Documentation Index for Hierarchical Algorithms

The tables on the following pages summarise the GSICS inter-calibration algorithm ("ATBD") for a hierarchical algorithm.

Two examples are given, both in the IR Inter-satellite/Inter-sensor GEO-LEO class:

- SEVIRI-IASI (based on EUMETSAT's current routine inter-calibration) – first
- GOES-AIRS (based on NOAA's v1.2 ATBD) – with yellow background!

The idea is that this table would be maintained on the GSICS Wiki pages (with restricted access). A single table would include the different algorithm versions for each step/process for all instrument pairs in all inter-calibration classes. Of course, this would eventually be a massive table! To make it more manageable, a user interface could be used to select the inter-calibration class and instrument pair from a pull-down menu system in the table header. Although this has not been implemented in full yet, an example table can be found at: http://tim.hewison.org/gsics

Cells show the version numbers of algorithms and hyperlink to their documentation. Colour coding could be added to indicate the status of documentation review and approval (this may be linked to version number). For example:
Red = Draft – work in progress, Orange = Under approval review, Green = Approved

Documentation for old versions of each algorithm should also be maintained, although it should be obvious from the version number and colour coding that they are not the current version. e.g. Pale green = Deprecated.

a) Inter-calibration classes

Inter-Calibration Class				Instruments
Instrument Type	Inter-Calibration Type	Orbital Class	Spectral Band	Instrument pairs
Infrared Sensor	Inter-satellite/Inter-sensor	GEO-LEO	Infrared	SEVIRI-IASI GOES-AIRS MVIRI-HIRS
		LEO-LEO	Infrared	AIRS-IASI
	Intra-satellite/Inter-sensor	LEO-LEO	Infrared	HIRS-IASI AVHRR-IASI AVHRR-HIRS
	Inter-satellite/Intra-sensor	GEO-GEO	Infrared	Met9-Met8 SEVIRI GOESE-W
		LEO-LEO	Infrared	NOAA17-NOAA16 HIRS

b) Algorithm Process Tagging

GSICS datasets and products should be tagged with their pedigree indicating the version number of each algorithm used in their production. This would ensure reproducibility of the results.

Each component of the algorithm is identified by the following tags:

Step	Process	Level	Class	Instruments	Version
1	b	4	IReeGL	SI	v0.3

e.g. **1b4IReeGLSIv0.3**, where:
IReeGL refers to Infrared Radiometer Inter-satellite/Inter-sensor GEO-LEO class,
SI refers to SEVIRI-IASI instrument pair (specific to this class)

This is a bit of a long label, but is a worst case – i.e. at the deepest level in the hierarchy. Also, the Class name could be reduced a lot – e.g. by using a look-up table, instead of abbreviations. Also, the 'v' is redundant!

c) Discussion Points

Before we go too deep, we need to check our class structure for consistency by reviewing the following discussion points:

Are the classes above defined in the right order?
e.g. Would the instrument type be better 'below' orbital class?
Do we need Spectral Band independent of Instrument Type?
Should the tables include any details of, or references to particular implementations?

Answers to these questions depend on how general the inter-calibration system is – i.e. How applicable is it to other instrument types are under consideration?

- It would seem to be similar for microwave radiometers.
- Radiometers in the solar band would be a little different, but broadly similar.
- However, other instrument types – e.g. scatterometers would require almost completely different inter-calibration techniques.

Do the basic principles (i) and general implementation options (ii) apply in general?
Do the class-specific details (iii) apply for other instrument pairs in the same class?

Once we have agreed the general principles, the details of the specific implementations may be discussed.

d) Further Clarification

1) Is there room for multiple algorithms for the same pair? For example, most collocations have some difference in time. One can assign binary weight of one/zero to a collocation based on whether it passes/fails a threshold, or non-binary weight that may relate to the magnitude of time difference. For the first approach, one may have various threshold values. For the second approach, one may have different functional (linear, quadratic, logarithm), or relate the weight to more than time difference (e.g., scene change in time). Additionally, there may be totally different approaches, and there are other similar issues (uniformity, spectral convolution, spatial average). We could call them different versions, but do we allow only one approved versions? It's unlikely (though possible) to have too many versions, but it is likely we will have similar "version" for different pairs.

Yes. There is plenty of scope within the table for different versions of the algorithm - even for each instrument pair. I have tried to illustrate this with reference to difference versions of the SEVIRI-IASI algorithm that I have used.

I would suggest that we try to keep a single 'approved' algorithm version for each process as the 'baseline' for each instrument and compare the performance of other versions to that, as part of the review and acceptance process. (Hence the idea of colour-coding the different algorithm versions.)

2) Is this table a collection of "indices" (like table of content), or is it the algorithm itself?

At present it is a table of indices for the version numbers of each algorithm. These can expanded into bullet point summaries by clicking on the '+' box. My original idea was to have the version numbers hyperlink to the descriptions of the full algorithm. However, the whole algorithm could be documented within the table. This would make it easier to compile a full algorithm for a given instrument pair from the table itself (e.g. for printing).

3) Do you envision all algorithms to have the same processes (1a-c, 2a-d, .), or each algorithm can add/omit processes as desirable?

Yes. The idea is that all algorithms will be based on the same processes - or at least a subset of them. However, not all processes will be needed for each particular implementation. For example, I do no explicitly filter out inter-calibration targets with high spatial variance - they are, however, given a low weighting in the regression.

At the last meeting, Marianne recommended to gain experience by working on a few specific algorithms, then think about how to summarize or organize these algorithms. We probably can try that and re-visit this topic later.

This is exactly what I hope can start to happen after the next meeting. Hopefully people can already have a think about how their algorithms fit (or don't fit) within this model in time for the next meeting. That way we can discuss how appropriate it may be.

#	id	Process description	i) Basic Principles	ii) General Options	iii) Class Specific for IR Inter-Sensor Inter-satellite GEO-LEO	iv) Instrument Specific for SEVIRI-IASI
1	1a	Select Orbit	A first rough-cut to: • Reduce data volume • Include only relevant portions (channels, area, time, viewing geometry)	V0.1: • Select data on per-orbit or per-image basis • Need to know how often to do inter-calibration – based on observed rate of change Defined iteratively with 2c & 2d	V0.1: • Define GEO Region of Interest: within 60° of GEO SSP • Subset GEO data to RoI • Select LEO data within GEO RoI for each inter-cal period • Subset LEO data to GEO RoI	V0.1: • GEO RoI = ±30° lat/lon of SSP • Take 1 Metop overpass with night-time equator crossing closest to GEO SSP • Subset IASI data to GEO RoI • Select SEVIRI image closest in time to LEO Equator crossing V0.2, as v0.1, except: • Select fixed GEO frame at nominal LEO local equator crossing time (21:30) • Extend RoI to ±35°
	1b	Collocate Pixels	Defining which pixels to compare: • Define FoV for all pixels • and environment around pixels • Identify pixels for both instruments within these areas meeting collocation criteria for time, space and geometry	v0.1: • Search for all pixels within FoV and environment v0.3: • Grid observations using 2D-histogram in lat/lon space	V0.1: • Geometric alignment: Select GEO/LEO pixels where secant of zenith angle is within 0.01 • Temporal alignment: Select GEO/LEO pixels with time differences <300s	v0.1 • IASI FoV=12km at nadir • SEVIRI FoV=3km at SSP • Time difference <900s • Select 5x5 SEVIRI pixels closest to centre of IASI FoV v0.3, as v0.1, except: • Select SEVIRI and IASI pixels in same bin of 2D histrogram with 0.125° lat/lon grid
	1c	Pre-select Channels	• Select only broadly comparable channels from both instruments (to reduce data volume)	V0.1: • Selection based on pre-determined criteria for each instrument pair	V0.1: • Select IR channels (3-15μm)	V0.1: • Select IR channels of SEVIRI • Select all channels for IASI

2	2a	Collect Radiances	Convert observations from both instruments to a common definition of radiance to allow direct comparison.	V0.1: • Convert instrument Level 1.5/1b/1c data to radiances, accounting for channel Spectral Response Functions	V0.1: • Perform comparison in radiance units: $mW/m^2/st/cm^{-1}$	V0.1: • Account for Meteosat radiance definition applicable to level 1.5 dataset
	2b	Spectral Matching	• Identify which channel sets provide sufficient common information to allow meaningful inter-calibration. • Transform these into comparable channels • Account for deficiencies in channel matches	v0.1 • Define SRFs for all channels • Co-average comparable channels • Use Radiative Transfer Model to account for differences • Estimate uncertainty due to spectral mismatches	v0.1 For hyper-spectral instruments: • Transform spectral response functions to common grid • Spectral Convolution to synthesise GEO channels • Account for spectral sampling and stability in error budget	v0.1 • Assume IASI channels are spectrally stable and contiguously sampled • Use published SRFs for MSG at 95K, interpolated to IASI grid. • Estimate radiance missing from IASI's coverage of SEVIRI IR3.9 channel by assuming a uniform brightness temperature
	2c	Spatial Matching	• Transform observations from each instrument to comparable spatial scales • Estimate uncertainty due to spatial variability	V0.1: • Identify Point Spread Functions of each instrument • Specify the target area and identify the pixels within it • Specify the 'environment' around target area • Average pixel radiances within specified target areas and • Calculate their variance	V0.1: • Define target area as LEO FoV • Average GEO pixels within target area and calc variance • Define environment as GEO pixels within 3x radius of target area	V0.1: • Assume IASI FoV circular near nadir with diameter of 12km • Assume SEVIRI pixels are contiguous, independent samples: 3km spacing @SSP • Calculate mean and variance of radiance in 5x5 SEVIRI pixels closest to centre of IASI FoVs V0.2, as v0.1, except: • Select SEVIRI and IASI pixels in same bin of 2D histogram with 0.125° lat/lon grid
	2d	Temporal Matching	• Establish timing difference between instruments' observations • Assign uncertainty based on (expected or observed) variability over this timescale.	v0.1 • Identify each instruments' sample timings	v0.1 • Select GEO image closest to time of LEO Equator crossing • Calculate time difference for each target v0.2: Interpolate GEO images	v0.1 • Select only targets with time difference <900s

3	3a	Uniformity Test	• Only compare observations in homogenous scenes to reduce uncertainty in comparison due to spatial/temporal mismatches	V0.1: • Compare spatial/temporal variability of scene within target area to pre-defined threshold and exclude scenes with greater variance from analysis • Performed on a per-channel basis	V0.1: • Calculate variance of GEO radiances with each LEO FoV V0.2: • Include interpolation between sequential GEO images	V0.0: • Not implemented as found to not change results significantly. (Results rely instead on inhomogeneous scenes having lower weighting in regression and include the full range of scene radiances.) V0.2: • Reject any targets with scene variance >5% of reference radiance
	3b	Outlier Rejection	• To prevent anomalous observations having undue influence on results • Identify and reject 'outliers' on a statistical basis.	V0.1: • Compare the radiances in the target area with those in the surrounding environment • Reject targets which are significantly different from the environment (3σ)	V0.1: • Compare difference between mean GEO radiances within LEO FoV and 'environment' • Reject targets where this difference is >3 times the variance of the environment's radiances	• Not implemented.
	3c	Auxiliary Datasets	• To allow analysis of statistics in terms of other geophysical variables – e.g. land/sea/ice, cloud cover	• Not yet implemented	• Not yet implemented	• Not yet implemented

4	4a	Regression	Systematically compare collocated radiances from 2 instruments. (This comparison may also be done in counts or brightness temperature.) This allows: • Investigating how biases depend on various geophysical variables. • Providing statistics of any significant dependences. • Investigating the cause of these dependences.	v0.1: • Simple averaging of differences between collocated radiances. v0.2: • Weighted linear regression of collocated radiances, using estimated uncertainty on each point as a weighting. v0.3: • Perform stepwise multiple linear regression to investigate dependence of various geophysical variables.	v0.2 • Repeat inter-calibration daily. • Use only night-time LEO overpasses. • Include only incidence angles <30°. • Weight collocations in regression by the inverse variance of target radiances. This allows the investigation of the sensitivity of the differences to Latitude, Longitude, Incidence angle/LEO scan angle, Time of day	v0.1: • Select only pixels with incidence angle ~15°±1°. • Repeat inter-calibration every 10 days (nights) v0.2: • Extend range of incidence angles to <40° • Inter-calibrations may be averaged over periods of ~1 week. (Longer periods are subject to drift due to ice contamination.) • Reset statistics following Meteosat decontaminations.
	4b	Define reference radiances	• Provide standard scene radiances at which instruments' inter-calibration bias can be directly compared. • Because biases can be scene-dependent, it is necessary to define channel-specific reference scene radiances. • More than one reference scene radiance may be needed for different applications – e.g. clear/cloudy, day/night.	v0.1 • Select representative Region of Interest (RoI). • Construct histogram of observed radiances within ROI. • Identify peaks of histogram corresponding to clear/cloudy scenes to define reference scene radiances. • These are determined *a priori* from representative sets of observations.	v0.1 • Limit target area to within 30° of GEO sub-satellite point. • Limit target times to night-time LEO overpasses.	v0.1: • Find mode of histogram of each channels' brightness temperature for collocated pixels in 5 K wide bins from 200 to 300 K. • For bimodal distributions, the mean of the modes is used. Ch: 3.9, 6.2, 7.3, 8.7, 9.7, 10.8, 12.0, 13.4 T_{bref}: 290,240,260,290,270, 290, 290, 270 K • Define low reference radiance scene for high cloud of 200 K for all channels.

4	4c	Calculate biases	• Perform direct comparison of inter-calibration biases for representative scenes in a way easily understood by users.	v0.1 • Apply regression coefficients to estimate expected bias and uncertainty for reference scenes in radiances. • Account for correlation between regression coefficients, when calculating uncertainty on the fitted radiances • Results may be expressed in absolute or percentage bias in radiance, or brightness temperature differences.	v0.1 • Convert biases (and uncertainties) from radiances to brightness temperatures	V0.1: • Use effective radiances definition to covert to brightness temperature
	4d	Test non-linearity	• Characterise any non-linearity in the relative differences between instruments, or place limits on their maximum magnitude. • May be used to account for detector non-linearity, calibration errors or inaccurate spectral response functions.	v0.1 • Compare results of linear and quadratic regression of collocated radiances from different instruments. • Estimate maximum departure from linearity, the scene radiance at which it occurs and uncertainty associated with it.	V0.1: • Combine multiple LEO overpasses need to produce enough data to identify relative instrument linearity to the level of the instruments' noise. (Any non-linearity is likely to be relatively constant in time.)	• Not implemented yet

4	4e	Recalculate calibration coefficients	• Produce revised set of calibration coefficients for one instrument following its inter-calibration against a reference instrument. • Allow users to recalibrate data from the target instrument to be consistent with the reference instrument. • Generate uncertainties with the calibration coefficients to allow users to specify the error bars on recalibrated data.	v0.1 • Read original calibration coefficients and calculate the changes required to reproduce observed relative biases. V0.2: • Read original counts observed by the target instrument and fit these to the collocated radiances observed by the reference instrument.	• Not implemented yet	• Not implemented yet
	4f	Report Results	Quantify the magnitude of relative biases by inter-calibration. This allows users to: • Monitor changes in instrument calibration in time, • Recalibrate observations, • Specify the uncertainty on observations, • Derive relative biases and uncertainties between various different instruments.	v0.1 • Produce plots and tables of relative biases and uncertainties for reference scene radiances. • Show evolution of these in time and dependence on geophysical variables. • Produce tables of recalibration coefficients for near-real-time and archive data.	V0.1: • Plot relative brightness temperature bias for clear sky reference scenes as time series with uncertainties • Calculate trend line in above time series (with uncertainties) • Calculate monthly mean bias from time series	V0.1: • Reset trends and statistics when decontamination procedures performed on MSG
5	5a	Operational Corrections				

#	id	Process description	i) Basic Principles	ii) General Options	iii) Class Specific for IR Inter-Sensor Inter-satellite GEO-LEO	iv) Instrument Specific for GOES-AIRS
	1a	Select Orbit	A first rough-cut to: • Reduce data volume • Include only relevant portions (channels, area, time, viewing geometry)	V0.1: • Select data on per-orbit or per-image basis • Need to know how often to do inter-calibration – based on observed rate of change Defined iteratively with 2c & 2d	V0.1: • Define GEO Region of Interest: within 60° of GEO SSP • Subset GEO data to RoI • Select LEO data within GEO RoI for each inter-cal period • Subset LEO data to GEO RoI	V0.1: • GEO RoI = ±60° lat/lon of SSP • Take all Aqua granules with observations with RoI in 1 day • Subset GOES data to the area of each AIRS granule • Select GOES image closest in time to LEO Equator crossing •
1	1b	Collocate Pixels	Defining which pixels to compare: • Define FoV for all pixels • and environment around pixels • Identify pixels for both instruments within these areas meeting collocation criteria for time, space and geometry	v0.1: • Search for all pixels within FoV and environment v0.3: • Grid observations using 2D-histogram in lat/lon space	V0.1: • Geometric alignment: Select GEO/LEO pixels where secant of zenith angle is within 0.01 • Temporal alignment: Select GEO/LEO pixels with time differences <300s	v0.1 • IASI FoV=12km at nadir • GOES FoV=4km at SSP • Select 5x5 SEVIRI pixels closest to centre of IASI FoV •
	1c	Pre-select Channels	• Select only broadly comparable channels from both instruments (to reduce data volume)	V0.1: • Selection based on pre-determined criteria for each instrument pair	V0.1: • Select IR channels (3-15μm)	V0.1: • Select IR channels of SEVIRI • Select all channels for IASI

2	2a	Collect Radiances	Convert observations from both instruments to a common definition of radiance to allow direct comparison.	V0.1: • Convert instrument Level 1.5/1b/1c data to radiances, accounting for channel Spectral Response Functions	V0.1: • Perform comparison in radiance units: mW/m^2/st/cm^{-1}	•
	2b	Spectral Matching	• Identify which channel sets provide sufficient common information to allow meaningful inter-calibration. • Transform these into comparable channels • Account for deficiencies in channel matches	v0.1 • Define SRFs for all channels • Co-average comparable channels • Use Radiative Transfer Model to account for differences • Estimate uncertainty due to spectral mismatches	v0.1 For hyper-spectral instruments: • Transform spectral response functions to common grid • Spectral Convolution to synthesise GEO channels • Account for spectral sampling and stability in error budget	v0.1 • Assume AIRS channels are spectrally stable and contiguously sampled • Flag and mask out bad channels. How? • Use gap-filling method published by Kato or Gunshor *et al.* 2004. ?
	2c	Spatial Matching	• Transform observations from each instrument to comparable spatial scales • Estimate uncertainty due to spatial variability	V0.1: • Identify Point Spread Functions of each instrument • Specify the target area and identify the pixels within it • Specify the 'environment' around target area • Average pixel radiances within specified target areas and • Calculate their variance	V0.1: • Define target area as LEO FoV • Average GEO pixels within target area and calc variance • Define environment as GEO pixels within 3x radius of target area	V0.1: • Assume AIRS FoV circular near nadir with diameter of 13km • Assume GOES pixels are sampled: 4km spacing @SSP • Calculate mean and variance of radiance in GOES pixels within AIRS FoVs • Account for GOES over-sampling
	2d	Temporal Matching	• Establish timing difference between instruments' observations • Assign uncertainty based on (expected or observed) variability over this timescale.	v0.1 • Identify each instruments' sample timings	v0.1 • Select GEO image closest to time of LEO Equator crossing • Calculate time difference for each target v0.2: Interpolate GEO images	•

3	3a	Uniformity Test	• Only compare observations in homogenous scenes to reduce uncertainty in comparison due to spatial/temporal mismatches	V0.1: • Compare spatial/temporal variability of scene within target area to pre-defined threshold and exclude scenes with greater variance from analysis • Performed on a per-channel basis	V0.1: • Calculate variance of GEO radiances with each LEO FoV V0.2: • Include interpolation between sequential GEO images	V0.1: • Reject any targets with scene variance >5% of scene radiance V0.2: • Reject any targets with scene variance >10 GOES counts
	3b	Outlier Rejection	• To prevent anomalous observations having undue influence on results • Identify and reject 'outliers' on a statistical basis.	V0.1: • Compare the radiances in the target area with those in the surrounding environment • Reject targets which are significantly different from the environment (3σ)	V0.1: • Compare difference between mean GEO radiances within LEO FoV and 'environment' • Reject targets where this difference is >3 times the variance of the environment's radiances	• Implemented directly
	3c	Auxiliary Datasets	• To allow analysis of statistics in terms of other geophysical variables – e.g. land/sea/ice, cloud cover	• Not yet implemented	• Not yet implemented	• Not yet implemented

4	4a	Regression	Systematically compare collocated radiances from 2 instruments. (This comparison may also be done in counts or brightness temperature.) This allows: • Investigating how biases depend on various geophysical variables. • Providing statistics of any significant dependences. • Investigating the cause of these dependences.	v0.1: • Simple averaging of differences between collocated radiances. v0.2: • Weighted linear regression of collocated radiances, using estimated uncertainty on each point as a weighting. v0.3: • Perform stepwise multiple linear regression to investigate dependence of various geophysical variables.	v0.2 • Repeat inter-calibration daily. • Use only night-time LEO overpasses. • Include only incidence angles <30°. • Weight collocations in regression by the inverse variance of target radiances. This allows the investigation of the sensitivity of the differences to Latitude, Longitude, Incidence angle/LEO scan angle, Time of day	v0.1: • Repeat inter-calibration every day •
	4b	Define reference radiances	• Provide standard scene radiances at which instruments' inter-calibration bias can be directly compared. • Because biases can be scene-dependent, it is necessary to define channel-specific reference scene radiances. • More than one reference scene radiance may be needed for different applications – e.g. clear/cloudy, day/night.	v0.1 • Select representative Region of Interest (RoI). • Construct histogram of observed radiances within ROI. • Identify peaks of histogram corresponding to clear/cloudy scenes to define reference scene radiances. • These are determined *a priori* from representative sets of observations.	v0.1 • Limit target area to within 30° of GEO sub-satellite point. • Limit target times to night-time LEO overpasses.	•

4	4c	Calculate biases	• Perform direct comparison of inter-calibration biases for representative scenes in a way easily understood by users.	v0.1 • Apply regression coefficients to estimate expected bias and uncertainty for reference scenes in radiances. • Account for correlation between regression coefficients, when calculating uncertainty on the fitted radiances • Results may be expressed in absolute or percentage bias in radiance, or brightness temperature differences.	v0.1 • Convert biases (and uncertainties) from radiances to brightness temperatures	•
	4d	Test non-linearity	• Characterise any non-linearity in the relative differences between instruments, or place limits on their maximum magnitude. • May be used to account for detector non-linearity, calibration errors or inaccurate spectral response functions.	v0.1 • Compare results of linear and quadratic regression of collocated radiances from different instruments. • Estimate maximum departure from linearity, the scene radiance at which it occurs and uncertainty associated with it.	V0.1: • Combine multiple LEO overpasses need to produce enough data to identify relative instrument linearity to the level of the instruments' noise. (Any non-linearity is likely to be relatively constant in time.)	• Not implemented yet

4	4e	Recalculate calibration coefficients	• Produce revised set of calibration coefficients for one instrument following its inter-calibration against a reference instrument. • Allow users to recalibrate data from the target instrument to be consistent with the reference instrument. • Generate uncertainties with the calibration coefficients to allow users to specify the error bars on recalibrated data.	v0.1 • Read original calibration coefficients and calculate the changes required to reproduce observed relative biases. V0.2: • Read original counts observed by the target instrument and fit these to the collocated radiances observed by the reference instrument.	• Not implemented yet	• Not implemented yet
	4f	Report Results	Quantify the magnitude of relative biases by inter-calibration. This allows users to: • Monitor changes in instrument calibration in time, • Recalibrate observations, • Specify the uncertainty on observations, • Derive relative biases and uncertainties between various different instruments.	v0.1 • Produce plots and tables of relative biases and uncertainties for reference scene radiances. • Show evolution of these in time and dependence on geophysical variables. • Produce tables of recalibration coefficients for near-real-time and archive data.	V0.1: • Plot relative brightness temperature bias for clear sky reference scenes as time series with uncertainties • Calculate trend line in above time series (with uncertainties) • Calculate monthly mean bias from time series	
5	5a	Operational Corrections				