Reference Network Strategies to Maximize Improvements for Operational Satellites

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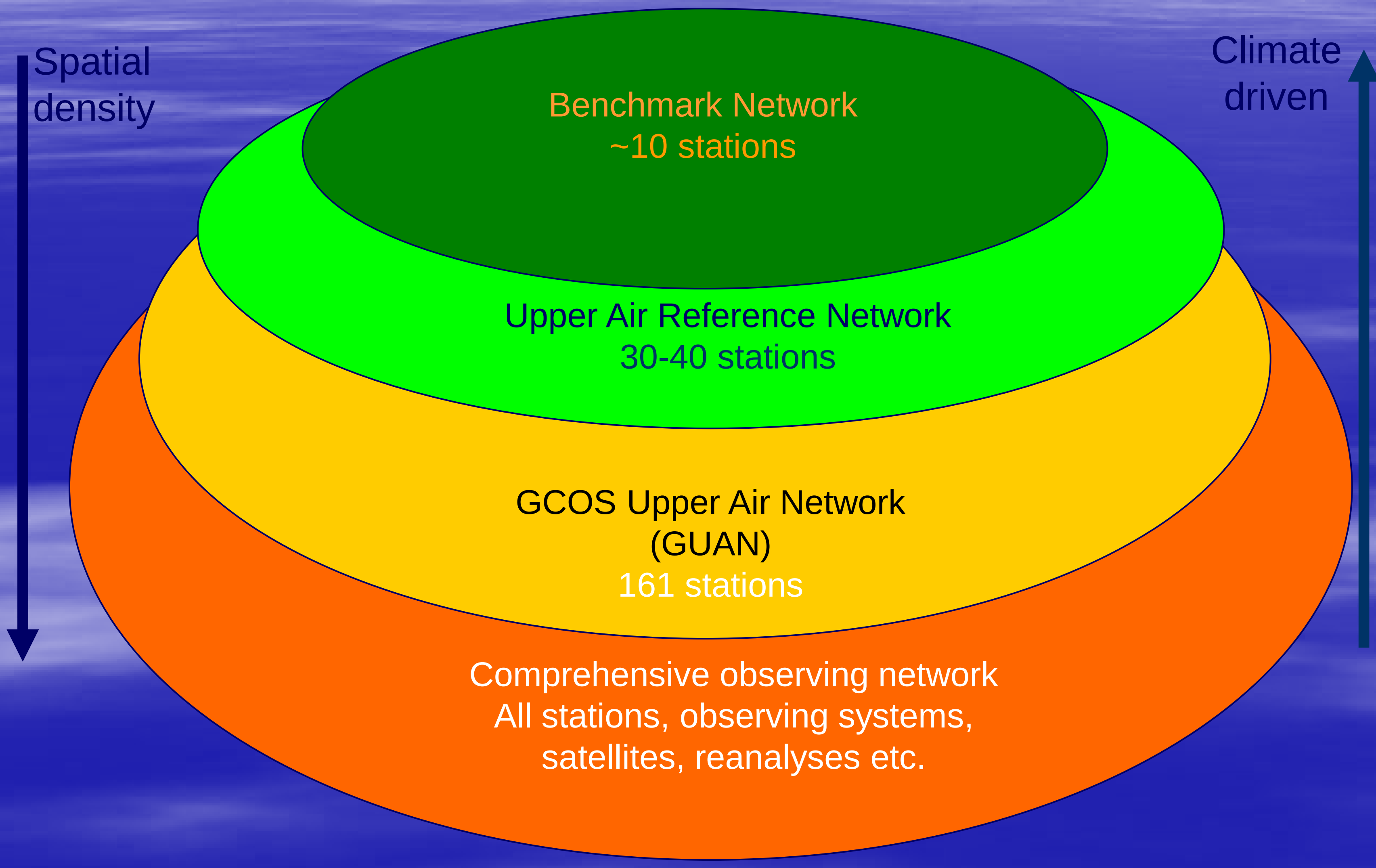
Camp Springs, Md

NOAA/GCOS Workshop:
Reference Upper Air Observations for the Global Climate Observing System: Potential Technologies and Networks

Cascade of Upper-Air Observations



A cascade of networks for future climate research

Peter Thorne
(UKMO)

NOAA/GCOS
Workshop-1

Feb 2005

Density of coverage

Degree to which climate is primary customer

Benchmark Network

- Traceable to international standards (SI units)
- Absolute accuracy

Reference Network

- Sites of Multi-instrument redundancy
- Coverage sufficient to act as anchor points for more globally complete networks
- provide continuity by monitoring effect of change (e.g. satellite, radiosonde)

Baseline Network

- Sufficient coverage of upper-air stations to characterise hemispheric and global scale change and variability.
- Commitment to twice-daily radiosonde launches

Comprehensive Network

- As globally complete coverage from multiple instruments and platforms as possible.
- Use of reanalysis systems.

Satellite Scientific Algorithm Tuning
(from collocation datasets)

- First-guess regression coefficients (T, q)
- Radiative Transfer (RT) model bias adjustment coefficients (Btemp, RT; T, q)
- Retrieval Solution Covariance Matrices (T, q)
- Retrieval Solution Noise Matrices (Btemp, RT; T, q)
- Coefficient Updating (weekly; monthly)
- ***Real-time (NWP) versus Retrospective (Climate) processing/tuning***
- ***ATOVS vs NPOESS***

Scientific Validation
(from collocation datasets)

- First Guess Profiles (apriori error)
- Final Sounding Profiles (product error)
- Cloud mask and products

- Sounder measurement
- Radiosonde (in-situ) data

- RT model

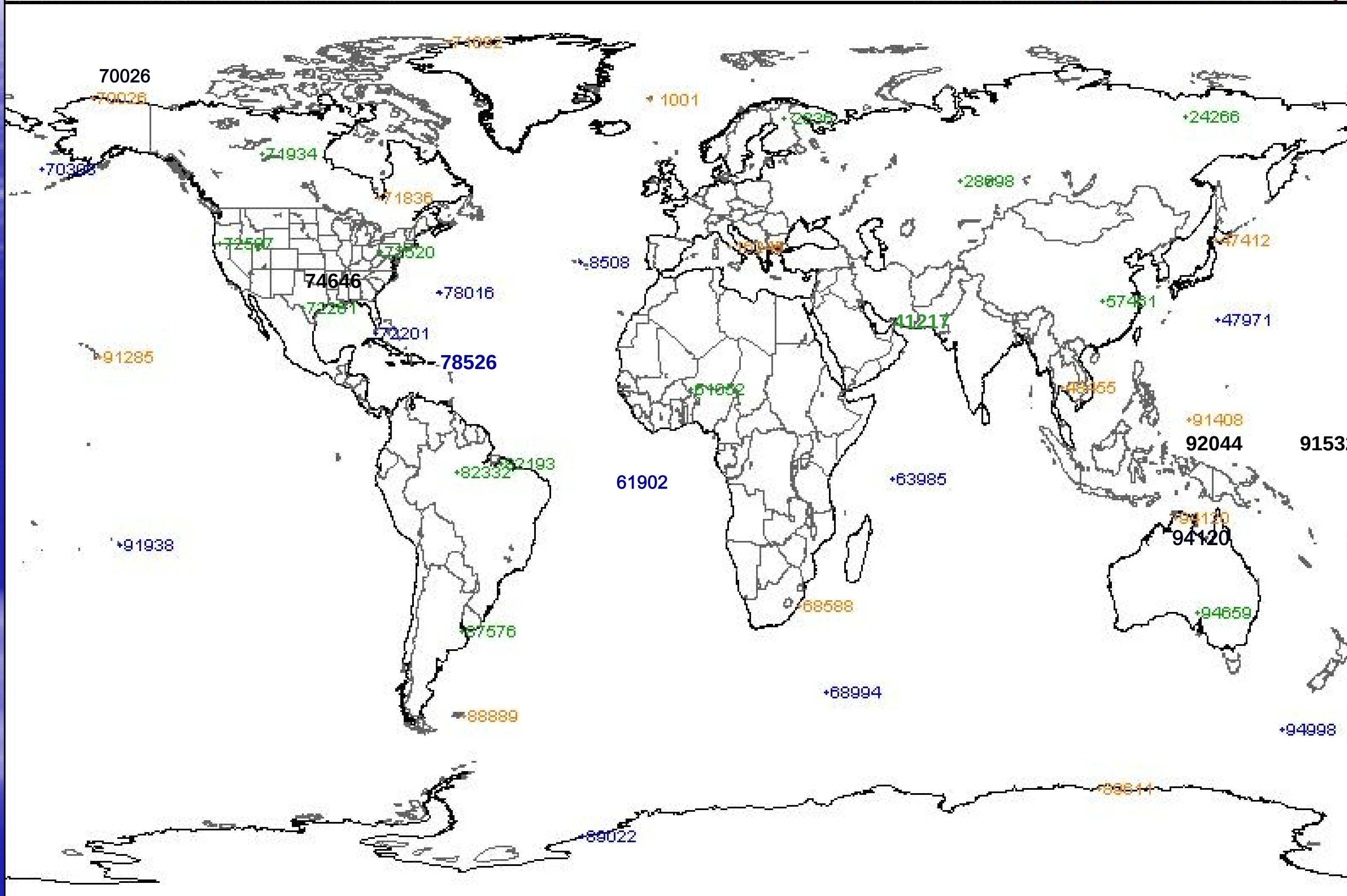
Optimal Reference Network for Satellite Support

- Robust and continuous
- Cross-section of useful measurements for scientific algorithm tuning and validation
  - Accuracy (traceable to benchmark)
- Spatially and temporally coincident (same-same)
- Reliable and consistent (site protocols)
  - In-situ
- Adequate sample size

NOAA/NESDIS Matched Profile Display

Retrieval/Radiosonde Collocations

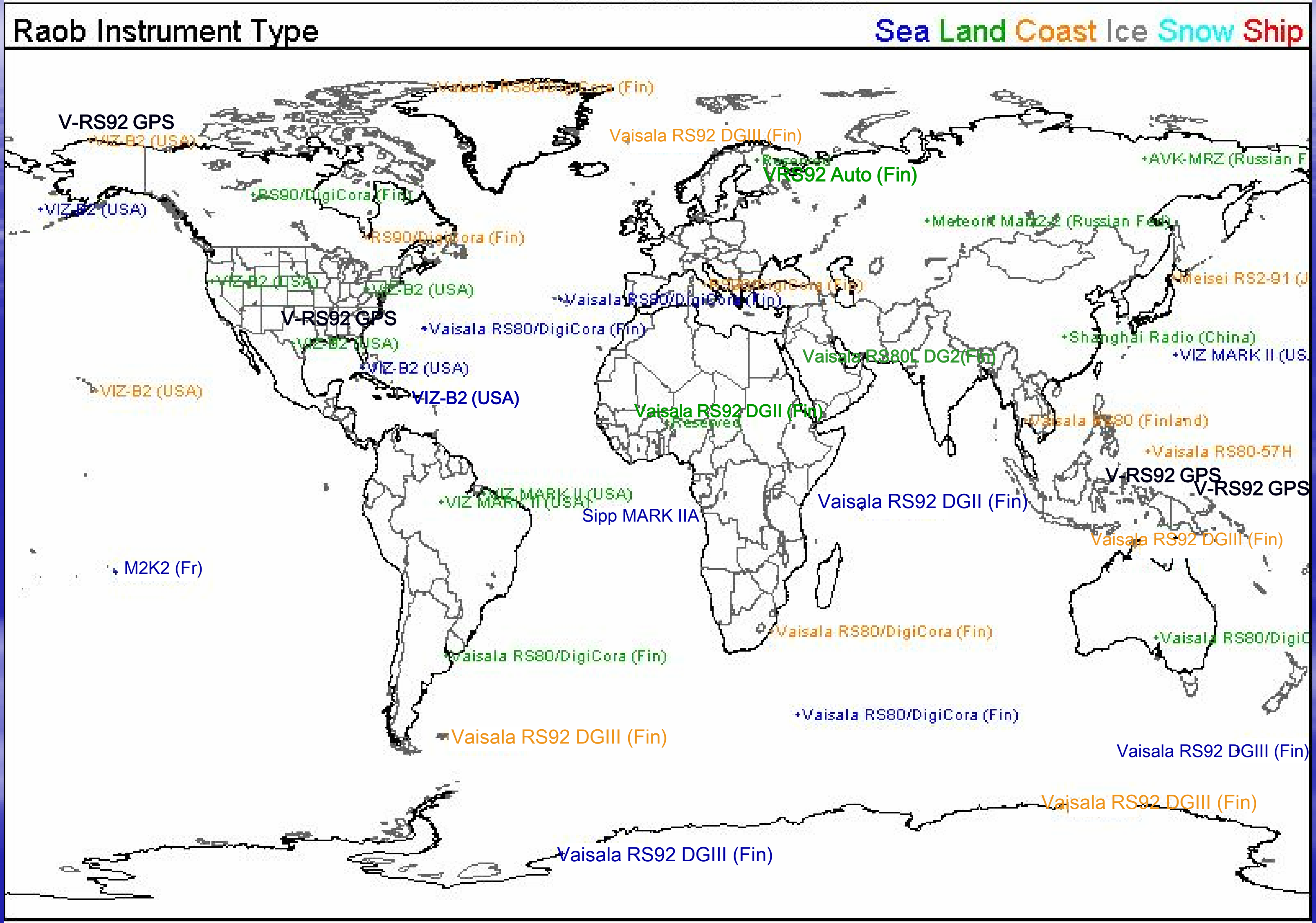
Number Is Raob Station ID — Sea Land Coast Ice Snow Ship



April 29, 2006 (0z) to April 30, 2006 (1z)

NOAA/NESDIS Matched Profile Display

Retrieval/Radiosonde Collocations



April 29, 2006 (0z) to April 30, 2006 (1z)

Radiosonde Type Distribution

- 10; (80) Vaisala RS92 DGIII (Fin) (*GPS*)
- 8; (51) Viz-B2 (US)
- 7; (61) VRS80L DGI,II or Mar (US)
- 3; (49) Viz Mark II (US)
- 3; (71) VRS90 DGI,II or Mar (Fin)
- 2; (79) VRS92 DG I,II or Mar (Fin)
- 2; (81) VRS92 Auto (Fin)
- 1; (27) AVKMRZ (Ru Fed)
- 1; (29) Meteorit, Marz2-2 (Ru Fed)
- 1; (32) Shanghai Radio (China)
- 1; (37) VRS80 (Fin)
- 1; (47) Meisei RS2-91 (Jap)
- 1; (52) VRS80-57H
- 1; (56) M2K2 (Fr)
- 1; (87) Sipp Mark IIA … NWS-RRS

Optimal Reference Network for Satellites

- Robust and continuous
- Cross-section of useful measurements used for scientific algorithm tuning and validation
  - Minimum Accuracy (traceable)
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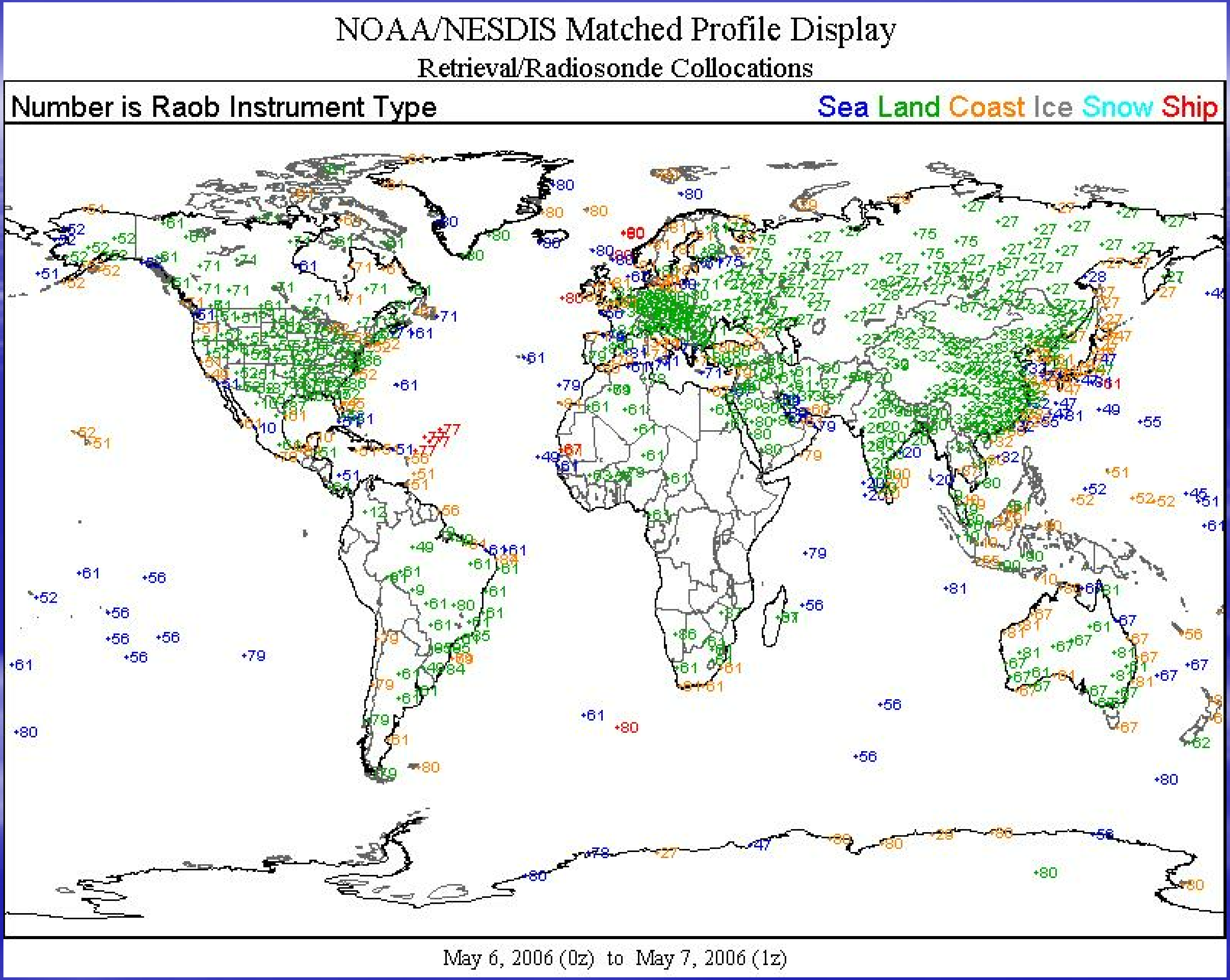
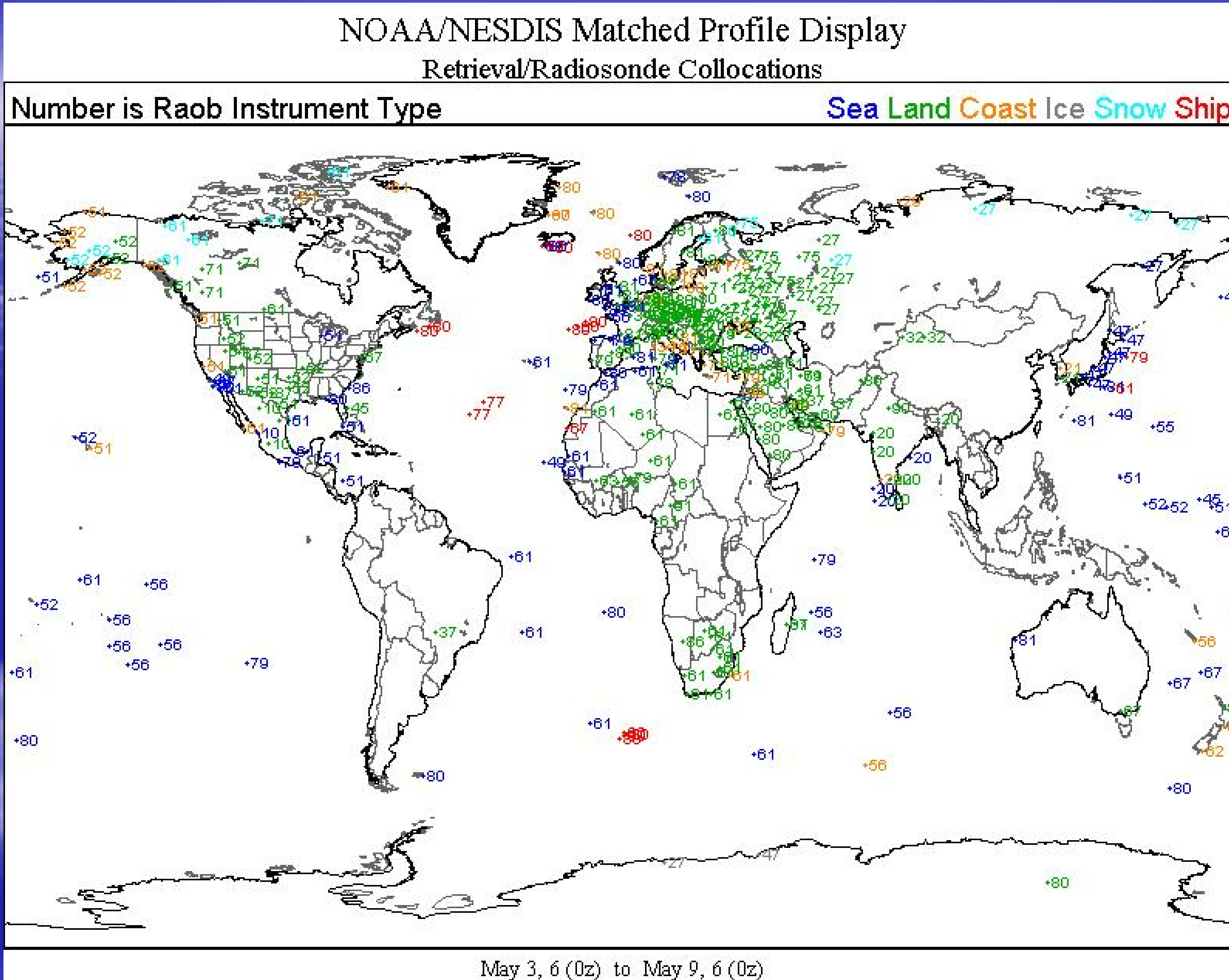
R A D I O S O N D E S



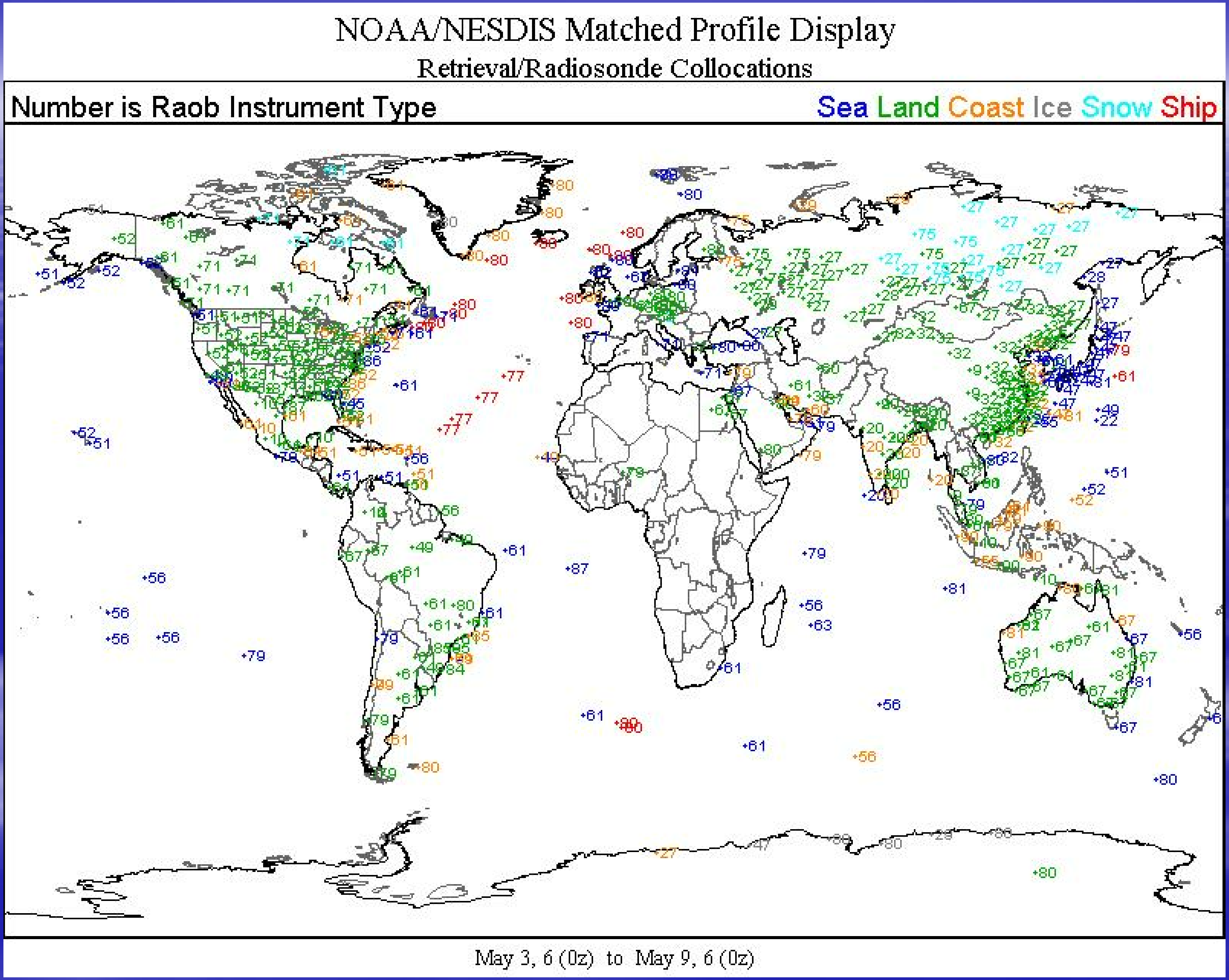
1468 Accepted Observations

Collocations w/NOAA-18 local X-over 1330 (A), 0130



2-3 hr Land; 3-4 hr Sea; 100km

Collocations w/NOAA-15 local X-over 1930 (A), 0730



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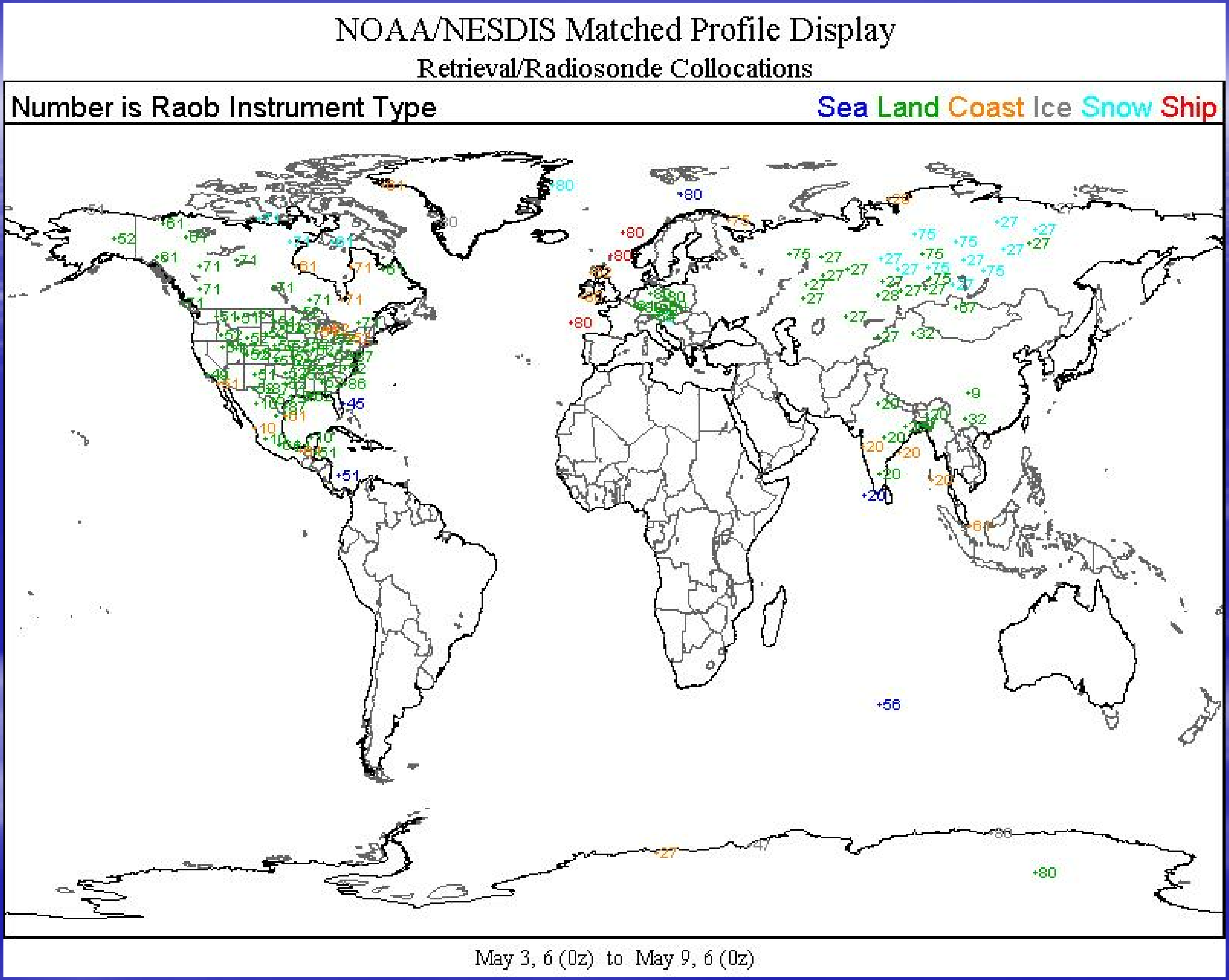
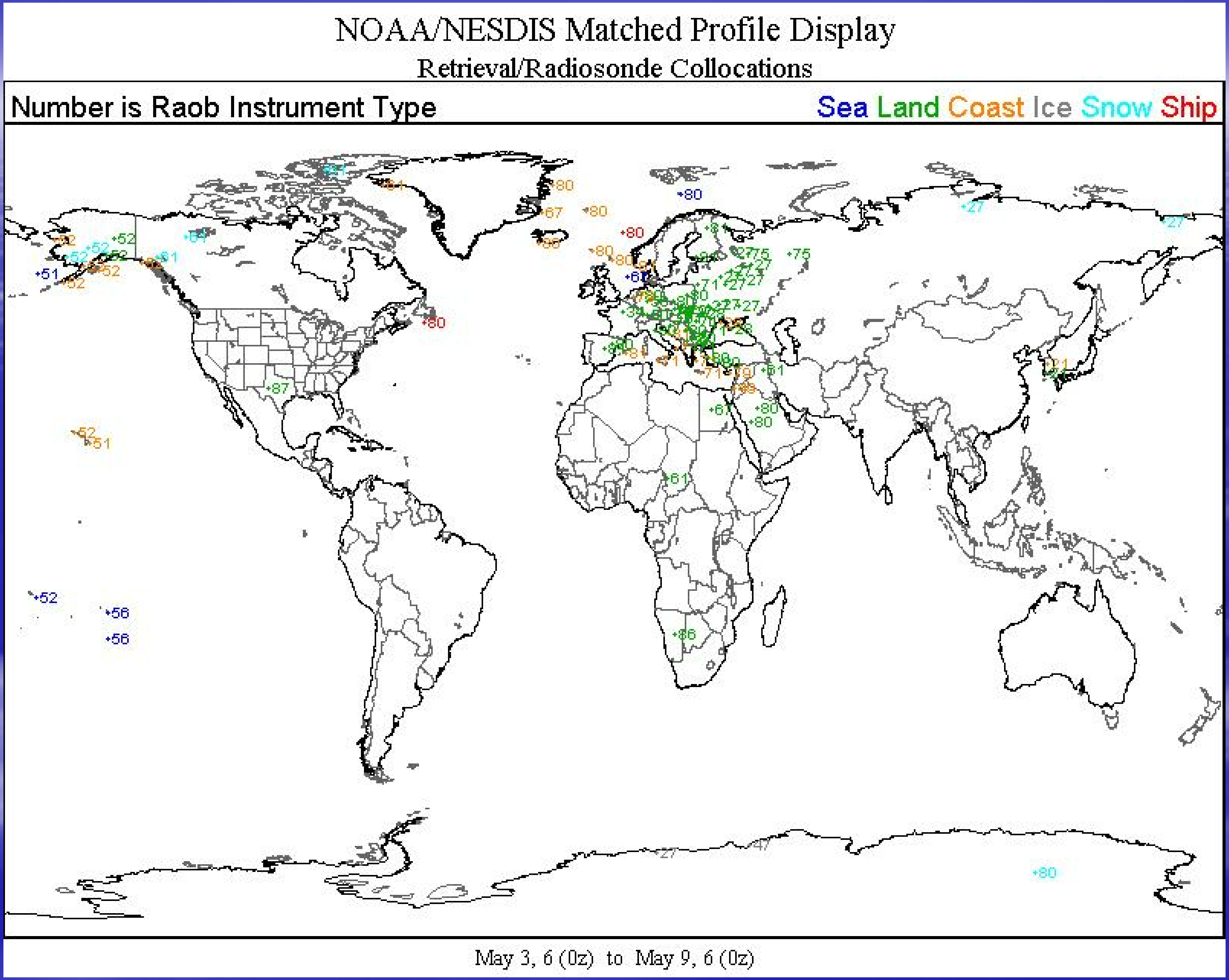
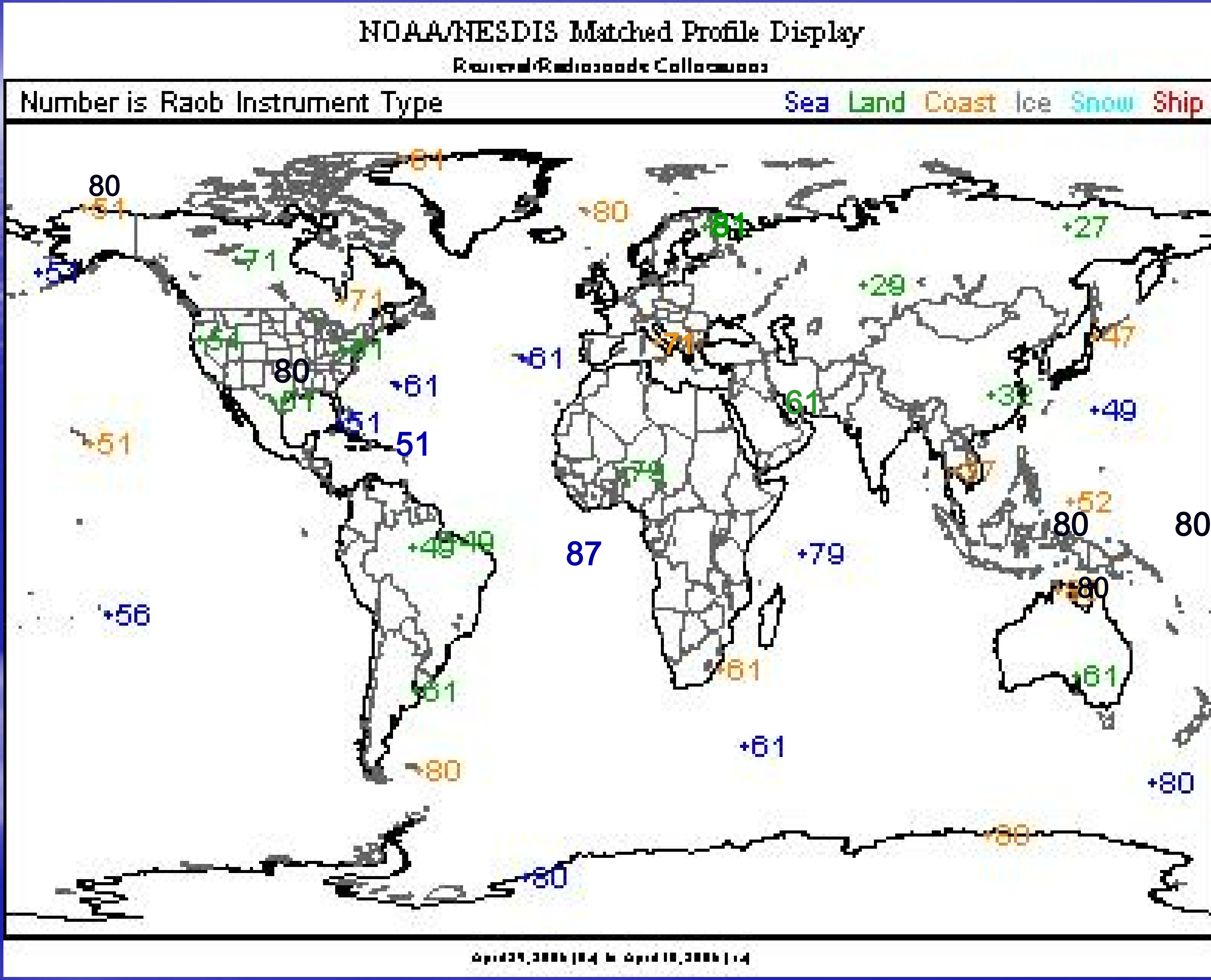


263 / 1717 ; @ -1 hr, 50km

Collocations w/NOAA-18 local X-over 1330 (A), 0130



162 / 1229 ; @ -1 hr, 50km


NOAA/NESDIS Matched Profile Display
Number is Raob Instrument Type
Sea
Land
Coast
Ice
Snow
Ship
80
80
61
51
87
79
27
29
49
61
61
61
56
80
80
80
80

Optimal Reference Network for Satellites

- Robust and continuous
- Cross-section of useful measurements used for scientific algorithm tuning and validation
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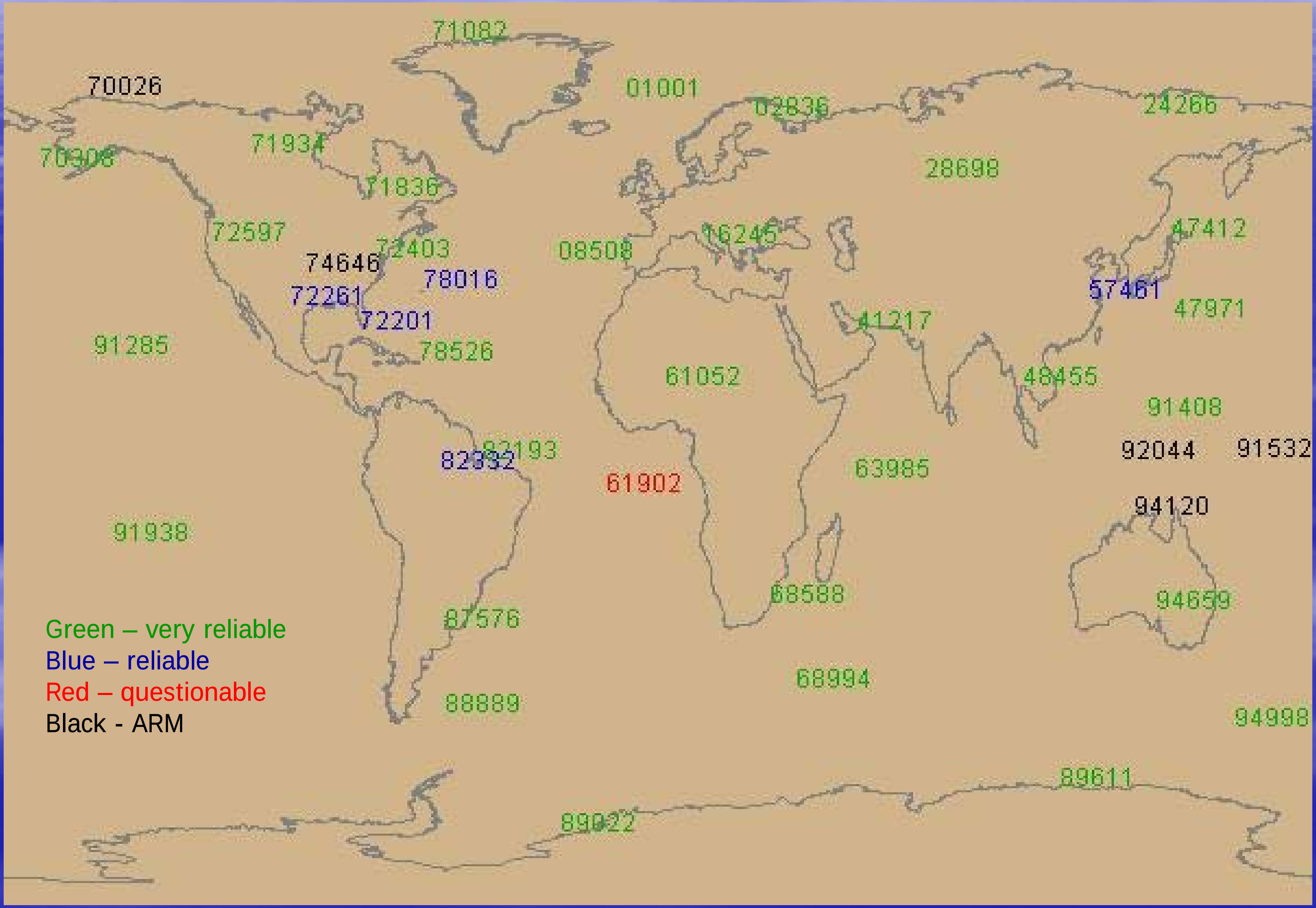
- Spatially and temporally coincident (same-same)
- Reliable and consistent (site protocols)
  - In-situ
- Adequate sample size

Identification and Prioritization of Candidate Sites

- Subset of GUAN (WMO/AOPC (Geneva, 4-04)
- Active and Reliable
  (***UKMO, w/McCarthy;   NESDIS, w/Tilley***)
- Global/Robust *(weather and terrain)*
- Low terrain (500m; 950mb)
- Non-coastal
- *ARM and NWS Sites*
- ***SHIPS !?***

Candidate REFERENCE Network

(performance)



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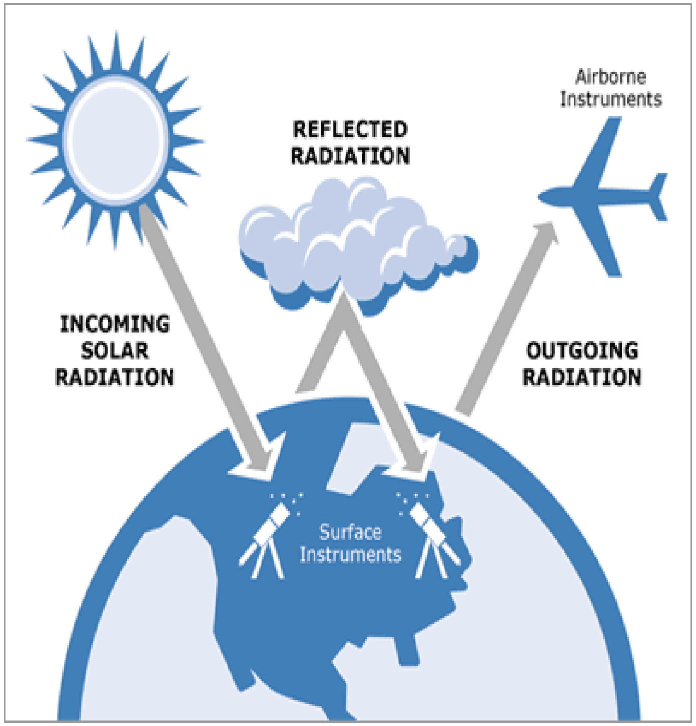
http://www.arm.gov/measurements/

Measurements

The Atmospheric Radiation Measurement (ARM) Program gathers a wide variety of measurements from many different sources. Each day, the Data Archive stores and distributes large quantities of data collected from these sources. Scientists then use these data to research atmospheric radiation balance and cloud feedback processes, which are critical elements of global climate change.



The ARM Program gathers cloud and radiation measurements from instruments on the ground, attached to aircraft, and sometimes placed on ships.

Measurement Categories

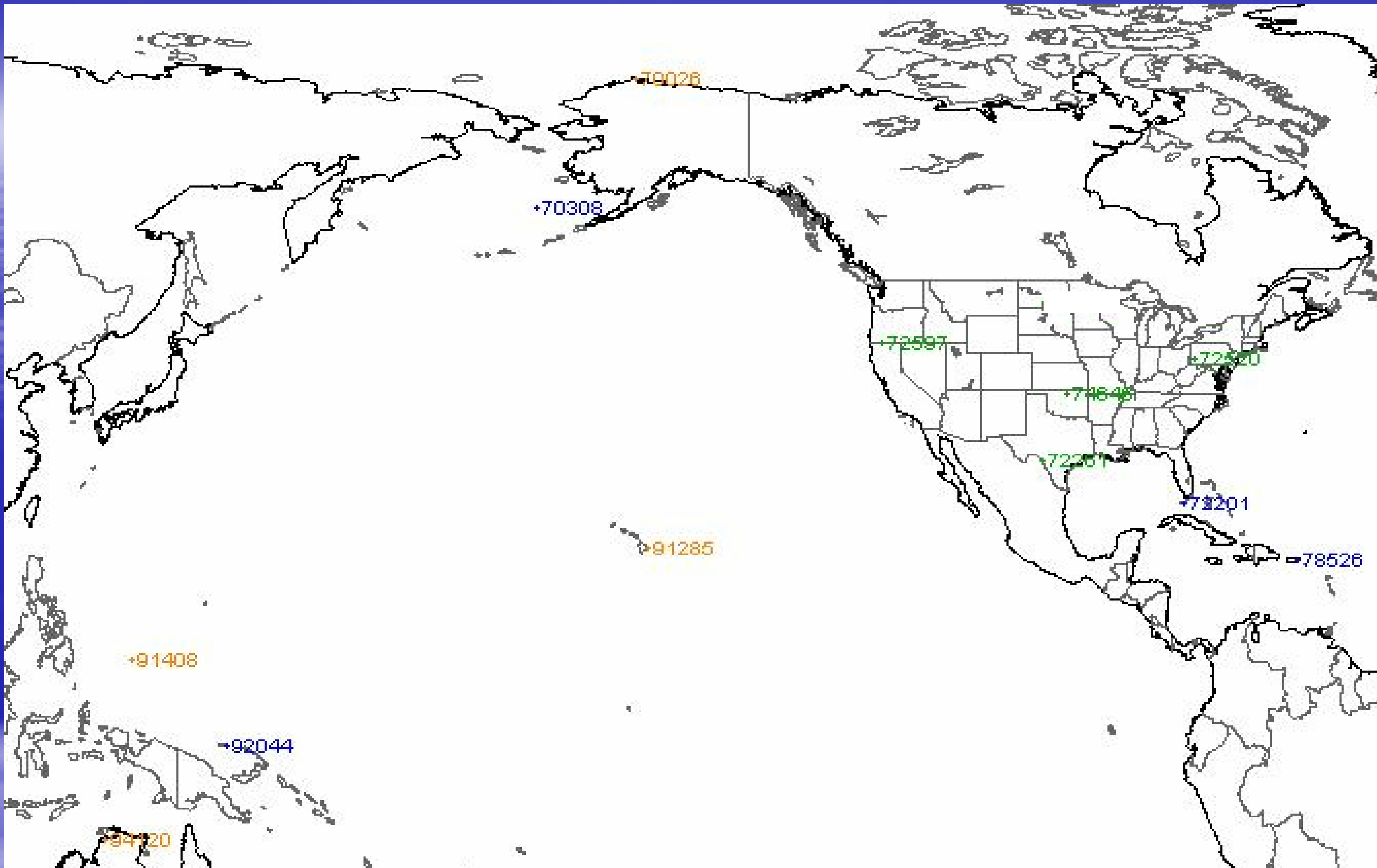
- Shortwave Spectral Radiation
- Cloud Properties
- Surface Meteorology
- Atmospheric Profiling
- Surface Energy Flux
- Aerosols
- Atmospheric Carbon
- Airborne Platforms
- Longwave Spectral Radiation
- Longwave Broadband Radiation
- Shortwave Broadband Radiation

ARM Site Radiosondes

- Tropical Western Pacific (RS92-SGP dual humicap; 4/05)
  - 91532 (Nauru)
  - 92044 (Manus)
  - 94120 (Darwin)
- South Great Plains (RS92-KL (LORAN-C, dual humicap; 2/05) (WMO Block 8/96)
  - 74646 (Lamont, OK)
  - 74547 (Hillsboro, KS)
  - 74641 (Vici, OK)
  - 74650 (Morris, OK)
  - 74651 (Purcell, OK)
- North Slope Alaska (RS90-AG, RS92 SGP occasional 1/05) (No WMO Block)
  - Barrow

ARM Site Measurements

- Atmospheric Profiling and Clouds
  - Microwave Radiometer (Column Integrated H20)
  - Microwave Radiometer Profiler (T, H20 and CLW profiles @ 20-30 and 50-60 GHz)
  - GVR (183 +/- 1,3,7,14 gHz)
  - Raman Lidar (H20 Vapor, Cloud, Aerosol)
  - Radiosonde (Vaisala RS-92)
  - AERI (RT, Clouds , T, H20 and Trace Gas @ 3 -20 (25) Microns)



Subset of proposed Reference Network comprised of NWS sites (9) and ARM sites (4)

SHIPS … *islands vs remote ocean*

National science vessels (like NOAA Ronald H Brown) often include automated (ASAP) radiosonde, in-situ measurement (cloud, radiometric, SST) capability … ***nice Reference platform !***

Network Operating Strategies …

Reference Upper Air Network

- Reliable and Consistent
- Provide suite of observations coincident with NOAA operational polar satellite overpass
- Process into "*carefully*" constructed collocation datasets *(in conjunction with NOAA polar satellite operations)* and archived

Site Observations
(launch strategies …)

- One set of "coincident" radiosonde, satellite (and in-situ) observations per day per site staggered among operational satellites and orbit nodes
- Launch Radiosondes *"45 minutes" prior to overpass*
  - *850mb (10min), 700(15), 500 (30), 300(50), 100(90), 50(120), 10(180), 5(210)*
- Daily radiosonde launch schedules (generated by NESDIS) distributed to each site up to two months prior
  - Fixed sites
  - Ships
- Available In-situ observation (GPS, ARM, …) collection strategies
  - Including satellite w/o sonde, etc
- Metadata … data corrections, etc
- Real-time data storage / transmission (to NESDIS)
- Training

Report Time and Vertical Drift

… data are used in the gridded models--not as a vertical stack but more along the line of where the temperature and RH were measured over the earths surface.

… using wind and assumptions on rise rate they (NCEP) can build time in. Nominal rise rates could be any where from 4.5 mps to 6 mps. These would be averages for an entire flight with rates faster or slower an any point within a flight.

… as we (NWS, Facundo, Bower) implement the Radiosonde Replacement Systems (RRS) the BUFR message will have items necessary for a 4 dimensional data set: time, height, latitude, longitude and the element of interest for every second for a flight.

With this data set, drift information will not have to be estimated …

Sample Size

- 42 Reference Sites
- One set of “coincident” radiosonde, satellite (and in-situ) observations per day per site staggered among operational satellites and orbit nodes
- 3 operational satellites (NOAA, METOP ... NPP … NPOESS) configured 4-hours apart :
  - 10 observations per satellite, per site, per month
  - *over 400* observations globally, per satellite, per month
  - *5000* observations globally, per satellite, per year
- **Not Enough or Too Much?**
  - cost; reductions through use and/or re-programming of existing resources
  - meteorological variability
  - instrument variability (drift…)
  - availability of data from other platforms
    - ground (as ARM)
    - satellite (COSMIC…)

N P O E S S

VIIRS - vis/IR imager
CMIS - µwave imager
CrIS - IR sounder
ATMS - µwave sounder
SESS - space environment
OMPS - ozone
ADCS - data collection

SARSAT - search & rescue
APS - aerosol polarimeter
ERBS - Earth radiation budget
SS - laser sensor
ALT - altimeter
TSIS - solar irradiance

NPOESS Payloads

NPOESS Instruments	1730	2130	1330	METOP 0930	NPP 1030
<u>IPO Developed</u>					
Visible/IR Imager Radiometer Suite (VIIRS)*	**X**	**X**	**X**	**X (AVHRR)**	**X**
Cross-track IR Sounder (CrIS)*	**X**		**X**	**X (IASI/HIRS)**	**X**
Conical MW Imager/Sounder (CMIS)*	**X**	**X**	**X**		
Ozone Mapper/Profiler Suite (OMPS)			**X**	**X (GOME)**	**X**
Space Environmental Sensor Suite (SESS)	**X**	**X**	**X**	**X (SEM)**	
Aerosol Polarimetry Sensor (APS)		**X**			
<u>Leveraged</u>					
Advanced Technology MW Sounder (ATMS)*	**X**		**X**	**X (AMSU/MHS)**	**X**
ARGOS-Data Collection System (A-DCS)	**X**		**X**	**X**	
Search and Rescue (SARSAT)	**X**	**X**	**X**		
Earth Radiation Budget Sensor (ERBS)			**X**		
Total Solar Irradiance Sensor (TSIS)	**X**				
Radar altimeter (ALT)	**X**				
Survivability Sensor (SS)	**X**	**X**	**X**		
Advanced Scatterometer (ASCAT)				**X**	

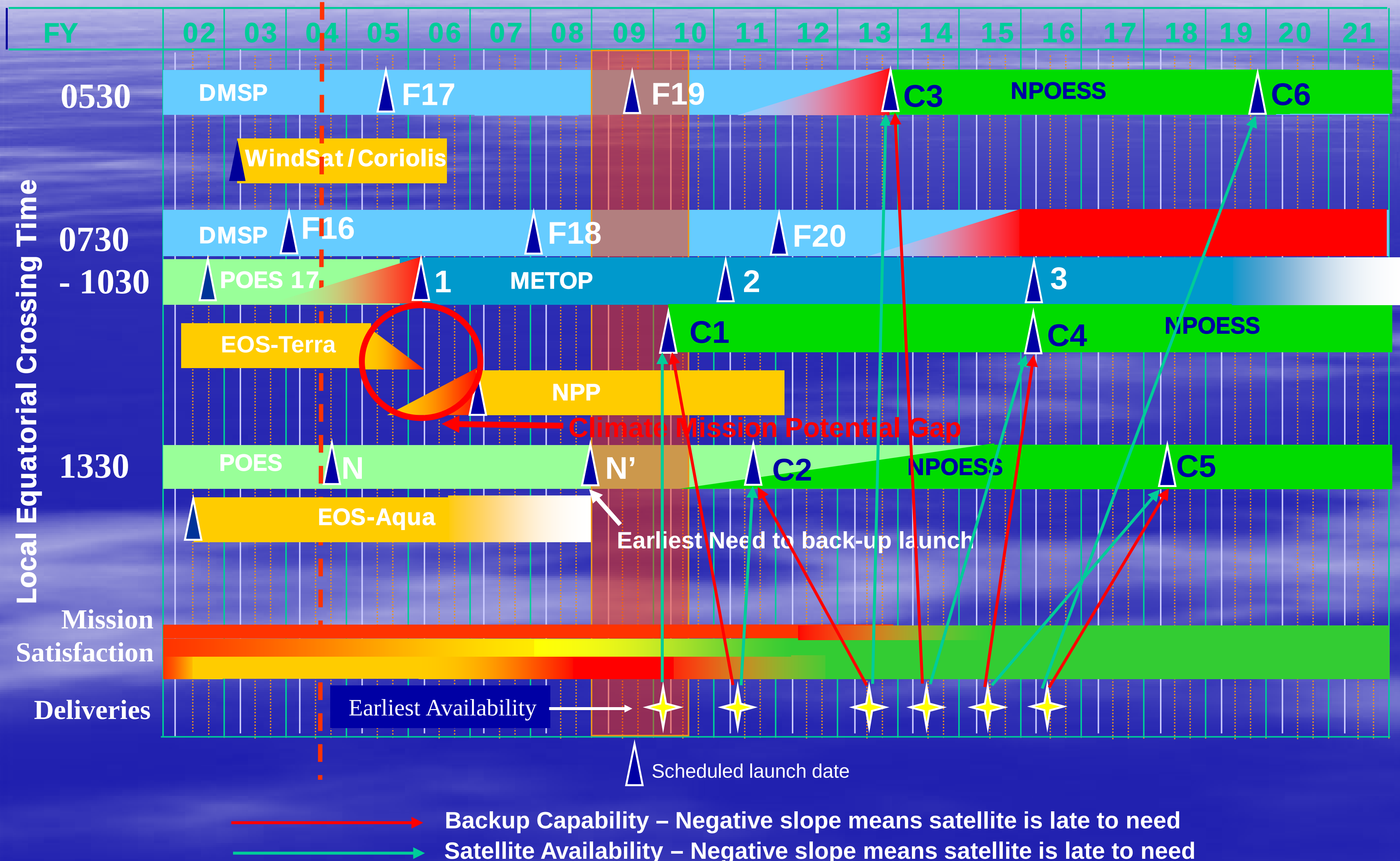
NPOESS EDR-to-Sensor Mapping
55 Product Sets [EDR, RDR, SDR]

☆ Atmospheric Vertical Moisture Profile	Cloud Top Pressure	Precipitable Water
☆ Atmospheric Vertical Temp Profile	Cloud Top Temperature	Precipitation Type/Rate
☆ Imagery	Downward Longwave Radiance (Sfc)	Pressure (Surface/Profile)
☆ Sea Surface Temperature	Downward Shortwave Radiance(Sfc)	Sea Ice Characterization
☆ Sea Surface Winds	Electric Field	Sea Surface Height/Topography
☆ Soil Moisture	Electron Density Profile	Snow Cover/Depth
Aerosol Optical Thickness	Energetic Ions	Solar Irradiance
Aerosol Particle Size	Geomagnetic Field	Supra-Thermal-Auroral Particles
Aerosol Refractive Index	Ice Surface Temperature	Surface Type
Albedo (Surface)	In-*situ* Plasma Fluctuations	Wind Stress
Auroral Boundary	In-*situ* Plasma Temperature	Suspended Matter
Auroral Energy Deposition	Ionospheric Scintillation	Total Water Content
Auroral Imagery	Medium Energy Charged Particles	Vegetation Index
Cloud Base Height	Land Surface Temperature	
Cloud Cover/Layers	Net Heat Flux	
Cloud Effective Particle Size	Net Solar Radiation (TOA)	
Cloud Ice Water Path	Neutral Density Profile	
Cloud Liquid Water	Color/Chlorophyll	
Cloud Optical Thickness	Ocean Wave Characteristics	
Cloud Particle Size/Distribution	Outgoing Longwave Radiation (TOA)	
Cloud Top Height	Ozone - Total Column/Profile	

- VIIRS (23)
- CMIS (19)
- CrIS/ATMS (3)
- OMPS (1)
- SES (13)
- ERBS (5)
- TSIS (1)
- ALTIMETER (3)
- APS (4)

☆ Environmental Data Records (EDRs) with Key Performance Parameters

Satellite Transition Schedule



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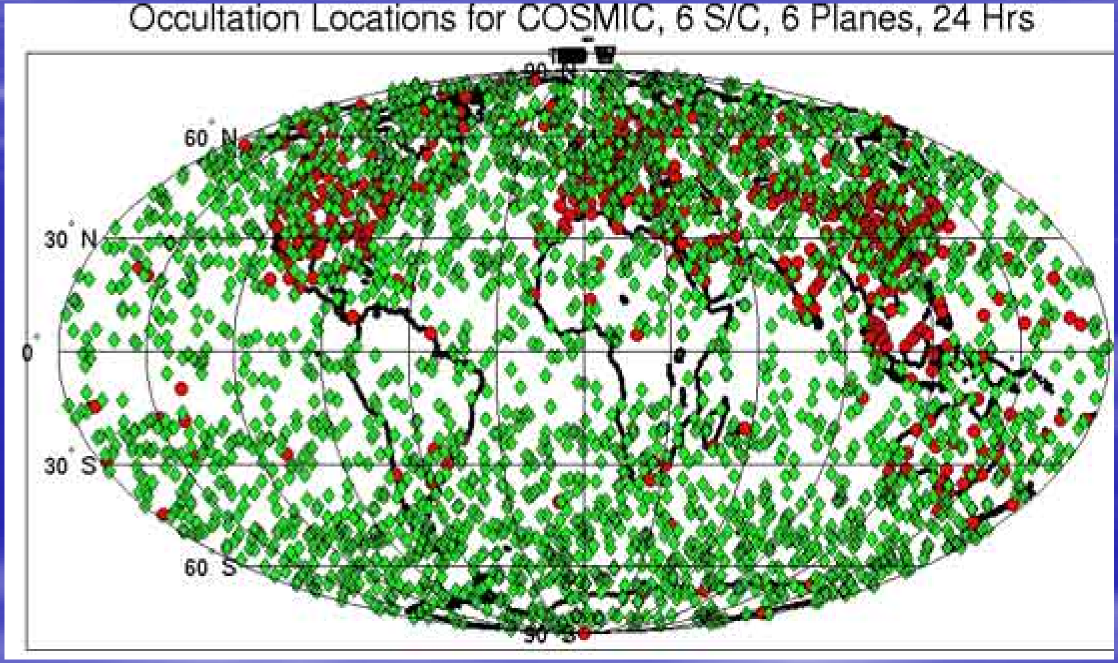
  - cost; reductions through use and/or re-programming of existing resources
  - meteorological variability
  - instrument variability (drift…)
  - availability of data from other platforms
    - ground (expendable, … see ARM)
    - satellite (COSMIC…)

C O S M I C

The COSMIC constellation of six satellites was launched successfully from Vandenberg Air Force Base in California at 6:40 p.m. PDT (9:40 p.m. EDT) on Friday, April 14, 2006. Ground stations have received signals from all six satellites.



By intercepting signals in a web around the planet, COSMIC will provide a homogeneity of coverage, especially over the oceans and other areas traditionally sparse in data, that operational weather balloons and monitoring stations can’t match. Its profile will start near Earth’s surface and extend to the height of the COSMIC satellites at 800 kilometers (500 miles) above Earth … the independent nature of *radio occultation soundings* make them highly complementary to other atmospheric sounding systems, such as infrared and microwave sounders …

Collocation Processing - Management

- Ongoing NOAA-SEARCH Program support to compile collocated radiosonde and TOVS-1b/1c observations from 1979 to 2005:
  (http://www.orbit.nesdis.noaa.gov/smcd/opdb/polarsearch)
  - ***Quantify TOVS Measurement bias (RT model …)***
  - ***Re-process TOVS for Arctic Climate change*** *(Francis / Schweiger)*
- Collocation strategy includes:
  - Closest fov (time, space) to a given sonde
  - Calibrated radiance (Btemp), calibration coefficients …
  - primary and surrounding fov per sounder (suitable for product derivation)
  - Derived products, NWP
  - GOES, AQUA, COSMIC, in-situ
  - QC (Sonde, BT) … *"new moisture screening"*
- Relational collocation data-base file structure
  - Documented and navigatable
  - *open to expansion*
- *Integrate into ATOVS / METOP … NPP, NPOESS … NOAA-wide data inter-comparison protocol … GEOSS*
  - *User Access (web site…)*

Collocation Management and Coordination

- Operational polar satellite deployment synonymous with integration into the reference network (… operational means reference):
  - Launch schedules
  - Data collection and archive
  - *Supports operational implementation*

- Operational polar satellites each serve as *reference data platform* for data collection at reference sites … at least insofar as NESDIS collocation processing

Reference Networks for Satellites

Tuning

- First-guess regression coefficients (T, q)
- ***Radiative Transfer (RT) model bias adjustment coefficients (BTemp)***
- Retrieval Solution Covariance Matrices (T, q)
- Retrieval Solution Noise Matrices (Btemp)
- Coefficient Updating (all)
- Real-time (NWP) versus retrospective (Climate) processing
- ATOVS vs NPOESS

Validation

- First Guess Profiles (apriori observational errors)
- Final Sounding Profiles (observational errors)
- Cloud mask and products
- ***RT model***
- Sounder measurement
- Radiosonde measurement

Benefactors of Reference Networks

- Climate:
  - via long-term record of critical upper air observation error characteristics
  - Retrospective climate product processing
- RT Model Validation / Applications via robust, same-same T, q and BT profiles
  - *R and D via Benchmark network*
- Satellite Data Providers (and nwp):
  - RT (above)
  - Consistent tuning / validation datasets per satellite

Satellite Products for Climate …

"Real-time" Database Compilation Effort

… satellite data and collocated ground truth

(compiled from reference networks
during satellite operational lifetime)

to serve as input for
"tuning"

"Retrospective" Climate Product Processing

…T, H2O, Clouds, BTemp ...

(at conclusion of satellite operational lifetime)

(including multi-parameter retrieval… Jim Liljgren)

Benefactors of Reference Networks

- Climate:
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  - R and D via Benchmark

- Satellite Data Providers (and nwp):
  - RT (above)
  - Consistent tuning / validation datasets per satellite

RT Models

- Useful (critical) for Cross-validation of Satellite, Radiosonde, Climate and NWP Data … ***using fast-codes***

- Are “***Key”*** to ascertaining absolute accuracy through the resolution of calculated (from Raob, Climate, NWP) vs observed (from Satellite) radiances

- Non-unique … different “T, q” profile shapes can satisfy same radiances … problem compounded by spatial / temporal and measurement errors

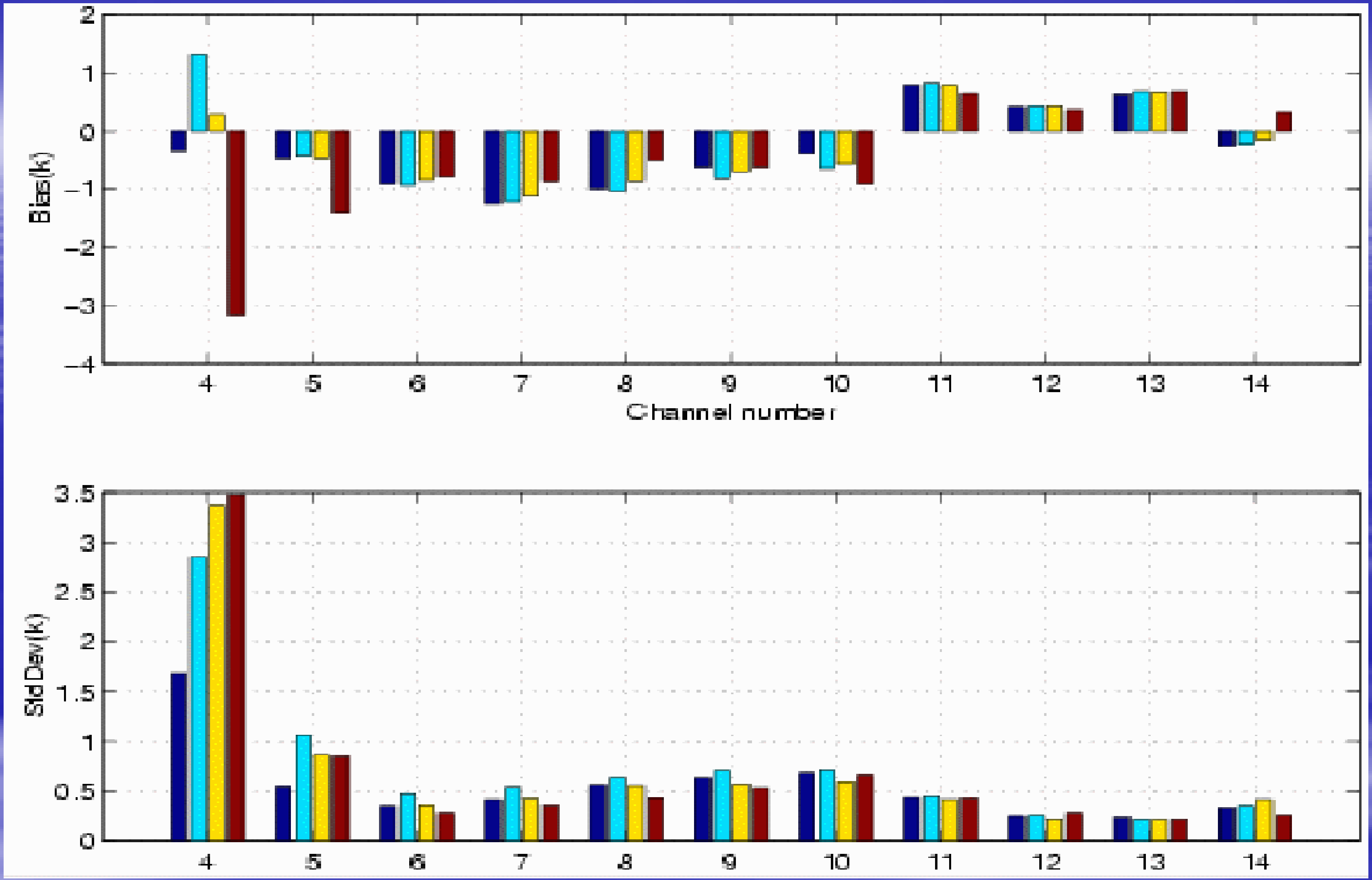
- ***REFERENCE sites good in support of RT model validation***
  - ***Benchmark for RT R & D***

RT Model Bias Adjustment
(tuning …satellite providers and nwp)

- Unresolved bias in RT model and/or satellite measurements leads to systematic bias products and applications (… nwp)

- Approach is to adjust measurements to compensate for such bias prior to retrieval (… assimilation)

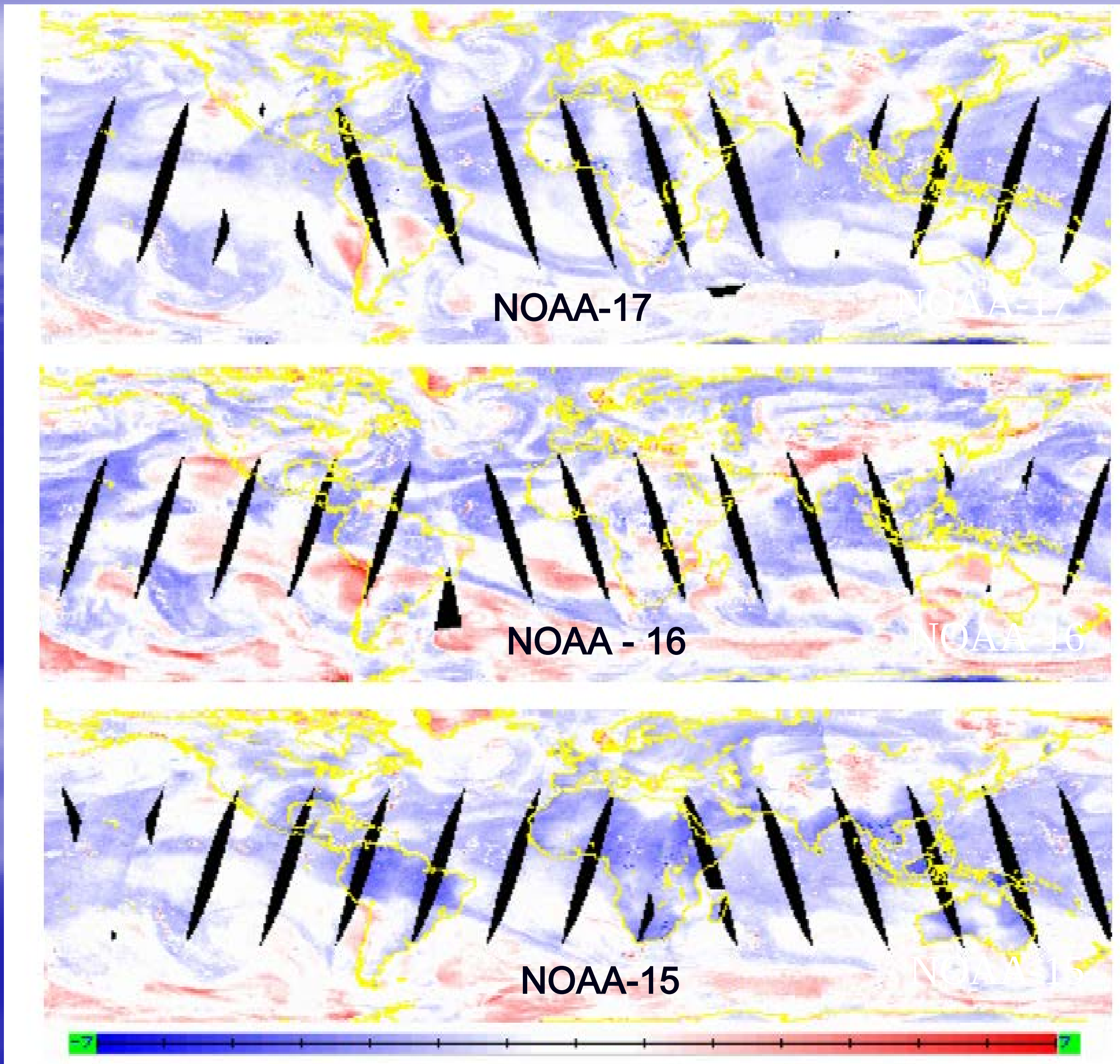
- ***Reference Network provides good observations for "bias tuning"***



“Observed minus Calculated (from Raob (or nwp) and RT) AMSU-A channels 4 to 14 (NOAA-16) are basis of RT-bias coefficients

Land Sea Ice and Snow Coast

RT Bias Adjustment Tuning



AMSU-B at 183 +/- 1 gHz
(upper troposheric moisture)

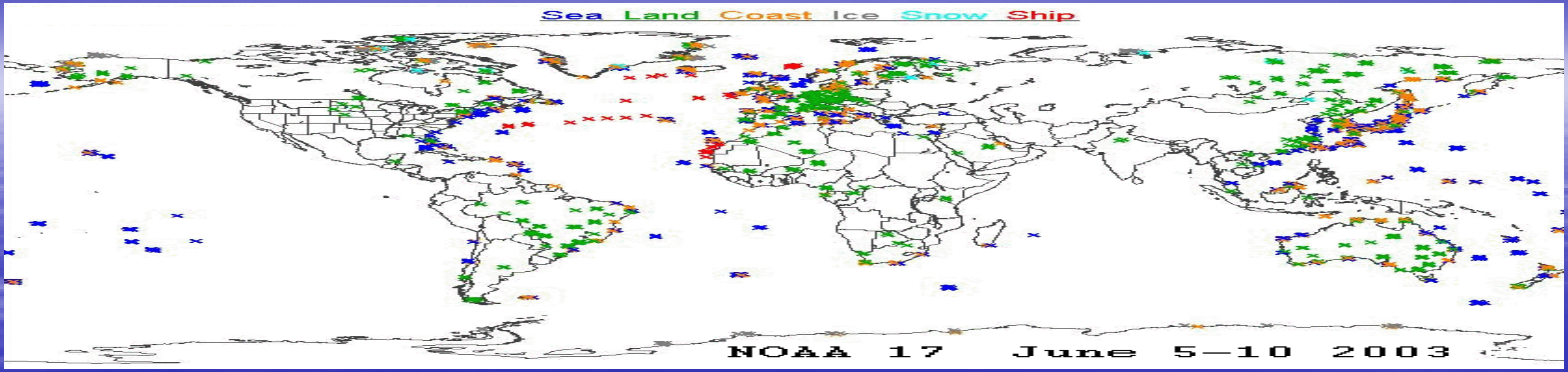
12-hour time composites
(18Z to 06Z)

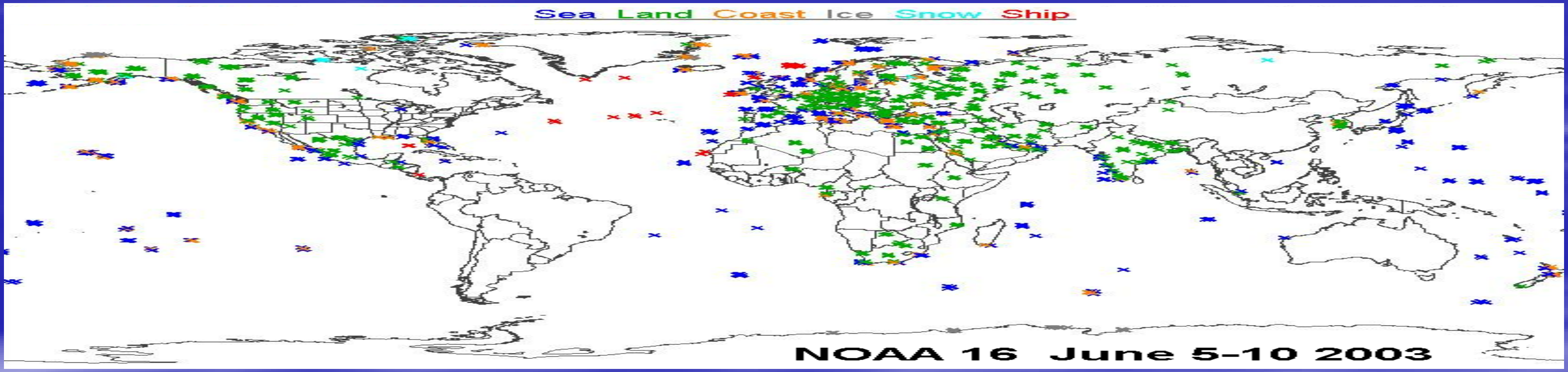
Adjustments as ***regressed from collocated satellite and radiosonde data*** **and applied during operational processing** …

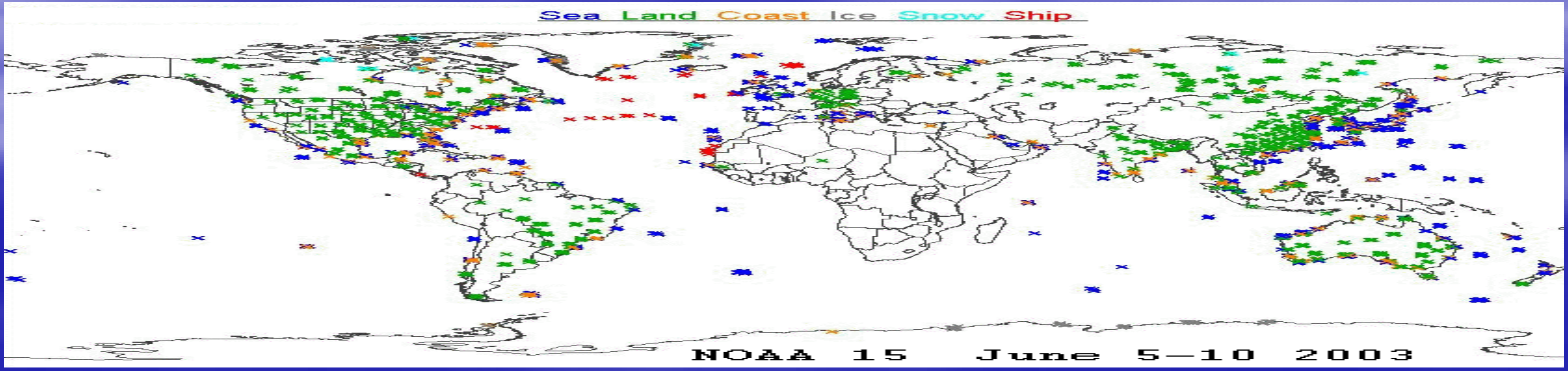
Magnitude and inter-satellite variability "skewed" by systematic radiosonde sampling differences,

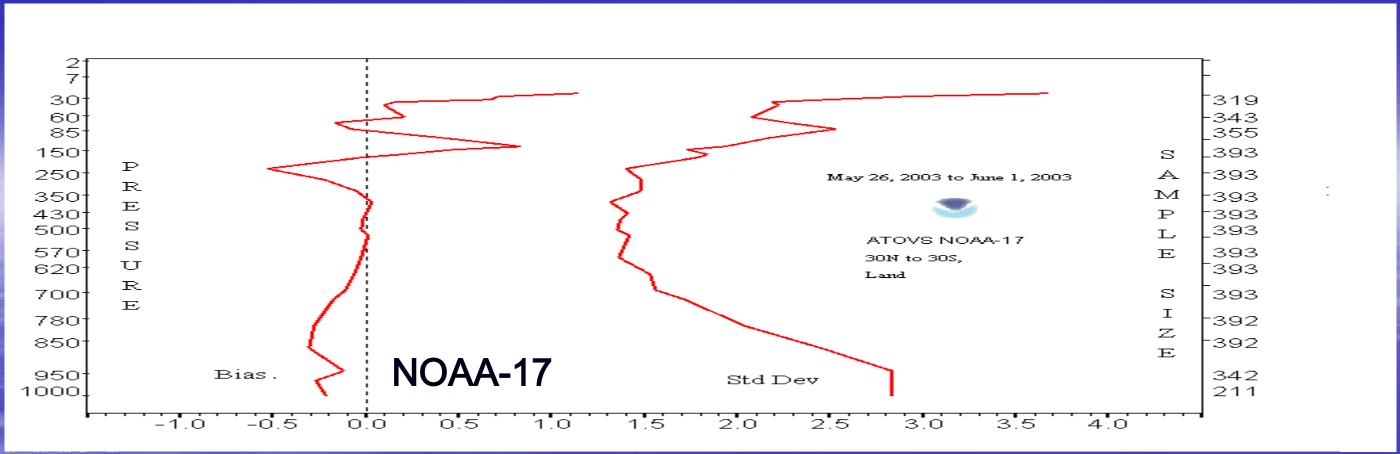
Adjustments appear weather related … ! ?

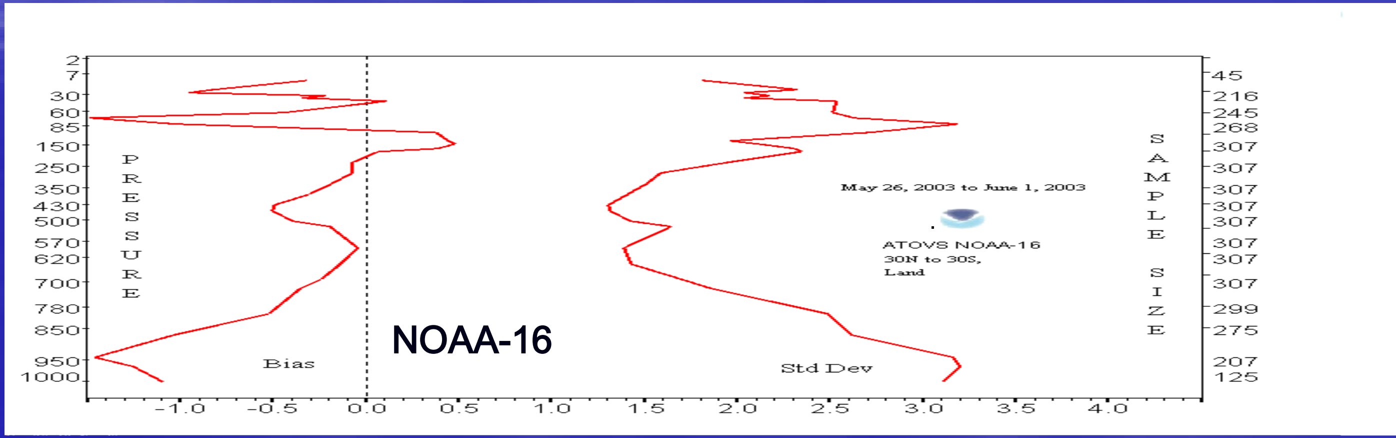
Operational Satellite and Radiosonde Collocations used for Products Validation

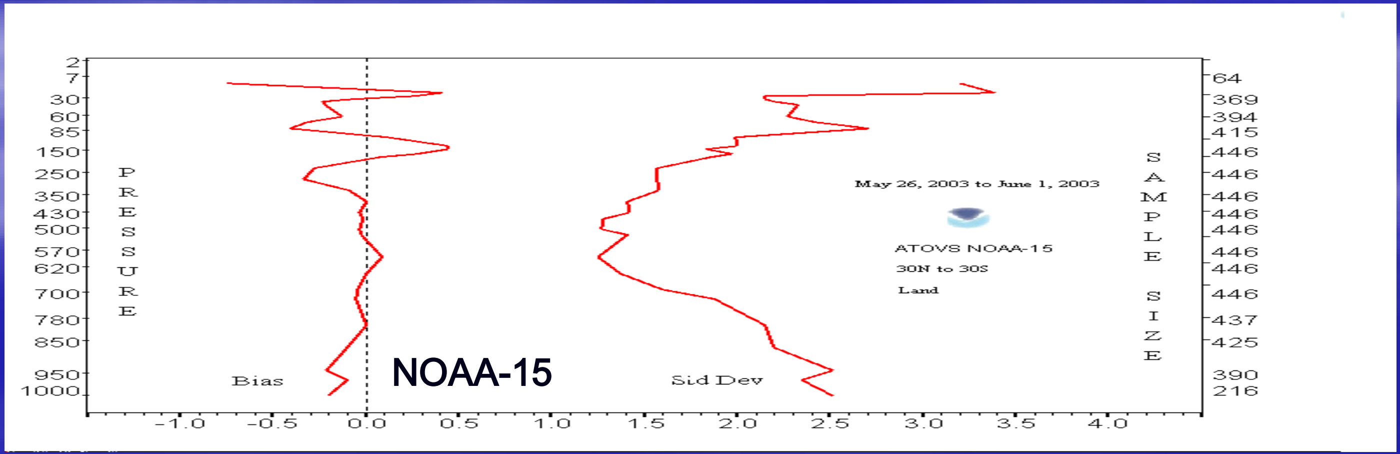










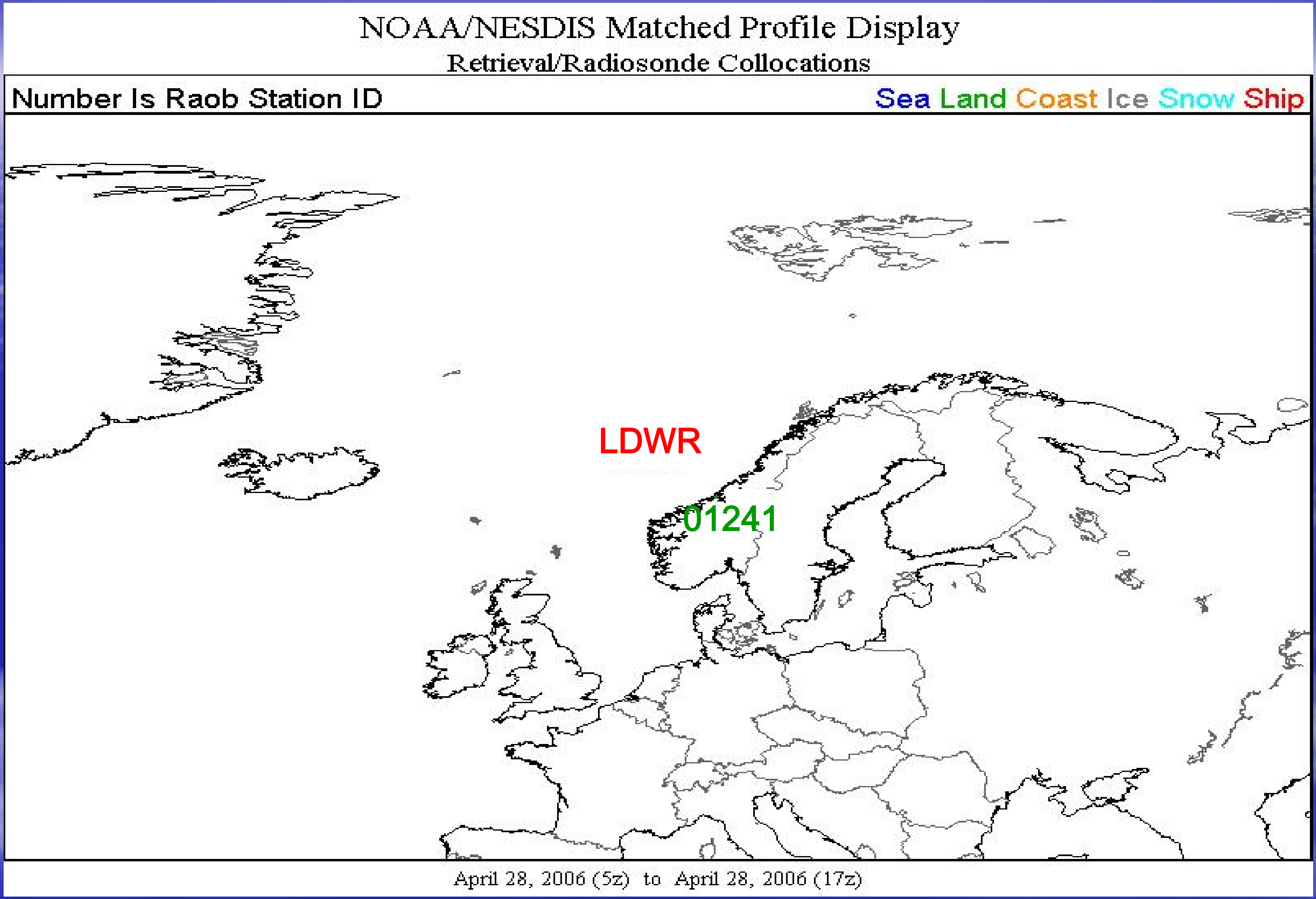


(Satellite – Radiosonde)
Temperature statistics

Tropical land
(30N to 30S)

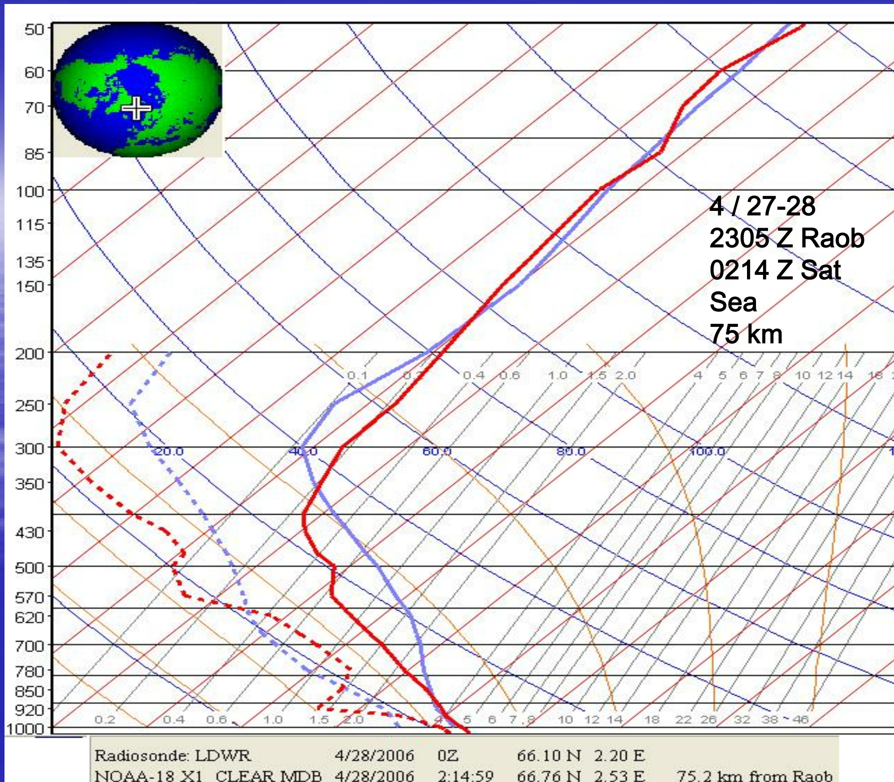
June 7-14, 2003

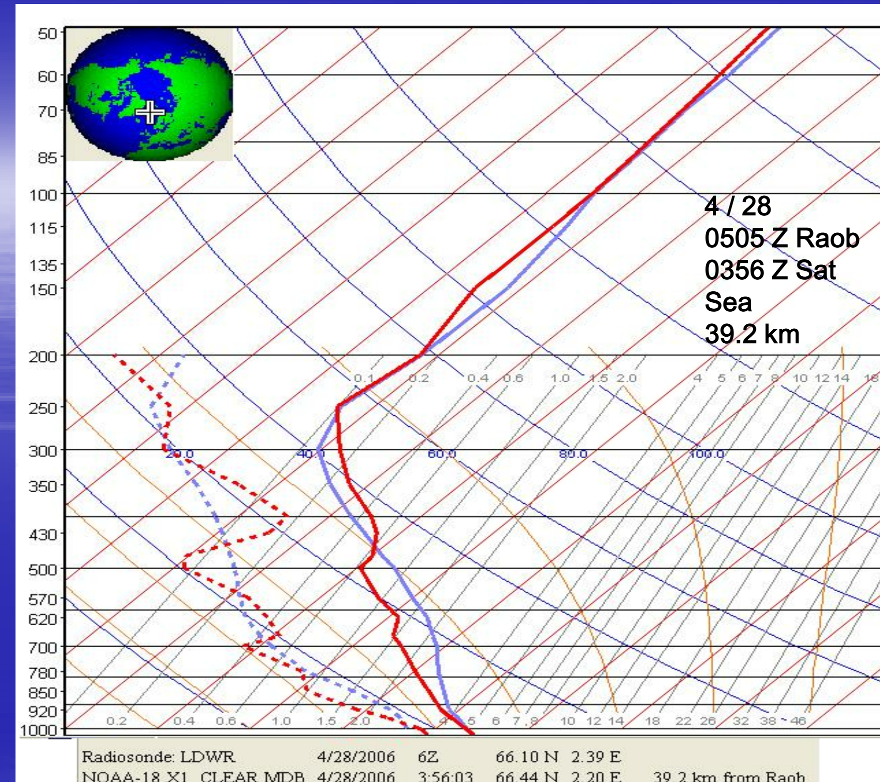
Validation Results "skewed" by regional sampling bias/error …



RT calculation (from radiosondes) versus satellite observation case study

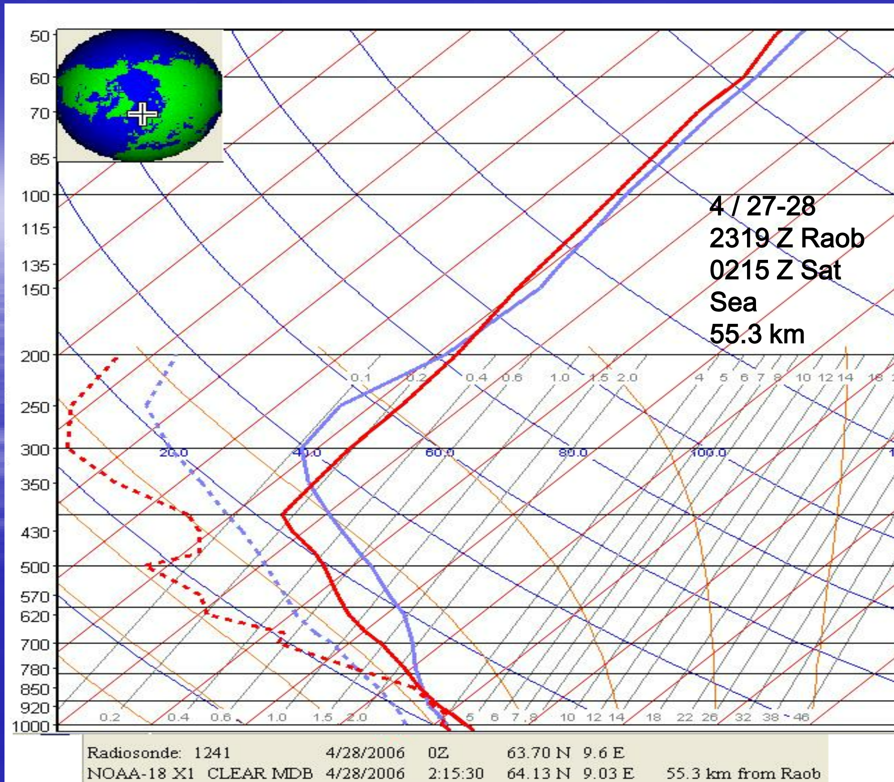
(… demonstrate benefit of reference vs currently available observations …)

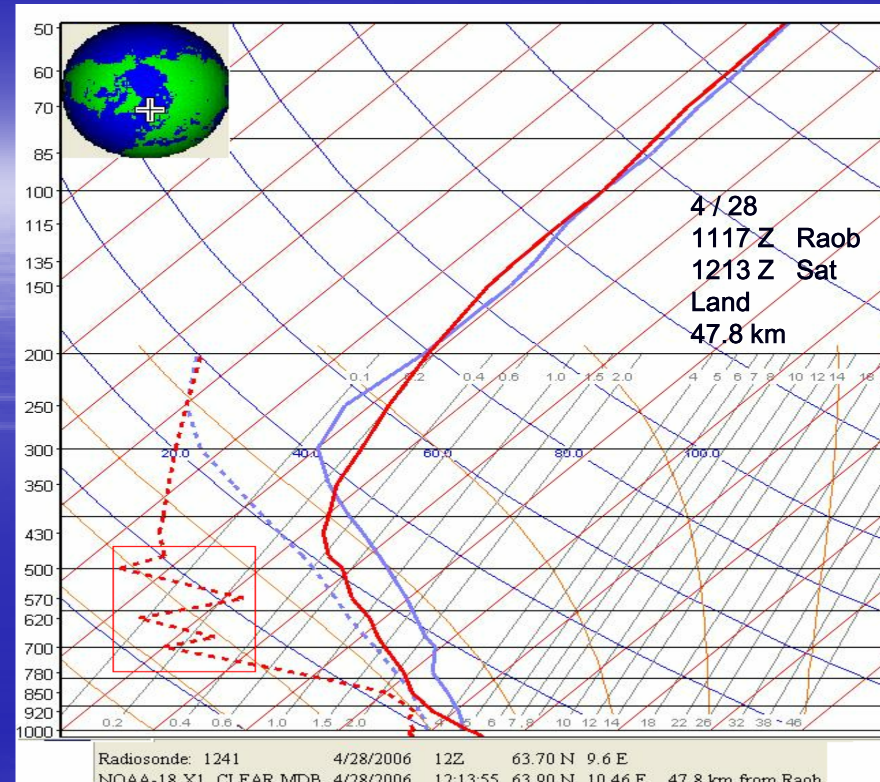




	AMSU-A				MHS	
143.1	142.8	143.2				
148.1	148.1	148.4		225.5	230.0	
207.2	213.8	207.6				
240.8	243.8	242.2	(850)			
				251.3	250.8	252.3
242.0	243.0	243.6	(600)	259.3	259.5	261.4
233.0	232.0	233.7	(400)	260.8	264.5	261.5
225.7	225.1	226.7	(250)			
222.8	221.6	222.5	(150)			
219.1	217.8	219.4	(80)			
218.4	217.0	218.6	(50)			
220.2	219.4	220.5	(20)			
227.7	227.1	228.1	(10)			
242.5	240.7	242.3	(5)			
257.4	256.1	256.6	(2)			
193.2	196.1	193.3		193.2	196.9	
R (RT)	Obs	B (RT)		R (RT)	Obs	B(RT)

	AMSU-A				MHS	
141.7	141.3	143.5				
147.6	147.2	148.8		221.7	230.0	
207.0	212.9	208.0				
241.6	244.0	242.9	(850)			
				250.0	249.7	253.8
242.9	243.5	244.1	(600)	260.2	259.7	262.9
233.1	232.4	233.9	(400)	258.6	264.8	262.4
225.8	224.7	226.4	(250)			
221.0	220.5	221.7	(150)			
217.3	216.8	218.3	(80)			
217.0	216.3	217.9	(50)			
219.4	219.0	220.2	(20)			
227.5	227.0	227.9	(10)			
242.0	240.4	241.8	(5)			
256.3	254.8	255.6	(2)			
191.6	195.0	193.7		191.6	196.2	
R (RT)	Obs	B (RT)		R (RT)	Obs	B (RT)





AMSU-A

R (RT)	Obs	B (RT)	
145.9	158.3	144.6	
149.2	162.2	148.5	
207.9	217.4	207.5	
240.8	243.7	241.7	(850)
241.8	242.3	243.1	(600)
232.9	232.1	233.8	(400)
226.9	225.7	227.3	(250)
223.4	222.9	223.6	(150)
219.7	219.2	221.0	(80)
218.8	218.3	219.9	(50)
220.6	220.6	221.3	(20)
227.7	227.1	228.2	(10)
241.4	239.8	241.3	(5)
255.7	254.1	254.8	(2)
196.7	207.2	194.4	

MHS

R (RT)	Obs	B (RT)
232.8	236.5	
251.1	248.6	248.3
259.2	257.6	257.7
263.8	263.6	261.5
196.7	197.3	

AMSU-A

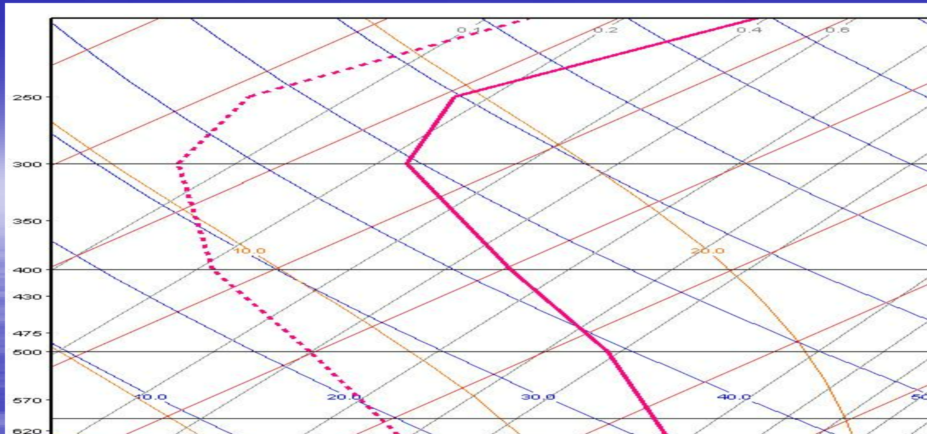
R (RT)	Obs	B (RT)	
246.5	206.7	248.5	
246.1	209.5	247.5	
252.8	244.9	254.5	
252.5	251.7	254.7	(850)
244.7	244.9	246.7	(600)
233.4	232.6	234.5	(400)
226.7	225.5	227.1	(250)
222.6	221.7	222.7	(150)
219.1	218.3	219.5	(80)
219.0	218.3	219.8	(50)
221.5	221.1	221.8	(20)
228.8	228.3	229.2	(10)
242.3	240.6	242.3	(5)
256.2	254.8	255.5	(2)
249.5	240.9	251.7	

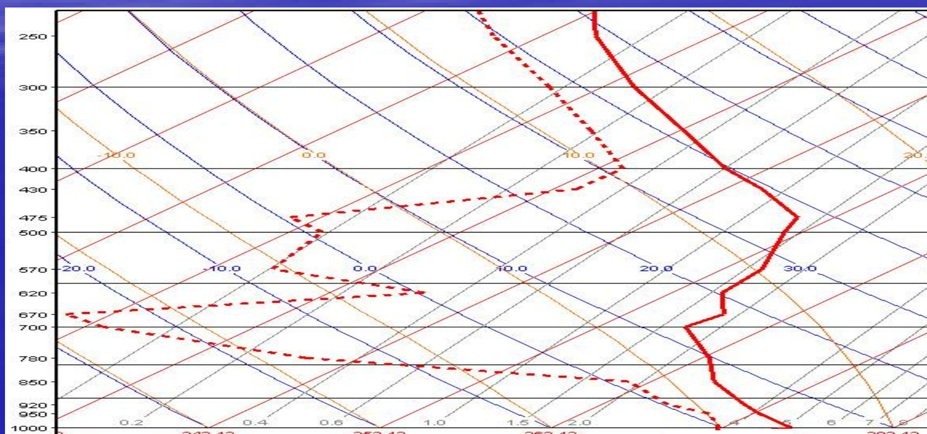
MHS

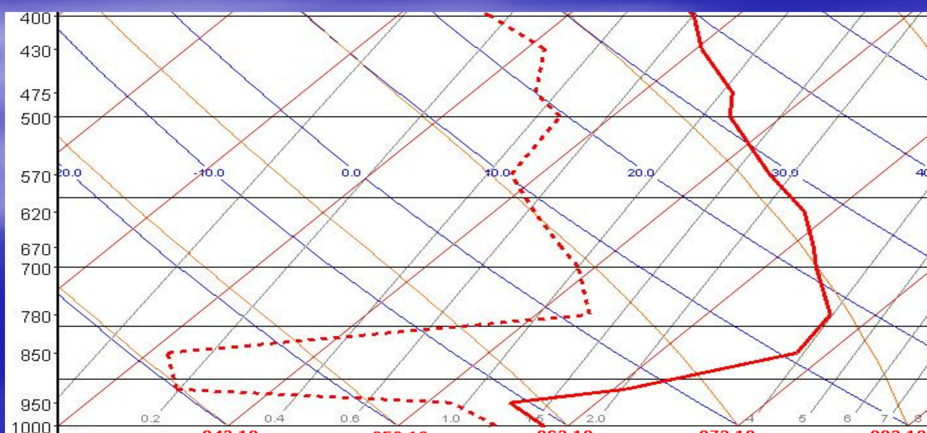
R (RT)	Obs	B (RT)
255.1	268.3	
254.1	250.0	246.2
262.2	259.2	256.4
266.0	267.3	264.8
249.5	260.1	

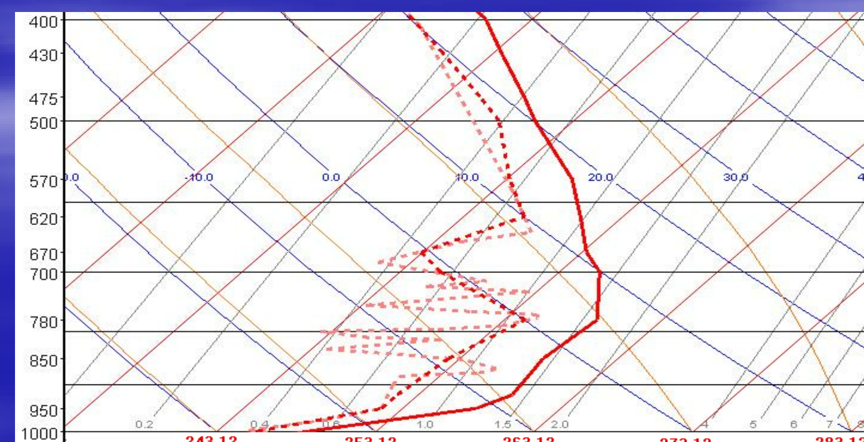
Prohibitive cases for tuning and validation due to RT ambiguity

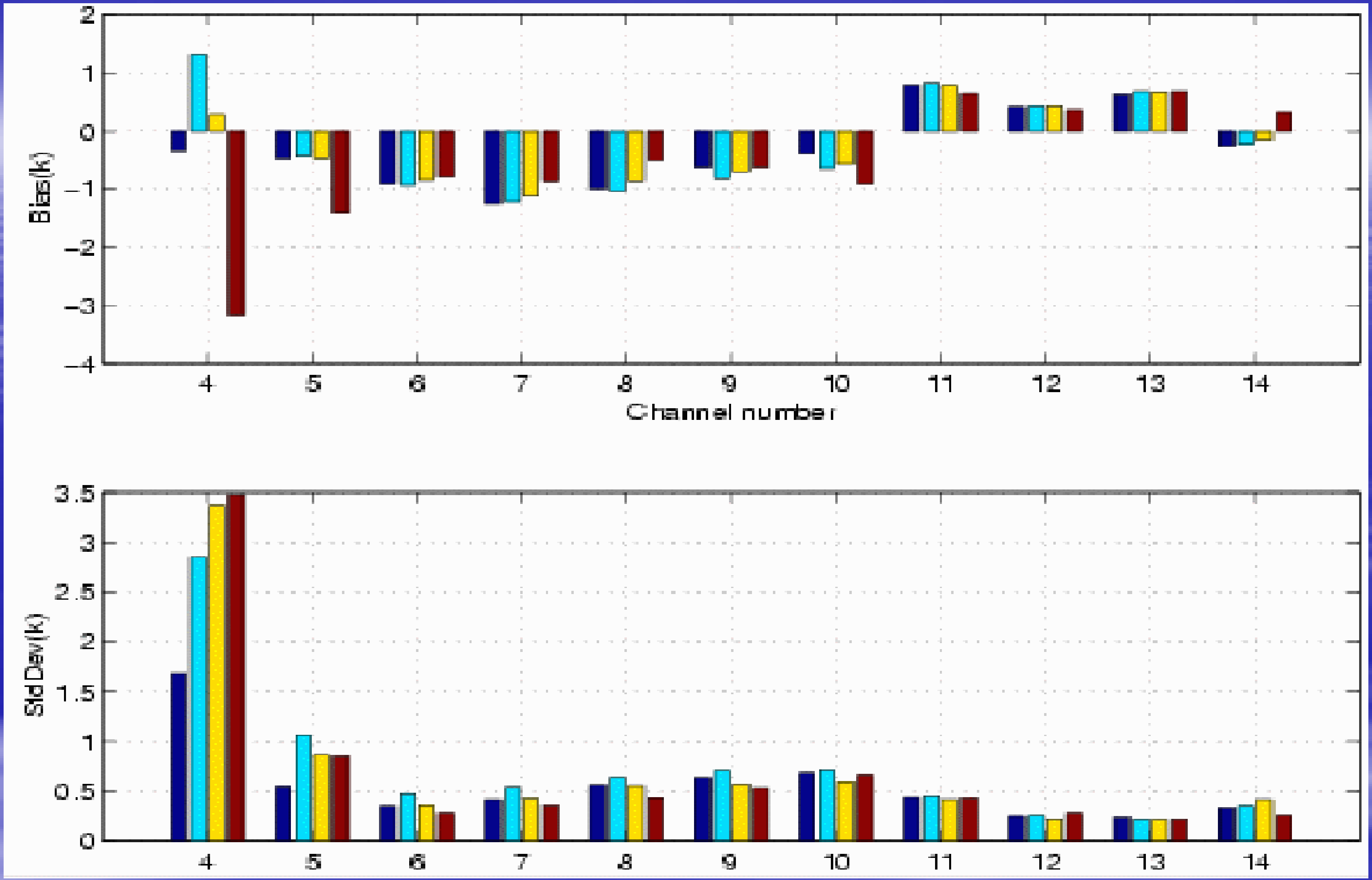
"*Operational Procedures to Process, Screen and Collocate Radiosondes with NOAA Polar Satellite Observations*"
… Reale and Tilley





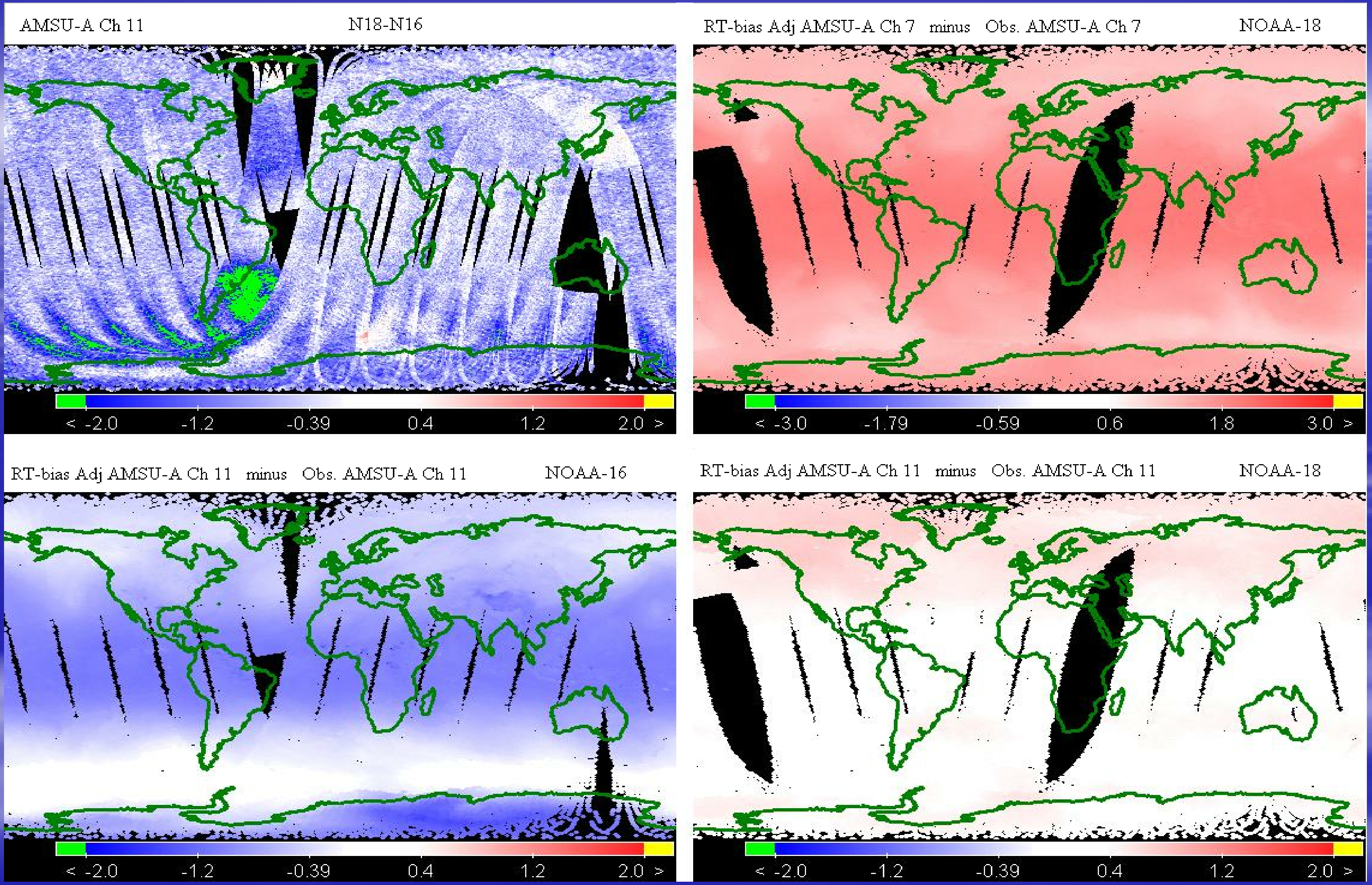




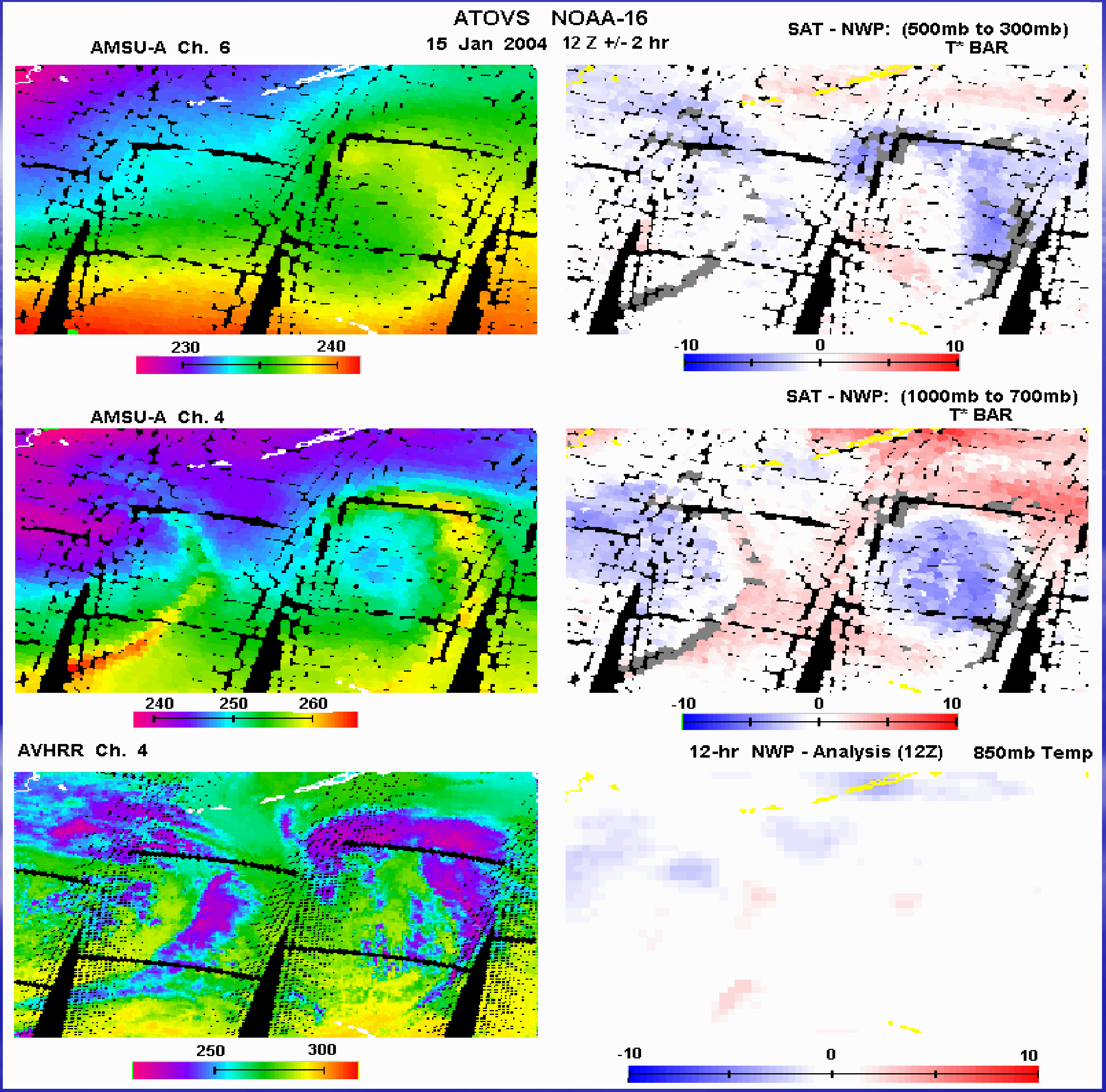


“Observed minus Calculated (from Raob and RT) AMSU-A channels 4 to 14 (NOAA-16) are basis of RT-bias coefficients

Land Sea Ice and Snow Coast



Differences in bias adjustments for AMSU-A Ch 11 between N18 and N16 (lower) confirmed by observational differences (upper left)



Reference Network provide NWP an independent platform for "bias tuning"

leading to improved satellite data impact in frontal zones?

Summary

- **Reference Network for optimizing satellite data**
  - **Tuning and Validation**
- **Candidate site selection … robust X-section of useful measurements**
- **Site measurement strategies**
  - **radiosondes and in-situ**
- **Data collection and archive management**
  - **integrate into NOAA Operations**
  - **expansion to include COSMIC, GOES, AQUA … NPP … NPOESS …**
- Impacts on RT model validation / applications
  - Benchmark for R and D