TKE budget analysis of a single long-lived winter bora flow

Nevio Babić[1], Željko Večenaj[1], Kristian Horvath[2], Branko Grisogono[1]
[1]Geophysical Institute Andrija Mohorovičić, Horvatovac 95, Zagreb, Croatia ; [2]Meteorological and Hydrological Service, Grič 3, Zagreb, Croatia

nebabic@gfz.hr, zvecenaj@gfz.hr, kristian.horvath@cirus.dhz.hr, bgrisog@gfz.hr

GOALS

- temporal and spatial variability of turbulent kinetic energy (*TKE)* gives insight into the nature of turbulence at a certain location of interest
- this case study concentrates on evaluating various terms in the simplified 1D *TKE* budget equation of a single bora event (downslope windstorm, east Adriatic coast)
- finally, calculation and exploration of these terms, especially their contribution to either local production or destruction of *TKE*, will decide how well are those simplifications justifiable for this particular event and location

DATA

- site of Pometeno Brdo (600 m ASL) on the eastern mid Adriatic coast (*Fig.1.)*
- WindMaster Pro ultrasonic anemometers (5 Hz sampling rate) → three wind components and sonic temperature @ {10,20,40} m AGL

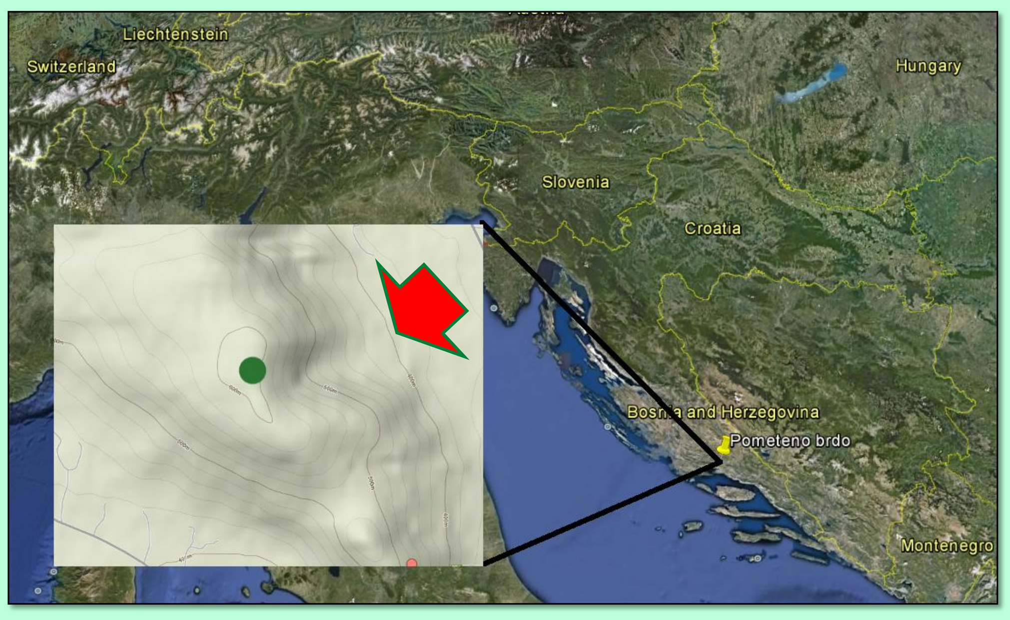

Fig.1. Site of Pometeno brdo: zoomed picture shows terrain and orientation of the hill relative to the mean bora direction (red arrow). Green circle denotes the position of the tower with anemometers.

BORA CRITERIA

- total horizontal speed ≥ 4.5 ms^{-1}
- wind direction ϵ [25°, 85°]
- duration ≥ 10 h
- longest event (123h) took place in Feb 2011 (*Fig.2.)*

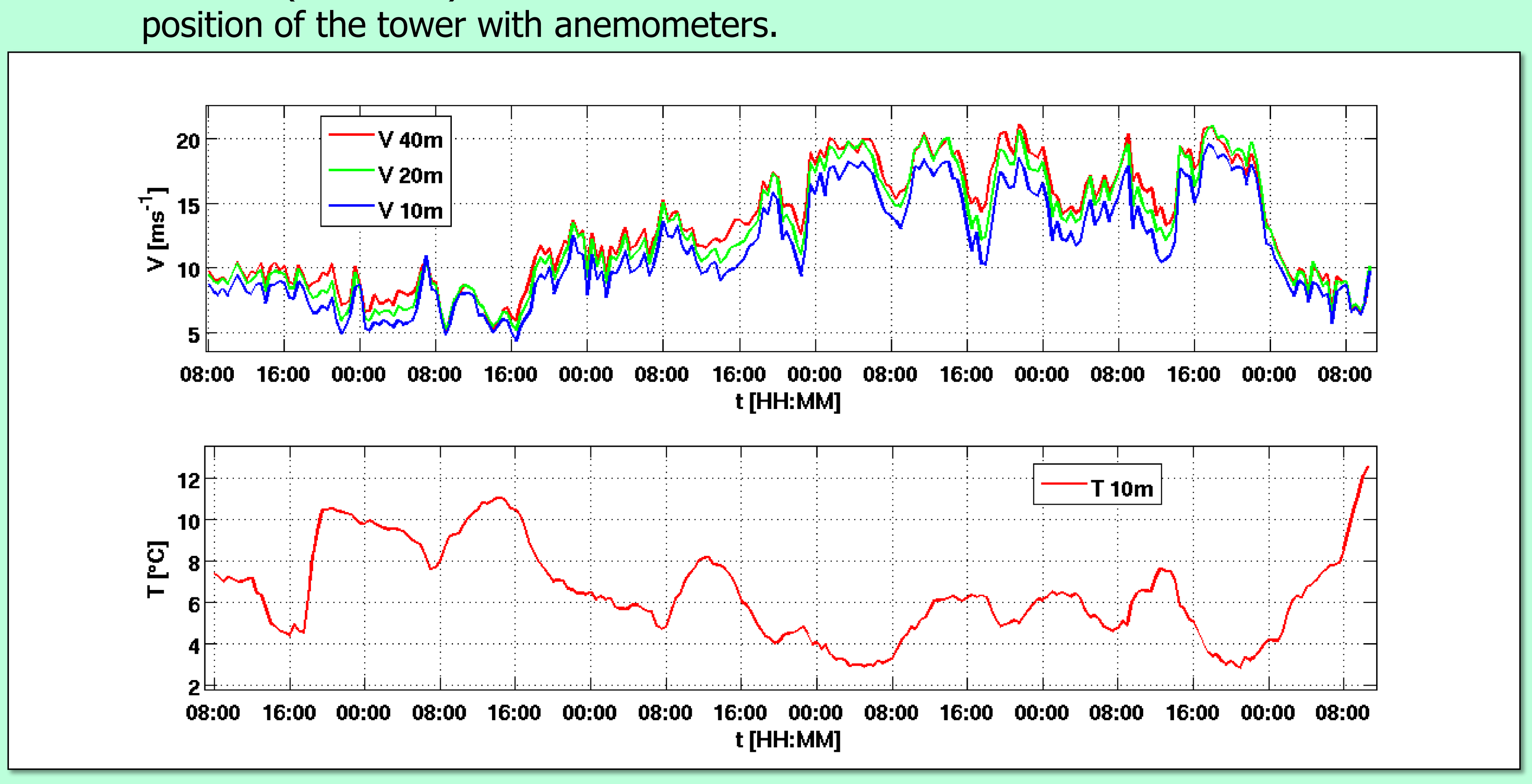

Fig.2. Total horizontal wind speed (all heights) and sonic temperature @ 10 m (30-min averages) for the longest registered bora event (123 h), blowing from 21 Feb, 8:15 UTC to 26 Feb, 11:15 UTC.

TKE

- *TKE* is calculated as the sum of variances of all wind velocity components, as in e.g. Stull, 1988 (*Fig.3.)* (overbars denote 30 min averaging, whilst all turbulent perturbations are defined based on the presence of a gap in the wind velocity spectra, using an estimated averaging period of 15 min):

$$\bar{e} = 0.5\left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right)$$

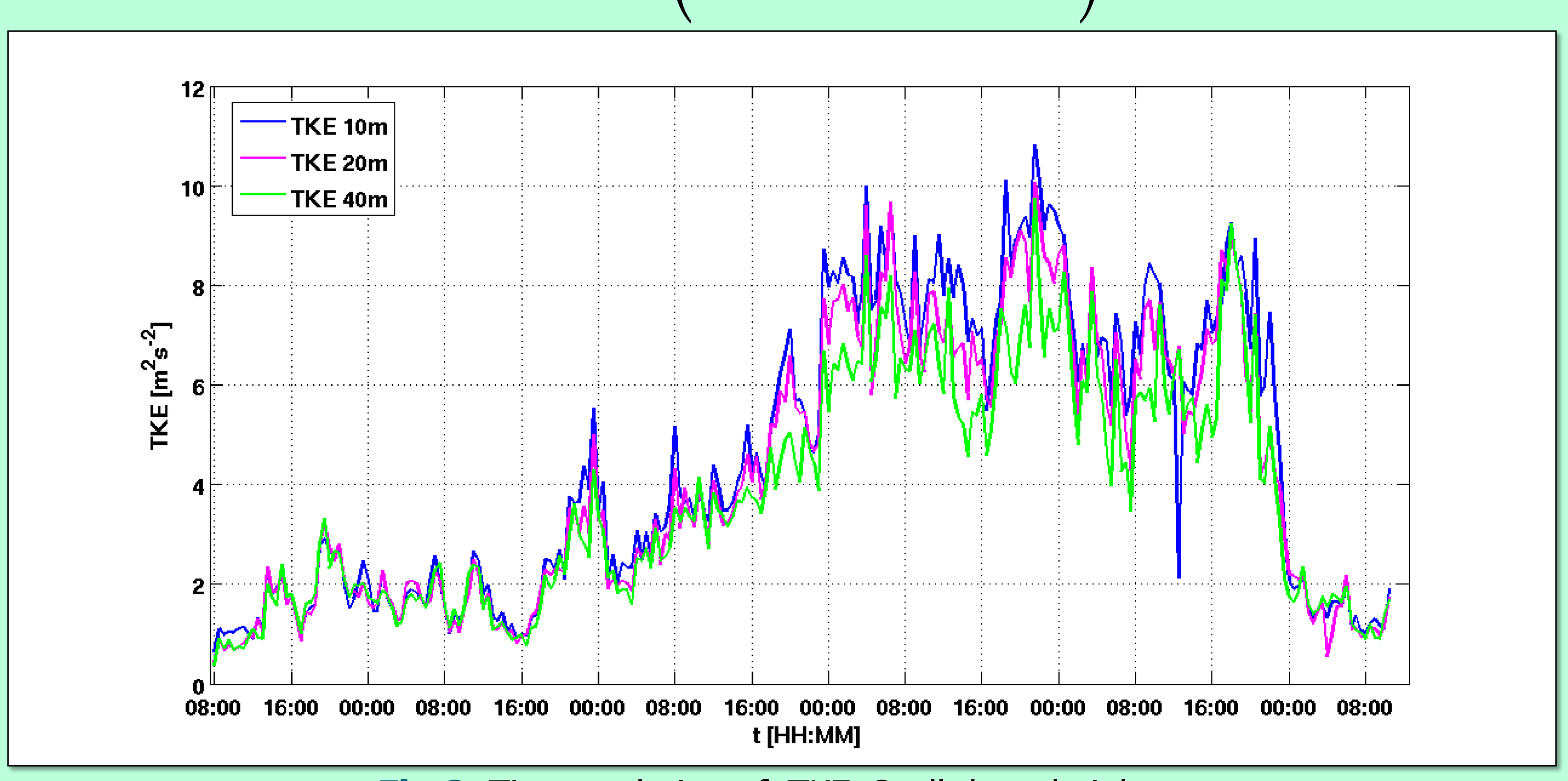

Fig.3. Time evolution of *TKE* @ all three heights.

1D TKE BUDGET ANALYSIS

- viscous dissipation ε is calculated using the inertial dissipation method (IDM), as in e.g. Večenaj et al, 2011:

$$\varepsilon = \frac{2\pi}{U}\left(\frac{f^{5/3} S_u(f)}{\alpha}\right)^{3/2}$$

- non-simplified *TKE* budget equation is derived as (e.g. Stull, 1988):

$$\frac{\partial \bar{e}}{\partial t} + \bar{u}_j \frac{\partial \bar{e}}{\partial x_j} = \delta_{i3}\frac{g}{\Theta_v}\overline{u_i'\theta_v'} - \overline{u_i' u_j'}\frac{\partial \bar{u}_i}{\partial x_j} - \frac{\partial \overline{u_j' e}}{\partial x_j} - \frac{1}{\rho}\frac{\partial \overline{u_i' p}}{\partial x_i} - \nu\overline{\left(\frac{\partial u_i'}{\partial x_j}\right)^2} \quad \textbf{(1)}$$

- due to the limitations of the measuring site (only one tower, no means of measuring pressure perturbations), horizontal homogeneity is assumed & all three pressure covariance terms are neglected (these terms are summarized under the residual term ***R***):

$$\frac{\partial \bar{e}}{\partial t} = -\bar{w}\frac{\partial \bar{e}}{\partial z} + \frac{g}{\Theta_v}\overline{w'\theta_v'} - \left(\overline{u'w'}\frac{\partial \bar{u}}{\partial z} + \overline{v'w'}\frac{\partial \bar{v}}{\partial z} + \overline{w'w'}\frac{\partial \bar{w}}{\partial z}\right) - \frac{\partial \overline{(w'e')}}{\partial z} - \varepsilon + R \quad \textbf{(2)}$$

- LHS term in **(2)** represents a local storage of *TKE* (**I**);
- RHS terms in **(2)** represent, respectively: vertical advection of *TKE* (**II**); buoyant production/consumption (**III**); mechanical production (**IV**); vertical transport (**V**); viscous dissipation; residual term R
- all terms involving spatial derivations are calculated on two mid-levels (15 & 30 m) (*Fig.4.)*

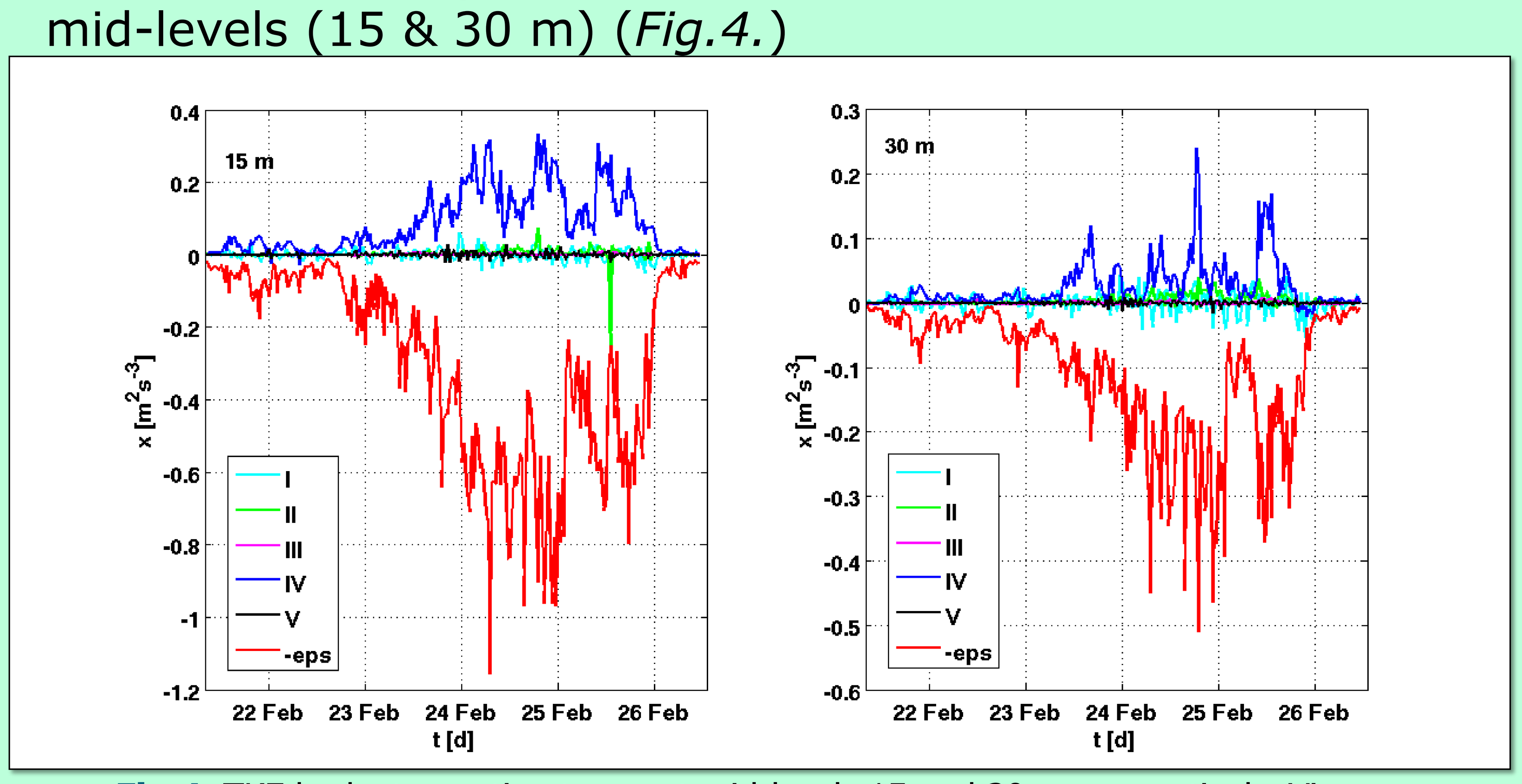

Fig.4. TKE budget equation terms at mid-levels 15 and 30 m, respectively. Viscous dissipation is multiplied by -1 for presentation purposes.

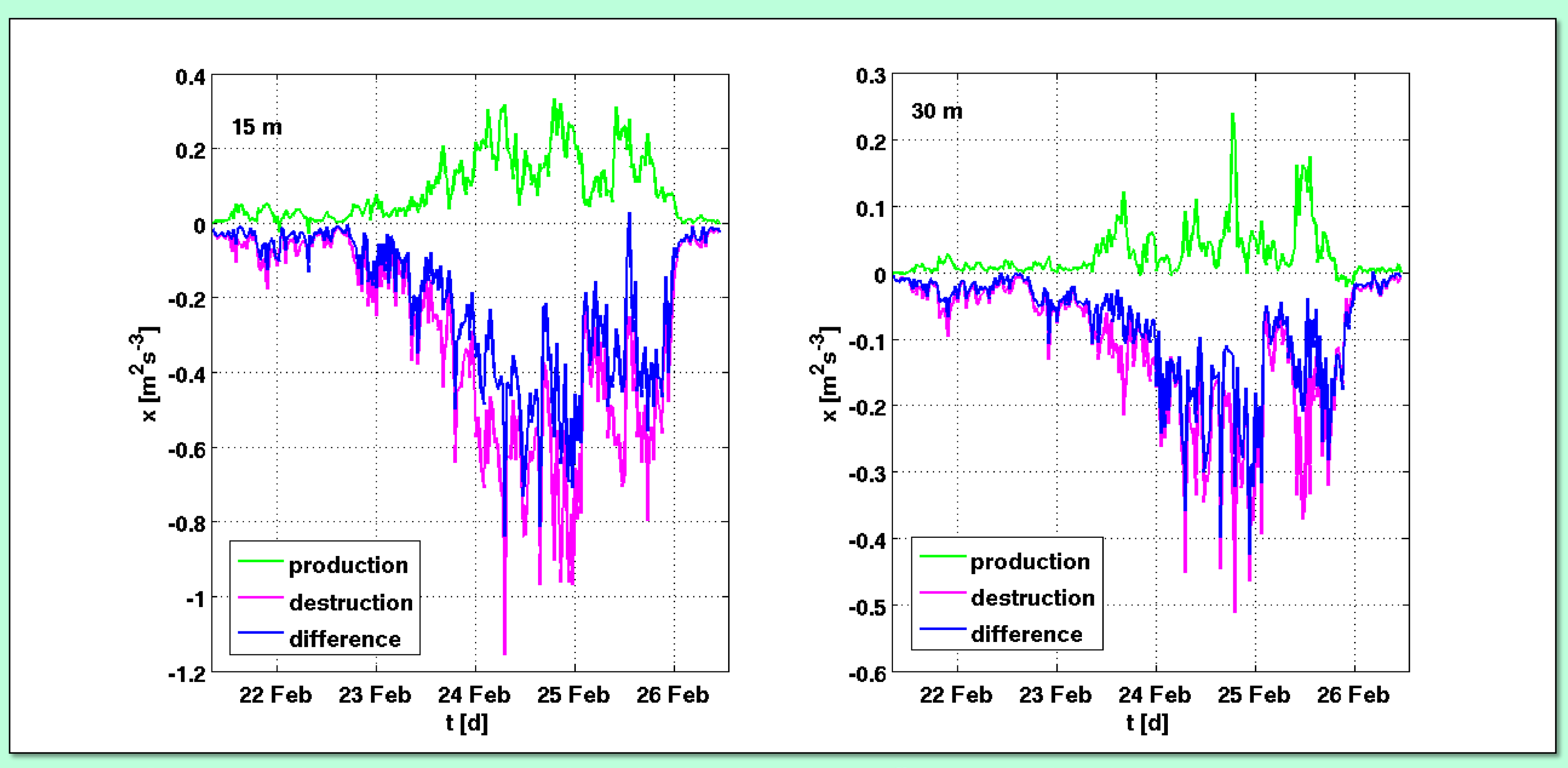

Fig.5. Production (term (IV) + (III) when heat flux >0), (-1)*destruction (viscous dissipation + (III) when heat flux <0) & their difference at 15 & 30 m.

CONCLUSION

- *Fig.4.* shows that mechanical production and viscous dissipation play dominant roles in temporal behavior of *TKE*
- however, *Fig.5*. proves that the simplified *TKE* budget equation is not applicable for this event, i.e. that horizontal heterogeneity and/or transport via pressure (neglected terms) also contribute to the local variability of *TKE*

- Stull, R.B., 1988: An introduction to boundary layer meteorology. Kluwer Academic Publishers, Dordrecht, 666 pp.
- Večenaj, Ž., De Wekker, S.F.J., Grubišić, V., 2011: Near surface characteristics of the turbulence structure during a mountain wave event. *J. Appl. Meteor. Climat.* **50**, 1088-1106.

K. Horvath is supported by HRZZ grant 08/40, while measurements on Pometeno brdo were supported by grant UKF 16/08.
Ž. Večenaj & B.G. are supported by the Croatian Ministry of Sci. Edu. & Sports, BORA, No. 119-1193086-1311 & HRZZ, CATURBO No. 09/151.