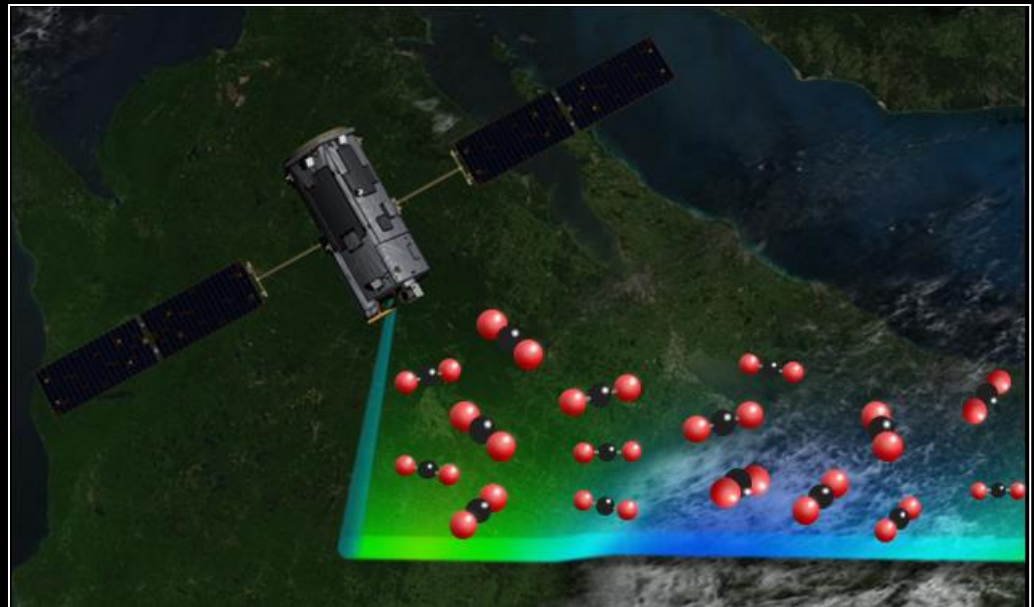


Truly Better the Second Time Around: The Application of OCO (Orbiting Carbon Observatory) Lessons on OCO-2

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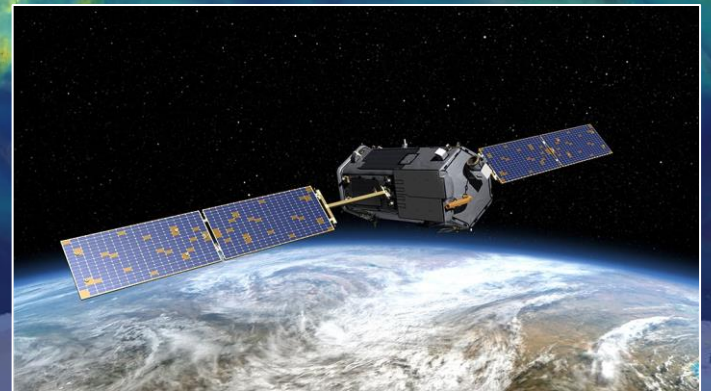
Credit: NASA/JPL

Calculated Risks and True Learning



Be willing to risk the lowest 'lows' in order to achieve the highest 'highs'

"Success does not consist in never making mistakes, but in never making the same one a second time." -- George Bernard Shaw



Credit: NASA/JPL

Credit: NASA/JPL

The OCO Mission



NASA's first dedicated CO₂ measurement mission



Credit: NASA/JPL

...to advance carbon cycle science and improve our understanding of global climate change processes

24 Feb 2009: A Beautiful OCO Launch



Credit: NASA/JPL



OCO Launch
24 Feb 2009
Matt Rogers, CSU
rogers@atmos.colostate.edu

Credit: NASA/JPL

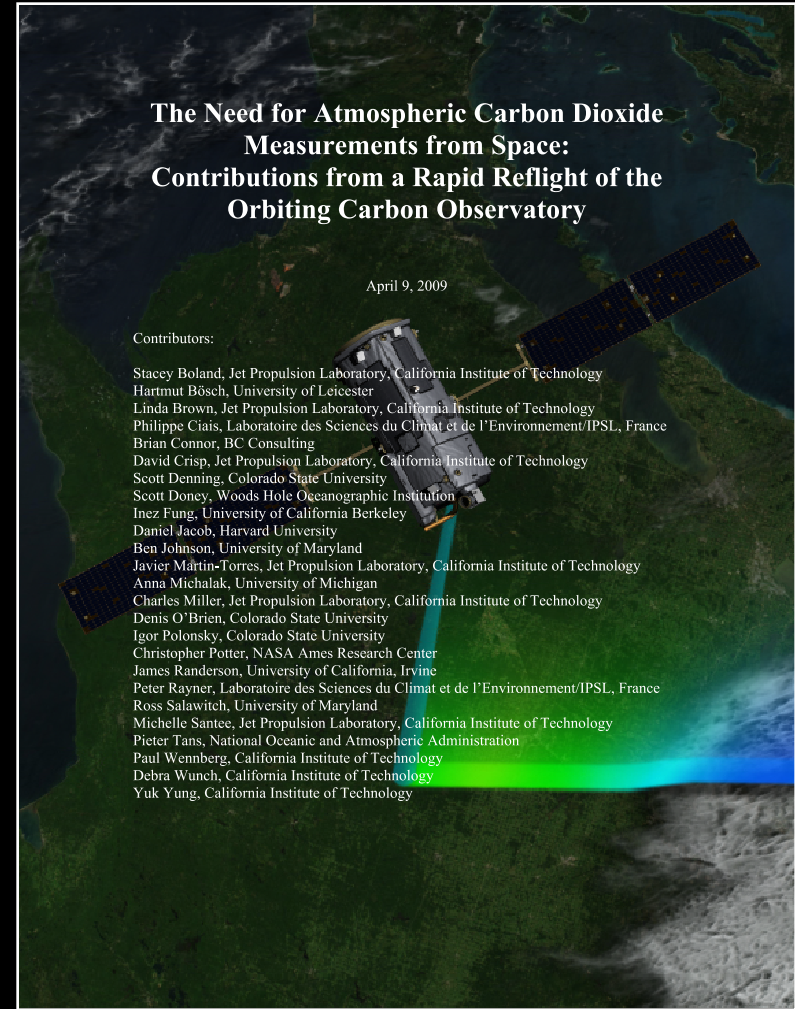
Then...



- No positive indication of launch vehicle payload fairing separation
- Launch vehicle trajectory solution indicates negative perigee!
- Launch vehicle fails to achieve orbital velocity due to excess mass carried into space
- A somber moment: Mission manager reports failure to acquire any signal from the observatory
- Another somber moment: Launch vehicle telemetry indicates positive observatory separation, albeit, inside the fairing

No Time for Grieving

- No one walked away
- The community needs the breakthrough that only the OCO mission can provide
- Strong demonstrated support from NASA and the Federal Government for an OCO re-flight
- The OCO-2 Project was authorized to commence on 01 March 2010...on a short 28-month schedule to launch!



Carbon Copy...to the Extent Possible

- NASA directs OCO-2 to “build to print” to reduce technical, schedule, and cost risk
- A need to temper this given realities, etc...
 - Inconsistent results
 - Obsolete hardware
 - Directed changes
 - Lessons learned





Peeling and Flaking of Black Chrome

- Black chrome was applied to OCO instrument machined parts to reduce stray light effects
- Same vendor, same preparation, same application process.....different results
 - Large percentage of parts exhibited poor adhesion (peeling and flaking) of black chrome
 - Situation attributed to the key technician retiring
- Different vendor and different process (black anodizing) produced acceptable results
- Take away – Expect the unexpected, especially on tasks that are on the critical path



Find Me a Cryocooler

- The instrument cryocooler used on OCO was the lone flight spare from another project
- The project worked with NASA and NOAA to obtain existing flight spare units from the Geostationary Operational Environment Satellite R-Series (GOES-R) Program
- Necessary mechanical, electrical, and software changes were made
- Obtaining existing cryocoolers was key to preserving the 28-month schedule to launch
- Take away – Go beyond your usual boundaries; the solution may lie just beyond your doorstep



Like Changing Horses Midstream

- NASA lost the Glory mission due to a second Taurus XL launch failure on 04 March 2011
- Following a competitive selection process, NASA directed OCO-2 in July 2012 to use the Delta II launch vehicle for a launch just 24 months later!
- Necessary mechanical and electrical changes were made and analyses revised
- The result was a perfect ride into space, and the real-time video feed of observatory separation was 'icing on the cake'
- Take away – Stuff happens, so you have to do what it takes for as long as it takes to achieve the ultimate goal



Lessons Learned

- A total of seventy-eight (78) OCO lessons were documented
- Positive and not-so-positive lessons were recorded and categorized as follows
 - Caused additional work and/or schedule impact
 - Resulted in additional cost
 - Lead to confusion (and increased risk)
- Project guidance: *“Don’t make a change unless there is a compelling reason to do so”; “fly it ‘as is’, warts and all”; “better can be the enemy of good enough”; and “only ‘make it work’, not ‘make it better’ changes will be considered”*



Lessons Learned Statistics

Transfer of OCO Lessons to OCO-2 (status as of Dec 2014)	Number
1. Implemented successfully	60
2. Intent of lesson met	2
3. Identified as a best practice	1
4. Business as usual [No specific lesson learned]	9
5. Partially implemented	1
6. Attempt to implement, but not successful	1
7. Lesson declined/rejected	3
8. Awaiting status determination	1
Total	78



Blinded by the Light

- Two of the three OCO instrument detectors were plagued by residual (or ghost) images, where scenes decay over time
- Deemed to be unacceptable risk given the direct connection to performance and Level 1 requirements
- An improved screening and selection process was instituted and all three detectors were operated at the same, low cryogenic temperature
- Improved detector performance was verified during thermal vacuum testing



Addition of Mechanical Stabilizers

- The OCO instrument design effectively placed each of the three spectrometer slits on the end of a cantilever beam
- It was difficult at best to keep the alignment of the three slits within alignment specifications after dynamic loading (e.g., simulated launch)
- Also deemed to be unacceptable risk given the direct connection to performance and Level 1 requirements
- Mechanical stabilizers were designed, installed, and verified to limit motion to acceptable levels



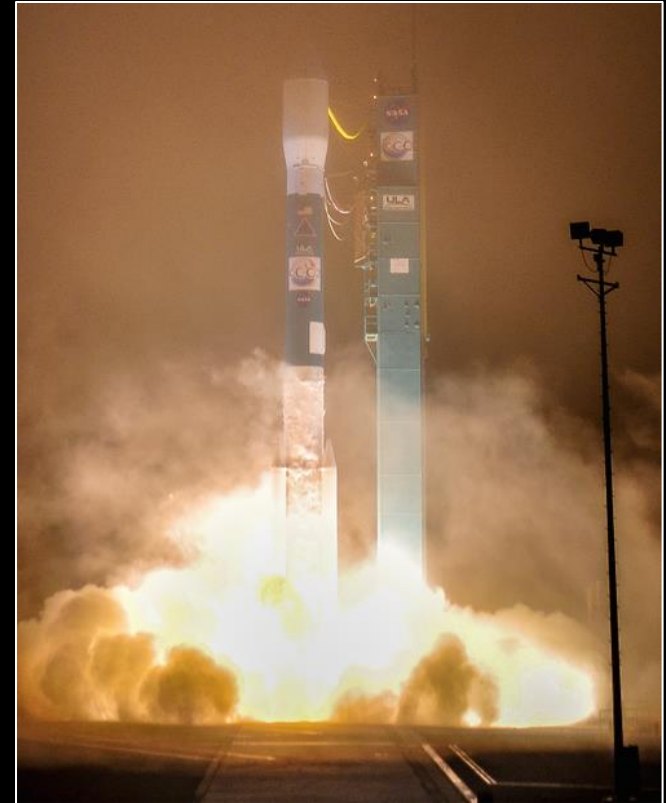
Like a Needle in a Haystack

- Four (4) of the OCO lessons were related to paperwork storage and access
- This was a combination of positive experiences (action item closures) and not-so-positive experiences (objective evidence for verification & validation of requirements)
- A single electronic repository was utilized as a one-stop shop for the distributed project team

Fast Forward to the OCO-2 Launch



Credit: Bill Ingalls, NASA



Lift-Off at 2:56 am PDT
02 July 2014

Streaking Across the Southern Sky



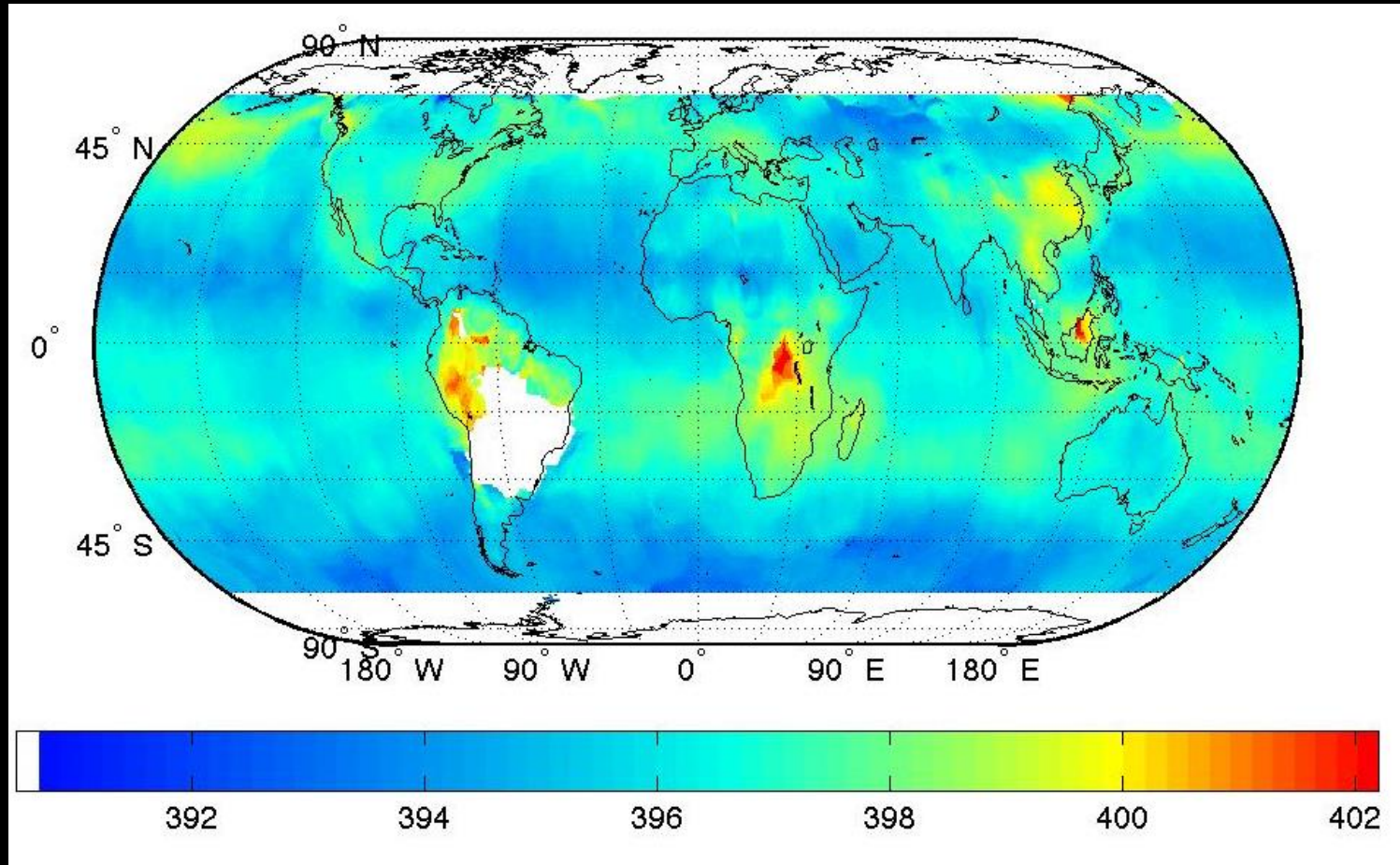
Credit: Jeff Sullivan

We Have Observatory Separation!



Credit: NASA / Caltech-JPL

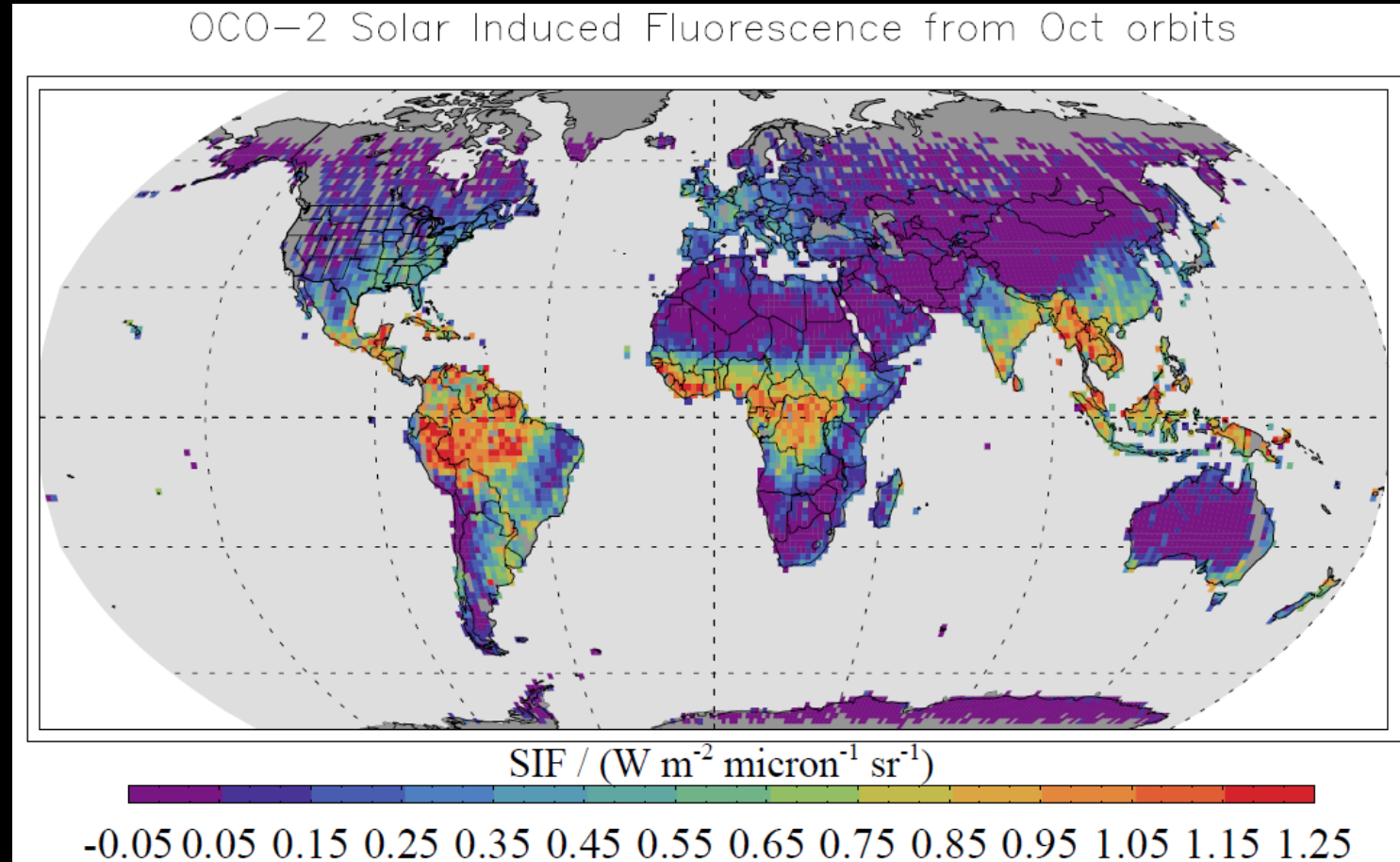
Initial Science Results are Promising



Credit: NASA/Caltech-JPL

Late October – Early November 2014 X_{CO_2} Global Map

Bonus Science (Plant Fluorescence)



Credit: C. Frankenberg, NASA/JPL

October 2014 Map of Solar-Induced Fluorescence (SIF)



Bonus Lesson

- SNR (Signal-to-Noise Ratio) levels were lower than expected when collecting science data over the oceans in glint mode
- It turned out that we got polarization wrong; the spacecraft and instrument coordinate frames are inconsistent
- To increase the SNR to acceptable levels, a 30 deg fixed offset (around the yaw axis) was incorporated in spacecraft pointing without compromising health and safety
- At least one take-away: Having healthy technical margins is a good thing!



Closing Remarks

- The OCO-2 Project stayed true to the “build to print...to the extent possible” philosophy
- Some changes were obviously necessary
- OCO-2 was in a unique position to incorporate lessons learned on OCO that served to reduce risk
- The mission will meet or exceed expectations

Shameless Plug



Read more about OCO-2:

OCO-2: A Second Chance to Fly (Case Study)

on the NASA Academy of Program/Project & Engineering Leadership (APPEL) website at:

<http://appel.nasa.gov>

- Check us out on the web at: <http://oco2.jpl.nasa.gov>
- Follow us on Twitter: @IamOCO2