NOAA DIVING PROGRAM
TECHNICAL REPORT 06-01

RELIABILITY OF DELTA P TECHNOLOGY LTD., *VR3* AND THE HYDROSPACE ENGINEERING, INC., *HS EXPLORER* COMPUTERS IN PRODUCING ACCEPTABLE MIXED GAS AND AIR DECOMPRESSION SCHEDULES AND PROVIDING ACCURATE DEPTH MEASUREMENT

PREPARED BY;

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EXECUTIVE SUMMARY

The purpose of the study was to provide data and an analysis to allow NOAA personnel to make informed decisions related to the selection of decompression computers and decompression tables that can increase the safety and efficiency of NOAA diving operations.

The dive computers evaluated in this study were the Delta P Technology Ltd., VR3 (1) and the HydroSpace Engineering, Inc., HS Explorer (2).

Both units are capable of use in an open circuit, semi-closed circuit, and closed circuit mode, with air, nitrox, heliox, and trimix gas mixtures. This study was limited to the open circuit mode with air and trimix. Adequacy of decompression profiles produced by the software packages, and by the computers during pressure exposure were the primary functions studied. The accuracy of the depth sensing system was determined.

Decompression profiles generated by the respective dive computer software packages and dive profiles produced by the computers during actual pressure exposures were compared to two computation methods that are considered “industry standards”, these being the US Navy (3) model, and the Hamilton (4) method, and to each other. This comparison of “apples and oranges” is accomplished via the “Multiplex” analysis program prepared by the author. This method “dissects” decompression profiles and computes compartment (tissue) inert gas pressures in a selected series of half time compartments. These half-times and the computation model are not necessarily those used by the respective original dive computer software systems, but rather, they normalize any decompression profile to a common basis, thus allowing a comparison. The normalizing compartment half-times used in this study are the nine used in the US Navy (3) model, 5, 10, 20, 40, 80, 120, 160, 200, 240 minutes.

CONCLUSIONS

VR3 Dive Computer

1. The depth readings produced by the dive computer were all within less than +1 foot of seawater of the pressure standard. None of the readings were shallower than the standard.
2. There was excellent agreement between the pressure generated profile compartment inert gas pressures and those generated by the software.
3. At a “safety factor” of “0”, compartment inert gas pressures were well within US Navy “M” values.
4. At a “safety factor” of “0”, compartment inert gas pressures were all very similar to those of the NOAA/Hamilton values.
5. There was very good agreement between the two computers during the pressurization tests.

HS Explorer Dive Computer

1. The depth readings produced by the dive computer were all within less than –1 and +4 feet of seawater of the standard.
2. There was good agreement between the pressure generated profile compartment inert gas pressures and those generated by the software.
3. At CF0, compartment inert gas pressures were significantly greater than those of NOAA/Hamilton, and in some cases approached the USN “M” values.
4. At CF3, compartment inert gas pressures remained significantly higher than those of NOAA/Hamilton.
5. At CF5, compartment inert gas pressures were, in general, slightly higher than those of NOAA/Hamilton, but were similar.
6. There was very good agreement between the computers during the pressurization tests.

INTRODUCTION

The NOAA Diving Center awarded a contract to the Undersea Research Foundation to evaluate the reliability of selected mixed gas dive computers in producing acceptable mixed gas and air decompression schedules and providing accurate depth measurement. This report fulfills the deliverable requirement stipulated in the contract.

The purpose of the study was to provide data and an analysis to allow NOAA personnel to make informed decisions related to the selection of decompression computers and decompression tables that can increase the safety and efficiency of NOAA diving operations.

The dive computers evaluated in this study were the Delta P Technology Ltd., VR3 (1) and the HydroSpace Engineering, Inc., HS Explorer (2).

Both units are capable of use in an open circuit, semi-closed circuit, and closed circuit mode, with air, nitrox, heliox, and trimix gas mixtures. This study was limited to the open circuit mode with air and trimix. Adequacy of decompression profiles produced by the software packages, and by the computers during pressure exposure were the primary functions studied. The accuracy of the depth sensing system was determined.

The software used in dive computers is normally available to the user to compute decompression tables for predicting in-water decompression, or to produce backup decompression tables for use during a dive. During an actual dive, this software receives real time input from sensors in the computer, and computes a real time decompression profile based on this input.

Decompression profiles generated by the respective dive computer software packages and dive profiles produced by the computers during actual pressure exposures were compared to two computation methods that are considered “industry standards”, these being the US Navy (3) model, and the Hamilton (4) method, and to each other. This comparison of “apples and oranges” is accomplished via the “Multiplex” analysis program prepared by the author. This method “dissects” decompression profiles and computes compartment (tissue) inert gas pressures in a selected series of half time compartments. These half-times and the computation model are not necessarily those used by the respective original dive computer software systems, but rather, they normalize any decompression profile to a common basis, thus allowing a comparison. The normalizing compartment half-times used in this study are the nine used in the US Navy (3) model, 5, 10, 20, 40, 80, 120, 160, 200, 240 minutes.

Sensors in the dive computers provide inputs to the software required to compute the real time dive profile. Pressure, time, breathing gas composition, and in some cases temperature data is used for the computation. The computer display provides the diver with information including depth, time of the dive, temperature, ascent rate, minimum acceptable depth, depth of decompression stops, time at decompression stops, estimated total decompression time, and the breathing gas used for computations.

PROCEDURES

Ten dive profiles were selected for use in this study. The profiles were provided by the NOAA Diving Center based on current or projected operational requirements. Each profile required breathing gas changes during ascent. The air dives involved a switch to oxygen at 20 feet while the trimix dives required a switch to nitrogen/oxygen mixture containing 36% oxygen, Nx36, at 110 feet and to oxygen at 20 feet. The profiles are listed below.

Depth (feet)	Time (minutes)	Breathing Gas
110	35	Air
130	35	Air
150	30	Air
170	20	Air
180	30	Tx18/50 (18% O2, 50% He, 32% N2)
200	25	Tx18/50
240	25	Tx18/50
270	15	Tx14/60 (14% O2, 60% He, 26% N2)
300	15	Tx14/60
300	20	Tx14/60

Two dive computers of the same brand were used in each actual dive. They were immersed in a water bath inside a pressure chamber. A video camera was positioned in the chamber view port in a position which allowed a clear view of both computer displays. A video “quad processor” and two additional video cameras allowed the recording of the view of the computers, a digital “standard pressure gauge” (5), and a digital stopwatch all in the same video frame. These views were recorded on VHS tape during the chamber dives.

Data from the videotapes were transcribed into hard copy dive profiles using the “forward” and “pause” controls of the VCR. The depth calibration data were obtained using a small bench-top chamber in the Undersea Research Foundation lab. The actual dives were conducted in a double-lock recompression chamber at the NOAA Diving Center in Seattle, WA. Both brands of computers required manual switching to different breathing gases at depth. This was accomplished by pressurizing a person in the outer lock of the chamber to the depth at which the switch was to be made, and holding them there until the inner lock arrived at that depth. The person then entered the inner lock and rapidly performed the gas switch on the dive computers. The person was then returned to surface pressure in the outer lock while the dive proceeded in the inner lock.

The software packages provided with the dive computers were used to produce decompression schedules which were analyzed in the same fashion as those produced during the actual pressure exposures.

Both computers have software options for making decompression computations more conservative. The VR3 uses a derivative of the Buhlmann ZHL 16 algorithm (1). On decompression dives it added deep water (microbubble) stops. Safety factors in 10% increments up to 50% can be applied at the user's discretion. Every 10% increase adds 2% to the inert gas content of the gas selected, and this value is then used for computing decompression requirements.

The HS Explorer system for adding conservative adjustments to the computations involves what they call the "computation formula" (CF). The CF levels go from 0-9, and in general, the computed decompression time increases with the CF level (2). The CF levels are based on various combinations of the Buhlman, US Navy, and Reduced Gradient Bubble Model (RGBM) models.

A safety factor of "0" was used on the VR3 for all chamber dives and software computations. CF values of "0, 3, and 5" were used for the HS Explorer.

RESULTS

The accuracy of the pressure sensors in dive computers is critical to the production of valid decompression profiles. Figures 1 and 2 show bar graphs of each of the computer's depth readings and the depth standard. Tables 1 and 2 show the numeric data. Note that the VR-3 depth readings were all within less than 1% of the "standard" reading. The HS Explorer readings were within +2%.

The results of the Multiplex analysis of the software produced decompression profiles, and those produced during the chamber dives are shown in Figs. 3-41.

Below are detailed definitions of the abbreviations used in the figures.

USN/M0, USN/M10, USN/M20, USN/M30 =	US Navy (3) M values for maximum acceptable inert gas pressures for depths of 0, 10, 20, 30 feet of seawater absolute (FSWA).
NOAA/P0, NOAA/P10, etc. =	Values of the respective inert gas pressures (FSWA) produced by Multiplex analysis of the NOAA/Hamilton decompression tables at the respective depths.
VR3P0C, VR3P10C, etc. =	Values of the respective inert gas pressures (FSWA) produced by Multiplex analysis of chamber dives of the VR3.

VR3P0, VR3P10, etc. =	Values of the respective inert gas pressures (FSWA) produced by Multiplex analysis of VR3 software generated decompression schedules.
HSP0C, HSP10C, etc. =	Values of the respective inert gas pressures (FSWA) produced by Multiplex analysis of chamber dives of the HS Explorer.
HSP0, HSP10, etc.=	Values of the respective inert gas pressures (FSWA) produced by Multiplex analysis of the HS Explorer software generated schedules.
HSP0cf0, cf3, cf5, etc. =	CF values 0, 3, 5 respectively for HS Explorer.

The numbers (1-9) along the horizontal axis of the graphs represent the 9 half-time compartments of 5, 10, 20, 40, 80, 120, 160, 200, 240 minutes respectively.

The numbers on the vertical axis of the graphs represent total inert gas partial pressure (FSWA) in the respective half time compartments.

The USN “M” values listed for air dives are those of nitrogen. The “M” values listed for the trimix dives are those of helium.

Chamber dives with the VR3 computer called for a direct ascent to the surface from the 20 foot oxygen stop. Since there was no 10 foot stop, no VR3P10C data is included in the graphs.

CONCLUSIONS

VR3 Dive Computer

1. The depth readings produced by the dive computer were all within less than +1 foot of seawater of the pressure standard. None of the readings were shallower than the standard.
2. There was excellent agreement between the pressure generated profile compartment inert gas pressures and those generated by the software.
3. At a “safety factor” of “0”, compartment inert gas pressures were well within US Navy “M” values.
4. At a “safety factor” of “0”, compartment inert gas pressures were all very similar to those of the NOAA/Hamilton values.
5. There was very good agreement between the two computers during the pressurization tests.

HS Explorer Dive Computer

1. The depth readings produced by the dive computer were all within less than –1 and +4 feet of seawater of the standard.
2. There was good agreement between the pressure generated profile compartment inert gas pressures and those generated by the software.
3. At CF0, compartment inert gas pressures were significantly greater than those of NOAA/Hamilton, and in some cases approached the USN “M” values.
4. At CF3, compartment inert gas pressures remained significantly higher than those of NOAA/Hamilton.
5. At CF5, compartment inert gas pressures were, in general, slightly higher than those of NOAA/Hamilton, but were similar.
6. There was very good agreement between the computers during the pressurization tests.

REFERENCES

1. VR3 Dive computer Operators Manual, Copyright Delta P Technology Ltd.2004 V2.1CXR
2. HS Explorer Dive Computer Owner’s Manual, Copyright 2000-2003,HydroSpace Engineering, Inc.
3. Workman, R.D., Calculation of Decompression Schedules For Nitrogen-Oxygen and Helium-Oxygen Dives, U.S. Navy Experimental Diving Unit Research Report 6-65, 1965.
4. Hamilton, R.W., 2004. NOAA-Hamilton Trimix Decompression Tables. Hamilton Research, Ltd., 80 Grove Street, Tarrytown, NY 10591-4138. 188 pages.
5. 3D Instruments, Inc., DPG-6600

ACKNOWLEGEMENTS

The following individuals played a key role in acquisition of data for this project:

Dave Dinsmore
Jim Bostick
Bill Gordon
Eric Johnson
Steve Urick

APPENDIX

Table 1		
D-STD	VR3 #1	VR3 #2
0	0	0
10	10	10
20	20	20
40	40	40
50	50	50
60	60	60
70	70	70
90	90	90
100	100	100
110	110	110
120	120	120
130.1	130	130
139	140	140
148.9	150	149
160	161	161
170	170	170
180	180	180
190	191	191
200	200	200
210.2	210	210
220	221	221
229	230	230
239	240	239
239.5	240	240
250	250	250
260.8	260	261
270	270	270
280	280	280
290	290	290
300	300	300

Table 1. VR3 depth comparison with standard

Table 2		
D-STD	HSE #1	HSE #2
0	0	0
10	10	9
20	19	20
30	29	30
40	40	41
50	51	51
60	62	61
70	71	71
80	81	81
90	92	91
110	112	113
120	122	122
130	132	132
140	142	142
150	152	152
160	163	162
170	172	171
180	183	182
190	193	192
200	204	202
210	212	212
220	222	223
230	233	232
240	242	243
250	252	252
260	263	262
270	273	272
280	283	282
290	293	292
300	303	303

Table 2. HSE depth comparison with standard

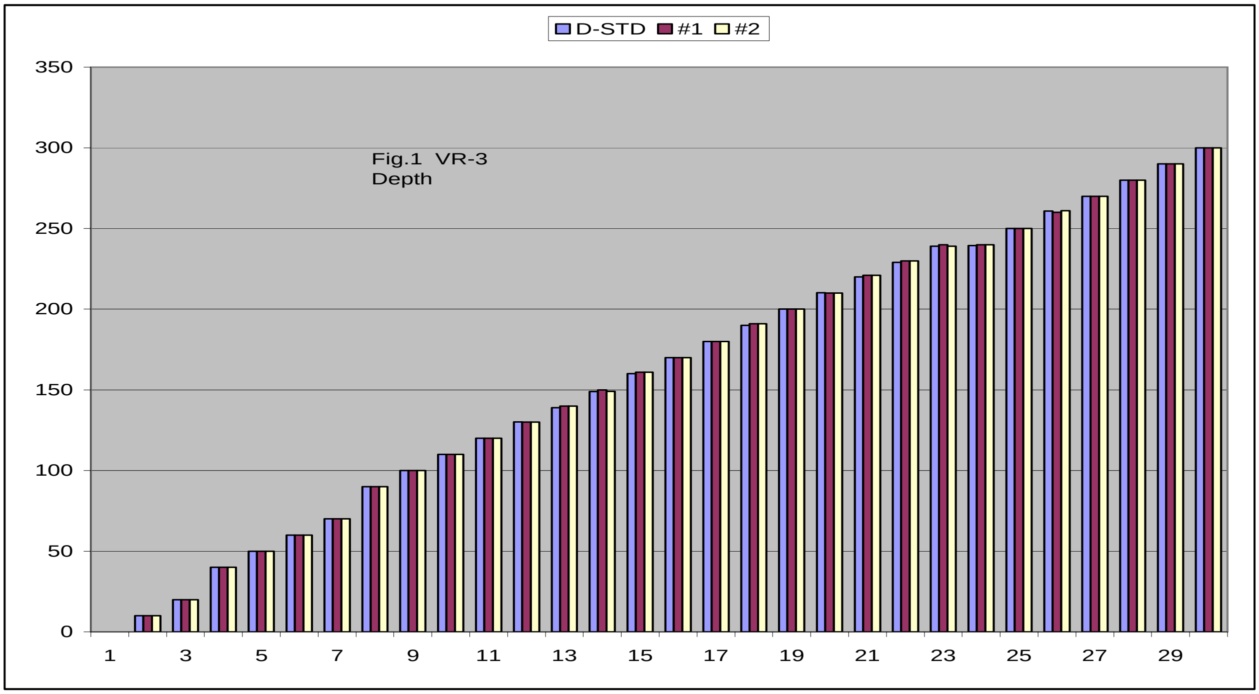


Figure 1. VR3 Depth

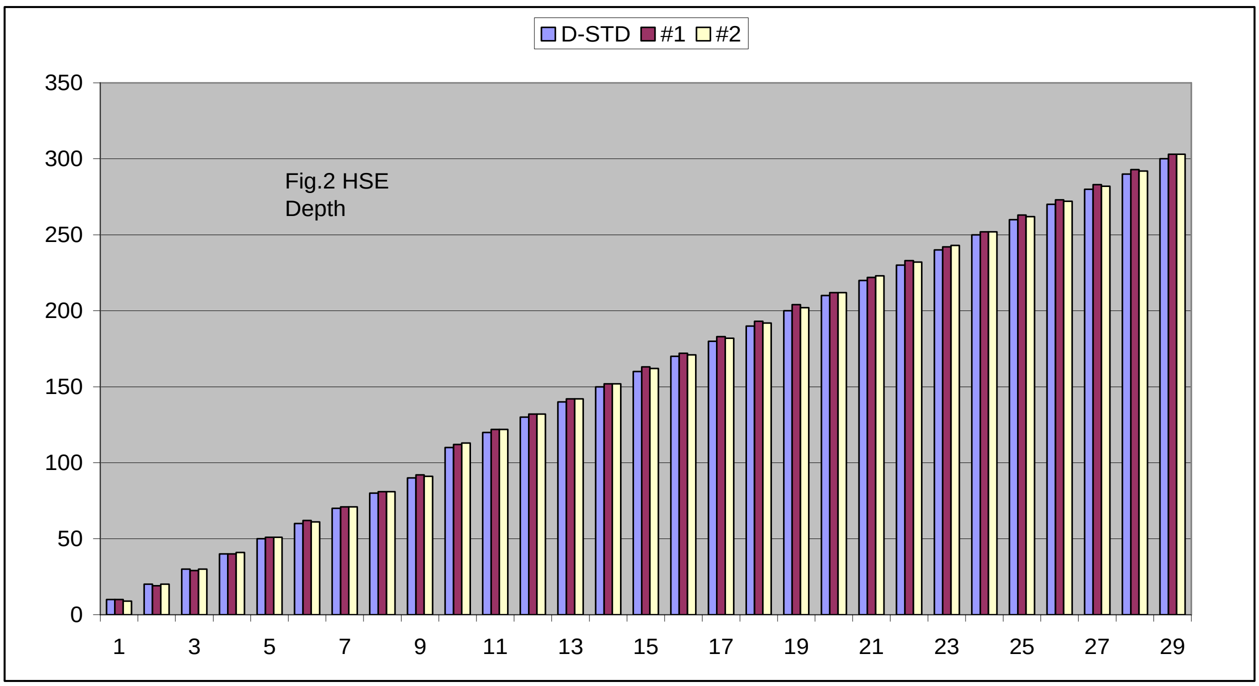


Figure 2. HSE Depth

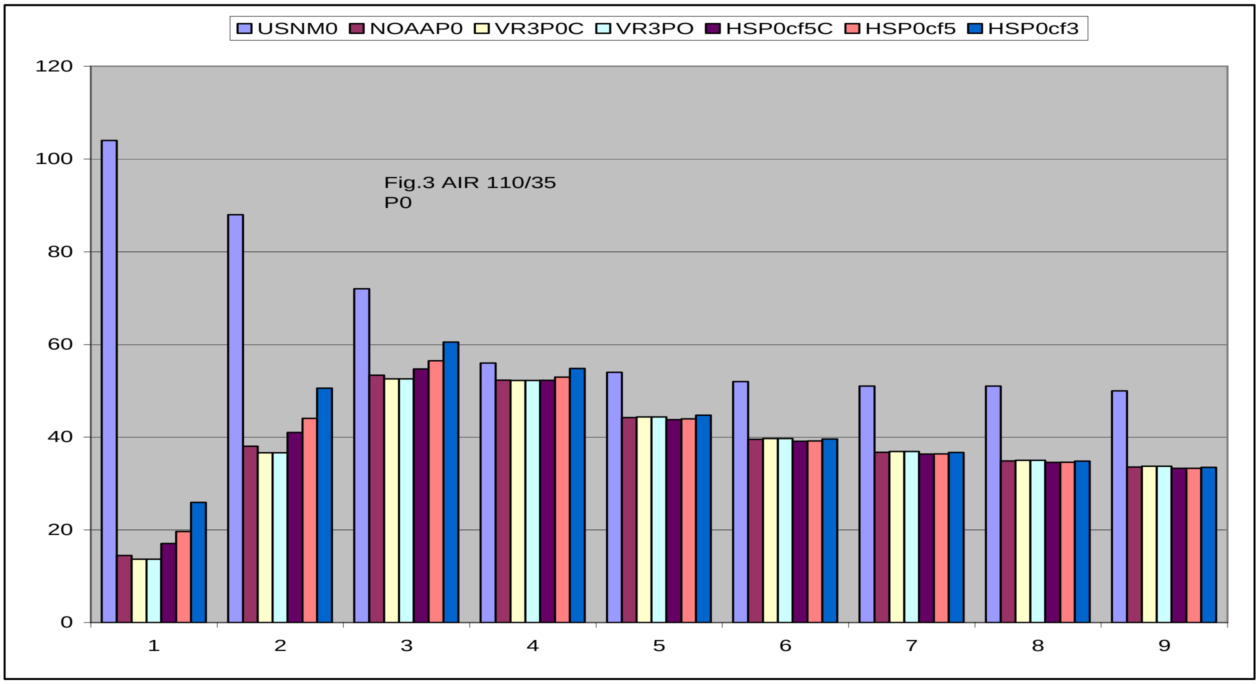


Figure 3. Air 110/35 P0 (arrive surface)

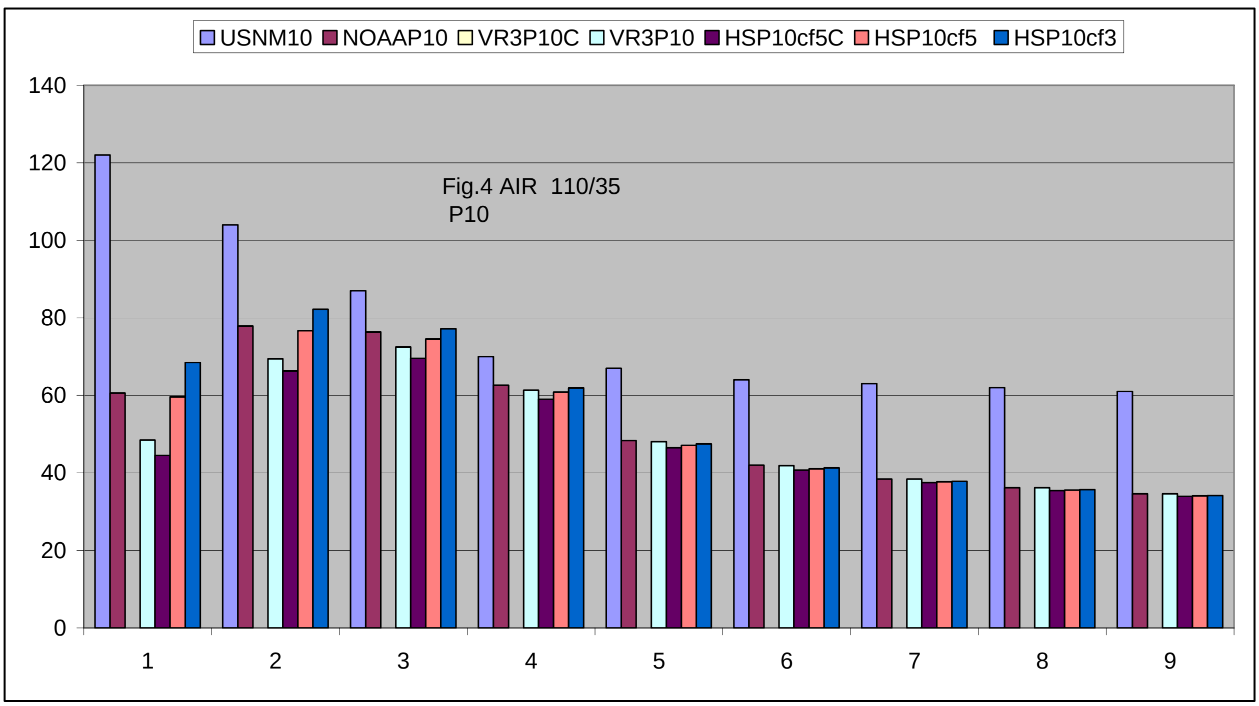


Figure 4. Air 110/35 P10 (arrive 10')

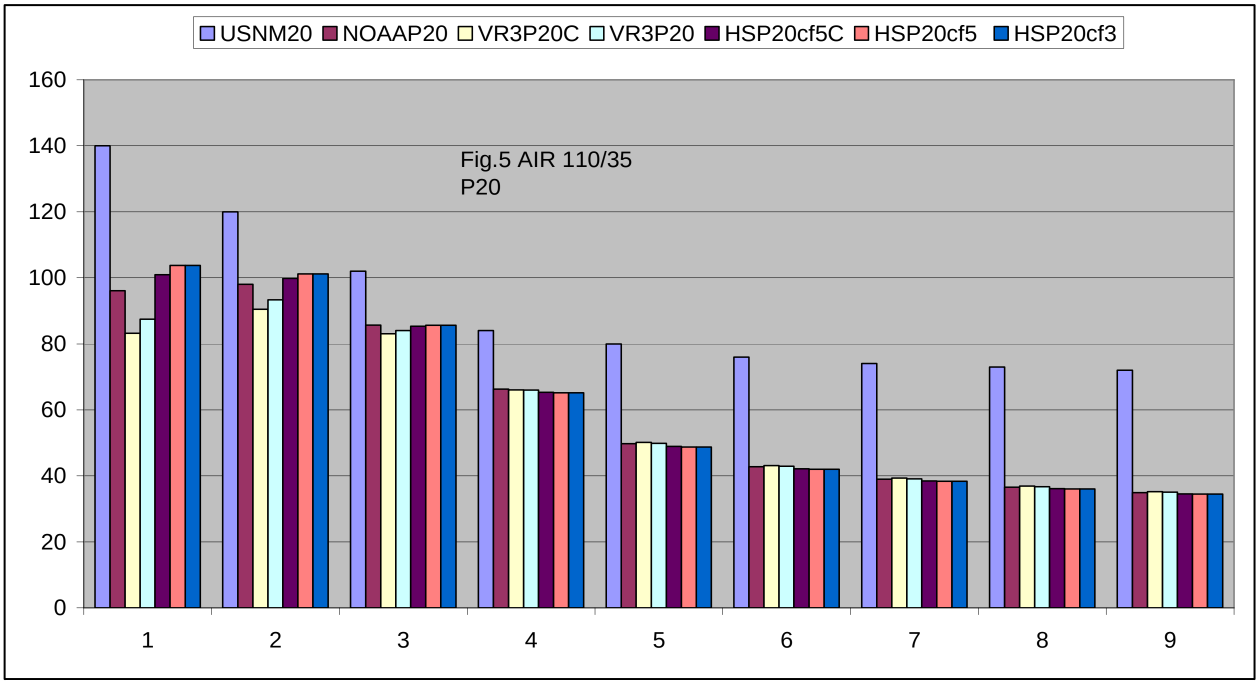


Figure 5. Air 110/35 P20 (arrive 20')

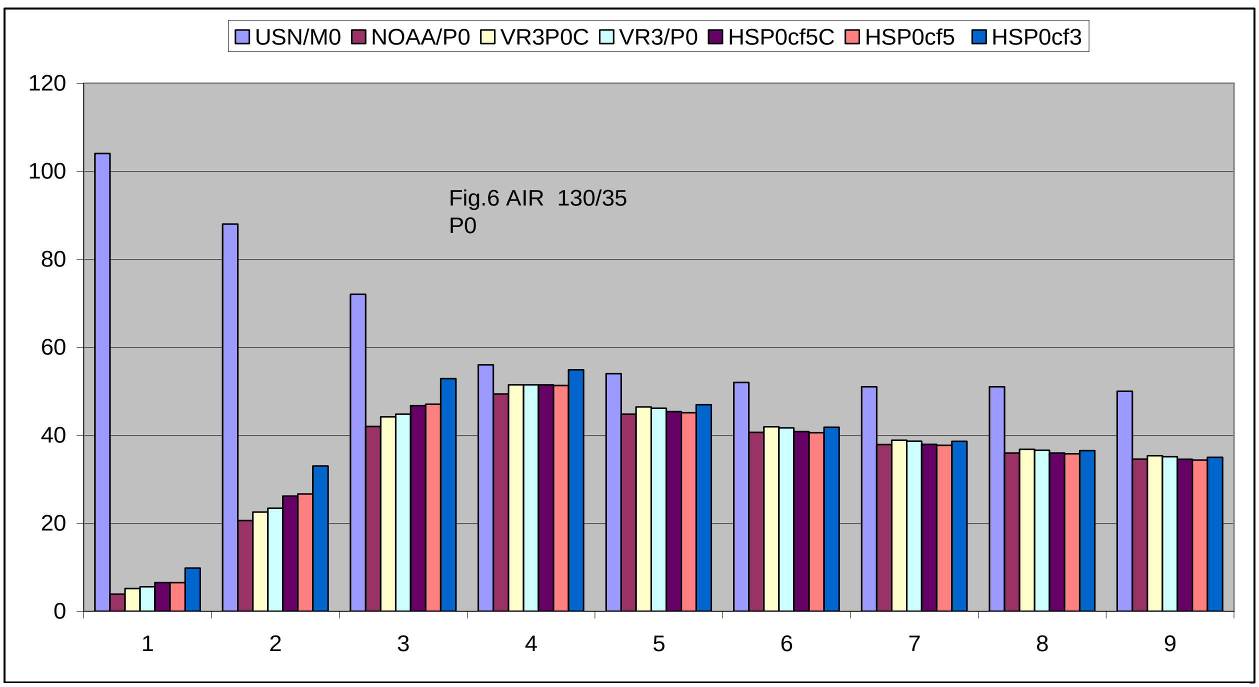


Figure 6. Air 130/35 P0 (arrive surface)

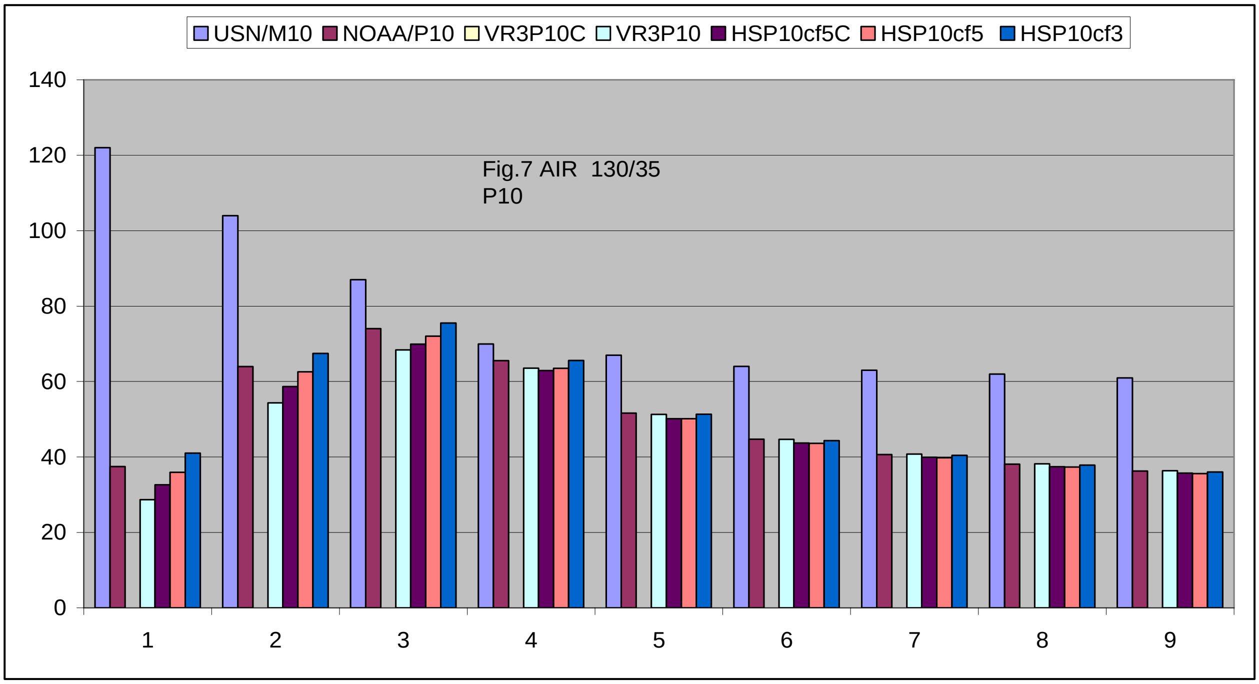


Figure 7. Air 130/35 P10 (arrive 10')

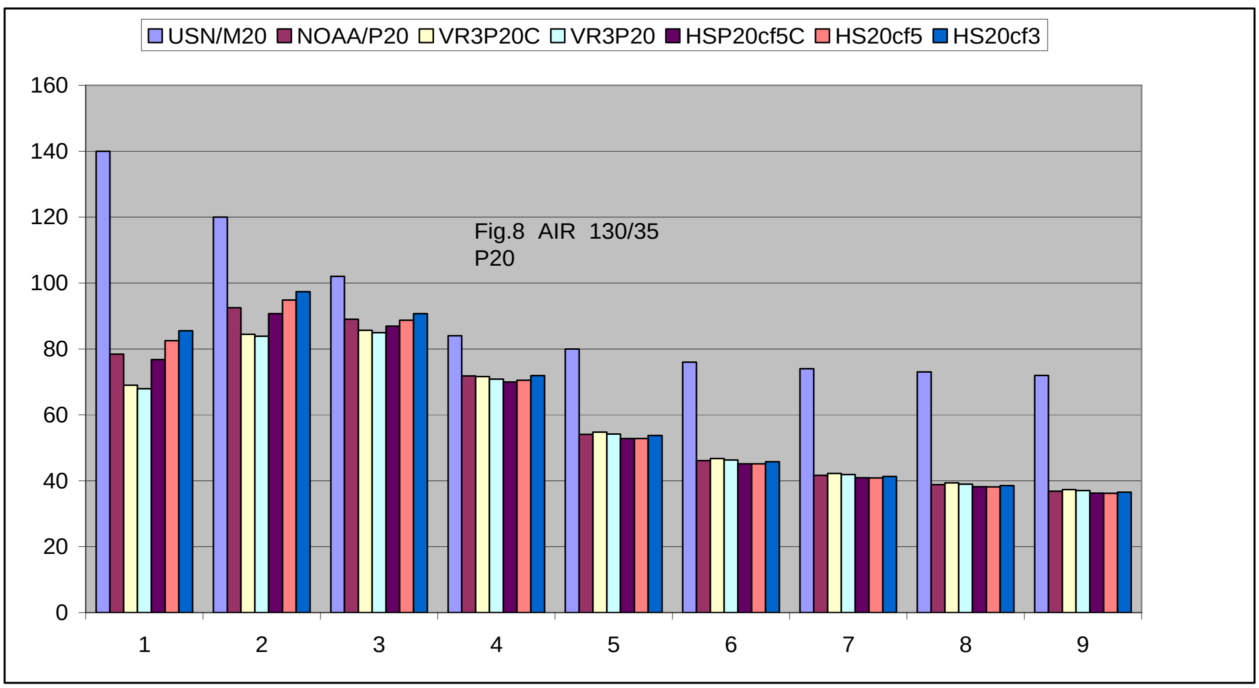


Figure 8. Air 130/35 P20 (arrive 20')

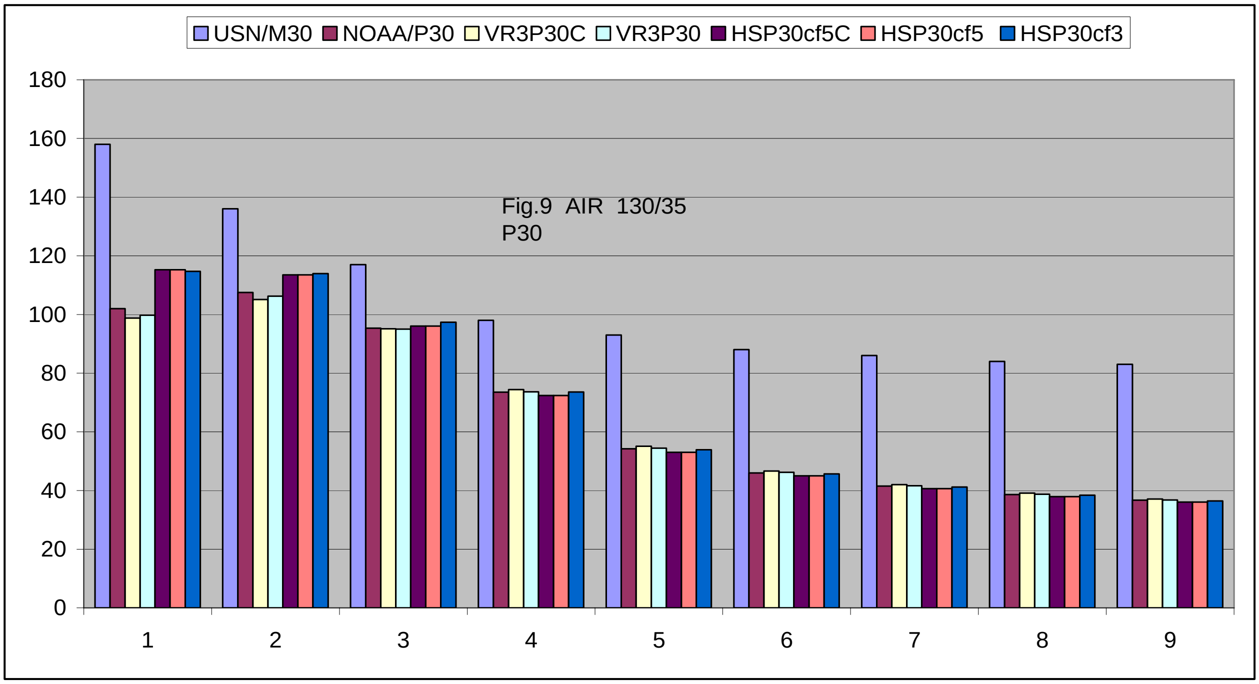


Figure 9. Air 130/35 P30 (arrive 30')

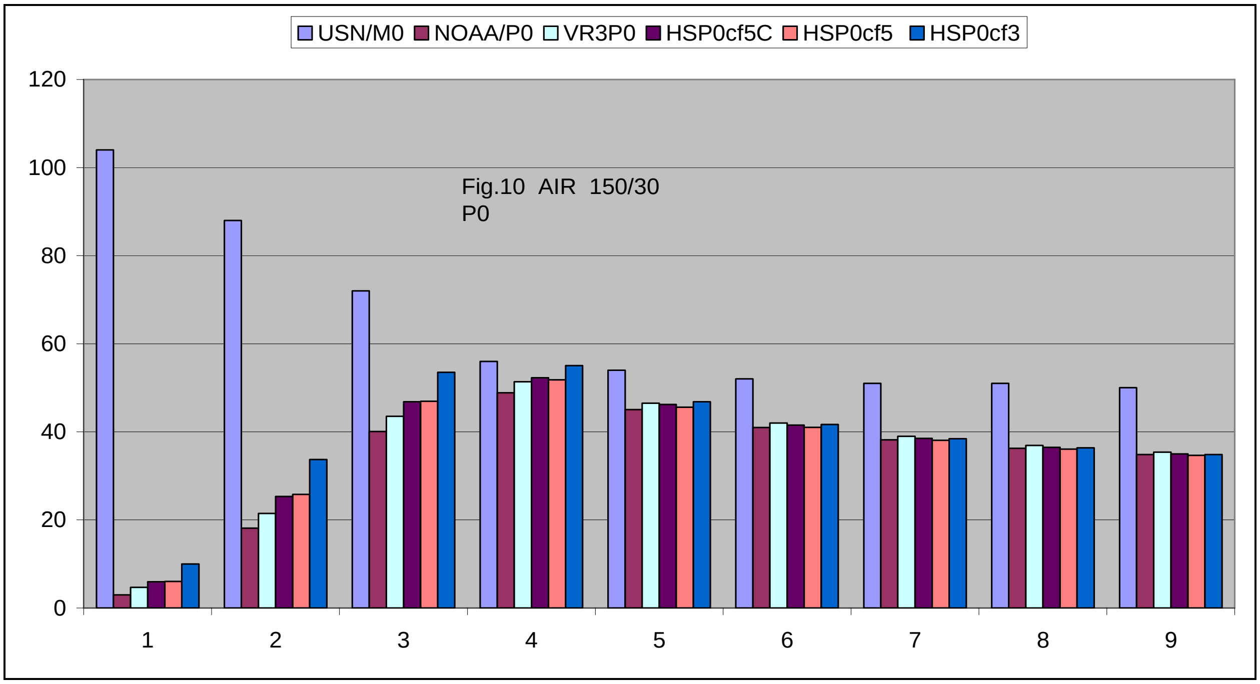


Figure 10. Air 150/30 P0 (arrive surface)

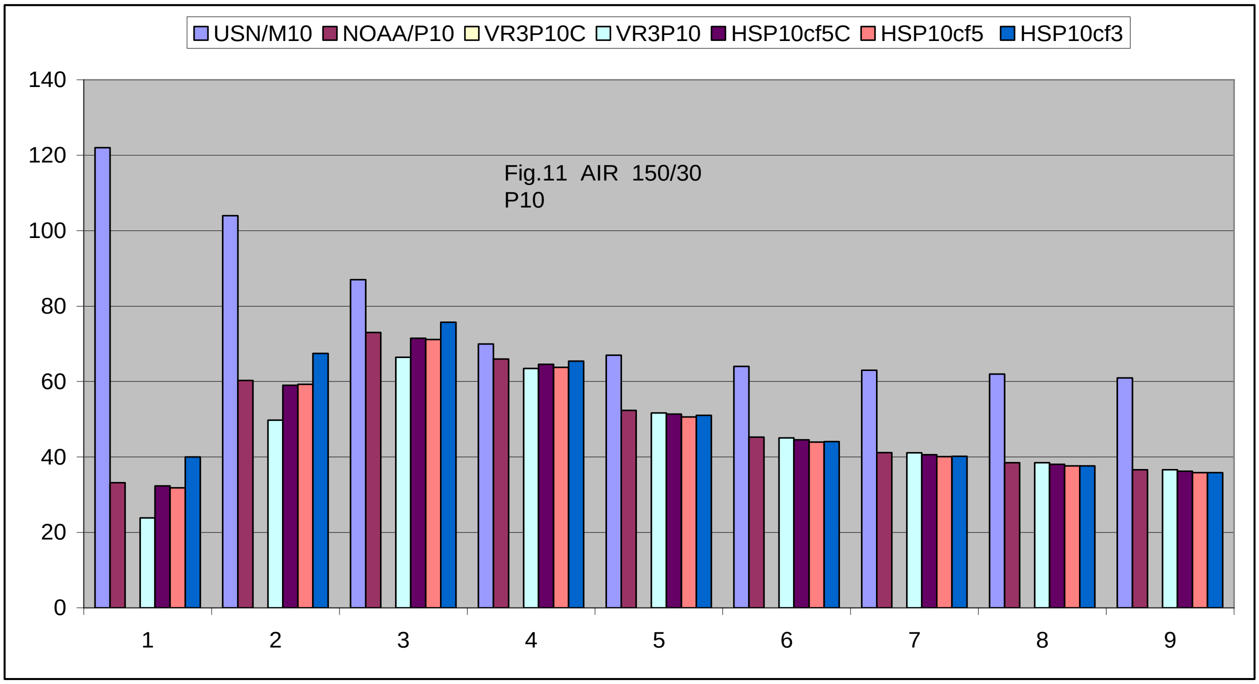


Figure 11. Air 150/30 P10 (arrive 10')

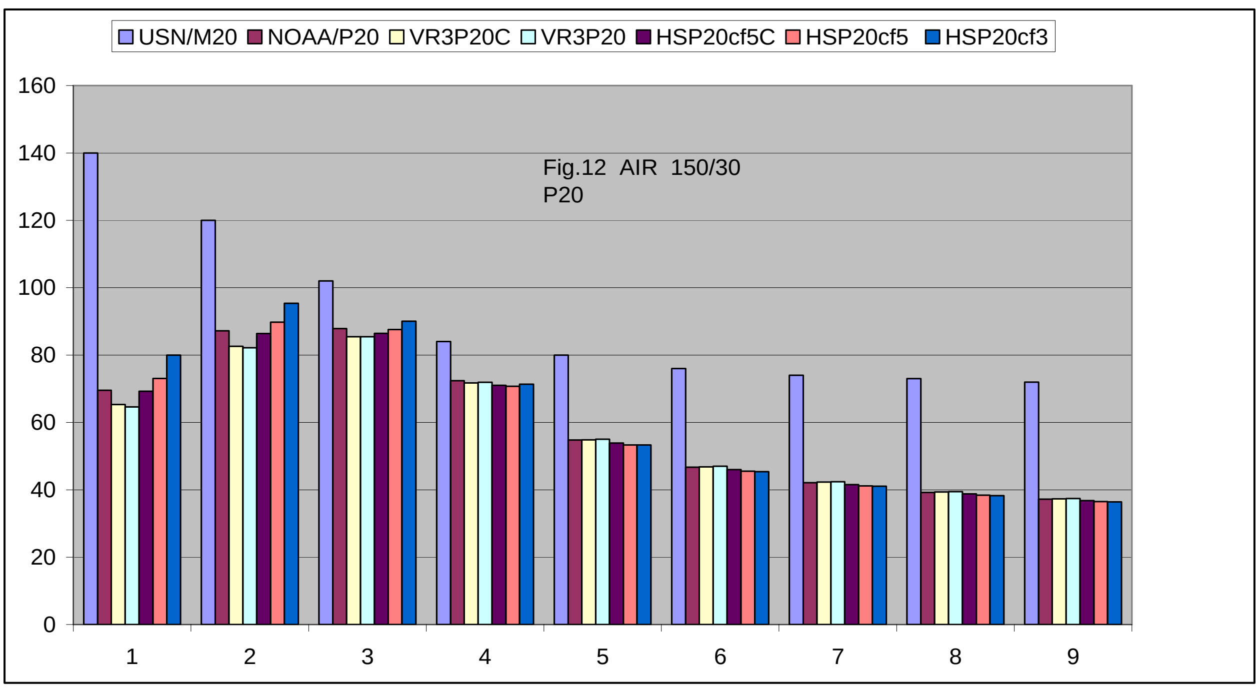


Figure 12. Air 150/30 P20 (arrive 20')

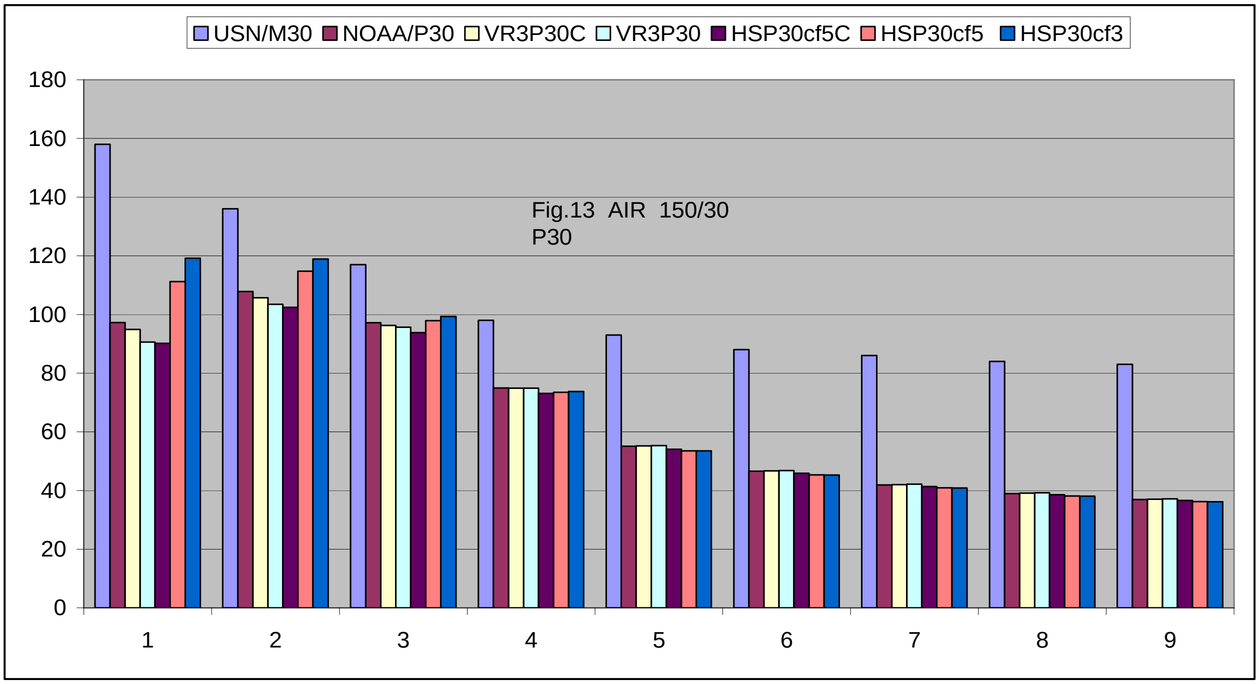


Figure 13. Air 150/30 P30 (arrive 30')

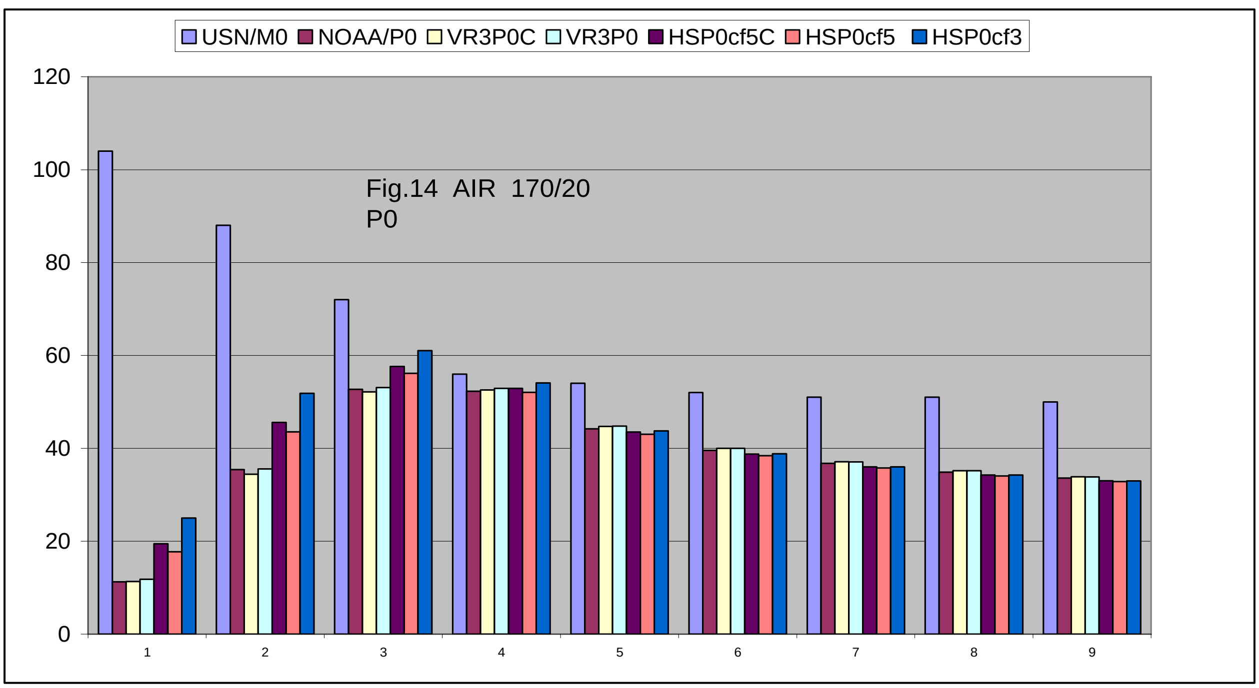


Figure 14. Air 170/20 P0 (arrive surface)

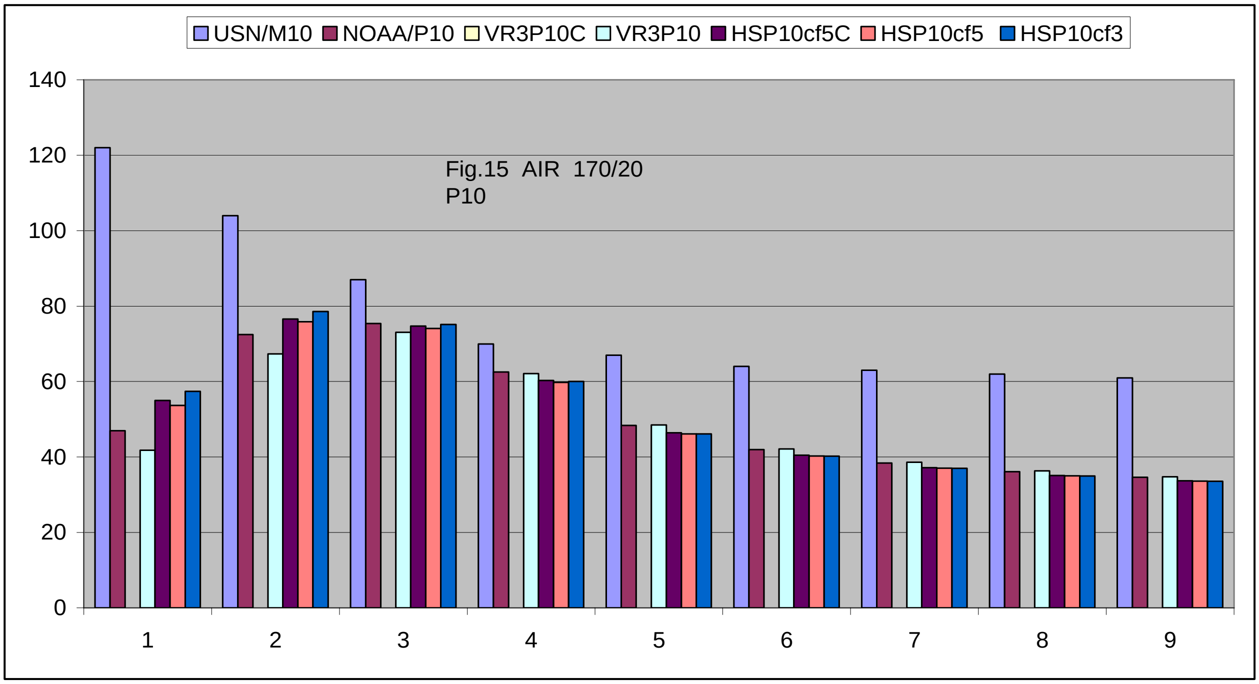
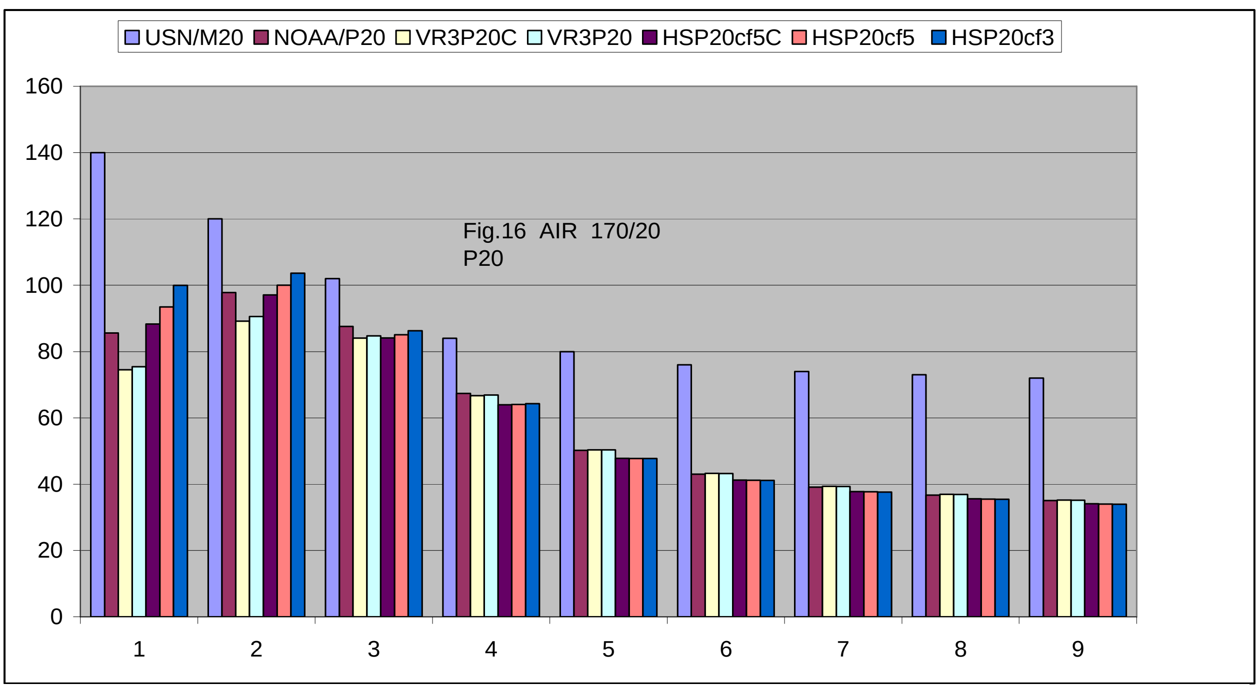


Figure 15. Air 170/20 P10 (arrive 10')



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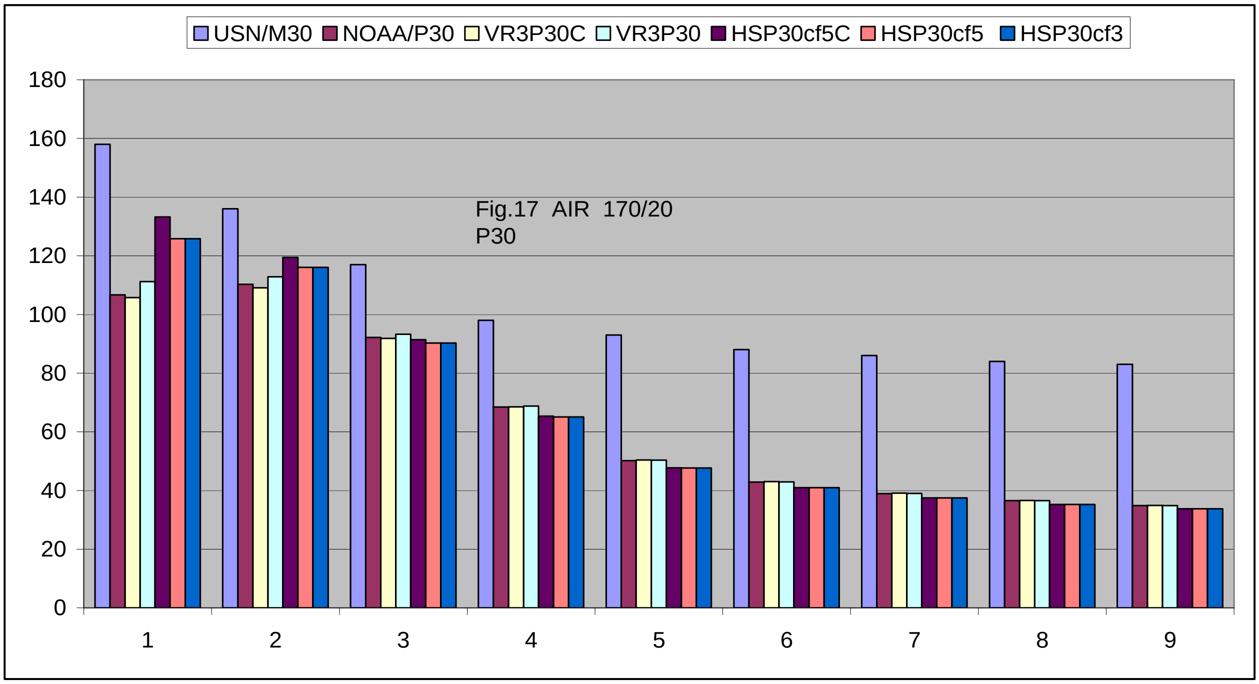


Figure 17. Air 170/20 P30 (arrive 30')

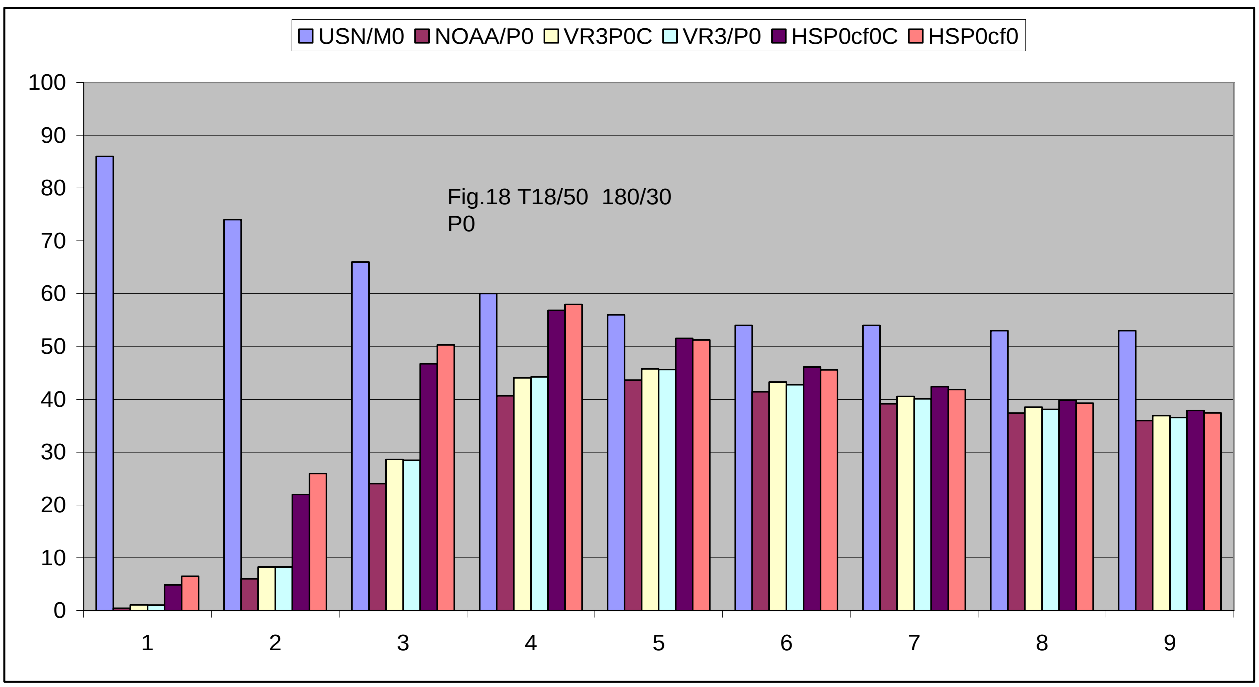


Figure 18. T18/50 180/30 P0 (arrive surface)

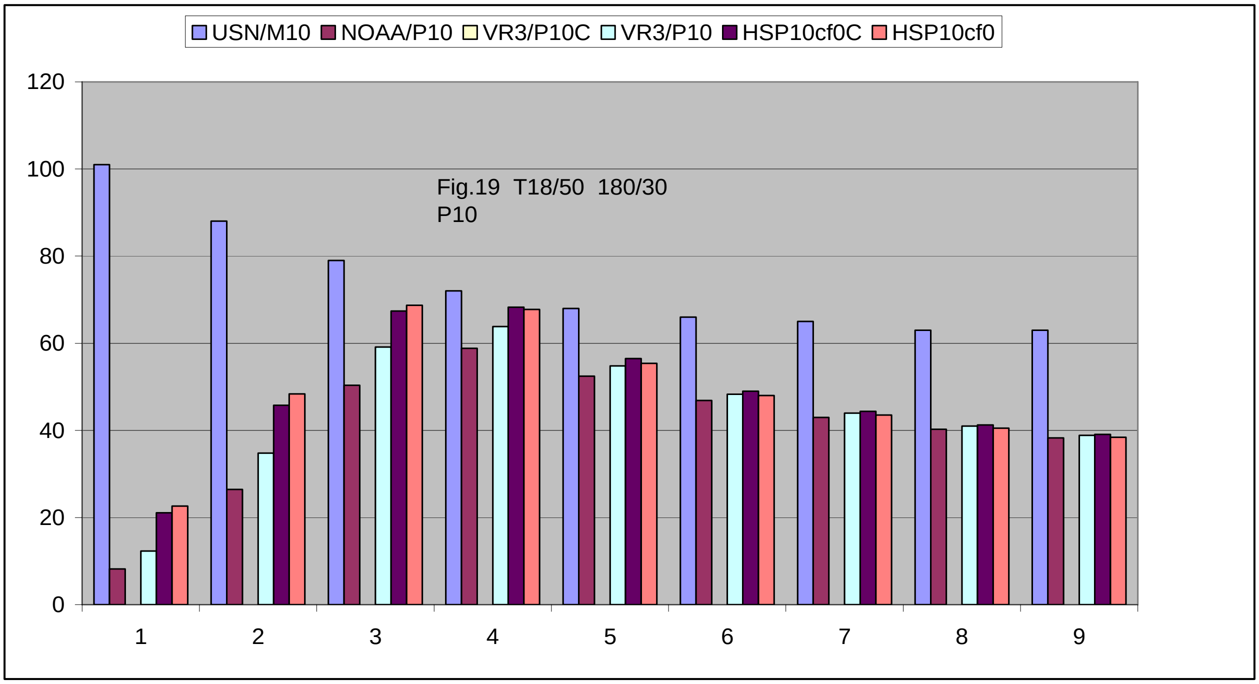


Figure 19. T18/50 180/30 P10 (arrive 10')

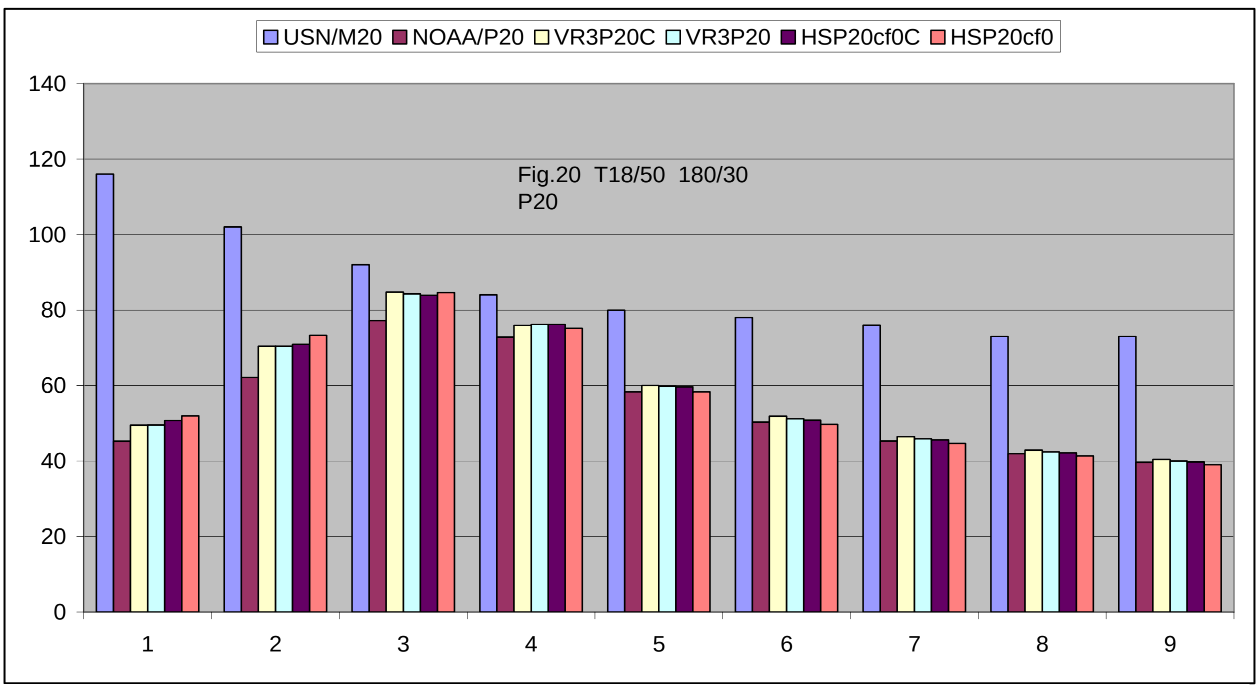


Figure 20. T18/50 180/30 P20 (arrive 20')

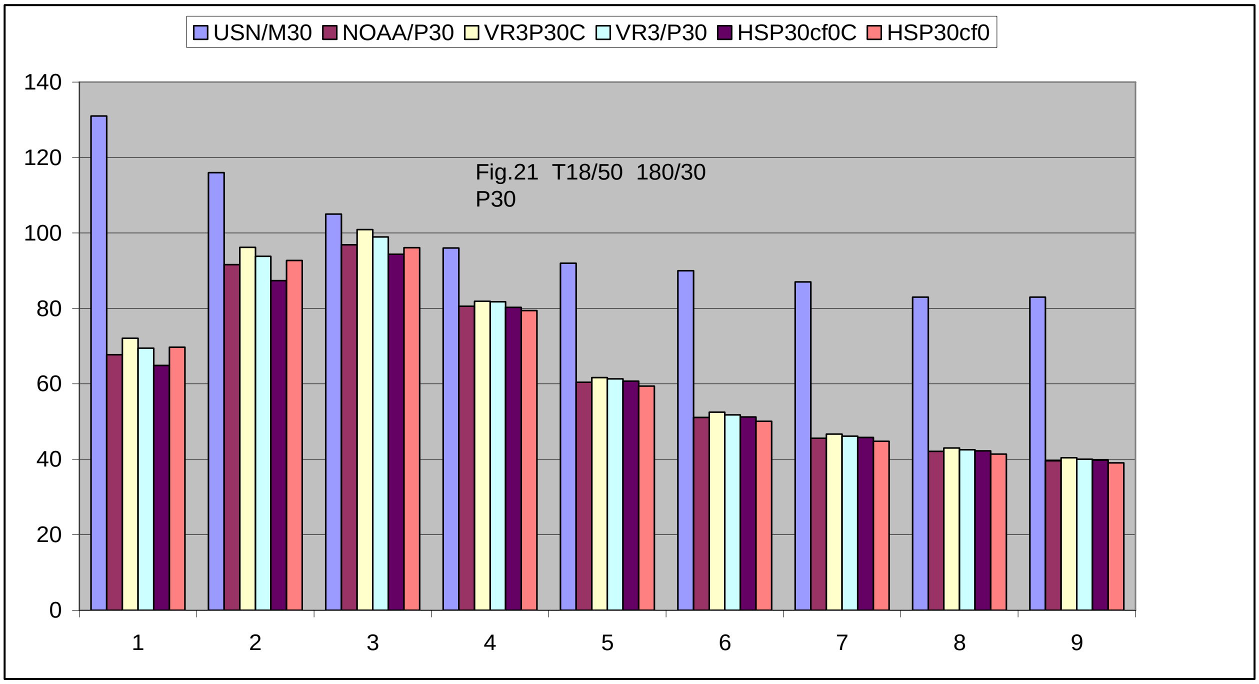


Figure 21. T18/50 180/30 P30 (arrive 30')

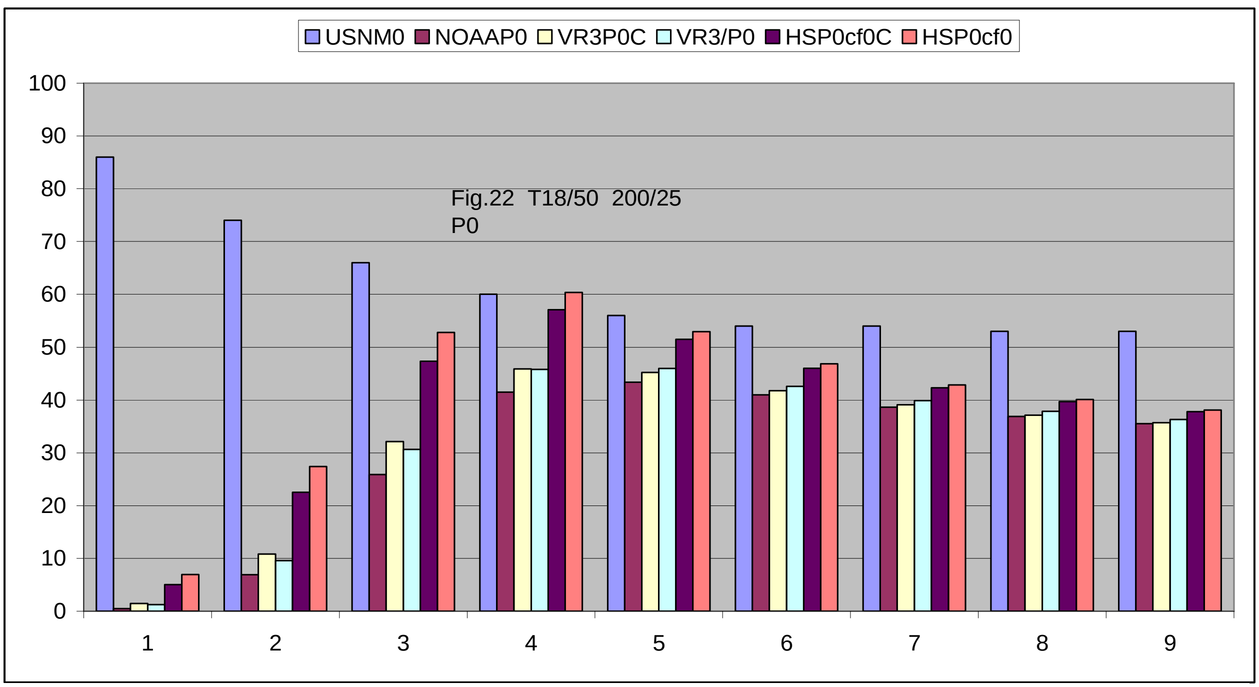


Figure 22. T18/50 200/25 P0 (arrive surface)

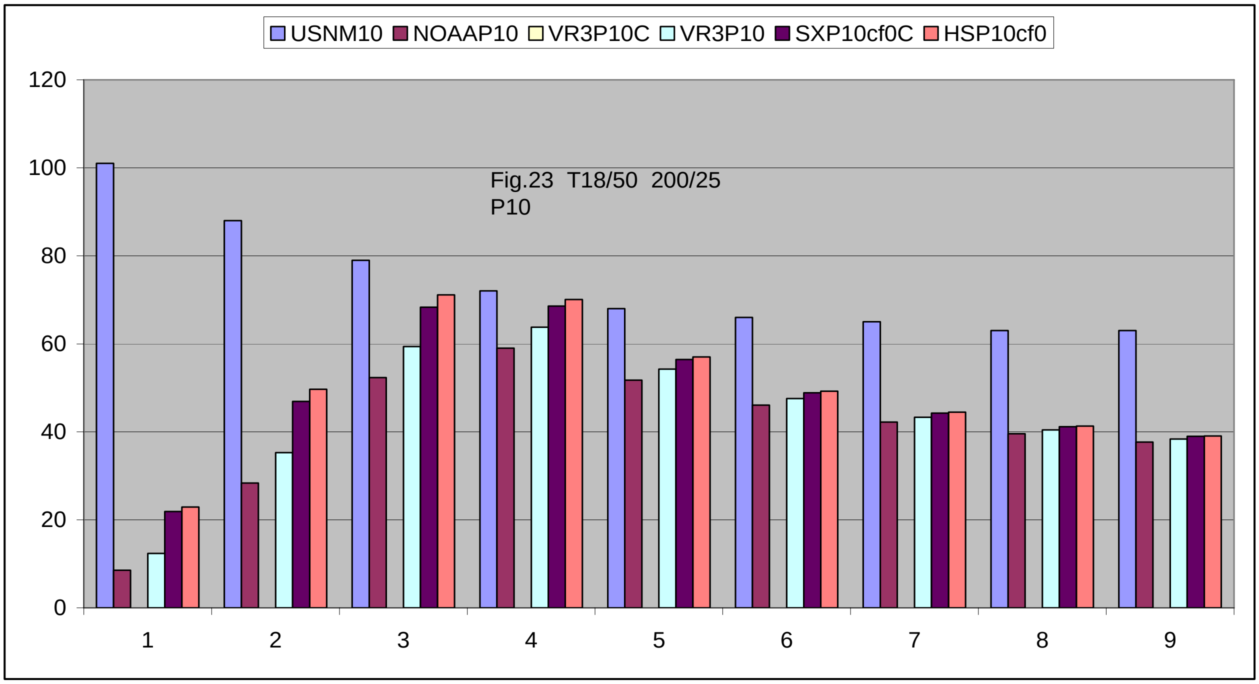


Figure 23. T18/50 200/25 P10 (arrive 10')

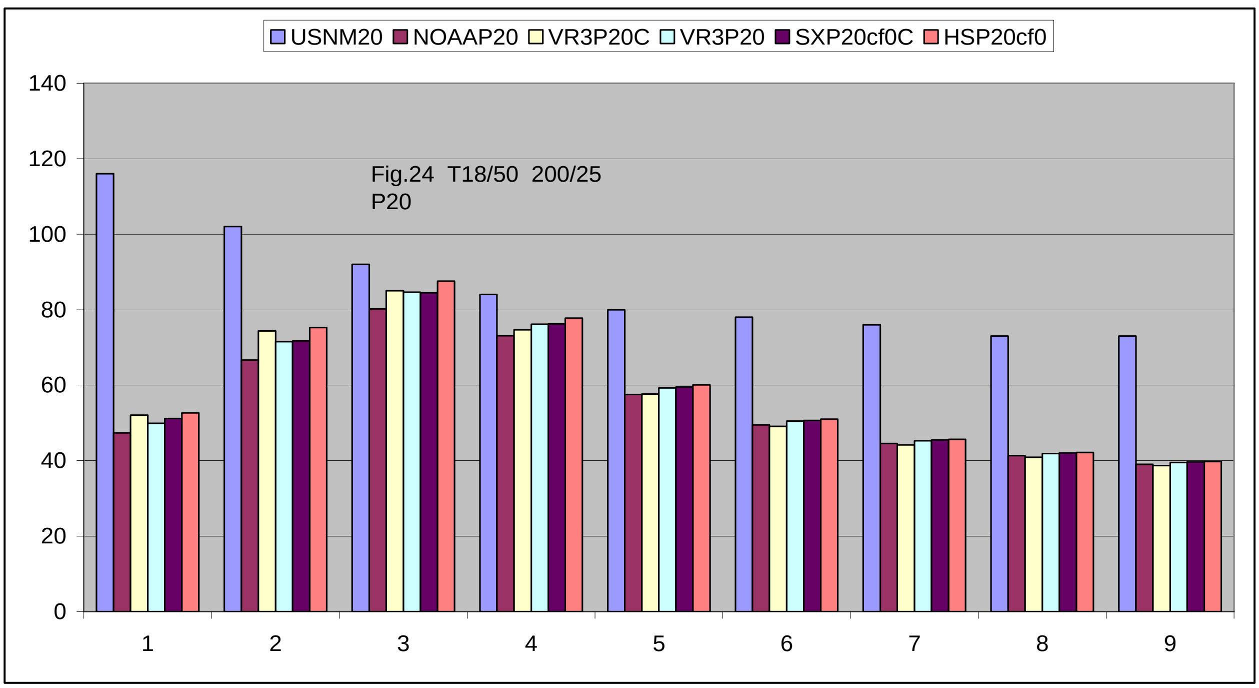


Figure 24. T18/50 200/25 P20 (arrive 20')

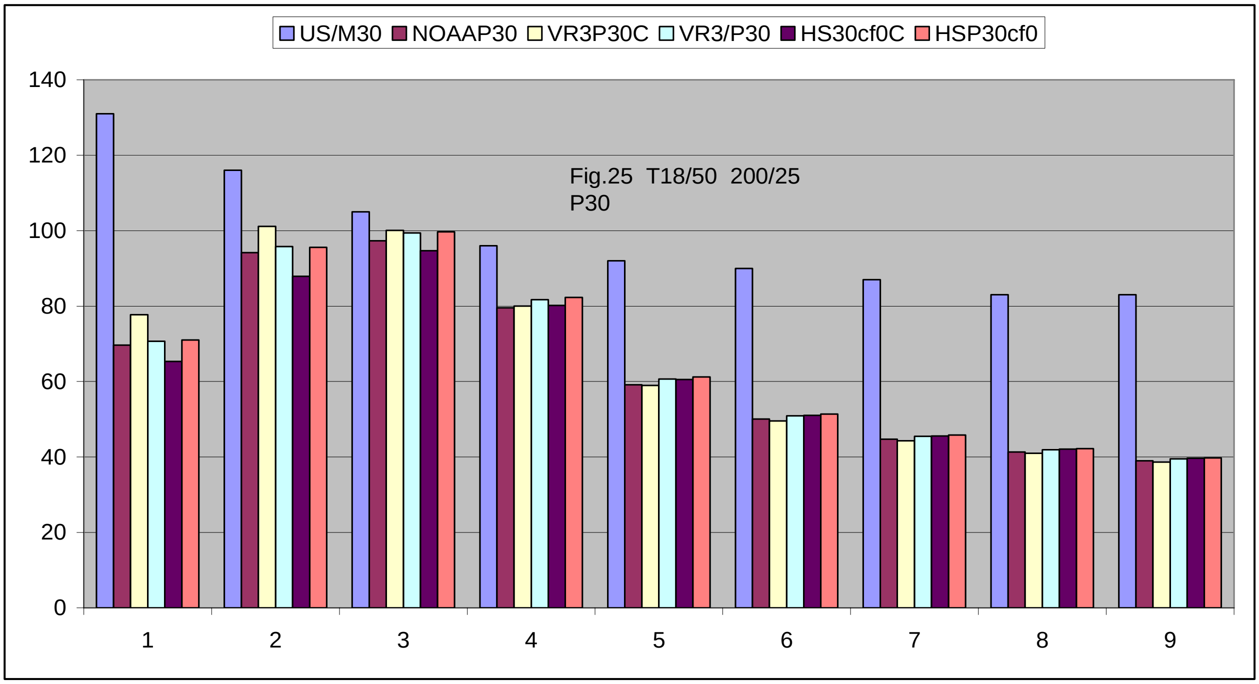


Figure 25. T18/50 200/25 P30 (arrive 30')

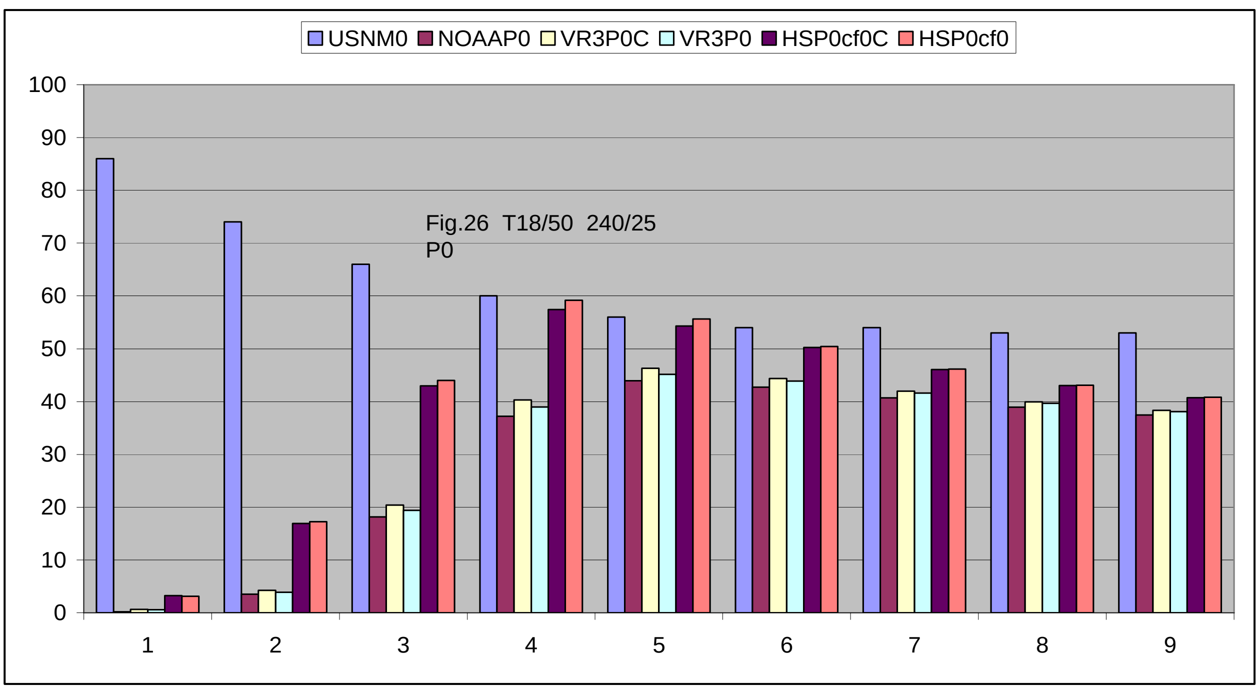


Figure 26. T18/50 240/25 P0 (arrive surface)

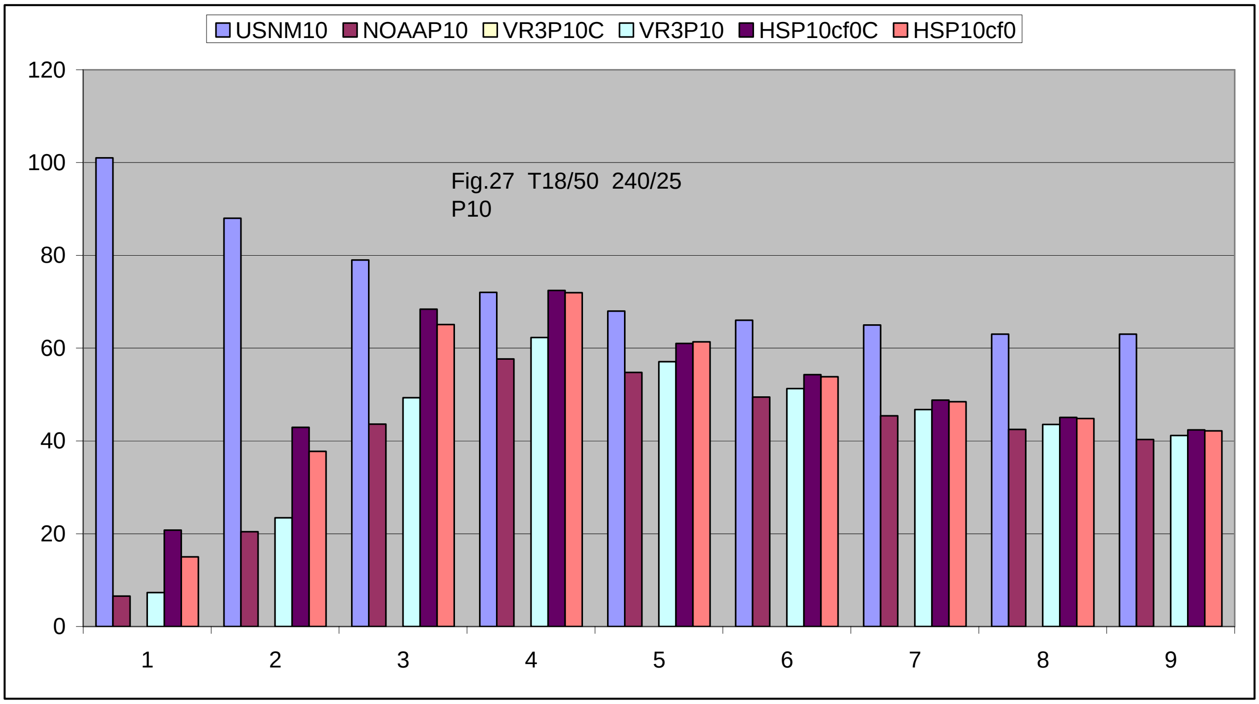
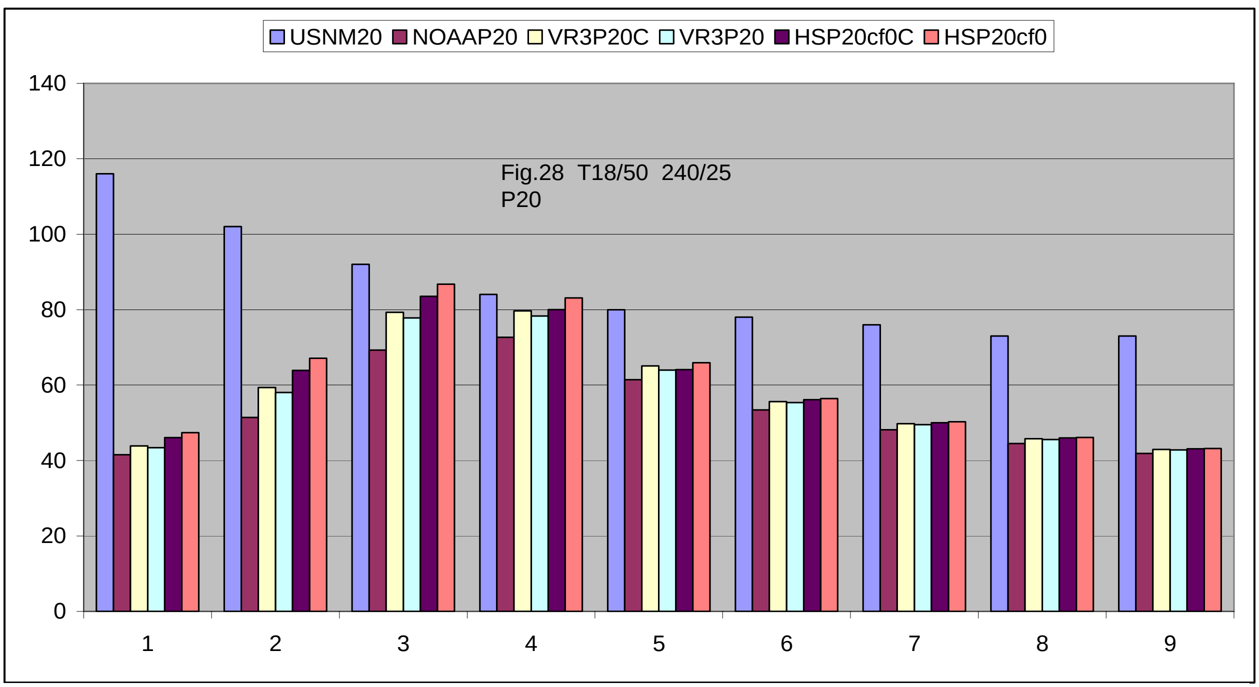


Figure 27. T18/50 240/25 P10 (arrive 10')



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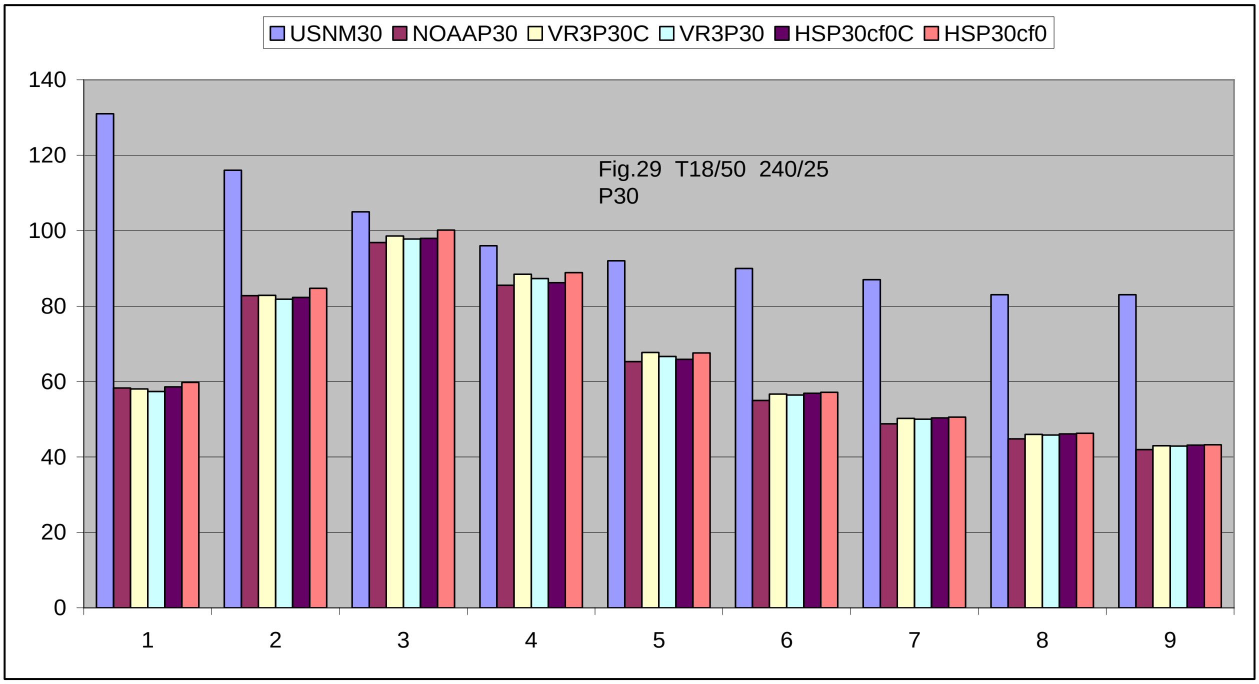

Figure 29. T18/50 240/25 P30 (arrive 30')

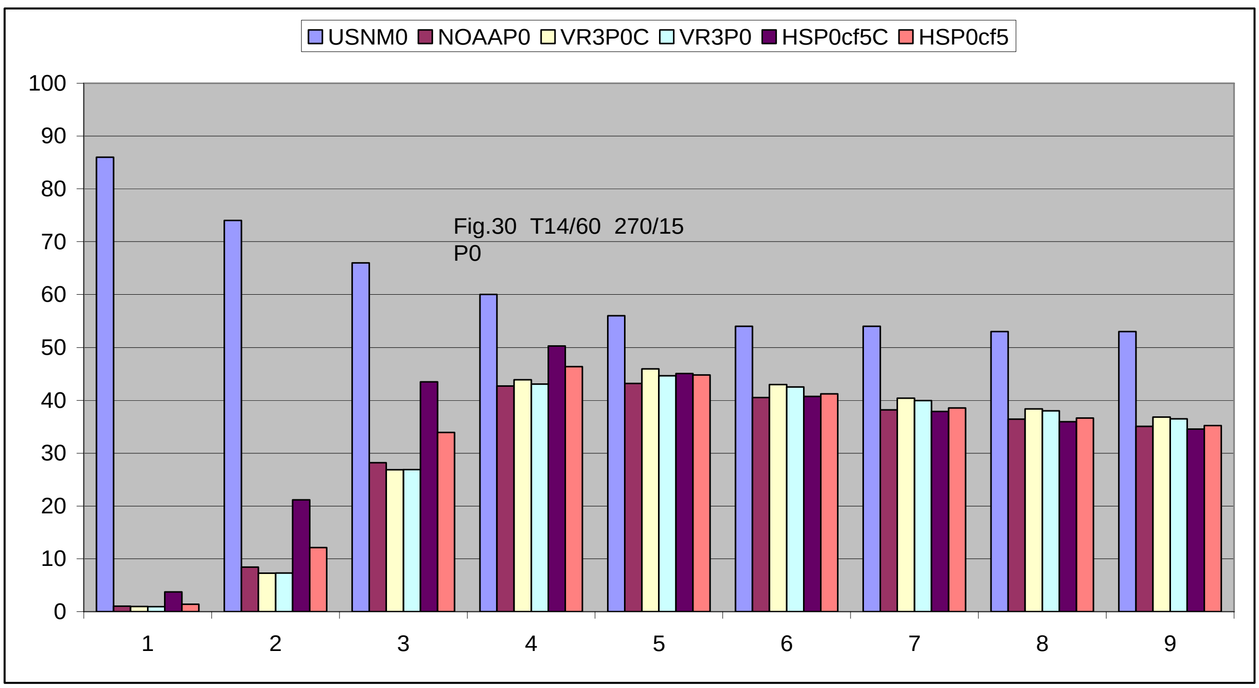

Figure 30. T14/60 270/15 P0 (arrive surface)

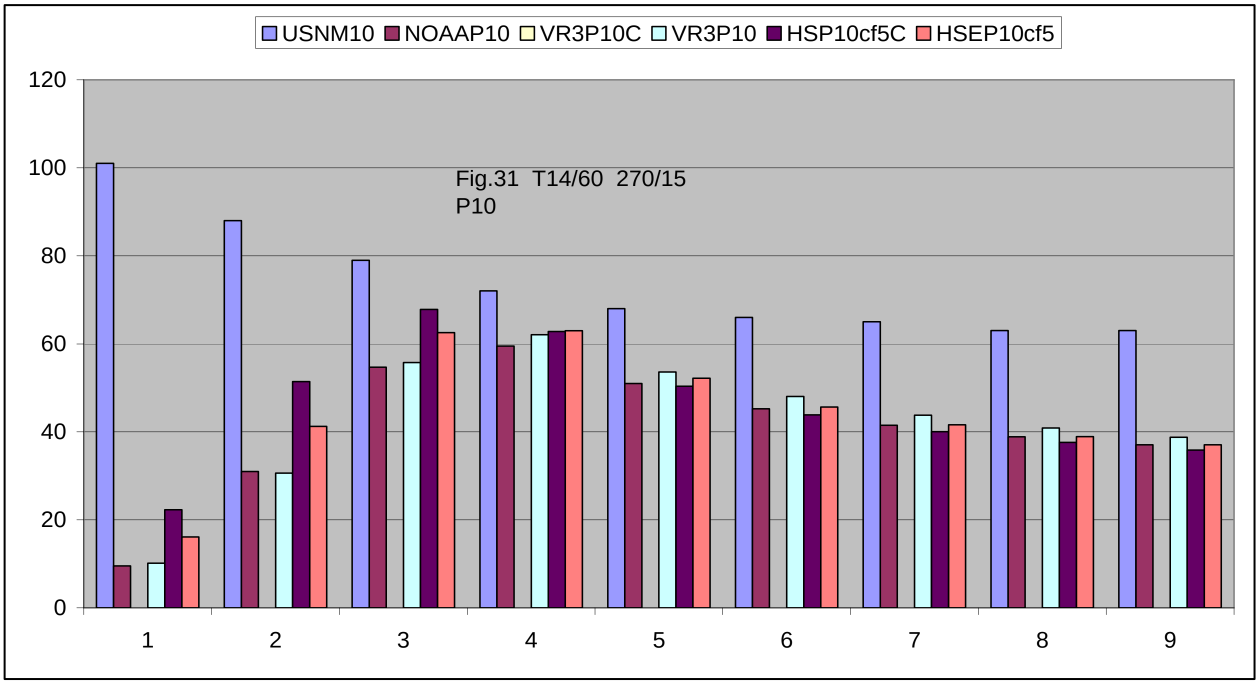

Figure 31. T14/60 270/15 P10 (arrive 10')

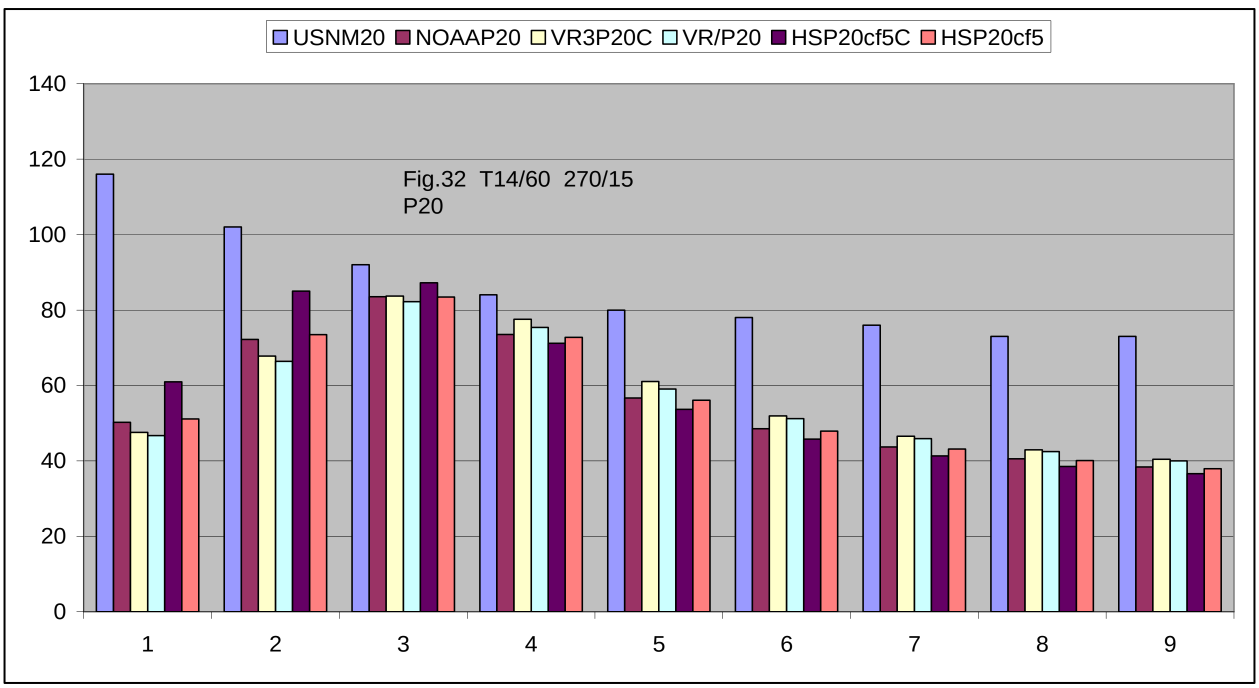

Figure 32. T14/60 270/15 P20 (arrive 20')

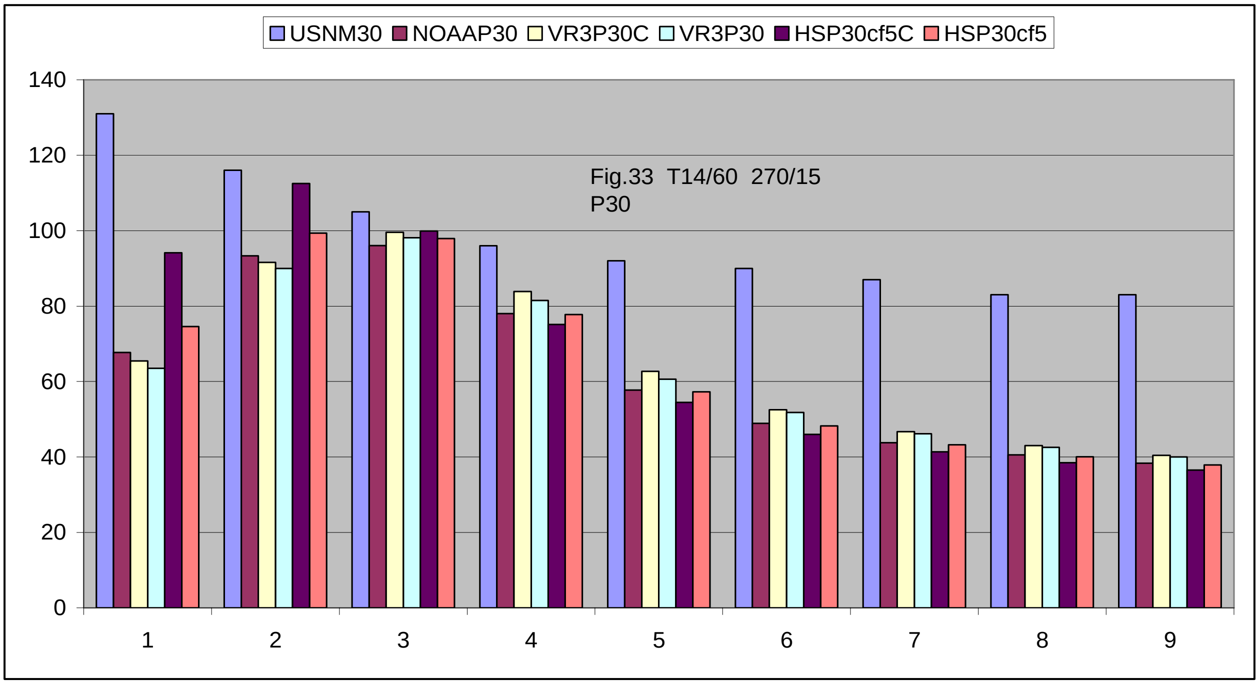

Figure 33. T14/60 270/15 P30 (arrive 30')

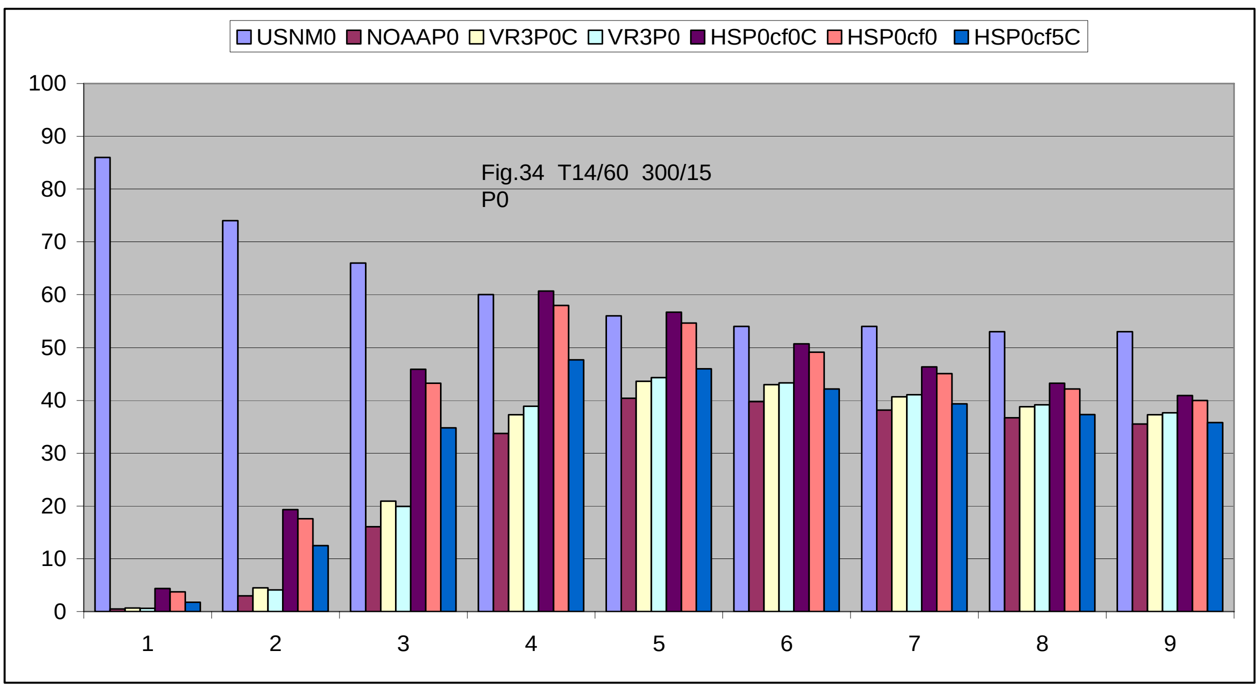

Figure 34. T14/60 300/15 P0 (arrive surface)

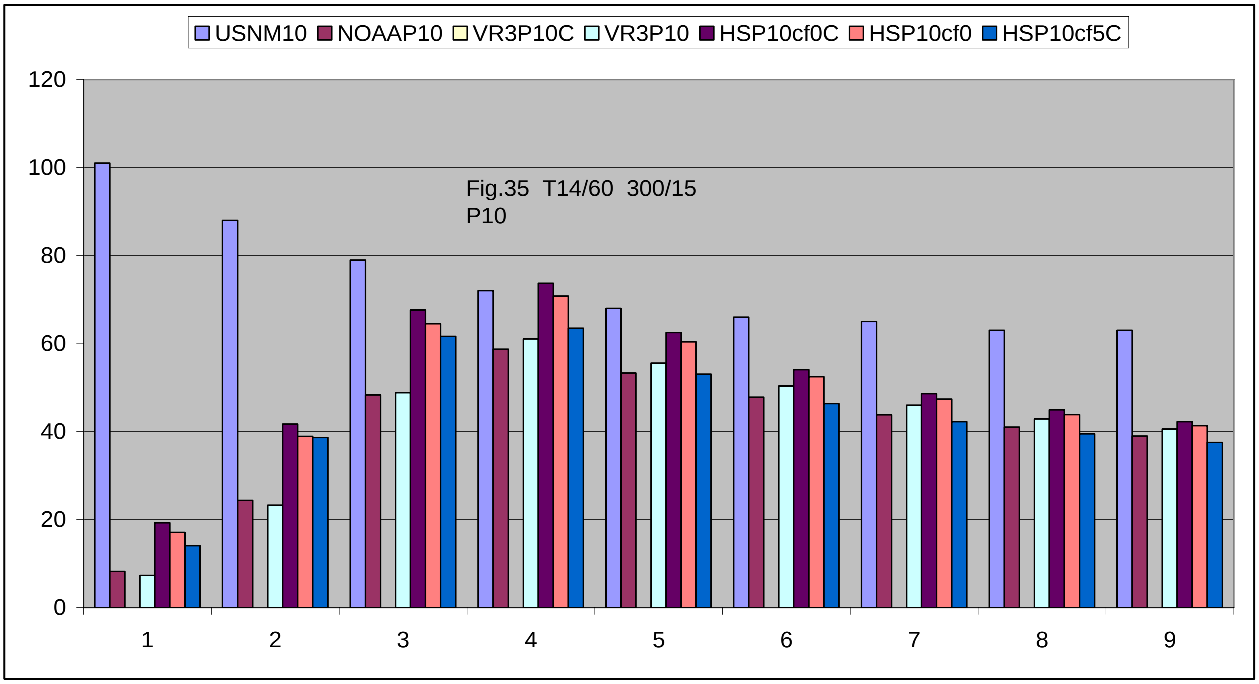

Figure 35. T14/60 300/15 P10 (arrive 10')

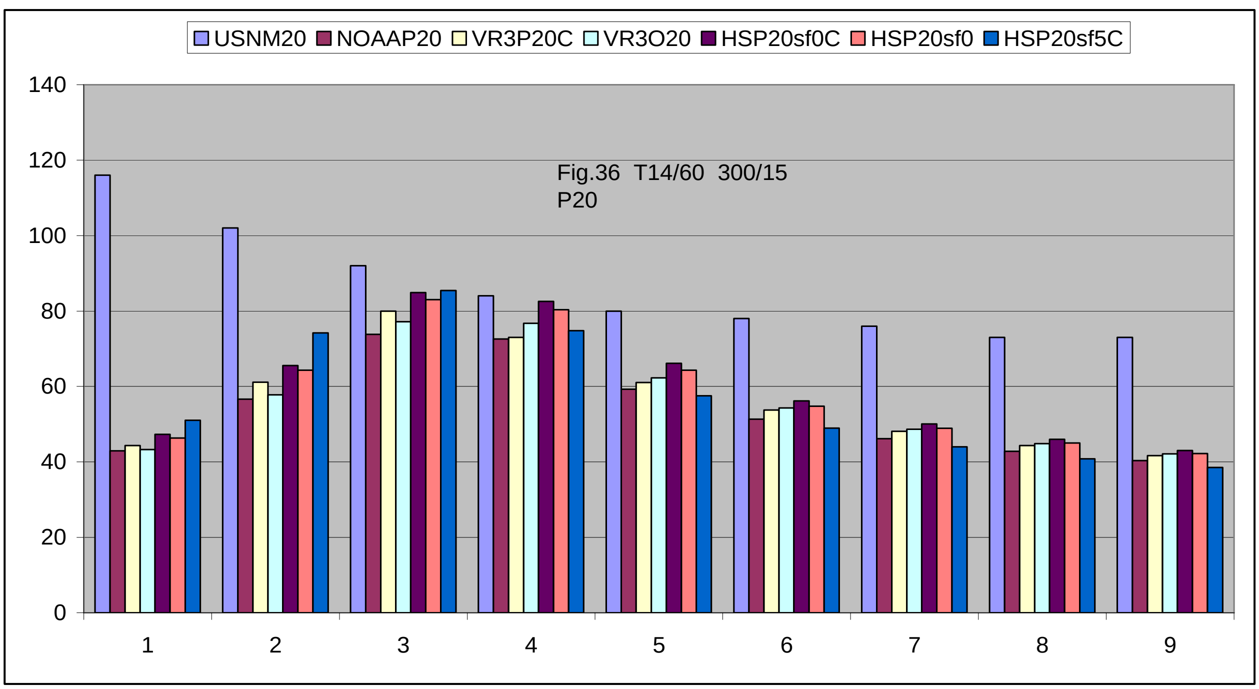

Figure 36. T14/60 300/15 P20 (arrive 20')

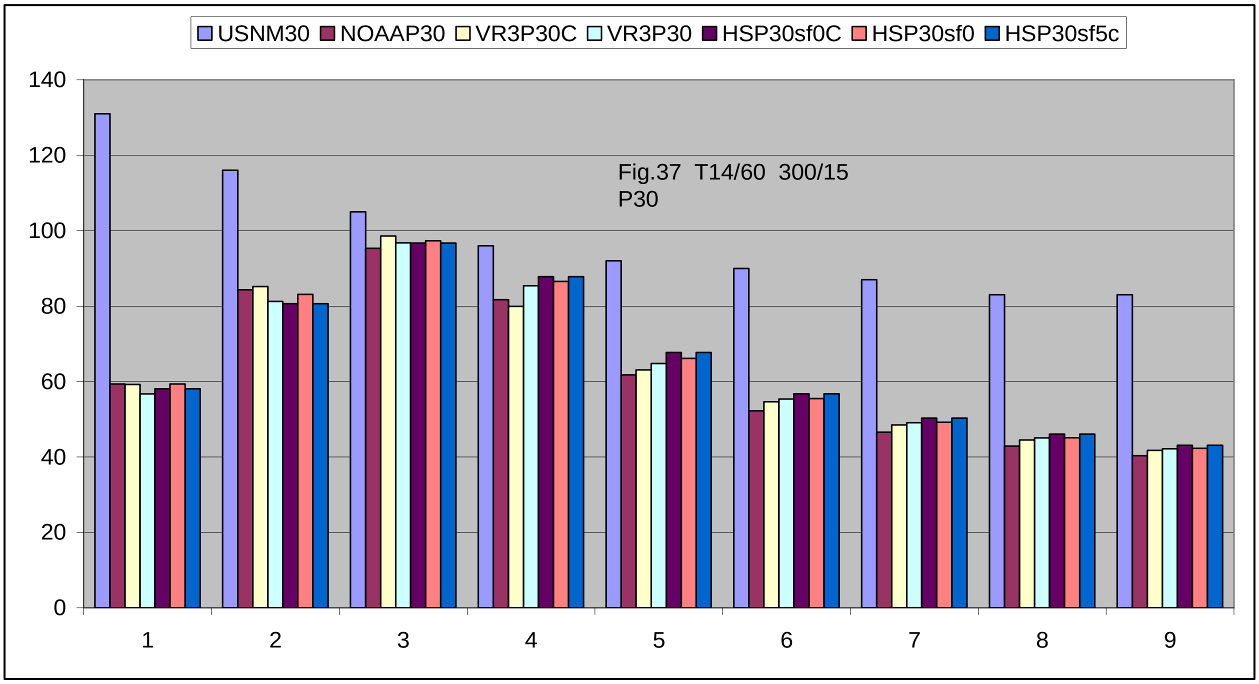

Figure 37. T14/60 300/15 P30 (arrive 30')

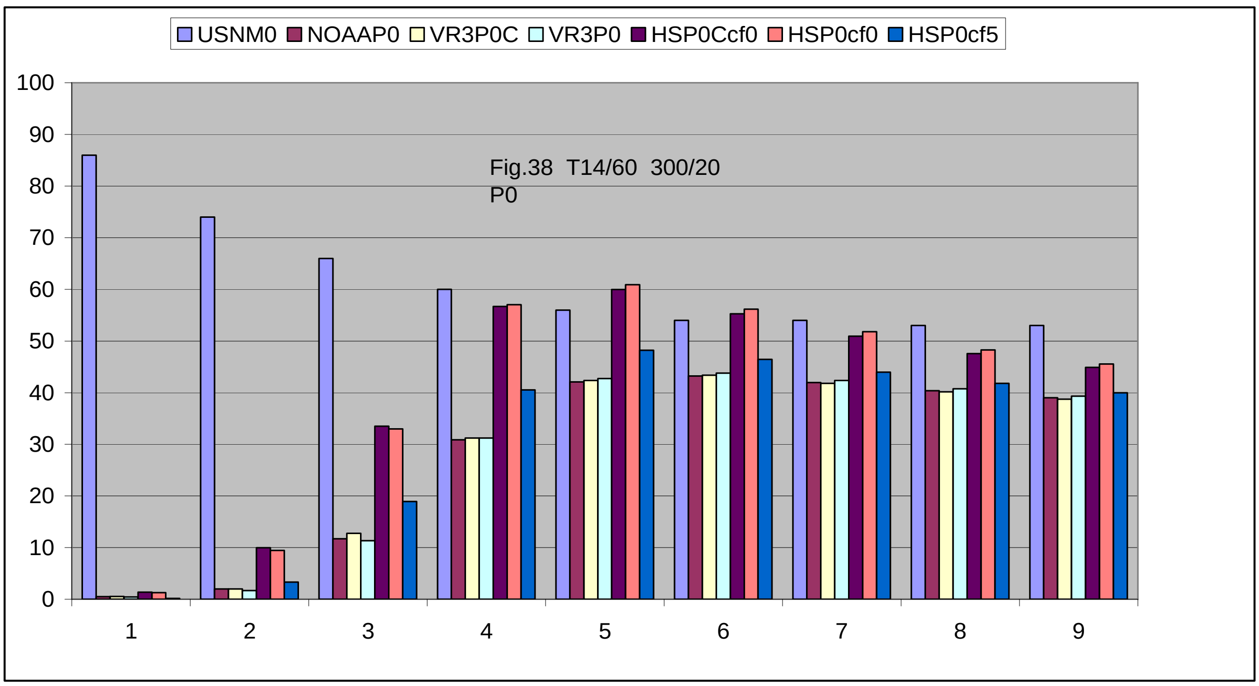

Figure 38. T14/60 300/20 P0 (arrive surface)

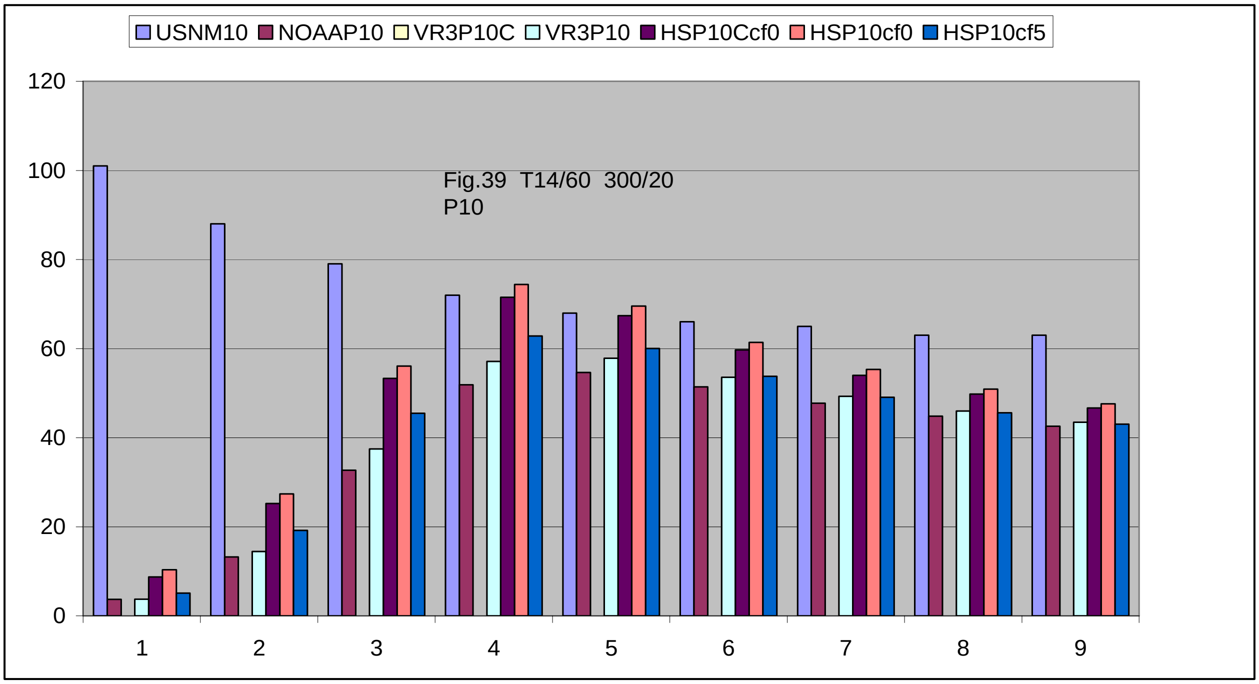

Figure 39. T14/60 300/20 P10 (arrive 10')

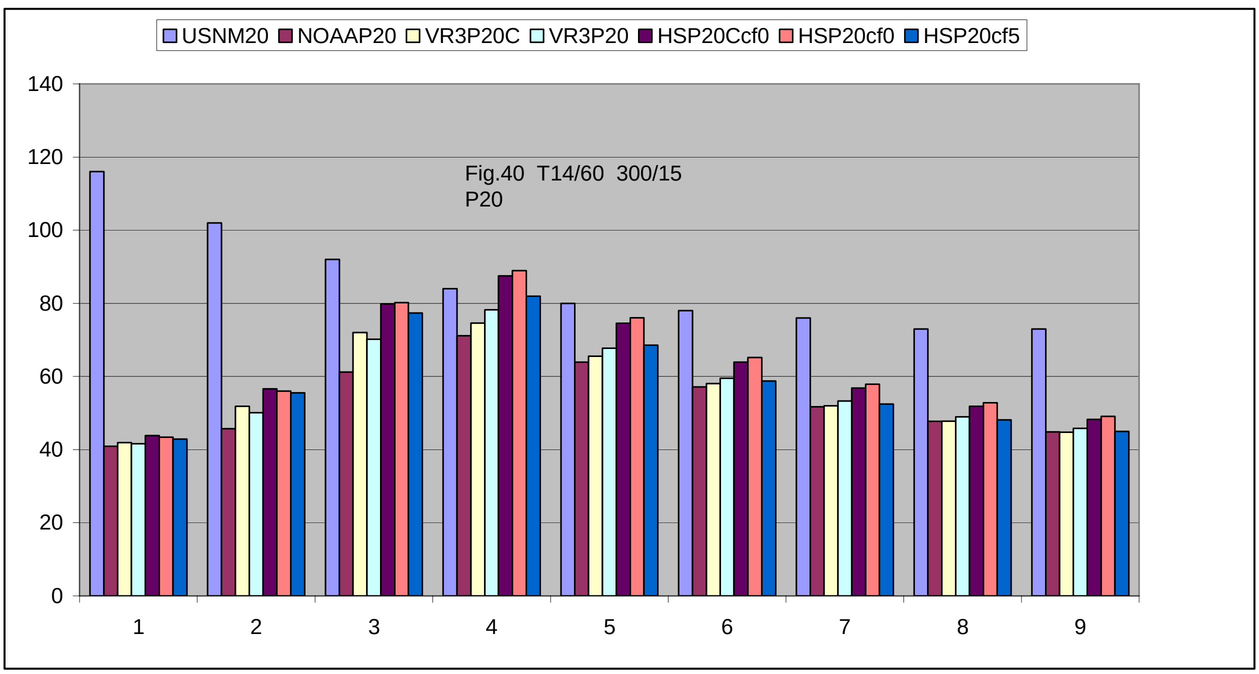

Figure 40. T14/60 300/15 P20 (arrive 20')

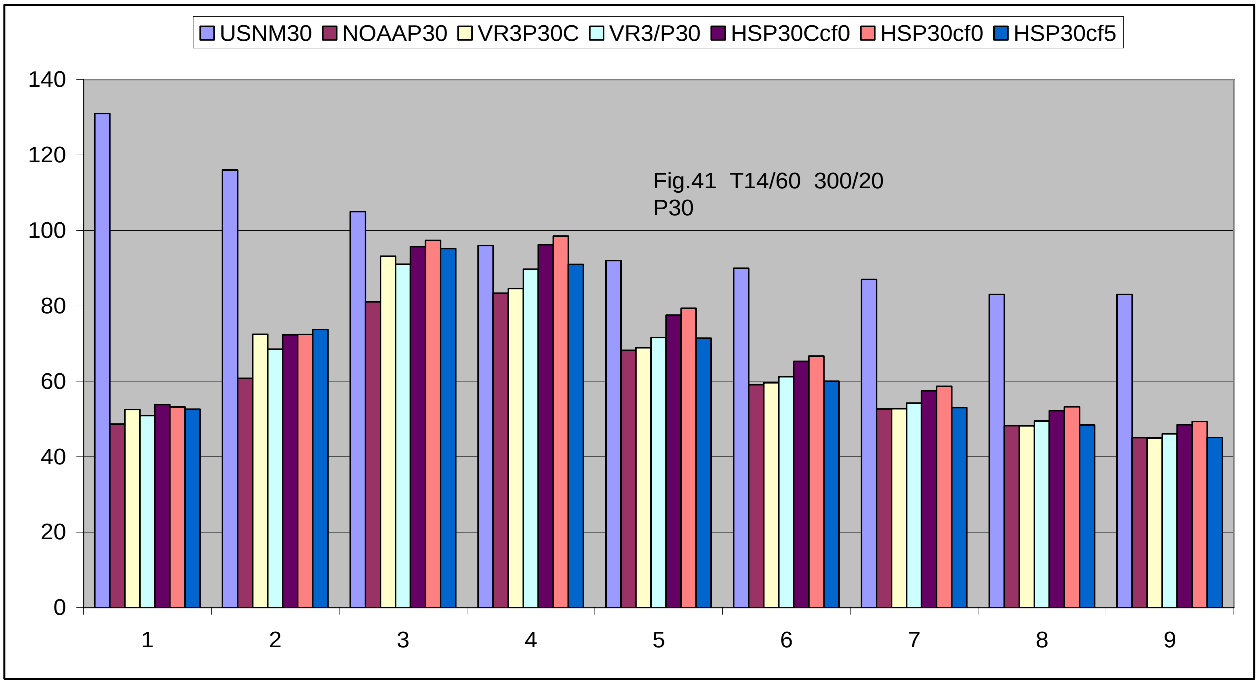

Figure 41. T14/60 300/20 P30 (arrive 30')