Summer convective gravity wave event over Europe characterized by Lidars, Satellite and All-Sky Imager

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Abstract

In this work, we present a case study of a summer convective gravity wave event that propagated across Europe. This event was observed by lidars and satellite July 11-12, 2023. For this case, we show how this gravity wave event propagates through the 3 wind lidars currently in operation in Europe: the newly developed IAP wind lidar located in Kühlungsborn, Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR) and Observatoire Haute Provence (OHP) wind lidar. In addition, we use radiance measurements obtained by NASA's Aqua satellite Atmospheric Infrared Sounder (AIRS) instrument and precipitation and cloud observations from the EUMETSAT to further characterize the event and the source of deep convection. We use ECMWF to complement our measurements, as well as to evaluate how the event looks in the model compared to the measurements. To see the propagation of the wave at around 90 km, we use airglow imagers co-located at Kühlungsborn. Convective gravity waves are highly intermittent in both space and time, and this event is in the tail of the distribution. Characterizing this event is important because it can provide observational guidance for model parametrizations.

Objectives of this study

- Characterize a large-amplitude convective gravity wave event as it propagates through the atmosphere using ground-based instruments and satellite
- Compare the wave characteristics, including momentum flux estimates, from the different instruments

Instruments

For this study, we used the following instruments and analysis techniques:

- Lidars
  - Kühlungsborn [Germany] (54°N, 11°E) - Hodograph Technique
  - ALOMAR [Norway] (69°N, 16°E) - Hodograph Technique
  - OHP [France] (45°N,6°E) - S-Transform
- AIRS Satellite Instrument Brightness Temps - 3D S-Transform
- All Sky Imager (54°N, 11°E) - 557.7 nm (O(^{1}S) green line), 864.5 nm (O_2), 695–1,050 nm (OH broadband filter)
- SIMONE Meteor Radar (54°N, 11°E) - Mesospheric winds
- EUMETSAT rain rate and cloud top height data products

Methodology

- Identify the convective wave in the different instrument datasets
- Use ray-tracing to confirm that the source of the gravity waves is convective
- Characterize gravity waves with the lidar, AIRS satellite instrument and airglow imagers using hodograph and S-transform methods
- Compare the properties of the wave observed by different instruments at different heights
- Evaluate the representation of the gravity wave event in ECMWF

Observations

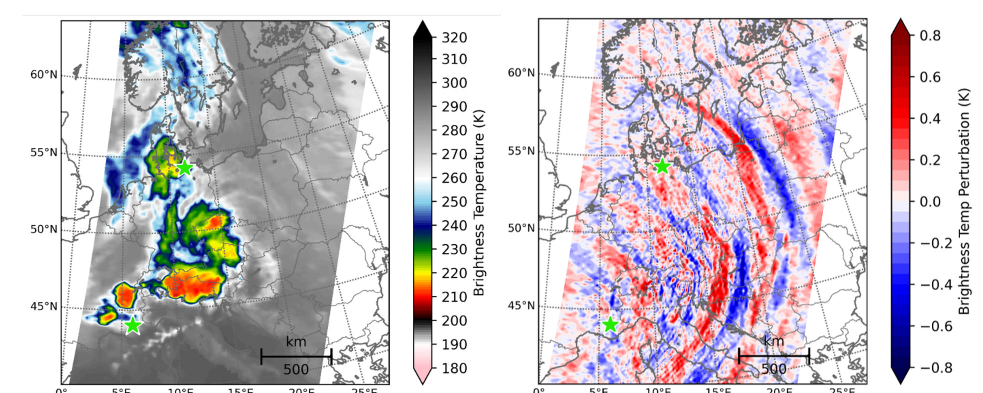
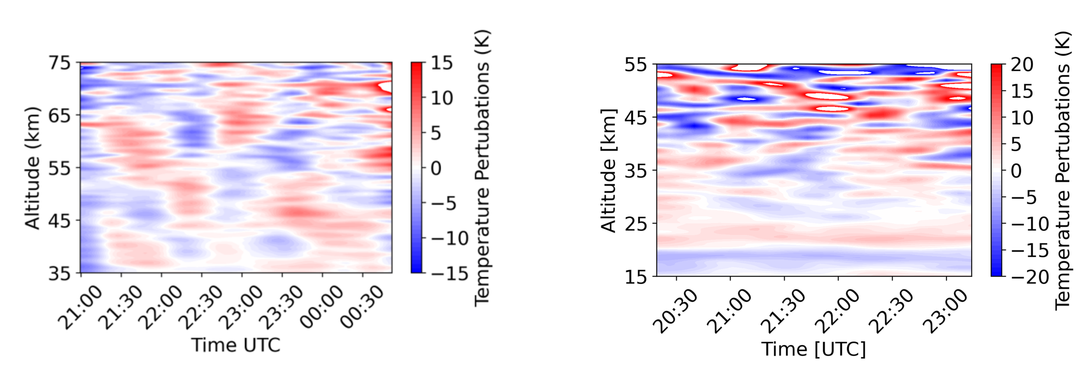


Figure 1: The convective event discussed in this study is presented here. The event took place on July 11-12, 2023 over Europe. The left panel shows deep convection as observed by the AIRS 8.1 µm brightness temperature and the right panel shows 4.3 µm brightness temperature perturbations to highlight the gravity wave activity. The peak of the 4.3 µm brightness temperature channel is around 40 km.



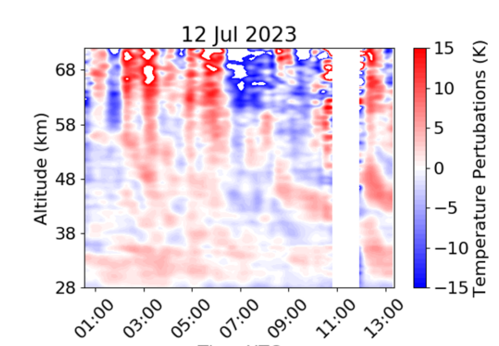


Figure 2: The lidar temperature perturbations from the 3 stations. On the upper left, we show the Kühlungsborn lidar (54°N). On lower left we show the ALOMAR lidar (69°N). On the upper right, we show the OHP lidar (45°N).

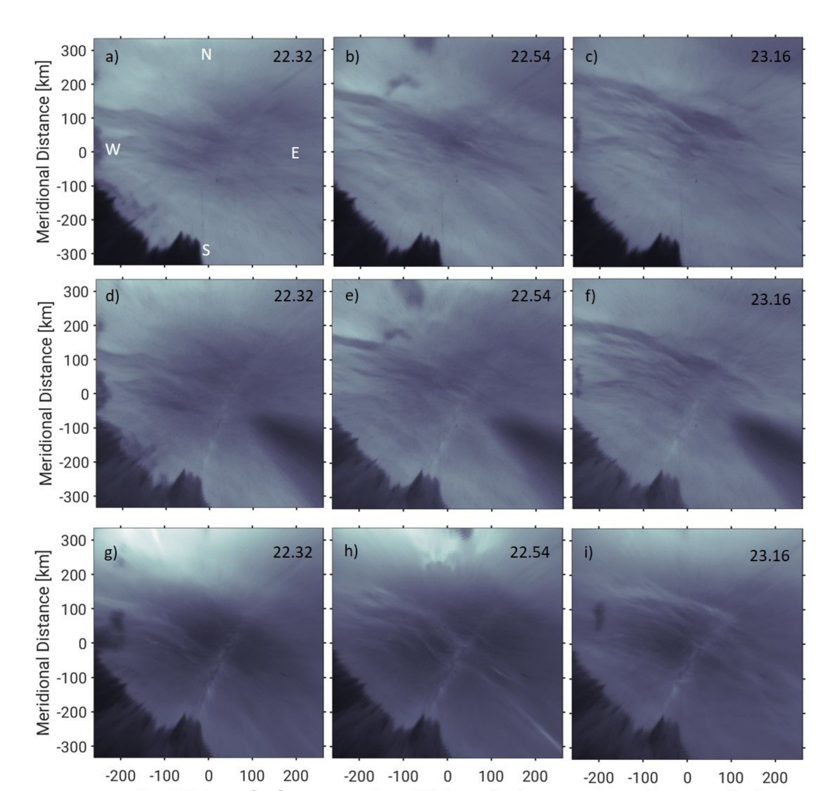


Figure 3: The images from the airglow imager located at Kühlungsborn (54°N) are shown here. The columns show the event at different times, as the rows show the different emissions. The top row shows the 557.7 nm (O(1S) green line) emission (~97 km). The middle row shows the 864.5 nm (O2) (~90 km) and the bottom row shows the OH broadband emission (~85 km). The wave is shown moving in the same direction as in the satellite.

Results

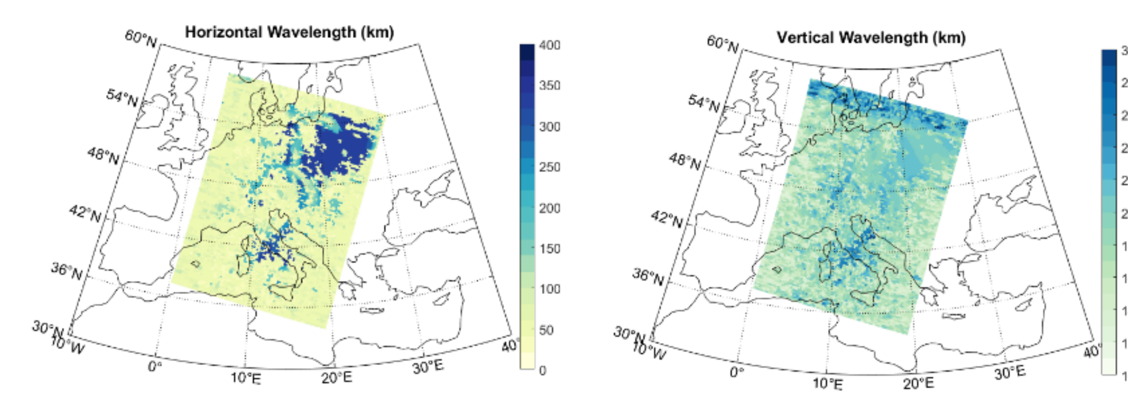


Figure 4: The results of the S-transform analysis of the AIRS data are shown in this figure. The resulting horizontal and vertical wavelengths are shown on the left and right panels respectively.

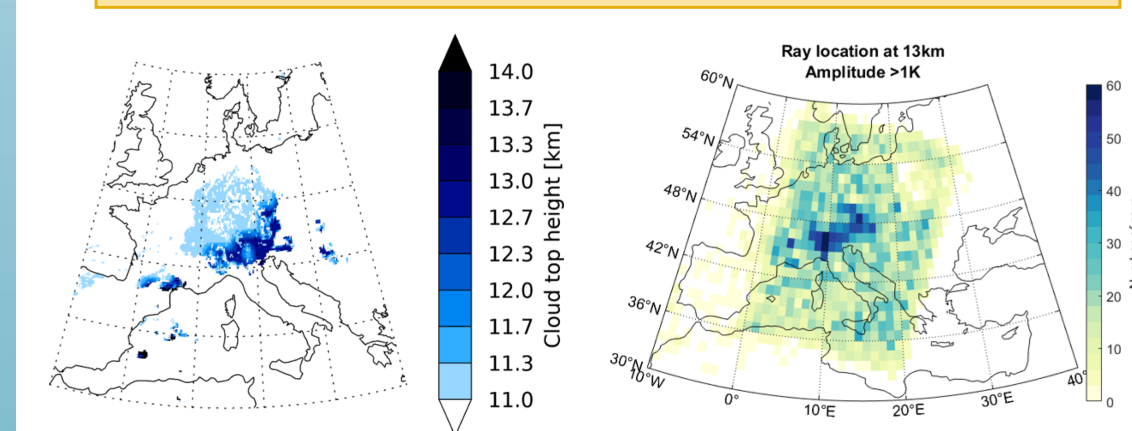


Figure 5: The left panel shows cloud top heights from the EUMETSAT MSG Cloud Top 0 degree data product. The tropopause for this day was at around ~11 km. We show only the clouds that overshoot the tropopause since deep convection overshooting the tropopause is a source of gravity waves. The right panel shows the ray tracing analysis. The backward traced rays concentrate in an area coinciding with the deep convection, providing strong evidence that these waves are convectively generated.

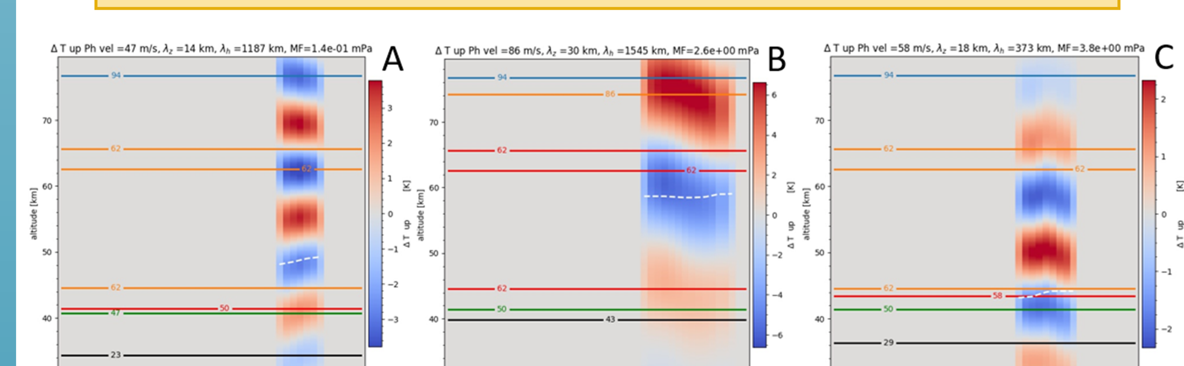
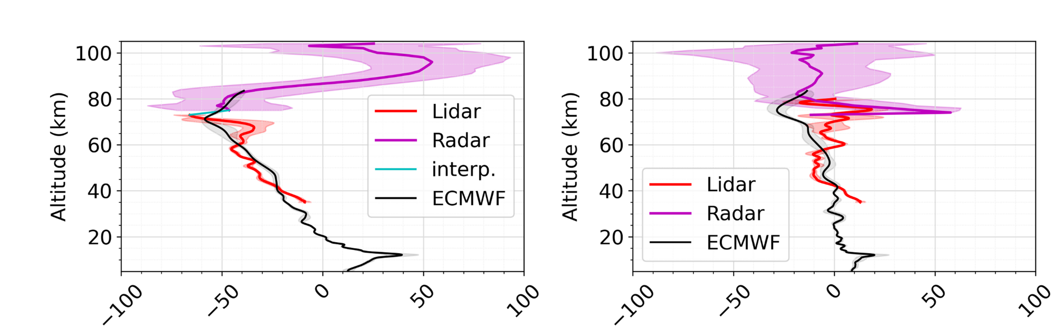


Figure 6: Waves identified by the hodograph analysis in the Kühlungsborn and Alomar lidar data. We selected waves that were propagating in the same direction as the waves observed by AIRS. The waves shown are from the Kühlungsborn lidar.



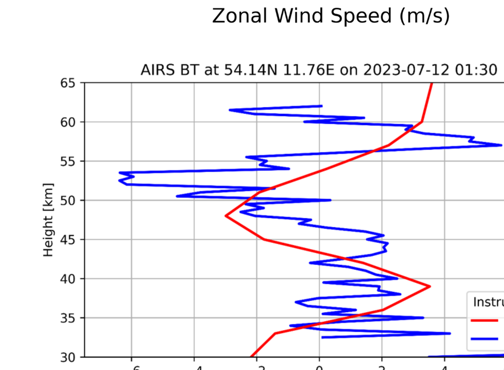


Figure 7: The upper right and left panels show the zonal and meridional wind profiles respectively at 54°N using lidar (red) and radar (purple). In the lower left panel , we compare the lidar perturbations (blue) with the AIRS perturbations (red).

Location	OHP 45° N	IAP 54° N					ALOMAR 69° N
Parameters	Lidar	Lidar			AIRS	Imager	Lidar
Horizontal Wavelength [km]	X	1545	373	47	384	88	1381
Vertical Wavelength [km]	~10 km	30	18	10	17.9	32	14
Amplitud [K]	2	3	2	2	3	X	2
Altitude [km]	45	59	44	45	~40	~87	40
Observed Period [min]	70	X	X	X	X	40	X
Intrinsic Period [h]	X	5	2	0.4	X	0.3	7
Propagation Speed [m/s]	X	86	58	31	X	79	56
Momentum Flux [mPa]	X	2.6	3.8	13	2	X	1

Table 1: The summary of the results of this paper are shown in this table. It shows all the characteristics of the waves using the different instruments.

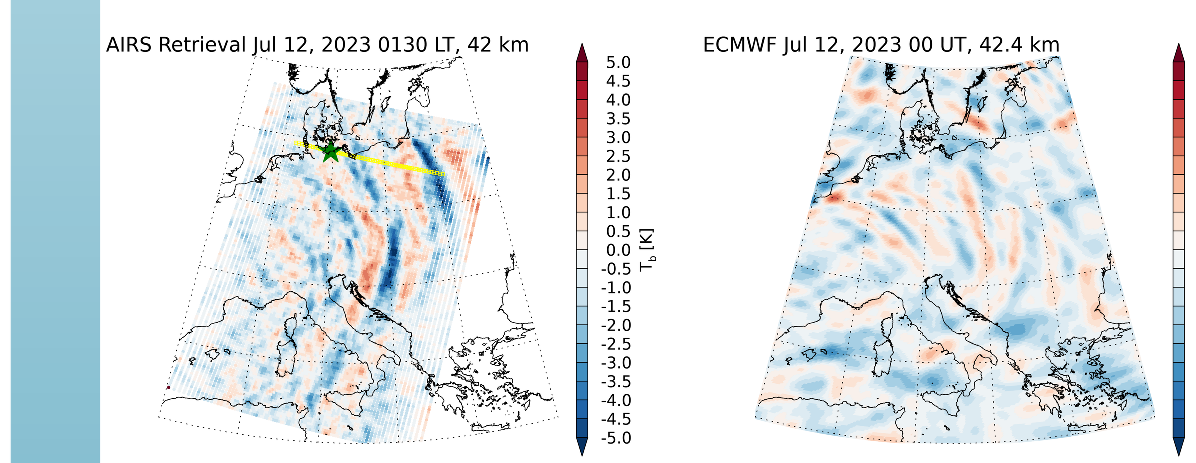


Figure 8: This figure compares the satellite (AIRS) observations to the ECMWF Integrated Forecasting System (IFS) data. We can see that while ECMWF does show a gravity wave with similar concentric rings and horizontal wavelength, the smaller scales are still not represented and the amplitudes are underestimated.

Conclusion

- A large amplitude convective gravity wave was observed with multiple instruments from its source in the Troposphere to the Thermosphere.
- Despite the different observational filters of the Kühlungsborn lidar and the AIRS instrument, both instruments observed the gravity wave event and both agreed on one of the dominant horizontal and vertical wavelengths.
- The lidar observed additional wavelengths, including one with a vertical wavelength of 10 km and very large momentum flux
- The airglow imager observed a wave moving in the same direction as the wave observed by the satellite and lidar. However, we have not investigated whether this is a primary or secondary gravity wave
- ECMWF IFS shows a similar horizontal structure as AIRS but the amplitudes are underrepresented.
- More multi-instrument studies are needed to better characterize convective gravity waves

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