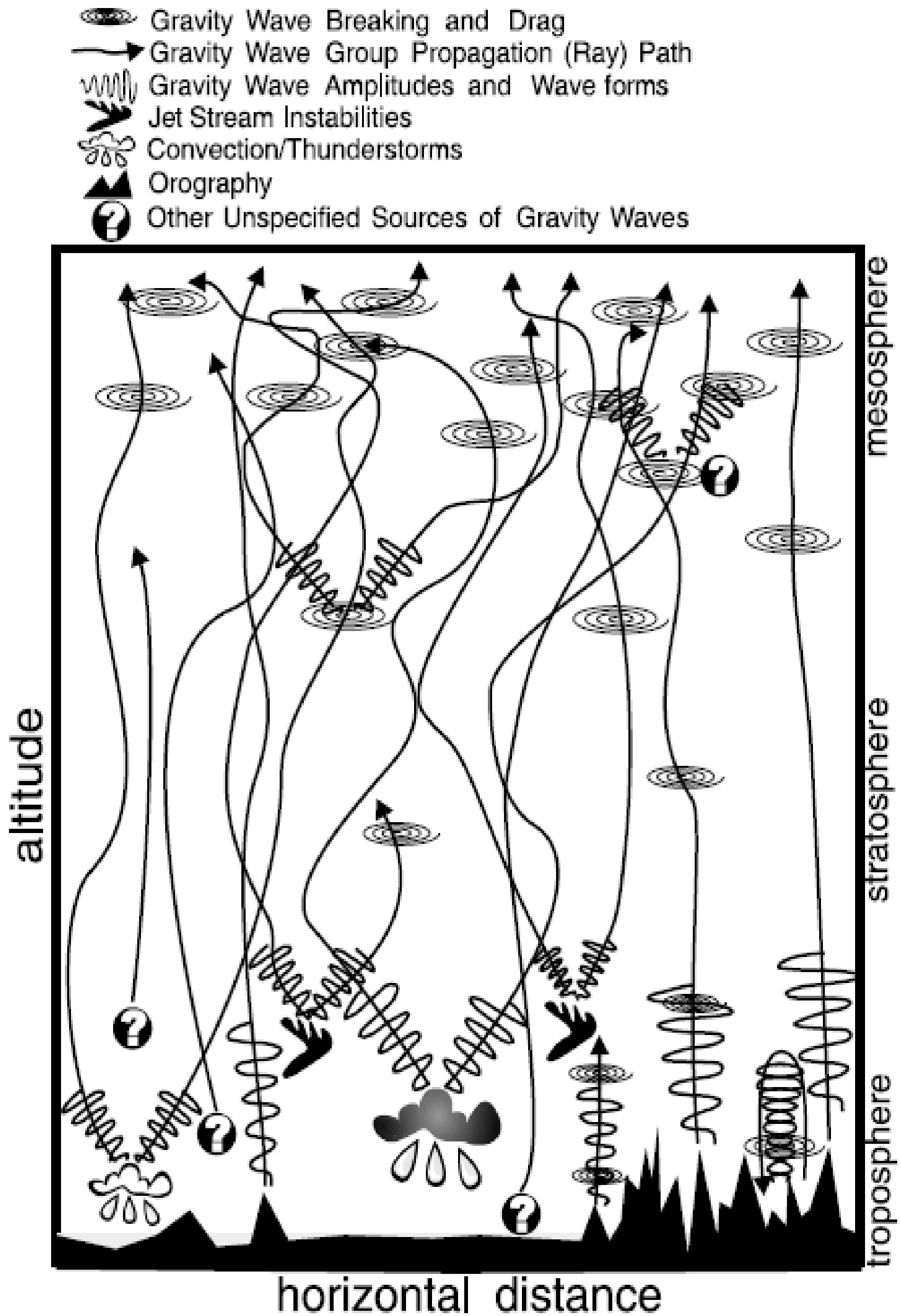
DEEPWAVE Mission overview DLR

Markus Rapp & Andreas Dörnbrack
on behalf of the DLR-IPA-team

DLR/German Aerospace Center
IPA/Institute of Atmospheric Physics



Kim et al., 2003

Scientific Aims

Further advances are needed in quantifying:

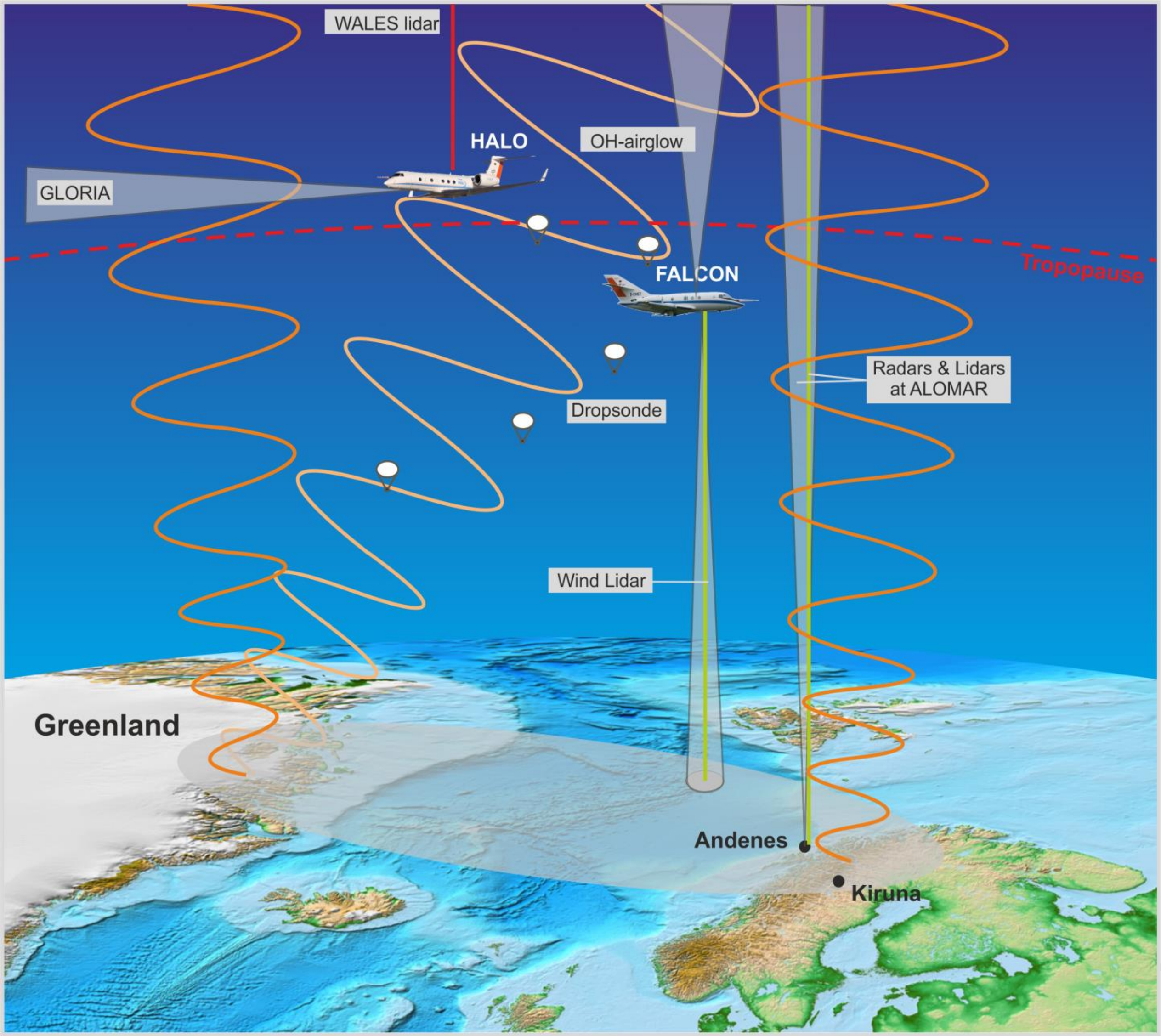
- GW sources
- GW propagation to the middle atmosphere
- GW dissipation
- GW mean flow interaction
- GW parameterizations in numerical models

BMBF Research Initiative: ROMIC 2014 -2017

DFG Research Group: MSGwaves 2014-2020

GW-LCYCLE

ROMIC-cooperative project: DLR, KIT, FZJ, IAP



GW-research at DLR: investigating internal gravity waves by combining airborne & ground based observation with modelling

GEFÖRDERT VOM

Bundesministerium für Bildung und Forschung

ROMIC - Field Campaigns

(1) GW-LCYCLE 1

- 2 – 14 December 2013, Kiruna, Sweden
- DLR Falcon, radiosondes, ground based

(2) DEEPWAVE (NSF, DLR contribution)

- total period: 6 June – 22 July 2014, New Zealand
- DLR Falcon, radiosondes, ground based lidar

(3) POLSTRACC/GW-LCYCLE 2

- winter 2015/2016, Kiruna, Sweden
- coordinated flights of HALO and Falcon
- simultaneous 3 hourly radiosonde launches along a West-East section from Andøya (N), Esrange (S) to Sodankylä (FIN)
- ground-based observations at ALOMAR (radars, lidars), Esrange (lidar, radar), and Sodankylä (lidars)

Deep propagation of internal gravity waves above New Zealand

German-Austrian contributions to DEEPWAVE-NZ

Photo: Sonja Gisinger

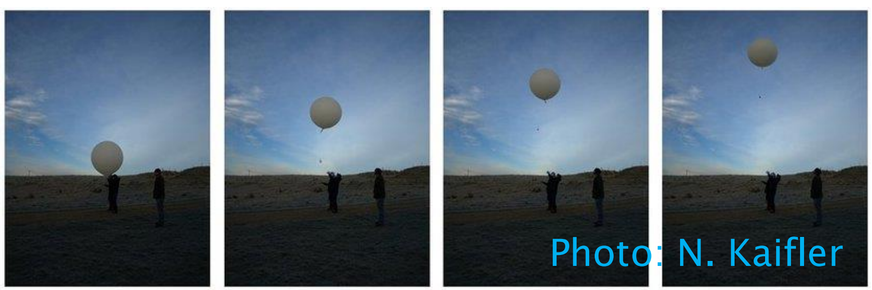


Photo: N. Kaifler

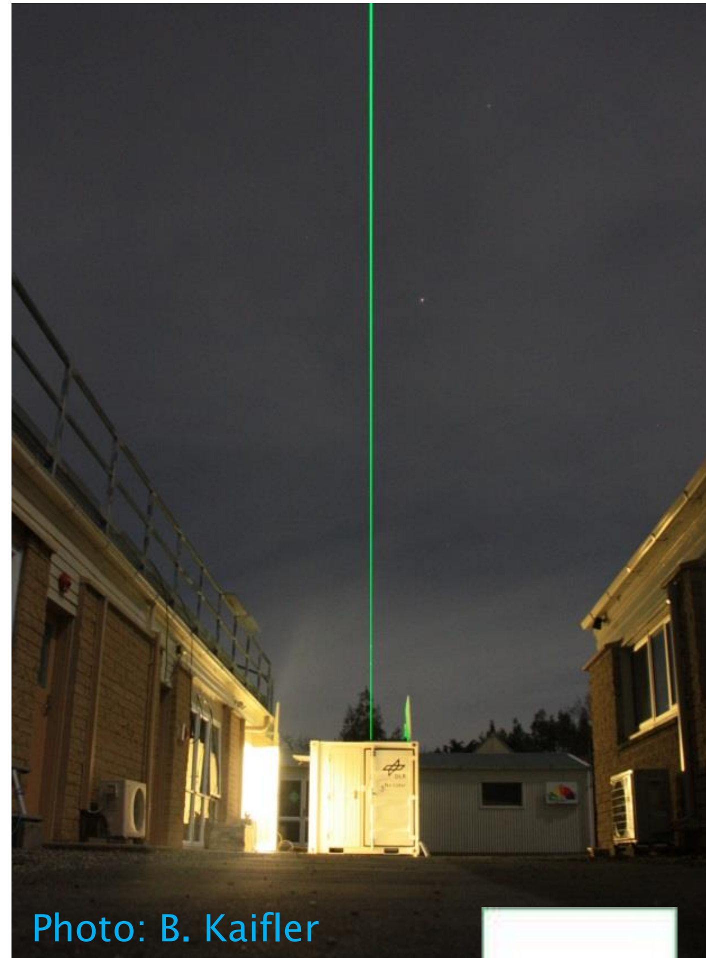


Photo: B. Kaifler

DLR

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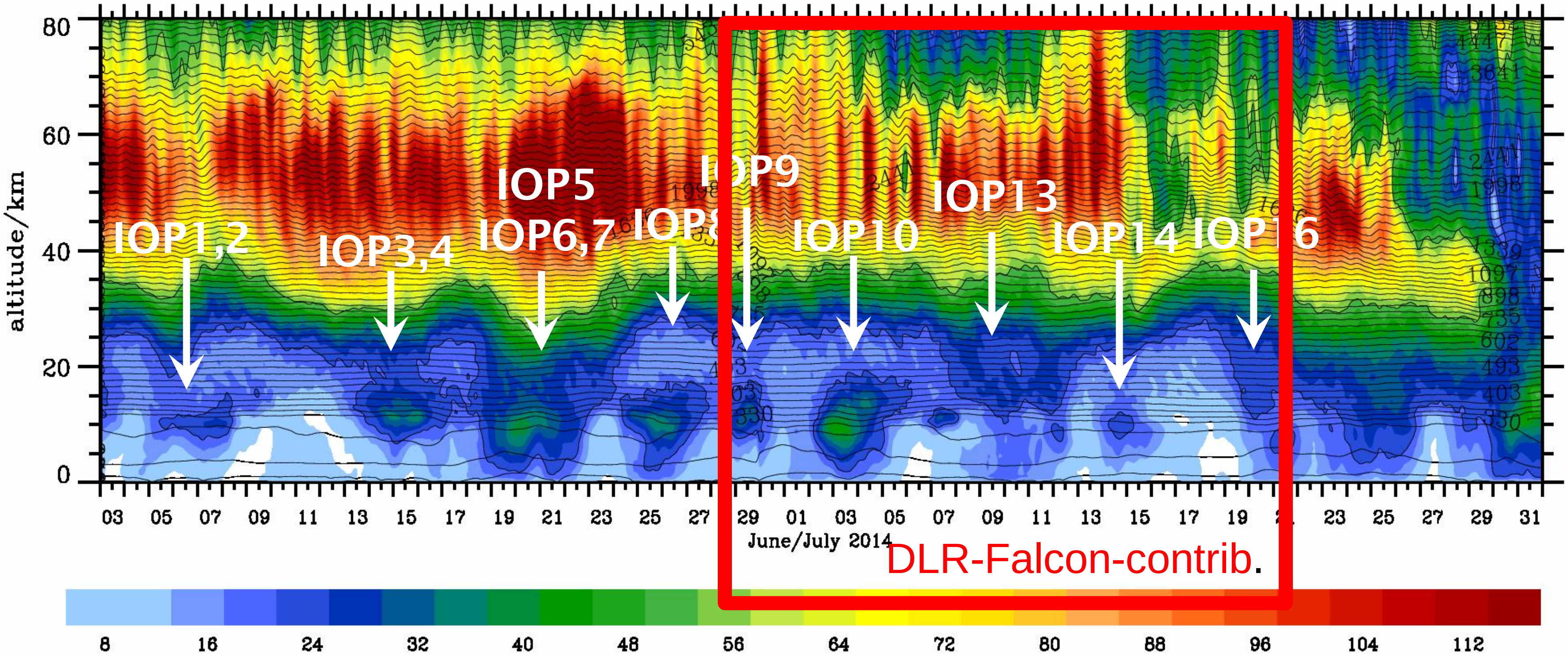
NIWA
Taihoro Nukurangi

LMU

universität innsbruck

Horizontal average of horizontal wind over the South Island/NZ



ECMWF T1279/L137 operational analyses (6 h) and 1 hourly high-resolution IFS predictions

V_{HOR}/ms^{-1}

Fritts et al., submitted to BAMS, 2015

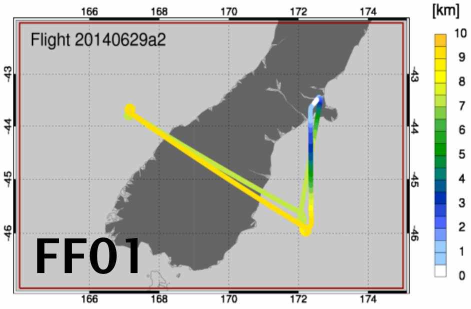
Falcon Research Flights

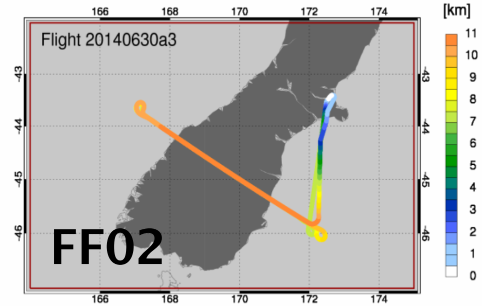
13 research flights in New Zealand, 10 coordinated with NCAR GV

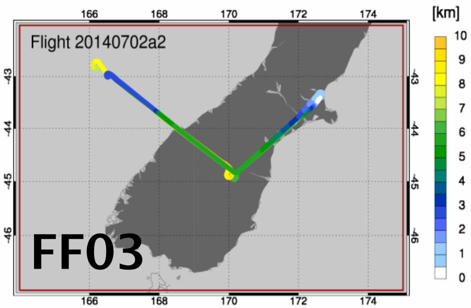
Flight No	IOP	NSF/NCAR GV	Date	Objective
RF-F01, RF-F02	9	sequential Falcon and GV flights RF12 and RF13	30 June 1 July	GW event under transient forcing
RF-F03		no	2 July	tropopause fold
RF-F04, RF-F05	10	Falcon flights before and during RF16	4 July	GW event under WSW flow
RF-F06	10	RF20	10 July	intercomparison
RF-F07, RF-F08	13	Falcon flights before and during RF21	11 July	GW event under strong NW winds
RF-F09, RF-F10	13	Falcon flights after RF22	12 July 13 July	GW wave event with locally varying responses
RF-F11		no	14 July	volcanoe
RF-F12	15	no	17 July	critical level flow
RF-F13	16	Falcon flight after RF26	20 July	GWs in SW flow

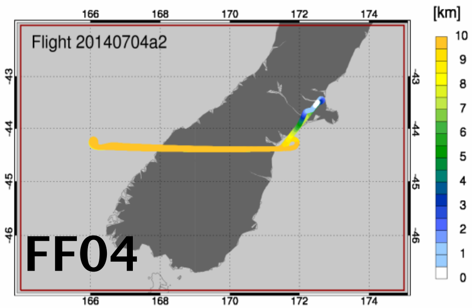
DLR Falcon Research Flights

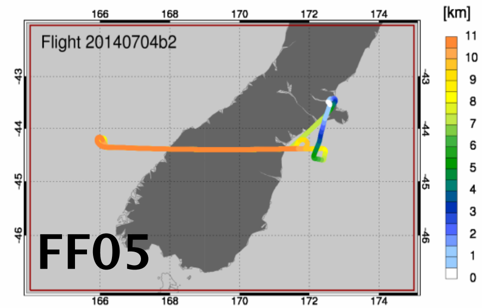
29 June – 20 July 2014

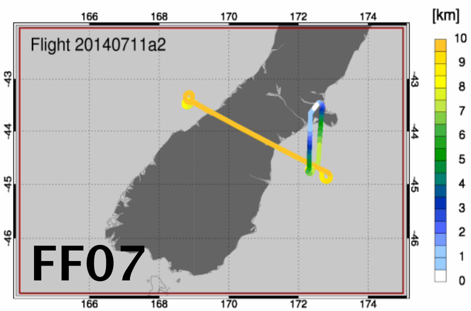


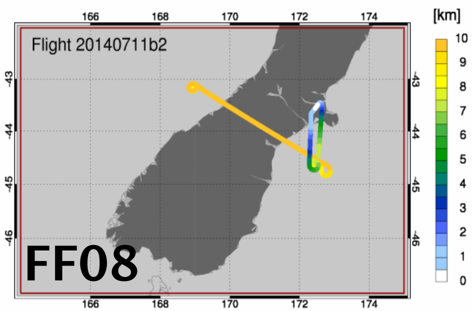


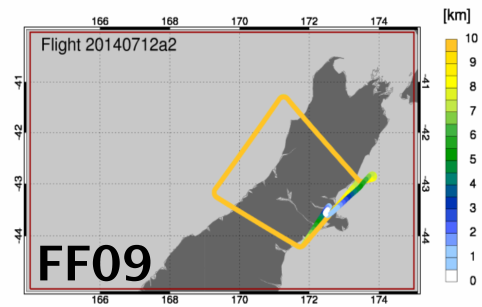


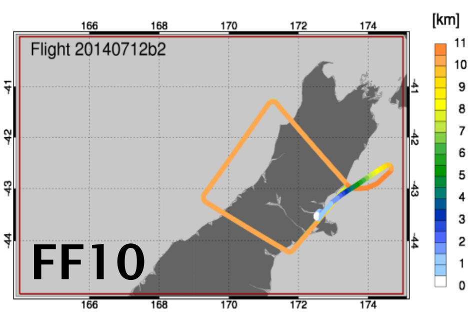


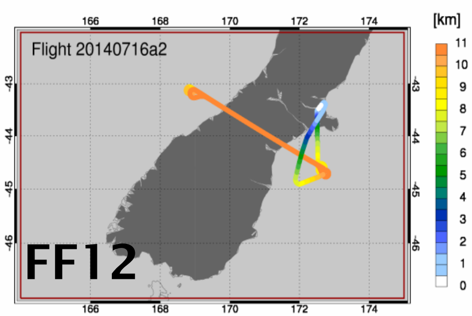


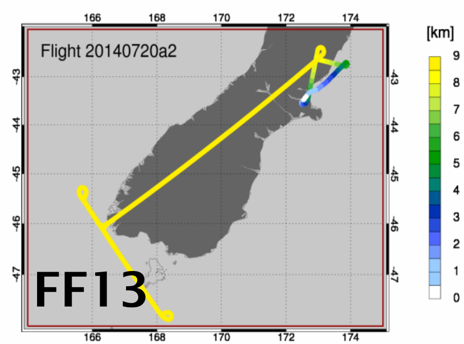










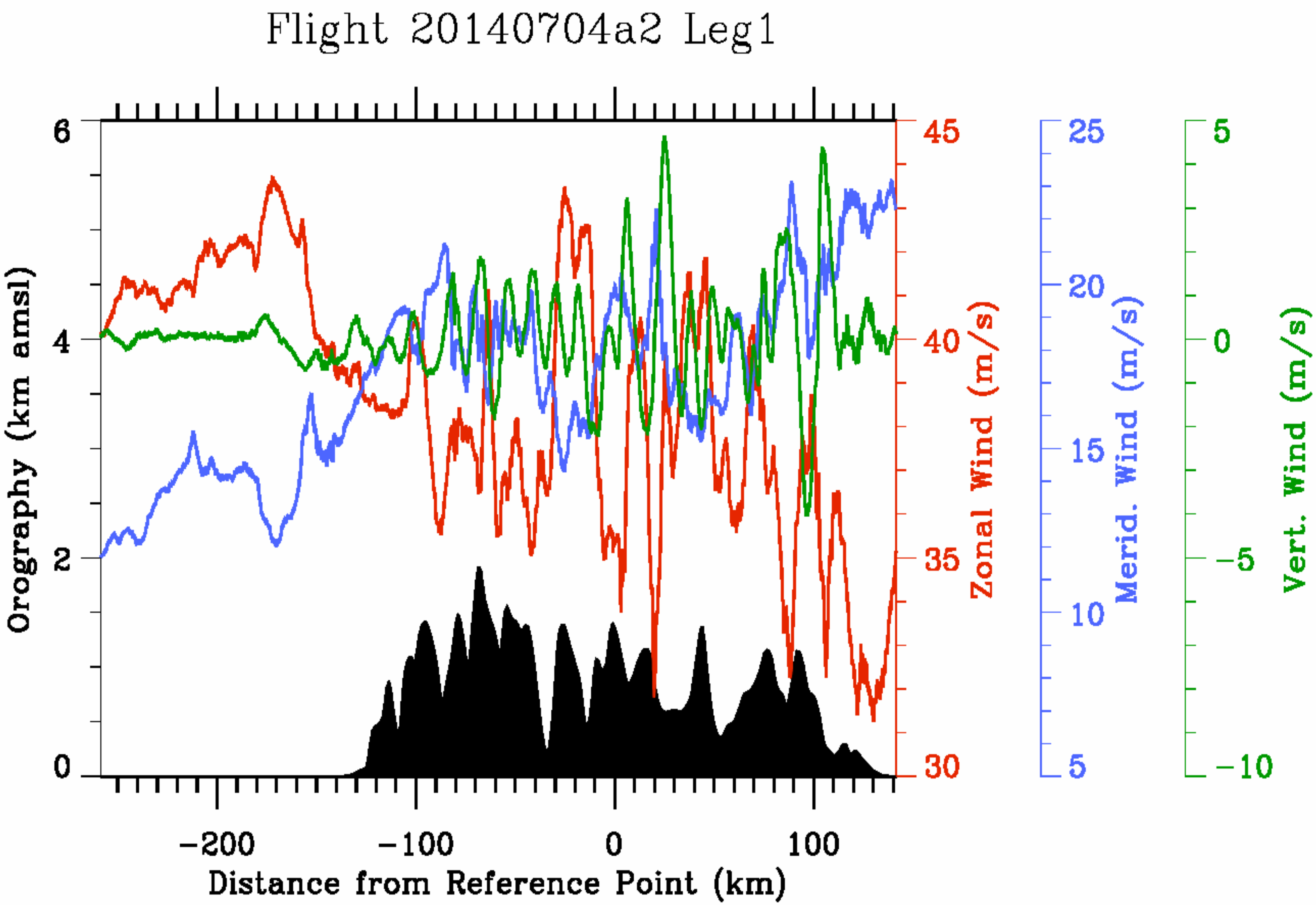


DLR Falcon measurements

DLR Falcon Research Flights

FF04 (4 July 2014)

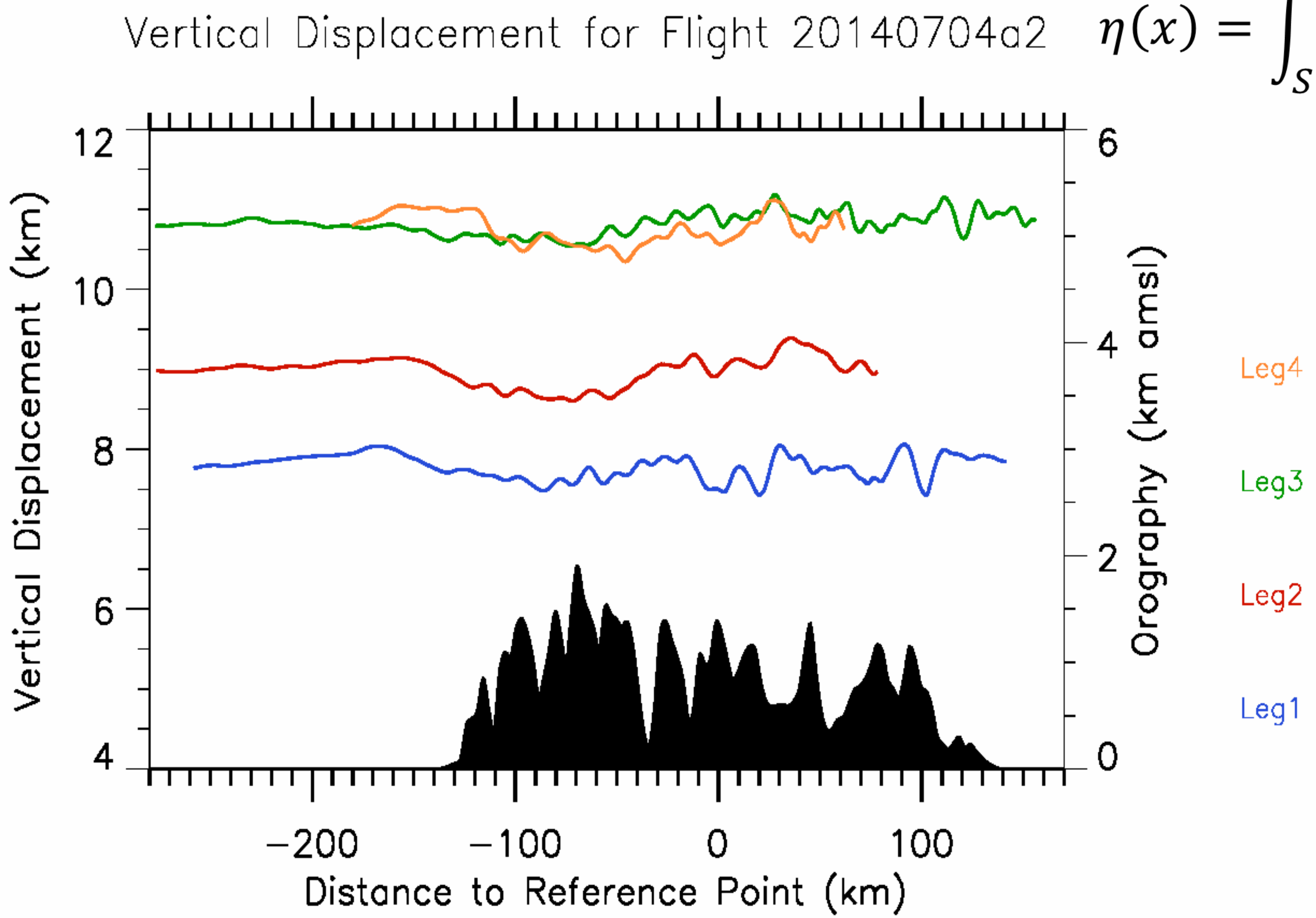
(analyzed by M. Bramberger, T. Portele, A. Dörnbrack following Smith et al., 2008)



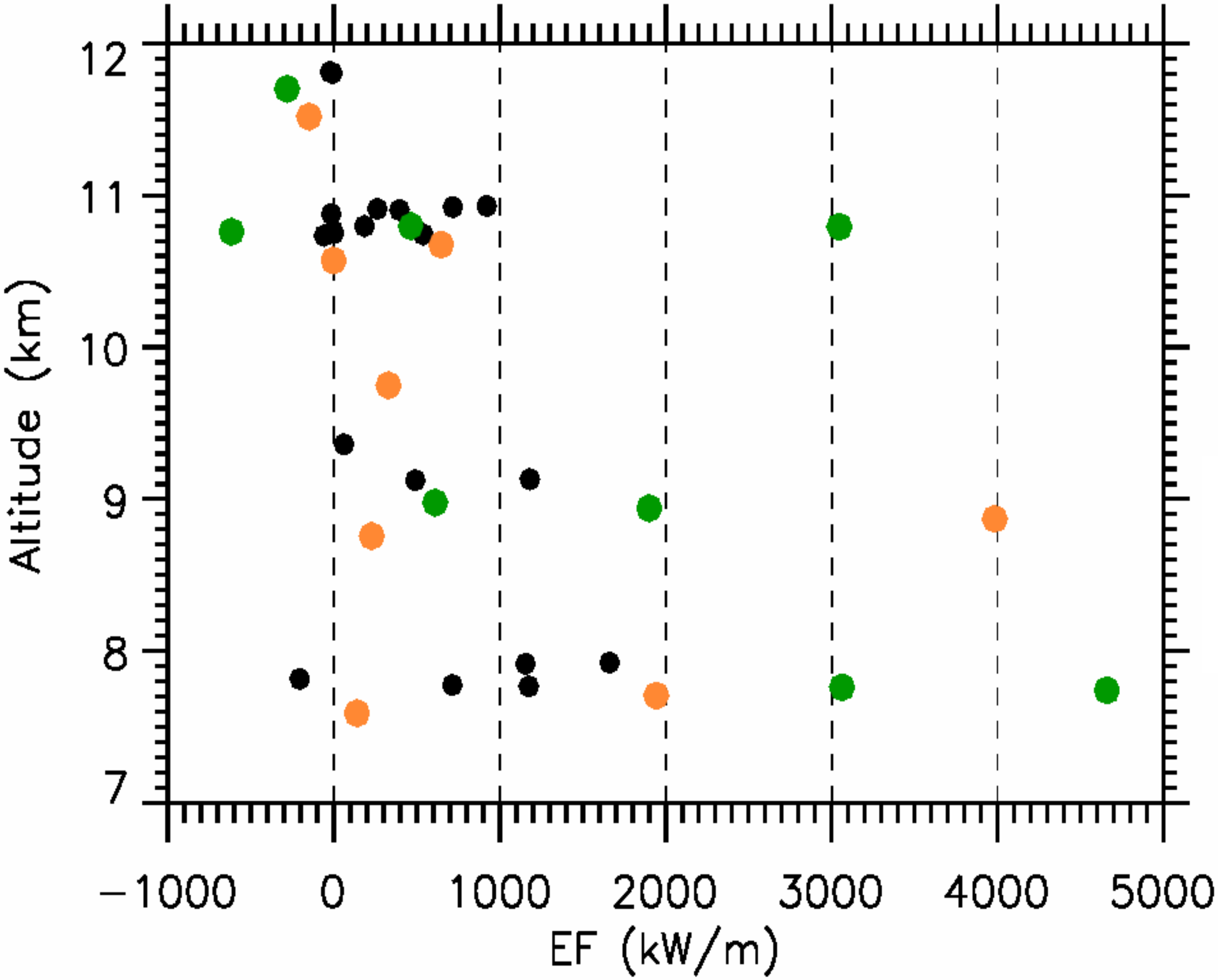
DLR Falcon Research Flights

FF04 (4 July 2014)

$$\eta(x) = \int_S^x \frac{w'}{U_B} dx_B$$



Altitude distribution of leg-integrated vertical energy fluxes EF



FF01 and FF02

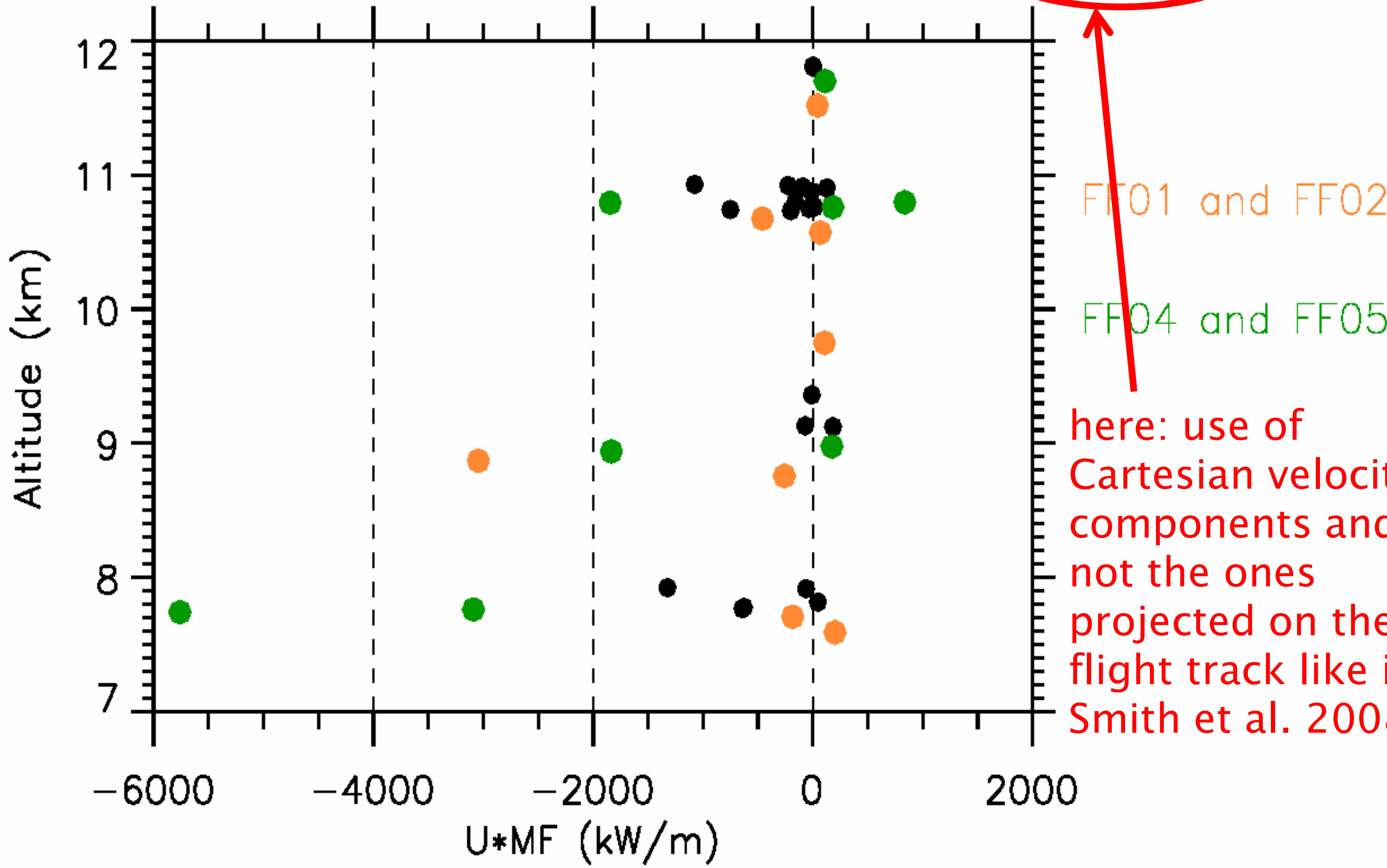
FF04 and FF05

$$\mathrm{EF} = \int p'w'\, dx_B,$$

GPS altitude corr. static pressure (but: no D-GPS yet)

for all 36 Falcon cross-mountain legs

Altitude distribution of leg-integrated values of $-\boldsymbol{U} \cdot \boldsymbol{MF}$



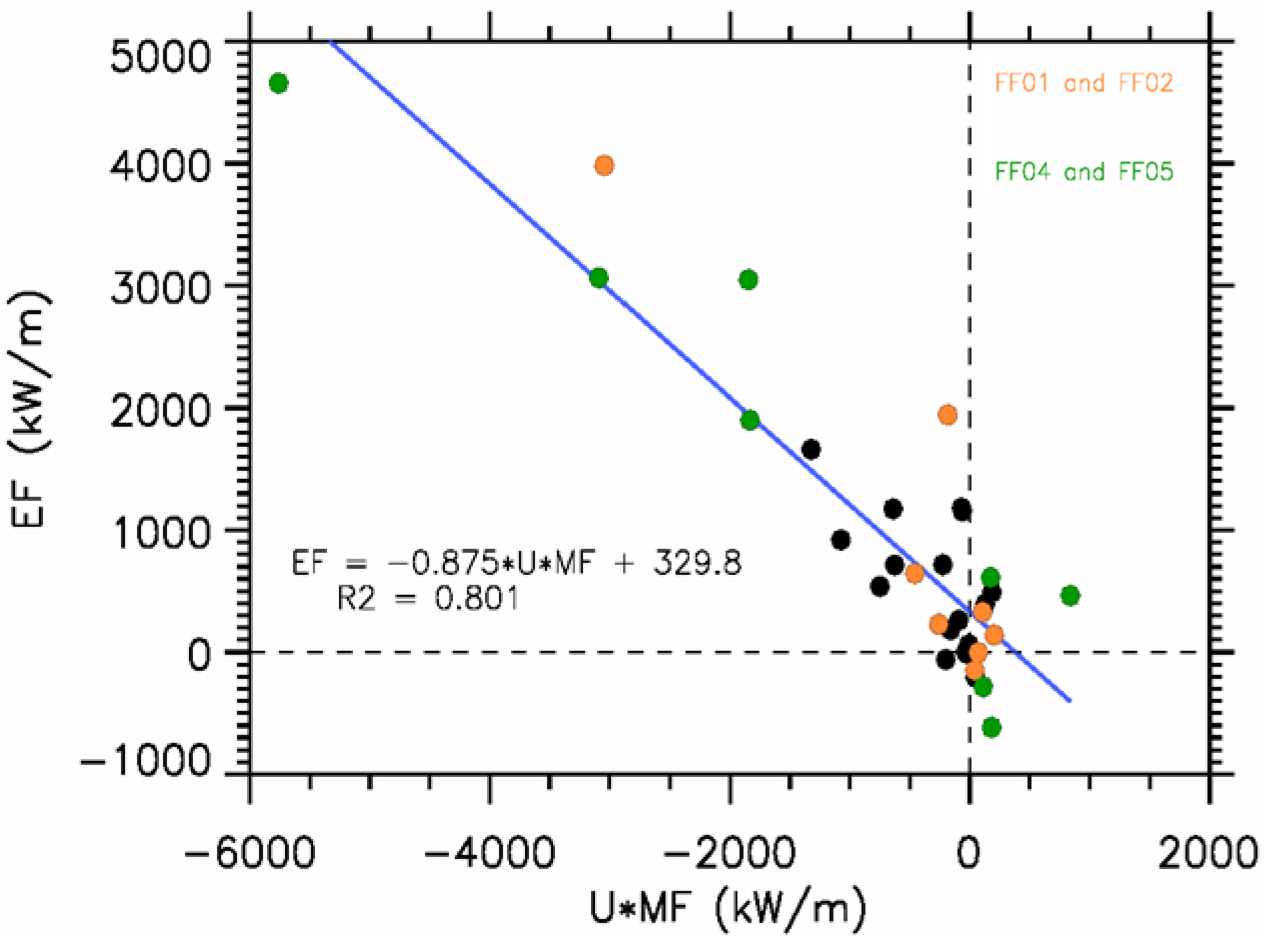
here: use of Cartesian velocity components and not the ones projected on the flight track like in Smith et al. 2008

for all 36 Falcon cross-mountain legs

Eliassen & Palm flux relationship

(steady, small-amplitude, non-dissipative flow)

$$EF = -\boldsymbol{U} \cdot \boldsymbol{MF}$$



Remarks:

Slope <1: non-linearities, unsteadiness, other errors

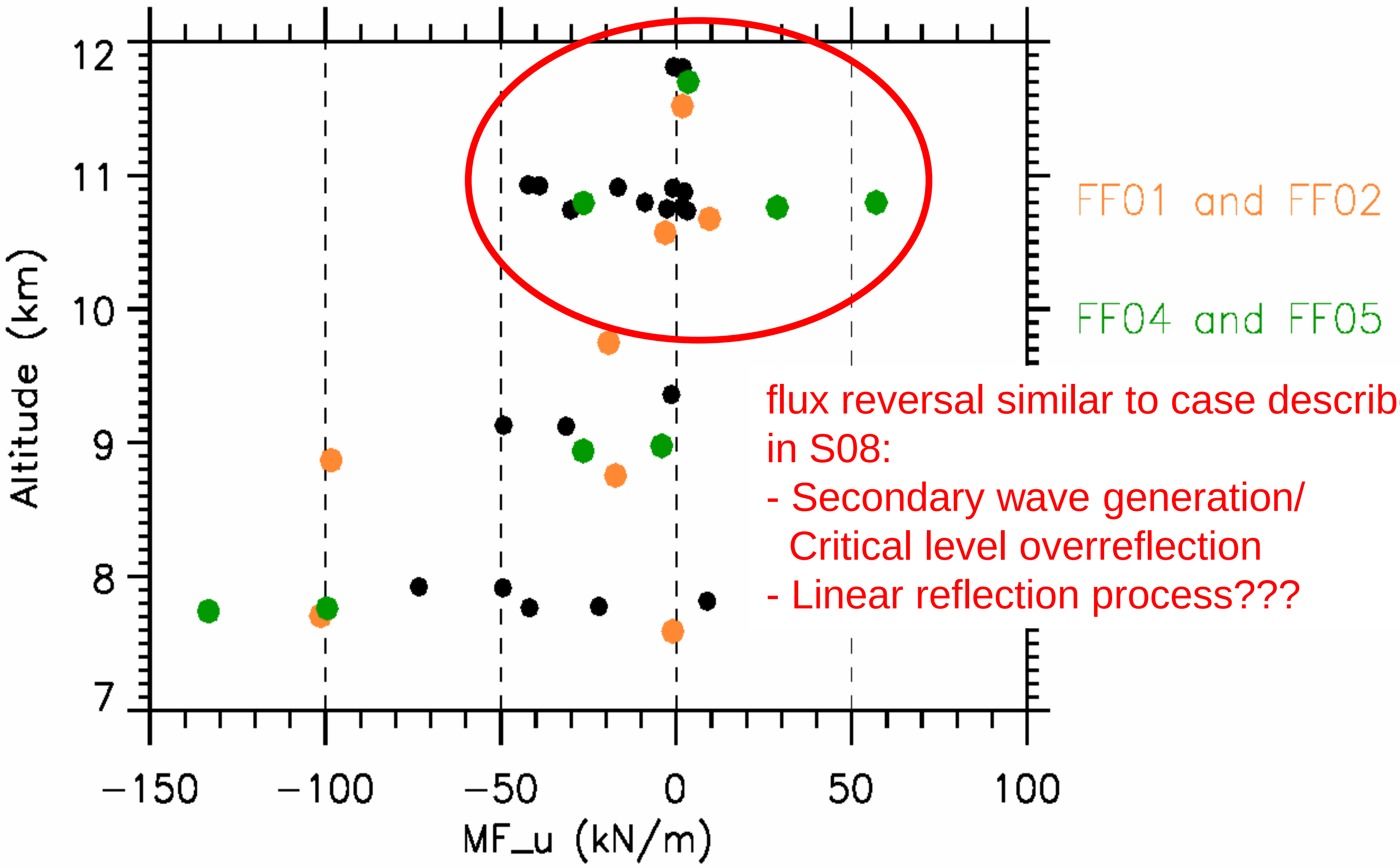
R2 less than in Smith et al. (2008)

Intercept larger than In S08; no dGPS yet; use of Cartesian wind components

much poorer statistics than S08

for all 36 Falcon cross-mountain legs

Momentum flux MF_u



flux reversal similar to case described in S08:
- Secondary wave generation/ Critical level overreflection
- Linear reflection process???

for all 36 Falcon cross-mountain legs

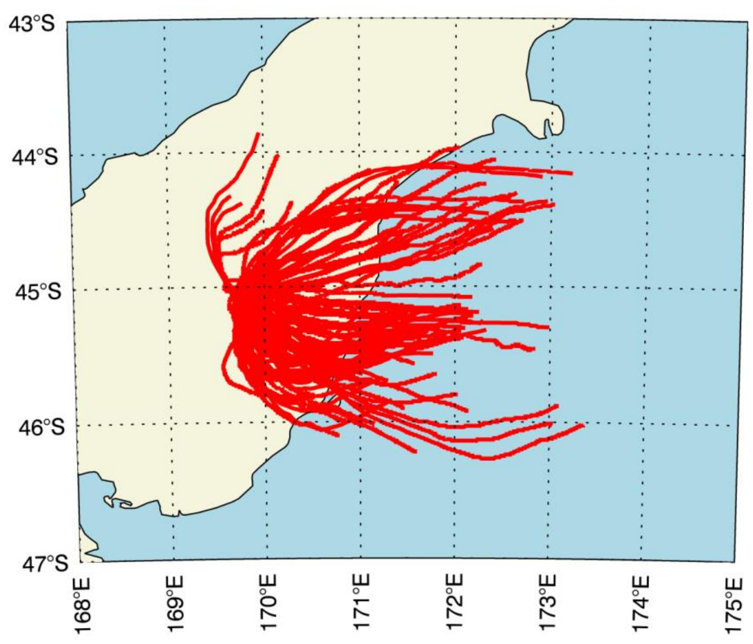
Radiosondes from Lauder (45 S, 169 E)

(analyzed by S. Gisinger)

98 soundings in total

mean height reached: 31.1 km

maximum height reached: 36.6 km

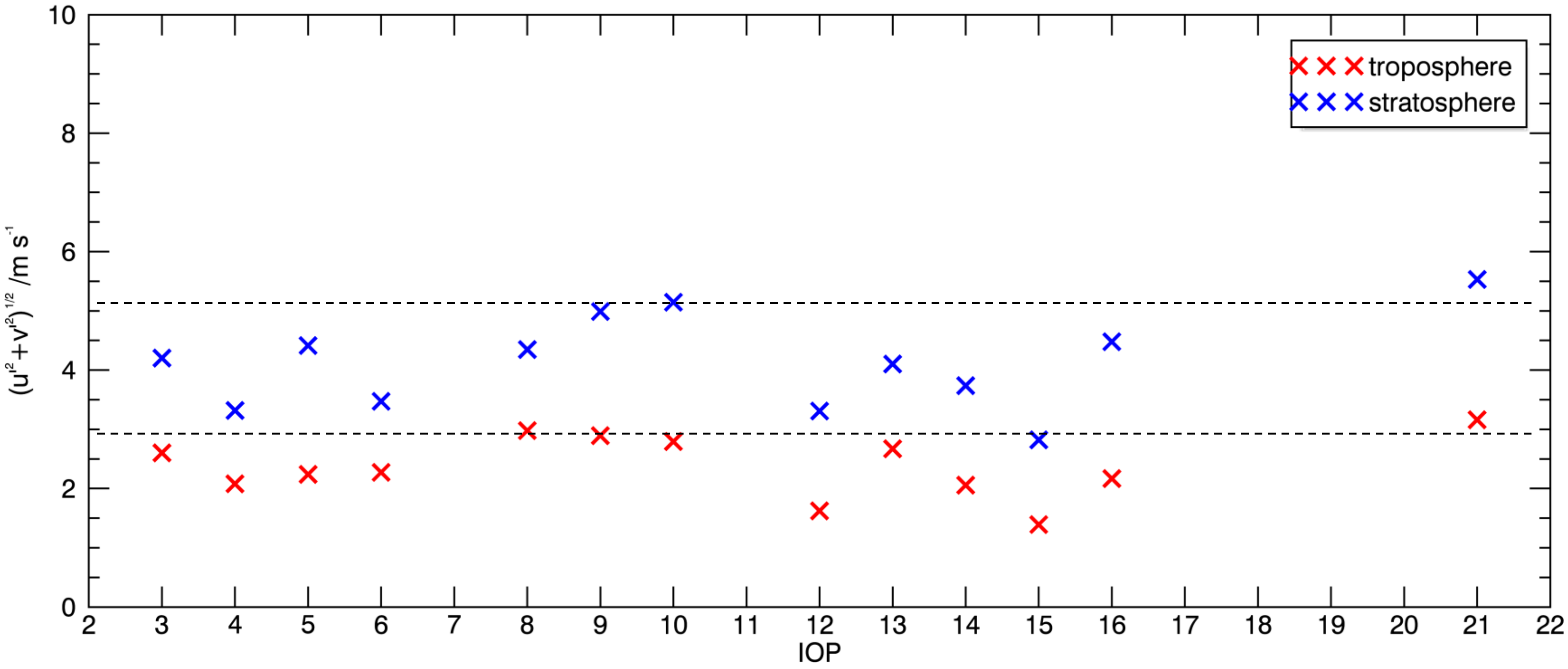


IOP	# sondes	IOP	# sonde s
3	9	**11**	-
4	4	**12**	1
5	1	**13**	19
6	5 (+1 NIWA)	**14**	1
7	-	**15**	6
8	12 (+1 NIWA)	**16**	4
9	15	**GB21 (no aircraft meas.)**	5
10	13	**Lidar inter-comparison and tests**	3

mean gravity wave activity (velocity perturbations)

$$\left\langle \sqrt{\langle u'^2 \rangle_z + \langle v'^2 \rangle_z} \right\rangle_{\mathrm{RS}}$$

troposphere: 1.5 to 7 km altitude
stratosphere: 13 to 24 km altitude

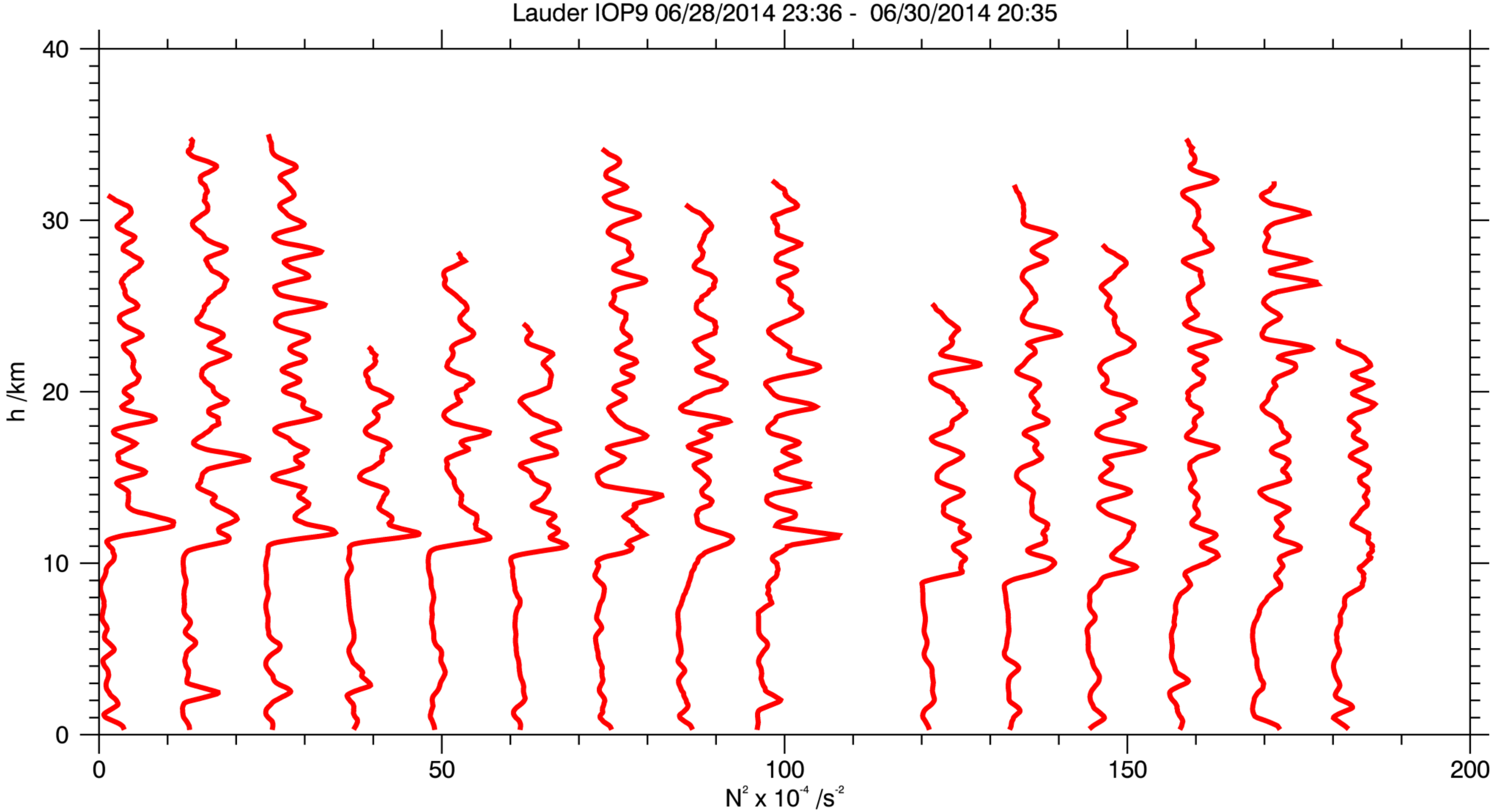


IOP 3: # 8
IOP 4: # 4
IOP 5: # 1
IOP 6: # 3
IOP 8: # 4
IOP 9: # 14
IOP 10: # 13
IOP 12: # 1
IOP 13: # 17
IOP 14: # 1
IOP 15: # 4
IOP 16: # 4
IOP 21: # 5

DLR

IOP 9

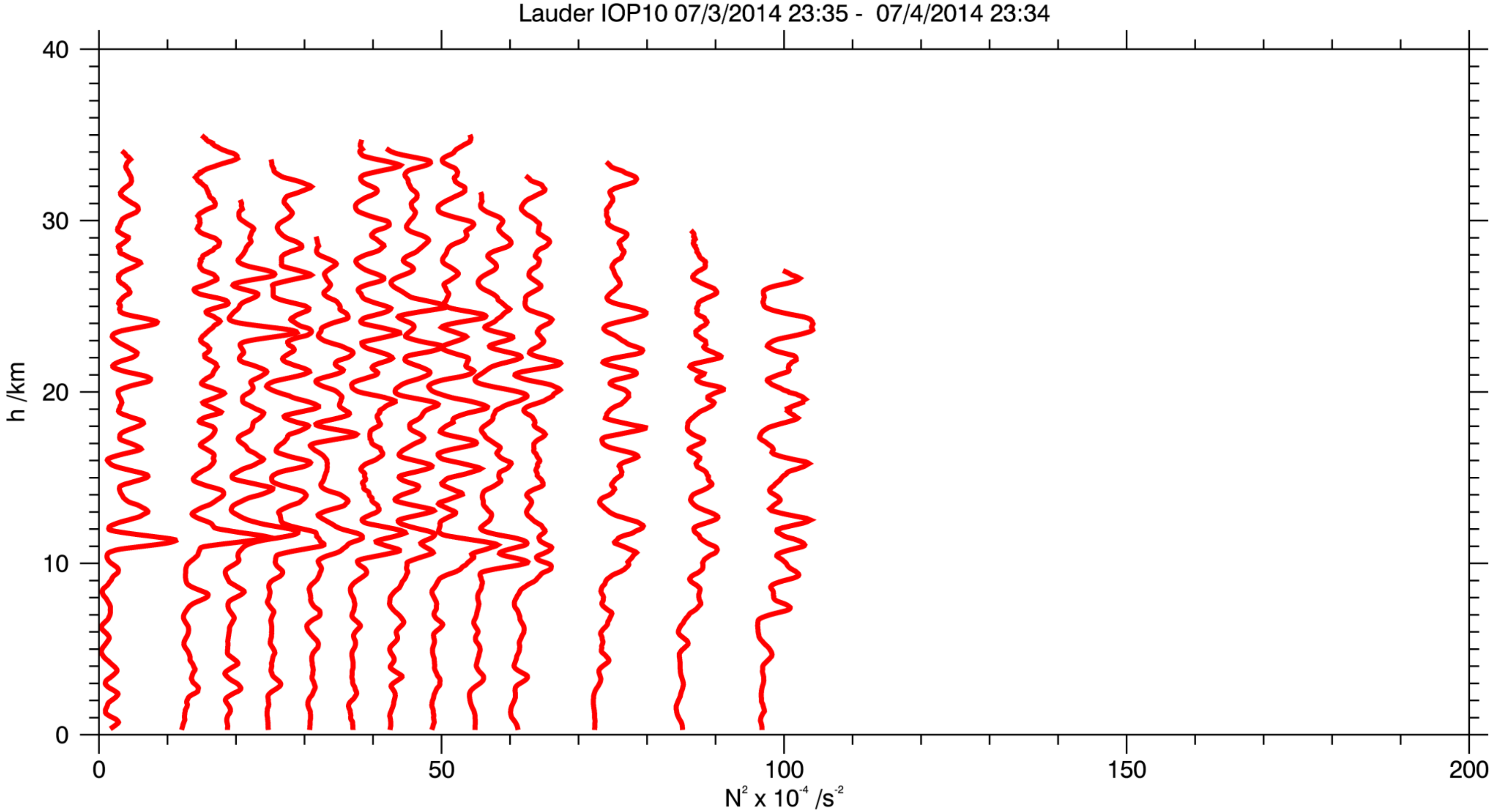
N² from soundings (profiles are shifted on the x-axis by 4 per hour time difference of the soundings)



for anticyclonic conditions the thermal tropopause is higher and sharper (tropospheric inversion layer TIL, pronounced peak in N²) than for cyclonic conditions (cf. Wirth 2003, JAS)

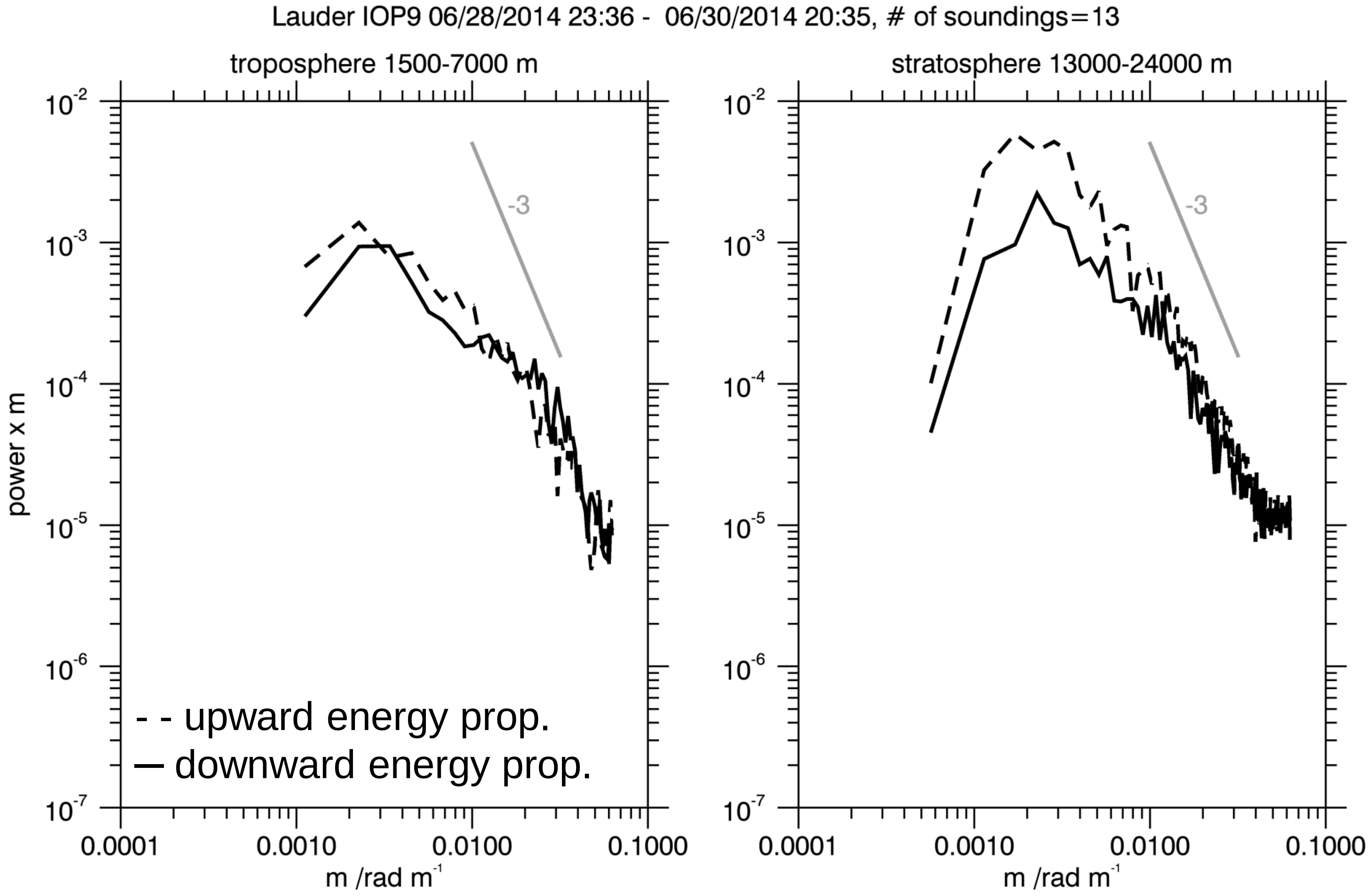
IOP 10

N² from soundings (profiles are shifted on the x-axis by 4 per hour time difference of the soundings)



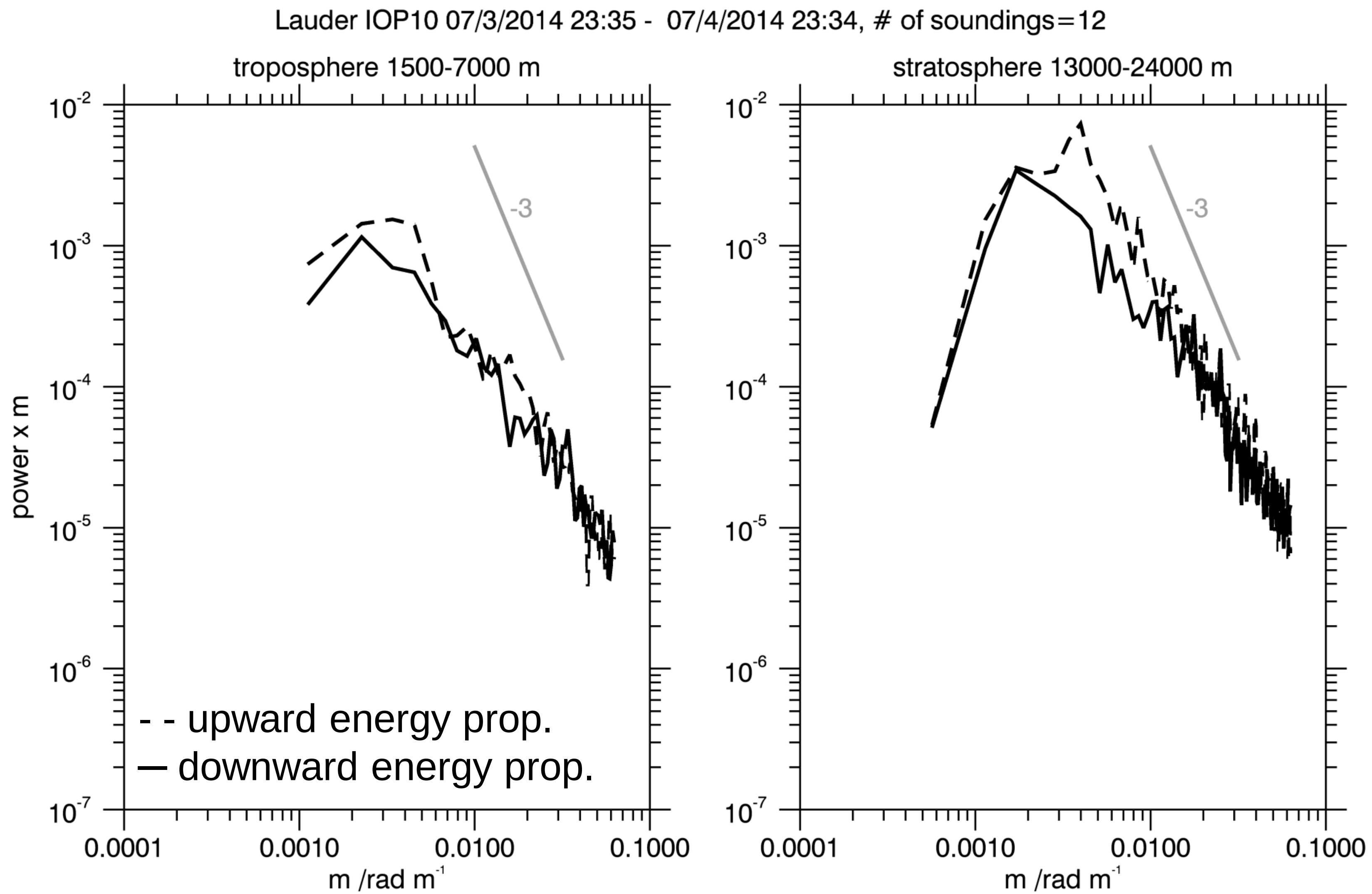
for anticyclonic conditions the thermal tropopause is higher and sharper (tropospheric inversion layer TIL, pronounced peak in N²) than for cyclonic conditions (cf. Wirth 2003, JAS)

IOP 9
mean rotary spectra (FFT of u+iv)



IOP 10

mean rotary spectra (FFT of u+iv)

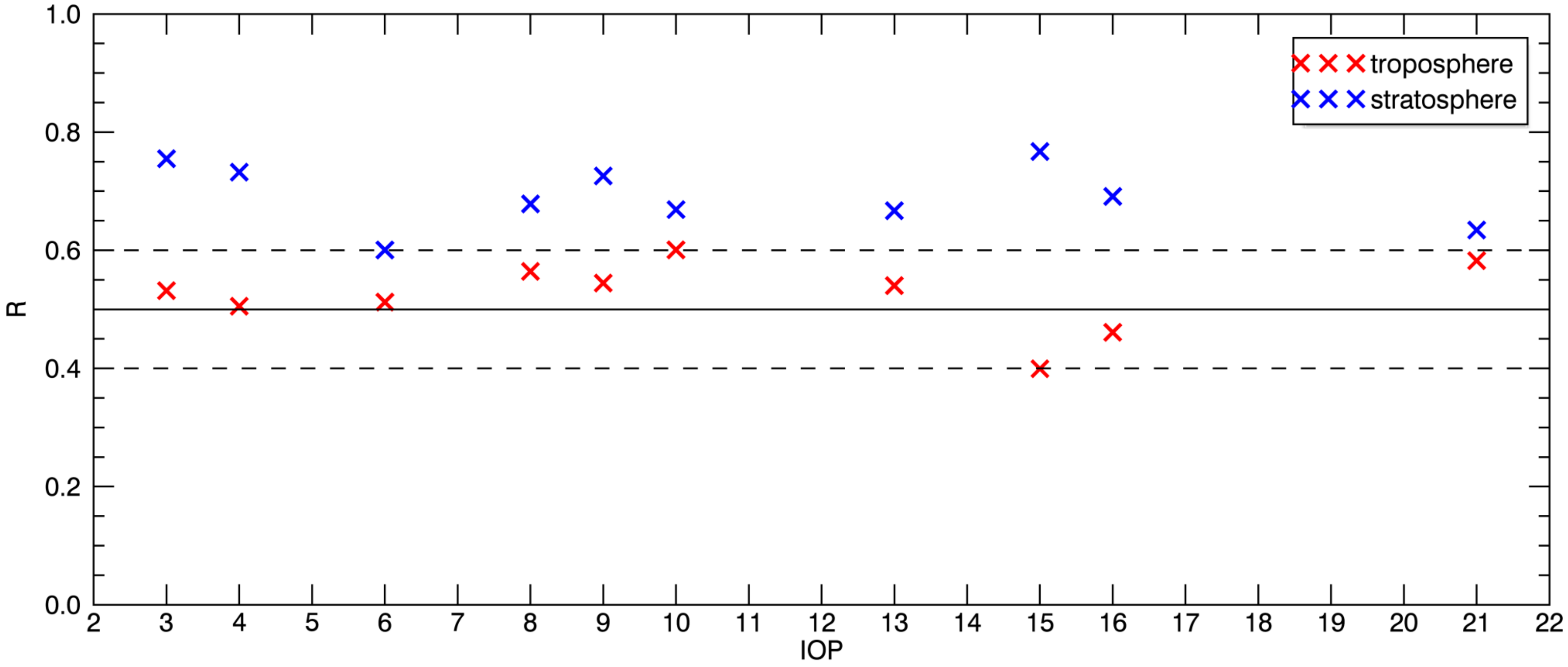


DLR

Ratio of upward and downward propagation from rotary spectra

$$R = \frac{\overline{(\text{power x m})_{\text{up}}}}{\overline{(\text{power x m})_{\text{up}}} + \overline{(\text{power x m})_{\text{down}}}}$$

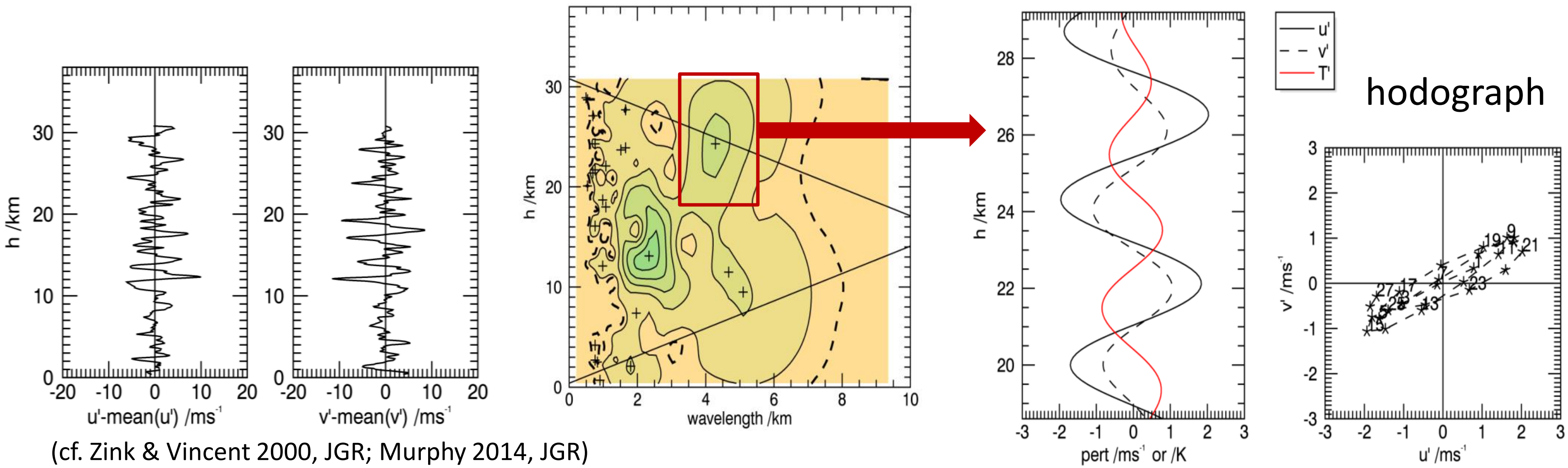
R > 0.6 significant upward energy propagation,
R < 0.4 significant downward energy propagation



DLR

Isolation of single wave packages using wavelet analysis

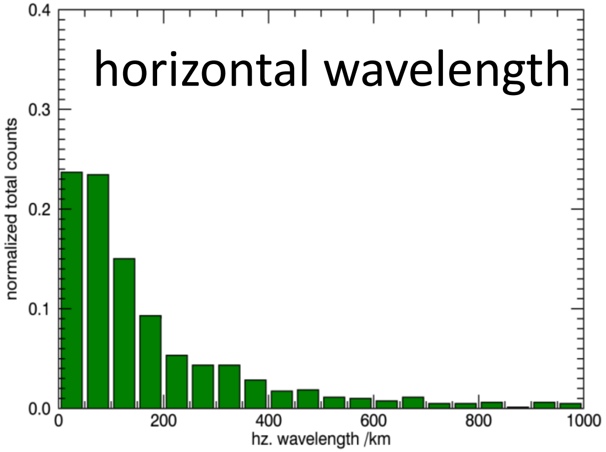
perturbation profiles u’ and v’ → wavelet spectrum → identify wave packages → reconstruct u’, v’, T’ for individual packages

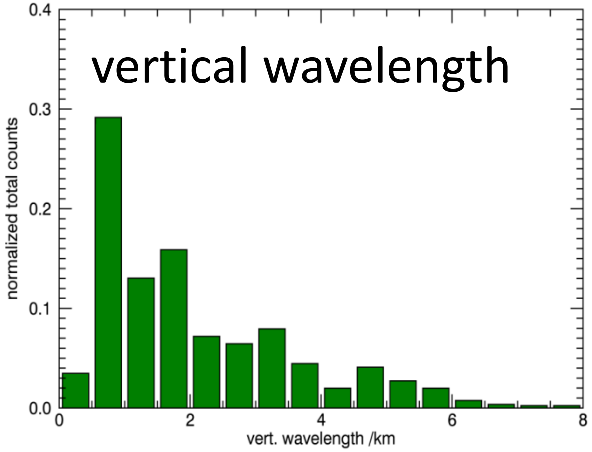


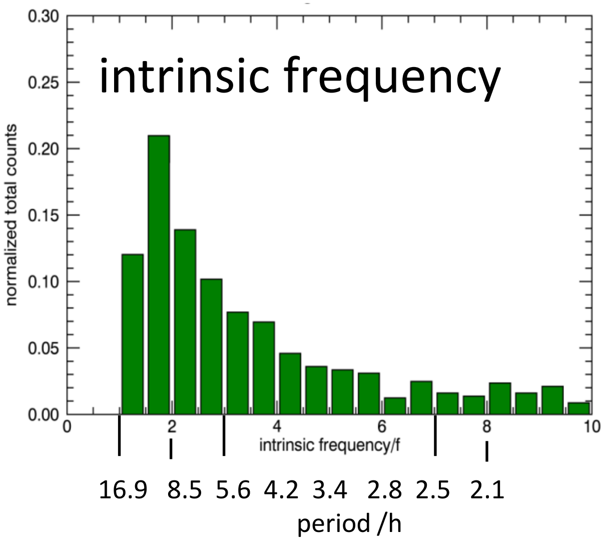
(cf. Zink & Vincent 2000, JGR; Murphy 2014, JGR)

total # 806 packages

Stokes analysis of wave packages







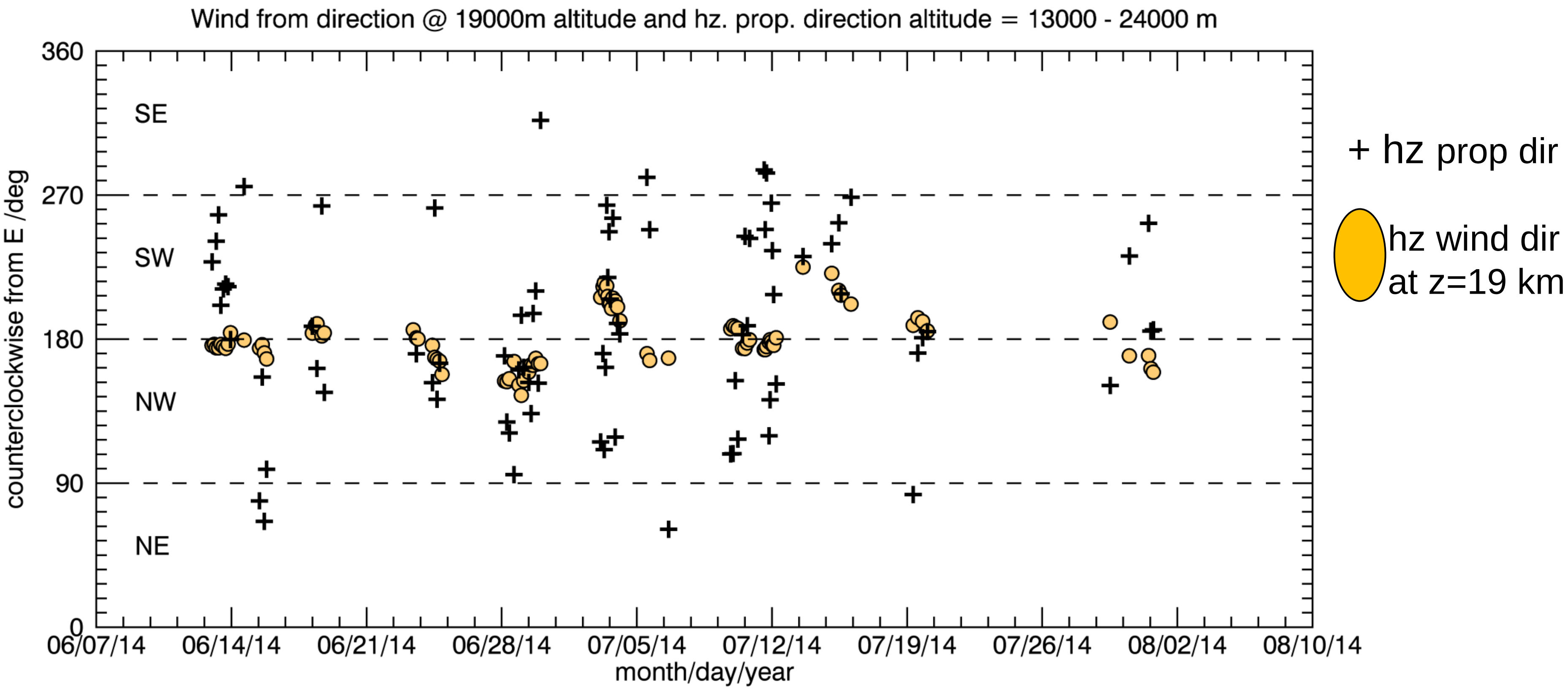
Percentage of upward propagating wave packages

IOP	3	4	6	8	9	10	13	15	16	GB21
up %	81	78	60	79	81	75	75	62	86	63

DLR

dominant horizontal propagation direction stratosphere (13 – 24 km altitude)

- using Stokes analysis (180° ambiguity)
- phase shift between temperature perturbation and hz. velocity perturbation in propagation direction



→ dominant horizontal propagation direction is in a westward direction

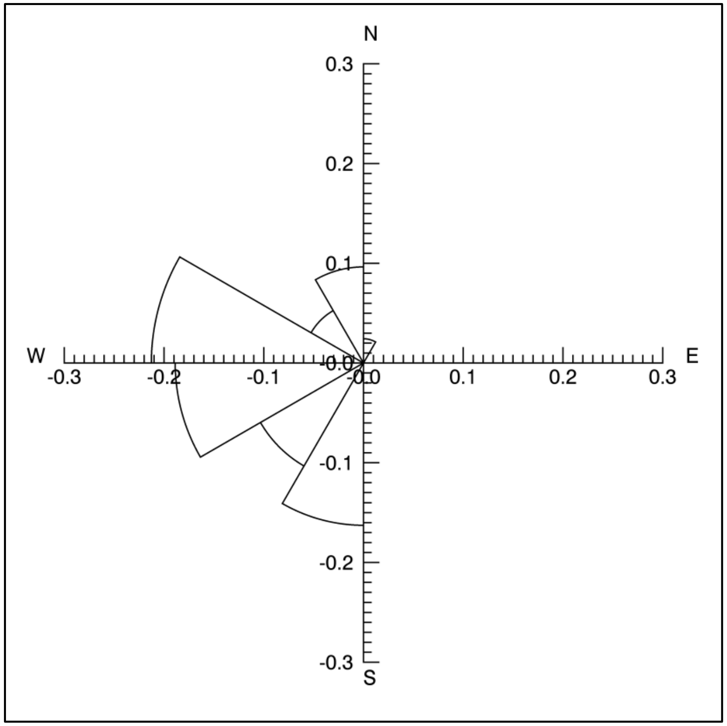
DLR

dominant horizontal propagation direction stratosphere (13 – 24 km altitude)

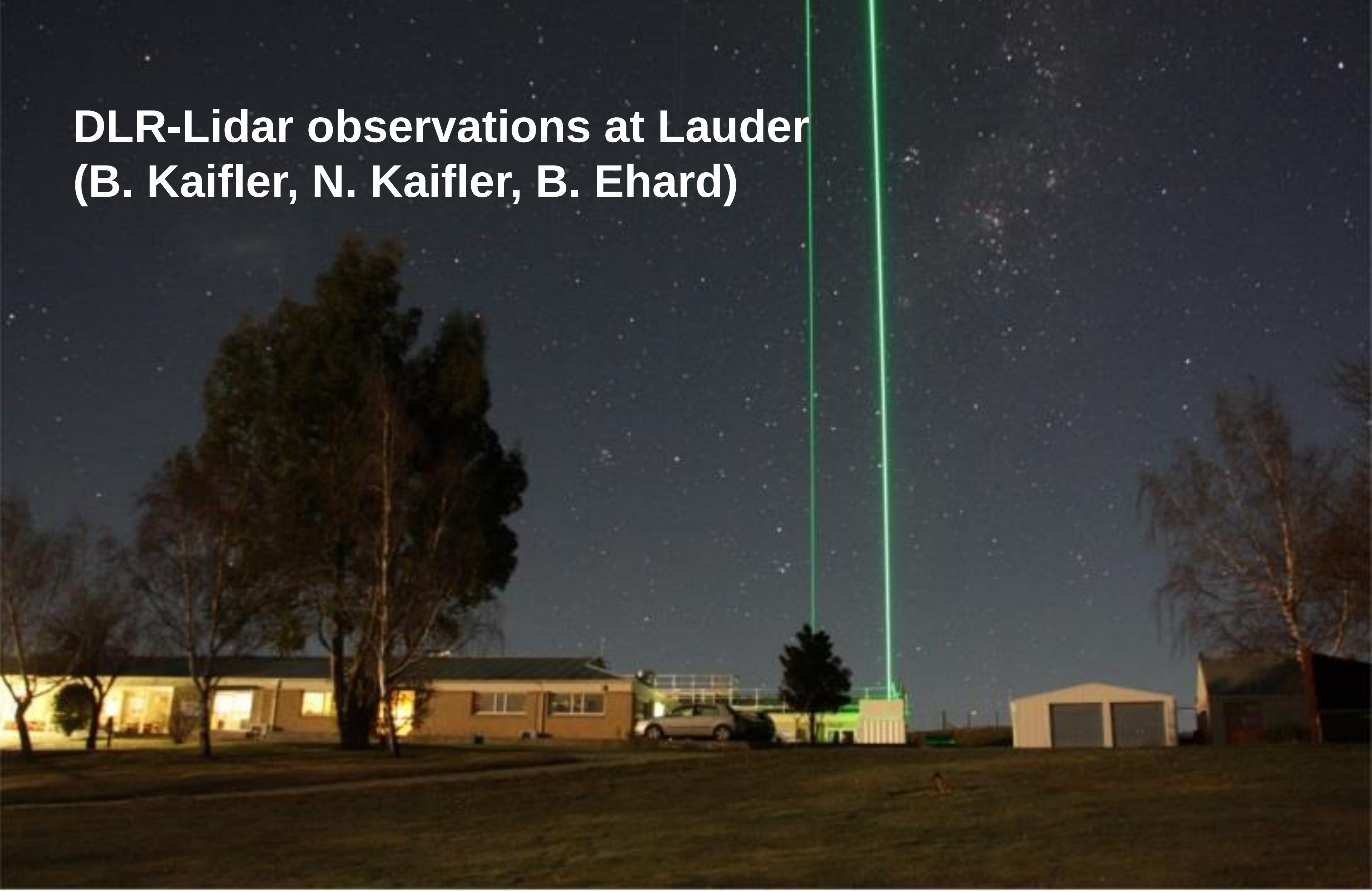
- using Stokes analysis (180° ambiguity)
- phase shift between temperature perturbation and hz. velocity perturbation in propagation direction

GW kinetic energy of all soundings in a segment weighted with the total GW kinetic energy of all soundings

(cf. Vincent et al, 1997)

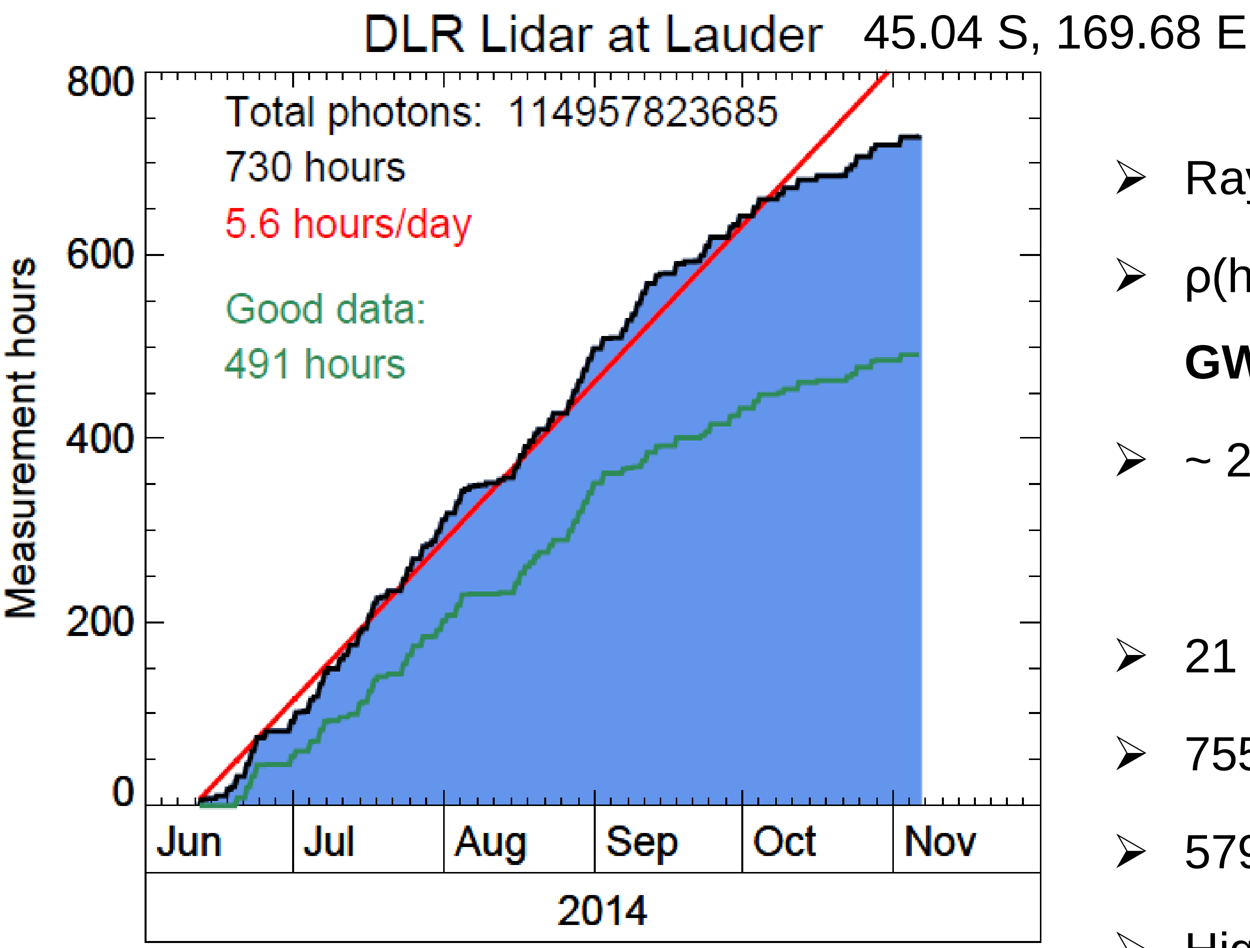


DLR-Lidar observations at Lauder
(B. Kaifler, N. Kaifler, B. Ehard)



DLR

DLR-Lidar Operation and dataset



- Rayleigh lidar
- ρ(h,t), **T(h,t), T'(h,t), GWPED(h,t)**
- ~ 22-85 km, nighttime
- 21 June – 2 Nov 2014
- 755 h operation, 99 nights
- 579 h data, 74 (87) nights
- High resolution 10 min, 900 m

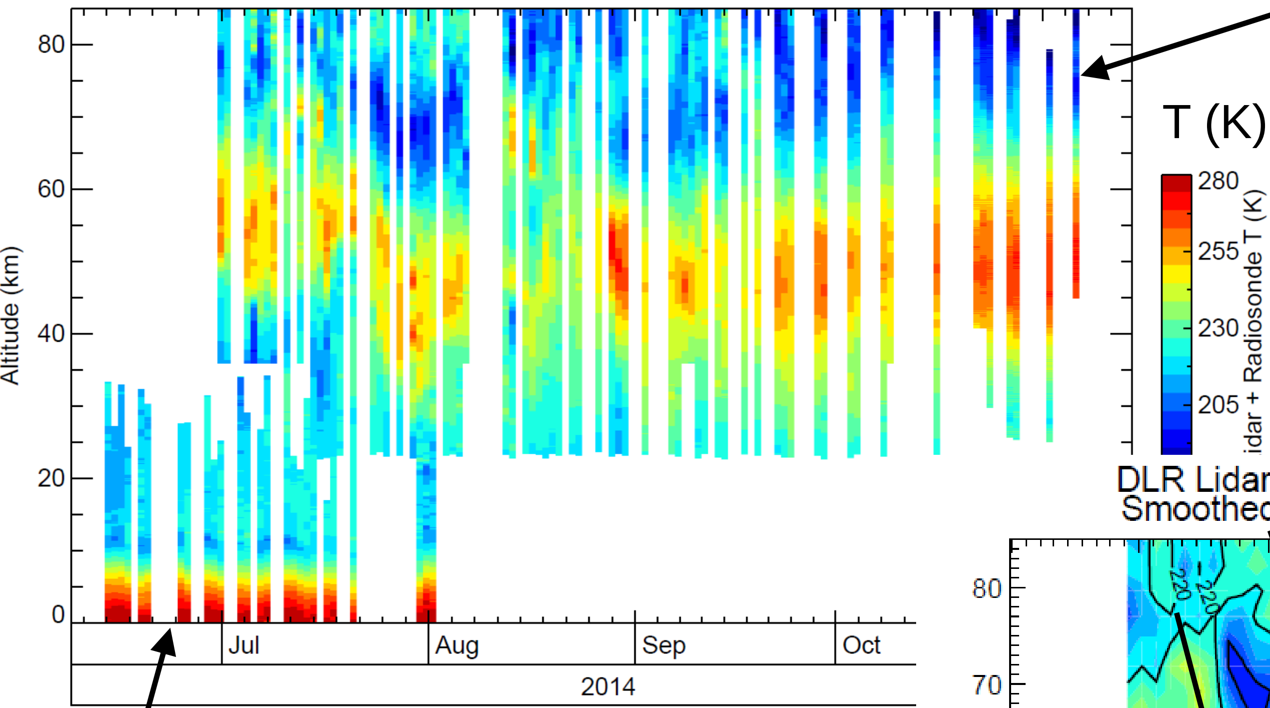
Relation to DEEPWAVE activities

Adapted from Fritts et al., BAMS

Date 2014	IOP	RF	FF (Falcon)	GB-IOP	Lidar	Radio-sonden
19 June	IOP06	RF07		GB09	✓	✓
21-23 June				GB10,11,12	✓	
30 June – 1 July	IOP09	RF13, RF14	F01, F02		✓	✓
4 July	IOP10	RF16	F04	GB15	✓	✓
7 July	IOP12	RF18			✓	✓
10 July	IOP13	RF20	F06	GB16	✓	✓
14 July	IOP14	RF23	F11	GB17	✓	✓
16 July	IOP15		F12	GB18	✓	✓
17 July				GB19	✓	✓
18 July	IOP16	RF25		GB20	✓	
29 July – 1 Aug				GB21	✓	✓

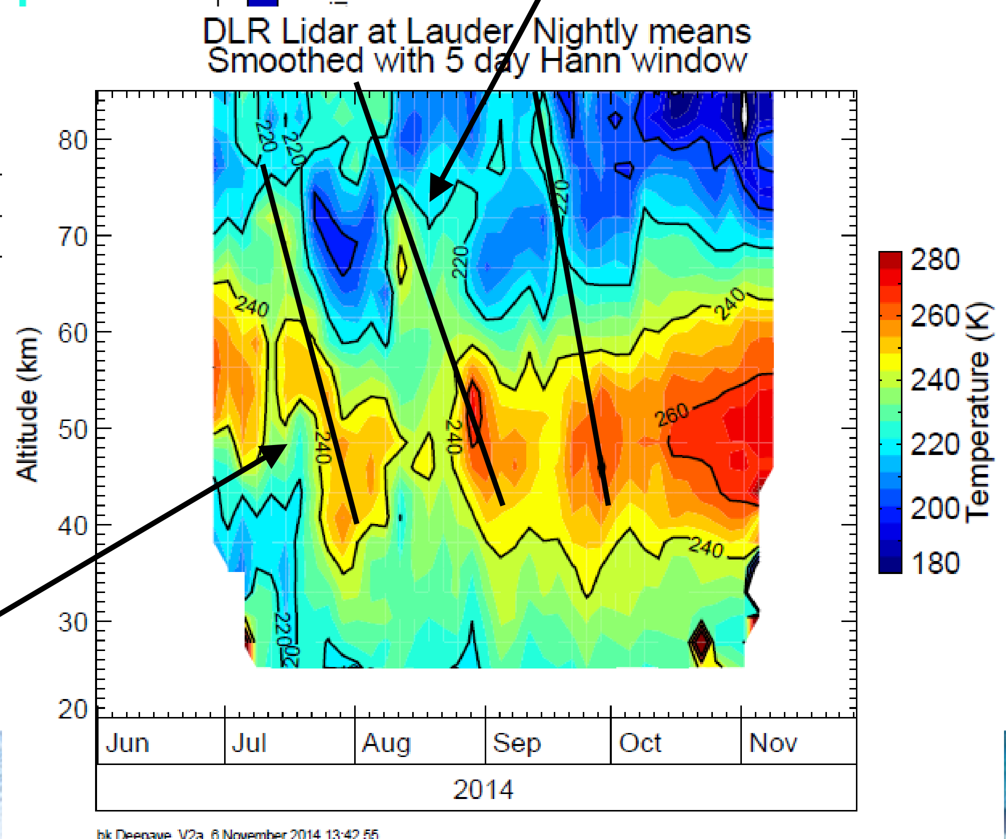
Thermal structure

Rayleigh-Lidar Lauder



Radiosondes Lauder

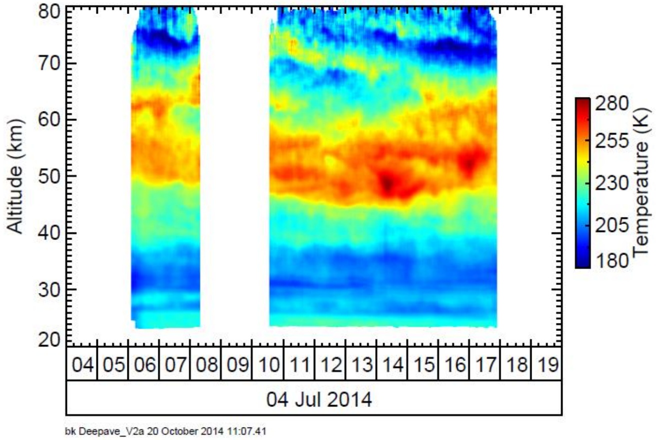
Planetary Waves?



Variable Winter-Stratopause

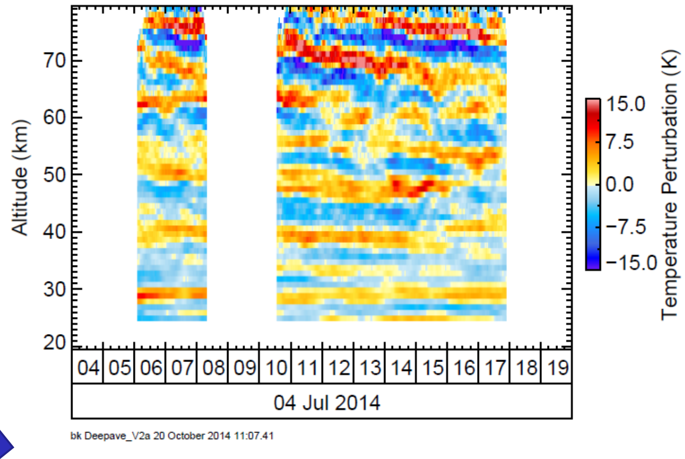
Temperature fluctuations and GWPED

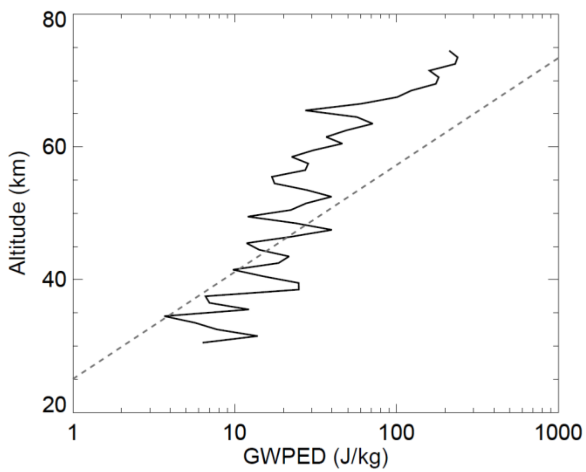
10 min x 900 m T-profile



Subtraction of background temperatures

Temperature fluctuations

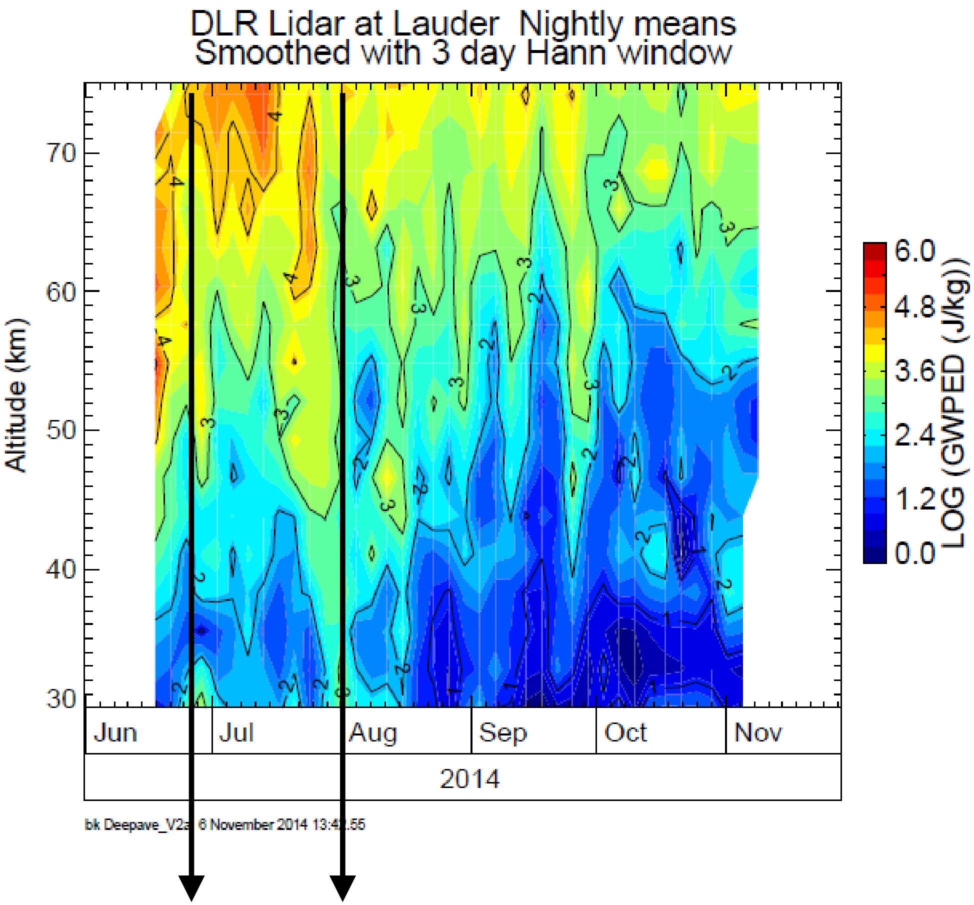


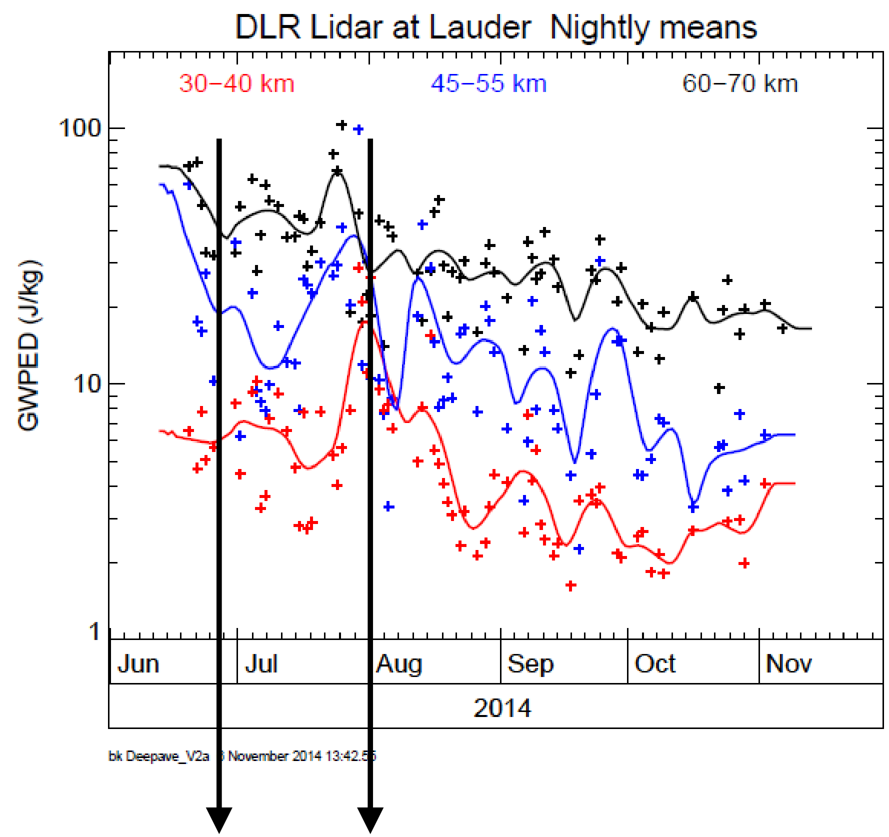


Gravity wave potential energy density GWPED:

$$E_p(z) = \frac{1}{2}\frac{g^2}{N^2(z,t)}\overline{\left(\frac{T'(z,t)}{T_0(z,t)}\right)^2}$$

GWPED due to gravity waves





Orographically excited waves?

No „deep propagation“?

Remarks

- Falcon met-data analyzed for MF& EF; consistent results with S08; improvements to be: dGPS; trajectory based coordinate system for MF-determination

- RS data analyzed for kinetic energy, stability, up- and downward propagation, wave package analysis: wave parameters incl. propagation directions

- Lidar observations: Mean temperatures and GW disturbances analyzed in terms of GWPED; phase velocity analysis under way (see Bernd‘s talk)

- Not shown: WRF simulations for FFs; Data projected on Falcon legs; case studies under way

Thank you!