The NASA-Funded EPIC Atmospheric Model: Advantages of Open-Code Status since 1998

Timothy E. Dowling
Dept. of Physics & Astronomy, University of Louisville, KY 40292
dowling@louisville.edu

December 2017

Abstract

This article details specific advantages of the open-source status, since 1998, of the Explicit Planetary Isentropic Coordinate (EPIC) Atmospheric Model, in response to a call for white papers by the National Academies' *Committee on Best Practices of a Future Open Code Policy for NASA Space Science*. The EPIC model's number of peer-reviewed papers and citations have more than doubled as a result of its open-code policy. Specific examples are given of independent code development enabled by this policy. The author's stand, based on two decades of experience, is that publically funded simulation software should be required to be open source and freely available. Self-adherence to this policy has significantly increased the EPIC model's scientific impact, with no negative side effects to its developers.

1. Introduction

This article is written in support of open-code policy for NASA-funded source code. The author is the lead architect and General Public License (GPL) copyright holder, since 1998, of the Explicit Planetary Isentropic-Coordinate (EPIC) atmospheric model. EPIC is a primitive-equation, general circulation model (GCM) designed for simulating planetary atmospheres. The model's concept is first introduced by Dowling (1991), the acronym "EPIC" is introduced by Dowling (1993), and the model's first scientific application is a prediction of the effects of the Comet Shoemaker-Levy 9 impacts on Jupiter by Harrington et al. (1994; featured on the cover of Nature).

The first complete description of the EPIC model is given by Dowling et al. (1998), and a full update is given by Dowling et al. (2006). The EPIC model's GPL license and its open source code, via the NASA Planetary Data System (PDS) Atmospheres Node, are both explicitly mentioned in both papers. The author was the first to list model source code on the PDS Atmospheres node, in 1998, and negotiated with the curators at that time to put the link under *Data and Services*/*Software*. At the time of this writing, there are two model source codes so linked (the EPIC model and a collection of Collision Induced Absorption models; note there is also a Mars GCM link, but it is data only). There are also now two additional software packages linked (OAL and ISIS; note there is also a NASAView link, but it is stale at the time of this writing).

The majority of the EPIC model's $2.3M development cost has come from NASA, with additional support from NSF and DOE. Consistent with its role as a leader in open-code practice, the EPIC model project has its own Google Scholars page, and at the time of this writing, has 1694 citations (see Fig. 1), an h-index of 21, and an i10-index of 32. Of the 32 EPIC-model papers with at least 10 citations, 53% do not include the author as co-author, corresponding to 61% of its citations. Thus, by these metrics the model's scientific contributions have been more than doubled by its open-source policy and its free availability on the NASA PDS Atmospheres Node.

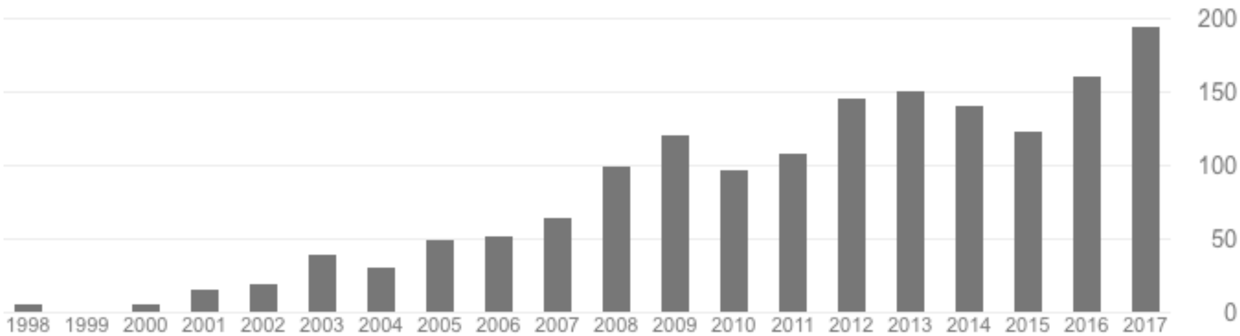

Figure 1. EPIC model citations per year (as of December 21, 2017), from the model's Google Scholar page. Over half of EPIC-model papers do not have the author (and GPL copyright holder) as co-author, which implies the open-code policy has more than doubled the model's scientific impact.

2. Downstream Code Development

To illustrate the significant leverage that springs from open-code policy, the following examples related to EPIC-model code are included. In the first two cases, former postdocs of the author, Profs. Kunio Sayanagi and Raul Morales-Juberias, worked with their PhD students to add new functionality to the EPIC model. In the remaining cases, code developers solved problems in a variety of models using pieces of the C-language version of the open-source DISORT radiative transfer code (Stamnes et al. 1988), which was translated from the original Fortran 77 by the author (Buras et al. 2011) as part of a NASA-funded project to add realistic gas-giant radiative transfer to the EPIC model.

First, Brueshaber and Sayanagi (2016) developed a gas-giant polar-region model for EPIC that does not have the longitude-latitude-grid pole problem, by starting with EPIC's Cartesian-coordinate option and adding a gamma-plane Coriolis force and appropriate lateral boundary conditions.[1] Second, Cosentino et al. (2017) added a gravity-wave drag parameterization to the EPIC model to simulate Jupiter's Quasi-Quadrennial Oscillation.

The author's translation of DISORT into C runs significantly faster than the Fortran version and does not suffer from numerical instabilities that plague the original code (Buras et al. 2011). These two improvements were serendipitous, but now benefit all users of DISORT; they were enabled by the open-code status of DISORT. The C version is now the default radiative-transfer

[1] The author has since joined this project, a year later.

engine for the popular libRadtran radiative-transfer package (Emde et al. 2016), and has been cited in an array of terrestrial applications, including studies of cloud cover, cloud microphysics, dust, ash, and other aerosols, chemical-gas spills, solar-power potential, spectrometer calibration, land use including Arctic snow properties, and UV fluxes (including the widely used Morelli et al. (2016) *HappySun* sun-burn-preventing app). The C version has also been cited in a wide range of planetary science and astronomical projects, including applications to the atmospheres of Venus, Jupiter, Titan, Earth-sized exoplanets, super Earths, and brown dwarfs (a full listing of citations is available on the EPIC-model Google Scholar page).

In turn, the C version of DISORT has enabled development on new platforms. For example, a team at UC Berkeley wrote a Python wrapper for the C version, which they call PyDISORT. This allows the DISORT functionality to be used directly in the popular Python environment. They applied this to an analysis of methane in Titan's atmosphere (Ádámkovics et al. 2016). Another example stems from the fact that to run efficiently on GPUs (graphical processor units), code cannot call subroutine libraries. Efremenko et al. (2014) needed to calculate eigenvalues and eigenvectors on GPUs, and they solved the problem by using the code c_asymmetric_matrix() from the C version of DISORT.

3. Conclusions

The author has practiced open-code policy with the EPIC atmospheric model since 1998, via the GPL license and NASA PDS Atmospheres Node. The result is a more than doubling of EPIC-model related publications, and the enabling of numerous code advances that would not have occurred otherwise.

The author has never been "scooped" by this open-code policy; in practice, there are simply too many potential projects available and too few modelers. Even if the number of applications for the EPIC model were to drop by an order of magnitude, it would still be distributed in the same open and free manner, because the model's development was paid for by federal tax dollars.

It is the author's opinion that source code developed by a Principal Investigator (PI) using NASA funding, and/or other public funding, should be required to be open source and made freely available, under terms similar to open data.

Acknowledgments. The author thanks Joseph Harrington for over two decades of open-code collaboration, and Google Scholar for providing the free citation statistics and links to downstream code development used in this article.

References

Ádámkovics M, Mitchell JL, Hayes AG, Rojo PM, Corlies P, Barnes JW, Ivanov VD, Brown RH, Baines KH, Buratti BJ, Clark RN, Nicholson PD, Sotin C, 2016, Meridional variation in tropospheric methane on Titan observed with AO spectroscopy at Keck and VLT, *Icarus* 270, 376–388.

Brueshaber SR, Sayanagi KM, 2016, Dynamics of giant planet polar vortices, 48th Meeting of the Div. for Planetary Science, Amer. Astron. Soc.

Buras R, Dowling T, Emde C, 2011, New secondary-scattering correction in DISORT with increased efficiency for forward scattering, *J. Quant. Spectr. Ra.* 112, 2028–2034, doi:10.1016/j.jqsrt.2011.03.019

Cosentino RG, Morales-Juberias R, Greathouse T, Orton G, Johnson P, Fletcher LN, Simon A, 2017, New observations and modeling of Jupiter's Quasi-Quadrennial Oscillation, *J. Geophys. Res. Planets*, 122, doi:10.1002/2017JE005342.

Dowling TE, 1991, Towards numerical weather prediction for Jupiter, *Bull. Amer. Astron. Soc*. 23, 1134.

Dowling TE, 1993, An explicit planetary isentropic-coordinate atmospheric model for Jupiter, Saturn, Uranus, and Neptune, *Bull. Amer. Astron. Soc.* 25, 1031.

Dowling TE, Bradley ME, Colón E, Kramer J, LeBeau RP, Lee GCH, Mattox TI, Morales-Juberías R, Palotai CsJ, Parimi VK, Showman AP, 2006, The EPIC atmospheric model with an isentropic/terrain-following hybrid vertical coordinate, *Icarus* 182, 259–273.

Dowling TE, Fischer AS, Gierasch PJ, Harrington J, LeBeau RP, Santori CM, 1998, The explicit planetary isentropic-coordinate (EPIC) atmospheric model, *Icarus* 132, 221–238.

Efremenko DS, Loyola DG, Doicu A, Spurr RJD, 2014, Multi-core-CPU and GPU-accelerated radiative transfer models based on the discrete ordinate method, *Comp. Physics Comm*. 185, 3079–3089.

Emde C, Buras-Schnell R, Kylling A, Mayer B, Gasteiger J, Hamann U, Kylling J, Richter B, Pause C, Dowling T, Reinhardt B, Bugliaro L, 2016, The libRadtran software package for radiative transfer calculations (version 2.0.1), *Geosci. Model Dev* 9, 1647–1672, doi:10.5194/gmd-9-1647-2016.

Harrington J, LeBeau RP, Backes KA, Dowling TE, 1994, Dynamic response of Jupiter's atmosphere to the impact of Comet Shoemaker-Levy 9, *Nature* 368, 525–527.

Morelli M, Masini A, Simeone E, Khazova M, 2016, Validation and *in vivo* assessment of an innovative satellite-based solar UV dosimeter for a mobile app dedicated to skin health, Photchem. Photobio. Sci. 15, 1170–1175.

Stamnes K, Tsay SC, Wiscombe W, Jayaweera K, 1988, Numerically stable algorithm for discrete-ordinate-method radiative transfer in multiple scattering and emitting layered media, Appl. Opt. 27, 2502–2509.