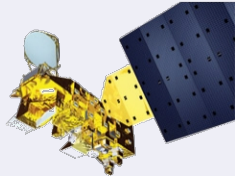
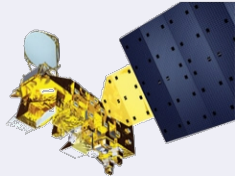


Introducing the AIRS V6 Tropospheric CO2 Product

Edward Olsen, Stephen Licata
Jet Propulsion Laboratory, California Institute of Technology

NASA Sounder Science Team Meeting
12-14 September 2016

Outline



- **AIRS V6 CO2 Product**
  - **3-Stage Retrieval/Enhanced QC**
  - **Level 2 Content (Granule Size: V6=344 KB; V5=320 KB)**
  - **Level 3 Content**
- **V5 vs V6 for 2015 Jan/Apr/Jul/Oct**
  - **Zonal**
  - **Global**
- **Validation against airborne in situ measurements**
  - **Extending CO2 profile above maximum altitude of measurement with CarbonTracker model**
  - **Comparison of V5 and V6 validation against HIPPO campaigns (2009-2011) as function of season and latitude**
    - **Average of AIRS retrievals collocated within ±12 hr and 200 km**
- **Comparison with OCO-2**
  - **2015 July Global Distribution**
  - **2015 August and October Zonal Variation**
- **Summary**
- **Publications using AIRS V5 CO2**

3-Stage CO2 Retrieval
Requires Solution Stable Within ± 2ppm for ± 5ppm Perturbation of FG
(Example: 1 Jan/Apr/Jul/Oct 2007)

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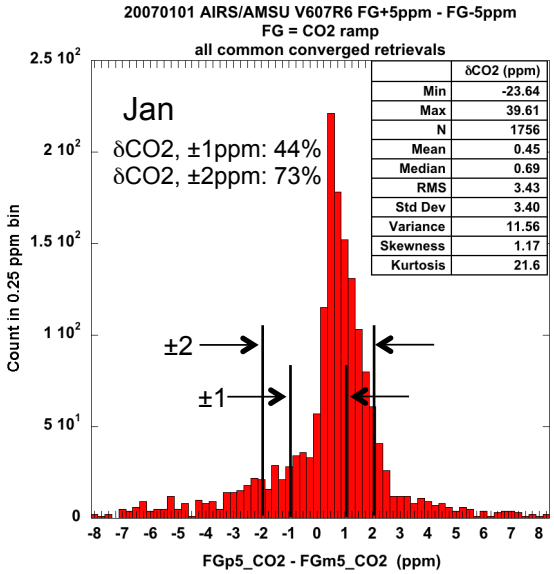
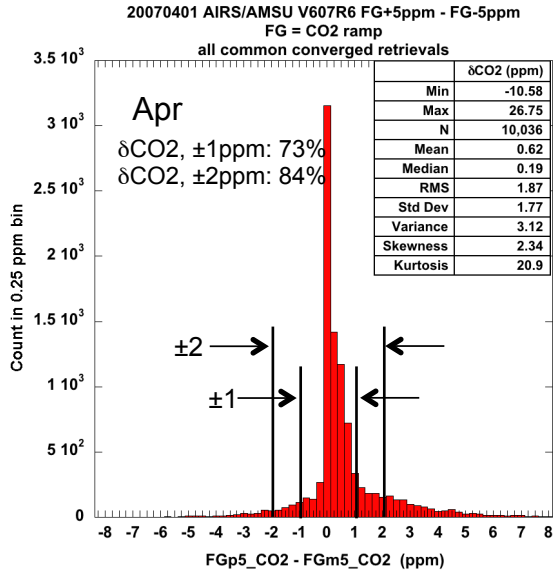
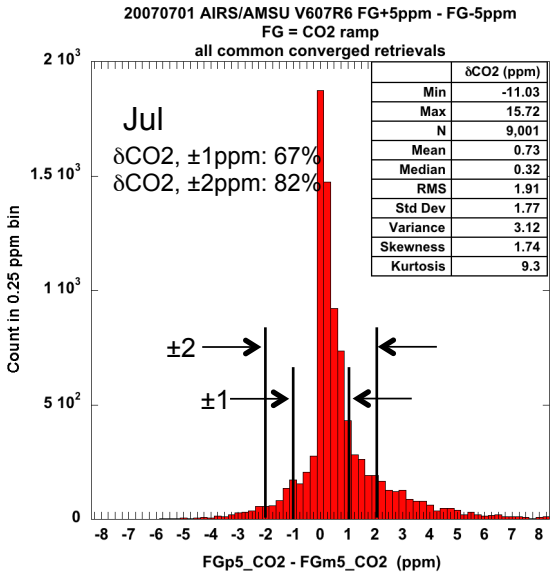
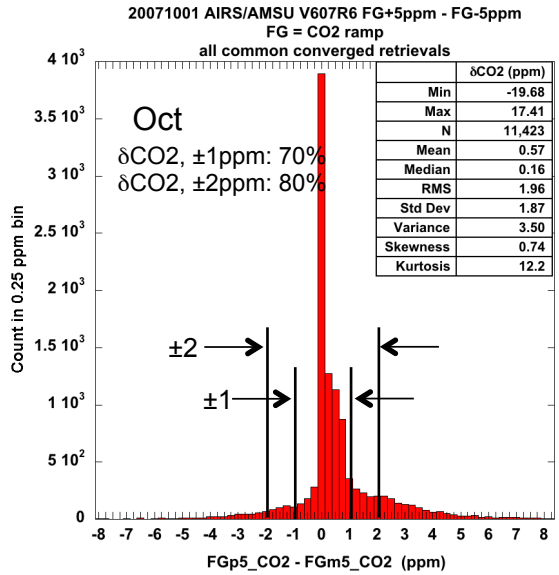




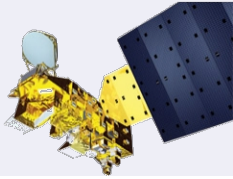




Initial Test of Stability of VPD Solution Against Perturbation of FG by ±5 ppm

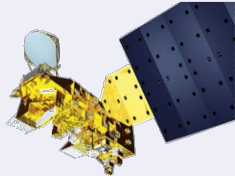
- Retrievals consistent within ±1 ppm for 10 ppm range of FG indicate their solutions are strongly constrained by radiances. Yield of retrievals satisfying this criterion is 44% to 70% of total yield.
- Retrievals consistent within ± 2ppm indicate their solutions are acceptably constrained by radiances but will be flagged. Yield of retrievals falling between ±1ppm and ±2ppm ranges between 10% to 29% of total yield.
- Solutions that move with FG by more than 20% of perturbation are not well constrained by radiances and are candidates for rejection. Yield of retrievals falling outside of ±2ppm ranges between 16% and 27% of total yield.
- Solutions disagreeing by more than perturbation of FG indicate runaways, i.e. solutions seeking adjacent local minima. These are placed in L2 support product.

V6 3-Stage Retrieval Enhanced QC



- At least 3 of 4 AIRS L2 physical product retrievals adjacent in a 2x2 array must satisfy these criteria for a CO2 retrieval to be attempted for that cluster :
  - PGood ≥ 700 hPa
  - PTropopause_QC < 2
- In each of the 3 stages, at least 3 of the retrievals in the 2x2 array must survive the iterative retrieval process
  - Stage 1
    - Shift the first guess CO2 by -5 ppm, execute full retrieval, pass survivors to Stage 2
  - Stage 2
    - Shift the first guess CO2 by +5 ppm, execute full retrieval, pass survivors to Stage 3
  - Stage 3 (processes only the survivors of the first two stages)
    - Assume the first guess CO2, execute full retrieval
    - Calculate Averaging Kernels for survivors
- QC Filtering – if QC fail flag is set in any test, place Stage 3 retrieval in Support Product
  - If ABS(CO2_stage1-CO2_stage2) > 2 ppm, set QC fail flag
  - If CO2std > 2 ppm (among the surviving 3 or 4 physical retrieval footprints), set QC fail flag
  - If final solution resulted in a perturbation shift to original T or O3 profiles that exceed limits (0.1% and 50% respectively), set QC fail flag
  - If the AK fails any one of a series of QC tests, set QC fail flag
    - Significant negative portion above 850 hPa (magnitude > 5% of total integrated AK)
    - Significant secondary peak detected (magnitude >10% of main peak)
    - Pressure of AK peak sensitivity falls above tropopause
    - Integrated AK above the tropopause exceeds 55%
      (important for polar regions, where tropopause altitude is depressed)

AIRS V6 CO2 Level 2 Product

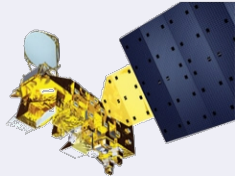


- **Resolution**
  - 100 km x 100 km at nadir (2x2 array of AMSU footprints)
- **Content (L2 Standard and L2 Support are identical in format)**
  - Separation of retrievals between L2 Standard and L2 Support will be determined by Pass/ Fail of the multi-stage QC in addition to CO2std < 2.0 ppmv
  - All contents are arrays dimensioned [15,22] except for AvgKern

Red Items are in V5

Level 2 Data Field	TYPE	DESCRIPTION	
N	INT	Cluster Index number (0-329)	
CFOV	INT	Cluster FOV index [0-1349]	
Nfp	INT	Number of footprints in cluster (3 or 4)(unitless)	QC Test requires Nfp > 2
UTC_Time	FLT	UT (hr, 0.0 -> 23.99)	
Year	INT	Year (i.e., 2009)	
Month	INT	Month (1 -> 12)	
Day	INT	Day of month (1 -> 31)	
Hour	INT	UT HR (0 -> 23)	
Minute	INT	UT MIN (0 -> 59)	
Seconds	FLT	UT SEC (0.0 -> 59.9999)	
Latitude	FLT	Latitude (deg)	
Longitude	FLT	Longitude (deg, +E/-W)	
Solzen	FLT	Solar zenith angle (deg, 0.0 -> 180.0)	
LandFrac	FLT	Fraction FOV that is land (0.0-1.0)	
TotCldFrc	FLT	Average total cloud fraction (0.0-1.0)	
TropCO2VMR	FLT	Retrieved CO2 (mole fraction)	
TropCO2std	FLT	CO2 error measure by spatial coherence QA (mole fraction)	
T700	FLT	Initial Tair at 700 hPa, from L2 Product (K)	
PGood	FLT	Pressure of PGood (minimum PGood of FOVs in cluster) (hPa)	QC Test requires PGood ≥ 700 hPa
PTrop	FLT	Tropopause pressure (hPa)	
TTrop	FLT	Tropopause temperature (K)	
PSurf	FLT	Surface pressure (hPa)	
TSurf	FLT	Surface temperature (K)	
QCfail	INT	QC test success (0=PASS; 1=FAIL)	QC Flag (will = 0 for standard product; = 1 for support product)
AKout	INT	Averaging kernel available? (0=No; 1=Yes)	in standard product, this will always be = 1; not so in support product
AKmax	FLT	Maximum value of AK (unitless)	Result of AK QC
AKpmax	FLT	Pressure at which maximum value of AK occurs (hPa)	Result of AK QC
AKpk2amp	FLT	Amplitude of secondary peak in AK if present (unitless)	Result of AK QC
AKpk2pres	FLT	Pressure at which secondary peak in AK occurs if present (hPa)	Result of AK QC
AKpk2flg	INT	Flag set to 2 if secondary peak is significant (unitless)	Result of AK QC
AKStrat	FLT	Integrated AK occurring above the tropopause (unitless)	Result of AK QC
AKTrop	FLT	Integrated AK occurring below the tropopause (unitless)	Result of AK QC
AKTotNeg	FLT	Integrated negative tail of AK above 850 hPa (unitless)	Result of AK QC
AKTotPos	FLT	Integrated positive AK over all levels (unitless)	Result of AK QC
AKdPTrop	FLT	AKpmax - PTrop (hPa)	Result of AK QC
AKdPSurf	FLT	PSurf - AKpmax (hPa)	Result of AK QC
dCO2	FLT	Difference between retrieved CO2 assuming FG+FGoffset and CO2 retrieval assuming FG-FGoffset (i.e. Stage 1 CO2 - Stage 2 CO2)(ppm)	QC Test
Talpha	FLT	Final Fractional VPD shift of temperature profile, alpha = (T-T0)/T0	QC Test
Qalpha	FLT	Final Fractional VPD shift of moisture profile, alpha = (Q-Q0)/Q0	QC Test
Oalpha	FLT	Final Fractional VPD shift of ozone profile, alpha = (Oz-Oz0)/Oz0	QC Test
AvgKern	FLT	Averaging kernel, ordered from TOA to surface at preslyrs Dimension [100,15,22] (unitless)	

AIRS V6 CO2 Level 3 Product

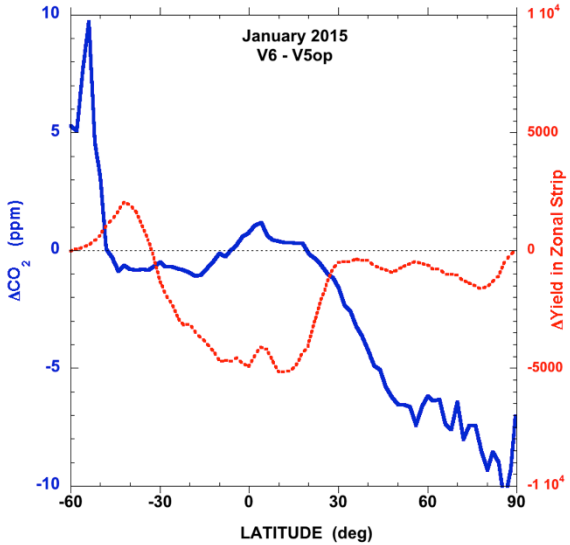


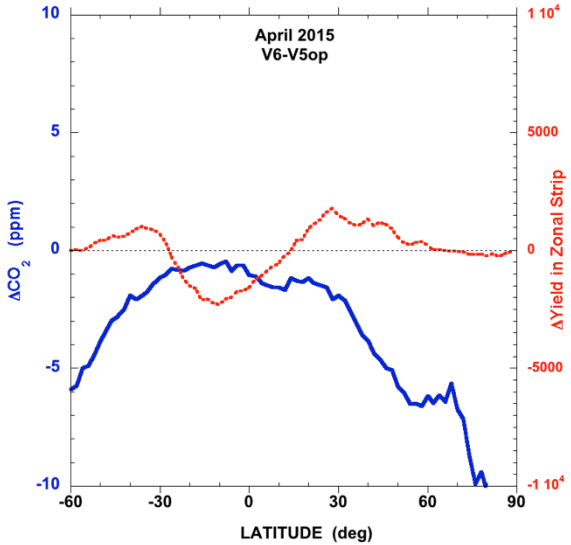
- **Resolution and Time Granularity**
  - **1° x 1° gridded (same as other AIRS L3 products; V5 was 2° x 2.5°)**
  - **1-day, 8-day, calendar monthly**
- **Content**
  - **Gridded averages derived from L2 Standard Product**
  - **All contents are arrays dimensioned [360,180]**

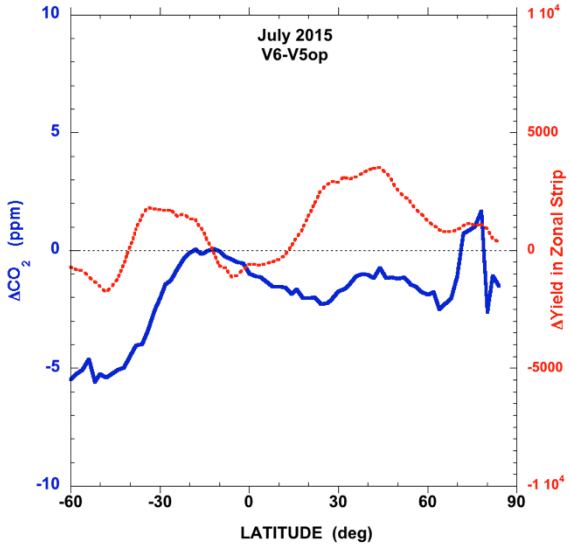
Red Items are in V5

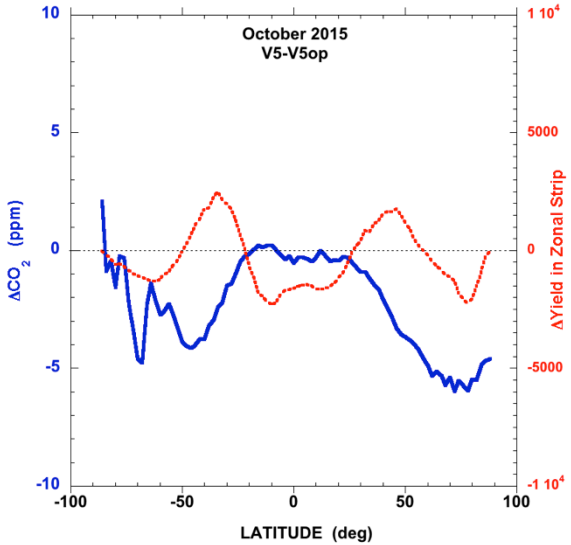
Level 3 Data Field	TYPE	DESCRIPTION (averages of L2 CO2 standard product in grid cell)
Latitude	FLT	Average Latitude (deg)
Longitude	FLT	Average Longitude (deg, +E/-W)
TropCO2VMR	FLT	Average of L2 CO2 retrievals in cell (mole fraction)
TropCO2std	FLT	Standard deviation of L2 CO2 retrievals in cell (mole fraction)
TropCO2cnt	INT	Number of L2 CO2 retrievals averaged in this grid cell
TotCldFrc	FLT	Average Total cloud fraction (0.0-1.0)
T700	FLT	Average Initial Tair at 700 hPa, (from L2 physical retrieval) (K)
PTrop	FLT	Average Tropopause pressure (hPa)
TTrop	FLT	Average Tropopause temperature (K)
PSurf	FLT	Average Surface pressure (hPa)
TSurf	FLT	Average Surface temperature (K)
AKmax	FLT	Average Maximum value of AK (unitless)
AKpmax	FLT	Average Pressure at which maximum value of AK occurs (hPa)
AKStrat	FLT	Average Integrated AK occurring above the tropopause (unitless)
AKTrop	FLT	Average Integrated AK occurring below the tropopause (unitless)

V6 - V5 Operational
Zonal Average δCO2 and δYield

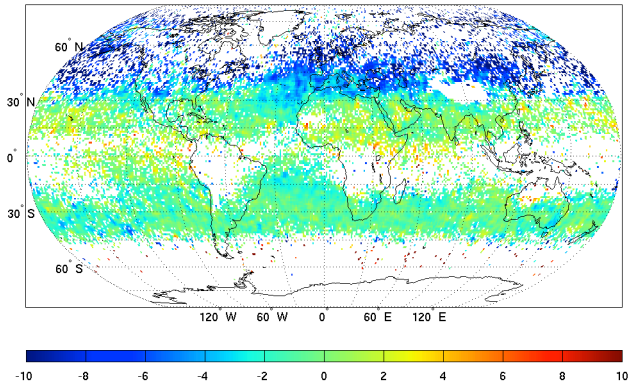




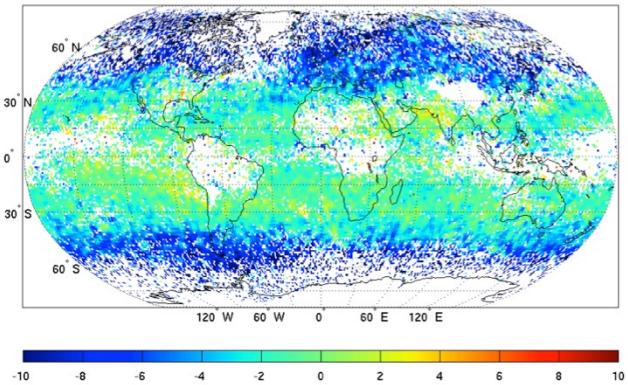




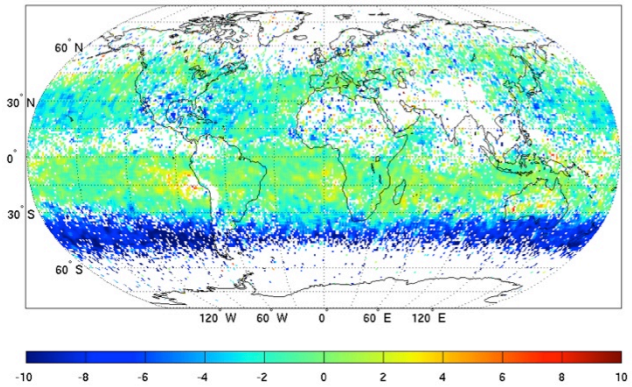
Smoothed V6 - V5Operational
January April July October 2015



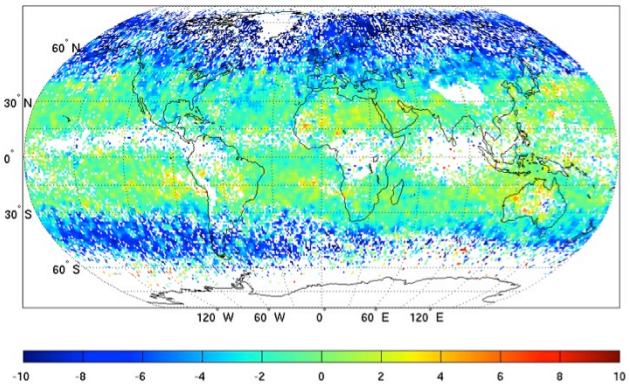
January 2015



April 2015



July 2015



October 2015

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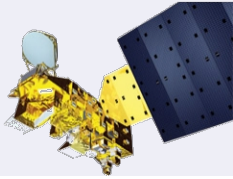
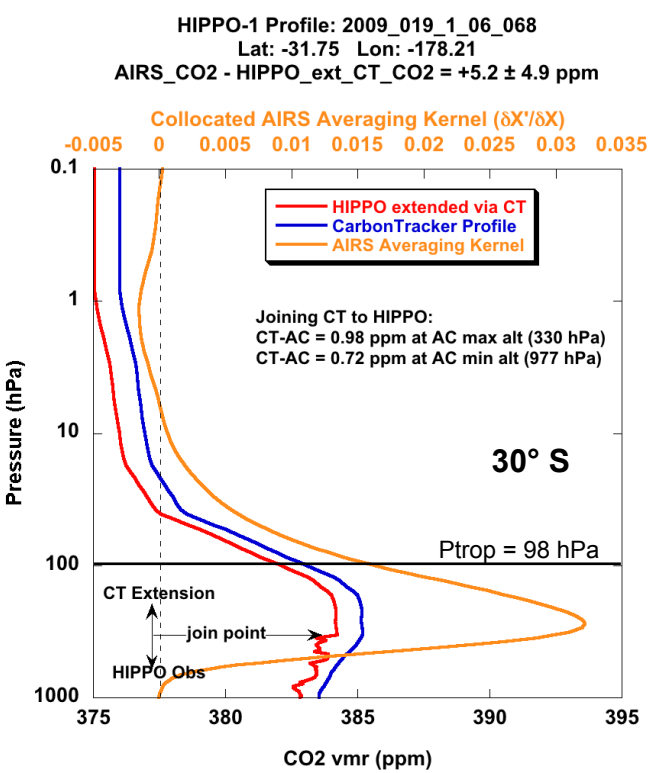
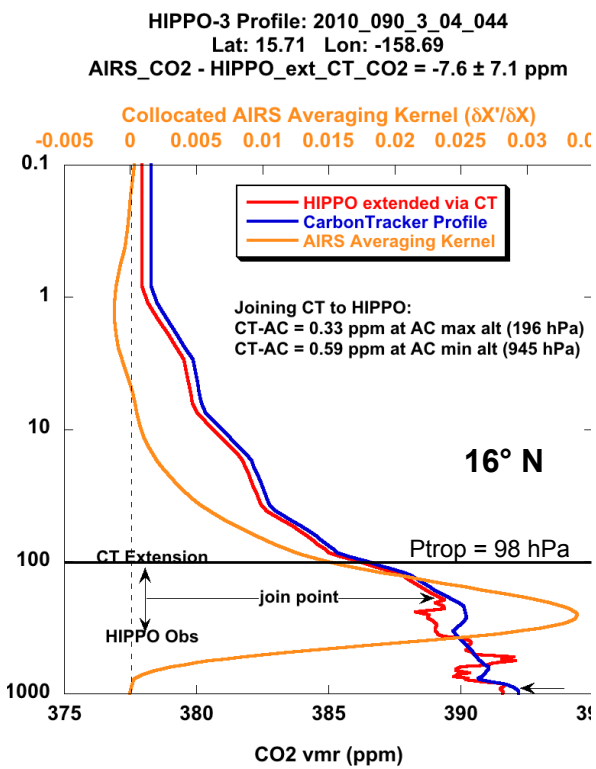
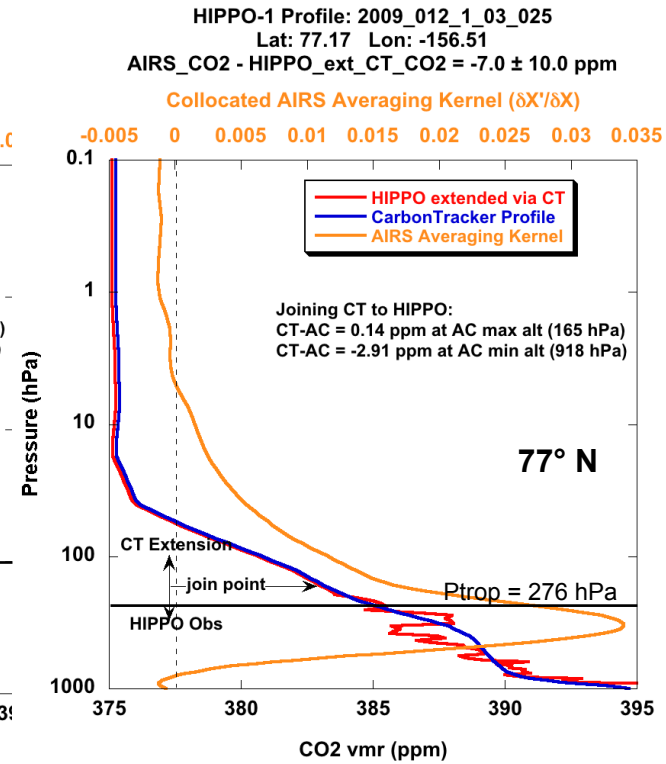
Example Aircraft Profile Extension via CarbonTracker for Validation of Collocated AIRS CO_2 Retrievals



Extending the *in situ* measurements to higher altitude via the CarbonTracker vertical transport model that assimilates low altitude and surface measurements allows the validation task to use aircraft measurements that do not span extent of column where AIRS is most sensitive to CO2







AIRS sensitivity to CO2 is shown by the Averaging Kernel profile (gold)
It peaks at ~ 400 hPa and AIRS retrievals represent the average CO2 in an atmospheric layer that is approximately 200 hPa thick. Thus it is a partial column sample of the CO2 concentration.

HIPPO data sets available at: http://hippo.ornl.gov/node/27

CarbonTracker data sets are available at:
ftp://aftp.cmdl.noaa.gov/products/carbontracker/co2/CT2013B and ftp://aftp.cmd./noaa.gov/products/carbontracker/co2/CT2015

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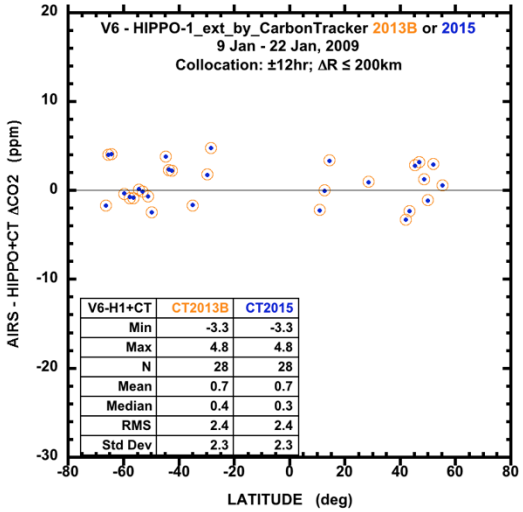
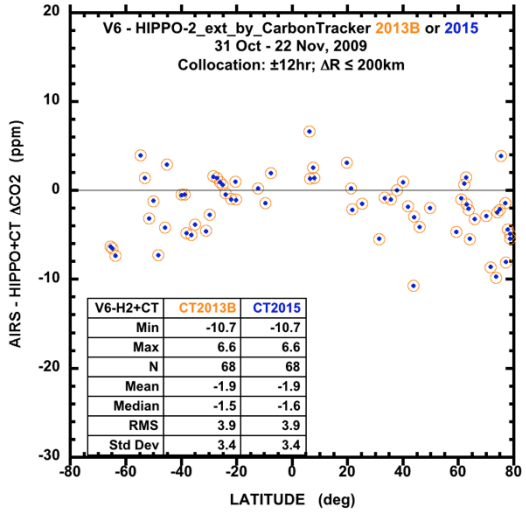
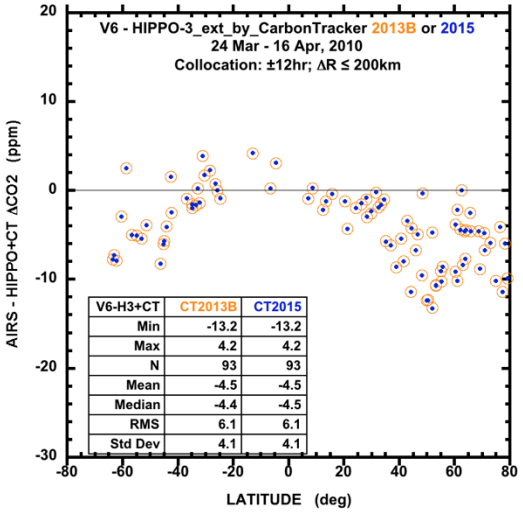
V6 vs HIPPO Extended to Higher Altitude via CarbonTracker 2013B and 2015



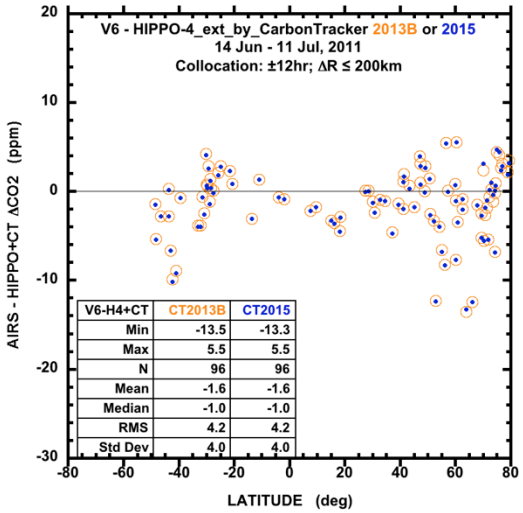
V6-H1+CT	CT2013B	CT2015
Min	-3.3	-3.3
Max	4.8	4.8
N	28	28
Mean	0.7	0.7
Median	0.4	0.3
RMS	2.4	2.4
Std Dev	2.3	2.3



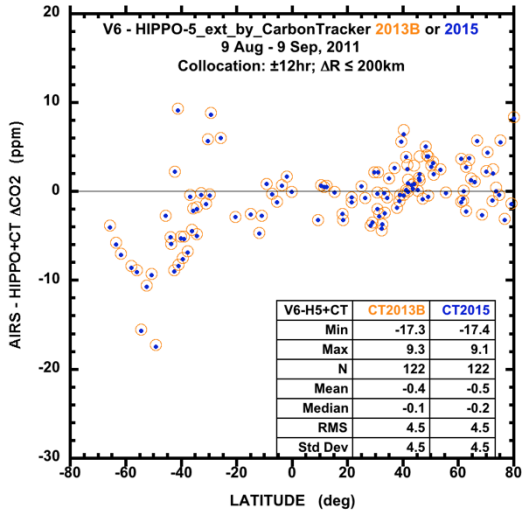
V6-H2+CT	CT2013B	CT2015
Min	-10.7	-10.7
Max	6.6	6.6
N	68	68
Mean	-1.9	-1.9
Median	-1.5	-1.6
RMS	3.9	3.9
Std Dev	3.4	3.4



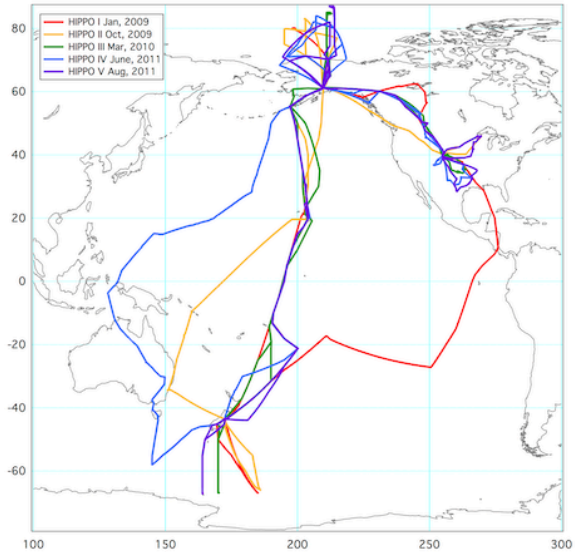
V6-H3+CT	CT2013B	CT2015
Min	-13.2	-13.2
Max	4.2	4.2
N	93	93
Mean	-4.5	-4.5
Median	-4.4	-4.5
RMS	6.1	6.1
Std Dev	4.1	4.1



V6-H4+CT	CT2013B	CT2015
Min	-13.5	-13.3
Max	5.5	5.5
N	96	96
Mean	-1.6	-1.6
Median	-1.0	-1.0
RMS	4.2	4.2
Std Dev	4.0	4.0



V6-H5+CT	CT2013B	CT2015
Min	-17.3	-17.4
Max	9.3	9.1
N	122	122
Mean	-0.4	-0.5
Median	-0.1	-0.2
RMS	4.5	4.5
Std Dev	4.5	4.5



No Discernable Difference Using CT2013B or CT2015

HIPPO data sets available at: http://hippo.ornl.gov/node/27

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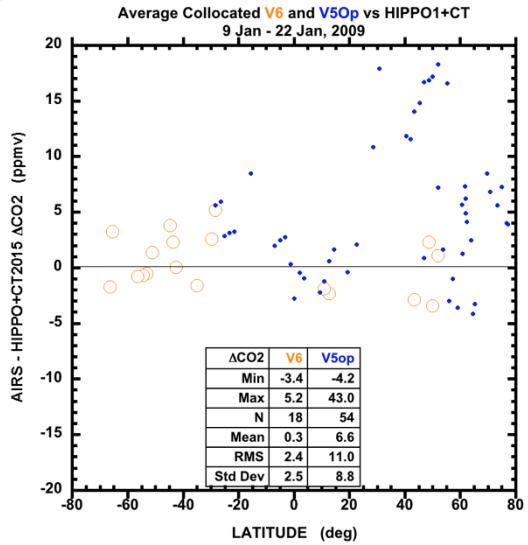
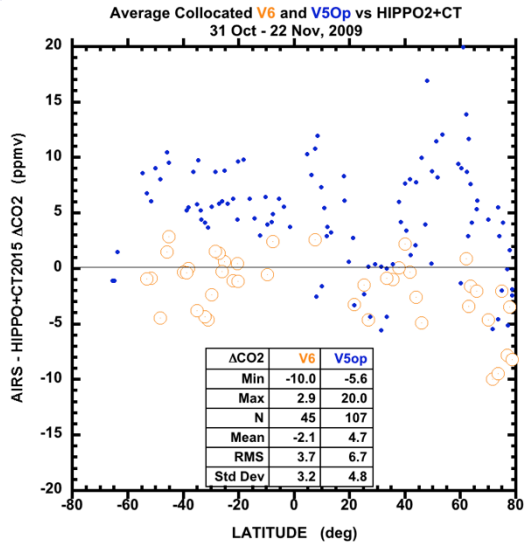
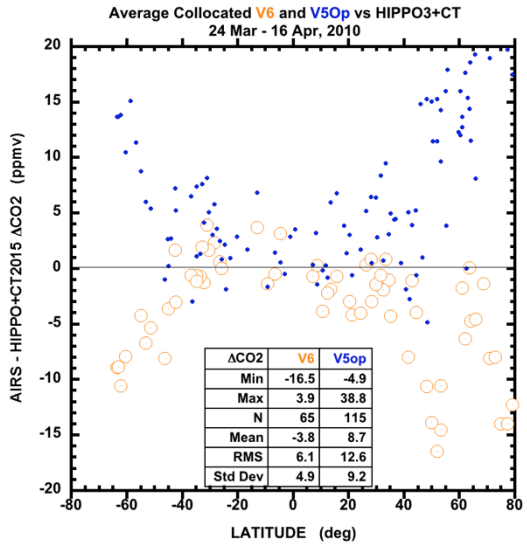
V6 and V5Op vs HIPPO Extended to Higher Altitude via CarbonTracker



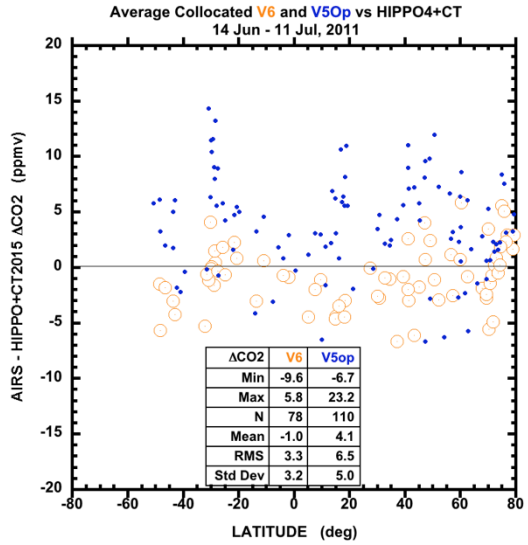
ΔCO2	V6	V5op
Min	-3.4	-4.2
Max	5.2	43.0
N	18	54
Mean	0.3	6.6
RMS	2.4	11.0
Std Dev	2.5	8.8



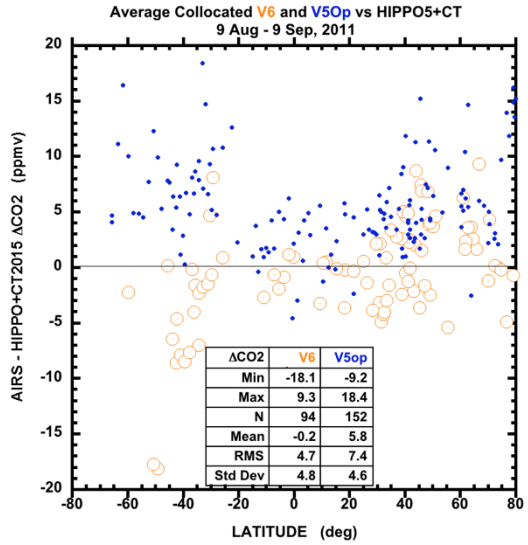
ΔCO2	V6	V5op
Min	-10.0	-5.6
Max	2.9	20.0
N	45	107
Mean	-2.1	4.7
RMS	3.7	6.7
Std Dev	3.2	4.8



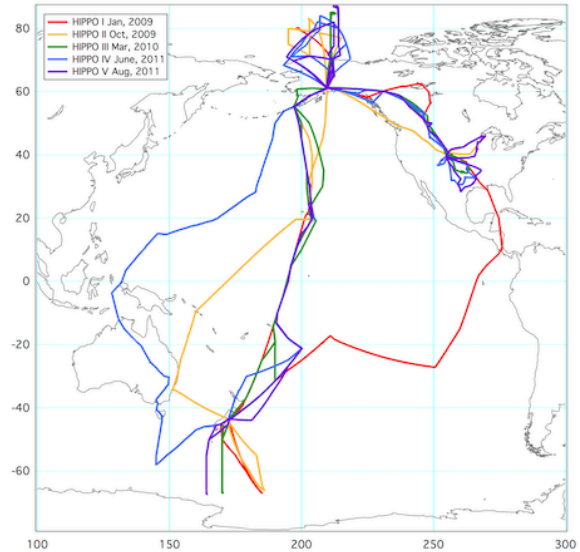
ΔCO2	V6	V5op
Min	-16.5	-4.9
Max	3.9	38.8
N	65	115
Mean	-3.8	8.7
RMS	6.1	12.6
Std Dev	4.9	9.2



ΔCO2	V6	V5op
Min	-9.6	-6.7
Max	5.8	23.2
N	78	110
Mean	-1.0	4.1
RMS	3.3	6.5
Std Dev	3.2	5.0



ΔCO2	V6	V5op
Min	-18.1	-9.2
Max	9.3	18.4
N	94	152
Mean	-0.2	5.8
RMS	4.7	7.4
Std Dev	4.8	4.6



Positive Bias and Outliers Mitigated in V6

HIPPO data sets available at: http://hippo.ornl.gov/node/27

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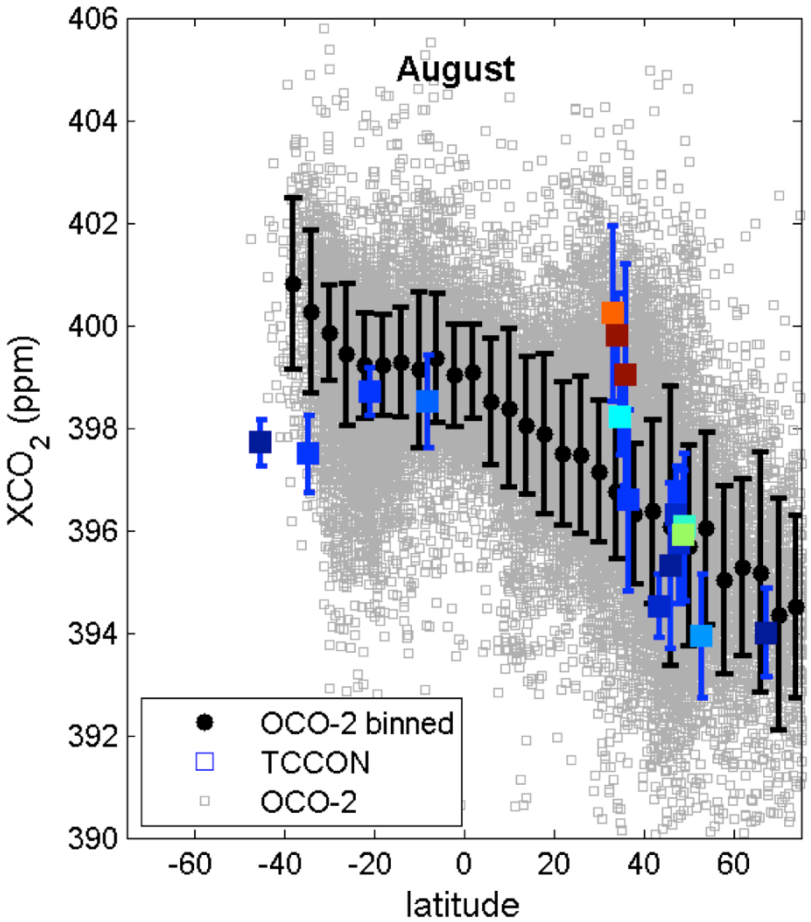
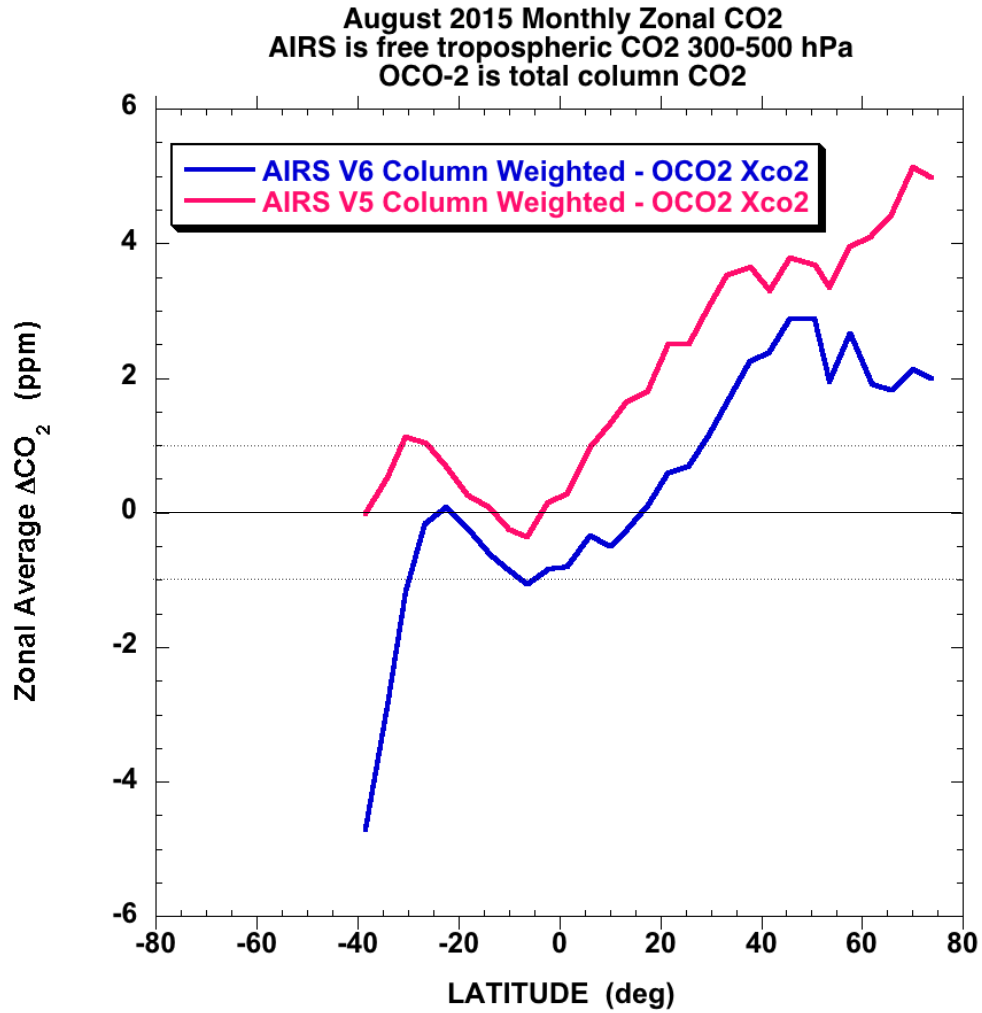
California Institute of Technology

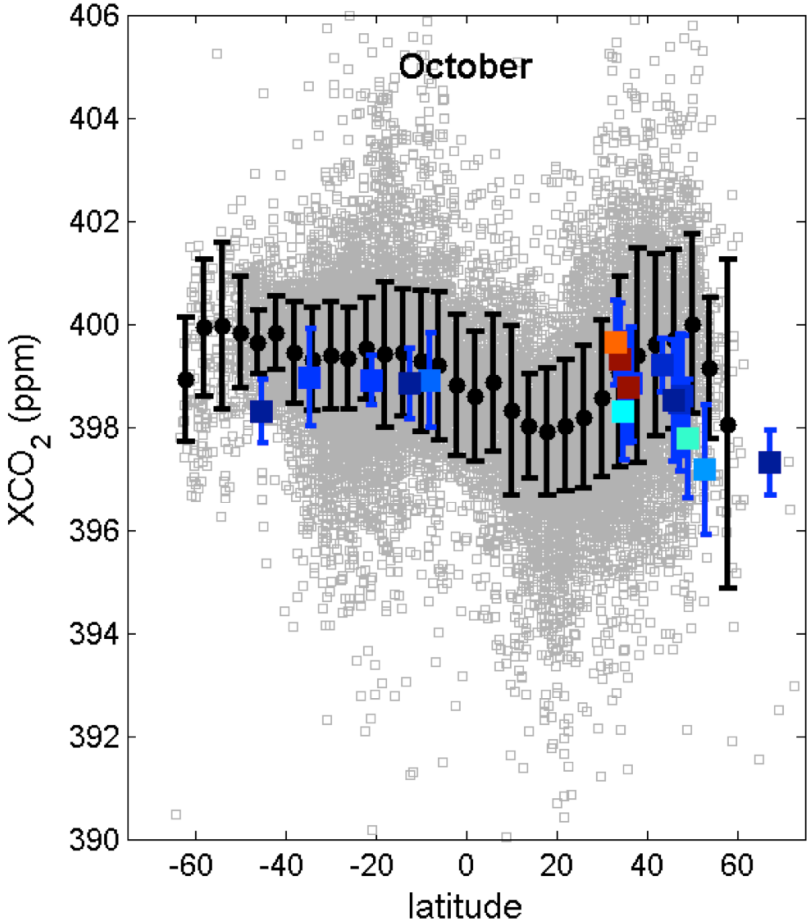
AIRS V6 and V5op vs OCO-2 August 2015 Zonal Variation

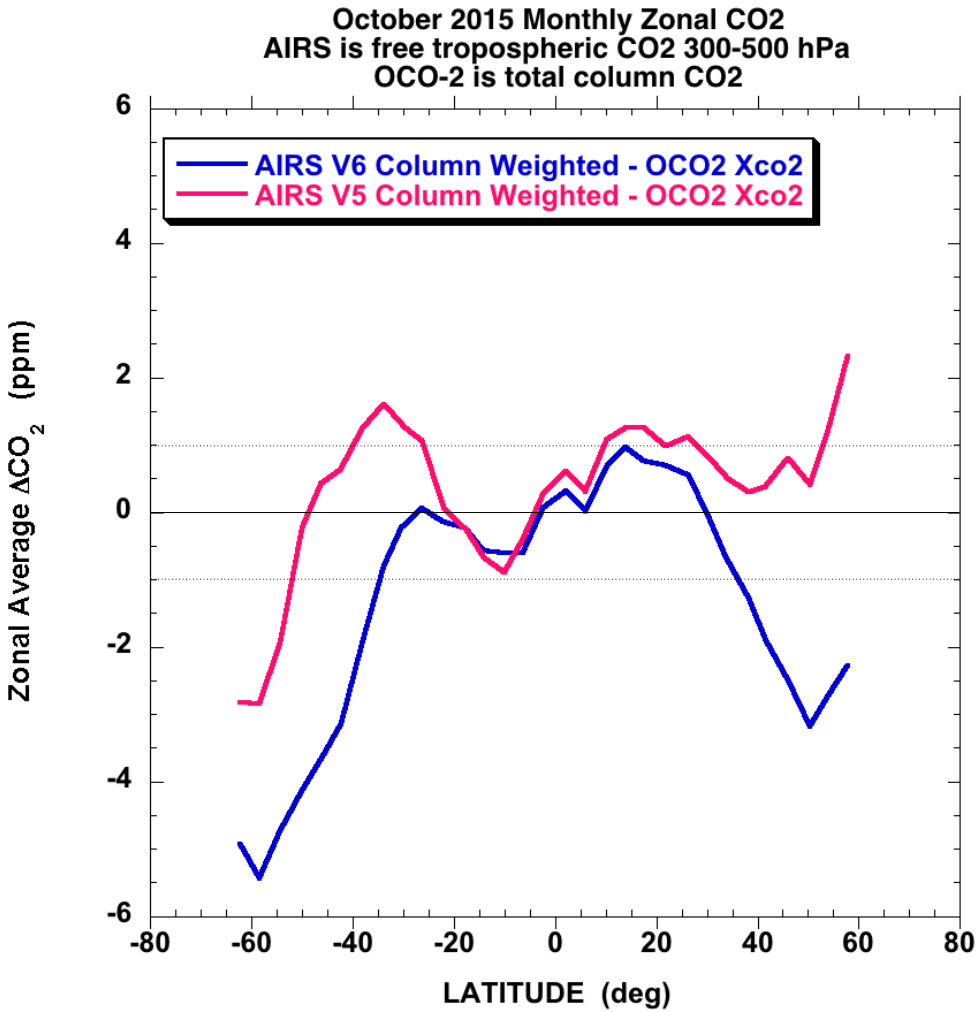




OCO-2 Xco2 from AMT discussion paper:
Wunch, D., Wennberg, P. O., Osterman, G., Fisher, B., Naylor, B., Roehl, C. M., O'Dell, C., Mandrake, L., Viatte, C., Griffith, D. W., Deutscher, N. M., Velazco, V. A., Notholt, J., Warneke, T., Petri, C., De Maziere, M., Sha, M. K., Sussmann, R., Rettinger, M., Pollard, D., Robinson, J., Morino, I., Uchino, O., Hase, F., Blumenstock, T., Kiel, M., Feist, D. G., Arnold, S. G., Strong, K., Mendonca, J., Kivi, R., Heikkinen, P., Iraci, L., Podolske, J., Hillyard, P. W., Kawakami, S., Dubey, M. K., Parker, H. A., Sepulveda, E., Rodriguez, O. E. G., Te, Y., Jeseck, P., Gunson, M. R., Crisp, D., and Eldering, A.: Comparisons of the Orbiting Carbon Observatory-2 (OCO-2) X_{CO2} measurements with TCCON, Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2016-227, in review, 2016.

AIRS V6 and V5op vs OCO-2 October 2015 Zonal Variation





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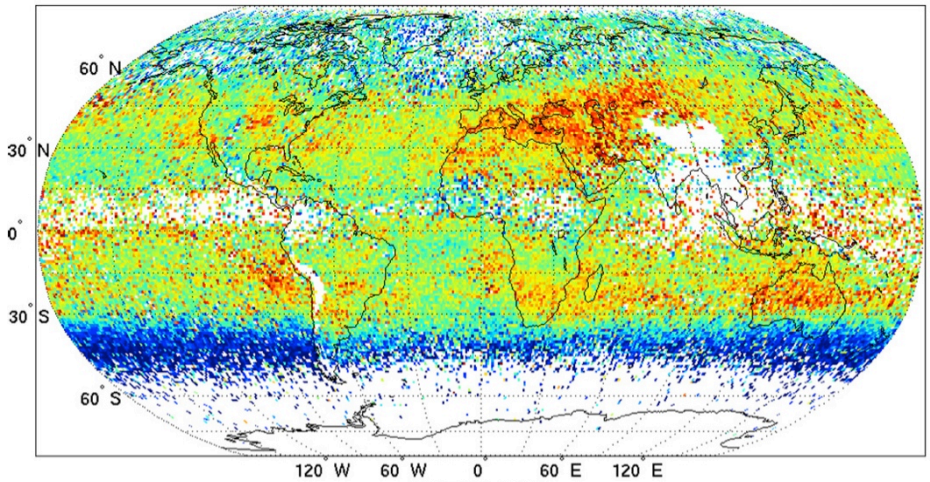
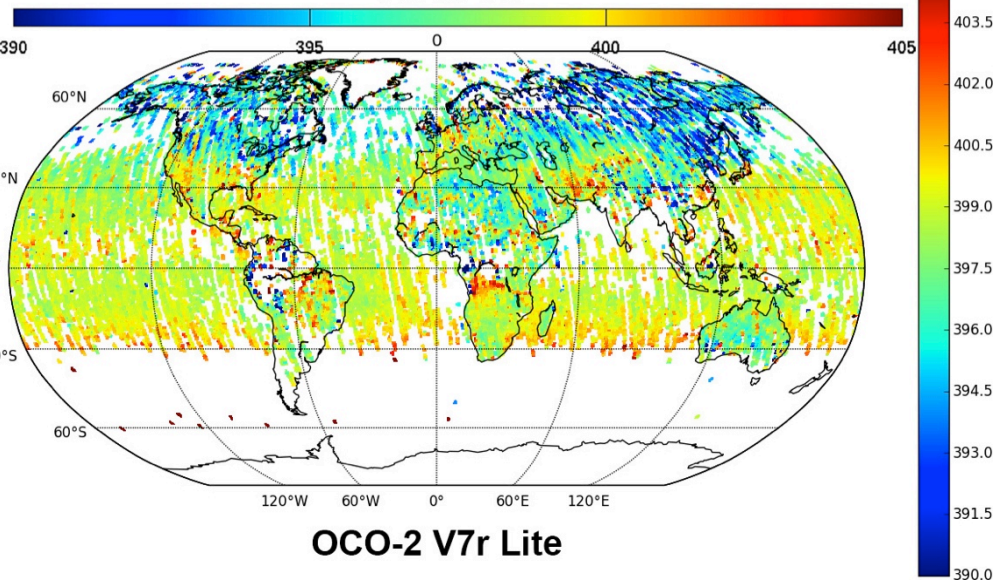
AIRS vs OCO-2
July 2015 Globe

Weighted Column
300 to 500 hPa



AIRS V6

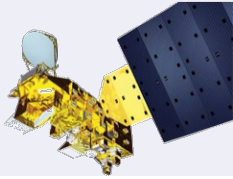


Total Column
TOA to Surface

OCO-2 V7r Lite

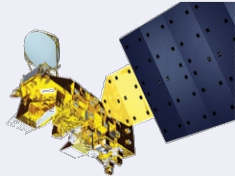
OCO-2 Xco2 image from:
http://disc.sci.gsfc.nasa.gov/uui/datasets/OCO2_L2_Lite_FP_V7r/summary?keywords=OCO%20ACOS

Summary



- **V6 Product**
  - Algorithm requires stability of retrieval product against perturbation of first guess
  - Algorithm QCs calculated CO2 averaging kernel to determine acceptability of product
- **V6 vs V5**
  - V6 Standard Product bias and outliers significantly reduced at the cost of yield
- **Validation tools extend airborne profiles to higher altitude via CarbonTracker 2015 model data**
- **Validation Results**
  - V6 removes global bias present in V5
    - Tropical bias well below 2 ppm relative to HIPPO+CT and OCO-2
    - Negative bias of 2 to 4 ppm for |lat| > 40° relative to HIPPO+CT during some seasons
    - Positive bias of 2 ppm for lat > 40° relative to OCO-2 in NH summer
  - Total cloud fraction has no discernable effect on CO2 retrieval bias
- **Next Steps**
  - Complete PGE converting output to L2 and L3 HDF product files
  - Begin generation of L2 and L3 HDF product files
  - Document (ATBD and User Documentation)

Published Studies Bearing on CO_2 Transport Around the Globe Using AIRS V5



- **Published studies demonstrate that the AIRS data contain signals arising from the large-scale circulation patterns in both the tropics and at high latitudes: ENSO, MJO, Walker Circulation,TBO, AO, and SSW in addition to the interannual growth of global CO2 and its annual seasonal cycle.**

  - Jiang, X et al. (2010), "Interannual variability of mid-tropospheric CO2 from Atmospheric Infrared Sounder", *GRL*, 37, L13801, doi: 10.1029/2010GL042823
  - Li, KF et al. (2010), "Tropical mid-tropospheric CO2 variability driven by the Madden–Julian oscillation." *PNAS*, 107, no. 45, 19171-19175.
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  - Ott, L. E., et al. (2015), Assessing the magnitude of CO2 flux uncertainty in atmospheric CO2 records using products from NASA's Carbon Monitoring Flux Pilot Project, J. Geophys. Res. Atmos., 120, doi:10.1002/2014JD022411.
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  - Revadekar, J. V., K. Ravi Kumar, Y. K. Tiwari, and V. Valsala (2016), "Variability in AIRS CO2during active and break phases of Indian summer monsoon", Sci.Total Environ., 541, 1200-1207, doi: http://dx.doi.org/10.1016/j.scitotenv.2015.09.078
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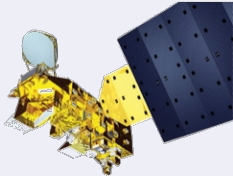
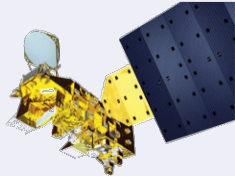
Thank You

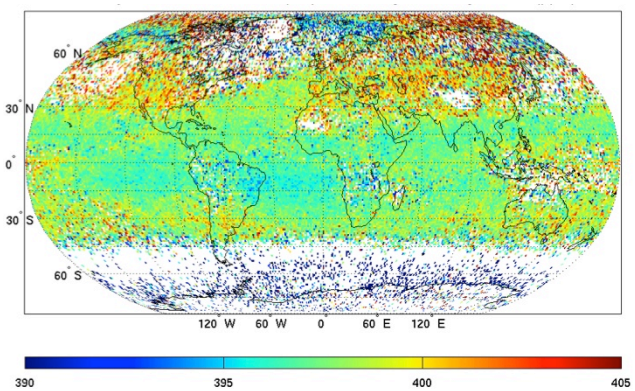


- **Acknowledgement**
  - **This task is funded by**
    - **AIRSPproject**
    - **Terra and Aqua Algorithms – Existing Data Products/13 TERAQEA13-0035**
    - **and a ROSES grant for algorithm maintenance**
  - **Special thanks to Tom Pagano and Ramesh Kakar for their encouragement and support**

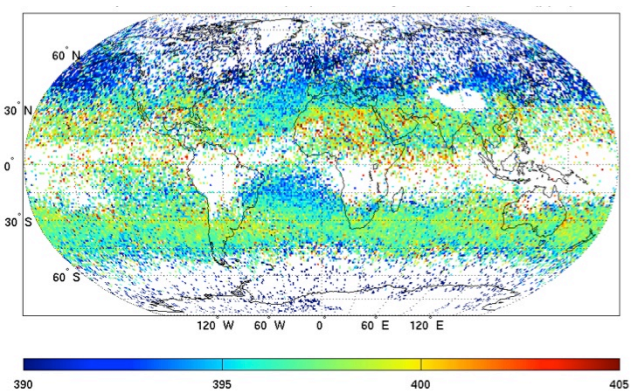


BACKUP

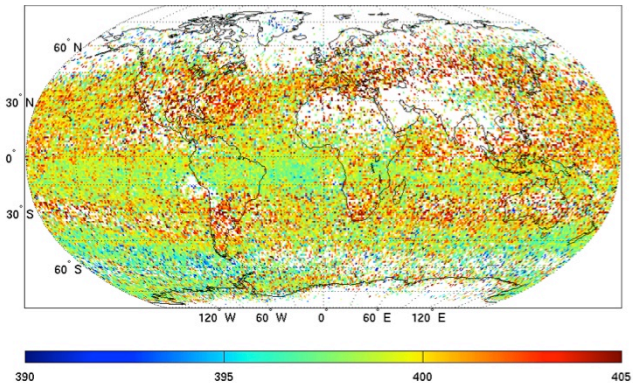
V6 vs V5Operational January and July 2015



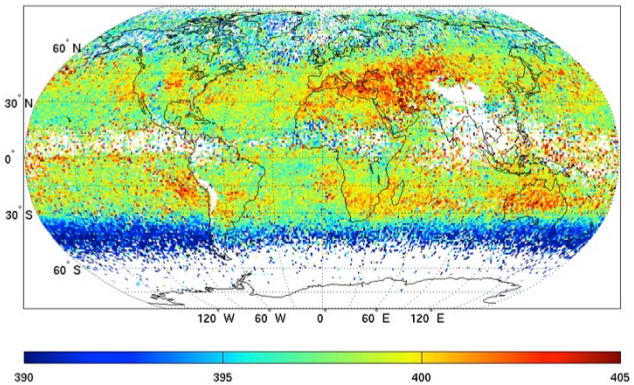
V5op January 2015



V6 January 2015

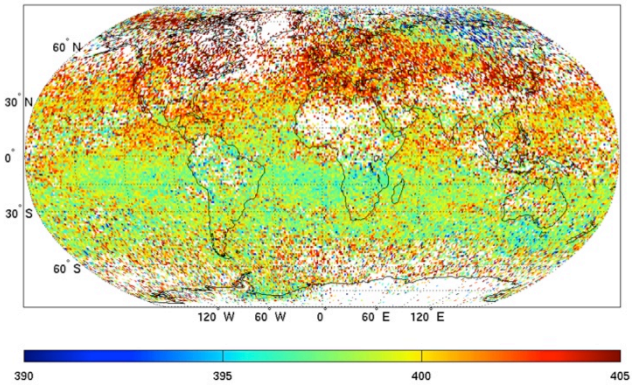


V5op July 2015



V6 July 2015

V6 vs V5Operational
April and October 2015



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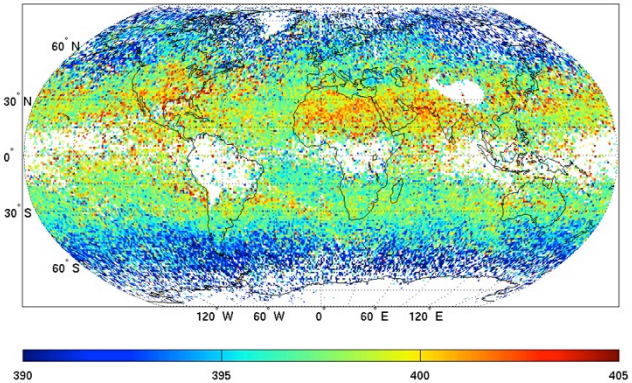

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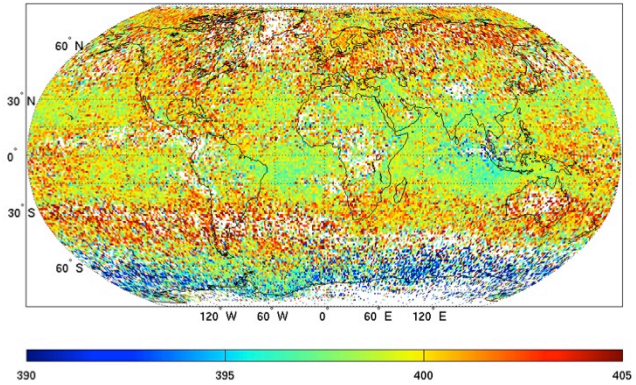
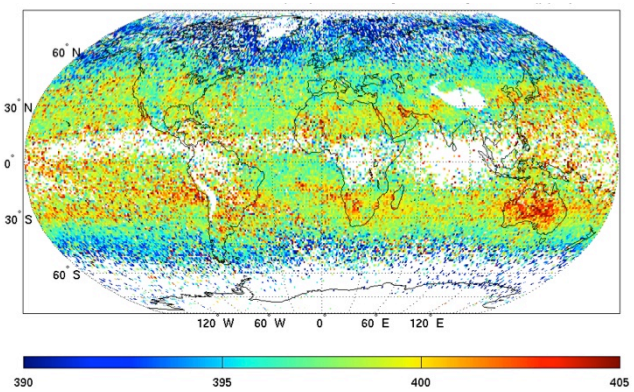


V5op October 2015

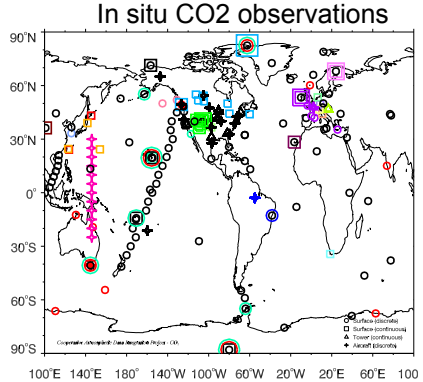


V6 October 2015

Rationale for Retrieving Free Tropospheric CO_2

- Why is the retrieval of free tropospheric CO_2 important?
  - Atmospheric CO_2 is a major agent for radiative forcing
    - Interannual increase due to human activity, and ~50% of anthropogenic CO_2 remains in the atmosphere
    - Increased CO_2 concentration warms the troposphere and cools the stratosphere
  - The free troposphere is the pathway by which CO_2 produced at the surface by natural and anthropic processes is circulated around the globe to be deposited in the natural sinks and transported to the stratosphere
    - SH, "the garbage dump for the NH CO_2 emissions", very sparsely observed from surface/airborne
  - The free tropospheric (and stratospheric) CO_2 are the background which must be accounted for in the process of determining the near-surface concentration most closely coupled to the local carbon flux by remote sensing of total column
  - Modeling of atmospheric transport processes are continuing to be refined and can benefit from the study of the distribution and transport of the long-lived trace gas
    - Vertical lofting
    - Inter-hemispherical transport
- Combined satellite retrievals provide the vertical, spatial and temporal coverage over the globe necessary to elucidate the transport of CO_2 and to ultimately identify the regional sources and sinks and net fluxes around the globe (AIRS, GOSAT, SCIAMACHY, TES, and OCO-2)

In situ CO2 observations



AIRS CO2 (month)