Satellite Data Assimilation in WRF-Var

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Collaborations… but no support :-(

Outline

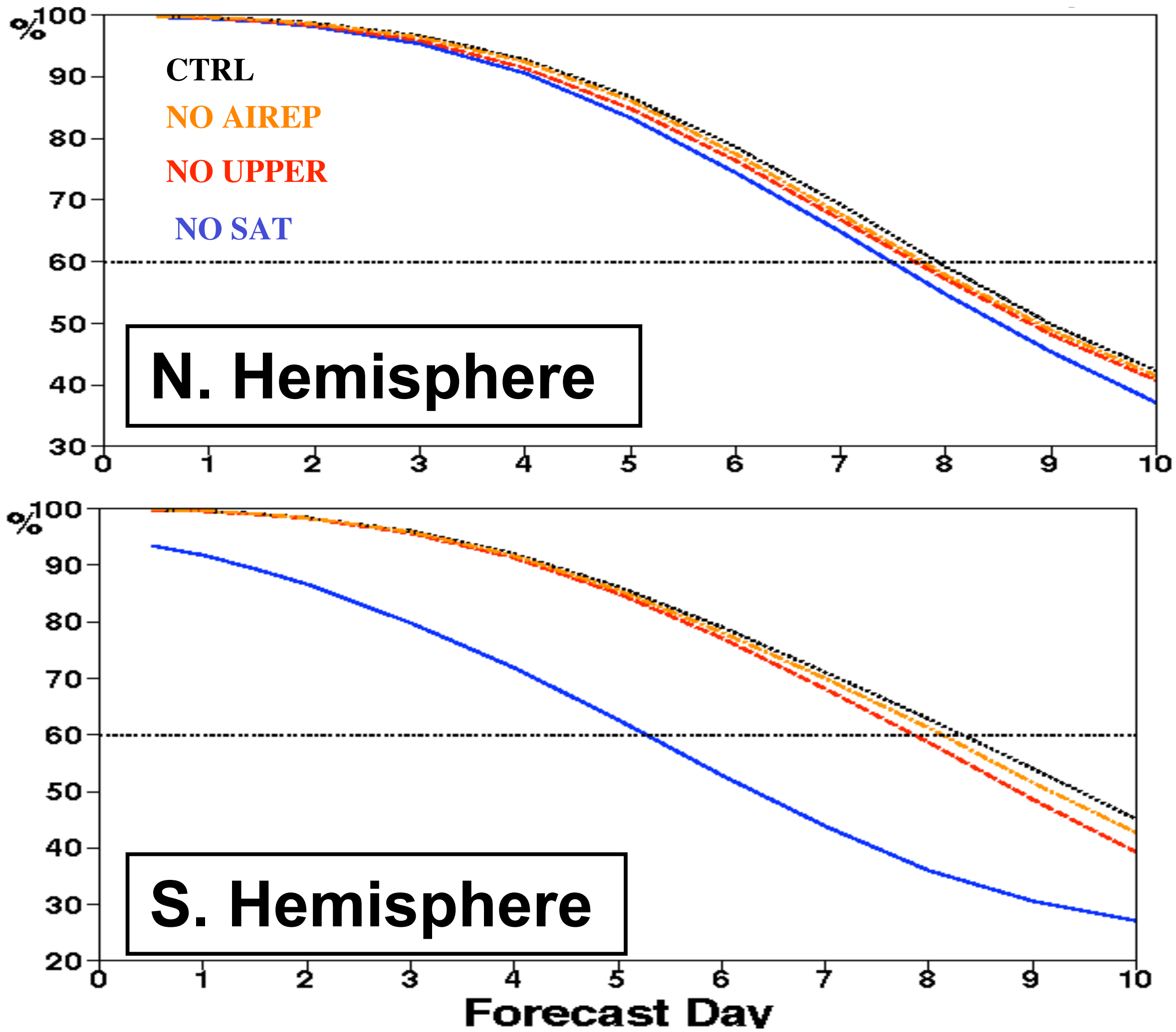
- ♠ Basic concepts of satellite data assimilation
- ♥ Satellite DA in WRF-Var + impact studies
- ♦ Practical issues: current status on satellite work
- ♣ Conclusions

Basic Concepts

Why should I care about satellites?

Basic Concepts: Satellite Impact

Satellites = main source of information within observing network for NWP



4-month Observing System Experiments (OSEs)

Courtesy ECMWF

Basic Concepts

What do satellites measure?

Basic Concepts: Satellites measure…

- ♠ Temperature / Humidity / Ozone profiles

- ♥ Surface Temperature / Emissivity / Albedo

- ♦ Wind

- ♣ Radiance / Radio Signal

Basic Concepts: Radiative Transfer

$$L(\nu) = \int_0^\infty B(\nu, T(z)) \left[\frac{d\tau(\nu)}{dz} \right] dz \; + \; \text{Surface} \; + \; \text{Cloud/rain}$$

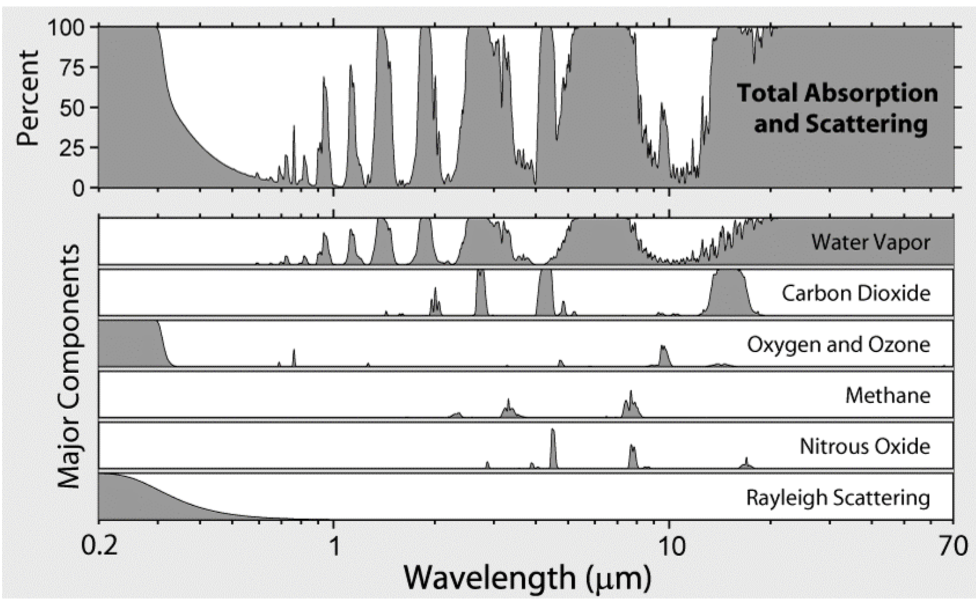
TOA radiance at frequency ν

Planck function

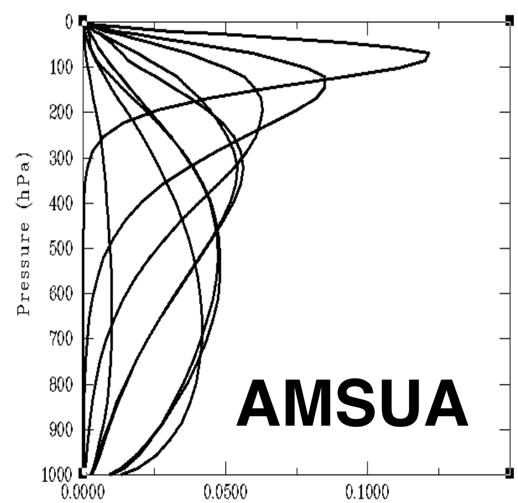
Atmospheric absorption

Emission/reflection

Diffusion/scattering



- Temperature information derived from well-mixed absorbents (CO2, …)
- Channels sensitive to Humidity, Ozone, …
- Surface channels: “window” parts of spectrum



Basic Concepts: Radiative Transfer

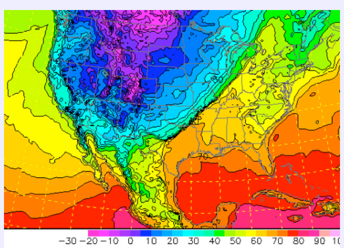
$$L(\nu) = \int_0^\infty B(\nu, T(z)) \left[\frac{d\tau(\nu)}{dz} \right] dz \; + \; \text{Surface} \; + \; \text{Cloud/rain}$$

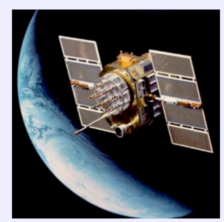
- $L(\nu)$: TOA radiance at frequency ν
- $B(\nu, T(z))$: Planck function
- $\frac{d\tau(\nu)}{dz}$: Atmospheric absorption
- Surface: Emission/reflection
- Cloud/rain: Diffusion/scattering

CRTM, RTTOV, …

T, Q, O3, … → Forward model → L(ν)

RT





L(ν) → Inversion → T, Q, O3, …

Regression, neural network, 1D-Var

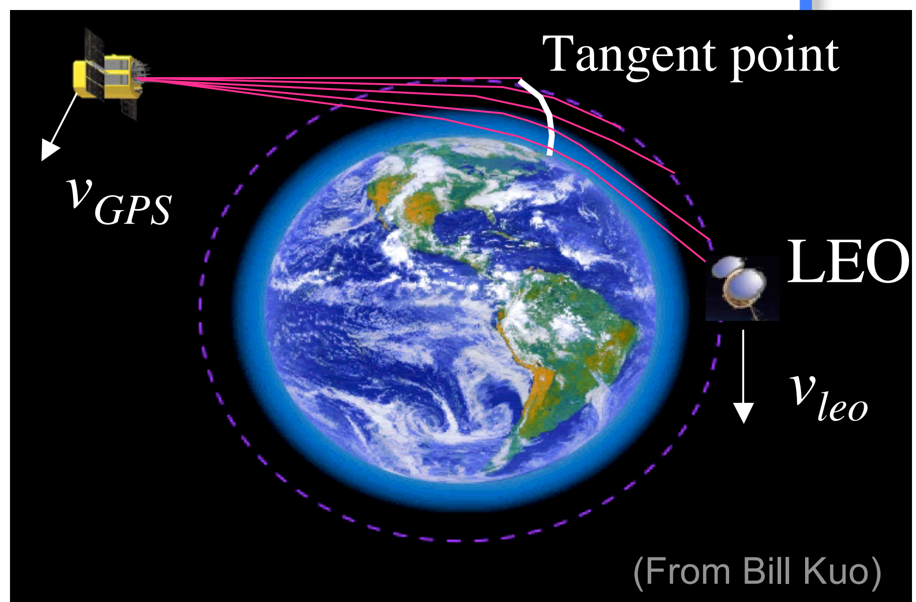
Basic Concepts: GPS Radio Occultation

The ray path of a transmitted radio signal during an occultation is bent due to the atmospheric refraction related to the atmospheric state (T, p and q) in neutral atmosphere.

Constellation Observing System for Meteorology, Ionosphere & Climate (COSMIC)

Features of measurements

- high vertical resolution
- all-weather
- unbiased
- coarse horizontal resolution
- multi-path problem in lower levels



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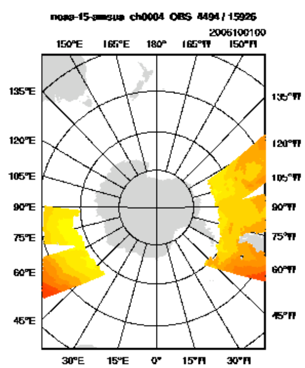
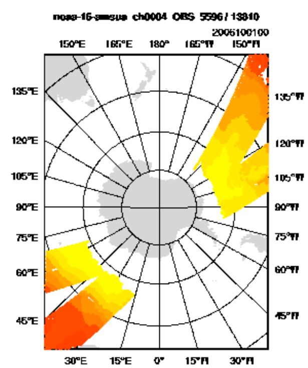
Satellite DA: WRF-Var capabilities

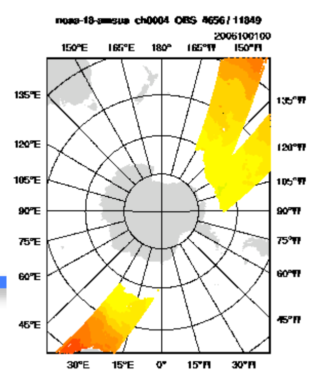
- **Retrievals (T / Q profiles)**
  - SATEM (from AMSU)
  - AIRS retrievals (V5)
- **GPS Radio Occultation**
  - Retrieved refractivity from COSMIC
- **Winds**
  - Retrieved winds: polar MODIS, SATOB
  - Active sensors: Quikscat
- **Radiances**
  - Microwave sounders: AMSU-A/B, MHS, SSMIS
  - Infrared sounders: HIRS, AIRS
- **Radiative Transfer Model**
  - CRTM (V1.1)
  - RTTOV (V8.7)
- **Radiance monitoring tools**

Impact study: Antarctic Region

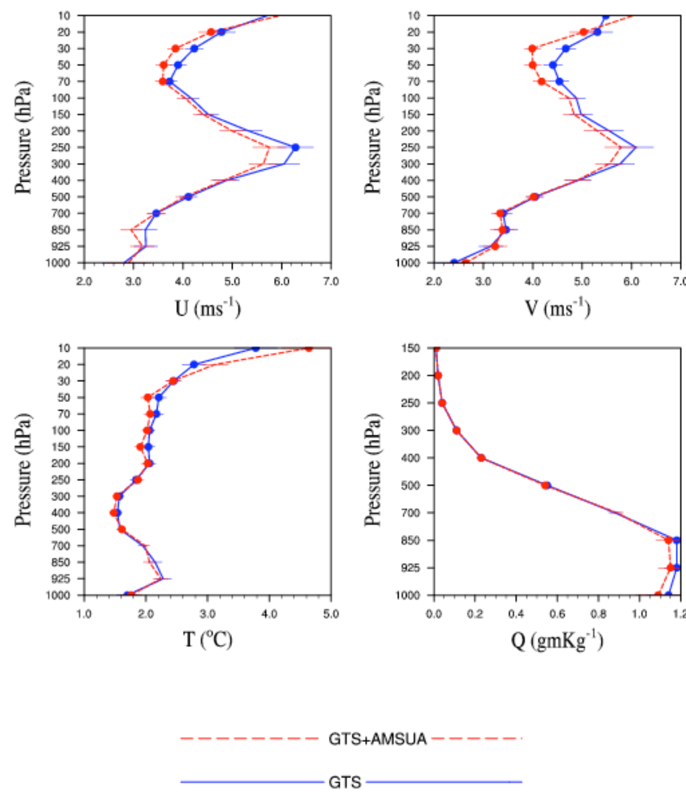
- 60km horizontal resolution
- 57 vertical levels, model top = 10mb
- Full cycling expt for 14 days
  (1 ~ 14 October 2006)
- NOAA 15/16/18 AMSUA ch. 4~9







RMSE: 36h forecast *vs*. Radiosondes



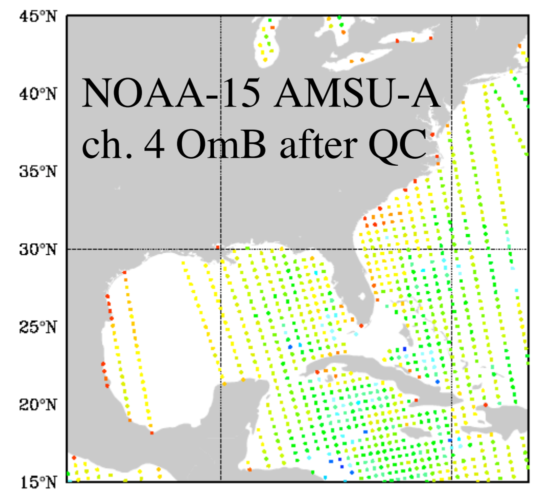
Case Study: Hurricane Katrina

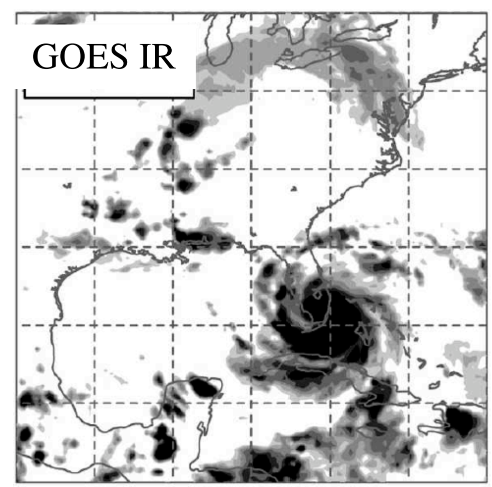
12km51L, model top 10mb

RTTOV Radiative Transfer Model

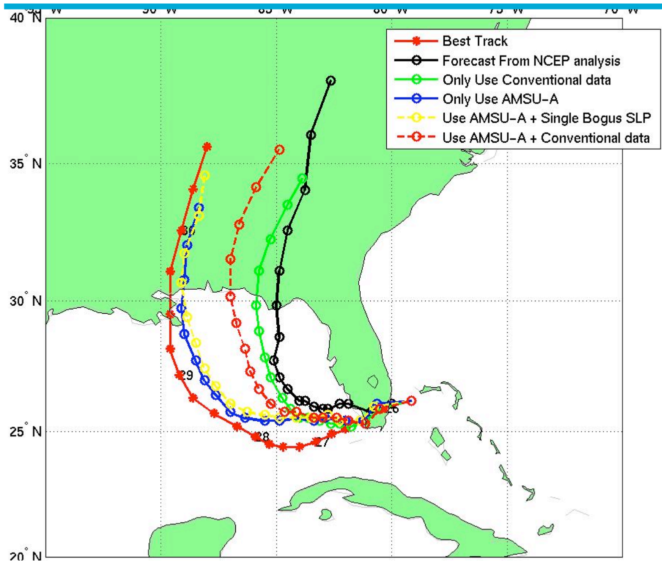
AMSU-A assimilated
Ch. 1~4 over sea
Ch. 5~10 both over sea and land

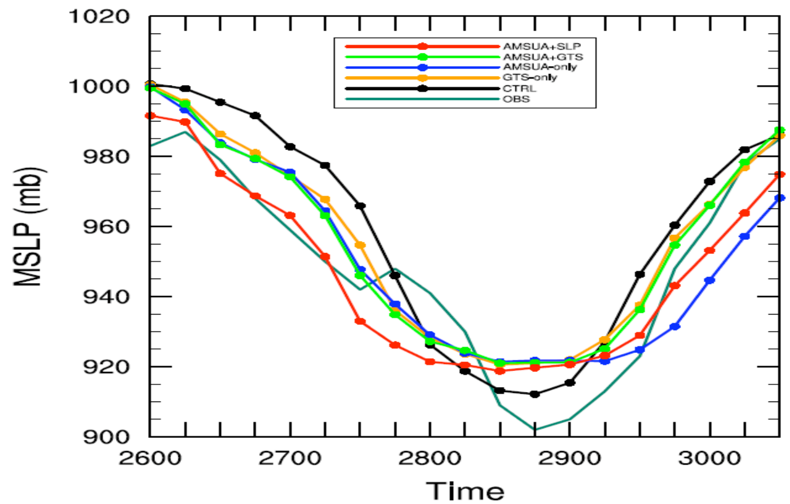
Pixels over precipitating area rejected

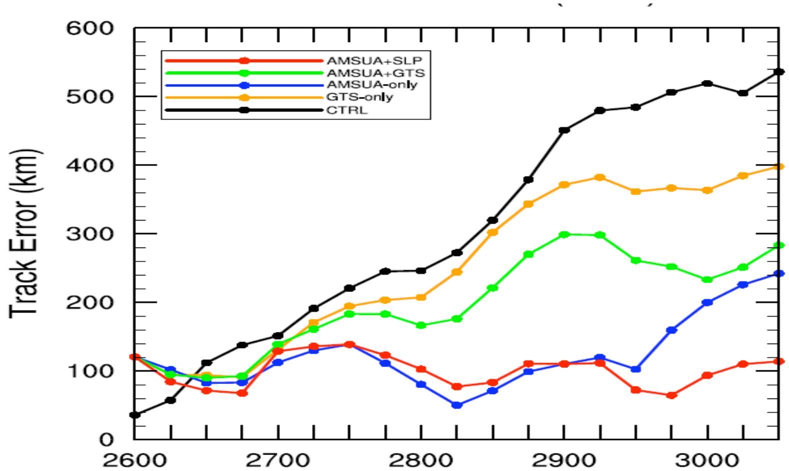


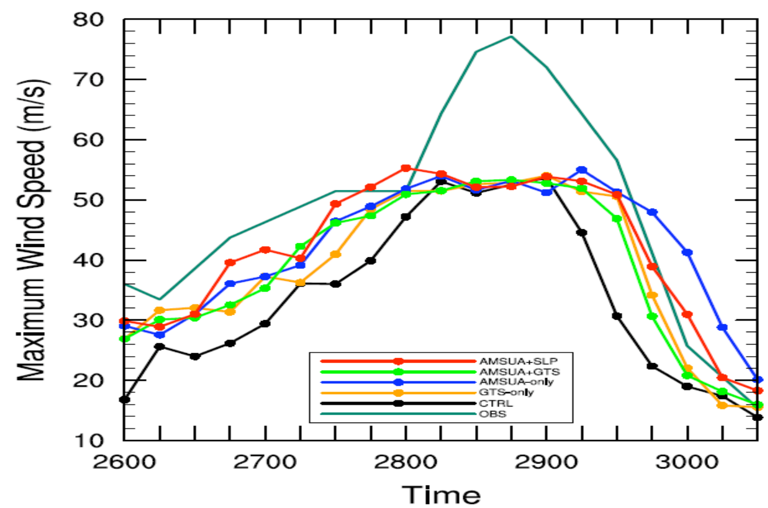


Case Study: Hurricane Katrina









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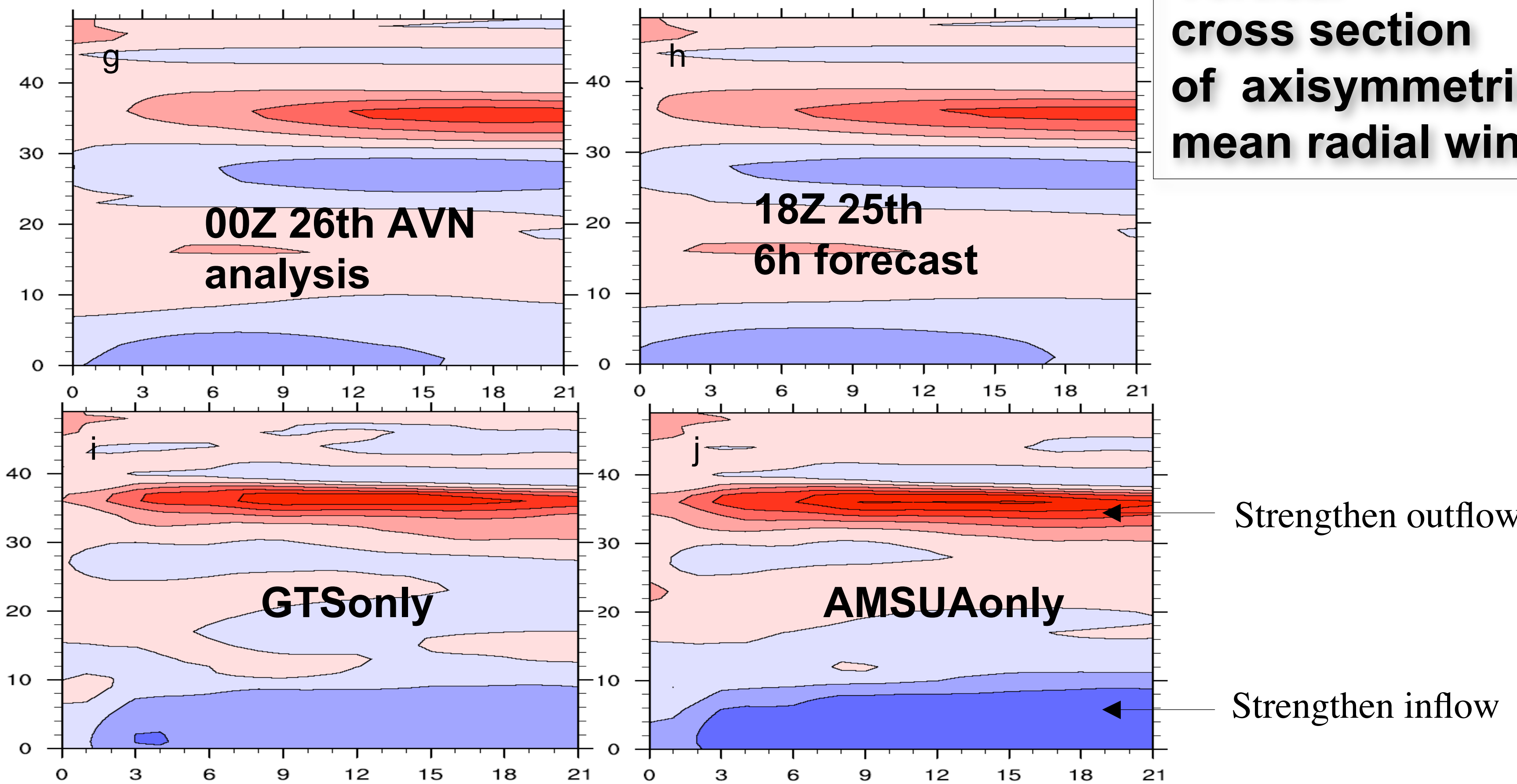

Vertical cross section of axisymmetric mean radial wind

Advantage for TC intensification

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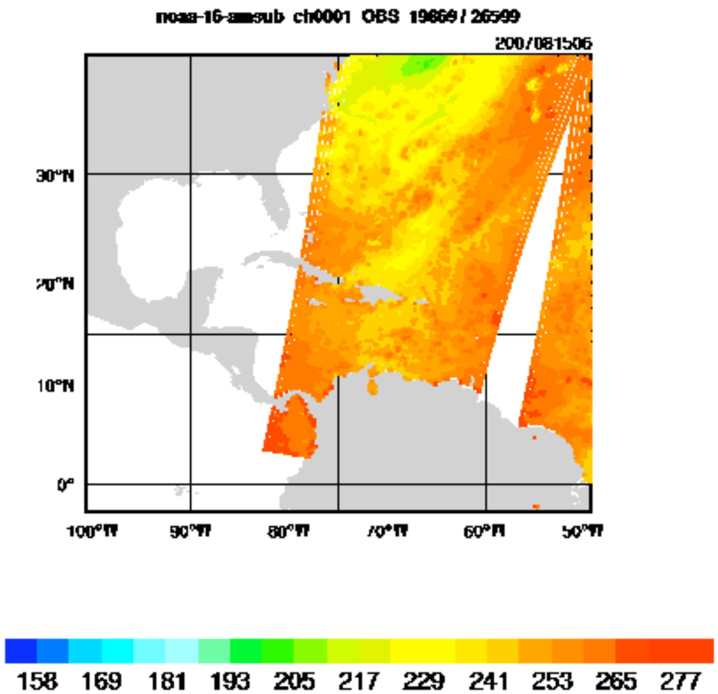
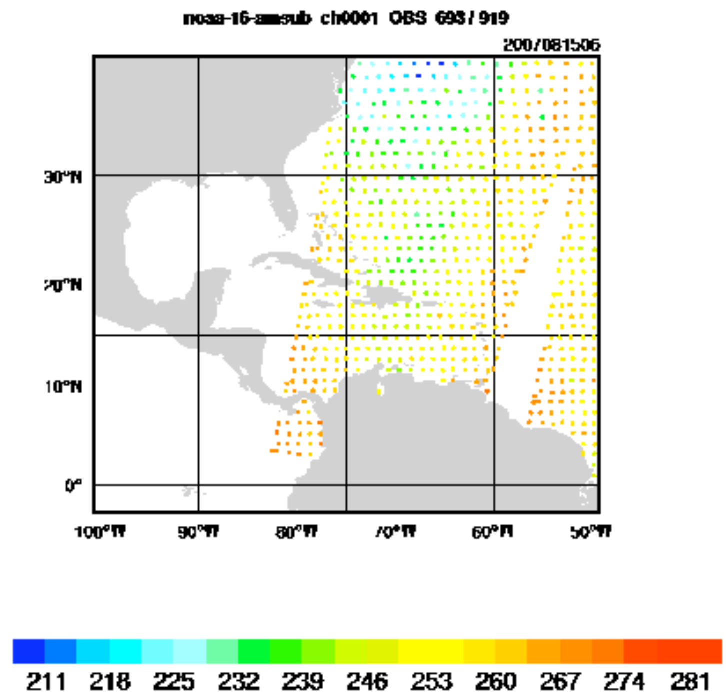
Practical issues: Thinning

No Thinning



120km Thinning Mesh



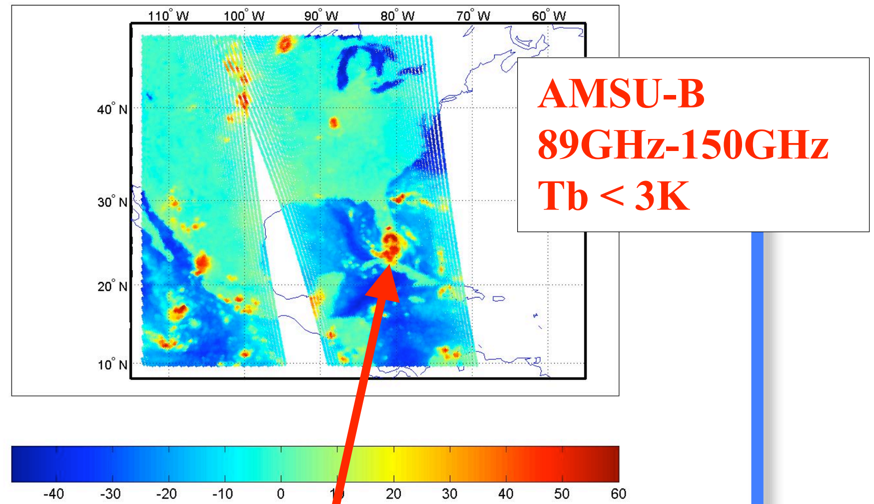
Practical issues: Quality Control

- **Specific QC for each sensor**
  AMSU-A, AMSU-B, MHS, SSMIS, AIRS

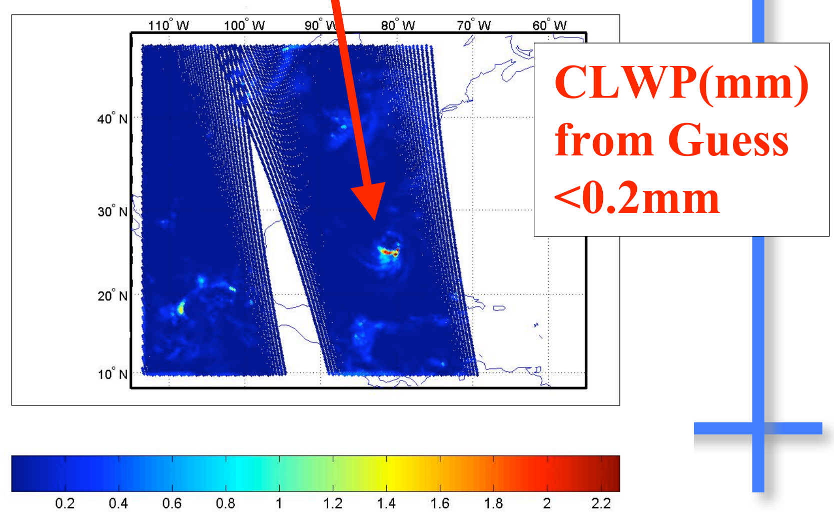
- **Pixel-level QC**
  - Reject **limb** observations
  - Reject pixels over **land** and **sea-ice**
  - **Cloud/Precipitation** detection
  - **Synergy** with imager (AIRS/VIS-NIR)

- **Channel-level QC**
  - **Gross check** (innovations <15 K)
  - **First-guess check** (innovations < $3\sigma_o$).

- **Observation error tuning**
  - Error factor tuned from objective method (Desrozier and Ivanov, 2001)



Katrina Location (2005/08/26/06Z)



Practical issues: Bias Correction

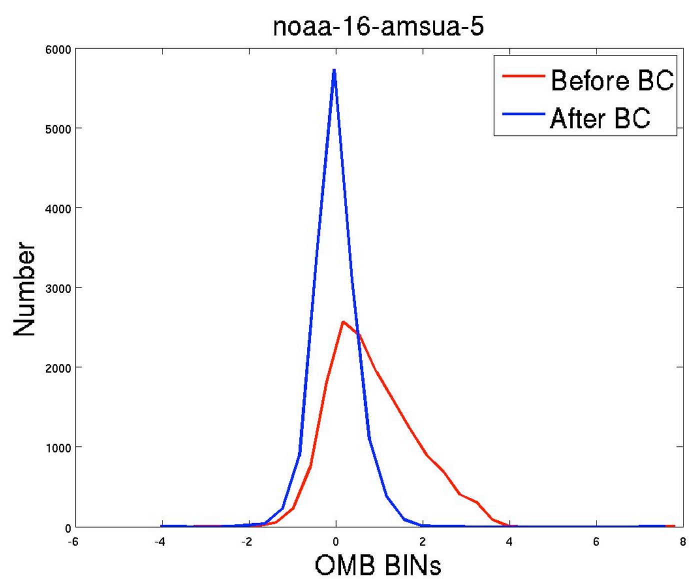
Modeling of errors in satellite radiances:

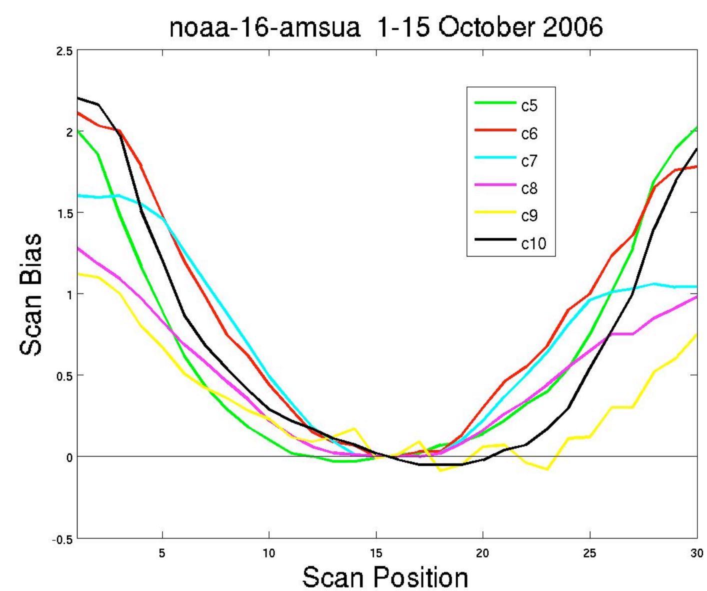
$$y = H(x_t) + B(\beta) + \varepsilon \qquad \begin{cases} \langle \varepsilon \rangle = 0 \\ B(\beta) = \sum_{i=1}^{N} \beta_i p_i \end{cases}$$

Parameters (β_i)

Predictors (p_i):

- Offset
- 1000-300mb thickness
- 200-50mb thickness
- Surface skin temperature
- Total column water vapor
- Scan





Practical issues: Variational Bias Correction

Modeling of errors in satellite radiances:

$$y = H(x_t) + B(\beta) + \varepsilon$$

$$\begin{cases} \langle \varepsilon \rangle = 0 \\ B(\beta) = \sum_{i=1}^{N} \beta_i p_i \end{cases}$$

Parameters (β_i)

Predictors (p_i):

- Offset
- 1000-300mb thickness
- 200-50mb thickness
- Surface skin temperature
- Total column water vapor
- Scan

Bias parameters can be estimated within the **variational assimilation**, jointly with the atmospheric model state (Derber and Wu 1998) (Dee 2005) (Auligné et al. 2007)

Inclusion of the bias parameters in the control vector : $x^T \rightarrow [x, \beta]^T$

J_b: background term for x

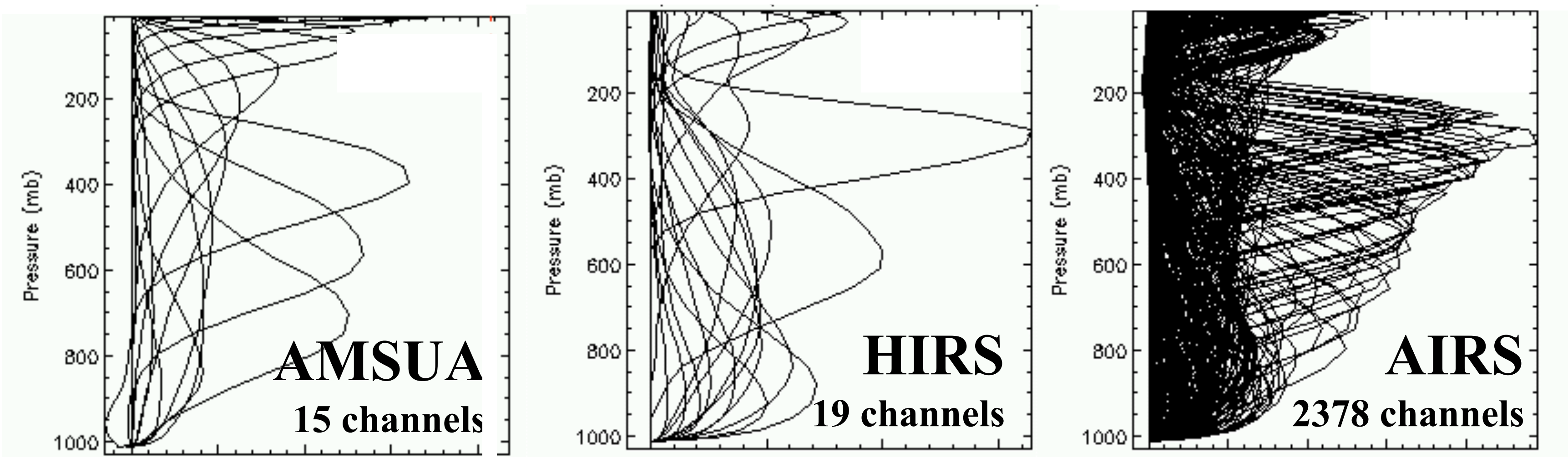
J_o: corrected observation term

$$\mathbf{J}(\mathbf{x},\beta) = (\mathbf{x}_b - \mathbf{x})^T \mathbf{B}_x^{-1} (\mathbf{x}_b - \mathbf{x}) + [\mathbf{y} - H(\mathbf{x}) - B(\beta)]^T \mathbf{R}^{-1} [\mathbf{y} - H(\mathbf{x}) - B(\beta)]$$
$$+ (\beta_b - \beta)^T \mathbf{B}_\beta^{-1} (\beta_b - \beta)$$

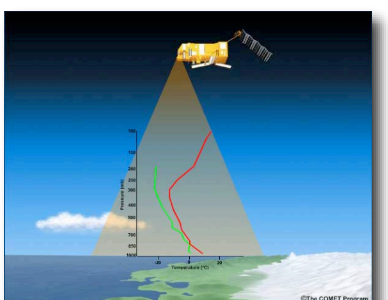
J_β: background term for β

«Optimal » bias correction considering all available information

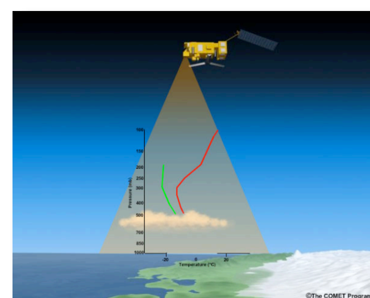
Practical issues: AIRS Cloud Detection



From « **hole hunting** »
(identifying clear pixels)…



… to **identifying clear channels**
(insensitive to the cloud).



Practical issues: AIRS Cloud Detection

RTM

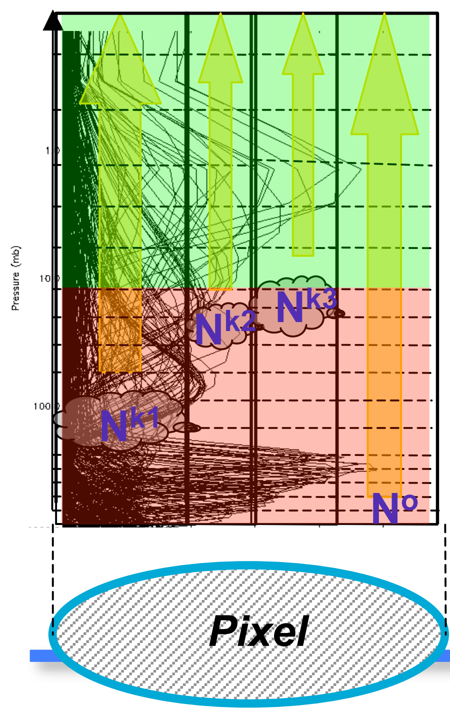
- R_ν° = Radiance calculated in **clear** sky
- $R_\nu^{\bullet k}$ = Radiance calculated for **overcast black cloud** at level k

Multivariate Minimum Residual (MMR):

$$R_\nu^{Cld}(N^\circ, N^1, ..., N^n) = N^\circ R_\nu^\circ + \sum_{k=1}^{n} N^k R_\nu^{\bullet k}$$

Cloud fractions $\mathbf{N^k}$ are ajusted **variationally** to fit observations:

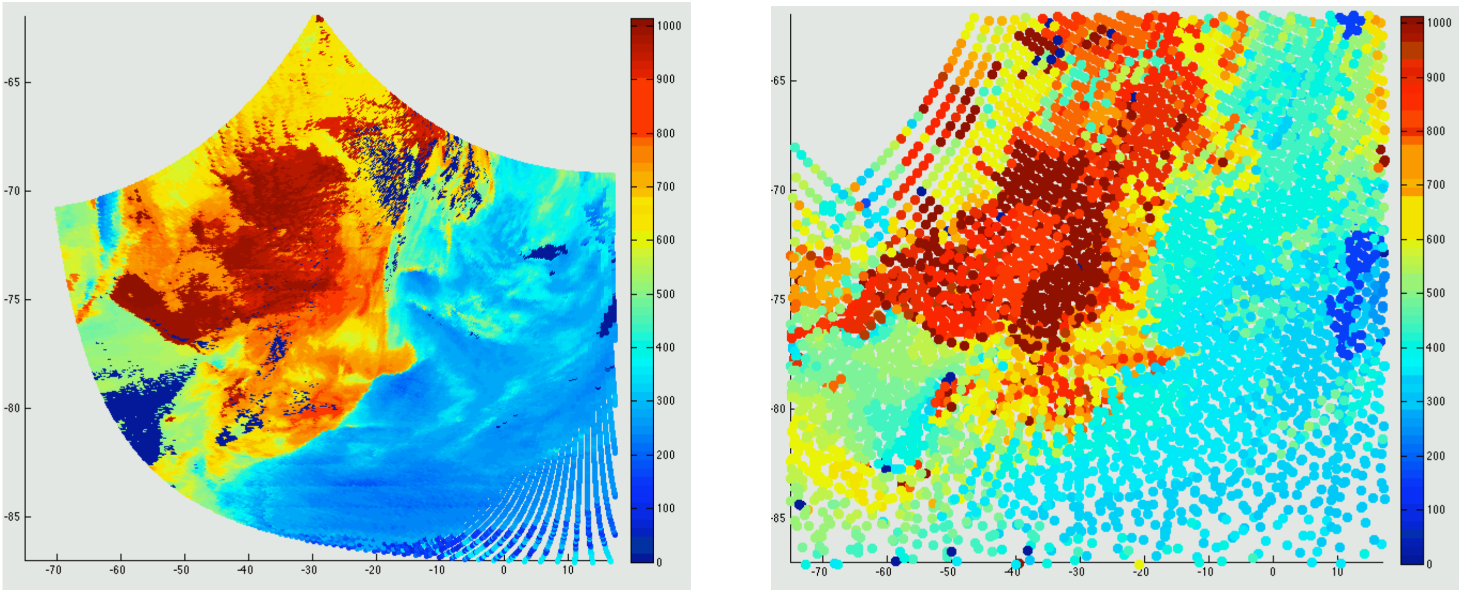
$$J(N) = \frac{1}{2}\sum_\nu \left(\frac{R_\nu^{Cld} - R_\nu^{Obs}}{R_\nu^\circ} \right)^2 \quad \text{with} \quad \begin{cases} 0 \le N^k \le 1 \\ N^\circ + \sum_{k=1}^{n} N^k = 1 \end{cases}$$



Channel Number (LW band)

Practical issues: AIRS Cloud Detection

Cloud Top Pressure (hPa)



MODIS Level 2 Product

AIRS MMR

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Conclusions

- **Satellite data are important**
  - Major source of information within observations for global NWP
  - Positive impact on Limited Area Models

- **Satellite DA is not trivial**
  - Very easy to degrade the analysis!
  - Each sensor requires a lot of attention (observation operator, bias correction, QC, observation error, cloud/rain detection, …)

- **It's only the beginning…**
  - New generation of satellite instruments
  - Future developments will increase satellite impact
    - Better representation of surface emissivity over land
    - Use of cloudy/rainy radiances
    - ……………………………………………………

Conclusions: Steps for Collaboration

- **Get familiar with WRF-Var code**
  - Run test cases
  - Run your Control expt, assimilating conventional data
- **Plan your satellite experiments**
  - Sensors of interest for your application
  - Ways to get data and corresponding format
  - Potential code developments
- **Contact NCAR/MMM developers**
  - Zhiquan Liu: liuz@ucar.edu
  - Tom Auligne: auligne@ucar.edu
  - Hans Huang: huangx@ucar.edu

Questions