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Multi-dimensional retrievals of wind speed for the WIRA-C instrument

Jonas Hagen, Niklaus Kämpfer

Institute of Applied Physics (IAP), University of Bern, Switzerland

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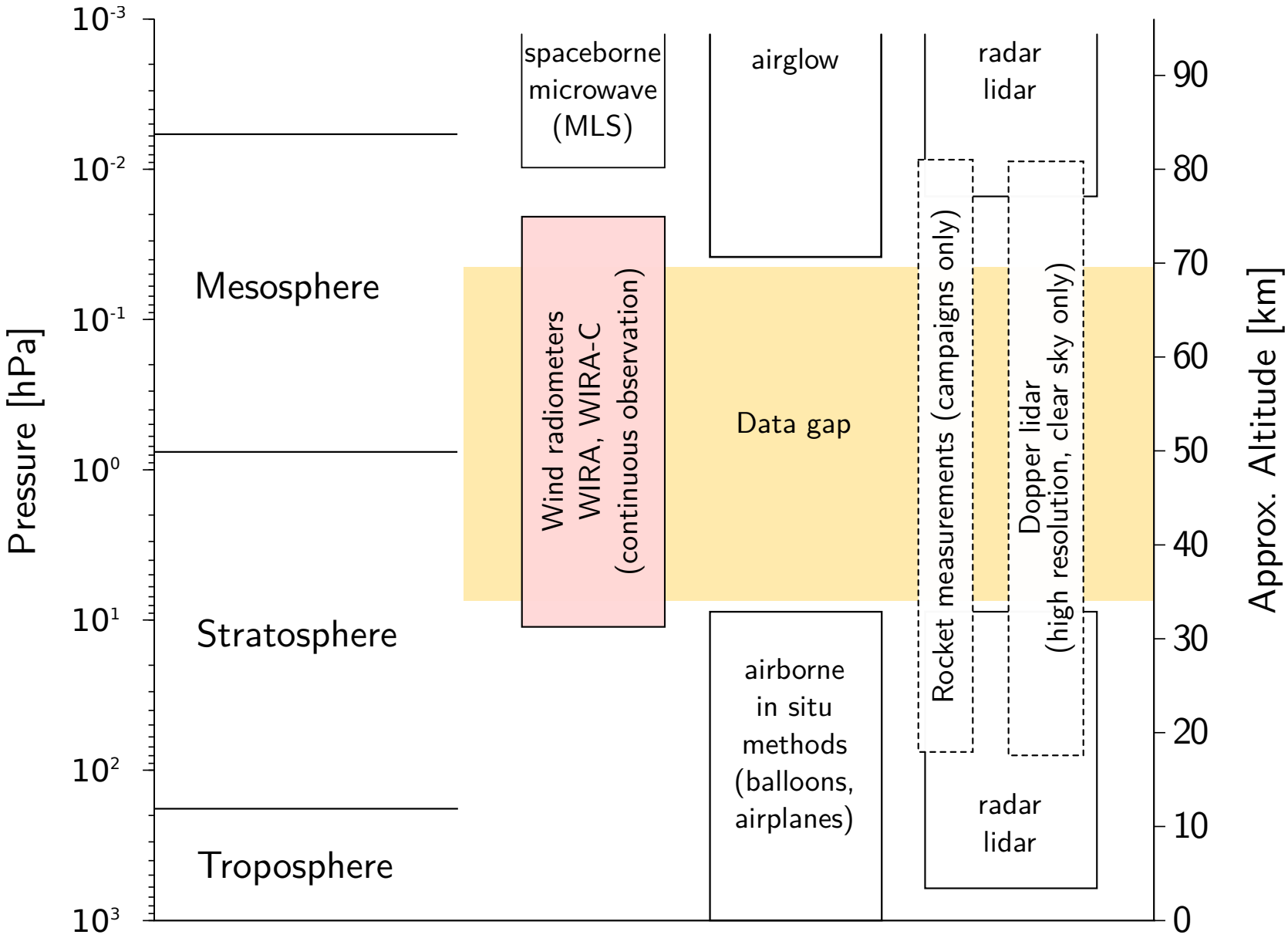
Motivation for microwave wind radiometry



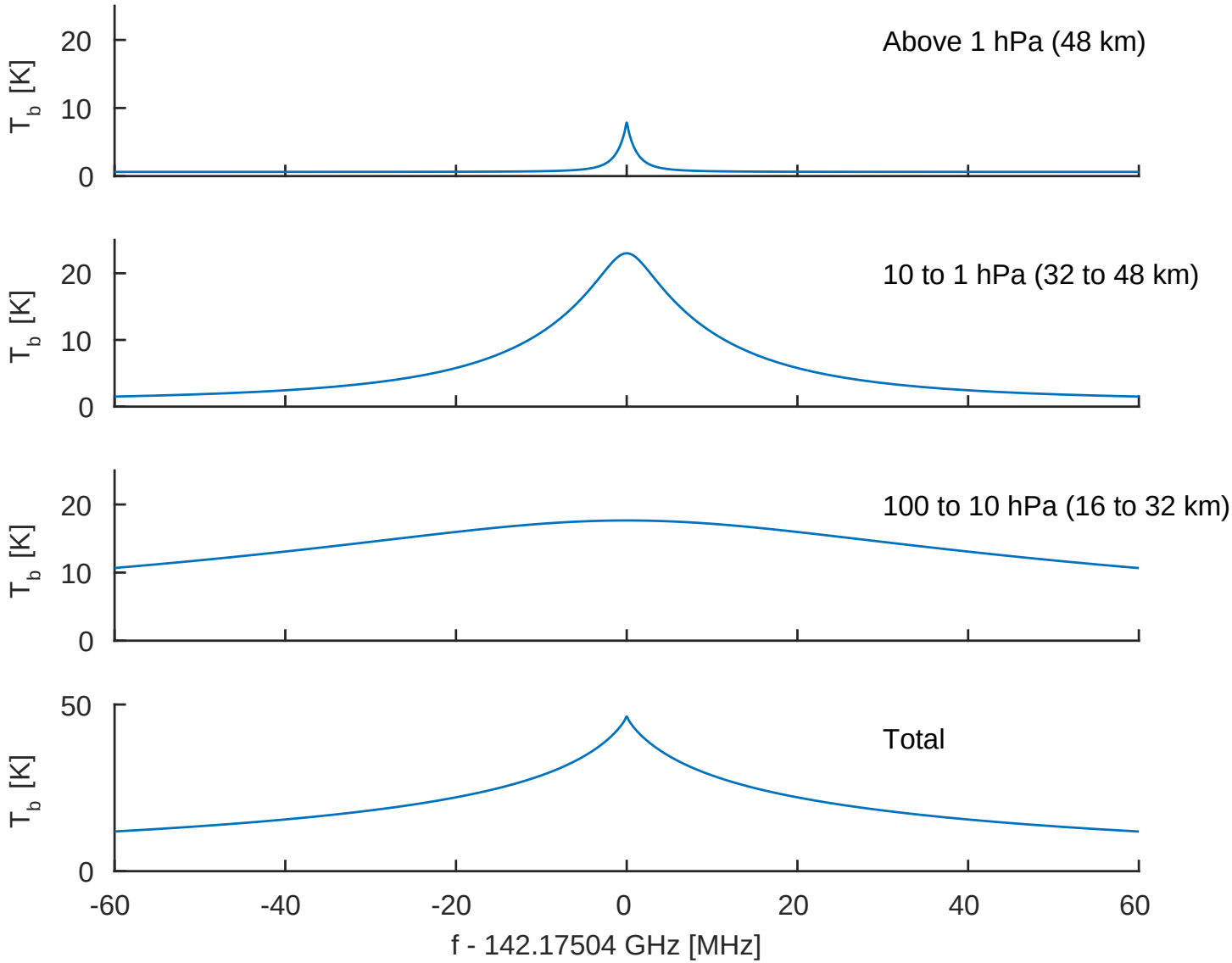
What is wind radiometry?

- Passive and ground based
- Measurement of zonal and meridional wind by exploiting the Doppler shift of emission lines at microwave frequencies

$$\Delta\nu = \frac{v_{\text{los}}}{c}\nu_0.$$

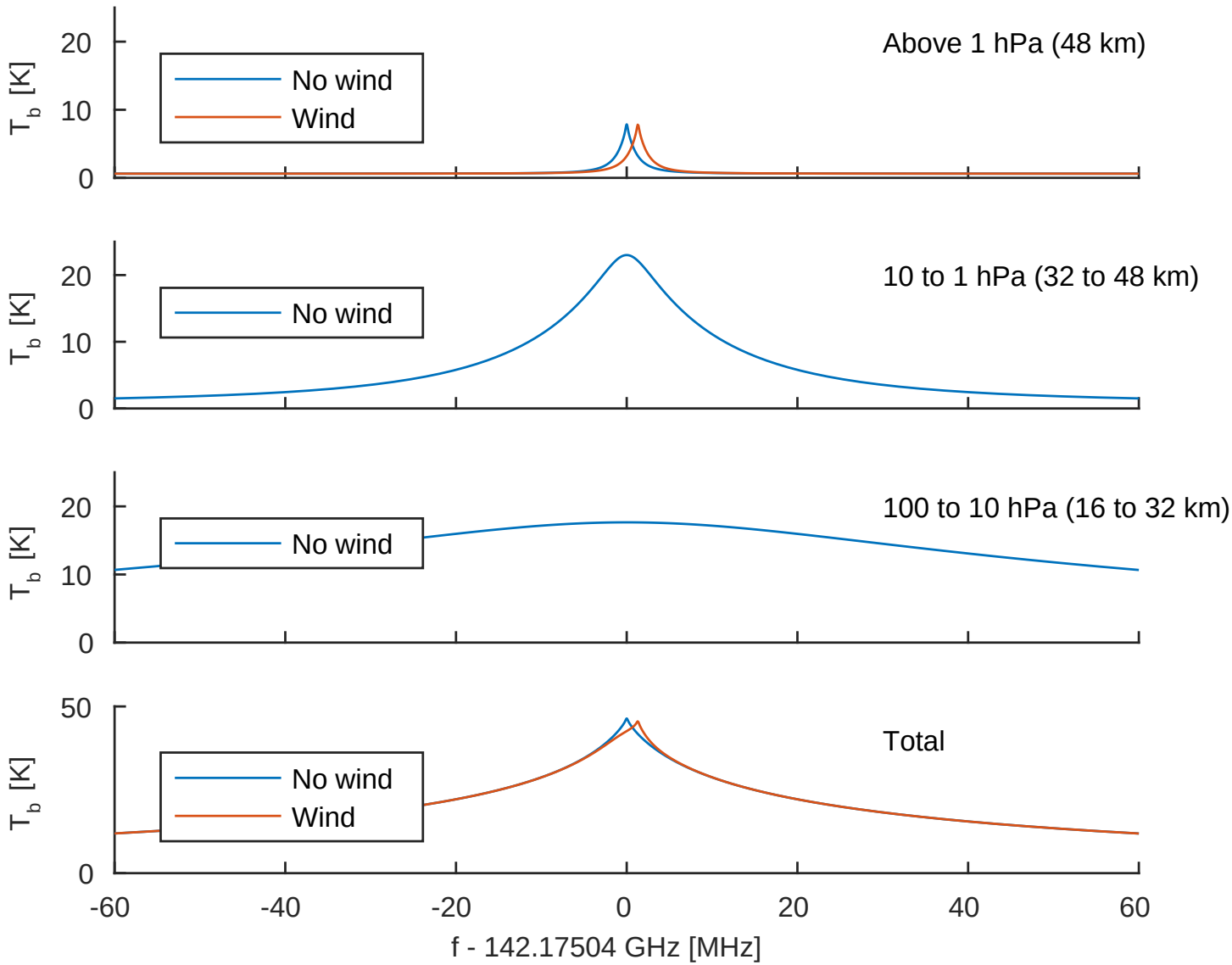
- High frequency and strength of O_3 emission line at 142 GHz is advantageous.
- Pressure broadening allows the retrieval of altitude resolved wind profiles.
- Observations during day and night, also in cloudy conditions.

Illustration of the measurement principle



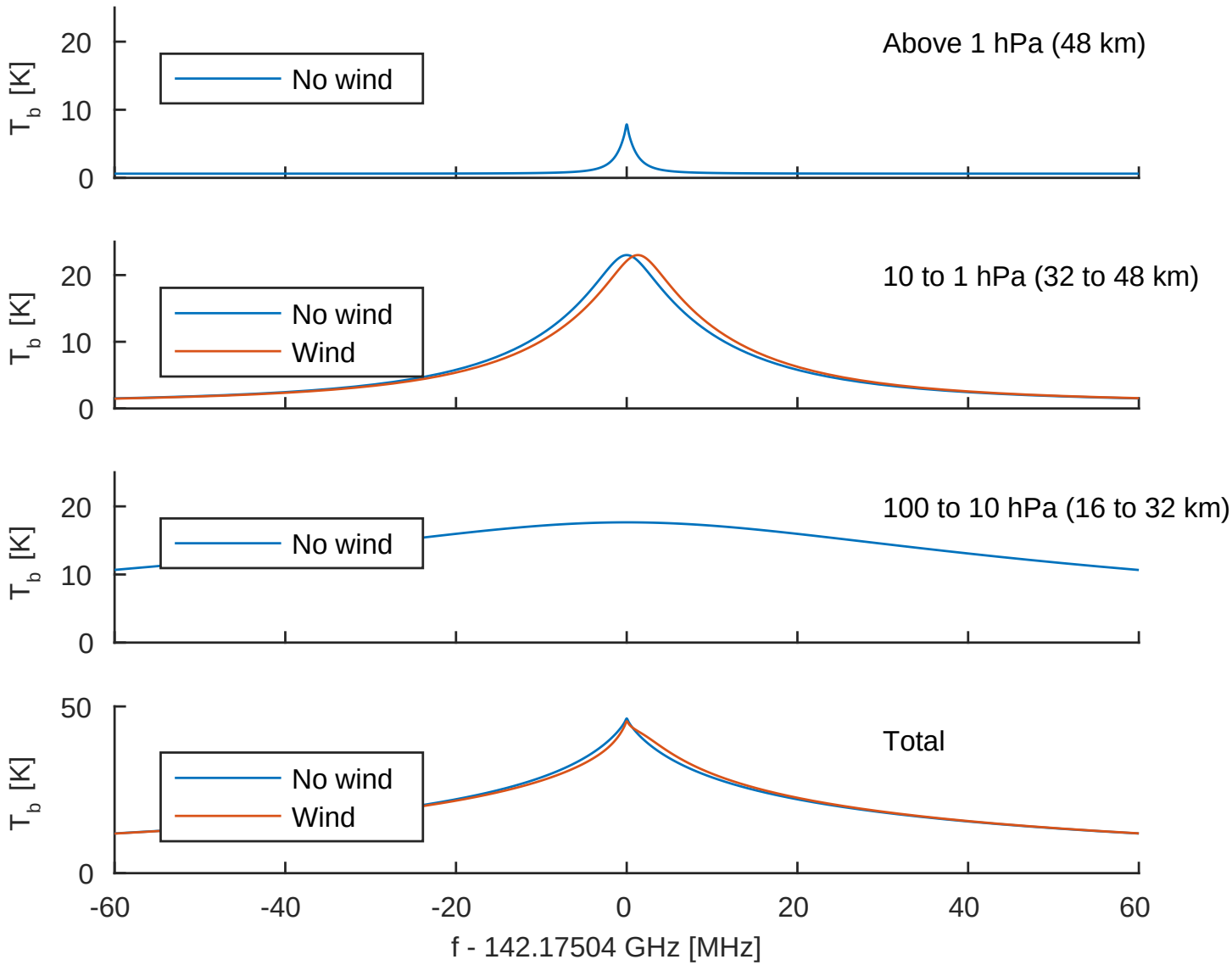
Ozone emission line for different atmospheric layers.

Illustration of the measurement principle



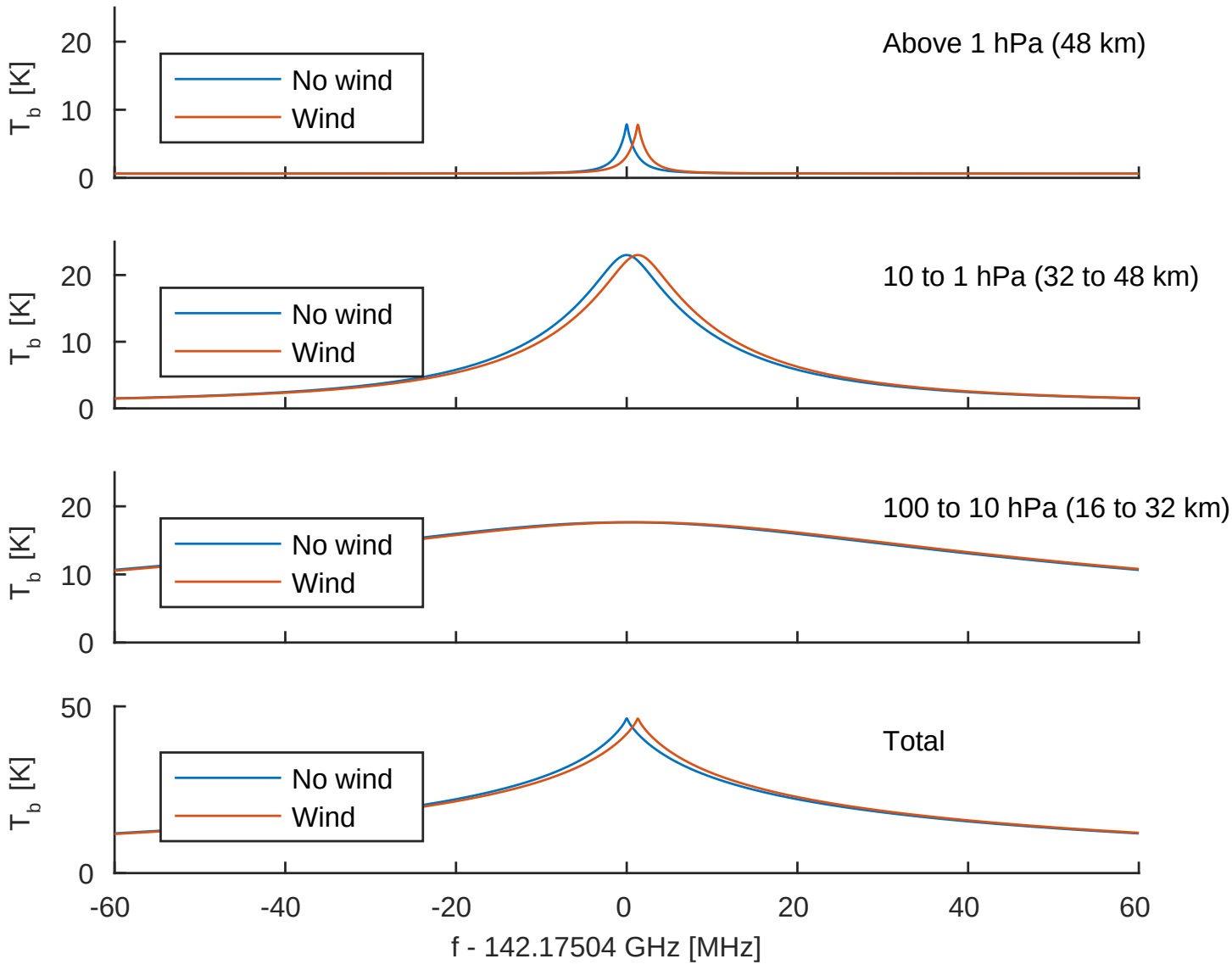
Wind in the mesosphere. (exaggerated wind speed of 3000 $\frac{m}{s}$)

Illustration of the measurement principle



Wind in the stratosphere only. (exaggerated wind speed of 3000 $\frac{m}{s}$)

Illustration of the measurement principle



Wind in all layers. (exaggerated wind speed of 3000 $\frac{m}{s}$)

WIRA-C on La Réunion island, 21° S

Maïdo observatory, 2200 m a.s.l.

The WIRA-C instrument

- WInd RAdiometer for Campaings – Compact version of the WIRA instrument
- Improvements over WIRA:
  - Very compact (single unit)
  - More versatile positioning
  - Path length modulator
  - Internal wedge calibration target
- Built at the IAP, University of Bern
- Radiometer: 510 K noise temperature
- Spectrometer: 200 MHz bandwidth, 12.2 kHz channel width

The WIRA-C instrument

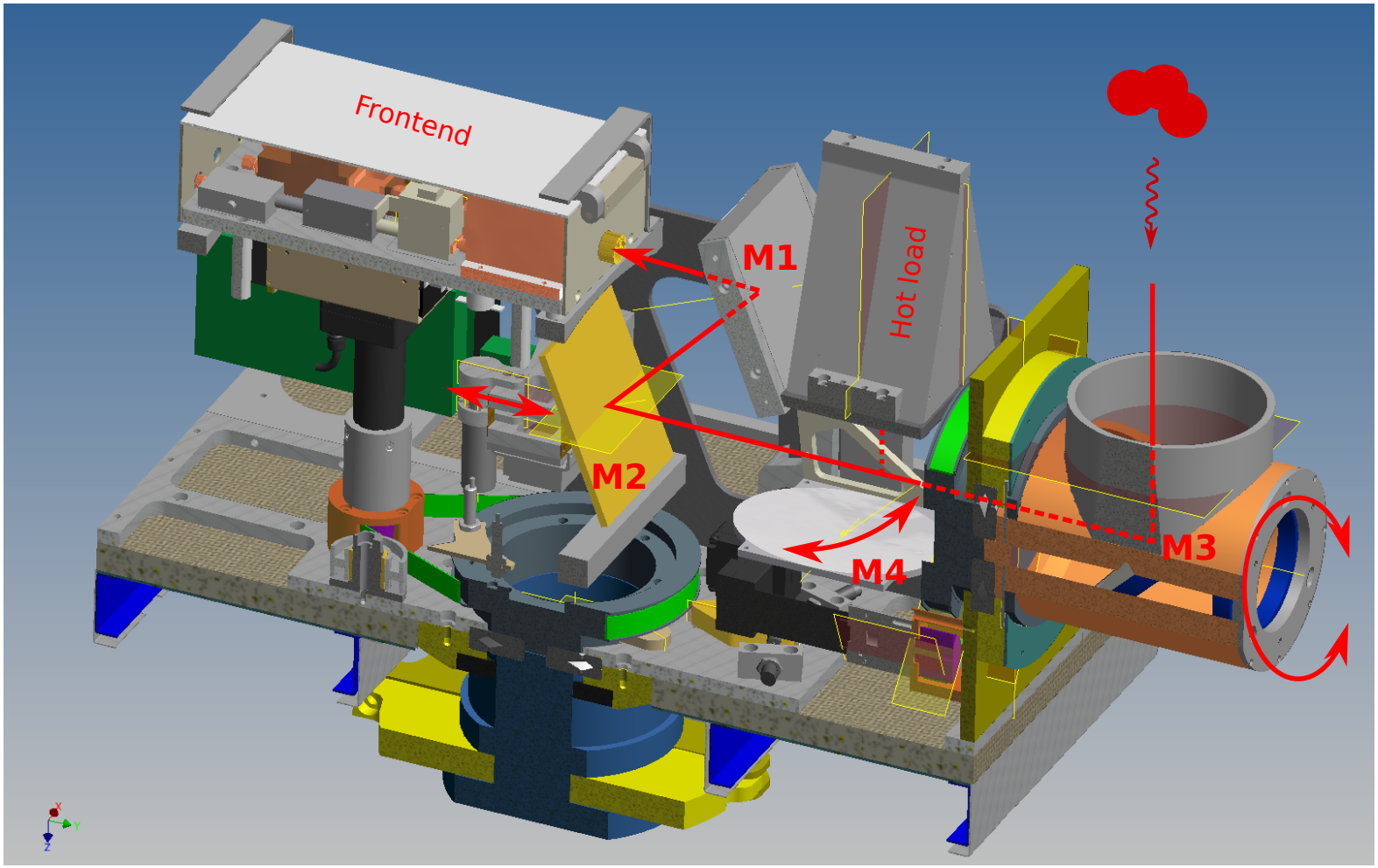


Figure: M1: elliptical, M2: shiftable, M3: rotatable, M4: slewable. Whole instrument turns around azimuth axis.

Retrieval overview

- Measured:
  - East / West / North / South, 22° elevation
  - Zenith
- Retrieved:
  - Zonal (and meridional) Wind speed (0 $\frac{\text{m}}{\text{s}}$ a priori)
  - Ozone (model a priori)
  - Frequency shift (0 Hz a priori)
  - Baseline
  - If needed: Tropospheric water vapour

All the statements about East / West / zonal wind also hold for North / South / meridional wind.

One-dimensional setup

WIRA retrievals

- Procedure:
  - Estimate frequency shift with mirror method
  - Retrieve wind (and other species) from East observation
  - Retrieve wind (and other species) from West observation
  - Take averages $\Rightarrow$ zonal wind profile
- Advantages:
  - Simple usage of Qpack (1D setup)
  - Tropospheric correction via retrieval of water vapour
- Disadvantages:
  - Does not fully leverage the differential measurement (East / West)
  - Frequency shift estimation is done separate from OEM
  - Error estimation is difficult

One-dimensional setup

Qpack setup sketch

```
Y(1).Y = [ east_spectrum ];
Y(2).Y = [ west_spectrum ];
...
Q.ATMOSPHERE_DIM = 1;

Q.ABS_SPECIES(idx_O3).SX = covmat1d_from_cfun(...);
Q.ABS_SPECIES(idx_O3).GRIDS = {p_grid, 21, 54};

Q.WIND_V.GRIDS = {p_grid, 21, 54};
Q.WIND_V.SX = covmat1d_from_cfun(...);
...
wind_u = (L2(1).wind_v_x - L2(2).wind_v_x) / 2;
```

Multi-dimensional setup

New, currently used for WIRA-C

- Combine both measurements (East and West) to retrieve one wind profile and frequency shift but allow for different Ozone profiles via the same MAP optimisation.

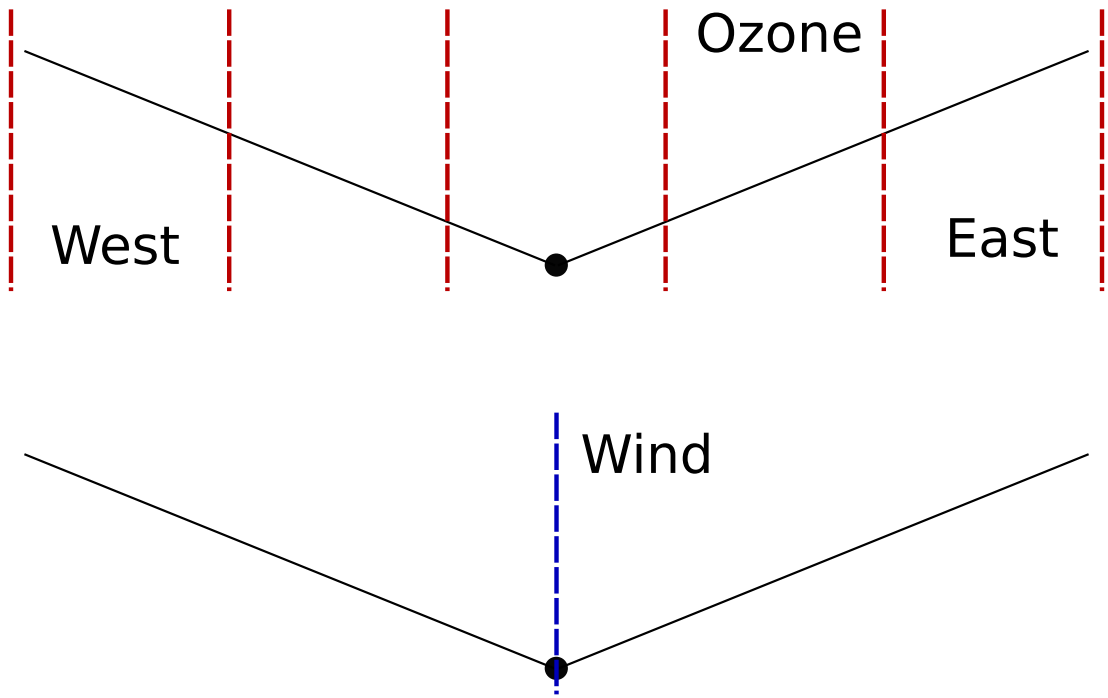


Figure: Grid setup for zonal wind retrievals. Red grid is used for Ozone, blue grid is used for wind.

Multi-dimensional setup

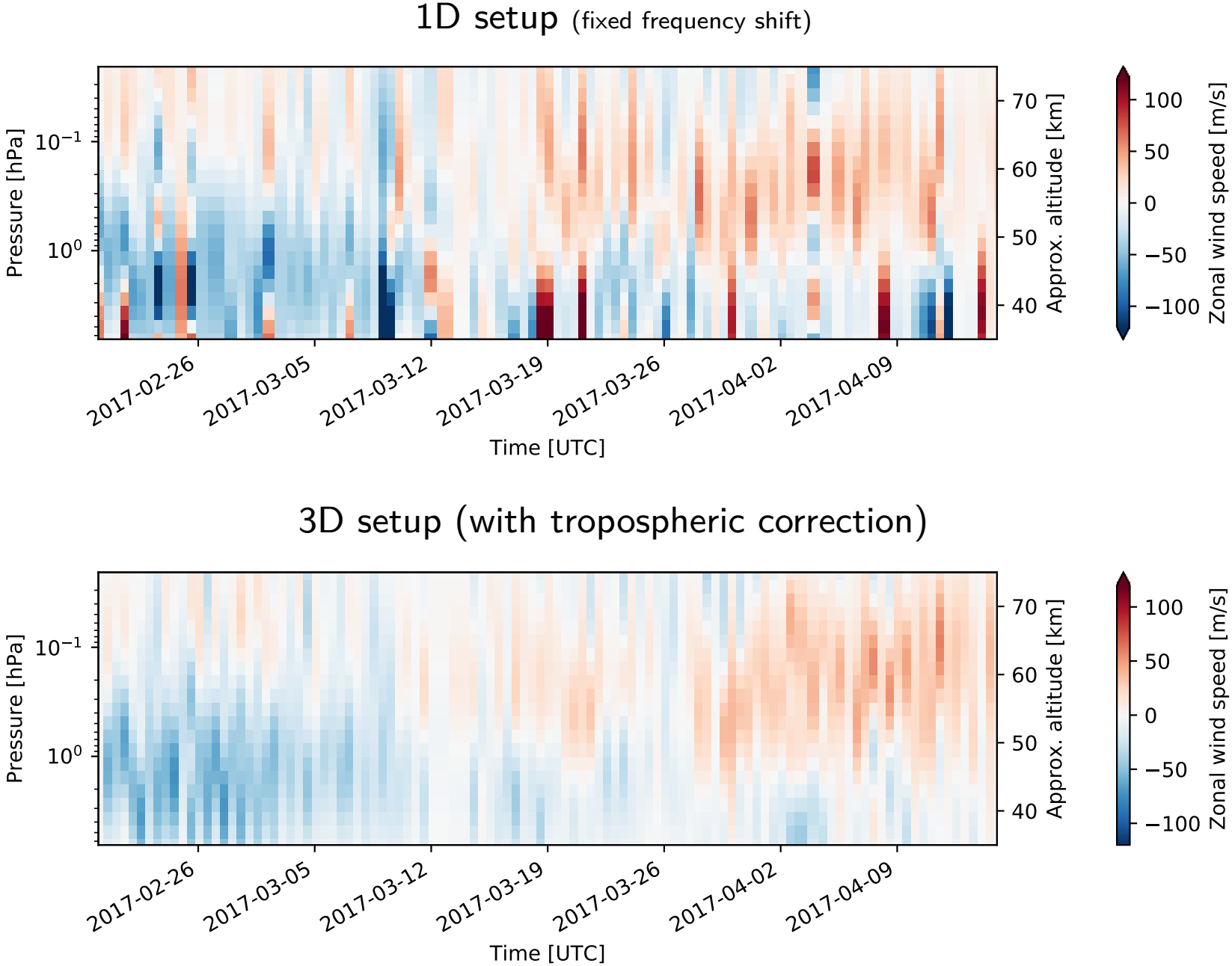
Qpack setup sketch

```
Y.Y = [ east_spectrum ; west_spectrum ];
Y.ZA = 90 - [22; 22];
Y.AA = [90; -90]
...
Q.ATMOSPHERE_DIM = 3;
Q.LAT_GRID = [21];
Q.LON_GRID = [51   52   53   55   57   58];

Q.ABS_SPECIES(idx_O3).SX = covmat3d(...);
Q.ABS_SPECIES(idx_O3).GRIDS = {p_grid, Q.LAT_GRID,
    ↪ Q.LON_GRID};

Q.WIND_U.GRIDS = {p_grid, 21, 54};
Q.WIND_U.SX = covmat1d_from_cfun(...);
...
wind_u = L2.wind_u_x;
```

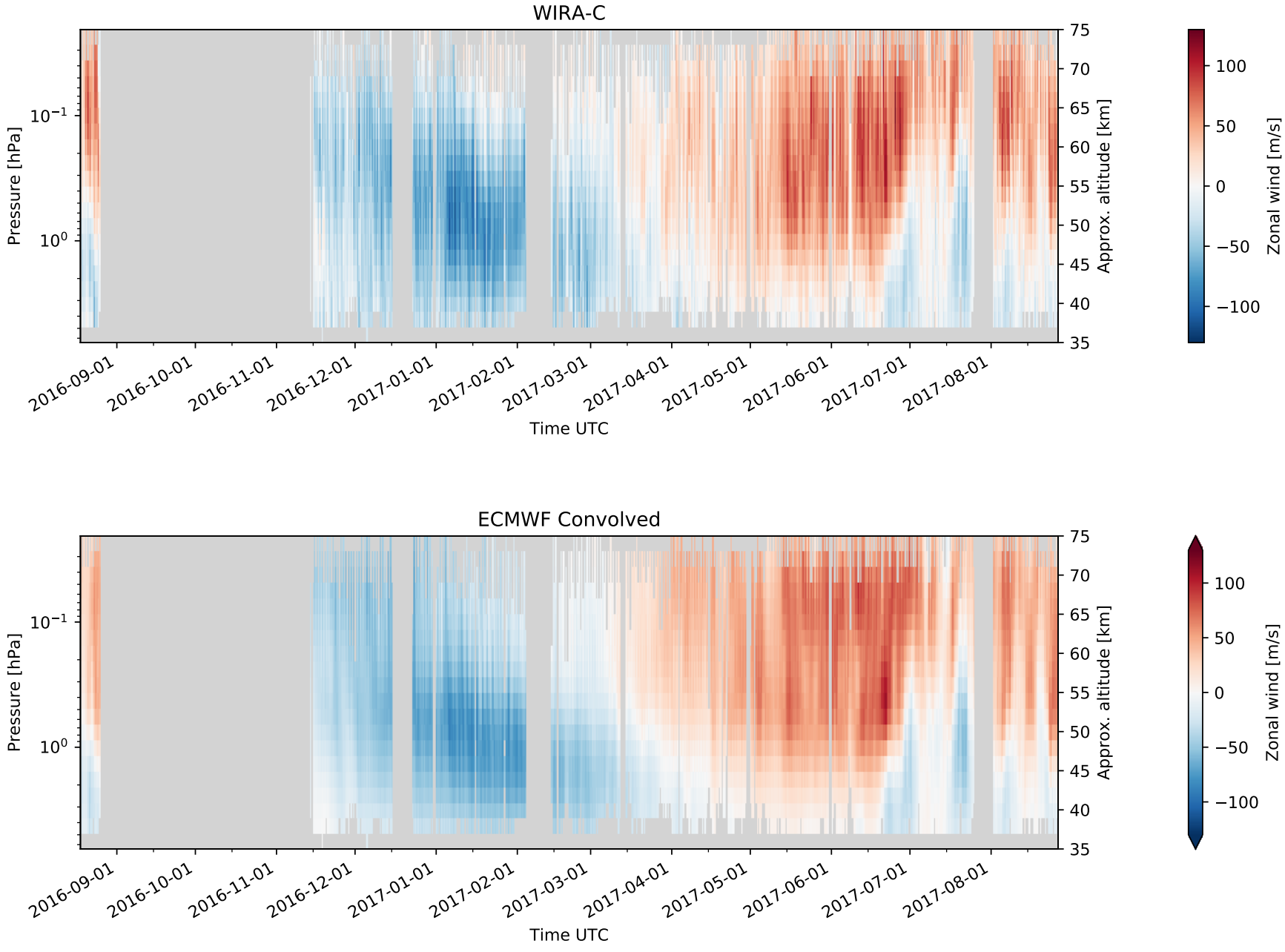
Multi-dimensional setup

- Advantages:
  - East / West measurements are combined in one OEM run
  - Reliable retrieval of frequency shift
  - Appears to be very stable
  - Useful observation error
- Disadvantages:
  - Understandin and set up of spacial grids for ozone

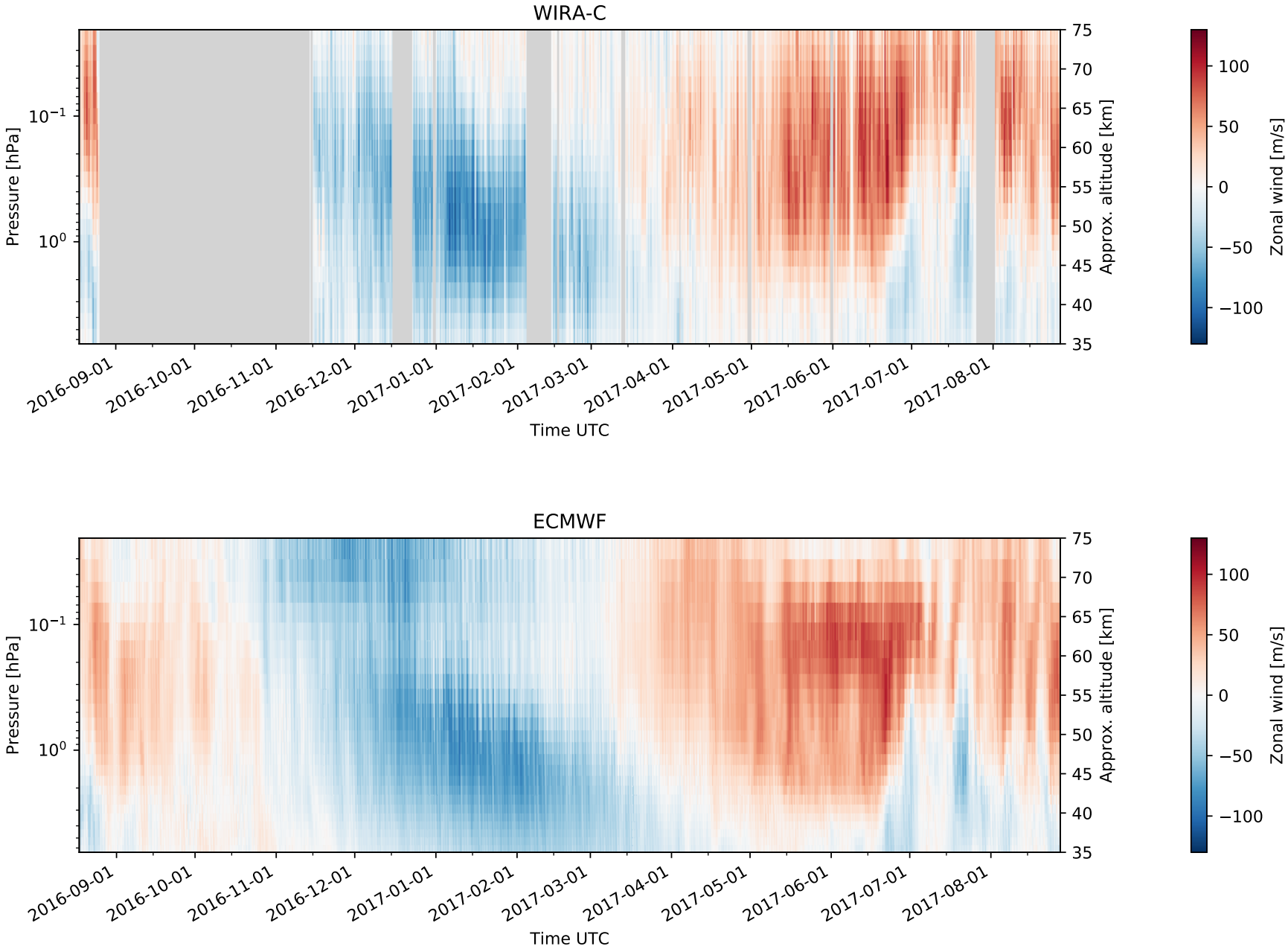
Comparison


1D setup (fixed frequency shift)
Pressure [hPa]
10^{-1}
10^{0}
2017-02-26
2017-03-05
2017-03-12
2017-03-19
2017-03-26
2017-04-02
2017-04-09
Time [UTC]
70
60
50
40
Approx. altitude [km]
100
50
0
−50
−100
Zonal wind speed [m/s]
3D setup (with tropospheric correction)
Pressure [hPa]
10^{-1}
10^{0}
2017-02-26
2017-03-05
2017-03-12
2017-03-19
2017-03-26
2017-04-02
2017-04-09
Time [UTC]
70
60
50
40
Approx. altitude [km]
100
50
0
−50
−100
Zonal wind speed [m/s]

Zonal wind time series from WIRA-C

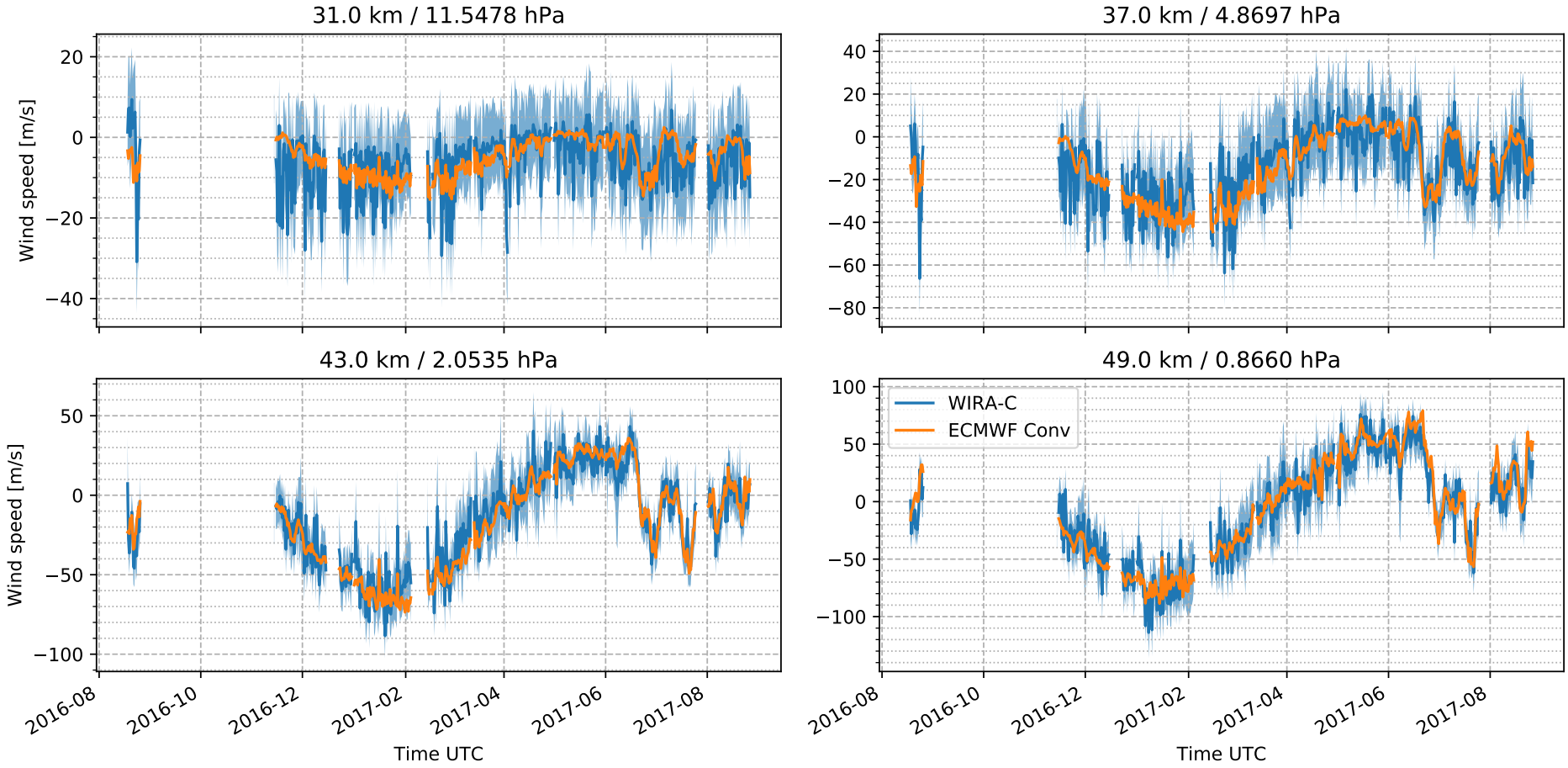


Zonal wind time series from WIRA-C



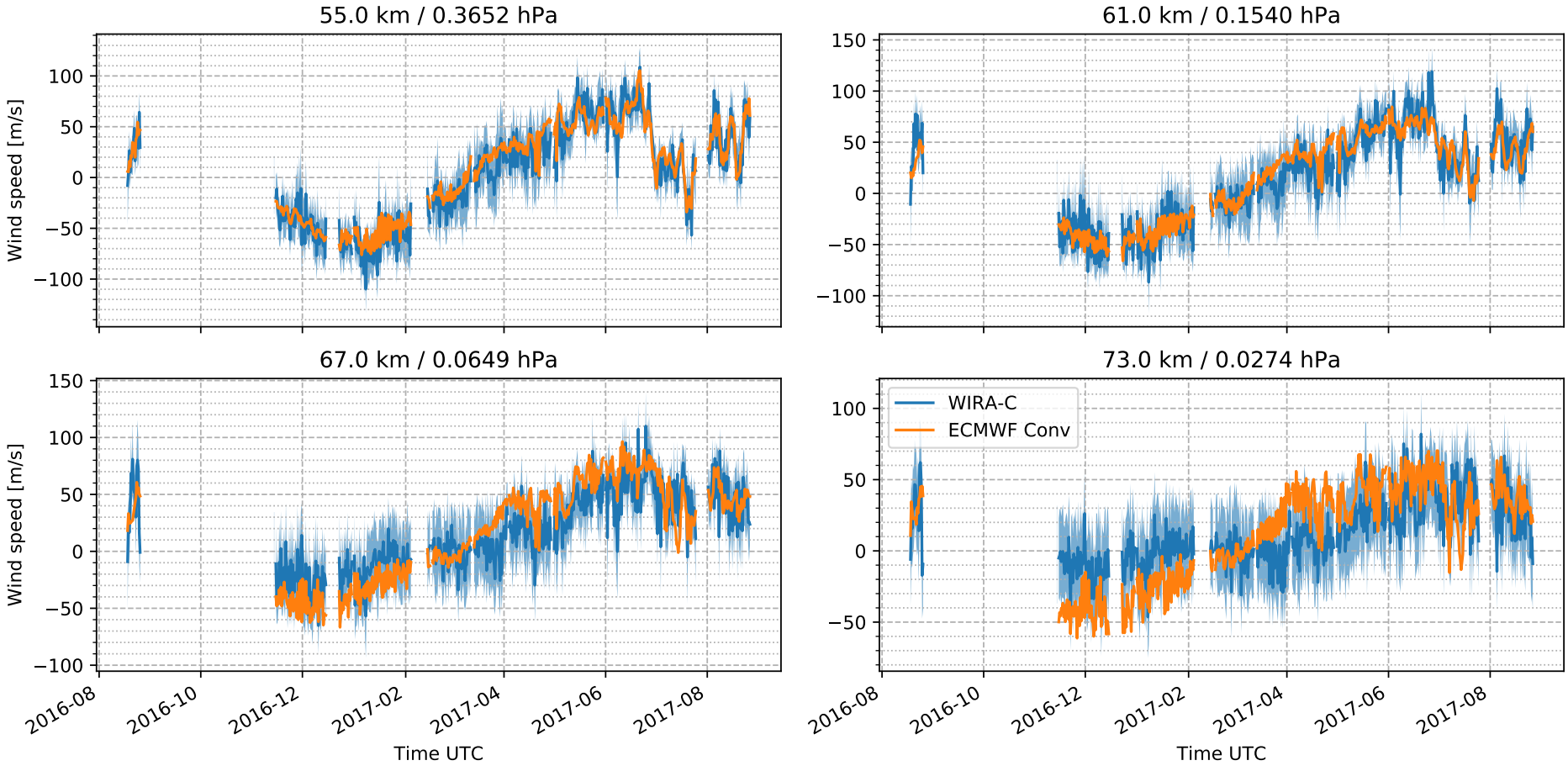
ECMWF comparison

Integration time: 12 h, daylight and nighttime respectively



ECMWF comparison

Integration time: 12 h, daylight and nighttime respectively



Possible outlook concerning ARTS

- Run the retrieval inside ARTS
- Let the retrieval grid coincide with the line-of-sight for ozone retrievals.

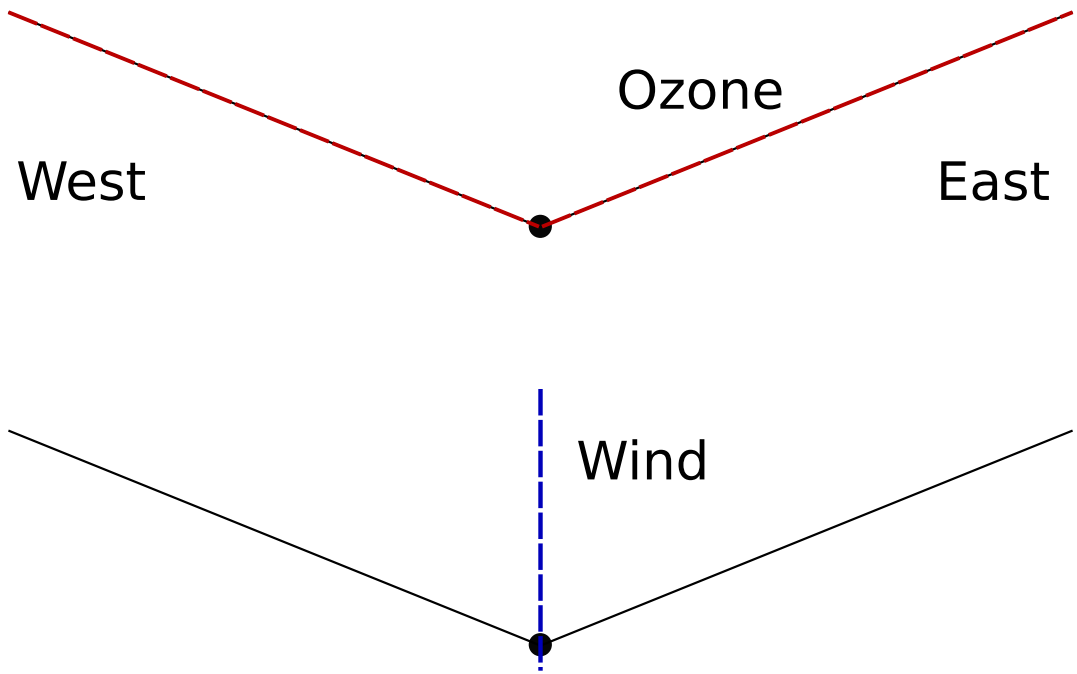


Figure: Red grid is used for Ozone, blue grid is used for wind.

Conclusions

- The 3D setup of ARTS / atmlab is very useful for wind retrievals
- The setup might not be ideal yet

Thanks for your attention!

jonas.hagen@iap.unibe.ch

WIRA-C in action

Looking east

WIRA-C in action

Looking west

WIRA-C in action

Looking at zenith

WIRA-C in action

Internal calibration target

WIRA-C in action

Looking south

WIRA-C in action

Looking north