Geo-microwave Sounder/GeoSTAR Development and PATH (Precipitation All Weather Temperature and Humidity Soundings) Status

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Advanced Satellite Planning and Technology
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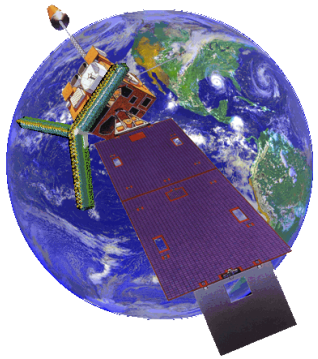


Topics

- Overview
- Background
- Limitations of Current GOES IR Sounder
- Polar IR and MW Soundings
- NOAA Sample User Requirements
- GeoSTAR development and Current Status
- GeoSTAR Applications and Benefits
- NOAA GeoSTAR Working Group
- Potential Next Steps

Overview

- OSD has been working with NASA and JPL (Bjorn Lambrigtsen, PI) to advance the Technology Readiness Level (TRL) of a geostationary microwave sounder, the Geostationary Thinned Aperture Radiometer (GeoSTAR) to better meet NWS requirements.
- Benefits of a geostationary microwave sounder:
  - Continuous coverage in all weather conditions
  - Rapid data refresh for monitoring severe weather
  - Improved hurricane tracking capability
- JPL's work (PI Bjorn Lambrigtsen) on Geo-STAR since ~ 2000 is leading to manifesting on the Decadal Survey mission called PATH, after 2020, and potentially on GOES-R follow-on Program
- JPL is looking for an earlier flight opportunity through the NASA Earth Venture Instrument (EV-I1) – seeking partnership with NOAA.

Background

- **Microwave Sounders have been flying on NOAA's Polar-orbiting Operational Environmental Satellites (POES) since 1978.**
  - **Microwave Sounding Unit (MSU), 100 km res, 4-channels, (1978-1998)**
  - **Advanced MSU A, 45-km res, 15 channels (1998-)**
  - **Advanced MSU B / Microwave Humidity Sounder, 15-km res, 5 channels (1998-)**
  - **Advanced Technology Microwave Sounder (ATMS), (2011-)**
- **AMSU observations have contributed to improvement of weather and severe storm prediction.**
- **However, limited refresh rate of AMSU and IR-only capability of GOES leaves a gap in NOAA's ability to improve the accuracy of severe storm forecasts, especially over the data-sparse oceans. Therefore, a geostationary microwave capability, such as Geo-STAR, was recommended by the science community and National Research Council (NRC) in 2007.**
  - **A sounding suite of IR and Geo-STAR will be able to make observations under clear as well as cloudy conditions, every 15-30 minutes, leading to more accurate hurricane prediction**
  - **Geo-STAR humidity observations will improve our ability to predict severe weather and pre-tornado environment, leading to improved lead time for tornado warnings.**

Background (continued)

- 1980s: NOAA has been interested in Geo-microwave sounder. Large antenna, accommodation on s/c and scanning were considered problems.

  Dr Fred Moser NWS/Storm Center and Dr. Norm Grody /ORA were active.

- 1995: Geosynchronous Microwave Sounder Working Group (GMSWG) was established and a NOAA funded study was conducted; final report in 1997.

  - 59 Participants including NWS, NESDIS, NASA, JPL, MIT,

  -The group concluded that:

  (1) Geo-microwave Sensors penetrate clouds to permit temperature and humidity soundings that can drive mesoscale numerical weather predictions with update time of one hour,

  (2) Geo-microwave sensors can map most precipitation from space at one hour intervals and,

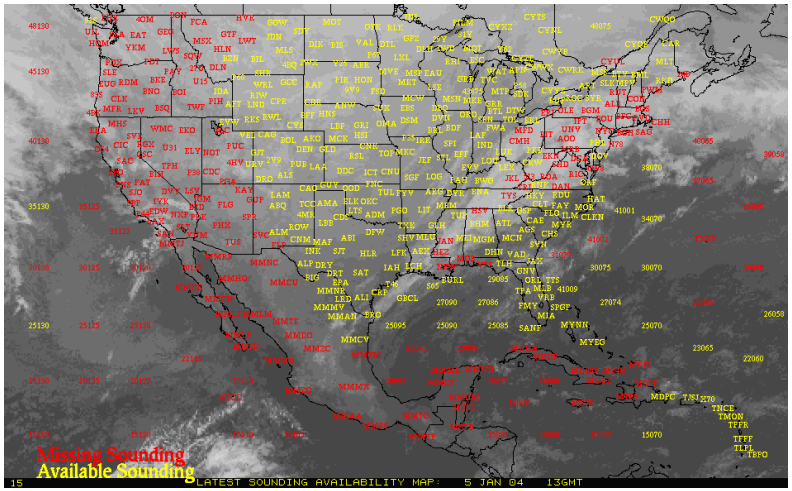
  (3) Technological advances permit microwave sounders to augment IR sounders in geostationary orbit in a practical, affordable manner

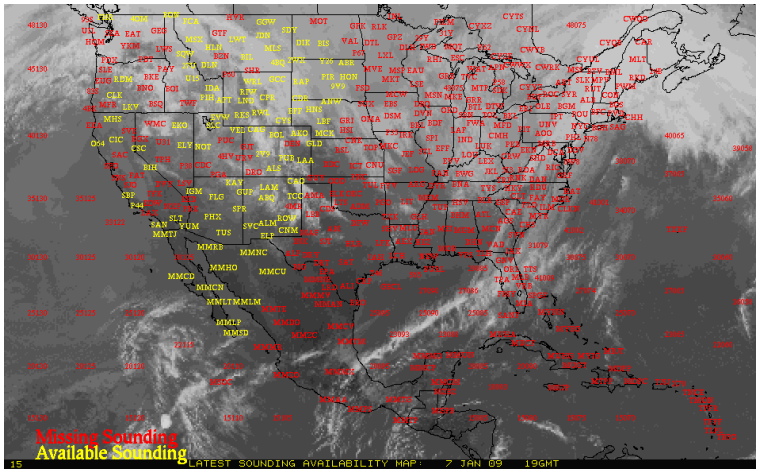
  - Baseline instrument: 118, 183, 380 and 485 GHz, with 2 m antenna and spot diameters of 66, 42, 20 and 20 km respectively.

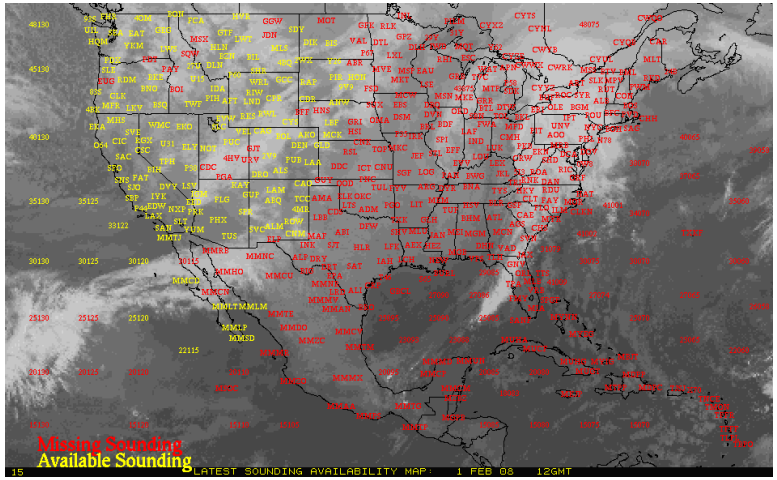
  -Small team of members visited JPL, Aerojet, TRW, Hughes, Millitec to learn the current state of the art of component and antenna technologies.

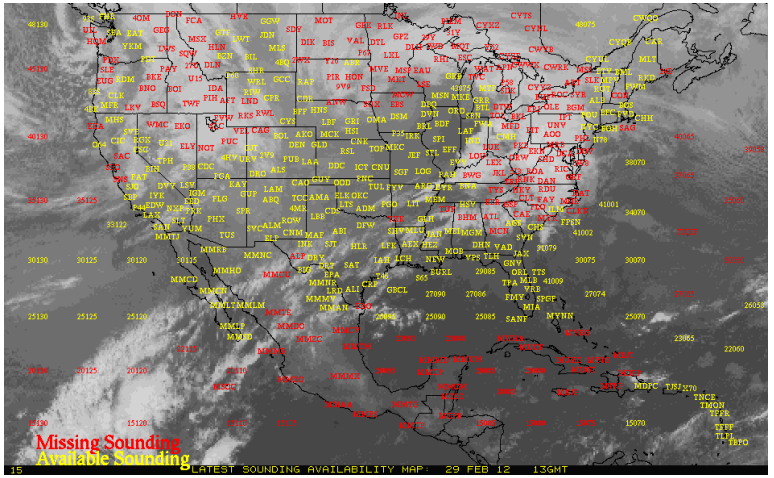
Limitations of GOES IR Sounder

Yellow: Available Soundings (No clouds), Red: Not Available (Clouds)



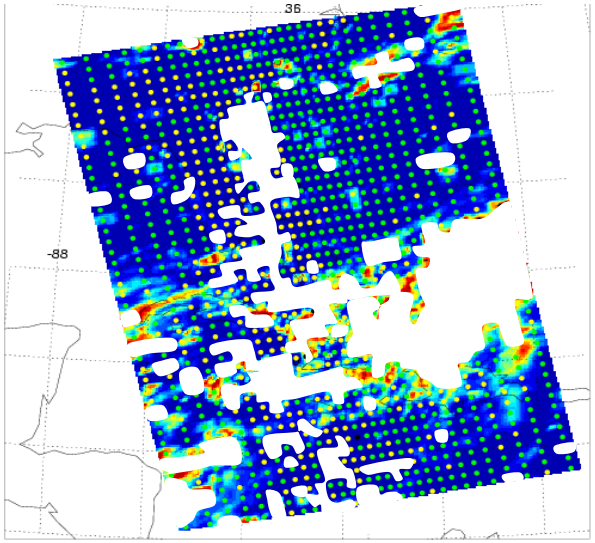




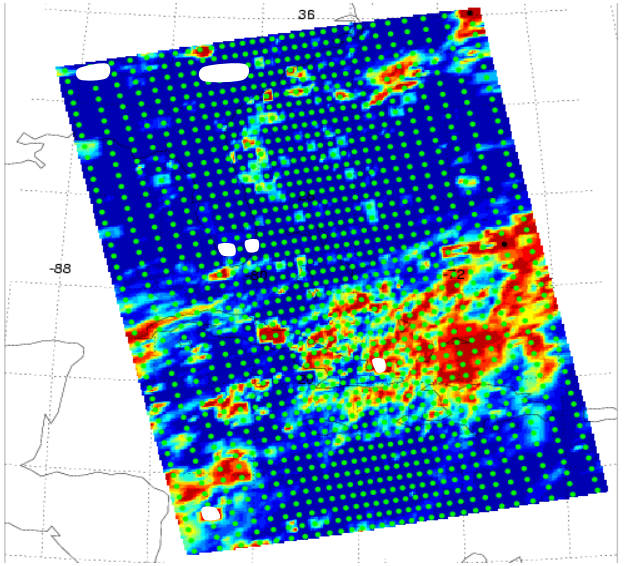


Current GOES IR sounding http://www.orbit.nesdis.noaa.gov/smcd/opdb/goes/soundings/skewt/html/skewhome.html

Impact of AMSU on Sounding Retrievals from NASA's Aqua Satellite



(a) Atmospheric Infrared Sounder (AIRS) Cloudy Retrievals



(b) AIRS + AMSU Cloudy Retrievals

GeoSTAR capability will be similar to Fig. b with better refresh rate. Example: GeoSTAR will refresh every 30 minutes as compared to single polar orbiting satellite with refresh rate of 12 hours.

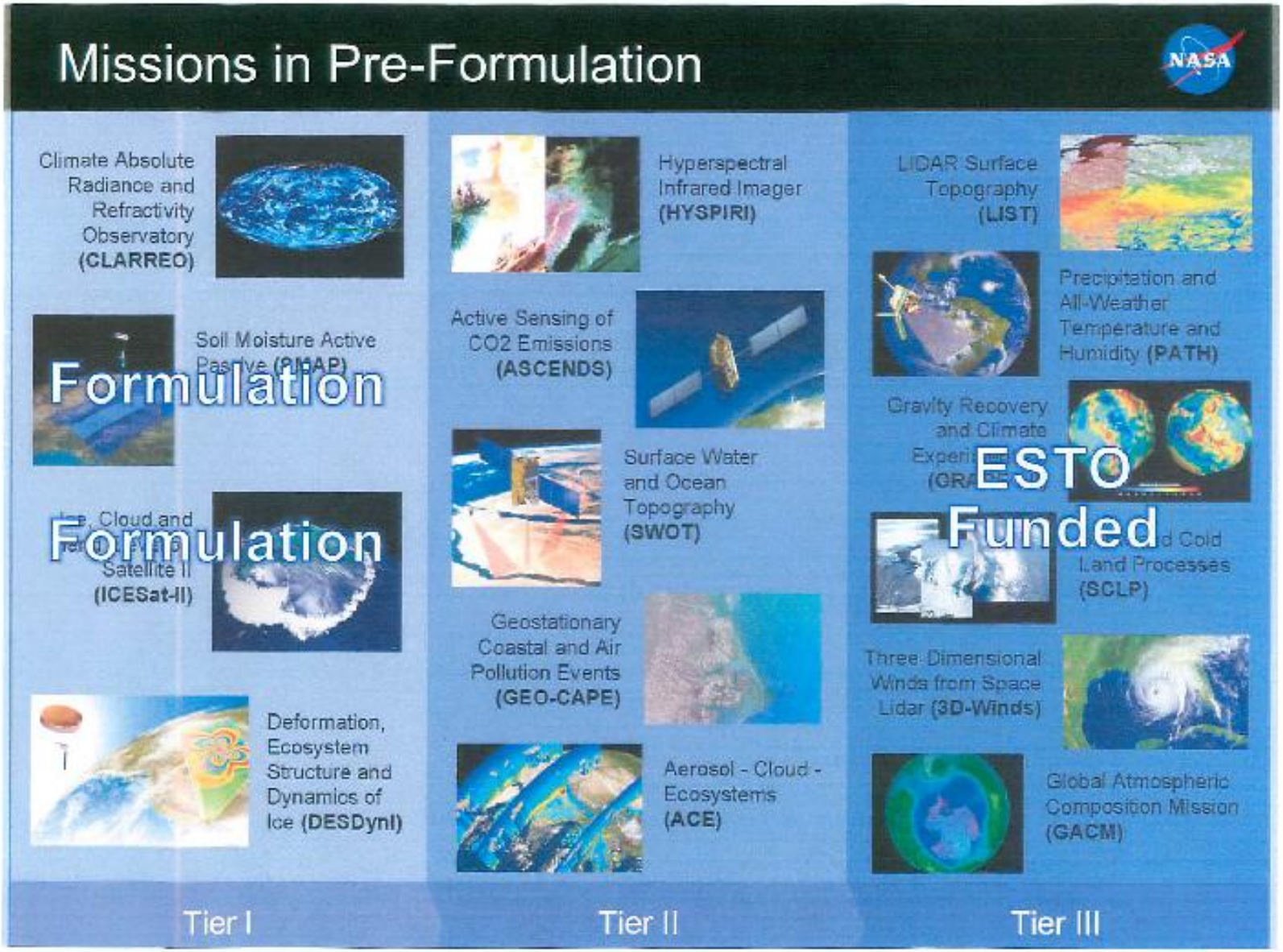
Fig. (a-b) Show Sounding Retrievals on May 20, 2006.

- **Blue Color Indicates 0% clouds**
- **White Color indicates absence of valid retrieval due to clouds**
- **Dark Red indicates clouds**
- **Dots are markers that show center of FOV.**

(courtesy of Bjorn Lambrigtsen / JPL)

(Sample NOAA User Requirements)

Observational Requirements	Coverage	Spatial Resolution	Vertical Resolution	Refresh Rate
Atmospheric Vertical Temperature	CONUS	10 km	1 – 3 km	60 min
	Hemisphere	10 km	1 – 3 km	60 min
Atmospheric Vertical Moisture	CONUS	10 km	1-3 km	60 min
	Hemisphere	10km	1-3 km	60 min
Total Water Content	CONUS	25 km	-	60 min
	Hemisphere	100 km	-	180 min
Precipitation Rate	CONUS	10 km	-	5 min
	Hemisphere	10 km	-	30 min
Sea Surface Winds	Coastal	1 km	-	60 min
	CONUS/Offshore	10 km	-	60min
Hail Detection	CONUS	2 km	TBD	5 min
	Hemisphere	2 km	-	15 min



NASA's Decadal Survey Missions

Aperture Synthesis Concept in Operation

Very Large Array (VLA) at National Radio Astronomy Observatory (NRAO)

ESA's Soil Moisture and Ocean Salinity (SMOS) launched in 2009

GeoSTAR System Concept

GeoSTAR is an *interferometric* system

Concept

- Sparse array employed to synthesize large aperture
- Cross-correlations (Fourier transform of Tb field)
- Inverse Fourier transform on ground (Tb field)
- Optimal Y configuration: 3 sticks; N elements. Each element is one receiver, 3.5 λ wide (2.1 cm @ 50 GHz, 6 mm @ 183 GHz). Example: N = 100 $\Rightarrow$ Pixel = 0.09° $\Rightarrow$ 50 km at nadir (nominal)
- One "Y" per band.

Technology

MMIC receivers

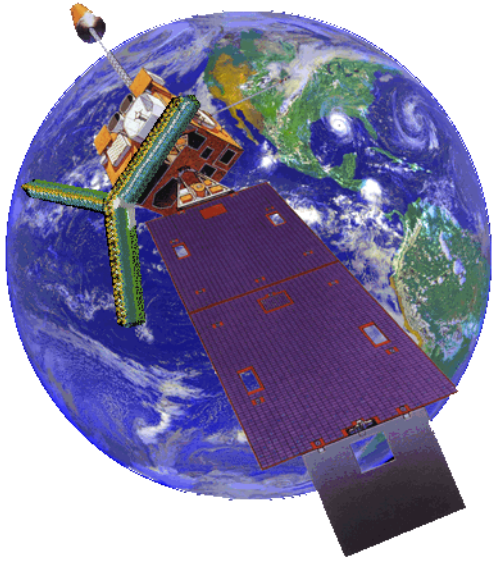
- Receivers off-the-shelf @ < 100 GHz; Chips available

Correlator chips

- Chips developed for IIP, some issues remain, development Continues under IIP-10

System

- Image reconstruction (Brightness temps from correlations) demonstrated under Proto-type GeoSTAR development



JPL GeoSTAR development and Current Status

- **1998-1999: NASA New Millennium Program (EO-3 mission) - $0.7M**

  -"**GEO/SAMS (Synthetic Aperture Microwave Sounder)" Concept selected for Phase A: Concept, instrument & mission study was completed.**

- **2003-2006: NASA/ESTO Instrument Incubator Program (IIP-03) - $3.0M**

  -Proof-of-concept prototype: T-sounder operating at 50 GHz

  -Technology: 50-GHz MMIC receivers; low-mutual-coupling feed horn array

  -Outcome: Successful, proved that STAR concept works.

  -OSD: Provided strong Letter of support to Lambrigtsen for his IIP Proposal.

- **2004: NOAA Study of GeoSTAR for Geo/MEO Missions- $100K**

- **2007 Decadal Survey: PATH (Precipitation and All weather Temperature Humidity Mission) is Selected as one of the Missions by NRC.**

- **2007: NOAA GeoSTAR Assessment study – ($150K)**

JPL GeoSTAR development and Current Status (contd.)

- **2008-2011: NASA Instrument Incubator Program (IIP-07) - $3.6M + NOAA funding ($750 K)**

  -Develop technology required for q-sounding at 183 GHz (subsystems only)

  -Technology: 183-GHz MMIC receivers; alias-rejecting antenna array; ASIC correlator & digitizer

  -Outcome: Successful (except for ASIC correlator)

- **2011-2014: NASA Instrument Incubator Program (IIP-10) - $4.5M**

  -Develop all elements required for "GeoSTAR-full" (PATH mission)

  -Fully functional q-sounder with flight-like ASIC correlator

  -Technology: All elements brought to near TRL 6, ready for PATH implementation

  - OSD: Provided strong Letter of Support to Bjorn Lambrigtsen for his proposal.

- **Status of GeoSTAR Technology in 2011**

  -Receivers & antenna: Ready to implement for all bands, all near TRL 6

  -Correlator: Ready to implement with FPGA (per feasibility study), at TRL 6; Swedish ASIC correlator, now being tested, may be substituted when ready TRL 6

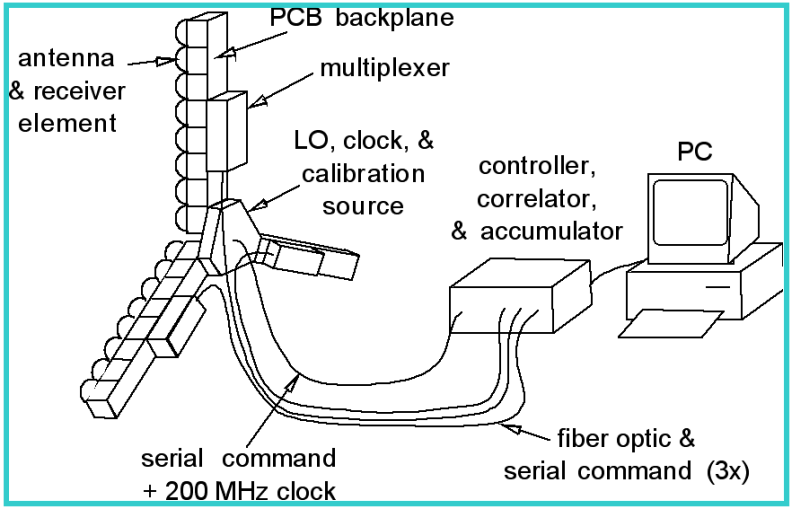
  -Mass, power, volume: Moderately low estimates per Team-X studies

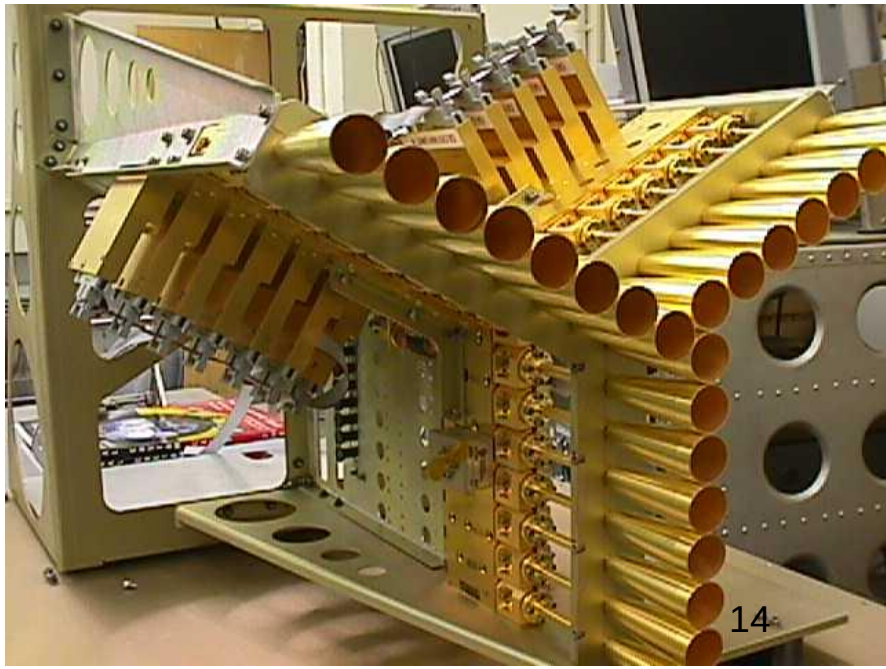
  -Summary: Ready to implement "GeoSTAR-lite" (PATH precursor/demonstrator)

GeoSTAR Prototype Development

- **Objectives**
  - Technology risk reduction
  - Develop system to maturity and test performance
  - Evaluate calibration approach
  - Assess measurement accuracy

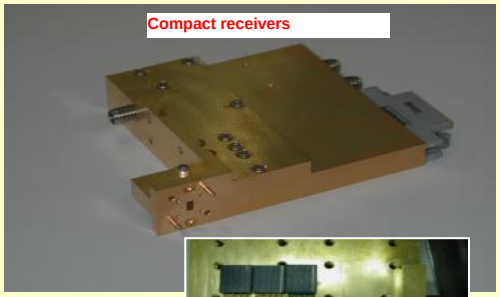
- **Small, ground-based**
  - 24 receiving elements - 8 per Y-arm
  - Operating at 50-55 GHz
  - 4 tropospheric AMSU-A channels: 50.3 - 52.8 - 53.71/53.84 - 54.4 GHz
  - Implemented with miniature MMIC receivers
  - Element spacing as for GEO application (3.5 λ)
  - FPGA-based correlator
  - All calibration subsystems implemented

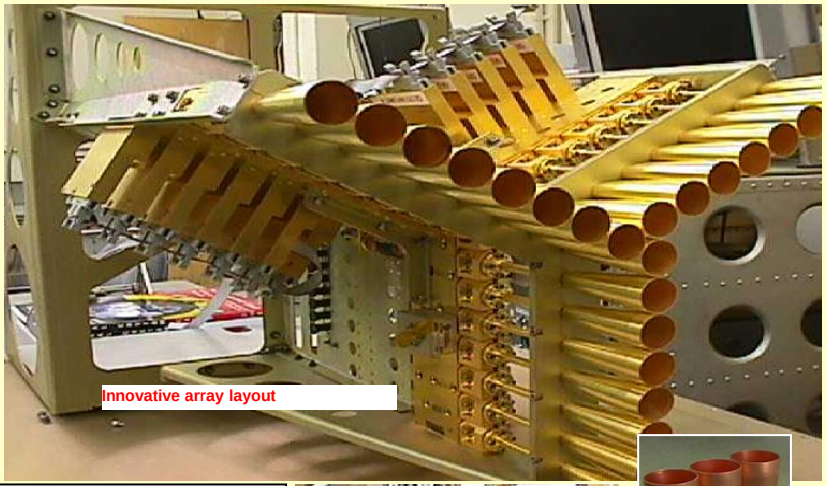


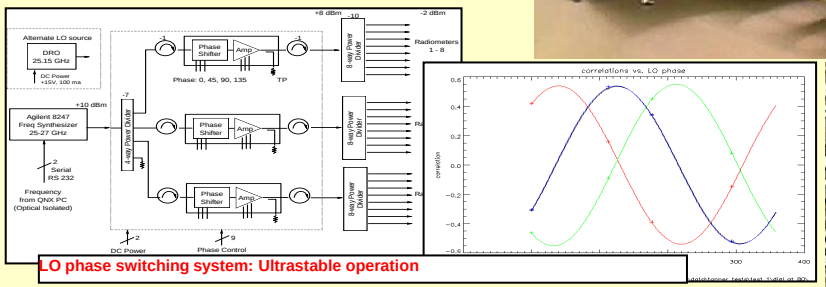


GeoSTAR Prototype Development

STAR concept and key technologies developed & tested

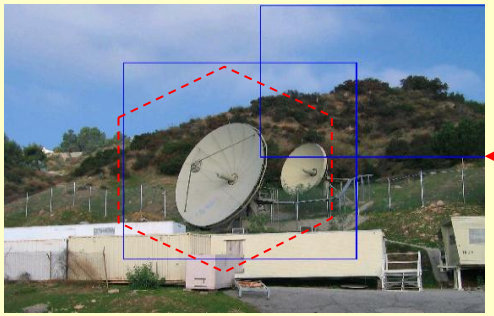


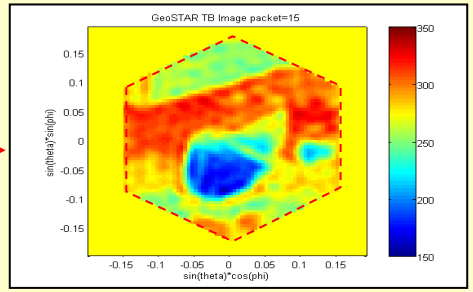




LO phase switching system: Ultrastable operation

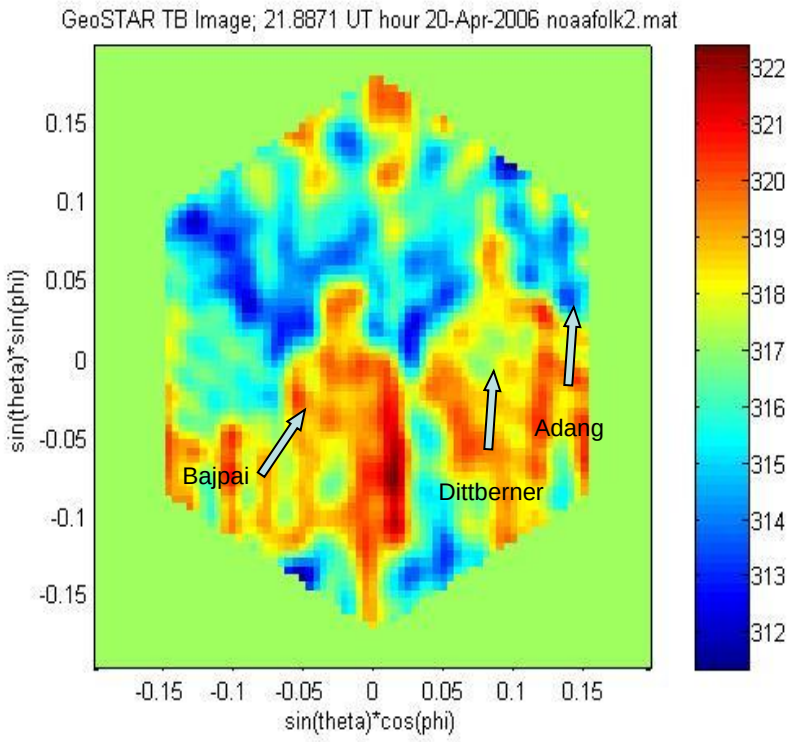
Feedhorns:
Low mutual coupling





First images
at 50 GHz
by aperture
synthesis

The image of NOAA Team at JPL
April 20, 2006, taken by proto-type GeoSTAR



From Left: Shyam Bajpai, Gerry Dittberner, Tom Adang is seen in part, he is out of field of view

NOAA Geo-STAR Users Working Group

- A NOAA Working Group on Geostationary Microwave Soundings was established in 2010 with members from STAR, NHC, NWS/ST, OSD, and GOES-R.
- The Working Group meets periodically to discuss the requirements and benefits of GeoSTAR, assess development progress, and determine what further steps are needed to continue development and implementation of GeoSTAR at NOAA.

  - As a result of a July 2010 mid-term progress review in Silver Spring, the Group recommended the following steps for the final (3rd) year of the current GeoSTAR IIP effort by JPL
    - Potential impacts on NWP and hurricane intensity forecast using OSSE's
    - Better understanding of instrument specifications (NEDT, Spectral coverage…)
    - Validation of GeoSTAR's precipitation and cloud parameter capabilities by testing STAR's microwave – only retrieval systems.

GeoSTAR Applications and Benefits to NOAA Operational Services

The Geo-STAR Users Working Group determined that GeoSTAR will benefit the following applications:

- Tropical Cyclone Center Location
- Tropical Cyclone Structure Determination
- Microwave-based Intensity Estimates
- CIMSS SATCON Technique
- Rainfall Analysis and Forecasting
- Severe Local Storm Forecasting
- All Weather Temperature and Humidity Soundings

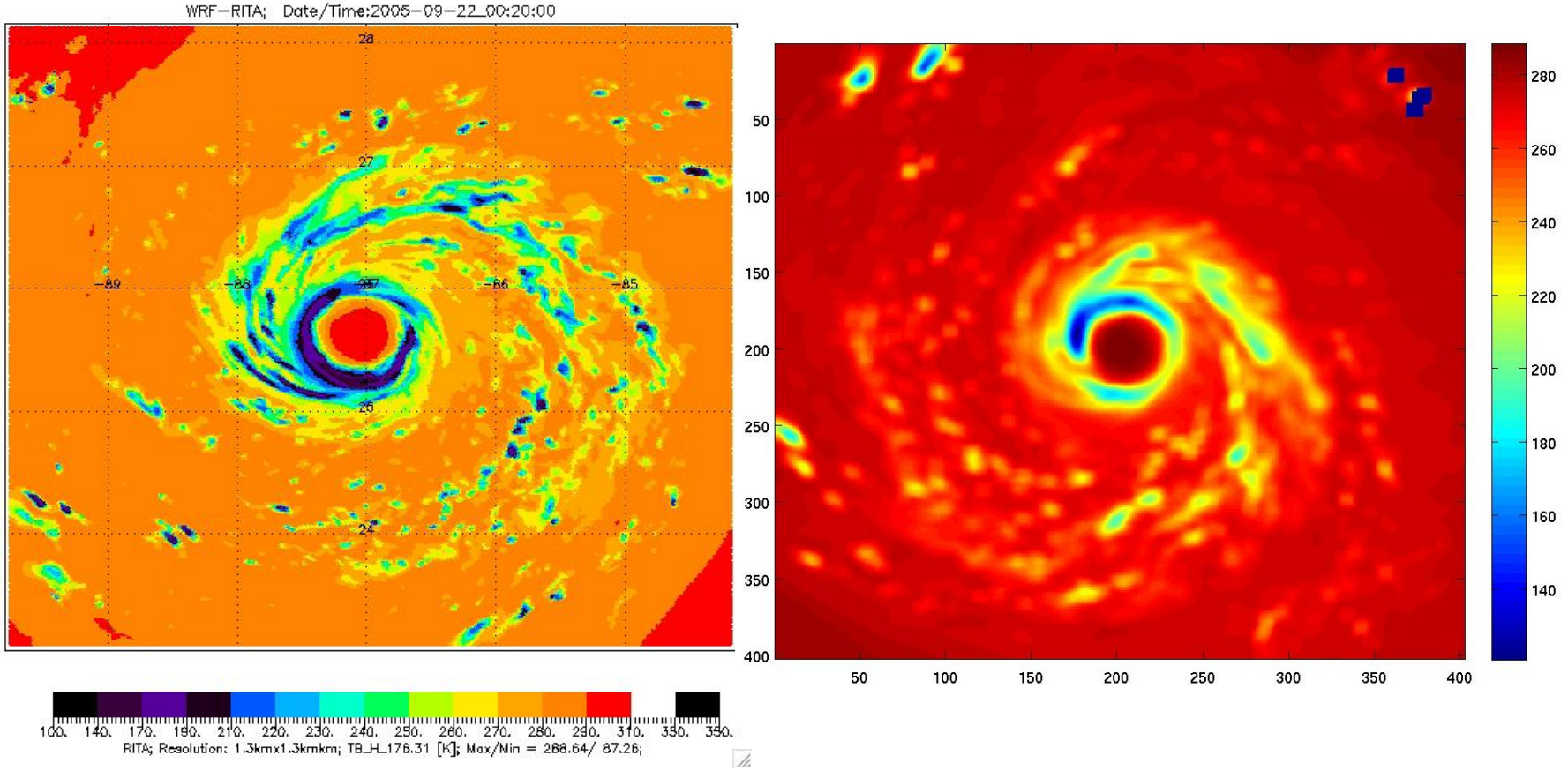
Example of expected performance from GeoSTAR

Brightness Temperature Images at 183±7 GHz

Left: At full WRF (Weather research Forecast Model) spatial resolution (1.3 km)

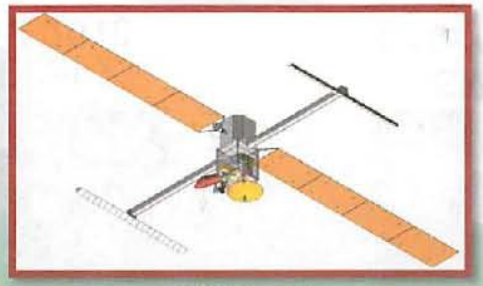
Right: At GeoSTAR spatial resolution (25 km)

(Horizontal axis in the units of 1.4 km, vertical axis in the units of 1.33 km)



ESD Missions in Pre-Formulation thru 2020

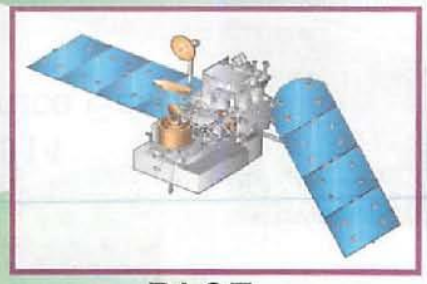
EV-2
2017



SWOT
2019
w/CNES, Ocean &
fresh water topography

DESDynI-Radar
LRD TBD

ASCENDS
>2020
CO2 & other GHG



PACE
2019/2020
Ocean Color & Polarimetry

Instrument
Developments

EV-I4
~2019

EV-I3
~2018

EV-I2
~2017

EV-I1
~2016

Conclusions and Potential Next Steps

- **Conclusions**
  - In past 10 years, the GeoSTAR instrument has matured from a concept to a capability ready for space demonstration
  - Technology similar to GeoSTAR is flying on ESA's SMOS polar-orbiting sun-synchronous research satellite
  - NOAA has partnered with NASA and JPL on GeoSTAR at nearly every stage of its development
- **Next Steps-** As a precursor to the Decadal Survey recommended PATH mission (Tier III – several years away):
  - Bjorn Lambrigtsen/JPL plans to submit a proposal under NASA Earth Ventures Instrument Announcement of Opportunity for an early pathfinder demonstration of GeoSTAR
  - JPL is requesting partnership where NOAA might contribute in the areas of both science and ground activities including data processing, product generation, and archiving.
  - This is an excellent opportunity for NOAA/NESDIS to form a partnership with JPL for the demonstration Mission!