Parameterized Rain Impact Model (PRIM) data user's guide

August 2023

1. Introduction

The Parameterized Rain Impact Model (PRIM) quantifies the near-surface salinity gradients generated by rainfall, and is an improved version of the original Rain Impact Model (RIM) developed by Santos-Garcia et al. (2014), which is included in the Aquarius V5.0 salinity dataset (https://doi.org/10.5067/AQR50-2SOCS).

Each PRIM data file corresponds to a single file of the JPL SMAP Level 2B CAP Sea Surface Salinity V5.0 Validated Dataset (Fore et al., 2016; https://doi.org/10.5067/SMP50-2TOCS). At the time and location of each L2 SMAP ocean salinity datapoint, PRIM uses satellite rainfall data, reanalysis winds, and bulk salinity to estimate the rain-generated vertical salinity anomaly at several depths as well as the probability of salinity stratification.

2. PRIM Algorithm

2.1 Overview

PRIM is a semi-empirical model that estimates rain-induced freshening as a function of depth by applying 24 hours of satellite rain accumulation observations to the ocean surface in a layer, and then evolving the resulting salinity anomaly in time using one-dimensional model of vertical diffusion in the upper ocean (Asher et al., 2014). This model uses as inputs satellite rainfall data and reanalysis wind speeds; the initial condition is the surface salinity from a gridded Argo product. The output of PRIM is an estimated salinity anomaly (relative to the initial condition) due to rainfall, at several depths in the upper ocean, and estimate of the probability of salinity stratification.

2.2 PRIM algorithm and development

PRIM uses a modified version of the diffusion equation given by Crank (1975) to express salinity (S) as a function of depth (z) and time (t) as follows:

$$S(z,t) = S_o d_o \Omega \text{ , where}$$
$$\Omega = \left(d_o + \frac{A}{\sqrt{K_z t}} exp(\frac{-z^2}{4K_z t})\right)^{-1} \quad (1)$$

S_o is the initial bulk salinity; A is the rain impulse, equal to the accumulated rainfall integrated over a depth of 1 m; d_o is the characteristic mixing depth over which the pulse of freshwater is mixed (taken to be 1 m as per Santos-Garcia et al., 2014), and K_z is the diffusion coefficient. Whereas the original RIM used a constant K_z value of 1 x 10^{-4} m^2s^{-1}, the major innovation of PRIM is to incorporate a parameterized K_z that is dependent on both wind speed and rain rate, reflecting the fact that the mixing represented by K_z is known to vary with both of these factors. The parameterized K_z used in PRIM was developed by forcing a set of 1-dimensional ocean simulations with idealized rain rates and wind speeds (following Drushka et al., 2016) and fitting Eq. (1) to the output salinity from each simulation to determine K_z as a function of the input rain rate (R) and wind speed (U). The resulting set of K_z values were then empirically fitted to a function of the form

$$K_z = exp\big((a_o + a_1 U + a_2 U^2 + a_3 U^3)(b_1 R + b_2 e^{b_3 R})\big) \quad (2)$$

where $a_0, a_1, a_2, a_3, b_1, b_2$ and b_3 are time-dependent constants with time varying over 24 hours.

Eq. (2) was fitted using a two-step iterative process where least-squares linear regression was used to find a_n holding b_n constant; and then a nonlinear optimization was used to find b_n while holding a_n constant. This procedure, although cumbersome operationally, ensured stability of the nonlinear part of the optimization. Eqs. (1) and (2) are valid for U < 10 m s^{-1}; at higher wind speeds, K_z becomes unrealistically large and is set to its U = 10 m s^{-1} value.

The parameterized K_z given by Eq. (2) compare well to K_z values obtained by fitting observational data from the SPURS-2 central mooring (https://doi.org/10.5067/SPUR2-MOOR1) to Eq. (1), indicating that it is reasonable to parameterize the time evolution of rain-induced near-surface salinity anomalies using this method.

Eq. (1) gives the salinity dilution due to rain at one time in the past. PRIM estimates the cumulative impacts of rain over the previous 24 hours as a set of successive dilutions, by computing Eq. (1) over 30-minute timesteps ranging from $t_1 = 0$ (the time of the SMAP measurement) to t_{49} = -24 h (24 hours prior to the SMAP measurement):

$$S_{PRIM}(z,t) \equiv S_z(t) = S_o \prod_{i=1}^{49} \Omega(t_i) \quad (3)$$

2.3 Input data and pre-processing

The following input datasets are used to produce PRIM:

Rain rate from the IMERG V6B Final Run product (Huffman et al., 2014). Data is downloaded directly from https://arthurhouhttps.pps.eosdis.nasa.gov/gpmdata/. These data have 30 minute, 0.1 degree resolution and are first interpolated to a grid with 0.25 degree resolution.

Wind speed from the ERA5 reanalysis product (Hersbach et al., 2017). Data are pre-processed by the Precipitation Research Group at the Department of Atmospheric Science at Colorado State University to produce files with hourly, 30 km resolution to be ingested into the PRIM algorithm. The algorithm first interpolates the data in time and space to the same grid as the IMERG data. Wind speed is computed from the vector wind components. Wind speed from the SMAP radiometer is used as the "instantaneous" (i.e., at $t_1 = 0$, the time as the SMAP measurement) wind speed in the PRIM calculation.

Bulk salinity from the Roemmich & Gilson gridded Argo climatology (Roemmich and Gilson, 2009), downloaded from the Scripps Argo website (https://sio-argo.ucsd.edu/RG_Climatology.html). Monthly salinity data at 5-m depth on a 1 degree spatial grid were used in the PRIM calculation; as for the wind and rain datasets, these were first interpolated to a 0.25 degree grid.

2.4 PRIM calculation

For each SMAP L2 measurement, the gridded IMERG rain rate and ERA5 wind speed data from the previous 24 hours, and bulk salinity (S_o) from Argo, are interpolated to the location of the SMAP pixel. The local, parameterized K_z is computed using Eq. 1, and then Eq. (3) is evaluated at z = 0, 1, and 5 m to produce S_{om}, S_{1m} and S_{5m}. In addition, the probability of salinity stratification in the upper 10 m is estimated as

$$PSS\ (t) = \frac{S_{10\ m}(t) - S_{0\ m}(t)}{max(S_{10\ m}) - min(S_{0\ m})} \tag{4}$$

3. Dataset content

Each netCDF4 PRIM data file corresponds to a JPL SMAP Level 2B CAP Sea Surface Salinity V5.0 file, which corresponds to a single orbit on a given day. Files are named following the convention **PRIM_SMAP_L2_YYYYMMDD_rOO_v1.nc**, where YYYY, MM, and DD correspond to the year, month, and day; and OO corresponds to the orbit number of the given day.

Each file has dimensions **cross_track_bins** and **along_track_bins**. These correspond to the cross-track and along-track dimensions of SMAP's swath and are centered on the spacecraft sub-satellite. The cross-track dimension is generally perpendicular to the path traced out by the spacecraft sub-satellite point and has length 76, and the along-track dimension is aligned with it and has length 1624. Further details are found in the user guide for the JPL SMAP product (https://podaac.jpl.nasa.gov/dataset/SMAP_JPL_L2B_SSS_CAP_V5).

The variables contained in each are described in Table 1. Each variable has the dimensions **along_track_bins** x **cross_track_bins.**

Variable name	**Description**	**Data source**
SMAP variables: these are taken from the SMAP JPL L2B files		
time	time of SMAP observation, in days since 2015-1-1 00:00:00 UTC (identical to the SMAP 'time' variable)	SMAP JPL v5
lon	longitude of SMAP observation, in degree_east (identical to the SMAP 'longitude' variable)	SMAP JPL v5
lat	latitude of SMAP observation, in degree_north (identical to the SMAP 'latitude' variable)	SMAP JPL v5
PRIM Inputs		
S_ref	Reference salinity at 5 m depth, in 1e-3, collocated to the center of each SMAP measurement	Roemmich & Gilson monthly gridded Argo product
rain_rate	Rain rate, in mm hr^{-1}, closest in time to SMAP observation time closest in time to SMAP observation time & collocated to the center of each SMAP measurement	IMERG V6B
wind_speed	Wind speed, in m s^{-1}, at the time/location of each SMAP observation	SMAP JPL v5 (note that this is NCEP GFS wind speed that has been propagated to the time of the SMAP measurement as part of SMAP JPL processing)
PRIM Outputs		

PRIM_S0m	PRIM salinity estimate at 0m depth	Calculated by PRIM algorithm
PRIM_S1m	PRIM salinity estimate at 1m depth	Calculated by PRIM algorithm
PRIM_S5m	PRIM salinity estimate at 5m depth	Calculated by PRIM algorithm
PSS	Probability of salinity stratification between 0 and 10 m	Calculated by PRIM algorithm
Kz	diffusion coefficient at the time/location of each SMAP observation	Calculated by PRIM algorithm from rain_rate and wind_speed

Note that the PRIM algorithm uses as input data the rain rate and wind speed from the previous 24 hours (Eq. 3); to limit file sizes, PRIM data product only includes rain rate and wind speed at the time of the SMAP measurement and therefore cannot be used to reproduce PRIM estimates of salinity and stratification. Users wishing to reproduce the PRIM data can contact the data creators (see below) or consult the code.

4. Citation

Jacob et al. 2023. Parameterized Rain Impact Model near-surface salinity and stratification estimates. Ver. 1.0. PO.DAAC, CA, USA. Dataset accessed [YYYY-MM-DD] at https://doi.org/10.5067/PRIMS-2RSW1.

5. Code and point of contact

All Matlab code used to produce PRIM is freely available on GitHub at https://github.com/Marchuria/PRIM.

Direct questions or comments about this dataset to:

March Jacob: march.jacob@gmail.com
Kyla Drushka: kdrushka@apl.uw.edu.

6. Acknowledgements

This product was developed using funding from NASA grants NNX17AK03G and NNX17AK05G. The PRIM development team includes March Jacob, Kyla Drushka, Bill Asher, and Linwood Jones. PRIM is based on original work by Andrea Santos-Garcia.

7. Data Access

The PO.DAAC Cloud is now available to access all data. To use PO.DAAC Cloud, you may visit the dataset landing pages: https://podaac.jpl.nasa.gov/dataset/PRIM_SMAP_L2_V1

For information on how to cite this data in presentations or publications, please read: https://podaac.jpl.nasa.gov/CitingPODAAC

For general news, announcements, and information on this and all other ocean and sea ice datasets available at PO.DAAC, please visit the PO.DAAC web portal: https://podaac.jpl.nasa.gov/

8. References

Asher, W. E., Jessup, A. T., Branch, R., & Clark, D. (2014). Observations of rain-induced near-surface salinity anomalies. *Journal of Geophysical Research: Oceans*, *119*(8), 5483-5500.

Crank, J. (1975), The Mathematics of Diffusion, 2nd ed., Clarendon, Oxford, U. K.

Drushka, K., Asher, W. E., Ward, B., & Walesby, K. (2016). Understanding the formation and evolution of rain-formed fresh lenses at the ocean surface. *Journal of Geophysical Research: Oceans*, *121*(4), 2673-2689.

Fore, A.G, S.H. Yueh, W. Tang, B.W. Stiles, and A.K. Hayashi (2016). Combined Active/Passive Retrievals of Ocean Vector Wind and Sea Surface Salinity With SMAP. *IEEE Transactions On Geoscience And Remote Sensing*, 54(12). p.7396-7404. DOI: 10.1109/TGRS.2016.2601486.

Hersbach, H., et al.. (2017): Complete ERA5 from 1979: Fifth generation of ECMWF atmospheric reanalyses of the global climate. *Copernicus Climate Change Service (C3S) Data Store (CDS)*.

Huffman, G., D. Bolvin, D. Braithwaite, K. Hsu, R. Joyce, and P. Xie, 2014: Integrated Multi-satellitE Retrievals for GPM (IMERG), version 4.4. *NASA's Precipitation Processing Center*.

Roemmich, D. and J. Gilson, 2009: The 2004-2008 mean and annual cycle of temperature, salinity, and steric height in the global ocean from the Argo Program. *Progress in Oceanography*, 82, 81-100.

Santos-Garcia, A., Jacob, M. M., Jones, W. L., Asher, W. E., Hejazin, Y., Ebrahimi, H., & Rabolli, M. (2014). Investigation of rain effects on Aquarius Sea Surface Salinity measurements. *Journal of Geophysical Research: Oceans*, *119*(11), 7605-7624.