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5. We thank our fellow team members, D. Anderson, L. Orgel, J. Oro, P. Toulmin III, and especially A. O. Nier, for helpful discussions and enthusiastic support. We are indebted to J. A. Biller, L. Crafton, A. V. Diaz, E. M. Ruiz, and R. Williams for essential contributions to the success of the experiment. This work was supported by NASA research contracts NAS 1-10493 and NAS 1-9684.

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Mars Climatology from Viking 1 After 20 Sols

Abstract. *The results from the meteorology instruments on the Viking 1 lander are presented for the first 20 sols of operation. The daily patterns of temperature, wind, and pressure have been highly consistent during the period. Hence, these have been assembled into 20-sol composites and analyzed harmonically. Maximum temperature was 241.8°K and minimum 187.2°K. The composite wind vector has a mean diurnal magnitude of 2.4 meters per second with prevailing wind from the south and counterclockwise diurnal rotation. Pressure exhibits diurnal and semidiurnal oscillations. The diurnal is ascribed to a combination of effects, and the semidiurnal appears to be the solar semidiurnal tide. Similarities to Earth are discussed. A major finding is a continual secular decrease in diurnal mean pressure. This is ascribed to carbon dioxide deposition at the south polar cap.*

We have previously published a brief report (*1*) on the results of the first 3 sols (*2*) of data returned by the meteorology experiment on the Viking 1 lander on the surface of Mars. We now expand that report to include the first 20 sols. The system continues to perform normally and, barring a mishap, we may expect ultimately to receive a very long series of data.

The high degree of consistency of the daily patterns of temperature, wind, and pressure described earlier (*1*) has persisted. In view of this consistency, we have assembled these 20 sols of data into a preliminary diurnal climatology of this site in summer (*3*).

A composite ambient temperature curve for the first 20 sols is given in Fig. 1. The curve was generated by least-squares fitting of the data to a fifth-order harmonic function for each 0.1-hour interval. According to the model the maximum temperature of 241.8°K occurs at 15:00 local lander time (L.L.T.), and the minimum of 187.2°K occurs at 05:00 L.L.T., shortly before sunrise. The fifth-order function does not fit the rather sharp temperature changes at dawn; the curve is, accordingly, dashed between 05:00 and 06:00.

A composite ambient temperature diurnal cycle for Earth is given in Fig. 2, in order to provide a general comparison. These and other data from Earth contained in this report are from China Lake, part of a broad, dry basin in the Mojave Desert, California (*4*). We produced the composite by averaging the hourly readings from ten early- to midsummer cloudless days. Day-to-day climatological variations at China Lake during this period are small. The period covered is analogous to the present season on Mars at the Viking 1 landing site. If we disregard the obviously warmer clime at China Lake, we note the marked similarity in the phase relationships. The times of temperature maximum and minimum are about the same at both sites. The similarity in times of maximum temperature can be explained by the fact that the dominant heating mechanism near the surface is convective transfer from the ground. The temperature maximum is reached when the ground temperature has cooled enough that convection effectively ceases. This occurs at about the same time (15:00 local) on both planets since the rate of convection and the atmospheric heat capacity are both proportional to air density. Thus, the time of maximum air temperature near the surface does not depend, to first order, on the air density. The minimum temperature at China Lake lags somewhat compared to the minimum at the Viking 1 site. This may result from the dominance of radiative transfer at this time of day. The atmosphere of Mars should respond more rapidly than Earth's to radiative forcing. The much larger temperature range and atmospheric heating rate at the Viking 1 site is a consequence of the large martian diurnal ground temperature range which itself is a result of the very low air density.

Table 1. First two pressure harmonics for the Viking 1 site and China Lake. Entries are the times of maximum (max) and minimum (min) and the peak-to-peak (PTP) amplitudes.

Max or min	Viking 1 site: Local time	Viking 1 site: PTP ampl. (mbar)	China Lake: Local time	China Lake: PTP ampl. (mbar)
	First harmonic			
Max	03:10		07:30	
		0.16		3.34
Min	15:30		19:30	
	Second harmonic			
Max	10:50		09:45	
	23:10		21:45	
		0.07		1.55
Min	04:40		03:45	
	17:00		15:45	

The diurnal pressure variation at the Viking 1 landing site is shown in Fig. 3. The composite curve includes only the first and second harmonics, the only two components having statistical significance at this stage of the analysis (*5*). Figure 4 shows the corresponding composite pressure data from China Lake, a fifth-order harmonic fit in which the first and second harmonics dominate the diurnal behavior. The local times of maxima and minima and peak-to-peak (PTP) amplitudes are given in Table 1. Also given are the corresponding values for China Lake. The amplitude ratios of the first (diurnal) to second (semidiurnal) harmonics are similar at the two locations. The phases of the semidiurnal component are also similar at the two locations, particularly when one adjusts for the somewhat longer martian solar day. The amplitudes of both martian pressure oscillations, expressed as a fraction of the mean pressure, are more than five times the amplitudes of their China Lake counterparts. Finally, the first harmonic maximum and minimum at China Lake occur about 4.5 hours later than at the Viking site.

The semidiurnal pressure oscillation at China Lake is a semidiurnal tide produced by the sun. This variation on Earth is the atmospheric response to the semidiurnal component of solar heating through a large depth of the atmosphere. Its dominant component is a westward-propagating mode with longitudinal wave number 2, the so-called S^2_2 mode (*6*). It is global in scale and insensitive to ocean-continent and topographic effects. The analogous mode is expected on Mars. The close phase agreement between the Viking 1 and China Lake semidiurnal pressure oscillations indicates that the martian semidiurnal oscillation is probably also predominantly the S^2_2 mode of the solar semidiurnal tide. If this identification is correct, Viking 2, planned for landing at about 47.5°N, should also see this harmonic, with a similar phase but a somewhat smaller amplitude.

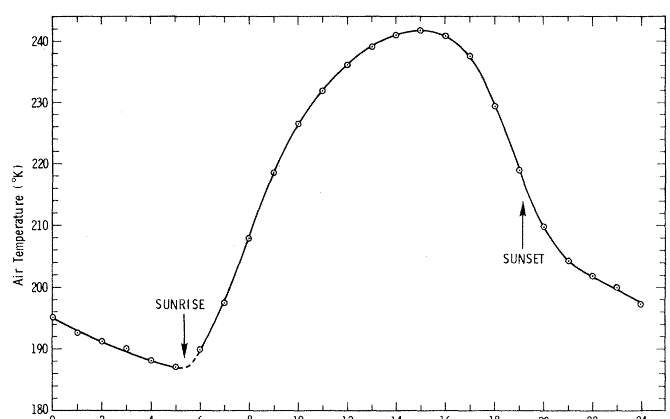
The diurnal oscillations appear to be much more complicated. A consideration of the wind data should precede any interpretation of those oscillations. Figure 5 is a composite diurnal wind hodograph based on harmonic analysis of the 20 sols. The curve represents the tip of the wind vector at hourly intervals during the composite sol. The mean vector wind is from the south at 2.4 m/sec. This wind direction is apparently representative of prevailing winds in the lower atmosphere, since the Viking 1 entry trajectory analysis showed winds generally from the southeast below 4 km over the site region (*7*). Although winds at our 1.6-m measurement height are strongly influenced by boundary layer effects, the prevailing south wind can nevertheless be understood in terms of the large-scale topography. Viking 1 is on the western slope of the broad Chryse basin. As on Earth, large-scale lowlands are expected to correspond to thermal high-pressure areas, at least during summer, with the uplands coinciding with low-pressure areas. Thus, pressure, at a fixed gravitational potential surface near the ground, should decrease from east to west (in the upslope direction) at the Viking 1 site. Prevailing southerly geostrophic winds are expected for such a pressure distribution. As a terrestrial example, mean southerly surface winds are found during the summer over the Great Plains, which are similarly situated with respect to regional slope.

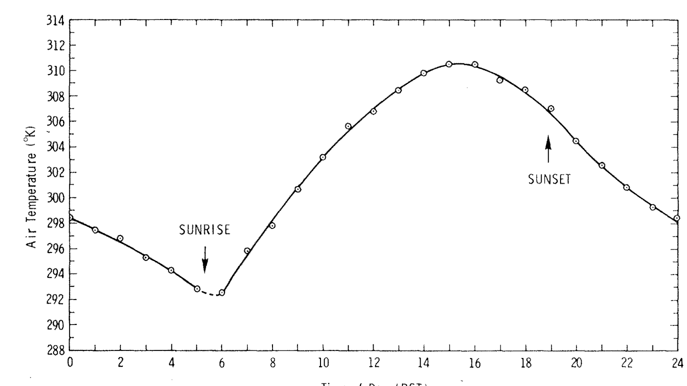
Table 2. Rates of decrease of pressure (mbar/sol) as observed and predicted.

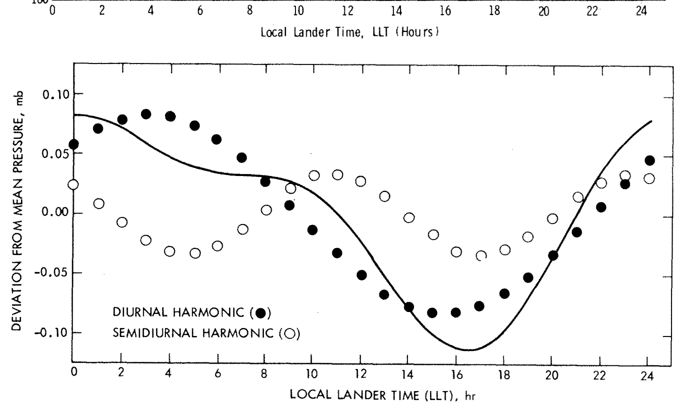
Source	Range of L_s	Pressure rate
Observed by Viking 1	98°–108°	−0.0122
Models		
Constrained; cap edge at 57°S	90°–120°	−0.0091
Unconstrained	80°–113°	−0.0123
Adsorption of CO_2	90°–120°	−0.0037

The diurnal hodograph is remarkably similar from one sol to the next, even to such small details as the small loop between 16:00 and 22:00 L.L.T. and the structure between 24:00 and 06:00 L.L.T. Significant features are the dominance of the first diurnal harmonic (one complete major revolution per sol) with amplitude of about 5 m/sec and the counterclockwise rotation.

A solar diurnal tide, not influenced by ocean-continent or topographic effects and producing a simple westward-moving global pressure wave in the latitude at which Viking 1 landed would be expected to produce maximum west-to-east winds in phase with the pressure minimum. It would also be expected to exhibit a clockwise hodograph rotation. However, the observed west-to-east winds are about 120° out of phase with minimum pressure, and the hodograph rotation is counterclockwise. We believe that at least two factors must be present in the diurnal oscillations of pressure and wind to cause this. The dominant part of the pressure oscillation is probably global in scale (although not necessarily westward-moving). If it were smaller than global, one would expect the pressure gradients to be sufficiently great that the amplitude of the wind-vector diurnal oscillation would be significantly greater than that observed. However, the observed wind oscillation could be produced mainly by a local or regional pressure oscillation of smaller amplitude which, though dominated in amplitude by global scale pressure oscillation, produces larger gradients because of its smaller scale. Such a pressure oscillation could be associated with the regional slope of the Chryse basin. Examples of diurnal wind oscillation on Earth governed by similar continent-scale topographic variations are not unknown (*8*). In fact, the diurnal wind oscillation observed by Viking 1 is similar in some respects to that observed on the Great Plains (*9*).







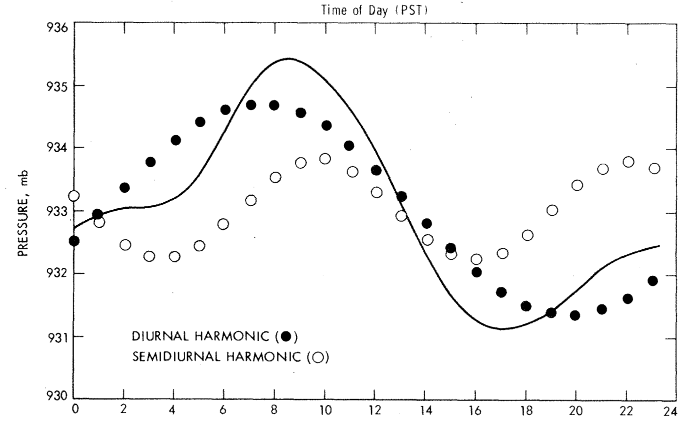


Fig. 1 (top left). Fifth-order, least-squares harmonic analysis of the temperature data from Viking 1 lander. Fig. 2 (top right). Mean daily temperature values at China Lake, California. Fig. 3 (bottom left). Second-order, least-squares harmonic analysis of the pressure data from Viking 1 lander. The solid curve is the composite of the two harmonics. A secular trend in pressure was removed before the data were analyzed. Fig. 4 (bottom right). Least-squares harmonic analysis of the pressure data from China Lake, California. The solid curve is the fifth-order harmonic fit.

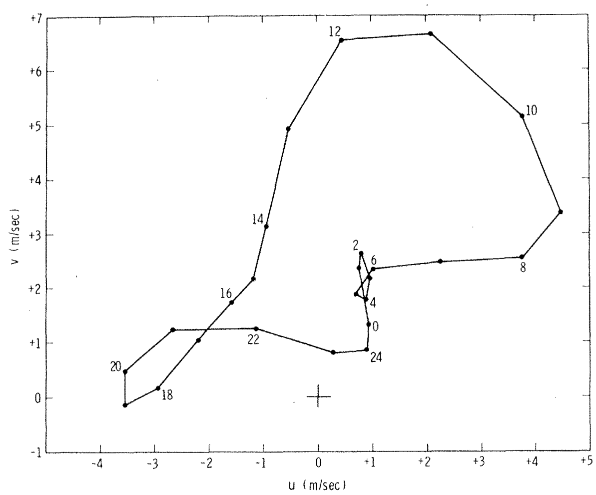


Fig. 5. Hodograph of the horizontal wind data from Viking 1 lander. This is based upon separate fifth-order, least-squares harmonic analyses of the west wind components (u) and south wind components (v). The values next to the points are the times from midnight (L.L.T.) in hours.

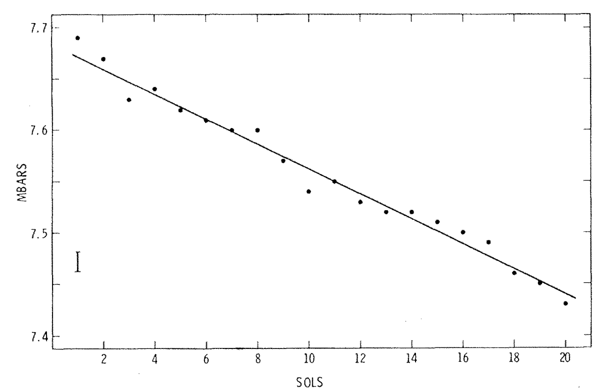


Fig. 6. Pressures from Viking 1 lander averaged over the period of a sol, as a function of time. The least-squares line is $p = 7.6844 - 0.0122n$, where p is pressure in millibars and n is the sol number. The bar in the lower left represents the digital increment (0.08 mbar) divided by $\sqrt{14}$, the square root of the typical number of values in each average.

Alternatively, the mixture of components that composes the diurnal pressure oscillation might include the eastward-moving diurnal Kelvin mode predicted for Mars by Zurek (*10*). This mode could be strongly excited by interaction between the primary westward-moving mode and large-scale topography, since it could be close to resonance under Mars conditions. Viking 2 observations will be of particular value in distinguishing the global scale modes, including the Kelvin mode, since these modes should have amplitudes nearly as large at the planned Viking 2 site (47.5°N) as at the Viking 1 latitude (22.5°N). All other tidal components would have smaller pressure amplitudes at the more northly location. In any case continued data collection and analysis are required to permit a more confident interpretation of the diurnal pressure-wind behavior.

The value of pressure averaged over the length of a sol has decreased with time (Fig. 6). In view of the extensive testing these sensors have received and their proven long-term stability, we do not believe this result is due to a defective instrument. Instead, we suggest that this is the result of condensation of CO_2, the major atmospheric constituent, on the winter cap. For the period of these measurements this is the south cap, the one more remote from the lander. To check this possibility we assume the pressure decline to be representative of the entire planet. Ignoring the effect of the summer cap, which is very small, the required rate of deposition of mass per unit area on the winter cap is:

$$dm/dt = -2(1 - \sin\phi)^{-1} g^{-1} dp/dt$$

where g is the acceleration of gravity (3.72 m/sec^2), dp/dt is the measured rate of decrease of pressure, and ϕ is the mean latitude of the edge of the cap. This can be converted to the rate of release of heat of condensation by multiplication with the latent heat of sublimation of CO_2 (6.02×10^5 joule/kg). Finally, one can determine the mean equivalent blackbody temperature of a polar cap region radiating this released heat. Based on infrared and imaging data from Viking (*11*) we estimate ϕ to be 50°S and find an equivalent blackbody temperature of 135°K. This is sufficiently close to the measured mean equivalent blackbody temperatures of the south cap (*11*) to provide some confidence in the proposed explanation of the declining pressure.

This rate of decrease in pressure can be compared with models of condensation at the polar cap. The models of Briggs (*12*) and Pollack *et al.* (*13*) are based on a simple balance between radiative loss from the cap region and latent heat release. Briggs's model treats meteorological processes parametrically and is premised on the assumption that the edge of the polar ice cap lies, in this season, at latitude 57°S, an assumption derived from the data available when the model was built. In the model of Pollack *et al.*, meteorological processes are treated explicitly, but the model incorporates no limiting assumptions regarding the latitude of the cap edge. Both of these models ignore the possible effect of adsorption of CO_2 in the regolith, which was considered by Dzurisin and Ingersoll (*14*).

This adsorption could buffer the atmosphere-cap CO_2 exchange, causing the amplitude of seasonal pressure variations to decrease and shifting the maximums and minimums to earlier times. The data we expect to obtain at the anticipated time of minimum atmospheric pressure (the last 3 months of 1976) should permit the best discrimination among these models. At present we can only compare the rates of decrease of pressure observed with those predicted (Table 2). There is substantial agreement with the model that accepts variation in the latitude of the cap's edge, reasonable agreement with the model that depends on the cap's edge being at 57°S, but a disagreement with the CO_2-adsorption model by a factor of 3. This suggests that the regolith may not be providing a substantial buffer for CO_2 on the time scale of a martian season.

It is particularly gratifying to find that a single meteorological station on Mars is providing not only the local data it was expected to obtain, but also appears to provide significant information on a global scale.

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2. The term "sol" refers to the martian day of 24.660 hours and is used to avoid confusion with the terrestrial day.
3. The best present estimate of the location of the Viking 1 lander is 22.48°N, 48.00°W. These differ slightly from the preliminary coordinates (*1*). The season is summer. Sols 1 to 20 correspond to L_s ranging from 98° to 108°, where L_s is the areocentric longitude of the sun with 90° being northern hemisphere summer solstice.
4. These data were collected by personnel of the China Lake Naval Weapons Center and compiled in computerized form, together with data from other stations in the American Southwest, for general distribution by the Aerospace Corporation, El Segundo, California. China Lake is located at 35.7°N, 117.7°W.
5. The pressure sensor has an intrinsic reproducibility (as determined by calibration) of at least 0.02 mbar. The data are returned with a digitization increment of about 0.08 mbar. During the period reported here, four samples of pressure were obtained during each of the approximately 14 modules per sol of the other meteorological data. The four samples have only rarely differed from one another by as much as one digital count, which indicates the stability of the instrument and the absence of significant dynamic effects of wind on the pressure at the inlet port. We have indications from a comparison of the sensor values during entry and just after touchdown that there may have been a zero-level shift, which would cause uncertainty about the absolute pressure of one or two digital counts. There is no comparable uncertainty about the slope of the calibration curve. The diurnal variation of pressure, and its secular trend also given in this report, depend on the slope of the calibration curve and not on the absolute value.
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15. We thank S. Albers, who assisted with data reduction, and R. W. Zurek for helpful comments. This research was supported by the National Aeronautics and Space Administration under contracts NASI 9693, NASI 11854, and NASI 9694.

2 September 1976

Preliminary Results from the Viking X-ray Fluorescence Experiment: The First Sample from Chryse Planitia, Mars

Abstract. *Iron, calcium, aluminum, silicon, and sulfur are major elements in the first surface sample of Mars that has been analyzed by the Viking x-ray fluorescence spectrometer. Titanium is present in minor quantities. This is consistent with the sample being a mixture of fine silicate and oxide mineral grains, with a significant proportion of sulfates, possibly hydrated. Ferric oxide is regarded as the red pigmenting agent on the martian surface, but if it coats silicate grains, the coatings must be very thin (≤ 2 micrometers) or discontinuous. A high abundance of Fe, relatively low abundances of Al, Rb, Sr, and Zr, and a high Ca/K ratio are distinctive features of the spectra. Preliminary determinations indicate the following abundances (as percentages by weight): Fe, 14 ± 2; Ti < 1; S, 2 to 5; the Ca/K ratio by weight is greater than 5.*

The x-ray fluorescence spectrometer on board the Viking 1 lander (*1*) is designed to determine the abundances of elements with $Z \geq 12$ and thus is capable of detecting most of the geochemically significant major elements and some minor elements, provided that they occur in sufficient concentrations (*2*). On sol 0 (the day of landing on Mars), the instrument was operated for calibration purposes, and an upper limit of argon in the martian atmosphere was established (*3*). Here, we present preliminary data on the composition of the first sample of martian surface fines, delivered on sol 8 and analyzed on sols 8 to 30.

Sample acquisition and description. Imagery obtained on the first few days after landing led to recognition of a safer sampling site than the one that had been preprogrammed. High-resolution stereoscopic imagery and detailed microtopographic profiles showed that this area, in front and to the left of the center of the lander's general field of view, was visibly free of rocks large enough to pose a threat to the surface sampler's safety and seemed to consist of a fairly uniform, fine-grained material. The surface is smooth and slopes gently to the right and toward the lander. It apparently forms part of a patch of wind-driven material, whose source is unknown.

It is important to note that while the sample collected may be representative of this geologic unit, one cannot regard it as representative of the overall composition at this site or over any larger region. A diversity of materials appears to exist in the landing site area; at least two types of fine-grained material and fragments of several rock types have been recognized (*4*).

At 6:54 lander local time (L.L.T.) on sol 8 the Viking surface sampler began the series of operations that provided a sample to the x-ray fluorescence spectrometer. After one sample was delivered to the biology instrument and two acquisitions in the same trench were made for organic analysis [combined gas chromatographer and mass spectrometer (GCMS) instrument], a double acquisition for the x-ray instrument was made by a 16.5-cm forward extension in the same trench. The material was delivered by sieving through the 2-mm screen in the sampler head. The acquisitions for the x-ray instrument were made between 10:35 and 12:06, and analysis began at 23:00 L.L.T. During the period of sample acquisition and delivery, the winds were blowing from a SE to SSW direction at 4 to 17 m sec^{-1} (*5*). Based on tests conducted in a reduced-pressure wind tunnel, it is unlikely that any serious distortion of the sample composition occurred as a result of aeolian winnowing during delivery.

The material delivered is apparently quite fine-grained and very cohesive, allowing very steep and sharp trench walls to be maintained [for images and detailed discussions, see (*6*)]. The disturbed material in the walls of the trench appears darker than the adjacent undisturbed surface, but colorimetric comparison studies suggest that there is little, if any, difference in actual color (*7*). Also, what appears to be a weakly cemented, thin surface crust may be seen in some images. The sample delivered to the x-ray fluorescence spectrometer was acquired at a depth of 4 to 6 cm below the martian surface. The possibility that some admixture of shallower material occurred cannot be excluded.

Instrument calibration and operation on Mars. The instrument can be calibrated on Mars to determine instrument gain and to verify overall performance by three independent techniques: (i) by measuring x-ray fluorescent emissions from calibration "plaques" exposed when no sample is present in the analysis cavity; (ii) by determining the mean channel of the backscatter peak from the sample; and (iii) by activating a solenoid which positions an Al and Ca calibration target, or "flag," between the sample and the ^{55}Fe source. Plaque calibrations were performed 32 hours prior to landing and again 7 hours after landing. Gain in each proportional counter (PC) had changed by less than 4 percent from that at the time of delivery of the flight unit to the Viking lander (January 1975). In addition, flag calibrations were performed six times on sol 25, which verified that the resolution functions of PC-1 and PC-2 were equal to or even slightly superior to the values prior to the flight.

Initially, all data on Mars were taken over all 128 channels and in the rapid mode, with a dwell time of 7.7 seconds per channel for the scanning single-channel analyzer. This provides a large body of repeated spectral measurements from which instrument precision can be evaluated. As expected, both temperature-dependent and time-dependent (secular drift) gain changes are evident in the