Main Preliminary Outcomes of SEVIRI Physical Retrieval for NWCSAF

Jun Li

Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin-Madison, 1225 West Dayton Street, Madison, WI 53706, U.S.A.

In collaboration with

Miguel A. Martinez, Marcelino Manso, Mercedes Velazquez, and Gabriela Cuevas

EUMETSAT NWCSAF, INM, Madrid, Spain

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CIMSS

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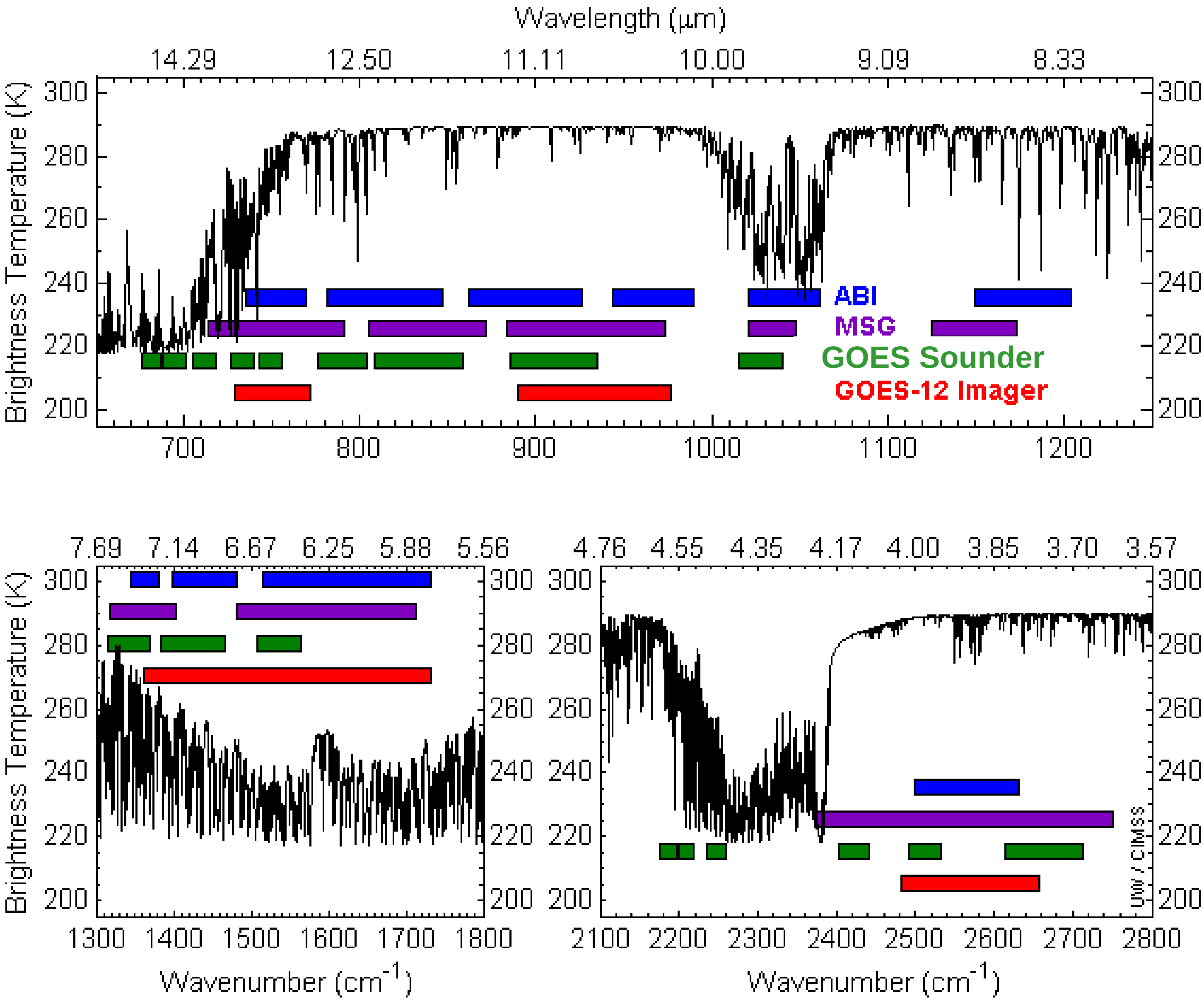
Thanks to my NESDIS/StAR colleage Tim Schmit for long time collaboration on GOES Sounder algorithm development

GOES Sounder/ABI legacy profile algorithm development is supported by NESDIS GIMPAP and AWG programs

Outline

- Mission goal
- Algorithm selection and recommendation
- Algorithm testing and validation
- Summary



ABI (blue) and current GOES sounder (green) spectral coverage over a high spectral resolution brightness temperature spectrum. (slide from Mat Gunshor)

SEVIRI spectral information (bands 5, 6, 8, 9, 10, 11 are used in retrieval)

Band ID	Channel	Bands	Spectral Band (µm)
	HRV	Visible and near IR	Broad-bank (peak within 0.6 - 0.9)
1	VIS 0.6		0.56 - 0.71
2	VIS 0.8		0.74 - 0.88
3	IR 1.6		1.50 - 1.78
4	IR 3.9	Window	3.48 - 4.36
7	IR 8.7		8.30 - 9.10
9	IR 10.8		9.80 - 11.80
10	IR 12.0		11.00 - 13.00
5	IR 6.2	Water Vapor	5.35 - 7.15
6	IR 7.3		6.85 - 7.85
8	IR 9.7	Ozone	9.38 - 9.94
11	IR 13.4	Carbon Dioxide	12.40 - 14.40

Mission Goal

- Analyse atmospheric profile physical retrievals (infrared measurements) in order to evaluate which is the most convenient method to use in future version of SAFNWC package; and
- Describe the way to follow in order to implement the selected approach for SEVIRI (Spinning Enhanced Visible and Infrared Imager (SEVIRI).

Evaluation of existing algorithms

- **MPEF algorithm**
- **CM-SAF algorithm**
- **GOES Sounder algorithm**

MPEF algorithm

$$J(X) = [Y^m - F(X)]^T E^{-1} [Y^m - F(X)] + [X - X^b]^T B^{-1} [X - X^b]$$

Measurements Forward Model Measurement Error Background Background Error

With Quasi-Newton Iteration

$$\delta X_{n+1} = (F_n^{'T} \cdot E^{-1} \cdot F_n^{'} + B^{-1})^{-1} \cdot F_n^{'T} \cdot E^{-1} \cdot (\delta Y_n + F_n^{'} \cdot \delta X_n)$$

Where $\delta X_n = X_n - X^b$ $\delta Y_n = Y^m - F(X_n)$

$F^{'}(X)$ matrix is the Jacobian of forward model $F(X)$

Background is from forecast

First guess X_0 is same as the background

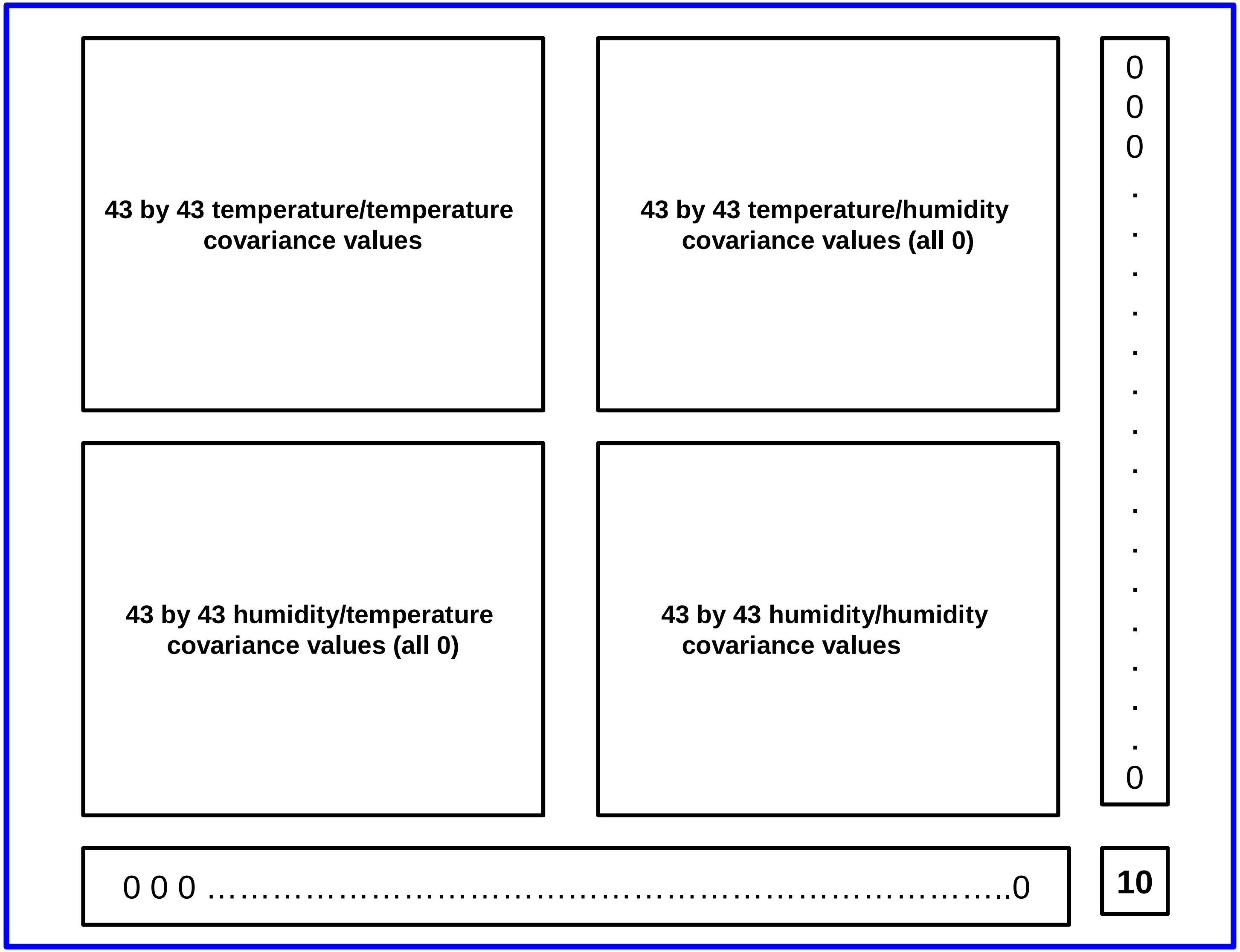
Atmospheric levels - 43

CM-SAF algorithm is similar to MPEF

Background – radiosonde analysis

Atmospheric layers - 12

MPEF background error covariance matrix



GOES Sounder algorithm

Regularization parameter

$$J(X) = [Y^m - F(X)]^T E^{-1}[Y^m - F(X)] + [X - X^b]^T \gamma B^{-1}[X - X^b]$$

Measurements Forward Model Measurement Error Background Background Error

With Quasi-Newton Iteration

$$\delta X_{n+1} = (F_n^{'T} \cdot E^{-1} \cdot F_n^{'} + \gamma B^{-1})^{-1} \cdot F_n^{'T} \cdot E^{-1} \cdot (\delta Y_n + F_n^{'} \cdot \delta X_n)$$

The regularization parameter is adjusted dynamically in the iterations (Li and Huang 1999; Li et al. 2000)

Using profile eigenvectors (1 for T, 3 for q, and 1 for Ts)

$X - X^b = \Phi A$ where $A = (\alpha_1, \alpha_2, ..., \alpha_M)$ and $\Phi = \begin{bmatrix} \Phi_T & 0 & 0 \\ 0 & \Phi_q & 0 \\ 0 & 0 & \Phi_{T_s} \end{bmatrix}$

Iteration form:

$$A_{n+1} = (\tilde{F}_n^{'T} \cdot E^{-1} \cdot \tilde{F}_n^{'} + \gamma B^{-1})^{-1} \cdot \tilde{F}_n^{'T} \cdot E^{-1} \cdot (\delta Y_n + \tilde{F}_n^{'} \cdot A_n)$$

$$A_0 = 0 \qquad \tilde{F}' = F' \cdot \Phi$$

Background: forecast

First guess: regression (optional)

Note on first guess and background

- X=(T1,T2, …., T43, lnq1, lnq2, …, lnq43, Ts)
- Background X^b, usually from forecast or climatological analysis, ideally X^b should be independent of satellite observations
- First guess X_0 , is the starting point in physical iteration. First guess is very important, for example, if the first guess contains structure similar to the real atmosphere, the final solution will be good. Usually two types of first guess can be used:
  - » From background: $X_0 = X^b$
  - » From regression: $X_0 = X^{Reg}$

Physically, regression can not be used as background since it already contains radiance information, mathematically/technically regression can be used as background since most information in regression is from forecast in this case

Similarity of three algorithms

- use one dimensional variational approach (1DVAR);
- use observation error covariance matrix (only diagonal elements are used);
- use background error covariance matrix;
- use quasi-Newton nonlinear iteration for solution.

Differences

- MPEF use 43 levels, GOES Sounder algorithm (CIMSS improved version, note that the operational GOES Sounder algorithm is also developed by CIMSS) used 101 levels, while CM-SAF uses 12 levels;
- GOES Sounder algorithm uses empirical orthogonal functions (EOFs) to represent profile in retrieval, while CM-SAF and MPEF retrieve profile directly;
- GOES Sounder algorithm uses regularization parameter for better convergence, while CM-SAF and MPEF only use background error covariance matrix.
- MPEF and CM-SAF use linear tangent model for Jacobian calculation, while GOES Sounder algorithm uses analytical Jacobian which is an efficient and approximate form.
- MPEF uses forecast as first guess, CM-SAF uses climate as first guess, while GOES Sounder algorithm uses regression as first guess.
- GOES Sounder algorithm uses logarithm of water vapor mixing ratio physical iterations.

Strength of each algorithm

- MPEF: theoretically steady, good background information, accurate Jacobian calculation
- CM-SAF: theoretically steady, accurate Jacobian calculation
- GOES Sounder algorithm: theoretically steady, good first guess, good convergence, computationally efficient due to EOF representation for the profile

Weakness of each algorithm

- MPEF: is computationally less efficiency
- CM-SAF: has inferiority on accuracy due to using poor background
- GOES Sounder algorithm: uses approximation for Jacobian calculation

Criteria for algorithm selection

- algorithm maturity and low risk;
- computationally efficiency;
- less dependent of ancillary data;
- good accuracy.

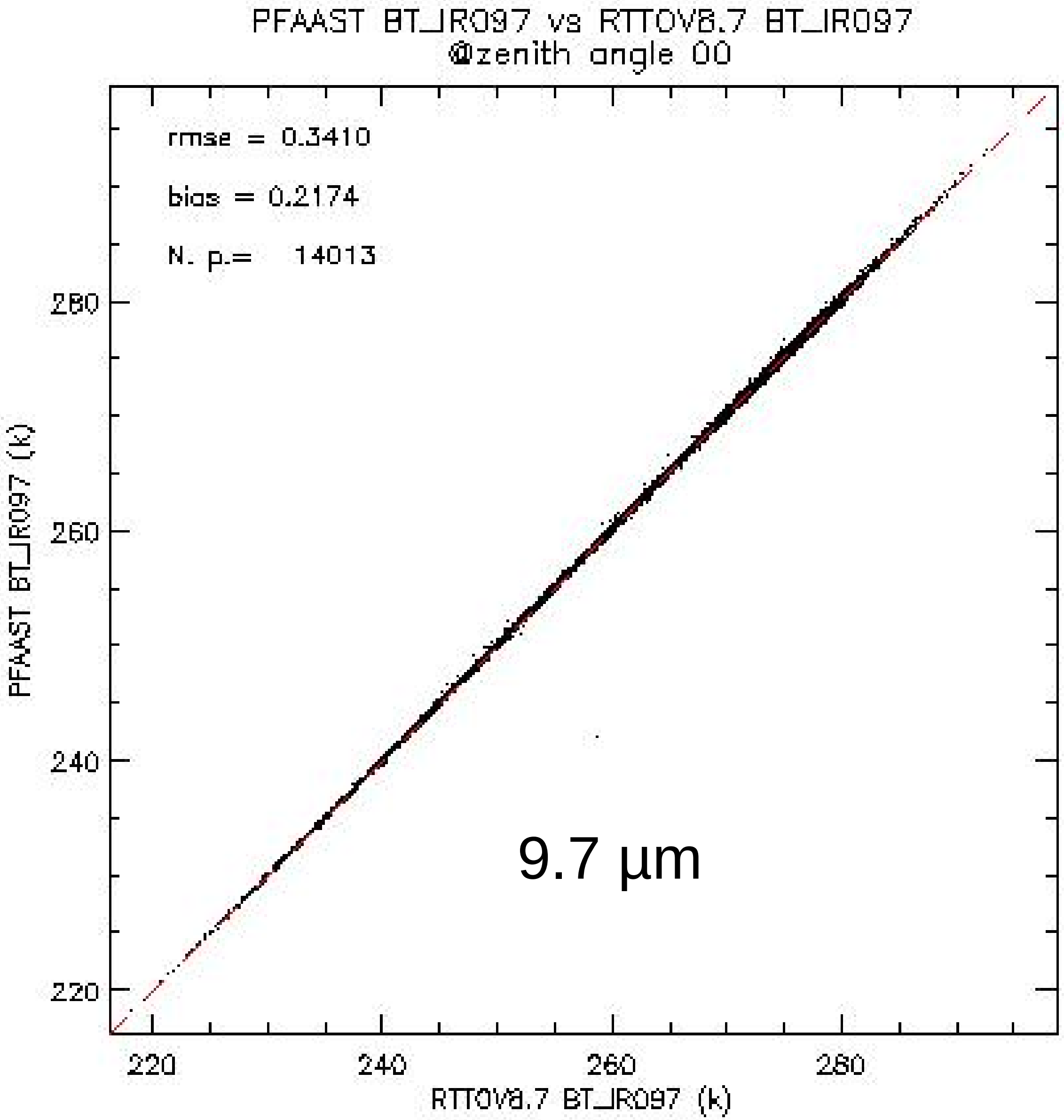
Recommendations on SEVIRI algorithm

- Maximum likelihood approach (CM-SAF, MPEF);
- Regularization with discrepancy principal (GOES Sounder algorithm);
- SEVIRI observation error covariance matrix (CM-SAF, MPEF, GOES Sounder algorithm);
- Using RTTOV8.7 radiative transfer model and its linear tangent model for Jacobian (MPEF);
- Use forecast as background (MPEF, GOES Sounder algorithm);
- Use background error covariance matrix (CM-SAF, MPEF, GOES Sounder algorithm);
- EOF representation for profile (GOES Sounder algorithm);
- Use regression as first guess (GOES Sounder algorithm) (optional);
- Use predetermined surface IR emissivities;
- Use radiance bias adjustment.

Components of each physical algorithms

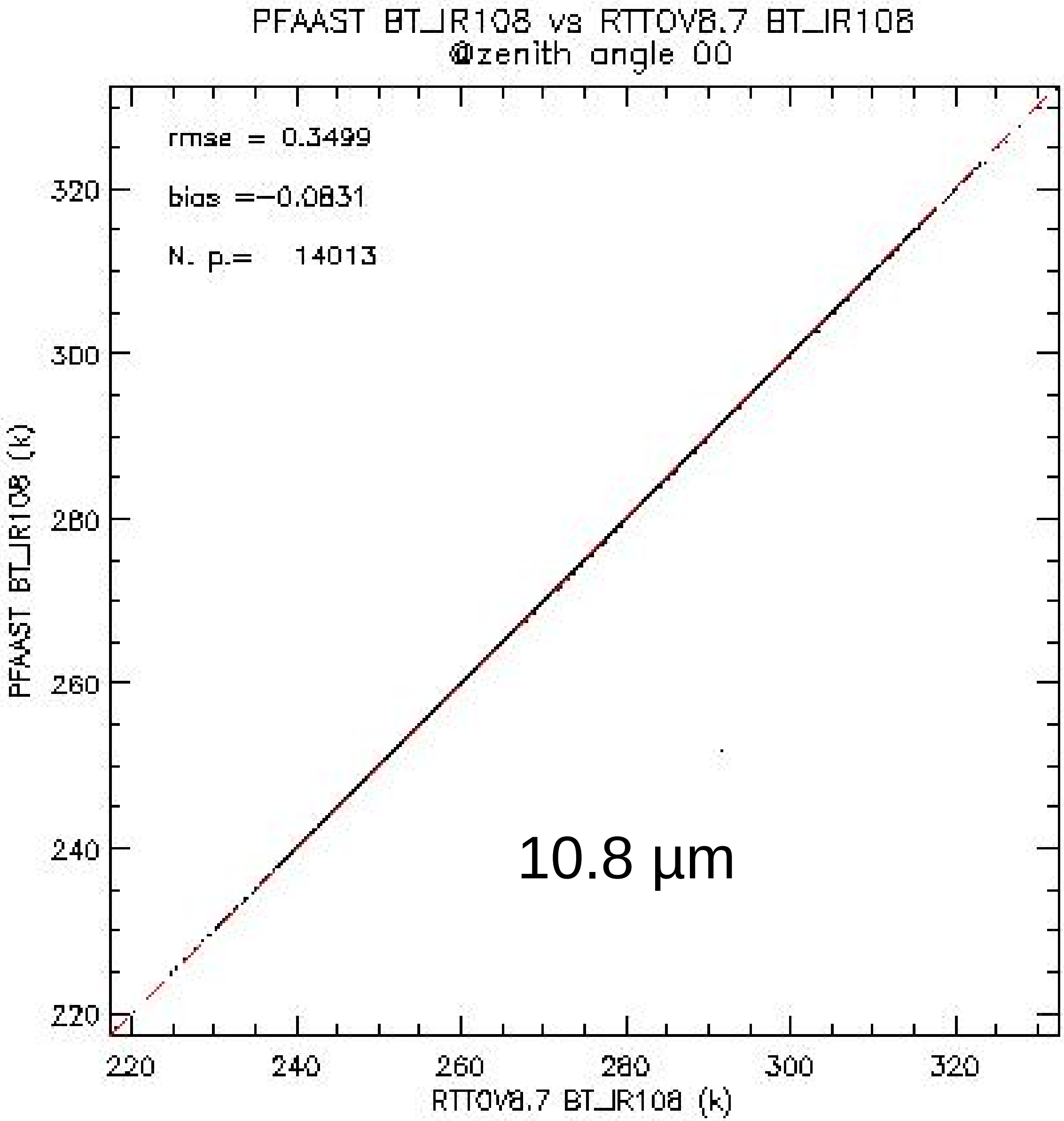
Components	MPEF	CM-SAF	GOES Sounder
Radiative Transfer Model	X	X	X
Jacobian	X (tangent model)	X (tangent model)	X (analytical)
Optimal Estimate	X	X	X
Observation Error Covariance Matrix	X	X	X
Background Error Covariance Matrix	X	X	X
Regularization parameter	No	No	Yes
Analytical Jacobian	No	No	Yes
Convergence Criteria	Cost Function Value	Weighted BT Residual	BT Residual
Number of parameters (No of unknowns)	87 (87)	25 (25)	211 (9 for GOES)
Using Profile EOFs	No	No	Yes
Background	Forecast	Climate profile	Forecast
First guess	Forecast	Climate profile	Forecast
Iteration method	Newtonian	Newtonian	Newtonian

RTA – use RTTOV8.7



(Figure from Miguel Miguel A. Martinez)

RTA – use RTTOV8.7



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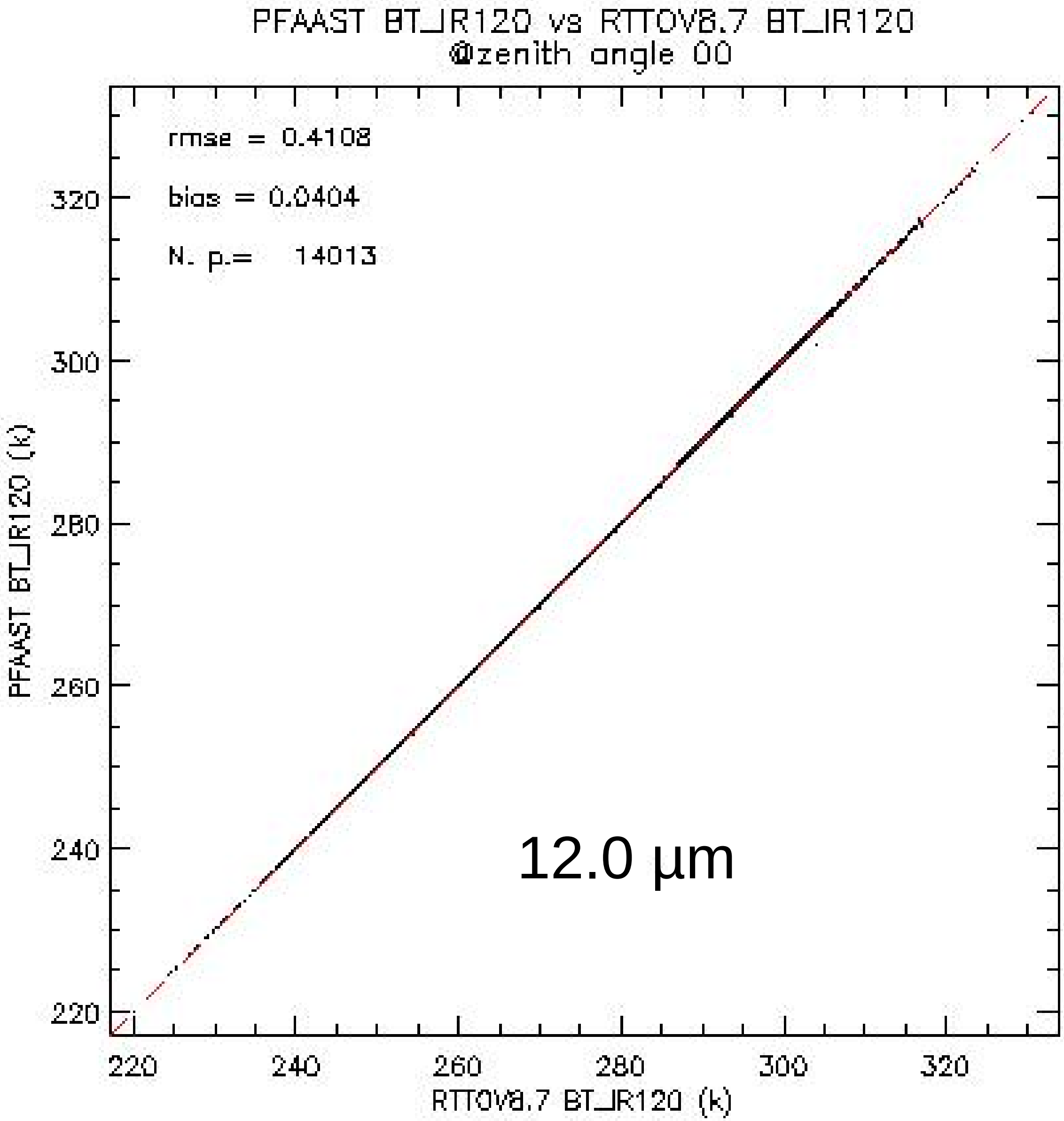
RTA – use RTTOV8.7



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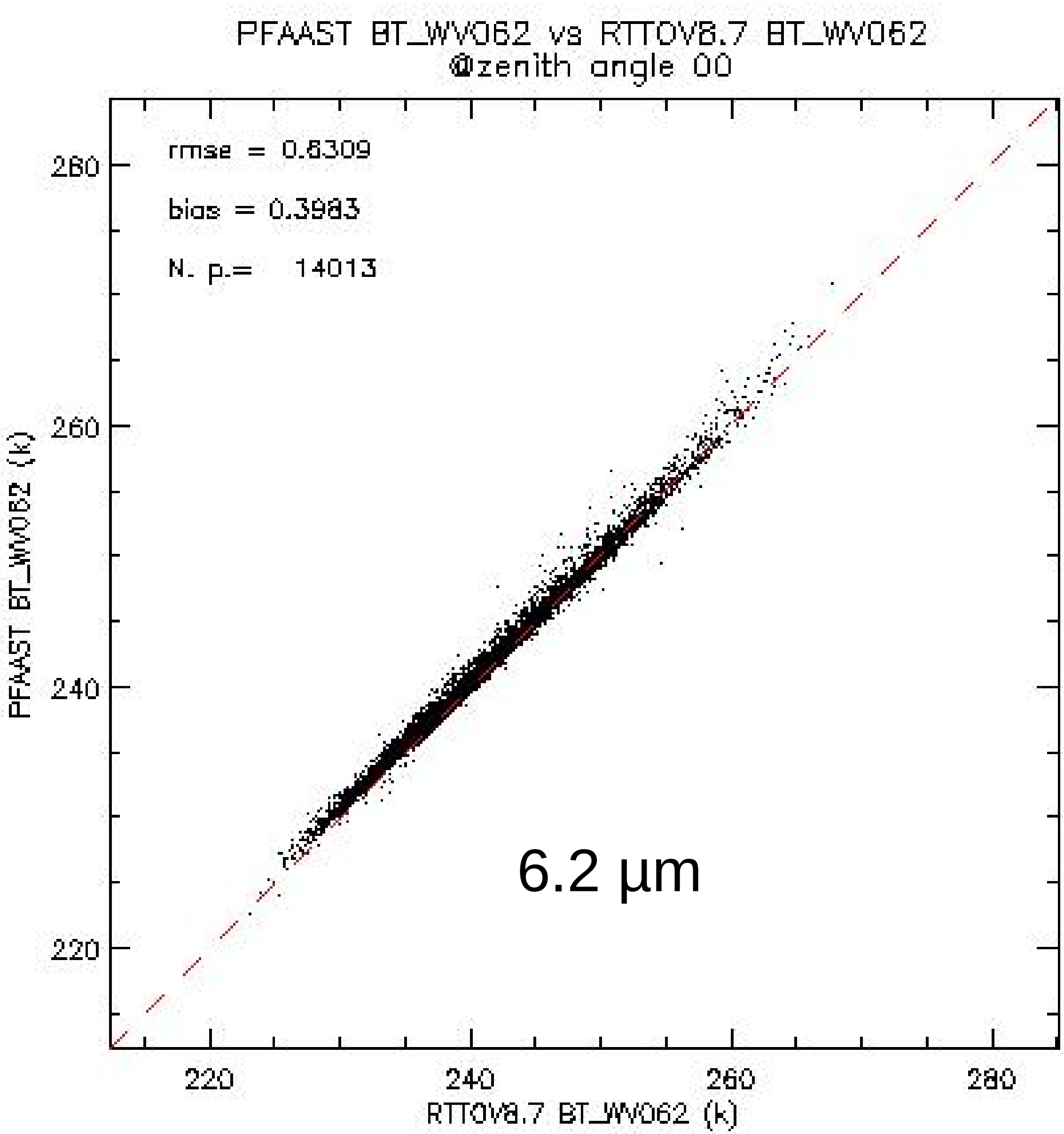
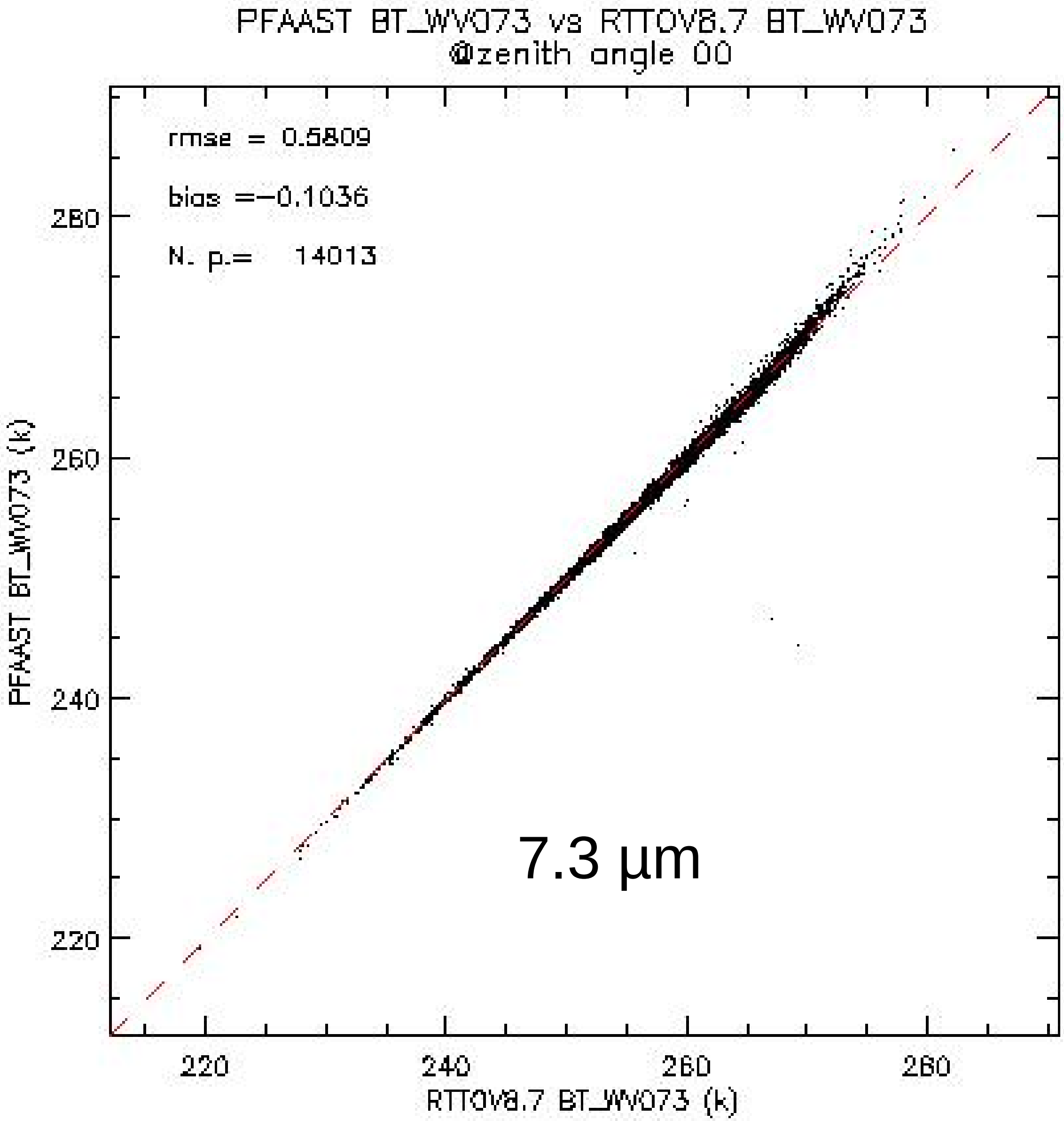


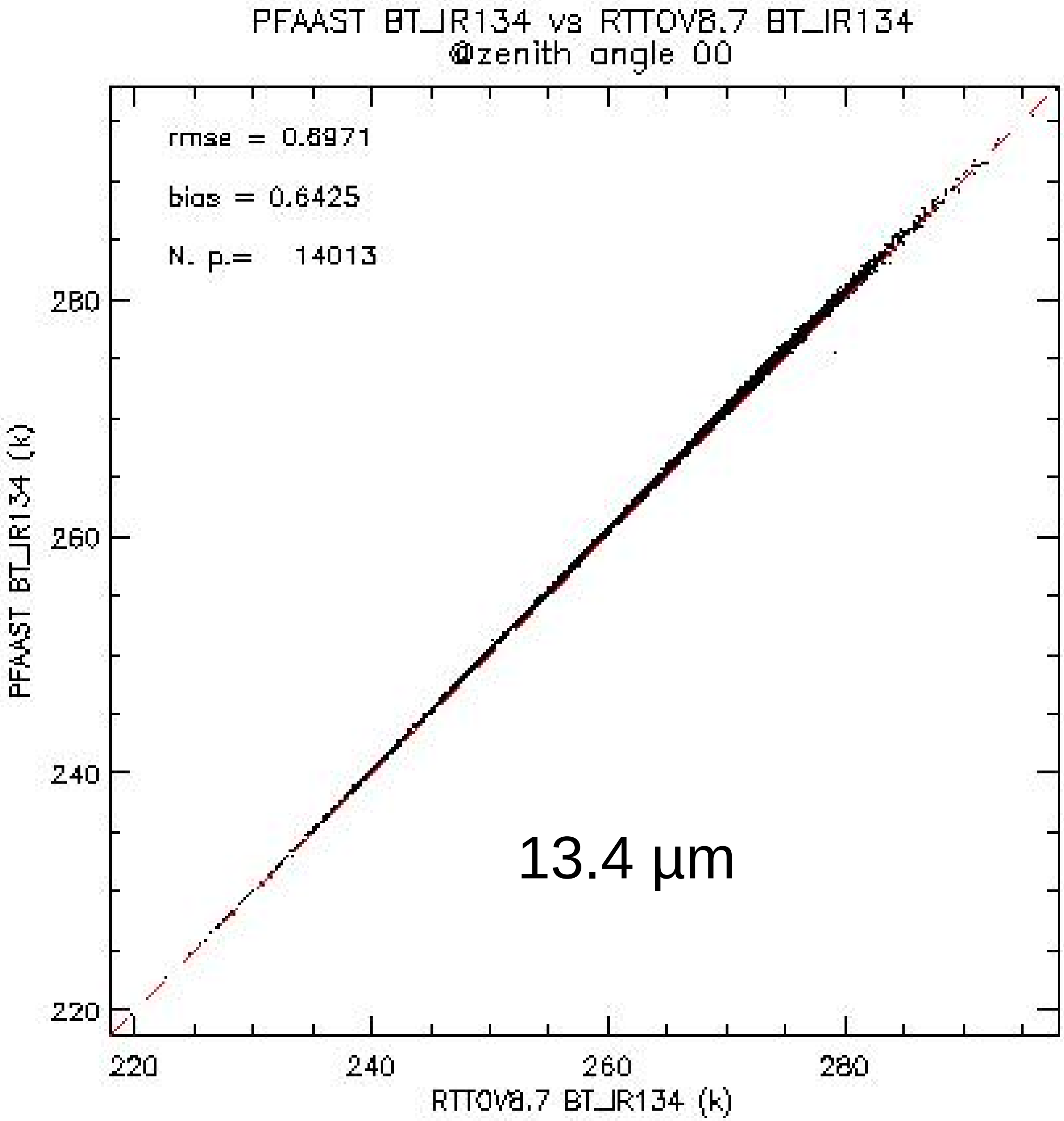
(Figure from Miguel Miguel A. Martinez)

RTA – use RTTOV8.7

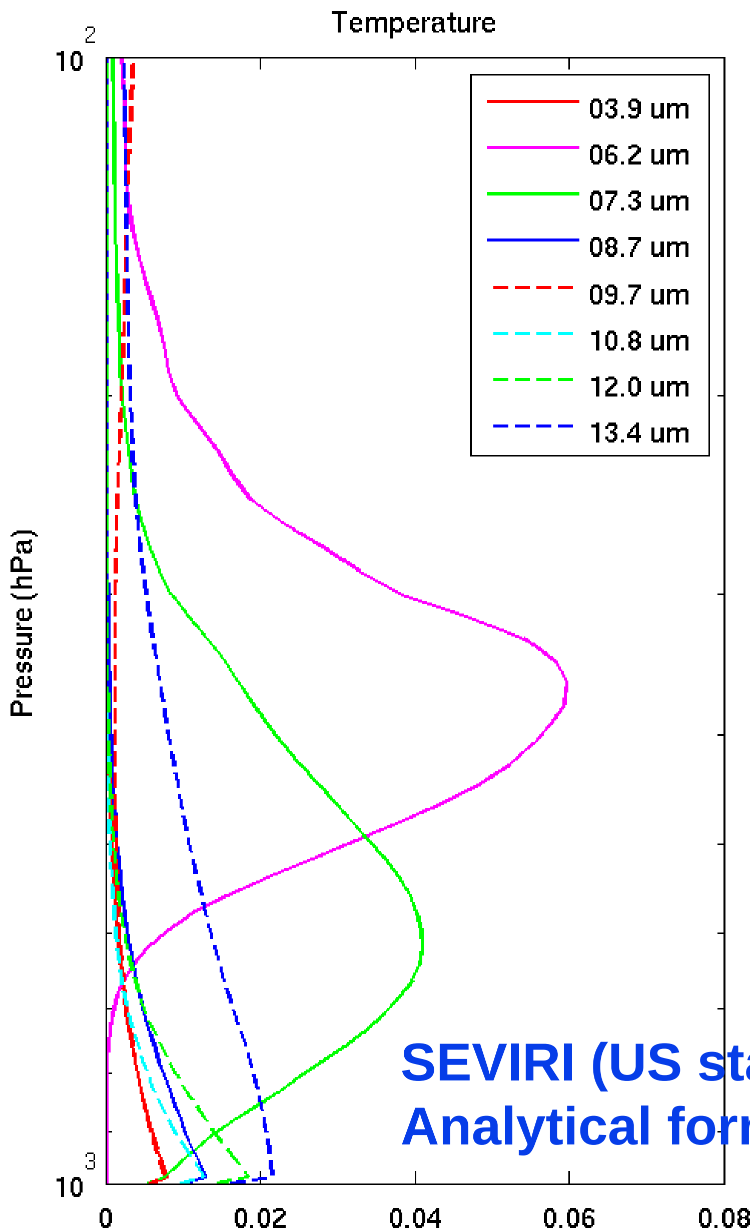


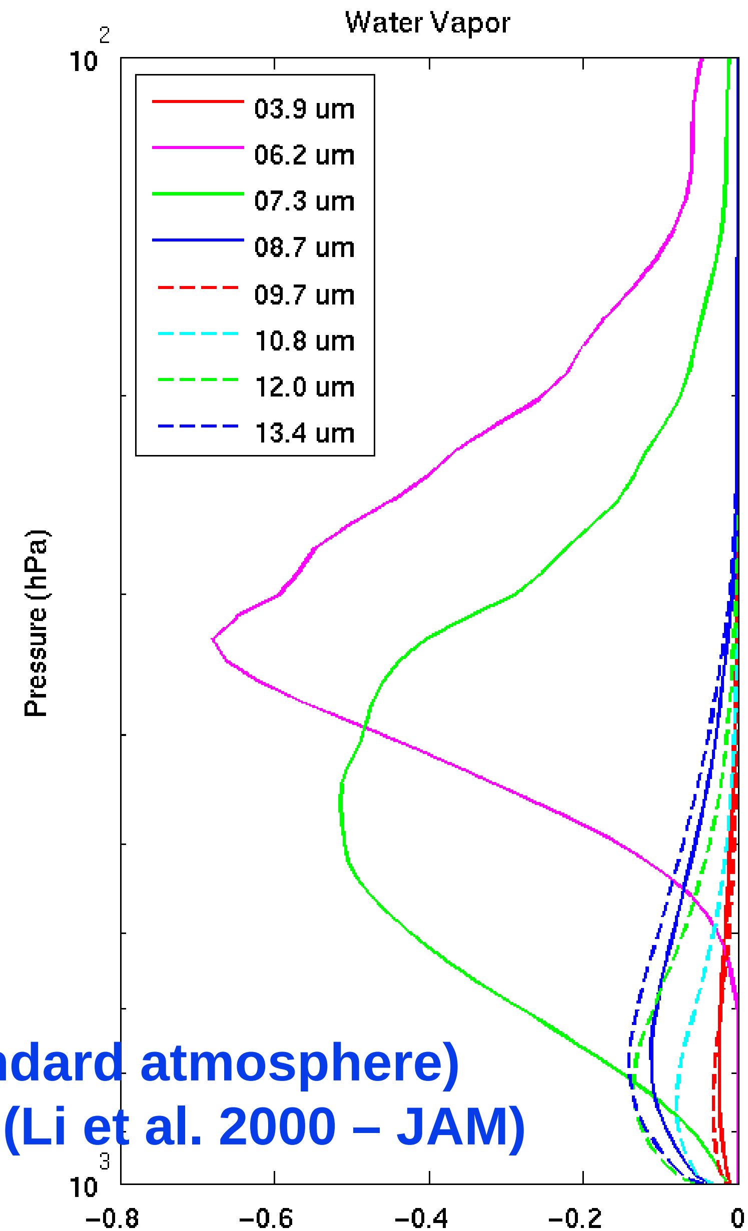
(Figure from Miguel Miguel A. Martinez)

RTA – use RTTOV8.7



(Figure from Miguel Miguel A. Martinez)



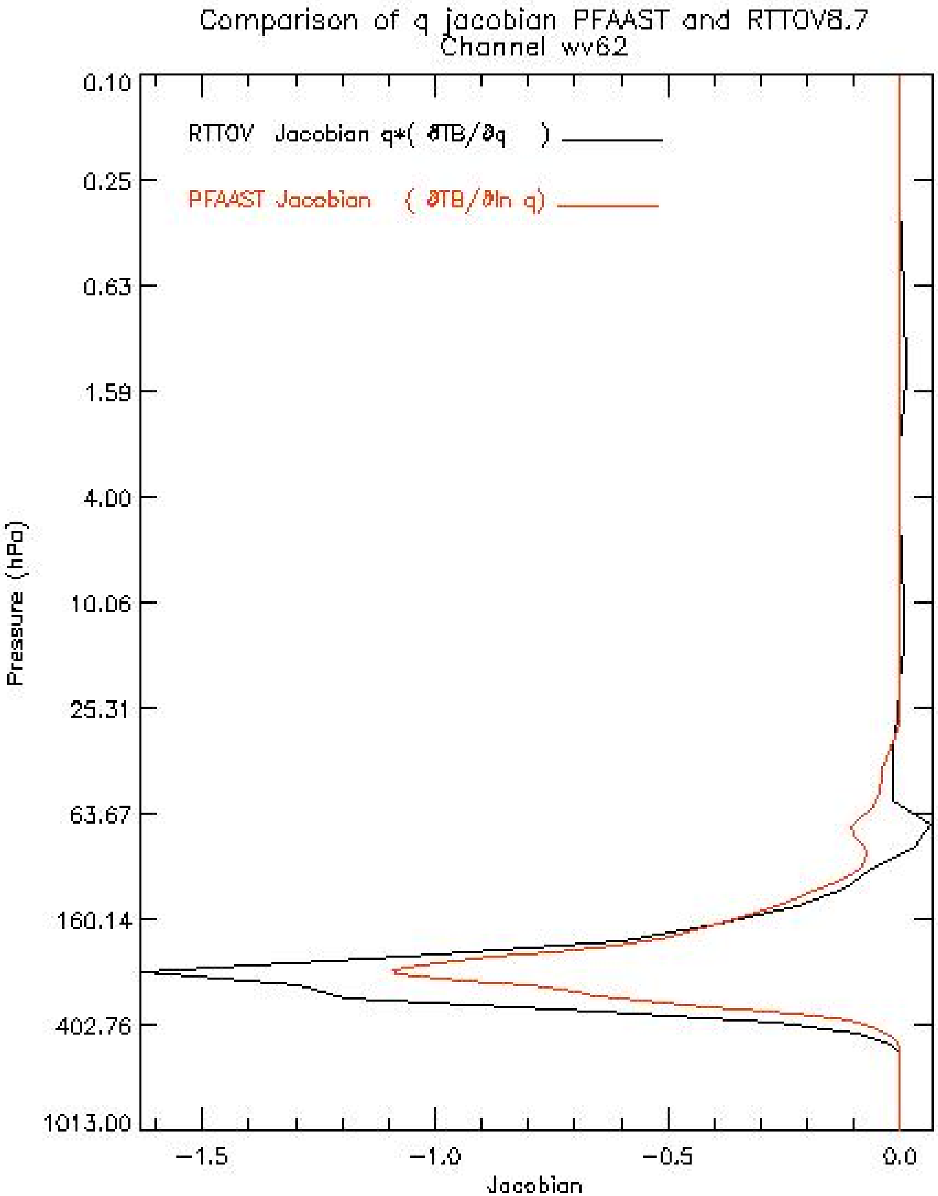


SEVIRI (US standard atmosphere)
Analytical form (Li et al. 2000 – JAM)

Temperature Jacobian

Water vapor mixing ratio Jacobian

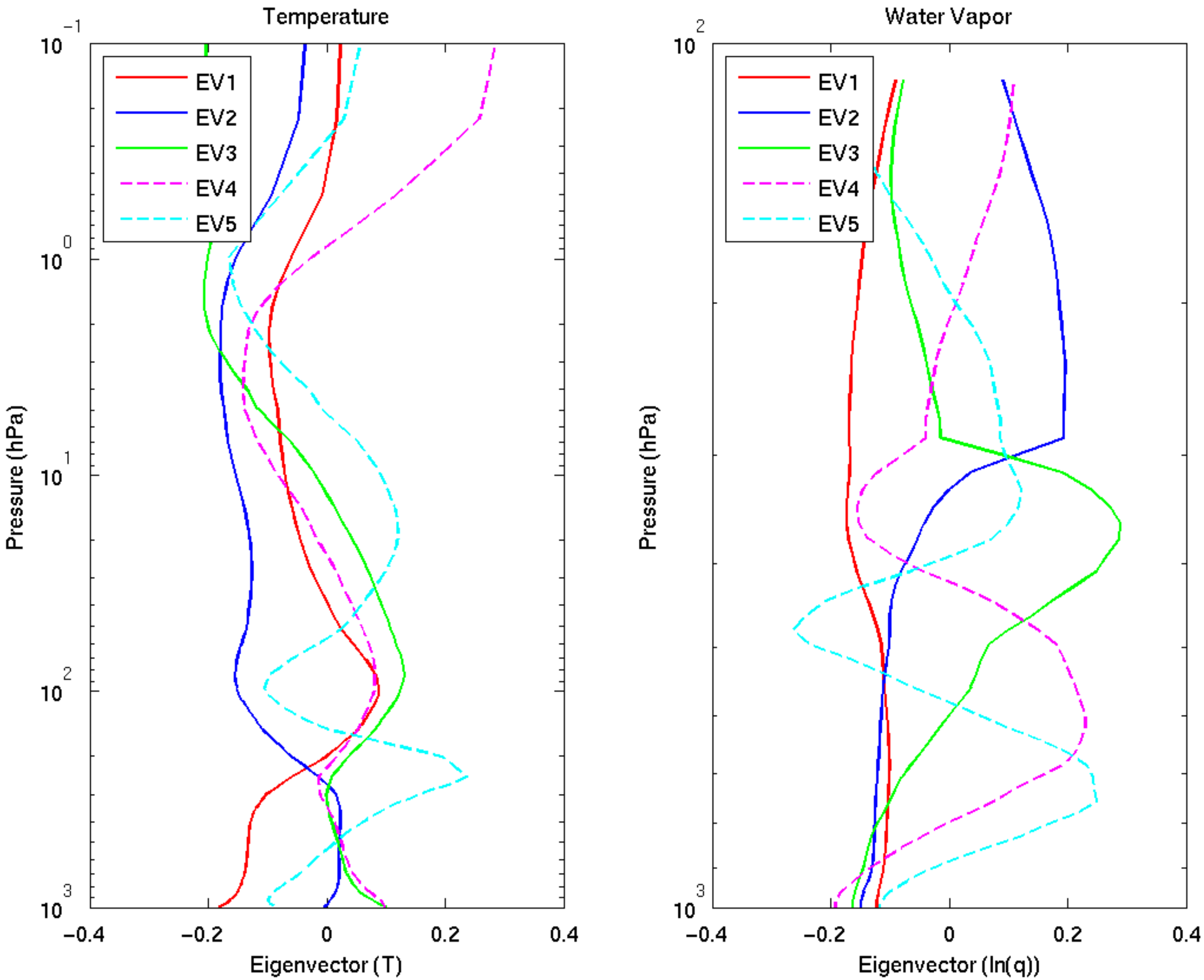
Jacobian (k-matrix) – use RTTOV



Analytical Jacobian is based on the assumption that the absorption coefficient is independent of absorption gas itself, which is an approximation. The analytical Jacobian might not be very accurate for retrieval using broad band radiances.

(Figure from Miguel Miguel A. Martinez)

Profile representation – use EOFs



EV	Cumulative Var for T	Cumulative Var for lnQ	Cumulative Var for lnO3
1	68.0%	39.3%	80.0%
2	81.5%	76.7%	87.6%
3	87.4%	85.7%	92.1%
4	90.5%	90.6%	94.4%
5	92.8%	93.2%	96.1%

EOF calculated from training data (10 < lat < 80, -75 < lon <75)

Handling surface emissivities

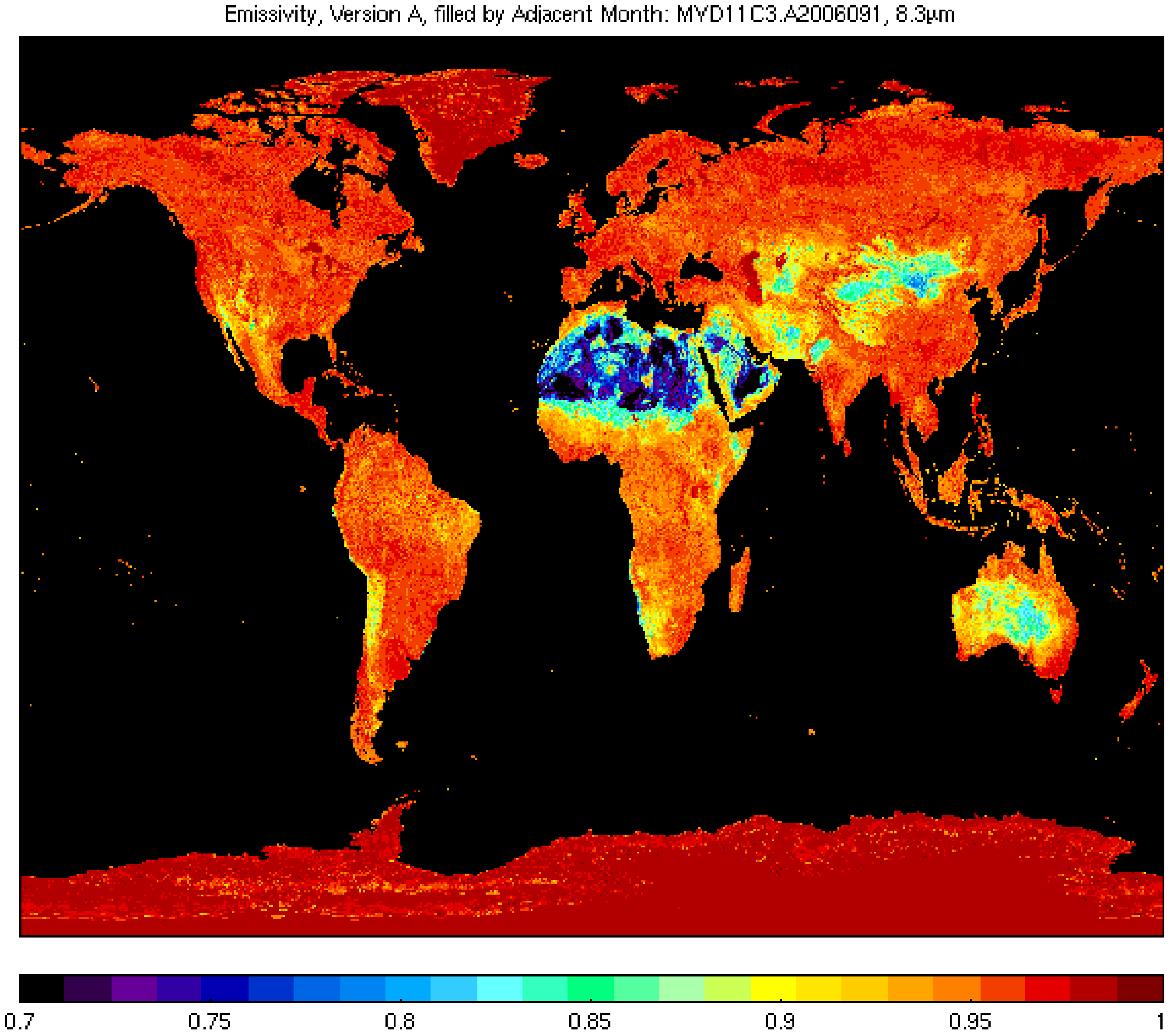
- Use emissivities from database. For example, emissivity from MODIS product
  - » Advantage – monthly global coverage
  - » Disadvantage – at MODIS bands

- Use emissivities from regression (used in test science codes)
  - » Advantage – dynamic emissivities, at SEVIRI bands
  - » Disadvantage – rely on emissivities in training data, might create false diurnal variation in SEVIRI emissivity retrievals

- Use independent retrieved emissivities with time continuity, assume skin temperature is temporally variable and emissivity is temporally invariable
  - » Advantage – avoid false diurnal feature
  - » Disadvantage - algorithm has not been tested, still in concept stage

- Use emissivities from LEO hyperspectral IR radiances – ideal case
  - » Advantage – emissivities can be updated routinely, can be any spectral bands
  - » Disadvantage? Is not immediately available

Emissivities – use pre-determined



e.g., Emissivity database from MODIS

Using radiances from many time steps to retrieve invariable emissivity and variable skin temperatures

$R_{14UTC}(\varepsilon, Ts_1)$

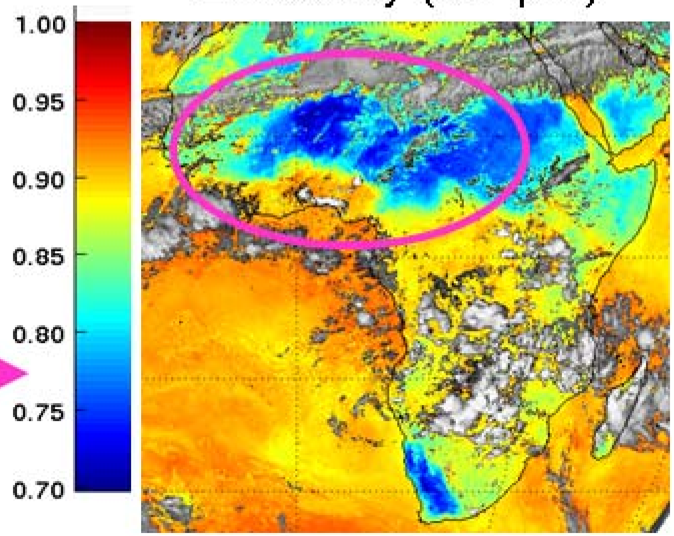
Assuming

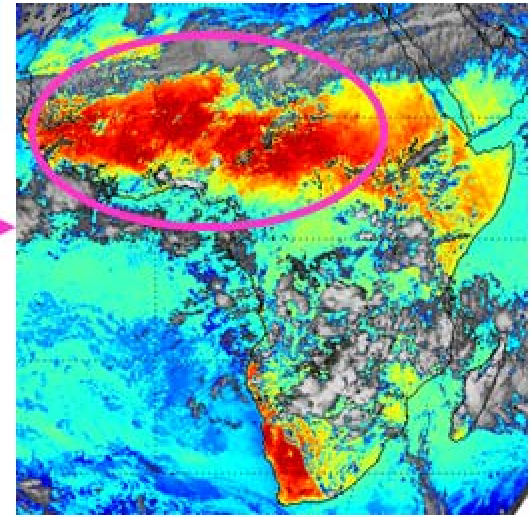
(1) ε is temporally invariable

(2) Ts is temporally variable

$R_{15UTC}(\varepsilon, Ts_2)$

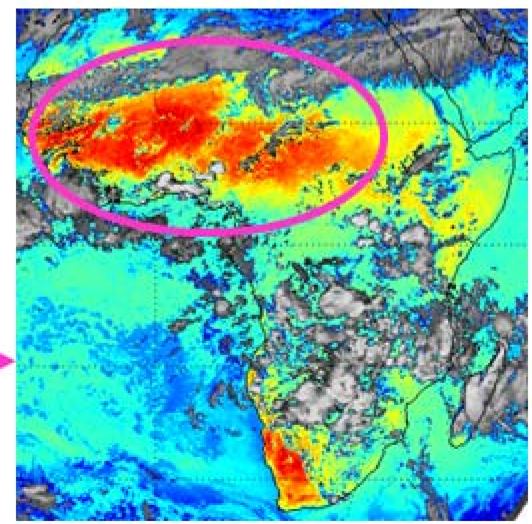
Emissivity (8.7 µm)



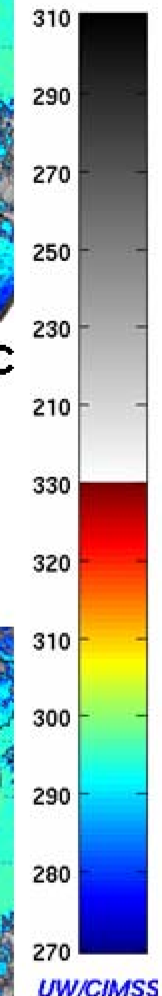


SEVIRI 2006045:**1400UTC**

Skin T decreases dramatically from 14UTC to 15UTC

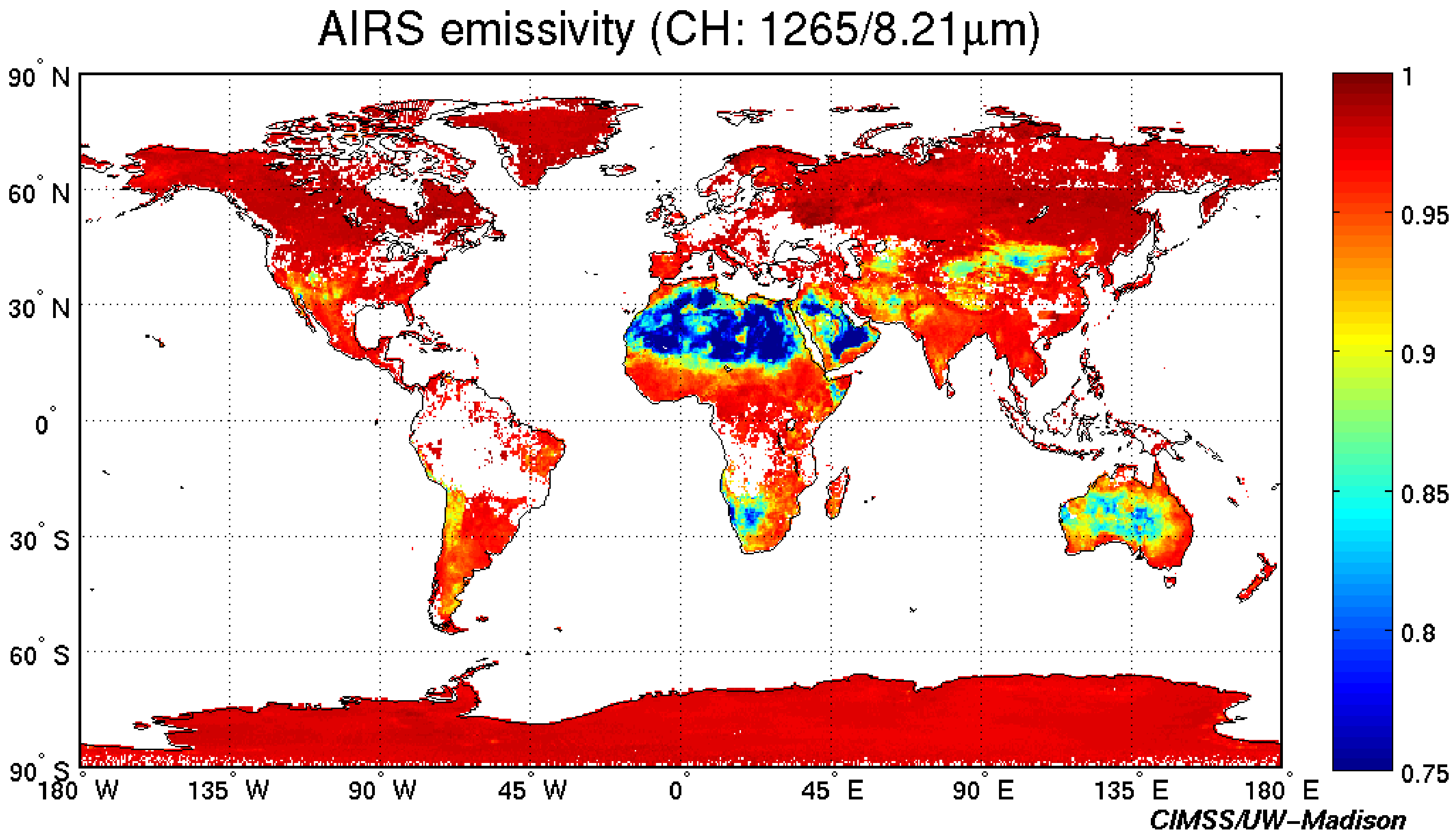


SEVIRI 2006045:**1500UTC**

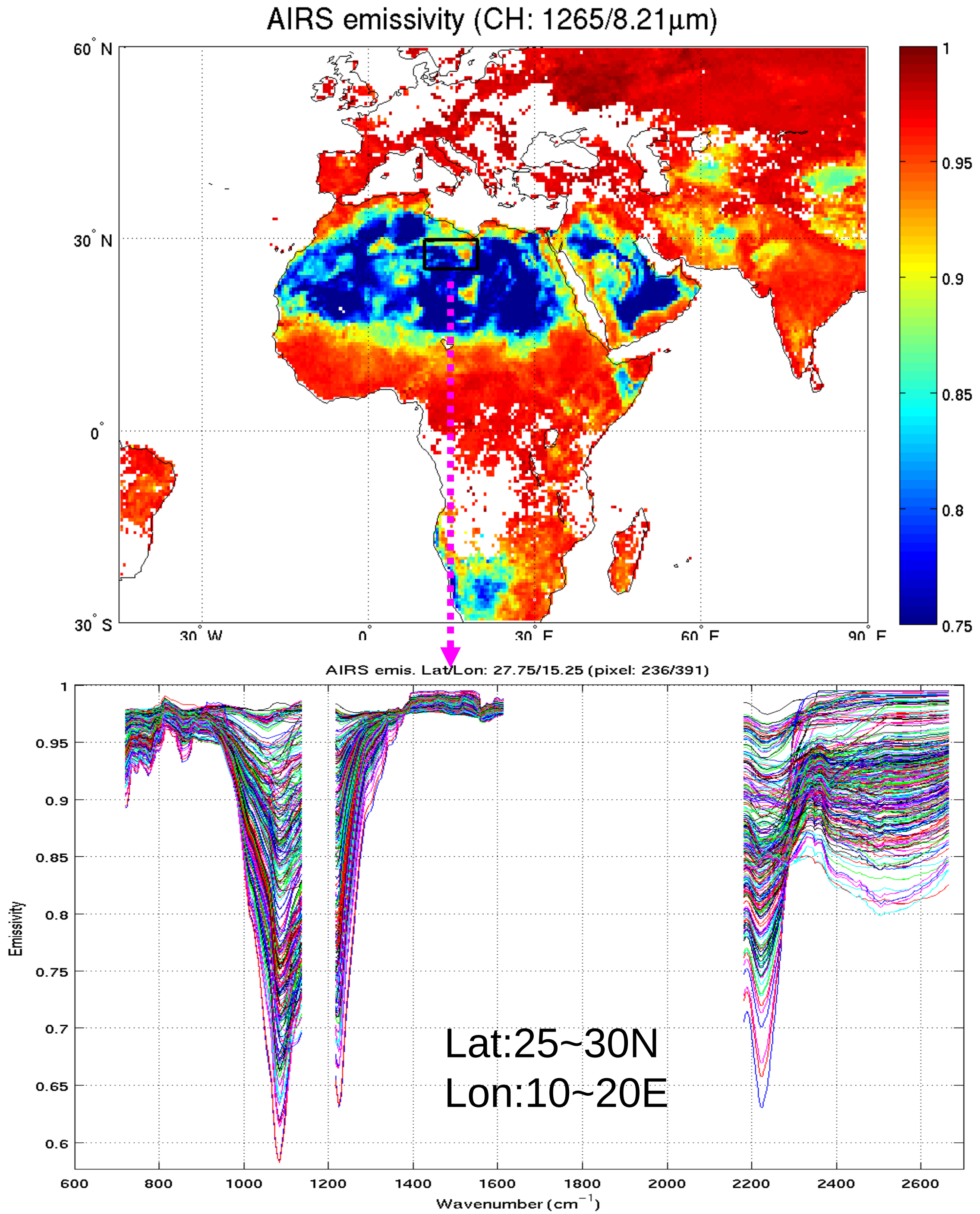


8-day composite of global hyperspectral IR emissivity spectrum from AIRS SFOV clear sky radiances between Jan. 1 and Jan. 8 of 2004 – CIMSS research product

Global AIRS emissivity map – CIMSS research product



Algorithm will also be applied to IASI for global emissivity product


AIRS emissivity (CH: 1265/8.21μm)
60° N
30° N
0°
30° S
30° W
0°
30° E
60° E
90° E
1
0.95
0.9
0.85
0.8
0.75
AIRS emis. Lat/Lon: 27.75/15.25 (pixel: 236/391)
Emissivity
Wavenumber (cm⁻¹)
Lat:25~30N
Lon:10~20E

Recommendation on emissivities

- Use emissivities from IASI, if not
- Use emissivities from database, if not
- Use default emissivities from regression
  - » Impact will be on skin temperature retrieval

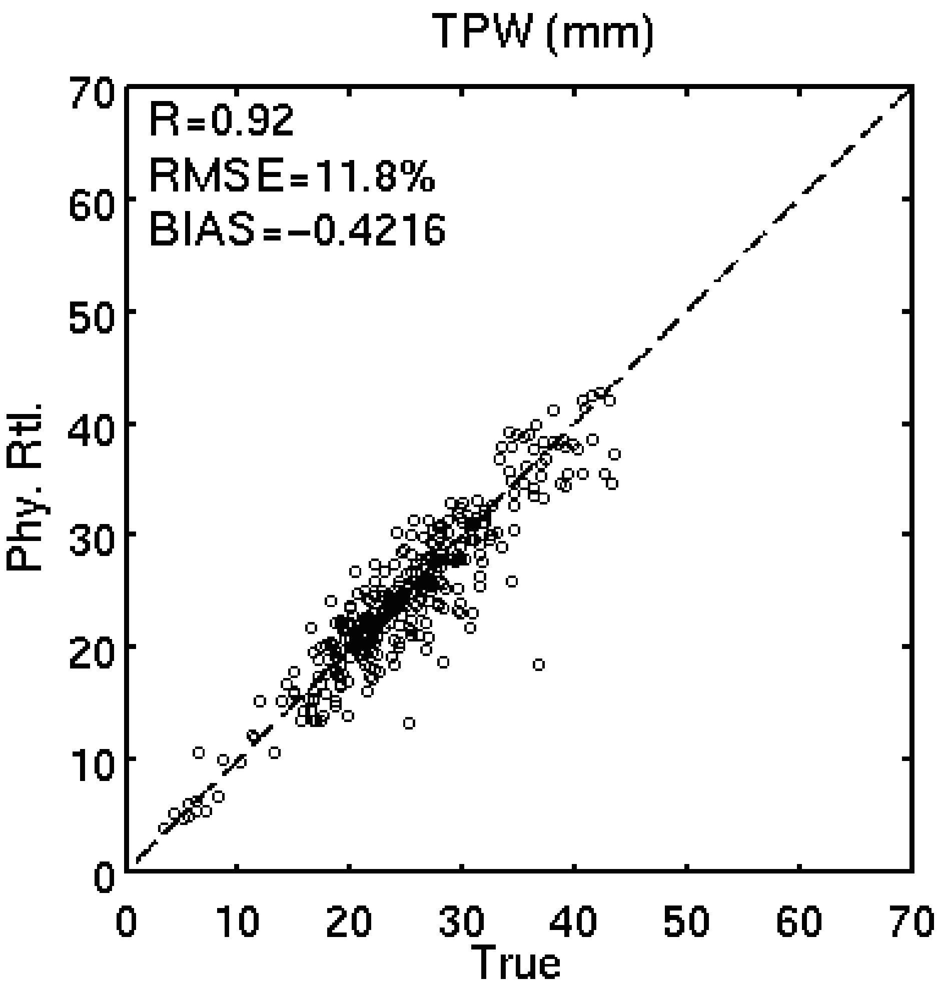
Algorithm evaluation

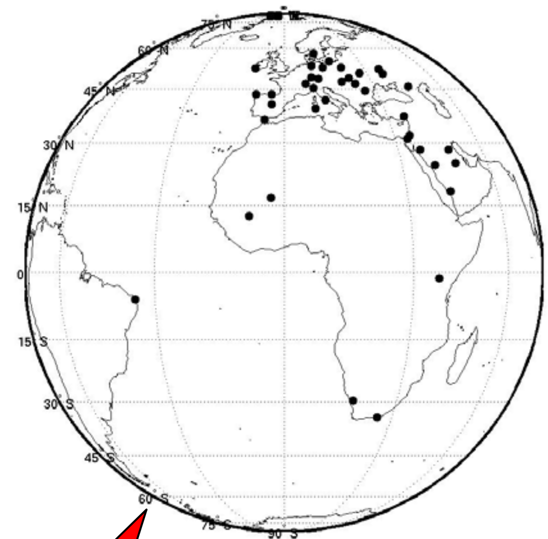
- Science codes have been developed for SEVIRI physical retrieval based on the recommendation, CIMSS PFAAST radiative transfer model is used for algorithm testing
- One month (August 2006)'s collocated SEVIRI and radisondes dataset is used for algorithm evaluation over land
- One month (August 2006)'s collocated SEVIRI and AMSR-E TPW dataset is used for comparison over ocean

Matchup data used for preliminary validation

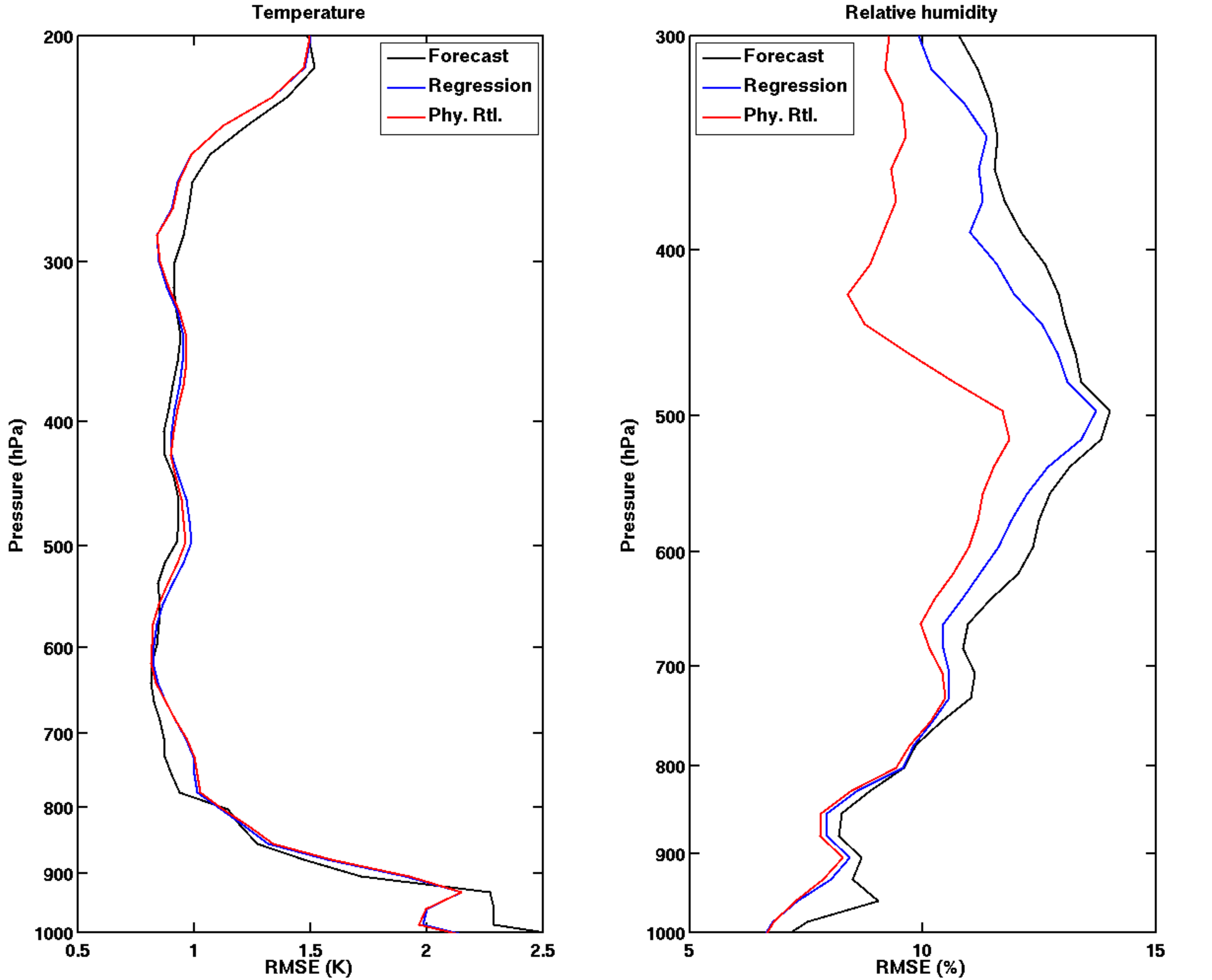
- Matchup data of ECMWF forecast, ECMWF analysis, Radiosondes, and SEVIRI profiles in August 2006 (small sample size)
  - » 6 hour forecast
  - » SEVIRI profiles are from physical retrieval (SEVIRI radiances + forecast)
- Matchup data of AMSR-E and SEVIRI TPW in August 2006 (large sample size)
- Matchup data of ECMWF analysis, ECMWF forecast, and SEVIRI profiles in August 2006 (large sample size)

Products: TPW



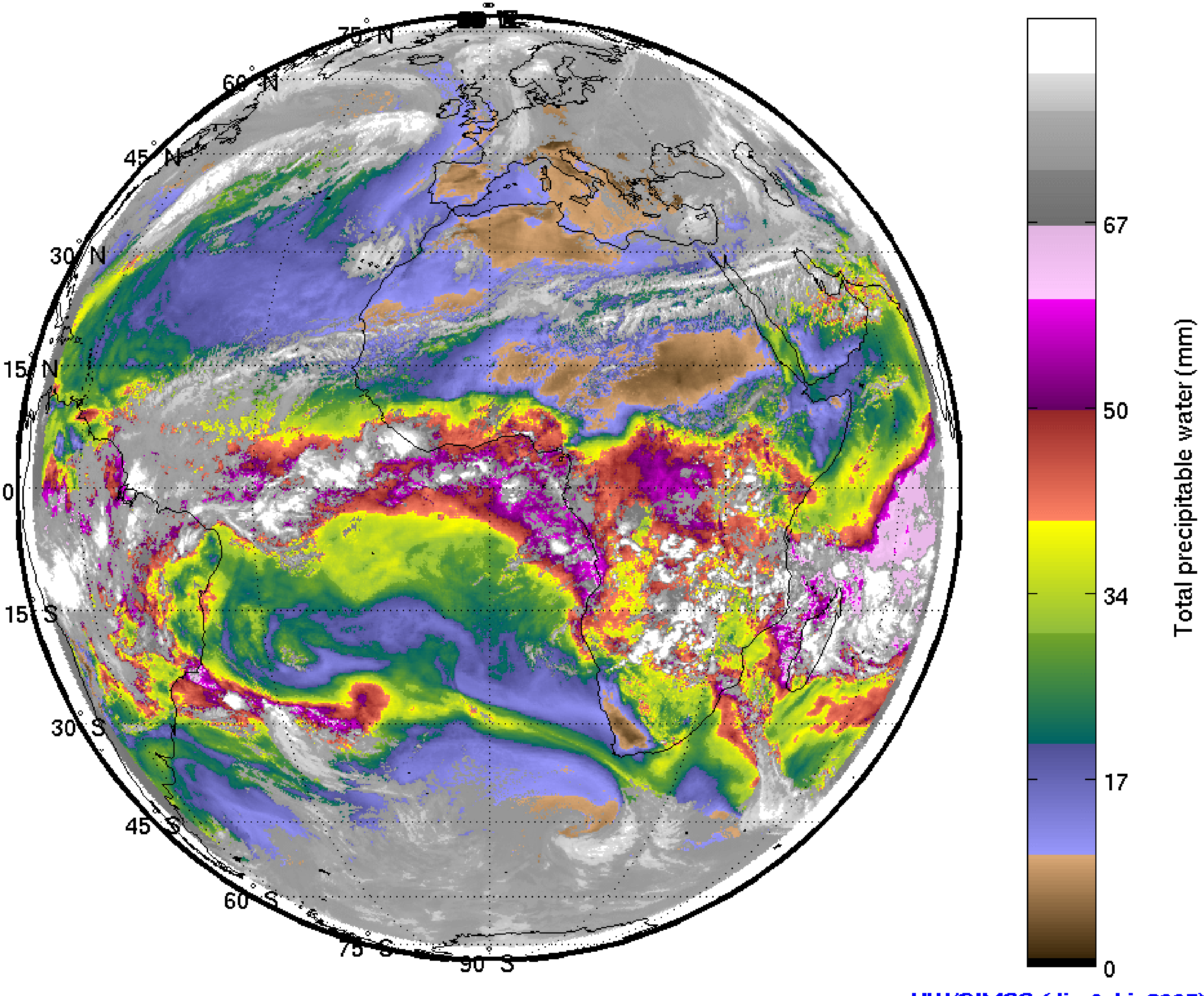


Radiosonde station map (ECMWF analysis profiles at these stations and RAOB times are used as true; 365 samples in August 2006)

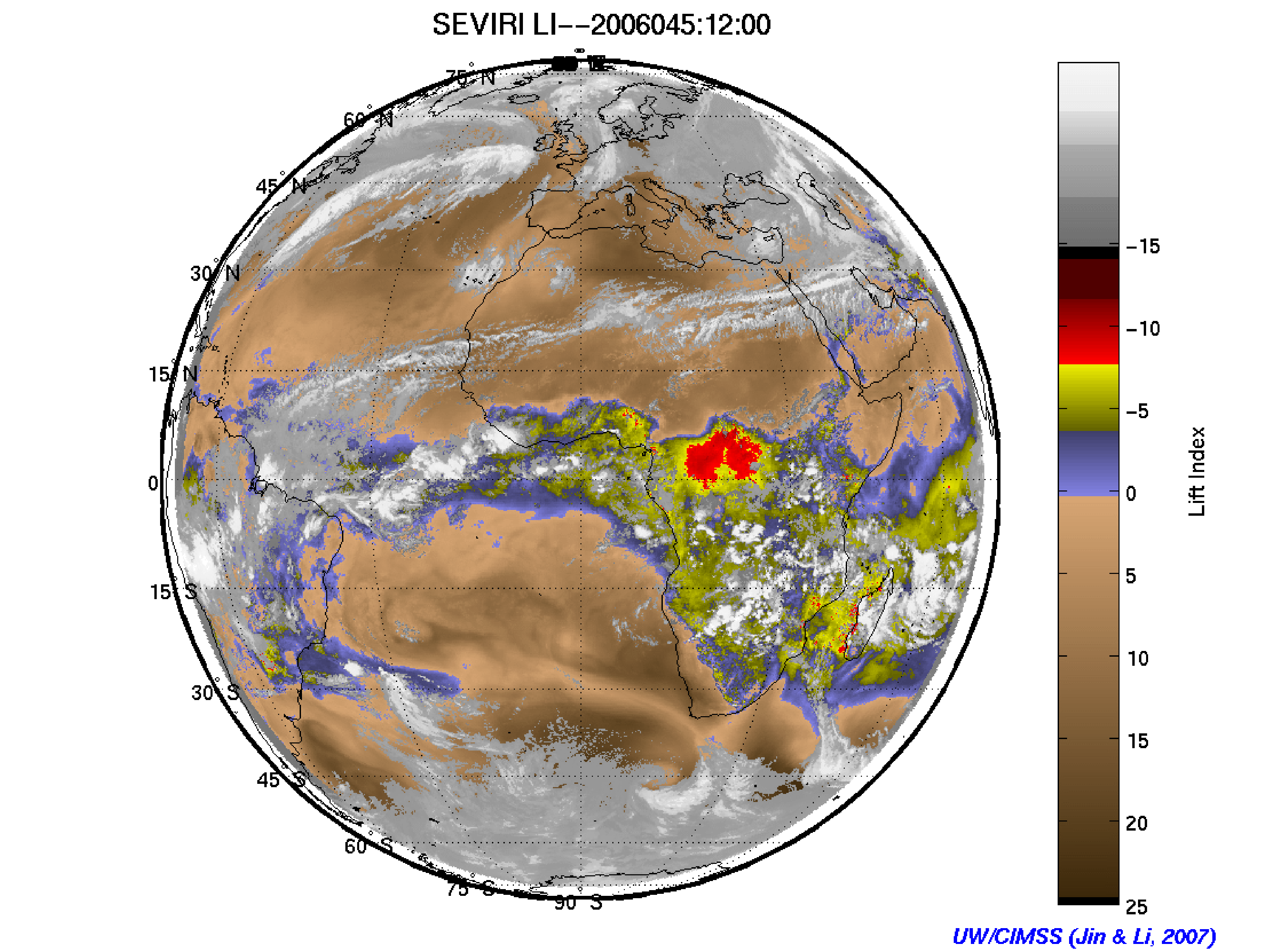


RMSE between SEVIRI profiles and ECMWF analysis at radiosonde sites/times (365 profiles) SEVIRI radiances are bias adjusted

SEVIRI TPW--2006045:12:00



UW/CIMSS (Jin & Li, 2007)

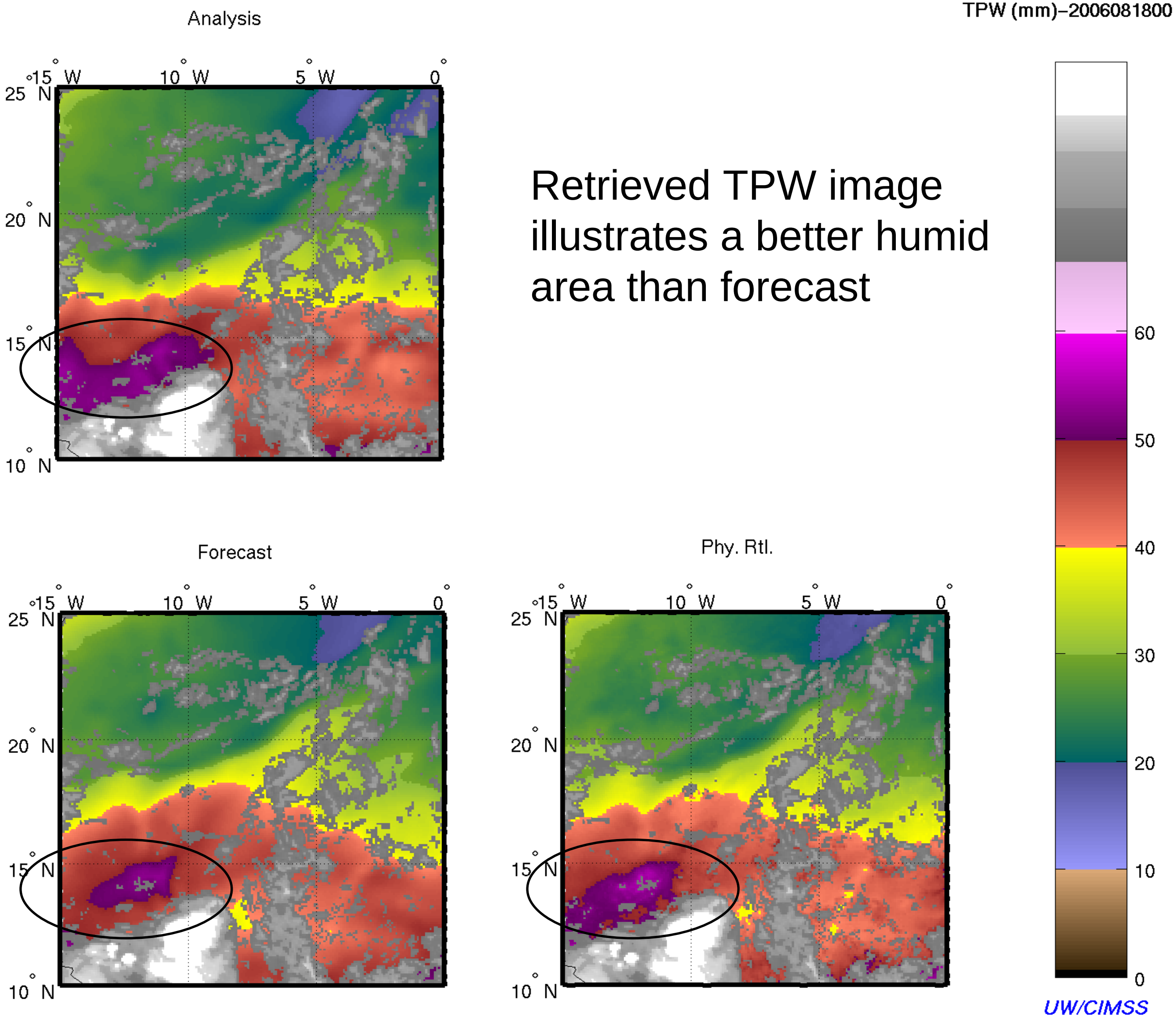


SEVIRI LI--2006045:12:00
75° N
60° N
45° N
30° N
15° N
0
15° S
30° S
45° S
60° S
75° S
90° S
-15
-10
-5
0
5
10
15
20
25
Lift Index
UW/CIMSS (Jin & Li, 2007)

Products: TPW (images)

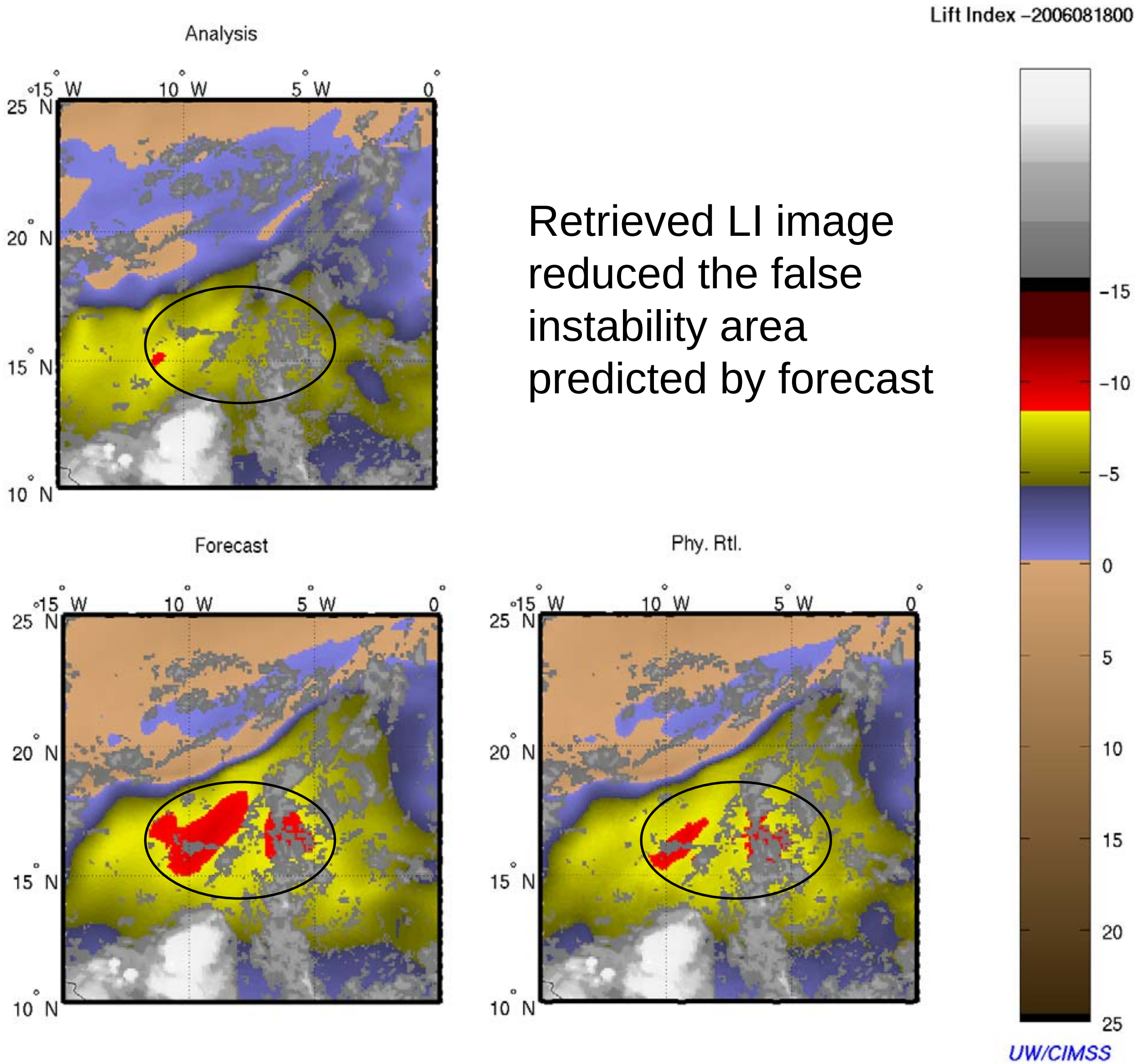
SEVIRI provides good spatial information !

Retrieved TPW image illustrates a better humid area than forecast

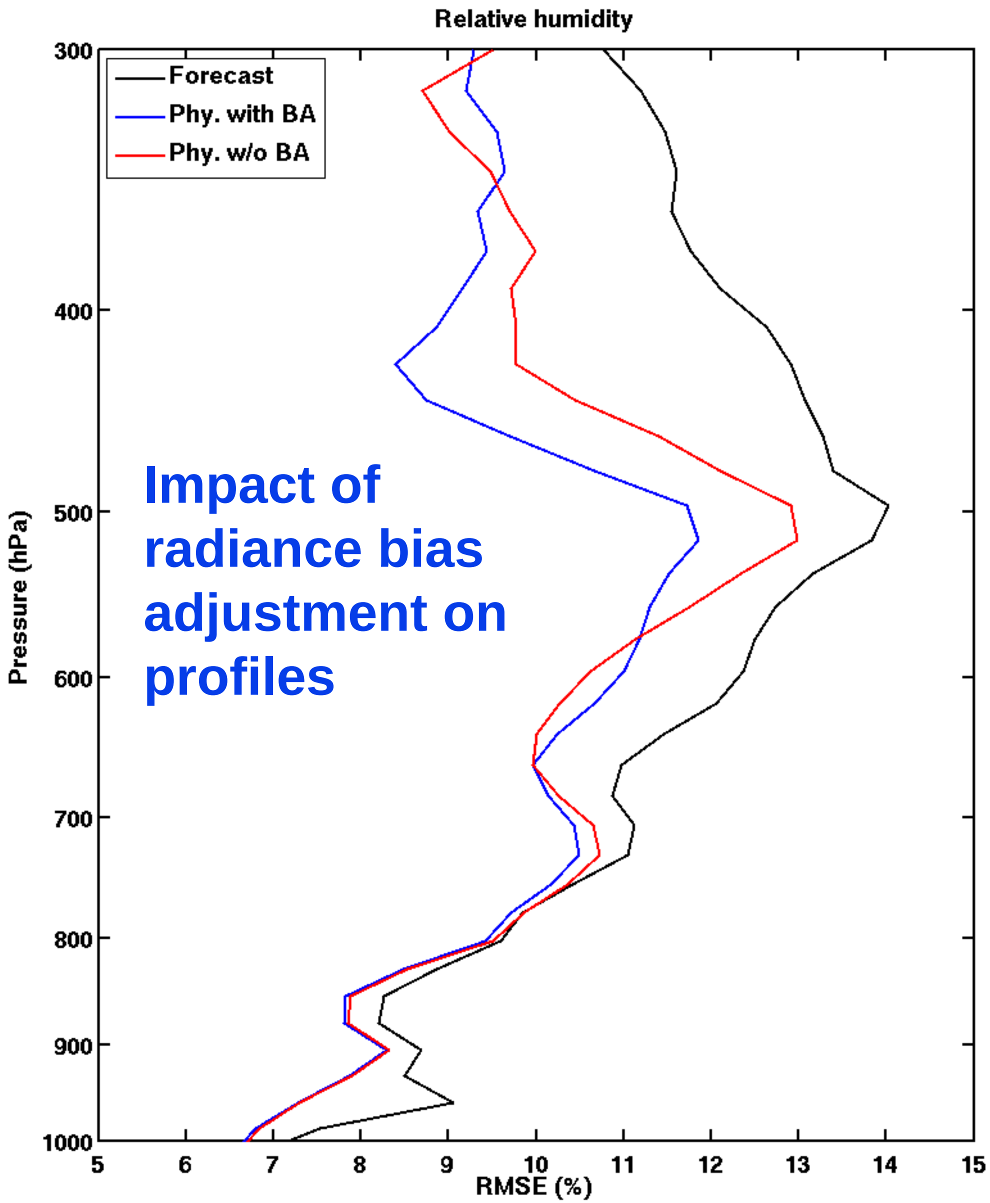


Products: Lifted index (images)

SEVIRI provides good spatial information !



Retrieved LI image reduced the false instability area predicted by forecast



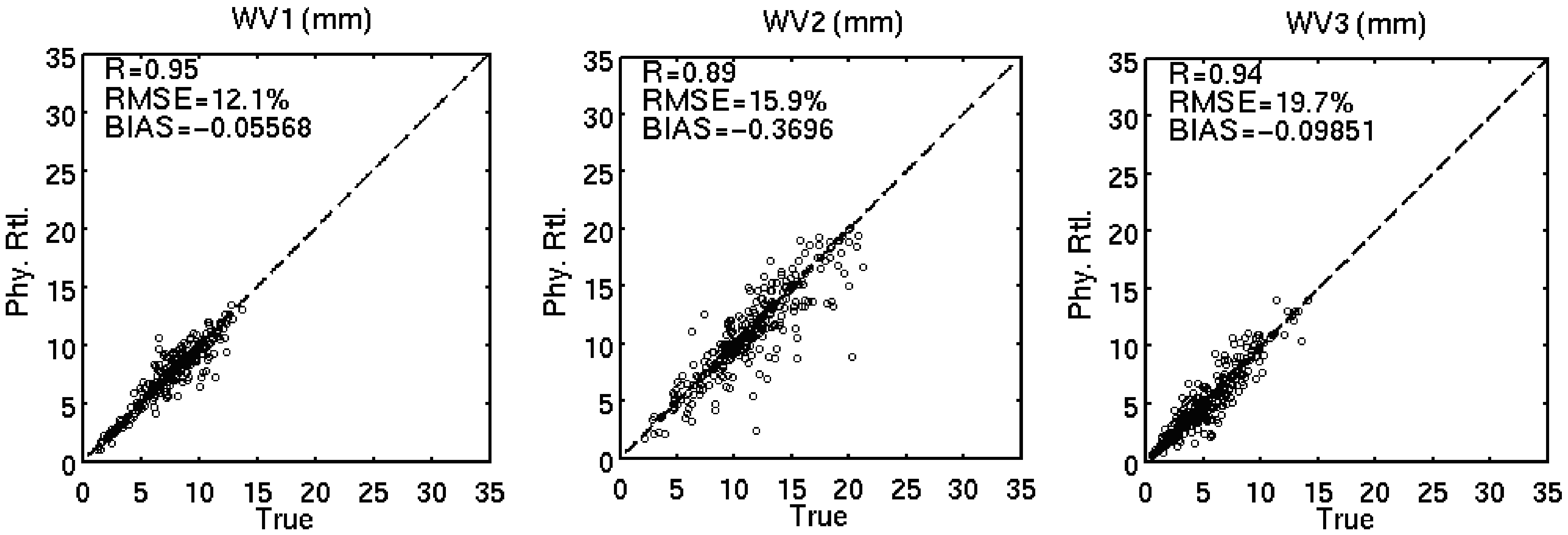
Bias adjustment over ocean is same but should be different ?

RMSE between SEVIRI RH profiles and ECMWF analysis at radiosonde sites/times (365 profiles), impact of radiance bias adjustment

Bias calculation

- Use collocated Radiosondes (or analysis at radiosonde sites) and SEVIRI brightness temperatures
- Use regression derived emissivities or emissivities from data base
- Calculate bias for 13.4 µm, 6.2 µm, and 7.3 µm

Products: WV1, WV2, and WV3



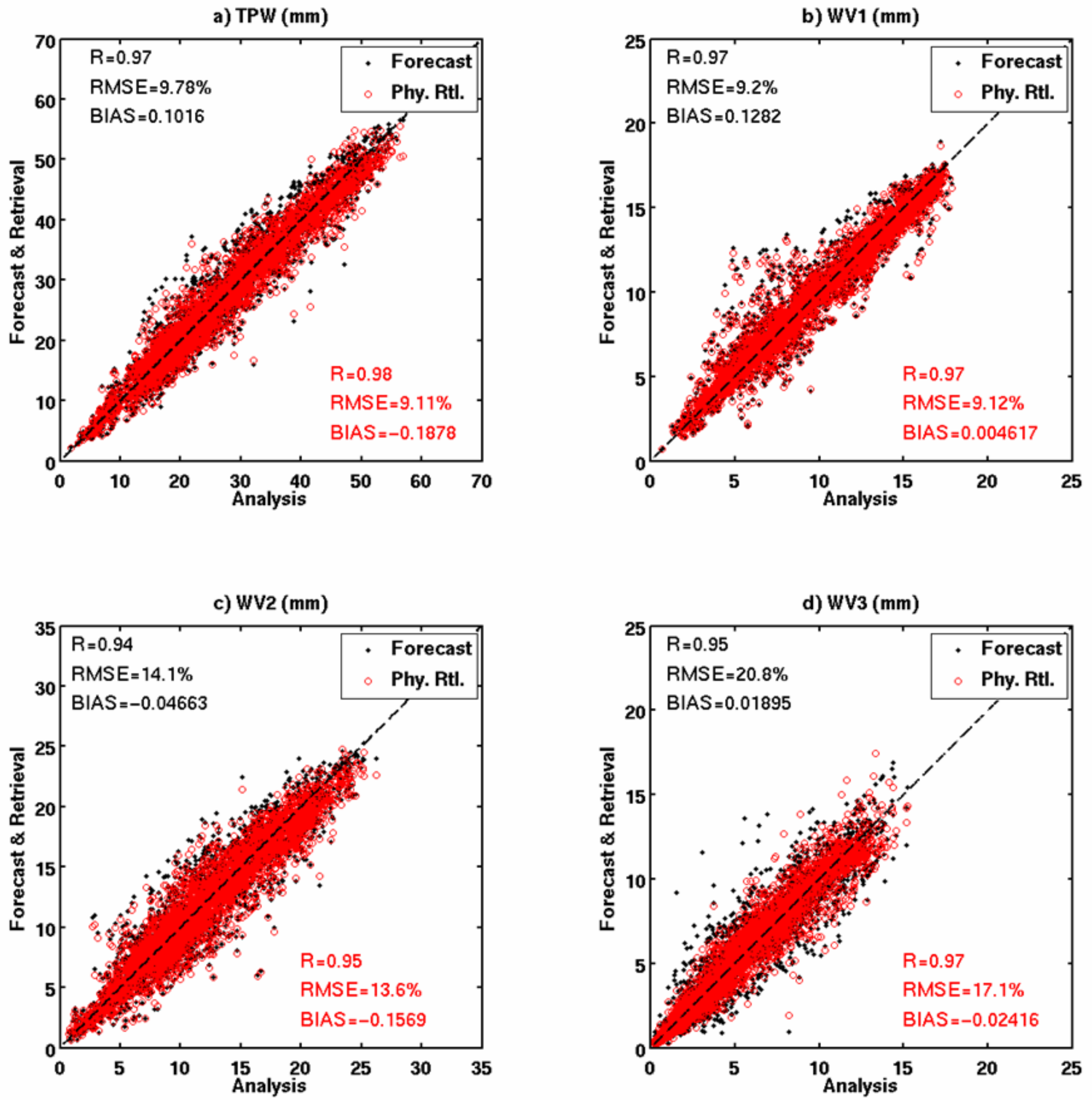
WV1: SFC – 900 hPa

WV2: 900 – 700 hPa

WV3: 700 – 300 hPa

Validation of WV1/WV2/WV3 from SEVIRI physical retrievals compared with ECMWF analysis at radiosonde sites/times over land in August 2006 (365 samples).

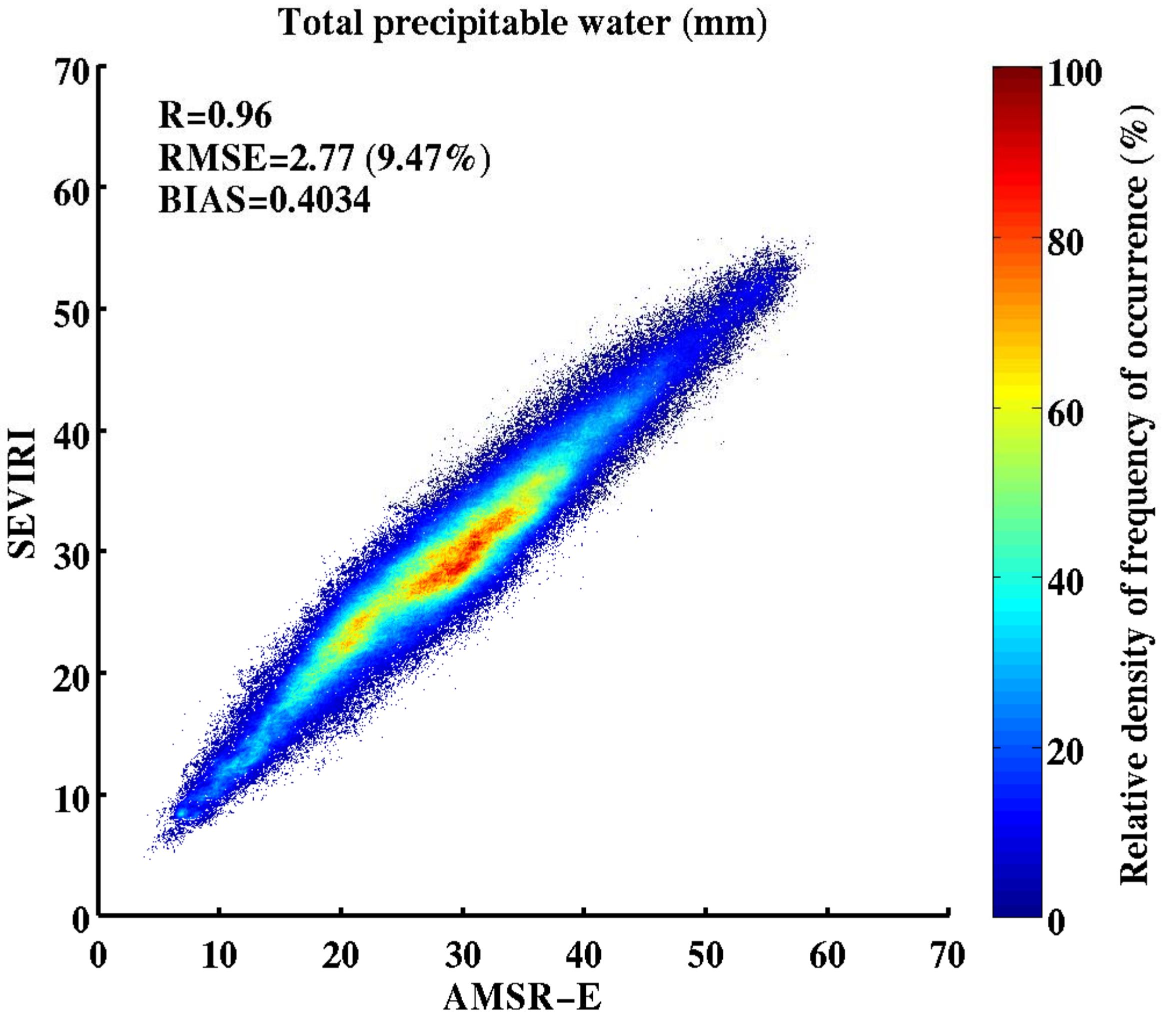
Products: TPW, WV1, WV2, and WV3



Validation of TPW/WV1/WV2/WV3 from SEVIRI physical retrievals against ECMWF analysis in August 2006 (31044 samples which is 1% of all samples).

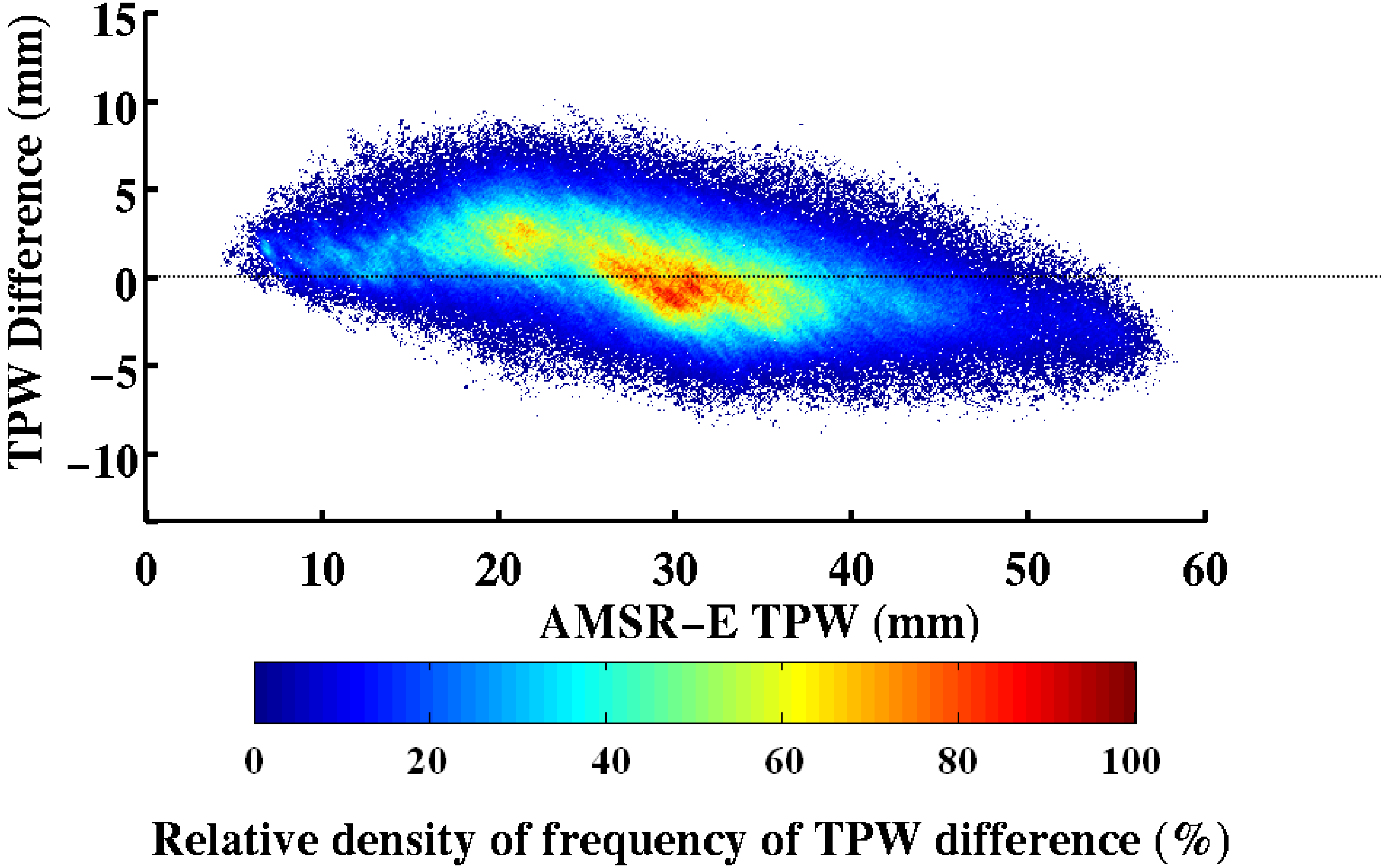
Products: TPW

Temporal dist < 15 minutes
Spatial dist < 10 km



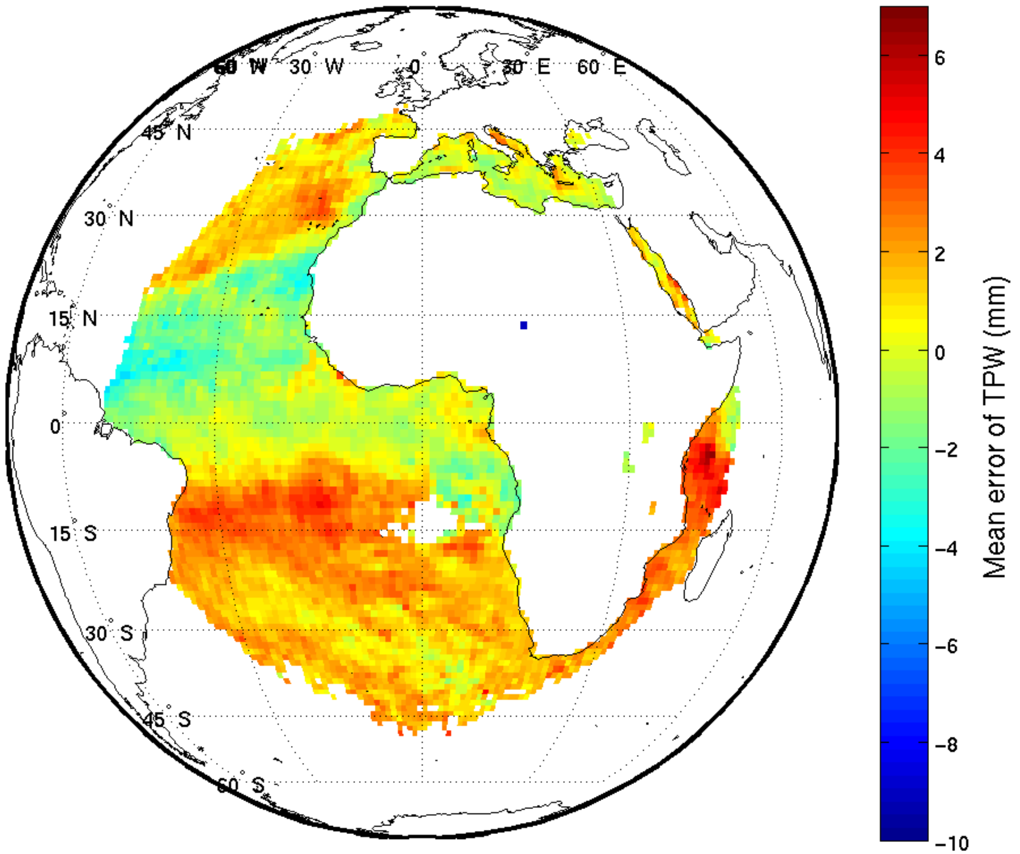
Validation of TPW from physical retrievals compared with TPW from AMSR-E over ocean in August 2006 (2,822,939 samples).

Products: TPW (SEVIRI minus AMSR-E)



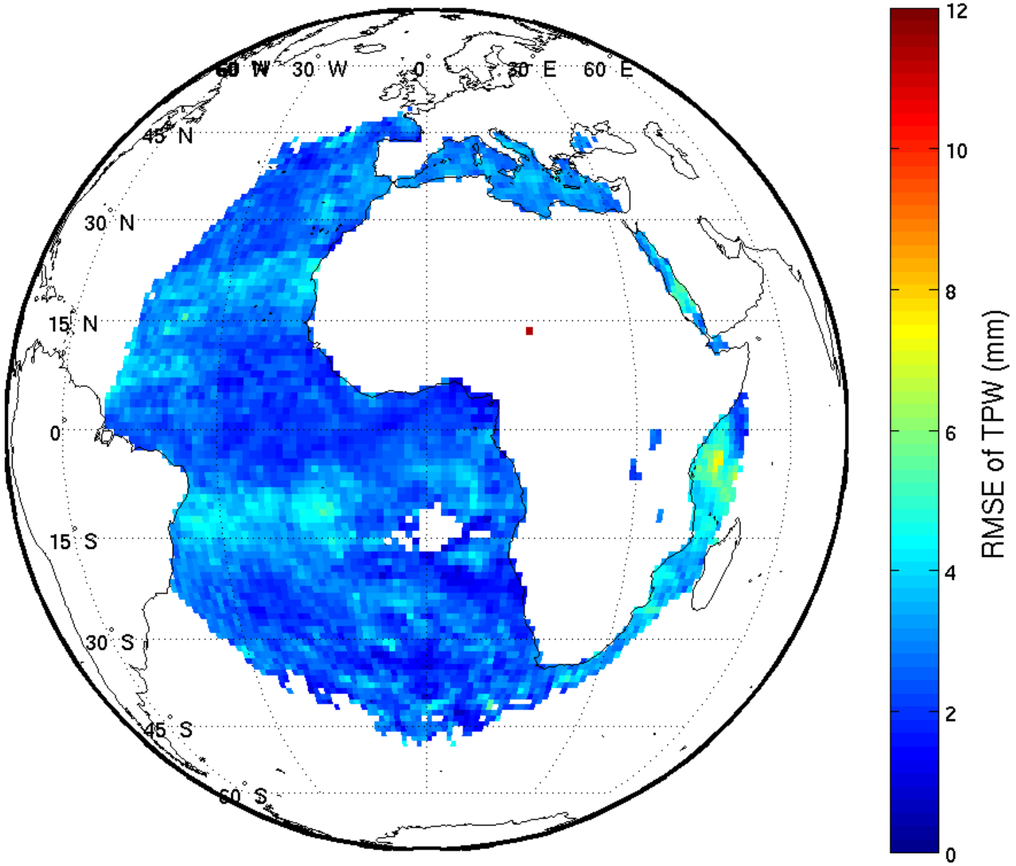
Dry bias when TPW>25mm, same as the comparison between MODIS TPW and MWR at ARM-SGP (Seemann et al, *J. Appl. Meteor.* 2003)

Bias between SEVIRI TPW and AMSR-E (SEVIRI minus AMSR-E)



Mean bias: pixels are grouped into each 1X1 deg. boxes, only boxes with more than 20 samples are considered.

RMSE between SEVIRI TPW and AMSR-E (AMSR-E as true)



RMSE: pixels are grouped into each 1X1 deg. boxes, only boxes with more than 20 samples are considered.

Other notes

- SO2 detection or flag is useful
- In regression, the fixed 6 SEVIRI bands are used
- In physical retrieval, band use is flexible, band use index is input
  - » Over ocean, 6.2 µm, 7.3 µm, 8.7 µm, 10.8 µm, 12 µm, and 13.4 µm shall be used (the 8.7 µm has good boundary layer moisture information but might be affected by dust aerosol)
  - » Over land 6.2 µm, and 7.3 µm, 10.8 µm, 12 µm, and 13.4 µm shall be used
- Forecast profiles (T/Q) should be spatially and temporally interpolated into SEVIRI FOVs
- Use of surface temperature and moisture information
  - » Science codes contain the option of including surface temperature and moisture observations
  - » The surface temperature and moisture observations are treated as two additional spectral bands in physical retrieval

Science codes provided

- ReadMe
- Source codes on radiative tranfer model (PFAAST)
- Source codes on regression
- Source codes on physical retrieval based on recommended algorithm
- Test dataset
- Training dataset

Code examples

------------Main program---------------------------------

- test_run.f main program
- test_run.mk make file
- input.nl namelist
- sampledata.txt sample data file
- ------------Surface layer--------------------------------
- lsurface.f
- ------------Elevation angle for LZA calculation-----------
- elvgeo.f
- ------------Non-linear regression------------------------
- msgind_ges_wTQ.f regression
- satmix.f
- eswat.f
- ------------Physical retrieval---------------------------
- seviri_phy_profile_EOF.f Physical retrieval
- eof_T_W_profile101.f load eigen vectors
- anoise.f generate normal-distribution random number based on a given expectation and standard deviation
- urand.f uniform random number generator
- brit_metsg.f convert radiance into brightness temperature
- dbdt_metsg.f Calculate partial R / partial BT
- msgtbbw.f calculate brightness temperature
- pfcometsg101.f Input MSG Planck-function and band-correction coefficients
- plan_metsg.f get radiance from brightness temperatures
- re4flip.f byte-flipping tool
- sbflip.f Single precision byte flipper
- tranmetsg101.f calculate vertical transmittance
- deltau.f transmittance difference profile
- getwq0.f get the weighting function of atmospheric component
- jcb_seviri.f T/W/O3/Ts weighting function calculation
- rtvsolx.f perform the iteration
- symvrt.f invert symmetric matrix
- ------------Total precipitable water---------------------
- tprecw.f

Dataset examples

/ancillary_data/: All ancillary binary data files are stored here:

- noaa88bevte101: EV of temperature profile
- noaa88bevwv56: EV of moisture profile
- ev_seviri_emis.bin: EV of surface emissivity
- training_db.bin: Training database
- RC_msg1_9km_15min_6ch.bin: Regression coefficient
- Generated by *regcoef_msg_TQprof*
- The following files are for atmospheric
- transmittance calculation by the RTE model
- metsecgenbnd.dat
- metsecgendry.dat
- metsecgenozo.dat
- metsecgenwco.dat
- metsecgenwtl.dat
- metsecgenwts.dat

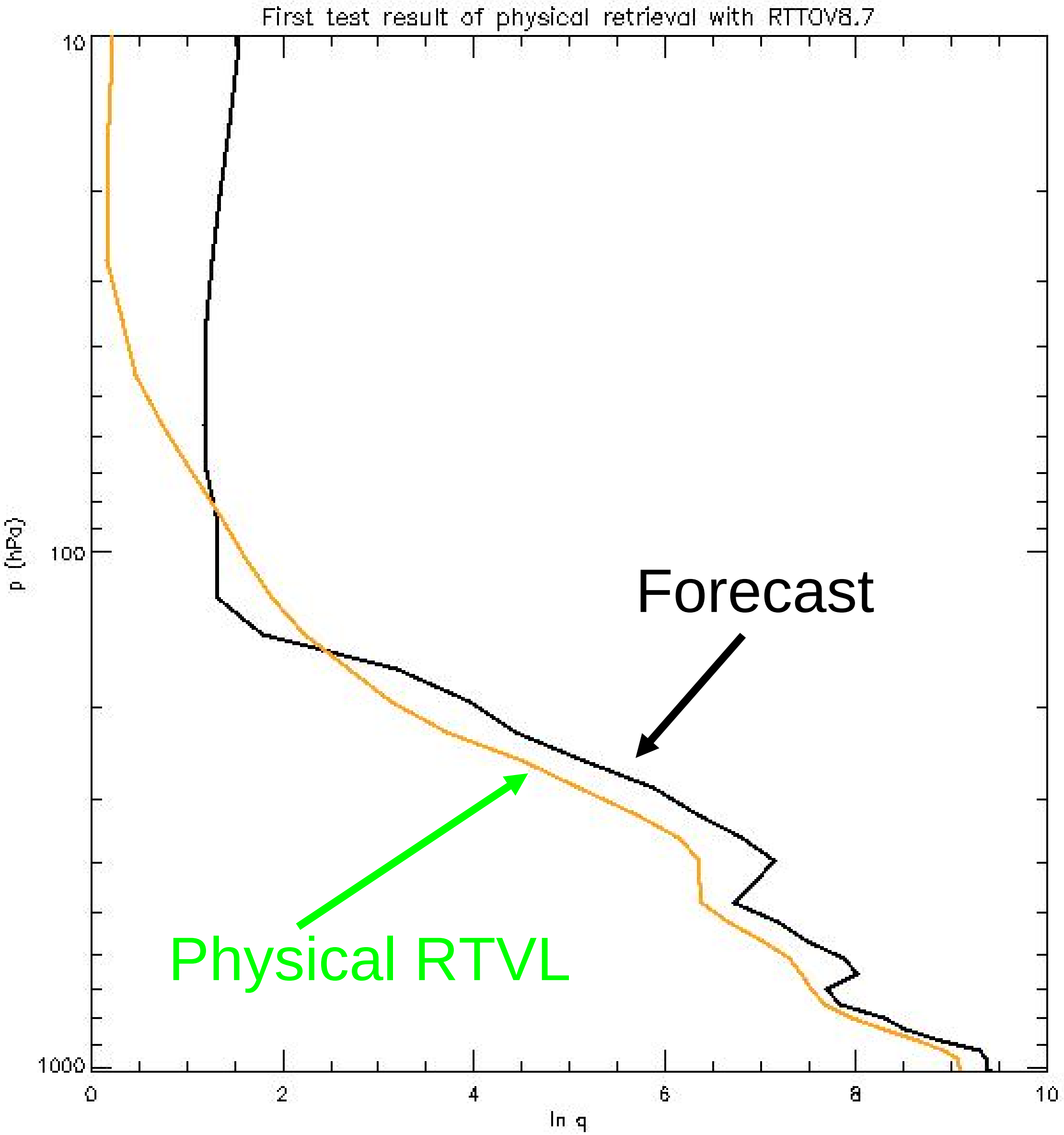
Computer system requirement

- The program is written in FORTRAN 77 language and compiled by the Intel FORTRAN 9.1 complier under a LINUX environment. All ancillary data files, if binary, are big-endian. Since the program processes the full disk data pixel by pixel, it does not require a very large memory but it does need a fast CPU and a large hard disk.
- Note that to speed up the calculation, some ancillary variables, such as the local zenith angle, surface emissivities, and etc, can be loaded from independent datasets if available.
- The physical retrieval procedure takes minutes for one full disk at a Dell computer with Linux.

Current status (by end of Nov. 2007) on science codes

- Codes with PFAAST RTA go through the compile and test at INM sun workstation.
- Regression has been changed to 43 levels
- EOFs have been computed based on 43 levels
- Physical retrieval codes have been modified to RTTOV8.7 and 43 pressure levels
- The physical codes with RTTOV8.7 are tested successfully with single SEVIRI pixel, the codes will be optimized for regional data test.

First physical retrieval result with RTTOV8.7 !



Retrieval made on 27 November 2007

(Figure from Miguel Miguel A. Martinez)

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Summary

- Physical algorithms for SEVIRI clear sky parameters have been evaluated, recommendation has been made on algorithm selection for SEVIRI nowcasting product
- Final report has been provided
- Science codes have been provided
- Science codes has gone through testing at INM