The prospect of studying atmospheric gravity waves with balloon lidars

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HEMERA Workshop
Rome, 5 July 2022

DLR

Overview

Our group studies **atmospheric gravity waves** with **lidar instruments**

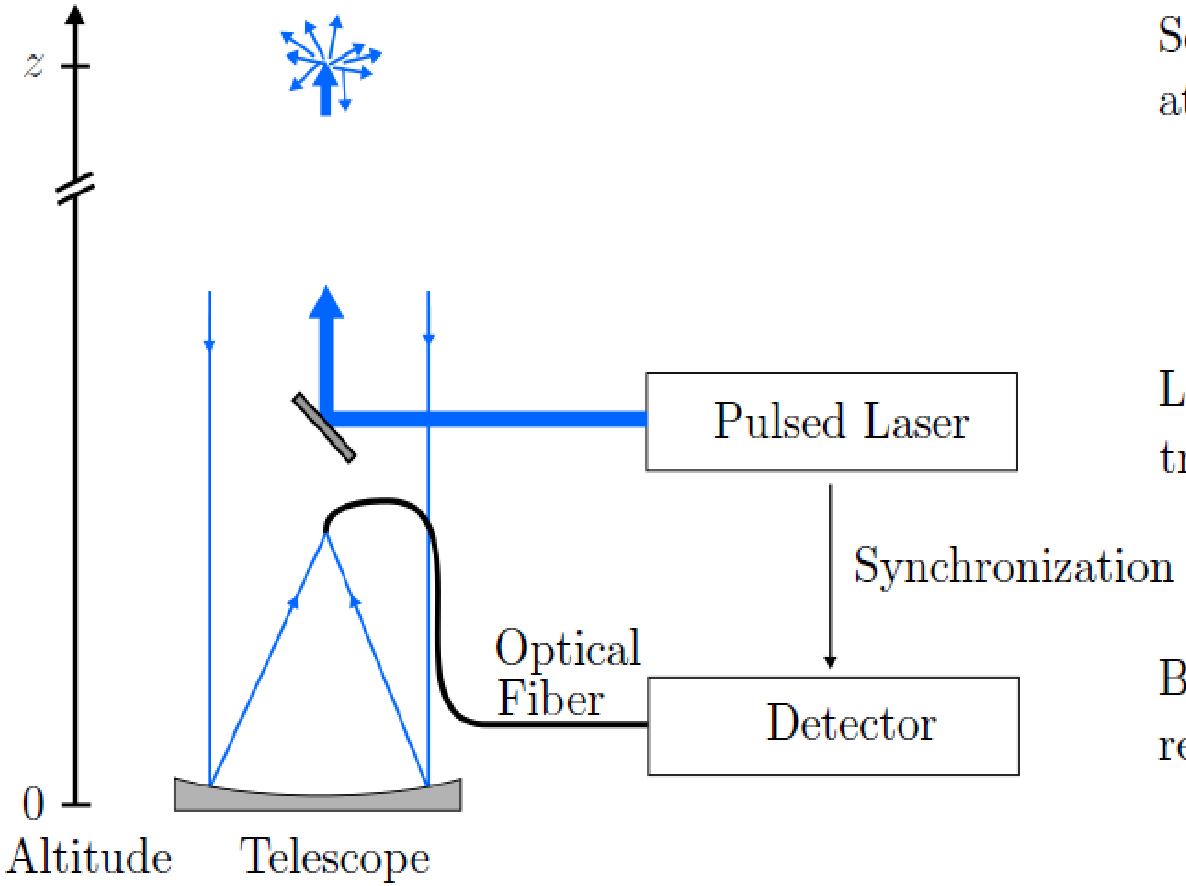
- ground
- balloon
- aircraft

- how do lidars work
- what are gravity waves
- and why are they important

We propose a **super-pressure balloon lidar campaign in Antarctica** to step forward in gravity wave research

A lightweight lidar can be built based on technology of the **BOLIDE balloon lidar used during PMC Turbo**

Lidar principle



Scattering
at altitude $z = c\frac{t-t_0}{2}$

Laser pulse
transmitted at time t_0

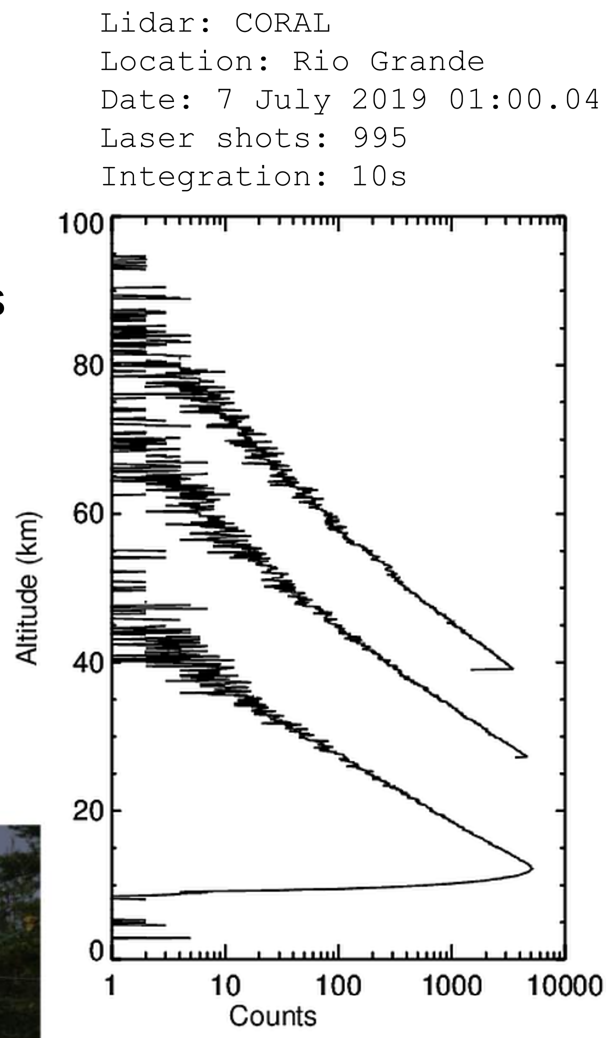
Backscattered pulse
received at time t

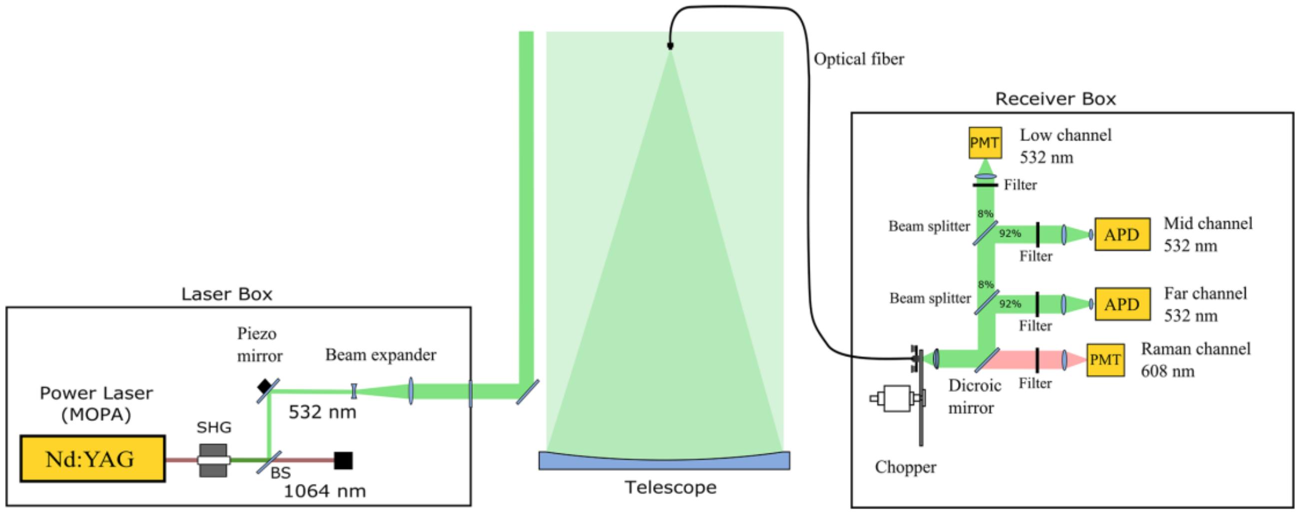
Lidar principle

- Transmission of a laser pulse
- Collection and detection of backscattered light
- Runtime → height resolution

Received count profiles

~ atmospheric density





Schematics of the CORAL lidar and optical paths

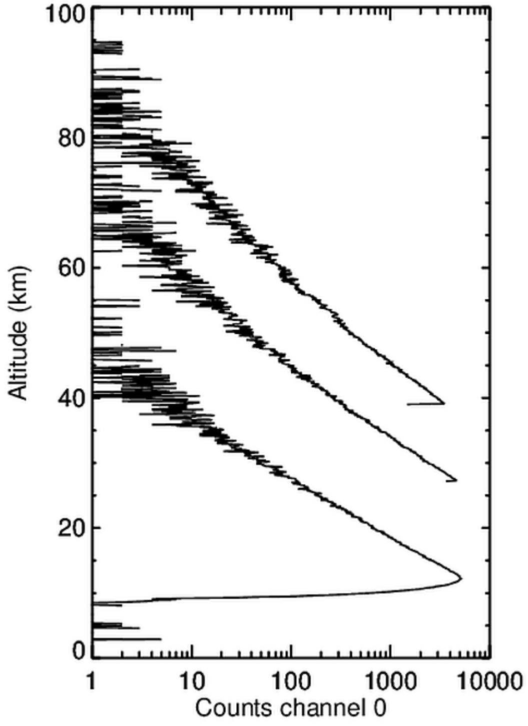
CORAL container at Sodankylä

Kaifler and Kaifler, 201

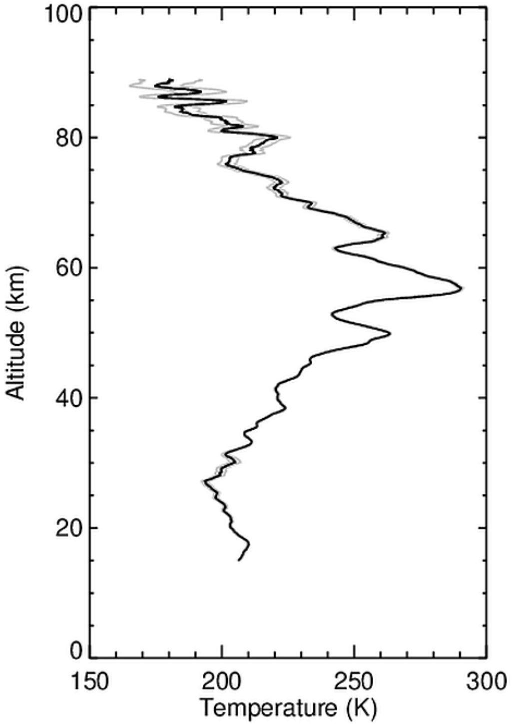
Hydrostatic temperature integration

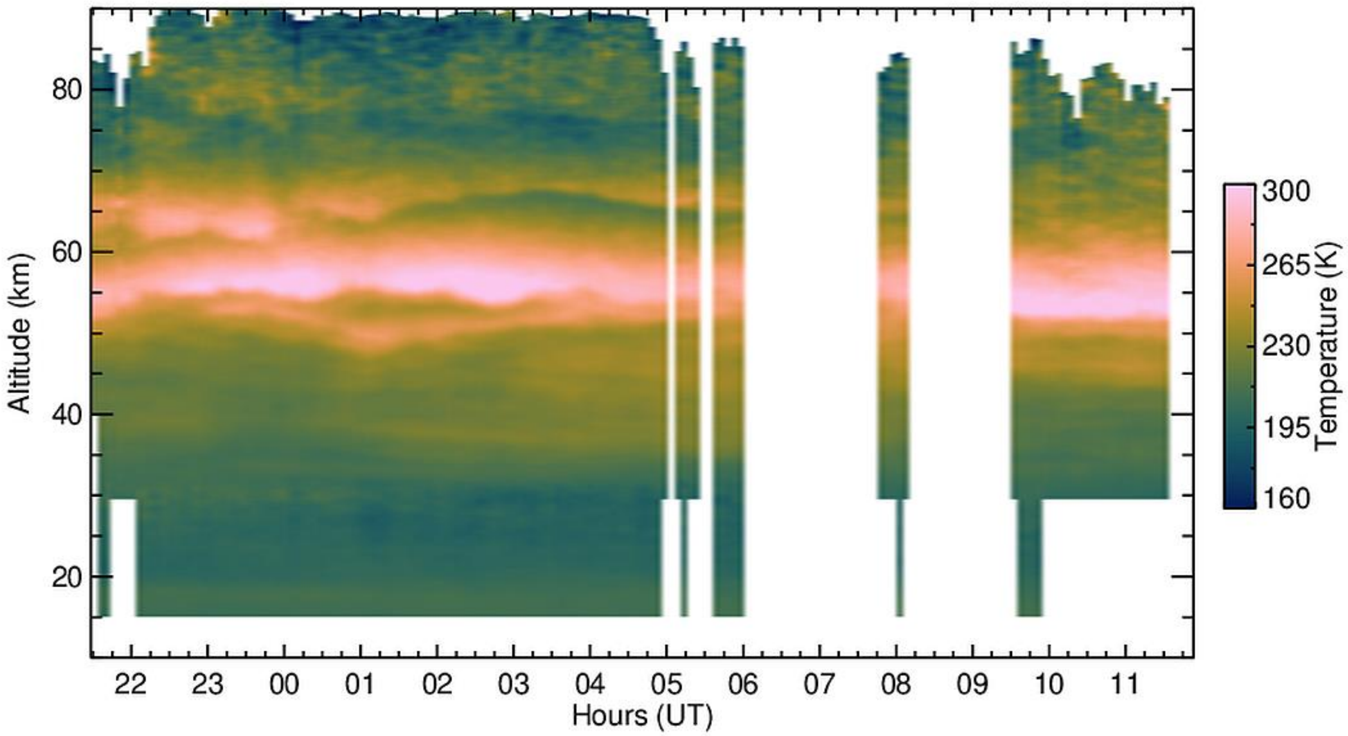
```
Lidar: CORAL
Location: Rio Grande
Start time: 6 July 2019 21:28
Stop time: 7 July 2019 11:35
Altitude resolution: 900 m
Temporal resolution: 15 min
```

10s

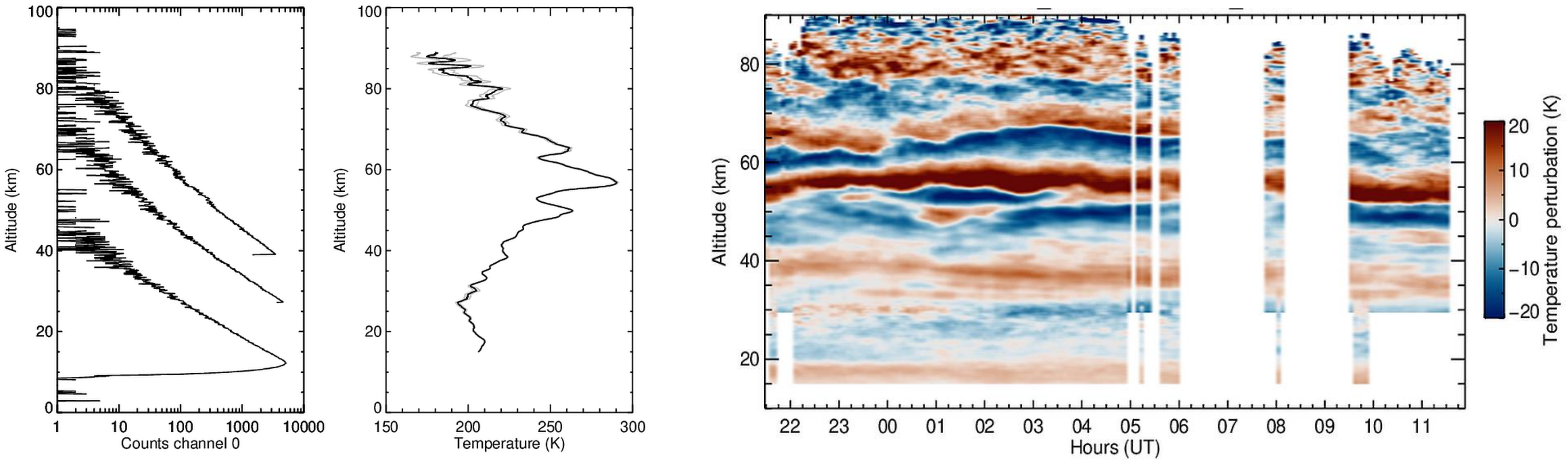


15 min





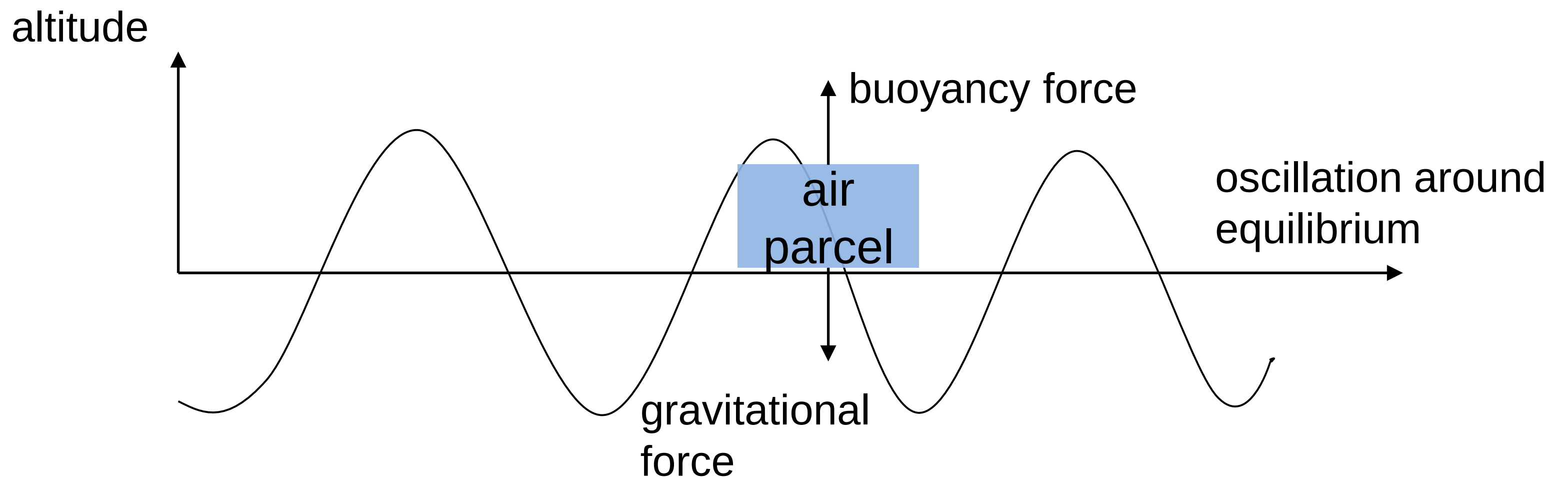
Temperature perturbations

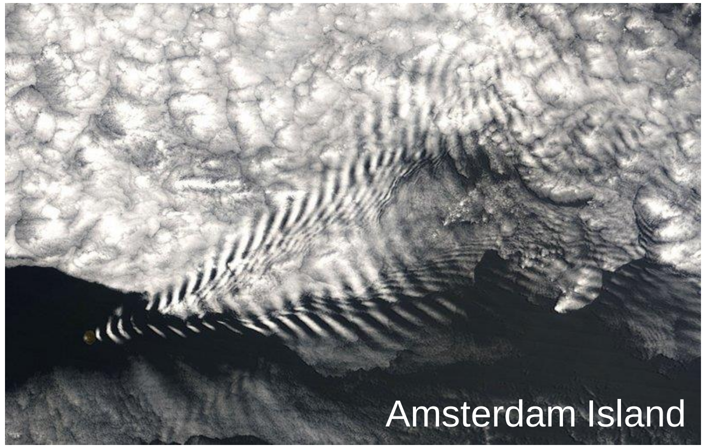


- filter vertically with Butterworth filter, 20 km cutoff: → signatures of gravity waves

What are gravity waves?

- Wave motions are generated by buoyancy





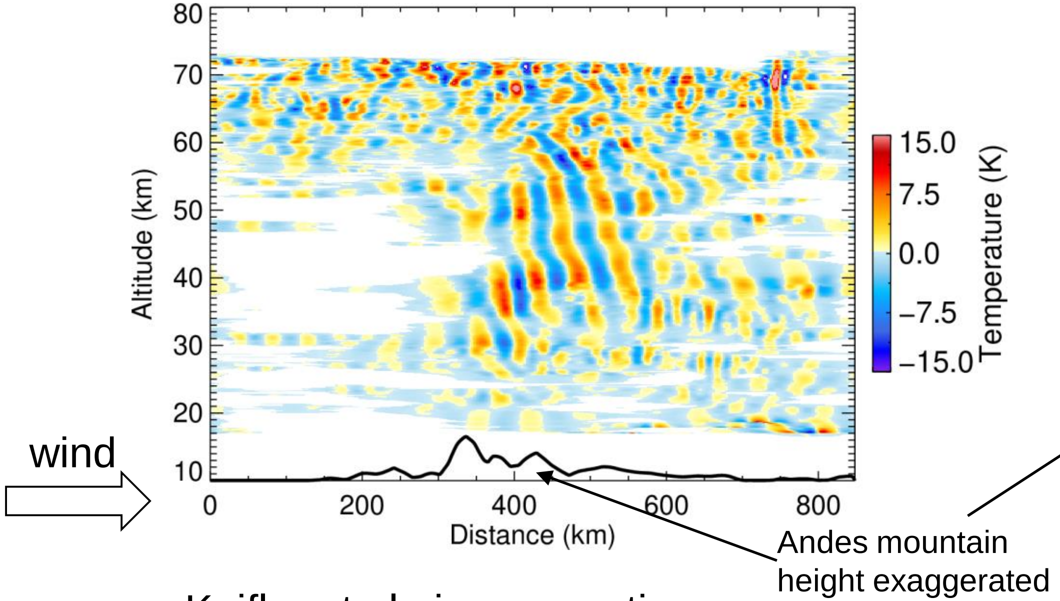
see review on atmospheric gravity waves by Fritts and Alexander, 2003

Gravity wave sources

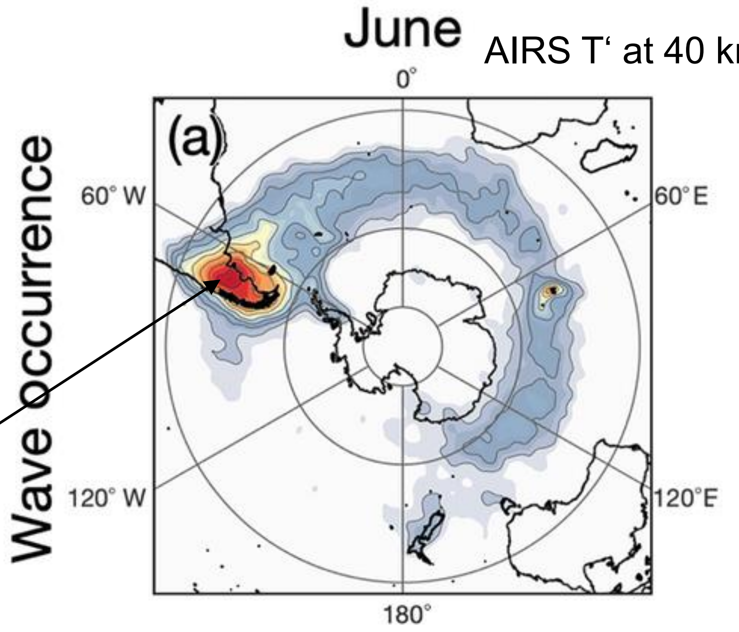
- vertical displacement of streamlines can be caused by topography, convection, shears, geostrophic adjustment, wave-wave interactions, volcanic eruptions

ALIMA lidar onboard HALO for SouthTRAC

spectrally filtered ALIMA lidar T‘, Sep 2019



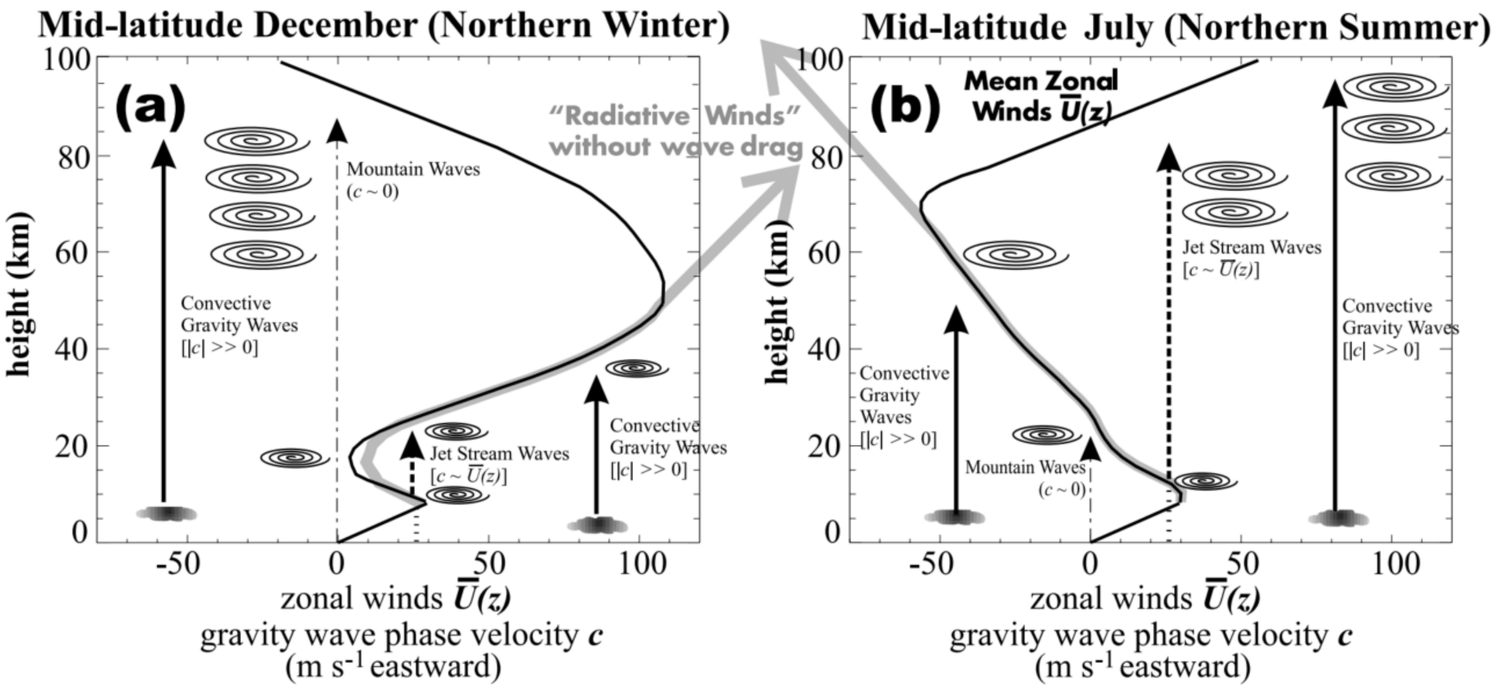
Kaifler et al., in preparation



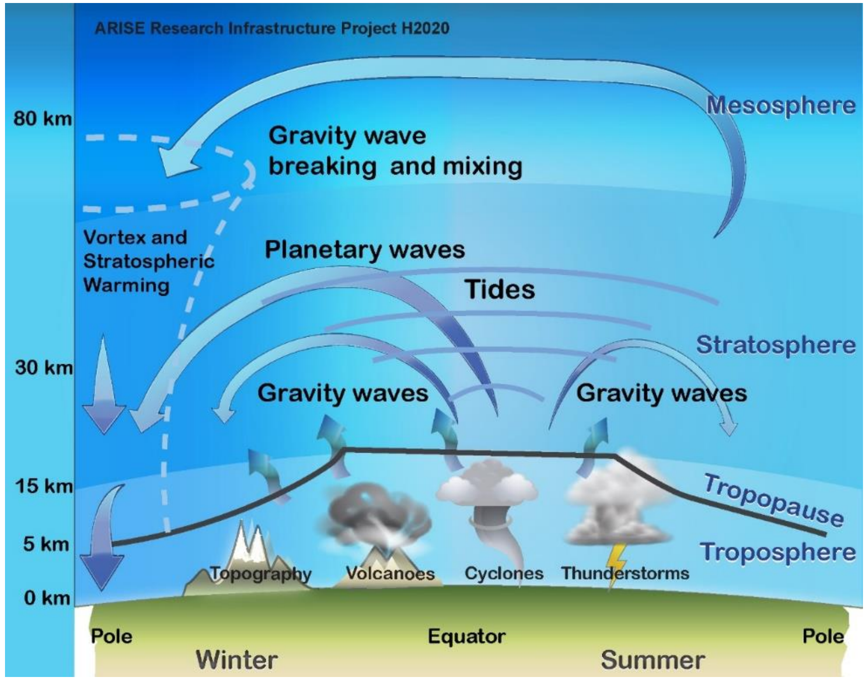
Hindley et al., ACP, 2019

Gravity wave propagation

Gravity waves
- transport energy and momentum vertically and horizontally
- exert drag on winds
- are filtered by winds



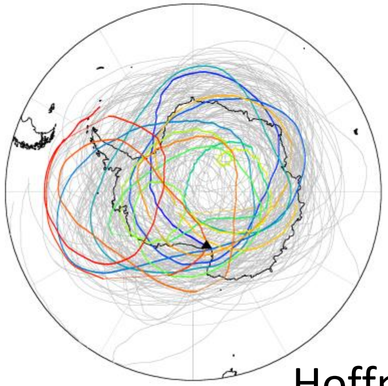
Kim et al., 2003



Mission idea

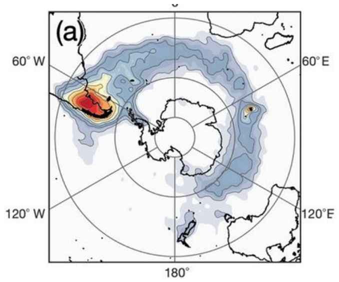
- Five to eight super-pressure balloons
- equipped with remote sensing and in situ instruments
- to be launched from McMurdo, Antarctica,
- into the stratospheric polar vortex beginning in early September

- The launches are timed such that a longitudinal spacing is achieved
- Expected float time at ~20 km altitude: 50-100 days
- Data downloads occur near real time via Iridium links
- Payloads to be sunk in the ocean at end of mission
- Overflights over stations with ground-based instrumentation

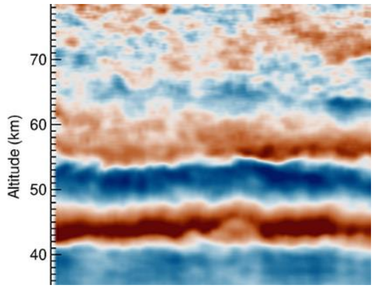


Hoffmann et al., 2017

Scientific objectives in gravity wave research of a HEMERA lidar mission



- Quantify the vertical and horizontal distribution of gravity waves within the polar night jet in the upper stratosphere and lower mesosphere, including their scales, amplitudes, momentum and energy fluxes



- Map sources of orographic and non-orographic waves

- Investigate the vertical propagation of waves in changing background conditions during the breakdown of the vortex

- Investigate processes leading to the breaking of gravity waves and to the excitation of secondary waves, and quantify the scales of secondary waves

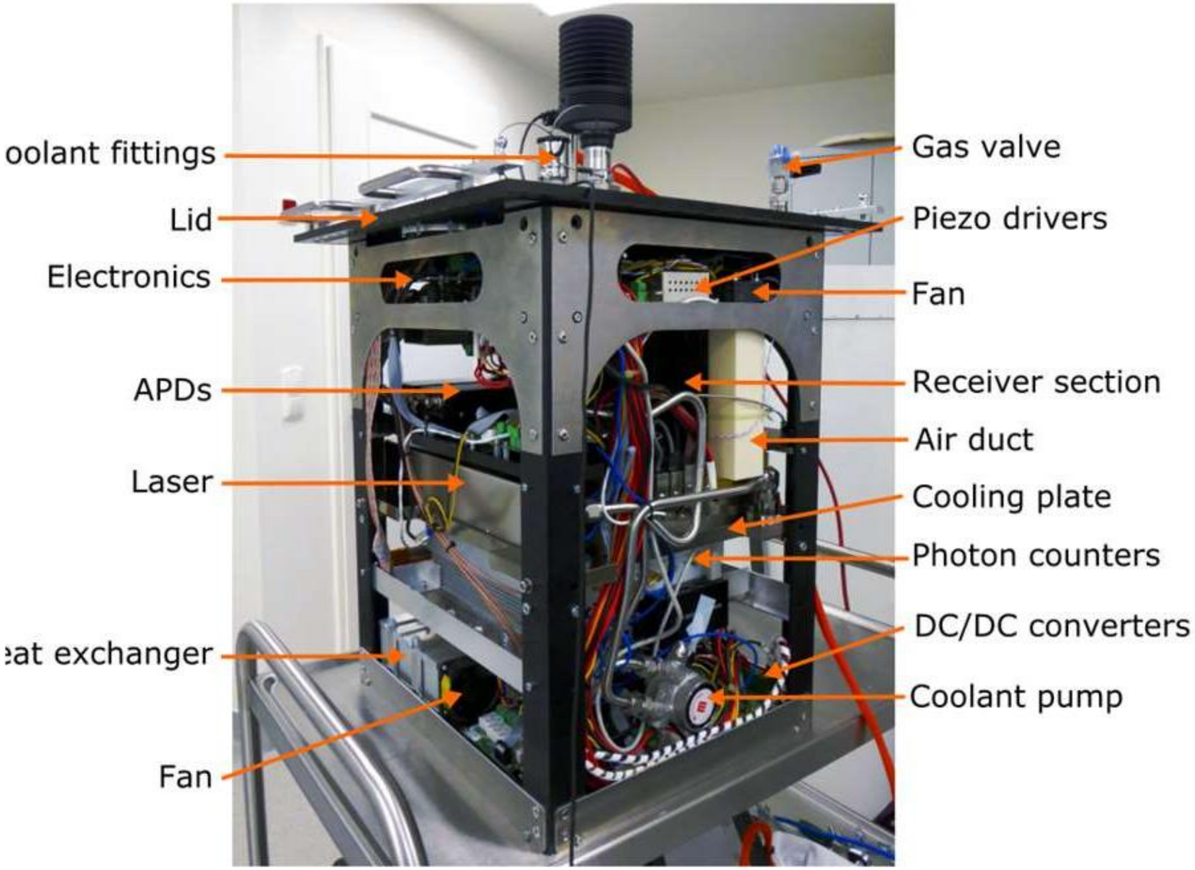
- Detect acoustic waves generated by wave breaking in the upper stratosphere

Challenges of a balloon mission for instrument development

Requirements for
Mass
Size
Power
Pressure
Cooling
Communication
Recovery
Solar background
Laser

The BOLIDE lidar

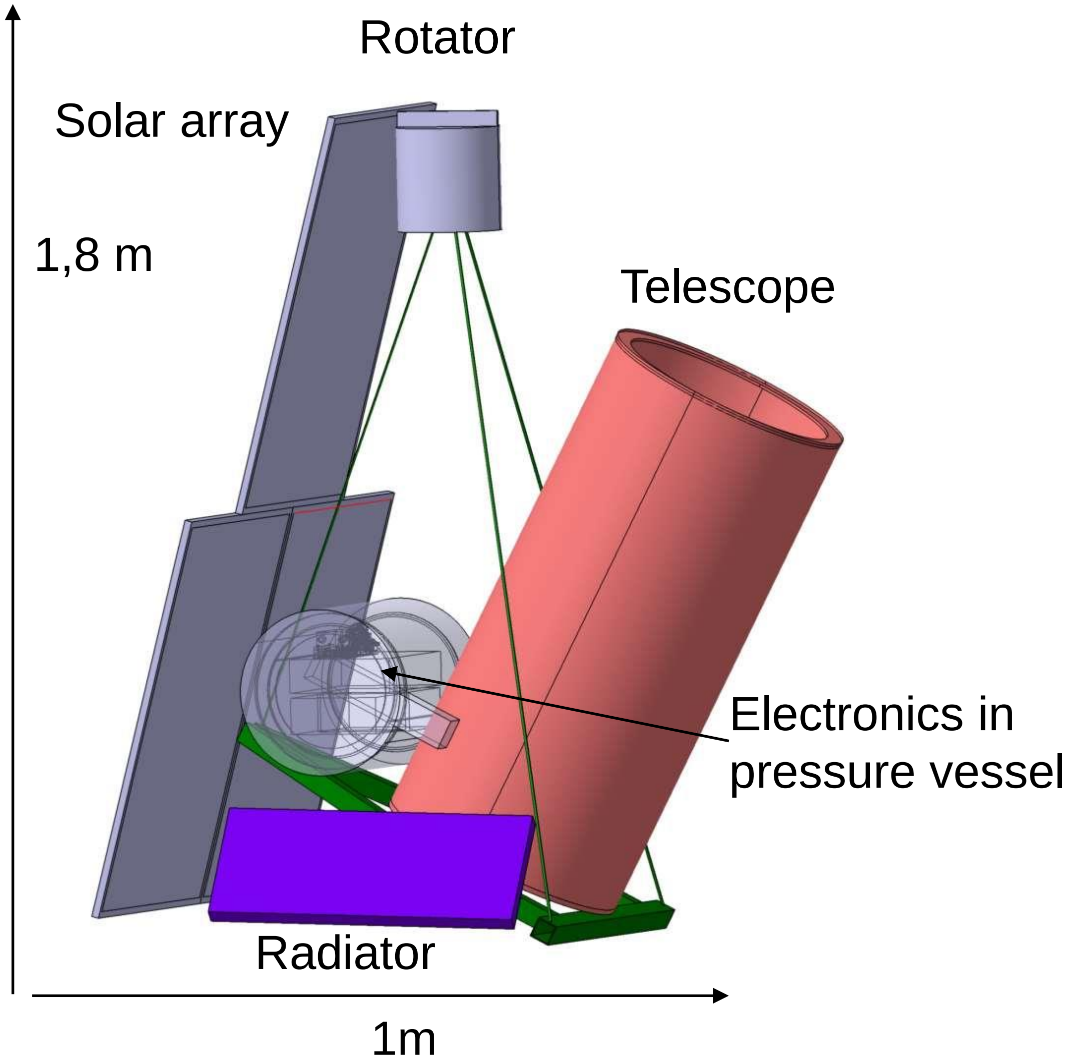
Requirements for	BOLIDE
Mass	140 kg
Size	45 x 45 x 60 cm^3 pressure vessel 51 cm diameter telescope
Power	500 W
Pressure	Electronics in pressure vessel
Cooling	1.6 m^2 radiator
Communication	Protocol for satellite links for commanding and quicklook data
Recovery	yes
Solar background	Full daylight
Laser	4.5 W, 532 nm



Kaifler et al., AMT, 2020

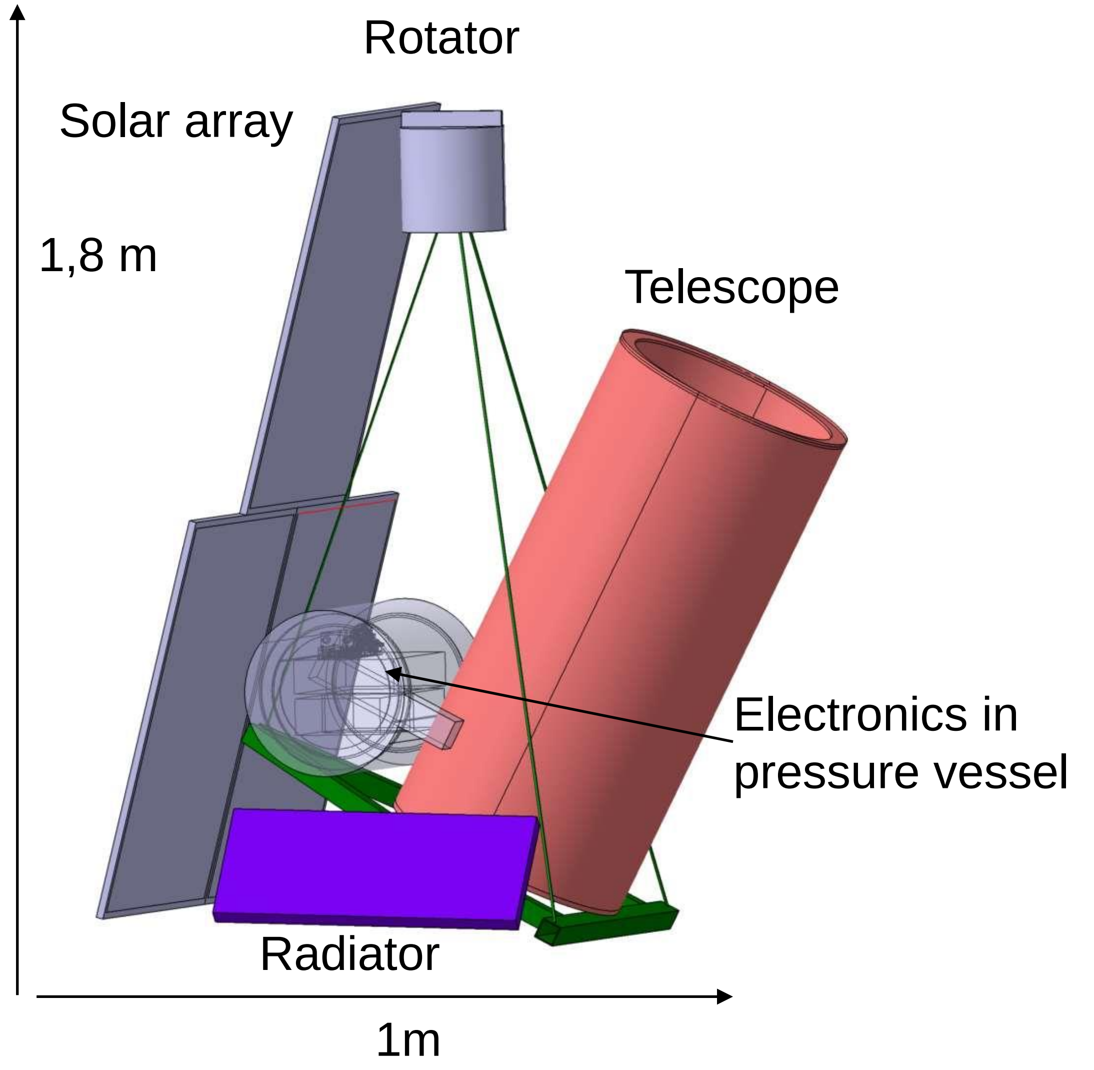
A scaled-down version of the BOLIDE lidar

Requirements for	Miniature lidar
Mass	35 kg
Size	Total 1 m x 1 m x 1.8 m Lightweight 40 cm diameter telescope, 308 µrad FOV
Power	<100 W 1 kWh battery for 9 h operation in darkness, recharged during day via solar cells
Solar array	300 W
Solar background	Operation primarily in darkness; possibly 27-40 km altitude coverage during daylight 2 elastic receiver channels
Laser	1 W (10 mJ), 532 nm



Payload instruments

Type	Observable
Rayleigh lidar	temperature measurements 27-80 km altitude
GPS receiver	3D position measurement
Laser gyroscope	Precise attitude measurements (detection of turbulence)
Microbarometer	
Infrasound measurements	
In situ temperature probe	
Airglow camera (if feasible)	OH emissions



Conclusion

Balloons are ideal platforms to study gravity waves because:

- spatial coverage to complement ground-based stations
- lidars have high vertical resolution
- continuous measurements
- research aircraft like HALO cannot fly in Antarctica

A lightweight balloon lidar can be developed based on technology of the BOLIDE balloon lidar

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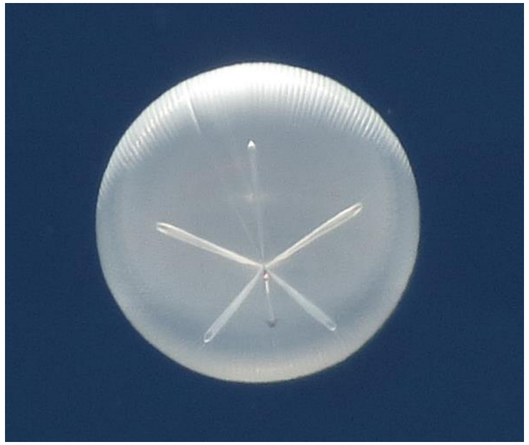
Additional slides

PMC Turbo launch

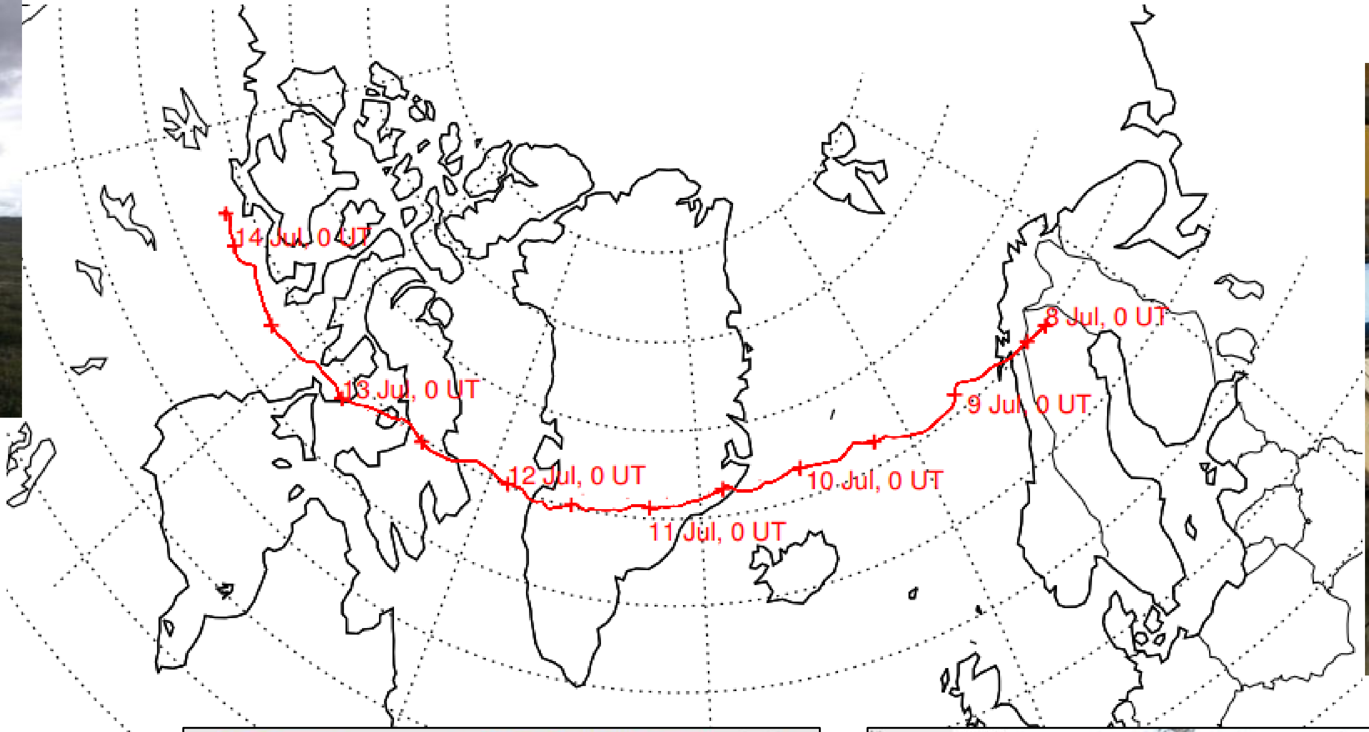


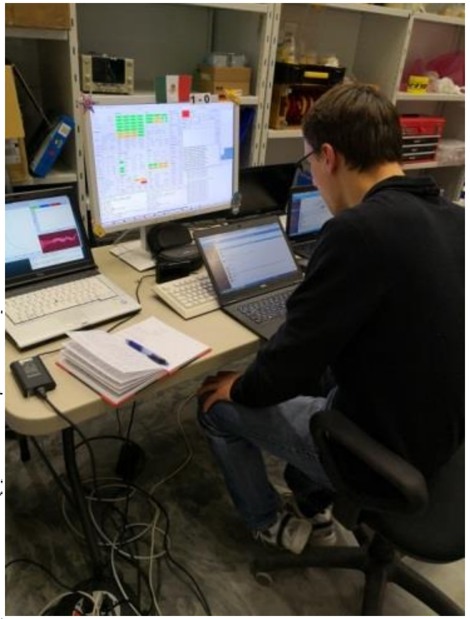
- NASA long duration balloon, CSBF
- Floating altitude 40 km
- 6-day trans-atlantic float from Kiruna to Nunavut, Canada
- landed undamaged

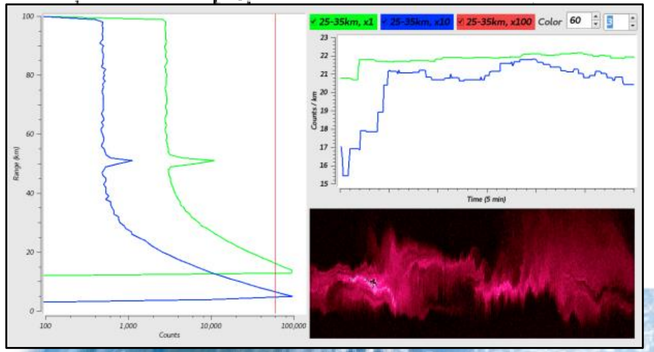
PMC Turbo Arctic flight

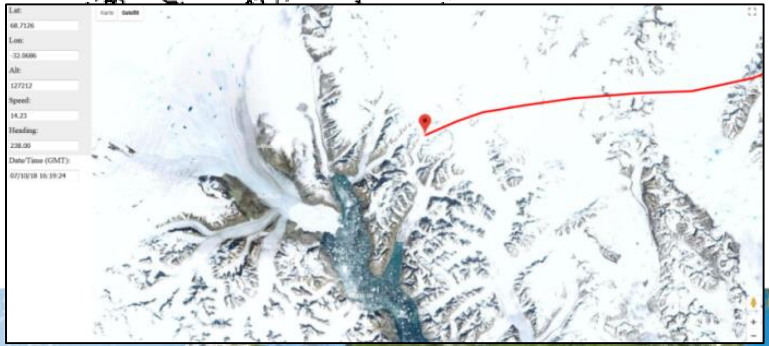
- Six days of flight

[Fritts et al. (2019) 10.1029/2019JD030298](https://doi.org/10.1029/2019JD030298)



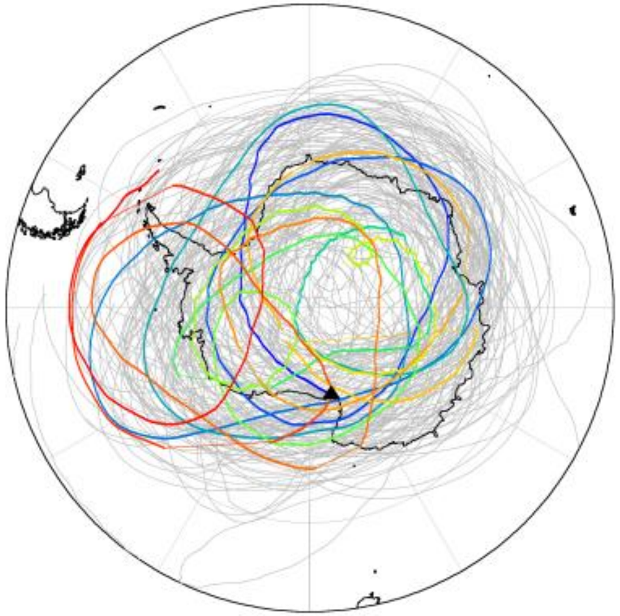






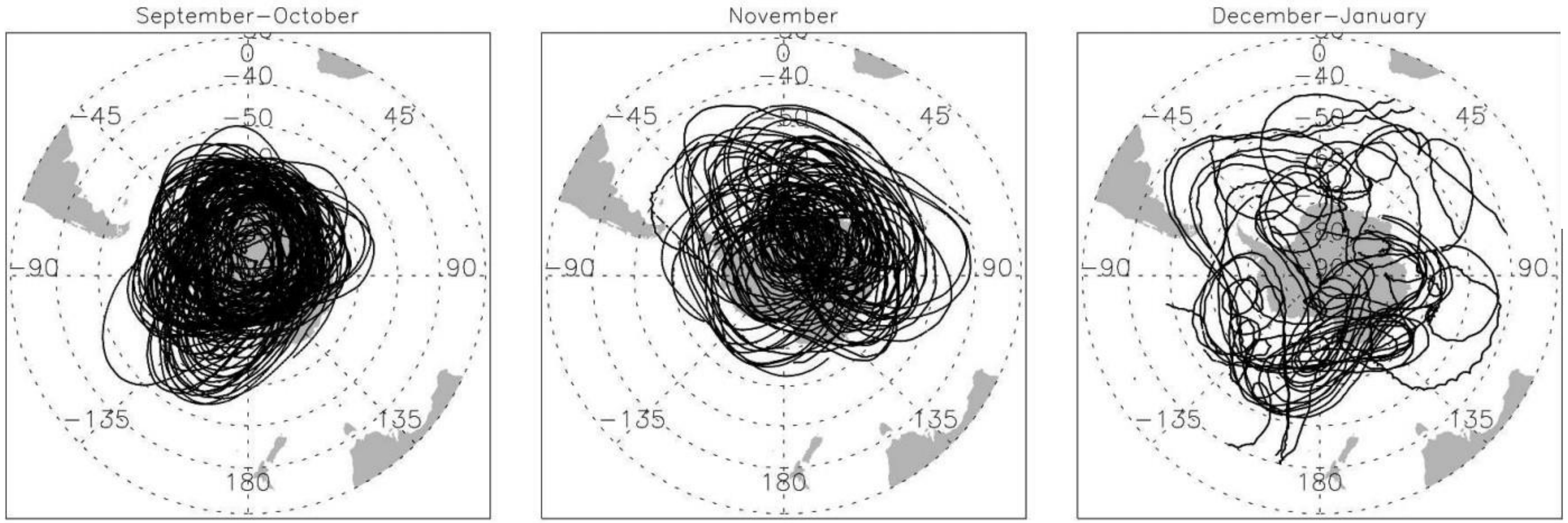
Expected trajectories from McMurdo station, Antarctica

Hoffmann et al., 2017



Multiple overflights of the Antarctic peninsula and coastal Antarctic stations

Hertzog et al., 2007



Overflights of ground-based instruments

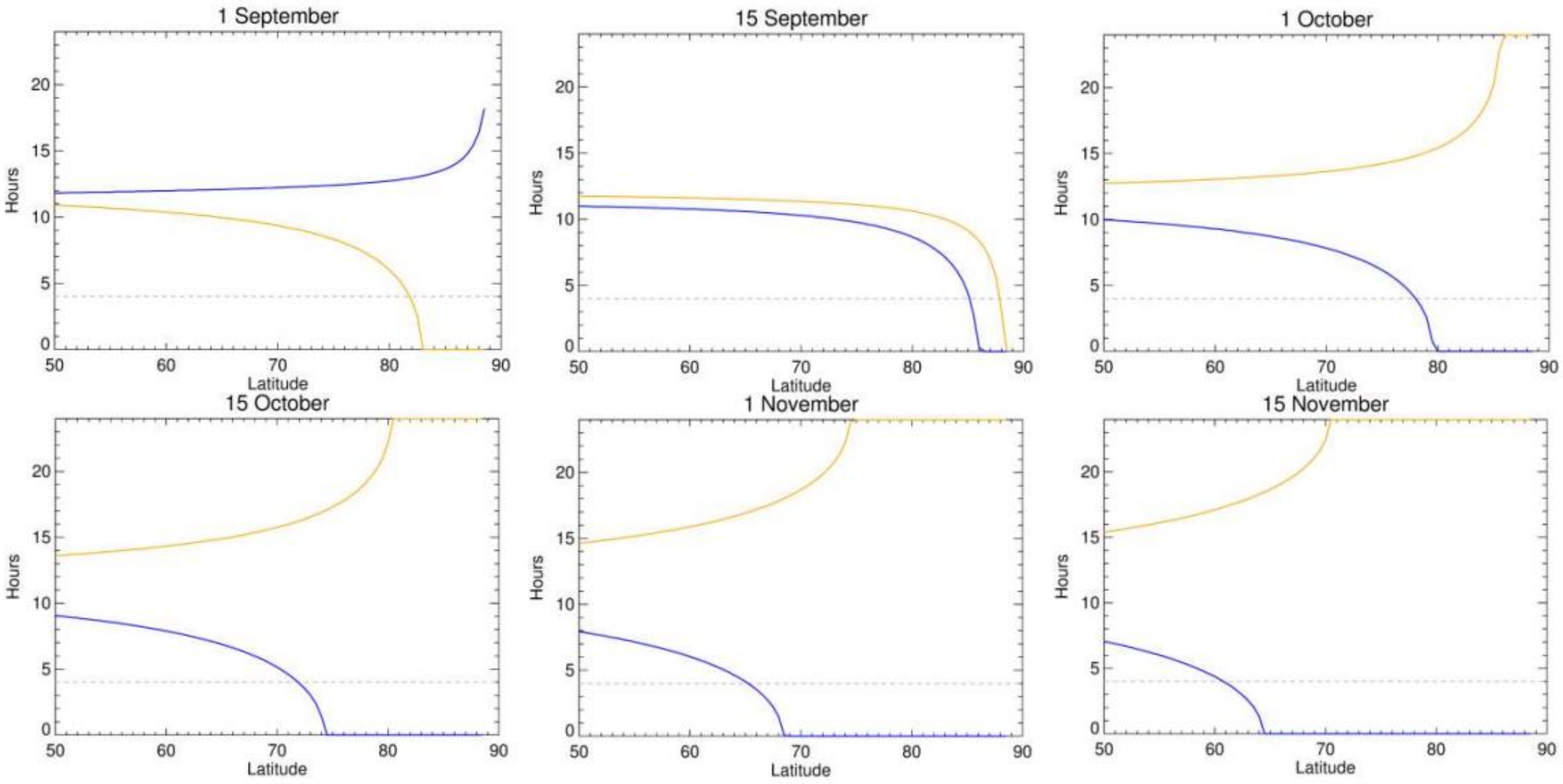
- **South Pole**: Rayleigh lidar, AMTM, meteor radar
- **McMurdo**: Na + Fe Lidar, airglow
- **Davis:** Rayleigh Lidar, airglow, MF + meteor radar
- **Mawson:** MF radar
- **Syowa:** PANSY radar, lidars, airglow
- **Neuymayer:** infrasound
- **Halley:** meteor radar, airglow
- **Rothera:** MF radar, airglow
- **All stations**: daily radiosondes
  Comprehensive set of instruments available
  Antarctica is the best instrumented region in the world!

Note: The list is not exhaustive

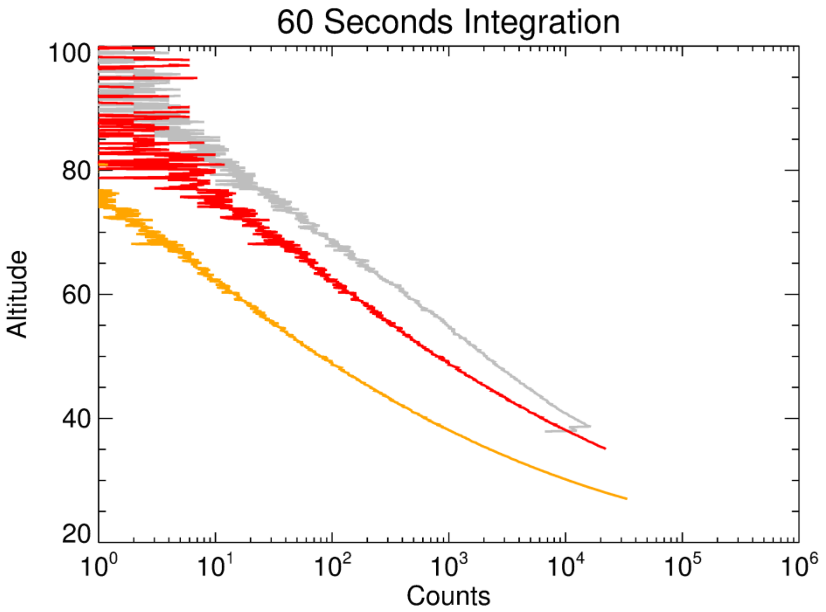
Operational Constraints

- Blue: darkness hours per day (potential lidar operation)
- Orange: daylight hours (recharging)

After 1 November lidar measurements are limited to latitudes <67° S and few hours per day
all other instruments operate 24/7
plenty of power for data download



Performance simulations



- Two channel system (red and orange)
- Aircraft lidar ALIMA performance is shown for comparison (gray)
- Because the balloon travels slower than ALIMA, the horizontal resolution and altitude coverage will be better (longer integration periods possible)