Emissivity Focus Group Report

Coordinator: Chris Barnet

NOAA/NESDIS/STAR

Mar. 8, 2006

AIRS Science Team Meeting

Walter Wolf: Near Real Time Processing & Gridding System
Lihang Zhou: Emissivity Regression Retrieval
Eric Maddy: Cloud Clearing Error Estimates.
Xingpin Liu: Re-processing
Fengying Sun: AIRS derived emissivity maps
Murty Divakarla: MODIS emissivity & AVN wind assessment.

Emissivity Team

Chris Barnet, NOAA	John LeMarshall, JCSDA
John Blaisdell, GSFC	Jean Luc Moncet, AER
Evan Fishbein, JPL	Nick Nalli, NOAA
Scott Hannon, UMBC	Joel Susskind, GSFC
Simon Hook, JPL	Jennifer Wei, NOAA
Fricky Keita, GSFC	Lihang Zhou, NOAA
Bob Kunteson, U. Wisc	

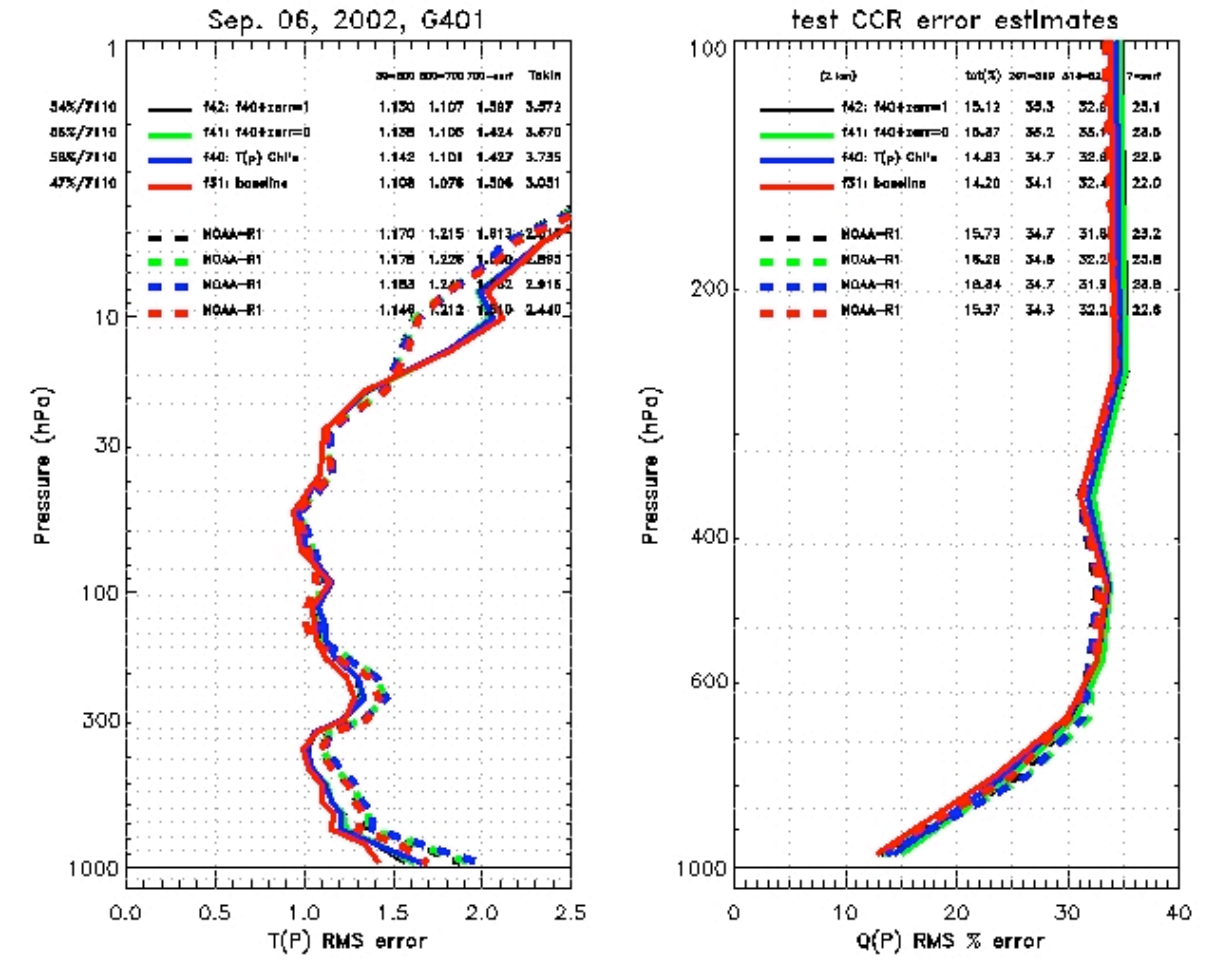
Recent Activities at NOAA

- Test alternative cloud clearing channel concepts.
- Install MODIS MDY11 product and test utility as
  - An emissivity first guess
  - Use estimate of emissivity variance as error term in retrieval of eta (CCR)
  - Stand alone emissivity product (*i.e.*, do NOT solve for emissivity w/ AIRS)
- Build an emissivity climatology from monthly averaged AIRS spectral emissivity on "easy" cases.
- Used AVN wind speed to improve Wu/Masuda emissivity first guess
  - Discussed at Sep. 27, 2005 ASTM & Jan. 17, 2006 Net Meeting
  - Improved retrieval of SST & BL T(p) but improvement was not significant enough to warrant ingestion of AVN model into our system.
- Evaluated specular form of down-welling thermal radiation (emissivity only)
  - Discussed at Sep. 27, 2005 ASTM & Jan. 17, 2006 Net Meeting
  - Degraded SST, Impact on SST was larger than expected.
  - Need to evaluate effect on transmittance model - TBD

Past Activities at NOAA

- Evaluate Physical Methods (Mar. 5, 2005 ASTM)
  - Fixed emissivity at Christenson frequency
  - Singular Value Decomposition (SVD) Methods
    - With and without simultaneous skin temperature
    - 2, 5, 15, and 16 functions for emissivity
  - On/off-line method (Bob Knuteson) for Tskin
  - LSQ for emissivity at 5, 15, 16 functions. Each one is determined independently (*i.e.*, without damping or grouping of functions).
- Most robust & stable system at this time is a 4 or 5 function system using SVD.
  - GSFC needs to evaluate and make recommendations.

Changing CCR Channels has impact on Statistics



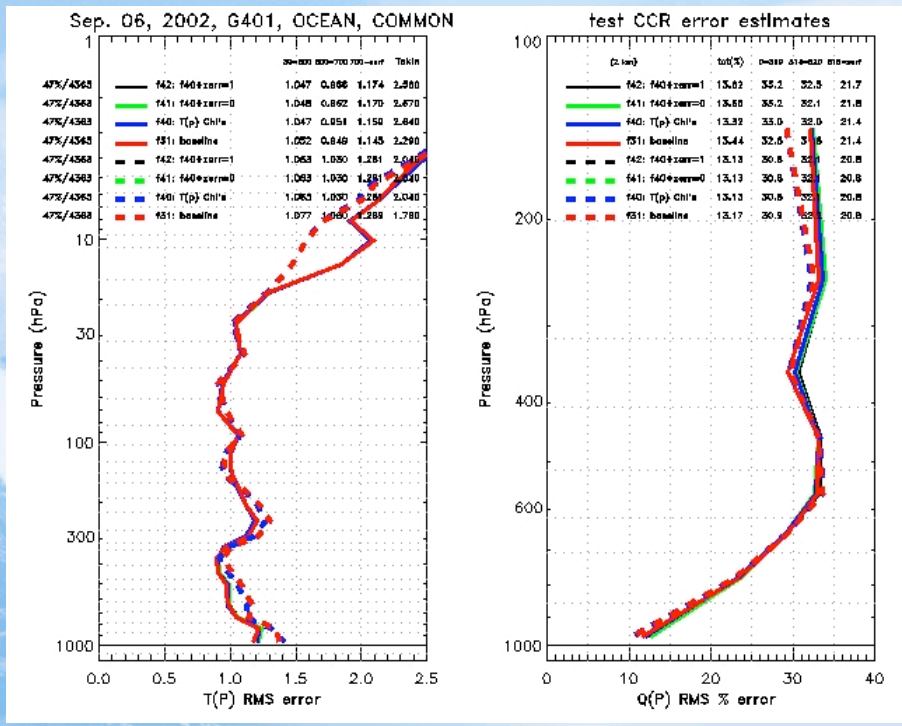
RED: v4.7 w/ v4.0 CCR channels

Blue: v4.7 w/ T(p) channels used in CCR (no window channels)

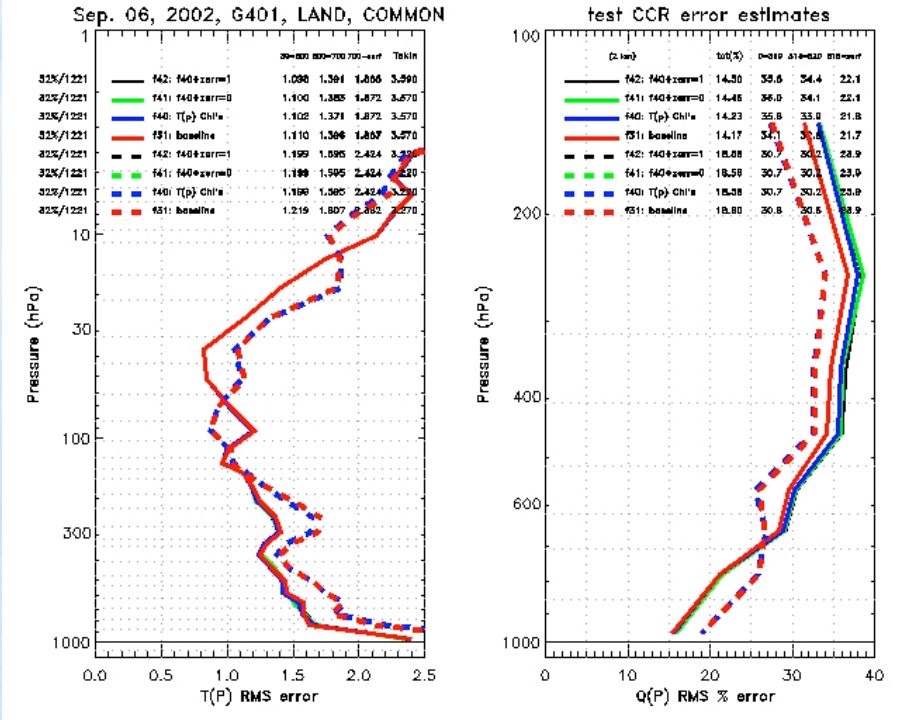
Green & Black (different error estimate methods)

But impact is negligible on a common accepted set

Ocean Cases



Land Cases

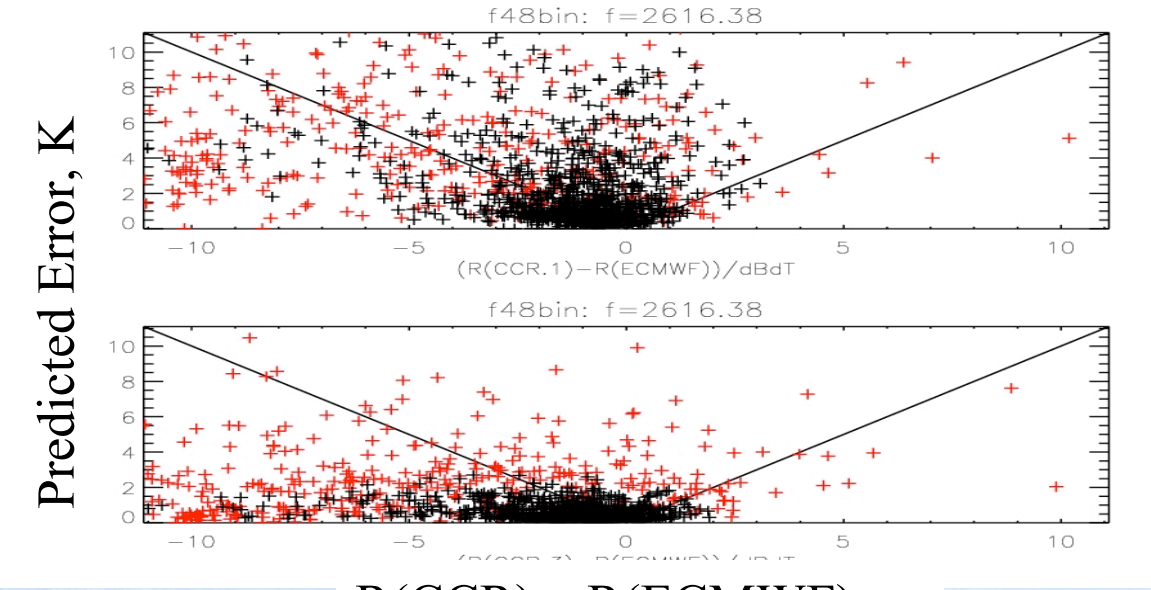


Internal Error Estimate of CCR's Predicted vs R(CCR)-R(ECMWF)

Ocean, lat ≤ 50

Accepted

Rejected



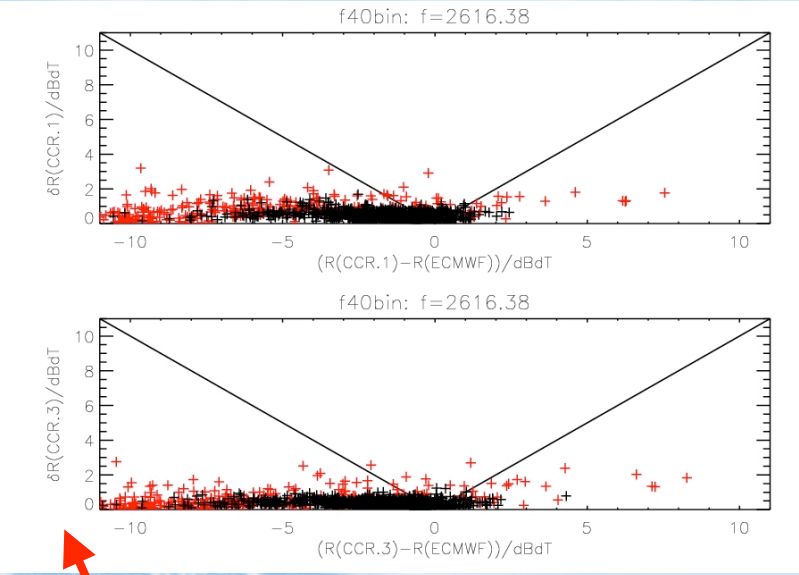
First CCR

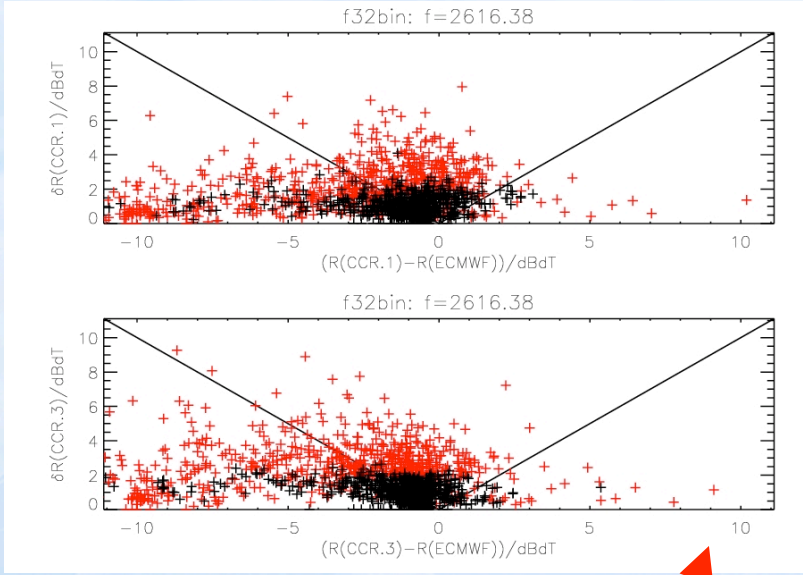
FINAL CCR (#3)

R(CCR) – R(ECMWF)

- V4.x (w/ v4.0 CCR channels) has
  - a lot of variability in error estimate, but not much skill
  - Skill diminished between first and final cloud clearing
  - Ensemble mean error is good on CCR #1
  - Real error (horizontal axis) is probably dominated by cloud contamination.

Changing CCR Channels Requires Understanding Internal Error Estimates





- Using T(p) sounding channels (*i.e.*, no window channels)
  - Has little predictive capability (can't estimate errors due to low clouds)
- Adding *a-priori* error estimate (from CCR radiance co-variance) improves estimate

Selecting CCR channels

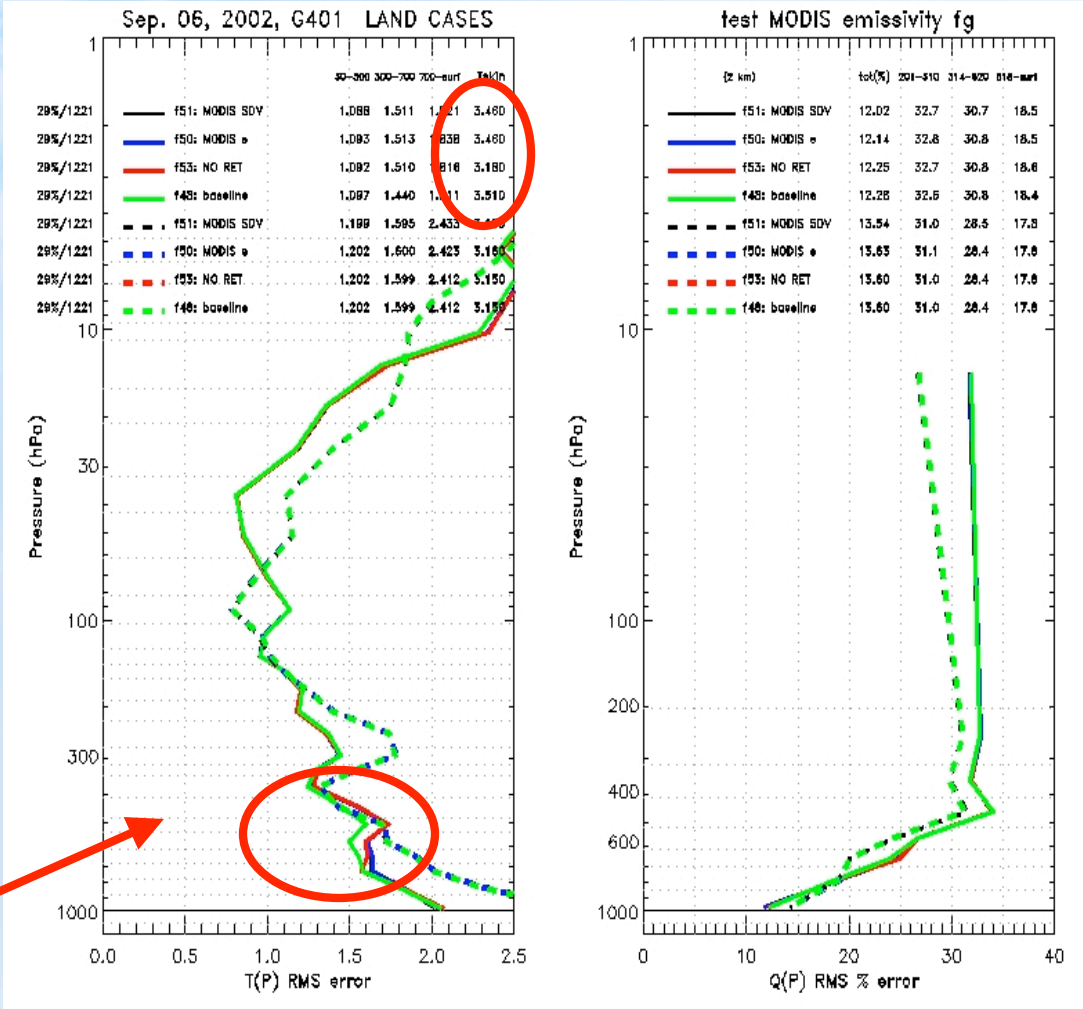
- PGE Methodology needs an estimate of low cloud errors.
  - Window channels are necessary to estimate the error in the CCR's.
    - These are the only channels that sense <u>all</u> clouds.
    - Window channels do not have to be used in the computation of eta, but they have to be part of the error estimate (residual) calculation.
  - The CCR error estimate of eta drives A_{eff}, one of the parameters that has the most skill in determining good/bad cases.
    - Changing channels dramatically changes rejection thesholds.
    - Changing channels dramatically changes down-stream error covariance matrices.
- Channel selection must consider the entire system.

Experiments w/ MODIS MDY11

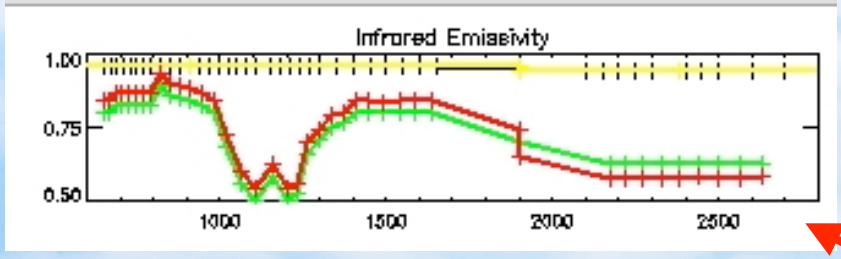
- Baseline Run: all v5.0 except
  - emissivity limit
  - v40 CCR channels
- ε RET's OFF: use 0.96/0.94 for all land
- ε RET's OFF: Use MODIS ε fg for land
- ε RET's OFF: Use MODIS ε & σ(ε)

- - - - - - - - - - - -

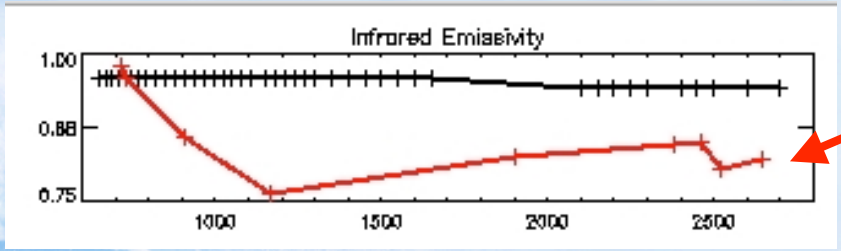
- NO Significant Difference in STAT's



Why Doesn't MODIS help?



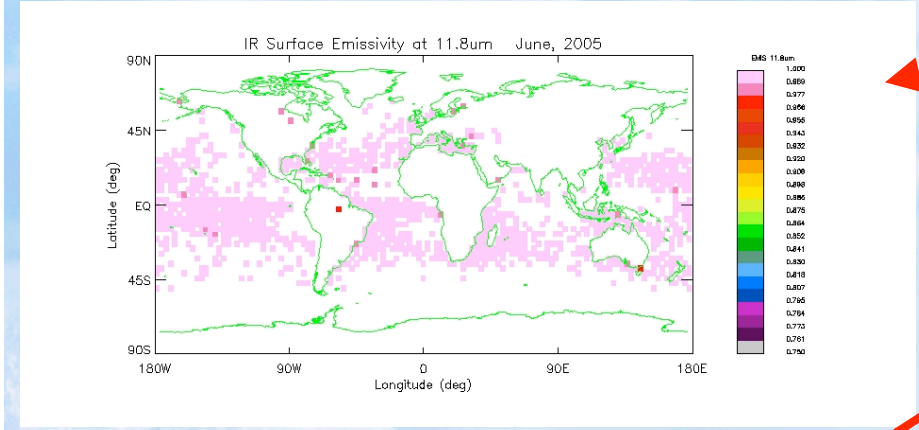
AIRS v5 Regression has significant spectral structure



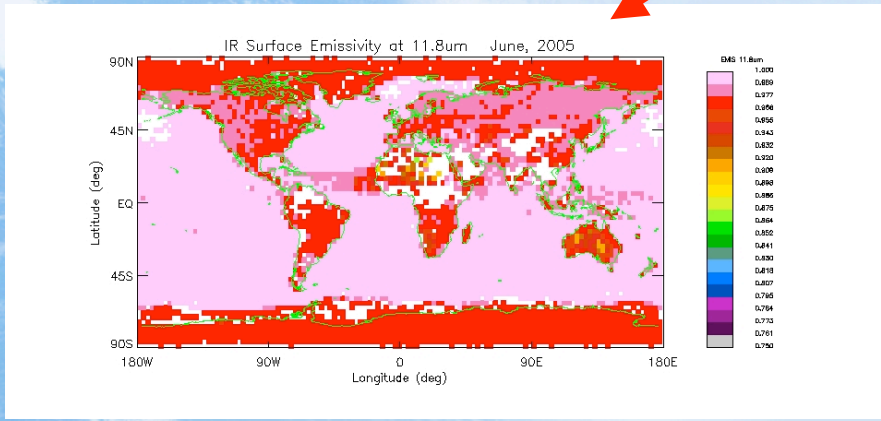
MODIS emissivity does not

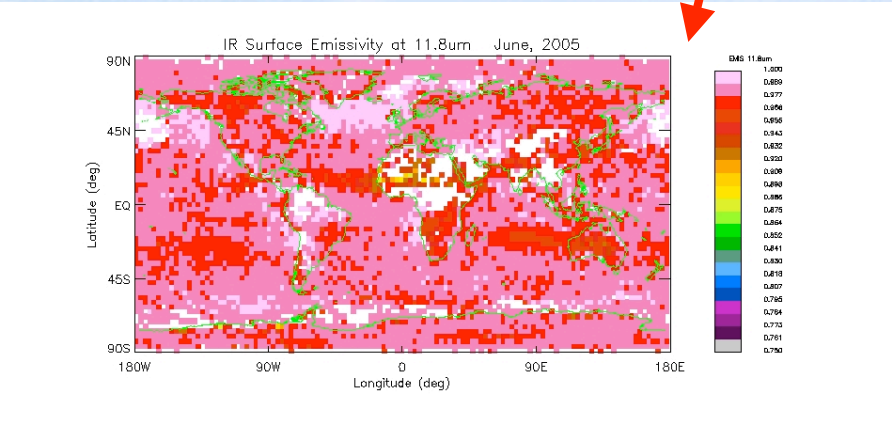
- Lack of impact on retrieval products over land, especially T_{skin} statistics implies that other errors (*e.g.*, CCR?) dominate.
- Until we fix cloud contamination and/or cloud clearing/emissivity interaction the emissivity retrieval methods cannot succeed.

AIRS derived monthly emissivity climatology from 3x3° grids: 11.8 um (850 cm^{-1})

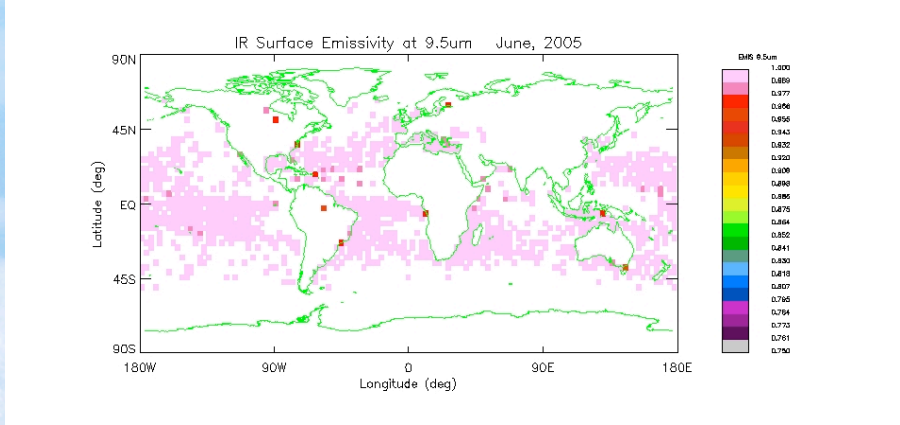


- Clear land scenes are rare (GSFC & UMBC implementation of Georges)
- need to implement a better (George's latest) clear flag over land
- Regression estimate with "easy" clouds (A ≤ 1) [obvious dust contamination]
- Physical emissivity seems to be impacted cloud contamination.





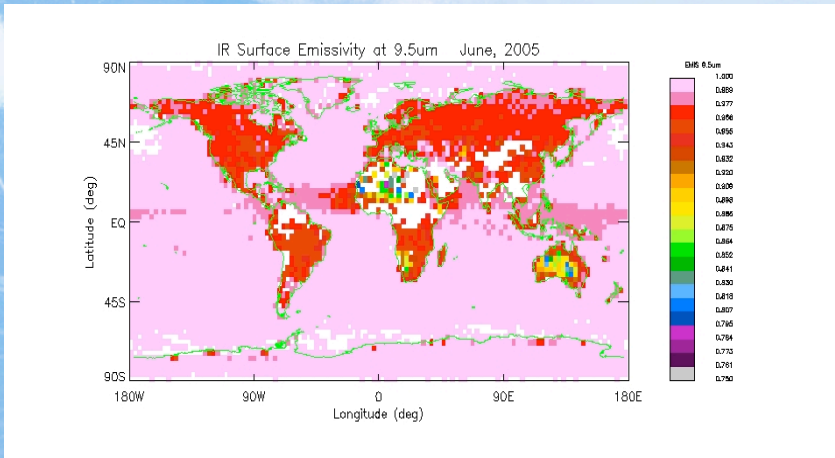
Ditto for 9.5 μm (1050 cm^{-1})

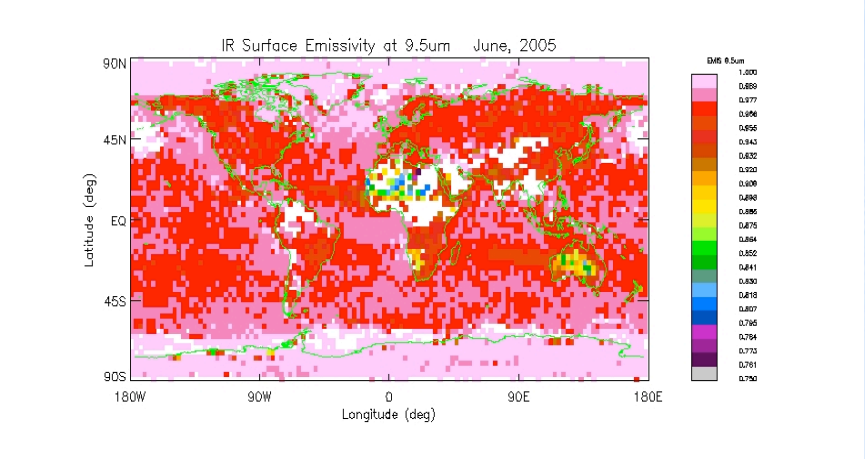


So: This is a good idea but it needs more work.

Our plans are to:

1. Install George's CLEAR flag for land
2. Fix CCR channels
3. Try other physical emissivity approaches (later in talk).



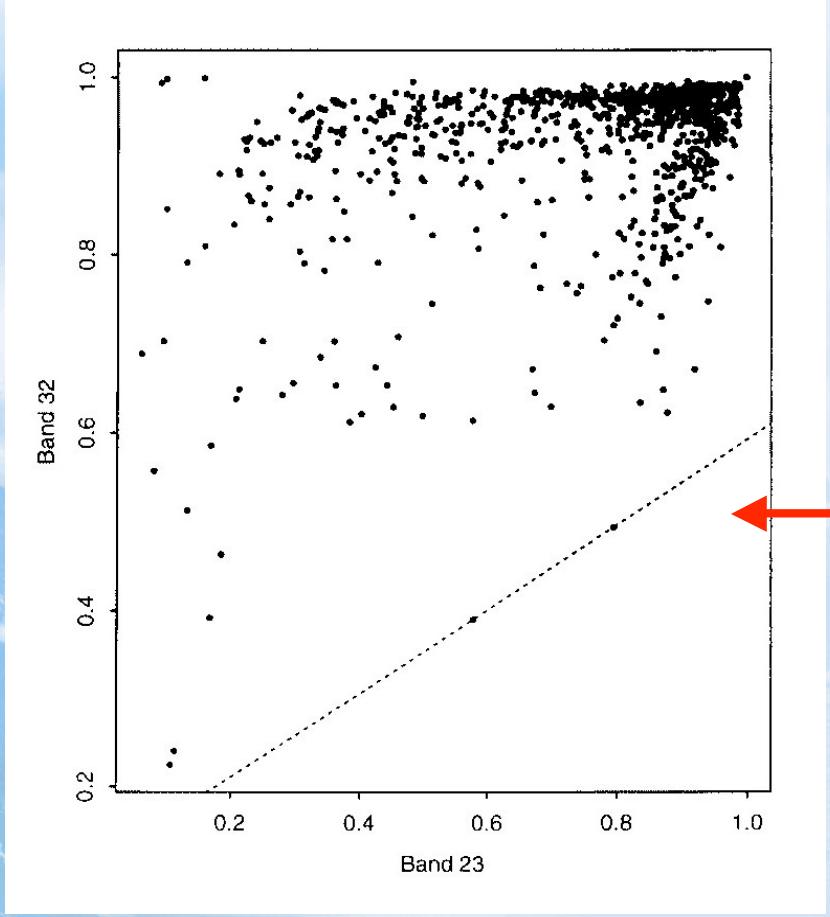


V5 upgrades to regression emissivity

- At this time (v4.0 system) the regression is defining the spectral emissivity shape.
  - Regression with better training is installed.
  - Explored using a separate desert regression
    - Not a significant improvement.
    - Not recommending for v5.0
  - Evaluate using more LW channels and some SW channels
    - At this time using SW channels degrades regression overall.- need to understand why…

Use of SW is a serious issue

4 µm

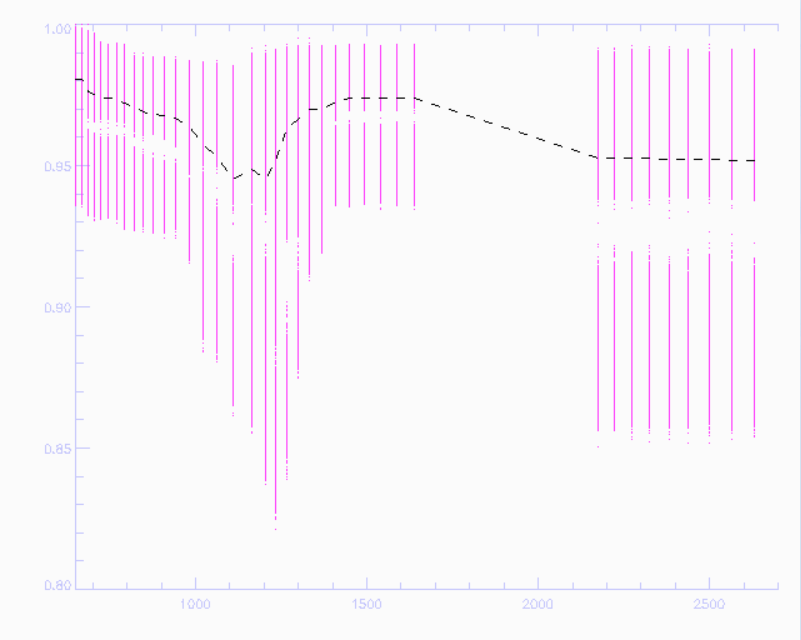


12 µm

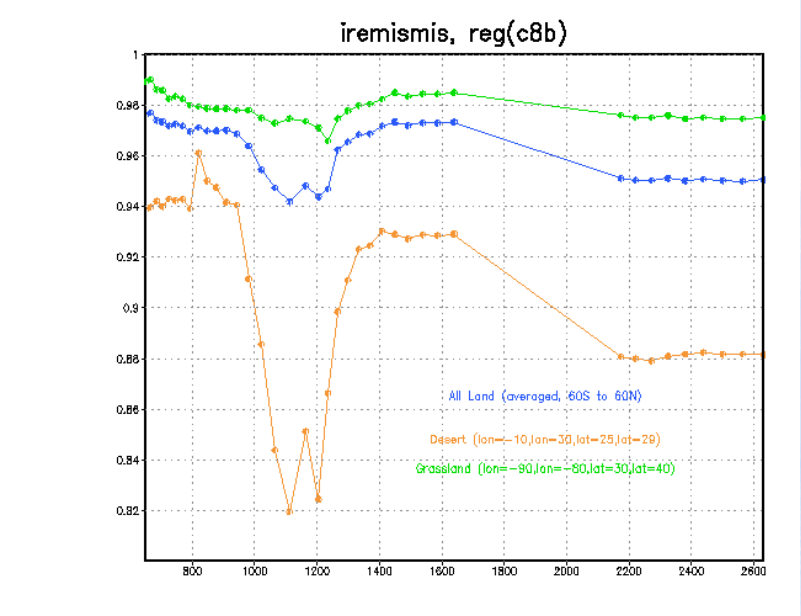
- We have added SW channels; however, solar contamination (and/or cloud contamination) causes problems
- We do not expect LW/SW correlations to be robust
  - ASTER Constraint (Liang, 2001, TGARS v.30, p.268)
- We will work on this and hopefully have a upgrade before v5.0 door closes.

Non-frozen land cases

Training ensemble

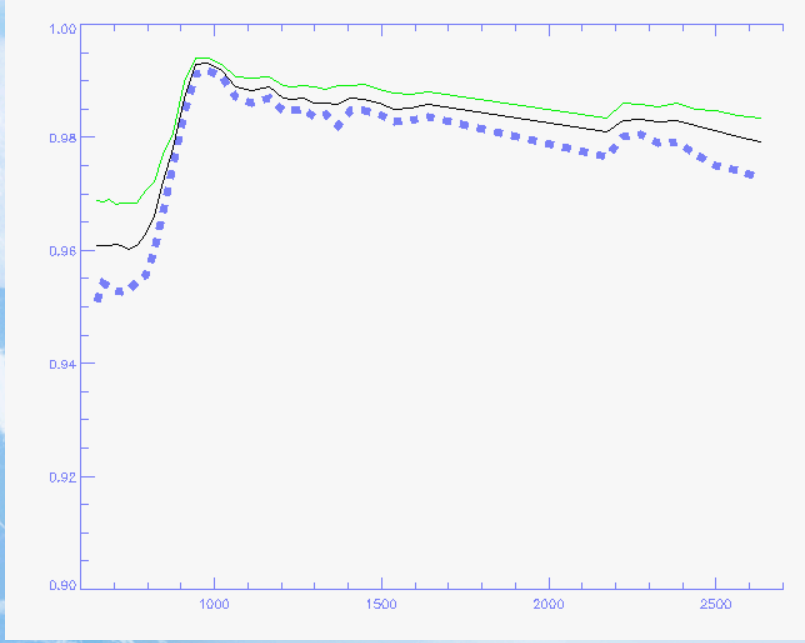


Retrieval over land (9/6/02)

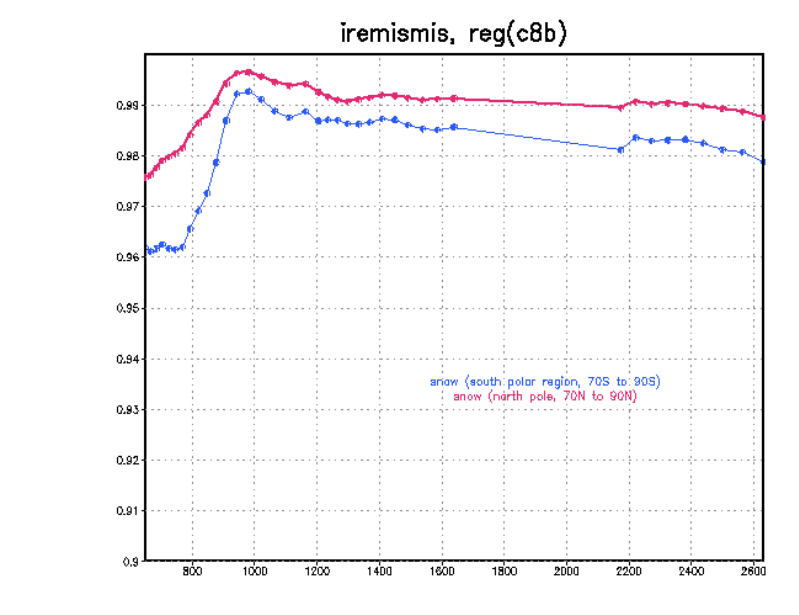


Snow or Ice Cases

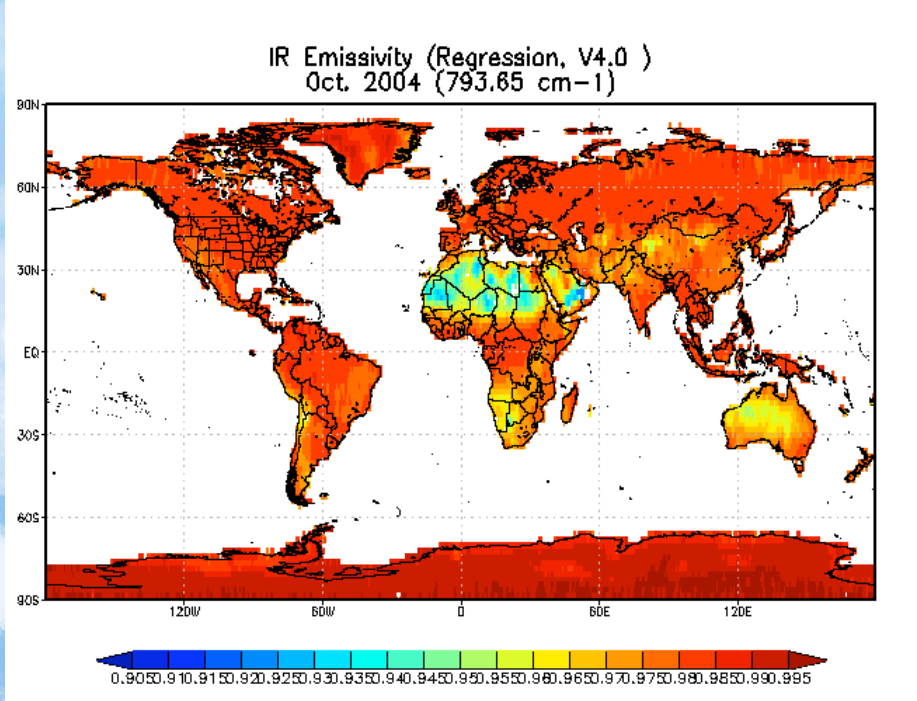
Training Ensemble

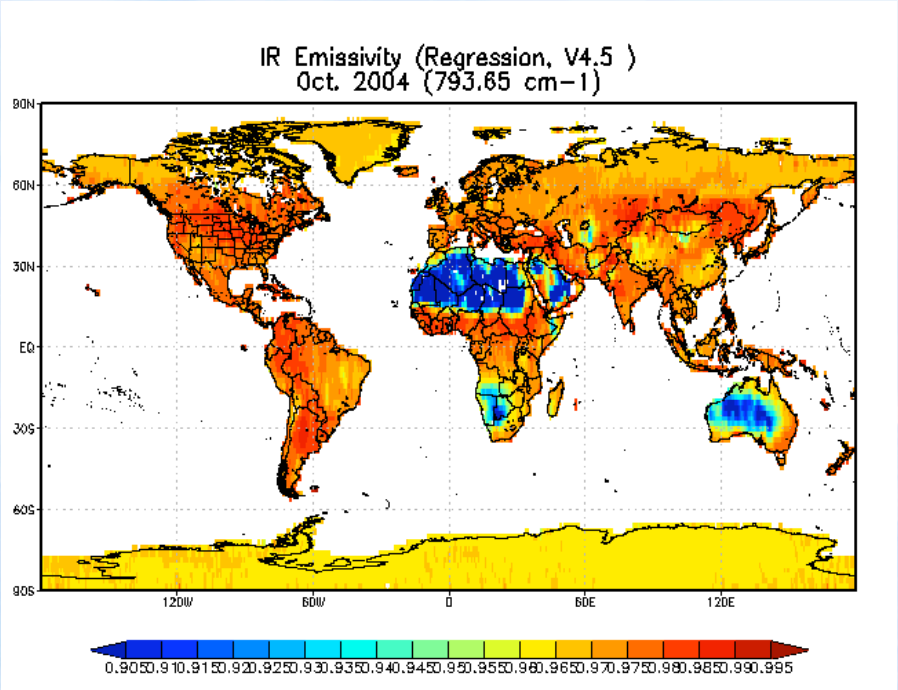


Retrieval over land (9/6/02)

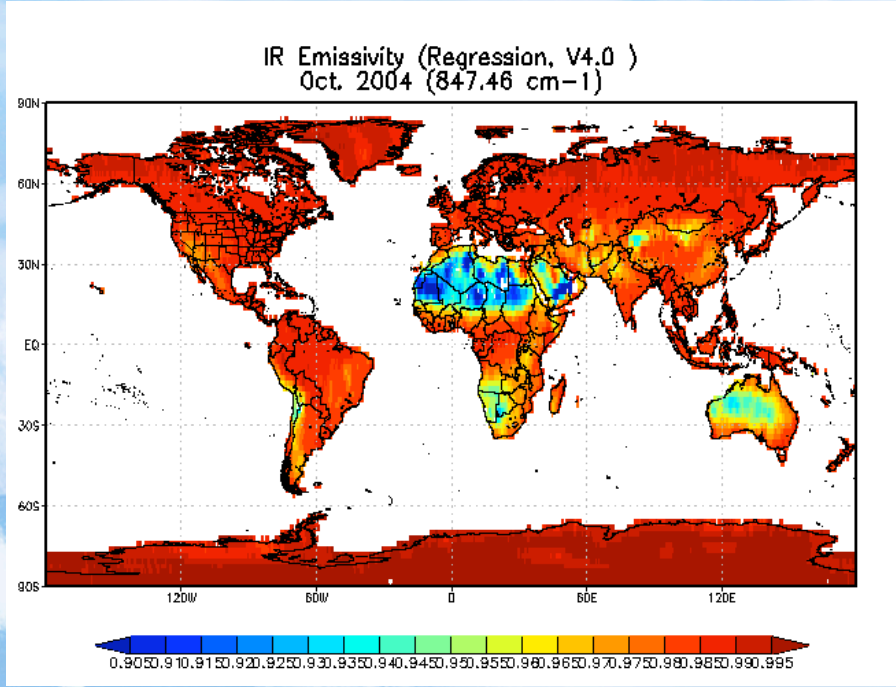


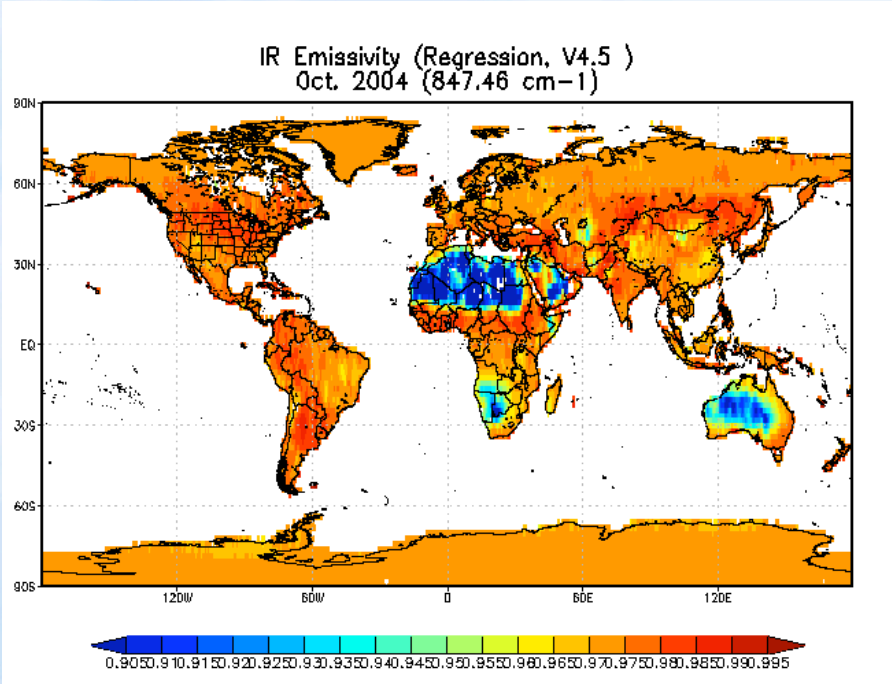
V4 versus V5 emissivity regression 793.65 cm^{-1} (12.6 µm)



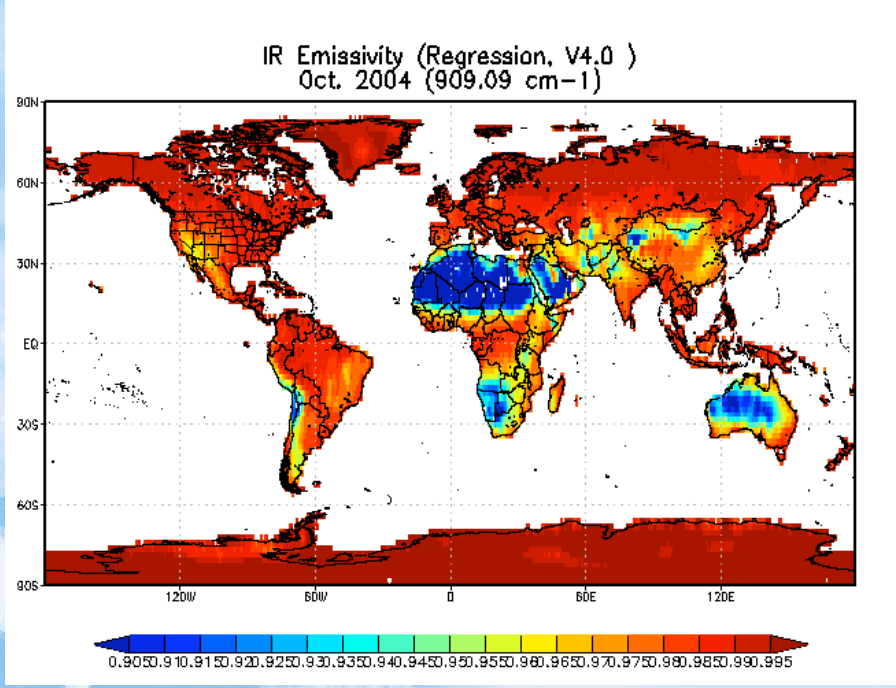


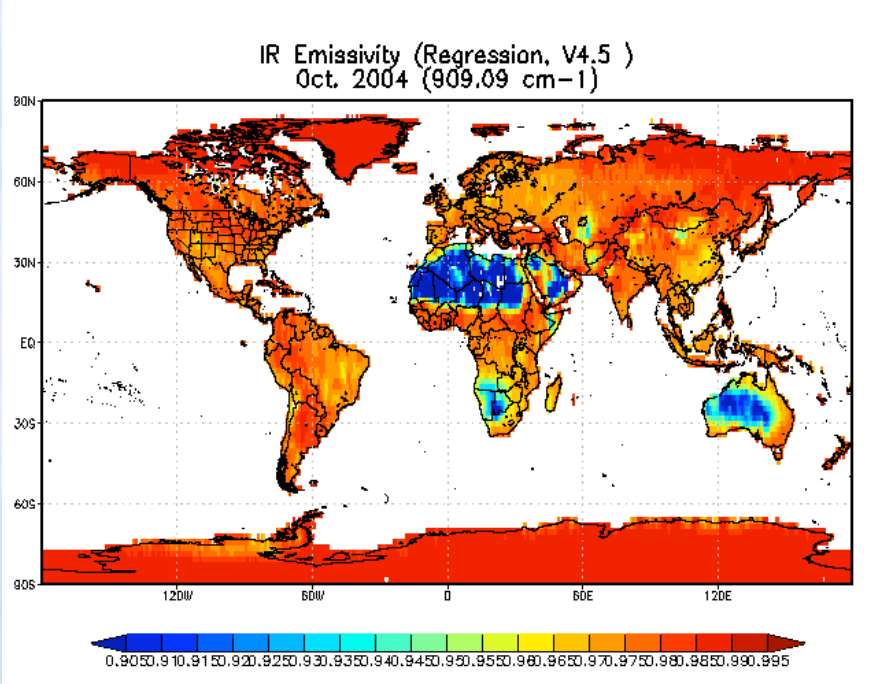
V4 versus V5 emissivity regression 847.48 cm^{-1} (11.8 μm)



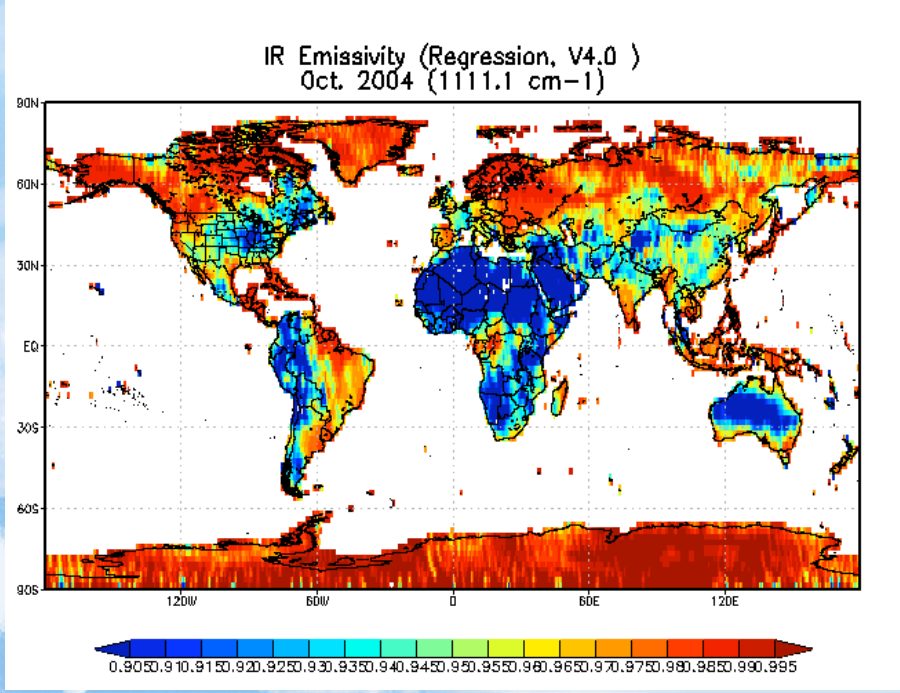


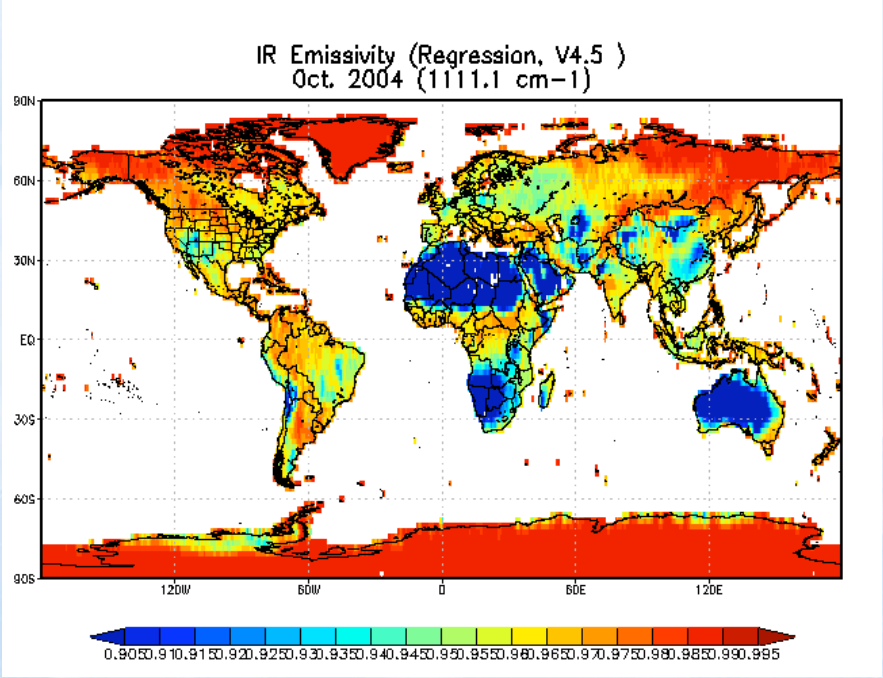
V4 versus V5 emissivity regression 909.09 cm^{-1} (11 μm)



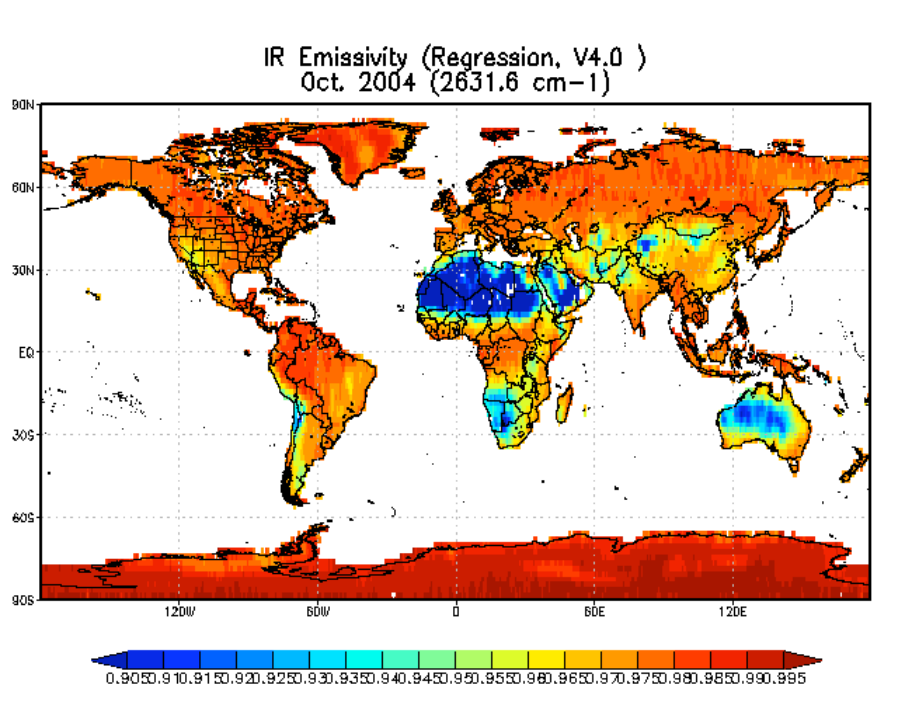


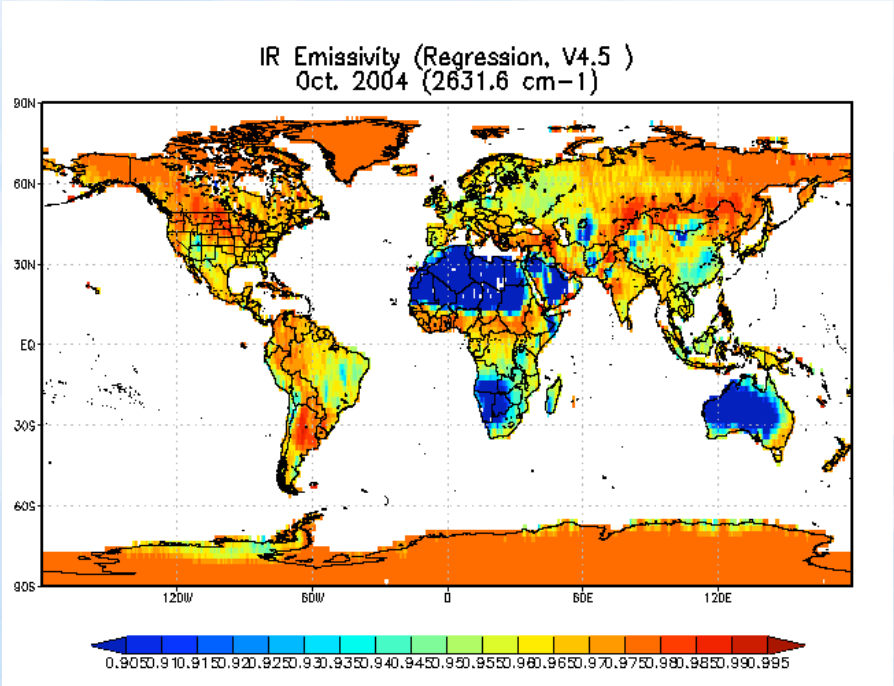
V4 versus V5 emissivity regression 1111.1 cm^{-1} (9.0 μm)





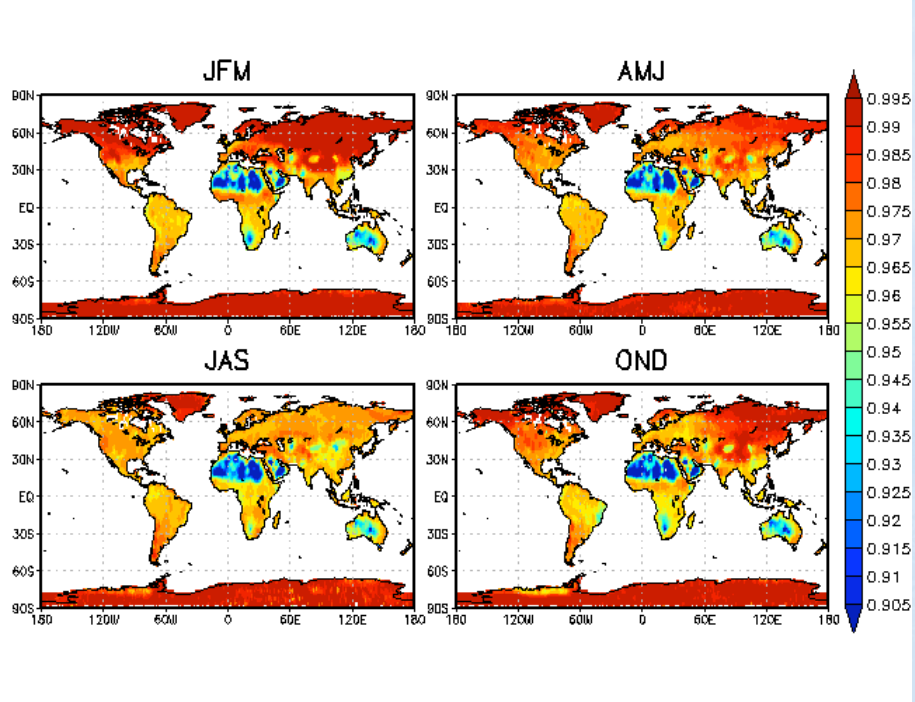
V4 versus V5 emissivity regression 2631.6 cm-1 (3.8 μm)



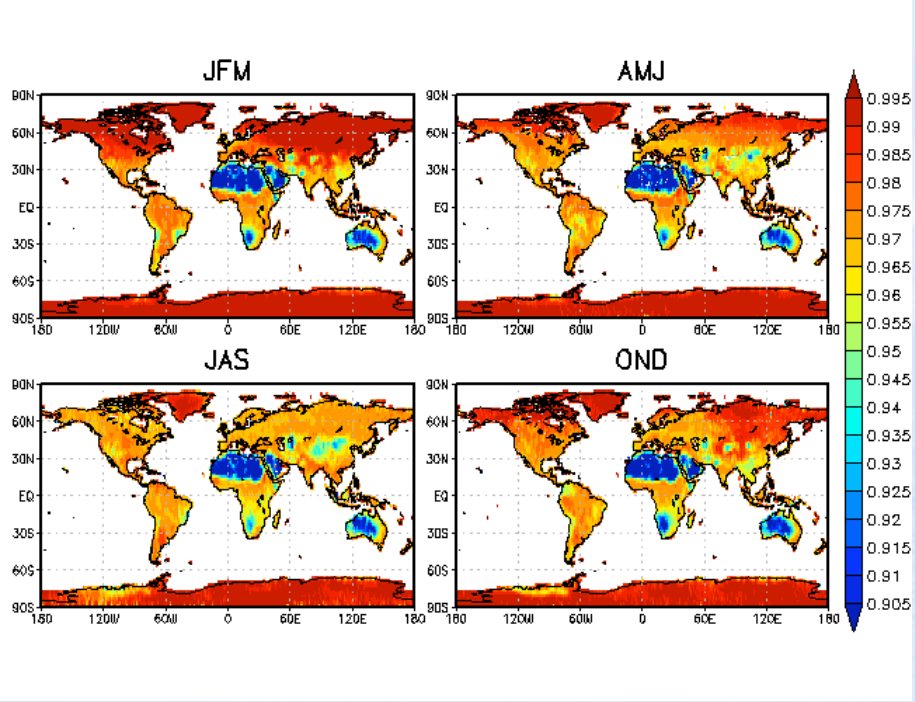


V4.5, seasonal characteristics 2005, 980 cm^{-1}

Decending (Night)

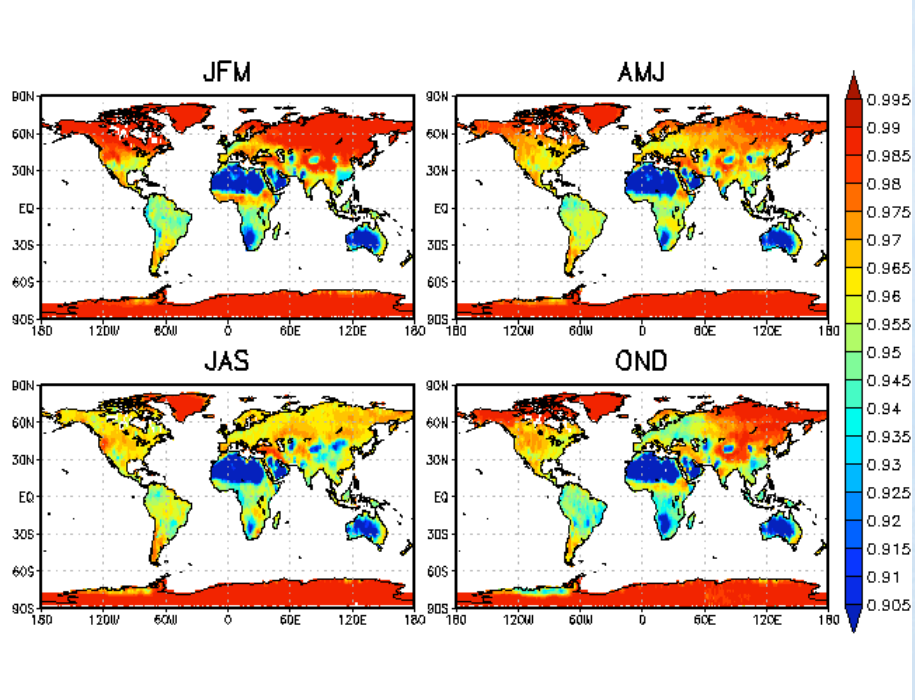


Ascending (Day)

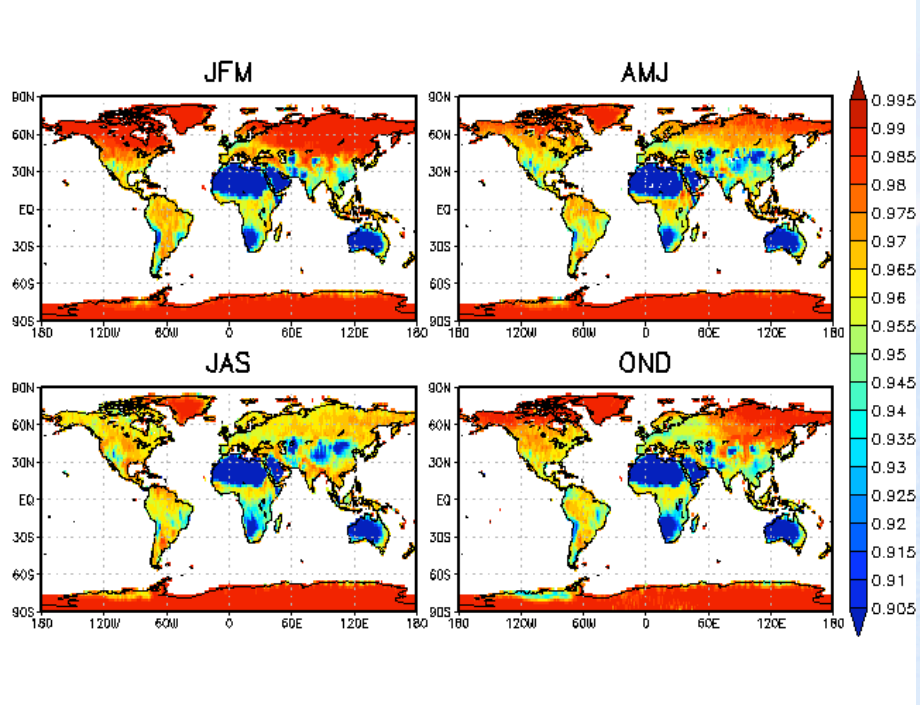


V4.5, seasonal characteristics 2005, 1120 cm^{-1}

Decending (Night)



Ascending (Day)



What do we have, in hand, for v5.0?

- V5.0 improvements for emissivity
  - CCR channels (Joel/Evan, TBD)
  - New Regression emissivity (installed)
  - Remove emissivity limits (GSFC, installed)
  - Upgrade to SVD functions/channels (Joel, TBD)
- Overall, emissivity problems seem to stem from cloud contamination.
  - Cloud clearing errors are dominant.
- We have 2 more ideas to explore – probably post v5.0 implementation (if successful)

1. ASTER TES approach
2. Optimal Estimation Approach`

1) ASTER Temperature Emissivity Separation (TES) Algorithm

1. The long-wave RTE for channel n is given by

$$R_n^{\text{obs}} \simeq \tau_n \cdot \left(\epsilon_n \cdot B_\nu(T) + \rho \cdot R_n^{\downarrow}\right) \quad + \quad R^{\uparrow} \tag{1.1}$$

2. Define a new function, G_n, that removes atmospheric effects

$$G_n = \frac{R_n^{obs} - R_n^{\uparrow}}{\tau_n} \quad = \quad \epsilon_n \cdot B_\nu(T) + \rho \cdot R_n^{\downarrow} \tag{1.2}$$

3. Set first guess emissivity to the maximum expected, $\epsilon_n^0 = \epsilon_{\max}$
4. Compute surface component of radiance

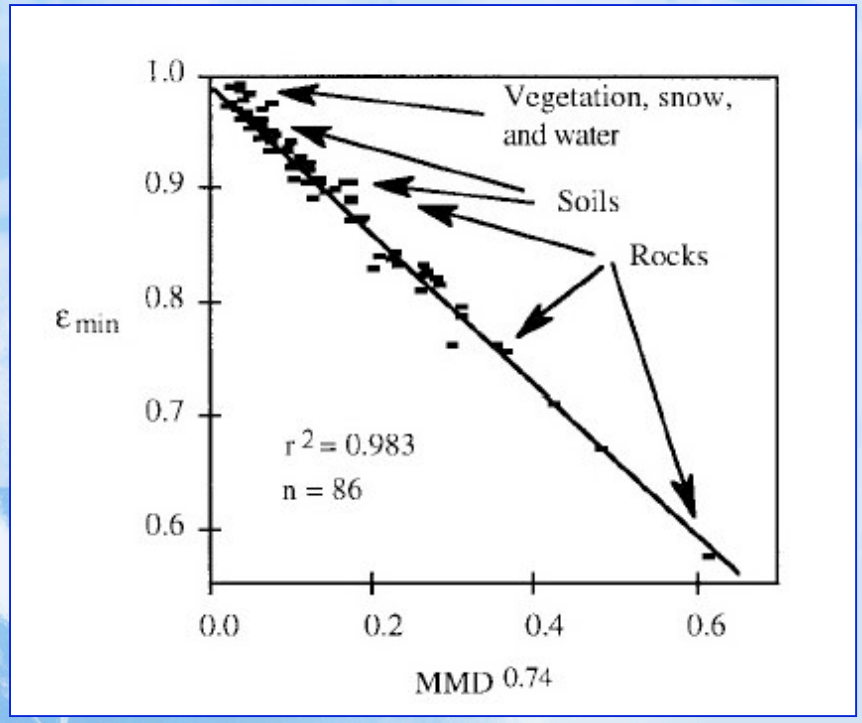
$$S_n^i = G_n - \left(1 - \epsilon_n^i\right) \cdot R_n^{\downarrow} \quad \simeq \quad \epsilon_n^i \cdot B\nu(T^i) \tag{1.3}$$

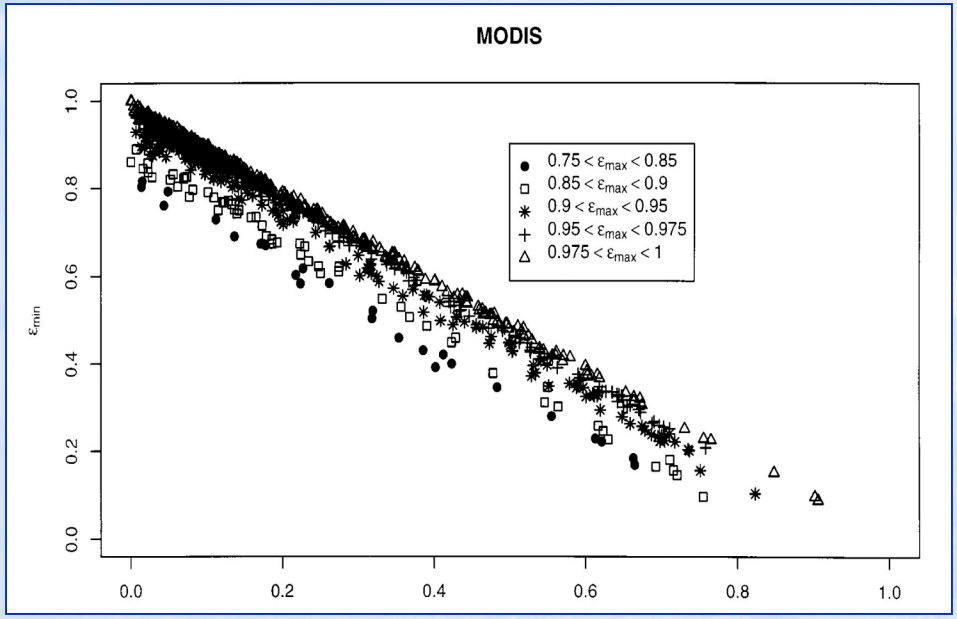
5. if $i > 12$ or $S^i > S^{i-1}$ then exit (, *i.e.* goto step # 8)
6. Compute skin temperature and solve for spectral emissivity

$$T_n^i = B_\nu^{-1}\left(\frac{S_n^i}{\epsilon_n^i}\right), \quad T_{\max}^i = \text{MAX}\left(T_n^i\right), \quad \epsilon_n^i = \frac{S_n^i}{B_\nu(T_{\max}^i)} \tag{1.4}$$

7. goto step # 4

We can add a constraint for the minimum emissivity, given the measured spectral variability





1) ASTER algorithm (continued)

8. Take ratio of emissivity

$$\beta_n^i \equiv \frac{\epsilon_n^i}{< \epsilon_n^i >_n} \tag{1.5}$$

9. find Maximum Minimum apparent emissivity Difference (MMD)

$$\mathrm{MMD} \equiv MAX(\beta_n^i) - MIN(\beta_n^i) \tag{1.6}$$

10. Use *a-priori* relationship between minimum ϵ and MMD

$$\epsilon_{\min} = f\,(MMD) \quad e.g. \quad \epsilon_{\min} = .994 - .685 \cdot \mathrm{MMD}^{.737} \tag{1.7}$$

11. Correct emissivity spectrum for minimum emissivity

$$\epsilon_n^i = \frac{\epsilon_{\min}}{\mathrm{MIN}(\beta_n^i)} \cdot \beta_n^i \quad \equiv \quad \frac{\epsilon_{\min}}{\mathrm{MIN}\epsilon_n^i} \cdot \epsilon_n^i \tag{1.8}$$

2) Optimal Estimation Approach

Use MODIS ε as a-priori state for physical retrieval and solve for the J MODIS frequency locations

$$\epsilon_j^i = \epsilon_j^A + \left[K_{j,n}^T \cdot N_{n,n}^{-1} \cdot K_{n,j} + C_{j,j}^{-1}\right]^{-1} \cdot K_{j,n}^T \cdot N_{n,n}^{-1} \cdot \left[R_n^{obs} - R_n(X^{i-1}) + K_{n,j} \cdot \left(\epsilon_j^{i-1} - \epsilon_j^A\right)\right]$$

Use regression emissivity as a first guess, $X^{i=0}$

Use MODIS standard deviation within FOV and emissivity spectral correlations as *a-priori* covariance