Retrieval Algorithm Using Super channels

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Outline

• Description of a super channel algorithm
  – Introduction to a Principal Component-based Radiative Transfer Model (PCRTM)
  – Description of a super channel physical retrieval algorithm
• Example of applying superchannel retrieval algorithm to IASI and NAST-I spectra
• Conclusions
Introduction

- Good News for hyperspectral remote sensing:
  - Modern Hyper/ Ultra spectral remote sensors have thousands of channels
  - High spectral resolution provides more details of atmosphere properties
  - Examples hyperspectral sensors:
    - AIRS (Atmospheric Infrared Sounder): 2378 x 1 x 1
    - CrIS (Cross Track Infrared Sounder): 1305 x 3 x 3
    - NAST-I (NPOESS Airborne Sounder Testbed): 8632 x 1 x 1
    - IASI (Infrared Atmospheric Sounding Interferometer): 8461 x 2 x 2
    - GIFTS (Geostationary Imaging Fourier Transform Spectrometer): 1827 x 128 x 128
    - FIRST (FAR Infrared Spectroscopy of the Troposphere): \(~1500\times10\) (or more)
    - COSAIR (Calibrated Observations of Radiance Spectra from the Atmosphere in the far Infra Red): thousands
    - CLARREO (Climate Absolute Radiance and Refractivity Observatory): thousands

- Challenges:
  - Need fast and accurate forward model
    - Line-by-line radiative transfer model too slow
  - New ways to analysis data are needed
    - Transform data into more compact form (e.g EOF)
  - A Principal Comonent-based Radiative Transfer Model (PCRTM) has been developed
    - Applied successfully to AIRS, IASI, and NAST-I
  - Example of observed IASI spectra and PCRTM calculated spectra is shown on the right corner
    - The blue curve: IASI instrument noise
    - The red curve: difference between observed and PCRTM calculated
Description of PCRTM

- Principal Component-based Radiative Transfer Model (PCRTM)
  - predicts PC scores ($Y$) instead of channel radiances ($R$)
  - PC scores (super channels) are linearly related to channel radiances
    \[ \tilde{Y} = A \times \tilde{R}_{\text{mono}} \]
- The relationship is derived from the properties of eigenvectors and instrument line shape functions:
  \[ \dot{Y} = U^T \times \dot{R}_{\text{chan}} \]
  \[ R_{\text{chan}}^i = \frac{\sum_{k=1}^{N} \phi_k R_{\text{mono}}^k}{\sum_{k=1}^{N} \phi_k} \]
- Very accurate relative to LBL
  - Accuracy of the model can be adjusted
- Very fast
  - No need to perform redundant calculations
- Cloud contributions included
  - Use cloud transmittances and reflectances
  - Use multiple scattering calculation at limited monochromatic frequencies
- Channel radiances (or transmittances) can be obtained easily
  \[ \bar{R}_{\text{chan}} = U \times \bar{Y} = \sum_{i=1}^{N_{\text{EOF}}} Y_i \bar{U}_i + \bar{e} \]
- Provide analytical jacobian
Results of Applying PCRTM to IASI

• An Example of the IASI spectrum and the difference between the LBL calculated radiance and the PCRTM calculated radiance
• Errors less than 0.05K

PCRTM accuracy:
• Top: RMS error
• Middle: Bias error
• IASI instrument noise
• Very good relative to LBL
• Much smaller error relative instrument noise
Comparison with NAST-I and AIRS observations

- NAST-I spectrum take over Potenza Italy on September 9th, 2004
- Emissivity fix to 0.98 (not the truth)
- T, H2O taken from LIDAR measurements
- O3 fixed to US standard atmosphere
- PCRTM and LBLRTM calculated radiances agree with each other (< 0.07K)
- main sources of error between the NAST-I observed and PCRTM calculated radiances
  - Spectroscopy
  - Uncertainty in the "true atmospheric state"

- An example of Observe vs forward model calculated AIRS spectra
- Temperature, H2O and O3 profiles are taking from ECMWF model
- Spikes due to AIRS popping noise not completely removed
- Ozone truth has poor quality

• Comparison of observed and calculated IASI spectra
Flow diagram of the PCRTM retrieval algorithm

\[ X_{n+1} - X_a = (K^T S_y^{-1} K + \lambda I + S_a^{-1})^{-1} K^T S_y^{-1} [(y_n - Y_m) + K(X_n - X_a)] \]

- All parameters retrieved simultaneously
  - No need to estimate errors of non-retrieved parameters
- Very robust
  - Can start from either climatology or regression first guesses
- Single FOV retrieval
  - High spatial resolution (no need for cloud clearing)
  - Cloud parameters retrieved explicitly
  - Multiple scattering effect included
- Provide error covariance matrix of state vector without extra calculations
  - Provides info needed by 3D/4Dvar
  - Error correlations included
  - Compressed state vector and associated error covariance matrix
- Both radiance and state vectors are in EOF domain
  - Small matrix and vector dimensions
  - Only 100 super channels needed
  - Simply minimizing cost function
  - No ad-hoc tuning parameters
Cloudy Retrieval Over Angra dos Reis

- Top left: a 3-D plot of retrieved temperature and moisture profiles taken on April 15th, 2008 near Angra dos Reis, Brazil
- Top right: Observed and fitted IASI spectra (ice cloud) taken on April 15th, 2008 near Angra dos Reis, Brazil
- Top right: Observed and fitted IASI spectra (Clear sky) taken on April 15th, 2008 near Angra dos Reis, Brazil
Highlights of Research (JAIEX Campaign Retrievals)

- Temperature, moisture, and ozone cross-sections from 4/19/07
- Plots are deviation from the mean
- Fine water vapor structures captured by the retrieval system
- NAST-I under flew over the CART ARM site
- A very cloudy sky condition

- Retrieved atmospheric Temperature and moisture profiles from IASI and NAST-I during JAIEX campaign
- All parameters retrieved
  - T, H\textsubscript{2}O, O\textsubscript{3}, CO
  - Surface emissivity
  - Surface skin temperature
  - Cloud optical depth
  - Cloud height
  - Cloud particle size
- Good agreement between IASI and NAST-I
- Good agreement with radiosonde
- Figure below is the cloud and surface properties retrieval on 4/29/07
3-D Atmospheric Temperature and Moisture Structures

- 3 movies showing IASI temperature and moisture cross-sections on November 4, 2007 over Anglet France
  - $T$ and $H_2O$ as a function of altitude
  - $T$ and $H_2O$ along satellite track
  - $T$ and $H_2O$ x-track
  - Note fine atmospheric features capture
  - Coherent spatial features
Fine Atmospheric Features Captured from IASI Retrievals

Statistics (101 levels, no vertical averaging)
Examples PCRTM Retrieved land and ocean emissivities

- Over CART ARM Site on April 19, 2007 using IASI data
- Soil (or Quartz, or ? ) + vegetation → produce ARM CART site observed emissivity
- Retrieval is not sensitive to emissivity at frequencies where the IASI does not see the earth’s surfaces → 645-750, 1400-2000 cm\(^{-1}\)

- NAST-I retrieved sea Emissivity
  → On Sept. 9, 2004 near Italy
  → Wind speed and scan angle dependencies included
- Retrieval is not sensitive to emissivity at frequencies where the IASI does not see the earth’s surfaces → 645-750, 1400-2000 cm\(^{-1}\)
Summary and Conclusions

• Super channel forward model and retrieval algorithm has been developed
  – PCRTM handles thousand of channels
    • Accurate relative to LBL
    • Very fast in speed
    • Cloud effect modeled (including multiple scattering)
    • Provides forward model and Jacobians in both spectral and EOF domain
  – Super channel retrieval algorithm provides atmospheric and surface properties
    • T, H₂O, O₃, CO vertical profiles
    • Cloud optical depth, cloud height and cloud effective size
    • Surface skin temperature and surface emissivities
• Super retrieval algorithm has been tested with IASI and NAST-I data
  – JAIVEX field campaign provides good data for algorithm testing
  – Spatial resolution can be enhanced using single field of view retrievals
    • Perform cloud parameter retrievals using single FOV
    • No need to make assumptions about variations between adjacent FOVS as required by cloud clearing approach
  – Retrieval using more than 8000 channels with efficient computational time
    • Only possible with super channel approach
  – Retrievals agree well with radiosondes, drops soundes and ECMWF profiles
• Lessons learned from IASI, NAST-I, and AIRS are beneficial to future hyperspectral sensors
  – CrIS, CLARREO……