ISCCP-H DATA USERS GUIDE

The International Satellite Cloud Climatology Project (ISCCP) was initiated in 1982 as the first project of the World Climate Research Program to collect global satellite measurements and to produce a global climatology of cloud properties (Schiffer and Rossow 1983, 1985, Rossow and Schiffer 1991, 1999, Young *et al*. 2018). The initial focus was on determining the effects of clouds on Earth's radiation budget, but the project goals have evolved over time to encompass the study of all cloud processes (including radiation and precipitation), the interactions of clouds and the atmospheric circulation, and the role of clouds in coupling the components of the climate system's energy and water exchanges.

This document provides a brief description of the third version of the ISCCP data products (called ISCCP-H, all formats are NetCDF except where noted) and their contents (see Appendix C in the full documentation, Rossow 2017), together with references to some studies that suggest possible uses of these data products. Metadata describing the contents of the NetCDF products are obtained by "ncdump -h": the variable names in the netCDF file are mentioned in the text below (in quotation marks). Some details of the analysis procedure that produced these products are also described. Full documentation is provided in the Climate-Algorithm Theoretical Basis Document (C-ATBD, Rossow 2017) found on the NOAA ISCCP website at https://www.ncei.noaa.gov/products/climate-data-records/cloud-properties-isccp.

DATA PRODUCTS

Level 1 Products: B1U/ GAC (binary) + HBT (ASCII)

Description of Contents: The B1U data are reduced resolution (sampled at 10 km) radiance images at 3 hr intervals from the geostationary weather satellites with earth-location and viewing-solar illumination geometry appended (format and contents documented in Young *et al.* 2018 and Knapp 2008). The GAC data are all of the orbit swath data (at a nominal 4 km spacing) from the AVHRR on the polar orbiting weather satellites (format and contents documented in Robel et al. 2014). After 2018, the polar orbiter imaging data are reduced-resolution versions of new instruments, VIIRS, in a form similar to GAC-AVHRR, called VGAC.

The radiance images come from several additional spectral channels, where available, beyond the standard window IR (about 10.5 µm wavelength) and VIS (about 0.6 µm wavelength) channels analyzed by ISCCP. The HBT data are individual IR and VIS calibration tables for each image or orbit segment in three parts showing the progression from the nominal calibration obtained from the satellite operator to the normalized calibration determined by ISCCP (relative to the concurrent "afternoon" polar orbiter for the B1U data and relative to the reference basis for all polar orbiters for the current polar orbiter) to the absolute calibration (Rossow and Ferrier 2015). The radiances are represented in two forms, one in physical energy units ($Wm^{-2}\ sr^{-1}$) and the other as IR brightness temperature (TB, 160--350 K) or VIS scaled radiance (VIS, 0.002--1.120, which is scaled by the instrument "solar constant", the integral of the solar spectrum and the instrument response spectrum). The IR brightness temperature and VIS scaled radiance forms mitigate the small spectral differences of the radiometers.

The calibrated IR and VIS radiances are also contained in the Level 2 and Level 3 products. Note that even though later radiometers provided radiances measurements with greater precision, the majority of the ISCCP record comes from measurements with 8-bit precision. Therefore all radiances and retrieved quantities are represented in the ISCCP datasets by 8-bit COUNTS for consistency.

Possible Uses: Archiving the radiance image data preserves the option to repeat the analysis when better information or analysis methods become available. For instance, the ISCCP-H products are the third version (previous versions were called ISCCP-C and ISCCP-D); a reprocessing of ISCCP-H is planned to include an even more homogeneous cross-calibration, improved Ancillary data, and the addition of some older image data missing from the first version. The Level 1 data can be used for alternative cloud analyses or other studies that require "cloud-cleared" radiances, such as retrieval of surface temperatures and reflectances, especially those using the extra spectral channels.

Level 2 Products: (B1U/GAC + HBT) --> HXS (binary) --> HXG

The HXS product is in a binary format with similar contents to the previous DX product (see Appendix for listing of contents per pixel); a READ program in IDL is available at https://www.ncdc.noaa.gov/cdr/atmospheric/cloud-properties-isccp. However, the HXG product, which is in netCDF, has the same contents as HXS except for the extra radiances, so in the description below of Level 2 products, the variable names mentioned (in quotation marks) can be found in the "ncdump -h" output for HXG.

Description of Contents: The B1U/GAC + HBT data for each satellite for each month, together with the Ancillary data, are analyzed by the ISCCP procedure (see Overview of Analysis section and Rossow 2017 for full details) to produce the HXS product for each satellite separately with all quantities reported as Counts (0-254 with 255 representing "no data"). HXS provides for each 3-hourly image pixel the calibrated IR and VIS radiances ("irad", "vrad"), along with up to nine additional channel radiances (excluded in HXG), earth-location ("lon", "lat") and viewing-solar illumination geometry (cosine satellite zenith angle, "mue" = 0.3-1.0, cosine solar zenith angle, "mu0" = 0.2-1.0, relative azimuth angle, "phi" = 0-180 degrees), flags indicating the results of the clear sky tests ("icslog", "vcslog") and cloud detection threshold results ("clddet") that decide whether that pixel is cloudy or clear ("cloud"), the IR and VIS clear-sky radiances estimated for each pixel ("icsrad", "vcsrad"), and the cloud and surface property retrieval results along with flags indicating type of retrieval ("irret", "vsret") – see Cloud Detection section.

At Level 2, a pixel is either completely clear or completely cloud covered. For cloudy pixels all day, the retrieval obtains cloud top temperature (TC, 160--350 K) and pressure (PC, 10--1025 mb) assuming a blackbody cloud using only IR information ("itmp", "iprs"); PC is determined from the corresponding atmospheric temperatures from the Ancillary data. For clear pixels, these two variables record the surface temperature and pressure (TS, 160--350 K, PS, 10--1025 mb). The values of TS and PS are also retrieved from the clear sky radiances for all pixels (“icstmp”, “icsprs”). For daytime (“mu0” ≥ 0.2), separate values of TC and PC are reported that have been corrected to account for scattering and transmitted radiation by aerosols and clouds using the visible cloud optical thickness (TAU, 0.01--450) retrieved for both liquid and ice phase microphysical models: TAU liquid is “vrefta”, TAU ice is “vtauic”, TC liquid is “vtmp”, TC ice is “vtmpic”, PC liquid is “vprs” and PC ice is “vprsic”.

For clear pixels the variables “vtmp” and “vrefta” represent TS and surface reflectance (RS, 0.002—1.120), respectively. The values of TS and RS are also obtained from the IR and VIS clear sky radiances for all pixels (“icstmp”, “vcsref”); there is also an alternative RS retrieval obtained with no aerosol correction (“vcsref_uncor”) that is used in the cloud retrieval. Cloud water path is not reported in these products but can be calculated for both liquid and ice phase (WP, 0.05—5355 gm/m^2, determined from TAU and the assumed cloud microphysical model) – see Rossow (2017) for formulae used. There are HXS products for each satellite separately.

The HXG product is a global merger of the HXS products (see description of procedure in Mapping and Satellite Merger section), providing global 3-hourly maps in a 0.1° equal-angle grid, which includes only the parameters common to all satellites. In both products all quantities are reported as Counts with Conversion Tables to physical units included, “tmptab” for temperatures, “pretab” for pressures, “refltab” for reflectances and “tautab” for optical thicknesses, and their use explained at the end of the "ncdump -h" output. An important feature of the Conversion Tables is that the value of visible reflectance in “refltab” corresponding to each Count value for TAU represents the spherical albedo of a cloud over a black surface. See Rossow 2017 for more details.

<u>Possible Uses:</u> The HXS products are convenient for regional studies or field experiments as the separate satellite results cover different geographic sectors with smaller data volumes (the polar orbiter results in HXS are divided into five sub-regions, including three longitude sectors at latitudes ≤ 55° and two polar regions). Examples of field campaign studies are Wang *et al.* (1999) and Rozendaal and Rossow (2003). The HXS products can also be used for development of cloud retrieval algorithms that may use more spectral channels to be compared with the two-channel results of ISCCP, or for developing retrievals that extend the ISCCP results to other cloud (or surface) properties using the other spectral channels (*e.g.*, Han *et al.* 1994), or for evaluating the cloud results by matching other satellite or surface measurements (*e.g.*, Lin and Rossow 1994).

The HXS data can also be used to determine surface properties exploiting the cloud detection results and clear-sky radiance estimates (cloud clearing). The HXG product is useful for global or extensive regional studies of cloud processes. For instance, the motion and evolution of cloud objects can be tracked (*e.g.*, Machado *et al.* 1998, Vant Hull *et al.* 2016) or cloud property evolution can be traced using air mass trajectories (*e.g.*, Luo and Rossow 2004). Another use of the HXG product is to examine the space-time cloud variation statistics (*e.g.,* spectral analysis of variability scales) (*e.g.*, Rossow and Cairns 1995) or to determine statistical property or cloud behavior regimes (*e.g.*, Tselioudis *et al.* 2013).

<u>Level 3 Products: (HXS) --> HGS --> HGG --> HGH --> HGM</u>

The Level 3 products are produced by collecting/averaging Level 2 information into a lower resolution map grid. The variables derived from the radiances have names composed of two parts, the physical quantity and the retrieval method/results that define subsets of pixels used for grid cell averages. For example, the number of cloudy pixels determined by both IR and VIS threshold tests are called "n-cloudy", but the number of cloudy pixels determined solely by IR tests is "n_ir_cloudy". The number of clear pixels is given by the difference of "n_total" and "n_cloudy" or "n_ir_cloudy". Additional information is given to indicate cloudy pixels detected only by IR but not VIS tests ("n_ironly_cloudy") or by VIS but not IR tests ("n_visonly_cloudy") and to indicate clouds just barely across the detection thresholds (see Cloud Detection section), called "marginal" with names "n_visirmarg_cloudy", "n_irmarg_cloudy" and "n_vismarg_cloudy". The retrieved variables follow a similar naming convention.

Description of Contents: The individual HXS products are first reduced to a 1° equal-area mapping covering their geographic sector and combined with the Ancillary products to produce the HGS products, still separate by satellite. Then these are merged globally to produce the global HGG products every 3 hr on the same 1° equal-area mapping (see Mapping and Satellite Merger Criteria section). The contents of these two products are the same. The HGG file identifies the particular satellite data present in each grid ("satcode" identifies the source satellite for each map grid cell, where "satcodes" and "satnames" document all the satellites present globally at that time). The program "ncdump -h" provides the complete content details, especially the "longnames" variable definitions.

The map grid information in the file header is of four types: the properties of the equal-area grid ("eqlon" and "eqlat" give the Earth location of the cell center, "eqcells" gives the number of cells at each latitude, and "eqarea" gives the surface area of each cell), fixed geographic information ("eqheight" and "sigma_eqheight", which are topographic height and standard deviation, and "eqveg", which is dominant surface type including water and vegetation categories on land, see table in the IR Retrieval Model section), the relationship to an equivalent equal-angle grid (the procedure for converting to the equal-angle grid from the equal-area grid is described at the end of the "ncdump -h" output), and scene identification ("scene" indicating, for example, day-water or day-land, "snoice" indicating fractional coverage, "inversion" indicating the presence of a near-surface temperature inversion, and viewing-illumination geometry angles described above).

In the Level 2 (pixel-level) products, the cloud cover fraction or cloud amount (CA) is either zero or one; but, when mapped to the 1° equal-area grid, there are on average about 100 pixels (the minimum number required is 25) so a cloud cover fraction (0--1) can be determined by counting the number of cloudy pixels divided by the total number of pixels. All cloud amounts are reported as the number of pixels in each category (*e.g.*, "n_cloudy") along with the total number of pixels in each map grid cell ("n_total").

Each cloudy pixel in Level 3 is assigned to a particular cloud phase, liquid or ice, depending on the value of retrieved cloud top temperature, TC: ice clouds have TC < 253.1 K. The grid-average retrieved and derived quantities are reported as: TC ("tc" retrieved), cloud top pressure PC ("pc" derived), optical thickness TAU ("tau" retrieved) and cloud water path WP ("wp" derived) for cloudy pixels (if any) and surface skin temperature TS ("ts" retrieved, alternate single channel results are "ts_ir" and "ts_vis) and surface visible reflectance RS ("rs" retrieved, alternate single channel results are "rs_ir" and "rs_vis") for clear pixels (if any). The values of TS and RS are also retrieved from the clear-sky radiance estimates ("ts_clrsky" and "rs_clrsky") and are more accurate by design. These variables also have values for alternate retrievals or specific subsets as indicated by the name extensions described above for cloudy pixel number.

The main variables are based on combined analysis of IR/VIS data for daytime conditions defined by "mu0" ≥ 0.2 (see VIS/IR Retrieval Models section), except for "n_cloudy" which has been corrected during nighttime conditions (see Nighttime Adjustments section). Alternate variables based only on IR data are reported all day if available (*e.g.*, "tc_ir" or "tau_ir", with no phase discrimination, see IR Retrieval Model section). Note that, for each map grid and time step, the averages of TC and TAU are performed linearly in the measured energy (*i.e.,* radiatively weighted, proportional to the COUNT values used to represent them), whereas PC (proportional to TC) and WP (proportional to TAU) are averaged linearly (the Conversion Tables are recorded as "tmptab" for temperatures, "tmpvar" for temperature standard deviations, "pretab" for pressures, "rfltabl" for visible reflectances, "ozntab" for ozone abundance, "humtab" for relative humidity and "wpatab" for cloud water path, see Use of Conversion Tables and at the end of the "ncdump -h" output).

In the HGS and HGG products, the sub-grid spatial variations of the retrieved cloud and surface properties are reported in three forms: standard deviations (variable name starts with "sigma" with results reported only for the IR analysis always present), the number and average properties for separate cloud types defined by combinations of PC and TAU (see Figure 1) and cloud property histograms (reported as numbers of pixels at each PC and TAU combination, see Histograms and Cloud Types section below). At all times of day based on only on the IR retrieval, the number of pixels are counted ("n_irtype") and the pixel values of PC and TC are averaged for three cloud types defined by three ranges of PC regardless of phase ("cloud_irtype" which are low, middle, high); the values of PC and TC for the IR-types are not reported explicitly but are obtained from the histogram values.

There are 1-dimensional histograms of PC in seven intervals based only on IR data ("n_pcdist"), together with the average PC and TC values in these intervals ("pc_pcdist", "tc_pcdist"). In daytime based on VIS/IR retrieval, the number of pixels are counted and the pixel values of PC, TC, TAU and WP are averaged for 18 cloud types (when present) defined by three ranges of PC and three ranges of TAU and two phases ("n_type", "pc_type", "tc_type", "tau_type" and "wp_type"); there are also 2-dimensional (joint) histograms of PC and TAU (regardless of phase) in seven and six intervals, respectively ("n_pctaudist").

Since larger errors in the retrieved cloud and surface properties are produced by missed or false cloud detections, the quality of the results is characterized by a set of average quantities that provides the changes in cloud and surface properties that would be produced by changing the detection thresholds by an amount equivalent to the estimated uncertainty of the clear-sky radiance values, referred to "marginal" clouds. Such clouds have radiances that are on the cloudy-side of the clear values in a range from one to two "uncertainty" (threshold) intervals: those pixels within one uncertainty interval are called clear but those between one and two intervals are called marginal clouds (see threshold definitions is Figure 2). For these categories, the average values of CA (number of pixels), TC, PC, TAU, and WP are reported with “irmarg”, “vismarg” and “visirmarg” in the variable name, representing different threshold conditions.

Given the magnitude of the detection thresholds, the ratio of these quantities to the thresholds provides an estimate of the first derivative of the quantities with threshold magnitude. Two other performance measures are provided: statistics from the cloud detection analysis and results of the FILL procedure for HGG (see discussion in Fill Procedure sections). The cloud detection statistics are “n_ir_longterm”, “ratio_ir_clear” and “ratio_vis_clear”: the first indicates how many pixels had to use the long-term statistics (monthly) for the clear sky estimate and the latter two indicate the ratio of the number of pixels with radiances just above and just below the estimated clear sky radiance values, which on average should be close to one (see Rossow 2017 for details).

The HGS and HGG products also contain the VIS and IR radiances (grid cell average and standard deviations) used in the retrievals but reported separately in several categories by the cloudy-clear decisions (including only IR, only VIS or VIS/IR). The procedure to use these subsets to reconstruct the grid-total original radiances is described near the end of the "ncdump -h" output.

The 3-hourly HGG products are averaged over each month separately at each of eight times of day UTC (0, 3, 6 …, not local time) to produce HGH; the eight HGH products for each month are then averaged to produce HGM, the monthly means. This averaging approach ensures equal weight over the diurnal cycle. In each of the time-averaged products, the variables reporting the number of pixels in various categories in HGG are replaced by variables reporting the number of observations comprising the averages: “n_obs” is the total number of all observations used, “n_day” is the number of days (more meaningful in HGM), “n_orig” is the number of observations exclusive of filled values, and “n_toplev” indicates the number of observations that came from the preferred satellite for that location. Instead of reporting the number of cloudy pixels, cloud amounts in HGH and HGM are given directly in units of 0.1%: “cldamt” is the total cloud amount, “cldamt_ir” is the cloud amount determined only from IR tests (other cloud amounts are reported for various threshold categories), “cldamt_types” is the cloud amounts for the 18 VIS/IR cloud types, and “cldamt_irtypes” is the cloud amount for the IR cloud types. A new variable is “cldamt_dist” which gives the frequency of occurrence of cloud amounts from HGG in 10% intervals. The time averages of all of the other cloud (and surface) variables are reported in Counts as in HGG (Conversion Tables provided in the datasets), except for “snoice” which is reported in units of 0.1%.

In addition to the time averages of the variables in HGG, the variation statistics of the main cloud variables (and surface temperature) are reported as standard deviations of the time variations of the spatial means in HGG (“sigma_’*variable*’_time”); for the IR-based cloud and surface variables, sigma_’*variable*’_space gives the time-averaged spatial standard deviation. Together with the time standard deviation, this quantity allows calculation of the total standard deviation. There are no PC or PC-TAU histograms in HGH and HGM; only the properties of the VIS/IR types (“*variable*_types”) and IR types (“*variable*_irtypes”) are reported. Note that in HGG the nighttime grid-averaged cloud properties (CA, TC/PC), originally based on IR retrievals, are adjusted during nighttime based on daytime results and TAU/WP interpolated over nighttime (see Nighttime Adjustments Section).

In addition the 18 daytime cloud type amounts, but not their properties are interpolated over the nighttime. Consequently in the monthly averaged products (HGH, HGM), the weighted average of the cloud type properties is no longer consistent with the grid-averaged properties. If the monthly averaged cloud type properties (TC, TAU) are used to calculate radiative fluxes, they should be scaled in Counts by the ratio of the grid-averages values and the weighted-average cloud type values for consistency. Note that the time averaged results are obtained for each variable separately, not weighted by CA. See Rossow (2017, C-ATBD) for more details.

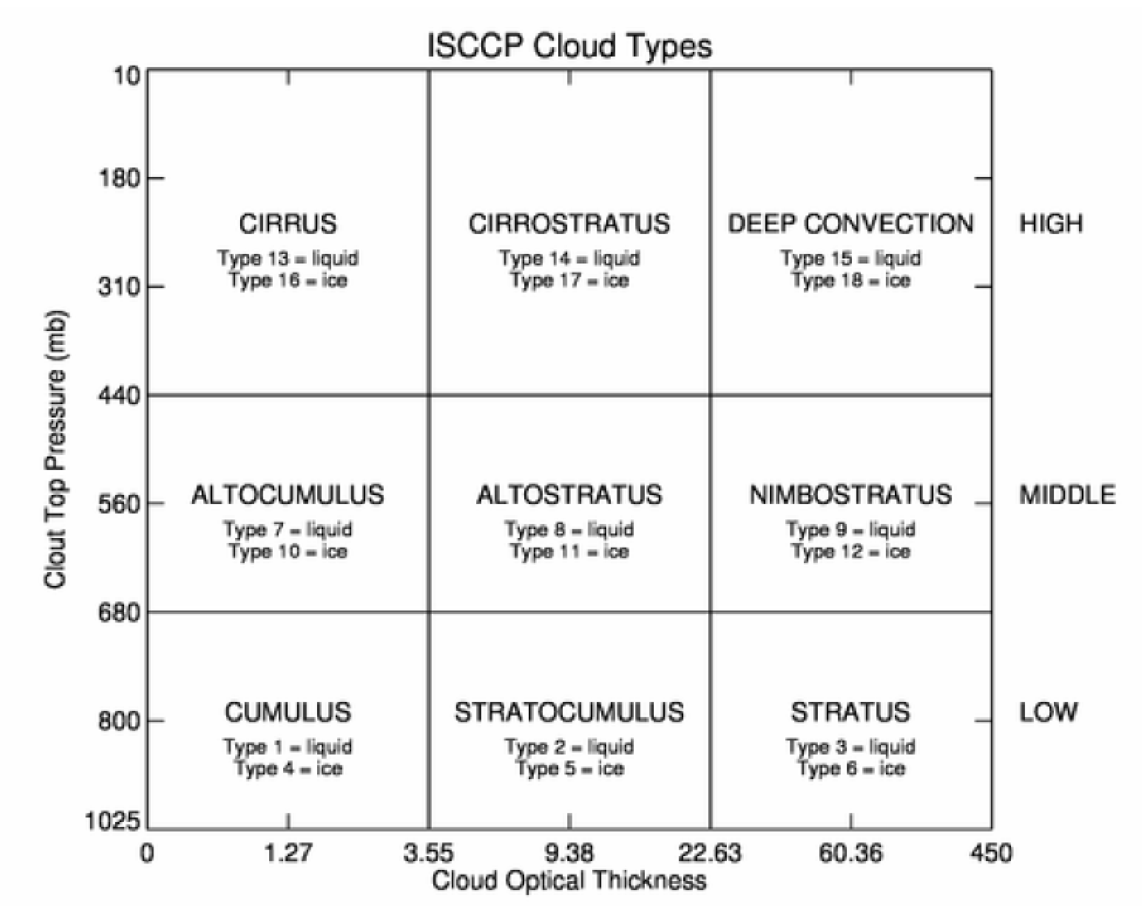

Figure 1: Definition of ISCCP cloud types based on IR-based cloud top pressures all day and IR/VIS cloud top pressures and optical thicknesses for daytime.

<u>Possible Uses:</u> The Level 3 products are the main ISCCP products and can be used for a variety of global studies. The main quantities are the grid summary results CA = “n_cloudy”/”n_total” or “cldamt”, PC = “pc”, TC = “tc”, TAU = “tau” and WP = “wp”, the cloud type amounts and properties, and the 1-D and 2-D histograms. The alternate variables provide uncertainty estimates and more information about the derivation of the results. Since the Ancillary data products that describe the properties of the atmosphere and surface are included, global diagnostic studies of the relationships of clouds to these

other components of the Earth weather-climate system are possible. The effects of clouds on radiative exchanges, the first goal of ISCCP, have been calculated using products like HGG (*e.g.*, Zhang *et al.* 2004 describes ISCCP-FD, the ISCCP-FH product is also available from Y. Zhang <yz7@columbia.edu>).

The Level 3 cloud properties can be used to composite precipitation measurements (*e.g.*, Rossow *et al.* 2013) or to study the relation of the cloud properties and their evolution with various aspects of the atmospheric circulation (*e.g.*, Tromeur and Rossow 2010, Mekonnen and Rossow 2011, 2018, Haynes *et al.* 2011, Romanski and Rossow 2013, Polly and Rossow 2016). The scales of weather-climate variations can be examined in the Level 3 products (*e.g.*, Rossow and Cairns 1995, Tselioudis and Rossow 2011). The PC-TAU histograms have been used to define Weather States (or cloud regimes) to examine cloud processes and compare to model representations (Tselioudis *et al.* 2013, Remillard and Tselioudis 2015), but Tan and Jakob (2013) developed WS from the PC histograms for diurnal studies.

Ancillary Products: TOPO [0.1°, 1.0°], SNOICE, NNHIRS, OZONE, AERO

Description of Contents: The Ancillary data products are used in the ISCCP cloud analysis as follows (see Appendix D in Rossow 2017 for details and references for original data sources). TOPO (equal-area mapping at 0.1° and 1.0° of topographic height and its standard deviation in m, land-water mask); this information is reported in the gridded products as "eqheight, "sigma_eqheight" and the "scene". SNOICE (daily fractional coverage, 0-1, at 1° equal-area of snow and permanent glaciers on land and sea ice and ice shelves on water) is reported in "snoice". These two products are used to define a variety of situations for the cloud detection procedure (land/water, shore meaning near coast line, rough topography, snow/ice, in addition illumination/viewing geometry define more conditions, day/night and water glint), which employs different values of test parameters and thresholds for each situation (see Cloud Detection section and Rossow 2017).

The NNHIRS (3-hourly, 1° equal-area) product reports atmospheric temperature (T, 160-350 K) and relative humidity profiles (0.1-150%); the profiles extend from the surface ("psurf") to 10 mb in 16 levels (some lower levels may be missing over elevated surfaces) and include near-surface values ("airtemp", "rh_nearsurf" at "psurf"), tropopause values ("ttrop", "rhtrop" at "ptrop") and values at the temperature maximum level, which is the surface unless a near-surface inversion is present ("tmax", "rhmaxt" at "pmaxt"). OZONE (1° equal-area, total column ozone, 40-600 Dobson units) is reported in "ozone". AERO (monthly, 1° equal-area, stratospheric aerosol optical depth and tropospheric aerosol optical depth (0-10) and fine fraction, 0--1) is not reported in the Level 3 products but is available. All five products are used in the ISCCP cloud and surface property retrievals to specify the other properties of the atmosphere and surface. All of these products, except AERO, are included in the HGS, HGG, HGH and HGM products.

Possible Uses: These products can be used for other research purposes aside from cloud studies. The calculation of atmospheric and surface radiative exchanges uses the HGG product plus a more detailed version of AERO (*e.g.*, Zhang *et al.* 2004 updated for

ISCCP-H). These products can also be combined with other datasets to diagnose other energy and water exchanges at the surface or within the atmosphere.

BASIC Product: (HGG & HGH & HGM) --> BASIC

Description of Contents: This product is a reduced version of the HGG, HGH and HGM products, where only the main cloud properties and Ancillary data are reported.

Possible Uses: Users seeking environmental information about clouds, without a need for the detailed documentation of the cloud analysis or the intention for diagnostics studies, can use the simpler BASIC product for such purposes.

COMMENTS ON ncdump

The "ncdump -h" output provides complete documentation of the contents of the data products, especially the definition of the variables in the “longnames”. There is a summary of the fill procedure employed in the HGG product. Near the end of the "ncdump -h" output are descriptions of several key procedures for manipulating the data contents (along with the definition of cloud types): (1) a procedure to re-project the data from its equal-area mapping into a square (latitude – longitude) mapping preserving the statistics, (2) the procedure to convert the variable Count values into physical units, (3) an alternate computation of cloud top height (m) using TC and TS with a fixed temperature lapse rate (only approximately correct for low-level clouds, other values of the lapse rate can be used) and (4) procedures for re-constructing the original total grid cell average IR and VIS radiances from the separate cloudy and clear values.

OVERVIEW OF ANALYSIS

A much more detailed description of the ISCCP analysis procedure is given in the C-ATBD (Rossow 2017). The description below mostly highlights the changes from previous versions.

Cloud Detection: The ISCCP cloud detection algorithm performs situation-dependent tests of the IR and VIS radiance variations, separately, at several different space and time scales over each month at each time of day for each individual satellite (Rossow and Garder 1993a,b). The situations are defined by the Ancillary data: TOPO provides a land-water mask and land topography and SNOICE provides snow/glacier cover on land and sea ice/ice shelf cover on water (in Rossow 2017 Table 3 provides the surface types defining the situations – see also the table in IR Retrieval Model section below -- and Table 4 gives the values of parameters used in the space-time variation tests).

The results of these tests are used to estimate clear-sky radiances for each pixel in each image because the clear-sky radiances are generally less variable that cloudy radiances. Comparison of the actual radiance values to the clear-sky values determines the presence of clouds: if the IR is less than the clear-sky value **OR** the VIS is greater than the clear sky value by more than a situation-dependent threshold amount (see Tables

5 and 6 in Rossow 2017), the image pixel is labeled cloudy, otherwise clear (the IR procedure is the same all day). Figure 2 shows the division of the radiances, where the intervals represent the threshold magnitudes, which are situation dependent. The threshold values represent the estimated uncertainty of the clear-sky values: pixels with radiances that differ by more than one but less than two threshold amounts (interval 4 in the figure) are labeled “marginally” cloudy.

The ISCCP-H cloud detection algorithm differs from earlier versions in three ways: there is an additional smaller-scale space-variation test in mixed land-water grids, some detection thresholds have been reduced (Table 6 in Rossow 2017 compares the new values to the previous values) and a special treatment for nighttime conditions over snow and ice in the polar regions changes the clear-cloudy labeling (see Figure 2) so that IR detection flags 1 and 2 are changed to 5 (cloudy) and flag 4 is changed to 3 (clear).

In the Level 2 products, the cloud-clear decision is recorded for each pixel in “cloud” and the details of the cloud detection procedure are documented by flag values (“clddet”, “icslog”, “vsclog”). In Level 3 products, three statistics are reported (“n_longterm”, “ratio_ir_clear”, “ratio_vis_clear”) that tell how many pixels used the longer time-scale (monthly) information to estimate clear sky values and the ratio of the number of pixels that have radiances just above and below the clear sky values (flag values 2 and 3). In the Level 3 products, cloud amounts are reported as the number of cloudy pixels in the map grid cell (*e.g*. “n_cloudy” *etc.*, see description above) and converted to CA by dividing this number by the total number of pixels present (*e.g.*, CA = “n_cloudy”/“n_total”, 0-1). In addition to the average properties of all clouds determined from the cloudy pixel values (average surface properties are reported for both any clear pixels and from the clear-sky radiances for all pixels), the average properties of clouds (and surface) for three categories of marginally cloudy pixels are determined: IR-only-marginal, VIS-only-marginal, and VIS/IR-marginal (see Figure 2).

Once cloudy pixels are identified, the properties of clouds are retrieved by comparison to three specific models of clouds, one based solely on IR with results reported all day for diurnal cycle studies and two based on VIS/IR for liquid and ice clouds during daytime.

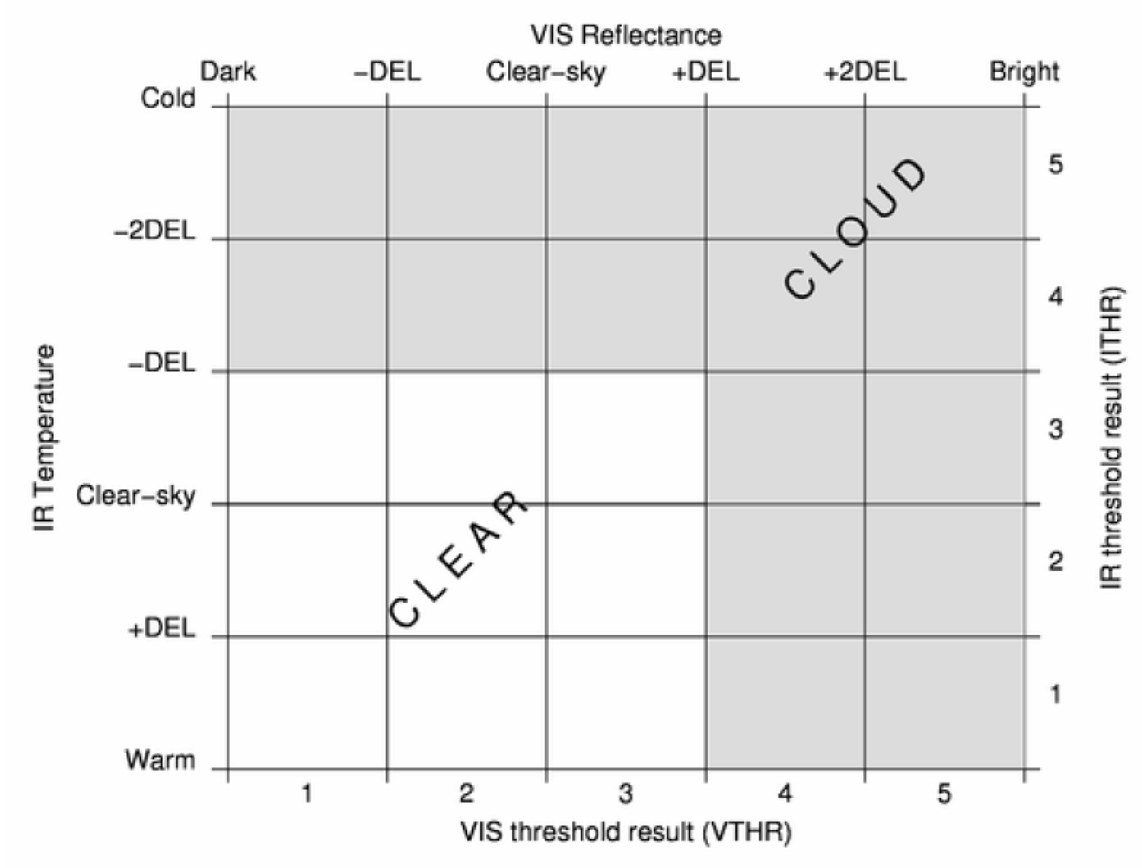

Figure 2: Definition of IR and VIS threshold flags that indicate the value of the pixel-level radiances relative to the estimated clear sky radiances and used to separate pixels into clear and cloudy categories. The clear sky values are represented by the lines between flags 2 and 3. The magnitude of the radiance intervals indicated by flag values 2, 3 and 4 is defined by the situation-dependent threshold values that represent the estimated uncertainty in the clear sky radiance values. The flags 1 and 5 indicate all radiances outside the range represented by 2 to 4. Pixels with radiance differences represented by flag = 4 are referred to as "marginal" clouds.

<u>IR Retrieval Model:</u> In the solely-IR retrieval model, clouds are assumed to be blackbodies, so that the observed IR brightness temperature, corrected for absorption by overlying water vapor using the NNHIRS Ancillary data, is taken to be the cloud top temperature (TC, 160-350 K); the atmospheric pressure in the NNHIRS profiles at the same temperature is the cloud top pressure (PC, 10-1025 mb). If the observed value of TC is less than the smallest value in the NNHIRS profile at the tropopause, the value of PC is calculated assuming adiabatic ascent from the tropopause level. In ISCCP-H the NNHIRS profiles have surface temperature inversions in some situations (wintertime polar regions and wintertime deserts at night) indicated by the flag "inversion". In such cases, since the temperature profile is searched downwards from the top for a match to TC, the cloud is placed at a pressure level at or above the maximum temperature level (the temperature and pressure at this level, which may be the surface, are given by "tmax" and "pmaxt"). If the TC value is larger than the maximum atmospheric

temperature at the top of the inversion layer, PC is taken to be the pressure at the top of the inversion layer; if TC is larger than TS in the absence of an inversion, PC is taken to be the surface pressure ("psurf") minus 20 mb, representing a clear boundary layer. The PC values are also used to create a 1D histogram of the number of cloudy pixels in seven PC ranges (given by "n_pcdist") in HGS and HGG and to define the number of three cloud types and their average properties ("n_irtype", "pc_irtype", "tc_irtype"). In ISCCP-H, IR radiances in clear pixels as well as all the clear-sky values are corrected for absorption by atmospheric water vapor to retrieve surface temperatures using a specified surface emissivity based on land-water and land-surface types (see table below).

Surface Type Code	Description	IRemiss
0	Water	0.990
1	Evergreen Needleleaf Forest	0.985
2	Evergreen Broadleaf Forest	0.980
3	Deciduous Needleleaf Forest	0.985
4	Deciduous Broadleaf Forest	0.980
5	Mixed Forest	0.985
6	Closed Shrubland	0.980
7	Open Shrubland	0.975
8	Woody Savanna	0.980
9	Savanna	0.980
10	Grassland	0.980
11	Permanent Wetland	0.980
12	Cropland	0.980
13	Urban and Built-up	0.980
14	Cropland/Natural Vegetation Mosaic	0.980
15	Permanent Snow and Ice (Glaciers)	0.990
16	Barren or Sparsely Vegetated	0.965
17	Unclassified	0.980
18	Permanent Ice Shelf	0.990

<u>VIS/IR Retrieval Models:</u> The VIS/IR retrieval models are used only for daytime conditions, defined by cosine solar zenith angles, "mu0" ≥ 0.2 (solar zenith angle < 78.5°). The iterative procedure begins with the IR retrieval of TC/PC assuming a blackbody cloud as described above. The cloud optical thickness (TAU) is then retrieved from the VIS radiances, corrected for stratospheric ozone absorption using OZONE Ancillary data and stratospheric aerosol scattering/absorption using AERO Ancillary data, for both liquid and ice phases at pixel-level. The retrieval of TAU accounts for the dependence on viewing and solar illumination geometry, cloud top pressure, the scattering/absorption of tropospheric aerosols assumed to be below the clouds, and surface reflectivity. Cloud layers in the retrieval model vary in physical thickness from 100 mb at the surface to 60 mb for liquid clouds just above mid-troposphere and to 200 mb for ice clouds just below the tropopause (see Figure 5 and the text just above it in Rossow 2017). VIS retrievals are performed for all pixels with two pre-calculated reflectivity models, one for liquid clouds (in ISCCP-H the effective droplet radius is 13

μm over land 15 μm over water both with a variance of 0.1) and one for ice clouds (in ISCCP-H the reflectivity model is an empirical model based on satellite polarimetry measurements). The grid cell average value of optical thickness ("tau") and the histogram values mix pixels with the two phases but separate results are found in "tau_type", where the phase for each pixel is determined by whether or not TC < 253.1 K. Cloud water path is calculated from TAU and the assumed effective particle radii (for ice clouds, the radii are assumed to be 20 μm for TAU < 3.55 and 34 μm for larger TAU, the grid cell average value mixes the two phases in "wp" but the separate results are found in "wp_type"). The value of TAU is then used to correct the blackbody values of TC/PC (reported in "tc" and "pc" averaged over all clouds and separately in "tc_type" and "pc_type") accounting for IR scattering and for transmission of IR radiation through thinner clouds (TAU < 14.5). Since the value of TAU depends weakly on PC, the procedure is iterated to obtain consistent values of TC/PC and TAU.

For very optically thin clouds, especially those detected only by the IR threshold test, the retrieved value of TAU can be so small that the TC value corrected for transmitted radiation from below is less than the smallest value in the NNHIRS profile at the tropopause (optically thick clouds for which TC is colder than the tropopause temperature are treated as described above for blackbody clouds). In this case, the values of TC/PC are set to the tropopause values and the radiatively-consistent value of TAU determined. In some geometries over snow- and ice-covered surfaces, an optically thin cloud can be less reflective than the clear-sky; when this condition is detected, a special look-up table is used to retrieve TAU. Both liquid and ice cloud results are reported in the Level 2 products; in the Level 3 products, ice cloud results are reported for all pixels with TC < 253.1 K and liquid cloud results reported for all pixels with TC ≥ 253.1K). The values of PC and TAU are used to create a 2D histogram of the number of cloudy pixels in seven PC ranges and six TAU ranges ("n_pctaudist") in HGS and HGG. Also, the values of PC, TAU and phase are used to report the amounts and properties of 18 cloud types ("n_type", "pc_type", "tc_type", "tau_type", "wp_type") – see Fig. 1.

The IR radiances in clear pixels, as well as all the clear-sky estimates, are corrected for absorption by water vapor and absorption by stratospheric and tropospheric aerosols to retrieve surface temperature ("ts" and other subsets). The VIS radiances in clear pixels, as well as all the clear-sky estimates, are corrected for absorption by stratospheric ozone and scattering/absorption by stratospheric and tropospheric aerosols to retrieve surface reflectivity ("rs" and other subsets).

<u>Mapping and Satellite Merger Criteria:</u> The results from the individual satellites are "merged" to form two global products. The Level 2 product HXG is produced by merging HXS products into a 0.1° equal-angle grid, keeping only the common variables and using the same rules described below. For all Level 3 products (HGS, HGG, HGH, HGM), the map is a 1.0° equal-area grid with constant latitude intervals and varying longitude intervals to (approximately) preserve areas: HGS is merged into HGG. HGH is the average of HGG at each of eight times of day UTC and HGM is the average of the eight HGH products. The merger is performed so that only one result is reported in each map cell ("satcode" identifies the source satellite in each map grid cell) by using a hierarchy defined for each map cell as follows. At latitudes ≤ 55° the primary satellite is the geostationary satellite with the "best" view defined by the smallest satellite viewing

zenith angle (largest value of the cosine, “mue”). In the absence of an image from the primary satellite, the data from any available secondary geostationary satellite that views that location is used subject to the constraint that the view zenith angle is < 72.5° (“mue” > 0.3). If secondary geostationary satellite data are not available, then the orbit swath from the afternoon polar orbiter is used, if available at that time; if not available then the morning polar orbiter is used if available. For latitudes > 55°, the hierarchy order is afternoon polar orbiter, morning polar orbiter, and any available geostationary satellite (subject to the view zenith angle constraint). If no satellite data are available, a FILL procedure is invoked (see below); if the FILL procedure fails, then no satellite image data are reported (Count = 255 for all quantities) but the Ancillary data variables will still be present in the grid cell at Level 3. The Level 3 datasets include information for each grid cell with which the mapping can be converted to 1° equal-angle; the procedure is described near the end of the "ncdump -h" output.

It is important to note that the values of TAU and TC in Level 3 products are averaged in a way that is linear in the radiance measurements (radiatively-weighted averaging) so as to preserve the radiation characteristics, but PC, which is proportional to TC in the atmospheric profile at grid/time step level, and WP, which is proportional to TAU at pixel-level, are averaged linearly: the ratios of these two averages can be used as a measure of the radiative effects of small-scale cloud property variations (*cf.* Rossow *et al.* 2002).

Histograms and Cloud Types: In HGS and HGG, in addition to the map grid cell average and spatial standard deviation (indicated by “sigma” in the variable name) of the retrieved cloud and surface properties, smaller-scale cloud variations are represented in two ways: histograms and cloud type properties. The all-day IR results are reported as the number of cloudy pixels in seven ranges of PC from the surface to 10 mb (“n_pcdist”) and their average PC/TC values (“pc_pcdist”, “tc_pcdist”) and as the number (“n_irtype”) of three cloud types (“cloud_irtype”) defined by PC range, low (PC > 680 mb), middle (680 ≤ PC < 440 mb) and high (PC ≤ 440 mb) – the average PC and TC can be determined from the histogram values. The daytime VIS/IR results report the joint PC-TAU distribution in seven by six intervals (“n_pctaudist”) and the number and average TC/PC (“tc_type”, “pc_type”) and TAU/WP (“tau_type”, “wp_type”) values for 18 cloud types (“cloud_type”) defined by two phases (liquid, ice) in the three PC ranges and three TAU ranges (0.02 – 3.55, 3.55 – 22.63, 22.64 -- 450) – see Fig. 1. The time average cloud type properties (“*variable*_types”, “*variable*_irtypes”), but not the histograms, are reported in HGH and HGM.

Nighttime Adjustments: Two changes to the nighttime grid-average cloud properties are made in the HGG product. The nighttime values of the grid cell values of CA (“n_cloudy”), PC (“pc”) and TC (“tc”) are originally equal to the IR values (“n_ir_cloudy, “pc_ir”, “tc_ir”), but are adjusted based on interpolation between the nearest daytime difference between these quantities, which can only increase CA (capped at 1.0) and decrease PC/TC (capped by the tropopause values). In other words the values become: “n_cloudy” = nighttime (“n_cloudy”) + interpolated-daytime (“n_cloudy” − “n_ir_cloudy”), “pc” = (nighttime) “pc” + interpolated-daytime (“pc”− “pc_ir”), and “tc” = nighttime (“tc”) + interpolated-daytime (“tc” − “tc_ir”). In addition the daytime values of TAU, WP and the number of VIS/IR cloud types ("n_type"), which were originally set to 255, are interpolated from adjacent daytime values. Flag values ("fill_type") indicate these changes. Given these changes, the grid-averaged cloud properties and the weighted-average of the cloud type properties in monthly averaged products (HGH, HGM) are no longer consistent. Consistency can be restored by scaling the time-averaged cloud type properties by the ratio in Counts of the grid-averages and the cloud type-weighted-averages.

Fill Procedure: Several procedures are performed to attempt to fill in missing satellite data (as indicated by flag values); missing values that remain are set to 255. In the HXG product, a simple and limited replication in space or interpolation in time is performed as indicated by "fill_type" and described in the summary at the end of the "ncdump -h" output: replication from the nearest longitude within ± 3°, or replication from the nearest latitude within ±3°, or interpolation in time by ±3 hr. In the HGG product the included Ancillary data have their own Fill procedures so they are always present in every map grid cell. First, interpolation from adjacent time slots (± 3 hr) at each location is attempted. If unsuccessful, interpolation from nearest day (within ± 5 days) at the same time of day at each location is attempted. A special polar procedure replicates results from nearby (± 3) equal-area cells, first in longitude, then in latitude. Finally, if needed, interpolation from nearest week (within ± 2 weeks) is attempted. Some cells may remain empty: in particular, since the near-coastal image pixels are deleted to avoid problems of earth-location errors, there are 10 map cells (mostly in the Maritime Continent area) that never have satellite data because there are not enough pixels available. The HGG Fill Procedure is described at the end of the "ncdump -h" output and documented in "cell_origin", "fill_gmts", "fill_days", "fill_weeks" and "fill_type".

Use of Conversion Tables: The physical values in the ISCCP datasets are represented by integer Count values (0-254), where 255 represents missing quantities. Conversion tables are provided in the data products (in HXG as "tmptab", "pretab", "refltab" and "tautab" and additionally in HGG/HGH/HGM as "tmpvar", "ozntab", "humtab" and "wpatab") to change these Count values to physical units (these tables are also available in the C-ATBD, Rossow 2017); the procedure is described at the end of the "ncdump -h" output. This approach preserves the measurement precision and allows for non-linear relationships. In particular, to preserve the relation of cloud properties to radiation, the Count values for TAU and TC should be averaged before conversion to physical units. A useful feature of these tables is that the associated values of surface reflectance (RS) also represent the spherical albedo of a cloud with a TAU values with the same Count value; similarly, the corresponding WP values if converted to TAU at the same Count value provide the linearly averaged TAU, which when compared to the radiatively averaged TAU indicates the effects of small-scale cloud variations on radiation (*cf.* Rossow *et al.* 2002).

PRODUCT EVALUATIONS

Evaluations of the previous versions of these products (ISCCP-C, ISCCP-D) are summarized and discussed in the C-ATBD (see also Rossow and Schiffer 1991, 1999, Stubenrauch *et al.* 2012, 2013) and form the basis, together with results from more advanced satellite measurements and field studies, for the small revisions to produce ISCCP-H. The radiance calibrations have been reviewed, compared with other analyses and updated in Rossow and Ferrier (2015).

Summary of Estimated Uncertainties: Random retrieval uncertainties are estimated to be: radiances (±3%), CA (±3%), TC (±2K in the lower atmosphere, ±4K in the upper atmosphere) and PC (±50mb in the lower atmosphere, ±100 mb in the upper atmosphere), TAU (±15%), RS (±5%), TS (±2-3K). The reported precision of these quantities in the products is 0.1% for CA, 0.4% for retrieved quantities, which represents for TAU a precision of 0.04 at 0.5 to 6 at 100 and for TC a precision of 2K at 200K to 0.5K at 300K (see Rossow 2017 for details and references). The larger errors in CA and the retrieved cloud and surface properties are produced by missed and false cloud detections; the random contribution to this source of uncertainty is documented in the data products by the marginal cloud amounts. There are three notable systematic sources of error. As discussed in Stubenrauch *et al.* (2013), different satellite sensors have different cloud detection sensitivities, ranging from solar wavelength imagers (including visual observations by surface observers) to multi-channel imagers to infrared sounders to lidar, in order of increasing sensitivity. Based on comparison to the satellite lidar observations, the ISCCP cloud detection misses about 0.05 of cloud cover that have TAU values less than about 0.3 and temperatures preferentially near the tropopause values; some of these clouds are only detected by the IR tests. The presence of such clouds, also produces a view-angle dependence in the ISCCP detections and retrievals, varying CA by of order 0.05 from nadir to slant view (Rossow *et al.* 1993). Finally as the ISCCP retrieval treats each cloud as a single layer, the occurrence of an optically thin cloud overlying lower-level clouds causes the retrieved cloud top in some cases to be biased to higher pressures/temperatures (Jin and Rossow 1997), producing an underestimate of the amount of high cloud and an overestimate of middle-level cloud by about 0.10 (compared to lidar results, Stubenrauch *et al*. 2012, 2013). Because of the difficult observing conditions and small contrast between cloud and clear conditions in the polar regions, the uncertainties of cloud amount and properties in the polar regions are larger than stated above (*e.g.*, see Stubenrauch *et al.* 2012, Bromwich *et al.* 2012).

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APPENDIX: Listing of Contents of HXS Binary Product per image pixel

(All quantities are encoded as one byte, 0 – 254, 255 indicates no data)

Geolocation: longitude (“on”), latitude (“lat”)

Conversion Tables (“tmptab”, “pretab”, “”refltab”, “tautab”)

Time (“time”): hours since 1970-01-01
Scene identification flags (“scene”): day/night, land/water, shore, rough topography, glint, snow/ice, surface or vegetation type

Fill information (“fill_type”): replicate in longitude, replicate in latitude, interpolate over night

Viewing geometry: Cosine satellite zenith angle (“mue”), Cosine solar zenith angle (“mu0”), Relative azimuth angle (“phi”)

Cloud detection test results (“clddet”)

Temperature inversion flag (“inversion”)

Cloud mask (“cloud”)

IR radiances: IR radiance (“irad”), IR clear-sky composite radiance (“icsrad”)

VIS radiances: VIS radiance (“vrad”), VIS clear-sky composite radiance (“vcsrad”)

(Additional channel radiances, up to nine, in HXS but not HGS)

Only IR retrievals: Cloud top for cloudy or Surface Temperature for clear pixel (“itmp”), Cloud top for cloudy or Surface Pressure for clear pixel (“iprs”), Clear-sky composite (surface) Temperature (“icstmp”), Clear-sky composite (surface) Pressure (“icsprs”)

VIS-adjusted retrievals: Cloud TAU (liquid) for cloudy or Surface (visible) Reflectance for clear pixel (“vrefta”), Clear-sky composite (surface visible) Reflectance for clear pixel (“vcsref”), Clear-sky composite (surface visible) Reflectance with no Aerosol correction for clear pixel (“vcsref_uncor”), Cloud top temperature (liquid) for cloudy pixel (“vtmp”), Cloud top pressure (liquid) for cloudy pixel (“vprs”), Ice cloud TAU for cloudy pixel (“vtauic”), Ice cloud top temperature for cloudy pixel (“vtmpic”), Ice cloud top pressure for cloudy pixel (“vprsic”)

Quality Flags: IR clear-sky logic (“icslog”), VIS clear-sky logic (“vcslog”), IR retrieval (“irret”), VIS retrieval (“vsret”)