New perspectives on gravity wave remote sensing by spaceborne infrared limb imaging

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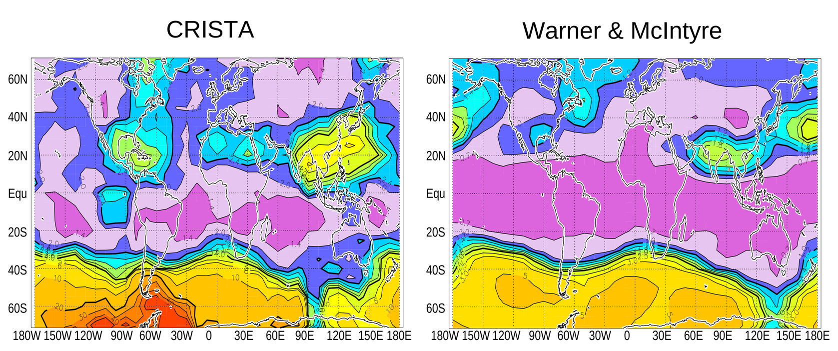
Gravity wave remote sensing from space now has reached a stage of maturity that it can be used to confine GW modeling. This is in particular due to global distributions of absolute values of GW momentum flux from the infrared limb sounders CRISTA and HIRDLS and due to images of the horizontal wave field provided by nadir viewing instruments such as AIRS and AMSU. The logical step forward is an Infrared Limb Imager which combines the good vertical resolution of limb sounding with imaging capabilities. In this poster we investigate:

- How will an Infrared Limb Imager (ILI) advance measurements of GW momentum flux?
- How important is the regular, 3D sampling for the accuracy of momentum flux?
- How important is the range of the GW spectrum covered by the ILI? and by all satellite instruments combined?
- Which additional benefits has GW limb imaging?
- How does an ILI compare to other measurements of GW momentum flux?

A corresponding paper is in preparation. Please contact **p.preusse@fz-juelich.de** for preprints

Heritage: CRISTA

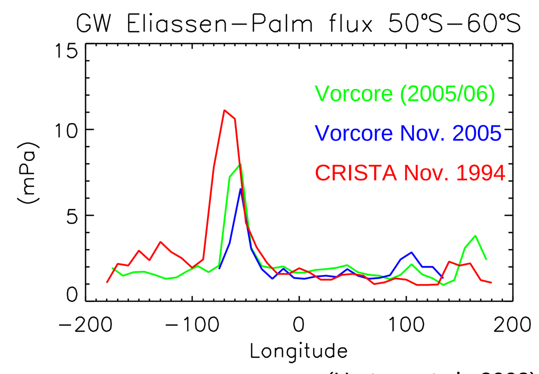
CRISTA-2, August 1997 $F \propto \frac{\lambda_z}{\lambda_h}(T')^2$



Absolute Values of Momentum Flux [mPa]

CRISTA measurements can be used to confine tunable parameters of W&M *Ern et al., JGR, 2004, 2006*

Cf. direct measurements of $u'w'$

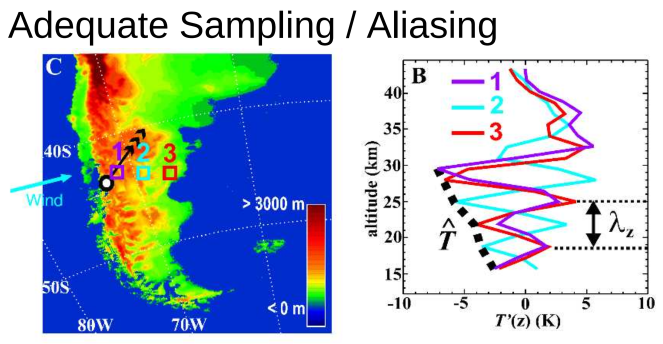


(Hertzog et al., 2008)

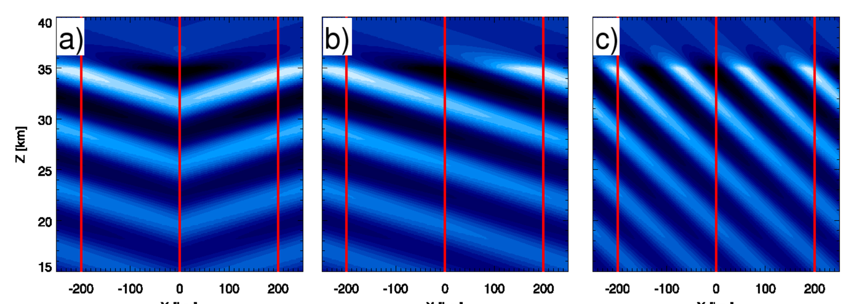
CRISTA-1: Unusual strong GWs above South America; Agreement well inside errors. *Hertzog et al., JAS, 2008*

How will an ILI advance GW momentum flux measurements?

Adequate Sampling / Aliasing

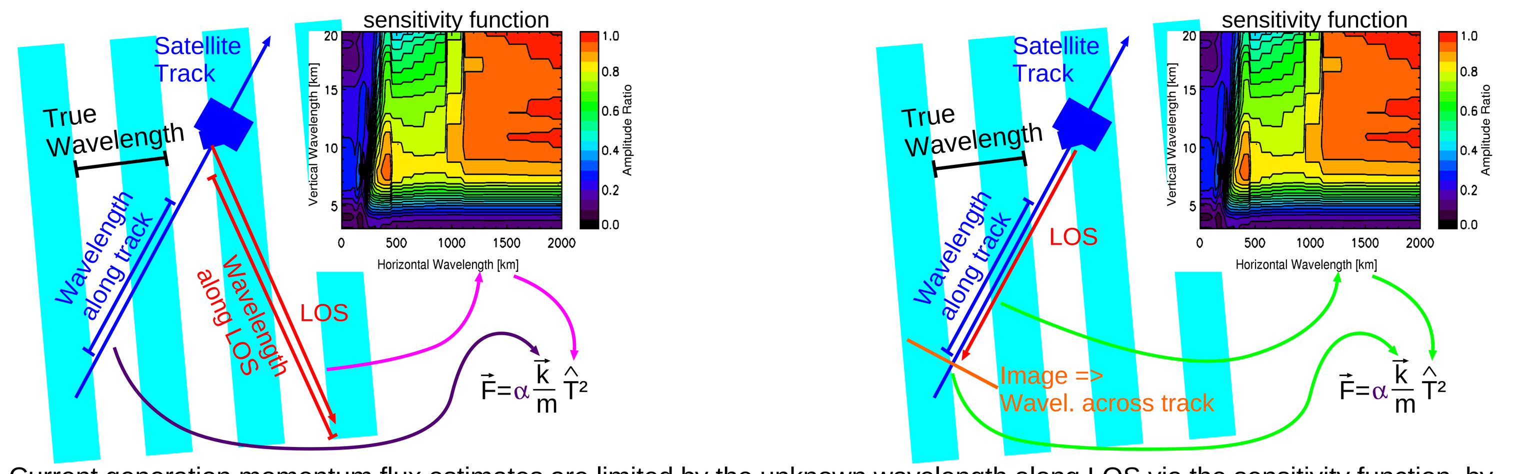


Subsequent profiles have opposite phases. At 200 km horizontal sampling distance this suggests 400 km wavelength. The figure to the right shows alternative reconstructions of the wave field all compatible to the measured profiles. *Eckermann and Preusse, Science, 1999*



Combining several orbits and knowledge about GW physics we find that the right panel most likely corresponds to the real atmosphere. Since momentum flux is inversely proportional to the horizontal wavelength, the difference between panels b) and c) is a factor of 3.

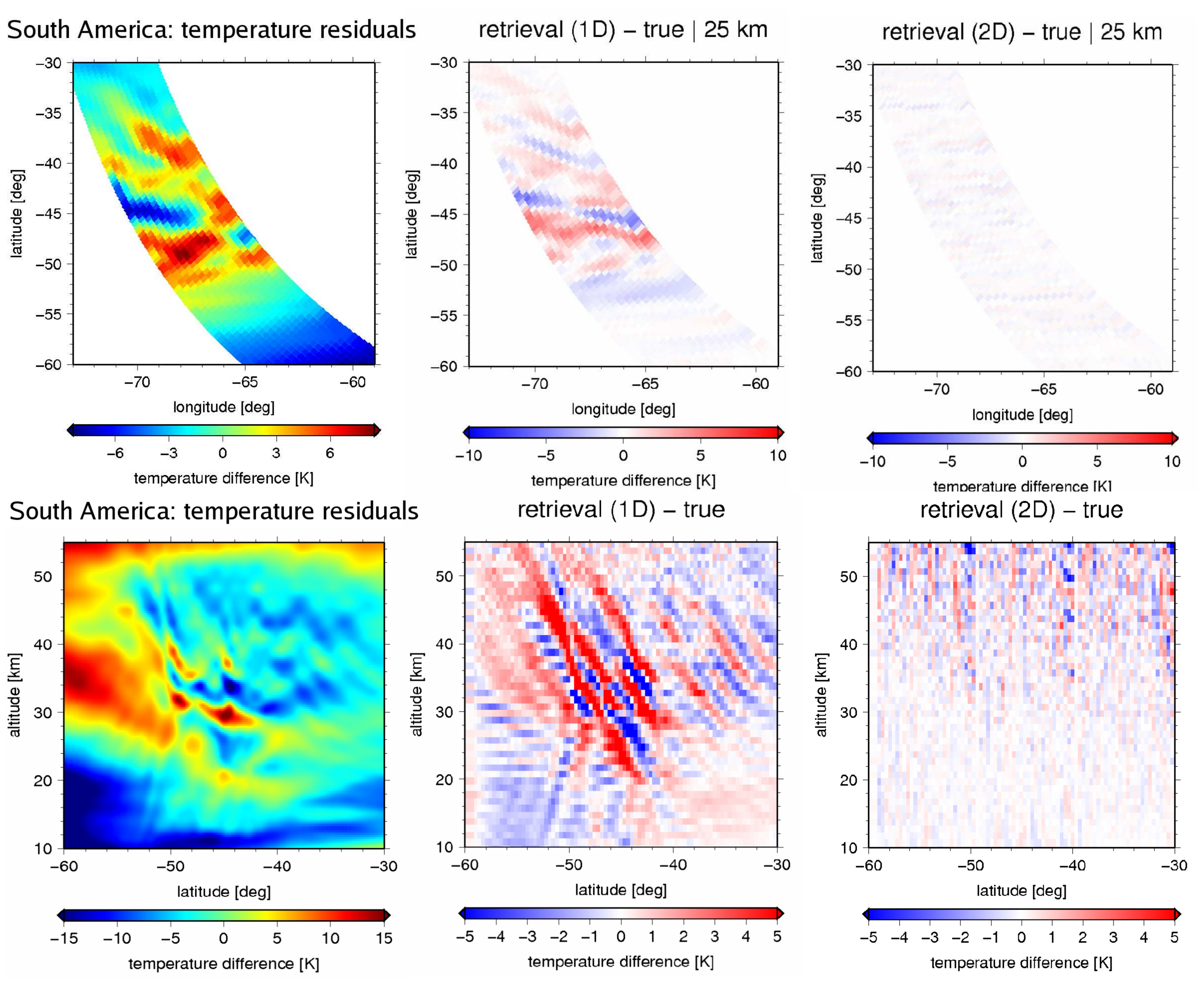
Knowledge of the along LOS wavelength; knowledge of the full wave vector



Current generation momentum flux estimates are limited by the unknown wavelength along LOS via the sensitivity function, by the undersampled wavelength along track via aliasing, and by the unknown true wavelength (true wavevector).

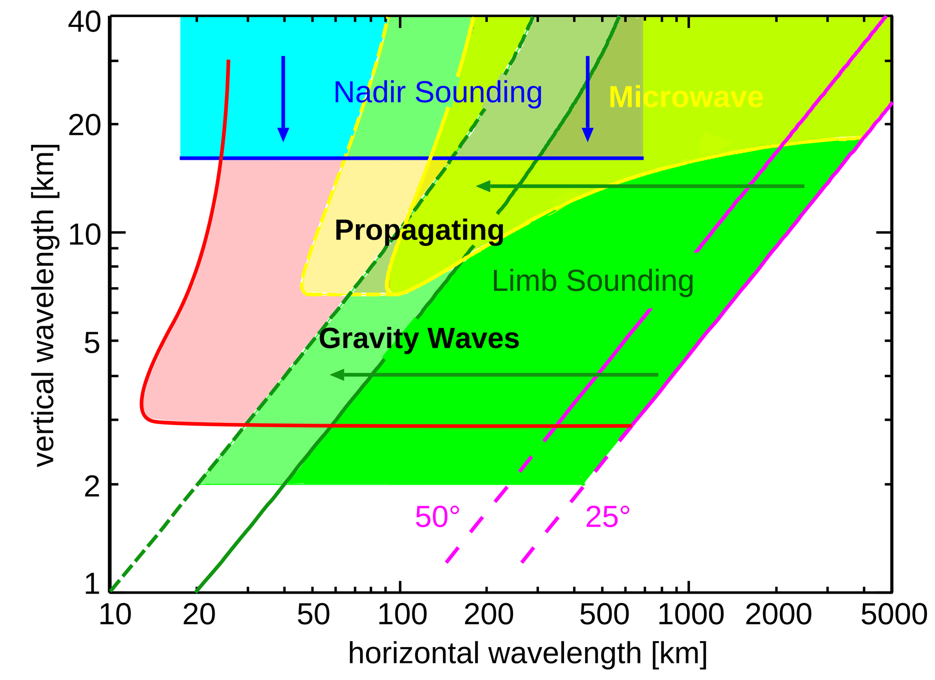
How important is regular, 3D sampling for GW-MF accuracy?

2D (tomographic) retrieval instead of post-corrections



2D retrievals can only be performed on densely sampled backward views. In addition to amplitude degradation 1D retrievals induce phase shifts. As long as these are consistent GW momentum flux can still be deduced, but **Multiple viewing directions must not be combined for GW analysis!**

How important is the range of the GW spectrum covered by the ILI? and by all satellite instruments combined?



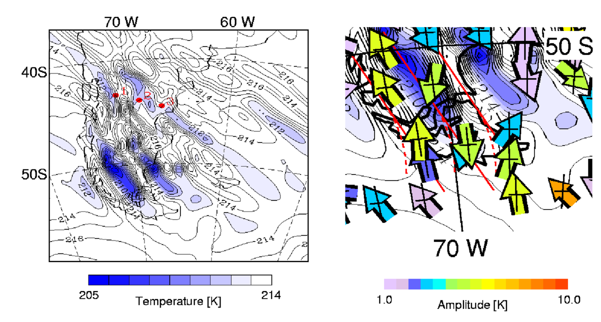
Which waves can reach the MLT?

Gravity waves are the main dynamical driving force of the mesosphere and lower thermosphere (MLT). However, not all GWs can reach the MLT. Slow phase speed waves (having short vertical wavelengths in the stratosphere) dissipate at low altitudes, short horizontal wavelength waves are evanescent or will be reflected. The red lines show the range of GWs which can reach the mesosphere. Limb sounding covers a large and important part of this range. It can be complemented by optically dense microwave limb sounding and nadir viewers. (Preusse et al., JGR, accepted).

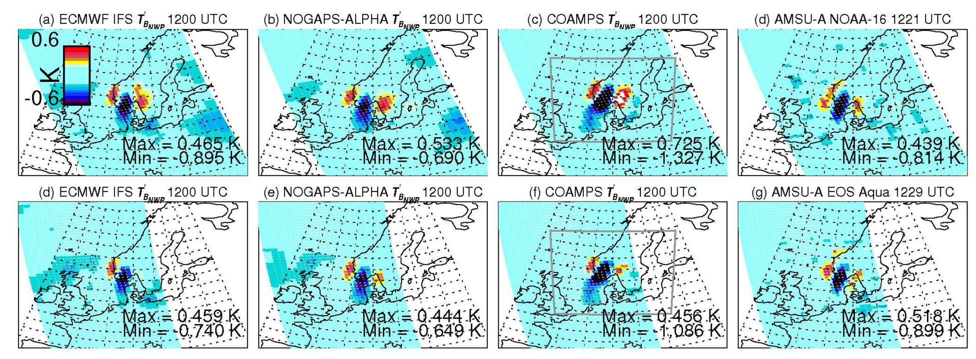
Together different remote sensing techniques can cover almost the complete range of propagating GWs.

Which additional benefits has GW limb imaging?

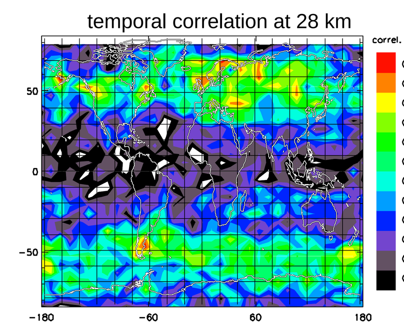
Accurate model tests



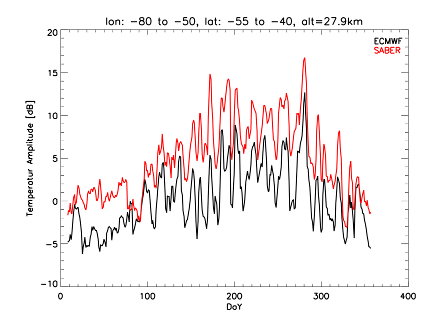
Mountain waves above the Andes modeled by MM5 (isolines and blue shading) and measured by CRISTA (arrows). For CRISTA, arrow direction indicates the phase of the wave, color the amplitude. Horizontal wave fronts in MM5 results correspond to constant phases measured by CRISTA, peak values of 205 to 215 K in MM5 results agree with 5 K amplitudes deduced from CRISTA.



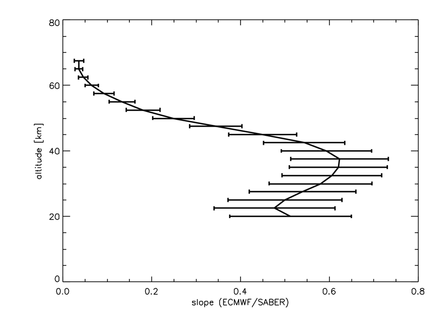
Mountain waves over Scandinavia as observed by AMSU and modeled by three different numerical models. The model data were convolved with the instrument sensitivity function and only contain long vertical wavelength GWs. The imaging data provide an accurate model test. However, note that this was an unsual wave event with exceptional long vertical wavelengths. Also, unfiltered model results reveal additional structures (not shown).



Correlation of time series in boxes of dlat=5°, dlon=10°, dalt=2 km and dt=3 days. Orographic forcing can be identified.



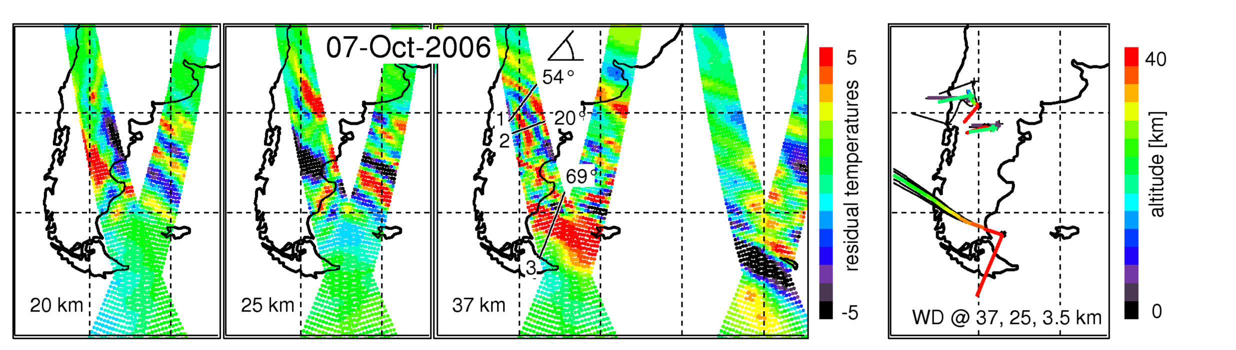
Time series of GW squared amplitudes above the Andes. Fine structures of the temporal evolution are captured. However, there is an offset of 4-6 dB corresponding to an underestimate of GW amplitudes by a factor 3-4 by ECMWF.



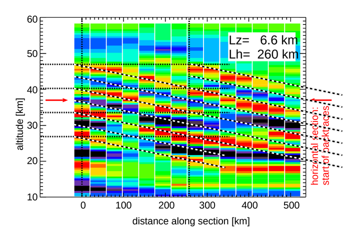
Altitude profiles of the ratio of GW squared-amplitudes modeled by ECMWF and measured by SABER reveals too strong wave dissipation in ECMWF.

Gravity wave measurements from limb sounding as well as nadir viewing satellite instruments have been employed in case studies of GW mesoscale modeling. Of particular value are such measurements which provide horizontal phase informations (cf. the two shown examples as well as recent work on typhoon generated GWs by So-Young Kim, Hye-Yeong Chun and Dong Wu). High resolution global modeling resolves waves with horizontal wavelengths longer than O(100 km) and vertical wavelengths longer than O(2 km). This is well matched by the observational filter of IR limb sounding.

Source identification by backtracing



ECMWF data sampled onto an ILI measurement grid for 20, 25 and 37 km altitude. For 37 km altitude three lines indicate positions perpendicular to the phase fronts, for which vertical sections were obtained. Using the directions, horizontal wavelengths and vertical wavelengths (the latter from the vertical sections) the waves are completely characterized and backward ray tracing can be performed (right panel). Backtraces for the best estimates are given in color, error variations are given in black. Events 1 and 2 are likely mountain waves, whereas event 3 has a different forcing mechanism. Note that for events 1 and 2 the wave direction is turning in both, the ray-tracing as well as the full model data.



ILI sampled ECMWF data along section 1. The dominating wave fronts can be identified. However, the wave field is more complex and sophisticated analysis methods have to be developed.

How does an ILI compare to other measurements of GW momentum flux?

	$u'w'$	MFlux	spatial coverage	altitudes	spectral cov.	temporal
In-Situ						
Radio Sonde	-	+	no ocean	<30 km	λ_z <10 km	+
Rocket Sondes	-	+	no ocean	<50 km	λ_z <10 km	-
Res. Aircraft	+	+	few campaigns	ca. 20 km	λ_h <500 km	-
Super P Balloon	+	+	SH/Eq.	ca. 20 km	in future: +	0
Ground-Based						
Airglow Imager	-	+	O(10) stations	86, 95 km	λ_h <100 km	good weather
Radar	+	+	O(10) stations	<20; >70 km	τ <10 h	0
Lidar	+	+	O(1) stations	85-100 km	τ <14 h	good weather
Satellite						
Nadir	-	?	global	20-40 km	λ_z >14 km	+
GPS	-	No!	global	10-30 km	λ_h >100 km	0
Microw. SubL	-	Abs. ?	global	15-70 km	λ_z > 9 km	+
Infrared Limb	-	Abs.	global	15-60(90) km	λ_h >100 km	+
Limb Imager	-	Yes!	global	15->60 km	λ_h >100 km	+

Direct measurements of $u'w'$ can be performed only by highly sophisticated ground based methods available only at a very limited number of sites or from in-situ aircraft and balloon measurements at ~20 km only (radio sonde ascends are too fast to measure w'). Satellites provide global coverage. However, only IR limb-imaging provides spatially and temporally collocated measurements of the same region with the same viewing direction at sufficient vertical resolution.

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