



A Scenic Tour of GNSS Radio Occultation

Past, Present and Future

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Jet Propulsion Laboratory
California Institute of Technology

JPL

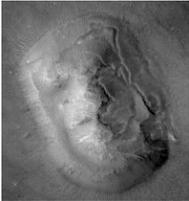
OPAC-3

Graz, Austria

17 September 2007

The Planetary Path



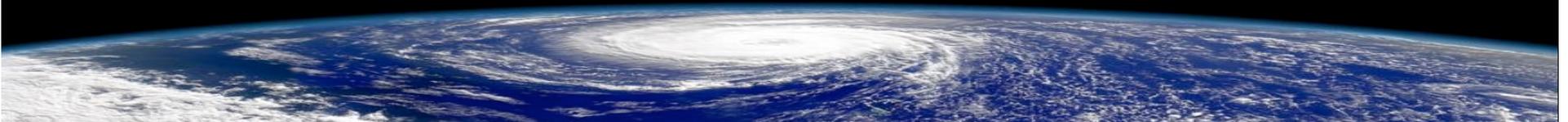


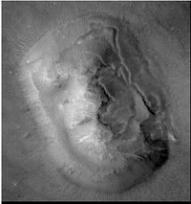
Origins of Planetary Radio Occultation



Mariner IV at **Mars**

July 1965





Mariner IV Occultation at Mars: Two Competing Proposals



Stanford

Ionosphere only

One-way: Earth → Mars

50 & 400 MHz

Ray-tracing inversion &
Abel integral inversion

Doppler counts only

“Neutral atmosphere not
detectable”

JPL

Neutral atmosphere only

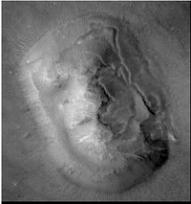
Two-way: Earth → Earth

2.1 - 2.3 GHz nav link

Model-fitting inversion

Doppler counts only

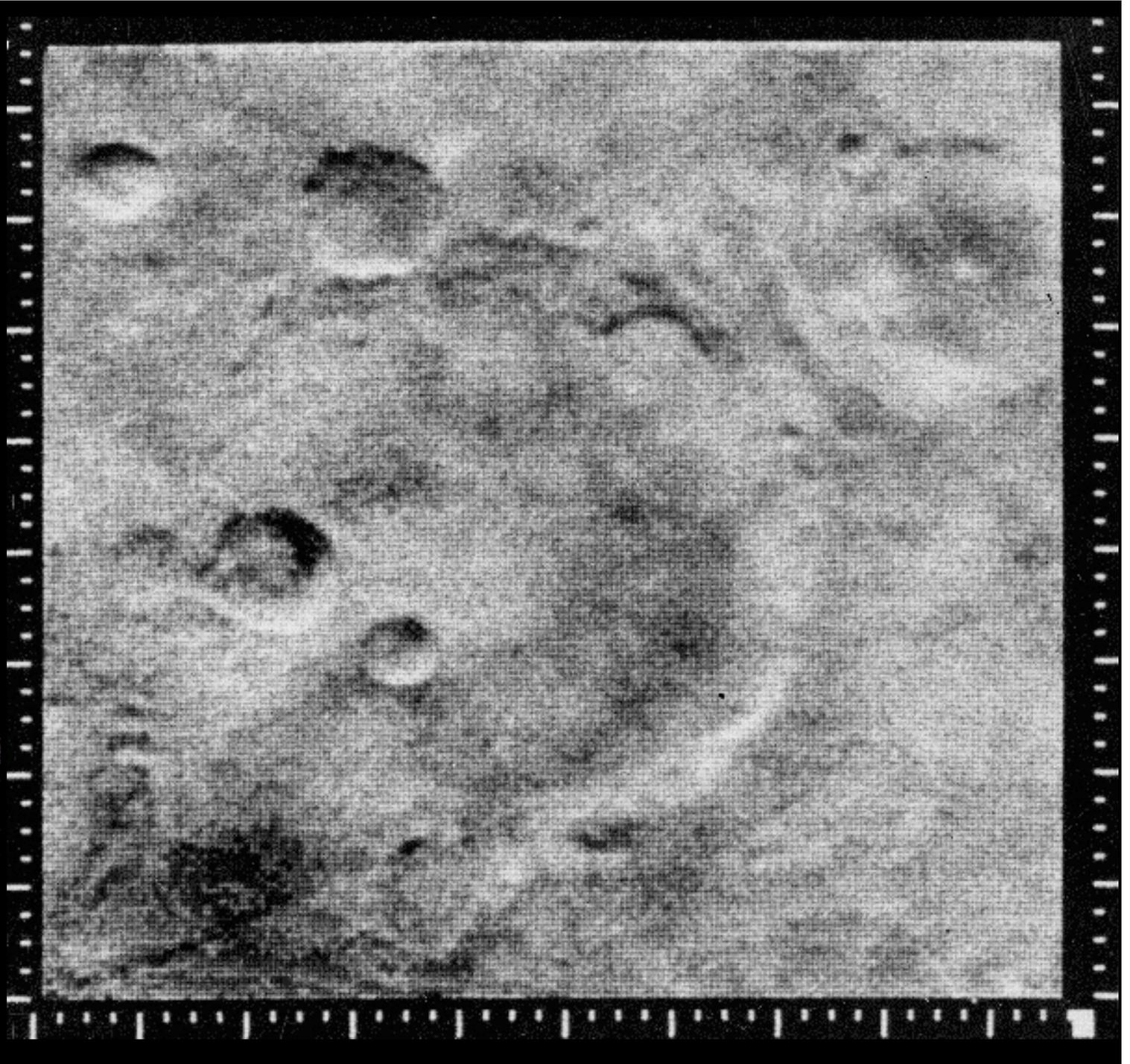
“Atmosphere-ionosphere
separable by altitude”

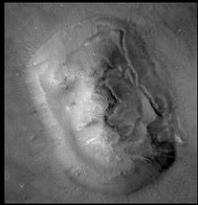


Mariner IV Mars

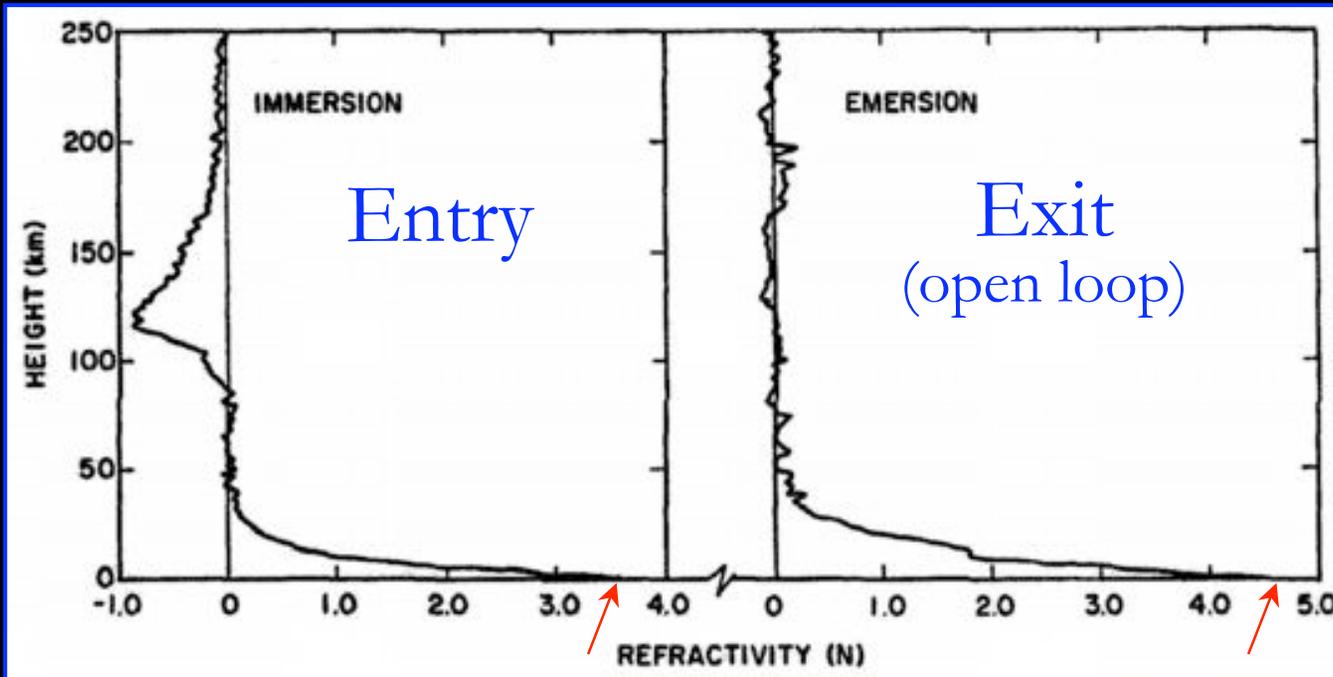
15 July 1965

(JPL
wirephoto)

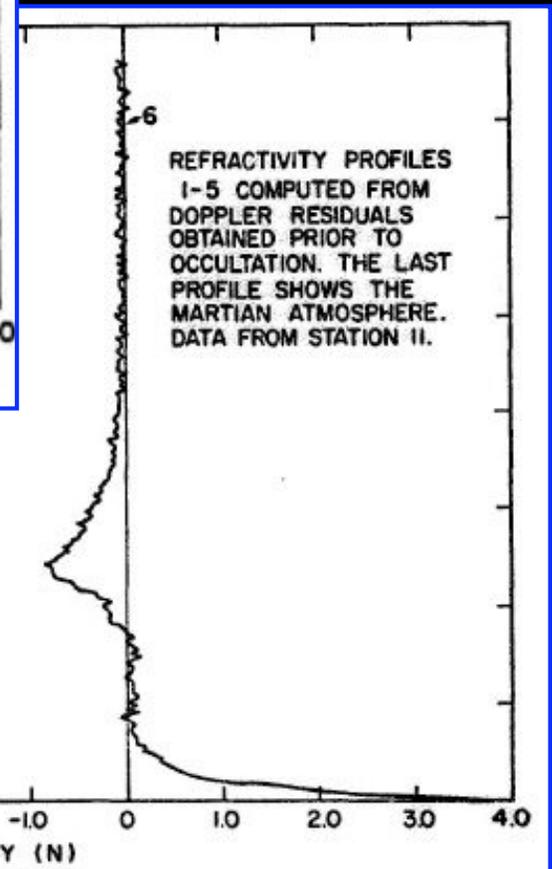




Mariner IV Occultation at Mars: Refined Results



Fjeldbo et al.,
Planet. Space Sci.
1968





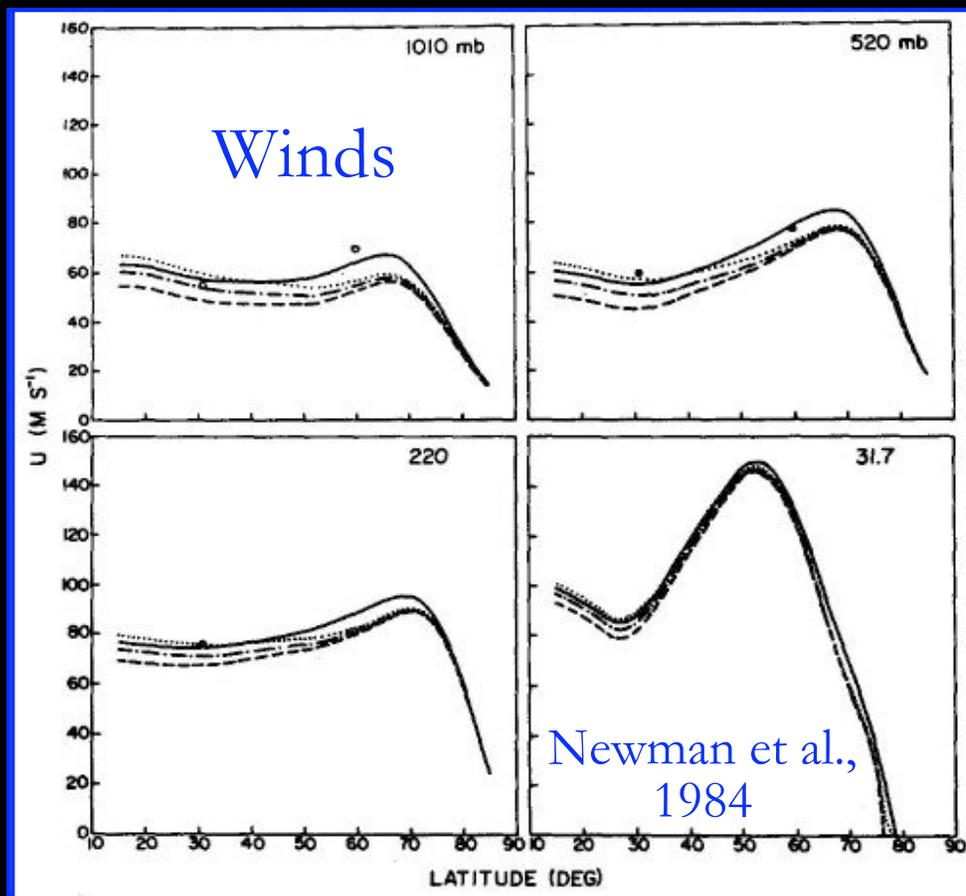
Pioneer Venus Orbiter

1979-1982

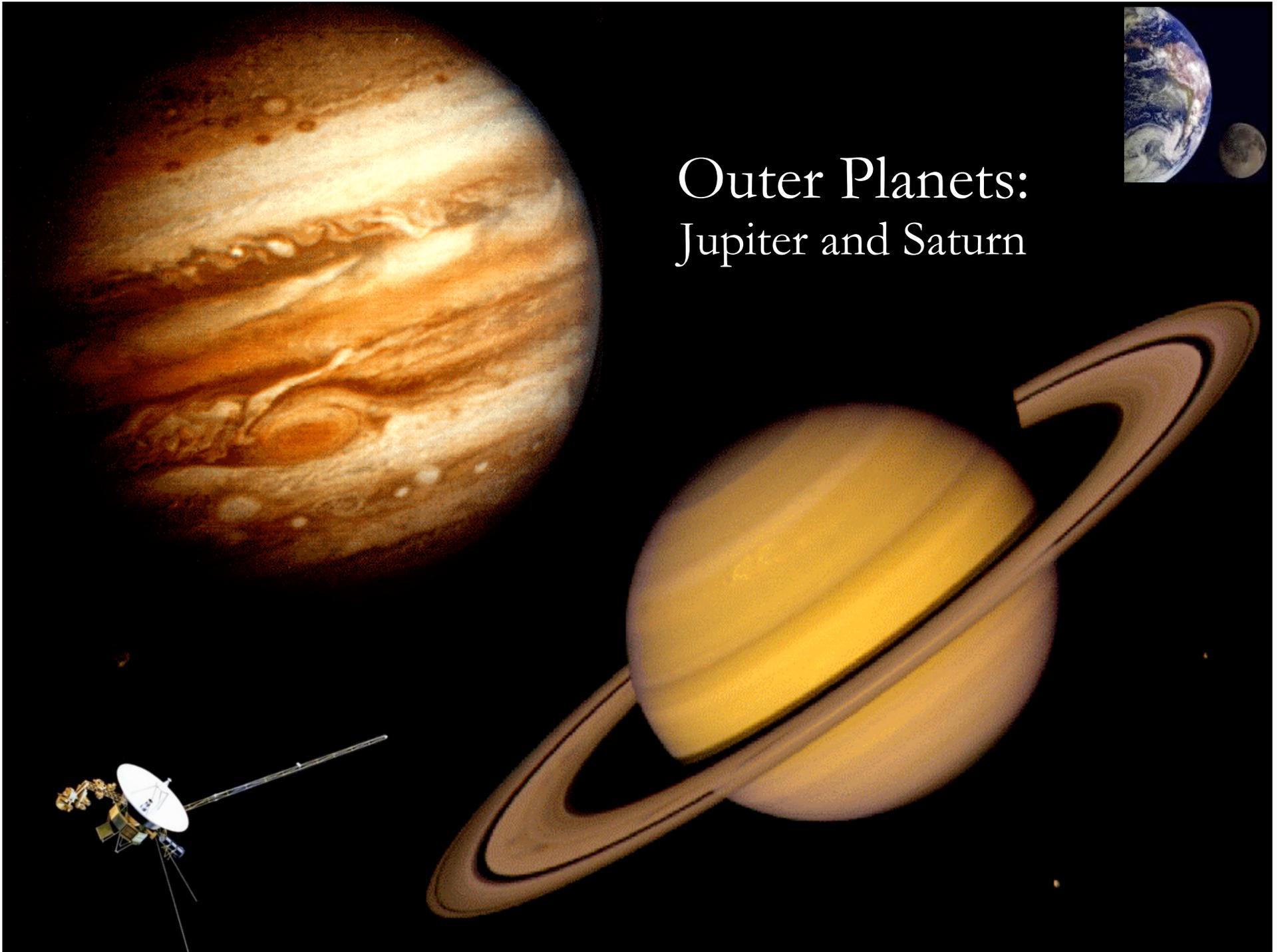


Data taken over multiple seasons

First recovery of zonal winds
from pressure contours

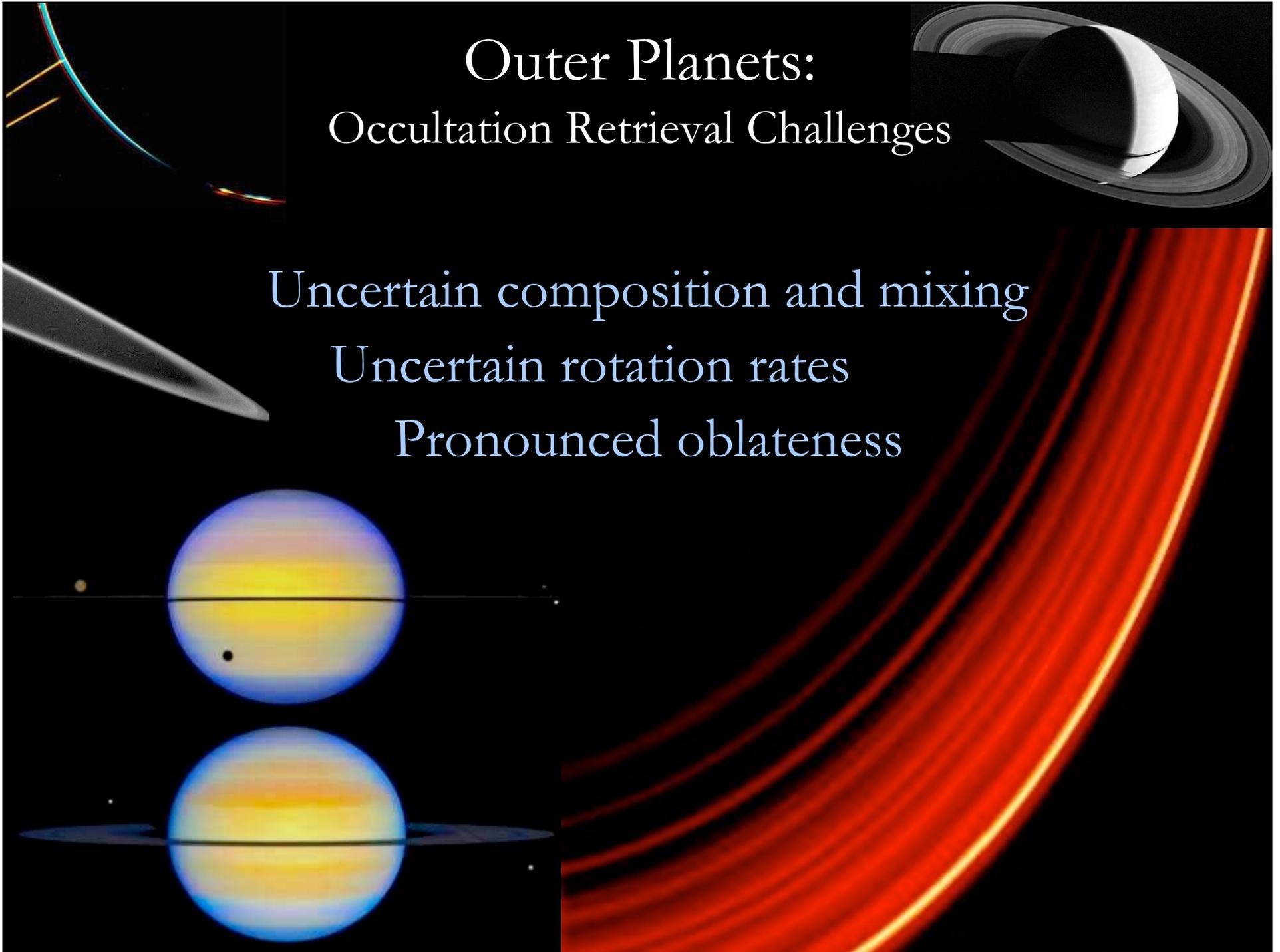


Outer Planets: Jupiter and Saturn

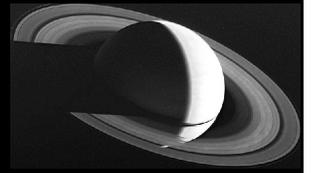


Outer Planets: Occultation Retrieval Challenges

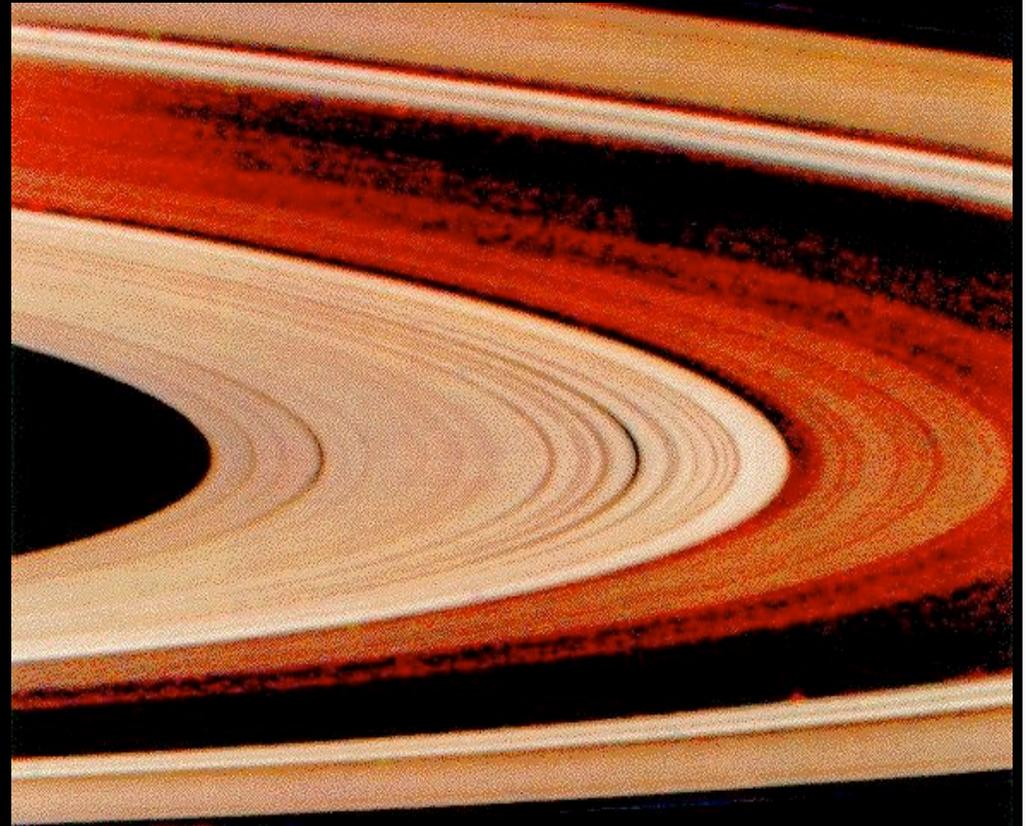
Uncertain composition and mixing
Uncertain rotation rates
Pronounced oblateness



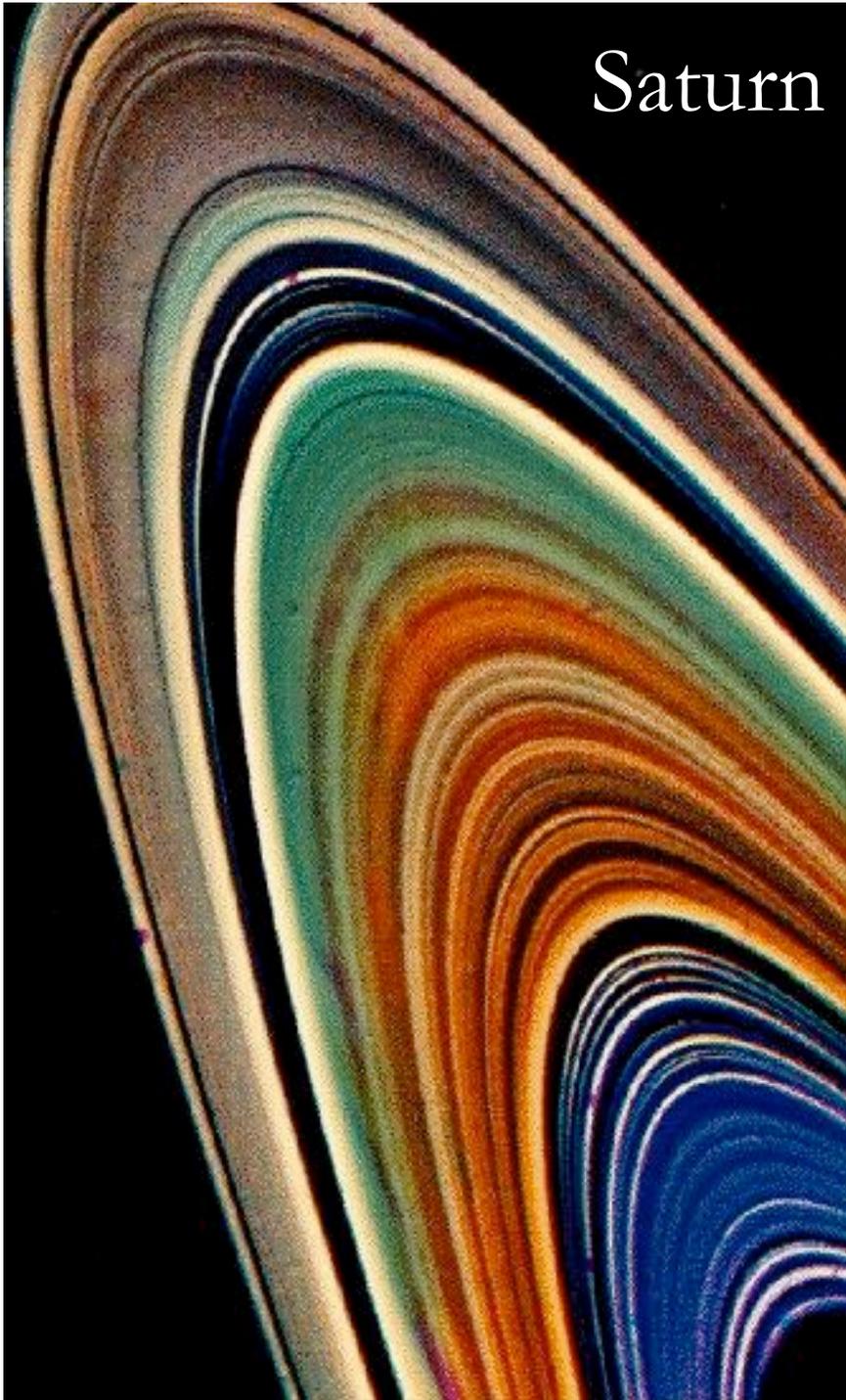
Saturn Ring Occultation



The rings act as a vast, thin, complex diffraction screen.

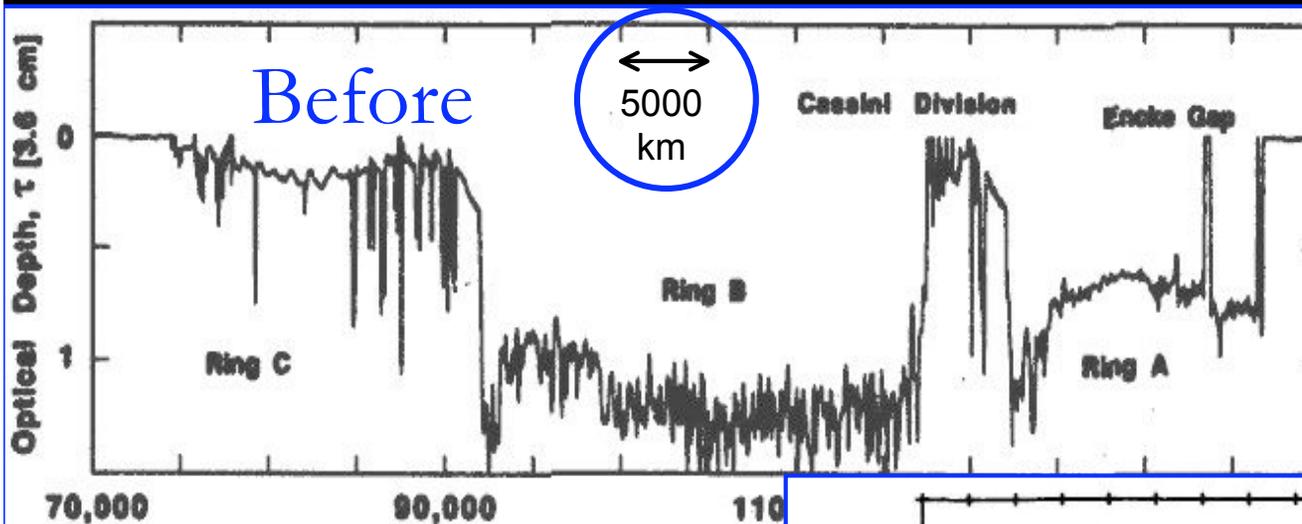


Sampling of the phase-amplitude hologram allows detailed reconstruction of the ring structure

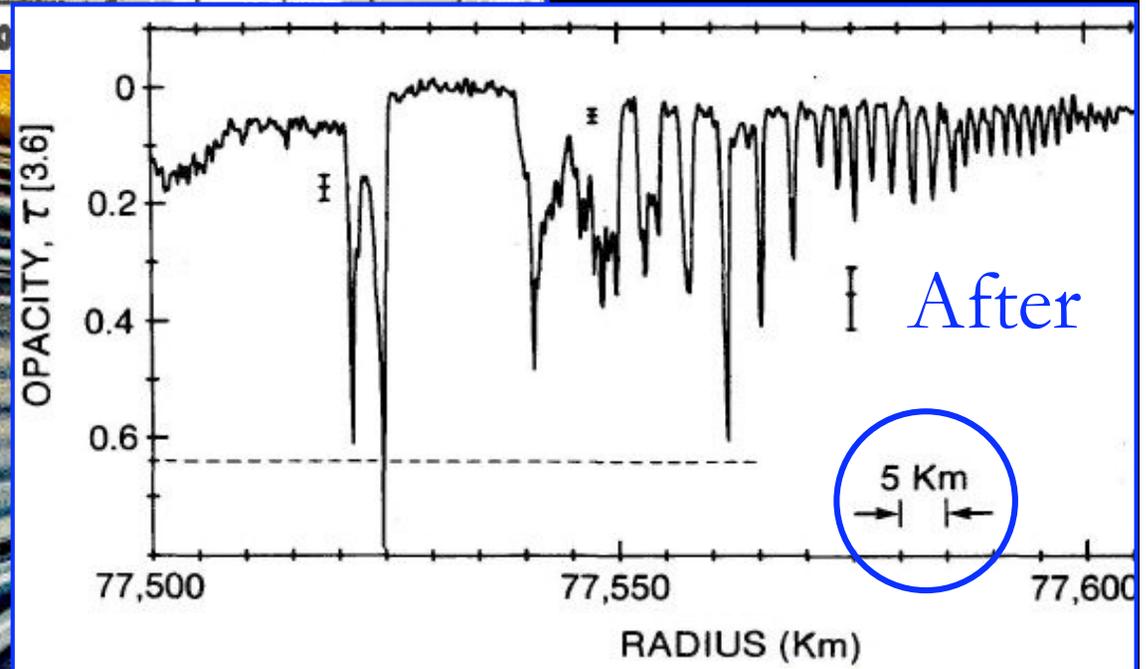
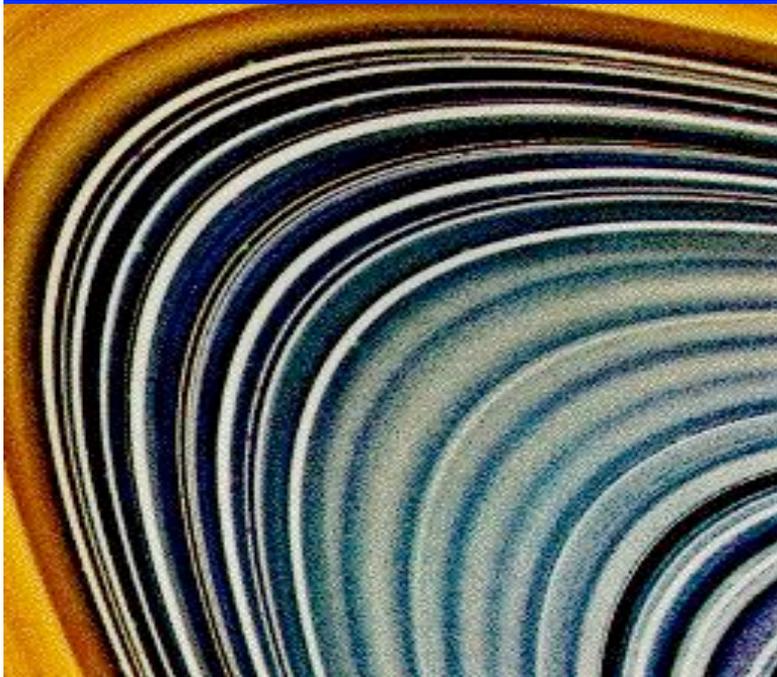




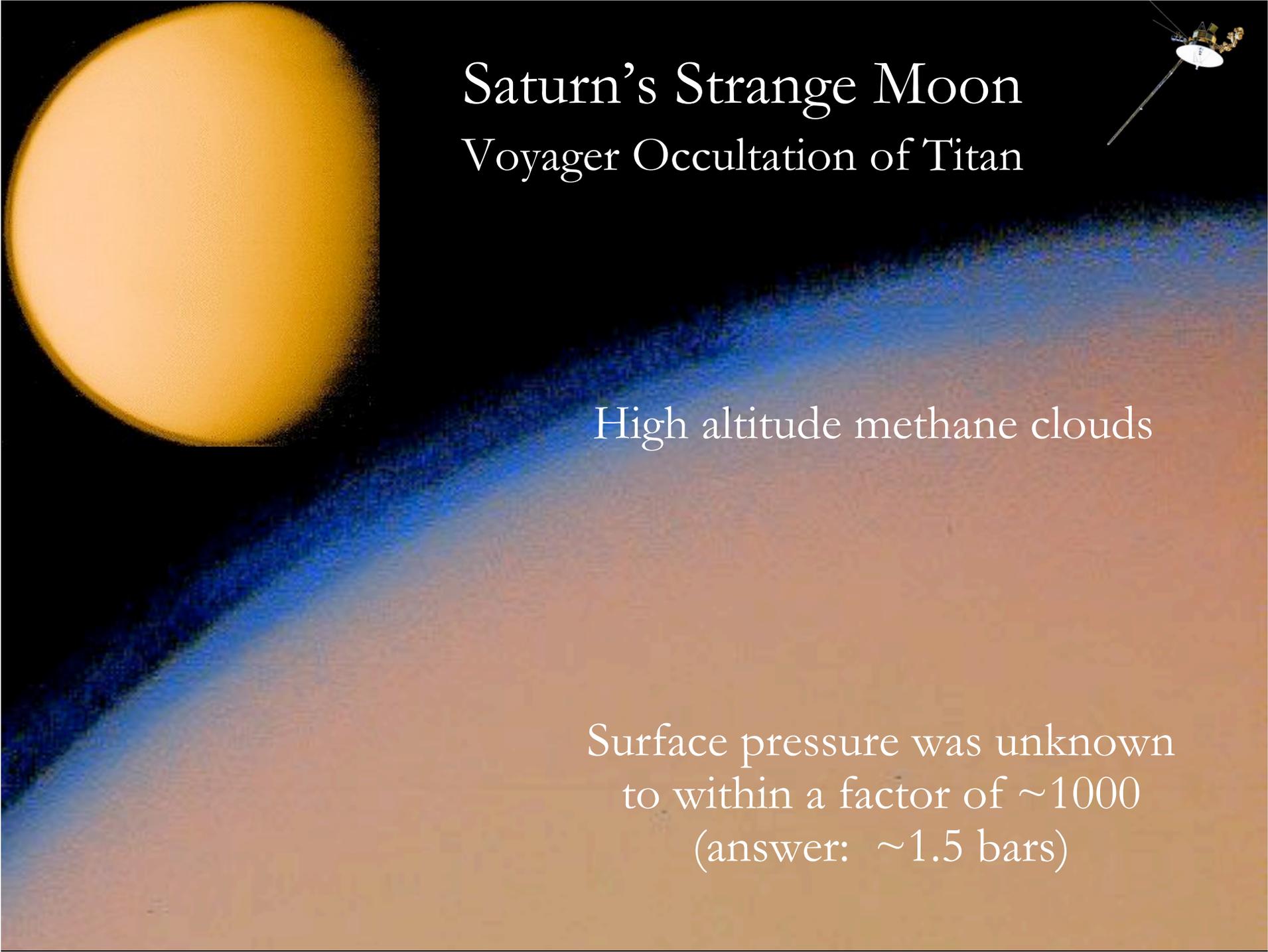
Saturn Ring Occultation



This 'inverse Fresnel filtering' improves resolution by x50-90 over the ~ 15 km Fresnel limit



Marouf, Tyler, Rosen, 1986



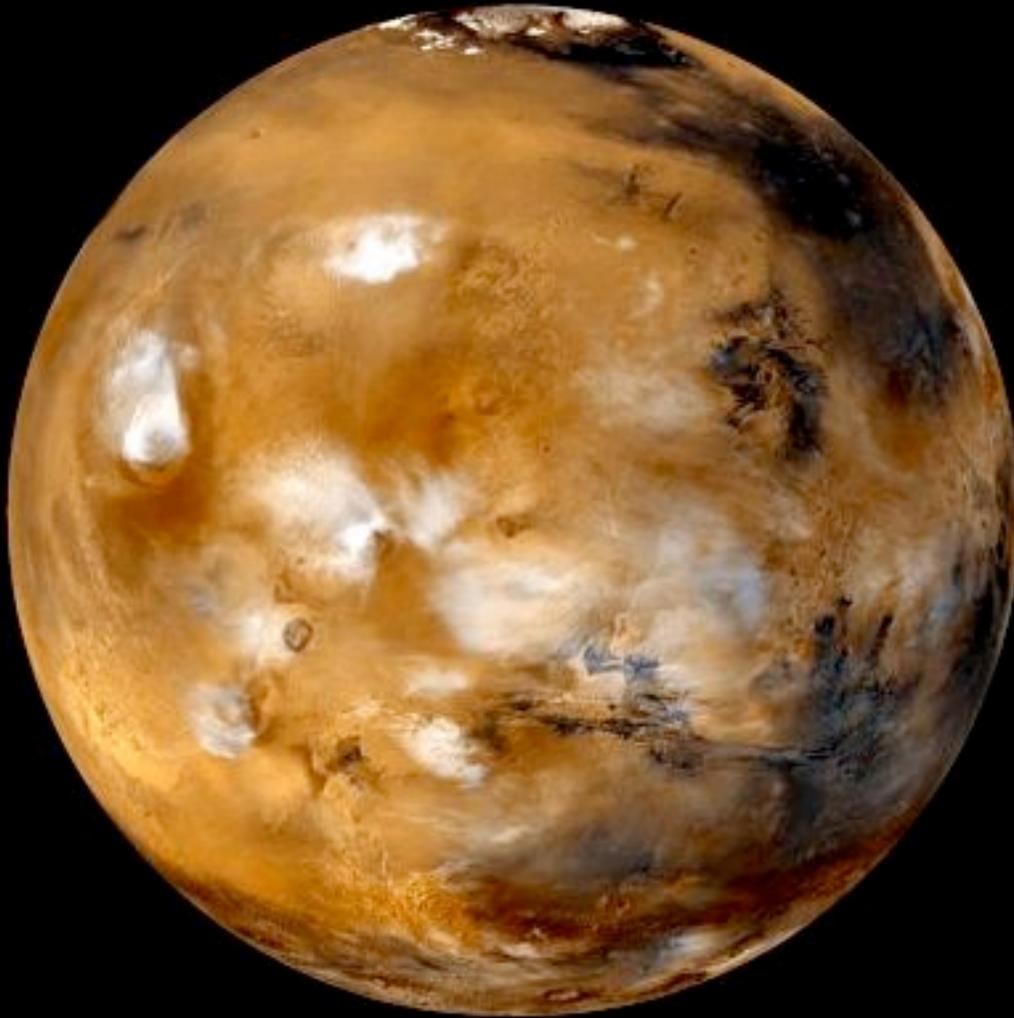
Saturn's Strange Moon

Voyager Occultation of Titan

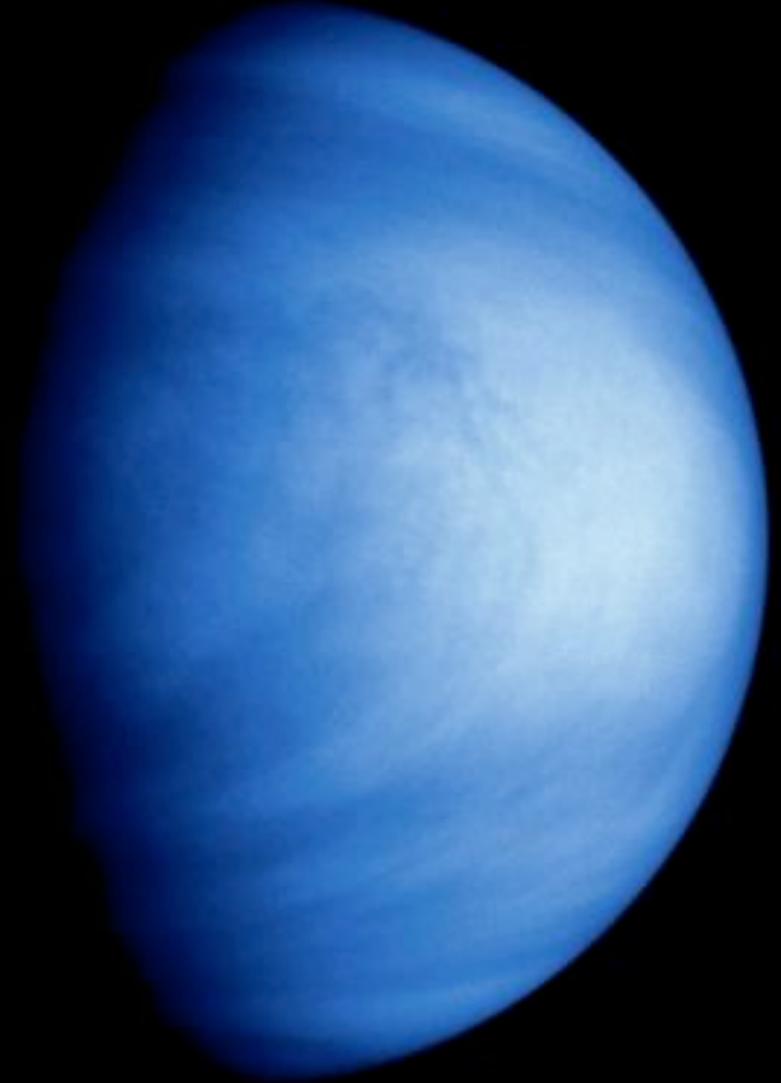
High altitude methane clouds

Surface pressure was unknown
to within a factor of ~ 1000
(answer: ~ 1.5 bars)

An Observation on the Terrestrial Planets



This atmosphere is too thin

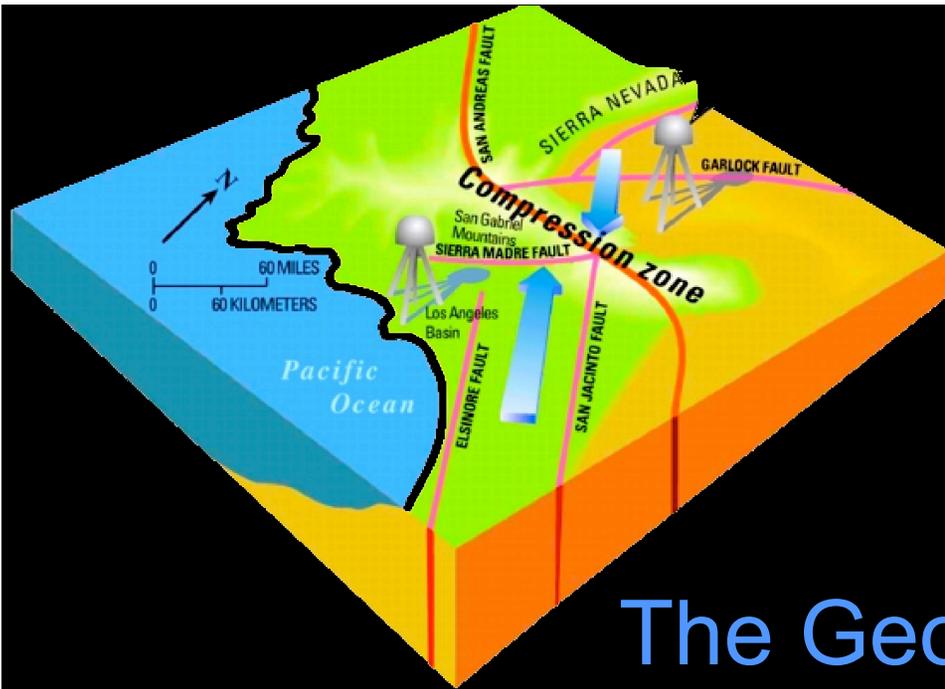


This atmosphere is too thick

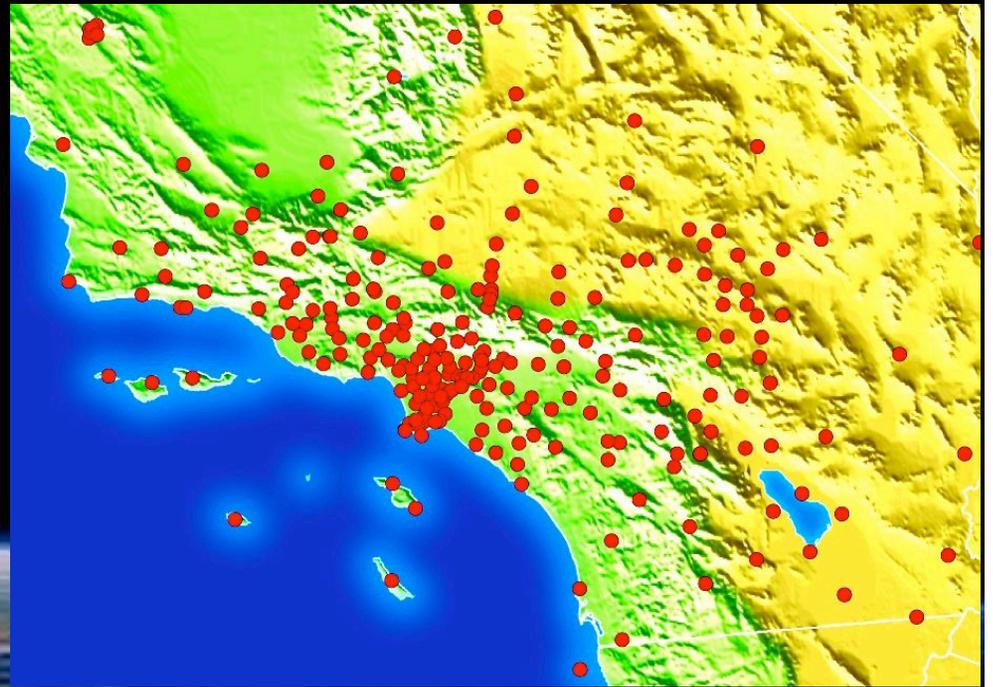


Just

right...

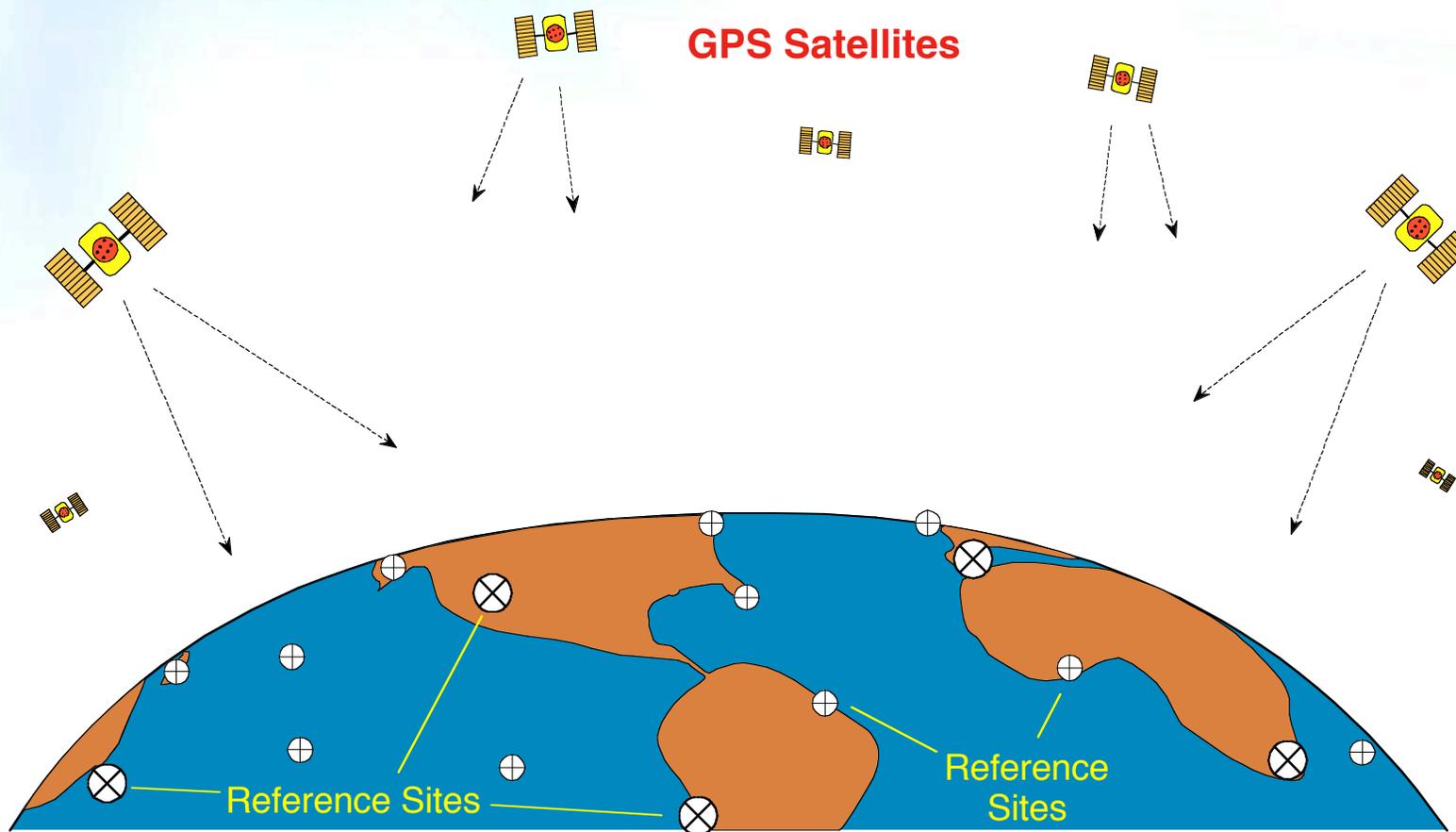


The Geodesy Path

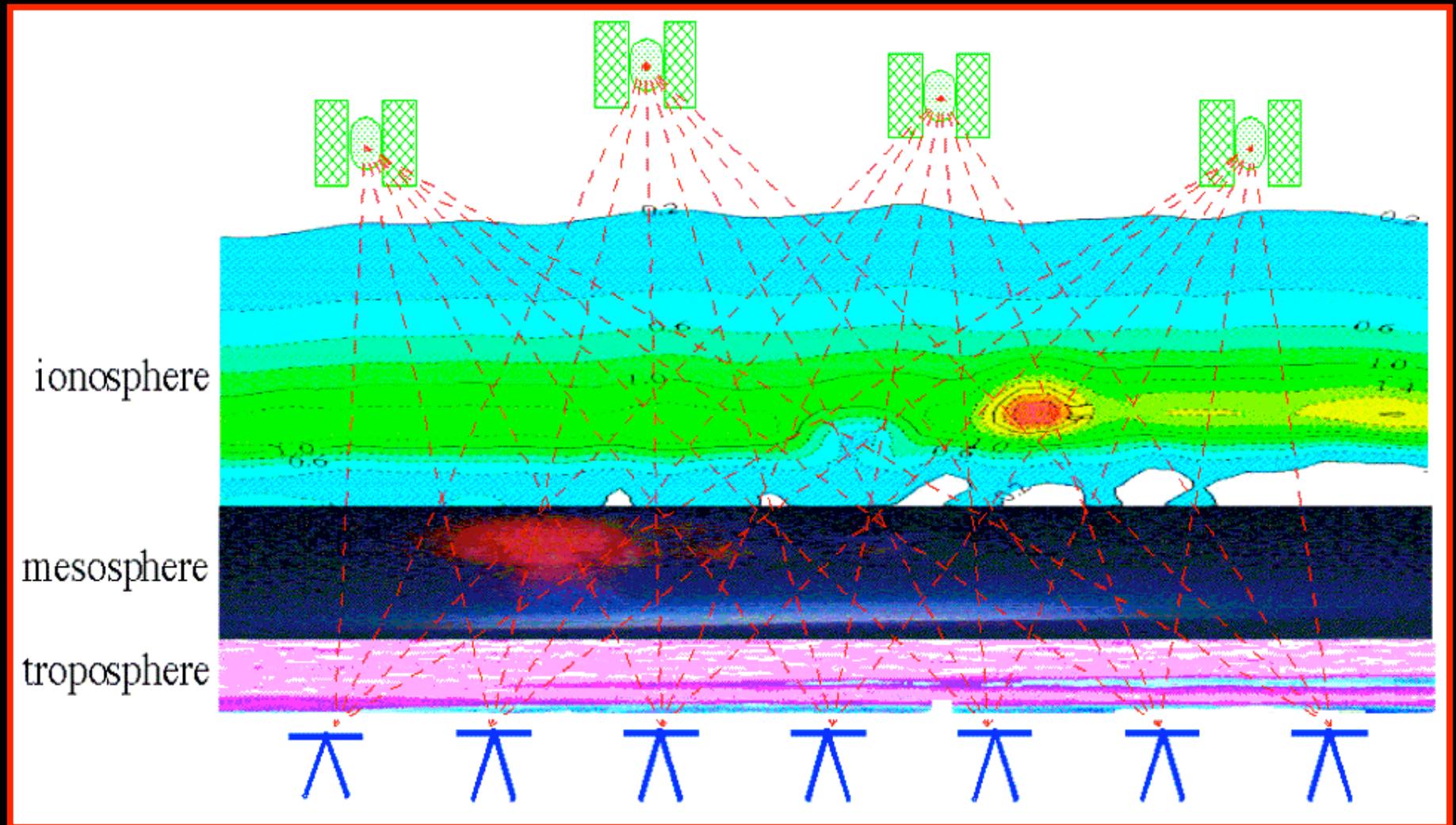




Early GPS Geodesy (1978-1987)

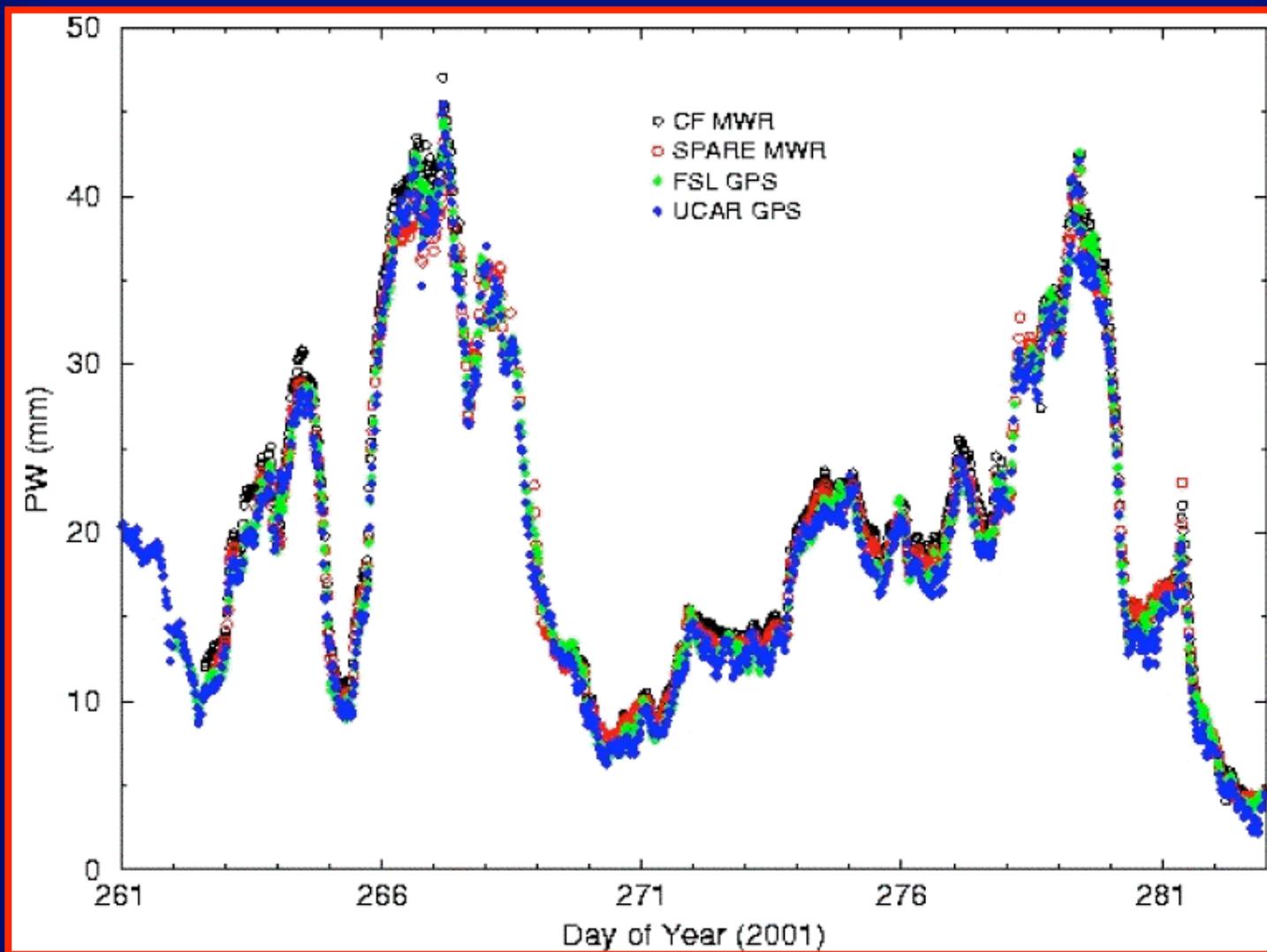


Media Affecting GPS Signals



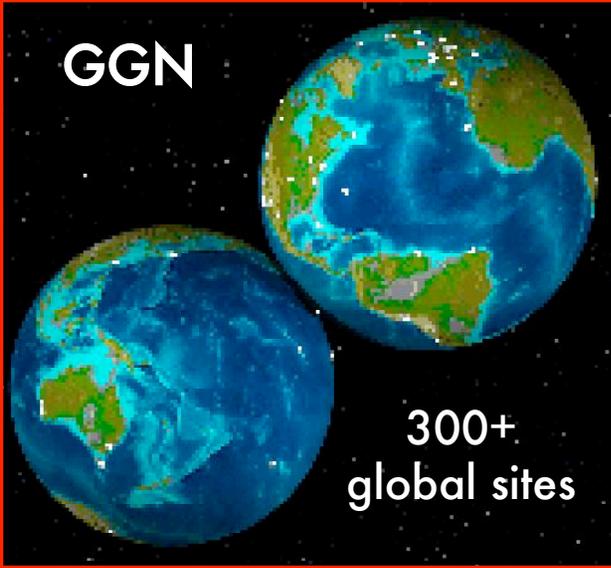
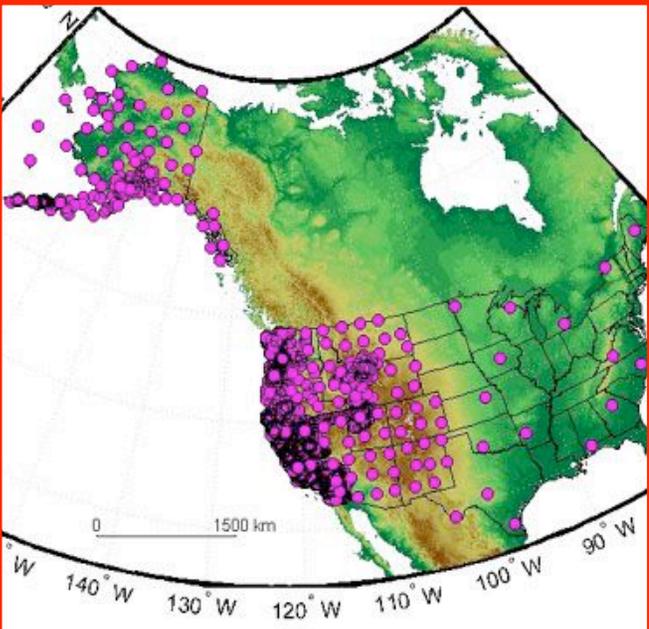
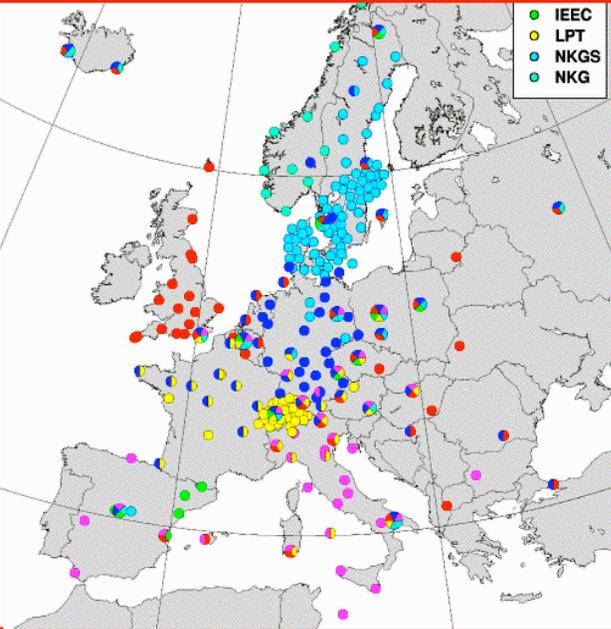
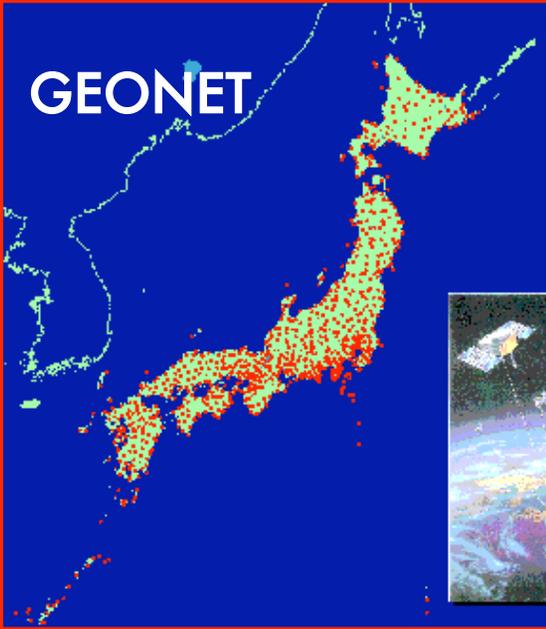
Rocken et al., 2003

PW: GPS vs Microwave Radiometer

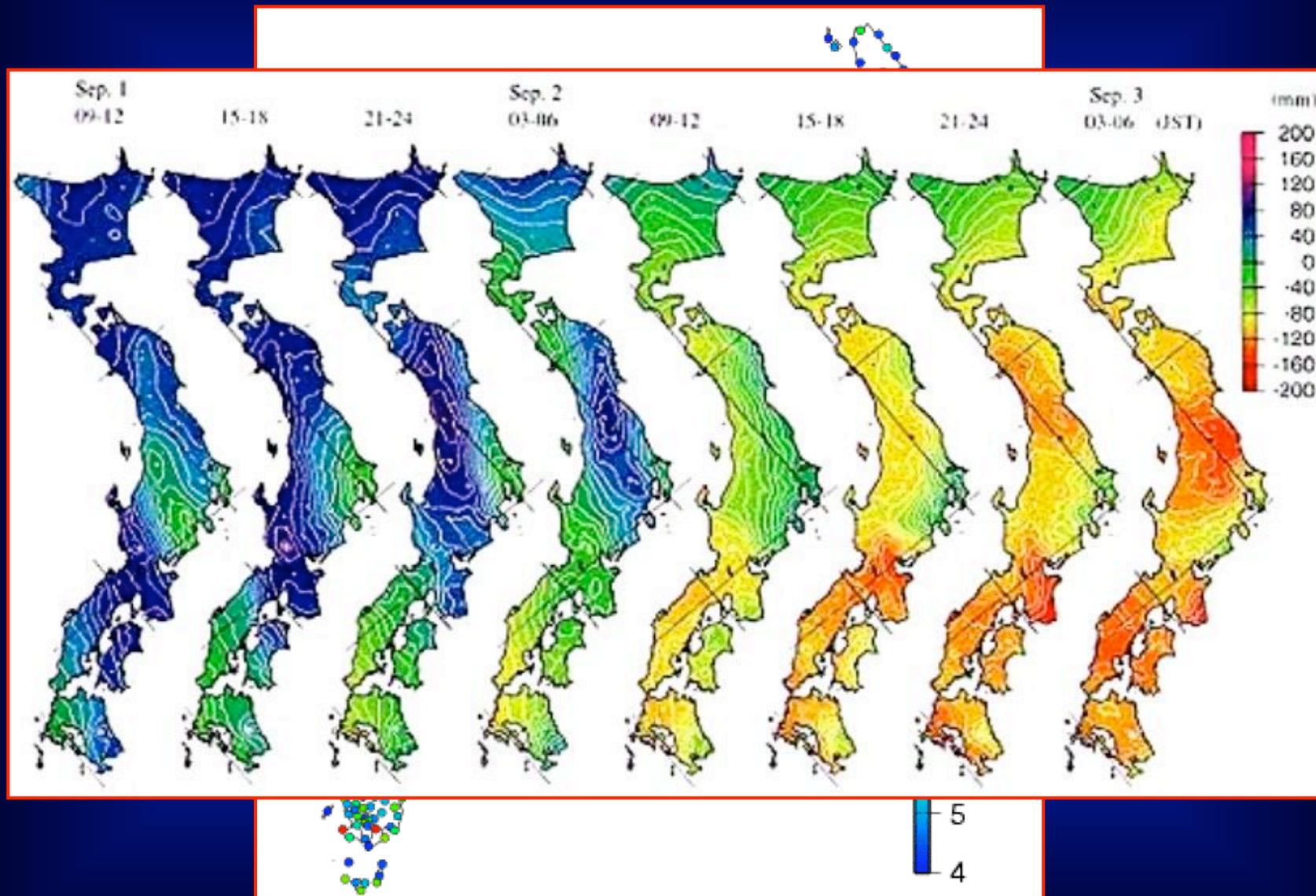


Rocken et al., 2003

GPS Ground Arrays

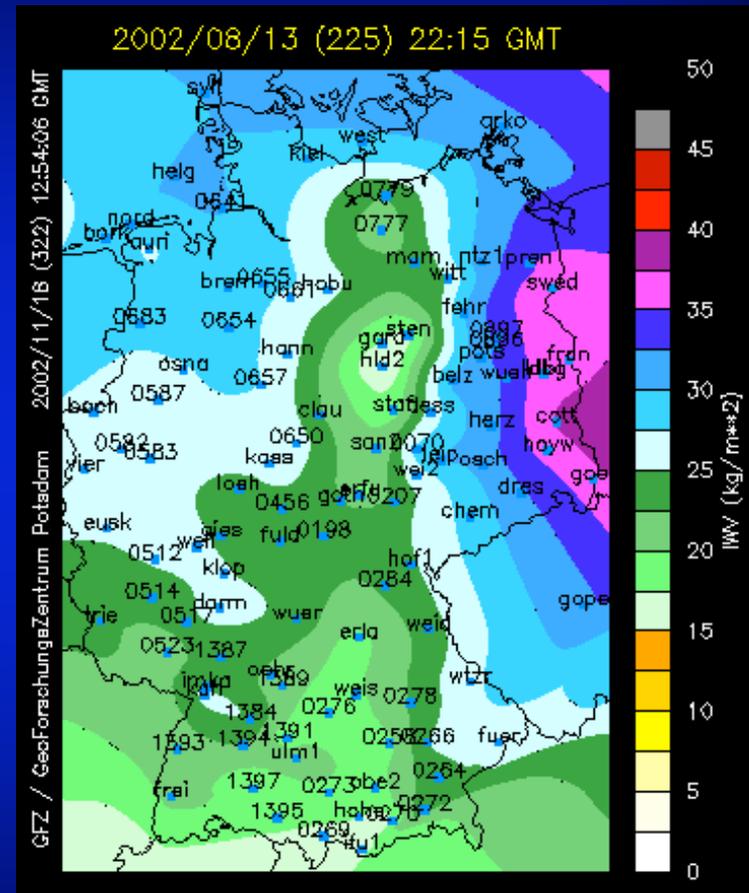
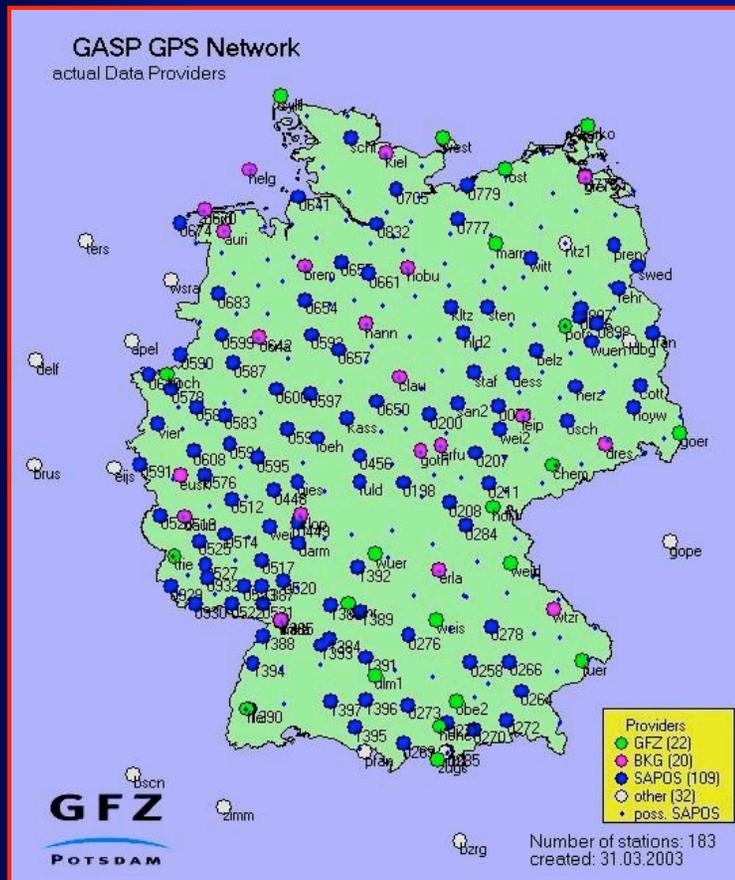


Maps of Precipitable Water (PW)



Japanese Meteorological Agency, 2003

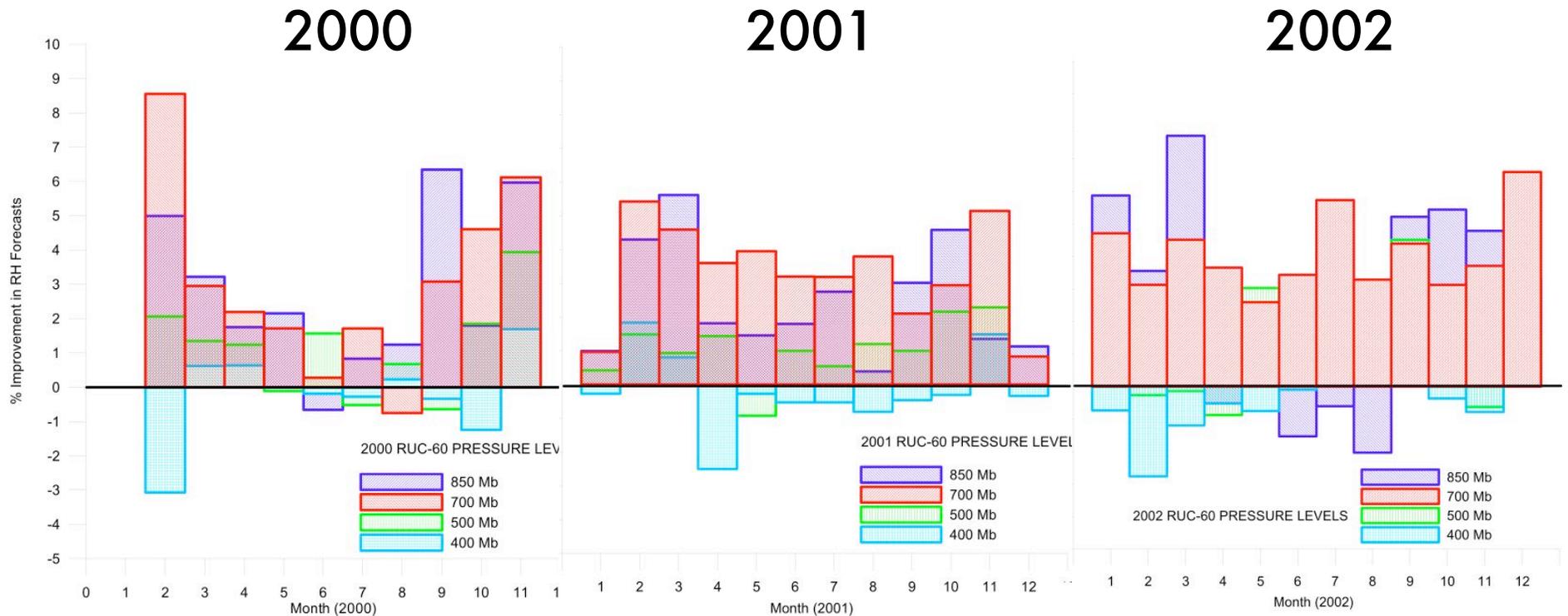
Maps of Precipitable Water



Gendt et al., GFZ, 2003

Effect of GPS on Relative Humidity Predictions

NOAA Assimilation Studies 2000-2002



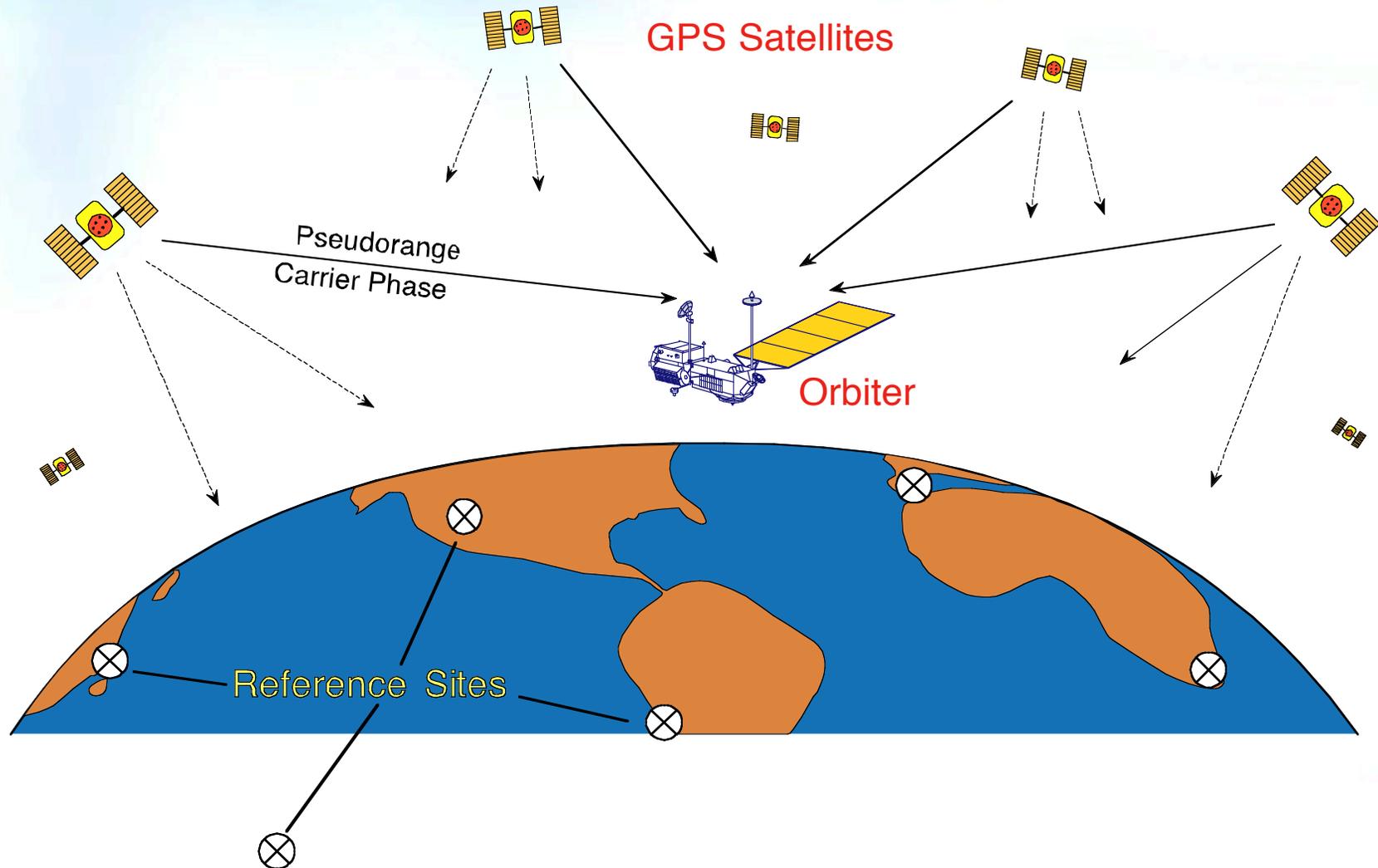
“GPS is one of the most cost effective remote sensing systems tested by FSL.”

S. Gutman et al., NOAA FSL, 2003

Spaceborne Sounding



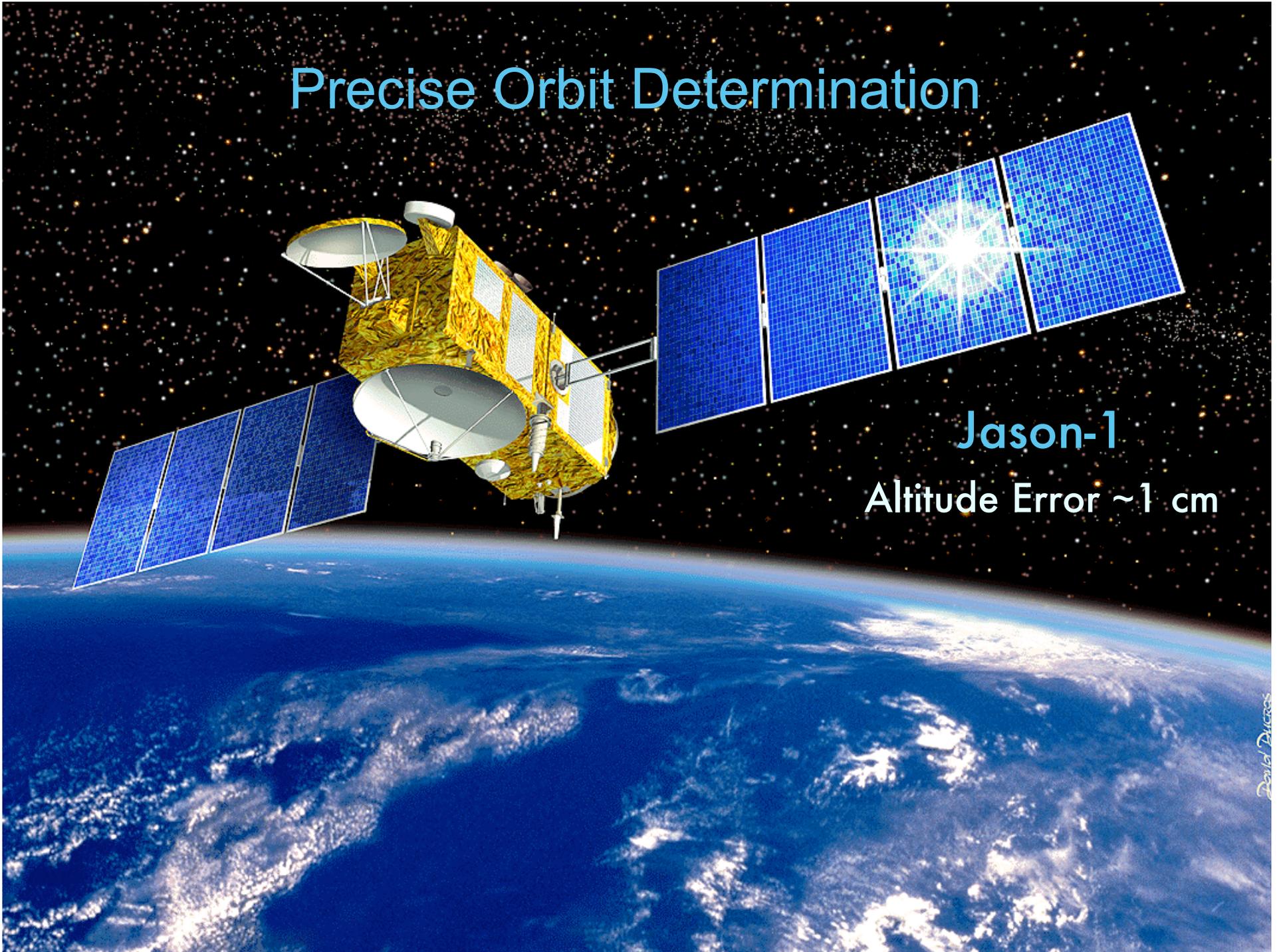
Precise Orbit Determination With GPS



Precise Orbit Determination

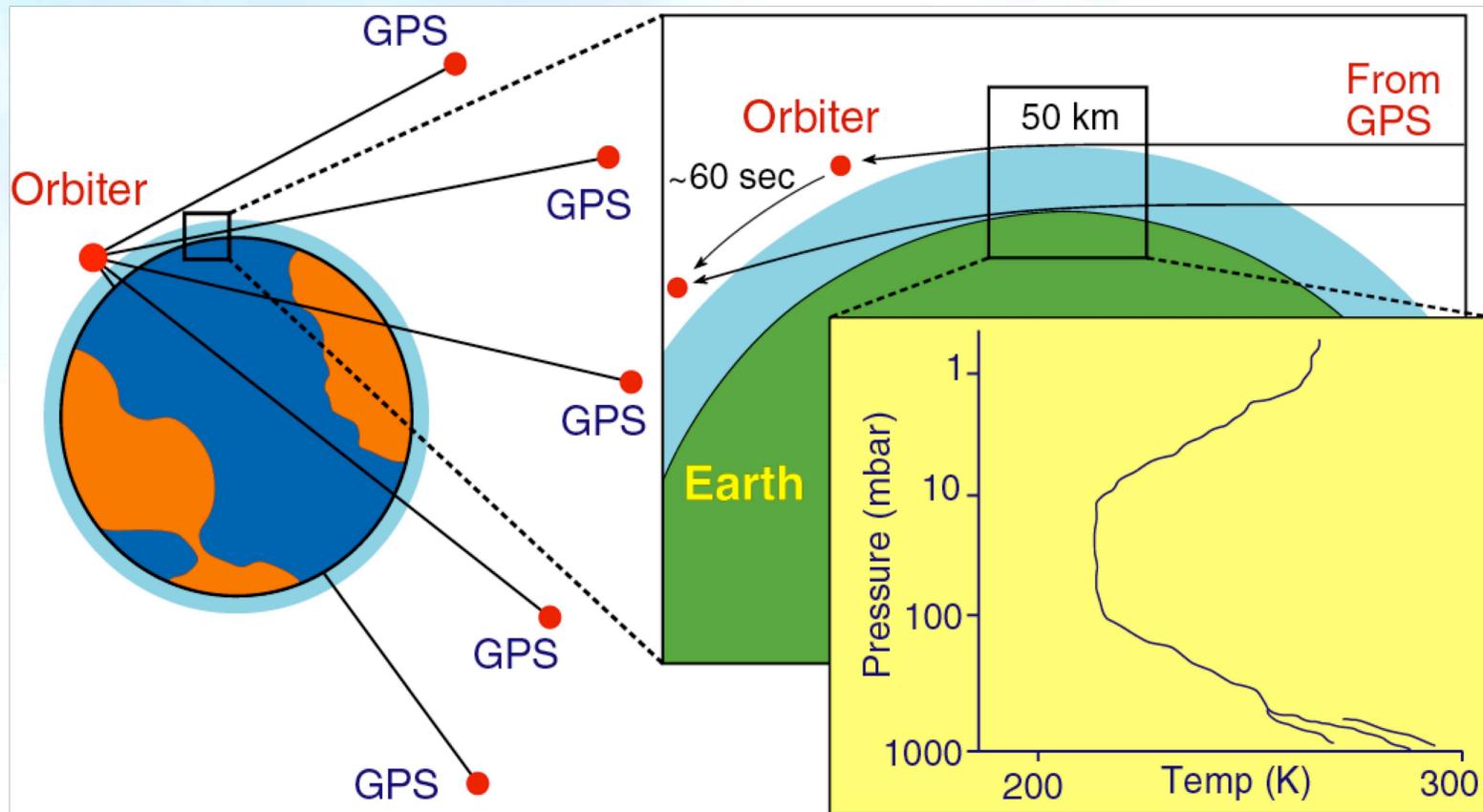
Jason-1

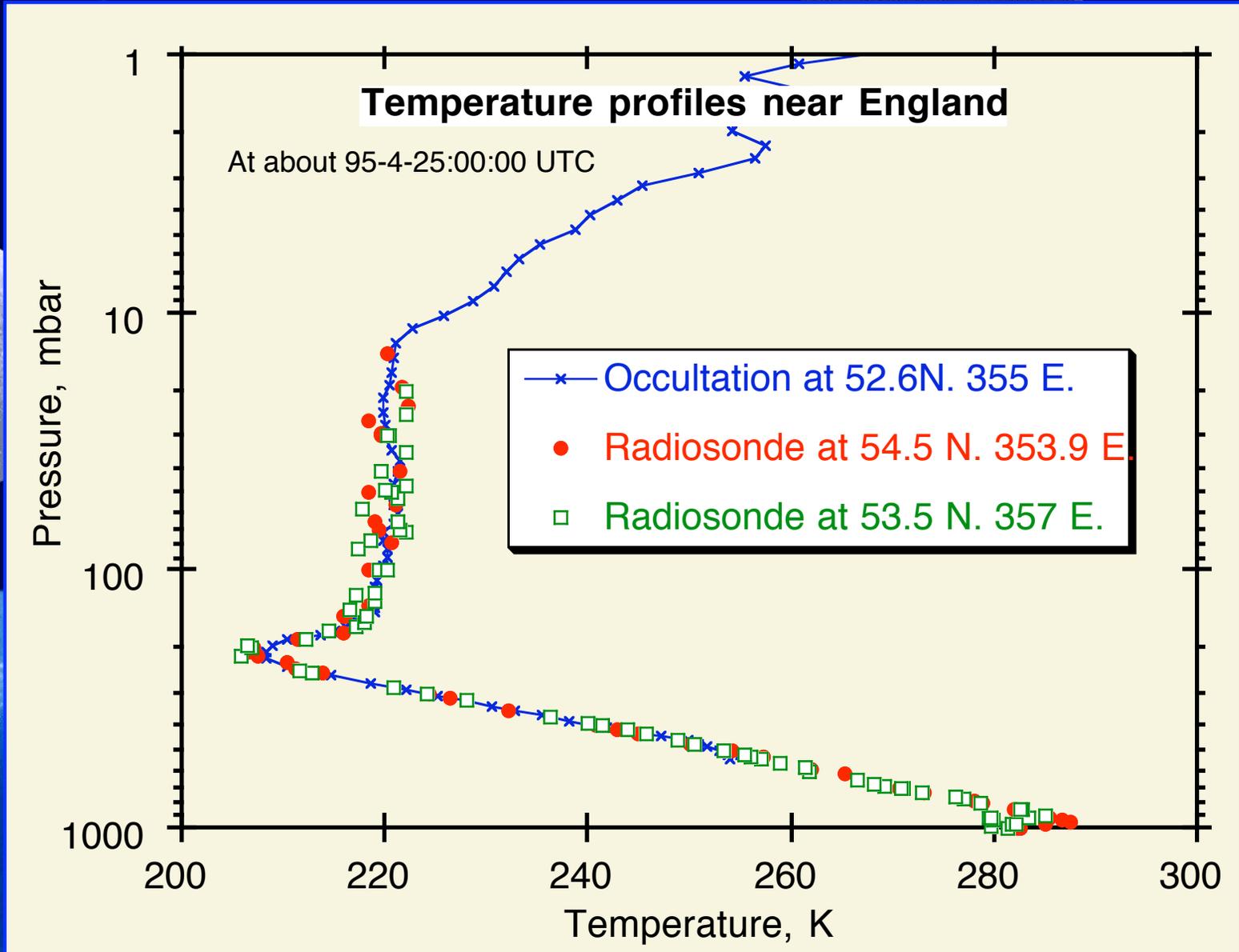
Altitude Error ~ 1 cm





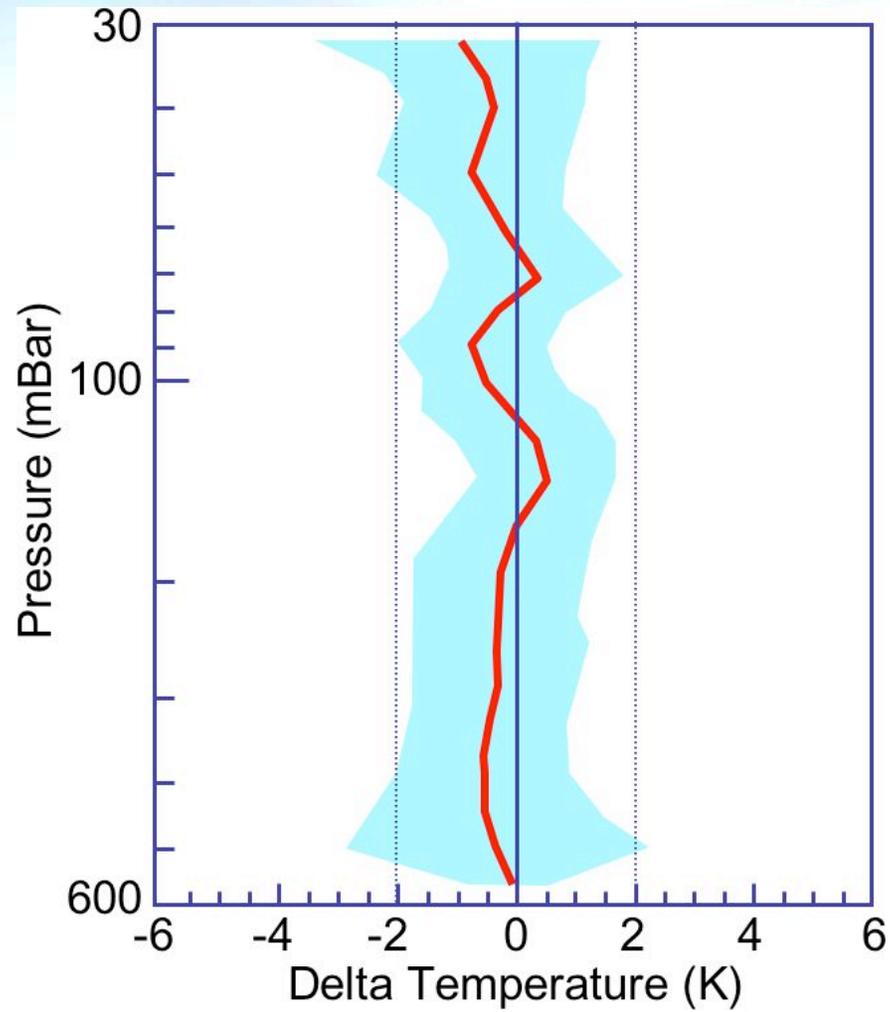
Atmospheric Limb Sounding

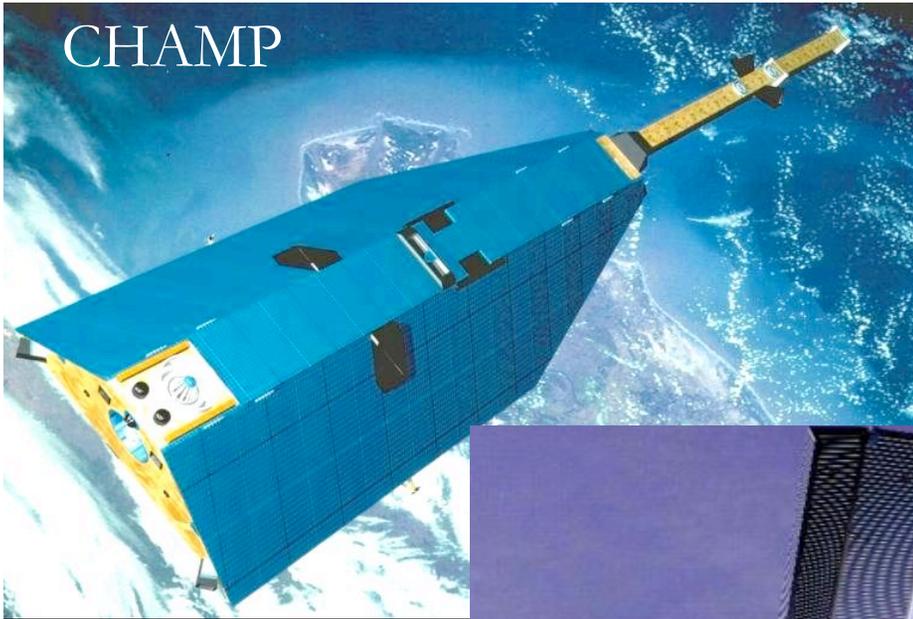




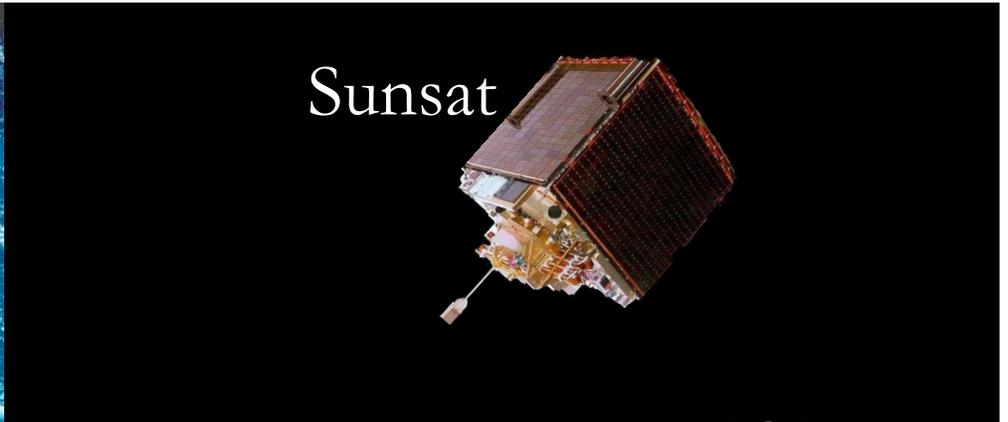


GPS-MET Agreement with Radiosondes (1995-96)





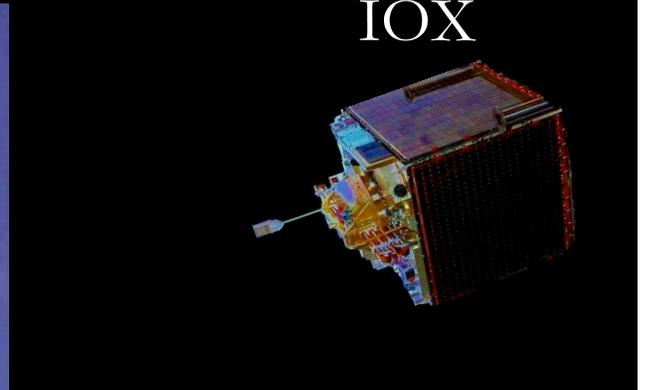
CHAMP



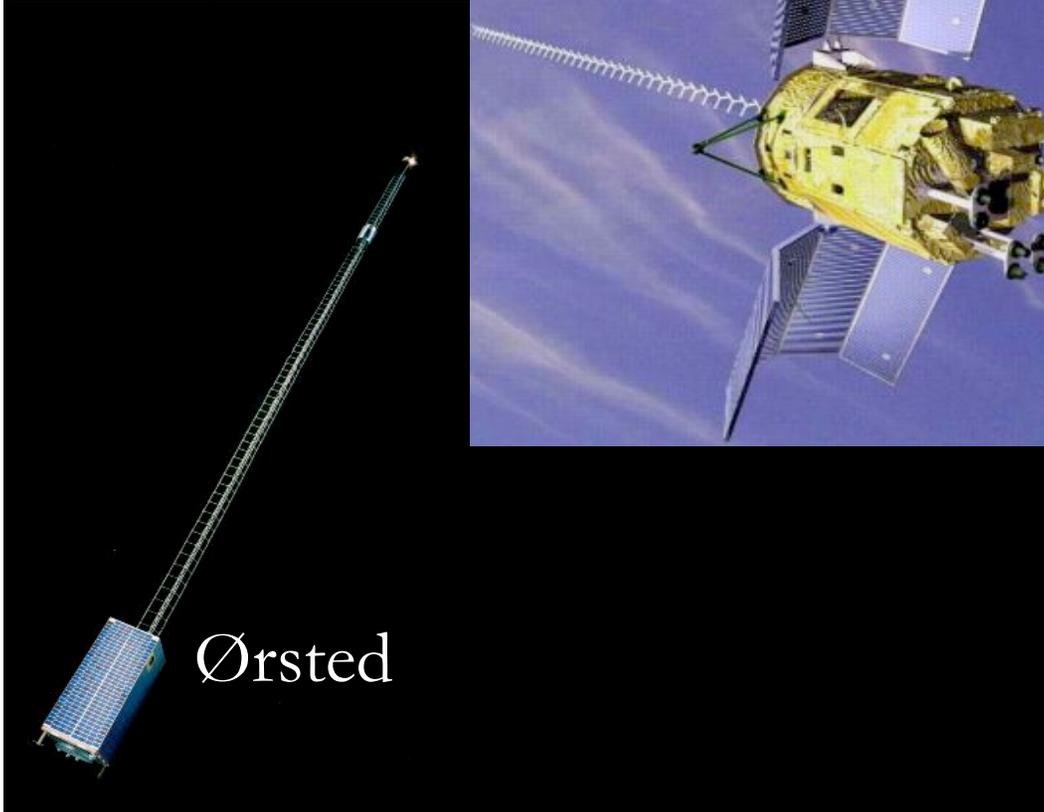
Sunsat



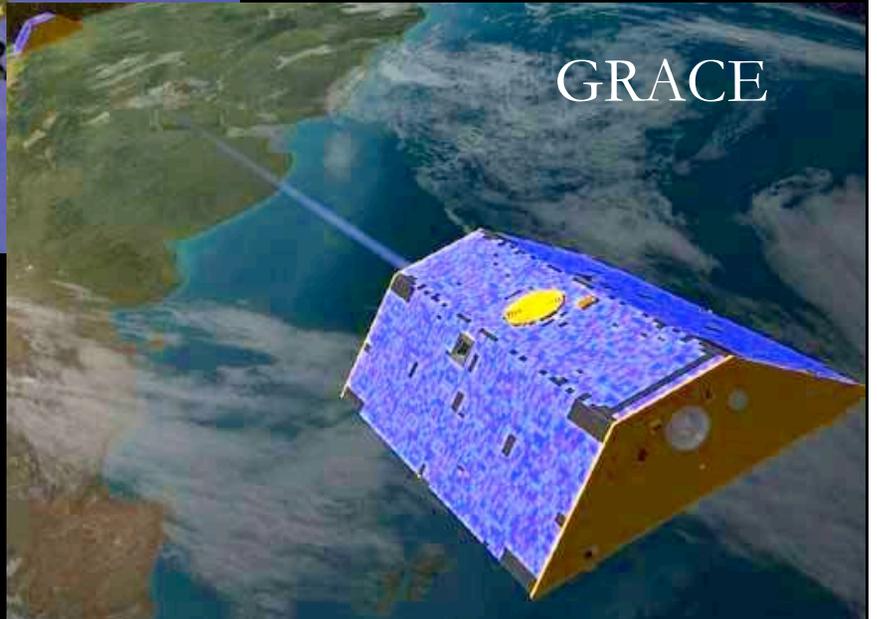
SAC-C



IOX

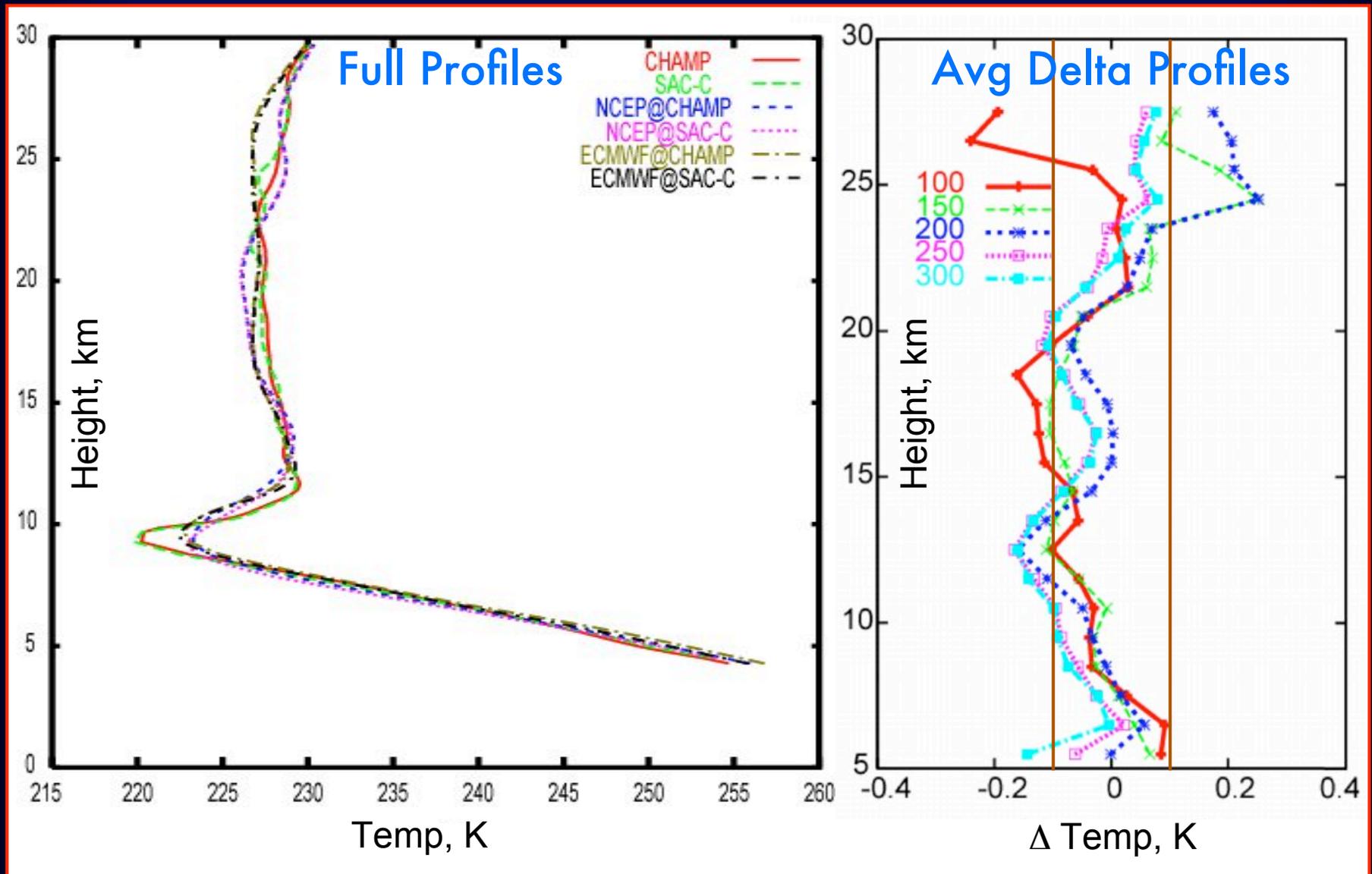


Ørsted



GRACE

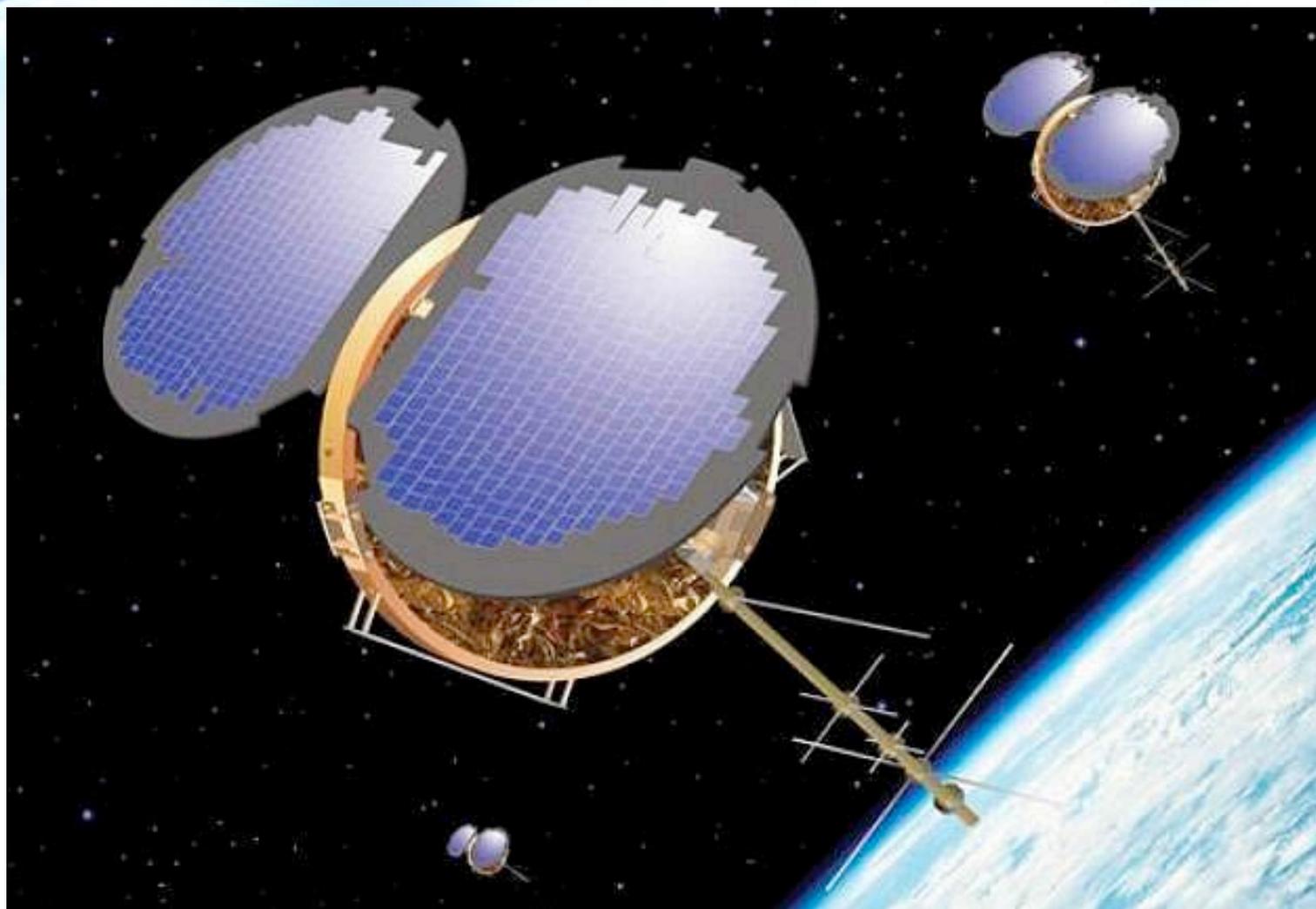
CHAMP-SACC Profile Comparison



Ref: Hajj et al., 2003

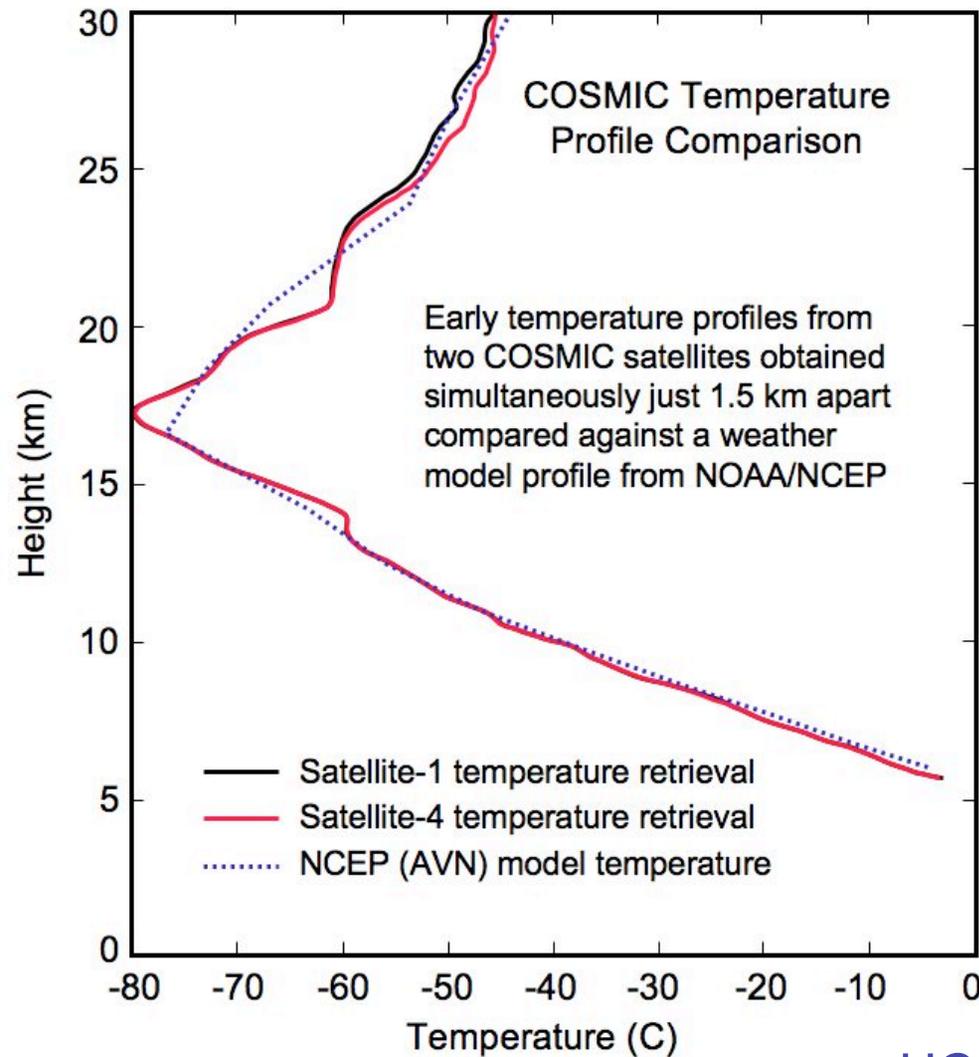


Formosat-3/COSMIC: 2006 – ?





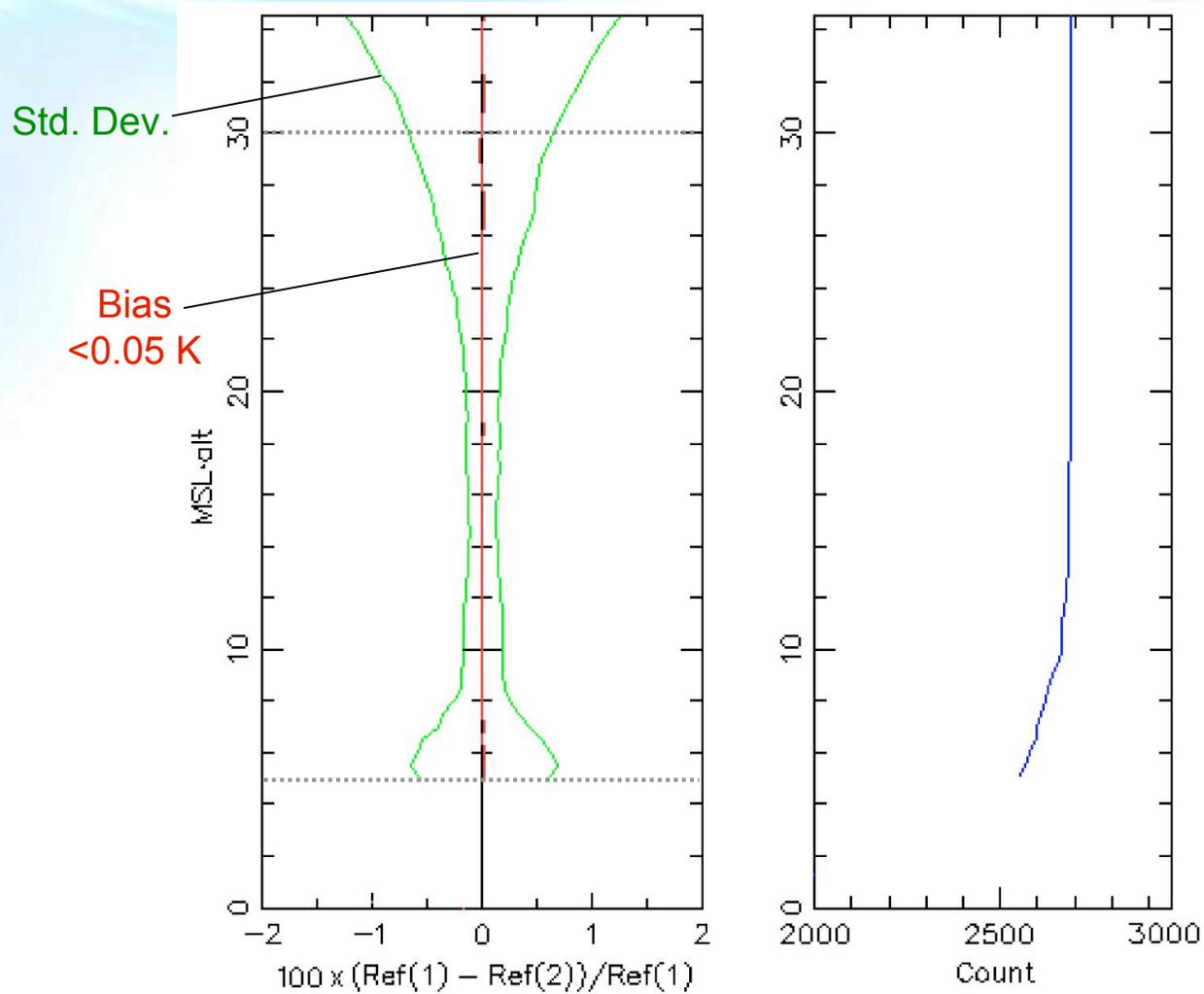
Early COSMIC Pair: <1.5 km separation



UCAR, April 2006



GPS-GPS Comparison Stats from COSMIC



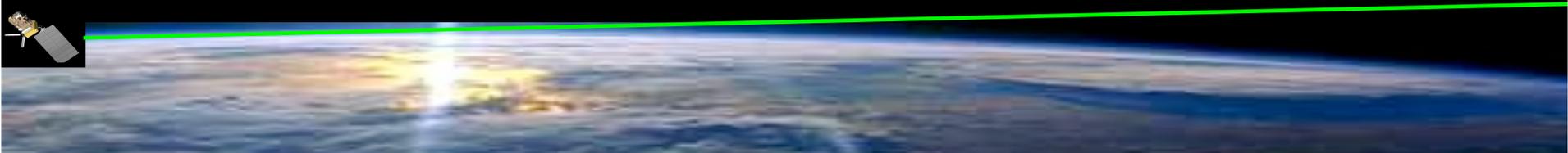
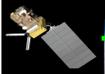
Unique Attractions of Radio Occultation

1. High accuracy: Averaged profiles to < 0.1 K
2. All-weather operation
3. Global 3D coverage: surface to stratosphere
4. Unrivalled vertical resolution
5. Independent height & pressure/temp data
6. Compact, low-power, low-cost sensor

What is it good for?

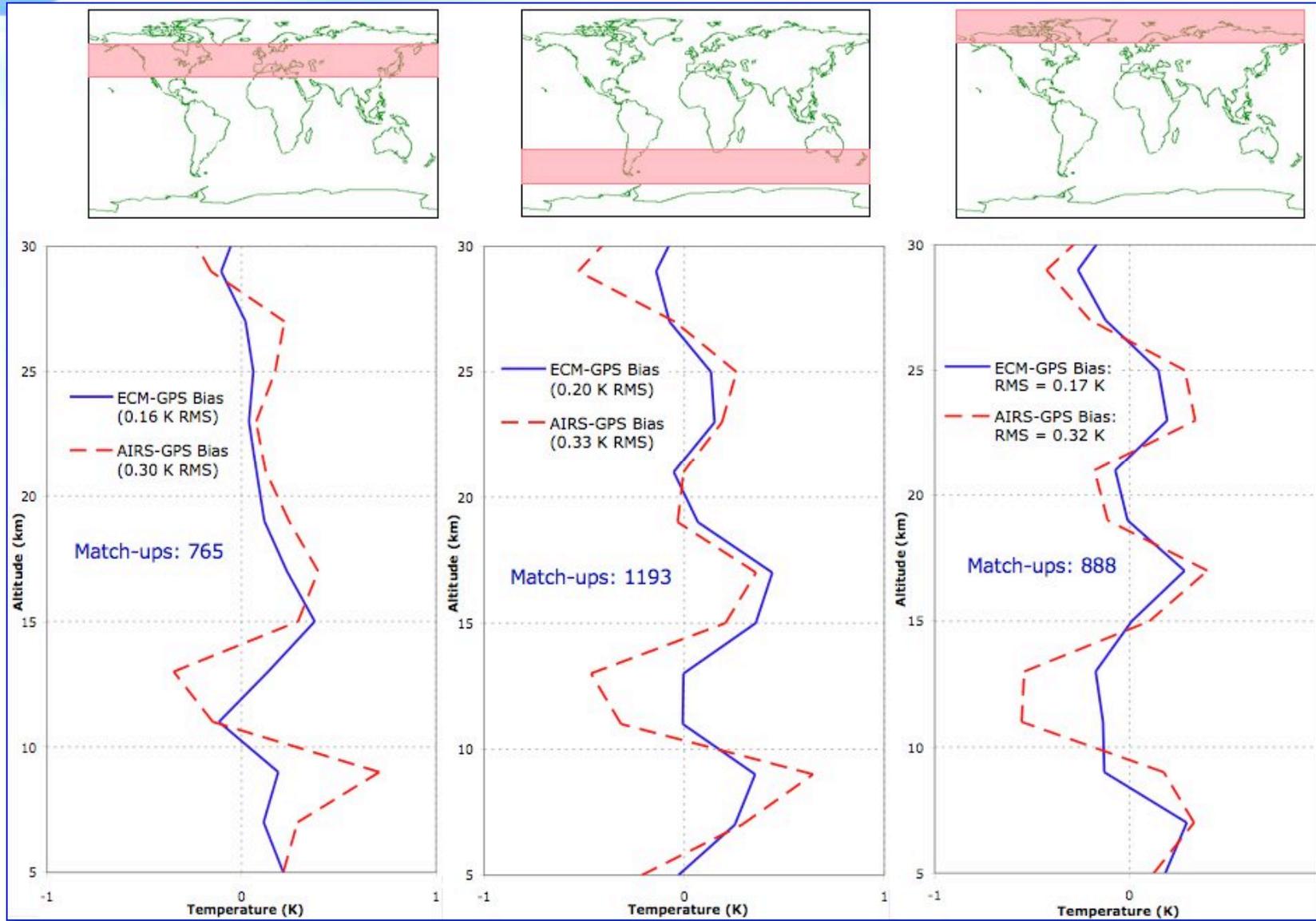


Calibrating Other Data Products



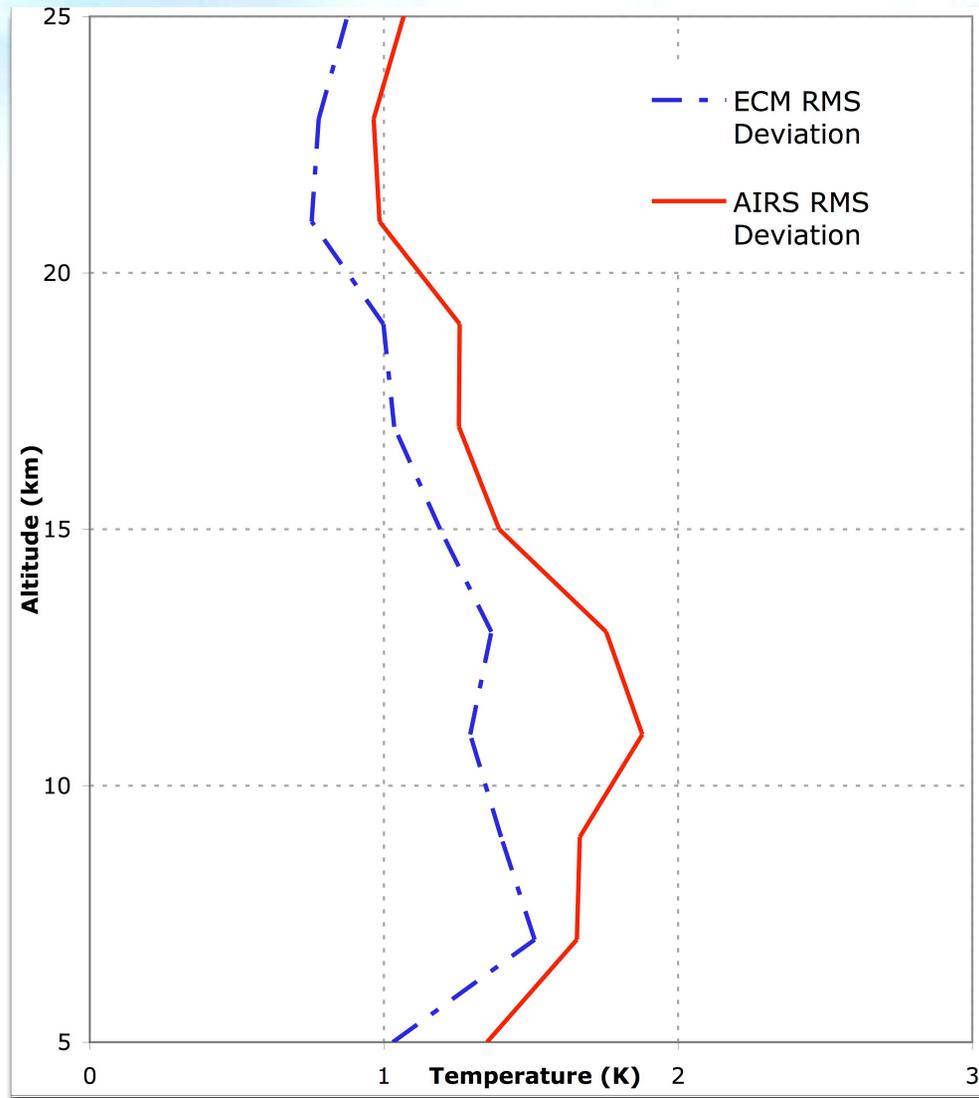


AIRS & ECMWF Biases v. GPS In 3 Zones





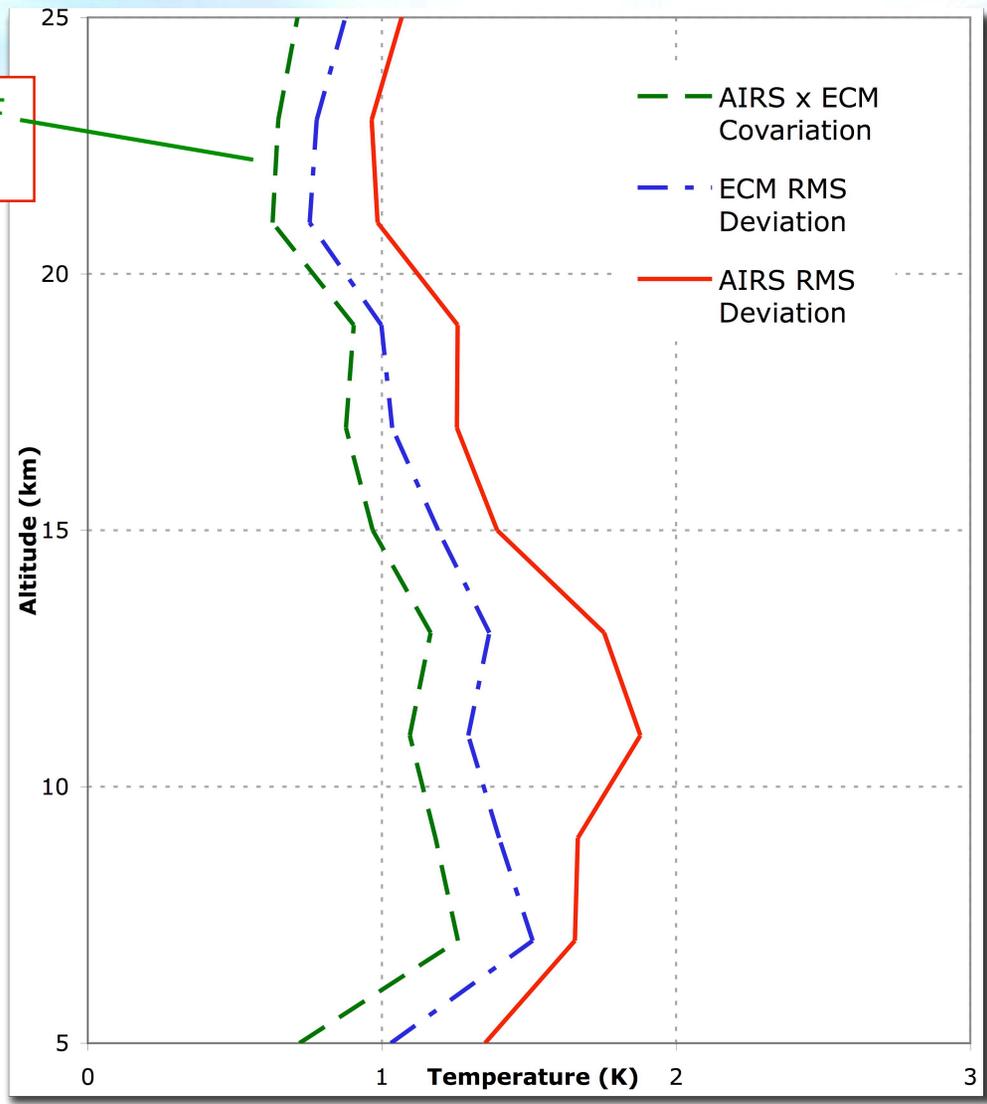
Derived AIRS & ECMWF RMS deviations





Derived AIRS & ECMWF RMS deviations

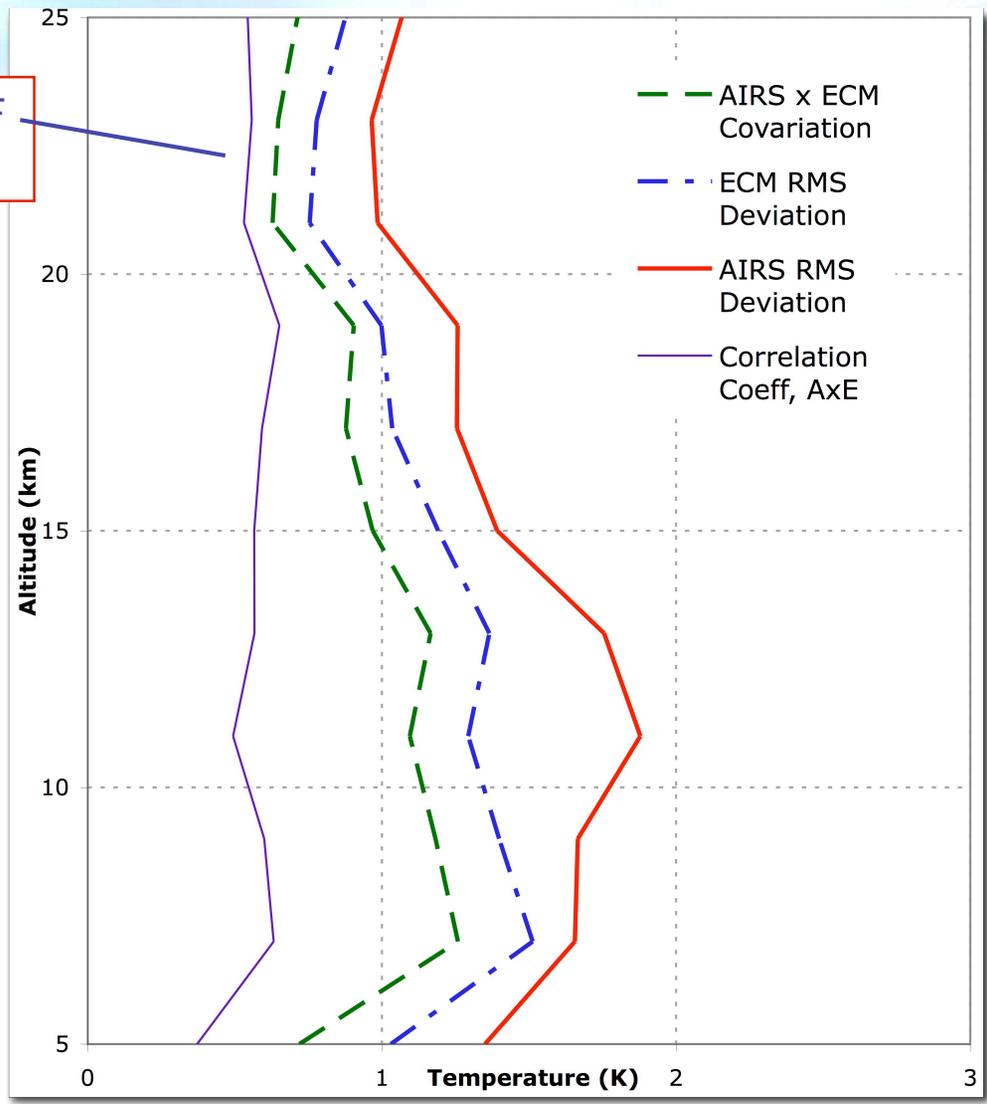
AIRS-ECMWF
"Covariation"



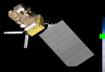


Derived AIRS & ECMWF RMS deviations

AIRS-ECMWF
Corr. Coeff.

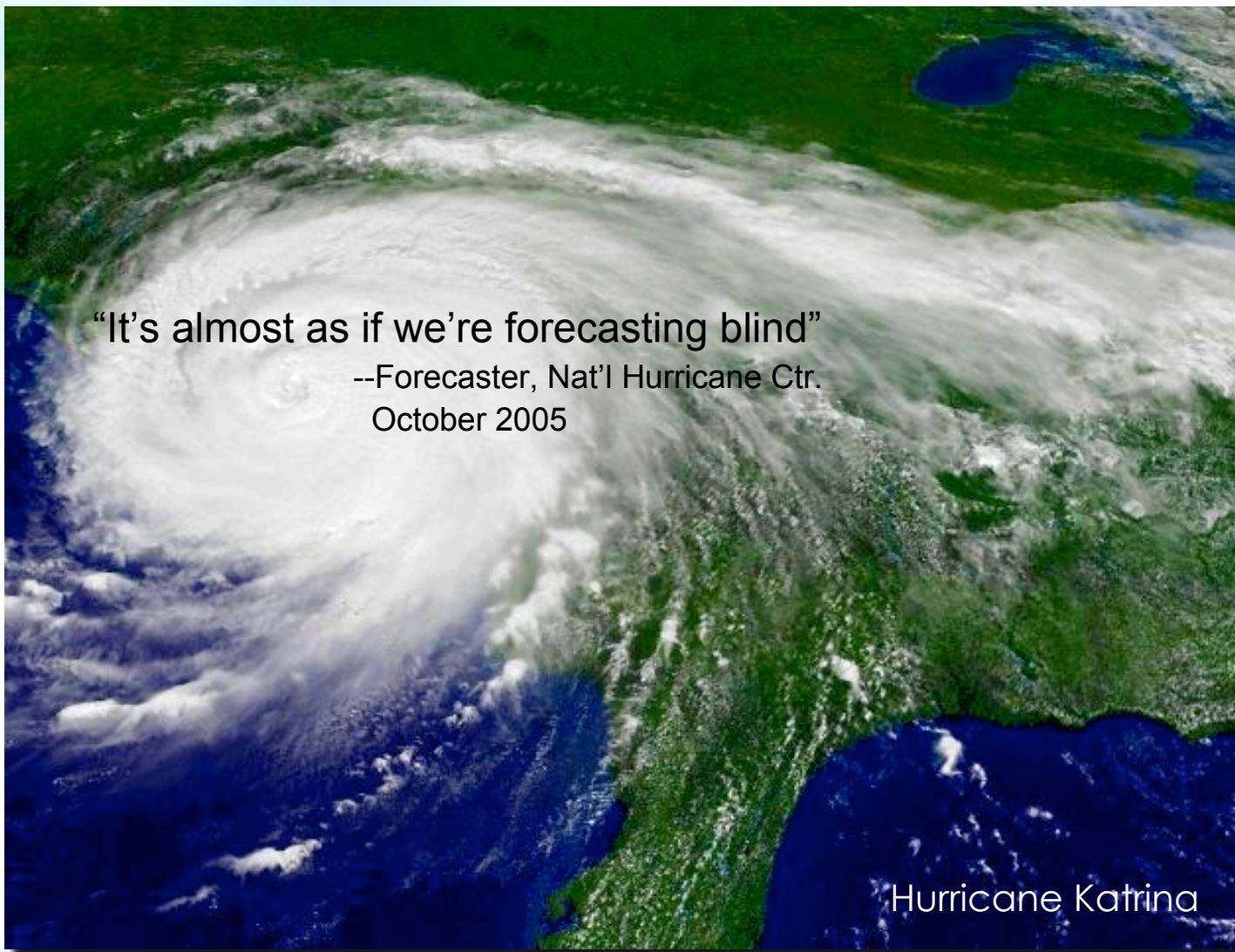


Storm Forecasting





Hurricane and Severe Storm Forecasting



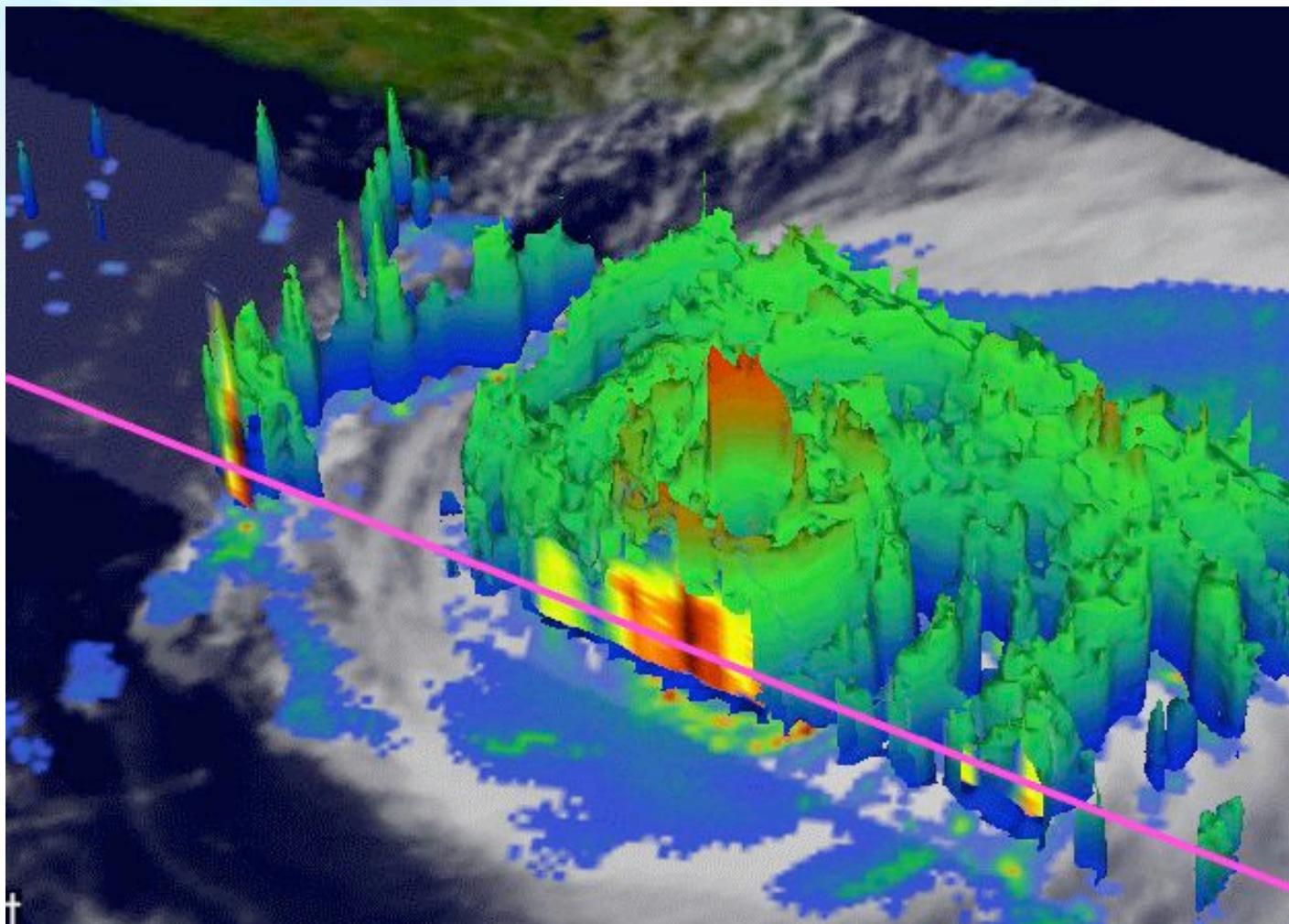
“It’s almost as if we’re forecasting blind”

--Forecaster, Nat’l Hurricane Ctr.
October 2005

Hurricane Katrina

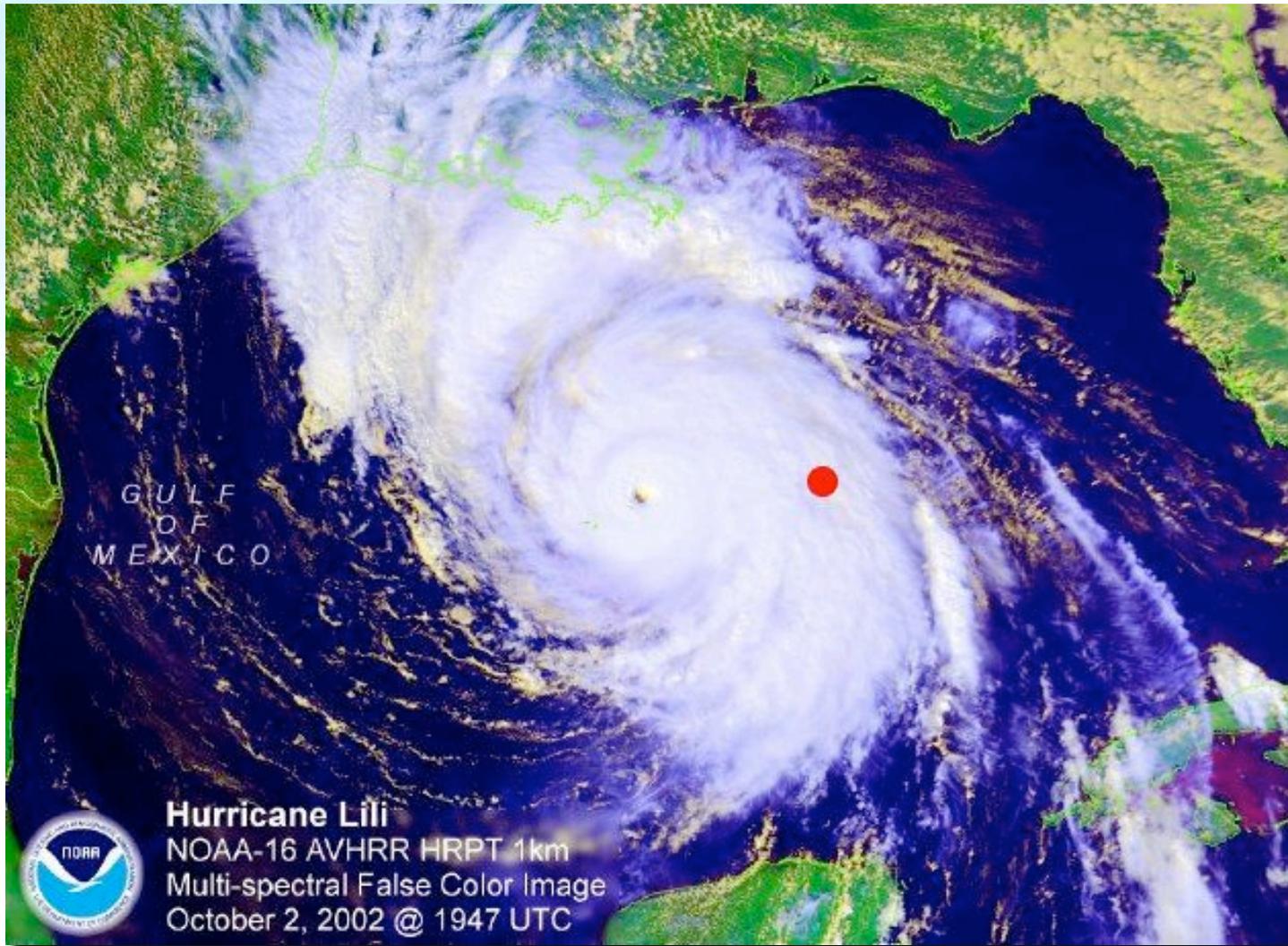


RO Offers Visibility Deep Into the Storm



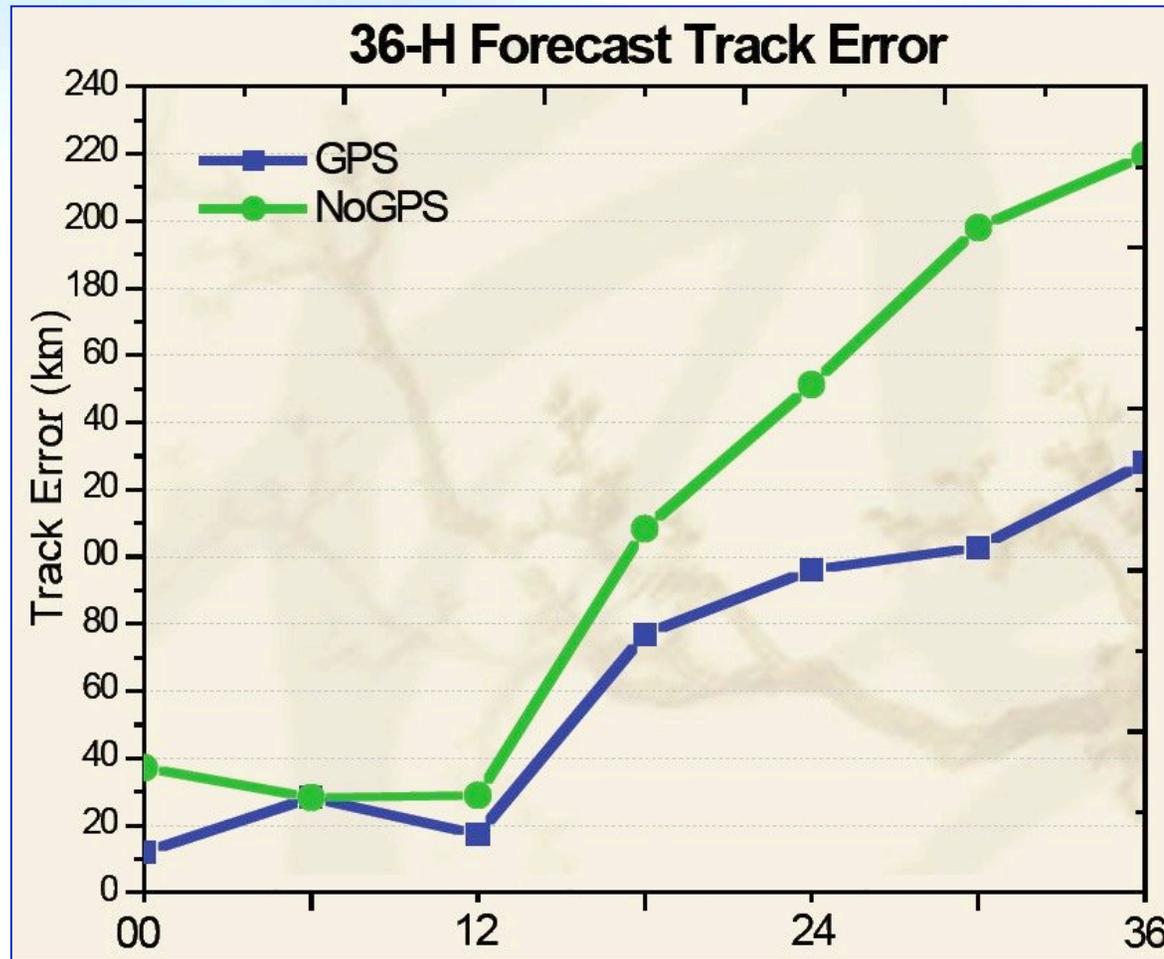


Lili Track Forecast Result from UCAR





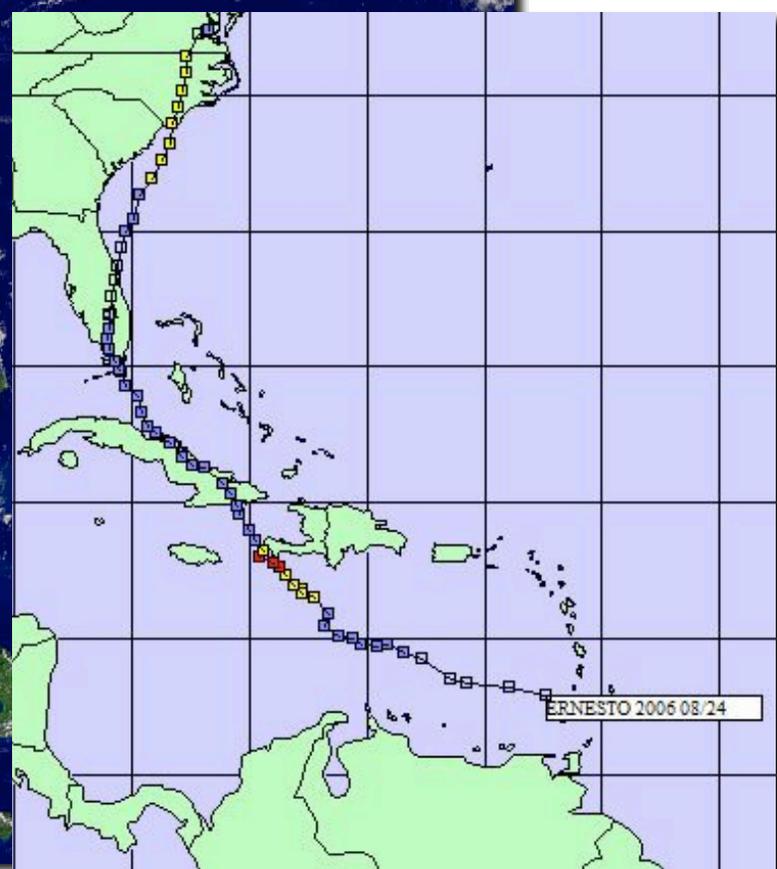
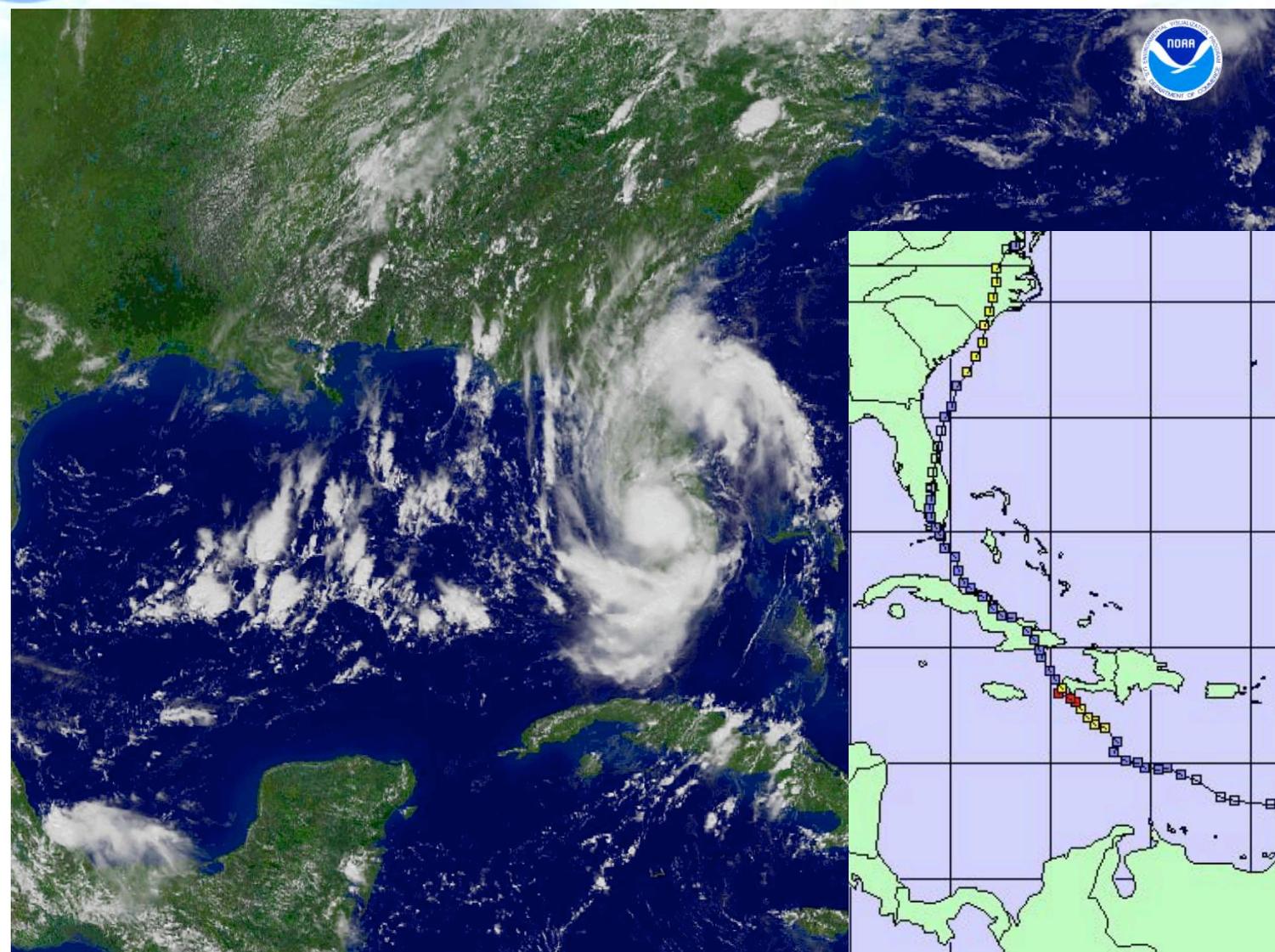
Lili Track Forecast Result from UCAR



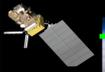
Zhang et al. (UCAR), 2005



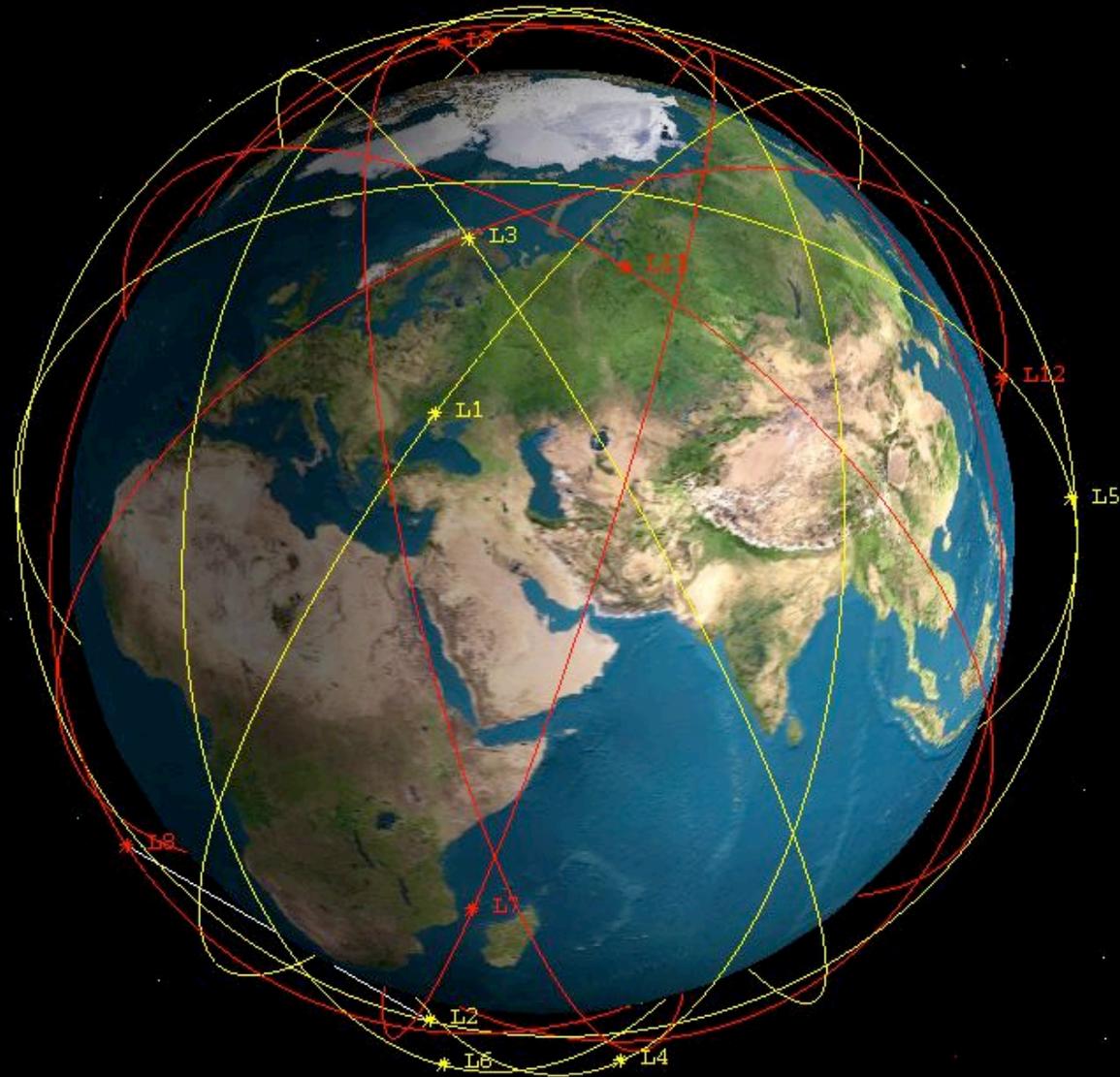
Hurricane Ernesto, Aug 2006



Future Directions



How many are enough?



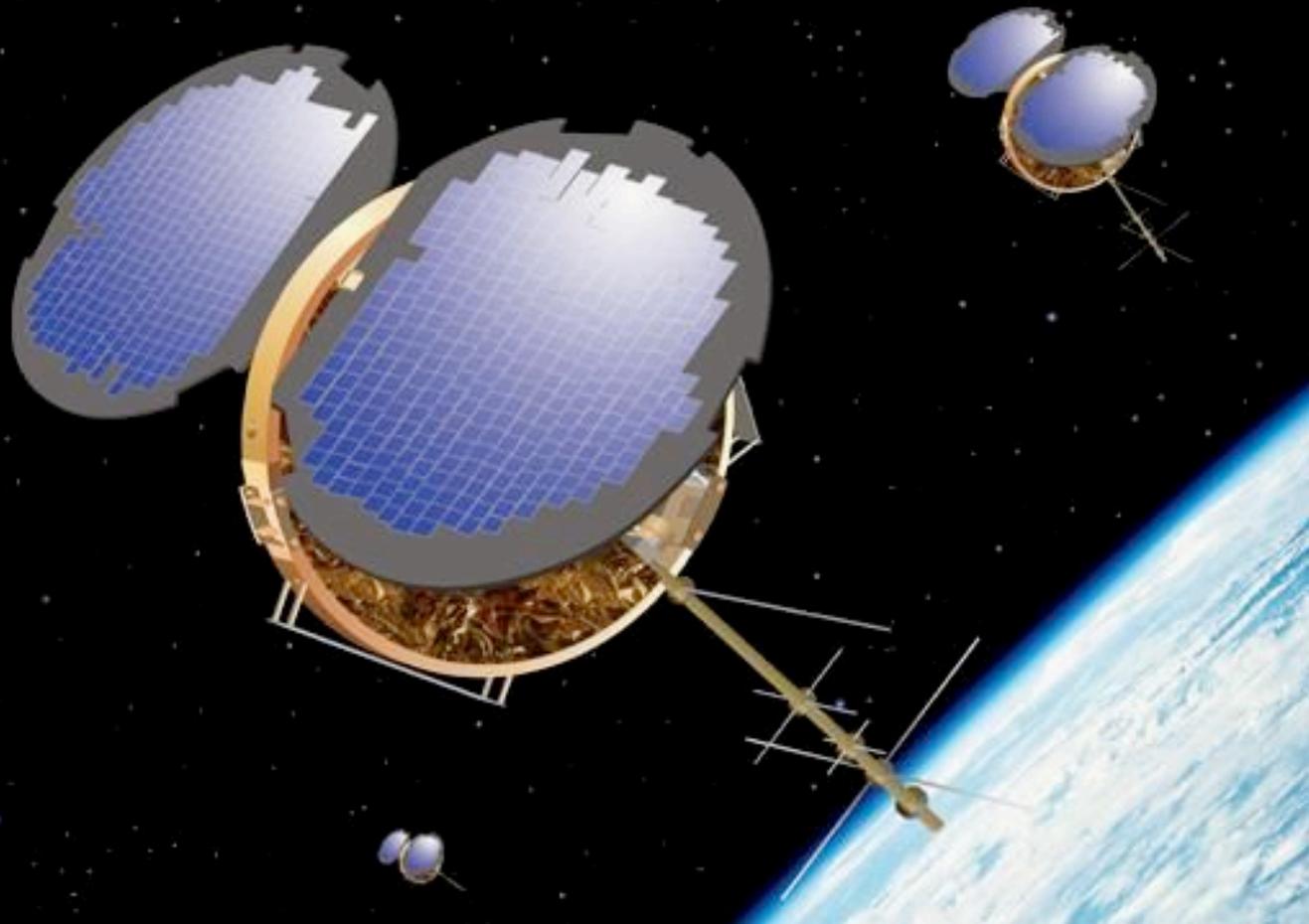
Analogy with GPS Geodesy/POD



A recent COSMIC follow-on proposal:

In 2012, let's launch COSMIC again:

- six satellites
- same Orbcomm bus
- enhanced receiver s/w





Go-Slow Phone Scenario...



Yo Digby,
Love the new
ringtone!



Some Features:

Wireless phone

Web browser

Color camera

Music player

Email server

Alarm clock

Video gamer

1000 mips processor

Bluetooth

QWERTY keyboard

Color LCD display

1 Gbyte RAM

2-week battery

Headphone jack

Loudspeaker

Camera flash

Trackball

GPS receiver (?)

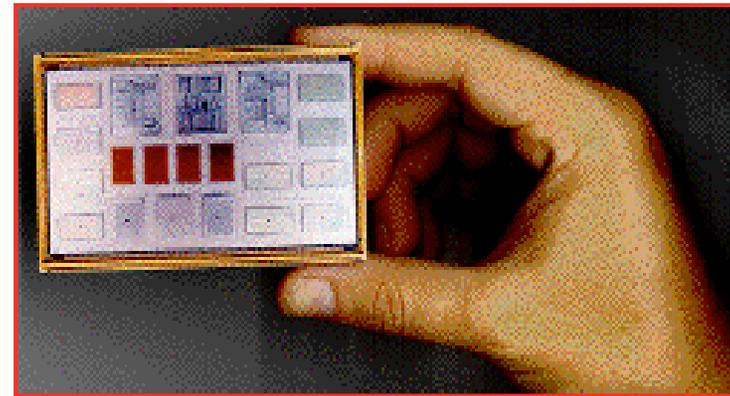


More sophisticated than
a GNSS-RO spacecraft



Multiple Receiver Functions

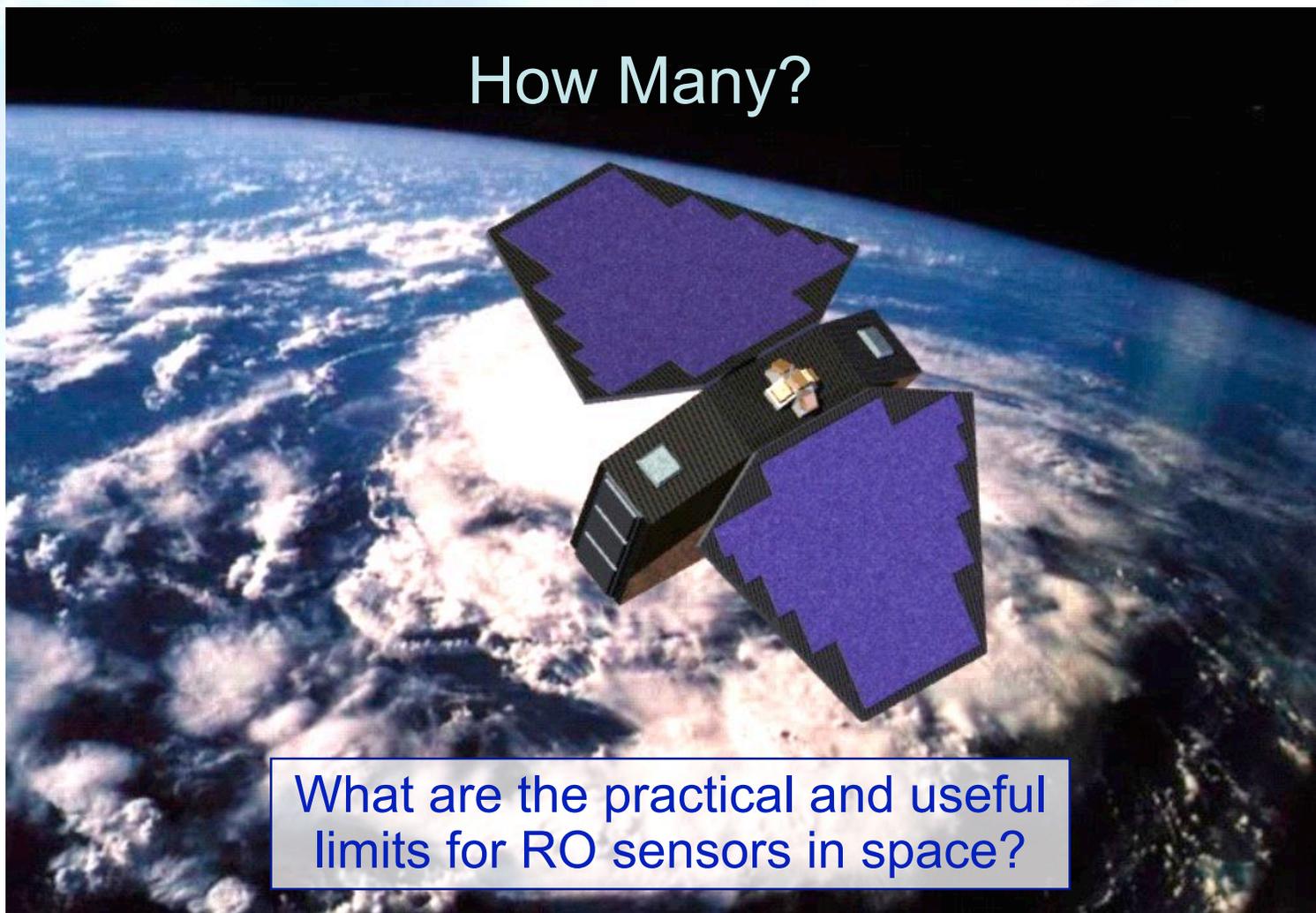
- Real-time position, velocity, attitude, and time
- On-board data storage
- Spacecraft operations
- GNSS-RO sensor



Future receiver concept



Another COSMIC-2 Concept

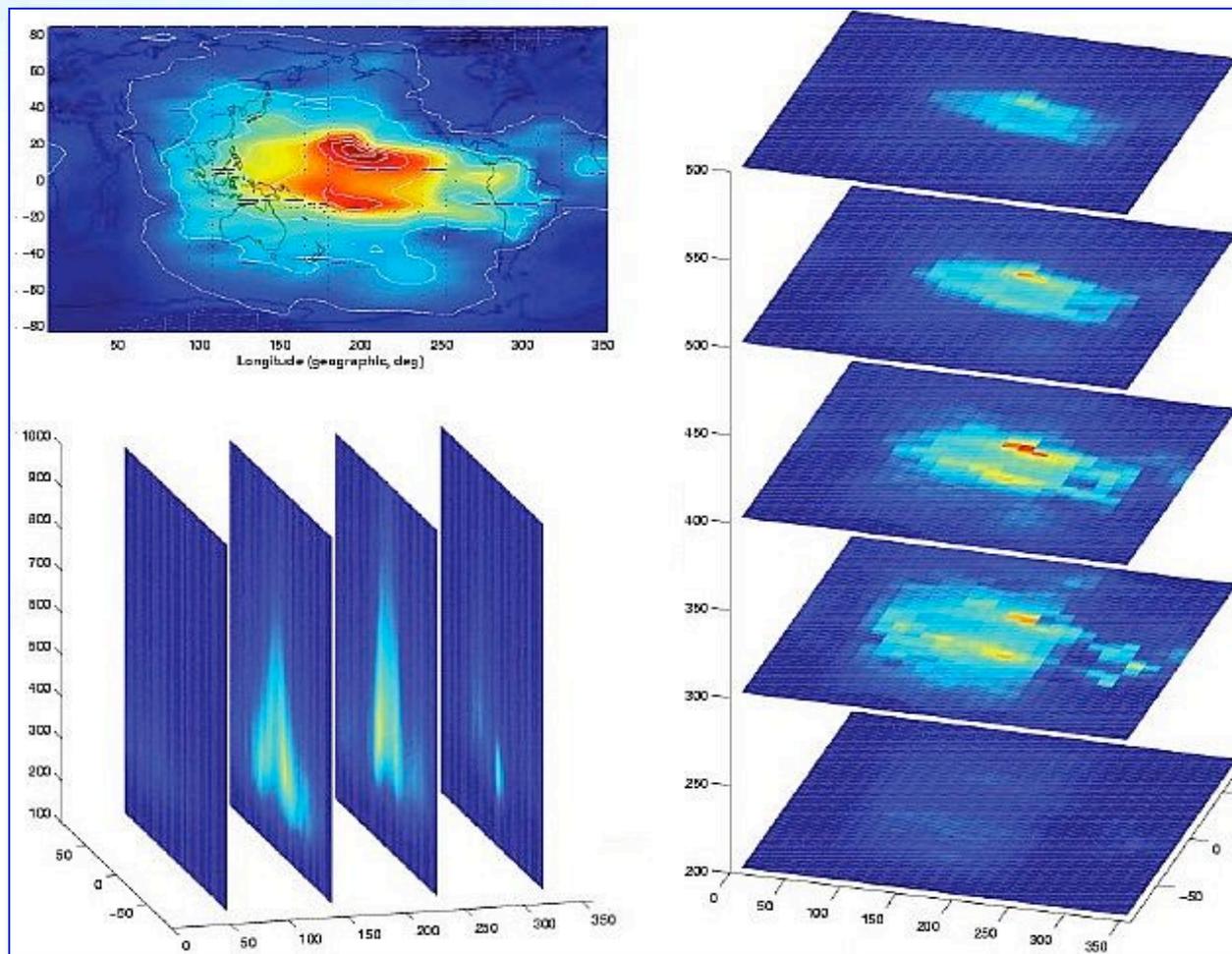


What are the practical and useful limits for RO sensors in space?

UCAR / Broad Reach

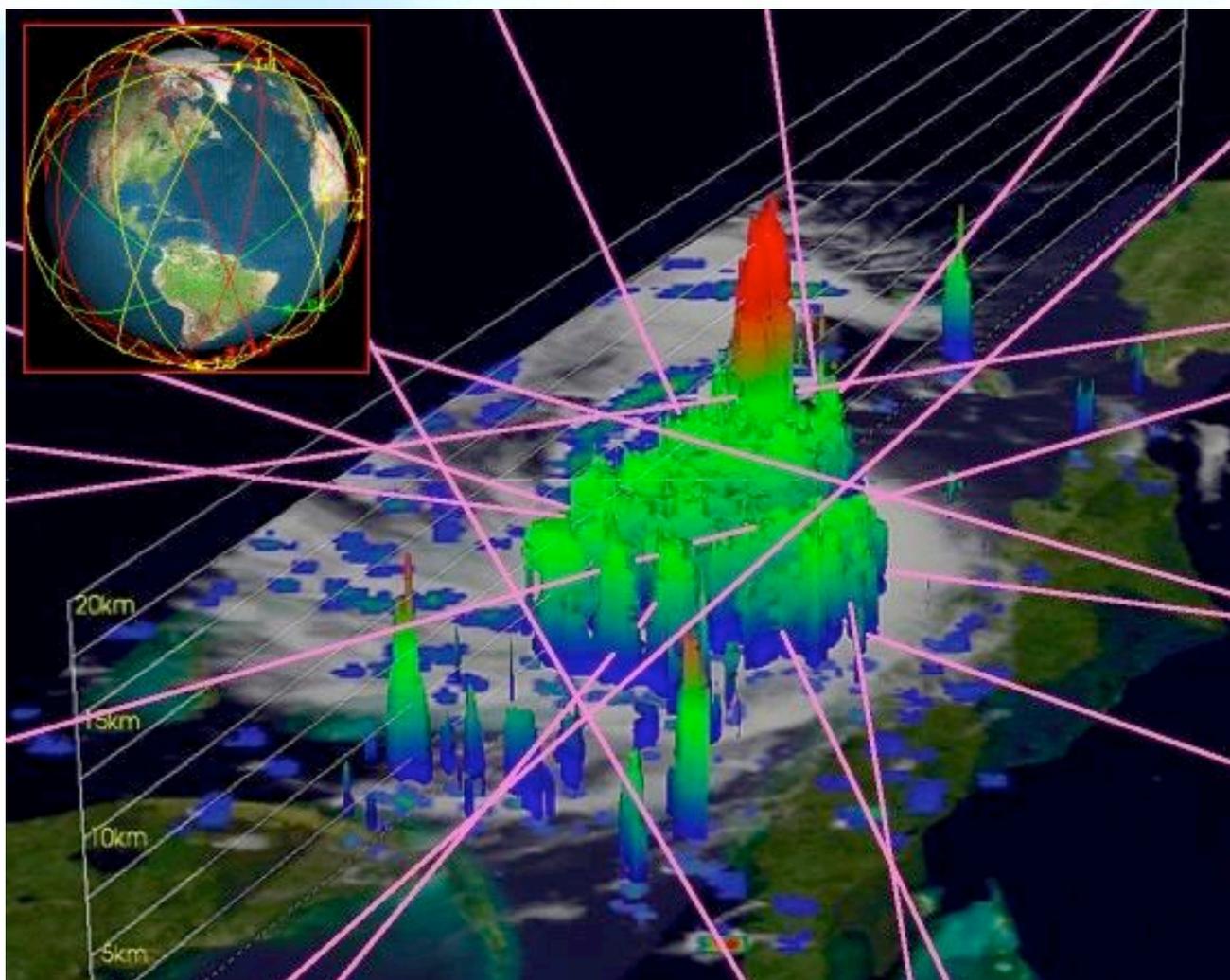


High-Resolution Snapshot 3D Global Ionospheric Imaging





12 GPS/Galileo RO Receivers



8-10 profiles/day in a hurricane-size region



Dense Occultation Constellations

