Application of the UW/CIMSS high spectral resolution global IR land surface emissivity database into the RTTOV model

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The RTTOV Uwiremis module: EUMETSAT NWP-SAF AS mission

•**Objective**: To provide an improved estimate and associated error of land surface emissivity for infrared radiometers for input to RTTOV (v9.3 and later)

•**Place:** Space Science and Engineering Center (SSEC), University of Wisconsin-Madison, and NRL, California, USA

•**Participants:**	Roger Saunders (Met Office, UK)
	Ben Ruston (NRL, USA)
	Eva Borbas (UW/SSEC, USA)
•**Support personals**:	Andrew Collard (Met Office, UK/NCEP, USA)
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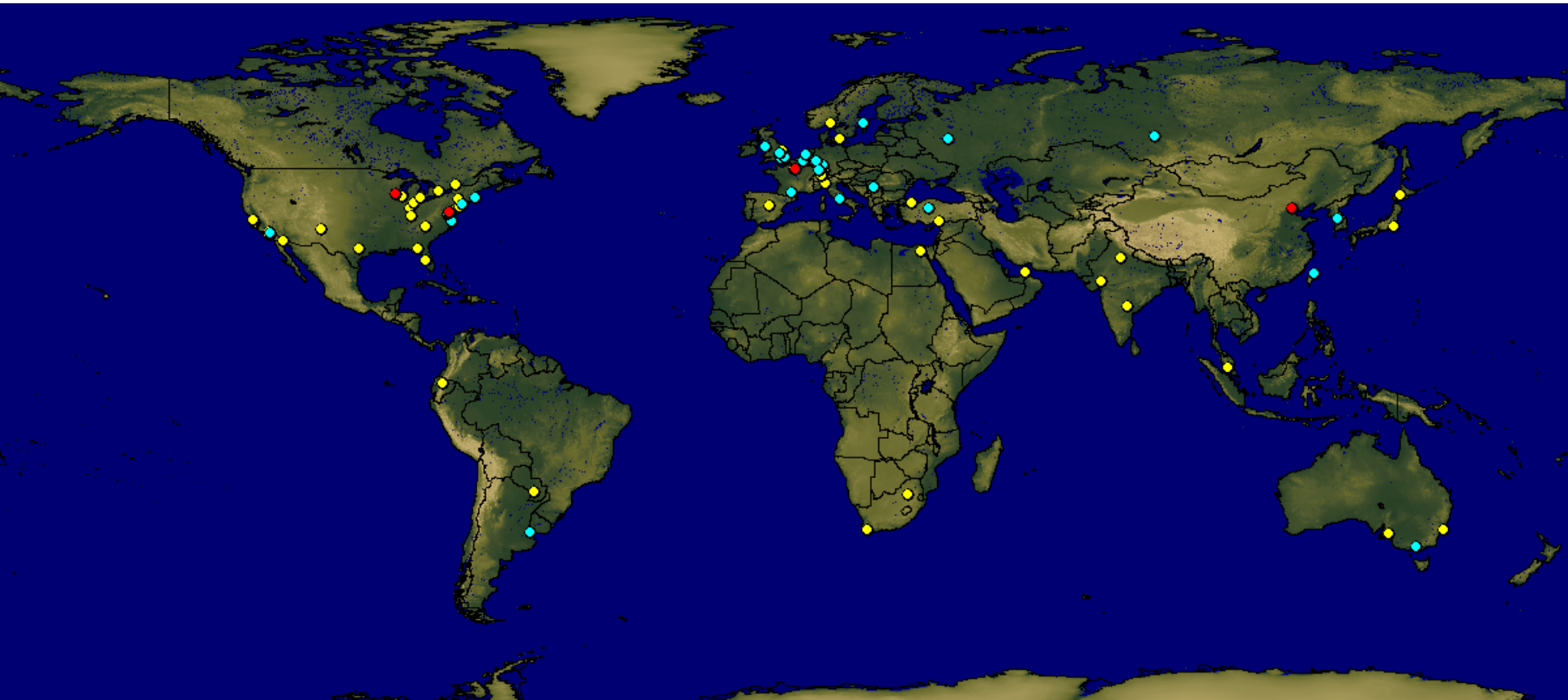
	Technical support: UW/SSEC TC,
	Ray Garcia, Graeme Martin, William Straka

Outline

- UW/CIMSS Global IR Land Surface Emissivity Database (UWiremis database)
- The RTTOV UWiremis module
- Evaluation of the module with satellite data (SEVIRI, IASI)
- Test of the UWiremis module in assimilation mode
- Conclusions

Current status of the UW Global Infrared Land Surface Emissivity Database

- Time coverage: Monthly: Oct 2002 - Dec 2006 - 4 years (based on MYD11 V4.0)
- Jan 2007 - Dec 2009 - 3 years (based on MYD11 V4.1)
- **No longer available data based on MYD11 V5.0 !!!!**
- Spatial Resolution: 0.05 degree ~ 5 km;
- Spectral Resolution: 10 hinge points (3.7 and 14.3 μm)
- Available**:** http:/cimss.ssec.wisc.edu/iremis

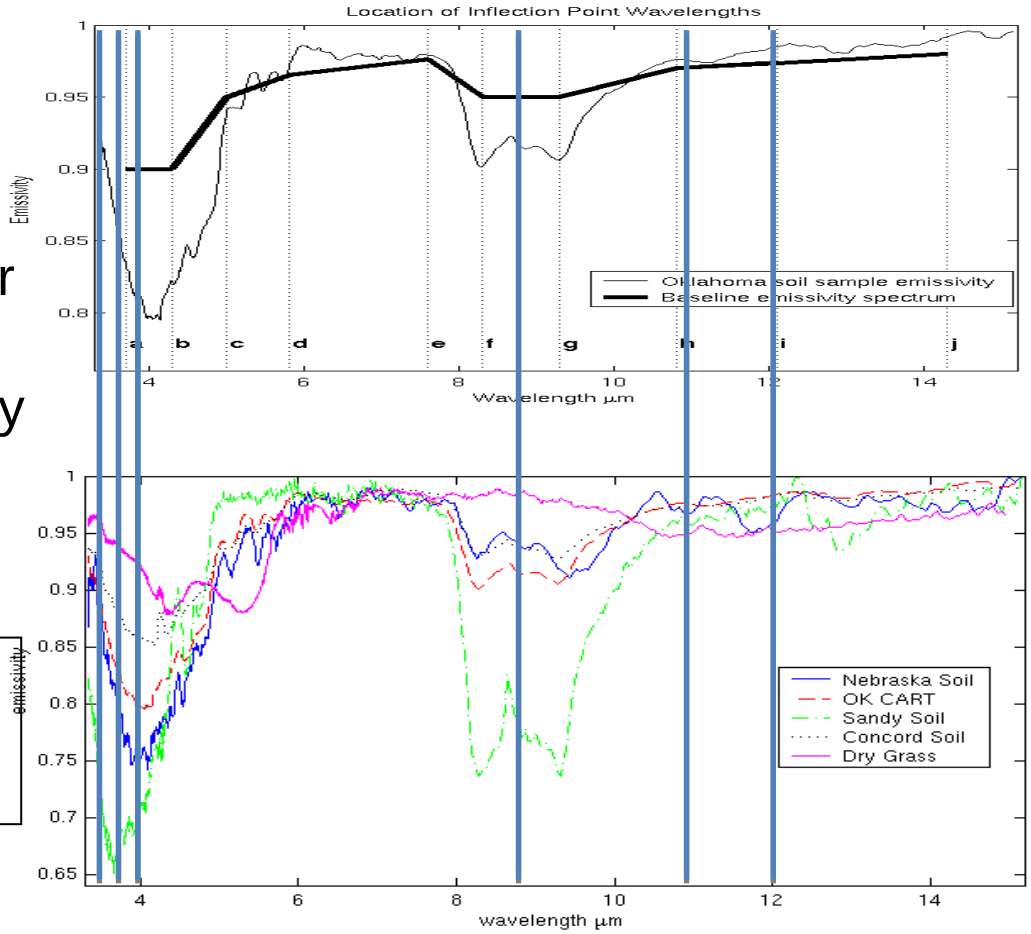


The UW Global Infrared Land Surface Emissivity Database: Baseline Fit Method

- Based on a **conceptual model** developed from **laboratory measurements** (UCSB) of surface emissivity is applied to fill in the spectral gaps between the six emissivity wavelengths available from **MYD11**
- **10 hinge points** were chosen between 3.7 and 14.3 μm

- Adjust a laboratory-derived "baseline emissivity spectra" based on the MOD11 values for every global latitude/longitude pair

- **Result:** a monthly global emissivity database at 10 wavelengths with 0.05 degree spatial resolution



Reference:
Suzanne W. Seemann et al., 2008;
J. Appl. Meteor. Climatol., Vol. 47, 108-123.

Method (Uwiremis HSR algorithm)

$$\vec{\mathbf{e}} = \vec{\mathbf{c}}\mathbf{U}$$

$$\vec{\mathbf{c}} = \vec{\mathbf{e}} * \mathbf{U}^{\mathbf{T}}(\mathbf{U}\mathbf{U}^{\mathbf{T}})^{-1}$$

$\vec{\mathbf{e}}$ is the HSR emissivity spectra

$\vec{\mathbf{c}}$ is the PCA coefficient vector

$\mathbf{U}$ is the matrix of the first PCs of the lab emissivity spectra

•Most Important Idea (Bill Smith)

Represent high spectral resolution infrared emissivity as a linear combination of a limited number (e.g. 6) of eigenfunctions of a set of laboratory spectra that covers 3.7 to 14.3μm.

•Accuracy depends on

- •UWiremis BF emissivity DB and MODIS MYD11 data
- •Set of laboratory spectra (current version contains 123 selected lab spectra on 5 wavenumber [cm^{-1}] spectral resolution)

•Output: emissivity spectra with 416 spectral points between 3.7 and 14.3 μm

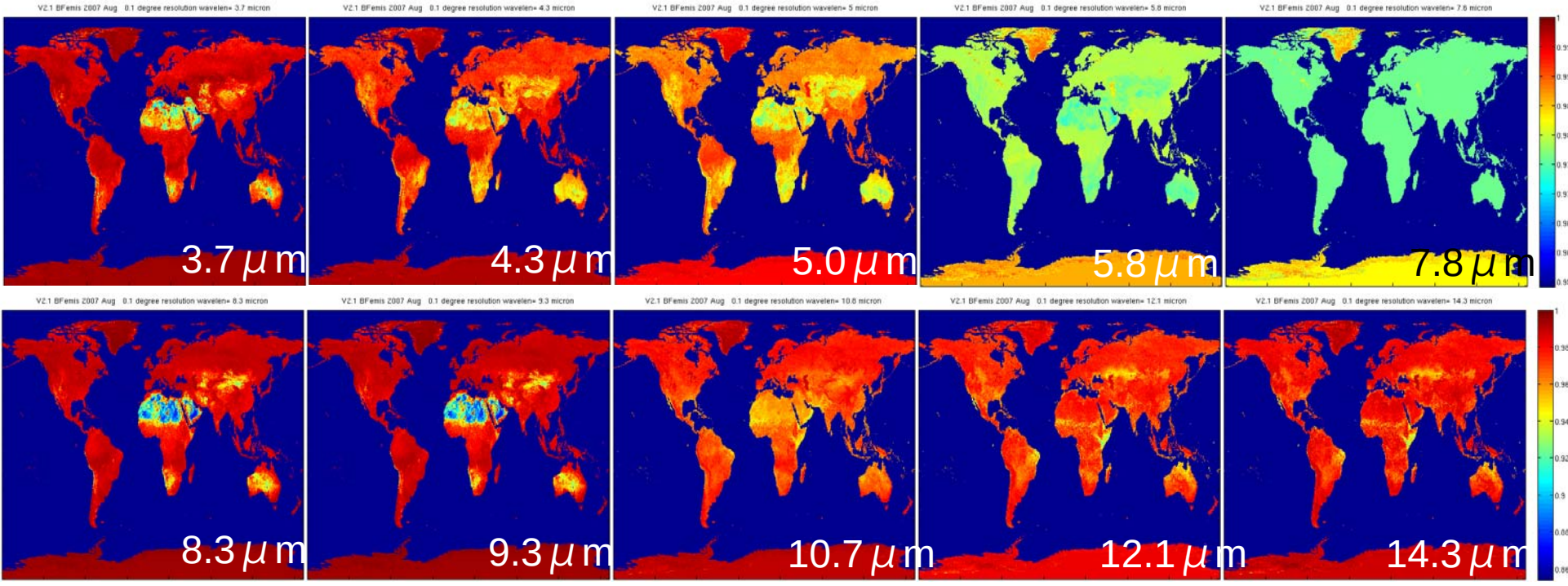
Outline

- UW/CIMSS Global IR Land Surface Emissivity Database (UWiremis database)
- The RTTOV UWiremis module
  - List of the components
    - Modification of the UW IR global land surface emissivity database for RTTOV
    - The new emis_flag
    - The variances of the UW IR global land surface emissivity
    - Emissivity over snow and sea ice
    - Subroutines (7) and test scripts
- Evaluation of the module with satellite data (SEVIRI, IASI)
- Test of the UWiremis module in assimilation mode
- Conclusions

The RTTOV Uwiremis IR emissivity module

Modification of the UW IR global land surface emissivity database for RTTOV

- The 0.05x0.05 degree resolution UW emissivity database has been reduced to a 0.1x0.1 degree resolution and a land/sea mask (MOD44) has been applied to reduce the file size. **545 MB -> 50 MB**
- The database was created for each month of the **2007** year data.
- A new Emis Flag was created (see later)
- **Filename**: Uwirbfemis_V2.1_0.1deg_2007*08*_mask.nc (netCDF format)



The RTTOV UW IR land surface emissivity module

The emis flag

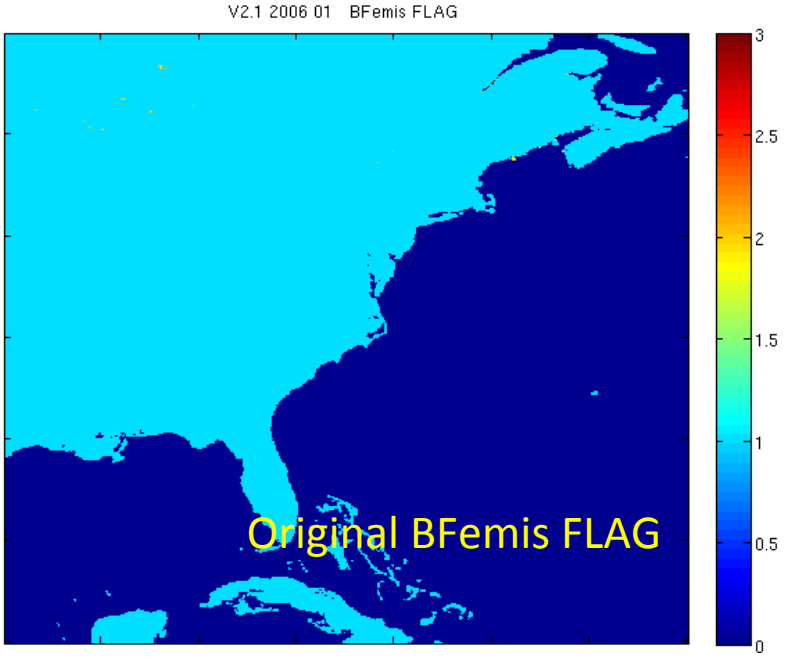
The emissivity flag is a combination of the original emissivity flag in UW emissivity database and a simplified version of the land/sea mask and the land fraction calculated during the 4x4 interpolation

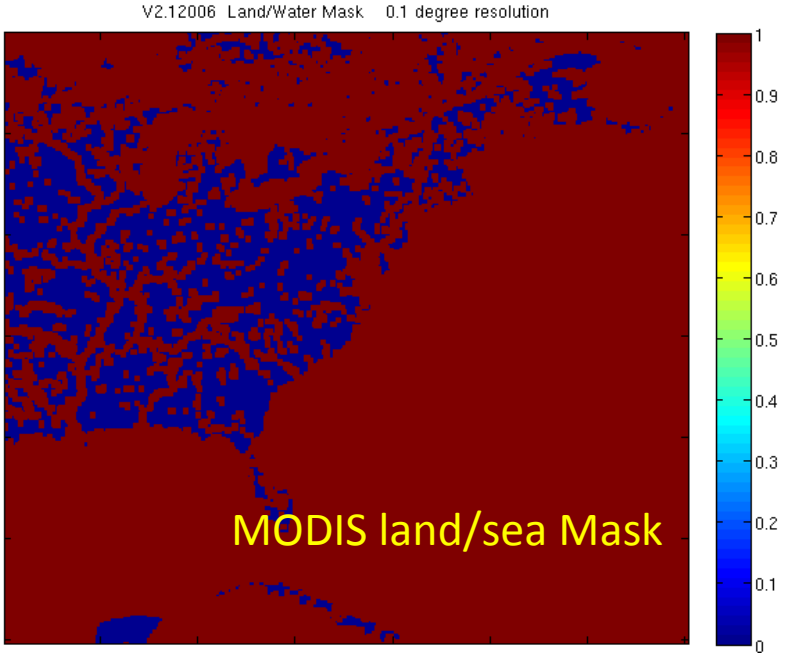
- The original UW flag (**BFflag**): 0= sea

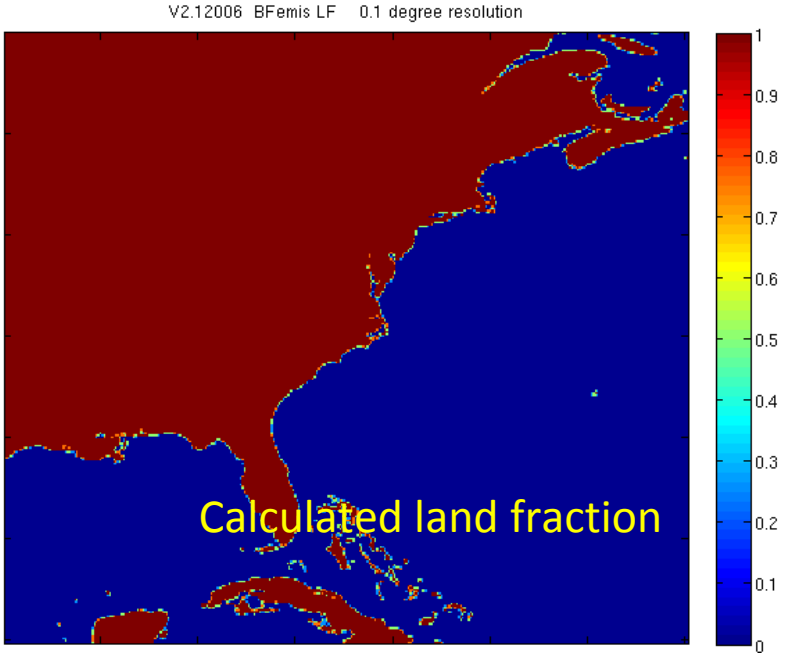
  1= BF method was applied,

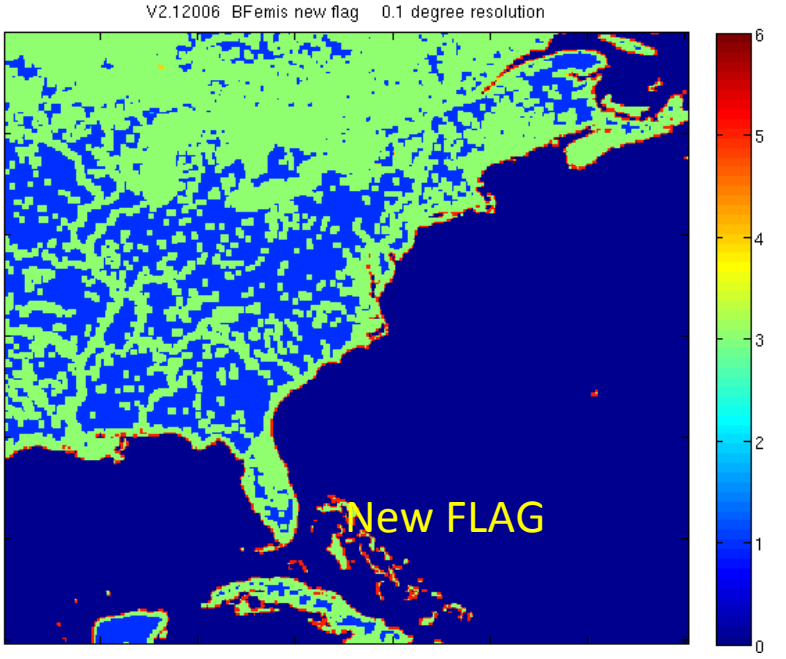
  2= missing data filled with average

- MODIS Land/Sea **Mask** (MOD44):
  - simplified version: 0=land 1=contains water
- Calculated land fraction (**LF**): from the 4x4 0.05 degree UW IR emissivity database (0 or 0.25 or 0.5 or 0.75 or 1)


V2.1 2006 01 BFemis FLAG
Original BFemis FLAG
3
2.5
2
1.5
1
0.5
0

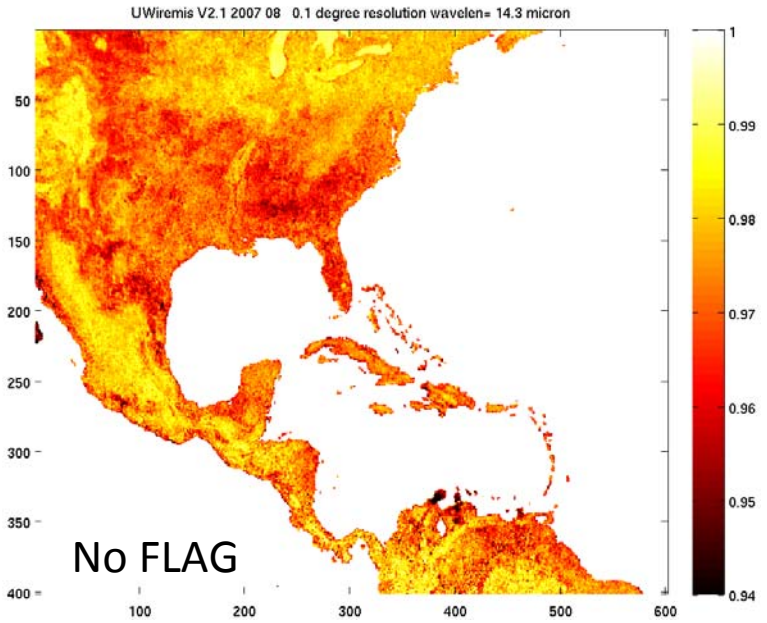

V2.12006 Land/Water Mask 0.1 degree resolution
MODIS land/sea Mask
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

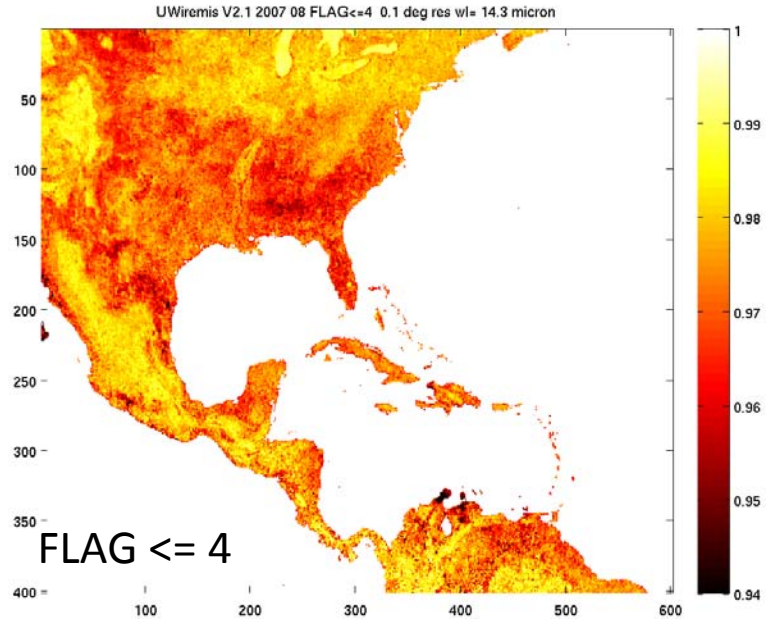

V2.12006 BFemis LF 0.1 degree resolution
Calculated land fraction
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

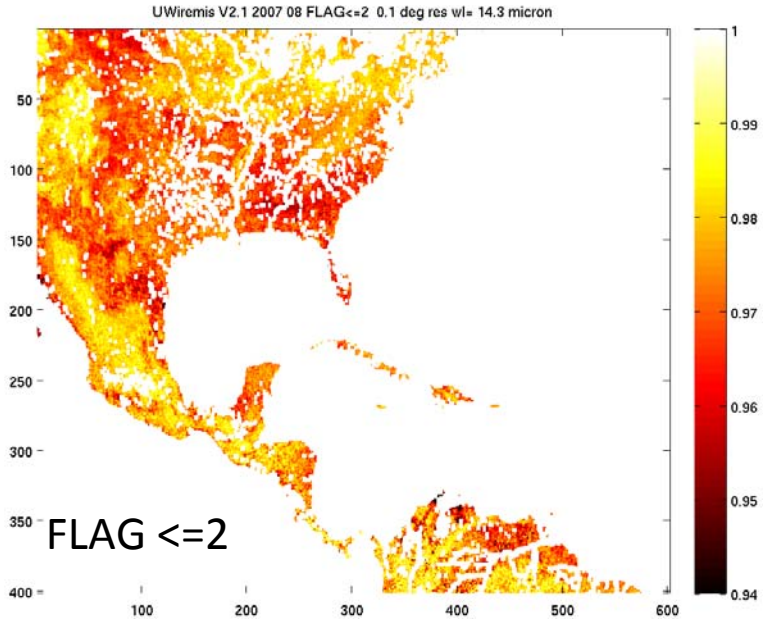

V2.12006 BFemis new flag 0.1 degree resolution
New FLAG
6
5
4
3
2
1
0

Applying the flag over the Caribbean Sea

August 2007 V2.1
(MYD11 C041) 14.3 μm





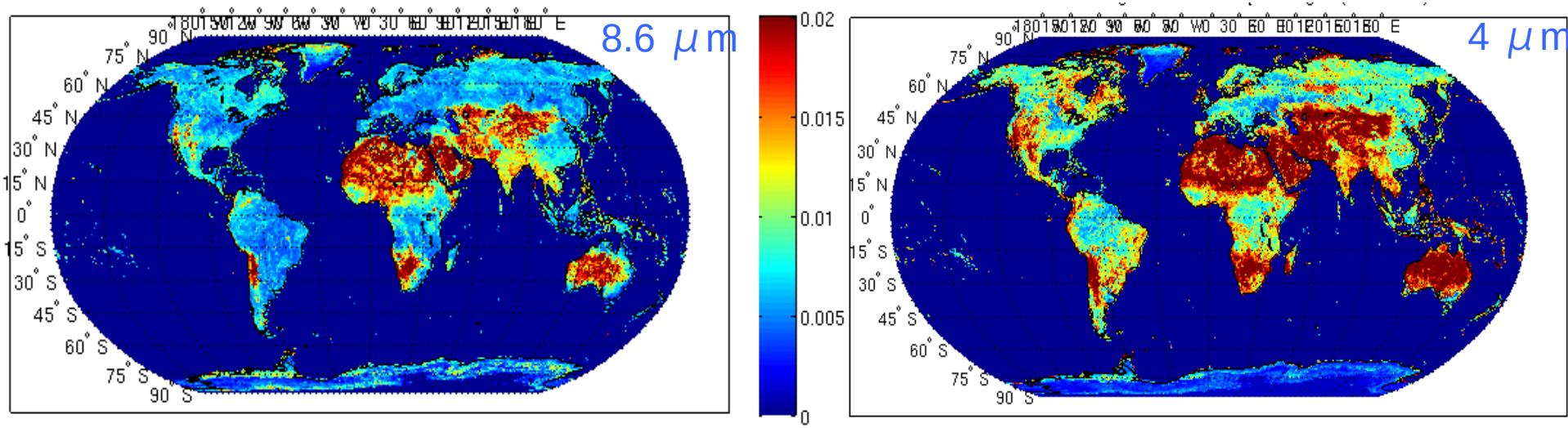


The RTTOV Uwiremis IR emissivity module

The variances of the UW IR global land surface emissivity

- The mean and the variance for **each month** has been created on 0.5x0.5 degree resolution between 2003 and 2006 data. -> 400 points/grid point
- The land/sea mask was also applied to store land grid point data only. -> 1/3 file size reduction **~ 158 MB**
- **Filename**: Uwiremis_hsremis_covmat_V1.0_deg0.5_month*08*_mask.nc (netCDF)
- Note, to store the full covariance matrix, the file size would be **500 MB**/file.

Standard deviation of the UW HSR emissivity data base on 0.5 degree resolution For August (2003-2006)



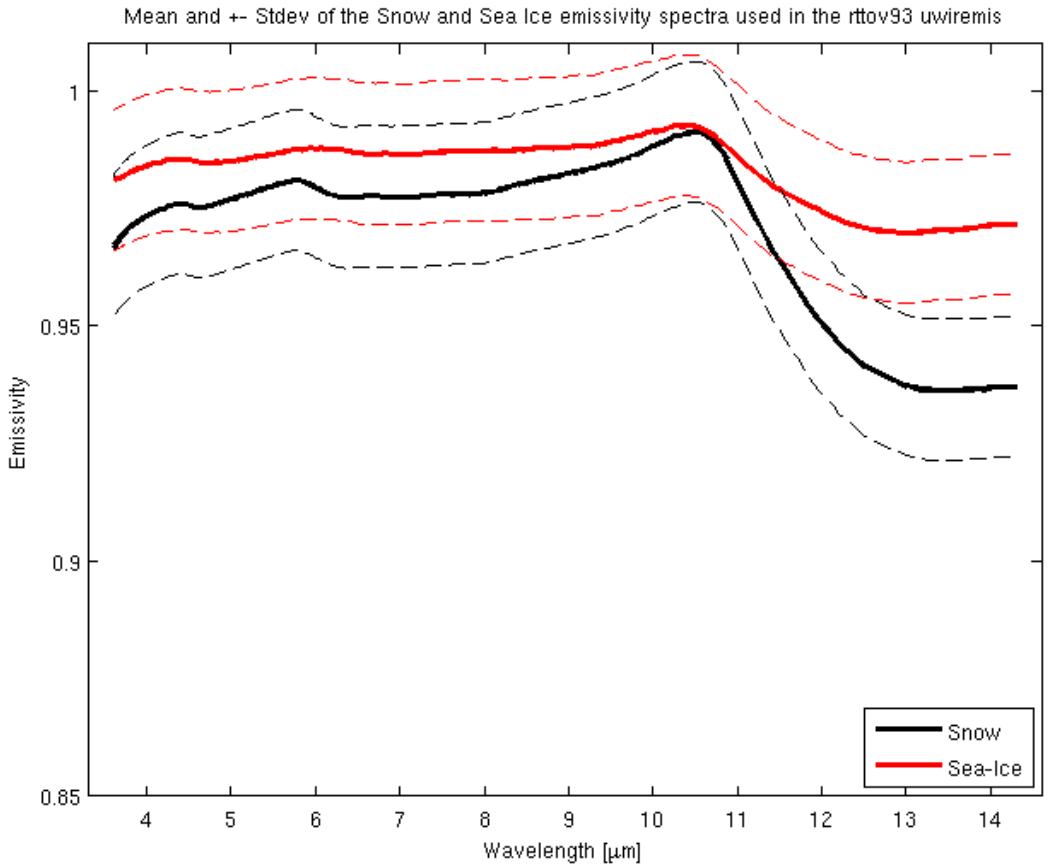
The RTTOV Uwiremis IR emissivity module

Emissivity over snow and sea ice

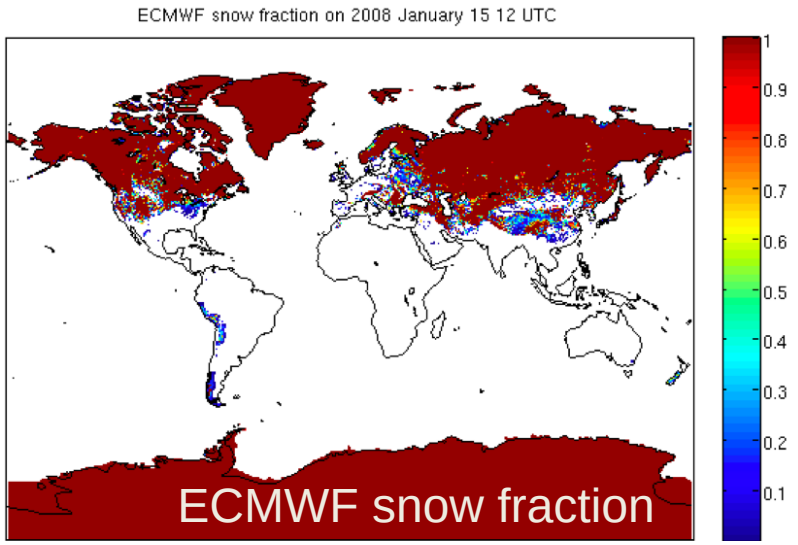
•Snow and ice cover is important at high latitudes.

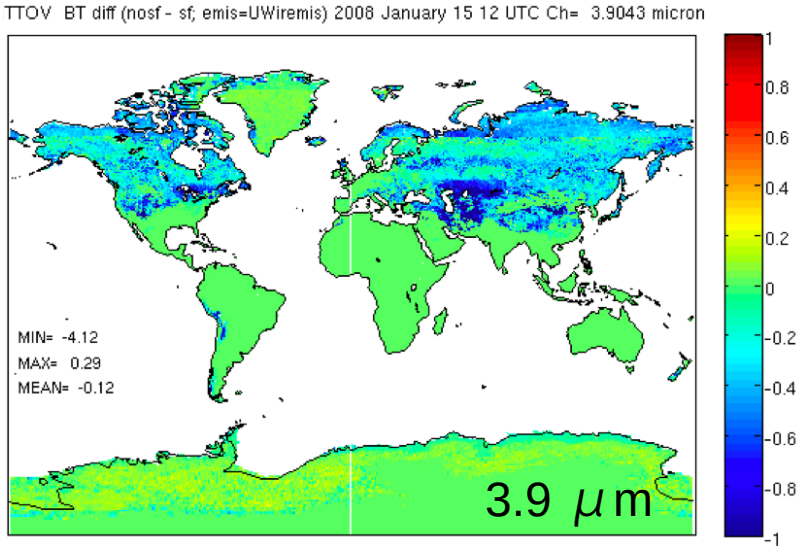
•Mean and standard deviation of snow and sea-ice emissivity spectra has been ddded to the Uwiremis module.

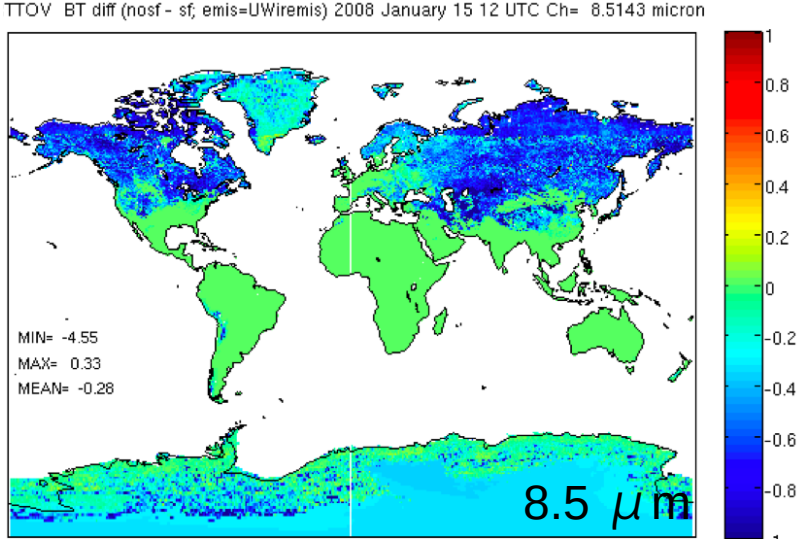
•Snow fraction was added to the RTTOV profile structure (Optional, default is 0) If the value is larger Than 0 the emissivity is linearly average of the snow and land emissivity.

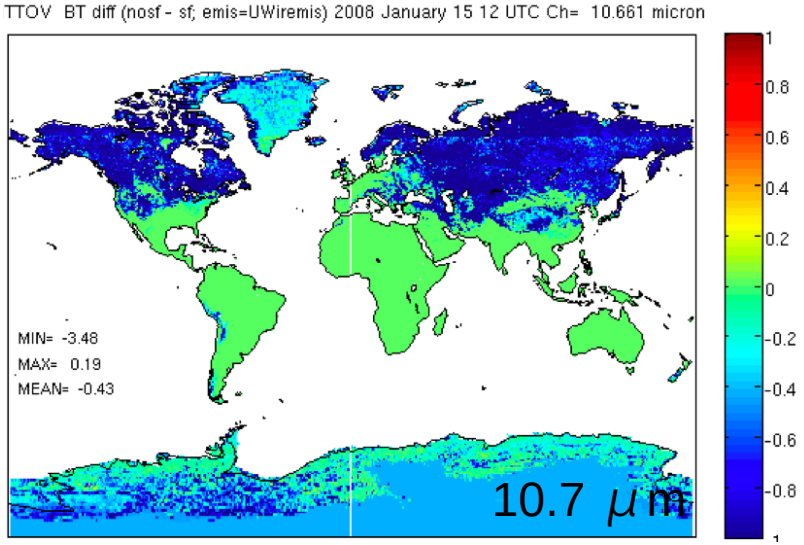


Calculated BT differences (noSF –SF) on January 15, 2008, 12 UTC









The RTTOV Uwiremis IR emissivity module

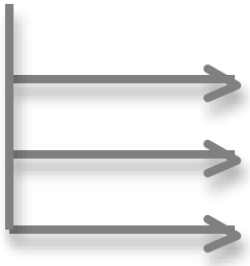
Data file for the eigenvectors of the laboratory measurements

- The eigenvectors of the 123 selected laboratory spectra is included in the ***Uwiremis_labeigvects.nc*** file.

The RTTOV Uwiremis IR emissivity module

Structure

STEP I. rttov_uwiremis_init (called in rttov_setup)

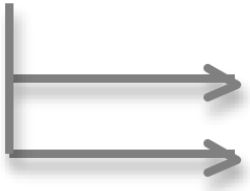


(1) rttov_uwiremis_read_db

(2) rttov_uwiremis_read_cov

(3) rttov_uwiremis_read_labeigvects

STEP II. rttov_uwiremis (called in rttov_calcemis_ir)



Rttov_uwiremis_recon_hsremis

ttov_uwiremis_select_wavenum

The RTTOV Uwiremis IR emissivity module

Input/Output

- **Input data**:
  - integer imonth — the number of the month [1,12]
  - Integer ncs — number of channels
  - Real lat — latitude [-90,90]
  - Real lon — longitude [0.360]
  - Real instr_wavenum(nchs) — wavenumber of the instrument channels
  - Logical addiremis — default is false.

- **Outputs:**
  - Real isntr_emis(nchs) — emissivity of the instruments channels
  - Real instr_emis_cov(nchs) — variance of the emissivity for the instrument channe
  - Integer isntr_emis_flag — quality flag for the emissivity for the given location

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Validation of the IR emissivity database

Comparison with other IR emissivity data:

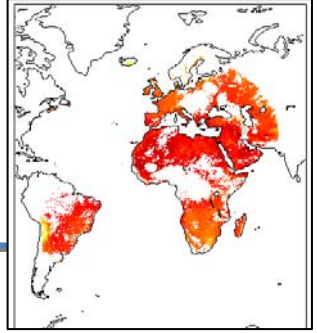
- UW AIRS Physical Retrievals (Jun Li et al)
- SEVIRI NWP_SAF LSA Products (Moy et al. and James Hocking (UKMO))
- Comparison with the NRL database (Ruston et al.)
- UW Best Estimate (Tobin et al.)
- ASTER products (Hook et al.)
- ARIES JaVex aircraft measurements (Taylor et al.)
- LaRC IASI database (Dan Zhou)

Indirect validation:

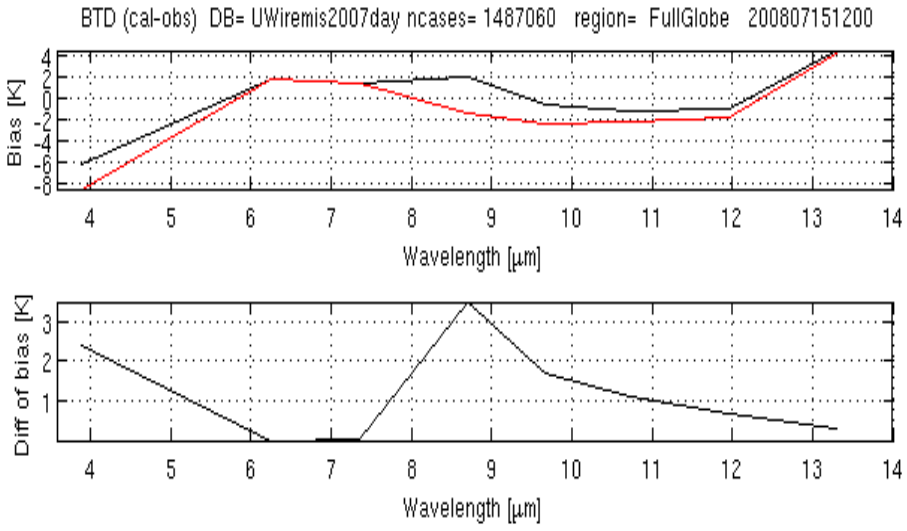
- comparison of observed and calculated AIRS radiances (Borbas et al.)
- dBT comparison with IASI and SEVIRI using RTTOV
- Application on retrieved satellite products:
    - Geocat, Leocat (Pavolonis et al.)
    - IMAPP and MOD07 MODIS TPW retrievals (Seemann & Borbas)
    - MSG Meteorological Product: SEVIRI TPW, SI (Konig et al.)
    - IMAPP AIRS retrievals (Weisz et al.)
    - UWPHYSRET (Antonelli et al.)

Statistics of SEVIRI BT differences (Calc –Obs) July 15 2008 (full area)

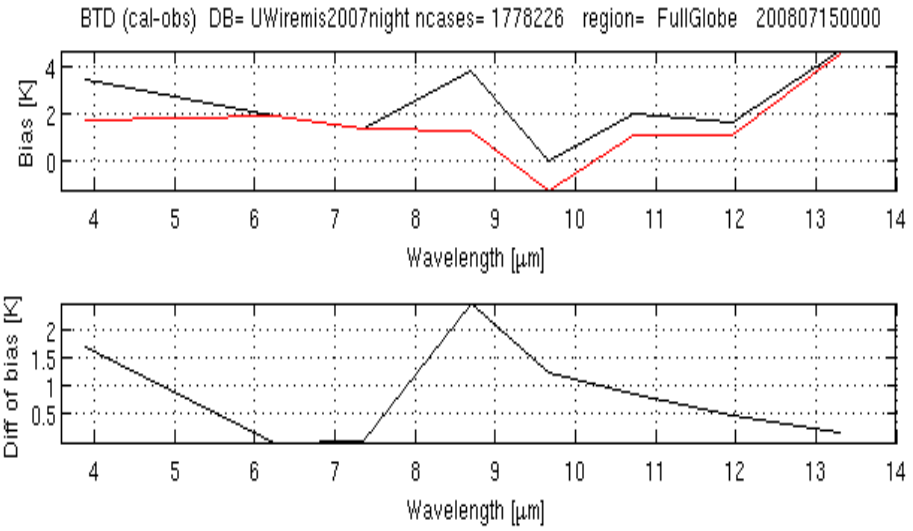
---- Emis=0.98 ---- Emis=UW



Day

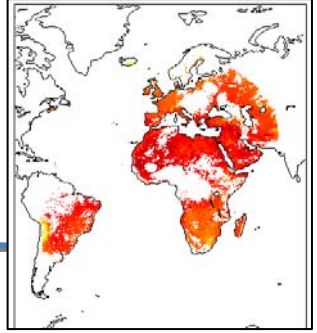


Night

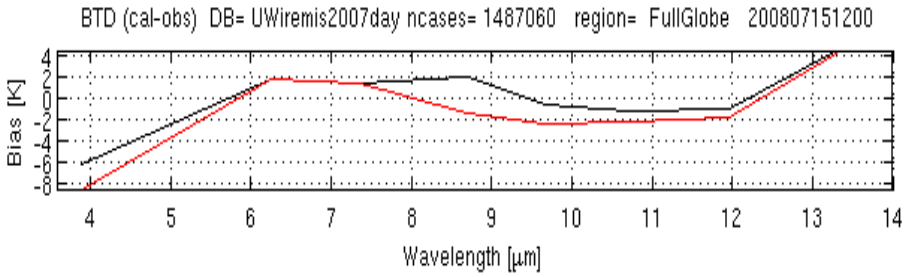


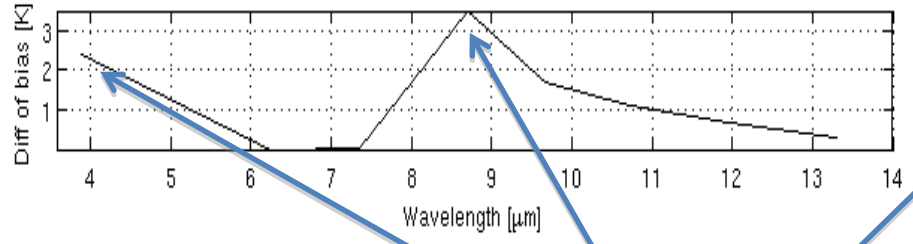
Statistics of SEVIRI BT differences (Calc –Obs)
July 15 2008 (full area)

---- Emis=0.98 ---- Emis=UW

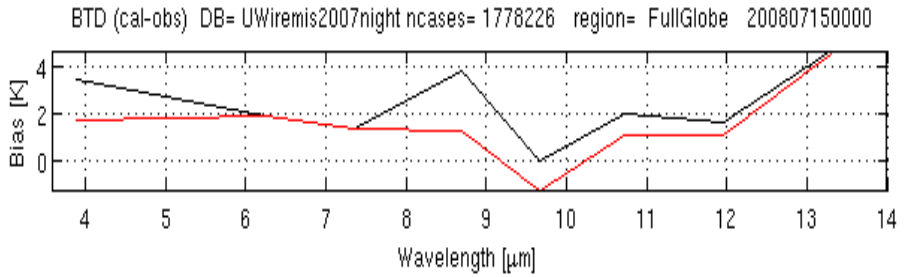


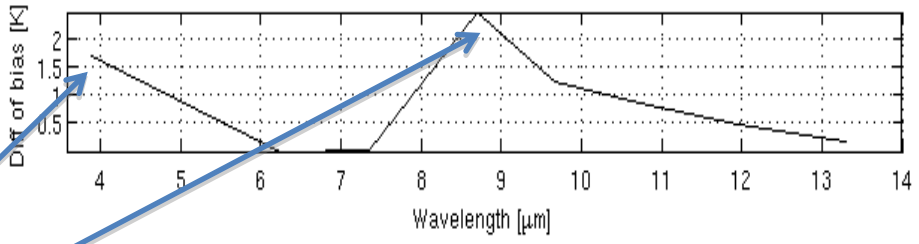
Day





Night





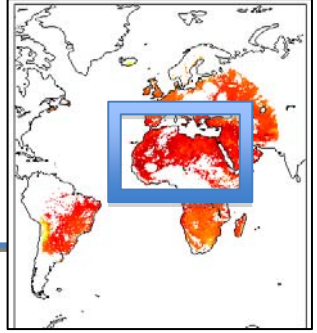
CONCLUSONS:

- The bias is reduced by 1.5 – 3.5 K at 4 and 8.7 μm region.
- Systematic bias across all surface sensitive channels can be attributed to bias error in model LST.
- SW error in daytime is caused by the uncertainty in the solar radiation component in the RTM.

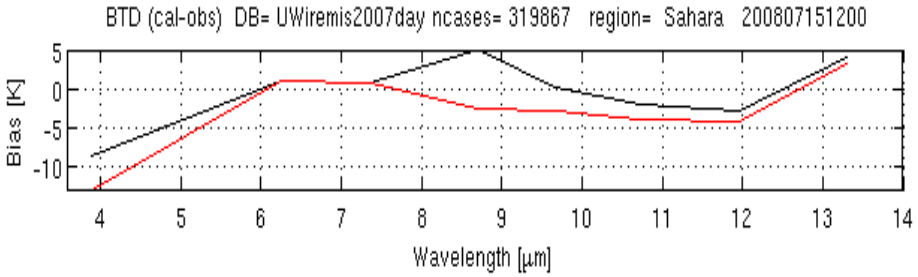
Statistics of SEVIRI BT differences (Calc –Obs)

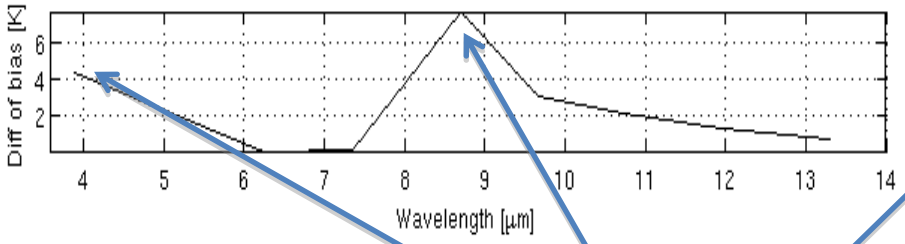
July 15 2008 over Sahara

---- Emis=0.98 ---- Emis=UW

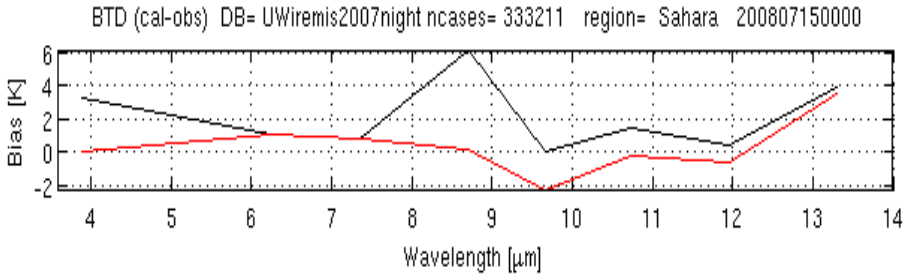


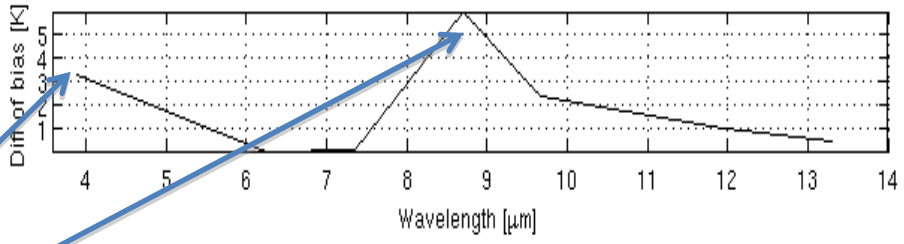
Day





Night

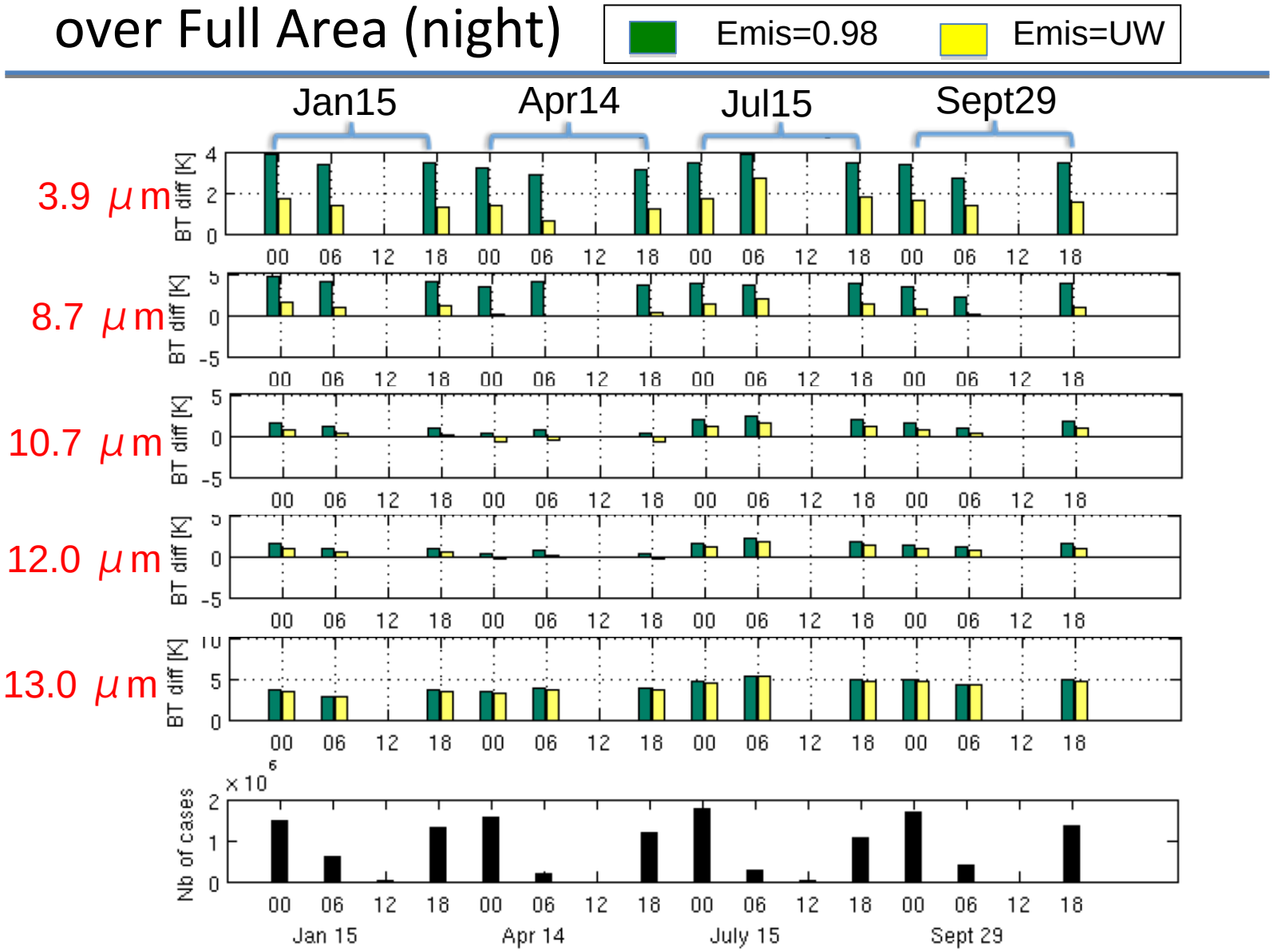




CONCLUSONS:

- The bias is reduced by (1.5 – 3.5) 3.5 – 8 K at 4 and 8.7 μm region.
- The most significant impact occur over very dry (sand) Sahara region.
- Systematic bias across all surface sensitive channels can be attributed to bias error in model LST.
- SW error in daytime is caused by the uncertainty in the solar radiation component in the RTM.

Time series of SEVIRI BT differences (Calc –Obs) over Full Area (night)

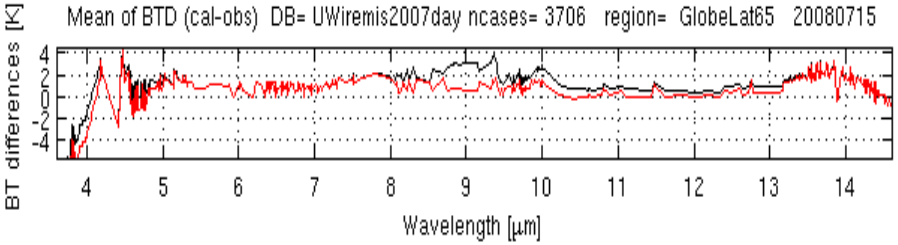


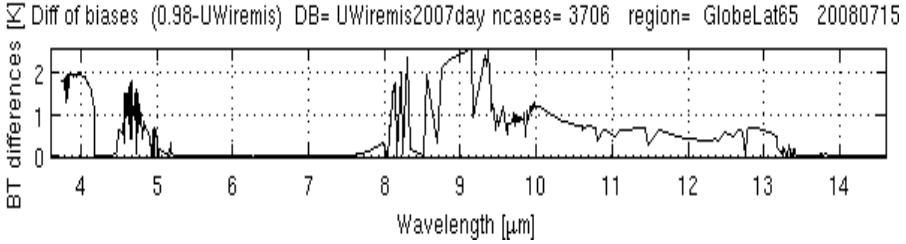
- The seasonal variation in bias is reduced using the Uwiremis RTTOV module.

Statistics of IASI BT differences (Calc –Obs)
July 15 2008 (full Globe Lat < 65)

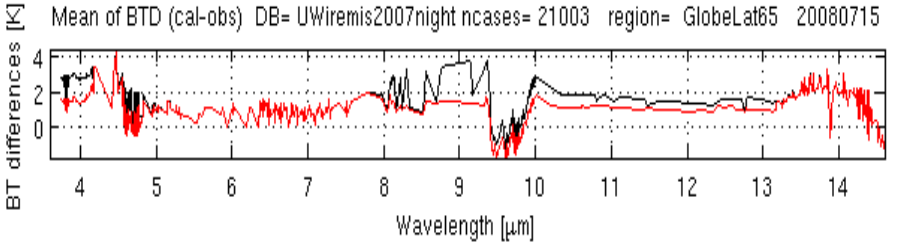
---- Emis=0.98 ---- Emis=UW

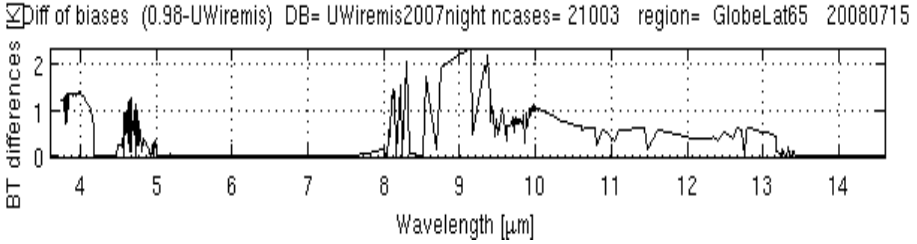
Day





Night

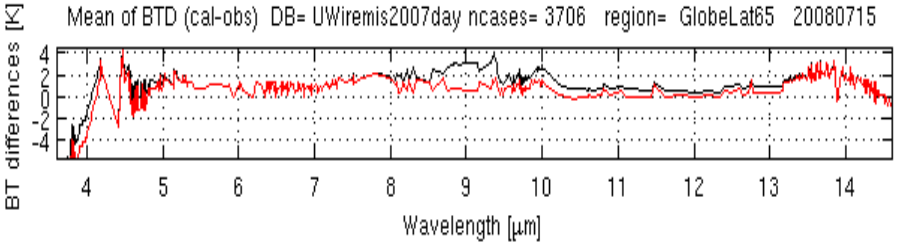


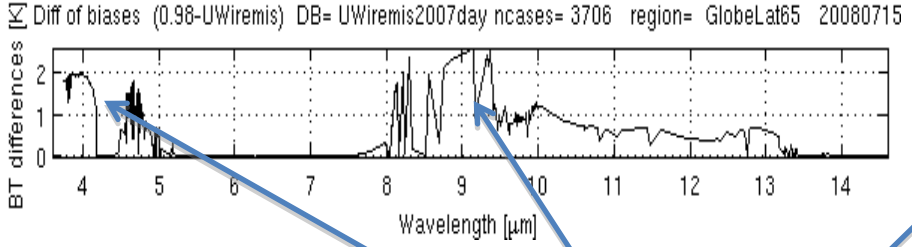


Statistics of IASI BT differences (Calc –Obs)
July 15 2008 (full Globe Lat < 65)

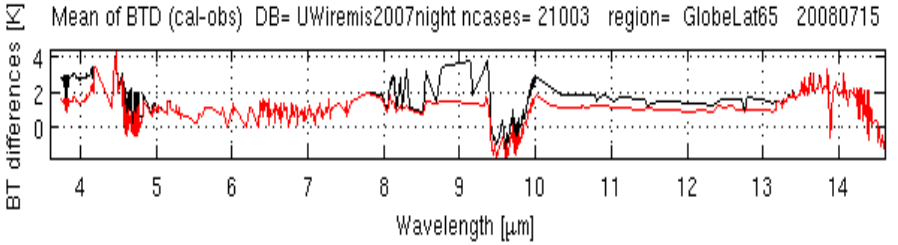
---- Emis=0.98 ---- Emis=UW

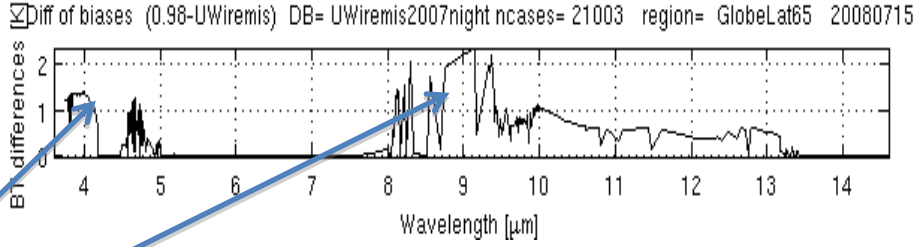
Day





Night

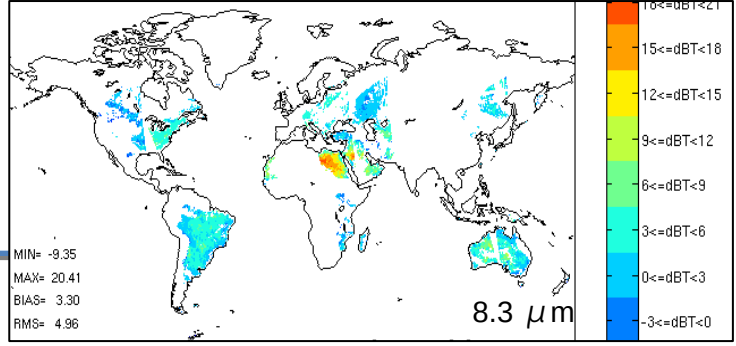


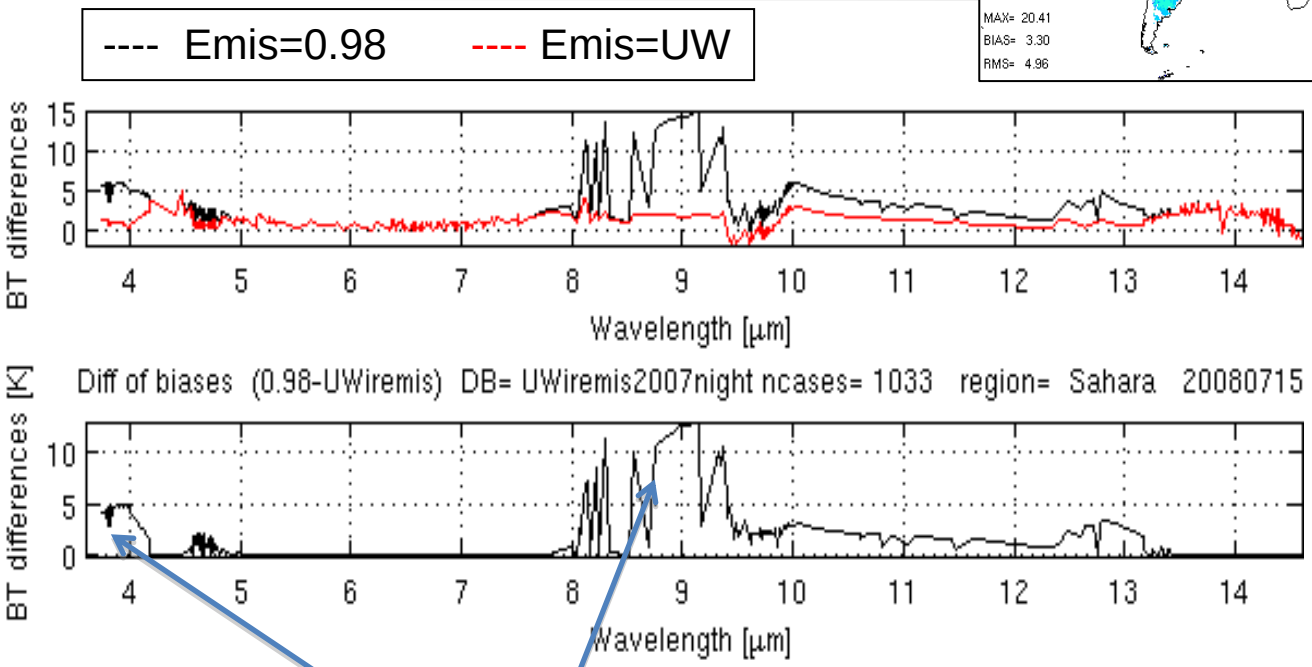


CONCLUSONS:

- The bias is reduced by 1.5 – 2.5 K at 4 and 8.7 μm region.
- Systematic bias across all surface sensitive channels can be attributed to bias error in model LST.
- SW error in daytime is caused by the uncertainty in the solar radiation component in the RTM.

Statistics of IASI dBT (Calc –Obs) July 15 2008 (night) over Sahara

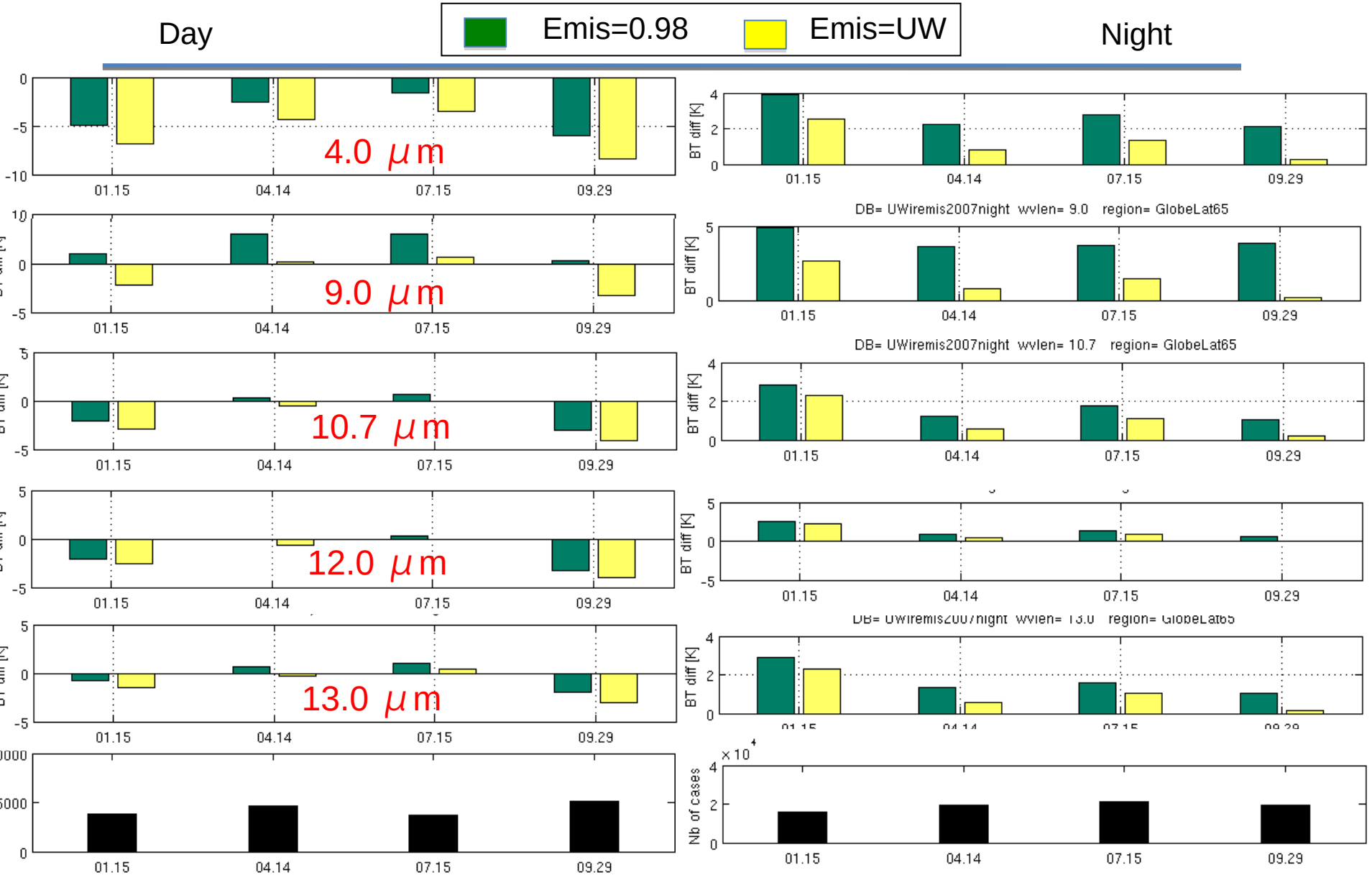




CONCLUSONS:

- The bias is reduced by (1.5 and 2.5 K) 5 and 12 K at 4 and 8.7 μm.
- The most significant impact occur over very dry (sand) Sahara region.
- Systematic bias across all surface sensitive channels can be attributed to bias error in model LST.
- SW error in daytime is caused by the uncertainty in the solar radiation component in the RTM.

Statistics of IASI BT differences (Calc –Obs) for Full Globe and 4 selected days: Jan15, Apr14, July15 and Sept29



Outline

- UW/CIMSS Global IR Land Surface Emissivity Database (UWiremis database)
- The RTTOV UWiremis module
- Evaluation of the module with satellite data (SEVIRI, IASI)
- Test of the UWiremis module in assimilation mode
- Conclusions

NAVDAS-AR forecast sensitivity tests

Ben Ruston, NRL

NOGAPS forecast model 0.04 hPa top, 4D-Var analysis

Includes Radiances:

MW - AMSUA ch3-10, SSMIS ch2-7

IR – IASI 39 channels, AIRS 34 channels

Experiments:

Base – IASI and AIRS ocean only

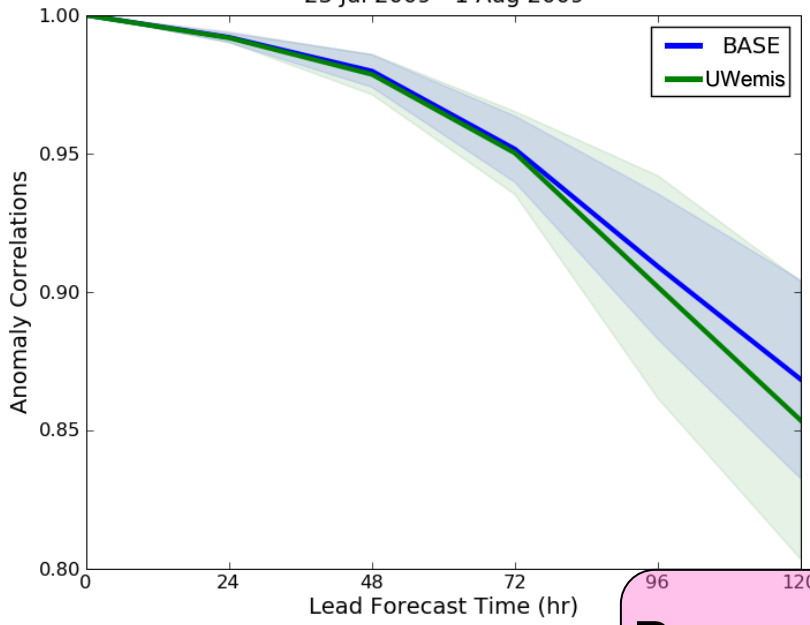
UWemis – add IASI and AIRS land points

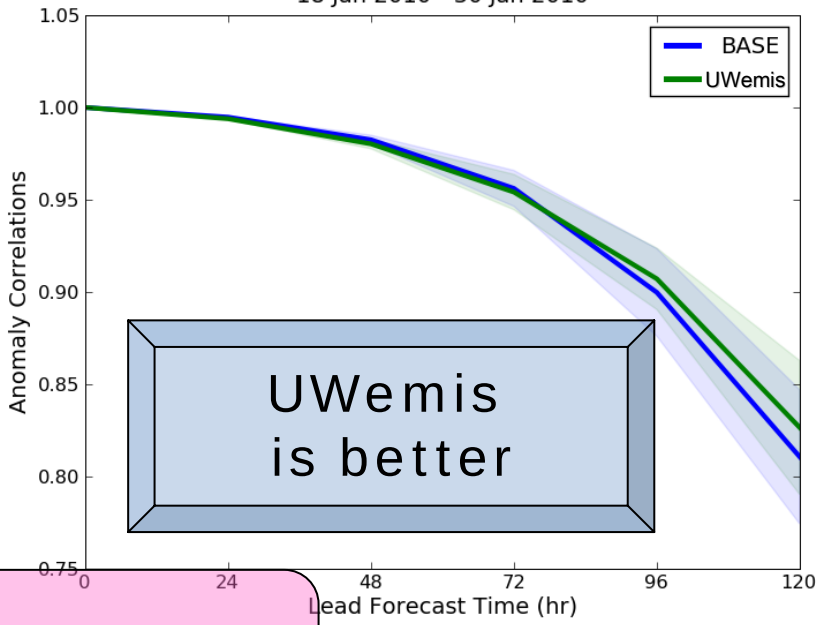
threshold check on: (innovation ✳ Tskin Jacobian)

Running 3 time periods

partially complete: Jul23 – Sep15, 2009; Jan18 – Mar15, 2010

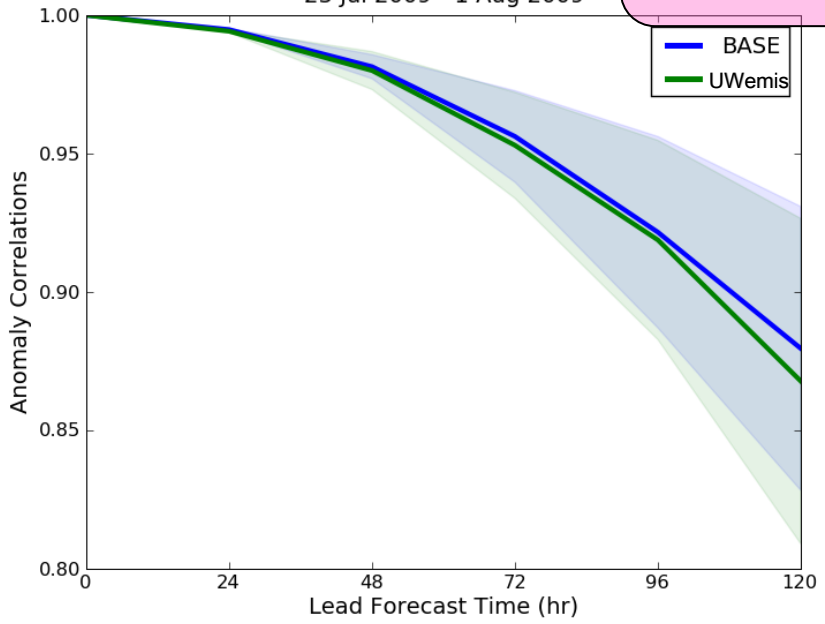
incomplete: Nov20, 2008 – Feb15, 2009

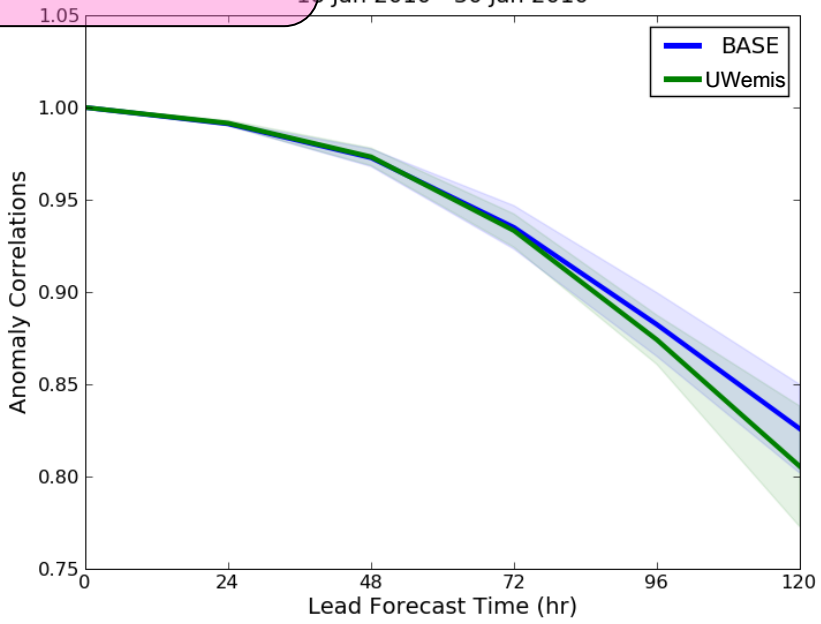


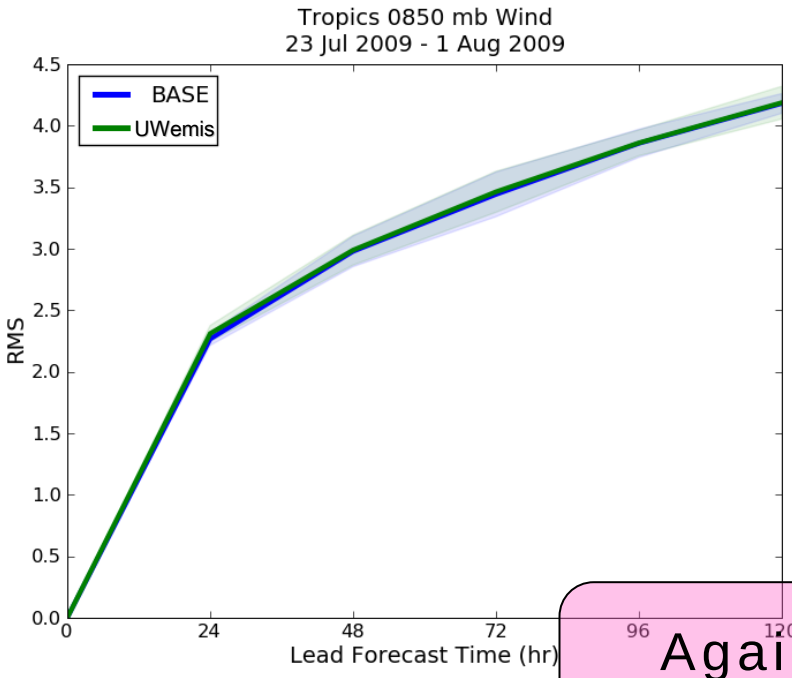


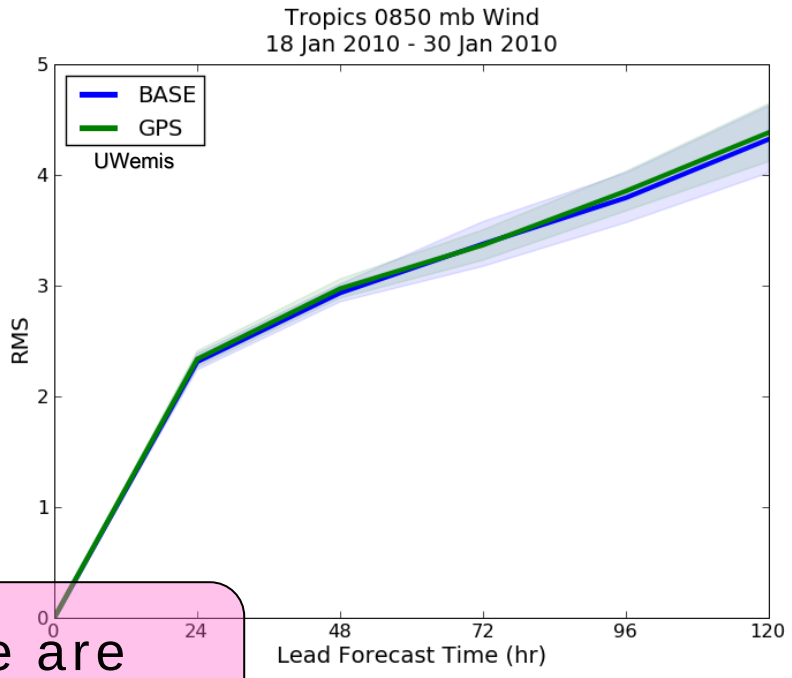
UWemis is better

Regrettably – none are statistically significant

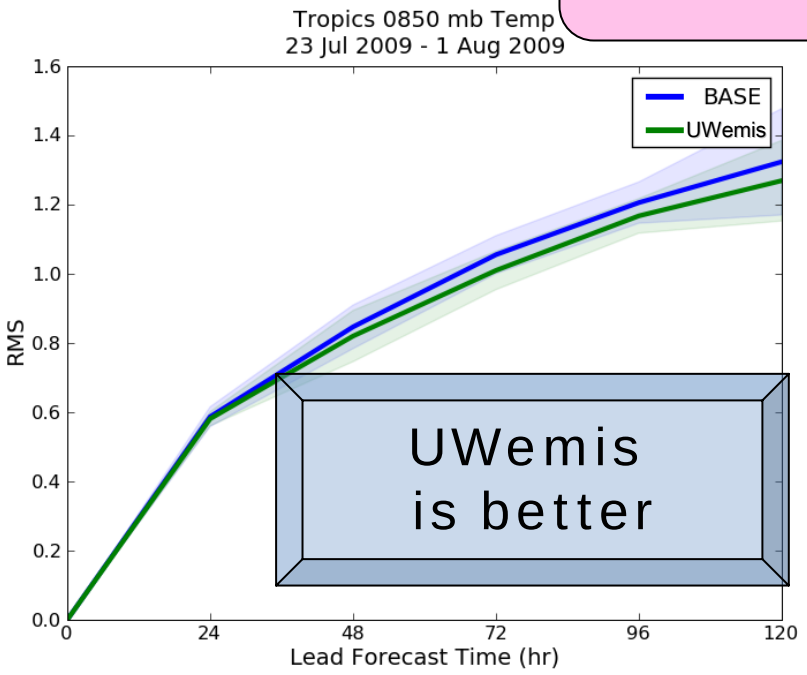




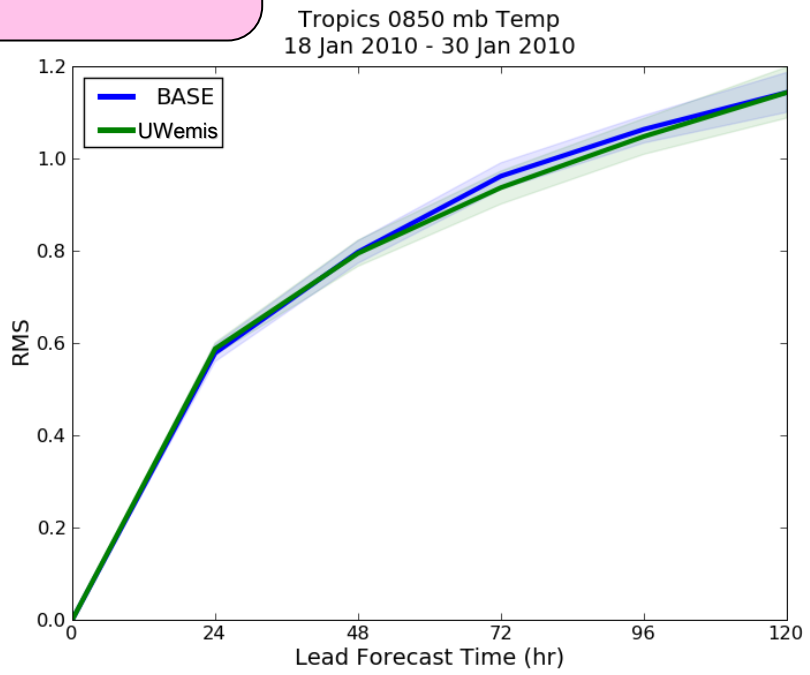


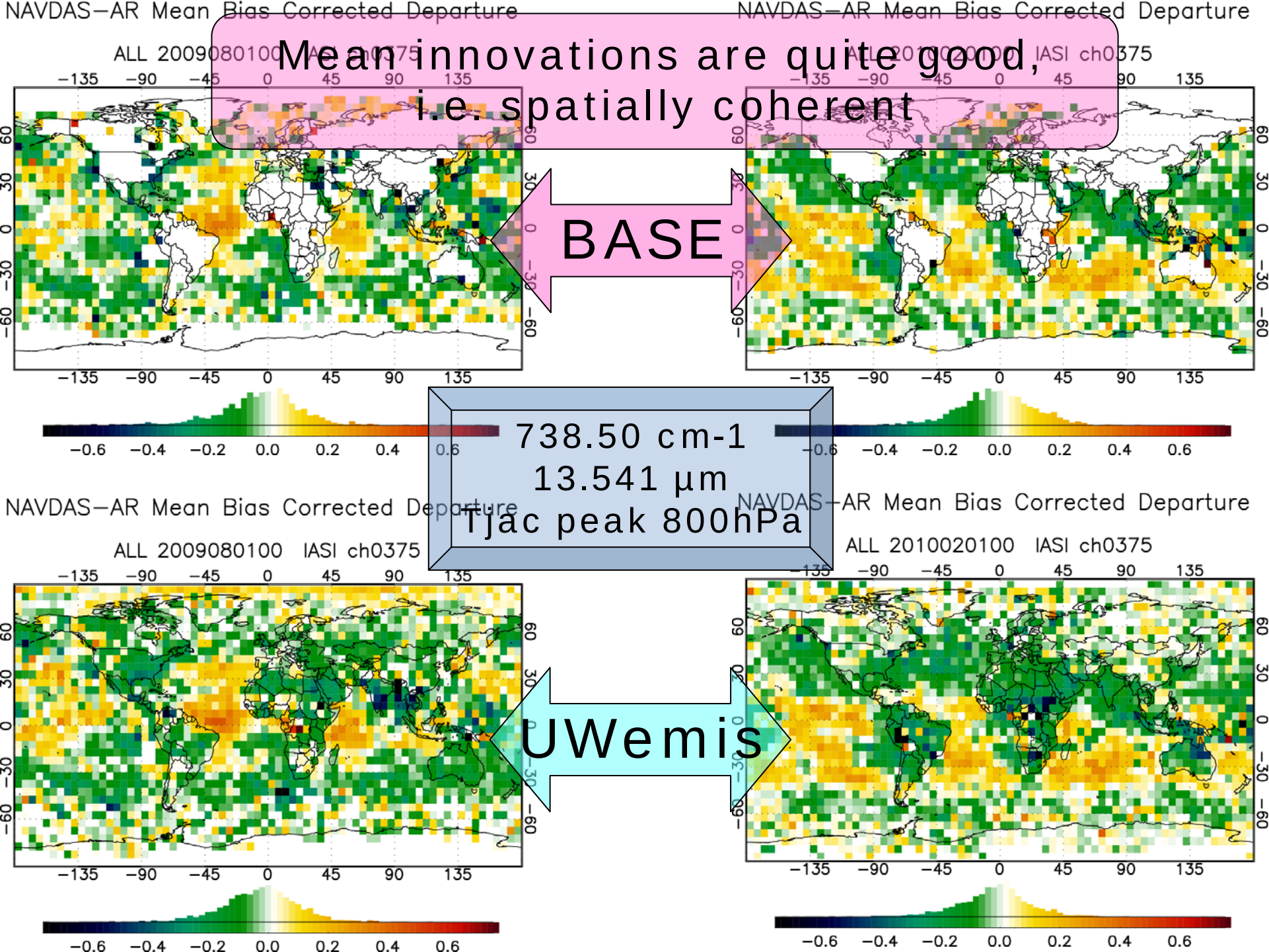


Again – none are statistically significant

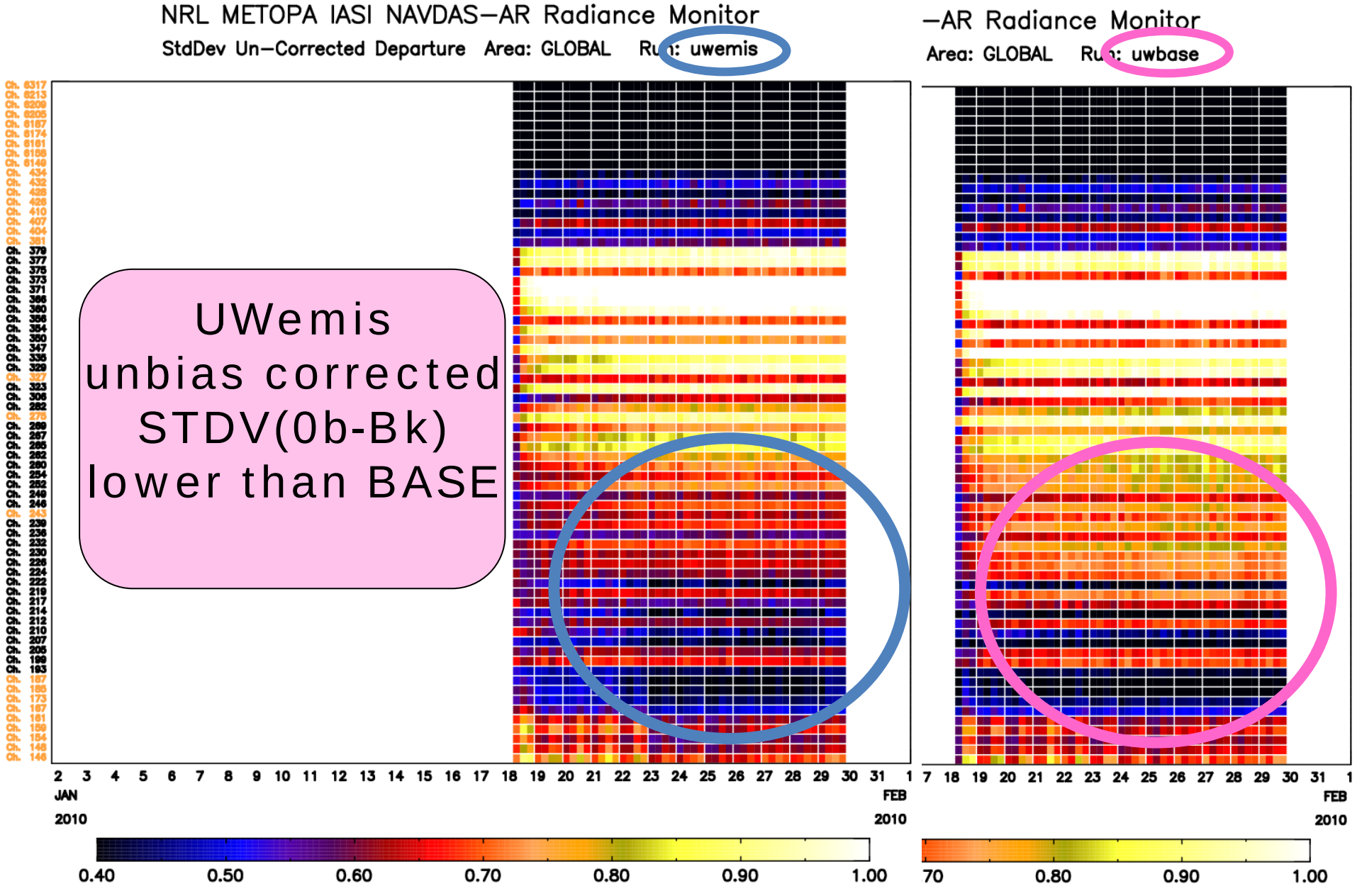


UWemis is better




NAVDAS–AR Mean Bias Corrected Departure
ALL 2009080100 IASI ch0375
NAVDAS–AR Mean Bias Corrected Departure
ALL 2010020100 IASI ch0375
Mean innovations are quite good,
i.e. spatially coherent
BASE
738.50 cm-1
13.541 µm
Tjac peak 800hPa
NAVDAS–AR Mean Bias Corrected Departure
ALL 2009080100 IASI ch0375
NAVDAS–AR Mean Bias Corrected Departure
ALL 2010020100 IASI ch0375
UWemis
−135 −90 −45 0 45 90 135
60 30 0 −30 −60
−0.6 −0.4 −0.2 0.0 0.2 0.4 0.6

Vertical Axis - IASI Channel
Horizontal Axis - 6hr update cycle



Conclusions (cont.)

NAVDAS-AR: Summary of forecast sensitivity tests

- The University of Wisconsin Emissivity Database (UWemis) provides estimates of infrared emissivity for all IASI and AIRS land, snow covered and sea-ice radiances.

- The innovations (observations – background) are spatially coherent passing from ocean to land.

- The standard deviation of the unbias corrected innovations are lower for many of the sounding channel using Uwemis.

- Forecast sensitivity results using 500hPa anomaly correlation metrics and 850hPa winds do not produce statistically significant differences.

Conclusions
Evaluation with IASI and SEVIRI

•Globally the UWiremis database decreases the BT differences over the RTTOV default values.

•The bias was reduced by 1.5 - 3.5 K at 4 and 8.7 μm region and by 0.5 – 2 K between 9.5 and 13.2 μm.

•The most significant impact occurs over very dry (sand) e.g. the Sahara region. The bias was reduced 5 - 12 K at 4 and 8.7 μm region.

•Systematic bias across all surface sensitive channels can be attributed to bias error in model LST.

•SW error in daytime is caused by the uncertainty in the solar radiation component in the RTM.

•The biases have been significantly reduced across all seasons by use of the UWiremis RTTOV module.

International TOVS Study Conference, 17th, ITSC-17, Monterey, CA, 14-20 April 2010. Madison, WI, University of Wisconsin-Madison, Space Science and Engineering Center, Cooperative Institute for Meteorological Satellite Studies, 2011.