Key Ingredients for Regression Inversion:
AIRS Satellite and NAST-I Aircraft Applications

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Empirical Orthogonal Function (EOF)  
NAST-I/AIRS Regression Retrieval

For clear sky and opaque cloud:

\[ R = \varepsilon_{s,c} B_{s,c} \tau_{s,c} - \int_{P_{ac}}^{P_{s,c}} Bd \tau - (1 - \varepsilon_{s,c}) \tau_{s,c} \int_{P_{s,c}}^{0} Bd \tau^* \]

Radiance EOF Amplitudes

\[ C_i = \sum_{j=1}^{n_c} R_{ji} E_{ji} \]

Retrieval Solution

\[ \left\{ T_s, \varepsilon_s(v), T(p), Q(p) \right\} = \sum_{i=1}^{n-1} K_{mi} C_i + K_{mn} P_s \]

- Physical Regression – EOFs and regression training based on calculated radiances
- Training should include cloud, sfc. emissivity, skin temp, and solar variability
- Null radiance errors assumed for PC specification and regression training
- EOF # selected by spatial radiance RMSD (observed minus retrieval) minimization

\( R = \) radiance  
\( \varepsilon_{s,c} = \) surface or cloud emissivity  
\( B_{s,c} = \) surface or cloud Planck radiance  
\( \tau = \) transmittance between aircraft and atmospheric Pressure level (P)  
\( \tau_{s,c} = \) atmospheric transmittance between aircraft and surface or cloud (P_{s,c})  
\( \tau^* = \) atmospheric transmittance between surface or cloud P and aircraft  
\( P_{ac} = \) aircraft pressure, \( P_s = \) surface pressure  
\( \mathcal{R} = \) radiance  
\( E = \) radiance covariance EOFs  
\( C = \) radiance EOF amplitudes  
\( T = \) temperature  
\( Q = \) H₂O mixing ratio  
\( K = \) regression coefficients
Important Notes on EOF Regression

**Training:**
- Regional (~3000 km), seasonal (~3 month) radiosonde sample
- Trace gases manufactured using statistical regression data sets
- Surface emissivity/reflectivity spectrum provided by random selection from the Salisbury/SEBASS data sets
- Cloud-free and cloud radiance spectra computed for each profile. Cloud profiles modified to be isothermal (@ cloud temperature) and humidity below cloud level diagnosed from radiosonde humidity profile
- Radiance EOFs and retrieval parameter regressions produced from “error-free” synthetic data
- For surface emissivity, 5 amplitudes of EOF representation of Salisbury/SEBASS data set are regressed against radiance
- Predictors are radiance EOF amplitudes and surface pressure
- Predictands are sfc skin temperature, sfc emissivity amplitude, reflected solar intensity amplitude, atmospheric temperature, $H_2O$, $O_3$, and CO mixing ratio.
Important Notes on EOF Regression

**Application:**
- EOF # selected as that value which minimizes the spatial radiance RMSD (observed minus retrieval) for a representative regional sample of the data set being analyzed
- Surface pressure used in regression estimated from surface height for standard atmospheric conditions
- Surface emissivity spectrum produced using 5 EOF representation and amplitudes predicted radiance spectra
- Cloud height altitude diagnosed from retrieved relative humidity profile and local (i.e., 3 x 3) variance of temperature profile retrievals
- Solar contribution should be accounted for by assuming that the surface reflectivity is proportional to the surface emissivity, given the solar zenith angle and measurement nadir angle as measured variables. Solar contribution is included in the training with a single coefficient (the amplitude of the solar reflectivity spectrum) being retrieved.
EOF Reduction of 1000’s of Spectral Channels of Radiance to 10’s of Independent Pieces of Information Improves S/N by an order of magnitude
Opaque Cloud Effects on Retrieval

NAST I-HOP June 12, 2002 Over Oklahoma

Cloud Tops
Moist Layers

NAST-I Temp (K) Cross Section

NAST-I RH (%) Vertical Cross Section

Cloud Tops
PBL Ht
Moist Layers
These retrievals, uncorrected for cloud attenuation, demonstrate the ability to sense the spatial structure of moisture below a scattered and semi-transparent cirrus cloud cover.
Thin Cirrus Effects on Retrieval

NASA SRL data
May 30, 2002 (19.5 – 23 UT)
(37.8N, 100W)

GOES IR (2208 UT)
GOES Visible (2208 UT)

Aerosol Backscatter

Thin cirrus produces little effect on retrieval

Aerosol Depolarization
Cloud Height Diagnosis

Temperature (K)

Relative Humidity (%)

Pressure (mb)

STD of local 3x3 Temperatures
Surface Temperature & Emissivity Retrieval

Buoy 297.4 K

NAST 296.52° K (σ= 0.54° K)

\[ \varepsilon = \frac{R_{\text{obs}} - A_{\uparrow} - A_{\downarrow}}{(B_s\tau_s - A_{\downarrow})} \]

Lab. measured (solid)
NAST-I retrieved (dashed)
NAST-I validation (dots)
Surface Emissivity Impact on PBL Moisture

Chesapeake Light Raob
July 14, 2001

\[ \varepsilon_s = 1 \]

Variable \( \varepsilon_s \)
AIRS, NAST, “CrIS”, and “GIFTS” Retrievals

**AIRS (IR Grating Spectrometer)**
- Spectral Range: 3.7 – 15.4 Microns
- Spectral Resolution: $\nu/\delta \nu = 1200$

**Spatial Resolution**
- 13.5 km @ nadir

**Swath Width**
- 1650 km

**NAST-I (IR Interferometer)**
- Spectral Range: 3.5 - 16 Microns
- Spectral Resolution: $\delta \nu = 0.5$ cm$^{-1}$ (apodized)

**Spatial Resolution**
- 2.6 km @ 20 km

**Swath Width**
- 40 km @ 20 km

930-945 cm$^{-1}$
AIRS, NAST, “CrIS”, and “GIFTS” Retrievals

(8.8 to 14.6 microns)  (4.4 to 6.1 microns)
NAST-I and AIRS Spectra and Retrieval Channels

Note: NAST Retrieval Channel NEdN @ AIRS Spatial Resulation < 0.05K
CRYSTAL-FACE
Aqua Validation Flight
July 26, 2002

Aqua Track

Proteus Track

Aircraft Altitude
AIRS and NAST-I Retrieved Surface Temperature
(AIRS FOV locations used for NAST-I comparisons shown)
**Temperature & Relative Humidity Comparisons**

**AIRS West of NAST Track**
- AIRS Temperature (14 km)
- AIRS Relative Humidity (14 km)

**NAST At AIRS Spatial Resolution**
- NAST Temperature (2 km)
- NAST Relative Humidity (2 km)

**Note:** Retrievals based on same algorithm (Physical EOF Regression) but different line-by-line codes (The UMBC kCARTA/SARTA for AIRS and the AER LBLRTM/OSS for NAST). SARTA stands for “Stand Alone AIRS Radiative Transfer Model” and OSS stands for “Optimal Spectral Sampling”.
Temperature & Relative Humidity (PC Filtered)

AIRS Temperature (14 km)

AIRS Relative Humidity (14 km)

NAST Temperature (2 km)

NAST Relative Humidity (2 km)
Temperature & Relative Humidity (AIRS Res.)

AIRS Temperature (14 km)

AIRS Relative Humidity (14 km)

NAST Temperature (14 km)

NAST Relative Humidity (14 km)
Temperature and Relative Humidity Retrieval Comparisons (Deviation from Mean)

Note: Retrievals based on same algorithm (Physical EOF Regression) but different line-by-line codes (The UMBC kCARTA/SARTA for AIRS and the AER LBLRTM/OSS for NAST). SARTA stands for “Stand Alone AIRS Radiative Transfer Model” and OSS stands for “Optimal Spectral Sampling”.

Unfiltered

NASTI Temp Deviation from Mean @ AIRS Spatial Resolution

NASTI RH Deviation from Mean @ AIRS Spatial Resolution
Temperature and Relative Humidity Retrieval Comparisons (Deviation from Mean)

PC filter removes noise but does not change the vertical resolution
**Difference: AIRS – NAST-I**

Differences Consistent with Current Retrieval and Forward Model Accuracy Expectation

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**Mean Temp Diff (K)** vs **Altitude (km)**

**Temp STD (K)** vs **Altitude (km)**

**Mean RH Diff (K)** vs **Mean RH Diff (K)**

**RH STD (%)** vs **Altitude (km)**
Radiosonde (Miami) Comparisons

Note: Radiosonde is ~160 km South of AIRS & NAST-I Soundings
AIRS and NAST Date Used for Intercomparison
Retrieval Comparisons (PC Noise Filtering)

AIRS MEAN

~Altitude (km)

Temp (K)

AIRS Temp Deviation from Mean (K) (Unfiltered)

Lat. (deg.)

20.0 20.4 20.6 20.8 21 21.2 21.4 21.6

20 15 10 5 0

-4 -2 0 2 4

AIRS MEAN

~Altitude (km)

Temp (K)

AIRS Temp Deviation from Mean (K) (Filtered)

Lat. (deg.)

20.0 20.4 20.6 20.8 21 21.2 21.4 21.6

20 15 10 5 0

-4 -2 0 2 4
Retrieval Comparisons (Full NAST Resolution)

NAST Vertical Resolution Appears To Be Higher Than AIRS Resolution. Why ???
Retrieval Comparisons (NAST at AIRS Resolution)

AIRS resolution appears to be higher than AIRS resolution. Noise Difference??

NASTI T-Dev@ AIRS Spatial Resolution
Comparisons With Dropsonde Cross-section
Retrieval Comparisons With Dropsonde
Retrieval Comparisons With Dropsonde
CrIS and AIRS Spectra and Retrieval Channels

CrIS and AIRS Spectral Resolution Comparable.

[Graphs showing spectral data for CrIS and AIRS]
Retrieval Comparisons (Deviation from Mean)

**Significant difference in spatial structure of temperature structure**
The factor of ten noise reduction from averaging of NAST to AIRS spectral and spatial resolution had little impact on vertical resolution indicating that full resolution NAST is already at a very low noise level. Why??
Retrieval Comparisons With Dropsonde

- **AIRS MEAN**
  - Temp (K) vs. Altitude (km)
  - Dropsonde Profile

- **AIRS Temp Deviation from Mean (K)**
  - Lat. (deg.) vs. Temp (K)

- **CrIS Mean**
  - Temp (K) vs. Altitude (km)
  - Dropsonde Profile

- **CrIS Deviation from Mean (K) @ AIRS Resolution**
  - Lat. (deg.) vs. Temp (K)

- **DROP MEAN**
  - Temp (K) vs. Altitude (km)
  - Dropsonde Profile

- **DROP Temp Deviation from Mean (K)**
  - Lat. (deg.) vs. Temp (K)
CrIS With AIRS Level Measurement Noise
(i.e., 0.6 K @650 cm⁻¹ to 0.2 @750 cm⁻¹ to 2650 cm⁻¹ @ 250K)

Adding AIRS noise to spatially averaged CrIS produces AIRS retrieval characteristics.

- **CrIS Mean**
- **CrIS (with AIRS noise) Deviation from Mean (K)**
Note that in 650-750 cm\(^{-1}\) temperature profiling spectral region the apparent NAST noise level appears to be much smaller than the AIRS noise level, as shown as a residual in the retrievals.
Retrieval Comparisons With Dropsonde

The graph shows the comparison of temperature (Temp, K) against altitude (Alt, km) for different methods:

- **CrIS** (blue line)
- **AIRS** (green line)
- **DROP** (red line)

The data suggests a trend where temperature decreases with increasing altitude, with minor variations between the methods.
Retrieval Comparisons With Dropsonde

The graph shows the comparison of retrieval data between CrIS, AIRS, and DROP. The x-axis represents Relative Humidity (RH) in percentage, while the y-axis represents altitude in kilometers. The lines indicate the variation of RH with altitude for each method.
NAST and GIFTS Spectra and Retrieval Channels
Retrieval Comparisons With Dropsonde

GIFTS Mean

GIFTS Deviation from Mean (K) @ GIFTS Resolution (~4 km)
GIFTS Sounding Capability

GIFTS MEAN

GIFTS RH Deviation from Mean (%)

NASTI MEAN

NASTI RH Deviation from Mean (%)
**Summary**

- EOF Regression provides high vertical resolution soundings from high resolution radiance spectra.

- The vertical resolutions of NAST and derived CrIS and GIFTS retrievals appear to be comparable. NAST appears to have a very low spectrally random noise level, on the scale of the absorption line spacing, since little change in vertical resolution results from spectral and spatial averaging of the data.

- Adding AIRS level random noise to CrIS (simulated from NAST) radiance spectra produces a vertical resolution of the retrieved profiles similar to that displayed by AIRS retrievals.

- The high vertical resolution of the NAST appears to be due to small spectrally random noise, on the scale of the absorption line spacing, as shown by the small spatial standard deviation of the retrieval calculated radiance residuals.

**Future Priority:** Simulate cloud radiances more properly in the training data set and train the algorithm to retrieve the true profile below a semi-transparent and/or a broken cloud cover.