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

- Benchmark Network
  - ~10 stations
- Upper Air Reference Network
  - 30-40 stations
- GCOS Upper Air Network (GUAN)
  - 161 stations
- Comprehensive observing network
  - All stations, observing systems, satellites, reanalyses etc.
A cascade of networks for future climate research

**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.

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Peter Thorne (UKMO)
NOAA/GCOS Workshop-1
Feb 2005
Satellite Scientific Algorithm Tuning
(from collocation datasets)

- First-guess regression coefficients $(T, q)$
- Radiative Transfer (RT) model bias adjustment coefficients $(B_{\text{temp}}, RT; T, q)$
- Retrieval Solution Covariance Matrices $(T, q)$
- Retrieval Solution Noise Matrices $(B_{\text{temp}}, RT; T, q)$
- 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
Radiosonde Type Distribution

- 10; (80) Vaisala RS92 DGIll (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)

- Spatially and temporally coincident (same-same)

- Reliable and consistent (site protocols)
  - In-situ

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

NOAA/NESDIS Matched Profile Display
Retrieval/Radiosonde Collocations

Number is Raob Instrument Type
Sea  Land  Coast  Ice  Snow  Ship

May 3, 6 (0z) to May 9, 6 (0z)

2-3 hr Land; 3-4 hr Sea; 100km
Collocations w/NOAA-15 local X-over 1930 (A), 0730

NOAA/NESDIS Matched Profile Display
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May 3, 6 (0z) to May 9, 6 (0z)

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Sea Land Coast Ice Snow Ship
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Collocations w/NOAA-18 local X-over 1330 (A), 0130

NOAA/NESDIS Matched Profile Display
Retrieval/Radiosonde Collocations

May 3, 6 (0z) to May 9, 6 (0z)

162 / 1229 ; @ -1 hr, 50km
Optimal Reference Network for Satellites

- Robust and continuous

- Cross-section of useful measurements used for scientific algorithm tuning and validation
  - Minimum Accuracy (traceable)

- 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)

Green – very reliable
Blue – reliable
Red – questionable
Black - ARM
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
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.
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)
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...)

**NPOESS**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>VIIRS</td>
<td>vis/IR imager</td>
</tr>
<tr>
<td>CMIS</td>
<td>μwave imager</td>
</tr>
<tr>
<td>CrIS</td>
<td>IR sounder</td>
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<tr>
<td>ATMS</td>
<td>μwave sounder</td>
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<tr>
<td>SESS</td>
<td>space environment</td>
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<tr>
<td>OMPS</td>
<td>ozone</td>
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<tr>
<td>ADCS</td>
<td>data collection</td>
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<tr>
<td>SARSAT</td>
<td>search &amp; rescue</td>
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<tr>
<td>APS</td>
<td>aerosol polarimeter</td>
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<tr>
<td>ERBS</td>
<td>Earth radiation budget</td>
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<tr>
<td>SS</td>
<td>laser sensor</td>
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<tr>
<td>ALT</td>
<td>altimeter</td>
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<tr>
<td>TSIS</td>
<td>solar irradiance</td>
</tr>
</tbody>
</table>

**Satellites:**

- NPP (1030)
- NPOESS 1330
- NPOESS 1730
- NPOESS 2130
# NPOESS Payloads

<table>
<thead>
<tr>
<th>NPOESS Instruments</th>
<th>1730</th>
<th>2130</th>
<th>1330</th>
<th>METOP 0930</th>
<th>NPP 1030</th>
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<td>X (IASI/HIRS)</td>
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<td>X (SEM)</td>
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<td>Leveraged</td>
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<td>Advanced Technology MW Sounder (ATMS)*</td>
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<td>X (AMSU/MHS)</td>
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<td>ARGOS-Data Collection System (A-DCS)</td>
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<td>Earth Radiation Budget Sensor (ERBS)</td>
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<td>Total Solar Irradiance Sensor (TSIS)</td>
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<td>Radar altimeter (ALT)</td>
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Environmental Data Records (EDRs) with Key Performance Parameters

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

55 Product Sets [EDR, RDR, SDR]

VIIRS (23)
CMIS (19)
CrIS/ATMS (3)
OMPS (1)
SES (13)
ERBS (5)
TSIS (1)
ALTIMETER (3)
APS (4)
<table>
<thead>
<tr>
<th>Local Equatorial Crossing Time</th>
<th>Mission Satisfaction</th>
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<td>DMSP</td>
<td>C2</td>
</tr>
<tr>
<td></td>
<td>F17</td>
<td>C1</td>
</tr>
<tr>
<td></td>
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<tr>
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<td>C3</td>
<td>NPOESS</td>
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<td>0730 - 1030</td>
<td>POES 17</td>
<td>C3</td>
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<td></td>
<td>F16</td>
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<tr>
<td></td>
<td>NPOESS</td>
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</tr>
</tbody>
</table>

- **Earliest Availability**: The earliest date a satellite becomes available.
- **Scheduled launch date**: The date a satellite is scheduled to be launched.
- **Backup Capability**: Negative slope indicates the satellite is late to need.
- **Satellite Availability**: Negative slope indicates the satellite is late to need.

**Legend**:
- Red line: Backup Capability – Negative slope means satellite is late to need.
- Blue line: Satellite Availability – Negative slope means satellite is late to need.
Sample Size

- 42 Reference Sites

- One spatially and temporally coincident set of 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 (expendable, ... see ARM)
    - satellite (COSMIC...)

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](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...)**
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:**
  - 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

- **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
AMSU-B at 183 +/- 1 gHz
(upper tropospheric 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
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

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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 for Land, Sea, Ice and Snow, and 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