CIMSS Hyperspectral IR Sounding Retrieval (CHISR) Processing & Applications

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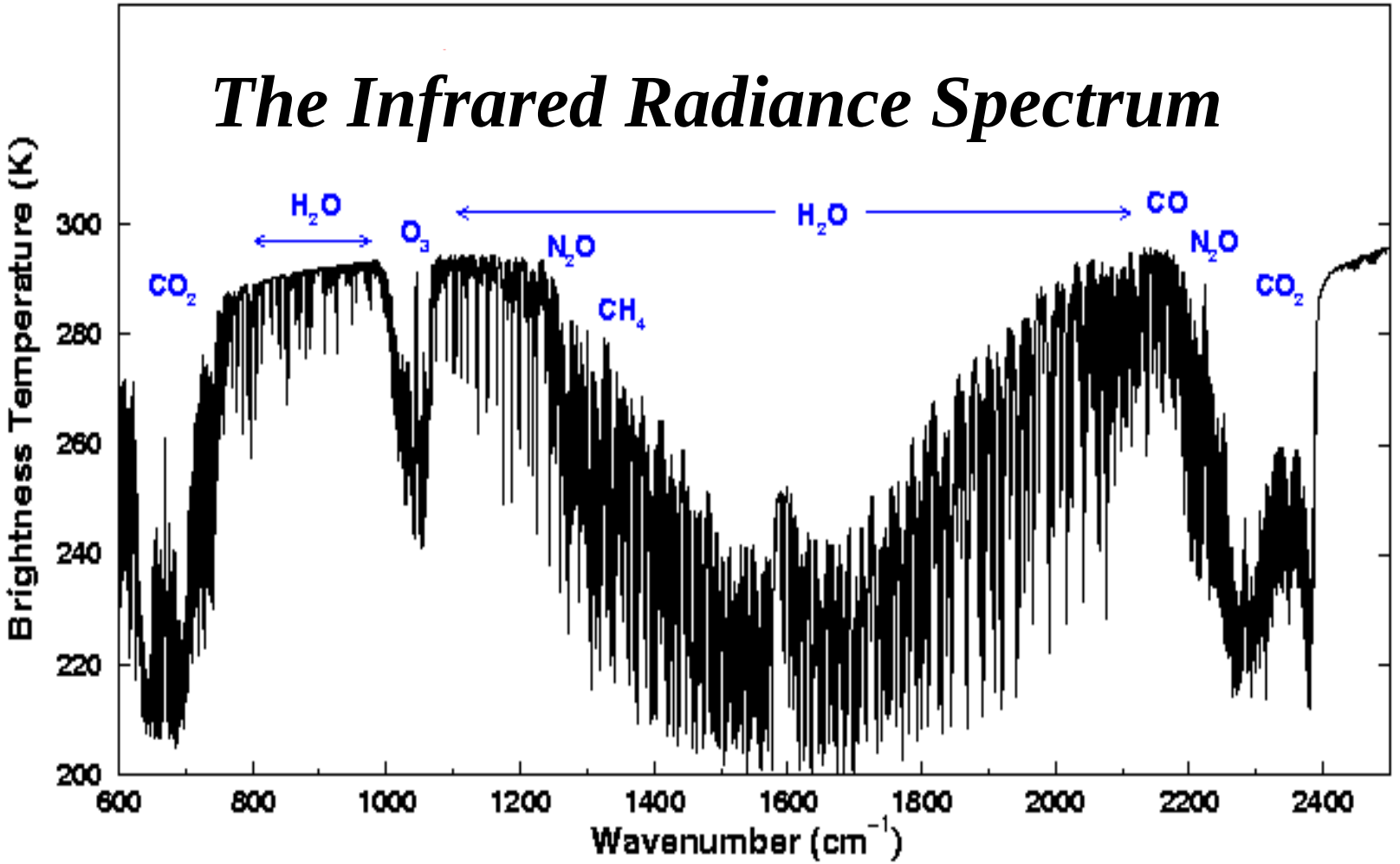
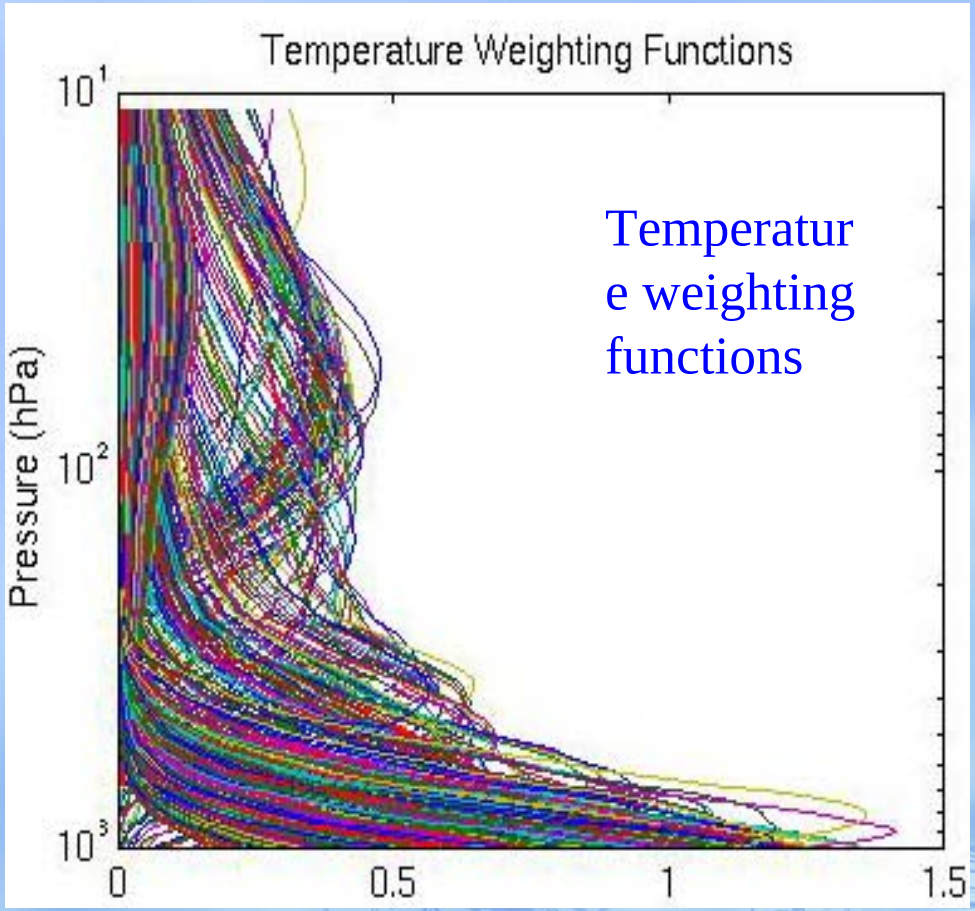
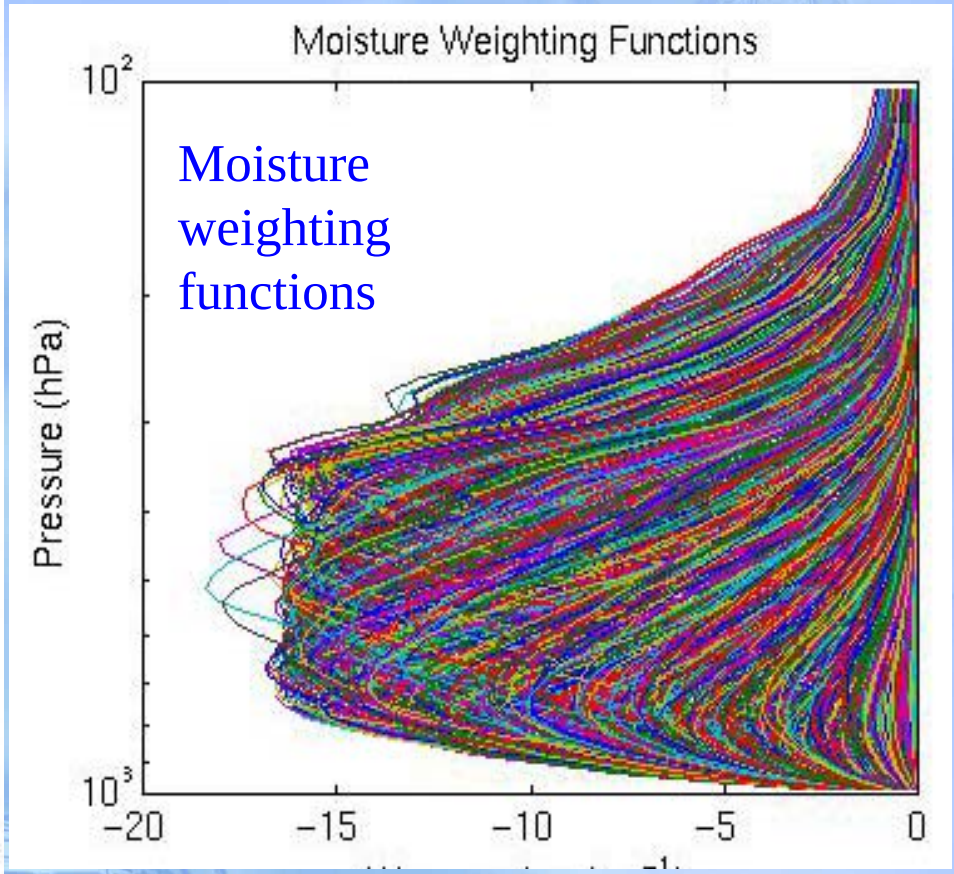
Outlines

- Introduction on hyperspectral IR sounder
- CIMSS Hyperspectral IR Sounding Retrieval (CHISR) Processing
- Hyperspectral IR sounding products and applications
- Summary and future perspective

Hyperspectral IR Sounder

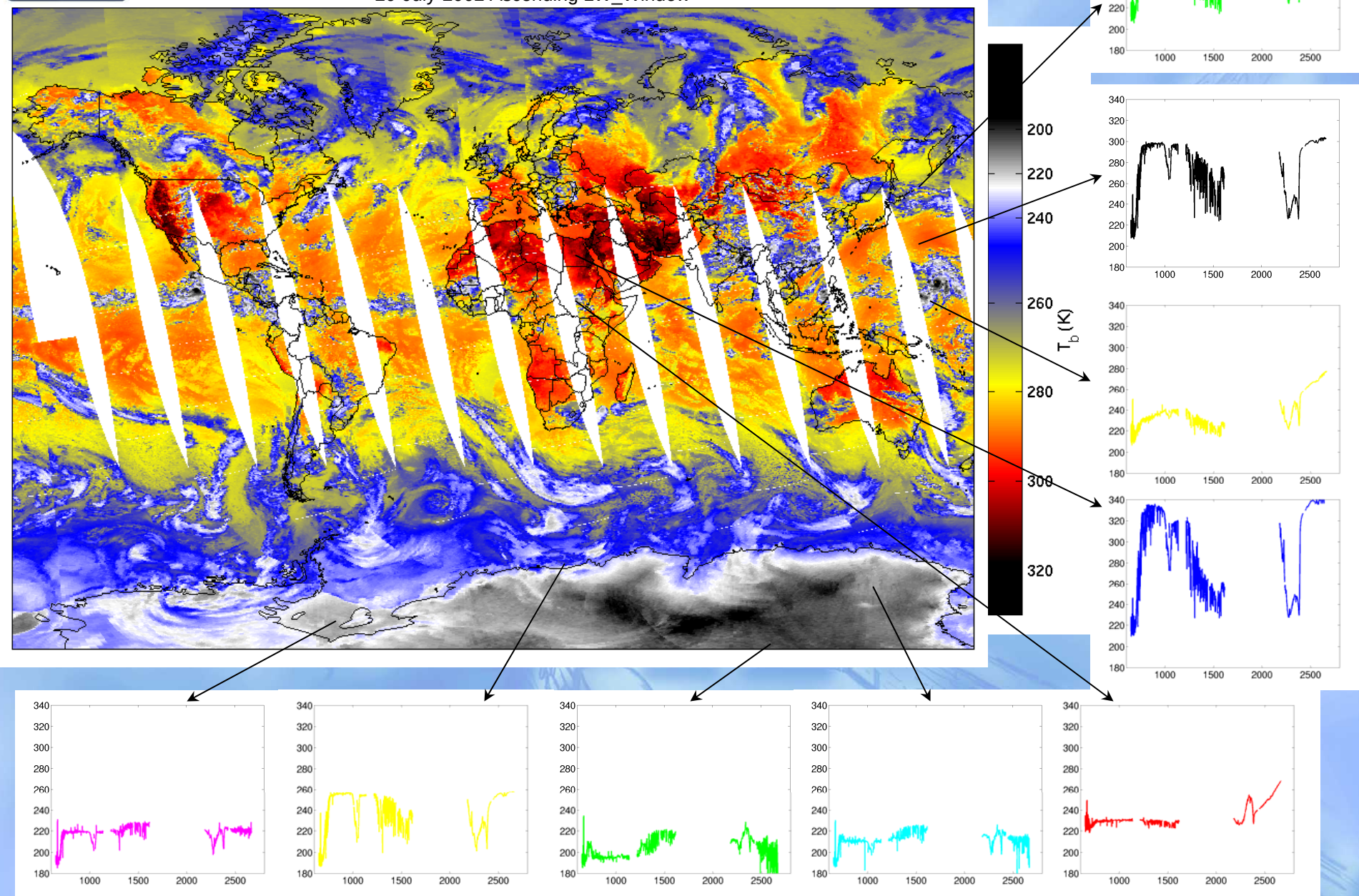




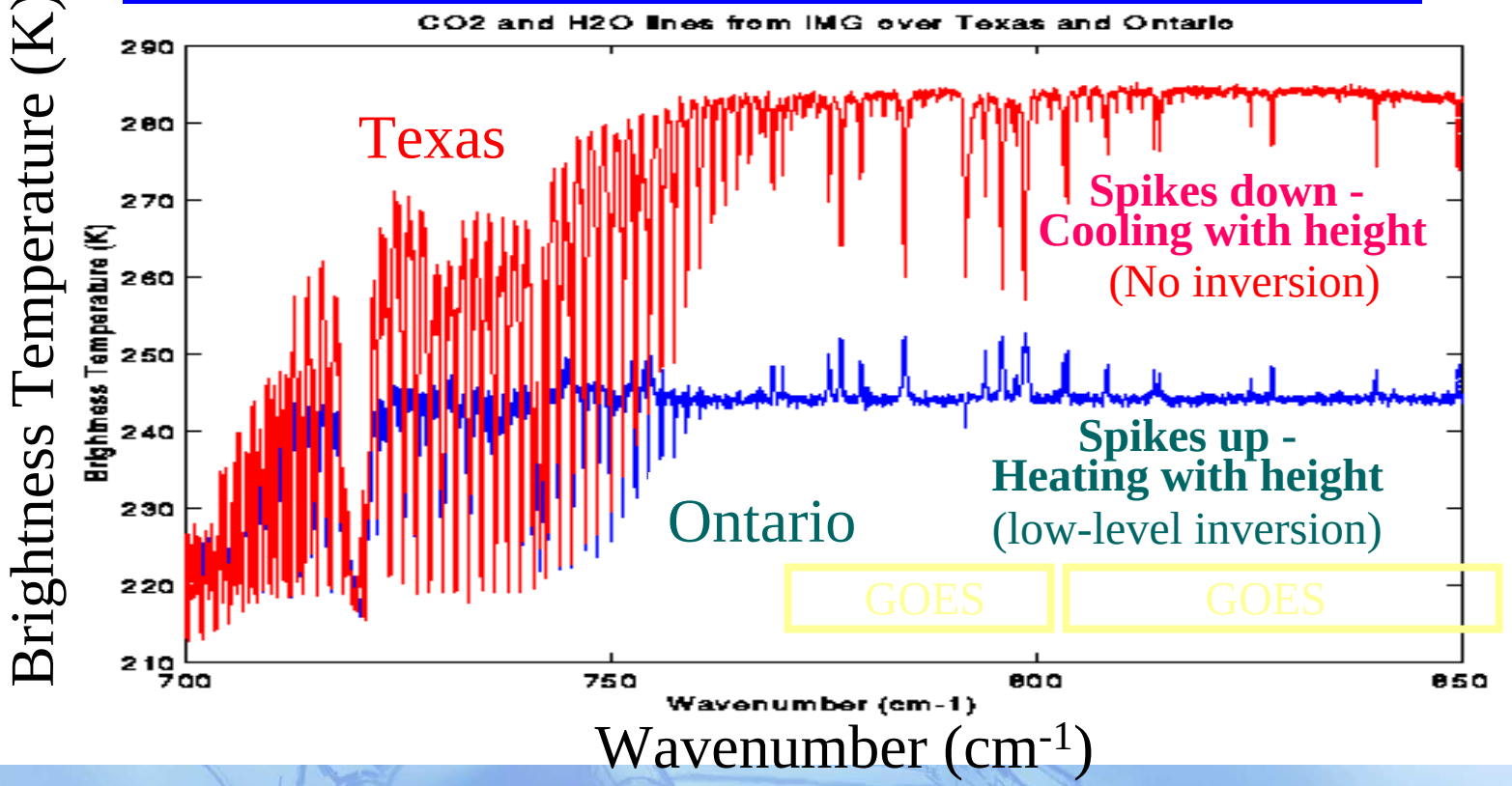


Abundant Information Content allows the high vertical resolution temperature and moisture profiles with high accuracy !

High Spectral Resolution - Global AIRS Data



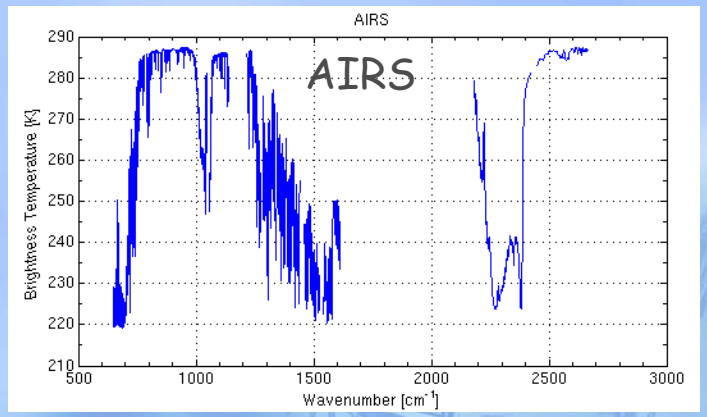
Hyperspectral/Ultraspectral Infrared Measurement Characteristics - continue

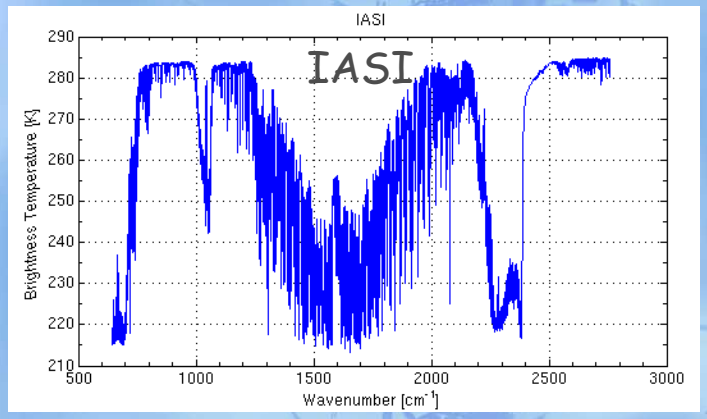


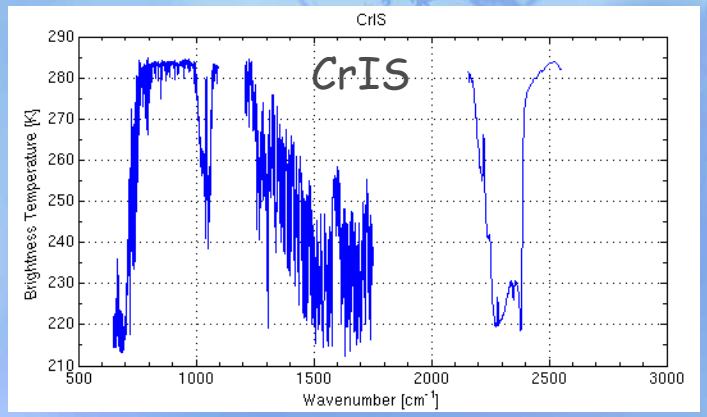
Detection of inversions is critical for severe weather forecasting. Combined with improved low-level moisture depiction, key ingredients for night-time severe storm development can be monitored.

Why sounding retrievals are needed?

- Easy to use
- Take advantage of full spectral coverage
- Less data volume







The goal of CHISR is to provide a physically based optimal retrieval algorithm to simultaneously derive atmospheric temperature and moisture profiles, surface parameters and cloud parameters from hyperspectral IR measurements (e.g. from AIRS, IASI, CrIS) alone at single FOV resolution.

CIMSS Hyperspectral IR Sounding Retrieval (CHISR) Processing

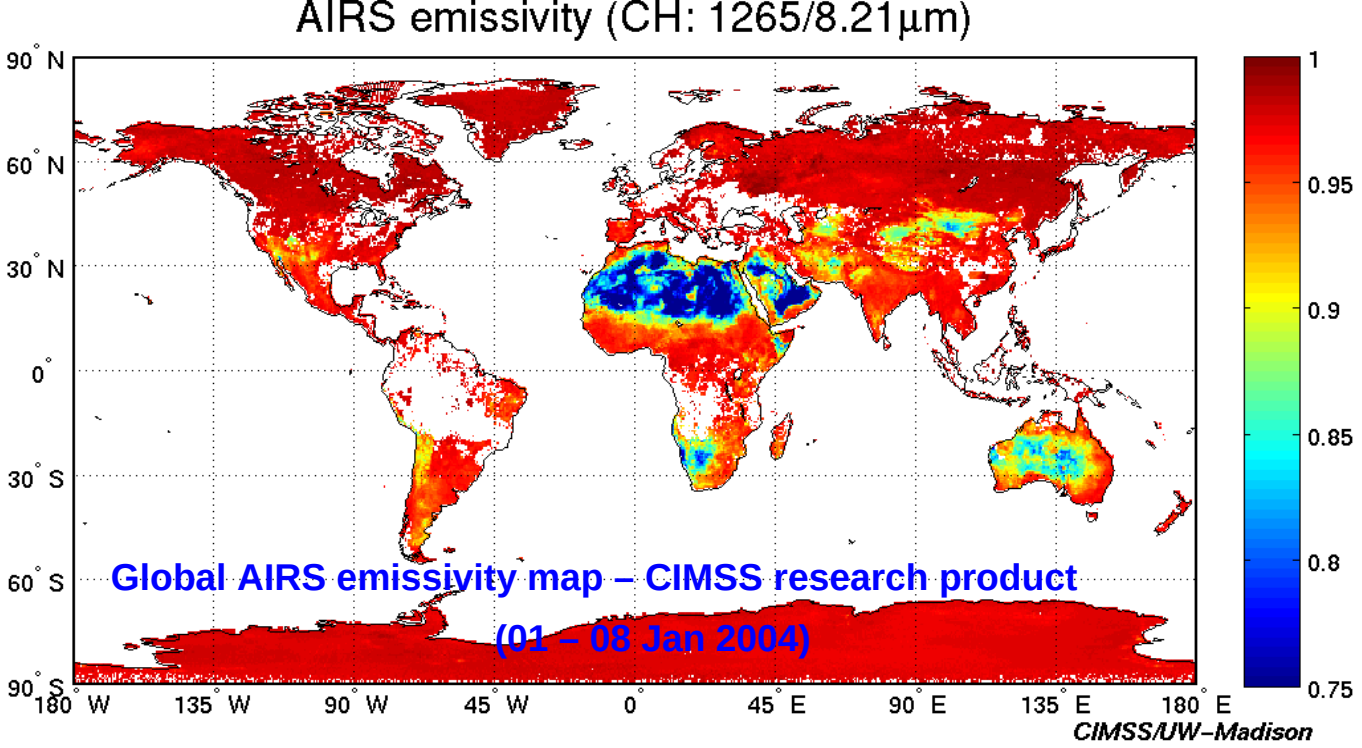
- Handle surface IR emissivity
- Handle clouds
- Retrieval algorithm

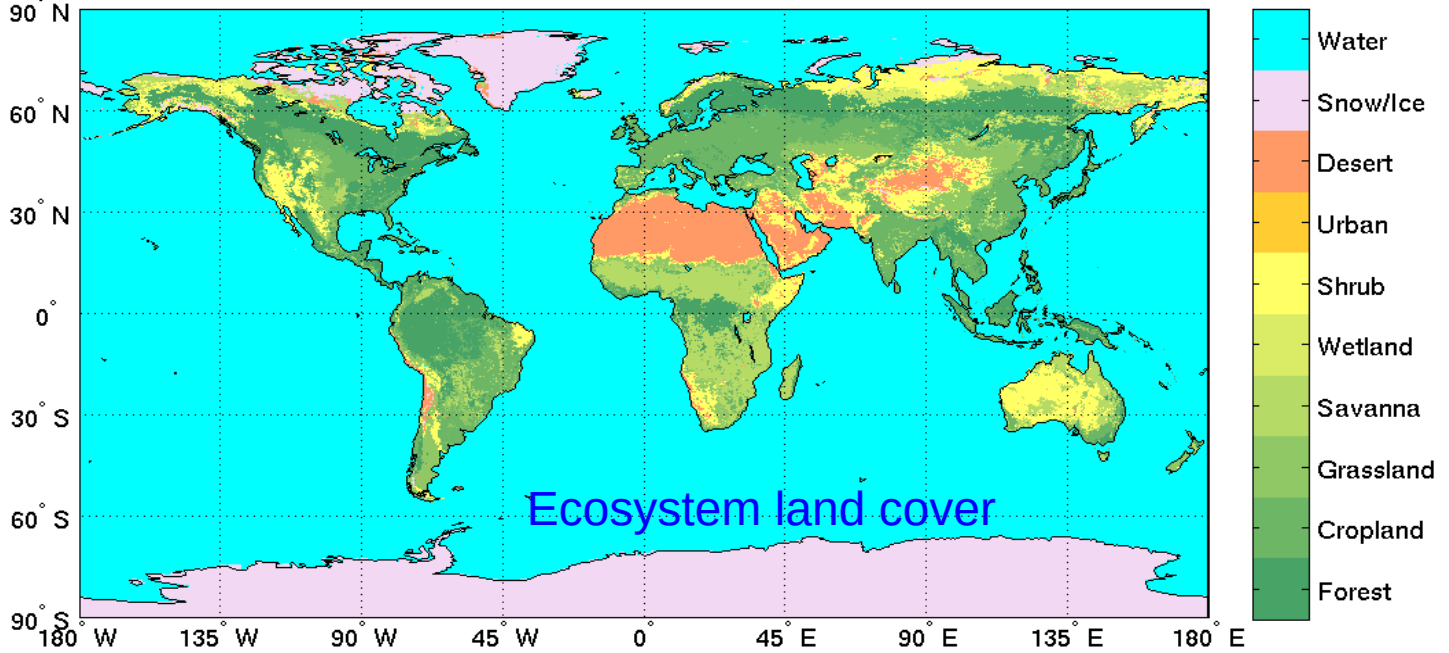
Handling surface IR emissivity

- Emissivity spectrum is expressed by its eigenvectors (derived from laboratory measurements)
- Regression retrieval are used as the first guess
- Simultaneous retrieval of emissivity spectrum and soundings in physical iterative approach (Li et al. 2007, 2008)

Re-group from IGBP category:

Forests: Evergreen needle forests Evergreen broad forests; Deciduous needle forests; Deciduous broad forests; mixed forests;
Shrubs: Opened shrubs; Closed shrubs;
Savanna: Woody savanna; Savanna;
Cropland: Cropland; Crop mosaic;
Snow/Ice: Snow; Ice; Tundra;
Desert: Desert/Barren;

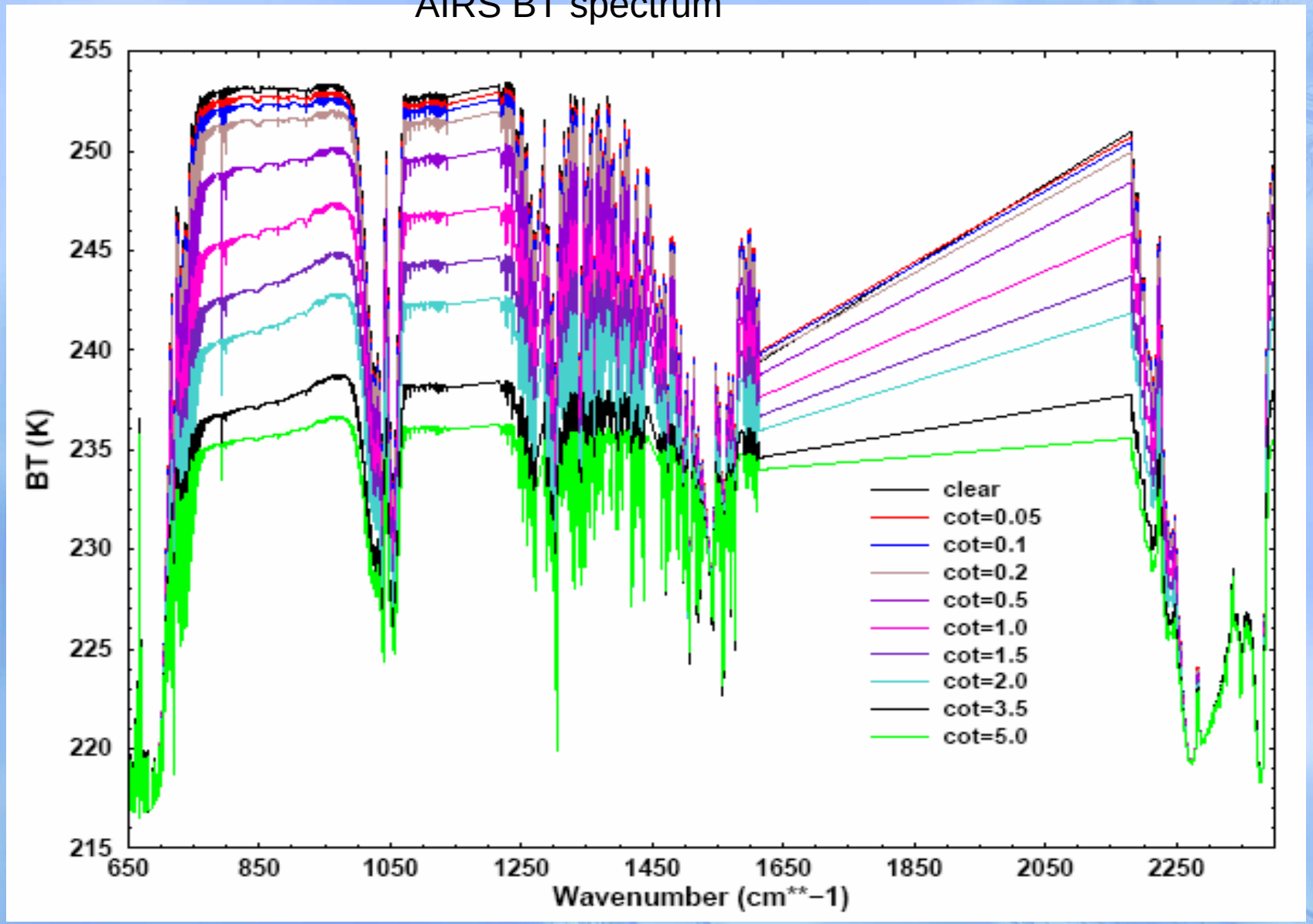




Handling clouds

- Using collocated MODIS cloud mask for AIRS cloud detection (Li et al. 2004).
- Employ a cloudy radiative transfer model accounting for cloud absorption and scattering (Wei et al. 2004)
- Retrieval sounding and cloud parameters simultaneously (Zhou et al. 2007, Weisz et al. 2007)

AIRS BT spectrum



Whole sounding in broken clouds and above-cloud sounding in thick clouds can be derived

First step: Regression

IMAPP RTV Software v1.3

CLEAR

Training data set
(SeeBor V5)

Radiance calculations
SARTA v1.7 (UMBC)

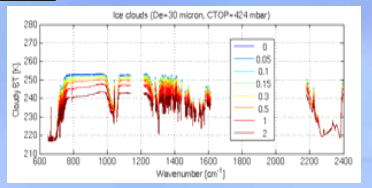
BT and Scanang
Classification

CLOUDY

Cloudy Training data set
(ice, water)

Radiance calculations
Fast RT cloud model (Wei, Yang)

Scanang
Classification



Additional
Predictors
(spres, solzen)

PC regression

$$C = dXA^T(AA^T)^{-1}$$

Clear Regr Coeffs

Ice Cloud Regr Coeffs
Water Cloud Regr Coeffs

Regression RTV

$$X = \overline{X_{tr}} + CA_{obs}$$

T, Q, O3, STemp, Emissivity
at single FOV

T, Q, O3, STemp, CTOP, COT
at single FOV

To physical inversion

Second step: Physical Inversion

Cost function for a quasi non-linear case:

$$J = (y - F(x))^T S_\varepsilon^{-1} (y - F(x)) + (x - x_a) S_a^{-1} (x - x_a)$$

Newton-Gauss Iteration with regularization parameter γ:

$$x_{i+1} = x_a + (K_i^T S_\varepsilon^{-1} K_i + \gamma S_a^{-1})^{-1} K_i^T S_\varepsilon^{-1} [y - F(x_i) + K_i (x_i - x_a)]$$

x, x_a	current /a priori atmospheric state vector
K	Jacobian
S_a, S_ε	A priori / measurement covariance matrix
F	Forward model

Transform to EOF space:

$$c_{i+1} = (\tilde{K}_i^T S_\varepsilon^{-1} \tilde{K}_i + \gamma \tilde{S}_a^{-1})^{-1} \tilde{K}_i^T S_\varepsilon^{-1} [y - F(x_i) + \tilde{K}_i c_i]$$

$c = \tilde{x} - \tilde{x}_a$ $\quad \tilde{K} = K\phi$ $\quad \phi$ eigenvector matrix

$\tilde{x} = x\phi$ $\quad \tilde{S}_a = \phi^T S_a \phi$

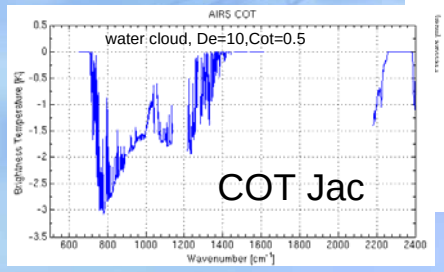
Second Step: Physical Inversion - flow chart

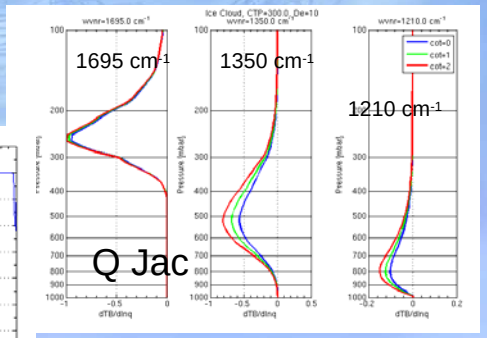
Regression
T,Q,O3,ctp,cot,de,emiss

Eigenvector matrix ϕ
Matrices S_a and S_ε

Forward model calculations

Jacobian calculations





$dy = y - y_c$

$d\bar{y}_i < d\bar{y}_{i-1}$

yes

no (fail)

Decrease γ

Increase γ

Physical Inversion

Update Profiles

fails < f max
iterations < it max
$dy > dy_{crit}$

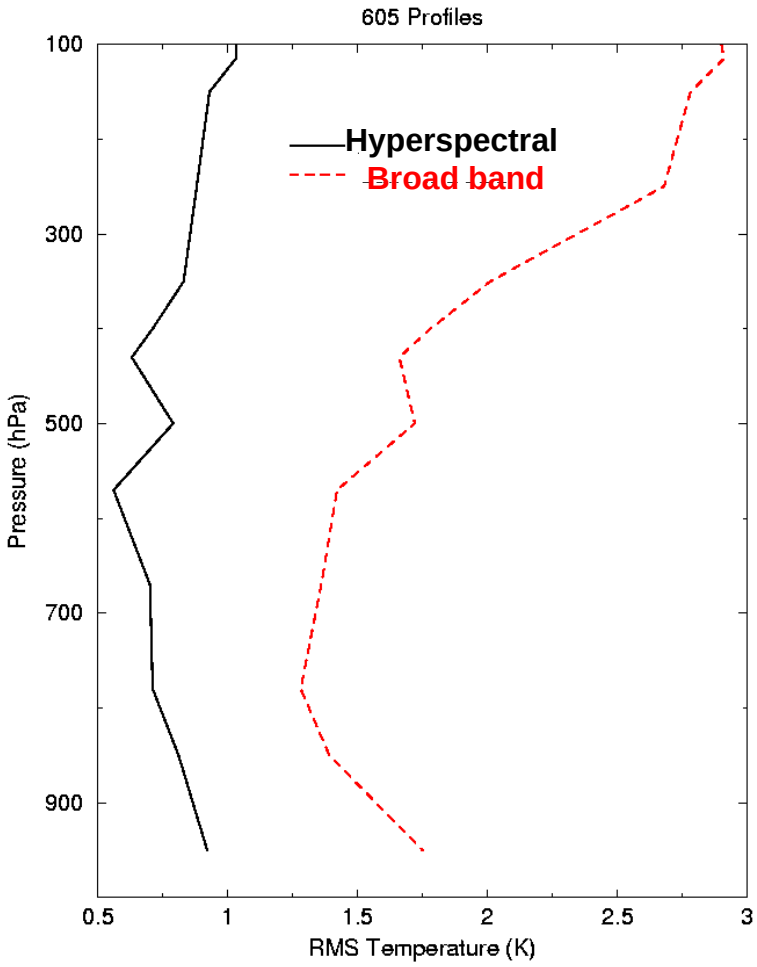
yes

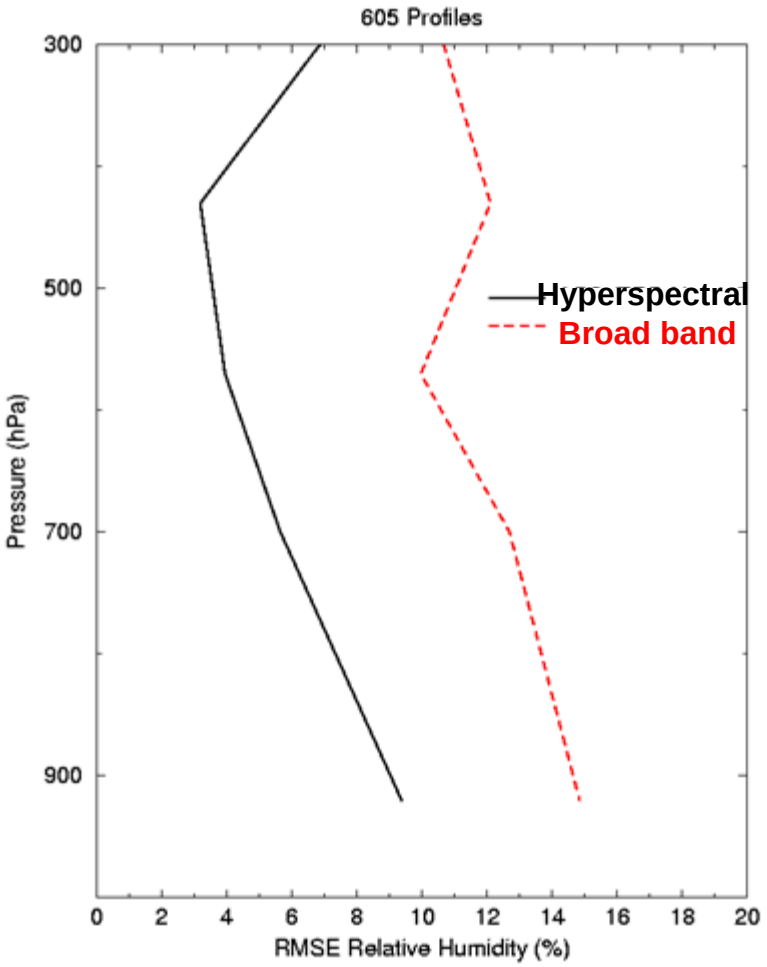
no

Next iteration

Physical RTV results
T,Q,O3,ctp,cot,de,emiss

Hyperspectral/Ultraspectral Infrared Sounding Performance in Clear Skies

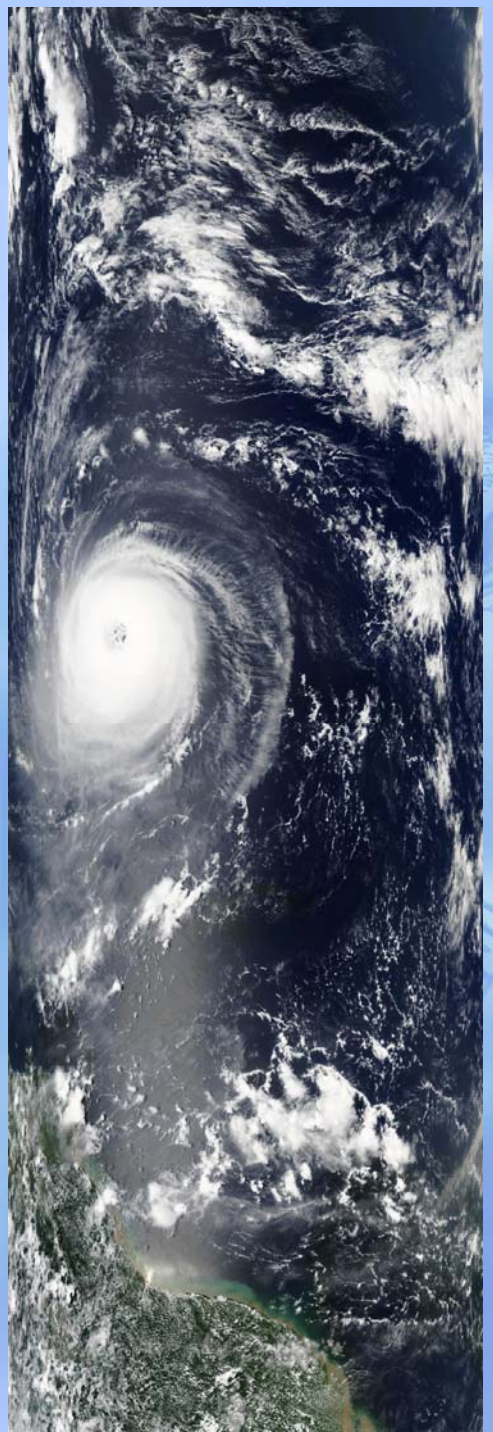




Can Achieve Improved Atmospheric Profile Accuracy

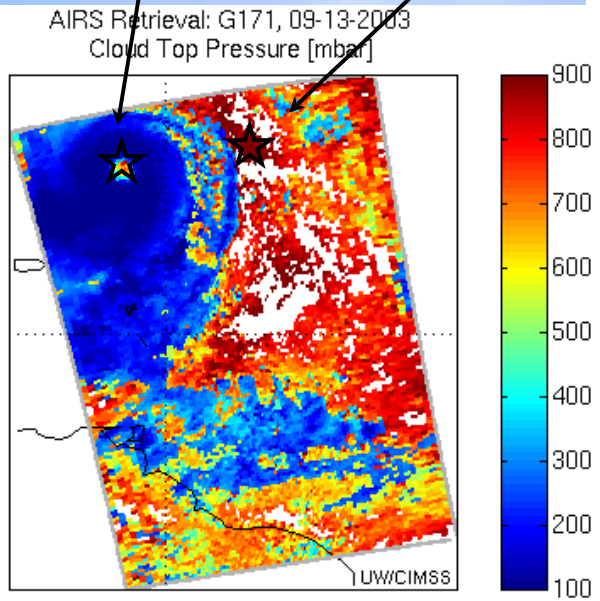
Hurricane Isabel case study

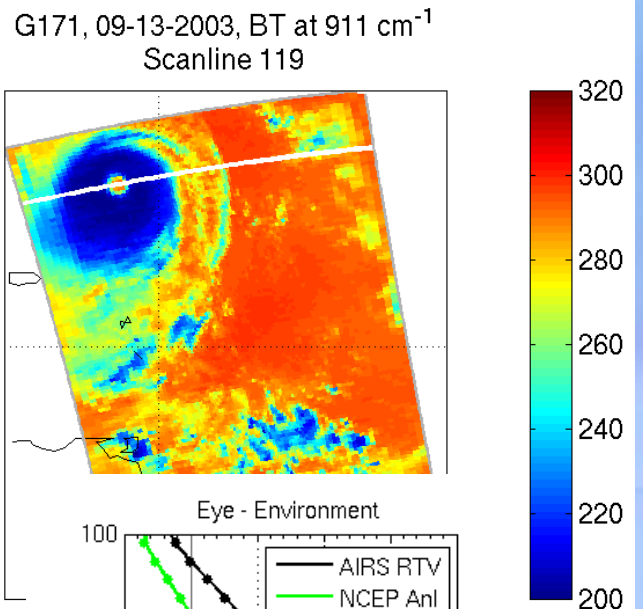
MODIS 1km images (1705, 1710)

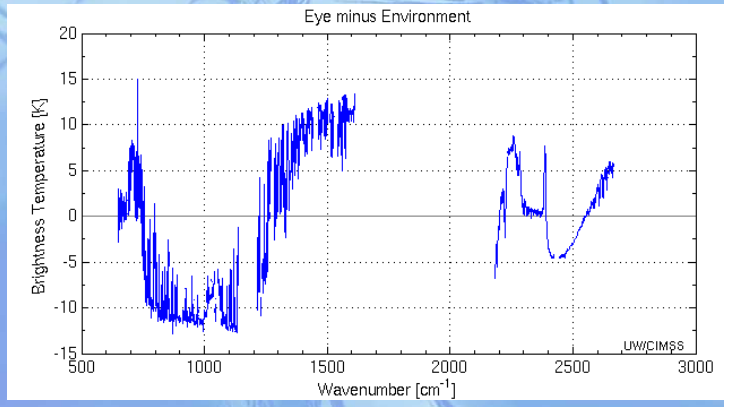


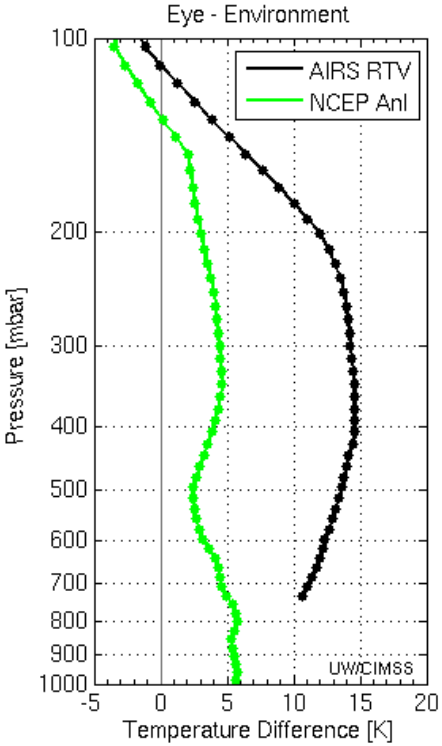
eye

environment





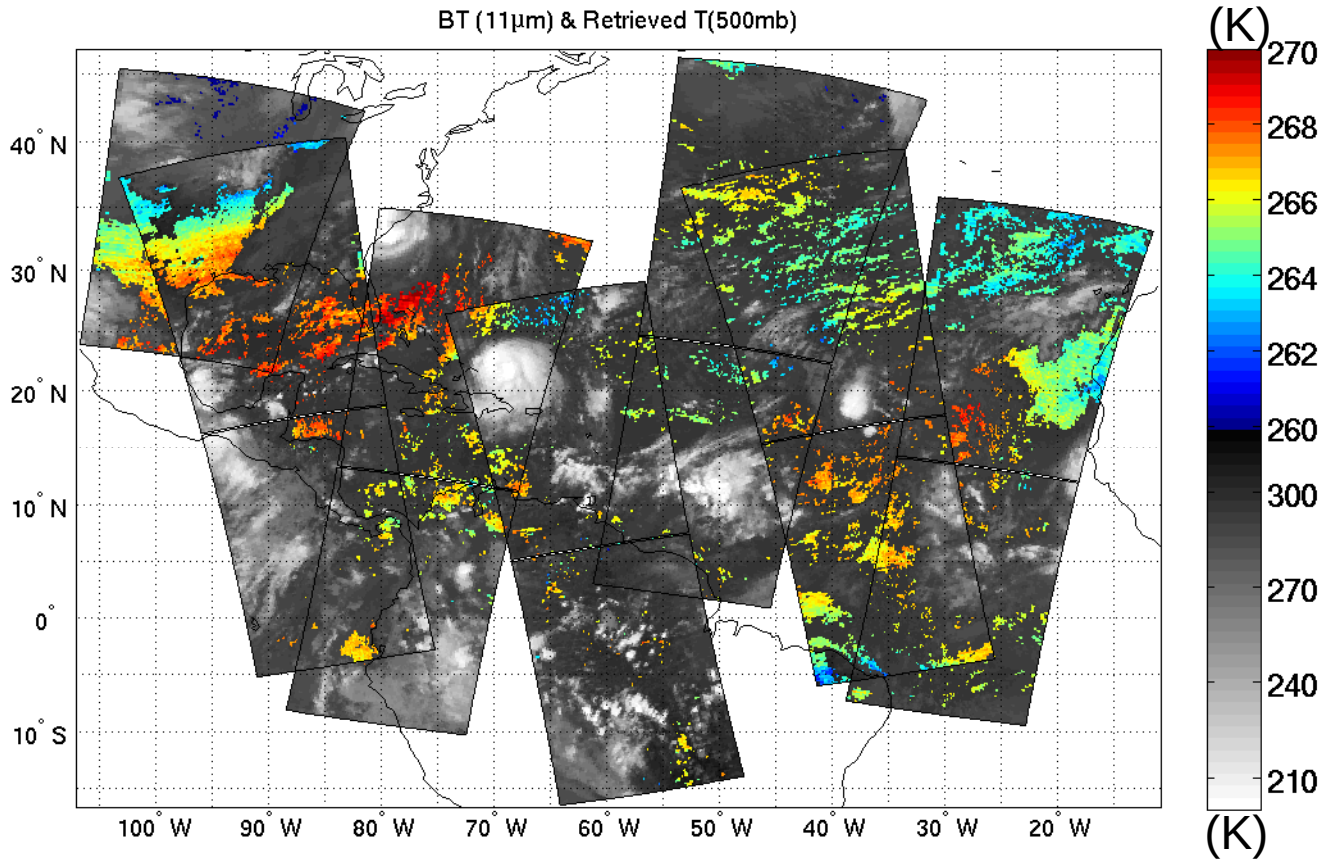




AIRS data used for Hurricane IKE (2008) study

- September 6-7, 2008 (115^{o}W – 30^{o}W; 0 – 40^{o}N)
- About 10 AIRS granules every day
- Single field-of-view (FOV) temperature and moisture profiles (13.5 km at nadir) from AIRS are derived using CHISR
- Clear sky only temperature and moisture soundings are provided in the assimilation experiment

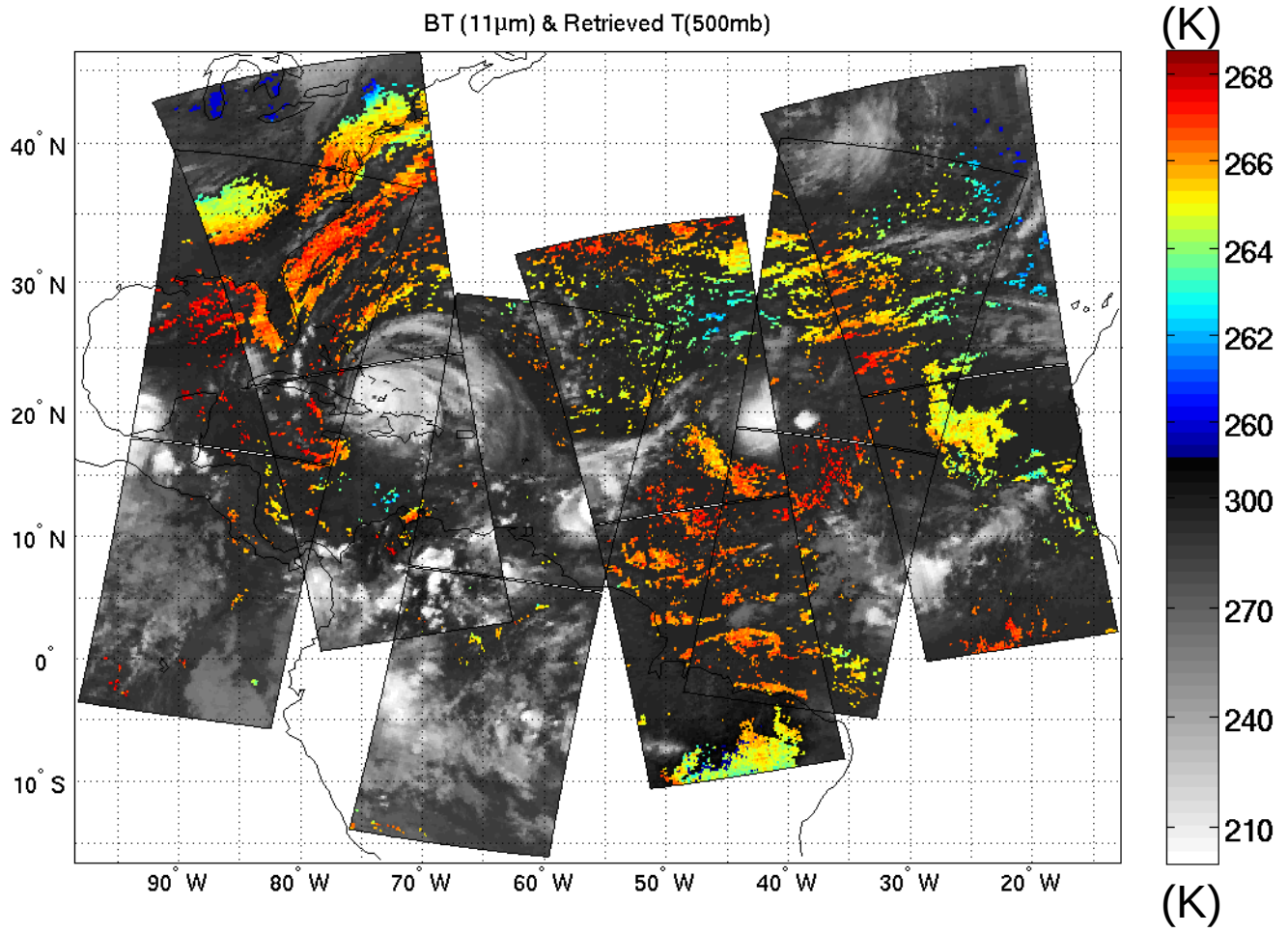
Retrieved 500mb temperature (2008.09.06 – Used in assimilation)



CIMSS/UW

Clear sky AIRS SFOV temperature retrievals at 500 hPa on 06 September 2008, each pixel provides vertical temperature and moisture soundings.

Retrieved 500mb temperature (2008.09.07 - Used in assimilation)

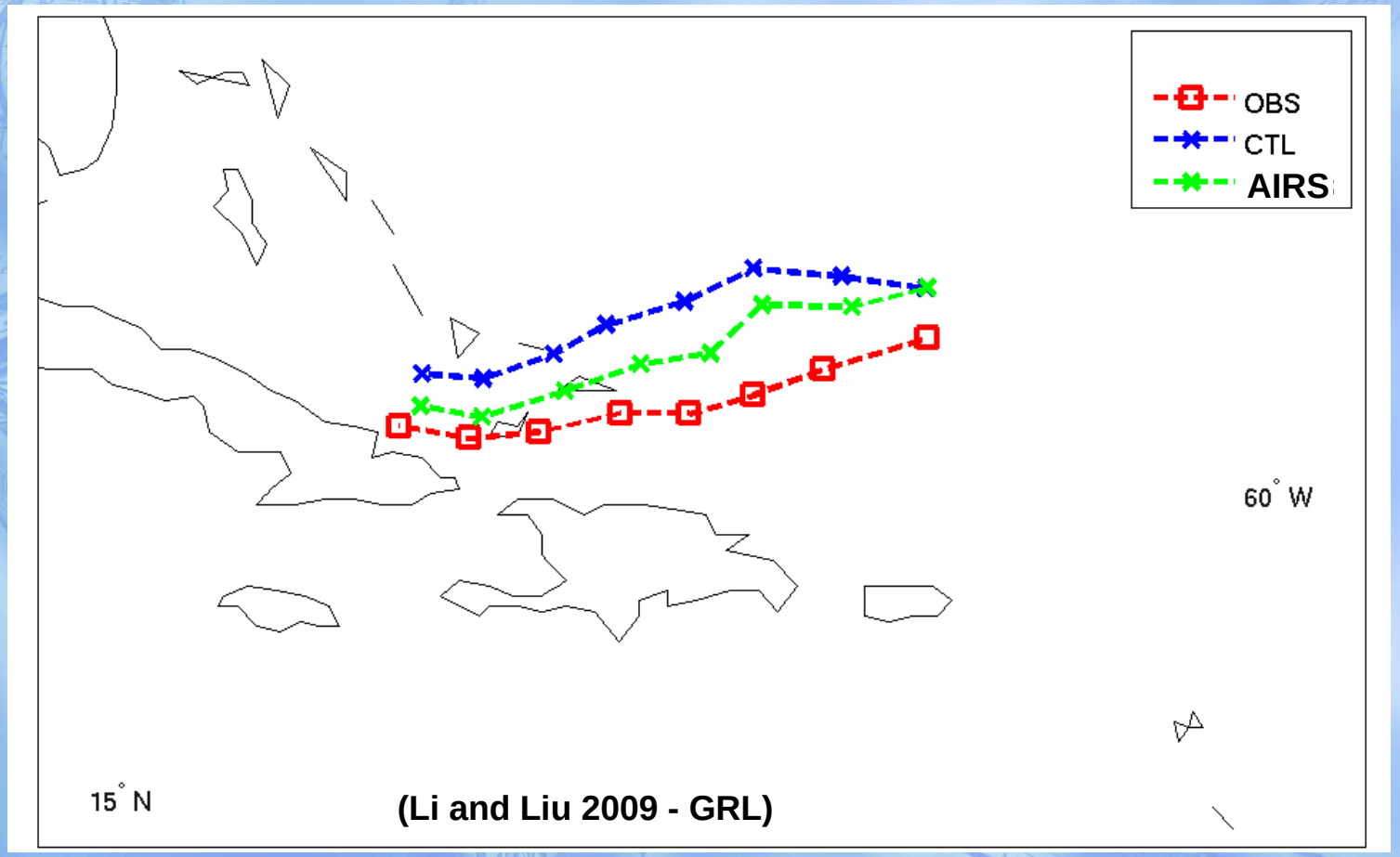


CIMSS/UW

Clear sky AIRS SFOV temperature retrievals at 500 hPa on 07 September 2008, each pixel provides vertical temperature and moisture soundings.

Tracks of ensemble mean analysis on Hurricane IKE

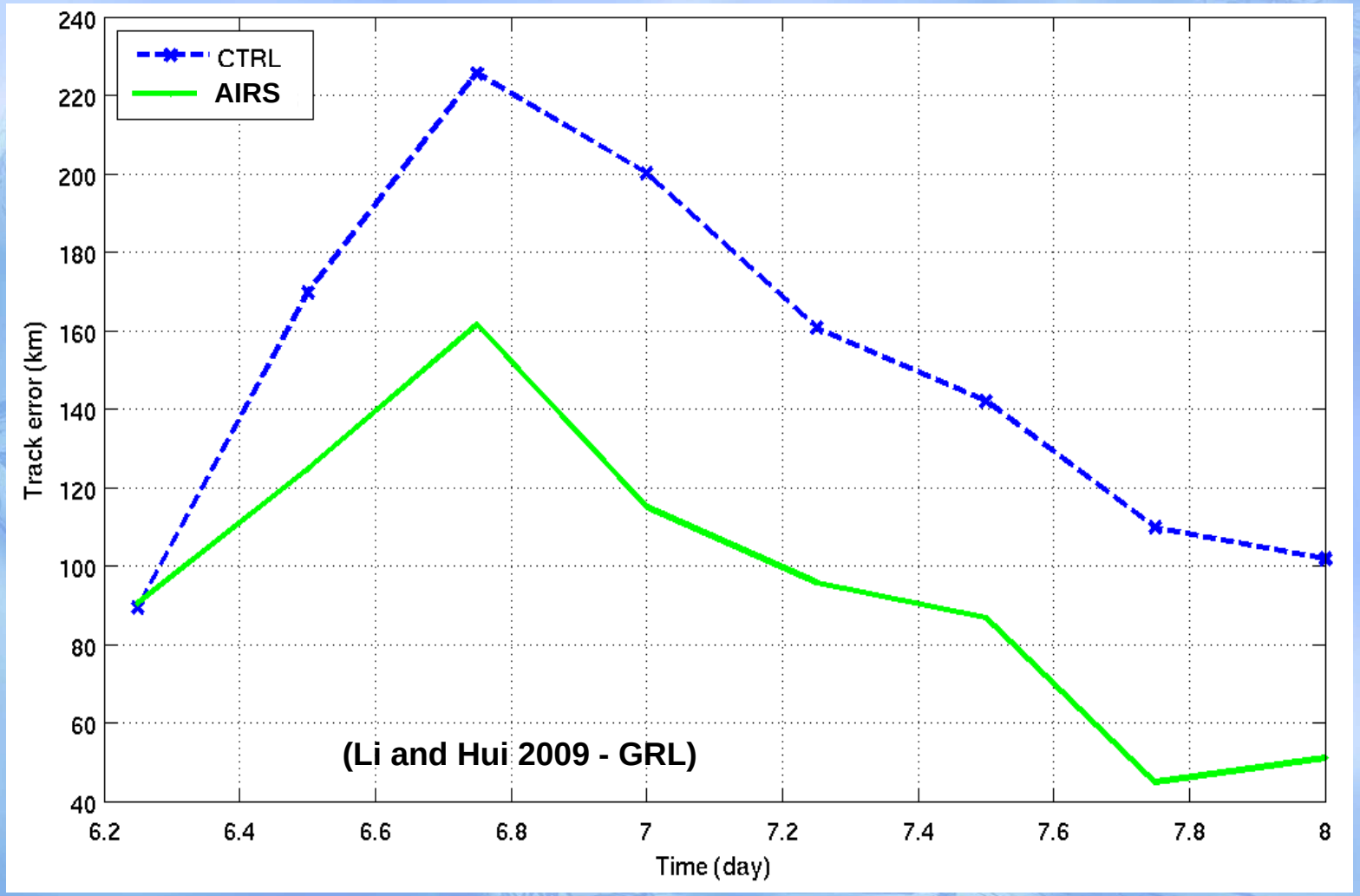
CTL run: **Assimilate radiosonde, satellite cloud winds, aircraft data, and surface data.**



(Li and Liu 2009 - GRL)

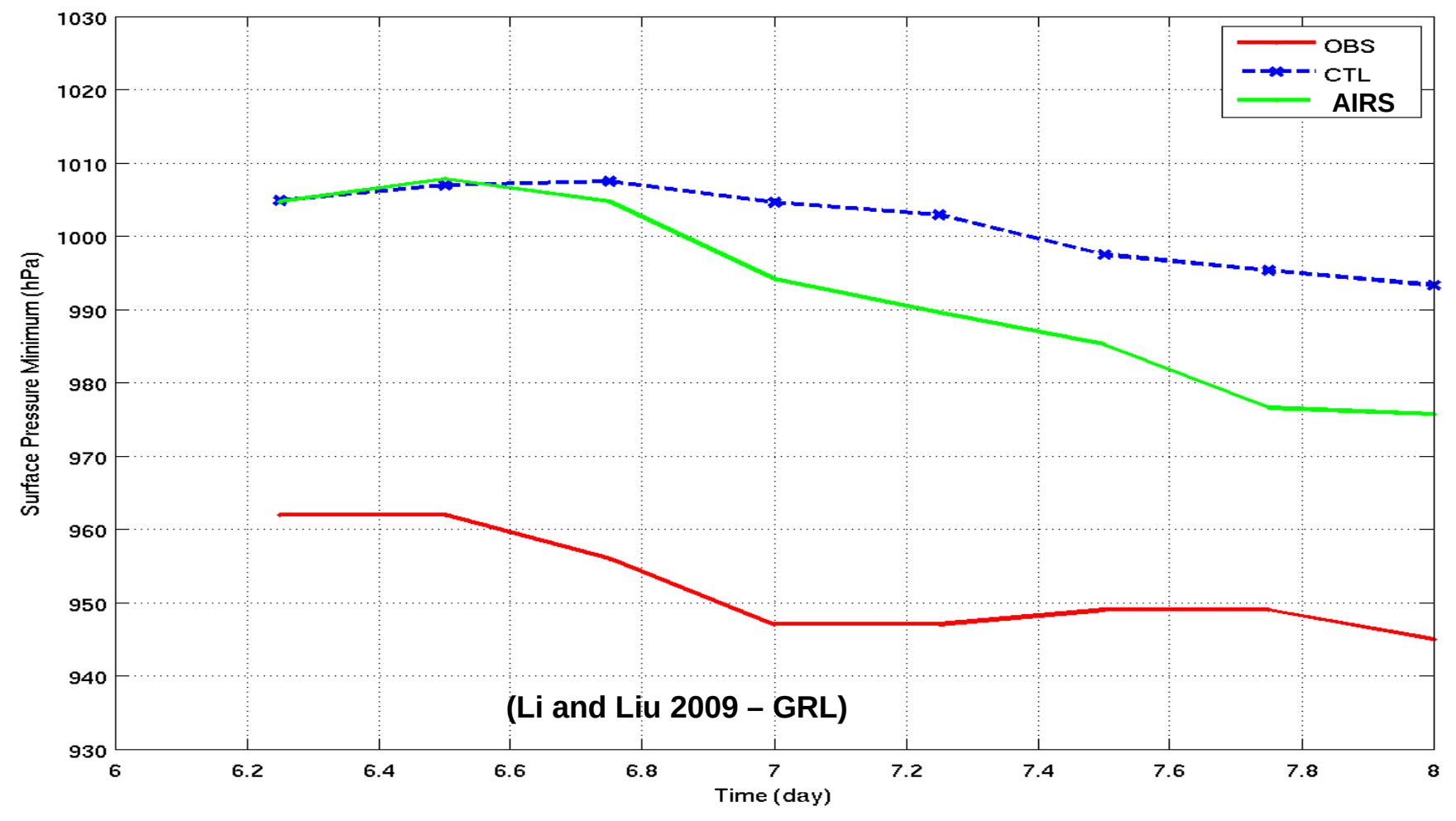
Analysis from 06 UTC 6 to 00UTC 8 September 2008

Track errors of on Hurricane IKE



Analysis from 06 UTC 6 to 00UTC 8 September 2008

SLP Intensity on Hurricane IKE

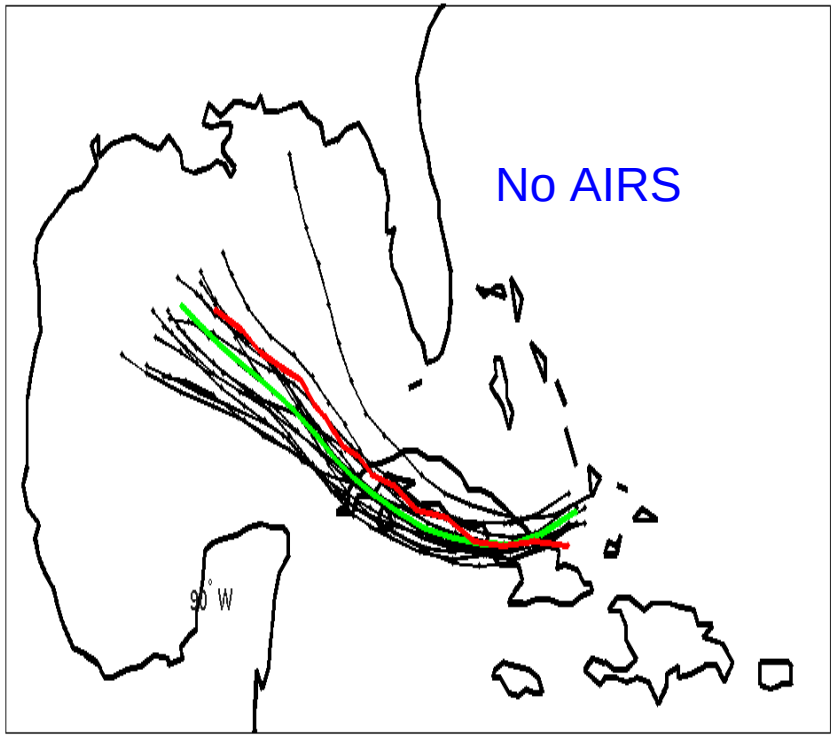


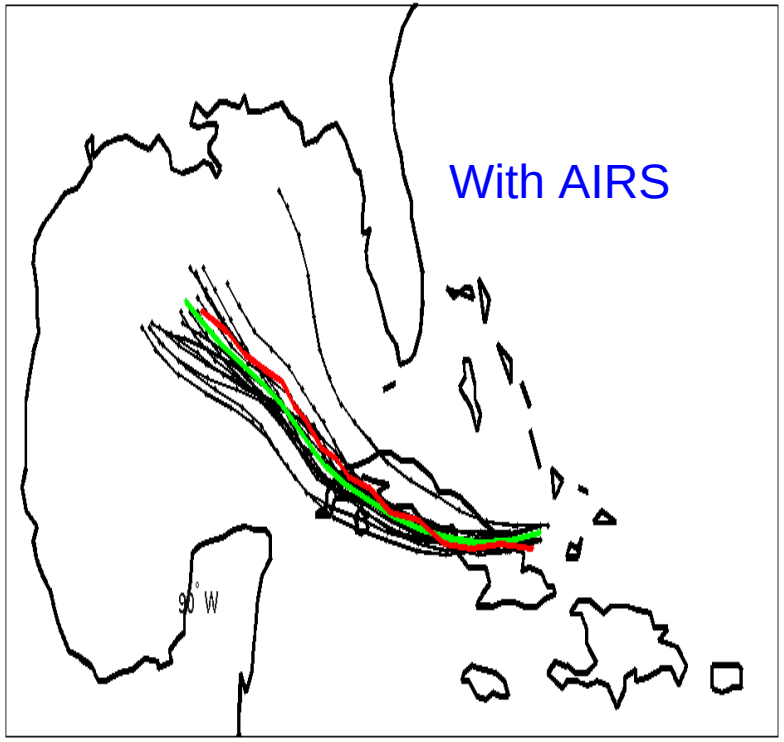
Analysis from 06 UTC 6 to 00UTC 8 September 2008

Assimilation Experiments (cont 1)

- 4-day ensemble forecasts (16 members) from the analyses on 00UTC 8 September 2008.
- Track trajectory and hurricane surface central pressure are compared (every 6-hourly in the plots).

Tracks of 96h forecasts on Hurricane IKE





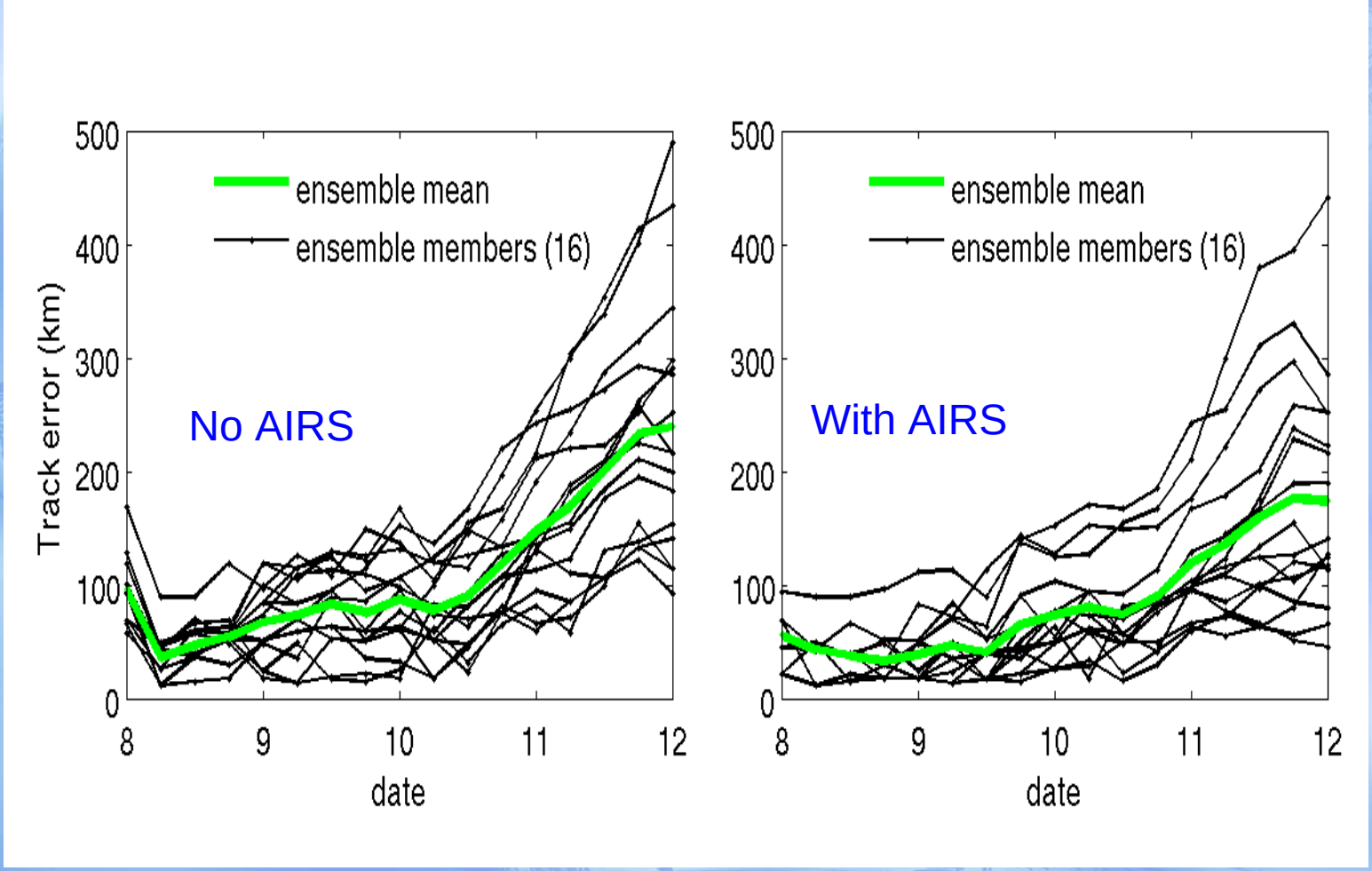
30° N

15° N

(Li and Liu 2009 – GRL)

Forecasts start at 00 UTC 8 September 2008

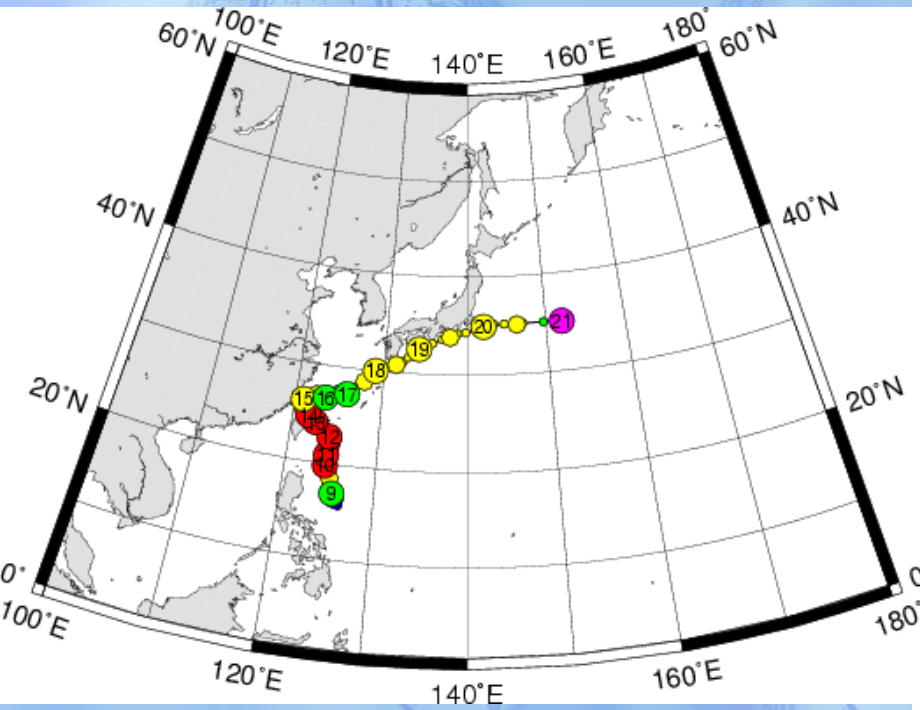
Track errors of 96h forecasts

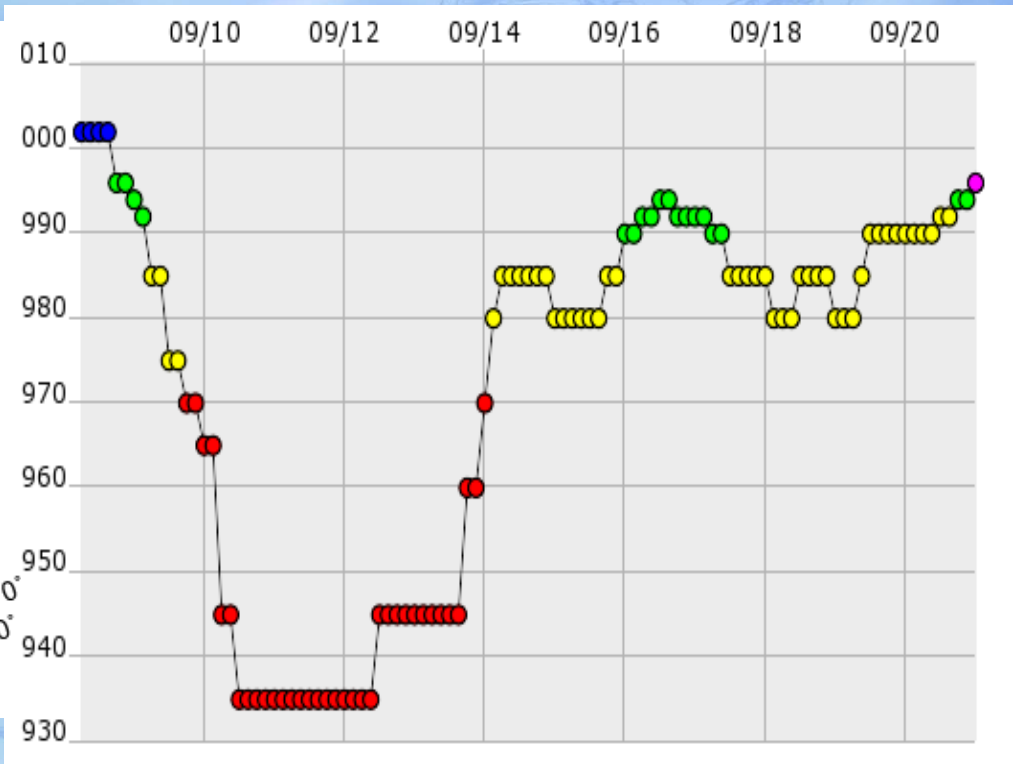


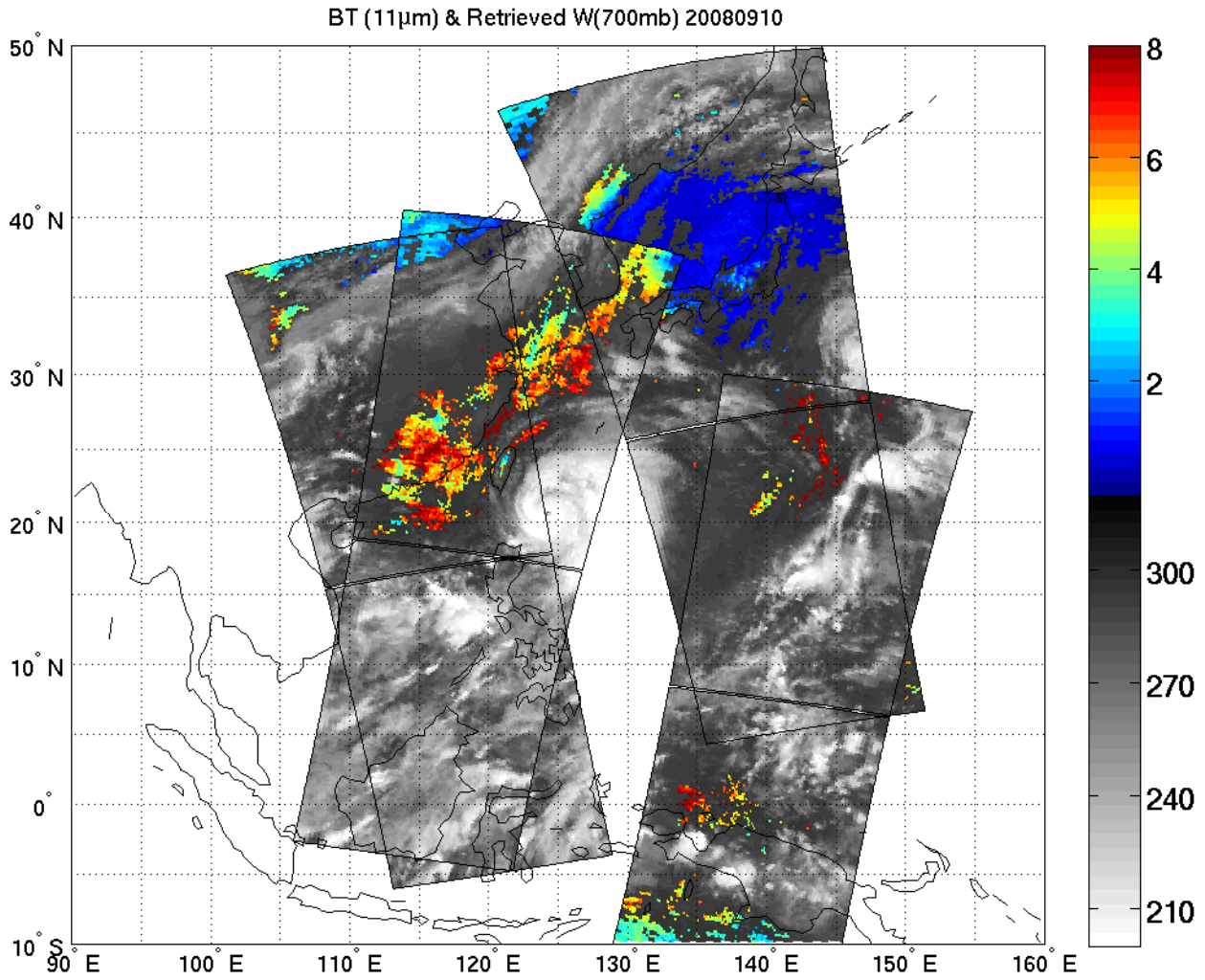
(Li and Liu 2009 – GRL)

Forecasts start at 00 UTC 8 September 2008

Typhoon Sinlaku (2008)

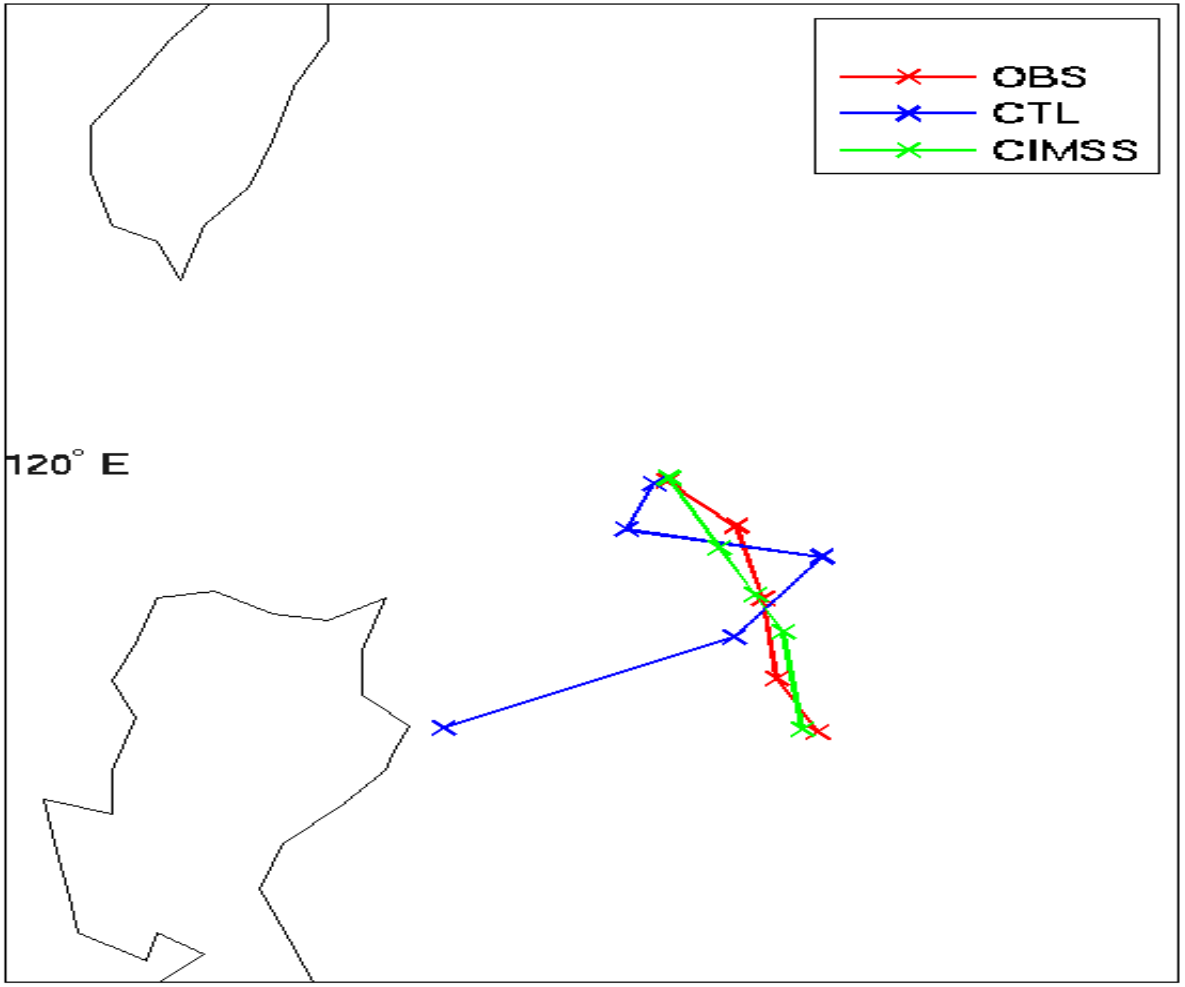






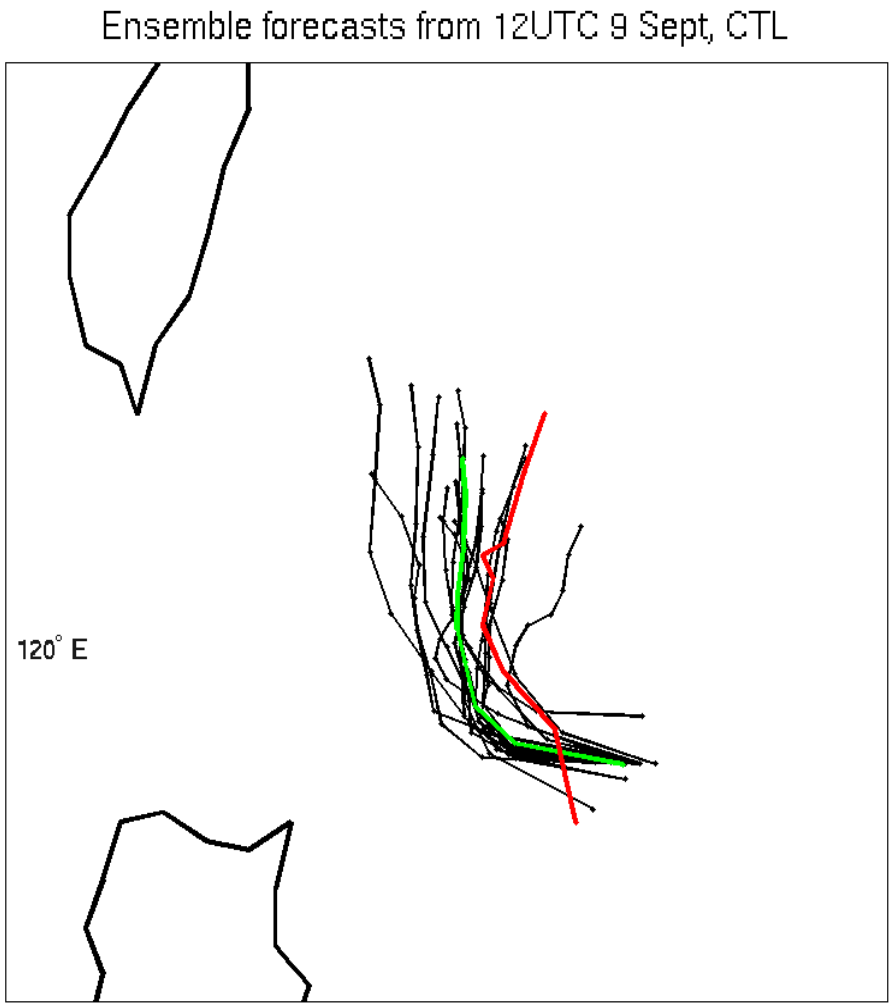
700 hPa water vapor mixing ratio (g/kg) (Sinlaku – 2008)

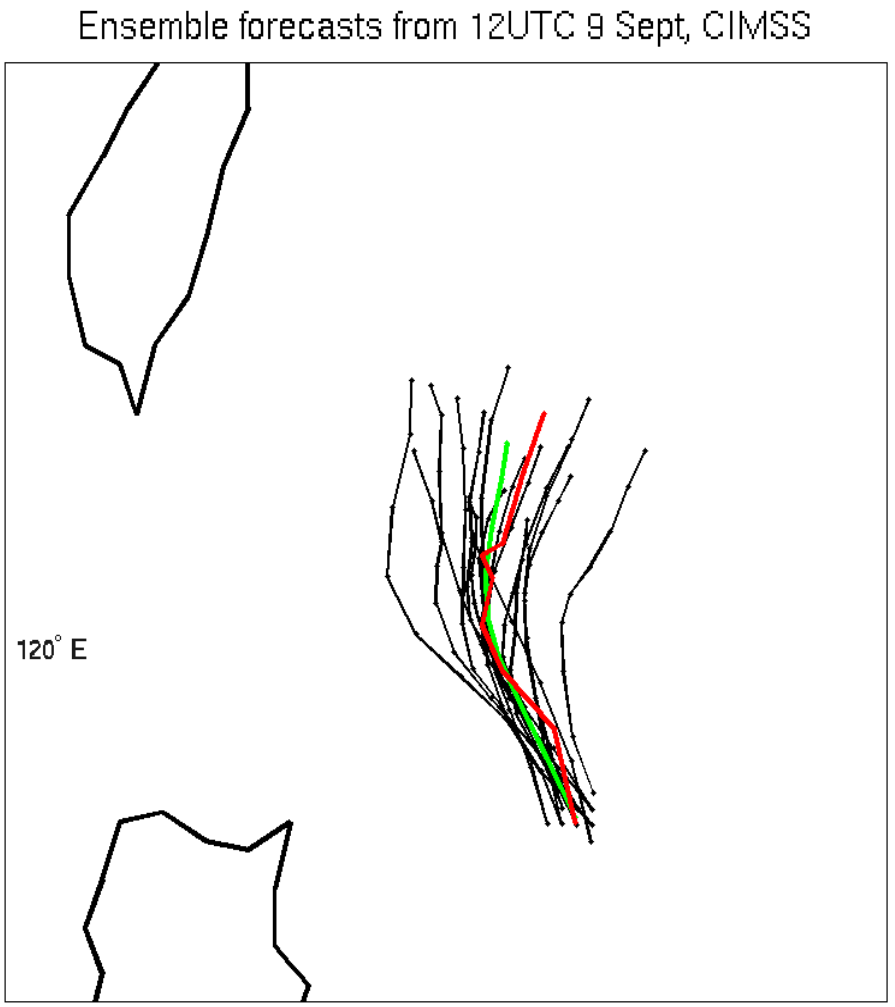
Tracks of ensemble mean analysis on Sinlaku



Analysis from 00 UTC 9 to 00UTC 10 September 2008

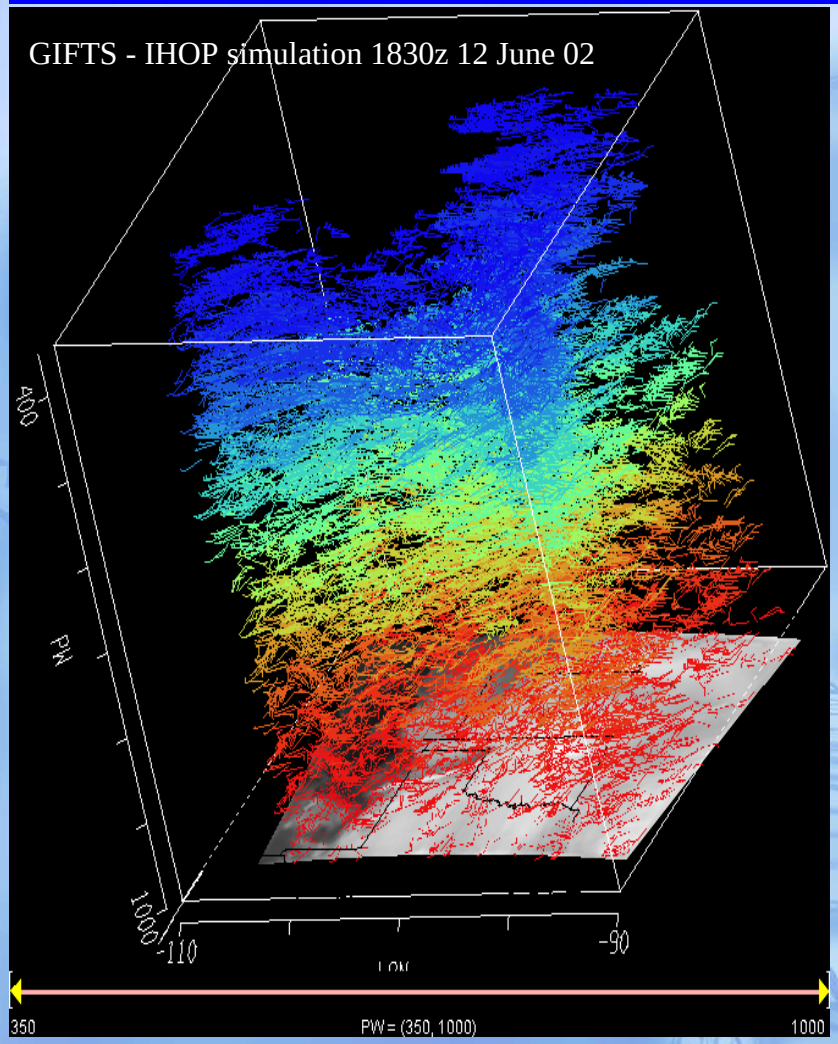
Tracks of 48h forecasts on Sinlaku

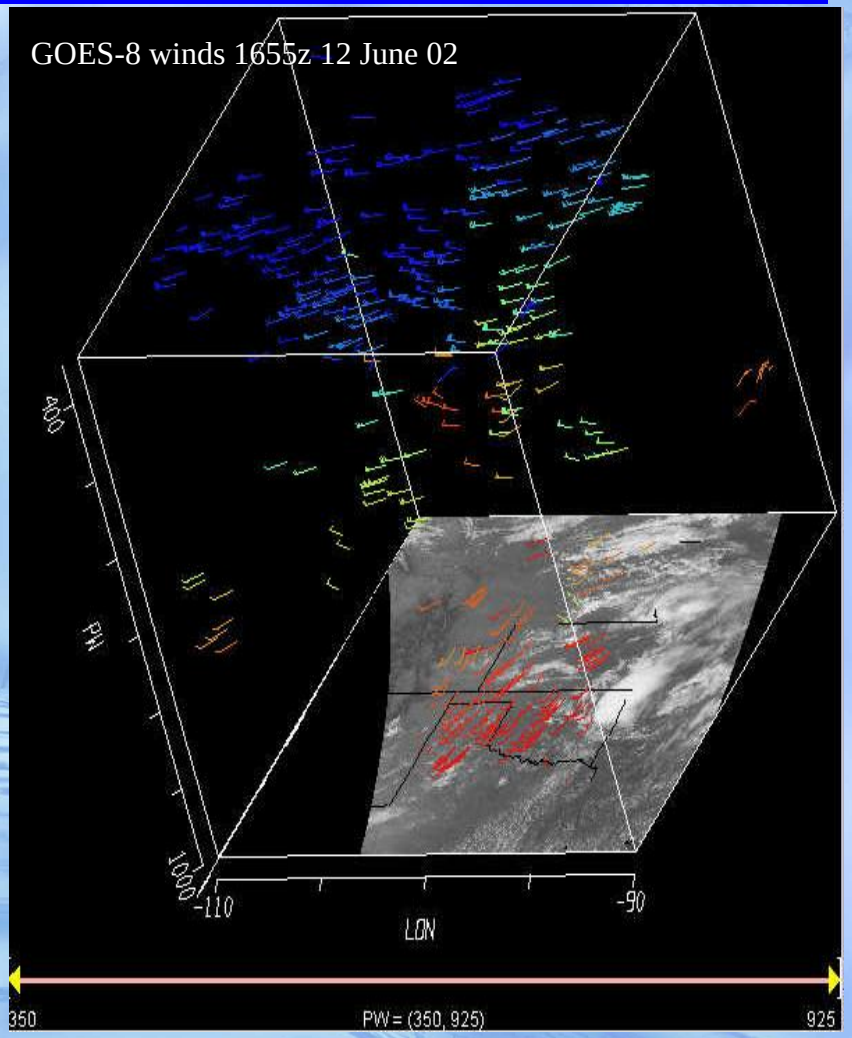




Forecasts start at 12 UTC 9 September 2008

Future Geostationary advanced IR sounder provides 4-D Temperature, Water Vapor, and Wind Profiling Potential





Simulated GIFTS winds (left) Vs. GOES current oper winds (right)

Summary

- CIMSS has developed an algorithm and processing package for full spatial resolution sounding retrieval from hyperspectral IR radiances in both clear and cloudy skies
- Hyperspectral IR sounder provides unprecedented global atmospheric temperature and moisture profiles that are critical for weather forecast and other applications
- Temperature and water vapor soundings from AIRS evidently improve ensemble forecast of hurricane track and intensity for Hurricane IKE and Typhoon Sinlaku (2008)
- Placing a hyperspectral IR sounder in geostationary orbit will provide four-dimensional fields of moisture, temperature and wind with high accuracy, which is critical for high impact weather nowcasting.