Investigation of gravity waves in the troposphere and stratosphere based on radiosonde observations at Lauder (45 °S 169 °E) during DEEPWAVE-NZ

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MS-GWaves ROMIC

DEEPWAVE Community

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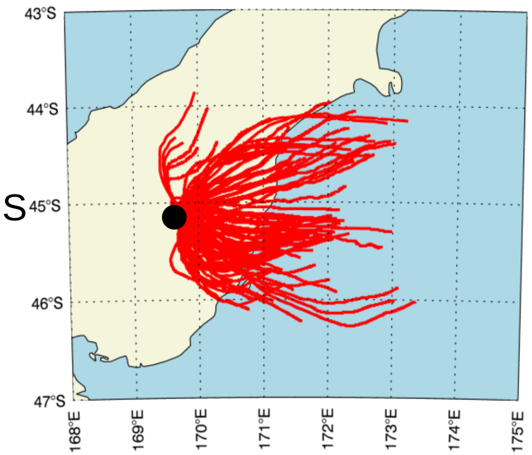
universität innsbruck

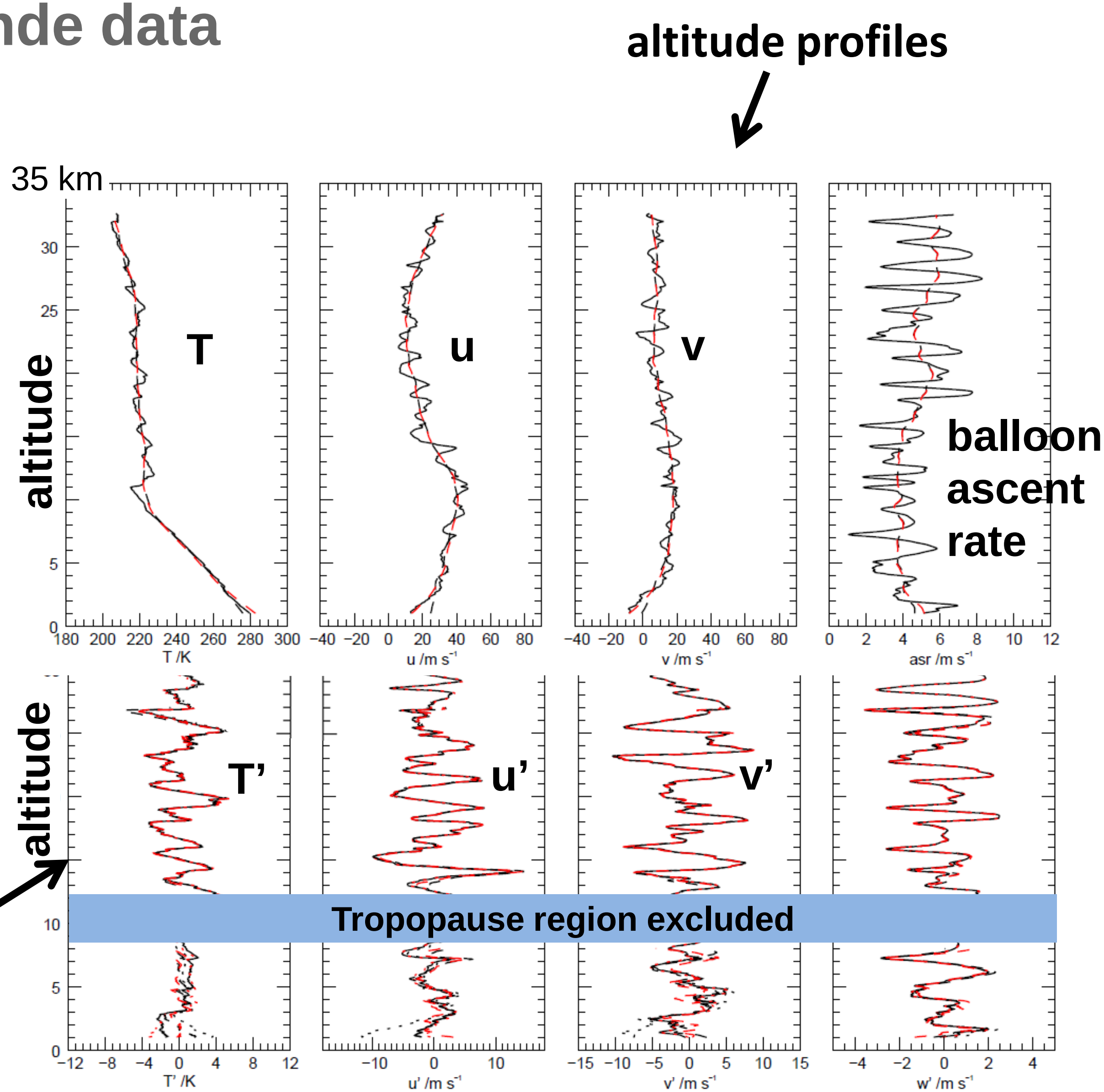
LMU

Analysis of radiosonde data

DEEPAVE LAUDER soundings

98 soundings during **14** intensive observation periods (**IOPs**)





perturbation profiles

measured profile minus background fit (2^{nd}-polynomial-fit with additional 5-km running mean)

Assumption: perturbations are caused by GWs

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Analysis of radiosonde data

- perturbations of **different variables** are **sensitive to different parts of the GW spectrum** (Lane et al 2000, Lane et al 2003, Geller and Gong 2010)

$$\frac{m^2}{k^2+l^2} = \frac{N^2-\Omega^2}{\Omega^2-f^2}$$

amplitude horizontal wind

$$A_u = \frac{-lA_v+mA_w}{k}$$

amplitude vertical wind

$$A_w = \frac{-kA_u+lA_v}{m}$$

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amplitude horizontal wind	amplitude vertical wind
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➢ $\boxed{\Omega \rightarrow f:\ \ m\uparrow, k\downarrow, \lvert A_u \rvert \uparrow}$

→ measurements of **hz. wind** emphasize **low frequency waves** (inertia-GWs)

- Gravity wave **energies** (Geller and Gong 2010)

– **kinetic energy**: $\langle KE_{mass} \rangle = \frac{1}{2}[\langle u'^2 + v'^2 \rangle]$ low frequency/inertia-GWs

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→ measurements of **vert. wind** emphasize **medium to high frequency waves**

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– **vertical energy**: $\langle VE_{mass}\rangle = \frac{1}{2}\langle w'^2\rangle$ high frequency GWs

Analysis of radiosonde data

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- $\Omega \rightarrow f: \; m\uparrow, k\downarrow, |A_u|\uparrow$
- $\Omega \rightarrow N: \; m\downarrow, k\uparrow, |A_w|\uparrow$

→ measurements of **hz. wind** emphasize **low frequency waves** (inertia-GWs)

→ measurements of **vert. wind** emphasize **medium to high frequency waves**

- Gravity wave **energies** (Geller and Gong 2010)
  - **kinetic energy**: $\langle KE_{mass}\rangle = \frac{1}{2}[\langle u'^2 + v'^2\rangle]$ low frequency/inertia-GWs
  - **potential energy**: $\langle PE_{mass}\rangle = \frac{1}{2}\frac{g^2}{N^2}\left\langle\frac{T'^2}{{T_b}^2}\right\rangle$ mixed
  - **vertical energy**: $\langle VE_{mass}\rangle = \frac{1}{2}\langle w'^2\rangle$ high frequency GWs

When can soundings be treated as vertical profiles?

- drift of the balloon is small enough compared to wave scales
- ascent of the balloon is fast enough compared to wave scales and wave frequency

$$\left|\frac{kU + lV}{m\overline{W}_B}\right| << 1$$

$$\frac{\omega}{m\overline{W}_B} << 1$$

k, l, m … wavenumbers
U, V … hz. background wind
$\overline{W}_B$ … mean balloon ascent rate
ω … frequency

(Gardener and Gardener 1993, Reeder et al. 1999, Lane et al. 2003)

✓ **low frequency/inertia-GWs**, e.g. when **horizontal velocity** perturbations are analyzed

X for **medium and high frequency GWs**, e.g. when **vertical velocity**/balloon ascent rate is analyzed (horizontal projection method, Shutts et al 1988, Lane et al 2000, Reeder et al 1999)

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this talk

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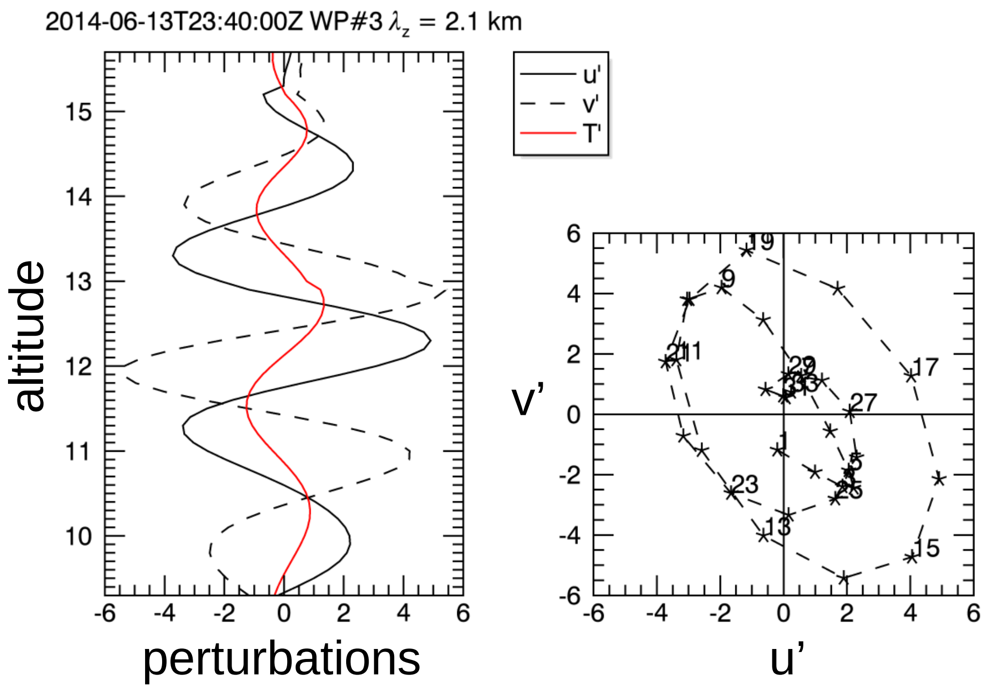
Inertia-GWs

horizontal velocity perturbations

- treat sounding as vertical profile
- **derive wave properties** (e.g., Allen and Vincent 1995, Vincent et al. 1997, Murphy et al 2014)



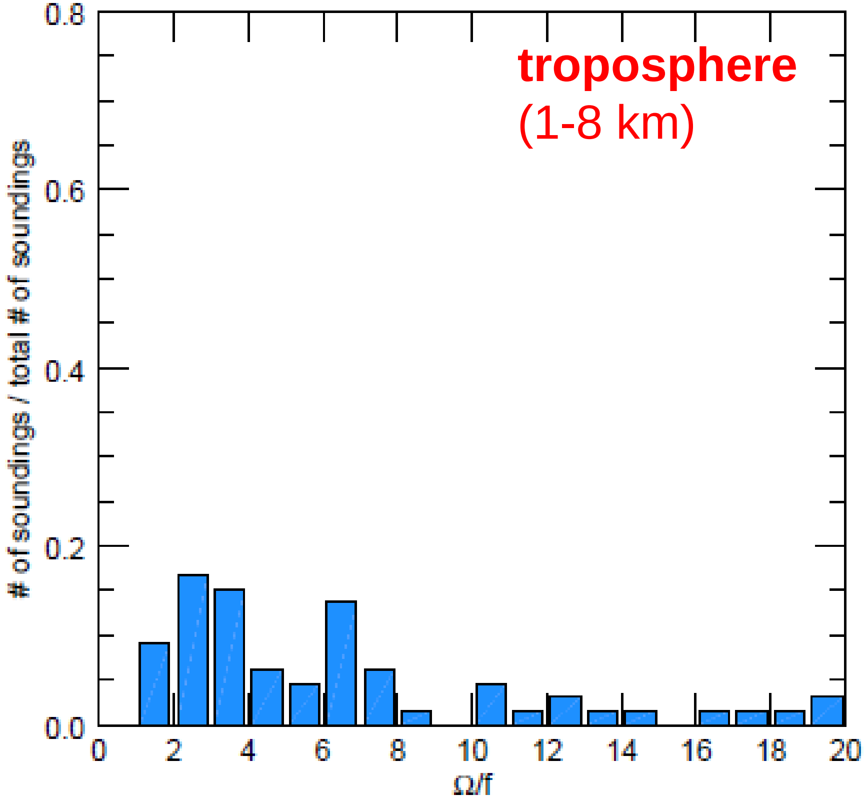
basic idea based on relationship of **u' and v'** (e.g. hodograph)

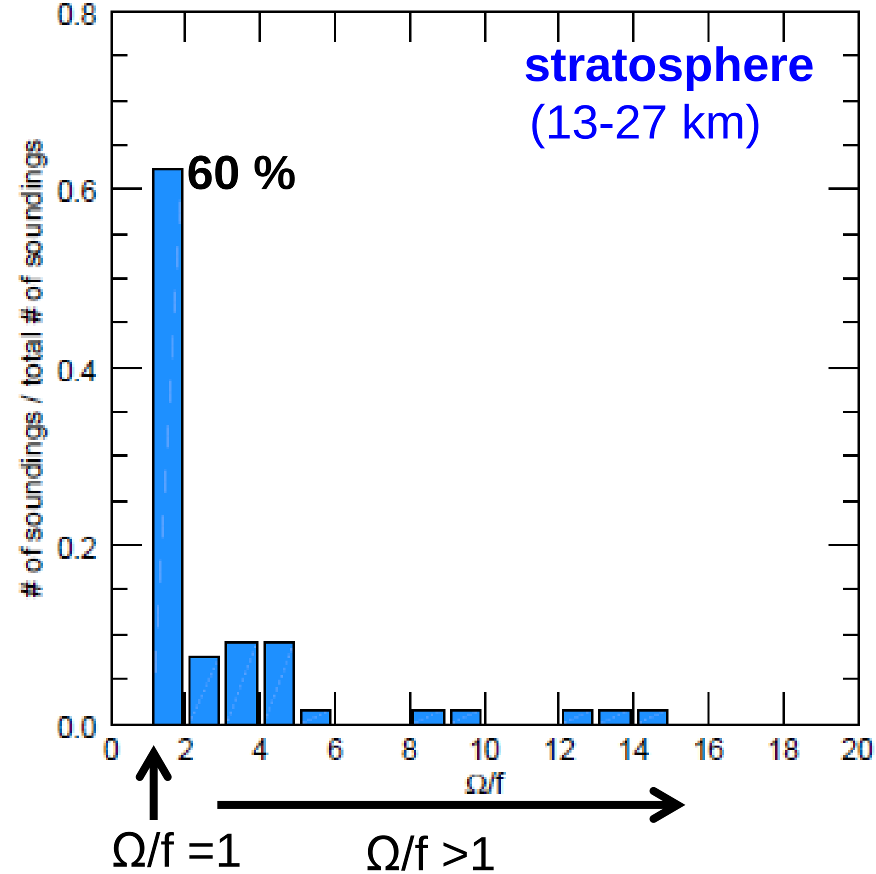
- sense of rotation gives upward/downward propagation
- orientation of major axis gives propagation direction
- axial ratio gives frequency

- contained in methods of **rotary spectra, stokes analysis**

Inertia-GWs

intrinsic frequency (Ω/f) from Stokes analysis





- data (**u', v'**) going into Stokes analysis **mainly contain inertia-GWs**
- determined intrinsic frequencies **more variable in troposphere**

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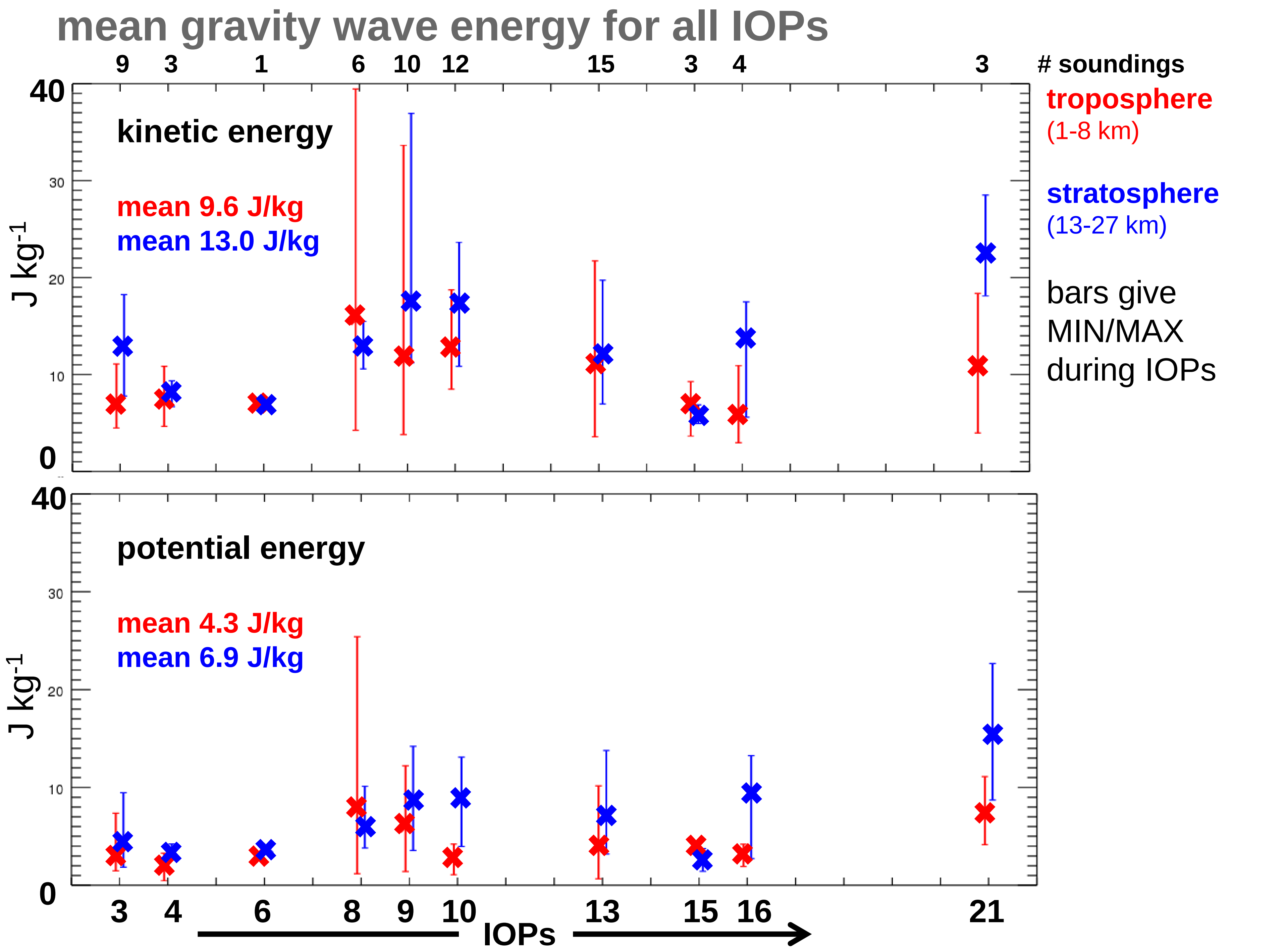
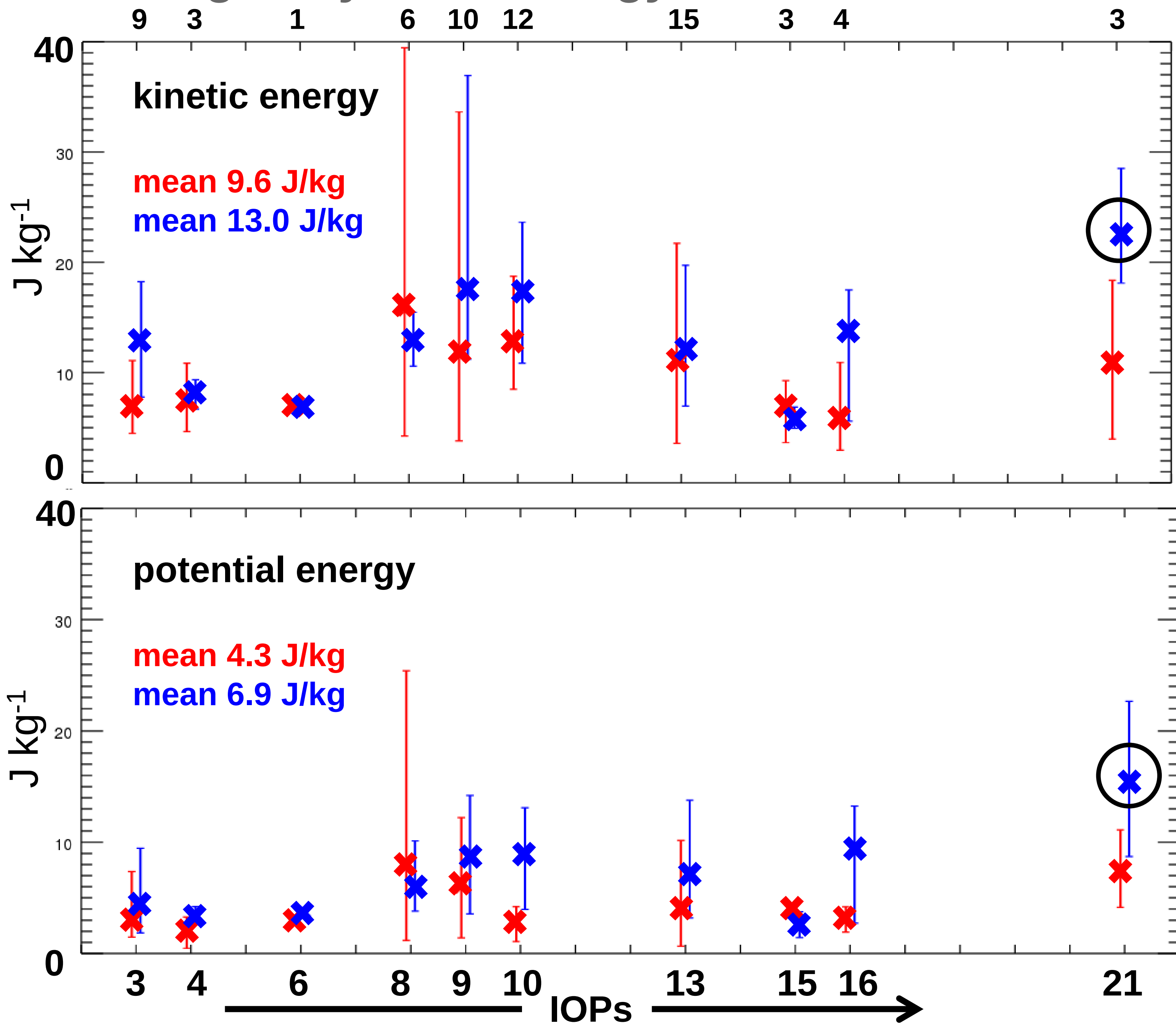

mean gravity wave energy for all IOPs
soundings
9 3 1 6 10 12 15 3 4 3
troposphere
(1-8 km)
stratosphere
(13-27 km)
bars give
MIN/MAX
during IOPs
kinetic energy
mean 9.6 J/kg
mean 13.0 J/kg
potential energy
mean 4.3 J/kg
mean 6.9 J/kg
J kg-1
J kg-1
0
10
20
30
40
IOPs
3 4 6 8 9 10 13 15 16 21

mean gravity wave energy for all IOPs



troposphere
(1-8 km)

stratosphere
(13-27 km)

bars give MIN/MAX during IOPs

IOP 21 on 31. Jul/1. Aug

largest KE and PE in the stratosphere

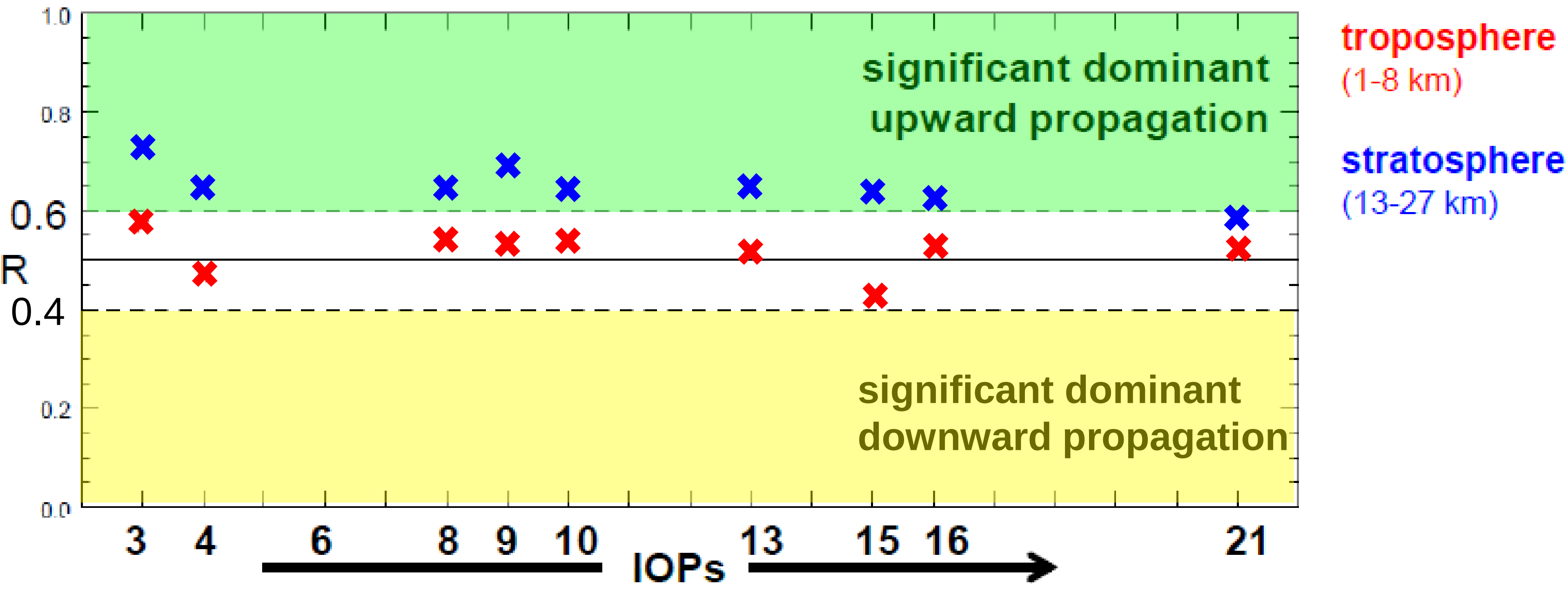
Inertia-GWs

vertical propagation direction

ratio (R) of upward and downward propagation from rotary spectra (u'+iv')

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

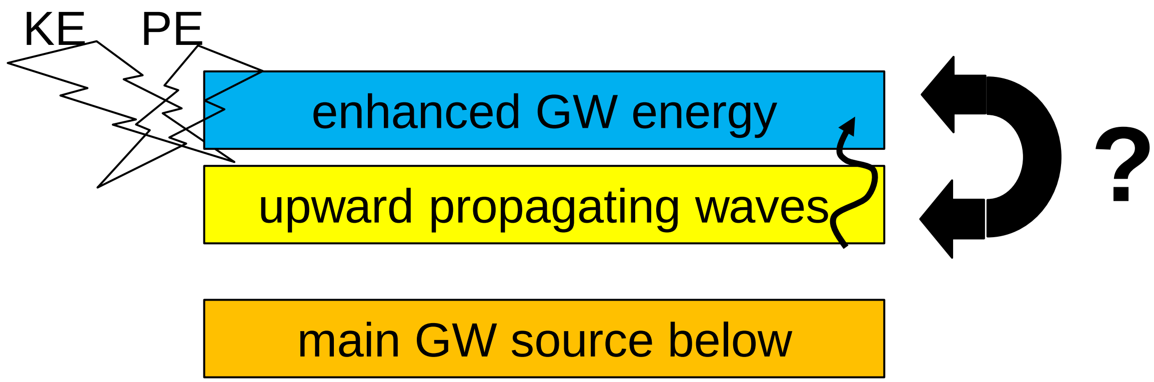
R > 0.6 significant upward energy propagation,
R < 0.4 significant downward energy propagation



- **dominant upward propagation** in the **stratosphere** (source lies below → troposphere, tropopause)
- no dominant propagation direction found for troposphere

Inertia-GWs

Correlation between vertical propagation direction and GW energy



– **low correlation** between **enhanced KE** and **PE** and **upward propagation** (0.6 or smaller, *in agreement with Guest et al. 2000*)

→even if **KE** and **PE are high**, **R** would be **close to 0.5**…

… if **upward- and downward-propagating waves** are present

… if **wave frequencies are large** compared **to inertial frequency *f* (medium to high frequency waves)**

Inertia-GWs: summary of properties from soundings

- **GW energy** is variable **for different events** (values distributed around **10 J/kg**)
- **GW energy** varies **during IOPs**
- **vertical propagation** direction **in troposphere** not clear
  → **upward and downward propagating waves** and/or **higher freq. waves**
- **not necessarily** only **upward propagating waves if KE** and **PE are enhanced**
- **dominant upward** propagation in the **stratosphere**
  → **source in troposphere/tropopause**

(not shown)

- dominant **vertical wavelength 2-4 km, horizontal wavelength 50-800 km**
- ground based **horizontal phase propagation** mainly **eastward with mean 10 m/s**
  → **source west of Lauder**

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Possible sources?

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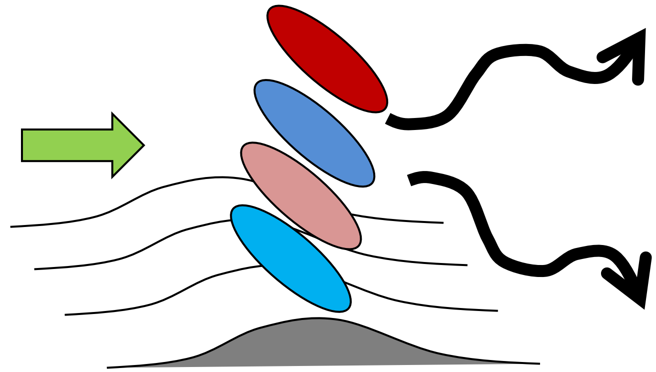
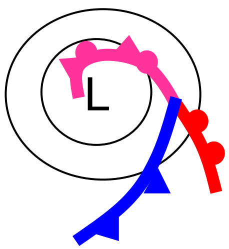
Known major sources for Inertia-GWs (e.g., Spiga et al. 2008)

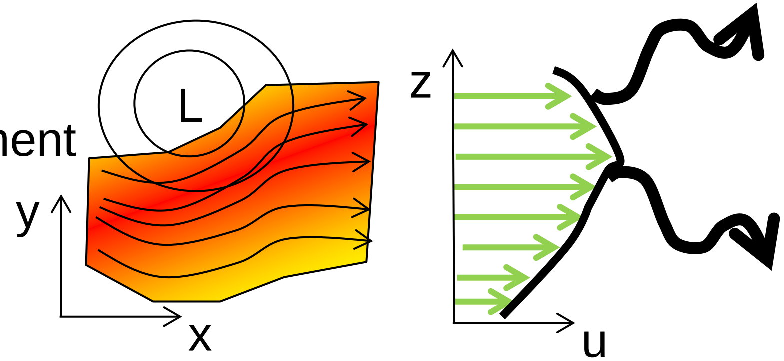
- **large amplitude mountain waves**: **adjustment of large-scale flow** due to high amplitude and eventually breaking of the **main mountain wave**

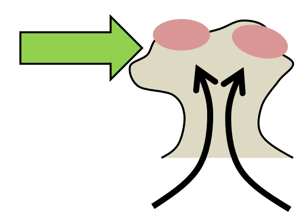


- **fronts**

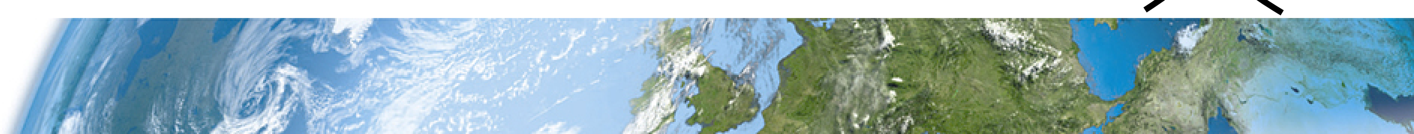


- **jets**: spontaneous adjustment



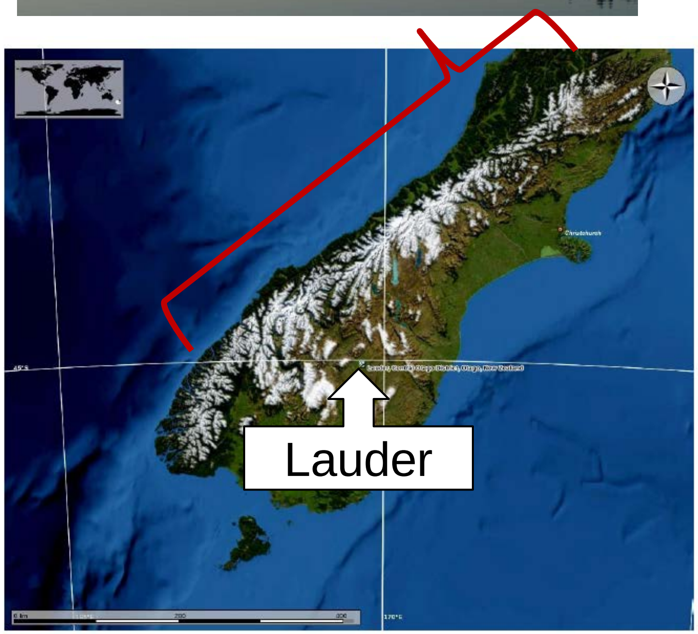


- deep **convection**: bulk release of latent heat, “obstacle effect”, mechanical oscillation

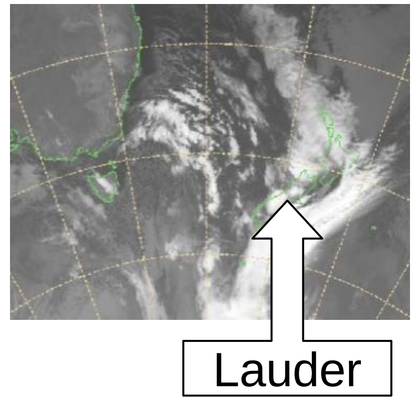


Known major sources for Inertia-GWs

mountains
west of Lauder

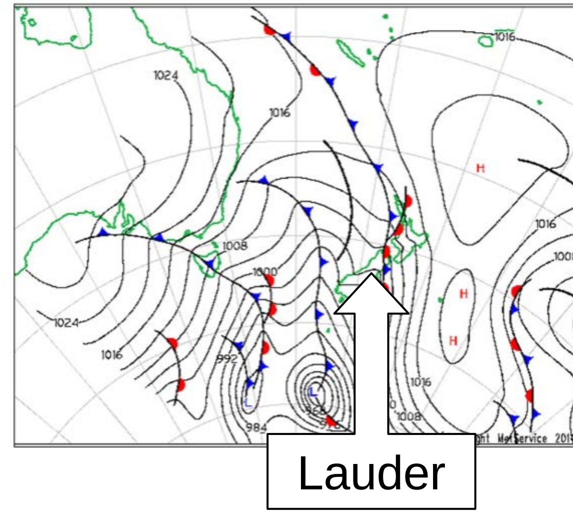


convection

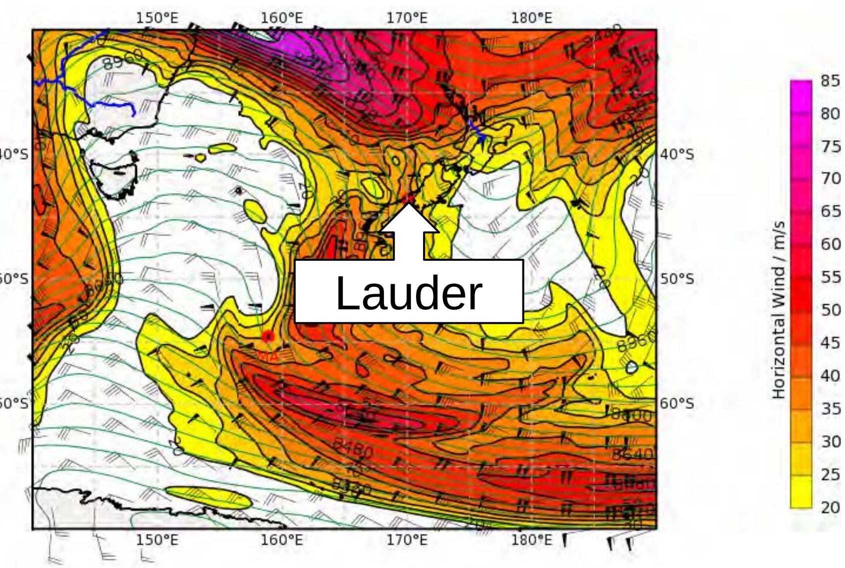


NZ Met Service
Surface Analysis
Vaild 12:00 NZST

fronts



wind @ 300 hPa



Jet maximum/Jet-exit region moving over NZ

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Known major sources for Inertia-GWs

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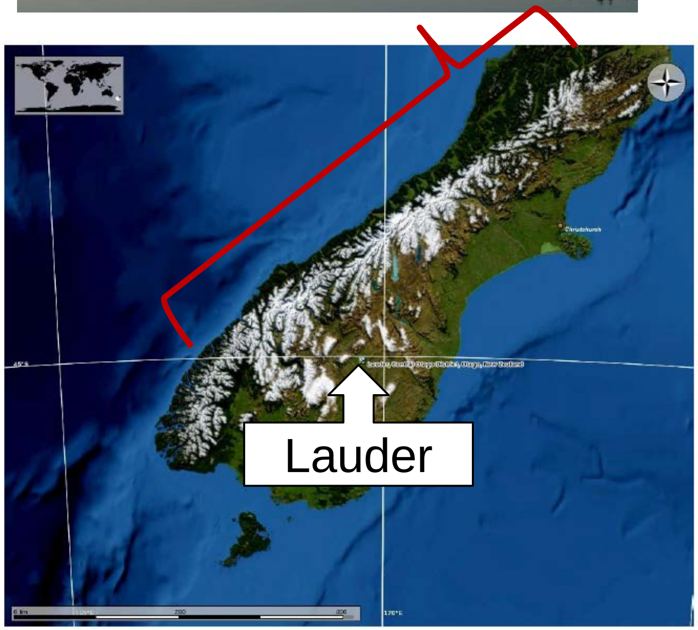
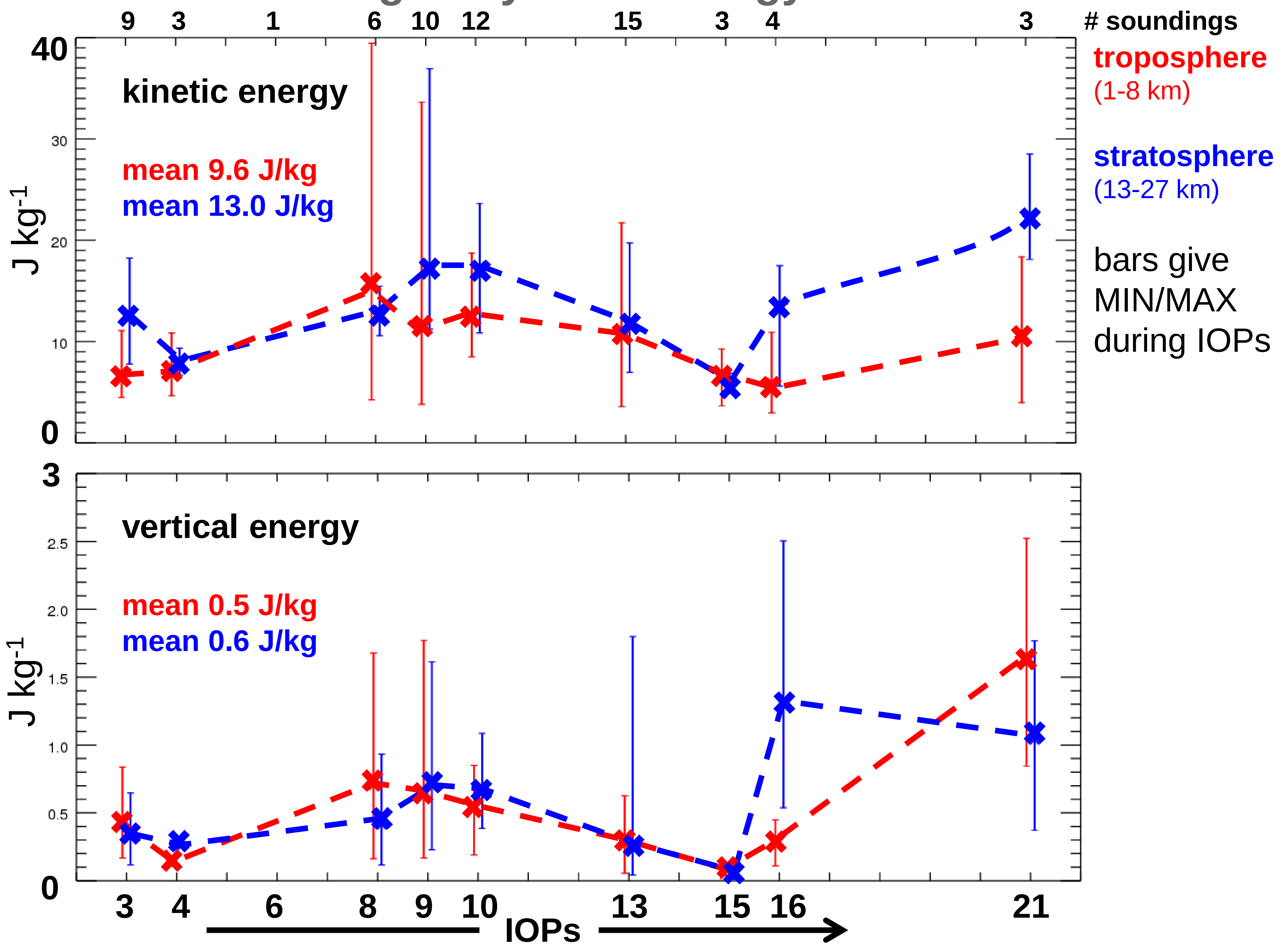


- **radiosondes** were released when **mountain waves** were expected
  → cross mountain flow

- **vertical energy** based on **balloon ascent rate** to quantify **mountain wave activity**

Results: mean gravity wave energy for all IOPs



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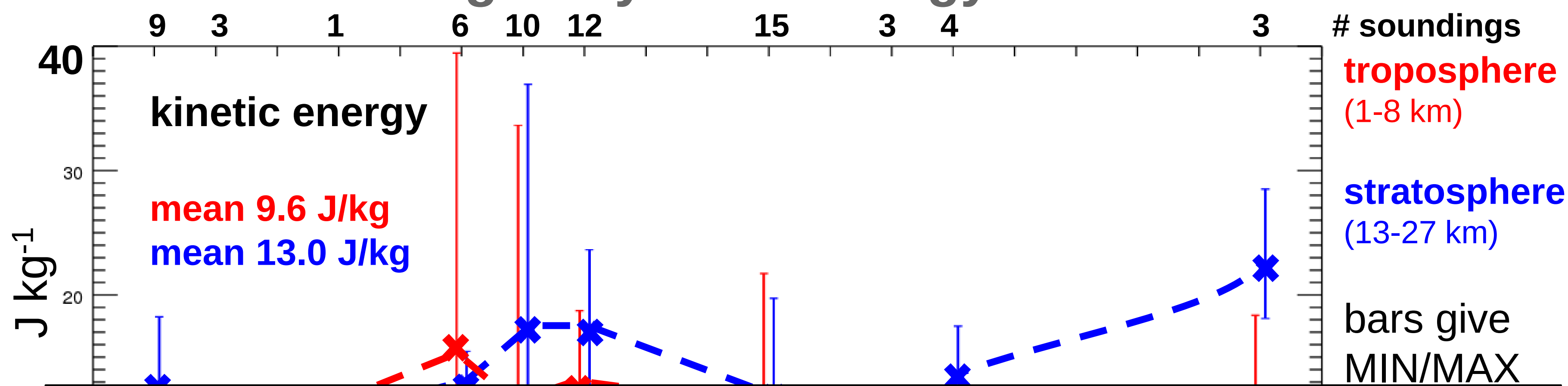


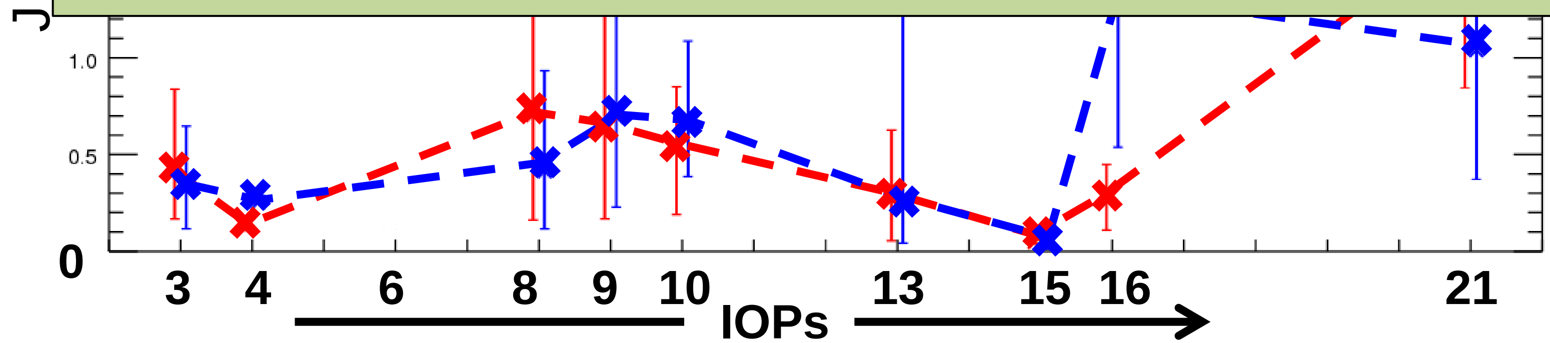
correlation coefficient of **IOP mean values**

- ➢ **KE stratosphere** and **VE troposphere**: **0.87**
- ➢ **KE stratosphere** and **VE stratosphere**: **0.72**

} **stratospheric inertia-GWs seem to be connected to mountain waves**

BUT correlation between **KE** and **VE** varies during IOPs

→ **possible contribution of other sources of inertia-GWs (more detailed analysis the different events necessary)**



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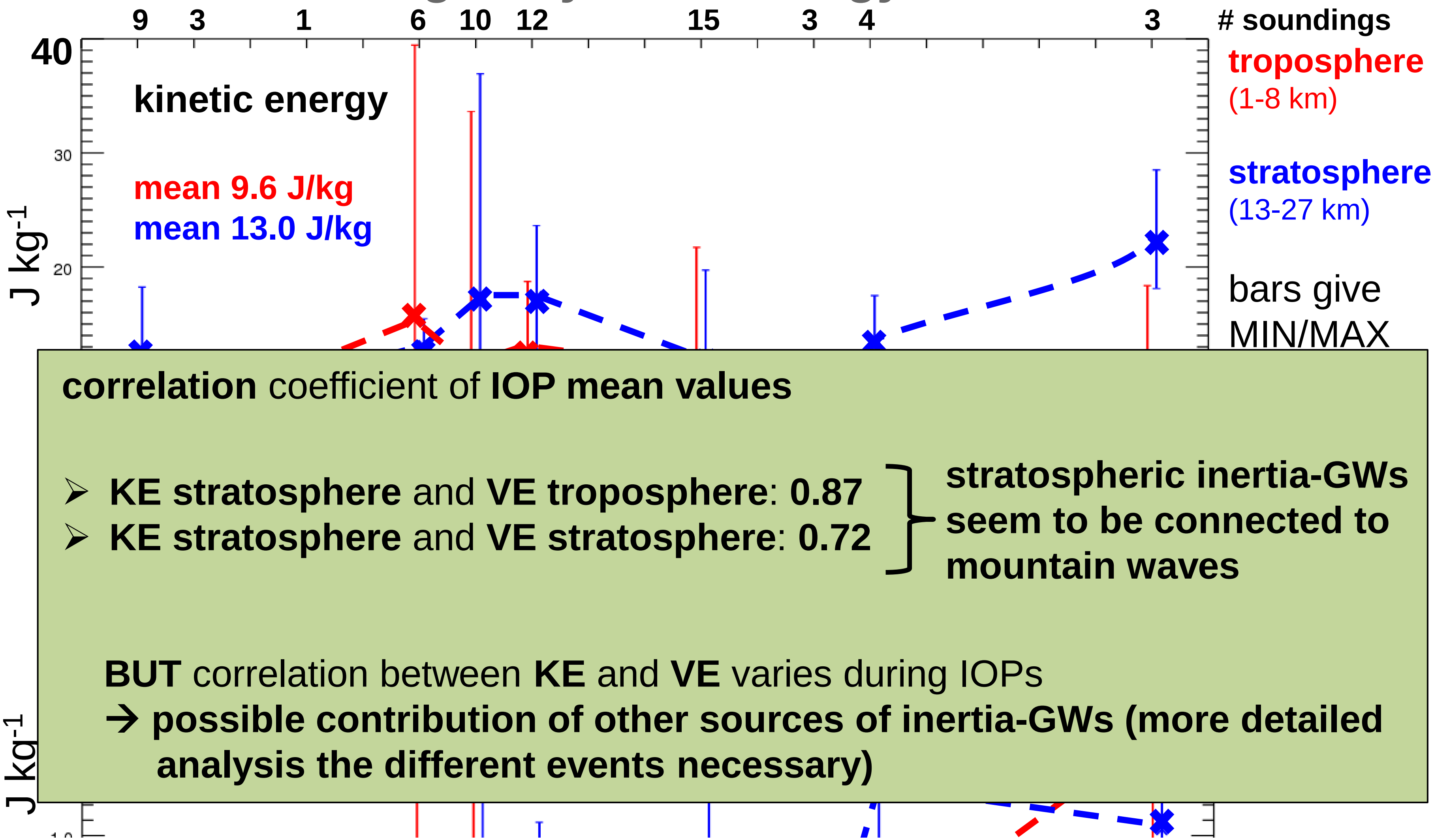

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Thank you for your Attention!

Attendance at the meeting was supported by WMO travel award