Assimilation of Satellite Observed Clouds in WRF

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Theme 2: Meteorological Modeling Need for Air Quality Forecasting

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Motivation:

To Improve the Simulated Clouds in Air Quality Decision Models

- Regulating the photochemical reaction rates
- Aqueous chemistry
- Vertical mixing/transport
- Evolution and partitioning of particulate matter
- Wet removal
- LNOx

IMPACT OF ERRORS IN CLOUD SIMULATION on AQ

The current effort: improve model location and timing of clouds in the Weather Research and Forecast (WRF) model by assimilating GOES observed clouds.

Background

- **Previously corrected photolysis rate (in CMAQ) for the radiative impact of clouds**:
  - Improved model predictions
  - Produced a physical inconsistency in the model system.
- Previous attempts at using satellite data to insert cloud water have met with limited success. Previous studies have also indicated that adjustment of the model dynamics and thermodynamics is necessary to fully support the insertion of cloud liquid water in models.
- **The current activity attempts to create an environment in the model that is conducive to creating clouds where there are observed clouds and remove clouds where it is clear.**
- The approach is to develop relationships between satellite-derived cloud properties and targeted variables internal to the model such as grid scale vertical velocity and to provide the dynamical and thermodynamical support needed to sustain or clear model clouds.
- **Since non-precipitating clouds are just as important as precipitating clouds in air quality simulations (radiative impact of clouds and heterogeneous chemistry) our metrics for evaluating the performance are cloud reflectance and precipitation.**

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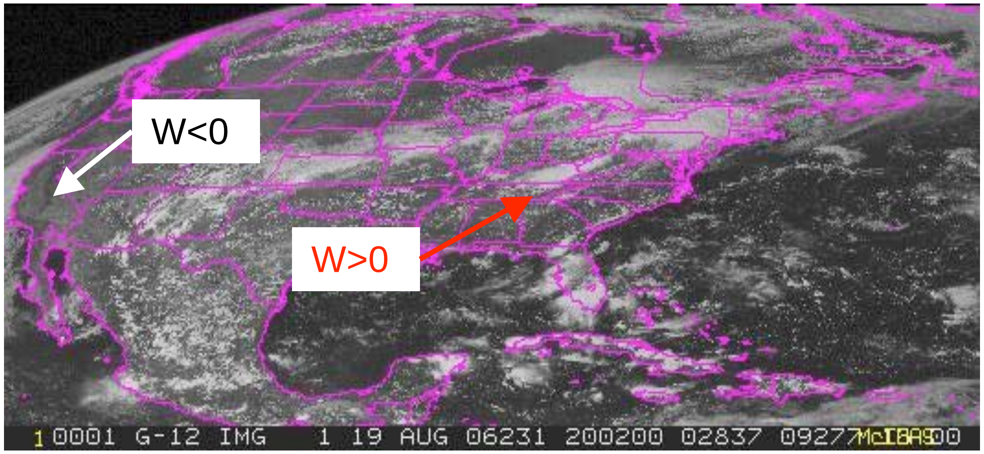
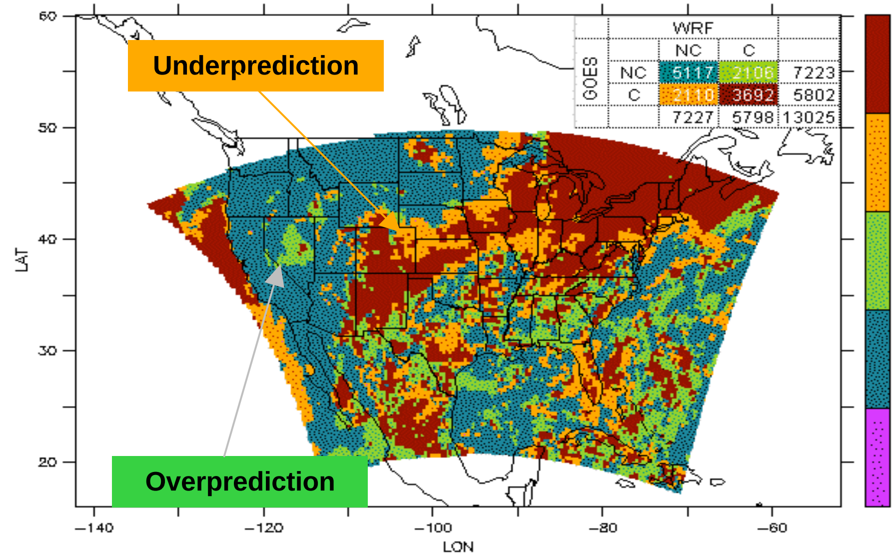
FUNDAMENTAL APPROACH

Satellite



0.65um VIS surface, cloud features

Model/Satellite comparison



- Use satellite cloud top temperatures and cloud albedoes to determine a **TARGET VERTICAL VELOCITY (Wmax)**.
- Adjust divergence to comply with Wmax in a way similar to O'Brien (1970).
- Nudge WRF winds toward new horizontal wind field to sustain the vertical motion.
- Remove erroneous model clouds by imposing subsidence (and suppressing convective initiation).

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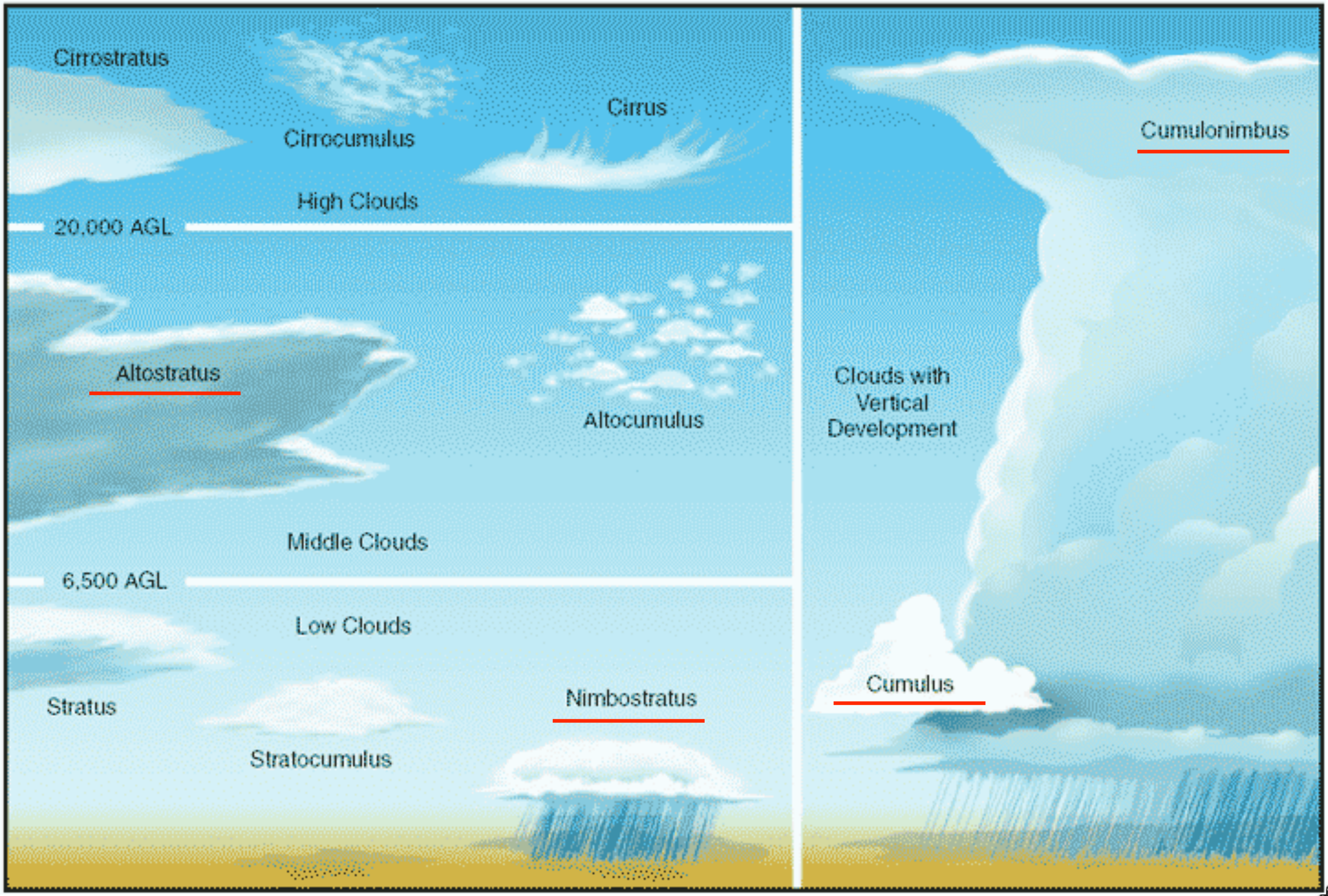
Cloud Types

We will not be able to have 100% agreement with observation



History for the Current Work

- The fundamental approach was first implemented in MM5 and was successful in improving model simulated cloud location and timing.
  - Used a multiple linear regression, 1-D VAR, cluster analysis.
  - Became to complex and computationally expensive.
- In transitioning the technique to WRF, a simple alternative threshold approach based on model statistics were used.
- The current approach presented here uses an analytical method to estimate the target vertical velocity.

IMPLEMENTATION IN WRF

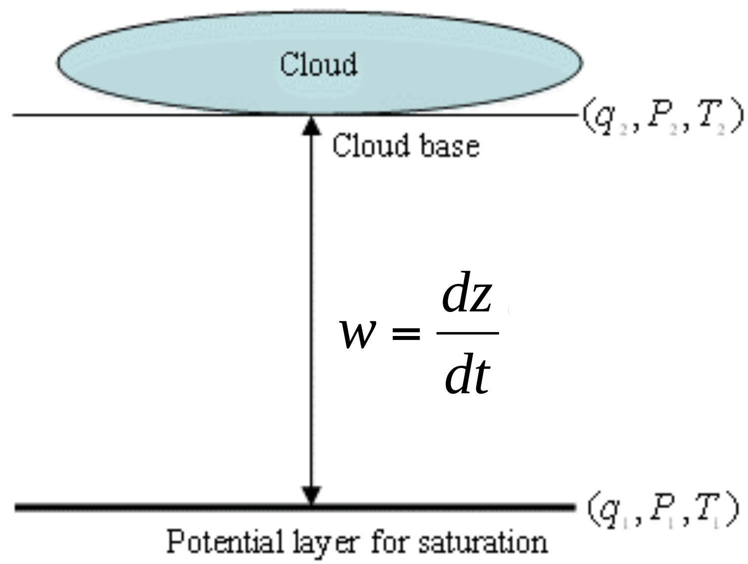
- **Clearing erroneous clouds are more difficult in WRF (compare to MM5). WRF's response to suppressing the convective parameterization is different from MM5 (WRF compensate by creating grid resolved clouds).**
- **Focusing on daytime clouds, analytically estimate the vertical velocity needed to create/clear clouds.**

CONCEPT

- **Under-prediction: Lift a parcel to saturation.**
- **Over-prediction: Move the parcel down to reduce RH and evaporate droplets.**

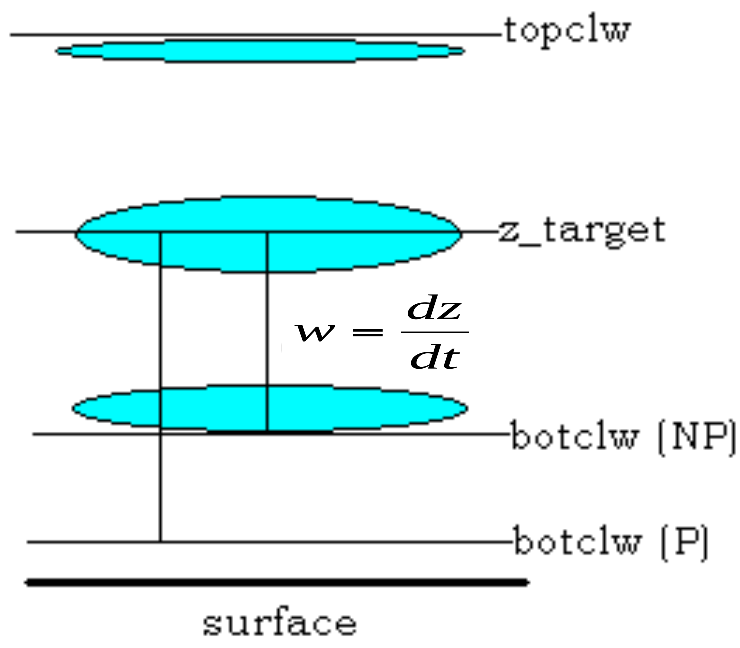
Analytical Approach: Under-prediction

- Cloud top is known from GOES
- Search the column (from top) for the air parcel that can be lifted to saturation.
- Given a fixed time period (30 min), estimate the target vertical velocity.
- Use 1-D variational technique to estimate horizontal wind components.
- Nudge the model winds.



Analytical Approach: Over-prediction

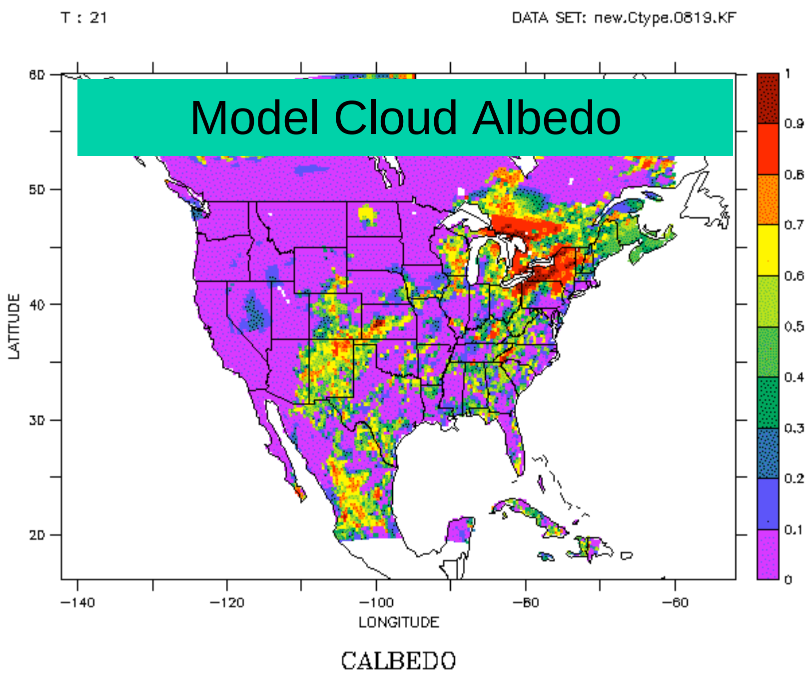
- Model cloud properties are known.
- Estimate the height needed to adequately reduce RH.
- Given a fixed time period (30 min), estimate the target vertical velocity (subsidence).
- Use 1-D variational technique to estimate horizontal wind components.
- Nudge the model winds.

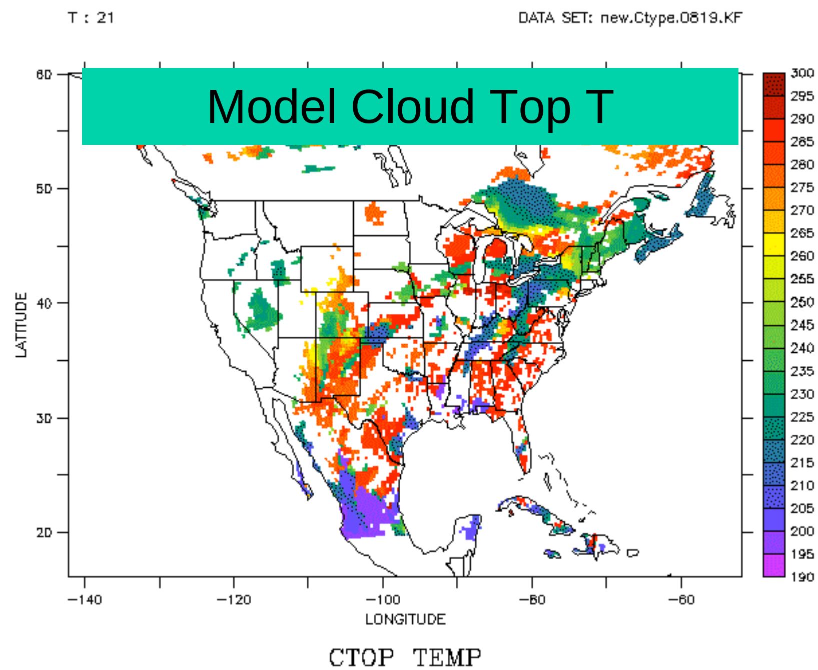


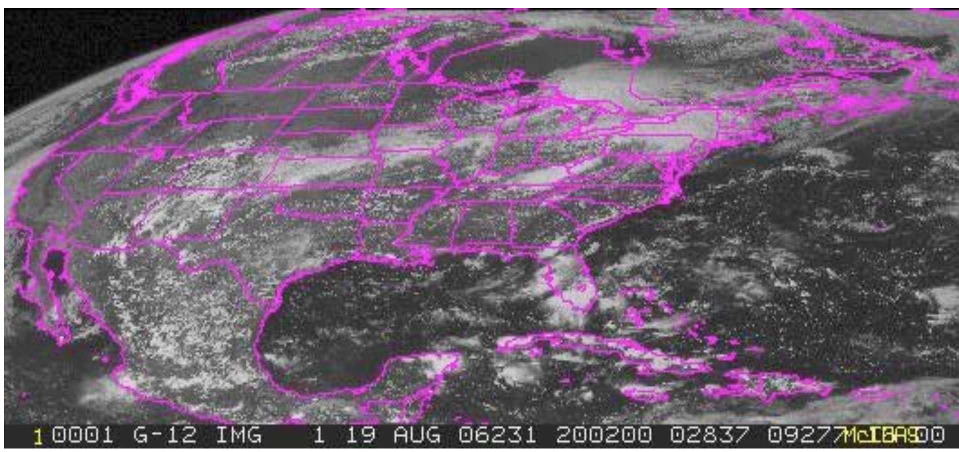
Case Study: August 2006, CONUS

	Domain 01
Running period	August 4^{th} – August 23^{th} in 2006
Horizontal resolution	36 km
Time step	90s
Number of vertical levels	42
Top pressure of the model	50 mb
Shortwave radiation	Duhia
Longwave radiation	RRTM
Surface layer	Monin-Obukhov similarity
Land surface layer	Noah (4-soil layer)
PBL	YSU
Microphysics	LIN
Cumulus physics	Kain-Fritsch
Grid nudging	Horizontal wind
Meteotological input data	EDAS

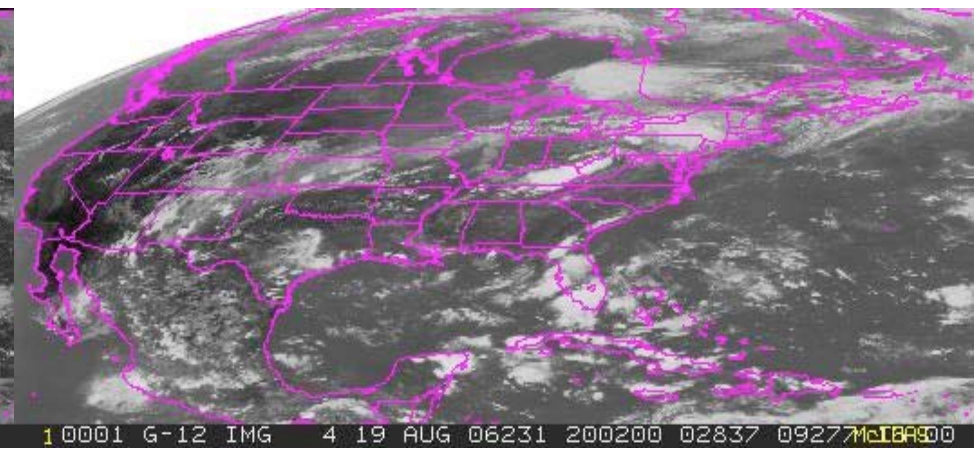
Use of Daytime Cloud Albedo/Cloud Top Temperature for Model Evaluation





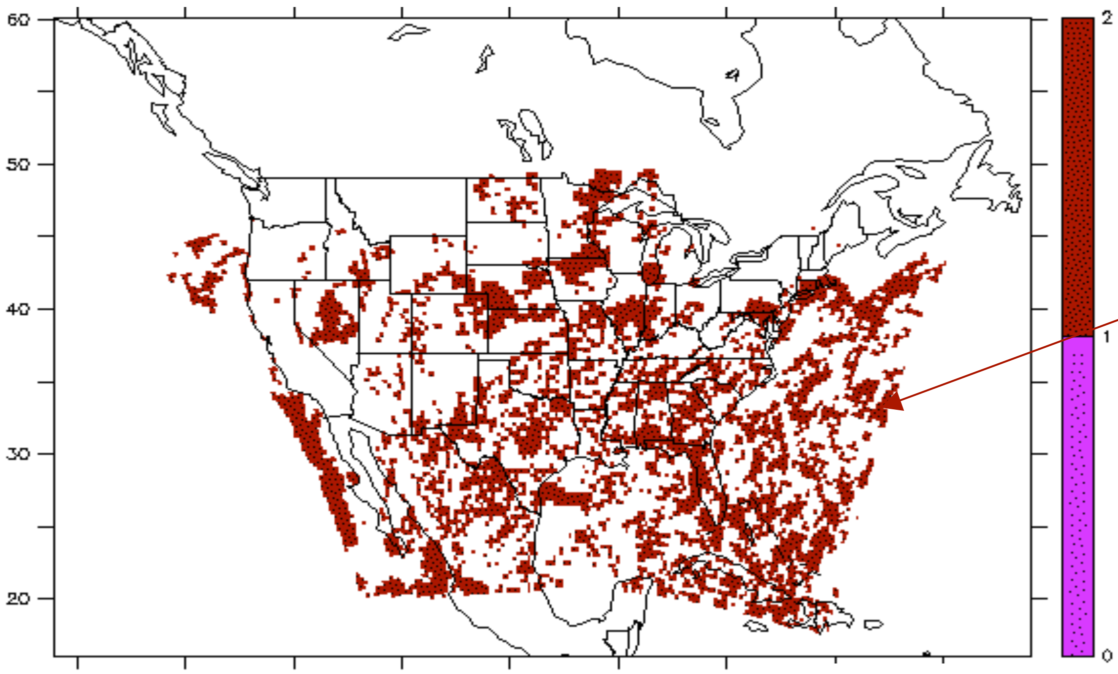


0.65um VIS surface, cloud features



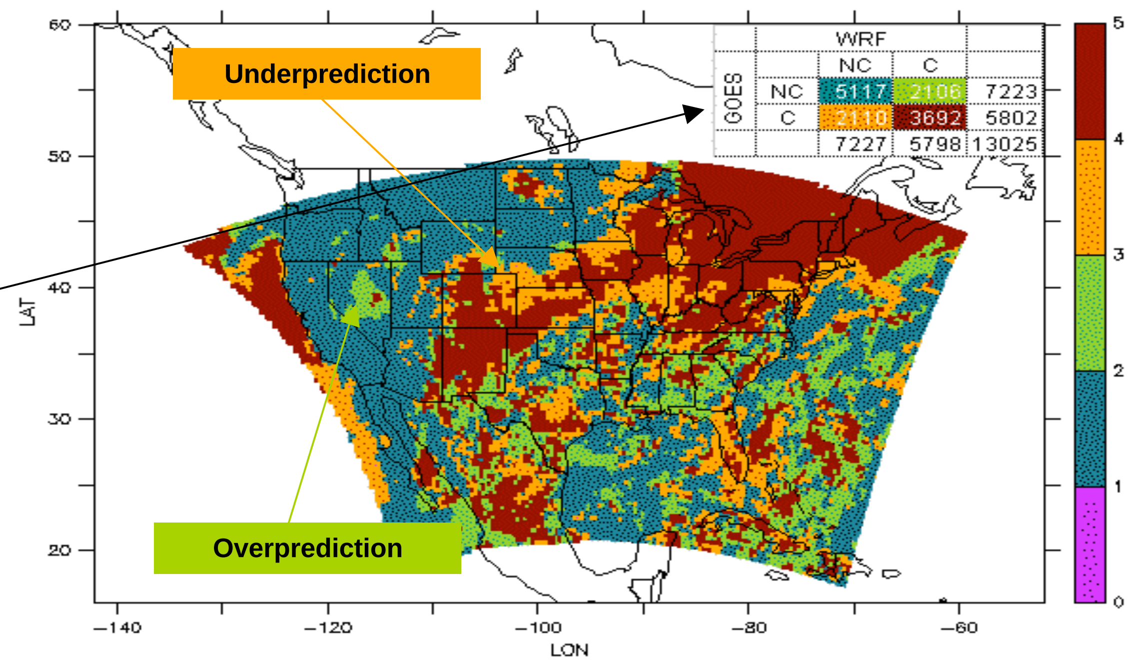
10.7um IR sfc/cloud top temperature

Areas of Underprediction/Overprediction can be identified for Correction



Areas of disagreement between model and satellite observation

A contingency table can be constructed to explain agreement/disagreement with observation



		WRF		
		NC	C	
GOES	NC	5117	2106	7223
	C	2110	3692	5802
		7227	5798	13025

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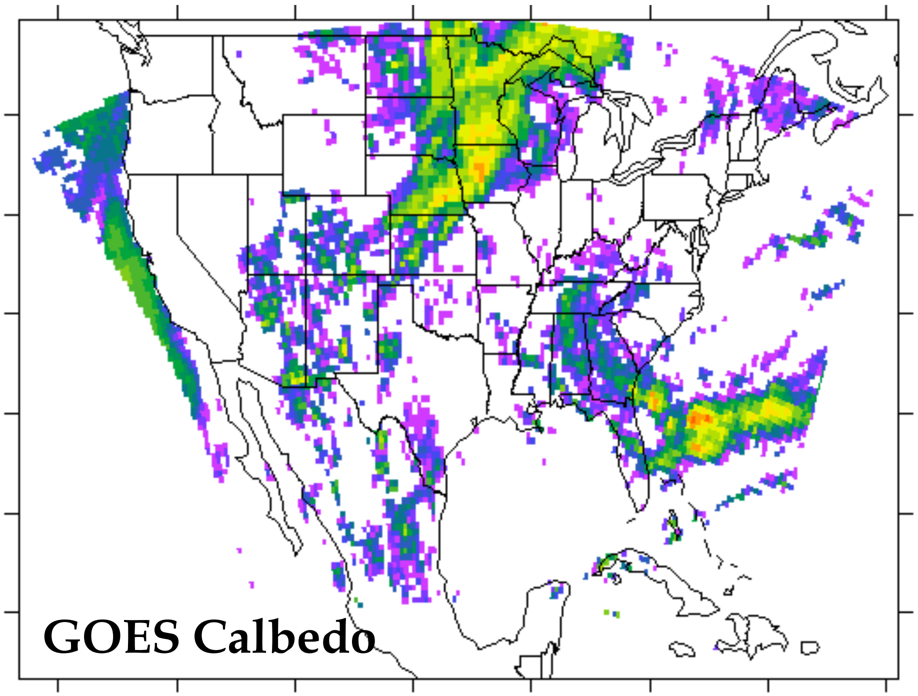
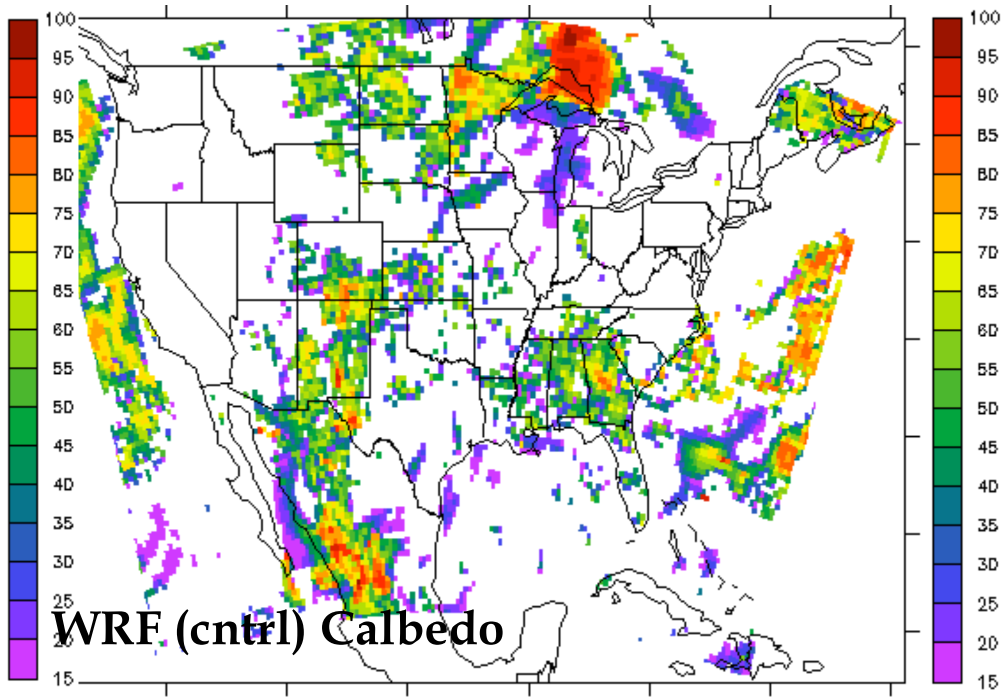
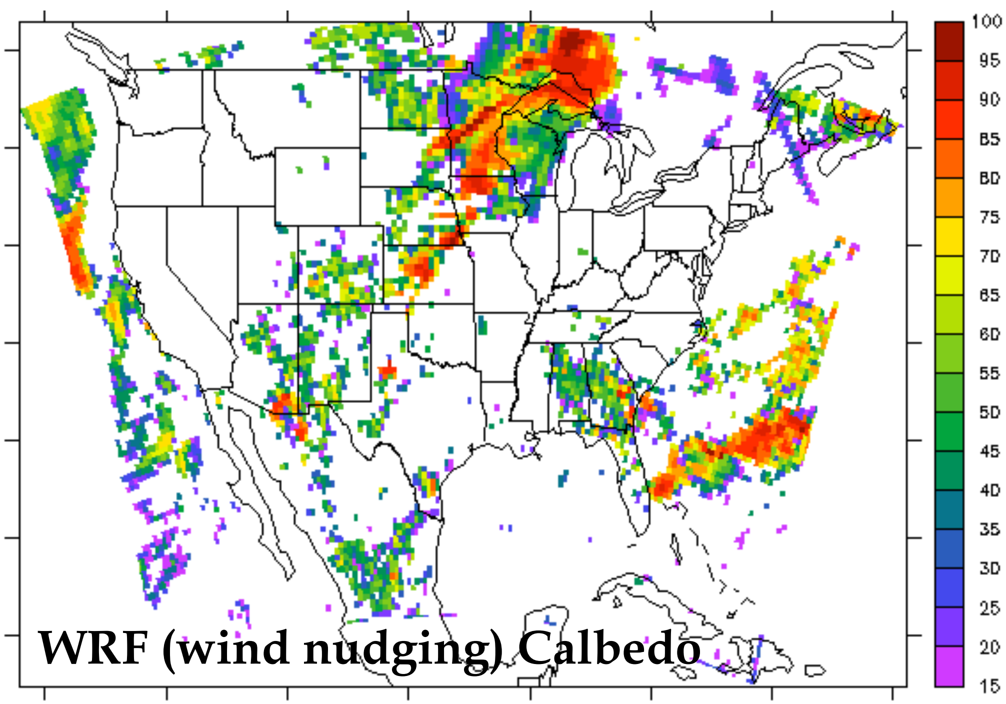




SNAPSHOT

Date: August 13th , 2006 at 19 UTC



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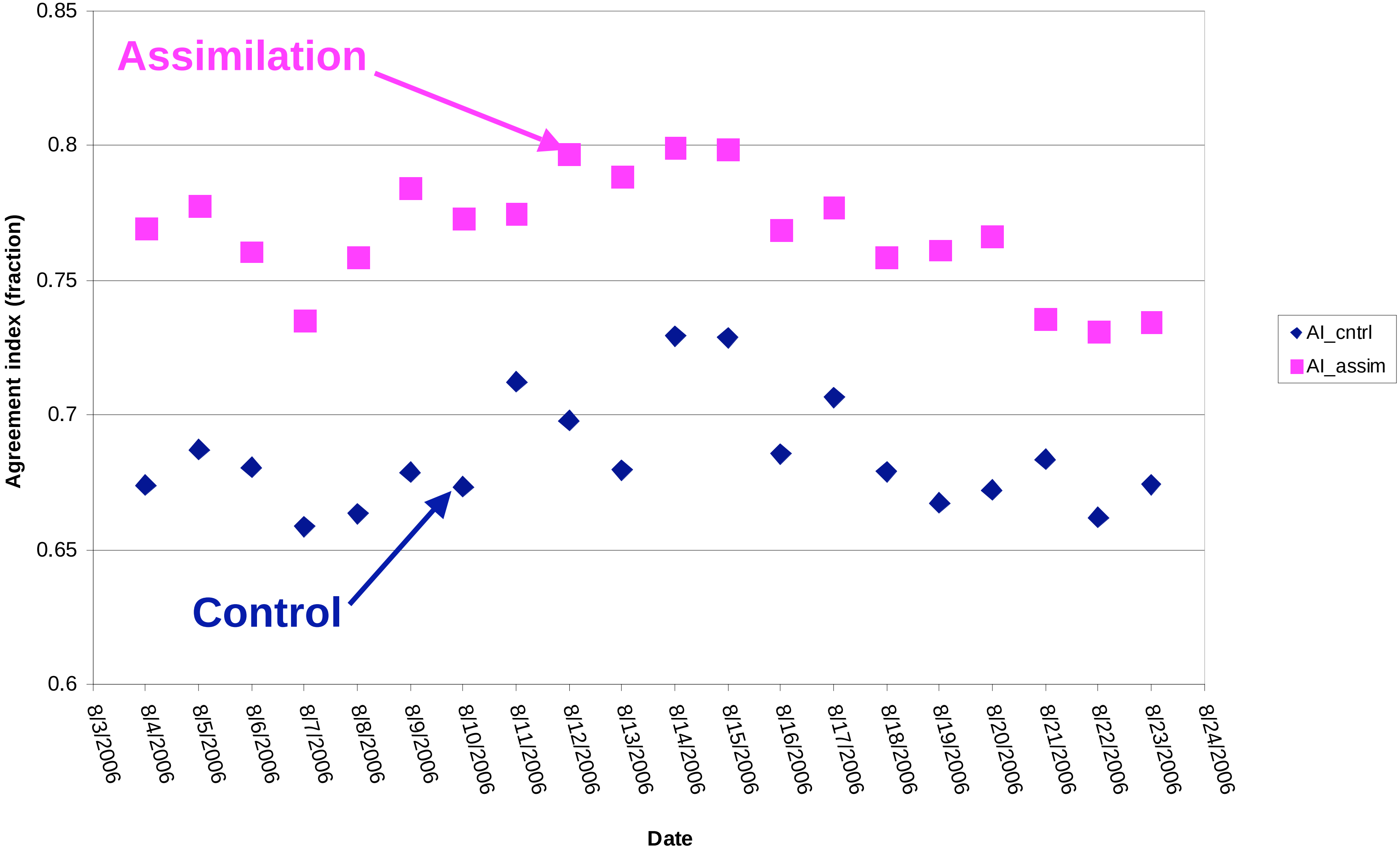
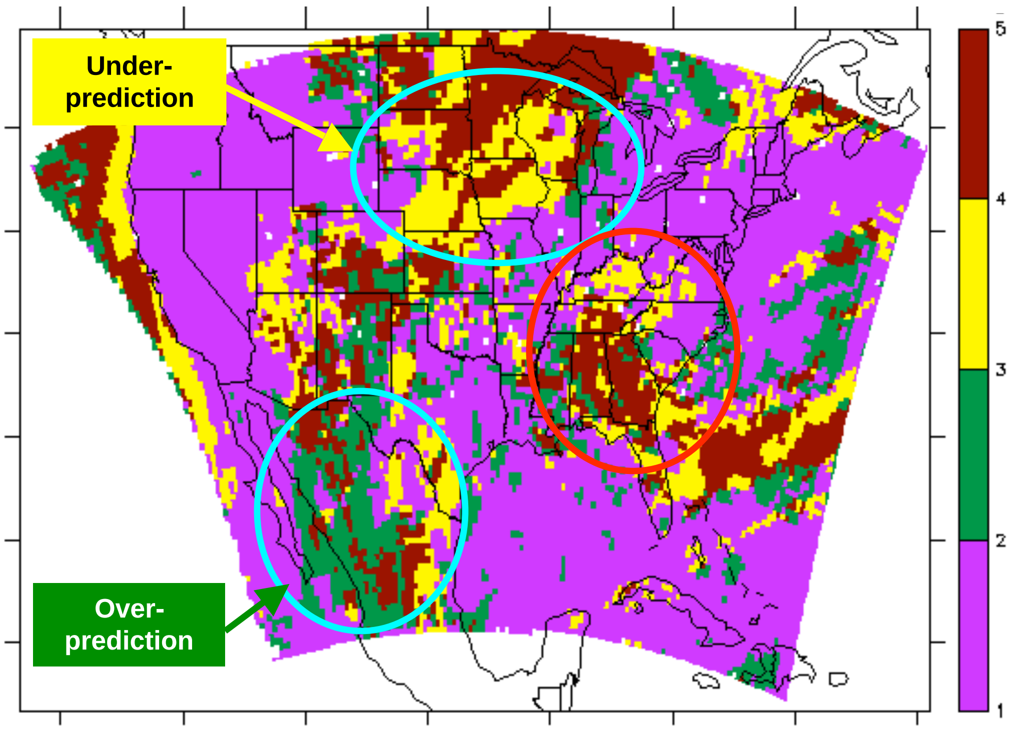
Agreement Index = (# of cloudy/clear grids in agreement) / (Total # of grids)

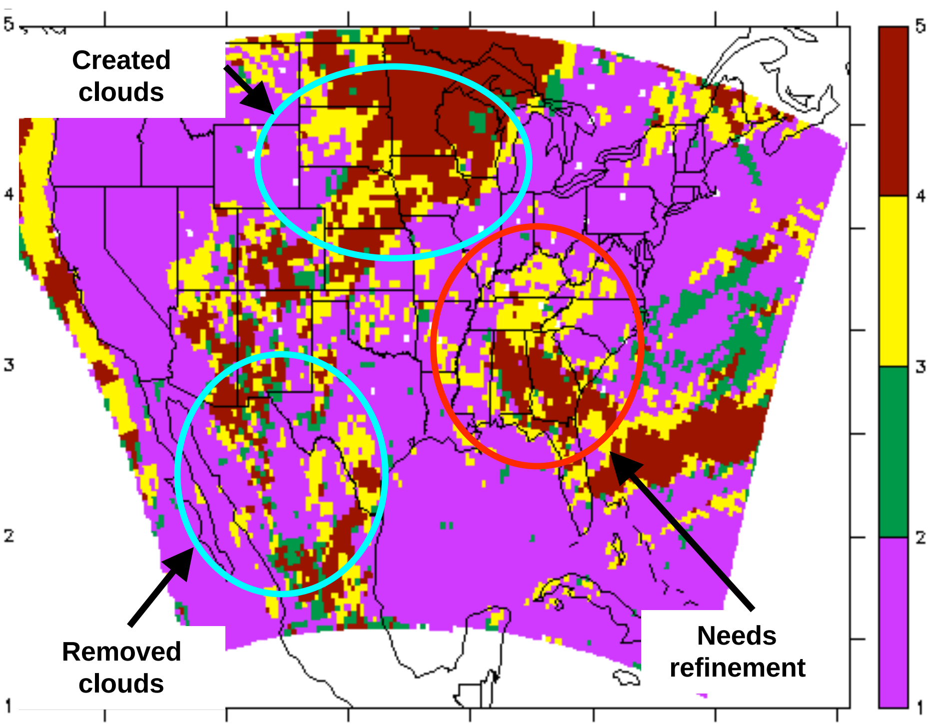


Agreement index increased by 7-10%

Agreement Index =
(# of cloudy/clear grids in agreement) / (Total # of grids)



AI for WRF_cntrl

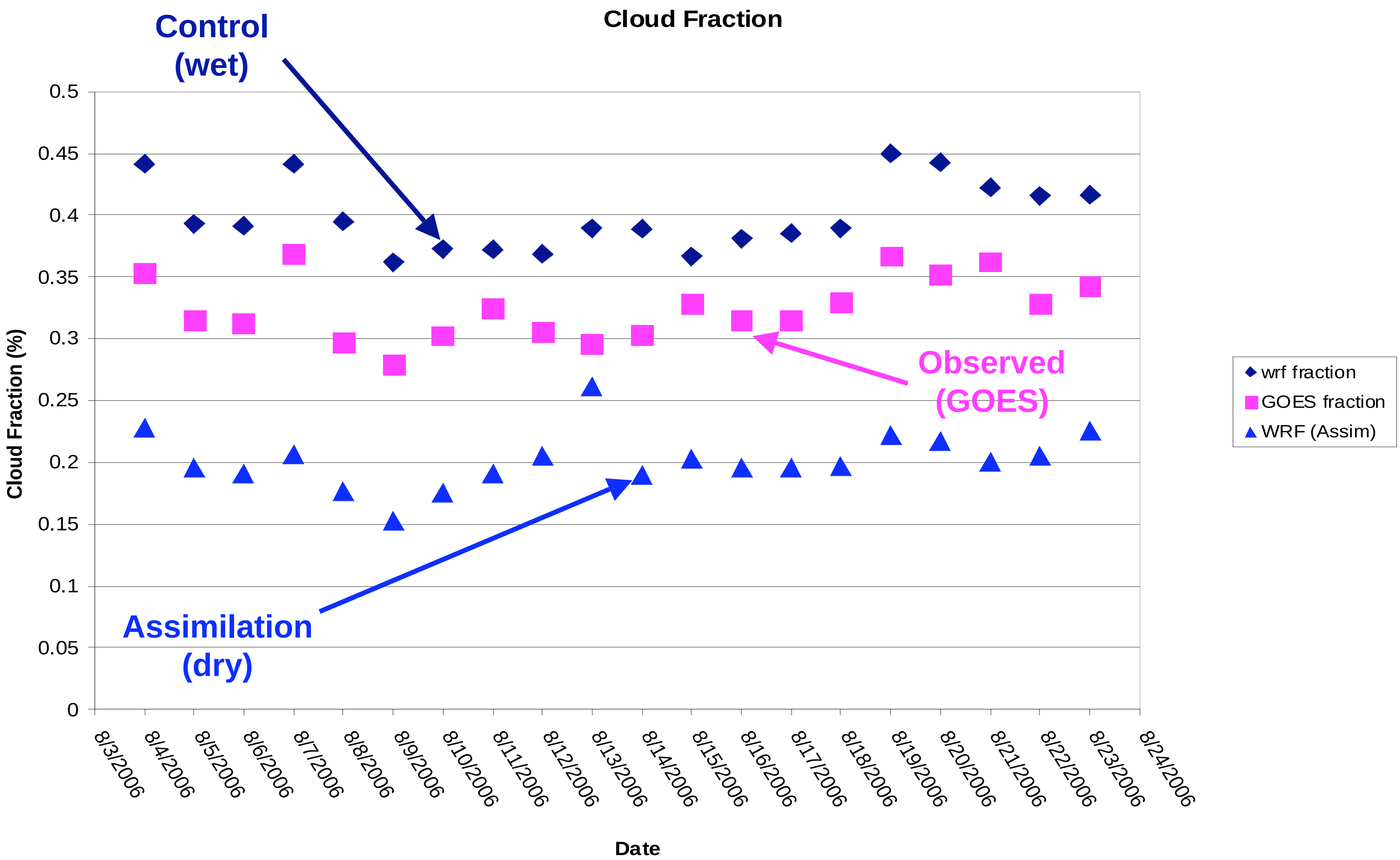


AI for WRF_assim

		WRF		
		NC	C	
GOES	NC	7174	1824	8998
	C	1943	2049	3992
		9117	3873	12990

		WRF		
		NC	C	
GOES	NC	8266	732	8998
	C	1892	2100	3992
		10158	2832	12990

Future Refinements and Improvements



CONCLUSION & FUTURE WORK

- Dynamical assimilation of clouds improved model cloud simulation. In this study an improvement of 7-10% was achieved.

- Future work will focus on concurrent adjustment of relative humidity consistent with the current approach to insure the effectiveness of dynamical adjustment.
- The technique will be tested for forecast initialization to assess its usefulness for AQ forecasting.

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Acknowledgment

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Note the results in this study do not necessarily reflect policy or science positions by the funding agencies.