Investigating greenhouse gases in Australia using atmospheric measurements with Fourier transform spectrometry and atmospheric modeling

Nicholas M. Deutscher
University of Wollongong
NOTE

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5. Total column amounts of trace gases at Darwin, 2005 – 2009

5.1. Overview

A number of gas column amounts, and their column-average dry-air mole fractions can be retrieved from the NIR spectra. The gases quantified in this study, and the spectral windows in which they are fitted, are summarised in Table 5.1. In this chapter we present the time series of each of these gases, and provide some preliminary discussion.

For any gases that are fitted in two or more windows, the error-weighted average of the retrievals from the windows is used. We also look at using some of these retrievals to validate satellite measurements from SCIAMACHY and GOSAT.

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<th>Width (cm⁻¹)</th>
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<td>N/A</td>
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<td>0.40</td>
<td>H₂O, CH₄</td>
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</tbody>
</table>
5.2. O₂

We start with the O₂ time series as the O₂ DMF should be constant to within the precision of the instrument, and thus it tells us about instrumental performance. The X₀₂ time series from installation until August 31, 2009 is shown in Figure 5.1. The data presented here have been filtered to include only data when: (i) the relative CO₂ and O₂ retrieval errors are less than 2%; (ii) the relative solar intensity variation during a spectral scan is less than 5%; and (iii) the spectral retrieval converged within the maximum allowed number of iterations. Known periods of poor performance, such as several periods with sudden unexplained jumps in retrieved instrument lineshapes, are also excluded. The same criteria are applied to all subsequent time series plots unless otherwise specified. The larger scatter present in the early couple of months is before DC collection was implemented, therefore these data cannot be corrected for source brightness fluctuations.
The $X_{O2}$ measurements show some time dependent structure, notably a gradual decrease from mid 2006 until a realignment was performed in January 2009. This instrumental effect occurred due to a gradual shear misalignment due to wear on the carriage bearings of the fixed interferometer corner cube, which resulted in a change to the instrument lineshape. As the fitting software, GFIT, assumes a perfect lineshape, the retrieved gas columns are subsequently affected. The fixed cube corner shear manifests itself in an artificial narrowing of the spectral lines, and subsequent negative zero offsets to the spectra. The variation in retrieved spectral zero offsets in the $O_2$ window is shown in Figure 5.2. The realignment in January 2009 can clearly be seen. Currently, work is being undertaken at JPL to provide a means to include the effect of a non-ideal instrument lineshape in GFIT, but that work is outside the timeframe of this thesis. We therefore present these results with the assumption that this instrumental misalignment similarly affects other gas species retrieved from the spectra, and therefore cancels in ratiointo $O_2$. This assumption is reasonable, but there may be some time-dependent systematic error introduced by the changing $X_{O2}$.
Figure 5.2  Retrieved zero offsets in the O$_2$ microwindow.

Figure 5.3  Calculated solar-terrestrial shifts (top) and frequency shifts relative to the linelists (bottom) in the O$_2$ 7885 cm$^{-1}$ window.

Figure 5.4  The continuum level retrieved in the O$_2$ 7885 cm$^{-1}$ window.
Figure 5.3 shows the time series of calculated solar-terrestrial shifts, and frequency shifts relative to the linelist retrieved when fitting the O$_2$ 7885 cm$^{-1}$ window. The solar-terrestrial shift is the relative difference in frequency scale between the solar and terrestrial lines compared to their theoretical frequencies. The frequency shift again highlights the effect of the gradual misalignment, with a gradual long-term decrease until instrument realignment on January 15, 2009. The step change on May 12, 2009 corresponds with a visit to the site. The only significant event that took place at that time was that the solar tracker mirrors were cleaned, however it was shortly after this time that the reference laser on the spectrometer started to fail, and was subsequently turned on only every third day. The solar-terrestrial shifts show little long-term temporal variability. There is a small step change in late 2005, when new solar tracker mirrors were installed, and the solar tracker was realigned, otherwise the shift ranges between 0 – 1 ppm for the duration of the record. The O$_2$ continuum level time series is shown in Figure 5.4. There is a small increase in signal intensity at the time of the visit on May 12, 2009, and the subsequent change in signal strength with time reduces after this time relative to previous, probably because the solar tracker mirrors were only being exposed to the environment every third day, reducing the chance of them collecting dust.
5.3. CO₂

Figure 5.5 Daily average XCO₂ retrieved from the Darwin solar FTS.

Figure 5.5 shows the time series of calibrated daily-average XCO₂ data collected at Darwin. The record is characterised by an apparent monotonic increase in the mole fraction, with an overlying seasonal cycle. The magnitude of the increase over the 4 year record is of the order of 8 μmol mol⁻¹, or 2 μmol mol⁻¹ yr⁻¹, in good agreement with values of the recent annual increase calculated elsewhere [Canadell et al., 2007].

The seasonal cycle exhibits a minimum in the tropical monsoonal season (December to March) each year, when photosynthetic uptake is dominant. This is apparent in the column despite the fact that transport of CO₂-enriched air from the Northern Hemisphere would be most prevalent at this time of the year. A consistent year-to-year pattern is observed, with rapid uptake occurring during the wet season, starting in the late year and lasting until approximately March of the following year. The magnitude of the decrease in XCO₂ seen due to this uptake is largest in 2005-6 and 2006-7, where it is about 2.5 – 3 μmol mol⁻¹. The change in the later years is still evident, but not as
pronounced. In between wet seasons, an increase in the $X_{CO2}$ is observed, of the order of 4 – 5 μmol mol$^{-1}$.

5.4. CH$_4$

![Figure 5.6](image)

**Figure 5.6** Daily average $X_{CH4}$ retrieved from the Darwin solar FTS. The light blue open circles show data obtained before a spectrometer realignment in January 2009. The dark blue plusses show data obtained after the realignment.

A similar time series for $X_{CH4}$ is presented in Figure 5.6. There is no apparent growth in mole fraction during 2006, before a renewed growth observed after 2007, and possible cessation of growth from late 2008. The 2007-2008 growth agrees well with measurements reported elsewhere from in situ surface records [Rigby et al., 2008]. Also apparent is considerable inter-annual variability, with mole fraction minimum at year’s end, corresponding with maximum loss due to reaction with the OH radical. It is likely that transport also plays some role in the variability, as OH does not have a strong seasonal cycle in the tropics, though the yearly minima seen here correspond with a time at which Darwin is (or is close to) being meteorologically part of the northern
hemisphere, and also when northern hemisphere CH$_4$ is most abundant, and OH least abundant. In 2006-2007, this late year decrease is well defined, but in other years there is considerably more scatter around that time of year, and the magnitude of decrease is smaller.

The comparative time series for both X$_{CO_2}$ and X$_{CH_4}$ at Lauder and Darwin are shown in Figure 5.7. The Lauder data have been provided by Vanessa Sherlock (National Institute of Water and Atmospheric Research). The difference in mole fractions with latitude is apparent for both methane and CO$_2$, but is proportionally larger for CH$_4$. This is because CH$_4$ is destroyed in the stratosphere, meaning that the column amounts are dominated by the tropospheric fraction. As a result, because of the higher relative tropopause height in the tropics, the methane column at Darwin is higher for a given tropospheric VMR. A tropospheric X$_{CH_4}$ can be derived using the method described by Washenfelder et al. [2003], which using the HF column as a proxy for the stratospheric portion of the observed column. CH$_4$ and HF have been demonstrated to be inversely correlated in the stratosphere [Luo et al., 1995], because the products of the oxidation reactions responsible for stratospheric CH$_4$ destruction eventually react with fluorine atoms formed from photolysis of chlorofluorocarbons (CFCs), forming HF.

\[
X_{CH_4, trop} = \frac{0.2095 \times (CH_4 \text{ column} - b \times HF \text{ column})}{O_2 \text{ column}} \quad (5.1)
\]

The CH$_4$-HF slope (b) can be applied via equation 5.1 to correct the total CH$_4$ column for stratospheric variations, thereby yielding a tropospheric volume mixing ratio [Washenfelder et al., 2003]. Using the value of b derived in Washenfelder et al. [2003], we derive tropospheric X$_{CH_4}$ for Lauder and Darwin as shown in Figure 5.8. The
Lauder-Darwin difference between the mole fractions is smaller than in the total column based $X_{\text{CH}_4}$, but the latitudinal difference is still obvious. The seasonality in both time series is very similar, driven by loss via reaction with the OH radical, but the two timeseries appear to diverge towards the end of the current record, after the renewed atmospheric methane growth, reflecting the fact that this regrowth has been attributed to increased sources in the Arctic and tropics [Dlugokencky et al., 2009], which would be observed at Darwin before Lauder.
Figure 5.7 Daily average (A) $X_{CO2}$ and (B) $X_{CH4}$ from Lauder (black) and Darwin (light/dark blue).

![Graph showing daily average $X_{CO2}$ and $X_{CH4}$ from Lauder and Darwin](image)

Figure 5.8 Daily average tropospheric $X_{CH4}$ from Lauder (black) and Darwin (blue).

5.5. Stable water vapour isotopes

Water vapour is the most potent greenhouse gas in the atmosphere. Saturation vapour pressure increases with temperature, therefore any global warming caused by increased anthropogenic greenhouse gas concentrations will result in an increased amount of water vapour in the atmosphere, and hence a positive feedback effect to the global warming trend. Accurate knowledge of hydrological cycles is necessary for climate predictions. Stable isotope measurements of water vapour provide a means of tracing water vapour transport in the atmosphere, and hence a better understanding of water cycling.
Recently, the first global tropospheric measurements of HDO from satellite were performed [Worden et al., 2007; Zakharov et al., 2004], but these lacked sensitivity to the lower troposphere, where most water vapour is present. A more recent study [Frankenberg et al., 2009] retrieved HDO and H$_2$O columns from SCIAMACHY spectra, with sensitivity to the lowest atmospheric levels. These column measurements were validated using ground-based solar FTS data. A comparison between the monthly average $\delta^2$H in H$_2$O from Darwin solar FTS measurements and SCIAMACHY monthly averages for three radii surrounding Darwin is shown in Figure 5.9. Note that the SCIAMACHY and FTS data are plotted on different scales, offset from each other by 60%. This shows that there is good agreement in the seasonal cycles, but an offset between the two instruments, for which calibration is necessary.

![Graph](image-url)

**Figure 5.9** Comparison of monthly average FTS retrieved $\delta^2$H in H$_2$O from column retrievals from spectra acquired by the Darwin solar FTS (red, right axis), and by SCIAMACHY in 200km (green), 500km (blue) and 1000km (black) radii around Darwin.
Figure 5.10  Column-average mole fractions of H₂O in Darwin.

Figure 5.10 shows the measured column-average mole fractions of H₂O above Darwin. The amount of water in the atmosphere varies by an order of magnitude across the course of the year, with a mid-year minimum in the dry-season. This dry period also corresponds with the time of the most HDO depleted columns. Drier airmasses are expected to be HDO depleted because ^2H is preferentially removed through condensation and rainout. Furthermore, at that time of year the source of airmasses sampled at Darwin is largely continental, meaning a greater distance from water vapour sources. In general, as an airmass becomes more distant from a vapour source, it becomes more isotopically depleted [Gat, 1996], hence the corresponding minimum in δ^2H. The full time series of X_{HDO} and δ^2H in H₂O are presented in Figure 5.11.
Figure 5.11 The $\delta^2$H in H$_2$O (top) and column-average HDO (bottom) measured at Darwin.

5.6. CO

Figure 5.12 Time series of $X_{CO}$ measured at Darwin.

Figure 5.12 presents the time series of column-average CO measured at Darwin. The record is characterized by a late dry-season maximum, when large scale biomass burning events occur. Elsewhere [Paton-Walsh, 2009; Paton-Walsh et al., 2009] data from the Darwin solar FTS have been used to investigate the influence of local and
Indonesian biomass burning events on the observed columns of CO, H₂CO, C₂H₃, C₂H₆, and HCN, and to derive emission ratios relative to CO for Australian savannah fires. In this work, a correlation between CO and Aerosol Optical Depth (AOD) was observed, but while the CO exhibits a higher peak in late 2006 than either 2005 or 2007, the AOD does not (Figure 5.13). This is because CO has a longer lifetime than aerosols, and a large amount of the CO observed in this period originates from unusually large Indonesian fires caused by El Niño conditions. The CO amounts exhibit a minimum in March-April driven by reaction with the OH radical and absence of biomass burning.

Please see print copy for image

Figure 5.13  Measured CO columns (black) and aerosol optical depth (grey) at Darwin, taken from Paton-Walsh et al. [2009].
5.7. N₂O

The time series of column-average N₂O measured at Darwin.

The N₂O time series from Darwin is shown in Figure 5.14. The dominant feature is the seasonality of up to 3%, with minima occurring mid year. These minima correspond with the minima in tropopause height, which varies by approximately 2% throughout the year, based on NCEP reanalysis tropopause pressure. N₂O is destroyed in the stratosphere, creating the ozone-depleting nitric oxide (NO) and nitrogen dioxide (NO₂). A plot of X_{N₂O} against X_{HF} (Figure 5.15) shows considerable scatter, but there seems to be a linear lower limit to the relationship. The lower limit is probably driven by the changing tropopause height, while the scatter is caused by real atmospheric variability in N₂O and retrieval error in HF. Taking the slope of this lower limit and following the procedure derived for CH₄, we derive a value for b of 400 mol mol⁻¹, from which we generate a measure of the tropospheric X_{N₂O}. The resulting tropospheric X_{N₂O} time series is shown in Figure 5.16, with what appears to be a linear increase, and no evidence of seasonality, suggesting that tropopause height variation is the major cause of seasonal X_{N₂O} variability. The tropospheric X_{N₂O} time series has more scatter than the total column X_{N₂O}. Using HF retrieved from the NIR spectra, rather than a fully
independent measure such as NCEP reanalysis data, is advantageous, because it takes into account the sensitivity of the column retrievals to altitude. This is not perfect, because the averaging kernels are different for the two gases, but it is more accurate than using the model NCEP data, which are interpolated from a relatively coarse spatial and temporal grid.

![Figure 5.15](image1)

**Figure 5.15** $X_{\text{N}_2\text{O}}$ plotted against $X_{\text{HF}}$, revealing that there is a lower limit to the relationship. The linear fit to this lower limit is used to generate the slope of $X_{\text{N}_2\text{O}}/X_{\text{HF}}$ which in turn used to correct for tropopause height variation.

![Figure 5.16](image2)

**Figure 5.16** Time series of tropospheric $X_{\text{N}_2\text{O}}$ from Darwin.
5.8. HF

Hydrogen fluoride is retrieved from a single line in a window centred at 4038.95 cm⁻¹. The time series of $X_{HF}$ is shown in Figure 5.17. HF is primarily produced in the stratosphere via photolysis of fluorocarbon compounds, and subsequent reaction of fluorine atoms with CH₄ and H₂O. HF is believed to be chemically inert in the stratosphere, so HF VMRs increase monotonically with altitude and the age of the air. Hence the $X_{HF}$ time series variations largely indicate variations in tropopause height. $X_{HF}$ is highest in the dry season, when the tropopause height is lowest, and hence the stratospheric contribution to the vertical column is relatively higher. As HF is a stratospheric gas, it can be used as a proxy for the total stratospheric column measured by the FTS, allowing generation of tropospheric and stratospheric column averages, such as seen above for methane and N₂O.

![Figure 5.17](image-url)  
**Figure 5.17**  
$X_{HF}$ time series from Darwin.
5.9. Comparison to GOSAT

Here we present an initial comparison to retrievals of $X_{\text{CO}_2}$ and $X_{\text{CH}_4}$ from GOSAT (see section 1.5.2) spectra. For the Level1B product provided by the Japanese National Institute for Environmental Studies (NIES), GOSAT data are considered to be over Darwin when they lie within the bounds of 11.165 to 13.879°S and 130.324 to 132.264°E, approximately a 200km radius from the Darwin FTS site. The NIES data presented here are preliminary results, with known limitations, including immature algorithms and suboptimal cloud detection. The FTS data are averaged between 1250 and 1450 local time, giving a one hour window either side of the satellite overpass time. Figure 5.18 shows the comparative time series of $X_{\text{CO}_2}$ retrieved from the Darwin FTS on GOSAT overpass days, and that retrieved from spectra obtained from the TANSO-FTS instrument on board GOSAT. The error bars for the FTS data are the 5 min precision on the retrievals, propagated in quadrature by the error in the airmass correction and calibration to the in situ scale. The GOSAT error bars are the sum of the Level1B reported interference errors, retrieval noise and smoothing error. The FTS retrievals are considerably less variable than those from GOSAT, and the GOSAT retrievals appear to be systematically low compared to the solar FTS. A scatter plot of the GOSAT and TCCON-FTS $X_{\text{CO}_2}$ retrievals is shown in Figure 5.19. NIES data are provided by Osamu Uchino and Isamu Morino.
Figure 5.18  Comparative time series of FTS (crosses) and NIES GOSAT retrievals (circles/triangles) of $X_{CO_2}$ at Darwin. Three low (below 330 μmol mol$^{-1}$) GOSAT values have been removed, along with 2 FTS values with high (> 1%) errors, to reduce the range of the y-axis.

Figure 5.19  Scatter plot of GOSAT vs FTS $X_{CO_2}$ for Darwin satellite overpasses.

An alternative retrieval procedure – the OCO full retrieval algorithm – applied to the same GOSAT spectra, results in raw $X_{CO_2}$ numbers that are approximately 15 μmol mol$^{-1}$ higher than the NIES product, and more in line with the TCCON retrievals [Boesch et al., 2009]. A preliminary comparison of these retrievals to Darwin and Park Falls TCCON FTS $X_{CO_2}$ is shown in Figure 5.20. These retrievals are for April 26 and 28, 2009, and spectra 4 and 9 are believed to be affected by cloud. Also shown, in Figure 5.21, is a comparison between the OCO and NIES retrieval algorithms over
Australia between April 24 and 29, 2009 [Boesch et al., 2009], highlighting the 15 µmol mol\(^{-1}\) systematic difference. Indeed, when using uncalibrated TCCON data, the agreement between the ground-based data and that from the OCO retrieval algorithm is even better, suggesting a similar calibration is necessary to bring the OCO retrieval algorithm data onto the standard scale. The relative measurement-to-measurement scatter between the two retrieval codes is similar, suggesting that calibration will be able to take care of the apparent bias in the NIES retrievals. The OCO algorithm retrievals are supplied by Hartmut Boesch and Rob Parker.

Figure 5.20  Comparison of TCCON FTS X\(_{\text{CO}_2}\) data from Park Falls and Darwin with retrievals from GOSAT data performed using the OCO Full Physics Retrieval Algorithm, for April 26 and 28, 2009. Spectra 4 and 9 are believed to be affected by clouds. The blue and green symbols denote the retrieved X\(_{\text{CO}_2}\) values from GOSAT spectra, and the black symbols the corresponding daily average X\(_{\text{CO}_2}\) from the TCCON sites. Figure provided courtesy of Hartmut Boesch, updated from [Boesch et al., 2009].
Figure 5.21  $X_{\text{CO}_2}$ retrievals using the NIES (blue) and OCO (red) retrieval algorithms, on GOSAT spectra acquired over Australia between April 24 and 29, 2009. Figure taken from Boesch et al. [2009].

Figure 5.22 and Figure 5.23 present comparisons of the average FTS $X_{\text{CH}_4}$ during 2 hour windows centred on GOSAT overpass times with $X_{\text{CH}_4}$ retrieved from GOSAT spectra using the GOSAT algorithm and the OCO algorithm, respectively. There is considerably more scatter in the satellite measurements than those from the solar FTS. The GOSAT retrievals appear to be biased low compared to the solar FTS by about 60 nmol mol$^{-1}$ when excluding what appear to be outliers. Relatively, this is a similar amount to the bias for the GOSAT retrievals of $X_{\text{CO}_2}$. In contrast, the retrievals using the OCO retrieval algorithm have better absolute agreement with the solar FTS. In fact, if retrievals using the OCO algorithm are filtered to only include those within a 400km radius of the Darwin TCCON site, a number of the low outliers are excluded, making the agreement even better. The reason that the points further distant from the TCCON site result is low outliers is because the majority of these are located at more southerly latitudes, where the latitudinal $\text{CH}_4$ gradient and lower tropopause heights mean lower $X_{\text{CH}_4}$ amounts.
Figure 5.22 A comparison of GOSAT $X_{\text{CH}_4}$ retrievals (circles, triangles) from satellite overpasses over Darwin with retrieved values from the ground-based solar FTS (crosses).

Figure 5.23 A comparison of GOSAT $X_{\text{CH}_4}$ retrievals made using the OCO retrieval algorithm (black diamonds) on satellite overpasses over Darwin with retrieved values from the ground-based solar FTS (grey circles).

The apparent bias between the GOSAT retrievals and the TCCON data is approximately the calibration necessary to ensure the GOSAT $X_{\text{CO}_2}$ and $X_{\text{CH}_4}$ are on the WMO scale.

The correction for the retrievals using the OCO algorithm will be smaller for $\text{CO}_2$, and
because the TCCON CH₄ values are not yet calibrated, the correction necessary for the TCCON and OCO retrieval values will be similar.

5.10. Comparison to models

In the following section we present a preliminary comparison of X_CO₂ measured at Darwin to simulations using two models: CCAM (see Chapter 2) and the NOAA-ESRL CarbonTracker [Peters et al., 2007].

5.10.1. CCAM

![Graph showing comparison of daily averaged X_CO₂](image)

**Figure 5.24** Comparison of daily averaged X_CO₂ (black) measured by the Darwin solar FTS to CCAM simulated X_CO₂ based on the CASA (top, blue) and Simple Biosphere (bottom, red) ecosystem fluxes.

A comparison between daily average FTS X_CO₂ values and CCAM simulated X_CO₂ based on two different ecosystem flux models is shown in Figure 5.24. The two ecosystem models are the Carnegie-Ames-Stanford Approach (CASA) model [Potter et
al., 1993], introduced in Chapter 2, and the Simple Biosphere (SiB) model [Sellers et al., 1996a; Sellers et al., 1986; Sellers et al., 1996b]. The long-term divergence of the models and measurements is driven by the ‘neutral biosphere’ assumption, which normalizes biospheric fluxes to an annual mean of zero, when in reality the biosphere acts as a small sink. The models therefore overestimate the annual growth rate, by approximately 0.35 – 0.50 µmol mol\(^{-1}\). Consequently the data presented here have been linearly detrended, and arbitrary offsets applied to the model data to bring them into agreement with the FTS data.

Overall, the models capture the patterns exhibited in the FTS data well. Both models and measurements have a late wet season minimum following a pre-wet season maximum, and a relatively quiescent period in the middle of the year. The models overestimate the magnitude of the drawdown that occurs during the monsoonal wet season, and in 2007 appear to lead the measurements in the timing of this event, noticeably more so in the CASA model than SiB, where the appearance of mismatched timing is given because the FTS \(X_{CO2}\) is higher than the model at the start of the drawdown. The mismatch in this timing could be due to the models not capturing the interannual variability in when the monsoon season starts. The timing of synoptic time scale events seen in the measurement data is captured well by the model. Generally it seems that the SiB ecosystem model provides a better match to the FTS data, particularly in the first half of 2006, when CASA overestimates the seasonal growth, and in the last nine months of 2007, when CASA fluxes do not capture a second drawdown event after the major wet season uptake, and the \(X_{CO2}\) is subsequently high for the remainder of the year. This suggests that the SiB model does a better job of modeling the interannual variability in tropical monsoon ecosystems than does CASA.
5.10.2. **CarbonTracker**

A comparison between the FTS data and CarbonTracker over the same time frame as for CCAM is shown in Figure 5.25. In this case, neither measured nor modeled data have been detrended, because the agreement in the long-term growth rates is good. CarbonTracker is a data assimilation system, based on the transport model TM5, driven by ECMWF meteorological fields. The model has 6° x 4° resolution, with nested regions with with 1° x 1° resolution over the USA, and 3° x 2° resolution over all of North America. The agreement with CarbonTracker occurs because CarbonTracker is a data assimilation system, which uses real observations to minimize the mismatch between the model forecasts and observations [Peters et al., 2007]. While versions with higher resolution over other parts of the globe are being developed, at present the model and observation resolution are poor outside North America, particularly in the Southern Hemisphere.

![Figure 5.25](image-url)  
**Figure 5.25**  FTS measured and CarbonTracker modelled XCO2 at Darwin.
Once again, there is some good general agreement between the observations and the model. Synoptic time scale events match well, and mole fractions agree in the last few months of each year. In between, CarbonTracker fails to replicate any drawdown in $X_{CO2}$ during the monsoonal wet season, thus failing to match the magnitude of the seasonal cycle. This is not likely to be a product of the coarse model resolution, as the model would be unlikely to capture the synoptic scale events so well if that was the case. The mismatch could be related to modelling of interhemispheric exchange, which could be overestimated throughout the wet season. The InterTropical Convergence Zone (ITCZ) is southernmost at this time of the year, reaching as far south as Alice Springs (23.7°S), and so chemically Darwin could be a part of the Northern Hemisphere. However, a chemical equator forms to the north of Darwin [Hamilton et al., 2008], limiting northern hemisphere air from reaching northern Australia. CarbonTracker could be failing to model the effect of the chemical equator, especially higher in the atmosphere.

It is also possible, given the vigorous convection and vertical transport that occurs in the tropics in the wet season, that the model does not accurately represent these phenomena. Vertical transport in CarbonTracker’s data assimilation system has been validated against aircraft profiles, to the best of our knowledge none of which occurred in the tropics. Column observations at Darwin have a potentially important role in understanding and modeling tropical vertical transport.

Also, the ecosystem model used in CarbonTracker is CASA, which has already been shown with CCAM to not fully capture the seasonality of $X_{CO2}$ at Darwin, especially in the middle of 2007. This no doubt contributes to the mismatch between CarbonTracker
and the FTS, but given the different patterns of disagreement between CarbonTracker and CCAM, there are obviously transport and/or data assimilation issues that also play a role.

Note that both the CarbonTracker and CCAM model columns shown here have not had the FTS averaging kernels applied to them, something which will likely cause both a small change in the absolute values and a weak seasonal dependence.

5.11. Conclusions

The Darwin solar FTS has been operating since August 2005, and producing data that is capable of and useful for satellite validation of a number of gases. From these data, we can see that the seasonal cycle in δ²H in H₂O matches well with satellite retrievals from SCIAMACHY. Also, uncalibrated XₖCH₄ and XₖCO₂ values are in good agreement with results from GOSAT using the OCO full physics retrieval algorithm, but systematically higher than those using the NIES algorithm, but with similar scatter. We have compared XₖCO₂ measured by the Darwin solar FTS to modelled XₖCO₂ values, which generally show good synoptic scale agreement, but fail to capture some seasonal events. The FTS column measurements in the tropics are important for improving modelling of interhemispheric exchange, and vertical exchange.