The Application of Satellite Radiance Data at NASA GMAO

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GEOS-5 General Descriptions

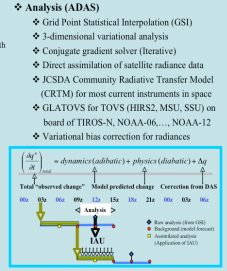
- **Atmospheric GCM (AGCM)**
  - Finite-volume dynamic core
  - Updated moist physics
  - Physics integrated under the Earth System Modeling Framework (ESMF)
  - Catchment land surface model
  - Prescribed aerosols
  - Interactive ozone
- **Analysis (ADAS)**
  - Grid Point Statistical Interpolation (GSI)
  - 3-dimensional variational analysis
  - Conjugate gradient solver (Iterative)
  - Direct assimilation of satellite radiance data
  - JCSDA Community Radiative Transfer Model (CRTM) for most current instruments in space
  - GLATOVS for TOVS (HIRS2, MSU, SSU) on board of TIROS-N, NOAA-06,…, NOAA-12
  - Variational bias correction for radiances

Assimilation

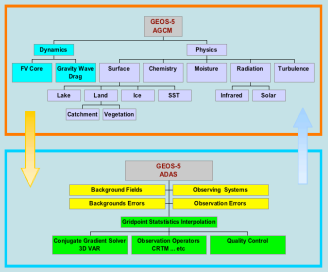
- Apply Incremental Analysis Increments (IAU) to reduce shock of data insertion
- IAU gradually forces the model integration throughout the 6 hour period

$$\left(\frac{\partial \psi}{\partial t}\right)_{total} = dynamics(adiabatic) + physics(diabatic) + \Delta q$$

Total "observed change" — Model predicted change — Correction from DAS

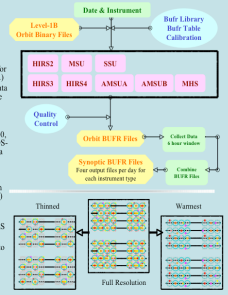


GEOS-5 AGCM/ADAS Components



In-house Radiance Data Processing

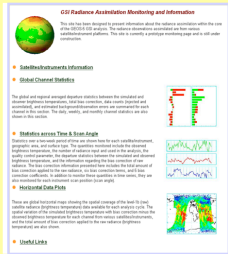
- In house data processing to support Modern Era Retrospective-analysis for Research and Applications (MERRA)
- Level-1b TOVS/ATOVS radiance data were converted to calibrated radiance in BUFR format with appropriate quality controls
- Data available from 1979 to current
- Data blacklists from ECMWF ERA40, JMA25 reanalysis, and GMAO GEOS-4 reanalysis (CERES) for further data screening
- Can reprocess the radiance data if calibration coefficients can be estimated from a better technique such as SNO (simutaneous nadir overpass)

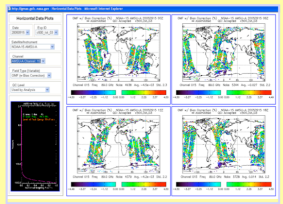


- Receiving full spatial resolution AIRS and AMSU-A data from NESDIS
- Processing full resolution data set into thinned and warmest data sets in BUFR format

Radiance Monitoring

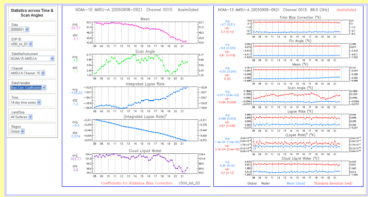
- The use of satellite radiance for each instrument channel is monitored through several variables
  - Brightness temperature
  - Departures statistics between simulated and observed brightness temperatures (OMF & OMA)
  - Total bias correction
  - Individual bias correction term and coefficient
  - Estimated observation and background errors in the analysis
  - Minimization penalty function
  - Data counts (injected& assimilated)
- Variables being monitored are summarized in terms of:
  - Spatial coverage
  - Channel statistics globally and regionally
  - Statistics across time and scan angle



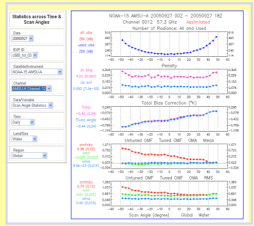


- Spatial coverage of departure statistics (OMF & OMA) and total bias correction for each instrument channel at each analysis time are monitored
- The example plots show spatial coverage of OMFs for NOAA-15 AMSU-A channel 15 along with the channel weighting function.

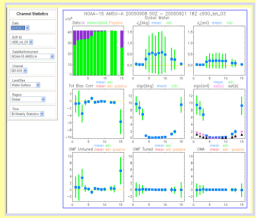
- Global and regional averaged values are also monitored in time series for each instrument channel
- The left panel shows a summary for observation in time series. These plots summarize the observation data counts, brightness temperatures and also the departure statistics (OMF). This is very useful in detection instrument anomalies (observation summary)
- The right panel shows a summary for radiance analysis in time series. These plots summarize the use of radiance data in the analysis in terms of data counts, observation error, penalty function, and OMF/OMA in time time series (analysis summary)
- Summary plots for NOAA-15 AMSUA channel data over water are shown here as an example.



- Regression coefficients used in the variational bias correction are monitored in time series (left panel)
- Radiance bias across the scan angles are corrected through a globally averaged value for each scan angle and this correction in scan angle si also monitored in time series
- Each term contributing to the total bias corrections for each instrument channel is summarized in the right panel.
- Plots for NOAA-15 AMSU-A channel 15 are shown here as an example



- Global and regional averaged departure statistics, total bias correction, penalty function, and data counts are shown as a function scan angles
- Channel 12 for NOAA-15 AMSU-A is shown here as an example
- The known AMSU-A bias in scan angles is evident in the OMF values (red curve)
- The bias correction scheme in GSI removed the biases in scan angles efficiently



- Statistics such as OMF, OMA, total bias correction, estimated background & observation error, data counts (injected & assimilated) of each instrument channel are monitored
- NOAA-15 AMSU-A channel 14 day averaged statistics over the water area are shown here as an example

Assimilation of AIRS in GEOS-5

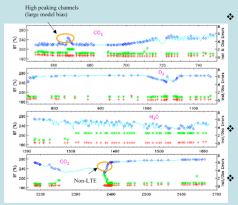
Configurations

- GEOS-5 Model with IAU
- Other satellite radiance data used within GEOS-5 includes SSMI, MSU, HIRS-2, HIRS-3, AMSU-A, and AMSU-B, and MHS

Two Impact Experiments

- **Trial #1**
  - GEOS-5 Model resolution 1/2° x 2/3° x 72 Levels
  - Period – 2006 January and February
  - Control - baseline no AIRS
  - Focus - control with AIRS
    - Full spatial resolution AIRS data set
    - 251 AIRS channels
- **Trial #2**
  - GEOS-5 resolution - 1° x 1.25° x 72 Levels
  - Period - 2003 January
  - Control – baseline with AIRS
    - Thinned AIRS data set
    - 152 AIRS channels
  - Focus – control with AIRS moisture channel turned off
    - 108 AIRS channels

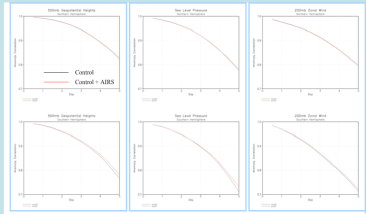
Channel Errors and Selection



- 251 out of 281 channels were used in the assimilation
  - channel 73-86 removed due to channels peaking in Mesosphere (large background bases)
  - channel 1937-2109 removed due to non-LTE effect
  - Channel 2357 removed due to large noise
- Shortwave channels:
  - wavenumber > 2000 cm^{-1} down weighted
  - Wavenumber > 2400 cm^{-1} used only due to night
- NCEP observation errors used
  - Larger error assignment for water vapor channels

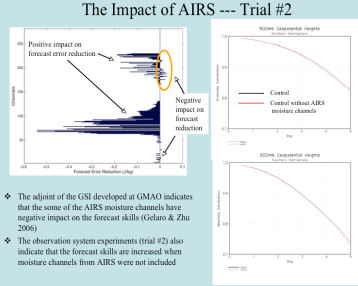
The Impact of AIRS --- Trial #1

500mb Geopotential Height — Sea Level Pressure — 200mb Zonal Wind



- Forecast skills were calculated based on 59 cases
- Slightly positive impact in North Hemisphere; clear positive impact in South Hemisphere

The Impact of AIRS --- Trial #2

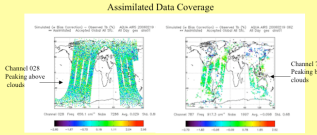


- The adjoint of the GSI developed at GMAO indicates that the some of the AIRS moisture channels have negative impact on the forecast skills (Gelaro & Zhu 2006)
- The observation system experiments (trial #2) also indicate that the forecast skills are increased when moisture channels from AIRS were not included

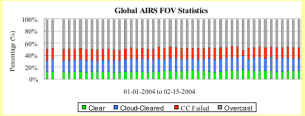
The Plan of Using Cloud Cleared AIRS Radiance

- **Background**
  - The presence of clouds has drastically limited the ability to use AIRS data so far. Currently, only clear AIRS channels are used in most of the data assimilation systems.
  - The direct use of cloudy AIRS data is currently prohibited by the immense computational burden in accurate infrared cloudy radiative transfer calculation
  - Cloud cleared AIRS radiance can provide sounding data beneath the clouds and may potentially beneficial in numerical weather forecasting especially in the troposphere.

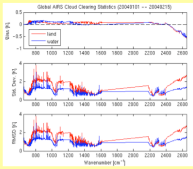
Assimilated Data Coverage

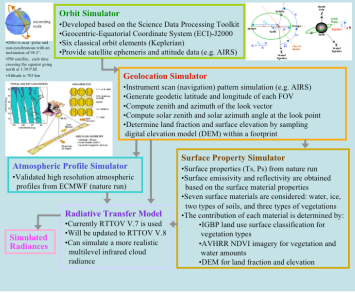


- **AIRS/MODIS Synergistic Cloud Clearing Approach**
  - Cloud-clearing is a procedure that removes cloud radiative effects through comparison of partly cloudy adjacent pixels
  - Optimal cloud clearing procedures to retrieve clear column radiances for all AIRS Channels can be obtained by combining collocated MODIS IR clear radiance observations and the AIRS cloudy radiance measurements
  - The collocated MODIS pixels along with their cloud mask, cloud phase mask, and cloud height information can help to determine the cloud properties within in the AIRS footprints
  - No background information is needed
  - Results indicate that approximately 13% of the AIRS footprints are clear, and 21% of the AIRS footprints can be cloud cleared successfully



- **Objectives**
  - To evaluate the characteristics of Infrared Imager/Sounder synergistic cloud-cleared radiances with GEOS-5 background information
  - To explore the potential of these cloud-cleared radiances for improving numerical weather analysis and forecasting
  - Targeted time period is January and February in 2004
- **Error Estimation**
  - Need to access the "observation error" for the cloud cleared radiances to use in the data assimilation system
  - Quantitative cloud cleared radiance error estimation (bias and RMS errors) had been calculated using collocated MODIS clear and near by AIRS clear data (Hong et al., 2006)



Radiance Simulation System for OSSE

- **Objectives**
  - To evaluate the impact of observing system data under the context of numerical weather analysis and prediction
  - To access the data impact for those observing systems which are not yet operational.
  - For satellite observing systems, OSSEs provide a way to evaluate the impact of an instrument while it is still in the design or pre-flight stage
  - For NWP centers, radiance simulation system for OSSEs help to facilitate the development of the forward operator for the instrument and also helps to shorten the time for the new data type to be used in the current operational data assimilation systems
- **Progress**
  - Developing radiance simulation system of advanced sounders for OSSEs based on the system built by Kleespies (NESDIS) and Sun (QSS).
- **Issues**
  - Representativeness of the background cloud information
  - Modeling cloud optical properties in the radiative transfer model
  - Modeling instrument noise, both correlated and independent
  - Estimation of observation errors from instrument and radiative transfer model