



Development and Application of a Satellite-based Convective Cloud Object-Tracking Methodology



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Key Objectives...

- General overview of an independent, automated satellite-based convective cloud object-tracking framework
- Connecting satellite decision support to radar data - object tracking / validation system can have any number of fields added allowing for an objective inter-comparison of a fused set of data types (EUMETSAT Nowcasting session 2010 Dennis Stich – Cordoba)
- Connectivity to GOES-R Proving Ground feedback

Object Tracking Motivation – What?

- Consider clouds not as single pixel entities, but rather cloud objects, as a human does.
- A cloud object (in WDSS-II framework) is three or more satellite pixels, grouped together and identified as a single entity (temporally tracked from infancy to maturity).
- Using geostationary imagery cloud objects can be tracked in space and time while maintaining a unique ID.
 - The higher the temporal resolution, the better tracking
 - ABI CONUS temporal resolution will be 5 minutes
 - Current GOES Imager temporal resolution is 15 minutes, 5-15 in rapid scan
 - Largest current limitation are 30 minute GOES Imager gaps every 3 hours



Object Tracking Motivation – Why?

1) As a validation tool (Satellite-based convective decision support vs Radar)

2) Fusion of any number of data fields from any sensor type (satellite, satellite algorithm output, radar, lightning, NWP model, surface and upper air observations, etc.) into a single framework for 0-1 hour nowcasting relationships

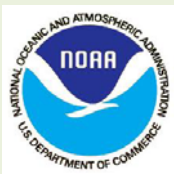
All these quantities are used in cloud object space, not single pixel space, allowing for easy monitoring of temporal as well as spatial trends

- A continuously (not discrete) changing field is key, in this case: Top of Troposphere Cloud Emissivity (Pavolonis, 2010)



WDSS-II Background

- Warning Decision Support System—Integrated Information (WDSS-II) has many utilities and was developed primarily for use with NEXRAD data (Lakshmanan et al. 2007)
- Our focus been to use WDSS-II to create cloud objects and assign those objects unique, consistent IDs that are tracked across space and time
- WDSS-II builds objects using an ‘extended’ watershed method (presented at EUMETSAT Nowcasting session 2011)
- Input into WDSS-II for creating cloud objects is 11 μ m top of troposphere cloud emissivity (GOES-R algorithm) (Pavolonis, 2010)



Top of Troposphere Cloud Emissivity (GOES-R methodology)

$$\varepsilon(\lambda) = \frac{R_{obs}(\lambda) - R_{clr}(\lambda)}{[B(\lambda, T_{eff})T_{ac}(\lambda) + R_{ac}(\lambda)] - R_{clr}(\lambda)}$$

From Pavolonis, 2010

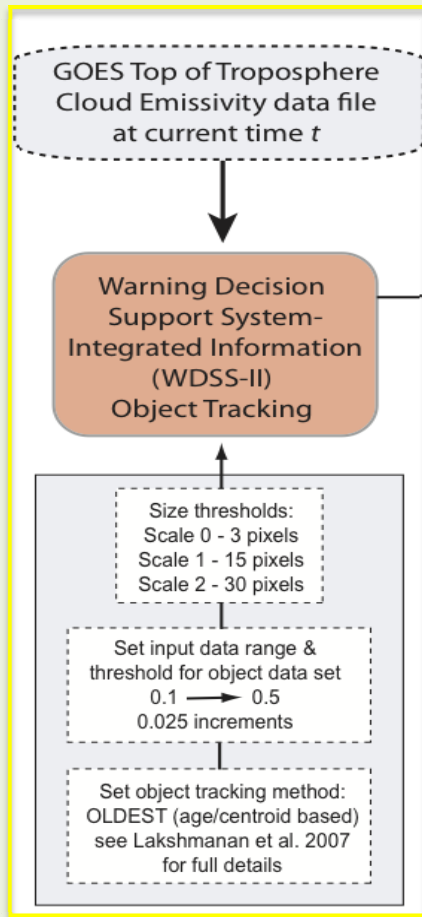
- Non-scattering radiative transfer equation solved for effective cloud emissivity
- For top of troposphere emissivity the cloud temperature is assumed to be that of the NWP tropopause
- $\lambda = 11 \mu\text{m}$
- Key: Normalized cloud emissivity from top of tropopause therefore cirrus will have low TCE while growing convective cells will incrementally increase

Why Top of Troposphere Cloud Emissivity?

- Normalized emissivity relative to tropopause
- Nearly independent of season and latitude. The tropopause can vary significantly with latitude and season and therefore so does cloud top temperature at the tropopause. The top of troposphere emissivity is normalized 0 to 1, so varying brightness temperature thresholds are not necessary.
- Top of troposphere cloud emissivity is only calculated where the cloud mask identifies clouds and therefore no clear-sky pixels will be included in cloud objects.

Warning Decision Support System- Integrated Information (WDSS-II; Lakshmanan et al. 2007)

Robust *Satellite-based* Object Tracking



WDSS-II generates objects from the input data set using user-defined thresholds, parameters, and object tracking method

Input and output from WDSS-II is equally spaced lat/lon netCDF files

Data is all remapped to 0.04 deg spacing for use with GOES data (nadir 4km IR resolution)

WDSS-II: Extended Watershed

- See Lakshmanan et al. 2009 for full details of object building methodology within WDSS-II

14	22	34	44	39	32	22	14	10
32	37	44	52	52	42	37	22	20
31	42	49	70	72	51	38	30	16
39	39	55	55	64	45	29	21	12
24	27	39	46	46	36	19	14	8
12	19	16	12	25	29	12	14	5

Top of Troposphere
Emissivity Range and
Binsize:

10-50;2.5
50-100;50.0

Scale 0:
3 pixel minimum

Object building stops for
each scale once minimum
is achieved



WDSS-II: Extended Watershed

- See Lakshmanan et al. 2009 for full details of object building methodology within WDSS-II

14	22	34	44	39	32	22	14	10
32	37	44	52	52	42	37	22	20
31	42	49	70	72	51	38	30	16
39	39	55	55	64	45	29	21	12
24	27	39	46	46	36	19	14	8
12	19	16	12	25	29	12	14	5

Top of Troposphere
Emissivity Range and
Binsize:

10-50;2.5
50-100;50.0

Scale 1:
15 pixel minimum

Object building stops for
each scale once minimum
is achieved



WDSS-II: Extended Watershed

- See Lakshmanan et al. 2009 for full details of object building methodology within WDSS-II

14	22	34	44	39	32	22	14	10
32	37	44	52	52	42	37	22	20
31	42	49	70	72	51	38	30	16
39	39	55	55	64	45	29	21	12
24	27	39	46	46	36	19	14	8
12	19	16	12	25	29	12	14	5

Top of Troposphere
Emissivity Range and
Binsize:

10-50;2.5

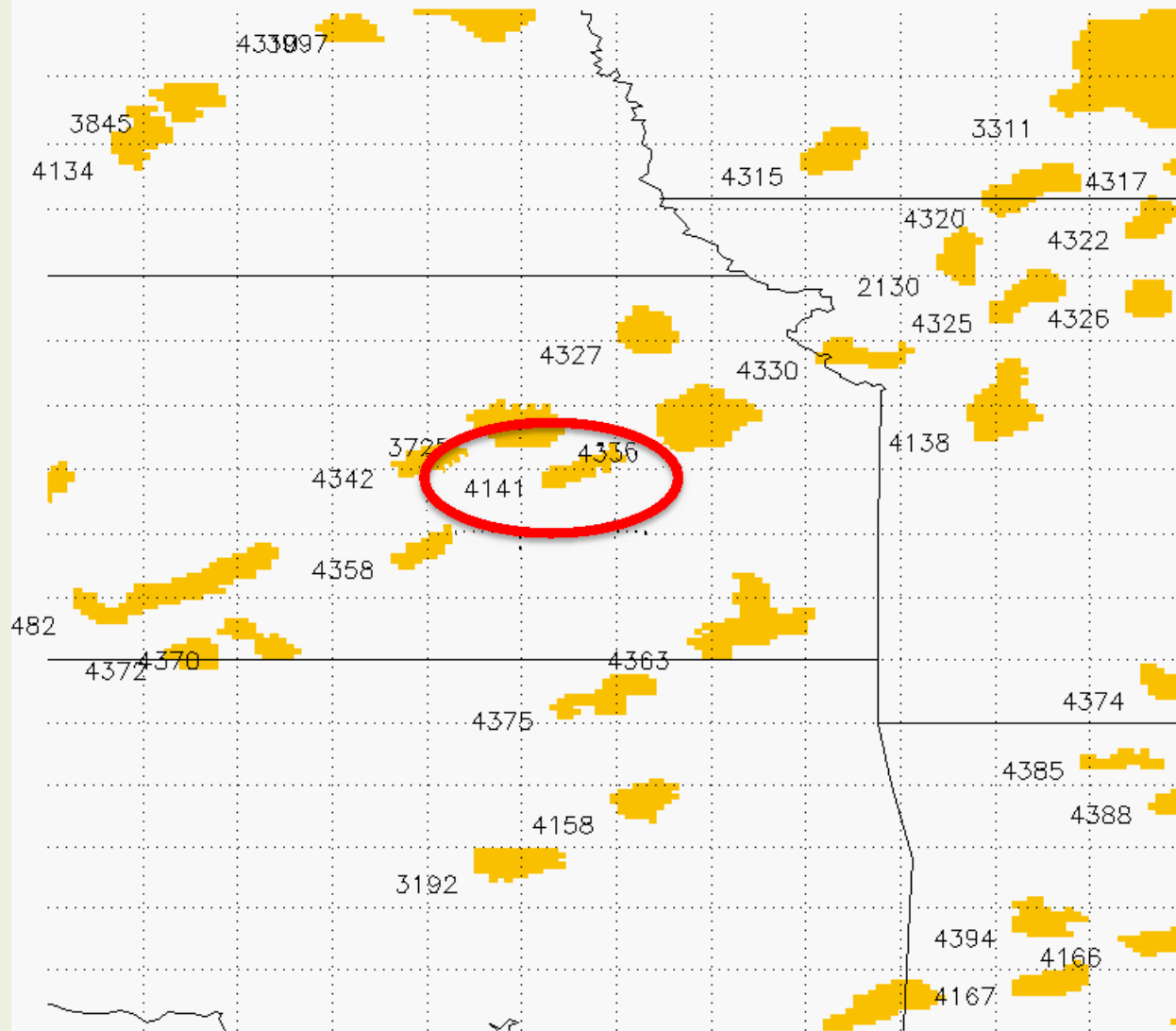
50-100;50.0

Scale 2:
30 pixel minimum

Object building stops for
each scale once minimum
is achieved



Scale_2 Object IDs20090513-2115



Warning Decision Support System- Integrated Information (WDSS-II; Lakshmanan et al. 2007)

Robust *Satellite-based* Object Tracking

GOES Top of Troposphere

WDSS II

UW-CTC rate and as well as NEXRAD radar fields are remapped to an equally spaced lat/lon grid matching the WDSS merged output

Support System-
Integrated Information
(WDSS-II)
Object Tracking

Provides an automated framework for validation of the UW-CTC rate algorithm vs. radar as well as a lead time analysis of different thresholds of CTC to various other radar field thresholds (i.e. VIL > 30 kg/m² or POSH > 50, etc.)

Set object tracking method:
OLDEST (age/centroid based)
see Lakshmanan et al. 2007
for full details

Additional mature convection WDSS-II configuration and UW-CIMSS post-processing allows for the continued tracking of anvil cores that are initially undetected in the infancy WDSS run. Mature objects are then remerged for additional times in the total object file to increase the likelihood of tracking the development of intense radar signatures of mature convective objects.

UW-CTC Objectives

- Provide a CTC nowcast signal during day and night (using GOES-R day/night cloud typing)
- Minimize false alarm at the expense of some probability of detection
- Provide coherent satellite-based CTC signal as future radar inference

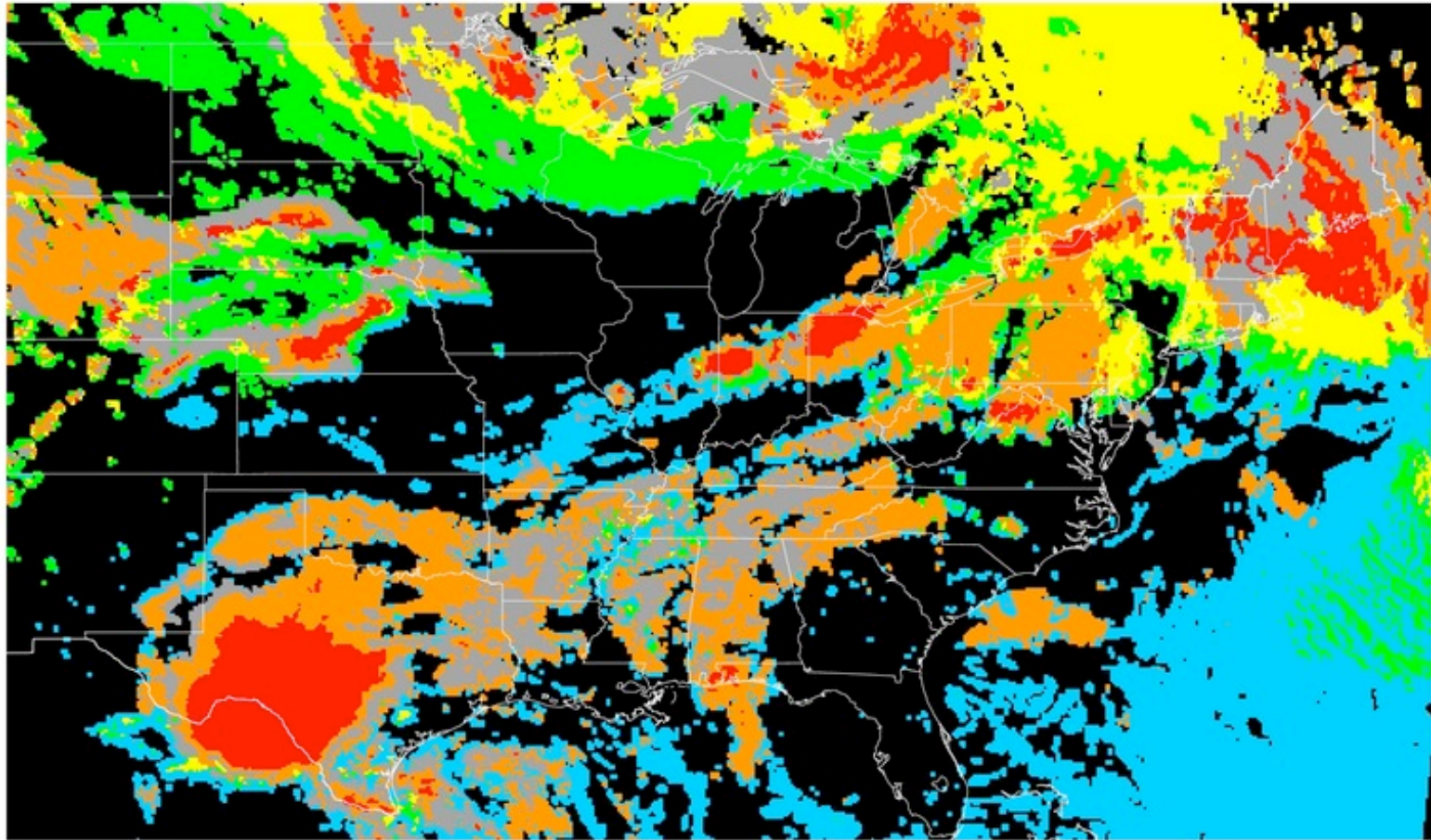


Characteristics of UW Cloud Top Cooling

- Nowcasts cloud development in regions not dominated by cirrus
- Uses only IR channels from GOES satellite
- Results available ~2 minutes after satellite scan
(distribution to AWIPS takes an additional 5-10 minutes)
- Operates in regular and RSO mode
- Large spatial coverage: GOES-East/West, SEVIRI
- Low FAR (20-25%), good POD (50-55%), error sources understood



Cloud Type: 20120328 at 0745 UTC

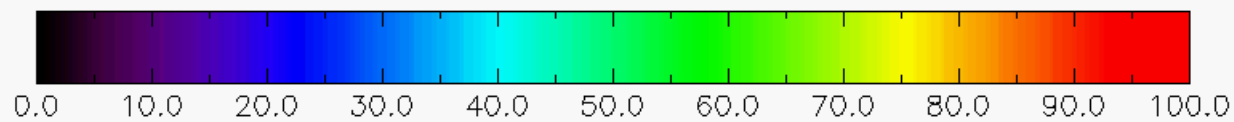
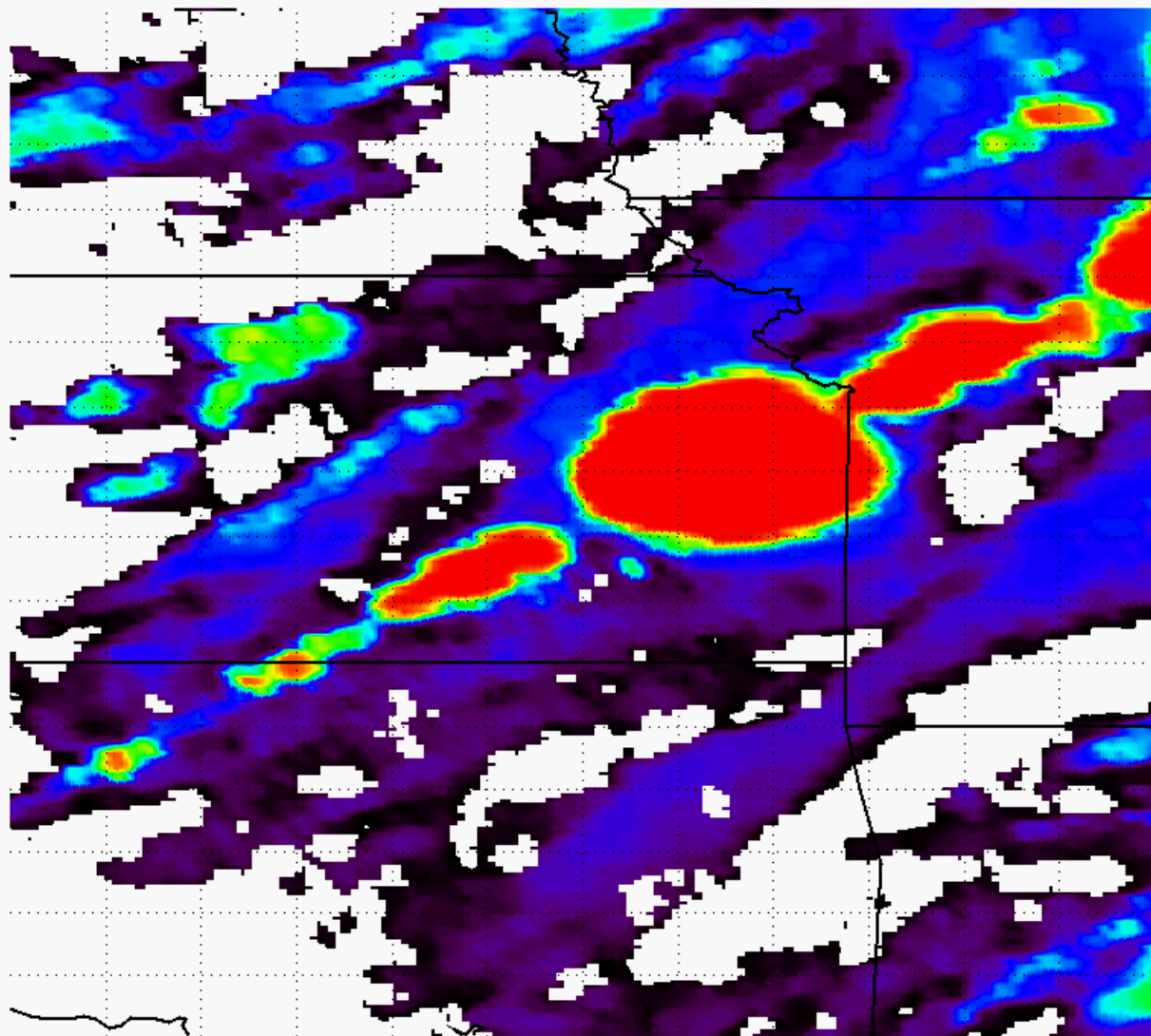


Cloud Type

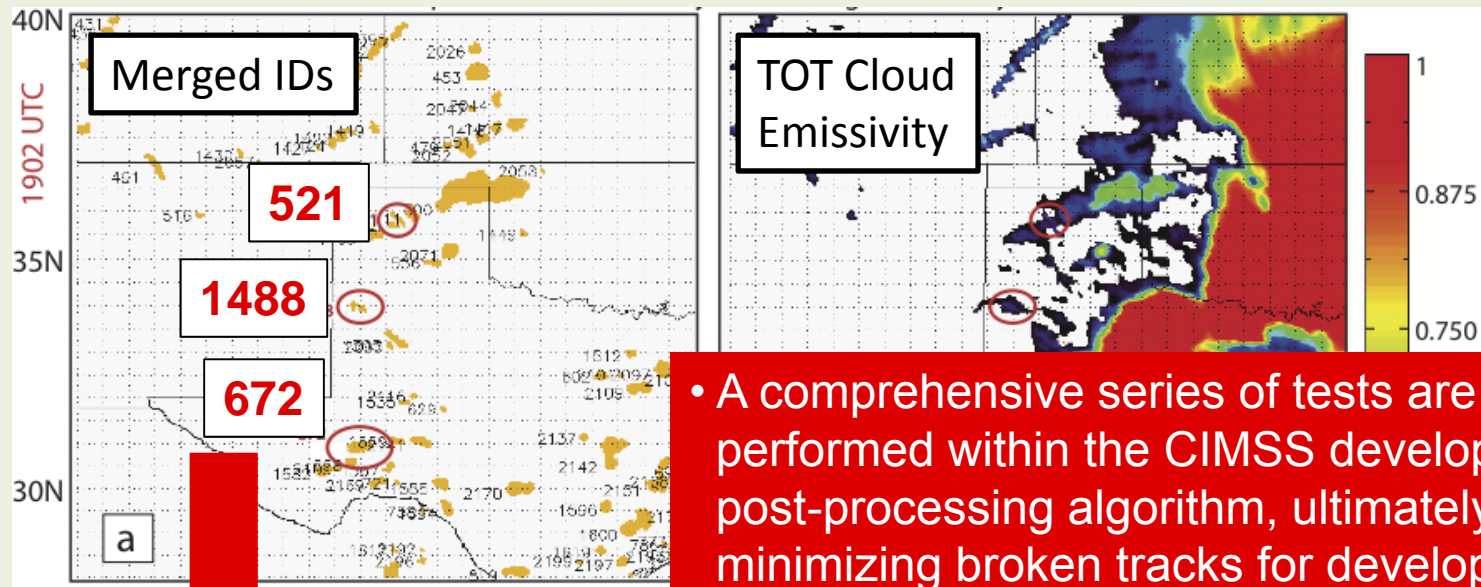


Pavolonis, 2010 – GOES-R Cloud Typing

TOT Emiss20090513-2232

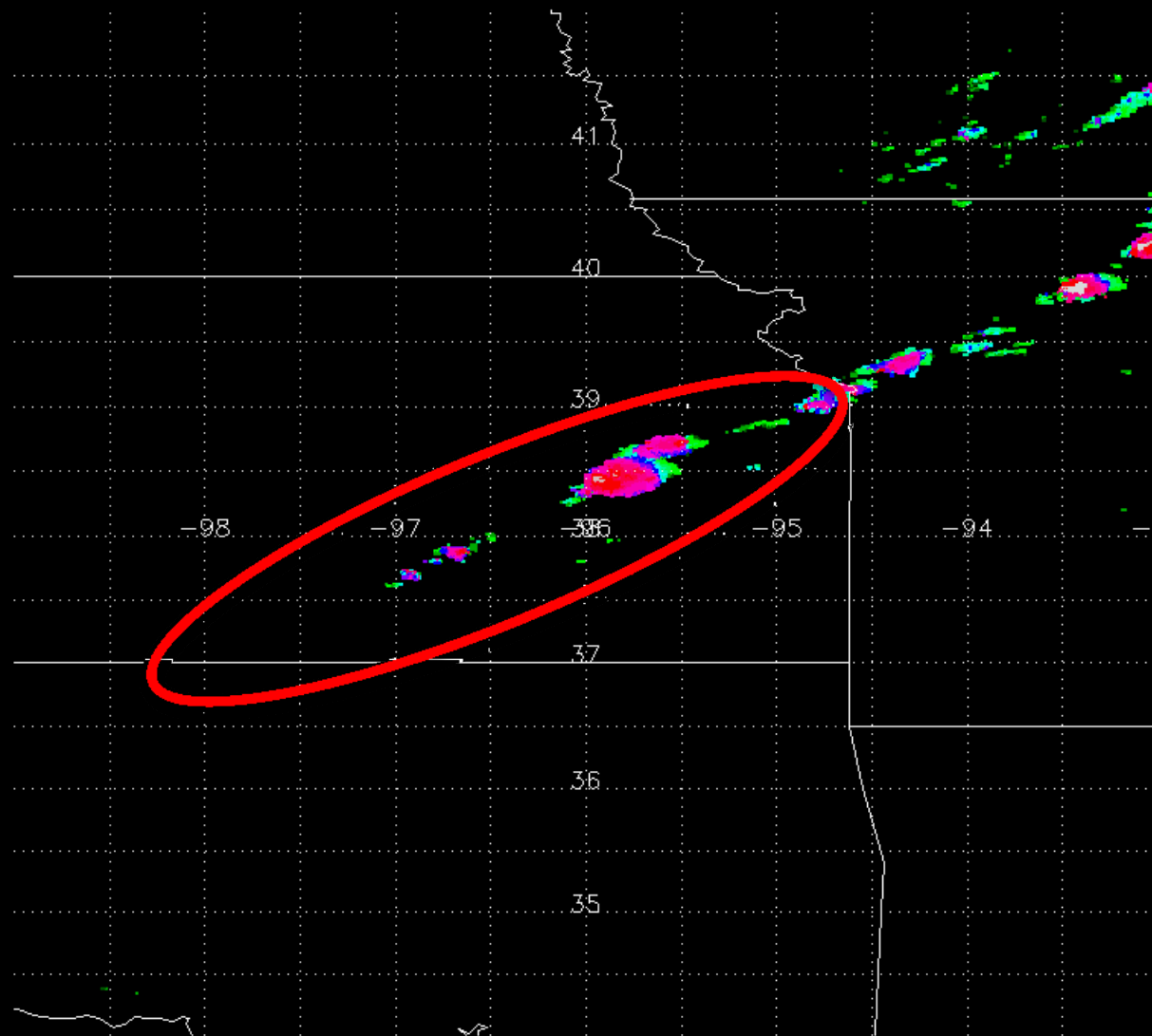


WDSS-II Object Tracking Example (29 April 2009)

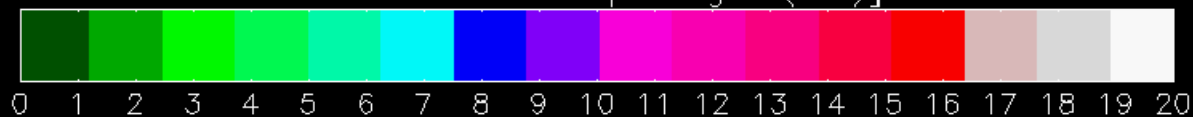


- A comprehensive series of tests are performed within the CIMSS developed post-processing algorithm, ultimately minimizing broken tracks for developing

30 dBZ Echo Top Height:20090513-2216



30 dBZ Echo Top Height (km)]



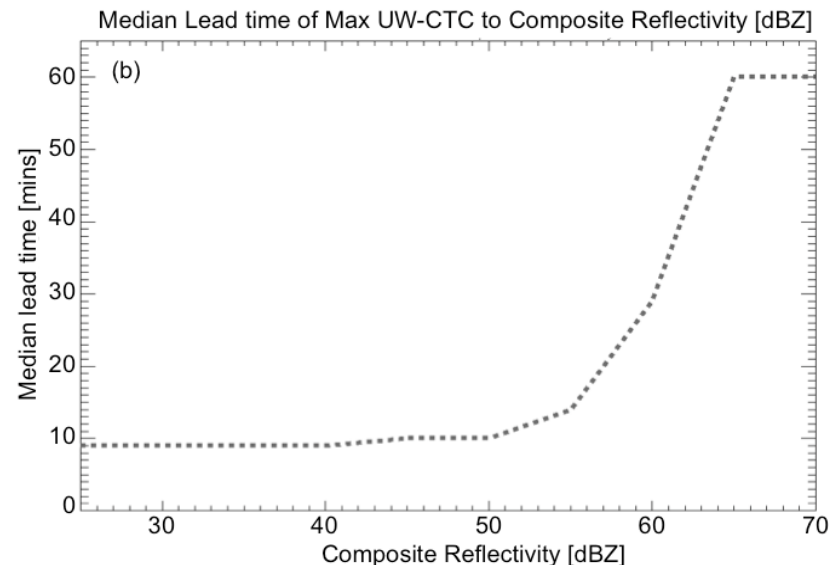
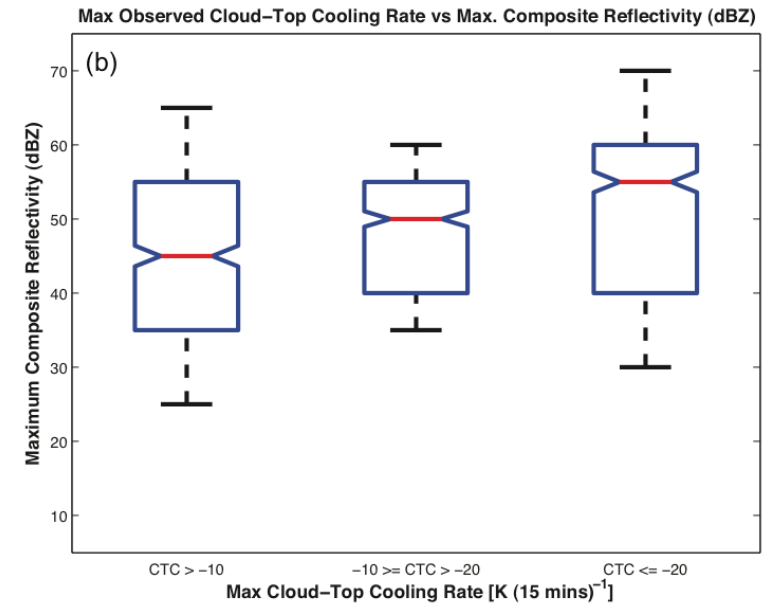
Proving Ground Feedback: Relating UW-CTC to NEXRAD

- Relating Cloud-Top Cooling rates to various NEXRAD fields (reflectivity, VIL, MESH, Echo Tops, etc.)
 - Proving ground activities relayed that forecasters preferred the cloud-top cooling rate over the CI nowcast decision; many hypothesized more intense cloud-top cooling rates correspond to more rapid and vigorous short-term convective development (NOAA Hazardous Weather Testbed, NWS offices)
- Utilizing the above convective cloud object-tracking methodology Hartung et al., 2012 have related UW-CTC rates to various NEXRAD fields for 34 convective events



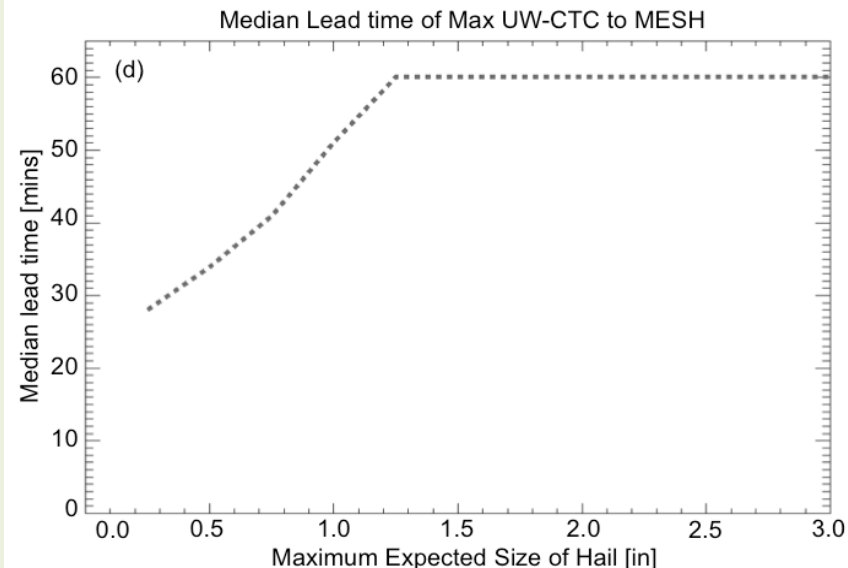
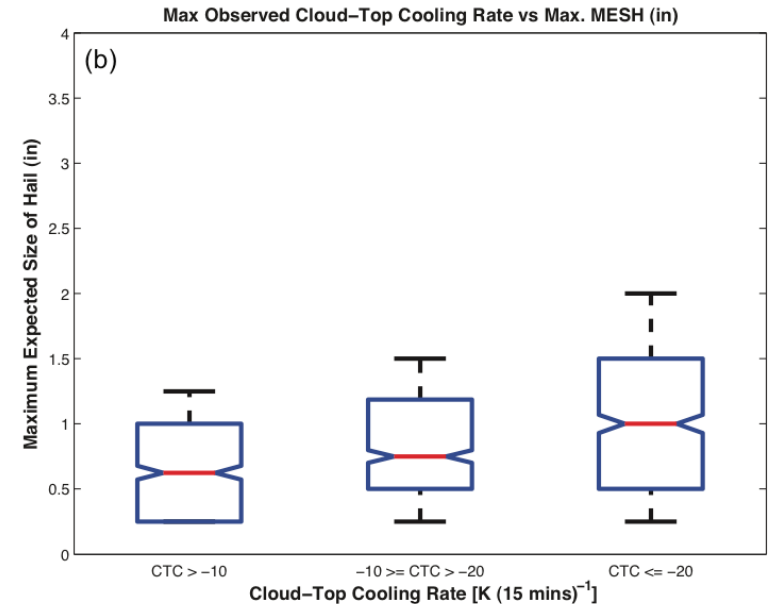
Relating UW-CTC to NEXRAD

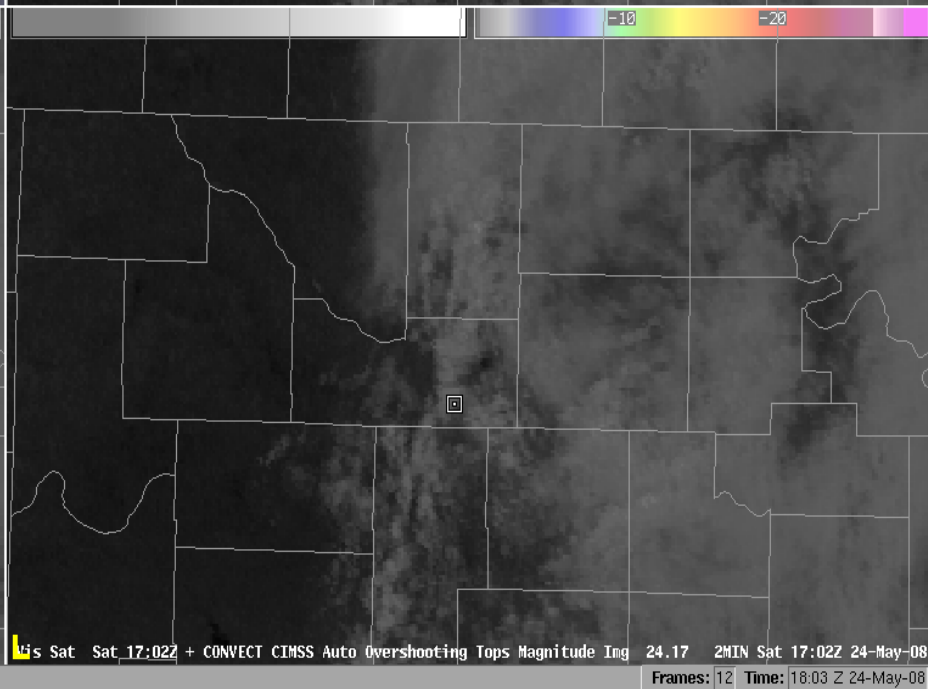
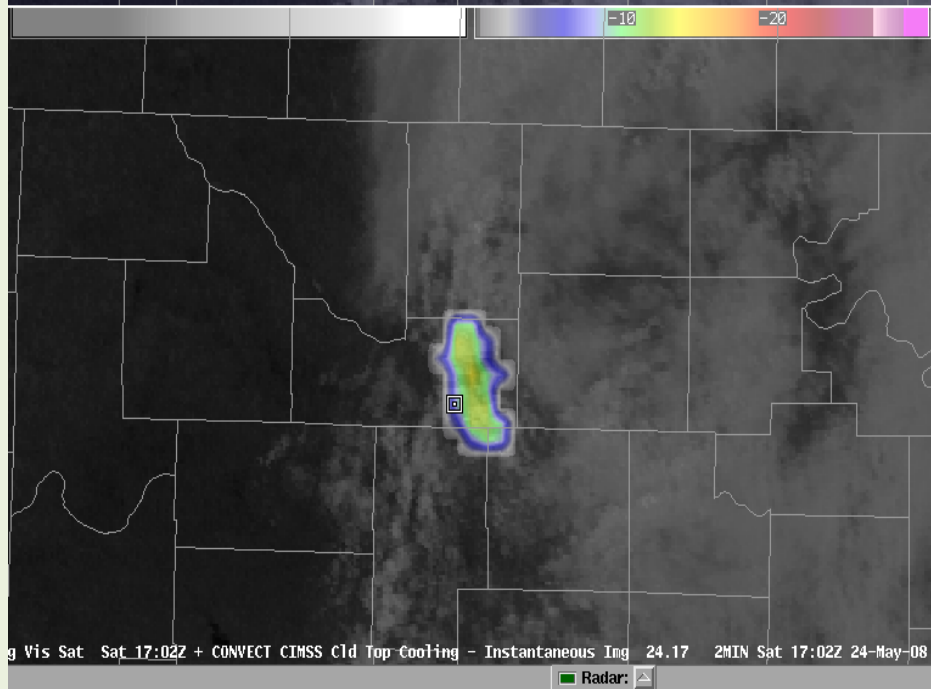
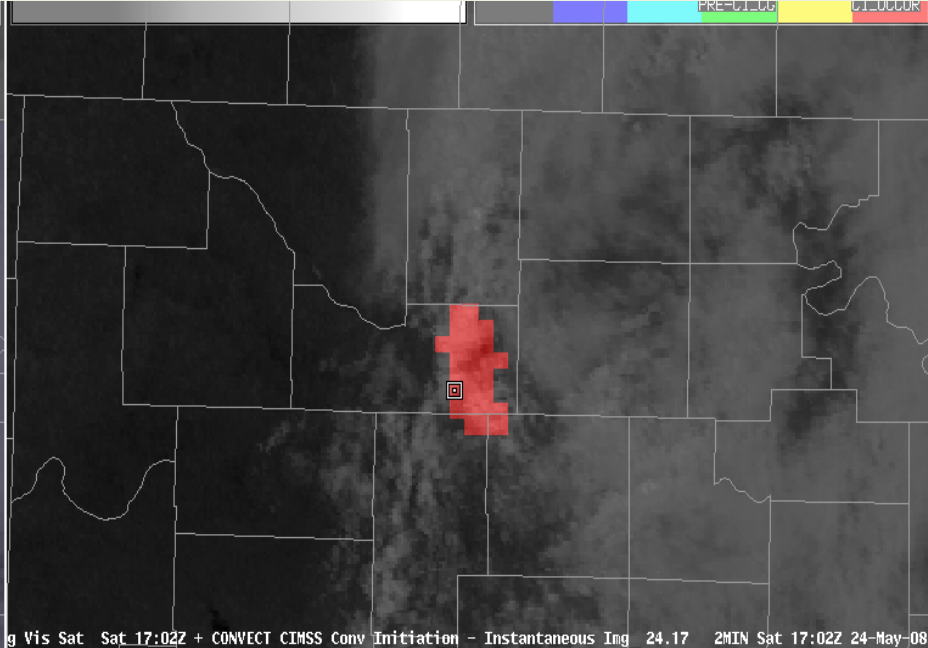
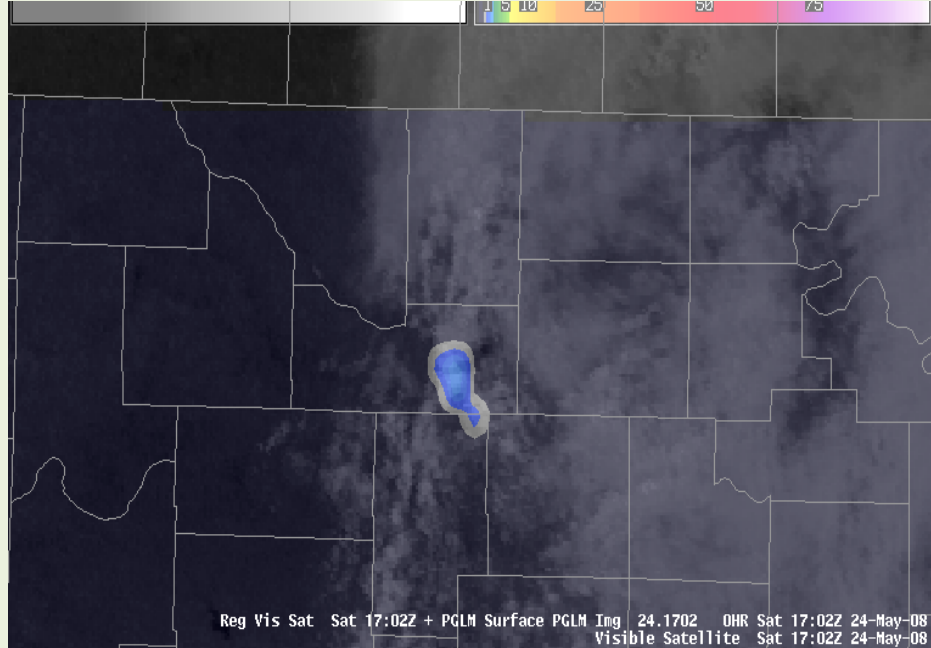
- Stronger UW-CTC relates to higher future composite reflectivity
- Median lead-time of maximum UW-CTC rate is ~10 minutes to 50 dBZ with rapidly increasing lead-time to 65+ dBZ
- False alarm rates decrease with stronger UW-CTC



Relating UW-CTC to NEXRAD

- Stronger UW-CTC relates to larger future Maximum Expected Size of Hail (MESH)
- Median lead-time of maximum UW-CTC rate :
 - ~30 minutes to 0.5" MESH
 - ~50 minutes to 1.0" MESH
- 70% of storms that achieved severe (1.0") MESH were identified with a UW-CTC rate





Looking Ahead

- Short-term: implement daytime capability of capturing vertical convective cloud growth in areas of thin cirrus clouds into UW-CTC algorithm
- Short-term: focus various testbed users on utility of UW-CTC rates for future radar development; not just convective initiation time frame



Looking Ahead

- Long-term: Utilize methodology developed for current UW-CTC – radar relationships to fuse rapidly refreshing NWP data and satellite-based convective cloud growth metrics into a probabilistic nowcast that a developing storm will become severe in the near-term (0 to 60 minutes)
- Long-term: Work with University of Oklahoma - CIMMS to combine knowledge gained from above fusion methodology with other datasets (i.e.- GOES cloud products, cloud-top cooling rates, GLM data, NEXRAD data, etc.) into new convective initiation suite; allow for history for each convective cloud-object opposed to instantaneous, per pixel fields that are currently computed, this has direct connection to NOAA Hazardous Weather Testbed for Proving Ground demonstration

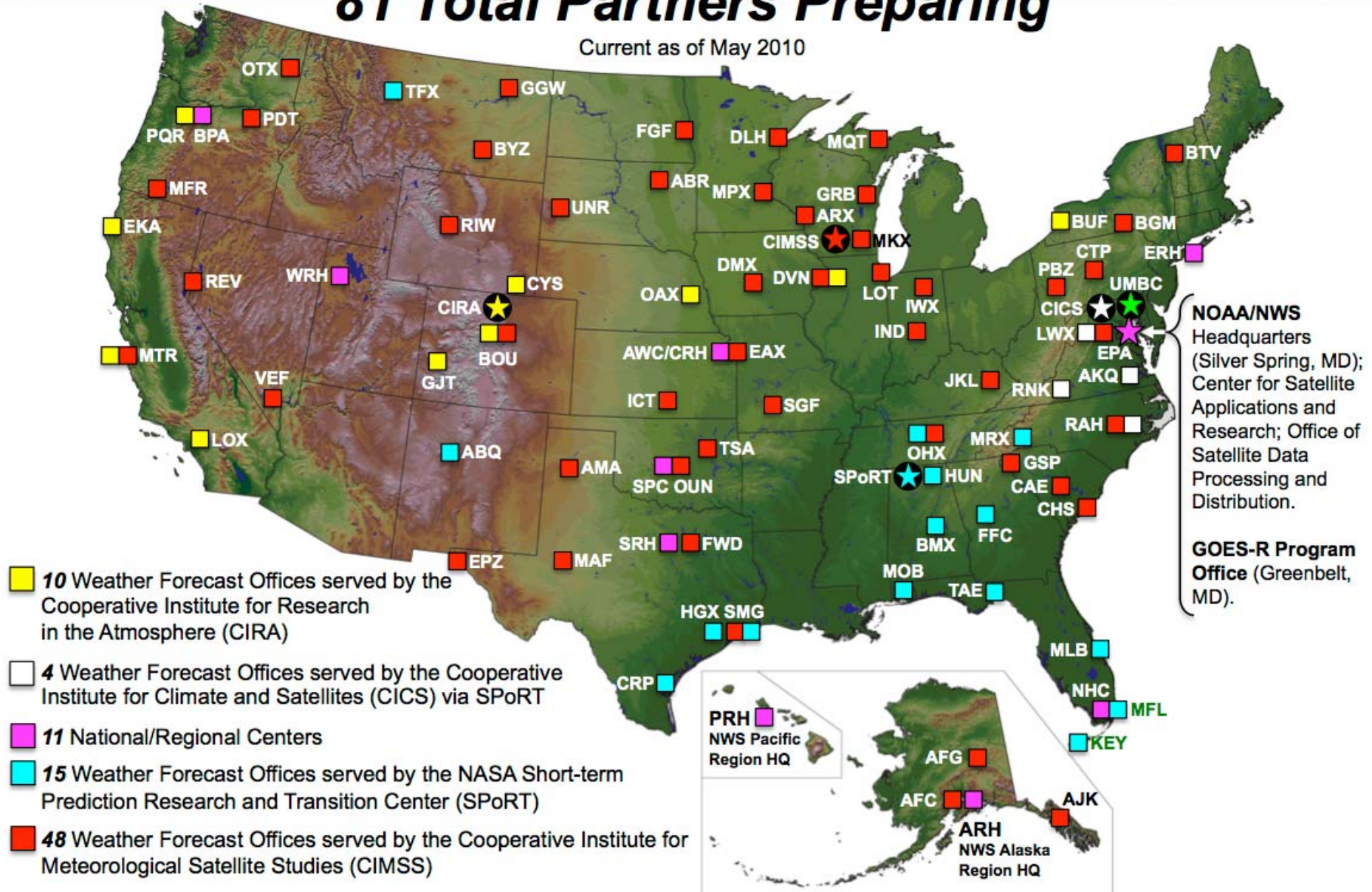


Satellite Proving Ground Collaboration Opportunities



81 Total Partners Preparing

Current as of May 2010



GOES-R Proving Ground @ CIMSS

The following list of products offers the opportunity for near-real time Warning-Related utility: Now Available – Blue / Near Future - Orange

•

Baseline Products:

- Volcanic Ash: Detection & Height - Alaska, Pacific, and AWC
- Cloud Top Phase / Cloud Type – Alaska, AWC, and OPC/HPC
- Cloud Top Height - AWC
- Cloud and Moisture Imagery – All testbeds
- Hurricane Intensity – NHC
- Total Precipitable Water – Pacific, HWT, OPC
- Fire / Hot Spot Characterization – HWT (Hydrologic and Fire, WRH)

Future Satellite Capabilities:

- Aircraft Icing Threat - NASA LaRC, Bill Smith Jr
- Turbulence - AWC
- **Cloud top cooling (UWCTC)**
- **“Enhanced-V” / Overshooting Top Detection – HWT and HPC**
- Low Cloud and Fog – AWC and Alaska
- SO₂ Detection – Alaska, AWC, and Pacific

Nearcasting – AWC, HWT, HPC





GOES-R Proving Ground

» Home » GOES-R Proving Ground

Resources

CIMSS NOAA Testbed Support Products

CIRA Products

SPoRT

Air Quality (UMBC)

Meetings and Presentations

Teleconferences

Proving Ground Partners

GOES-R Advanced Baseline Imager (ABI) Bands

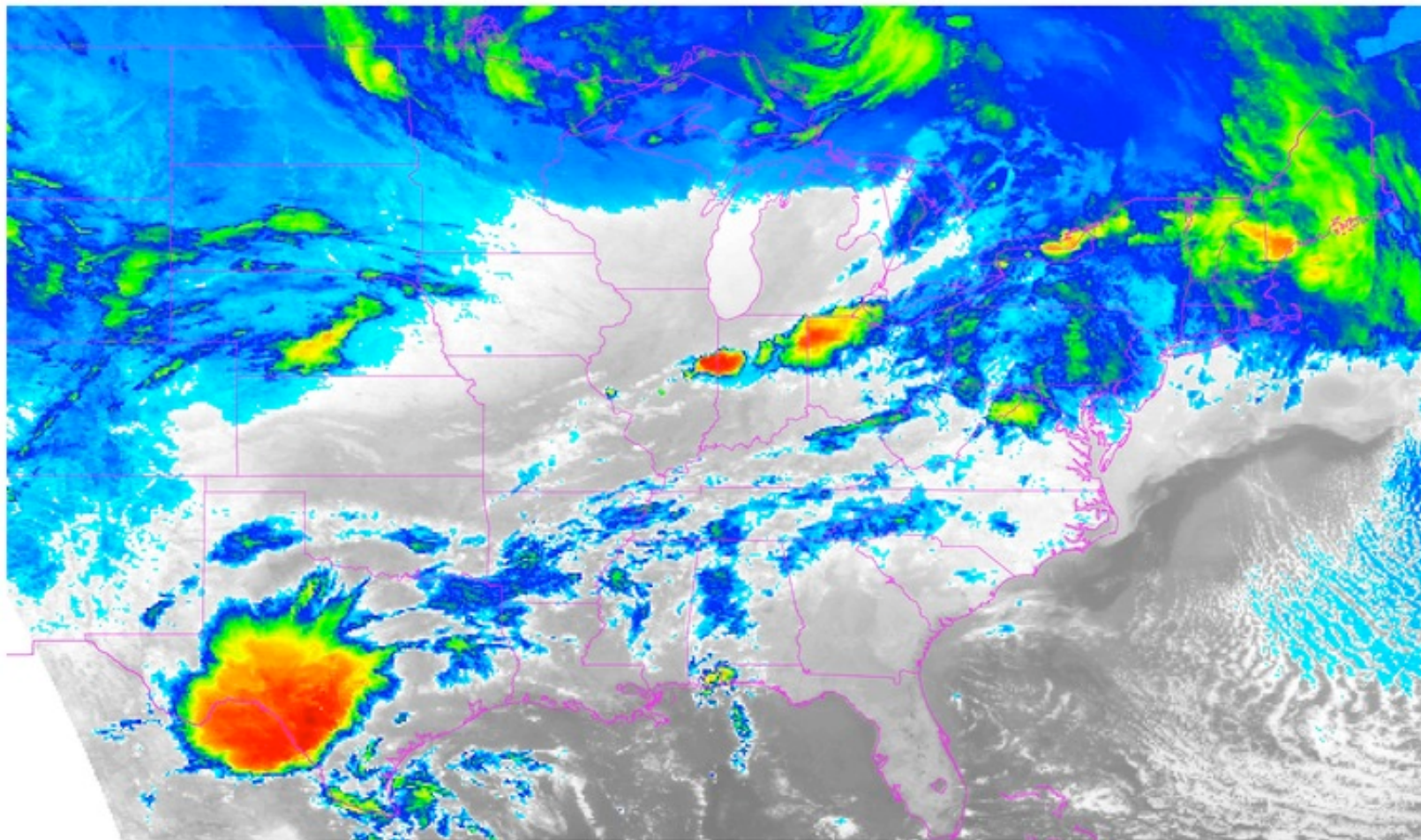
GOES-R ABI Sample Product Table

GOES-R ABI Weighting Function Examples

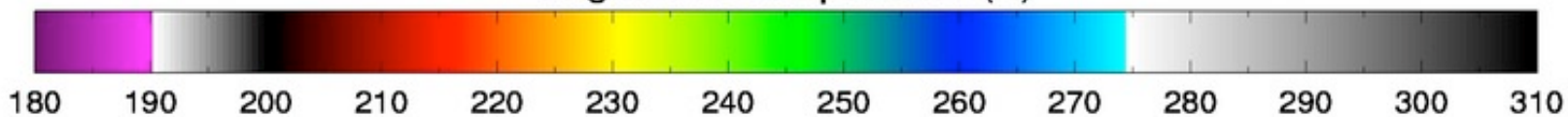
UW/CIMSS NOAA Proving Ground Decision Support Products

Product	Contact	Training		AWIPS Setup	Web Quicklooks	Satellite Platform	WFO Testbed Feedback	Product Type
		VISIT	PPT					
Convective Initiation(UWCI)	Wayne Feltz	X	X	X	X	GOES Imager	HWT , AWC, PR	Product Variant
Overshooting Top (OTTC) and Enhanced-V	Wayne Feltz Kris Bedka	X	X			GOES Imager, MODIS/AVHRR	HWT , HLT	AWG Proxy
WRF Simulated Radiances (ABI Simulated Radiances)	Justin Sieglaff		pdf		X		HWT	Risk Reduction
WildFire ABBA (WFABBA)	Chris Schmidt				X	GOES Imager	HWT	AWG Proxy
NearCast	Ralph Petersen	X	X	X	X	GOES Imager, GOES Sounder	HWT	Risk Reduction
Cloud Mask	Andrew Heidinger		X		X	GOES Imager, MODIS (Adaptable to any imager)	AAWU, AWC, HLT, PR, OPC	AWG Proxy
Cloud Height	Andrew Heidinger		X	Contact Researcher	X	GOES Imager, AVHRR (Adaptable to any imager)	AAWU, AWC, HLT, PR, OPC	AWG Proxy
Volcanic Ash	Mike Pavolonis	X	X	Contact Researcher		MODIS, SEVIRI	AAWU, AWC, HLT, PR	AWG Proxy
Low Clouds, Cloud Type, Fog	Mike Pavolonis		X Quick Facts			MODIS-Alaska, GOES-CONUS	AAWU, AWC, HLT, HWT	AWG Proxy

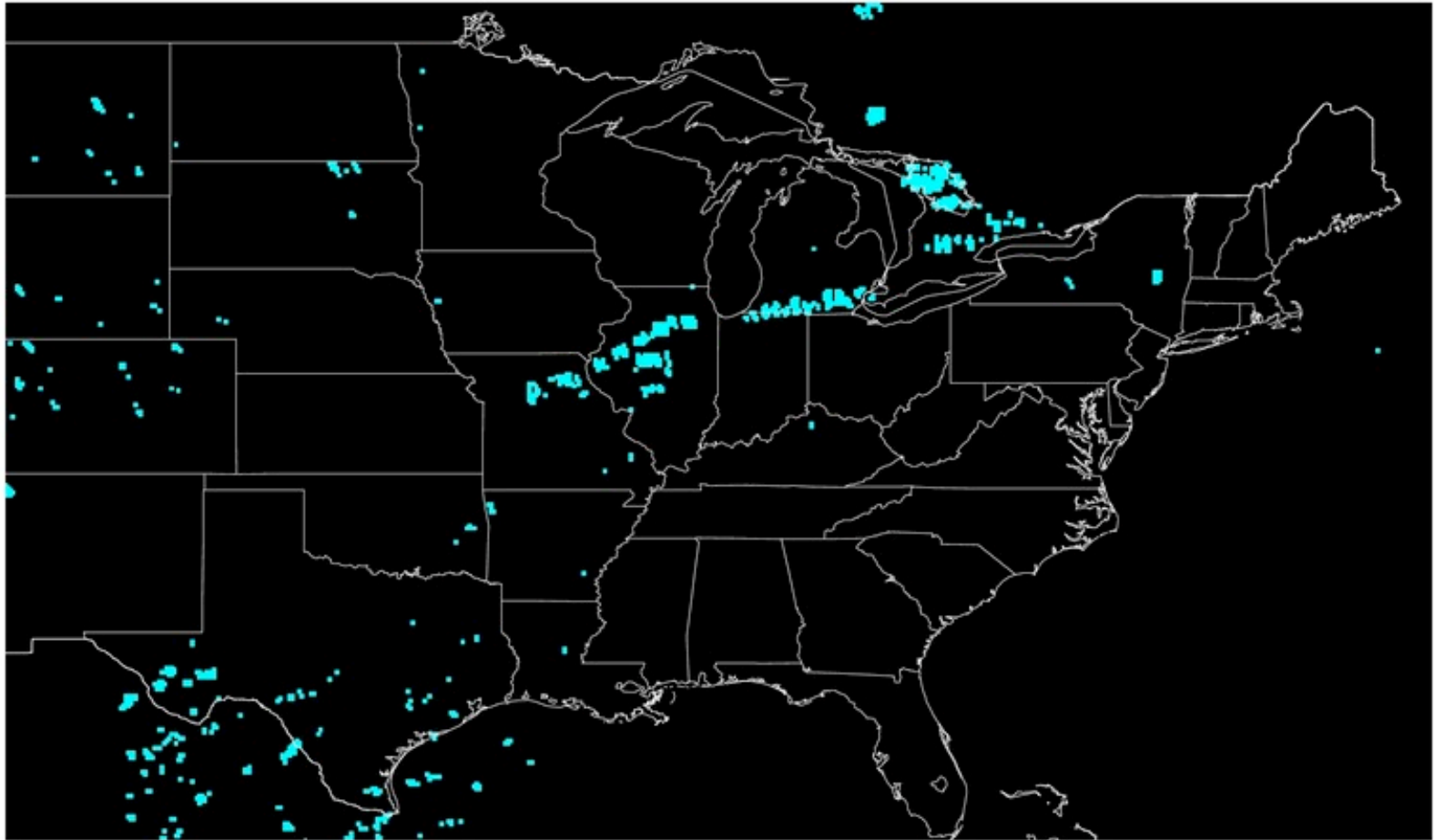
GOES-13 4km IRW: 20120328 at 0732 UTC



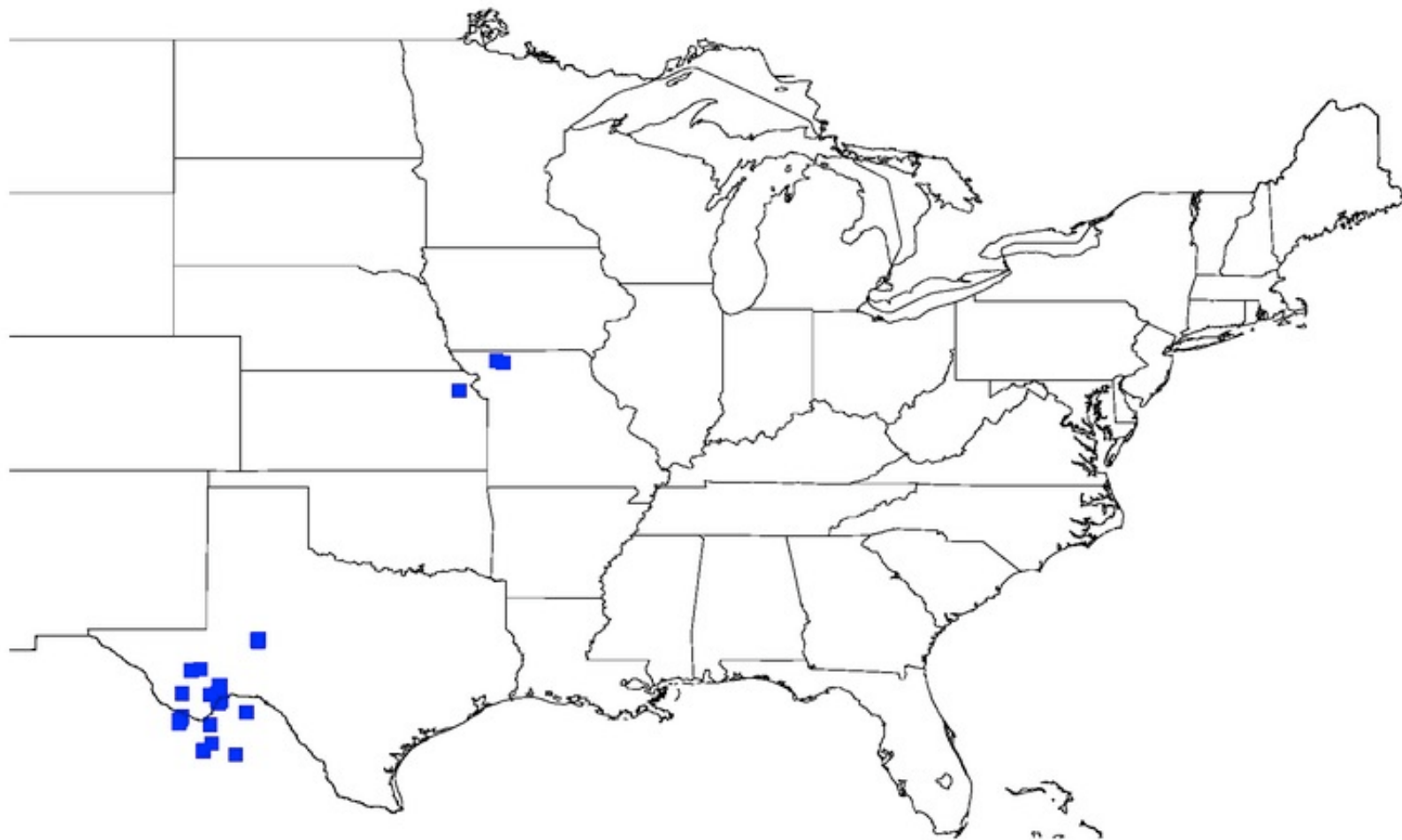
Brightness Temperature (K)



Daily Cumulative CTC Hits: 20120328 at 0732 UTC



Daily Cumulative OT/TC Detects: 20120328 at 0732 UTC



ESSL Testbed Collaborations?

- SEVIRI based cloud top cooling
- SEVIRI based overshooting-top
- SEVIRI based Nearcasting (next year)

