Views from the 6 aircraft campaigns: ACT-America, HIPPO, CONTRAIL, ATom, ORCAS, and ABoVE
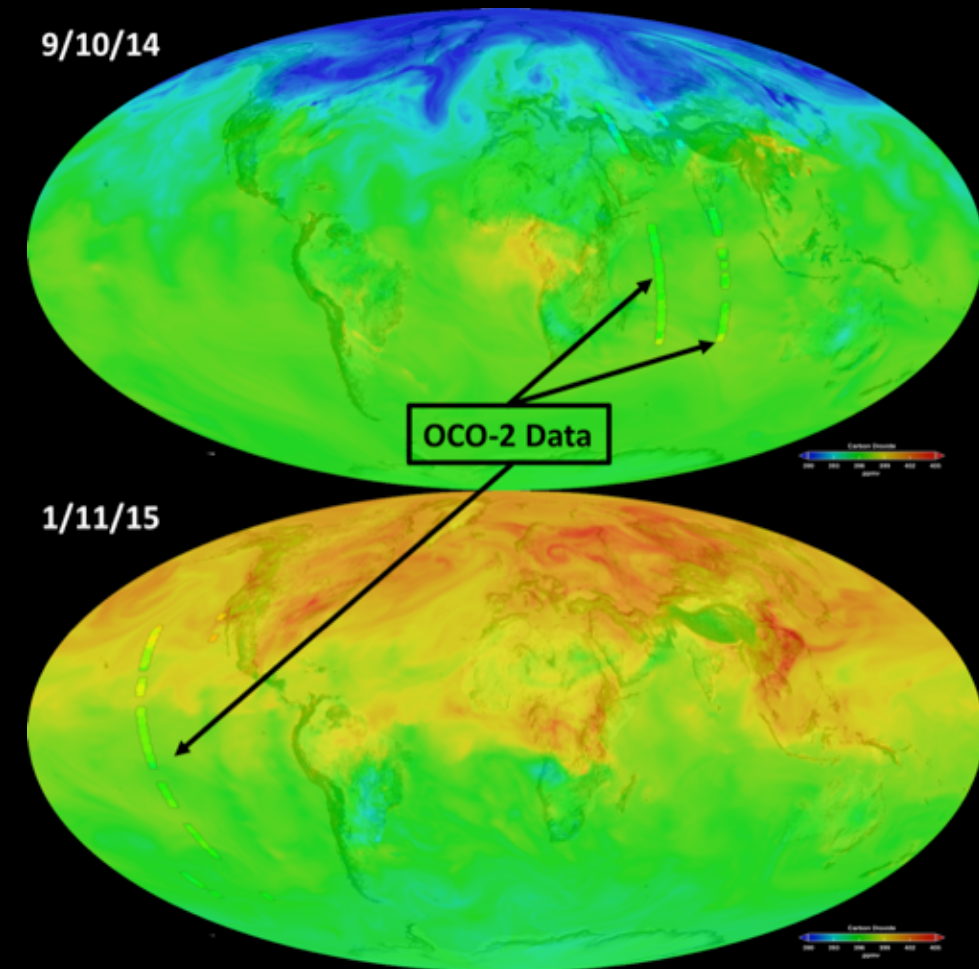
Assimilation of airborne CO_2 measurements into GEOS and comparisons with satellite retrievals

B. Weir[1,2], C. O'Dell[3], E. Bell[3], L. Ott[2], A. Chatterjee[1,2], and S. Pawson[2]
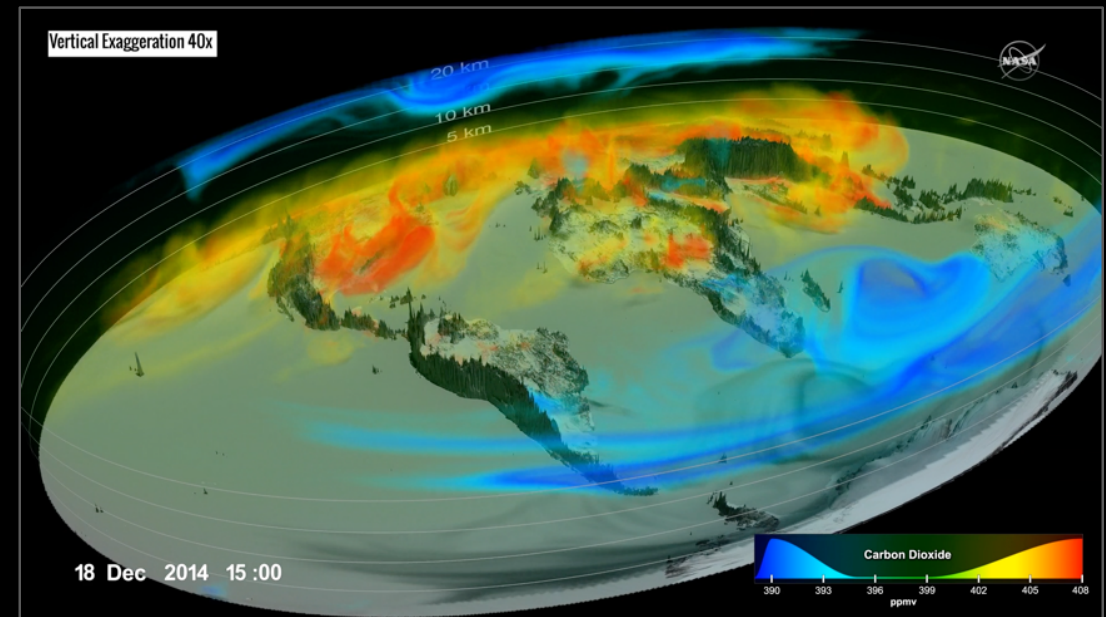
1) USRA, 2) NASA GMAO, 3) CSU

OUR ASSIMILATION APPROACH

- Traditionally, GMAO produces analyses of met vars (wind, temp, pres) and short-lifetime trace gases (water vapor, ozone), e.g. MERRA-2 and GEOS FP

- We've applied the same approach to analyze CO_2 based on OCO-2 (right) and GOSAT-ACOS retrievals

- Still, (like everyone) assim struggles to show skill over prior

- What can we learn from met/NWP analysis?


9/10/14

OCO-2 Data

1/11/15

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Vertical Exaggeration 40x

20 km
10 km
5 km

18 Dec 2014 15:00

Carbon Dioxide
390 393 396 399 402 405 408
ppmv

LESSONS FROM MET ANALYSIS

- **In situ <u>met</u> obs:** 2nd greatest total impact (top) and greatest (bottom) per-ob impact

- They are <u>basis of VarBC bias correction</u>:

  - Rough assumption that model + in situ analysis has little bias

  - Used as baseline to bias correct radiance assim

- **NWP based on satellites alone would likely struggle to show skill** (paraphrasing Kalnay)

- <u>**For CO_2:**</u> **Need to build an anchor for satellite assim based on in situ obs**


Total impact

Per-ob impact
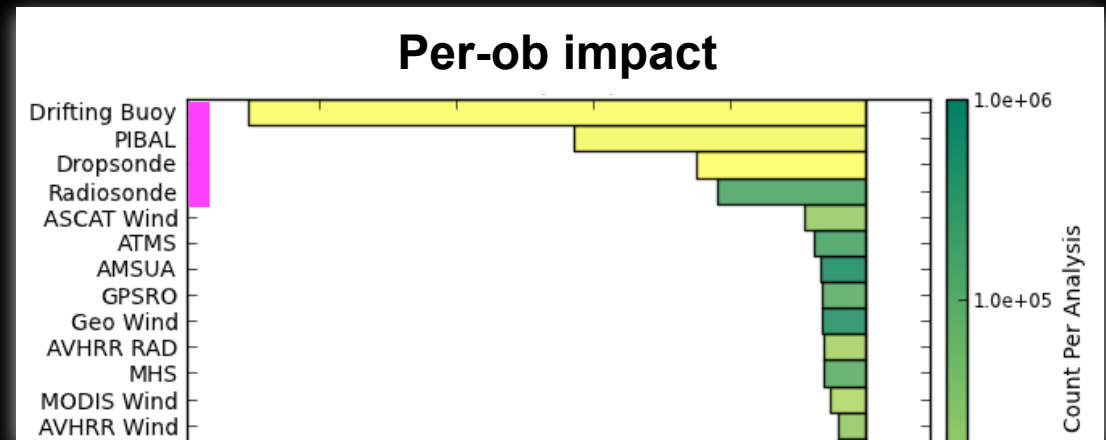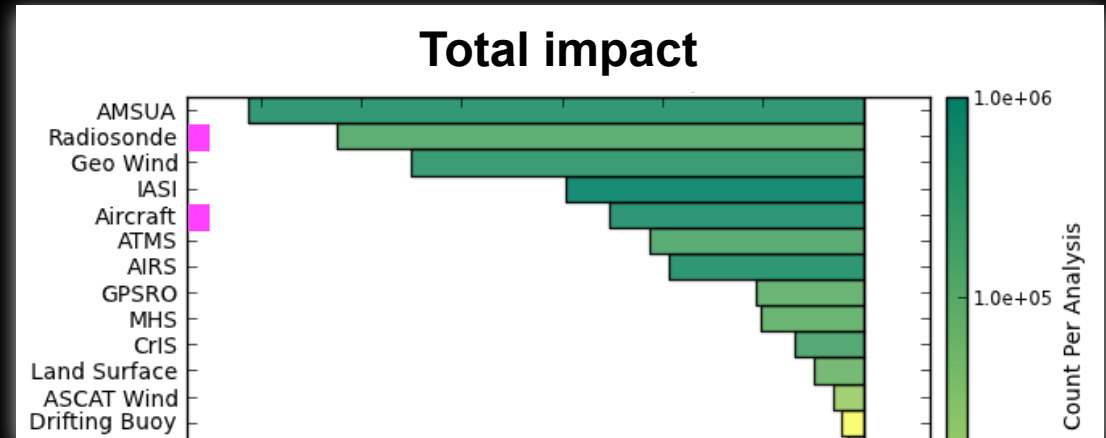
AN IDEA FROM CHRIS

- Use assimilation machinery to ingest aircraft campaign data, then compare to satellite retrievals (similar to VarBC approach)

- Then …

  1. If aircraft <u>improves</u> model agreement w/ satellite data, <u>suggests model errors</u>

  2. If aircraft <u>degrades</u> model agreement w/ satellite data, <u>suggests retrieval errors</u>
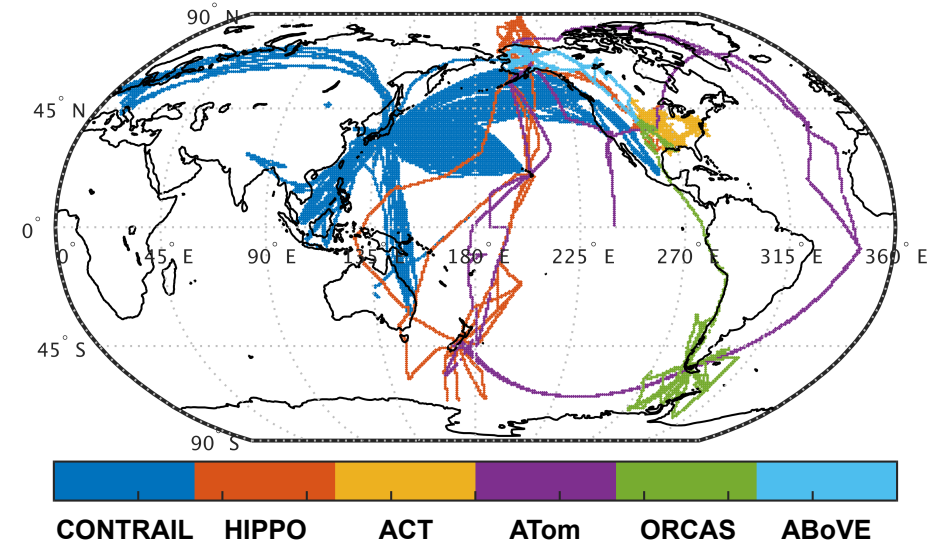
AIRCRAFT CURTAINS OF CO$_2$

- Basic approach: 1) build 2D "curtains" of CO$_2$ by assimilating aircraft obs into GEOS and 2) compare to satellite overpasses

- Pros: no ad hoc coincidence criteria or stitching of stratosphere on top, no need for direct overpass (correlations)
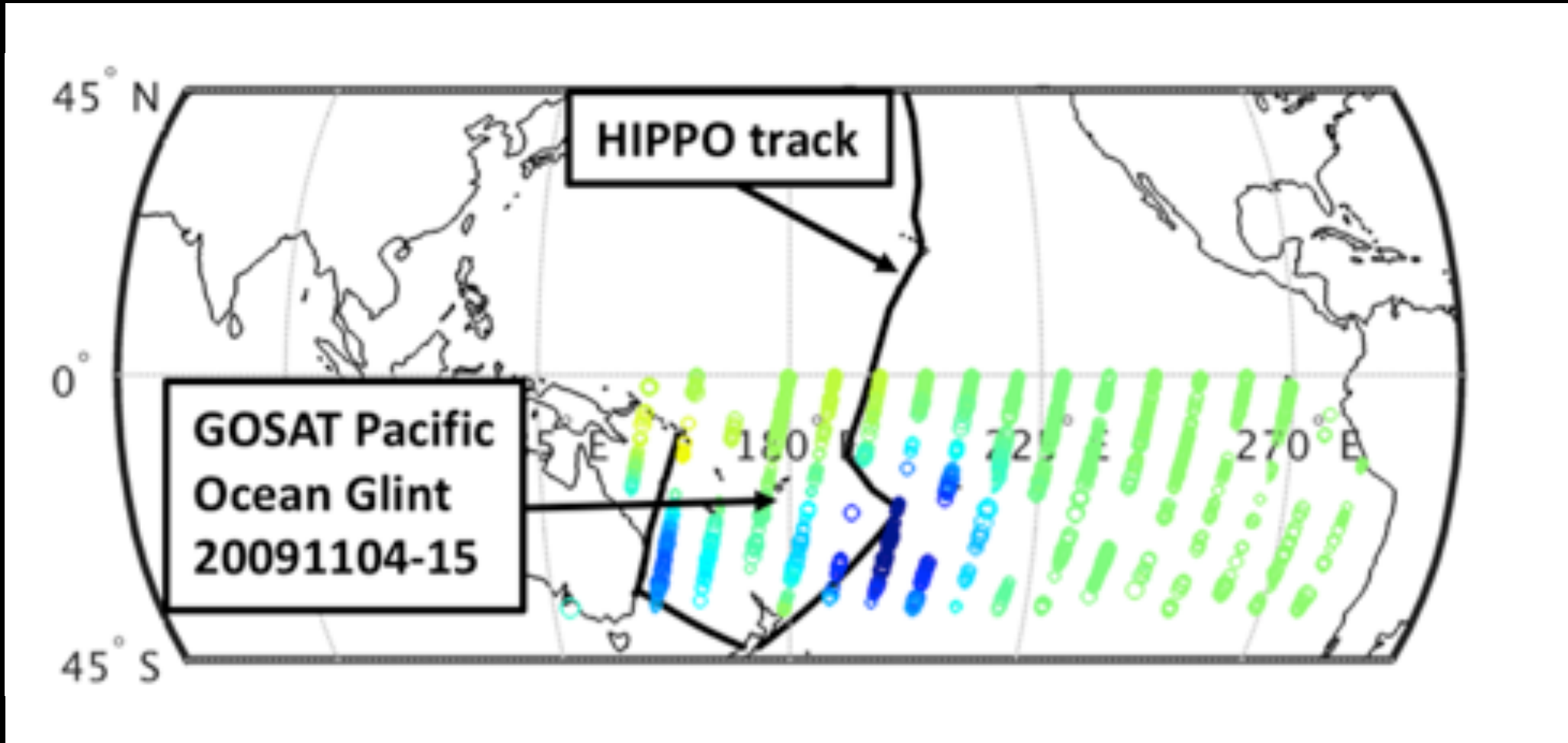
- Cons: reliance on model data
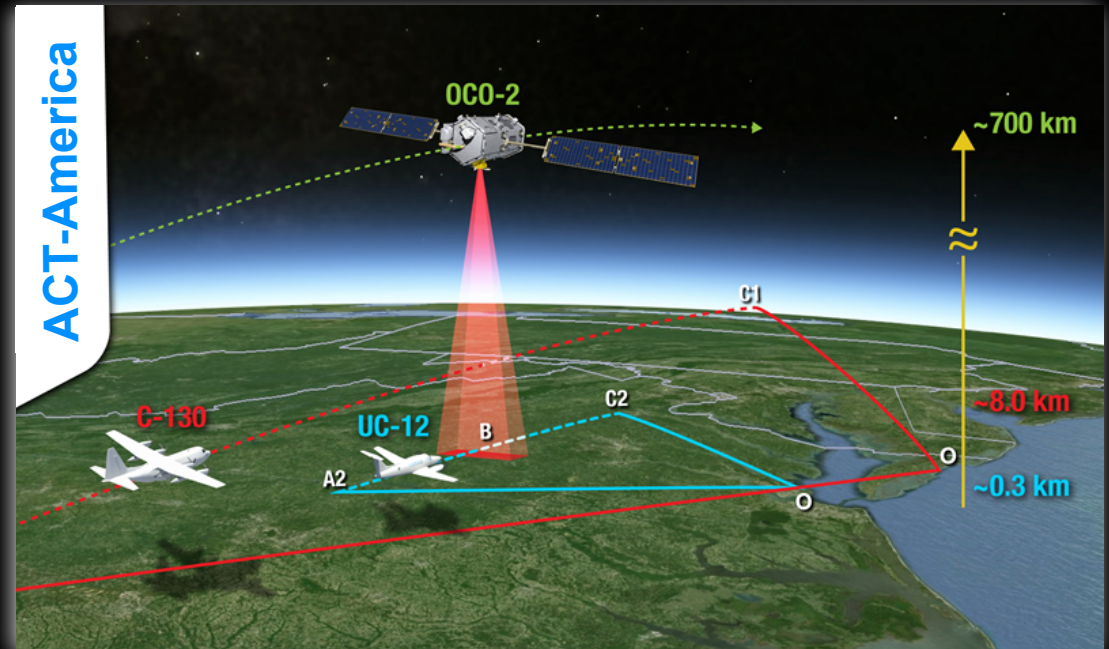
AIRCRAFT CURTAINS OF CO$_2$

- Coverage

  - Open ocean — HIPPO & ATom

  - Arctic — ABoVE

  - Mid-lat. land — ACT-America

  - S. Hem. — ORCAS

  - UTLS — CONTRAIL

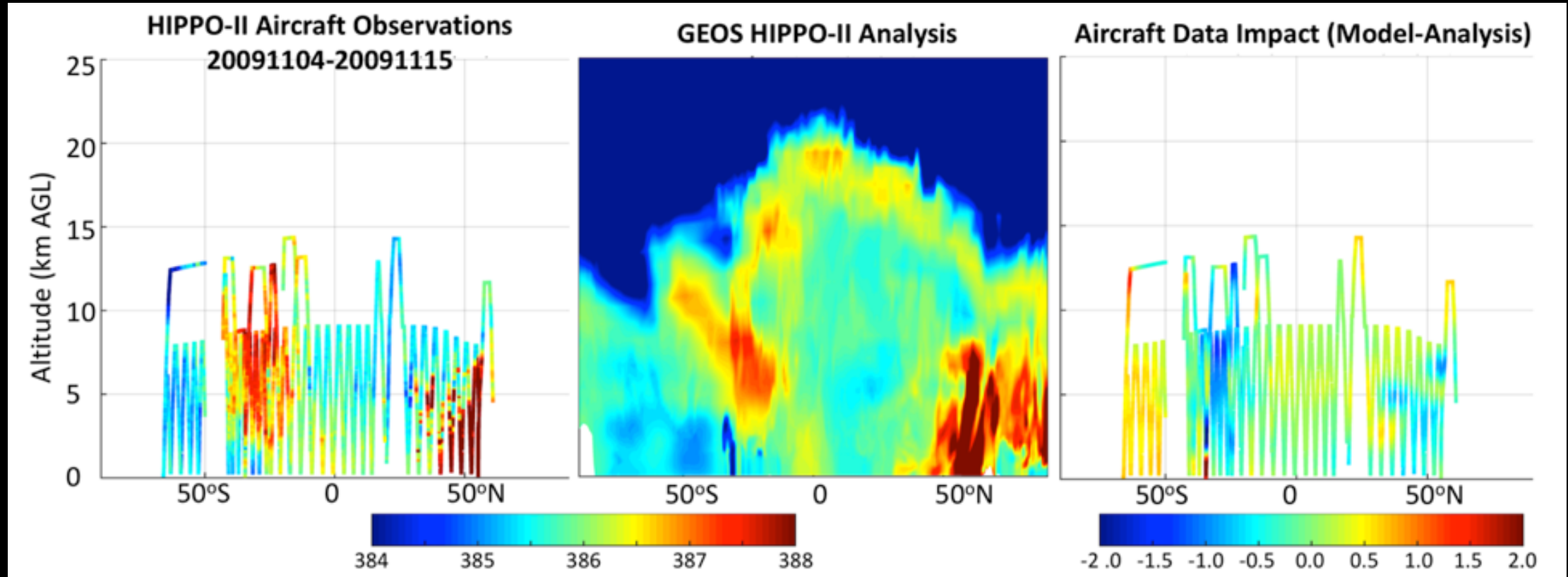- By no means an exhaustive: AirCore, CARVE, ASCENDS test flights, DISCOVER-AQ, SEAC4RS, AJAX, …
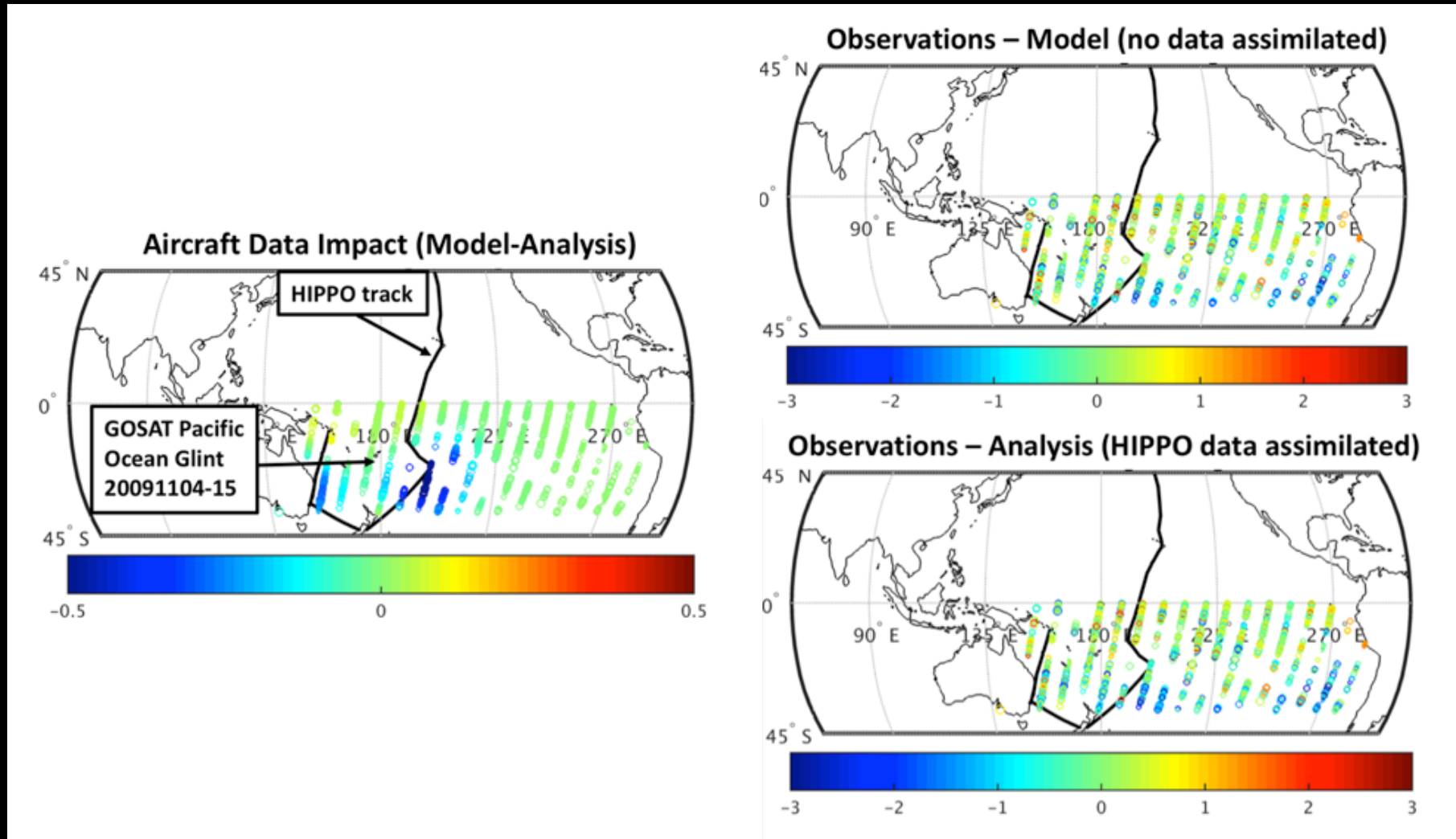
Data in NOAA ObsPack from 2009 thru 2017

CONTRAIL HIPPO ACT ATom ORCAS ABoVE

1) HIPPO II: Nov 2009

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Aircraft Data Impact (Model-Analysis)

HIPPO track

GOSAT Pacific Ocean Glint 20091104-15

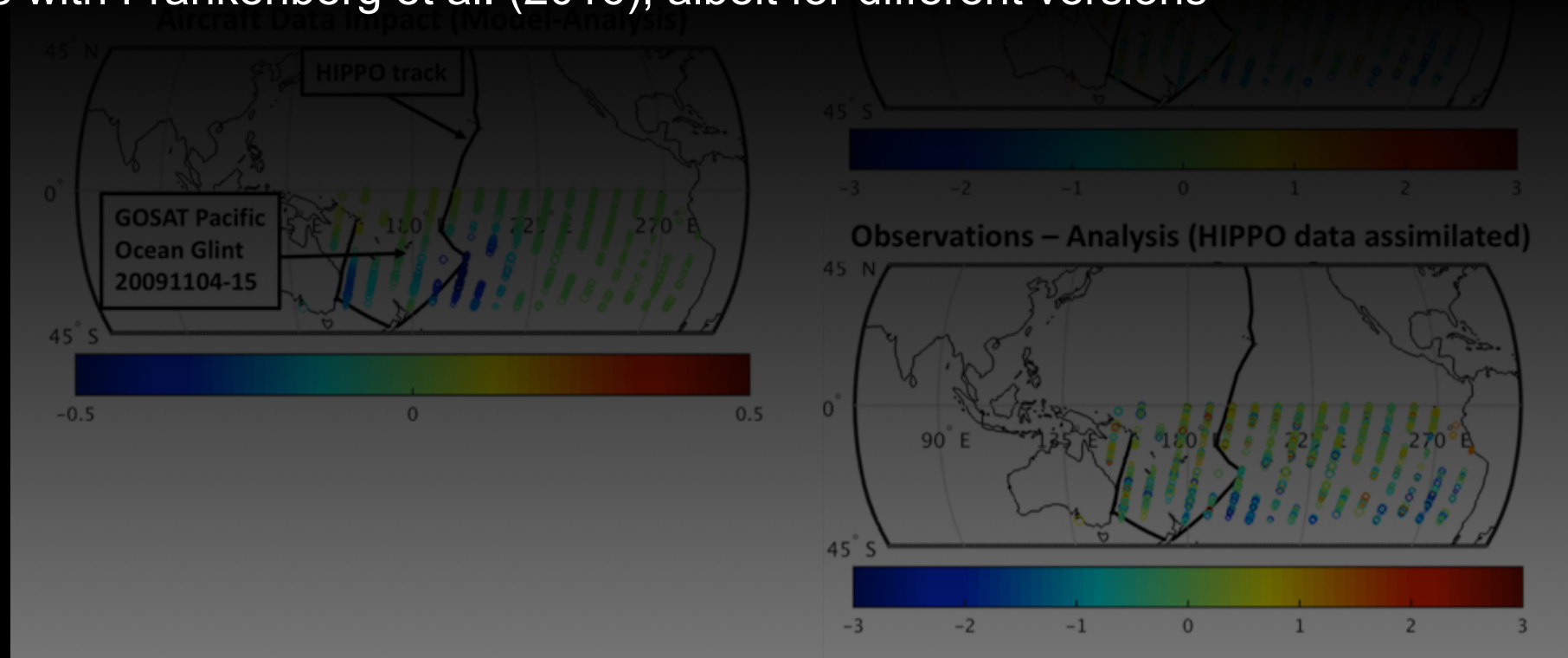Observations – Model (no data assimilated)

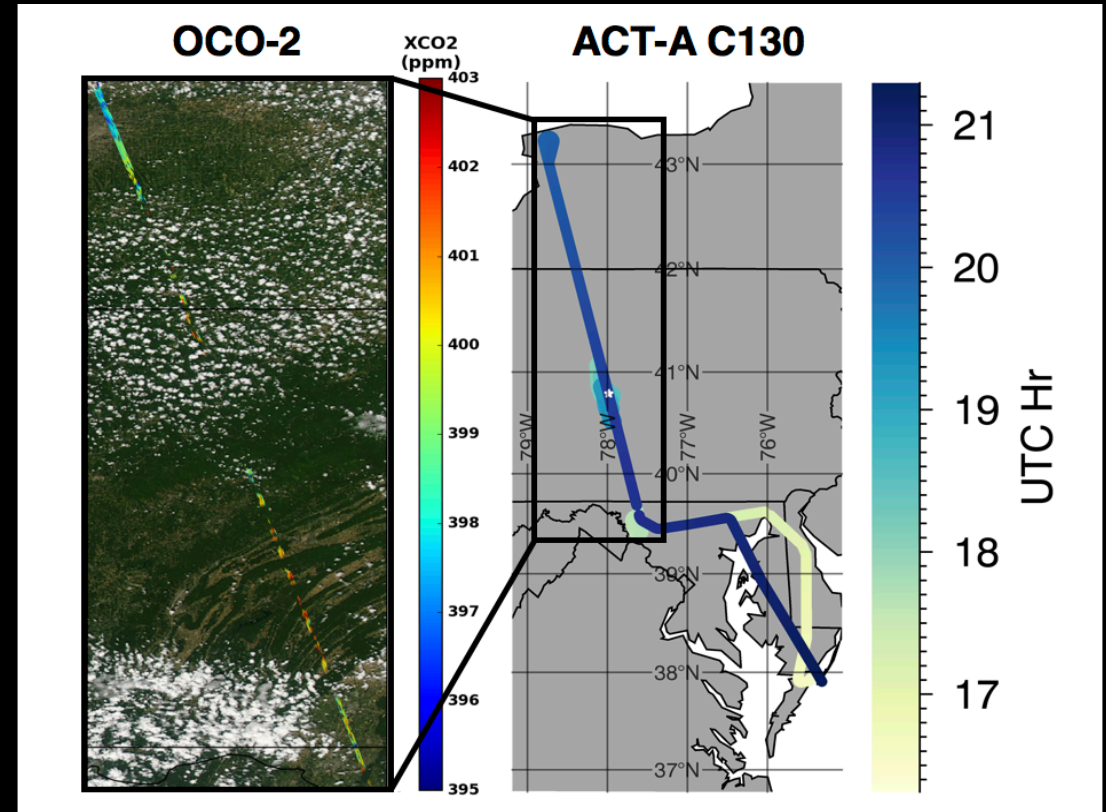Observations – Analysis (HIPPO data assimilated)

1) HIPPO II: Nov 2009

- Assimilation of HIPPO II indicates low bias of GOSAT-ACOS v7 retrievals

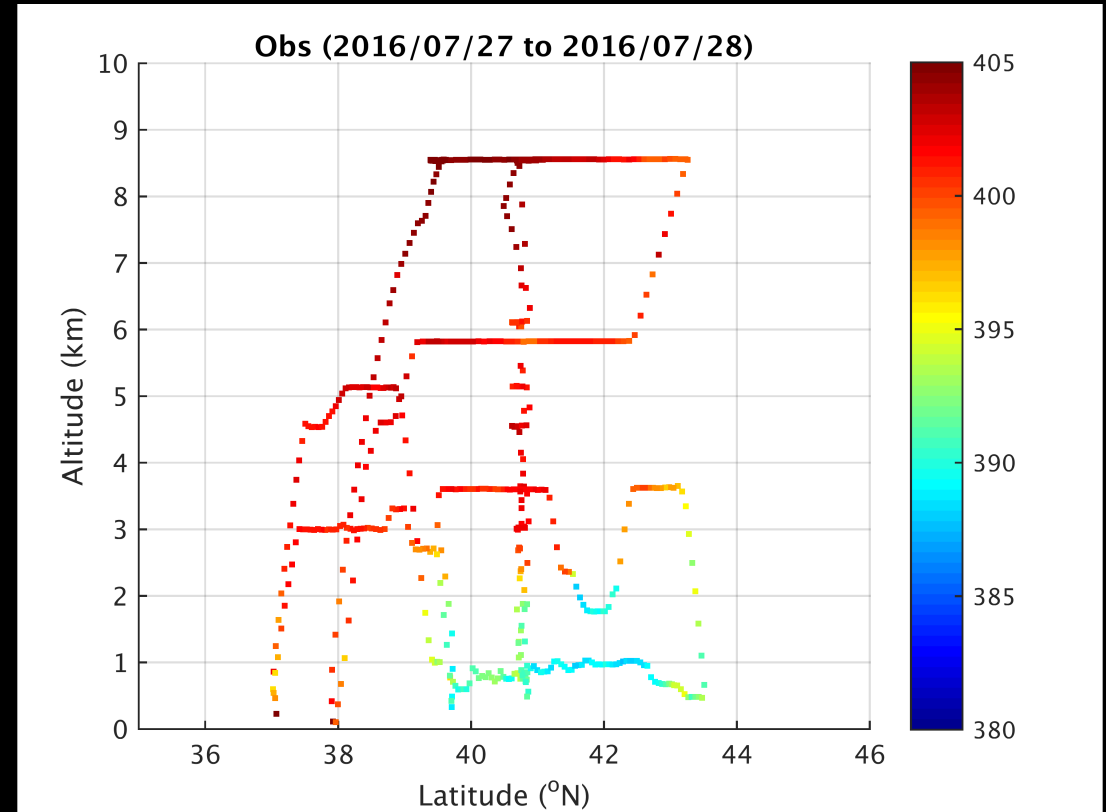- In line with Frankenberg et al. (2016), albeit for different versions
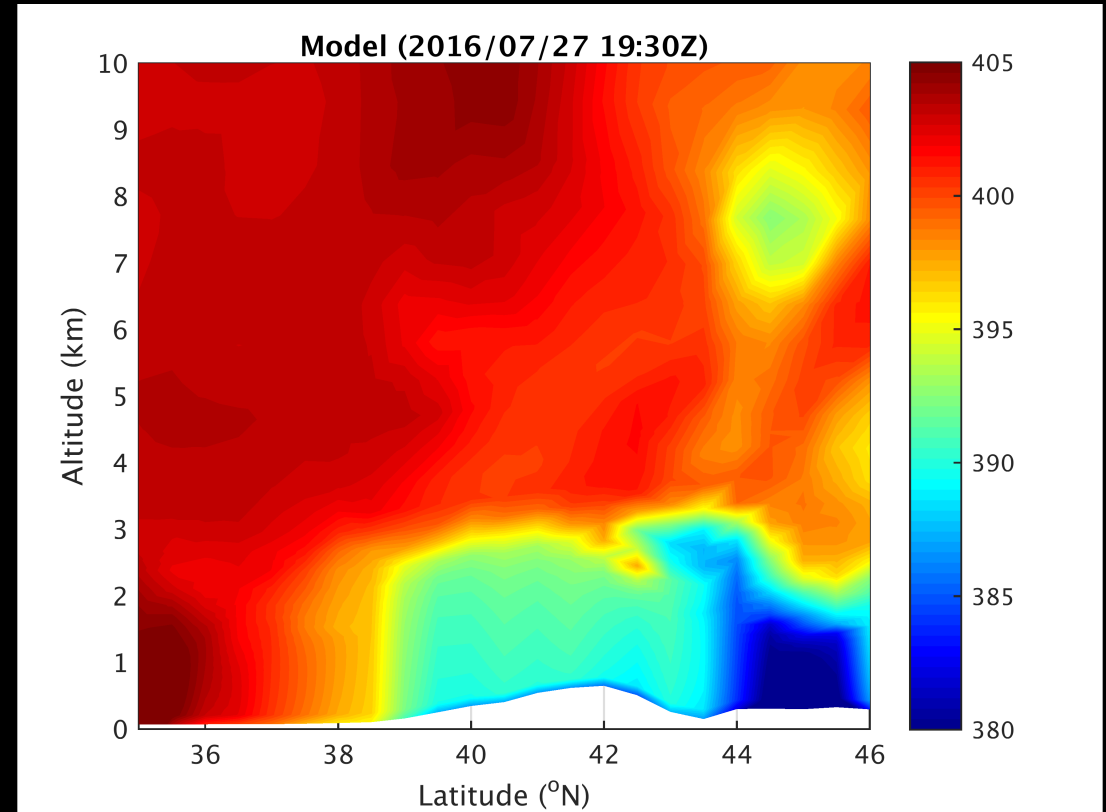
2) ACT-AMERICA: 27 JULY 2016

- ACT-America campaign has a number of coordinated underflights of OCO-2

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Obs (2016/07/27 to 2016/07/28)

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Model (2016/07/27 19:30Z)

2) ACT-America: 27 July 2016

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- Assimilation of aircraft obs indicates that model PBL was too high
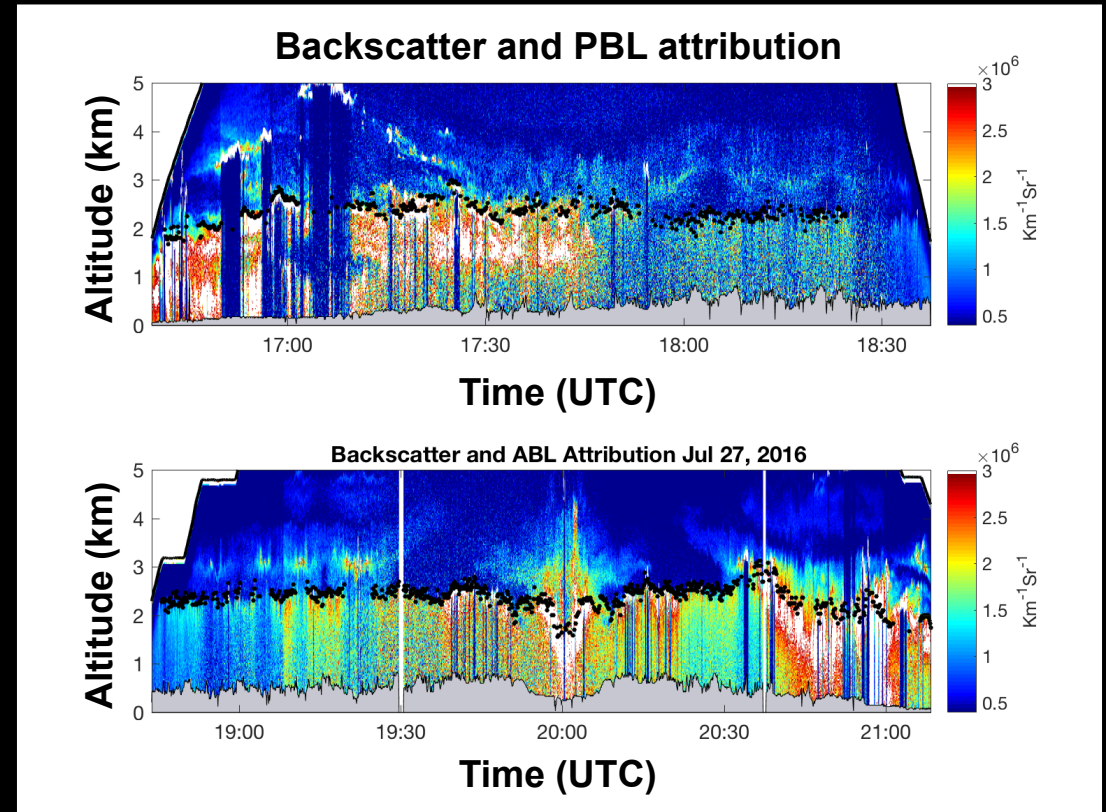

Analysis (2016/07/27 19:30Z)

2) ACT-AMERICA: 27 JULY 2016

- ACT-America campaign has a number of coordinated underflights of OCO-2

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- Conclusion is consistent with APL backscatter measurements

Backscatter and PBL attribution

Backscatter and ABL Attribution Jul 27, 2016
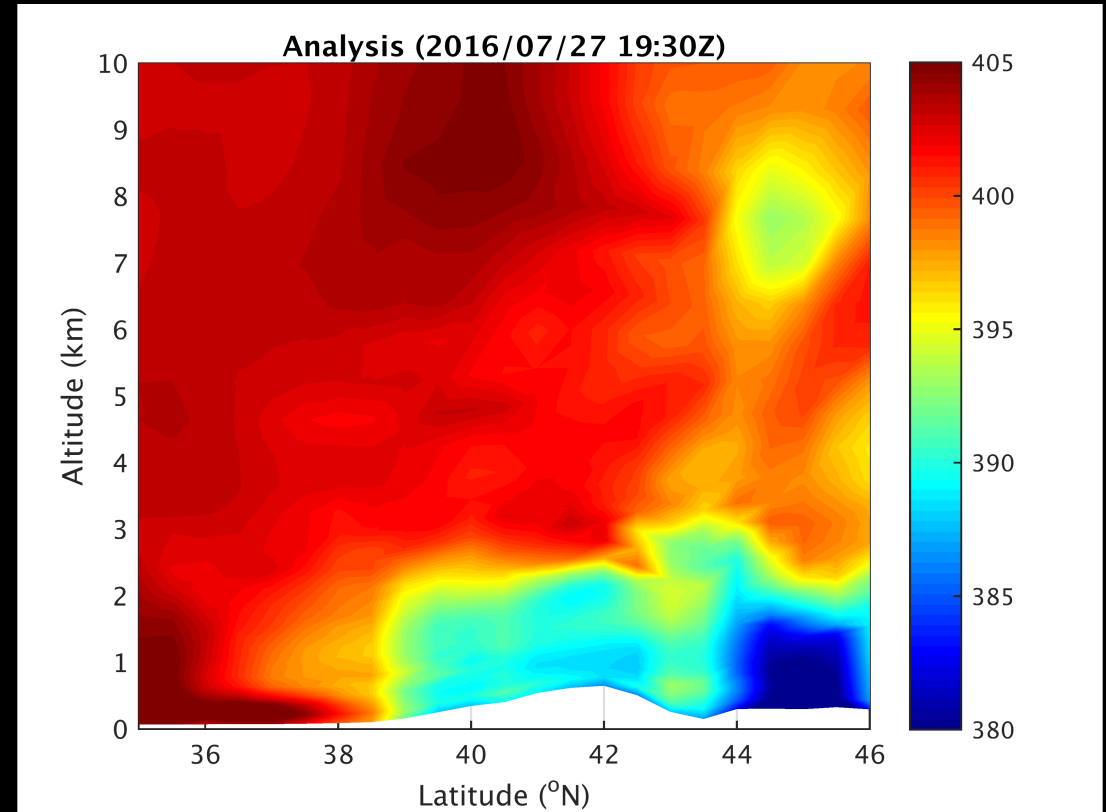
# 2) ACT-America: 27 July 2016

- Assimilation of aircraft obs indicates that model PBL was too high

- Conclusion is consistent with APL backscatter measurements

- Fixing the PBL height improves model agreement w/ OCO-2
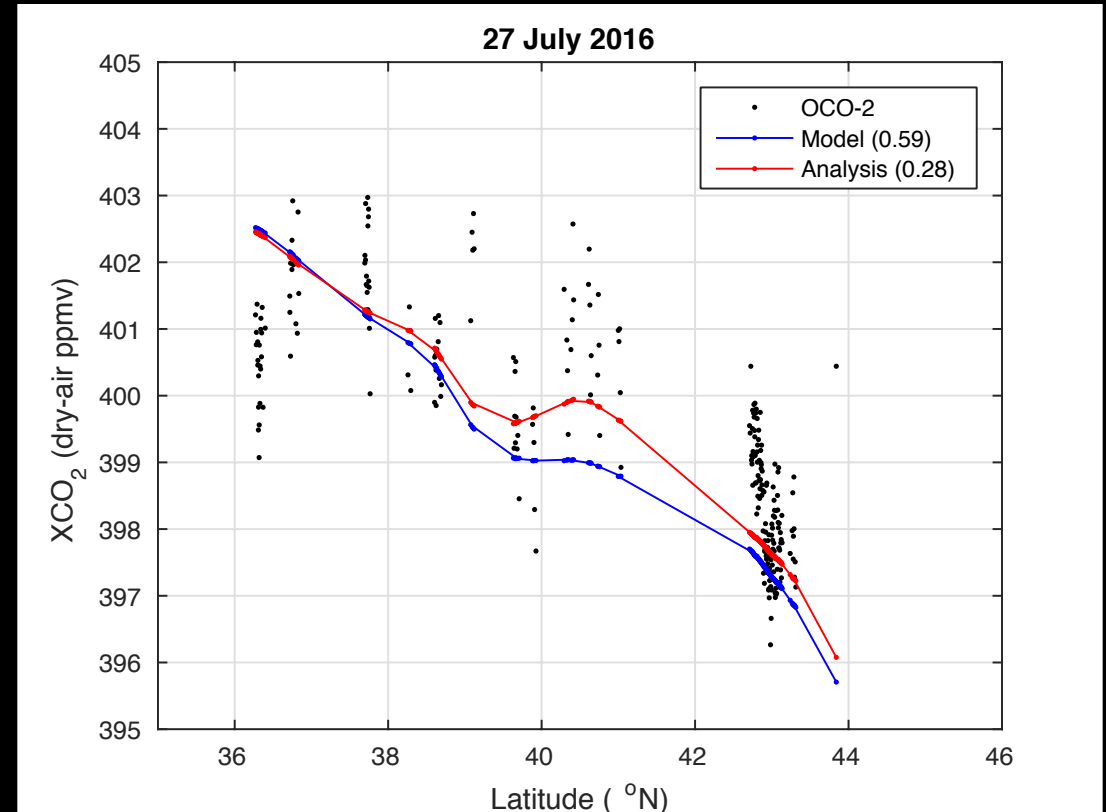
27 July 2016
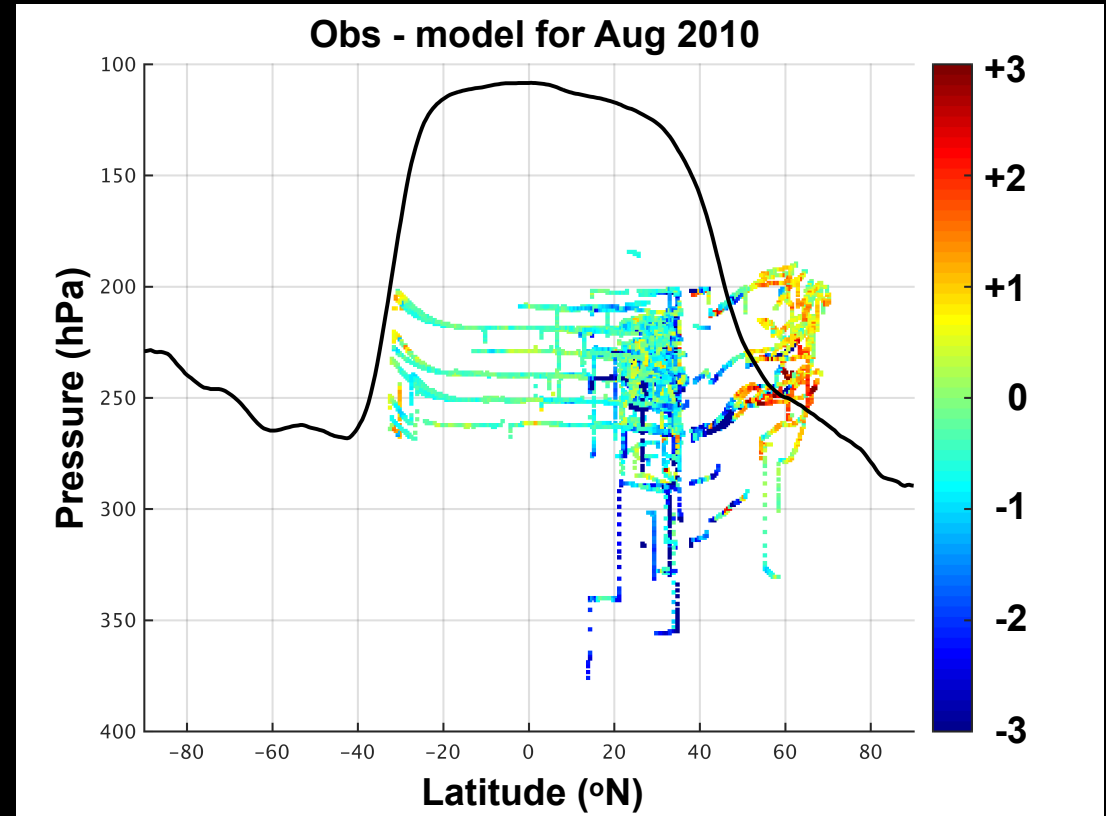
3) CONTRAIL

- Stratosphere is provided by the model in most of these comparisons

- How good is our model at high altitude?

CONTRAIL flights for Aug 2010
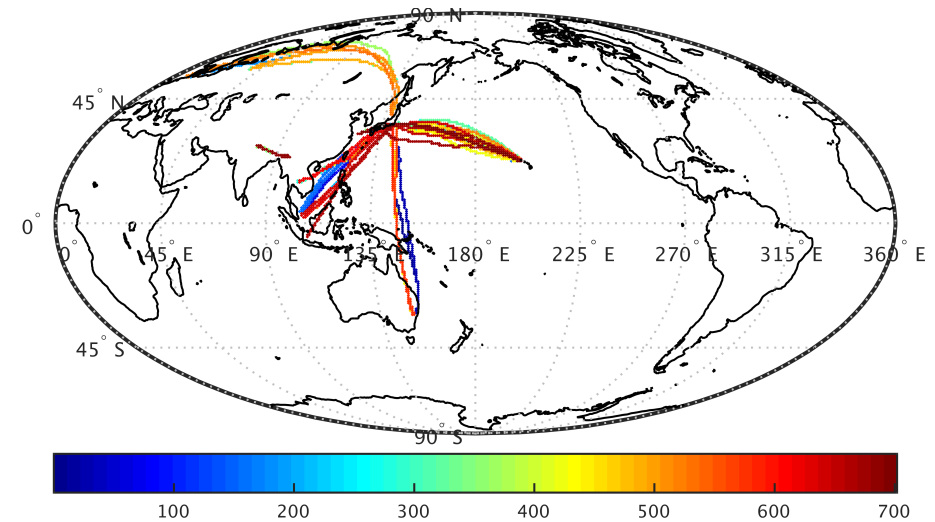
3) CONTRAIL

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- How good is our model at high altitude?

- Some indication model is too low in NH lower strat and too high in upper trop

Obs - model for Aug 2010

CONCLUSIONS, FUTURE DIRECTIONS & PROBLEMS

- Model is wrong sometimes, satellite is wrong others

- Where we started, but starting to attribute blame: HIPPO II — retrieval bias, ACT-America — model PBL too high, CONTRAIL — not enough model STE?

- More data: other campaigns, profiles from aircraift and AirCore

- Curtains can be cylinders too — potential to estimate fluxes using mass balance? e.g. using SEAC4RS + AJAX for Yosemite Rim Fire

- No **obvious** way to evaluate curtains — we've assimilated all available data

- Background error covariances: ¯_(ツ)_/¯
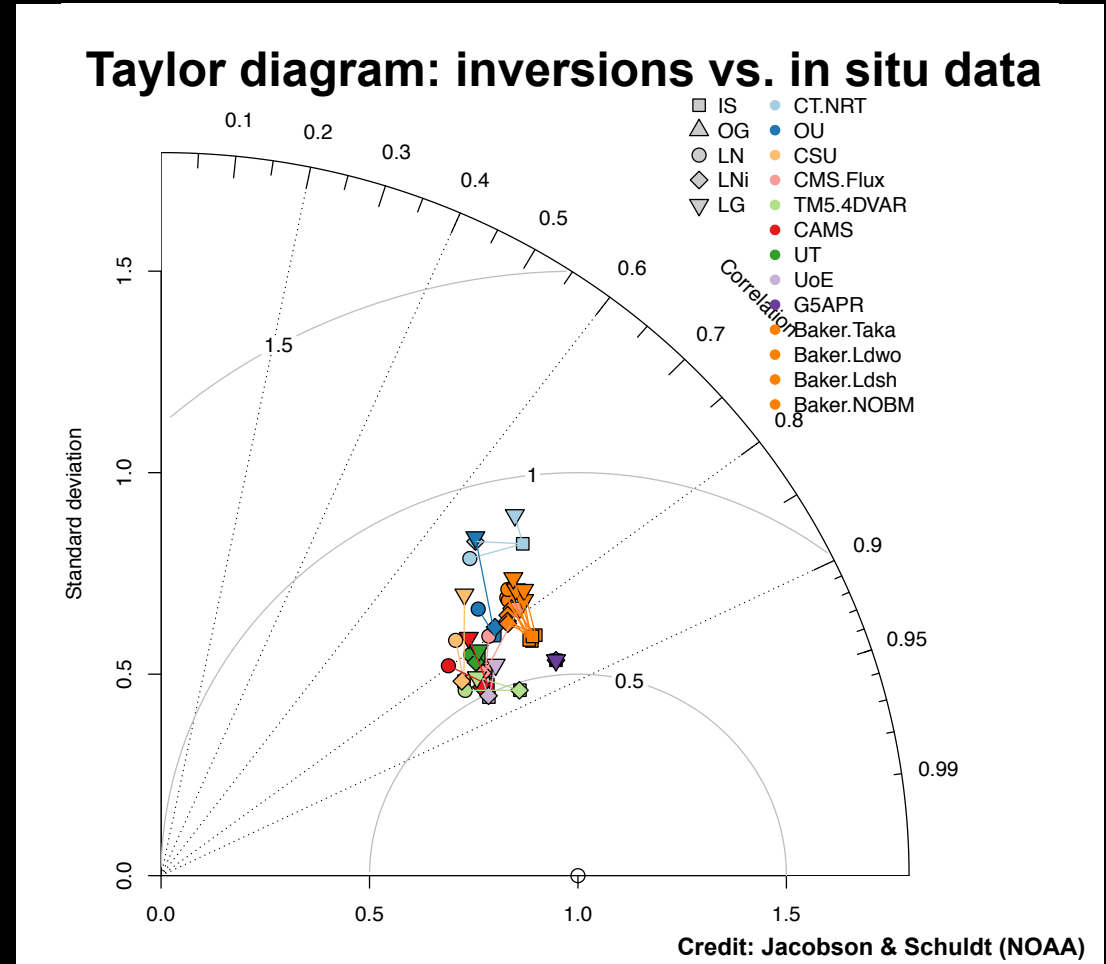
Thank you!

Acknowledgements: the OCO-2 project at JPL, CalTech, NOAA ESRL, HIPPO, ACT-America, CONTRAIL, and NASA CMS projects, & everyone I forgot
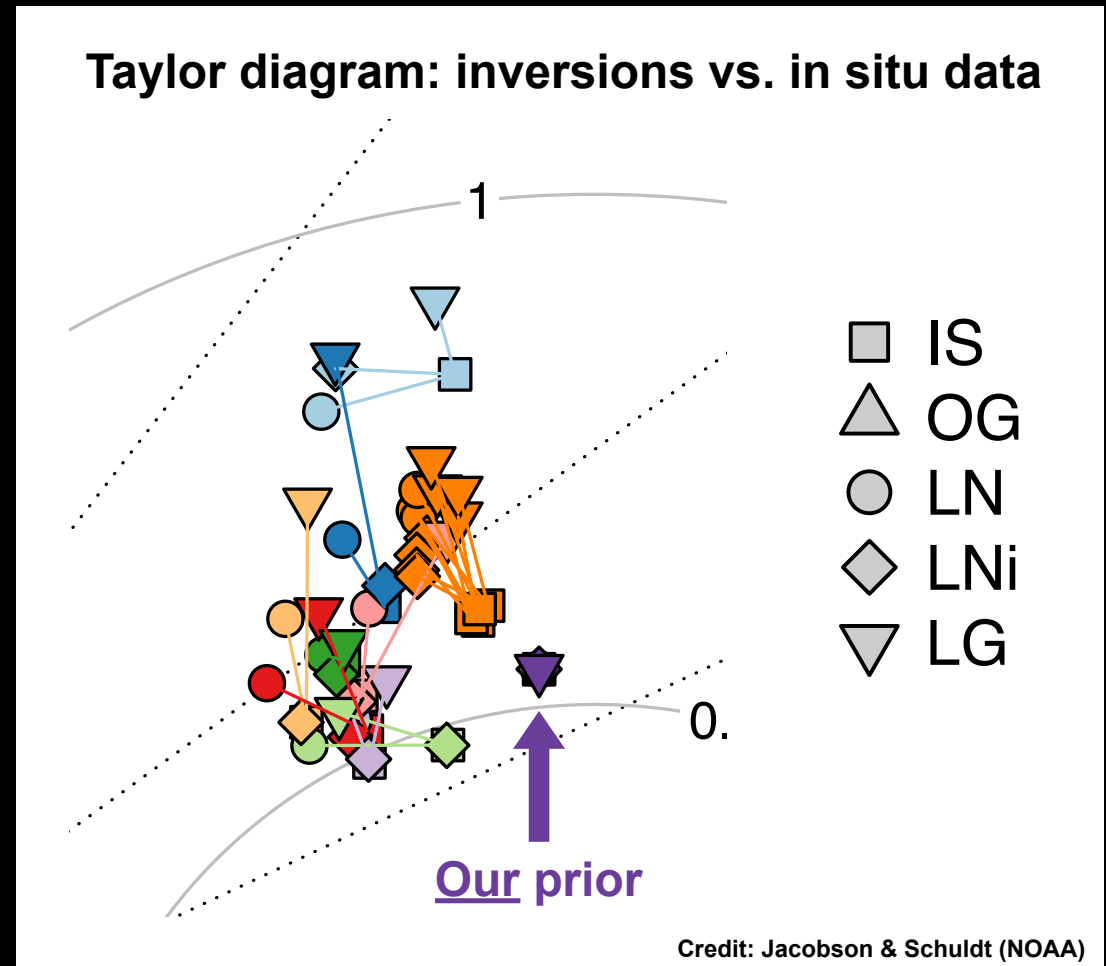
Backup slides

SLIDE TO MAKE (~~ALMOST~~) EVERYONE ANGRY

- Flux inversions are no better than a high-res simulation w/ a well-made prior

Taylor diagram: inversions vs. in situ data

Credit: Jacobson & Schuldt (NOAA)

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- Flux inversions are no better than a high-res simulation w/ a well-made prior

- It's easy to blame retrieval bias (satellite) or sparsity (in situ), but …

- Maybe model transport

- Maybe Taylor diagram not the best metric

Taylor diagram: inversions vs. in situ data

Our prior

IS
OG
LN
LNi
LG

Credit: Jacobson & Schuldt (NOAA)

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- Land fluxes based on "poor man's inversion" of Chevallier

- Ocean fluxes based on suggestions from Jacobson

- Input from Baker, Collatz, Poulter, Kawa, many others …

<u>Our</u> prior

BACKGROUND

- Can we construct a consistent picture of CO_2?

- Notably, 4D fields in space and time that agree with:

  1. Surface in situ measurements

  2. Aircraft in situ measurements

  3. Column retrievals (TCCON & satellites)

  4. A model based on reasonable scientific assumptions

- For me at least: answer is no, but yes is if #3 is excluded

- How do we attribute blame? … Most people trust #1 & #2, but not #3 & #4

- Basic idea: assimilate #1 & #2 into #3 and compare to #4