CURRENT GPS/GLONASS TIME REFERENCES AND UTC

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Abstract

The world's two global satellite navigation systems, GPS and GLONASS, will both become operational during the early 1990's. Each will offer, independently of the other, precise location and time transfer continuously anywhere in the world and indeed in space itself. Many potential users, in particular the civil aviation community, are keenly interested in a joint GPS/GLONASS operation since it would offer substantial advantages in defining and maintaining the integrity of the navigation aid. The question arises of compatibility of GPS/GLONASS from the point of view of satellite on-board clocks, their system references, their national standards and ultimately UTC. Results are presented on the characterisation of GLONASS system and spacecraft clocks as compared to their Navstar GPS counterparts.

INTRODUCTION

GLONASS provides worldwide time dissemination and time transfer services in the same manner as Navstar GPS with both exhibiting substantial advantages over other existing timing services. Time transfer is both efficient and economic in the sense that direct clock comparisons can be achieved via GLONASS between widely separated sites without the use of portable clocks. Event time tagging can be achieved with the minimum of effort and users can reacquire GLONASS time at any instant due to the continuous nature of time aboard the satellites.

The first release from the Soviet Union of detailed GLONASS information occurred at the International Civil Aviation Organisation (ICAO) special committee meeting on Future Air Navigation Systems (FANS) in Montreal in May 1988 [1]. In full operation GLONASS will have 24 satellites in orbit, 8 satellites separated by 45 degrees in phase in each of three planes 120 degrees apart. During the present pre-operational phase only two of the planned orbital planes have been occupied. Currently eight GLONASS satellites are in full operation, four each in planes 1 and 3 (see Table 1); this gives single satellite coverage at most locations almost 24 hours a day.

SAT ID	COSMOS	GLONASS	CHN	L1/MHz	PLANE
1988-43A	1946	34	12	1608.7500	1
1988-43C	1948	36	24	1615.5000	1
1988-85C	1972	39	10	1607.6250	3
1989- 1A	1987	40	9	1607.0625	1
1989- 1B	1988	41	6	1605.3750	1
1990-45A	2079	44	21	1613.8125	3
1990-45B	2080	45	3	1603.6875	3
1990-45C	2081	46	15	1610.4375	3

Current Active GLONASS Satellites 30-11-90.
Table 1

The only new satellites to appear during 1990 have been the three with international identifiers 1990- 45A,B and C.

TIME FROM GPS/GLONASS

Time transfer from GPS/GLONASS is achieved in a straightforward manner, Figure 1. Each satellite transmits signals referenced to its own on-board clock. The Control Segment monitors the satellite clocks and determines their offsets from the common GPS/GLONASS system time. The clock offsets are then uploaded to satellites as part of their transmitted data message. A user at a known location receives signals from a satellite and by decoding the data stream modulated on to the transmission, is able to obtain the position of the satellite, as well as the satellite's clock offset from the common system time. Hence the signal propagation time can be calculated at any instant. The time at which the signals are transmitted is also contained in the data message; by combining this with the propagation time and correcting first for atmospheric effects and other delays and then for the satellite's own clock offset, the user can effect transfer to GPS/GLONASS system time. Correction to an external time scale (such as UTC(USNO) or UTC(SU)) is then possible since the relevant offset is one of the transmitted data parameters. Any other user who has the same satellite visible is also able to transfer to the same common time scale.

SATELLITE CLOCK OFFSETS

GLONASS clock offsets are transmitted as part of each satellite's ephemeris data once every half-hour. The clock information arrives in the form of two parameters (i) the SV clock phase offset from GLONASS system time, a0 and (ii) the SV clock fractional frequency offsets from the GLONASS system reference, a1. The clock offset a2, the second rate of change of phase used in GPS, is not employed by GLONASS as the half-hour update makes this unnecessary.

GLONASS does transmit one additional timing parameter - the phase offset between system time and its reference standard, A0. This last offset is normally only updated once a day. There is again a parallel here between the two satellite navigation systems as GPS also transmits a phase offset between GPS system time and its reference standard, UTC(USNO). The added complication in the case of GLONASS is that the reference standard has not been fixed with time. In the official Soviet documentation, this parameter is described as "..... correction to the system time scale relative to the time scale to which the ephemeris and satellite synchronisation parameters are calculated". At certain times, this latter reference standard has been UTC(SU) but at other times a second (and different standard) has been employed probably for experimental purposes. In the absence of any solid information, this second reference standard is described (by us) as Moscow Time. Perhaps a more appropriate name would be "auxiliary reference standard". Table 2 shows the range and resolution of the GLONASS clock correction parameters.

GLONASS	Bits*	Scale	Range	Resolution	Units
a0	22	2^{-30}	$\pm 2 \times 10^{-3}$	9×10^{-10}	s
a1	11	2^{-40}	$\pm 9 \times 10^{-10}$	9×10^{-13}	s/s
A0	28	2^{-27}	± 1	7×10^{-9}	s

* MSB = sign bit.
GLONASS clock correction parameters
Table 2

GPS/GLONASS TIME TRANSFER MEASUREMENTS

A series of measurements has been conducted of the difference between UTC(USNO) and both GPS and GLONASS system times. A prototype single channel GLONASS/Navstar GPS receiver [2] allows time comparisons between system times and a 1 pps reference synchronised to UTC(USNO). The Navstar system time / UTC(USNO) comparison is used as a calibration of the measurement since the offset between GPS time and UTC(USNO) is already known - it is transmitted as part of the GPS data message.

DATE	SATELLITE	READINGS (1/SEC)	AVERAGE OFFSET/ns	STANDARD DEVIATION/ns
26/10/90	NAVSTAR 2	2336	-194	76
26/10/90	NAVSTAR 3	2157	-195	49
26/10/90	NAVSTAR 6	3413	-242	54
26/10/90	NAVSTAR 9	4850	-228	72
26/10/90	NAVSTAR 11	4312	-185	55
26/10/90	NAVSTAR 12	3058	-214	51
26/10/90	NAVSTAR 13	4300	-192	58
26/10/90	NAVSTAR 19	538	-205	50
26/10/90	GLONASS 34	3224	5425	58
26/10/90	GLONASS 36	4291	5444	64
26/10/90	GLONASS 39	3052	5449	60
26/10/90	GLONASS 40	4111	5437	71
26/10/90	GLONASS 41	4484	5436	54
26/10/90	GLONASS 44	4130	5478	65
26/10/90	GLONASS 45	3585	5436	62
26/10/90	GLONASS 46	4828	5437	55

Navstar and Glonass system time offset from UTC(USNO).
Table 3.

Table 3 shows a set of measurements over a typical 24 hour period on 26 October 1990. Each individual measurement lasts 180 seconds; satellites are accessed many times in the course of the day during which time they complete 2.125 orbits. The data has been corrected for tropospheric, relativistic and earth rotation effects but not for ionospheric effects. Only two of the available GPS block II satellites were used; the absence of "Selective Availability" on both at this time is noticeable. Both sets of data are consistent in the sense that all eight satellites individually produce results which differ from the average by much less than the standard deviation. Current research is aimed at reducing the uncertainty in these measurements to the order of 10 ns.

GLONASS TIME SCALES & UTC(SU)

Data which relates UTC(USNO) timing edges to both GPS and GLONASS system and reference times (such as is presented in Table 3 for 26 October 1990) are routinely averaged on a daily basis over the ensemble of available satellites. These daily values can then be related to GPS/GLONASS reference times through the transmitted offsets. The end result is a set of daily averaged values of the difference between the local estimate of UTC(USNO) and the GLONASS reference time which can be either UTC(SU) or Moscow time. Figure 2 shows a plot of UTC(USNO) against UTC(SU)/Moscow Time over a period of more than 2 years starting in mid-1988 and finishing towards the end of 1990. Superimposed on the Leeds University data are the 10-day values of UTC(USNO) - UTC(SU) as produced independently [3] by the BIPM in Paris. The plot shows clearly the two phases of operation - GLONASS was referred to Moscow time during the second half of 1988 and the first half of 1990; the reference time was UTC(SU) during the whole of 1989 and the second half of 1990. The step in reference time at the end of 1989 was -1.5 microseconds, followed by an equal and opposite step on 20 June 1990. The slopes of the two sets of data during the first half of 1990 would lead one to conclude that the Moscow Time reference is offset from UTC(SU) in phase by around 1.5 microseconds but very close to UTC(SU) in frequency.

As mentioned previously, a step in the GLONASS reference time from Moscow Time back to UTC(SU) took place on 20 June 1990. Coincidentally, GLONASS system time was also reset to a value very close to UTC(SU) itself. The means of observing these changes is illustrated in Figure 3. The continuous measurement of GLONASS system time with reference to UTC(USNO) showed up the step change in the former as it occurred. Soon afterwards the transmitted SV offsets from GLONASS system time also reflected the same change. By referring the SV phase offsets to the same reference time (12:00 GMT on 20 June), the change in the averaged SV offsets was computed to be

89

+38.147 µs (standard deviation 16 ns). The difference between UTC(USNO) and GLONASS system time obtained at the Leeds University ground station averaged over the previous and following 24 hours amounted to +38.140 µs (standard deviation 64 ns).

As a result of the confirmed change in system time together with the step in reference time, it was possible to conclude that the opportunity had been taken on 20 June by the control segment both to synchronise GLONASS reference time once again to UTC(SU) and to bring system time to within +/- 1 µs of UTC(SU). It will be recalled that GPS system time is constrained to lie within +/- 1 µs of UTC(USNO).

Since January 1990 data has been provided by Leeds University to the BIPM in Paris [3] in the following format:-

1)   Daily measurements at the University of Leeds averaged over the available ensemble of GLONASS satellites of UTC(USNO) against GLONASS system time.

2)   Daily measurements at the University of Leeds averaged over the available ensemble of GPS satellites of UTC(USNO) against GPS system time.

3)   Daily values of the difference between GLONASS system time and the GLONASS reference time contained in the satellite data message.

Daily values of the difference between GPS system time and UTC(USNO) are transmitted by GPS satellites and can be used to validate the data obtained in 2). This validation is an important feature of the measurement as most of the measurement equipment is common to both GPS and GLONASS. By means of the transmitted offsets, A0, it is possible to deduce a value for UTC(USNO) - UTC(SU) obtained by the satellite navigation systems GPS and GLONASS with an uncertainty of less than 100 ns.

GLONASS CLOCK PERFORMANCE

Data on the performance of certain GLONASS satellites has already been published. Over the years 1986-1989 a steady improvement in performance has been demonstrated with clocks on-board spacecraft launched during 1989 showing the qualities of high-quality Cesium standards of roughly the same level of performance as the GPS block 1 Cesiums.

It is all the more interesting to look at the behaviour of the most recently launched (19 May 1990) satellites - GLONASS 44,45 and 46, (1990 - 45A,B and C). These spacecraft have been operational in space for about 4 months. The clock phase and frequency offsets (a0 and a1) for GLONASS 44 are shown in Figure 4 averaged out once per day over a period of nearly 140 days. There is a curious cyclic variation in the frequency data whose period is around 8 days (the period of satellite ground track repeat). This behaviour is also observed in the frequency offset plots of both GLONASS 45 and 46 and is probably due to thermal effects or modelling effects of the spacecraft orbits and clock; no such cyclic changes have yet been observed in data obtained from earlier satellites.

The phase data displays the quadratic behaviour arising from a fixed frequency offset and drift. When these two are removed, the resulting data points produce an Allan variance plot shown in Figure 5, typical of a high-quality space-borne Cesium clock with a flicker noise floor of 5 times e - 14. For the purposes of comparison, an Allan variance plot for one of the better GPS Cesiums (PRN 13) is found in Figure 6.

CONCLUSIONS

On the basis of daily measurements made of a local reference and satellite system times, it is clear that one can produce consistent results averaged over an ensemble of available spacecraft. It is routinely possible to deduce values of UTC(USNO) - UTC(SU) on a daily basis to precisions of less than 100 ns. These levels of uncertainty can without doubt be reduced once the most common sources of error have been accounted for.

At the time when measurements were first calibrated in the University of Leeds GLONASS system time was referred to Moscow time (auxiliary time reference) and remained in this state from the middle till the end of 1988. During the whole of 1989, system time was then referred to UTC(SU). A second period of reference to the "auxiliary standard" began at the start of 1990 and continued for six months. The direct linking between GLONASS system time and UTC(SU) was resumed during June 1990 and has continued in this state until the present (end November 1990). Data on both reference clocks indicate that the "auxiliary time reference" is related to UTC(SU) by a straightforward phase offset; there seems to be very little difference in frequency between the two standards. Now

that both Navstar GPS and GLONASS are both referred to their respective national time standards, UTC(USNO) and UTC(SU) respectively, the prospects for international time transfer and coordination of UTC by satellite are very encouraging.

Allan variance frequency stability profiles of the most recently launched GLONASS spacecraft (1990- 45A,B and C) indicate the continued use of high-quality Cesium beam standards on board. Daily values of the fractional frequency offsets of these recent satellites demonstrate an unusual and unexplained cyclic change with period around 8 days.

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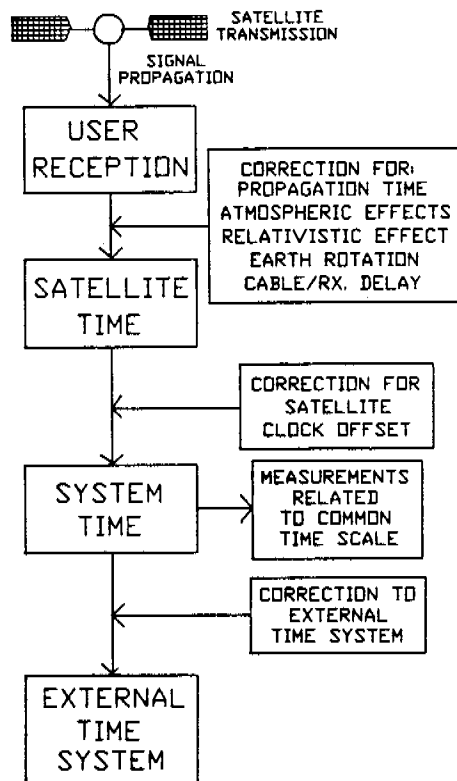
TIME TRANSFER FROM GLONASS
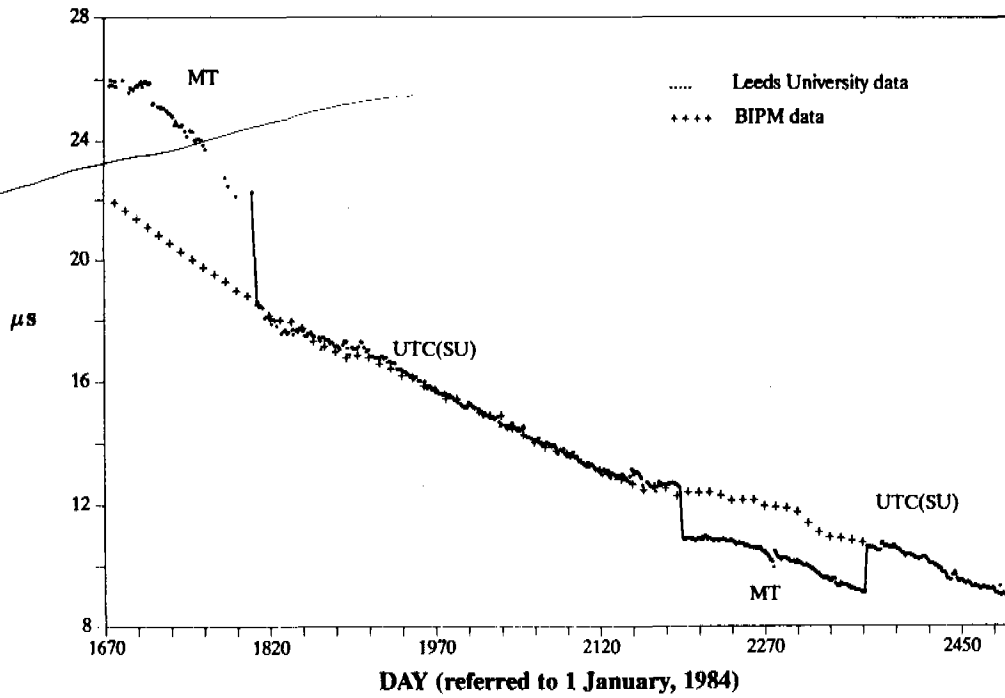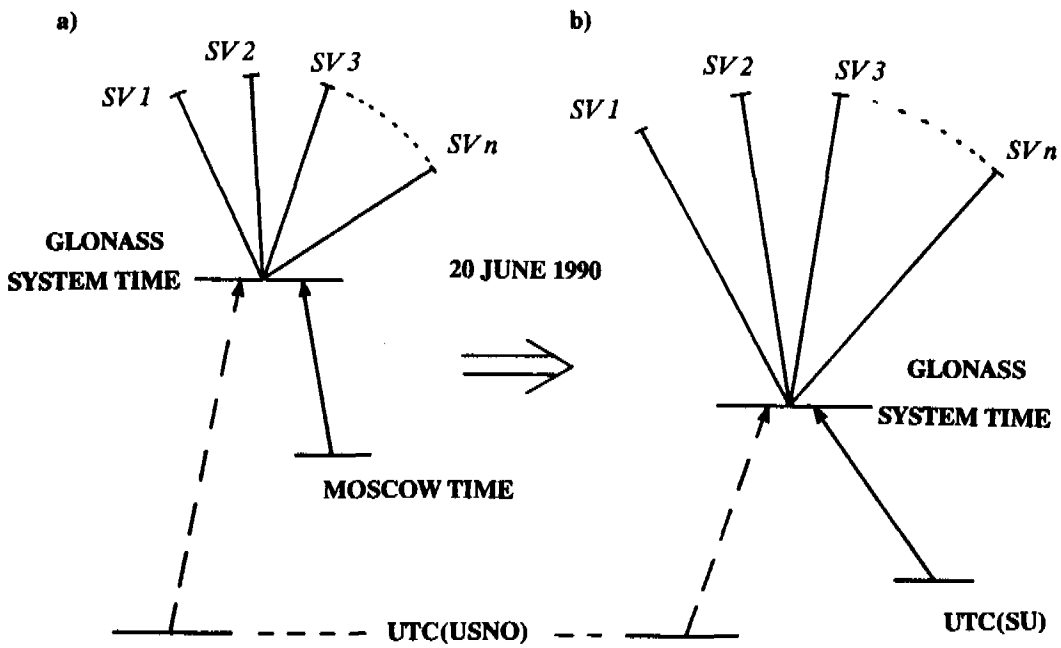

FIGURE 1

UTC(USNO) - UTC(SU)/MOSCOW TIME

DAY (referred to 1 January, 1984)

FIGURE 2

GLONASS TIME REFERENCES

FIGURE 3

GLONASS 44   (CHANNEL 21)

Day referenced to 1 Jan 1984

FIGURE 4

GLONASS 44 - CHANNEL 21

FREQUENCY OFFSET = -2.1 x 10^{-13} s/s

FREQUENCY DRIFT = -4.7 x 10^{-15} s/s/day

DURATION OF DATA = DAYS 170 - 304, 1990

log (secs)

FIGURE 5

NAVSTAR GPS - PRN 13

FREQUENCY OFFSET $= 2.1 \times 10^{-12}$ s/s

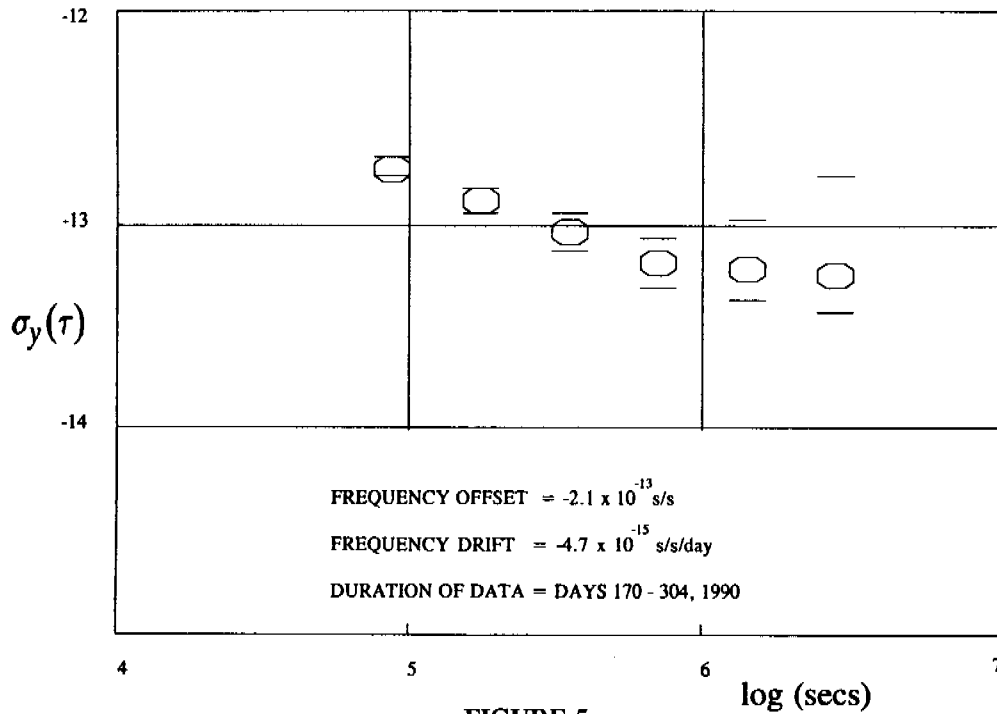FREQUENCY DRIFT $= -2.7 \times 10^{-16}$ s/s/day
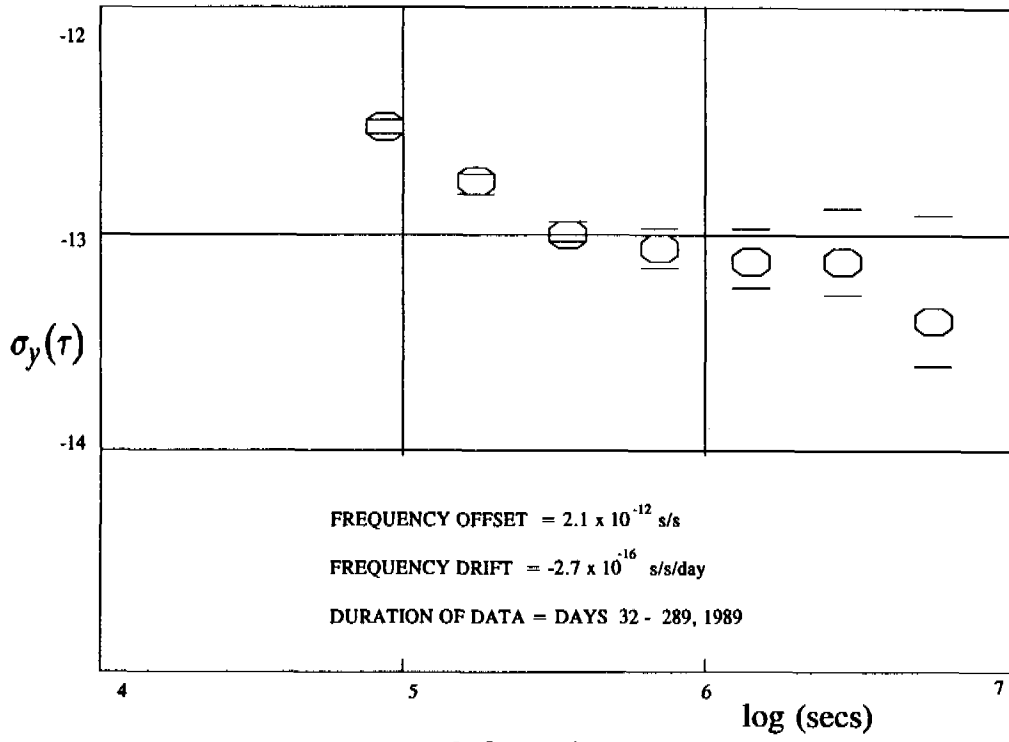
DURATION OF DATA $=$ DAYS 32 - 289, 1989

FIGURE 6

94

QUESTIONS AND ANSWERS

Carroll Alley, University of Maryland: I have had an extensive briefing in Moscow on the GLONASS system. The satellites have a large array of corner reflectors and they are tracked with high precision by laser ground stations. They told me that whenever the orbit gets off by 20 centimeters, they make a correction.

Professor Daly: I have a question — Do you believe the 20 centimeters?

Professor Alley: Yes.

Profesor Daly: People that are familiar with GPS orbits, and I am not an expert on the subject, would not claim the same certainty for GPS orbits.

Professor Alley: I agree with that too.

Professor Daly: I rest my case.