Cloud / Solar Analysis and Forecasting with LAPS

Steve Albers, Zoltan Toth, Yuanfu Xie, Hongli Jiang, Paul Schultz

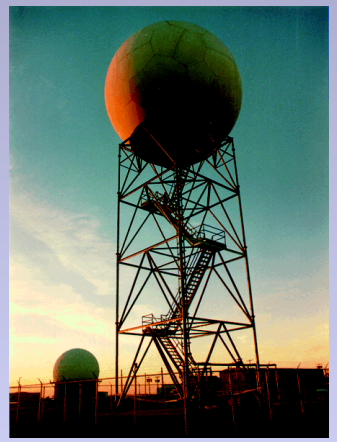
NOAA/ESRL/GSD/FAB & CIRA

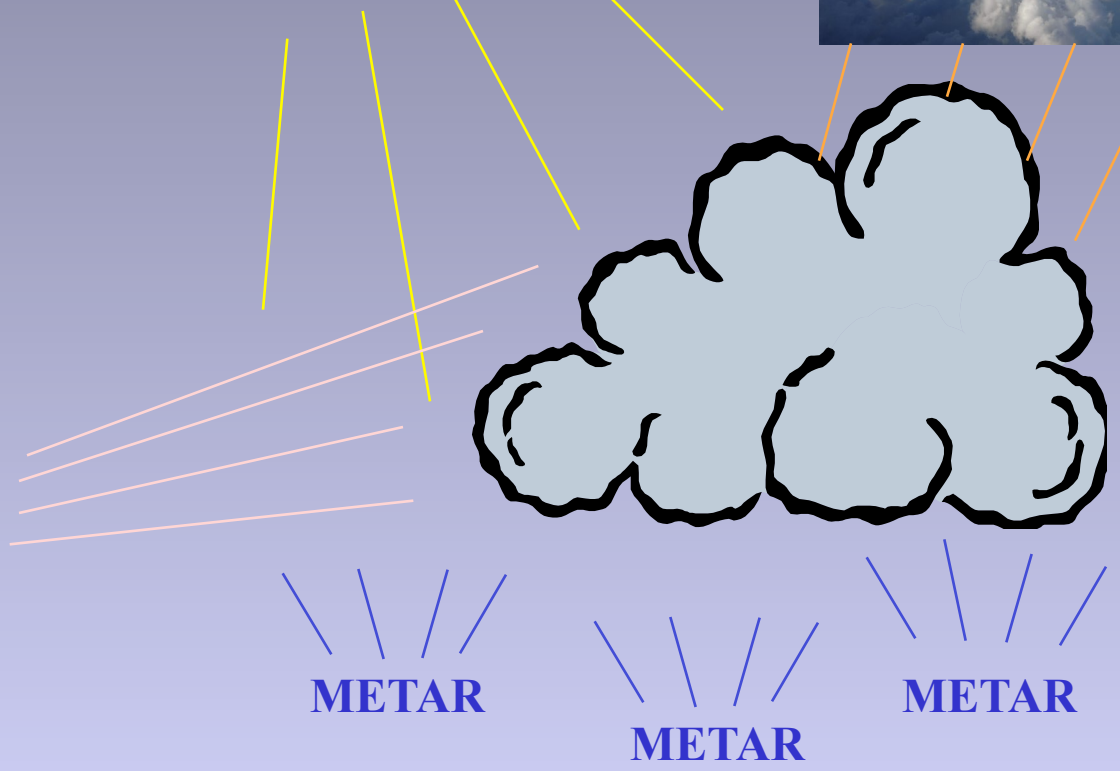
2nd LAPS User Workshop

October, 2012

LAPS Cloud analysis

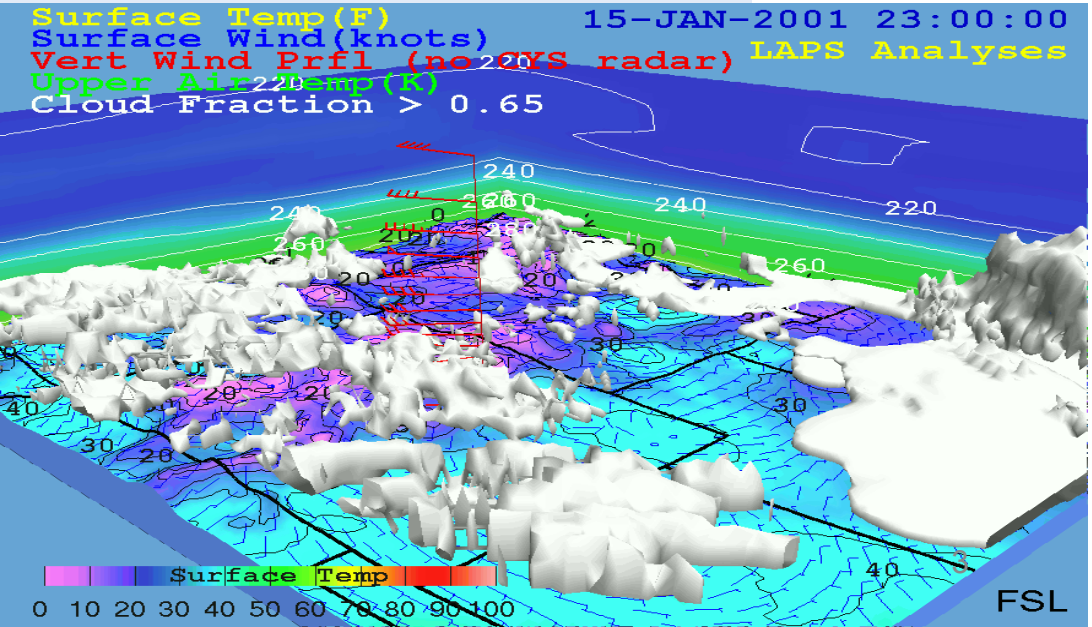
First Guess →

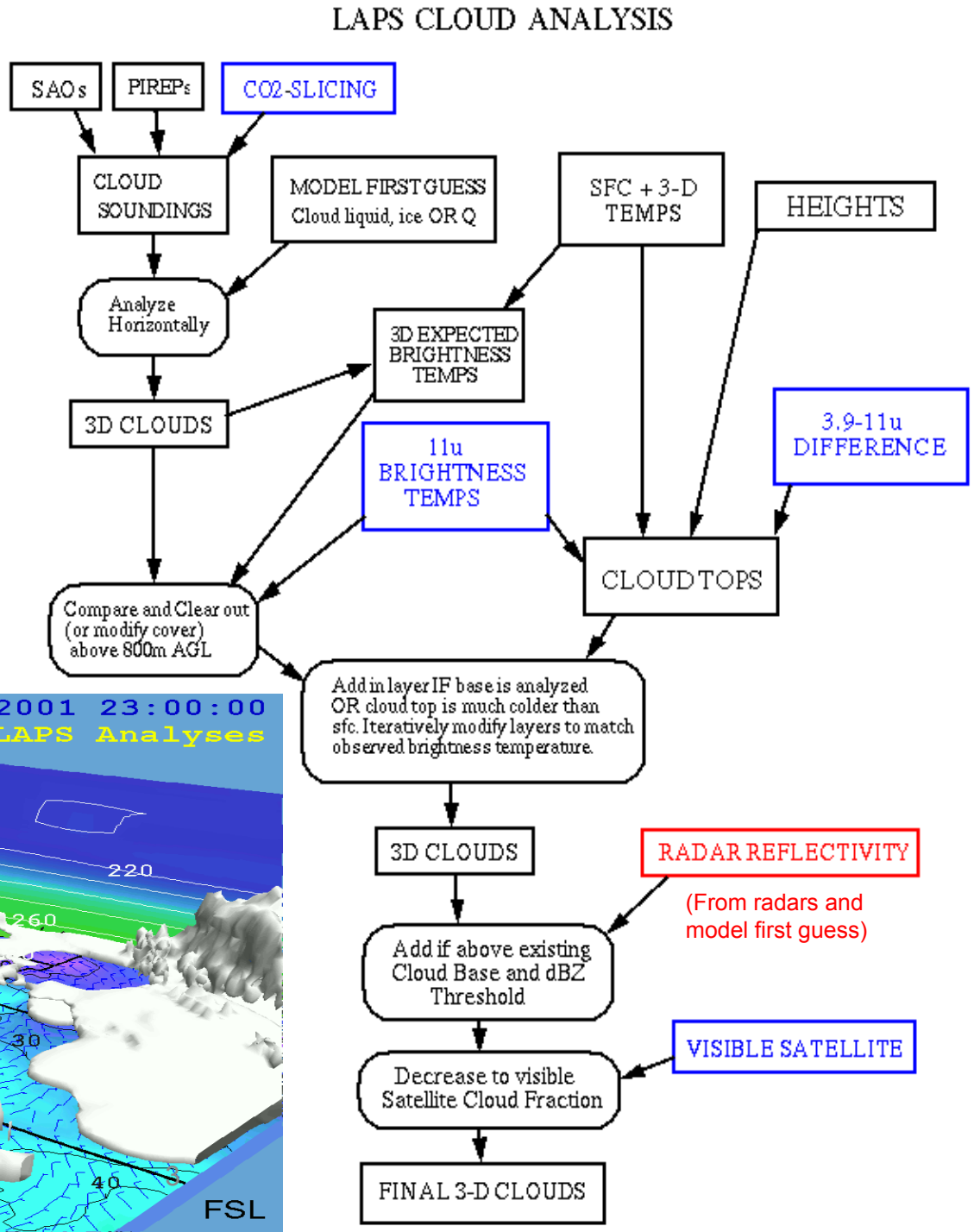




Cloud Analysis Flow Chart

Cloud Fraction 3-D Isosurface



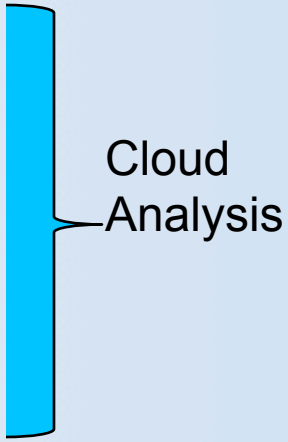


Satellite use in LAPS / STMAS

(GOES / SEVIRI*)

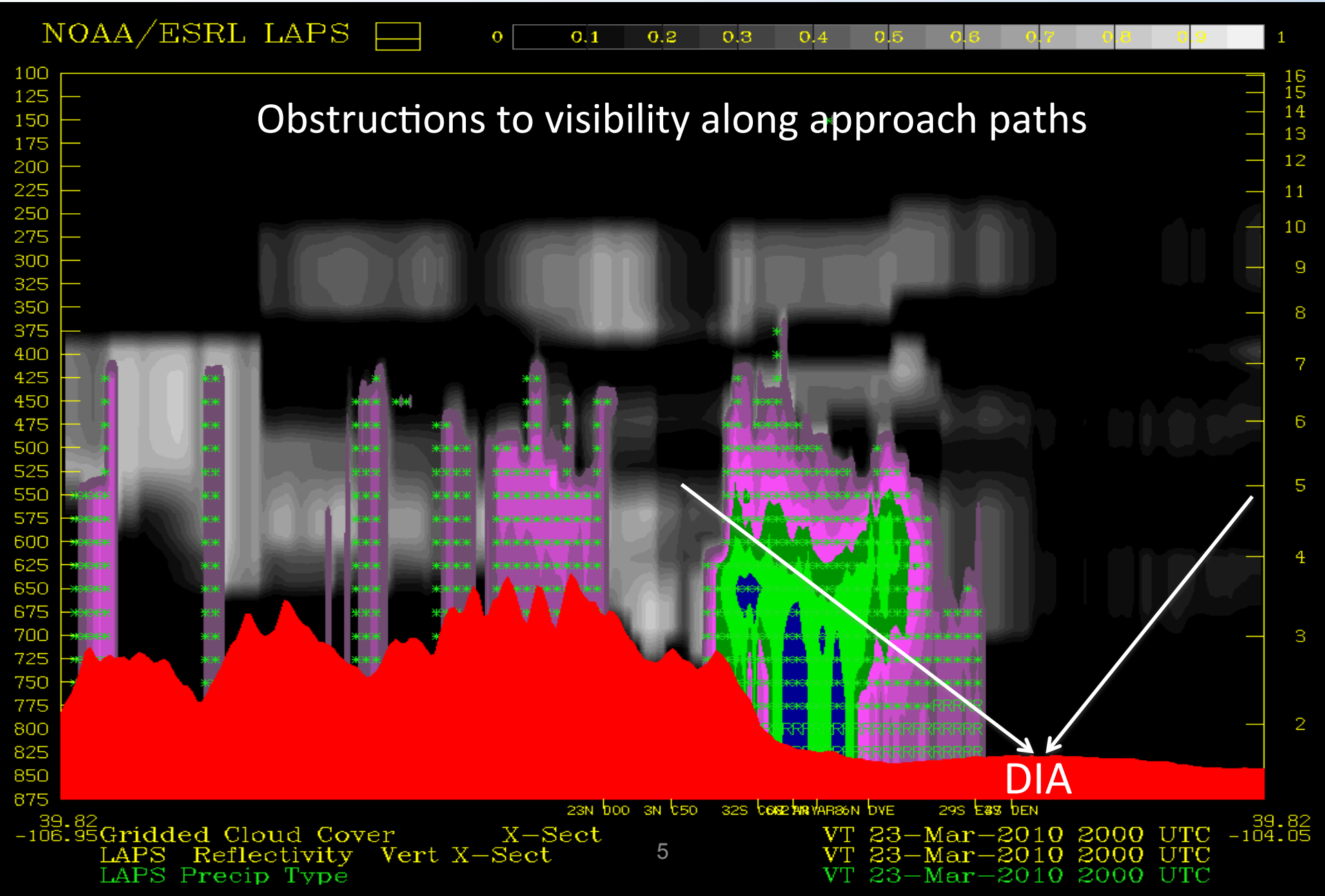
- 11 micron IR (Imager)
- 3.9 micron data (Imager)
- Visible (Imager - with terrain albedo database)
- CO2-Slicing method (Cloud-top pressure)

**2010 Paper with Italian Collaborators*

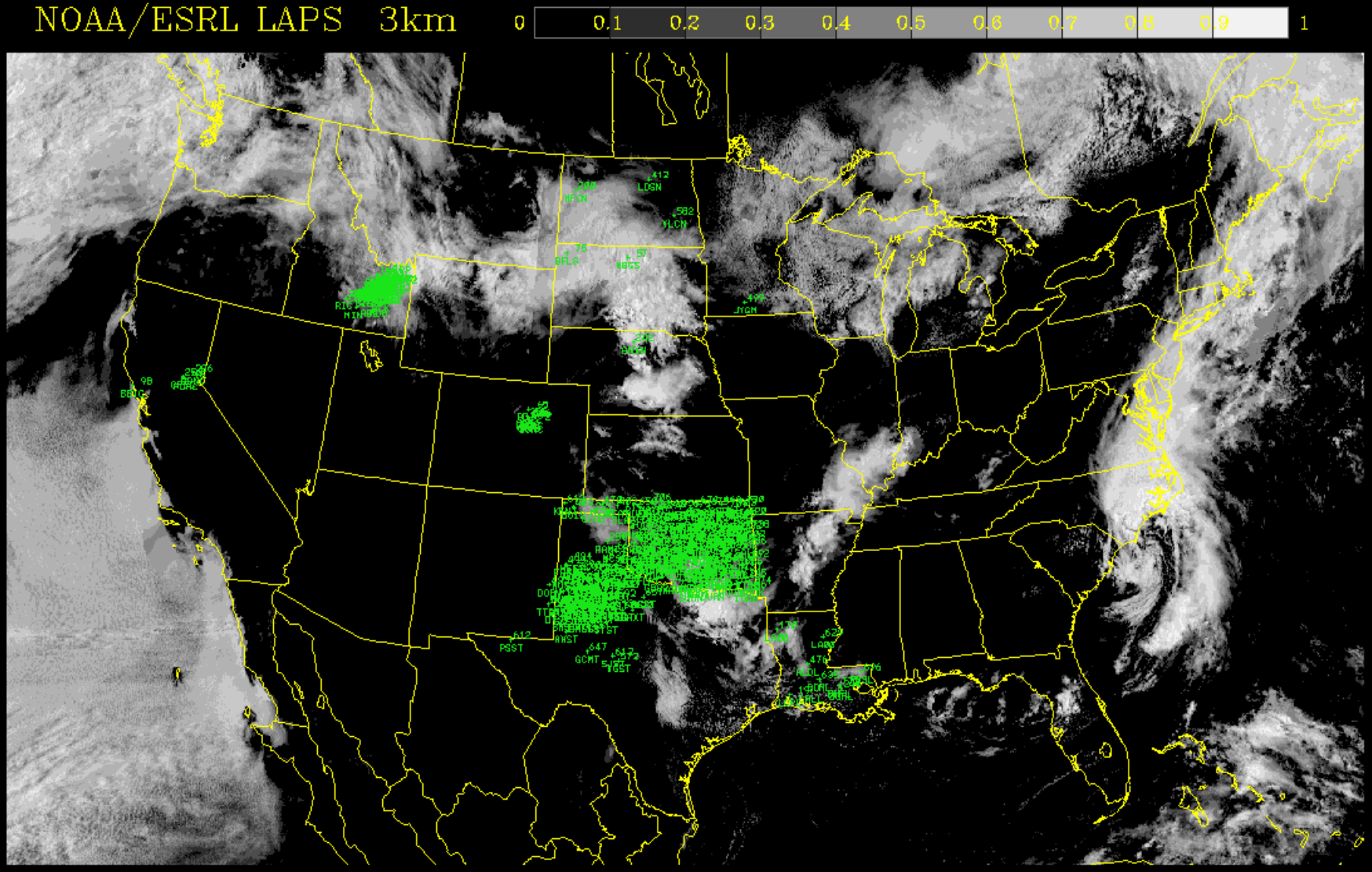


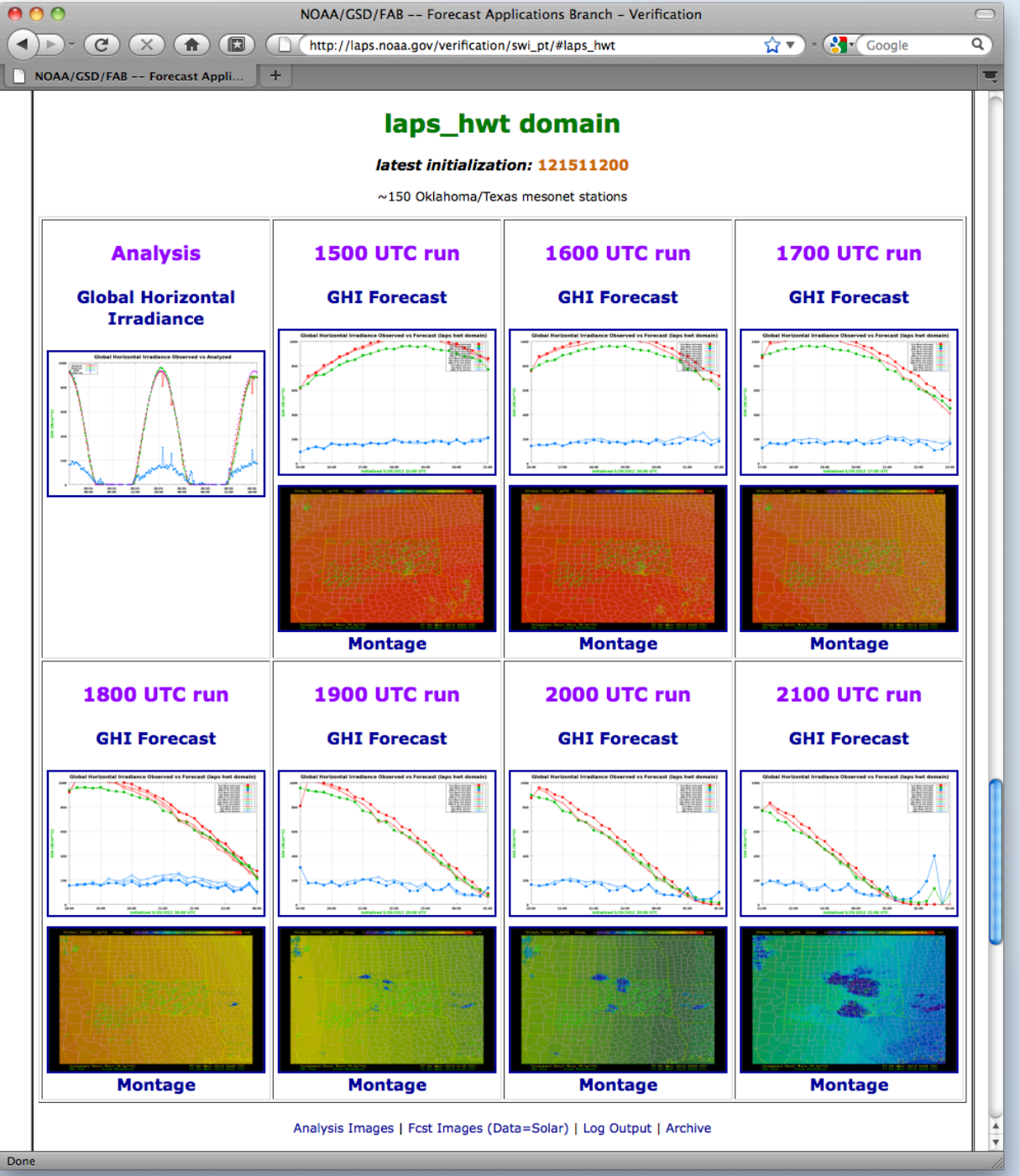
- Cloud-Drift Winds
- Retrieved Soundings (T, Td)

Cloud / Reflectivity / Precip Type (1km 15-min analysis)



MADIS Solar GHI Obs (<= 15min, Defined in Metadata)





Solar Radiation Web Page

Verified at station locations measuring global solar radiation on time scales <= 15min

Mean Analyzed / Forecast

Mean Observed

RMS differences

Global Horizontal Irradiance (GHI) Analysis

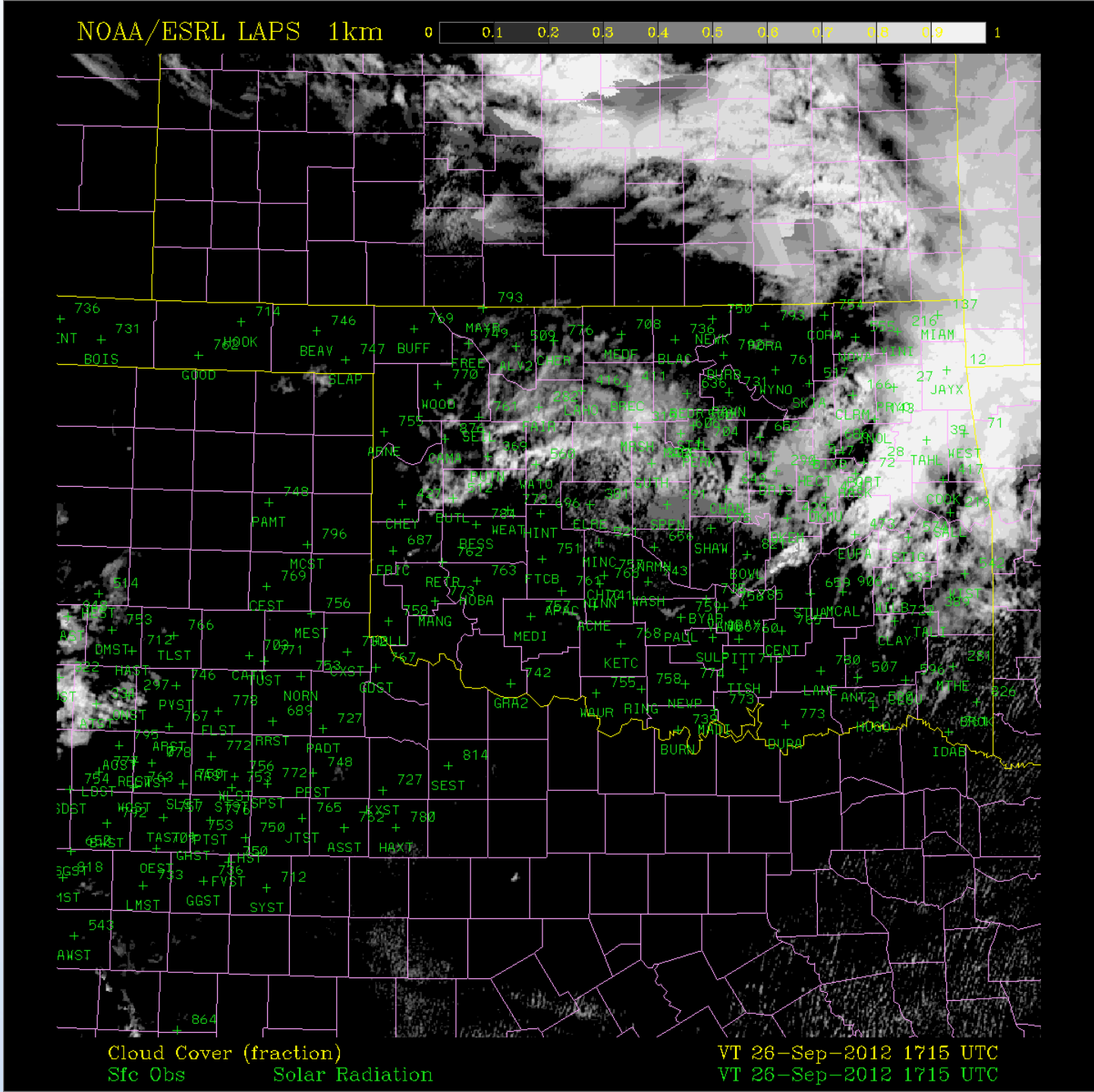
- Derived from 3-D cloud fraction analysis and simple clear-sky solar radiation calculation
  - High Resolution (e.g. 1km)
  - Rapid Update (e.g. 15min)
  - Compares well with independent observations

- GHI = I_o t a f
  - I_o = Top of Atmosphere Normal Incident Radiation
  - T = Overall Transmittance (0.73)
  - a = 0.9 * sin(altitude) + 0.1 * $\sin^2$(altitude)
  - f = cloud fraction term

LAPS 1-km Cloud Fraction Analysis with Independent GHI Obs. Overlay

3-Frames at 15-minute interval

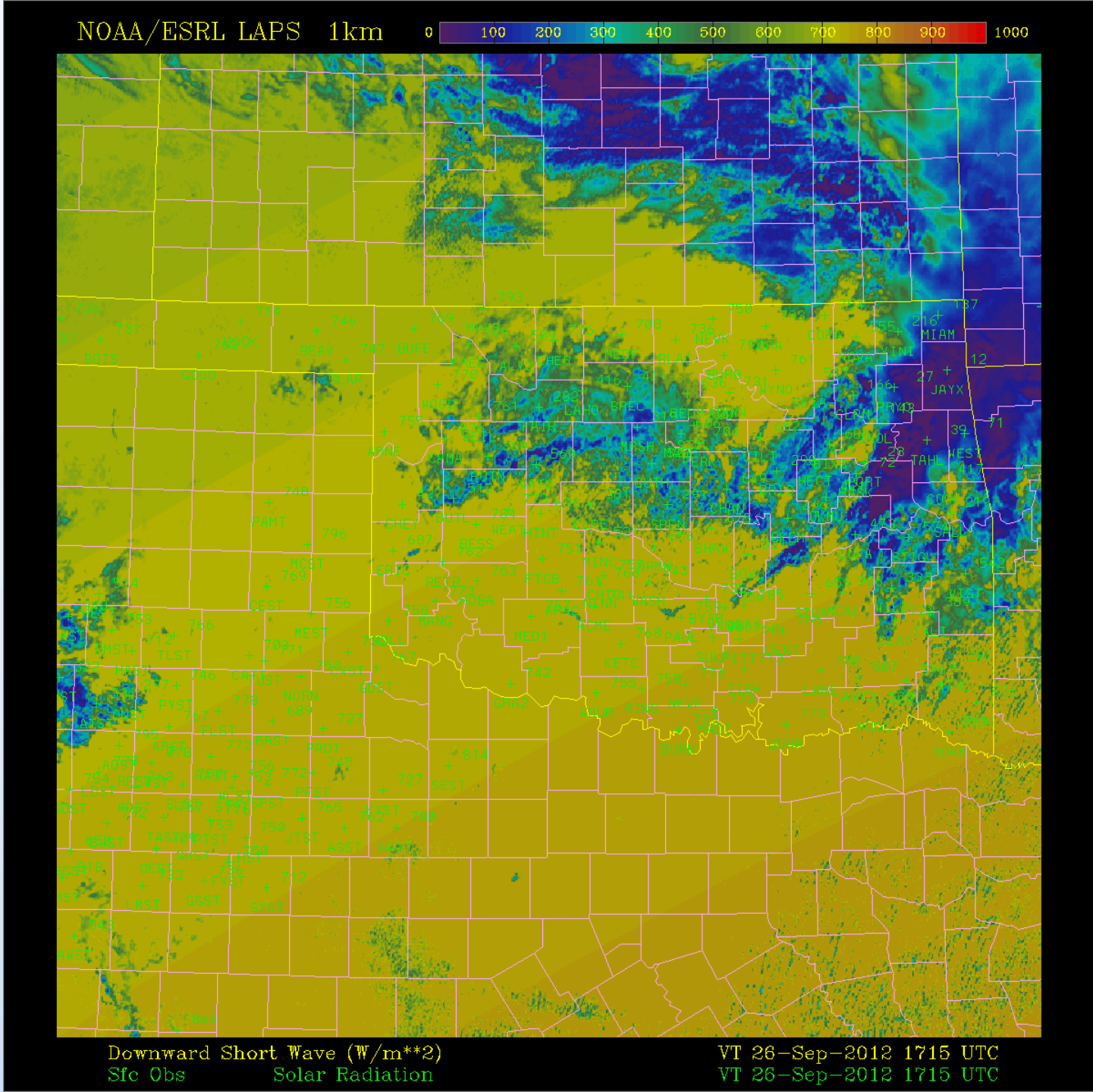
Utilizes GOES imagery and other data allowing rapid 1km resolution update



Global Horizontal Irradiance Analysis + Observations

3-Frames at 15-minute interval

Utilizes GOES imagery and other data within 3-D cloud analysis allowing rapid 1km resolution update

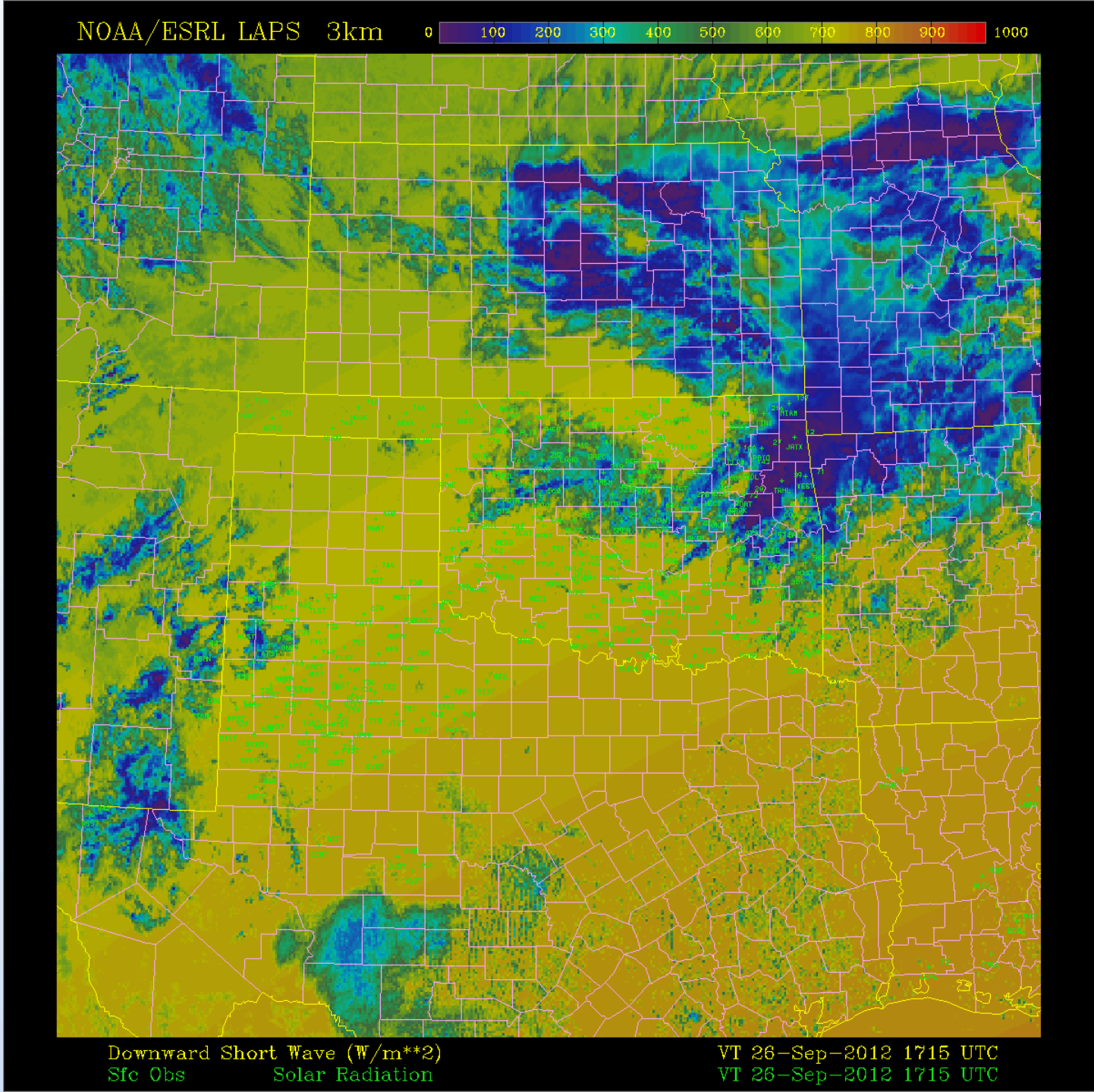


Global Horizontal Irradiance Analysis + Observations

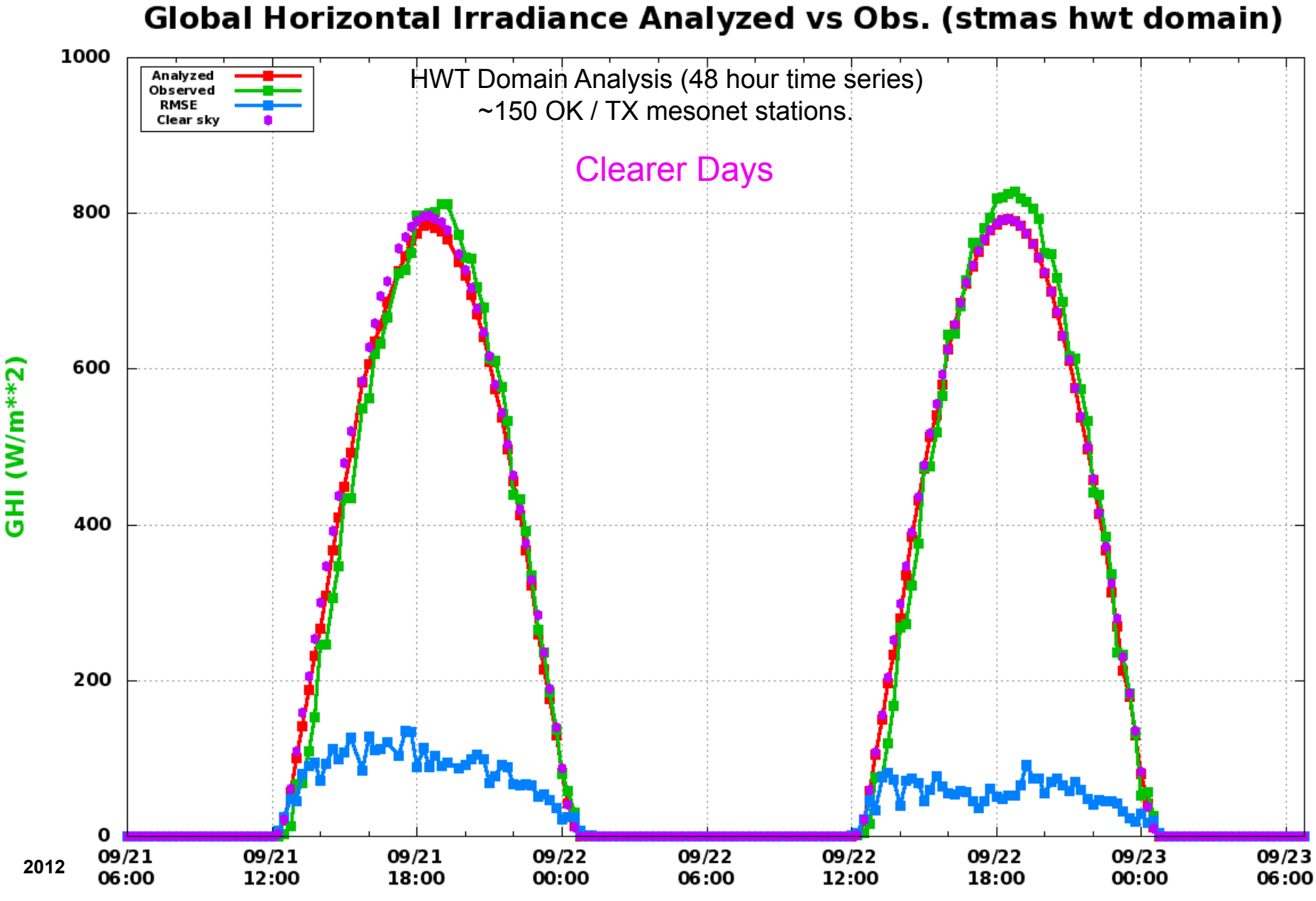
Partly Cloudy Case

3-Frames at 15-minute interval

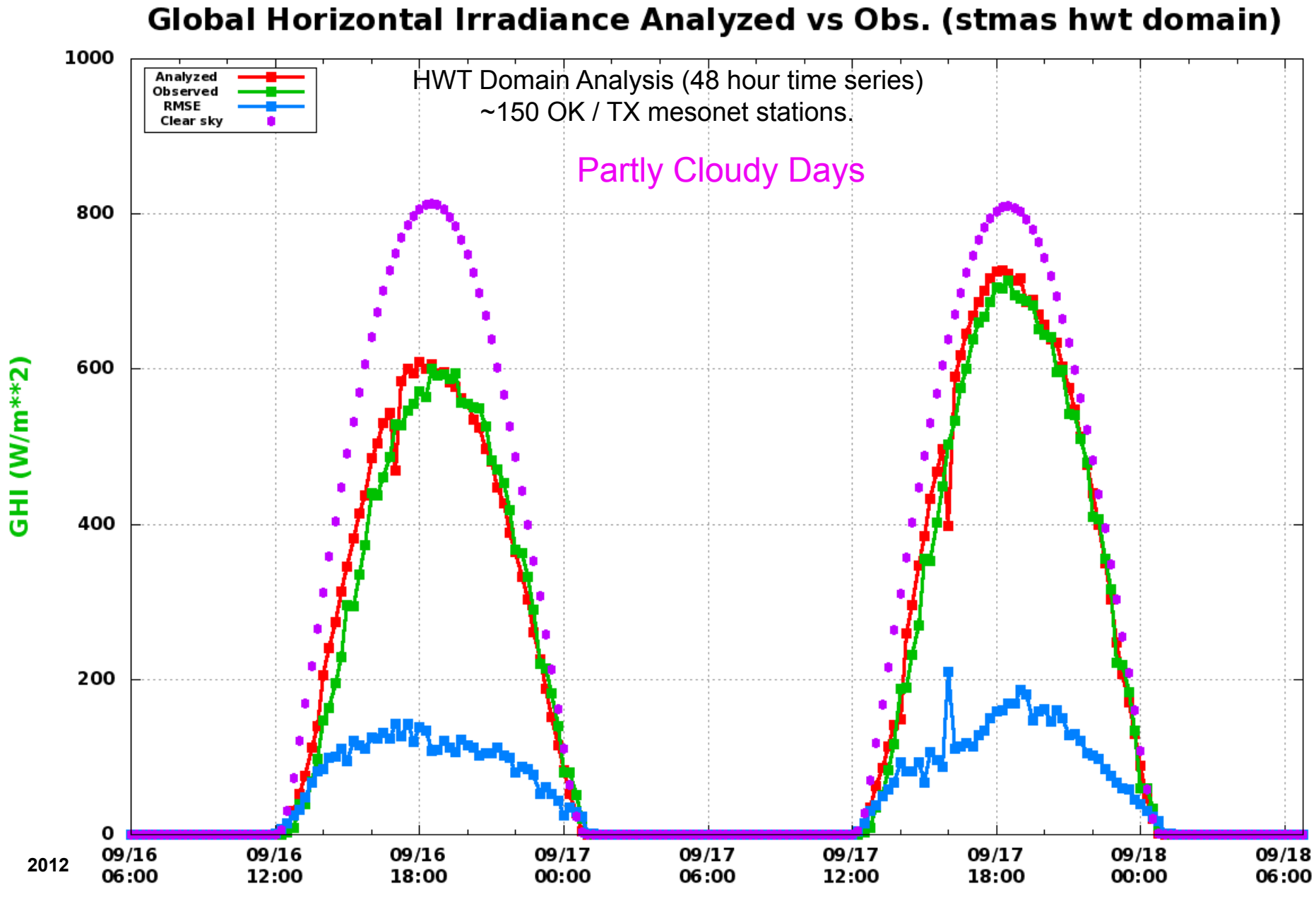
Utilizes GOES imagery and other data within 3-D cloud analysis allowing rapid 1km resolution update



Solar Radiation Analysis (GHI) Verification



Solar Radiation Analysis (GHI) Verification



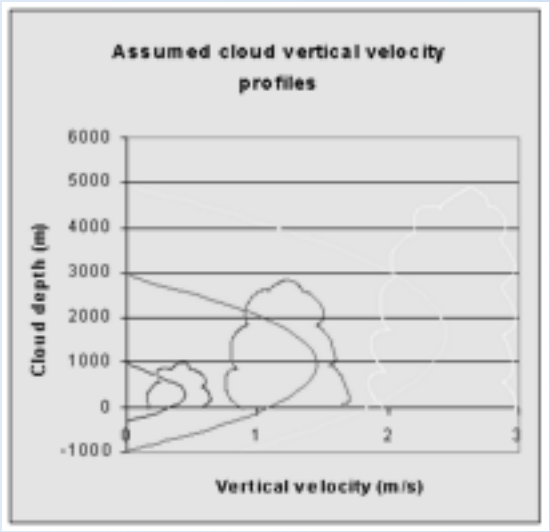
Global Horizontal Irradiance (GHI) Forecast

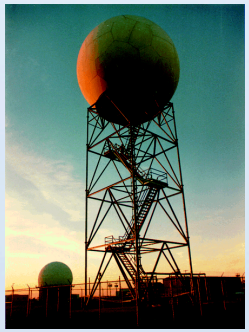
- **Generated from LAPS initialized WRF model**
  - Uses WRF Downward Short-Wave Radiation Output
  - Dudhia Short-Wave Scheme
  - Thompson Microphysics

- **"Hot-Start" procedure used to help get clouds into model**
  - Vertical Velocity / Horizontal Divergence
  - Temperature / Height Adjustment
  - Hydrometeor Assimilation
  - Consistent Water Vapor Fields

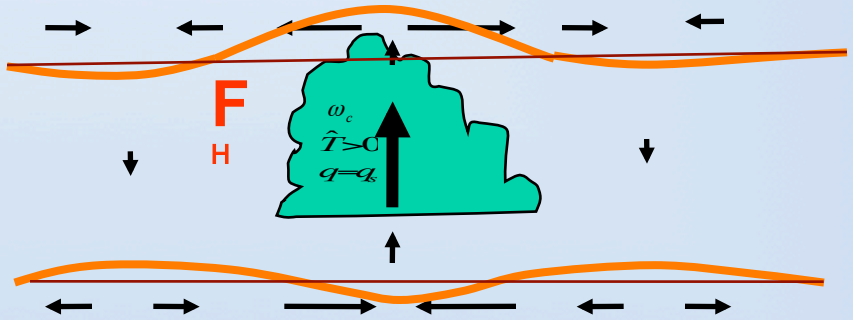
LAPS HOT START INITIALIZATION

Three-Dimensional Cloud Analysis

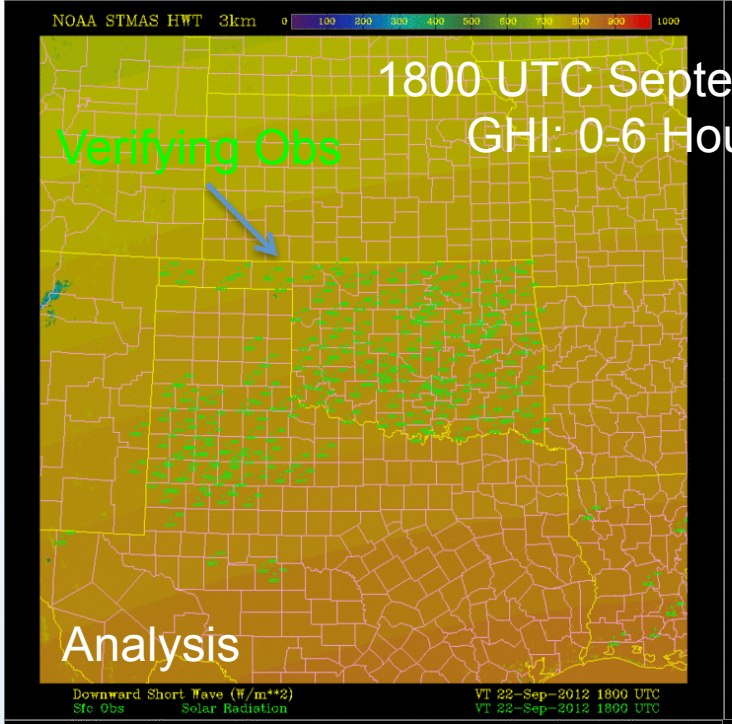


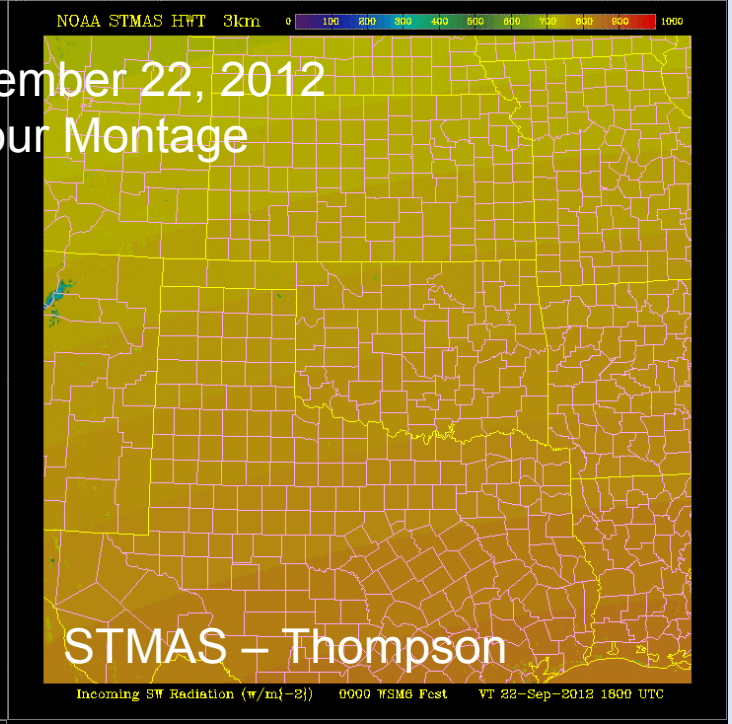


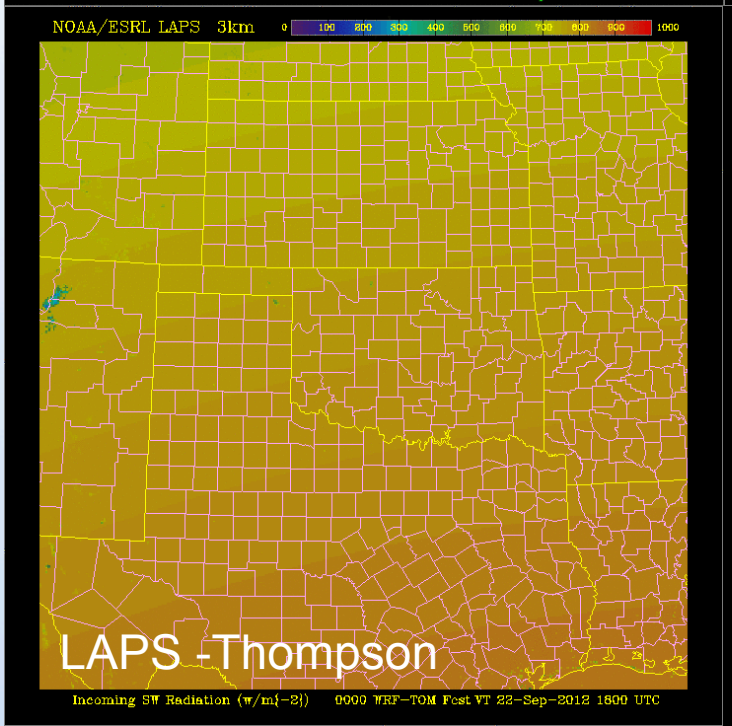
METAR



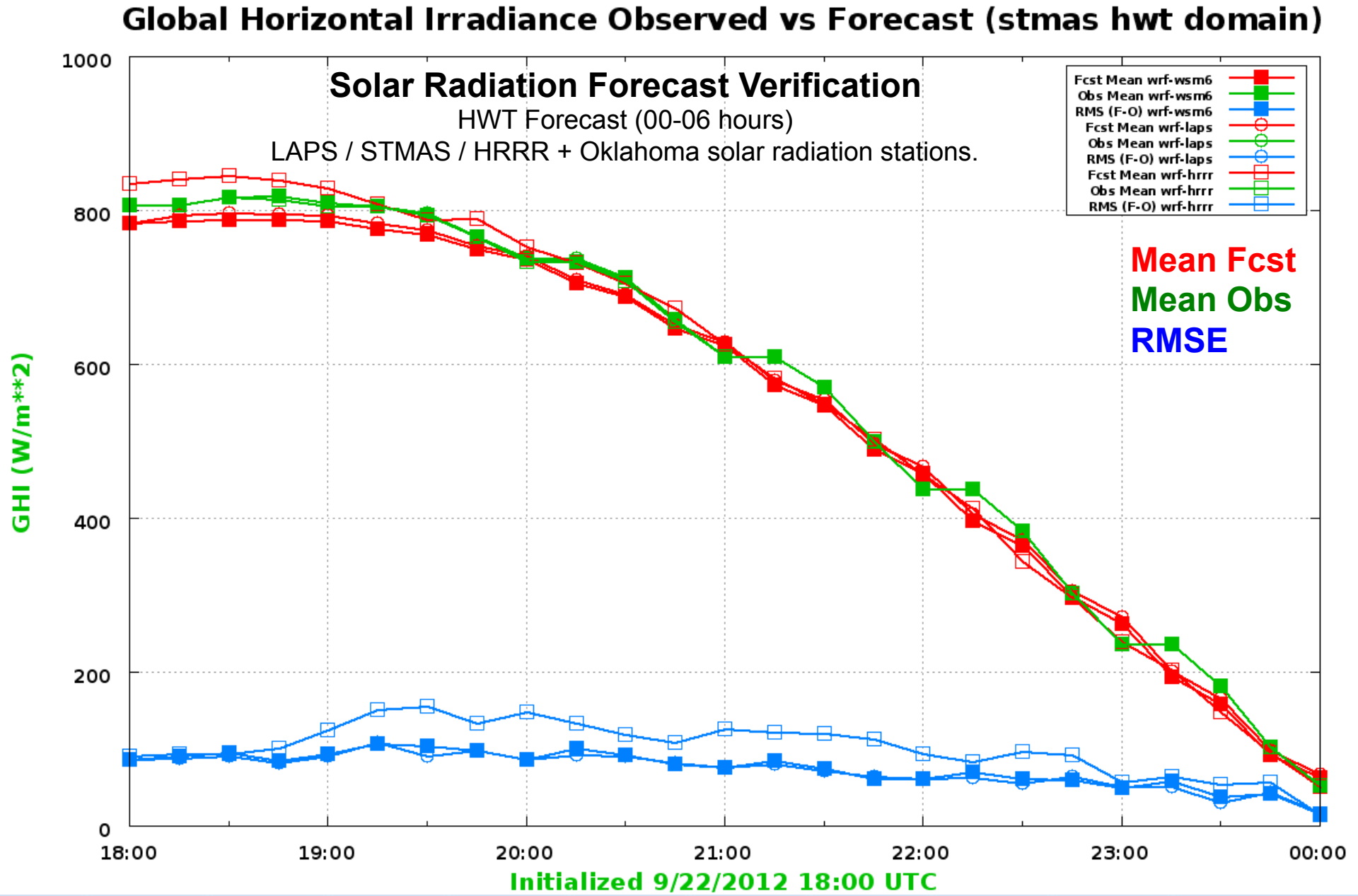
+ FIRST GUESS

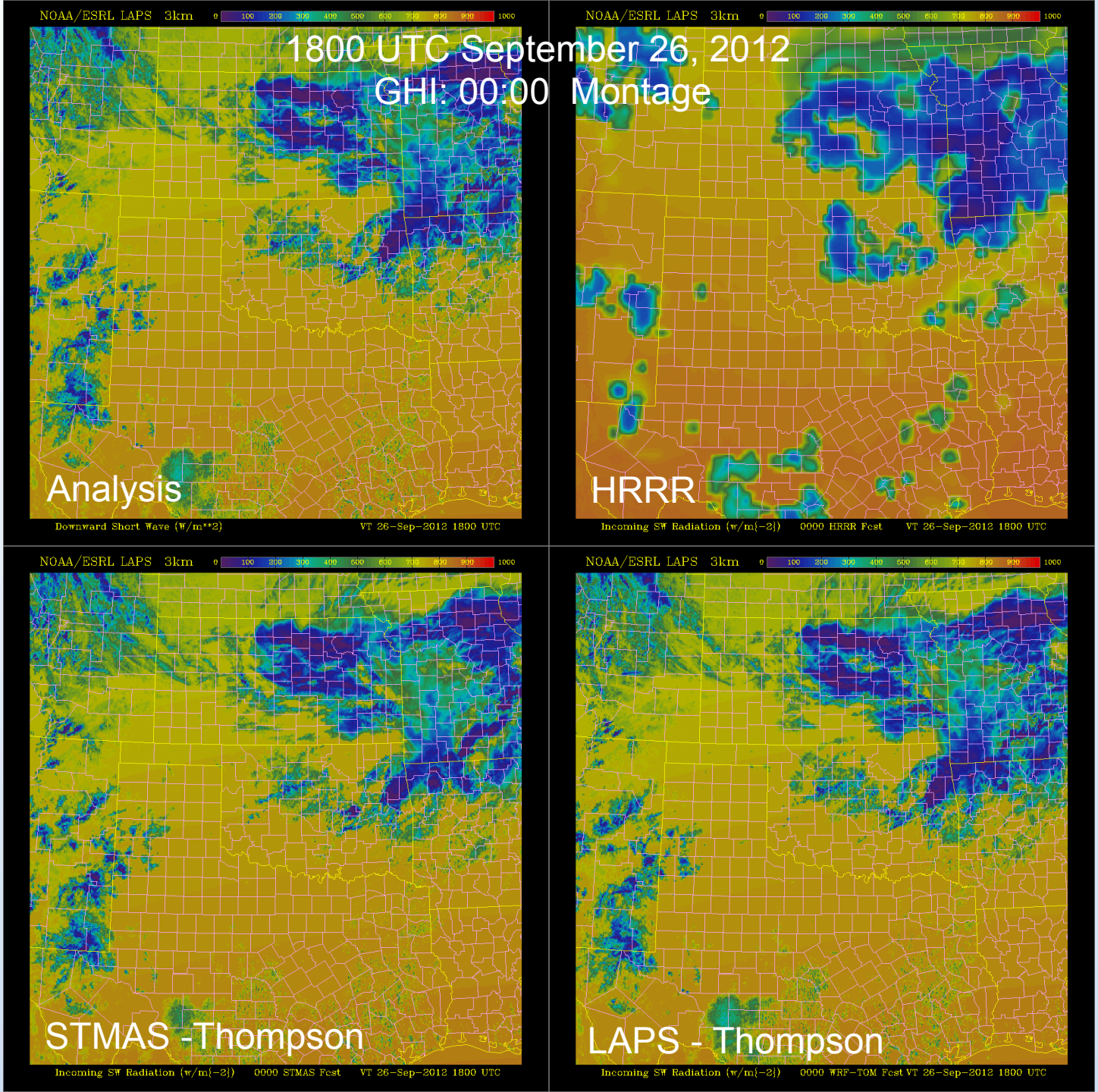

NOAA STMAS HWT 3km
0 100 200 300 400 500 600 700 800 900 1000
1800 UTC September 22, 2012
GHI: 0-6 Hour Montage
Verifying Obs
Analysis
Downward Short Wave (W/m**2)
Sfc Obs Solar Radiation
VT 22-Sep-2012 1800 UTC
VT 22-Sep-2012 1800 UTC

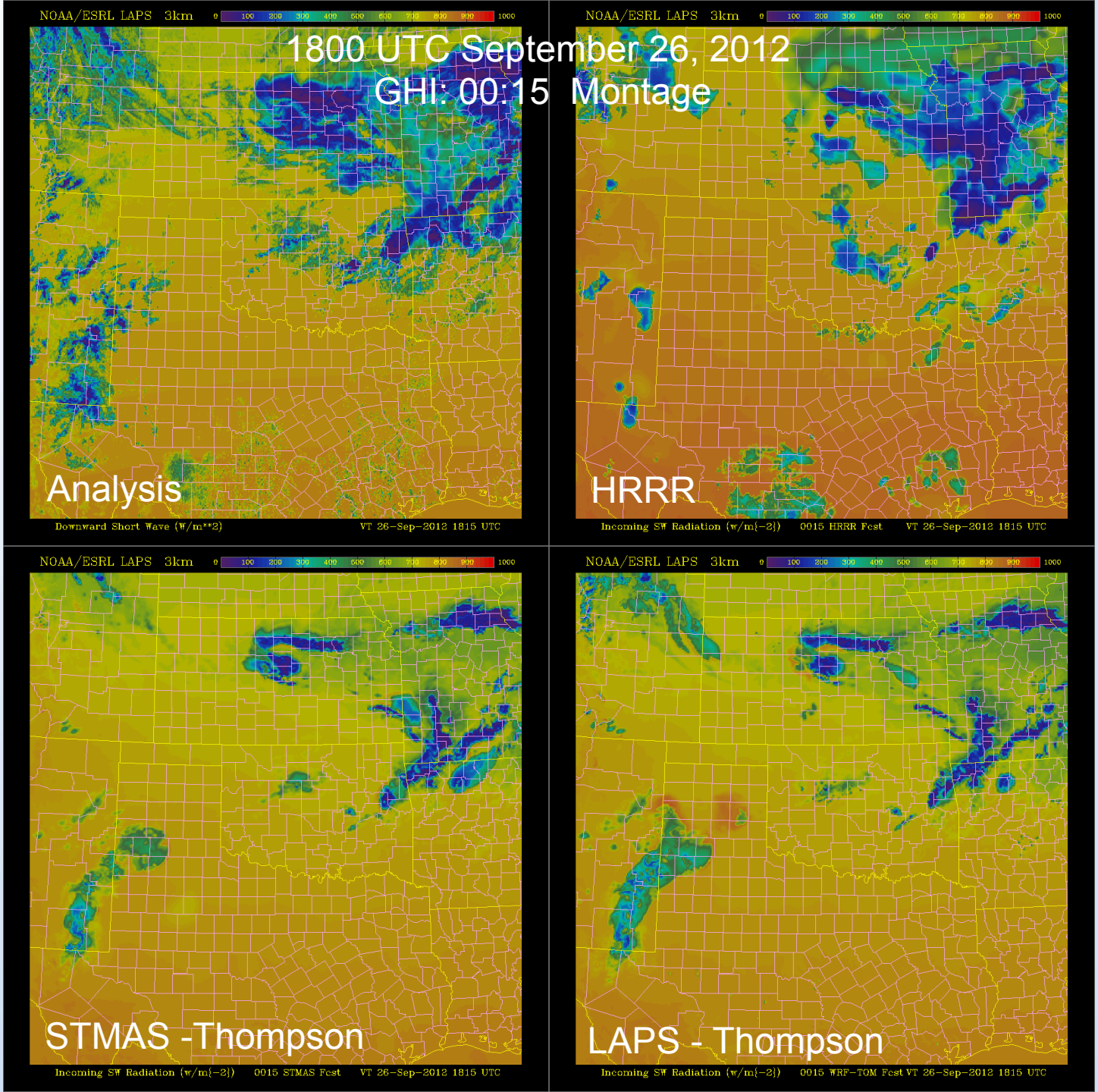

NOAA STMAS HWT 3km
0 100 200 300 400 500 600 700 800 900 1000
STMAS – Thompson
Incoming SW Radiation (w/m{-2}) 0000 WSM6 Fcst VT 22-Sep-2012 1800 UTC

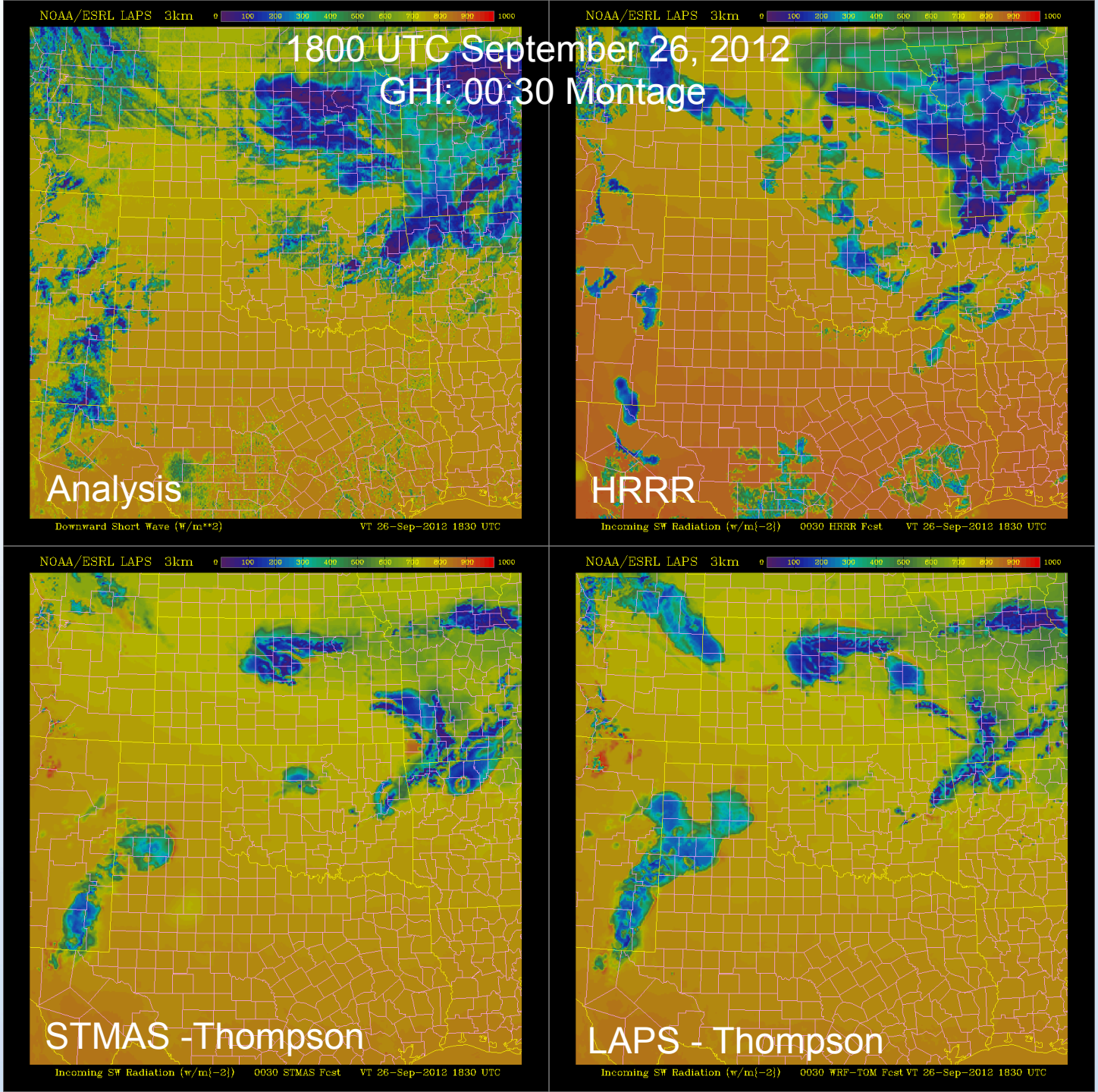

NOAA/ESRL LAPS 3km
0 100 200 300 400 500 600 700 800 900 1000
LAPS -Thompson
Incoming SW Radiation (w/m{-2}) 0000 WRF-TOM Fcst VT 22-Sep-2012 1800 UTC

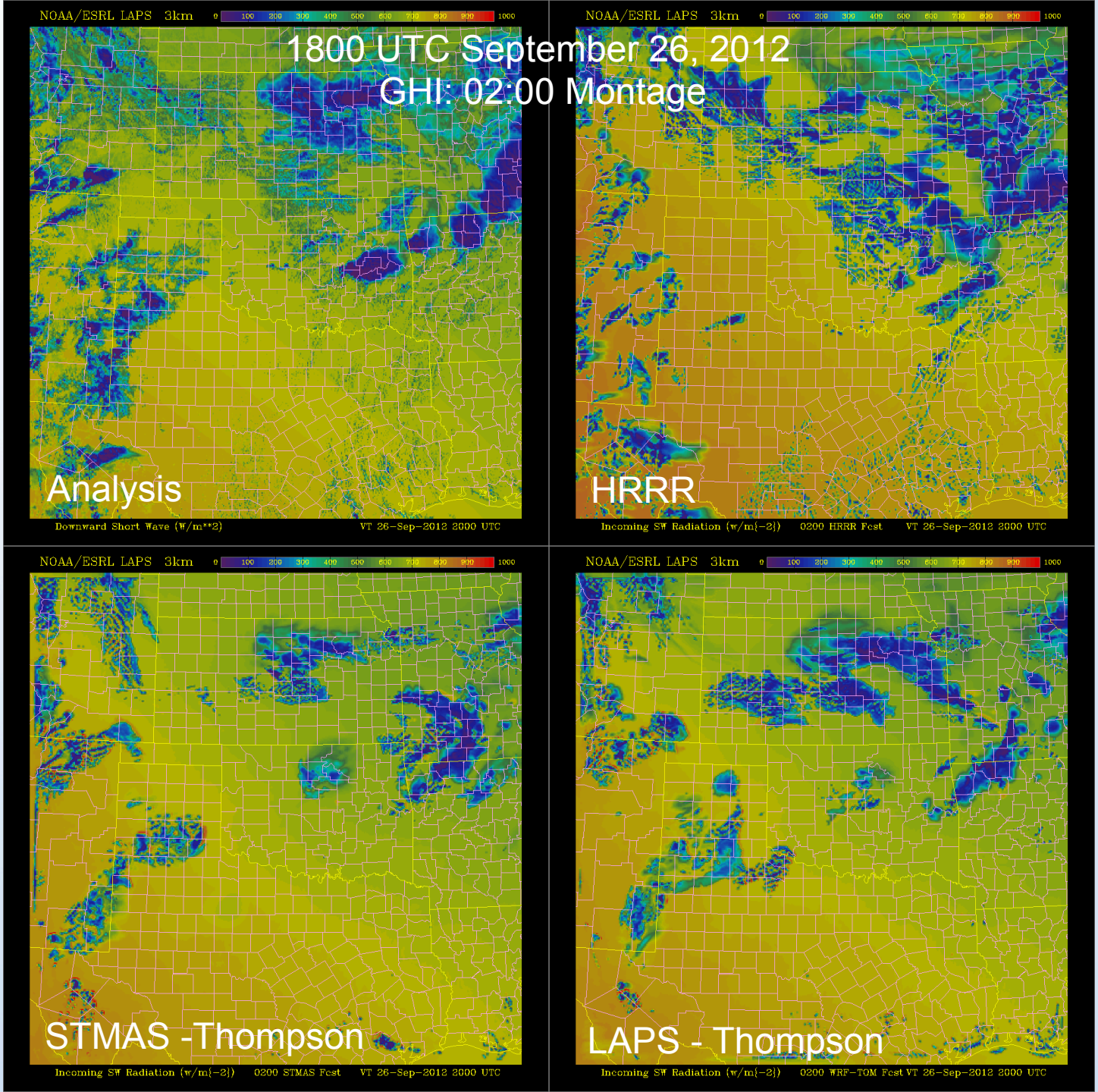
HRRR

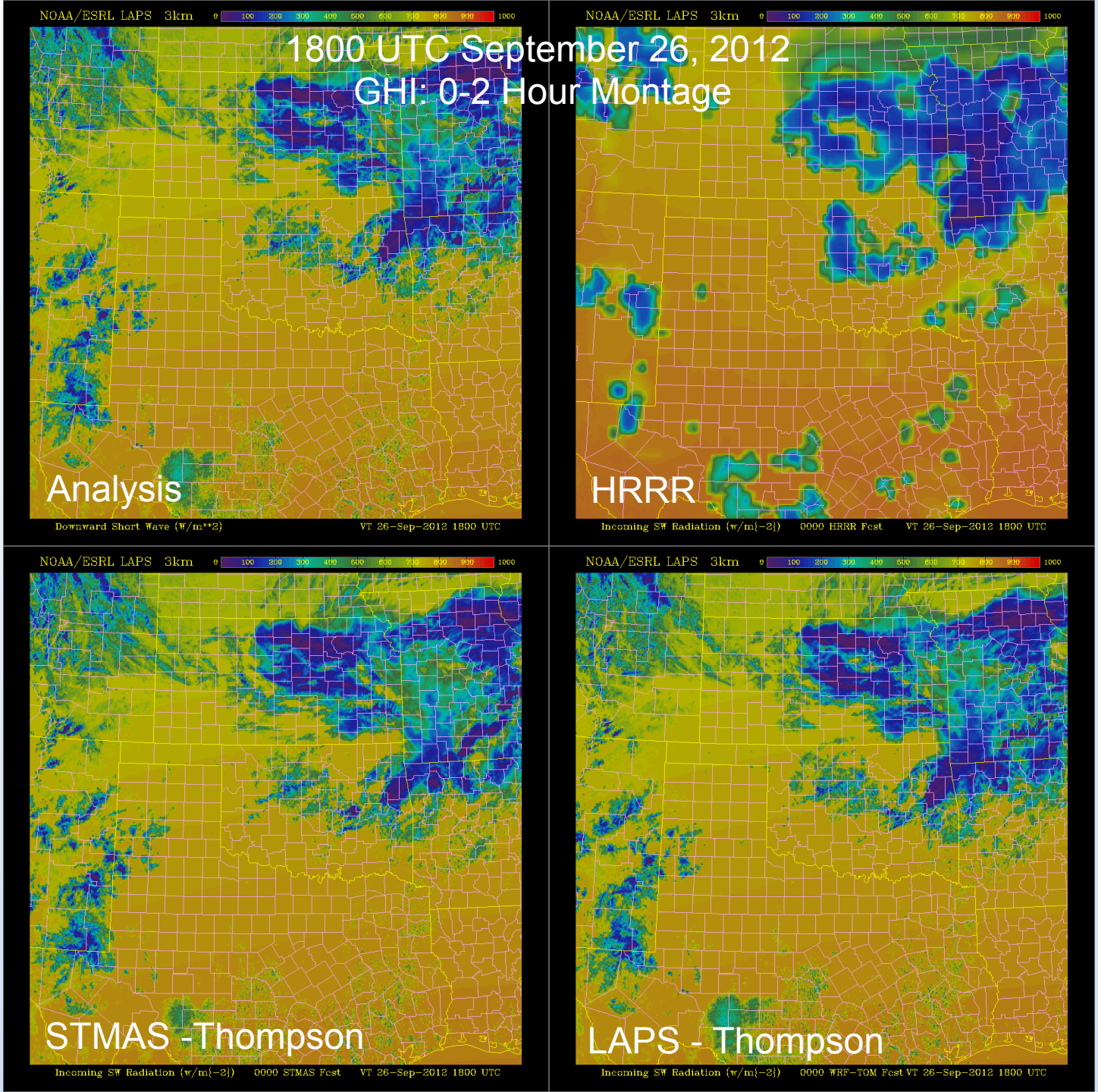

Global Horizontal Irradiance Observed vs Forecast (stmas hwt domain)
Solar Radiation Forecast Verification
HWT Forecast (00-06 hours)
LAPS / STMAS / HRRR + Oklahoma solar radiation stations.
Fcst Mean wrf-wsm6
Obs Mean wrf-wsm6
RMS (F-O) wrf-wsm6
Fcst Mean wrf-laps
Obs Mean wrf-laps
RMS (F-O) wrf-laps
Fcst Mean wrf-hrrr
Obs Mean wrf-hrrr
RMS (F-O) wrf-hrrr
Mean Fcst
Mean Obs
RMSE
GHI (W/m**2)
1000
800
600
400
200
0
18:00
19:00
20:00
21:00
22:00
23:00
00:00
Initialized 9/22/2012 18:00 UTC

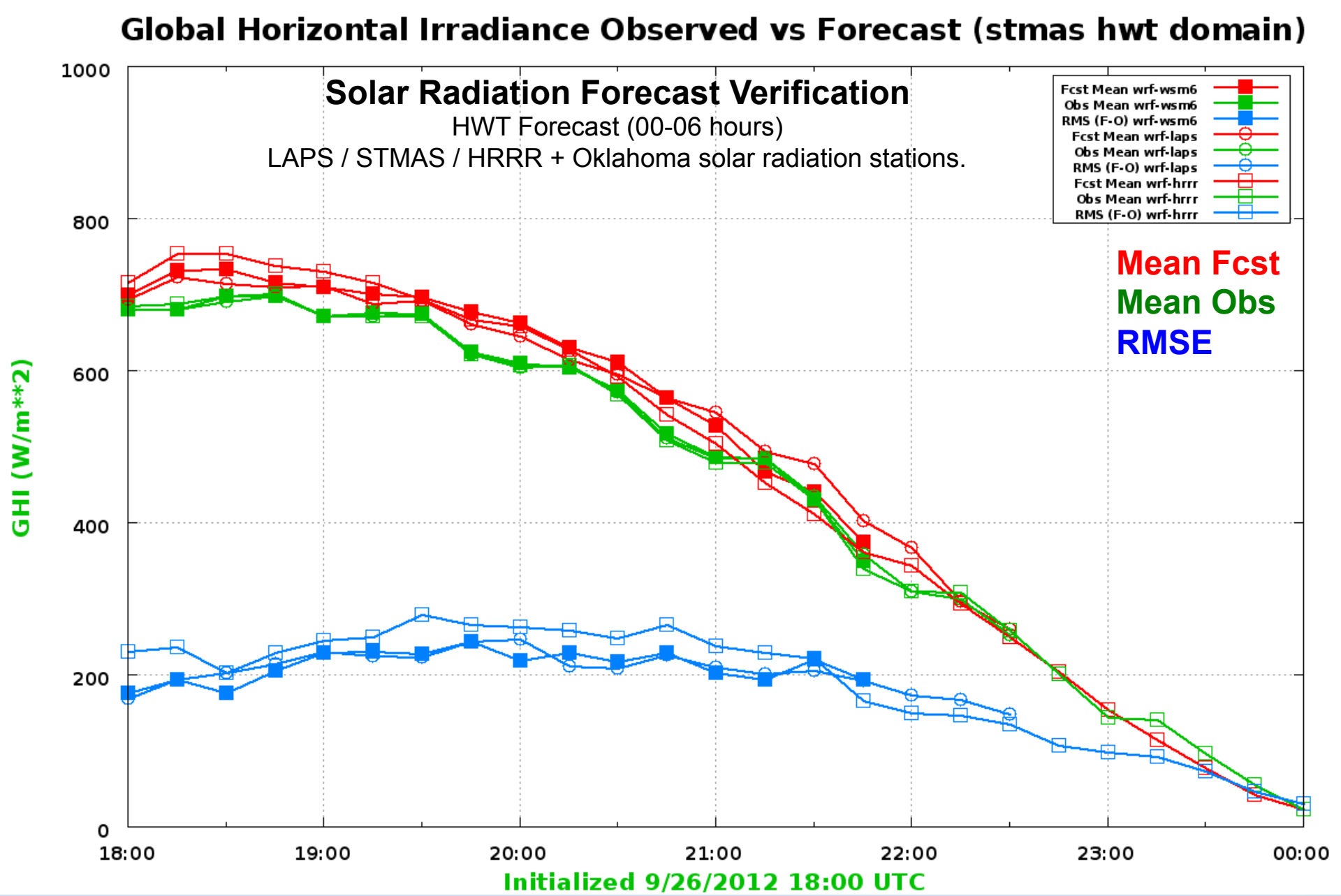

1800 UTC September 26, 2012
GHI: 00:00 Montage
NOAA/ESRL LAPS 3km
0 100 200 300 400 600 800 1000
Analysis
Downward Short Wave (W/m**2)
VT 26-Sep-2012 1800 UTC
NOAA/ESRL LAPS 3km
0 100 200 300 400 600 800 1000
HRRR
Incoming SW Radiation (w/m{-2})
0000 HRRR Fcst
VT 26-Sep-2012 1800 UTC
NOAA/ESRL LAPS 3km
0 100 200 300 400 600 800 1000
STMAS -Thompson
Incoming SW Radiation (w/m{-2})
0000 STMAS Fcst
VT 26-Sep-2012 1800 UTC
NOAA/ESRL LAPS 3km
0 100 200 300 400 600 800 1000
LAPS - Thompson
Incoming SW Radiation (w/m{-2})
0000 WRF-TOM Fcst
VT 26-Sep-2012 1800 UTC

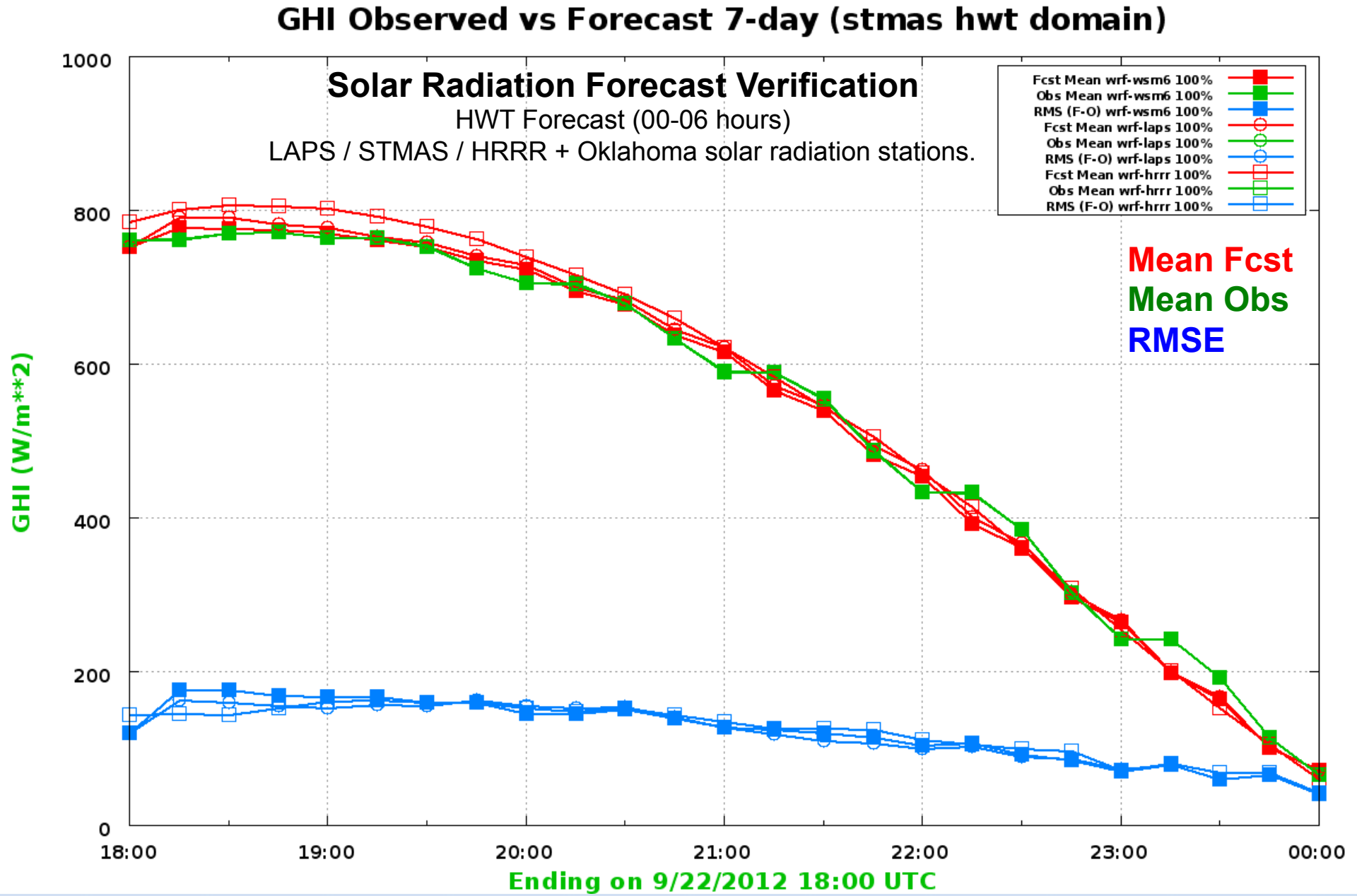

1800 UTC September 26, 2012
GHI: 00:15 Montage
NOAA/ESRL LAPS 3km
0 100 200 300 400 600 800 1000
Analysis
Downward Short Wave (W/m**2)
VT 26-Sep-2012 1815 UTC
NOAA/ESRL LAPS 3km
0 100 200 300 400 600 800 1000
HRRR
Incoming SW Radiation (w/m{-2})
0015 HRRR Fcst
VT 26-Sep-2012 1815 UTC
NOAA/ESRL LAPS 3km
0 100 200 300 400 600 800 1000
STMAS -Thompson
Incoming SW Radiation (w/m{-2})
0015 STMAS Fcst
VT 26-Sep-2012 1815 UTC
NOAA/ESRL LAPS 3km
0 100 200 300 400 600 800 1000
LAPS - Thompson
Incoming SW Radiation (w/m{-2})
0015 WRF-TOM Fcst
VT 26-Sep-2012 1815 UTC


1800 UTC September 26, 2012
GHI: 00:30 Montage
NOAA/ESRL LAPS 3km
0 100 200 300 400 500 600 700 800 900 1000
Analysis
Downward Short Wave (W/m**2)
VT 26-Sep-2012 1830 UTC
NOAA/ESRL LAPS 3km
0 100 200 300 400 500 600 700 800 900 1000
HRRR
Incoming SW Radiation (w/m{-2}) 0030 HRRR Fcst VT 26-Sep-2012 1830 UTC
NOAA/ESRL LAPS 3km
0 100 200 300 400 500 600 700 800 900 1000
STMAS -Thompson
Incoming SW Radiation (w/m{-2}) 0030 STMAS Fcst VT 26-Sep-2012 1830 UTC
NOAA/ESRL LAPS 3km
0 100 200 300 400 500 600 700 800 900 1000
LAPS - Thompson
Incoming SW Radiation (w/m{-2}) 0030 WRF-TOM Fcst VT 26-Sep-2012 1830 UTC


1800 UTC September 26, 2012
GHI: 02:00 Montage
NOAA/ESRL LAPS 3km
0 100 200 300 400 500 600 700 800 900 1000
Analysis
Downward Short Wave (W/m**2)
VT 26-Sep-2012 2000 UTC
NOAA/ESRL LAPS 3km
0 100 200 300 400 500 600 700 800 900 1000
HRRR
Incoming SW Radiation (w/m{-2}) 0200 HRRR Fcst VT 26-Sep-2012 2000 UTC
NOAA/ESRL LAPS 3km
0 100 200 300 400 500 600 700 800 900 1000
STMAS -Thompson
Incoming SW Radiation (w/m{-2}) 0200 STMAS Fcst VT 26-Sep-2012 2000 UTC
NOAA/ESRL LAPS 3km
0 100 200 300 400 500 600 700 800 900 1000
LAPS - Thompson
Incoming SW Radiation (w/m{-2}) 0200 WRF-TOM Fcst VT 26-Sep-2012 2000 UTC


1800 UTC September 26, 2012
GHI: 0-2 Hour Montage
NOAA/ESRL LAPS 3km
0 100 200 300 400 600 800 1000
Analysis
Downward Short Wave (W/m**2)
VT 26-Sep-2012 1800 UTC
NOAA/ESRL LAPS 3km
0 100 200 300 400 600 800 1000
HRRR
Incoming SW Radiation (w/m{-2})
0000 HRRR Fcst
VT 26-Sep-2012 1800 UTC
NOAA/ESRL LAPS 3km
0 100 200 300 400 600 800 1000
STMAS -Thompson
Incoming SW Radiation (w/m{-2})
0000 STMAS Fcst
VT 26-Sep-2012 1800 UTC
NOAA/ESRL LAPS 3km
0 100 200 300 400 600 800 1000
LAPS - Thompson
Incoming SW Radiation (w/m{-2})
0000 WRF-TOM Fcst
VT 26-Sep-2012 1800 UTC

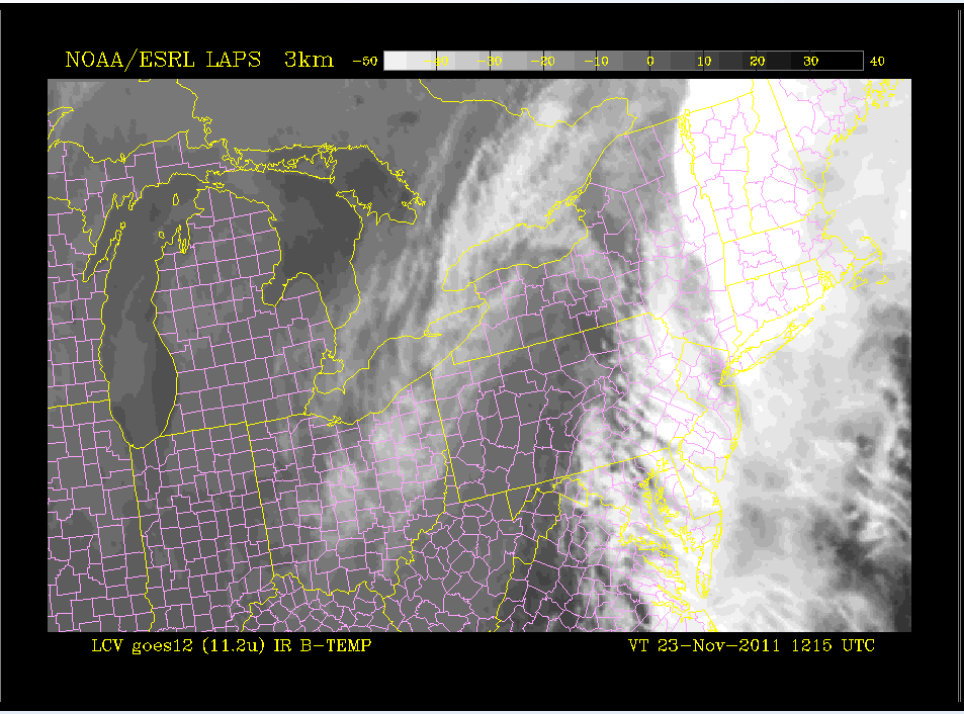

Global Horizontal Irradiance Observed vs Forecast (stmas hwt domain)
Solar Radiation Forecast Verification
HWT Forecast (00-06 hours)
LAPS / STMAS / HRRR + Oklahoma solar radiation stations.
Fcst Mean wrf-wsm6
Obs Mean wrf-wsm6
RMS (F-O) wrf-wsm6
Fcst Mean wrf-laps
Obs Mean wrf-laps
RMS (F-O) wrf-laps
Fcst Mean wrf-hrrr
Obs Mean wrf-hrrr
RMS (F-O) wrf-hrrr
Mean Fcst
Mean Obs
RMSE
GHI (W/m**2)
1000
800
600
400
200
0
18:00
19:00
20:00
21:00
22:00
23:00
00:00
Initialized 9/26/2012 18:00 UTC

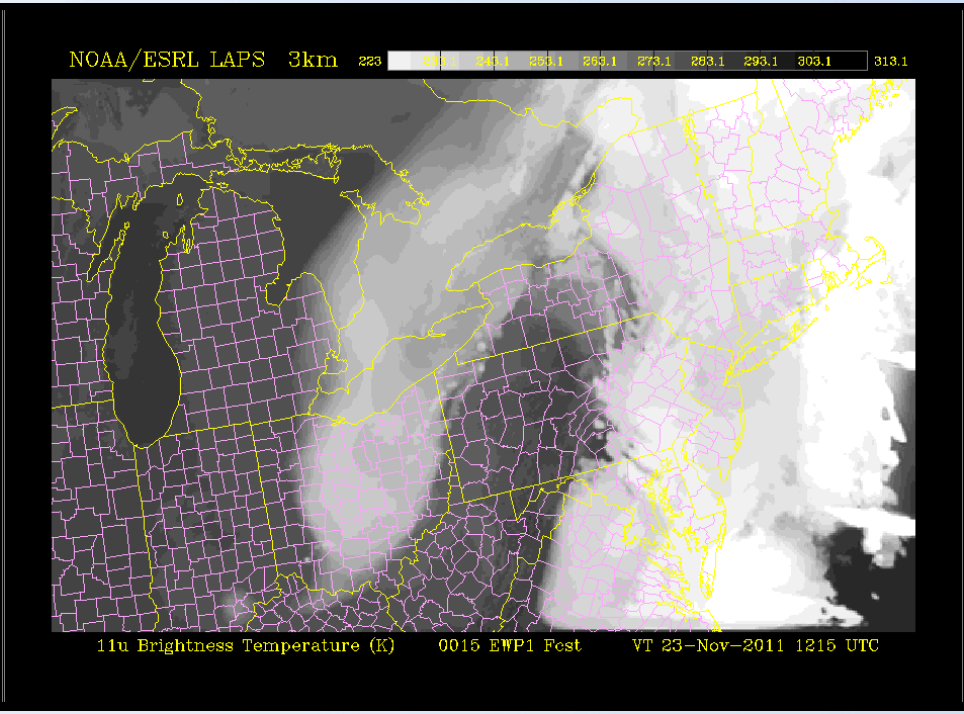

GHI Observed vs Forecast 7-day (stmas hwt domain)
Solar Radiation Forecast Verification
HWT Forecast (00-06 hours)
LAPS / STMAS / HRRR + Oklahoma solar radiation stations.
Fcst Mean wrf-wsm6 100%
Obs Mean wrf-wsm6 100%
RMS (F-O) wrf-wsm6 100%
Fcst Mean wrf-laps 100%
Obs Mean wrf-laps 100%
RMS (F-O) wrf-laps 100%
Fcst Mean wrf-hrrr 100%
Obs Mean wrf-hrrr 100%
RMS (F-O) wrf-hrrr 100%
Mean Fcst
Mean Obs
RMSE
GHI (W/m**2)
1000
800
600
400
200
0
18:00
19:00
20:00
21:00
22:00
23:00
00:00
Ending on 9/22/2012 18:00 UTC

Forecast - Preliminary Results

- Clear sky cases are now being corrected for a high forecast bias in LAPS
  - Empirically determined bias correction from clear sky cases
- Cloudy cases sometimes show evidence of low bias from clouds that are too thick – this might also be bias corrected
- LAPS analysis can be utilized to provide a "zero-hour" forecast

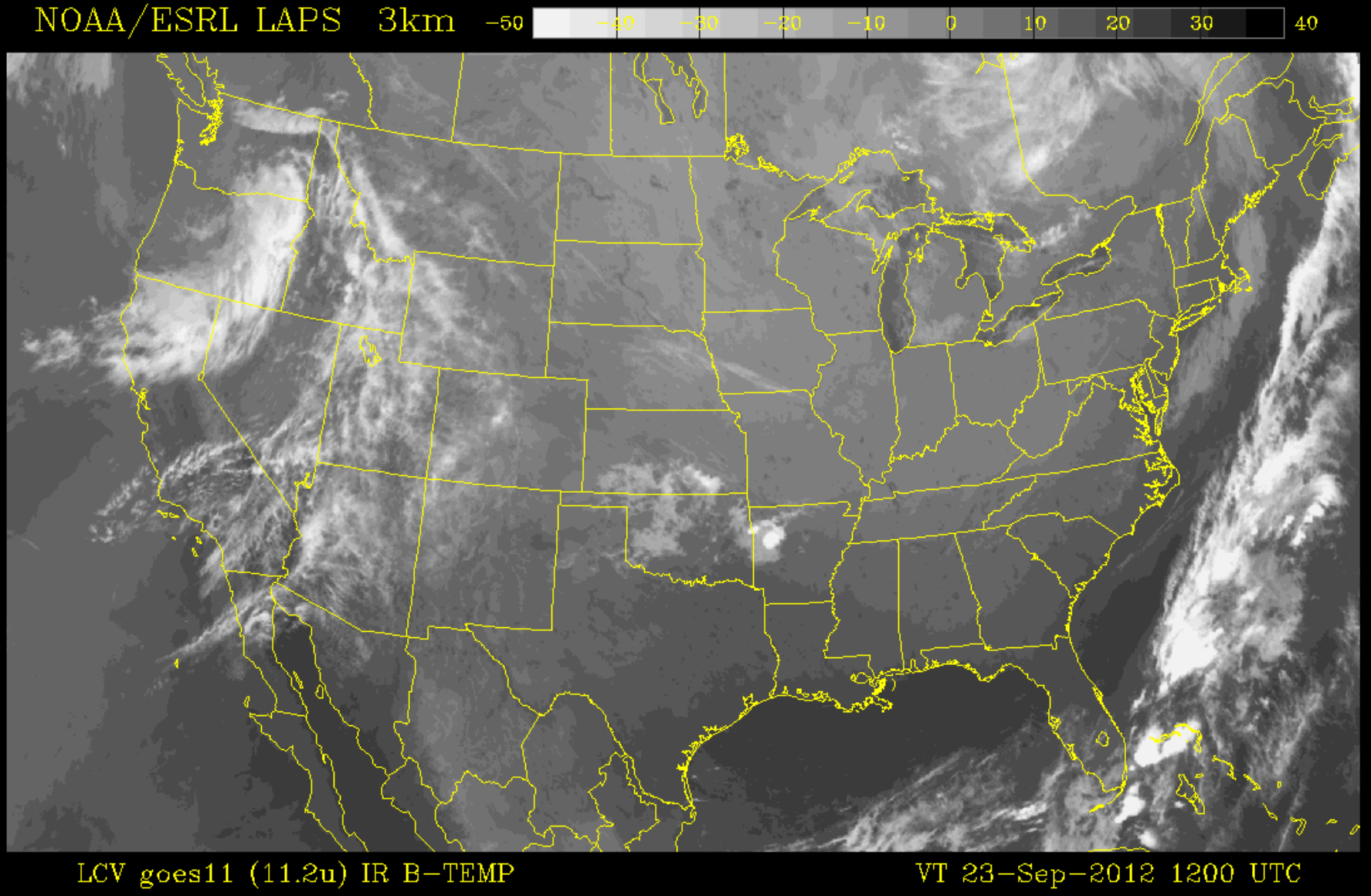
Simulated IR Satellite Forecast





- Simulated VIS also available – derived from cloud amount
- Forecasters are naturally familiar with satellite images
- Objective cloud forecast verification in place for IR sat

Simulated IR Satellite LAPS / WRF 6-Hr Forecast Verification



Forecast high clouds tend to be too thick

Cloud / Radiation Plans - Analysis

- Develop forward models for all data sources being used to more fully implement a variational approach
  - Set up constraints based on model microphysics and radiation packages (e.g. CRTM)
  - Will allow assimilation of pyranometers
  - May require improved consistency between these packages
  - Test using present algorithm as a benchmark

- Improve analysis radiation model to handle direct radiation
  - Start with simple model that can use clouds and aerosol optical depth (if available)

- Consider wavelengths of solar radiation measurements and PV arrays

Future Cloud / Radiation Plans - Forecast

- Test at 1km horizontal resolution and more vertical levels

- Improve Hot-Start Elements and model microphysics
  - More Variational Cloud / Moisture Analyses
  - Examine various WRF short-wave radiation options
  - Improvements in WRF Aerosols
  - Allow partial clouds with sub-saturation in model

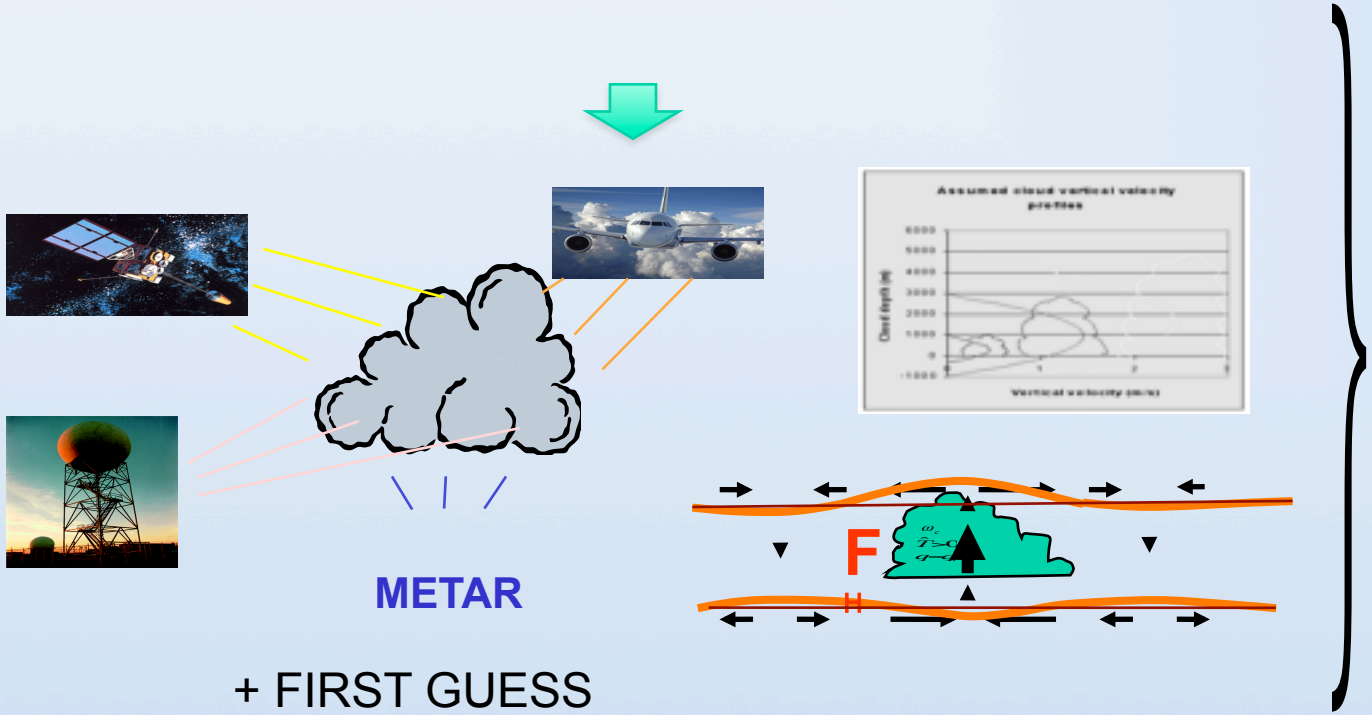
- Add direct radiation forecast

Cloud / Radiation Plans - Verification

- Implementing 7 & 30 day verification scores with matched model runs
- Additional models for comparison / verification?
- Verify against various 2-D fields (in addition to IR sat)
  - Visible imagery and/or cloud fraction
  - Solar Radiation Analysis

VARIATIONAL HOT-START INITIALIZATION

- Minimization of LAPS variational cost function
  (simultaneous analysis of multiple variables)
- Currently under development (see “Variational LAPS” talk by Yuanfu Xie)
- Subject to dynamical constraints and appropriate forward models



Thanks!

Questions?

More info online at…
http://laps.noaa.gov/solar