SeaIceRT: a python interface for a Delta-Eddington radiative transfer model

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Summary

SeaIceRT is a python interface for the single column Delta-Eddington sea ice radiative transfer model from the Community Ice CodE (CICE) sea ice model used in the NCAR Community Earth System Model version 2 (CESM2). The python code provides a simple interface to the underlying FORTRAN radiative transfer model. Model parameters and forcing variables (ice thickness, snow depth and density, and melt pond depth) can be set and explored from an interactive environment such as ipython or Jupyter notebooks, as well as incorporated into python scripts to estimate under-ice light over periods of time, along transects or for grids for the Arctic Ocean. We demonstrate setting up and running the model for several transects collected during the MOSAiC cruise. We hope that the software package provides a framework for both simplifying and expanding access to these modelling tools. SeaIceRT is open source software. Documentation and code can be found at https://github.com/andypbarrett/seaice_radiative_transfer.

Motivation

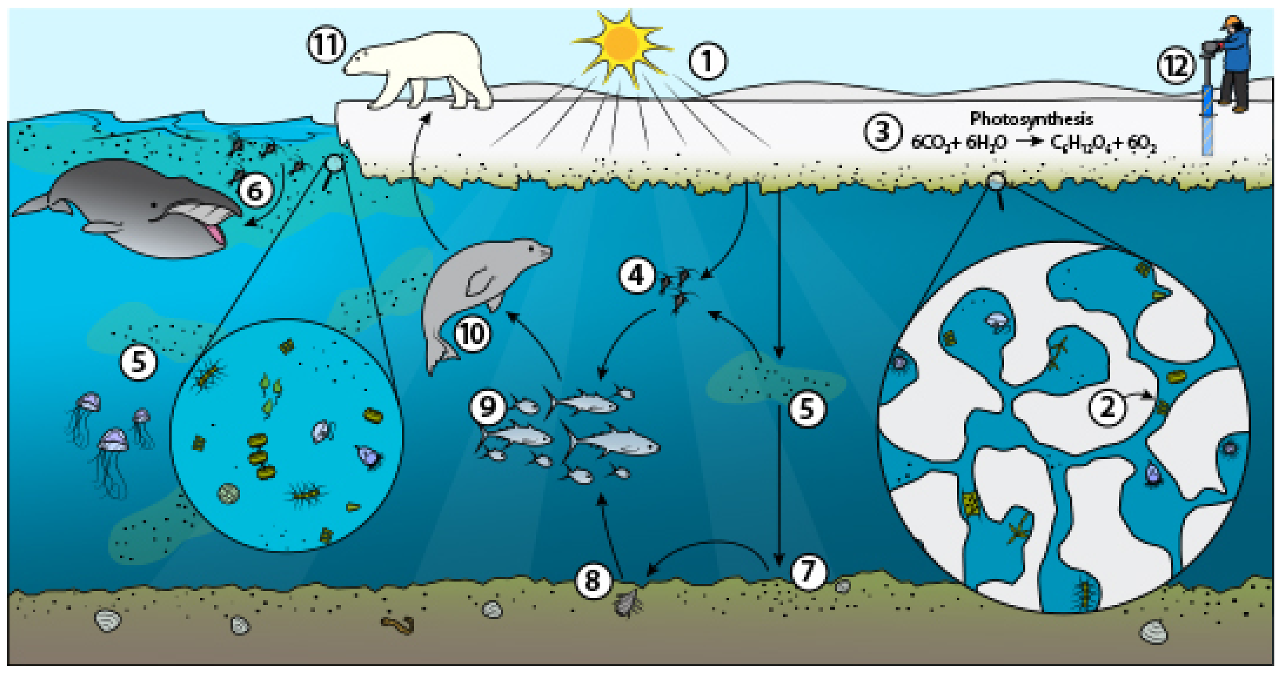

Figure 1. The Arctic Sea Ice Ecosystem https://askabiologist.asu.edu/explore/frozen-life ©Arizona Board of Regents ASU Ask A Biologist.

Sunlight transmitted through snow and sea ice to the upper ocean plays an important role in regulating biological activity in Polar regions, and determining the timing of initiations of algal and phytoplankton blooms. Measurements of under-ice photosynthetically active radiation (PAR) are available from field campaigns and from autonomous buoys. However, understanding of the spatial distribution and time evolution of PAR for larger regions and over longer time periods requires estimates of light transmission through snow and sea ice from radiative transfer models. Even intensive and observation rich field campaigns such as MOSAiC can only collect measurements from a limited number of measurement points over selected periods of time. Radiative transfer models can be used to "fill in" gaps in the under ice light field, enabling observations of the atmosphere, snow and ice characteristics, oceanography and biology collected at distributed locations to be combined. However, many radiative transfer codes are not simple to run, and are often written in compiled languages. Simple to use interfaces to these codes greatly simplify use, increasing accessibility to a wider user-base.

The Delta-Eddington Radiative Transfer Model

The Delta-Eddington (also δ-Eddington) model is a multiple scattering parameterization of radiative transfer that uses Inherent Optical Properties (IOP) (extinction coefficients, single scattering albedo, and asymmetry parameter) for snow, ice and other absorbers, along with snow depth, ice thickness and pond depth, and incident radiation to calculate albedo, internal absorption and light transmission to the upper ocean. Radiation calculations are made for direct and diffuse components of visible ($200\mathrm{nm} - 700\mathrm{nm}$) and near-infrared ($700\mathrm{nm} - 5000\mathrm{nm}$) solar radiation. The sea ice column consists of snow covered ice, ponded ice or bare ice. Snow and melt ponds are represented as two layers, of which the upper layer in both cases is a surface scattering layer. Sea ice is represented as five layers, with the top layer being a ice surface scattering layer. Refraction of incident radiation at pond water surfaces and the interface between the ice SSL and underlying ice is accounted for by including a refractive (Fresnel) layer. A complete description of the Delta-Eddington model is described in [1].

Technical details

The original program `1D_SIR_DE` is a stand alone version of the CESM3 radiative transfer code and is written in a mixture of Fortran 77 and Fortran 95. Parameters are defined in an input text file and results written to an output file. The motivation for writing a Python wrapper for the code, was to allow model runs from interactive python interpreters, executable notebooks and scripts. The original Fortran code was modified to allow input parameters and results to be passed between compiled Fortran routines and the Python wrapper directly, without the need for input and output files. This was done using `ctypes`, a foreign function library for Python. The modified fortran code was compiled as a shared library using `gfortran`. `ctypes` data types were defined to allow the Python Wrapper code to access data in Fortran `COMMON BLOCKS`.

References

[1] B. Briegleb and B. Light, "A Delta-Eddington Mutiple Scattering Parameterization for Solar Radiation in the Sea Ice Component of the Community Climate System Model," tech. rep., UCAR/NCAR, 2007. Artwork Size: 5209 KB Medium: application/pdf.

[2] K. Kinzler, "Frozen life," 2014.

[3] P. Itkin, S. Hendricks, M. Webster, L. von Albedyll, S. Arndt, D. Divine, M. Jaggi, M. Oggier, I. Raphael, R. Ricker, J. Rohde, M. Schneebeli, and G. E. Liston, "Sea ice and snow characteristics from year-long transects at the MOSAiC Central Observatory," *Elementa: Science of the Anthropocene*, vol. 11, p. 00048, Feb. 2023.

Running `SeaIceRT`

`SeaIceRT` is available from the https://github.com/andypbarrett/seaice_radiative_transfer github repository. Installation instructions along with software requirements are provided there.

Once installed, SeaIceRT can be run in a Python interpretter, IPython or a Jupyter notebook. I can also be included in other python scripts. Example notebooks are provided in the `notebooks` folder.

A simple `Hello World` example for running `SeaIceRT` is given below.

```
(seaice_radiative_transfer) nsidc-abarrett-442:seaicert$ ipython
Python 3.7.6 | packaged by conda-forge | (default, Mar  5 2020, 15:27:18)
Type 'copyright', 'credits' or 'license' for more information
IPython 7.17.0 -- An enhanced Interactive Python. Type '?' for help.

In [1]: from ccsm3_sir_de import SeaIceRT
In [2]: model = SeaIceRT()
In [3]: model.run()
In [4]: model.print_results()
----------------------------------------------------------------------
CCSM3 Sea Ice Delta Eddington calculation
----------------------------------------------------------------------
----------------------------------------------------------------------
Visible and near-ir direct and diffuse albedos
Visible: 0.2 to 0.7 micrometers
Near-IR: 0.7 to 5.0 micrometers
----------------------------------------------------------------------
Albedo shortwave direct: 0.17
Albedo shortwave diffuse: 0.19
Albedo longwave direct: 0.06
Albedo longwave diffuse: 0.06
 ----------------------------------------------------------------------
Surface ansorption and Albedos
----------------------------------------------------------------------
Visible solar absorbed by ocean: 27.5656681060791
Near-IR absorbed by ocean: 0.0
----------------------------------------------------------------------
Surface absorption ad albedos
----------------------------------------------------------------------
Solar vs direct surface irradiance:   0.12 Wm-2
 ----------------------------------------------------------------------
Snow/Sea ice transmitted flux (Tr fraction) and absorption (Q Wm-2)
----------------------------------------------------------------------
Level      depth Tr_vs  Q_vs   Tr_ni  Q_ni   Q_total
----------------------------------------------------------------------
0 surface                26.88          68.01  94.89
           0.000 1.0000        1.0000
1 pond                   12.76          67.06  79.82
           0.250 0.9494        0.0130
2 pond                   12.08           0.93  13.01
           0.500 0.8625        0.0002
3 ice                     2.05           0.02   2.07
           0.050 0.7888        0.0000
4 ice                    10.84           0.00  10.84
           0.375 0.6228        0.0000
5 ice                     9.41           0.00   9.41
           0.750 0.4730        0.0000
6 ice                     6.78           0.00   6.78
           1.125 0.3551        0.0000
7 ice                     4.61           0.00   4.61
           1.500 0.2612        0.0000
8 ocean                  27.57           0.00  27.57
```

Estimates of Under Ice Sunlight for MOSAiC ice thickness transects

Ice thickness, snow depths and pond depths measured during the MOSAiC expedition from Magnaprobe snow and melt pond depth measurements from the 2019-2020 MOSAiC expedition (https://doi.org/10.1594/PANGAEA.937781) [3] are used to estimate shortwave radiation transmitted to the ocean.. Snow depths and pond depths were measured using Magnaprobe automatic snow depth probes at 1 m to 3 m intervals, along established transects regularly during the expedition. Ice thickness was estimated by subtracting snow depths from combined snow and ice thicknesses measured using the GEM-2 electromagnetic induction instrument.

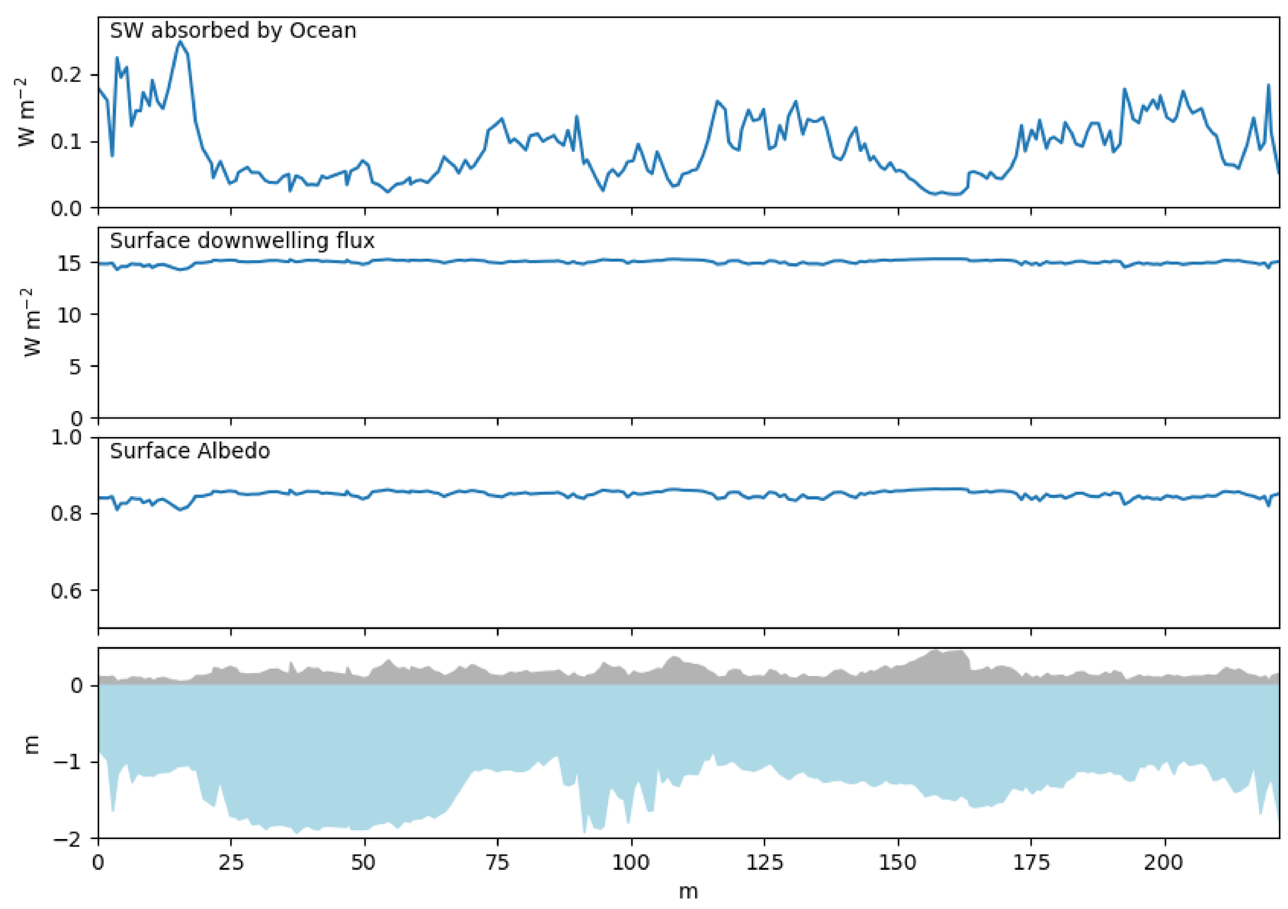

Figure 2. Shortwave radiative flux at the ice-ocean interface, surface downwelling shortwave radiation and albedo estimated by `SeaIceRT`, along with ice thickness, snow depth and pond depth