Handling clouds in assimilating high spectral resolution infrared radiances

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Motivation

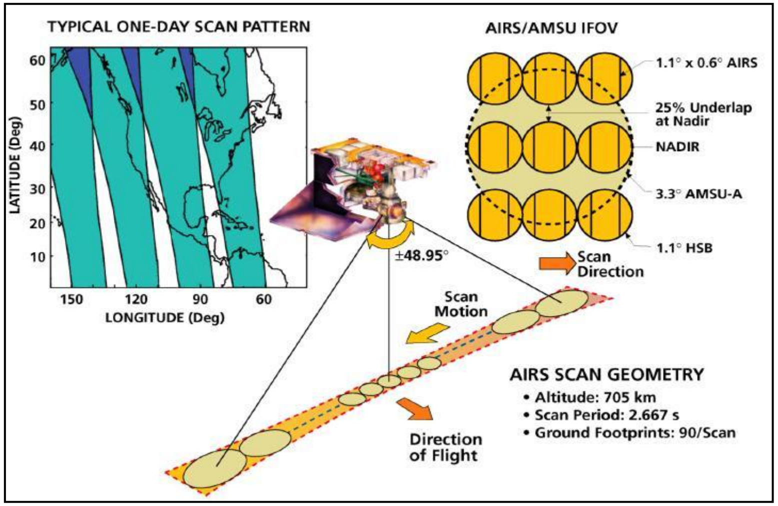
- Usually only clear IR channels (not affected by clouds) are used in most of data assimilation systems, and cloud contaminated channels have not been used effectively due to difficulties in modeling clouds in both forecast and radiative transfer models.

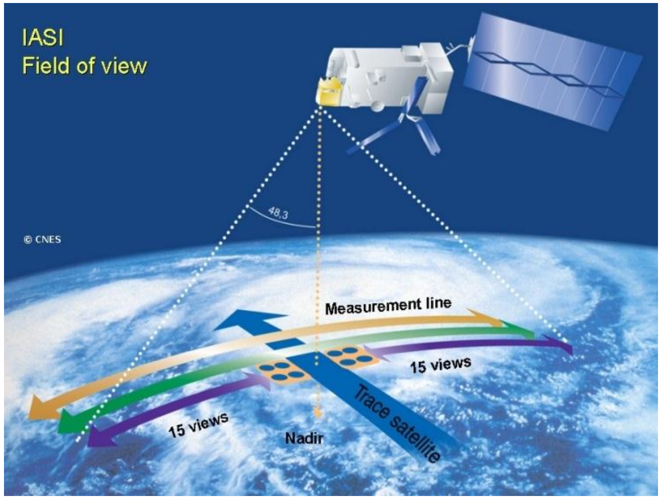
- Accurate cloud detection is very important for hyperspectral infrared (IR) radiance assimilation; a better cloud detection could reduce the data rejection and improve the assimilation.

- Since only 10 ~15% of hyperspectral IR footprints are clear globally, we need innovative ideas on assimilating radiances in cloudy situations.

Satellites with hyperspectral Infrared sunders

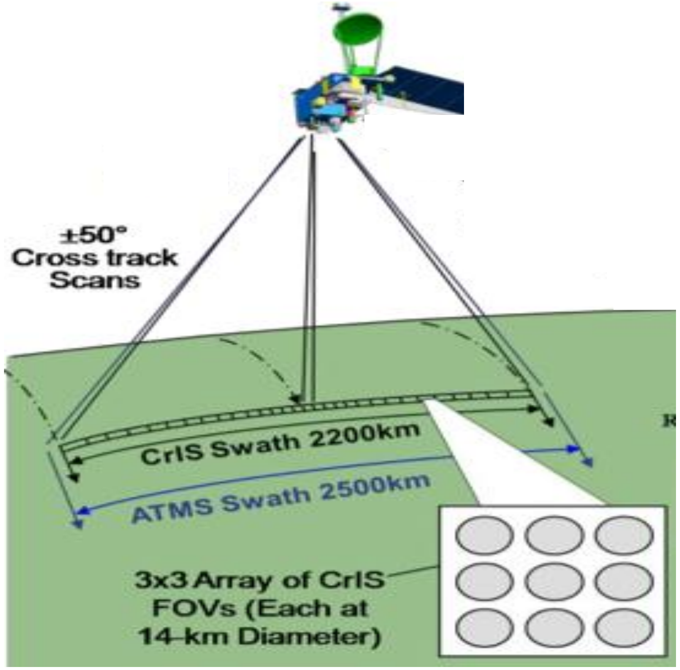
Aqua





Metop

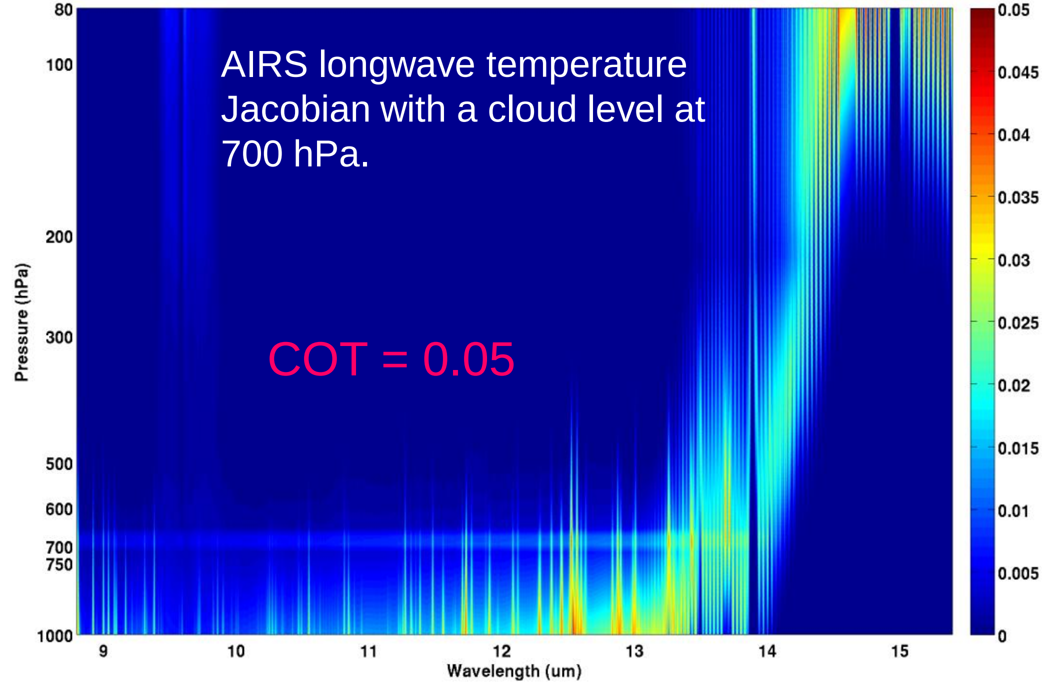
Suomi NPP/JPSS

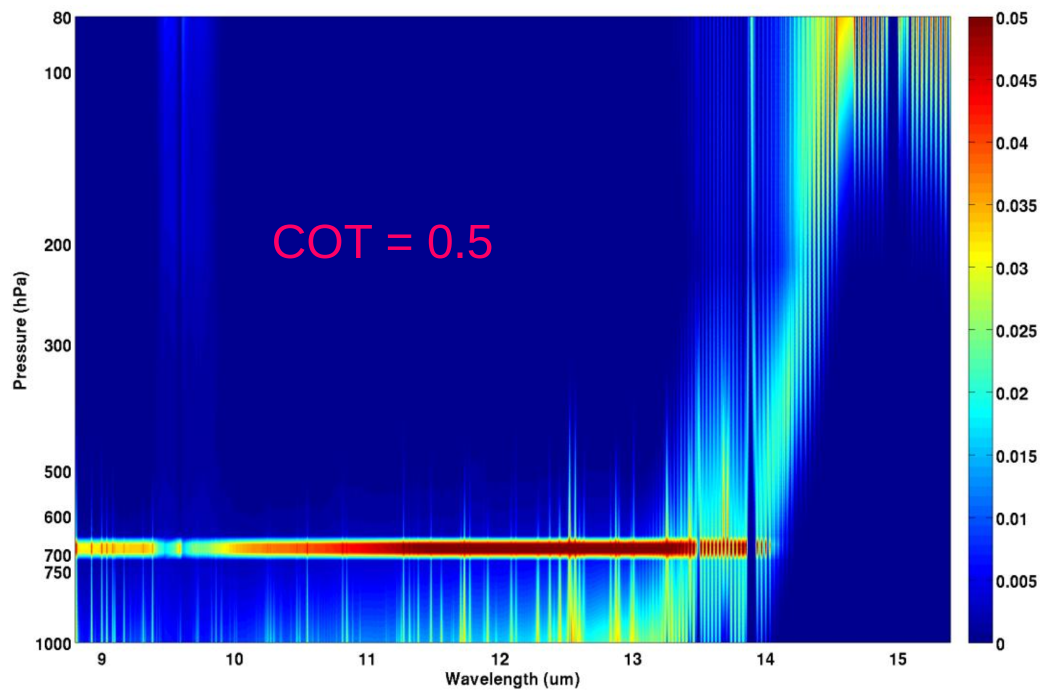


Challenges on assimilating radiances in cloudy situation:

(1) Both NWP and RTM have larger uncertainty;

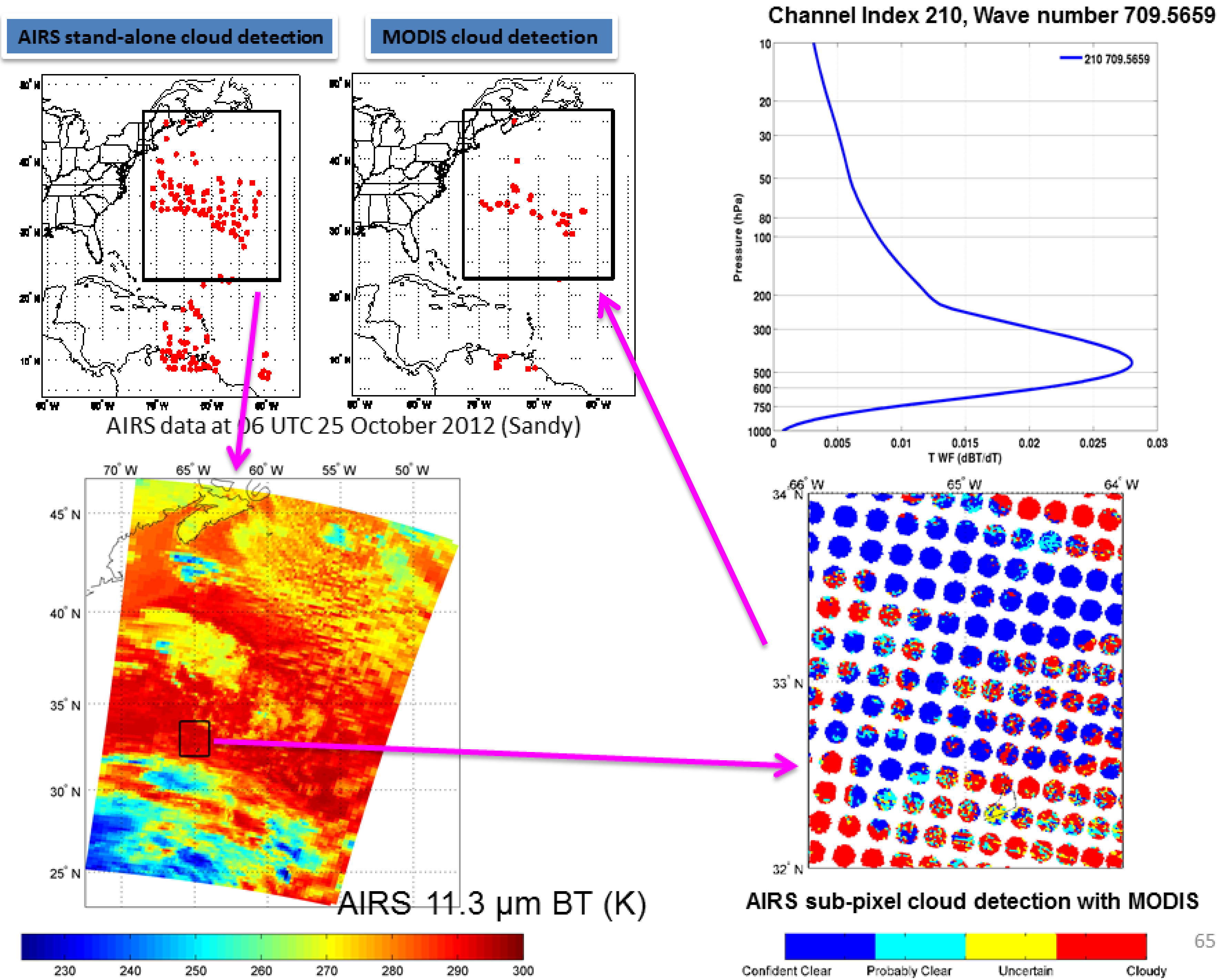
(2) Big change of Jacobian at cloud level





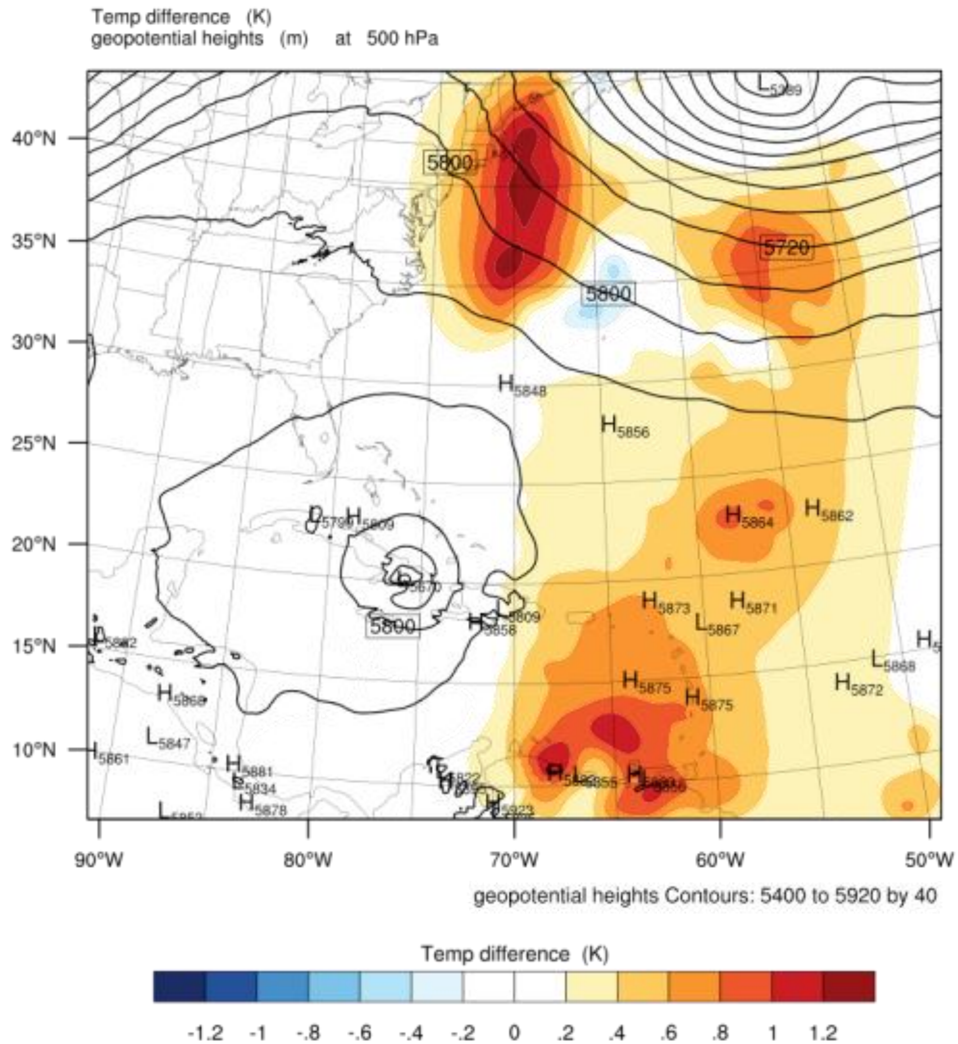
Handling clouds in IR radiance assimilation

- Black cloud assumption – rise the surface to cloud-top
- Hole hunting – excluding cloudy pixels
  - Stand-alone cloud detection with sounder data
  - Sub-pixel cloud detection with collocated high spatial resolution imager data
- Cloud-removal or cloud-clearing technique that transform the a cloud radiance spectrum to a clear equivalent radiance spectrum so that radiance assimilation can be treated as that in clear skies
- Direct assimilate radiance in cloudy skies – an accurate RTM in cloudy situation is very important



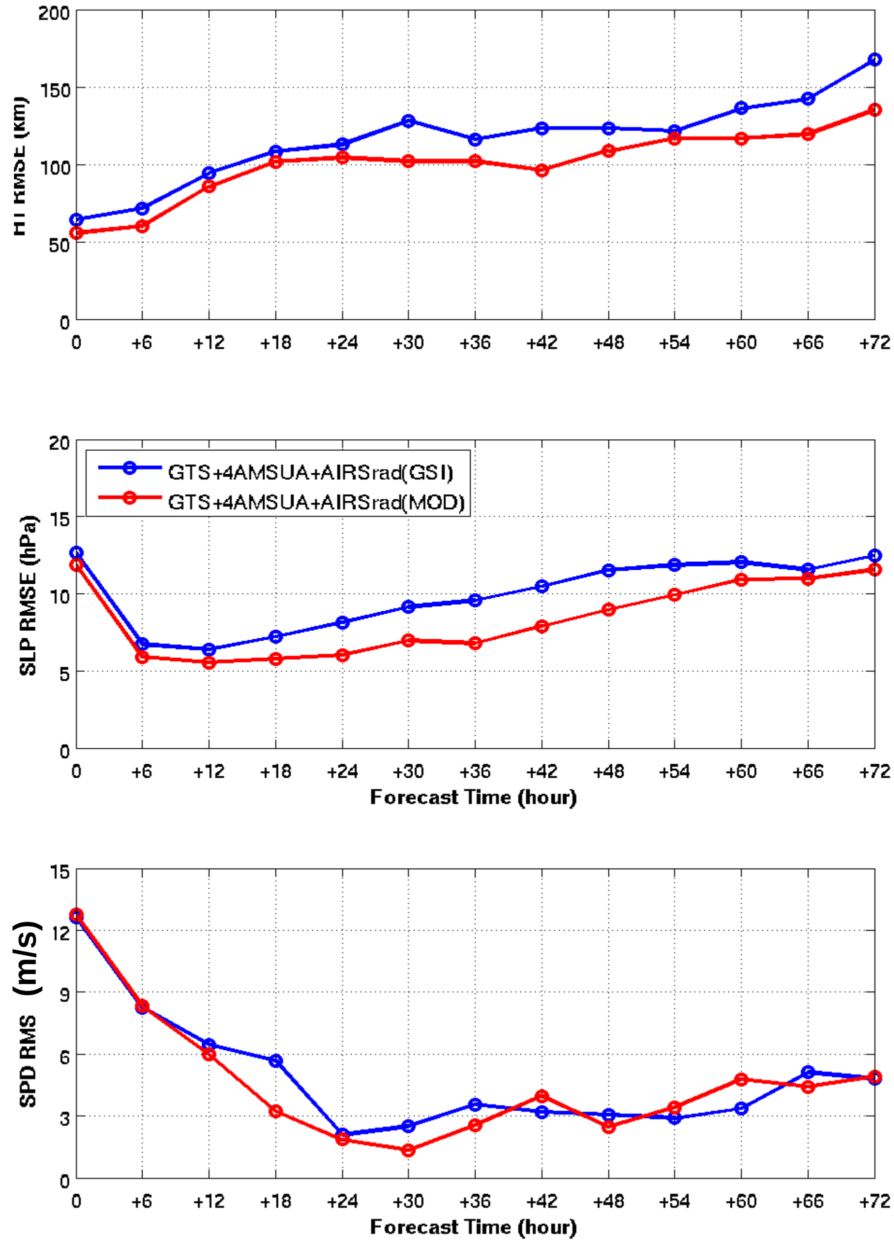
AIRS stand-alone cloud detection
MODIS cloud detection
AIRS data at 06 UTC 25 October 2012 (Sandy)
Channel Index 210, Wave number 709.5659
210 709.5659
Pressure (hPa)
T WF (dBT/dT)
AIRS 11.3 μm BT (K)
230 240 250 260 270 280 290 300
70° W 65° W 60° W 55° W 50° W
45° N 40° N 35° N 30° N 25° N
66° W 65° W 64° W
34° N 33° N 32° N
AIRS sub-pixel cloud detection with MODIS
Confident Clear
Probably Clear
Uncertain
Cloudy

Hurricane Sandy (2012) forecast RMSE



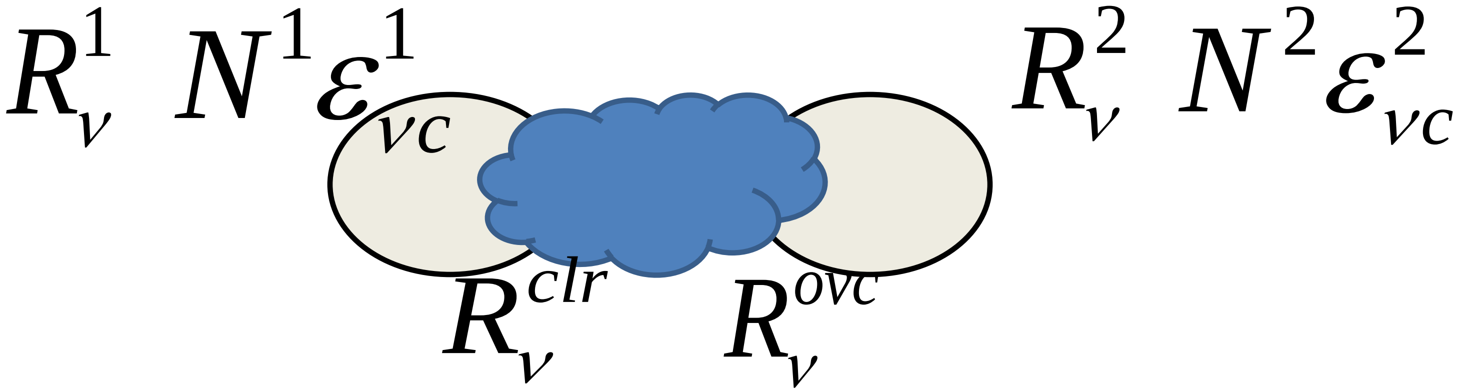
500 hPa temperature analysis difference

(AIRS(MOD) - AIRS(GSI))



Wang et al. 2014, GRL (accepted)

72-hour forecasts of Sandy from 06z 28 to 00z 30 Oct, 2012



$$R_\nu^1 = (1 - N^1 \varepsilon_{\nu c}^1) R_\nu^{clr} + N^1 \varepsilon_{\nu c}^1 R_\nu^{ovc}$$

$$R_\nu^2 = (1 - N^2 \varepsilon_{\nu c}^2) R_\nu^{clr} + N^2 \varepsilon_{\nu c}^2 R_\nu^{ovc}$$

If we can estimate N^*(e.g. from MODIS) the cloud-cleared radiance R_ν^{cc} can be obtained by

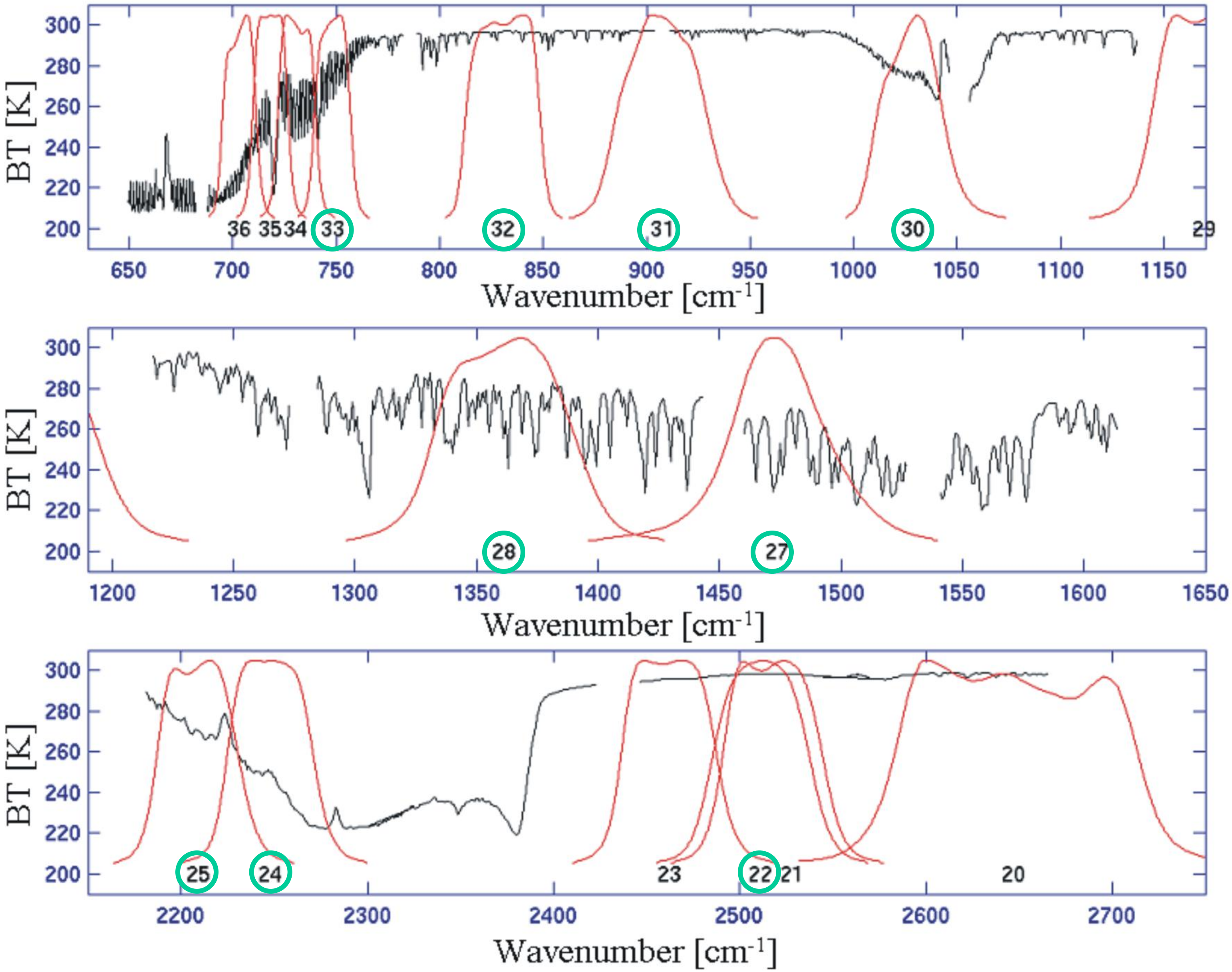
$$\Rightarrow \quad R_\nu^1 - R_\nu^{clr} = N^1 \varepsilon_{\nu c}^1 (R_\nu^{ovc} - R_\nu^{clr})$$

$$R_\nu^2 - R_\nu^{clr} = N^2 \varepsilon_{\nu c}^2 (R_\nu^{ovc} - R_\nu^{clr})$$

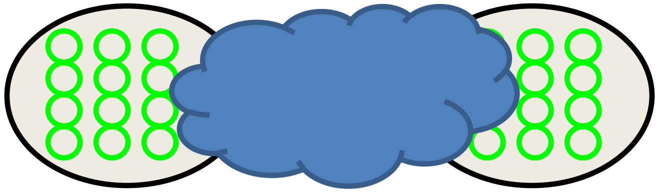
$$\frac{R_\nu^1 - R_\nu^{clr}}{R_\nu^2 - R_\nu^{clr}} = \frac{N^1 \varepsilon_{\nu c}^1}{N^2 \varepsilon_{\nu c}^2} = N^*$$

$$R_\nu^{cc} = \frac{R_\nu^1 - R_\nu^2 N^*}{1 - N^*}$$

Aqua MODIS IR SRF Overlay on AIRS Spectrum



Direct spectral relationship between IR MODIS and AIRS provides unique application of MODIS in AIRS cloud_clearing !



Using all MODIS IR bands (Li et al. 2005)

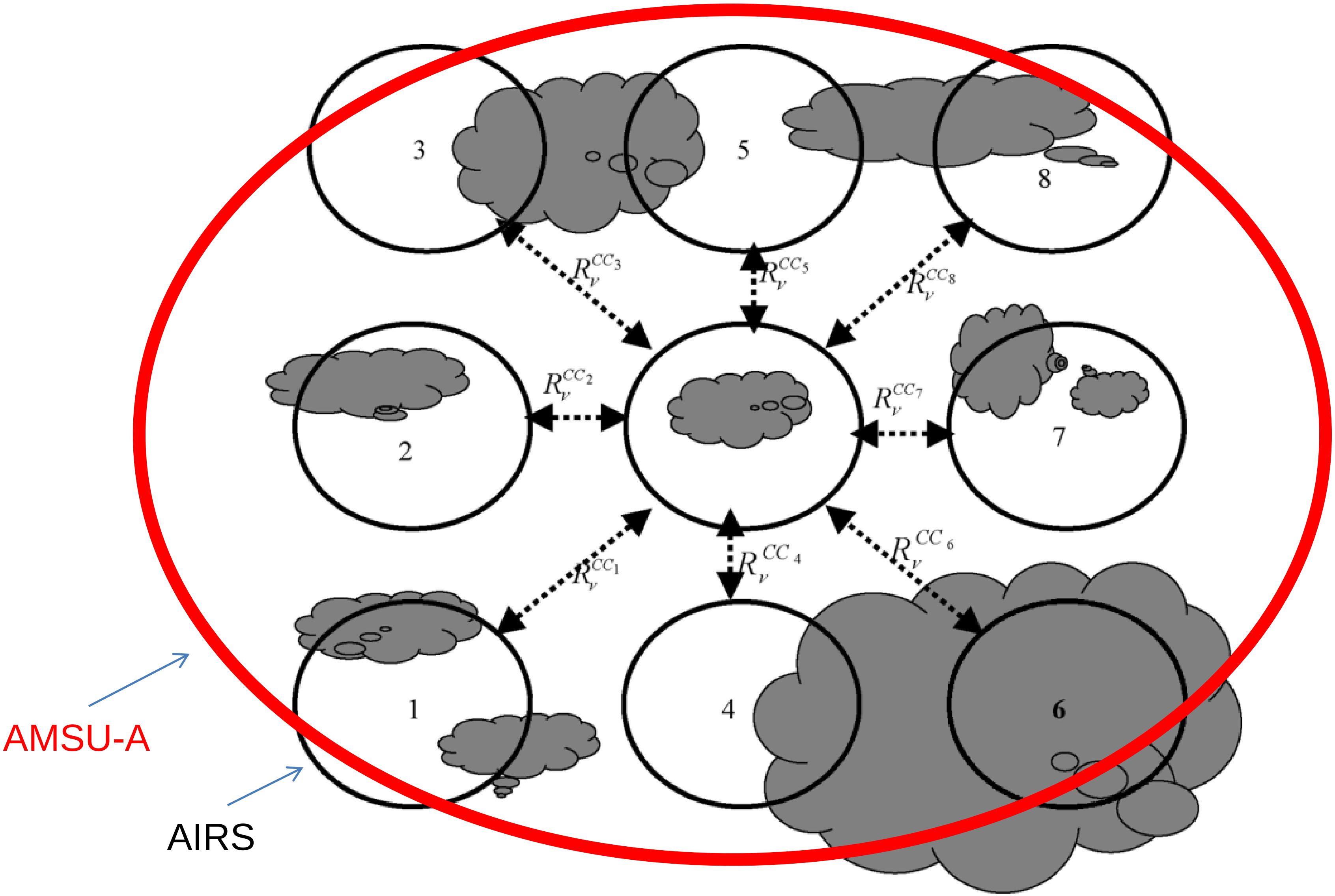
$$J(N^*) = \sum_i \frac{1}{\sigma_i^2}[(R_{M_i}^{clr} - f_i(R_\nu^{cc}))]^2 = \min$$

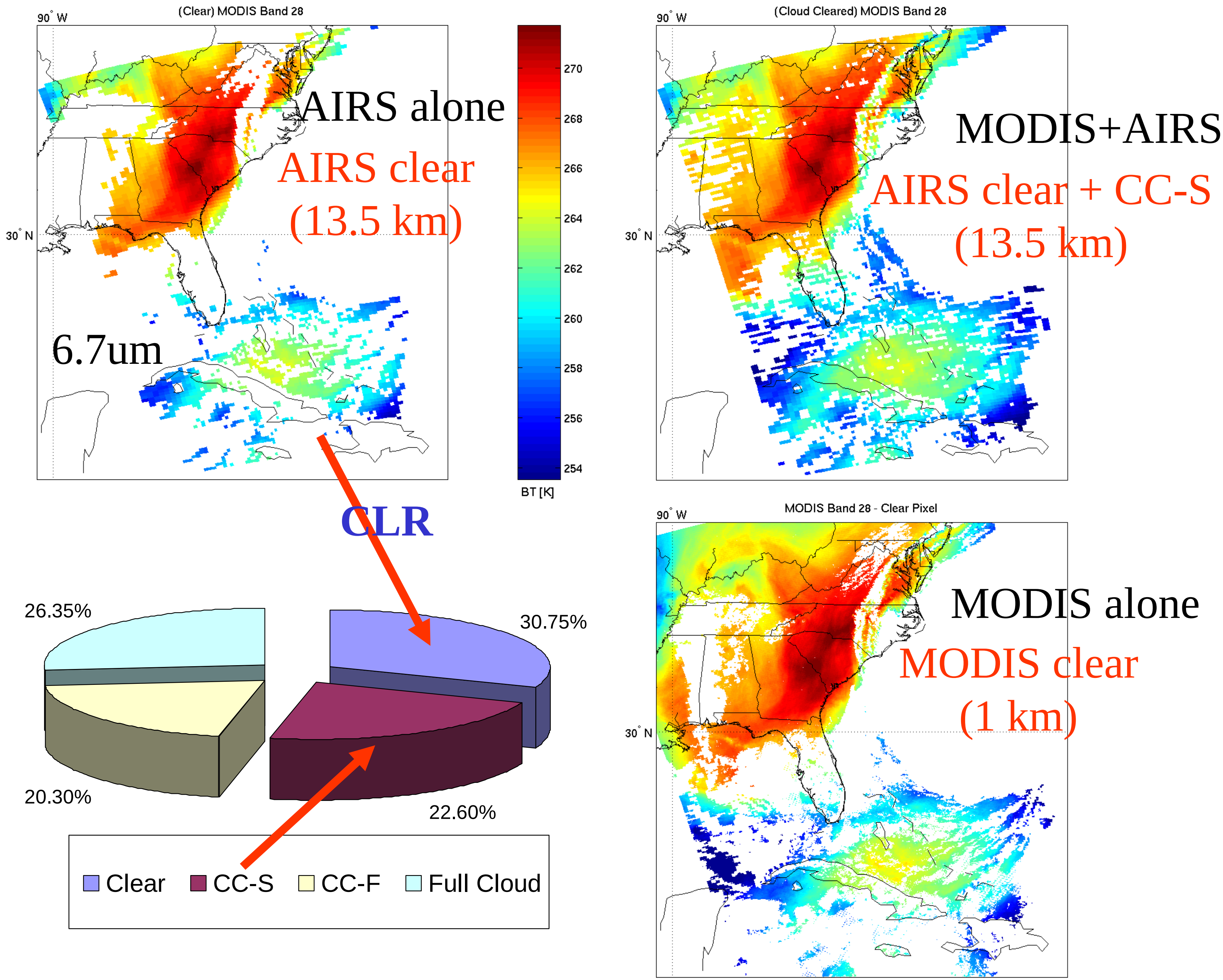
$$J(N^*) = \sum_i \frac{1}{\sigma_i^2}[(R_{M_i}^{clr} - f_i(\frac{R_\nu^1 - R_\nu^2 N^*}{1 - N^*}))] = \min$$

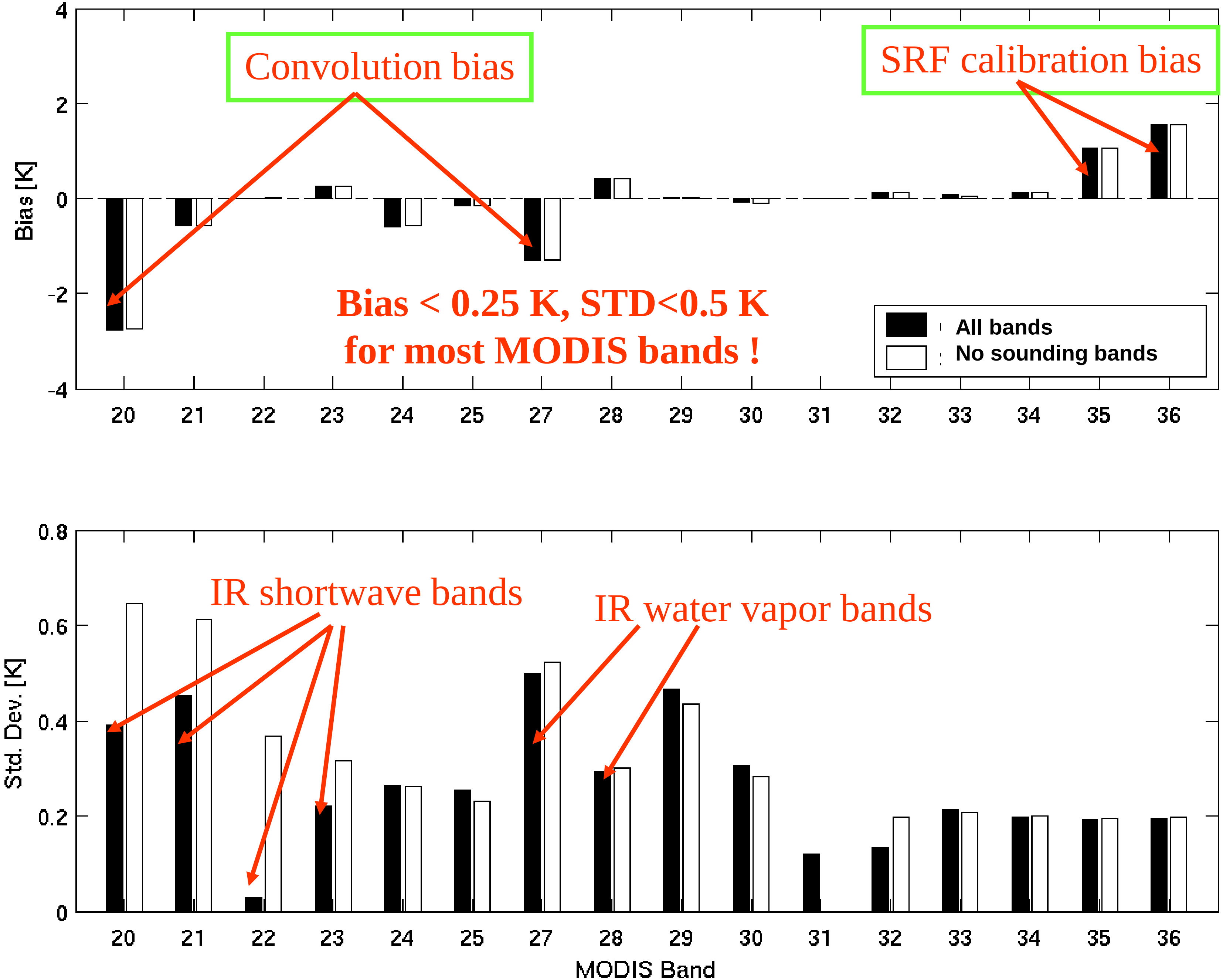
σ_i is NEdR for MODIS band *i*

Solve $\frac{\partial J(N^*)}{\partial N^*} = 0$ ⇒ $N^* = \frac{\sum_i \frac{1}{\sigma_i^2}[f_i(R_\nu^1) - R_{M_i}^{clr}][f_i(R_\nu^1) - f_i(R_\nu^2)]}{\sum_i \frac{1}{\sigma_i^2}[f_i(R_\nu^2) - R_{M_i}^{clr}][f_i(R_\nu^1) - f_i(R_\nu^2)]}$

(1) For each cloudy AIRS FOV, 8 pairs are used to derive 8 AIRS CC radiance spectra;
(2) Compare AIRS CC radiances with MODIS clear radiance observations within the AIRS FOV, find the best pair and the corresponding CC radiance spectrum.

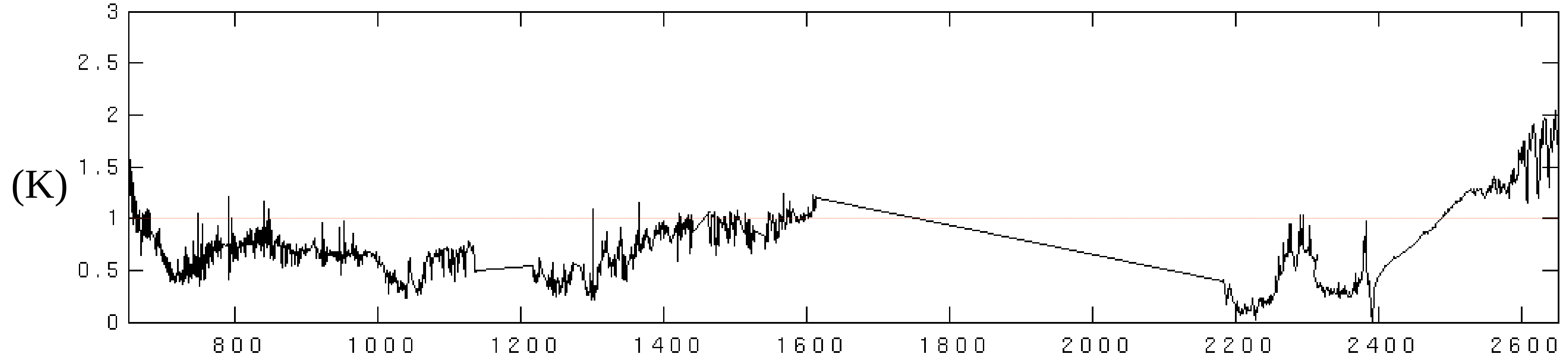


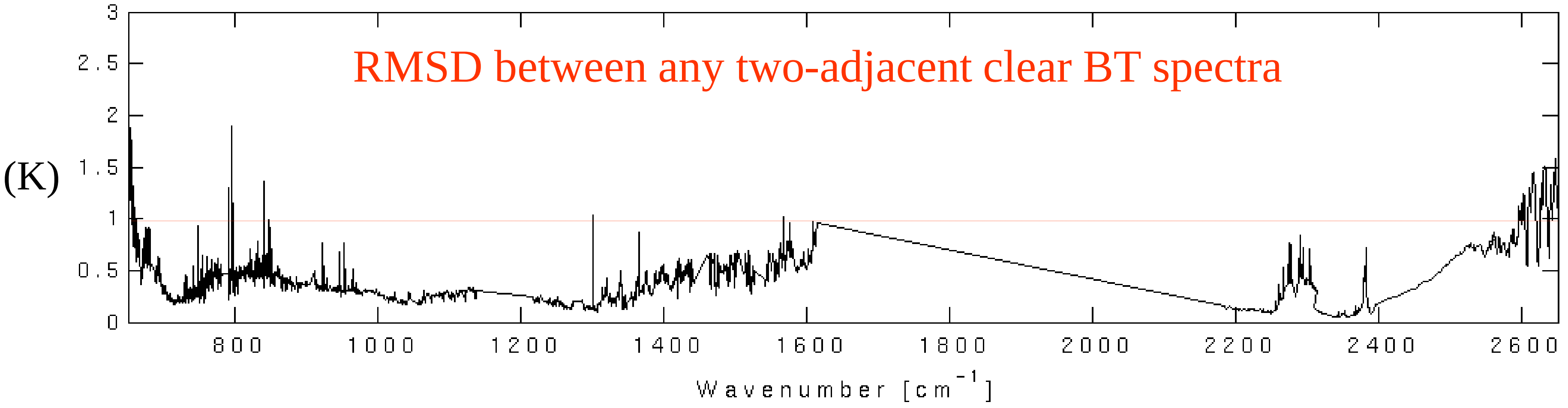

(Clear) MODIS Band 28
90° W
30° N
AIRS alone
AIRS clear
(13.5 km)
6.7um
270
268
266
264
262
260
258
256
254
BT [K]
(Cloud Cleared) MODIS Band 28
90° W
30° N
MODIS+AIRS
AIRS clear + CC-S
(13.5 km)
CLR
26.35%
30.75%
20.30%
22.60%
Clear
CC-S
CC-F
Full Cloud
MODIS Band 28 - Clear Pixel
90° W
30° N
MODIS alone
MODIS clear
(1 km)

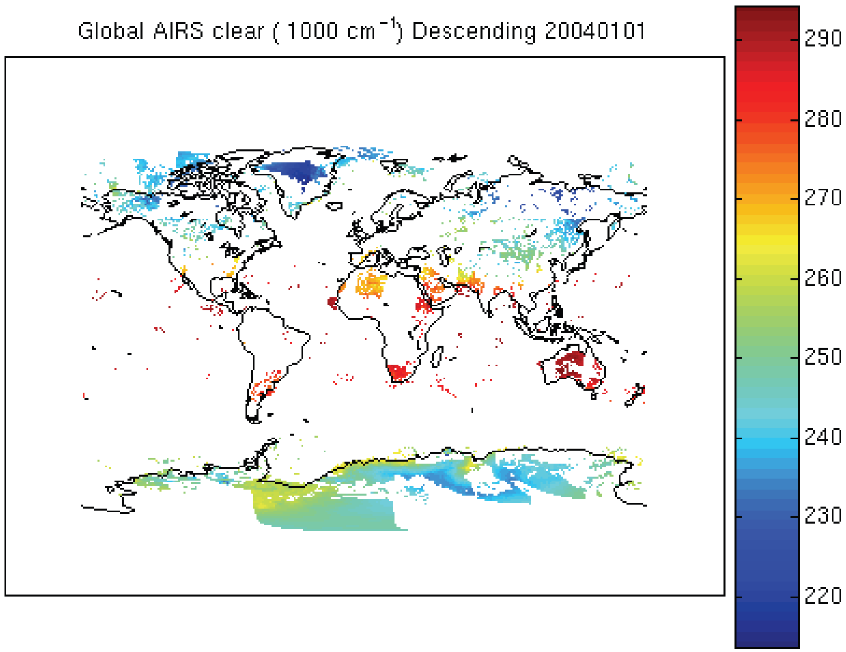


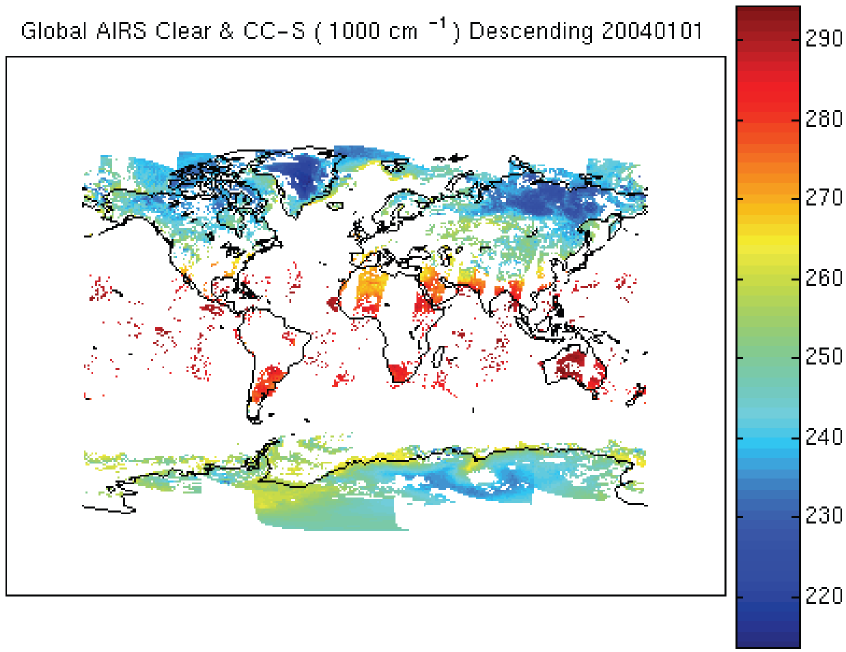
Convolution bias
SRF calibration bias
Bias < 0.25 K, STD<0.5 K
for most MODIS bands !
All bands
No sounding bands
Bias [K]
IR shortwave bands
IR water vapor bands
Std. Dev. [K]
MODIS Band

RMSD between CC BT spectra and their nearby clear BT spectra
(930 comparisons, AIRS granule 184 on 17 Sept. 2003)

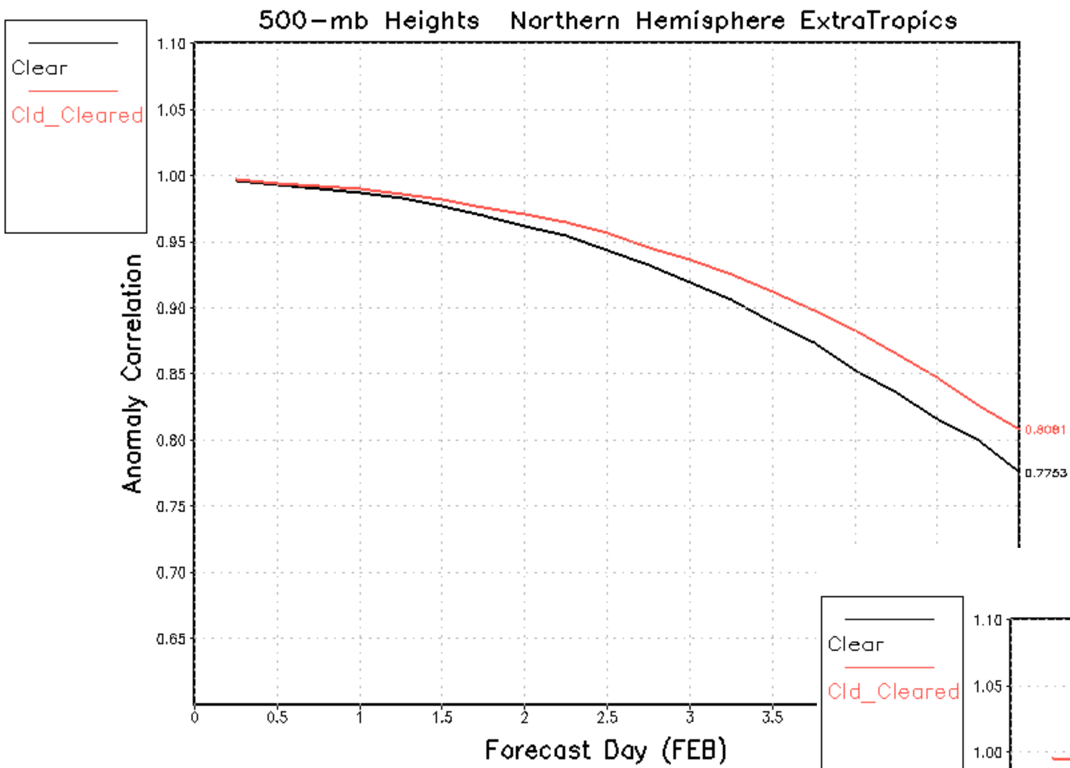




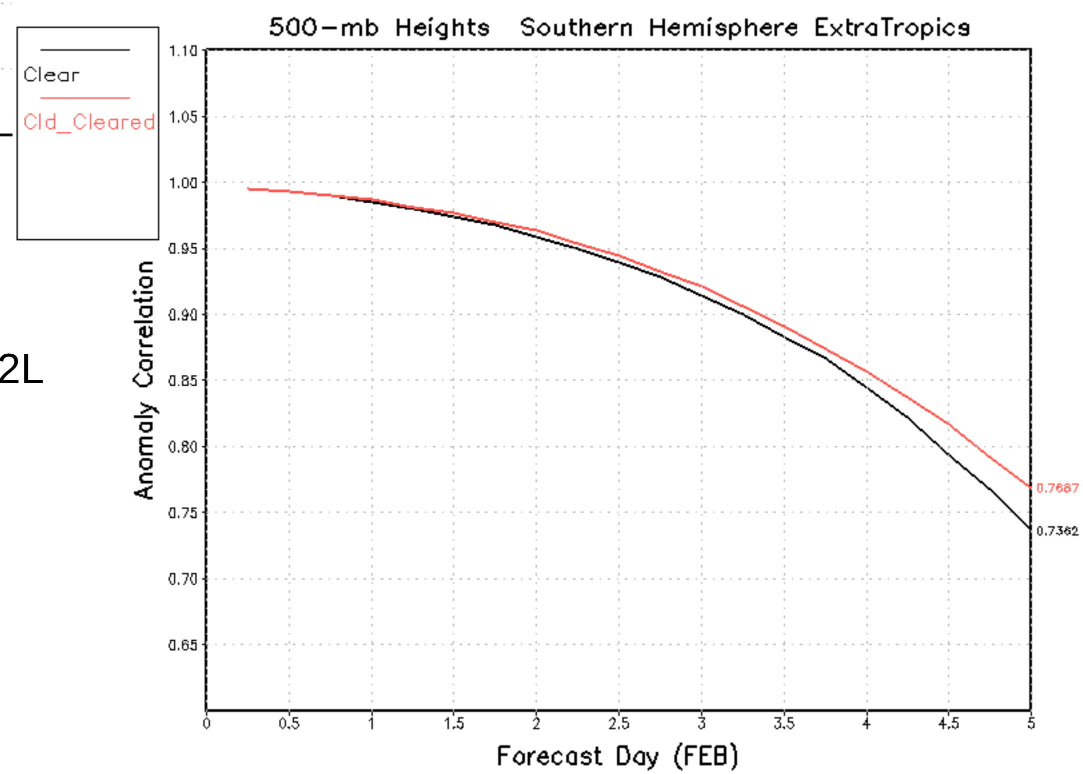




AIRS global clear and cloud clearing brightness temperature (descending) on Jan. 1, 2004.



Rienecker et al. 2008: GMAO's Atmospheric Data Assimilation Contributions to the JCSDA and future plans, *JCSDA Seminar*, 16 April 2008.



- GEOS-5 model resolution: 1° x1.25° x72L
- Time frame: Jan 01 to Feb 15 2004
- Other Radiance data:
  - HIRS-2/HIRS3 (clear channels)
  - AMSU-A/EOS-AMSU-A
  - AMSU-B/MHS
  - SSM-I
  - GOES Sounders

Summary and future work

- Better cloud detection on AIRS with MODIS leads to significant NWP forecast improvement using GSI and WRF ARW systems;
- The approaches can be applied to CrIS/VIIRS, IASI/AVHRR;
- IR sounder cloud-clearing with collocated imager could expand the "clear" coverage for radiance assimilation;
- Future work will focus on assimilating the cloud-cleared IR sounder radiances in NWP.