# GMI-IPS: Processing & Visualization Software used in ATom DC-8 Aircraft Studies

Megan Damon[1], Junhua Liu[2], Sarah Strode[3], Stephen Steenrod[4], and Sarah Benish[5]

[1]NASA Goddard Space Flight Center
[2]Harvard Univ
[3]Universities Space Research Association
[4]USRA GESTAR
[5]University of Maryland

November 23, 2022

## Abstract

NASA's Atmospheric Tomography Mission (ATom) deployed in each of the four seasons during 2016-2018, the DC-8 aircraft in order to establish global-scale datasets intended to improve the representation of chemically reactive gases in global atmospheric chemistry models (ACMs). The Global Modeling Initiative (GMI) executed simulations for each ATom flight using the GMI Chemistry Transport Model (GMI-CTM) to provide species concentrations of chemical gases along the DC-8 flight transects. To solve the problem of translating the GMI-CTM simulation data to the unique spatial resolutions of each ATom flight, the GMI ICARTT Processing Software (GMI-IPS) was developed. The GMI-IPS is written in Python and provides data processing, flight extraction, and visualization support for aircraft research projects using ICARTT format, which is a standard format for airborne instrument data. Additionally, the GMI-IPS interpolates global gridded model data from Hierarchical Data Format (HDF) to ICARTT flight transects. Software classes for instruments and collections provided by the ATom DC-8 aircraft such as MER10, MMS, etc. are derived from a common base class. Other functionality provided by the GMI-IPS are: deriving missing flight entries along a transect, reading ICARTT entries from file, providing Python data structures for storing flight and model information, and more. The GMI-IPS is GIT source controlled, has approximately 30,000 lines of code, and supports parallelization across data collections. It delivered GMI-CTM data for more than forty distinct DC-8 aircraft flights that took place under ATom. The output ICARTT files adhere to format standard V1.1, and pass the scan utility provided by NASA LaRC Airborne Science Data for Atmospheric Composition. This presentation will include a software and methods overview, and results from ATom, including assessments using the GMI-CTM showing how well observations from ATom flight transects represent a broader region.

# GMI-IPS: Processing & Visualization Software used in ATom DC-8 Aircraft Studies

Damon, M.R. (1,2), Liu, J. (3), Strode, S.A. (2,3), Steenrod, S.D. (2,3), Benish, S.E. (4)
(1) Science Systems and Applications, Inc., Lanham, MD, USA (2) NASA Goddard Space Flight Center, Greenbelt, MD, USA
(3) Universities Space Research Association (USRA), GESTAR, Columbia, MD, USA (4) Department of Atmospheric & Oceanic Science, University of Maryland, College Park, MD, USA

## Background

- The Global Modeling Initiative (GMI) develops state-of-art modular 3D chemistry and transport models (CTMs)
- The Atmospheric Tomography Mission (ATom) studies the impact of human-produced air pollution on chemically reactive gases in the atmosphere
- Airborne instruments on NASA's DC-8 aircraft provide air parcel measurements of chemical species that inform the CTM community about fine-scale atmospheric structures, which matter to ozone ($O_3$) and methane ($CH_4$) budgets
- CTM & ATom researchers are using DC-8 flight track data to further understand how chemical species are affected by pollution

## Motivations for GMI-IPS

- Interfacing between GMI data and DC-8 ATom flight data requires ICARTT and NetCDF interoperability & specialized analysis
- Computationally intensive interpolation (x,y,z,t) for 50+ model fields along 40+ DC-8 ATom flight paths
- Adaptability opportunities to flight campaigns beyond ATom

## Software Approach

- The GMI-IPS is a workflow-based software solution to science-driven requirements
- Python with numpy & netCDF interfaces
- Inheritance from base classes
  - ICARTT entry base type (time, press, lat, lon)
  - DC-8 instruments (MER, MMS, etc.) software classes are derived from the ICARTT base type
- Matplotlib and mpl_toolkits for analysis

Figure 1

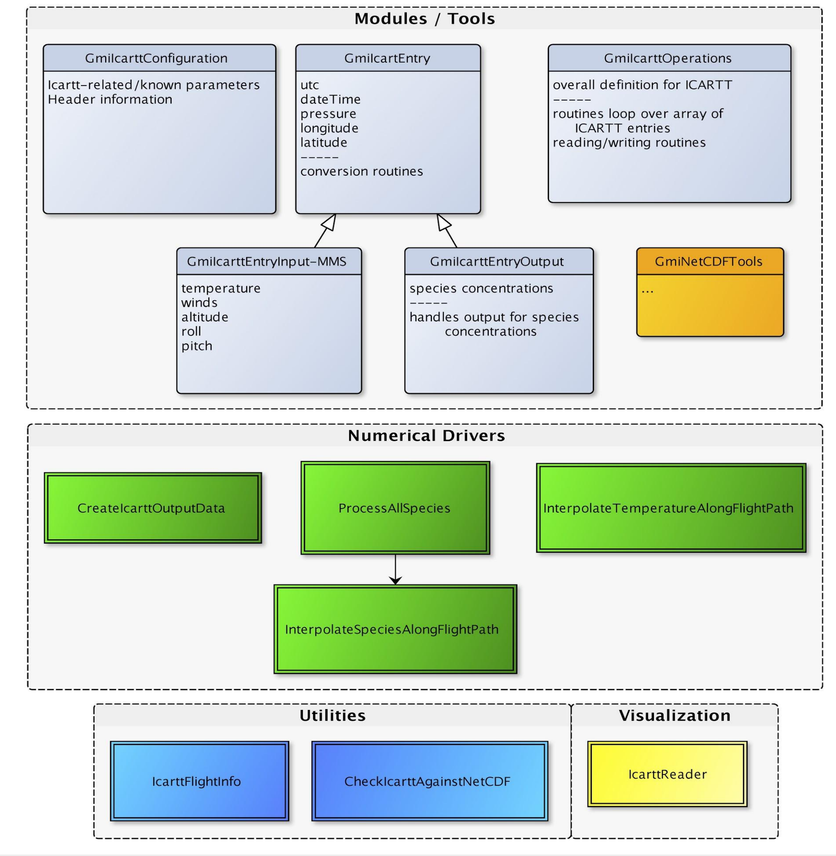


**Fig. 1)** The GMI-IPS architecture. Classes and configurations modules are shown in grey and orange. The green components represent functionalities that consume the bulk of CPU time. Blue and yellow components are for validation and analysis.

## Workflows

Figure 2

*DC-8 aircraft photo provided by NASA ESPO

Figure 3

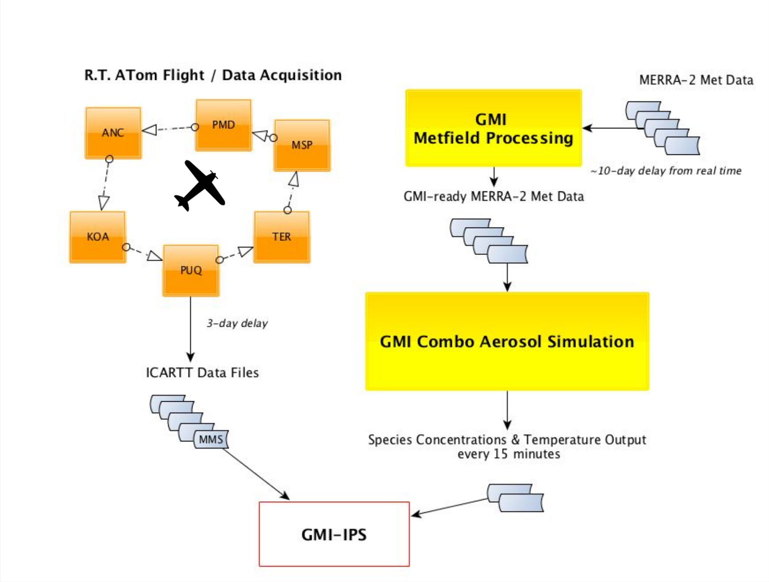


**Fig. 2)**

NASA's DC-8 aircraft started and ended each of the four seasonal ATom campaigns from Palmdale, CA. The DC-8 has a maximum cruising altitude of 41,000 ft (12.5 km) and requires 42 onboard operators and 8 flight crew for ATom field operations.

**Fig. 3)**

The acquisition of ATom flight data is shown side-by-side with GMI simulation processes. The GMI model ingests MERRA-2 meteorological inputs, and generates species concentrations and other quantities on a global scale. The GMI-IPS ingests both ICARTT and model NetCDF data.

**Fig. 4)**

The GMI-IPS internal workflow consists of self-contained numerical and visualization drivers. Users of the GMI-IPS determine the workflow steps depending on their specific requirements.

**Fig. 5)**

Data parallelization is used to interpolate GMI global model data to the DC-8 flight tracks.

**Fig. 6)**

The GMI-IPS GUI initiates workflows from user-selected ICARTT files. Flight track data, workflow updates, and basic visualizations are available as the workflow creates NetCDF and ICARTT files for further analysis.

Figure 4

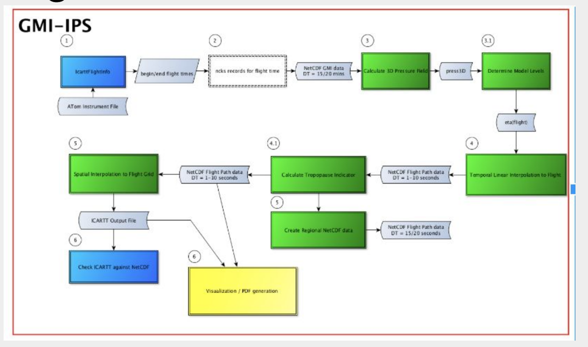


Figure 5

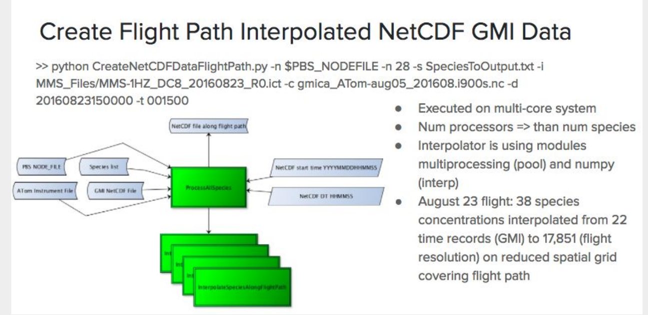
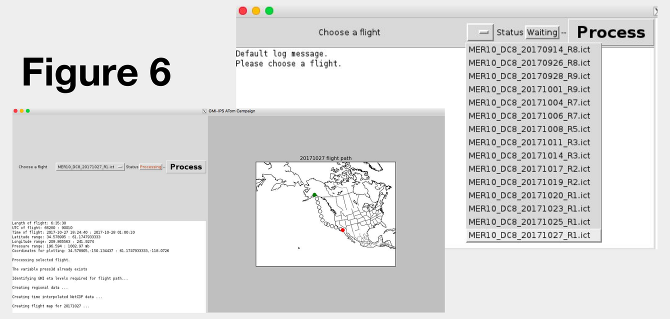


Figure 6



## Numerical Methods

$$y = y0 + (x - x0)\frac{y1 - y0}{x1 - x0}$$

1D linear interpolation from model time to UTC flight records

$$press3d = am*pt + bm*psf$$

3D model pressure calculation

$$\bar{x} = \frac{\sum_{i=1}^{n} wi*xi}{\sum_{i=1}^{n} wi},$$

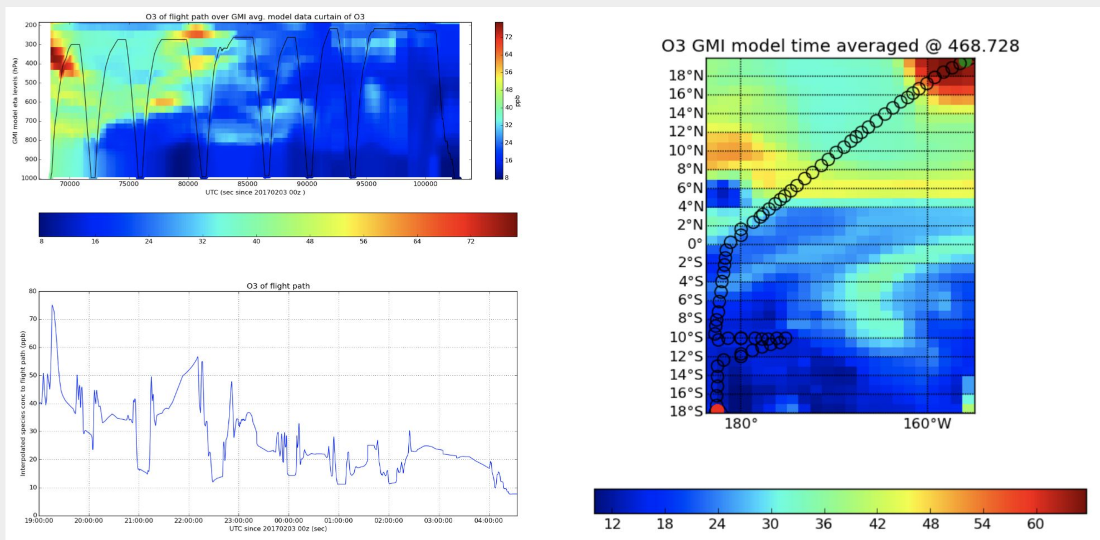
Weighted arithmetic mean for background curtain visualization

Trilinear interpolation from coarse model grid points to fine-resolution flight path points

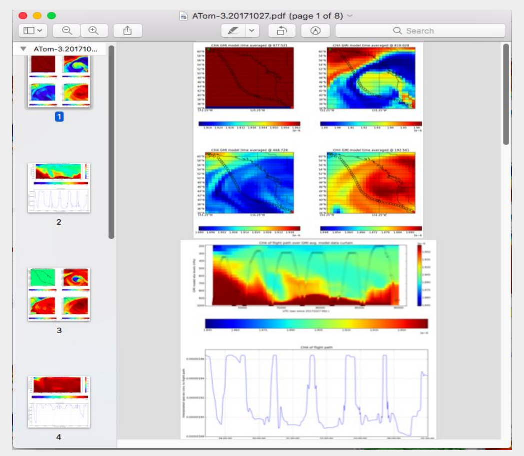
$$f(x,y,z) \approx a0 + a1x + a2y + a3z + a4xy + a5xz + a6yz + a7xyz$$

## Data Visualization

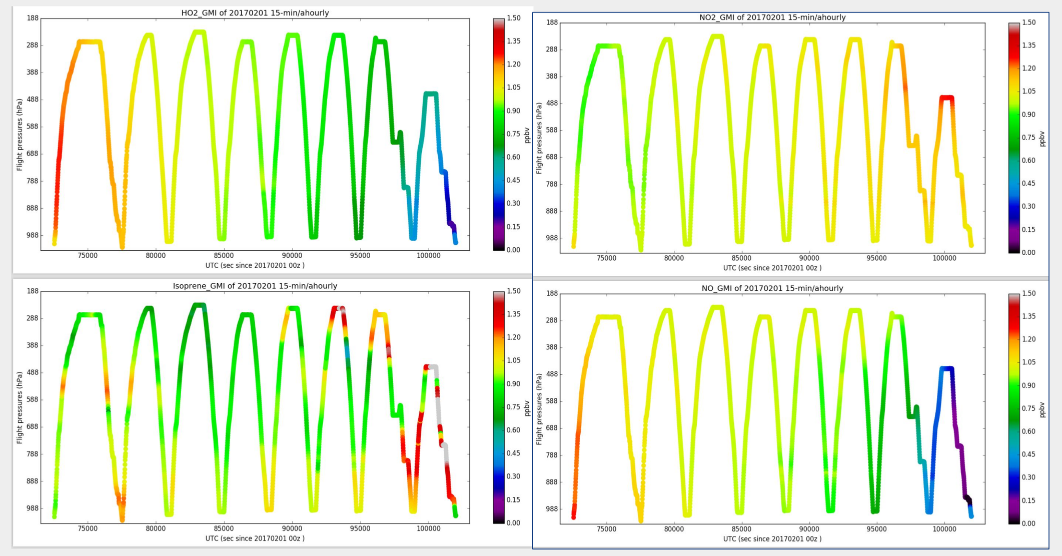
a



(a)
GMI data for the DC-8 Pacific ocean basin flight leaving Hawaii, landing in Fiji on Feb 02 2017



(b) GMI-derived ATom-3 data from Oct 27 2017. PDF packages include 2D model-averaged slices for 977, 810, 468, and 192 mb, model background curtains with flight track overlays, and time series plots.



(c)
The GMI-IPS also provides flight tracks differences of quantities from the same flight transect, or model data derived for transects. Shown here are GMI-derived flight transect differences from different GMI output products for HO2, Isoprene, NO2, and NO.

*data presented is from GMI simulations, and not observations from the DC-8 aircraft

## Conclusions

- The GMI-IPS generated ICARTT files approved by NASA LaRC for ATom-1-4, as well as regional NetCDF model data for each flight.
- GMI-derived flight transects are being widely used by ATom researchers.
- ATom O3 is generally well-reproduced by GMI in magnitude and variability, and GMI is performing very well in the mid-latitudes and decent in the tropics.
- The GMI-IPS was adapted with minimal effort for ICARTT files from flights taking place in the Baltimore/Washington D.C. area under the Regional Atmospheric Measurement Modeling and Prediction Program (RAMMPP).

E-mail: megan.damon@nasa.gov | Web: gmi.gsfc.nasa.gov

National Aeronautics and
Space Administration