Assimilation of Compact Phase Space Retrievals (CPSRs): Comparison with Independent FRAPPE, IAGOS, and IASI Observations and Assimilation of Retrieval Partial Profiles

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8th International Workshop on Air Quality Forecasting Research
January 10 – 12, 2017
Toronto, ON Canada

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Overview

- WRF-Chem/DART (FRAPPE and 2008 Case).
- Compact phase space retrievals (CPSRs) and extension to truncated retrieval profiles.
- Comparison with independent FRAPPE, IAGOS and IASI observations.
- Dependence on form of the retrieval forward operator.
- Summary and Conclusions.

WRF-Chem/DART: Overview

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WRF-Chem/DART

- **WRF-Chem/DART** – a regional chemical weather forecast/ensemble data assimilation system (ensemble adjustment Kalman filter) developed by NCAR/ACOM and NCAR/IMAGe.
- **WRF-Chem** – the Weather Research and Forecasting (WRF) model with online chemistry.
- **DART** – the Data Assimilation Research Testbed (a flexible software environment for exploring different ensemble data assimilation methods, models, and observations.

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WRF-Chem/DART cont.

- **WRF-Chem/DART:**
  - ✓ Assimilate MOPITT and IASI CO total and partial column retrievals, IASI O_3 total and partial column retrievals (under development), OMI total column NO_2 retrievals (under testing), MODIS total column AOD retrievals, and AirNow *in situ* observations.
  - ✓ Assimilate partial column retrievals as raw (RETRs), quasi-optimal (QORs), and compact phase space retrievals (CPSRs).
  - ✓ State variable localization to enable joint, independent, and specified correlation assimilation of chemistry observations.
  - ✓ Uses State Augmentation Method (SAM) to obtain emission updates from assimilation of chemistry observations.
  - ✓ Real-time scripting system.

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WRF-Chem/DART cont.

- **WRF-Chem/DART:**
  - ✓ Being applied to 2008 Case Study (NCAR/ACOM – Mizzi, Arellano, Edwards, and Anderson); FRAPPE/DiscoverAQ (NCAR/ACOM – Mizzi, Pfister, and Edwards; UC-Berkley – Cohen and Liu), and PANDA (NCAR/ACOM – Mizzi and MPI-M – Brasseur and Bouarar).
  - ✓ **2008 Case Study** – CONUS domain with western extension 100 km (101x41x34) resolution; 20-member ensemble; June 1– 30, 2008; assimilate MOPITT and IASI CO and MODIS AOD.
  - ✓ **PANDA** – Central and East Asia nested domain with 60 km (150x112x37) and 20 km (148x157x37) resolutions; 10-member ensemble; assimilation on coarse grid; quasi-real time; assimilate MOPITT (development and testing).

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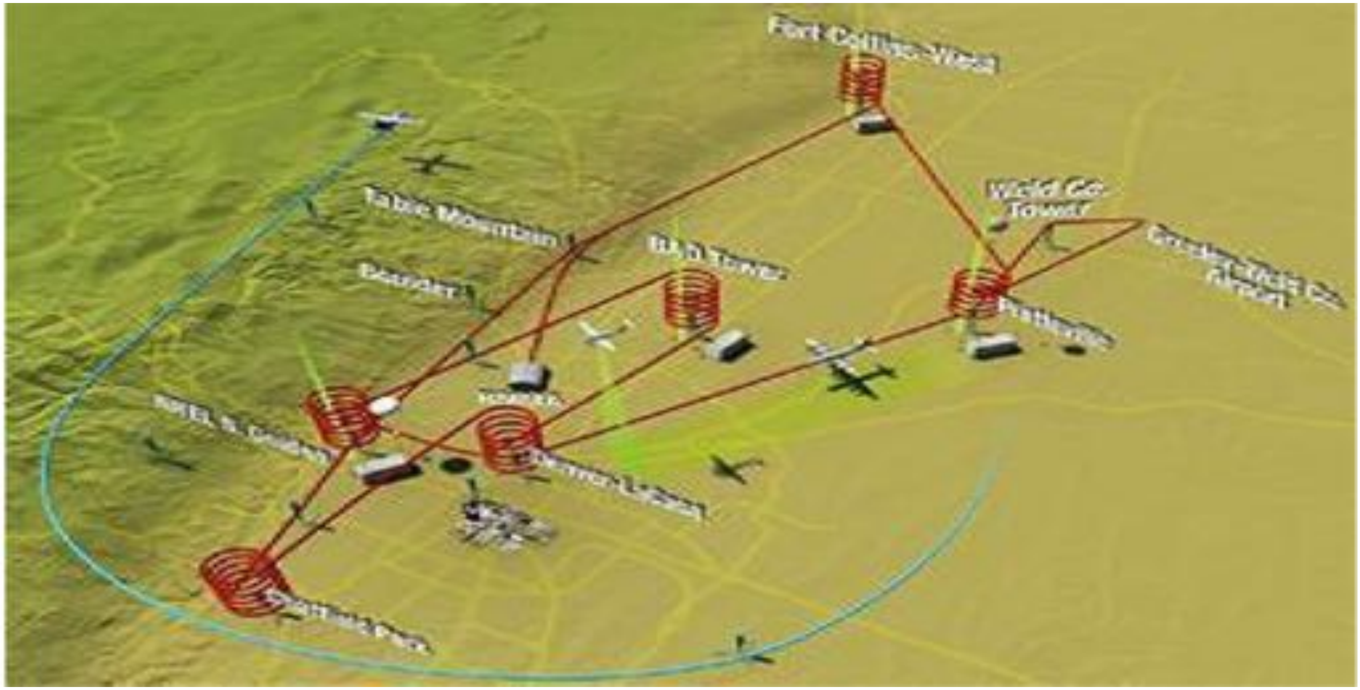
WRF-Chem/DART cont.

- **WRF-Chem/DART cont:**
  - ✓ **FRAPPE** – Western US nested domain with 15 km (180x140x37) and 3 km (321x291x37) resolutions; data assimilation on coarse grid; July 14 – August 3, 2014; 30-member ensemble; assimilate MOPITT CO; real time scripting.

FRAPPE/Discover-AQ Observation Domain



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Compact Phase Space Retrievals (CPRS): Extension to Truncated Retrieval Profiles

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CPSRs: Full Retrieval Profiles

- $y_r = Ay_t + (I - A)y_a + \varepsilon \Longrightarrow y_r - (I - A)y_a - \varepsilon = Ay_t$ where A is singular and its leading left singular vectors span its range.
- Project the quasi-optimal retrieval onto the leading left singular vectors of A: data compression step.
- That transform reduces the number of observations from the dimension of the retrieval profile to the number of non-zero singular values.
- The transformed E_m^2 is non-diagonal: use an SVD diagonalization (Anderson, 2003; Migliorini et al., 2008): diagonalization step.
- 1st SVD: $A = \Omega\Sigma\Psi^T = \Omega_0\Sigma_0\Psi_0^T$ - Compression Transform;

  2nd SVD: $\Omega_0^T E_m^2 \Omega_0 = \Pi\Lambda\Theta^T$ - Diagonalization Transform;

  Assimilate CPSRs:

$$\Pi^T\Lambda^{-1/2}\Omega_0^T(y_r - (I - A)y_a - \varepsilon) = \Pi^T\Lambda^{-1/2}\Sigma_0\Psi_0^T y_t.$$

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CPSRs: Extension to Truncated Retrieval Profiles

- Mizzi et al. (2017a):

$$\boldsymbol{y_r} - (\boldsymbol{I} - \boldsymbol{A})\boldsymbol{y_a} - \boldsymbol{\epsilon} = \boldsymbol{A}\boldsymbol{y_t}$$

  - ✓ Discard $\boldsymbol{m}$ elements of $\boldsymbol{y}_r$. The resulting dimension is $\boldsymbol{n}-\boldsymbol{m}$.
  - ✓ Discard the corresponding rows of $\boldsymbol{A}$, and the corresponding rows and columns of $\boldsymbol{E}_m$ (resulting dimension $(\boldsymbol{n}-\boldsymbol{m})\times(\boldsymbol{n}-\boldsymbol{m})$).
  - ✓ $\boldsymbol{A}$ was a square $\boldsymbol{n}\times\boldsymbol{n}$ matrix. It is now a rectangular $(\boldsymbol{n}-\boldsymbol{m})\times\boldsymbol{n}$ matrix. Thus, assimilation of retrieval partial profiles is called "CPSRs applied to rectangular systems."
  - ✓ The rest of the derivation follows Mizzi et al. (2016) due to their use of SVDs for the "compression" and "diagonalization" transformations.

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Comparison with Independent Observations (IASI, IAGOS/ MOZAIC, and FRAPPE)

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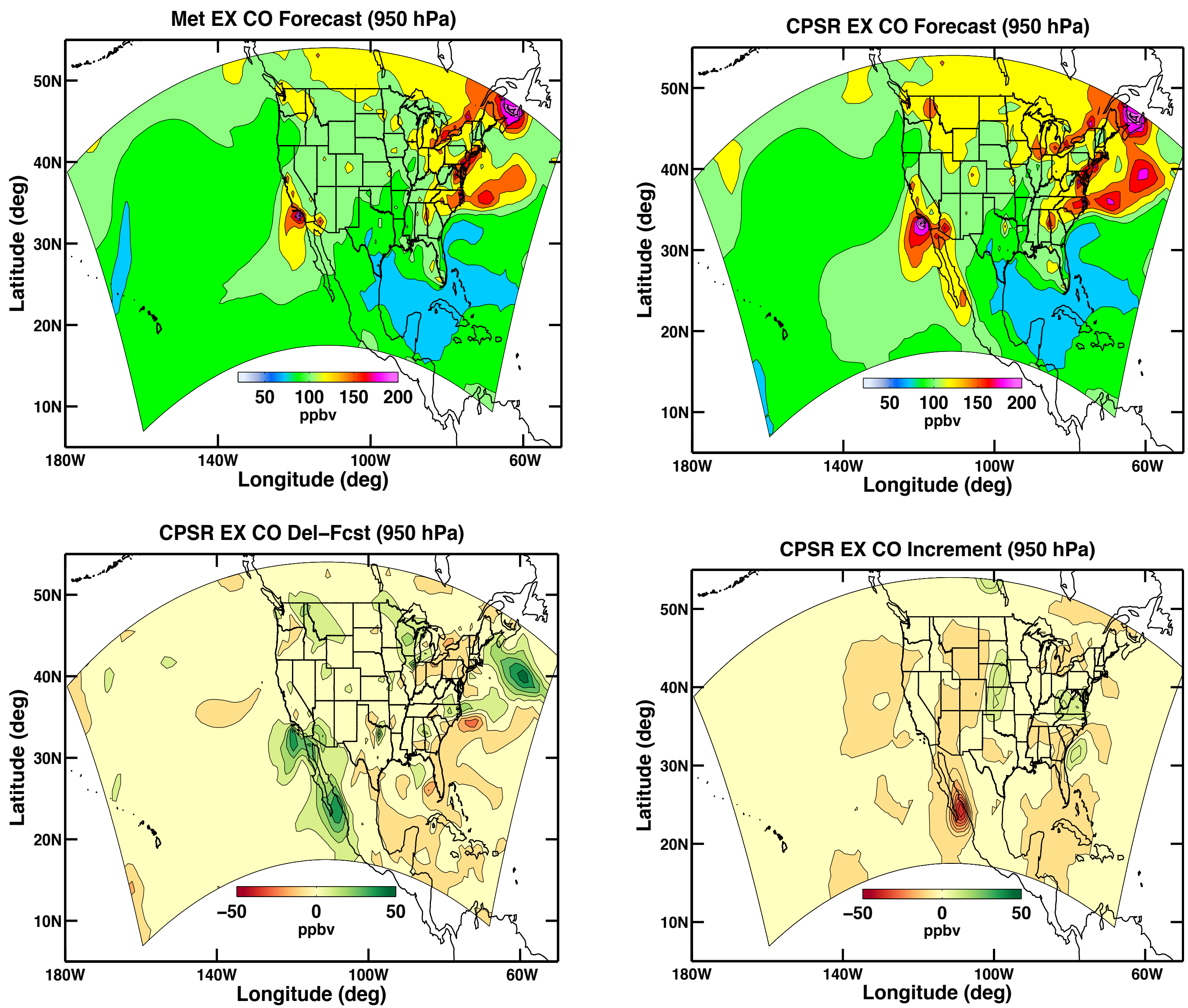
2008 Case Study: (June 19, 2008 18 UTC)



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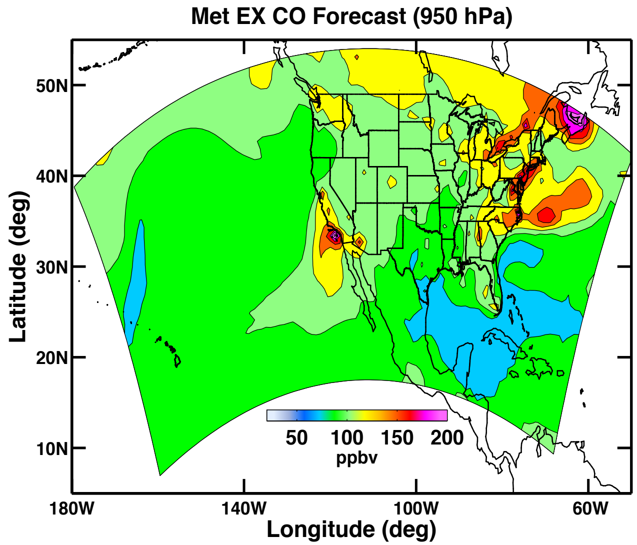
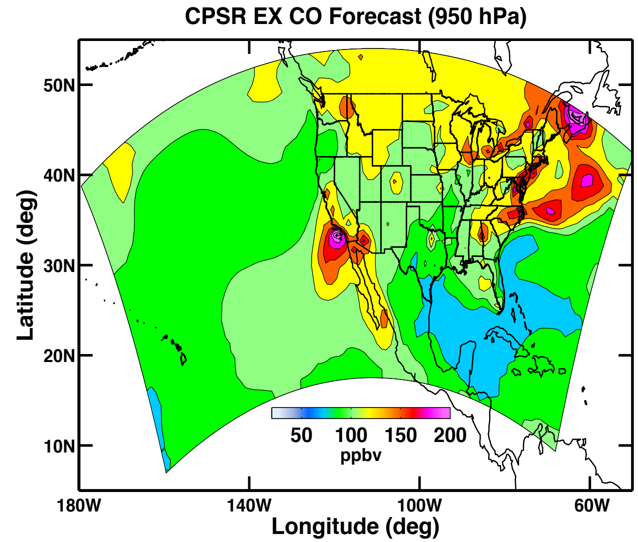
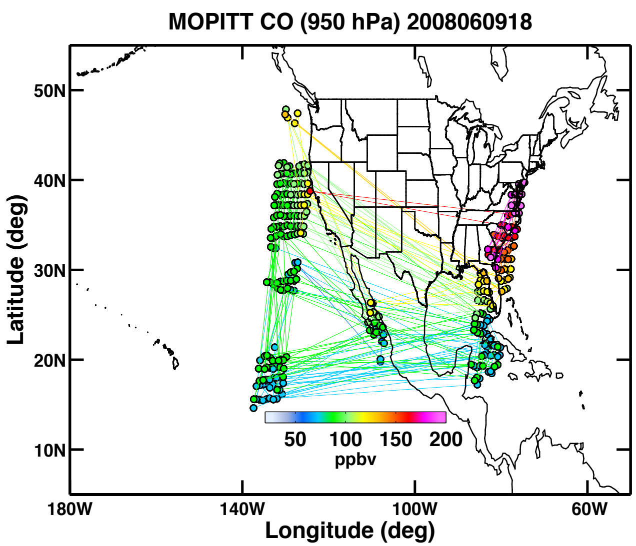
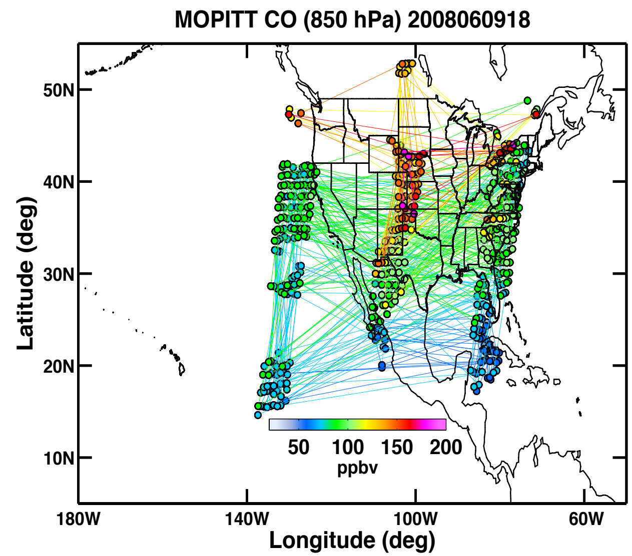
Comparison with MOPITT CO









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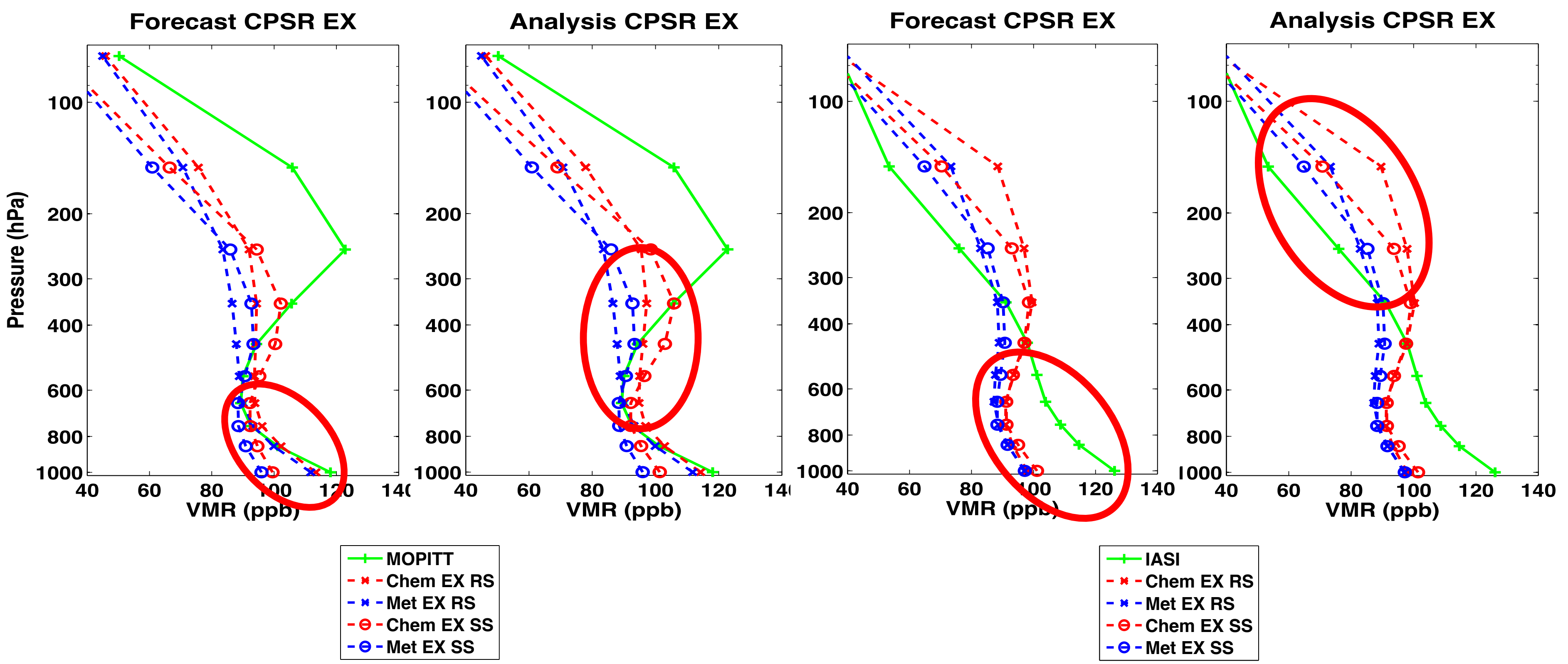
Vertical Profiles (Full Retrieval Profiles)



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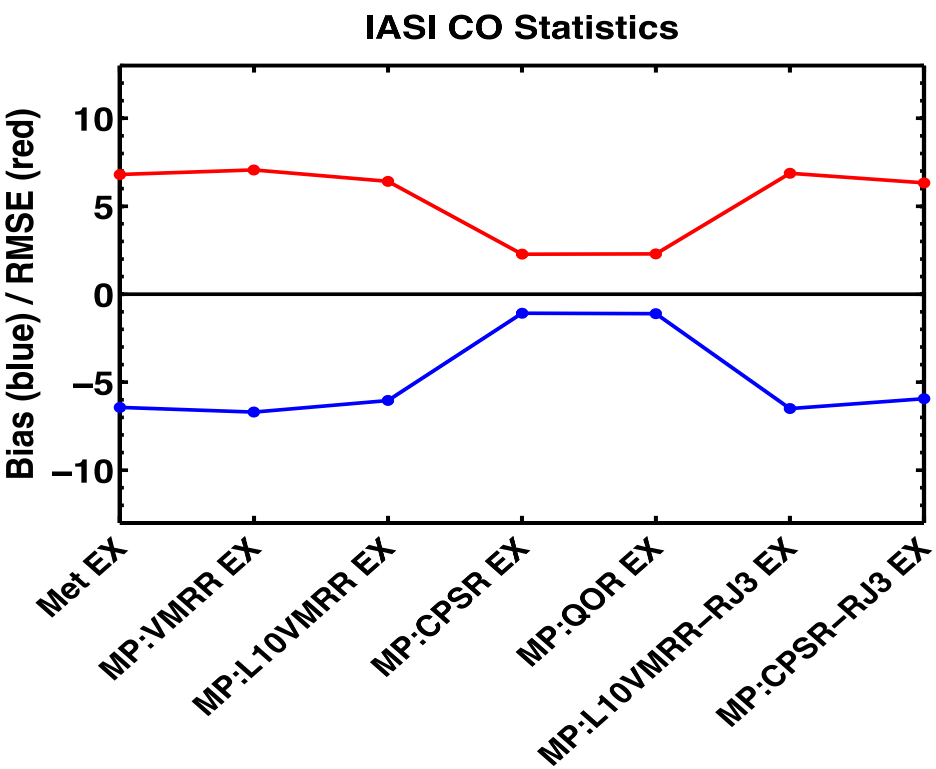
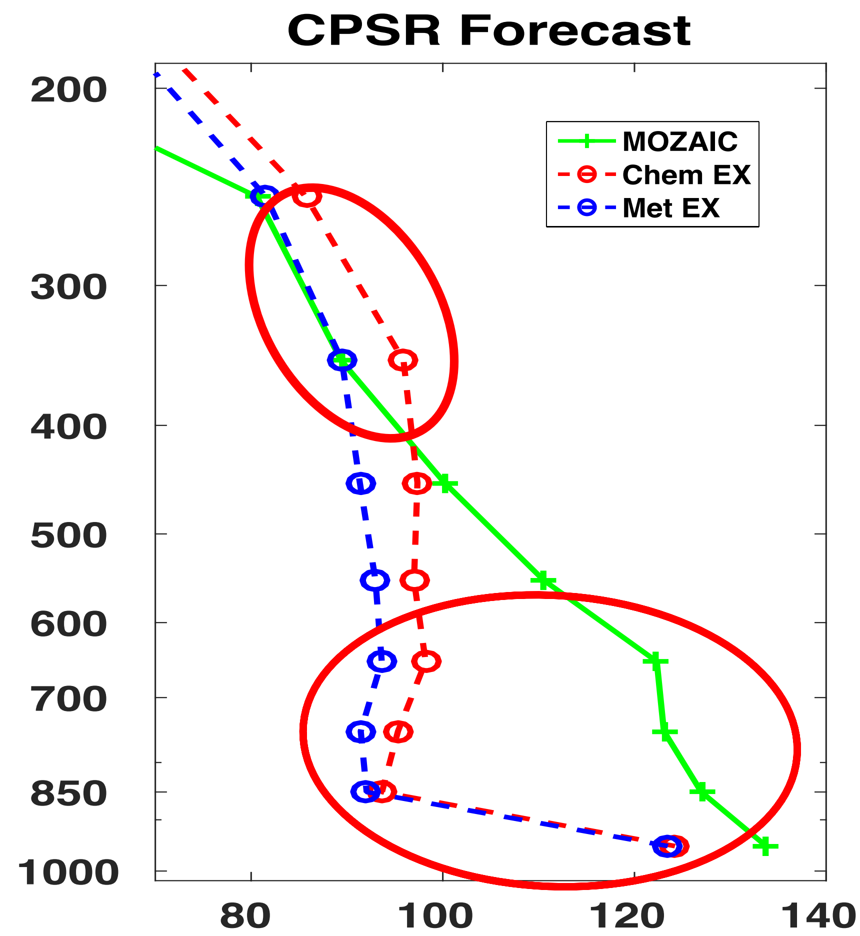
2008 Case Study: Forecast Verification





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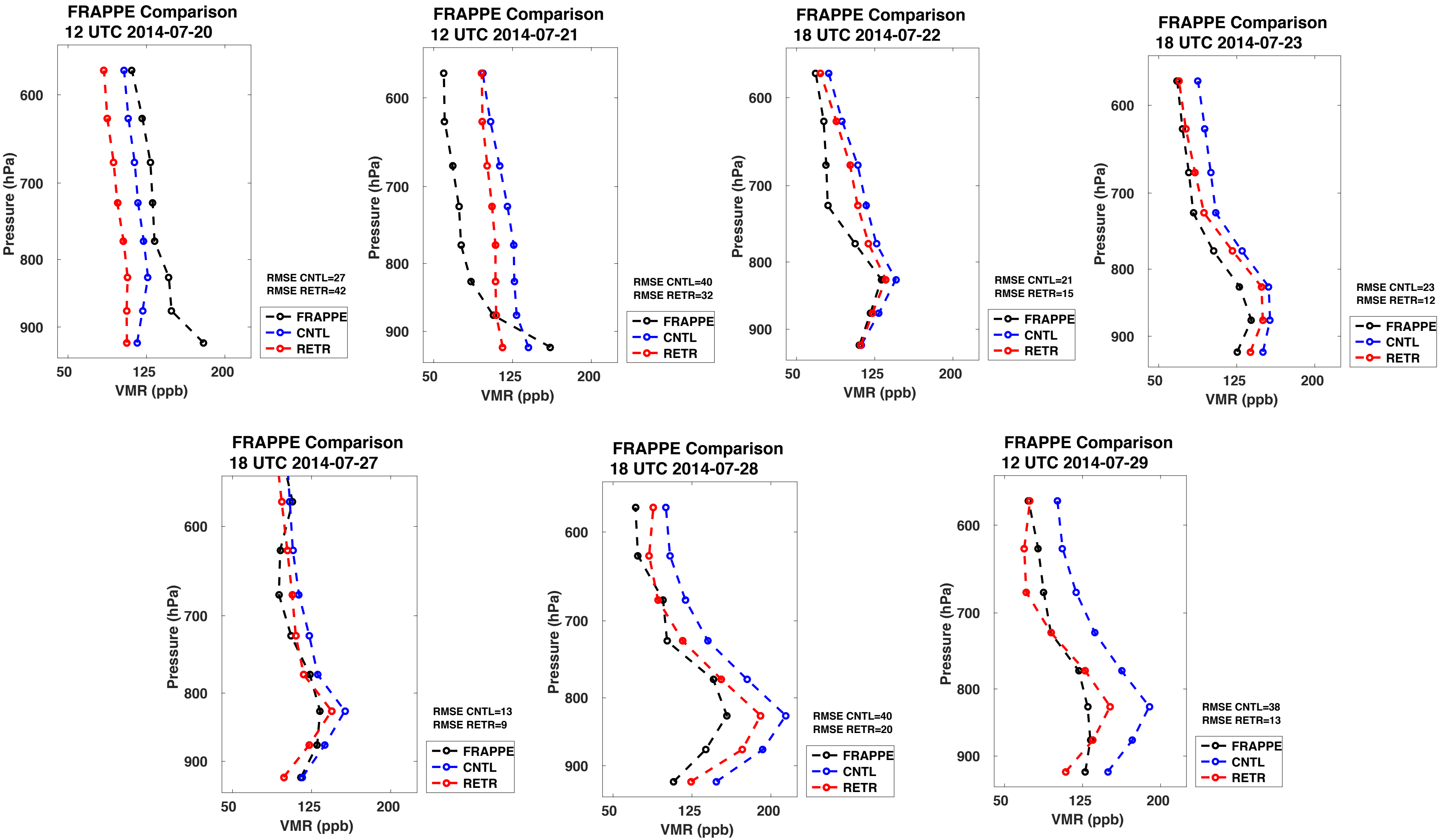
FRAPPE Results (July 14 – August 3, 2014)



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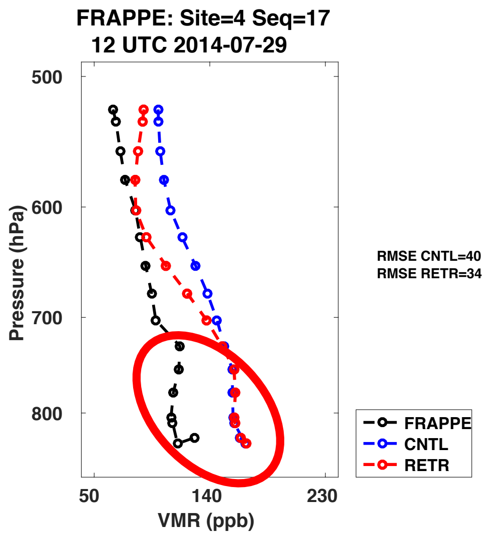
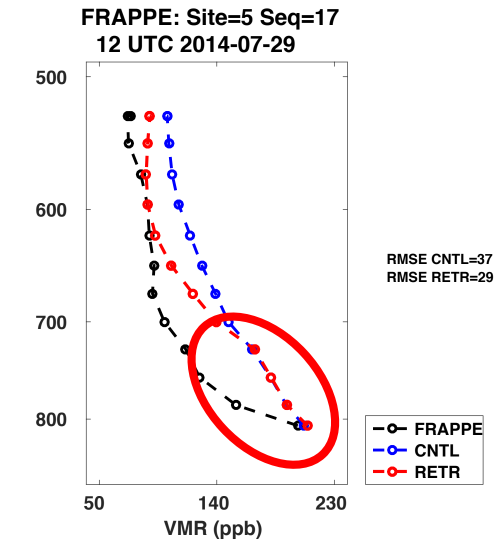
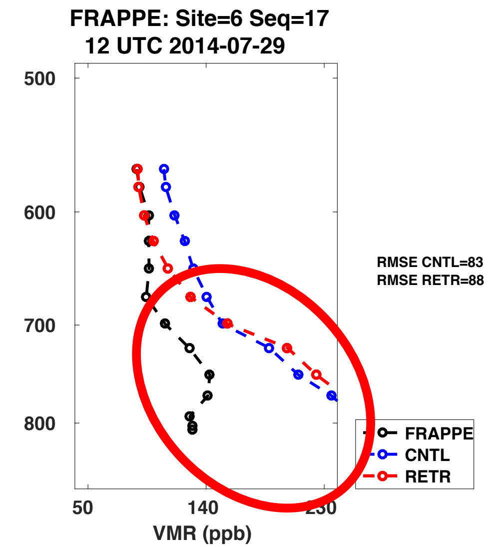
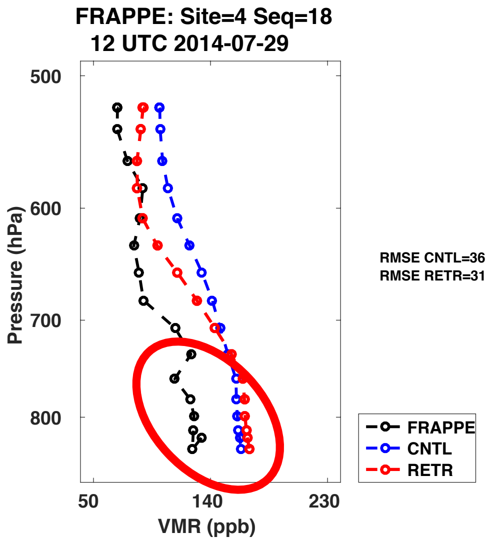
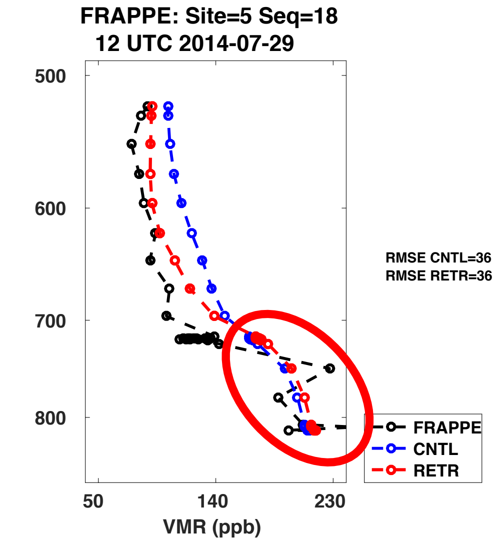
FRAPPE Results (July 29, 2014)

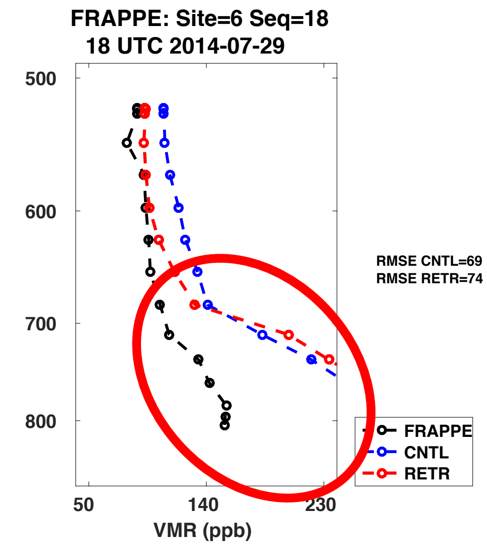












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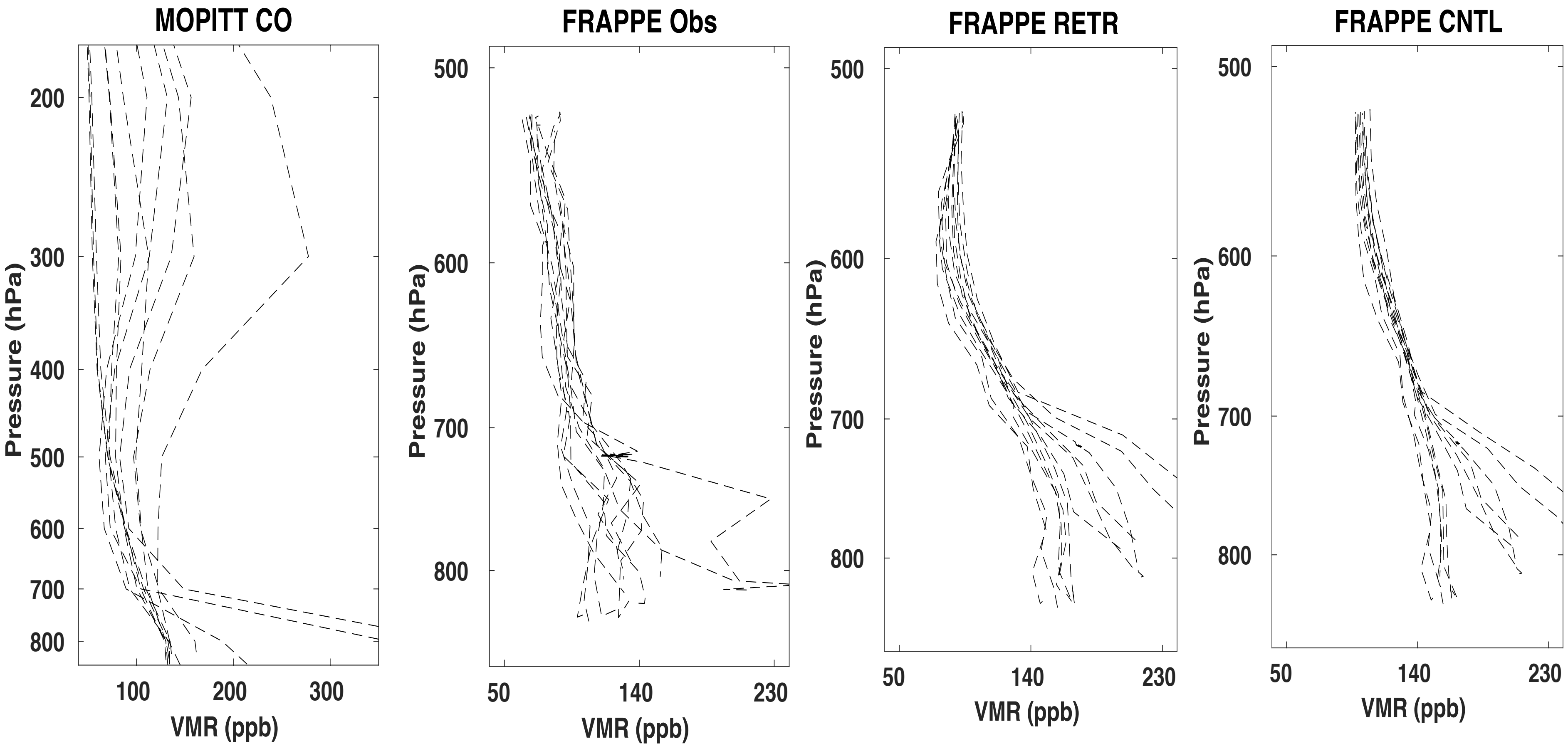
FRAPPE/MOPITT CO Results (July 29, 2014)



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Dependence on Form of the Retrieval Forward Operator

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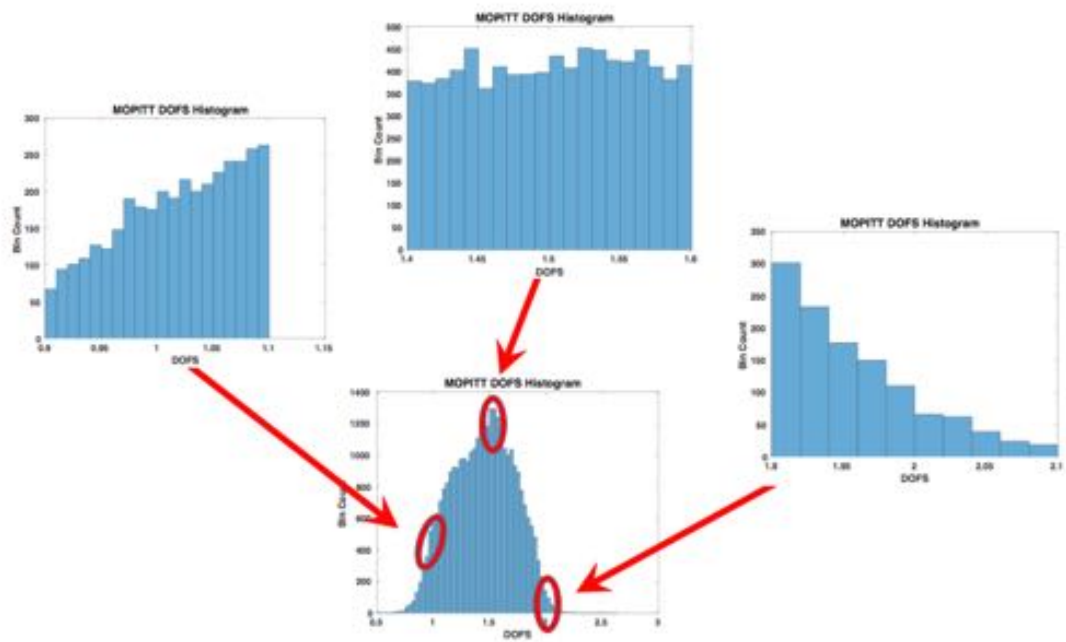
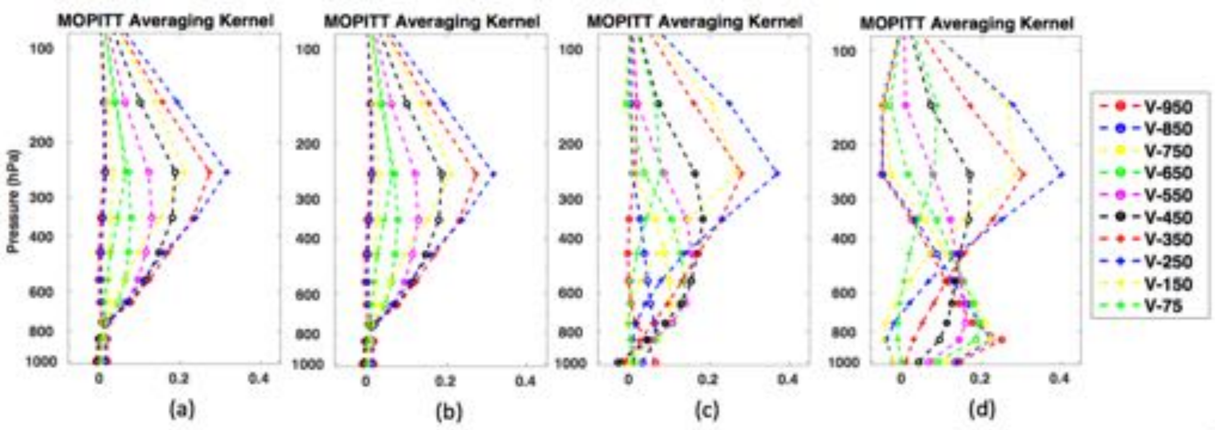
Dependence on the Retrieval Forward Operator

MOPITT DOFS Histograms





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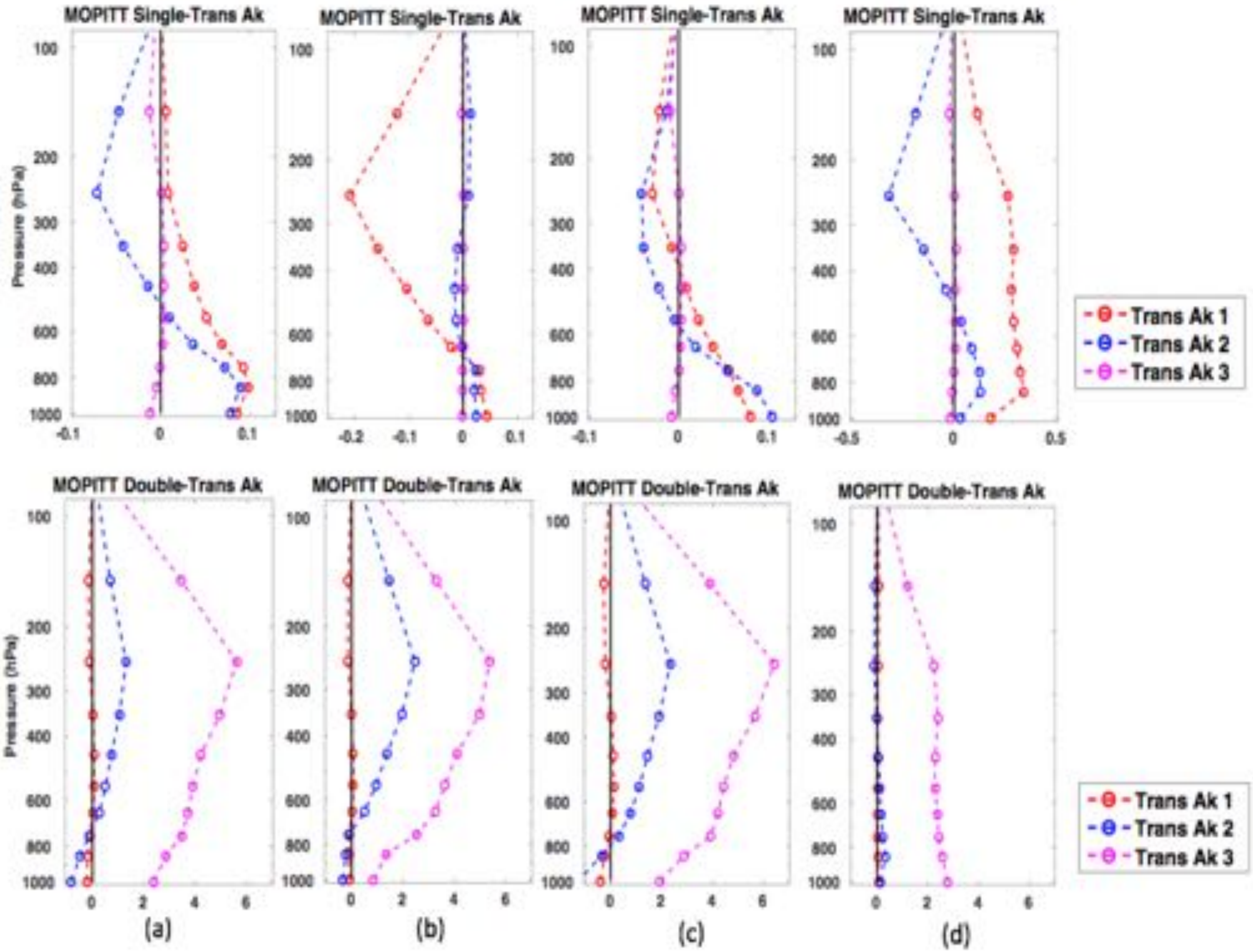
Dependence on the Retrieval Forward Operator



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Summary and Conclusions

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Summary and Conclusions

- Extended CPSRs to assimilation of truncated retrieval profiles to enable discarding of elements with known errors.
- Comparison of MOPITT CPSR CO assimilation/forecasts with 2008 Case IASI partial column CO retrievals, IAGOS/MOZAIC *in situ* CO, and FRAPPE *in situ* CO confirms that CPSRs improve the fit/skill (~80%) at a computational cost reduction (30% - 50%) compared to assimilation of raw or quasi-optimal retrievals.
- CPSRs can be applied to any partial column retrieval obtained through optimal estimation. Has implications to assimilation of total column retrievals.
- CPSRs successfully applied to joint assimilation (MOPITT and IASI CO CPSRs; MOPITT/IASI CO CPSRs and MODIS AOD RETRs) and emission estimation (MOPITT and IASI CO CPSRs, MODIS AOD RETRs to estimate dust and fire emissions).
- Analysis of different retrieval forward operators shows that averaging kernel sensitivities, and therefore assimilation/forecast results, depend on the form of the forward operator.

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References

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- Mizzi, A. P., D. P. Edwards, and J. L. Anderson: Assimilating compact phase space retrievals (CPSRs): Comparison with independent observations (MOZAIC in situ and IASI retrievals) and extension to assimilation of retrieval partial profiles. [*under internal review*], 2017a.
- Mizzi, A. P., X. Liu, A. F. Arellano, J. Liang, R. C. Cohen, Y. Chen, D. P. Edwards, and J. L. Anderson: Assimilating compact phase space retrievals (CPSRs): Joint assimilation of MOPITT and IASI CO as CPSRs and MODIS AOD as raw retrievals with constrained emissions. [*in preparation*], 2017b.

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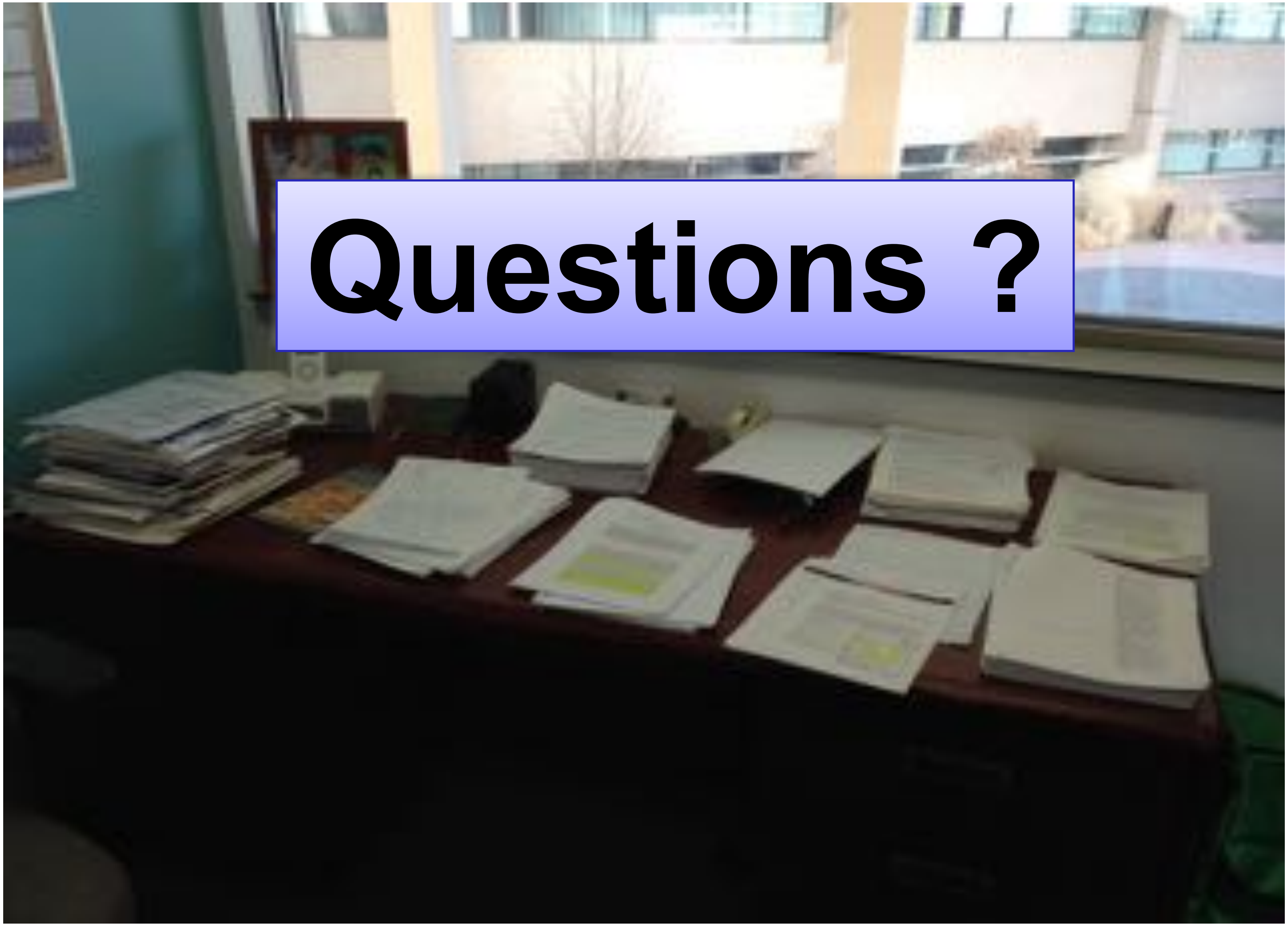

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Extra Slides (2008 Case – IASI CO Comparisons)

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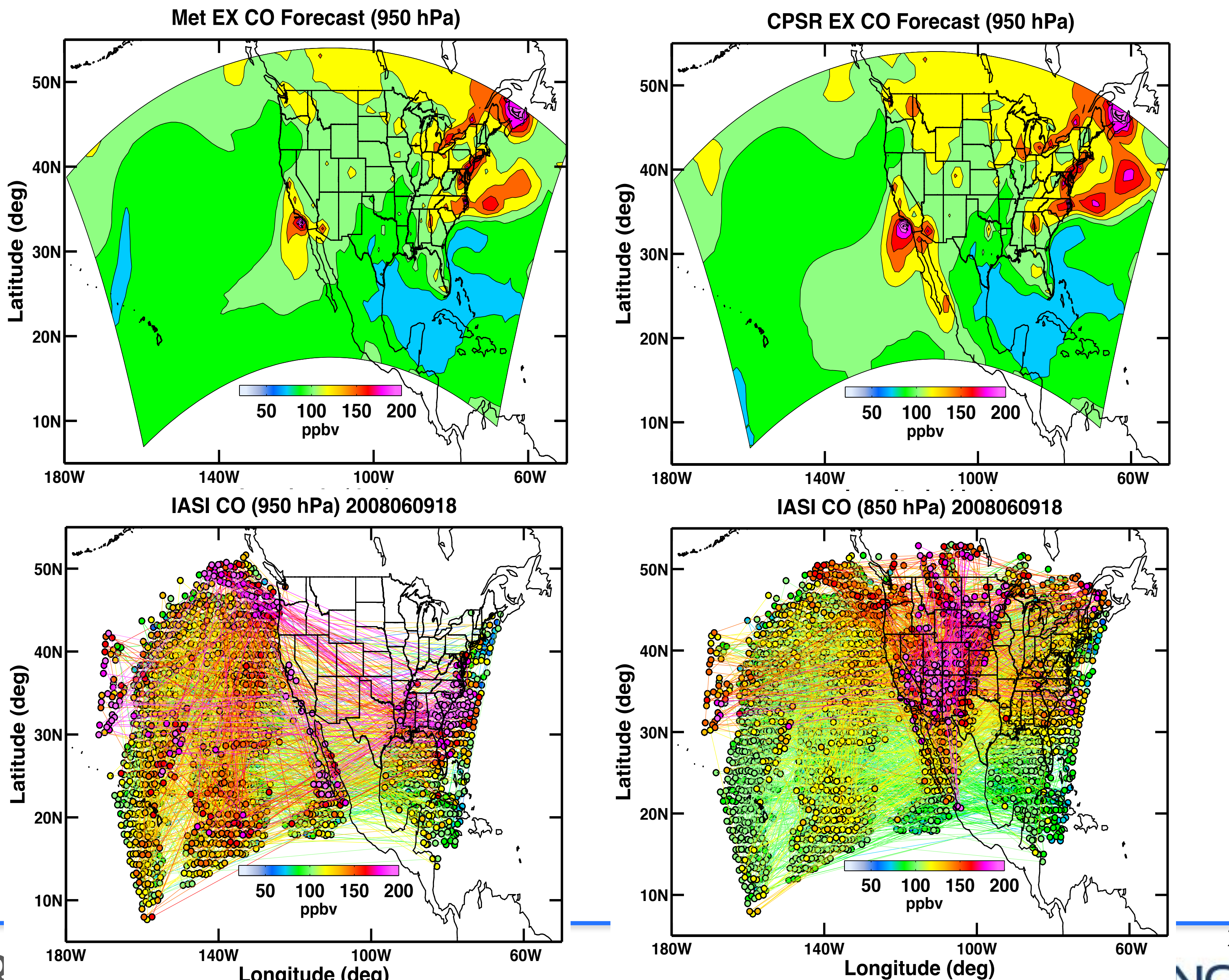
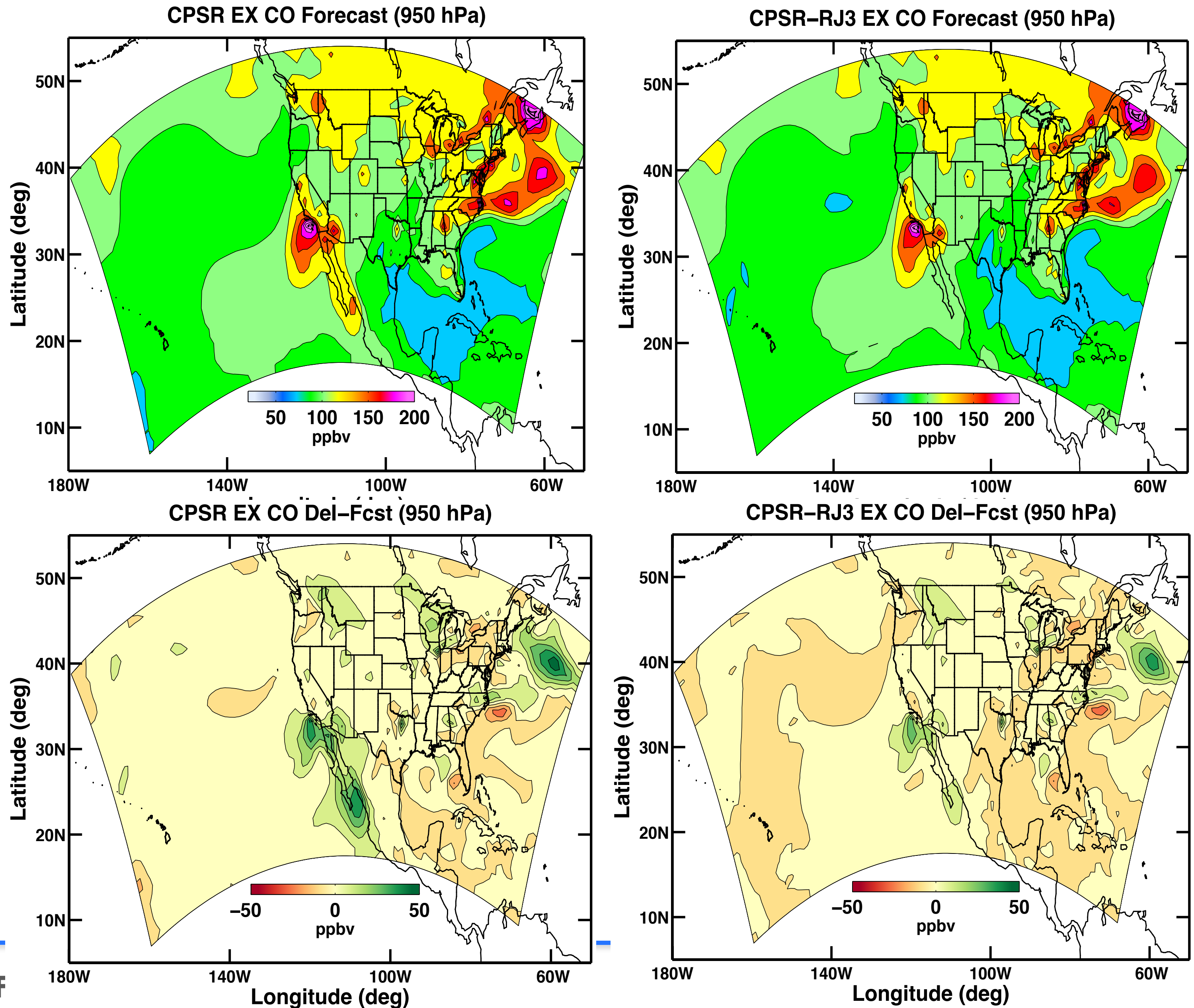
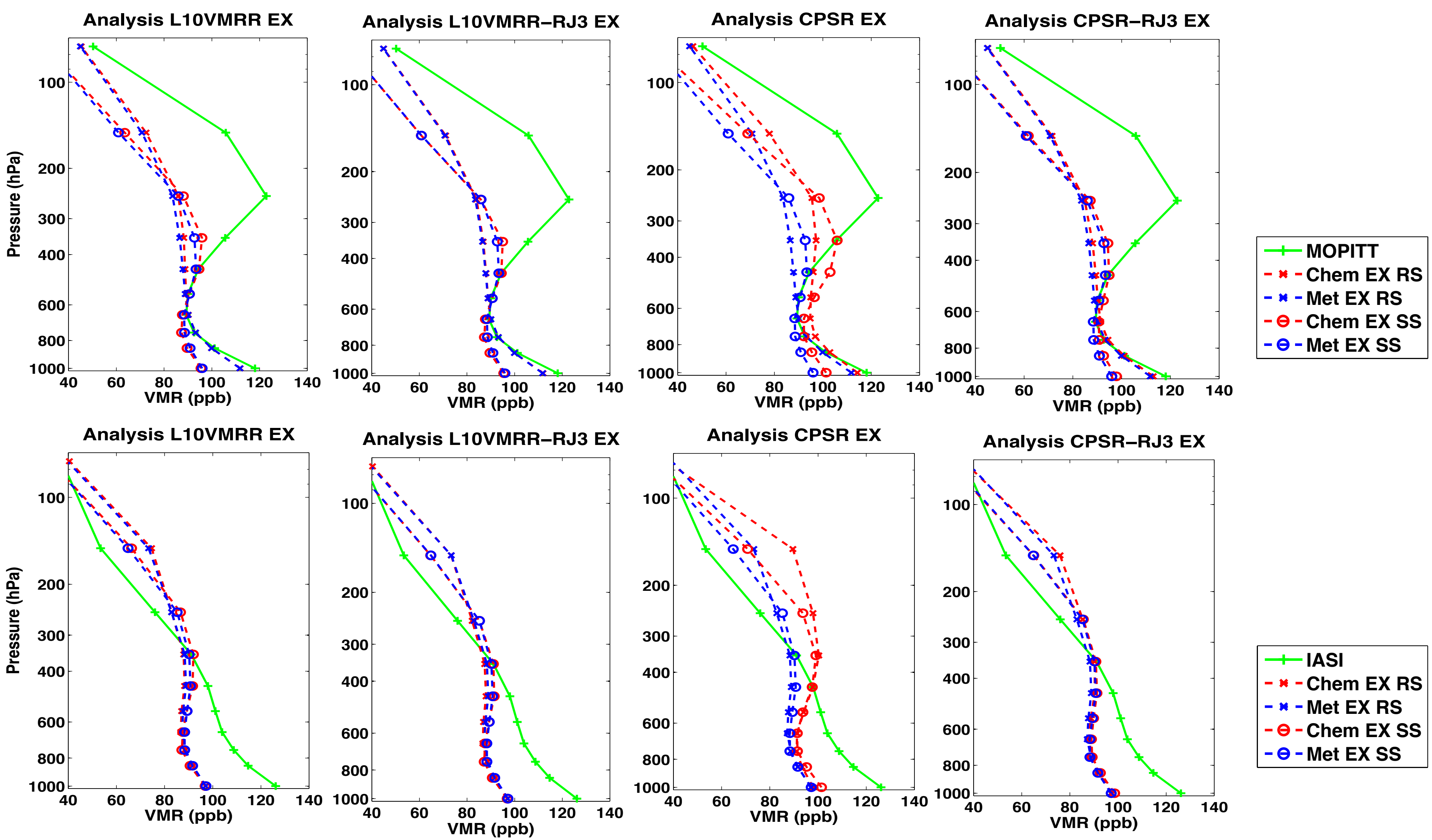
Comparison with IASI CO



CPSR Extension to Retrieval Partial Profiles



CPSR Extension to Truncated Retrieval Profiles



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