

High-resolution Precipitation and Wind Measurements from Passive Aquatic Listeners (PALs)

Prepared for:

Global Precipitation Measurement (GPM)
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Prepared by:

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1. Summary

Passive Aquatic Listeners (PALs) provide high-quality, high-resolution estimates of precipitation over ocean regions¹, but have been underutilized as a reference dataset for the evaluation of satellite-based precipitation estimates (SPEs). PALs are uniquely suited for this purpose due to their 5 km surface listening area when sampling at 1 km depth on drifting Argo Floats, providing rain rate estimates on a spatial scale similar to the native grid spacing of many SPEs (see Fig. 1). In support of the NASA Precipitation Measurement Missions (PMM), a dataset of ~12 years of research-based precipitation and wind observations from PALs is produced, which includes 58 PALs deployed on moorings and drifting Argo floats. The trajectories of these 58 PALs are illustrated in Fig. 2.



Fig. 1. Passive Aquatic Listener (PAL) deployed over ocean. See Yang et al. (2015) and Riser et al. (2019) for more information about the system configurations.

¹Yang, J., Riser, S.C., Nystuen, J.A., Asher, W.E., and Jessup, A.T. (2015). Regional Rainfall Measurements Using the Passive Aquatic Listener During the SPURS Field Campaign, *Oceanography*, **28**(1), 124–133, doi: 10.5670/oceanog.2015.10.

Riser, S.C., Yang, J., and Drucker, R. (2019). Observations of Large-Scale Rainfall, Wind, and Sea Surface Salinity Variability in the Eastern Tropical Pacific, *Oceanography*, **32** (2), 42-49, doi: 10.5670/oceanog.2019.211.

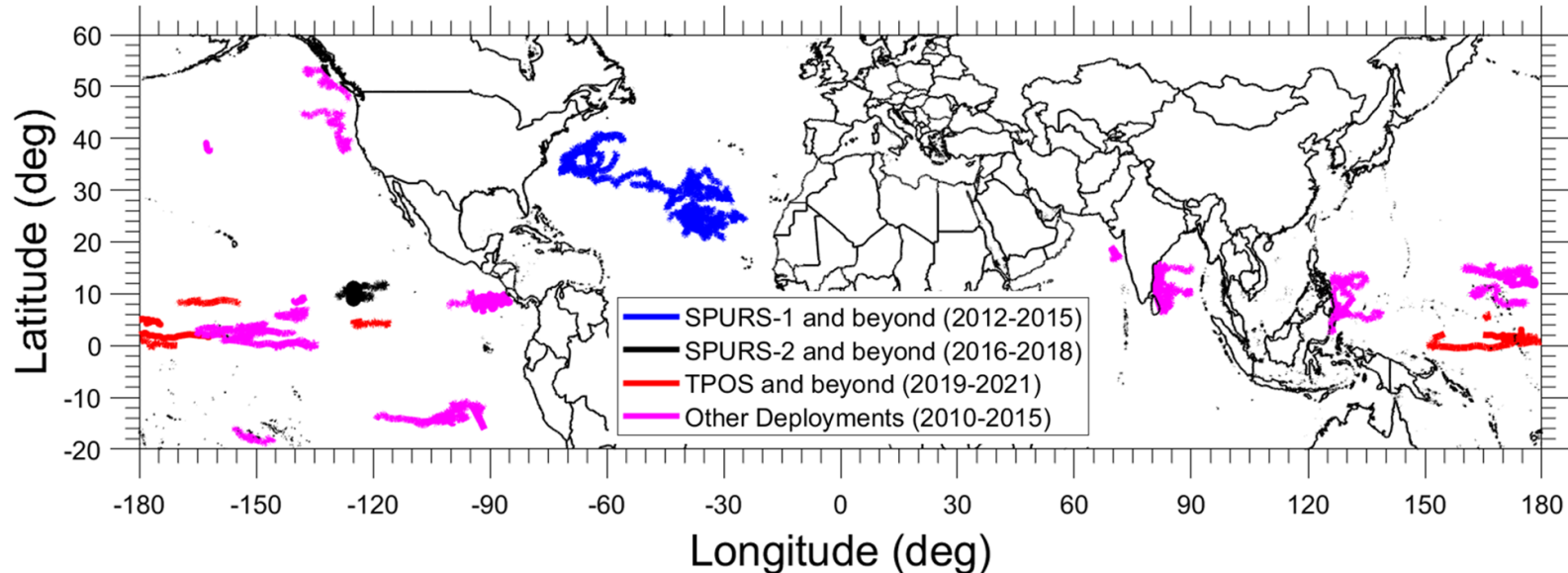


Fig. 2. Location of PALs deployed from 2010-2015. Different colors are used for different field projects to aid visibility.

2. PAL dataset in support of NASA PMM

The 58 PALs include those deployed as part of the NASA Salinity Processes in the Upper Ocean Regional Study (SPURS-1 and SPURS-2), the Tropical Pacific Observing System (TPOS) project, and some other field programs (see Table 1). Detailed information about the Argo Floats where the PALs were deployed, as well as the measurement start and end time, is summarized in Table 2.

Table 1. PALs deployed for different field projects from 2010 to 2021.

SPURS-1 field experiment	SPURS-2 field experiment	Tropical Pacific Observing System (TPOS) project	Other deployments (26 platforms)
Argo float 6923	Argo float 8435	Argo float 17350	Argo float 6862
Argo float 7547	Argo float 8444	Argo float 12780	Argo float 6872
Argo float 7569	Argo float 9302	Argo float 12792	Argo float 6874
Argo float 7572	Argo float 12360	Argo float 19644	Argo float 6877
Argo float 7582	SPURS-2 central mooring (500m)	Argo float 19090	Argo float 6879

Argo float 7587	SPURS-2 central mooring (1000m)	Argo float 19412	Argo float 6915
Argo float 7607	SPURS-2 south mooring (650m)	Argo float 19017	Argo float 6918
Argo float 7635			Argo float 6919
Argo float 7660			Argo float 6920
Argo float 7681			Argo float 6921
Argo float 7699			Argo float 6922
Argo float 7574			Argo float 7543
Argo float 7595			Argo float 7548
Argo float 7598			Argo float 7576
Argo float 7599			Argo float 7586
Argo float 7605			Argo float 7589
Argo float 7611			Argo float 7600
Argo float 7585			Argo float 7606
			Argo float 7609
			Argo float 7610
			Argo float 7612
			Argo float 7648
			Argo float 7650
			Argo float 7695
			Argo float 7704
			Argo float 8469

Table 2. Deployment information of the 58 PALs archived in this dataset.

PAL Argo float #	Field Campaign	Start Year	Start Day	Start Time	End Year	End Day	End Time
Argo float 6923	SPURS-1	2012	261.5	2012-09-17 1200UTC	2015	1431	2015-12-01 0000UTC
Argo float 7547	SPURS-1	2012	260.5	2012-09-16 1200UTC	2016	1543	2016-03-22 0000UTC
Argo float 7569	SPURS-1	2012	263	2012-09-19 0000UTC	2016	1462	2016-01-01 0000UTC
Argo float 7572	SPURS-1	2012	261.5	2012-09-17 1200UTC	2016	1563	2016-04-11 0000UTC
Argo float 7582	SPURS-1	2012	260.5	2012-09-16 1200UTC	2016	1533	2016-03-12 0000UTC
Argo float 7587	SPURS-1	2012	262.5	2012-09-18 1200UTC	2016	1546	2016-03-25 0000UTC
Argo float 7607	SPURS-1	2012	262.5	2012-09-18 1200UTC	2016	1592	2016-05-10 0000UTC

Argo float 7635	SPURS-1	2012	263	2012-09-19 0000UTC	2015	1224	2015-05-18 0000UTC
Argo float 7660	SPURS-1	2012	261.5	2012-09-17 1200UTC	2016	1562	2016-04-10 0000UTC
Argo float 7681	SPURS-1	2012	263	2012-09-19 0000UTC	2016	1587	2016-05-05 0000UTC
Argo float 7699	SPURS-1	2012	262.5	2012-09-18 1200UTC	2015	1413	2015-11-13 0000UTC
Argo float 7574	SPURS-1	2012	281	2012-10-07 0000UTC	2016	1547	2016-03-26 0000UTC
Argo float 7595	SPURS-1	2012	280.5	2012-10-06 1200UTC	2016	1518	2016-02-26 0000UTC
Argo float 7598	SPURS-1	2012	281.5	2012-10-07 1200UTC	2016	1547	2016-03-26 0000UTC
Argo float 7599	SPURS-1	2012	280	2012-10-06 0000UTC	2016	1547	2016-03-26 0000UTC
Argo float 7605	SPURS-1	2012	256.5	2012-09-12 1200UTC	2016	1547	2016-03-26 0000UTC
Argo float 7611	SPURS-1	2012	255.5	2012-09-11 1200UTC	2016	1547	2016-03-26 0000UTC
Argo float 7585	SPURS-1	2012	253	2012-09-09 0000UTC	2015	1133.5	2015-02-06 1200UTC
Argo float 8435	SPURS-2	2016	244	2016-08-31 0000UTC	2018	962	2018-08-19 0000UTC
Argo float 8444	SPURS-2	2016	252	2016-09-08 0000UTC	2018	962	2018-08-19 0000UTC
Argo float 9302	SPURS-2	2016	250	2016-09-06 0000UTC	2018	964	2018-08-21 0000UTC
Argo float 12360	SPURS-2	2016	250	2016-09-06 0000UTC	2018	963	2018-08-20 0000UTC
SPURS-2 central mooring (500m)	SPURS-2	2016	238	2016-08-25 0000UTC	2017	538	2017-06-21 0000UTC
SPURS-2 south mooring (650m)	SPURS-2	2016	238	2016-08-25 0000UTC	2017	486	2017-04-30 0000UTC
SPURS-2 central mooring (1000m)	SPURS-2	2016	238	2016-08-25 0000UTC	2017	538	2017-06-21 0000UTC
Argo float 17350	TPOS	2019	301	2019-10-28 0000UTC	2021	940	2021-07-28 0000UTC
Argo float 12780	TPOS	2018	228.5	2018-08-16 1200UTC	2021	1303	2021-07-26 0000UTC
Argo float 12792	TPOS	2019	248	2019-09-05 0000UTC	2021	929.5	2021-07-17 1200UTC
Argo float 19644	TPOS	2020	259.5	2020-09-15 1200UTC	2021	487.5	2021-05-01 1200UTC
Argo float 19090	TPOS	2020	244.5	2020-08-31 1200UTC	2021	487.5	2021-05-01 1200UTC
Argo float 19412	TPOS	2020	245.5	2020-09-01 1200UTC	2021	496	2021-05-10 0000UTC
Argo float 19017	TPOS	2020	258	2020-09-14 0000UTC	2021	496.5	2021-05-10 1200UTC
Argo float 6862	Others	2011	110.5	2011-04-20 1200UTC	2014	1273	2014-06-26 0000UTC
Argo float 6872	Others	2010	291	2010-10-18 0000UTC	2014	1778	2014-11-13 0000UTC
Argo float 6874	Others	2011	111.5	2011-04-21 1200UTC	2014	1304	2014-07-27 0000UTC
Argo float 6877	Others	2011	112.5	2011-04-22 1200UTC	2014	1288	2014-07-11 0000UTC
Argo float 6879	Others	2011	300.5	2011-10-27 1200UTC	2015	1555	2015-04-04 0000UTC
Argo float 6915	Others	2010	332.5	2010-11-28 1200UTC	2011	523	2011-06-07 0000UTC
Argo float 6918	Others	2011	353.5	2011-12-19 1200UTC	2014	1424.5	2014-11-24 1200UTC
Argo float 6919	Others	2013	293	2013-10-20 0000UTC	2014	491.5	2014-05-06 1200UTC
Argo float 6920	Others	2011	244	2011-09-01 0000UTC	2015	1624.5	2015-06-12 1200UTC
Argo float 6921	Others	2011	301	2011-10-28 0000UTC	2015	1497	2015-02-05 0000UTC

Argo float 6922	Others	2011	248	2011-09-05 0000UTC	2015	1605	2015-05-24 0000UTC
Argo float 7543	Others	2014	0	2014-01-01 0000UTC	2017	1205	2017-04-19 0000UTC
Argo float 7548	Others	2012	104.5	2012-04-13 1200UTC	2015	1293.5	2015-07-16 1200UTC
Argo float 7576	Others	2013	293	2013-10-20 0000UTC	2014	490.5	2014-05-05 1200UTC
Argo float 7586	Others	2012	105.5	2012-04-14 1200UTC	2014	920	2014-07-08 0000UTC
Argo float 7589	Others	2012	108	2012-04-17 0000UTC	2015	1209	2015-04-23 0000UTC
Argo float 7600	Others	2013	317.5	2013-11-13 1200UTC	2017	1570.5	2017-04-19 1200UTC
Argo float 7606	Others	2013	314.5	2013-11-10 1200UTC	2016	1421.5	2016-11-21 1200UTC
Argo float 7609	Others	2013	320	2013-11-16 0000UTC	2017	1573.5	2017-04-22 1200UTC
Argo float 7610	Others	2013	1259.5	2016-06-12 1200UTC	2017	1574.5	2017-04-23 1200UTC
Argo float 7612	Others	2013	293.5	2013-10-20 1200UTC	2017	1496	2017-02-04 0000UTC
Argo float 7648	Others	2012	347.5	2012-12-12 1200UTC	2014	960.5	2014-08-17 1200UTC
Argo float 7650	Others	2012	348	2012-12-13 0000UTC	2016	1588.5	2016-05-06 1200UTC
Argo float 7695	Others	2013	293.5	2013-10-20 1200UTC	2017	1503	2017-02-11 0000UTC
Argo float 7704	Others	2013	319.5	2013-11-15 1200UTC	2017	1572	2017-04-21 0000UTC
Argo float 8469	Others	2015	33	2015-02-02 0000UTC	2015	204	2015-07-23 0000UTC

The irregular rain and wind measurements from the PALs are reprocessed to regular time steps. The data are provided as netCDF files following the Climate and Forecast conventions. Header information of an example NetCDF file (*PAL_precip_wind_SPURS2_Argo_float8435_v1.nc*) is given below:

```
PAL_precip_wind_SPURS2_Argo_float_8435_v1 {
dimensions:
  time = 1033921;
variables:
  double time(time) ;
    time:standard_name = "time" ;
    time:units = "seconds since 1970-01-01 00:00:00UTC" ;
    time:cdm_data_type = "coordinate" ;
    time:comment = "original irregular 2-9 min samplings are resampled to regular 1-min intervals";
  int  year(time) ;
    year:long_name = "year" ;
  int  month(time) ;
    month:long_name = "month" ;
  int  day(time) ;
```

```

    day:long_name = "day" ;
int  hour(time) ;
    hour:long_name = "hour" ;
int  minute(time) ;
    minute:long_name = "minute" ;
double lat(time) ;
    lat:standard_name = "latitude" ;
    lat:long_name = "PAL latitude" ;
    lat:units = "degrees_north" ;
    lat:cdm_data_type = "coordinate" ;
    lat:method = "Interpolated position between GPS fixes when float comes to the surface, which happens about every 9.5 days. Float drifts slowly with 1
km depth ocean currents between vertical profiles and GPS fixes.";
double lon(time) ;
    lon:standard_name = "longitude" ;
    lon:long_name = "PAL longitude" ;
    lon:units = "degrees_west" ;
    lon:cdm_data_type = "coordinate" ;
    lon:method = "Interpolated position between GPS fixes when float comes to the surface, which happens about every 9.5 days. Float drifts slowly with 1
km depth ocean currents between vertical profiles and GPS fixes.";
double rain_rate(time) ;
    rain_rate:_FillValue = -9999. ;
    rain_rate:long_name = "instantaneous rain rate" ;
    rain_rate:altitude = "surface" ;
    rain_rate:units = "mm/hr" ;
    rain_rate:cdm_data_type = "modelResult" ;
    rain_rate:surface_area = "5 km; circular diameter listening area of PAL is about 5 times as wide as the instrument depth during listening periods, which
is 1 km for this Argo float." ;
    rain_rate:method = "measured sound pressure levels at different frequencies are used to estimate surface rain rate and wind speed using a regionally-
tuned algorithm tested extensively with in-situ data." ;
    rain_rate:comment = "The fillvalue of -9999 are missing data because these are times when the PAL was not listening during float descent, ascent, and
when telemetering data at the ocean surface. This occurs for a few hours at a time about every 9.5 days.";
double wind_speed(time) ;
    wind_speed:_FillValue = -9999. ;
    wind_speed:long_name = "wind speed" ;
    wind_speed:altitude = "surface" ;
    wind_speed:units = "m/s" ;
    wind_speed:cdm_data_type = "modelResult" ;
    wind_speed:surface_area = "5 km; circular diameter listening area of PAL is about 5 times as wide as the instrument depth during listening periods,
which is 1 km for Argo float. (and etc. recalculated and with different numbers for other PALs at different depths." ;

```

wind_speed:method = "measured sound pressure levels at different frequencies are used to estimate surface rain rate and wind speed using regionally-tuned algorithm tested extensively with in-situ data." ;

wind_speed:comment = "No wind data are recorded during rainy periods, so are marked with fillvalue -9999. Additionally, the fillvalue of -9999 is also used to denote missing data when the PAL was not listening during float descent, ascent, and when telemetering data at the ocean surface. This occurs for a few hours at a time about every 9.5 days." ;

// global attributes:

:date_created = "29-Sep-2022 13:08:31" ;
:date_issued = "29-Sep-2022 13:08:31" ;
:date_metadata_modified = "29-Sep-2022 13:08:31" ;
:date_modified = "29-Sep-2022 13:08:31" ;
:product_version = "v1: first release" ;
:geospatial_lat_min = "8.927" ;
:geospatial_lat_max = "10.355" ;
:geospatial_lon_min = "-129.131" ;
:geospatial_lon_max = "-122.151" ;
:geospatial_lat_bounds = "POLYGON [-129.131, -122.151, 8.927, 10.355]" ;
:time_coverage_start = "2016-08-31 00:00:00UTC" ;
:time_coverage_end = "2018-08-19 00:00:00UTC" ;
:time_coverage_duration = "718.000 days" ;

:acknowledgement = "Dataset collected and processed by Jie Yang with funding from the NASA Ocean Salinity Science Team and the NASA Precipitation Measurement Mission. Dataset archived and managed by Elizabeth Thompson and Haonan Chen with support from the NASA Precipitation Measurement Mission." ;

:cdm_data_type = "Trajectory" ;
:comment = "Corrections" ;
:conventions = "CF-1.6 ACCD-1.3" ;
:coverage_content_type = "modelResult, coordinate" ;
:creator_email = "elizabeth.thompson@noaa.gov, haonan.chen@colostate.edu, jieyang@apl.washington.edu" ;
:creator_institution = "(1) NOAA Physical Sciences Laboratory (PSL); (2) CIRA Cooperative Institute for Research of the Atmosphere at the Colorado State University in partnership with NOAA PSL, (3) Applied Physics Laboratory at University of Washington" ;
:creator_name = "Elizabeth J. Thompson (1), Haonan Chen (2), Jie Yang (3)" ;
:creator_type = "group" ;
:geospatial_lat_units = "degrees_north" ;
:geospatial_lon_units = "degrees_east" ;
:history = "v0: original data, v1: first release, v2: reformatted second release" ;
:id = "doi = not yet assigned";
:instrument = "Passive Aquatic Listener (PAL) hydrophone" ;
:instrument_vocabulary = "GCMD Version 12.3" ;
:keywords_library = "GCMD Version 12.3" ;


```

:license = "Please use these global attributes when acknowledging and using these data: acknowledgement, creator_name, creator_institution. These data may be redistributed and used without restriction.";
:naming_authority = "gov.noaa.ncei" ;
:platform = "PAL Argo float 8435" ;
:platform_vocabulary = "GCMD Version 12.3" ;
:processing_level = "processed and quality controlled" ;
:program = "Funding agencies: NASA Ocean Salinity Science Team, NASA Precipitation Measurement Mission." ;
:project = "NASA Salinity Processes in the Upper Ocean Regional Study (SPURS-2)" ;
:references = "Bytheway, J., Thompson, E. J., Yang, J., and Chen, H. (2022): Evaluating Satellite Precipitation Estimates over Oceans Using Passive Aquatic Listeners, Geophysical Research Letters, (in progress)."; "Yang, J., Riser, S.C., Nystuen, J.A., Asher, W.E., and Jessup, A.T. (2015). Regional Rainfall Measurements Using the Passive Aquatic Listener During the SPURS Field Campaign, Oceanography 28(1), 124–133, doi: 10.5670/oceanog.2015.10."; "Riser, S.C., Yang, J., and Drucker, R. (2019). Observations of Large-Scale Rainfall, Wind, and Sea Surface Salinity Variability in the Eastern Tropical Pacific, Oceanography, 32 (2), 42-49, doi: 10.5670/oceanog.2019.211.";
:source = "observations from Passive Aquatic Listener hydrophones whose sound pressure levels are used in an algorithm to produce a time series of surface rain rate and wind speed. The algorithm has been adjusted for each ocean basin using extensive in-situ data for validation.";
:standard_name_vocabulary = "CF Standard Name Table, Version 77, 19 January 2021, https://cfconventions.org/Data/cf-standard-names/77/build/cf-standard-name-table.html" ;
:summary = "Data collected from this instrument is critical for supporting the study of physical oceanography, air-sea interaction, meteorology, as well as global weather and climate variability and predictability. This includes improvement to our fundamental understanding of precipitation and wind processes over the ocean and their influence around the globe including the Continental United States.";
:title = "Acoustic rain rate and wind speed measurements from Passive Aquatic Listener on Argo float 1236 during SPURS-2 2016-2017 experiment." ;
:sea_name = "Eastern Pacific Ocean";
:ncei_template_version = "netCDF_single_trajectory_v2.0" ;
:keywords = "Earth Science > Atmosphere > Atmospheric Winds > Surface Winds; Earth Science > Oceans > Ocean Winds > Surface Winds > Wind Speed; Earth Science > Atmosphere > Precipitation > Precipitation Rate; Earth Science > Oceans > Ocean Volume Budget > Precipitation; Earth Science > Oceans > Salinity/Density > Ocean Salinity Budget > Precipitation" ;
}

```