GOES-Retrievals

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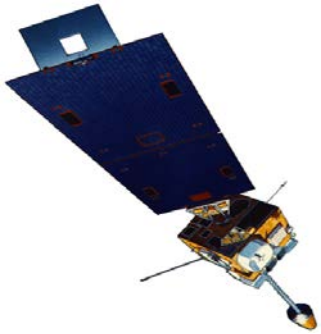
Advanced Satellite Products Team (ASPT)

Jun Li

CIMSS

Madison, WI

And many others



Retrieval Meeting
March 22, 2005

GOES Retrieval Meeting ***March 22, 2005***

Current GOES Sounder

- Overview (TJS)
- Applications overview (TJS)
- Retrieval theory (JL)
  - current version
  - ITPP
- GOES Retrieval Research (JL)

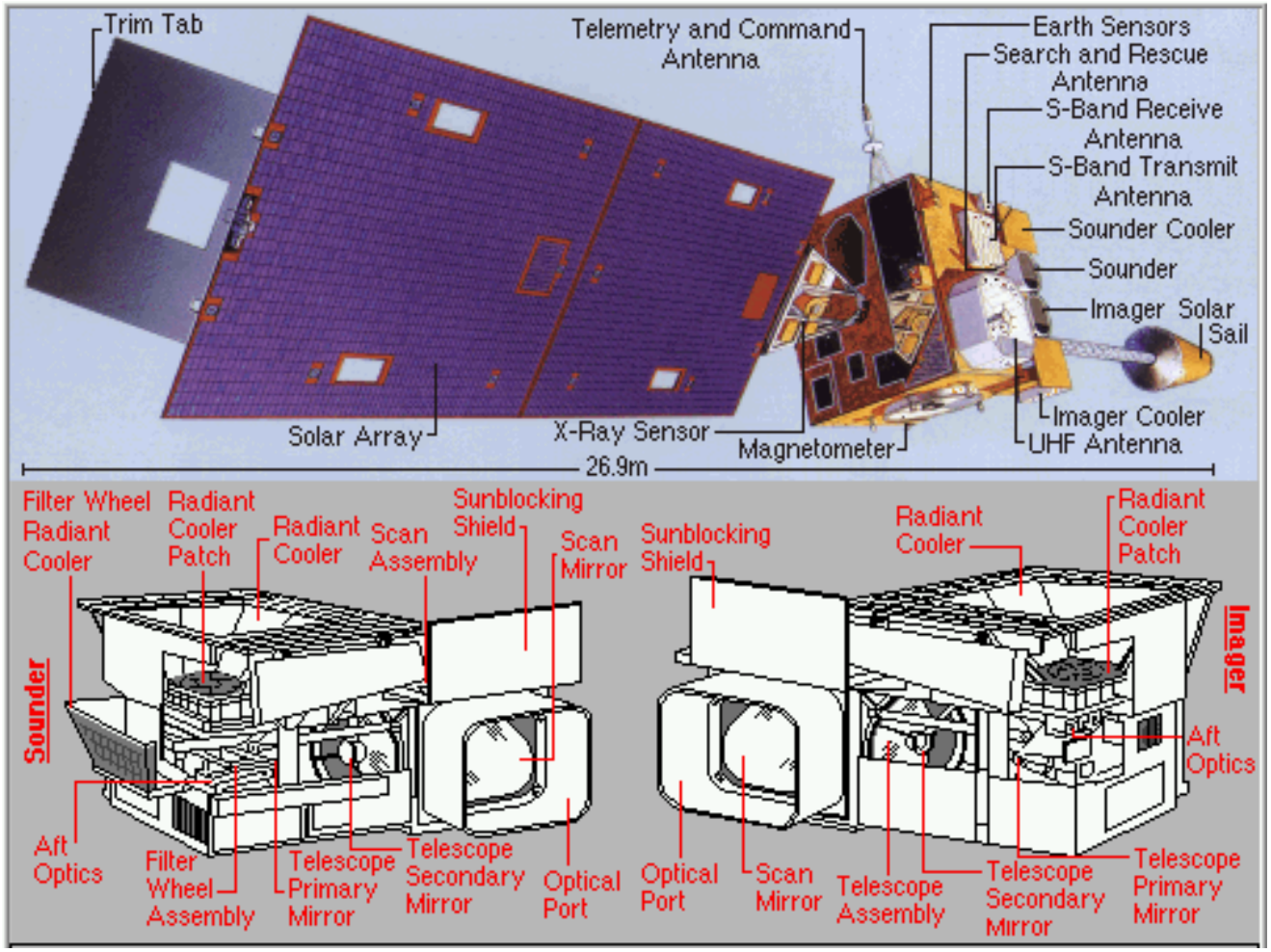
Future GOES Sounder

- HES Instrument (TJS)
- Retrievals (JL/TJS)
  - leverage/merge where it makes sense
  - NWP independent
  - Issues

More information (web pages + select references)

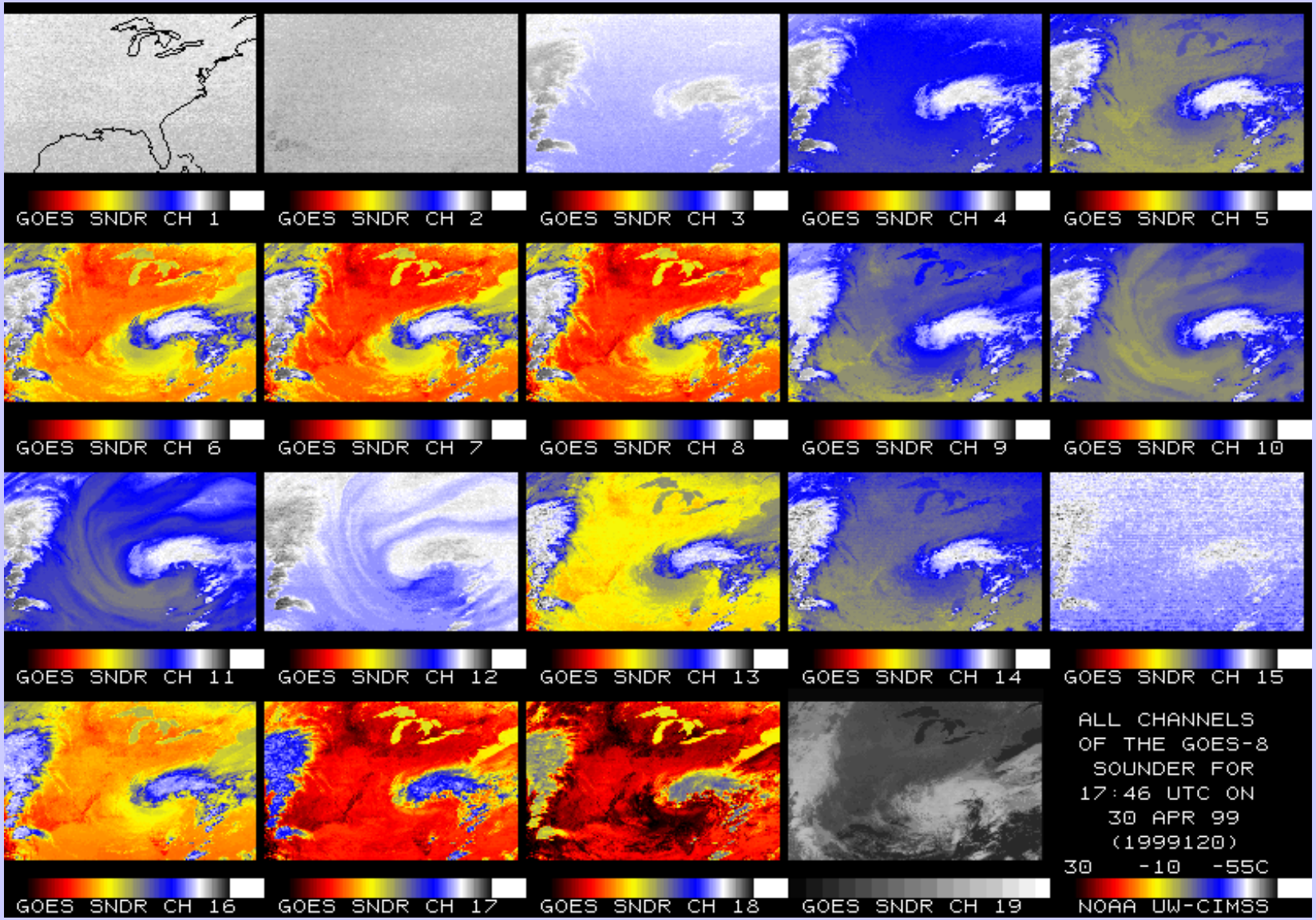
GOES-8/M Sounder

18 Infrared Channels (1 Visible Channel)
Filter Wheel Radiometer



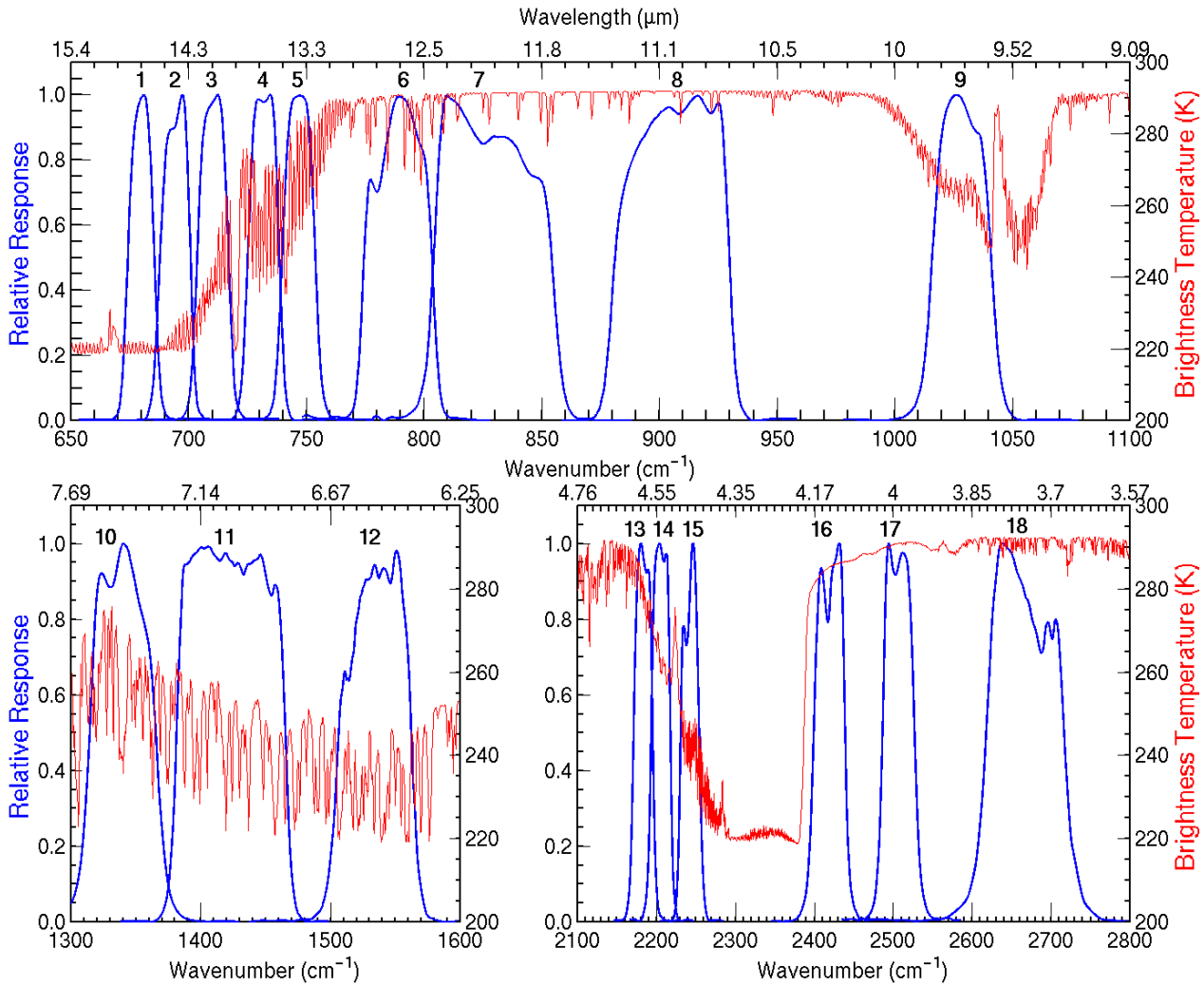
- Operational
- Higher Signal-to-Noise

GOES Sounder Spectral Bands: 14.7 to 3.7 um & Vis



GOES Sounder Spectral Coverage

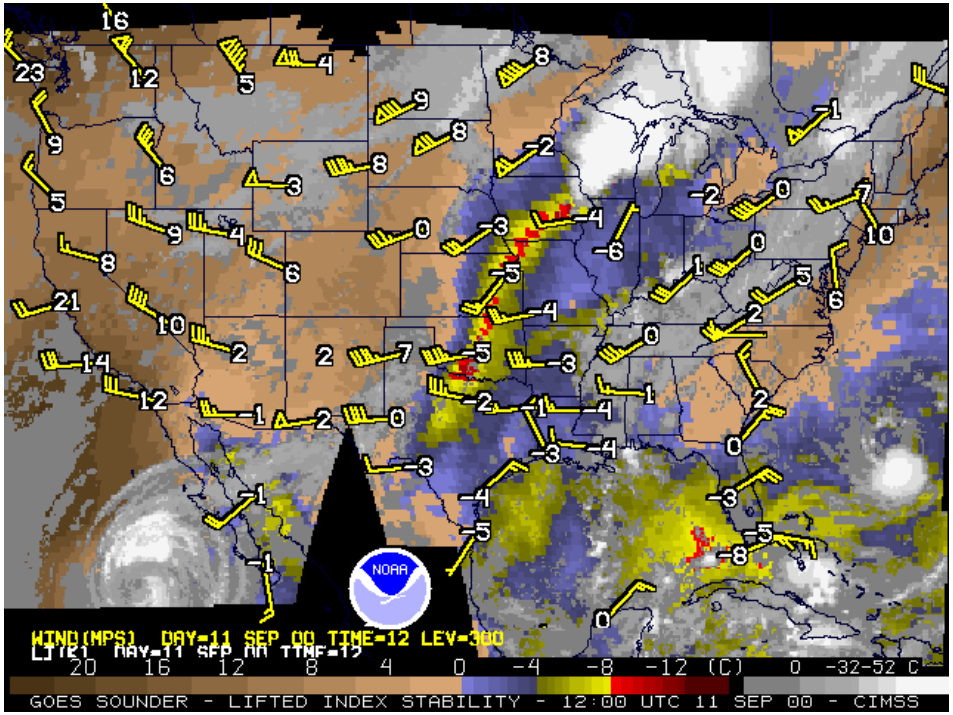
Current instrument has 18 infrared bands.



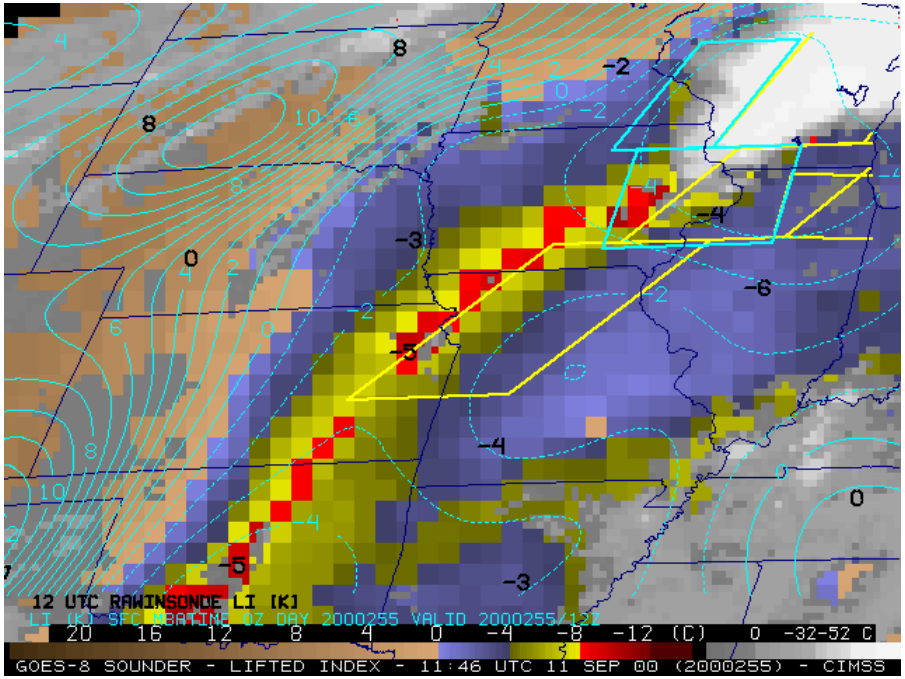
GOES Sounder Uses (non-NWP)

- Radiances/Images
- Moisture Profiles
- Derived Quantities from the retrieved profiles
- 3-layers of Precipitable Water
- Derived Products Images
- Cloud Top Information
- Mid-Level Winds
- 12 micrometer channel (GOES-12 and beyond)
- Possible test-bed for additional imager channels

12 UTC Sounder LI



Zoomed in view:



With Eta forecast and watch boxes

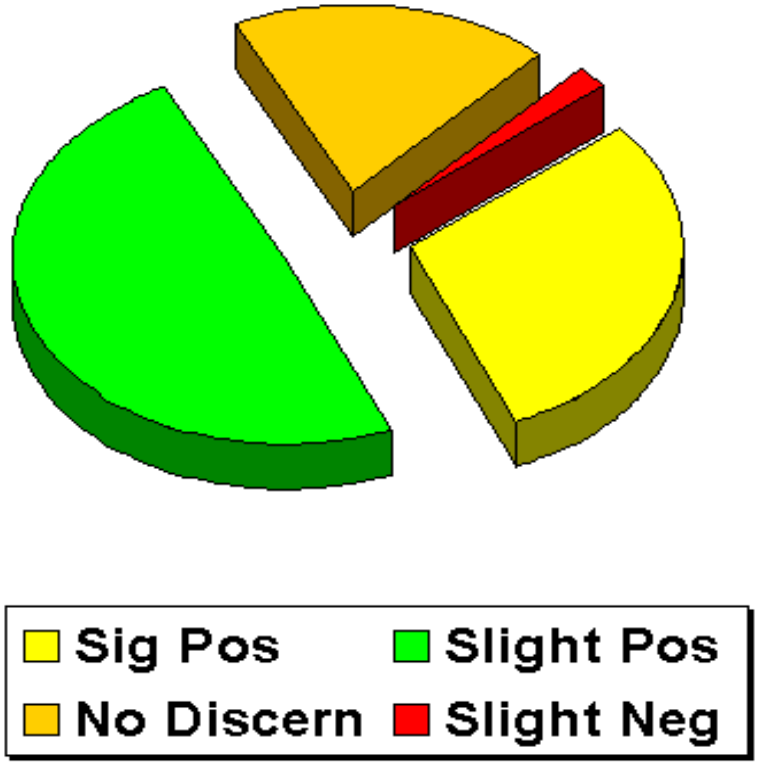
EXCESSIVE RAINFALL POTENTIAL OUTLOOK

HYDROMETEOROLOGICAL PREDICTION CENTER...NWS...CAMP SPRINGS MD

GOES SOUNDER DATA SHOWS THAT PWS SOUTH OF THE OUTFLOW BOUNDARY ARE IN THE 1.60 TO 1.70 INCH RANGE. THE SOUNDER DATA ALSO INDICATES THAT THE AIRMASS TO THE WEST ACROSS IL IS CONTINUING TO DESTABILIZE. ALL THE ABOVE ARGUE FOR THE POTENTIAL FOR ISOLD 3 TO 5 INCH RAINFALL BEFORE THE SYSTEM STARTS SHIFTING EWD.

Janesville, WI received 4 inches of rain; Sullivan, WI had 3 inches.

NWS Forecast Office Assessment of GOES Sounder Atmospheric Instability



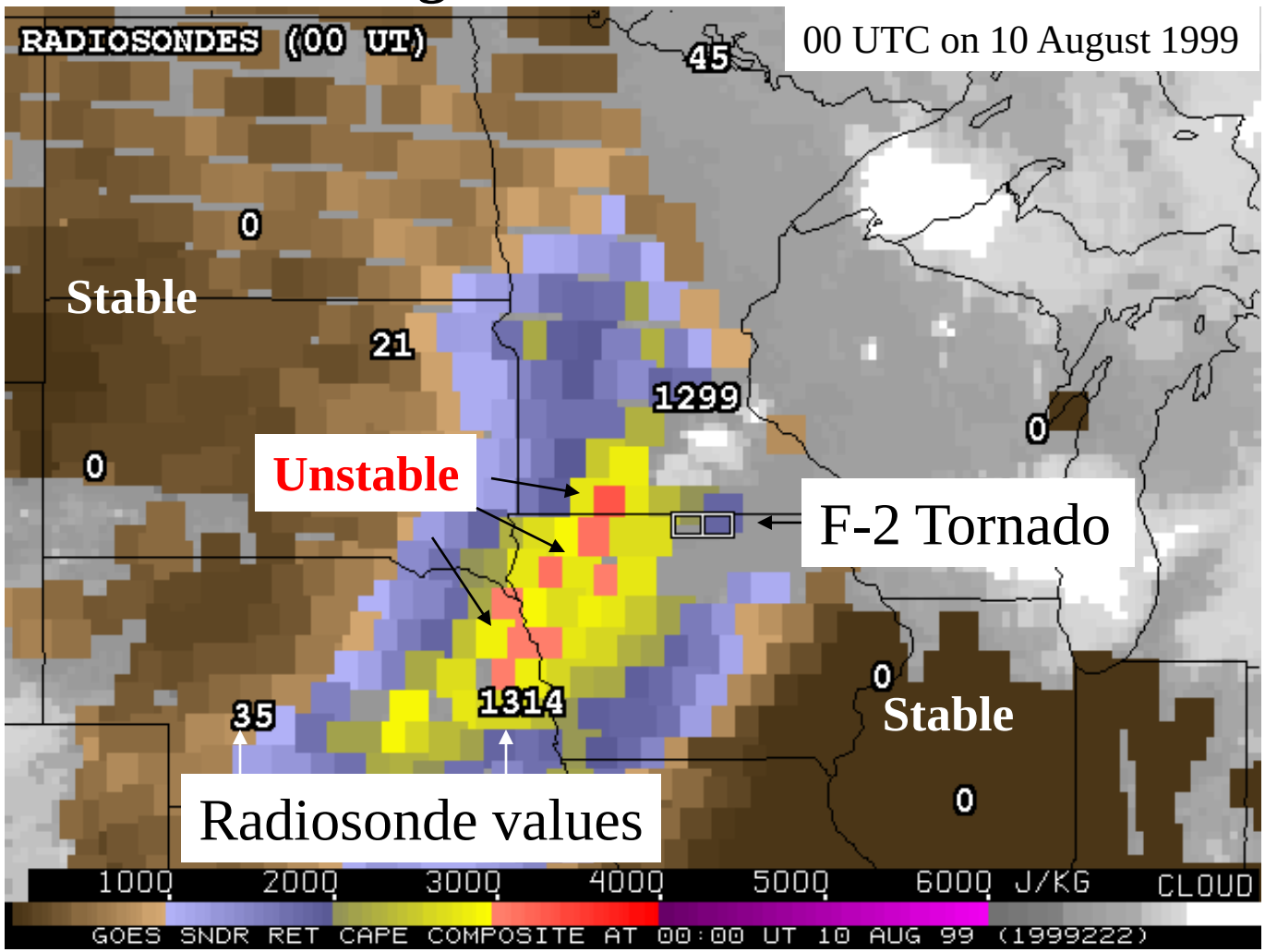
Summer 99 Forecaster assessment of usefulness of changes in hourly LI, CAPE, & CINH product for predicting location/timing of thunderstorms

There were 248 valid weather cases.
- Significant Positive Impact (30%)
- Slight Positive Impact (49%)
- No Discernible Impact (19%)
- Slight Negative Impact (2%)
- Significant Negative Impact (0)

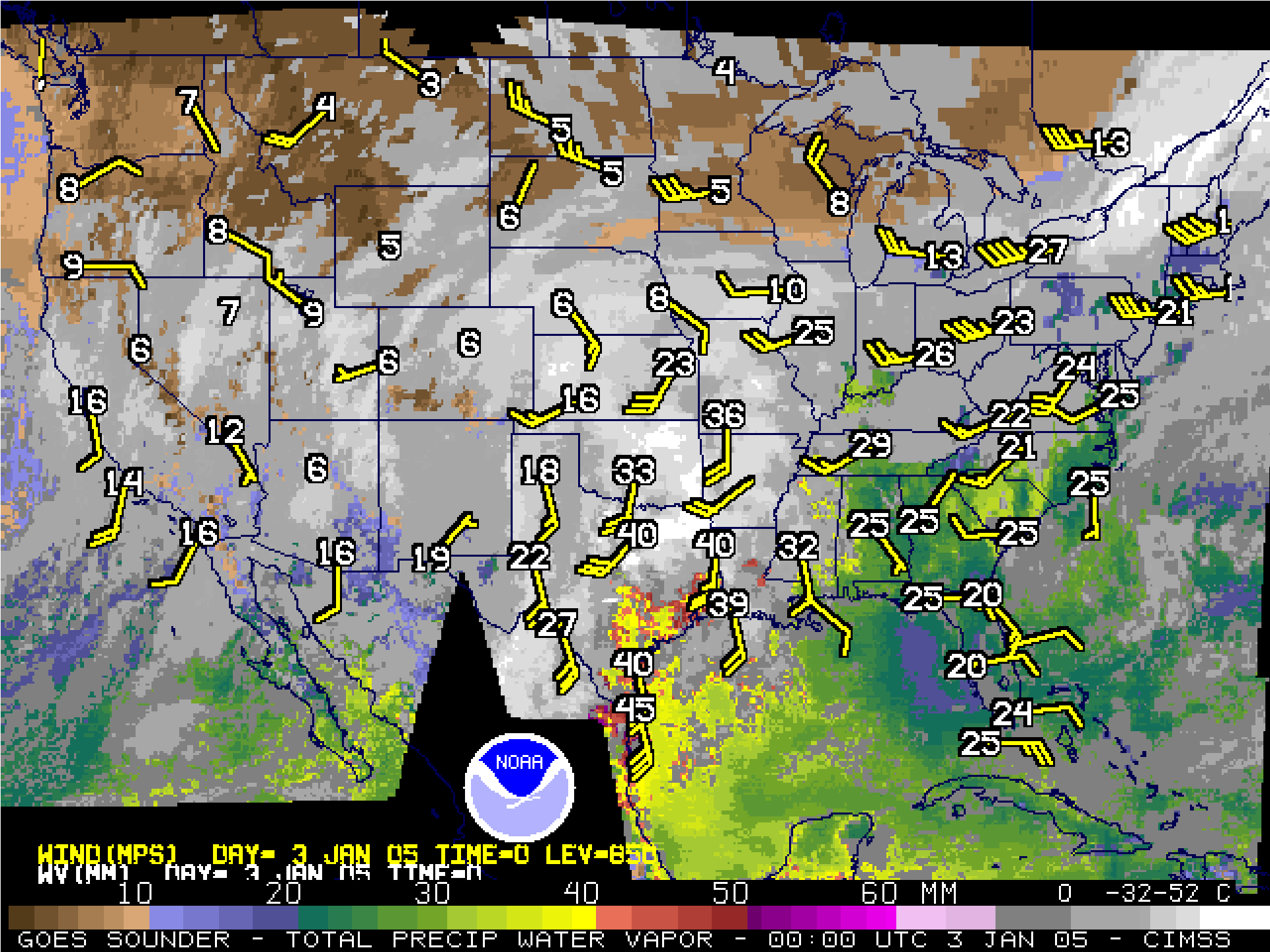
Figure from the National Weather Service, Office of Services

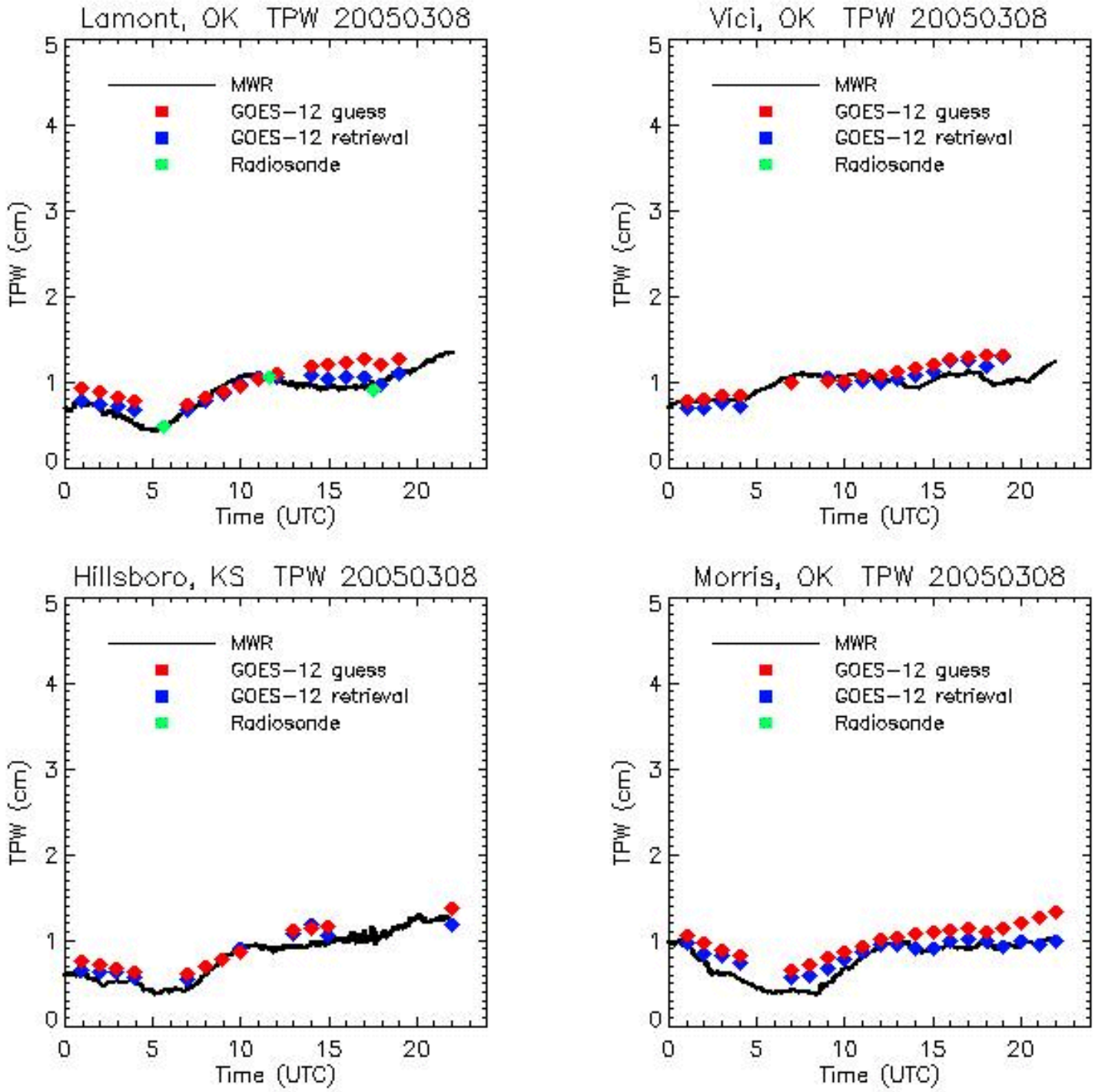
A Derived Product Image of CAPE from the GOES-8 Sounder

NOAA
NESDIS
ORA
ARAD
ASPT

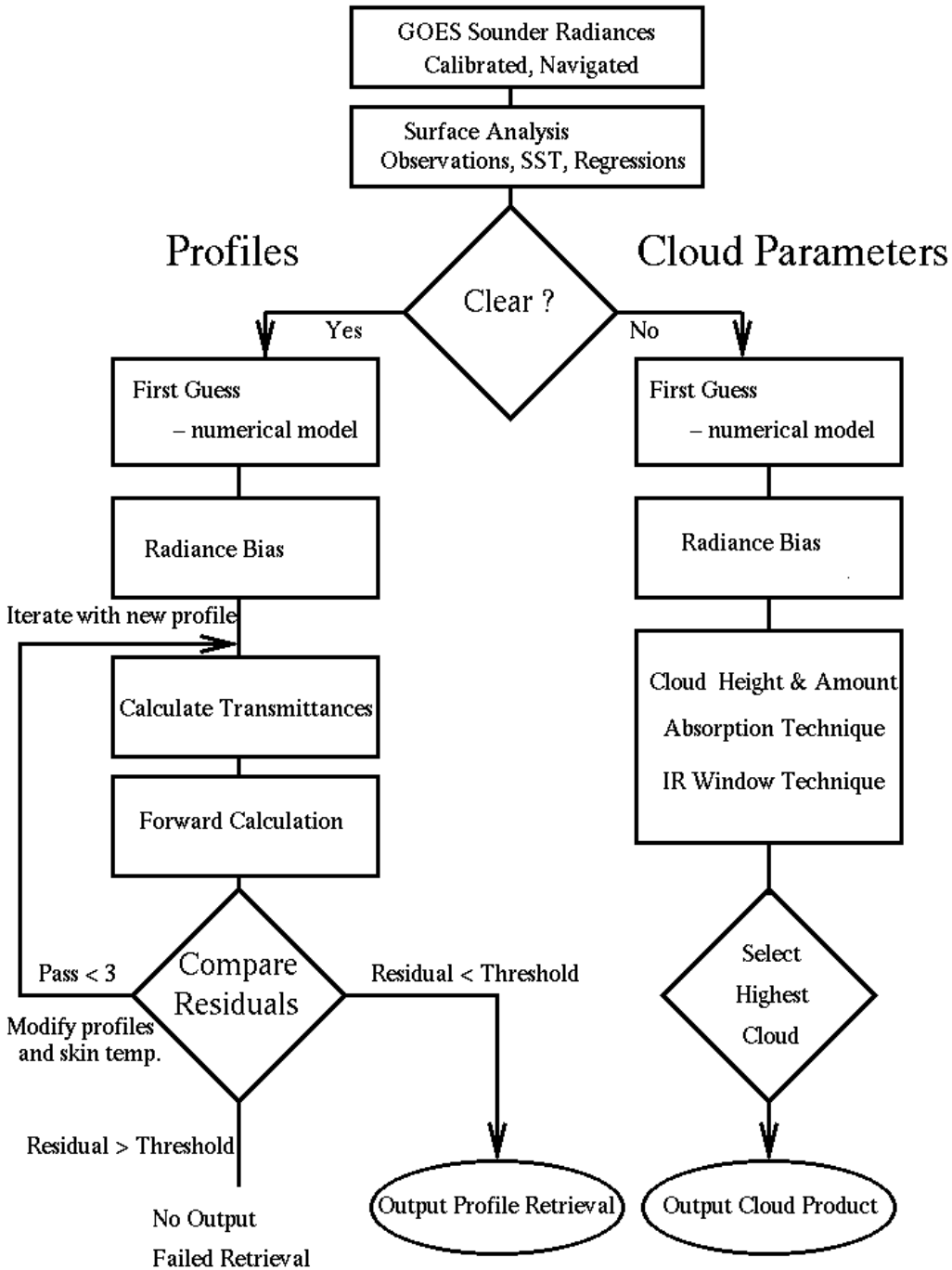


Geostationary Operational Environmental Satellite (GOES)-8 Sounder Convective Available Potential Energy (CAPE) values. The axis of CAPE values greater than 2500 J/kg extended from eastern Nebraska into southern Minnesota. CAPE values calculated from the 00 UTC radiosondes were too sparse to capture this feature. The two counties outlined in northern Iowa show the location of an F-2 tornado that occurred just over two hours later. A NWS forecaster used Sounder data to help correctly forecast this event.


WIND(MPS) DAY= 3 JAN 05 TIME=0 LEV=850
WV(MM) DAY= 3 JAN 05 TIME=0
10 20 30 40 50 60 MM 0 -32-52 C
GOES SOUNDER - TOTAL PRECIP WATER VAPOR - 00:00 UTC 3 JAN 05 - CIMSS

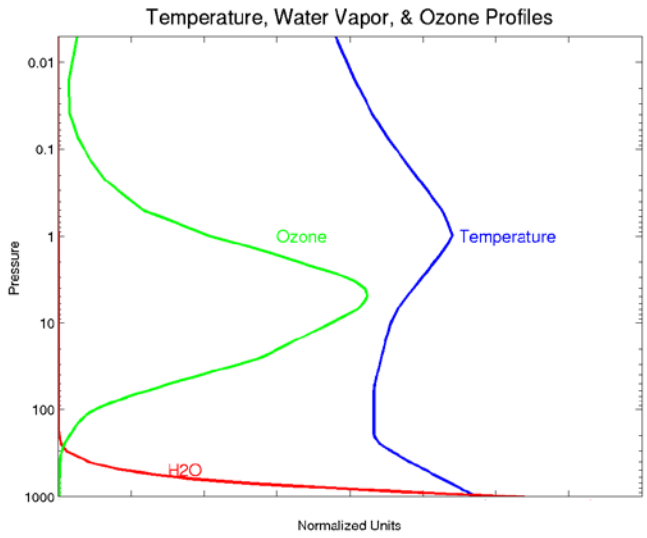

Lamont, OK TPW 20050308
Vici, OK TPW 20050308
Hillsboro, KS TPW 20050308
Morris, OK TPW 20050308
MWR
GOES−12 guess
GOES−12 retrieval
Radiosonde
TPW (cm)
Time (UTC)
0
1
2
3
4
5
0
5
10
15
20

GOES Retrieval System

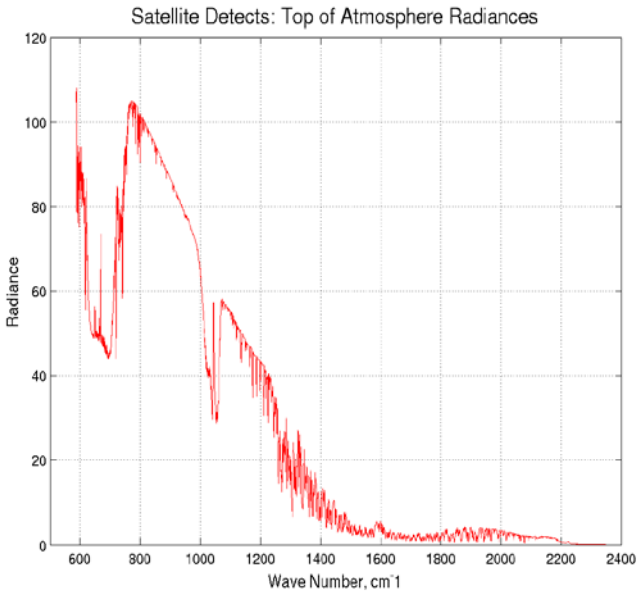


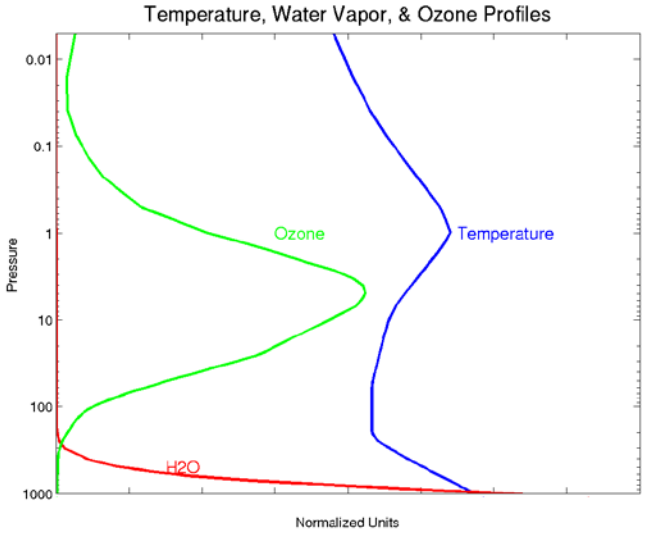
IAPP, IMAPP and GOES physical retrieval algorithm

- Regularization
- Discrepancy principal
- First guess
  - Regression for IAPP and IMAPP
  - Numerical

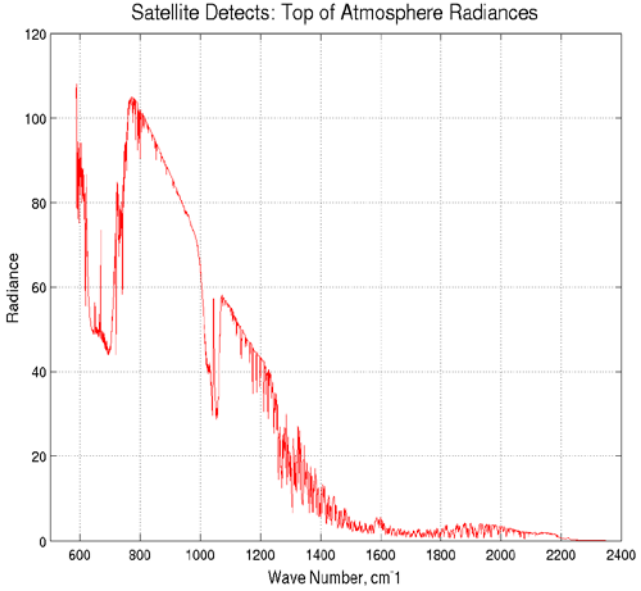


FAST FM





Inverse



Regularization Inversion

Equations

$$J(X) = \left\| Y^m - Y(X) \right\|^2 + \gamma \left\| X - X_0 \right\|^2$$

First guess

Unknowns

$$X, \quad \gamma$$

Solutions

X Newton Iteration

γ

1. Empirical (Susskind 1984; Smith 1985; Hayden 1988)
2. Discrepancy Principle (Li and Haung 1999)

$$\left\| Y^m - Y(X) \right\|^2 = [Y^m - Y(X)] E^{-1} [Y^m - Y(X)]^T$$

$$\left\| X - X_0 \right\|^2 = [X - X_0] H^{-1} [X - X_0]^T$$

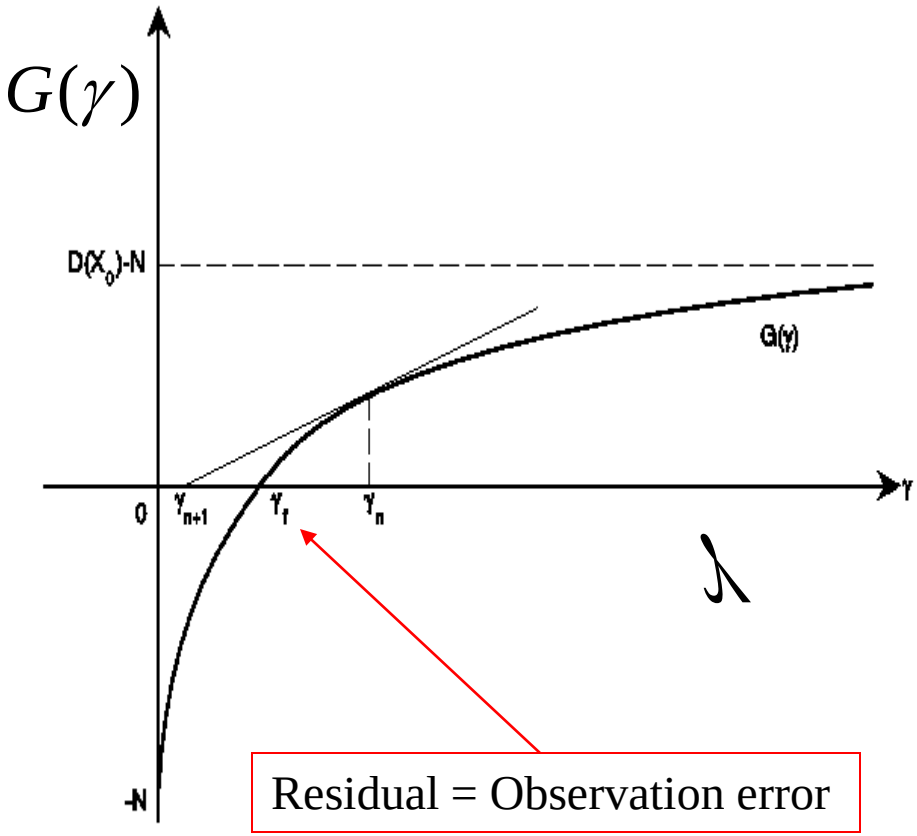
H can be identity matrix or covariance matrix, background information is not necessary, X_0 is the first guess, can be numerical model output, retrieval from regression, or a climate state.

Discrepancy Principal

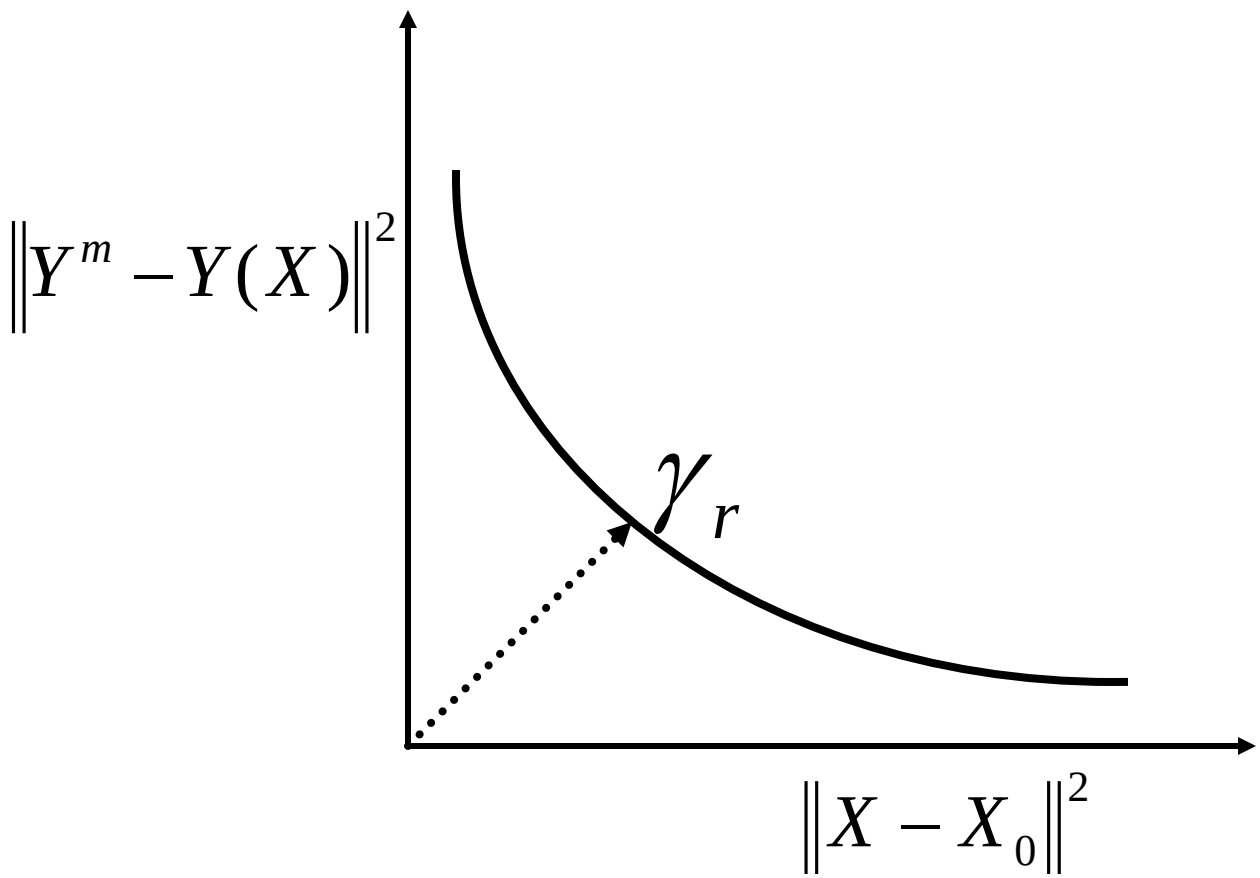
- Iterative solution of γ (Li and Huang 1999, AO).
- Simple adjustment of γ during iterations (Ma et al. 1999; Li et al. 2000, JAM)

Discrepancy Principle

$$G(\gamma) = \left\| Y(X(\gamma)) - Y^m \right\|^2 - \sigma^2$$



L-Curve



1DVAR approach

$$J(X) = \left\| Y^m - Y(X) \right\|^2 + \left\| X - X_B \right\|^2$$

$$\left\| Y^m - Y(X) \right\|^2 = [Y^m - Y(X)] E^{-1} [Y^m - Y(X)]^T$$

$$\left\| X - X_B \right\|^2 = [X - X_B] B^{-1} [X - X_B]^T$$

$$X_{n+1} = X_n - J'(X_n) / J''(X_{n-1})$$

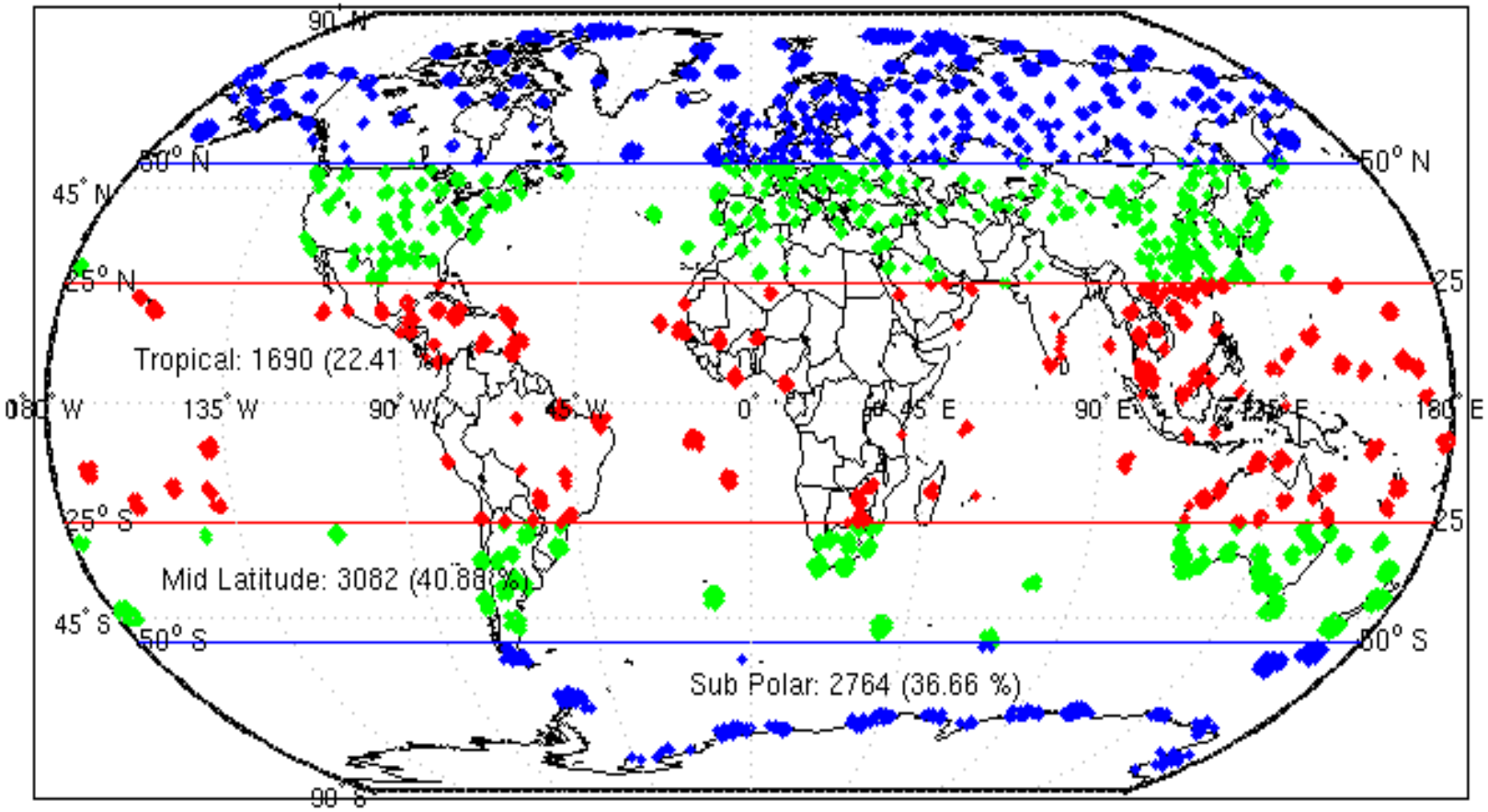
Note that X_0 does not necessary be X_B, X_0 can be X_B or other Initial state such as a retrieval from regression

- 1DVAR good for real data
- Regularization good for both real data and simulation study

Some issues in retrieval

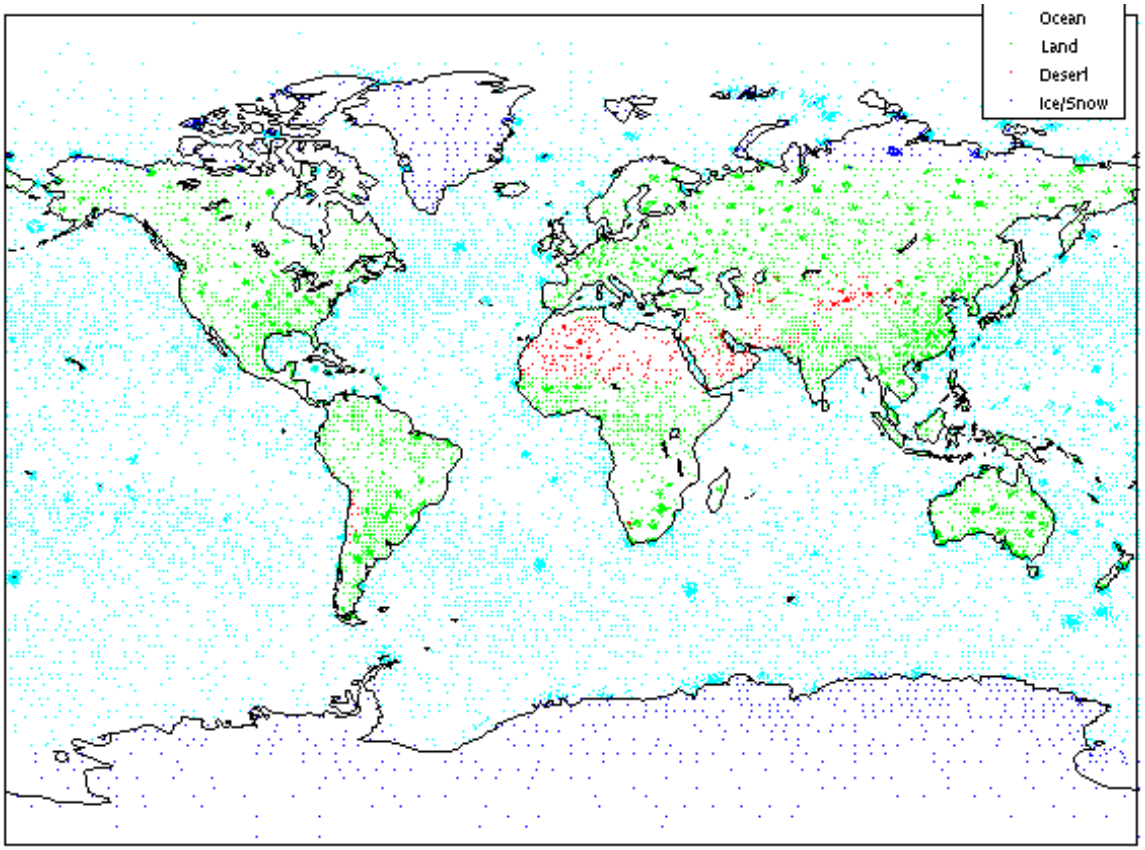
- Methodology
- Handling of surface emissivity
- Model uncertainty
- First guess
  - Training data set
  - Model uncertainty estimation

Spatial Raob Distribution



New Training Database of Global profiles: 12,208 global profiles of temperature, moisture, and ozone for training data set. Profiles are from NOAA-88, ECMWF training set, TIGR-3, ozonesondes, desert radiosondes: all with saturation checks and other QC.

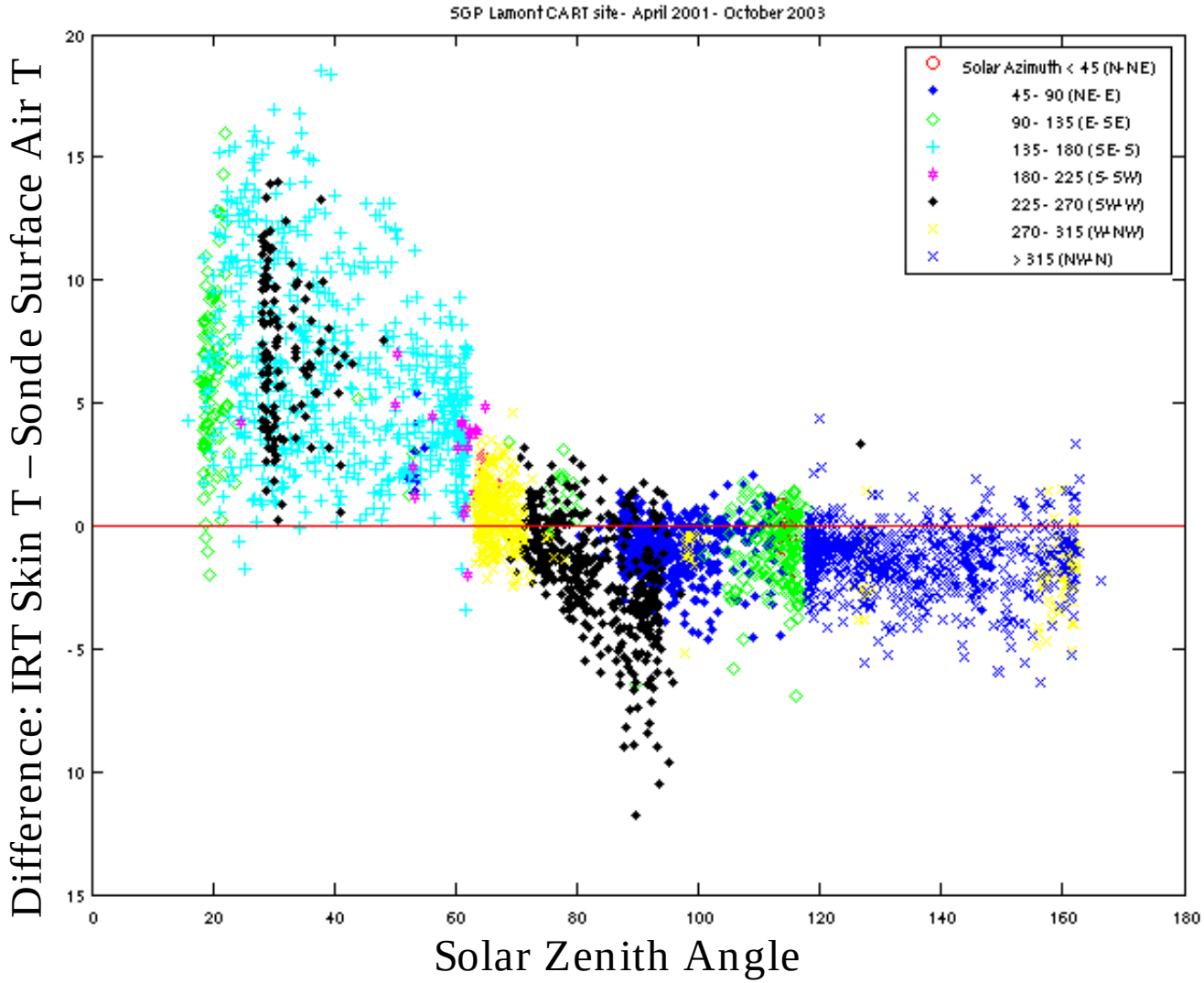
Profiles:	95% RH
NOAA-88b	5356
TIGR-3	1125
Desert sondes	553
Ozonesondes	992
ECMWF profiles	4182
Total	12208



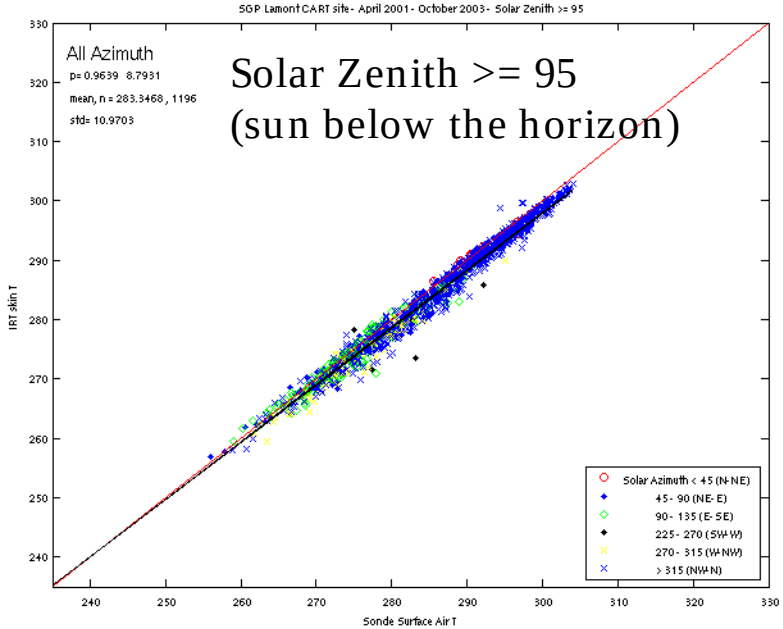
New Skin Temperature assigned to profiles

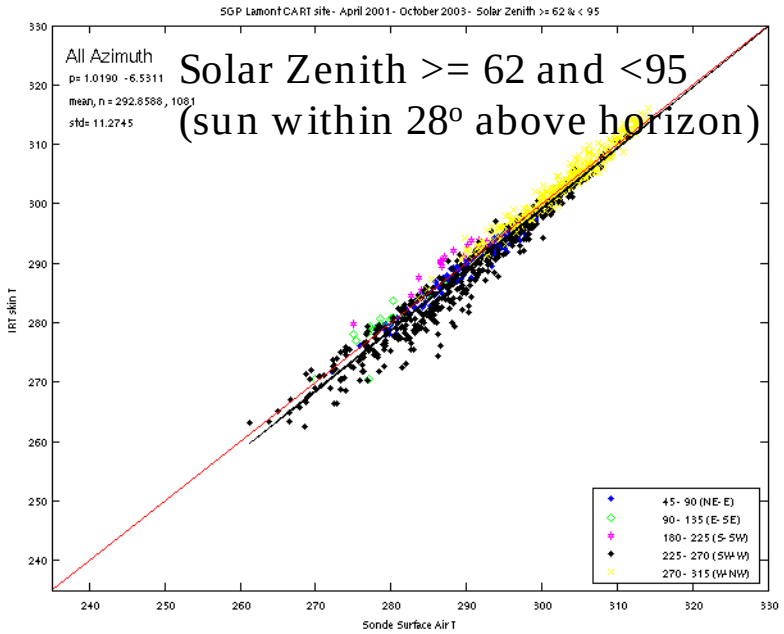
Skin T / Surface Air T relationship for the SGP CART site based on clear sky observations between April 2001 and October 2003.

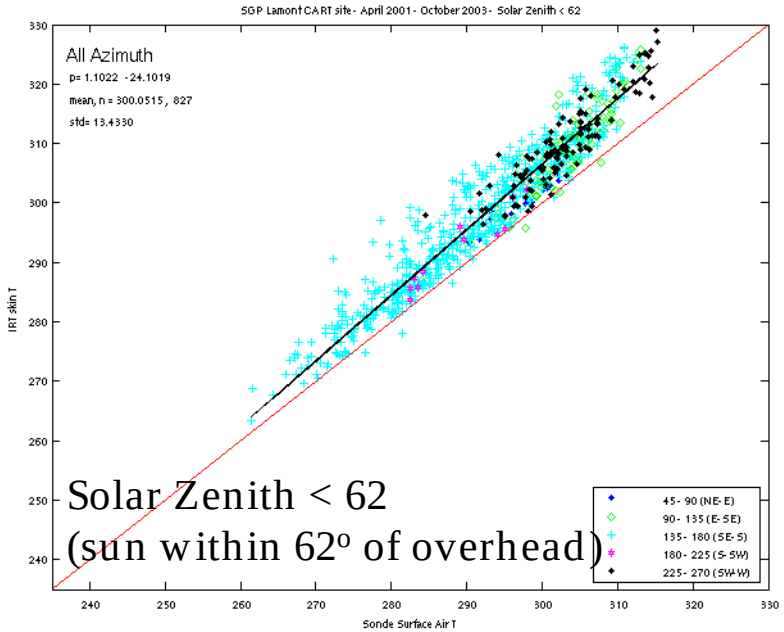
Points are colored by solar azimuth category.



Another look at these relationships, as a function of solar zenith (3 categories) & azimuth (8 categories)

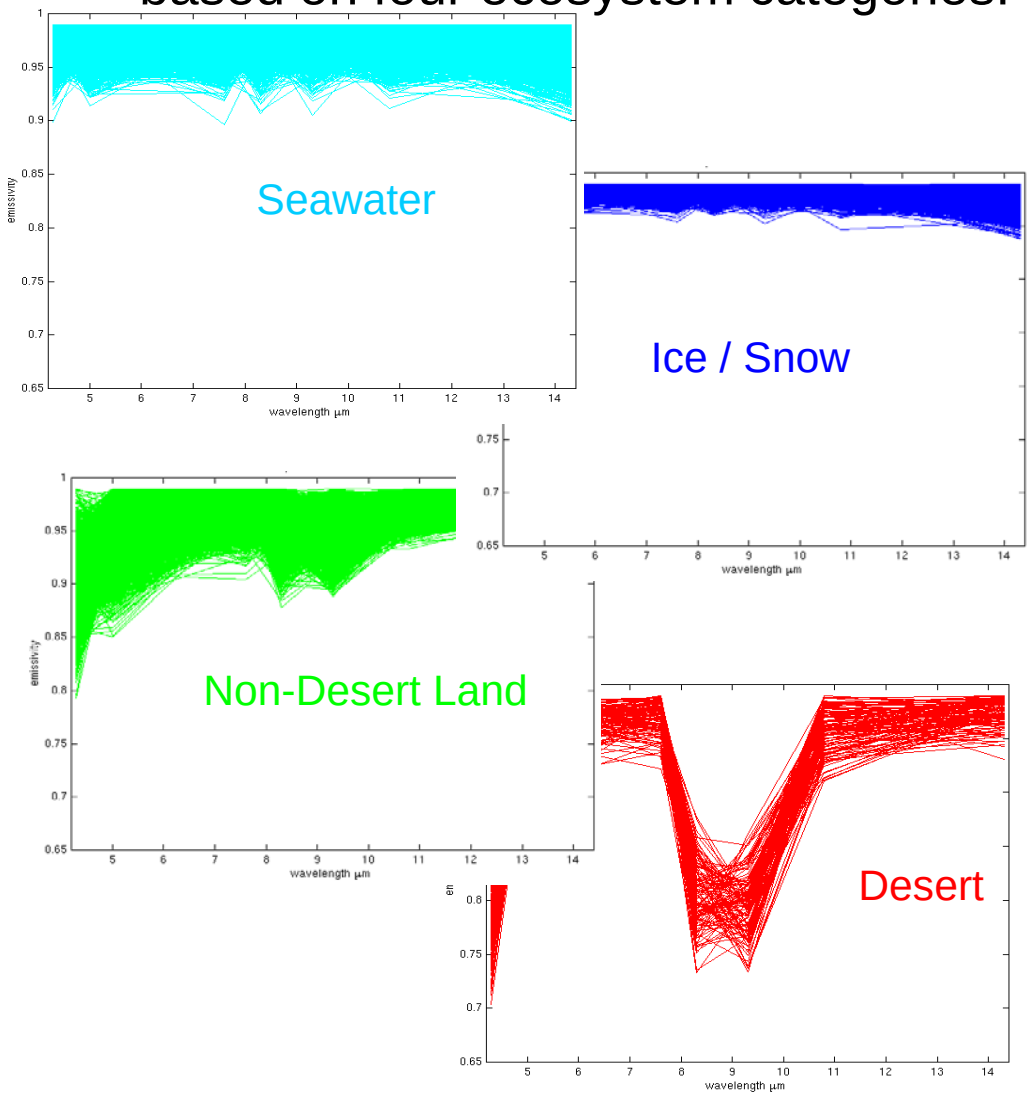






New Surface Emissivity assigned to profiles

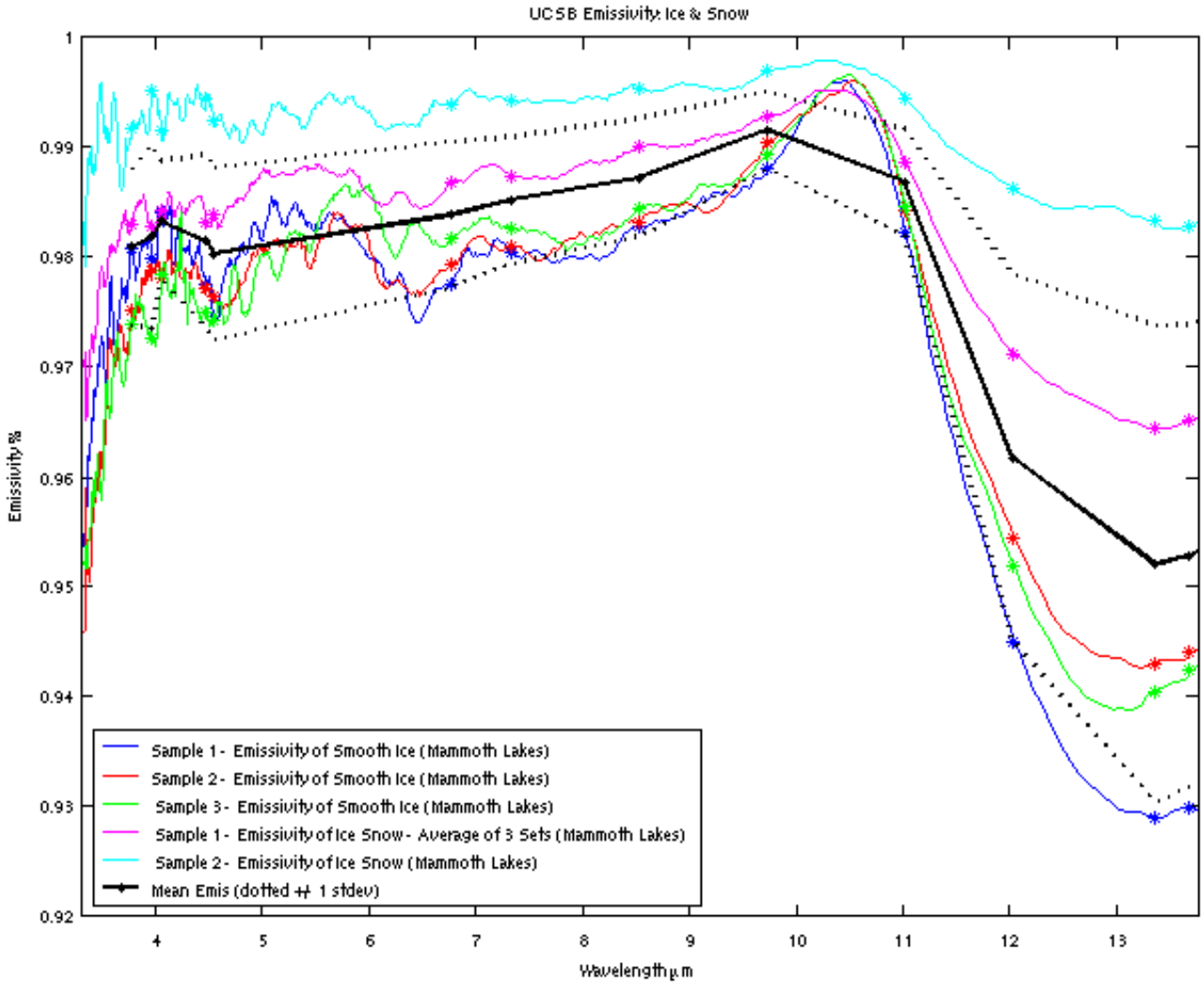
Old Emissivity in collection 4 was based on four ecosystem categories:



New Emissivity in collection 5 further divides the “non-desert land” category into 14 IGBP ecosystem groups, as a function of month and latitude band. New seawater, desert, and ice/snow emissivities also used.

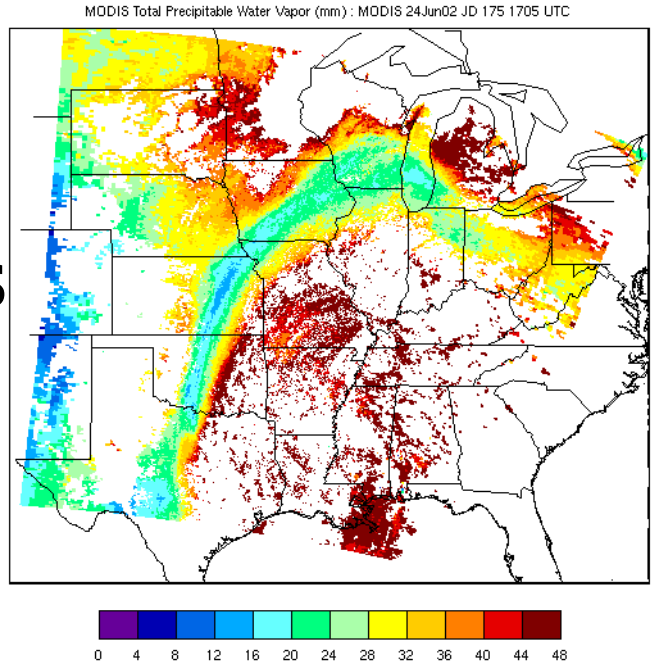
MODIS MOD11 emissivity and laboratory measurements were used to derive these new emissivities.

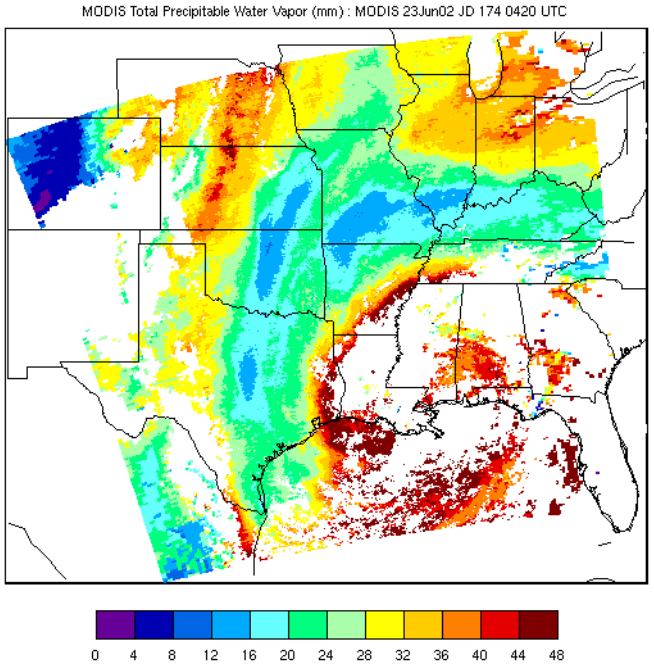
See next slides for more on new emissivity.



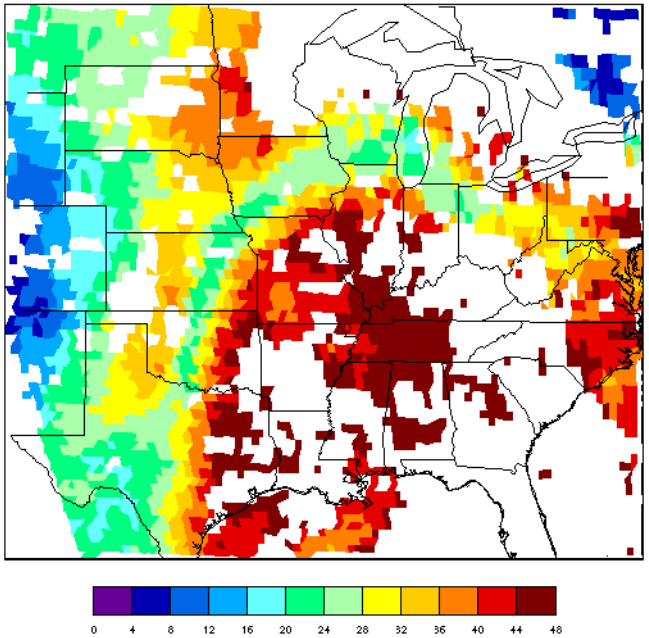
Ice & Snow emissivity is based on the the average of a number of ice and snow laboratory measurements from USCB's emissivity library (Dr. Wan).

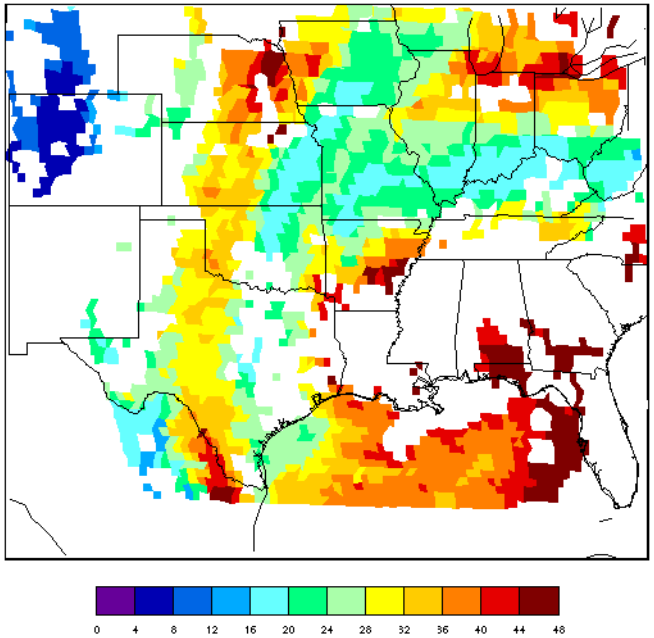
MODIS


MODIS Total Precipitable Water Vapor (mm) : MODIS 24Jun02 JD 175 1705 UTC
0 4 8 12 16 20 24 28 32 36 40 44 48


MODIS Total Precipitable Water Vapor (mm) : MODIS 23Jun02 JD 174 0420 UTC
0 4 8 12 16 20 24 28 32 36 40 44 48

GOES


0 4 8 12 16 20 24 28 32 36 40 44 48


0 4 8 12 16 20 24 28 32 36 40 44 48

GOES uniqueness: time continuity for GOES Sounder retrieval – Current plans

1. Two time steps
2. 3 by 3 FOVs
3. Spatial smoothing
4. Forecast + GOES Sounder in statistical

General Forward Model: $R = F(Y)$

General Inverse Model: $Y=F^{-1}(Y^b, R)$

Physical Inverse Model (can be iterative form):

$$Y=Y^b+[F'^T*E^{-1}*F'+\gamma I]^{-1}*F'^T*E^{-1}*[R-F(Y^b)]$$

Regression inverse model: $Y=C_0+C_1Y^b+C_2R$

$$Y_1=C_0+C_1Y_0+C_2R_1$$

$$Y_2=C_0+C_1Y_1+C_2R_2$$
$$=C_0+C_0C_1+C_1^2Y_0+C_1C_2R_1+C_2R_2$$

$$Y_3=C_0+C_1Y_2+C_2R_3$$
$$=C_0+C_0C_1+C_0C_1^2+C_1^3Y_0+C_1^2C_2R_1+C_1C_2R_2+C_2R_3$$

$$Y_4=C_0+C_1Y_3+C_2R_4$$
$$=C_0+C_0C_1+C_0C_1^2+C_0C_1^3+C_1^4Y_0+C_1^3C_2R_1+C1^2C_2R_2+C_1C_2R_3+C_2R_4$$

$$Y_i=C_0+C_1Y_{i-1}+C_2R_i$$
$$= C_0\Sigma C_1^{j-1}+C_1^iY_0+C_1^{i-1}C_2R_1+C_1^{i-2}C_2R_2+C_1^{i-3}C_2R_3+\ldots\ldots+ C_1^2C_2R_{i-2}+C_1C_2R_{i-1}+C_2R_i$$
$$= C_0^*+C_1^iY_0+A_1R_1+A_2R_2+A_3R_3+\ldots\ldots+A_{i-2}R_{i-2}+A_{i-1}R_{i-1}+A_iR_i$$

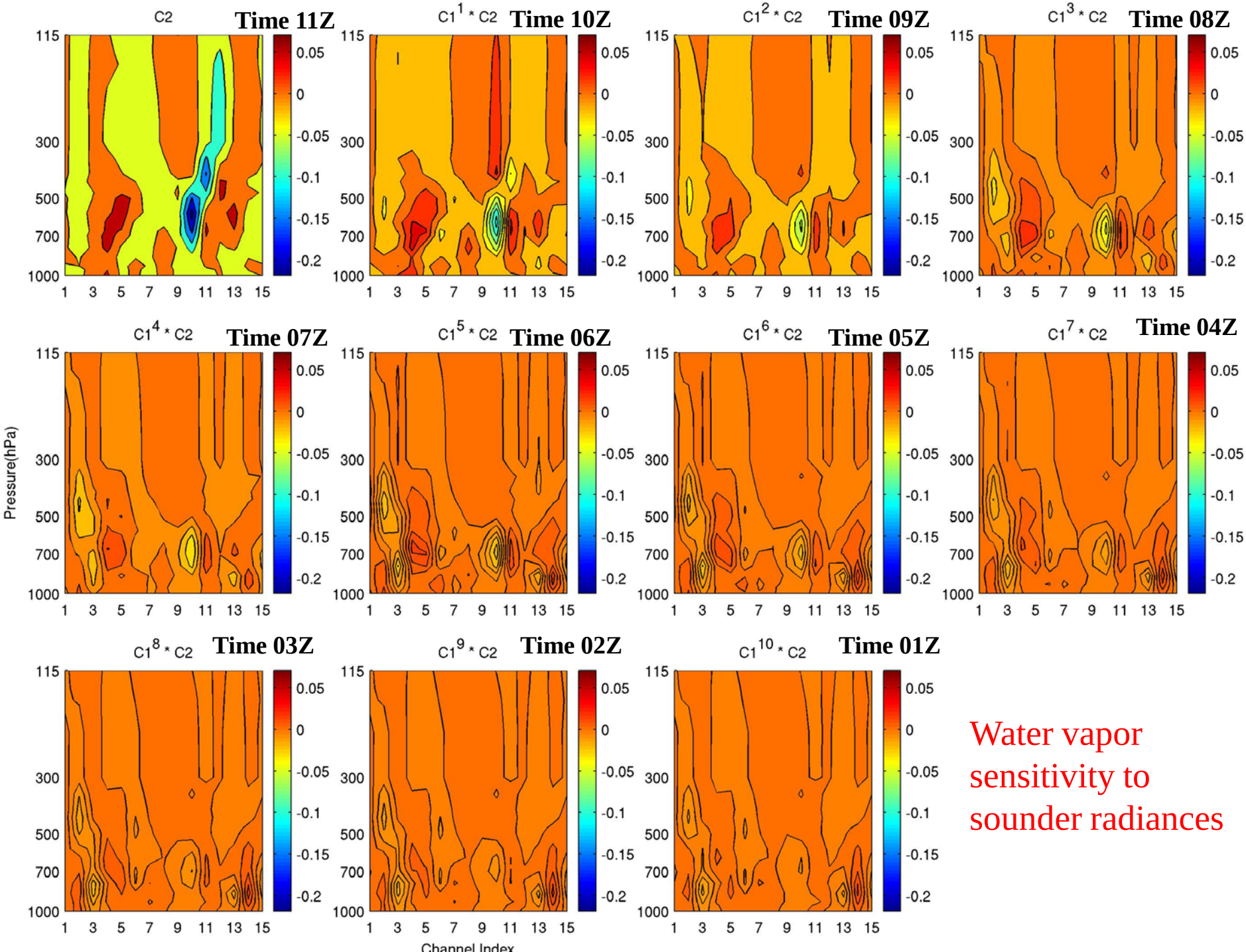
(j=1, 2, ……, i)

1. Time continuity (TC)

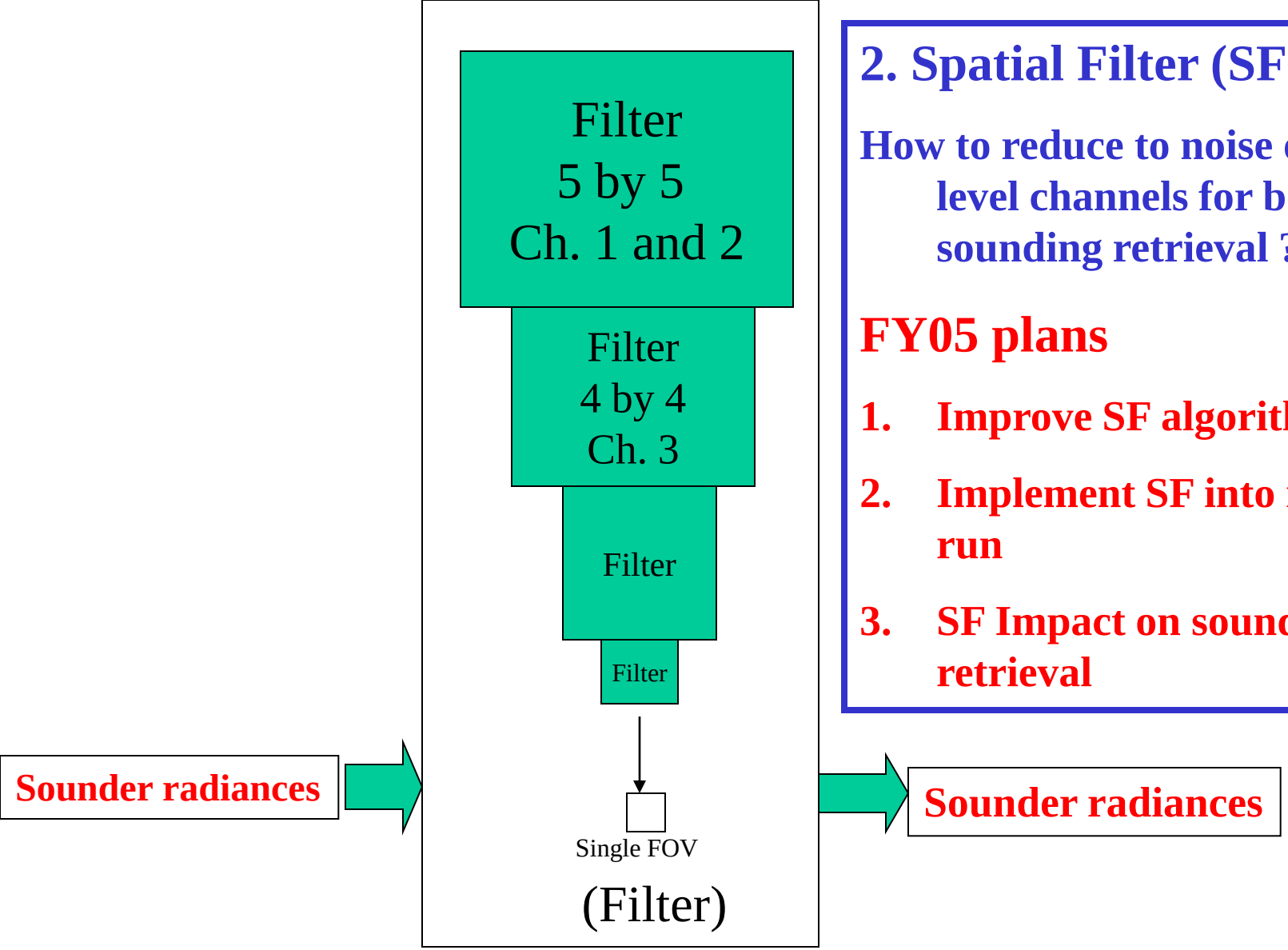
How to take the advantage of high temporal resolution to improve the sounding retrieval ?

FY05 plans

1. Implement time (TC) algorithm into routinely run
2. Validate the TC improvement over the current approach



Water vapor sensitivity to sounder radiances



2. Spatial Filter (SF)

How to reduce to noise of upper level channels for better sounding retrieval ?

FY05 plans

1. **Improve SF algorithm**
2. **Implement SF into routinely run**
3. **SF Impact on sounding retrieval**

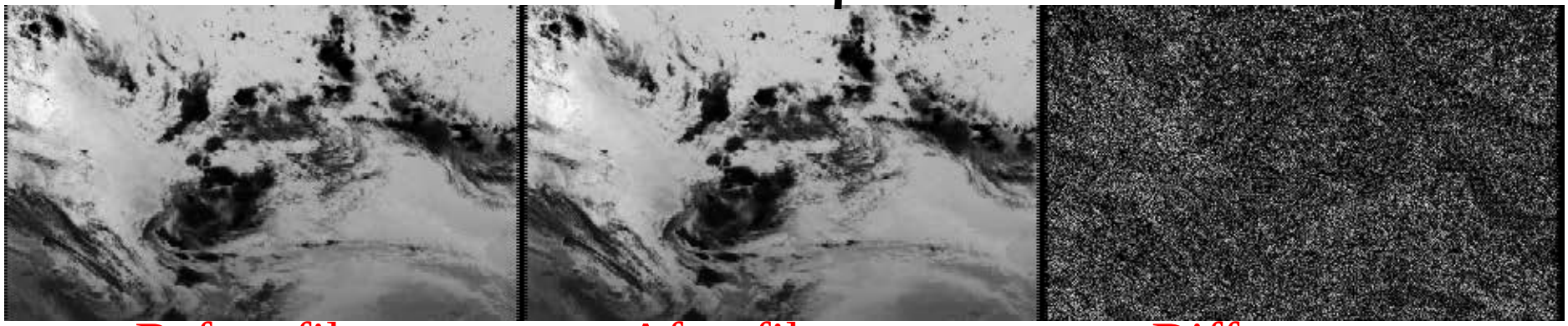
(1) Only average clear FOVs' radiances !

(2) Do cloud check using Sounder radiances only !

Band 1: 14.7 µm

Before filter | After filter | Difference

Band 9: 9.7 µm



Before filter | After filter | Difference

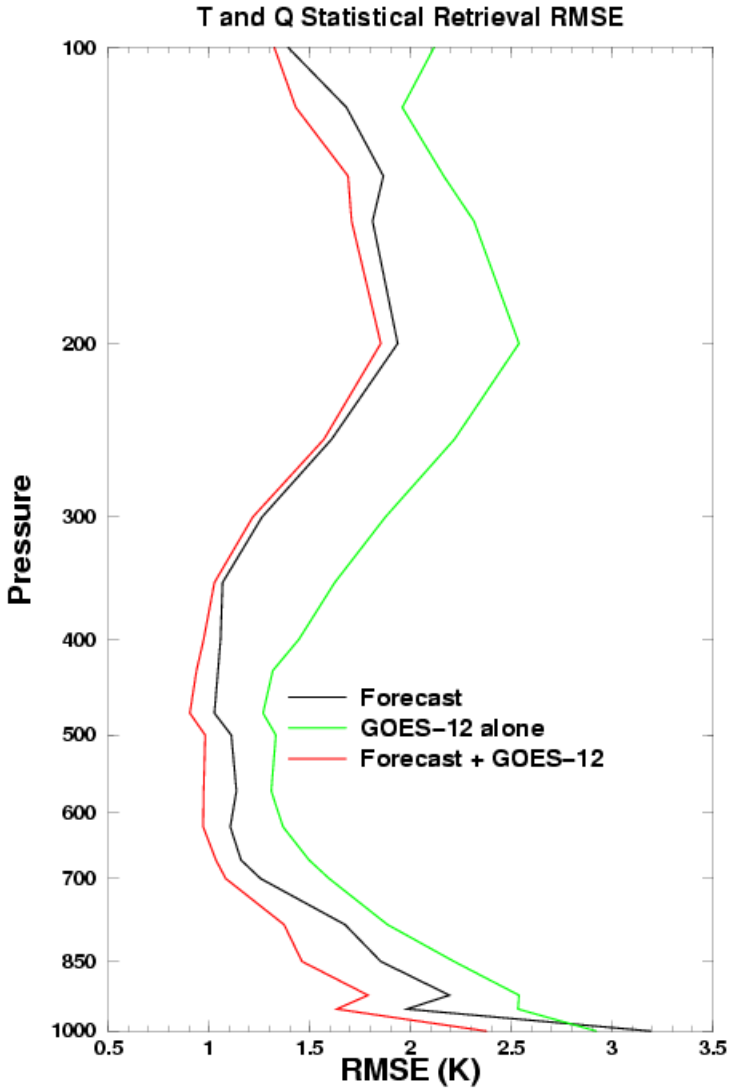
(789 profiles)

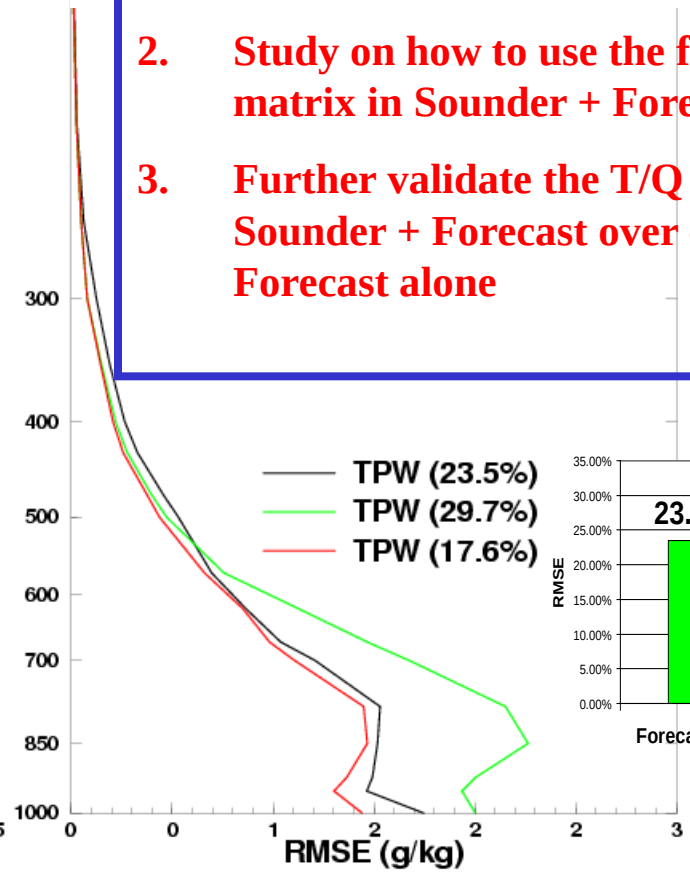
3. Sounder + Forecast for sounding improvement

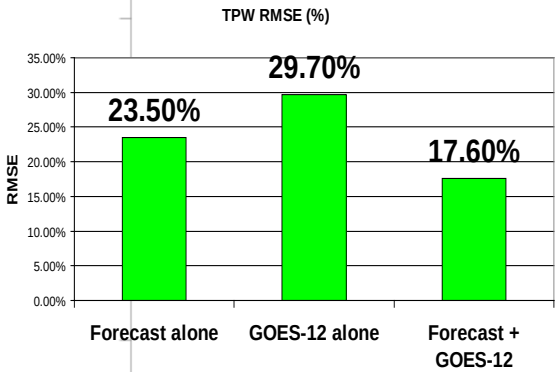
How to use GOES sounder radiances optimally to improve the forecast ?

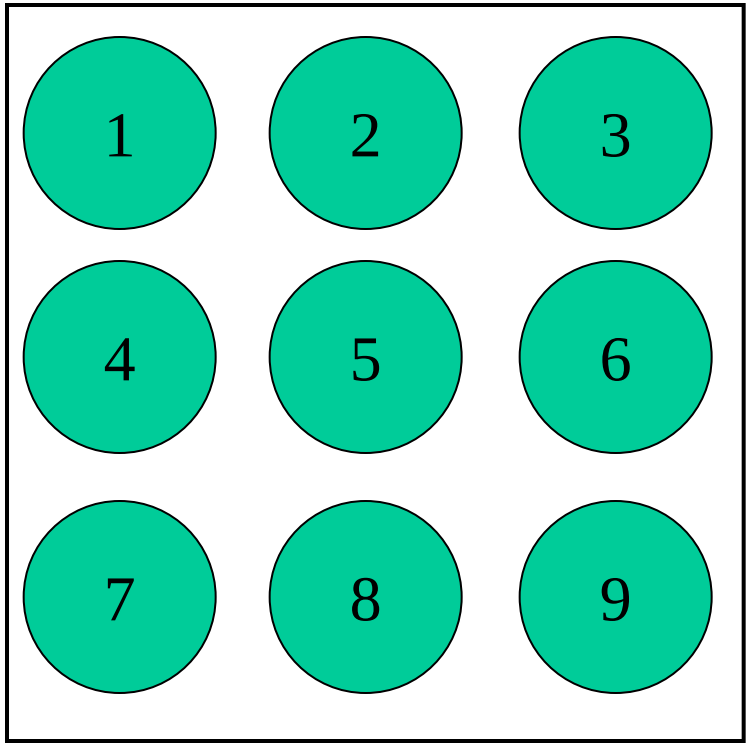
FY05 plans:

1. **Implement algorithm into routine run for GOES-10 and GOES-12;**
2. **Study on how to use the forecast error covariance matrix in Sounder + Forecast retrieval**
3. **Further validate the T/Q improvement of Sounder + Forecast over either Sounder alone or Forecast alone**









i: channel index (i=1, 2, …, 18)
j: time step index (j=1, 2)
k: FOV index (k=1, 2, …, 9)

T(p): constant spatially and temporally
q(p): variable spatially and temporally
ε: constant spatially and temporally
Ts: variable spatially and temporally

$$R_{i,j,k} = B_s(Ts_{j,k})\tau_s[T(p), q_{j,k}(p)]\varepsilon_s - \int_0^{p_s} B[T(p)]d\tau[T(p), q_{j,k}(p)]$$

$$+(1-\varepsilon_s)\int_0^{p_s} B[T(p)d\tau^*[T(p), q_{j,k}(p)]$$

where $\tau^* = \tau_s^2 / \tau$

Total number of equations = 18 * 9 * 2

GOES-R Instruments

- Advanced Baseline Imager (ABI)
- **Hyperspectral Environmental Suite (HES)**
  - **Disk Sounding**
  - **Severe Weather Mesoscale**
  - Coastal Imager
- Solar Instrument Suite (SIS)
- Space Environment In Situ Suite (SEISS)
- Auxiliary Services (AUX)
- Magnetometer (MAG)
- Geostationary Lightning Mapper (GLM)

The road to HES-IR

(~1600) ***HES*** (2013-)

(~1600) ***GIFTS*** (2008?-)

CrIS (2006-)

(~8500) **IASI** (2005-)

(~2400) **AIRS** (2002-)

NAST-I (1998-)

IMG (1997)

(18) ***GOES Sounder*** (1994-)

HIS (1985-)

(12) ***VAS*** (1980-)

VTPR, HIRS (1973, 1975-)

SIRS, IRIS (1969)

time

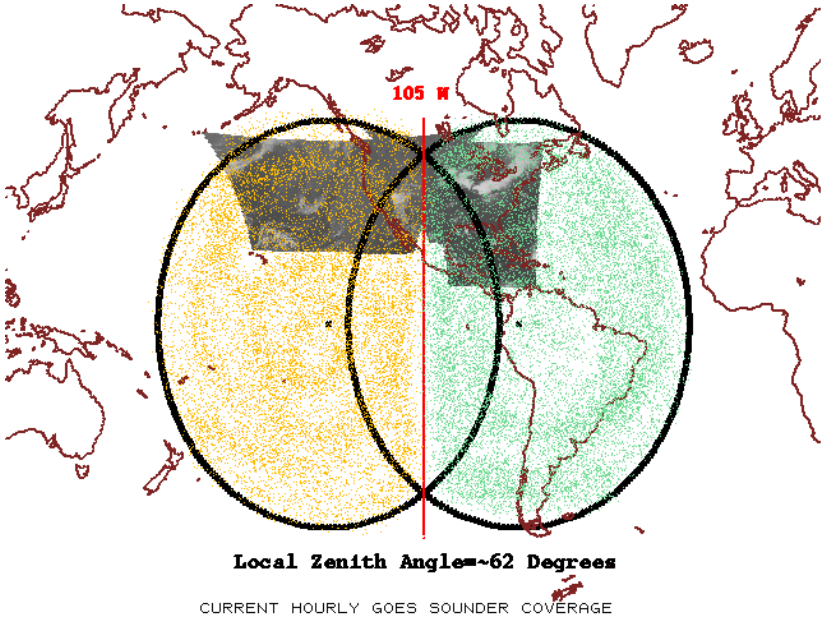
HES-IR Tasks

- HES - Disk Sounding (HES-DS)
  - Provide **vertical moisture and temperature information**, and **other environmental data** that will be used by NOAA and other public and private agencies to produce routine meteorological analyses and forecasts
  - Provide data that may be used to extend knowledge and understanding of the atmosphere and its processes in order to **improve short/long-term weather forecasts**.

- HES - Severe Weather / Mesoscale (HES-SW/M)
  - Provide **environmental data** that can be used to expand knowledge of **mesoscale** and synoptic scale storm development and provide data that may be used to help in forecasting severe weather events.
  - Backup mode in the event of a GOES-R ABI failure (both).

HES-Disk Sounding (HES-DS) task

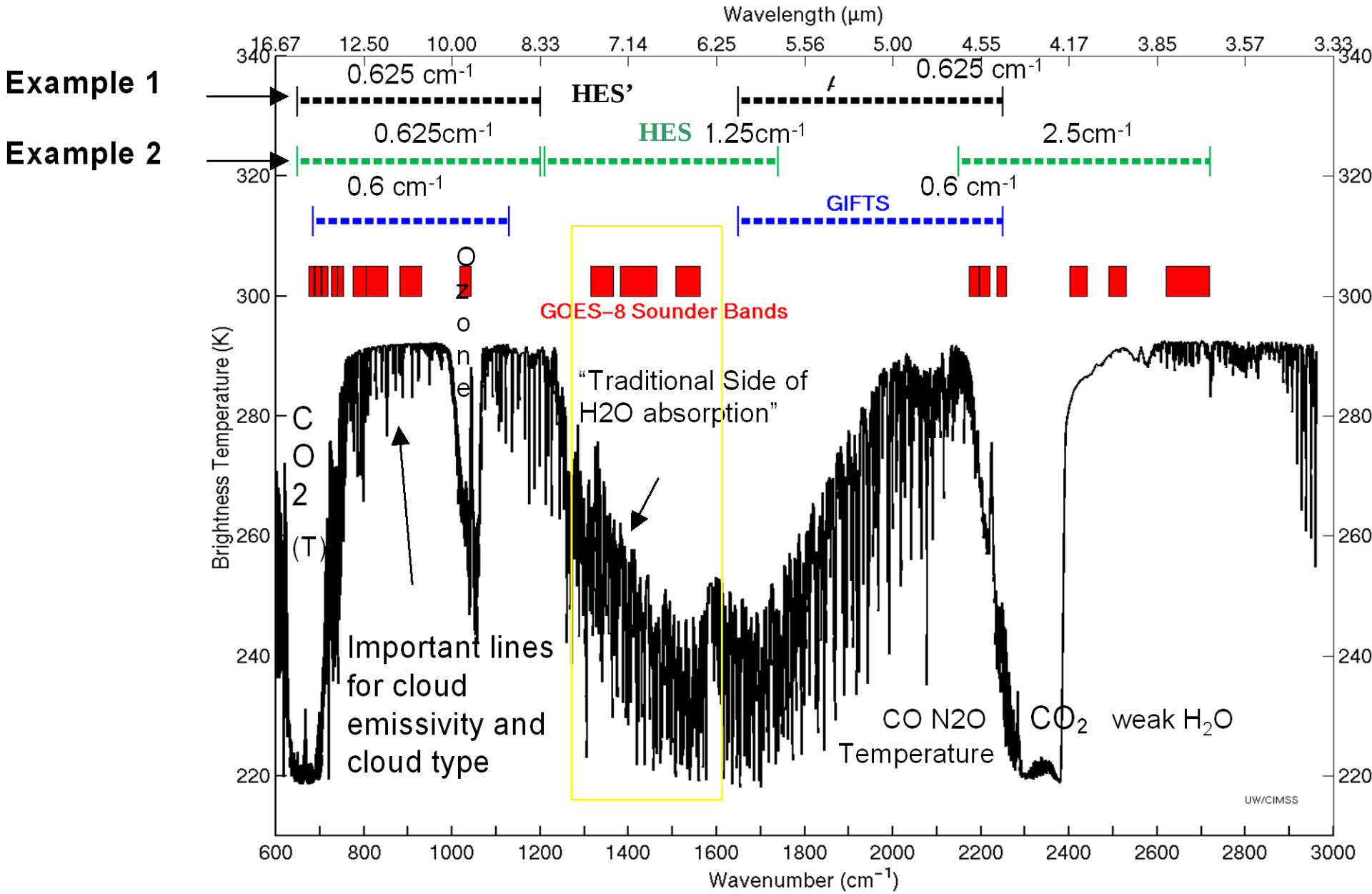
- Spatial Resolution
  - IR: Threshold=10 km, Goal=2 km,
  - Vis: Threshold=1.0 km, Goal= 0.5 km
- Coverage rate (Threshold)
  - 62 degree LZA / hour at 10 km resolution
    - Coverage area must be flexible and selectable.



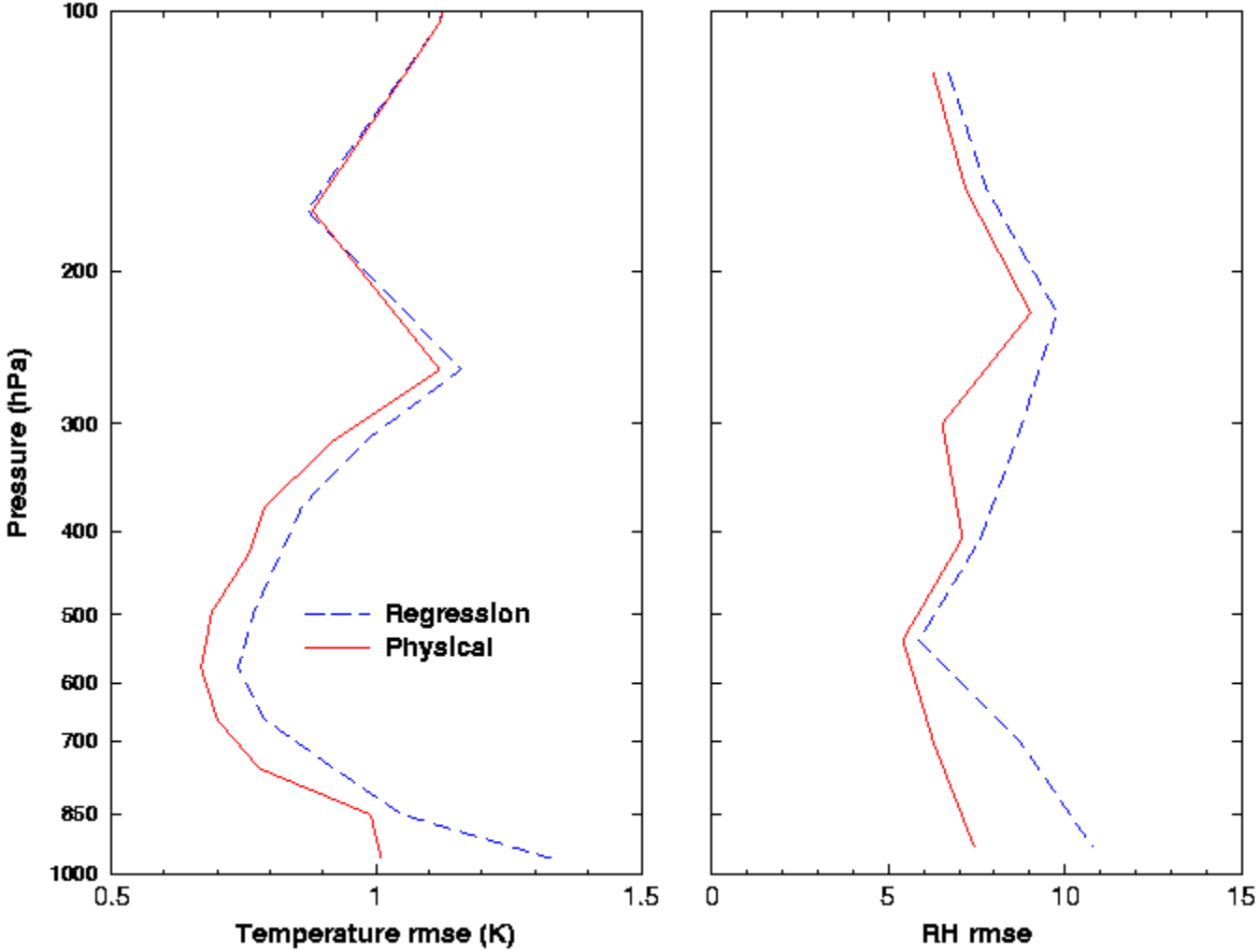
HES-Severe Weather/Mesoscale task

- Spatial Resolution
  - IR: Threshold=4 km, Goal=2 km,
  - Vis: Threshold=1.0 km, Goal= 0.5 km
- Coverage rate
  - 1000 km x 1000 km (locations vary) in 4.4 minutes
  - Coverage area must be flexible and selectable.
- Spectral coverage:
  - Specific examples are cited in the MRD, same as HES-DS
- Spectral resolution:
  - 15 um CO_2 band: 0.6 cm^{-1}, Windows: 0.6-1.0 cm^{-1}, Ozone: 1 cm^{-1}, H_2O: 1-2 cm^{-1}, near 4 um: 2.5 cm-1, Visible: 0.18 um

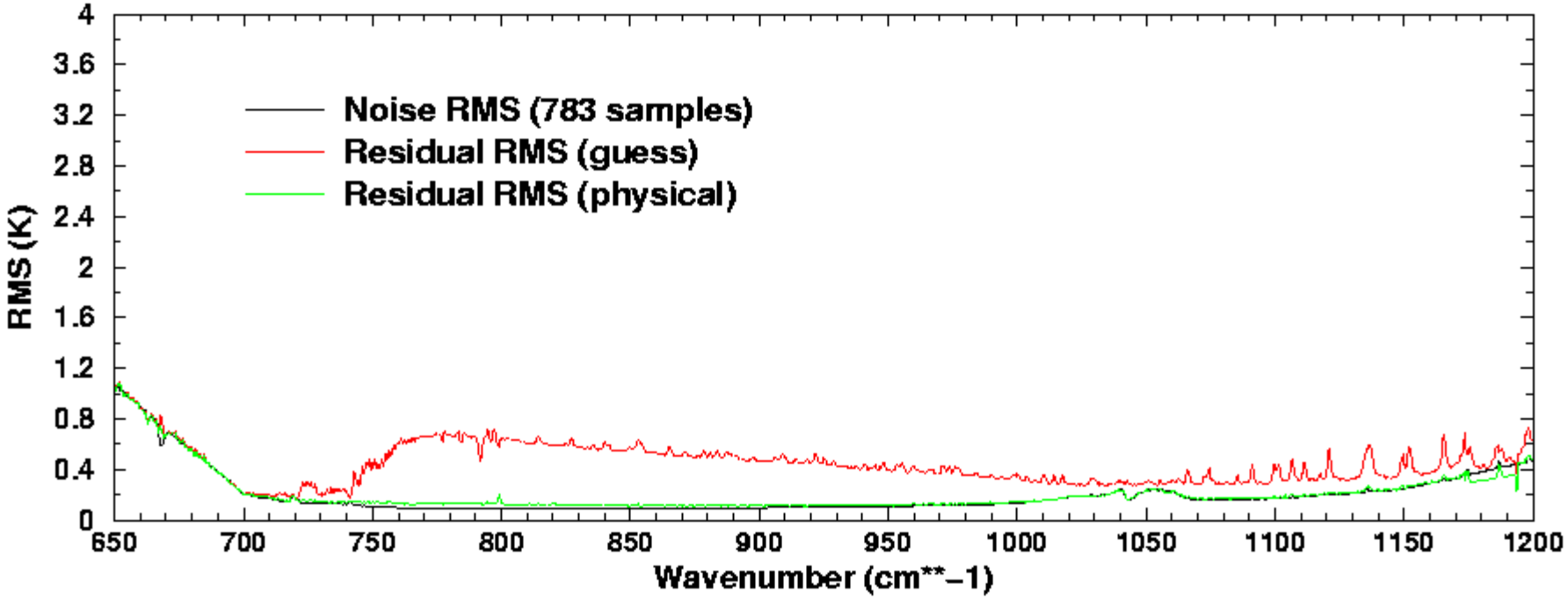
IR Spectral Coverage (DS or SW/M)

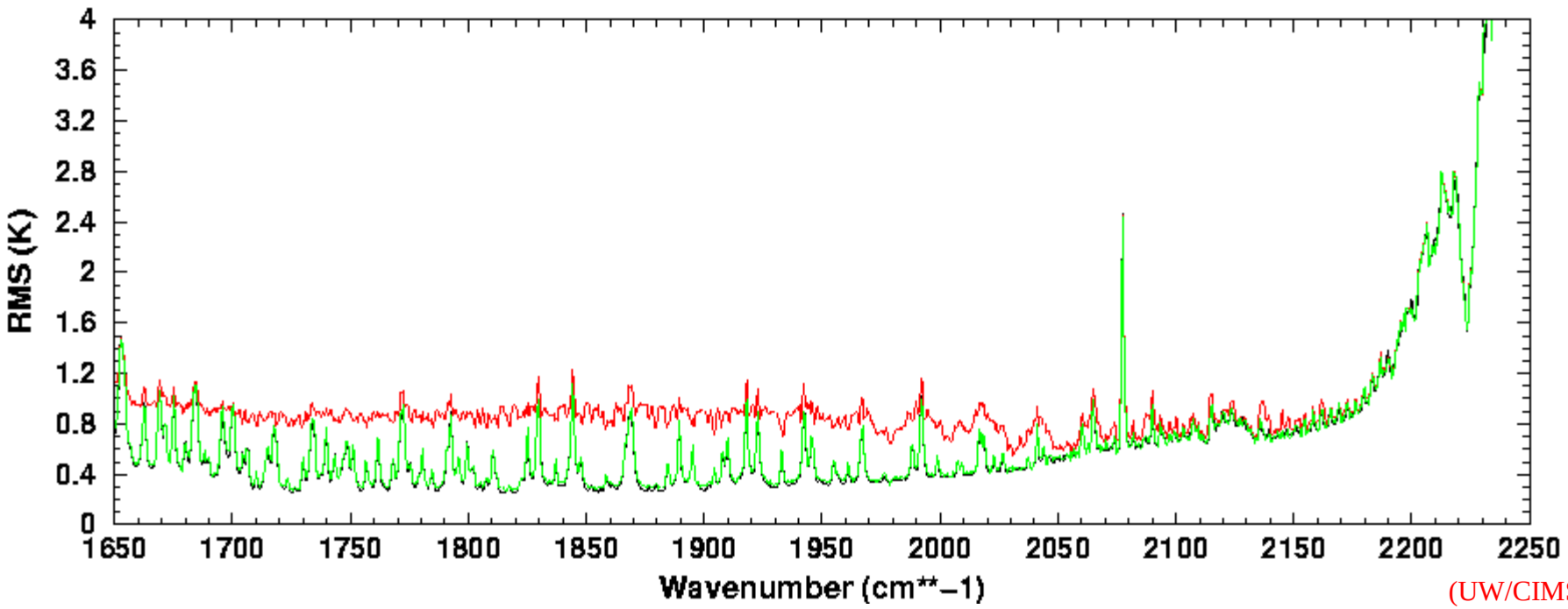


GIFTS retrieval simulation, 463 global profiles)

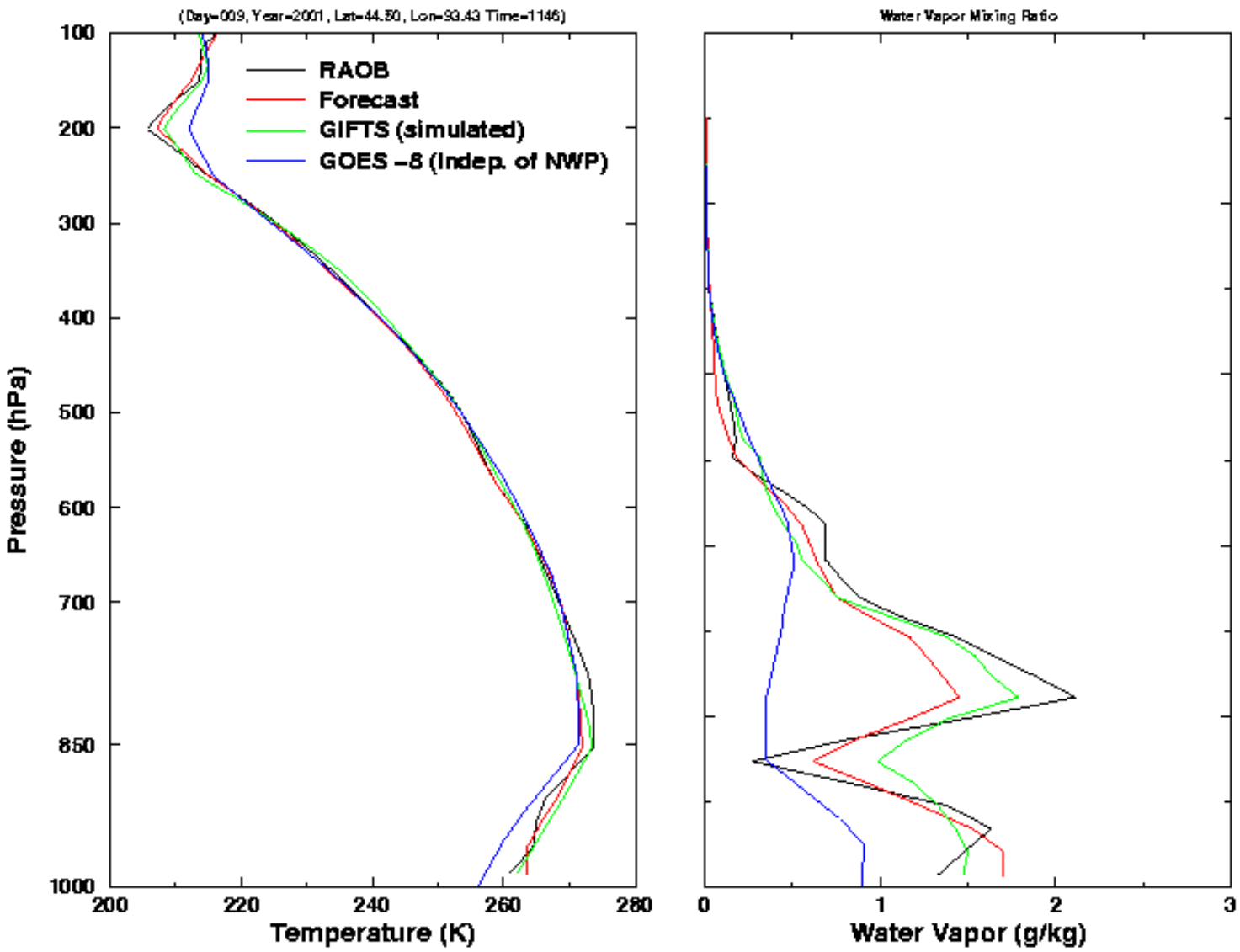


(UW/CIMSS)

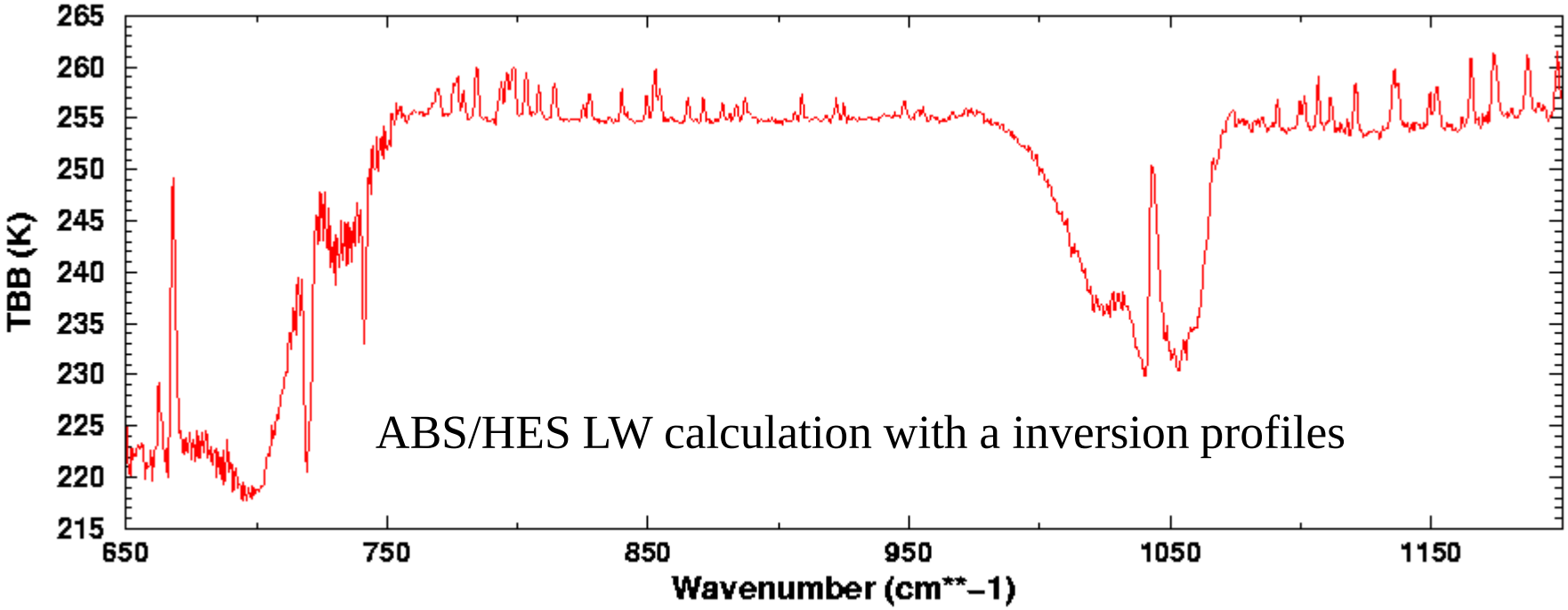

Noise RMS (783 samples)
Residual RMS (guess)
Residual RMS (physical)
RMS (K)
Wavenumber (cm**−1)
0
0.4
0.8
1.2
1.6
2
2.4
2.8
3.2
3.6
4
650
700
750
800
850
900
950
1000
1050
1100
1150
1200

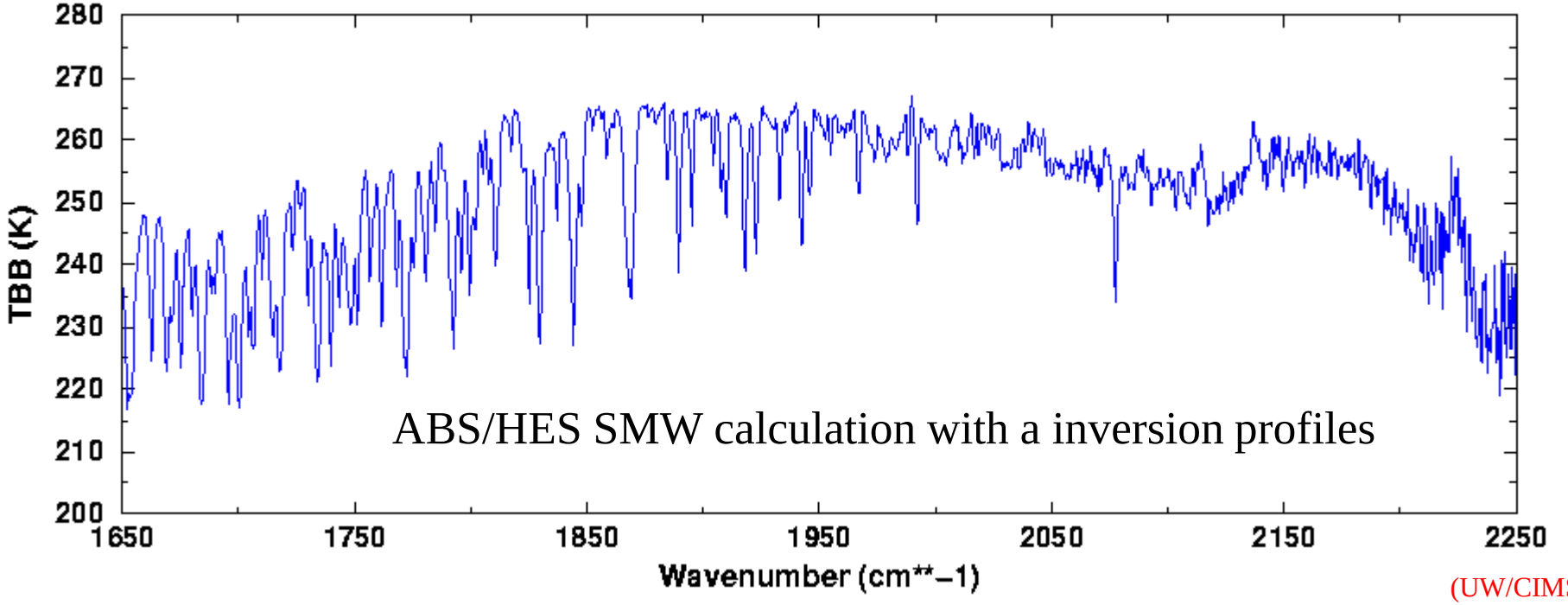

RMS (K)
Wavenumber (cm**−1)
0
0.4
0.8
1.2
1.6
2
2.4
2.8
3.2
3.6
4
1650
1700
1750
1800
1850
1900
1950
2000
2050
2100
2150
2200
2250

(UW/CIMSS)

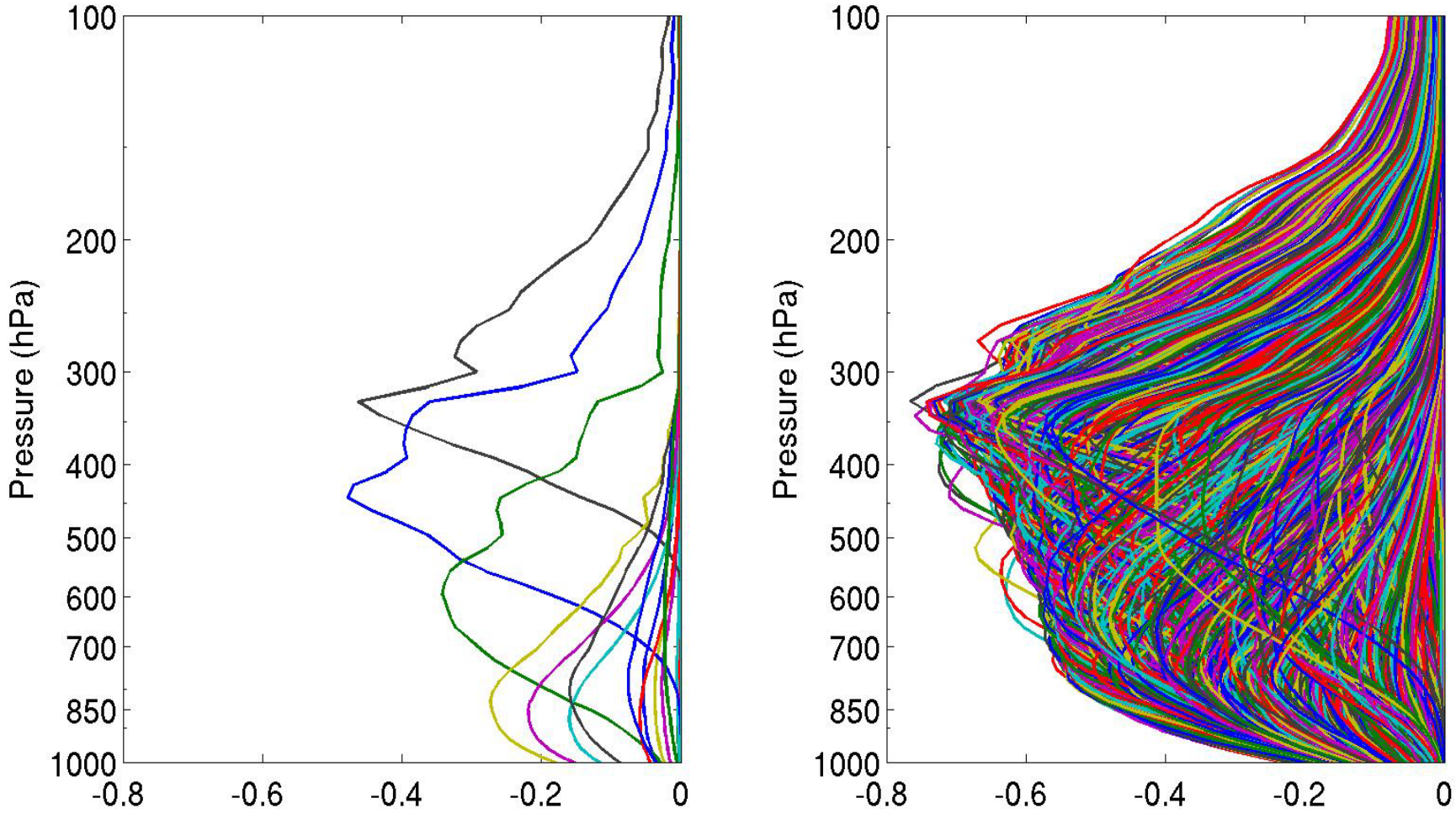

(Day=009, Year=2001, Lat=44.50, Lon=93.43 Time=1146)
RAOB
Forecast
GIFTS (simulated)
GOES –8 (Indep. of NWP)
Pressure (hPa)
100
200
300
400
500
600
700
850
1000
200
220
240
260
280
Temperature (K)
Water Vapor Mixing Ratio
0
1
2
3
Water Vapor (g/kg)

(UW/CIMSS)

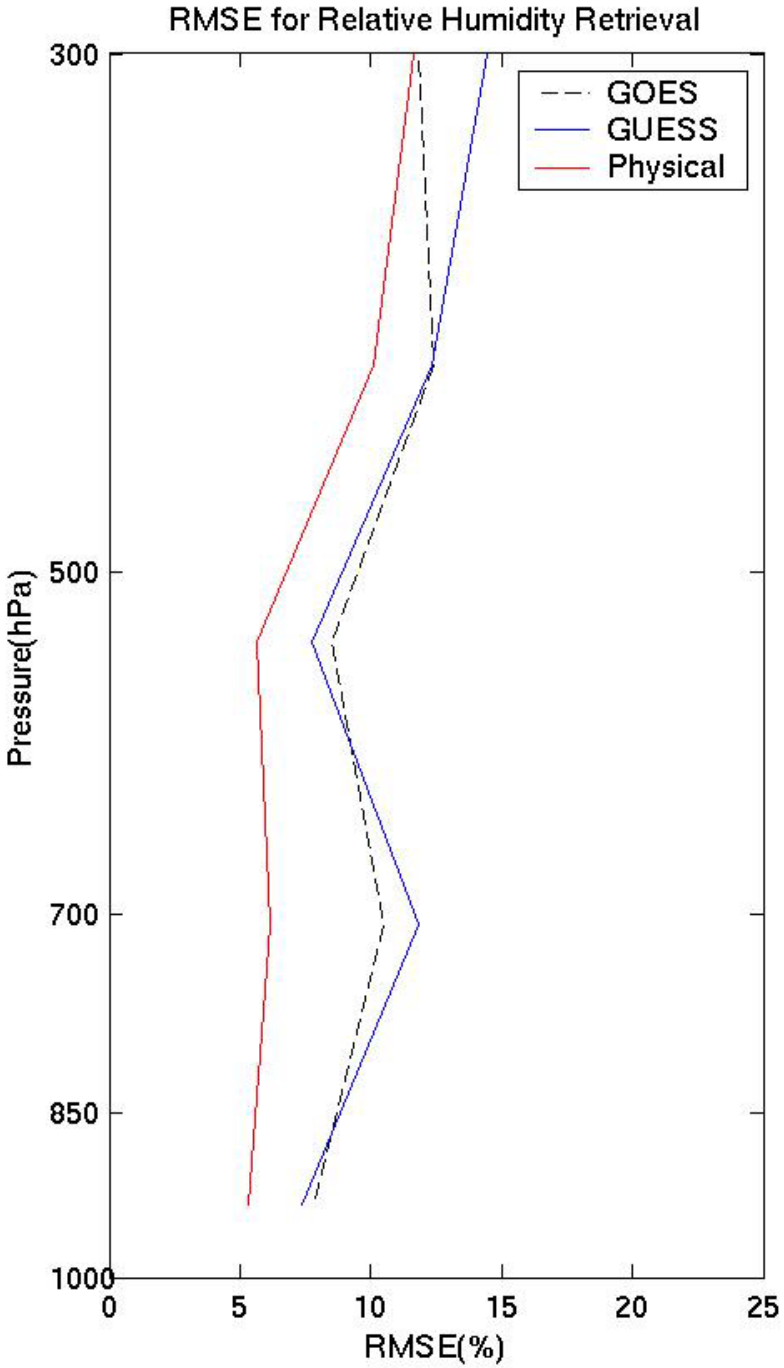

ABS/HES LW calculation with a inversion profiles
TBB (K)
265
260
255
250
245
240
235
230
225
220
215
650
750
850
950
1050
1150
Wavenumber (cm**−1)


ABS/HES SMW calculation with a inversion profiles
TBB (K)
280
270
260
250
240
230
220
210
200
1650
1750
1850
1950
2050
2150
2250
Wavenumber (cm**−1)

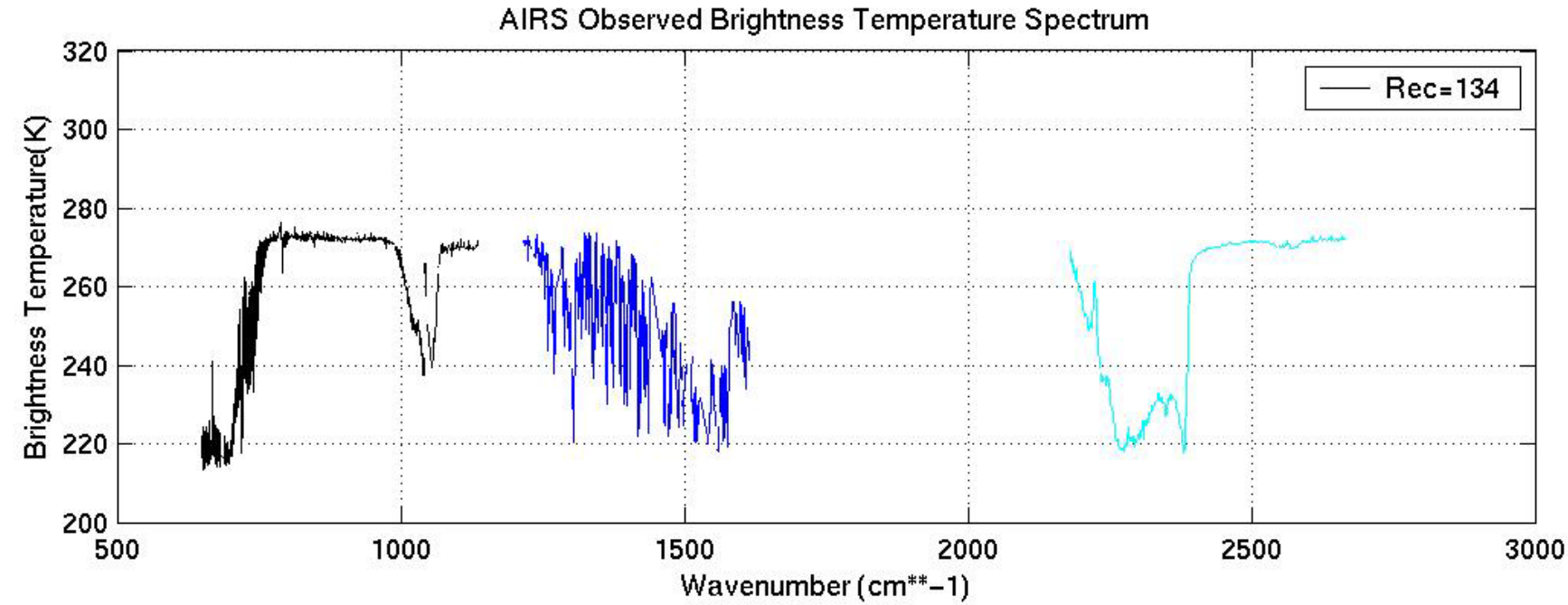
(UW/CIMSS)

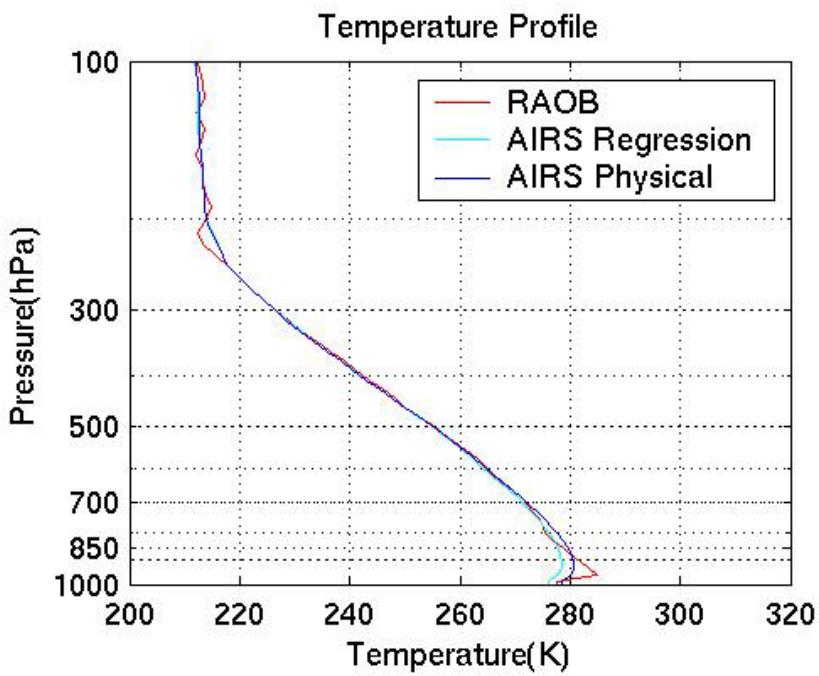


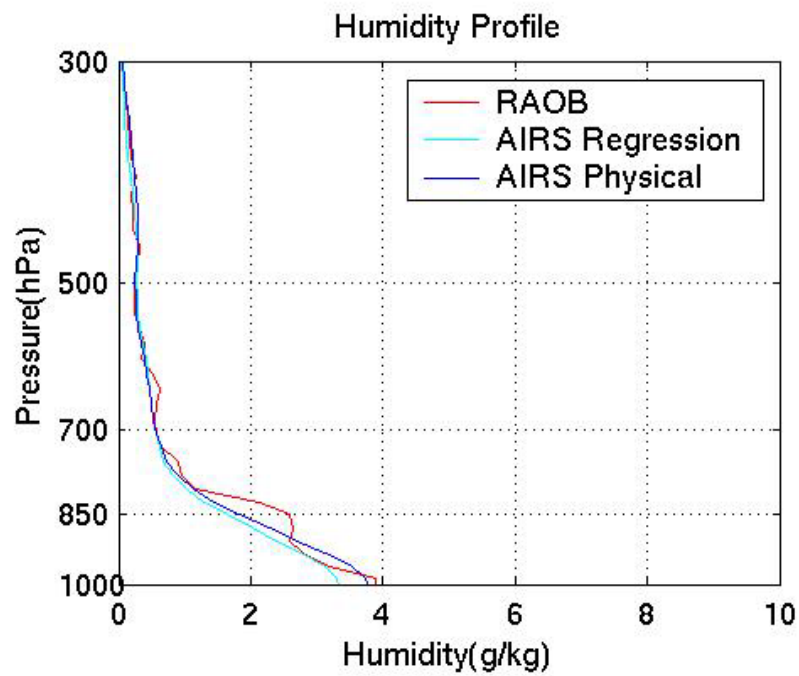
Water vapor Weighting functions



25 comparisons between AIRS retrievals (CIMSS) and RAOB at ARM cart Site


AIRS Observed Brightness Temperature Spectrum
Rec=134
Brightness Temperature(K)
Wavenumber (cm**−1)
320
300
280
260
240
220
200
500
1000
1500
2000
2500
3000


Temperature Profile
RAOB
AIRS Regression
AIRS Physical
Pressure(hPa)
Temperature(K)
100
300
500
700
850
1000
200
220
240
260
280
300
320

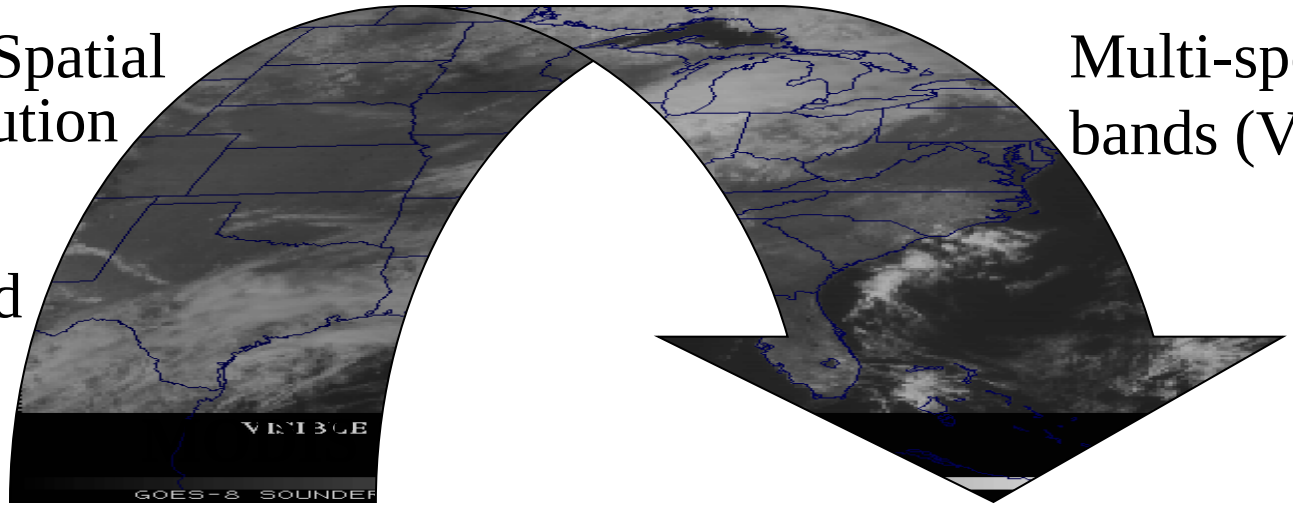

Humidity Profile
RAOB
AIRS Regression
AIRS Physical
Pressure(hPa)
Humidity(g/kg)
300
500
700
850
1000
0
2
4
6
8
10

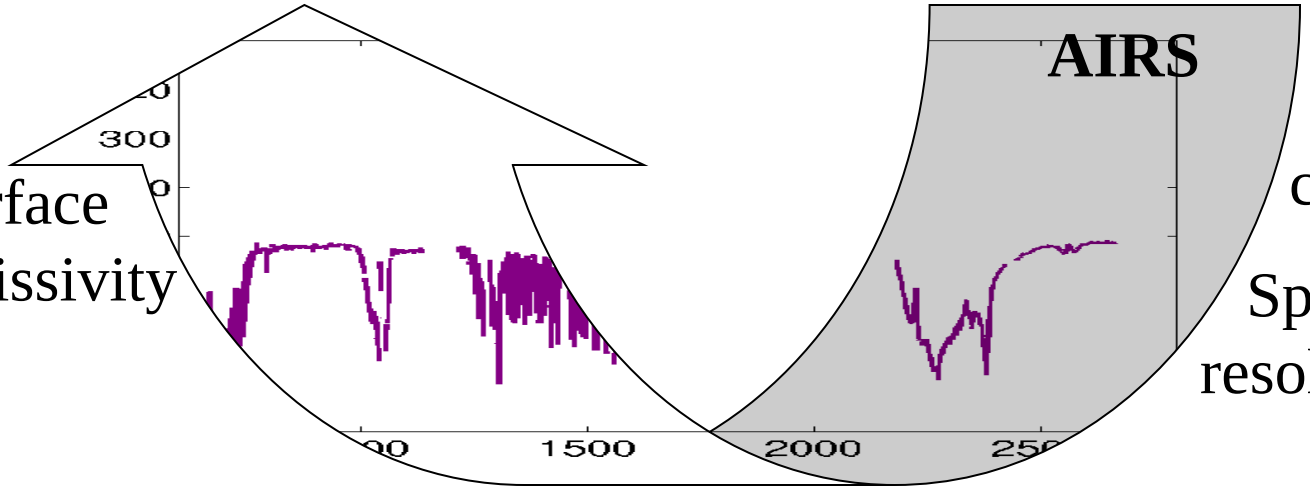
Best products will be realized from combinations of ABI *and* HES (Hyperspectral Environmental Suite) data (IR and Visible/near IR on the HES-Costal Water)!

Spatial resolution

Multi-spectral bands (VIS/NIR)

Cloud masking





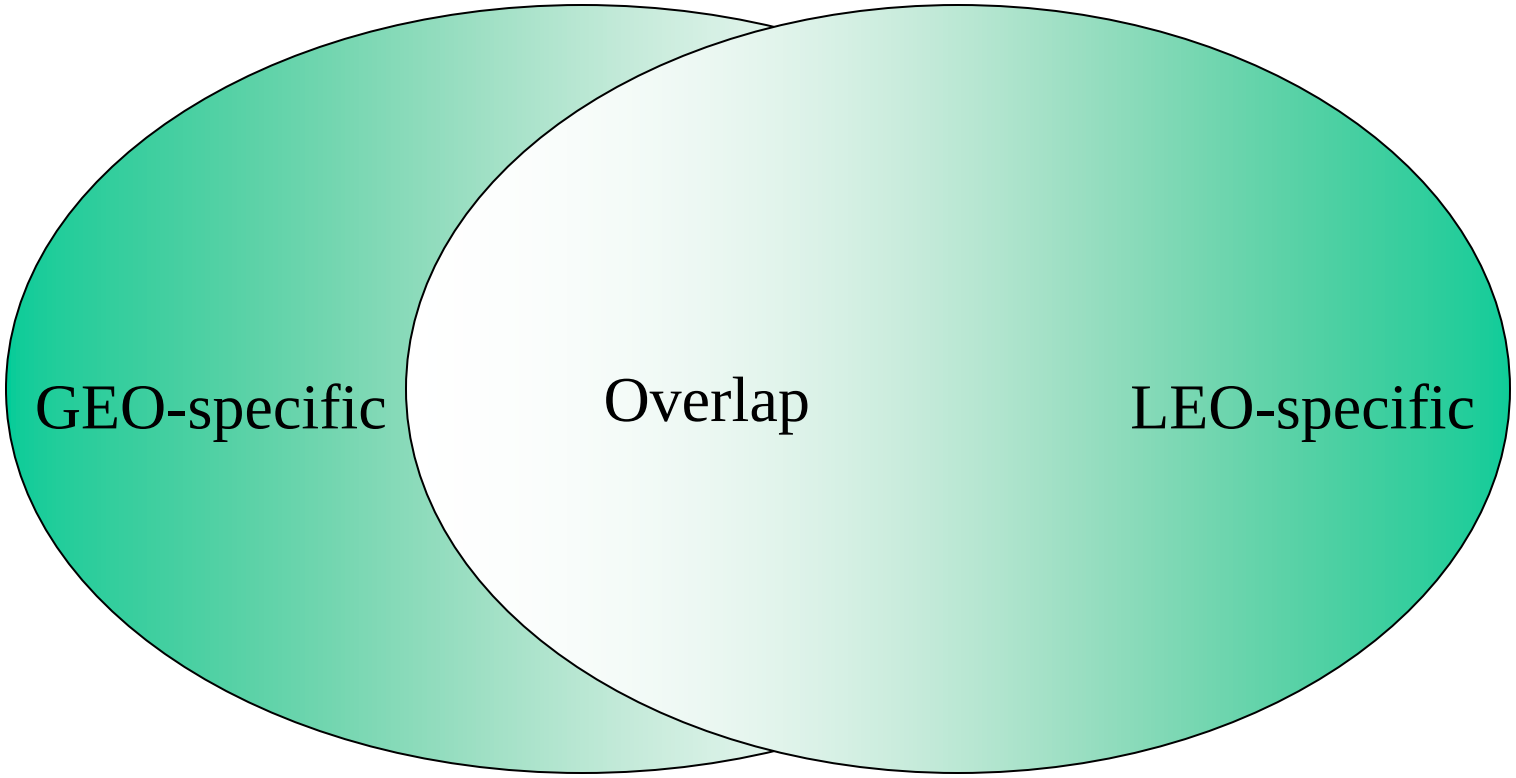
Surface emissivity

Spectral coverage

Spectral resolution

Leverage/merge where it makes sense:

- Common modules for most functions (same radiative transfer model, linear model, the same spectroscopy, etc)
- GOES must use time continuity, must be SFOV
- Codes should be modular and modern
- LEO can use microwave instruments



Questions:

Is NESDIS planning on using/leveraging the NCEP CRTM framework?
http://www.ssec.wisc.edu/~paulv/Fortran90/CRTM/Prototype/

Can we all use the same bias correction method?

Can we all use the same emissivity model?

More information

http://cimss.ssec.wisc.edu/goes/realtime/realtime.html

http://cimss.ssec.wisc.edu/goes/hes/

http://osd.goes.noaa.gov/

http://goespoes.gsfc.nasa.gov/HEShome.htm

http://cimss.ssec.wisc.edu/opsats/polar/iapp/IAPP.html

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Schmit T. J., W. F. Feltz, W. P. Menzel, J. Jung, A. P. Noel, J. N. Heil, J. P. Nelson III, G. S. Wade, 2002: Validation and use of GOES sounder moisture information, *Wea. Forecasting*, **17**, 139-154.

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Li, J., H.-L. Huang, C.-Y. Liu, P. Yang, T. J. Schmit et al., 2004: Retrieval of cloud microphyiscal properties from MODIS and AIRS. J. Appl. Meteorol., (manuscript submitted)

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Achtor, T. H., Feltz, W. F. Feltz, J. Li, H. Woolf and H. B. Howell, 2003: Validation of IAPP retrievals using DOE ARM site observations. Conference on Satellite Meteorology and Oceanography, 12th, Long Beach, CA, 9-13 February 2003 (preprints). American Meteorological Society (AMS), Abstract P4.4.

Li, J., T. J. Schmit, C.-Y. Liu, W. P. Menzel, and J. Gurka, 2004: Studies on the Hyperspectral Environmental Suite (HES) on GOES-R. 13th Conference on Satellite Meteorology, Norfolk, VA, 20 - 23 September 2004 (preprints). P1.11, American Meteorological Society.

Li, J., J. P. Nelson, C. C. Schmit, T. J. Schmit, and W. P. Menzel, 2004: An approach to improve temperature and moisture retrievals from GOES sounder measurements. 13th Conference on Satellite Meteorology, Norfolk, VA, 20 - 23 September 2004 (preprints). P.8.5, American Meteorological Society.

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