

ENLISTING MODIS CLOUD FRACTION DATA TO ASSESS LANDSAT 7 LTAP PERFORMANCE

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Objective

- ▣ Improve yield of Landsat 7 scene value
 - More clear scenes
 - Better coverage of regions of interest
- ▣ To accomplish that goal we need to:
 - Comprehensively characterize existing LTAP
 - Identify potential weaknesses of LTAP
 - Propose enhancements to LTAP
 - Rigorously test those enhancements

Past LTAP Validation

- ▣ LTAP originally deployed in July 1999 when Landsat 7 transitioned to operations
- ▣ LTAP Validation study conducted in 2002^{1,2}
- ▣ Validation revealed weaknesses
- ▣ Validation itself was weak regarding assessment of *cloud avoidance*

¹ T.Arvidson, S.Goward, J.Gasch, D.Williams, ***Landsat 7 Long-Term Acquisition Plan: Development and Validation***, PE&RS, Vol 72, No. 10, October 2006, pp. 1137-1146.

² T.Arvidson, R.Irish, B.Markham, D.Williams, J.Feuquay, J.Gasch, S.Goward, ***Validation of the Landsat 7 Long-Term Acquisition Plan***, Proceedings of Pecora 15, ASPRS, Bethesda, MD

LTAP Validation – Focus on Cloud Avoidance

- ▣ Validation process demonstrated that cloud avoidance was beneficial
 - Better than *random selection* (such as Landsat 5)
 - Evidence was circumstantial – validated only over CONUS, where full coverage offered full spectrum view
 - Extrapolating “CONUS Success” argument to the rest of the globe was never scrutinized
- ▣ Cloud Avoidance strategy is beneficial,
- ▣ **But, Can it do better?**

New Tools Needed

- ▣ A comprehensive examination of Cloud Avoidance performance demands:
 - A high fidelity model to run long-term scenarios to assess various proposed enhancements to the LTAP.
 - ▣ The existing model, used for the past 12 years, uses an ACCA simulator that computes ACCA scores as the model runs based on historic statistics.
 - ▣ This ACCA model, which derives simulated ACCA scores based on local NCEP cloud forecasts, has an accuracy of approximately $\pm 5\%$.
 - ▣ The model requires an ACCA simulator accurate to better than $\pm 1\%$.
 - A knowledge base of *cloud truth* to quantify performance

We need a source of “Cloud Truth”.

Why “Cloud Truth” ?

- ▣ Independent corroboration of ACCA
- ▣ Knowledge of cloud conditions of scenes NOT acquired by L7
- ▣ Basis of simulated ACCA for new LTAP modeling system

Terra/MODIS as a source of “Cloud Truth”

- ❑ Terra orbits in formation with Landsat 7 – on same WRS ground track, lagging L7 by 30 minutes.
- ❑ Landsat WRS width is 182km, centered in MODIS swath.
- ❑ MODIS acquires blanket coverage of daylit Earth surface
- ❑ Nearly every ETM+ image is coincidentally acquired by MODIS (lagging by 30 minutes)
- ❑ MODIS spectral bands afford excellent cloud discrimination
- ❑ Clouds change very little in a 30-minute span

MODIS Cloud Fraction (CF) Data Sources

- ▣ **MOD08_D3 - Daily Global Gridded Product**
 - Furnishes Daily Average cloud fraction on 1-degree lat/long grid
 - Smallest, most convenient source of cloud fraction data
- ▣ **MOD35_L2 - Cloud Mask Product**
 - Cloud fraction data at 1 Km spatial resolution
 - 10:30 A.M. MLT - ideally suited to L7's 10:00 MLT
 - Disadvantage - high data volume
 - 288 files per day, at ~25 Mb per file (2.5 T.bytes/year)
- ▣ **MODATML2 - Joint Atmosphere Product**
 - Contains the "greatest hits" of atmospheric products
 - Cloud fraction data at 5 Km spatial resolution
 - 10:30 A.M. MLT
 - Reasonable data volume
 - 288 files per day, at ~2 Mb per file (200 G.bytes/year)
- ▣ *We chose MODATML2 for this study.*

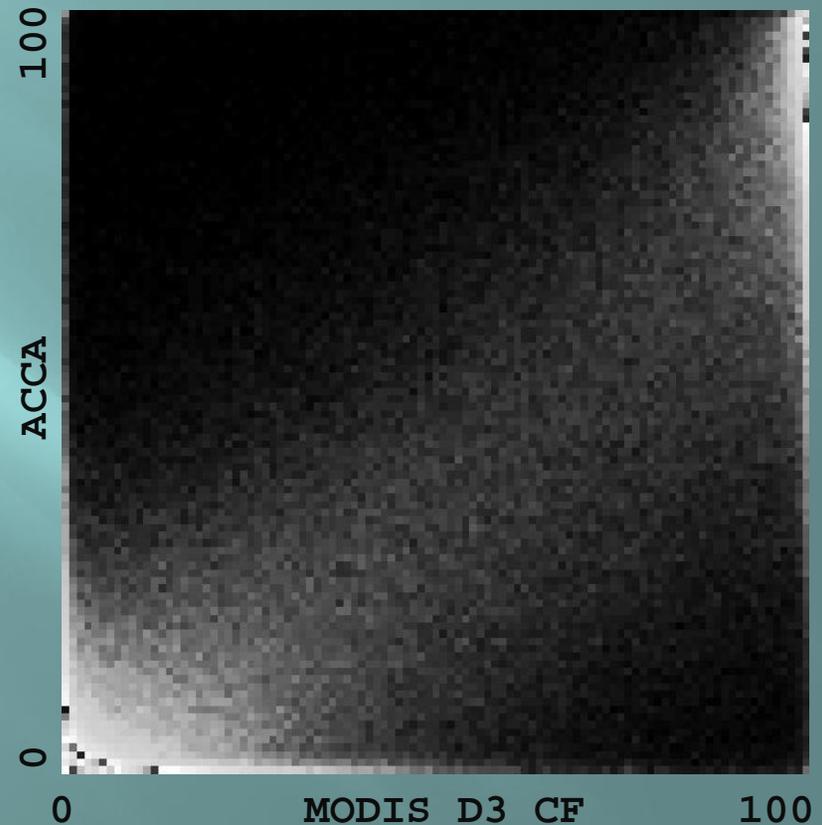
New Methodology for Validating LTAP Cloud Avoidance

- ▣ Extract Terra/MODIS science data sets
 - Cloud-Fraction
 - Cloud Optical Thickness
 - Latitude + Longitude
 - Land/Water flags
- ▣ Populate a database with this MODIS data
- ▣ For each WRS scene
 - Extract data for all MODIS 5 km pixels within this WRS scene area
 - Compute and compare cloud fraction against ETM+ ACCA score

ETM+ ACCA Correlation with MODIS D3 Daily Average Cloud Fraction - 2005-2009

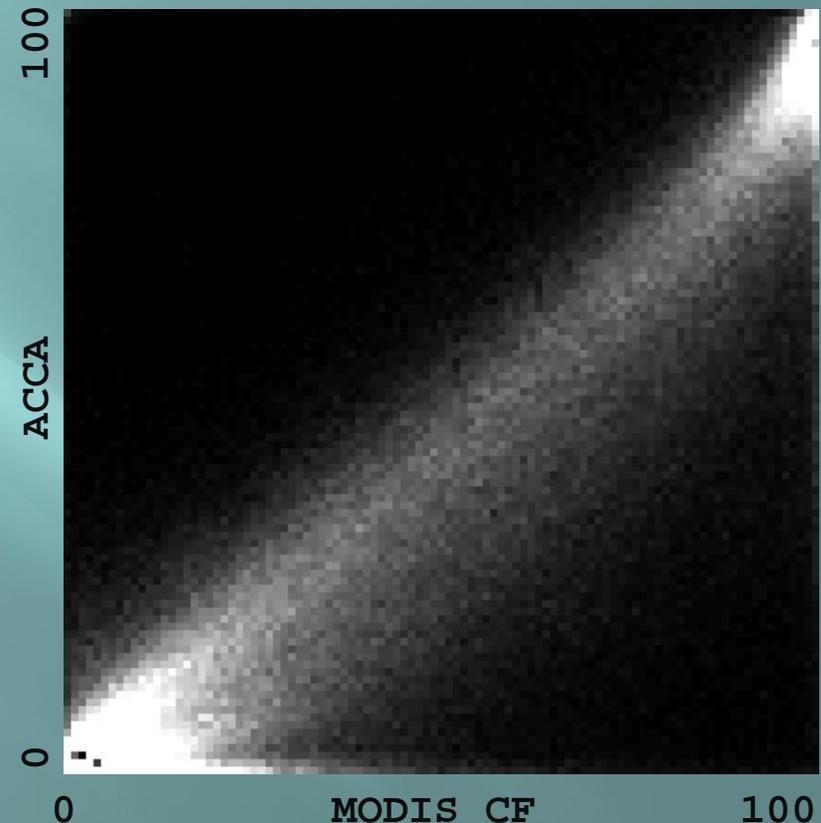
- ▣ Scattergram shows relative correlation between MOD08_D3 CF and ACCA.
- ▣ Each point on this plot represents the population of scenes with the corresponding CF and ACCA values
- ▣ Bimodal - most of population clustered around 0/0 and 100/100
- ▣ Poor correlation of mid values
- ▣ Many gross disagreements

D3 CF correlation with ACCA is unacceptable.



ETM+ ACCA Correlation with MODIS L2 Cloud Fraction - 2005-2009

- Considering only Cloud_Fraction
- **Improved correlation**
 - As opposed to MOD08_D3 CF
- Bi-modal Population Distribution
 - Clusters around 0/0 and 100/100.
- Fewer *disagreements*, particularly in lower right quadrant.
- Minor bias evident
 - Ideal correlation would be a straight diagonal line.
- Thin cirrus clouds and small cumulus clouds account for disagreements in lower right quadrant

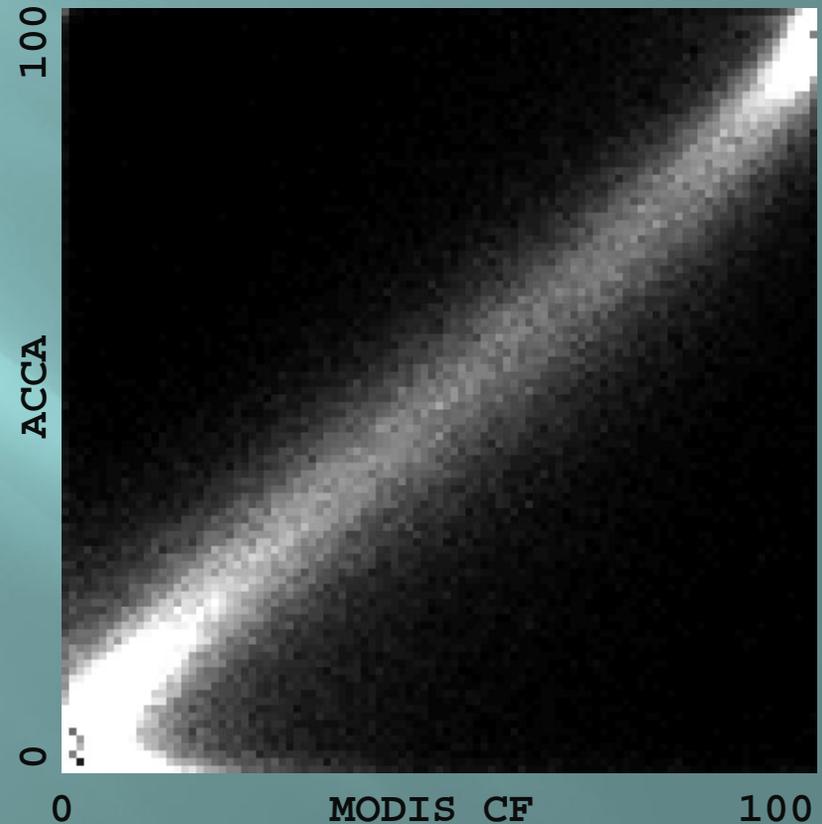


We can do better!

ETM+ ACCA Correlation with MODIS L2 Cloud Fraction + Cloud Optical Thickness - 2005-2009

- Applying threshold tests:
 - *Cloud Optical Thickness* test over water
 - Cloud Fraction threshold over land
- **Superior correlation**
 - As opposed to L2 Cloud Fraction alone
- Far fewer *gross disagreements* (in upper left and lower right quadrants)

Suitable for LTAP Analysis

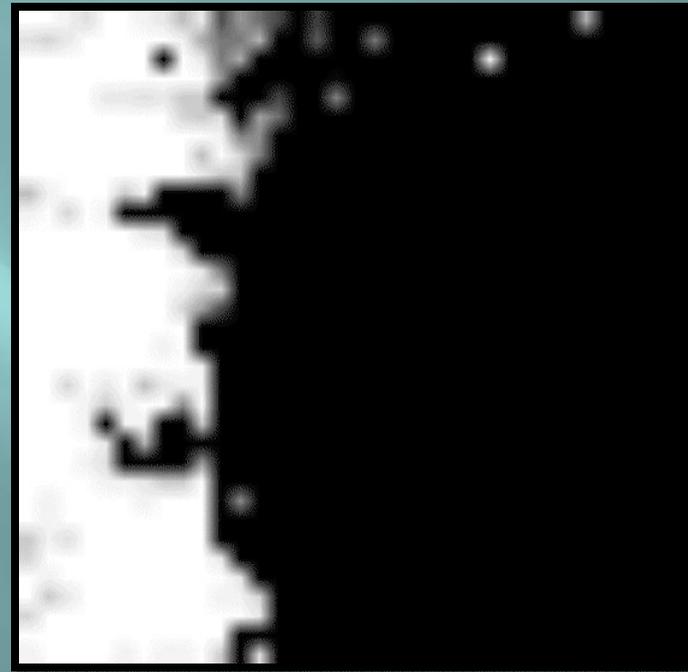


CF of some Randomly Sampled Scenes

WRS 26/41 5-Aug-2009



ETM+ ACCA = 3

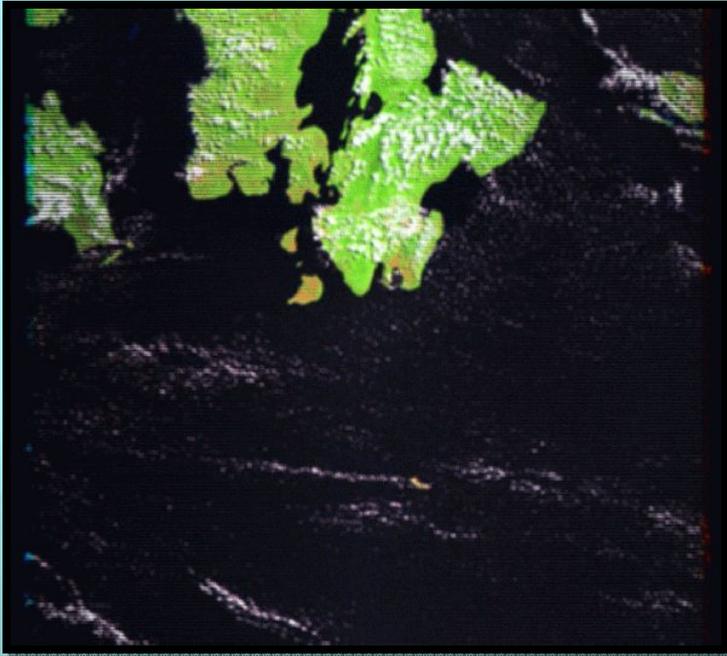


MODIS CF = 28.1

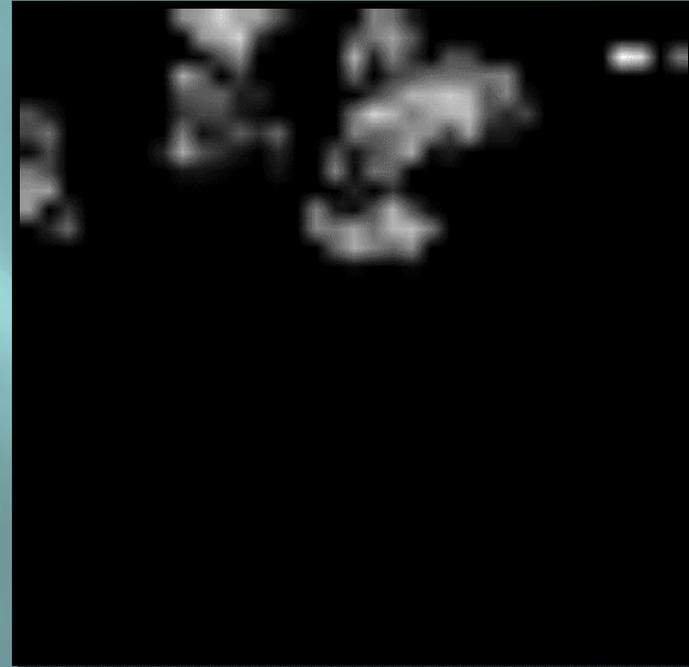
Example of problematic scene.
Sensor resolution affects discrimination of fair
weather cumulus clouds

More Sample CF Scenes

WRS 112/64 10Apr2009



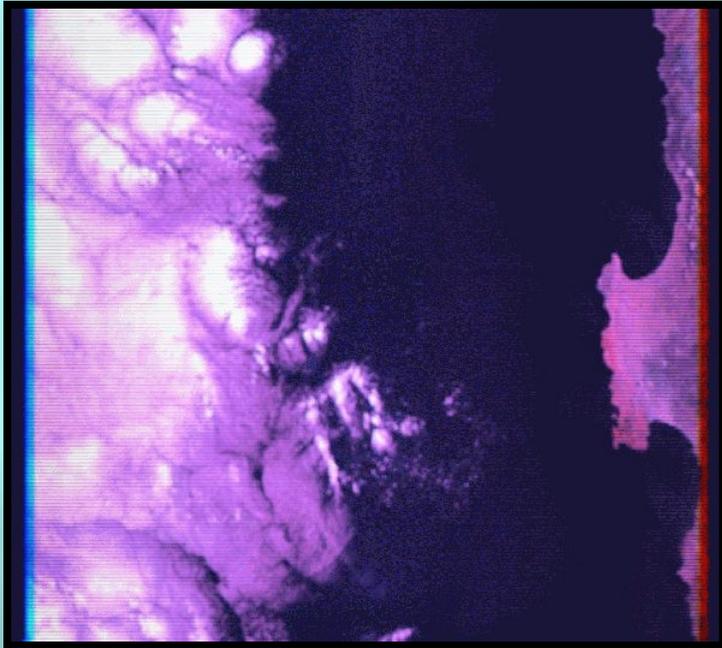
ETM+ ACCA = 5



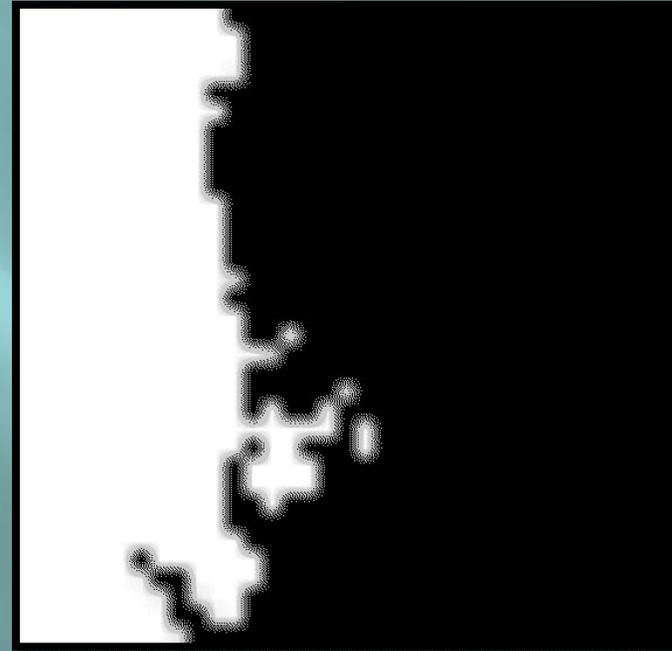
MODIS CF = 4.7

More Sample CF Scenes

WRS 2/76 1-Jan-2009



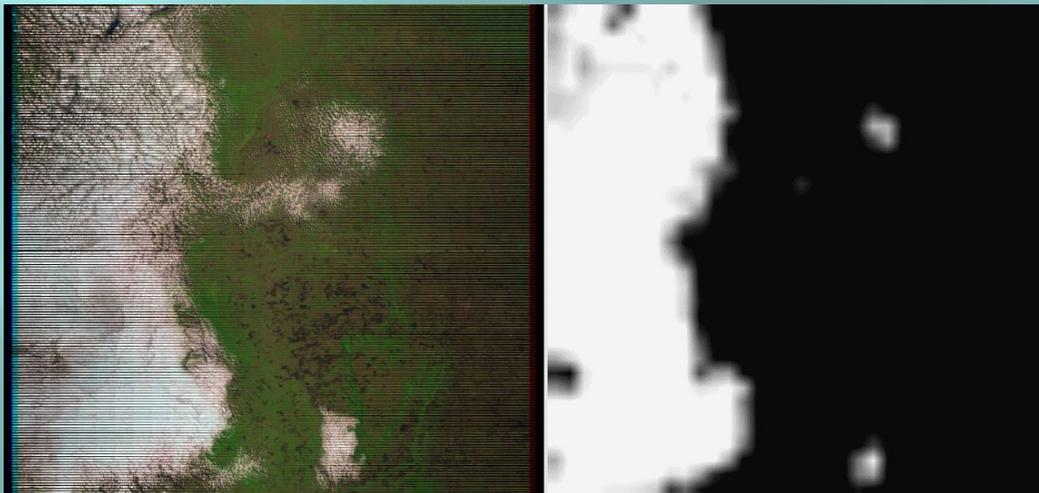
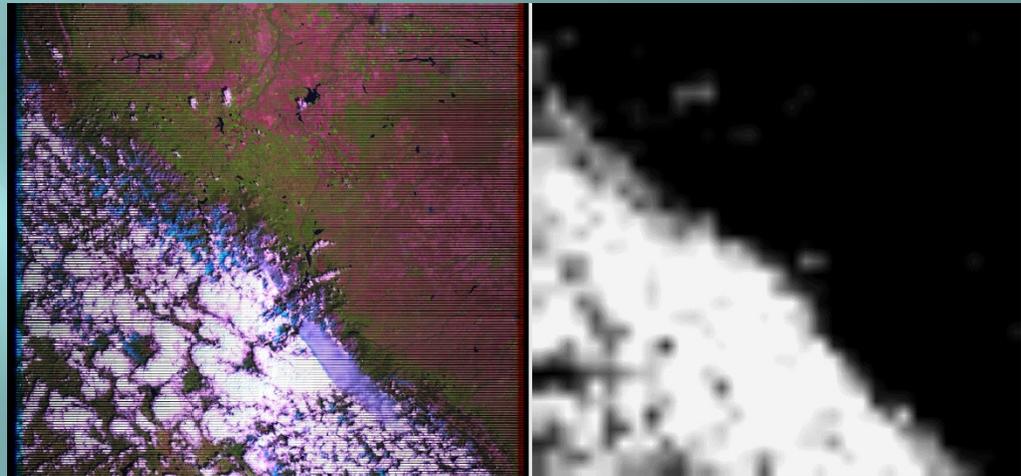
ETM+ ACCA = 29



MODIS CF = 33.8

More Sample CF Scenes

WRS 41/26
2006/154
ACCA = 31
MODIS_CF = 32.1

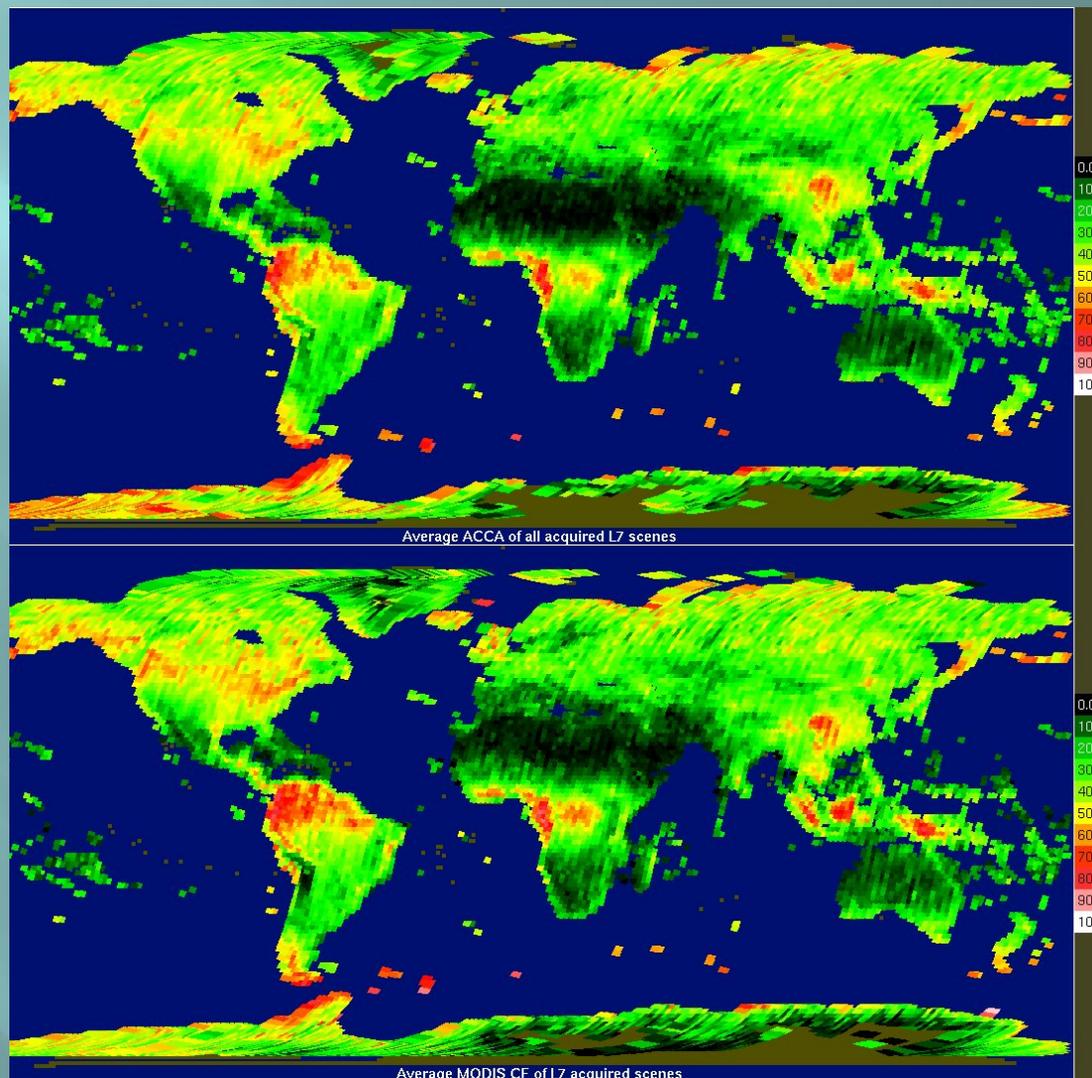


WRS 182/64
2006/182
ACCA = 40
MODIS_CF = 31.5

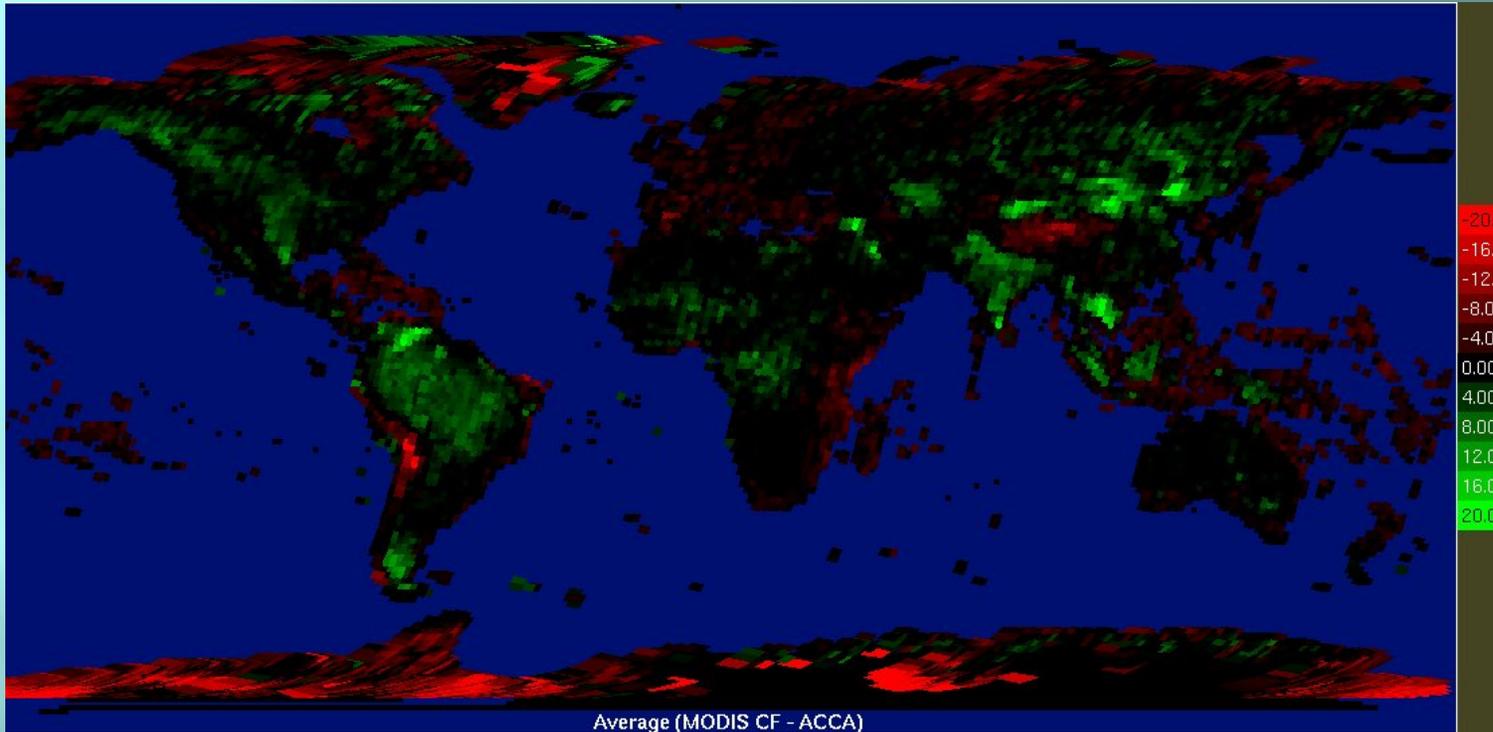
Average Cloud Fraction 2005 - 2009

Average ACCA
= 31.0

Average MODIS
CF of all acquired
ETM+ scenes
= 32.7

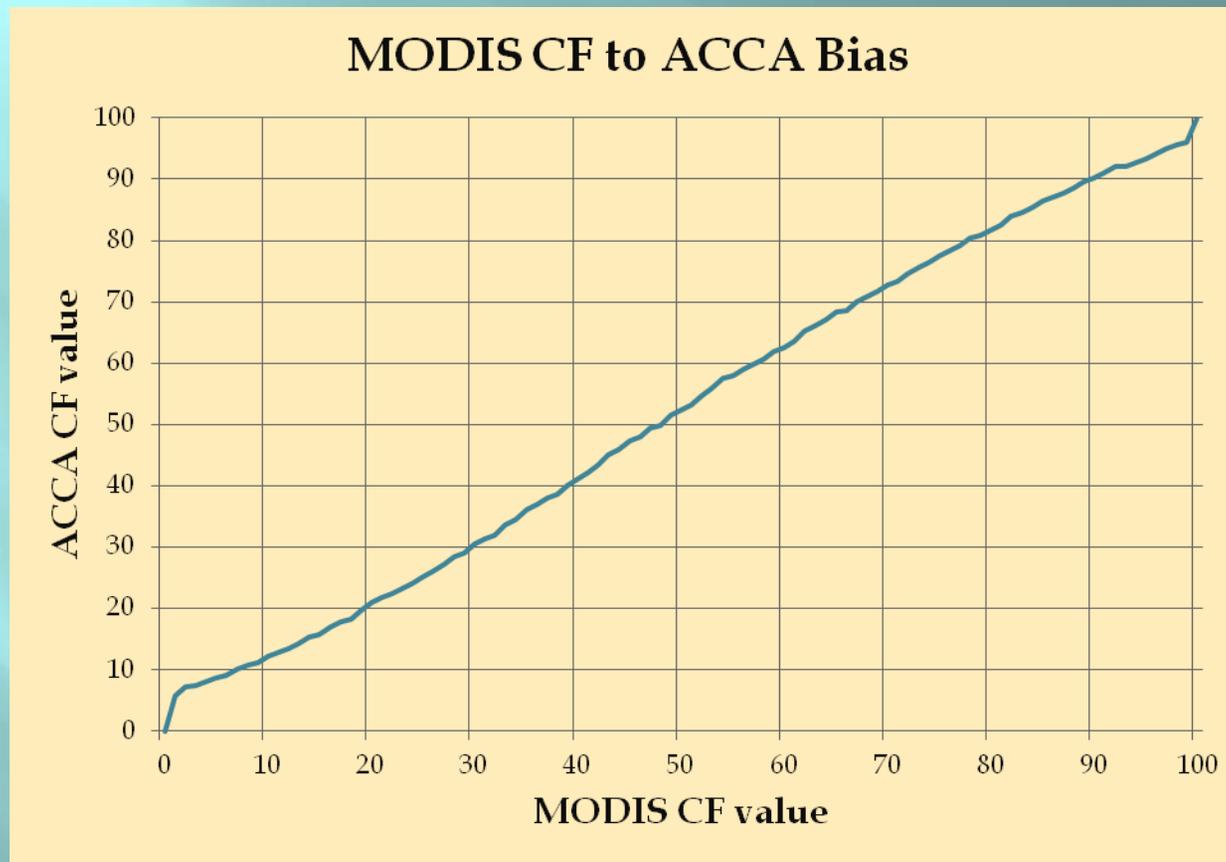


Difference between MODIS Cloud Fraction and ETM+ ACCA



- Greater MODIS CF (green) possibly due to
 - MODIS overestimation of fair weather cumulus clouds, and
 - ETM+ under detection of thin cirrus.
- Consistently greater ACCA (red) over permanent ice.

Relative bias between MODIS CF and ETM+ ACCA



Using this function to *normalize* MODIS CF yields
average CF = **31.4** for all acquired ETM+ scenes

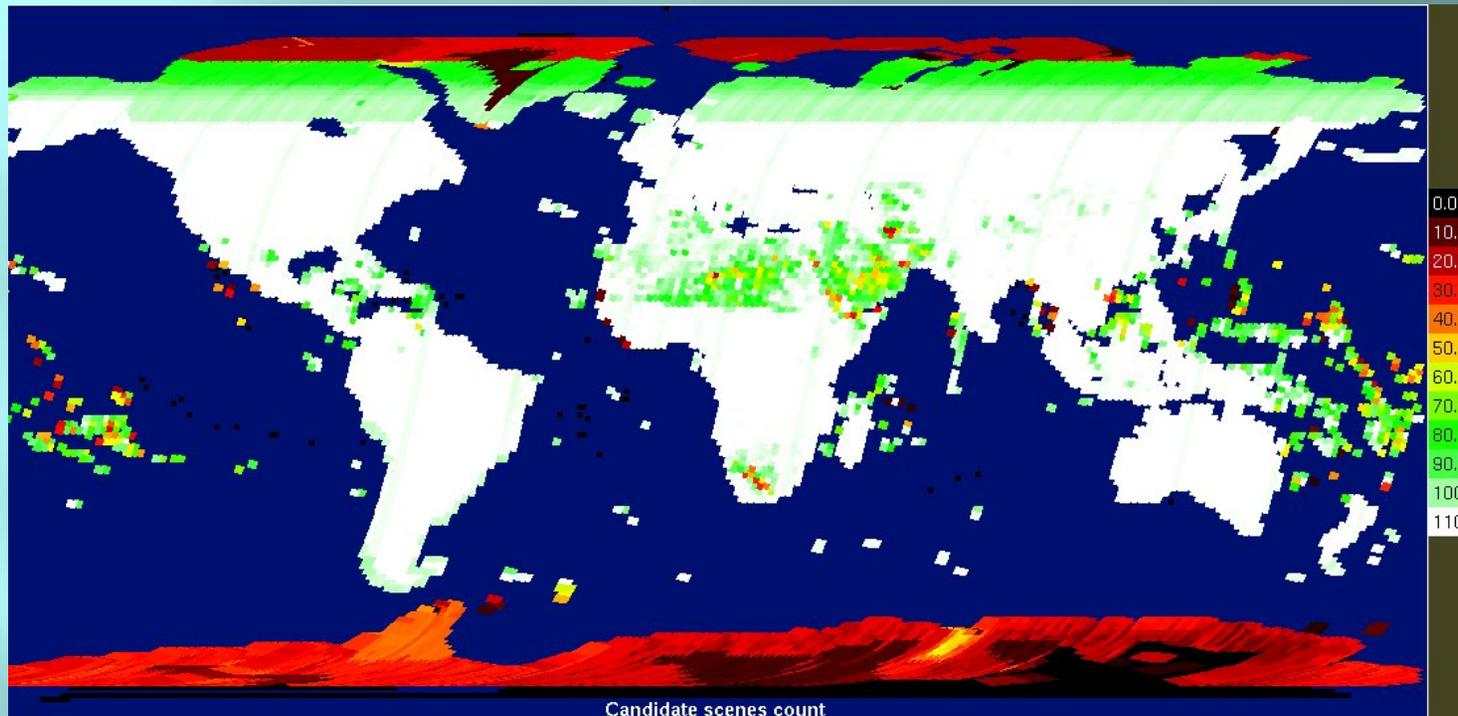
Factors contributing to Disagreements between ACCA and MODIS CF

- ▣ Framing (cross-track orbital drift from WRS center)
- ▣ Temporal Difference (30 minute lag)
- ▣ Sensor spatial resolution (1 Km vs. 30m)
- ▣ Spatial quantization (1 Km => 5Km translation)
- ▣ Cloud detection algorithm differences (MODIS relies on many IR bands)

Further study necessary to assess impact on objectives

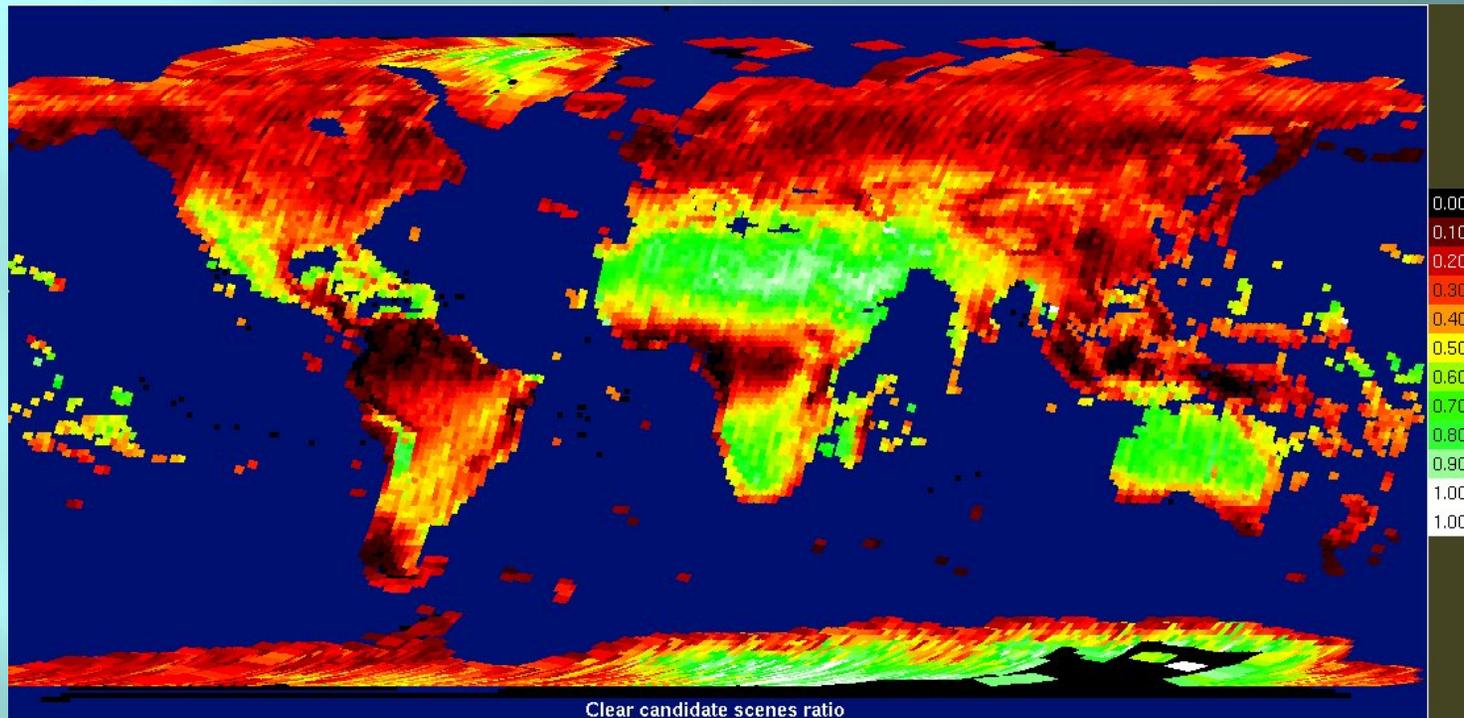
A GLANCE AT LANDSAT 7 LTAP CLOUD AVOIDANCE PERFORMANCE

Candidate scene count



- There was a maximum of $5 \times 365 / 16 = 114$ opportunities for each WRS scene for 2005-2009.
- The LTAP chooses some to acquire, and skips others based on many factors.
- High latitudes have fewer candidate scenes due to sun angle constraints.
- Desert scenes (principally Sahara, Saudi Arabia) have candidate scenes due to LTAP seasonal *single acquisition* considerations.

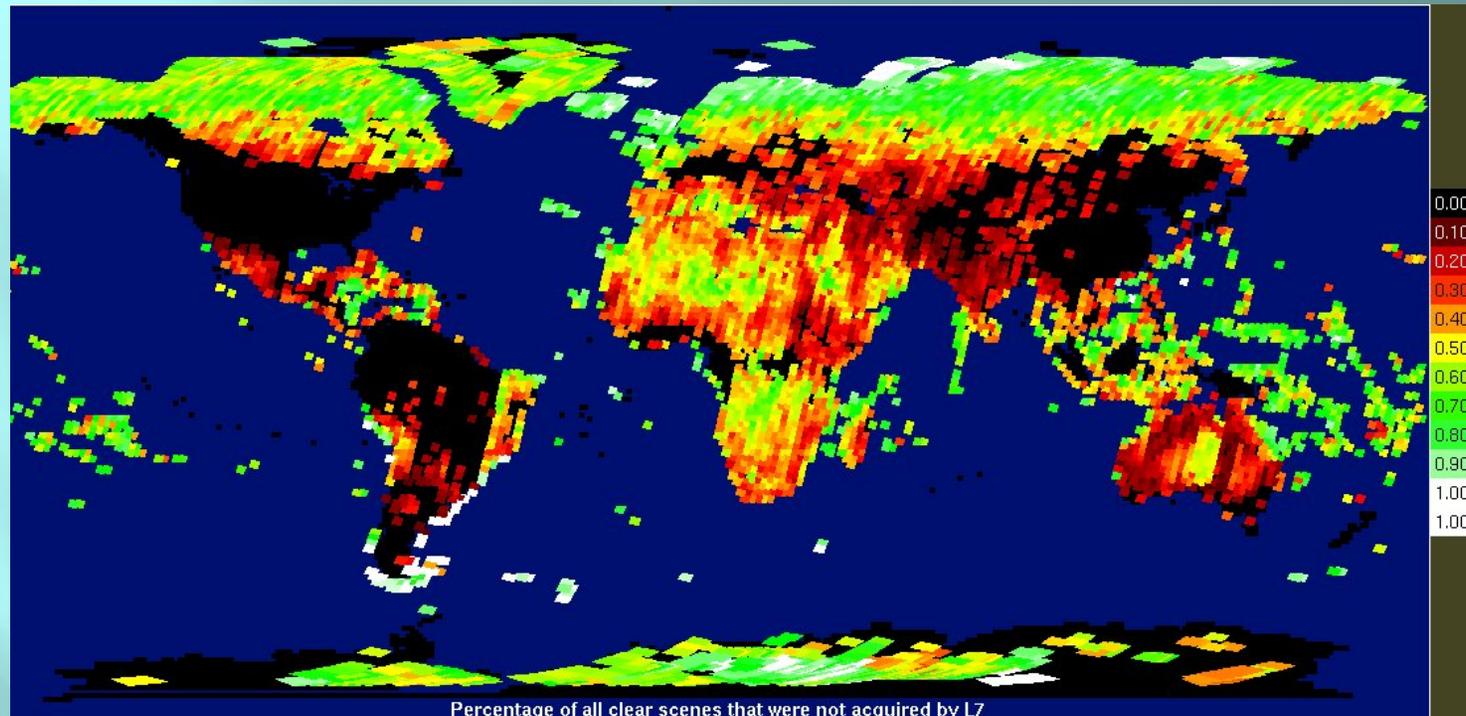
*Clear** candidate scenes ratio



This map shows the percentage of *all candidate scenes that were clear*, according to MODIS.

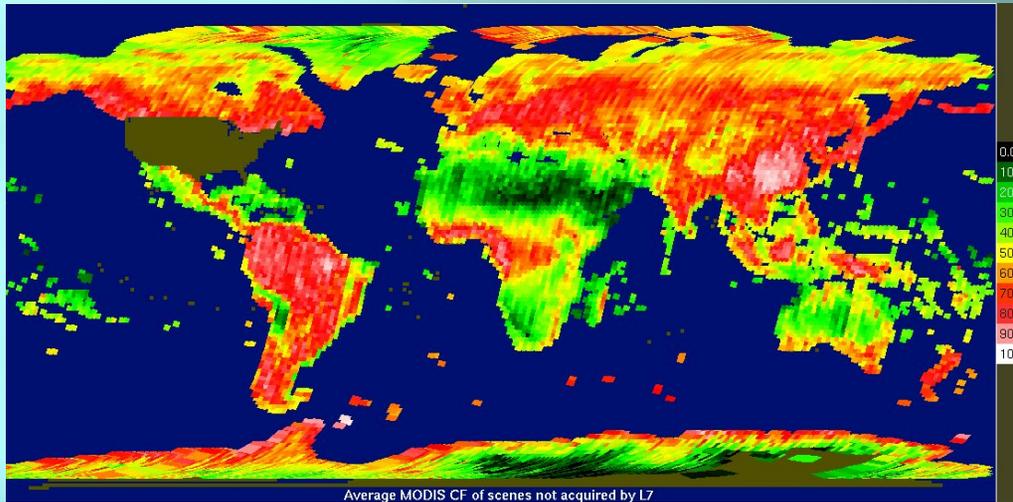
* A *Clear* scene by convention is one with cloud fraction $\leq 10\%$.

Percentage of clear scenes that were uncollected



- Considering *all candidate scenes that were clear* (as seen by MODIS CF), this map shows the percentage of those clear candidate scenes that were *NOT collected* by L7. These represent the *pearls* that fell on the floor.
- This is a very revealing metric that MODIS CF data enables us to visualize.
- *This suggests that there is room for improvement over Siberia.*

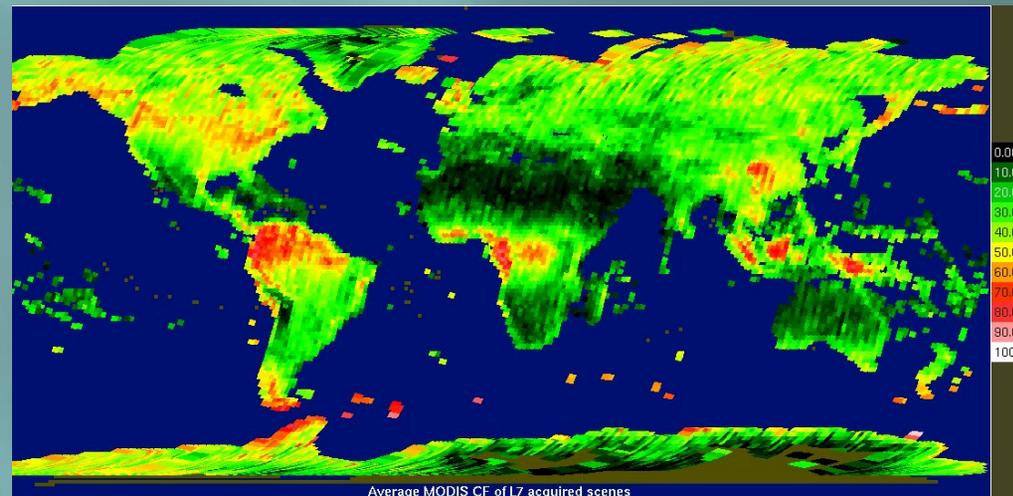
Average MODIS CF of scenes *not* acquired by L7



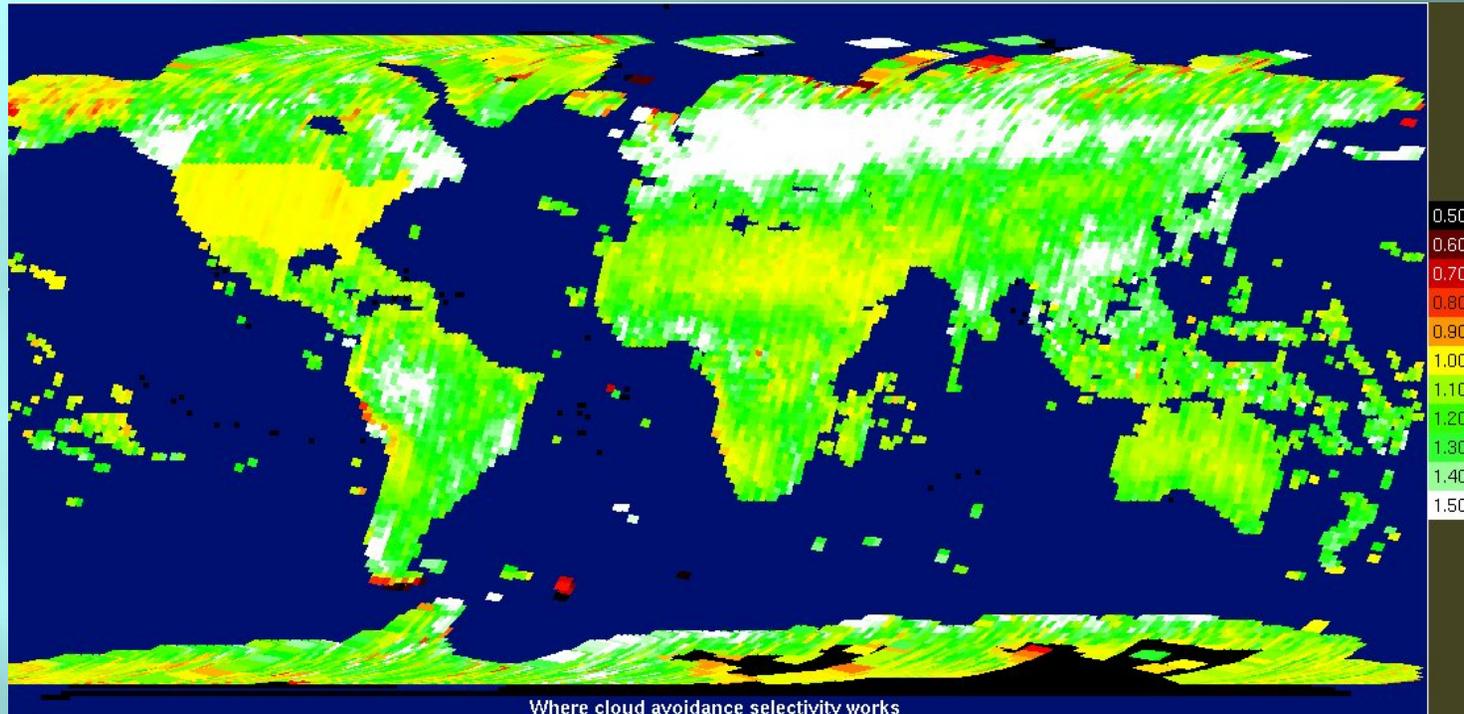
Black and Dark-Green are regions where consistently clear candidate scenes were routinely skipped by L7

(Note that CONUS is always acquired)

Contrast above with this map of average MODIS CF of scenes acquired by L7 (as seen earlier)
These depict the advantage of the cloud avoidance approach.



Advantage of Cloud Avoidance

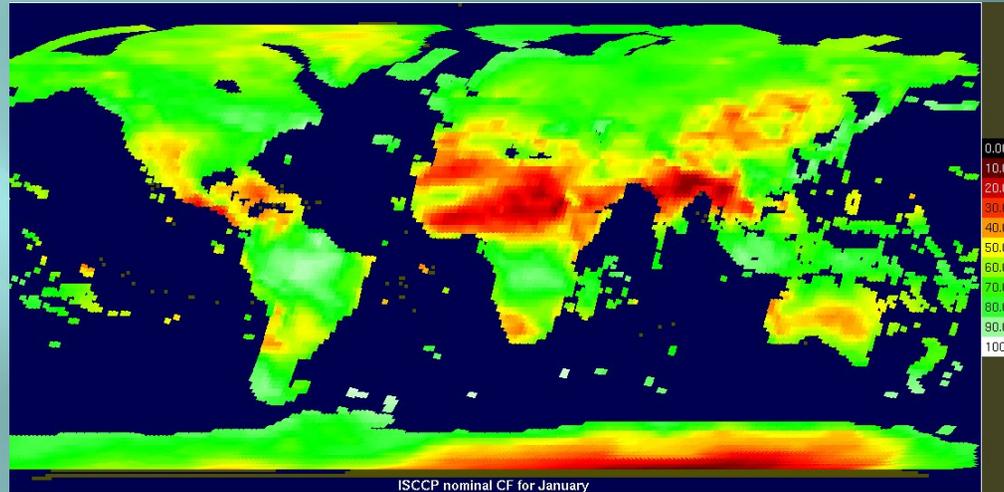


- This shows the ratio of average *clear sky fraction* ($1 - CF$) of all collected scenes versus the average *clear sky fraction* of all candidate scenes.
- Yellow is “neutral”, where cloud avoidance yields no advantage.
- Green toward white shows beneficial performance.
- White shows where the average clear sky fraction of collected scenes exceeds the average clear sky fraction of all candidate scenes by greater than 50%.
- Note the sparseness of black and red scenes, where cloud avoidance rules are *detrimental*.

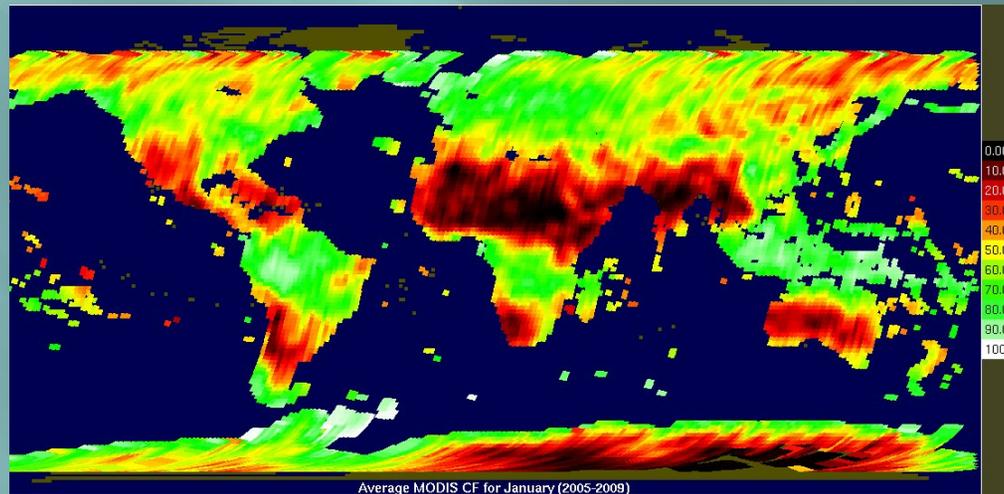
CLIMATOLOGY: COMPARING ISCCP NOMINAL CLOUD COVER WITH MODIS CF

Comparison: MODIS to ISCCP

ISCCP D2 Nominal CF-
(January 1983 - 1997)
Land CF = 56



Average MODIS L2 CF -
(January 2005-2009)
Land CF = 45



Consider Replacing ISCCP D2 data set with monthly avg MODIS CF for LTAP

- ▣ Advantages of MODIS CF
 - Higher spatial resolution and sampling
 - Comes from a more sophisticated algorithm (more spectral tests)
 - *Represents nominal conditions at 10:30 MLT*

- ▣ Monthly average MODIS CF may be computed on the fly centered on the planned acquisition times.
 - Not an option with ISCCP, which is furnished in discrete monthly data sets of very coarse gridding (280 km).

Conclusions

- ▣ Terra/MODIS cloud data products are valuable resources for:
 - Assessing past performance of L7 LTAP cloud avoidance.
 - Formulating an improved *ACCA simulator* for the LTAP model.
 - Potentially improving the LTAP by replacing the ISCCP D2 nominal climatology database.
- ▣ Improvements to L7 LTAP are potentially beneficial toward LDCM LTAP-8.

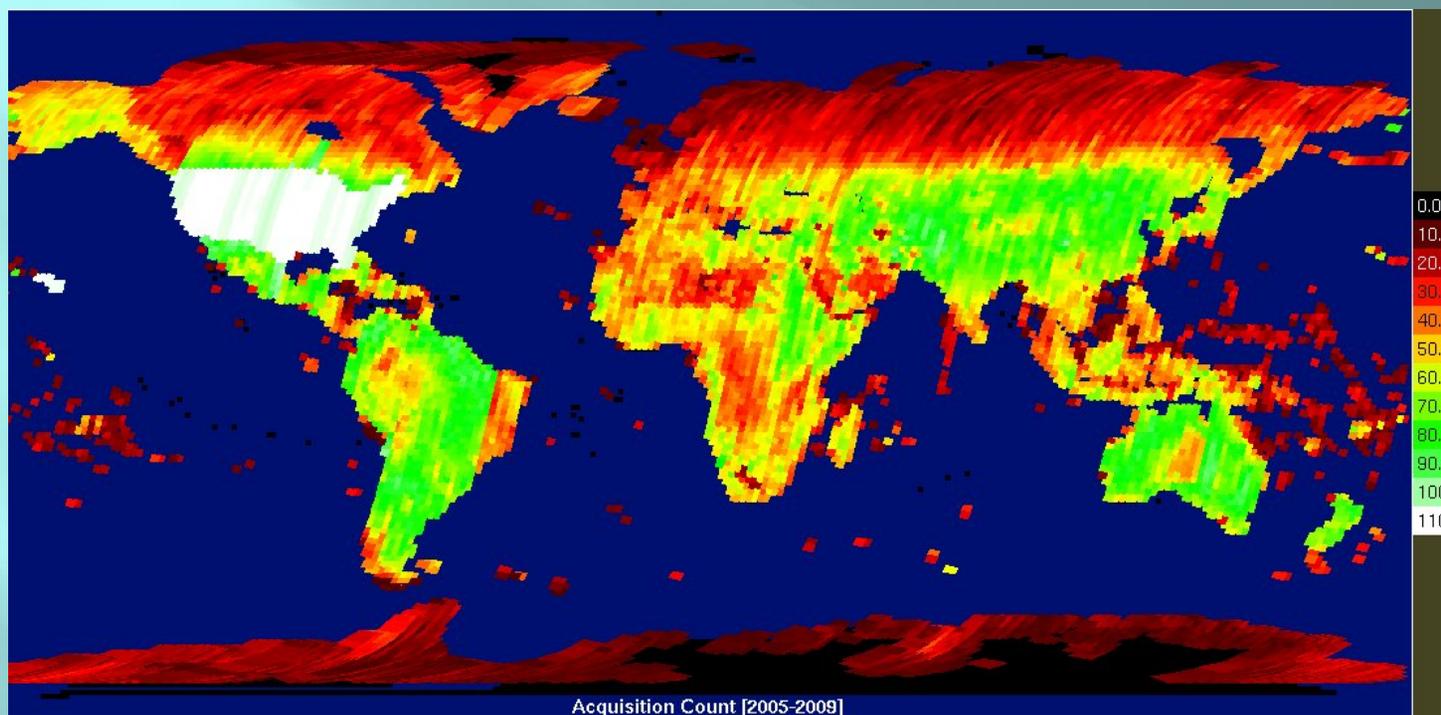
Next Steps

- ▣ Investigation differences involving
 - Fair weather cumulus and cirrus clouds
 - Permanent ice
- ▣ Produce a new ACCA simulator for LTAP model based on MODIS CF.
- ▣ Test proposed enhancements to the L7 LTAP by running hindcast scenarios using the new LTAP model.
- ▣ Characterize NOAA/NCEP cloud forecast global and regional reliability.
- ▣ Assess value of using custom MODIS CF in place of ISCCP for nominal seasonal climatology.

Questions?

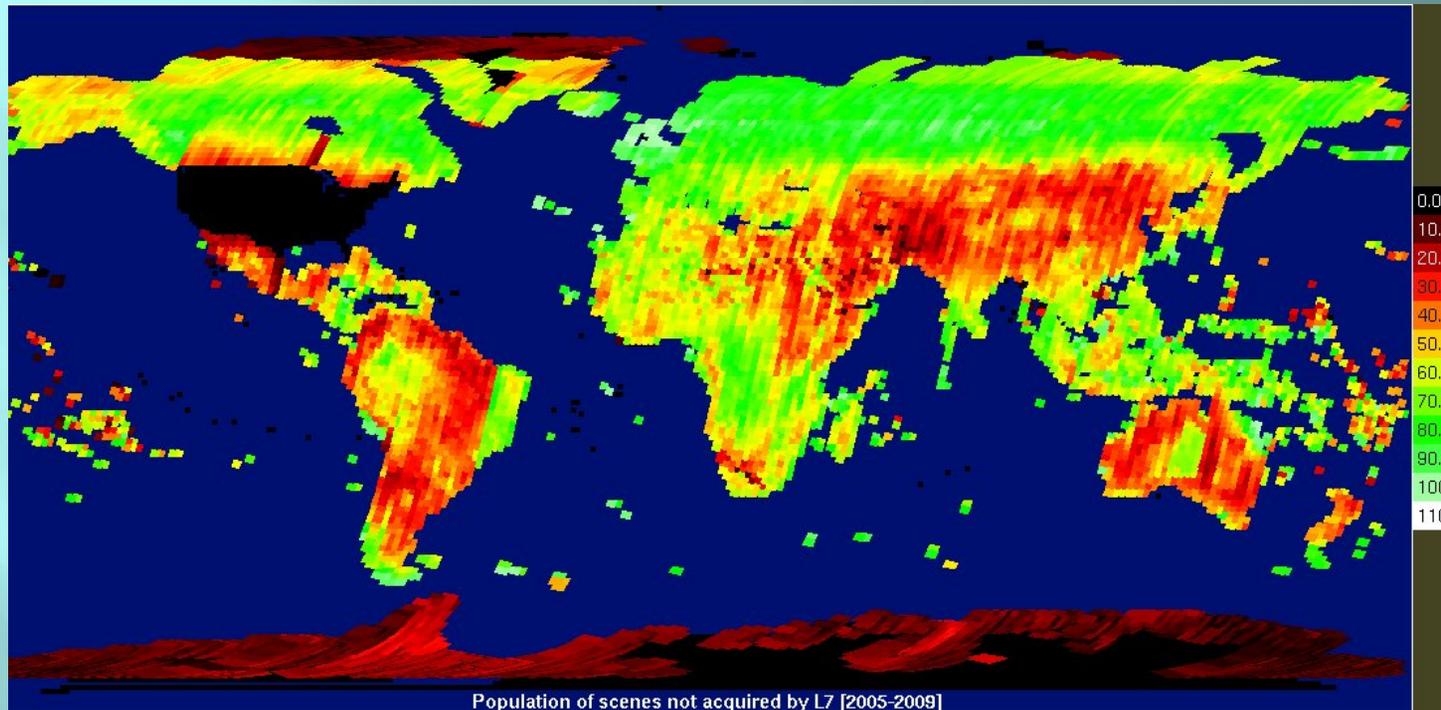
BACKUP SLIDES

L7 Acquired Scene Population 2005 thru 2009



White represents 100 or more acquisitions out of 114 opportunities - 2005 through 2009.

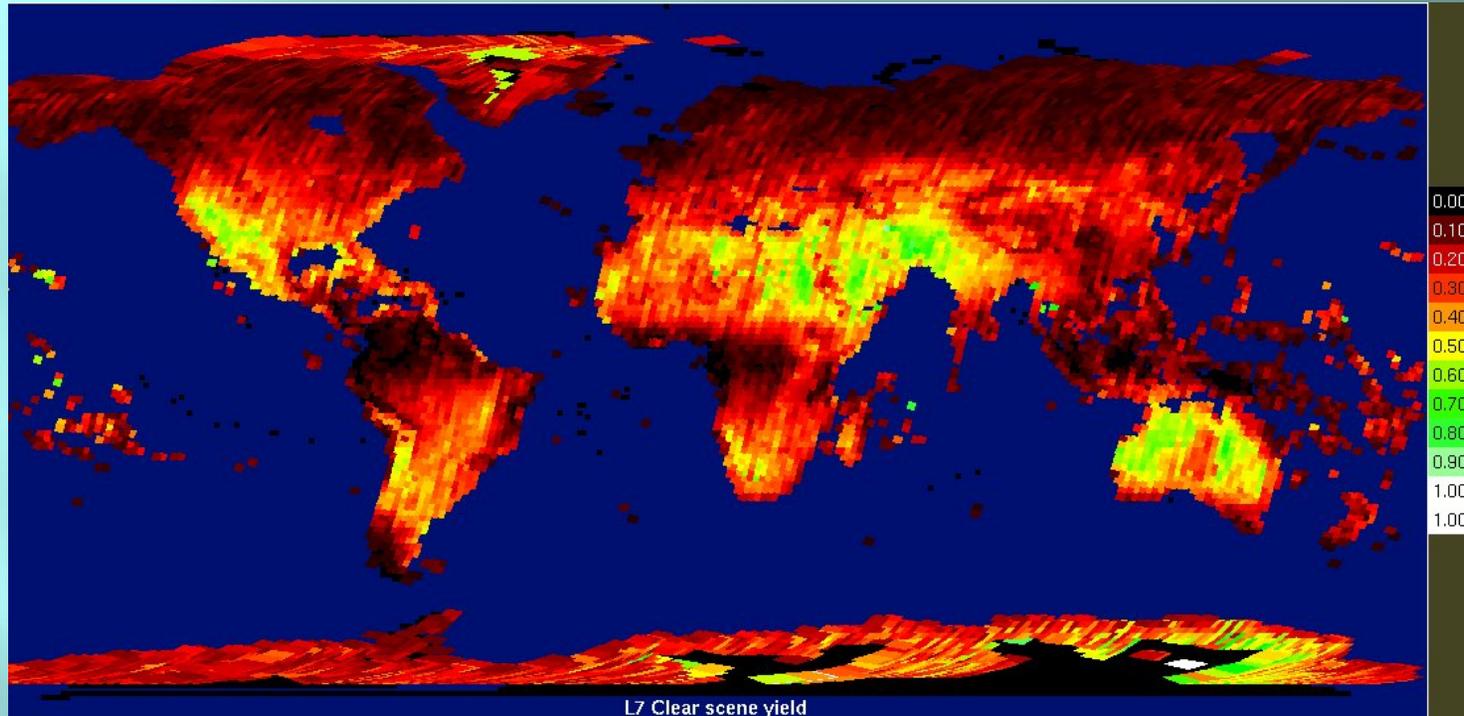
What is Landsat 7 NOT Acquiring?



Population of scene opportunities skipped by Landsat 7.
Green toward white scenes are those that were skipped most frequently

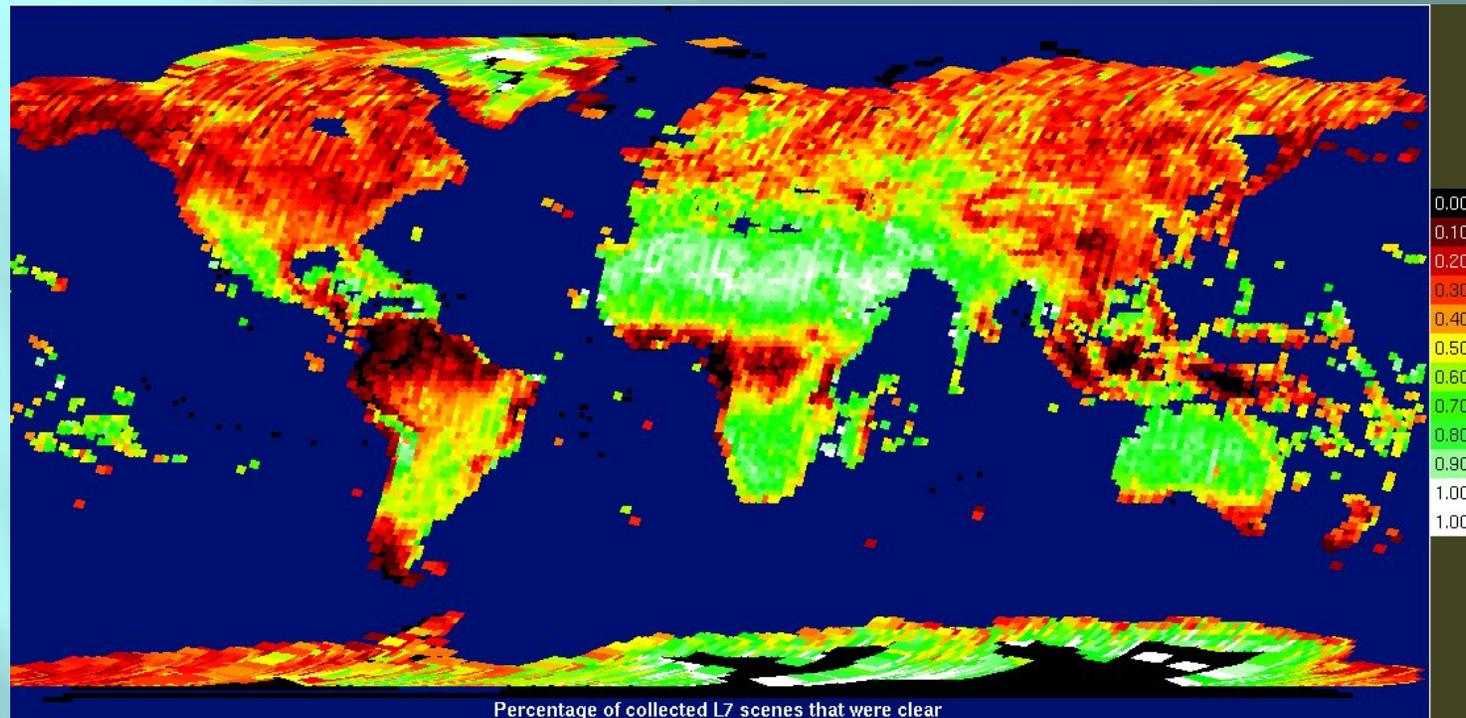
There were 114 opportunities per scene from 2005 through 2009

Clear scene acquisition yield



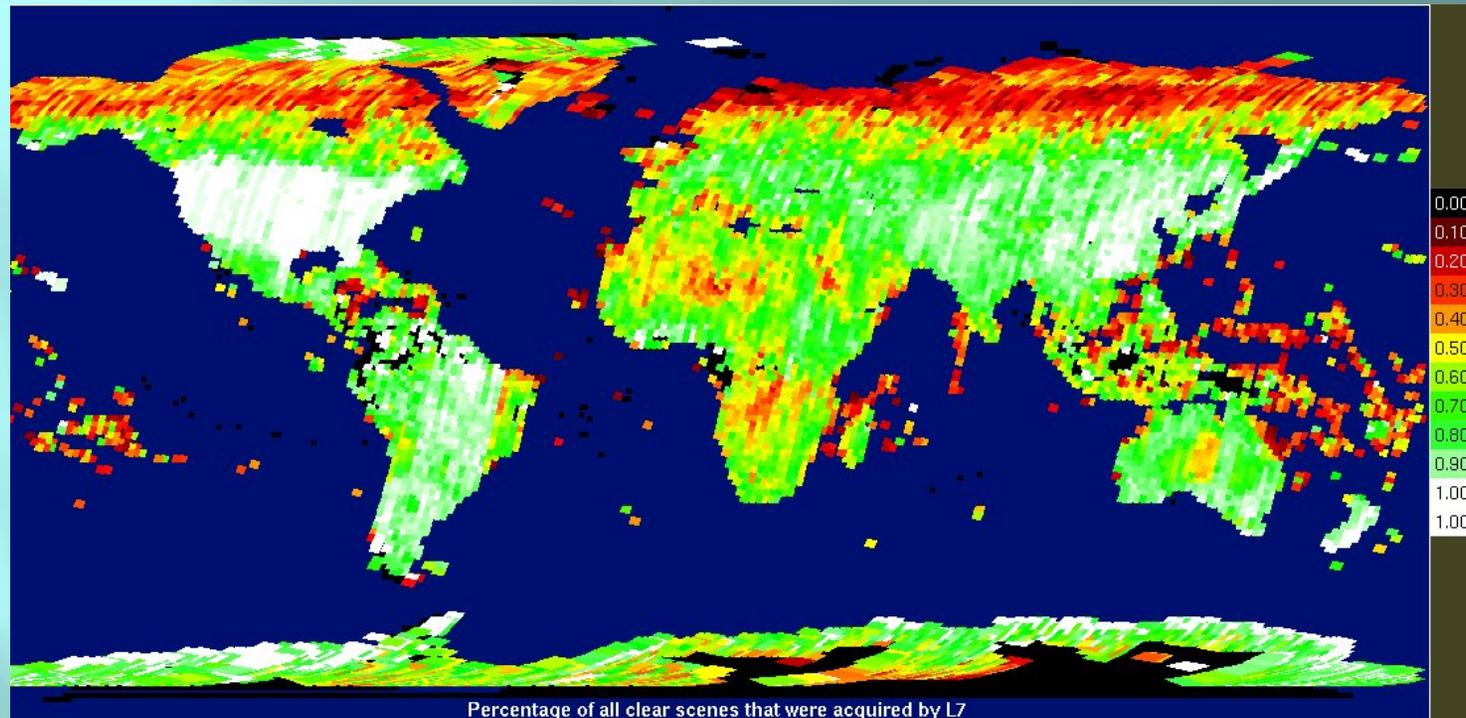
This map shows the ratio of clear scenes collected by L7 with respect to the population of all candidate scenes (judgement of "clear" is based on MODIS CF ≤ 10)

Percentage of collected scenes that were clear



This map shows the ratio of acquired clear scenes versus the set of all scenes collected by L7 between 2005 thru 2009 (judgement of "clear" is based on MODIS CF ≤ 10 .)

Percentage of clear scenes that were collected



Considering *all opportunities that were clear* (as seen by MODIS CF), this map shows for each WRS scene the percentage of those clear opportunities that were *collected* by L7.

Follow-up Studies

- ▣ In-depth investigation (on selected WRS scenes) on why MODIS and ETM+ cloud fractions disagree
- ▣ An Assessment of NCEP GFS Cloud Forecast Accuracy using MODIS Cloud Fractions and Landsat 7 ETM+ ACCA as “Cloud-Truth” source
- ▣ A New Approach to Landsat 7 LTAP - Improving upon Success.
- ▣ Modeling the Landsat 7 LTAP - Developing a Testbed for LTAP Performance Evaluation.
- ▣ Applying MODIS CF in GLS-2010 scene selection