5.4 TESTING OF LOCAL TURBULENCE CLOSURES IN MESOSCALE MODEL TO BE APPLIED IN THE SAGA DECISION SUPPORT SYSTEM

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SUMMARY

The mesoscale meteorological model ARPS (Advanced Regional Prediction System, Xue et al, 2001) is being used at the As Pontes coal-fired power plant (over the Galicia region, a coastal and complex terrain domain located in the northwestern of the Iberian Peninsula) as part of an air quality decision support system (namely, SAGA). This model is nested to the NCEP GFS operational weather forecast at different resolutions in order to provide inputs of winds, temperature and stability profiles, mixings depths and other turbulence parameters that are required for different Lagrangian dispersion models (both puff and particle models) to simulate the plume transport. One of the main critical points in order to obtain accurate results from this system is to obtain a good representation of the vertical structure of the planetary boundary layer, as the main pollutants plume is dispersed on it.

In this work, an evaluation of results obtained using two types of local turbulence closures, over the As Pontes power plant environment, is presented. Results from the mesoscale model are compared to rawinsonde measurements in the boundary layer, over selected test cases corresponding to the most typical synoptic conditions in the area.

1. INTRODUCTION

Since 1994, operational air pollution forecast is routinely applied at the As Pontes coal-fired power plant, with a 350-m stack, in order to prevent local fumigation episodes. Over the last ten years, several improvements in the software and numerical models were done, to obtain more accurate air pollution forecasts on a daily basis.

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Currently, a decision support system for air quality management (namely, SAGA) provide meteorological and air quality forecasts to the As Pontes power plant staff, in order to schedule the operation of this process one-day before, depending on the risk of fumigation.

The meteorological model ARPS is a critical piece in SAGA, as it provide the boundary layer parameters that allow to obtain an accurate meteorological and air quality forecast, applied to the decision support. As ARPS model is not only focused in the boundary layer, all its different parameterizations must be tested against PBL measurements. In this case, different closure schemes can have a significant effect in the boundary layer parameters and, in particular, in the PBL vertical structure.

Local closure schemes (Stull, 1991), as the approaches included in the ARPS model, are easier and faster for being applied in a mesoscale model than non-local closure schemes. However, the last one usually provide better results on the PBL, specially over complex terrain.

In this work, two closure schemes including four different parameterizations have been evaluated, by comparison to the most significant PBL mean parameters in air pollution dispersion.

2. MODEL AND LOCAL CLOSURE SCHEMES

The Advanced Regional Prediction System (ARPS) is a well-known comprehensive regional to stormscale atmospheric modeling / prediction system developed at the Center for Analysis and Prediction of Storms (CAPS) at the University of Oklahoma (Xue et al., 2000; Xue et al., 2001).

ARPS has been undergoing real-time prediction tests at the synoptic level through storm scales in the past several years over the continental United States as well as in part of Asia. During the last five years, ARPS has also applied as an operational numerical weather prediction model for regional weather forecast in Galicia (NW of the Iberian Peninsula) (Balseiro et al., 2001), nested to the NCEP-GFS weather forecast with a two grids nesting (50 km and 10 km). In addition, a 2 km resolution grid is applied to local high resolution plume dispersion estimation.

The first one is the local closure scheme developed by Smagorinsky (1963) and Lilly (1962) (namely, O1), based on a first-order closure method. The second one is a 1.5-order closure scheme that predicts turbulent kinetic energy (1.5-TKE), tested with three different parameterizations: Moeng & Wyngaard (1986) (namely, T4TK1), Deardorff (1980) (namely, T4TK2), and Sun & Chang (1986) (namely, T4).

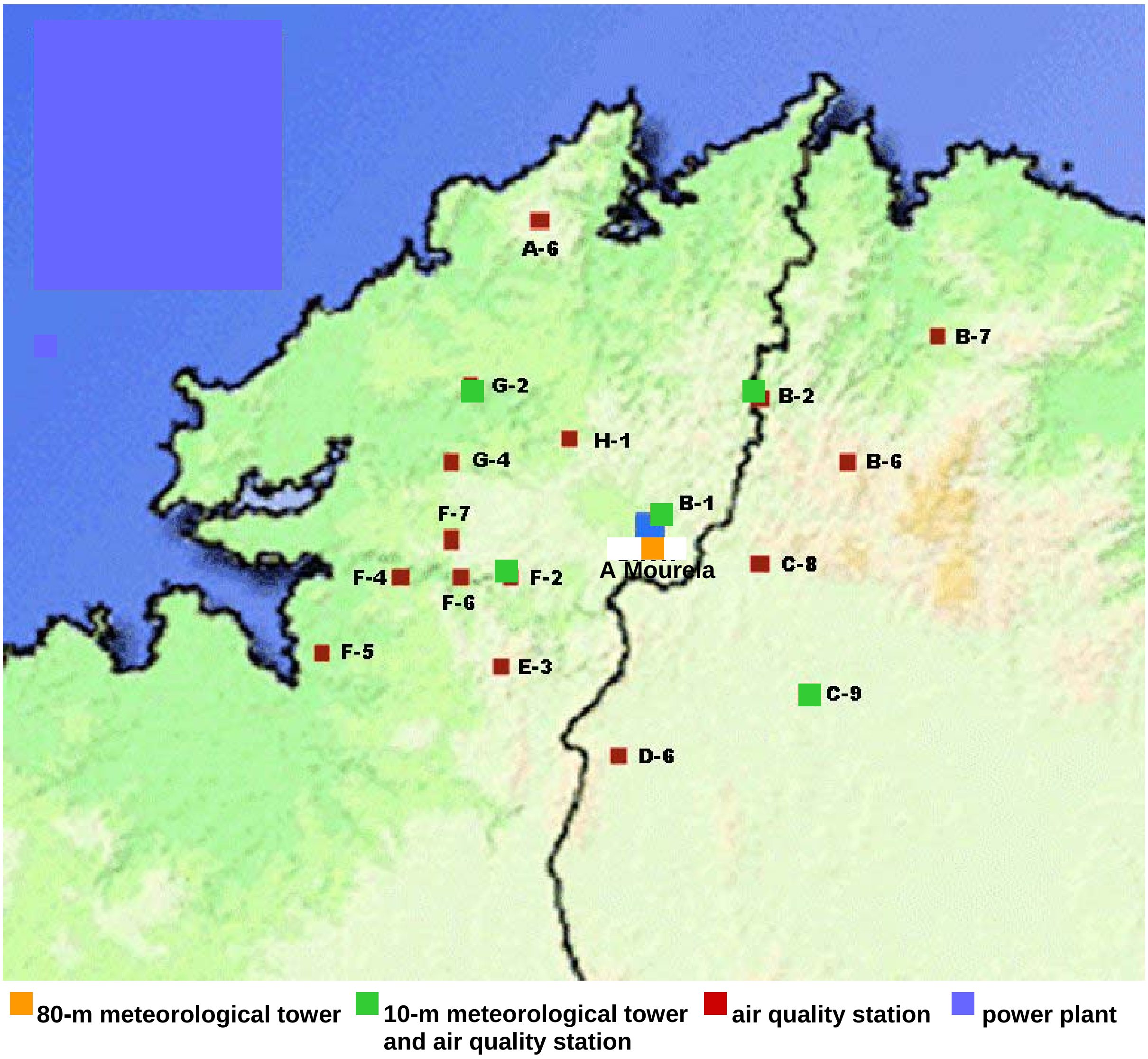


Figure 1. Air quality network over the domain around the As Pontes Power Plant, with the 6 meteorological towers available.

3. TEST CASES

The main goal for testing the ARPS model was to select the best parameterizations for its application in the forecast of PBL vertical structure around As Pontes power plant. Therefore, a careful selection of days, with specific synoptic conditions that represent the usual local meteorological conditions, was done.

Climate experience in the region and year 2003 meteorological and air quality data was considered for this analysis. Three typical conditions were considered,

- Changeable weather, typical in spring; March is a representative month of this condition.
- High pressure with moderate to strong winds from the ENE in summer; it is typical in June-July.
- Low pressure with Atlantic fronts and SW winds in winter, as in November.

A summary of the synoptic conditions in these months along 2003 is included on table 1.

In addition, in order to evaluate the ARPS model in different air pollution dispersion conditions, attending both episodic meteorological conditions and ground level concentrations measurements of SO_2 (as the main pollutant emitted by the power plant), some specific dates was selected, as it is shown on table 2.

March 2003
• SW circulation, from 1st to 5th. • Blocking by high pressure over Atlantic, from 6th to 22nd. • Changeable weather, from 24th to 31st.
June 2003
• Wet weather, from 1st to 4th. • High pressure, convection, from 5th to 25th. • Low pressure, from 25th to 30th.
July 2003
• Typical high pressure summer conditions. • Some fronts, 14th-15th, 24th-25th.
November 2003
• West circulation, with several fronts. • High pressure on 6th, 7th and 17th to 20th.

Table 1. Typical synoptic conditions along different months in the region.

Date	Weather	Air quality
March, 19th	High pressure Moderate ENE winds	SO_2 detected over SW downwind
July, 7th	High pressure. Low ENE winds	None of SO_2 detected
November, 29th	Active front. Strong SW winds	None of SO_2 detected

Table 2. Selected dates along year 2003 for testing. Both meteorological and air quality conditions were considered.

With these selection, the main synoptic conditions in the region are represented. In addition, different local air quality episodes (due to the power plant emissions) are considered.

4. RESULTS

The performance of a mesoscale meteorological model for its application to local air pollution dispersion depends mainly on a good description of the PBL vertical structure. However, in order to assure that the model represent properly along the testing dates the main meteorological conditions, a comparison of both estimated and measured surface meteorological parameters was done.

4.1. *Surface measurements*

Measurements from 6 meteorological towers 30 km around the power plant (figure 1) was compared to the model estimations. Results using the 1.5 TKE closure schemes with ARPS, compared to surface measurements of three different stations (A Mourela, F2 and C9) are shown on figures 2, 3 and 4, as the other closure schemes provide similar results. Wind direction will be compared with rawinsonde data.

For the three days, there is a good agreement between estimated and measured surface temperatures (2-m), although a softer daily cycle in ARPS results. Usually, maximum temperatures are underestimated by the model. However, surface wind speed (10-m) is usually overestimated by the model (sometimes, in twice). As it will be shown later, this tense will change when wind profiles are compared.

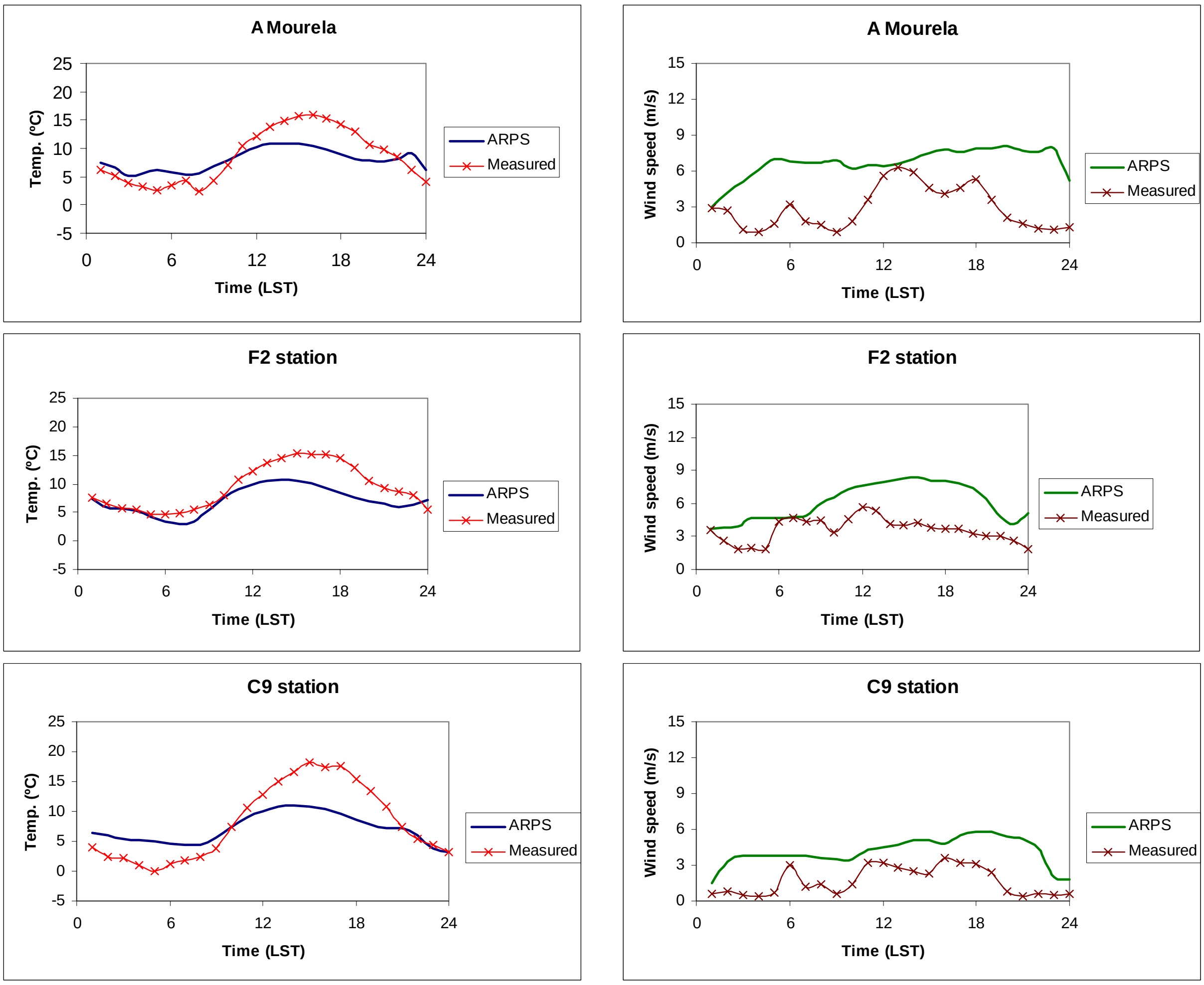


Figure 2. Estimated vs. measured hourly surface wind (10-m) and surface temperature (2-m) along March, 19th 2003.

4.2. *Vertical profiles*

As the main meteorological parameters applied in the Lagrangian dispersion models, estimated wind and temperature profiles should achieve a good representation of the PBL vertical structure, in order to obtain an accurate air pollution dispersion estimation. Other meteorological parameters related to pollutants dispersion can be derived from these basic profiles.

For this test, measured profiles were obtained from,

(a) wind and temperature measurements at the 80-m height of a meteorological tower located in the A Mourela station (see figure 1).

(b) a rawinsonde launched twice-a-day (at 12Z and 24Z) from 40-km on the west of the domain centre (at A Coruña city). In this case, wind and temperature observations up to 1500-m are used.

These measurements were compared to the estimations of the ARPS model obtained by using the four closure approaches mentioned before, for the three days of testing.

About the comparison of wind and temperature at 80-m height (figure 5), results are similar for the different closures applied, so the comparison for the results using the first-order scheme are shown In general, as in surface measurements, temperature estimations are in agreement to measurements (with a general underestimation), although on March, 19th the daily temperature is strongly underestimated.

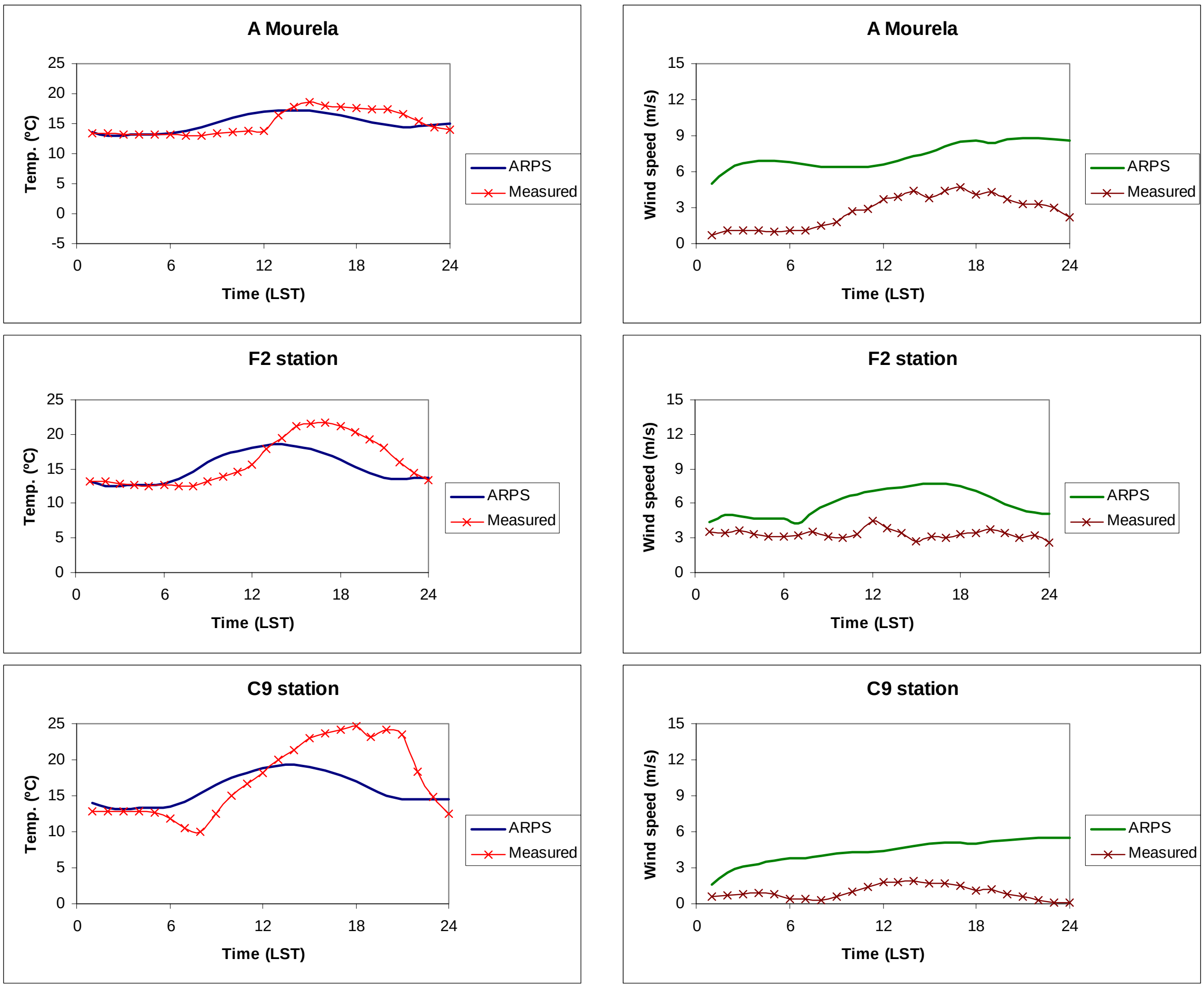


Figure 3. Estimated vs. measured hourly surface wind (10-m) and surface temperature (2-m) along July, 7th 2003.

The underestimation on March, 19th is coherent to the bad 80-m wind speed estimation along the same day (figure 5a). As the mesoscale modelling system estimates stronger ENE winds (especially at nightime), it estimates that cold winter air masses from the European Centre comes faster than real one.

Wind speed along the other two days (figure 5b and c) is again overestimated by the model, as in the surface measurements.

From these results, it seems that an accurate or slightly overestimation of wind speed is necessary for an accurate temperature estimation, because of the strong synoptic influence in the temperature values.

Figure 6 shown the temperature profiles estimated by the tested 1.5 TKE parameterizations, compared to measurements from the 12Z and 24Z A Coruña rawinsondes. As results from the three parameterizations are equal, only results with T4 parameterization are shown.

Temperature profiles on March, 19th and November, 29th are quite similar to measurements, except on the night of November. However, in this case a difference of around 2 ºC keeps along the profile, so the estimated lapse rate is in a good agreement. Especially significant are the nocturnal thermal inversions estimated and observed on these two days: A higher inversion on March, 19th, and a lower surface inversion on November, 29th. Both of them (with some differences) are quite good represented by the model.

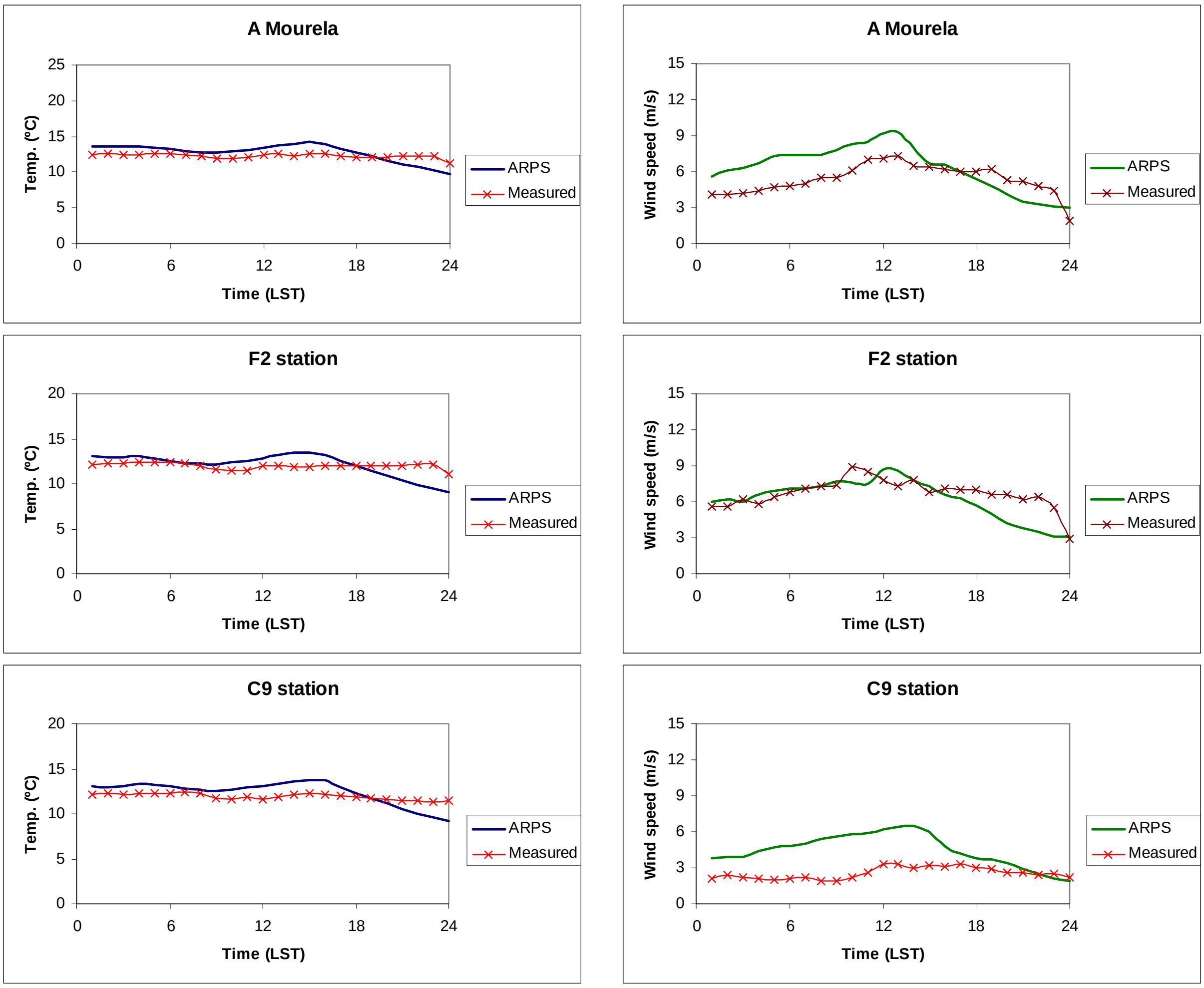


Figure 4. Estimated vs. measured hourly surface wind (10-m) and surface temperature (2-m) along November, 29th 2003.

Different results are obtained on July, 7th. In this case, both diurnal and nocturnal temperature profiles includes strong thermal inversions below 1500-m. The model cannot represent this profiles, especially at night, so it estimates a different inversions both in lapse rate and height. In this case, the strong solar radiation and soft warm ENE winds are favourable to convective mixing conditions andthat local closure schemes are not able to estimate correctly.

Comparison of estimated wind speed profiles (figure 7) show wore results than in temperature profiles. None of the local closure schemes tested can represent the real profile shapes. Although differences from the external weather forecast (NCEP-GFS) are clear (because of the difference in the 1500-m level), local ARPS cannot represent the complex wind profiles on March, 19th and July, 7th and, even, the simpler on November, 29th (which approximate to a logarithmic wind profile).

Although wind profiles from any of the local closure schemes seems not to be appropriate for their application to plume dispersion, T4 scheme seems to obtain wind profiles a little better than the other two, as it can be observed on March, 19th and July, 7th at 12Z.

In addition, estimated wind speed at 1500-m is usually lower than measured (except on November, 29th at 12Z). Therefore, the overestimated surface wind (figures 2 to 5) change to a wind underestimation in height. As the plume transport is mainly conditioned by the wind in height, surface winds are not a good reference for this mesoscale model comparison.

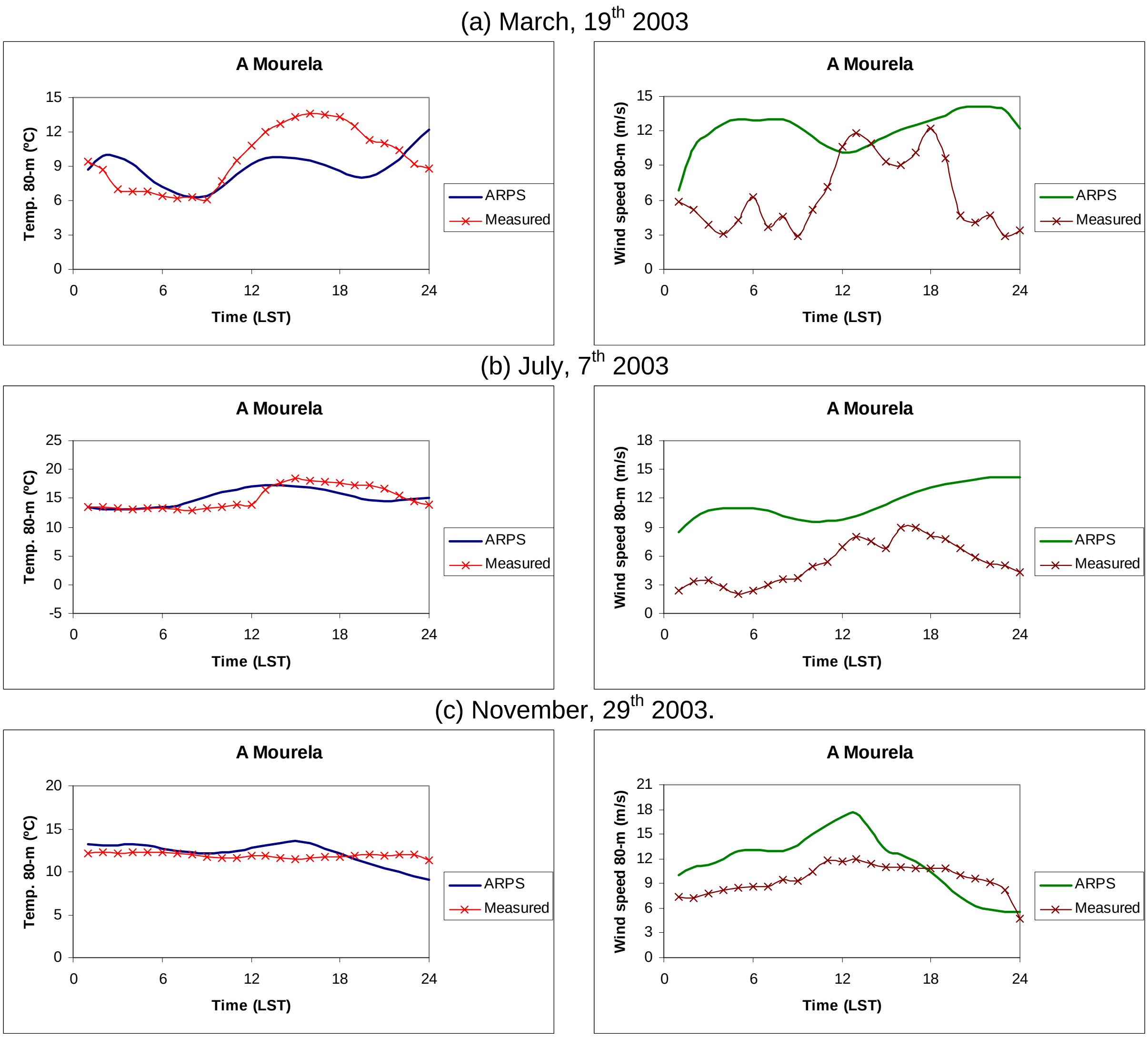


Figure 5. Comparison of estimated hourly temperature and wind speed at 80-m height in the A Mourela station along (a) March, 19th (b) July, 7th, and (c) November, 29th.

For all of the local closure schemes tested, estimated wind direction (figure 8) shows differences similar to wind speed, but no correlation is between both differences. In fact, strong wind speed differences on November, 29th at 12Z corresponds to an accurate estimation of wind direction from 0 to 1500-m. Again, the modelling system cannot represent properly the wind profiles and, for these cases, it is not appropriate to be applied to plume dispersion estimation.

Finally, T4 scheme (as the one that produce better wind speed results) is compared to a classical first order approach (namely, O1), in order to evaluate the advantage of using a more complex 1.5 TKE scheme.

Figure 9 shows estimated and measured temperature profiles on March, 19th and July, 7th. Both closure schemes results are similar, with good results on March, 19th and bad one on July, 7th. In this case, the strong influence of the external conditions produce similar results with both schemes, so O1 can be applied too.

Figure 10 compares wind speed profiles for the same days. It can be observed that O1 wind speed is usually lower than T4 results, especially when the model overestimates the maximum wind speed. However, at 1500-m the strong differences between measurements and model results remain. About wind direction (figure 11), both closure schemes results present strong differences with measurements in two cases (March, 19th at 12Z and July, 7th at 24Z). In fact, none of the model results are good enough to be applied with a plume dispersion modelling.

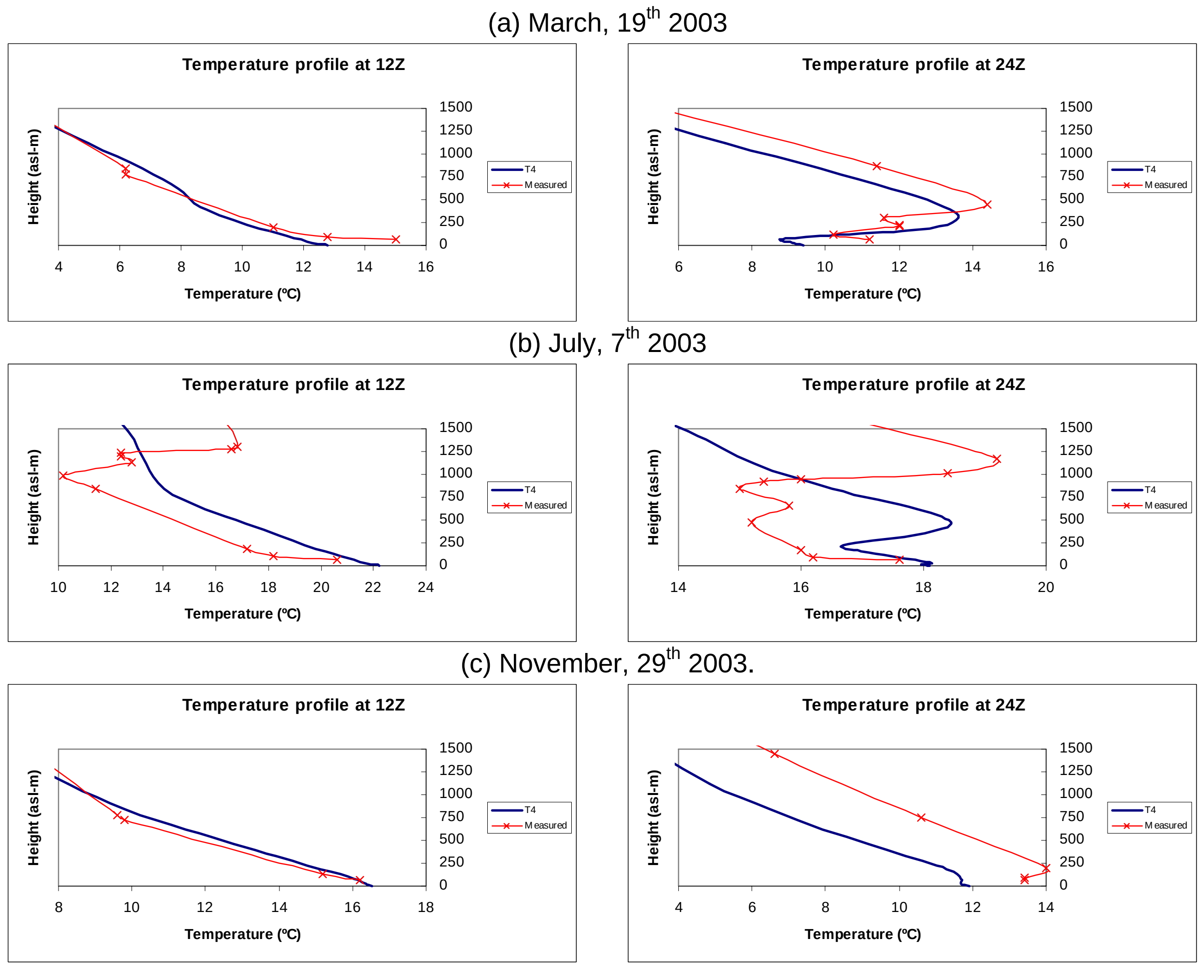
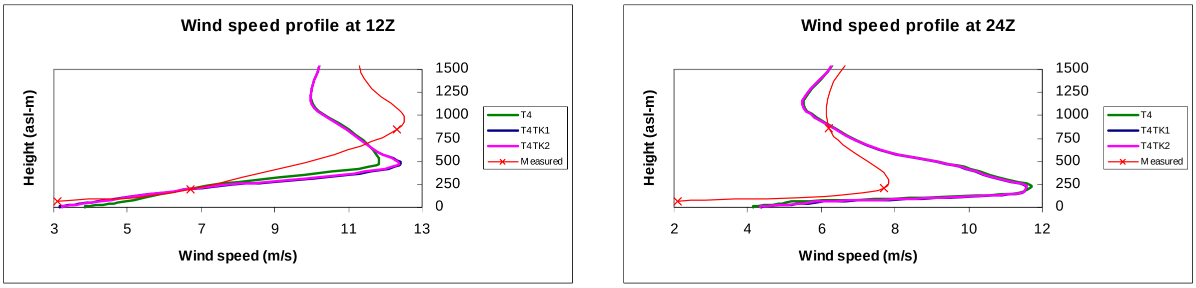


Figure 6. Testing of temperature profiles with different 1.5 TKE parameterizations: T4 (Sun and Chang, 1986), T4TK1 (Moeng and Wyngaard, 1986), and T4TK2 (Deardorff, 1980). Estimated (all parameterizations) vs. measured temperature profiles on the PBL are compared at 12Z and 24Z on (a) March, 19th (b) July, 7th, and (c) November, 29th. Temperature profiles for the T4TK1 and T4TK2 are equals to T4 profile.

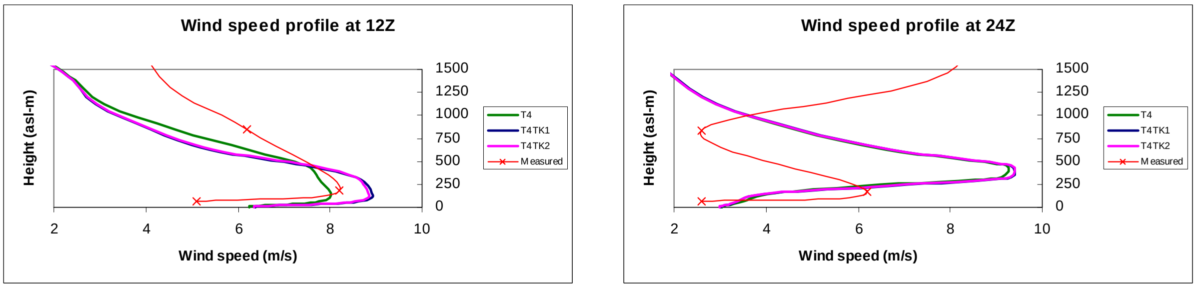
From the comparison of the application of four local closure schemes in ARPS (T4, T4TK1, T4TK2, and O1) to the estimation of PBL wind and temperature profiles, in order to be applied to the plume dispersion estimation, it is clear the high dependence of the model application of the external weather forecast (NCEP-GFS). Therefore, any improvement in this application should consider both the use of other external weather forecasts and the improvement of nesting with more grids and more resolution. In this last case, the use of the well-known 1:3 ratio in grids nesting is recommended.

With these improvements, a mesoscale high resolution model (like ARPS) could be applied in a local environment in order to obtain accurate estimations of turbulence parameters that can be applied in the plume rise and plume growth estimation. However, mean variables, as wind and temperature, depend mainly on the external weather forecast, so even the use of a hydrostatic model (like PMETEO, ref.) can provide the same results.

(a) March, 19th 2003



(b) July, 7th 2003



(c) November, 29th 2003.

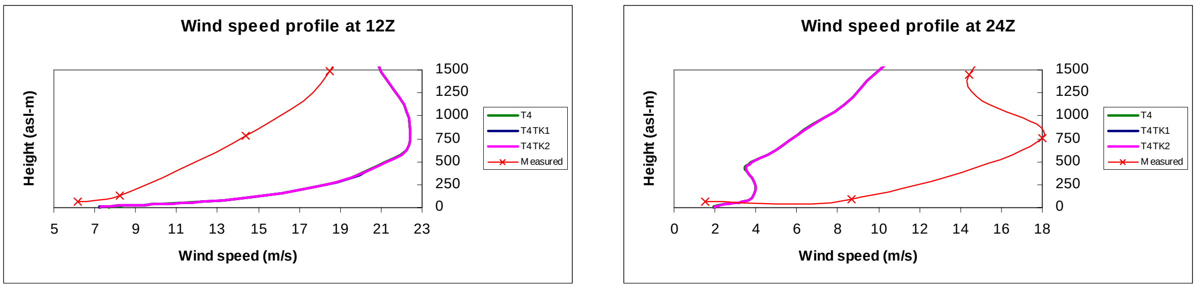


Figure 7. Testing of wind profiles (speed) with different 1.5 TKE parameterizations: T4 (Sun and Chang, 1986), T4TK1 (Moeng and Wyngaard, 1986), and T4TK2 (Deardorff, 1980). Estimated vs. measured wind speed profiles on the PBL are compared at 12Z and 24Z on (a) March, 19th (b) July, 7th, and (c) November, 29th.

5. CONCLUSIONS

In this work, the use of ARPS model in a high resolution mesoscale modelling system, nested to the NCEP-GFS weather forecast, for the application to local plume dispersion is tested.

Four different local closure schemes (three .5-TKE and a first order approach) were tested by comparison of wind and temperature surface and height measurements, as the main mean variables that affect to the plume dispersion.

Models results are quite good for temperature profiles but, unfortunately, the performance of wind profiles (both in speed and direction) is bad. Although T4 (Sun and Chang, 1986) and first order (Smagorinsky, 1963, and Lilly, 1962) approaches seems to provide better results, the use of the different closure schemes did not improve significantly this results.

The influence of the external weather forecast applied is clear in these results, so any improvement in the application of a high resolution mesoscale model for plume dispersion estimation should consider both the use of other external weather forecasts and the improvement of nesting with more grids and more resolution. However, the use of different closure schemes can have a significant influence in the estimation of turbulence parameters, that can be use in the estimation of the plume rise and plume growth.

From these conclusions, two lines of work is be developing in order to obtain an improved high resolution mesoscale meteorological modelling,

a) Testing of the influence of external weather conditions, both using ECMWF reanalysis and other external weather forecasts, as ECMWF deterministic forecasts.

b) Testing other non-local closure schemes implemented in other mesoscale model, MM5, using a more complex nesting (27:9:3:1) with one more grid and more resolution.

ACKNOWLEDGEMENTS

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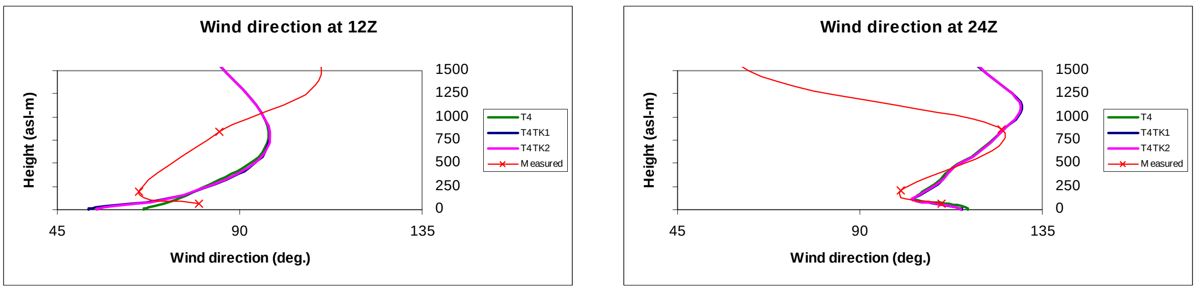
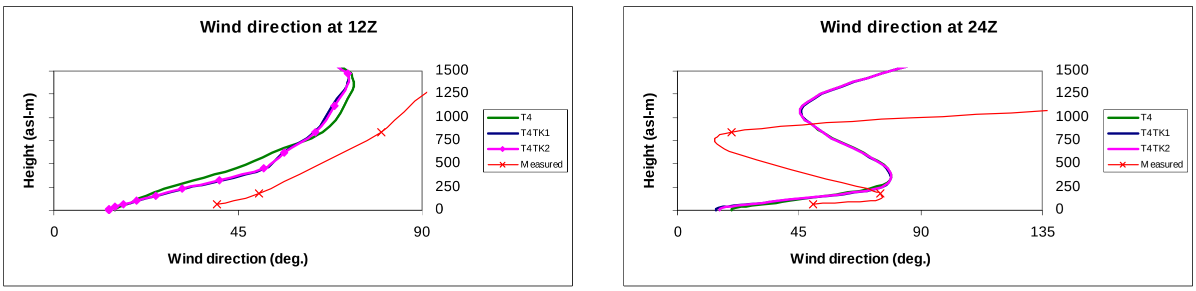
(a) March, 19th 2003



(b) July, 7th 2003



(c) November, 29th 2003.

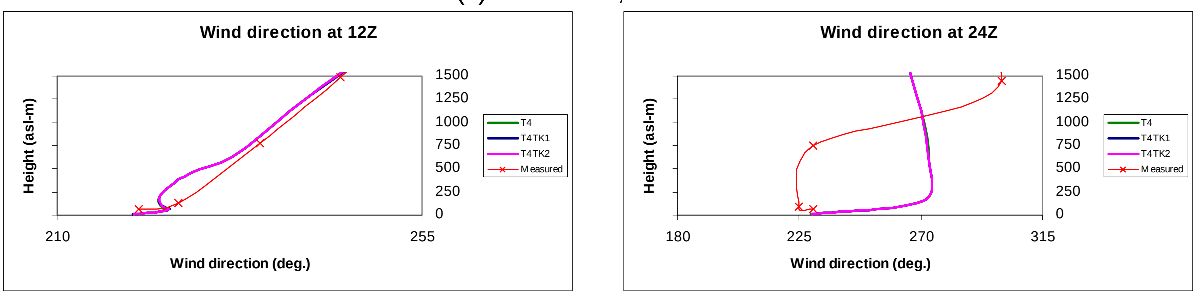
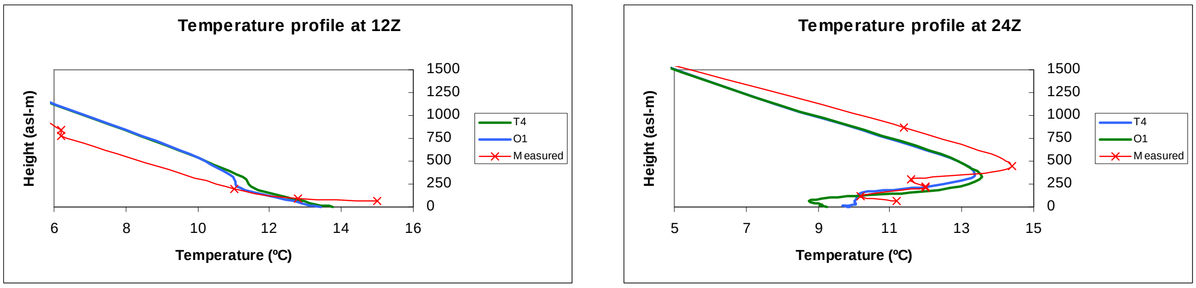


Figure 8. Testing of wind profiles (direction) with different 1.5 TKE parameterizations: T4 (Sun and Chang, 1986), T4TK1 (Moeng and Wyngaard, 1986), and T4TK2 (Deardorff, 1980). Estimated vs. measured wind direction profiles on the PBL are compared at 12Z and 24Z on (a) March, 19th (b) July, 7th, and (c) November, 29th.

(a) March, 19th 2003



(b) July, 7th 2003

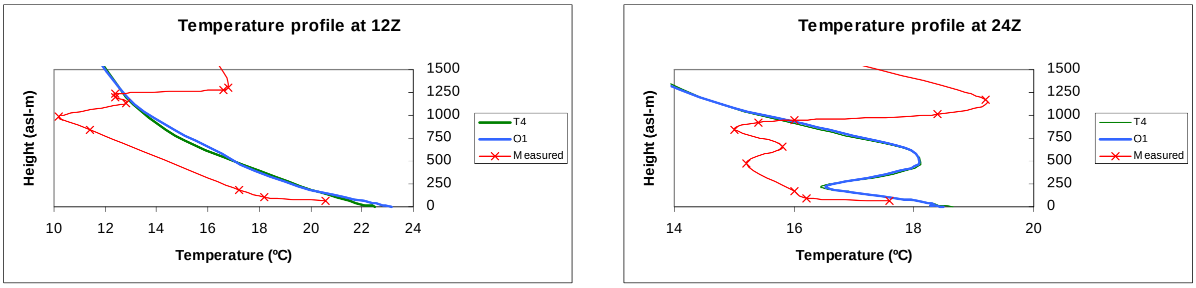
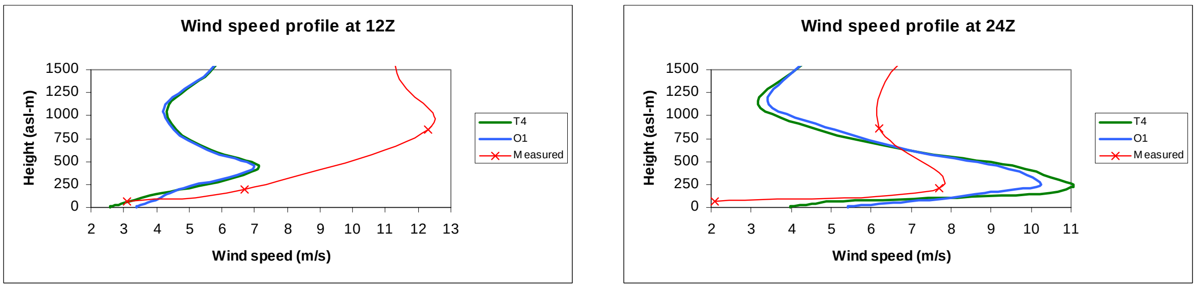


Figure 9. Testing of temperature profiles with different local closures: T4 (Sun and Chang, 1986) and O1 (first order). Estimated vs. measured temperature profiles on the PBL are compared at 12Z and 24Z on (a) March, 19th and (b) July, 7th.

(a) March, 19th 2003



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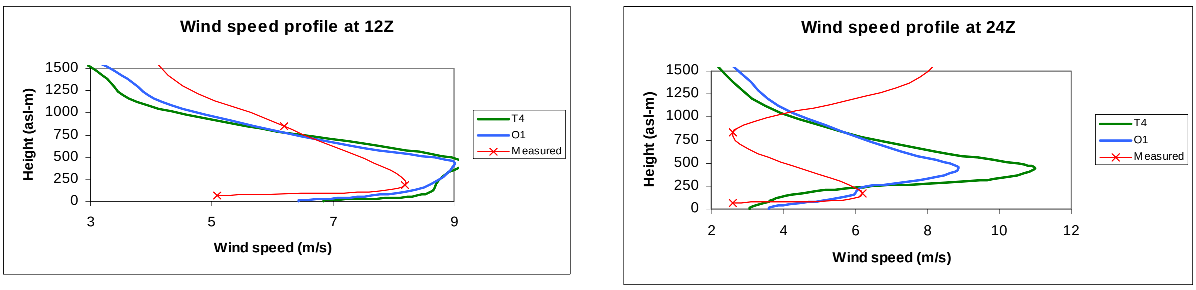
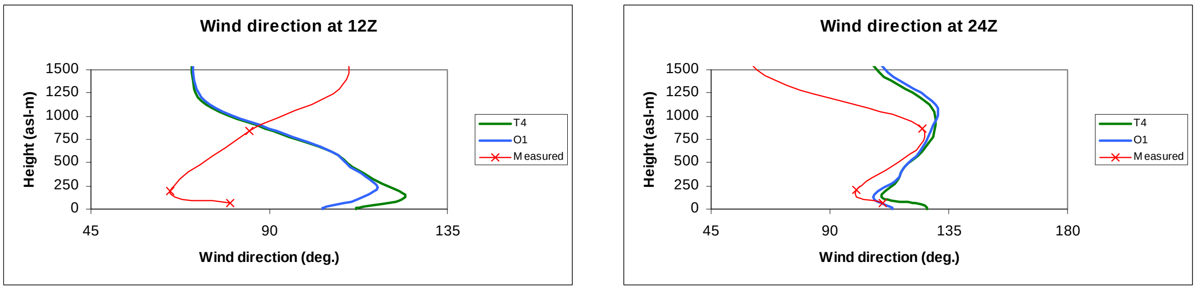


Figure 10. Testing of wind profiles (speed) with different local closures: T4 (Sun and Chang, 1986) and O1 (first order; Smagorinsky, 1963 and Lilly, 1962). Estimated vs. measured temperature profiles on the PBL are compared at 12Z and 24Z on (a) March, 19th and (b) July, 7th.

(a) March, 19th 2003



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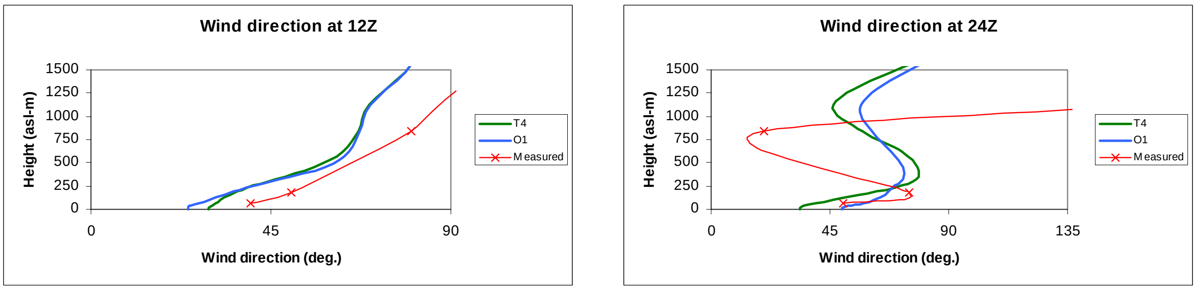

Figure 11. Testing of wind profiles (direction) with different local closures: T4 (Sun and Chang, 1986) and O1 (first order; Smagorinsky, 1963 and Lilly, 1962). Estimated vs. measured temperature profiles on the PBL are compared at 12Z and 24Z on (a) March, 19th and (b) July, 7th.

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