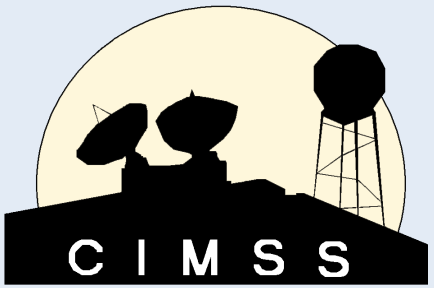
Comparing Clear Sky Profiling with MIR and FIR Radiance Spectra

Aronne Merrelli and David D. Turner
UW – Madison Dept. of Atmospheric and Oceanic Sciences
2011 Workshop on Far-Infrared Remote Sensing
November 8, 2011



Outline

- Quick review of Clear Sky Profiling
- Simulation Framework
  - Simulated FIR & MIR Sensor characteristics
  - A priori information for retrievals
  - Performance metrics
- MIR / FIR comparison results
- Conclusion

Clear Sky Profiling

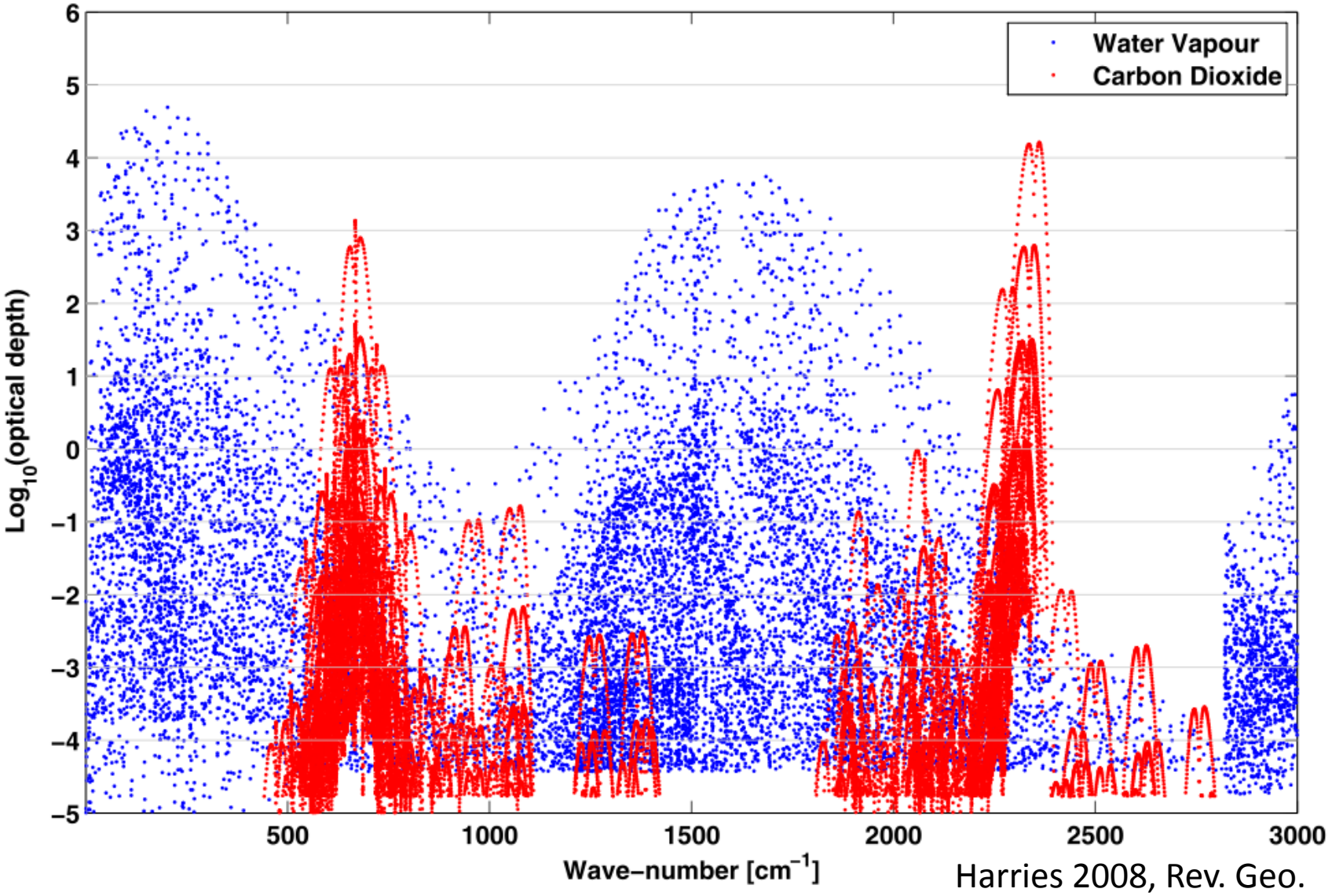
- Non scattering, plane-parallel Radiative Transfer Equation for upwelling radiance (clouds, aerosols not included):

$$L^{\uparrow}(\nu) = L^{\uparrow}{}_{s}(\nu)t^{*} + \int_{0}^{z_T} B(T,\nu)W^{\uparrow}(z,\nu)dz$$

$$W^{\uparrow}(z,\nu) = \frac{d}{dz}e^{-\frac{1}{\mu}k(\nu)u(z)}$$

- Effective Profiling requires wide variety of weighting function shapes, via different values of the absorption coefficients, *k(v)*

Carbon Dioxide and Water Vapor abs. lines



Harries 2008, Rev. Geo.

Retrieval Framework

Gauss-Newton nonlinear Optimal Estimation
(Rodgers 2000, Carissimo 2005)

$$\hat{\mathbf{x}} - \mathbf{x}_0 = \left(\mathbf{B}^{-1} + \mathbf{K}^{\mathrm{T}}\mathbf{S}^{-1}\mathbf{K}\right)^{-1}\mathbf{K}^{\mathrm{T}}\mathbf{S}^{-1}\left(\mathbf{y} - \mathbf{y}_0\right) = \mathbf{G}\left(\mathbf{y} - \mathbf{y}_0\right)$$

State vector (**x**) = temperature and ln(q)

Measurement (**y**) = radiance spectrum

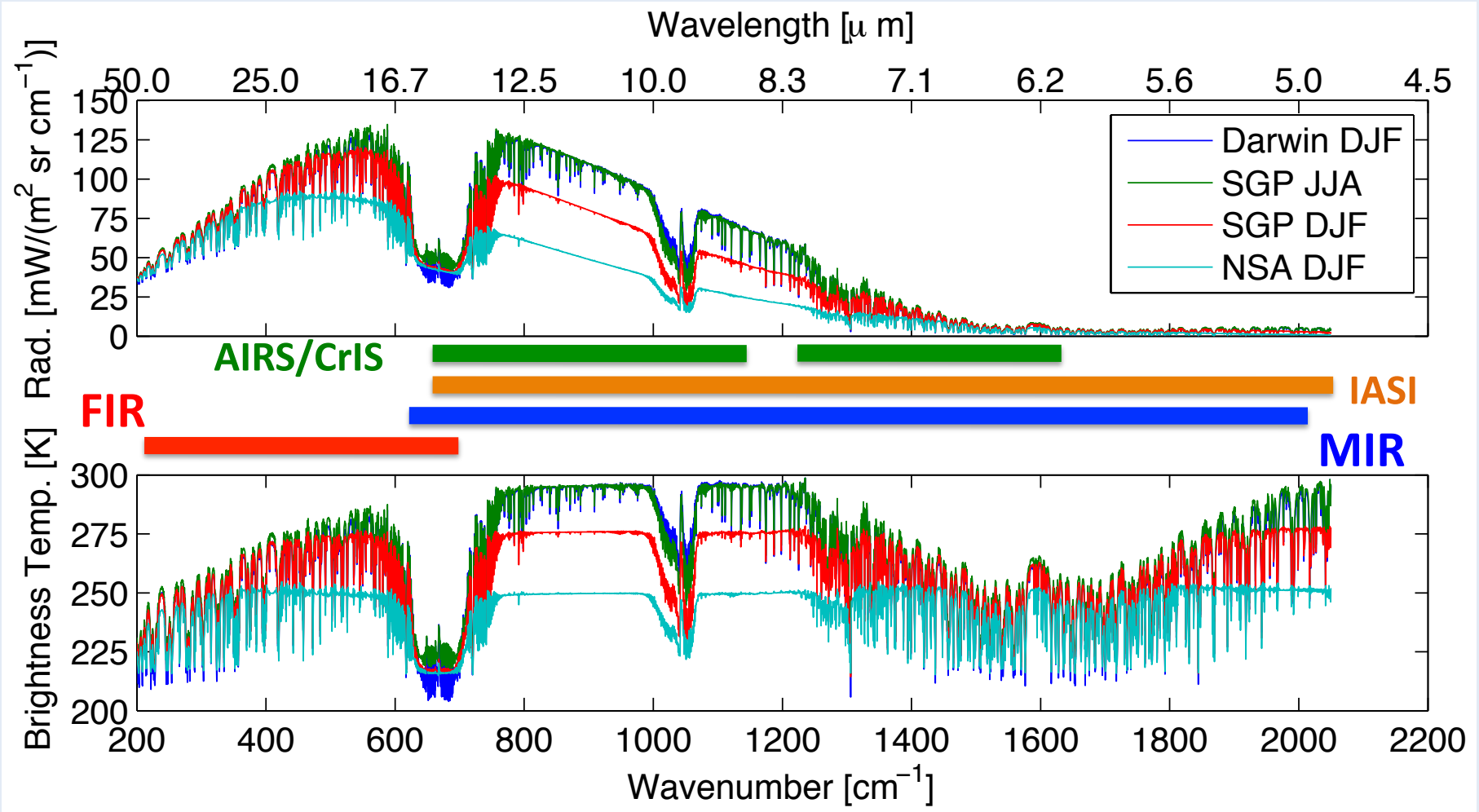
Measurement covariance (**S**) = diagonal, NEdR

Background covariance (**B**) = "prior covariance"

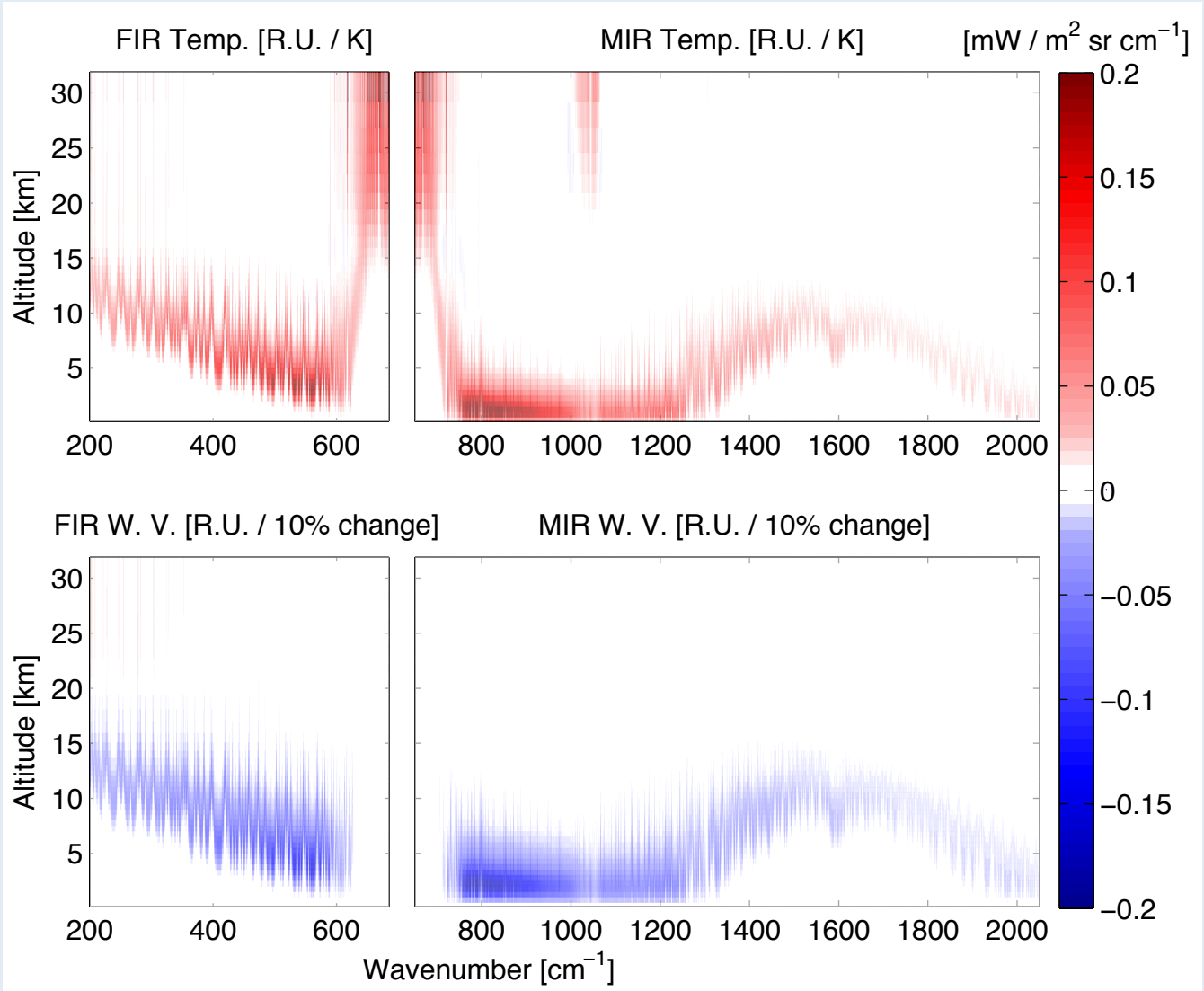
Forward model Jacobian (**K**) from LBLRTM

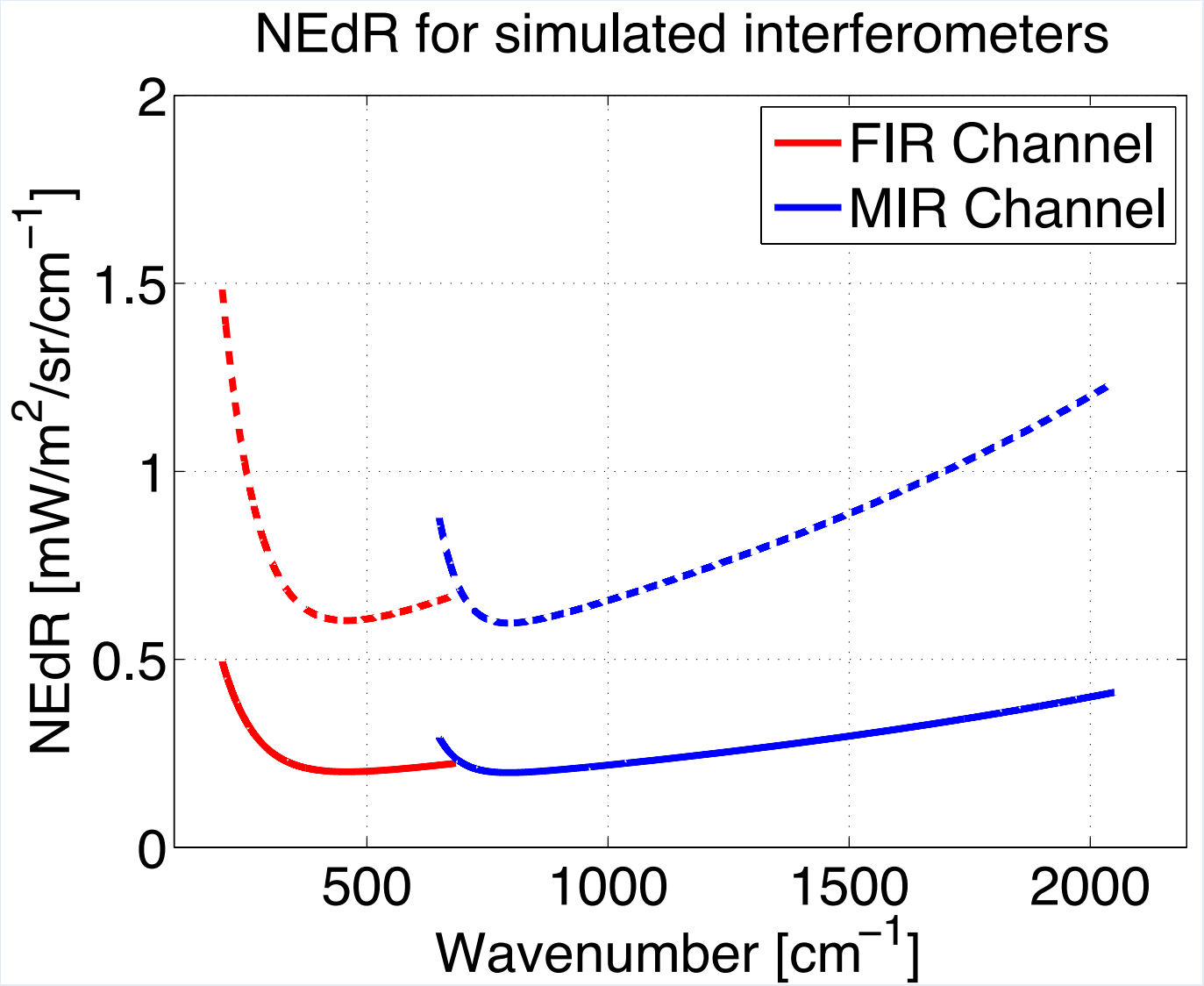
$\mathbf{x_0}$, $\mathbf{y_0}$ = state and meas. at prior mean (1st guess)

Example Upwelling Spectra



Example Jacobians (tropical atm.)





Both unapodized with OPD=1cm / Δν=0.5 cm^{-1}

(HeNe sampling frequency, 15799 cm^{-1}, same as AERI)

Background Covariance

- Realistic priors from ARM radiosonde:
  - Seasonal mean profile & covar. for troposphere
  - Standard atm. for stratosphere
- Synthetic prior – Correlation exponentially decays with vertical separation (Lerner 2002 JGR)

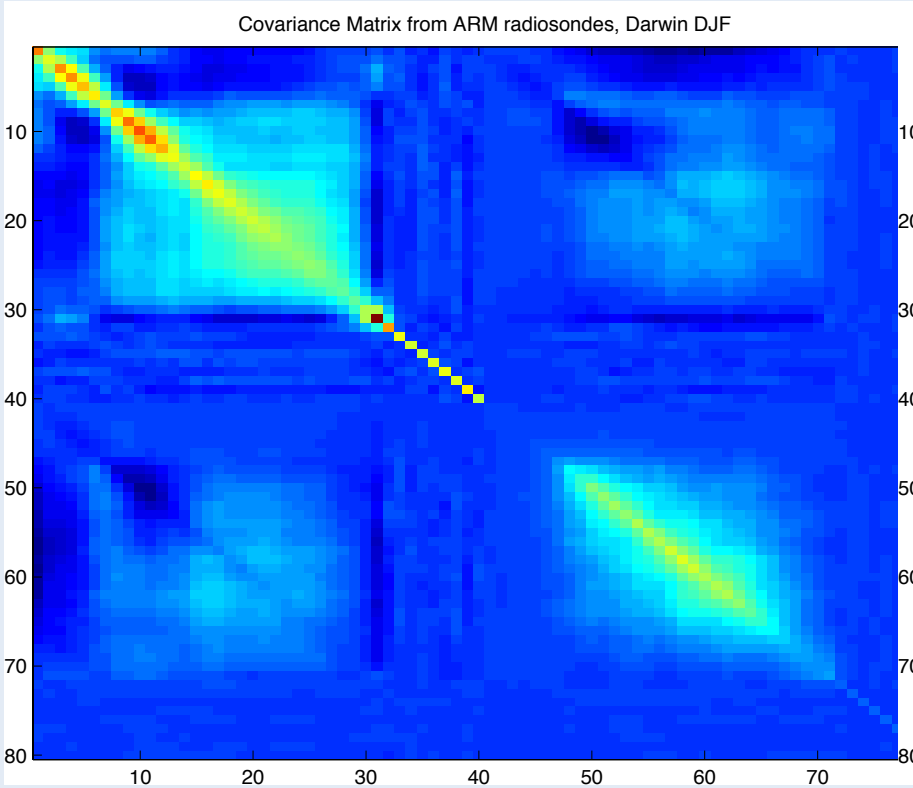
$$B(i,j) = \sigma_i \sigma_j \exp\left(-\frac{\left| z_i - z_j \right|}{L} \right)$$

- Framework applied identically to both simulated sensors

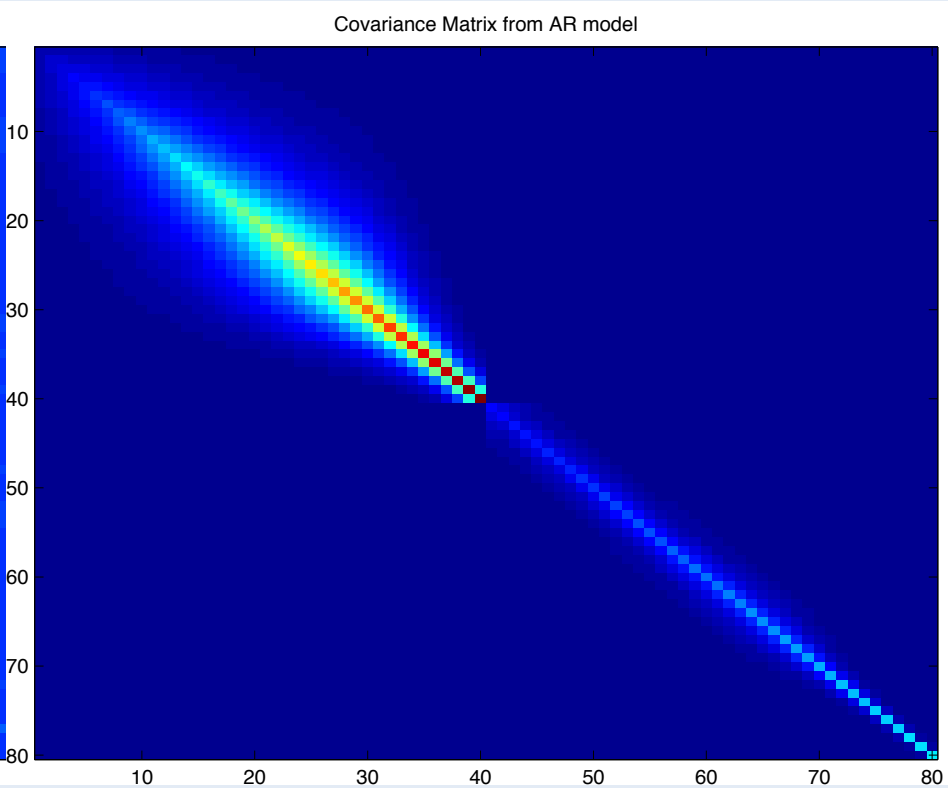
Example Background Covariance Matrices

$$\begin{bmatrix} \mathbf{T} & \mathbf{TQ} \\ \mathbf{TQ} & \mathbf{Q} \end{bmatrix}$$

Measured - ARM Darwin DJF



Simulated AR



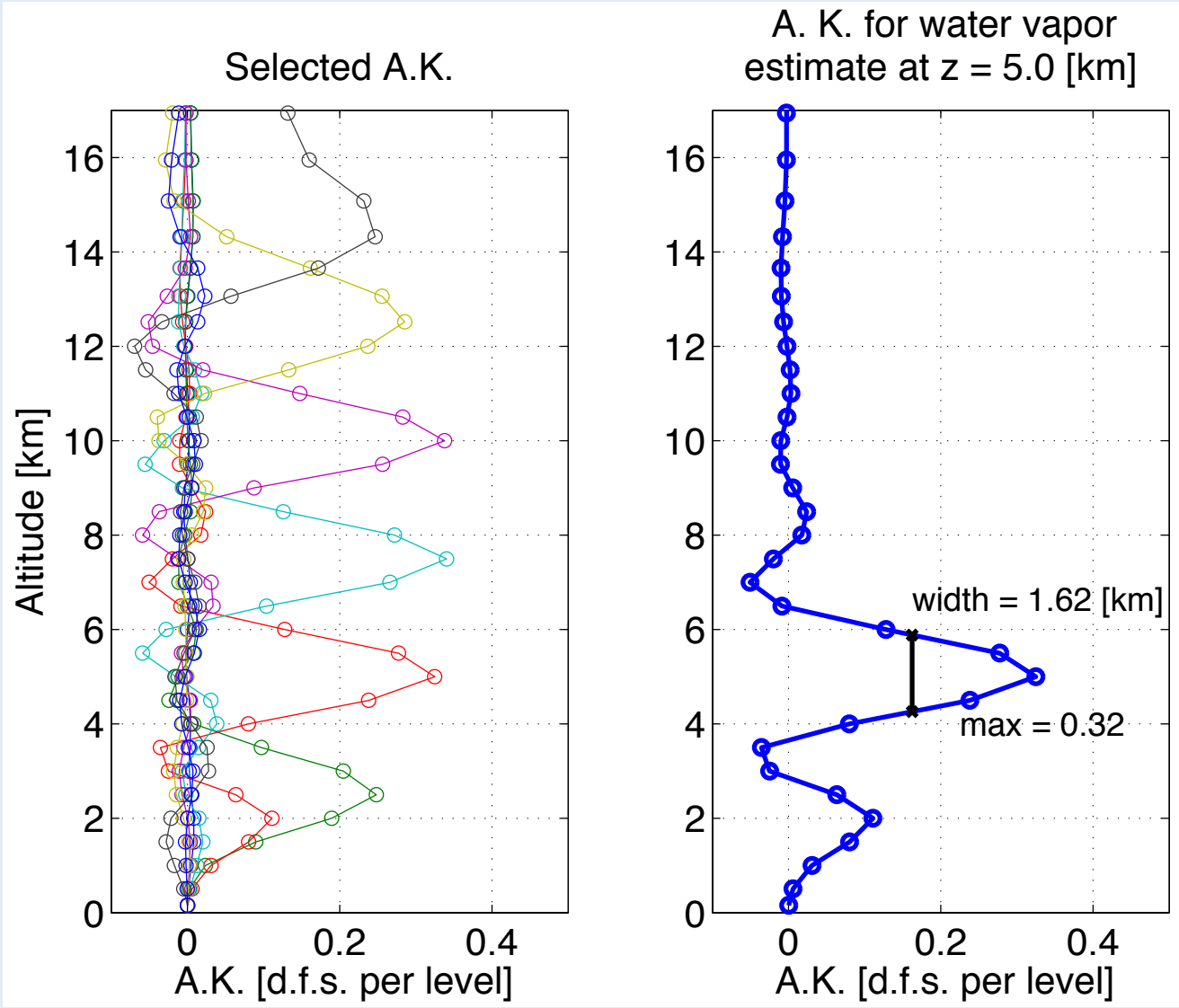
Performance Metrics

- Based on Averaging Kernel matrix

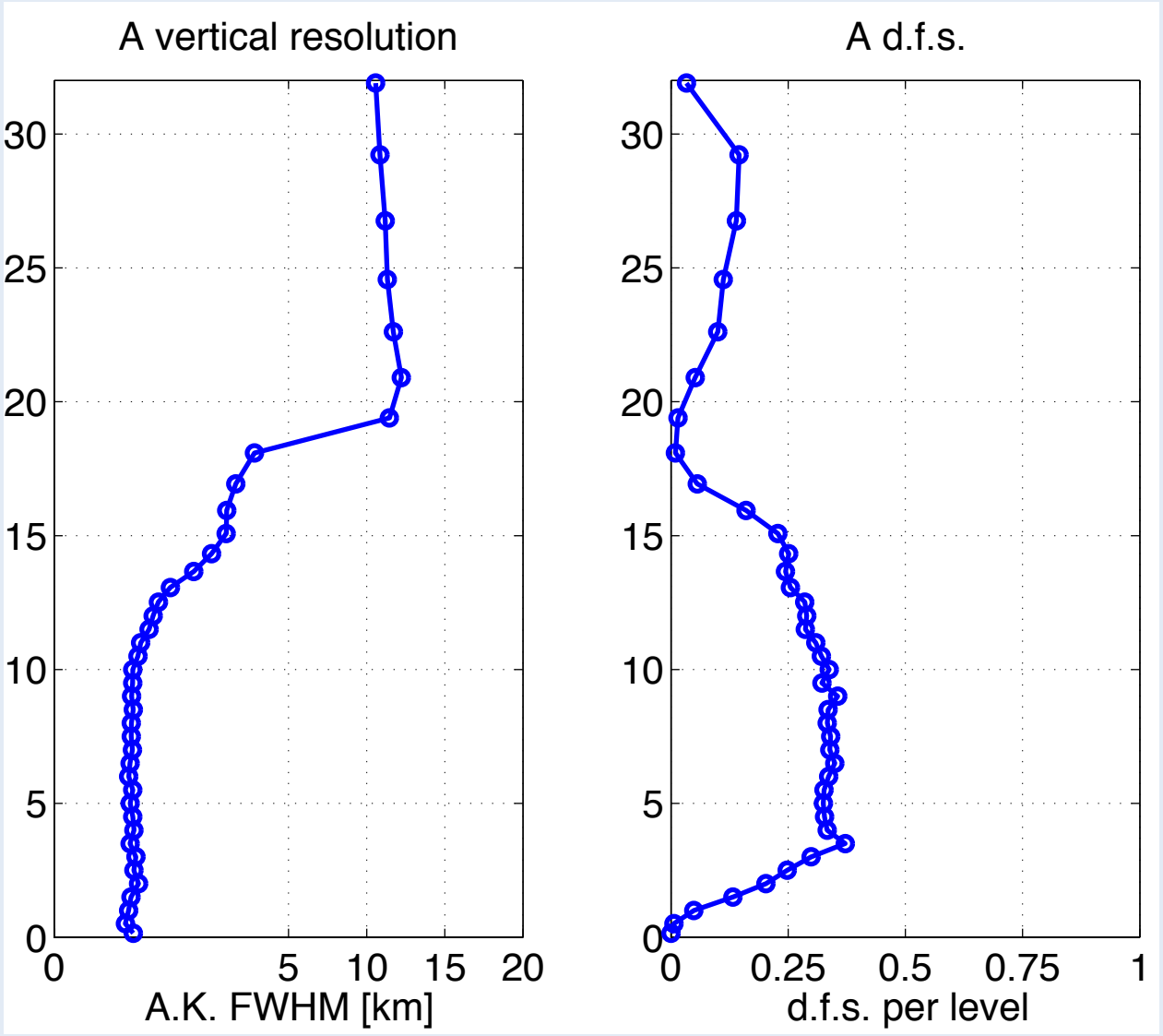
$$\mathbf{A} = \mathbf{GK} \qquad \hat{\mathbf{x}} - \mathbf{x}_0 = \mathbf{A}\left(\mathbf{x} - \mathbf{x}_0\right)$$

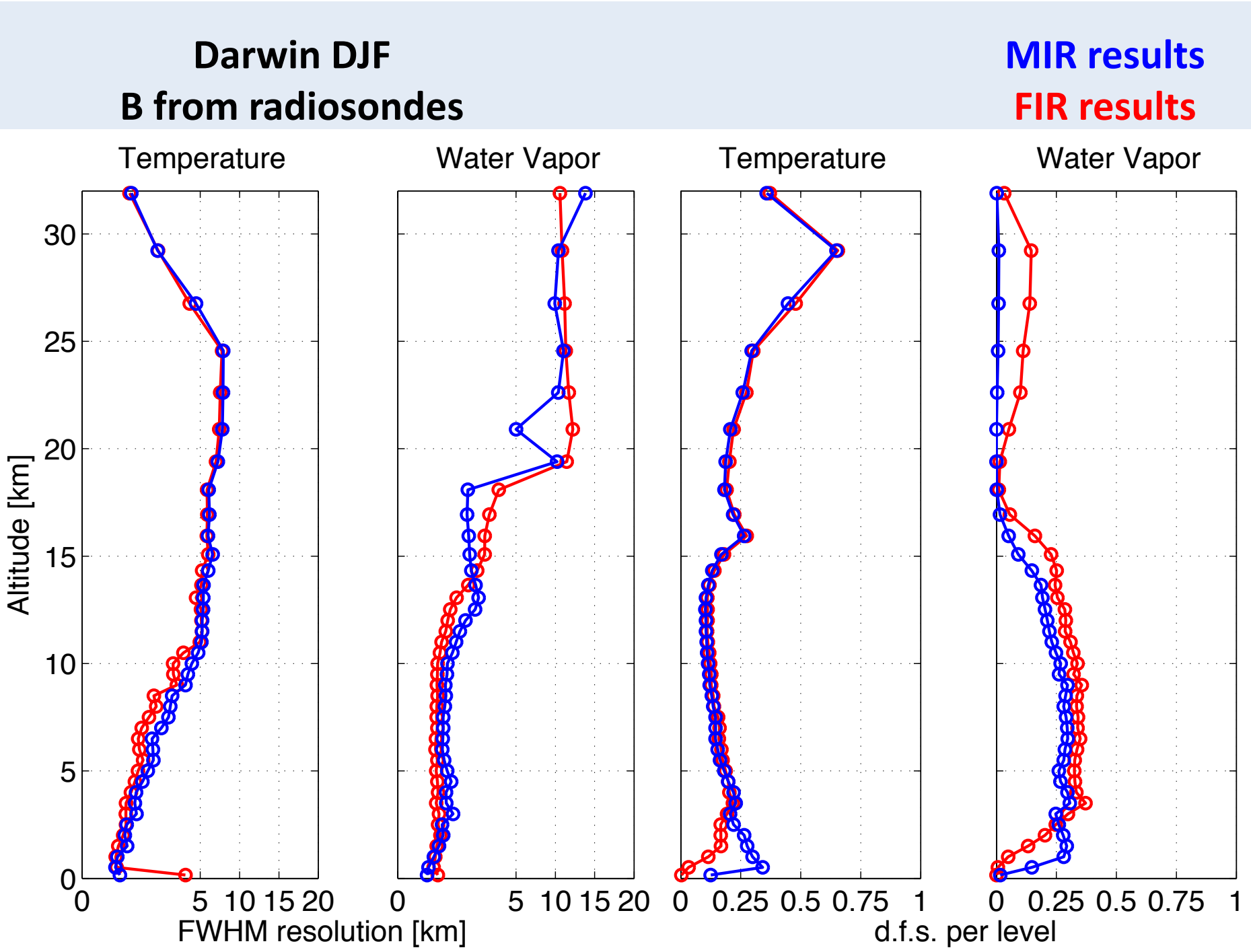
  - Rows of A = averaging kernels; FWHM around peak values gives estimate of vertical resolution
  - Diagonal of A = “degrees of freedom for signal”
- Note all metrics depend on the assumed prior (**B**) as well as the sensor characteristics (**S**, **K**)

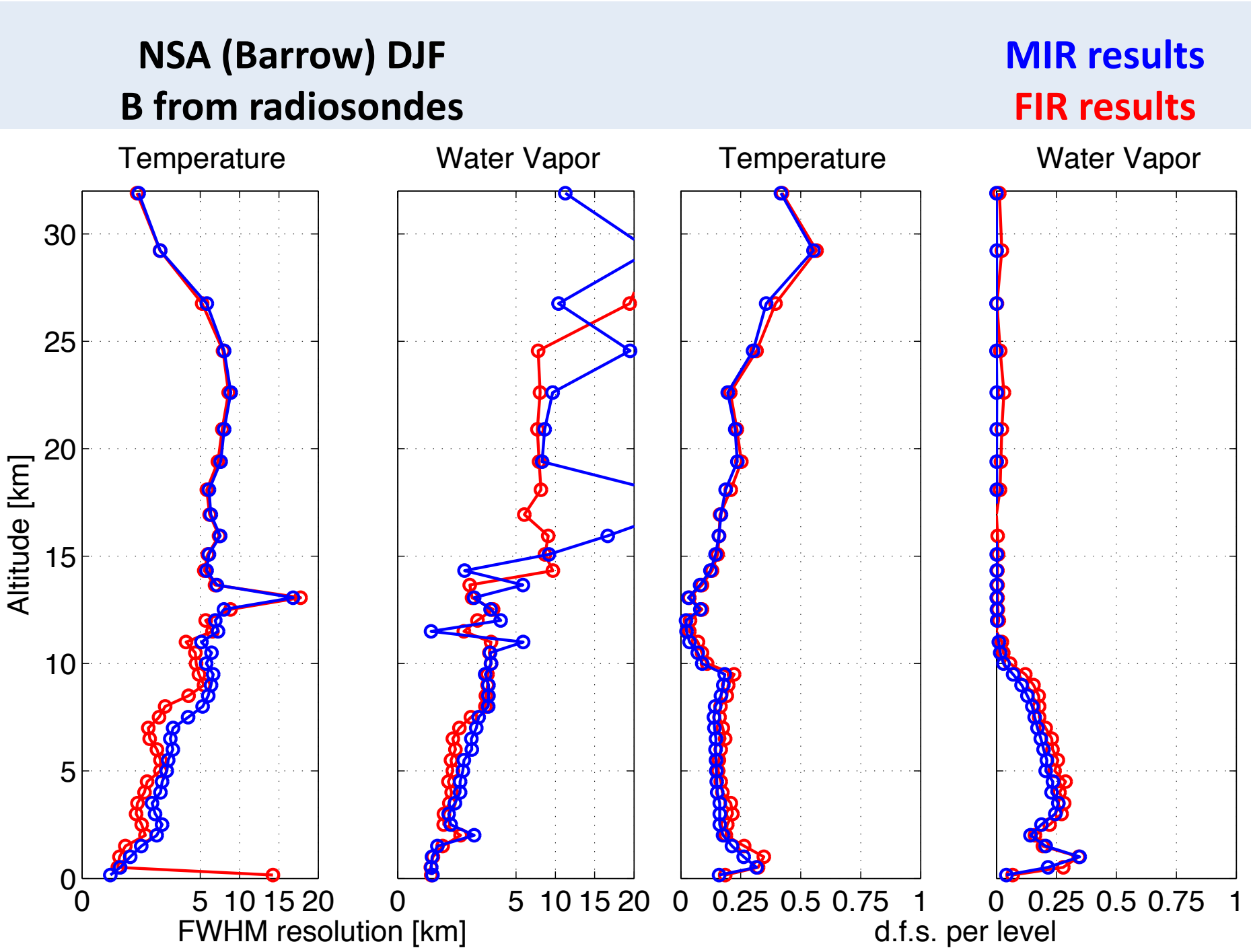
Performance Metrics

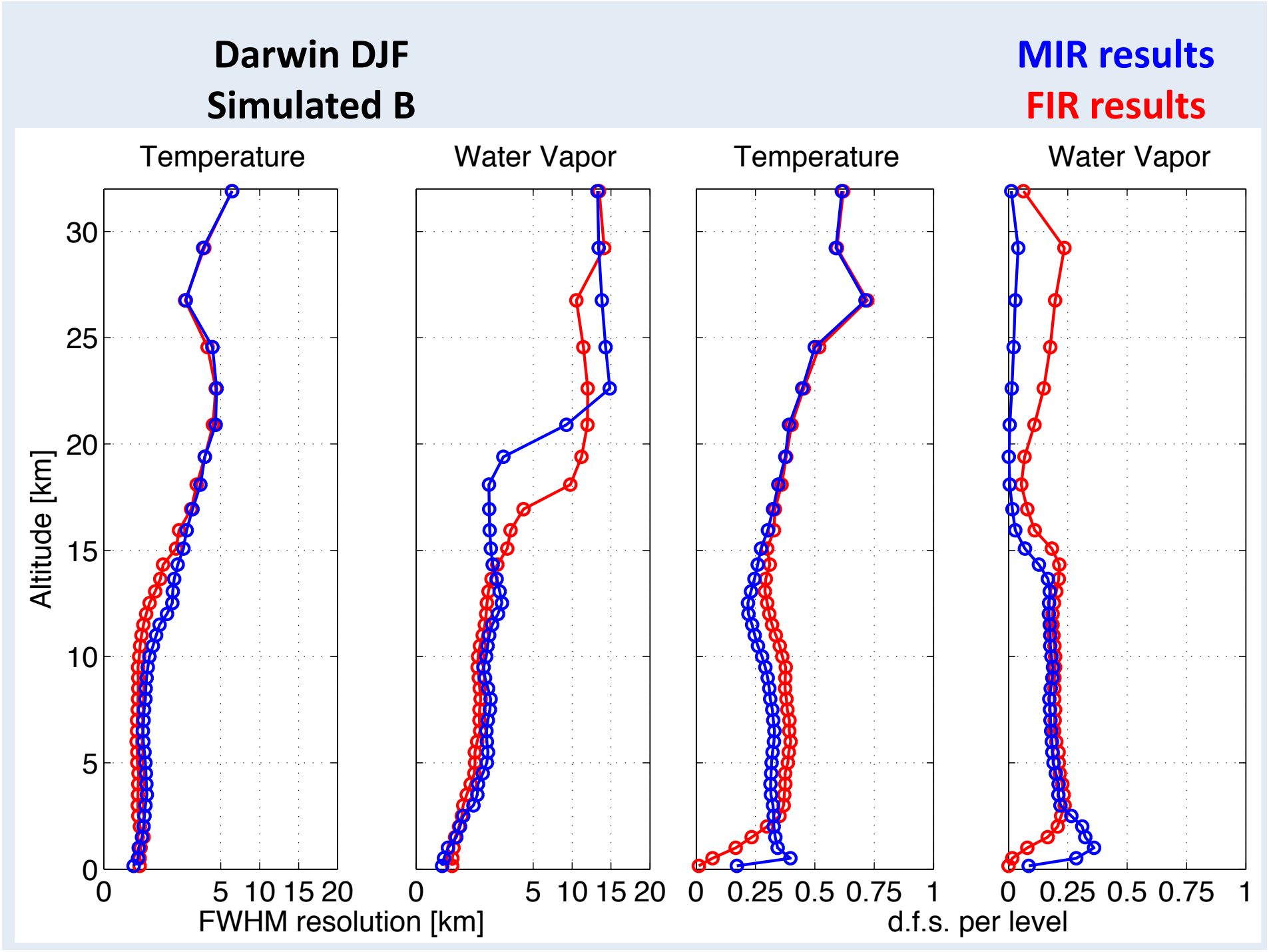


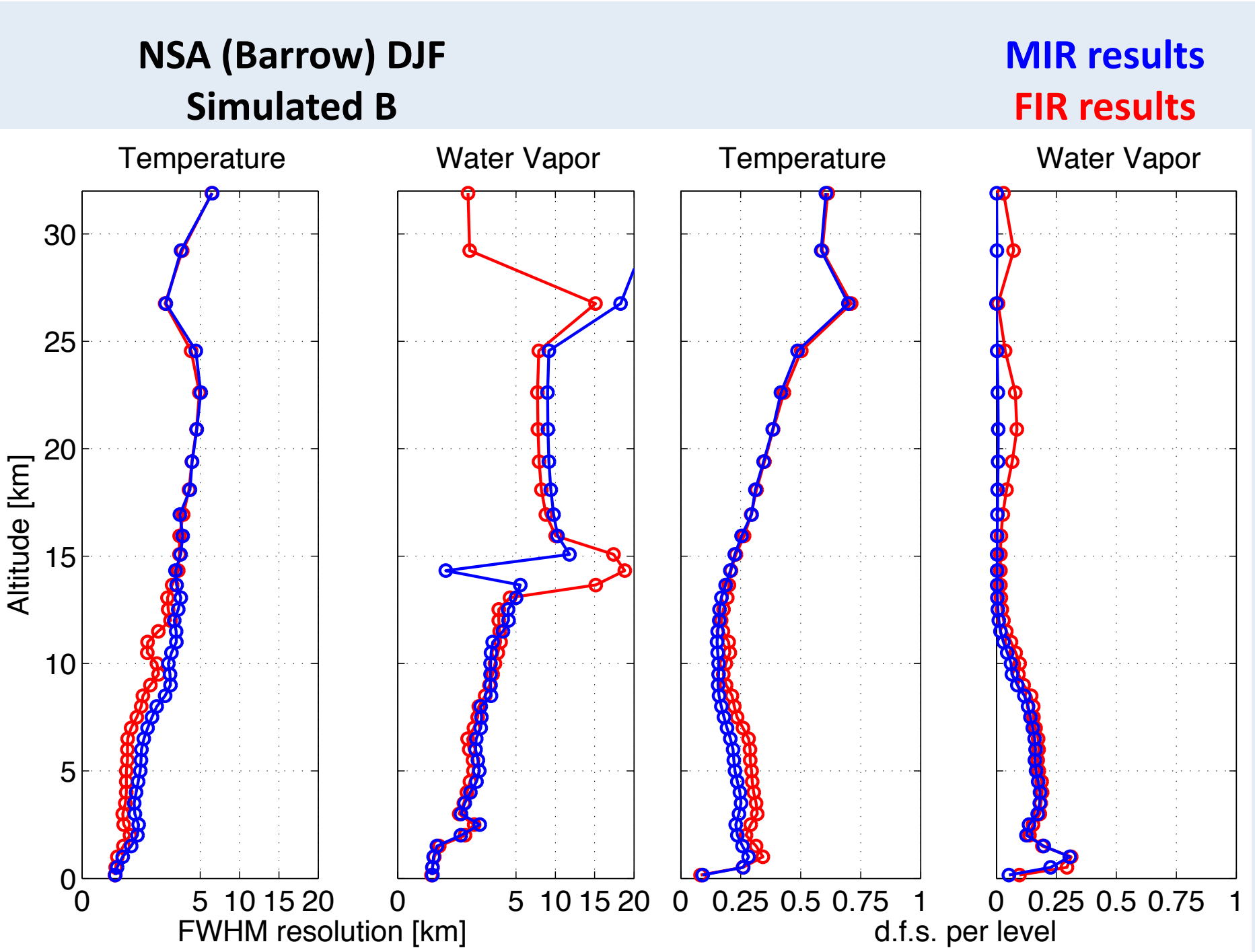
Performance Metrics

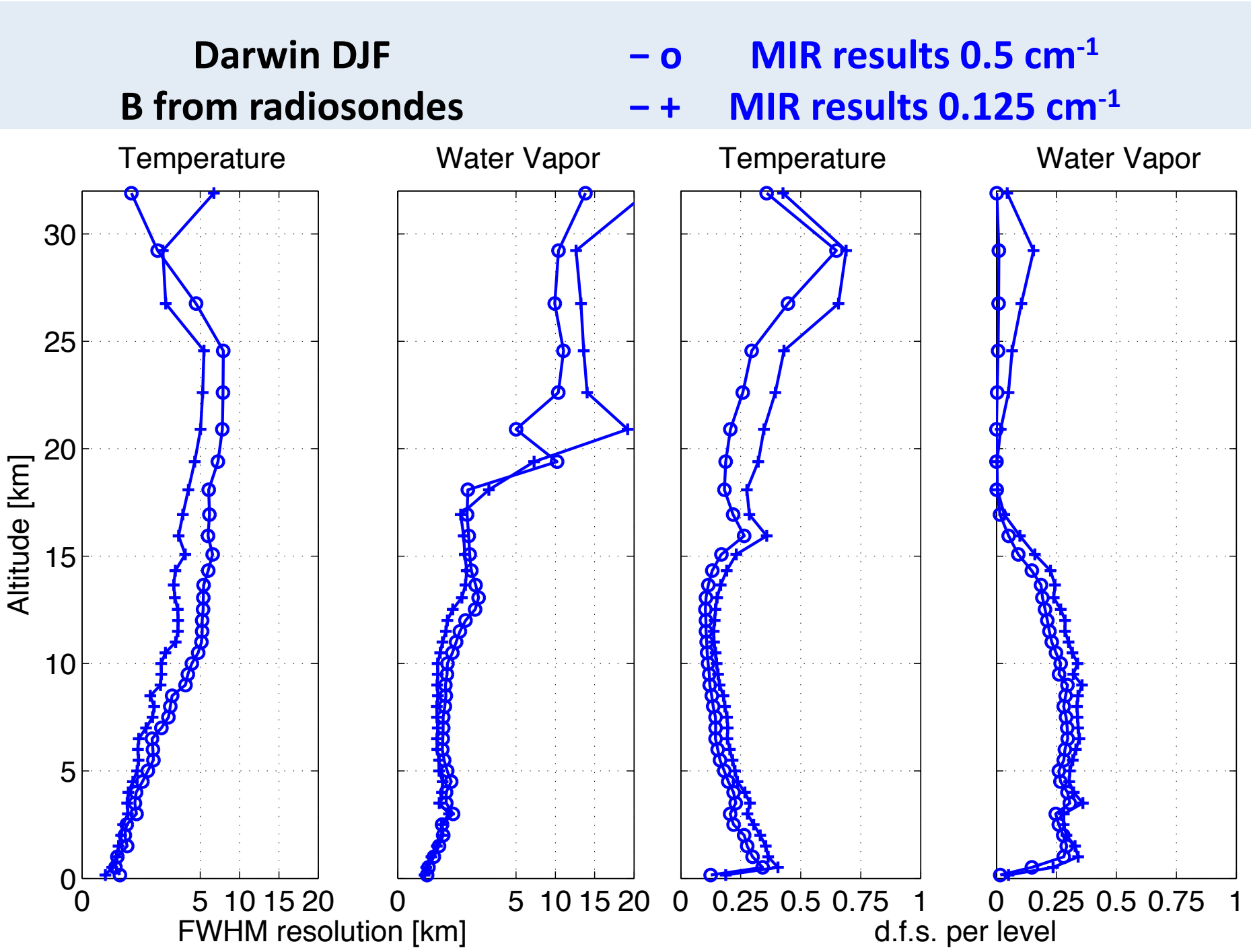



Darwin DJF
B from radiosondes
MIR results
FIR results
Temperature
Water Vapor
Temperature
Water Vapor
Altitude [km]
0
5
10
15
20
25
30
0
5
10
15
20
FWHM resolution [km]
0
0.25
0.5
0.75
1
d.f.s. per level


NSA (Barrow) DJF
B from radiosondes
MIR results
FIR results
Temperature
Water Vapor
Temperature
Water Vapor
Altitude [km]
0
5
10
15
20
25
30
0
5
10
15
20
FWHM resolution [km]
0
0.25
0.5
0.75
1
d.f.s. per level

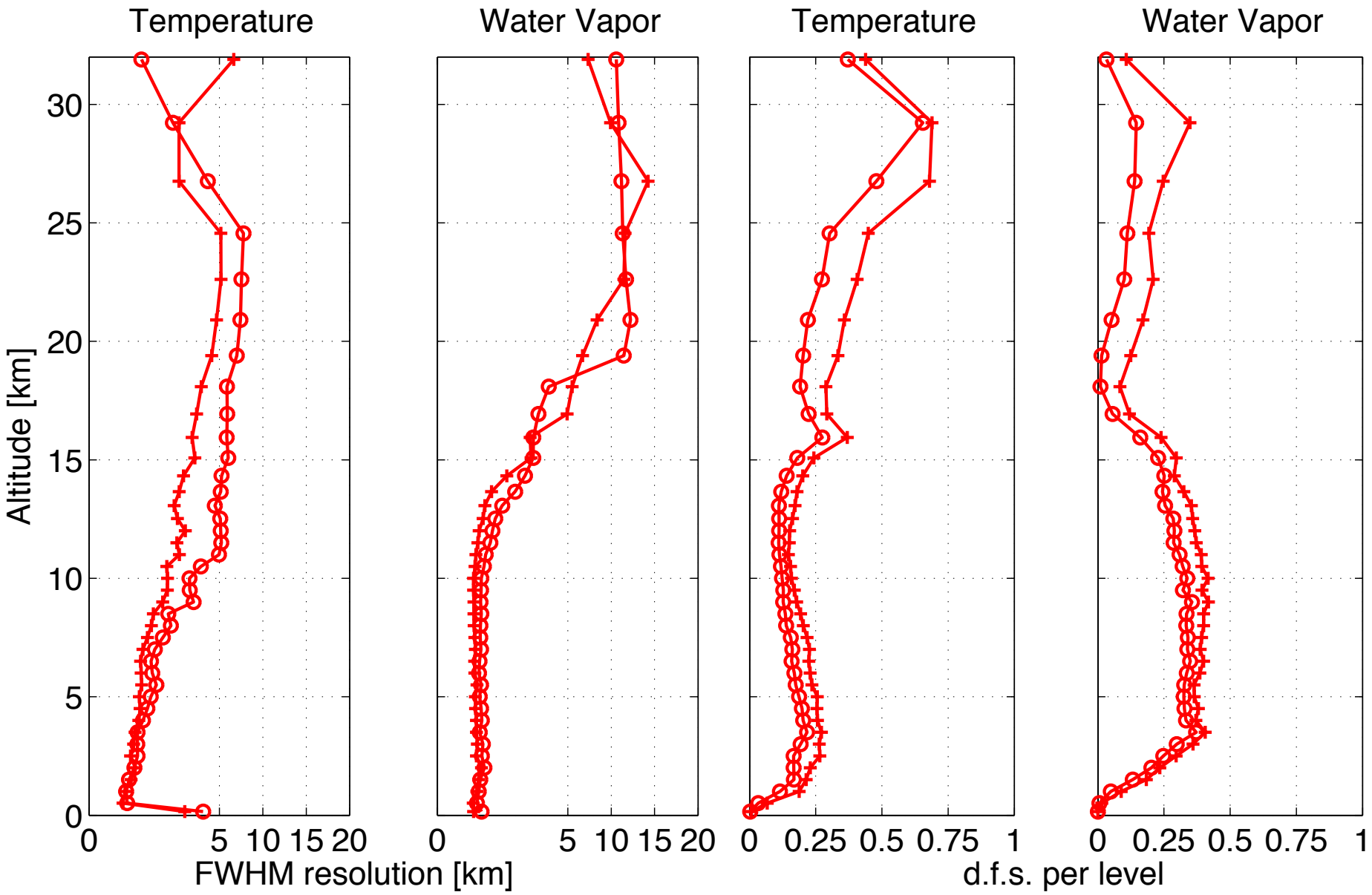

Darwin DJF
Simulated B
MIR results
FIR results
Temperature
Water Vapor
Temperature
Water Vapor
Altitude [km]
0
5
10
15
20
25
30
0
5
10
15
20
FWHM resolution [km]
0
0.25
0.5
0.75
1
d.f.s. per level

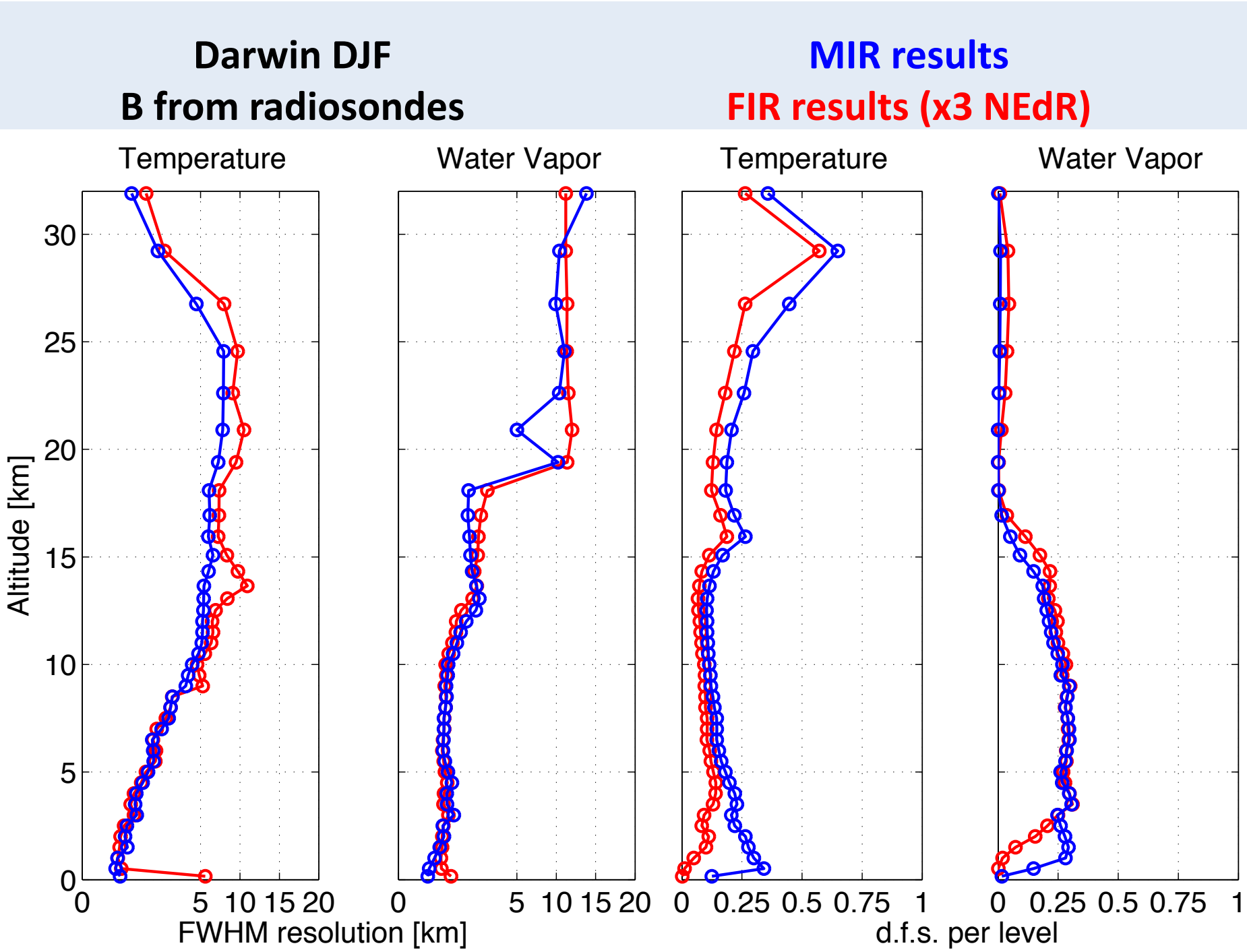

NSA (Barrow) DJF
Simulated B
MIR results
FIR results
Temperature
Water Vapor
Temperature
Water Vapor
Altitude [km]
0
5
10
15
20
25
30
0
5
10
15
20
FWHM resolution [km]
0
0.25
0.5
0.75
1
d.f.s. per level


Darwin DJF
B from radiosondes
– o MIR results 0.5 cm-1
– + MIR results 0.125 cm-1
Temperature
Water Vapor
Temperature
Water Vapor
Altitude [km]
0
5
10
15
20
25
30
0
5
10
15
20
FWHM resolution [km]
0
0.25
0.5
0.75
1
d.f.s. per level

Darwin DJF **– o** **FIR results 0.5 cm^{-1}**

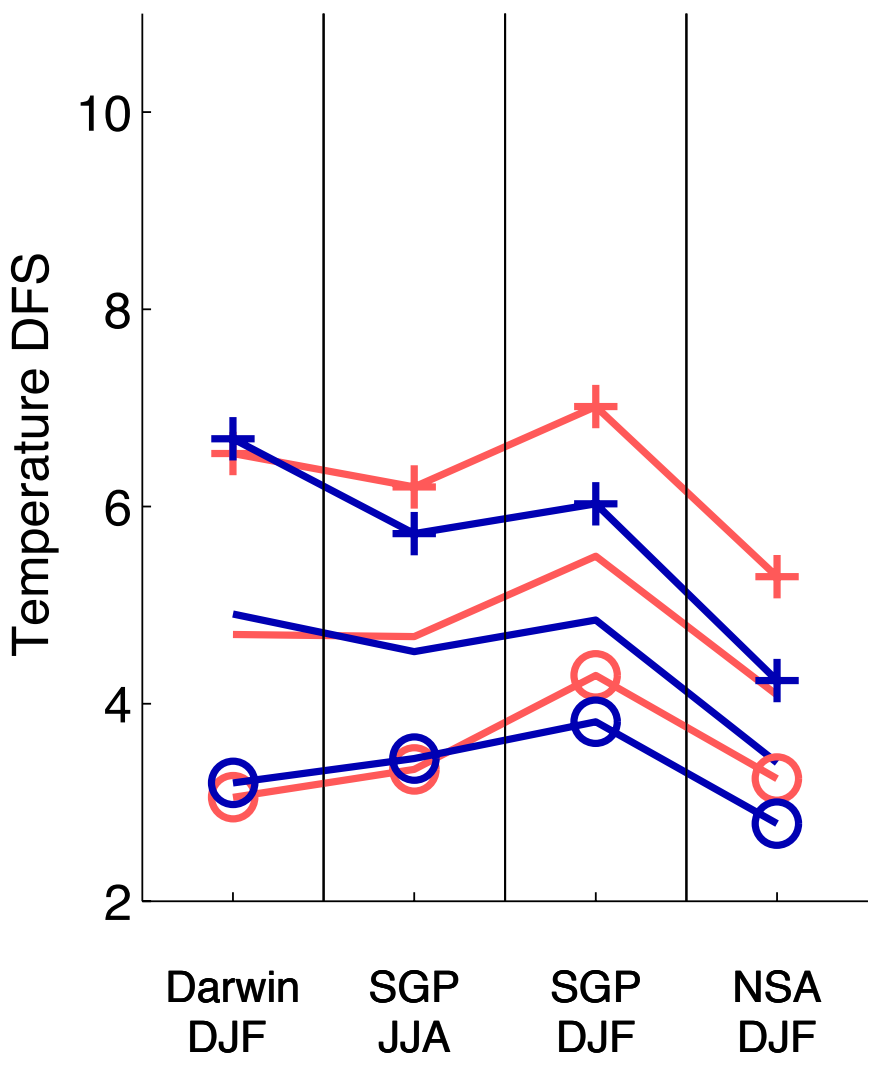
B from radiosondes **– +** **FIR results 0.125 cm^{-1}**

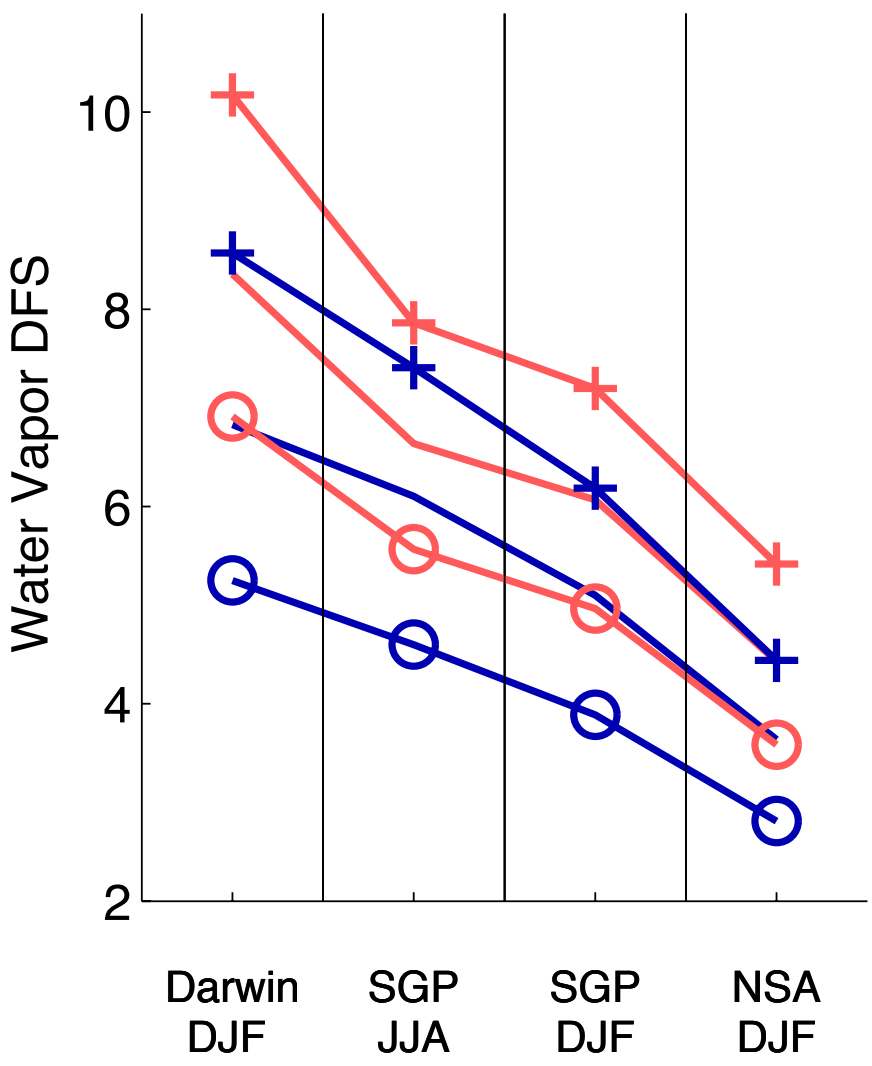



Darwin DJF
B from radiosondes
MIR results
FIR results (x3 NEdR)
Temperature
Water Vapor
Temperature
Water Vapor
Altitude [km]
0
5
10
15
20
25
30
0
5
10
15
20
FWHM resolution [km]
0
0.25
0.5
0.75
1
d.f.s. per level

Summary

FIR MIR –– base sensor –+ dv/4 –o NEdR ×3





Discussion (1)

- FIR has a small advantage over MIR
  - Primarily in upper troposphere/stratosphere
  - Relative increase (T vs Q) dependent on B
  - No sensitivity to lower troposphere in high water vapor climate
  - Higher performance instrument (higher spectral resolution or lower NEdR) shows increased information in tropopause / stratosphere

Discussion (2)

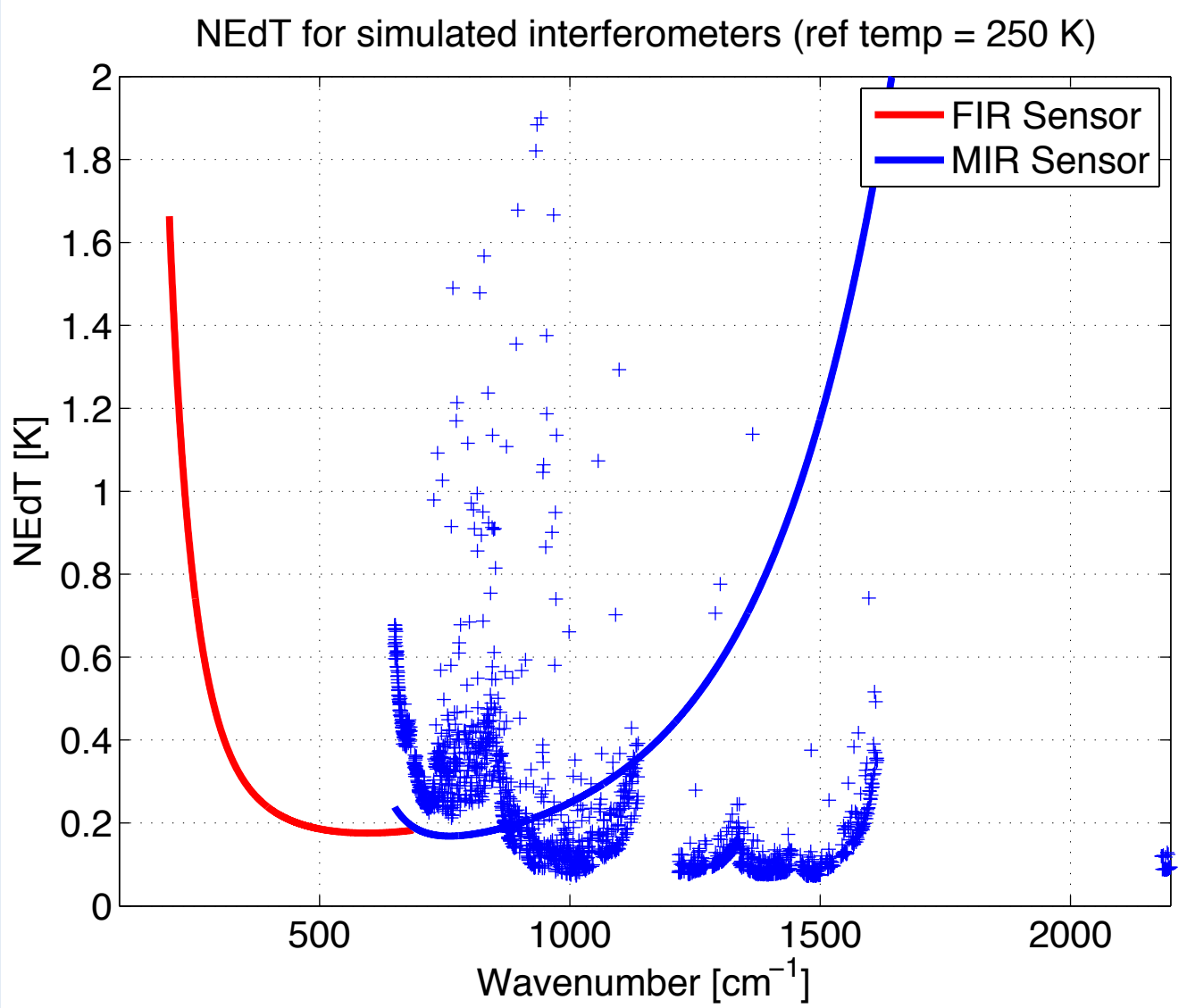
- However, strongly dependent on assumed **S**
  - Higher noise in FIR (x3) might be more realistic; FIR shows no clear advantage over MIR
  - The assumed MIR **S** is also poorer for Q retrieval compared to state of the art (CrIS, IASI, have separate detectors for the MIR carbon dioxide and water vapor bands)

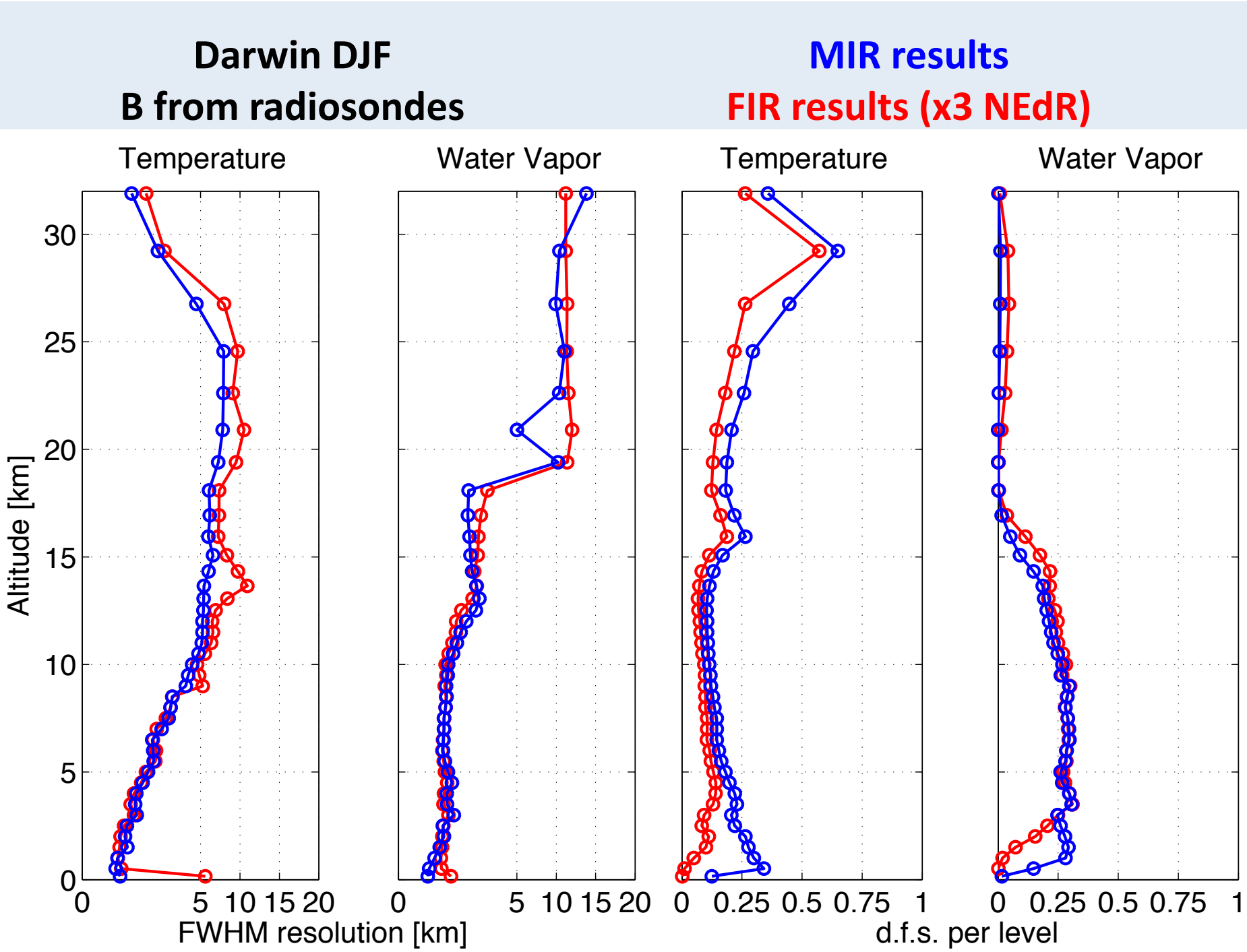
Questions?

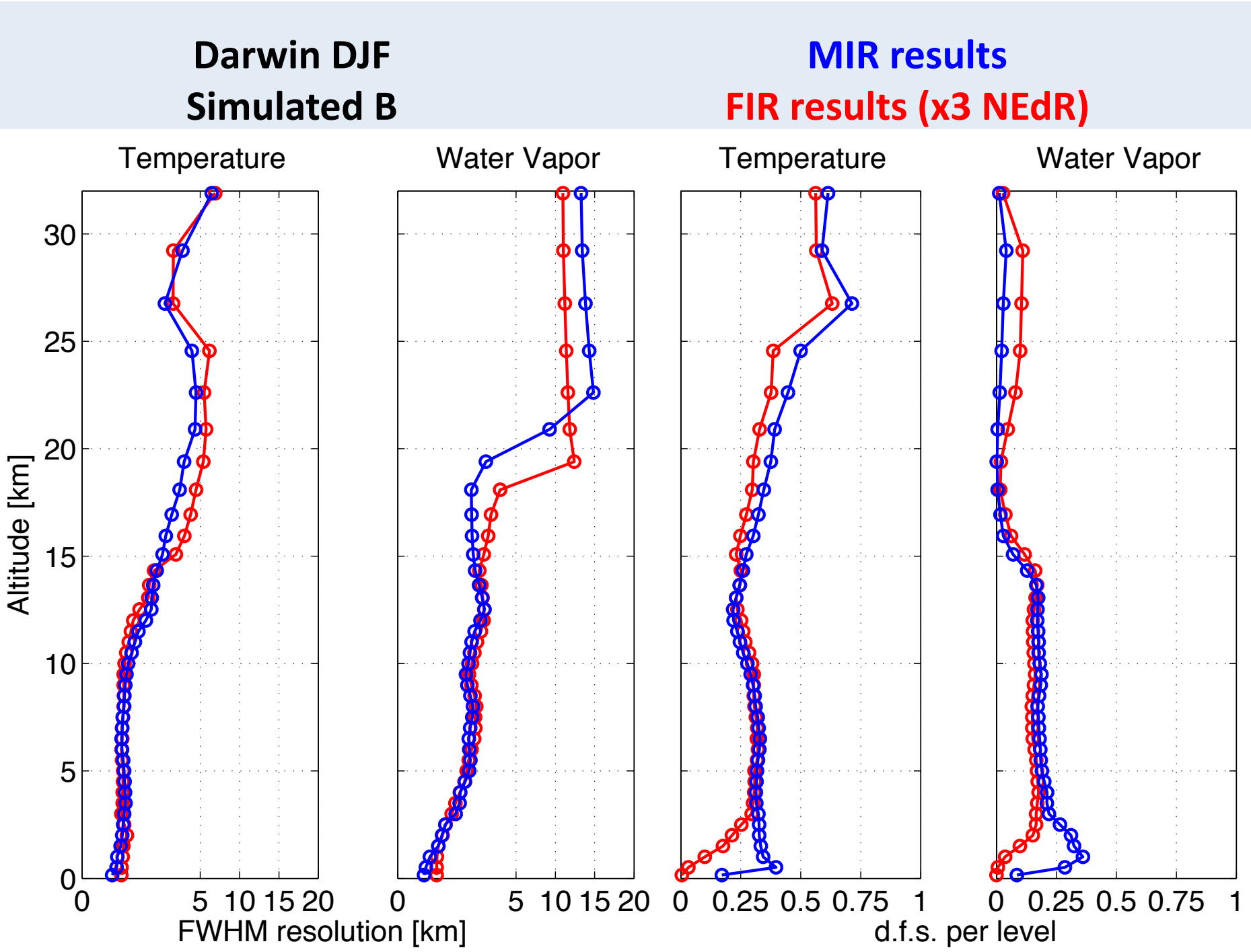
References:

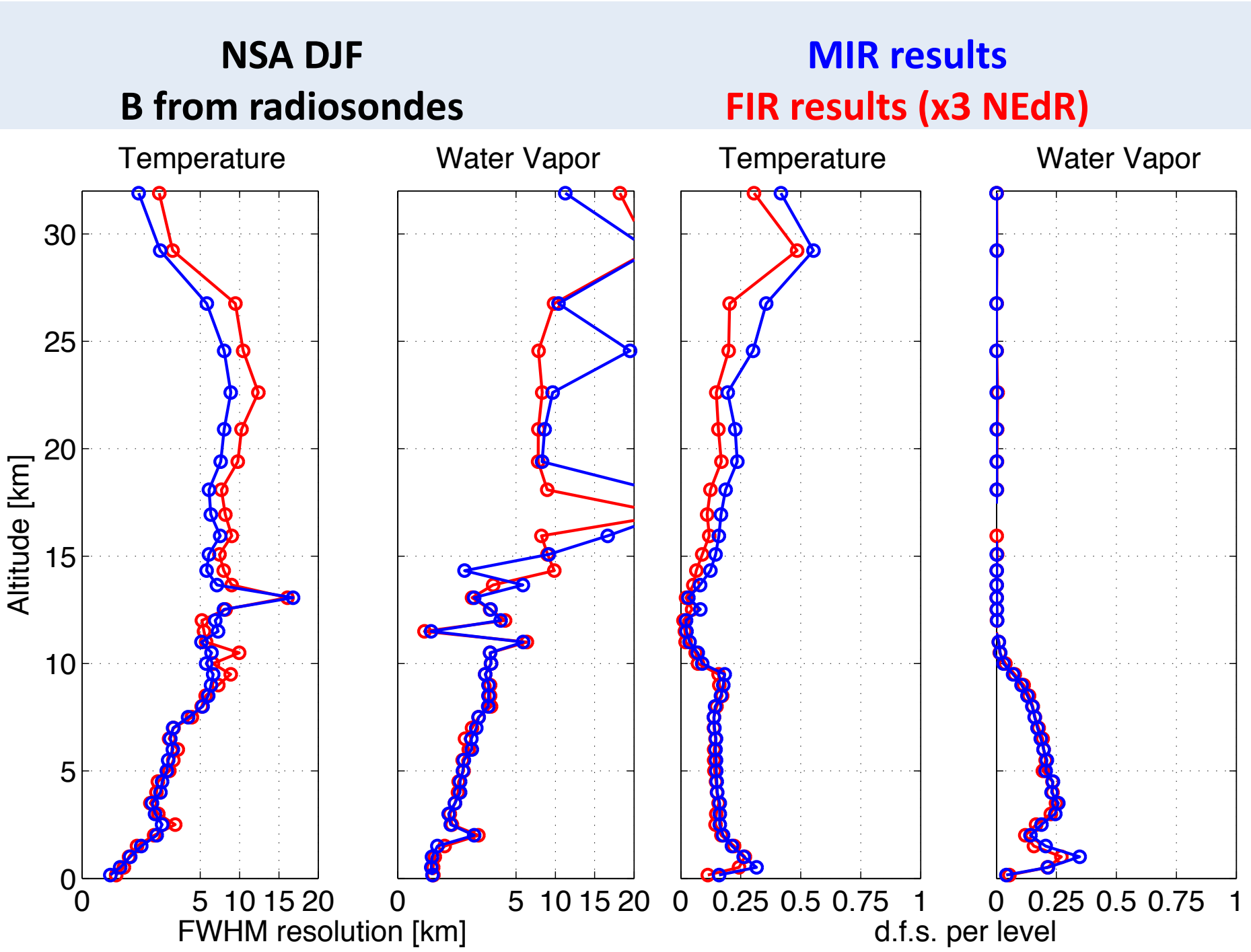
- Carissimo, A., De Feis, I. & Serio, C. The physical retrieval methodology for IASI: the [delta]-IASI code. *Environmental Modelling & Software* **20**, 1111-1126 (2005).
- Harries, J. *et al.* The Far-infrared Earth. *Rev. Geophys.* **46**, RG4004 (2008).
- Lerner, J.A., Weisz, E. & Kirchengast, G. Temperature and humidity retrieval from simulated Infrared Atmospheric Sounding Interferometer (IASI) measurements. *J. Geophys. Res.* **107**, 4189 (2002).
- Rodgers, C.D. Information content and optimization of high-spectral-resolution measurements. *Optical Spectroscopic Techniques and Instrumentation for Atmospheric and Space Research II* **2830**, 136-147 (1996).
- Rodgers, C.D. *Inverse Methods for Atmospheric Sounding*. **2**, (World Scientific: 2000).

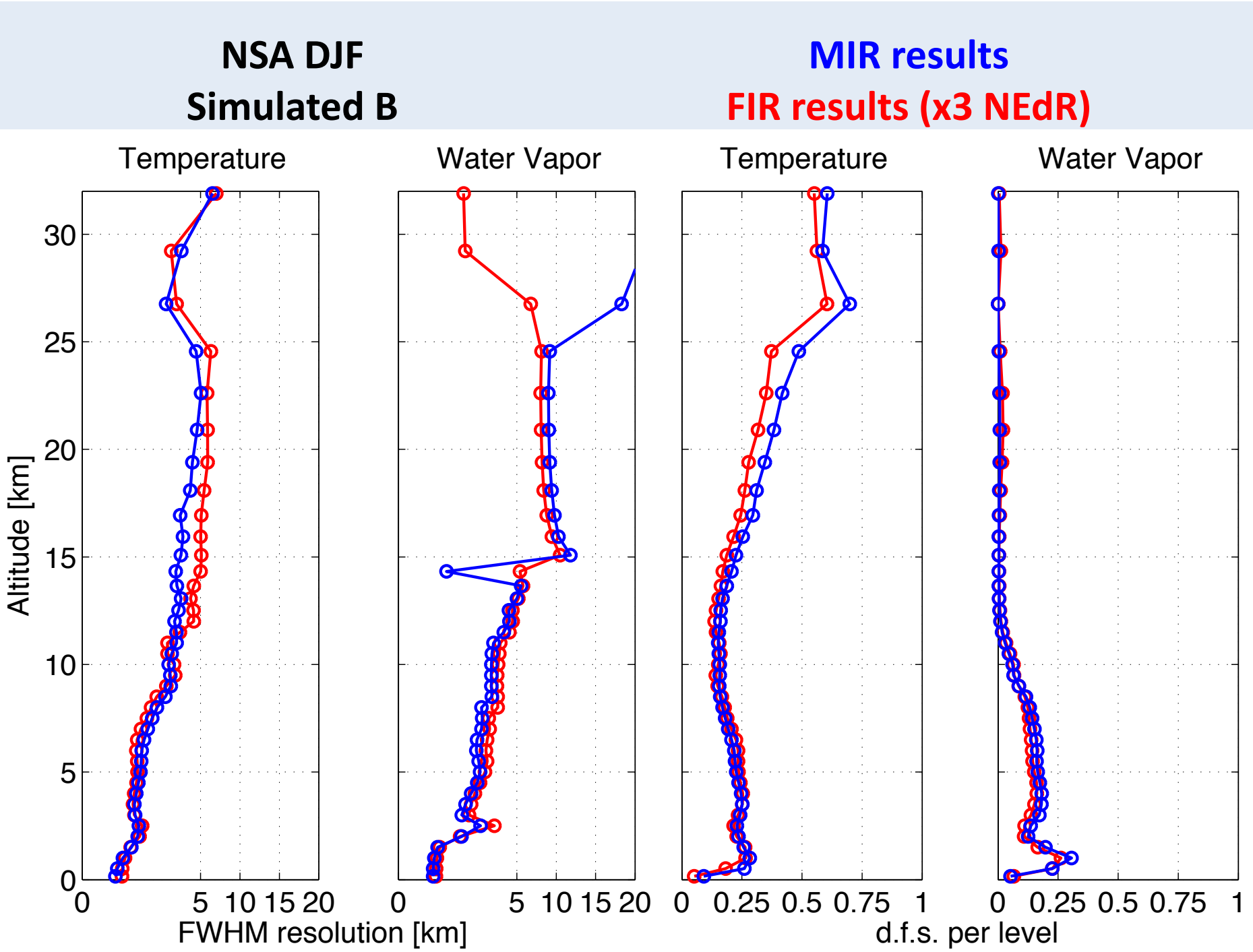
Additional Slides




Darwin DJF
B from radiosondes
MIR results
FIR results (x3 NEdR)
Temperature
Water Vapor
Temperature
Water Vapor
Altitude [km]
0
5
10
15
20
25
30
0
5
10
15
20
FWHM resolution [km]
0
0.25
0.5
0.75
1
d.f.s. per level


Darwin DJF
Simulated B
MIR results
FIR results (x3 NEdR)
Temperature
Water Vapor
Temperature
Water Vapor
Altitude [km]
0
5
10
15
20
25
30
0
5
10
15
20
FWHM resolution [km]
0
0.25
0.5
0.75
1
d.f.s. per level


NSA DJF
B from radiosondes
MIR results
FIR results (x3 NEdR)
Temperature
Water Vapor
Temperature
Water Vapor
Altitude [km]
0
5
10
15
20
25
30
0
5
10
15
20
FWHM resolution [km]
0
0.25
0.5
0.75
1
d.f.s. per level


NSA DJF
Simulated B
MIR results
FIR results (x3 NEdR)
Temperature
Water Vapor
Temperature
Water Vapor
Altitude [km]
0
5
10
15
20
25
30
0
5
10
15
20
FWHM resolution [km]
0
0.25
0.5
0.75
1
d.f.s. per level