Use of Surface Emissivity Data Sets in Radiative Transfer Models for Data Assimilation:
an Evaluation of Satellite-derived Emissivity

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Surface Emissivity

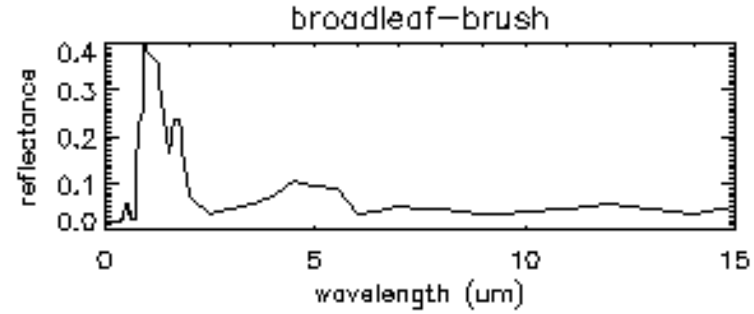
- Radiative transfer models require accurate surface emissivity for simulating TOA radiance of surface-sensitive satellite channels
  - Assimilation of satellite data into numerical weather prediction (NWP) models relies on radiative transfer models
- Land surface emissivity contains much inherent spatial, temporal and spectral variability
  - Assimilation of satellite data over land surfaces is hampered by inaccuracies in characterization of land surface emissivity and surface temperature
- Satellite retrieval algorithms also rely on accurate emissivity:
  - land surface temperature
  - atmospheric temperature & moisture profiles
  - surface radiation budget (energy balance)

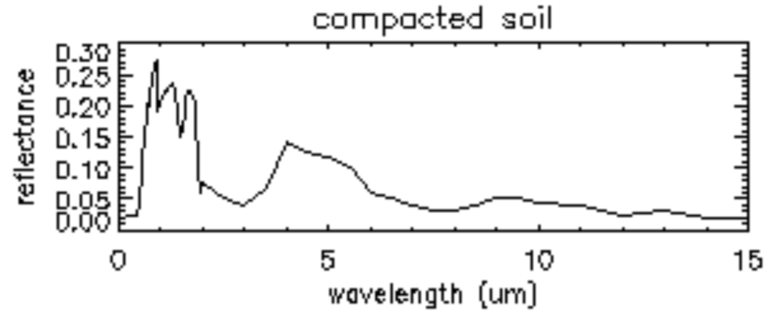
Community Radiative Transfer Model

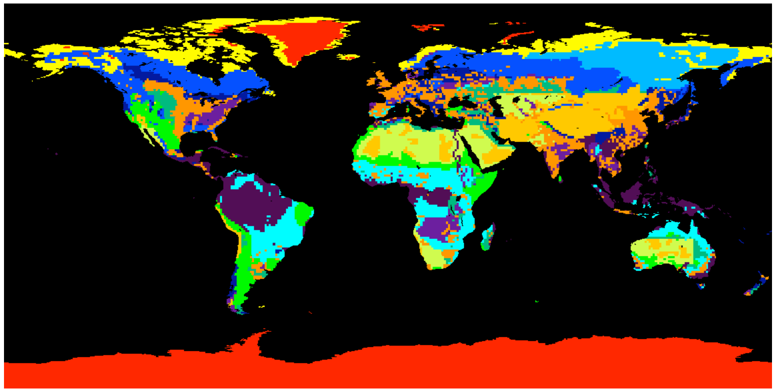
- Community Radiative Transfer Model (CRTM): fast, accurate radiance and radiance-gradient simulations for data assimilation, algorithm development, sensor design, satellite product validation
- CRTM is the operational radiative transfer model in NOAA/NCEP data assimilation systems for weather forecasting (used at other US agencies too)
- CRTM accuracy
  - TOA Tb accuracy of 0.1K compared to line-by-line transmittance calculations (Chen et al., 2010)
- CRTM sensitivity to emissivity variation:
  - Emissivity variation of 0.02 results in a Tb variation of 0.5 K for vegetated surfaces and 1.5 K for bare ground surfaces for AVHRR 11 and 12 µm channels.
- Surface temperature error of 1K due to emissivity error of 0.015 (Hulley & Hook, 2009)

CRTM's Land Surface IR Emissivity

- NPOESS Reflectance Table
  - Static reflectance value for each of 24 surface types
  - Emissivity = 1-Reflectance, assumes Lambertian surface
  - Spectral range: 0.2 – 15.0 μm
  - Spectral resolution: 0.025 – 1.0 μm depending on wavelength
- User input: surface type and wavelength
- Drawbacks
  - No time dimension, no seasonality
  - User must match surface types between classification schemes (assumes emissivity characteristics of class are similar in different schemes)
  - Surface types oversimplify small-scale spatial variation



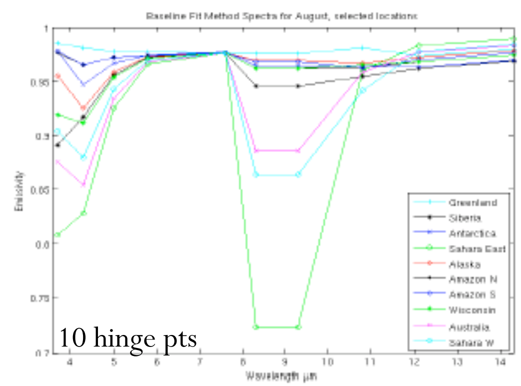


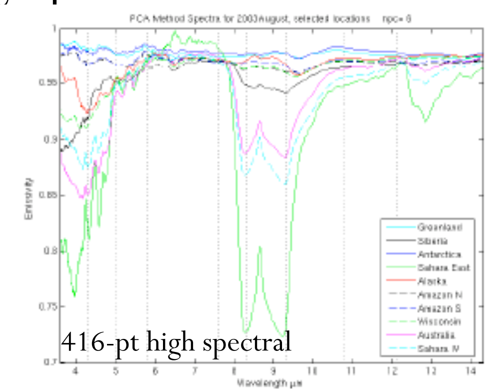


Surface Types in Global Forecast System (GFS)

Univ. Wisconsin MODIS-derived Infrared Emissivity (UWIREMIS)

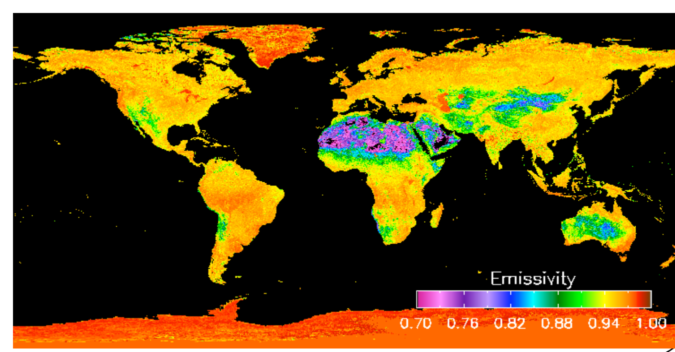
- Derived from MODIS satellite-retrieved emissivity (Wan & Li, 1997), monthly composite (Aqua-MODIS)
- Uses a generalized emissivity spectrum (from lab measurements) to fit emissivity at 10 hinge points from retrieved values at MODIS channels
- Principal components regression used to convert 10 hinge points to 416 spectral wavenumbers using eigenvectors from 123 lab-measured emissivity spectra
- Spectral range: 3.5 – 14.3 µm
- Advantages
  - Varies monthly
  - Latitude-longitude grid, so no classification scheme
  - High spatial resolution (0.05 deg)
  - High spectral resolution (5/cm ~ 0.0005 µm)





E. Borbas, U.Wisc./CIMSS

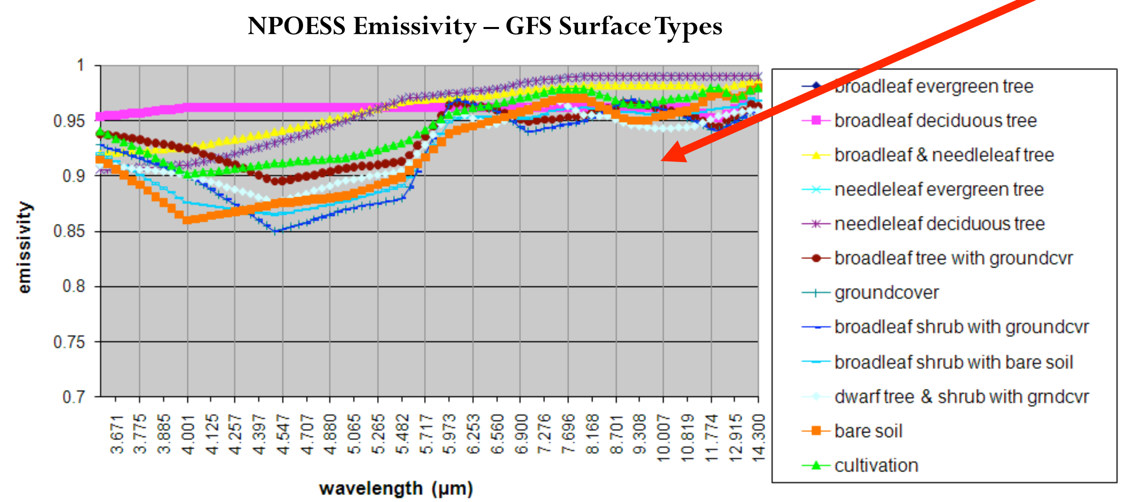
UWIREMIS
8.3 µm
July 2006
0.05 deg map



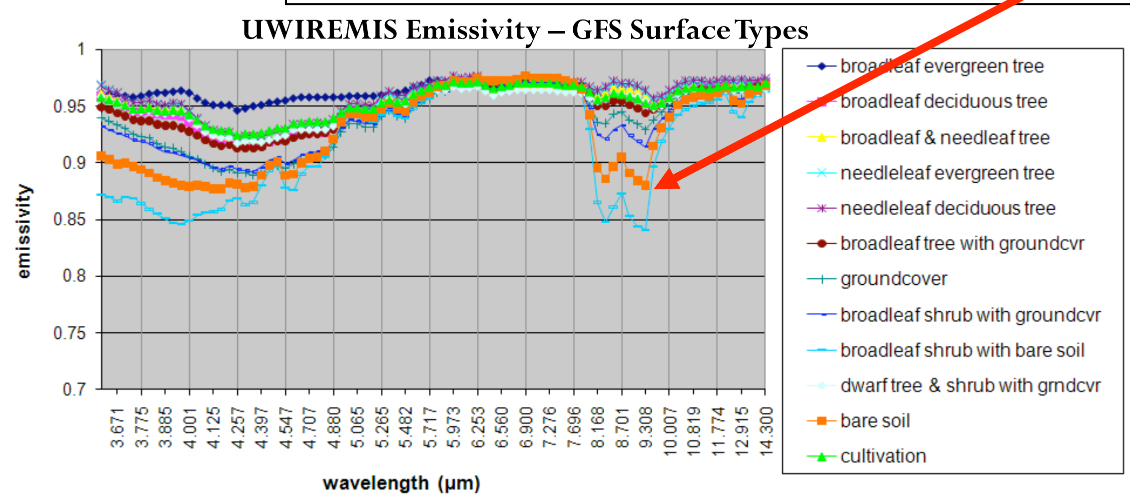
NPOESS vs UWIREMIS Emissivity

- Spectral comparison
  - NPOESS surface types matched to GFS surface types
  - UWIREMIS averaged globally for GFS surface types
- Emissivity of bare ground surfaces is much more variable than vegetated surfaces
- Current operational NPOESS emissivity database does not account for bare ground emissivity variation

CRTM default emissivity does not vary for soils in 8-10 µm region



Satellite-derived emissivity shows soil variability



Evaluation Method (1): Observation minus Simulation

- Comparison of satellite-observed TOA brightness temp (Tb) to CRTM-simulated TOA brightness temp (Tb)
  - Using NPOESS and UWIREMIS as surface emissivity inputs
  - **Meteosat-9 SEVIRI** IR chs: 3.9, 8.7, 10.8, 12.0 μm
  - One time period: 2010, May 30, 00 UTC
    - Low cloud coverage over land
  - CRTM run with NCEP GDAS atmos profiles & surface conditions
    - Atmos profiles: temp, pressure, humidity, ozone, 64 vertical layers, 768 x 384 global grid
    - Surface parameters: temp, surface type, 1152 x 576 global grid
    - Profiles & surface parameters in GDAS grid interpolated to satellite pixel
    - SEVIRI not included in GDAS assimilation, so not correlated with CRTM TOA Tb sim
  - Cloud-free, land surface pixels only
  - CRTM Tb compared to SEVIRI Tb
    - (1) NPOESS emissivity / (2) UWIREMIS emissivity

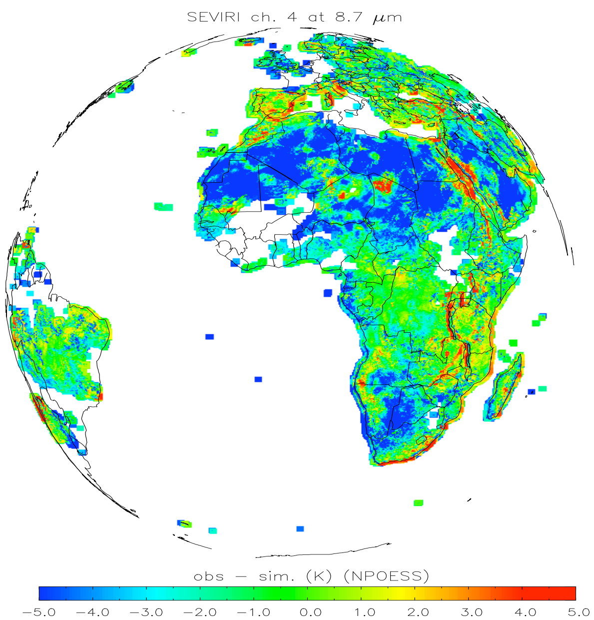
Results:
Observation minus Simulation

Tb Difference (K), SEVIRI obs minus CRTM sim

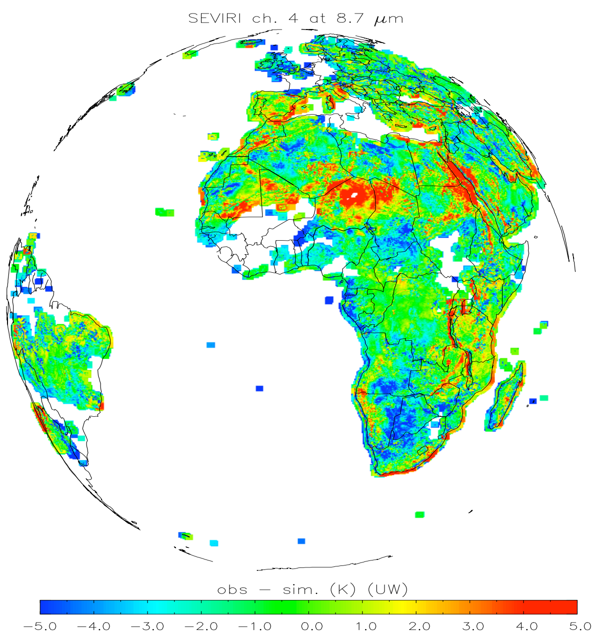
8.7 µm

May 30, 2010, 00 UTC

CRTM run with NPOESS



CRTM run with UWIREMIS



Negative differences: simulation too high,
NPOESS emis is too high

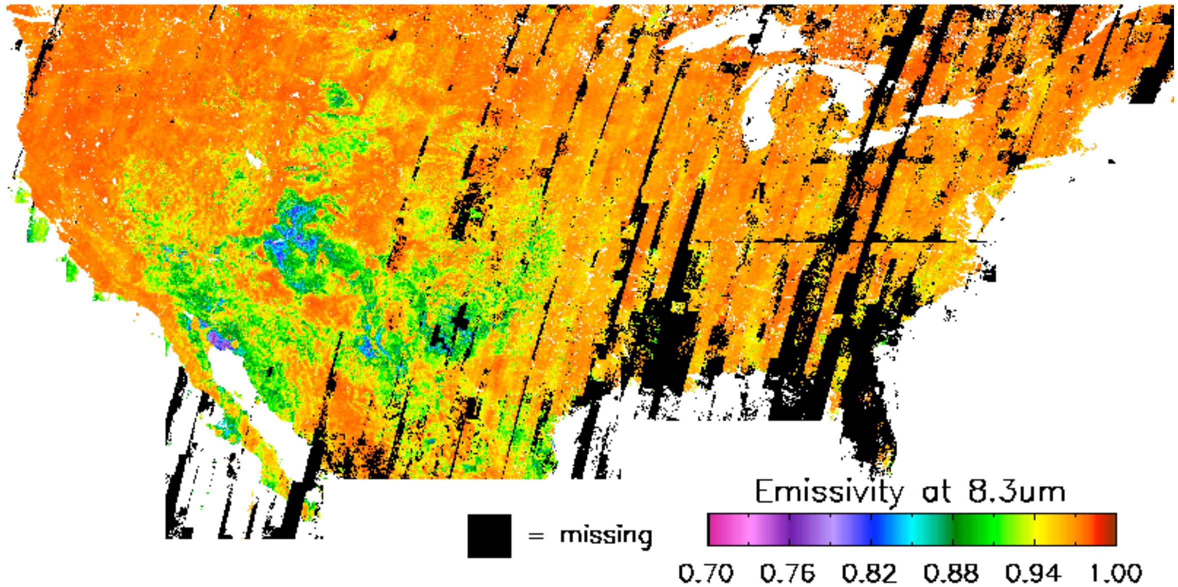
Evaluation Method (2):

Verification of UWIREMIS against a Validated Data Set

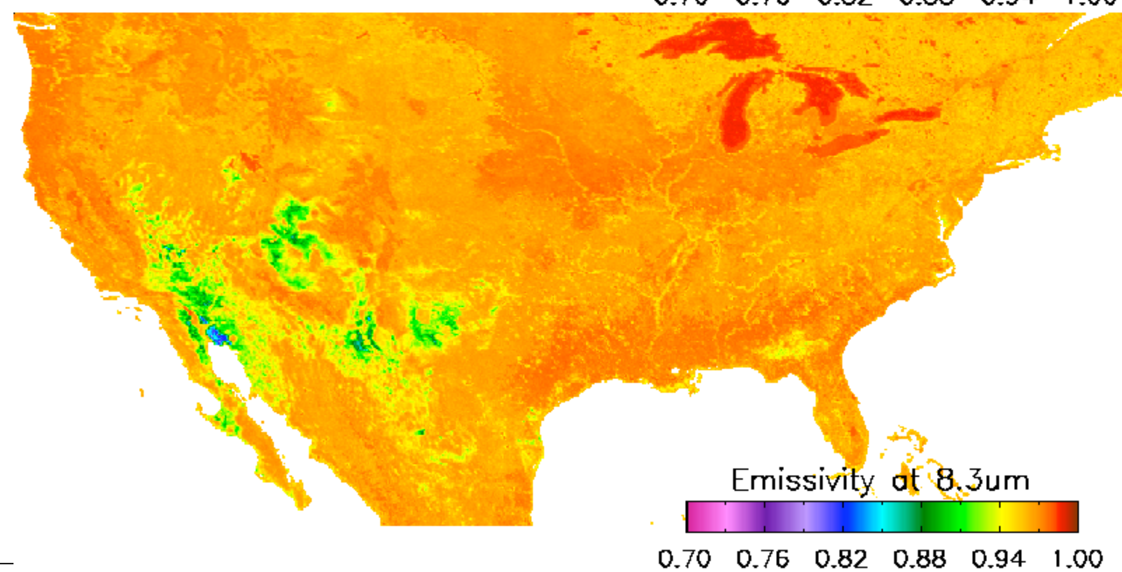
- **North American ASTER Land Surface Emissivity Database (NAALSED),** Hulley and Hook (2008, 2009)
  - Mean emissivity of all Terra/ASTER scenes over North America for entire mission 2000-2008
    - Summer mean = Jul, Aug, Sep scenes
    - Winter mean = Jan, Feb, Mar scenes
  - ASTER TIR bands: 8.3, 8.65, 9.1, 10.6, 11.3µm
  - Validated against desert in-situ sites in western U.S.
    - **Mean absolute difference for validation sites (all TIR chs) = 0.016**
  - High spatial resolution of 100m - Excellent data set for spatial scaling studies of emissivity
- Compare UWIREMIS to NAALSED
  - UWIREMIS monthly climatology (2003-2006) averaged for NAALSED summer/winter months (Jan,Feb,Mar / Jul,Aug,Sep)
  - UWIREMIS 416-frequency spectrum convolved for ASTER channel spectral response function
  - NAALSED spatial grid (1km dataset) scaled to UWIREMIS 0.05 degree grid
  - UWIREMIS minus NAALSED emissivity difference & bias

Results:
Verification of UWIREMIS against a Validated Data Set

NAALSED emissivity
8.3 µm
Summer (Jul, Aug, Sep
for years 2000-2008)



UWIREMIS emissivity
8.3 µm (convolved from 416 pts)
Summer (Jul, Aug, Sep
for years 2003-2006)



Results:

Verification of UWIREMIS against a Validated Data Set

- UWIREMIS minus NAALSED emissivity bias
  - Mean absolute difference (all channels)

    Summer: 0.004

    Winter: 0.007
  - UWIREMIS verification to NAALSED is within NAALSED's own validation (bias of 0.016)

Emissivity Bias & RMSE for each ASTER channel, UWIREMIS minus NAALSED

ASTER band	**8.3µm**	**8.65µm**	**9.1µm**	**10.6µm**	**11.3µm**	**N**
Summer bias: Summer RMSE:	0.003 0.017	0.003 0.015	0.007 0.018	-0.004 0.007	0.001 0.006	341,853
Winter bias: Winter RMSE:	-0.011 0.017	-0.008 0.014	-0.007 0.015	-0.007 0.009	-0.004 0.007	251,351

Conclusion

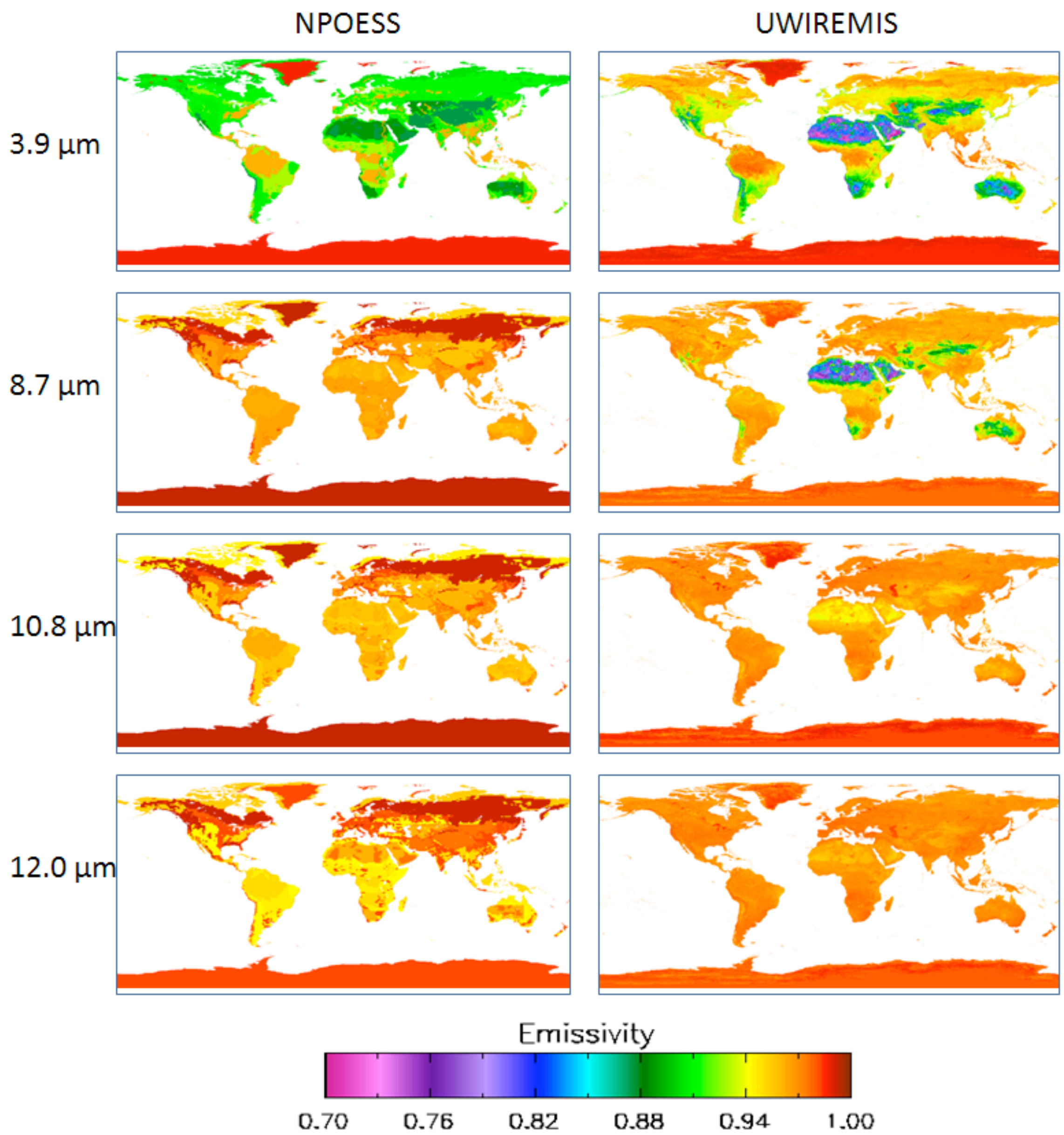
- UWIREMIS improves characterization of bare ground emissivity in 8-10 μm spectral region, compared to NPOESS
- UWIREMIS is accurate over NAALSED spatial domain and spectral region of the ASTER channels
  - UWIREMIS is accurate within NAALSED's validation
- Radiative transfer models require
  - high-spectral resolution emissivity for data assimilation of many channels on many satellite sensors
  - high-spatial resolution emissivity for characterizing emissivity variability of land surfaces

  UWIREMIS provides both requirements
- Accurate surface temperatures are necessary for evaluating emissivity data sets

Back-up Slides

NPOESS vs UWIREMIS Emissivity

- Spatial comparison at surface-sensing channels
- Major emissivity differences at:
  - 3.9 µm
    - northern latitudes:
      - needle forest
      - tundra
      - cropland
      - Sahara Desert
  - 8.7 µm
    - all major desert areas
      - UWIREMIS values are lower for all deserts



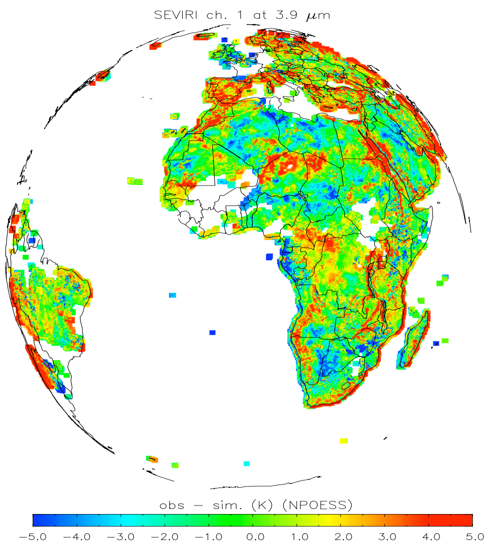
Results:
Observation minus Simulation

Tb Difference (K), SEVIRI obs minus CRTM sim

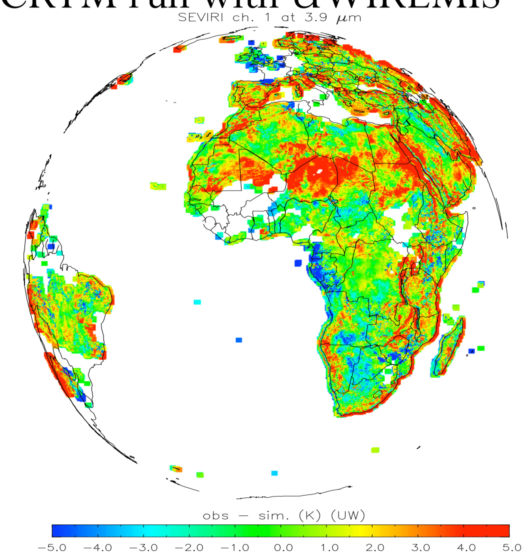
3.9 µm

May 30, 2010, 00 UTC

CRTM run with NPOESS

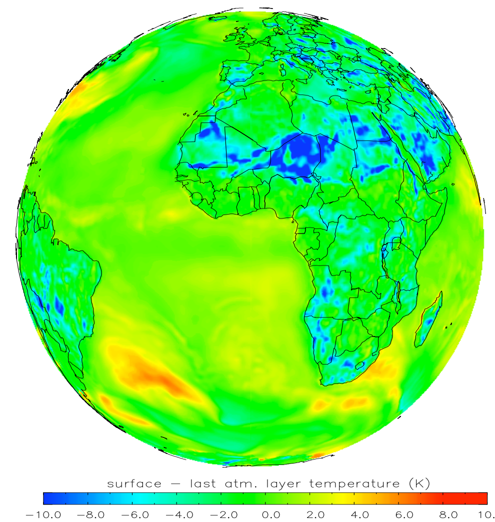


CRTM run with UWIREMIS



More positive diffs, simulation too low b/c Ts has neg bias. UW has lower emis, or high NPOESS compensates for low Ts? Which emis is correct?

Ts minus Tair



Model Ts minus model Tair (lowest Tair layer): Ts unreasonably biased low (>8K)

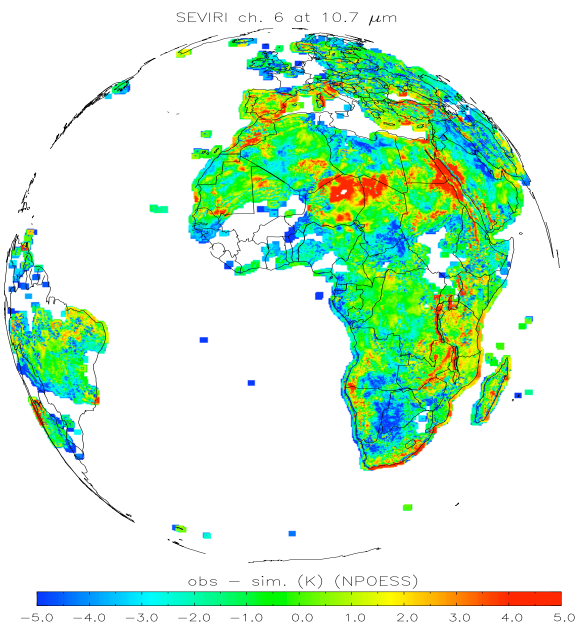
Results:
Observation minus Simulation

Tb Difference (K), SEVIRI obs minus CRTM sim

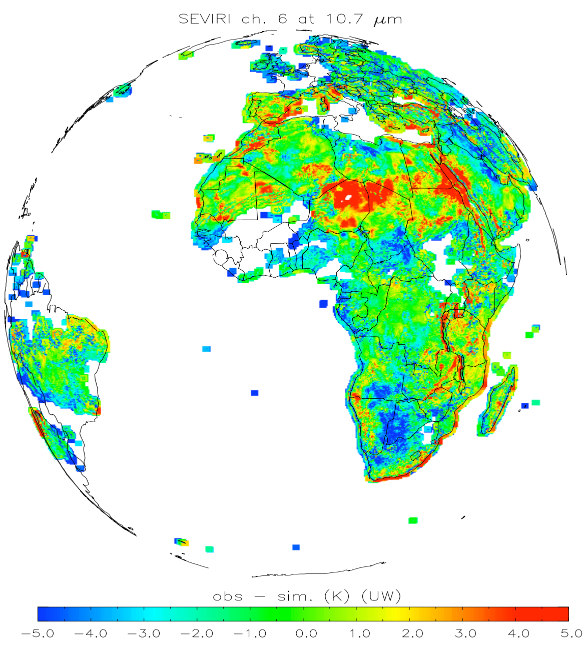
10.8 μm

May 30, 2010, 00 UTC

CRTM run with NPOESS



CRTM run with UWIREMIS



Nearly the same errors, also in region of negative Ts bias

Results:
Observation minus Simulation
Tb Difference: Bias and RMSE

Channel (μm)	NPOESS		UWIREMIS	
	Bias (K)	RMSE (K)	Bias (K)	RMSE (K)
	SEVIRI full-disk view, land & cloud-free only, N=2,281,241			
3.9	0.03	2.39	0.81	2.48
8.7	-2.46	3.89	-0.73	2.31
10.8	-0.59	2.21	-0.41	2.25
12.0	-0.01	2.22	-0.13	2.16
	Sahara Desert, cloud-free only, N=133,748			
3.9	-0.49	1.92	2.55	3.14
8.7	-4.51	5.03	0.77	2.32
10.8	0.43	1.92	1.29	2.33
12.0	1.96	2.69	1.73	2.49

Improvement at 8.7 μm due to realistic emissivity variability in UWIREMIS for bare surfaces