Entwicklung und Einsatz von automatischen Lidarsystemen zur Erforschung der mittleren Atmosphäre

Natalie Kaifler, PA-LID OP

Matrix-Gruppe Mittlere Atmosphäre

RB-Institutsseminar

26. Oktober 2018

DLR

Development and operation of autonomous lidar instruments for studying the middle atmosphere

Natalie Kaifler, PA-LID OP

Middle atmosphere group

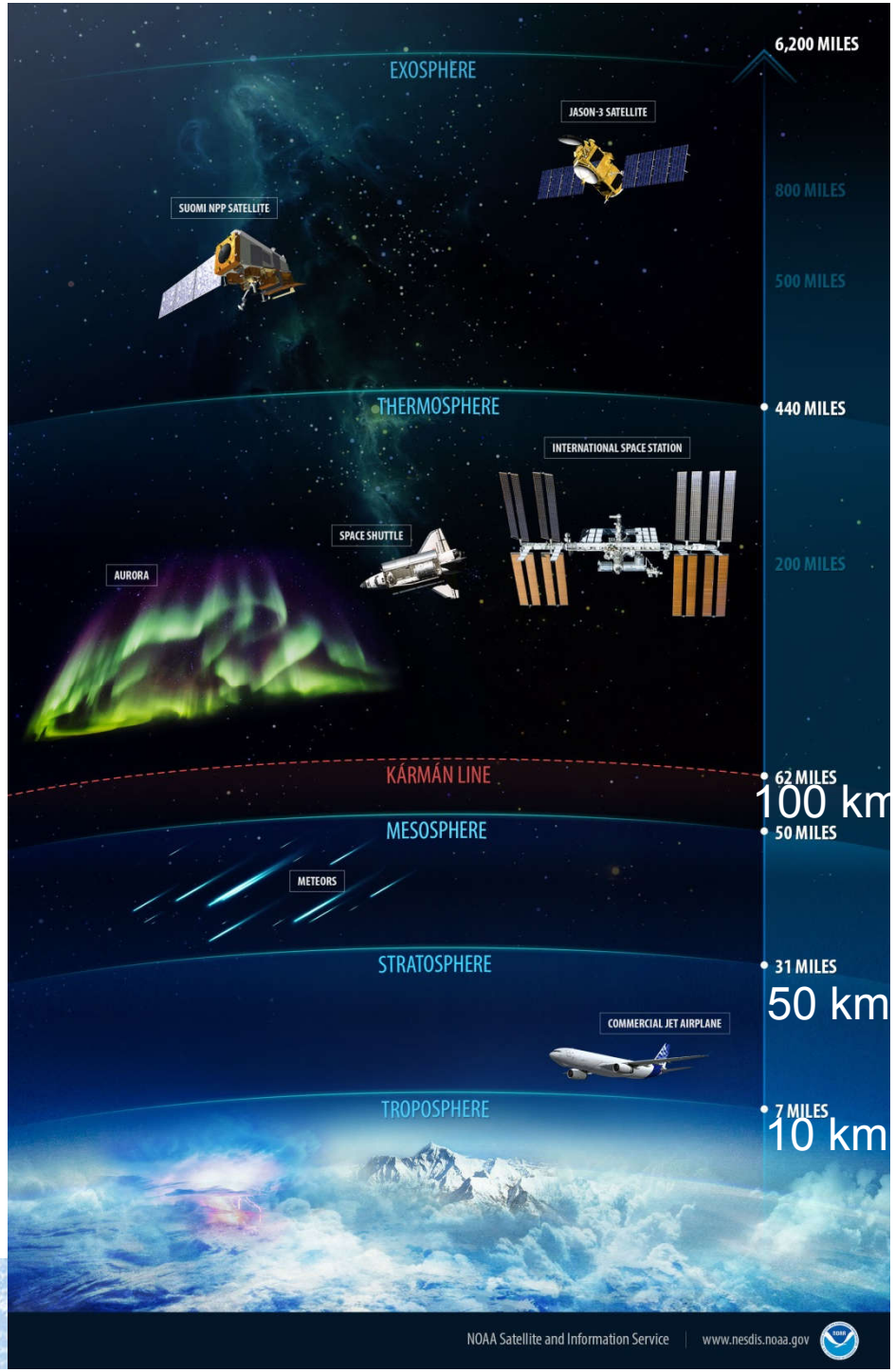
RB institute seminar

26 October 2018

DLR

Earth’s atmosphere

Mesosphere
+ Stratosphere
= Middle atmosphere
= 10-100 km



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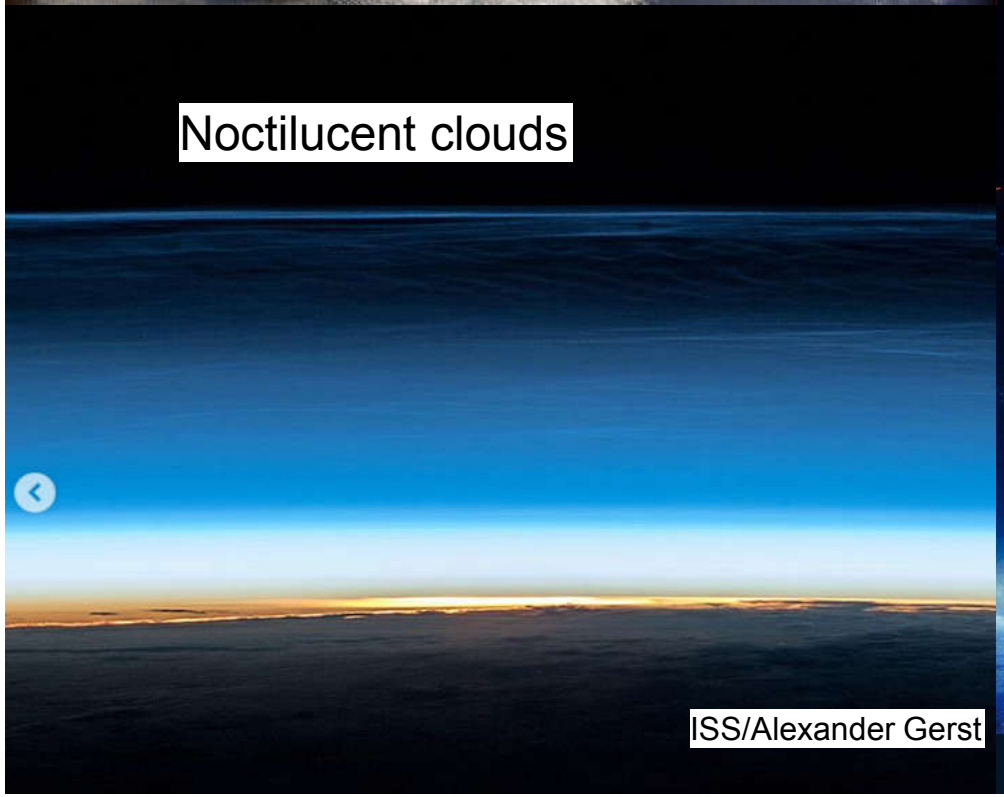
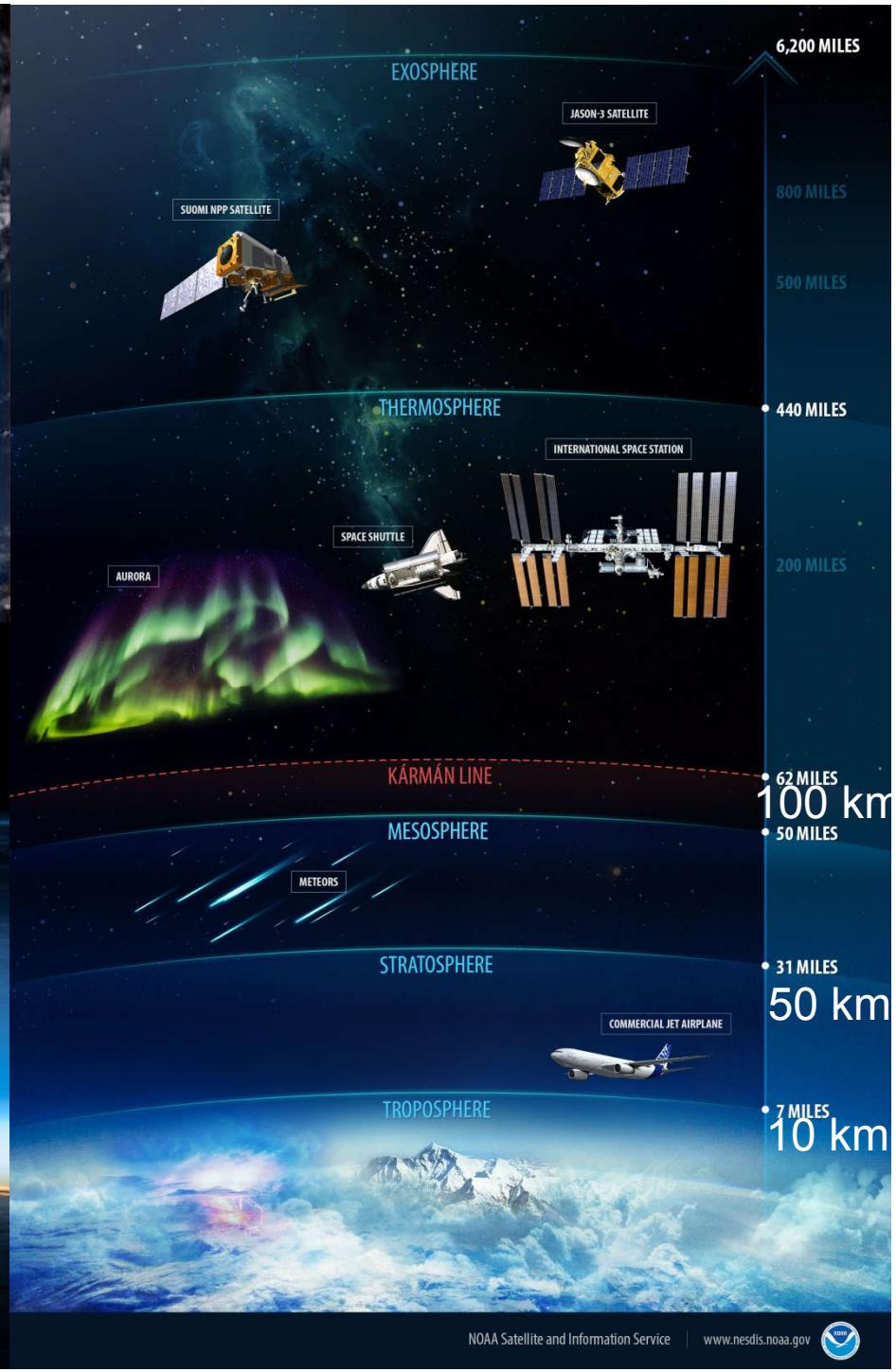
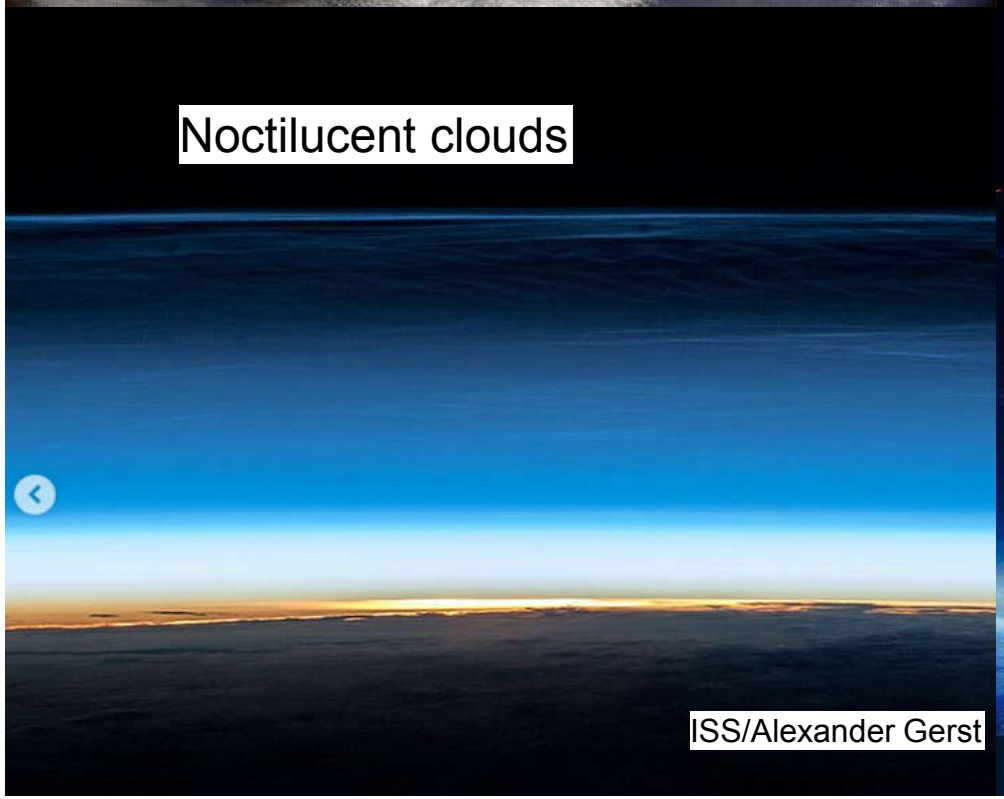
Gravity waves


Noctilucent clouds
ISS/Alexander Gerst


6,200 MILES
EXOSPHERE
JASON-3 SATELLITE
SUOMI NPP SATELLITE
800 MILES
500 MILES
THERMOSPHERE
440 MILES
INTERNATIONAL SPACE STATION
SPACE SHUTTLE
AURORA
200 MILES
KÁRMÁN LINE
62 MILES
100 km
MESOSPHERE
50 MILES
METEORS
STRATOSPHERE
31 MILES
50 km
COMMERCIAL JET AIRPLANE
TROPOSPHERE
7 MILES
10 km
NOAA Satellite and Information Service
www.nesdis.noaa.gov


Gravity waves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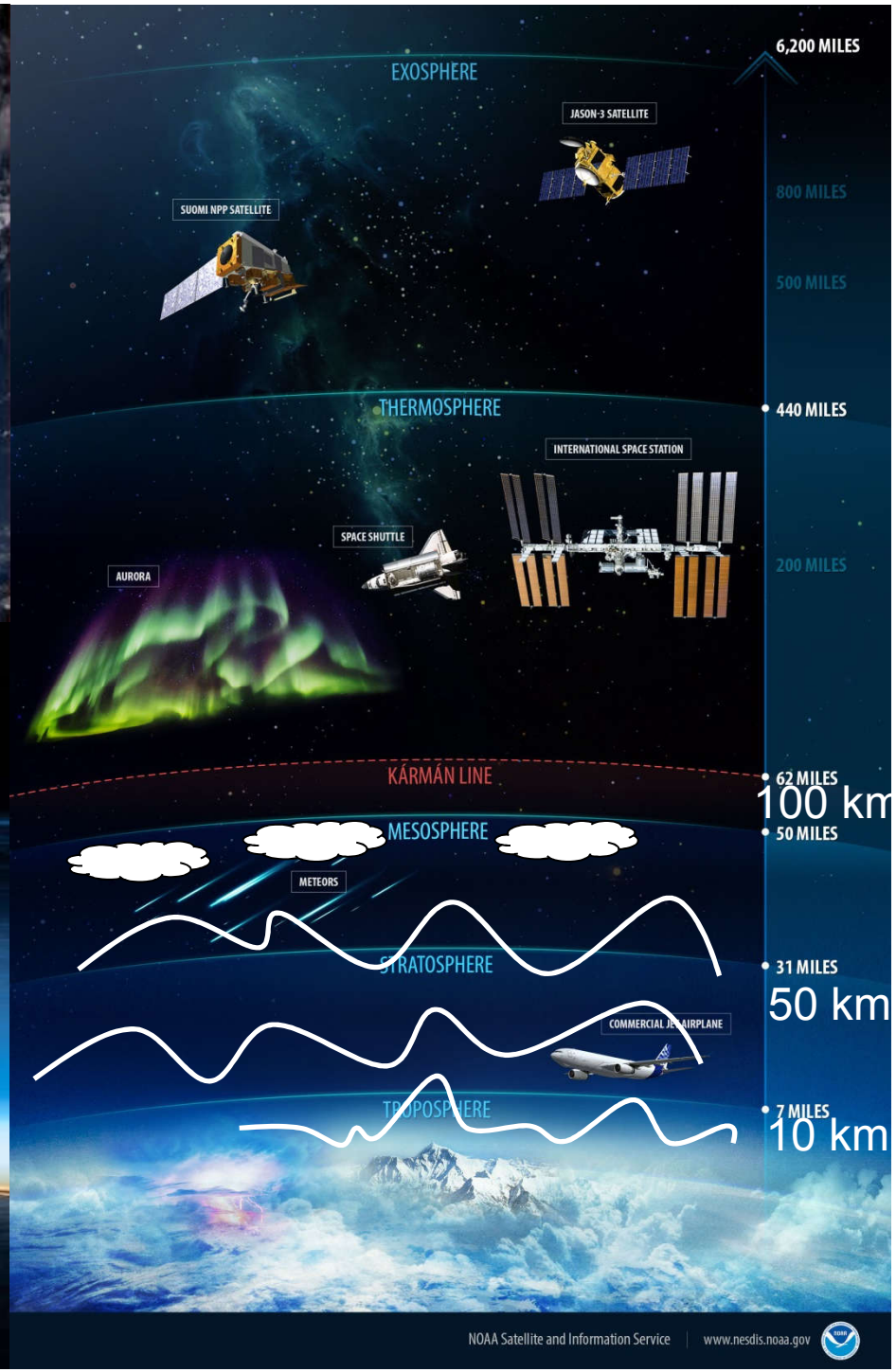
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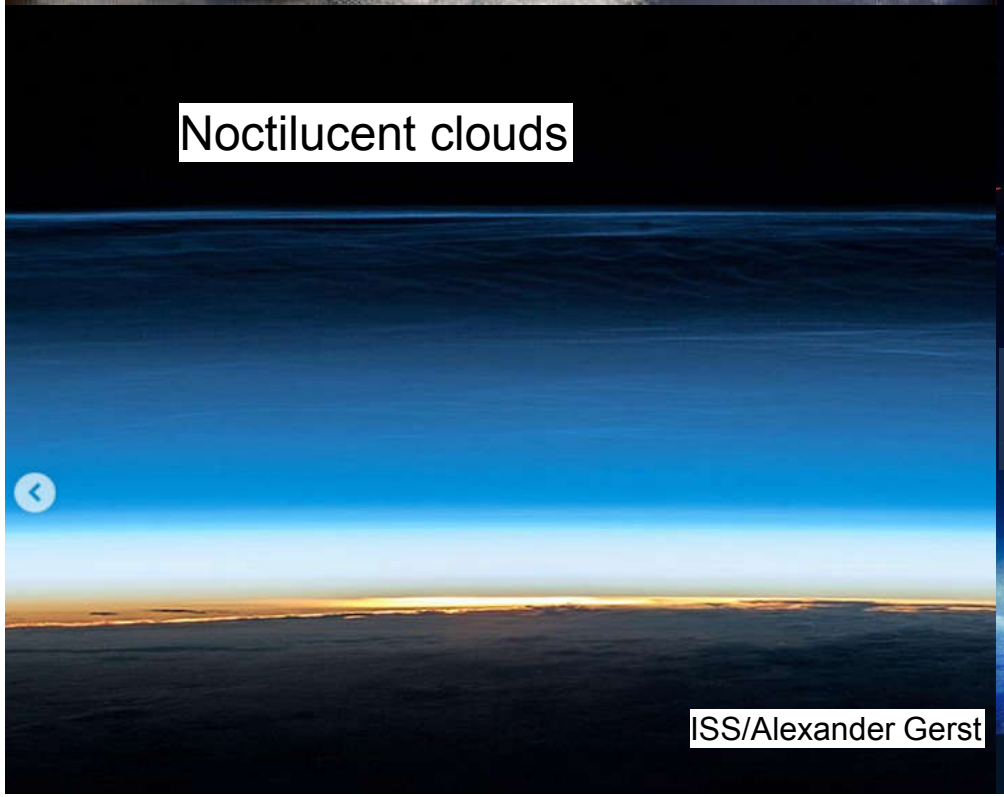
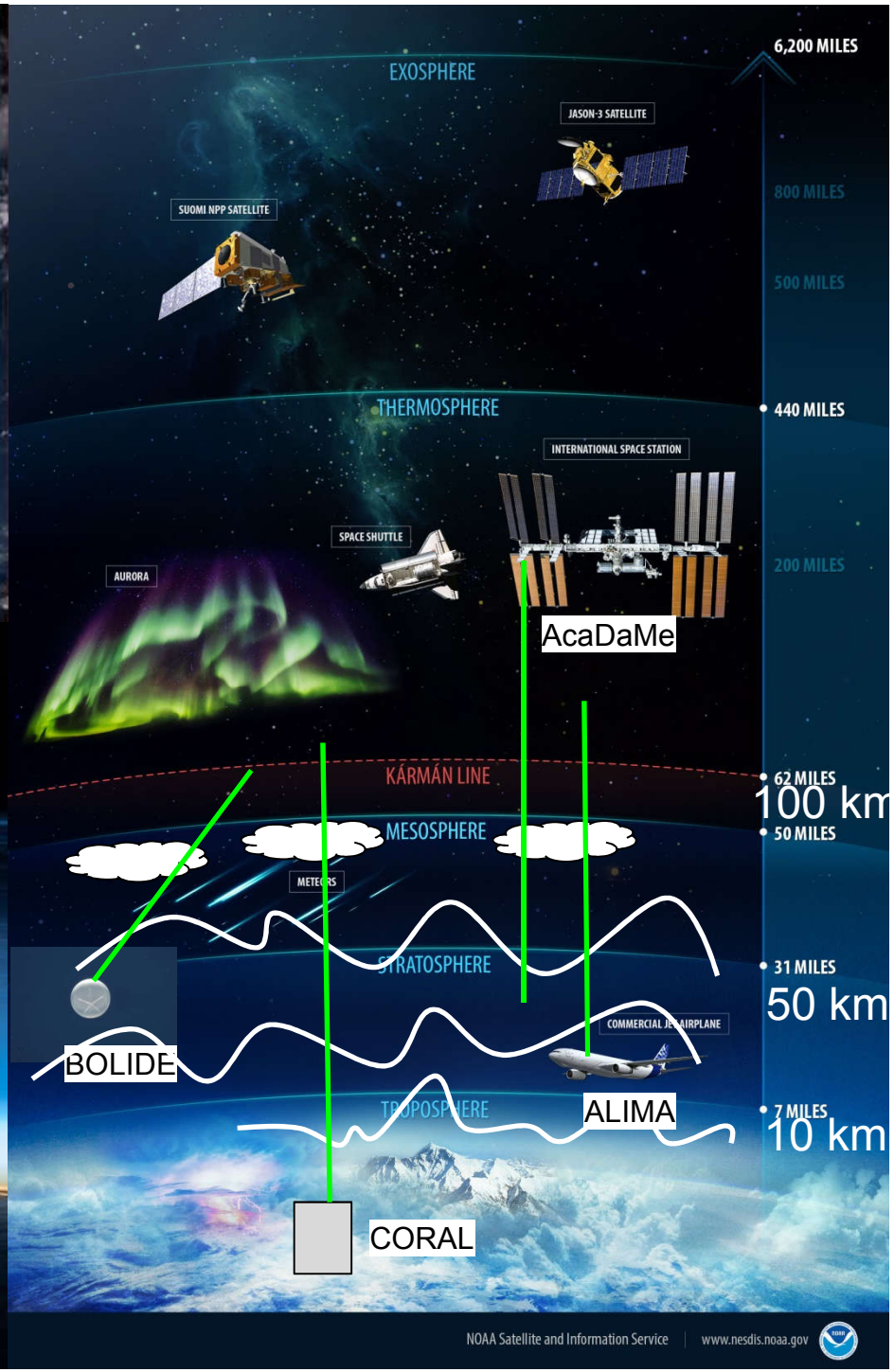
Gravity waves


Noctilucent clouds
ISS/Alexander Gerst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AURORA
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AcaDaMe
KÁRMÁN LINE
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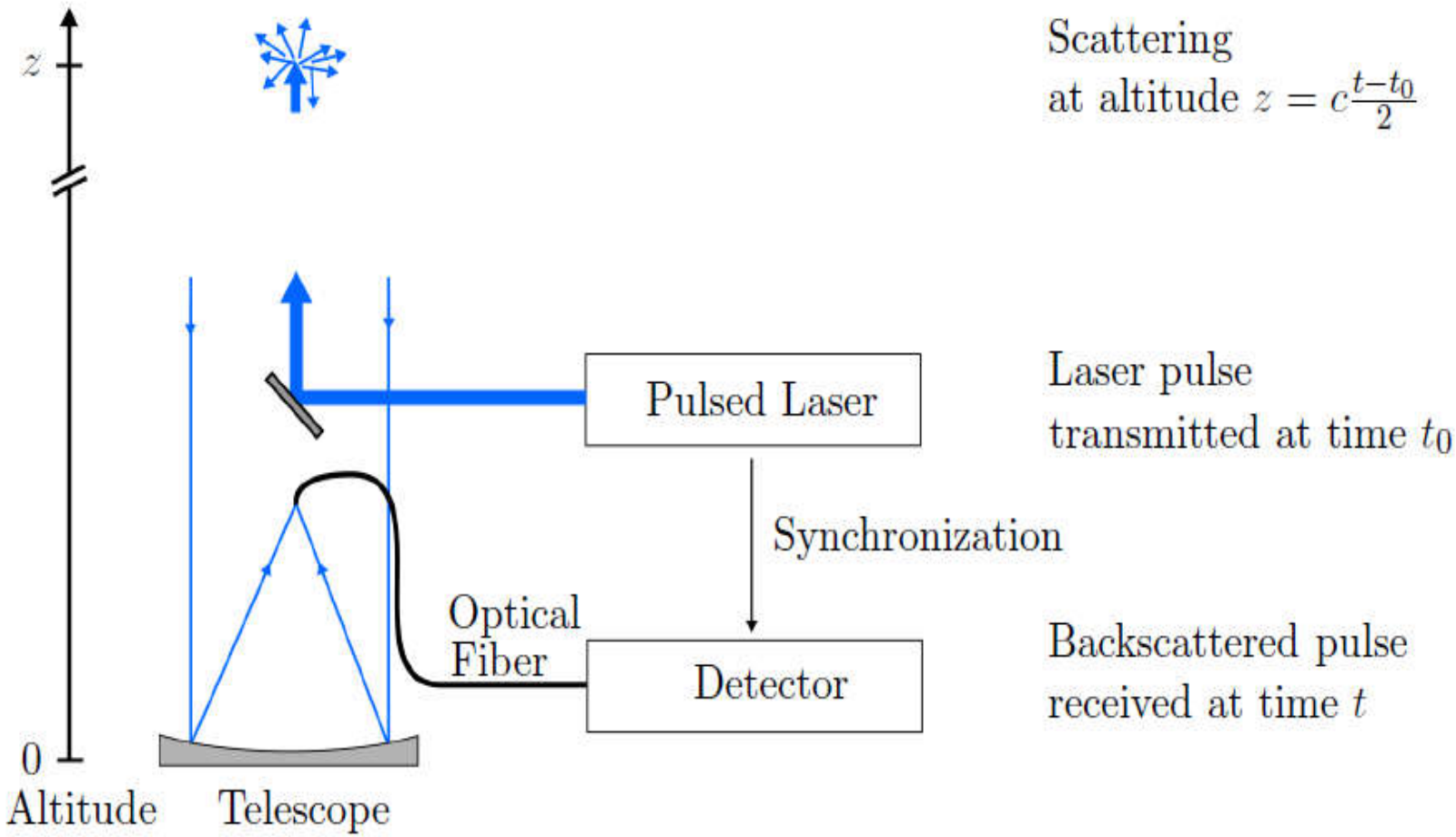
MESOSPHERE
50 MILES
METEORS
STRATOSPHERE
31 MILES
50 km
COMMERCIAL JET AIRPLANE
BOLIDE
TROPOSPHERE
ALIMA
7 MILES
10 km
CORAL
NOAA Satellite and Information Service
www.nesdis.noaa.gov

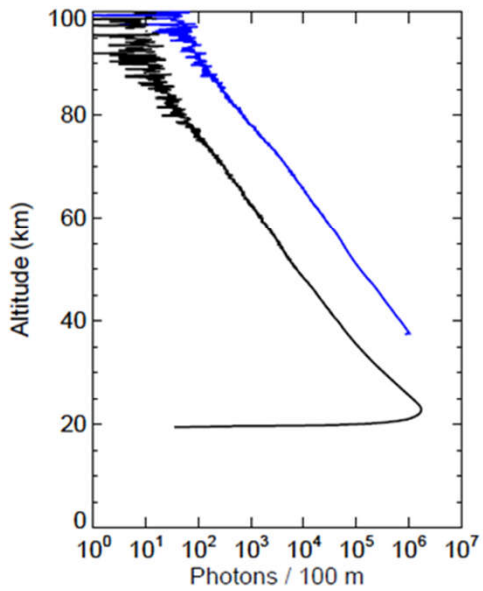
Sounding of the atmosphere with lidar



Lidar data

Measurement

Photon counts



Data Processing

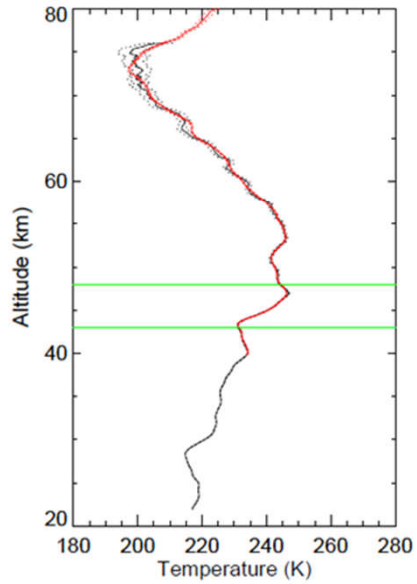
- Atmosphere is in hydrostatic equilibrium
- Ideal gas law
- Temperature T_0 at top of profile is „known“

Integration of photon count profiles from top z_0 to bottom z:

$$T(z) = \frac{S(z0)}{S(z)} T_0 + \frac{M}{k_B} \int_{z_0}^{z} \frac{S(z')}{S(z)} g(z')\, \mathrm{d}z$$

Data Product

Temperature profiles



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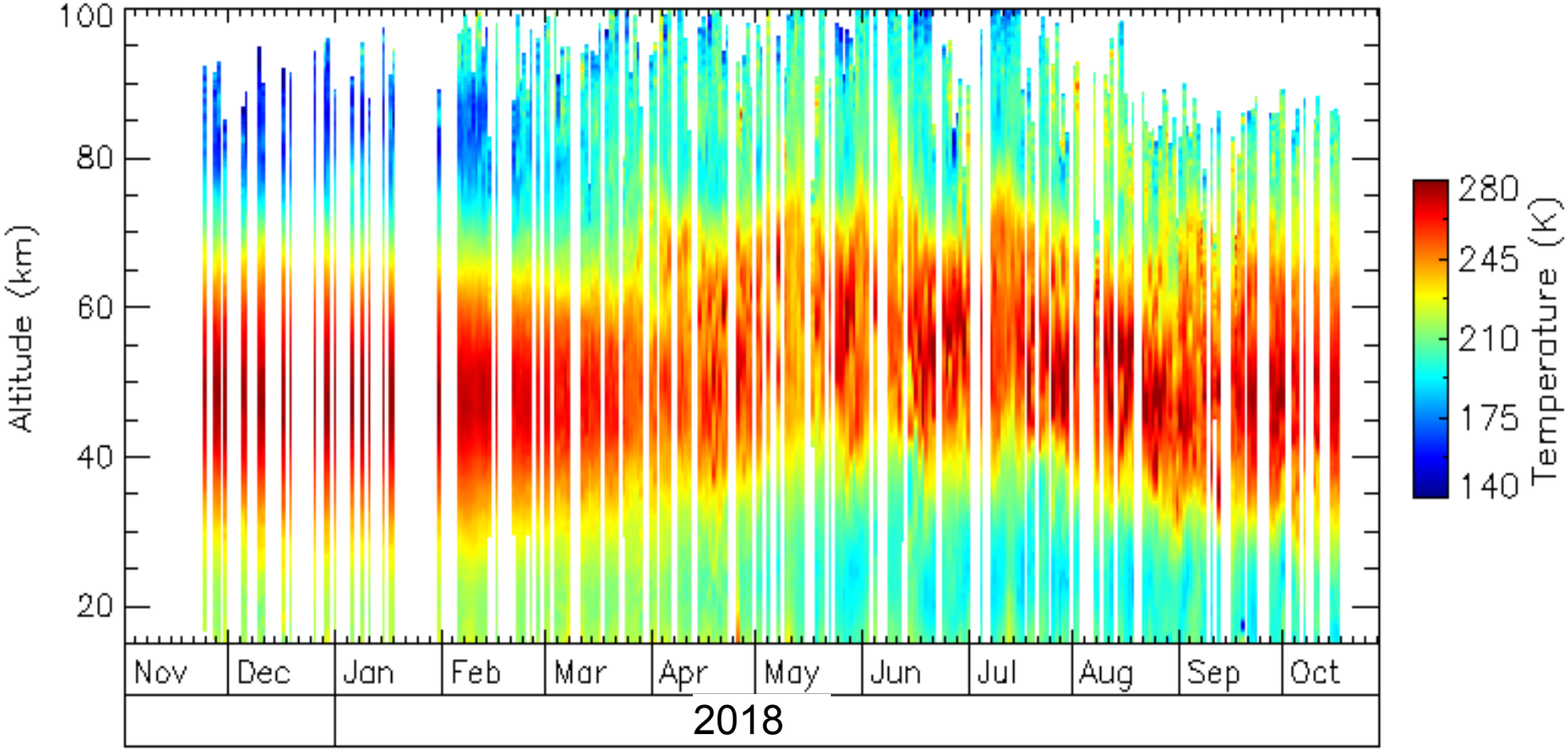
Thermal structure



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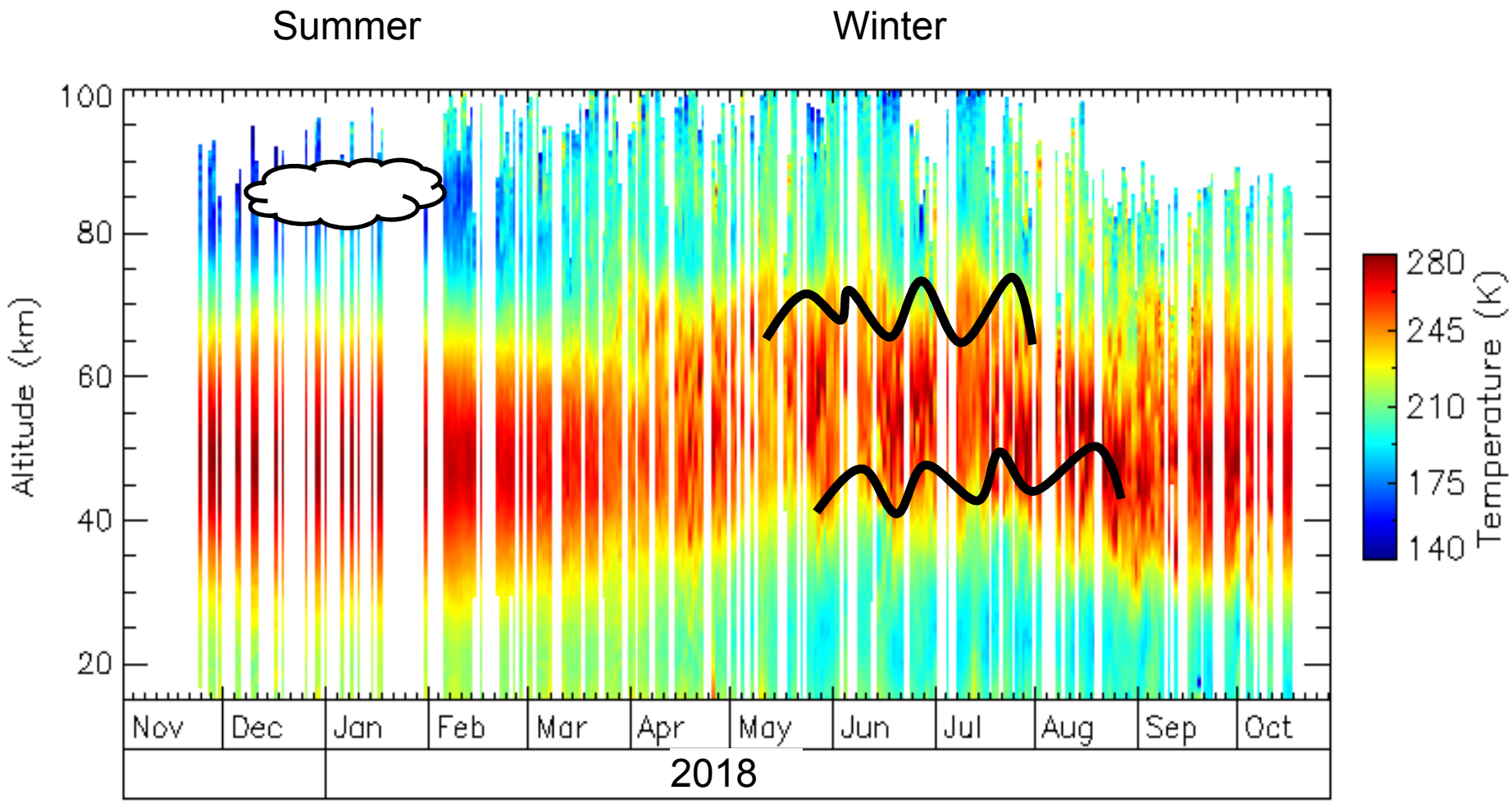
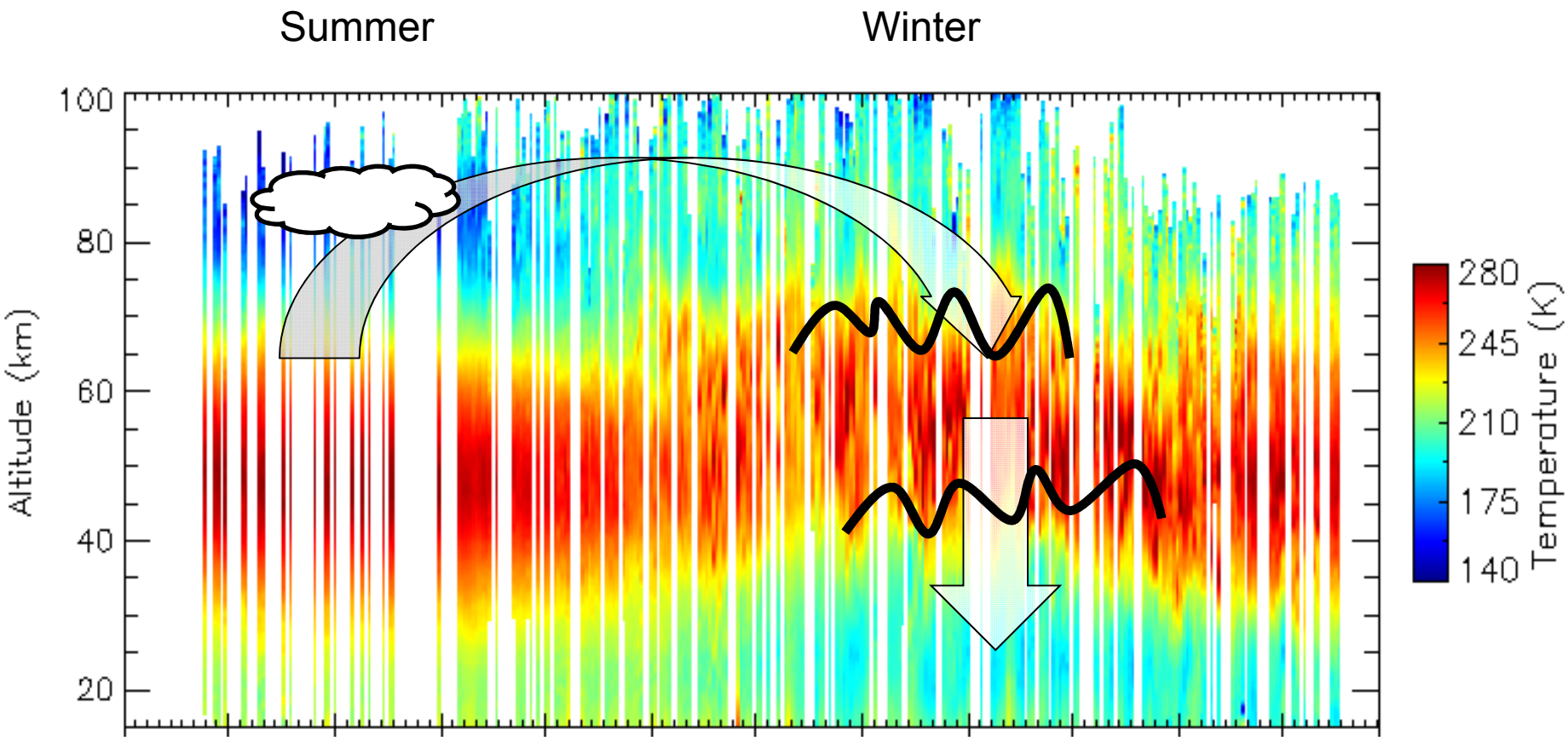
Thermal structure at 54°S, 68°E

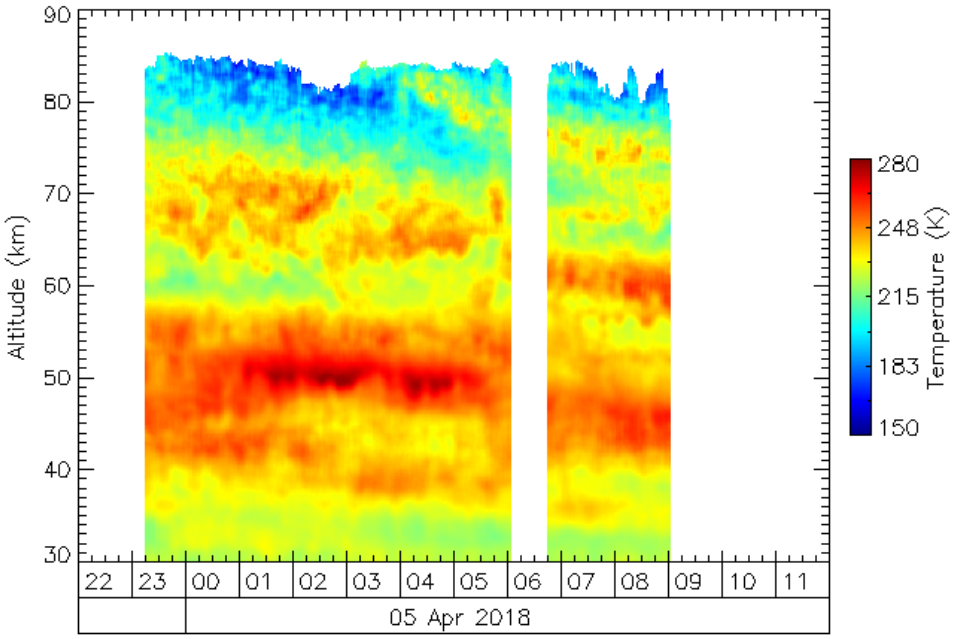


Global circulation

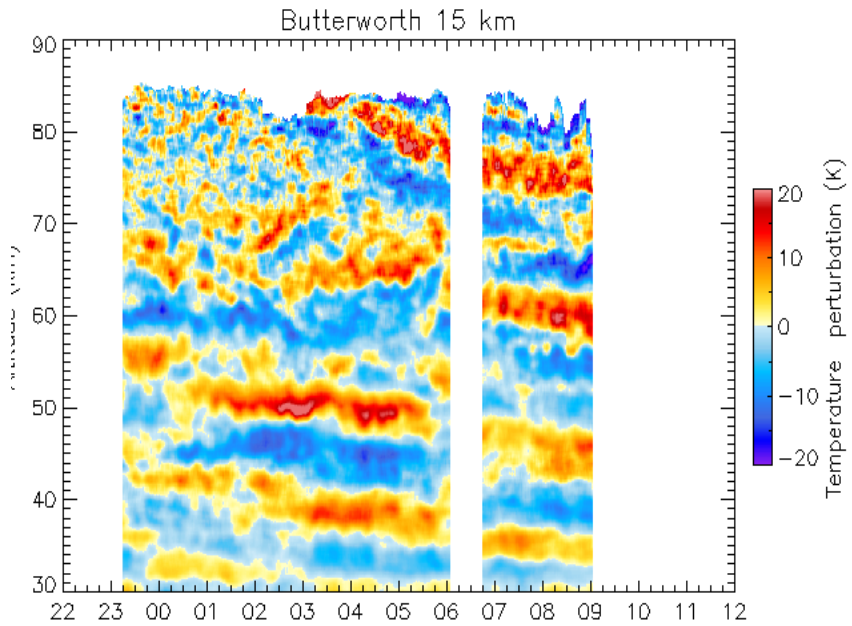


From temperatures to waves

- Temperature

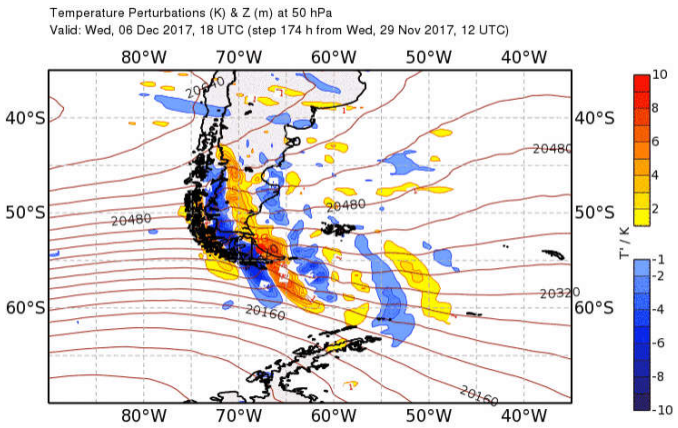


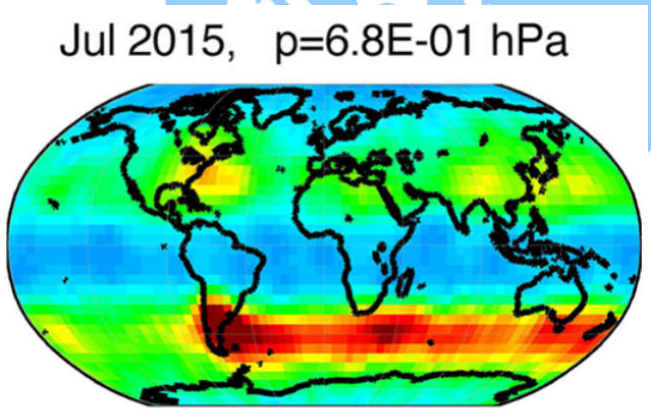
- Temperature perturbation
  = Gravity waves



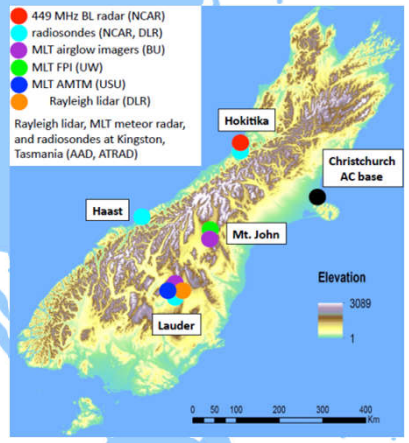
Vertical filter

Global map





Hocke et al., 2016



Fritts et al., 2015

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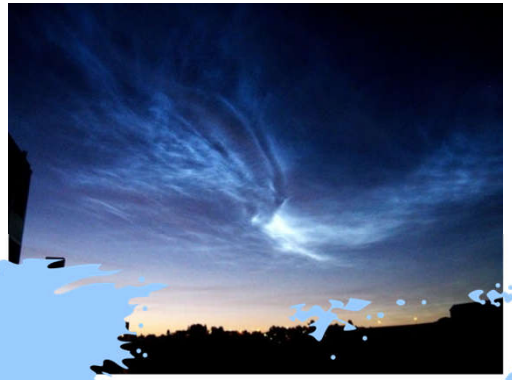
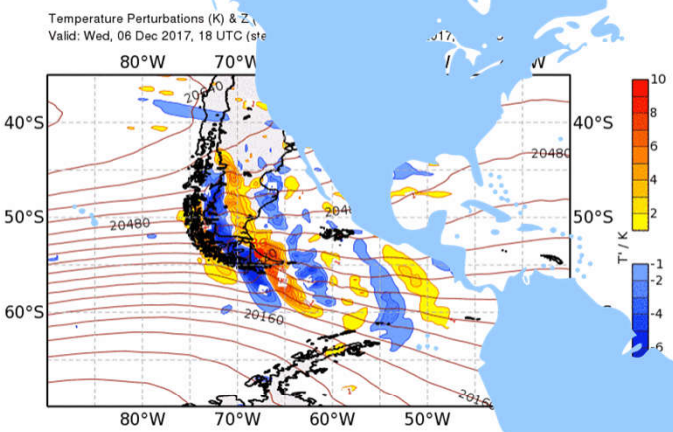
Lidar operations

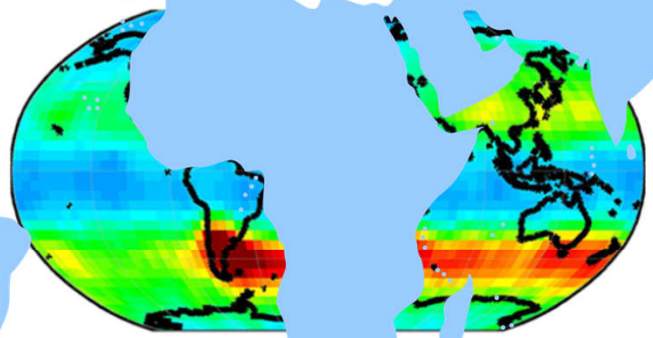


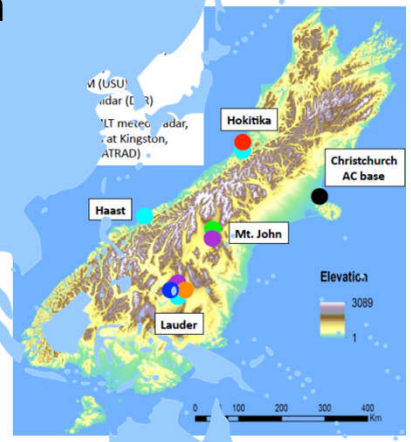
★ TELMA
★ CORAL

★ 2015/16 winter, 492 h

★ May - Sep 2016, 485 h







Rio Grande,
Argentina
Since Nov 2017 ★
> 1200 h

Lauder,
New Zealand ★
2014 winter
754 h

DLR

Ground-based lidars

2014: DEEPWAVE
(New Zealand)

„Hands on“ experiment

2015/2016: GWCYCLE2
(Finland)

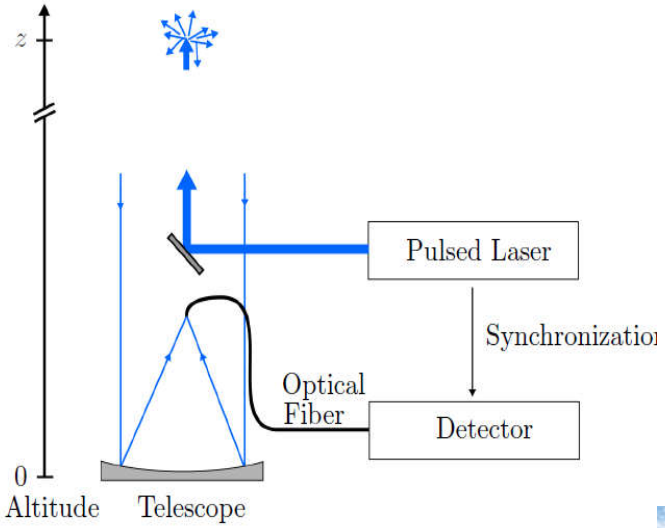
Remotely controlled instrument

Since 2017: SOUTHWAVE
(Southern Argentina)

Fully automatic system

Technical description

- Mobile lidar systems (11- and 8-foot container) of 1500 kg
- 2 kW power consumption
- 12 W laser power @ 532 nm wavelength
- 63 cm telescope
- 3 Rayleigh and 1 Raman detector channels



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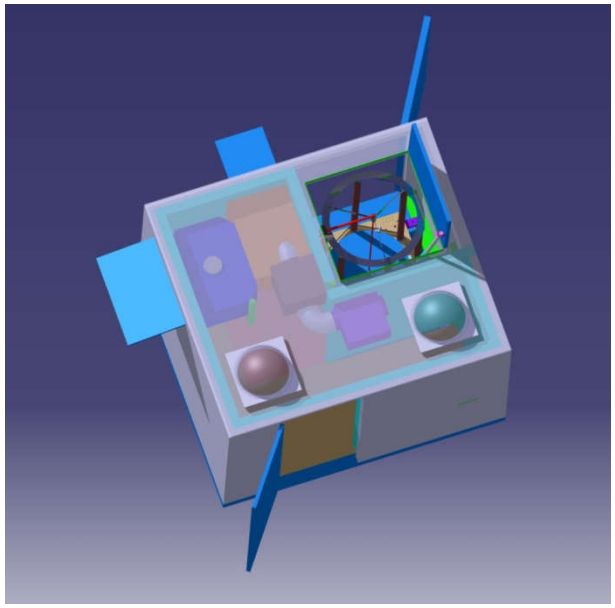
Thermal control

- Telescope room at outside air temperature
- Heating
  - Motors
  - hatch to melt snow
- Insulated compartment for electronics, laser and optics
- Temperature differences of 50 K in January 2016 in northern Finland

CORAL Housing



Wind direction
and anemometer

Hatch for
laser
beam and
telescope

Door to
telescope
room

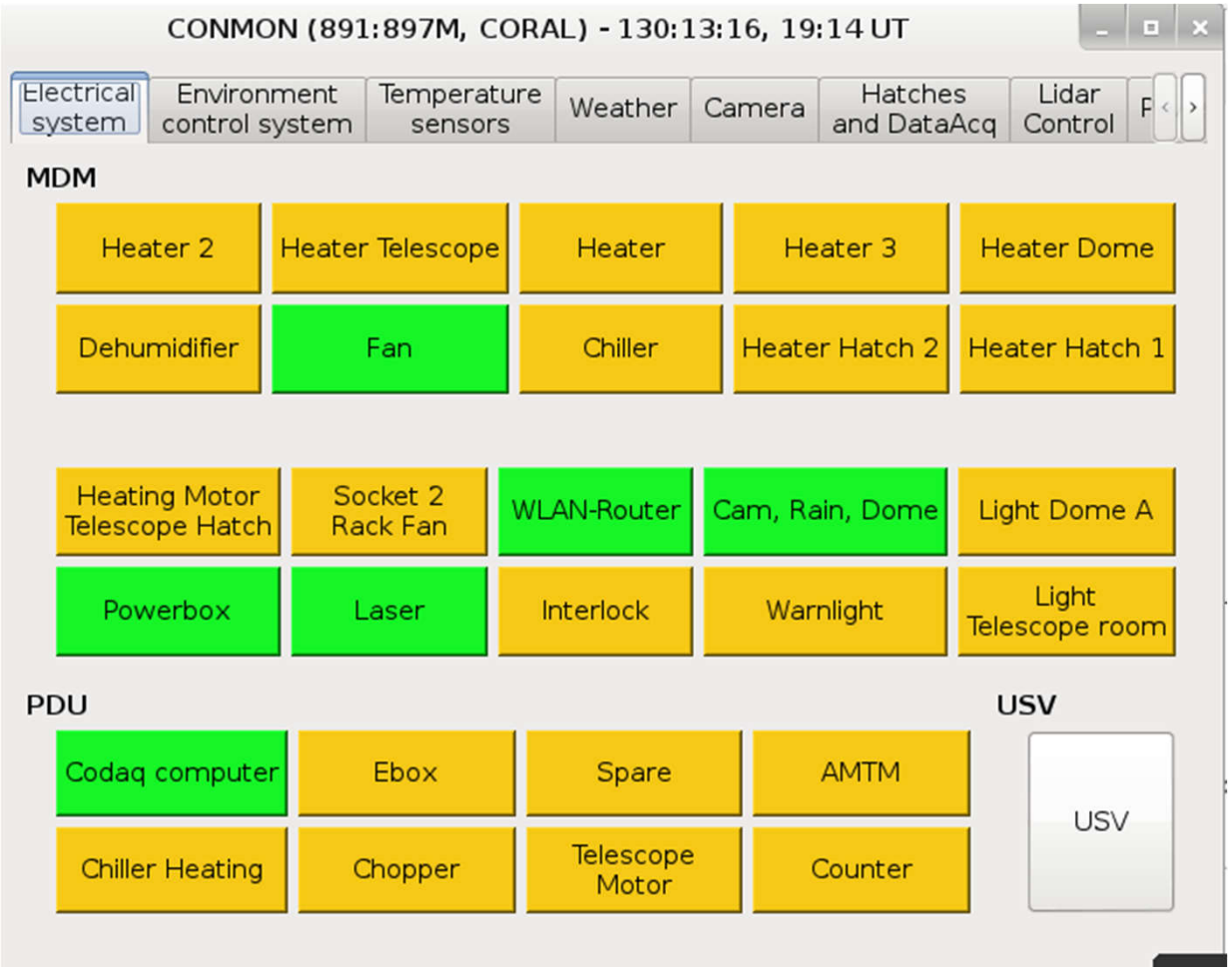
Door to
insulated
electronics
compartment

Air inflow
for chiller

Air outflow
for chiller

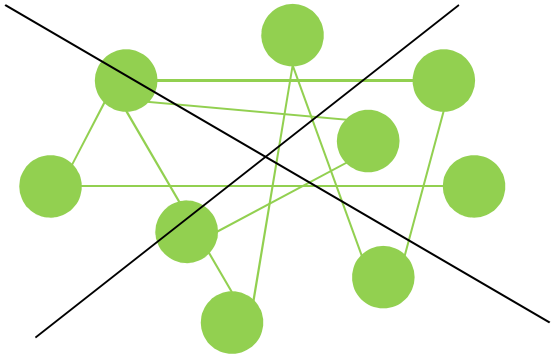
Environment

- Temperature sensors
- Heaters, chillers
- Fans
- Relais
- Light
- Motors
- Filter wheels
- Pumps
- GPS
- Humidity
- Pressure
- Wind
- Rain
- Allsky-Cam



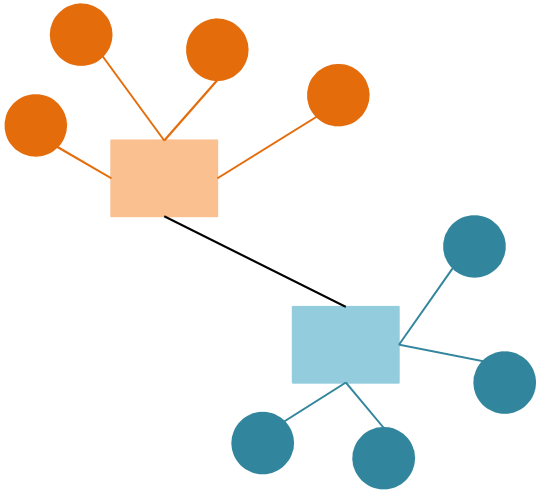
DLR

Command and Control System



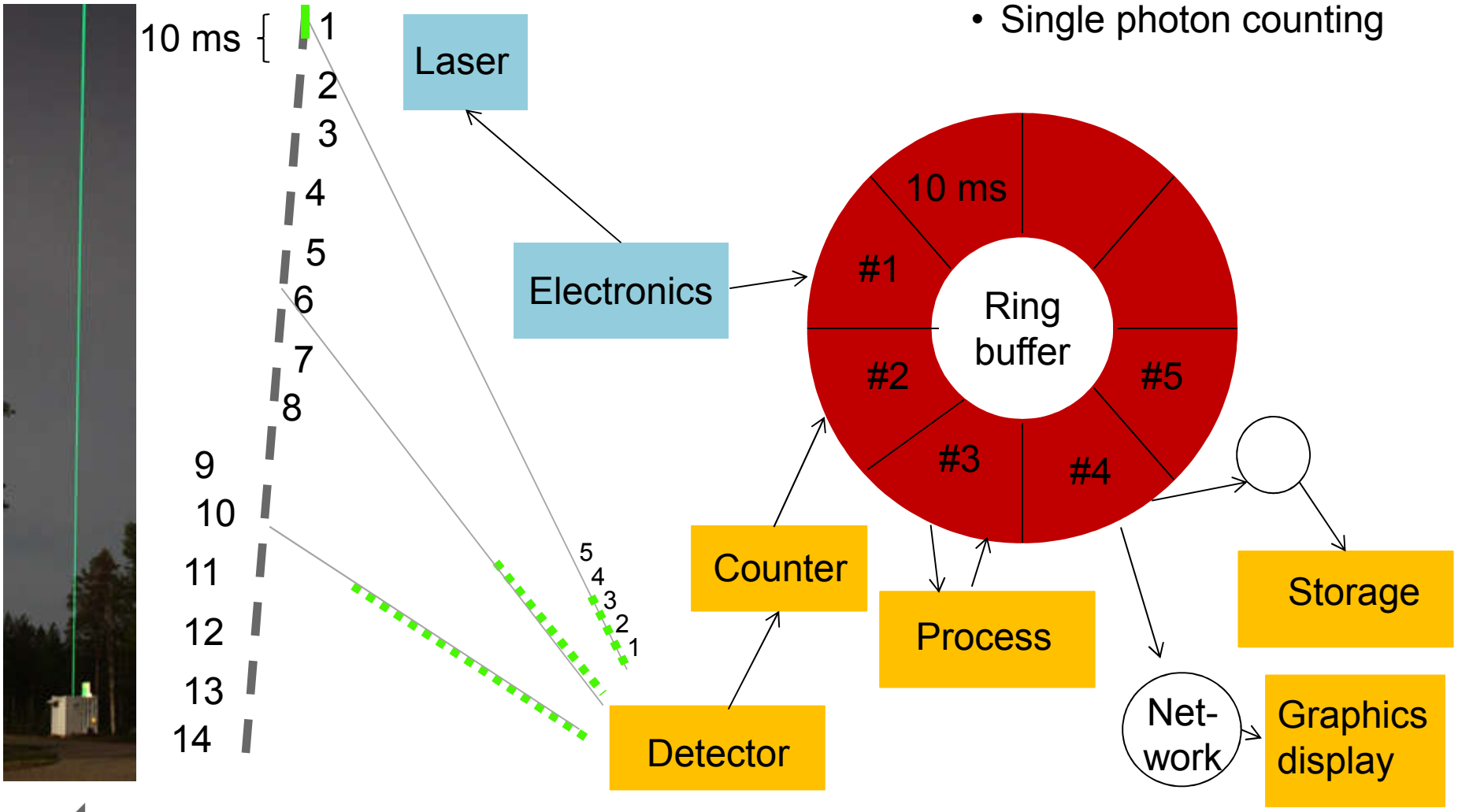
- Integration of all hardware components
- Modular design
- Communicate over sockets
- Unified messaging format

```
MDM2:CHILLER?
> MDM2:CHILLER 0
MDM2:CHILLER 1
FPGA:APD2 1
LASER:CMD SET_SHUTTER_STATE=OPEN
```



Timing constraints & data flow

- LRP 100 Hz
- Light run-time 2.5 ms
- Single photon counting



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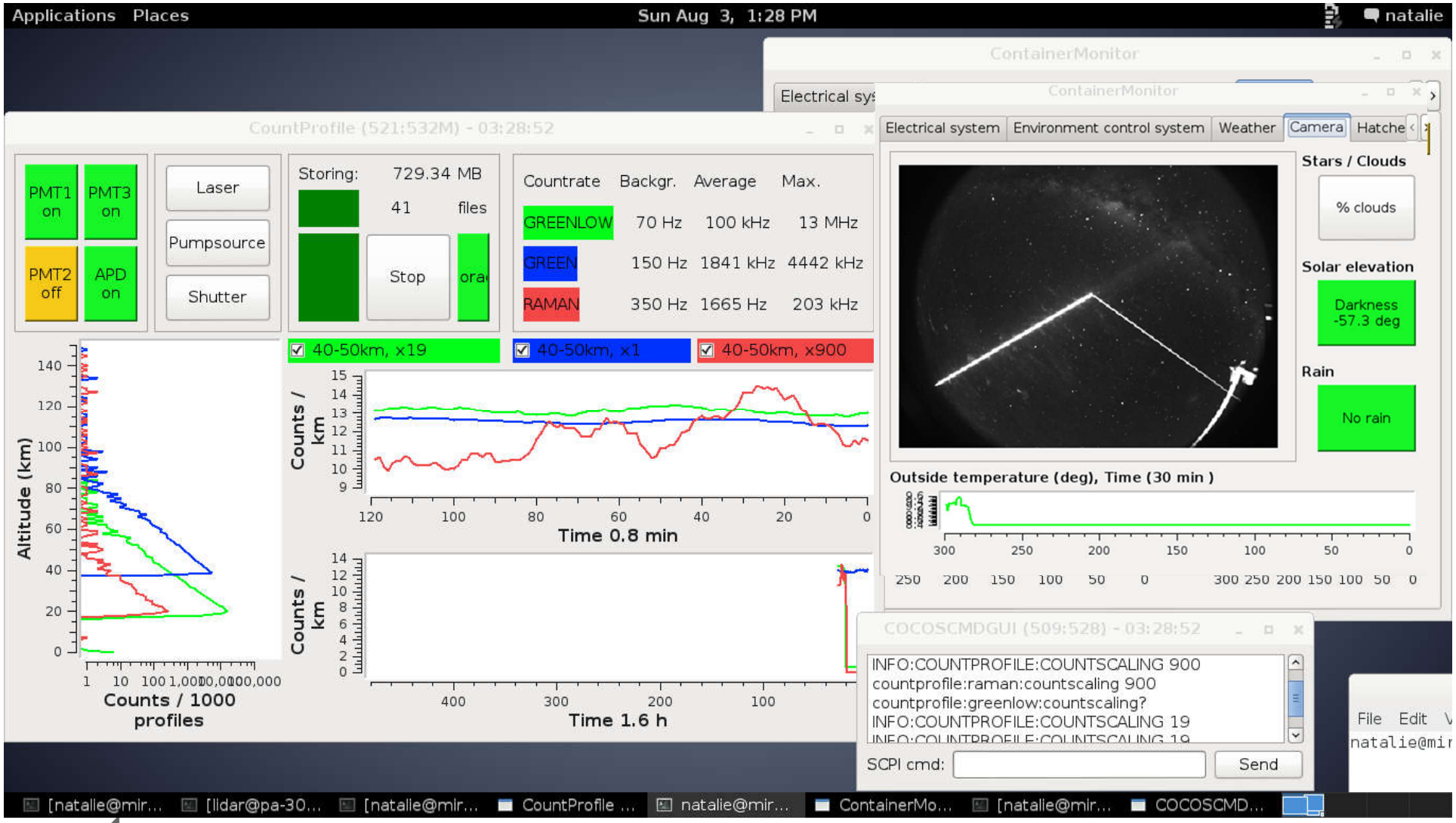
Remote lidar operation



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State Machine

- Activate auto control
- Conditions:
  - Solar elevation, rain & wind
- Handle errors:
  - Data transmission, storage and laser

State	Off/Shutdown
0	Init
10	Shutdown, microcontroller will shutdown in 220 s
11	Wait 30 min
12	initiate shutdown, turn off detectors and laser, shut covers
13	stop script
14	wait 10 min

State	Startup
50	wait for solar elevation, cloud forecast and stars
51	startup script
52	start laser within 10 min, go to 12 on error
53	turn on flashlamp within 5 min
54	Start emission
55	Wait for temperature
56	turn on lowest APD

State	Running
60, 61, 62	turn on next detector, wait for low background
79	Run with full signal
75	cloudy
70	Very cloudy, turn off after 20 min, check if laser running

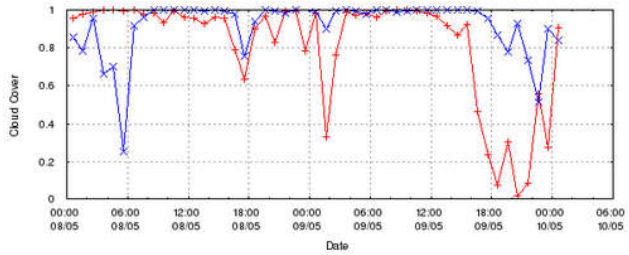
CORAL at the EARG Station in Tierra del Fuego, Argentina

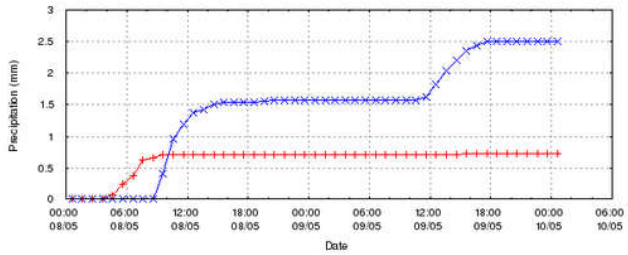
Live at http://kaifler.net/coral/

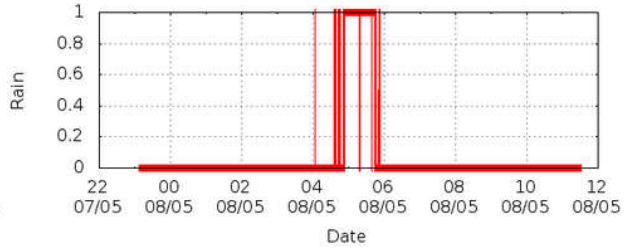
Cloud Cameras

ECMWF Forecast

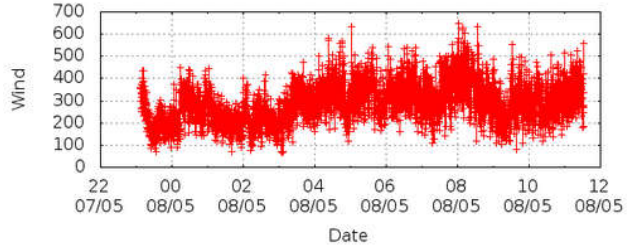
Rio Grande (red) and Rio Gallegos (blue)

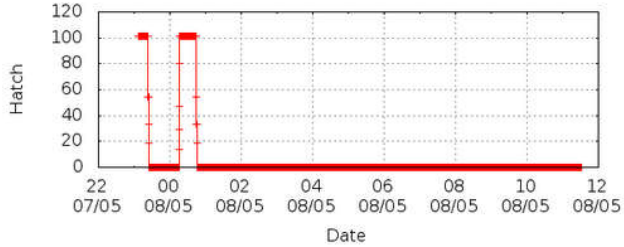


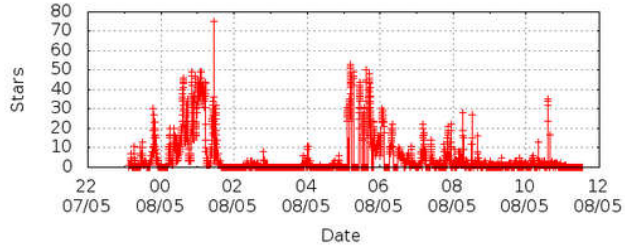


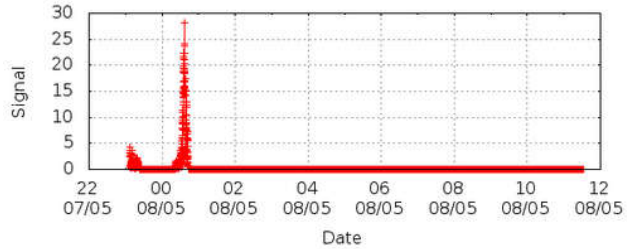


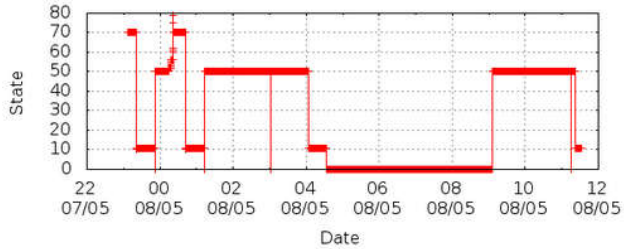
Lidar

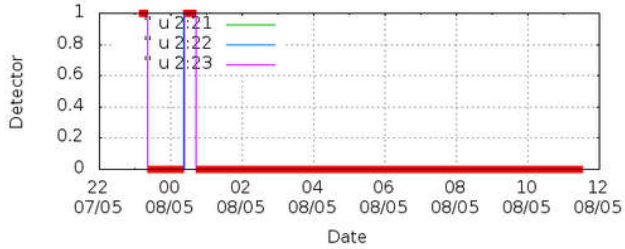












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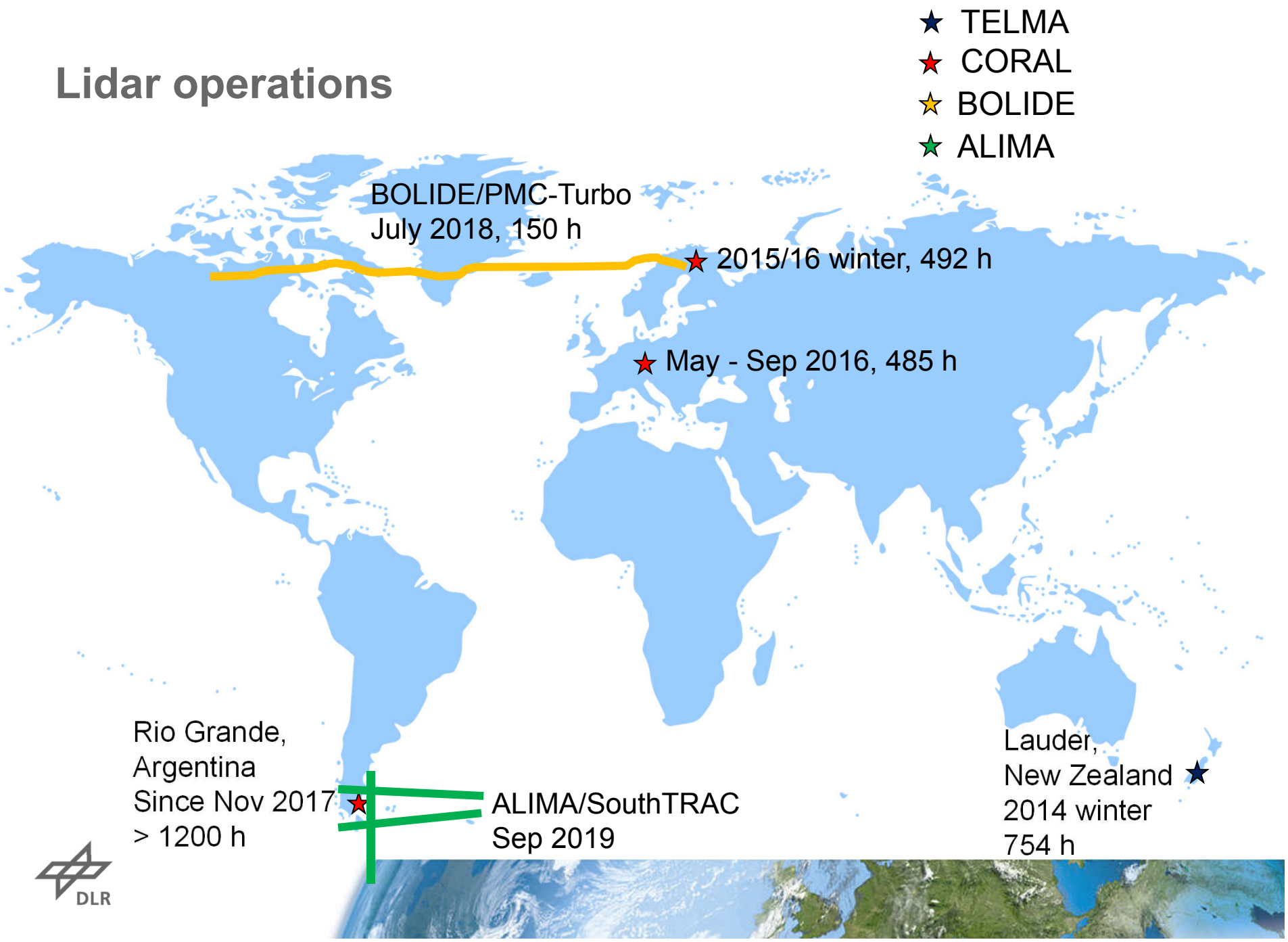
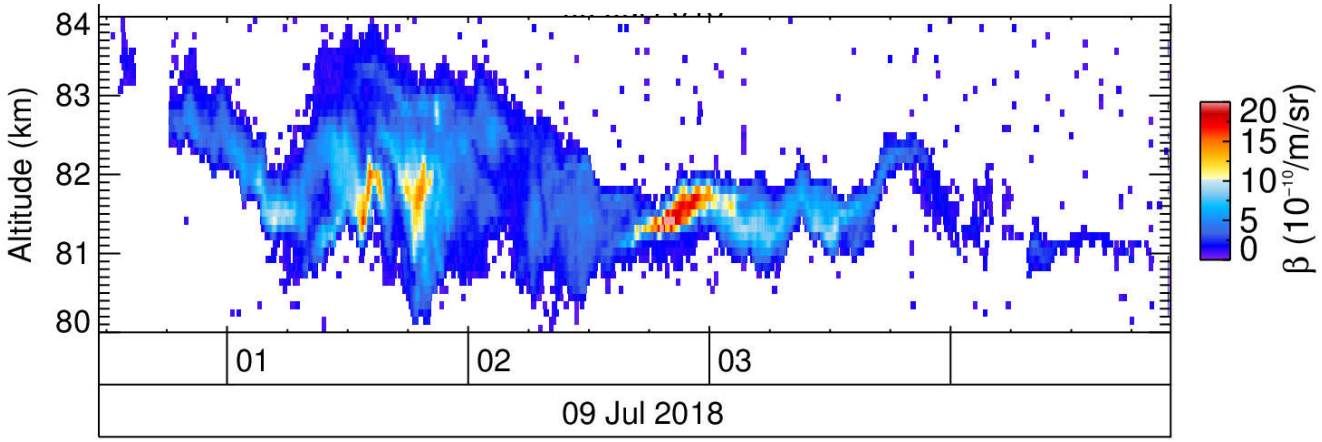
Lidar operations



PMCTurbo balloon campaign



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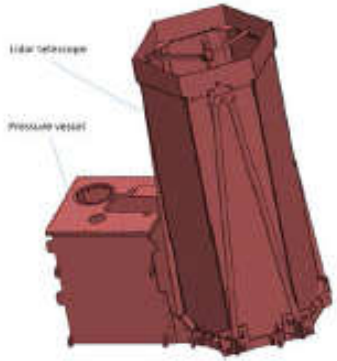
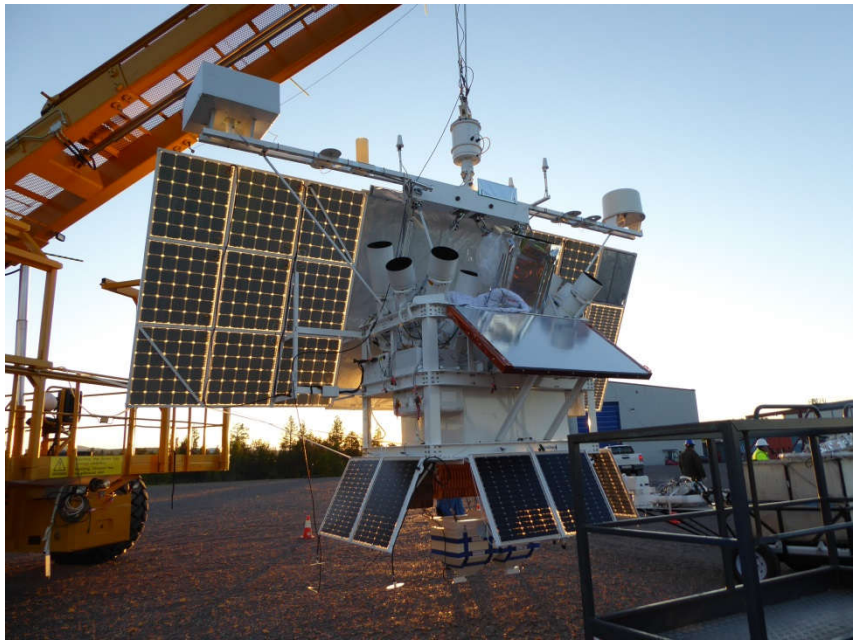
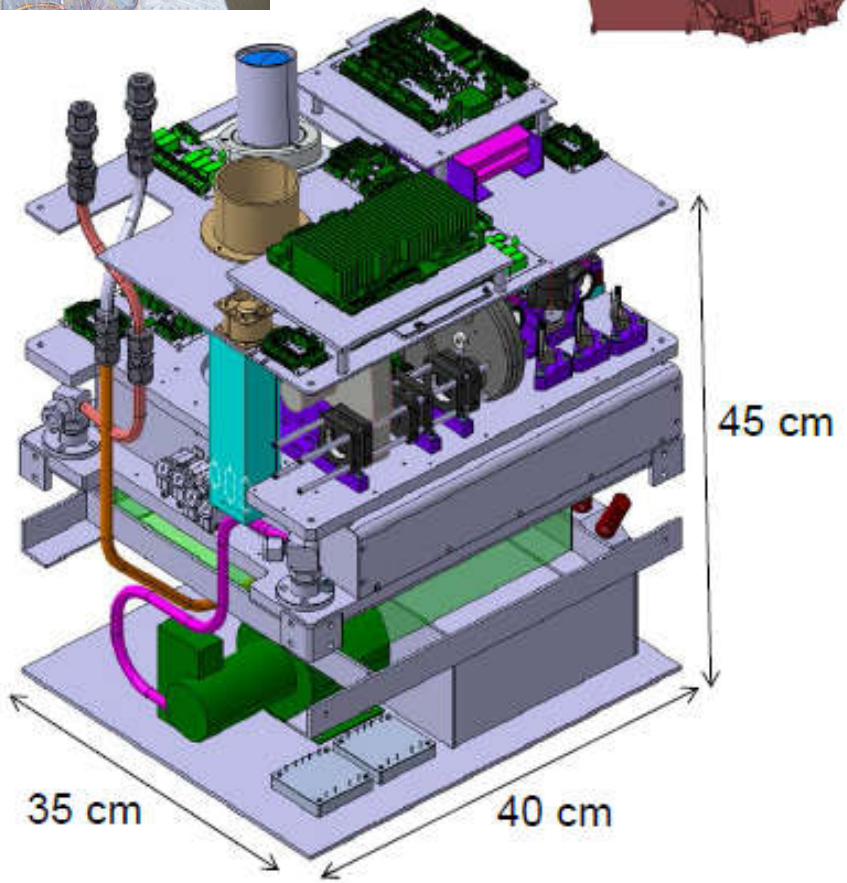
Balloon lidar BOLIDE

- Miniaturized Rayleigh backscatter lidar
- 145 kg, 268 W
- Pressure vessel







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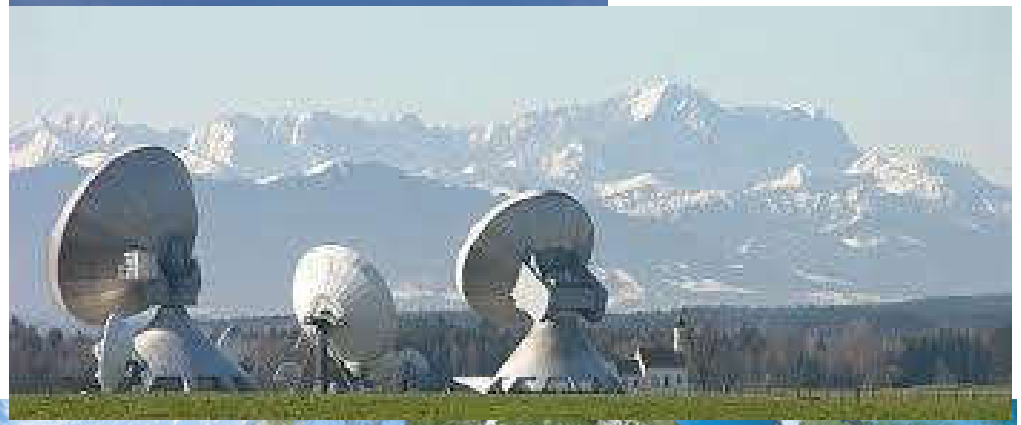
Telemetry

- Line of sight, Iridium, TDRSS
- Telemetry modes (engineering, science, channels, resolutions)
- Command language incl. shell access
- Downlink of science data
- Successful recovery



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Telemetry

Misc

Pressure1	957	mbar
Pressure2	900	mbar
Rel. hum	4	%
Laser killtimer	0	0
Colossus State	1	

Computer

Time	1531538200		
	2018-07-14 03:16:40		
Uptime	76	Load	0.64
Disk MB	1425184		466714
	309320		
Telemetry Mode	1		
Downlink Bandwidth	20	kbit/s	
Downlink Telemetry	14.69	kbit/s	
Files queued	0		

Storage

	Disk	Format	Files
Lidar1	0	0	0
Lidar2	0	0	0
Tel 1	1	0	1
Tel 2	2	0	1
IRCam1	0	0	0
IRCam2	0	0	0
VisCam1	0	0	0
VisCam2	0	0	0

Sequencer

Commands stored	0
ID of last valid message	0
ID of last invalid message	0
Command counter	0
Latest frame no	18
crc errors	0

Electrical

PUMP, LASER, COMP, FPGA
MFAN, EFAN, CFAN, SFAN
PZL, PZM, CHOP, COUNT
DET1, DET2, DET3, IRCAM
THEAT1, THEAT2, THEAT3, HUB
MH1, MH2, MH3, VISCAM
TEC, TEC HEAT, BHEAT, FLTWHL

MAIN	1419 mA	11.96 V	16.97 W
PUMP	0 mA	27.88 V	0.00 W
LASER	0 mA	27.83 V	0.00 W
HEAT	6 mA	27.89 V	0.17 W
DET	0 mA	5.01 V	0.00 W
TOTAL	17 W		17 W

Thermal Control

Tank	33.15 °C	Level	3937
Pump	65535 rpm	0.00 W	27.75 °C
CFAN	Inlet	27.55 °C	TEC
	Outlet	28.90 °C	OFF
			29.50 °C
MFAN	Air	25.35 °C	COOLING
EFAN	Comp	29.10 °C	FAN OFF

Navigation

Height	3 m	Source	0
Lat	0.0000 deg	Sats	6
Long	0.0000 deg	PTNFLT	SNFLT
SunS	-4.80 °C		SNFLTO
	714.00	738.00	722.00	578.00
IMU acc	-7309	-364	14020
IMU gyro	-139	358	226

LIDAR

CHOP SYNC, ILOCK1, ILOCK2
FIRE ENABLE, CHOP FLT, M2, M2
PC ENABLE, TRG FLT, M1, M1

PZL	0	0		
PZM	0	0		0
	0	0		
CHOP	Mean	0	Stddev	0
CYCLE	Mean	34450	Stddev	0
FILTER		0		
NLC OFFSET		0		

	SG (Hz)	SGMAX (kHz)	BG (Hz)
CH1	0	0	0
CH2	0	0	0
CH3	0	0	0

Radiator

Inlet	0.85 °C		-3.65 °C
Outlet	-6.45 °C	4.25 °C	-1.50 °C
Rib	0.60 °C		-2.05 °C
Insul	-15.20 °C	HEAT	0.0 W

HEAT1, HEAT2, HEAT3, HEAT4
HEAT5, HEAT6, HEAT7, HEAT8

Laser

Status	0	0	0	0
Plate	0.00 °C		25.60 °C	
Board	0.00 °C			
Cryst TEC	25.60 °C			
LD TEC	0.00 °C		0.00 °C	
LD	256.00 A		256.00 A	
LD TEC	0.00 A		0.00 A	
PC DELAY	256	Beam exp	0	

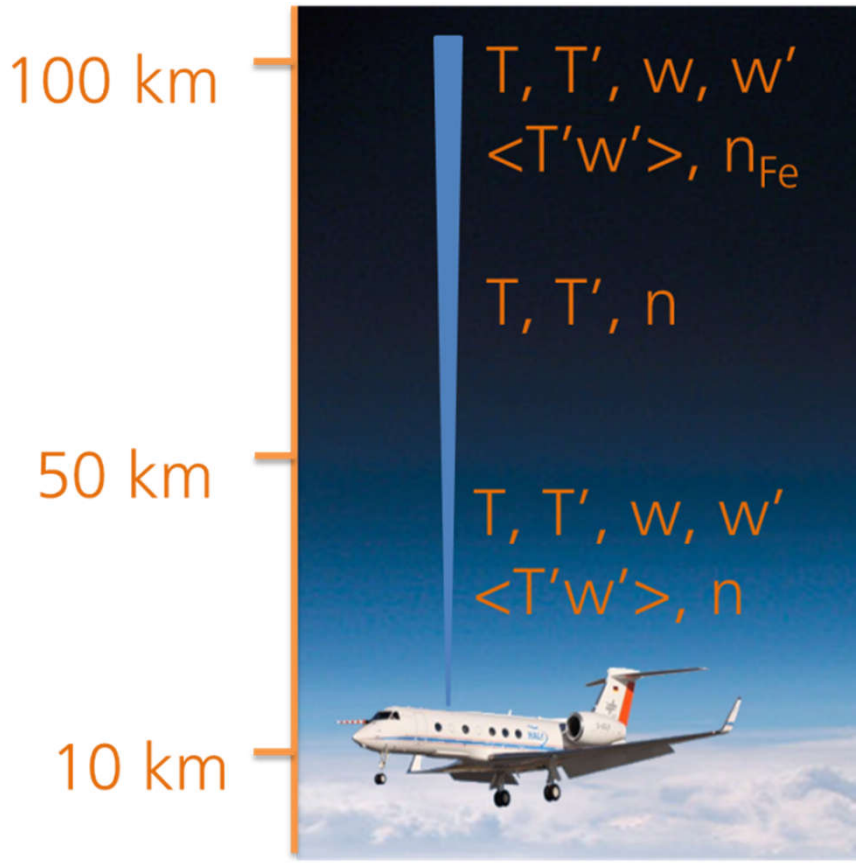
Temperatures

Electronics Section	
Lid	17.25
Computer	29.10
Plate	26.60
DC Conv	44.05
Receiver Section	
APD1	24.70
APD2	24.45
Chopper	24.60
Counter1	0.00
Counter2	0.00
Pump Section	
Laser DC Conv	29.10
12V DC Conv	31.10
Pressure Vessel	
PZ Motor2	6.00
PZ Motor1	4.80
Mirror Holder	-1.00
Hose Vessel	-0.40
Hose Mid	0.05
Hose Radiator	6.40
Air	-20.90
Gondola	-9.25
Telescope	
PZ Motor3	-26.50
Collar left	-28.70
Collar right	-29.35
Back panel	-12.65
Front panel	-13.70
Truss	-14.35
Mirror	8.65
Baseplate	11.70
VIS Cam	-4.35
IR Cam	0.00

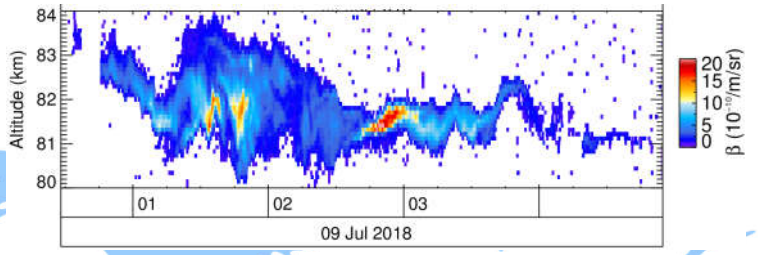
DLR

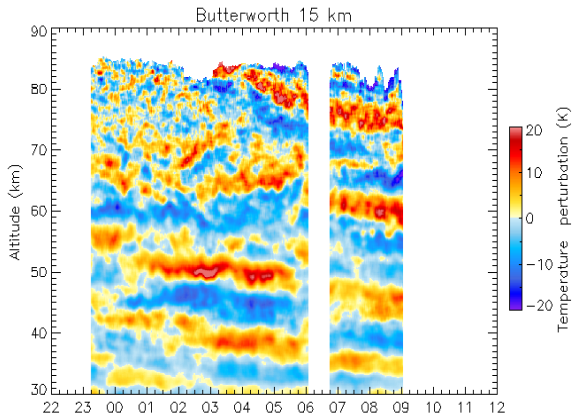
ALIMA - Airborne lidar for middle atmosphere research

- Upward-viewing Iron Doppler lidar
- Test campaign March 2019
- SouthTRAC campaign Sep-Nov 2019
- 10-105 km
- Temperature
- Vertical wind
- Iron density
- High resolution

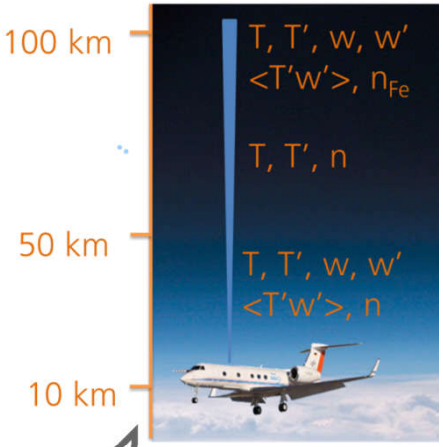


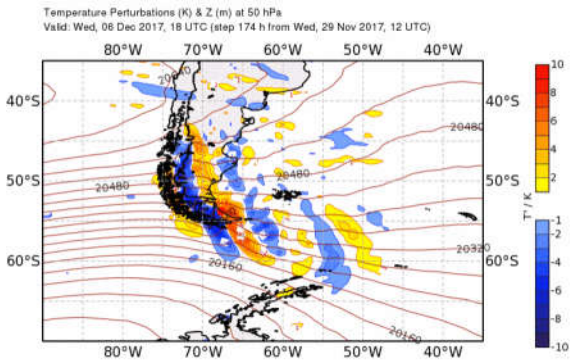
Summary





Middle atmosphere dynamics with lidars





DLR