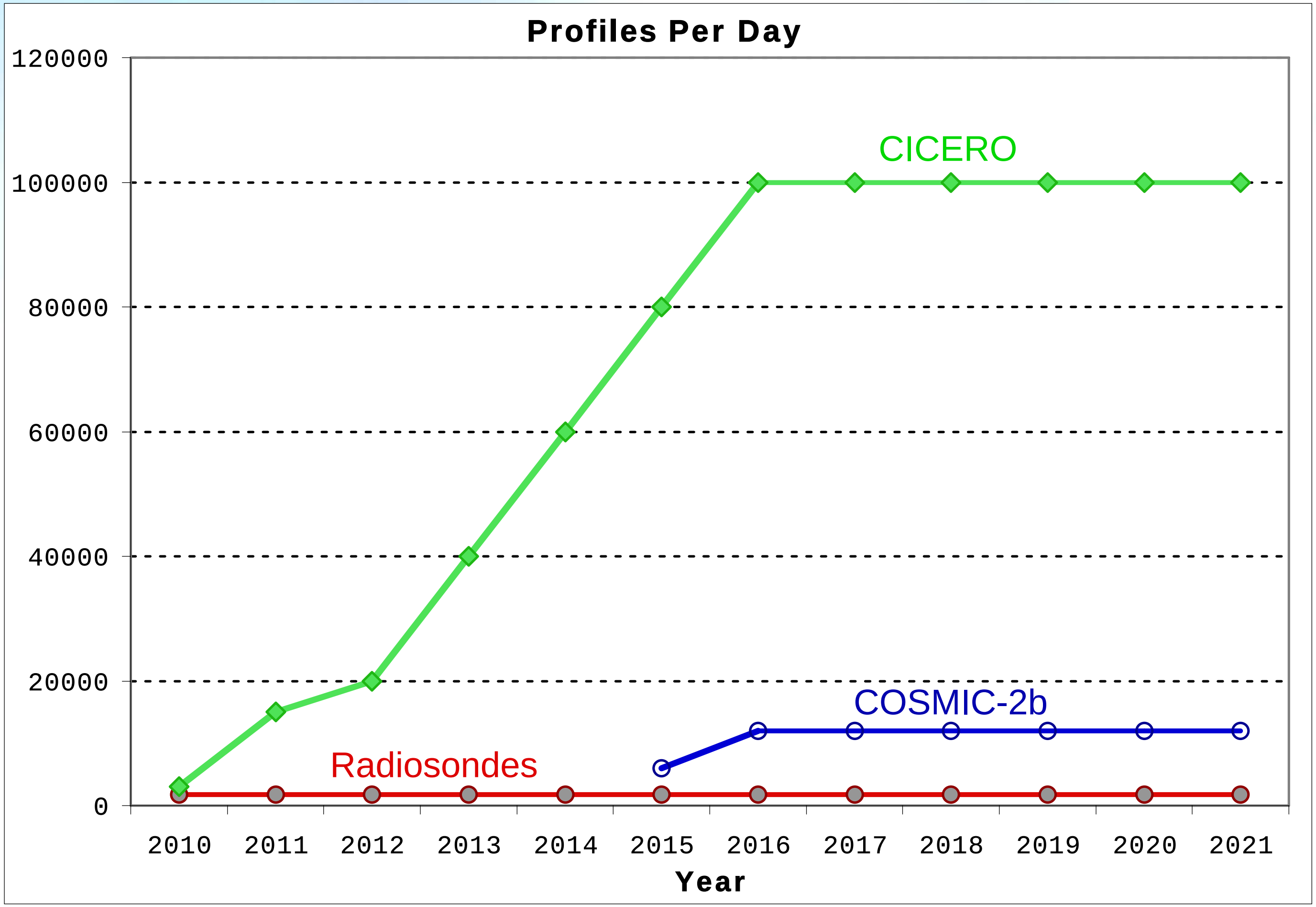


Comparison of Proposed Post-COSMIC Systems

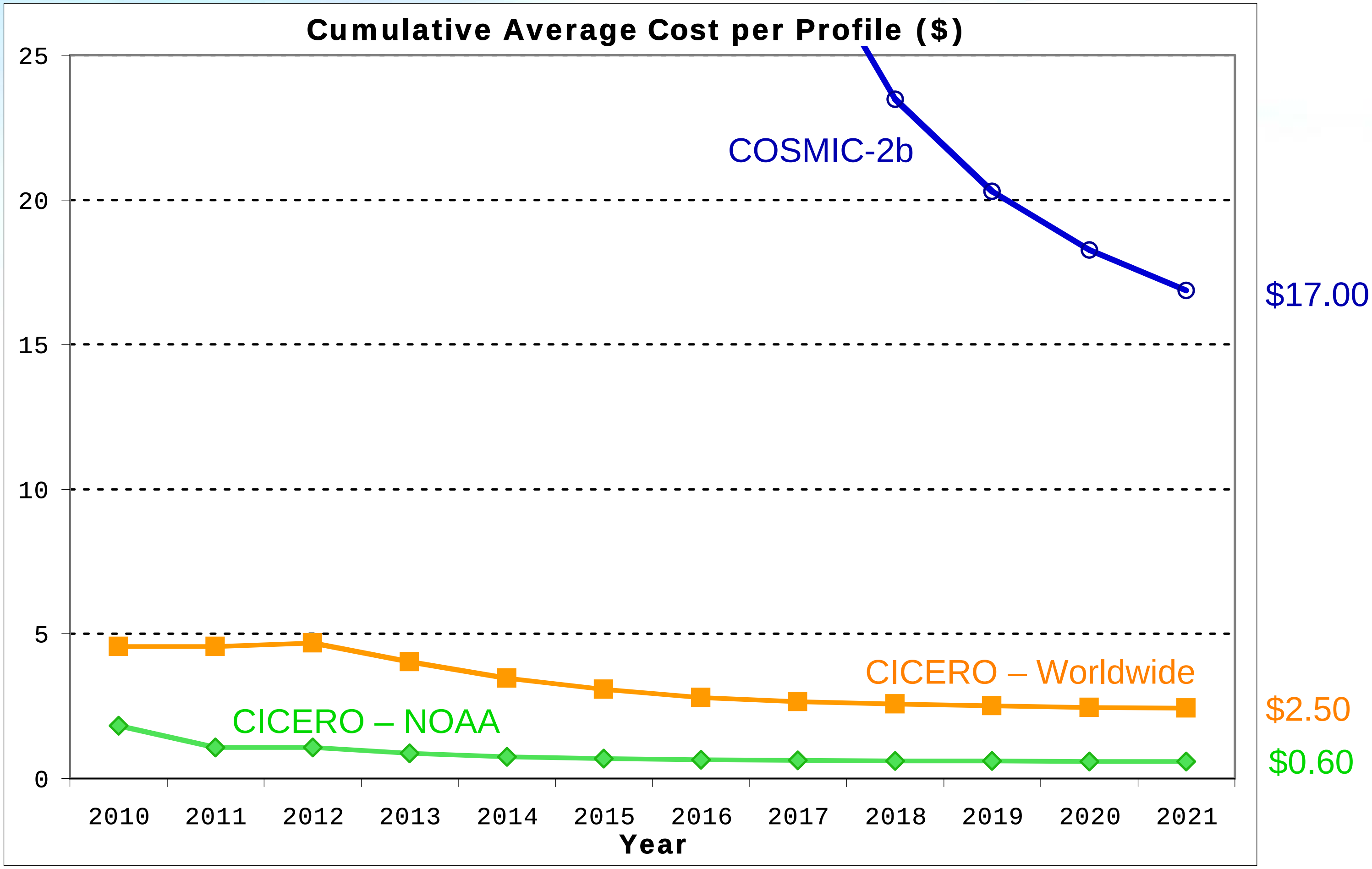
	COSMIC-2a	COSMIC-2b	CICERO
Operational Date	2015	2015	2010-11
Satellites in 2016	6	12	100
Profiles per day	6,000	12,000	100,000*
Profiles/day in a hurricane region	2-3	4-6	40-60
Approx. 10-year cost to NOAA	300M$	480M$	135M$
Approx. cost per profile to NOAA	$20	$16	$0.60
Pre-data cost to NOAA	140M$	200M$	0
Risk to NOAA	100%	100%	0

*Assuming only GPS and Galileo.

Radiosondes v. COSMIC-2b v. CICERO

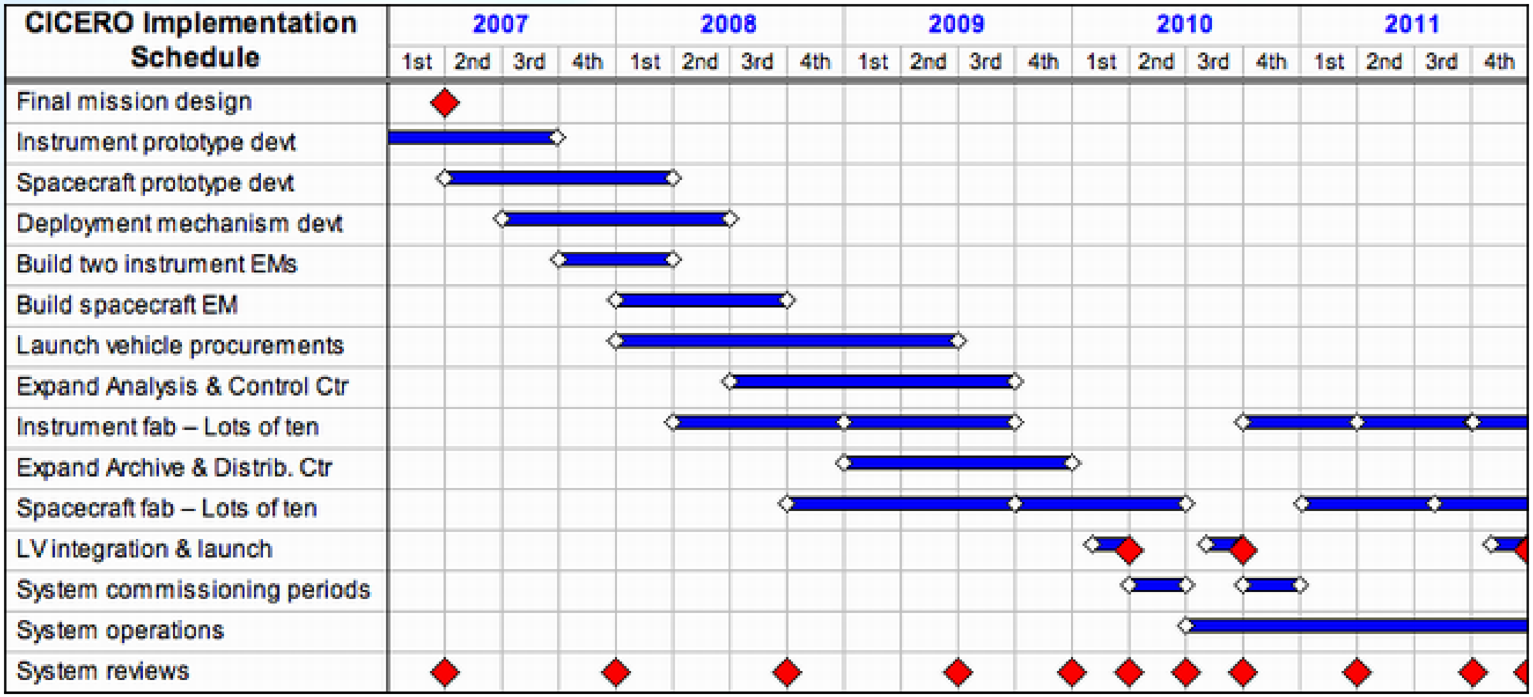


Radiosondes v. COSMIC-2b v. CICERO



Cumulative Avg. Cost/Profile = Total expended to date / Total profiles to date.

The CICERO Development & Deployment Schedule



- First launch of 10 satellites by mid-2010
- Succeeding launches every 4-6 months