Sky Cover:

Shining Light on a Gloomy Problem

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Objective

What

- Improve the analysis and short-term forecasts of sky cover across the United States and adjacent coastal areas using geostationary satellite and in-situ surface station observations

How

- Use linear and/or mixed integer optimization to minimize the mean absolute difference between multi-source sky cover observations and short-term numerical weather prediction forecasts of cloud and moisture variables

Objective I

Create an hourly sky cover analysis based on the following requirements:

- Sky cover is an average over an entire hour.
- Satellite and in-situ surface observations of cloud are complementary.
- The range of the sky cover output is between 0 and 100%.

Goal I

Produce an operations-grade sky cover product for the field

Objective II

Create an optimal sky cover forecast based on the following assumptions:

- The relationship between sky cover and numerical weather prediction cloud/moisture variables is roughly linear
- The model variables adequately represent the atmosphere at the initial time and at times in the future

Goal II

Produce an operations-grade sky cover forecast for the field

Defining Sky Cover

- Effective cloud amount (ECA), the product of fractional cloud cover within the field of view (FOV) and cloud emissivity, is the most common method to assess sky cover from satellite observations.
- The United States Federal Meteorological Handbook (FMH) No. 1 defines sky cover as “the amount of the celestial dome hidden by clouds and/or obscurations”.

Observing the Sky

There are three primary sources of sky observations:

- Space-based imagers (i.e., radiometers onboard low earth-orbiting and geostationary satellites)
- Stationary, surface-based instrumentation (e.g., ceilometers)
- Trained human observers (typically with aid of instrumentation)

Observing the Sky

There are issues with each observation type:

- Satellites observe the atmosphere from the top, such that high clouds obscure low clouds.
- Near-surface clouds and clouds smaller than the satellite field of view (FOV) may not be properly represented.
- Satellite observations are instantaneous.

Observing the Sky

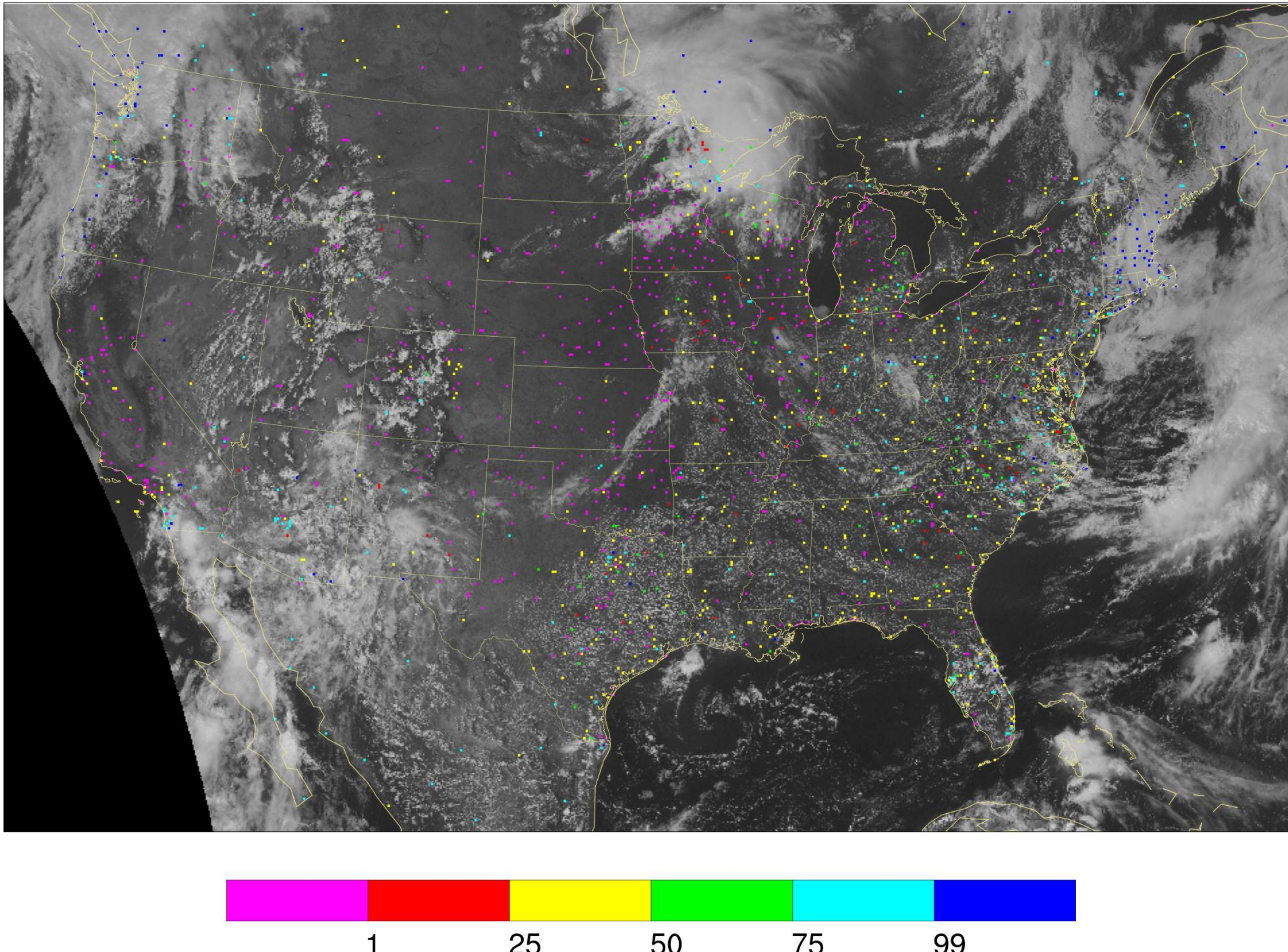
There are issues with each observation type:

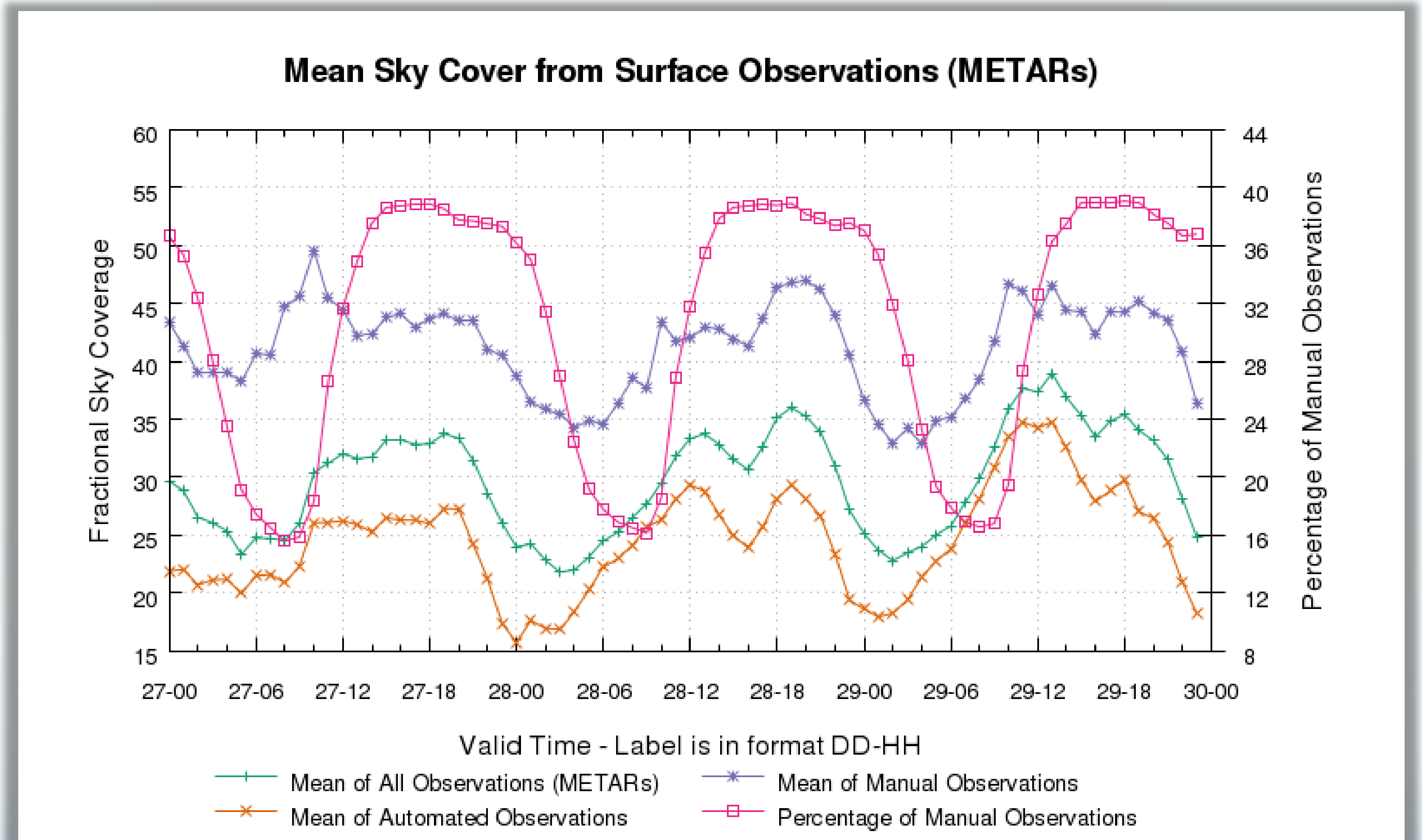
- Ceilometers fail to detect/report high cloud (over 12 kft) and do not observe the celestial dome.
- The human observations require estimation and are not as precise.
  - Sky conditions reported as one of five coverage modes.

Sky Cover Comparison

Thu Aug 29 19:00:00 UTC 2013

Surface Sky Observations/METARs (%)





Mean Sky Cover from Surface Observations (METARs)
Fractional Sky Coverage
Percentage of Manual Observations
60
55
50
45
40
35
30
25
20
15
44
40
36
32
28
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28-18
29-00
29-06
29-12
29-18
30-00
Valid Time - Label is in format DD-HH
Mean of All Observations (METARs)
Mean of Manual Observations
Mean of Automated Observations
Percentage of Manual Observations

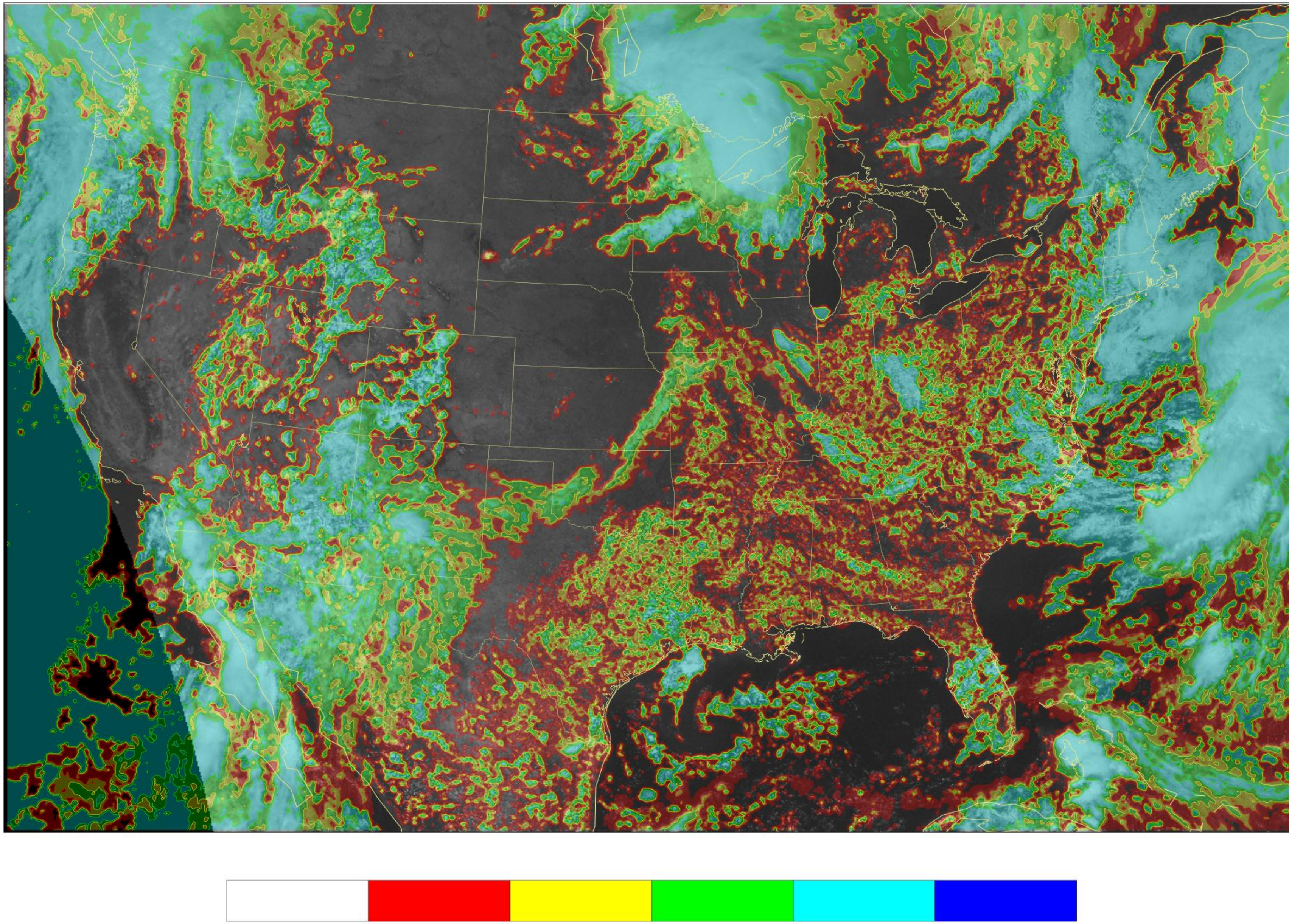
Satellite Sky Cover Product

- Based on effective cloud amount obtained from GOES imagers
- Corrected when high (low effective emissivity) cloud obscures underlying low cloud
- High effective emissivity enhanced
- Every scan is spatially averaged to produce an ad hoc celestial dome (pixel-centered 11 x 11 box)
- Temporally averaged over a one-hour window

Sky Cover Comparison

Thu Aug 29 19:00:00 UTC 2013

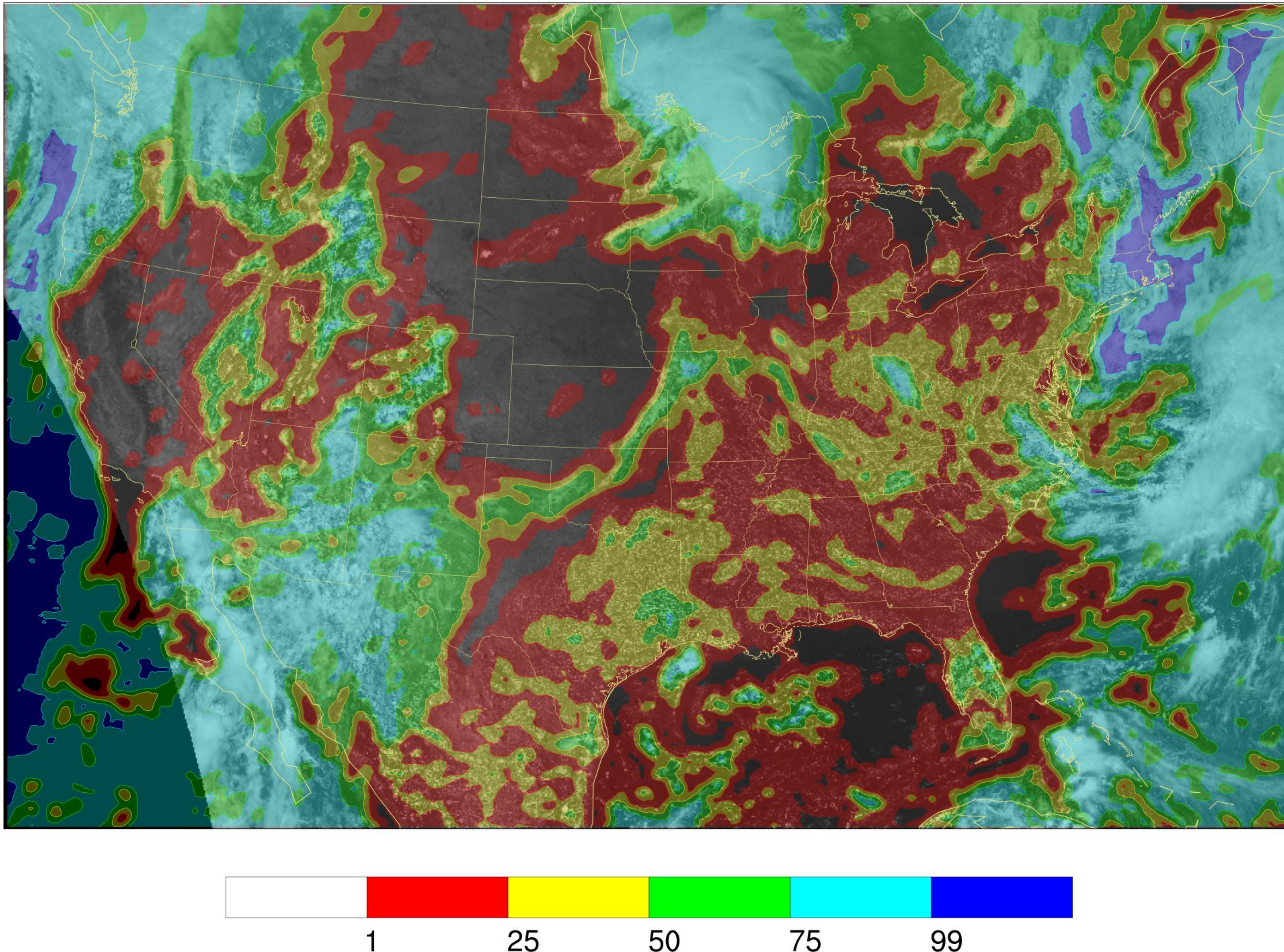
GOES Imager Effective Cloud Amount (%)



Sky Cover Comparison

Thu Aug 29 19:00:00 UTC 2013

GOES Imager Sky Cover Product (%)



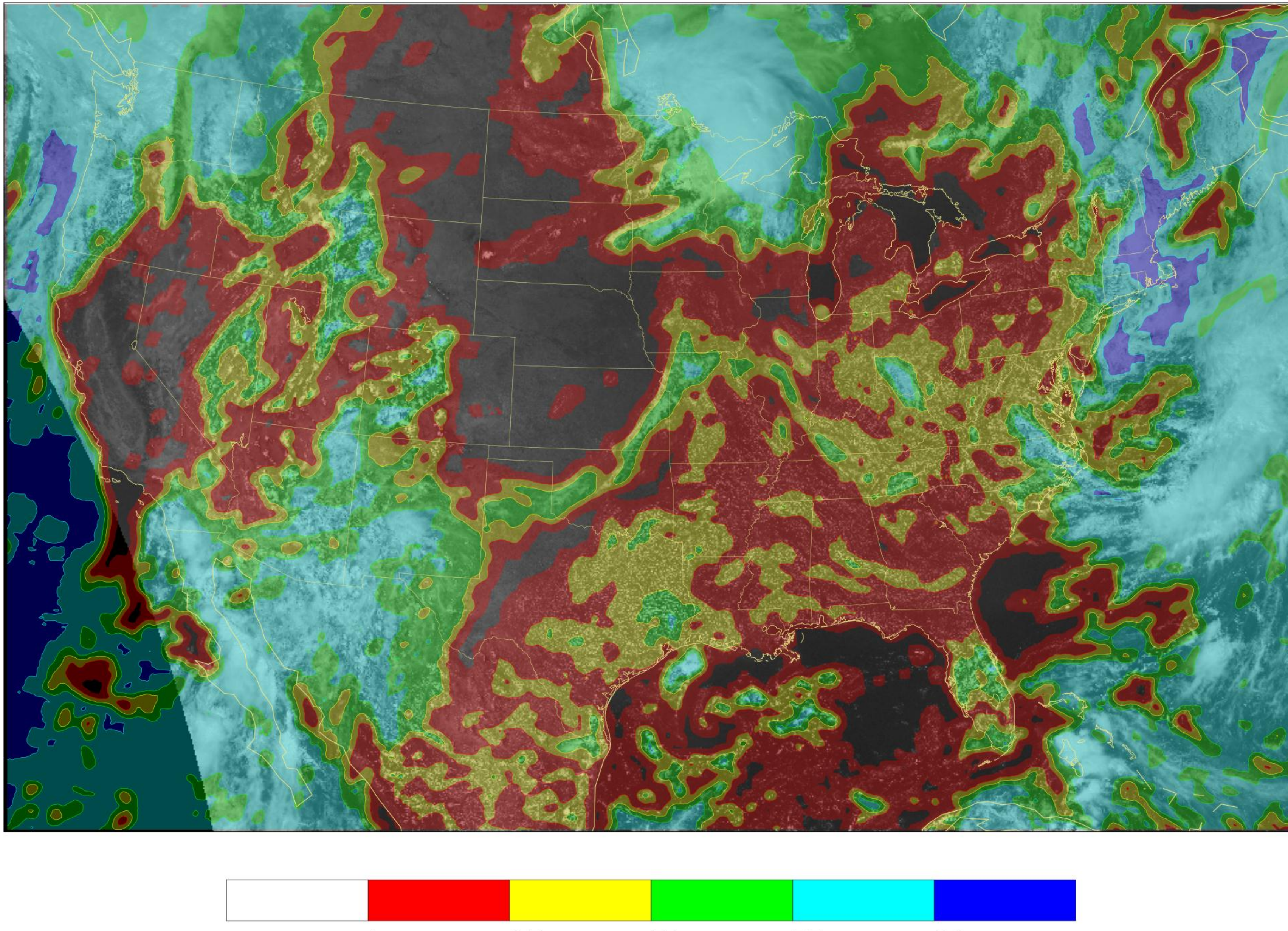
Blended Sky Cover Analysis

- If the surface station observation reports clear (less than 5% celestial dome coverage), the satellite sky cover product value is used.
- If the surface station observation reports some cloud (5% or better coverage of the celestial dome), the surface observation is used when the value is greater than that from the satellite.
- In other situations where both observations are available, a weighted average is performed.

Sky Cover Comparison

Thu Aug 29 19:00:00 UTC 2013

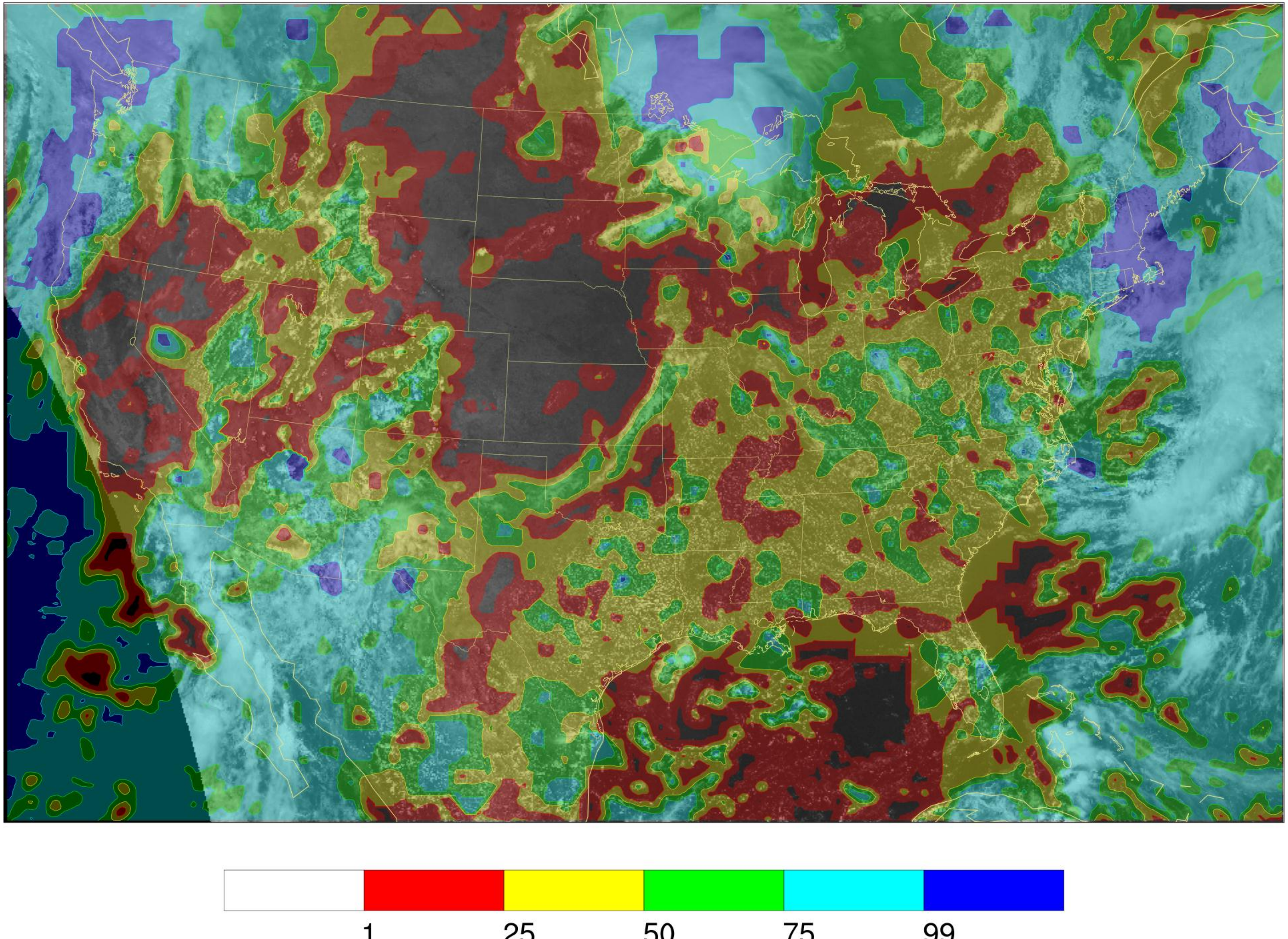
GOES Imager Sky Cover Product (%)



Sky Cover Comparison

Thu Aug 29 19:00:00 UTC 2013

Satellite/Surface Blended Sky Cover (%)



Blended Sky Cover Analysis

The advantages of the blended analysis creation process are that it:

- Evaluates all available data and leverages strengths of multiple observational sources
- Preserves cloud gradients
- Adequately resolves diurnal cumulus fields (not missing, not bimodal)
- Is a temporally continuous and spatially contiguous field (available hourly over the contiguous United States)

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Goal II

Produce an operations-grade sky cover forecast for the field

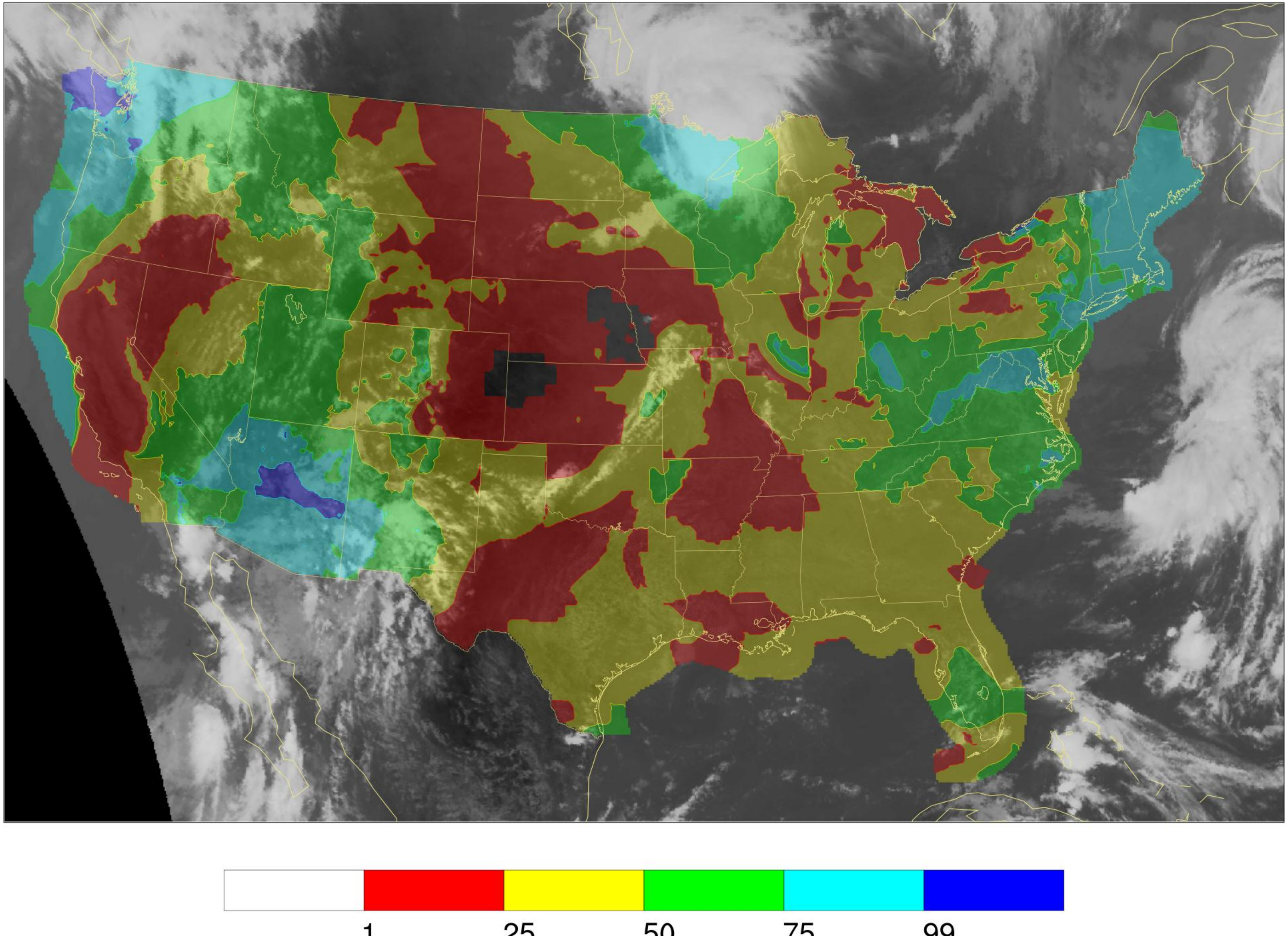
Forecasting Sky Cover

The NWS' National Digital Forecast Database (NDFD) contains the gridded operational forecast for sky cover. Issues with the national one-hour forecast include:

- Clear areas with non-zero cloud cover
- Vastly different cloud classifications for similar cloud scenes
- Lack of spatial continuity between forecast areas
- Temporal trends do not match observations

Sky Cover Comparison

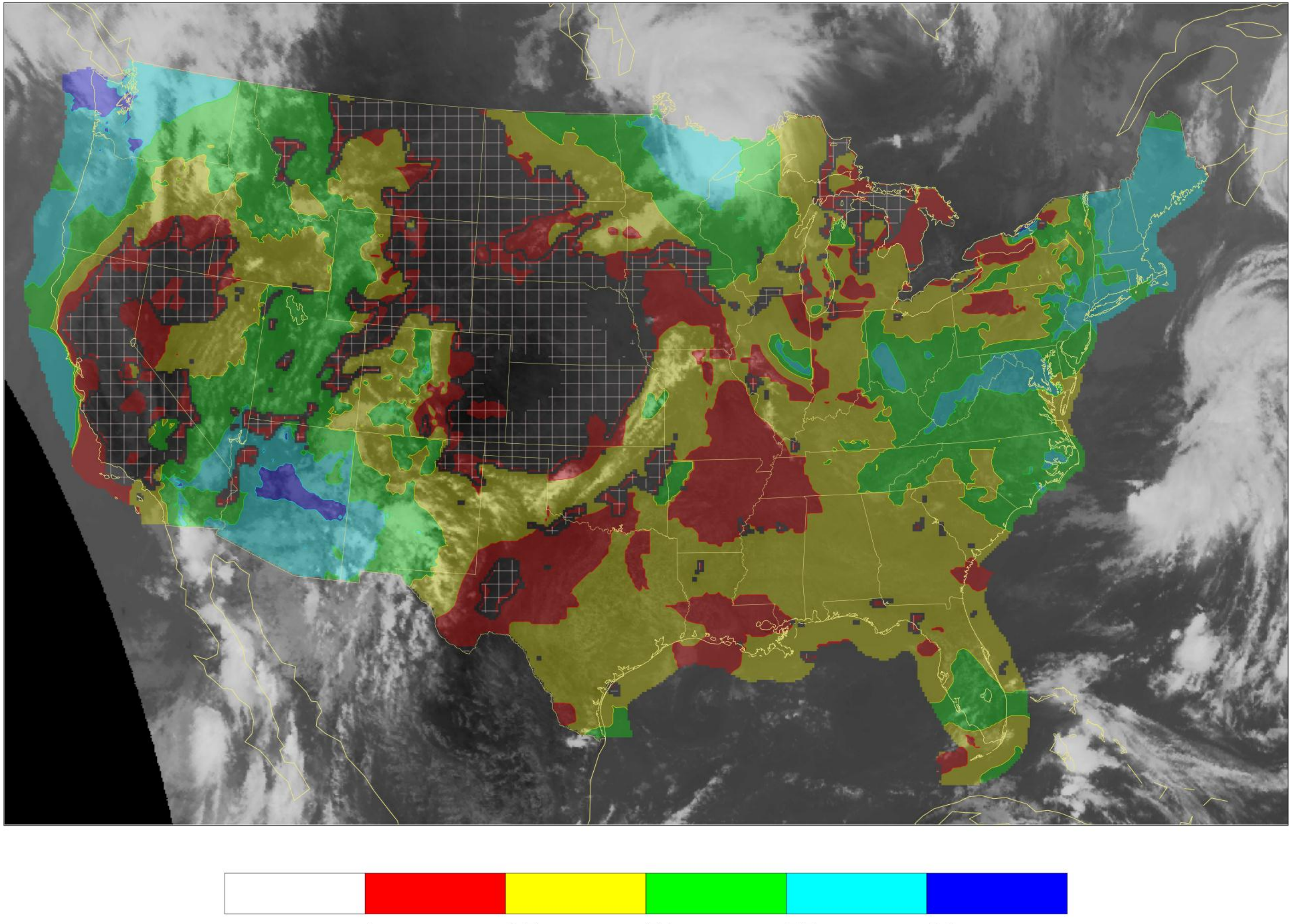
Thu Aug 29 18:00:00 UTC 2013 NDFD Total Cloud Cover (%)

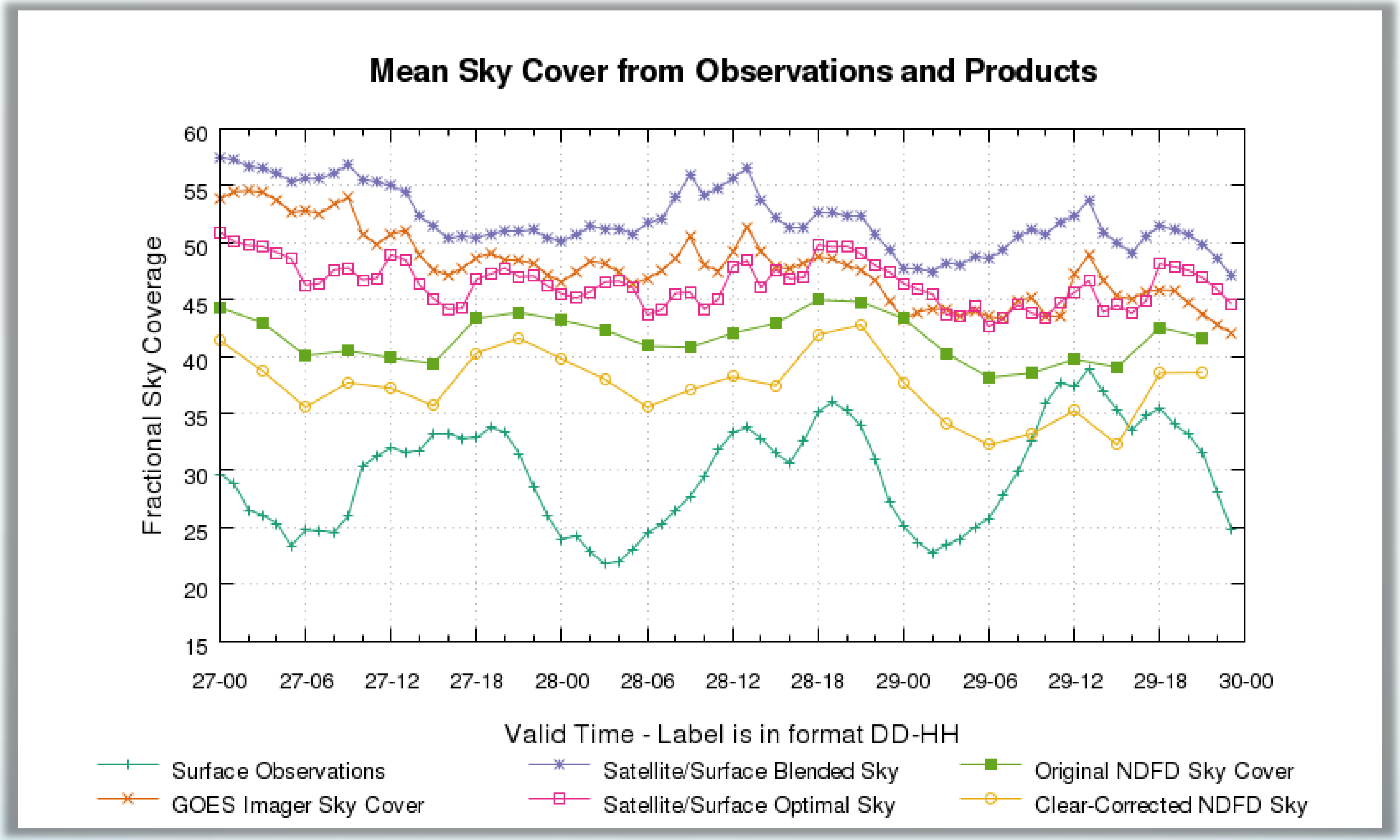


Sky Cover Comparison

Thu Aug 29 18:00:00 UTC 2013

NDFD Total Cloud Cover (%)





Mean Sky Cover from Observations and Products
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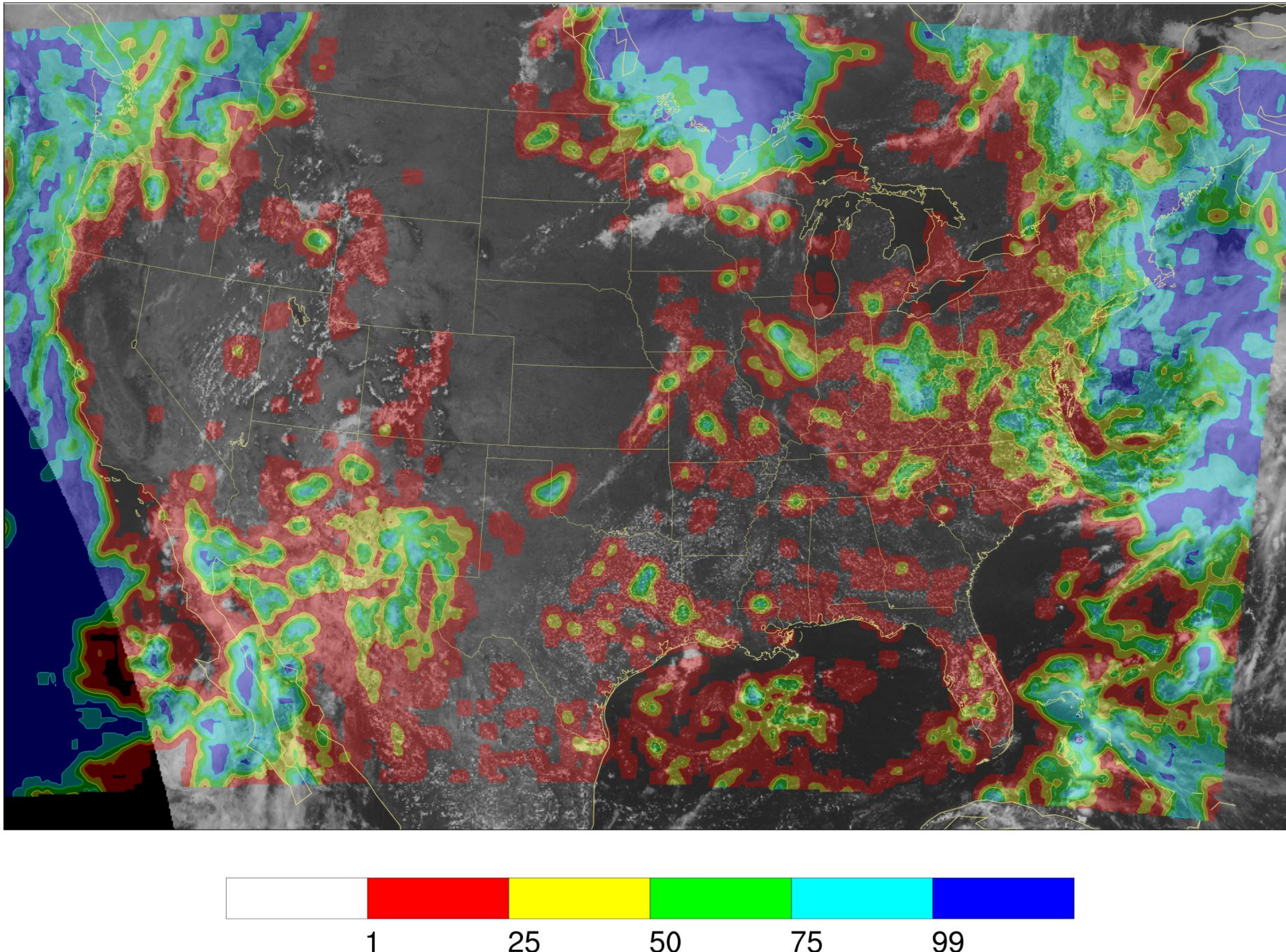
28-06
28-12
28-18
29-00
29-06
29-12
29-18
30-00
Valid Time - Label is in format DD-HH
Surface Observations
GOES Imager Sky Cover
Satellite/Surface Blended Sky
Satellite/Surface Optimal Sky
Original NDFD Sky Cover
Clear-Corrected NDFD Sky

Sky Cover Comparison

Thu Aug 29 18:00:00 UTC 2013

HRRR Total Cloud Cover (%)



Optimizing Sky Cover

- Input fields (subset of points)
  - Truth: Adjusted blended sky cover analysis
  - Components
- Design model (formats: linear, mixed integer, others)
  - Objective using free variable, subject to constraint
  - Terms, matching variables and components
  - Constraints involving terms
- Execute optimizer
  - Commercial solvers (free for academia)
    - CPLEX
    - Gurobi
  - Open source options (slower)

Optimizing Sky Cover

Components:

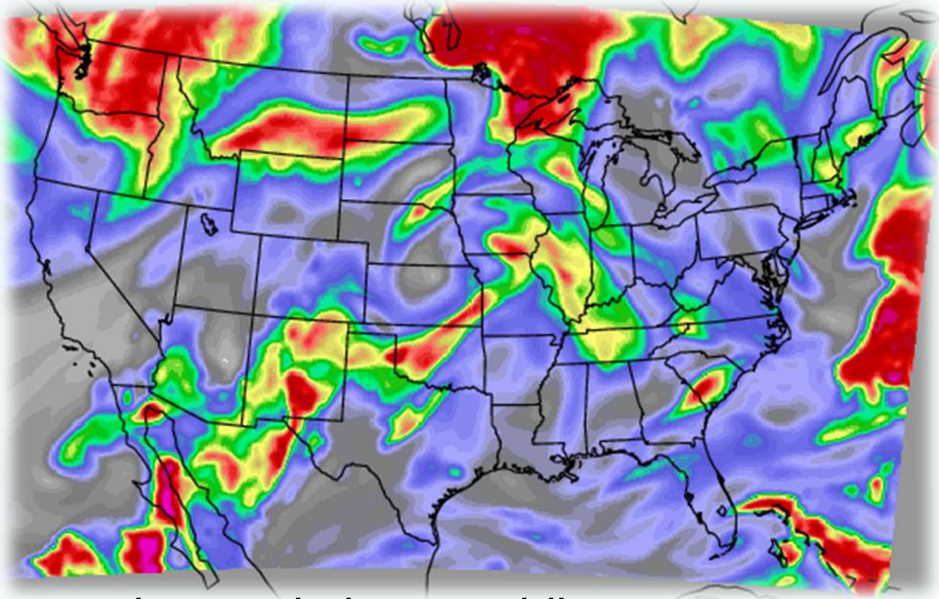
- Relative Humidity (all levels)
- Cloud Water Mixing Ratio, Cloud Ice Mixing Ratio, Rain Water Mixing Ratio, Snow Mixing Ratio (all levels)
- Absolute Vorticity (200 hPa only), partitioned into positive and negative components

- Pressure levels:
  - 200 hPa
  - 300 hPa
  - 500 hPa
  - 700 hPa
  - 800 hPa
  - 850 hPa
  - 900 hPa
  - 950 hPa
  - 1000 hPa

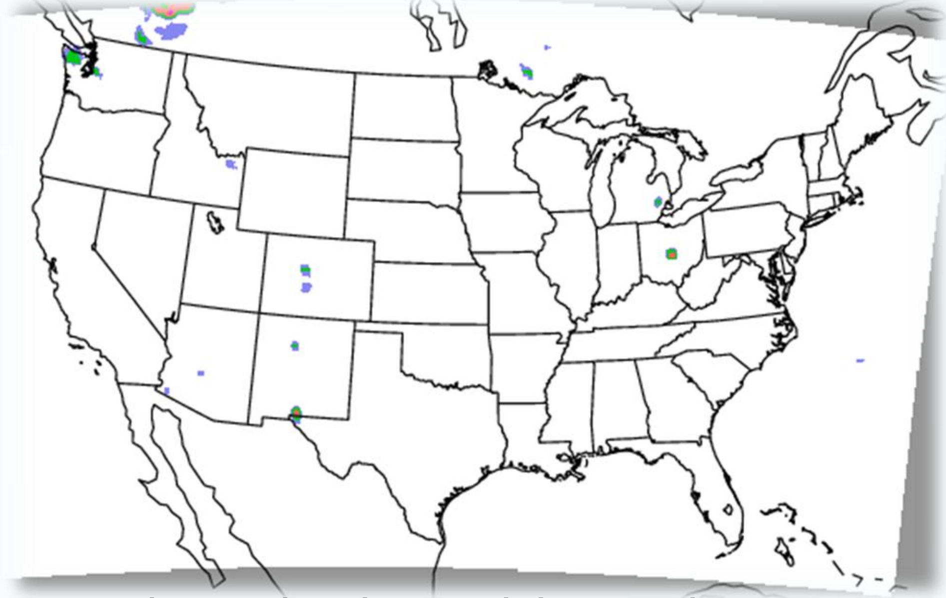
Optimizing Sky Cover

- Optimization objective: Minimize the mean absolute error between the affine expression of adjusted input fields and the truth field

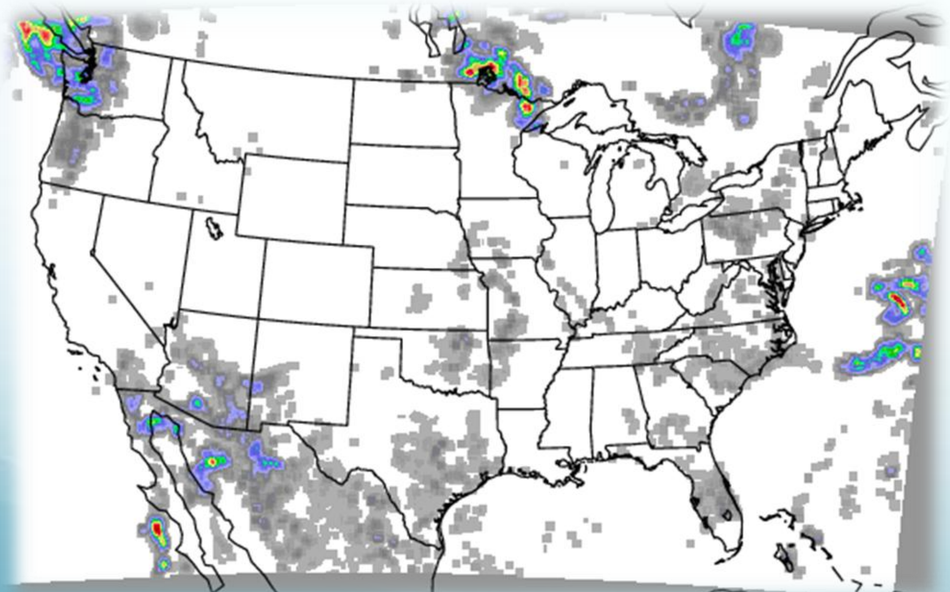
- Terms:
  - Coefficient allowed for 200 hPa positive and negative absolute vorticity ($m_{200}AV_{200}$)
  - Coefficient allowed for relative humidity quantities (m_xRH_x)
  - Threshold allowed for applying coefficient to 1000 hPa relative humidity field ($m_{1000}RH_{1000}$ if $RH_{1000} > RH_T$)
  - Coefficient and scalar allowed for non-zero mixing ratio quantities ($m_yMR_y+b_y$ if $MR_y > 0$, otherwise m_yMR_y)



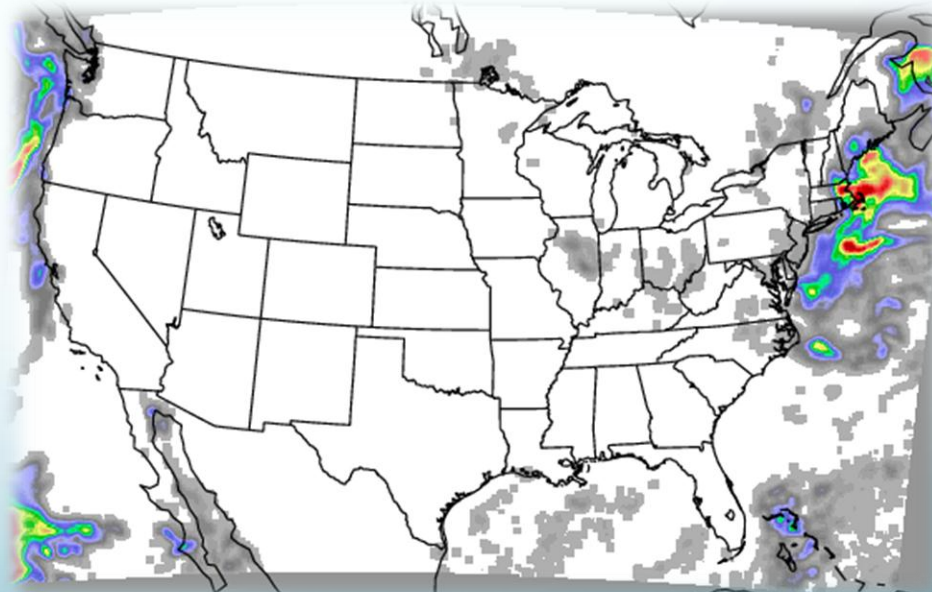
300 hPa Relative Humidity



500 hPa Cloud Ice Mixing Ratio



700 hPa Cloud Water Mixing Ratio



950 hPa Cloud Water Mixing Ratio

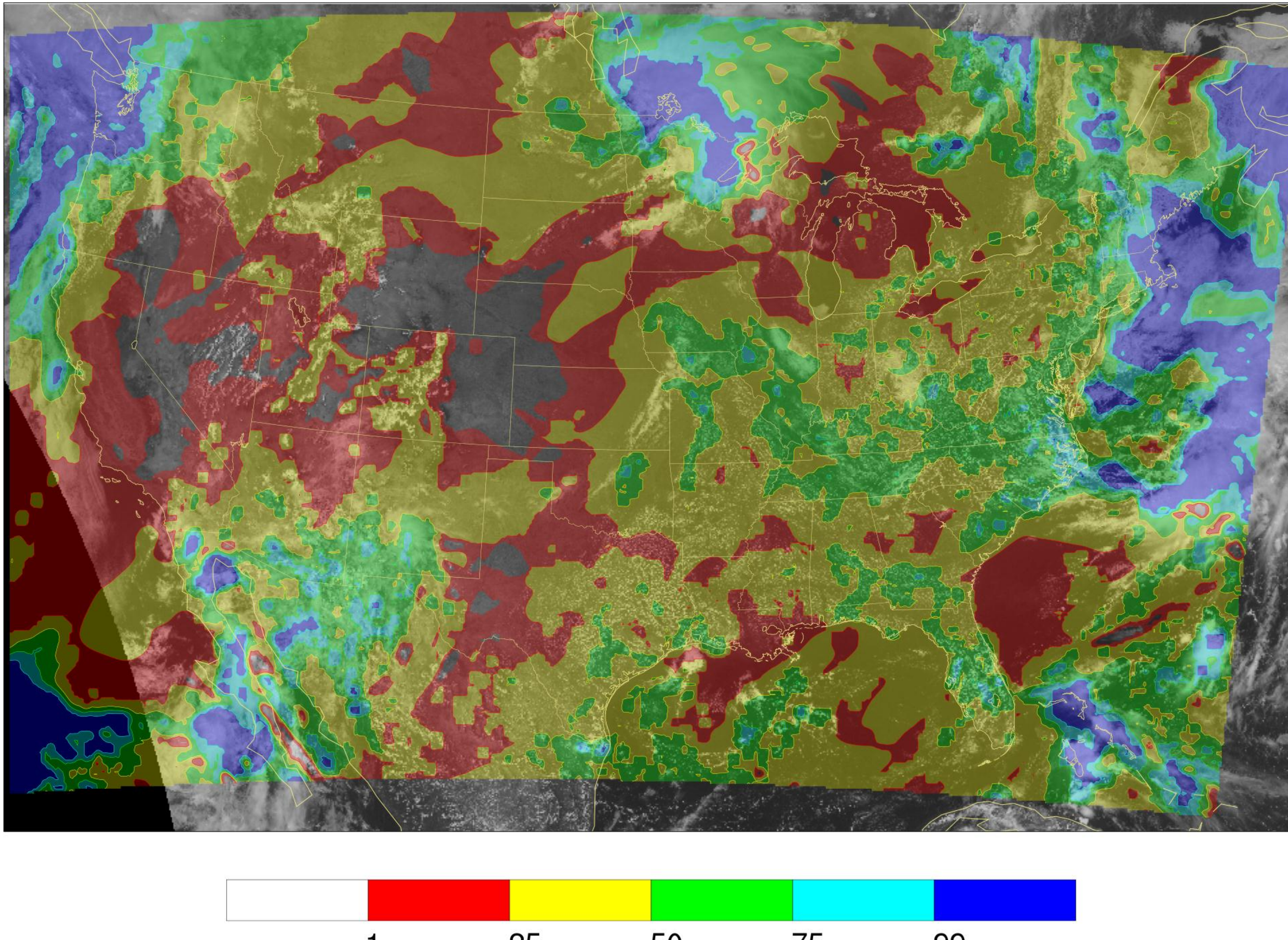
Optimizing Sky Cover

- Constraints:
  - Enforce physical relationships
    - Range of acceptable values (0 to 100)
    - Extent of relative humidity and absolute vorticity correlating to cloud
  - Enforce thresholds (mixed integer)
  - Maintain mean and approximate value distribution of output field to similarly match truth field
  - Guide optimizer
    - Away from scalar adjustments, toward coefficient adjustments (maintain spatial gradients)

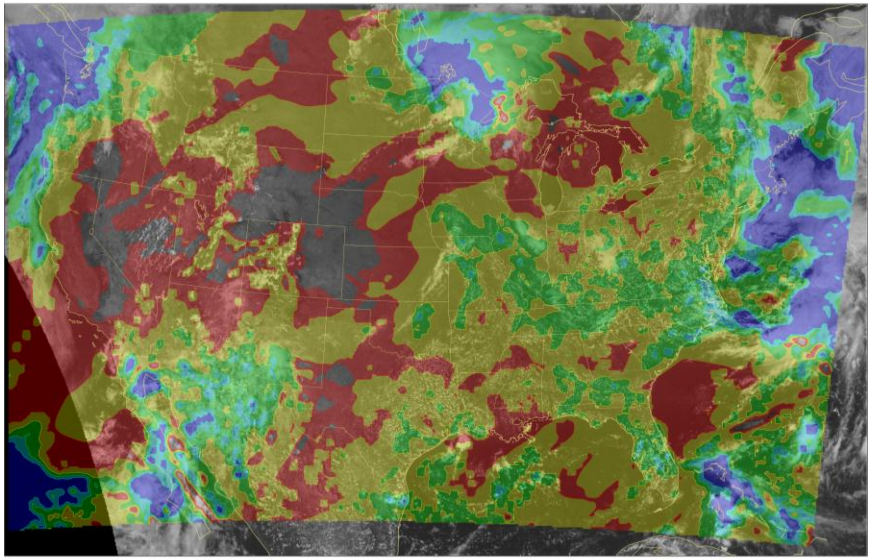
Sky Cover Comparison

Thu Aug 29 18:00:00 UTC 2013

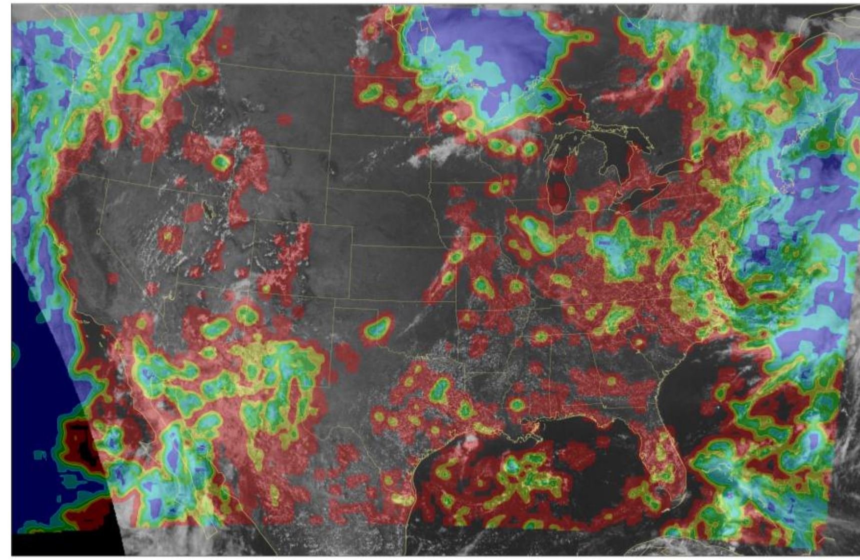
HRRR Optimal Sky Cover (%)



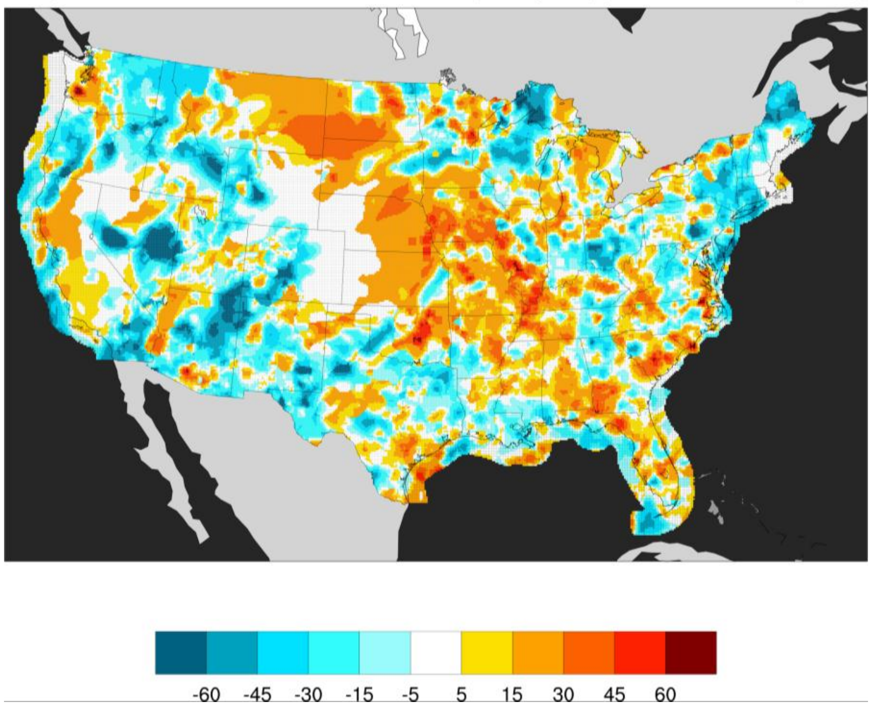
Thu Aug 29 18:00:00 UTC 2013 HRRR Optimal Sky Cover (%)



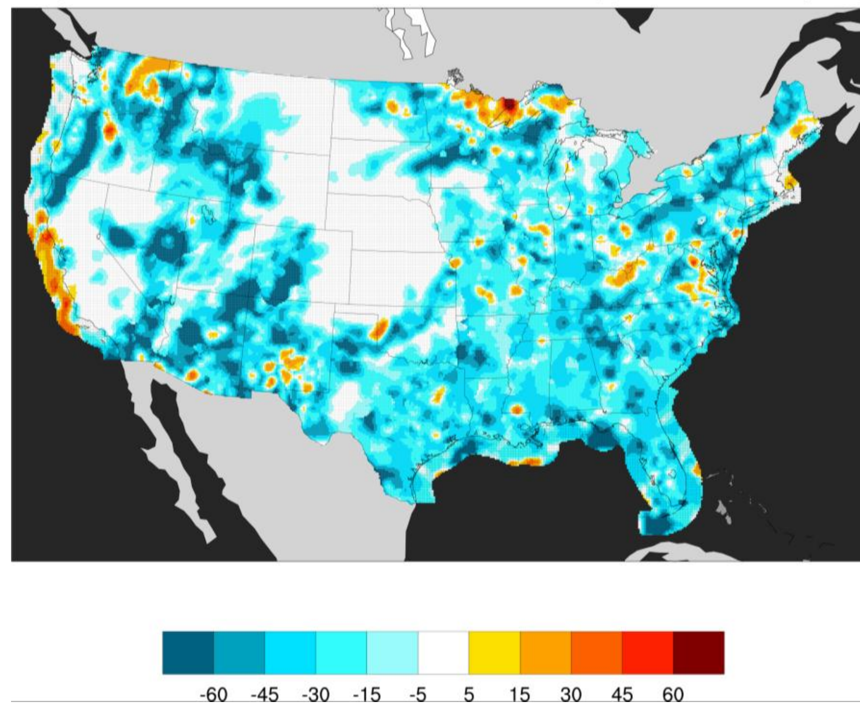
Thu Aug 29 18:00:00 UTC 2013 HRRR Total Cloud Cover (%)



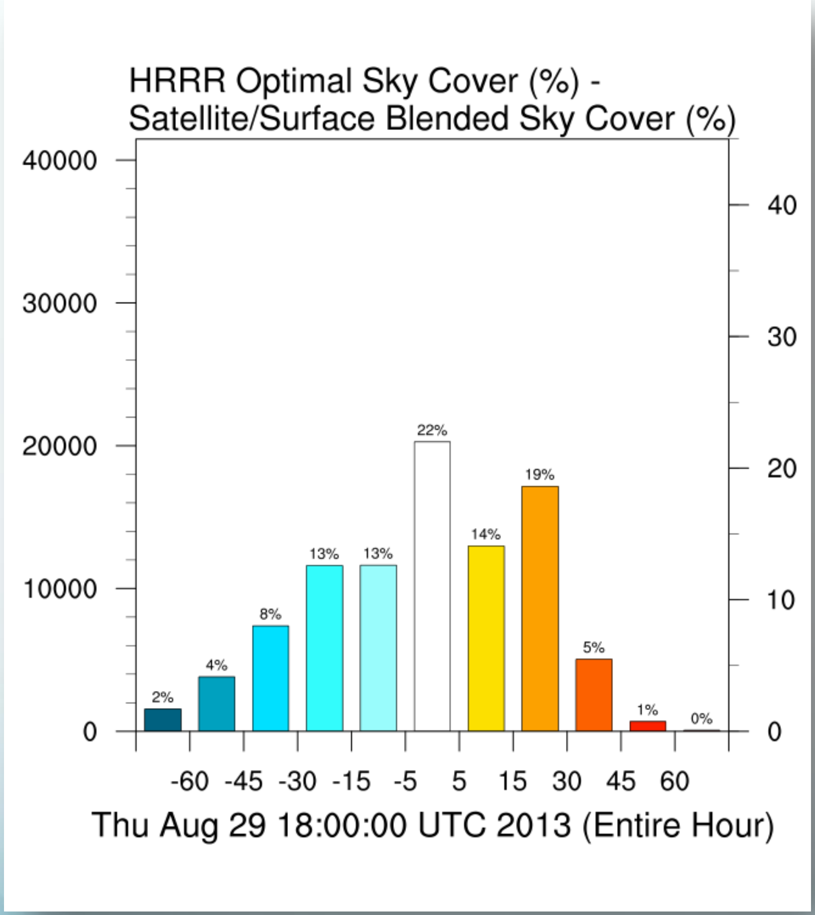
Thu Aug 29 18:00:00 UTC 2013 HRRR Optimal Sky Cover (%) - Satellite/Surface Blended Sky Cover (%)

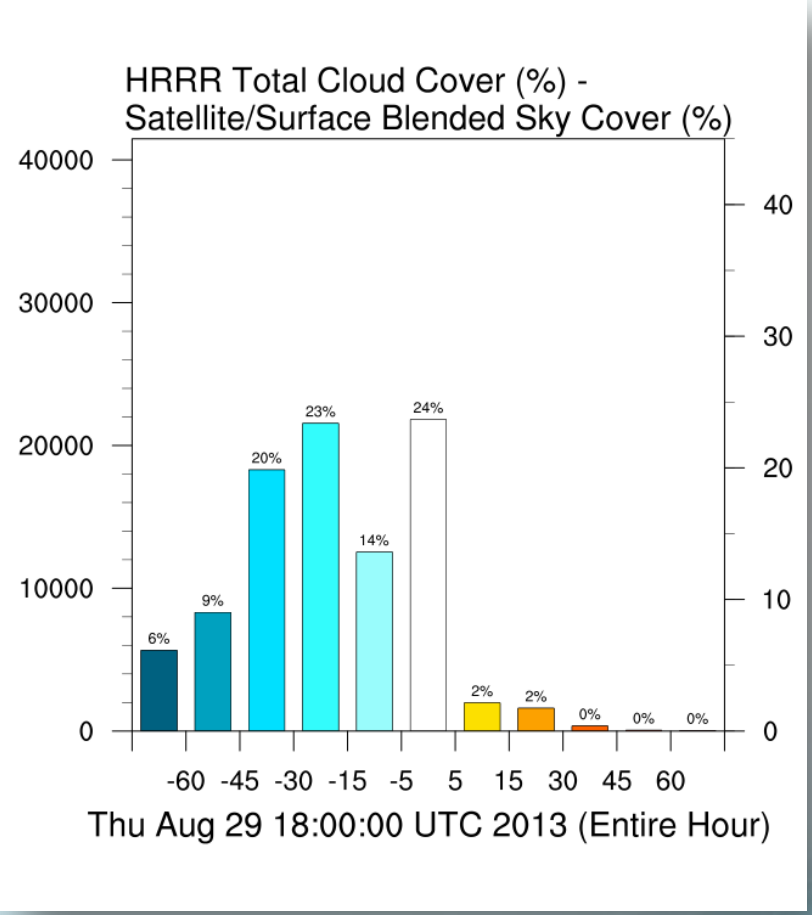


Thu Aug 29 18:00:00 UTC 2013 HRRR Total Cloud Cover (%) - Satellite/Surface Blended Sky Cover (%)

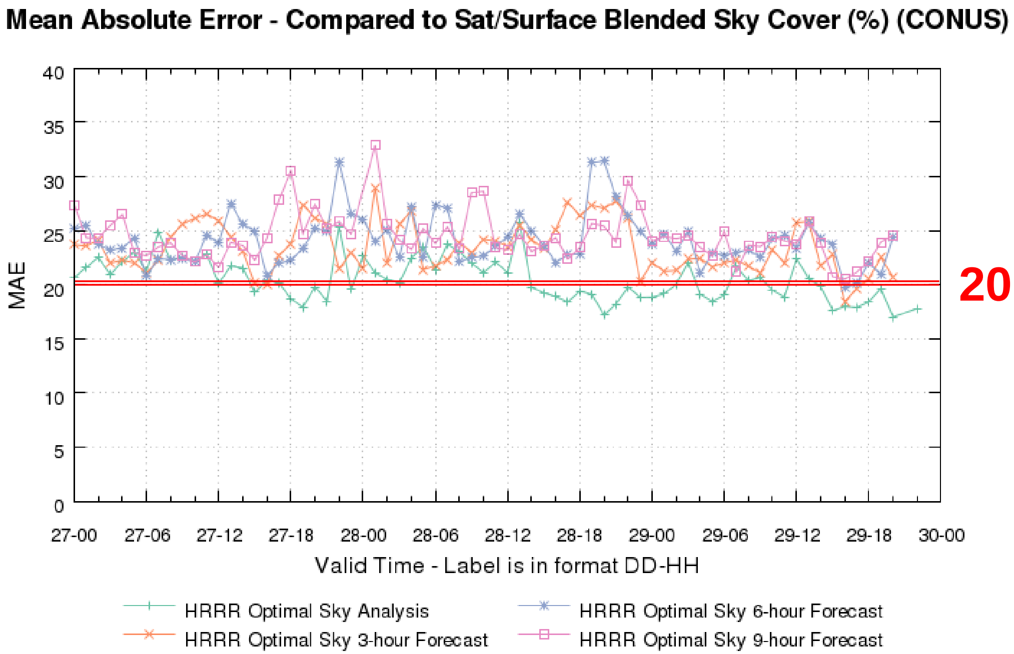


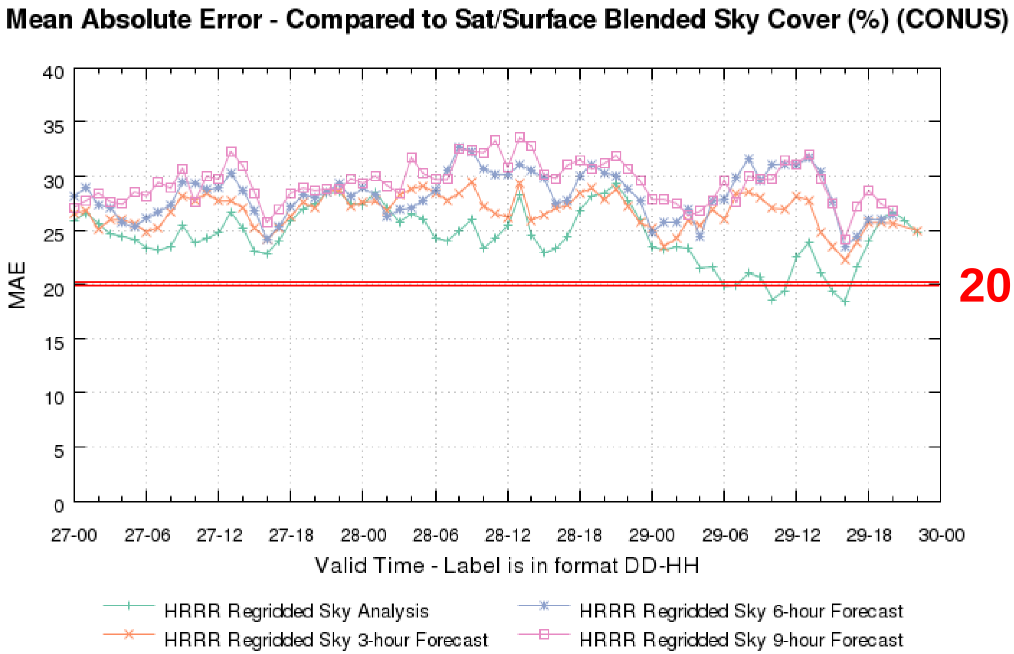
Preliminary Results





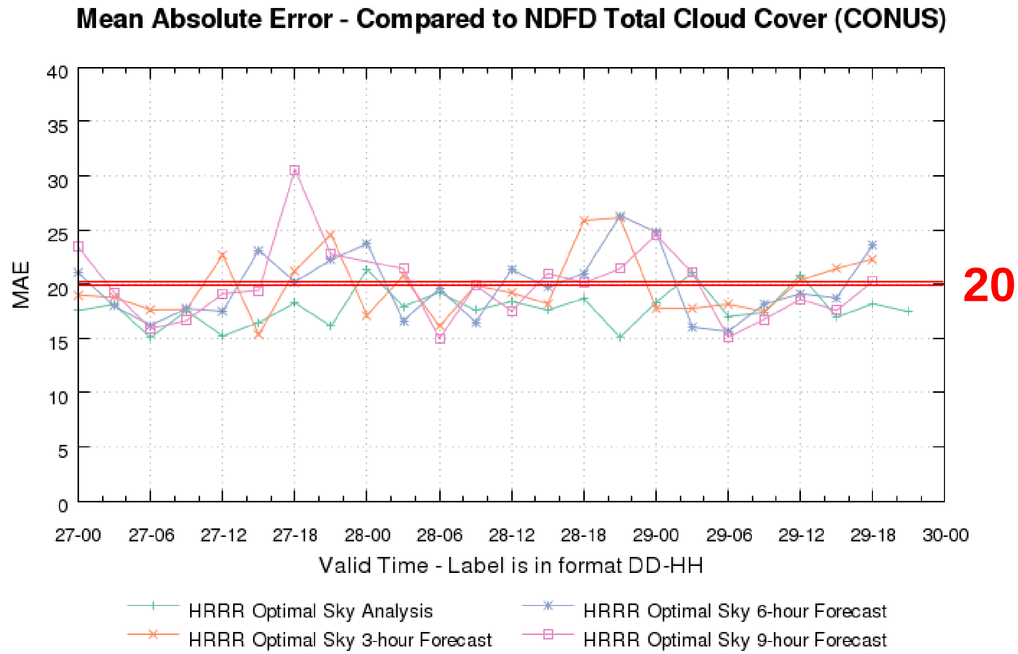
Optimizing Sky Cover

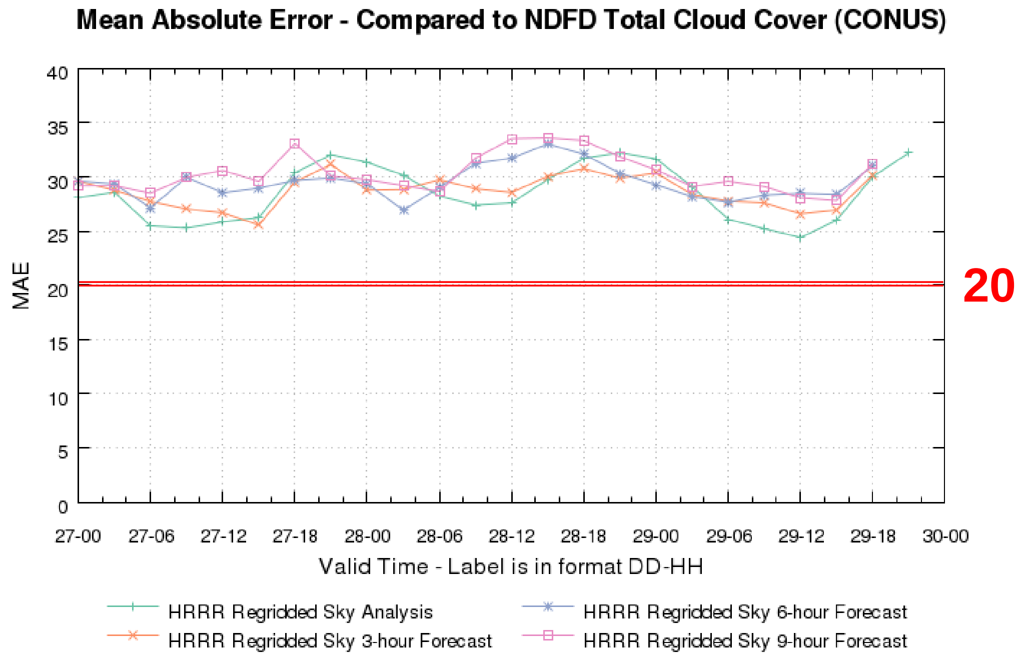




Preliminary Results

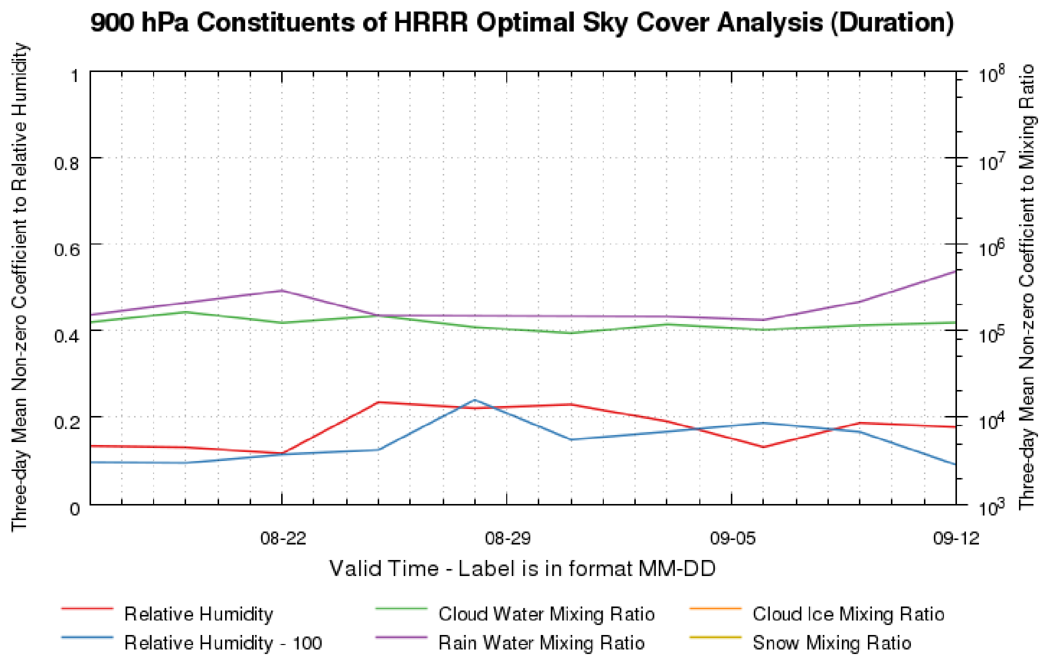
Optimizing Sky Cover

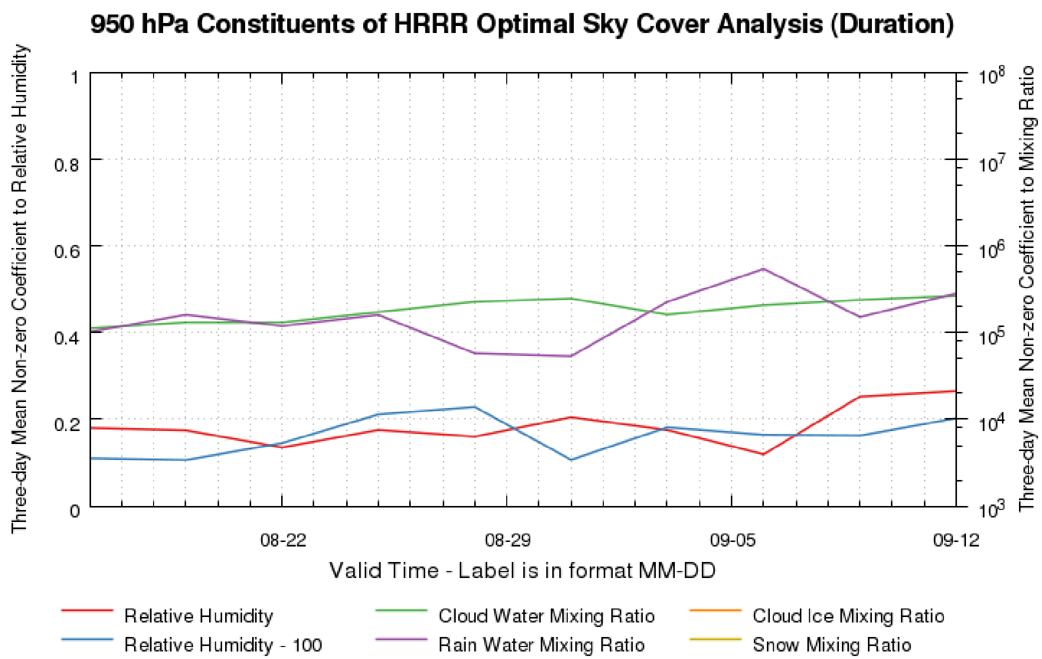




Preliminary Results

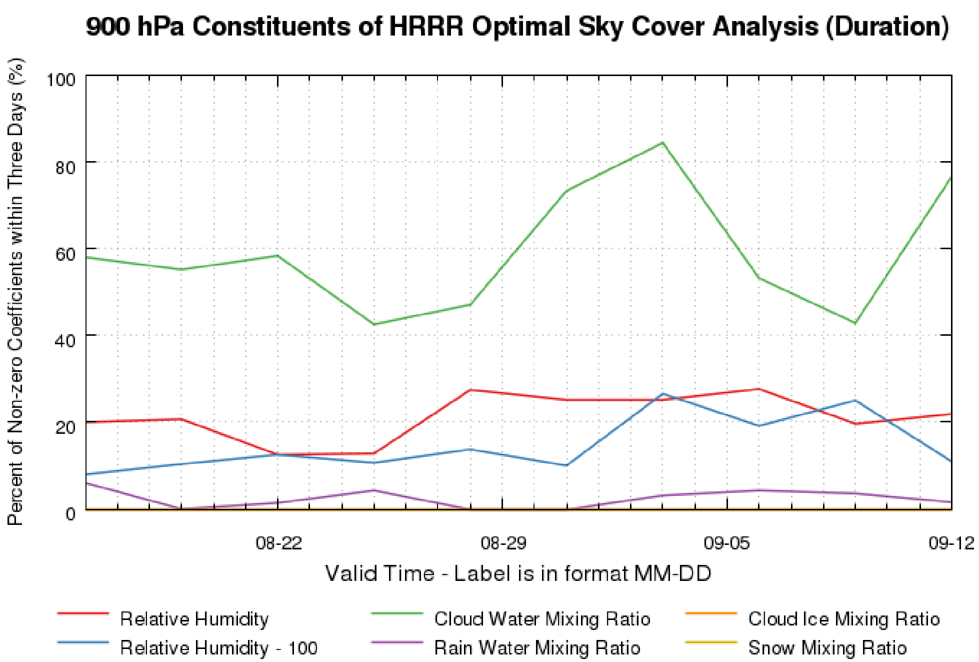
Optimizing Sky Cover

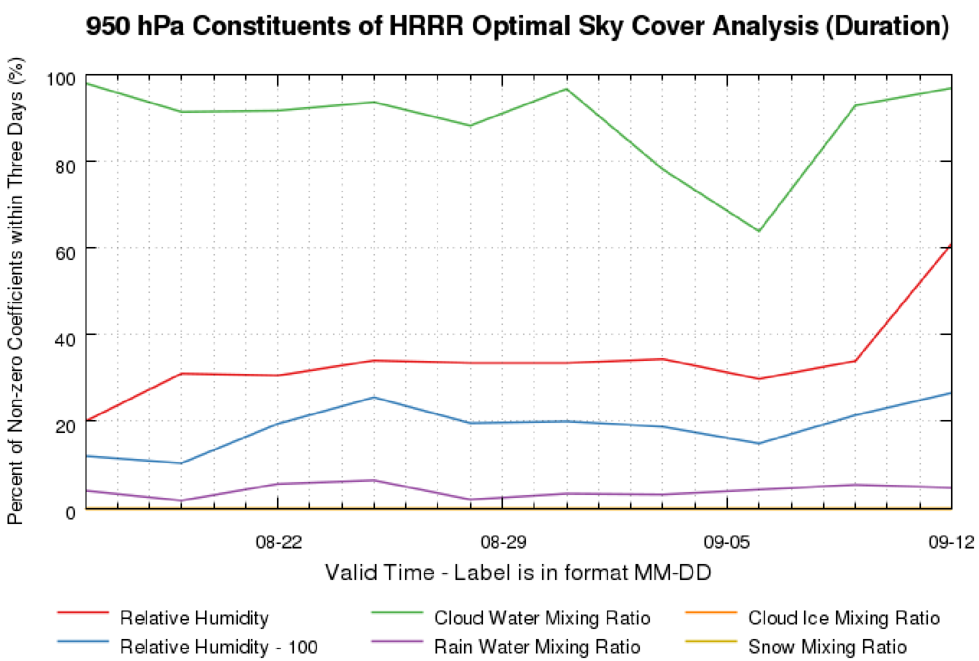




Preliminary Results

Optimizing Sky Cover





Preliminary Results

Preliminary Results

- Results are from 13 August to 12 September 2013 over the United States.
- 950 hPa cloud water mixing ratio is the most frequently selected field in the solved affine relationship.
  - Cloud water mixing ratio from one or more levels in the lower troposphere is frequently correlated with sky cover.
- Higher in the troposphere, there is less reliance on cloud water mixing ratio and more reliance on relative humidity.
- Snow mixing ratio and rain mixing ratio are not commonly included in optimized formulations.
  - Indicates limited model skill on placement of summertime precipitation processes in input prediction model

Summary

- An hourly blended sky cover analysis was produced using multiple sources of sky cover observations.
- Depending on the dataset, the mean value of all observations varies.
  - Surface observations are the clearest.
- The adjusted analysis was used to build better numerical weather prediction model output of sky cover, using an optimization methodology.
- The new model output compared to the adjusted analysis (truth) and NDFD one-hour forecast consistently has less mean absolute error than the original/current output.
- Future work will focus on the short-term forecasts.

Questions? Comments?

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