CRTM's SSU Module that Accounts for Spectral Response Functions Variations

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Outline

1. SSU unique features
2. Issues and solutions
3. SSU fast radiative transfer model and validation
4. Summary and conclusions

SSU Data

- Stratospheric Sounding Unit data is a three-channel sensor in the CO_2 15 μm absorption band onboard NOAA series satellites (started from TIROS-N in 1978 and ended at NOAA-14 in 2006).

- The data in past 29 years is an unique near-global source on temperature for middle and upper stratosphere.

- The SSU data has been extensively used to study the temperature trends in the stratosphere, as well as their possible causes (e.g. Nash and Forrester, 1986; Ramaswamy et al., 2001; Shine et al., 2003; World Meteorological Organization (WNO), 1988, 2007; Liu and Weng, 2009).

SSU system

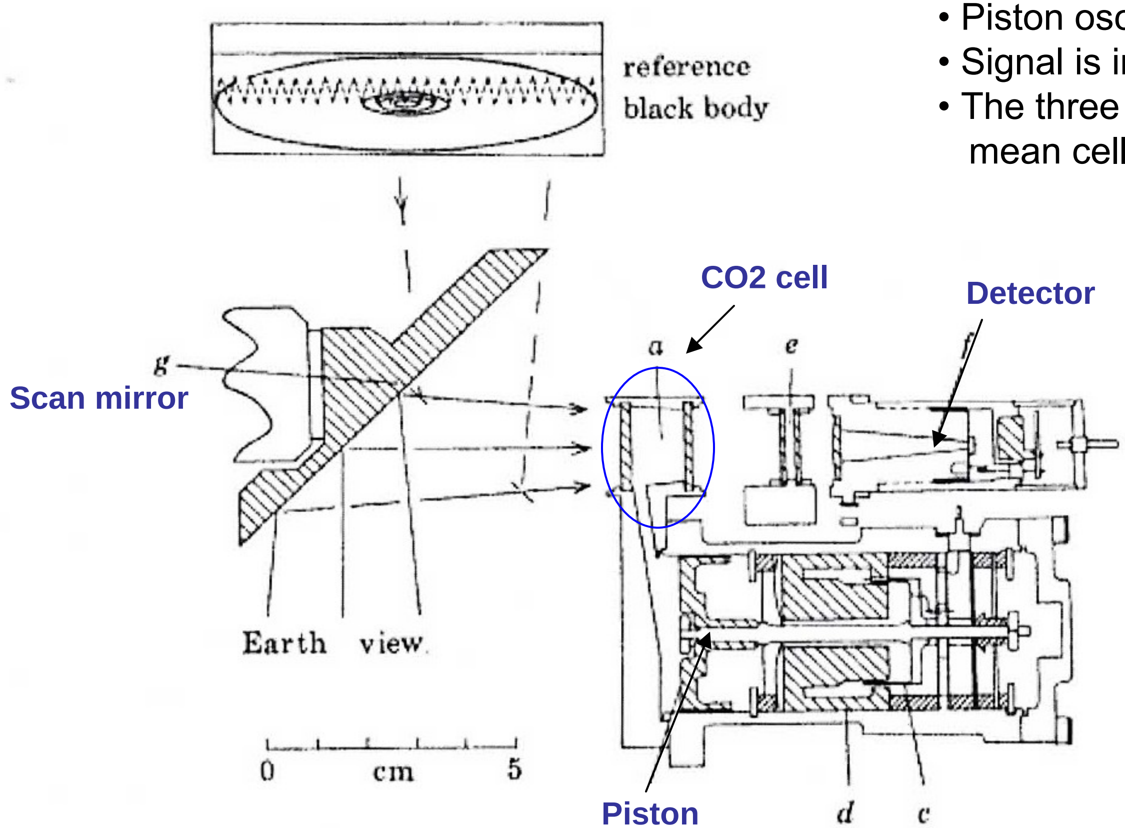


FIGURE 1. The optical system and pressure modulator of a stratospheric sounding unit. *a*, Absorption cell; *b*, piston; *c*, drive coil; *d*, magnet; *e*, interference filter; *f*, detector; *g*, scan mirror. Another two optical channels share the scan mirror.

- Piston oscillation frequency: 40 Hz
- Signal is integrated for about 3.5s
- The three channels differ in the mean cell pressure

From Miller, 1980, Phil. Trans. R. Soc. Lond.

Sensor Response Function (SRF)

Different from a conventional sensor response function, the SSU SRF is a product of traditional broadband and the CO_2 cell absorption line responses.

High-frequency gas cell response

Filter function

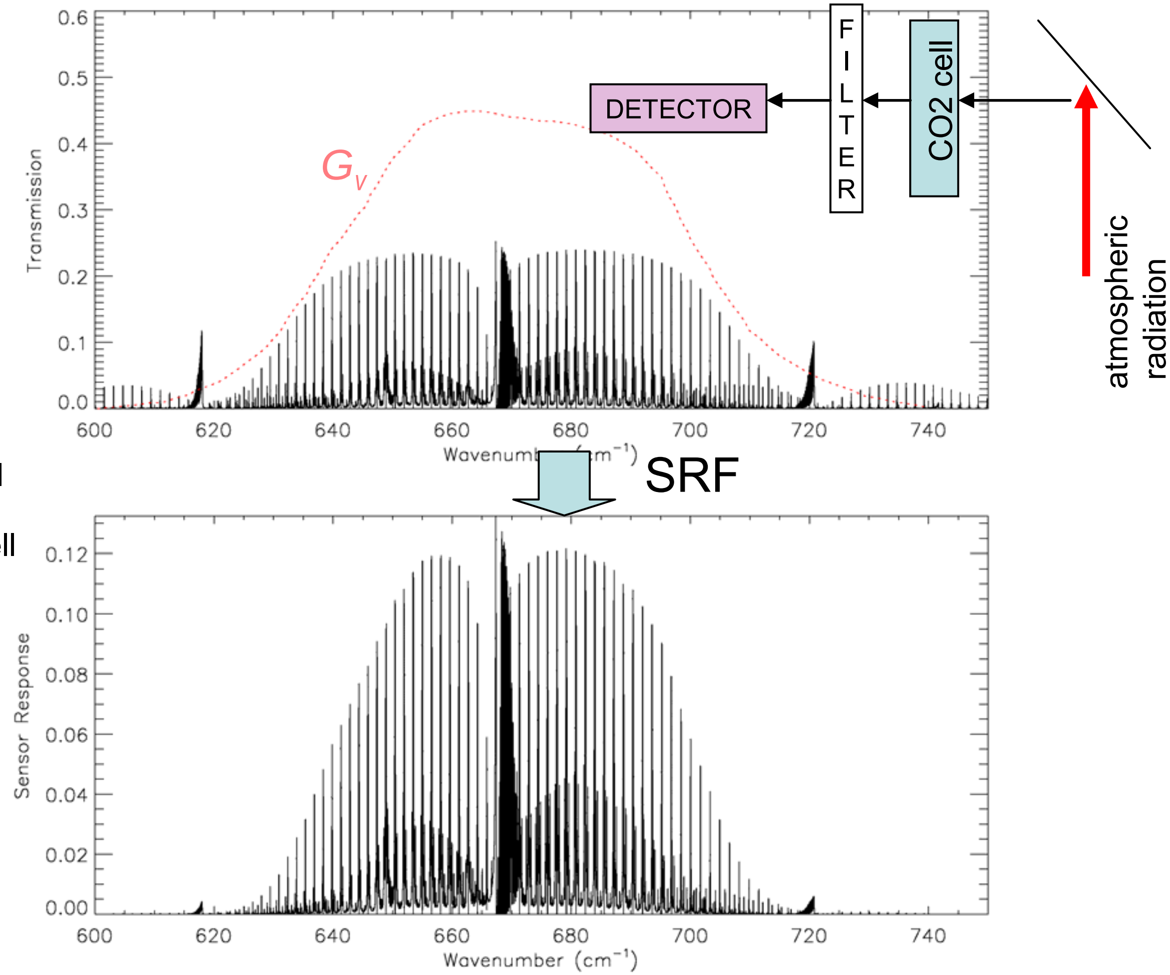
SSU SRF = $G_\nu H_\nu$

Two cell approximation (Brindley et al., 1998):

$$H_\nu = \tau_\nu^{\,low\ p\ cell} - \tau_\nu^{\,high\ p\ cell}$$

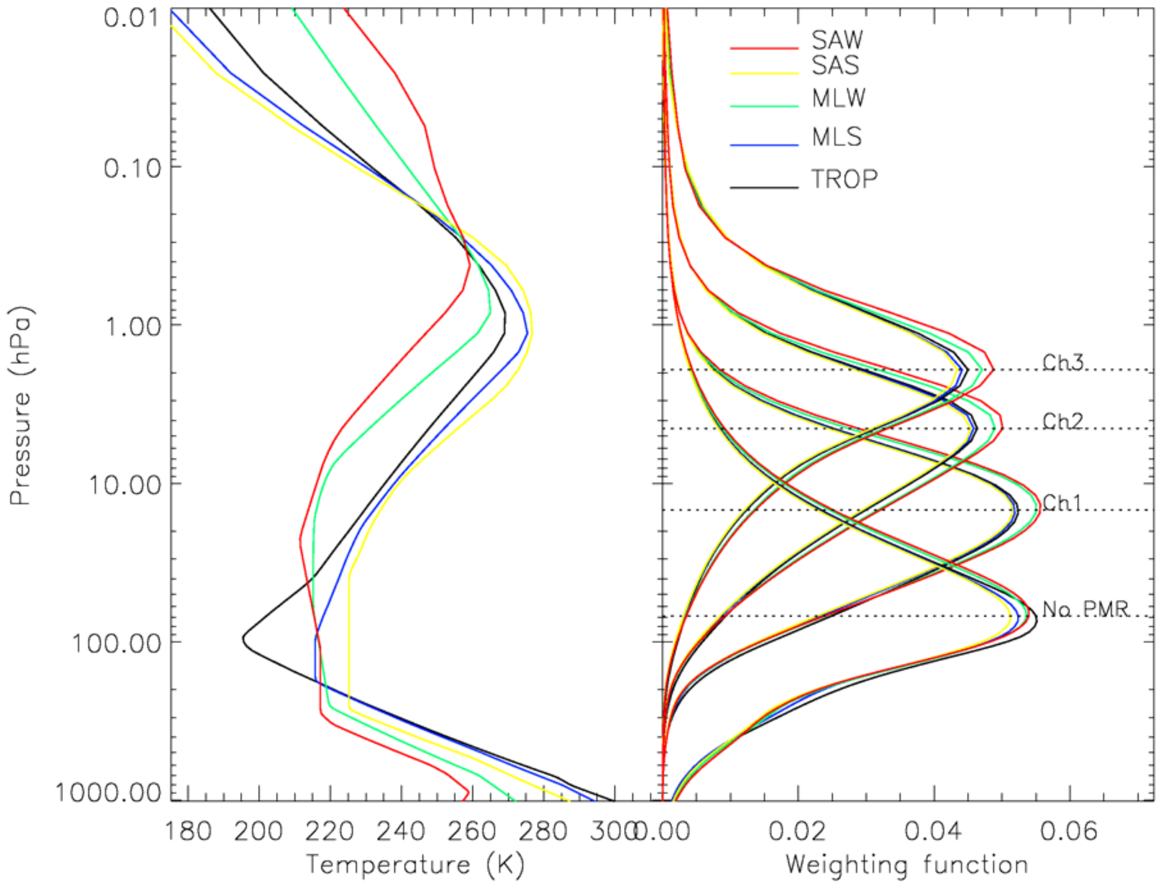
Transmittance of the low CO_2 pressure cell

Transmittance of the high CO_2 pressure cell



Weighting Function

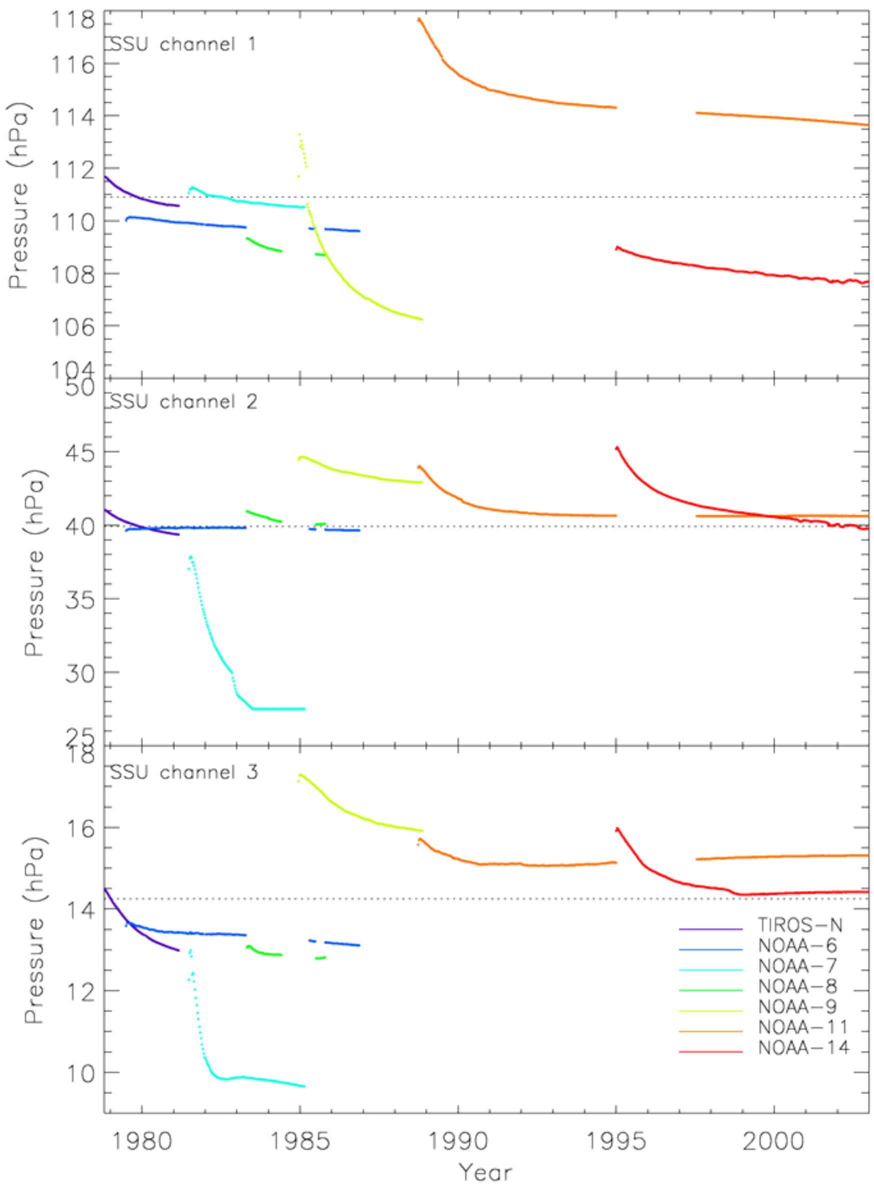
Split into 3 channels and shifted upward middle and upper stratosphere



Issues

- Modeling the cell CO_2 absorption
- Cell CO_2 leaking, causing variations of the spectral response functions (SRFs)
- Incomplete cell pressure data
- Variations of cell temperature, causing variations of SRFs

CO_2 Leaking problem in cell pressure modulator

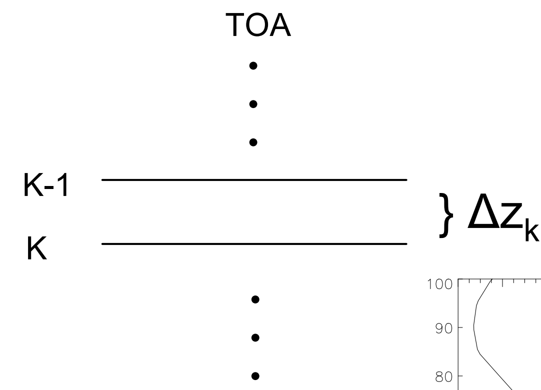


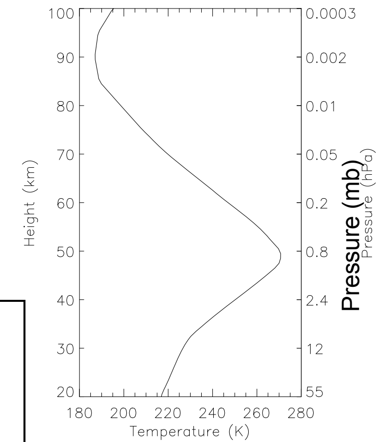
Measured cell pressures for SSU three channels from 1978 to 2003 (data from Dr. Shinya Kobayashi at ECMWF).

Weighting function shift due to cell CO_2 leaking

Weighting function

$$R_{ch} = \sum_{k=1}^{N} \frac{\tau_{ch,k-1} - \tau_{ch,k}}{\Delta z_k} \Delta z_k B(T_k)$$





Atmospheric transmittance:

$$\tau_{ch,k} = \int_{\nu 1}^{\nu 2} \tau_\nu \phi_\nu \, d\nu$$

SRF

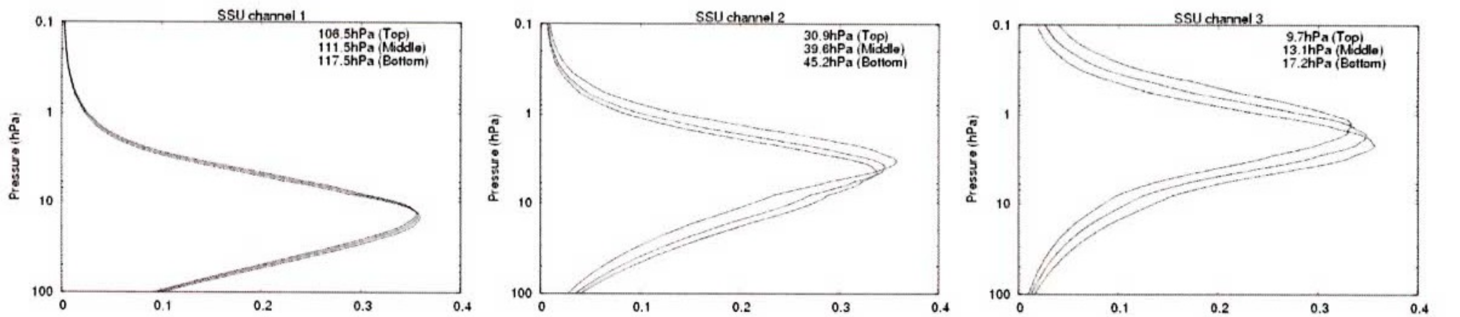


Figure 4 Impact of the changes of the mean cell pressure on the weighting functions.

figure from Dr. Shinya Kobayashi, ECMWF

WF peak height $p_{PEAK} = [4(1+\beta)L/a]^{1/2} p_{cell}$ (Taylor et al. 1972)

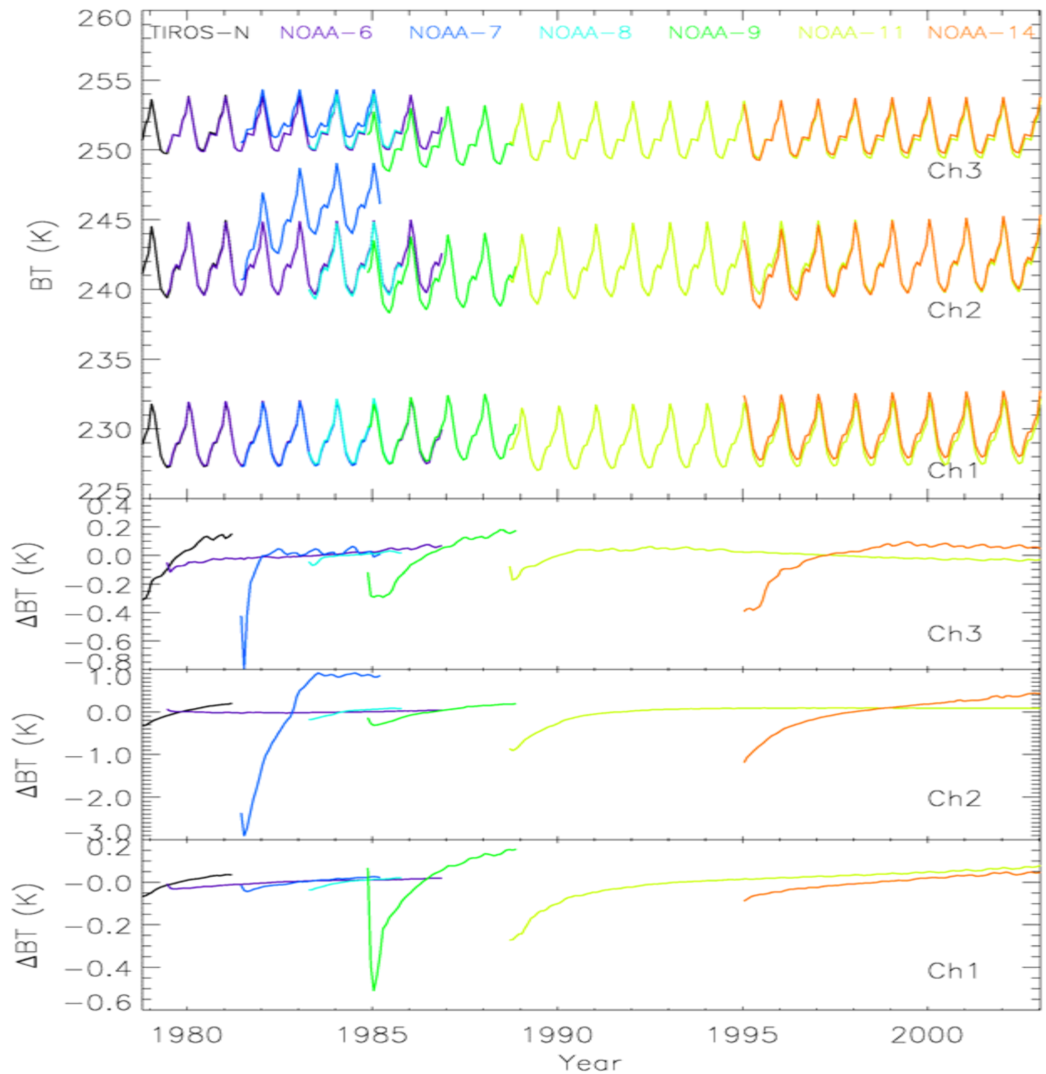
$1+\beta$: a correction for the self-broadening effect in the pure CO_2 in the cell length L

a : the thickness that the total column of CO_2 would have if it were compressed to standard temperature and pressure.

Impact of Cell Pressure on Brightness Temperature

Time series global and monthly mean brightness temperature due to cell pressure shift for SSU 3 channels by using the zonal and monthly mean temperatures profiles from COSPAR International Reference Atmosphere (Fleming et al., 1988) (CIRA) with a 5° latitudinal resolution from 80° S to 80° N, and ozone profiles taken from the US Standard Atmosphere.

The CO_2 concentration variation with times is also considered in the simulation.



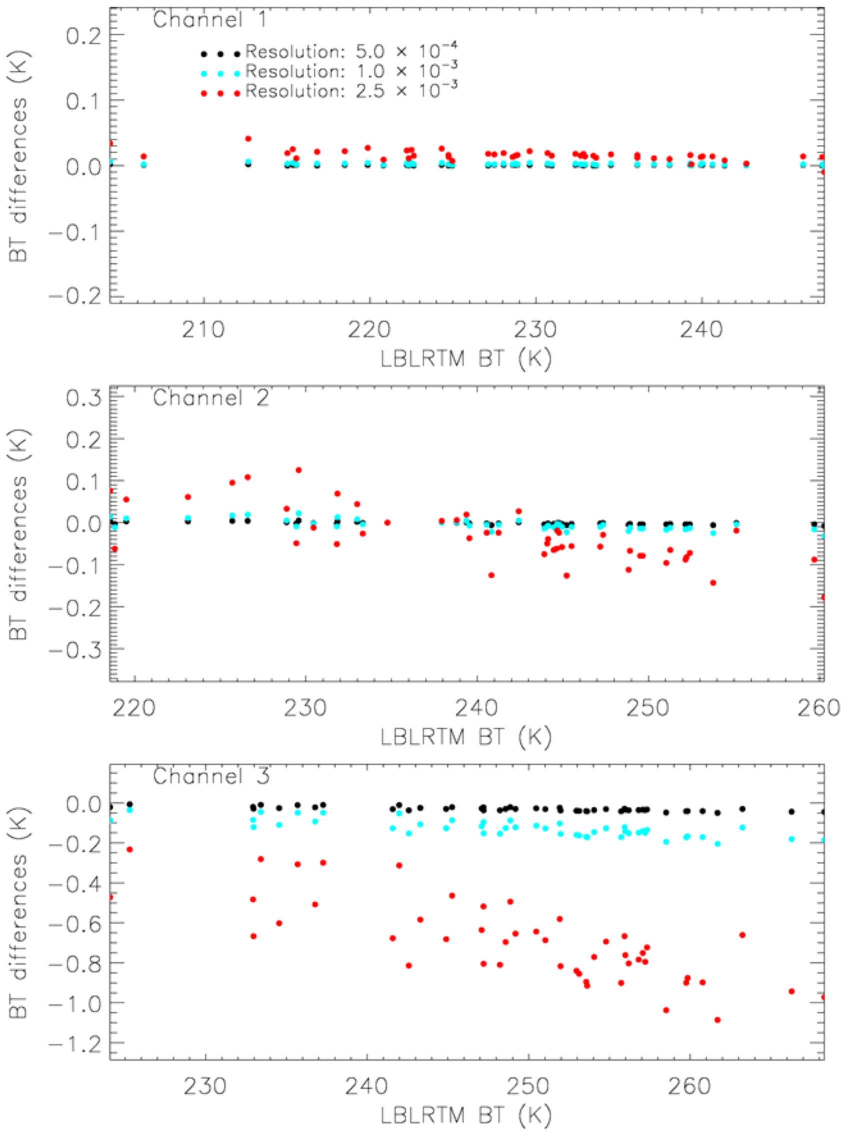
Spectral resolution for calculations of SSU SRFs

Gases included	Resolution (cm-1)	Difference from control (K)			Standard Deviation (K)		
		Ch 1	Ch 2	Ch3	Ch 1	Ch 2	Ch3
First 7 mols	5×10^{-4}	0.001	-0.002	-0.031	0.001	0.003	0.010
First 7 mols	2.5×10^{-3}	0.016	-0.032	**-0.693**	0.008	0.066	0.203
First 7 mols	1×10^{-3}	0.002	-0.006	-0.129	0.001	0.012	0.041

Sensitivity of SSU channels brightness temperature (BT) to spectral resolutions.

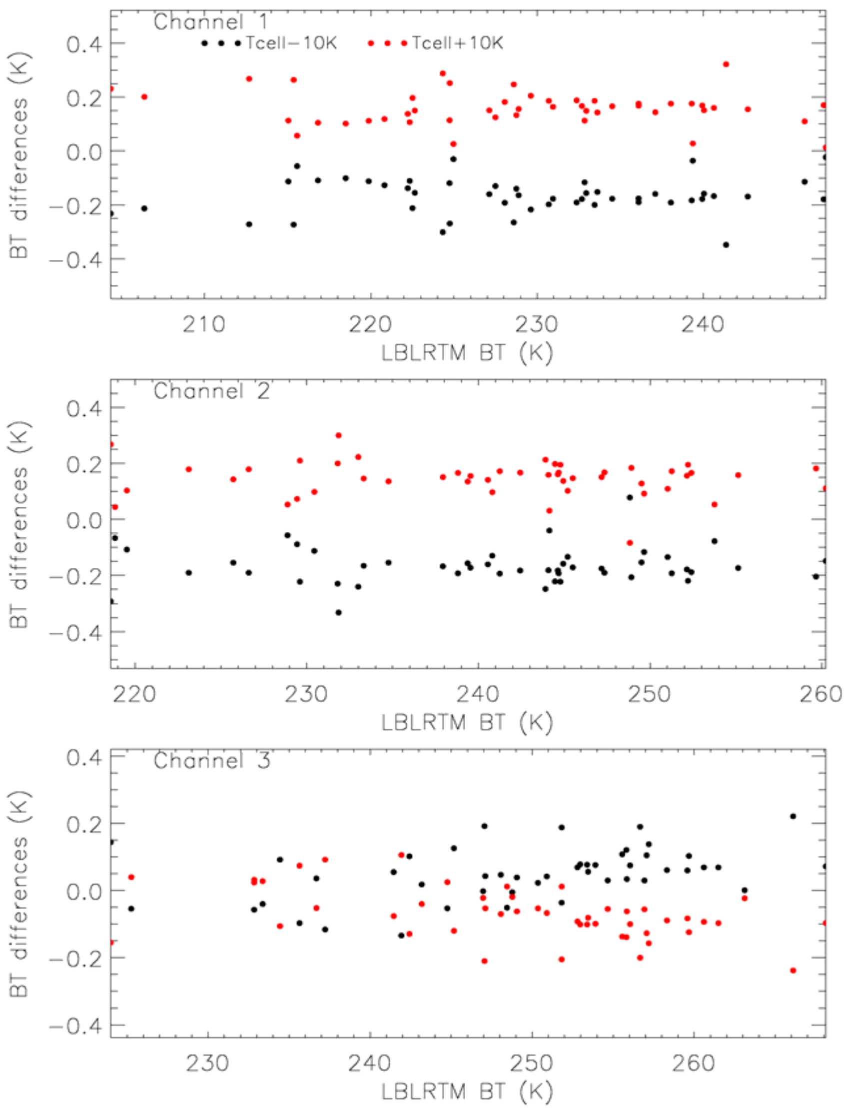
The reference resolution is 1×10^{-4} cm^{-1}. UMBC 48 atmospheric profiles are used.

Sensitivity to spectral resolution



Cell temperature variation

Sensitivity to cell temperature



Cell temperature variation

SRF variation

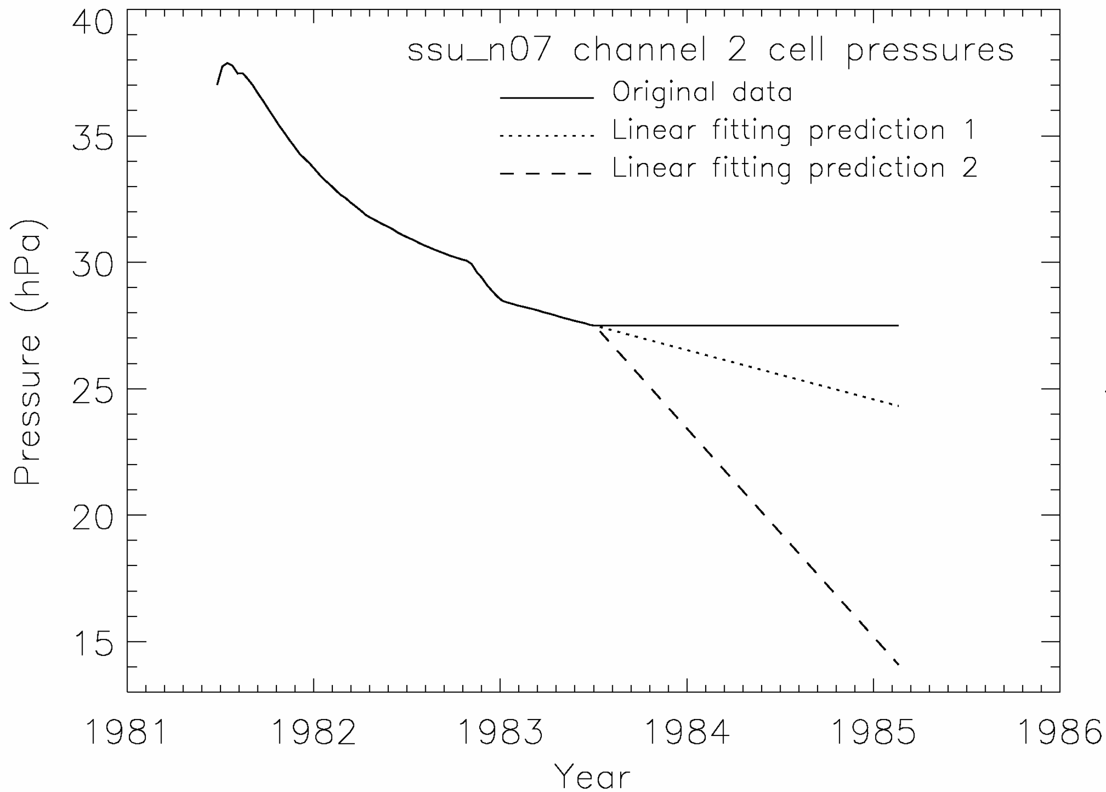
Weighting function shift

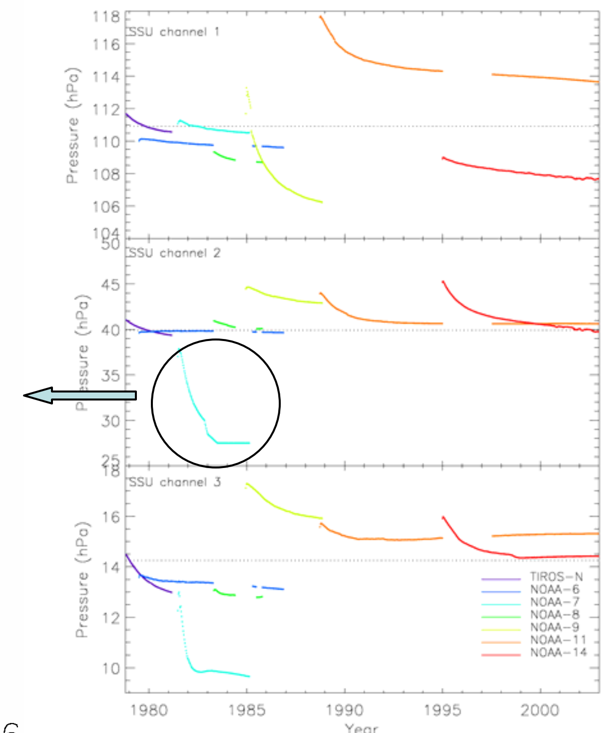
Radiance variation

Unfortunately we don't have the temperature data

Fitting the Cell Pressures for missing cell pressure data in SSU NOAA-7 Channel 2

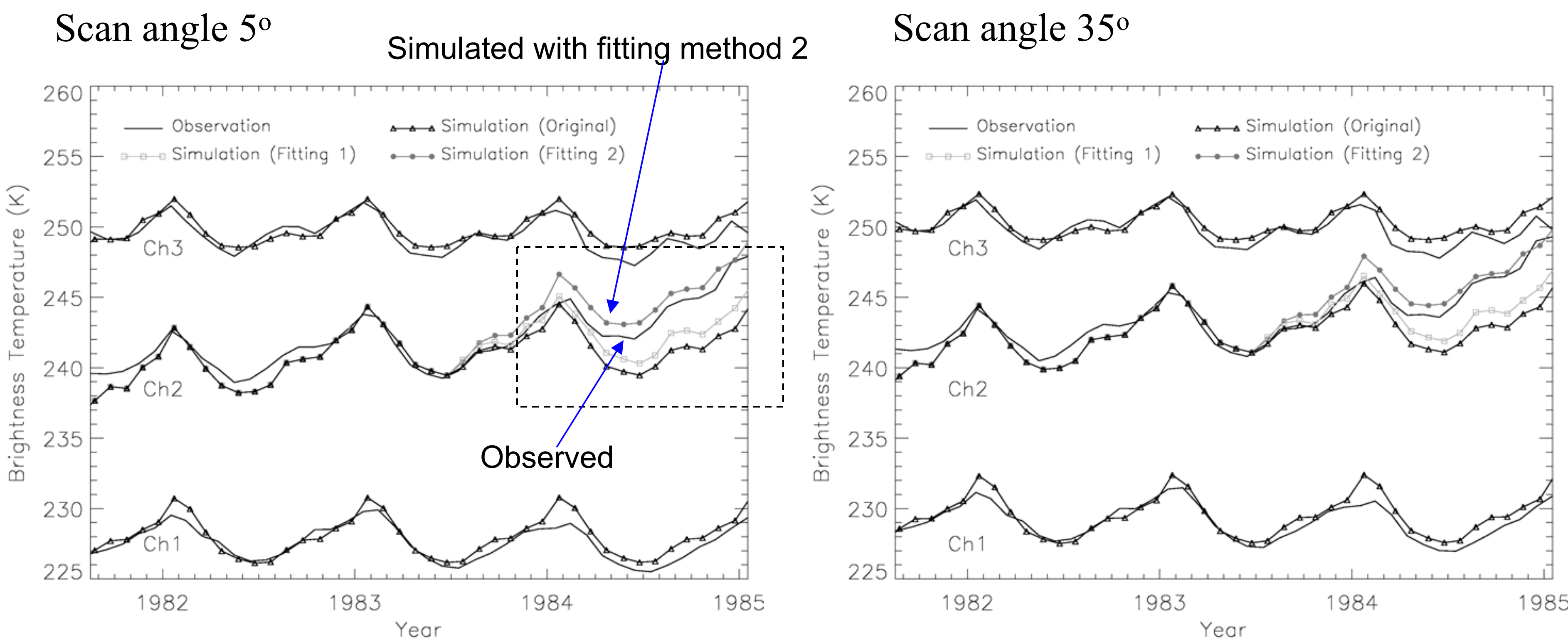
Cell CO_2 pressure





Linear fitting the ssu_n07 channel 2 cell pressures and predicting the cell pressures after year 1983.534. The first one using linear fitting with the decreasing rate from period year 1983.038 to 1983.507, while the second one with the decreasing rate from period year 1982.874 to 1983.011.

Fitting the Cell Pressures for SSU NOAA-7 Channel 2

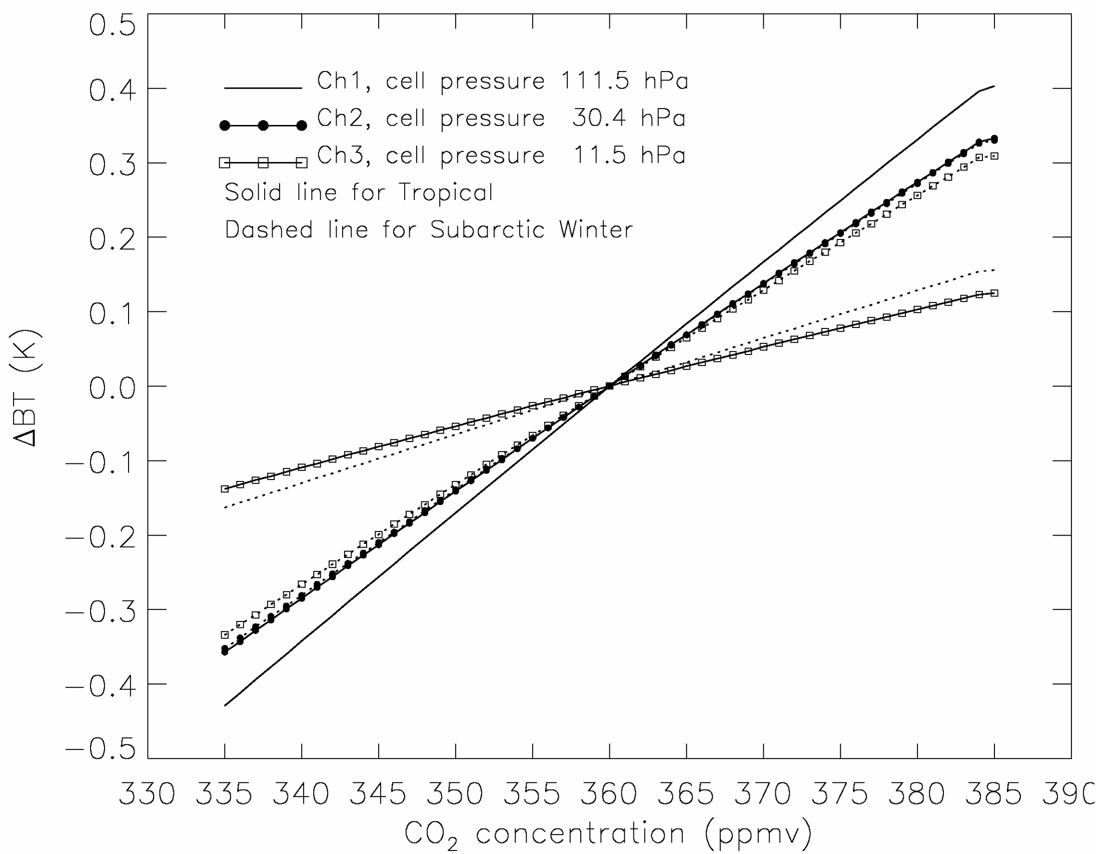


Time Series for global monthly mean measured brightness temperatures and simulated brightness temperatures using the fast model from the CIRA temperature profiles for SSU NOAA-7 channels.

SSU Fast RT Model that takes CO_2 leaking into account

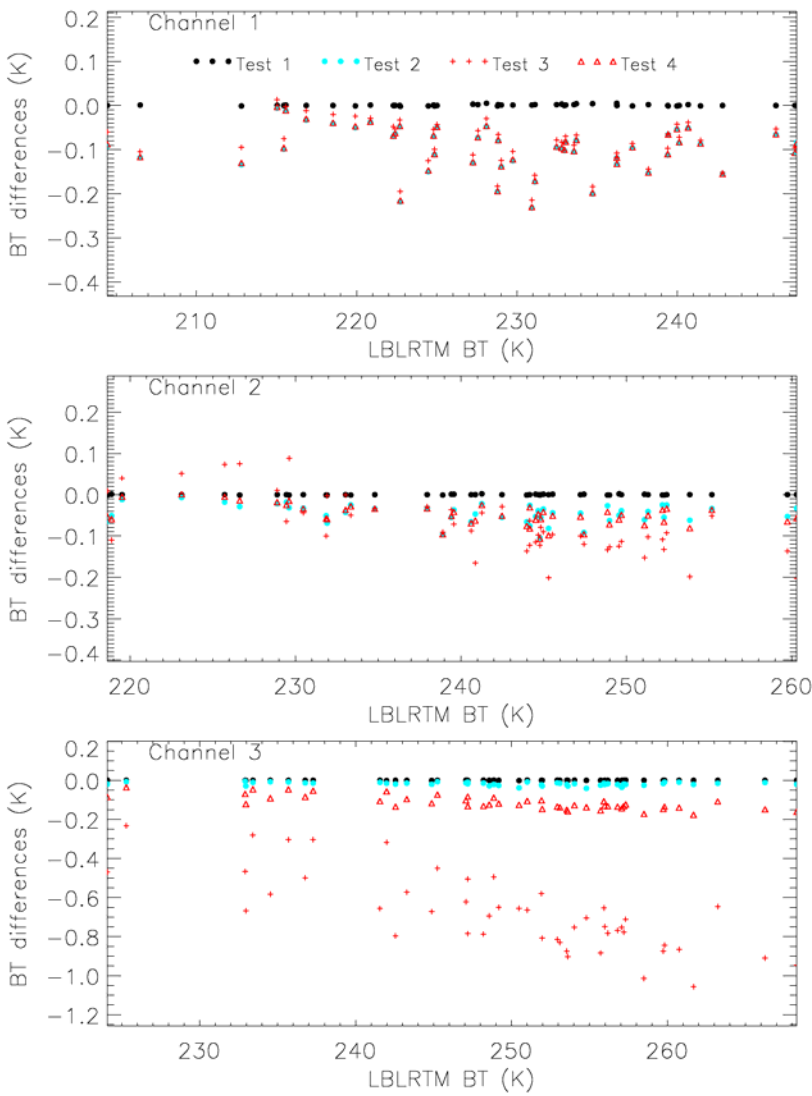
- Based on the sensitivity studies, the fast RT model for SSU utilizes a spectral resolution of 5×10^{-4} cm^{-1}
- CO_2 and O_3 as variable gases.
- The fast model (implemented in CRTM version 2) takes account of the variations of the cell pressures:
  - Use a series of the transmittance coefficient sets for each sensor at different values of CO_2 cell pressure with corresponding SRF.
  - The transmittances at an arbitrary value of CO_2 cell pressure are obtained through interpolation from the transmittances computed at two adjacent CO_2 cell pressure nodes which bracket the desired value.

Impact of atmospheric CO_2 concentration change on SSU brightness temperature



Sensitivity to gaseous absorbers

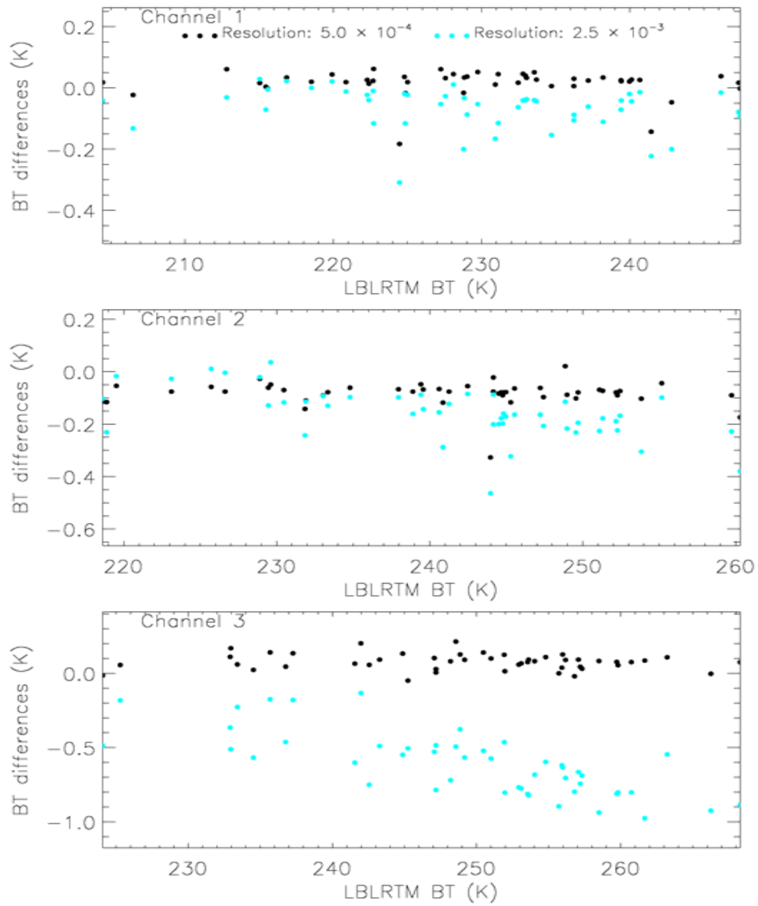
Test	Gases included	Resolution (cm-1)	Difference from control (K)			Standard Deviation (K)		
			Ch 1	Ch 2	Ch3	Ch 1	Ch 2	Ch3
1	CO_2, O_3	5×10^{-4}	0.001	0	0	0.002	0.001	0.001
2	CO_2 only	5×10^{-4}	**-0.099**	-0.046	-0.018	0.051	0.022	0.008
3	CO_2 only	2.5×10^{-3}	-0.083	-0.076	-0.680	0.051	0.071	0.196
4	CO_2 only	1×10^{-3}	-0.077	-0.050	-0.116	0.051	0.025	0.034



The reference resolution is 5×10^{-4}, and 7 first molecules in LBLRTM.

Atmospheric O_3 is important for channel 2

Independent test CRTM results with LBLRTM



Gases included	Resolution (cm-1)	Difference from control (K)			Standard Deviation (K)		
		Ch 1	Ch 2	Ch3	Ch 1	Ch 2	Ch3
CO_2, O_3	5×10^{-4}	0.016	-0.083	0.077	0.044	0.047	0.054
CO_2 only	2.5×10^{-3}	-0.066	-0.160	-0.613	0.069	0.097	0.213

Comparisons between observation and modeling

The SSU and SABER data are matched:

•A SSU scan angle 5° pixel (near-nadir) data was collocated with a SABER profile (using time and location at ~5 hPa, near the SSU channel 2 weighting function peak)

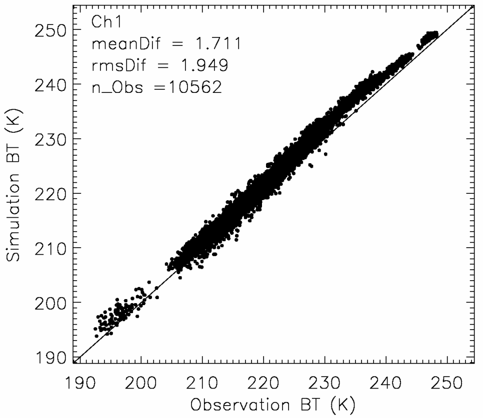
•The absolute differences of latitudes and longitudes were less than 2.5 degrees

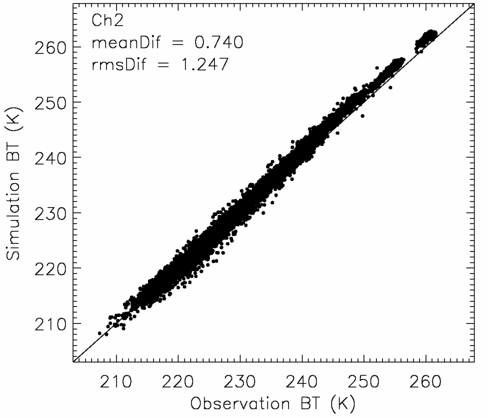
•Their distance was a minimum among all the data pairs and less than 200 km,

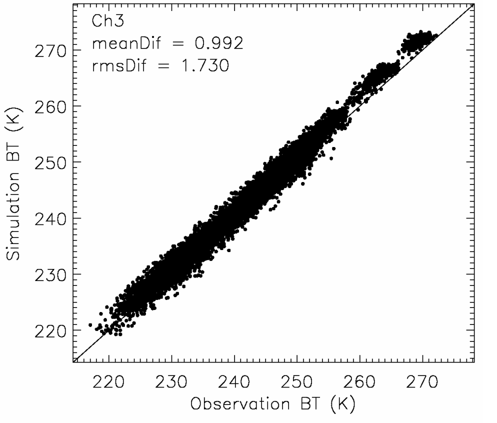
•And the absolute time difference was less that 2 hours.

•4 months of 2003: January, April, July, and October to consider the seasonal and global coverage

A total 10562 matched samples were collected for the comparison. Of these samples, 1786 are in January, 3771 in April, 1969 in July, and 3036 in October.







SSU Pseudo Sensor covering SSU Data from 1978 to 2007

Channel 1 reference cell pressure range [105, 118];
Channel 2 reference cell pressure range [14.8, 46];
Channel 3 reference cell pressure range [5, 18].

Time series from 1978 to 2007, every 0.1115 year.

Total reference cell pressure 261 for every 0.05 hPa for channel 1 and channel 3, and 0.12 hPa for channel 2.

The TauCoeff cell number is 50 for each channel, every 0.27 hPa for channel 1 and 3, and 0.65 hPa for channel 2, which results in the ranges for channel 1 [104.865, 118.095], channel 2 [14.475, 46.325], channel 3 [4.865, 18.095] that should cover all the possible cell pressure for all the SSU sensors.

Spectral resolution: 5×10^{-4}
Gaseous absorbers included: CO_2 and O_3

Model applications in calibration and inter-calibration

CRTM-SSU may be used for

- data quality check and consistency check between different satellites
- analyzing problems in deriving CDRs from measurements
- understanding and determining ΔR (radiance adjustment):
  - formula
  - contributors
  - residual errors

Summary and Conclusions

• The SSU observation provides unique data for global stratospheric temperature study over the long period from 1978 to 2006.

• In order to accurately estimate temperature from the SSU measurements, the SSU fast RT model include schemes to accurately model the CO_2 cell transmittance for each of the three channels and account for the variations of the SRFs caused by the CO_2 cell pressure variations.

• Based on the sensitivity studies, the fast RT model for SSU utilizes a spectral resolution of 5×10^{-4} cm^{-1}, with CO_2 and O_3 as variable gases.

• The fast RT model is much fast than LBLRTM (hours to seconds), and validated against LBLRTM and measurements.

• The impact of the CO_2 cell pressures shift for SSU has been evaluated by using the CIRA model profiles. It is shown that the impacts can be in order of 1 K, especially for SSU NOAA-7 channel 2. Two linear fittings methods are proposed to solve the larger brightness temperature gap between observation and model simulation using the available cell pressures for NOAA-7 channel 2 after July 1983. The results show that the new cell pressures using fitting method 2 are reasonable.