UNIVERSITÉ DE FRANCHE-COMTÉ

FRANÇAISE DES JEUX

Accuracy of the estimation of cycling power output during uphill exercise in competition

Fred Grappe, Ph.D.

Equipe EA4267 - Research Department in Prevention, Innovation and Technico-Sporting Watching
University of Franche-Comté (Besançon, France).

Trainer of the Pro Cycling Team "La Française Des Jeux".
Scientific Adviser of the French Cycling Federation

www.fredericgrappe.com

Questions :

Is it possible to estimate with accuracy the Power Output (PO) in the field from a routine method during uphill exercise in competition ?

Is it possible to determine differences in PO between cyclists during uphill exercise in competition ?

Is it possible to determine different maximal performance levels according to time of exercise ?

PowerTap

Valid measurement

SRM Training System

Direct method

Measurement of Power Ouput

Low accuracy
Problem with AC_d !!!!!

Indirect method

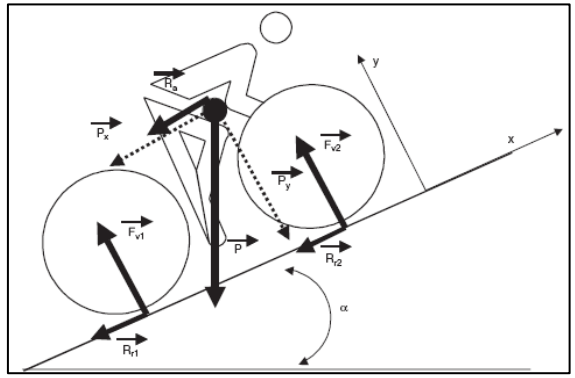
Possible because importance of the gravity force

Flat terrain

Estimated PO from a model

Uphill

Estimated Power Output (PO_{est}) from a model



$$PO_{est} = \underbrace{0.5\,\rho\,AC_d\,(V_d + V_w)^2\,V_d}_{\text{Aerodynamic PO}} + \underbrace{(M\,g\,h\,/\,d)\,V_d}_{\text{Potential PO}} + \underbrace{C_r\,M\,g\,\cos\alpha\,V_d}_{\text{Rolling PO}}$$

5 W/kg,	Aerodynamic PO	Potential PO	Rolling PO
slope 8%	7%	90%	3%
slope 5%	18%	78%	4%
flat 0%	93%	0%	7%

ρ is the air density (kg.m^{-3}), AC_d (m^2) the effective frontal area, V_d (m.s^{-1}) the cyclist's speed, V_w (m.s^{-1}) the wind velocity, M (kg) the mass of cyclist + bicycle, h (m) the height climbed up, d (m) the distance climbed up, C_r the rolling coefficient, g the gravity (9.81 m.s^{-2}), cosα the angle of the slope climbed up.

Validation of estimated PO in laboratory

Power Output Measurement during Treadmill Cycling

D. A. Coleman , J. D. Wiles , R. C. R. Davison , M. F. Smith , I. L. Swaine

Int J Sport Med, 28(6): 525-30, 2007

The study used a motorised treadmill as a cycling ergometry system to estimate PO during treadmill cycling.

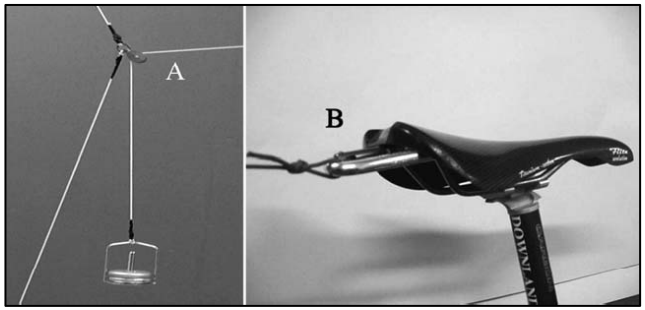


Fig. 1 A and B The pulley system, **A** the weights basket and the pulley, **B** the saddle rail attachment.

For graded cycling, there was no significant difference between measured and predicted power output ($p > 0.05$, SEE 1.2%).

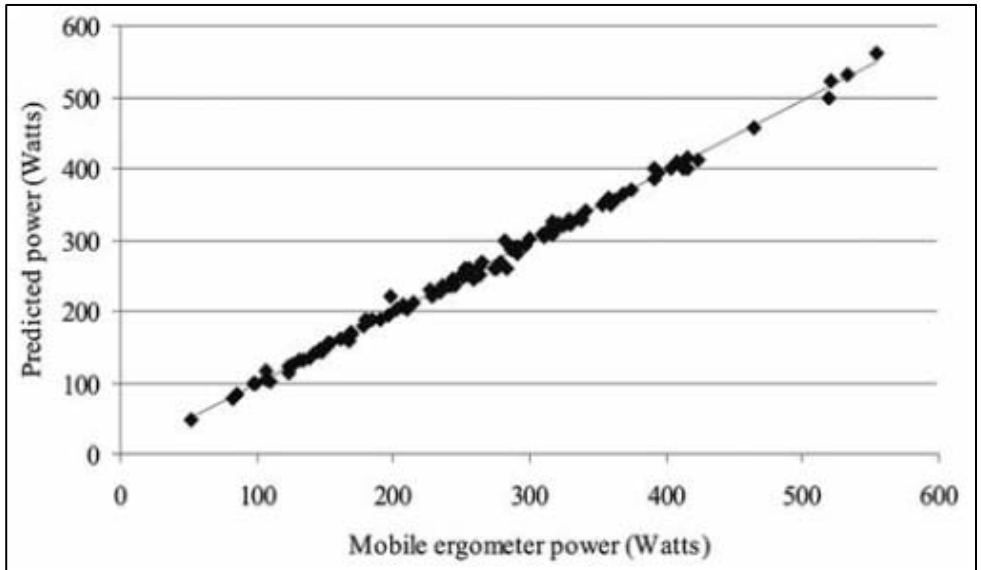


Fig. 2 The relationship between mobile ergometer power output and predicted power during treadmill cycling. ($Y = 0.9891 x + 0.1603$, $r = 0.998$, $p < 0.05$, SEE 1.2% [95 CI 1.06 – 1.38 %]).

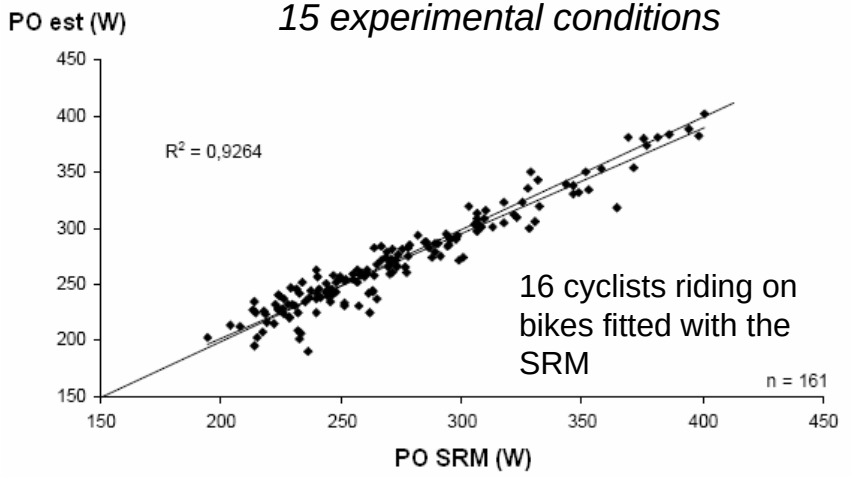
Treadmill cycling can be used as an ergometry system to estimate PO in cyclists with acceptable accuracy.This technique is similar to the locomotion of a cyclist.

Validation of estimated PO in the field from experimental conditions

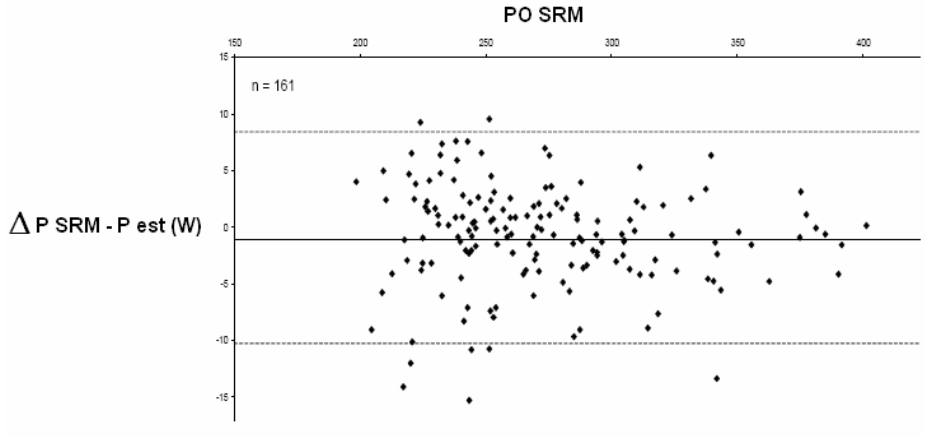
Study of Tronche* (Master Degree, 2003)

Relationship between PO_{SRM} and PO_{est} on 15 different climbs (4.4% to 10.7%)

Relationship between PO_{SRM} and PO_{est} in 15 experimental conditions

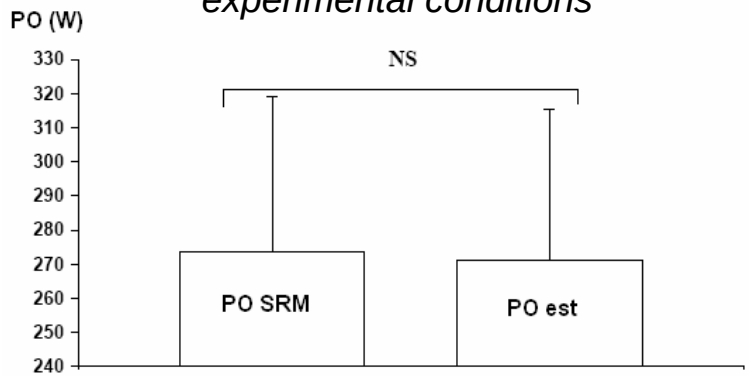


Bland and Altman model

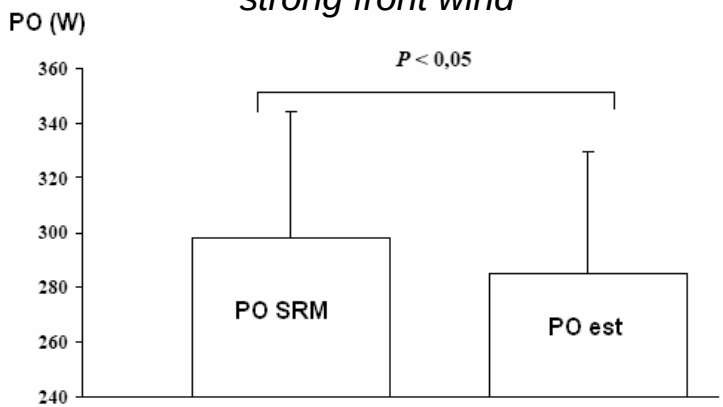


The indirect field method is valid to estimate PO with slopes > 4% and no important wind

Comparison between PO_{SRM} and PO_{est} in the 15 experimental conditions



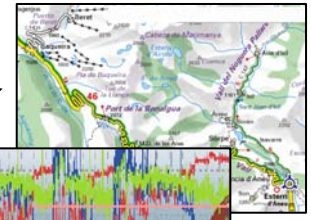
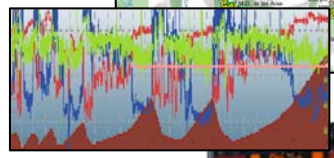
Comparison between PO_{SRM} and PO_{est} with a strong front wind



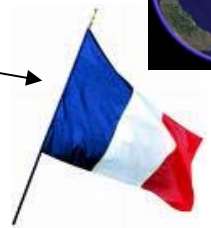
Validation of estimated PO in professional competitions

Tools to determined the variables

- accurate road map
- altimeter (Polar)
- TV images
- Google Earth
- Flag (for the wind)





Input variables

- P_B (mmHg)
- Temp (°C)
- M (kg)
- Altimetry (m)
- Δh (m)
- d (m)
- Time (s)

ρ (kg.m^{-3})

Slope (%)

Model

In the uphill exercise conditions, the model considers that :

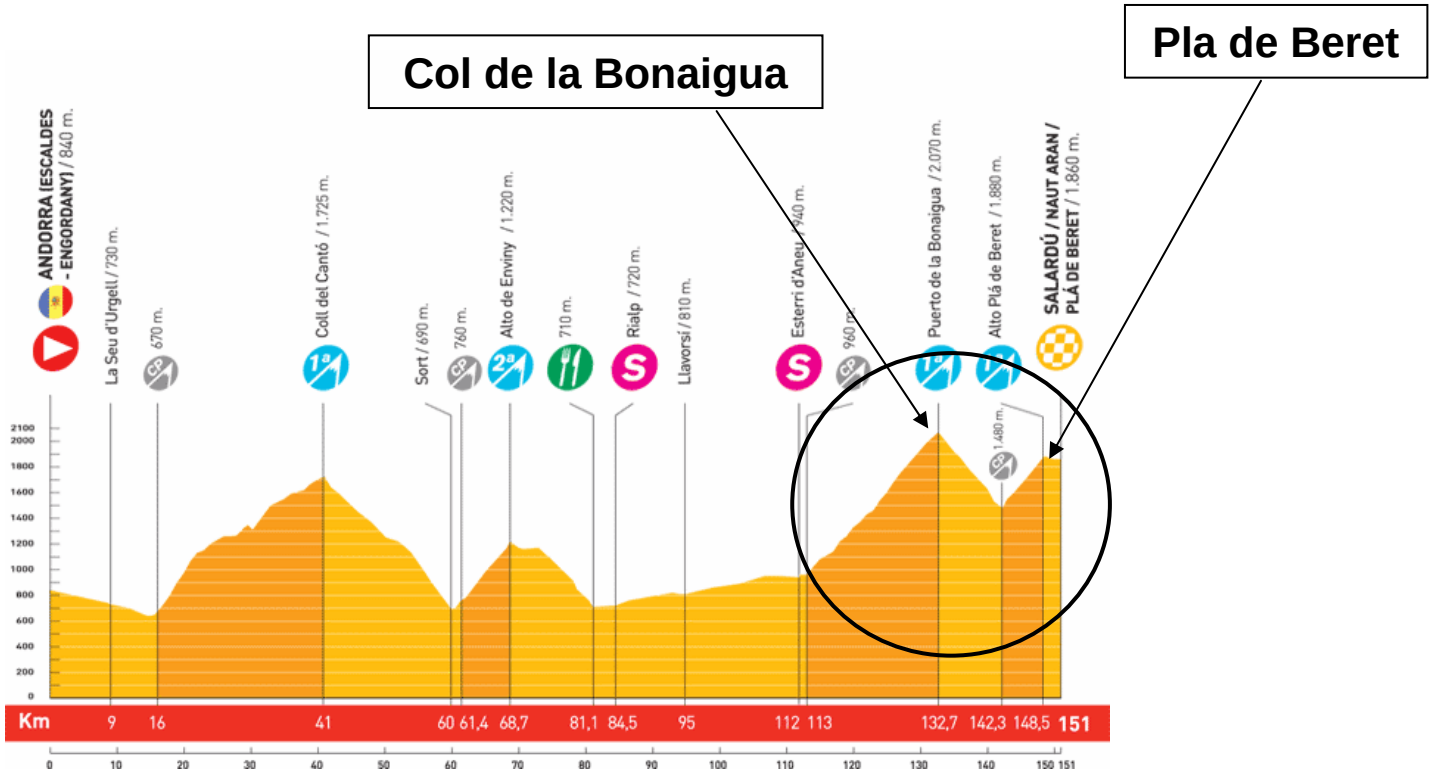
- $V_w = 0$
- acceleration - deceleration periods = 0 (cst movement)
- $AC_d = 0.35\ m^2$ (alternating seated and standing position)
- $C_r = 0.0025$ (rolling resistance on smooth terrain)

Ouput variables

Estimated PO

When an input variable was considered as "not sure" the uphill condition was not validated and PO_{est} was not calculated.

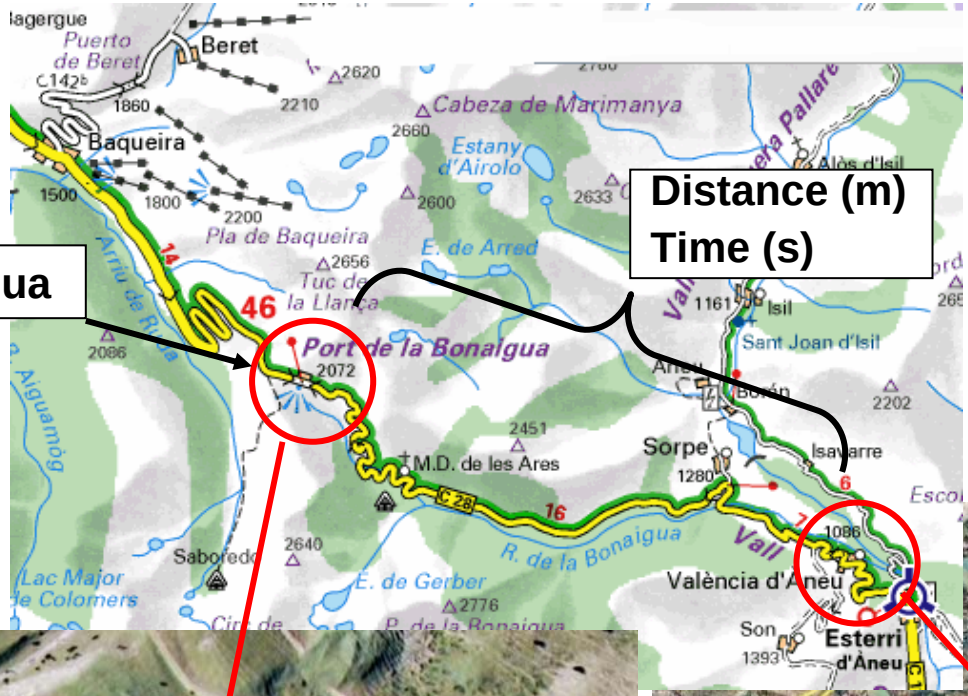
Example : Vuelta 2008, stage 8 : Andorre – Pla-de-Beret, 151km

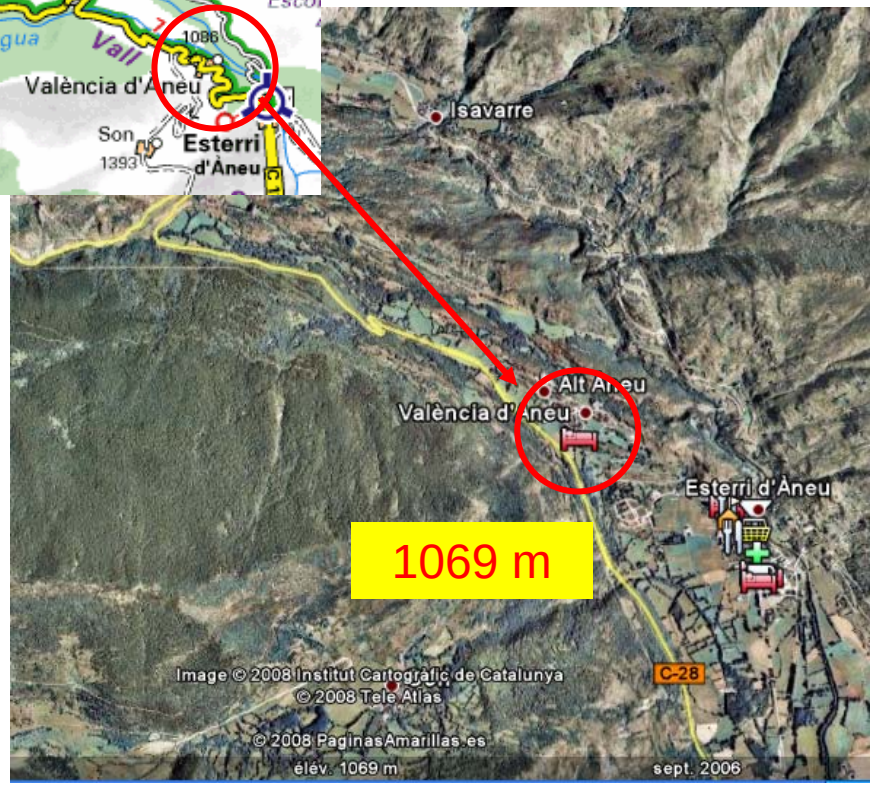


Alt.	City	km
950	La Guingueta d' A'neu	109,0
940	Esterri d' Aneu SPRINT INTERMEDIO (Paso estrecho)	112,0
960	Cruce izda. dirección Vielha por la C-28	112,1
960	Comienza puerto	113,0
1090	Valencia d' Aneu	115,4
2070	**Port de la Bonaigua PM 1ª cat.**	132,7
1490	Baqueira	142,0
1480	Cruce dcha. dirección Pla de Beret por la C-142B. Comineza puerto	142,3
1880	**Alto de Pla de Beret PM 1ª cat.**	149,3

Col de la Bonaigua

Distance (m)
Time (s)





Col de la Bonaigua : input variables

CHARACTERISTICS				
Variables	**Cyclist**	**Bike**	**Atmosph.**	**Terrain**
SC_x (m^2)	0.35			
$P_{méca}$ (puissance méca. ext, W)				
Masse (kg)	74	8.000		
C_r		0.0025		
Altitude 1 (m)			1069	
Altitude 2 (m)			2076	
Altitude moyenne (m)			1572.5	
P_B moyenne (mmHg)			630	
T (°C)			23	
T (°K)			296	
$\rho 0$ (ρ à air sec à 273°k et 760 mmHg)			1.292	
ρ ($kg.m^{-3}$)			0.988	
V_v ($m.s^{-1}$)			0	
Pente (%)				5.8
h (m)				58
d (m)				1000

Peloton

Results	
Temps montée :	00:43:35
Temps montée (s) :	2615
Distance (km) :	17.3
V_d (m/s) (km/h) :	6.6
$P_{méca}$ (W) =	372
$P_{méca}$ (W/kg) =	5.03
$V_{\Delta h}$ (m/min) =	23.0
(m/h) =	1381

23.8

Breakaway

Results	
Temps montée :	00:46:30
Temps montée (s) :	2790
Distance (km) :	17.3
V_d (m/s) (km/h) :	6.2
$P_{méca}$ (W) =	343
$P_{méca}$ (W/kg) =	4.63
$V_{\Delta h}$ (m/min) =	21.6
(m/h) =	1295

22.3

Pla-de-Beret : input variables

CHARACTERISTICS				
Variables	**Cyclist**	**Bike**	**Atmosph.**	**Terrain**
SC_x (m^2)	0.35			
$P_{méca}$ (puissance méca. ext, W)				
Masse (kg)	74	8.000		
C_r		0.0025		
Altitude 1 (m)			1500	
Altitude 2 (m)			1880	
Altitude moyenne (m)			1690	
P_B **moyenne** (mmHg)			622	
T (°C)			23	
T (°K)			296	
$\rho 0$ (ρ à air sec à 273°k et 760 mmHg)			1.292	
ρ ($kg.m^{-3}$)			0.975	
V_v ($m.s^{-1}$)			0	
Pente (%)				6.5
h (m)				65
d (m)				1000

Moncoutier

Results		
Temps montée :	00:14:40	
Temps montée (s) :	880	
Distance (km) :	5.85	
V_d (m/s) (km/h) :	6.6	23.9
$P_{méca}$ (W) =	411	
$P_{méca}$ (W/kg) =	5.56	
$V_{\Delta h}$ (m/min) =	25.9	
(m/h) =	1556	

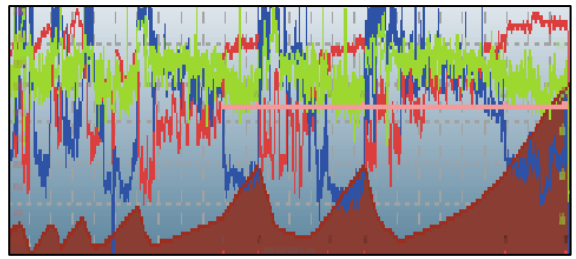
Contador, Valverde, Anton

Results		
Temps montée :	00:13:45	
Temps montée (s) :	825	
Distance (km) :	5.85	
V_d (m/s) (km/h) :	7.1	25.5
$P_{méca}$ (W) =	446	
$P_{méca}$ (W/kg) =	6.02	
$V_{\Delta h}$ (m/min) =	27.7	
(m/h) =	1659	

Possible errors of measurement

Powermeter

Altimeter

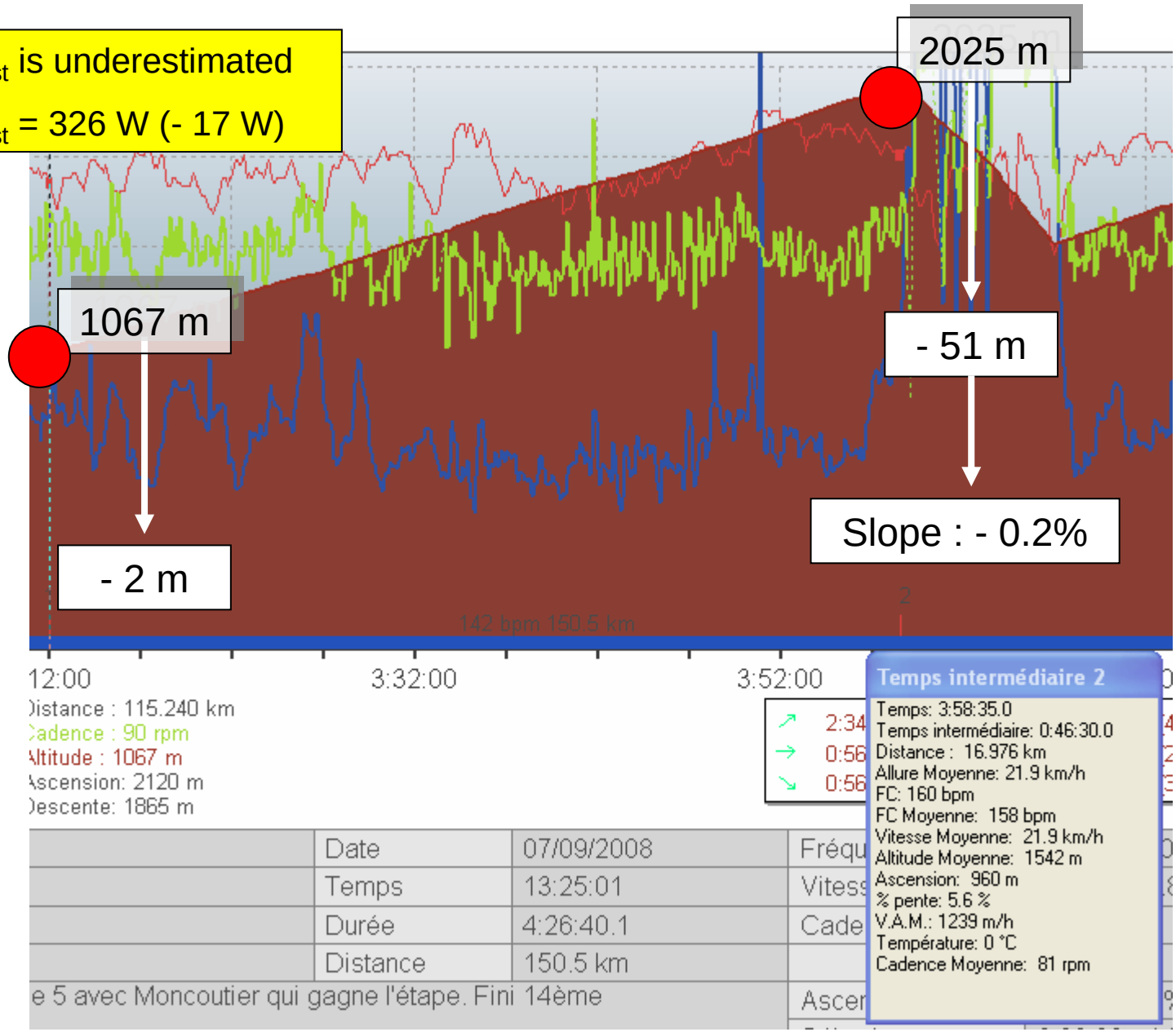


Problems of calibration !!!

Measurement error of the altimeter in the Col de la Bonaigua

PO_{est} is underestimated

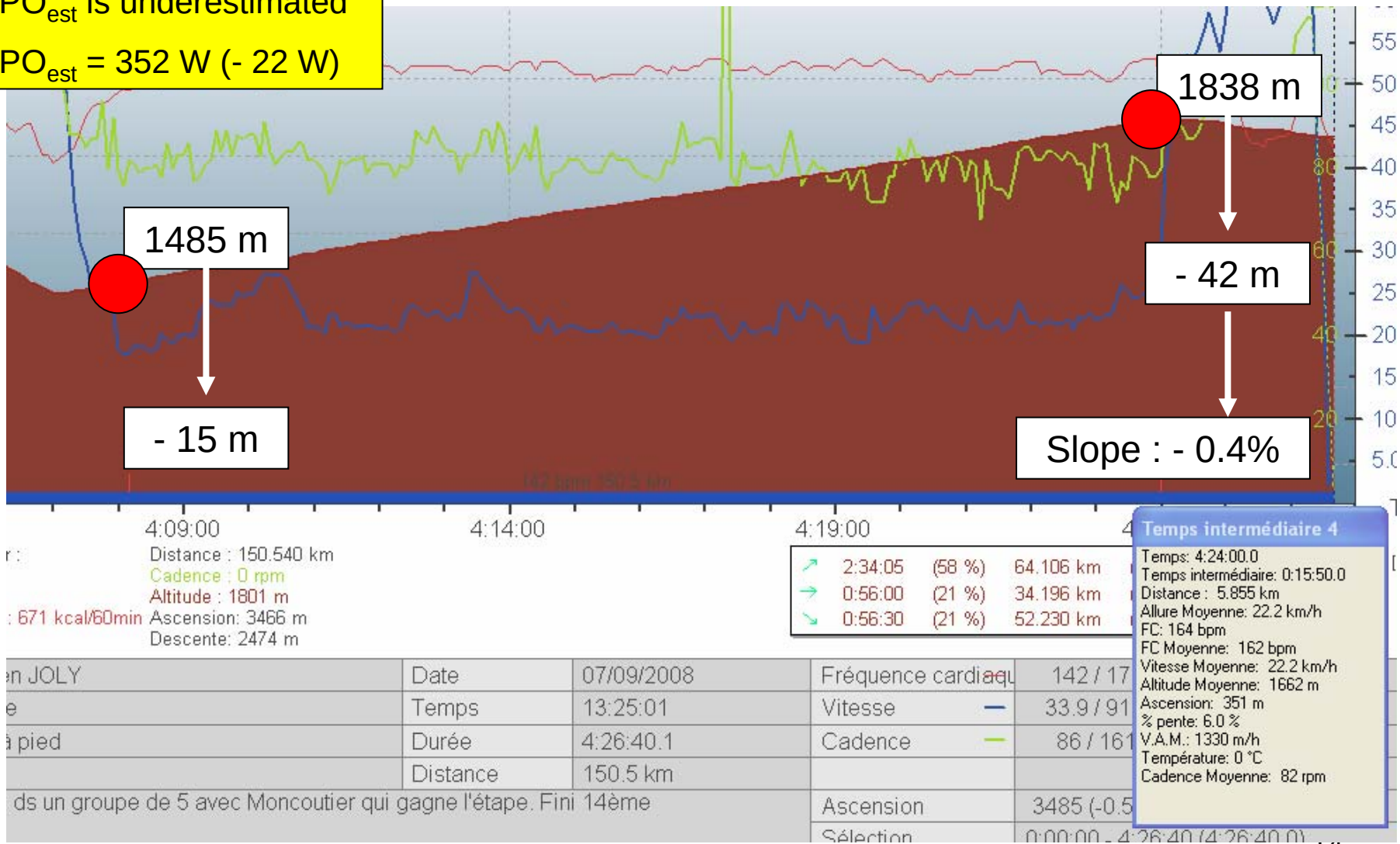
PO_{est} = 326 W (- 17 W)



Measurement error of the altimeter in the Pla-de-Beret

PO_{est} is underestimated

PO_{est} = 352 W (- 22 W)



Measurement error of the powermeter

Example : time trial in Alpe d'Huez

Estimated PO

CHARACTERISTICS				
Variables	Cyclist	Bike	Atmosph.	Terrain
SC_x (m^2)	0.35			
Masse (kg)	76	8.000		
C_r		0.0025		
Altitude 1 (m)			760	
Altitude 2 (m)			1850	
Altitude moyenne (m)			1305	
P_B moyenne (mmHg)			615	
T (°C)			25	
T (°K)			298	
P_0 (ρ à air sec à 273°k et 760 mmHg)			1.292	
ρ ($kg.m^{-3}$)			0.958	
V_v ($m.s^{-1}$)			0	
Pente (%)				7.9
h (m)				79
d (m)				1000

???

Time = **43 min**

Measured PO = **440 Watt (5,78 W/kg)**

Cyclist = 76 kg

Difference = 55 W

Results		
Temps montée :	00:43:00	
Temps montée (s) :	2580	
Distance (km) :	13.8	
V_d (m/s) (km/h) :	5.3	19.3
$P_{méca}$ (W) =	385	
$P_{méca}$ (W/kg) =	5.06	
$V_{\Delta h}$ (m/min) =	25.4	
(m/h) =	1521	

Measurement error of the powermeter
Analyse of the performance in the Alpe d'Huez

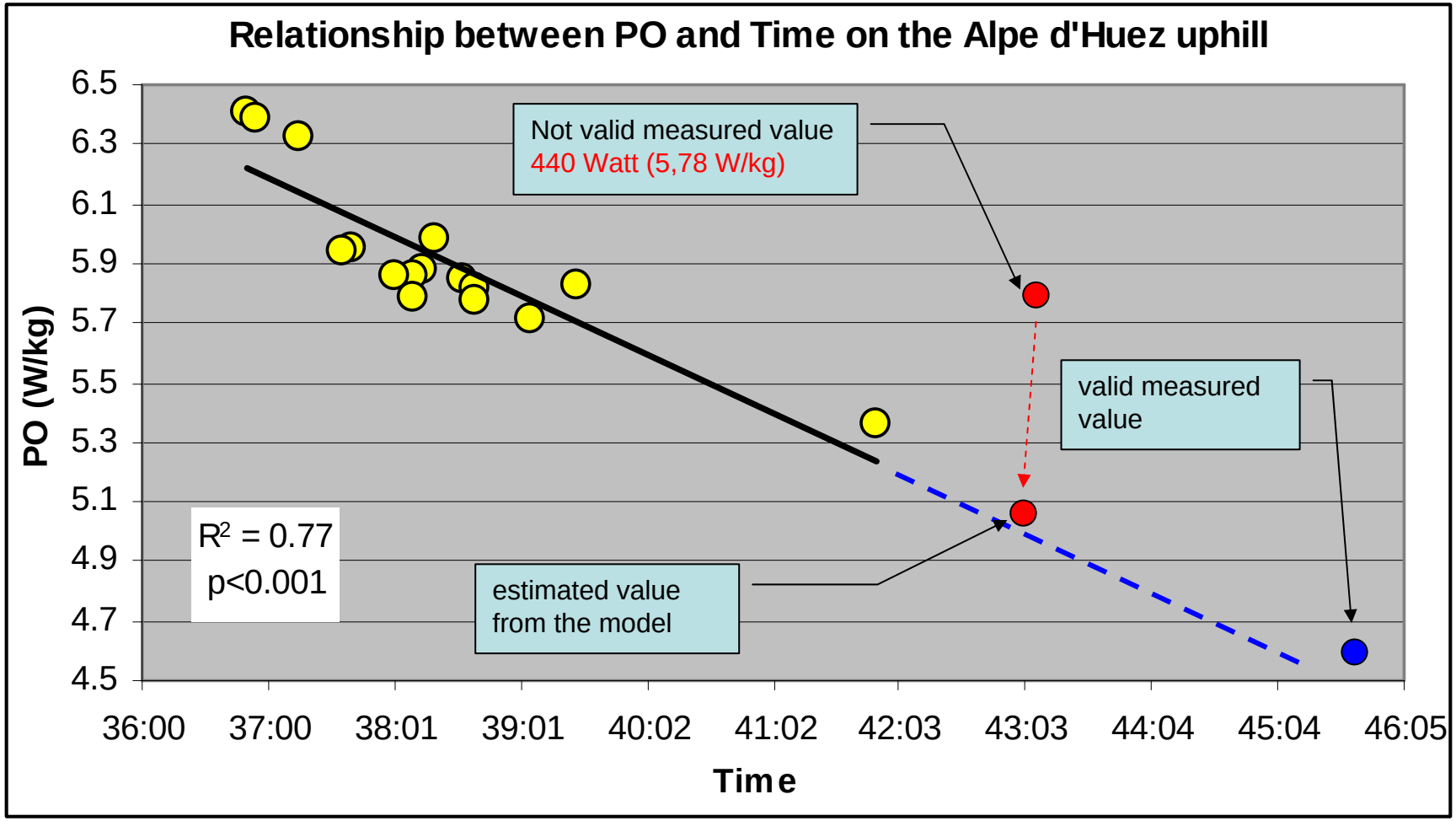
Estimated Power output

Years	Riders	Time	Weight	Type	PO (W)	PO (W/kg)
1995	M. Pantani	36:50	57		365	6.41
1997	M. Pantani	36:55	57		364	6.39
1994	M. Pantani	37:15	57		360	6.32
1997	R. Virenque	38:20	63		377	5.98
1997	J. Ullrich	37:40	72		429	5.95
2004	L. Armstrong	37:36	74	ITT	439	5.94
1995	B. Riis	38:15	70		411	5.88
1995	A. Zülle	38:10	72		422	5.86
2001	L. Armstrong	38:01	74		434	5.86
2006	F. Landis	38:34	68		398	5.85
2008	C. Sastre	39:29	60		350	5.83
1995	L. Madouas	38:40	69		401	5.82
1995	M. Indurain	38:10	78		451	5.78
2004	J. Ullrich	38:40	72		416	5.77
2003	I. Mayo	39:06	71		406	5.71
1999	Guerini	41:52	65		348	5.36

Measured Power output

2004	xxxxx	45:42	68		316	4.64

Measurement error of the powermeter
Analyse of the performance in the Alpe d'Huez



Effects of changes in the different input variables on the estimated PO

Example for a climb like "Alpe d'Huez" (13.8 km at 7.9%)

Variables	Changes	Watts
distance (m)	± 100	± 3
Time (s)	± 15	± 3
Height climbed up (m)	+ 10 / - 10	+ 5 / - 2
Temperature (°C)	± 10	± 1
Altitude (m)	+ 1000	- 5
AC_d (m^2)	- 10% / + 10%	± 4
Mass (kg)	± 1	± 5
C_r	± 10	± 1
Wind ($m.s^{-1}$)	+ 1 / - 1	+ 13 / - 11

Validity of the indirect method in cycling competitions

SRM and PowerTap data from 3 different riders in different races

Comparison between PowerTap measured PO and PO_{est} (ACd = 0.35, Cr = 0.0025, cyclist = 68kg, bike = 8kg) during different climbs of stage 17 of Tour de France 2006 (St Jean-de-Maurienne - Morzine, 200.5 km)

Climbs	Time PowerTap	$PO_{PowerTap}$ (W)	$PO_{PowerTap}$ (W/kg)	Time model	PO_{est} (W)	PO_{est} (W/kg)	delta (W)	error (%)
Col des Saisies	36:55	395	5.81	36:20	396	5.82	-1	-0.25
Col des Aravis	16:49	371	5.46	16:20	373	5.49	-2	-0.54
Col de la Colombière	27:45	392	5.76	28:15	374	5.50	18	4.81
Col de Joux-Plane	37:34	372	5.47	37:00	370	5.44	2	0.54
								1.14

Comparison between SRM measured PO and PO_{est} (ACd = 0.35, Cr = 0.0025, cyclist = 74kg, bike = 8kg) during different climbs of stage 9 of Tour de France 2008 (Toulouse - Bagnière-de-Bigorre, 224 km).

Climbs	Time SRM	PO_{SRM} (W)	PO_{SRM} (W/kg)	Time model	PO_{est} (W)	PO_{est} (W/kg)	delta (W)	error (%)
Col des Ares	13:55	372	5.03	13:50	376	5.08	-4	-1.06
Col de Peyresourde	39:00	369	4.99	38:55	370	5.00	-1	-0.27
Col d'Aspin	35:30	349	4.72	35:50	346	4.68	3	0.87
								-0.16

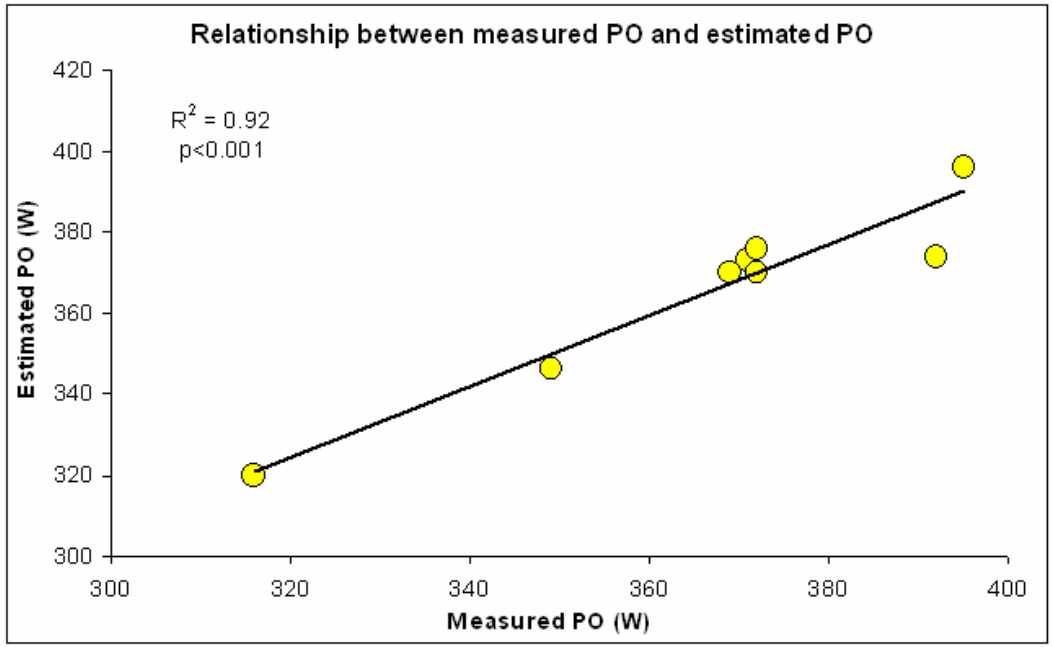
Comparison between SRM measured PO and PO_{est} (ACd = 0.35, Cr = 0.0025, cyclist = 67kg, bike = 8kg) during different climbs of stage 17 of Tour de France 2008 (Embrun - L'Alpe-d'Huez, 210.5 km).

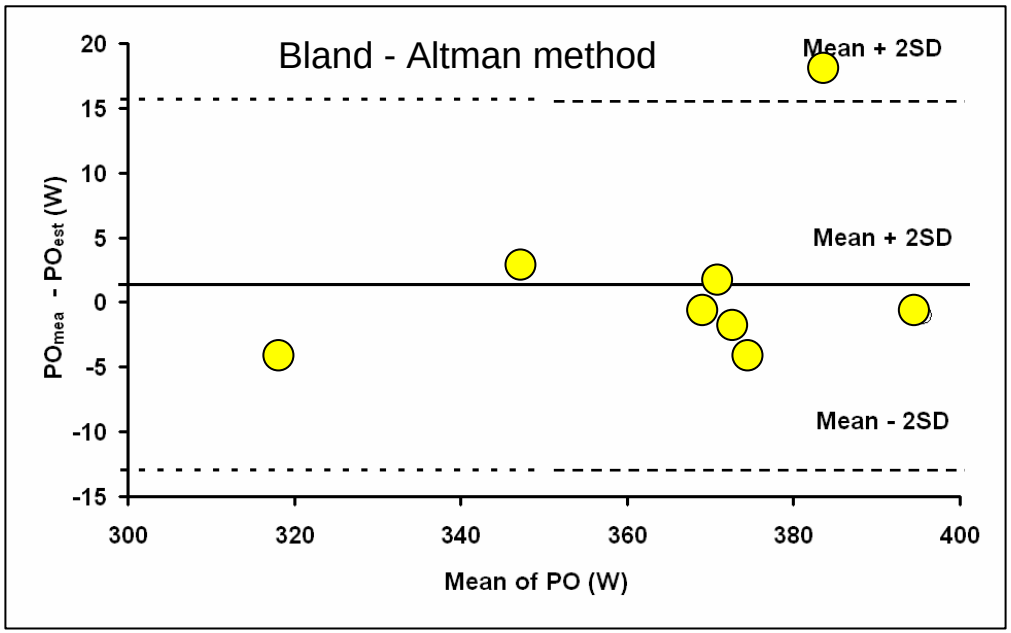
Climbs	Time SRM	PO_{SRM} (W)	PO_{SRM} (W/kg)	Time model	PO_{est} (W)	PO_{est} (W/kg)	delta (W)	error (%)
Alpe d'Huez 2008	45:42	316	4.72	45:42	320	4.78	-4	-1.25

Validity of the indirect method in cycling competitions

The indirect method used in competition is a **potential accurate tool** for the assessment of cycling performances in races.

The method is usable in routine with a low cost.





To improve the accuracy of the PO_{est} **the help of race organizers** will be essential for providing valid characteristics of the hills climbed by the cyclists.

Various distinctive levels of PO during uphill exercise

Grouped peloton : 4 - 4.5 W/kg

+ 0.5 W/kg

Small peloton : 4.5 - 5 W/kg

+ 0.5 W/kg

Leaders' group : 5 - 5.5 W/kg

+ 0.2 W/kg

Group with the best : 5.5 - 5.7 W/kg

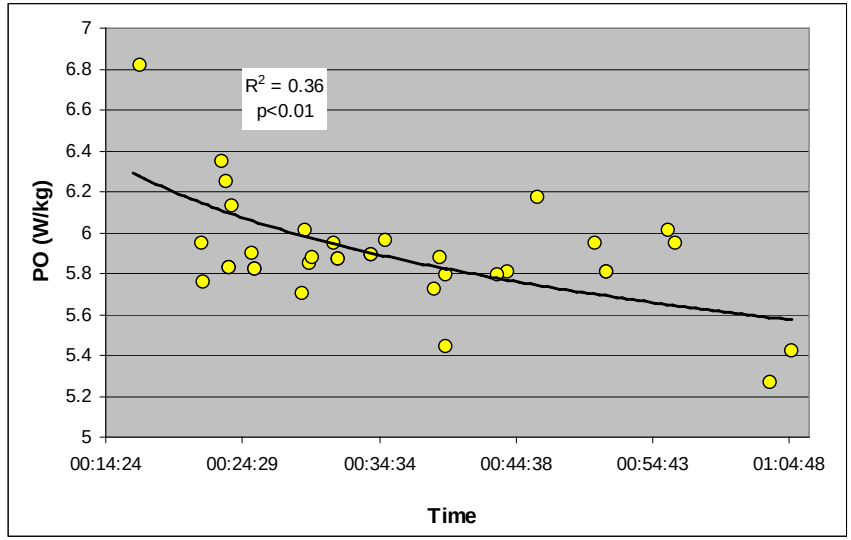
+ 0.2 W/kg

The best : 5.7 - 6 W/kg

Maximal performances in the « Grands Tours » of positive controled cyclists since 2004

The model consider : cyclist standard = 74 kg and bike = 7 kg

Name	Race	Year	Event	Time	PO W/kg
C	Tour de France	2008	Col d'Aspin	00:29:25	5.85
C	Giro	2008	Alpe di Pampeago	00:25:09	5.9
A	Giro	2008	Alpe di Pampeago	00:25:26	5.82
B	Giro	2008	Alpe di Pampeago	00:25:26	5.82
M	Giro	2008	Passo Manghen	01:05:00	5.42
M	Giro	2008	Passo Fedaia	00:39:30	5.44
B	Giro	2007	Montevergine di Mercogliano	00:31:30	5.87
C	Giro	2007	Montevergine di Mercogliano	00:31:30	5.87
A	Giro	2007	Santuario Nostra	00:23:00	6.35
B	Giro	2007	Santuario Nostra	00:23:18	6.25
C	Giro	2007	Santuario Nostra	00:23:40	6.13
A	Giro	2007	Santuario di Oropa	00:28:56	5.7
A	Giro	2007	Monte Zoncolan	00:39:00	5.88
B	Giro	2007	Monte Zoncolan	00:39:31	5.79
D	Tour de France	2007	Plateau de Beille	00:44:00	5.81
D	Tour de France	2007	Col d'Aubisque	00:43:15	5.79
E	Giro	2006	Passo Lanciano	00:35:00	5.96
E	Giro	2006	Colle San Carlo	00:34:00	5.89
A	Giro	2006	Colle San Carlo	00:34:00	5.89
E	Giro	2006	Monte Bondone	00:46:15	6.17
F	Tour de France	2006	Alpe-d'Huez	00:38:35	5.72
G	Vuelta	2006	Alto de Monachil	00:21:35	5.76
G	Vuelta	2006	Sierra de la Pandera	00:23:30	5.83
H	Vuelta	2006	Sierra de la Pandera	00:23:30	5.83
I	Dauphiné	2005	Ventoux	00:56:27	5.95
E	Giro	2005	Zoldo Alto	00:21:30	5.95
B	Giro	2005	Colle delle Finestre	01:03:20	5.27
E	Tour de France	2005	Courchevel	00:51:21	5.81
D	Tour de France	2005	Courchevel	00:50:30	5.95
E	Tour de France	2005	Courchevel	00:51:21	5.81
J	Dauphiné	2004	Ventoux	00:55:51	6.01
E	Tour de France	2004	La Mongie	00:31:15	5.95
K	Vuelta	2004	Estacion de Esqui La Covatilla	00:29:04	6.01
L	Vuelta	2004	Estacion de Esqui La Covatilla	00:29:36	5.88
K	Vuelta	2004	Puerto de Navacerrada	00:16:25	7.09
L	Vuelta	2004	Puerto de Navacerrada	00:16:56	6.82



Average time

35:13 ± 13:00

Average PO

5.92 ± 0.3 W/kg (74 kg)

6.15 ± 0.3 W/kg (60 kg)

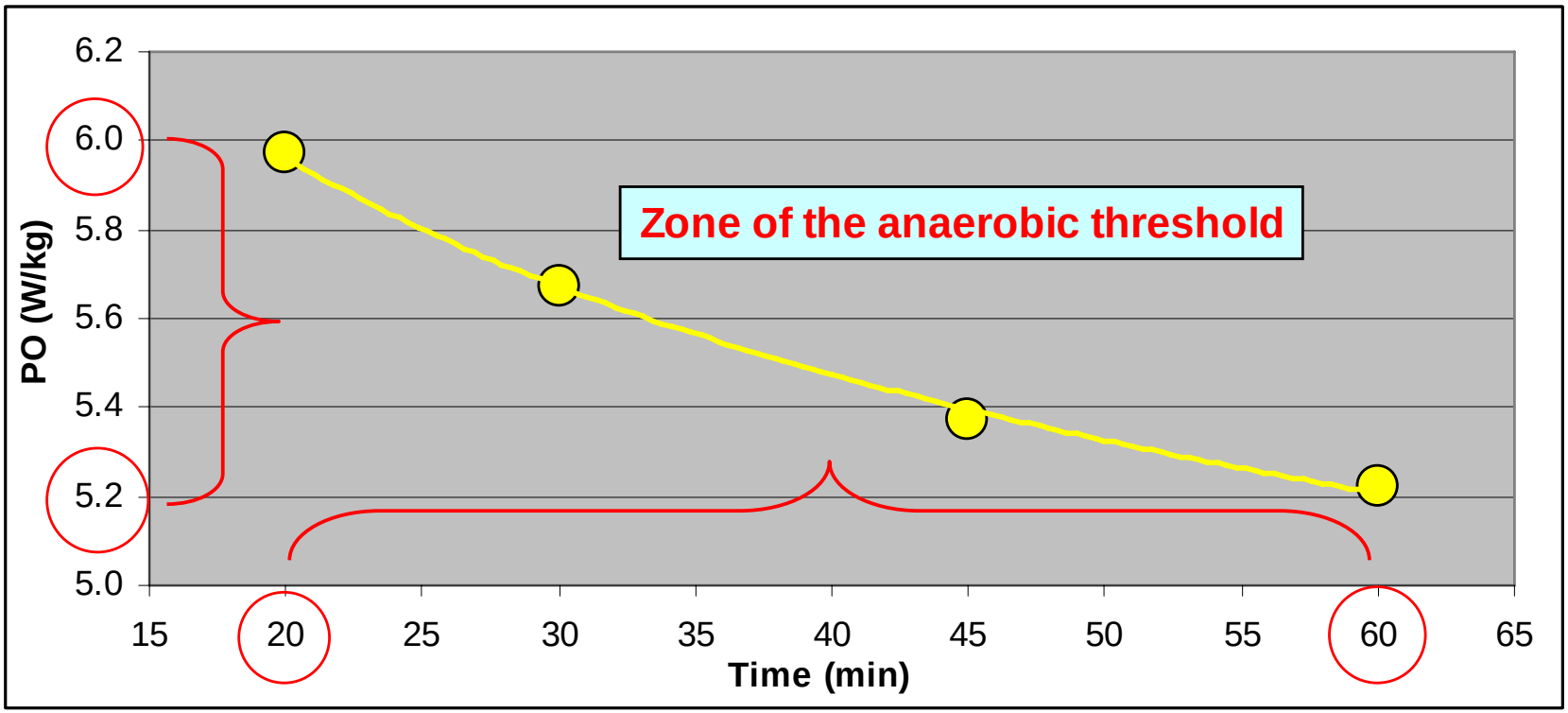
VO_2max = 90ml/min/kg

with, GE = 22% and PO = 85%VO_2max

Maximal physiological profile of Time - PO_{max}

The maximal values in the anaerobic threshold zone depend of each cyclist.

It depend of VO_2max, the terrain and the level of training



Future studies should allow an improvement of the accuracy of the Maximal Power profile

Conclusion

The model used to estimate PO during competition can be used :

- To create an observatory of the performances in competitions

- To have a historical of the performances of the cyclists in competitions

- To analyze the differences in performance level between the cyclists

- To follow the evolution of the performance in certain races

- To give informations to the cyclist about its performance level for training

- To establish a physiological passport to complet the data of the biological passport

- It seems that a PO close to 6 W/kg (time ~ 35 min) corresponds to a "critical" intensity level difficult to reach by clean cyclists in the final col of a stage