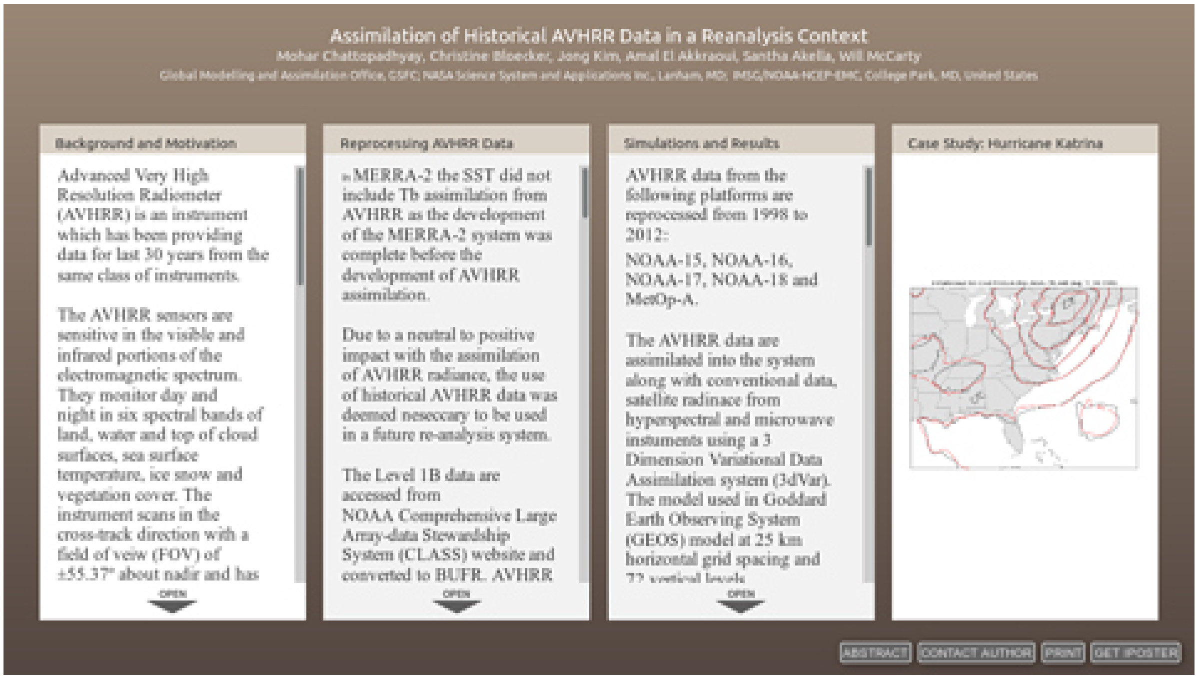
Assimilation of Historical AVHRR Data in a Reanalysis Context



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BACKGROUND AND MOTIVATION

Advanced Very High Resolution Radiometer (AVHRR) is an instrument which has been providing data for last 30 years from the same class of instruments.

The AVHRR instrument is sensitive in the visible and infrared portions of the electromagnetic spectrum. They monitor day and night in six spectral bands of land, water and top of cloud surfaces, sea surface temperature, ice snow and vegetation cover. The instrument scans in the cross-track direction with a field of veiw (FOV) of ±55.37º about nadir and has an instanteneous FOV (IFOV) of 1.1 km at nadir.

Channel	Center Wavelength (µm)	Spectral Range FWHM (µm)	Typical Use
1	0.63 (VISIBLE)	0.58 – 0.68	Daytime cloud and surface mapping
2	0.862 (VISIBLE/NEAR INFRA RED)	0.725 – 1.00	Land water boundaries
3a	1.61 (NEAR INFRA RED)	1.58 – 1.64	Snow ice detection
3b	3.74 (INFRA RED - window)	3.55 – 3.93	Night cloud mapping, sea surface temperature
4	10.80 (INFRA RED - window)	10.30 - 11.30	Night cloud mapping, sea surface temperature
5	12.00 (INFRA RED - window)	11.50 – 12.50	Sea surface temperature

Table 1. AVHRR Channel Specification

Assimilation of brightness temperature (Tb) observations from AVHRR began as the interface between Community Radiative Transfer Model (CRTM) and Grid-point Statistical Interpolation (GSI) was modified to account for the skin temperature at the sea surface.

AVHRR Tb observations from both NOAA−18 and Metop−A satellites are used in the GEOS−ADAS observing system. Level 1B, global area coverage (GAC) ocean−only data are obtained at a resolution of about 4 km x 4km; they include a cloud mask and have information in three IR window channels (3B centred around 3.7 μ, and channels 4 and 5 at ≈11 and 12 μ m wavelengths respectively). Due to solar contamination channel 3B daytime data are not used. The Tb from AVHRR has since been assimilated in GEOS from February 2012.

REPROCESSING AVHRR DATA

In MERRA-2 the SST did not include Tb assimilation from AVHRR as the development of the MERRA-2 system was completed before the development of AVHRR assimilation.

Due to a neutral to positive impact with the assimilation of AVHRR radiance, the use of historical AVHRR data was deemed necessary to be used in a future re-analysis system.

The Level 1B historical data are accessed from NOAA Comprehensive Large Array-data Stewardship System (CLASS) website and converted to BUFR. AVHRR from the following platforms are re-processed NOAA-15, NOAA-16, NOAA-17, NOAA-18 and MetOp-A from October 1998 to April 2012.

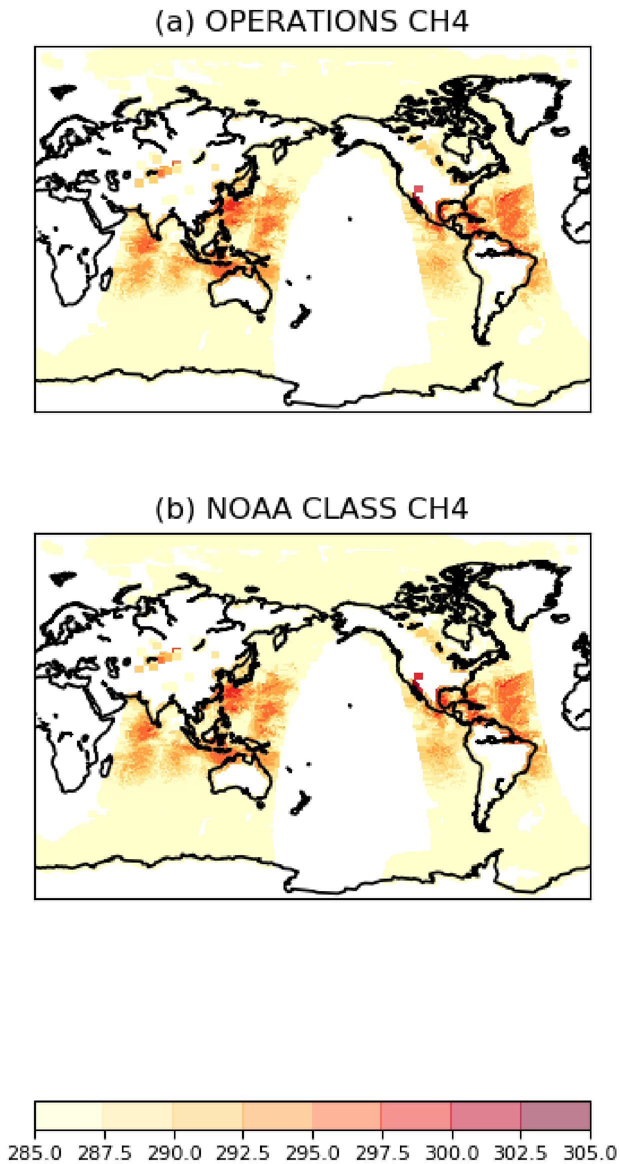


Fig. 1. AVHRR Channel 4 Tb (a) Operational (b) Reprocessed (NOAA-CLASS)

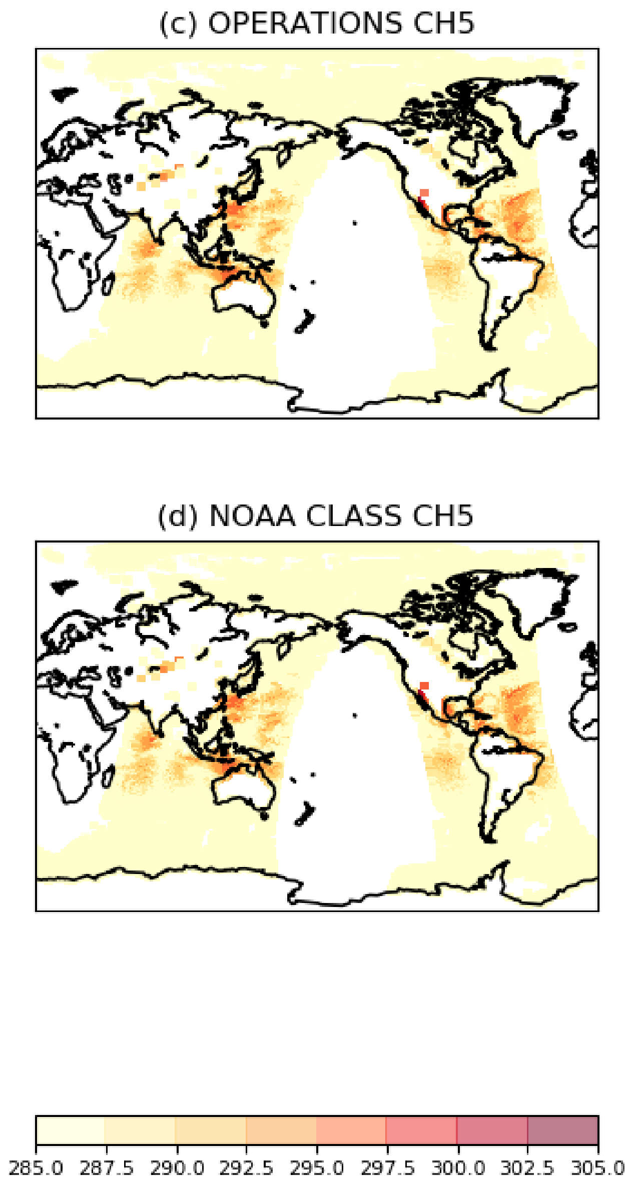
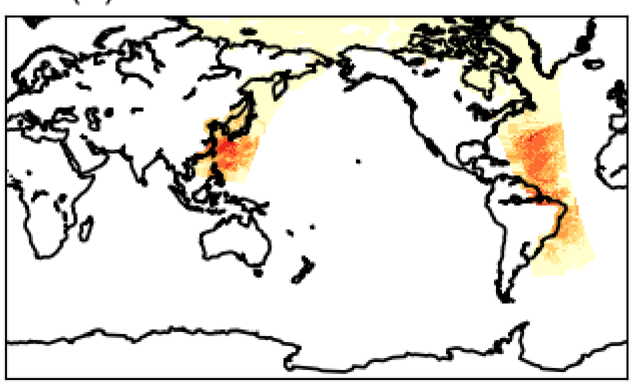


Fig. 1. AVHRR Channel 5 Tb (c) Operational (d) Reprocessed (NOAA-CLASS)

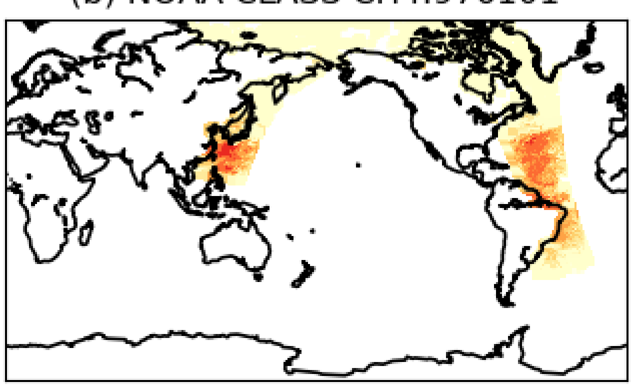
Number of Tb observations obtained from reprocessed NOAA-CLASS (Tb-repro) are found to be larger than Operational Tb observations (Tb-ops). Figs 1 (a - d) show that the swaths of data for the two data streams Tb-repro and Tb-ops for channels 4 and 5 are similar to each other for the time period 15 August 2017 at 18Z.

However, evaluation of the observation counts from the two data sources for various times shows that the Tb-repro has a higher data density (approximately, 15% more) than Tb-ops as shown in Fig. 2. Here, the data for 15 October, 2017 at 22z are counted to show that the data density is high even in the middle of the 3 hour time window of data collection.

(a) OPERATIONS CH4:837919



(b) NOAA CLASS CH4:976101



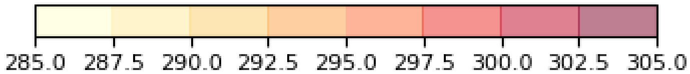


Fig. 2. AVHRR Tb counts at 20170815 22Z (a) Tb-ops 837,919 (b) Tb-repro 976,101.

SIMULATIONS AND RESULTS

AVHRR data from the following platforms are reprocessed from 1998 to 2012:

NOAA-15, NOAA-16, NOAA-17, NOAA-18 and MetOp-A.

The Tb from AVHRR are assimilated into the system along with conventional data, satellite radiance from hyperspectral and microwave instuments using a 3 Dimensional Variational Data Assimilation system (3dVar). The Goddard Earth Observing System (GEOS) model used in simulation has 25 km horizontal grid spacing and 72 vertical levels.

The time period chosen to test the sensitivity of AVHRR data is 1 June 2005 to 10 September 2005 which covers the time period of Hurricane Katrina that impacted southern USA.

Channels 4 and 5 from AVHRR are assimilated in EXP and results are compared with CTL where no AVHRR Tb are assimilated. Fig. 3 and 4 show the values of mean background departure (BkgD) and standard deviation of BkgD for Channels 4 and 5. The mean BkgD for channel 4 and 5 is 0.04 K and 0.03 K respectively and the values decrease over the one month indicating that the bias correction scheme is reducing the systemic errors in the observation. The BkgD std. dev is stable across the two channels as shown in Fig 3 and 4.

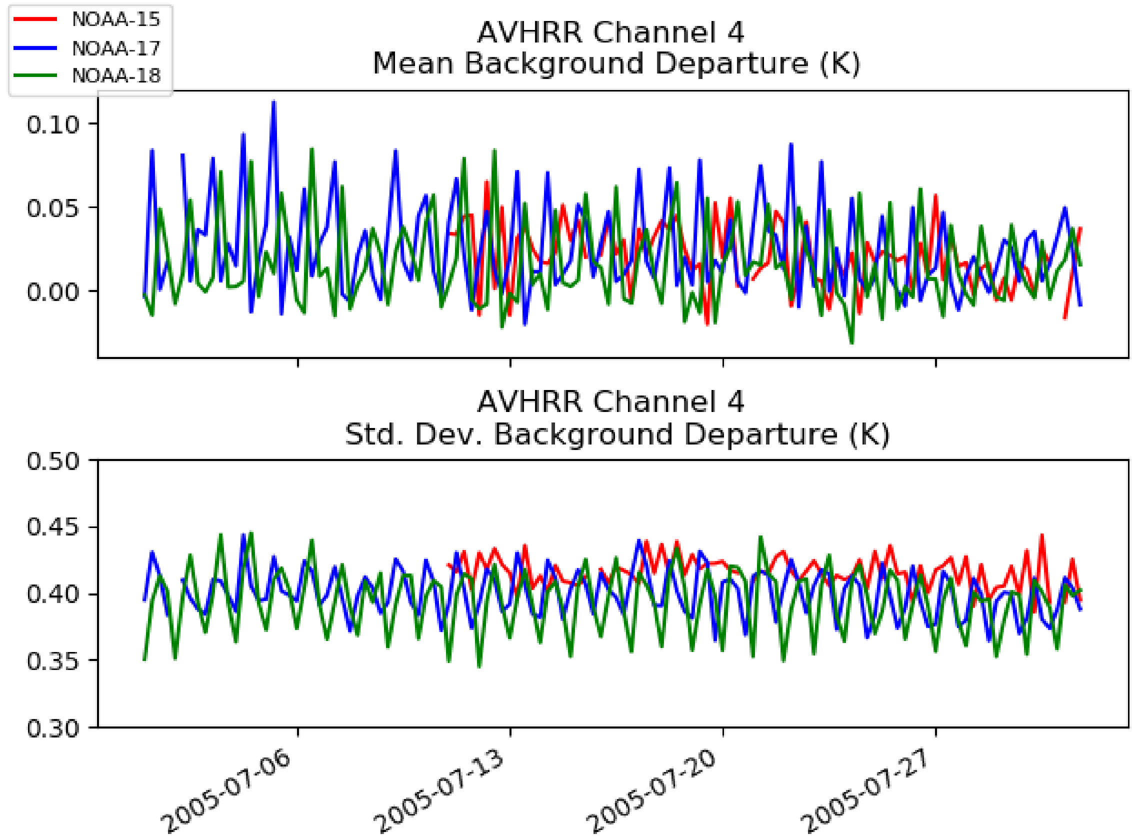


Fig. 3. AVHRR channel 4 background depature for NOAA-15, NOAA-17 and NOAA-18 (a) mean (b) standard deviation

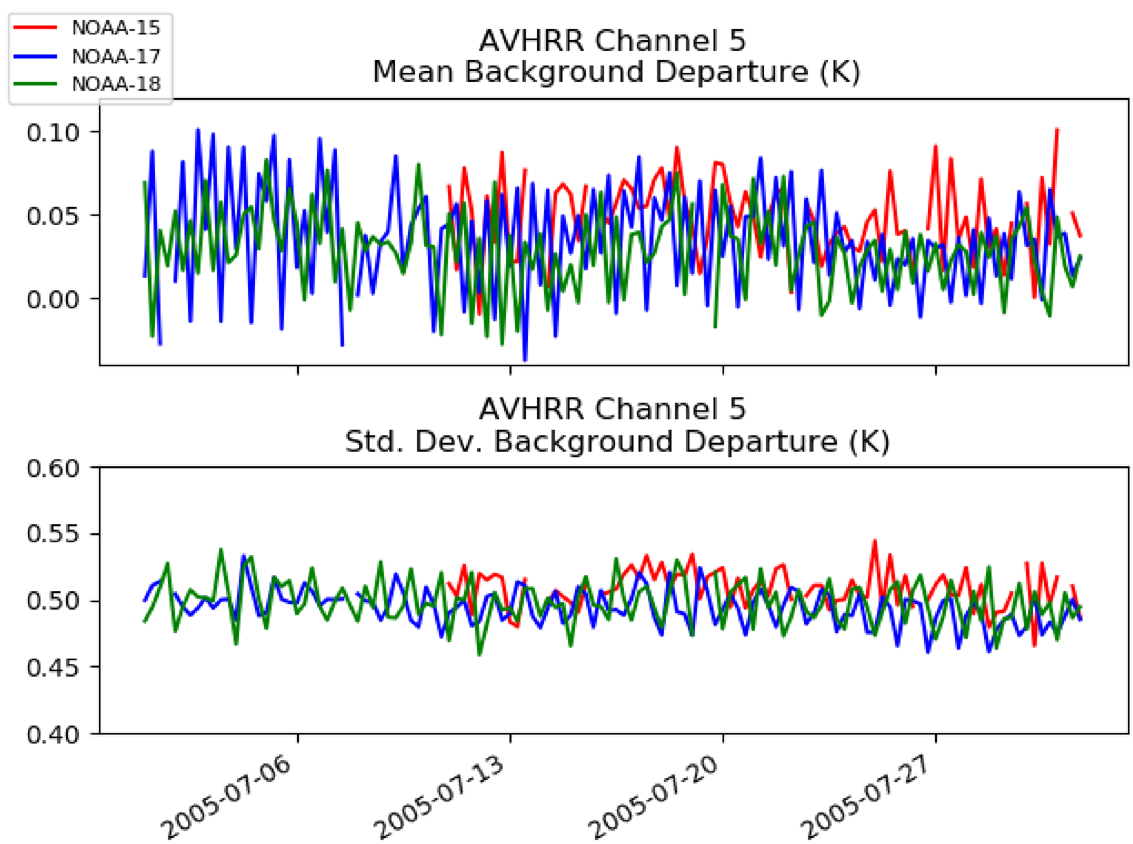


Fig 4. AVHRR channel 5 background depature for NOAA-15, NOAA-17 and NOAA-18 (a) mean (b) standard deviation

The effect of AVHRR assimilation can be seen in the analysis increment of the sea surface skin temperature (DTs/Dt) as shown in Fig. 5. The monthly mean value of DTs/Dt at analysis time for July 2005 show increment values between 0.6×10^{-4}

Ks^{-1} to -0.8×10^{-4} Ks^{-1} .

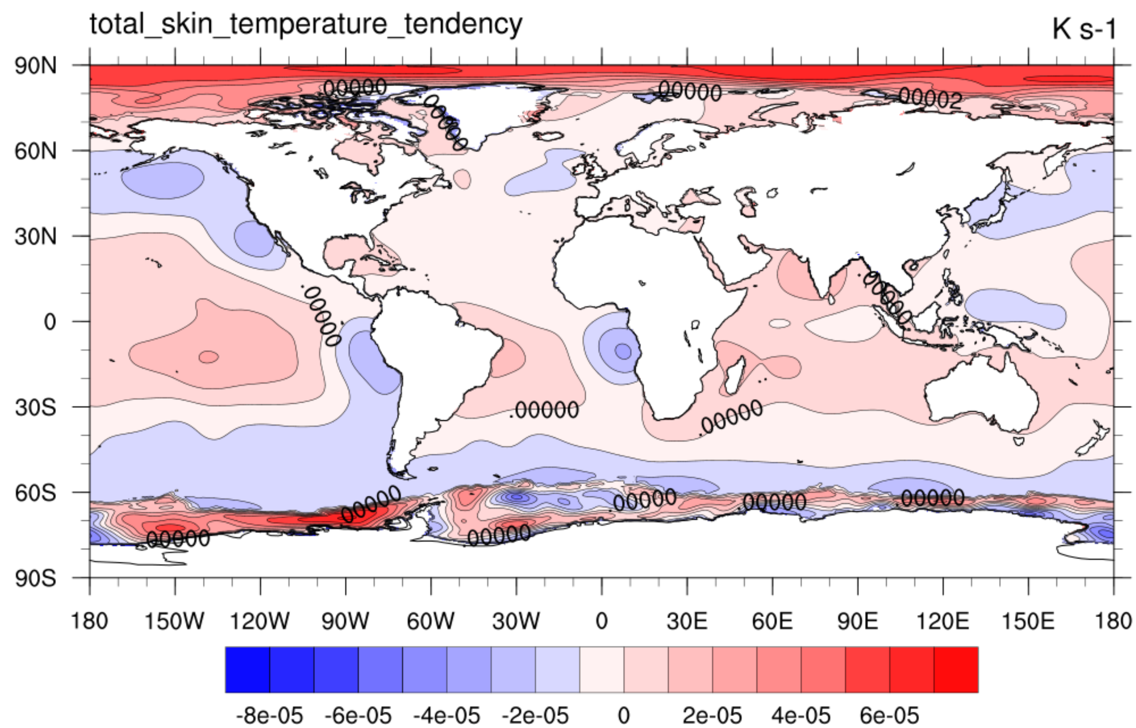


Fig. 5. Monthly mean analysis increment of sea surface skin temperature for July 2005.

The comparison of CTL and EXP shows that the assimilation of AVHRR has not caused large changes in the skin temperature analysis. The largest difference is found in the values of DTs/Dt in the Southern Hemisphere for EXP where the values are smaller than that of CTL. Given the overall performance of the system we can infer that the assimilation of AVHRR data is not degrading the model's performance in climatological time-frame.

CASE STUDY: HURRICANE KATRINA

In order to assess the performance of the EXP in a shorter time-scale such as NWP time-scale, the system is run through August 2005 as we study Hurricane Katrina which occurred from 23 August to 31 August 2005. The sea level pressure fields are studied for EXP, CTL and observation from TCvitals (OBS) over this period.

To obtain the model minimum pressure, a bounding box from 100°W to 70°W and 10°N to 30°N is subsected from the data to separate Katrina’s track region from other storms in the Atlantic basin for the period of 24 August 2005 - 30 August 2005. (No other tropical cyclones intersected this box during this time). The lowest pressure values in the field at each 3-hour time interval for EXP and CTL, and 6-hourly OBS are extracted at the corresponding times. The resulting Fig 6 shows the obtained minimum pressure (Katrina’s center) at each time from EXP (blue), CTL (green), and observations (red).

The minimum pressure for the observation is around 902 hPa, but neither EXP nor CTL is able to resolve pressure lower than about 942 hPa. Both simulations capture the period of rapid intensification (RI) at the same time, and although RI onset of EXP is 6-12 hours later than CTL, it reaches the same minimum pressure at the same time as the CTL around landfall.

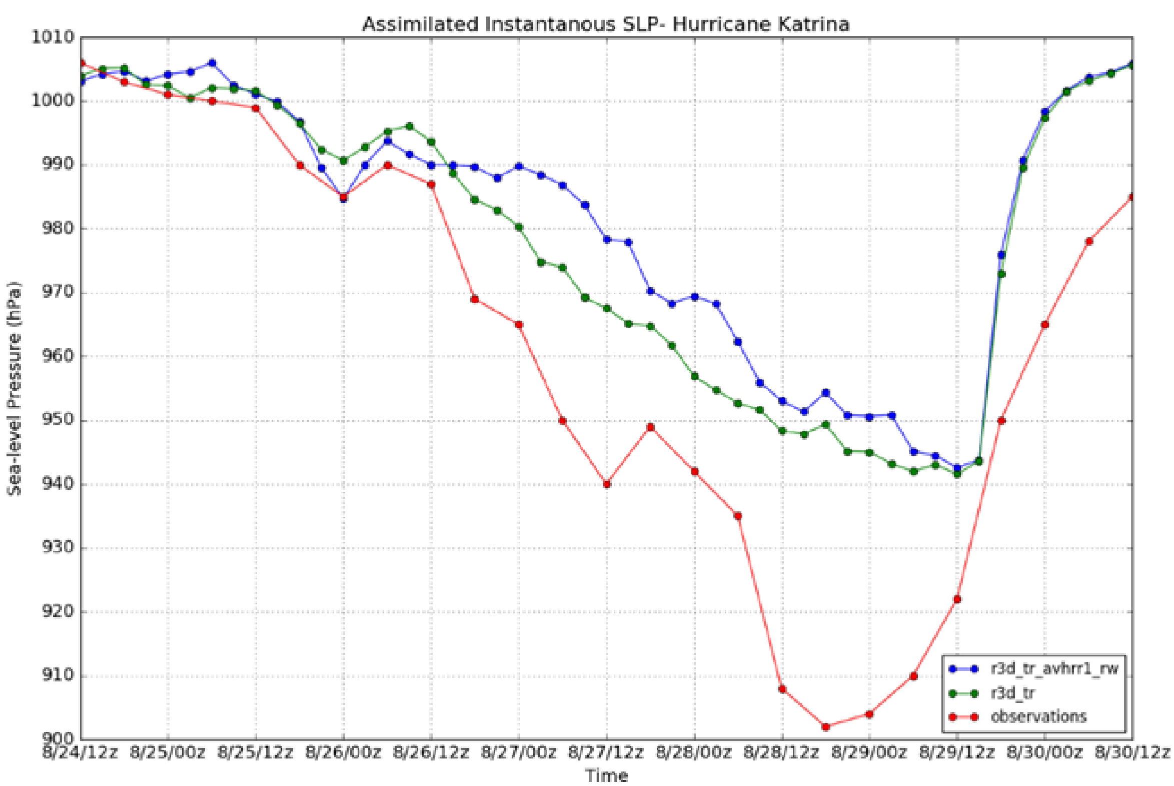


Fig 6. Assimilated central minimum sea-level pressure from EXP (blue), CTL (green), and OBS (red) of Hurricane Katrina, from Aug. 24 12z - Aug. 30 12z 2005. This hurricane track period was over both land and sea.

This is further illustrated in Fig. 7 by the nearly identical SLP fields from the experiment (black) and control (red) upon landfall on 29 August 2005 at 1200z.

Instantaneous Sea-Level Pressure (Exp=black, Ctl=red) (Aug. 25 00z 2005)

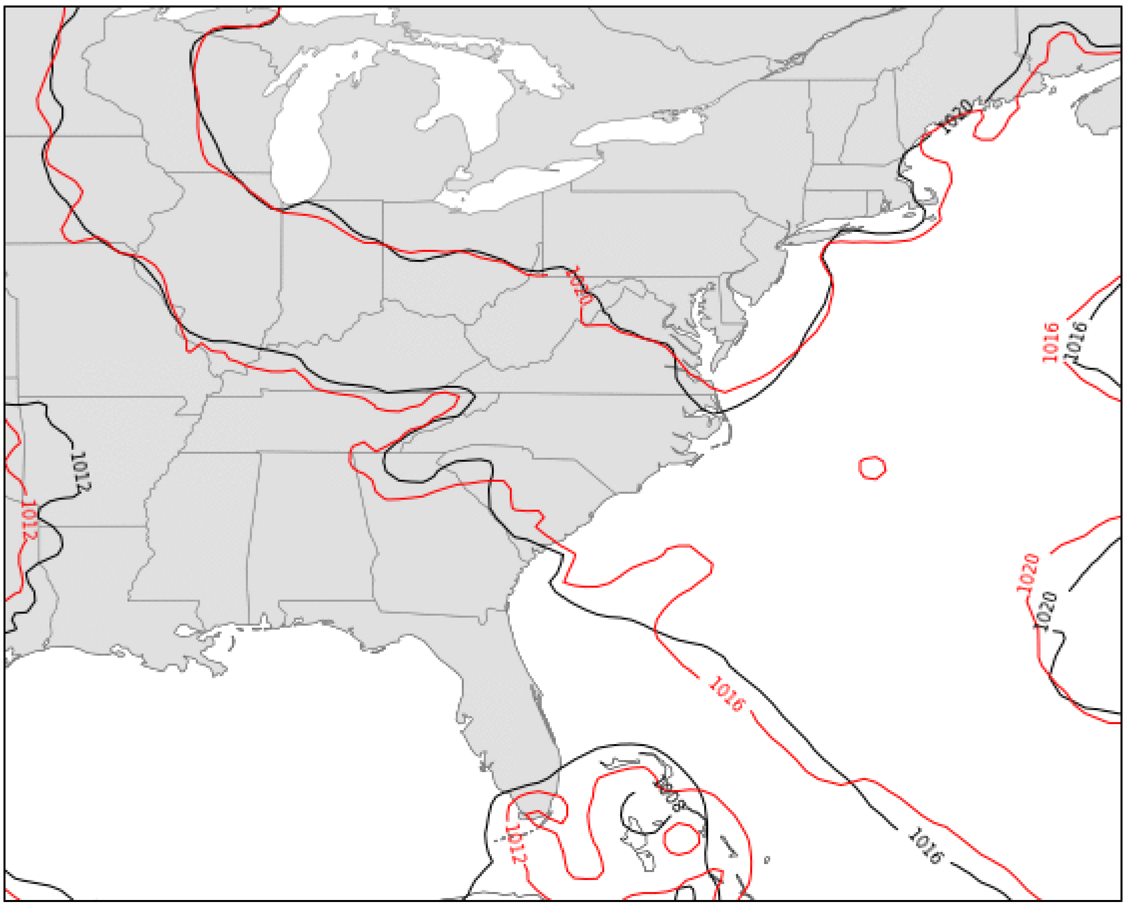


Fig 7. SLP from the EXP (black) and CTL (red) from August 25 00z – Aug. 31 21z, 2005, when Hurricane Katrina made landfall in Louisiana. Each contour represents intervals of 4 hPa.

The landfall characteristics of Hurricane Katrina are nearly identical between EXP and CTL suggesting very little difference with the assimilation of AVHRR data, however there are small but noticeable differences in the evolution of the storm leading up to landfall. The lag between the EXP and CTL in the onset of RI occurred after Katrina made landfall in Florida on 25 August and spent some time over land as opposed to water, so it may be more beneficial to study a more uninterrupted track over water to see how the difference in ocean skin temperature assimilated data affects hurricane development.

It can be concluded from this study that assimilation of historical AVHRR radiance has not degraded the models performance in climatological time frame. The latest development has also shown promising results by simulating an individual hurricane track (Hurricane Katrina) and rapid intensification of the storm. It is expected that longer study periods with possibly more in-situ data along with Hybrid 4d EnVar data assimilation scheme would help further improve the model's performance in future.

ABSTRACT

The Advanced Very High-Resolution Radiometer (AVHRR) is a broad-band, four or five channel scanner, sensing in the visible, near-infrared, and thermal infrared portions of the electromagnetic spectrum. Data records from AVHRR instruments on-board Polar Orbiting Satellites span 30 years. The AVHRR radiance from the Infra-red channels have been directly assimilated over the ocean in NASA GEOS system since 2012 and have made a positive contribution towards the skin temperature analysis. Given the positive impact of the assimilation of AVHRR radiance it is necessary to exploit the data for reanalysis related application. The AVHRR data is currently being re-processed at GMAO NASA for historical periods and assimilated in the planned upcoming reanalysis framework. In this paper a description of the re-processing of AVHRR data will be provided and a case study from 2005 based on Hurricane Katrina will be presented.