Applying Analysis Method to Two Satellite Retrieved CO Data

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• Dr. Wei’s algorithm to match AIRS granules with TES observation
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1. Data assimilation formula
   Assumptions/approximations and the rationales behind
   • Background error covariance
     Error correlation model
   • Observation error covariance
2. Sanity check—whether the code works (correctly)
   It is very important to design a sufficient test scheme/procedure to ensure the code works as you expected.
3. Analysis results
4. Open questions
1. Data assimilation formula

\[ X^a = X^b + P^b H^T (H P^b H^T + R)^{-1} (X^o - H X^b) \]

- \( X^a \) is analysis variable
- \( X^b \) is background variable, here is AIRS CO (in unit of vmr)
- \( X^o \) is observation values, here is TES CO (in unit of vmr)
- \( P^b \) is background error covariance matrix
- \( H \) is observation operator
- \( R \) is observation error covariance matrix

\[ P^b = D^{1/2} C D^{1/2} \]

The elements of \( P^b \) is:

\[ P_{i,j}^b = \sigma_i \sigma_j \rho_h \rho_v \]

Here, \( D \) is the error variance in background field with elements of \( \sigma_i \); and \( C \) is error correlation model, \( \rho_h \) *is horizontal correlation model and \( \rho_v \) is vertical correlation model.*
1. Data assimilation formula

Assumptions/approximations and the rationales behind

*Background error covariance*

error variance and error correlation model

- Error variance—1D profile
- Separate error correlation models
  - Power-Law in horizontal direction (Dee and da Silva, 1999)
  - a “Gaussian” kind of vertical correlation model (Daley and Barker, 2000)

*Observation error covariance*

- No correlation- a diagonal matrix; variance: 1D profile
\[ \rho_n = \left( 1 + \frac{1}{2} \left( \frac{r}{L_o} \right)^2 \right)^{-1} \]

This Figure shows the power law function with 750 km as the horizontal error correlation length.
Exponential function of vertical error correlation:

\[ R_v = \exp(- (\Delta y)^2), \Delta y = (\ln P_n - \ln P_l)/L_z. \]  

\( \Delta y \) is a “scaled” pressure difference between two vertical levels, \( \ln \) is the logarithm note; \( L_z \) is a tunable parameter.

![vertical correlation function L=0.1706](image)
Experiment runs:

Background field: AIRS CO
Observation: TES CO

*In analysis:*
Three AIRS granules are matched with TES CO. Each AIRS granule consists of 30*45 foot prints (6 minutes covering range).

Vertical level: surface to about 80mb

Time period: March 2006
2. Sanity check—whether the code works

Check 1

When $L_0$ is very small, the analysis value at a footprint of AIRS will be close to $x_a = x_b + K(O-h(x_b))$, here $O-h(x_b)$ is called innovation, also written as OMF.

$K$ approximately equals to $\frac{\sigma_b^2}{\sigma_b^2 + \sigma_o^2}$
(approximation: $H=1$), here $\sigma_b$ and $\sigma_o$ are the error standard deviation in background variable and observation variable, respectively.

Check 2

The shape and magnitude of the OMF spreading change with values of $L_0$.
3. Analysis Results

In this simple analysis case, it is easy to see the roles of the parameters/assumptions in the final analysis results.

For example:

1. Horizontal error correlation model and the length $L_0$—they determine the spreading range and magnitude of observation information at background space. This length is a tunable variable.

2. You can tell which data ($x_b$ or $x_o$) are dominant in the magnitudes of the analysis field at a given vertical level by comparing the values of sigb and sigo.

Examine the results:

- Horizontal fields
- Statistics of innovation and analysis increment
- Histogram of OMF/OMA—bias check
- Comparison of analysis results with in-situ observation (not covered here, refer to J. Warner etc., 2013)
Grid-averaged monthly mean CO distribution at about 944 mb. TES CO (top panel), AIRS CO (middle panel) and Assimilated CO (bottom panel).
Grid-averaged monthly mean CO distribution at about 510 hpa. TES CO (top panel), AIRS CO (middle panel) and Assimilated CO (bottom panel).
Grid-averaged monthly zonal means. Left column shows the fields projected in AIRS observation space: AIRS CO (top panel), analysis CO (middle panel) and analysis increment (bottom panel). Right column shows fields projected in TES observation space: AIRS CO interpolated to TES observation location (top panel), TES CO (middle panel), and OMF (bottom panel).
Histogram of OMF averaged globally at 510 hpa
4. Discussion and questions

• Relaxing the assumptions - balance between considering realistic assumptions and computation feasibility.
  example: error covariance modeling
• In this data analysis application whether need to include averaging kernels (AK) in the forward model (H)? If yes, under what situation(s) the role of the AK is significant?
• In general tracer assimilation (with model as first guess) whether need to include averaging kernels (AK) in the forward model (H)? Two kinds of treatments are used as I know. Under what situation(s) the role of the AK is significant?

Reference:
About retrieval averaging kernel:
• Barnet and Maddy, 2009: What are retrieval averaging kernels? (seminar at the UMD)
About data assimilation:
• K. Wargan, 2013, Ozone Data Assimilation (seminar)
• Other papers