UV and EUV Intensity Images from the Atmospheric Imaging Assembly (AIA)

AIA captures full images of the Sun and lower atmosphere with four 4096 x 4096-pixel CCD cameras having 1.2 arc second resolution (pixel size of 0.6 arcseconds). Intensity is measured in two ultraviolet (UV) wavelength bands centered at 1600 and 1700 A, seven extreme ultraviolet (EUV) passbands centered at 94, 131, 171, 193, 211, 304, and 335 A, and one visible channel centered at 4500 A.

The HelioCloud AIA dataset comprises a subset of AIA observations consisting of 2 UV and 7 EUV channels (1600, 1700, 94, 131, 171, 193, 211, 304, and 335 A) obtained at 4-minute intervals. Generally the image taken nearest in time to the four-minute tick mark is used, but images with shortened exposure times during flares have been excluded. The data preparation pipeline begins with AIA Level 1 images released through SDO Joint Science Operations Center (JSOC) at Stanford. These were further processed to Level 1.5 with the most recent and accurate pointing information and interpolated to a common grid in which the y-axis of the images is aligned with solar north. The image values have been normalized by the exposure time to units of DN/pixel/s. For more information about the standard Level 0 to Level 1 to Level 1.5 processing, please refer to Lemen+2012 or to the JSOC Website.

To facilitate use of the HelioCloud AIA images and to simplify comparison with the HMI data, two additional processing steps were performed.

1. Degradation Correction - The sensitivity of the AIA EUV channels degrades over time due to the deposition of organic molecules from the telescope structure onto the optical elements and to the decrease in detector sensitivity following (E)UV exposure. To account for this, the AIA team models the change in transmission as a function of time (Boerner+2012) and provides a table of correction parameters publicly available via the JSOC that can be retrieved using IDL or Python routines. The degradation correction has been applied to the Level 1.5 AIA data, and the correction factor is saved as a FITS keyword (DEG_COR) with the version of the degradation correction saved in the FITS HISTORY keyword.
2. Image Upscaling - The AIA HelioCloud images are interpolated onto a larger grid of 5k x 5k using bicubic interpolation in order to have the same pixel scale (0.5000 arcsec/pixel) as the HelioCloud HMI data. The image is centered, with solar north at the top. The processing level for HelioCloud is defined as "h2," the HelioCloud version of Level 3. See below for some additional information.

Magnetic Field, Velocity, and Intensity Images from the Helioseismic and Magnetic Imager (HMI)

HMI is an imaging spectro-polarimeter that collects narrow-band polarized filtergrams at six wavelengths across the 6173 A Fe I absorption line (Schou+2012). A full set of 36 polarized full-disk filtergrams was observed with two 4096 x 4096-pixels CCD cameras (about 0.504 arc seconds per pixel) every 135 seconds from 2010.05.01 until 2016.04.13 and every 90 seconds after that date.

The line-of-sight *observables* are determined every 45s in the JSOC pipeline, but the full set of vector quantities are ordinarily computed every 12 minutes from the 24 Stokes parameters (I, Q, U, and V at each of the six wavelengths). Maps are interpolated in space and time to account for differential rotation and to reduce the impacts of temporal changes. A Milne-Eddington inversion and azimuth disambiguation are performed to derive the vector magnetic field components along with their uncertainties. Performing the computation every 12 minutes using data collected over a 20-minute interval reduces the contribution of the 5-minute p-mode oscillations used for helioseismology (Hoeksema+2014, Couvidat+2016).

Ten observable quantities were provided to the HelioCloud including the line-of-sight velocity corrected for Sun-spacecraft motion; the line-of-sight magnetic field; computed continuum intensity (both as-observed and corrected for limb darkening); and the three components of the vector magnetic field and the uncertainty in each component.

The HMI images for HelioCloud have been further processed for ease of use. The images have been scaled to 0.5000 arc seconds per pixel, the same scale used for the HelioCloud AIA images. The images have also been centered and rotated such that north-south on the Sun at central meridian runs in the vertical direction in each image.

Ancillary Data

Four ancillary data values for each point on the HMI disk have been computed every 4 minutes. These are collected into a single 3D FITS file that includes four quantities for each of the 4096*4096 image pixels. *This is unlike the other quantities, which contain a single value at each pixel.*

- Heliographic longitude [*,*,0]
- Heliographic latitude [*,*,1]
- Line-of-sight component of the satellite velocity at each pixel, accounting for both Earth and SDO motions [*,*,2]
- Center-to-limb angle, mu [*,*,3]

Note that the size of the images in pixels changes depending on the distance of the Sun from the SDO spacecraft for both instruments. The distance changes daily due to the geosynchronous orbit and annually due to the ellipticity of Earth's orbit. Similarly, the heliographic coordinates of the disk center change depending on solar rotation and the position of the Earth and the SDO spacecraft. These values are available in FITS Keywords for each image.

All of the SDO HelioCloud data products were generated exclusively for HelioCloud and are not available for export from the SDO JSOC.

HelioCloud Image Names

Image names, or AWS object keys, are unique to the kind of data and the time at which the Sun was observed. The names look like Unix path names. The name indicates the satellite, instrument, date and time, image quantity, and version number. Examples of each kind of name appear in Table 1. Name times are provided in TAI rather than UT, because there are no leap seconds in TAI. The image name can be computed for any valid time, but in some cases no observation was made or the observation was not of sufficiently good quality. In that case, no image file with the corresponding name will exist.

HelioCloud SDO images are stored in FITS format. SDO FITS files consist of header information made up of KEYWORDS and one or more 2D image segments. Only the Ancillary data FITS files have more than one image segment, with four. The KEYWORDS contain useful and important information about the images, and most are the same as those found in the original JSOC data series descriptions. For example, the Keyword **T_REC** gives the time of the image (as it would have been observed at 1.00 AU in TAI) and bits in the Keyword **QUALITY** provide information about possible issues with the input data (generally QUALITY>0 is OK). There can be many Keywords. Some additional information about the HelioCloud data products is provided in new KEYWORDS. Some KEYWORDS may eventually be available for searching in the HelioCloud database. Some keywords with statistical values for particular images are not described.

Table 1: HelioCloud Example Image Names for each Quantity. A link to a google doc describing the keywords for each series is provided in the left column.

AIA 94A EUV image at time 2022.06.01_00:00:00 TAI	sdo/aia/20220601/0094/sdo_aia_h2_20220601T000000_94_v1.fits
AIA 131A EUV image at 2022.10.02:00:04:00 TAI	sdo/aia/20221002/0131/sdo_aia_h2_20221002T000400_131_v1.fits
AIA 171A EUV image at 2022.06.01_05:56:00 TAI	sdo/aia/20220601/0171/sdo_aia_h2_20220601T055600_171_v1.fits
AIA 193A EUV image	sdo/aia/20220601/0193/sdo_aia_h2_20220601T000000_193_v1.fits
AIA 211A EUV image	sdo/aia/20220601/0211/sdo_aia_h2_20220601T000000_211_v1.fits
AIA 304A EUV image	sdo/aia/20220601/0304/sdo_aia_h2_20220601T000000_304_v1.fits
AIA 335A EUV image	sdo/aia/20220601/0335/sdo_aia_h2_20220601T000000_335_v1.fits
AIA 1600A UV image	sdo/aia/20220601/1600/sdo_aia_h2_20220601T000000_1600_v1.fits
AIA 1700A UV image	sdo/aia/20220601/1700/sdo_aia_h2_20220601T000000_1700_v1.fits
HMI 720s Line-of-sight Magnetic field (M) at 2022:10:02_00:00:00 TAI	sdo/hmi/20221002/M/sdo_hmi_h2_20221002T000000_M_v1.fits
HMI 720s Continuum Intensity proxy (Ic)	sdo/hmi/20221002/Ic/sdo_hmi_h2_20221002T000000_Ic_v1.fits
HMI 720s Continuum Intensity corrected for limb darkening	sdo/hmi/20221002/Ic_noLimbDark/sdo_hmi_h2_20221002T002400_Ic_noLimbDark_v1.fits
HMI 720s Velocity	sdo/hmi/20221002/V/sdo_hmi_h2_20221002T000000_V_v1.fits
HMI Radial magnetic field component	sdo/hmi/20221002/B/sdo_hmi_h2_20221002T003600_Br_v1.fits
HMI Radial field uncertainty	sdo/hmi/20221002/B/sdo_hmi_h2_20221002T003600_Br_err_v1.fits
HMI Westward magnetic field component	sdo/hmi/20221002/B/sdo_hmi_h2_20221002T000000_Bp_v1.fits
HMI Westward field uncertainty	sdo/hmi/20221002/B/sdo_hmi_h2_20221002T000000_Bp_err_v1.fits
HMI Southward magnetic field component	sdo/hmi/20221002/B/sdo_hmi_h2_20221002T001200_Bt_v1.fits
HMI Southward field uncertainty	sdo/hmi/20221002/B/sdo_hmi_h2_20221002T001200_Bt_err_v1.fits

Ancillary latitude, longitude, and line-of-sight SDO velocity	**sdo/hmi/20221002/latlon/sdo_h2_20100430T021200_latlon_v1.fits**

Artifacts in the Interpolated images.

The interpolation used is a two-dimensional bi-cubic method (Park+1983). This works well for most features, but introduces significant visible anomalies when the values are dominated by noise or where there are strong gradients. This is inherent to the method because remapped pixels that are close to an original pixel are dominated by the measurement made in a single pixel, whereas remapped pixels farther from an original pixel more effectively average over several nearby measurements. This results in more smoothing and less random noise in remapped pixels that are farther from an observed pixel; this can introduce a regular *waffle* pattern. See Shine2019 for a more complete discussion. Bi-cubic interpolation in the image plane can also introduce geometric distortions in shapes of features far from disk center (see section 3.1 of Mahajan+2021 for additional discussion). The spatial-scale interpolation to 0.5000 arc seconds per pixel is much less for HMI (initially 0.504042" pixels) than for AIA (initially 0.6" pixels).