GDA Corp.

VALIDATION OF THE CLOUD AND CLOUD SHADOW ASSESSMENT SYSTEM FOR LANDSAT IMAGERY (CASA-L VERSION 1.3)

GDA Corp. has developed an innovative system for **C**loud **A**nd cloud **S**hadow **A**ssessment (**CASA**) in Landsat imagery. The system relies on spectral (VNIR), spatial and contextual information present in the image, and hierarchical self-learning logic to provide automated, per-pixel detection of clouds and cloud shadows. Average runtime per scene, on a standard 2GHz Pentium development computer, is 5 to 12 minutes with limited algorithm/code optimizations to date.

A diverse set of 194 Landsat 7 ETM+ images was collected to assess the performance of the CASA-L algorithm. Landsat imagery was collected from a variety of sources providing access to free data including: UMD's Global Land Cover Facility and the USGS Global Visualization Viewer. Three of the scenes were deleted from the analysis due to two cases of corrupted image files and one case of corrupted metadata, bringing the total validation set to 191 images.

The dataset encompassed imagery for four regions, including: (1) the U.S. Western/Pacific, (2) the U.S. Eastern/Atlantic, (3) tropical areas of South America, Africa, and Indonesia located between 23.5^{o}N and 23.5^{o}S, and (4) polar areas of Russia and North America located north of 60^{o} latitude. The aim of the collection was to obtain approximately fifty scenes per region, covering different seasons and various atmospheric, cloud, haze, and ground conditions.

Each scene was visually inspected to assess per scene percent cloud cover and generate a "truth" dataset. For each scene, two independent assessments of cloud cover were made. Results were then compared and cases of significant disagreement were resolved by scene re-evaluation simultaneously by both operators. Cloud cover mean and standard deviation values were calculated from the visual assessments and recorded for each scene. The distribution of cloudy scenes within the dataset is presented in **Table 1**. As can be seen, while scenes with up to 60% cloud cover are present in the dataset, the majority of scenes (96%) have 30 or less percent of cloud cover.

% Cloud Cover	Percent of Scenes
0 to 5%	50%
0 to 10%	71%
0 to 30%	96%
0 to 50%	98%
0 to 70%	100%
Max Cover	60%

Table 1: Distribution of cloud contaminated scenes in the validation dataset

CASA performance was assessed through the comparison of its results against the "truth" dataset as well as against the results from a re-implementation[1] of the Automatic Cloud Cover Assessment (ACCA) algorithm. ACCA is the standard, operational cloud detection algorithm for Landsat 5 TM and Landsat 7 ETM+ imagery. ACCA relies heavily on the use of thermal bands present in Landsat 5 and 7 imagery.

Our results indicate that CASA performs as well or better than ACCA in a majority of the 191 Landsat images tested. While ACCA relies heavily on thermal band data which may be unavailable from future Landsat sensors, CASA achieves comparable and, in many cases, superior accuracy without the use of any thermal band data.

Table 2 summarizes the correlation coefficients between each comparative assessment of the cloud detection results.

	Overall	**Atlantic**	**Pacific**	**Tropical**	**Polar**	**Leaf On**	**Leaf Off**
CASA *vs.* "Truth"	90%	92%	79%	89%	91%	83%	94%
ACCA *vs.* "Truth"	59%	70%	57%	51%	39%	63%	59%
CASA *vs.* ACCA	46%	61%	42%	44%	30%	46%	50%

Table 2: Summary of statistical results – correlation coefficients

As can be seen from **Table 2**, the CASA results closely correlate with the visual cloud estimates for every image class tested with an overall correlation between CASA and visual estimate being 90%. In all cases, correlation coefficients for CASA *vs.* visual estimates equal or exceed 79%. Regionally, CASA performed the best on US Atlantic coastal imagery, although the difference in CASA performance among regions and seasons is fairly small when CASA is compared to the visual estimates. CASA did not perform quite as well on the US Pacific coastal and leaf-on seasonal imagery, although the relatively small difference in performance and lack of detailed stratification in the validation dataset makes it hard to draw definitive conclusions from this result. **Figure 3** displays a summary of the CASA *vs.* visual assessment differences for the entire validation dataset. Overall, CASA is within 10% of the visual estimate for 94% of all images tested, and within 5% for 81% of all images tested. Comparable values for ACCA were found to be 83% and 74%, respectively (**Table 3**).

[1] Procedures outlined in Irish 1998 and Irish 2000 publications were used in the ACCA reimplementation. While ACCA may have been updated since these publications, attempts to obtain any updated algorithm descriptions from the authors were unsuccessful. To our knowledge, no published references beyond 2000 exist for the algorithm. However, a close correlation between percent cloud cover reported in Landsat metadata (presumably from ACCA) and our ACCA implementation has been found.

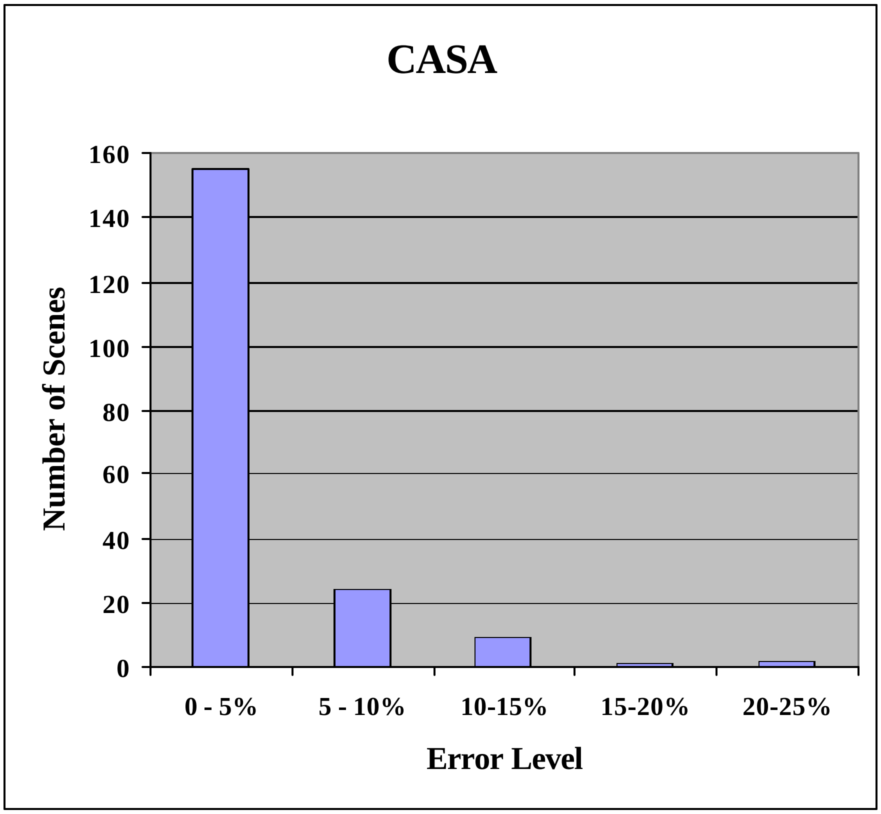

Figure 3: Summary of CASA results *vs*. visual (truth) estimate of cloud cover: Differences by level of error

Error Level	CASA		ACCA	
	Number of Scenes	Percent of Scenes	Number of Scenes	Percent of Scenes
0 to 5%	155	81%	142	74%
0 to 10%	179	94%	159	83%
0 to 15%	188	98%	174	91%
0 to 20%	189	99%	178	93%
0 to 25%	191	100%	180	94%
>25%	--	--	191	100%
Max Error		25%		45%

Table 3: CASA and ACCA results *vs*. visual (truth) estimate of cloud cover: Differences by level of error

Analysis of the overall results shows that, in comparison to ACCA, the CASA cloud cover values much more closely approximate the visual (truth) estimates (**Figure 4**). While ACCA correlates well with a large number of images that contain between 0 and 15% cloud cover, it performs significantly worse on the images with greater than 15% cloud contamination, thereby reducing its overall correlation with the visual estimates much below that of CASA.

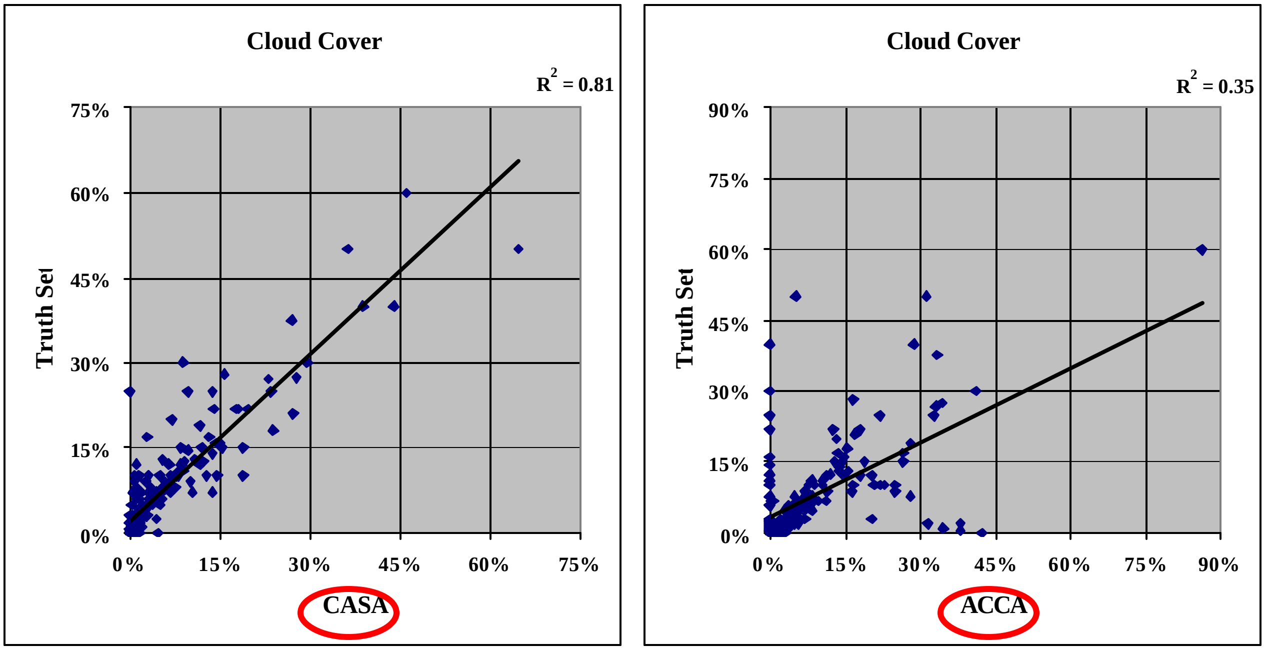

Figure 4: CASA (left) and ACCA (right) correlation with visual (truth) cloud cover estimates for all scenes

Region-specific and season-specific results

As can be seen from **Figure 5**, CASA results track the visual estimates fairly well for each region under study. Among the regions, CASA performed best on US Atlantic coastal imagery, and least well on US Pacific coastal imagery; however, the lower correlation scores are in part caused by the lower cloud cover present in these images, as absolute error as a percentage of scene area remained relatively constant.

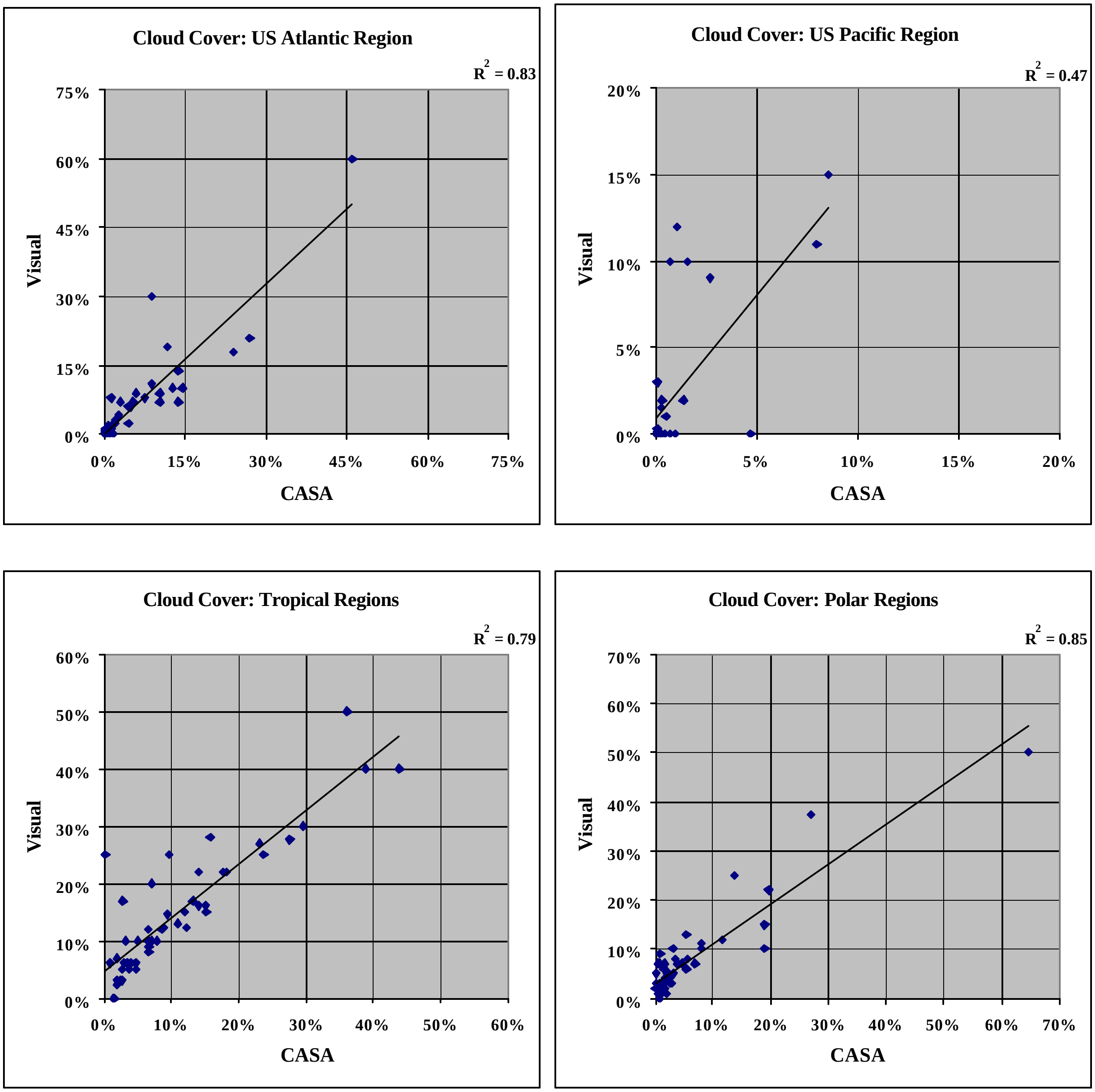

Figure 5: CASA correlation with visual (truth) cloud cover estimates by region

As **Figure 6** illustrates, CASA seems to perform better on images acquired during the leaf-off period. This seems to be a larger factor in performance than geographic location.

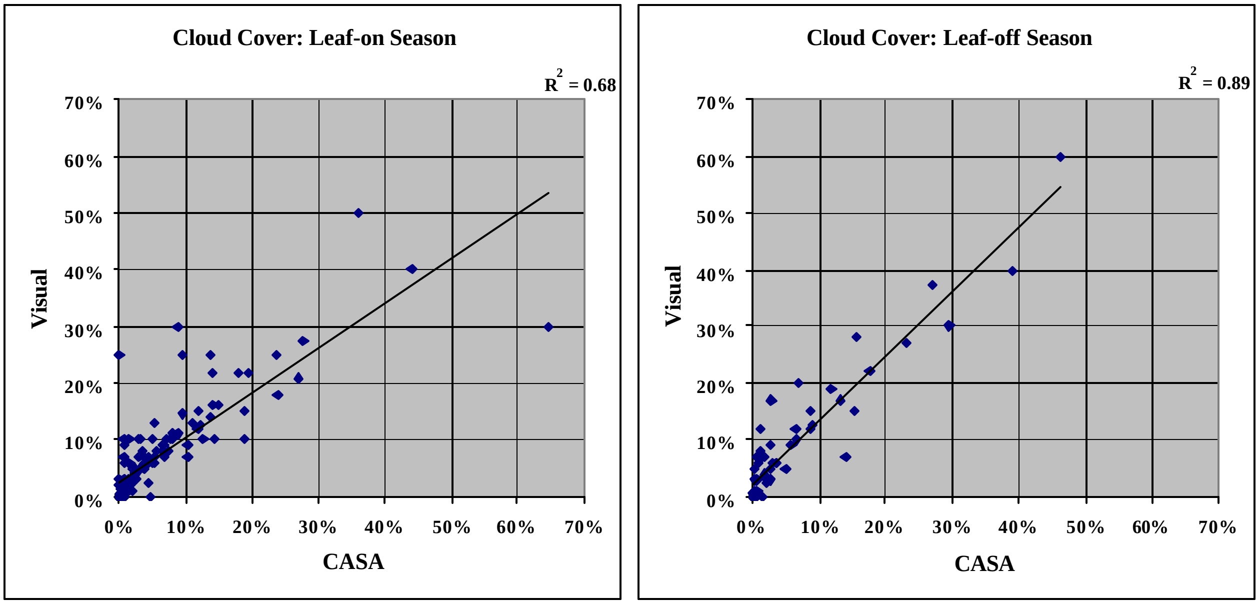

Figure 6: CASA correlation with visual (truth) cloud cover estimates by season

Analysis of Results

Overall, CASA performed as well or better than ACCA in the majority of the Landsat 7 ETM+ scenes that were tested. Situations where CASA outperformed ACCA include:

- Haze and light clouds. In nearly every scene where CASA and ACCA performance is similar, CASA more accurately detected thin cloud and haze areas. We hypothesize that the thermal effects of the cloud coverage are insufficient to exceed ACCA's thermal band thresholds.
- CASA detected far fewer false positive clouds (*e.g.*, bright non-cloud features such as urban areas, roads, snow, and bare soil) than ACCA. However, some bright non-cloud features – especially large features with spatial properties similar to cloud cover – were still erroneously reported as cloud.
- CASA performed more accurately than ACCA in tropical areas where warm, low-lying clouds do not have a sufficiently low thermal signature to pass ACCA's thermal threshold tests.

While it is possible to find individual situations in which either CASA or ACCA outperforms the other, overall CASA outperforms ACCA, both statistically and visually, in each of the regions that were studied. CASA was found to be within 10% of the visual estimate for 94% of all images tested, and within 5% for 81% of all images tested. This level of accuracy, together with the lack of reliance on thermal band data, makes CASA a suitable candidate to replace ACCA, especially if future Landsat missions will not have thermal band data.

One limitation of the study presented here is the relatively poor stratification of the validation dataset and limited number of scenes with more than 30% cloud contamination. Due to limited access to source images, limiting the validation dataset to a stratified subset of all available images would have resulted in a very small validation dataset. Instead, we chose to include all of the available images at our disposal, significantly increasing the size and quality of the validation dataset. This approach, however, did introduce some seasonal and regional biases into the evaluation. A similar validation study was performed for ACCA by Arvidson *et al*. (2002) which used a carefully stratified image dataset. It may be valuable to recreate the dataset used in that study for future CASA validation.

Initial implementation of the CASA-L version necessarily focused on accuracy over speed. Due to the complexity of the CASA algorithm, running CASA on a single Landsat image typically requires two to three times the computation time as running our re-implementation of the ACCA algorithm on the same image. However, performance is still quite reasonable (typically 5 to 12 minutes on a reasonably complex Landsat image on a standard desktop PC). Also, it should be noted that while care has been taken to develop a computationally efficient implementation of CASA, there are many steps that could be taken to improve its performance.

Regardless of algorithm improvements, as with any fully automated system, there will always be cases where CASA may miss existing clouds or cloud parts and/or falsely label non-cloud objects as clouds. To aid identification of CASA results with potentially questionable quality of cloud detection, GDA Corp. is providing a quality flag in the textual output for each processed image. The flag grades CASA results as “good”, “fair” or “poor” on the basis of (i) an internal CASA assessment of probabilities that detected features are indeed clouds and (ii) the use of ancillary land cover, cloud probability, snow/ice probability datasets.

Furthermore, for situations where increased per pixel accuracy is desired, a user can request the generation of additional CASA spatial outputs to aid in editing CASA cloud masks. This would allow the user to improve the accuracy by manually correcting CASA output images. In addition to the standard cloud / cloud shadow mask, the user would be able to request various spatial outputs including: (i) a raster output depicting different cloud categories, (ii) raster outputs providing IDs for each individual cloud, separately for each cloud category, (iii) a raster output providing IDs for each individual cloud shadow, and (iv) raster with each cloud and/or cloud shadow being enlarged to a user-specified number of pixels/meters. These additional outputs give the image analyst more information with which to make decisions on individual potential cloud objects. The analyst’s job would be simplified by the ability to remove/preserve either individual objects (based on their IDs) or object categories.

References:

Arvidson, T., R. Irish, B. Markham, D. Williams, J. Feuquay, J. Gasch, and S. Goward. 2002. Validation of the Landsat 7 Long-term Acquisition Plan. Pecora 15/Land Satellite

Information IV, ISPRS Commission I, FIEOS 2002 Conference Proceedings, November 10-15, 2002: Denver, CO.

Irish, R.R. 1998. Automatic Cloud Cover Assessment (ACCA). Presentation on Landsat-7 Science Team Meeting, December 1-3, 1998. http://ltpwww.gsfc.nasa.gov/IAS/pdfs/ACCA_slides.pdf

Irish, R. 2000. Landsat 7 Automatic Cloud Cover Assessment. In: Algorithms for Multispectral, Hyperspectral, and Ultraspectral Imagery IV, Sylvia S. Shen, Michael R. Descour, Editors, *Proceedings of SPIE*, 4049: 348-355.

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