Exploiting the high resolution of GRAS limb soundings

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- Why bother with profile retrievals?
- Examples of gravity wave characteristics
- Radio occultations and noise
- Variational retrievals

NWP analyses and short range forecasts

- Simmons and Hollingsworth, 2002:
  - “The implied r.m.s. error of 500 hPa height analyses […and 1 day forecasts...] has fallen well below the 10 m level typical of radiosonde error”
  - on NH *and* SH, for all analyses (varying)
  - due to introduction of 3D/4DVar, direct radiance assimilation, improvements in radiative transfer and modelling
- Simmons et al., 2003:
  - “Analysis error is estimated to be substantially less than radiosonde observation error” […in SH stratosphere during September 2002]
- Best way of using radio occultation data by data assimilation

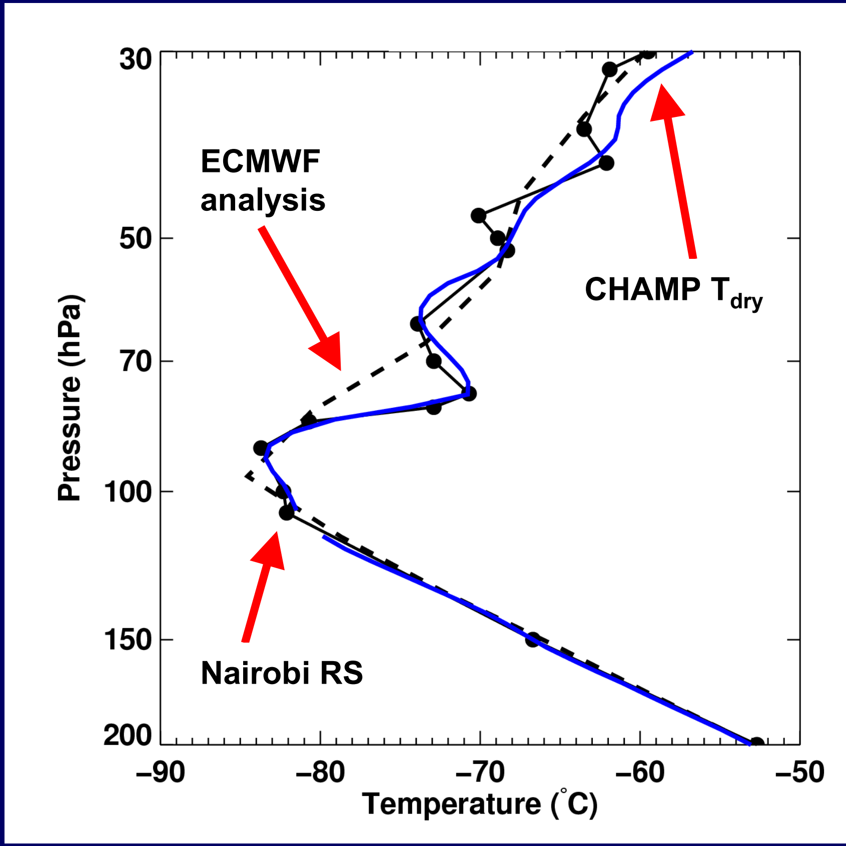
Why bother with profile retrievals?

…because NWP products do not represent everything

- e.g., small vertical scales in the stratosphere are not well resolved
  - tropopause structure
  - gravity waves
- some features are are actively suppressed by initialisation
  - gravity waves

➔ Exploit specific characteristics of GRAS limb soundings on scales not (yet?) or not well represented by NWP models

Example



- CHAMP profile on May 15, 2001, 21:11 UT
- dry (classical) temperature retrieval
- close (~27 km, 2.5 hrs) to Nairobi radiosonde
- Analysis on model levels (L60)

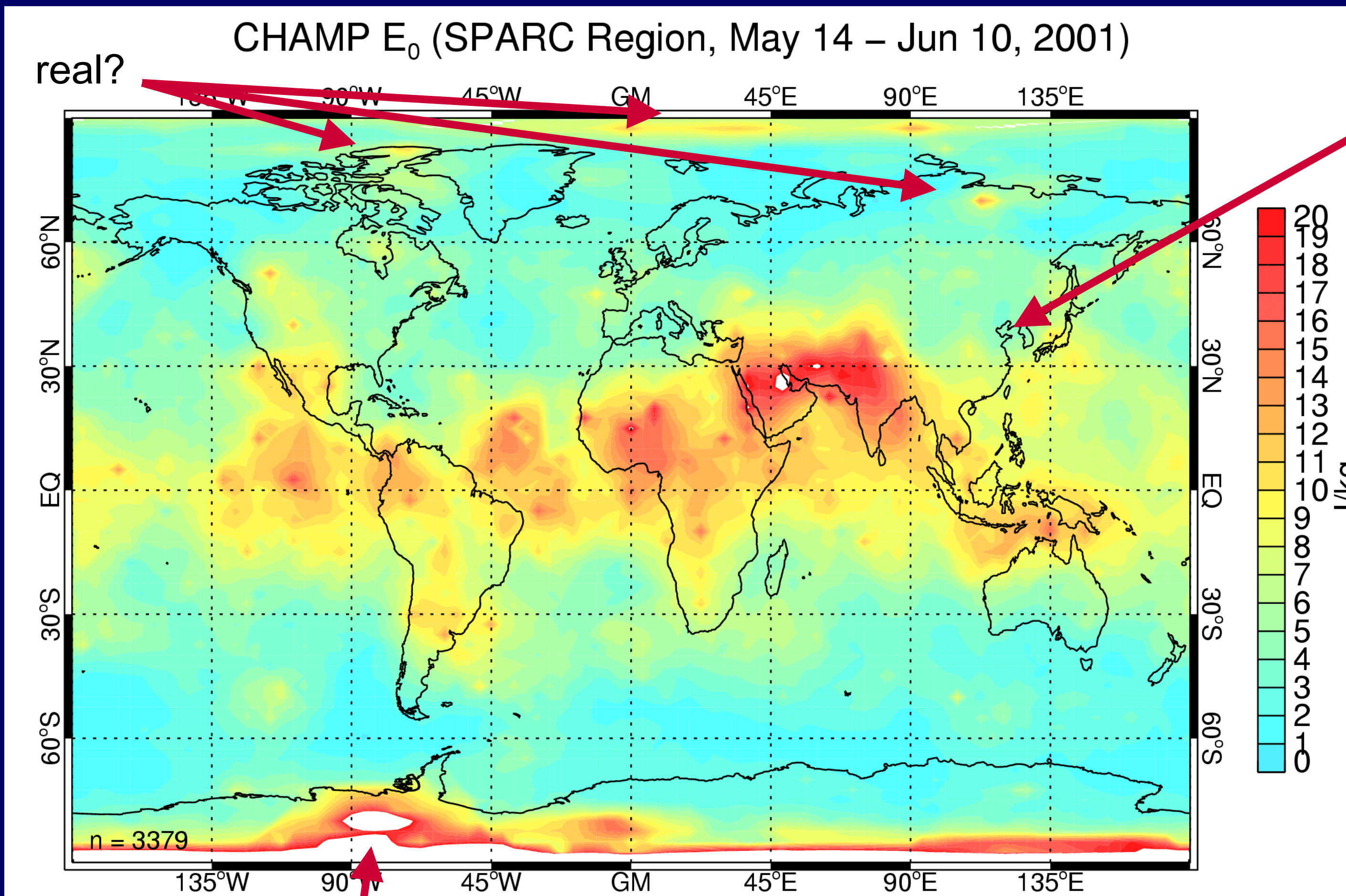
Gravity waves

- all atmospheric fluctuations related to / caused by buoyancy, i.e. with gravity being the restoring force
- cover a wide range of spatial and temporal frequencies
- Generated by mountains (“lee waves”), convection (tropics), and geostrophic adjustment (mid latitudes)
- propagate upwards (until they “break”)
- interact with the zonal mean flow

The problem:

- What’s their climatology (i.e., distribution of their energy density)?

GW energy density (May / June 2001)



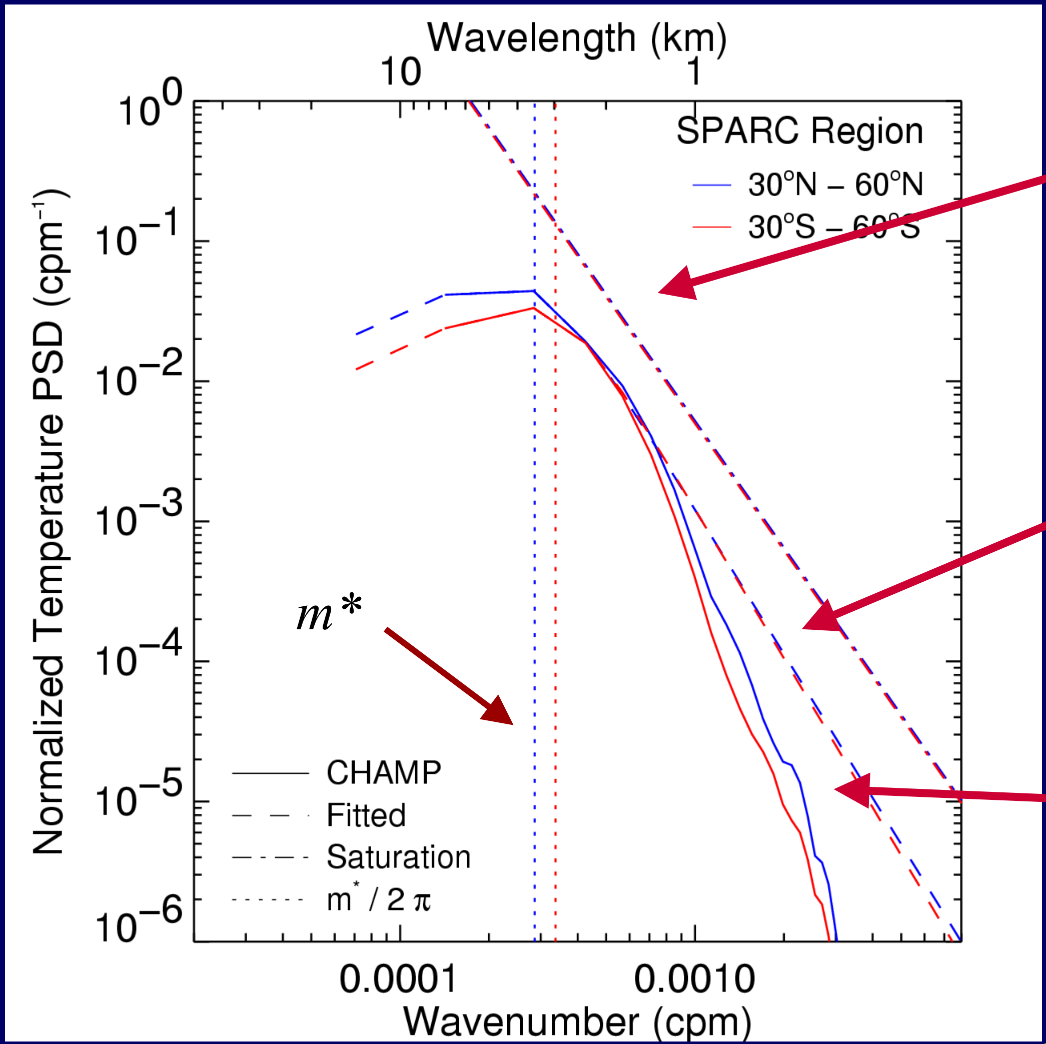
Exit region of the subtropical jet?

Altitude range:

- 7 km, begins
- 2 km above (clim.) tropo-pause
- Manual QC

Artefact? Improper QC?
Only a few profiles...

GW vertical wave number spectra



Saturation limit (Smith et al., 1987)

Fitted Desaubies spectrum (λ_z > 750 m)

Deviation from theoretical slope due to smoothing of excess path delays (Steiner and Kirchengast, 2000)

What's needed...

Ideally,

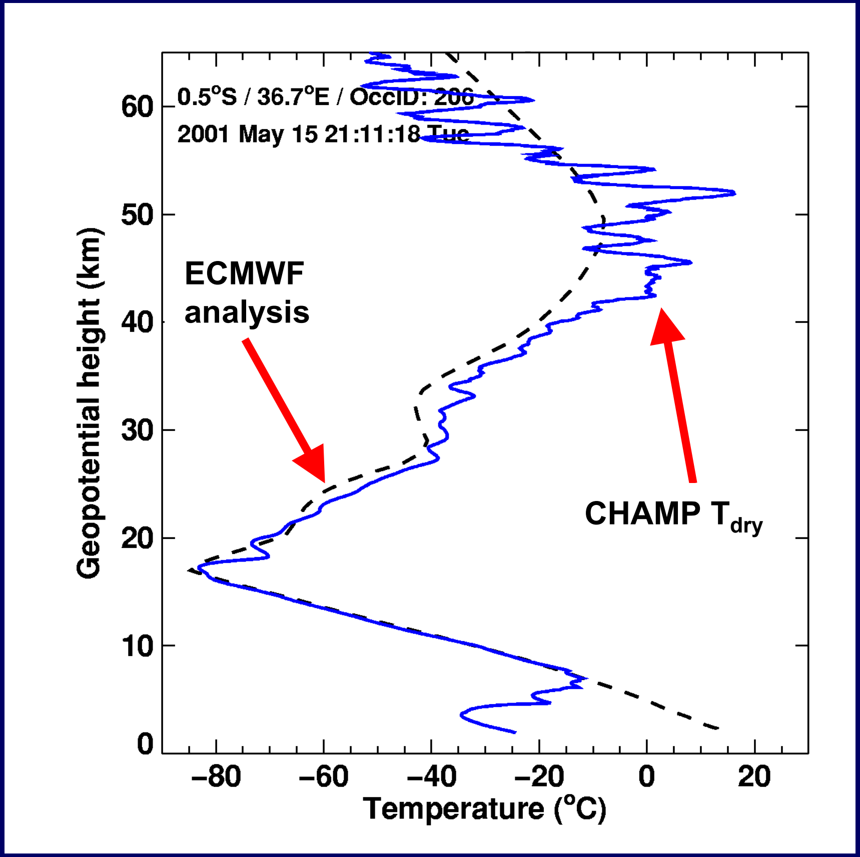
- the "observational filter" (Alexander, 1998) of radio occultation measurements, i.e.

$$\frac{\partial \tilde{\mathbf{x}}}{\partial \mathbf{x}_t}(\mathbf{k}_z) \quad , \qquad \tilde{\mathbf{x}} \text{ retrieval, } \ \mathbf{x}_t \text{ truth}$$

Heuristically (Tsuda and Hocke, 2002):

- "Tune" smoothing parameters to match expected spectra in the lower stratosphere ("optimised retrieval for gravity waves")
- interprete results
  - Saturation theory might be wrong for vertical wavelengths < 2km

Example (cont'd)



- CHAMP profile on May 15, 2001, 21:11 UT
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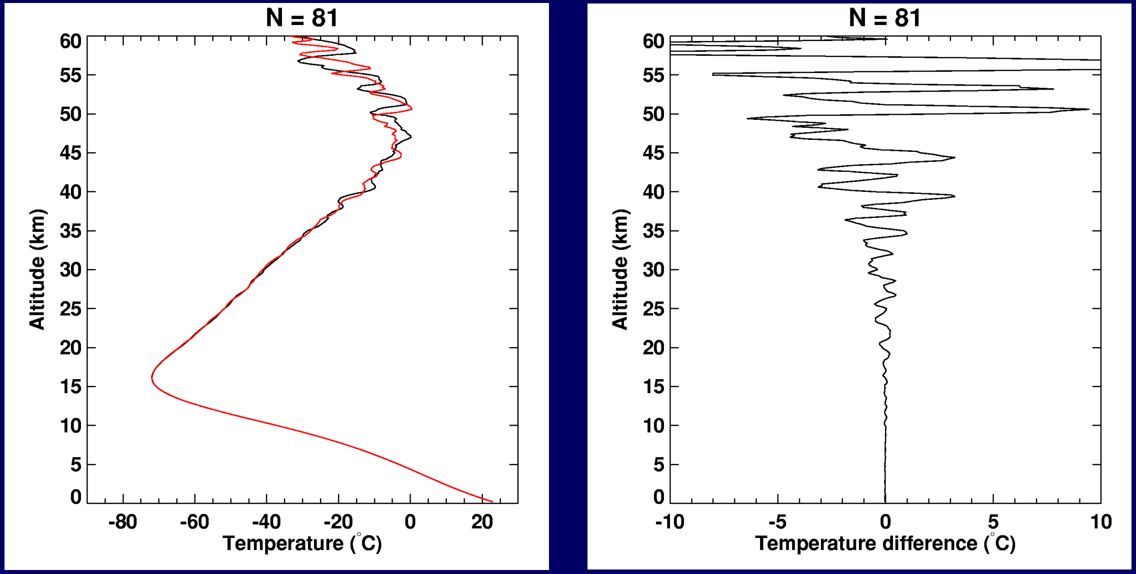
Noise in radio occultation data

- Excess path delay noise (thermal, double differencing,…)
- Ionospheric residual bending angle noise

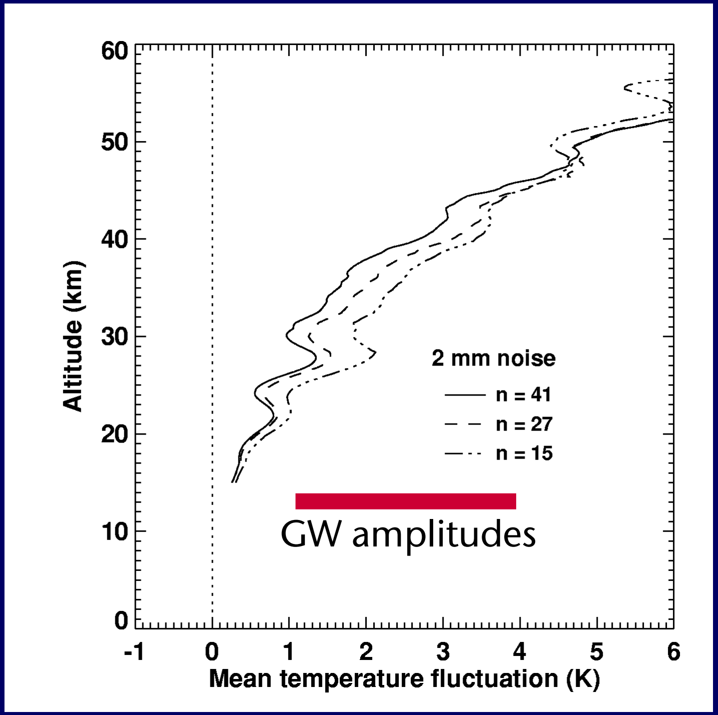


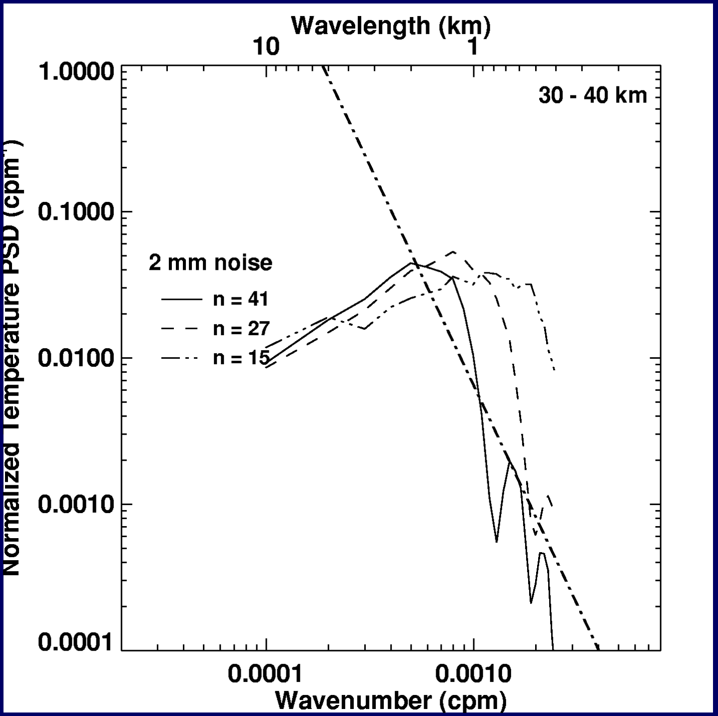
Monte-Carlo simulation:

- Forward modelled path delays through CIRA (and simple ionosphere) with GO ray tracer, CHAMP orbits
- Gaussian random noise added
- dry retrieval

Randomly selected examples from MC simulation
• Gaussian path delay noise 2 mm / 2.3 mm (L1/L2)
• Path delay filter width 1.62 s
• NO simulation of 1Hz / 5Hz spikes as in CHAMP data

Noise and GW parameters



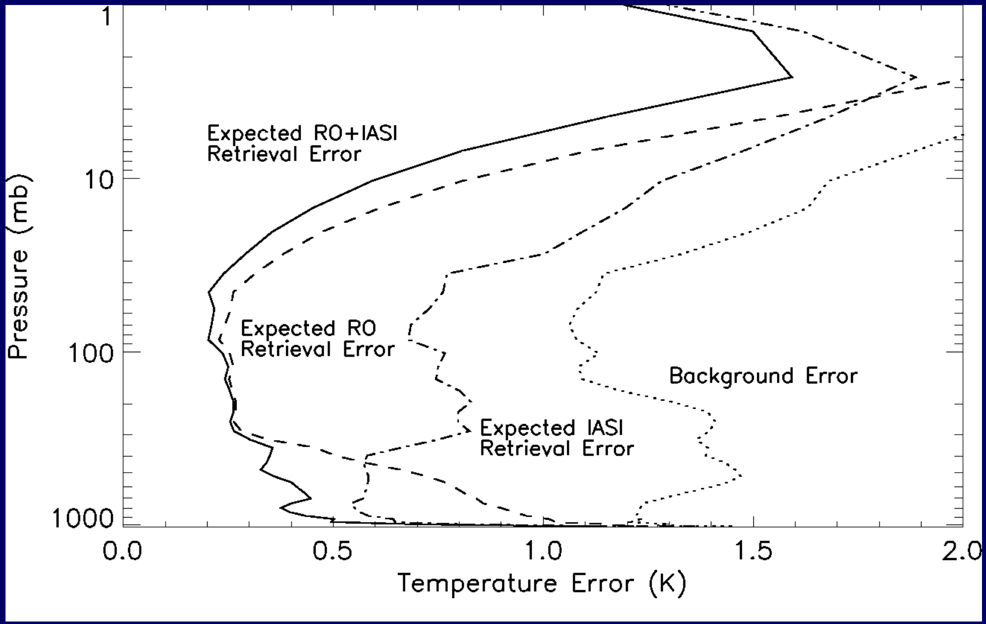


- Above ~30 - 35 km, "GW signal" contaminated by noise
- Probably no GW interpretation possible for wavelengths < 2 km

What can we do?

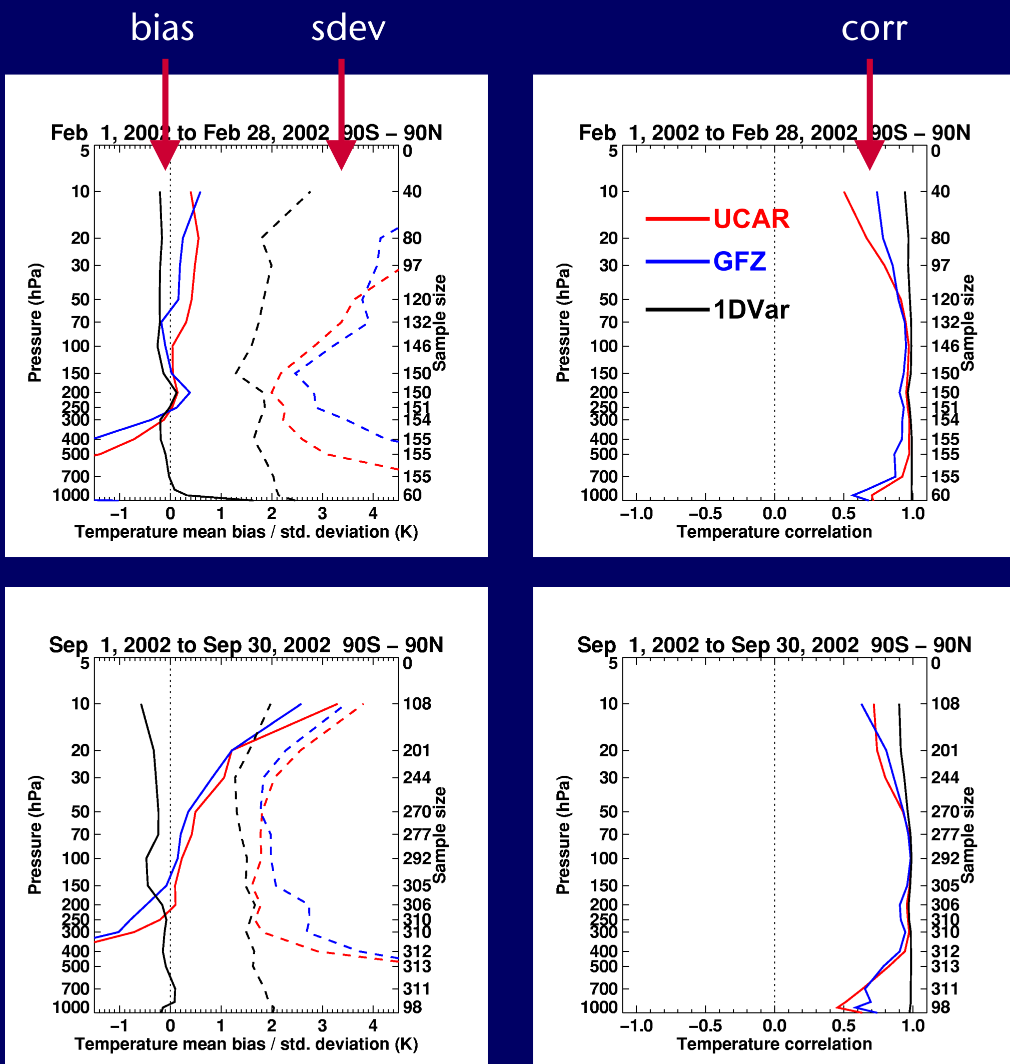
- Gravity wave problems are consistent with the estimated information content of RO.
- If the signal is smaller than the noise, we can't retrieve it.
- Use retrieval methods that
  - take noise into account properly,
  - provide suitable diagnostics (like error characteristics, resolution, observational filter, QC, ...)

➔ 1DVar



(Collard and Healy, 2002, QJRMS, in print)

1DVar

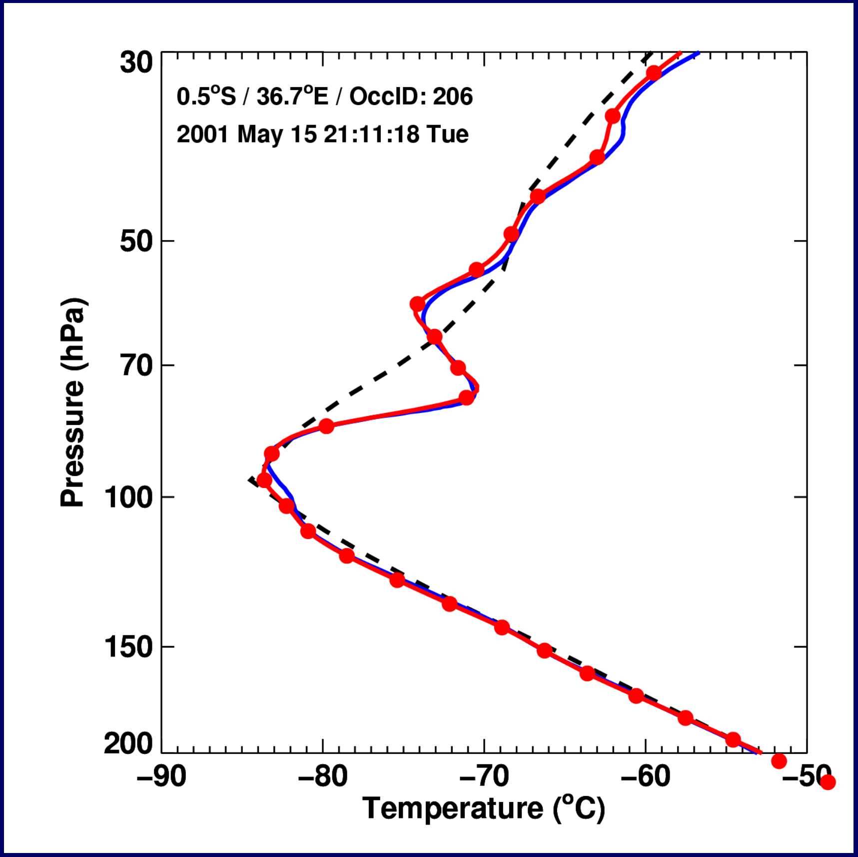


- Based on refractivity (from GFZ excess phases)
- observation errors follow Kursinski et al. (1997)
- 60 / 90 vertical hybrid levels, surface - 65 km (L90: thanks to Agathe Untch)
- ECMWF short range forecasts / error estimates
- background error correlations close to operational ones for L60 (thanks to Mike Fisher)

Stats based on a robust M-estimator (Tukey's bi-weight)

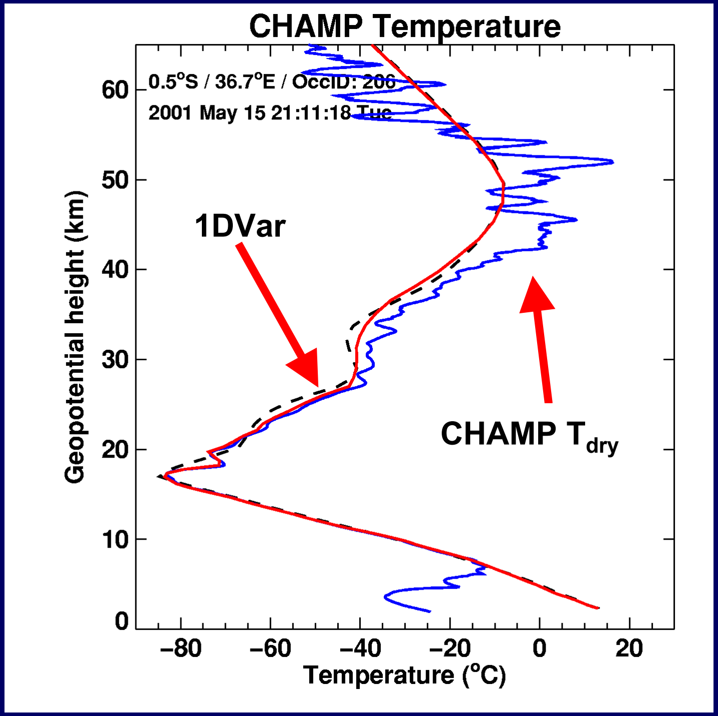
Note: GFZ has an improved version available.

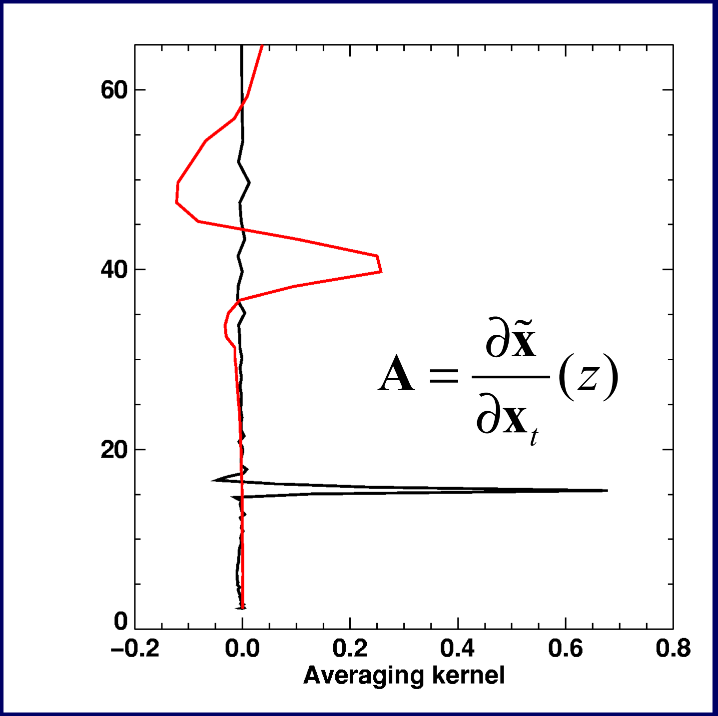
1DVar (cont'd)



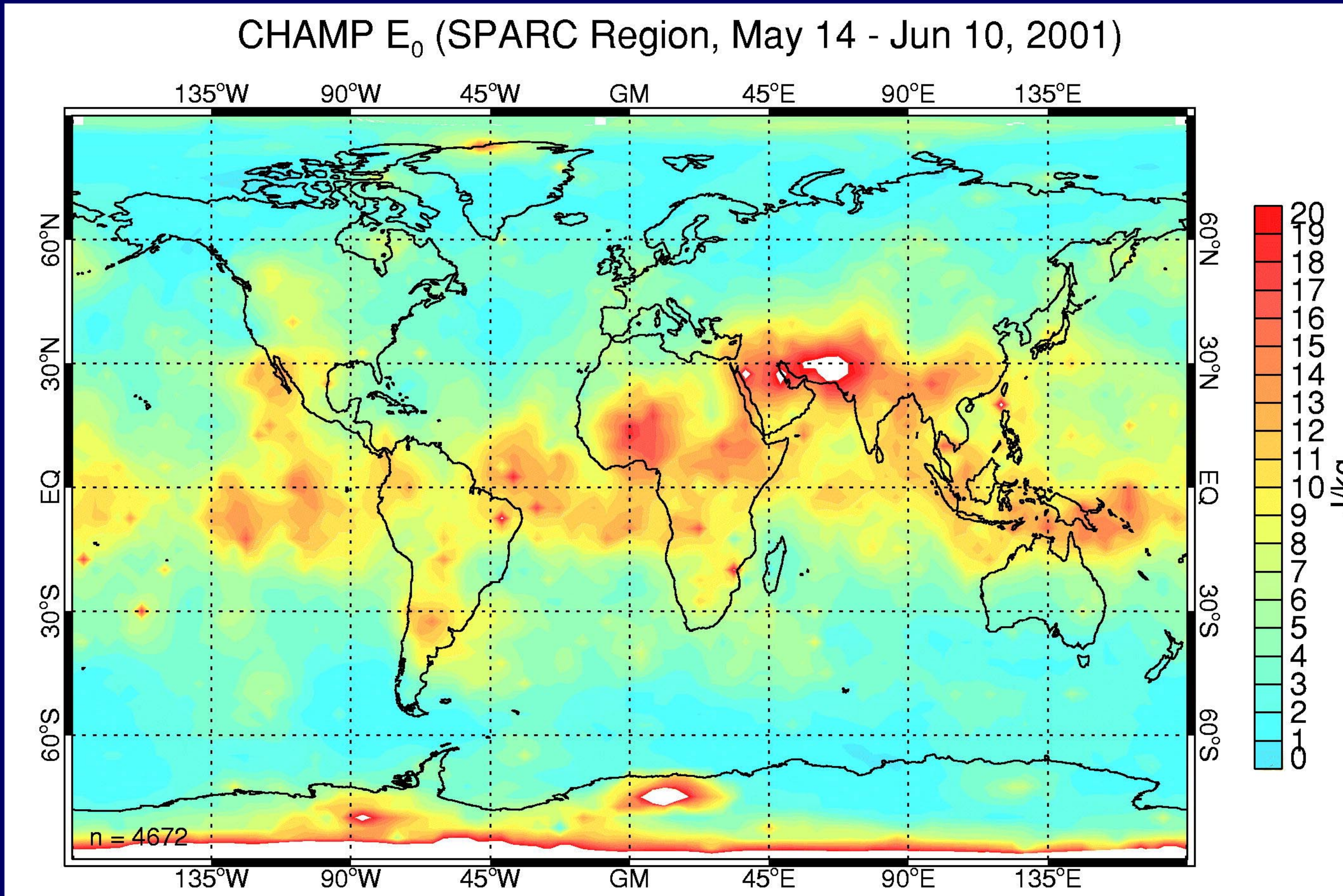
- GW characteristics in the lower stratosphere can be retrieved in a 1DVar using an ECMWF type level structure
- Requires modification of background error covariances
- How to modify them properly?

1DVar (cont'd)



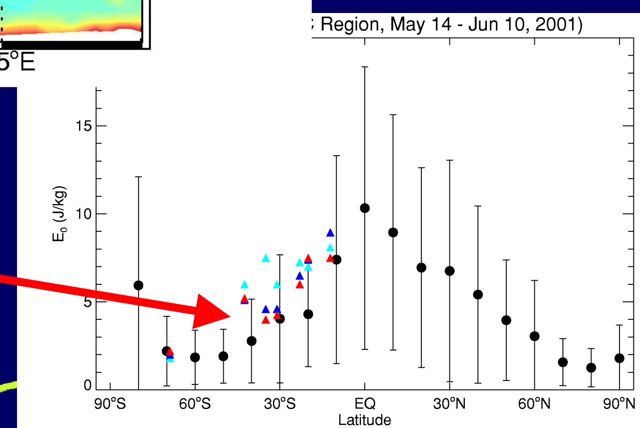


- Lots of diagnostics, e.g.:
  - Averaging kernels for resolution and as "observational filter"
  - Cost function for QC

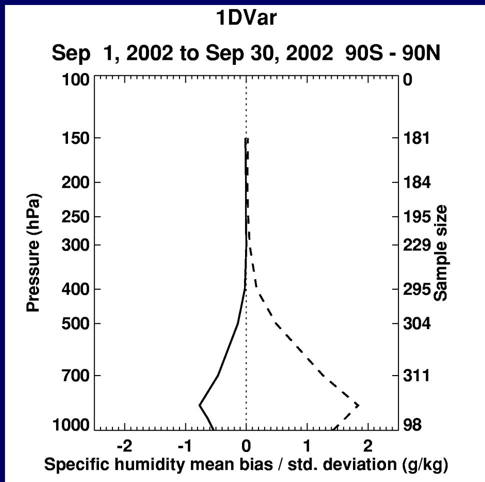


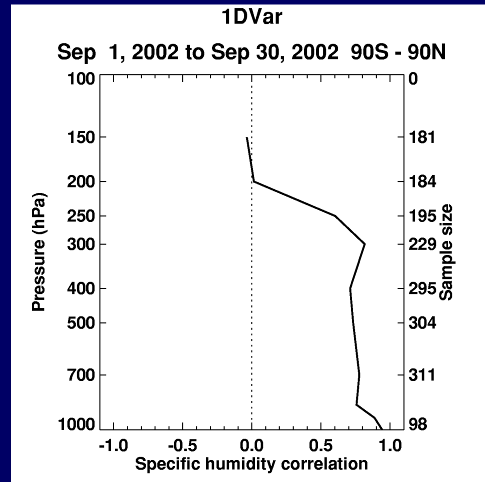
1DVar

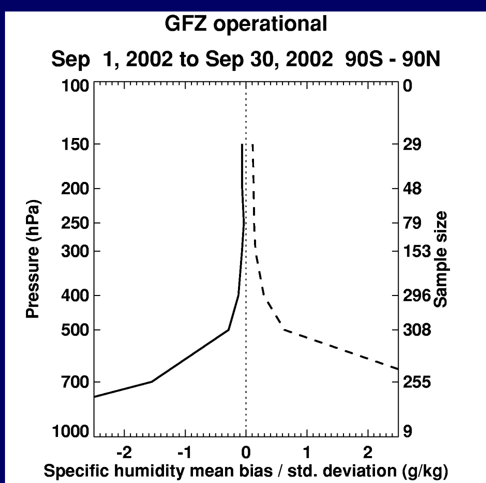
Allen & Vincent (1995)

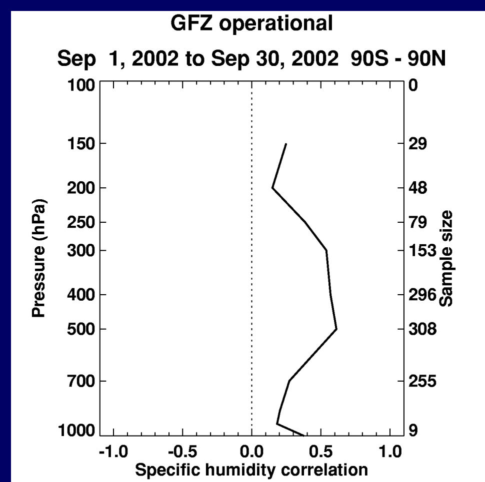


Specific humidity









- 1DVar
  - allows objective QC for biased data (still not good, though)
  - provides humidity *and* temperature information
- “Classic” humidity retrieval
  - large biases
  - highly sensitive to errors in observations and a priori

Stats based on a robust M-estimator (Tukey’s biweight)

Conclusions

- GW parameters from radio occultation measurements
  - in the lower stratosphere only (consistent with information content)
  - noise ~ GW signal above 30 - 35 km, depending on error characteristics of measurements
  - little or no information on vertical scales < 2km (for phase retrieval)
- Dry retrieval
  - sensitive to noise
  - no diagnostics to distinguish between signal and noise
  - no “observational filter”
- Variational retrieval
  - may provide gravity wave retrieval if set up properly
  - averaging kernels (i.e., “observational filter”), QC

