The authors wish to thank both referees and the editor for helpful, thoughtful and insightful comments. Each comment is addressed individually below. The referee comments are in boldface red, and our responses are in black.

The main changes to the paper since the ACPD version are:

- The sections have been rearranged to put the approach to evaluating X_{CO_2} from space-borne measurements before the description of the ACOS data. In the interest of brevity, the description of the TCCON data has been condensed and added to the introduction.

- The Bialystok data used in the comparisons in the Northern Hemisphere were recently updated (Sept 30, 2011) to correct for an instrument error. This makes an insignificant difference to the overall comparison between TCCON and ACOS-GOSAT, but the numbers change slightly.

- Figures 1 (the locations of the TCCON stations) and 2 (the map of M versus H gain) were combined into a single map.

- Table 3 was added to quantify the results (site-by-site) of the comparison between ACOS-GOSAT and TCCON data.

- Four supplementary figures were added: two maps and histograms of the four fitting parameters, a figure showing the latitude dependence of the seasonal cycle induced by adjusting the ACOS-GOSAT retrievals to the TCCON a priori, and a figure illustrating the orthogonality of the four fitting parameters.

- A second appendix was added to preview the v2.9 data. This section outlines the improvements to the algorithm and data product, and shows that the v2.9 data still correlates with the same 4 parameters as the v2.8 data.

Response to Anonymous Referee #1

The general approach is based on the assumption that atmospheric variability of total column CO2 is small in the Southern hemisphere and that a linear relationship exists between retrieval bias and 4 correction parameters. The bias correction is then gauged through observations in the Southern hemisphere mid-latitudes and extrapolated to the global scale. These assumptions are appropriately discussed by the manuscript. In general terms, however, I would prefer correcting forward model and instrument deficiencies before the actual retrieval, in particular since physical understanding seems at hand for some aspects discussed here.

We would also prefer to correct the forward model and instrument deficiencies. Some of the biases were discovered in the process of this evaluation effort, and will feed back into future versions of the algorithm. (For example, the O_2 A-band spectroscopic cross-sections were scaled for v2.9 to eliminate much of the large-scale bias. This is discussed in the new Appendix B.) Of course, for the purposes of evaluating the v2.8 ACOS-GOSAT dataset, which is already publicly available, we cannot alter the algorithm.

Concerning the proposed posterior bias correction, one might wonder whether data users that dispose of a modeling framework actually prefer to device their own correction scheme since their modeling framework should provide the generally best estimate of the CO2 total column concentrations in Southern hemisphere mid-latitudes.

We agree. This paper was meant as a guide to illustrate the utility of the Southern Hemisphere data in identifying bias in X_{CO_2}. We have rearranged the paper sections to attempt to focus more on the approach than on our specific application. What was section 3 ("Comparing satellite-based Xco2 with ground-based TCCON measurements") is now section 2.

1. The manuscript points out that a considerable fraction of the overall XCO2 bias is due to a bias in retrieved surface pressure (used to calculate the column-average CO2 mixing ratio, XCO2). Surface pressure is also one of the parameters for the bias corrections scheme (p.20909, l.2. . .). I suggest to first evaluate retrieved surface pressure, then retrieved XCO2, in order to disentangle the related uncertainties. If the observed bias is dominated by contributions

from the surface pressure retrieval, one might consider to use the a priori surface pressure (derived from meteorological and topographic databases) to calculate XCO2.

This is a good suggestion and one we have partially undertaken elsewhere. O'Dell et al. (2011) have shown that the algorithm causes the relationship between ΔP and X_{CO_2} and that it is independent of the large-scale bias caused by the O_2 A-band spectroscopy. Because this is clearly caused by the algorithm itself, it makes sense to investigate it more thoroughly with simulated data.

We have attempted to correlate the surface pressure retrievals with signal o2, blended albedo and airmass, and the correlations do not significantly reduce the scatter ($\sigma_{uncorrected}$ = 255.11 Pa v.s. $\sigma_{corrected}$ = 254.98 Pa). Further, the difference between the retrieved and ECMWF surface pressure is relatively Gaussian (Figure 1), which is what one would expect for random error.

2. The study justly emphasizes that the bias correction needs extrapolation (beyond the parameter range used for gauging) to cover all ACOS-GOSAT retrievals (p.20911, l.2. . .). When discussing this assumption, no particular focus is given to tropical regions, ie. 25°S to 25°N, which is a very interesting region. Could the bias correction fail there eg. because of generally low air mass or low infrared albedo (and large "blended albedo") of dense tropical vegetation? A figure showing the global distribution of the 4 correction parameters could help identify potentially difficult regions.

There are two new figures included in the supplementary material that show both maps and histograms of the four parameters. These are included at the end of this document as Figures 2 and 3. The distributions in the tropics are similar to those in the SH. The most dissimilar values, compared with the SH, are from the NH, which has significantly higher airmass and blended_albedo values in the summer and winter, and lower signal_o2 values in the winter.

3. The study discusses that a comparison of ground-based TCCON data with ACOS-GOSAT retrievals requires taking into account (1) differences in the a priori assumptions and (2) differences in retrieval sensitivity represented by the averaging kernels (p.20911, l.12. . .). While I agree that step (2) is generally difficult due to the true ensemble covariance being unknown on the global scale, step (1) seems feasible for all TCCON stations since the "ensemble" profile chosen here is actually the TCCON a priori. If this is correct, it would be straightforward to carry out adjustment (1) and to quantify its effect for all stations (not only Lamont) covering a range of latitudes.

The sensitivity to the prior profile for several latitude bands is plotted in Figure 4 below, and has been added to the supplementary material. (Latitude bands are appropriate in this case because the TCCON a priori profiles vary only in latitude and time.)

4. Evaluation of the proposed bias correction needs more quantification. While the comparison of ACOS-GOSAT zonal averages and TCCON (p.20913, l.9. . .) seems dispensable to me, the site-by-site comparisons between GOSAT and TCCON lack detailed quantitative discussion. Figures 13 and 14 are not convincing enough:

- **The paper requires a table where the residual bias and the number of considered data is listed with/without bias correction with/without T700 criterion. Numbers should be listed per station in order to quantify bias variation on the regional scale.**

A new Table has been added to the paper and also below (Table 1).

- **What ACOS data are actually shown and evaluated in Fig. 13 and Fig. 14? Is this individual measurements or daily averages or 10-day averages?**

It is the 10-day averages. This has been clarified in the figure captions.

- **On what grounds do the authors conclude on a "time-dependent difference" (p.20915, l.1) between ACOS-GOSAT and TCCON? This pattern does not seem obvious from Fig. 13.**

When plotting the difference between the Lamont TCCON and ACOS-GOSAT time series over Lamont, there are several step-changes over time. It is not clear what these step-changes correspond to, but they cause an apparent drift in time of the bias between ACOS-GOSAT and TCCON data. These step-changes have also been seen in the RemoteC data (Butz et al., 2011) by Hiroshi Suto (JAXA, personal communication) and so it is not likely an algorithm effect. There are several potential culprits, including a time-dependent change in the spectral shifts caused by a frequency shift of the on-board metrology laser, a time-dependent calibration parameter that is not properly determined, or a change in the nonlinear response of the O_2 A-band with time. We have been in touch with the scientists at JAXA to try to find a solution.

- **Likewise, I tend to disagree that "the assumed linear regression reduces the agreement" (p.20915, l. 6) in the Sodankyla time series.**

The new table better illustrates the effect and the Referee is correct that it is not obvious that the Sodankyla agreement worsens, though its variance decreases less than most of the lower latitude sites. It is clear that the Eureka comparison worsens, however.

- **How does the T700 criterion perform in comparison to relaxed geographic criteria, eg. 5°radius around the TCCON stations?**

Using a relaxed ($\pm 5°$) box around a TCCON station gives a worse slope (further from 1) than the tighter geographic constraint. (0.86 ± 0.02 ppm/ppm) This has been noted in the text.

- **Would it be possible to quantify the "noise" in the ACOS-GOSAT data to support the discussion on seasonal cycle amplitudes (p. 20915, l.13...)?**

The mean standard deviation for August 2009 (2010) is 2.5 ppm (2.9 ppm) and for December 2009 (2010), it is 3.7 ppm (3.4 ppm). These numbers have been added to the text.

Minor comments

p.20901, l.2 (due to my comment in the quick review): the method by applying the method → the method by applying it

Done.

p.20901, l.26: There are recent GOSAT validation studies to be referenced here and possibly in other places of the manuscript: Butz et al., 2011, Parker et al., 2011. The authors should consider to discuss their results with respect to these studies, not only with respect to Morino et al., 2011.

A reference to Butz et al. and Parker et al. have been added to the introduction, and a paragraph has been added to the discussion section comparing Butz et al. and Morino et al. with the current work. (Parker et al. only discuss CH_4.)

Appendix A: Figure references in the text are misleading: Fig. 1 → Fig. A1 ,. . .

This has been fixed.

Equations A8 and A9 have been removed.

These equations complete the mathematics, and although not applied in this analysis, could be useful in the future, so we would prefer to leave those in the appendix.

Done. And the caption has been updated accordingly.

Done.

Response to Peter Rayner, Referee #2

The intention of this paper was to present a method of identifying bias for satellite X_{CO_2} data by using the "clean" southern hemisphere. The application to the ACOS-GOSAT data was meant to be a test of

this method. We have rearranged the paper to put the description of the correction method first, and a description of its application to the ACOS-GOSAT data later. We hope this makes the intention of the paper clearer.

Finding corrections that are more or less important is difficult, and we restricted ourselves to parameters which we know should not systematically affect southern hemisphere ΔX_{CO_2} (albedo, airmass, spectral fits, etc.). These parameters were fitted and their relative effects on the ΔX_{CO_2} were assessed. The most important were retained (blended albedo, ΔP, airmass and signal o2). These are not orthogonal parameters (Table 2 and Figure 5), and some are related nonlinearly (e.g., signal_o2 and airmass), but they can represent different properties of the atmosphere or retrieval. It is possible that they do "manifest different faces of a single underlying problem," and we are undertaking exercises to disentangle the parameters. The simulated data will be of great importance for this, because it is not affected by instrument or spectroscopic errors.

A paragraph similar to the one above has been added to the text, and Fig. 5 has been added to the supplementary material.

There is also a disturbing result noted by the authors which warrants more comment. The regression slope between the corrected ACOS/GOSAT and TCCON data seems far enough from 1 to suggest serious systematic problems in one or both measurements. Presumably the validation of the TCCON measurements by direct profile measurement rules out TCCON so something is happening to the ACOS/GOSAT estimates either as a function of time or of CO2. given that CO2 is increasing with time this isn't trivial to tease out but the seasonal cycle should make this possible. If it is a drift with time it would reward some more digging.

When plotting the difference between the Lamont TCCON and ACOS-GOSAT time series over Lamont, there are several step-changes over time that do not appear to be related to X_{CO_2}. It is not clear what these step-changes correspond to, but they cause an apparent drift in time of the bias between ACOS-GOSAT and TCCON data. These step-changes have also been seen in the RemoteC data (Butz et al., 2011) by Hiroshi Suto (JAXA, personal communication) and so it is not likely an algorithm effect. There are several potential culprits, including a time-dependent change in the spectral shifts caused by a frequency shift of the on-board metrology laser, a time-dependent calibration parameter that is not properly determined, or a change in the nonlinear response of the O_2 A-band with time. We have been in touch with the scientists at JAXA to try to find a solution.

Response to Ilse Aben, Editor

Please address the individual reviewers' comments in your reply and subsequently in your revised manuscript. I believe they are all valuable comments.

We have addressed each reviewer's comments individually above.

In addition to the reviewers comments I have the following comments :
Major : you should put your work and the GOSAT results obtained in the context of already published GOSAT results (a.o. Morino et al, 2011, Butz et al, 2011)

A new paragraph has been added to the discussion which puts our results into the context of the Morino et al. and Butz et al. papers.

Minor :
line 14, p 20902 indentified → identified

Done.

line 21, p 20904 is it possible to say something more about what exactly is done for the pre-screening for clouds ? (or can a reference be made ?)

References to Taylor et al. (2011) and O'Dell et al. (2011) have been added which describe the cloud screening in detail.

line 27, p 20905 : anomalously low values → anomalously low XCO2 values

Done.

Line 27, p 20905, what is the underlying problem over snow/ice-covered land ? Is it discrimination with clouds, low signal, ... ?

Text has been added to describe this more fully:
"A fraction of the ACOS-GOSAT retrievals exhibit anomalous X_{CO_2} values due to the presence of the higher-albedo snow- and ice-covered land surfaces, which are indistinguishable from low-lying cloud or aerosol in the current version of the algorithm."

line 7, p. 20908 : mean ratio or mean difference ?

It is the ratio, and it's corrected by division.

line 28, p 20910 : outside the simulator, ... bit strange formulation. maybe you can improve. In addition to what can be simulated/tested with the simulator, there are additional known ...

Done.

Fig.3 please add in caption which period data is used so we get a feeling how much data this is (in terms of time and not only in counts).

Done.

Fig. 4 please add that measurements were over the Pacific Ocean in the caption.

Done.

Fig. 7 you really mean adjusted data here ? Maybe unclear to me what adjusted means here. Also mention units where appropriate.

The caption has been rewritten to make it clearer.

Fig. 11 are these really 2K bins ? looks more like 3K or so

This has been fixed.

Fig. 12 are these coincidence criteria or areas that fulfill the coincidence criteria ? (1st sentence) What do you mean with 'would be restricted' here ? (is that not 'are restricted' ?)

Yes, they are areas that fulfill the coincidence criteria. The caption has been reworded to explain this.

References

Butz, A., Guerlet, S., Hasekamp, O., Schepers, D., Galli, A., Aben, I., Frankenberg, C., Hartmann, J.-M., Tran, H., Kuze, A., Keppel-Aleks, G., Toon, G.,Wunch, D.,Wennberg, P., Deutscher, N., Griffith, D.,Macatangay, R., Messerschmidt, J., Notholt, J., and Warneke, T.: Toward accurate CO_2 and CH_4 observations from GOSAT, Geophys. Res. Lett., 38, L14812, 2011.

Morino, I., Uchino, O., Inoue, M., Yoshida, Y., Yokota, T., Wennberg, P. O., Toon, G. C., Wunch, D., Roehl, C. M., Notholt, J., Warneke, T., Messerschmidt, J., Griffith, D. W. T., Deutscher, N. M., Sherlock, V., Connor, B., Robinson, J., Sussmann, R., and Rettinger, M.: Preliminary validation of column-averaged volume mixing ratios of carbon dioxide and methane retrieved from GOSAT short-wavelength infrared spectra, Atmos. Meas. Tech., 4, 1061–1076, 2011.

O'Dell, C. W., Connor, B., Bösch, H., O'Brien, D., Frankenberg, C., Castano, R., Christi, M., Crisp, D., Eldering, A., Fisher, B., Gunson, M., McDuffie, J., Miller, C. E., Natraj, V., Oyafuso, F., Polonsky, I., Smyth, M., Taylor, T., Toon, G. C., Wennberg, P. O., and Wunch, D.: The ACOS CO_2 retrieval algorithm – Part 1: Description and validation against synthetic observations, Atmos. Meas. Tech. Discussions, 4, 5, 6097–6158, 2011.

Parker, R., Boesch, H., Cogan, A., Fraser, A., Feng, L., Palmer, P.I., Messerschmidt, J., Deutscher, N., Griffith, D.W.T., Notholt, J. ,Wennberg, P.O., and Wunch, D.: Methane observations from the Greenhouse Gases Observing SATellite: Comparison to ground-based TCCON data and model calculations, Geophysical Research Letters, 38, L15807, 2011.

Suto, H., Frankenberg, C., Crisp, D., and Kuze, A.: Characterization and correction of non-linearity effect on oxygen spectra of TANSO-FTS onboard GOSAT, AGU Fall Meeting, A33C-0210, 2011.

Taylor, T. E., O'Dell, C. W., O'Brien, D. M., Kikuchi, N., Yokota, T., Nakajima, T. Y., Ishida, H., Crisp, D., and Nakajima, T.: Comparison of Cloud-Screening Methods Applied to GOSAT Near-Infrared Spectra, IEEE Transactions on Geoscience and Remote Sensing, 99, 1–15, 2011.

Table 1: This table presents the results of three comparisons between northern hemisphere TCCON X_{CO_2} and the ACOS-GOSAT X_{CO_2}. Coincidence between the two datasets are determined either by the T_{700} constraint (ACOS-GOSAT soundings within $\pm 2K$, $\pm 10°$ latitude by $\pm 30°$ longitude and 10 days of a TCCON measurement), or a geographic constraint ($\pm 0.5°$ latitude by $\pm 1.5°$ longitude). Biases are computed by subtracting the TCCON X_{CO_2} from the ACOS-GOSAT X_{CO_2}. The 'No Modification' fields include the 0.982 bias correction, but not the correction described by equation 4. The 'Modified' fields have had equation 4 applied. The 'ACOS σ' field lists the mean standard deviation of the ACOS-GOSAT data for a particular location. The column labeled 'N_{med}' is the median number of ACOS-GOSAT spectra involved in a single coincidence for a particular site. The columns labeled 'N_{tot}' are the total numbers of ACOS-GOSAT spectra involved with the comparison for all times at that site. The averages in parentheses are weighted by N_{tot}. There are no ACOS-GOSAT data coincident with the Eureka site using the geographic constraint.

	T$_{700}$ Coincidence						Geographic Coincidence		
	No Modification		Modified by Equation 4				Modified by Equation 4		
	Bias	ACOS σ	Bias	ACOS σ	N$_{med}$	N$_{tot}$	Bias	ACOS σ	N$_{tot}$
	ppm	ppm	ppm	ppm			ppm	ppm	
Bialystok	1.19	3.05	0.70	2.70	10	700	0.46	2.68	19
Eureka	1.57	2.23	4.71	2.32	12	63	—	—	0
Garmisch	1.32	2.69	0.78	2.52	11	765	6.14	3.57	9
Lamont	-0.49	2.25	-0.62	1.77	28	2269	-0.55	1.83	171
Orleans	0.39	2.59	0.12	2.26	9	327	1.08	2.15	7
ParkFalls	0.97	3.11	0.53	2.70	14	791	1.01	3.08	81
Sodankyla	3.12	3.98	2.24	3.78	6	178	-0.62	3.44	8
Tsukuba	1.62	1.56	1.51	1.50	2	63	1.50	2.38	57
Average	1.21 (0.46)	2.68 (2.63)	1.25 (0.18)	2.44 (2.25)	11.5	644.5	1.29 (0.40)	2.73 (2.34)	44

Table 2: Fit results between the four covariates.

| Parameter	Fit Result	Blended Albedo	ΔP (hPa)	Airmass	Signal O$_2$ (Wcm^{-2}sr^{-1}(cm^{-1})$^{-1}$)
Blended Albedo	Slope	1.00	-3.85	0.65	0.99
	Intercept	0.00	12.09	2.33	3.10
	r^2	1.00	-0.09	0.54	-0.07
ΔP (hPa)	Slope	-0.01	1.00	-0.00	-0.05
	Intercept	0.37	0.00	2.50	3.94
	r^2	0.47	1.00	0.56	-0.07
Airmass	Slope	0.03	-0.13	1.00	-1.29
	Intercept	0.18	11.36	0.00	6.73
	r^2	0.41	-0.15	1.00	0.38
Signal O$_2$ (Wcm^{-2}sr^{-1}(cm^{-1})$^{-1}$)	Slope	0.03	-0.33	-0.23	1.00
	Intercept	0.16	12.13	3.29	0.00
	r^2	0.48	-0.13	0.78	1.00
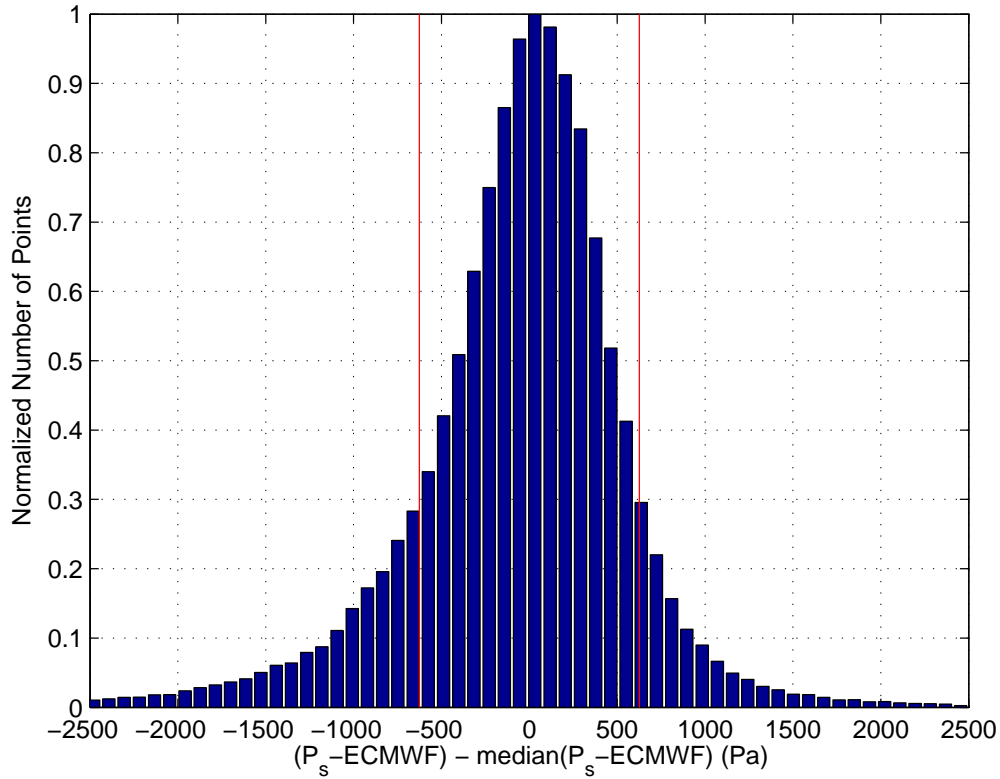
Figure 1: The surface pressure distribution about the ECMWF prior value in Pa. The red vertical lines are the locations of the filter bounds.
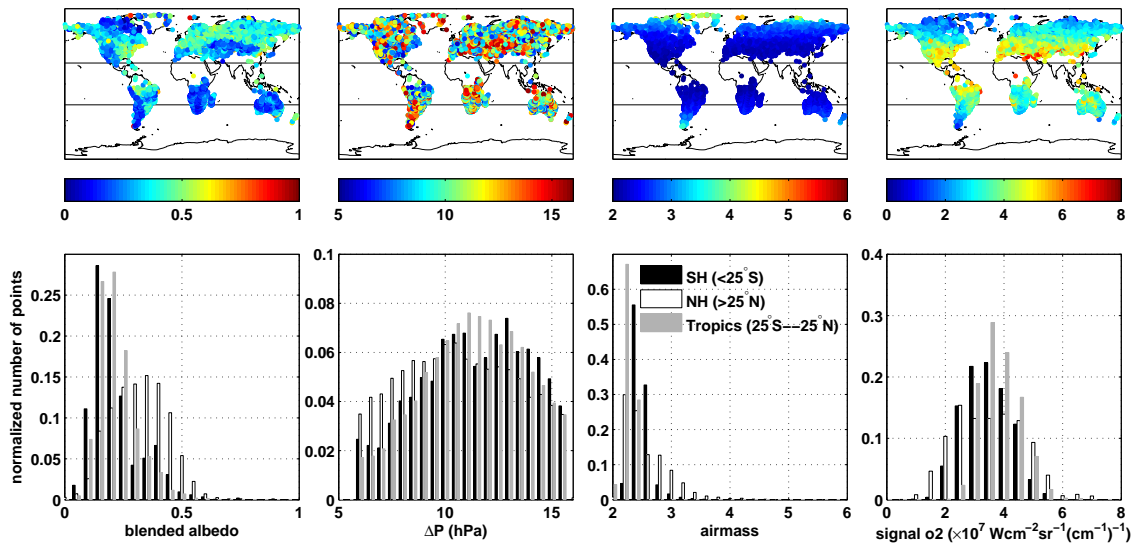

Figure 2: A map and histogram of the parameters used in equation 4 in August. The horizontal black lines on the maps denote the 25°N and 25°S latitudes.
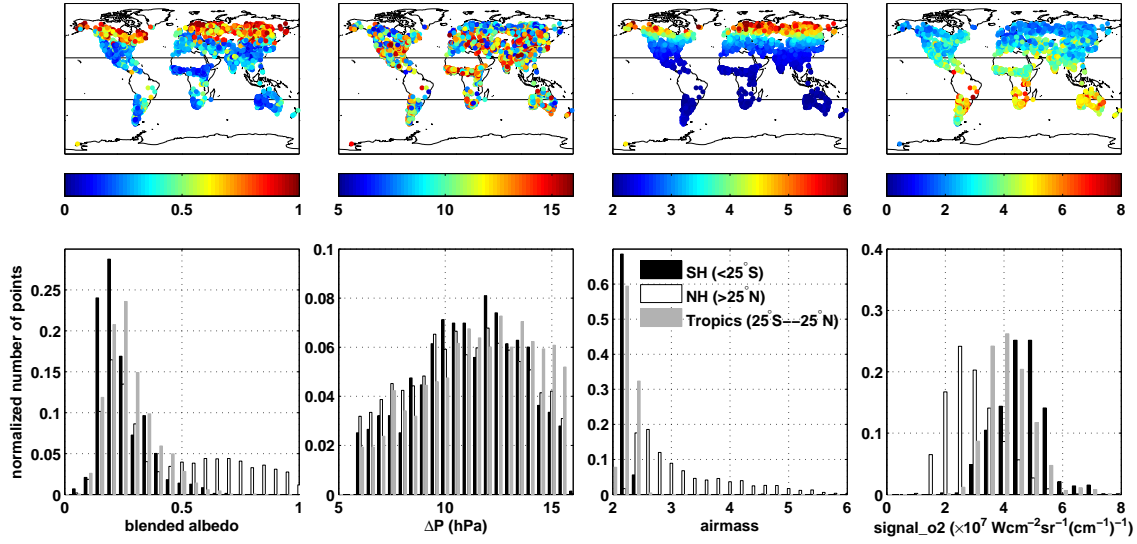
Figure 3: A map and histogram of the parameters used in equation 4 in February. The horizontal black lines on the maps denote the 25°N and 25°S latitudes.
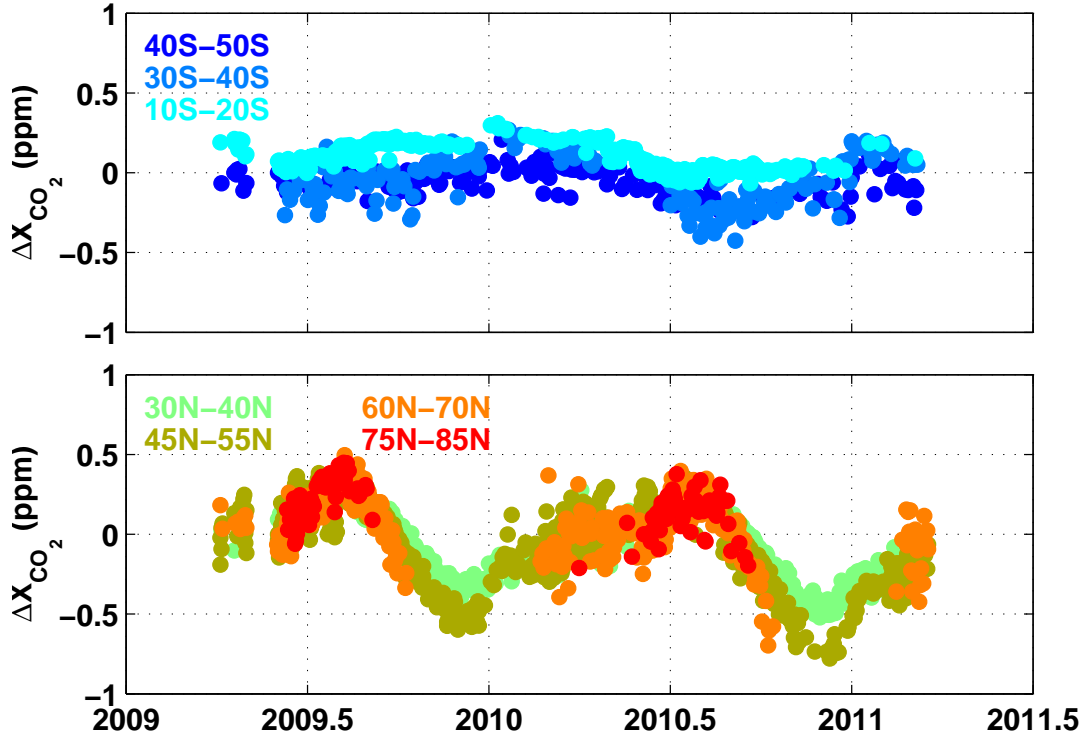

Figure 4: The latitude-dependence of the difference between using the TCCON *a priori* profile and the ACOS *a priori* profile (TCCON−ACOS plotted here) on the ACOS-GOSAT retrievals (e.g., $\hat{c}_1' - \hat{c}_1$ from equation A10). The latitudes are binned around TCCON sites.
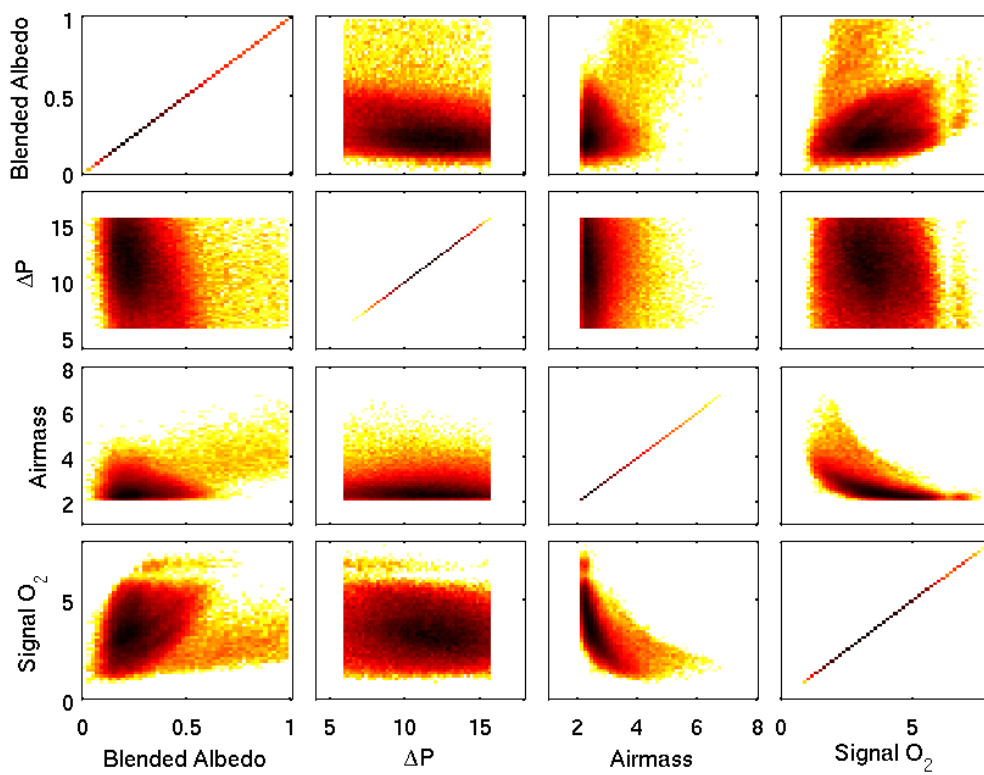
Figure 5: A heat map of the four covariates, illustrating their orthogonality to each other. Darker colours represent denser data.