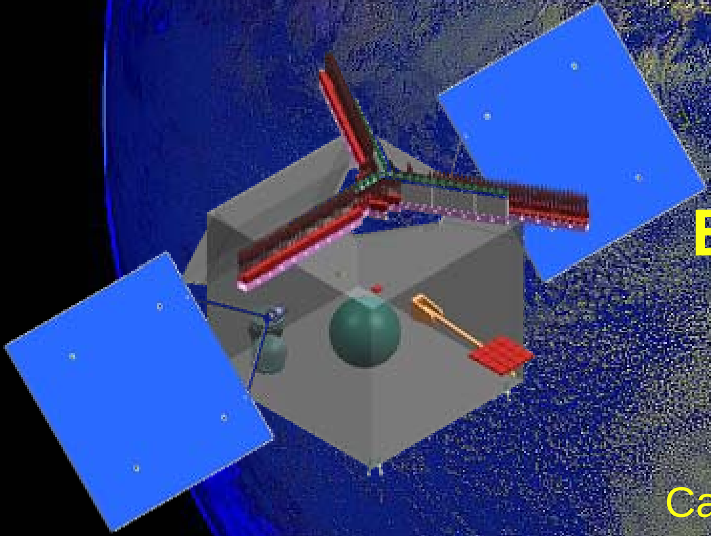
National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Developing a geosynchronous AMSU

A GeoSTAR update



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Jet Propulsion Laboratory
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ITSC-XVII

Monterey; April 14-20, 2010

The bottom line: GeoSTAR is coming!

Two years ago we posed a question at IHC:

…and the answer is:

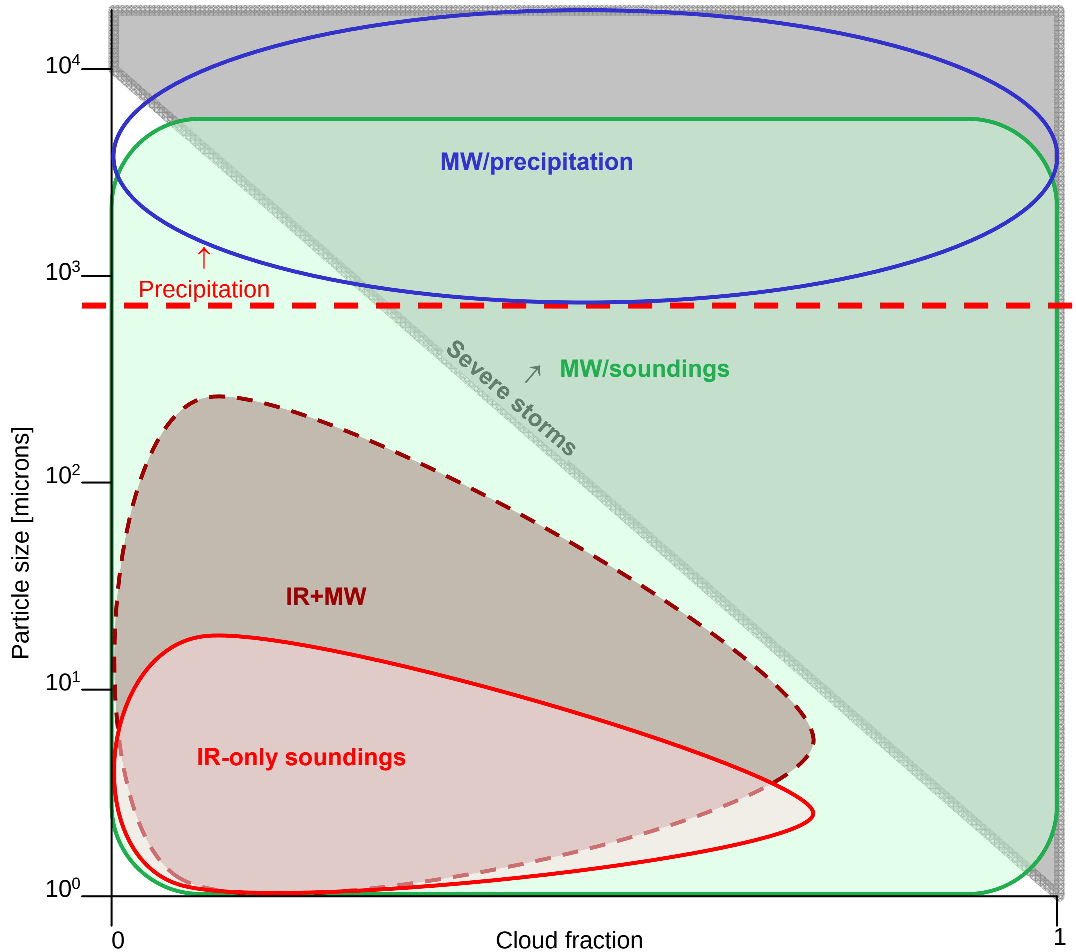
- The technology is maturing rapidly
- Ready to build a mission ~2012
- GeoSTAR could fly ~2016-2018
- Low-cost "mission-of-opportunity"
  - Possibly hosted on GOES-S
- **Get ready!**

The "GeoSTAR-pathfinder" mission concept:

- Partners: NASA + NOAA + others [TBD]
- Funding: NASA + partner contributions [TBD]
- Themes: Hurricanes, severe storms, cloudy weather
- Satellite: Positioned over N. Atlantic?
  - Tropical weather moving west → US
  - Midlatitude weather moving east → Europe

Research-to-Ops in partnership!

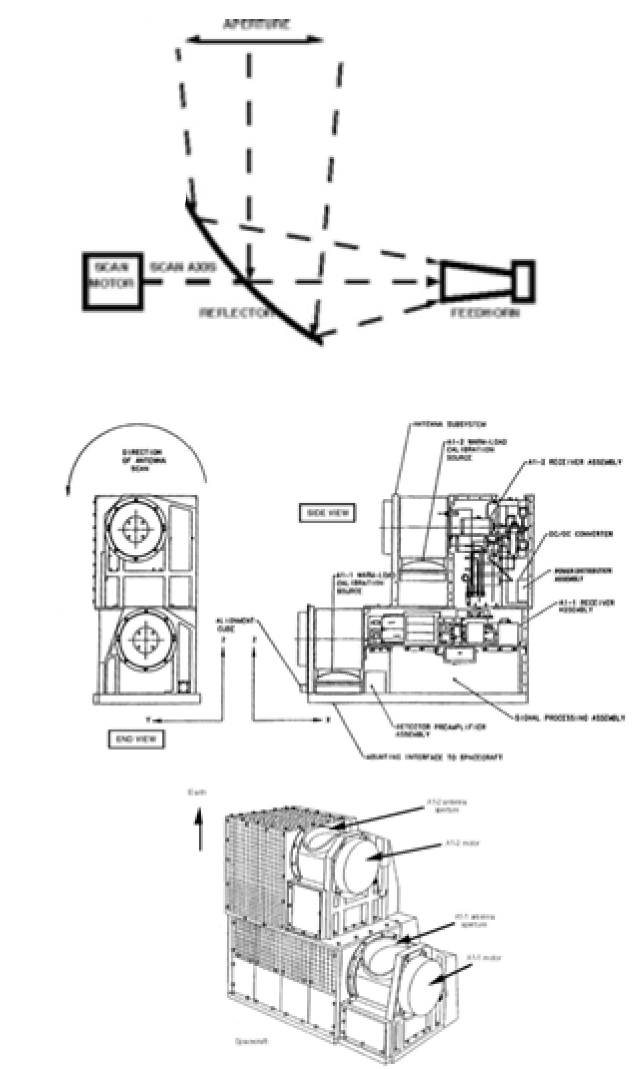
Why we need microwave sounders



Note: This is a 2-D view of a multidimensional world

Additional dimensions include spatial and temporal scales

Geosynchronous microwave sensors



Low-earth-orbiting MW sounder (AMSU)

The *antenna* is the key…

- Antenna size is determined by distance and "spatial resolution"
- AMSU antenna is 6" in dia. ⇒ 50-km resolution from 870 km
- GEO orbit is ~37000 km ≈ 43 x 870 km
- AMSU-antenna must then be 43 x 6" to give 50-km res. from GEO
- This is 21 feet (6.5 meters)! Not feasible!

  This can be reduced somewhat by degrading the antenna efficiency - but still impractical

•Solution: *Synthesize* large antenna ⇒ GeoSTAR

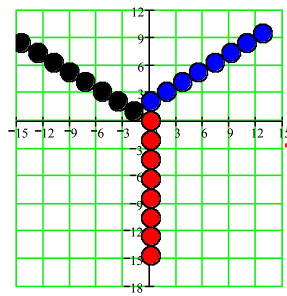
…and *time* is of the essence

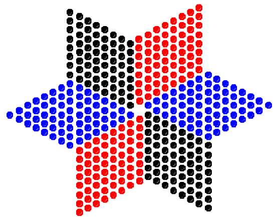
Observe continuously; full set of products every 15 minutes

GeoSTAR overview

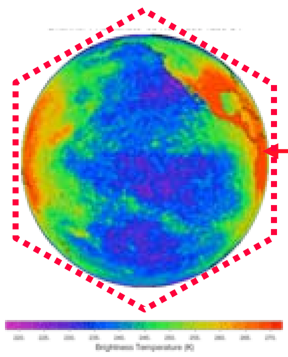
- **Problem: How to develop a microwave sounder for geostationary orbit?**
  - Need: Time-continuous all-weather observations of the atmosphere
  - Challenge: Achieve adequate spatial resolution from 37,000 km
- **Solution: Aperture-synthesis concept**
  - Can make a very large aperture w/out large parabolic dish antenna
  - Sparse array employed to synthesize large aperture
  - Spatial interferometry -> Fourier transform of Tb field
  - Inverse Fourier transform on ground -> Tb field
  - Bonus: No moving parts, simultaneous 2-D “synoptic” imaging
- **Design: Sparse array - GeoSTAR**
  - Optimal: Y-configuration; 3 “sticks”; 100-200 elements each
  - Each element = I/Q receiver, ~4λ wide (6 mm @ 183 GHz!)
  - Example: 100/arm ⇒ Pixel = 50 km at nadir ≈ LEO sounders
  - One “Y”-array per sounding band, interleaved
- **Proof of concept**
  - Ground-based prototype under NASA/ESTO/IIP, 2003-2006
  - Performance is excellent & as predicted => Proof of concept
- **Risk reduction for space mission**
  - Further technology development under IIP, 2008-2010
  - Mission design studies
- **“PATH” decadal-survey mission**
  - Precipitation and All-weather Temperature and Humidity
  - Ready to start implementation ~2012
- **“GeoSTAR-pathfinder”**
  - GeoSTAR-lite
  - Mission of opportunity
  - Launch ~2016-18

Receiver array & resulting uv samples

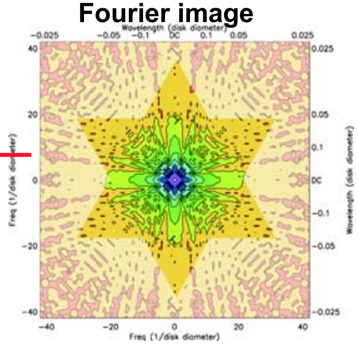


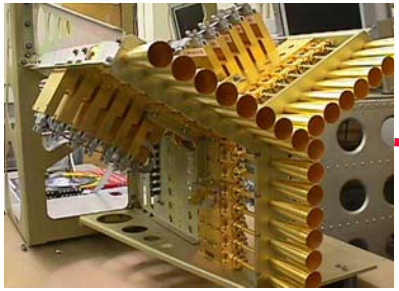


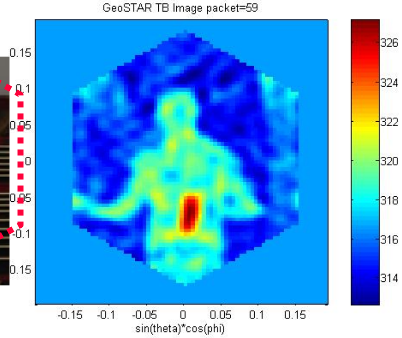
Radiometric image



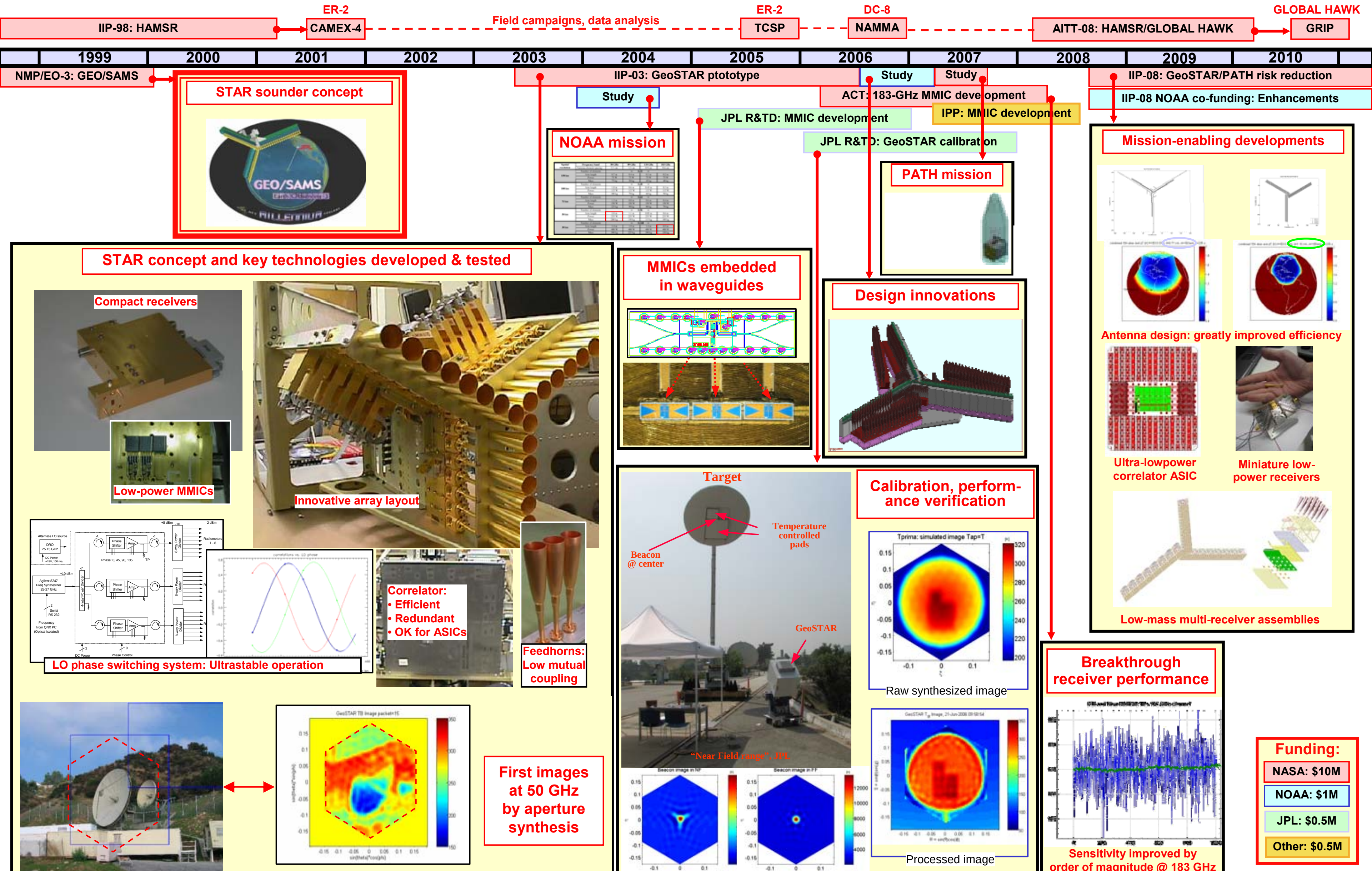
Fourier image



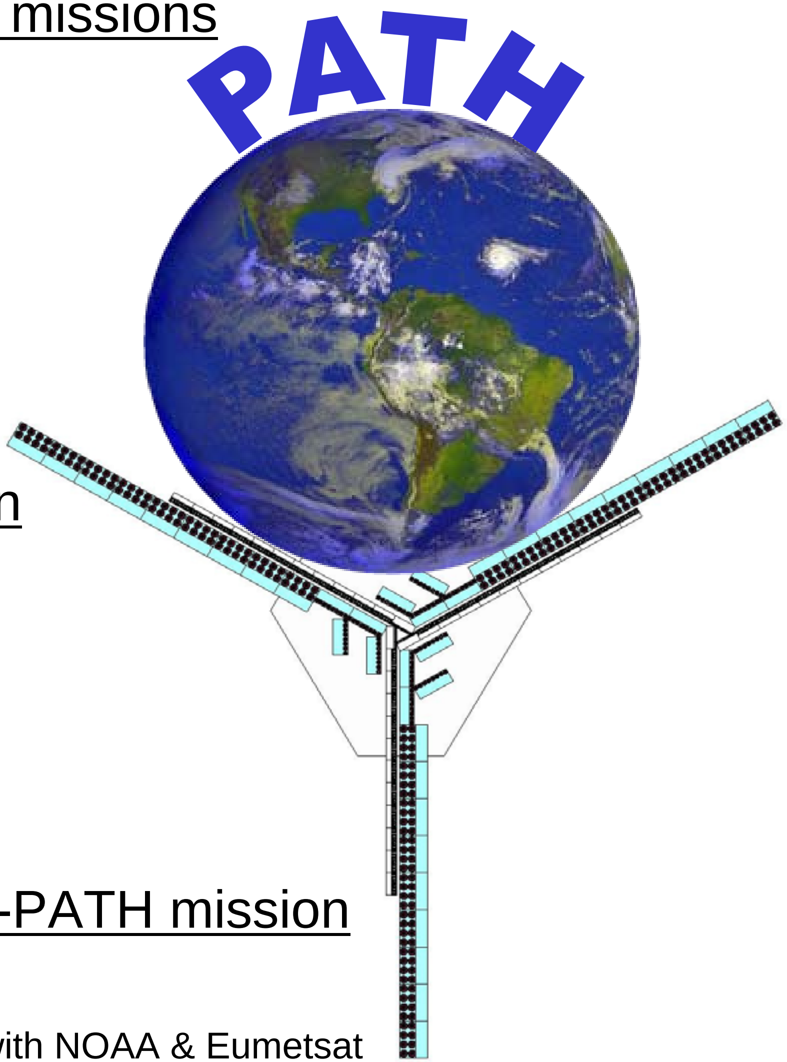




GeoSTAR technology development



PATH and GeoSTAR



"PATH" is one of 15 NASA "decadal-survey" missions

"**P**recipitation and **A**ll-weather **T**emperature and **H**umidity"

Recommended by U.S. Nat'l Acad. Sci./NRC in 2007

First *microwave sensor* in geostationary orbit

Weather & climate observations: *clouds, storms & hurricanes*

Improve models re. the hydrologic cycle ⇒ *Improved forecasts*

Improve *hurricane intensity* forecasts

"GeoSTAR" is baseline for the PATH mission

"**Geo**stationary **S**ynthetic **T**hinned **A**perture **R**adiometer"

GeoSTAR is the *first* microwave sounder for GEO

New instrument concept has been developed/demo'd at JPL

We have developed new cutting-edge *technology*

We are ready to proceed to a *space mission*

"GeoSTAR-pathfinder" is envisioned as pre-PATH mission

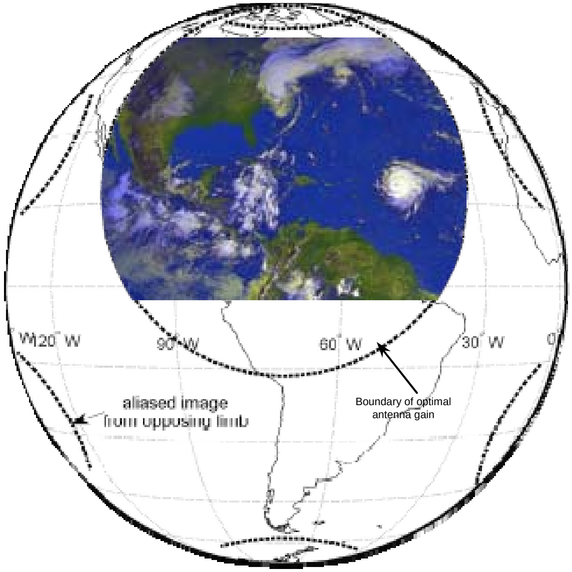
Science objectives: Subset of PATH

Mission of opportunity, costing ~1/3 of full PATH, in partnership with NOAA & Eumetsat

Ready to fly when GOES-R/S and MTG are launched

Provides the U.S. with GOES "advanced sounder" in lieu of HES

GeoSTAR/PATH applications



Hurricanes - Severe storms - Moisture flow - Hydrologic cycle - Climate

Weather forecasting **-Improve regional forecasts; severe storms**

- All-weather soundings, including cloudy and stormy scenes
- Full hemispheric soundings @<50/25 km every ~ 15-30 minutes (continuous)
- "Synoptic" rapid-update soundings => Forecast error detection; 4DVAR applications

Hurricane diagnostics **-Quintessential hurricane sensor**

- Scattering signal from hurricanes/convection easily measurable
- Measure *location*, *intensity* & vertical *structure* (incl. *shear*) of deep convection
- Detect *intensification/weakening* in real time, frequently sampled (< 15 minutes)
- Measure all three phases of water: vapor, liquid, ice - including rain/snow
- Use for operational analysis & in research to improve microphysics of models

Rain **-Compliments current capabilities**

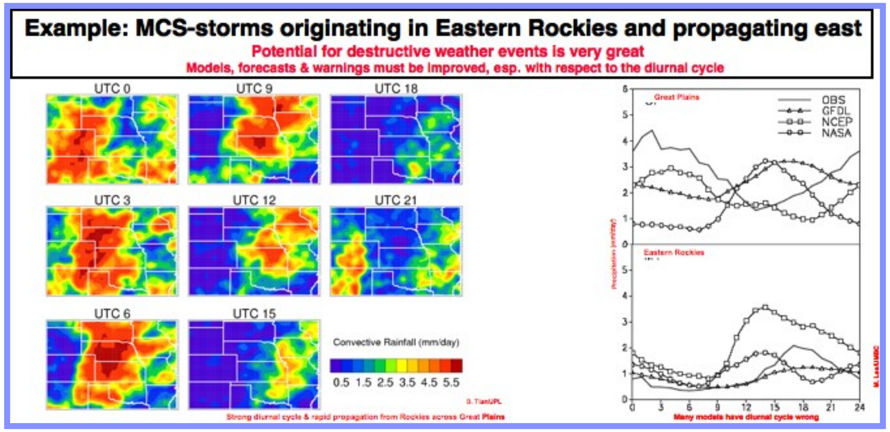
- Full hemisphere @ $\leq$ 25 km every 15 minutes (continuous) - both can be improved
- Directly measure storm and diurnal *total rainfall*: predict flooding events
- Measure *snowfall*, light rain, intense convective precipitation

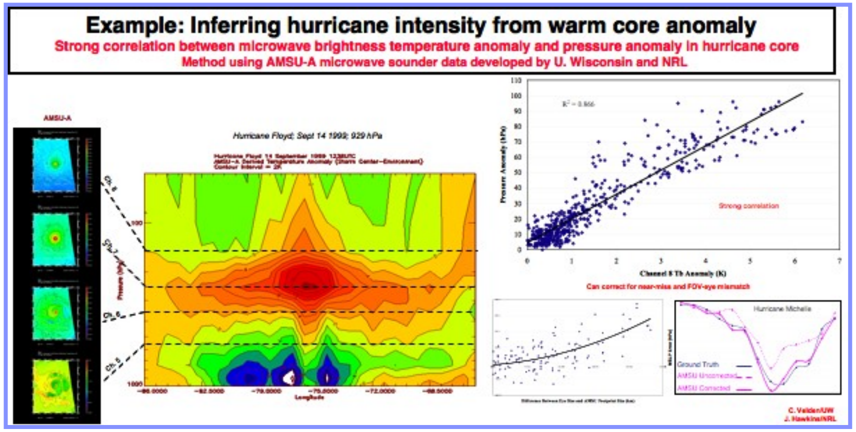
Tropospheric wind profiling **-NWP, transport applications**

- Surface to 300 mb; very high temp.res.; in & below clouds
- Major forecast impact expected (OSSE planned) - particularly for hurricanes
- Air quality applications (pollution transport)

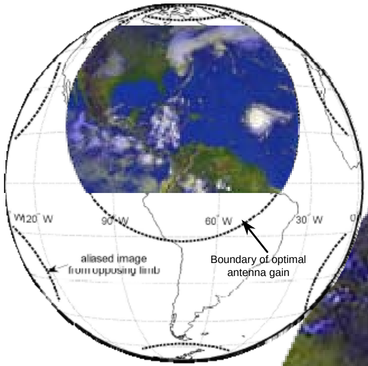
Climate research **-Hydrology cycle, climate variability**

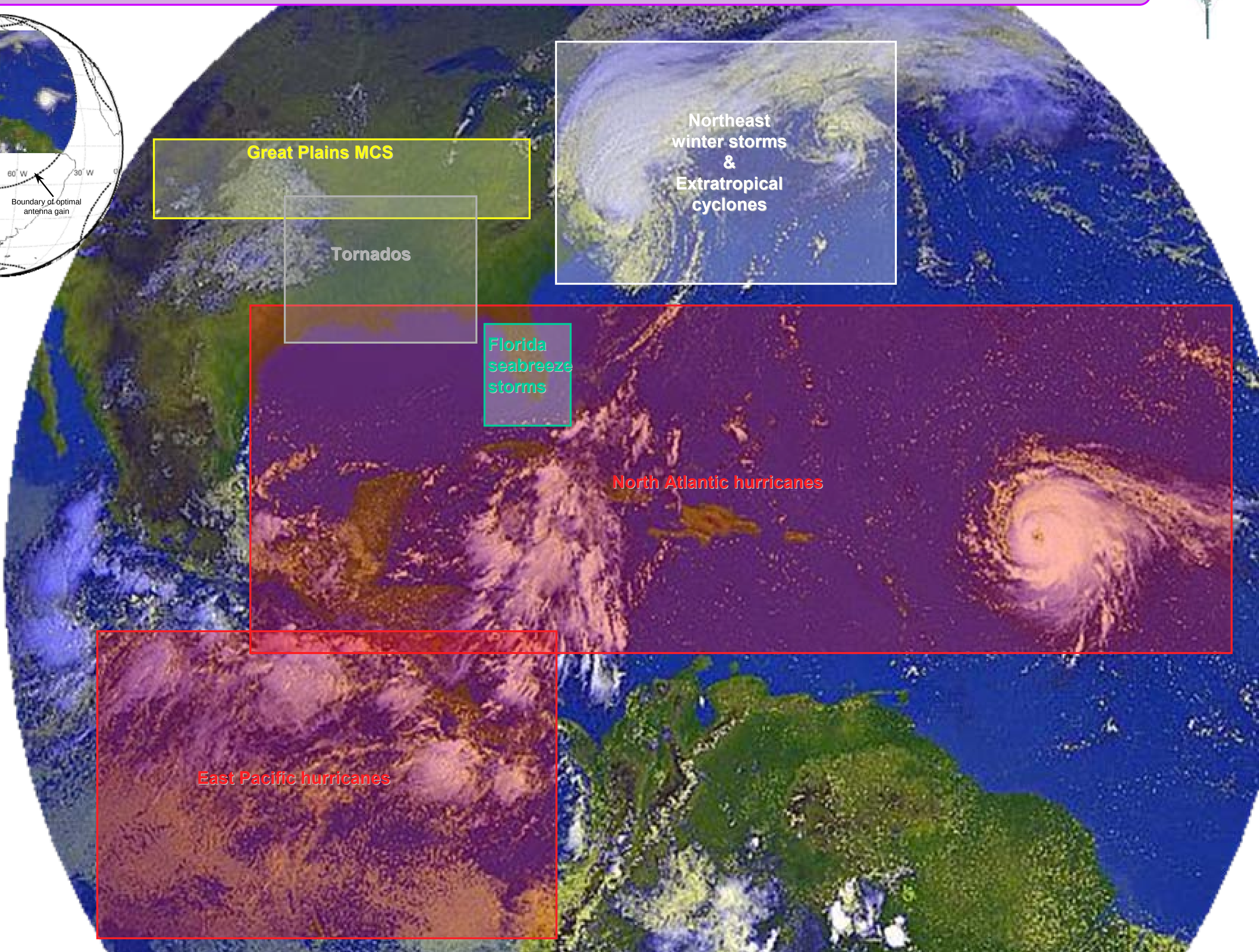
- Stable & continuous MW observations => Long term trends in T & q and storm stats
- Fully resolved diurnal cycle: water vapor, clouds, convection
- ENSO observer: Continuous observations from "warm pool" to Pacific coast under all conditions
- "Science continuity": PATH $\approx$ AMSU (currently operating LEO sounders)





Hurricanes & severe storms





The U.S. view

Application: Hurricane intensity

Science question: How can we improve hurricane intensity observations?

- Current capabilities and their limitations
  - Aircraft flights/SFMR: Sparsely sampled
  - QuickScat: Sampled 1–2x per day, obscured by rain
  - TRMM: Sampled 1–2x per day
  - GOES/IR (Dvorak): Cloud tops only, indirect empirical
  - AMSU & SSM/I: Each storm sampled 1–3x per day (varies)

- GeoSTAR capabilities
  - Continuous monitoring
  - Measure warm core anomaly
  - Measure rain rate, convective intensity
  - Infer all-weather wind vector profiles
  - Snapshot every 15 minutes

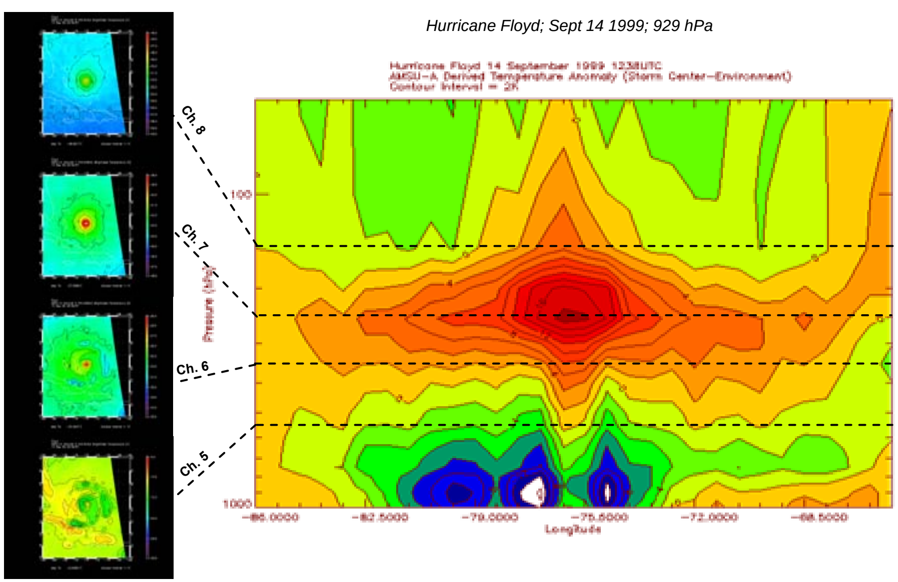
Example: Inferring hurricane intensity from warm core anomaly

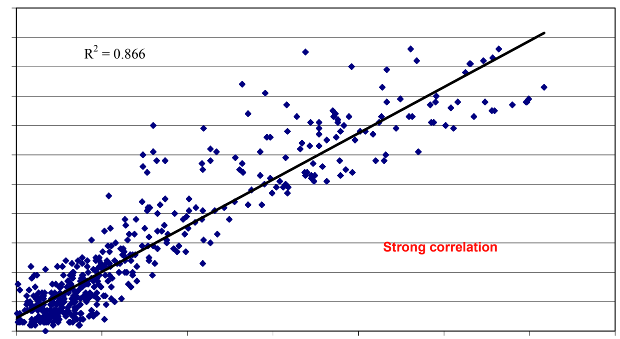
Strong correlation between microwave brightness temperature anomaly and pressure anomaly in hurricane core

Method using AMSU-A microwave sounder data developed by U. Wisconsin and NRL

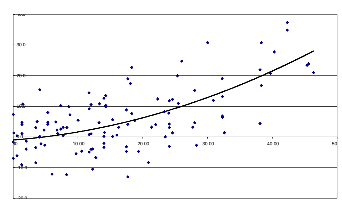
AMSU-A

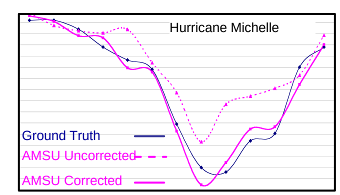
Hurricane Floyd; Sept 14 1999; 929 hPa





Can correct for near-miss and FOV-eye mismatch





C. Velden/UW
J. Hawkins/NRL

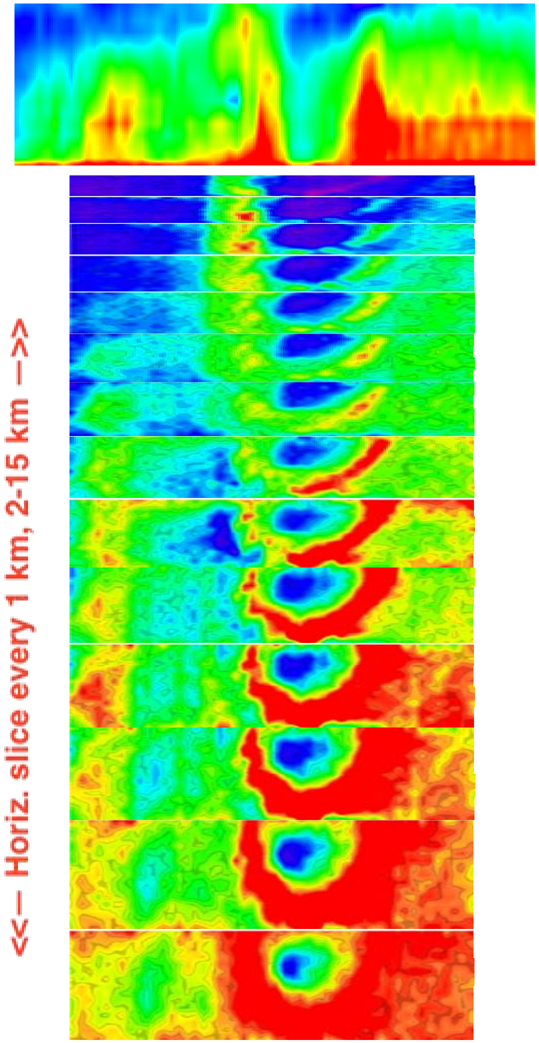
Application: 3-D reflectivity

Snapshot every 15 minutes; use to detect hurricane shear; assimilate into forecast models

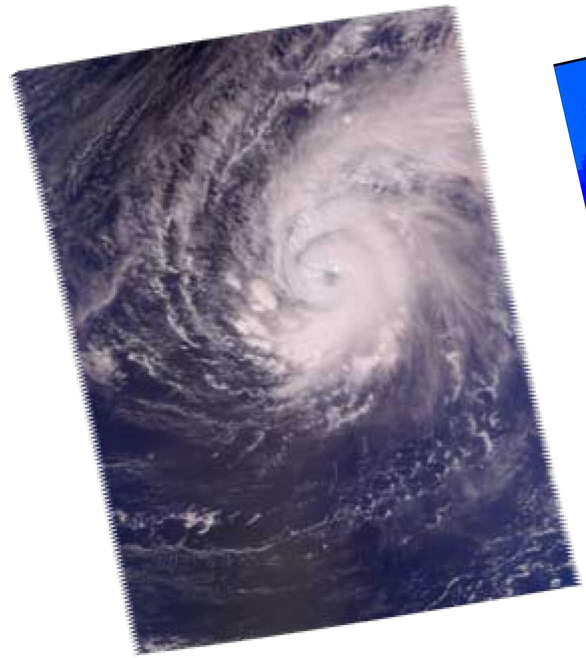
Algorithm developed to infer reflectivity-height profiles from MW sounder/radiometer observations

Based on simultaneous HAMSR-EDOP observations during TCSP (Costa Rica)

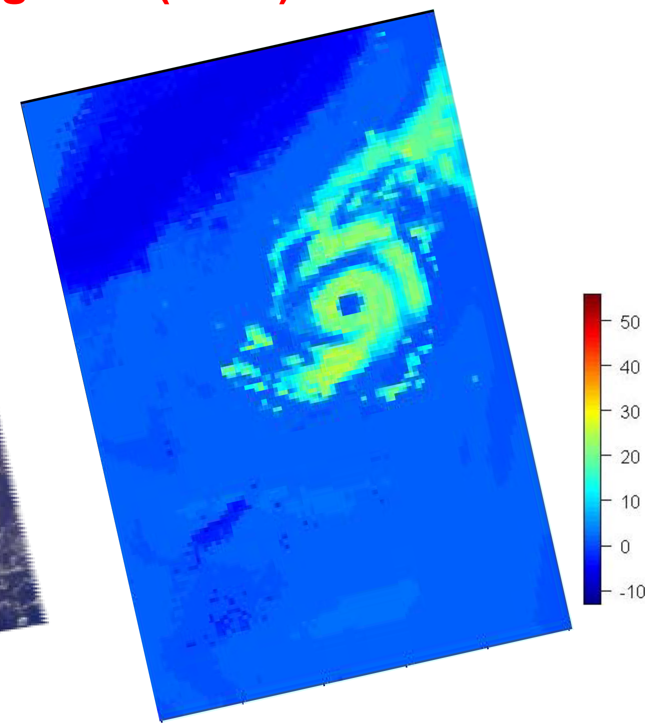
Aircraft: Emily (2005)



Satellite: Pongsona (2002)



AIRS/Vis image



Refl. at 9 km (example)

MW sounder
Is equivalent
to low-res radar!

Height resolved "Radar reflectivity"

⇒ Use radar algorithms to derive

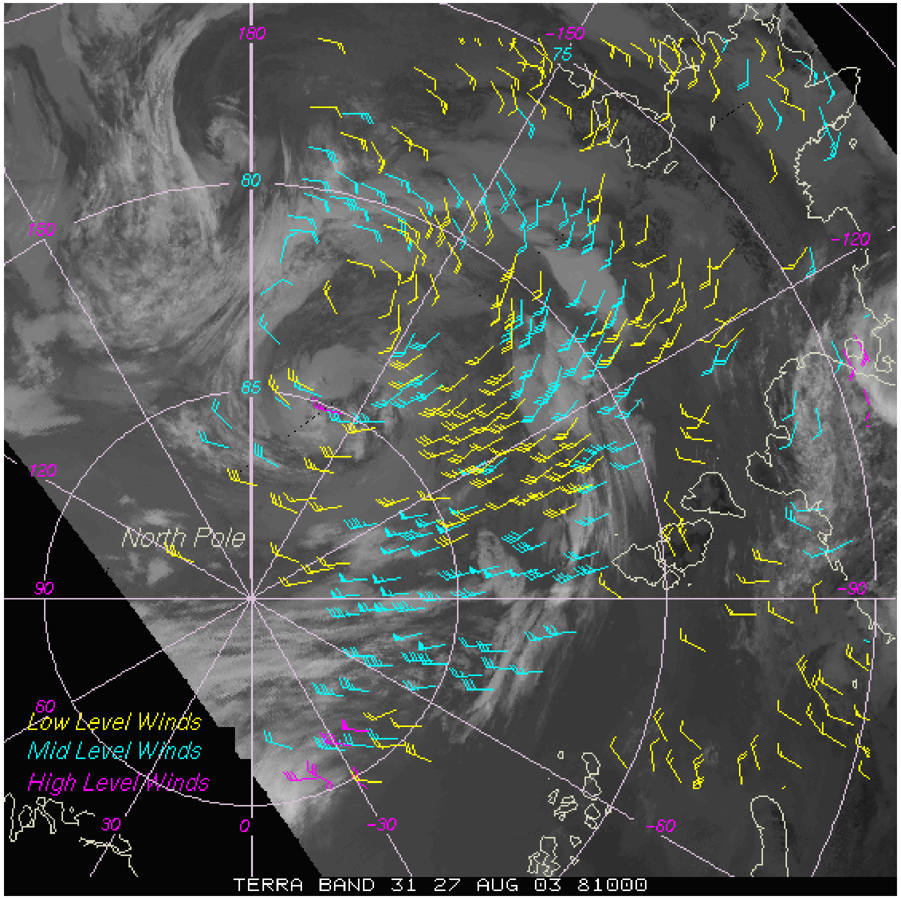
- **Precipitation rate**
- **Ice water path**
- **Convective intensity**
- **Vertical structure**

Application: 3-D tropospheric wind

<u>Tropospheric wind vector profiles</u>

– Derived from moisture feature tracking
– Key parameter for improved numerical weather prediction
– *Tropospheric* wind (esp. at 500 mb) will have more impact on forecast accuracy than *surface* wind (Bob Atlas)

- Current capabilities
  - LEO satellites: MODIS
    - Polar regions only
    - Limited-accuracy water vapor profiles
  - GEO satellites: IR sounder
    - Poor sampling: clear only
    - Uncertain height assignment
  - GEO satellites: IR/Vis imager
    - Cloud tracking: cloud tops only
- GeoSTAR capabilities
  - Clear *and* cloudy
    - Including below clouds
  - Continuous: no time gaps
  - Applicable algorithms available
    - UW (Velden et al.)



Example wind vectors from MODIS

Application: Hurricane forecasting

Science question: How can weather forecast duration and reliability be improved?

- Issues and problems
  - Models deficient re: clouds and convection
  - Initialization data deficient, incomplete, obsolete
  - Cause: sparse and incomplete observations in storms
  - Result: poor storm forecasts

- GeoSTAR capabilities
  - Use obs. to diagnose and fix model problems
  - Initialize with current, complete state variables
  - Re-initialize with current observations
  - Nudging and phase-correction/4DVAR

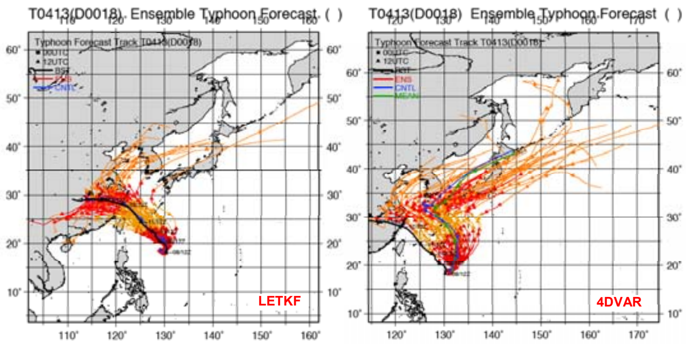
Example: New assimilation methods under development

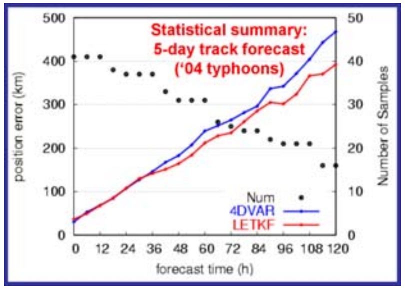
Can use *continuous* obs. of "process measures" in stormy areas: rain, clouds, stability

These observations will be provided by GeoSTAR

- Two methods that potentially can assimilate continuous information from PATH:
  - 4D-Var
  - 4D-Ensemble Kalman Filter: Local Ensemble Transform Kalman Filter (LETKF)
- 4D-LETKF works well and is simple. It is being tested at JMA, NCEP, Brazil and being considered for testing at ECMWF (see figures).
- The analysis in 4D-LETKF is a linear combination of the ensemble forecast members. When assimilating CAPE, for example, the member with CAPE closest to observations will simply be given more weight.
- In the next few years we will develop considerable experience with the assimilation of these "unconventional" but important observations.
- GeoSTAR will provide estimates of cloud, precipitation, CAPE (stability), as well as moisture-tracked winds, in and near storm areas, where they are most needed.
- The new 4D data assimilation methods can for the first time assimilate this important source of observations (GeoSTAR) that should result in major improvements in the prediction of storms and hurricanes.

Example: JMA tests re. '04 Typhoon #18





E. Kalnay/UMD

Application: Great Plains MCS storms

Science question: How can we improve understanding of continental storms?

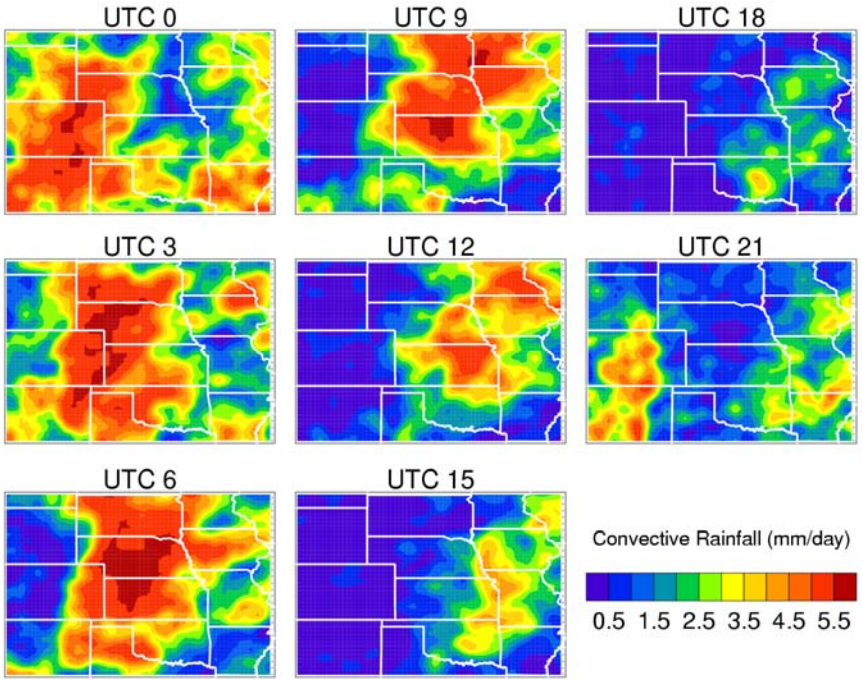
- Issues and problems
  - Convection shows very strong diurnal cycle
  - Poorly sampled by satellites
  - Models show significant amplitude and phase errors

- GeoSTAR capabilities
  - Diurnal cycle fully resolved
  - Convection/rain measured in RT
  - Atmospheric stability measured concurrently

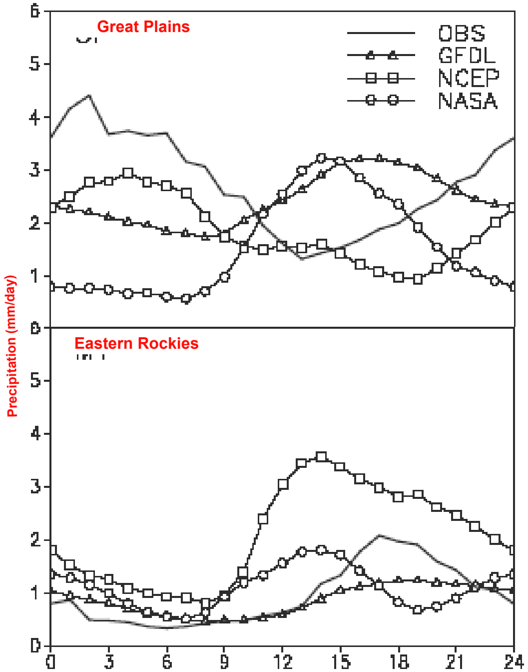
Example: MCS-storms originating in Eastern Rockies and propagating east

Potential for destructive weather events is very great

Models, forecasts & warnings must be improved



Strong diurnal cycle & rapid propagation from Rockies across Great Plains



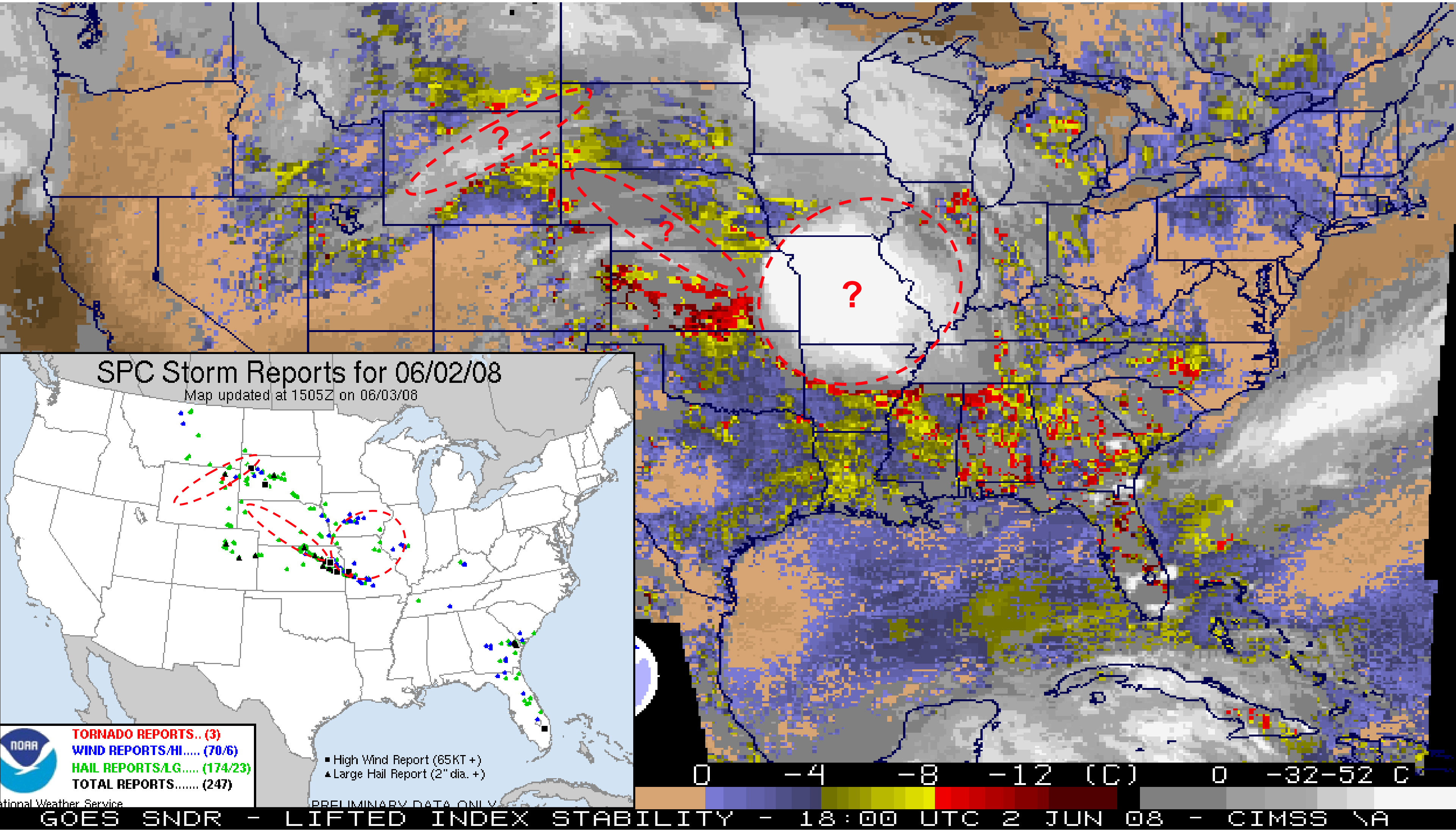
Many models have diurnal cycle wrong

This is also relevant to aviation weather applications

What’s going on below those clouds?

Current capabilities: Poorly observed; infrequently sampled; poorly modeled

GeoSTAR capabilities: *All* conditions, obs. *in* storms; every 15 minutes



GeoSTAR data products

Mature products:

Parameter	Horizontal	Vertical	Temporal	Accuracy
Tb (50 GHz)	50 km	(6 channels)	3 min per ch.	< 1/3 K
Tb (183 GHz)	25 km	(4 channels)	4 min per ch.	< 1/3 K
Temperature	50 km	2 km	20 min	1.5-2 K
Water vapor	25 km	2 km	20 min	25%
Liquid water	25 km	3 km	20 min	40%
Stability index	50 km	N/A	20 min	N/A
TPW	25 km	N/A	20 min	10%
LWC	25 km	N/A	20 min	20%
SST	100 km	N/A	1 hour	< 0.5 K

Evolving experimental products:

Parameter	Horizontal	Vertical	Temporal	Accuracy
Rain rate	25 km	N/A	20 min	2 mm/hr
Convect. intens.	25 km	N/A	20 min	N/A
IWC	25 km	N/A	20 min	30%
Wind vector	25 km	2 km	30 min	TBD

Channels are sampled sequentially-interleaved, with variable, commandable duty cycle

⇒ We can use more integration time for rapid processes and less for slow processes

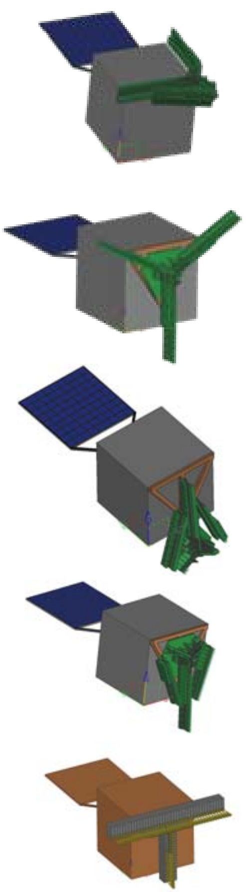
⇒ We can sample precip/convection every 5 min and T-fields every 30 min (for example)

Mission of opportunity

- **Currently there is no HES payload on GOES-R and GOES-S (and maybe -T)**
  - But there is a strong desire at many levels for "advanced sounder"
  - The need for this is when GOES-R/S is launched: 2015-2018
- **NASA could develop and "demo" GeoSTAR on GOES-R/S**
  - The new "Venture" program is well suited for this
  - Venture cost cap ~$100M requires "mission of opportunity" – i.e. free ride to space
  - Many potential partners exist: NOAA, DoD/Navy, FAA, Eumetsat/ESA, JMA, etc.
- **Mission-of-opportunity options**
  - GOES-R (~2015) or GOES-S (~2016): "contributed" by NOAA
  - Commercial comm-sat (steady stream of launches)
  - Overall very low cost: $100M + satellite space + launch + data system/science
    - This is << PATH mission cost (est. $530M)
- **GeoSTAR-lite**
  - Smaller version of full GeoSTAR
    - To meet mass & power constraints of host mission
  - Low cost ($100M), short development time (3-4 years)
  - Will have 90% of full-GeoSTAR functionality
- **Ready for launch in 2016-2018**
  - Instrument start ~ mid-2012
  - Instrument ready for integration ~ end of 2015
  - Ready for launch 6 months – 1 year later

Flexibility: Many accommodation options

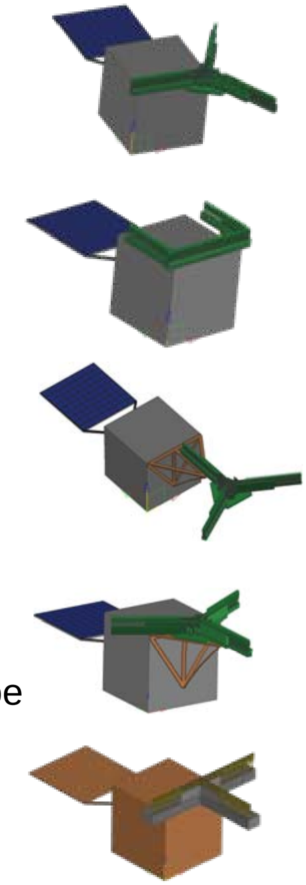
Stowed ← Example accommodation options → **Deployed**



- **Baseline configuration: Integrated Y-array**
  - GeoSTAR-lite: single array, 1-meter arms
  - Integrated with central “hub” containing electronics & special circuitry
- **Separate array & electronics**
  - Y-array may be positioned remotely from electronics - connected w/cables
- **Other array configurations**
  - Rectangular “U”: Antenna arms positioned along 3 S/C edges
  - Rectangular “T”: Antenna arms positioned along 1 S/C edge + ⊥ arm
  - Distributed: Antenna arms distributed in “free” areas on nadir deck
- **Position on S/C**
  - Preferred: Corner; all 3 arms outside S/C envelope
  - Option: Edge; “T”-array + one arm deployed outside S/C envelope
  - Option: Any location; array deployed on boom fully outside S/C envelope

Bottom line:

- ***There are many feasible options***
- ***GeoSTAR is essentially easy to accommodate***
- ***We will design to fit available space & resources***



Let's make it happen!

Why?

- GeoSTAR promises to be one of the most useful sensors for the sounding community
  - Recommended by science community, through US Nat'l Acad. Sci. ⇒ Decadal Survey
- A GEO MW sounder would have very high value for NOAA & other agencies
  - Solidly documented basis for need
  - Adds key "advanced-sounder" functionality to the GOES system, in lieu of HES
  - Strong user community interest: NHC, NCEP, HRD, ECMWF, etc.
- Science community has a strong interest (per NRC decadal survey)
  - NASA will build PATH, but probably not for a long time
  - *We need this system now!*
- A "GeoSTAR-pathfinder" mission is very low-cost & is ready to proceed
  - Almost a freebie for NOAA: *This is a "no-brainer"!*

How?

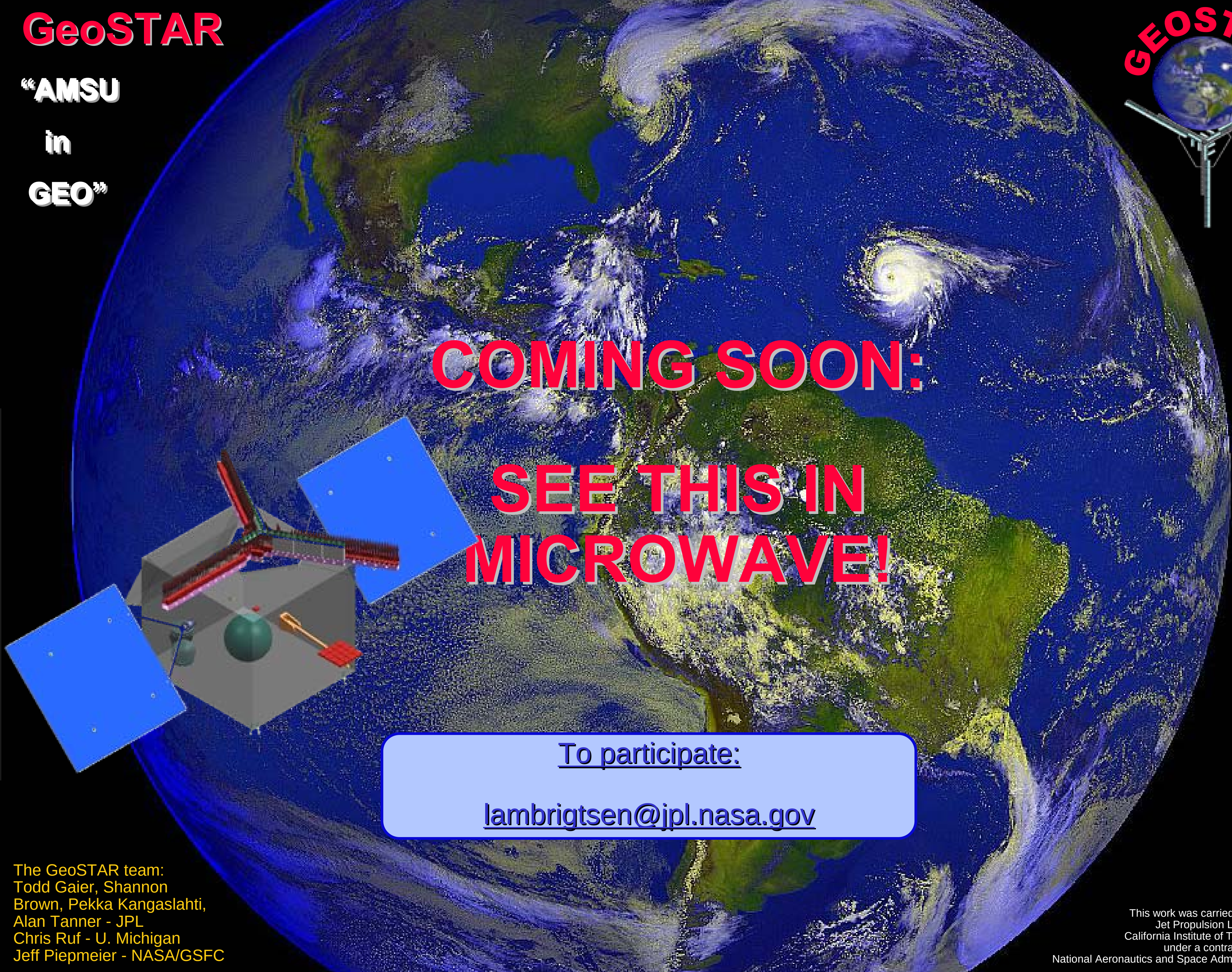
- Must have strong advocacy from *you*, the user community
  - *Users must communicate with parent agencies, which must in turn communicate with NASA*
- Time is short
  - Must start by 2012 to be ready in the GOES-R/S and MTG time frame
  - Before that, must have commitments from partner agencies

In the meantime…

- Community workshop next month (@ AMS Hurr.Conf. in Tucson)
  - Develop consensus on objectives, requirements, basic design & architecture
- Conduct science/impact studies
  - All interested parties are urged to participate

GeoSTAR

"AMSU in GEO"



COMING SOON:

SEE THIS IN MICROWAVE!

To participate:

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The GeoSTAR team:
Todd Gaier, Shannon Brown, Pekka Kangaslahti, Alan Tanner - JPL
Chris Ruf - U. Michigan
Jeff Piepmeier - NASA/GSFC

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