GRAS SAF Open Loop Workshop
Helsingør, Denmark
June 6-8, 2005

DMI Technical Report 05-11
ISSN: 1399-1388
Kent B. Lauritsen and Frans Rubek, editors

Information Content of Radio Occultation Soundings in the Troposphere: Results and Implications for Data Processing

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The 'information content' of measurements as derived from variational retrievals (1DVar) has become a well established tool in data assimilation to infer about the potential impact of existing and future measurements on the quality of NWP analyses and forecasts. For example, the interpretation of information content data for stratospheric radio occultations was fully confirmed in recent data assimilation trials both at the Met Office and ECMWF as well as in validation against, e.g., SABER data.

An information content study for tropospheric radio occultation data presented in this paper shows the - somewhat surprising - result that radio occultations may have a measurable impact in the tropical troposphere below 500 hPa even for large relative bending angle errors in the order of ~30% or ~40% near the ground, as long as the measurements are unbiased. We discuss the sensitivity of this result with respect to the assumed error characteristics and some implications for data providers from an NWP user's point of view.

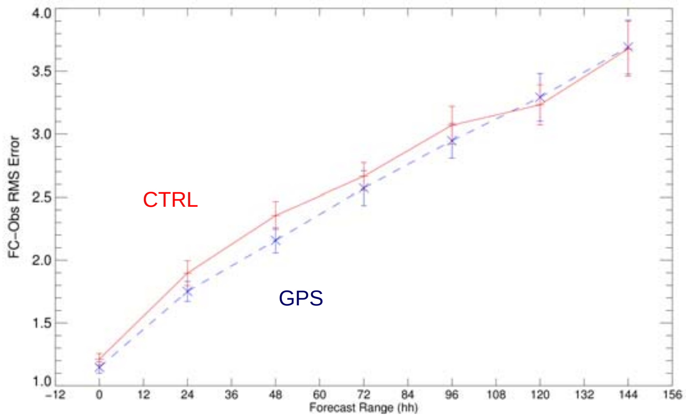
Information content of radio occultation soundings in the troposphere: results and imlications for data processing

C. Marquardt, S. B. Healy, A. von Engeln

- Information content
- What's it good for? Examples from the stratosphere…
- …and the troposphere (i.e., humidity)
- Conclusions

Refractivity assimilation (Met Office)

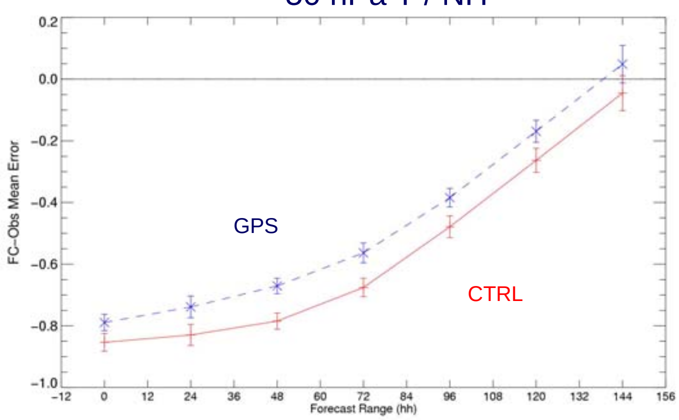
250 hPa T / SH



2 weeks in May/June 2001, Met Office operational system (Healy et al., 2005, GRL)

Refractivity assimilation (Met Office)

50 hPa T / NH



2 weeks in May/June 2001, Met Office operational system (Healy et al., 2005, JGR)

A cautionary note:

- This talk is from a *user's* perspective – and in particular, from an *NWP user's* perspective.
- We think we know some aspects of the atmosphere rather well (temperature, winds), others …(humidity) – well…
- We would like to know what a new observation gives us *on top of what we already know*.
- We call the *additional amount of information* we get by assimilating data its ***information content***.

Variational data assimilation / retrieval

In a variational data assimilation (3DVar, 4DVar) and retrieval (1DVar), we minimise

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x}-\mathbf{x}_b)^{T}\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_b) + \frac{1}{2}(\mathbf{y}_0 - \mathbf{H}[\mathbf{x}])^{T}(\mathbf{E}+\mathbf{F})^{-1}(\mathbf{y}_0 - \mathbf{H}[\mathbf{x}])$$

The solution can be written as

$$\hat{\mathbf{x}} = \left(\mathbf{H}'^{T}(\mathbf{E}+\mathbf{F})^{-1}\mathbf{H}' + \mathbf{B}^{-1}\right)^{-1}\left(\mathbf{H}'^{T}(\mathbf{E}+\mathbf{F})^{-1}\mathbf{y}_o + \mathbf{B}^{-1}\mathbf{x}_b\right)$$

analysis = weighted sum of measurement & ***a priori***

and it's (inverse) error covariance as

$$\mathbf{P}^{-1} = \mathbf{B}^{-1} + \mathbf{H}'^{T}(\mathbf{E}+\mathbf{F})^{-1}\mathbf{H}'$$

analysis accuracy | ***a priori*** accuracy | measurement accuracy

Measuring information content (one way)

- Information is always relative - relative to what we already know, i.e. the *a priori*.
- The error covariance of the analysis / retrieval

$$\mathbf{P} = \mathbf{B} - \mathbf{BH}^{\mathrm{T}}\underline{\left(\mathbf{HBH}^{\mathrm{T}} + \mathbf{E} + \mathbf{F}\right)^{-1}\mathbf{HB}}$$

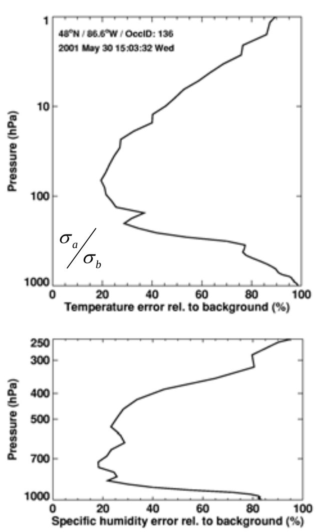
positive definite

i.e. *the retrieval's error is at least as small as (or smaller than) the a priori's error* (if all error covariances are correct, unbiased, etc.)

- A *simple* measure of how much information is contained in a remote sensing measurement is the amount of error reduction obtained in the retrieval, i.e. compare σ_a with σ_b, or look at σ_a / σ_b

retrieval error

RO information content (refractivity)



Theoretical error estimates derived from refractivity based 1DVar.

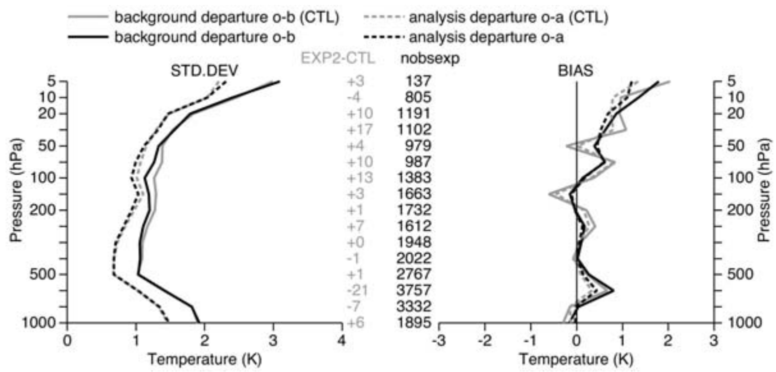
Note: refractivity errors in the lower troposphere to small (1% near surface) compared to more recent work (Kuo et al., Steiner et al., myself). Correlations were also neglected.

What do such studies tell us in practise?

(Marquardt et al, 2003; also see: Healy and Eyre, QJRMS, 2000; Collard and Healy, 2003)

Bending angle assimilation (ECMWF)

Met Office

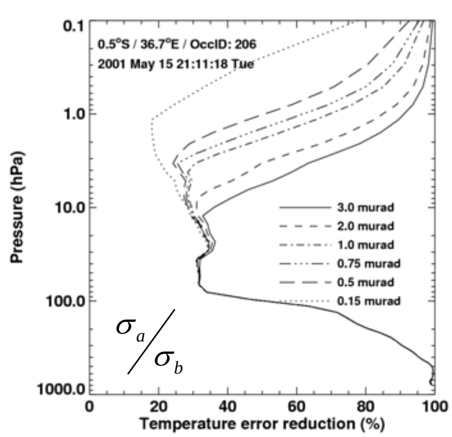


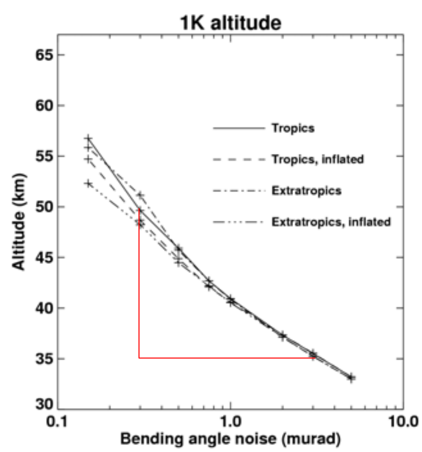
- Analysis & background vs radiosondes over Antarctica (Sep/Oct 2003)
- Note:
  - shown are radiosondes – analysis / bg
  - dark uses radio occultations

(Healy & Thebaut, 2005, QJ)

Information content and upper level noise

Met Office

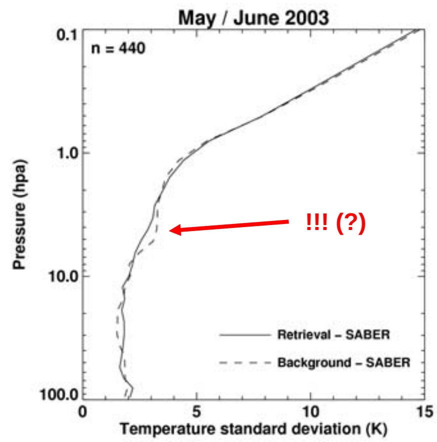




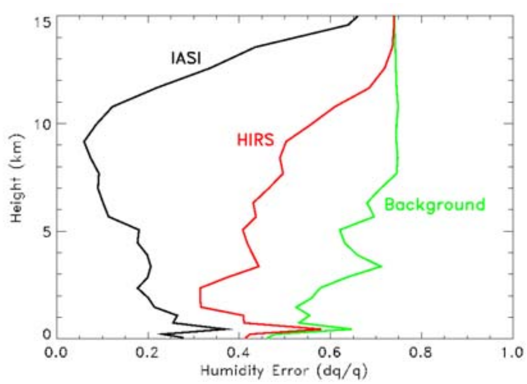
Tropical CHAMP profile

SABER on TIMED

- SABER: *Sounding of the Atmosphere using Broadband Emission Radiometry*
- heritage from LIMS, HALOE, CLAES, ISAMS; passiv limb scanning in the IR (1 – 17 µm)
- In 1DVar:
  - Improvement over background around 5hPa
  - unclear below (consistent with radiosonde comparisons)
- Apparently some strange biases in SABER data



IASI and HIRS information content



(Collard, 1998)

- HIRS: Not used anymore in the Met Office - no impact.
- Information content studies are idealised
- In practice, only massive error reductions in 1DVar studies ensure measurable impact in numerical NWP

ECMWF B

- Globally averaged vertical correlation structure **C** for temperature, humidity, and surface pressure vs. temperature (thanks to M. Fisher, ECMWF)
- Standard deviations (σ) for many variables of the first guess diagnosed operationally by randomisation by ECMWF, available through MARS
- inflate σ's according to forecast time (error doubles in 1.5 days)
- Calculate B via

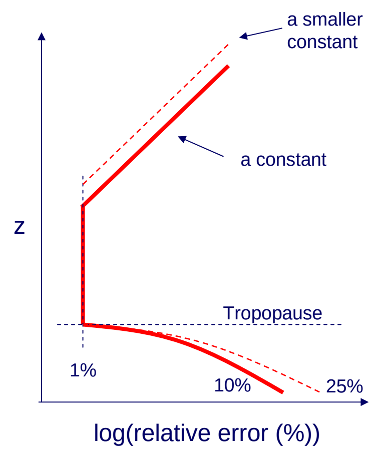
$$\mathbf{B} = \mathbf{D}^{t}\mathbf{C}\mathbf{D}$$

where

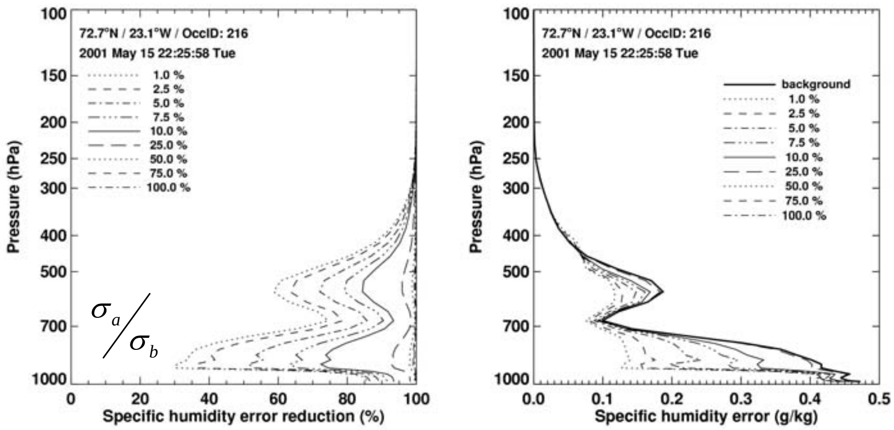
$$\mathbf{D} = \mathrm{diag}(\sigma)$$

"Standard" error model for bending angles

- stratosphere: bending angle errors ~1%, or a constant (whatever is larger); typical constants ~ 3 – 6 μm
- troposphere: increasing linearly towards towards ~ 10%
- similar to refractivity errors as in Kursinski (1997), with Kuo et al. (2003) in mind, and bending angle error ~ 4 x refractivity error, uncorrelated

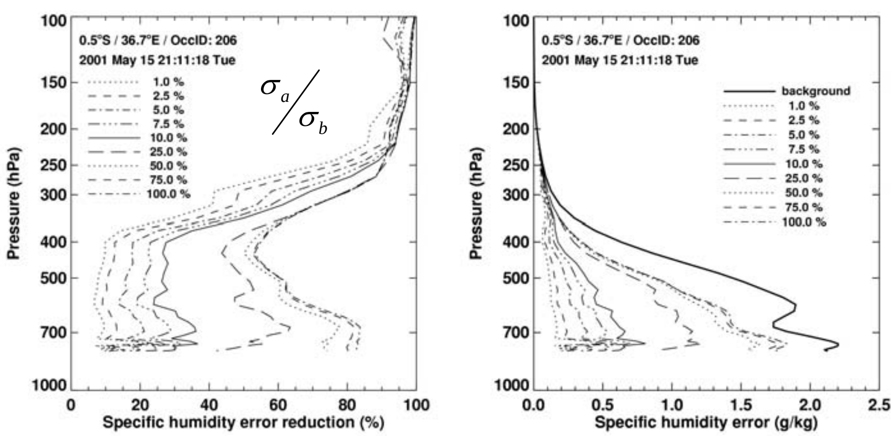


Tropospheric information content / NH



NH high latitude CHAMP profile

Tropospheric information content / tropics

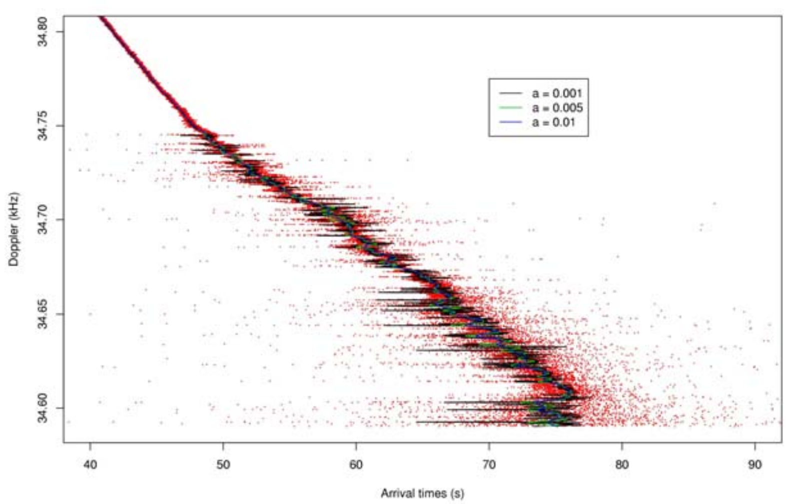


Tropical CHAMP profile

Conclusions (I)

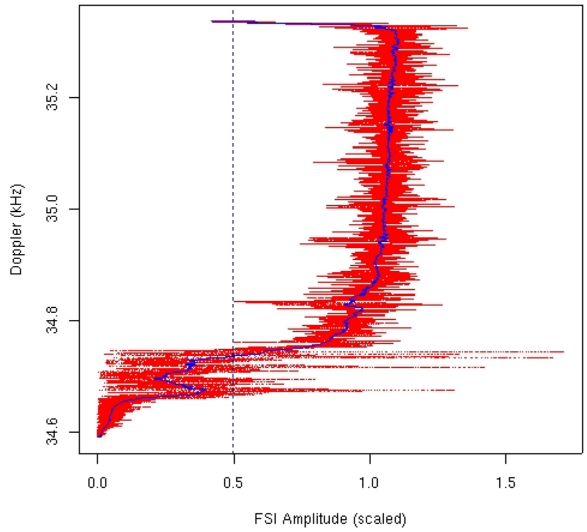
- Information content studies are *idealised studies!*
- As much as the "standard" error model is realistic (for the troposphere): we would expect
  - little or no impact of RO soundings in high latitudes
  - some impact in the tropics below ~400 - 500 hpa, even if relative bending angle errors are larger than 10% (say 30 – 40%; and are unbiased and normally distributed)
- Correlations decrease the impact of observations

Noise in FSI processing

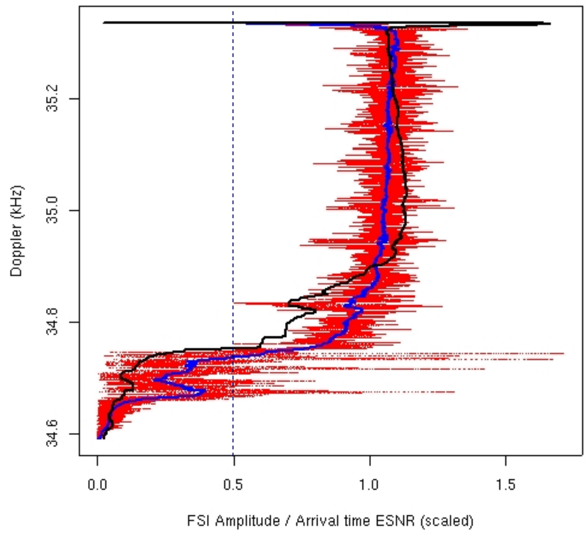


Upsampled FSI arrival times vs. doppler

Amplitude as cut-off criterium



Amplitude as cut-off criterium



Conclusions (II)

- Experience with CHAMP data (Axel) suggests tropical profiles are often cut off at 6 – 8 km (50% criterium).

- Data quality doesn't degrade immediately…
- …so don't cut it off – we might be able to use it.

- Variational methods can handle varying degrees of uncertainty in data quite easily,
- ***provided we have a good statistical error characterisation***