The Cooperative Institute for Meteorological Satellite Studies
University of Wisconsin, Madison

Initializing Water Vapor and Clouds in Prediction Models Using Satellites

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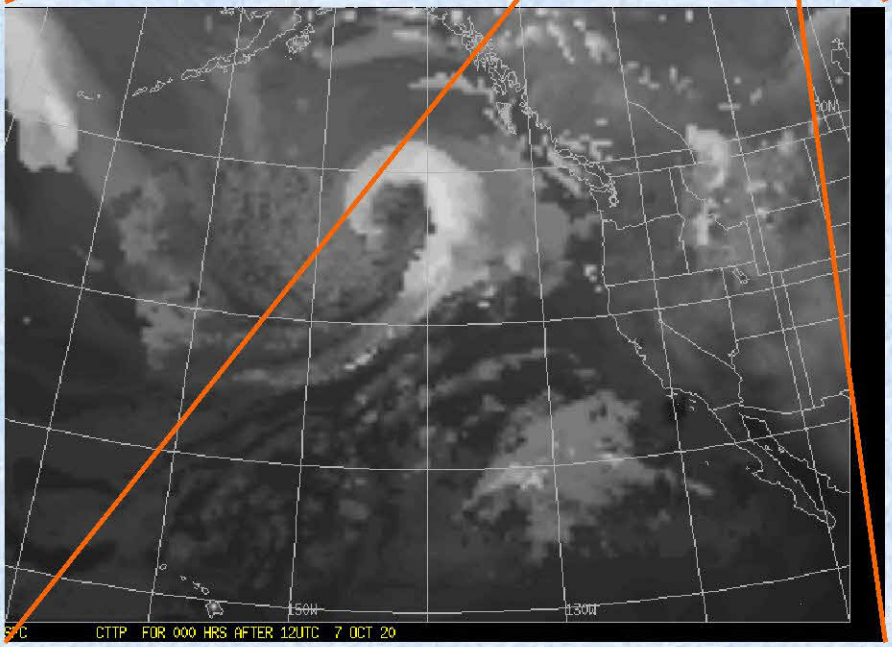
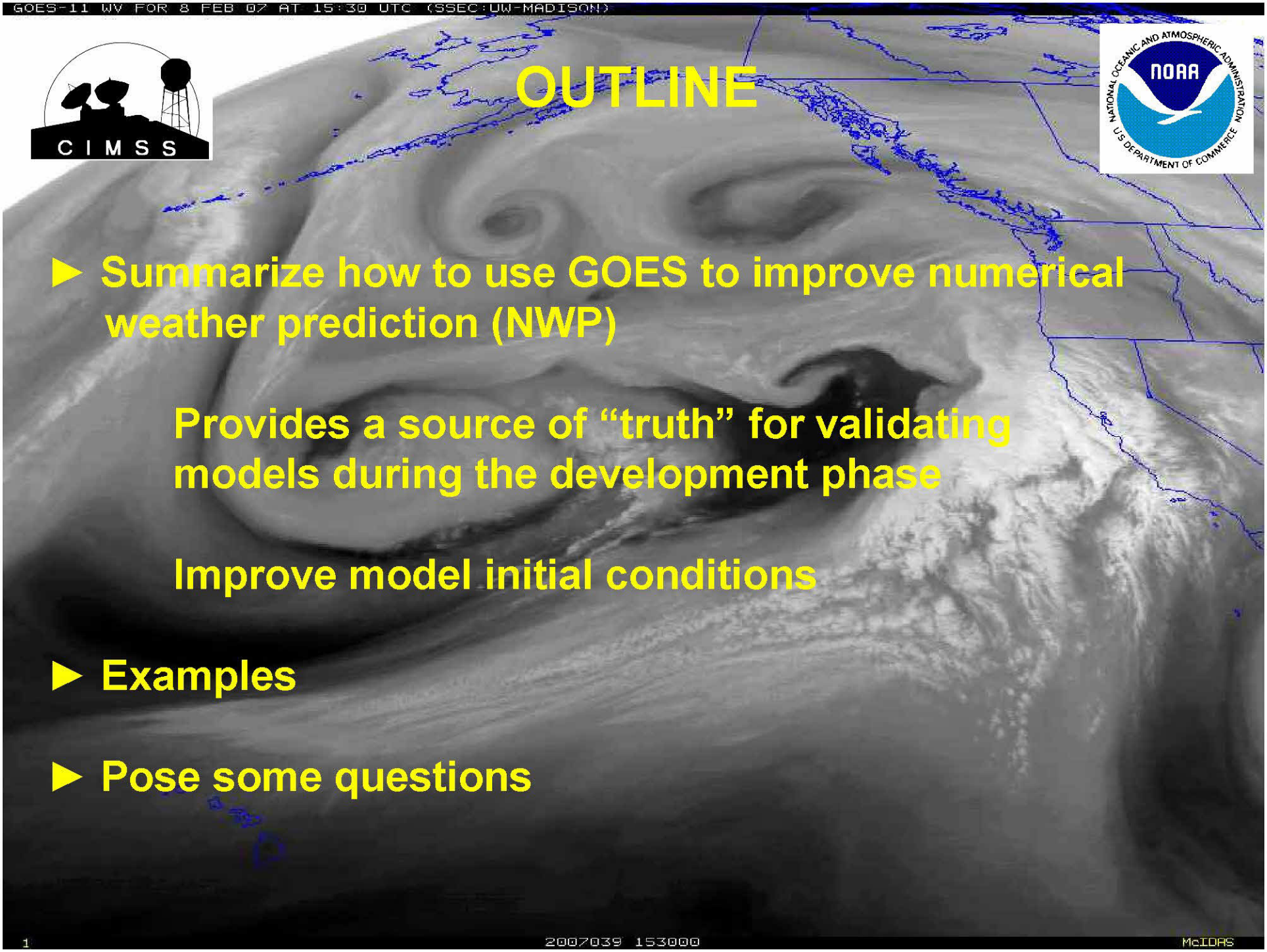


OCONUS GOES-R Proving Ground Meeting
July 28-30, 2010, Honolulu, Hawaii



OUTLINE

- Summarize how to use GOES to improve numerical weather prediction (NWP)

  Provides a source of "truth" for validating models during the development phase

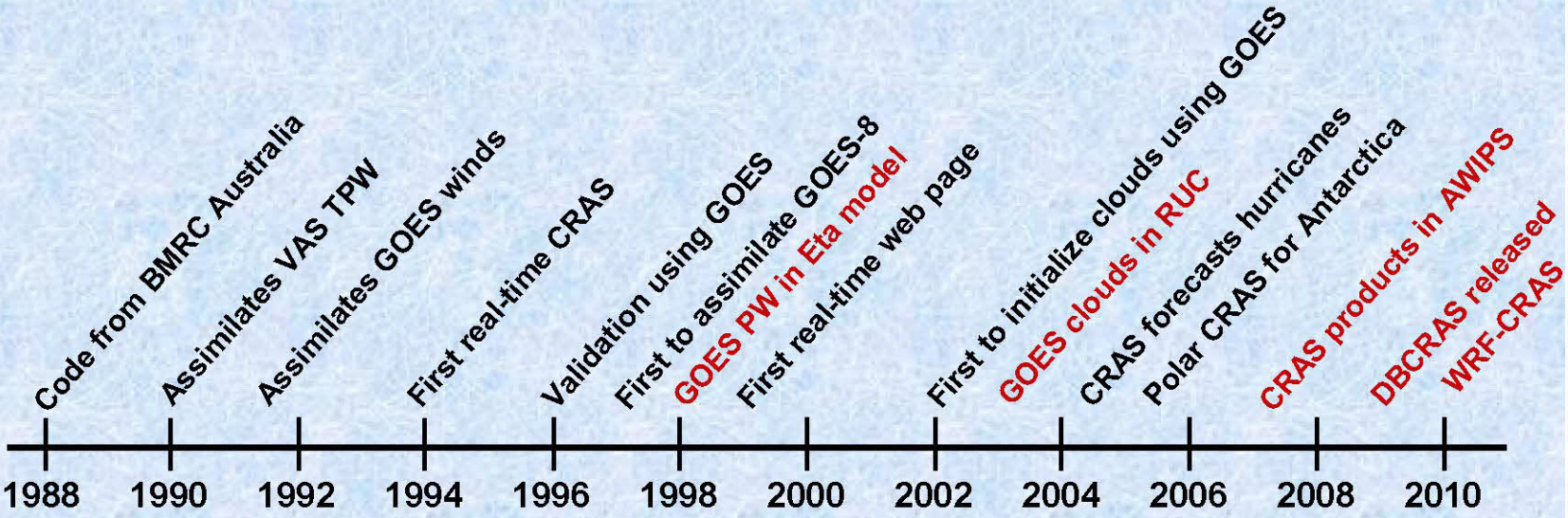
  Improve model initial conditions

- Examples

- Pose some questions

CIMSS Regional Assimilation System

Scientists at the Cooperative Institute for Meteorological Satellite Studies (CIMSS) use the CIMSS Regional Assimilation System (CRAS) to assess the impact of satellite observations on numerical weather prediction.

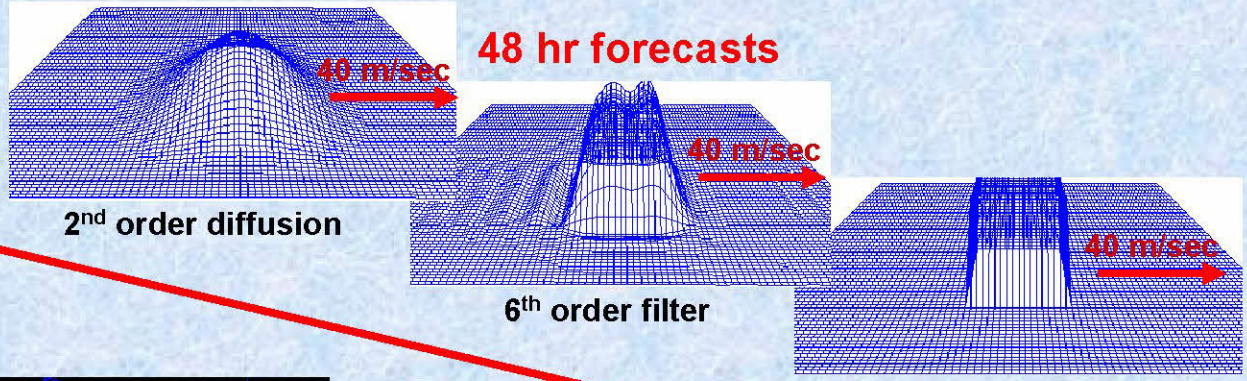


CRAS History

CRAS TEMPESTUS HODIE - Tomorrow's Weather Today

Forecast Model Development Validated Using GOES

1. Preservation of information:
- Mass conservation in advection
- Reduced gradient dissipation

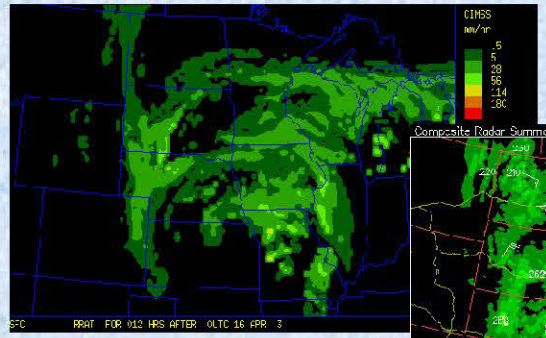


2nd order diffusion

6th order filter

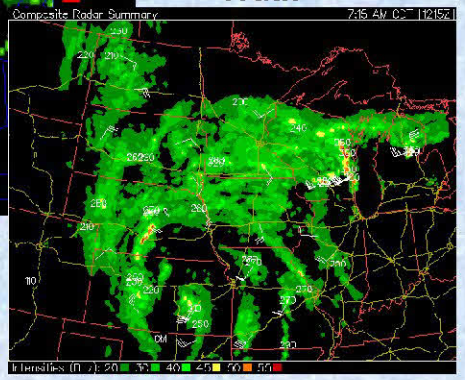
Exact solution

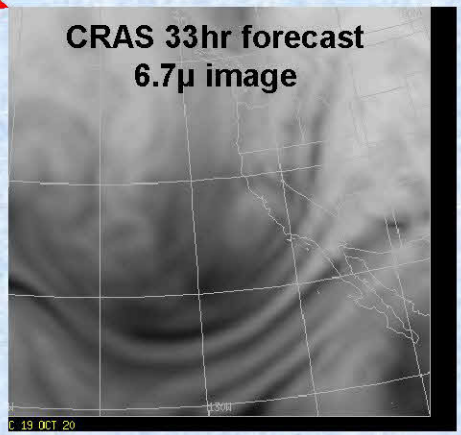
2.Improved physics:
- Radiative fluxes
- Moist physics



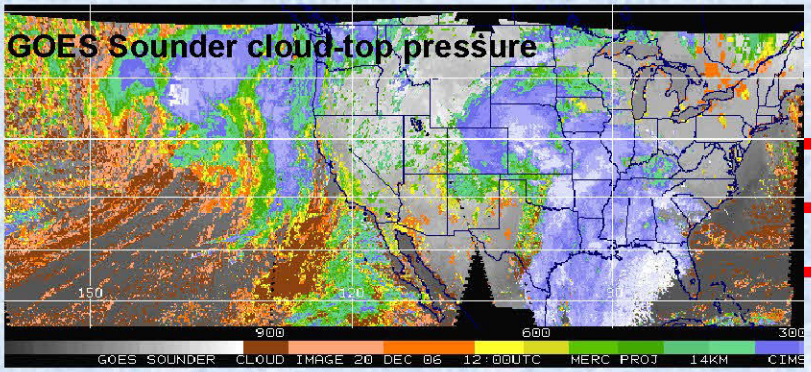
12-hour forecast rain-rate from 20 km CRAS valid 12UTC 16 April 2003.

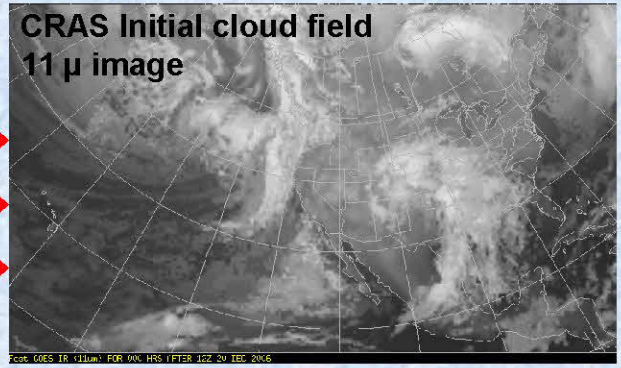
Truth





3. Improved Initial Conditions:
- Water vapor
- 3D clouds
- Upper-level winds





Assimilating 3-Layer Precipitable Water from GOES

Water Vapor Adjustments using GOES 3-layer precipitable water retrievals are performed for clear fields-of-view only.

Procedure

r_M = MODIS total precipitable water

r_B = Background total precipitable water

$w(\sigma)_B$ = background mixing ratio

$w'(\sigma)_B$ = background mixing ratio perturbation

w_0 = surface mixing ratio

$w_S(T)$ = saturation mixing ratio

$w(\sigma)_F$ = final mixing ratio

Let,

$\bar{r}_M = \frac{1}{n}\sum_n r_M$, n = number of MODIS obs in grid cell

Precipitable water is defined as : $r = \frac{p_0}{g}\int_\sigma w(\sigma)d\sigma$

Define a mean mixing ratio profile : $\hat{w}(\sigma) = w_0\sigma^\lambda - w'_B(\sigma)$ such that

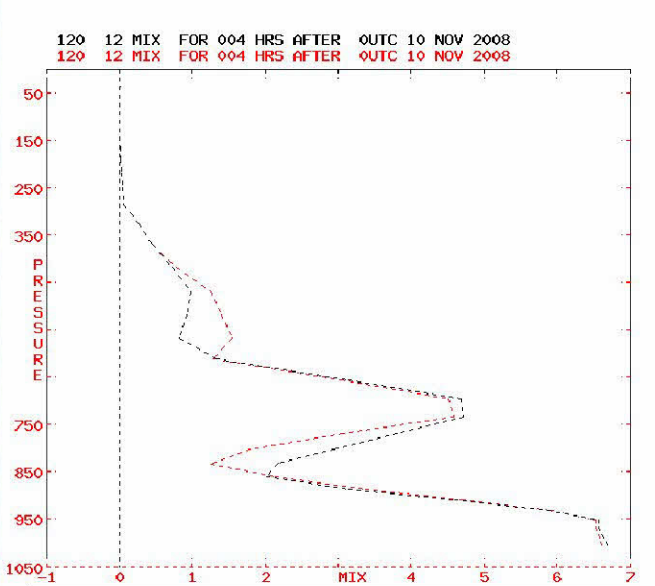
$\frac{p_0}{g}\int_\sigma w'_B(\sigma)d\sigma$ is a minimum and $1.0 < \lambda < 3.5$ following Smith, 1966.

Solve for $\lambda = \lambda'$ such that :

$$\bar{r}_M = \frac{p_0}{g}\int_\sigma \hat{w}_0\sigma^{\lambda'} + w'_B(\sigma)d\sigma \qquad \text{with : } [\hat{w}_0\sigma^{\lambda'} + w'_B(\sigma)] < w_S(T)$$

The final adjusted mixing ratio is :

$$w_F(\sigma) = \hat{w}_0\sigma^{\lambda'} + w'_B(\sigma)$$

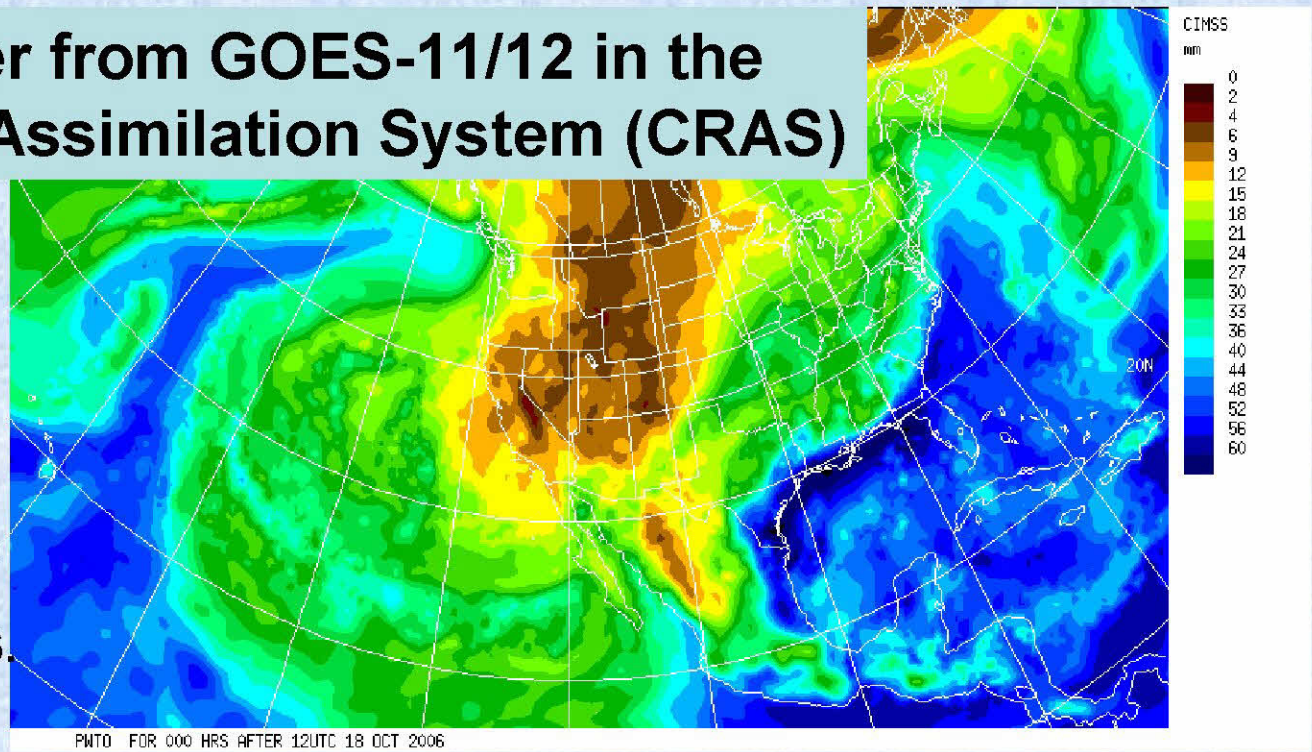


Mixing ratio profile before (red) and after assimilating total precipitable water from the GOES sounder

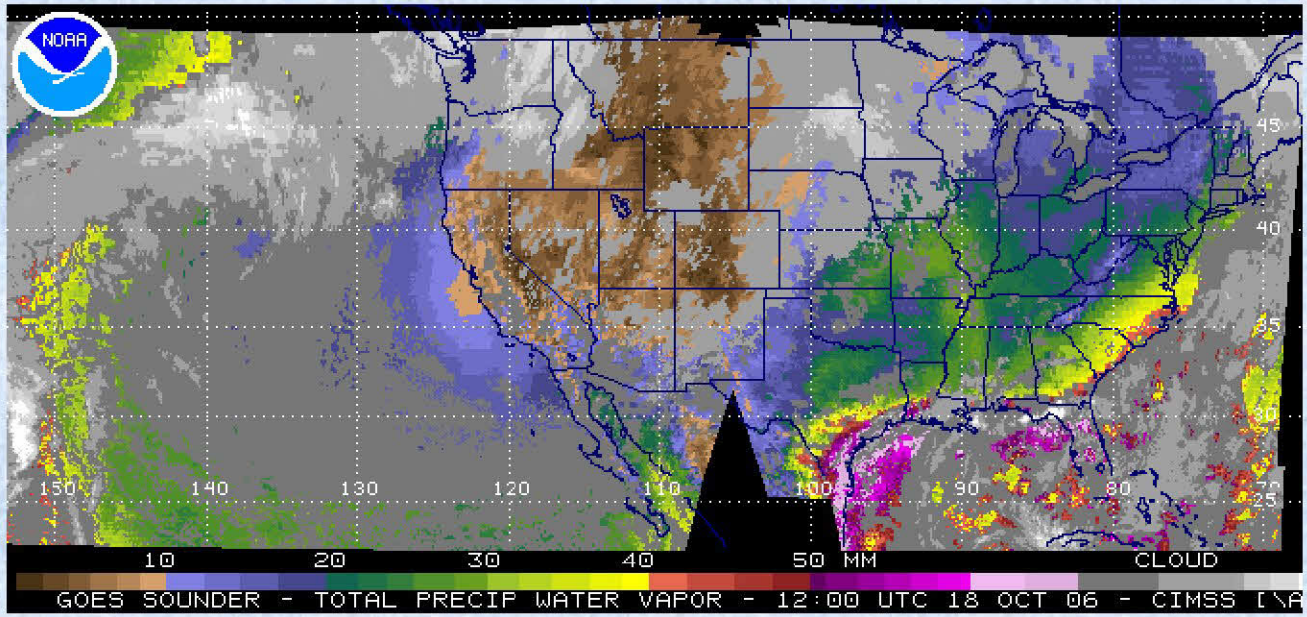
* Smith, W.L., 1966: Note on the relationship between total precipitable water and surface dew point. J. Appl. Meteor., 5, 726-727.

Precipitable Water from GOES-11/12 in the CIMSS Regional Assimilation System (CRAS)

Three layers of precipitable water, retrieved from the GOES-11/12 sounders, are used to initialize mixing ratio in the CRAS. Here is an example of the initial total precipitable water from the 48 km North American CRAS, valid 12UTC, 18Oct06. Detailed structures are present.



Here is the derived product image of total precipitable water from the GOES-11/12 sounders valid 12UTC, 18Oct06. Note the map projection and color enhancement are not equivalent.

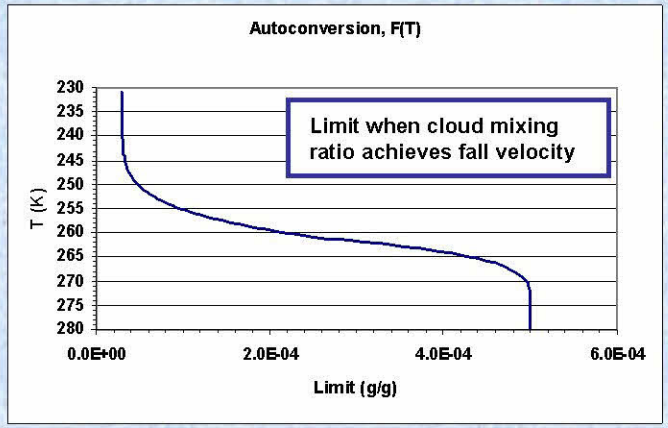


Assimilating Clouds from GOES

Retrievals of cloud-top pressure (CTP) and effective cloud amount (ECA) from GOES are used to adjust cloud water mixing ratio in the CRAS spin-up forecast. (Similar to Bayler et.al., 2000, Mon. Wea. Rev. 128, 3911-3920.)

Cloud Modification Options

Background	MODIS	Operation
Clear	Clear	Check RH
Cloudy	Clear	Clear cloud, adjust RH
Clear/Cloudy	Cloudy	Build cloud, adjust RH, match top



Procedure

Given:

$CTP_M(n)$ = GOES cloud-top pressure vector at grid cell, n = count

$ECA_M(n)$ = GOES effective cloud amount vector at grid cell, n = count

$q_c(k)$ = cloud mixing ratio at model level k

$q^*_c(T)$ = Max cloud mixing ratio (Autoconversion)

n(k) = # MODIS per model grid cell

1. Bin 5km $CTP_M(n)$ onto a model grid cell
2. Sort grid cell CTP_M and ECA_M onto model pressure levels
3. If $RH(k) > RH_{evap}(k) - 20\%$, proceed
4. Clear cloud above CTP_M , $q_C(k) \mid (CTP_M , top) = 0$
5. For layers above 600hPa: $q_c(k) = [\ \Sigma_n\ ECA_M(k)\ ] / n(k) \times q^*_c(T)$
6. For layers below 600hPa: $q_c(k) = n_{cld}(k) / n(k) \times q^*_c(T)$

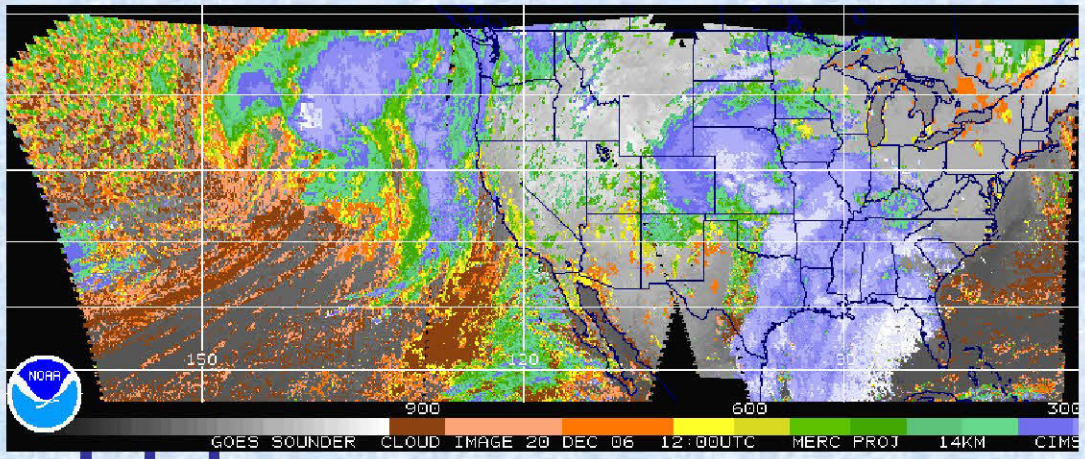
Impact of a single MODIS sounder cloud insert on a 12-hour CRAS forecast. Verification using cloud-top temperature from MODIS.

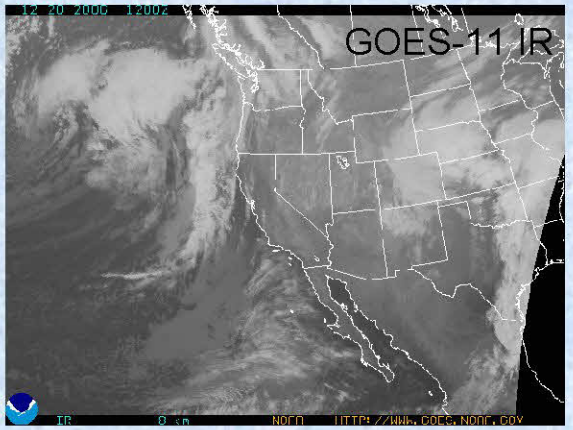
	MODIS	No MODIS
OBS	714	714
RMS	13.99	18.13
Bias	-3.17	-3.93

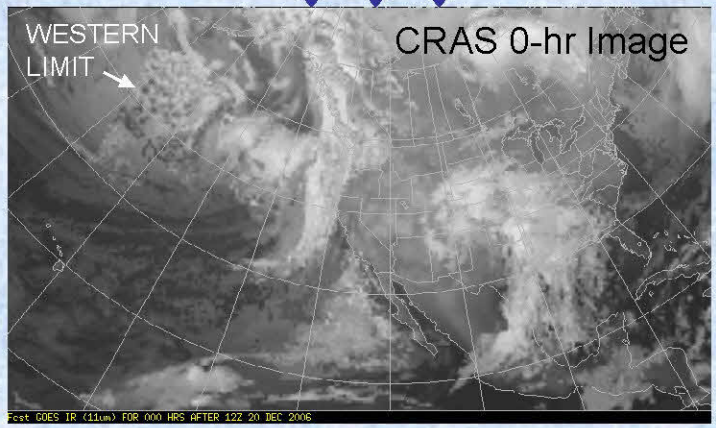
CRAS Forecast Model Exploits the Spatial and Temporal Advantages of the GOES Sounders to Initialize Clouds

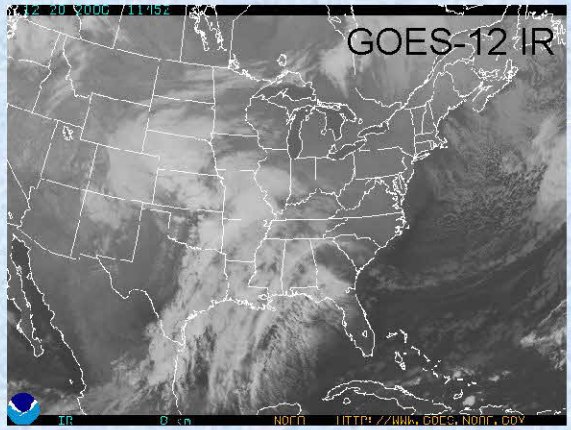
The Cooperative Institute for Meteorological Satellite Studies (CIMSS) uses the CIMSS Regional Assimilation System (CRAS) to test the impact of using digital cloud-top pressure and effective cloud amount from the GOES-11/12 sounders on forecast accuracy.

The 11μ image shown below (center) was generated from CRAS initial conditions that contain information from the sounder DPI image at right.

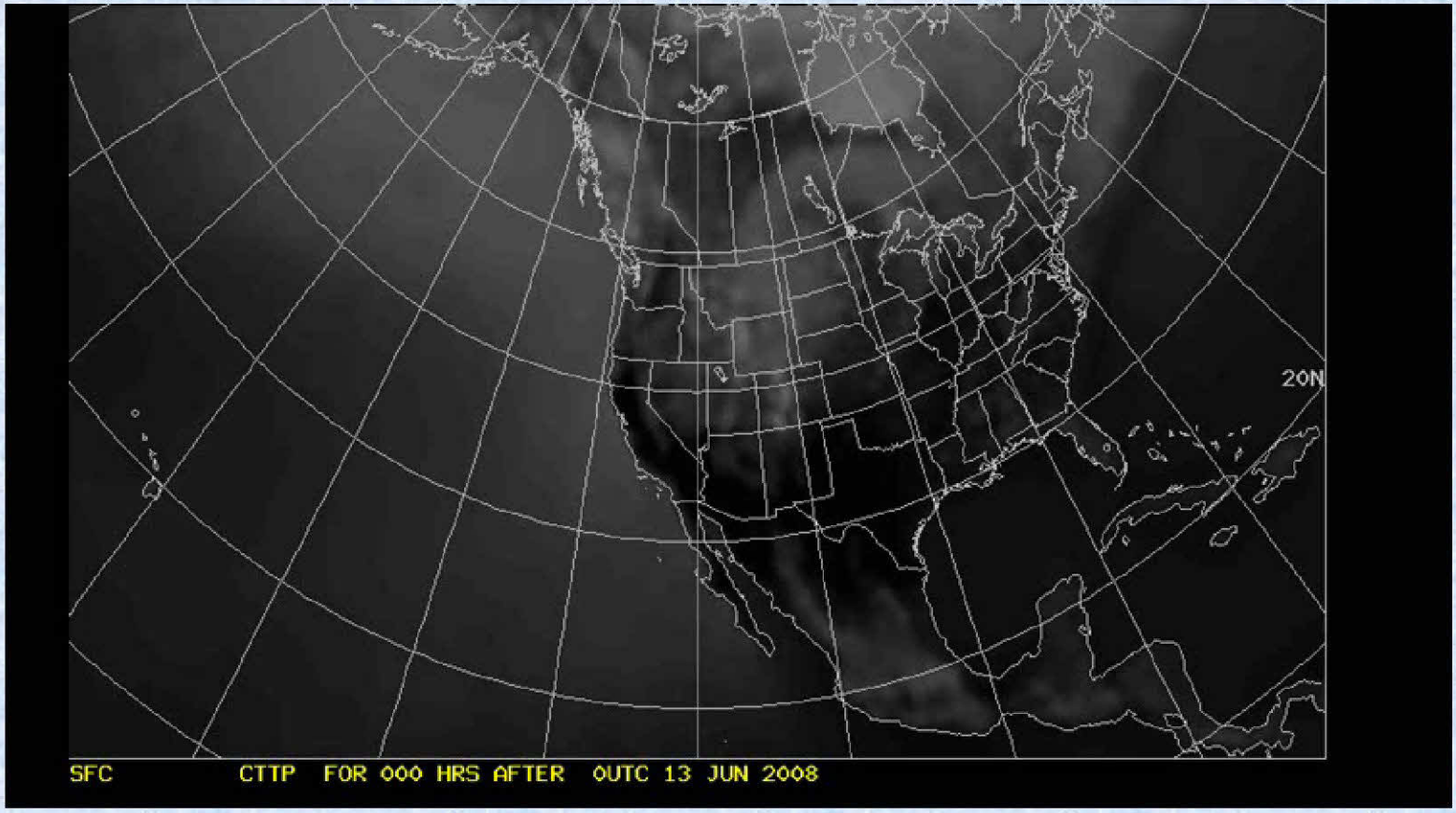








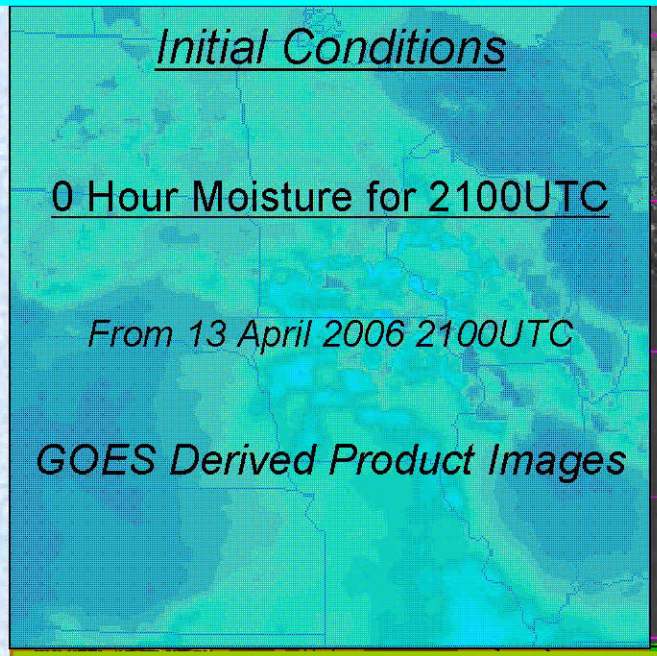
To improve forecast accuracy the North America CRAS is now assimilating each GOES sounder scan at each specific central scan time.

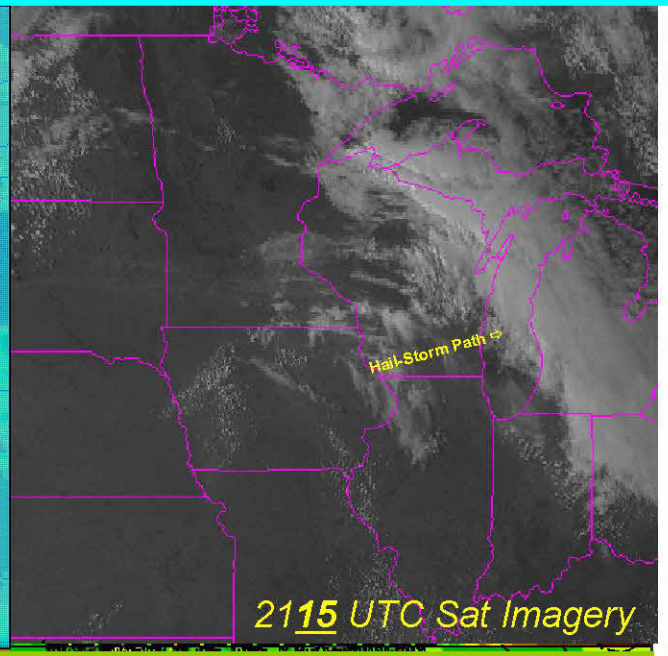


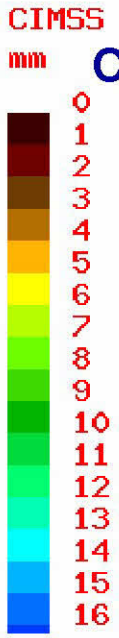
CRAS forecast IR image from 12-hour spin-up forecast commencing 00UTC 13Jun08, 10-min frames.

Moving GOES data from Observations to Forecasts

NWP Analysis Comparison



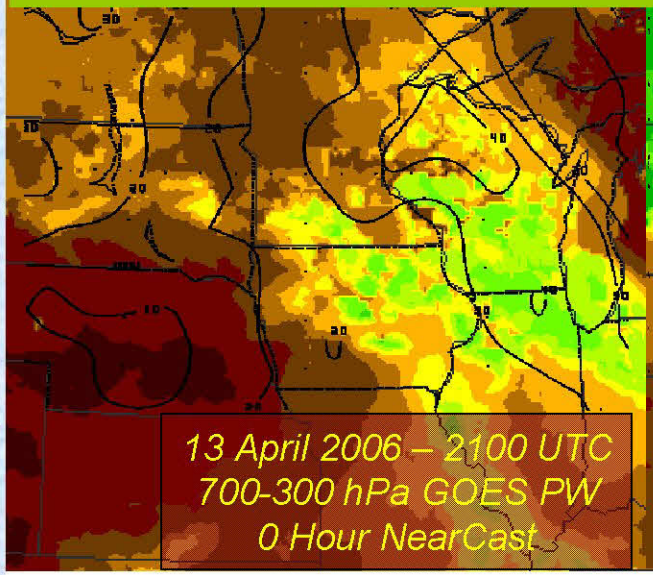


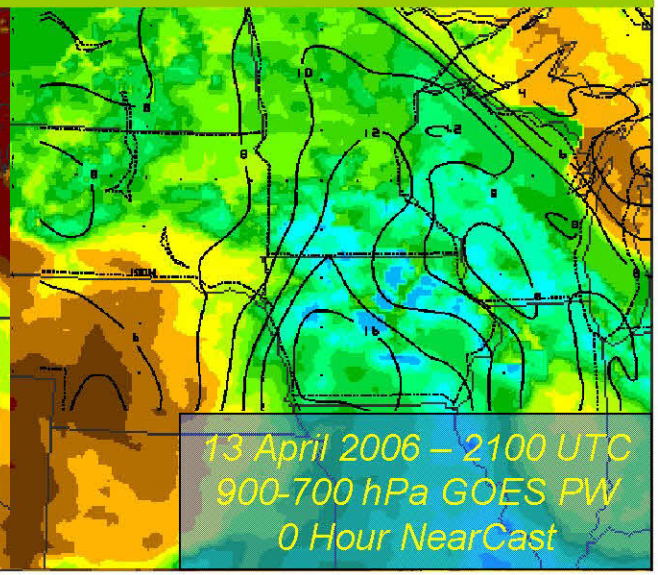


Comparison with integrated NWP Moisture fields

Initial GOES DPIs

NAM 03h Forecast of 700-300 hPa and 900-700 hPa PW valid 2100 UTC





Valid 2100 UTC

NWP has:

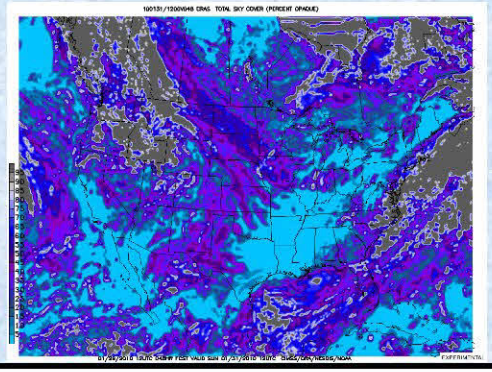
Moisture in wrong locations

Gradients too weak by factor of 4-8

CIMSS Regional Assimilation System

The Advanced Satellite Products Branch (ASPB) has teamed with scientists at the Cooperative Institute for Meteorological Satellite Studies (CIMSS), University of Wisconsin, to develop the CIMSS Regional Assimilation System (CRAS). It's purpose is to evaluate the impact of space-based observations on mesoscale numerical weather prediction accuracy.

CRAS is a regional mesoscale numerical prediction model. It is unique in that, since 1996, it's development was guided by validating forecasts against information extracted from the GOES imager and sounder.



48-hour forecast sky cover (0-100%) from CRAS is currently being evaluated at NWS Forecast Offices.

CRAS History (2004 to present)

Domain	Active	Grid(km)	BCs	Hrs	Sat	Observations	Research-> Ops	Notes
North America*	Y	45	GFS	84	GOES	PW3/Cld/wind	GOES PW in Eta	First forecast IR imagery (1996)
Central US (nest)	Y	15	CRAS	36	GOES	PW3/Cld		Severe weather forecasting
Pacific NW (nest)	Y	15	CRAS	12	GOES	PW3/Cld		Cloud forecast for solar power
Eastern Pacific	Y	48	GFS	72	GOES-11	PW3/Cld	Forecast IR/WV	Evaluation by Pacific Region
					AVHRR	Cld		
South America	N	48	GFS	72	GOES-10	PW3/Cld		Evaluate goes-10 soundings
CONUS (nest)	Y	20	CRAS	48	GOES	PW3/Cld	GOES Cld in RUC	GOES sounder assimilation test
South Pole	Y	48	GFS	72	MODIS	TPW/Cld	Forecast IR/WV	Supporting Govt/private sector
Alaska*	Y	45	GFS	84	MODIS	TPW/Cld	Forecast IR/WV	Evaluation by Alaska Region
					AVHRR	Cld		
					GOES-11	PW3/Cld		
N Hemisphere	Y	90	GFS	168	None	GFS Grids		CRAS model evaluation
DBCRAS (portable)	Y	48	GFS	72	MODIS	TPW/Cld	Local MODIS-IMAPP	Used in 14 countries

* Forecasts transmitted to NWS AWIPS for evaluation

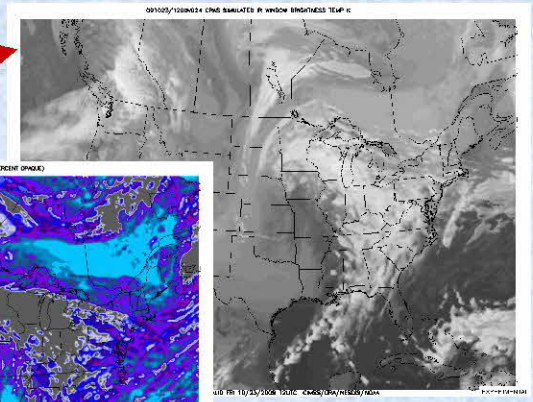
Forecasts available for viewing at http://cimss.ssec.wisc.edu/cras/

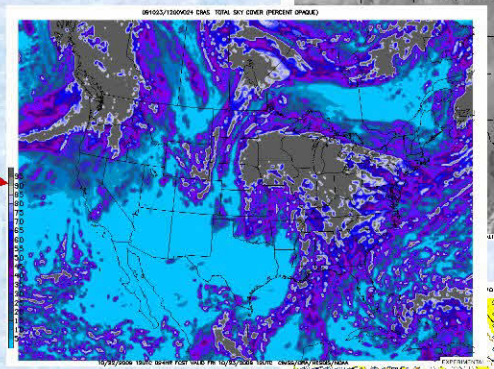
R. Aune, CoRP/ASPB

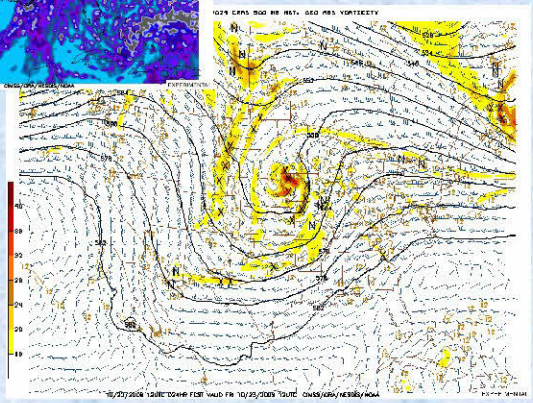
CIMSS Regional Assimilation System

Supporting NWS operations

CRAS products in AWIPS
- Forecast IR/WV imagery
- 45km CRAS output in grib2
- Skycover product

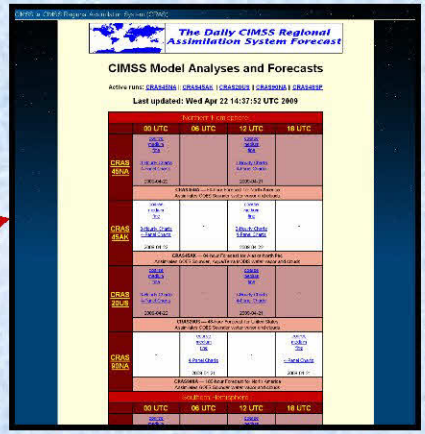






Initialize MKX WRF with CRAS
- Generate parallel run
- Uses GOES sounder
- SSTs from MODIS

New CRAS webpage
- Same format as NCEP
- Gempak graphics



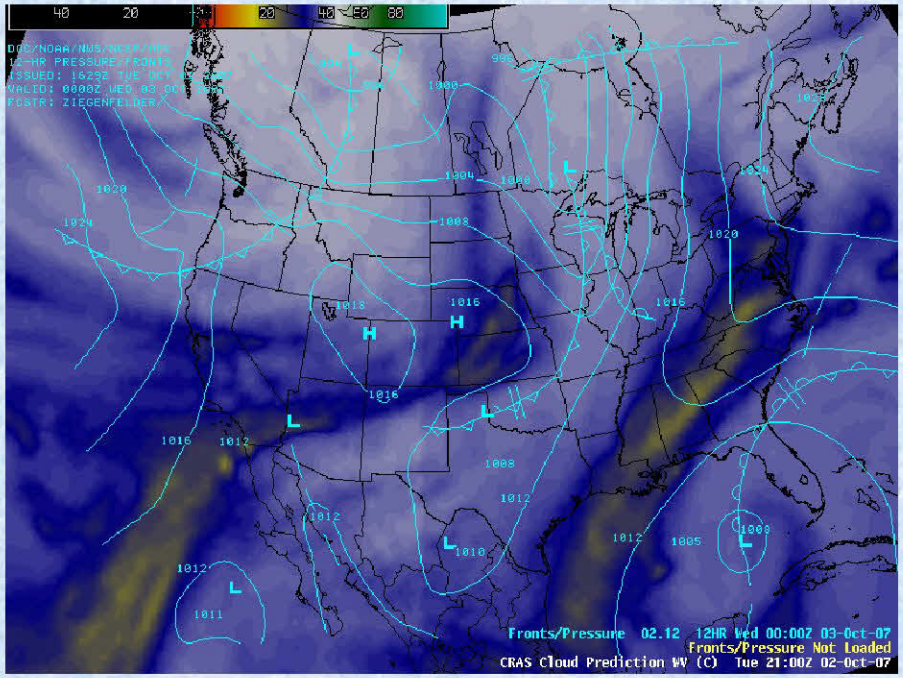
CRAS Forecast Satellite Imagery In AWIPS

For the last two years CRAS forecast 11µm and 6.7µm imagery have been generated in real-time and transferred to the NWS Central Region for distribution to NWS Forecast offices as part of an experimental satellite products evaluation project. The real-time CRAS uses 3-layer precipitable water and cloud-top pressure retrievals from the GOES sounders to initialize water vapor and clouds.

AREA FORECAST DISCUSSION
NATIONAL WEATHER SERVICE MILWAUKEE/SULLIVAN WI
836 PM CST THU NOV 30 2006

.....IN ADDITION CRAS IR HAS VERY GOOD INITIAL DEPICTION OF BAROCLINIC LEAF SIGNATURE DEVELOPING OVER KANSAS AND PROGS SOUTHERN EDGE OF THIS SIGNATURE OVER WARNING AREA BETWEEN 12Z AND 15Z FRIDAY.....

(From a recent forecast discussion message.)



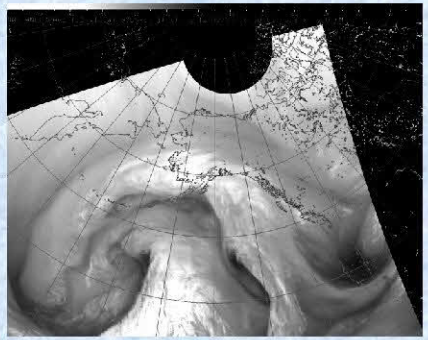
(Screen captures courtesy of S. Bachmeier, CIMSS)

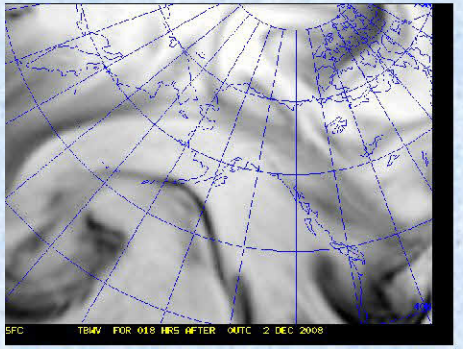
CRAS Forecast Products for the Alaska Region

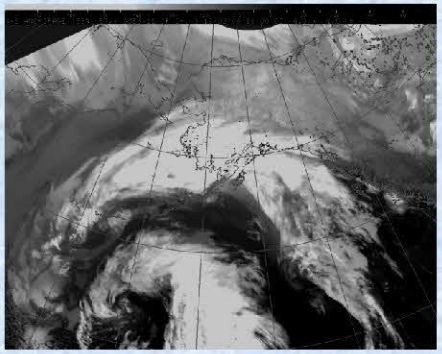
CIMSS has configured the CRAS for Anchorage, Alaska. It uses precipitable water and cloud-top pressure from MODIS and from the GOES-11 sounder to initialize water vapor and clouds. The domain is a superset of the AWIPS 216 grid so forecast products can be transferred directly to AWIPS.

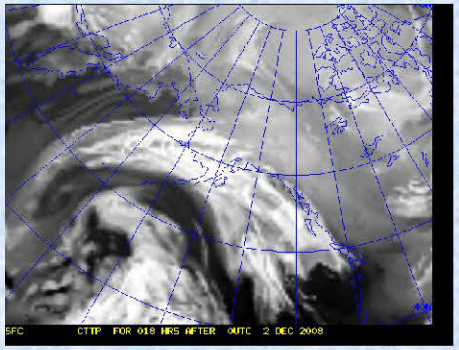
Shown at right are some comparisons between 18-hour CRAS forecast images and images from the GOES-11 imager. The 6.7u CRAS images are generated using the GOES-11 radiative transfer model to generate clear sky brightness temperatures. The 11u CRAS images are computed using the predicted cloud mixing ratio to attenuate the predicted skin temperature.

Note: The map projection on the GOES-11 images are slightly different than on the CRAS images.

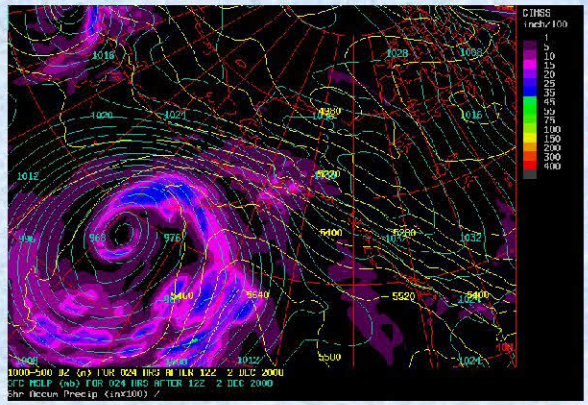


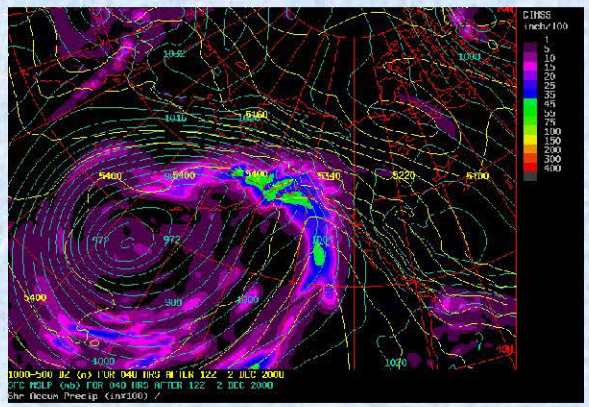


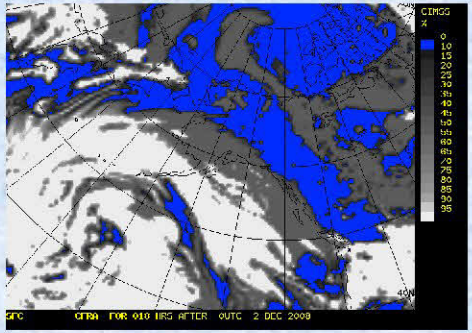




24 and 48-hour forecasts of 6-hour accumulated precipitation, 1000hPa – 500hPa thickness and mean sea-level pressure valid 12UTC 04Dec08

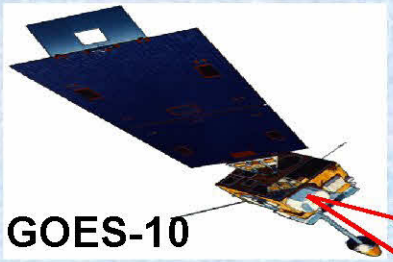






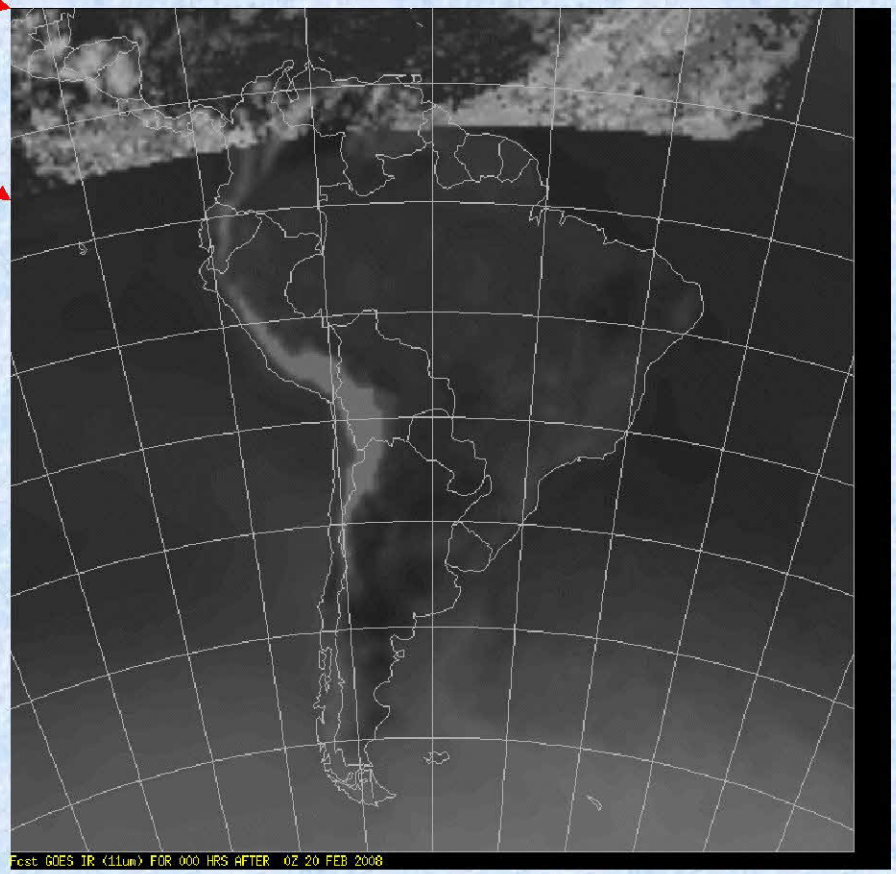
18-hour forecast sky cover (0% - 100%) valid 18UTC 02Dec08

Initializing Water Vapor and Clouds in the South America CRAS using Products from the GOES-10 Sounder



Cloud-top pressure, and effective cloud amount from the GOES-10 sounder are used to clear erroneous model clouds and to construct multi-layer cloud profiles in the CRAS 12-hour spin-up forecast.

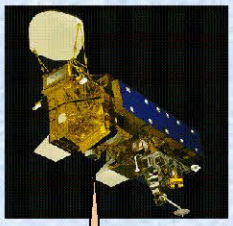
3-layer precipitable water is used to adjust water vapor profiles in the clear fields of view.



12-hour loop of simulated 11 micron images showing the hourly cloud adjustments due to the assimilation of GOES-10 sounder products.

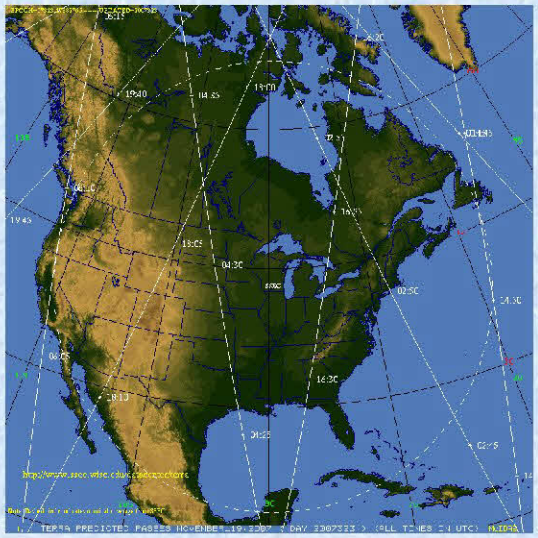
Can CRAS be configured to assimilate MODIS from direct broadcast sites around the world?

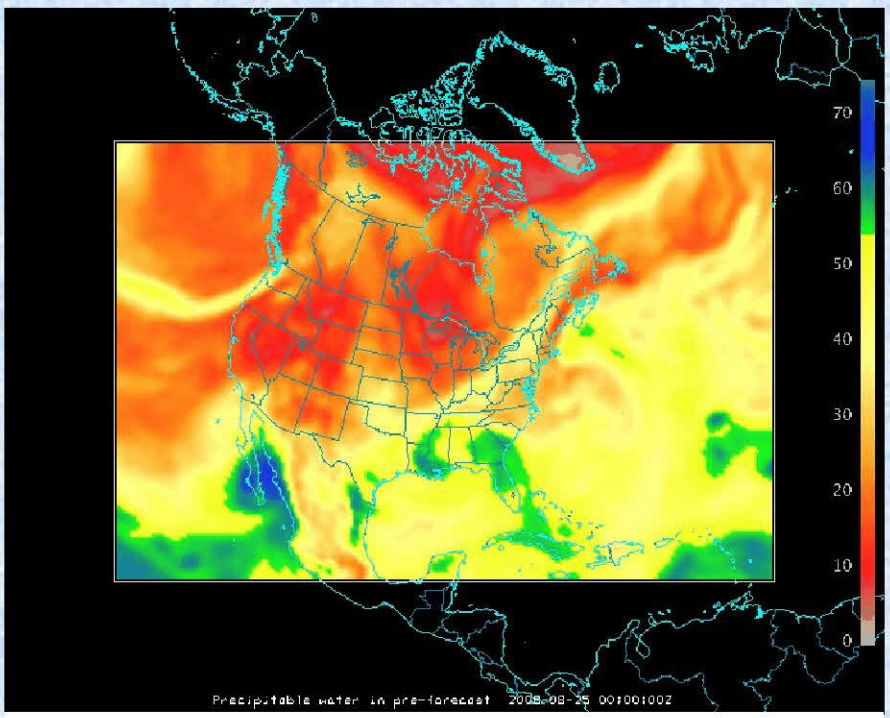
CIMSS has configured a version of CRAS that assimilates products from the Moderate Resolution Imaging Spectroradiometer (MODIS). It is installed at MODIS direct broadcast sites and assimilates MODIS products generated locally using IMAPP.



DBCRAS was tested using MODIS direct broadcast products from the antenna at the Space Science and Engineering Center, University of Wisconsin, Madison.

TERRA Orbital Tracks





12-hour loop of total precipitable water (TPW) from the Direct Broadcast CRAS (DBCRAS) spin-up forecast illustrating how MODIS moisture modifies the GFS water vapor in CRAS. Note how MODIS adds detail to the TPW in the vicinity of Tropical Storm Fay.

Design Requirements for Direct Broadcast CRAS (DBCRAS)

Free distribution with International MODIS/AIRS Processing Package

Must run on a modest Linux 32 or 64 bit platform

Medium bandwidth internet connection

One time install using center lat/lon provided by the user

Automated identification and download of ancillary input data

Backup server at SSEC for ancillary input data

Execution via simple shell scripts

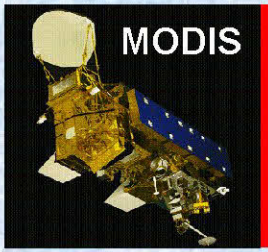
72 hour forecasts of standard meteorological fields on 48 km grid

Output is grib2 format

Option to generate graphics using McIdas-V

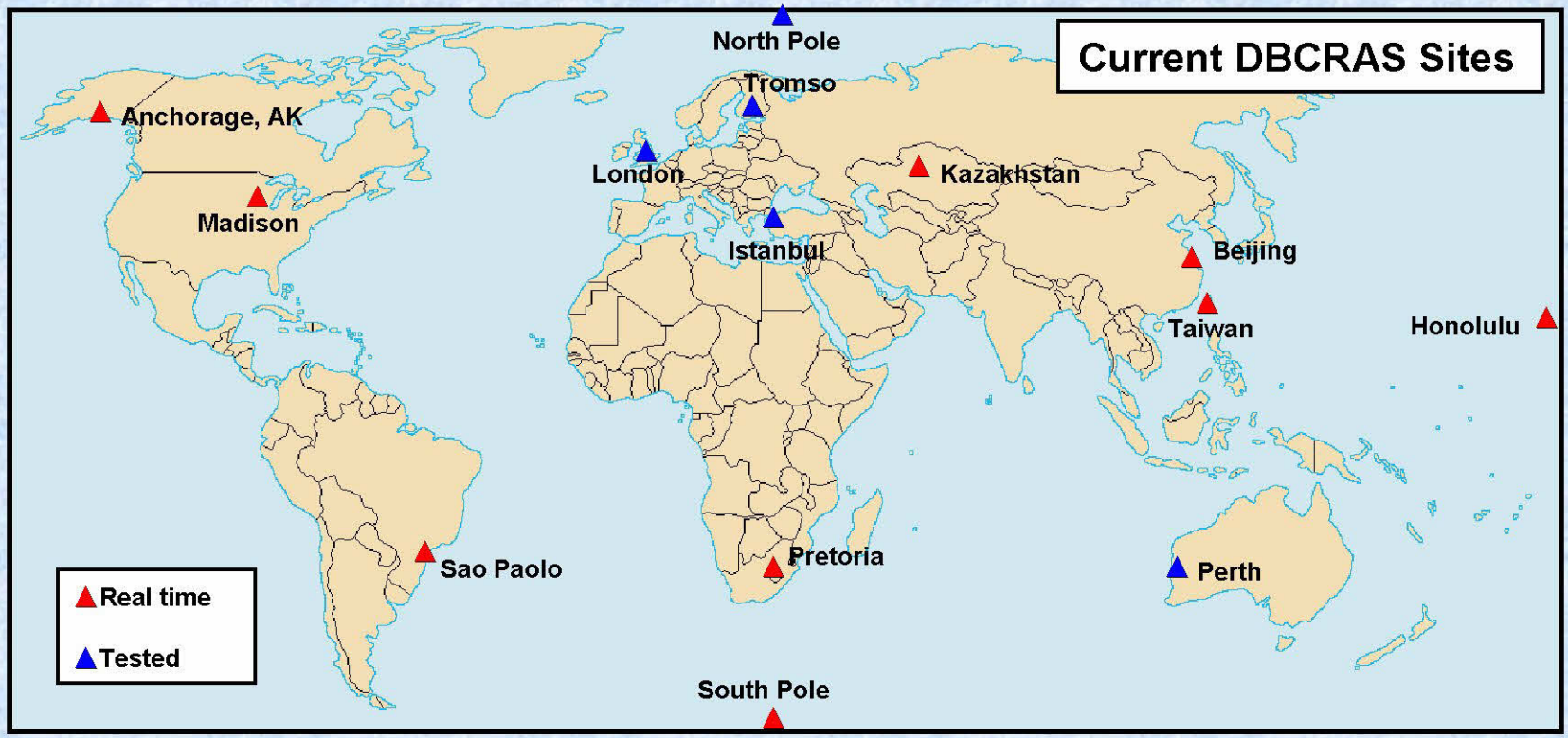
Note: DBCRAS requires 200Mb of forecast grids for boundary conditions. 12 hours of MODIS passes generates ~ 2Gb of retrievals. With limited bandwidth it makes sense to take the forecast model to the local ground station.

SSEC Releases Version 1.0 of the CIMSS Regional Assimilation System for the IMAPP Direct Broadcast Package (DBCRAS)



SSEC has released Version 1.0 of DBCRAS. It is a complete numerical weather prediction (NWP) package designed to assimilate products generated by the International MODIS/AIRS Processing Package (IMAPP). DBCRAS can be installed on a Linux PC anywhere in the world bringing NWP and satellite data assimilation capability to remote locations.

View Wisconsin DBCRAS at http://cimss.ssec.wisc.edu/model/realtime/cras48_WI/daily.html



DBCRAS Team: Robert Aune, Kathy Strabala, Scott Lindstrom, Allen Huang

Nearcasting Severe Weather Using the GOES Sounder

A Lagrangian approach is used for Nearcasting

- Extends a proven diagnostic approach to prediction
- Efficient - 10-15 minute time steps, minimal computer resources
- Can be used 'stand-alone' or to 'update' other NWP guidance

System is *DATA DRIVEN* – Observations are projected into the future

- Direct use of observations - No 'analysis smoothing'
- Retains observed maxima and minima and extreme gradients
- GOES data is projected forward at full resolution
- Spatial resolution adjusts to available data density
- Moves mid-/low-level features into areas where low clouds form
- Provides information even after IR obs are obscured by cirrus
- New data are added at time observed

Nearcasting Equivalent Potential Lapse Rate

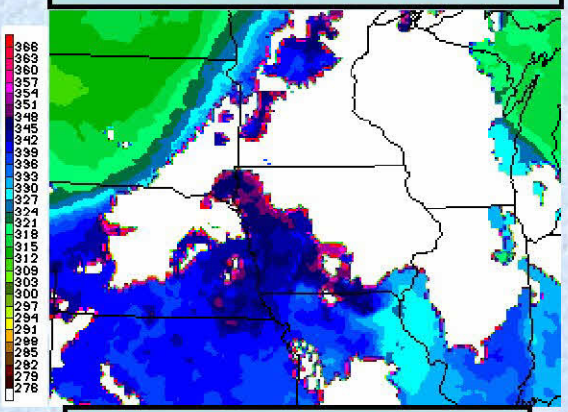
Bob Aune and Ralph Petersen

The CIMSS Nearcasting Model continues to have success at predicting severe weather outbreaks up to *6 hours in advance!*

In addition to tracking multi-layer moisture observed by the GOES sounder, it now tracks layered equivalent potential temperature (thetaE) which measures the *total moist energy* of the airmass.

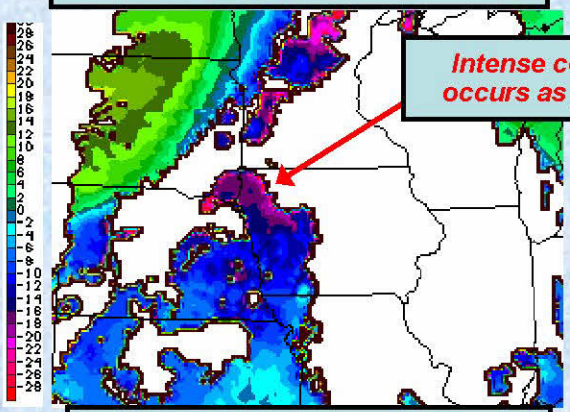
Destabilization is indicated when thetaE decreases with height.

Low-level Theta-E NearCasts shows warm moist air band moving into far NW Iowa by 2100 UTC.



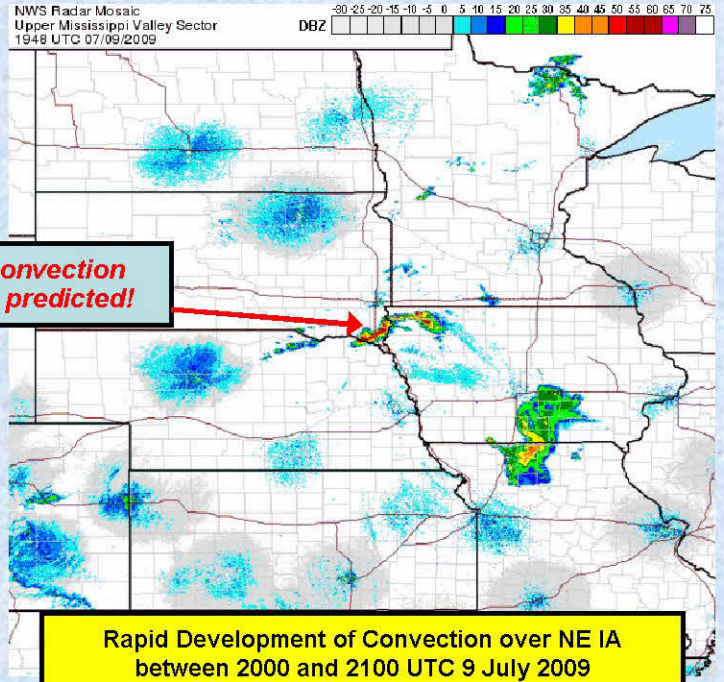
6-hour NearCast for 2100 UTC
Low level Theta-E

Vertical Theta-E Differences predict complete convective instability by 2100 UTC.



6-hour NearCast for 2100 UTC
Low to Mid level Theta-E Differences

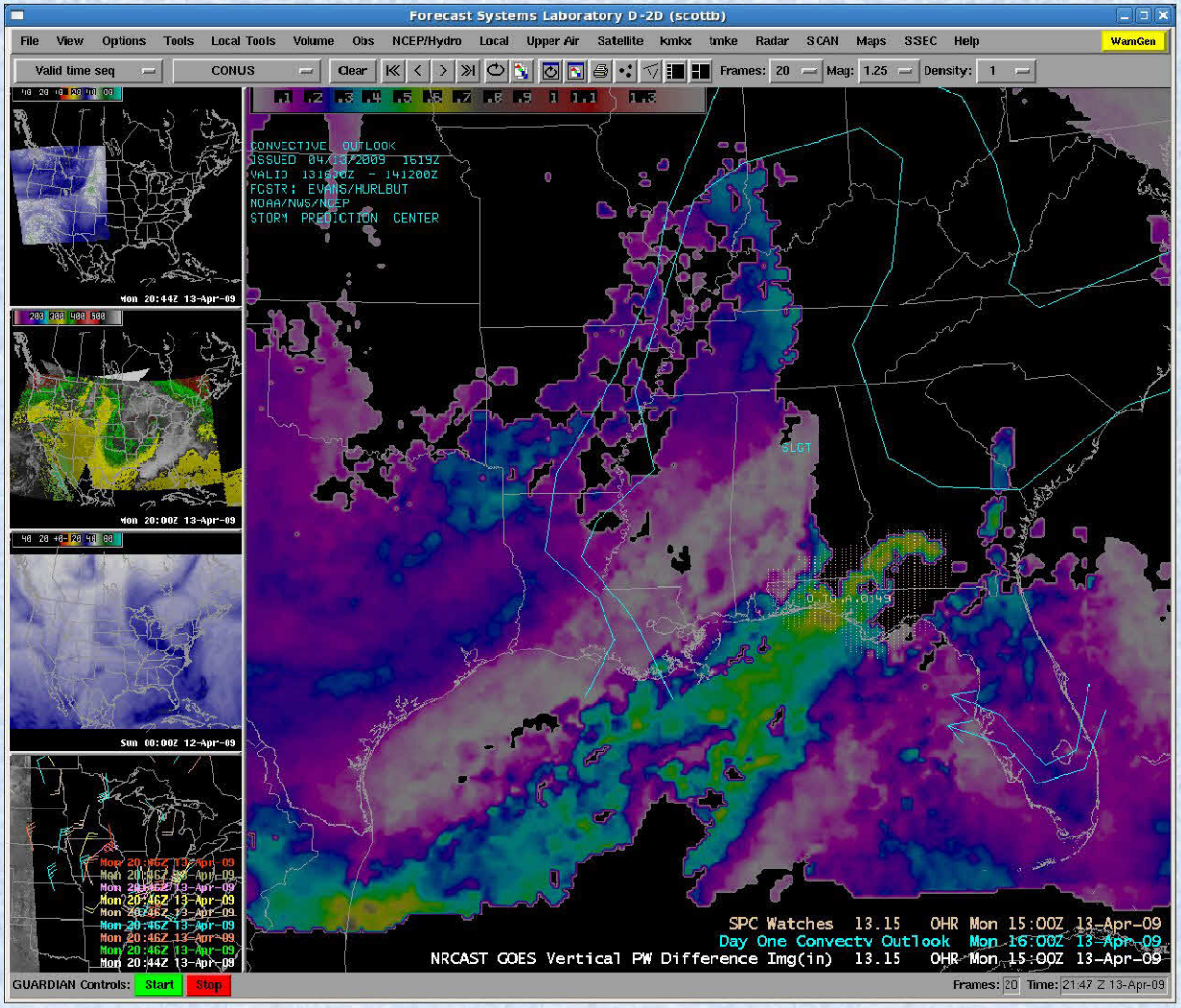
Intense convection occurs as predicted!



Rapid Development of Convection over NE IA
between 2000 and 2100 UTC 9 July 2009

GOES Sounder Nearcasts of Convective Destabilization In AWIPS

GOES sounder nearcast products are now available in AWIPS in real-time. An AWIPS display of precipitable water lapse rate is shown.



Significance:

Nearcasting severe weather up to 6 hours in advance fills the gap between nowcasting observations and numerical weather prediction. It supports NOAA's Weather and Water mission goal.

Near-Term Plans

CRAS products in AWIPS:

- 45km CRAS on 216 grid for Alaska (AVHRR)
- Full output suite in grib2
- Skycover for GFE

Initialize MKX WRF with water vapor and clouds from the GOES sounder:

- Generate parallel WRF run
- Uses GOES moisture and clouds

Nearcast GOES sounder products:

- 6-hr nearcasts updated hourly
- New stability indices
- Cloud tracking for solar power industry

Questions

Should Proving Ground have a forecast model validation component?

Should Proving Ground support local NWP in the forecast office?

Should Proving Ground support power industry applications?

GOES-R Proving Ground

Moving forward to prepare for GOES-R