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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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
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.)
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.
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).
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](image-url)
Compact Phase Space Retrievals (CPRS): Extension to Truncated Retrieval Profiles
CPSRs: Full Retrieval Profiles

- \( y_r = Ay_t + (I - A)y_a + \varepsilon \Rightarrow y_r - (I - A)y_a - \varepsilon = Ay_t \) 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.

1\textsuperscript{st} SVD: \( A = \Omega \Sigma \Psi^T = \Omega_0 \Sigma_0 \Psi_0^T \) - Compression Transform;

2\textsuperscript{nd} SVD: \( \Omega_0^T E_m^2 \Omega_0 = \Pi \Lambda \Theta^T \) - Diagonalization Transform;

Assimilate CPSRs:

\[ \Pi^T \Lambda^{-1/2} \Omega_0^T (y_r - (I - A)y_a - \varepsilon) = \Pi^T \Lambda^{-1/2} \Sigma_0 \Psi_0^T y_t. \]
CPSRs: Extension to Truncated Retrieval Profiles

Mizzi et al. (2017a):

\[ y_r - (I - A)y_a - \epsilon = Ay_t \]

✓ Discard \( m \) elements of \( y_r \). The resulting dimension is \( n - m \).
✓ Discard the corresponding rows of \( A \), and the corresponding rows and columns of \( E_m \) (resulting dimension \( (n - m) \times (n - m) \)).
✓ \( A \) was a square \( n \times n \) matrix. It is now a rectangular \( (n - m) \times n \) 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.
Comparison with Independent Observations (IASI, IAGOS/MOZAIC, and FRAPPE)
2008 Case Study: (June 19, 2008 18 UTC)

Met EX CO Forecast (950 hPa)

CPSR EX CO Forecast (950 hPa)

CPSR EX CO Del–Fctd (950 hPa)

CPSR EX CO Increment (950 hPa)
Comparison with MOPITT CO

Met EX CO Forecast (950 hPa)

CPSR EX CO Forecast (950 hPa)

MOPITT CO (950 hPa) 2008060918

MOPITT CO (850 hPa) 2008060918
Vertical Profiles (Full Retrieval Profiles)

Forecast CPSR EX

Analysis CPSR EX

Forecast CPSR EX

Analysis CPSR EX

Pressure (hPa)

VMR (ppb)

MOPITT
- Chem EX RS
- Met EX RS
- Chem EX SS
- Met EX SS

IASI
- Chem EX RS
- Met EX RS
- Chem EX SS
- Met EX SS
2008 Case Study: Forecast Verification

IASI CO Statistics

CPSR Forecast

Bias (blue) / RMSE (red)

Pressure (hPa)
FRAPPE Results (July 14 – August 3, 2014)

FRAPPE Comparison 12 UTC 2014-07-20

FRAPPE Comparison 12 UTC 2014-07-21

FRAPPE Comparison 18 UTC 2014-07-22

FRAPPE Comparison 18 UTC 2014-07-23

FRAPPE Comparison 18 UTC 2014-07-27

FRAPPE Comparison 18 UTC 2014-07-28

FRAPPE Comparison 12 UTC 2014-07-29
FRAPPE Results (July 29, 2014)
FRAPPE/MOPITT CO Results (July 29, 2014)
Dependence on Form of the Retrieval Forward Operator
Dependence on the Retrieval Forward Operator
Dependence on the Retrieval Forward Operator
Summary and Conclusions
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.
References


- 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.

Questions ?
Extra Slides (2008 Case – IASI CO Comparisons)
Comparison with IASI CO

Met EX CO Forecast (950 hPa)

CPSR EX CO Forecast (950 hPa)

IASI CO (950 hPa) 2008060918

IASI CO (850 hPa) 2008060918
CPSR Extension to Retrieval Partial Profiles

CPSR EX CO Forecast (950 hPa)

CPSR–RJ3 EX CO Forecast (950 hPa)

CPSR EX CO Del–Fcst (950 hPa)

CPSR–RJ3 EX CO Del–Fcst (950 hPa)
CPSR Extension to Truncated Retrieval Profiles

Analysis L10VMRR EX

Analysis L10VMRR–RJ3 EX

Analysis CPSR EX

Analysis CPSR–RJ3 EX

Analysis L10VMRR EX

Analysis L10VMRR–RJ3 EX

Analysis CPSR EX

Analysis CPSR–RJ3 EX

Pressure (hPa)

VMR (ppb)

MOPITT

Chem EX RS

Met EX RS

Chem EX SS

Met EX SS

IASI

Chem EX RS

Met EX RS

Chem EX SS

Met EX SS