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Development of synthetic GOES-R ABI aerosol products

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Abstract

An Observing Systems Simulation Experiment (OSSE) for GOES-R Advanced Baseline Imager (ABI) aerosol products has been carried out. The generation of simulated data involves prediction of aerosol chemical composition fields at one-hour resolution and 12 km × 12 km spacing. These data are then fed to a radiative transfer model to simulate the on-orbit radiances that the GOES-R ABI will see in six channels. This allows the ABI aerosol algorithm to be tested to produce products that will be available after launch.

In cooperation with a user group of 40+ state and local air quality forecasters, the system has been tested in real-time experiments where the results mimic what the forecasters will see after 2016 when GOES-R launches. Feedback from this group has allowed refinement of the web display system for the ABI aerosol products and has creatively called for new products that were not envisaged by the satellite team.

1 Background for an Observing Systems Simulation Experiment (OSSE) for GOES-R

In 2016, NOAA plans to launch and turn on a new series of geostationary satellites in the Geostationary Operational Environmental Satellite (GOES) series, the first of which is given the designator GOES-R. These satellites will carry a new generation of technology with an ABI that has 16 spectral channels (compared to the current five-channel imager). The United States has no geostationary satellite in orbit that will have this spectral resolution and, therefore, the experience in using such an instrument from a geostationary position is limited. The ABI instrument is designed to take advantage of the multi-wavelength physics of radiative transfer in the visible and infrared that has previously been demonstrated on polar orbiting systems such as the Moderate Resolution Imaging Sensor (MODIS) on NASA's Terra and Aqua satellites and the Visible Infrared Imaging Radiometer System (VIIRS) on the National Polar-orbiting Partnership (Suomi

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NPP) and Joint Polar-orbiting Satellite System (JPSS; Kaufman et al., 1997; Levy et al., 2010; Liu et al., 2014; Ciren and Kondragunta, 2014).

GOES-R will have significant advantages over polar orbiting sensors since it will view a wide region of the western hemisphere continuously from a stationary orbit. GOES-R will be able to visualize atmospheric motions against a static underlying surface. The new spectral information of GOES-R will allow increased precision in retrieving atmospheric parameters from ratios of wavelengths and atmospheric/cloud/surface correction techniques employed on MODIS-like sensors to be applied to a geostationary platform. Aerosol optical depth (AOD) is retrieved utilizing multi-wavelength bands on the European Meteosat Second Generation Satellites Spinning Enhanced Visible and Infrared Imager (SEVIRI) geostationary sensor over ocean areas off Africa and Europe (Thieuleux et al., 2005; EUMETSAT, 2014), but have not been available to date in the western hemisphere. SEVIRI wavelengths are not amenable for testing the ABI algorithm as there is no near infrared 2.1 µm band which can be used for an estimate of surface reflectance. SEVIRI's 1.6 µm channel is used for snow/ice discrimination. The SEVIRI AOD algorithm is thus fundamentally different from the operational algorithm which will be used on GOES-R. Moreover, SEVIRI is an eastern hemisphere imager and enticing North American air quality forecasters to evaluate imagery from another continent would be difficult.

These advantages (rapid-temporal refresh rates, high spatial resolution, stationary viewing geometry, and increased spectral coverage) have excited the scientific community about GOES-R's potential. The community of users of such data, however, includes air quality forecasters and analysts who, generally, are unaware of the development of GOES-R and do not have tools or understanding to utilize this remarkable flood of information that will arise from the instrument. To build a user community and make them ready for the data from GOES-R on "day 1" of the mission, the National Oceanic and Atmospheric Administration (NOAA) has created a number of "Proving Grounds" (Goodman et al., 2012). These Proving Grounds are demonstration testbeds where the GOES-R data can be refined, prior to launch, and where tools that will be used by the public can be tested. The feedback from the Proving Grounds provide product developers with a "near-real time" experience with GOES-R prior to its launch and guide development changes to the ABI processing algorithms that can be implemented prior to launch. The GOES-R Air Quality Proving Ground (AQPG) is described by Huff et al. (2012).

Unfortunately at this time, there are no available measured upwelling radiance data at GOES-R orbit in the spectral bands covered by the new radiometer. This paper describes a process by which such radiances can be simulated from real-world atmospheric conditions, including anthropogenic aerosols and smoke (dust has not been included in these simulations at the present time). It should be emphasized that this is a "synthetic" procedure to allow the ABI aerosol processing to be used as it will be when the satellite is in orbit. Two large models need to be used to generate the radiance data and the realism of the simulation is controlled by the accuracy of those models. The method of simulating pre-operational behavior of a satellite observing system can be referred to as an OSSE and we will use that terminology here.

2 Retrieving aerosol optical depth from the ABI

The radiative transfer involved in retrieving aerosol optical depth from satellite radiances is well established (Kaufman, 1997). In simple terms, over very dark targets, aerosols create excess upwelling radiance, enhancing the reflectivity over the surface reflectance. Compensating for that background radiance from the surface, models of aerosol scattering, such as 6S (Vermote et al., 1997), CRTM (Han et al., 2013; Ding et al., 2011) or SBDART (Ricchiazzi et al., 1998), can be used to generate a look up table of expected aerosol optical depths for various viewing angles of the satellite and the solar illumination. These tables are tailored for the underlying surface and different algorithms are run over land and over water surfaces. The GOES-R ABI AOD algorithm has heritage in the early MODIS algorithm (Kaufman et al., 1997; Remer et al., 2005; Levy et al., 2010). In the MODIS algorithm over land, surface reflectance at 2.13 µm is assumed to be predominantly free of aerosols. Ratios of surface reflectance at 0.47 and 0.66 µm to the 2.13 µm reflectance are assumed to be 25 and 50 %, respectively; offsets from these base reflectivities are used for visible wavelength retrievals (Remer et al., 2014; online Algorithm Theoretical Basis Document, ATBD). Aerosol models are chosen for land, water, and in the more recent Collection 5 and Collection 6 algorithms (Levy et al., 2010), models are adjusted spatially for the expected dominant aerosol types. GOES-R ABI carries this heritage forward but the algorithm is not identical to the MODIS algorithms (Aerosol Product Application Team, 2012). The process for choosing the environmental variables to be derived from the ABI sensor went through a multiagency (Department of Defense, NOAA and National Aeronautics and Space Administration) requirements setting process and these variables, called Environmental Data Records or EDRs, were set very early in the ABI design process. Baseline aerosol products are Aerosol Detection (including smoke and dust), aerosol optical depth, suspended matter (µg m^{-3}), aerosol particle size, and volcanic ash (detection and height). Suspended Matter is a vague variable for satellite retrievals as it is based on mass quantities (µg m^{-3}) rather than radiometric quantities such as AOD. An aerosol fact sheet for GOES-R can be found at http://www.goes-r.gov/education/docs/fs_aerosols.pdf.

GOES-R has sixteen spectral channels shown in Table 1. Details on the instrument design and spectral properties is given in Schmit et al. (2008). In Fig. 1, we show a representative scene from Europe with the radiances as will be seen by the satellite. In this simulated image (Schmit et al., 2005), real radiances from MODIS, Meteosat-8 and the Advanced Imaging Radiometer Suite (AIRS) were used to approximate the channels on the ABI. The first six channels are necessary for the ABI aerosol algorithm to operate. However, other channels are used in cloud estimation in other products that are called by the ABI aerosol algorithm as cloud mask, for example. In comparison with the heritage MODIS algorithms, it is immediately obvious that fewer visible wavelength and near IR channels are available and in particular, the MODIS bands at 0.412, 0.44, 0.55 and 1.24 µm are not available.

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On orbit in current planning scenarios, GOES-R will initially be placed in a 135° W geostationary position (where GOES-West resides at present) and GOES-S, the next in the series, will assume the GOES-E position (75° W) two years later than the GOES-R launch. This should occur by 2019 and both ABI sensors will give full western hemispheric coverage from nearly pole to pole (83° local zenith angle). GOES-R gives full disk coverage every 15 min and coverage of the continental US (CONUS) every five minutes in what is termed "Flex Mode". The red channel on the ABI will provide this spatial refresh at 500 m resolution making the GOES-R series revolutionary in our ability to monitor the CONUS continuously during daylight hours for aerosols. In addition for hazardous conditions (weather or emergencies), the scans can be switched to a mesoscale mode giving 30 s refresh of the data. In continuous full disk mode, the disk is refreshed every 5 min.

3 The procedure for generating simulated on-orbit radiances for the ABI algorithm

The introduction above on the instrument is necessary to understand the process of simulating the behavior of the ABI prior to launch. We do not have those radiances at this point. The closest simulacrum to what we should expect from GOES-R can be found by taking on-orbit radiances from existing polar orbiters and mapping those radiances onto a geostationary orbit and with the right spectral bandwidths. Many of the GOES-R Proving Grounds (see Table 2 for the suite of Proving Grounds) use MODIS simulated scenes at 10:30 or 01:30 LT (the nominal overpass times of the MODIS instruments) to train users in what they will see with GOES-R.

Two methods, then, can generate the required on-orbit radiances to exercise the GOES-R ABI processing system: (1) modify MODIS radiances to simulate what GOES-R would see or (2) use a large scale air quality forecast model, such as WRF-SMOKE-CMAQ, to synthetically predict aerosol loading over the US in advance, and then run a radiative transfer model, the Community Radiative Transfer Model (CRTM), to

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generate the on-orbit radiances. Only the latter method can give time sequences of images to show users what the product would look like. This is the method ultimately chosen for the AQPG. We have, however, used the first technique (as have the other Proving Grounds) to verify that the ABI algorithms will be comparable to the prior MODIS heritage for these products.

3.1 MODIS proxy imagery

The on-orbit radiances for GOES-R for MODIS geometry were generated by using retrieved parameters such as AOD, surface reflectance along with other meteorological and atmospheric parameters as inputs to the 6S radiative transfer model (Vermote et al., 1997). Figure 2a gives an example of the ABI retrieval using MODIS radiances and Fig. 2b shows the MODIS AOD for 30 July 2011. Figure 2c and d shows the correlation between the MODIS Collection 5 (MODIS-C5) AOD and the GOES-R ABI retrieved AOD from these MODIS radiances on that day. There are slightly higher AOD's retrieved from the ABI algorithm but the over water difference (24 %) is close to the MODIS AOD product's estimated error (0.05 ± 0.2 AOD; Remer et al., 2005). The differences are expected since the MODIS algorithm does not use a variable wind speed over water and the ABI algorithm uses NCEP winds and varies the ocean surface reflectance.

While this gives confidence in the ABI retrievals, it does not take advantage of the temporal refresh rate that will occur on GOES-R. To demonstrate this, it is necessary to simulate the radiance inputs from a model.

3.2 Modeling approach: ABI proxy data generated by WRF-SMOKE-CMAQ

In order to break away from the approximate 10.30 a.m. and 1.30 p.m. restriction from the MODIS radiances, a modeling approach was developed to predict the aerosol structure of the domain, use those aerosol parameters as input to radiative transfer models, predict the on-orbit radiances at the GOES-R position, and then use those results for

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input to the ABI processing algorithms as would the real instrument. This becomes, then, an OSSE by which we can characterize the utility of the new instrument. The flow of the processing algorithm is shown in Fig. 3.

NOAA Air Research Laboratory (ARL) provided WRF-SMOKE-CMAQ runs at 12 kilometer resolution for a domain which covered the CONUS for several test days in 2012. During this period, fires in Colorado brought smoke to much of the US and was overlaid over anthropogenic haze in the US southeast. The simulations have coarser spatial resolution than the GOES-R ABI, which has 0.5 to 1 km spatial resolution in the visible bands. Computational and latency time considerations (shown in Fig. 3) limited the processing to the 12 km resolution and even so, we were just able to provide near-real time simulations for subsequent days.

The simulated ABI products are based on 00:00 UTC runs of the Weather Research and Forecasting (WRF)-Community Multi-scale Air Quality (CMAQ) model, provided by Dr. Pius Lee of NOAA's Air Resources Laboratory (ARL). The NOAA ARL WRF-CMAQ configuration has 12 km × 12 km horizontal resolution over CONUS. The model incorporates the Carbon Bond 5 module and Blue Sky fire emissions.

A preferred set of parameters for the run would have been to have WRF-CMAQ capable of generating all aerosol precursors and aerosol types at a 4 km × 4 km resolution for the CONUS. A quick calculation for this 21-layer air quality model shows that such a computation is a daunting challenge, even for the largest supercomputers. Post-facto, 4 km × 4 km WRF-SMOKE-CMAQ runs were generated for two days of the experiment and were used to demonstrate what such runs would add to the visualization of AOD from the ABI proxy. These runs could not be sustained in near-real time processing for the ABI processor as we very quickly lost time over the projected forecast domain and could not keep up. At 12 km × 12 km spatial resolution, however, WRF-SMOKE-CMAQ could compute a CONUS domain in about 2 h for a 48 h forecast. Figures 4 and 5 show the column and surface predicted chemistry from WRF-SMOKE-CMAQ for 4 July 2012. As expected, sulfate (Fig. 4a) from anthropogenic sources was confined to a wide band off the US east coast, black carbon and organic carbon (Fig. 4c and d) was dominated

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by fires in Colorado and some dust (Fig. 4e) was generated in Wyoming. Figure 4f shows other aerosol mass not otherwise classified, which includes sea salt.

The next modeling step was to use the CRTM (Han et al., 2005) to produce the on orbit radiances. CRTM has not previously been used with WRF-CMAQ but rather aerosols have been generated from the Goddard Chemistry Aerosol Radiation and Transport (GOCART; Chin et al., 2002) runs. Table 4 lists the WRF-SMOKE-CMAQ variable names that are necessary for CRTM to calculate radiances.

The input data for CRTM could be reformatted in 50 min and pushed through CRTM to generate on-orbit radiances in another 6 h of processing. Once the radiances had been generated, the ABI processor and post-processing to present the results on a web site could be done in a little over an hour. Figure 3 shows the processing flowchart and latency times.

3.3 Generating the on-orbit radiances

The second model is the CRTM. CRTM was not designed to take inputs from WRF-CMAQ. The species types and aerosol sizes are matched in CRTM to the GOCART model (Chin et al., 2002) and some modification of the inputs to CRTM had to be made to closely approximate the expected CRTM source types. In addition, CRTM uses a threshold to predict cloud cover from the WRF humidity fields. A problem in the simulation was that clouds tended to be too continuous (popcorn cumulus occurred in reality but the model predicts continuous cloud cover). This distorts the viewer's acceptance of the realism of the scene.

Figure 6 shows the radiances in the six ABI relevant bands from 4 July 2012, as simulated by CRTM. Earlier, we pointed out that CRTM is only one of a suite of models for radiative transfer that can be used to simulate on-orbit radiances. In a separate sub-experiment, University of Alabama Huntsville employed SBDART (Ricchiazzi et al., 1998) to simulate these radiances independently of the process used at NESDIS STAR (Christopher, 2014). SBDART is designed for the analysis of a wide variety of radiative transfer problems encountered in satellite remote sensing and atmospheric energy

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budget studies. In that study, three additional and non-coincident days of observation were used and cannot be compared directly to the period in this work.

3.4 Exercising the ABI aerosol optical depth retrieval for GOES-R

Summarizing, ABI synthetic products can be produced in about 8 h for a 48 h prognostic run and therefore it was possible to take the 18:00 UTC observations each day to initialize WRF, spin up and run for the daylight hours for the next day and have those results ready to play out in “real-time”. The experiment, then, was to present a new frame hourly during the day as if it had been generated by GOES-R and the ABI processor.

The AOD product is shown in Fig. 7 for 17:00 UTC on 4 July 2012. During the course of the demonstration, frames from 12:00 UTC (8 a.m.) through 22:00 UTC (6 p.m.) were spooled out of the NOAA webserver each hour as their time tag came up. In this way, the experiment allowed users to visualize how they would receive GOES-R AOD throughout the day, rather than just twice daily for the current MODIS product. The website also allowed looping of the image through the existing frames which showed the aerosol development through the day.

Ideally, OSSE produced satellite products should undergo rigorous calibration and validation steps of a quantitative nature. Here, the ABI Proxy products are the result of three very complicated and not well integrated models and our intent is not to validate these complicated models. WRF-SMOKE-CMAQ in our implementation has smoke sources, generated from the ABBA wildfire product estimates of smoke emissions, again including another embedded model. CMAQ uses the EPA SMOKE preprocessor for generating anthropogenic precursors to the numerical forecast of aerosol species concentrations, again another model.

It is possible, of course, to convince oneself that each model is running correctly independently of the other. Yang et al. (2011) compared the WRF-SMOKE-CMAQ model to surface data from three cases of wildfires in the US southeast in 2007. In that work, the CMAQ-predicted $PM_{2.5}$ from smoke was in reasonable agreement with measurements from AIRNOW when a scaling factor of 3 was used to increase the emissions estimates.

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Unlike other OSSEs, however, we have very limited ability to test the output in anything other than a qualitative nature. Generally, there is insufficient data to test even the input fields of chemical constituents in a column sense as will be observed by GOES-R. Christopher (2014) showed that the agreement of WRF-CMAQ and surface $PM_{2.5}$ has a correlation coefficient, r, of 0.63 for the cases he studied. Christopher did not simulate the AOD from his cases but errors in computation of the extinction profile and then vertical integration into AOD can have no higher correlation coefficients. Errors in the total AOD simulation of this OSSE can be no better than the WRF-CMAQ simulations that are the input to this process.

3.5 The proving ground demonstration

Figure 7 is but one panel of the Proving Ground demonstration conducted in 2012. A full suite of the daytime images presented to the AQPG User Group can be found at http://www.star.nesdis.noaa.gov/smcd/spb/aq/aqpg_v3/index.php. In that demonstration, GOES-R simulated natural color imagery shown along with aerosol optical depth images such as Fig. 7. GOES-R does not have a green channel so estimation of what the natural color image would look like was based on a model developed at NESDIS. In this model, the green channel radiances over land were estimated by making a Rayleigh correction to the radiances and applying a ratio that the green channel would be 0.68 of the red channel radiance plus an offset of 0.04. Over water, the green channel radiance was 1.07 times the red channel radiance plus an offset of 0.01. The resulting three color image from blue, synthetic green and red was subjectively similar to what one would see from MODIS. On the active demonstration URL, one can change a slider to transition from AOD only to Natural Color Imagery only. This was a suggestion made by the User Group as helpful in real time analysis of the imagery.

Additional features added to the OSSE output simulations were the ability to scale images down to as fine a level as county resolution and county boundaries were provided as an overlay. For forecasting visibility impacts, the users felt such control on the display resolution was needed. Fires as detected by Wildfire Automated Biomass

Burning Algorithm (WF_ABBA; Koltunov et al., 2012) were also added to the images in a toggle. Animation speed controls (the ability to toggle forwards and backwards in time) were helpful suggestions from the users. Quantitive AOD contours (either with or without the color contour overlays) was requested.

Additional output panels include the aerosol type product from the ABI algorithm, and forward trajectory information on high AOD parcels, 850 mb wind field and precipitation fields forecasted. The users also requested 3 h average composite AOD images to discriminate against transient cloud features. Surface $PM_{2.5}$ estimates using existing ratios between AOD and $PM_{2.5}$ used in the current GOES Aerosol and Smoke Product (GASP; Zhang et al., 2009) and Integrating satellite Data into Environmental Applications (IDEA; Hoff et al., 2009) products have also been included in the presentation suite for the ABI aerosol processor data.

4 Conclusions

A numerical demonstration of the GOES-R ABI aerosol products has now been demonstrated for a number of case studies of smoke and anthropogenic haze. Feedback from a user group of professional forecasters in the US has provided guidance to the product developers at NOAA on how to make the data most relevant for use in their day-to-day work (Huff et al., 2012).

While the products generated are synthetic, they have sufficient fidelity that the users can visualize what they will have in front of them when GOES-R launches and is commissioned. At this point, it is impossible to reproduce model simulated proxy data at the full GOES-R ABI resolution, because of the shear volume of data required to fill the CONUS at 4 km × 4 km (or the final GOES-R 2 km × 2 km) resolution. Because of that, the proxy data undersimulate the finesse that will be available when GOES-R launches.

The Proving Ground process, however, revealed what is important to the GOES-R ABI real-time user community. The ability to visualize and control the display of aerosol information from the new sensor has been refined based on user feedback and the

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product developers have additional confidence that GOES-R ABI data will be used as soon as it is released after launch.

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Table 1. Channels on ABI on GOES-R (bold channels are necessary for the ABI aerosol algorithm).

ABI Band	Wavelength (µm, FWHM)	Center λ (µm)	Spatial Resolution (km)	Intended Use	Heritage
1	**0.45–0.49**	**0.467**	**1**	**Aerosol**	**MODIS**
2	**0.59–0.69**	**0.633**	**0.5**	**Aerosol**	**GOES**
3	**0.846–0.885**	**0.865**	**1**	**Fire scar, aerosol**	**VIIRS**
4	**1.371–1386**	**1.378**	**2**	**Daytime cirrus**	**VIIRS, MODIS**
5	**1.58–1.64**	**1.61**	**1**	**Cloud phase, snow**	**VIIRS, AVHRR**
6	**2.225–2.275**	**2.25**	**2**	**Surface reference reflectance**	**VIIRS, close to MODIS**
7	3.80–4.00	3.9	2	Fires, cloud, winds	GOES
8	5.77–6.6	6.19	2	Upper trop H_2O	GOES
9	6.75–7.15	6.95	2	Middle trop H_2O	GOES sounder
10	7.24–7.44	7.34	2	Lower trop H_2O	modified GOES
11	8.3–8.7	8.5	2	SO_2, dust	MAS
12	9.42–9.8	9.61	2	Ozone	modified GOES
13	10.1–10.6	10.35	2	Surface/cloud	MAS
14	10.8–11.6	11.2	2	SST, clouds, rainfall	GOES sounder
15	11.8–12.8	12.3	2	Ash, SST, total water	GOES sounder
16	13.0–13.6	13.3	2	T, cloud heights, cover	GOES-12

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Table 2. Current NOAA GOES-R proving grounds.

Proving Ground	Lead
Aviation Weather	Kansas City WFO/NASA Langley Research Center
Hurricane Season Experiment	National Hurricane Center/Cooperative Institute for Meteorological Satellite Studies (CIMSS)/Cooperative Institute for Research in the Atmosphere (CIRA)
Storm Prediction Center and Hazardous Weather Testbed	Storm Prediction Center (Norman, OK)/CIRA/Short-term Prediction Research and Transition Center (SPORT)
Ocean Prediction Center	Center for Satellite Applications and Research (STAR)/SPORT
Hydrometeorological Prediction Center	STAR
Air Quality Proving Ground	**UMBC/STAR**
High Latitude and Arctic	Alaska Region NWS/CIMSS
Pacific Region (OCONUS)	Hawaii region NWS/CIRA/SPORT/CIMSS

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Table 3. Model inputs and configurations.

	WRF	SMOKE	CMAQ
Horizontal	12 km × 12 km	12 km × 12 km	12 km × 12 km
Vertical	21 layers	1 and 15* layers	21 layers
Input	RUC	NEI 2002	WRF Output SMOKE emissions Fire emission
Option	Kain–Fritsch (cu.) WSM-6 (cloud) RRTM/Dudhia (rad.) YSU (PBL) Noah (land surface)		CB-IV (gas phase) AE4 (aerosol) AQ (aqueous-cloud)

Notes: WRF = Weather Research Forecast Model; RUC = Rapid Update Cycle; WSM = WRF single moment microphysics scheme; RRTM = rapid radiative transfer model; YSU= Yonsei University PBL scheme; PBL = Planetary Boundary Layer, SMOKE = Sparse Matrix Operator Kernel Emissions model; NEI = National Emissions Inventory; CMAQ = Chemical Model for Air Quality; CB-IV = Chemical Bond IV mechanisms; AE4 = fourth generation CMAQ aerosol module; AQ = CMAQ aqueous cloud model.

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Table 4. CMAQ species names required for input to CRTM (square brackets indicate mass concentration by volume; Hutzell, 2014).

Species Name	Description	Species Name	Description
A25I	Aitken mode $PM_{2.5}$	CO	Carbon Monoxide
A25J	Fine mode $PM_{2.5}$	DENS	Atmospheric density
ACLI	Aerosol aitken mode chloride	LAND TYPE	land classification flag
ACLJ	Aerosol fine mode chloride	NO2	Nitrogen dioxide
ACLK	Aerosol coarse mode chloride	NUMACC	Accumulation mode number concentration
ACORS	Aerosol coarse mode primary PM	NUMATKN	Aitken mode number concentration
AECI	Aerosol aitken mode elemental carbon	NUMCOR	Coarse mode number concentration
AECJ	Aerosol fine mode elemental carbon	O3	Ozone
AH2OI	Aerosol aitken mode water	PRES	Pressure
AH2OJ	Aerosol fine mode water	QC	Water mass mixing ratio for cloud
AH2OK	Aerosol coarse mode water	QG	Water mass mixing ratio for graupel
ANAI	Aerosol aitken mode sodium	QI	Water mass mixing ratio for ice
ANAJ	Aerosol fine mode sodium	QR	Water mass mixing ratio for rain
ANAK	Aerosol coarse mode sodium	QS	Water mass mixing ratio for snow
ANH4I	Aerosol aitken mode Ammonium	QV	Water mass mixing ratio
ANH4J	Aerosol fine mode ammonium	SO2	Sulfur dioxide
ANO3I	Aerosol aitken mode nitrate	SRFACC	Accumulation mode surface area
ANO3J	Aerosol fine mode nitrate	SRFATKN	Aitken mode Surface concentration
ANO3K	Aerosol coarse mode nitrate	TA	Temperature
AORGAI	Aerosol aitken mode organic	ZF	Altitude
AORGAJ	Aerosol fine mode organic	ZH	Layer thickness (m)
AORGBI	aitken mode biogenic primary carbon		
AORGBJ	aerosol biogenic fine mode secondary organic		
AORGPAI	Aerosol aitken mode primary organic		
AORGPAJ	Aerosol fine mode primary organic		
ASO4I	Aerosol aitken mode sulfate		
ASO4J	Aerosol fine mode sulfate		
ASO4K	Aerosol coarse mode sulphate		
ASOIL$	Aerosol soil		

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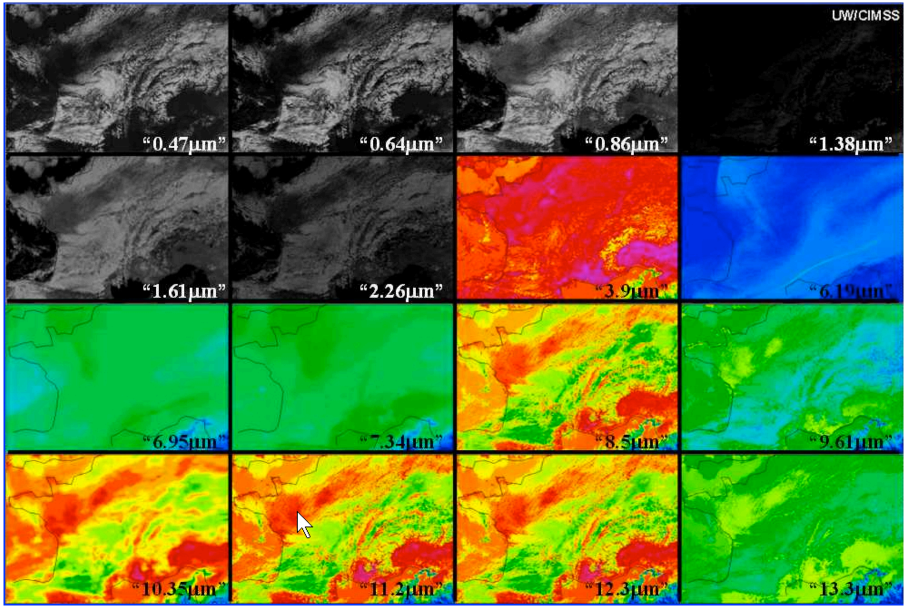

Figure 1. Simulated radiances from the 16 channels of GOES-R ABI for an over-land scene centered on France at 13:00 UTC, 11 April 2004. This image is built from measurements from three separate satellite instruments (MODIS, Meteosat-8, and AIRS). Channel wavelengths are approximated by the existing sensors and thus the use of quotes on the wavelengths. The visible channels through 2.26 µm will be used for the GOES-R ABI AOD retrieval algorithm (from Schmit et al., 2005).

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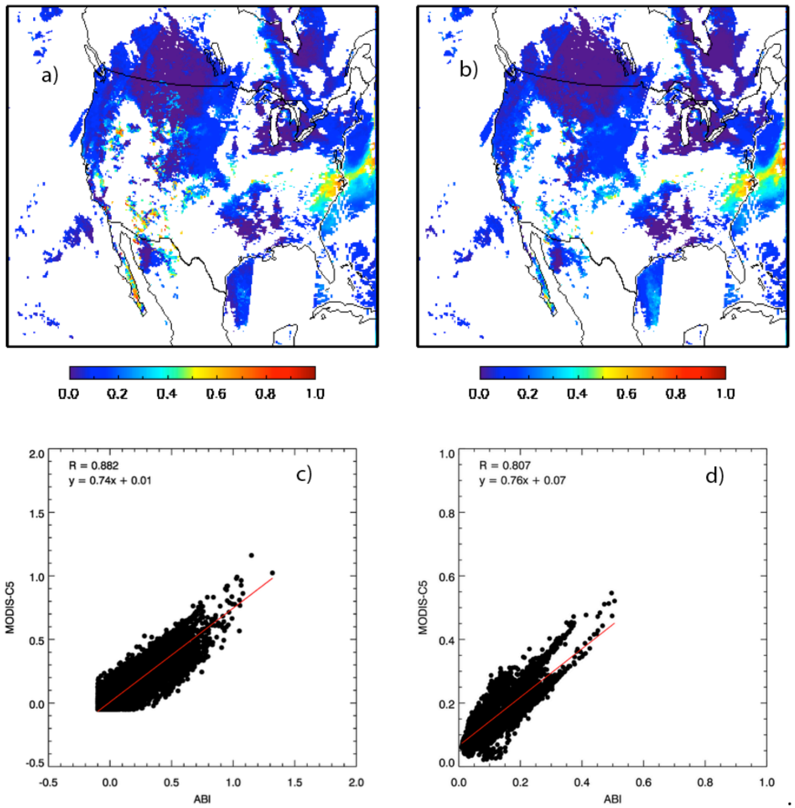

Figure 2. Comparison of the GOES-R ABI AOD product, derived from MODIS input AOD and reflectivities and 6S **(a)** vs. the MODIS retrieved AOD **(b)**. Data was from 30 July 2011 at 16:45 UTC. This was a period with a wildfire in North Carolina and was used in training of the AQPG User Group. The ABI algorithm AOD's are plotted in **(c)** and **(d)** vs. the MODIS-Collection 5 (MODIS-C5) AOD results.

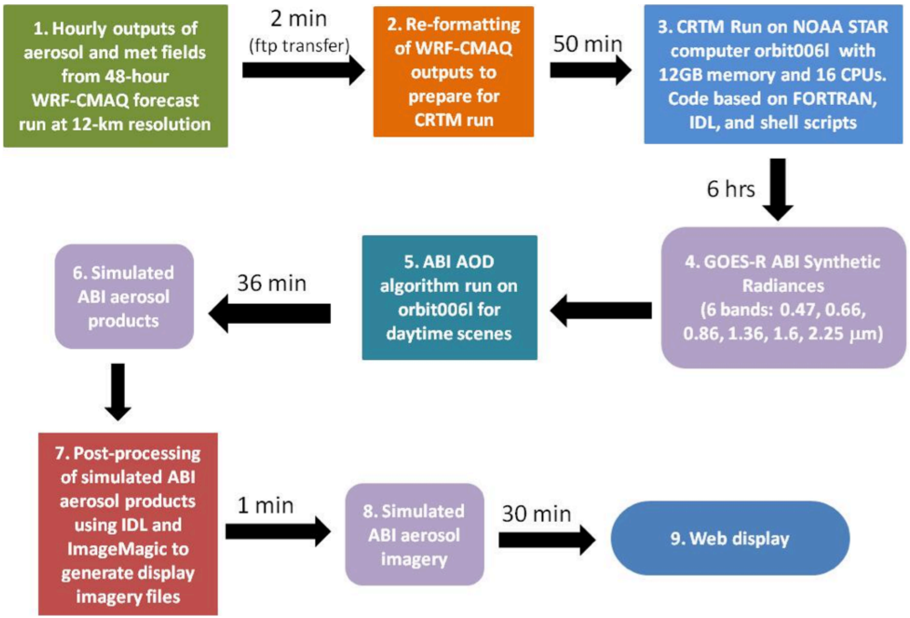

Figure 3. Process for generating GOES-R simulated ABI aerosol imagery.

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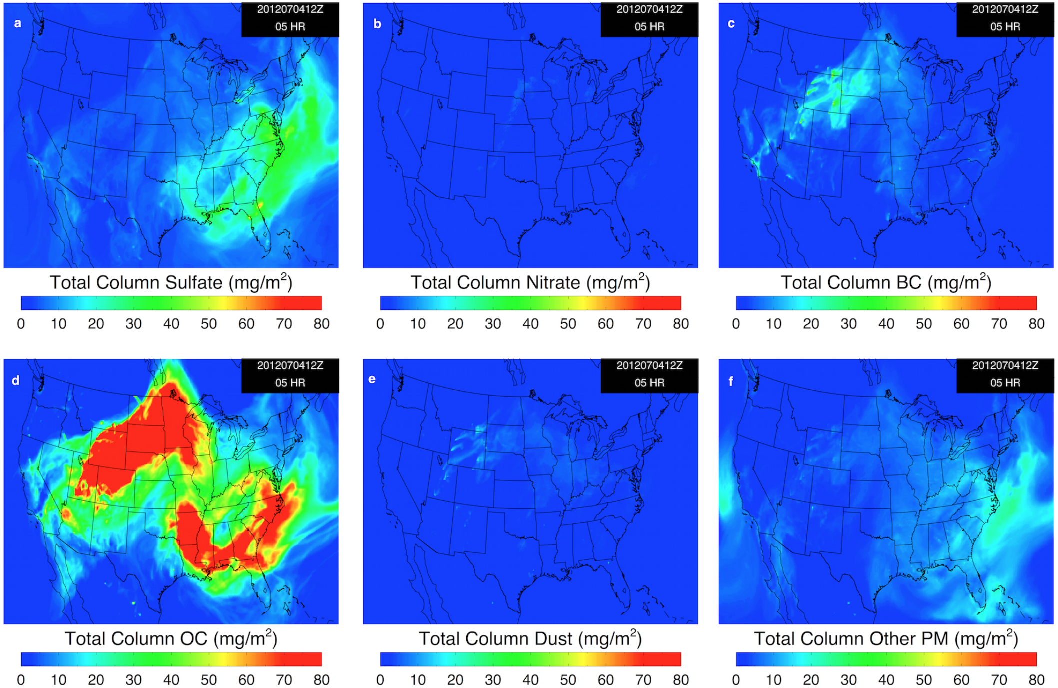

Figure 4. CMAQ modelled **(a)** total column sulfate **(b)** nitrate, **(c)** black carbon, **(d)** organic carbon, **(e)** dust and **(f)** other particulate matter for 4 July 2012 at 17:00 UTC. This was twelve hours into the simulation.

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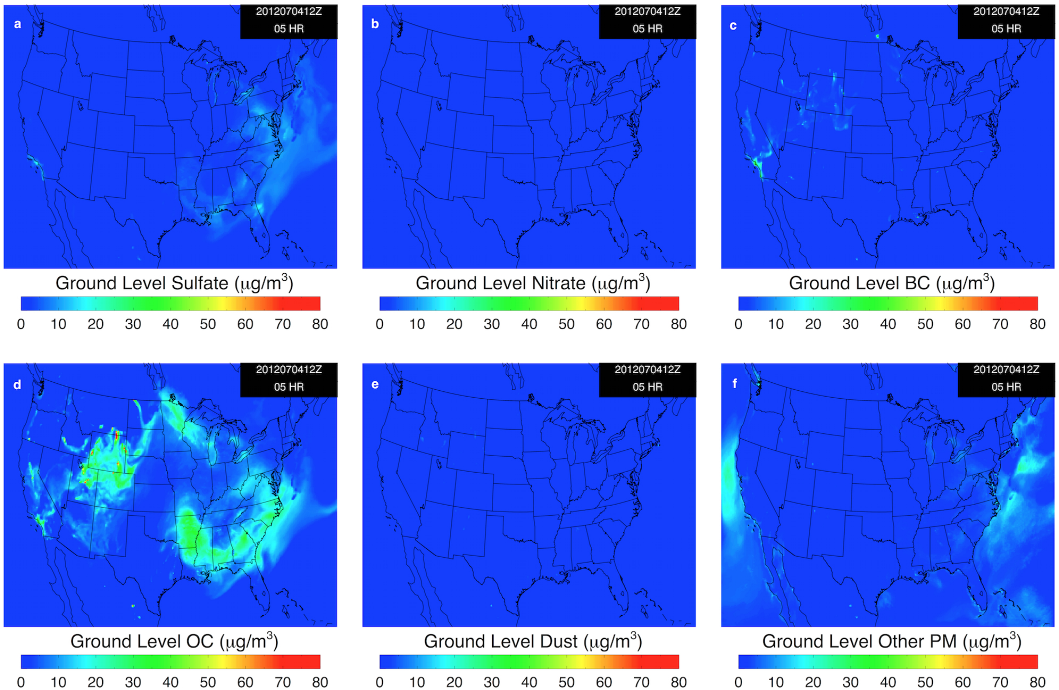

Figure 5. CMAQ modelled **(a)** surface concentration of sulfate **(b)** nitrate, **(c)** black carbon, **(d)** organic carbon, **(e)** dust and **(f)** other particulate matter for 4 July 2012 at 17:00 UTC.

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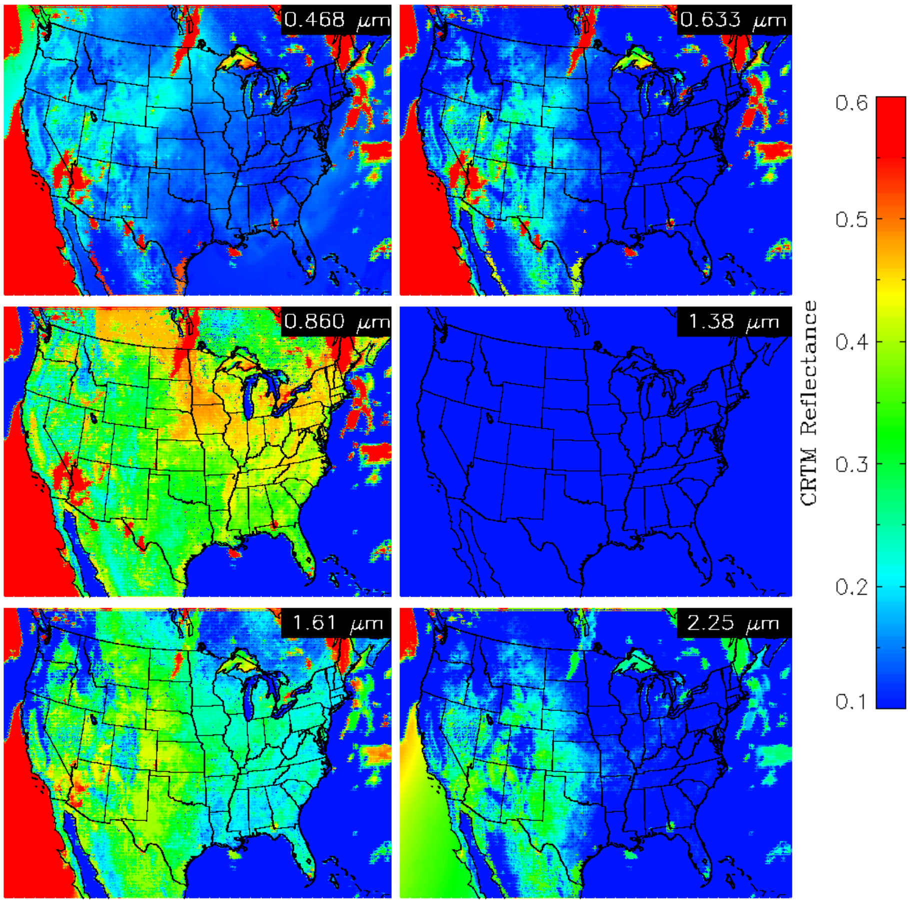

Figure 6. CRTM simulated radiances from the WRF-CMAQ simulated output of Figs. 4 and 5. The six ABI wavelength channels simulated are 0.468, 0.663, 0.86, 1.38, 1.61 and 2.25 μm.

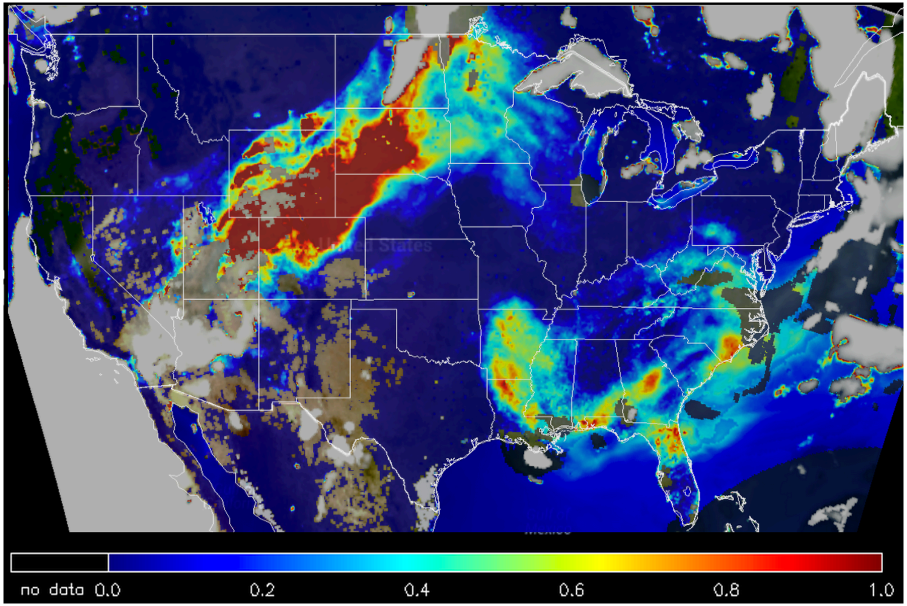

Figure 7. ABI AOD for 16:00 UTC on 4 July 2012 predicted from the OSSE.

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