Using AIRS data in the presence of dust

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• AIRS can play major role in addressing the largest uncertainty in atmospheric radiative forcing a/c to IPCC 2007 report: aerosol radiative forcing.

• Ignoring dust is impacting AIRS L2 products during important weather/climate events.

• Validation: UMBC dust optical depth retrievals compare very well against other A-Train instruments (MODIS, CALIPSO, OMI and PARASOL). AIRS can often retrieve reasonable dust heights, although climatology will work for dust radiative forcing.

• We have a win-win situation, we improve standard L2 products while producing an important component of a new, very important climate measurement that is highly uncertain: longwave dust radiative forcing.
GLOBAL MEAN RADIATIVE FORCINGS

- **RF Terms**
  - Long-lived greenhouse gases
  - Ozone
  - Aerosol
  - Surface albedo
  - Total net anthropogenic

- **RF values (W m⁻²)**
  - Long-lived greenhouse gases: 1.66 [1.49 to 1.83] Global High
  - Ozone: -0.05 [-0.15 to 0.06] Continental to global Med
  - Aerosol: -0.7 [-1.8 to -0.3] Continental to global Low
  - Surface albedo: -0.2 [-0.4 to 0.0] Local to continental Med - Low
  - Total net anthropogenic: 1.6 [0.6 to 2.4] Global Low

- **Spatial scale**
  - Global
  - Continental to global
  - Local to continental
  - Med - Low

- **LOSU**
  - High
  - Med
  - Low
Unique AIRS Contributions

- AIRS can detect and retrieve dust day or night (unlike other instruments)
- AIRS has some sensitivity to dust height, but OLR forcing and L2 retrievals relatively insensitive to height, unlike dust optical depth.
- AIRS dust detection (flag) works well over clear ocean (which happens quite often) and reasonably well over land (will improve with better emissivity product). MODIS and OMI have higher sensitivities, but that is relatively unimportant for dust radiative forcing.
- MODIS Deep Blue has problems over bright surfaces (deserts) and OMI may not detect low-altitude dust.
- AIRS retrieved ODs compare very well with other A-Train instruments
ASL

Approach for AIRS

- **L2 : Dust affecting atmospheric profiles**
  - Retrieve dust optical depths from cloud-cleared radiances to improve L2 products, esp. SST, LST.
  - **BUT,** dust optical depths retrieved in this fashion may be of little scientific use - cloud clearing “removes” in-homogenous component of dust.
  - Only done on FOVs where dust flag is set

- **L2 : OLR forcing for climate**
  - This product is similar to existing AIRS cloud products
  - If dust flag is set using CC’d radiances, then
    - Examine 3x3 L1B FOVs for dust, and if evident
    - Retrieve dust optical depth if clear enough, (not required!!)
    - Then compute OLR dust forcing = R_Observed - R_Computed (with no dust, but using L2 clear and cloudy products). Very simple *if* dust has not contaminated cloud retrievals. If so, need to avoid dust channels for cloud retrieval (use 1231 cm$^{-1}$ for window channel for example).
    - Most dust observations, and radiative forcing, are under otherwise clear conditions.
Large duststorms can have uniform enough dust to adversely impact AIRS retrievals. This is an issue for L2 products, and needs to be considered for L2 improvements.

About 10% AIRS observations in certain regions can be dust contaminated seasonally eg Atlantic during hurricane season, Pacific in spring time.

Examining AIRS L2 products shows retrievals avoid dust regions and/or do not retrieve all the way to the surface.

Improve AIRS retrieval products by including dust as a retrieved variable in the future (probably not feasible for v6).

- easiest done on cloud cleared radiances? (needs to be tested)
- **BUT** nonuniform dust will be removed from the radiances, so this would lead to physically inaccurate dust optical depths.
UMBC retrievals used Optimal Estimation to simultaneously retrieve

- Temperature upto 200 mb (ECMWF first guess)
- Water vapor upto 200 mb (ECMWF first guess)
- Surface Temperature (ECMWF first guess)
- Dust loading (UMBC first guess)
- Dust top height (GOCART climatology or CALIPSO)
- Dust effective diameter (4 um first guess)
- 1d VAR method
- $\approx$ 1 minute per profile
Looking at AIRS L2 in presence of dust

- AIRS L2 retrievals chosen had Quality Flags set good or best for
  - Cloud_OLR
  - Temp_Profile_Bot
  - H2O
  - Surf (*not used in some plots*)
  - Guess_PSurf
Feb 24, 2007: Area coverage and biases

Left plot shows retrieved $\tau(900\,cm - 1)$
Right plot shows biases and std deviations over the channels used
Feb 24, 2007 : Area coverage

Left plot shows retrieved $\tau(900\,cm - 1)$
Right plot shows coincident AIRS retrievals (Red = surface quality best or good, Blue = ignore surface quality)
(far fewer FOVs!)
Solid = mean, dashed = std deviation
Crosses show the position of the mean dust layer
Blue = UMBC compared to ECMWF
Red = “Good2Surface” AIRS L2 compared to ECMWF
AIRS L2 is much drier in trop, and much cooler at surface
Histograms of SST differences and col water ratios (upto 200mb)

Blue = UMBC compared to ECMWF
Red = “Good” AIRS L2 compared to ECMWF
AIRS L2 has higher SST, and is overall drier
Feb 24, 2007 : Stemp grids

Left = ECMWF, top right = AIRS, bottom right = UMBC
Feb 24, 2007 : Col Water grids

Left = ECMWF, top right = AIRS, bottom right = UMBC
Aerosols and clouds affect outgoing radiation. Eg look at Tropical Profile with dust and cirrus.

SW forcing can be about $\approx 10 \text{ W/m}^2$.

OLR forcing over ocean can be ($\approx 5 \text{ W/m}^2$).

OLR forcing over land can much larger ($\approx 20 \text{ W/m}^2$).
Feb 2007 over Sahara (L) over Med Sea (R) over land and sea. The dots are coded according to (L) latitude (R) land fraction.
Histograms of OLR(obs) - OLR(calc)
AIRS L2 “Good2Surface” has almost zero dust forcings while UMBC, ECMWF have negative dust forcings
to be submitted to JGR soon

- **AIRS** : Sergio DeSouza-Machado, Larrabee Strow, Scott Hannon, Breno Imbiriba
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- **CALIPSO** : Kevin McCann and Ray Hoff
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- **PARASOL** : D. Tanré, J.L. Deuzé, F. Ducos
  Atmospheric Laboratory of Optics, Universite of Sciences and Technologies of Lille, Lille, France
- **MODIS** : J. Vanderlei Martins
  Dept of Physics and JCET, UMBC
- **OMI** : Omar Torres
  Department of Atmospheric and Planetary Sciences, Hampton University, VA
## Instrument Characteristics

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Footprint (km)</th>
<th>Retrieval (km)</th>
<th>Swath (km)</th>
<th>Available channels</th>
<th>Retrieval reported at</th>
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<tbody>
<tr>
<td>AIRS</td>
<td>15</td>
<td>15</td>
<td>2000</td>
<td>IR</td>
<td>900 cm$^{-1}$</td>
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<td>CALIPSO</td>
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<td>15</td>
<td>0</td>
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<td>10</td>
<td>2330</td>
<td>Vis,NIR,IR</td>
<td>550 nm</td>
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<td>PARASOL</td>
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<td>20</td>
<td>2400</td>
<td>UV, Vis,NIR</td>
<td>865 nm</td>
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<td>13x24</td>
<td>2600</td>
<td>UV</td>
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<tr>
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<td>point</td>
<td>point</td>
<td>ground</td>
<td>VIS</td>
<td>550 nm</td>
</tr>
</tbody>
</table>
Feb 2007 duststorm

- Tropical cyclone blew in from Atlantic on Feb 20, 2007
- Dust seen A-train from 1200Z (Feb 20) till 2300Z (Feb 24), from Mauritania to Algeria to Libya to Egypt, over Mediterranean towards Turkey
- Two AERONET locations (dust blew over inhospitable regions)
- Different swath widths and instrument sensitivities mean dust detected in different regions/times by the instruments
- We are very competitive with ALL instruments, and can also retrieve heights if necessary
AIRS contributions
L2 : dust impact
OLR forcing : Fast estimate
February 2007 duststorm
Future Work
Conclusions
Backup slides

5 instruments on the A-Train (Feb 24, 2007 duststorm) on CALIPSO track

AIRS 10 um (x3), Calipso 0.55 um and MODIS 0.55 um and OMI and PARASOL optical depths retrieved along Calipso track
Optical Depths for Feb 24, 2007

Calipso track overlaid on crosses
Top: (L) AIRS at 900 cm$^{-1}$; (R) MODIS at 0.55 um
Bottom: (L) OMI at 500 nm; (R) PARASOL at 850 nm
Height information for Feb 24, 2007 on CALIPSO track
Height info for Feb 24, 2007

Left side: OMI/GOCART model; Right side: AIRS retrieval using 4, 10 um

![Map showing height info for Feb 24, 2007 with OMI/GOCART model on the left and AIRS retrieval using 4, 10 um on the right.]
Overall OD comparison for Feb 24, 2007

February 24, 2007

- AIRS contributions
- L2: dust impact
- OLR forcing: Fast estimate
- February 2007 duststorm
- Future Work
- Conclusions
- Backup slides
Future Work with NOAA

- Chris Barnet wants to improve T(z), RH(z), stemp in presence of dust
- Nick Nalli will have data in Summer 2008 from an AEROSE cruise, which should include data obtained during dust events
- Probably a two step process where we separately do an “offline” dust height/size/quantity estimate (eg on cloud cleared radiances), and then include this estimate directly in the final T(z), RH(z), stemp retrieval
- Low priority (unfunded)
Future Work with JPL

- Have previously seen cases where dust flag fails over ocean; due to different spectral features, or dust transport affecting the applicability of current dust flag
- Olga Kalashnikova would like to collaborate on improving the dust flag, using her experience in studying dust eg with MISR, MODIS
Future Work with JPL
Future Work with JPL

Case studies (transport)

July 23, 2006

July 24, 2006

July 25, 2006

July 26, 2006

July 27, 2006

July 28, 2006

This is the only case during summer of 2006 when AIRS mask detects dust transported across Atlantic (up to 70W)
We will compare model BT spectra calculated for the range of dust refractive indices at different dust loadings (as determined by MODIS) and vertical profiles (as determined by CALIPSO) with AIRS spectra at the same atmospheric conditions.
Conclusions

By integrating data from AIRS, MODIS and CALIPSO, and MODTRAN model simulations we aim to:

- Investigate AIRS sensitivities to dust composition and size distribution changes during transport
- Investigate AIRS sensitivities to different dust types (different sources)
- Suggest AIRS dust mask improvements for optically thin dust cases
- Investigate AIRS capabilities for cases of thin cirrus overlying mineral dust

MODEL comparisons will be presented at Spring AGU
Climate implications of AIRS dust and dust-corrected retrievals

- Long-wave radiative forcing (spectrally-resolved properties are needed by models)
- Hurricane research (dust load, SST, wind, water vapor profiles - improved retrievals are needed in presence of dust)
- Dust deposition estimates - ocean fertilization
- Shortwave radiative forcing - dust size distribution is one of key parameters
Conclusion

- AIRS data can be used to estimate OLR forcing
- AIRS L2 quality flag rejects the surface retrievals on many dust contaminated FOVs
- Dust contaminated FOVS leads to incorrect L2 retrievals (stemp, T(z),Q(z)), or not good down to lower atm
- AIRS data can be used to complement other instruments dust sources, optical depths, vertical resolution, size distribution (affects SW forcing)
\[ x_{i+1} = x_i + (S_a^{-1} + K^T S_\epsilon^{-1} K)^{-1} K^T S_\epsilon^{-1} (y_{obs} - y_i) - S_a^{-1} (x_i - x_a) \]

\[ A = GK = (S_a^{-1} + K^T S_\epsilon^{-1} K)^{-1} K^T S_\epsilon^{-1} K \]

where

- \( K \) = Jacobian (use SARTA-cloudy for each layer/cloud param
- \( S_a \) = diagonal covariance matrix, whose terms are 1 K for temperatures, and \( \log(1+0.1) \) for water amounts/cloud parameters
- \( S_\epsilon \) = diagonal matrix whose terms are on the order of 0.2 K

Channel list includes channels for 15 um for \( T(z) \) retrieval, 6 um for water(\( z \)) and 10 um window channels for lower atmosphere/surface/dust parameters
Left plot shows retrieved $\tau(900 \text{ cm} - 1)$
Right plot shows biases and std deviations over the channels used
Left plot shows retrieved $\tau(900 cm - 1)$
Right plot shows coincident AIRS retrievals
(Red = surface quality best or good, Blue = ignore surface quality)
(far fewer FOVs!)
March 09, 2006: T(z) and Q(z)

Solid = mean, dashed = std deviation
Crosses show the position of the mean dust layer
Blue = UMBC compared to ECMWF
Red = “Good2Surface” AIRS L2 compared to ECMWF
AIRS L2 is much wetter, and a little cooler, at dust top
Histograms of SST differences and col water ratios (upto 200mb)
Blue = UMBC compared to ECMWF
Red = “Good2Surface” AIRS L2 compared to ECMWF
AIRS L2 has similar SST, but is overall wetter
March 09, 2006 : Stemp grids

Left = ECMWF, top right = AIRS, bottom right = UMBC
March 09, 2006: Col Water grids

Left = ECMWF, top right = AIRS, bottom right = UMBC
Histograms of OLR(obs) - OLR(calc)

AIRS L2 “Good2Surface” has almost zero dust forcings while UMBC, ECMWF have negative dust forcings.
OLR calculations

Radiance at the top of a clear sky atmosphere

\[ R(\nu, \theta) = \epsilon_s B(\nu, T_s) \tau_{1\rightarrow N}(\nu, \theta) + \sum_{i=1}^{N} B(\nu, T_i)(\tau_{i+1\rightarrow N}(\nu, \theta) - \tau_{i\rightarrow N}(\nu, \theta)) \]

Outgoing Longwave Radiation from top of a clear sky atmosphere
Let \( \cos(\theta) = \mu \)

\[ OLR = 2\pi \int_{0}^{\infty} d\nu \int_{0}^{1} R(\nu, \mu) \mu d\mu \]

Or directly from AIRS radiances
\( OLR_{\text{forcing}} = \sum_{i=1}^{2378} (robs_i - rclr_i) \pi, \) Extremely FAST!!!!
FASTER method

- uses ECMWF (or AIRS retrievals) for $T(z), Q(z)$ fields
- climatology or CALIPSO guess for dusttop, use 2 um radius
- weighted average of $BT_{i}^{obs} - BT_{i}^{calc}$, and $(BT_{i}^{obs} - BT_{j}^{obs}) - (BT_{i}^{calc} - BT_{j}^{calc})$ for selected set of thermal IR channels
- use linear fit with SARTA CLOUDY to estimate cloud loading $n BT_{i}^{obs} = BT_{i}^{calc}(n) + \delta BT_{i}^{errors}$
- very fast $\leq 1$ second per profile