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Measurement of Greenhouse Gases from Satellite: Challenges and Some Applications in China

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China Meteorological Administration

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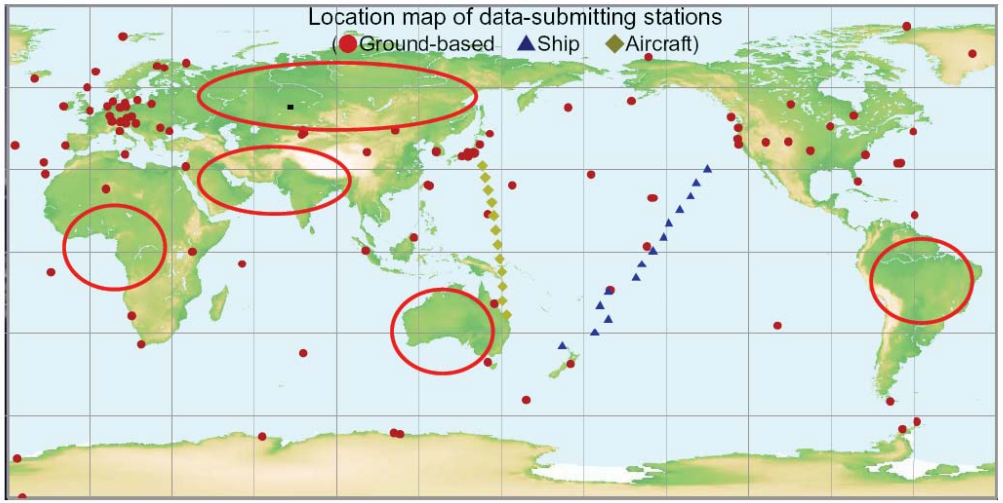
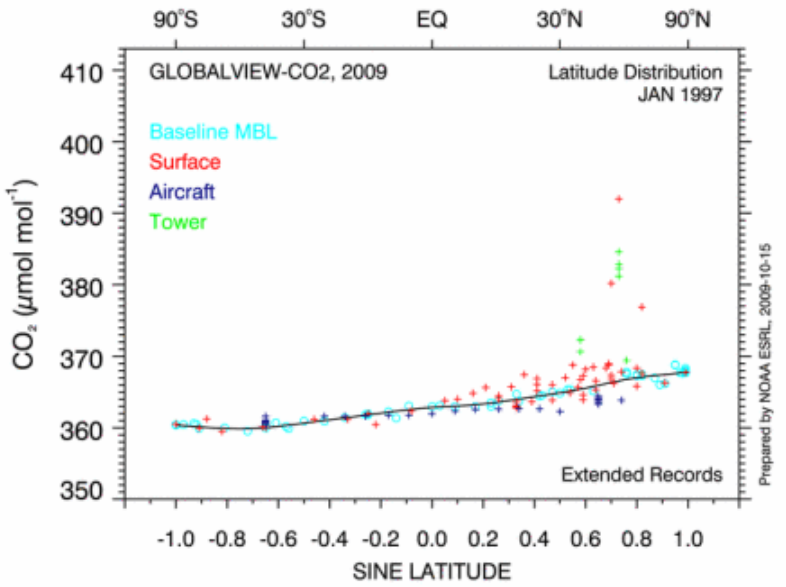
Green house gas ground base measurements

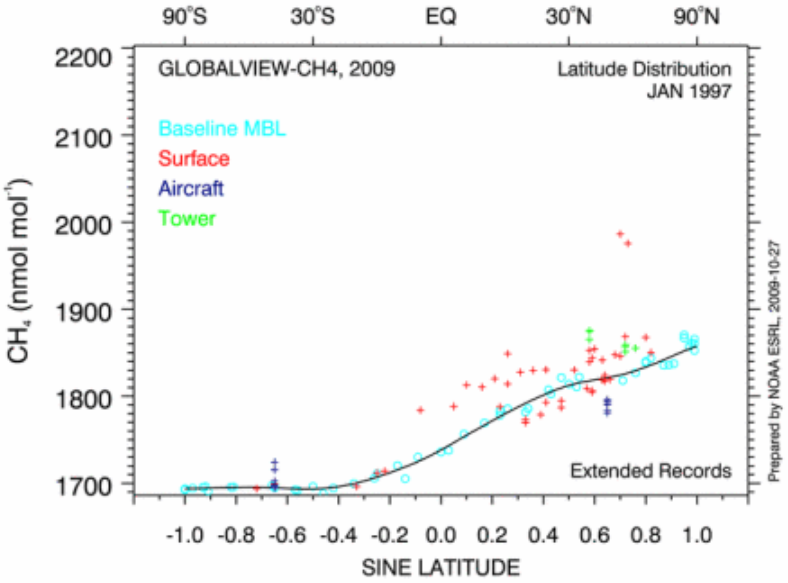
WDCGG

WMO World Data Centre for Greenhouse Gases

- (GHG monitoring stations: 282, CO_2 measurement: 182)





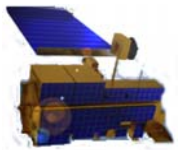
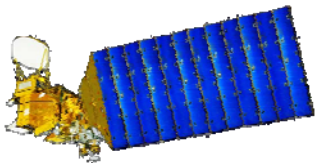
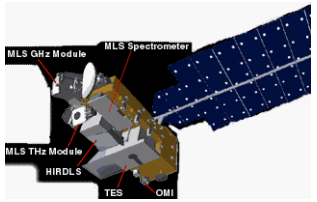


182 ground-base observation stations

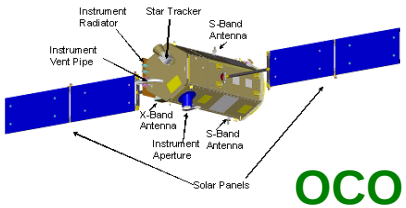
GV-CO2; cf. Gloor et al., 2000

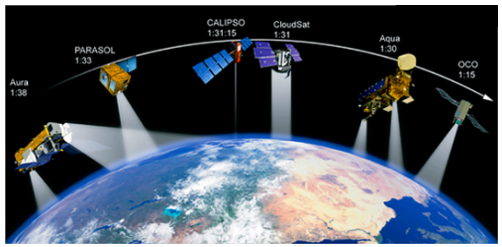
Cite: http://www.esrl.noaa.gov/gmd/ccgg/globalview

- **Satellites are carrying out pioneering studies on global carbon budgets.**

1999	2002	2002	2004	2006
				
MOPITT on Terra	**AIRS on AQUA**	**SCIAMACHY on ENVISAT**	**TES on AURA**	**IASI on METOP-A**

- **Orbiting Carbon Observatory, OCO (NASA, 2009)**
  - Three near infrared grating spectrometers
  - Spectral resolution ~ 0.3 cm^{-1}
  - Measuring CO_2 only at high (1 km) spatial resolution





OCO

- **Greenhouse Gases Observing Satellite, GOSAT (JAXA, Japan, 2009)**
  - Fourier Transform Spectrometer
  - Moderate spatial resolution ~ 10 km
  - Single pixel detector

GOSAT

Outline

- Study on spatiotemporal variation of Mid-upper tropospheric methane over China by Satellite observations
- CO_2 temporal and spatial distribution characteristics over China based on satellite data
- Challenges of remote sensing CO_2 from satellite

1. Study on spatiotemporal variation of Mid-upper tropospheric methane over China by Satellite observations

- Validation of AIRS CH_4 Measurements
- Spatial distribution of CH_4 over China
- Seasonal cycle of CH_4 over China
- Long-term CH_4 trends over China
- Conclusions

NSMC FTIR measurement campaigns：

- **Beamsplitter :**

  KBr (600-5000 cm-1)

  CaF2 (1000 -12000cm-1) , (in using)

- **Detector:**

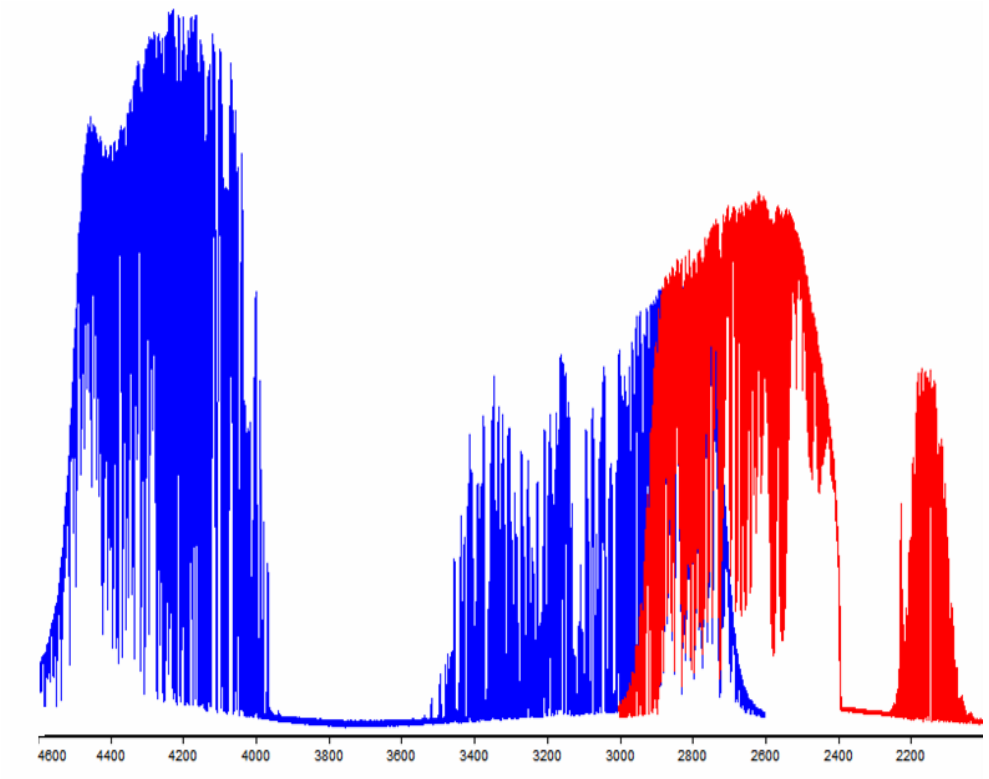
  MCT (600-6000 cm-1), (in using)

  InSb (1800-12000 cm-1)

- **Filters:**

  Filter1 (2000-3000 cm-1)

  Filter2 (2700-4500 cm-1)



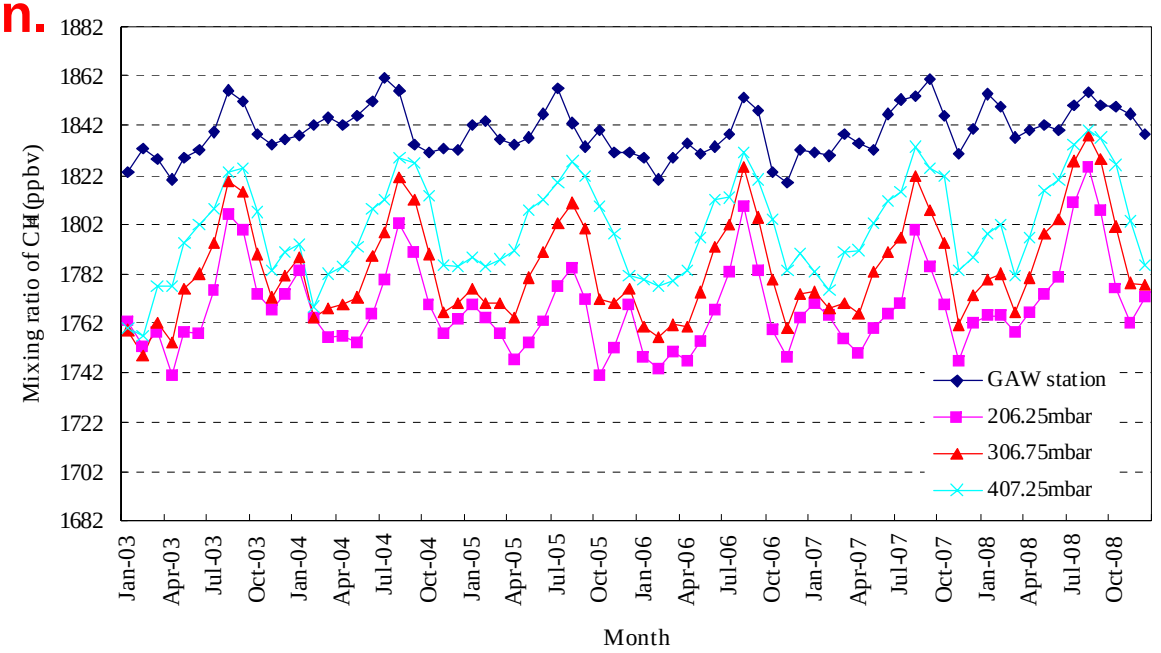
Use two filters to get our spectrum from 2000 to 4500 cm-1

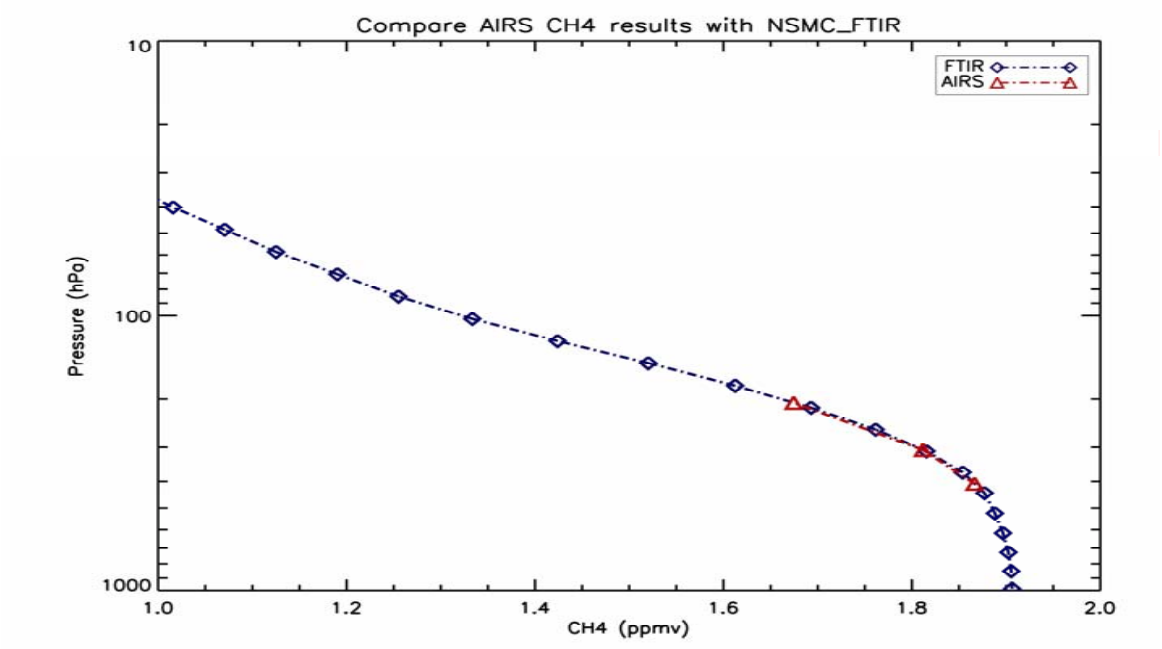
Molecule	Micro-windows (cm-1)	Spectrum resolution (cm-1)	Interfering species	DOF
CH_4	2613.7-2615.4 2650.6-2651.3 2835.5-2835.8 2903.6-2904.06 2921.0-2921.6	0.01	H2O、CO2、NO2	1.6
N_2O	2481.3-2482.6 2526.4-2528.2 2537.85-2538.8 2540.1-2540.7	0.01	H2O、CO2、CH4	2.9
CO	2069.4-2069.9 2140.4-2141.4 2153.2-2160.0	0.01	H2O、CO2、N2O、OCS	2.0
CO_2	2620.55-2621.1 2626.40-2626.85 2627.1-2627.6 2629.27-2629.95	0.01	H2O、CH4	1
O_3	3041.48-3041.94 3042.93-3043.24 3044.25-3044.62 3045.26-3045.55	0.01	H2O、CH4	1.69

Proffit 9.5 from KIT/German using to do the retrieval.

AIRS CH_4 product validation.

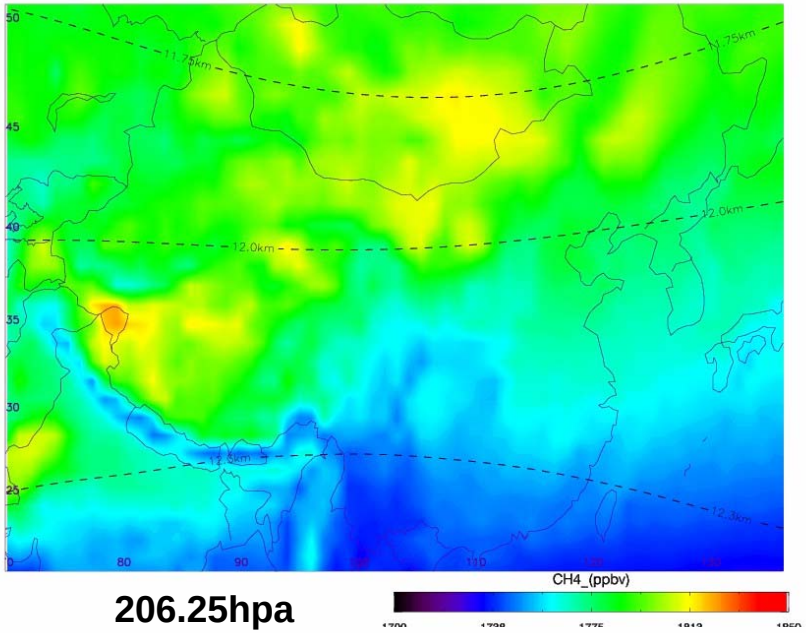
The seasonal cycle of AIRS is similar to the Waliguan in-situ measurements. And the CH_4 concentration decreased with an increasing of altitude.



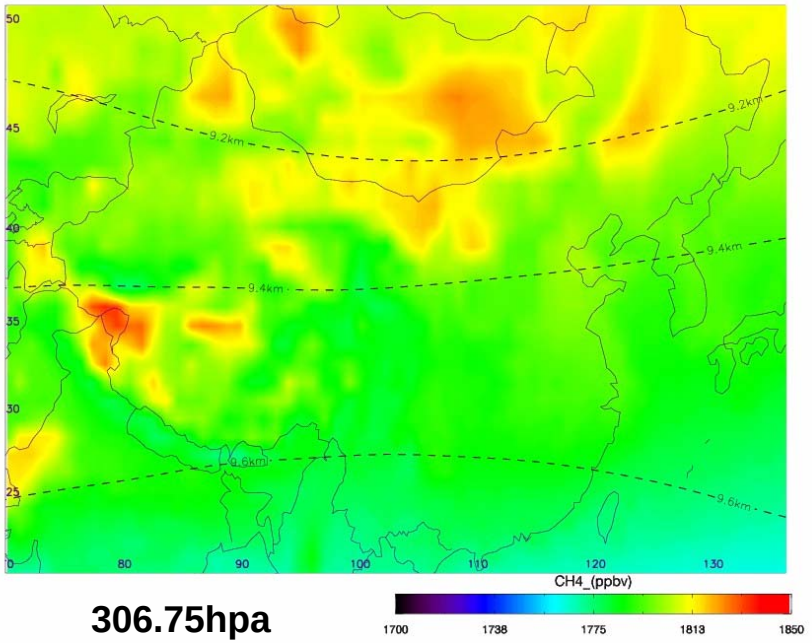


The AIRS product at three different heights is very close to the FTIR measurements. The bias is 0.2~1.1%, which is similar to aircraft validation results (0.5~1.6%).

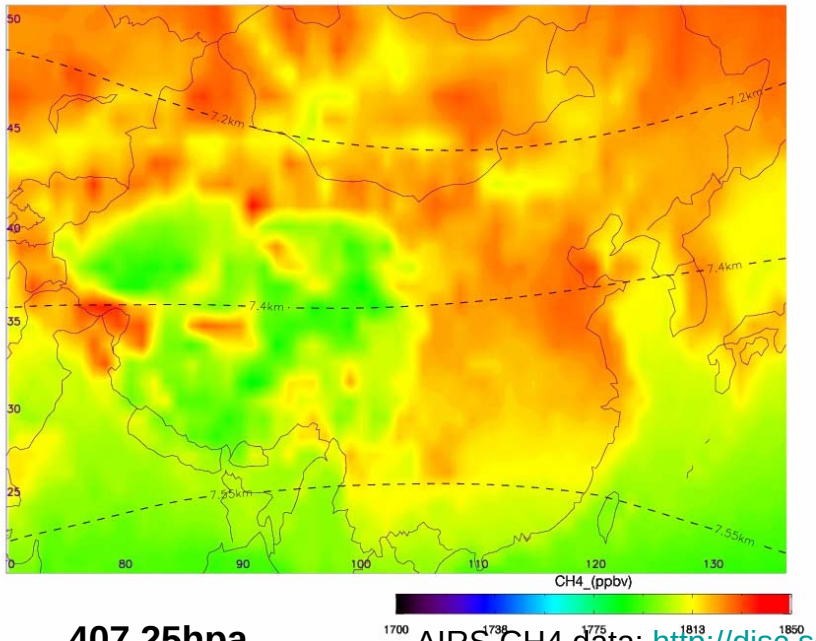
Spatial distribution of CH_4 over China



206.25hpa



306.75hpa



407.25hpa

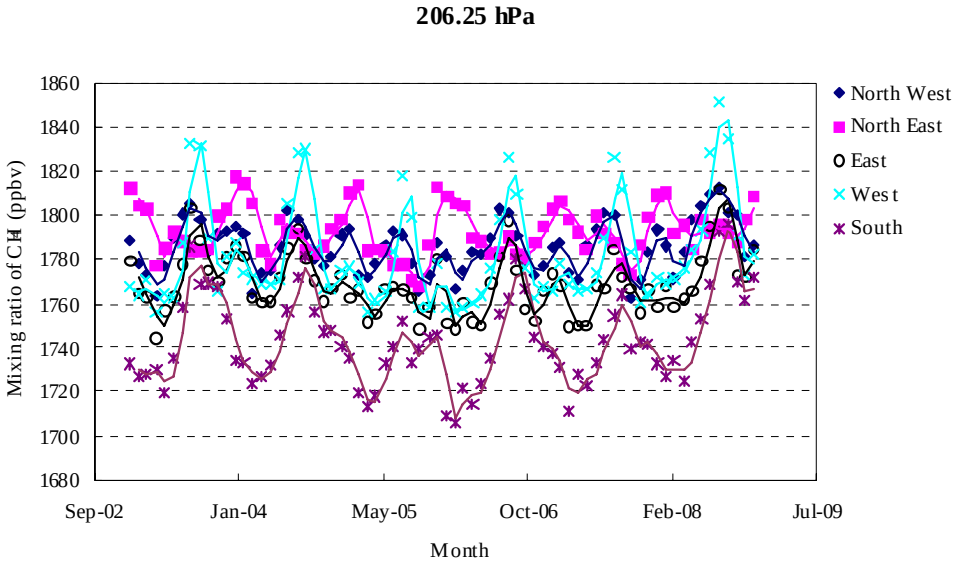
middle > upper > top of troposphere

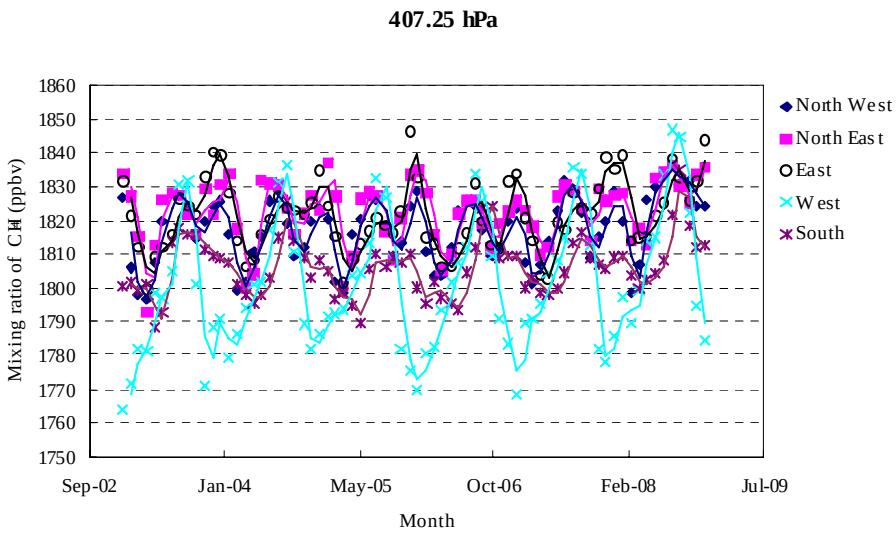
middle of troposphere: highest concentration exist in the east, northeast, and south of China; low in the west; coast than over ocean;

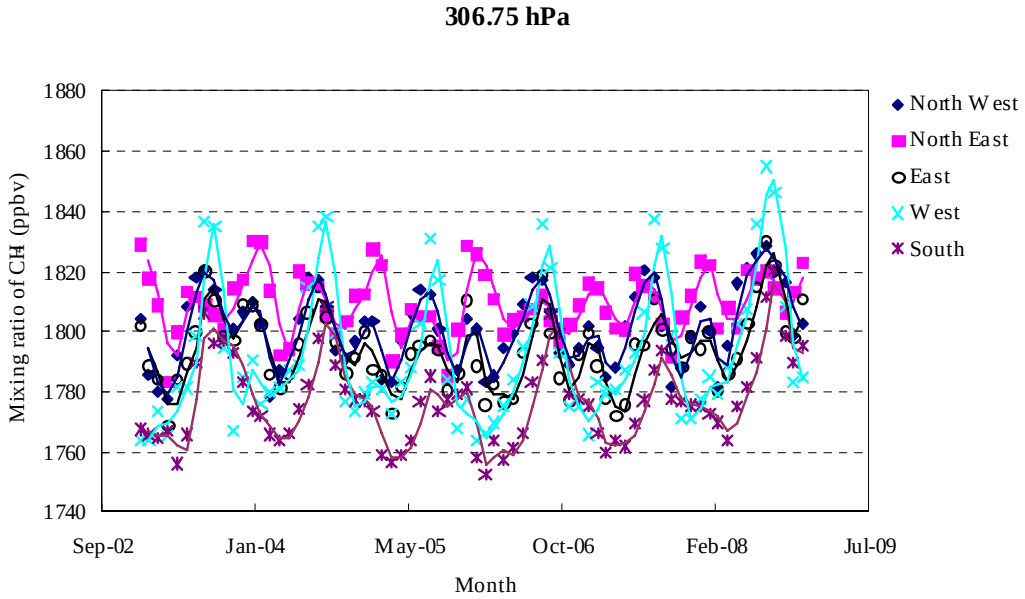
up and top troposphere: highest CH4 in the inland; low exist in the southeast China.

AIRS CH4 data: http://disc.sci.gsfc.nasa.gov/AIRS/data-holdings/by-data-product/airsL3_STM.shtml

Spatial distribution of CH4 over China







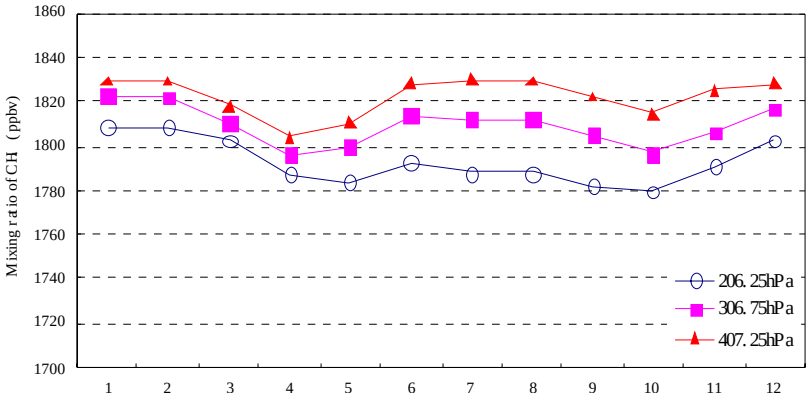
Top: lowest CH4 concentration occur in the southern of China;

Upper: well mixing in all region;

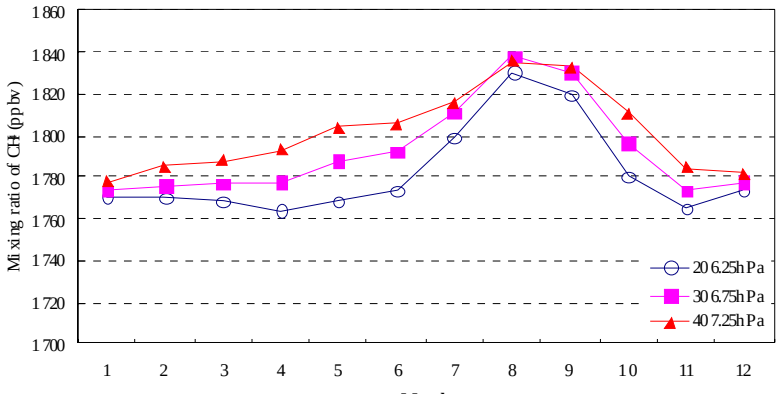
Middle: low center located over western.

Seasonal cycle of CH_4 over China

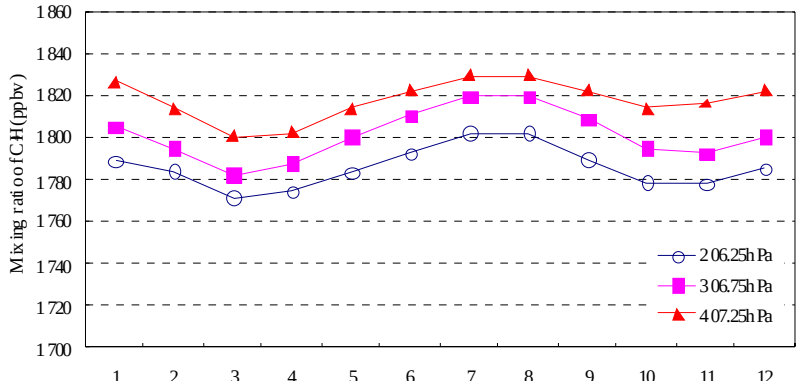
North East



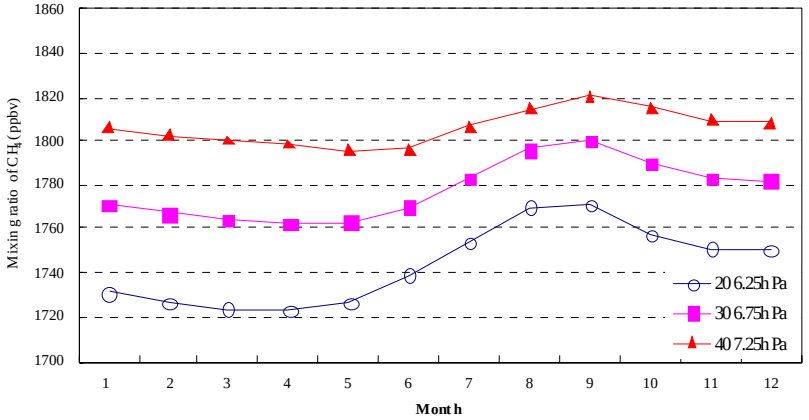
West



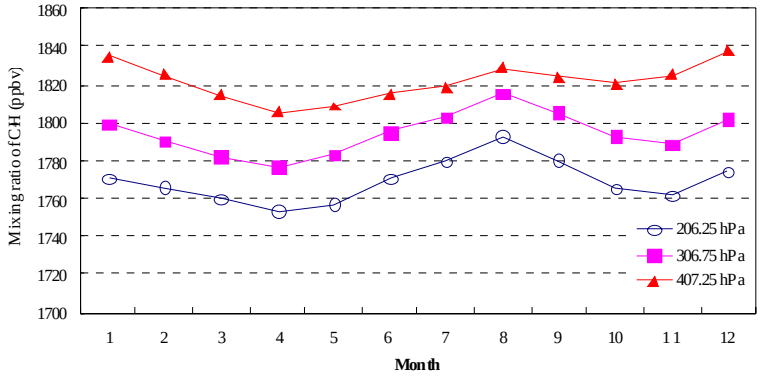
North West



South



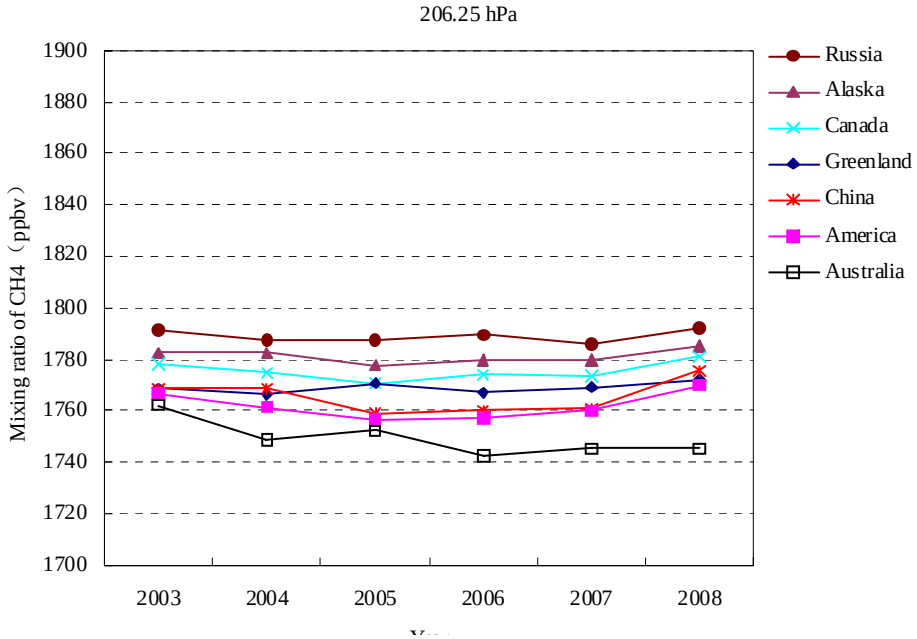
East

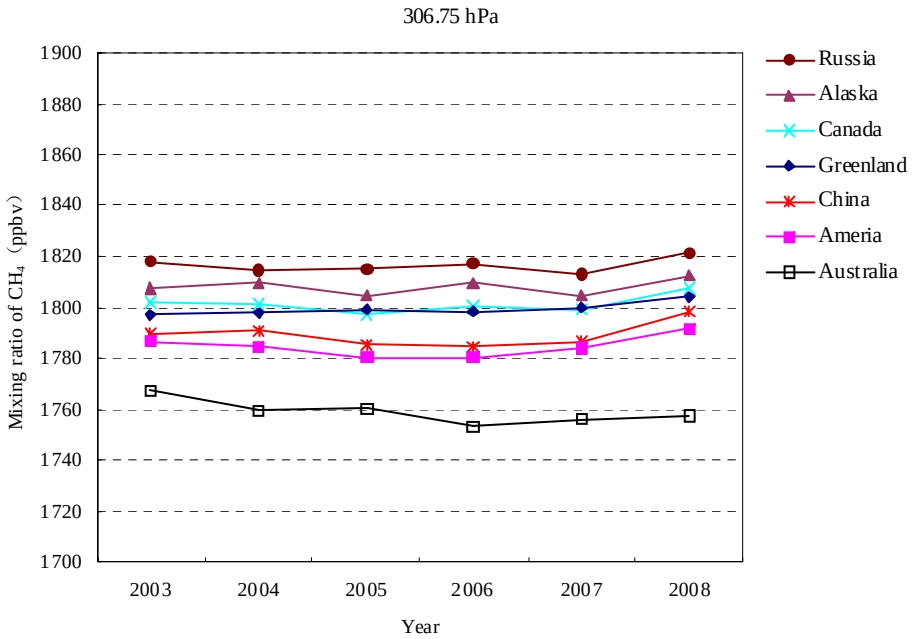


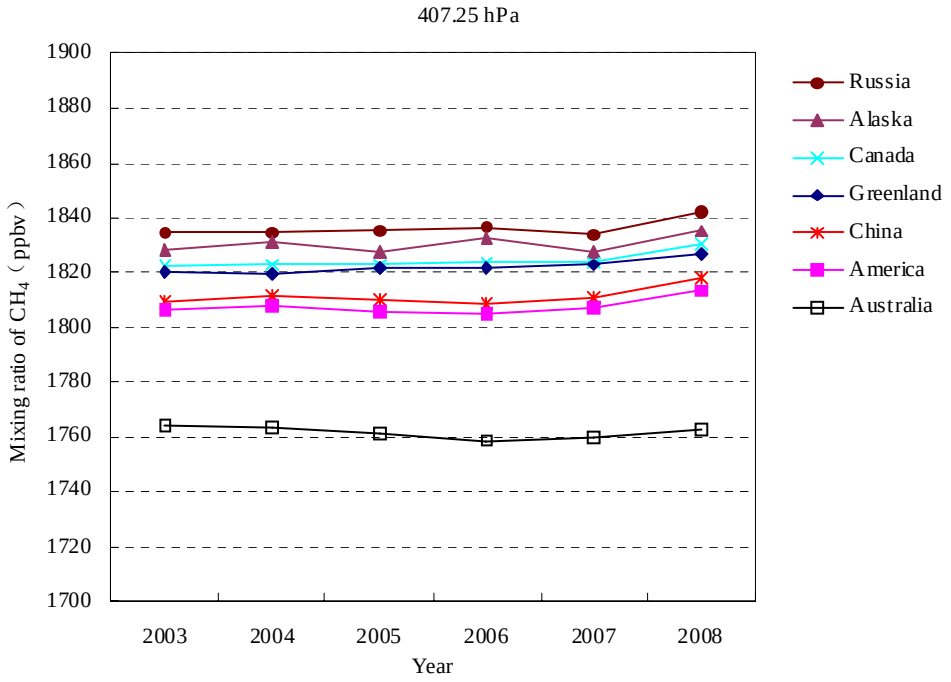
Two peaks apparent in summer and winter over eastern, northeast, and northwestern China.

One peak occurs over southern and western of China.

Long-term CH_4 trends over China







2007: Significant increase;

Before 2007: stable;

Averaging CH4 mixing ratio almost same in NH;

Australia shows little decreasing trend.

Long-term CH_4 trends over China

Table 1

Area	Position		206.25 hPa	306.75 hPa	406.25 hPa
	Lat	Lon	(ppbv)	(ppbv)	(ppbv)
China	22-42°N	90-120°E	12.4	11.3	8.5
America	33-48°N	124-75°W	9.1	8.7	6.7
Canada	50-65°N	130-90°W	6.6	7.4	7.0
Alaska	60-70°N	163-142°W	4.9	5.5	5.6
Russian	55-70°N	45-135°E	4.0	5.4	7.0
Granada	65-80°N	50-20°W	3.8	5.5	5.7
Australia	30-20°S	120-150°E	-4.9	-2.1	1.2

Significant increase found in China than in other areas;

Slightly downward trend in Australia found;

Table 2

Altitude	2006	2007	2008	Growth rate (ppbv/year)
206.25 hPa	1760.14	1760.81	1775.77	4.9
306.75 hPa	1785.04	1786.55	1798.77	6.9
407.25 hPa	1808.60	1810.77	1818.37	7.8
Mt. Waliguan	1832.67	1841.57	1846.22	6.8

The annual growth rate is 5~8 ppbv, similar to Waliguan measurement (6.8ppbv).

Conclusion

1) Validation with ground-based measurements demonstrated that the retrieval RMS errors of AIRS CH_4 are mostly less than 1.5%.

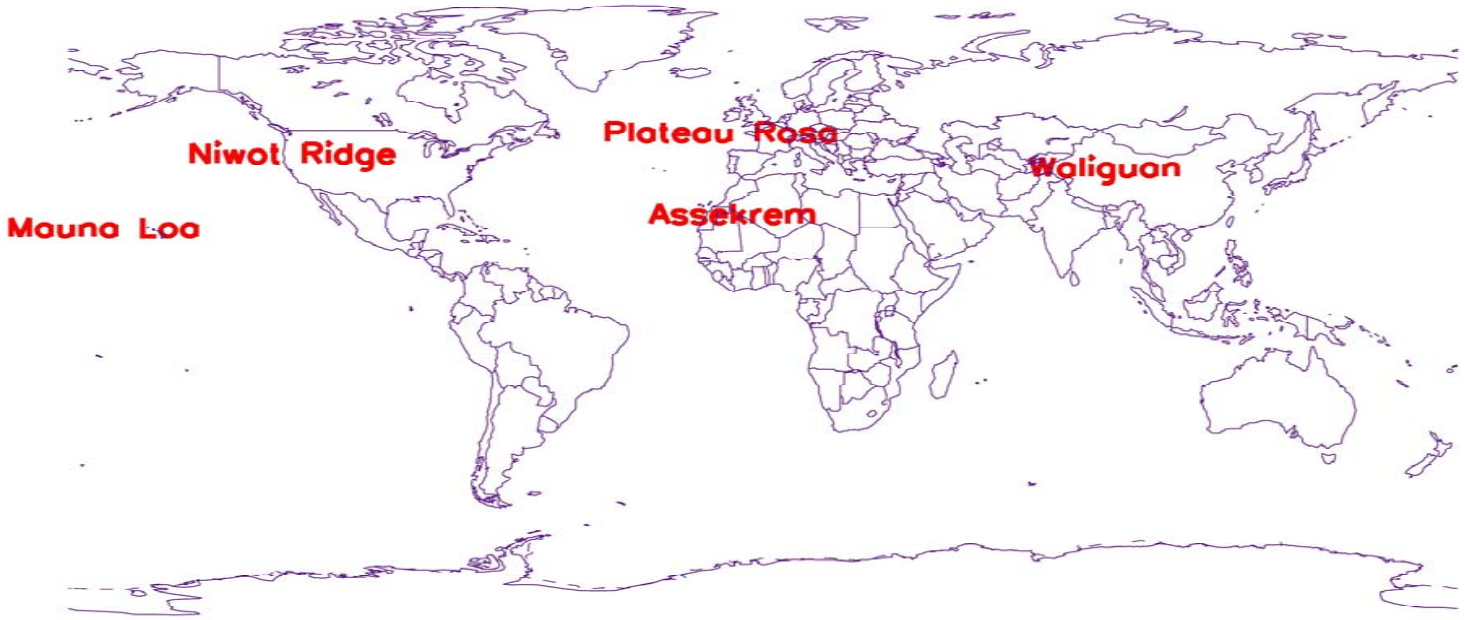
2) Methane mixing ratios decrease with an increase in height because of the effects of human activities and natural emission of CH_4 from the boundary layer.

3) Obvious bimodal seasonal variations in CH_4 concentrations exist in most areas of China, with the highest values in summer and the second highest in winter. Only the summer peak occurs in the western and southern areas of China.

4) The mixing ratio of MUT-CH_4 is relatively stable before 2007 over several main regions of the northern hemisphere (including China). Significant growth is found after 2007, with China having the highest growth rate.

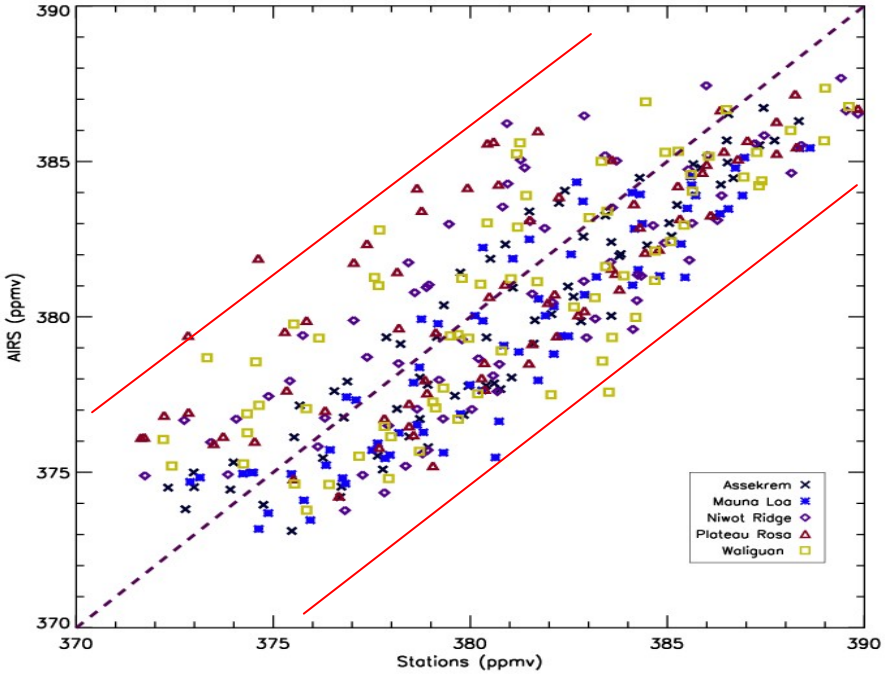
2. CO_2 temporal and spatial distribution characteristics over China based on satellite data

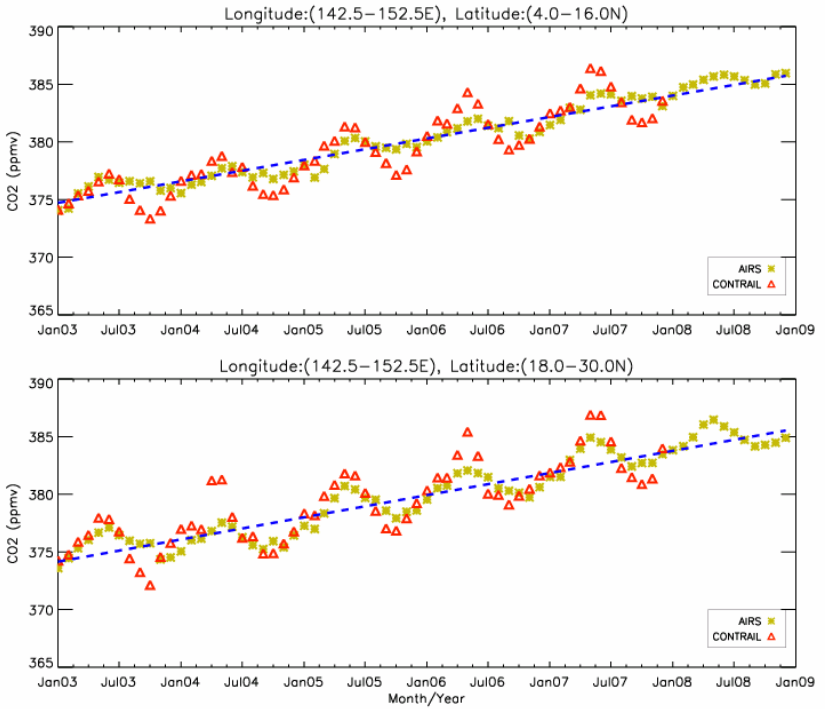
- AIRS CO_2 product Ground-based validation
- Global Troposphere CO_2 distribution Character
- Spatial and temporal distribution of troposphere CO_2 over China
- Seasonal variation in Mid-troposphere CO_2
- Conclusions



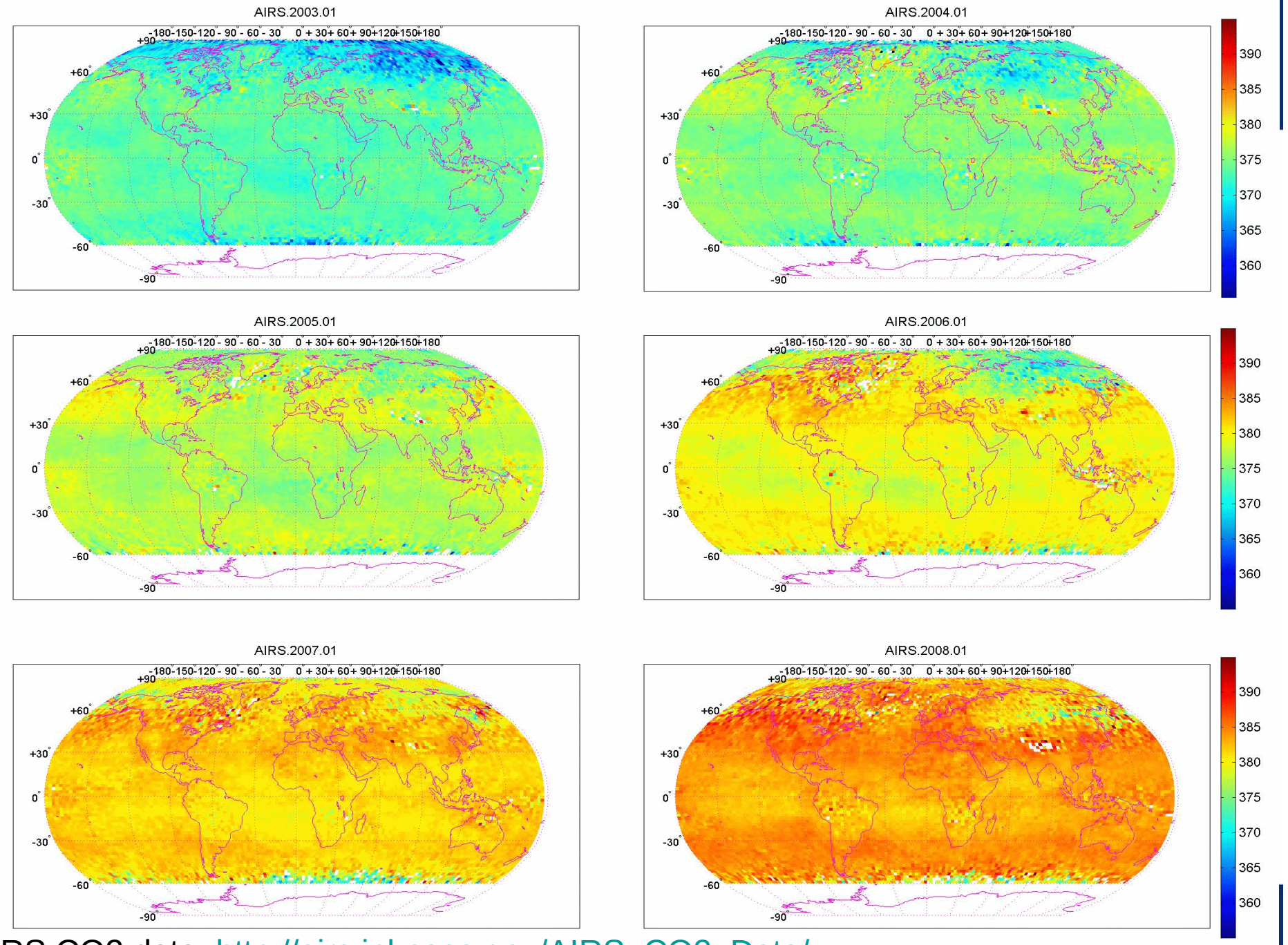
WDCGG http://gaw.kishou.go.jp/wdcgg/

AIRS CO2 product Ground-based validation



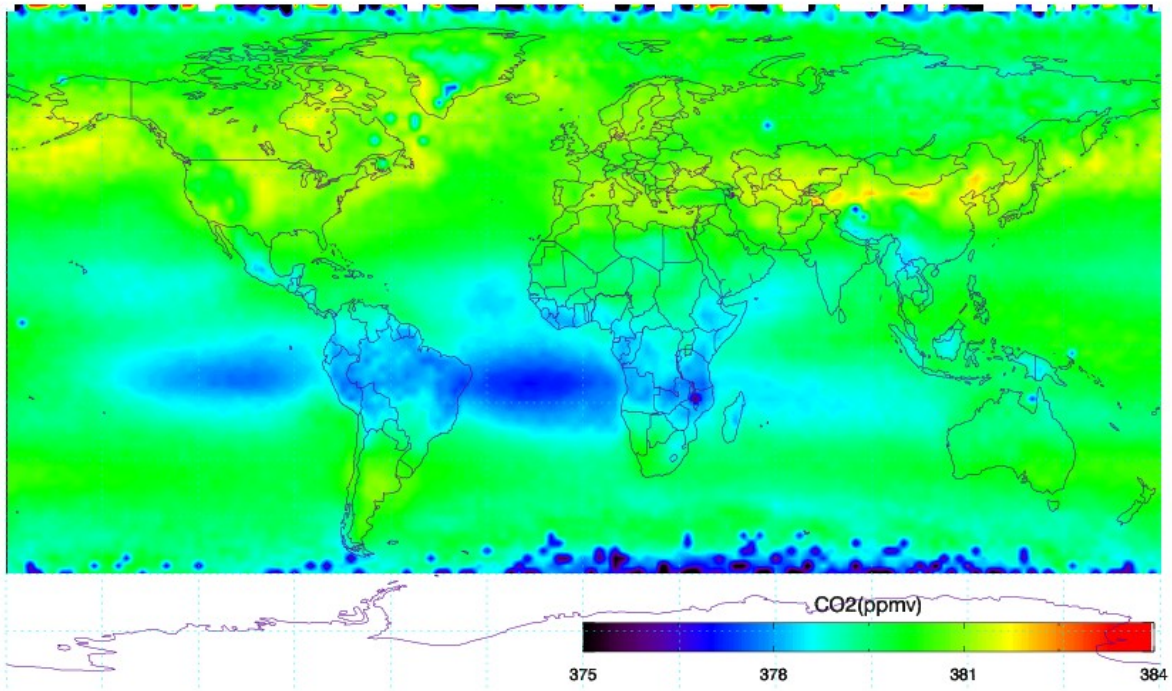


	Ground-base Station			Annual growth rate (ppmv/a)		Mean (ppmv)		Average deviation (ppmv)	Monthly average standard deviation (ppmv)	R
	lat	lon	h(m)	Ground	Satellite	Ground	Satellite			
Assekrem	23.27	5.63	2710	1.995	2.076	380.734	379.822	0.912	1.609	0.922
Mauna Loa	19.54	-155.58	3397	1.992	2.034	380.786	379.286	1.500	1.598	0.915
Niwot Ridge	40.05	-105.59	3523	2.018	2.149	381.293	380.811	0.482	2.614	0.806
Plateau Rosa	45.93	7.70	3480	1.935	2.040	380.729	381.007	-0.278	2.976	0.771
Waliguan	36.28	100.9	3810	1.977	2.100	381.209	380.730	0.479	2.692	0.806
Average				1.983	2.080	380.950	380.331	0.619	2.298	-



AIRS CO2 data: http://airs.jpl.nasa.gov/AIRS_CO2_Data/

Global Troposphere CO_2 distribution Character



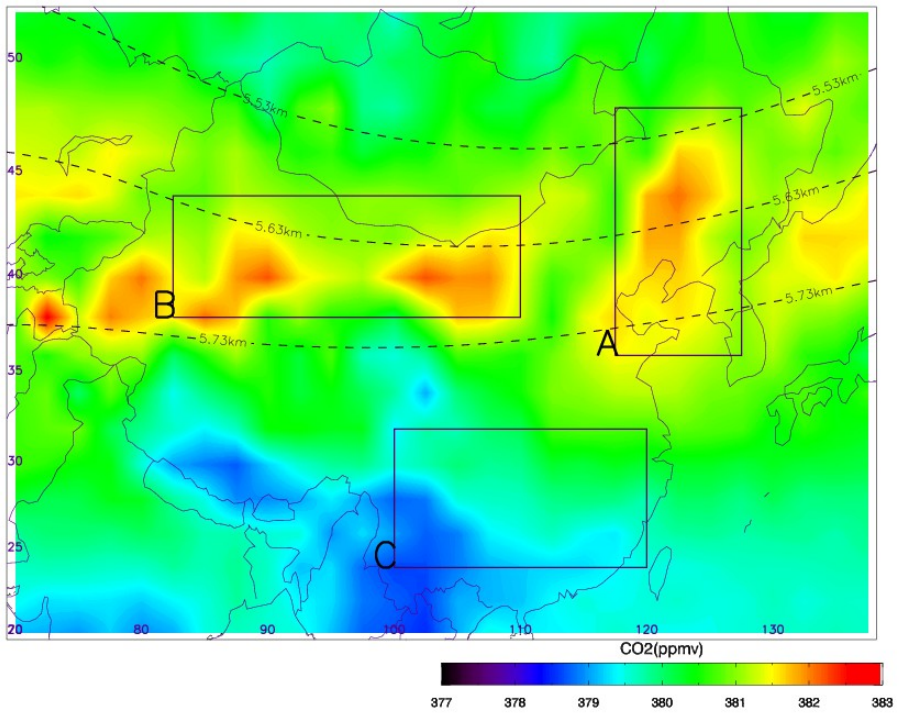
Northern Hemisphere higher than Southern Hemisphere;

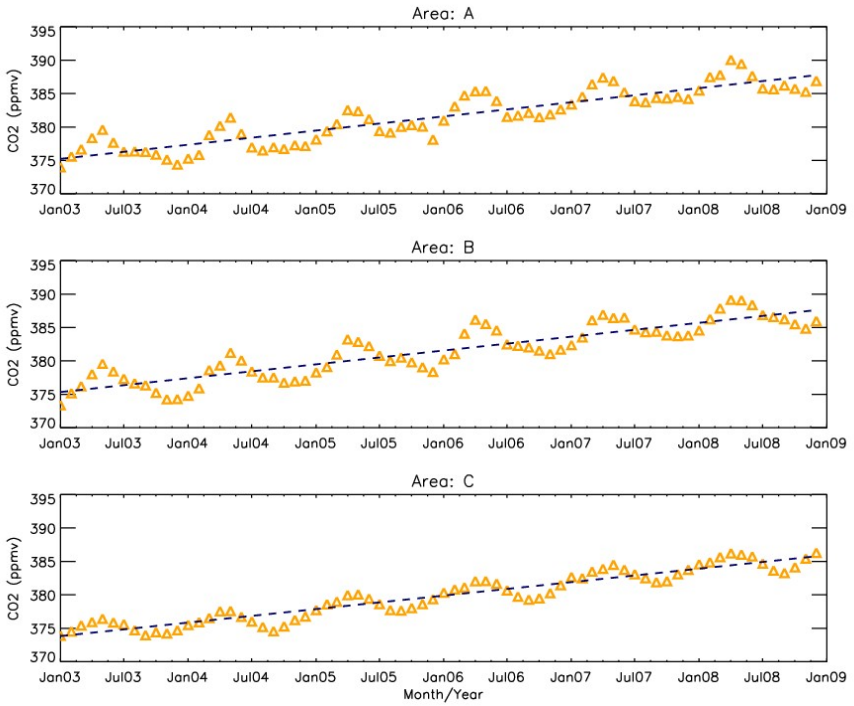
Highest occurring in the northern China, Europe, center US; southern Canada; nearby sea Alaska; form a belt.

Lowest belt is in the Atlantic region.

	Area		*Mean (ppmv)*	*Monthly average Variance (ppmv)*	*Annual growth rate (ppmv/a)*	*Seasonal fluctuation (ppmv)*
	Longitude	Latitude				
America	122.5–72.5° W	33–48° N	381.00	3.76	2.11	3.70
Canada	130–90° W	50–65° N	381.04	4.21	2.26	7.72
China	90–120° E	22–42° N	380.36	3.75	2.09	4.06
Russian	45–135° E	56–70° N	380.04	4.76	2.32	10.99
Australia	120–150° E	30–20° S	379.83	3.71	2.09	2.87
Europe	0–30° E	40–60° N	381.00	3.82	2.10	5.02
India	72.5–85° E	14–30° N	379.70	3.63	2.03	2.94

Spatial and temporal distribution of troposphere CO_2 over China



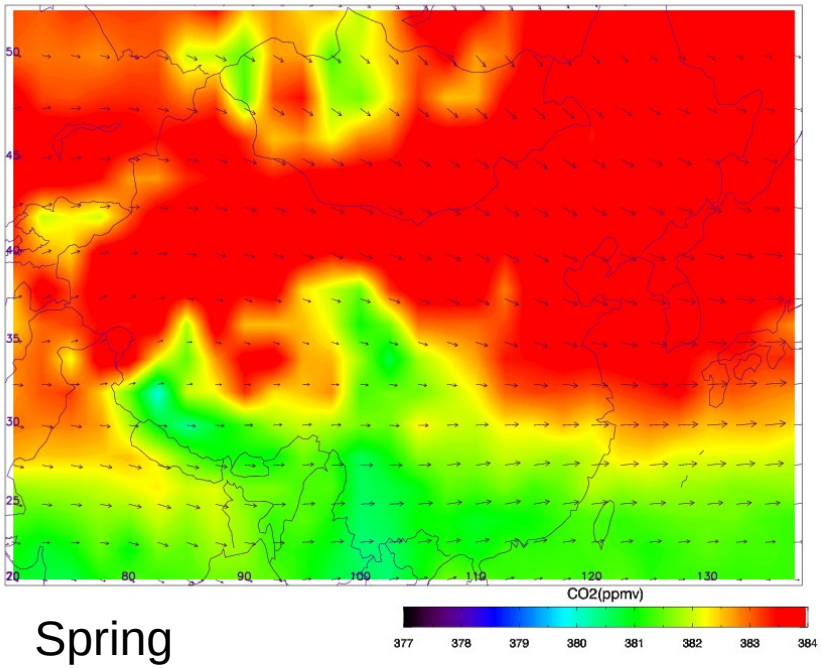


The highest CO_2 level occurred in four regions (35~45N): Northeast Plain; Inner Mongolia; Taklimakan desert; Tarim Basin.

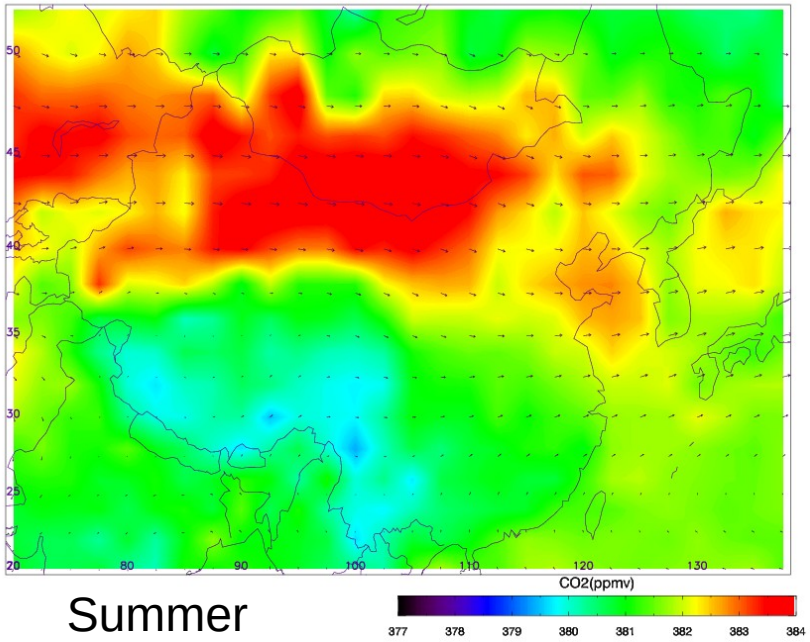
The Yunnan region (20~30N) is low in CO_2 concentration.

An overall increasing trend from 2003 to 2008 in all different areas, the annual growth rate are 2.215, 2.160, 2.092 ppmv/a, little higher than Waliguan.

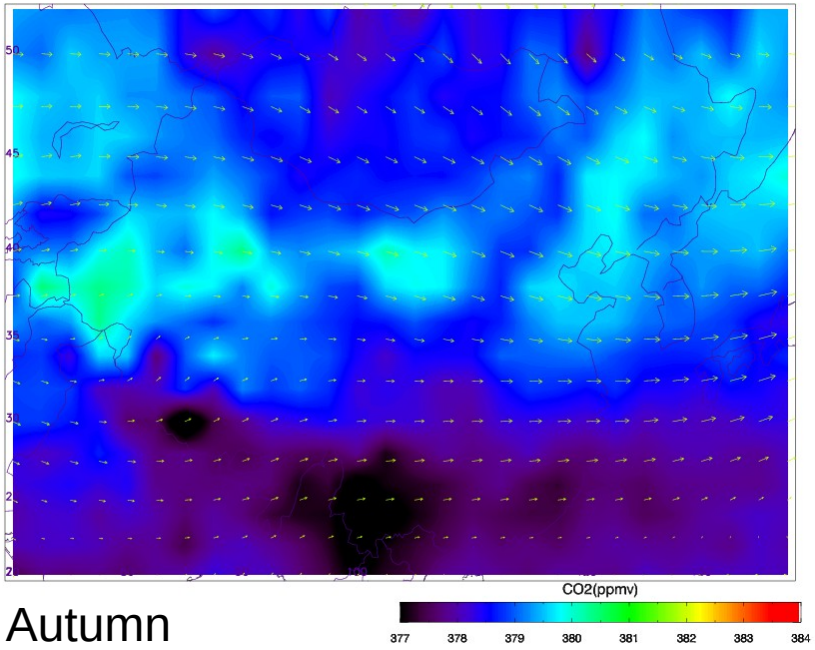
Seasonal variation in Mid-troposphere CO_2



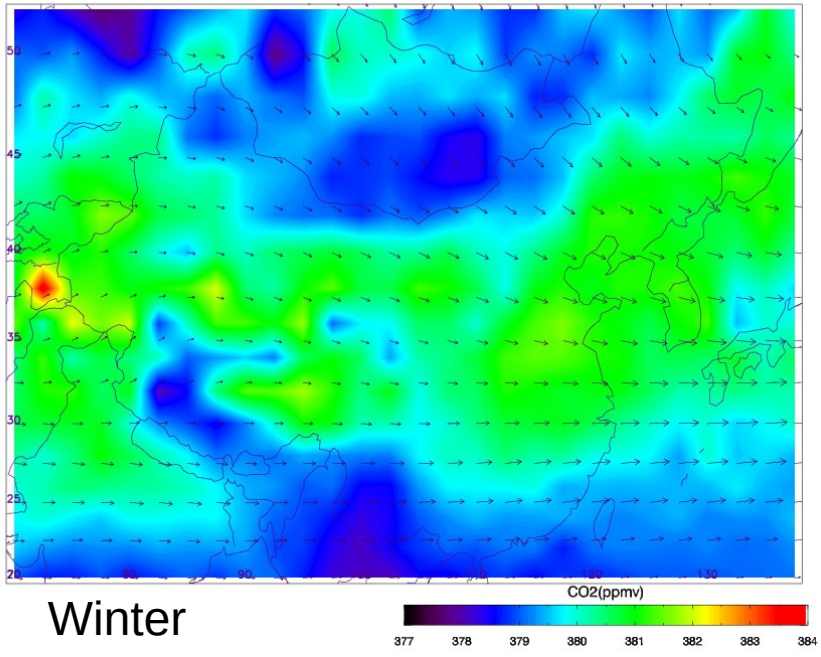
Spring



Summer



Autumn



Winter

Conclusion

1) The AIRS mid-troposphere CO_2 data show consistency with ground-based observation and measurement data from aircraft. The monthly average bias is less than 3 ppmv, which validates the ability of the AIRS product to capture seasonal CO_2 concentration change precisely.

2) CO_2 concentration is higher in the Northern Hemisphere than in the Southern Hemisphere. The CO_2 concentration annual growth rate for China is about 2 ppmv, which is similar to the United States, Europe, Australia and India, but slightly lower than Canada and Russia. This rate still has some uncertainty because of limited satellite data.

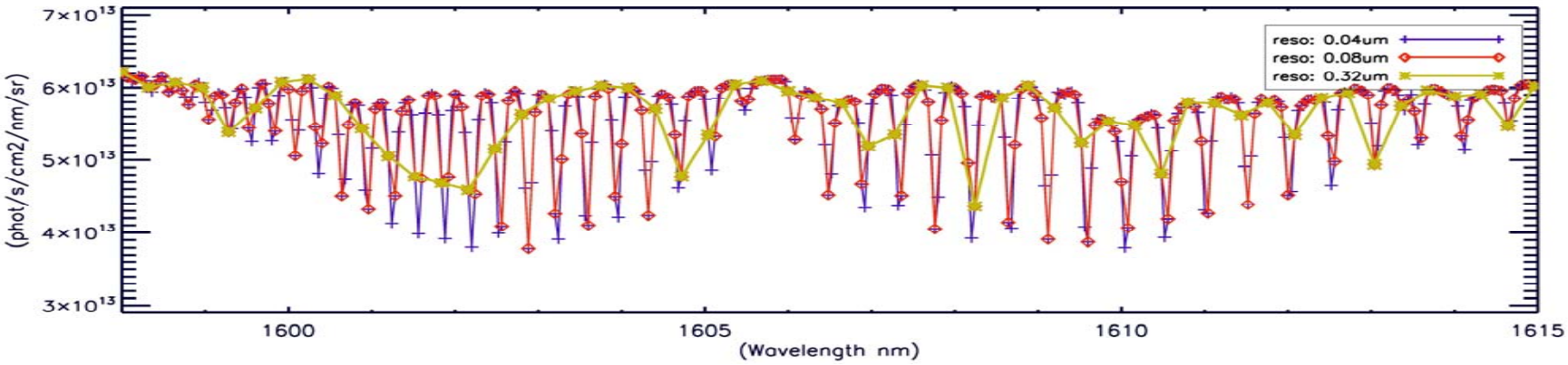
3) Mid-troposphere CO_2 is higher in the north than in the south over China, and significant enhancements are seen at four centers in the range 35° N-45° N. The Yunnan area is the lowest CO_2 concentration center.

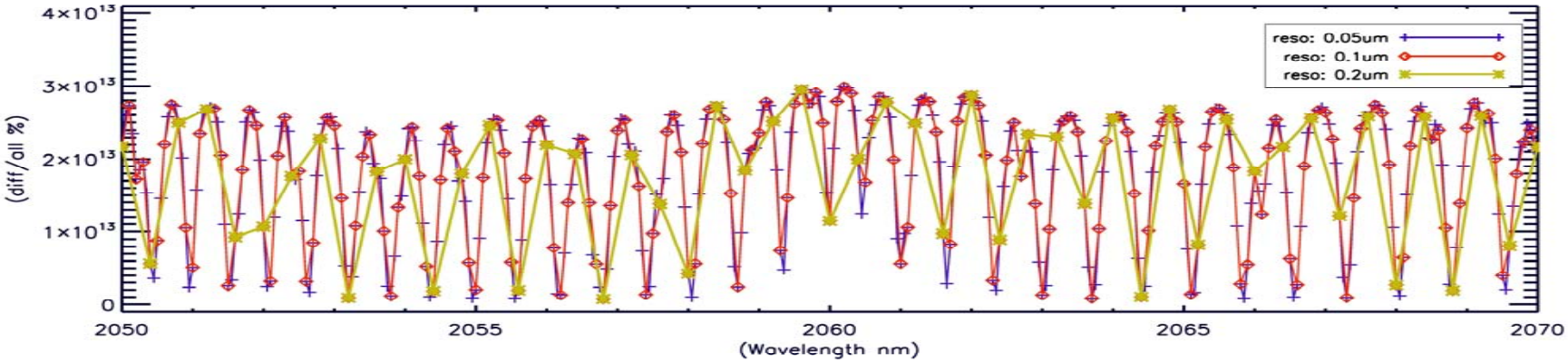
4) A rise in Mid-troposphere CO_2 occurs over China in the spring, when the Northern Hemisphere Greenup begins, and reaches a minimum in autumn when the quantity of biomass undergoing photosynthesis is the greatest.

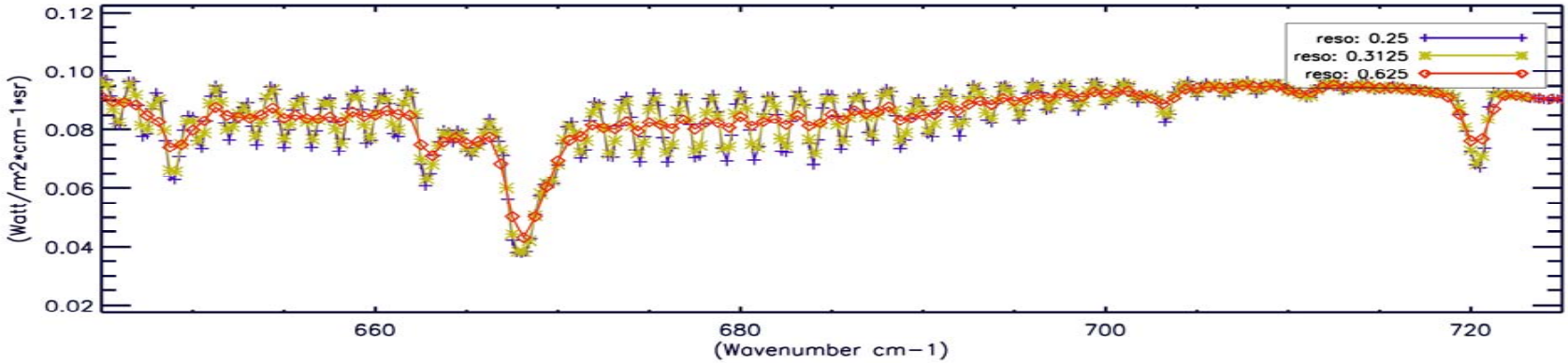
3. Challenges of remote sensing CO_2 from satellite

- Spectrum Band Used to Remote Sensing CO_2
- Instrument Spectral Resolution
- Radiance Detection Sensitivity
- Interference Factors to the CO_2 Retrieval
- Surface Reflectivity Difference
- …

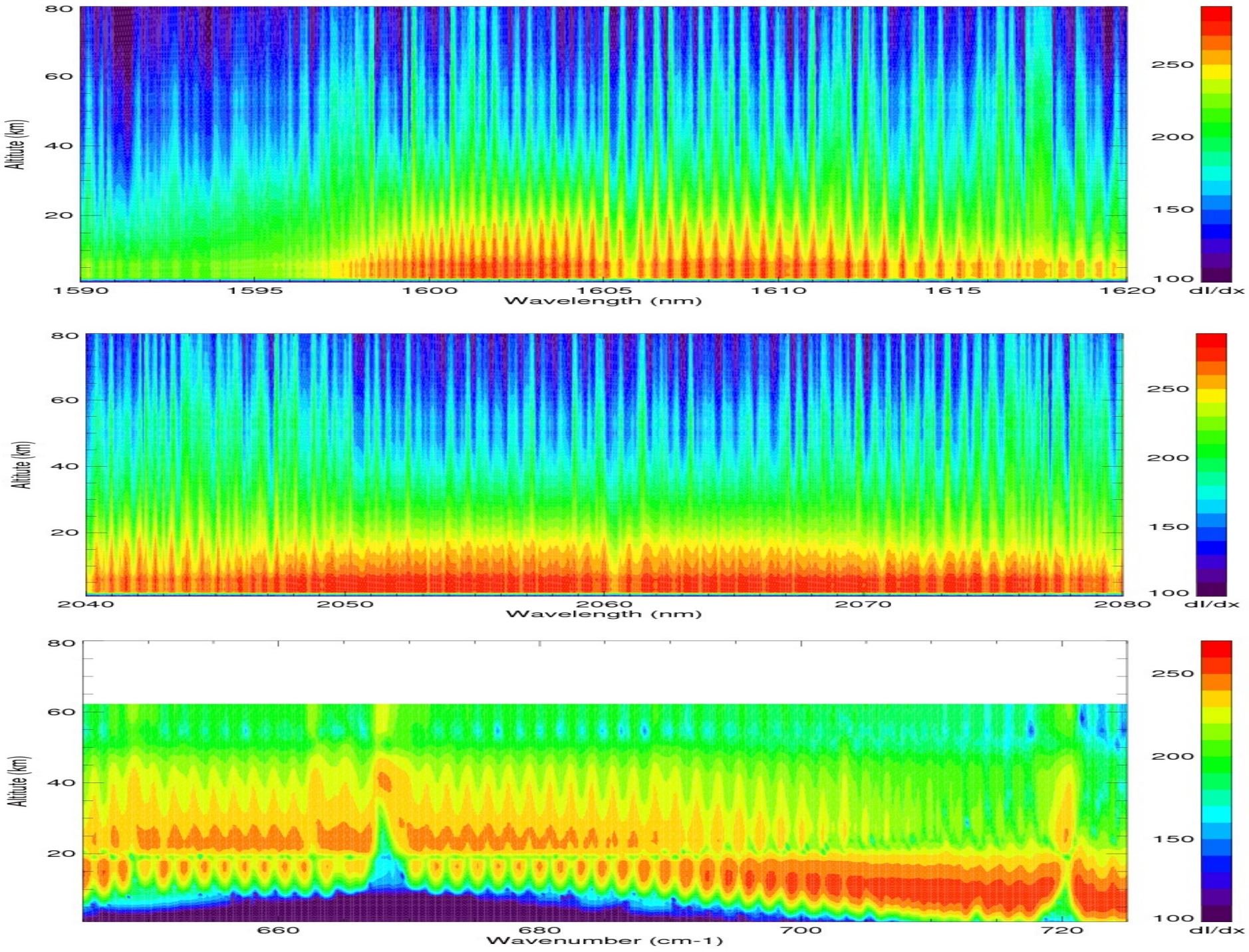
Spectrum Band Used to Remote Sensing CO_2 & Instrument Spectral Resolution

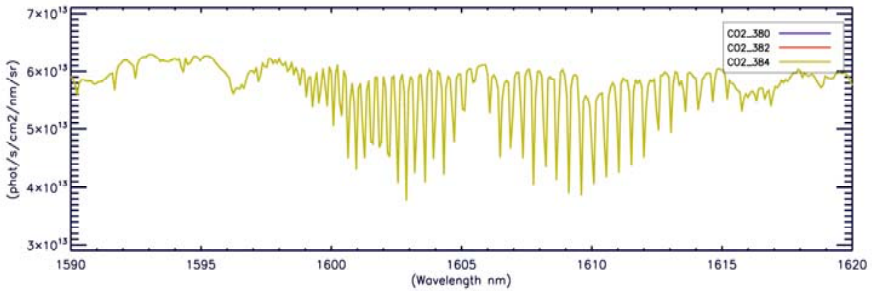


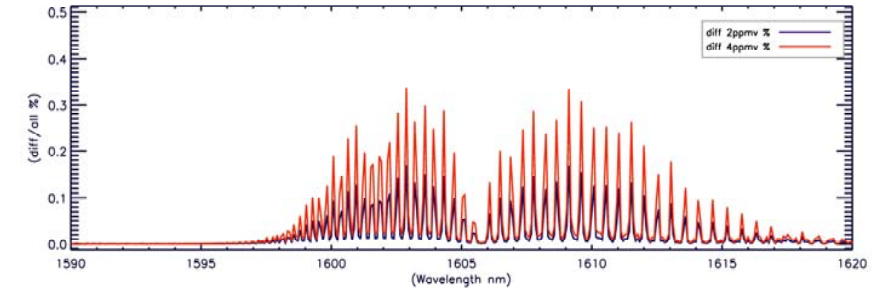


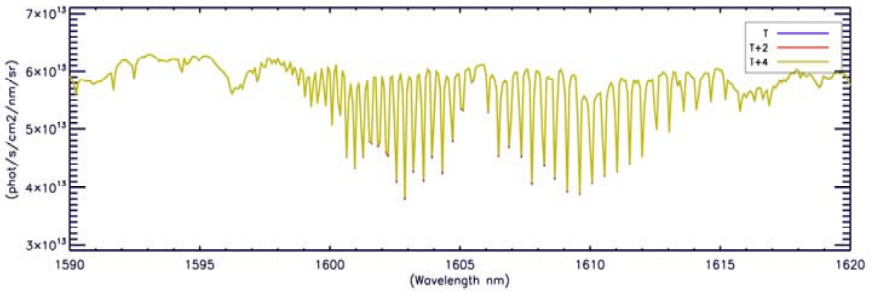


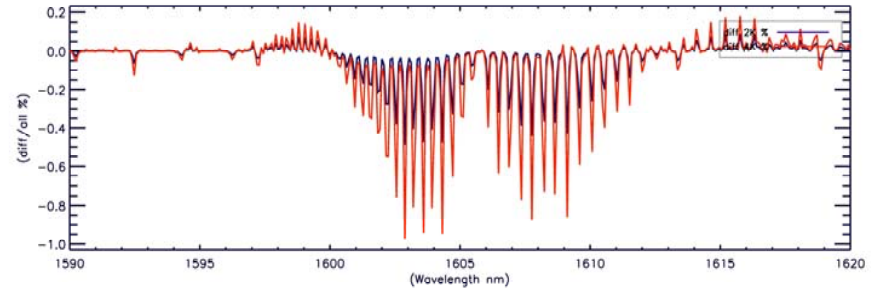
SCIATRAN: http://www.iup.uni-bremen.de/sciatran

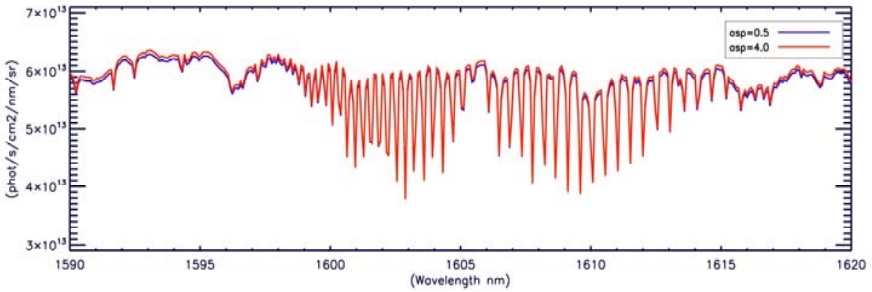

Altitude (km)
80
60
40
20
1590
1595
1600
1605
1610
1615
1620
Wavelength (nm)
250
200
150
100
dI/dx
Altitude (km)
80
60
40
20
2040
2050
2060
2070
2080
Wavelength (nm)
250
200
150
100
dI/dx
Altitude (km)
80
60
40
20
660
680
700
720
Wavenumber (cm-1)
250
200
150
100
dI/dx

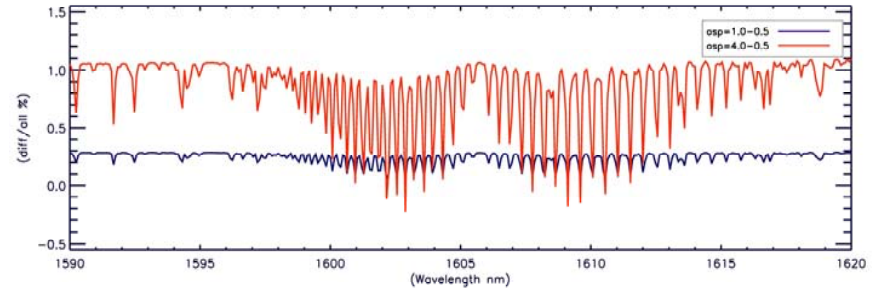

CO2_380
CO2_382
CO2_384
(phot/s/cm2/nm/sr)
(Wavelength nm)

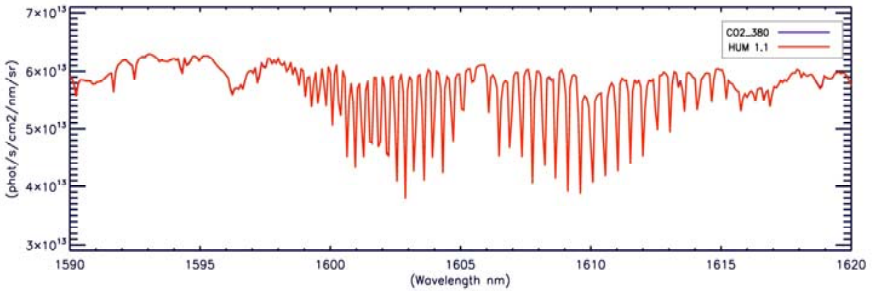

diff 2ppmv %
diff 4ppmv %
(diff/all %)
(Wavelength nm)

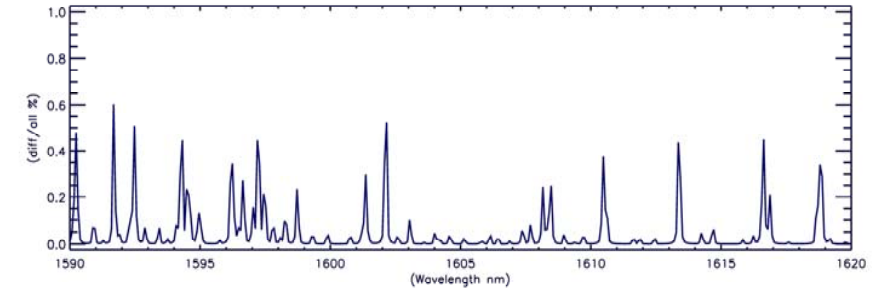

T
T+2
T+4
(phot/s/cm2/nm/sr)
(Wavelength nm)

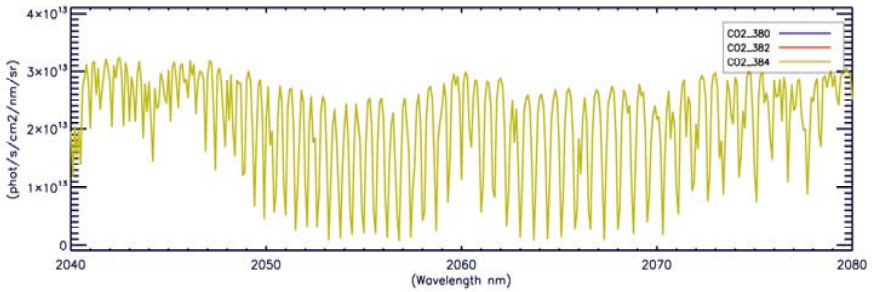

(diff/all %)
(Wavelength nm)

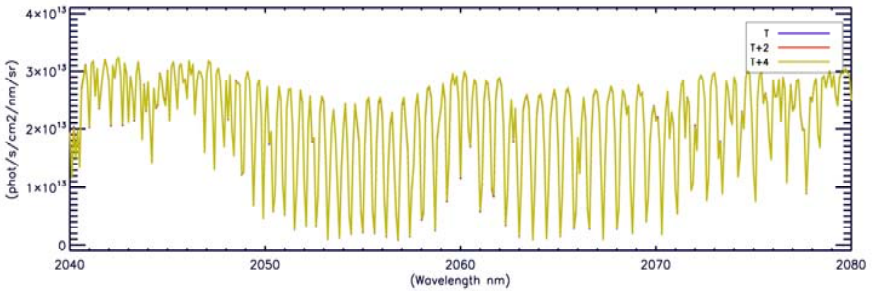

osp=0.5
osp=4.0
(phot/s/cm2/nm/sr)
(Wavelength nm)

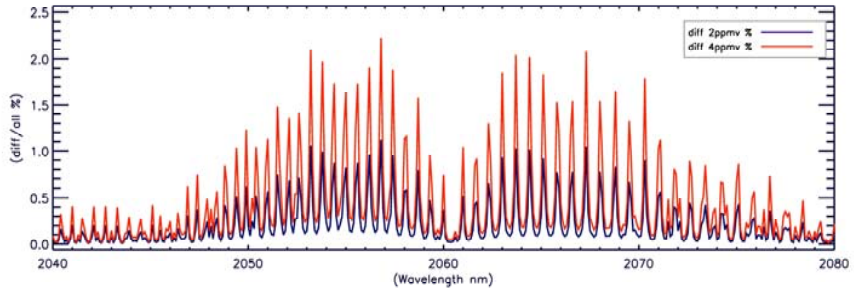

osp=1.0-0.5
osp=4.0-0.5
(diff/all %)
(Wavelength nm)

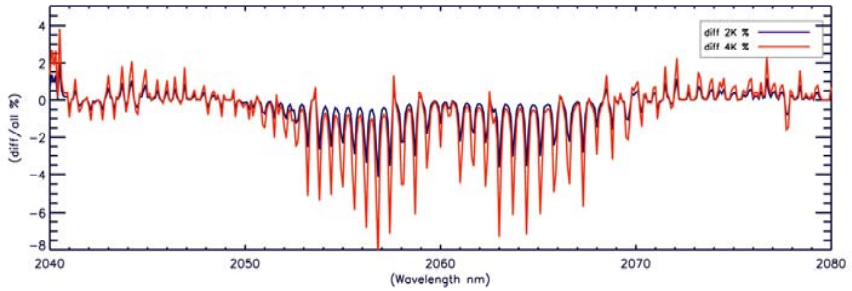

CO2_380
HUM 1.1
(phot/s/cm2/nm/sr)
(Wavelength nm)

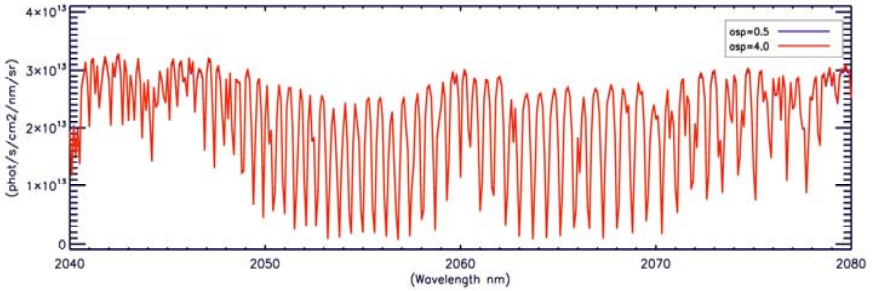

(diff/all %)
(Wavelength nm)

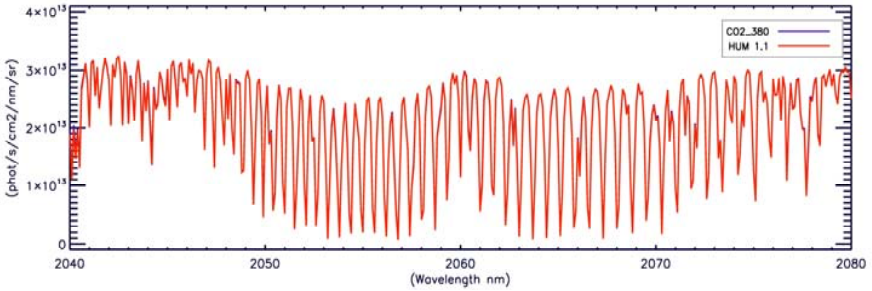

CO2_380
CO2_382
CO2_384
(phot/s/cm2/nm/sr)
(Wavelength nm)

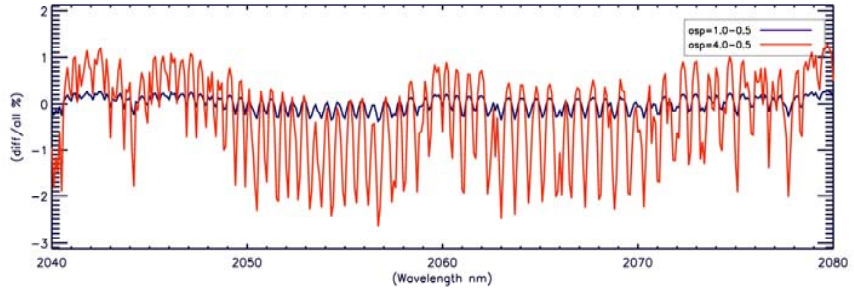

T
T+2
T+4
(phot/s/cm2/nm/sr)
(Wavelength nm)

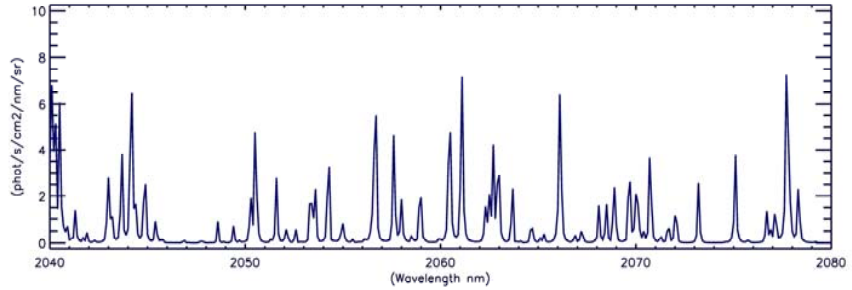

diff 2ppmv %
diff 4ppmv %
(diff/all %)
(Wavelength nm)

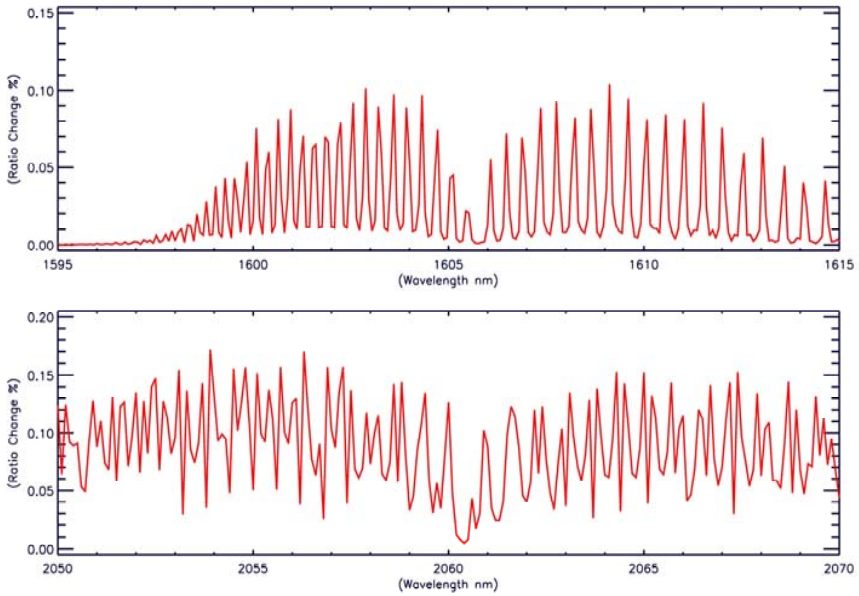

diff 2K %
diff 4K %
(diff/all %)
(Wavelength nm)


osp=0.5
osp=4.0
(phot/s/cm2/nm/sr)
(Wavelength nm)

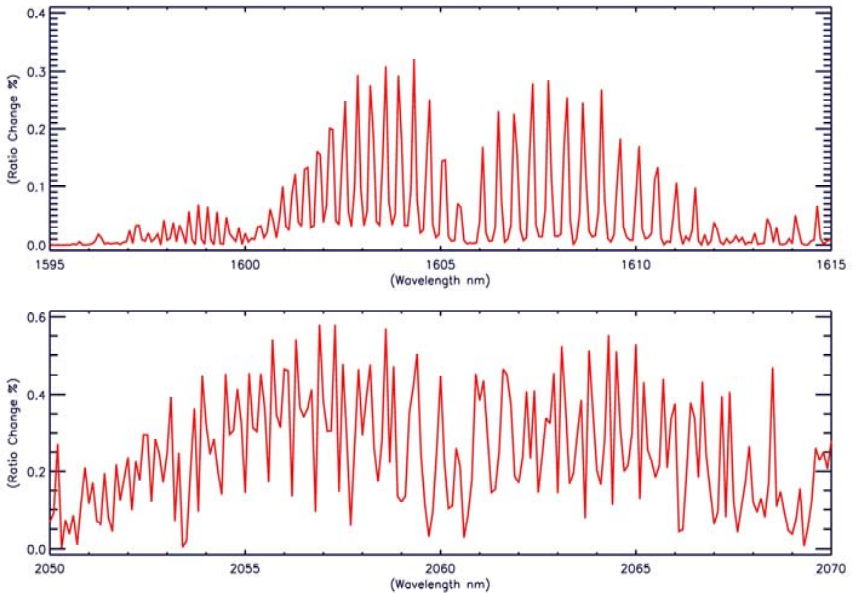

CO2_380
HUM 1.1
(phot/s/cm2/nm/sr)
(Wavelength nm)


osp=1.0-0.5
osp=4.0-0.5
(diff/all %)
(Wavelength nm)

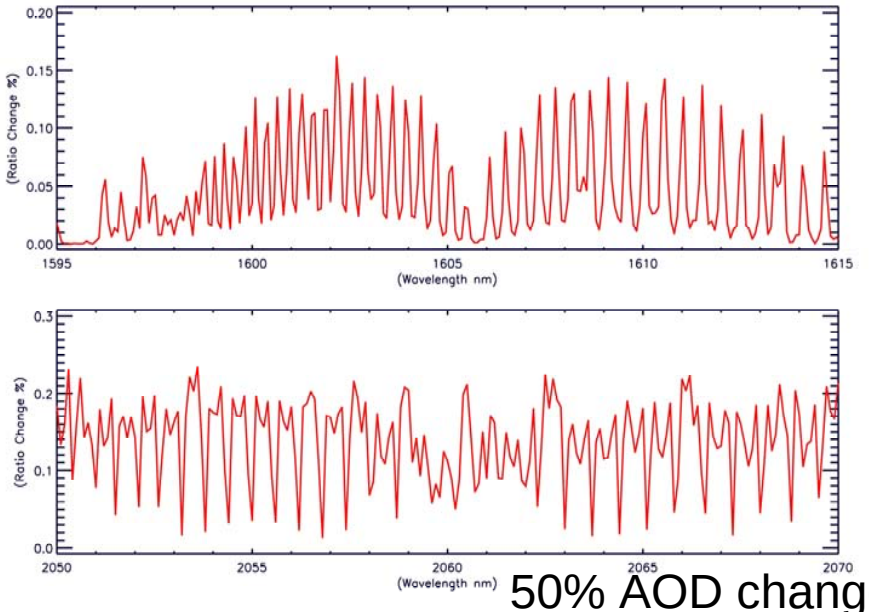

(phot/s/cm2/nm/sr)
(Wavelength nm)



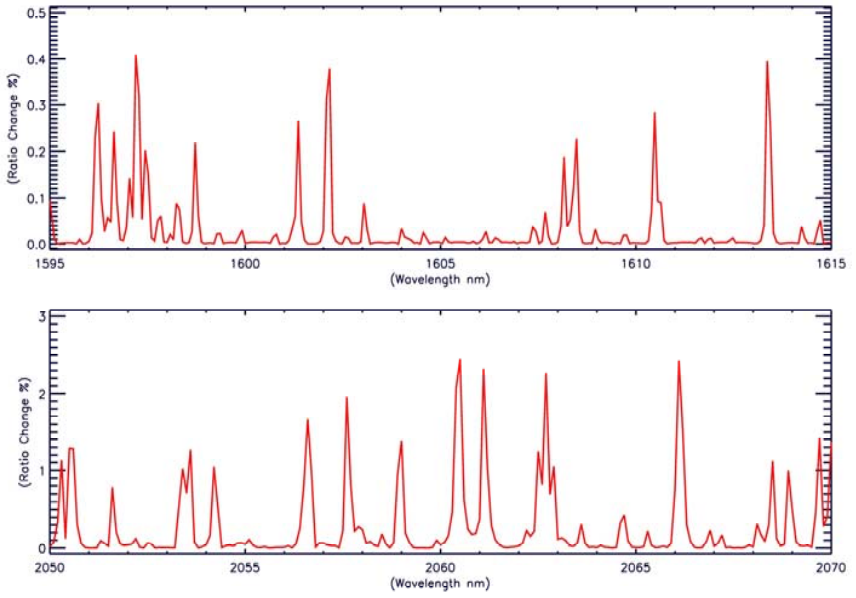
2ppmv CO_2 change



2K temperature change

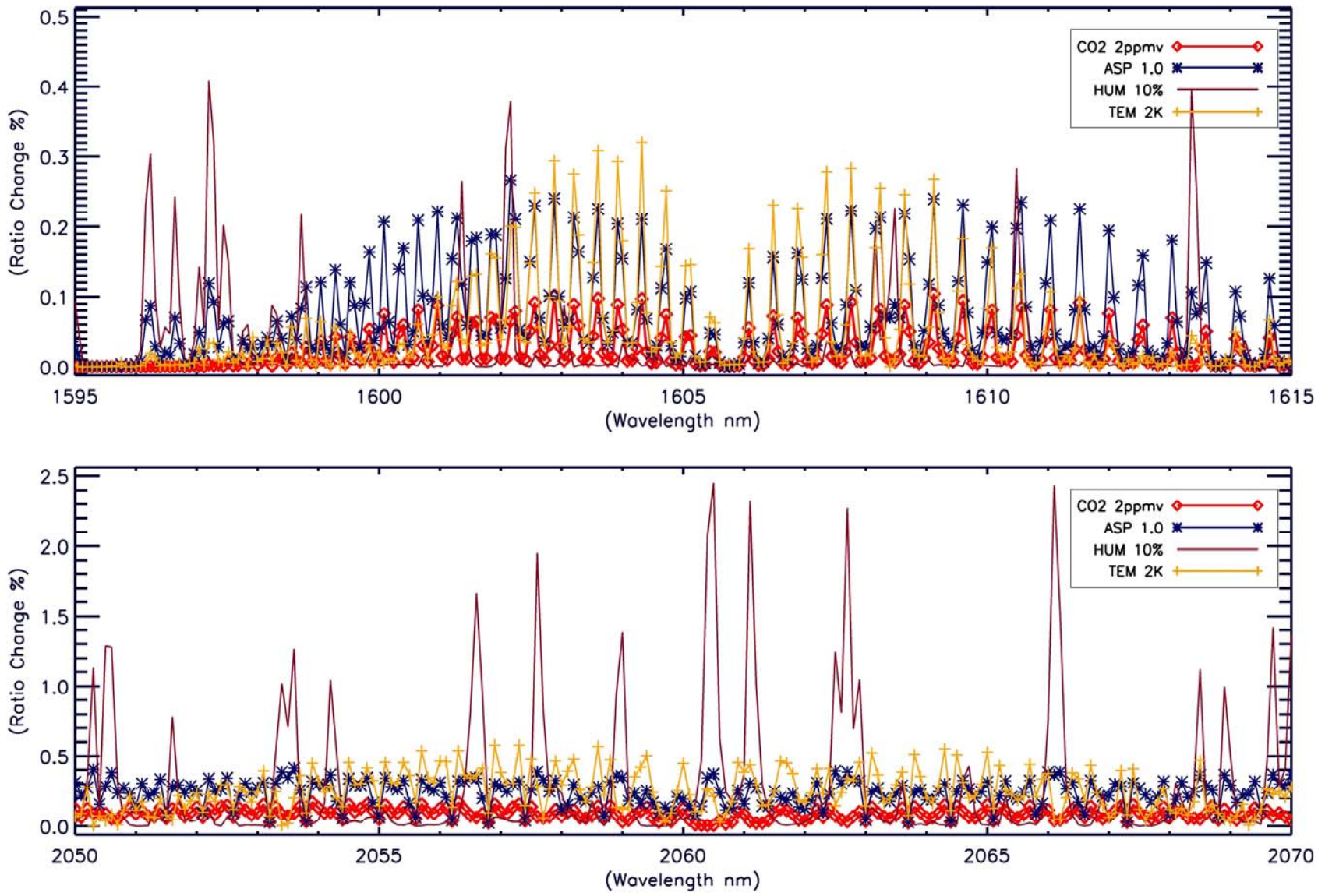


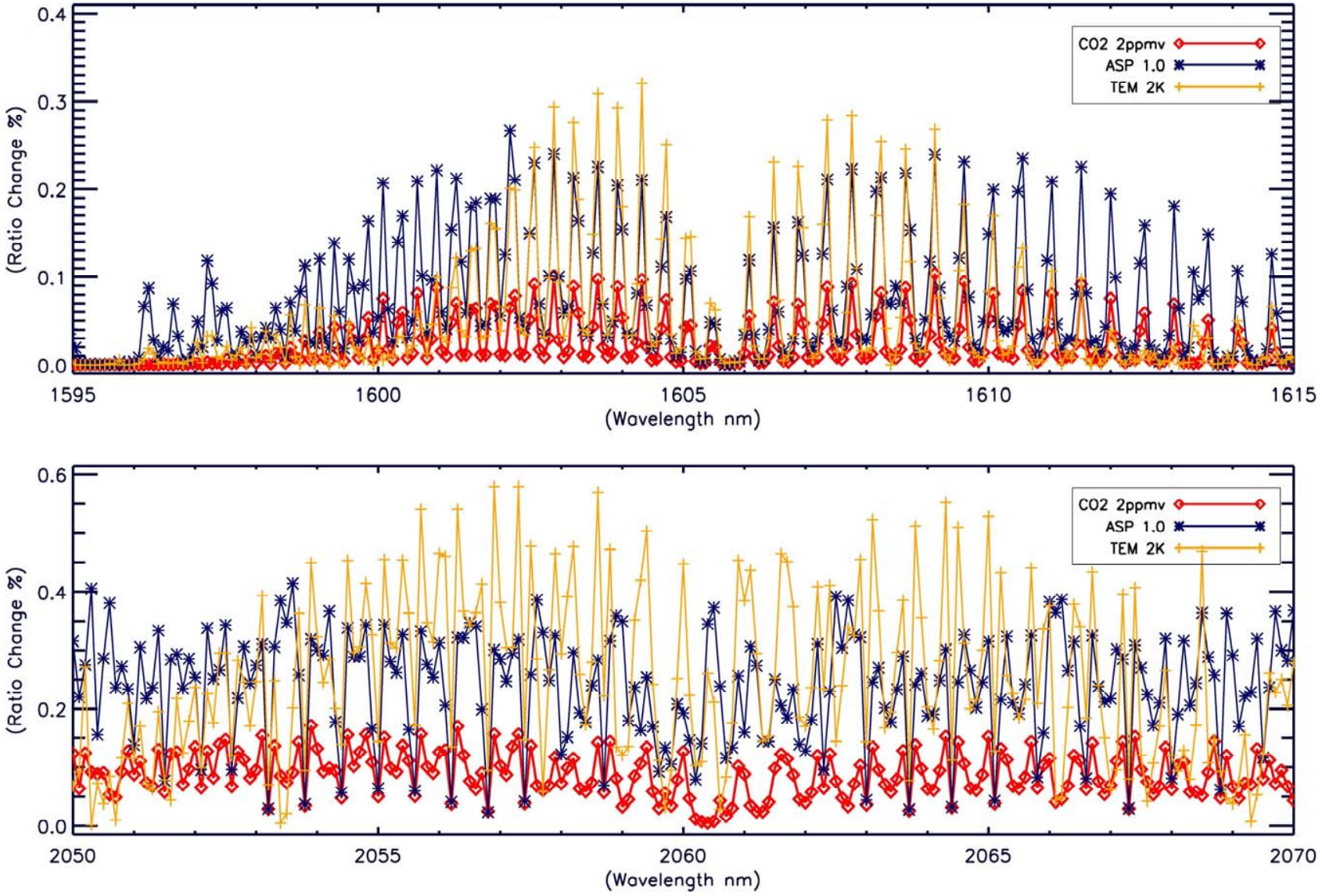
50% AOD change

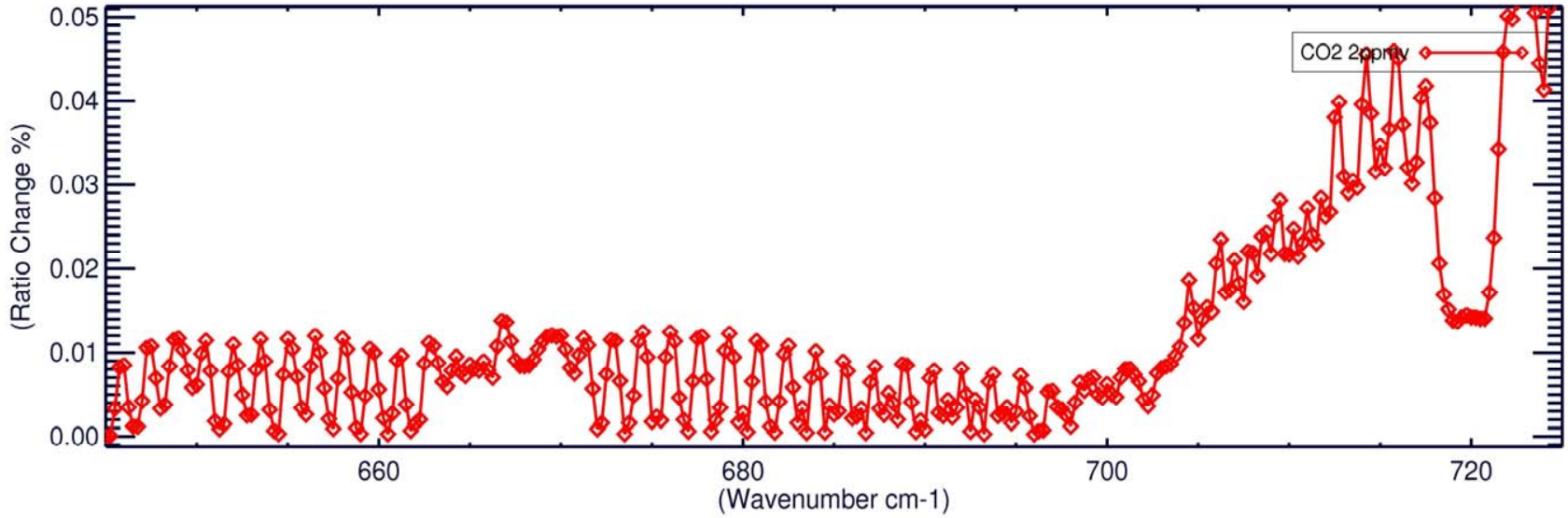


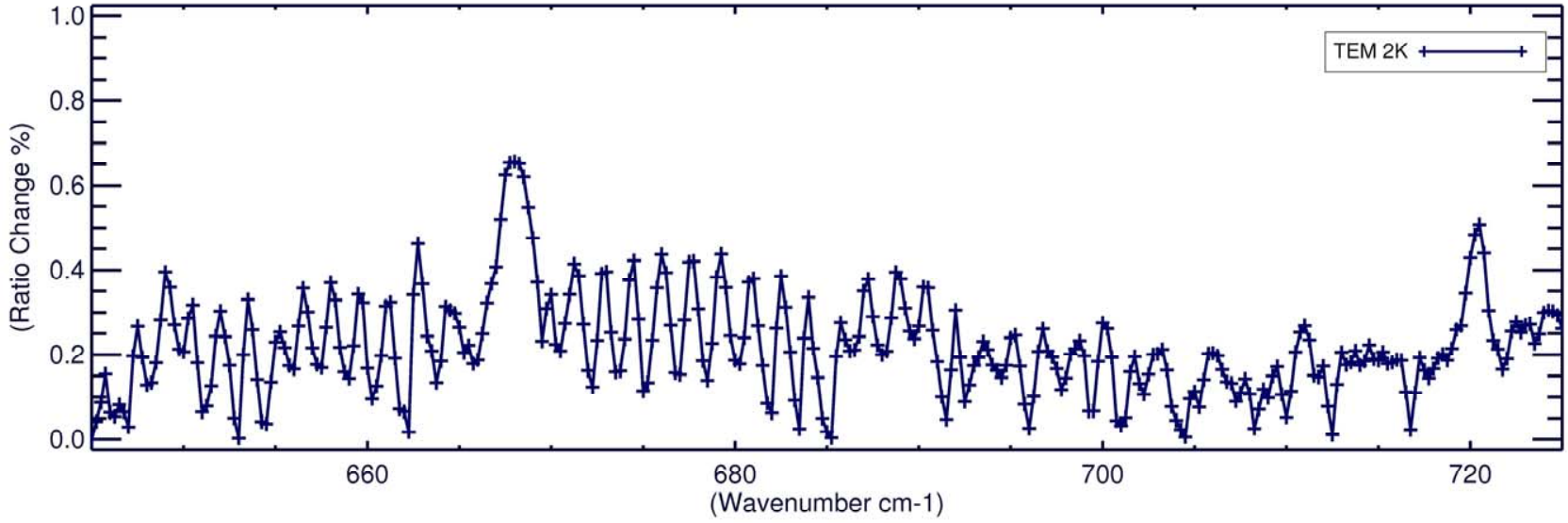
10% water vapor change

Interference Factors to the CO_2 Retrieval

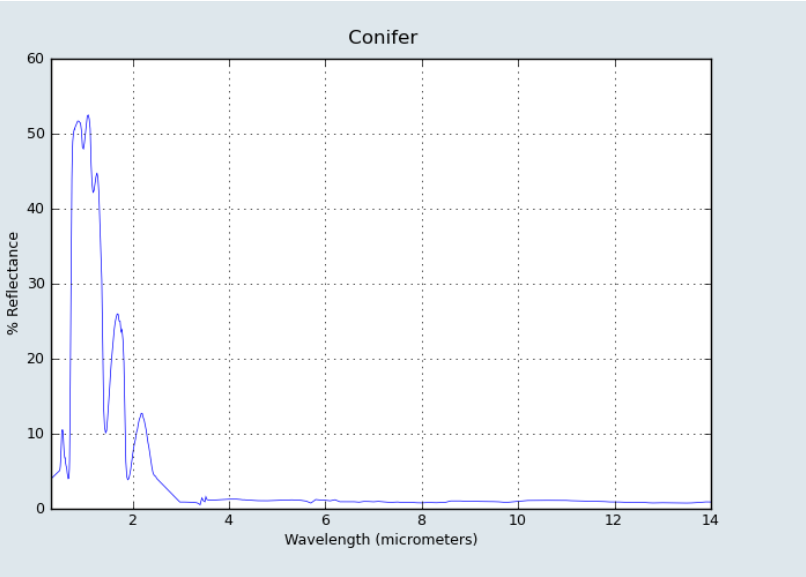



CO2 2ppmv
ASP 1.0
TEM 2K
(Ratio Change %)
0.0
0.1
0.2
0.3
0.4
1595
1600
1605
1610
1615
(Wavelength nm)
CO2 2ppmv
ASP 1.0
TEM 2K
(Ratio Change %)
0.0
0.2
0.4
0.6
2050
2055
2060
2065
2070
(Wavelength nm)


CO2 2ppmv
(Ratio Change %)
0.05
0.04
0.03
0.02
0.01
0.00
660
680
700
720
(Wavenumber cm-1)

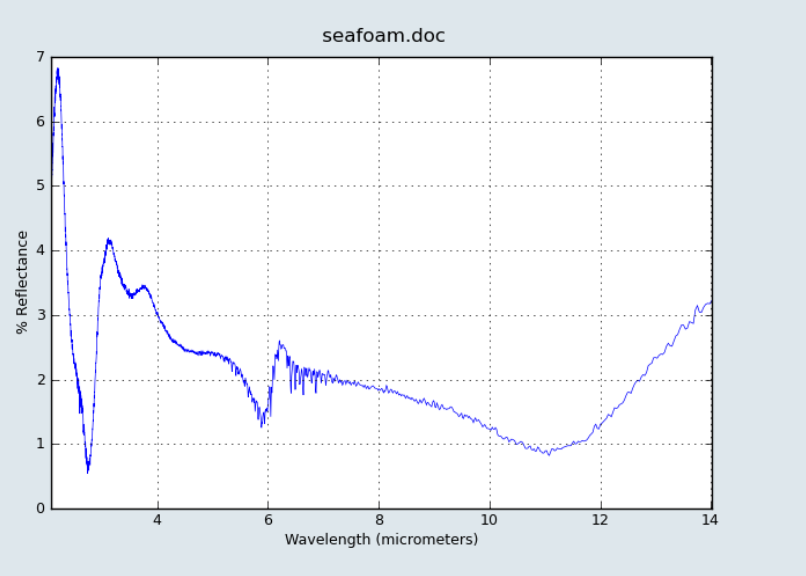

TEM 2K
(Ratio Change %)
1.0
0.8
0.6
0.4
0.2
0.0
660
680
700
720
(Wavenumber cm-1)

Surface Reflectivity Difference

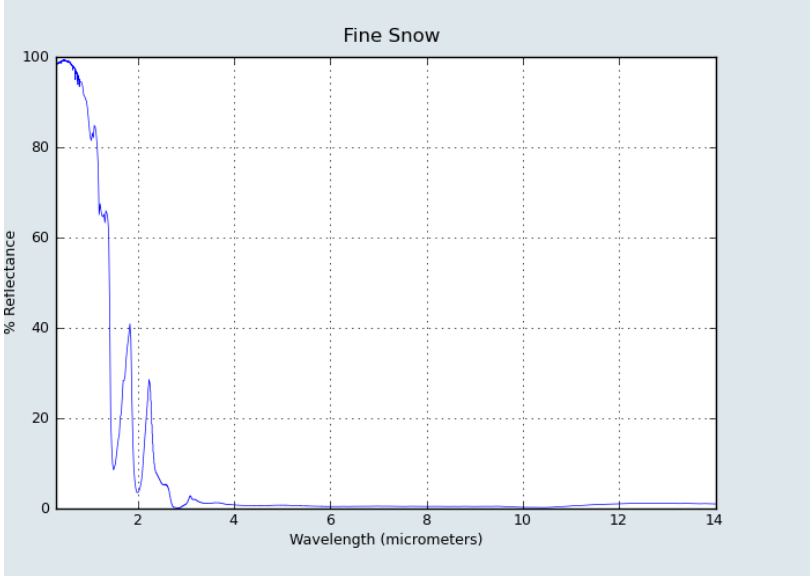


Trees

Dry grass



Sea Water



Fine Snow

Conclusion

1) Need satellite instrument with high spectrum resolution and S/N.

2) How to select bands which are sensitive to all altitude of CO_2 profile?

3) How to remove other interfering factors effect to the CO_2 retrieval?

4) How to decide the satellite measurement pixel surface type?

5) ….

It is challenging to get 2ppmv of CO_2 retrieval accuracy from Satellite!

Thanks very much

for your attention!