Environmental Parameters Value Added Product (VAP) dataset version 1.41

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1.0 Introduction

This value added dataset has been developed to advance scientific studies associated with the Department of Energy supported the Measurements of Aerosols, Radiation and CloUds over the Southern Oceans (MARCUS) field campaign and the Macquarie Island Cloud and Radiation Experiment (MICRE). During MARCUS, the ARM program Mobile Facility-2 (AMF-2) was installed on the icebreaker *Aurora Australis* (AA) as it made four routine transits from Hobart to the Australian Antarctic stations Mawson, Casey and Davis, as well as Macquarie Island from October 2017 to March 2018. While during MICRE, the DOE ARM program, the Australian Antarctic Division (AAD) and the Australian Bureau of Meterology (BoM) collaborated in deploying a variety of ground-instrumentation to Macquarie Island between March 2016 and March 2018.

This product merges measurements and derived products obtained from both ARM and other sources. The files contain the quantities listed below, at the location of the AA or at Macquaire Island at 10-min resolution. A more detailed description of the file contents is provided in section 2, followed by additional details on how some fields are determined in section 3.

(i) Basic time and location information

(ii) Local meteorological conditions including:
sea surface temperature (SST), lower tropospheric stability (LTS), marine cold air outbreak (MCAO) index, inversion height, and lifting condensation level (LCL).

(iii) Location relative to the oceanic polar front (PF), center of the closest cyclone, and nearest warm fronts and cold fronts

(iv) Location of air parcels 72 hours prior to its arrival at/above the ship computed using the HYSPLIT back trajectory model

(v) Aerosol Properties (*TBD, still under construction but will include CN and CCN*).

(vi) Cloud & Precipitation Properties, including:
Cloud base/top height, and cloud base/top temperature (precip. fields are not included yet).

(vii) Coincident cloud properties retrieved from the Himawari-8 satellite including: cloud fraction, cloud base/top height, cloud top temperature, cloud top pressure, liquid water path, optical depth, cloud effective radius, cloud droplet number concentration.

Collaboration with Dr. Greg McFarquhar (mcfarq@ou.edu) and Saisai Ding (dingss@pku.edu.cn) on the use of these data in publications and conference proceedings is strongly encouraged; there are limitations & uncertainties associated with these data, which are difficult to quantify and are not documented here.

2.0 File Contents

Note: in many cases additional details on how parameters are calculated are given later in later sections. Each file is in netCDF format.

For MICRE, the files are monthly, while for MARCUS one files exists for each voyage of the AA and named as follows:

'MARCUS_Environmental_VAP_V#_YYYYMMDD_YYYYMMDD.cdf', where # corresponds to the MARCUS voyage number recorded on the shipping schedule for 2017/18 and 'YYYYMMDD_YYYYMMDD' indicates the departure date and return date of the voyage. The files include data for periods when the ship was docked at the Antarctic continent.

2.1 Basic Time & Location

'base_time': the base time in POSIX time (also known as Epoch time, UNIX time, seconds since the Epoch, or UNIX Epoch time), corresponding to midnight of the start date for the voyage.
'base_time_string': base time in string format.

'seconds': time offset from the base time in seconds.

'doy': time in days (and fractions of a day) since the start of the calendar year.

'ship_lon': ship longitude in degrees E.

'ship_lat': ship latitude in degrees N.

2.2 SST & Local Meteorological Parameters

See also additional discussion in sections 2.2 and 2.3.

'ship_oisst': Optimum Interpolation Sea Surface Temperature (OISST) at the ship location. The OISST SST provided here is retrieved from the AVHRR satellite in degrees Celsius.

'ship_irtsst': sea surface temperature detected by Infrared Thermometer in Kelvins.

‘aosmet_temperature’: air temperature in degrees Celsius measured by the ARM Aerosol Observing System (AOS).

‘aosmet_pressure’: air pressure in millibars measured by the AOS.

‘aosmet_RH’: relative humidity in percent measured by the AOS.

‘aosmet_wind_speed’: wind speed in m/s measured by the AOS. The winds speed AND direction have been corrected for ship motion.

‘aosmet_wind_dir’: wind direction in degrees clockwise from true North measured by the AOS (not corrected for ship motion).

‘LTS’: lower tropospheric stability in Kelvin defined as potential temperature difference between 700hPa and surface. Obtained from nearest-in-time available radiosonde profile within 3 hours and is set to -9999 otherwise. See also section 2.2.

‘M’: index for marine cold air outbreak index in Kelvin defined as the difference between SST and potential temperature at 800 hPa. Obtained from ‘ship_irtsst’ and nearest-in-time available radiosonde profile within three hours.

‘zinv’: the bottom height of lowest inversion layer in meters following criteria of Heffter (1980), and obtained using the nearest-in-time available radiosonde profile within three hours. See section 2.3 for additional details.

‘zinv_top’: the top height of lowest inversion layer in meters, obtained following ‘zinv’.

‘LCL_srf’: lifting condensation level (LCL) based on radiosonde profiles. Pressure at the LCL is obtained from ‘aosmet’.

‘LCL25’: lifting condensation level of the parcel at 25% of the inversion height in meters.

‘LCL75’: lifting condensation level of the parcel at 75% of the inversion height in meters.

2.3 Location Relative to Cyclonic Systems and the Oceanic Polar Front

See section 2.5 for additional calculation details

‘nearest_storm_merra2’: 4 parameters describing the center of the nearest low pressure derived from ERA-interim sea level pressure (SLP): longitude (in degrees E), latitude (in degrees N), SLP (in millibar) and land fraction (unitless) at the center.

‘nearest_clod_front_merra2’: longitude (in degrees E) and latitude (in degrees N) of the nearest cold front in the nearest cyclone system derived from ERA re-analyses.

'nearest_warm_front_merra2': longitude (in degrees E) and latitude (in degrees N) of the nearest warm front in the nearest cyclone system derived from ERA re-analyses.

'nearest_storm_ncep': longitude (in degrees E) and latitude (in degrees N) of the nearest cyclone center derived from the NCEP reanalysis SLP.

'PF_dist_grdt': distance from the oceanic polar front in kilometers. The location of the PF is determined by the southernmost place at which the daily-mean SST gradient exceeds 0.015 °C/km directly south or north of the ship. Additional description is given in section 2.1. A positive (negative) value means the ship was north (south) of the PF.

'PF_dist_iso': distance from the daily oceanic polar front in kilometers, where the location of the PF location is determined as the northernmost 2℃ SST isotherm over Southern Hemisphere directly south or north of the ship. See also more description section 2.1 A positive (negative) value means the ship was in the north (south) of PF.

2.4 Backtrajectories

See section 2.6 for additional calculations details:

'BT_height': ending altitude (in meters) above the ship for the back-trajectory simulation.

'BT_mins_previous': number of minutes before current time corresponding to original latitude/longitude of the air parcel.

'BT_latitude': original air parcel latitude in degrees N that ended at 'BT_height' above the ship track after 'BT_mins_previous'.

'BT_longitude': original air parcel longitude in degrees E that ended at 'BT_height' above the ship track after 'BT_mins_previous'.

'BT_altitude': original air parcel altitude in meters that ended at 'BT_height' above the ship track after 'BT_mins_previous'.

2.5 Cloud and Precipitation Properties:

These data are subset of parameters, from the MARCUS and MICRE Cloud and Precipitation Properties VAP. As with other data in the Environmental VAP, the cloud and precipitation data have been reduced using median values to 10 minute scale. Cloud top and base temperature use sonde data, see section 2.4 for additional details).

As of version 1.4 there is no precipitation data, yet, but such is coming in future versions.

'lidar_base': Cloud base height in meters (above mean sea level) retrieved from the ARM Ceilometer. Provided is the median value for the lidar cloud base determined for every 10-

minute interval. Up to 5 hydrometeor layers (which can be detect by radar or lidar) are permitted. A value of zero indicates clear sky. A value of -9999 means no lidar base is available because (a) there was no n-th layer or (b) the lidar beam was block or attenuated and unable to detect a layer or (c) the lidar was not functioning at the time.

‘lidar_base_MAD’: Median absolute deviation (MAD) of lidar cloud base height for each 10-minute interval. MAD = median(abs(X - median(X))).

‘radar_base’: Hydrometeor layer base altitude above mean sea level in meters retrieved from vertically pointing W-band cloud radar. The base value is the median over periods when the layer is present over a 10-minute interval. Up to five hydrometeor layers are permitted. A value of -9999 means either (1) there given layer is not being used (see num_layers) or (b) the given layer was only detected by the lidar.

‘radar_base_MAD’: Median absolute deviation of radar cloud base height for each 10-minute interval.

‘radar_top’: Cloud top height in meters retrieved from W-band cloud radar averaged over 10-minute interval. As with radar-base, up to five hydrometeor layers are permitted.

‘radar_top_MAD’: Median absolute deviation of radar cloud top height for each 10-minute interval.

‘cbt_lidar’: temperature at each ‘lidar base’ height determined from lidar-base altitude and nearest-in-time available radiosonde profile within 3 hours. If no radiosonde is available (or there is no lidar base) the value is set to -9999. Units are degrees Celsius.

‘cbt_radar’: temperature at each ‘radar base’ height determined by radar base altitude and nearest-in-time available radiosonde profile within 3 hours. If no radiosonde is available (or there is no radar base) the value is set to -9999. Units are degrees Celsius.

‘ctt_radar’: temperature for each “radar top” height and nearest-in-time available radiosonde profile within 3 hours. If no radiosonde is available (or there is no radar top) the value is set to -9999. Units are in degrees Celsius.

2.6 Himawarii-8 Retrievals

All values are based on satellite retrievals within 18 km radius of the AA (or Macquaire), see section 2.7 for additional details.

‘sat_reflectance_vis’: median value of Himawari-8 observed visible reflectance (0.65 μm, unitless).

‘sat_solar_zenith_angle’: median value of Himawari-8 observed solar zenith angle (in degrees).

'sat_tot_num_pixel': total number of Himawari-8 pixels.

'sat_liq_num_pixel': total number of Himawari-8 pixels identified as containing liquid clouds.

'sat_ice_num_pixel': total number of Himawari-8 pixels identified as containing ice clouds.

'sat_cloud fraction': number of non-clear-sky Himawari-8 pixels divided by total number of Himawari-8 pixels.

'sat_liq_fraction': sat_liq_num_pixel/sat_tot_num_pixel

'sat_ice_fraction': sat_ice_num_pixel/sat_tot_num_pixel

'sat_liq_cbh': median of Himawari-8 cloud base height (in kilometers) for liquid pixels.

'sat_liq_cbh_mad': MAD of sat_liq_cbh

'sat_liq_cth': median cloud top height (in kilometers) of liquid Himawari-8 pixels.

'sat_liq_cth_mad': MAD of sat_liq_cth in meters

'sat_liq_ctt': median of Himawari-8 cloud top temperature (in Kelvins) for liquid.

'sat_liq_ctt_mad': MAD of sat_liq_ctt in degrees Celsius.

'sat_liq_ctp': median of Himawari-8 cloud top pressure (in millibars) for liquid.

'sat_liq_ctp_mad': MAD of sat_liq_ctp

'sat_liq_water_path': median of Himawari-8 liquid water path (in g/cm^2) for liquid phase pixels.

'sat_liq_water_path_mad': MAD of sat_liq_water_path

'sat_liq_optical_depth': median of Himawari-8 cloud optical depth for liquid pixels.

'sat_liq_optical_depth_mad': MAD of sat_liq_optical_depth

'sat_liq_d': median of Himawari-8 cloud effective radius (in microns) for liquid.

'sat_liq_d_mad': MAD of sat_liq_d.

'sat_liq_nd': median of Himawari-8 cloud droplet number concentration (in $\#/m^3$) for liquid pixels.

'sat_liq_nd_mad': MAD of sat_liq_nd in $\#/m^3$.

'sat_liq_cw': median of Himawari-8 adiabatic condensation rate of liquid water in g/cm^4.

'sat_ice_cbh': median of Himawari-8 cloud base height (in kilometers) for ice.

'sat_ice_cbh_mad': MAD of sat_ice_cbh

'sat_ice_cth': median of Himawari-8 cloud top height (in kilometers) for ice.

'sat_ice_cth_mad': MAD of sat_ice_cth

'sat_ice_ctt': median of Himawari-8 cloud top temperature (in Kelvins) for ice.

'sat_ice_ctt_mad': MAD of sat_ice_ctt

'sat_ice_ctp': median of Himawari-8 cloud top pressure (in millibar) for ice.

'sat_ice_ctp_mad': MAD of sat_ice_ctp

'sat_ice_water_path': median of Himawari-8 ice water path (in g/m^2) for ice.

'sat_ice_water_path_mad': MAD of sat_ice_water_path

'sat_ice_optical_depth': median of Himawari-8 cloud optical depth (unitless) for ice.

'sat_ice_optical_depth_mad': MAD of sat_ice_optical_depth

'sat_ice_d': median of Himawari-8 cloud effective radius (in microns) for ice.

'sat_ice_d_mad': MAD of sat_ice_d

3.0 Calculation methods

3.1 Antarctic polar front

To calculate the position of the ocean polar front, it is assumed that the diurnal variability of sea surface temperature (SST) is weak so that a daily averaged SST can be used (Gille 2012). The NOAA 1/4° daily Optimum Interpolation Sea Surface Temperature (or daily OISST) from the Advanced Very High Resolution Radiometer (AVHRR) was used to derive the location of Antarctic PF (AVHRR data can be found at: https://www.ncei.noaa.gov/data/sea-surface-temperature-optimum-interpolation/access/avhrr-only/). Two methods described by Dong et al. (2006) were used to determine the PF location: 1) the southern-most location at a specified longitude where the SST gradient was above a specified limit (assumed here to be 0.015˚C km^{-1}); 2) the northern-most location in South Hemisphere where the SST was equal to a fixed value, taken here as 2˚C (Botnikov, 1963). Here positive values are used when ship is north of the PF (at the ships longitude). Following Dong et al. (2006), the SST gradient was computed as the absolute gradient, $|\nabla T| = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2}$.

Figure 1 shows an example comparing the PF locations determined by the two methods for conditions on 21 November 2017. There is an average difference of 395±318 km between the two methods during all periods included in this VAP, the isotherm determined PF is typically further north and has less meridional variation than that determined by SST gradients. This difference could be reduced by adjusting the thresholds used in the methods, but the threshold of $0.015°C/km$ is used for consistency with previous studies.

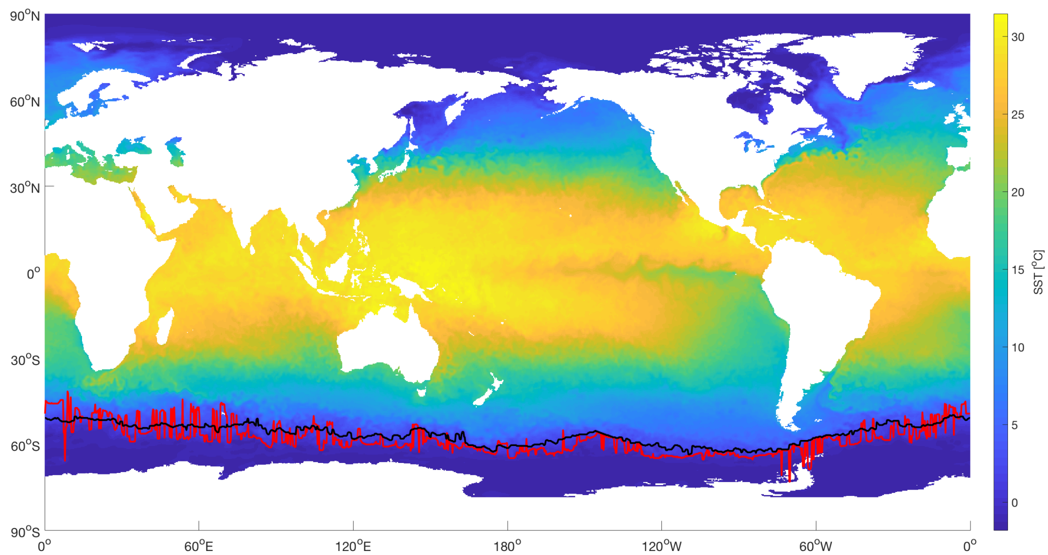

Figure 1. Global SST map on 21 Nov 2017 based on AVHRR SST data. Red and black curves are the PF determined using the SST gradient method with a threshold $0.015°C/km$ and by the northern most location of the 2°C isotherm respectively.

3.2 LTS and MCAO index

LTS is defined as the difference in potential temperature between the free troposphere (700 hPa) level and the surface, $LTS = \theta_{700} - \theta_0$ (Wood and Bretherton 2006). A MCAO index M is defined as the potential temperature difference between the surface skin and 800 hPa, M = $\theta_{SKT} - \theta_{800}$ (Fletcher et al., 2016).

During MARCUS, when conditions on the AA allowed, a Balloon-Borne Sounding System (SONDE) was released at 6-hour intervals and provided vertical profiles of temperature, pressure, relative humidity and wind. In the calculation of LTS, potential temperature at the lowest altitude of each SONDE profile, which is usually ~17 m, is treated as the surface potential temperature θ_0. Temperature profiles were interpolated to 700hPa to estimate θ_{700}. Because a calculation is desired for each 10-minute period, the computed value LTS is assigned to all 10 minute time samples within 3 hours of each sonde as depicted in Figure 3. Time (10-minute samples) more than 3 hours from a sonde launch are assigned a value of -9999 to indicate no LTS value has be calculated. (Users can obviously take the closest in time value for LTS, as desired).

In the calculation of M, 10-min averaged SST measured by the infrared thermometer on board the AA is used as θ_{SKT}. θ_{800} is estimated by interpolating the sounding profiles to 800hPa and extended to 10 mins interval following the same way of deriving LTS (with a value of -9999 is assigned when no sonde is available within 3 hours).

Retrievals of other environmental parameters associated with atmospheric profiles like cloud base/top temperatures, inversion heights, LCLs, also follow the same method of determining the coincident sounding data to be used.

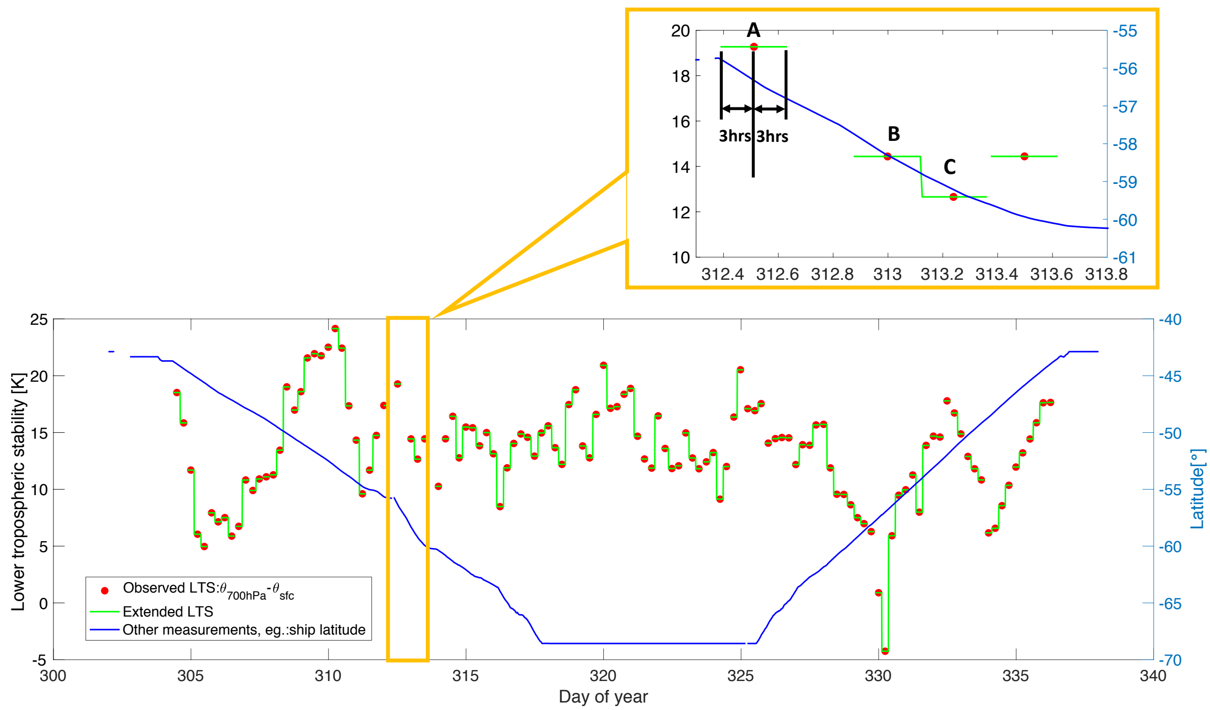

Figure 3. Example of the extended use of SONDE data.

3.3 Inversion height and LCL

A critical temperature inversion definition from Heffter (1980) is used to calculate inversion height, which is assumed to indicate the top of the boundary layer. The inversion is identified as the height z at which the potential temperature lapse rate and the temperature difference between the inversion base (zinv) and top (zinv_top) meet the following criteria

$$\Delta\theta/\Delta z \geq 0.5\,K/100m,$$

$$\Delta\theta > 2K,$$

where θ is the potential temperature.

LCL, LCL25, and LCL75 are derived following XXX using temperature, mixing ratio, and pressure measured at the surface, at 25% of the zinv, and at 75% of the zinv respectively using the radiosondes measurements (as discussed in section 2.2).

3.4 Cloud base temperature (CBT) and cloud top temperature (CTT)

Temperatures at cloud base and cloud top provide useful information, such as whether supercooled water might be present at either location. Temperature profiles from the SONDE were extrapolated 3 hours before and after each launch following the same method as the calculation of LTS (see section 2.2). Cloud base and top heights were retrieved by Prof. Roger Marchand from the University of Washington and are included the MARCUS/MICRE Cloud-And-Precipaition (CAP) VAP. Temperature vertical profiles from the SONDE are used to determine CBT and CTT by linear interpolation.

It is necessary to note that except the first layer, all these bases and tops and associated temperatures are not recommended to use at this stage, as a jump could be present when the resolution in the CAP is reduced to 10mins. E.g. if the first 2 minutes (of the 10 min interval) has 2 layers and second 5 minutes has 3 layers with a new "middle layer" between the initial two layers, median of the second layer could be biased. This problem will be improved in the future version of VAP.

3.5 Relative location in cyclone system

Distance to cyclone centers based on two reanalysis datasets are included in the VAP, one based on NCEP/NCAR reanalysis and one based on MERRA2.

NCEP/NCAR 6 hourly reanalysis sea level pressure (SLP) fields were examined to manually identify the location of the low-pressure centers over the Southern Ocean (SO) (data can be found at https://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html). Low center locations are recorded only when the AA location is sufficiently close and associated with a cyclone system via manual and subjective judgement. The associated cyclone center is used during the period 3 hours before and after the time of each reanalysis data. A value of -9999 was assigned when there was no associated storm system.

The Extratropical Cyclones and Fronts Database (Naud et al., 2010) was also used to generate environmental variables associated with cyclone systems. This dataset includes 6 hourly cyclone information detected and tracked by the MCM system version 4 using the ERA-interim SLP, and front locations detected by the MERRA-2 gridded SLP (data can be found via https://portal.nccs.nasa.gov/datashare/Obs-ETC/Fronts-ETC/). In this VAP, the nearest storm was first found by distance between the ship and storm center, and the nearest location (to the AA) is then calculated to cold and warm front associated within the same storm. In the Fronts-ETC database, the front are defined by a set of piecewise line segments. This information is used to interpolated the shortest distance to the front. The VAP includes the location of the nearest cyclone center, center SLP, land fractions at the storm center, and location of the points along the warm/cold fronts (interpolated).

3.6 HYSPLIT back trajectory simulation

7 parcel back trajectories ending at altitudes between 1 and 7 km above the ship at 1 km intervals was simulated for 72 hours via the HYSPLIT transport and dispersion model (Stein et al. 2015) every 10 minutes. Output from Global Data Assimilation System (GDAS) 3 hourly 1-degree archive data is used as the input meteorological data for the model (data are available at ftp://arlftp.arlhq.noaa.gov/pub/archives/gdas1/).

3.7 Collocation with Himawari-8 satellite

This VAP also includes coincident measurements of cloud properties retrieved from instruments on board the geostationary satellite Himawari-8, including cloud fraction, cloud liquid/ice water path, cloud optical depth, cloud effective radius, cloud droplet number concentration, cloud base/top height/temperature/pressure. The cloud products derived with Visible Infrared Solar-Infrared Split Window Technique (VISST)/Solar-Infrared Infrared Split Window Technique (SIST)algorithm (Minnis et al., 1995, NASA RP 1376, pp135-164) are utilized.

Hourly pixel-level data are used rather than gridded data to obtain finer spatial resolution. Details about this product can be found at https://www-pm.larc.nasa.gov/cgi-bin/site/showdoc?docid=22&lkdomain=Y&domain=hima8-fd&mode=fileview. The Himawari-8 data we used is available hourly, and the Himawari data stored in the VAP is assigned to the nearest VAP timestamp.

Cloud fraction is calculated based on Himawari cloud mask using all pixel values with in 18 km of the AA (example shown in Figure 4). Median and the median absolute deviation (MAD) for cloud liquid/ice water path, optical depth, etc. are also calculated using the same set of pixels, but for variables associated with a particular cloud phase, for example, liquid water path and ice water path, the median and MAD values are calculated using only the values of liquid and ice pixels respectively.

For each liquid pixel within the analysis circle, the cloud droplet number concentration (N_d) is estimated using the relation given by Painemal and Zuidema (2011), namely

$$N_d = 1.4067\times10^{-6}\left[cm^{-\frac{1}{2}}\right]\frac{\tau^{\frac{1}{2}}}{r_e^{\frac{5}{2}}}\sqrt{\frac{c_w}{0.002}},$$

where τ is the optical depth, r_e is the effective radius, and c_w is the adiabatic condensation rate. The condensation rate is a function of temperature and pressure and is also stored in the VAP.

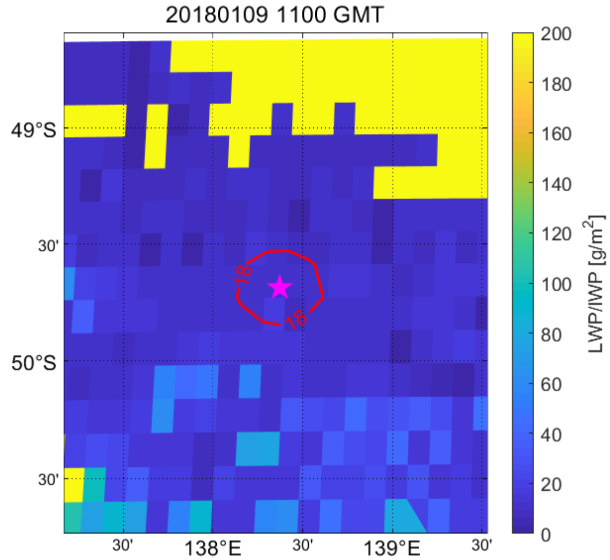

Figure 4: Example showing the method of collocation. The red contour represents the 18km analysis circle with the ship (star) centered, median of pixel values within this analysis circle is considered as the collocation with ship observation.

4.0 References

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