Interactive comment on "A case study of a low level jet during OPALE" by H. Gallée et al. **Anonymous Referee #1** , Received and published: 12 January 2015

This is an interesting case where the wind at the top of the boundary layer accelerates in response to the cutoff of convective mixing in the boundary layer. It is mentioned in a MAR focused paper by Gallee in the OPALE collection. In that discussion it is noted that such events were frequent during the OAPLE experiment. In such cases with the simplest dynamics, there is an ageostrophic component of the wind that rotates inertially: That was not found here. However, there are other observations and modeling with similar dynamics involved, associated with seabreezes which were found to rotate both clockwise and anticlockwise, counter to expectations. The authors may want to consult Atmos. Chem. Phys., 14, 13471– 13481, 2014 doi:10.5194/acp-14-13471- 2014, Dynamical analysis of sea-breeze hodograph rotation in Sardinia. I am sure there are other examples in the literature. At this point I do not feel that the analysis is complete enough to justify publication as a stand-alone paper in the OPALE collection.

1.1. Dynamics of sea-breeze winds and low level jets (LLJ) are not similar, in particular when one consider the rotation of the winds. Although the Coriolis force plays a central role in the rotation of the wind speed, the rotation occurs in the bulk of the boundary layer of the sea breeze and is observed near the surface. The LLJ simulated in the present paper is supergeostrophic and results from an inertial oscillation occurring above the boundary layer. Another point is that our paper does not compare differences between two observations but differences between the observation and a simulation: anticlockwise rotation is observed while the model simulates an anticlockwise rotation followed by a clockwise rotation.

The study of Andreas, E.L., Claffey, K.J., and Makshtas, A.P. (2000, "Low-level atmospheric jets and inversions over the western Weddel Sea" BLM 97, pp. 459 - 486) is an exemple of a case study observed over the Weddel Sea and a simulation made with a simplified 1D atmospheric model. It is mentioned on p.31092 line 16.

Two alternatives might be considered:

1) Include a figure showing the development of the LLJ from model and observations in the primary paper in this collection, and/or 2) because these are frequent, develop more statistics on their occurrence and behavior and, hopefully, determine if there is a related signature in the surface chemistry (the was some work done as part of the ANTCI program at the South Pole that showed a LLJ and elucidated the mixing processes below the wind maximum and the effect on the vertical profile of NOx.)

1.2. To the authors knowledge this is the first time that a so shallow LLJ is simulated by a 3D meteorological model.

Observation				Simulation			
Date		h (m)	LLJ (m/s)	Date		h (m)	LLJ (m/s)
12 Dec	21h00	18.2	4.33	13 Dec	00h00	08.0	4.34
14 Dec	03h30	18.2	3.26	14 Dec	04h30	10.0	3.80
15 Dec	00h00	25.6	5.40	15 Dec	01h00	10.0	5.44
16 Dec	01h00	18.2	5.59	16 Dec	01h00	08.0	4.83
17 Dec	01h00	18.2	7.56	17 Dec	02h00	14.0	6.52
17 Dec	23 h 30	32.9	8.53	18 Dec	00h30	22.0	8.26
22 Dec	05h30	25.6	6.40	22 Dec	05h30	14.0	4.22
22 Dec	00h30	18.2	1.02	22 Dec	23h30	10.0	3.68
25 Dec	00h00	18.2	6.47	25 Dec	00h00	16.0	6.85
26 Dec	04h30	25.6	7.70	26 Dec	04h30	16.0	5.72
26 Dec	06h00	25.6	6.14				
27 Dec	00h30	18.2	6.59				
28 Dec	02h30	32.9	7.12				
28 Dec	04h00	18.2	6.72				
29 Dec	04h30	25.6	10.6				

Table 1: Observed and simulated LLJs at Dome C during OPALE. h is the height of the LLJ.

It was possible to observe LLJ occurring only at a height below the top of the tower. As LLJs occur where turbulence shuts down this means that in these cases stabilization of the vertical column of air is strong, i.e., when the wind shear is not too large and a strong radiational cooling of the surface occurs.

Observed and simulated LLJs during the OPALE period (12 December 2011 - 14 January 2012) are listed in table 1. They are obtained by searching from below the lowest wind speed maximum below the highest level of the tower. Note that the vertical resolution of the model (2 m) is higher than that of the observations (6 levels, respectively at 3.5 m, 10.8 m, 18.2 m, 25.6 m, 32.9 m and 42.1 m). Consequently the estimation of the height of the LLJ in the observations may be very crude. No LLJ is simulated nor observed in January 2012, but no observations at the tower were made between 1 and 9 January and generally we did not get clear sky conditions in the first half of January 2012 (see e.g. fig. 2a of the companion paper - Gallée et al., 2014). MAR simulated a LLJ on 15 December below the top of the tower while it was very weak in the observation. No LLJ was simulated below the top of the tower on 26, 27 and 28 December, when MAR underestimated cloud cover and consequently overestimated day-time solar warming the day before. This caused an overestimation of turbulence and precluded the formation of a shallow inversion layer during night-time. In short the good simulation of a LLJ by MAR or not in December 2011 was mainly the result of the good behavior of turbulence or not in the model, which itself results mainly from a good behavior or not of the simulated cloud cover. LLJs are more sensitive to turbulence than the winds simulated near the surface. Consequently the evaluation of their behavior may help us in evaluating vertical mixing of chemical species. Of course a longer time serie must be analysed in order to confirm this result. Hereafter we focus on a well marked case study which is accurately simulated, in order to infer in a deeper way how to evaluate the simulation of a LLJ by a 3D model.

Section 3 is divided in two subsections and this discussion is included as the first subsection on p. 31093, line 18. We mention also that statistics of observed LLJs at Dome C are already given in Barral et al. (2014).

1.3. A wind speed maximum near the surface has also been observed at South Pole during ANTCI (Neff et al., 2008). In constrast with the LLJs observed at Dome C it is associated to events of inversion winds. Indeed South Pole is situated on a slope, while Dome C is not. The LLJ at Dome C is related to the PGF extending well above the BL while at South Pole the wind speed maximum is caused by the downslope pressure gradient force (PGF) developing only in the bulk of the inversion winds layer. Another difference is that there is no diurnal cycle at South Pole. Consequently a LLJ could not develop there at the end of day-time, when turbulence shuts down. Possibly a LLJ could develop at South Pole with a rapid stabilization of the atmosphere associated with changes in synoptic scale conditions. A consequence of the absence of a diurnal cycle is that turbulence in the stable boundary layer of South Pole may reach an equilibrium, while this is not the case at Dome C. Note that Neff et al. (2008) mention that the behavior of NO below the wind speed maximum they observe is not fully understood since it could depend (but not always) on an accumulation process of NO over a thin drainage flow which thickness increases gradually before it reaches South Pole. In our case no drainage flow reaches Dome C so that the above-mentioned accumulation process does not exist.

A common point between our simulation and the observations of Neff et al. (2008) is that the wind shear is zero at the jet maximum, so that turbulent transport could not exist through the jet core (gradient Richardson number is “infinite” there). Note however that the LLJ at Dome C forms at a height where turbulence has already shut down, so that the LLJ is not strictly necessary for precluding vertical turbulent transport there. In contrast the wind speed maximum at South Pole is associated to the turbulent inversion winds, and probably plays a more important role in causing the shutdown of turbulence.

Finally the shutdown of turbulence by a wind speed maximum remains an open question. Indeed turbulence bursts have been simulated through a jet core in a LES by Cuxart and Jiménez (2007), but only when the wind and air temperature near the surface are prescribed in their model.

This discussion is included on p. 31092, line 16.

Anonymous Referee #2 , Received and published: 15 January 2015

The paper describes, with the model MAR, the acceleration of the wind (Low Level jet) in the PBL due to the cut-off of the turbulence. The subject is very interesting especially the connection between in the inertial oscillation and turbulence. Nevertheless, the lector would like probably to have more diagnostics and analysis.

In Fig2: the wind speed increases from 5m/s to 7m/s at 25m and above in the observations, it is less in MAR. Some comments ?

2.1. The model also simulates a wind speed maximum which is weaker than the observed one. In fact the night-time wind speed maximum is weaker in the simulation than in the observation at and above the level of the jet core. Possibly horizontal diffusion in the model may be responsible for such a weaker LLJ and the weaker wind speed above.

See more details in the response 2.6.

Could you also explain when the model start the simulation at 00Utc 16th December or at 12UTC ? forecast length ? The initial condition ?

2.2. The simulation is started on 1 November 2011 and the model is not reinitialized until the end of the experiment (end of January 2012). Thus the simulation is sufficiently long to allow the influence of lateral boundary conditions to reach the central part of the domain, in contrast to what happens in a simulation starting from prescribed initial conditions, and lasting of few hours or days only. As lateral boundary conditions are over-specified in a limited area model, they may distort the solution of the model and cause some differences between the simulation and the observation (see also response 2.4 for an exemple of this behavior).

Clarification is included in the section 2 about the model, on p. 31093, after line 16.

A mean (30mn or 1h) vertical profile with the observed value along the mast and the model for theta, U and V at 16LT and 24LT would be interesting.

2.3. Vertical profiles of simulated temperatures, wind speeds and wind directions are compared on (a new) Figure (referred to here as Fig. 1) to the observations made at the tower for 16 h LT and 24 h LT. Temperatures are overestimated during day-time and overestimated above the LLJ during night-time. The overestimation above the LLJ during night-time may be due to an underestimation of turbulence by the E – e model. Similarly momentum mixing seems to be well simulated during day-time but the wind speed is underestimated at midnight above the LLJ, as the temperature. Possibly this is linked to the representation of large scale winds in the model (see Fig. 2 at the end of this note and response 2.4). Wind direction seems to be well simulated.

The new figure (referred to here as Fig. 1) is included at the end of the present note and in the paper. The above-mentioned comment on it is included in the text on p. 31094, line 9.

In general concerning the wind and the geostrophic wind above the mast, is it possible to have some information about the "reality" with sounding data or analysis from ECMWF or NCEP ?

2.4. It appears that the model captures reasonably well the wind vector above the tower, as it can be seen from a comparison with the forcing (ERA-Interim) at 100 and 300 m a.g.l. The error in the wind speed and direction may amount respectively to 1.5 m/sec and 30^o (see Fig. 2 at the end of the note). Note that universal time is used and that the crude time discretisation of ERA forcing (data provided each 6 hours only) influences strongly the time evolution of the simulated wind speed and direction. Indeed MAR data are provided with a time resolution of 10 min but exhibit significant changes only each 6 hours.

This is mentioned on p. 31094, after line 21.

Line 85: The underestimation of the downward LW probably generates too cold surface temperature and then an overestimation of the vertical stability. This case was selected (line 67) because the surface energy balance was much better so the surface temperature is well simulated ? It is possible to prescribe the surface temperature in MAR ?

2.5. I would prefer to say "better" than "well" since a model is not correct by construction. Surface temperature is better simulated when simulated DLW radiation is better simulated. Nevertheless it seems that simulated surface temperature is still underestimated during night-time, as it can be deduced from the underestimation of air temperature near the surface (compare lower and upper panels in Figure 2 of the manuscript). It should be possible to prescribe surface temperature in a future 1D version of the model but not in the 3D version since observations of surface temperature are available at Dome C only. Here the use of the 3D version allows us to fully represent the non-linearity of atmospheric dynamics, including the sinking of air over the Dome caused by the divergence of mass due to downslope winds around the Dome. Such a sinking could be responsible for a thinning of the BL, as it could be inferred from temperature isocontours in Figure 5.

I am interesting to see the vertical profile of the wind budget (up to 100m) of the three contributions at 16LT and 24LT, in particular the advection and the PGF contribution.

2.6. Vertical profiles of advection, PGF, the contribution of turbulence and horizontal diffusion, and their sum at 16 h LT and 24 h LT are shown in (a new) Figure (referred to here as Fig. 3). The last is interpreted as the tendency of the wind speed. These profiles are roughly homogeneous along the vertical during daytime (16 h LT), with PGF counterbalancing roughly the turbulent contribution. A similar equilibrium between PGF and turbulent contribution exists at midnight but their absolute values are reinforced. The contribution of turbulence is zero at the level of the LLJ and just above, where turbulence production by the wind shear is almost zero. Horizontal diffusion contributes negatively (positively) below (above) the height of the jet core. The negative contribution in the bulk of the boundary layer could be related to the weakening of the wind speed on the slope directed towards negative values along the x axis during night-time. The maximum in the wind speed tendency results from the dominant contribution of the PGF just above the boundary layer, i.e., where the contribution of turbulence cancels.

The new figure (referred to here as Fig. 3) is included at the end of the present note and in the paper. A comment on it is included in the text on p. 31095, line 7.

In your plot PGFu is only –dphi/dx ? so it is not really the term used in the budget equation ? It is the same legend for 5a and 5b ? 5a it is PFGu and 5b PGF ? Line 200 Figure 5a ? PGFu is only –dphi/dx as shown in the appendix. 5a it is PFGu and 5b PGF

2.7. PGFu = –dphi/dx is plotted on Figure 5a, while PGF = (u/V) PGFu + (v/V) PGFv is plotted on Figure 5b. Caption of Figure 5a is correct in the discussion paper, but not in the manuscript you received before publication in acpd.

I don't really understand line 195-198

2.8. Inversion winds are generated by the downslope pressure gradient force. The thickness of the layer over which such a circulation occurs is generally no larger than a few tens of meters. Here the pressure gradient force is homogeneous along the vertical up to 2500 m a.g.l.

Clarification is included in the discussion paper on p.31097, line 4.

Fig6: Could you add the tendency of the wind speed ? Could you also comment the change in the advection between 19LT and 23LT ? Is it local ? Is it the same above at 25m ?

2.9. Advection weakens between 18 h LT and 21 h LT and recovers after that time. The weakening of advection occurs mainly below 20 m a.g.l. and decreases progressively upwards. It is found that turbulence is larger to the South of (upstream) Dome C than at Dome C at 14 m a.g.l. (height of the jet core) and at 19 h LT, while this is not the case at 22 h LT. Also at 19 h LT the wind speed is larger upstream Dome C than at Dome C. But at 17 h LT the contribution of turbulence is smaller everywhere at 14 m a.g.l. while the wind speed is already larger upstream Dome C. A possible mechanism upstream Dome C could be a slight reinforcement of the wind speed during day-time by an upslope PGF, leading to a larger wind shear and turbulence there at the end of the day. While the inertial oscillation starts at Dome C due to the shutdown of turbulence, this is not yet the case upstream. Turbulence shuts down there only a few hours later. Consequently the advection of momentum at Dome C could be weaker during a few hours at the end at the day. In short if surface temperature is overestimated by the model the reinforcement of the wind speed and turbulence upstream Dome C during day-time could be overestimated by the model, and could lead to an overestimation of turbulence during a few hours at the end of day-time, a subsequent underestimation of advection at Dome C at the height of the LLJ and an underestimation of its strength.

This discussion is included on p. 31098, line 8. New Figure 6 (referred to here as Fig.4) is added at the end of the present note.

Line 270: The IO disappears at1h30 in the model, and as you said the turbulence is one possibility, advection also ? The turbulence starts with the SW , in the model and in the reality , but may be too active in the beginning or it is not the reason of disappearance of the IO in the model. Do you see also the IO in the observation below 14m and above at 25m ? The wind vector in the model is significantly different to the observed one around 4LT.

2.10. About a possible role of advection, see response 2.9 above. An IO is observed below 14 m and above 25 m but it is not simulated.

This is mentioned on p. 31098, line 6.

Cuxart et al (2006) with the GABLS1 case explain clearly the problem of the overestimation of the turbulence and the LLJ.

2.11. LLJ is not mentioned by Cuxart et al (2006, BLM 118: 273–303). Possibly the reviewer would mention the wind speed maximum observed and sometimes simulated in the frame of this intercomparaison experiment.

The study of Cuxart et al (2006) is mentioned on p. 31098 line 25.

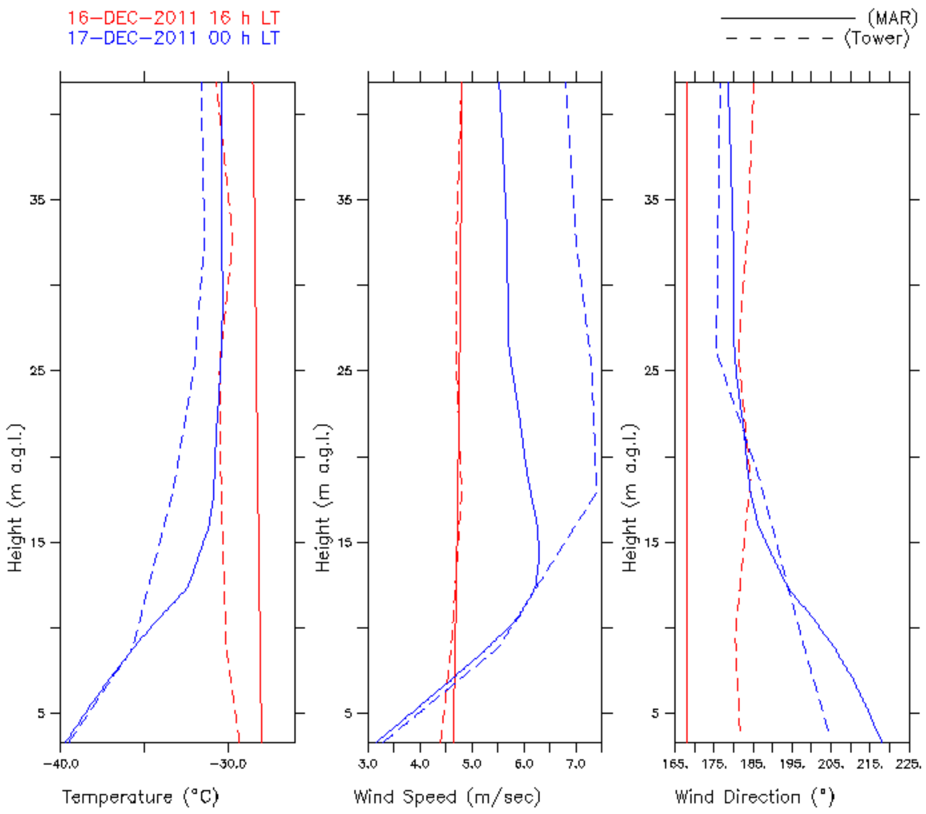
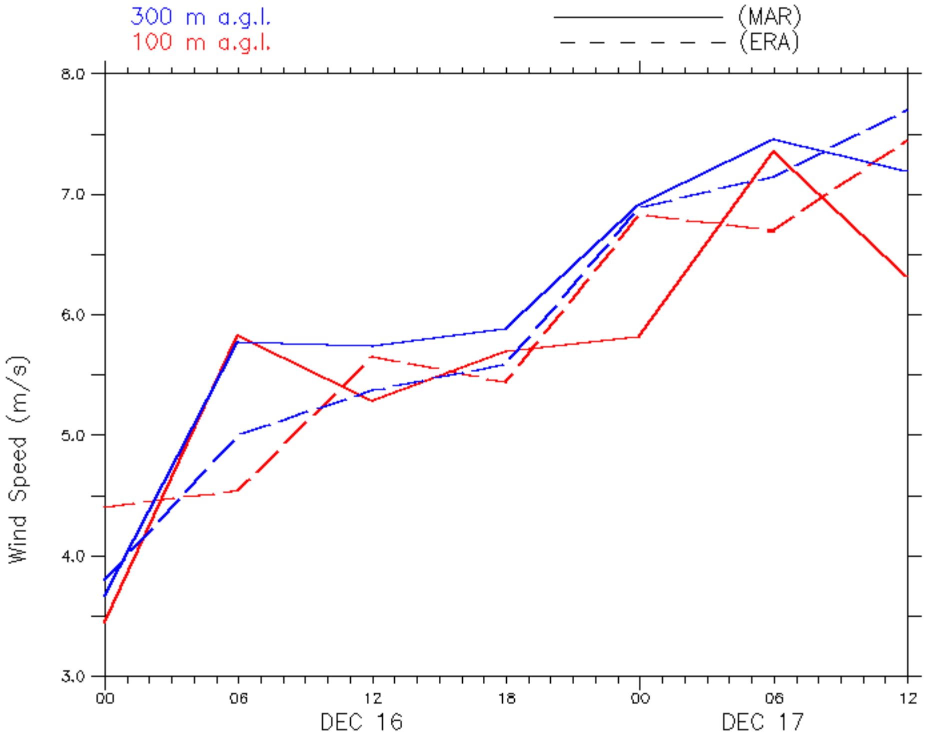


Figure 1: Vertical profiles of simulated temperatures, wind speeds and wind directions on 16 December 2011 at 16 h LT and midnight.



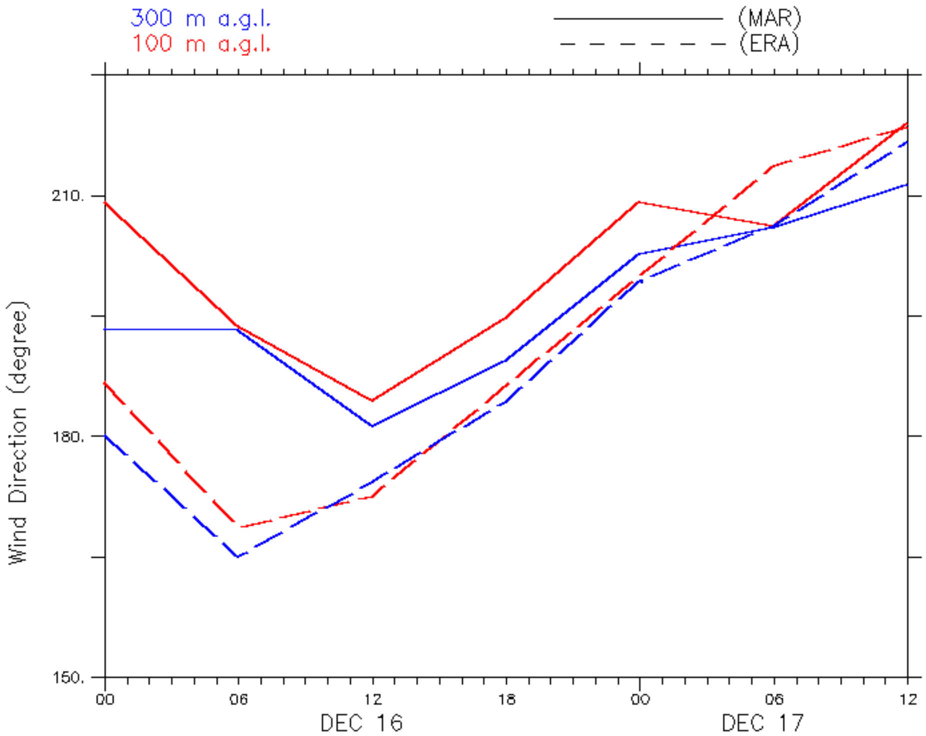


Figure 2: Comparaison beween the analysed wind speed (top) and direction (bottom) and the simulation, at 100 m a.g.l. and 300 m a.g.l. Note that universal time is used.

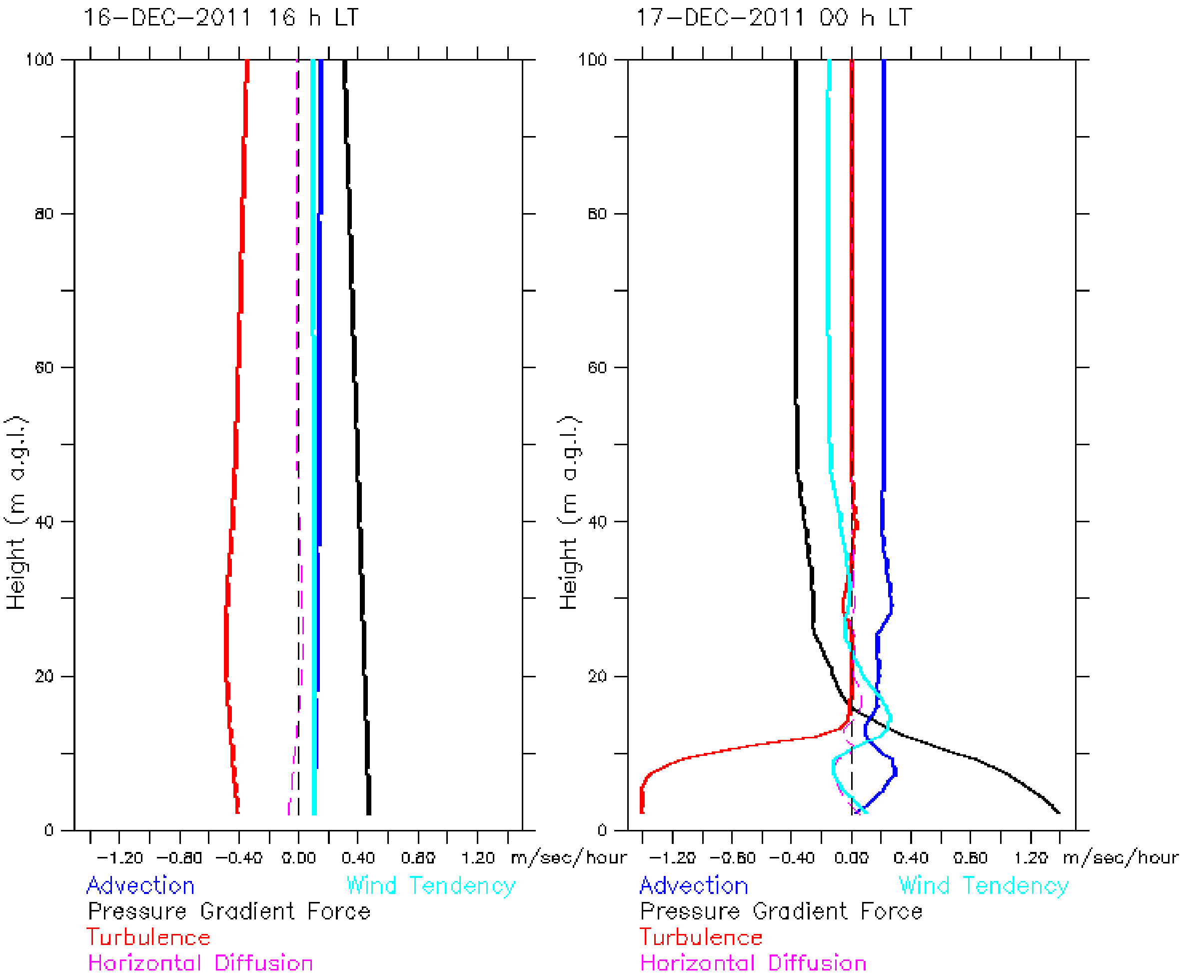


Figure 3: Vertical profiles of the contributions to the wind speed of PGF, advection, turbulence and horizontal diffusion.

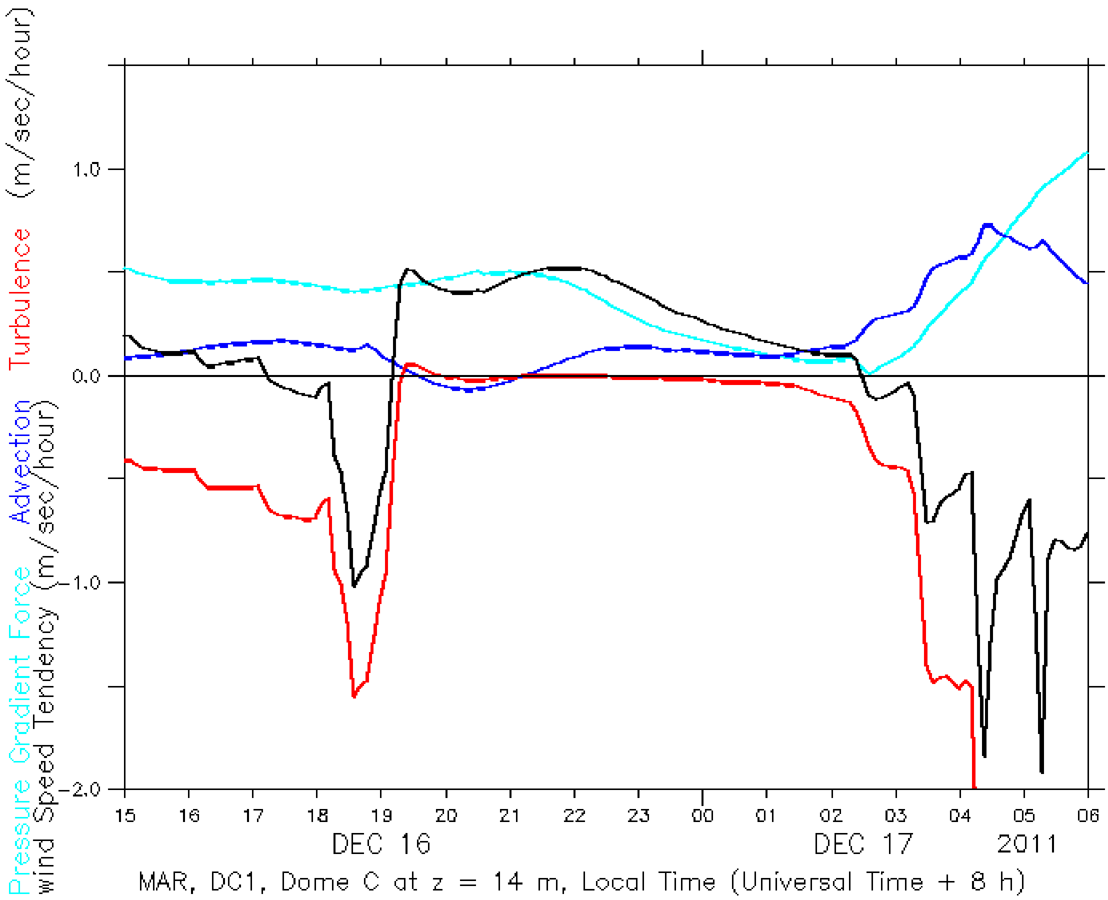


Figure 4: Simulated wind tendency and contribution of the forces to the wind speed, 14 m a.g.l. at Dome C on 16 \textendash{} 17 December 2011. Local Time LT (Universal Time UT + 8 h) is used. The shutdown of turbulence occurs at 19h LT.