Transfer of AVHRR SST Pathfinder to NODC to sustain long term production, distribution and archiving
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ARC/SDS review

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What is Pathfinder

- Daily global SST fields, resolution 4.63km for all of AVHRR 5 channel instruments – N7 to N18; (N19 and Metop future) using consistent calibration and processing methodology.
- Path group : SDS funded – University of Miami, and NOAA NODC with NCDC collaboration (R. Reynolds).
- Related activities and support:

  NASA MEASURES - URI, MIAMI, NODC addition of production and distribution of 1km AVHRR

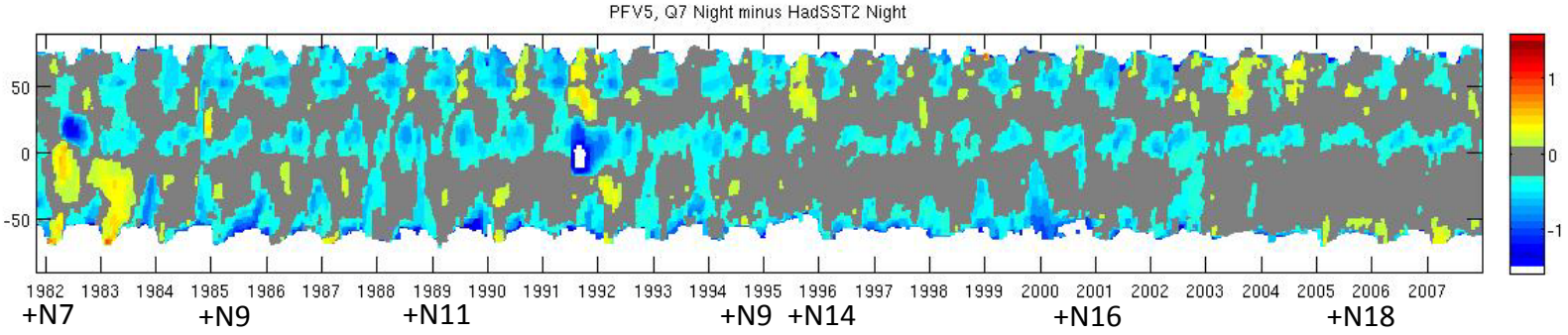
  GHRSST, consistent file format, uncertainty reporting

Background

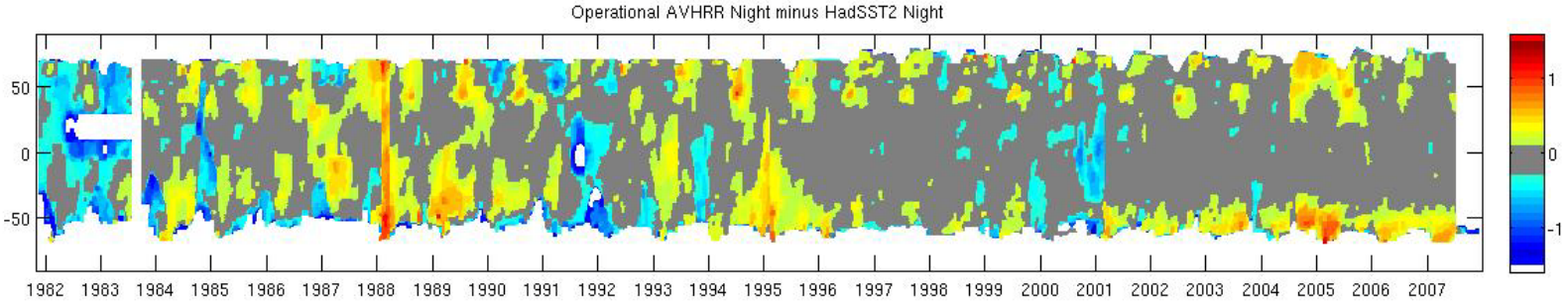
- **CDR – Length, Stability, Accuracy error budget**
- **Consistent processing across multiple sensors**
  - **Noaa-7 through Noaa-18 (future support for N19, METOP)**
- **Full time series reprocessing for each update of algorithm, data quality tests,…**
- **Match-up Data base – Sat observations, in situ, ancillary fields (e.g. wind speed, ozone, aerosols, water vapor…) [with P. Minnett]**
- **Improved spatial resolution:**
  - **18 -> 9 -> 4km global fields, 1km for LAC/HRPT**
- **Improved navigation (on-board clock resets, attitude correction)**
- **Improved Ancillary fields, e.g. Reference fields:**
  - **From Reynolds 1°, weekly AVHRR+InSitu**
  - **To Reynolds ¼°, daily V2 with Pathfinder, AMSR, InSitu**
- **Pathfinder SST products being integrated into international GHRSST file format– Group (for) High Resolution Sea Surface Temperature**
- **Pathfinder Application – order 600-1000 users/month and volume of 600-800 gigabytes of Pathfinder fields delivered/month (2004-2006) [per K. Casey, NODC]**

Pathfinder5–HADSST2 residuals for 1982 through 2007, provided by Casey and Brandon, NODC

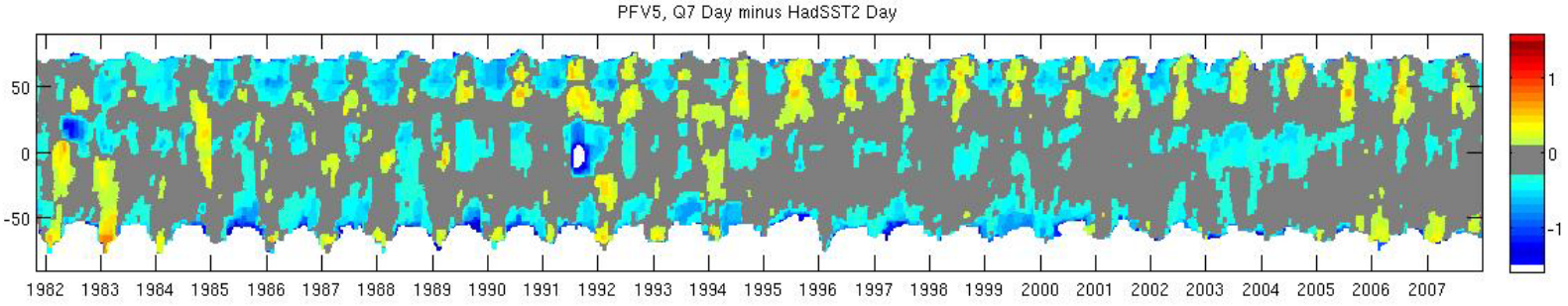
V5 Path – HadSST2 (night) 5.1 for N7



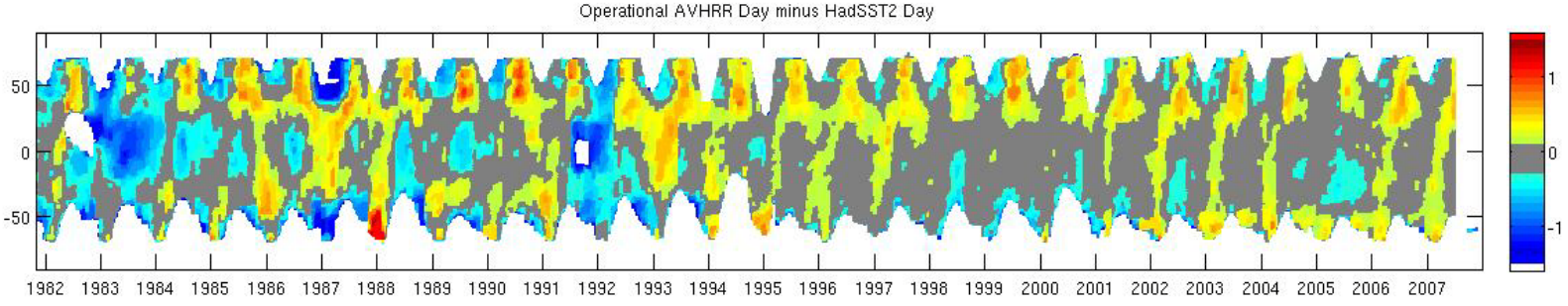
Operational AVHRR – HadSST2 (night)



V5 Path – HadSST2 (day)



Operational AVHRR – HadSST2 (day)



Processing Transfer to NODC

- **SST production software – Level 0/1 through product maps (local and global).**
- **Matchup database – Contemporaneous, co-located AVHRR, *in situ* observations.**
- **Methodology for determination of SST equation coefficients.**
- **Linux cluster processing environment control scripts.**

Pathfinder Process Flow

- **Matchup Database -> Algorithm Coefficient Determination.**
- **Quality control -> Test SST retrievals vs in situ.**
- **Daily processing for near real time.**
- **Track Pathfinder accuracy versus available satellite and L4 analysis products.**
- **Update algorithms as needed, *e.g.* algorithm improvements, calibration updates, ancillary data fields (SST reference field, ice mask).**
- **When sufficient improvement is achieved, reprocess historical AVHRR global data.**

Pathfinder Program Flow

Processing Setup

Define processing sequence
Data Type (GAC,LAC)

Load input:
AVHRR
ancillary

Determine
DataDay
Limits

Find poles
Day/night
Split into processing segments

Granule Processing ~ 100 minutes of satellite observations

Ingest
GAC, LAC
L1b, L0 (telemetry)

Geo-location
Clock Correction
Attitude Correction

L1 -> L2
Conversion
SST+Quality

SpaceBin
Swath to
Earth located
Equal area-4km

Granule Collection

TimeBin
Collect SpaceBin
Files into day/night
Orbit segments

TimeBin
Collect Orbit
Segments into
Day files

TimeBin
Collect Day into
Weekly or Longer
files

PathSpace
Lower resolution
25km, 36km, 1deg

Map
Standard
Projections

Distribution
File cleanup

Proceed to
Next day

GHRSST expands the SST processing to include Time and Error fields for each pixel (Mean and S.D.)

The SST hypercube (for MODIS, AVHRR and VIIRS) is a multi-dimensional look up table of SST retrieval uncertainty, bias and standard deviation, determined from comprehensive analysis of the MODIS, AVHRR, VIIRS Match-up Data Bases (MDB).

The MDB includes contemporaneous, co-located satellite brightness temperature, in-situ buoy and radiometer SST, environmental 'observations' from analyzed model or satellite observed fields, satellite viewing geometry, time and location.

A series of quality tests is applied to each pixel during processing of the MDB data to identify cloud and dust aerosol contaminated retrievals and assign each pixel to one of several quality levels (0-4 MODIS, VIIRS, 0-8 AVHRR).

RSMAS

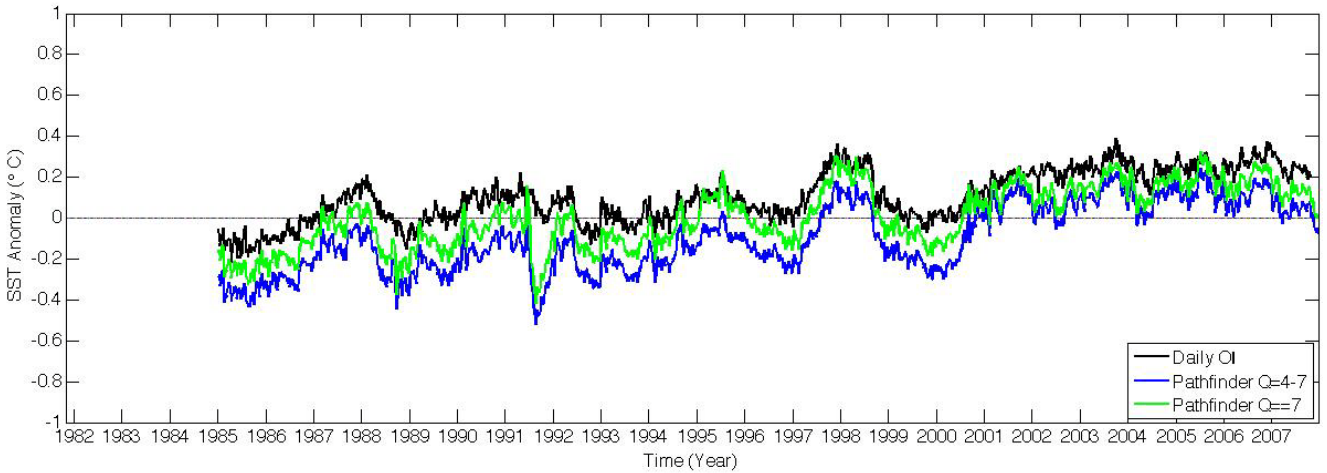
Version 6 Pathfinder Improvements

- Minimize High Latitude Seasonal Oscillation.
- Approach [LATBAND]:
  - Estimate Coefficients using 20° zonal bands centered at the Equator, ± 2.5° transition between bands
  - Coefficients estimated monthly and repeat for each year for a given sensor (volcano periods to be handled separately)
  - Reference SST – Reynolds ¼°, daily
    - Uses AVHRR, AMSR, Pathfinder and In situ observations
    - Retains high gradient regions in Pathfinder fields
- New algorithms are first developed and tested for MODIS (improved sensor characterization and more stable operating environment).
- LATBAND algorithms have been transitioned to AVHRR.

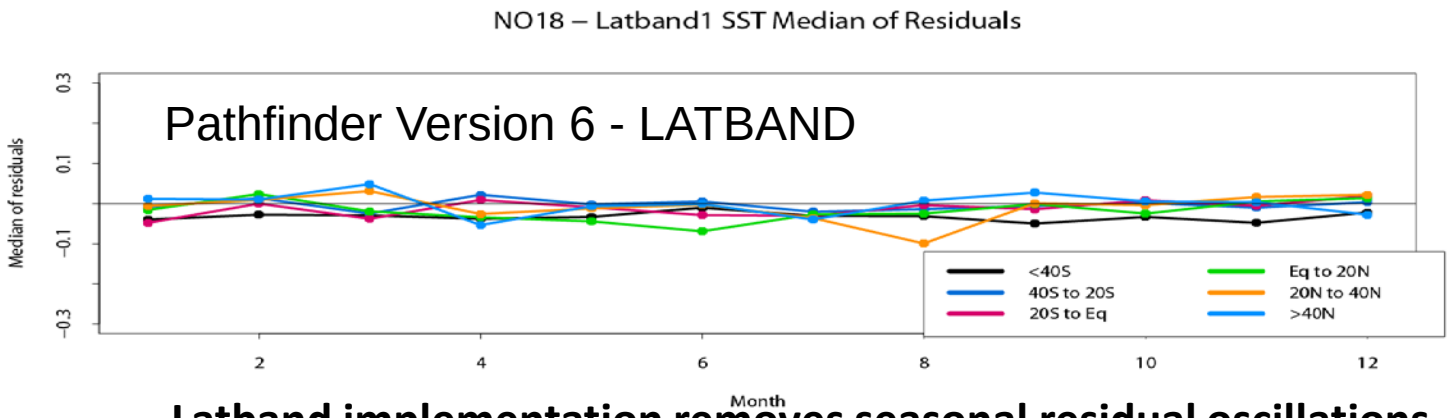
LATBAND Layout
40-90°N
20-40°N
0-20°N
20-0°S
40-20°S
90-40°S

Pathfinder V5 and the GCOS SST Intercomparison Facility

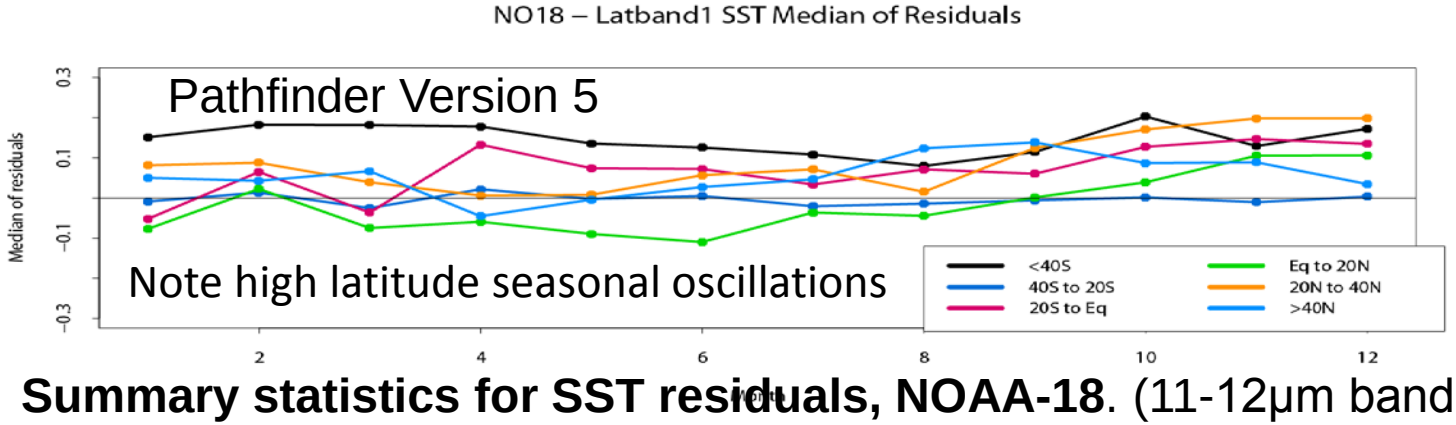
- **Project goals:** To understand differences between SST analyses and reconstructions with the aim of
  1. producing better, long-term SST climate data records, and
  2. linking the modern satellite-based records with the historical, primarily *in situ*-based records.
- Facility is hosted by NODC and includes 11 products from the international SST community
- The Pathfinder climatology is used as the common climatology against which all satellite-era SST products in the facility are evaluated, using a set of standard diagnostics, cross-product climatology analyses are also available
- Intercomparisons have been used to explore specific differences between analyses, e.g. the persistent cold-bias in Pathfinder (see figure below), PV5



Application of LATBAND to NOAA-18



Latband implementation removes seasonal residual oscillations

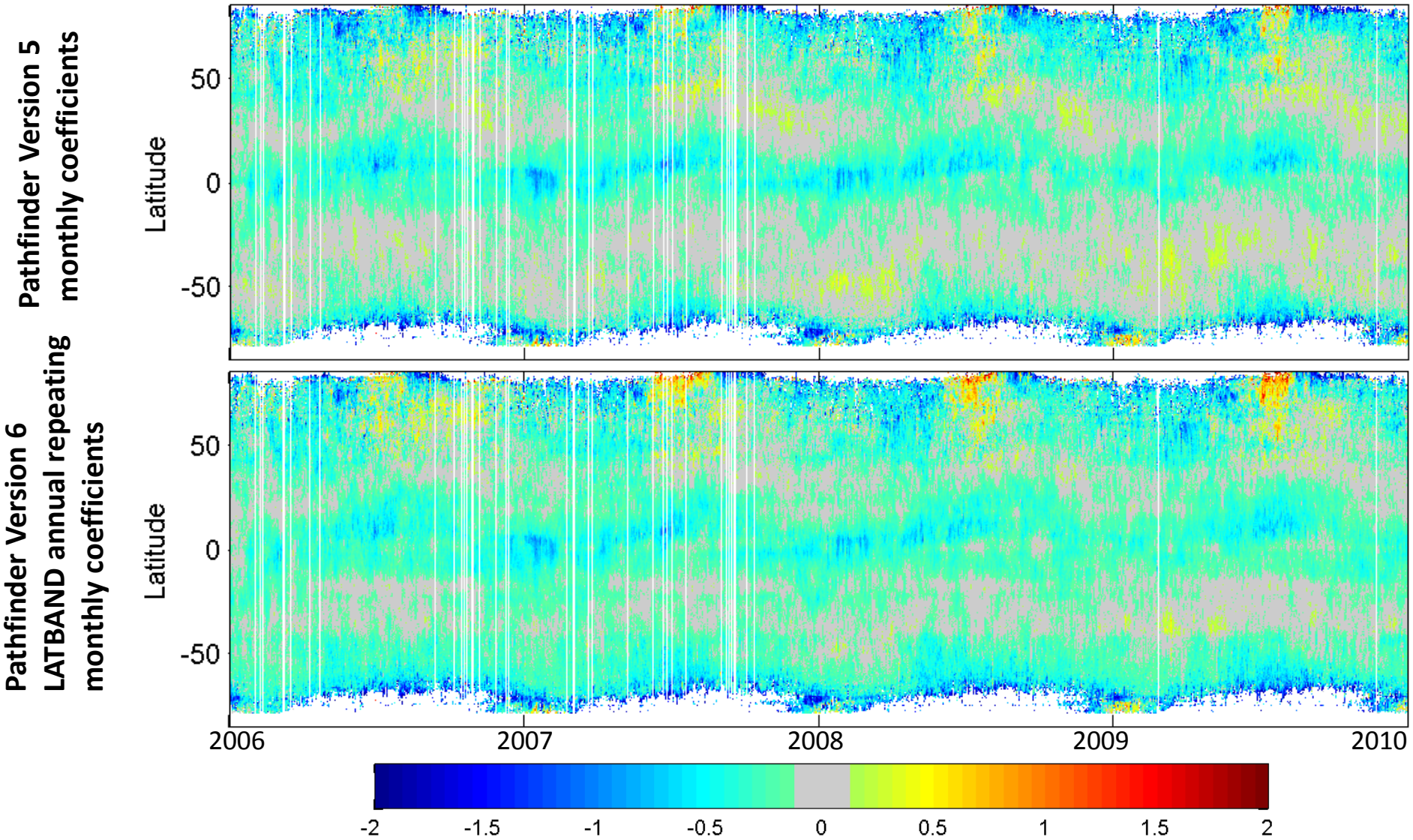


Summary statistics for SST residuals, NOAA-18. (11-12μm bands)

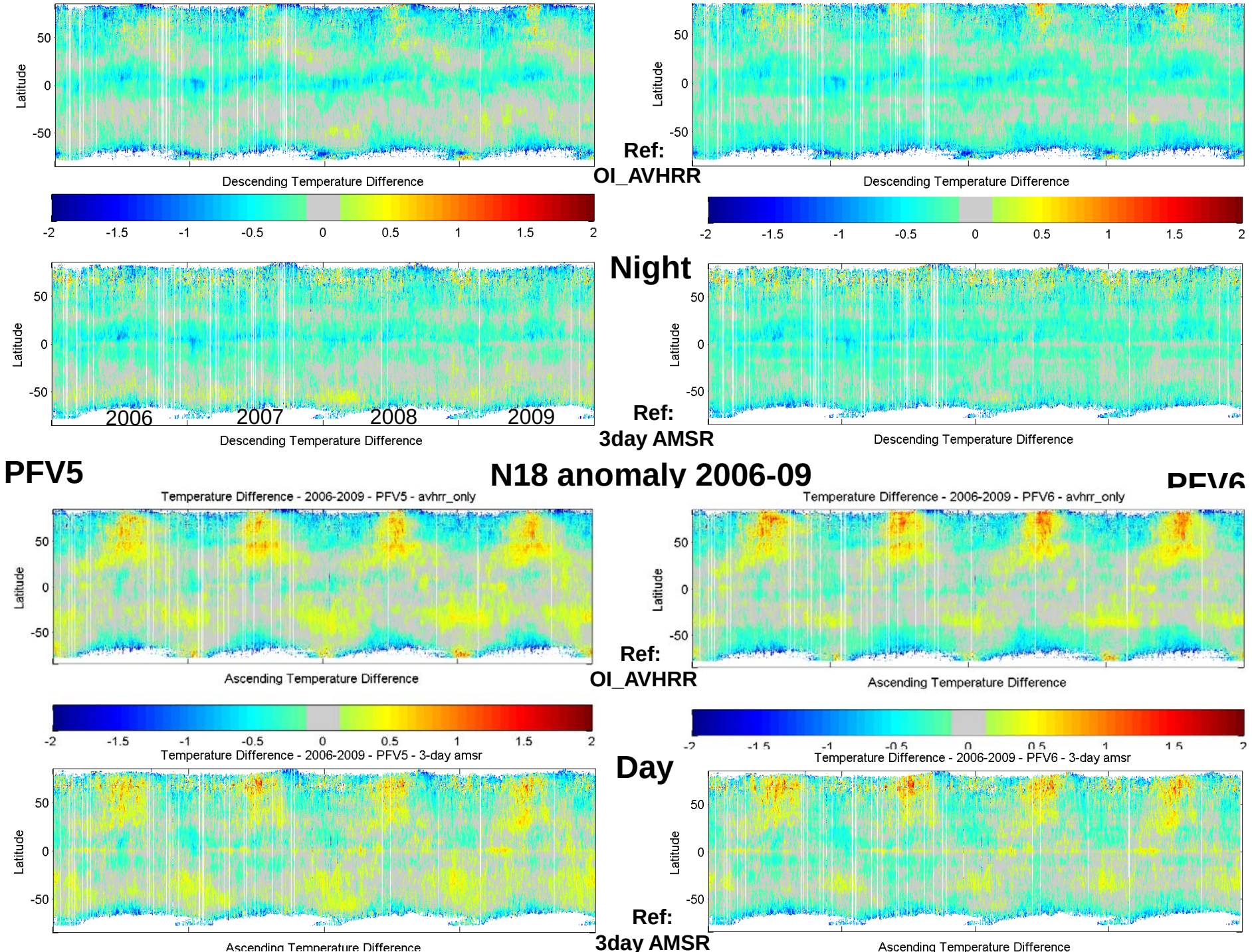
Pathfinder Algorithm		Median	Mean	StdDev
Validation	LATBAND (skin)	-0.178	-0.198	0.37
Validation	Pathfinder V5	-0.093	-0.115	0.39

Median of SST residuals (VALIDATION set) by quarter (2002-2008). Each line corresponds to a latitude band. Upper panel corresponds to latitude-specific SST; lower panel is previous SST (CSST).

Pathfinder – Reynolds V2 OI, ¼ deg, daily, NOAA 18 2006-2009 Night



Both equatorial cold band and mid-latitude warm bands show smaller deviations from Reynolds OI in Pathfinder Version 6 than is seen in Pathfinder Version 5. All processing elements, cloud flagging are the same for the comparisons.


Latitude
50
0
-50
Descending Temperature Difference
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Ref:
OI_AVHRR
Night
2006
2007
2008
2009
Ref:
3day AMSR
PFV5
N18 anomaly 2006-09
PFV6
Temperature Difference - 2006-2009 - PFV5 - avhrr_only
Temperature Difference - 2006-2009 - PFV6 - avhrr_only
Ascending Temperature Difference
Temperature Difference - 2006-2009 - PFV5 - 3-day amsr
Temperature Difference - 2006-2009 - PFV6 - 3-day amsr
Day

Pathfinder Version 6

- New algorithm approach (LATBAND) has resulted in a significant reduction of uncertainty in IR satellite SST retrievals.
- RMS reduced from 0.5 to <0.4 for 11, 12µm band retrievals.
- LATBAND algorithm approach has been implemented for AVHRR, MODIS and VIIRS.
- AVHRR, MODIS and VIIRS satellite observations will be available through community accessible SEADAS programs.
- Add GHRSST format output files including hypercube.
- L2GEN Pathfinder (SEADAS) has been delivered to Ken Casey, has been integrated into current GSFC L2GEN version SeaDAS 6.1. Tested on N16, 17, 18.
- NODC has run 2006 as validation test of NODC Pathfinder processing.

Accomplishments to date

- Version 1 GAC generation delivered to NODC and tested on one year of data.
- Clock corrections for early AVHRR instruments, 1982-2002 generated.
- Attitude correction adjustments for 1km processing converted to LINUX.
- Precision navigation for LAC/GAC tested.
- Level 3 binning demonstrated.
- Mapping demonstrated.

Accomplishments, continued

- **Using NOAA-18 data as testbed, processed:**
  - **Full day and night granules for a 'data-day'**
  - **Determined granule sections that constitute complete day and night files**
  - **Binned day and night granules into complete files**
  - **Mapped equal area files into standard map projection**
- **Implemented LINUX cluster processing**
  - **Developed processing control scripts**
  - **Run N-18 2006-2009 multiple times for validation *vs.* multiple reference fields (equivalent of ~80 GAC years)**
  - **Processing time for 1 year of global GAC is order 60-75 minutes (on Miami cluster, 300 processors)**

Capabilities added for Pathfinder V6 beyond original proposal

in conjunction with K Casey, NODC and P Cornillon, URI

- Skin SST.
- Use Reynolds V2 as the reference SST field.
- Use LATBAND – will need to develop SST coefficients for all NOAA sensors.
- Uncertainty hypercubes (per sensor),
  - N7, N9, N11, N12, N14, N15, N16, N17, N18 (9 sets)
  - Future for N19, METOP.
- Comparison of Pathfinder V5 and V6 wrt:
  - Reynolds OI AVHRR; AVHRR+AMSR [day+night], AVHRR+AMSR [night only]
  - AMSR 3 day average
  - AATSR monthly average

Elements for a follow-on proposal

- **Develop ‘SCRIPPS’ L0 ingest capability to read L0 telemetry files.**
- **Generate SST retrieval coefficients and uncertainty hypercubes for all AVHRR 5 channel sensors.**
- **Add N19 and METOP-A.**
- **Validate LAC and GAC processing for all supported sensors.**
- **Introduce improved sensor calibration (Mittaz and Harris).**
- **Add SeaDAS/L2gen satellite-in situ matchup data extraction.**
- **Introduce and transfer unified SST Coefficient estimation code.**
- **Improve LATBAND by using geophysically based 11-12um (water vapor analog) determined boundaries (Pathfinder 7) vs fixed zonal boundaries in Version 6.**

PATHFINDER SEA SURFACE TEMPERATURE PRODUCT MATURITY

VERSION 5 TO VERSION 6

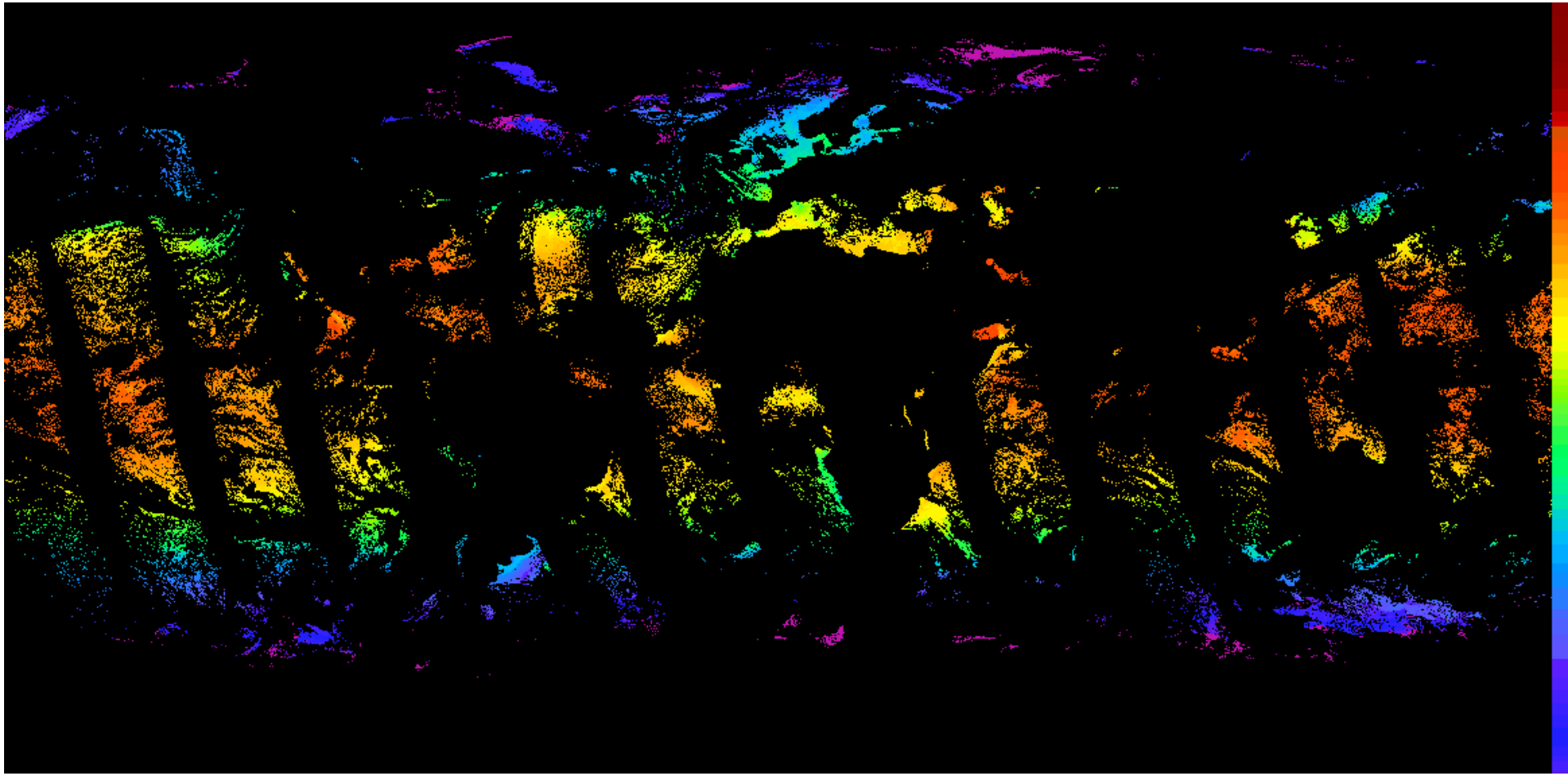
Estimate of current V5 maturity indicated by BLUE (today) outline, future V6 Maturity by GREEN (completion of SDS activity) outline

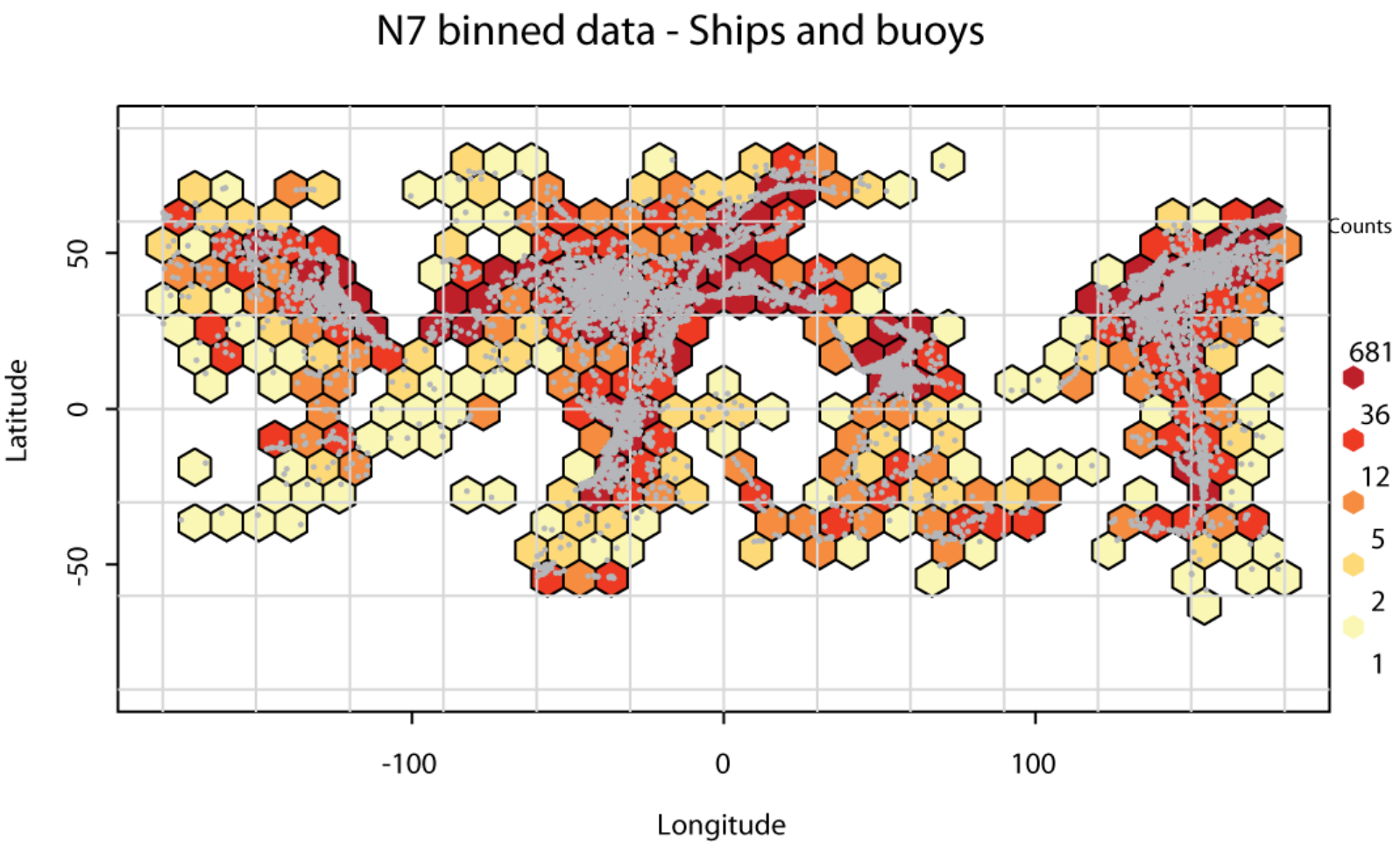
Maturity	Sensor Use	Algorithm Stability	Metadata and QA	Documentation	Validation	Public Release	Science and Applications
1	Research Mission	Significant changes likely	Incomplete	Draft ATBD	Minimal	Limited data availability to develop familiarity	Little or none
2	Research Mission	Some changes expected	Research grade (extensive)	ATBD Version 1+	Uncertainty estimated for select locations/times	Data available but of unknown accuracy; caveats required for use	Limited or ongoing
3	Research Mission	Minimal changes expected	Research grade (extensive); Meets International standards	Public ATBD; Peer-reviewed algorithm and product descriptions	Uncertainty estimated over widely distributed times/ locations by multiple investigators; Differences understood	Data available but of unknown accuracy; caveats required for use	Provisionally used in applications and assessments demonstrating positive value
4	Operational Mission	Minimal changes expected	Stable, Allows provenance tracking and reproducibility; Meets international standards	Public ATBD; Draft Operational Algorithm Description (OAD); Peer reviewed algorithm and product descriptions	Uncertainty estimated over widely distributed times/ locations by multiple investigators; Differences understood	Data available but of unknown accuracy; caveats required for use	Provisionally used in applications and assessments demonstrating positive value
5	All relevant research and operational missions; unified and coherent record demonstrated across different sensors	Stable and reproducible	Stable, Allows provenance tracking and reproducibility; Meeting international standards	Public ATBD, Operational Algorithm Description (OAD) and Validation Plan; Peer-reviewed algorithm, product and validation articles	Consistent uncertainties estimated over most environmental conditions by multiple investigators	Multi-mission record is publicly available with associated uncertainty estimate	Used in various published applications and assessments by different investigators
6	All relevant research and operational missions; unified and coherent record over complete series; record is considered scientifically irrefutable following extensive scrutiny	Stable and reproducible; homogeneous and published error budget	Stable, Allows provenance tracking and reproducibility; Meeting international standards	Product, algorithm, validation, processing and metadata described in peer reviewed literature	Observation strategy designed to reveal systematic errors through independent cross-checks, open inspection, and continuous interrogation	Multi-mission record is publicly available from Long-Term archive	Used in various published applications and assessments by different investigators

END

June 24 2009 – 2009175

Noaa18 - Cloud filtered – Night – 4Km




N7 binned data - Ships and buoys
Latitude
50
0
-50
-100
0
100
Longitude
Counts
681
36
12
5
2
1

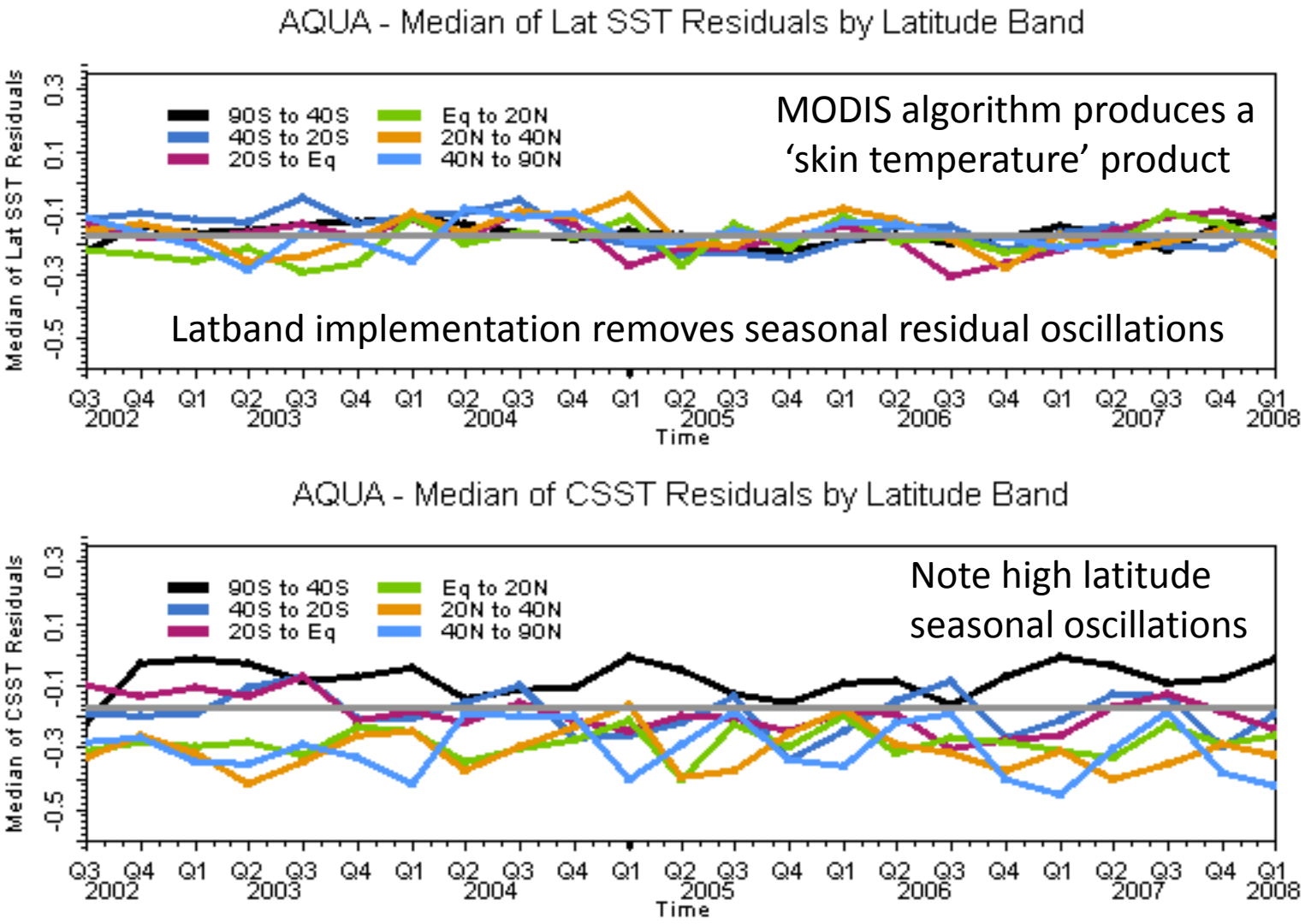
Conclusions

- New algorithm approaches (Latband) has resulted in a significant reduction of uncertainty in IR satellite SST retrievals
- RMS reduced from 0.5 to <0.4 for 11µm band retrievals
- Future implementation of 3 band algorithm for MODIS and VIIRS suggests that cold fringes around clouds and aerosols can be detected and correction in these conditions is significantly improved.
- Latband and 3 band algorithm approaches will be implemented for VIIRS.
- AVHRR, MODIS and VIIRS satellite observations will be available through community accessible SEADAS programs.
- Pathfinder processing is being transferred to NODC to ensure continued availability of the multi-decade Pathfinder SST time series.

Comments

- “Scientifically irrefutable” – there is no such thing
- “Sensor Use” maturity falls outside scope of any individual product project, so it not something that a PI or product team can realistically strive for… …“Unified and coherent record demonstrated across different sensors” presumes a unifying framework exists. Such a framework exists only for SST (GHRSST), though other communities are beginning to organize.
- **So – parts of this matrix as currently worded are really more of an evaluation of the international community framework, not of a given product’s contribution to it.**
- Recommend changes to text to reflect this idea… for example, change “All relevant research and operational missions; unified and coherent record demonstrated across different sensors” to “Contributes to unified and coherent multi-sensor record based on all relevant research and operational missions”
- Documentation – no mention of web pages, user manuals, or user services support staff? Unclear about ATDB “vs” peer reviewed descriptions… what if you have peer reviewed papers describing the algorithm, products, etc., but no ATDB?

Application of LATBAND to MODIS AQUA



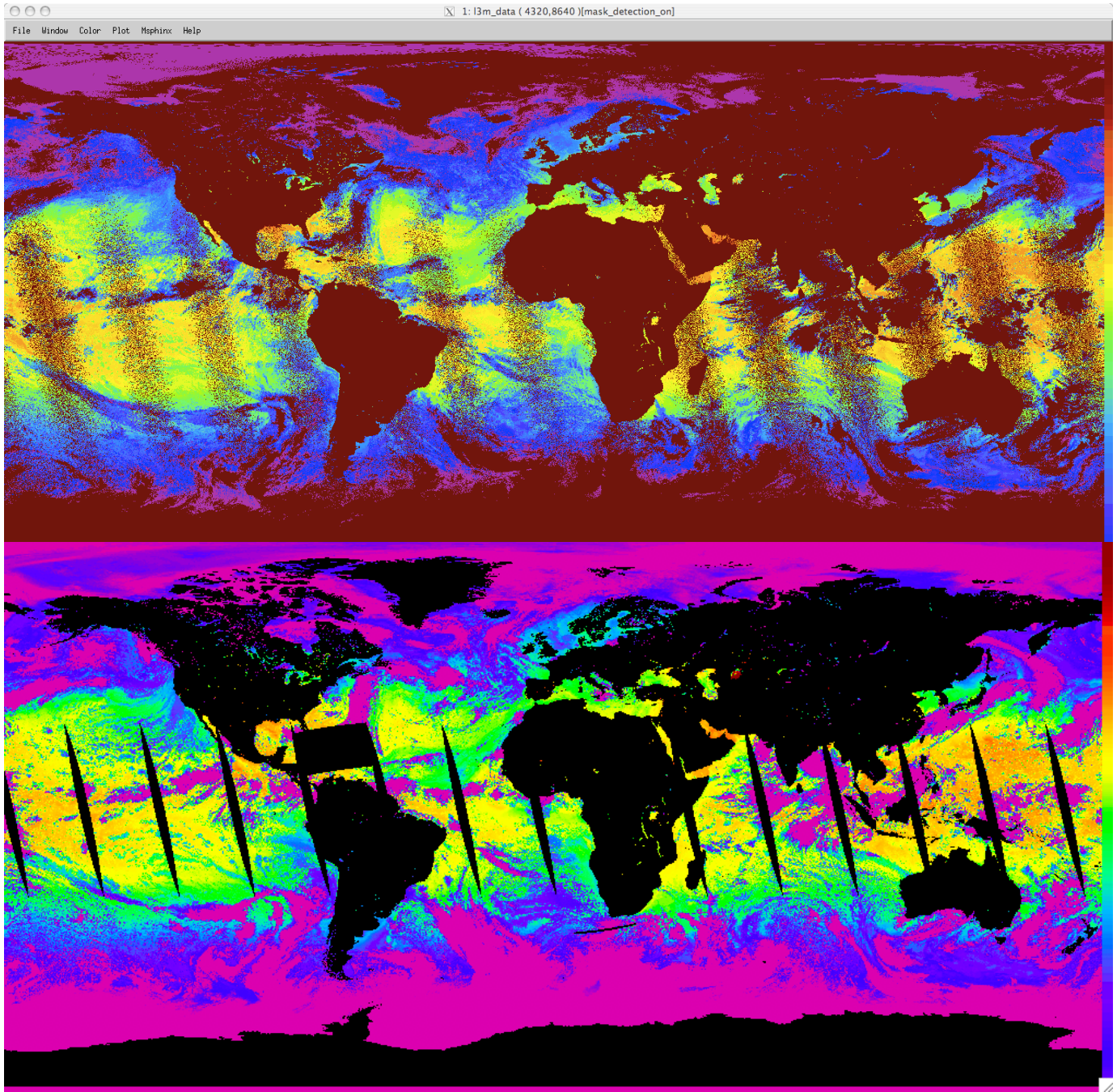
Median of SST residuals (VALIDATION set) by quarter (2002-2008). Each line corresponds to a latitude band. Upper panel corresponds to latitude-specific SST; lower panel is previous SST (CSST).

First global image from SEADAS/LINUX processing - 2009175

AVHRR
N18

Images are
NOT filtered
for clouds

MODIS
AQUA



Second year, continued

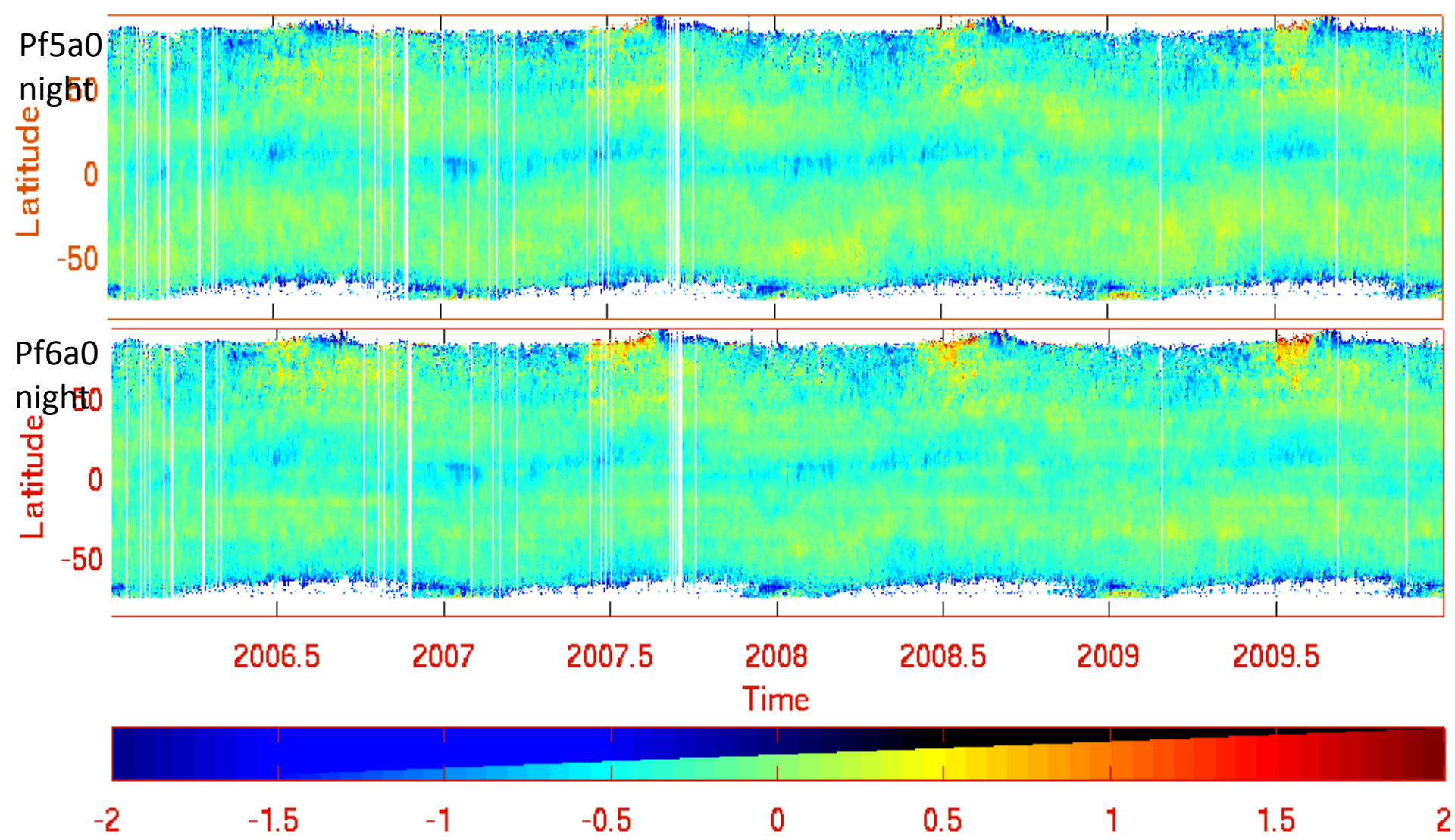
- Execute pole-finding and granule separating functions.
- Incrementally transfer processing elements to NODC as they are validated.
- Implement Pathfinder V6 changes as they become available:
  - Latband coefficients
  - Reynolds 1/4°, daily OI
  - Update Ice mask
- Process selected portions of the AVHRR record at Miami and NODC and compare.

Second year, continued

- Begin computation of AVHRR Latband algorithm coefficients. Volcano periods will require additional attention.
- Update output format to match GHRSST specification. (MEASURES)
- Add ingest capability for URI legacy 1km input files. (MEASURES)

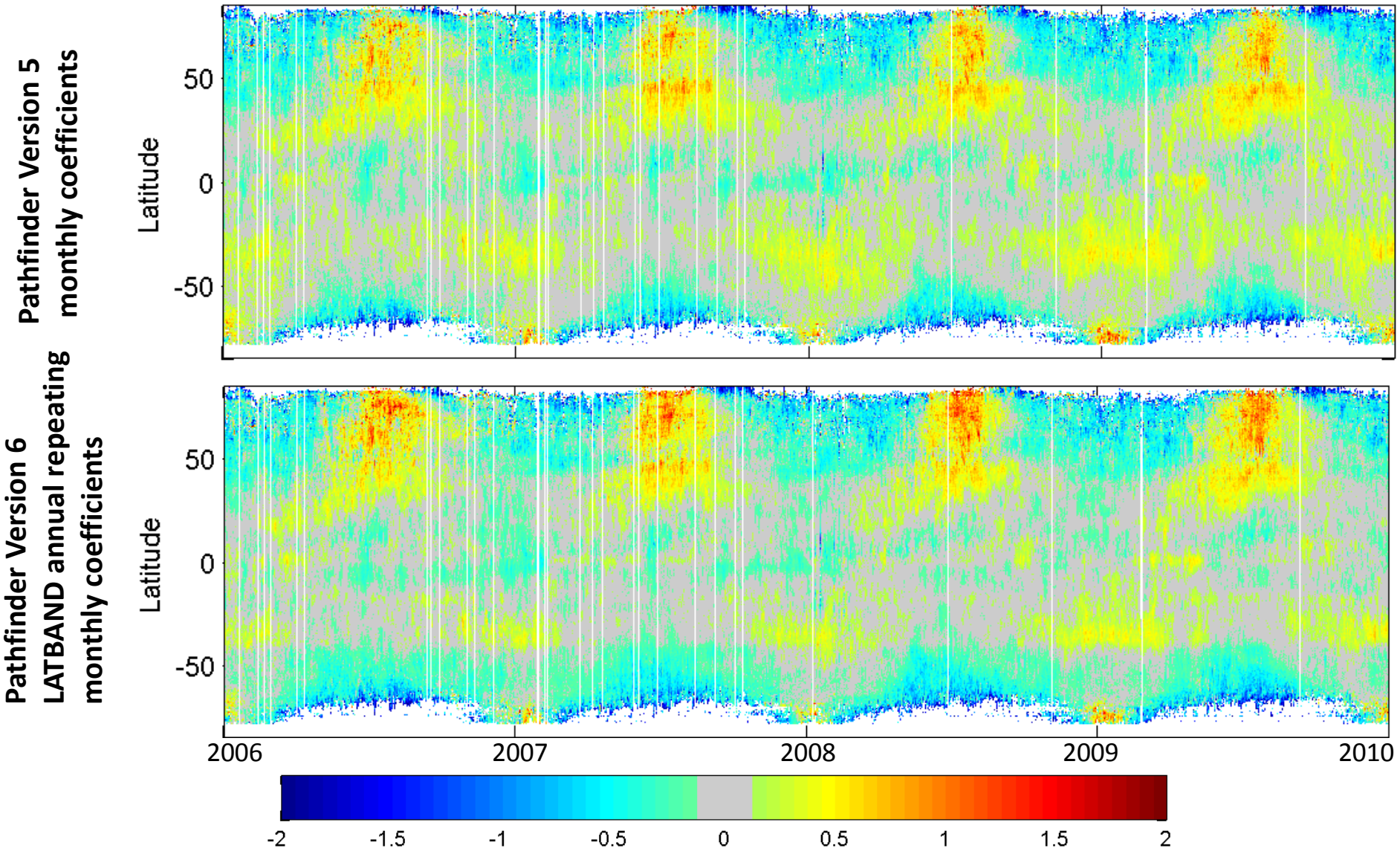
Third year

- Complete computation of LATBAND algorithm coefficients.
- Transfer Match-up database.
- Transfer of AVHRR LATBAND coefficient estimation process.
- NODC adds functionality to incorporate additional GHRSST required data fields, metadata.
- Support ongoing Pathfinder activities at NODC.
- Update to Pathfinder Version 6, process AVHRR time series:
  - GAC (SDS funding) NODC
  - LAC (MEASURES funding) URI

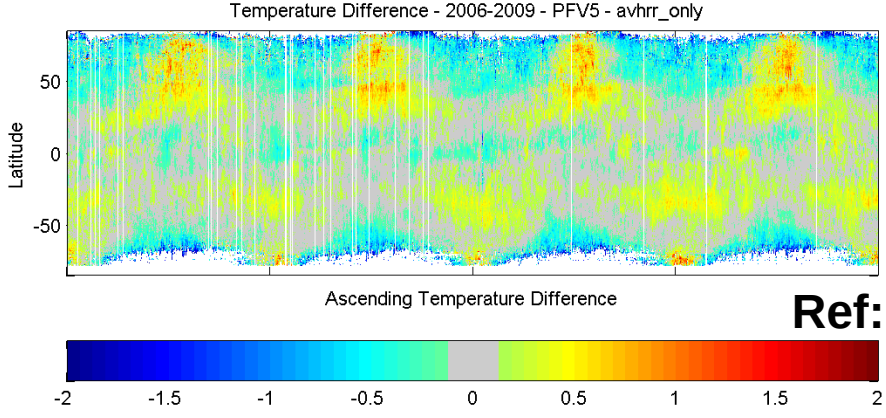

Pf5a0
night
Latitude
50
0
-50
Pf6a0
night
Latitude
50
0
-50
2006.5
2007
2007.5
2008
2008.5
2009
2009.5
Time
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

END

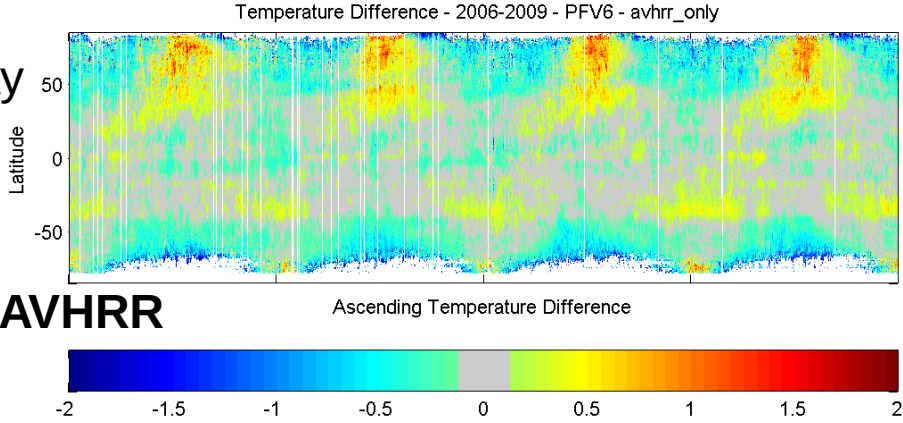
Pathfinder – Reynolds V2 OI, ¼ deg, daily, NOAA 18 2006-2009 Day



Both equatorial cold band and mid-latitude warm bands show smaller deviations from Reynolds OI in Pathfinder Version 6 than is seen in Pathfinder Version 5. All processing elements, cloud flagging are the same for the comparisons.



Day



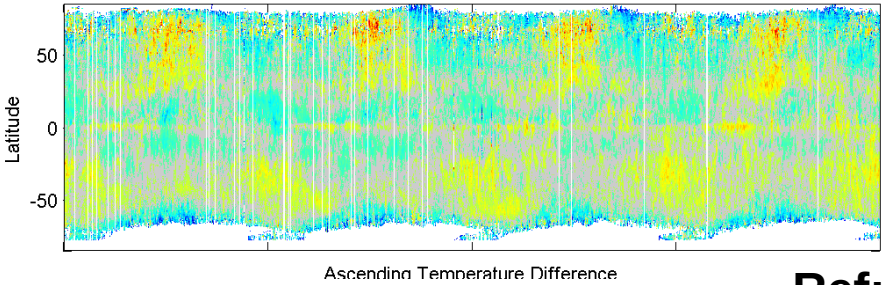
Ref: OI_AVHRR

Night

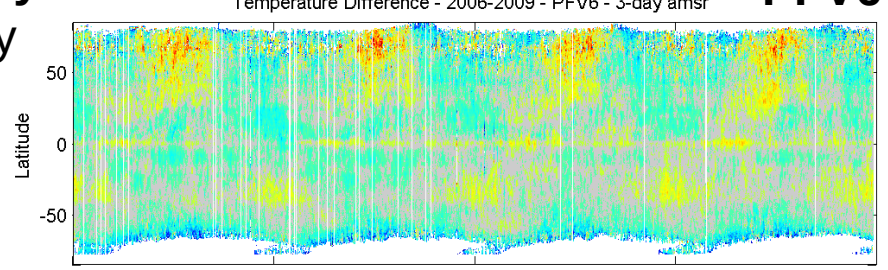
PFV5

N18 anomaly 2006-09

PFV6

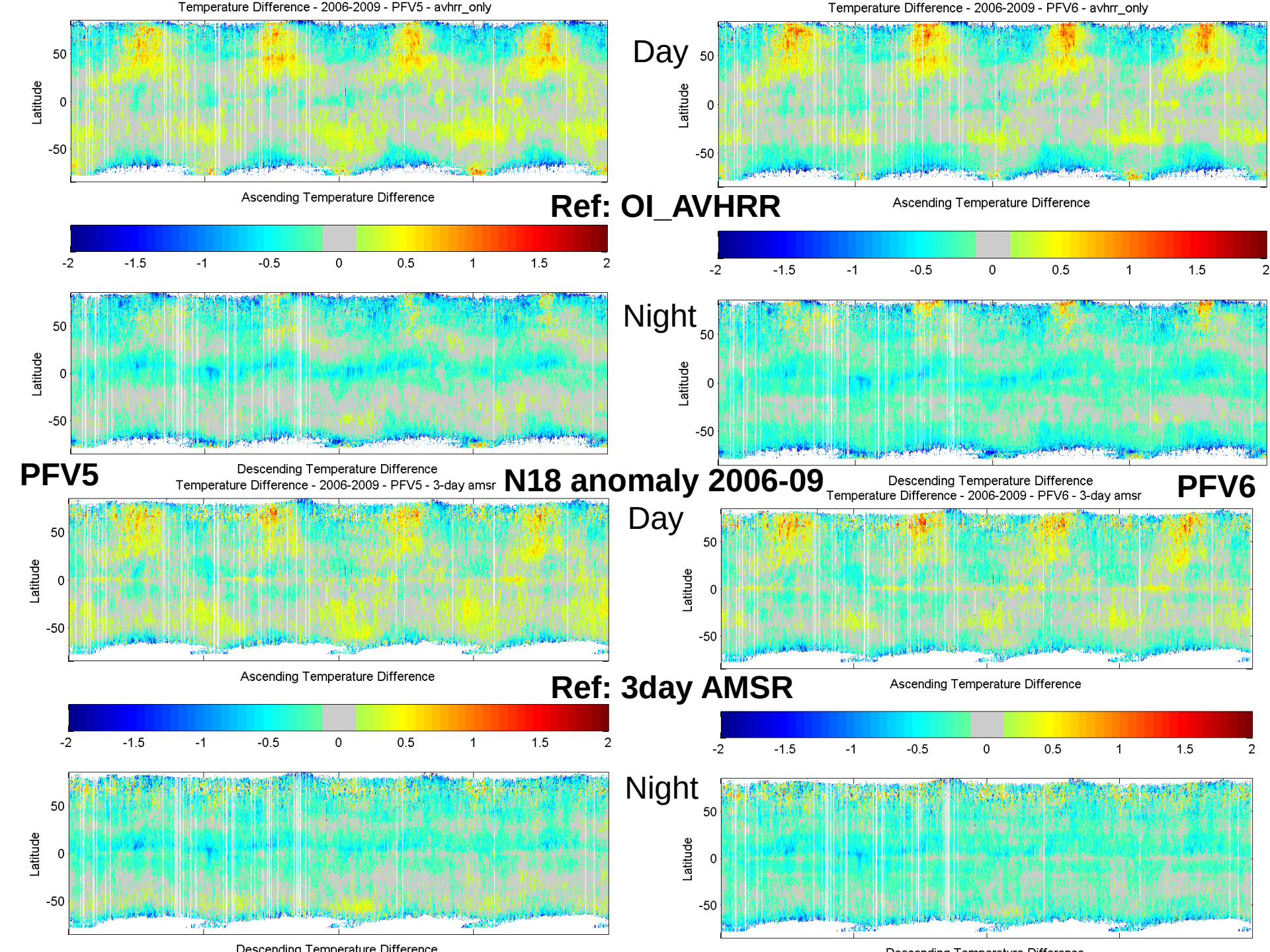


Day



Ref: 3day AMSR

Night


Temperature Difference - 2006-2009 - PFV5 - avhrr_only
Temperature Difference - 2006-2009 - PFV6 - avhrr_only
Day
Latitude
50
0
-50
Ascending Temperature Difference
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Ref: OI_AVHRR
Night
Descending Temperature Difference
PFV5
PFV6
Temperature Difference - 2006-2009 - PFV5 - 3-day amsr
Temperature Difference - 2006-2009 - PFV6 - 3-day amsr
N18 anomaly 2006-09
Ref: 3day AMSR

Path V6 continued

- SEADAS code base is being used to support MODIS and has been modified to support AVHRR Pathfinder, will facilitate distribution to interested users and algorithm transparency to the community.
- MODIS LATBAND code recently delivered to GSFC for incorporation into SEADAS.
- Add GHRSST format output files including hypercube.
- L2GEN Pathfinder (SEADAS) has been delivered to Ken Casey, has been integrated into current GSFC L2GEN version SeaDAS 6.1. Tested on N16, 17, 18.
- LATBAND for NOAA sensors has been integrated.