Observing Capabilities Required for Geo-Sounders

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Advanced High Spectral Resolution Infrared Observations
University of Wisconsin - Madison
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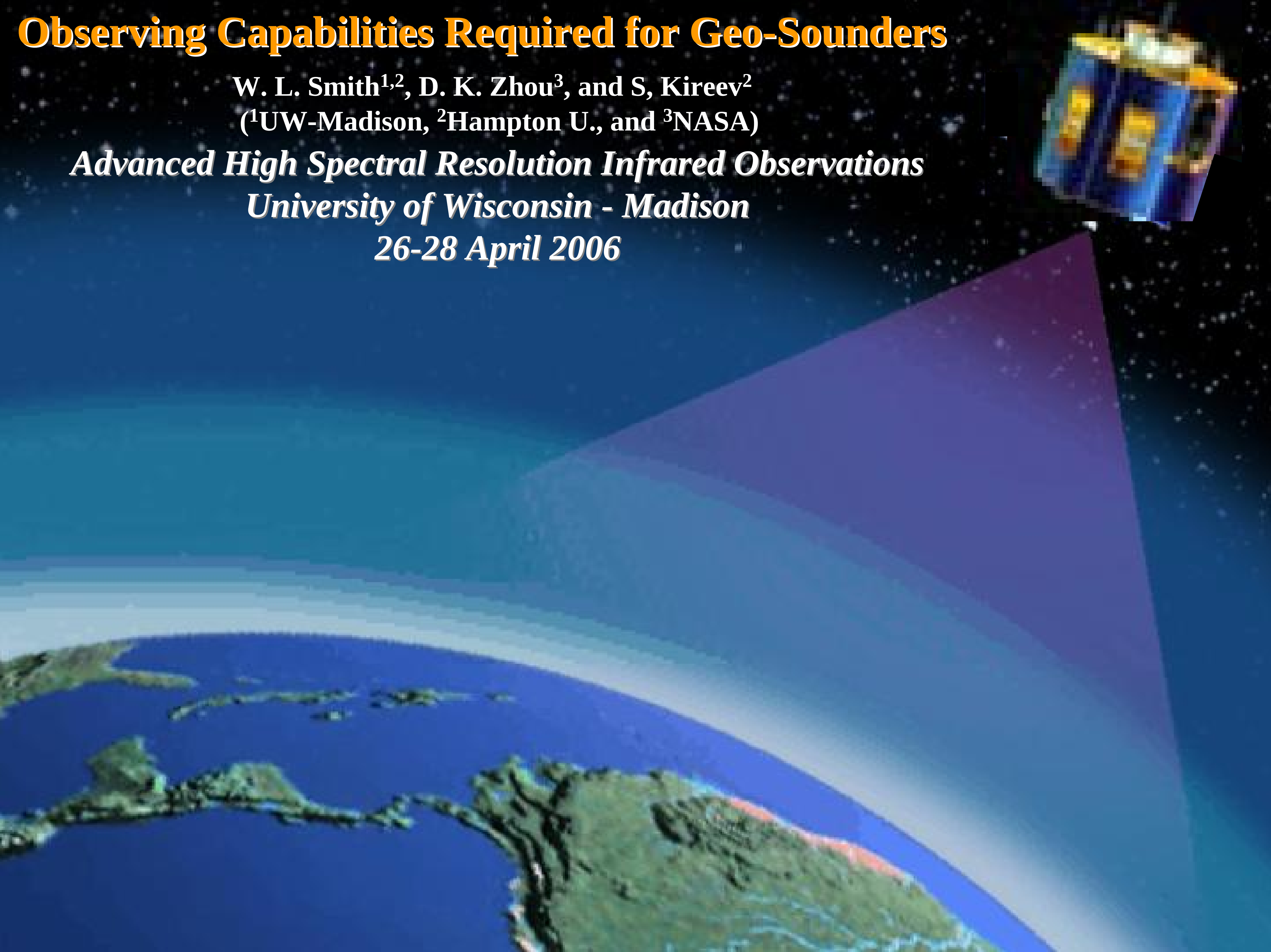


Weather Forecast Objectives of Geo-sounder

Continental Severe Convective Storms

- *Localize surface heating, moisture convergence, and thermodynamic stability change (boundary layer capping inversion, dry layer aloft, stable regions aloft)*
- *Jet stream position and upper level dynamic forcing*

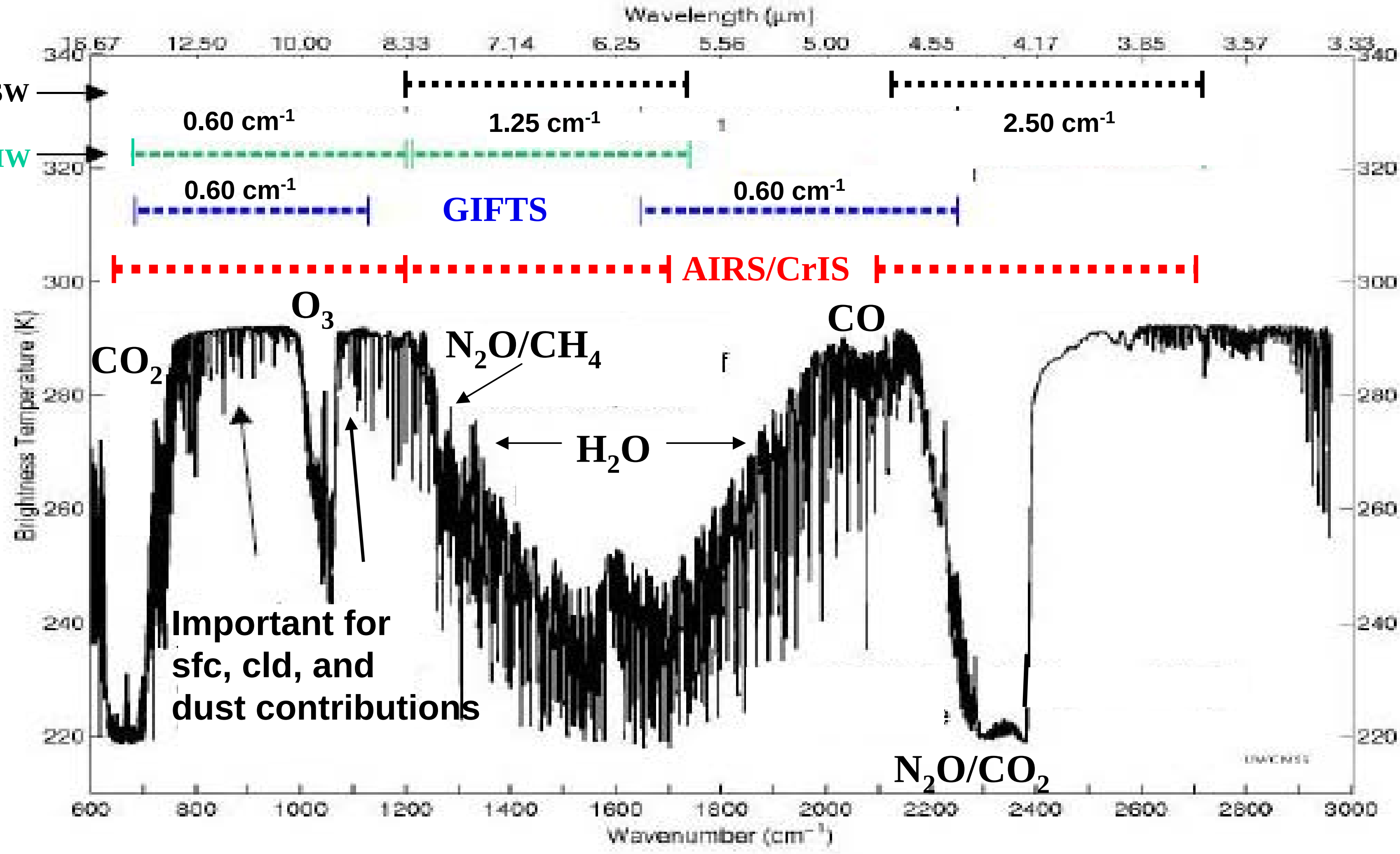
Tropical Storms and Hurricanes

- *Deep layer mean wind steering currents for forecasting storm trajectory and speed (i.e., landfall location and time).*
- *Vertically resolved moisture in-flow/out-flow controlling storm intensity and rainfall*
- *Ocean temperature ahead of storm (i.e., storm intensity change)*
- *Upper level vertical wind shear that leads to storm dissipation*
- *SST cooling produced by tropical storm winds*

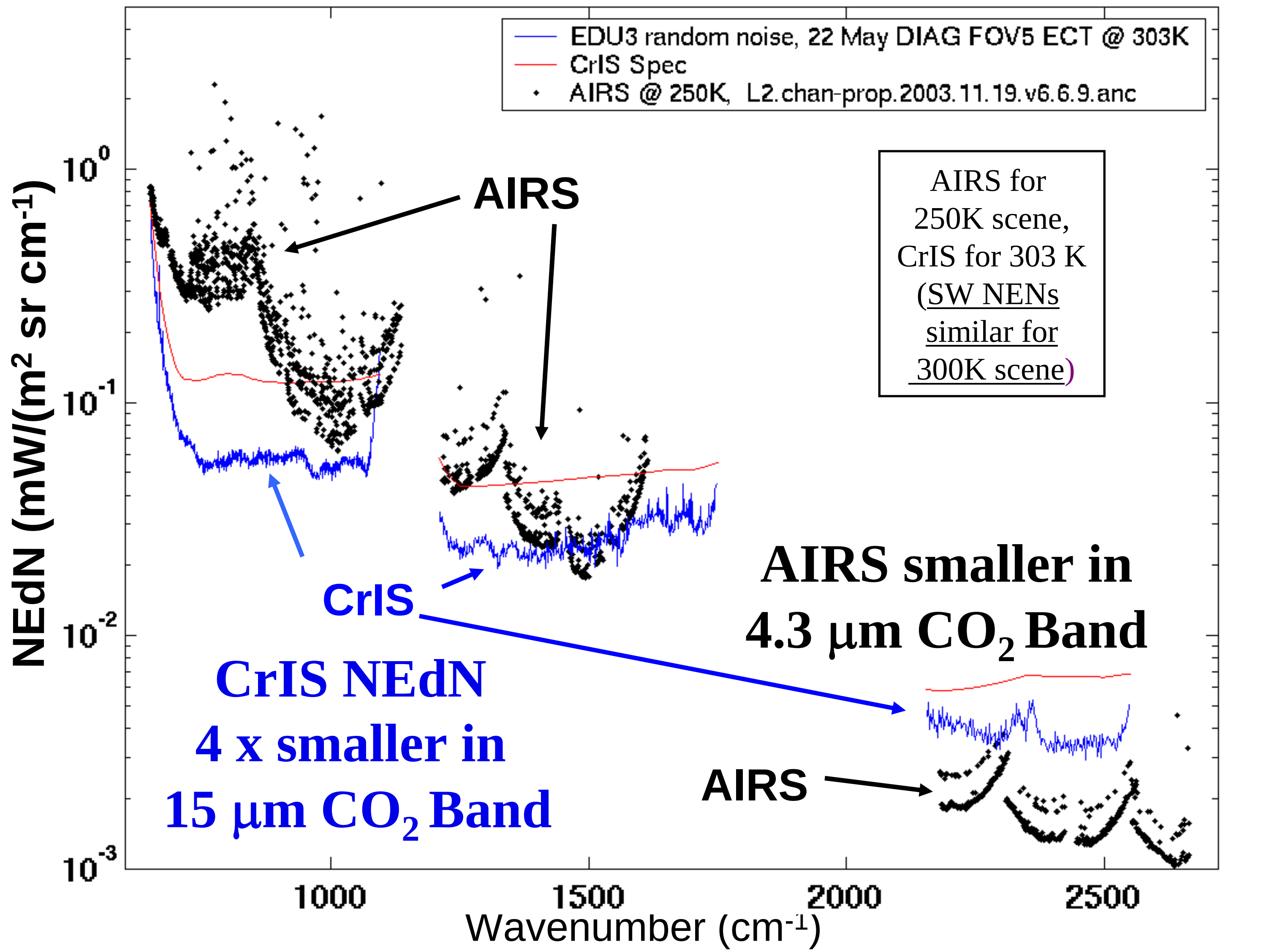
Global NWP

- *Vertically resolved winds (NWP wind field initialization)*
- *Vertically resolved large scale moisture flux (Hadley cell intensity)*
- *Sfc. T and T and Q profiles (temporal sampling enables cloudfree sampling)*

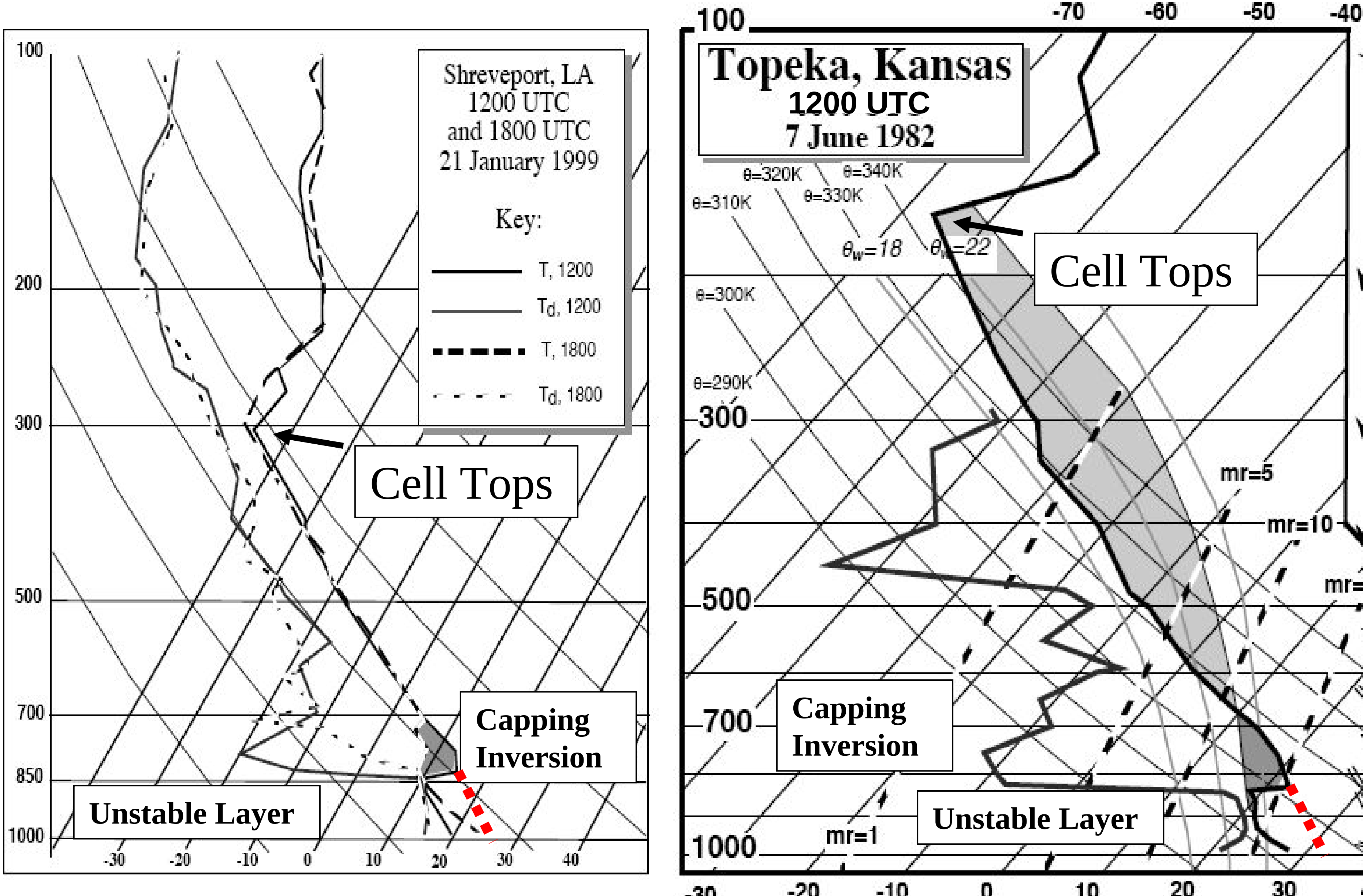
Different Sounding Band Options Being Considered for Geo-Sounder



Measurement Noise (AIRS Vs CrIS)



Typical Pre-convective Storm Soundings



Temperature at Storm Initiation Time

Radiative Transfer Equation and Its Inverse Solution

$$R_\nu \cong \varepsilon_\nu B_\nu(T_s)\tau_{s,\nu} + \int_{p_s}^{0} B_\nu[T(p)]\frac{\partial \tau_\nu(p,\theta_u)}{\partial p}dp$$

$$+(1-\varepsilon_\nu)\tau_{s,\nu}\int_{0}^{p_s} B_\nu[T(p)]\frac{\partial \tau_\nu^*(p,\theta_d)}{\partial p}dp + \rho_\nu \tau_{s,\nu}\tau_\nu(p_s,\theta_{sun})S_{0,\nu}\cos\theta_{sun}$$

The first term is the surface emission, the second term is the upwelling thermal emission, the third term is the reflected downwelling radiation, and the fourth term is the reflected solar radiation

The inverse solution is the method of optimal estimation (C.D. Rodgers)

$$\boldsymbol{x}_\mathbf{R} = \boldsymbol{x}_\mathbf{A} + [\mathbf{K}^\mathbf{T}\mathbf{S}_\varepsilon^{-1}\mathbf{K} + \mathbf{S}_\mathbf{A}^{-1}]^{-1}\,\mathbf{K}^\mathbf{T}\mathbf{S}_\varepsilon^{-1}(\boldsymbol{y} - \mathbf{K}\boldsymbol{x}_\mathbf{A})$$

where x_R is the retrieved vector for unknown atmospheric variables, x_A is the a priori vector of the atmospheric state, y is the vector of measurements, $K \equiv dy/dx$ is the Jacobian, S_ε is the measurement error covariance, and S_A is the a priori covariance matrix. The solution iterated until convergence is achieved.

Simulation Study Characteristics

- **True Atmosphere:** Pre-convective Storm Sounding data; Shreveport LA

- **A priori Atmosphere:** Vertically smoothed version of the true atmosphere with a bias temperature and humidity error of 2 K and 20 %, respectively. The surface temperature guess error was assumed to be 1 K with a “known” emissivity (I.e., surface emissivity retrieval problem ignored).

- **Radiative Transfer Model (LBLRTM):** All major gases, solar radiation, etc. AIRS ILS and channel characteristics assumed.

- **Inverse Solution :** Optimal Non-linear Inverse Method (minimum information form)

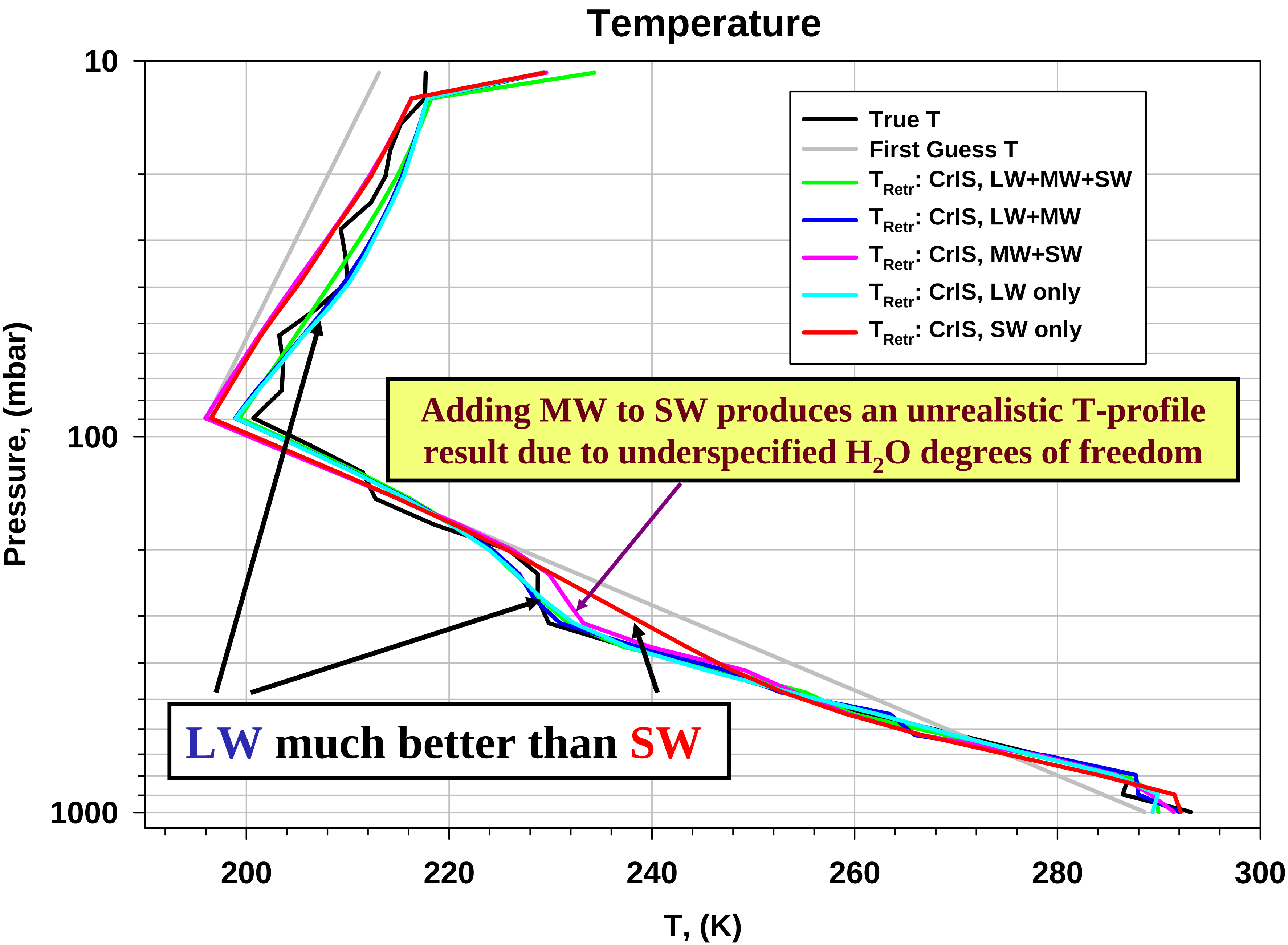
- **Noise model** (1σ mw/m^2 sr^{-1} cm^{-1}):

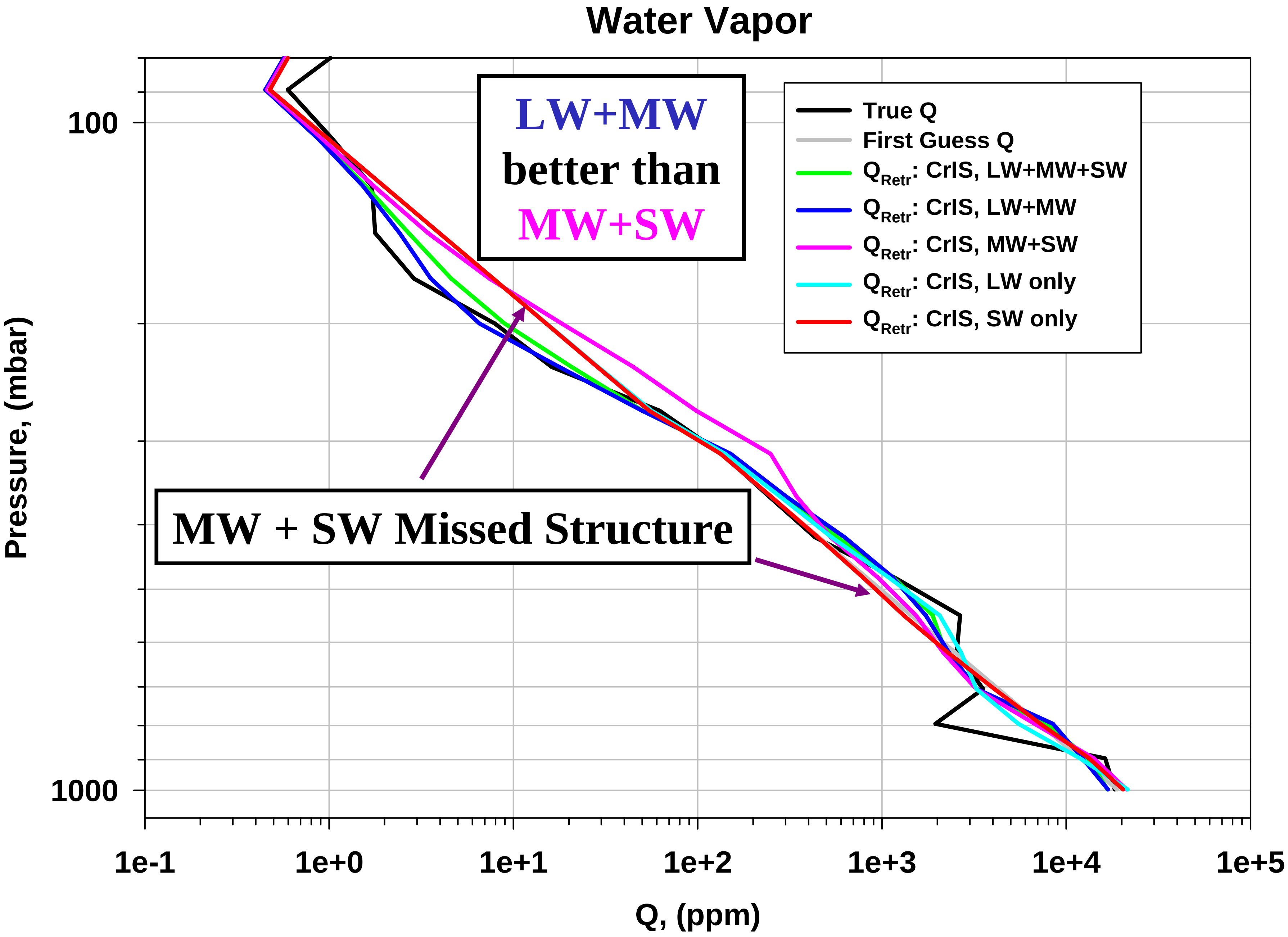
	AIRS-like	**CrIS-like**
$690 < \nu < 800$	0.4	0.1
$800 < \nu < 1200$	0.2	0.06
$1200 < \nu < 1400$	0.07	0.07
$1400 < \nu < 1700$	0.04	0.04
$1700 < \nu < 2500$	0.003	0.005

- **Noise added to simulated radiances:** 1σ random, according to instrument type

- **Assumed measurement noise covariance matrix:** Diagonal with 2σ

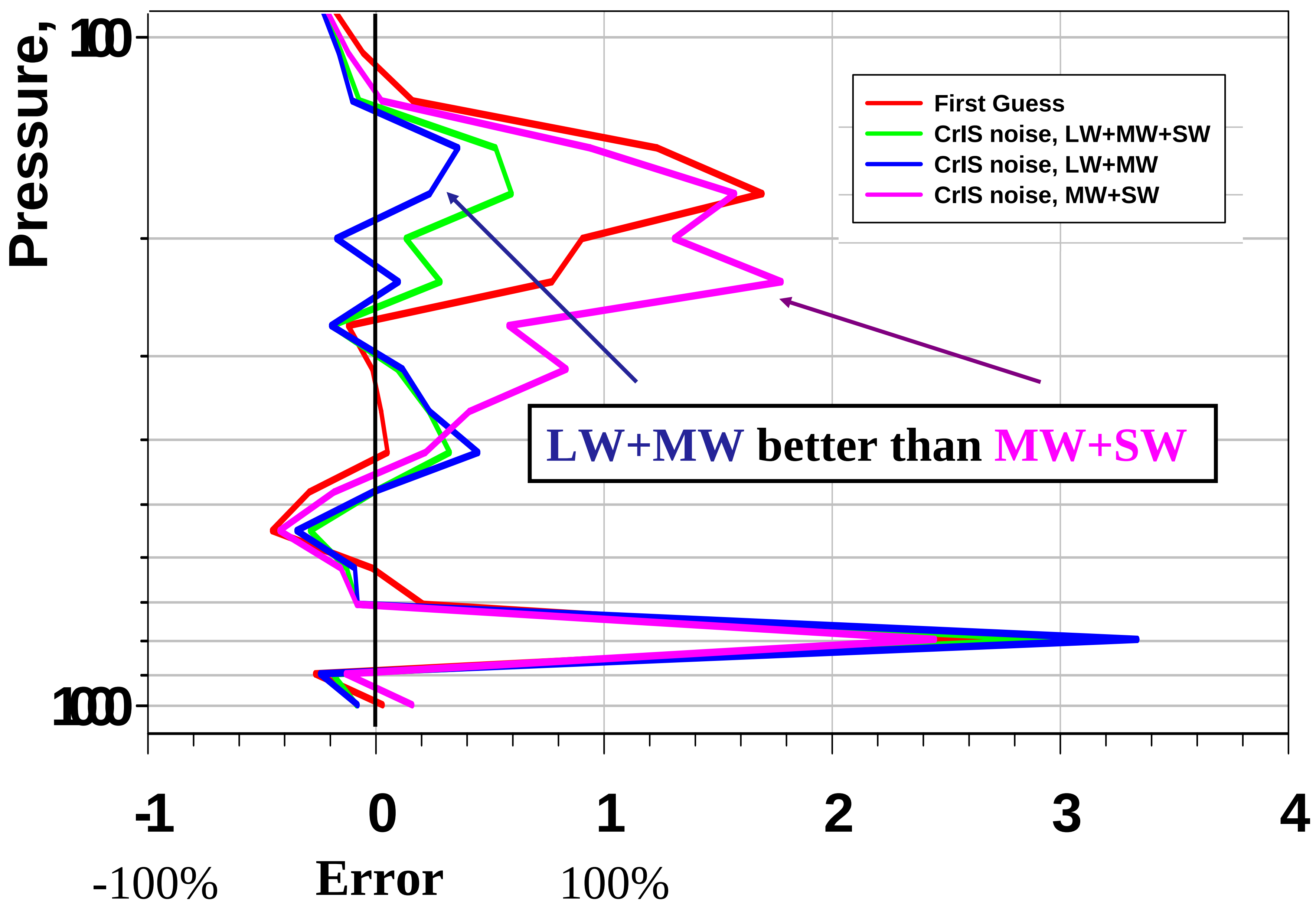
- **Assumed profile co-variance matrix:** Diagonal with σ (T) ranging from 3 to 1.5 K and σ (Q) ranging from 20 to 50%, from surface to 100 mb level and constant above.


Temperature
10
100
1000
Pressure, (mbar)
200
220
240
260
280
300
T, (K)
True T
First Guess T
T_{Retr}: CrIS, LW+MW+SW
T_{Retr}: CrIS, LW+MW
T_{Retr}: CrIS, MW+SW
T_{Retr}: CrIS, LW only
T_{Retr}: CrIS, SW only
Adding MW to SW produces an unrealistic T-profile result due to underspecified H_2O degrees of freedom
LW much better than SW

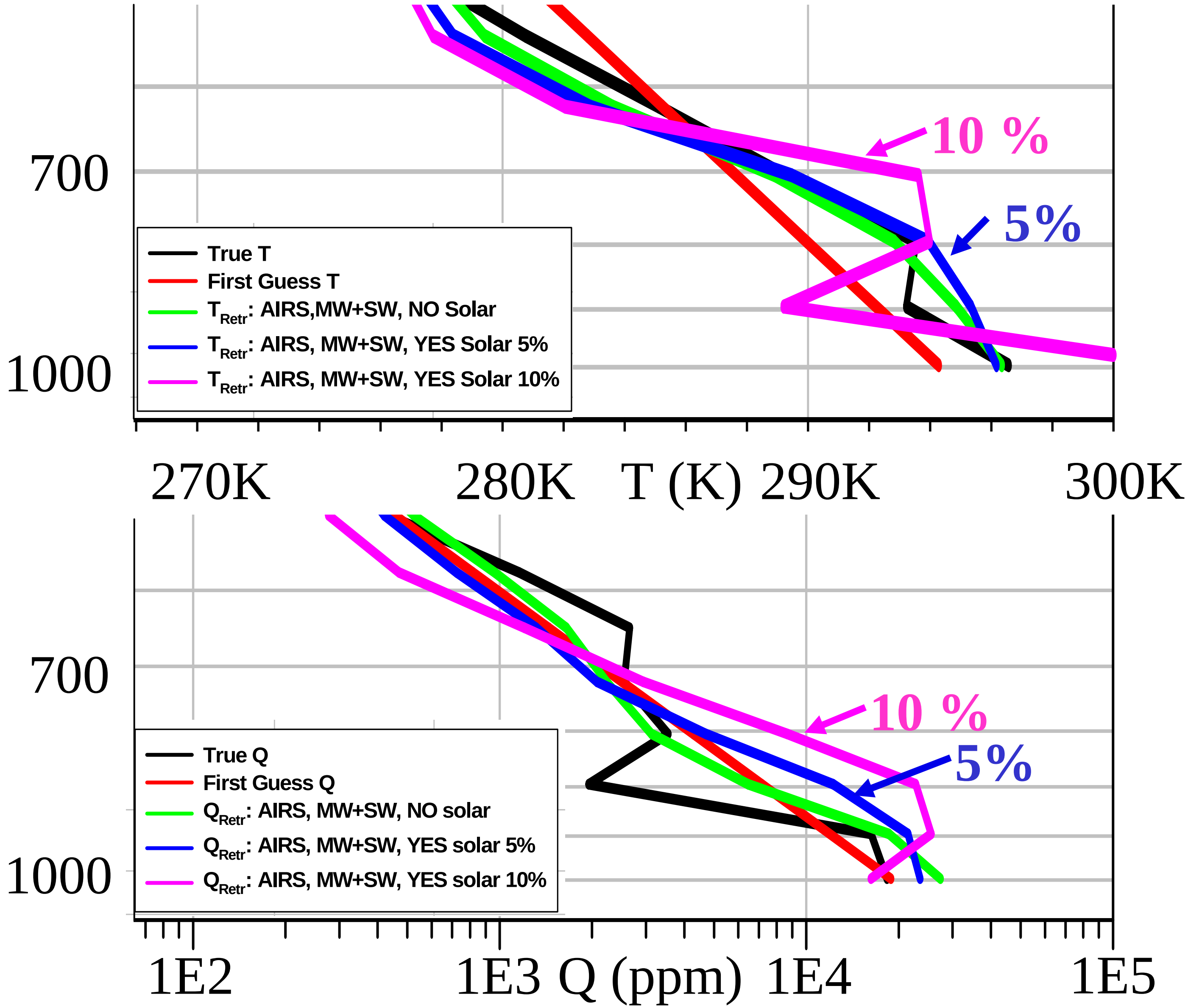


Water Vapor
LW+MW
better than
MW+SW
True Q
First Guess Q
Q_{Retr}: CrIS, LW+MW+SW
Q_{Retr}: CrIS, LW+MW
Q_{Retr}: CrIS, MW+SW
Q_{Retr}: CrIS, LW only
Q_{Retr}: CrIS, SW only
MW + SW Missed Structure
100
1000
Pressure, (mbar)
1e-1
1e+0
1e+1
1e+2
1e+3
1e+4
1e+5
Q, (ppm)

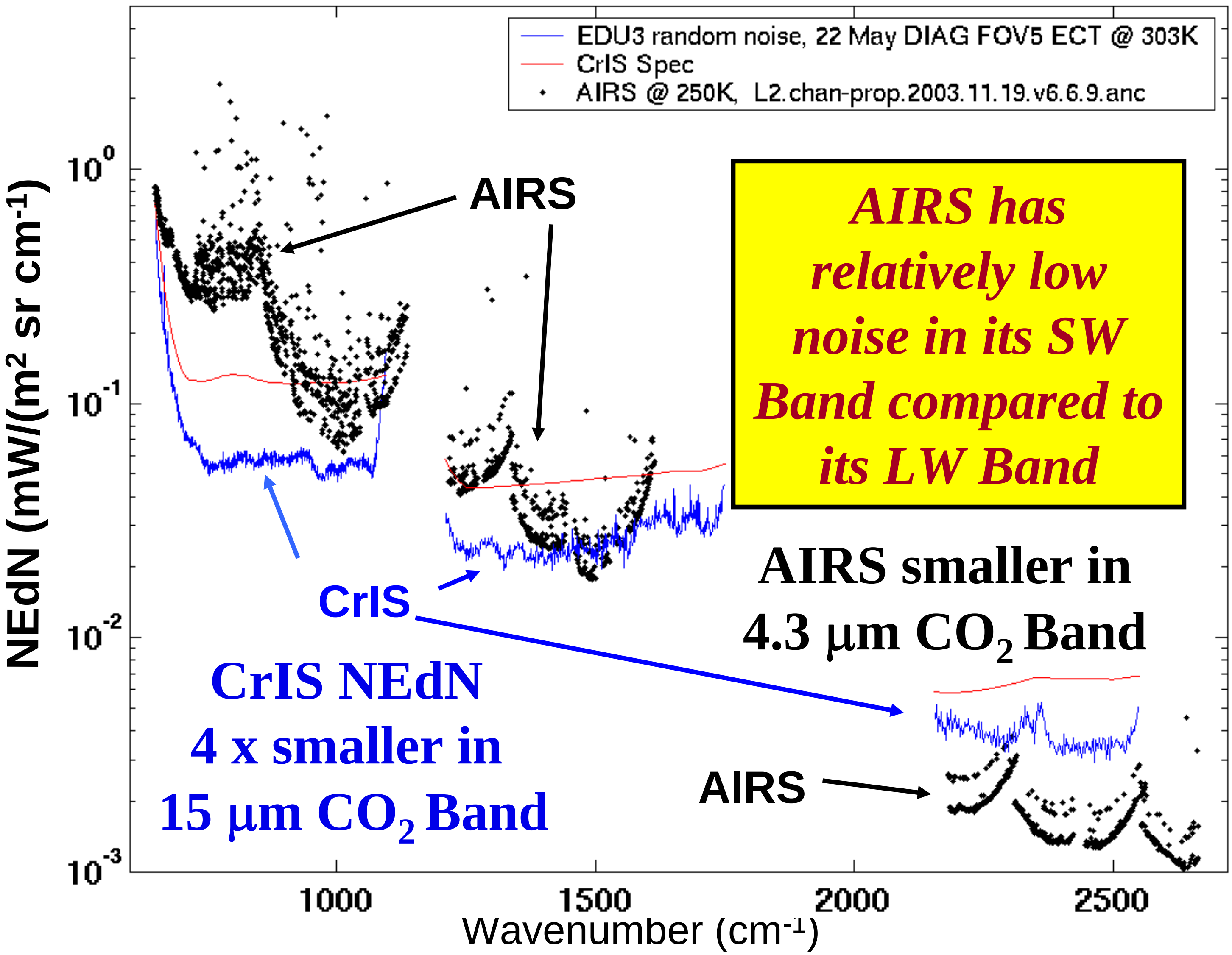
H2O Relative Error $(Q_{Retr} - Q_{True}) / Q_{True}$



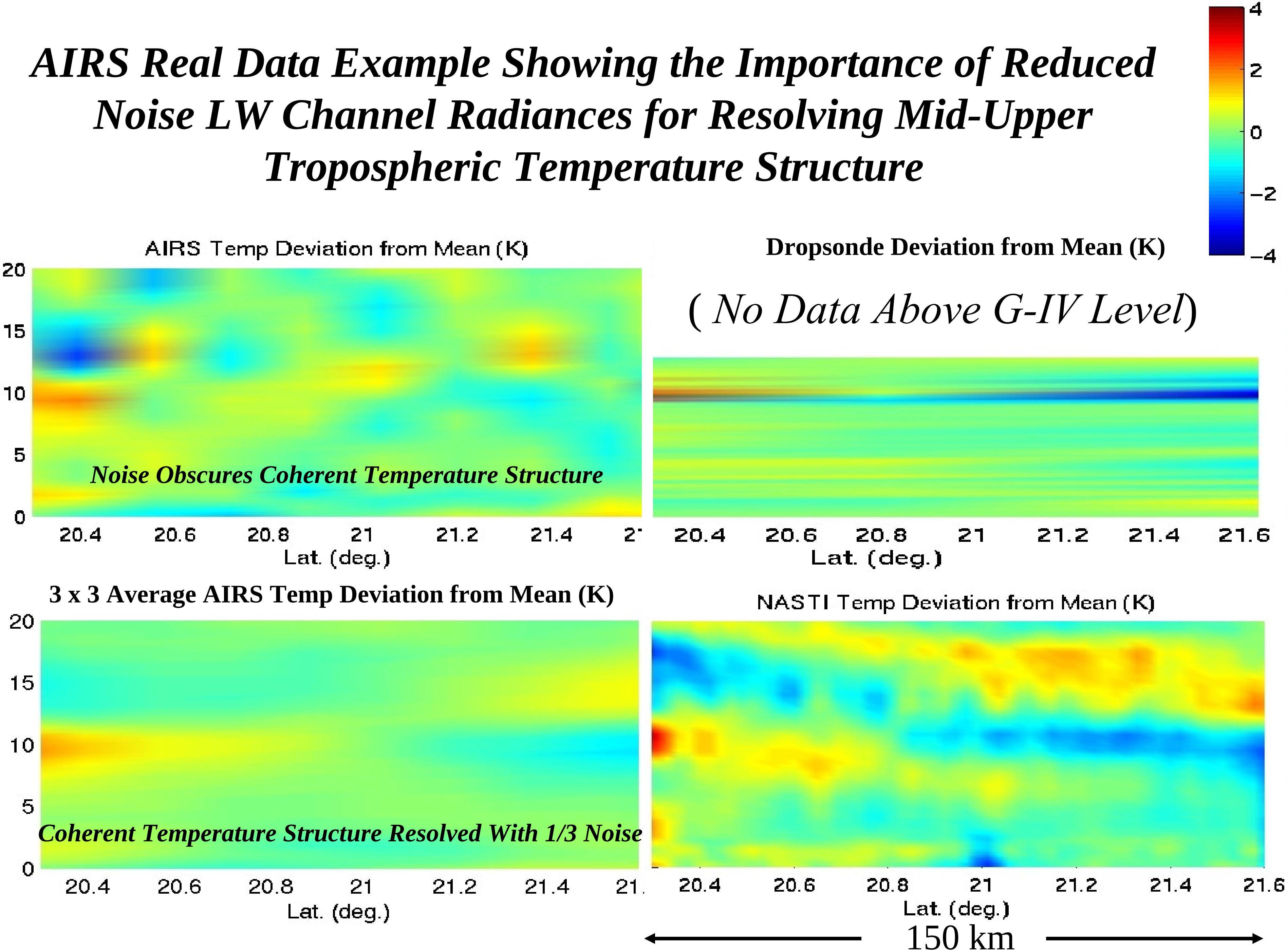
Influence of Surface Reflected Sunlight



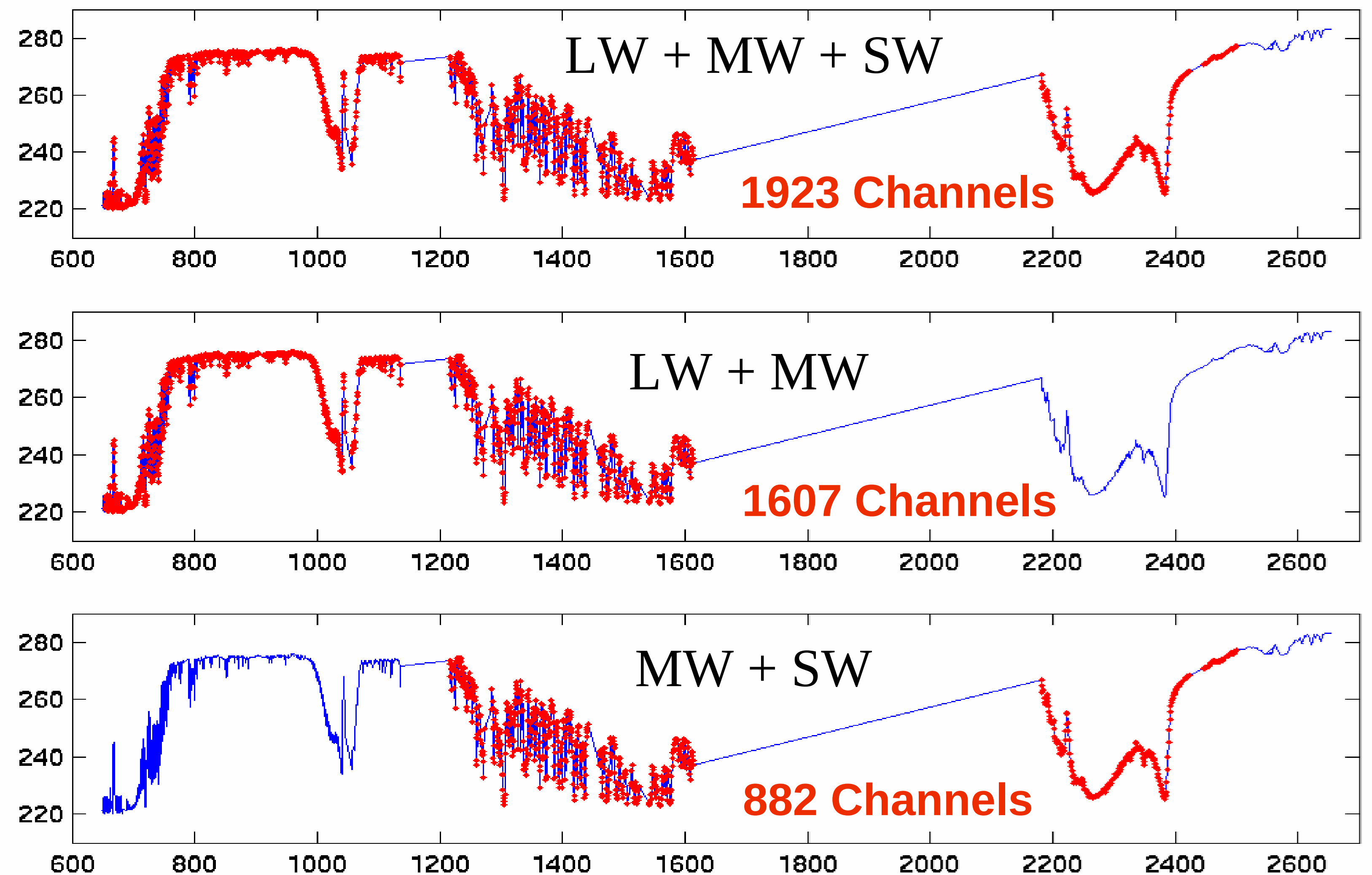
AIRS Vs CrIS Measurement Noise



AIRS Real Data Example Showing the Importance of Reduced Noise LW Channel Radiances for Resolving Mid-Upper Tropospheric Temperature Structure



LW + MW Vs MW + SW
A Case Study Using AIRS EAQUATE Data



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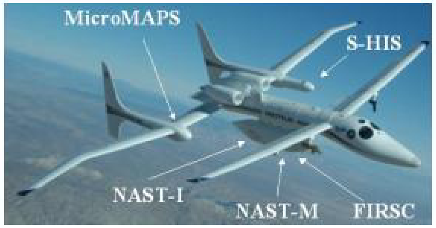
EAQUATE (European AQUA Thermodynamic Experiment)-

A project to validate radiance and geophysical products obtained by the Atmospheric Infrared Sounder (AIRS) aboard the Aqua satellite

<u>Italian Campaign (Naples It., Aug. 30 – Sept. 9, 04)</u>:

- US *<u>Proteus</u>* Aircraft

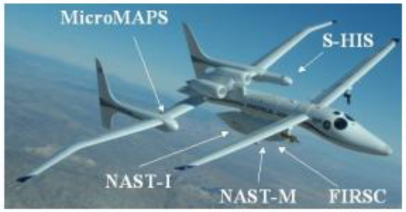


NAST-I: 3.6-16 μm, 0.25 cm^{-1}
NAST-M: 50-425 GHz (29*f*'s)
S-HIS: 3.0-17 μm, 0.50 cm^{-1}
FIRSC: 75-1000 μm, 0.1cm^{-1}
μMAPS: 4.5-4.9 μm, (3 *f*'s)

- IMAA/U of B-DIFA/U of Naples Ground-based Component
  - *Aerosol, Raman, DIAL LIDAR*: Potenza (3) & Naples (1)
  - *Radiosondes*: Potenza, Mobile unit, Standard Network
  - Mobile Upward-looking AERI: 3.0-20 μm, 1.0 cm^{-1}
  - Microwave Radiometer: 22, 31, 50-60GHz (5 *f*'s)

<u>United Kingdom (Cranfield UK, 12-24 Sept. 2004)</u>:

- US *<u>Proteus</u>* Aircraft



NAST-I: 3.6-16 μm, 0.25 cm^{-1}
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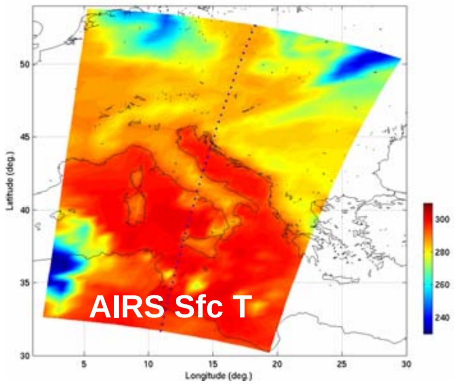
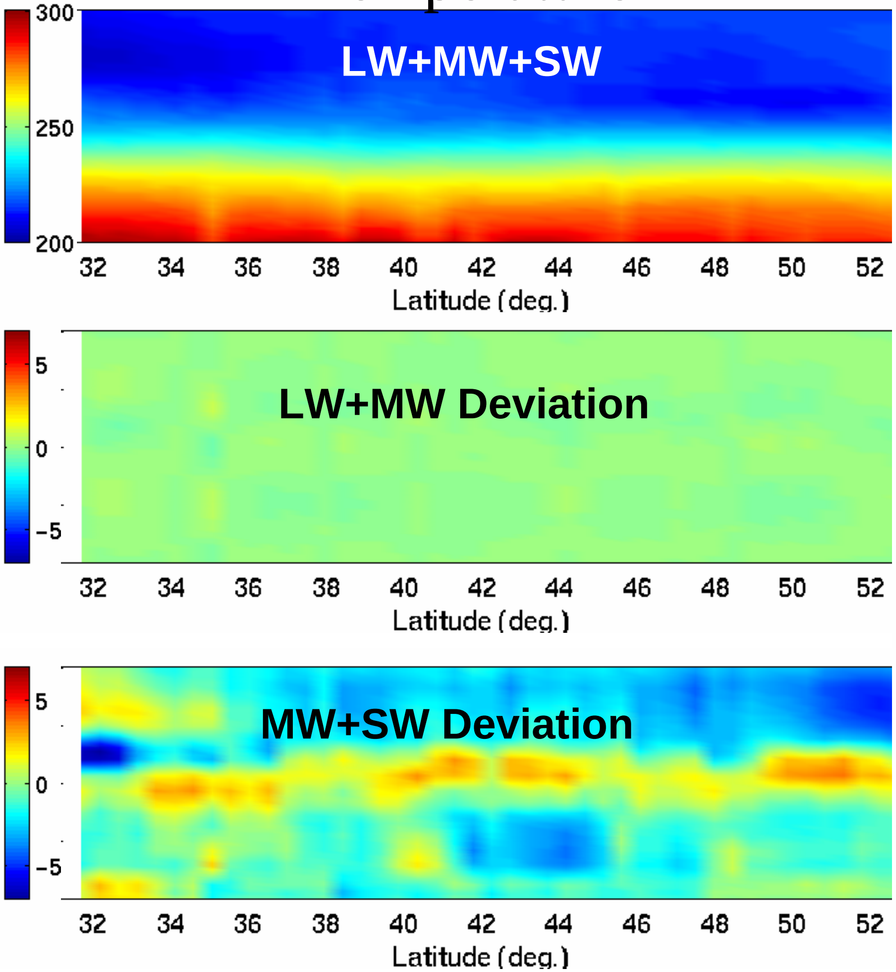
- UK *<u>BAe 146-130</u>* Aircraft

ARIES: 3.3-16 μm, 0.50 cm^{-1}
DIEMOS: 23 & 50 GHz (4*f*'s)
TAFTS: 12.5-125 μm, 0.1 cm^{-1}
MARSS: 89-189 GHz (5*f*'s)
Other: Dropsondes, Outside T, q, V, Chemistry, Radiative Fluxes

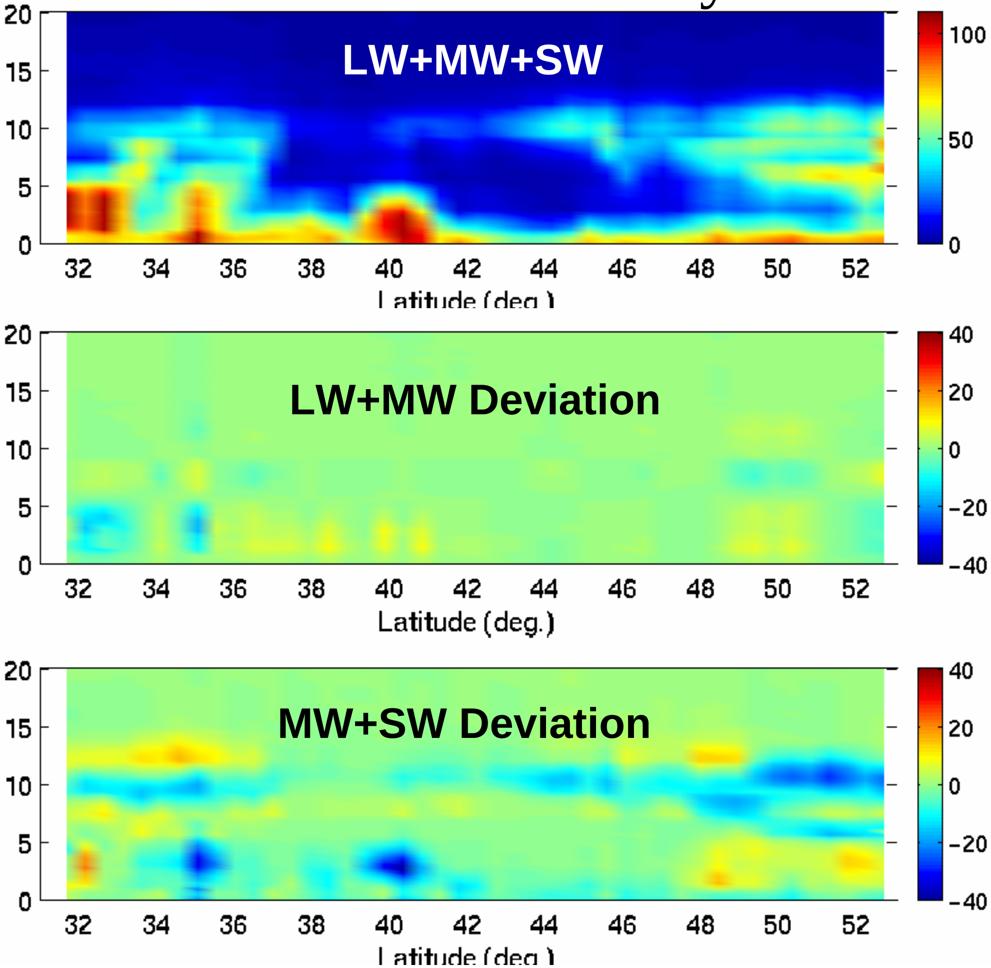


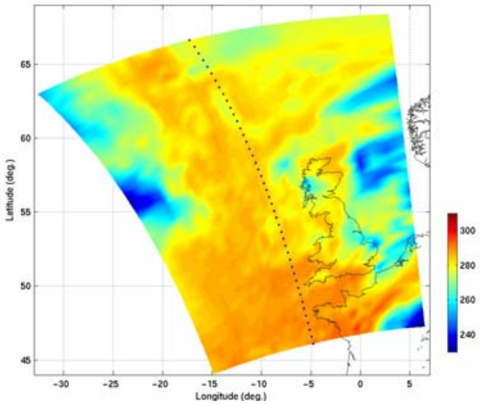
Comparison of Temperature and Humidity Cross-sections for the Mediterranean @ Night (9/8/04)

Temperature



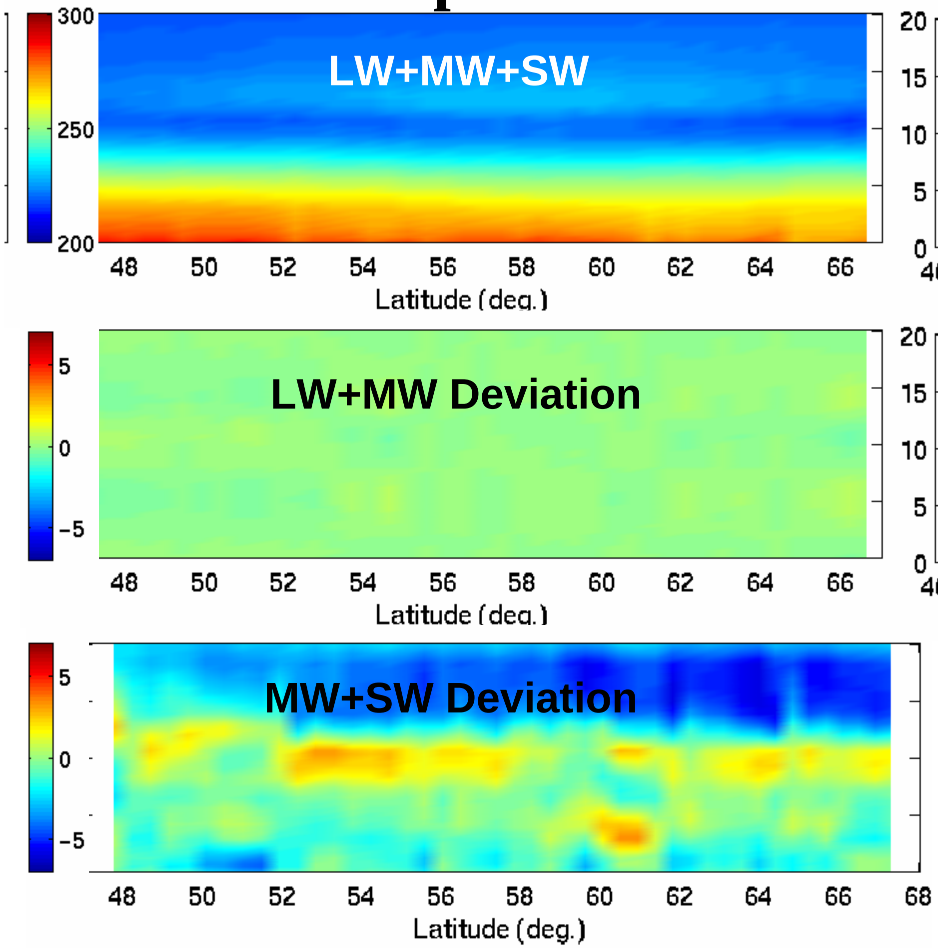
Relative Humidity



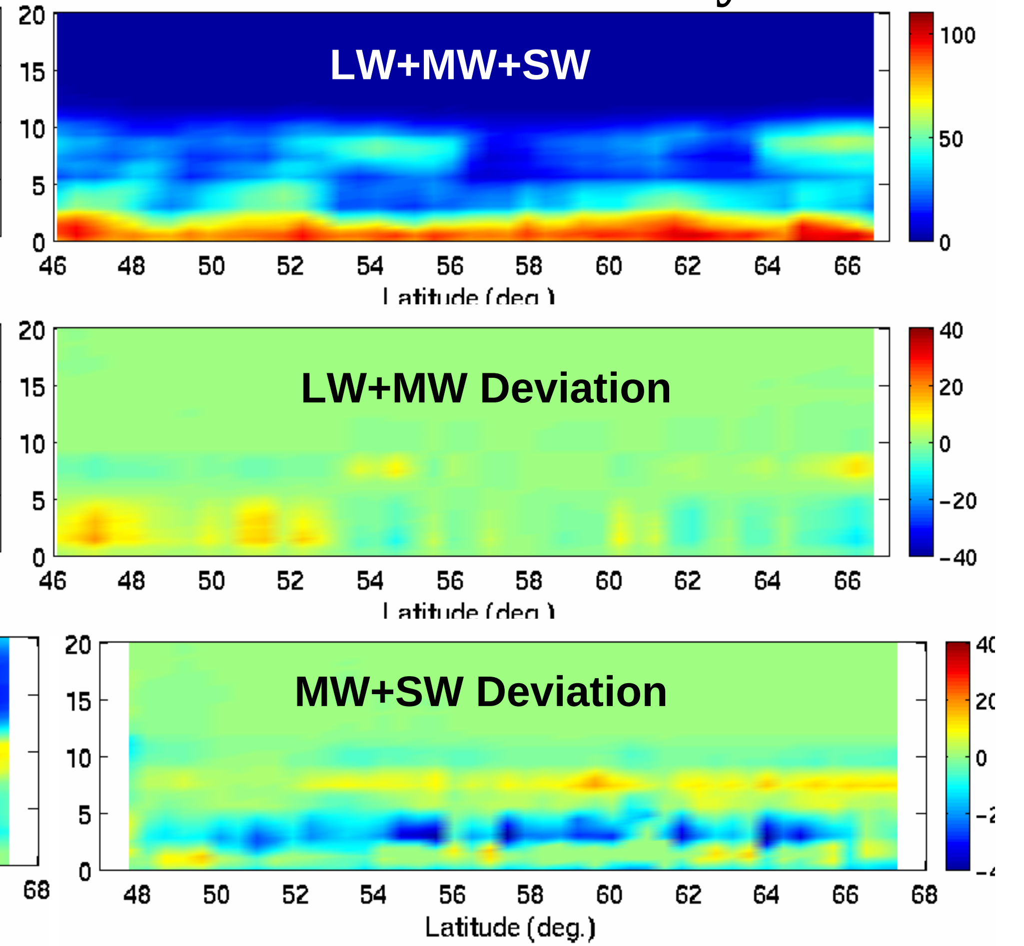


Comparison of Temperature and Humidity Cross-sections for the Northeast Atlantic (off UK coast) Ocean Day (9/14/04)

Temperature

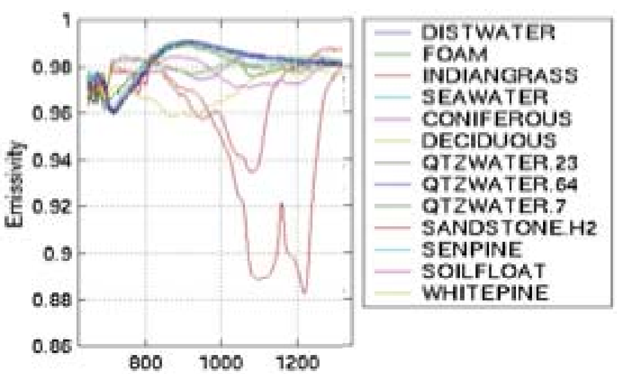


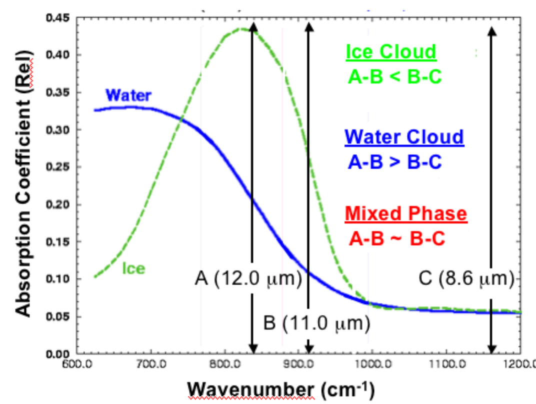
Relative Humidity

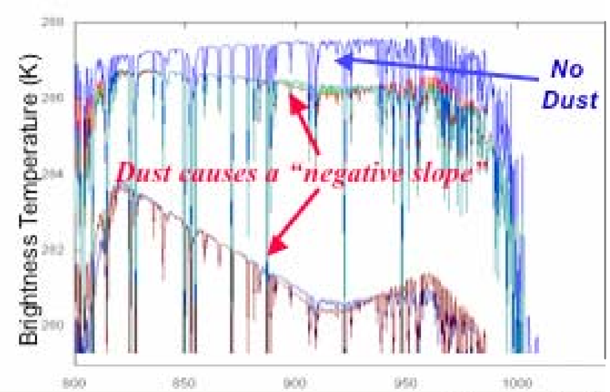


Other Considerations

<u>Surface, Cloud, and Dust Radiative Properties</u>: T*he LW window (10 - 12μm) region needed to accurately account for the spectral radiance dependence of surface emission/reflection and cloud and dust aerosol absorption/reflection/emission on the temperature and moisture retrieval. Only in this broad window band do unique spectral signatures of these radiative properties exist to isolate the contributions of these variables in the sounding retrieval process.*



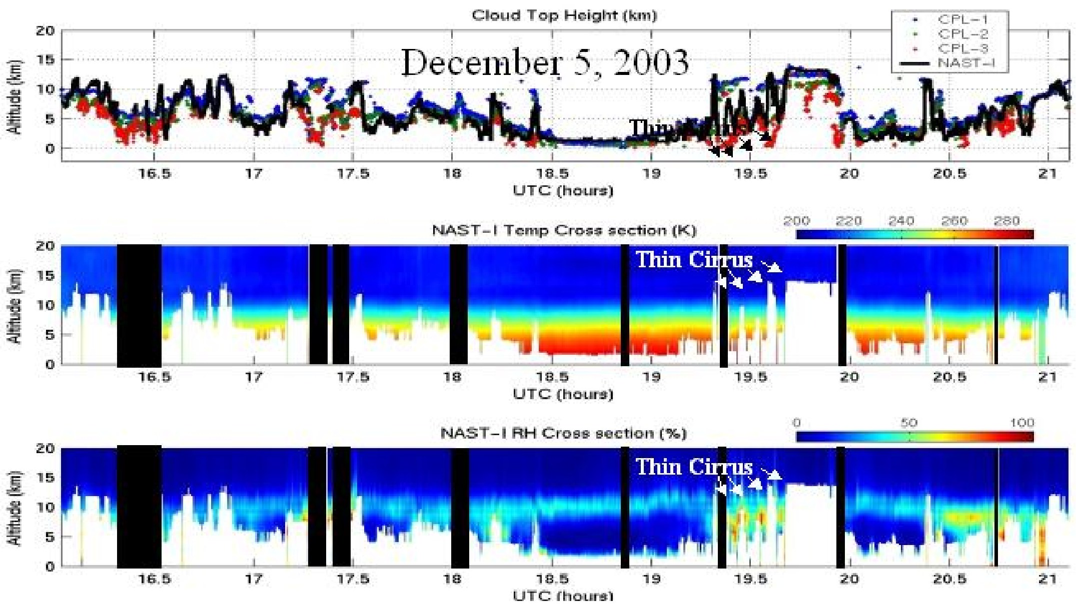


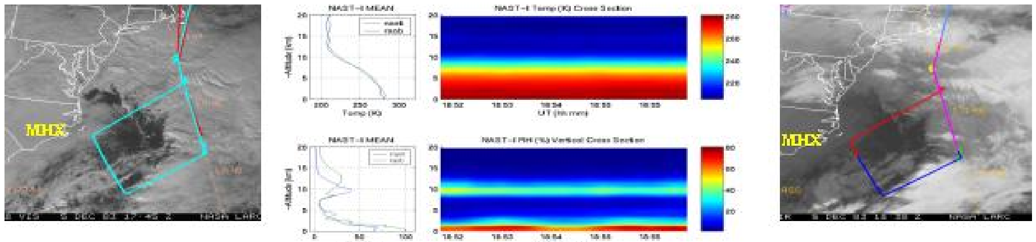


The LW window region is needed to achieve accurate soundings over land, and under cloudy and dust contaminated atmospheric conditions.

Other Considerations

<u>Thunderstorm Cloudiness</u>: The severe thunderstorm forecast application *requires sounding in a convectively cloudy areas, both day and night. In an area of active thunderstorms, cirrus blow-off will extend over much of the region to be sounded. Thus, the contribution by clouds, and the ability to sound through optically thin cirrus cloud, are required for the effective use of the Geo-sounder data for predicting the geographical location of thunderstorm development with useful accuracy.*





The LW band, which is not influenced by cloud reflected sunlight, enables accurate retrievals down to cloud top and below broken and/or optically thin cloud for diagnosing clear air convective instability

Other Considerations

Wind Profiles: Wind profiles are to be specified from Geo-sounding information (either through sounding retrieval or radiance data assimilation) from the motions of vertically resolved water vapor features.

- **Numerical Weather Prediction:** ***Middle and upper tropospheric winds provide the location and intensity of the Jet Stream which controls the dynamics of global and regional weather. Thus, vertically resolved water vapor motion obtained over large spatial scales will improve NWP.***

- **Tropical storm and Hurricane prediction:** ***the mid-upper tropospheric winds in the storm environment control the movement of these storms. Storm trajectory will be influenced by other weather systems (e.g., a frontal system) which interacts with the storm. Thus, wind profile information, over large spatial scales, is needed to accurately forecast hurricane trajectory, intensity, and landfall location and time, for extended ranges (i.e., 1-5 days).***

Upper tropospheric temperature sounding information is needed to specify upper tropospheric water vapor. Since the LW band radiance is more sensitive, than SW band radiance, to upper tropospheric temperature, <u>the LW band is important for obtaining wind profile information for the intended forecast applications</u>

Summary

- **Relatively low noise (~0.1 K) longwave band CO_2 radiance measurements (i.e.., CrIS-like) are needed to resolve important vertical structure features of pre-convective storm soundings. (Simulations which include mid-wave H_2O radiance measurements provide a misleading temperature profile result for the case where LW radiance measurements are not included in the retrieval)**
- **The radiance spectrum across the longwave window region (8 - 12 μm) is needed to account for surface emissivity, cloud radiative properties, and dust absorption in the sounding retrieval process.**
- **A small degree of surface reflected sunlight (i.e., 5-10%) causes severe lower tropospheric sounding retrieval errors for the case where the LW CO_2 band measurements are not included in the retrieval.**
- **The middle to upper tropospheric water vapor motion wind accuracy depends on the temperature profile accuracy in this region of the atmosphere.**

Important Geo-Sounder Design Consideration: ***Relatively low noise LW band radiometric measurements are needed to observe important mid-upper tropospheric T and H_2O features in pre-convection atmospheric soundings and for producing tropospheric wind profiles.***

The necessary S/N level can be achieved by increasing the dwell time of the radiance measurements for the location of interest.

Back-up

Other Considerations

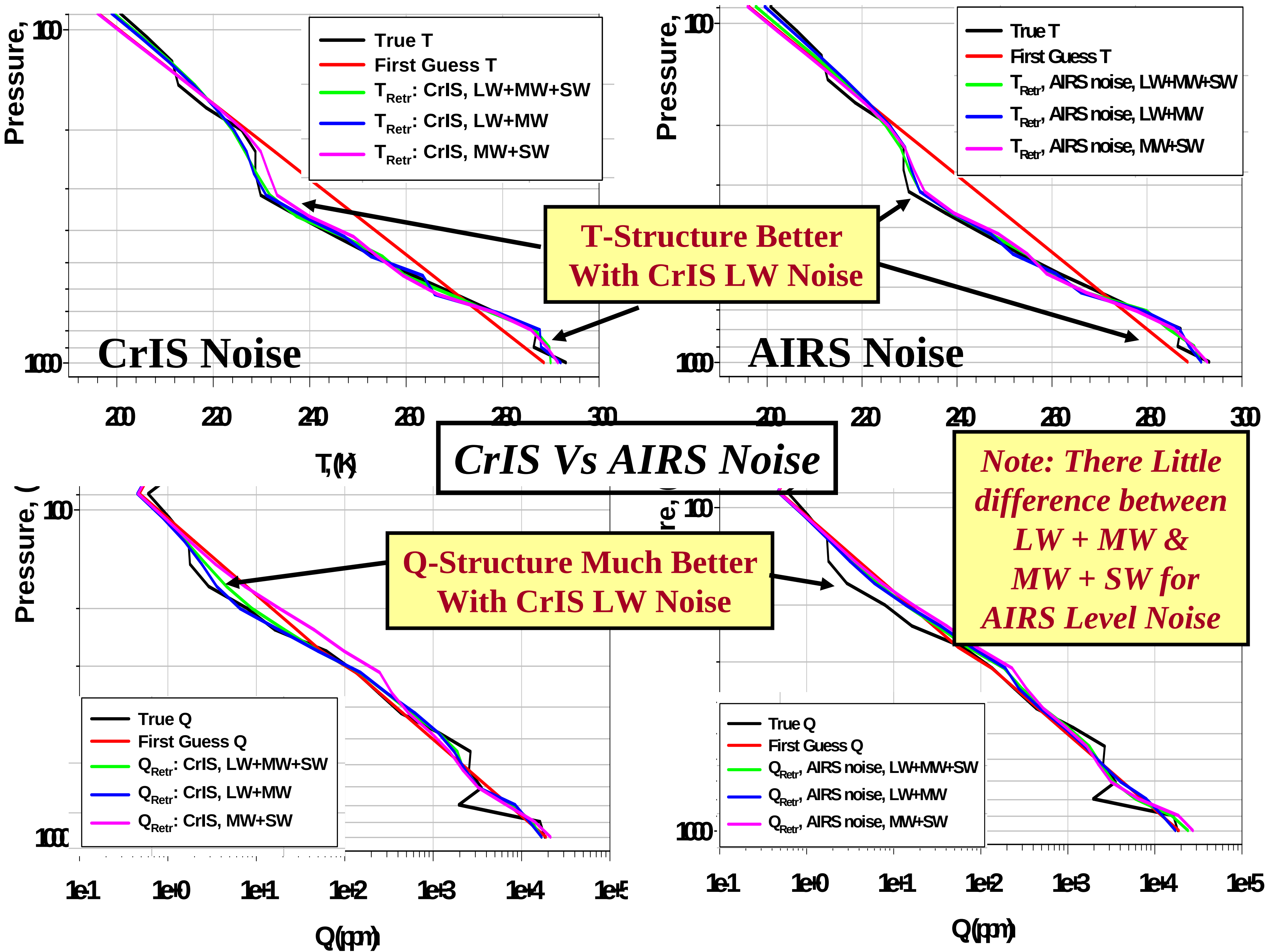
Imager Synergism: ***It is important to make use of the High Spatial Resolution Imager data simultaneously with Geo-sounder data to detect and account for cloud and surface contributions to the sounding radiance measurements, as well as quality control the derived sounding products.***

The Geo-sounder and Imager spectral measurement coverage should overlap across the longwave window band, which used to specify the cloud and surface spectral radiative properties.

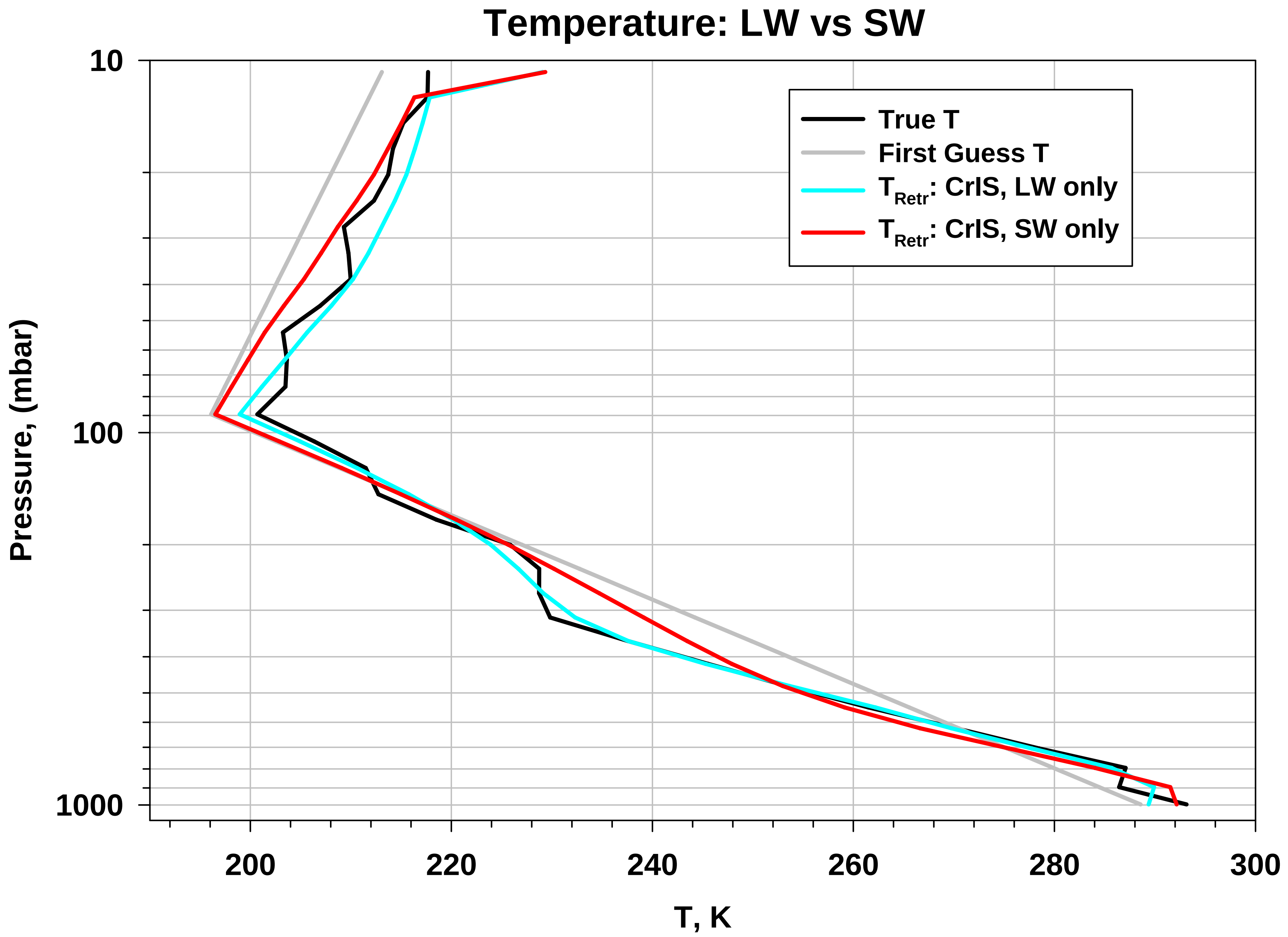
Information content of measurements: For 63 unknowns:

	AIRS-like	**CrIS-like**
LW+MW+SW	**15.0**	**17.2**
LW+MW	**14.3**	**17.1**
MW+SW	**13.6**	**13.4**

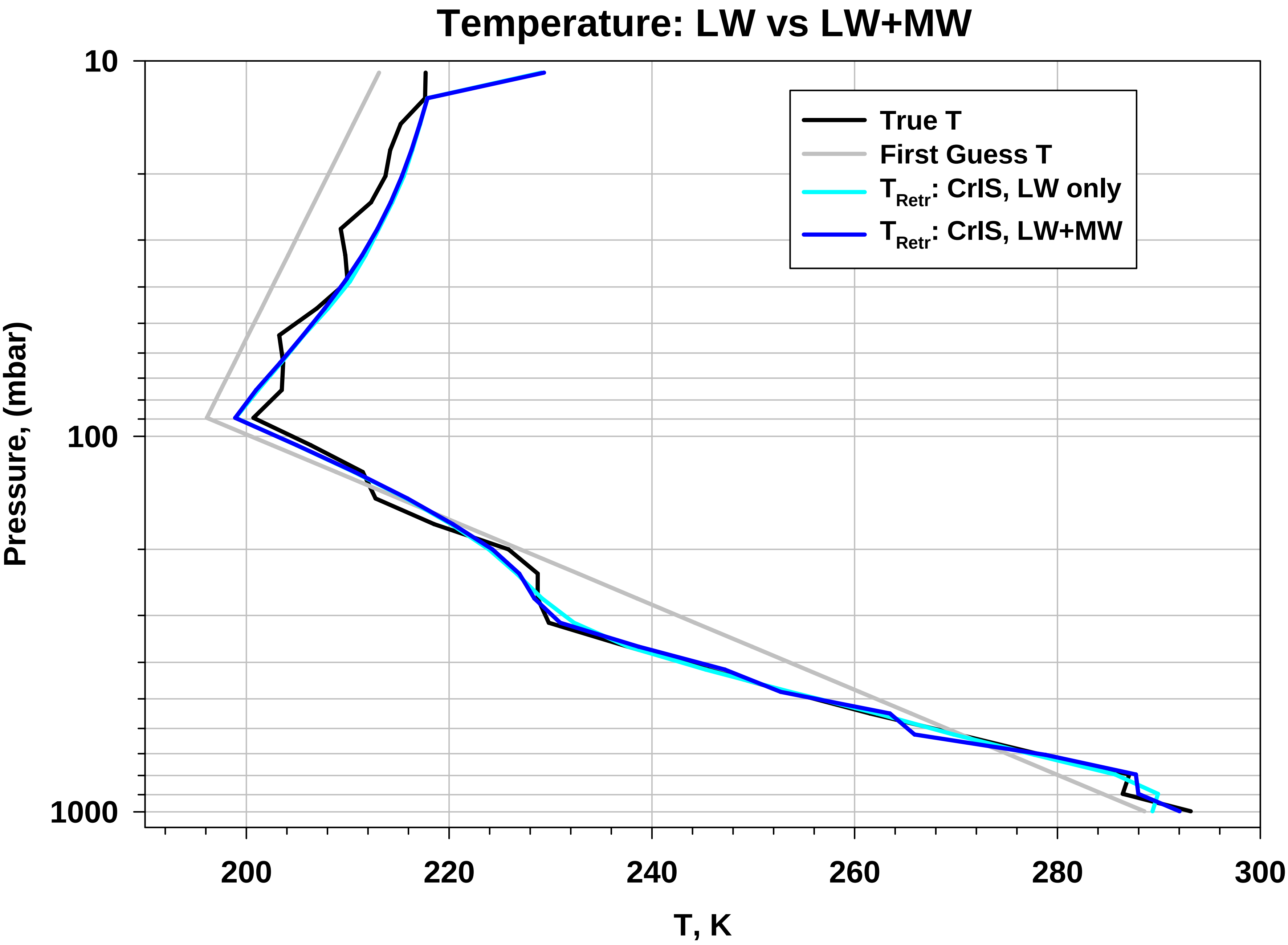
Information content dependent upon LW band noise level

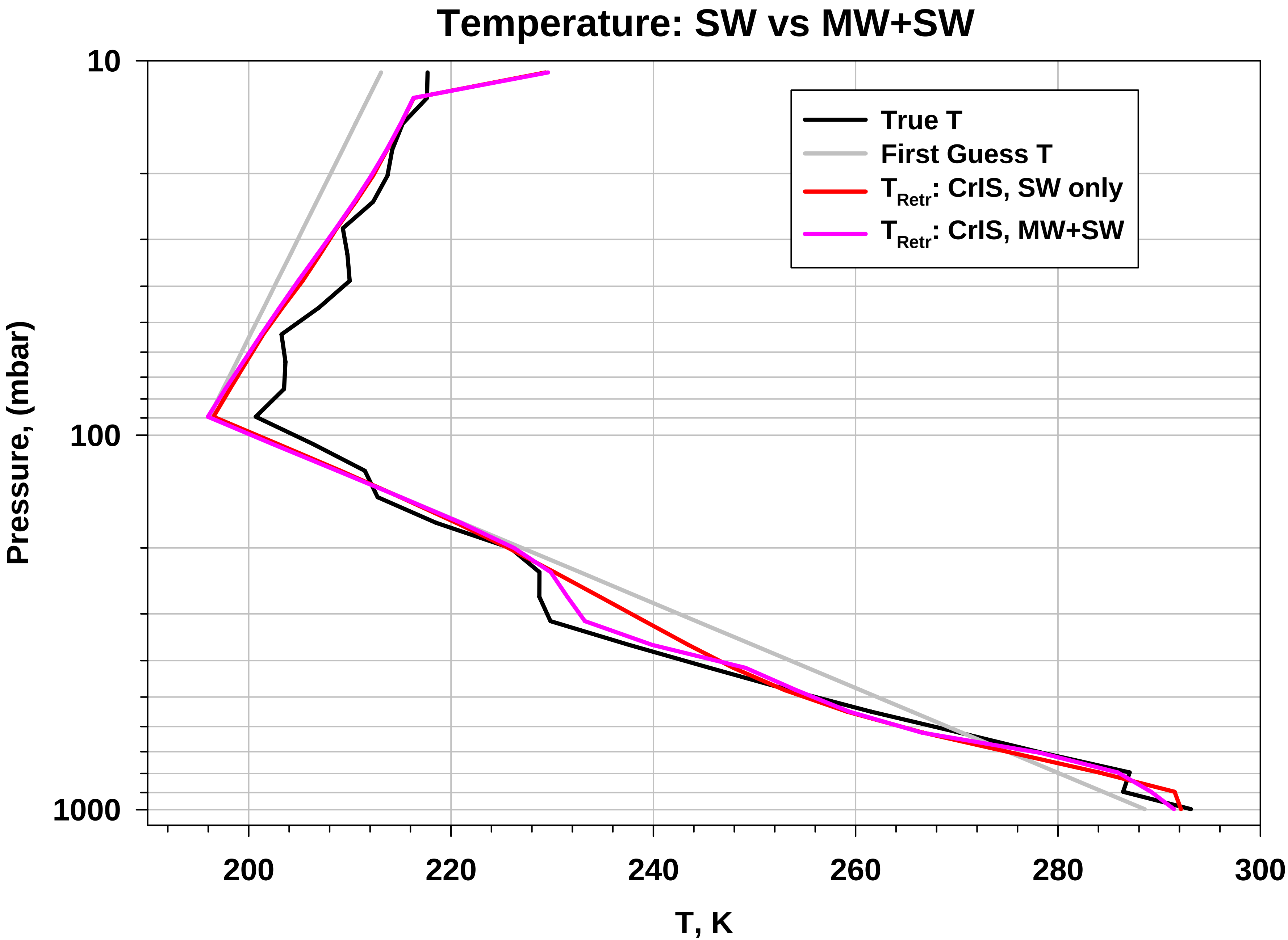


CrIS Vs AIRS Noise
CrIS Noise
AIRS Noise
Pressure,
T,(K)
Q(ppm)
True T
First Guess T
T_Retr: CrIS, LW+MW+SW
T_Retr: CrIS, LW+MW
T_Retr: CrIS, MW+SW
T_Retr, AIRS noise, LW+MW+SW
T_Retr, AIRS noise, LW+MW
T_Retr, AIRS noise, MW+SW
True Q
First Guess Q
Q_Retr: CrIS, LW+MW+SW
Q_Retr: CrIS, LW+MW
Q_Retr: CrIS, MW+SW
Q_Retr, AIRS noise, LW+MW+SW
Q_Retr, AIRS noise, LW+MW
Q_Retr, AIRS noise, MW+SW
T-Structure Better
With CrIS LW Noise
Q-Structure Much Better
With CrIS LW Noise
Note: There Little
difference between
LW + MW &
MW + SW for
AIRS Level Noise

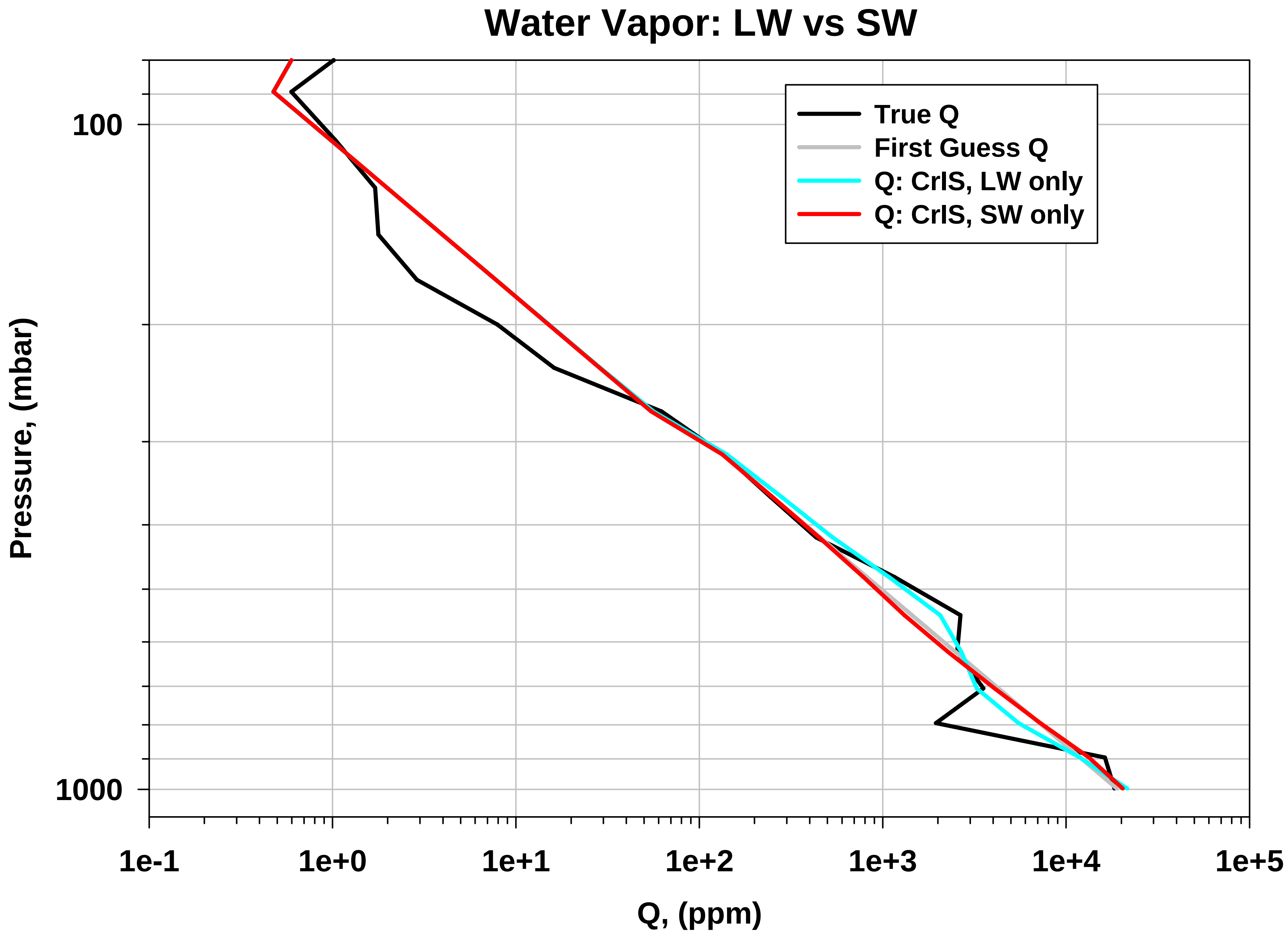


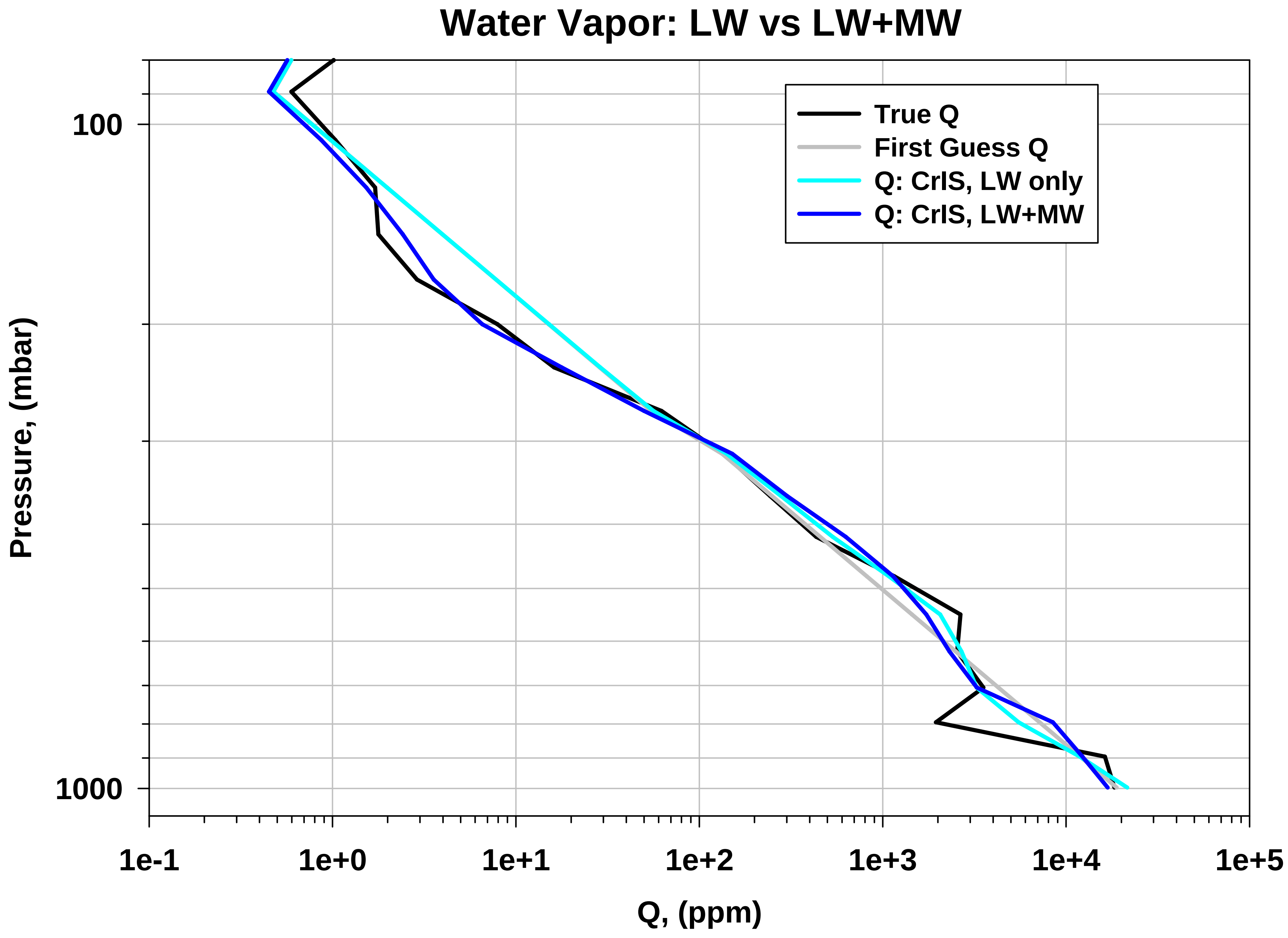
Temperature: LW vs SW
True T
First Guess T
T_{Retr}: CrIS, LW only
T_{Retr}: CrIS, SW only
10
100
1000
Pressure, (mbar)
200
220
240
260
280
300
T, K


Temperature: LW vs LW+MW
10
100
1000
Pressure, (mbar)
200
220
240
260
280
300
T, K
True T
First Guess T
T_{Retr}: CrIS, LW only
T_{Retr}: CrIS, LW+MW

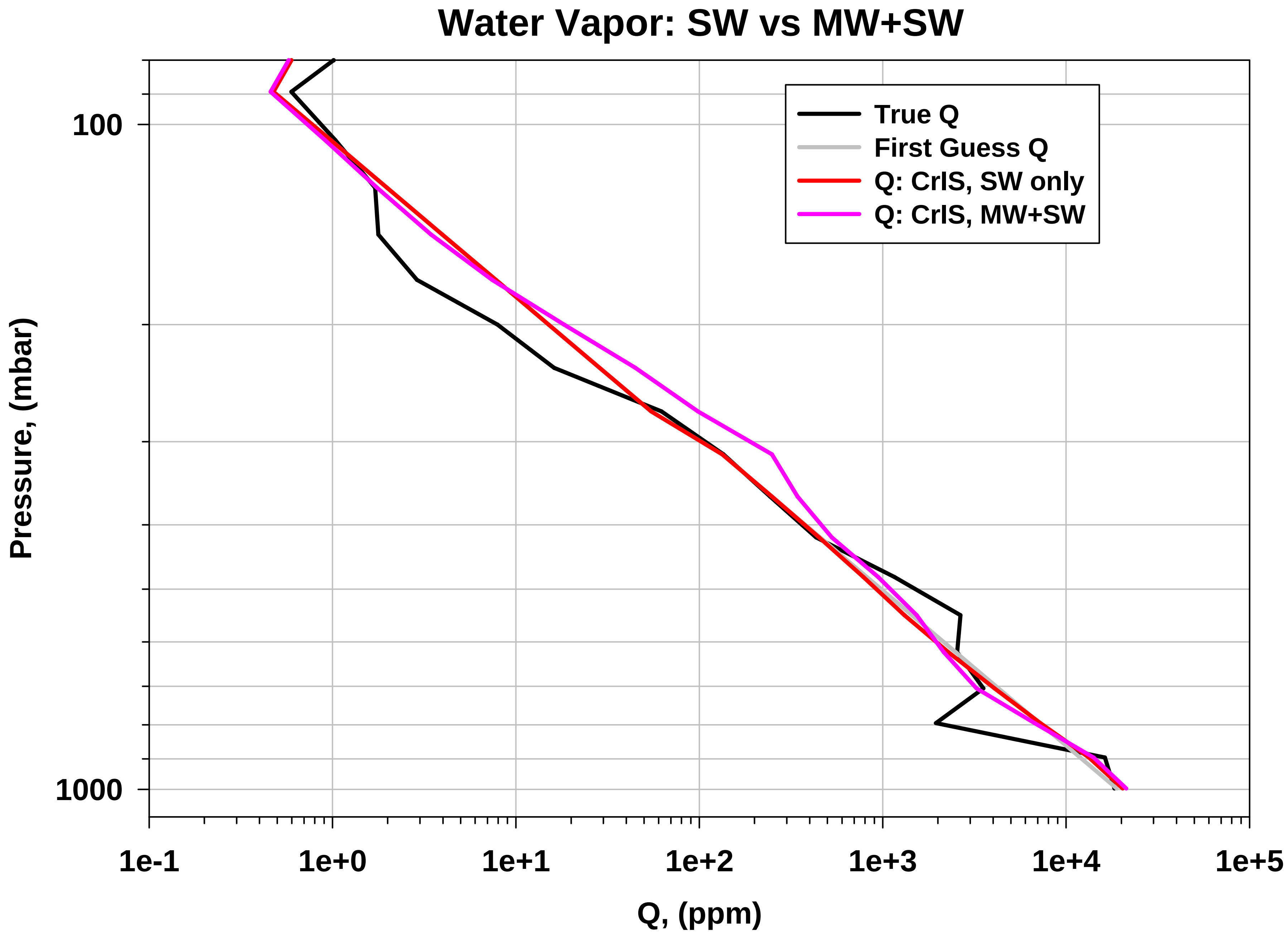


Temperature: SW vs MW+SW
True T
First Guess T
T_{Retr}: CrIS, SW only
T_{Retr}: CrIS, MW+SW
Pressure, (mbar)
10
100
1000
200
220
240
260
280
300
T, K


Water Vapor: LW vs SW
True Q
First Guess Q
Q: CrIS, LW only
Q: CrIS, SW only
100
1000
Pressure, (mbar)
1e-1
1e+0
1e+1
1e+2
1e+3
1e+4
1e+5
Q, (ppm)



Water Vapor: LW vs LW+MW
True Q
First Guess Q
Q: CrIS, LW only
Q: CrIS, LW+MW
Pressure, (mbar)
100
1000
Q, (ppm)
1e-1
1e+0
1e+1
1e+2
1e+3
1e+4
1e+5


Water Vapor: SW vs MW+SW
True Q
First Guess Q
Q: CrIS, SW only
Q: CrIS, MW+SW
100
1000
Pressure, (mbar)
1e-1
1e+0
1e+1
1e+2
1e+3
1e+4
1e+5
Q, (ppm)