Tuning, why and how, fwd computations

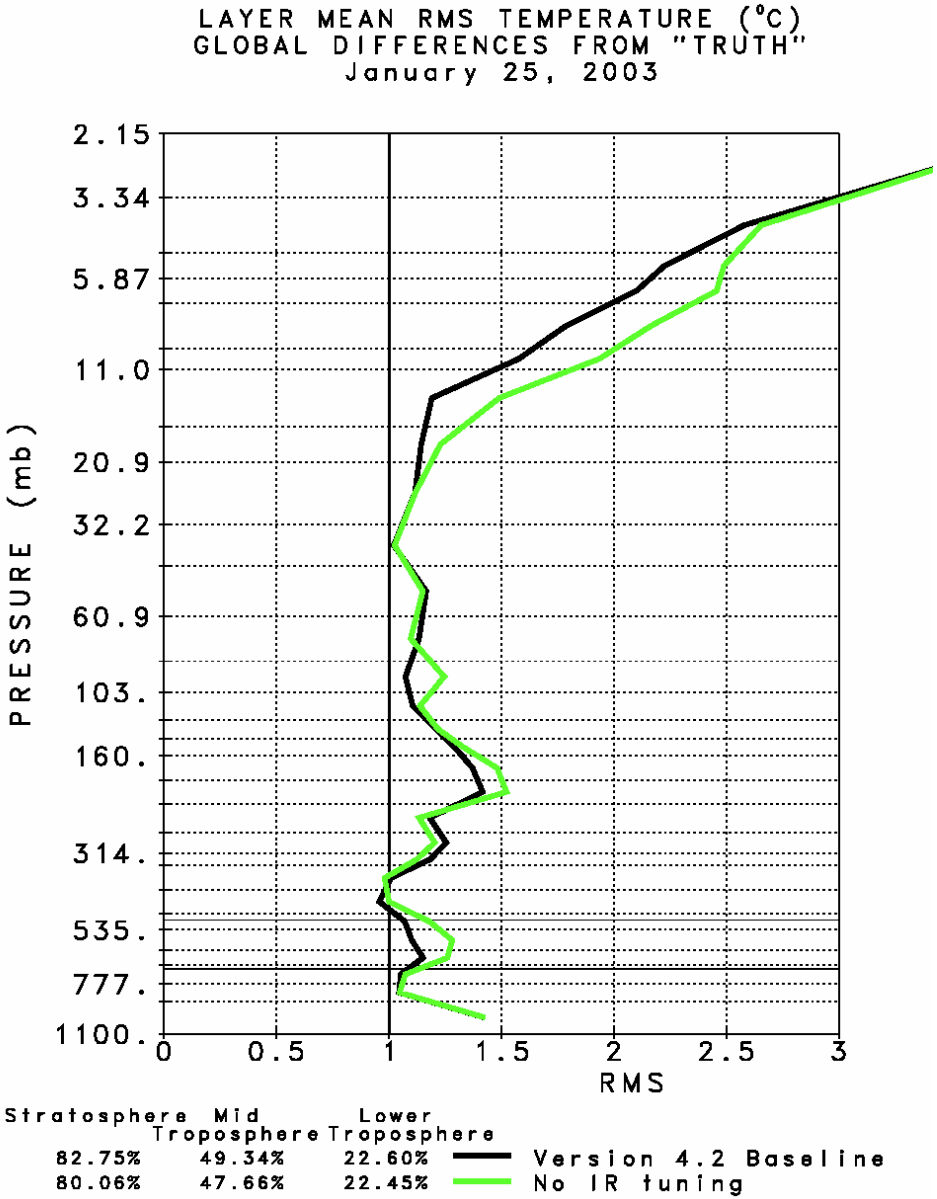
Eric Maddy, Murty Divakarla,
Chris Barnet, others

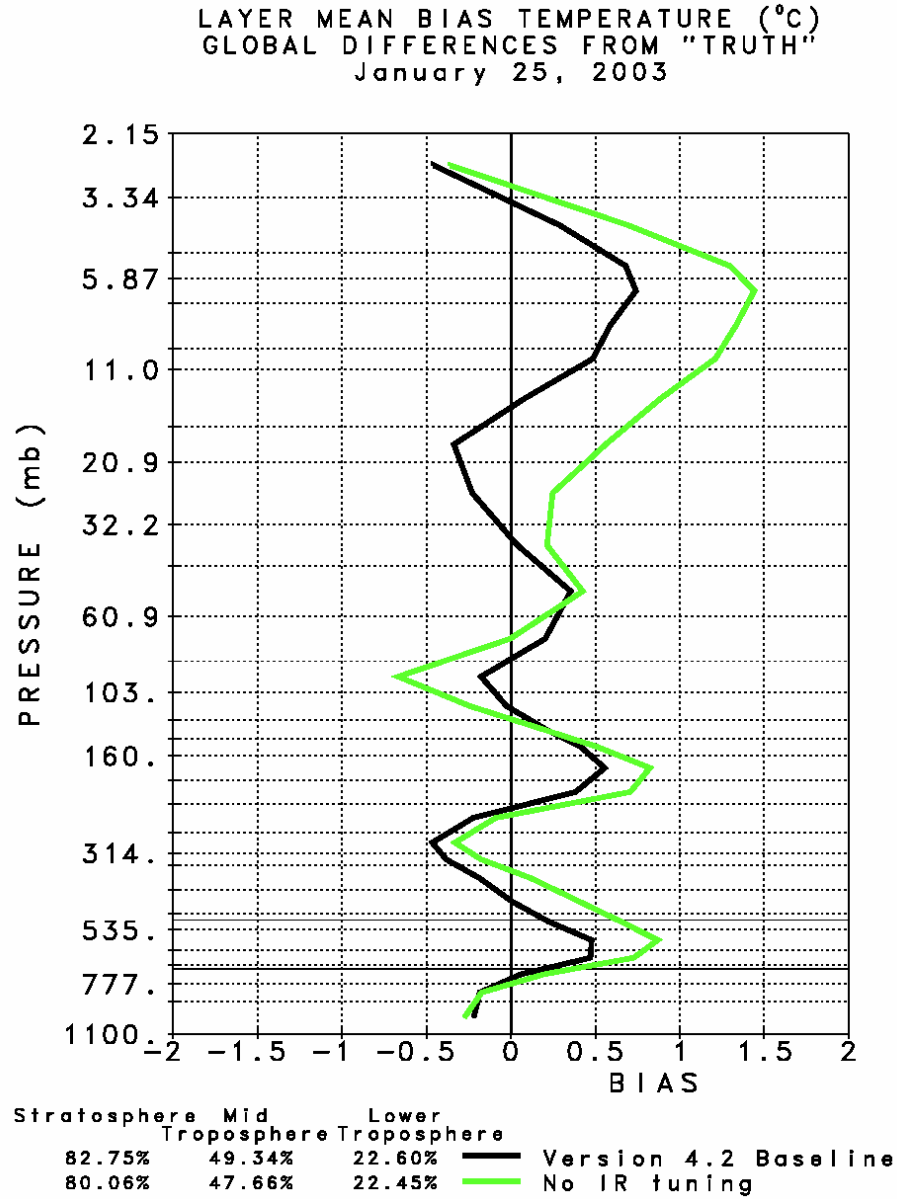
August 10, 2005

Outline

- Why do we tune?
  - Sonde or Model vs. AIRS retrievals
- What is it?
  - Forward model or Instrument effect or FG
- How do we compute/use it?
  - What is “truth”?
- Summary

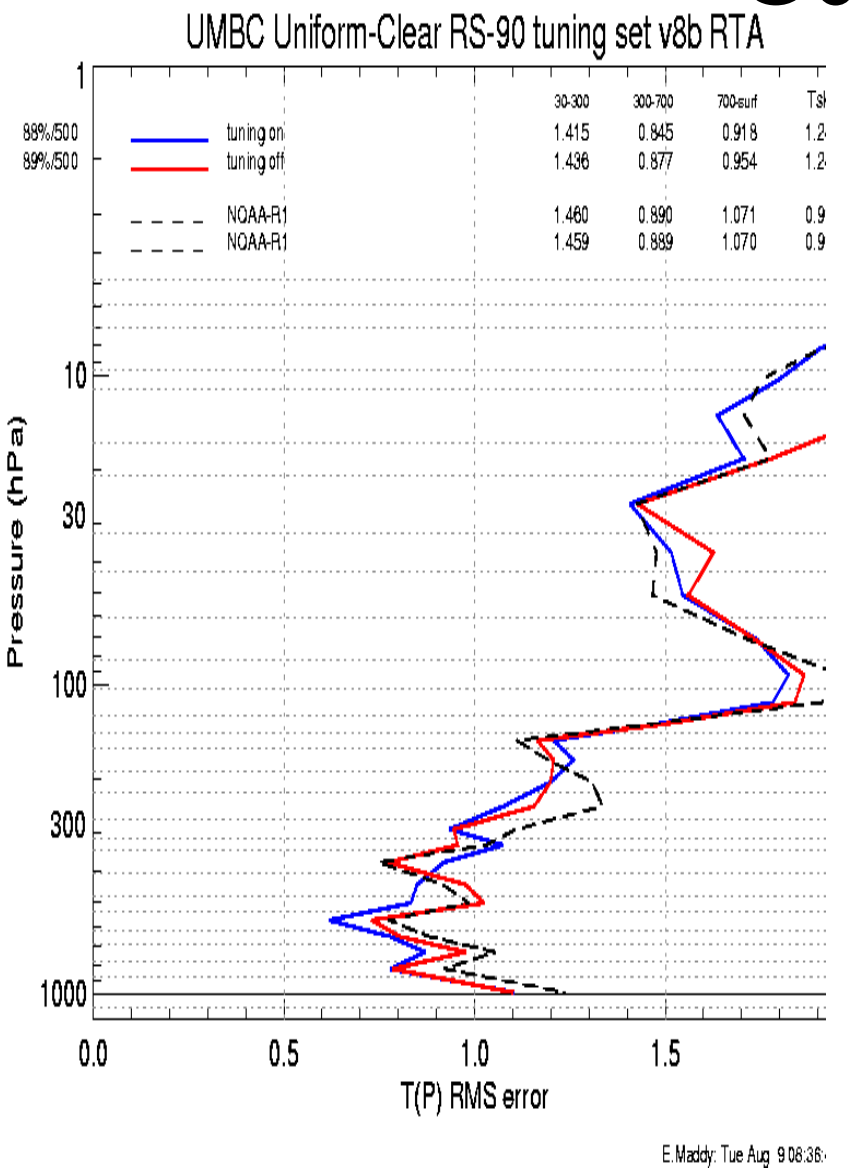
01.25.2003 ECMWF vs AIRS

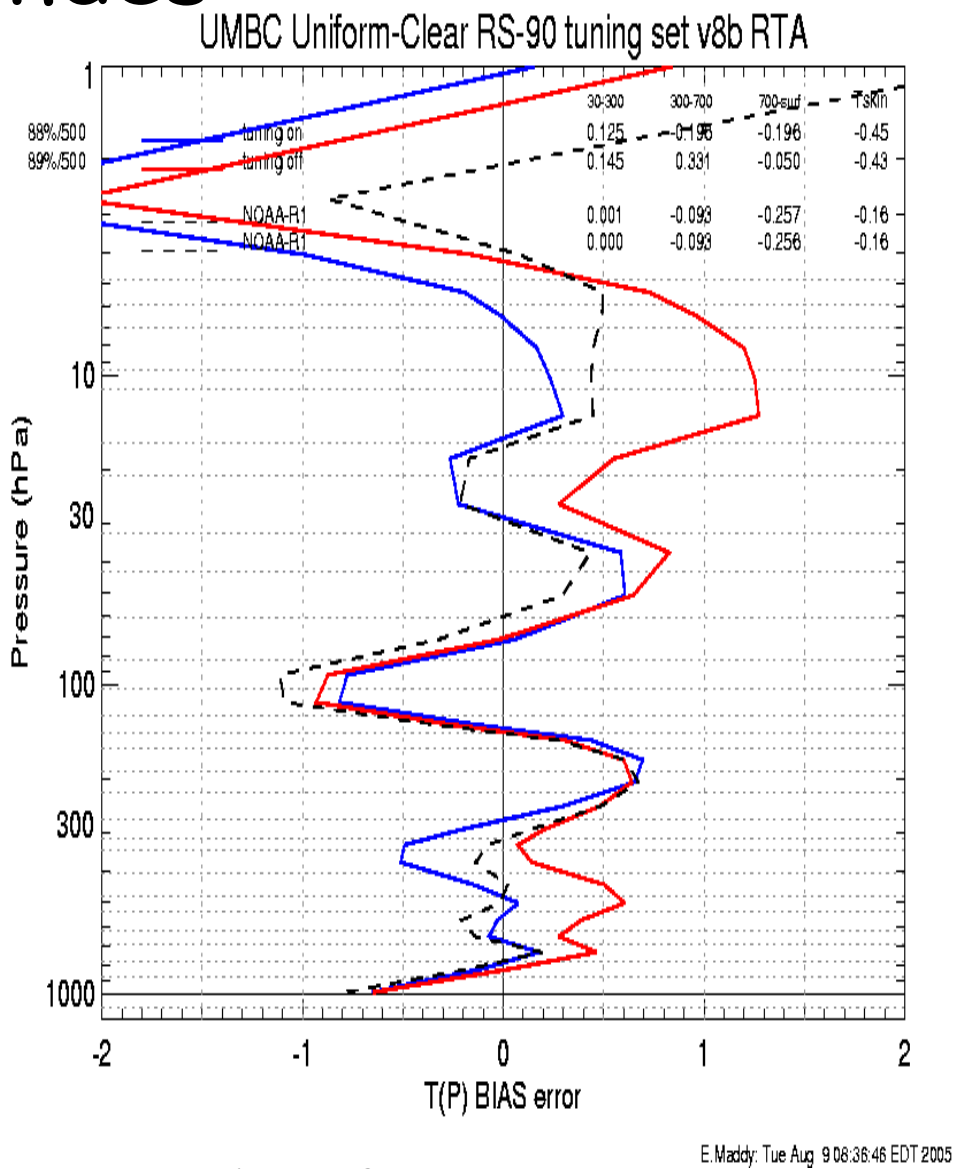




Susskind, *et al.*, *ASTM*, 2005

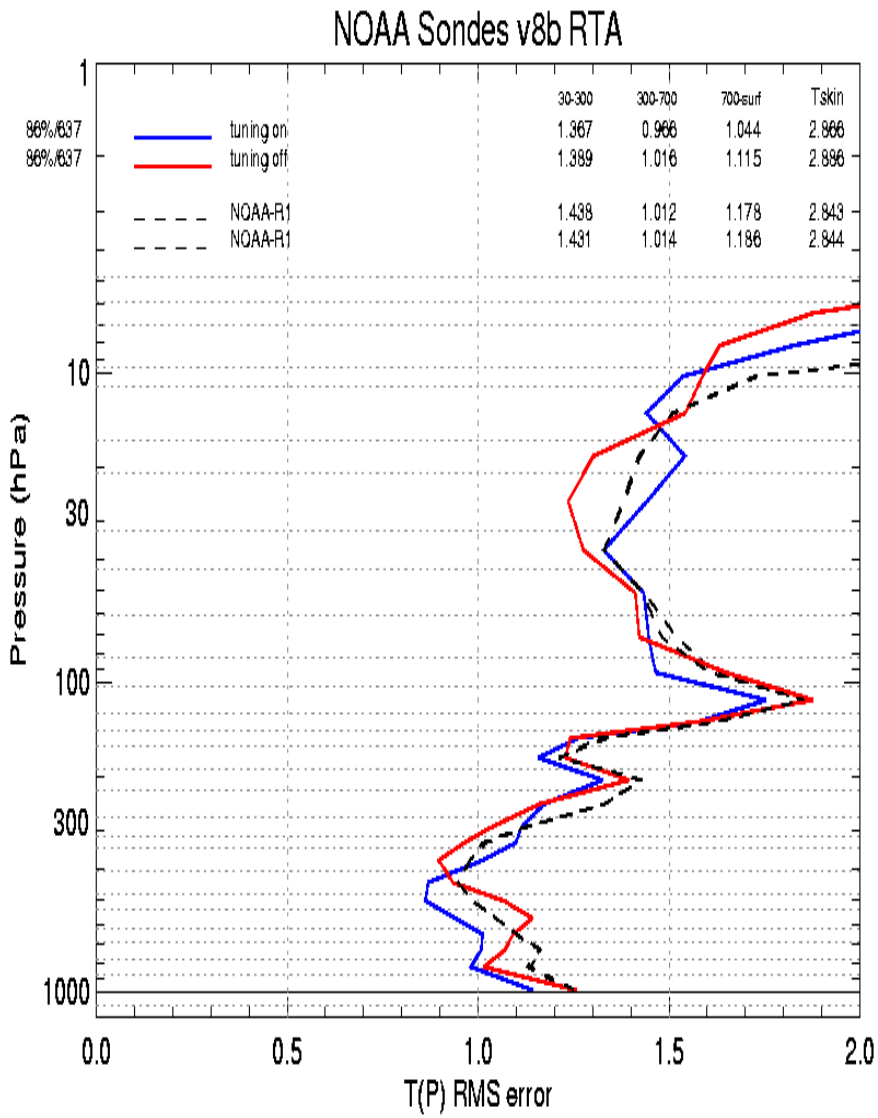
ABOVE, ARMTWP, Minnett Val Sondes

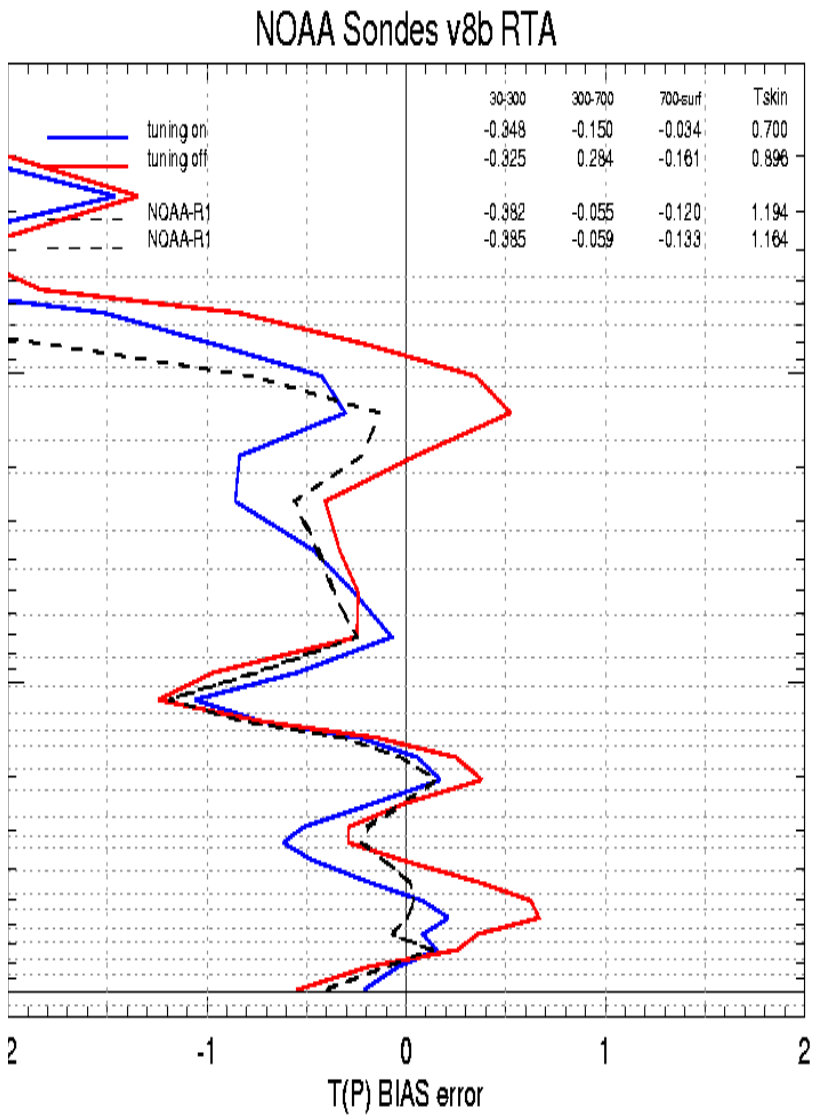




Raw matchups from L. Strow, UMBC

NOAA Operational Sondes





E.Maddy: Tue Aug 9 07:43:38 EDT 2005

Tuning…what is it? Retrieval Theory 101

- In mathematical terms:
  - The simple treatment of the problem starts from the unconstrained solution to a linear problem:

Linear Taylor expansion of our measurement about the calculated state R_n^0

$$\boldsymbol{R}_n = \boldsymbol{R}_n^0 + \boldsymbol{S}_{n,L}(\boldsymbol{X}_L - \boldsymbol{X}_L^0) \quad ; \quad \boldsymbol{S}_{n,L} \equiv \frac{\partial \boldsymbol{R}_n}{\partial \boldsymbol{X}_L}$$

Derivatives of our measurement wrt parameters being solved for.

The solution is proportional to the difference in radiances/BTs, ΔR=OBS-CAL

n = Channel index

L = Parameter index (*e.g.* CO_2 troposphere, CO_2 stratosphere)

$$\boxed{\Delta \boldsymbol{X}_L = [\boldsymbol{S}_{L,n}^T \boldsymbol{S}_{n,L}]^{-1} \boldsymbol{S}_{L,n}^T \Delta \boldsymbol{R}_n}$$

Retrieval Theory 101 (cont.)

- Minimization requires ability to calculate a accurate and precise radiance …
  - Random Errors in OBS-CAL(TRUTH) are used as channel weights which we call the "**Error term**".
  - Biases in the expectation of OBS-CAL(TRUTH) we call "**Tuning**".

    - Multiplicative (applied to RTA absorption coefs.) :

      $\kappa(n) = \kappa^0(n) * \Phi_n$ UMBC RTA v8b compared to v8a

    - Additive (applied to any OBS-CAL(RET,TRU,etc.) BTs) :

      $\Theta_{tuned}(n) = \Theta^0(n) + \Phi_n$

AIRS Retrieval currently uses a static tuning derived from ~500 clear ocean cases OBS-CAL(ECMWF) from Sept. 6, 2002

Is this good enough? … Probably Not!!!

Tuning … what is it?

- Errors in Forward Calculation:
  - Incorrect physics -- spectroscopy (multiplicative tuning – leave this to UMBC)
  - Trace gas sensitivity
  - Surface Emissivity/Downwelling Uncertainty (Nick/Chris next month)
  - T_{surf}/P_{surf} errors -- channels sensitive to surface and BL water tuning
- Instrument Effect
  - Degradation over time.
  - Changes within instrument optical properties (*e.g.* filter temp after Nov. 2003).

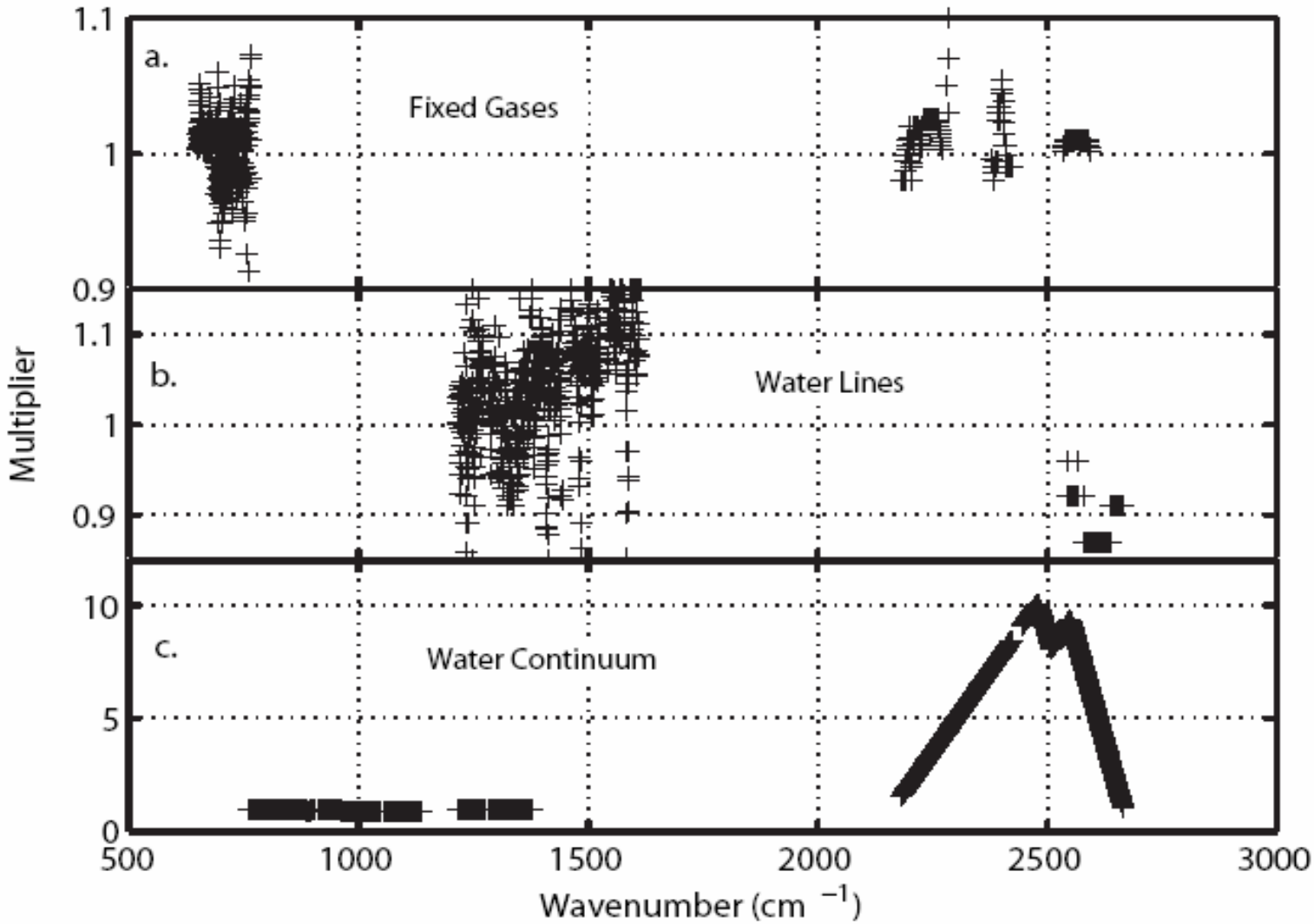
Errors in the Forward Calculation

- AIRS RTA uses a FAST regression scheme based on line-by-line calculations.
  - Spectroscopy may not be well understood (*e.g.* H2O continuum).
  - Account for "missing absorbers" using main absorbing gases in each spectral region -> reduces the bias in OBS-CAL nearly to zero

- Trace gases: CO_2, O_3, CH_4, CO, HNO_3, SO_2, N_2O, *etc.* and Main Gases: N_2 (P_{surf}), H_2O
  - Variability in these gases is detectable in AIRS spectra.

- Surface emissivity truth is taken from emissivity libraries:
  - Variability hard to characterize over land.
  - Parameterization may not be complete (*e.g.* sea $\varepsilon(T_{surf}$, windspeed, …))

Absorption Coef. Adjustments



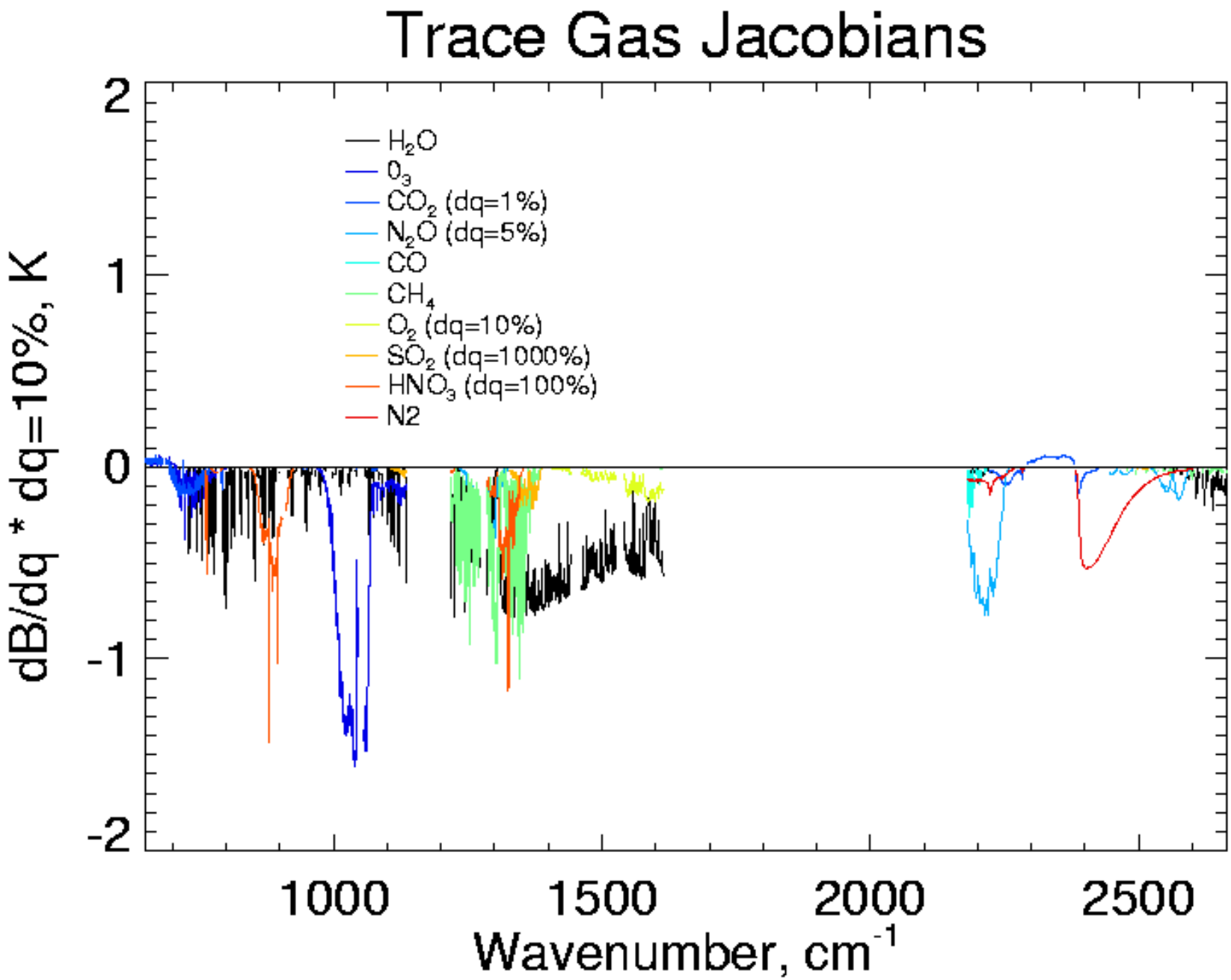
Strow, *et al.*, *JGR*, 2005

Errors in the Forward Calculation

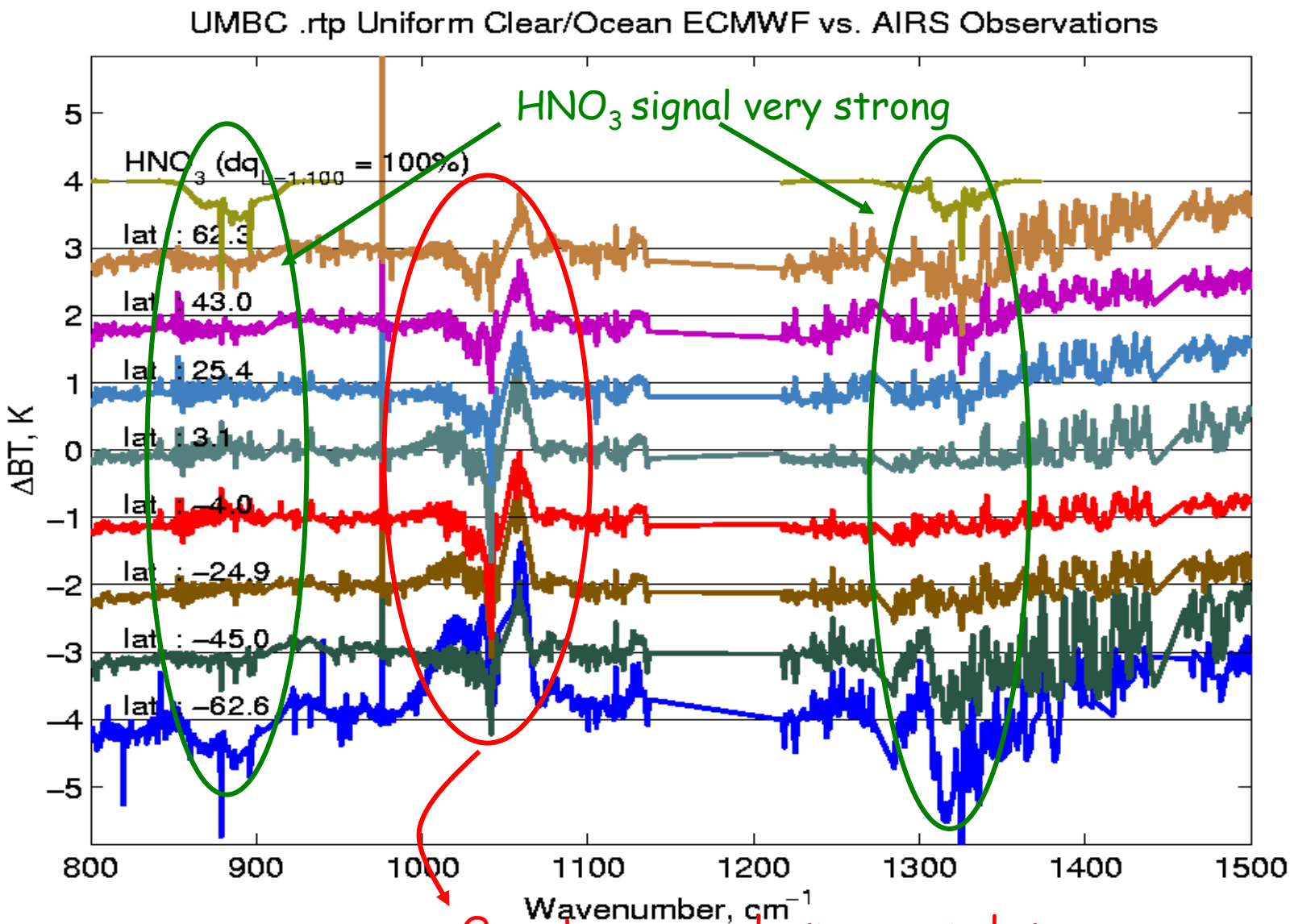
- AIRS RTA uses a FAST regression scheme based on line-by-line calculations.
  - Spectroscopy may not be well understood (*e.g.* H2O continuum).
  - Account for "missing absorbers" using main absorbing gases in each spectral region -> reduces the bias in OBS-CAL nearly to zero

- Trace gases: O_3, CO_2, CH_4, CO, HNO_3, SO_2, N_2O, *etc.* and Main Gases: N_2 (P_{surf}), H_2O
  - We want to solve for these gases not remove their effect.

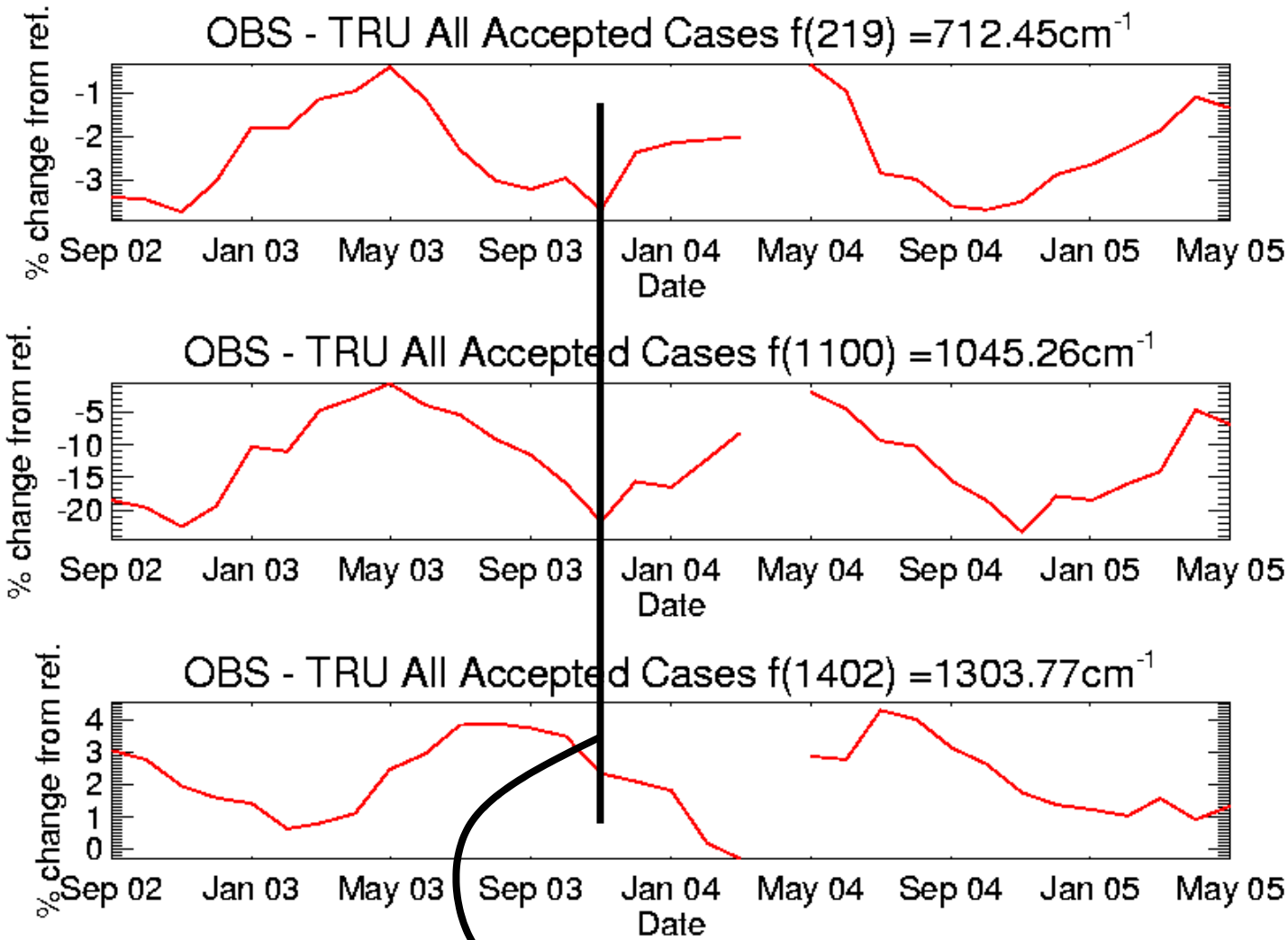
- Surface emissivity truth is taken from emissivity libraries:
  - Variability hard to characterize over land.
  - Parameterization may not be complete (*e.g.* sea $\varepsilon(T_{surf}$, windspeed, …))


Trace Gas Jacobians
H2O
O3
CO2 (dq=1%)
N2O (dq=5%)
CO
CH4
O2 (dq=10%)
SO2 (dq=1000%)
HNO3 (dq=100%)
N2
dB/dq * dq=10%, K
2
1
0
-1
-2
1000
1500
2000
2500
Wavenumber, cm-1

Trace gas sensitivity (OBS-ECMWF)



NOAA Operational Sonde OBS-CAL(TRU)



CO_2 Channel

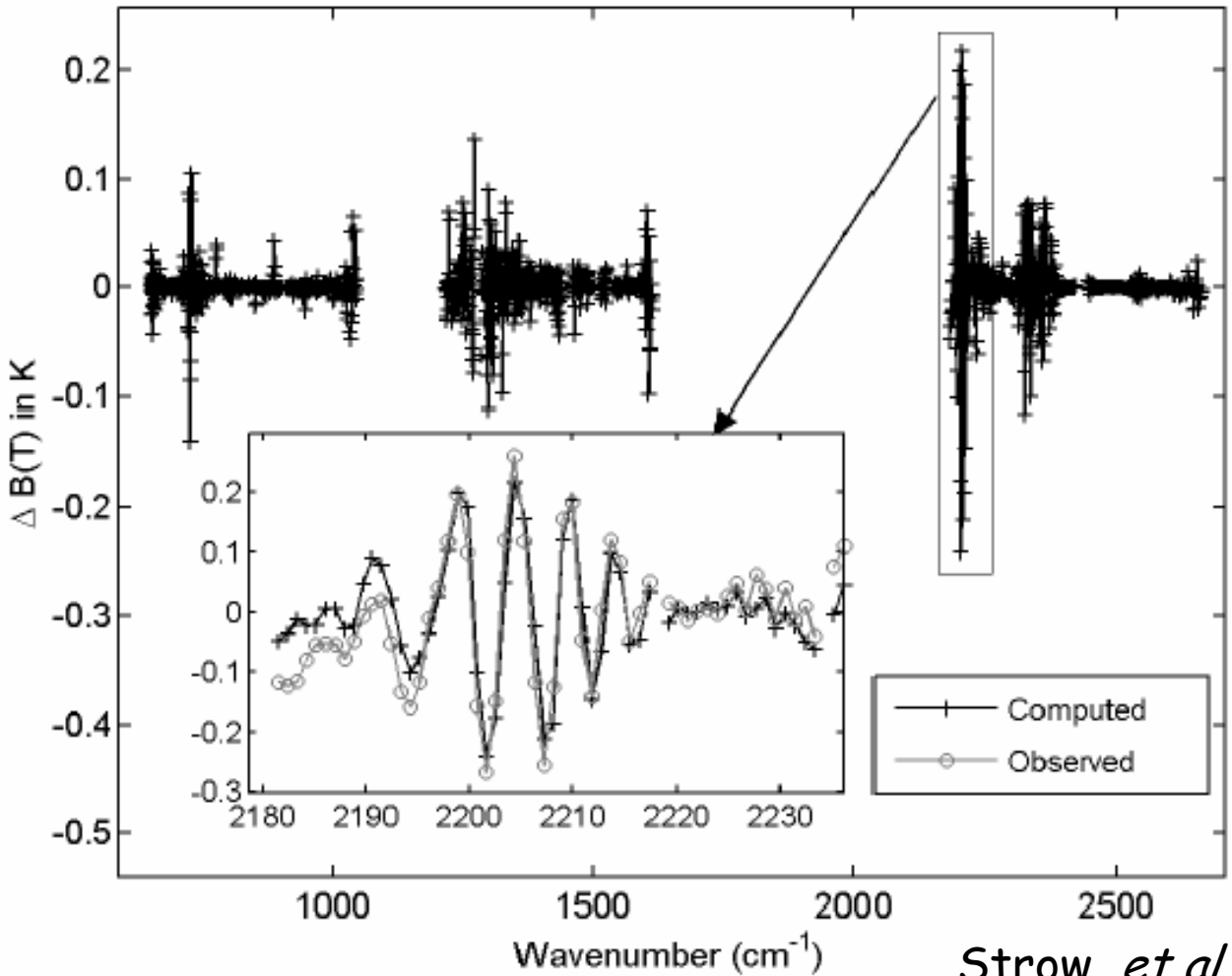
O_3 Channel

CH_4 Channel

Nov. 2003 Shutdown

Instrument Effects

AIRS: Change in spectrometer entrance filter temperature after Nov. 2003 shutdown.



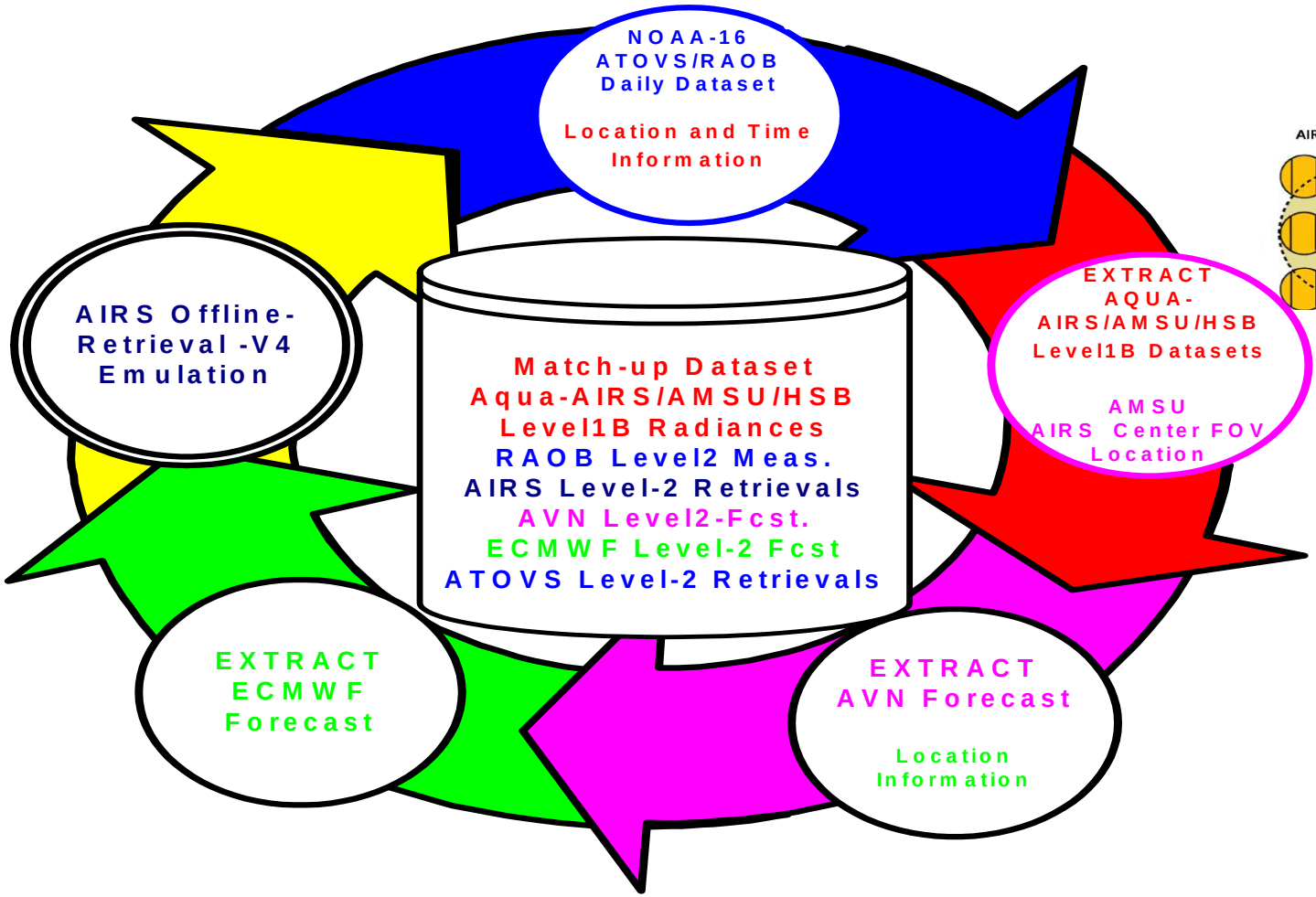
Strow, *et al.*, *JGR*, 2005

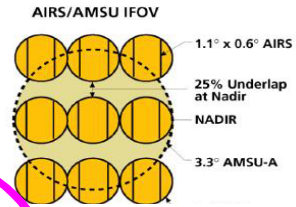
How do we compute tuning?

- Create "truth" datasets for T(p)/q(p)
  - Set 1 : to determine tuning and error estimates:
    - NOAA operational sondes (Murty)
    - AIRS Validation sondes (UMBC/JPL)
  - Set 2, collocated to Set 1: for independent assessment/evaluation of tuning.
    - ECMWF
    - NCEP-GFS
    - ATOVS

- Select <u>ocean/clear</u> (land/cloudy later) AIRS FOVs and/or FORs
  - Select a matchup window in time and space (e.g. 1.5hrs, 100km).

NOAA Match-up Dataset





How do we compute tuning?

- Sonde profiles:
  - Raw data has a large number of points (sampling ~0.5 Hz) and amount of structure:
    - Interpolation to AIRS levels does not capture the temperature at which each layer radiates (*i.e.,* it is a function of gas amount/pressure).
    - Integrate sonde to layer quantities (*e.g.,* use klayers [ftp://asl.umbc.edu/pub/packages/klayersV204_23jun05.gz]).
- ECMWF/NCEP-GFS T(p), q(p), O_3(p)
  - Interpolate model pressure level quantities to AIRS pressure levels/layers quantities.

What if the data doesn't exist?

AIRS RTA requires a complete atmospheric state
X(T(p),q(p),O_3(p),CO_2(p),CO(p),CH_4(p),Ts, etc.)
on a fixed pressure grid: p between 0.005mb, 1100mb

- Profiles without data upto 0.005 mb:
  - Sonde temperatures are usually limited to below ~50 mb (balloons pop!).
  - H_2O less reliable above 200 mb due to sensor response and uncertainty in parameterization of H_2O sat. vap. pressure at low temperatures.

- Above crossover points plug in :
  - ECMWF
  - Retrieved quantities w/o tuning
  - Something else?

What is "truth"?

- T/H_2O can have large variability over the coarse of the sonde ascent (~2 hrs.) and 15 km (AIRS FOV) or 50 km of AMSU (AIRS FOR).
  - Sonde representation error 0.2-0.5 K in T(p), 3% in q(p) [Tobin, *et al.*, *JGR*, 2005].
- ECMWF O_3 and stratospheric temperatures are <u>NOT</u> reliable and have known biases.
- Other trace gases such as CO_2, CH_4, CO, HNO_3, etc. are not included in analyses.

USE retrievals and/or trace gas climatologies derived using AIRS data to complete the atmospheric state …

We can use retrievals, BUT …

- By definition the retrieval will minimize the OBS-CAL(RET) (up to the noise estimate)
  - √ Check that retrieval product statistics are not degraded by the tuning derived using retrieval quantities.
  - √ Check that the std. dev. of the OBS-CAL(TRU) decreases as we add retrieval quantities to the state vector X.

$$X = (T, q, O_3, CO_2, CH_4, CO, T_{surf}, \ldots).$$

Use Both Set 1 and Set 2 for evaluation

Retrieval/"Truth" uncertainty may require other options…

Modify tuning

- We can turn off tuning in channels sounding pressures in which the truth file is suspect.
  - use a roll off function, r(n), based on where channels sound relative to a crossover point P_{xover}:

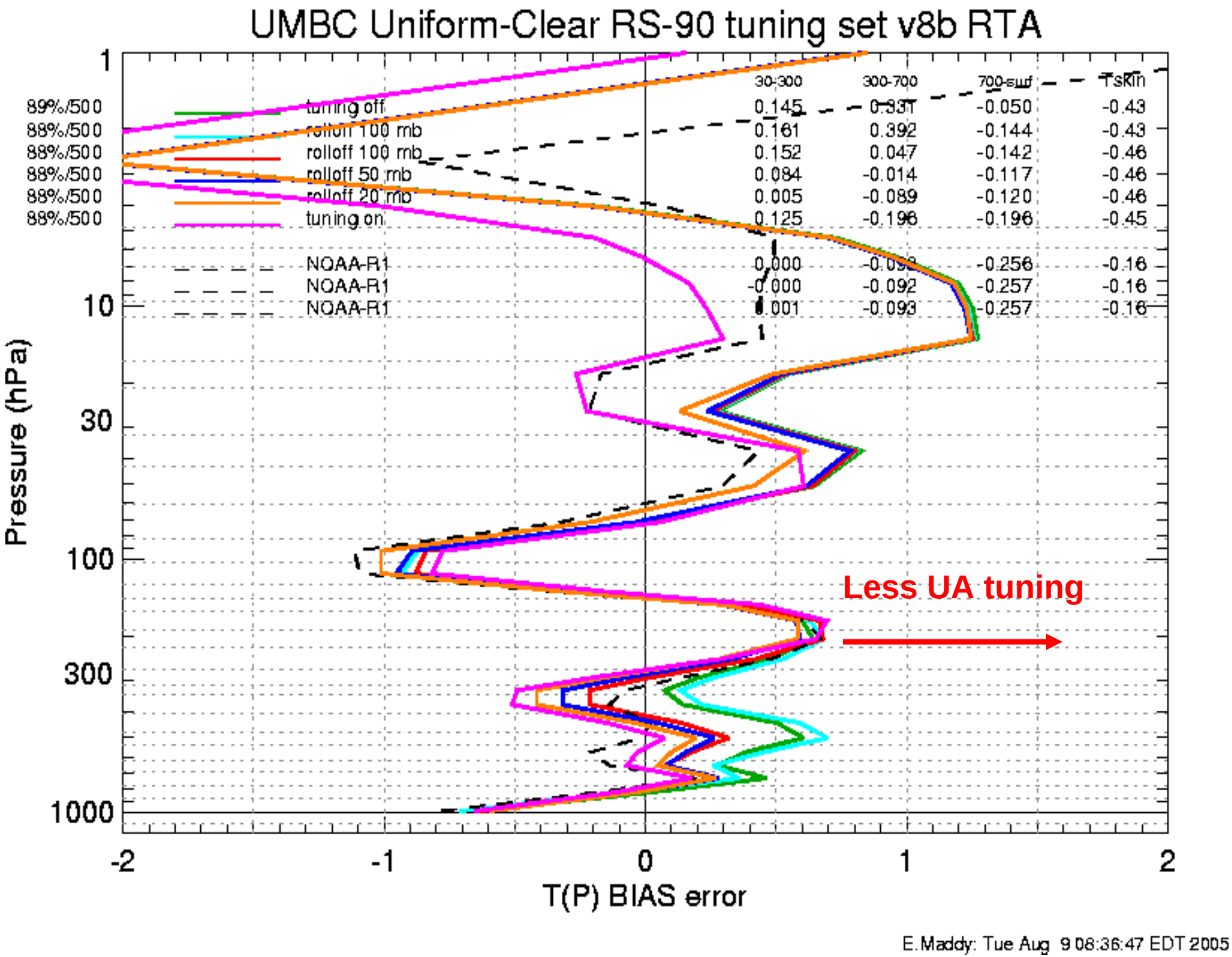
New tuning — Old tuning

$$\Phi'(n) = \Phi(n) * r(n)$$

$$r(n) = 1 - P_{xover}/P(\tau_n = \tfrac{1}{2})$$

$$\text{set: } r(n) = 0 \;\; \forall \;\; r(n) < 0$$

- Again we need to check that the derived tuning improves both OBS-CAL stats and retrieval product stats.


UMBC Uniform-Clear RS-90 tuning set v8b RTA
Pressure (hPa)
T(P) BIAS error
1
10
30
100
300
1000
-2
-1
0
1
2
89%/500
88%/500
88%/500
88%/500
88%/500
88%/500
tuning off
rolloff 100 mb
rolloff 100 mb
rolloff 50 mb
rolloff 20 mb
tuning on
NOAA-R1
NOAA-R1
NOAA-R1
30-300
300-700
700-sfc
Tskin
0.145 0.331 -0.050 -0.43
0.161 0.392 -0.144 -0.43
0.152 0.047 -0.142 -0.46
0.084 -0.014 -0.117 -0.46
0.005 -0.089 -0.120 -0.46
0.125 -0.196 -0.196 -0.45
0.000 -0.092 -0.256 -0.16
-0.000 -0.092 -0.257 -0.16
0.001 -0.093 -0.257 -0.16
Less UA tuning
E.Maddy: Tue Aug 9 08:36:47 EDT 2005

Steps for tuning

1. Calculate spectra (k=1,K # of cases) for this iteration's "TRUTH": $TRU^i(n)$ = Set 1 and Set 2
2. Compute statistics compared to AIRS observations:

Tuning: $\Phi(n) = \Sigma\{\langle R_n \rangle - TRU^i(n)\}/K$

Error Estimates: $\sigma^2(n) = \Sigma\{[\langle R_n \rangle - TRU^i(n) - \Phi(n)]^2\}/K$

3. Apply tuning to retrieval matchups and check that product/radiance statistics are satisfactory (Set 1 and Set 2).

   If so : goto 4.
   If not: try something else. (*e.g.* roll tuning off)

4. Append retrieval quantities, trace gas climatology, *etc.* into "TRUTH" and return to step 1 if something can be improved, otherwise stop.

Summary

- Any retrieval minimizing OBS-CAL requires the ability to calculate an accurate/precise radiance.

- Static tuning applied to AIRS retrievals based on ECMWF alone improves retrievals, BUT this tuning is based on a truth with large uncertainty (*e.g.* stratospheric biases/trace gas variability) .

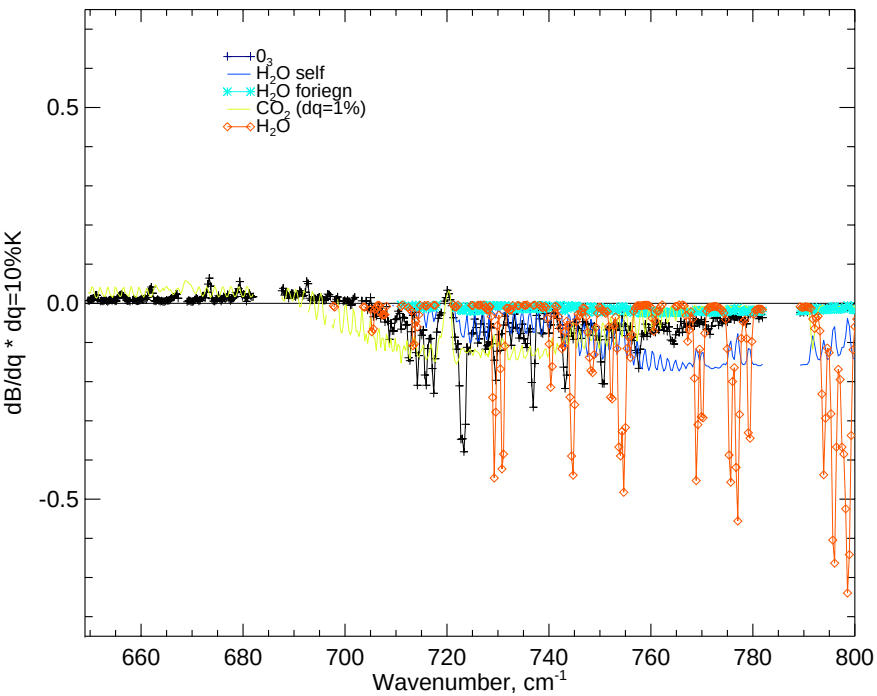
- NOAA, UMBC and GSFC researchers are now focusing on removing the effects of stratospheric errors and variable gases to decide what if any tuning is required for the AIRS RTA.

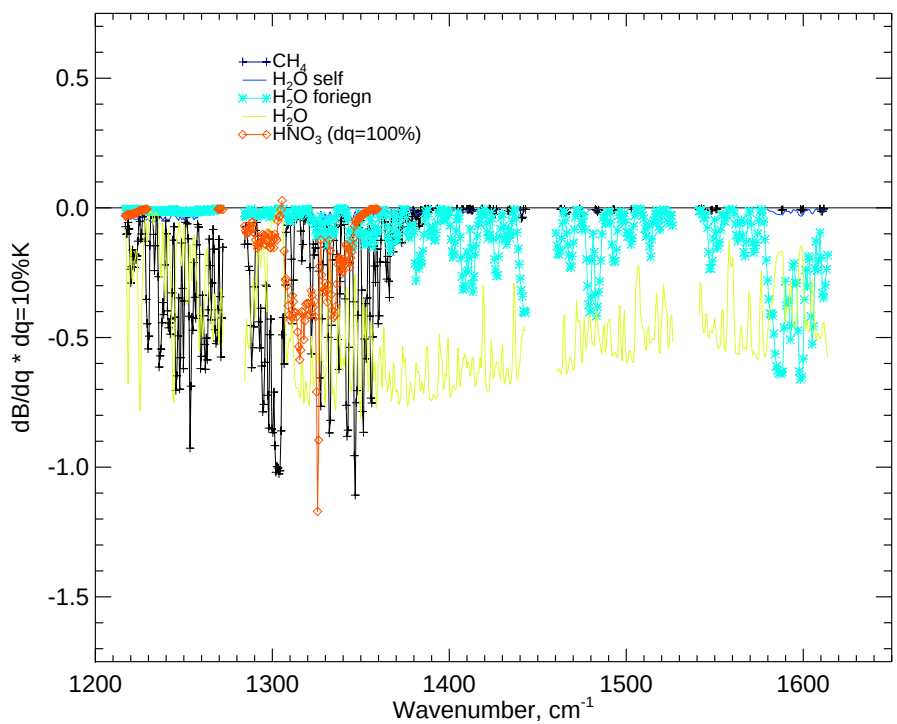
Calculation of Spectra

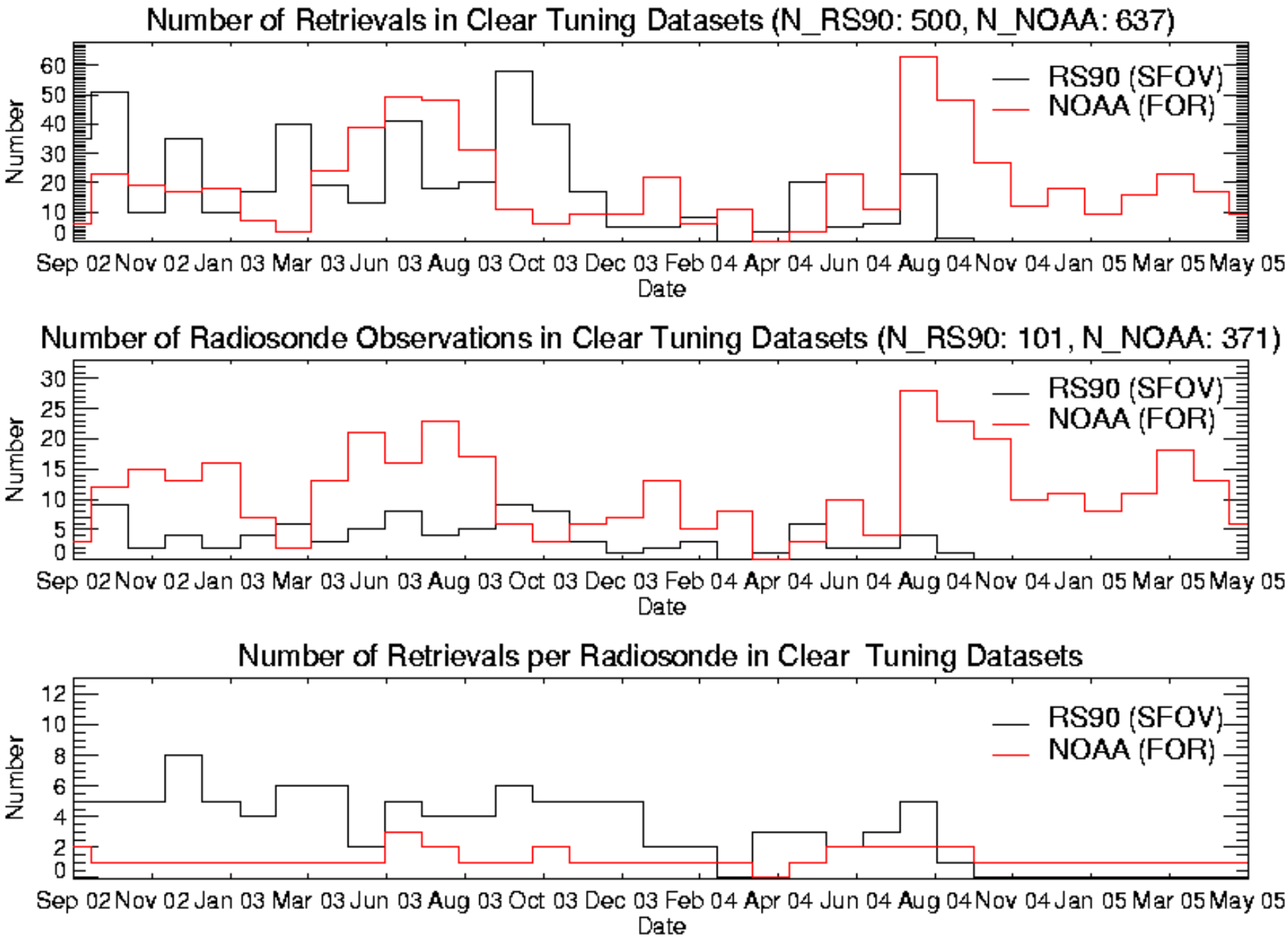
- Let the retrieval code do the work
  1. Set L2_i: TRUTH in .cnf file
  2. Run retrievals
  3. .f92 file contains radiance statistics.

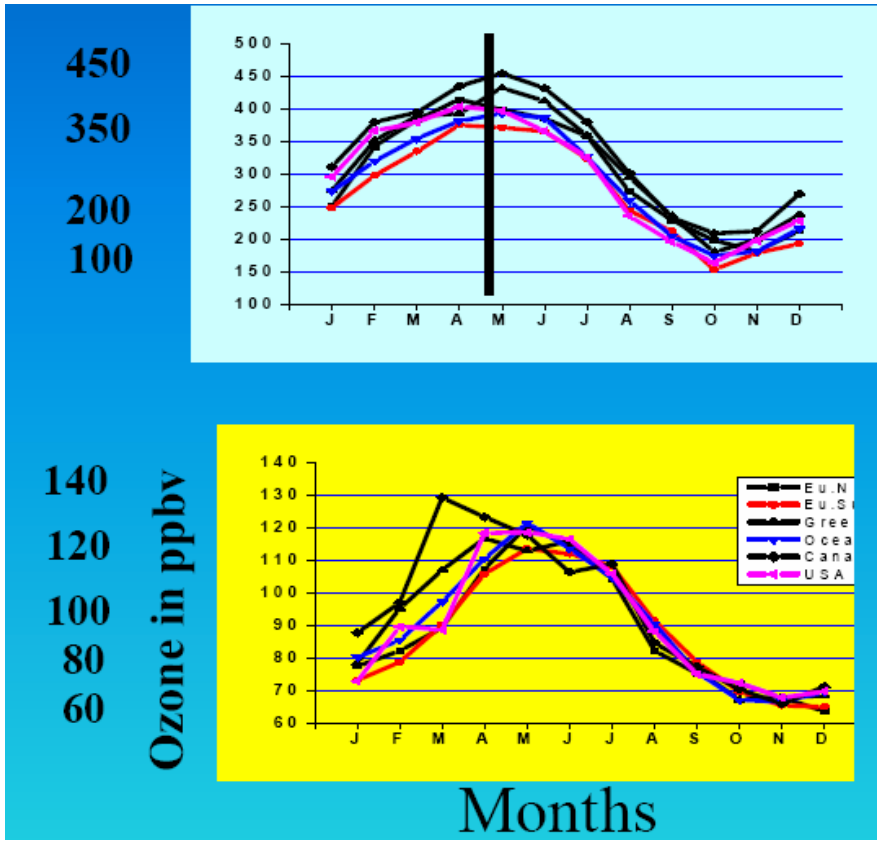
     .ccr file contains radiances based on io_airs.nl parameters (see code/doc/namelist.ema).
- Use comp_rad.F on TRUTH and RETRIEVAL files
  - E.g.) comp_rad.exe l2file.bin l1file.bin [options]
- Use klayers then sarta.F

Interference in T(p)/CO_2 and H_2O spectral regions






Number of Retrievals in Clear Tuning Datasets (N_RS90: 500, N_NOAA: 637)
Number
RS90 (SFOV)
NOAA (FOR)
Sep 02 Nov 02 Jan 03 Mar 03 Jun 03 Aug 03 Oct 03 Dec 03 Feb 04 Apr 04 Jun 04 Aug 04 Nov 04 Jan 05 Mar 05 May 05
Date
Number of Radiosonde Observations in Clear Tuning Datasets (N_RS90: 101, N_NOAA: 371)
Number
RS90 (SFOV)
NOAA (FOR)
Sep 02 Nov 02 Jan 03 Mar 03 Jun 03 Aug 03 Oct 03 Dec 03 Feb 04 Apr 04 Jun 04 Aug 04 Nov 04 Jan 05 Mar 05 May 05
Date
Number of Retrievals per Radiosonde in Clear Tuning Datasets
Number
RS90 (SFOV)
NOAA (FOR)
Sep 02 Nov 02 Jan 03 Mar 03 Jun 03 Aug 03 Oct 03 Dec 03 Feb 04 Apr 04 Jun 04 Aug 04 Nov 04 Jan 05 Mar 05 May 05
Date


450
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J F M A M J J A S O N D
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120
100
80
60
Ozone in ppbv
140
130
120
110
100
90
80
70
60
J F M A M J J A S O N D
Eu.N
Eu.S
Gree
Ocea
Cana
USA
Months