Optimal Spectral Sampling (OSS) Method: Current Research and New Prospects

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ITSC-14

Beijing May 25-31, 2005

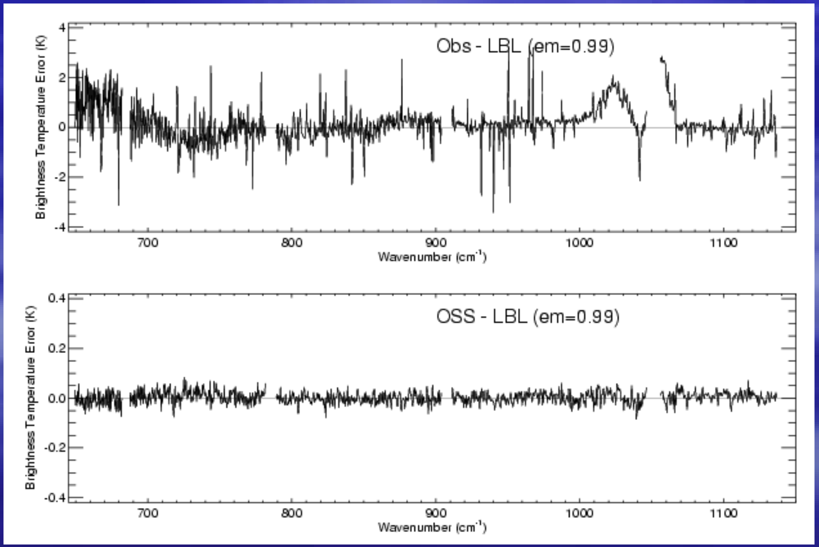
Overview of the OSS approach

- OSS method (Moncet *et al.* 2003,2001) models the channel radiance as

$$\overline{R} = \int_{\Delta\nu} \phi(\nu) R(\nu) d\nu \cong \sum_{i=1}^{N} w_i R(\nu_i); \qquad \nu_i \in \Delta\nu$$

- Wavenumber ν_i (nodes) and weights w_i are determined by fitting "exact" calculations (from line-by-line model) for globally representative set of atmospheres (training set)
- Monochromatic RT (using look-up tables of absorption coefficients for relevant species stored at the selected nodes)
  - Maximum brightness temperature error with current LUT < 0.05K in infrared and <~0.01K in microwave

OSS vs. LBLRTM - AIRS clear-sky, ARM TWP site (08/12/08)



OSS attributes

- Fast/accurate
  - Possibility of trade of between speed/accuracy and tailoring for specific applications
  - Possibility of fitting multiple channels/instruments (generalized training)
    - Speed only driven by total spectral coverage (not number of instruments)
- Flexible handling of variable molecular species
  - Easy selection of variable absorbers at runtime
  - Low memory/computational cost of adding minor absorbers
- Unsupervised training
  - No empirical adjustment: minimizes validation effort!
- Applicable to both high-resolution and wide band (models slow spectral functions within band) sensors
- Applicable to scattering atmospheres

Ongoing OSS efforts

- JCSDA/CRTM:
  - Joint NOAA/AER OPTRAN-OSS intercomparison in clear and cloudy atmospheres (SSMIS, AMSU, GOES sounder/imager, HIRS and AIRS)
    - Accuracy and timing
  - OSS currently being implemented in CRTM
    - Beta version of CRTM with OSS engine delivered
- MODTRAN (under DoD funding):
  - Look at best approach for interfacing OSS with MODTRAN for ***generic*** high/low resolution radiative transfer modeling
  - Wide array of users and applications
    - Same method should cover it all

Current priorities

- Cloudy sky training and validation (thermal and solar)
- Molecular optical depth database compression
  - Exploring new approaches for speeding up (and reducing memory requirements) the method in clear and cloudy skies
    - *Goal*: relax memory requirements and further increase model speed
  - "Local" compression (scale of the order of 100 cm^{-1}):
    - Multiple channel generalized training/clustering techniques
  - Large scale compression (MODTRAN application)
- Treatment of "slowly" varying functions (Planck, surface, clouds/aerosols)
  - Must consider both high-spectral resolution over wide spectral bands and single broadband channels

OSS cloudy validation

- Two aspects are being considered and tested separately:
  - Treatment of clouds on a narrow spectral intervals (cloud properties do not change across interval)
    - Can be done over wide range of conditions using line-by-line models over restricted spectral domains
  - Handling of spectral variations in cloud optical properties across broad intervals (single broadband “channel” or multiple high spectral resolution channels – see “generalized training”)
    - Use purely absorptive clouds first
    - With scattering: use high spectral resolution/high accuracy OSS model as reference

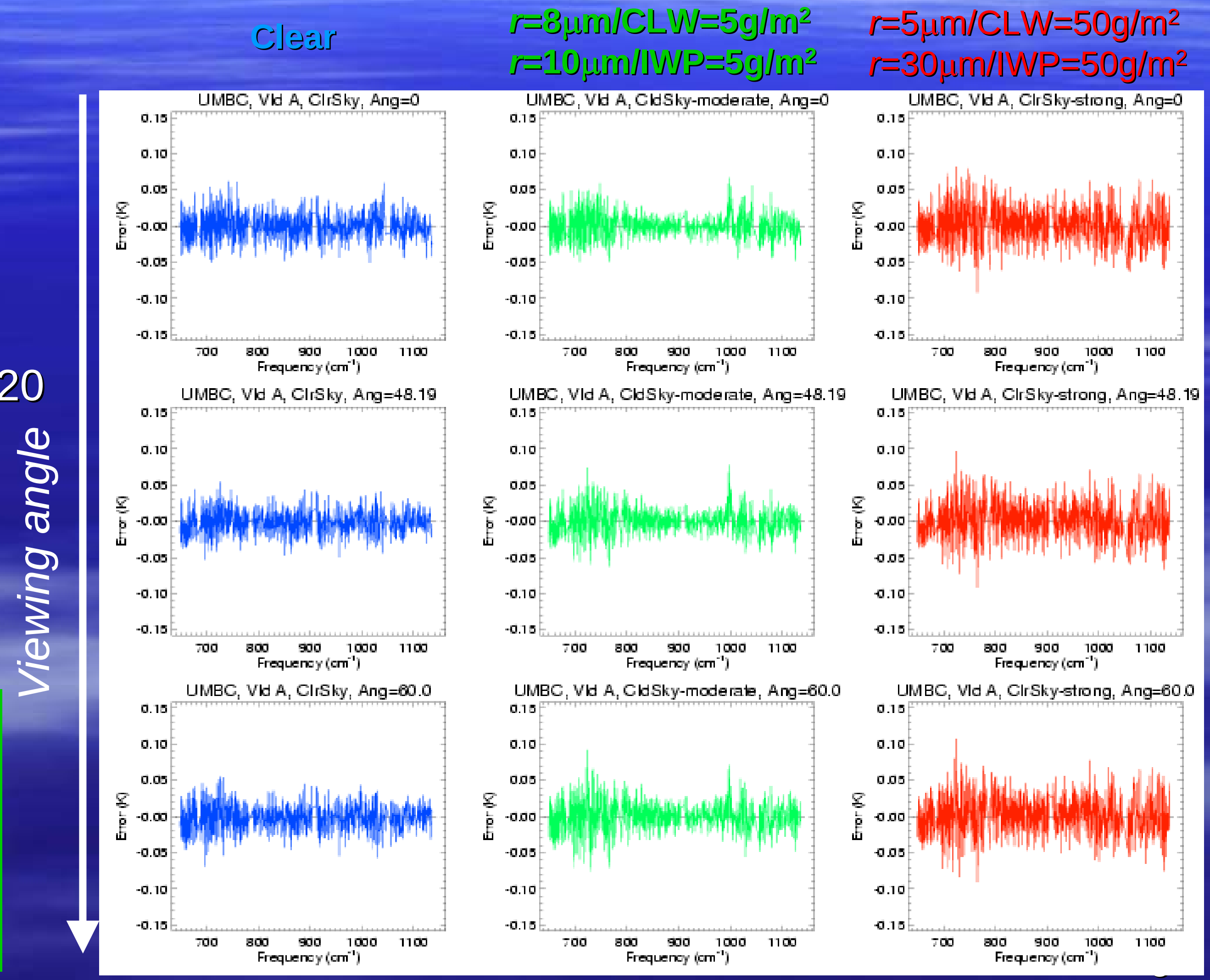
OSS cloudy validation (narrow spectral interval)

- Scatterers effect is to increase photon path lengths in the layers within and below the clouds (reflective surface)
- For narrow channels (*no spectral variation in cloud optical properties across channel*) clear sky (transmittance?) RT using representative distribution of path lengths may be used
- Present results were obtained without any modification to the present clear-sky training (i.e. clouds not accounted for in generating model parameters)
  - In thermal IR (and microwave) current clear-sky radiance training appears so far to work well

Example of OSS cloudy validation (no scattering)

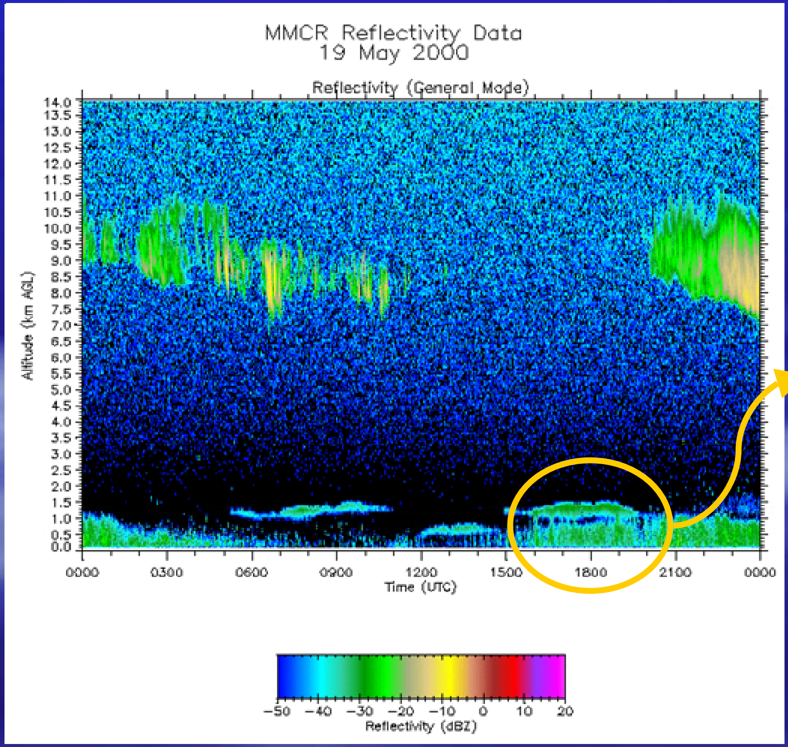
- Instrument: AIRS
- Mean UMBC profile
- 2 cloud layers:
  - liquid (P=670 mb)
  - spherical ice (P=220 mb)

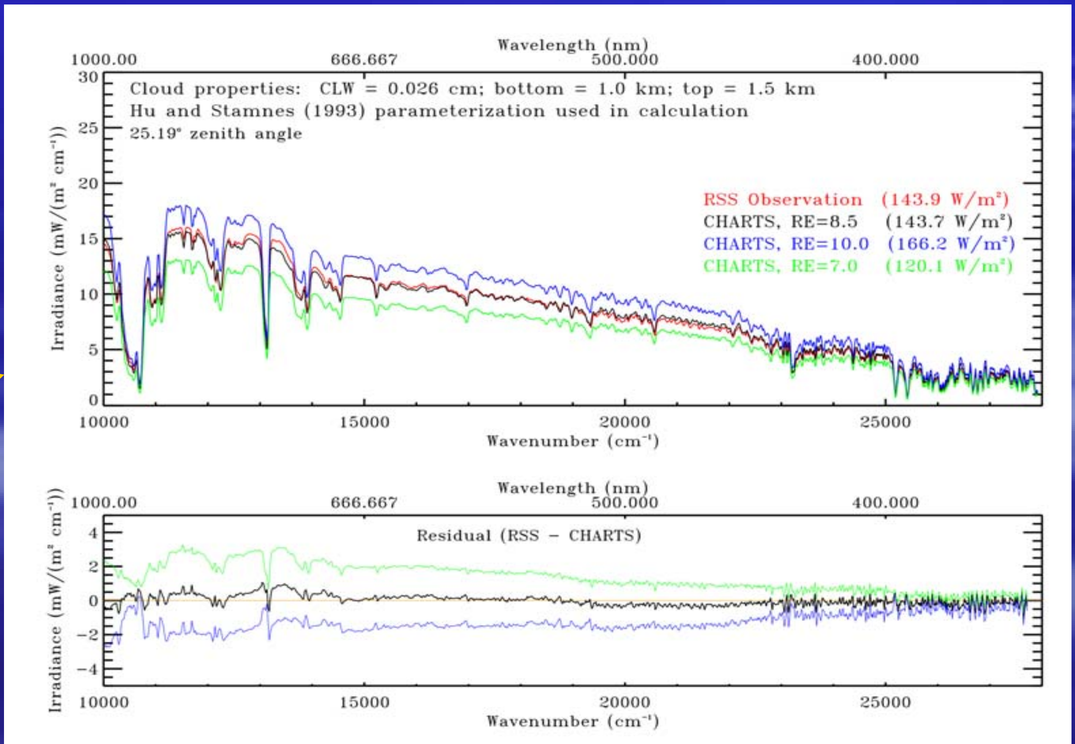
Performance quite insensitive to dependence on scan angle and cloud absorption



OSS/CHARTS Comparison

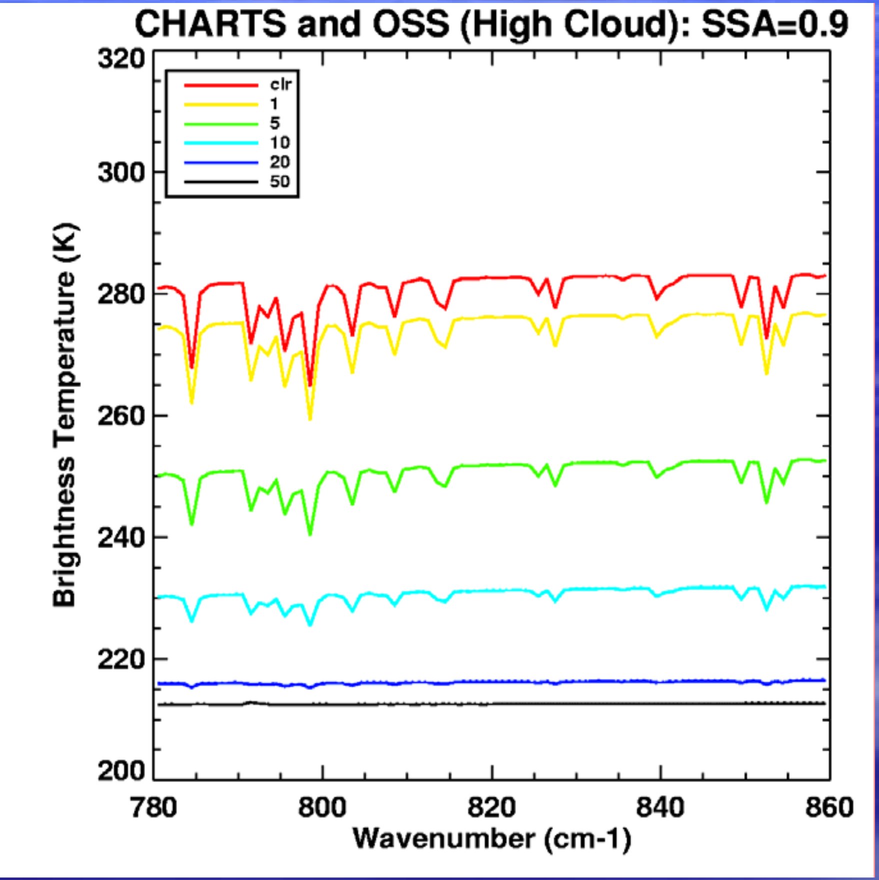
- CHARTS (Moncet and Clough, 1997):
  - Fast adding-doubling scheme for use with LBLRTM
    - Uses tables of layer reflection/transmittance as a function of total absorption computed at run time
  - Plans for routine analysis of Rotating Shadowband Spectroradiometer (RSS) spectra at the AMR/SGP site





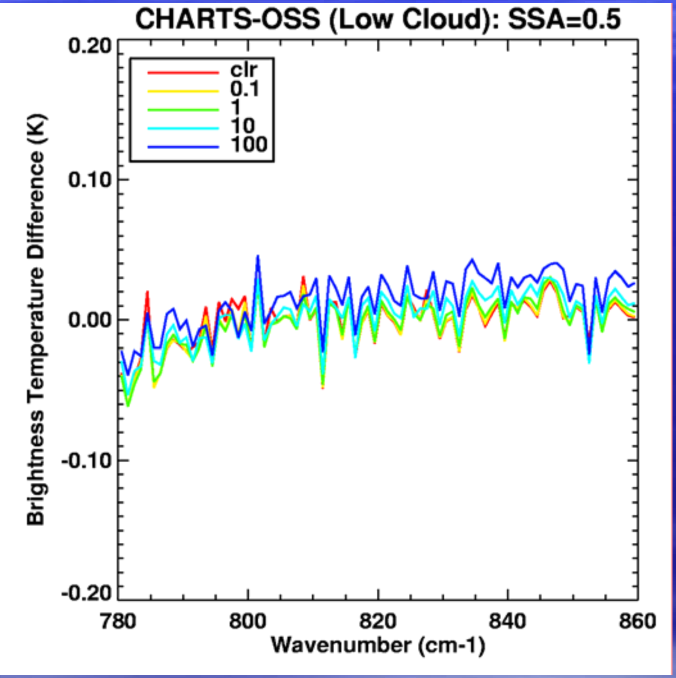
OSS/CHARTS Comparison (2)

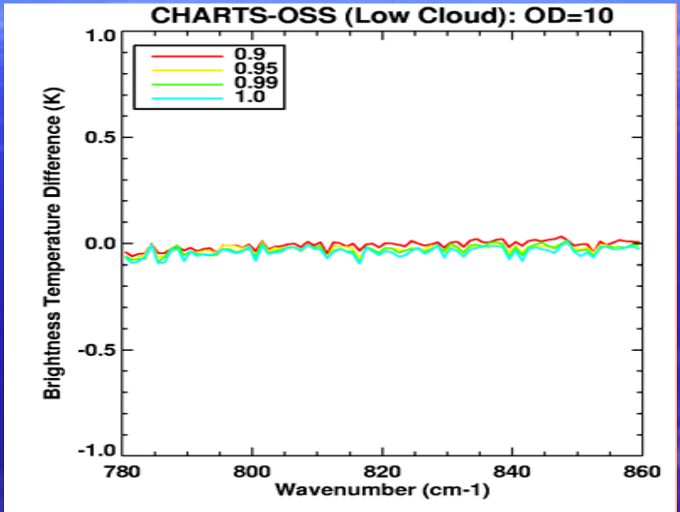
- OSSSCAT:
  - Single wavelength version of CHARTS (no tables)
- Cloudy validation:
  - Molecular absorption from 740-900 cm^{-1} domain
  - Full range of extinction optical depth, asymmetry and single scatter albedo explored
  - No spectral variation of scatterer's optical properties
  - Thermal and solar regimes considered

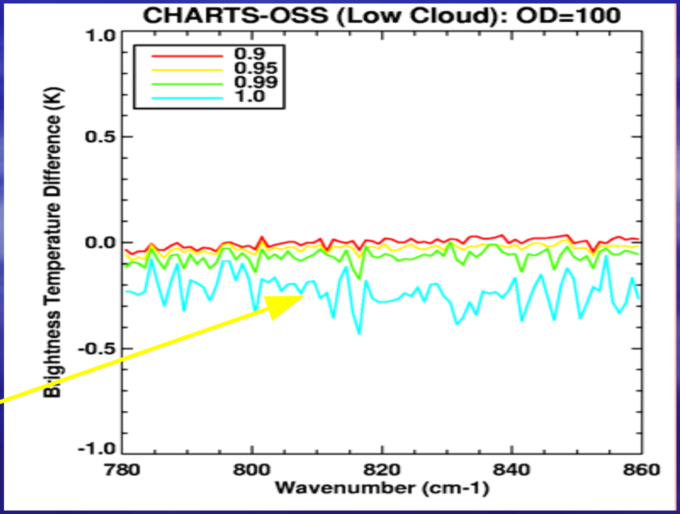


- 1 cm^{-1} boxcars, *thermal only* (high cloud: 300-200 mb)

OSS/CHARTS Comparison (3)



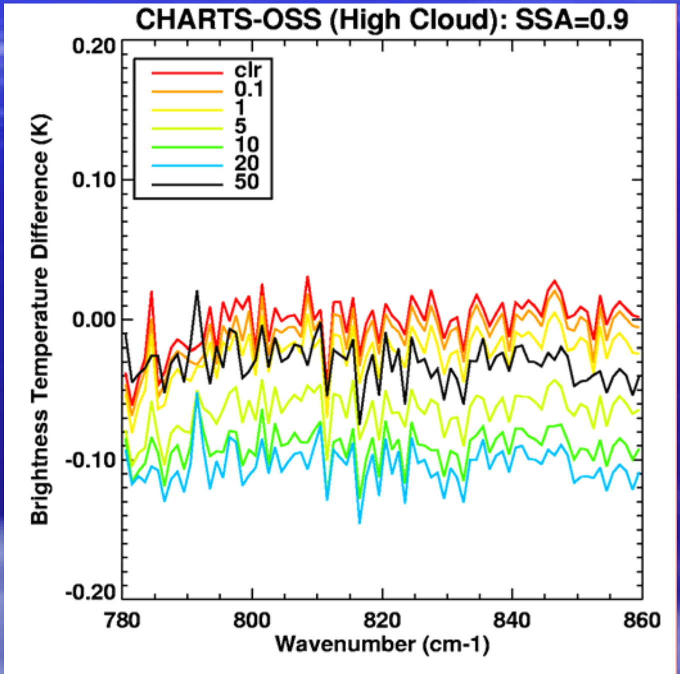


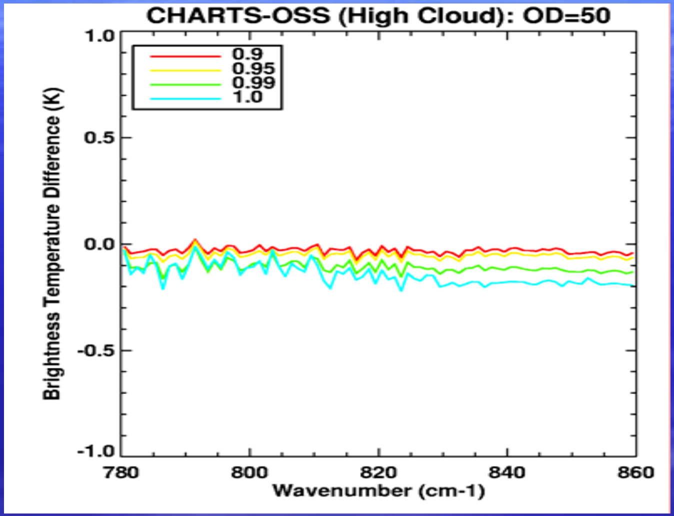


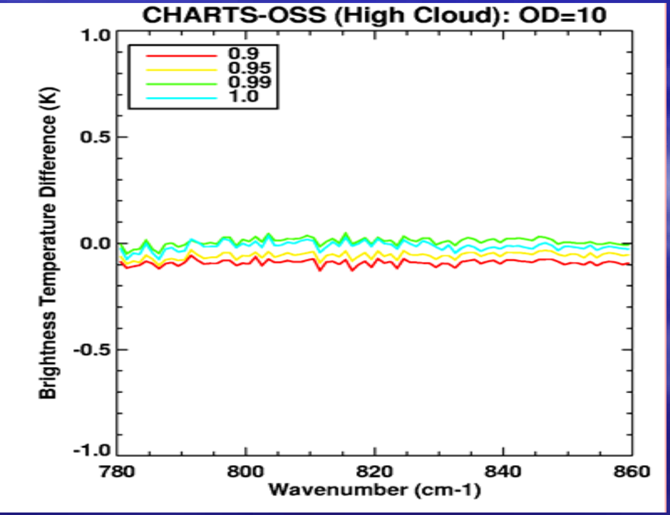
(low cloud: 925-825 mb)

Approaching the current CHARTS LUT accuracy for large OD's when SSA ~1

OSS/CHARTS Comparison (4)



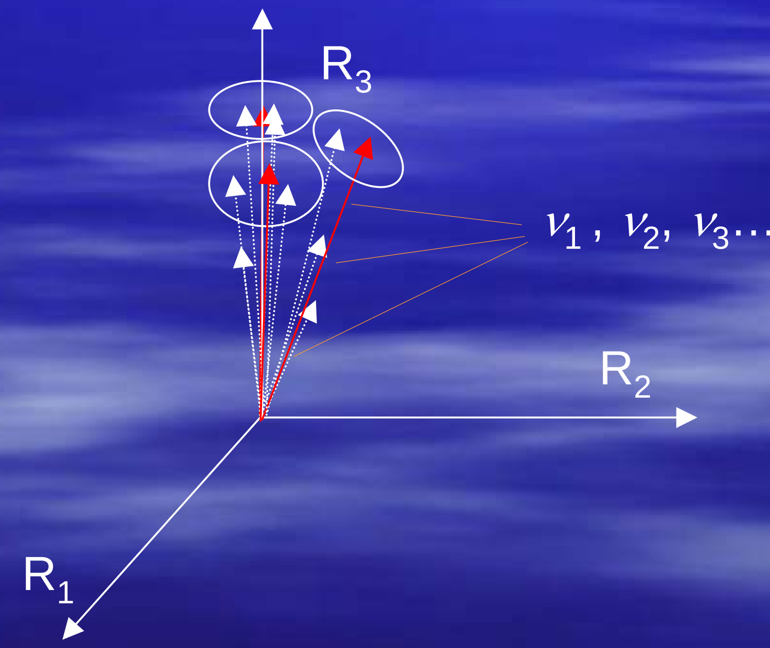




(high cloud: 300-200 mb)

Generalized training

- OSS selection simultaneously operates on *N* channels, instead of one channel at a time
- Two selection methods considered:
  - **Method A:** Extension of current method to multiple channels, i.e. nodes are successively added until *rms* difference between exact and approximate calculation for all channels in domain considered falls below prescribed threshold (reference)
  - **Method B:** Clustering: start from set of pre-selected nodes encompassing domain of interest and coalesce pairs of nodes with similar information content
  - Clustering (not optimized yet) is fast and applies to broad spectral domains (large number of channels) - Method A is limited to a few hundred cm^{-1}



Generalized training

- Large computational gains in clear sky (i.e. when cloud-clearing is used)
  - Gain is mainly the result of the fact that *eliminated nodes are reconstructed as linear combinations of the retained nodes*
  - Gain increases as size of spectral domain increases or spectral resolution increases
- In these examples, gain can be further increased by ~30-40%

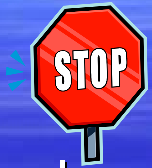
Interval (cm^{-1})	Interval width (cm^{-1})	# nodes (current method)	Gain (multi-channel approach)
645-675	30	286	9
780-820	40	141	6
645-745	100	1047	20
780-880	100	248	10
780-980	200	478	16

Examples of gain achievable with multi-channel/clustering approaches

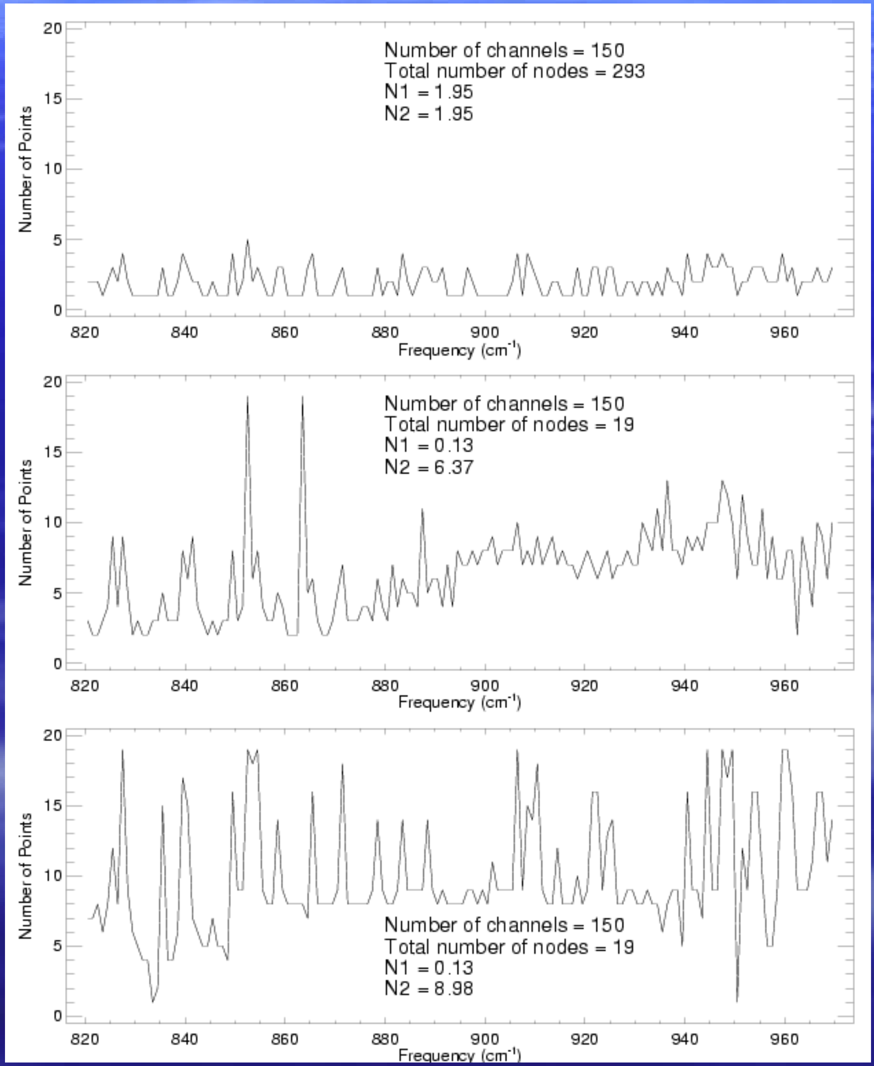
($1cm^{-1}$ boxcars)

Cloudy RT considerations

- Channel based RT



  - Required number of nodes for any given channel actually increases compared to single channel training (i.e. current approach is optimal)
  - In this example (gain ~ 15 in clear-sky), scattering calculations actually is ~3-4 times more time consuming than with current single channel approach

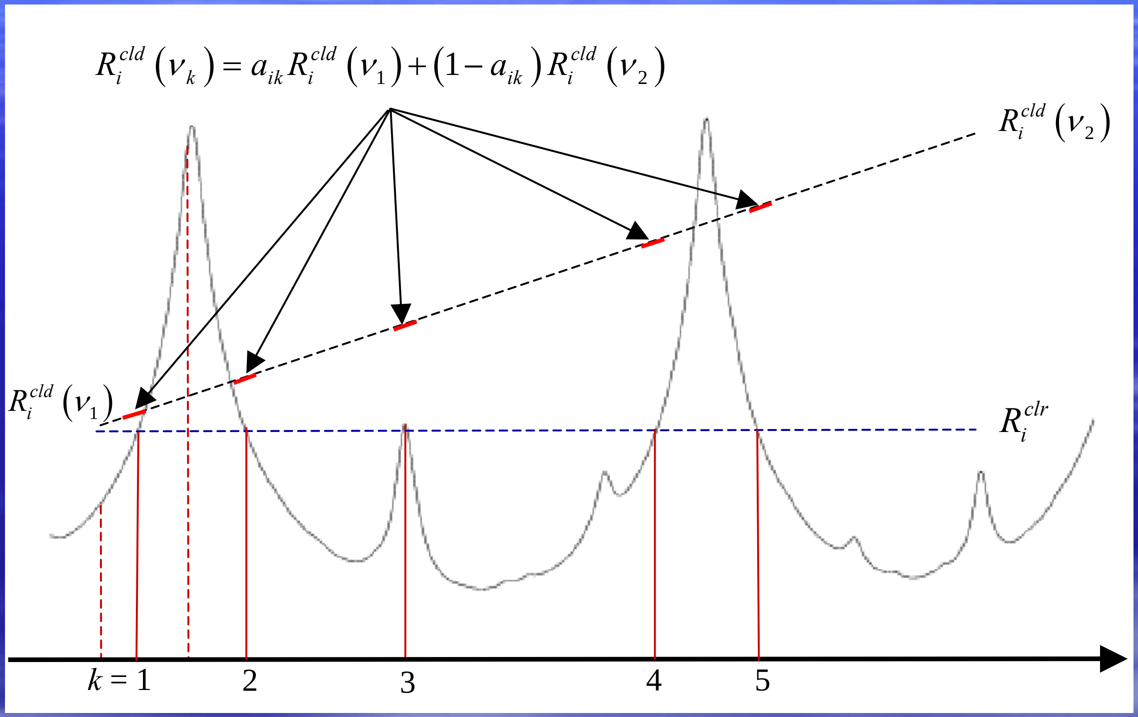


Generalized cloudy training

- Must include slowly varying cloud/aerosol optical properties in training
  - Over wide bands: training can be done by using a database of cloud/aerosol optical properties
  - More general training obtained by breaking spectrum in intervals of the order of 10 cm^{-1} in width (impact of variations in cloud/aerosol properties on radiances is quasi-linear) and by performing independent training for each interval (lower computational gain but increased robustness)
- Direct cloudy radiance training not recommended !
  - Clouds tend to mask molecular structure which makes training easier
  - If "recipe" for mixture of clear and cloudy atmospheres in direct training not right: clear-sky performance degrades

Generalized cloudy training

- Alternate two-step training preserves clear-sky solution
  - First step: normal clear-sky (transmittance/radiance) training to model molecular absorption
  - Second step: duplicate/ spectrally redistribute nodes and recompute weights to incorporate slowly varying functions in the model



$$\bar{R} = \sum_i w_i \sum_k \left(a_{ik} R_i(\nu_1) + (1 - a_{ik}) R_i(\nu_2)\right) \frac{\Delta\nu_{ik}}{\Delta\nu_i} = \sum_i w_i' R_i(\nu_1) + (w_i - w_i') R_i(\nu_2)$$

i= molecular database index

Training method performance comparison (AIRS Channel 1-1262)

	Wavenumber range (cm^{-1})	Channel number	Number of selected nodes		
			Current selection method	Method A (clear sky)	Method A (cloudy)
1	649-669	1-79	217	47	47
2	669-689	80-136	239	37	37
3	689-709	137-208	287	52	55
4	709-729	209-278	345	75	79
5	729-749	279-342	235	69	82
6	749-769	343-403	157	50	130
7	769-789	404-441	75	22	25
8	789-809	442-496	85	31	50
9	809-829	497-549	50	17	20
10	829-849	550-599	27	9	12
11	849-869	600-664	41	12	15
12	869-889	665-725	36	11	14
13	889-909	726-769	22	5	7
14	909-929	770-819	37	9	11
15	929-949	820-872	57	11	14
16	949-969	873-922	53	11	51
17	969-989	923-973	75	16	33
18	989-1009	974-1020	122	23	27
19	1009-1029	1021-1065	214	40	44
20	1029-1049	1066-1103	217	49	52
21	1049-1069	1104-1130	165	51	54
22	1069-1089	1131-1171	92	30	34
23	1089-1109	1172-1210	83	18	21
24	1109-1129	1211-1247	85	22	96
25	1129-1149	1248-1262	52	22	26
Total number of nodes			**2498**	**739**	**1036**
Avg. number of nodes/channel			**1.98**	**0.59**	**0.82**

- Training conditions:
  - ECMWF set
  - 7 angles (minimize *rms* for each angle)
  - Accuracy threshold = 0.05K
  - Domain size (Method A) = ~20 cm^{-1}
  - Random cloud spectra with smoothness constraint (1st and second spectral derivatives) derived from realistic optical properties
- AIRS results (Method A)
  - Clear-sky gain: ~3.4
  - Cloudy gain: ~2.4

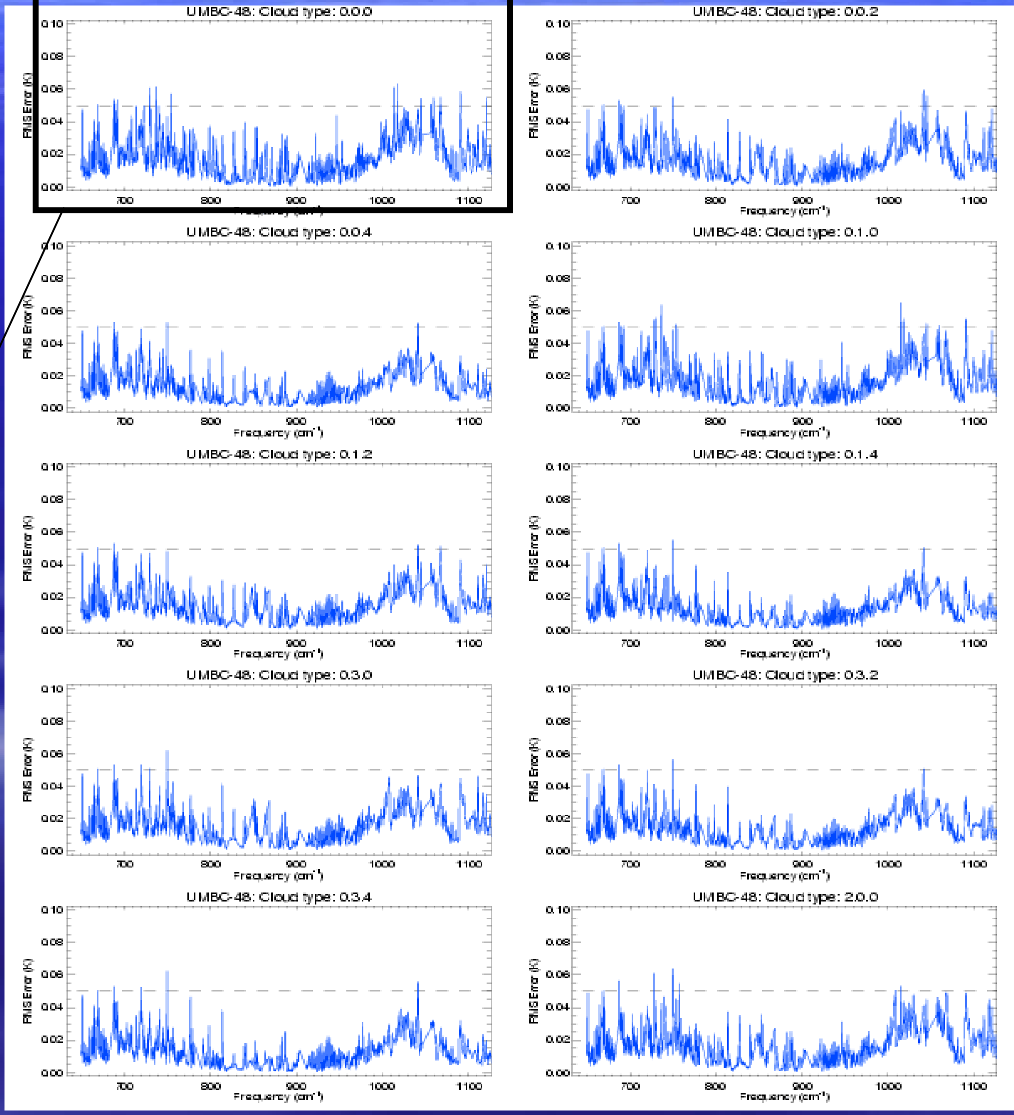
Generalized training validation (no scattering)

- 48 UMBC profiles
- 3 cloud layers: 300 mb, 500 mb, 700 mb
- Independent set of random cloud spectra

Cloud code	Optical depth range
0	=0
1	>0 and < 0.5
2	>0.5 and < 1
3	>1 and < 2
4	>2

Clear-sky solution left intact

Model accuracy tends to improve as cloud optical depth increases (which is a good sign!)



Summary

- OSS cloudy validation
  - Clear-sky transmittance training seem to be adequate for scattering atmospheres (thermal sources only)
  - Validation in solar regime just started - may need to use wider range of layer optical paths
- "Generalized training" offers potential for large memory/time savings over single channel approach in the modeling of clear (or cloud-cleared) radiances
  - Variations in cloud/aerosol optical properties limits gain achievable with multi-channel training
    - Estimated worst case for AIRS: gain 2-3
    - Higher gain when model is trained for limited number of particle types
  - Same training algorithm can handle multi-channel and single channel training

Summary (2)

- Robust approach for handling of slowly varying functions in the training
  - New approach for dealing with slow spectral functions (Planck, cloud/aerosols) preserves clear-sky solution and handles seamlessly clear/cloudy transition (optically thin limit)
  - Applies to surface emissivity/reflectivity as well
  - Deals with any spectral function – optimizes solution according to characteristics of input data
  - Can the method be generalized to handle band-to-band correlation?