# The LIMS Version 6 Level 3 Dataset

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December 2009

**Summary**

This report describes the Limb Infrared Monitor of the Stratosphere (LIMS) Version 6 (V6) Level 3 data products and the assumptions used for their generation.  A sequential estimation algorithm was used to obtain daily, zonal Fourier coefficients of the several parameters of the LIMS dataset for 216 days of 1978-79.  The coefficients are available at up to 28 pressure levels and at every two degrees of latitude from 64˚S to 84˚N and at the synoptic time of 12 UT.  Example plots have been prepared and archived for the data of January 1, 1979 at 10 hPa to illustrate the overall coherence of the features from the LIMS-retrieved parameters.

## 1 Introduction

The Nimbus 7 Limb Infrared Monitor of the Stratosphere (LIMS) instrument operated from October 25, 1978 through May 28, 1979 [Gille and Russell, 1984]. Its measured limb radiance profiles were processed originally with Version 5 (V5) Level 2 and 3 algorithms and archived in 1982-83. Subsequently, improved Level 2 profiles were retrieved with an updated, Version 6 (V6) algorithm and archived in 2002, in order to provide results that are more compatible with datasets from the Upper Atmosphere Research Satellite (UARS) (1991-2005), the Earth Observing System (EOS) Aura satellite (2004-present), and the Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics (TIMED) satellite (2002-present). The quality and improvements for the LIMS V6 profiles were reported for temperature and geopotential height, for ozone, for water vapor, and for nitric acid and nitrogen dioxide in Remsberg et al. [2004; 2007; 2009; and 2010], respectively.

The Nimbus 7 satellite operated in a Sun-synchronous, near polar orbit, and LIMS obtained its profiles at about 1:30 pm and 10:30 pm local time at low to middle latitudes. LIMS had a duty cycle of about 5-6 days on, followed by 1-2 days off for much of its 7¼ month mission life. A sequential estimation (or Level 3) algorithm was applied to each of the V6 profile parameters, in order to provide their continuous, synoptic datasets. Their Level 3 daily, zonal Fourier coefficients were obtained as a function of pressure and latitude for the synoptic time of 12 UT in the manner of Remsberg et al. [1990]. Such data products have been very useful for studies of the effects of atmospheric transport on the various LIMS parameters (e.g., Leovy et al. [1985]). The present report characterizes that V6 Level 3 (map) product. Section 2 is a brief description of the approach to the mapping, and it points out the several significant improvements for the V6 versus the V5 mapping algorithms and datasets. Section 3 reports on some findings from the V6 coefficients that indicate their coherence and relative accuracy, as well as several limitations.

## 2 Data characteristics and algorithm approach

The LIMS V6 profiles were generated and output at about every 1.6 degrees of latitude along their orbital, tangent-point tracks and tabulated at 18 levels per decade of pressure and with a nearly equal vertical spacing of 0.88 km. Conveniently, the UARS Level 3A data have pressure increments that are a subset of the LIMS V6 profile levels. In an attempt to obtain somewhat more detail about variations of the LIMS V6 parameters, it was decided to generate zonal Fourier coefficients from (or map) these profiles at every two degrees of latitude and at 28 pressure levels from 0.01 hPa to 316 hPa, which is the approximate pressure range of the LIMS temperature and geopotential height profiles. In other words, the mapping was conducted at 6 levels per decade of pressure or at a vertical spacing of about 2.64 km. By comparison the LIMS V5 Level 3 product was obtained from profiles at only every 4 degrees of latitude and at a maximum of 18 pressure levels that were not spaced at equal intervals of log pressure. The geopotential height (Gphgt) profiles of LIMS V6 were also processed to Level 3.

The sequential estimation (SE) algorithm that was used for the V5 Level 3 map analysis at each pressure level and latitude is described in detail in Remsberg et al. [1990] and in references therein. The SE algorithm transforms a time series of asynoptic data points to a set of zonal Fourier coefficients at a given synoptic time. This report is focused on the several modifications that were employed for the V6 algorithm. As before, the SE algorithm generates daily vectors (**X)** of sine and cosine coefficients representing the zonal mean and the 6 lowest zonal wave numbers, all at the synoptic time of 12 UT. By considering both the ascending and descending orbital data segments, a total of up to 13 daily, zonal coefficients were generated at a given pressure and latitude. Separate analyses extend to only 4 zonal waves for the subsets of the descending and of the ascending orbital data segments. The V6 SE algorithm was applied to the Level 2 data in 28-day sequences that overlapped at end points. The algorithm was run both forward and backward in time; their separate daily results were then averaged and output to file. For the case of the diurnally-varying $NO_2$, the SE algorithm was applied separately to its daytime and its nighttime profiles. Thus, the Level 3 output for $NO_2$ merely indicates the effects of the zonal waves on its daytime or nighttime distributions, while ignoring the rather large changes near sunrise and sunset that must be present in a truly synoptic map of $NO_2$.

The SE algorithm is constrained by the elements of its so-called "virtual dataset," as defined in Section 3 of Remsberg et al. [1990]; the steps for its operational processing are given in Section 4 of that reference. The elements of the "virtual dataset" determine how closely the SE algorithm must try to fit the individual points in a time series of the profile data. The most important element is $\sigma_{n,m}$, which is based on an empirical estimate of the measurement precision for single profiles of a given LIMS parameter. Those estimates were obtained as the minimum standard deviations from among the sets of 6 adjacent profiles along orbits near 64˚S for November 8, 1978. They are given in Table 1 for each parameter, and they remain unchanged with latitude and for each 28-day analysis sequence. Values in Table 1 for the LIMS species have been merely extrapolated beyond each of their retrieved pressure ranges. Note that part of the precision estimate may be due to the real atmospheric variability for a given parameter. In fact, the estimates for ozone grew larger than expected for the levels of 146 to 316 hPa, so those estimates were reset to 0.10 ppmv. Precision estimates for geopotential height were set to 30 meters below the 1-hPa level; its estimates for the mesosphere were set to the minimum values from the ascending orbital segments near 50˚S on January 16, 1979, when the presence of the summer, stratospheric easterlies inhibit the upward propagation of planetary wave activity.

The second important element of the "virtual dataset" is the error covariance matrix or **S**, which multiplies the vector of the 13 prescribed longitudes (the maximum number of coefficients or the sines and cosines for the 6 zonal waves plus the zonal mean value). More specifically, an estimate of how **S** grows in time is required. That element, d**S**/dt, is approximated by

$$d\mathbf{S}/dt \;=\; \mathbf{S}_{clim} \,/\, \tau \quad , \qquad (1)$$

where $\mathbf{S}_{clim}$ is the climatological covariance matrix for the observed parameter field, and $\tau$ is an estimate of the time for the autocorrelation of the wave amplitude as it decays to the noise level or precision of the data. These so-called "relaxation times" or $\tau$-values are a function of the amplitude of a given zonal wavenumber, and they are intended to represent the memory of how the data fields appeared at a previous time step. That memory is typically short for the small amplitude, intermediate-scale and traveling waves, but much longer for the zonal mean and for the standing, zonal waves 1 and 2. Data gaps for the LIMS measurements occurred about every 5 days, but for no more than a day or two. Therefore, the minimum relaxation time had to be of that order. In addition, memory is typically no longer than 3 to 4 days for the zonal mean and for waves 1 and 2 during dynamically active, wintertime periods [Remsberg et al., 1990]. For this reason the values of $\tau$ in Table 2 were used for the V6 SE algorithm for all latitudes, pressure levels and months of the LIMS data.

The values for $\mathbf{S}_{clim}$ in Eq. (1) were obtained by allowing d**S**/dt to be large and independent of wavenumber in preliminary 28-day runs. Those preliminary runs were constrained primarily by the precision values of Table 1, and their output was smoothed very little. New values of d**S**/dt for the final runs were obtained from the output fields of the preliminary runs and the values of $\tau$ from Table 2.

The Level 3 output files for a given parameter contain the Fourier coefficients for a given measurement mode (ascending-1, descending-2, or combined-3) and at a latitude and pressure level. The number that follows the coefficients for each output line of the Level 3 profile is the RMS of the set of differences of the observed LIMS Level 2 values and their estimates as obtained using the Fourier coefficients at each of the longitudes of the observed profiles. Essentially, it is a measure of the fit between the estimated 12 UT field and all the profile data taken within 12 hours of that time. If the measured field is stationary and the SE model is adequate, then the RMS difference should approximate $\sigma_{n,m}$. The last value of each output data line is the estimated uncertainty for the coefficients themselves.

The Level 3 files have been written to a DVD in ASCII format along with separate "Read Me" and plot files. They are archived at the NASA Goddard Earth Sciences and Data Information Services Center or GES DISC (http://daac.gsfc.nasa.gov/) under the menu entitled "Remote Sensing Data," and they can be obtained by ftp download.

## 3 Comments about the utility of the LIMS V6 Level 3 products

One set of postscript files named "jan1_10mb.ps" was generated and archived in addition to the Level 3 coefficients. They consist of 8 polar stereographic plots of the various LIMS V6 Level 3 parameters for January 1, 1979, at 10 hPa. These example fields were created using grid point values calculated from the Fourier coefficient data at the latitude spacing of 2 degrees (plots from 64˚S to Equator and also from 84˚N to Equator) and with a longitude spacing of 5.625 degrees (0 to 360˚E). Those northern and/or southern hemispheric plots indicate the good continuity of the data fields and their coherent structures due to the effects of large-scale transport by the zonal waves. One can envision being able to regenerate daily sequences of ozone and geopotential height [e.g., Leovy et al., 1985], time series of temperature and potential vorticity [e.g., Dunkerton and Delisi, 1986], and time series of potential vorticity, ozone, water vapor, and nitric acid [e.g., Butchart and Remsberg, 1986]. It is expected that similar analyses of the V6 data will be shown to be even more representative of the atmospheric state of 1978/79 than was the case from the V5 data.

Hitchman and Leovy [1985] compared the day minus night differences in the LIMS V5 temperatures with those reported from rocketsonde soundings near the Equator. They reported that the tidal amplitudes appeared to be dampened considerably in the LIMS V5 dataset, compared with those from the rocketsonde measurements. Remsberg et al. [2004] gives several examples of the improved agreement for the V6 temperature profiles as compared with co-located rocketsondes, particularly for the mesosphere. It is noted that the V6 algorithms provide for a better estimate of the orbital attitude of the LIMS instrument, which slightly alters the registration of its measured radiance profiles. The V6 temperature retrievals were also begun at altitudes of the mesosphere that are higher than those for V5, and this change has improved the accuracy of the V6 temperatures in the middle mesosphere. Even so, the apparent tidal amplitudes are not increase by much with V6, perhaps because of the moderate vertical resolution for its retrieved profiles.

There are also some limitations for the Level 3 data. For instance, the successive up/down radiance scans were averaged along the orbits in order to minimize the effects of intermediate-scale, spacecraft motions prior to profile retrieval. But a net effect of the averaging is a smoothing of the signatures of vertically-propagating gravity waves. In another example, one can analyze the LIMS V6 temperature profile data for signatures of Kelvin waves in the manner of Hitchman and Leovy [1986]. In Section 3a of their paper they reported finding Kelvin wave amplitudes from their analyzed LIMS V5 temperatures that also appeared to be dampened. The amplitudes of vertically propagating Kelvin waves are similar to those of the temperature tides. While it should be easy to resolve the amplitude and vertical propagation of the slow to intermediate scale Kelvin waves, the time variations of the diurnal tide signals are under-sampled with the sun-synchronous LIMS measurements. The 12 UT ascending and descending wave-1 coefficients of LIMS Level 3 are really only representative of two local times that are separated by about 10 hours. Therefore, a clear separation of Kelvin wave-1 from the tidal signatures may be somewhat problematic with the LIMS dataset, particularly in the mesosphere. Similar caveats apply to ozone, which also varies diurnally in the upper stratosphere and mesosphere.

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Table 1—LIMS Version 6 Precision Estimates

| P (hPa) | Temp (K) | O3 (ppmv) | NO2 (ppbv) | H2O (ppmv) | HNO3(ppbv) | Gphgt (km) |
|---|---|---|---|---|---|---|
| | | | | | | |
| 0.01000 | 3.67 | 0.32 | 0.34 | 0.24 | 0.16 | 0.159 |
| 0.01468 | 3.67 | 0.32 | 0.34 | 0.24 | 0.16 | 0.159 |
| 0.02154 | 3.67 | 0.32 | 0.34 | 0.24 | 0.16 | 0.154 |
| 0.03162 | 2.40 | 0.32 | 0.34 | 0.24 | 0.16 | 0.151 |
| 0.04642 | 1.89 | 0.32 | 0.34 | 0.24 | 0.16 | 0.147 |
| 0.06813 | 1.60 | 0.212 | 0.34 | 0.24 | 0.16 | 0.143 |
| 0.1000 | 1.39 | 0.10 | 0.34 | 0.24 | 0.16 | 0.136 |
| 0.1468 | 1.24 | 0.065 | 0.34 | 0.24 | 0.16 | 0.132 |
| 0.2154 | 1.10 | 0.060 | 0.34 | 0.24 | 0.16 | 0.124 |
| 0.3162 | 1.00 | 0.056 | 0.34 | 0.24 | 0.16 | 0.112 |
| 0.4642 | 0.90 | 0.060 | 0.34 | 0.24 | 0.16 | 0.101 |
| 0.6813 | 0.82 | 0.062 | 0.34 | 0.24 | 0.16 | 0.080 |
| 1.000 | 0.76 | 0.068 | 0.34 | 0.24 | 0.16 | 0.053 |
| 1.468 | 0.70 | 0.075 | 0.27 | 0.24 | 0.16 | 0.03 |
| 2.154 | 0.63 | 0.085 | 0.25 | 0.25 | 0.14 | 0.03 |
| 3.162 | 0.60 | 0.10 | 0.34 | 0.22 | 0.13 | 0.03 |
| 4.642 | 0.55 | 0.12 | 0.53 | 0.20 | 0.125 | 0.03 |
| 6.813 | 0.52 | 0.13 | 0.64 | 0.175 | 0.12 | 0.03 |
| 10.00 | 0,50 | 0.125 | 0.68 | 0.16 | 0.115 | 0.03 |
| 14.68 | 0.50 | 0.12 | 0.66 | 0.15 | 0.112 | 0.03 |
| 21.54 | 0.49 | 0.10 | 0.50 | 0.15 | 0.11 | 0.03 |
| 31.62 | 0.51 | 0.085 | 0.33 | 0.155 | 0.11 | 0.03 |
| 46.42 | 0.56 | 0.080 | 0.22 | 0.17 | 0.11 | 0.03 |
| 68.13 | 0.63 | 0.087 | 0.16 | 0.215 | 0.115 | 0.03 |
| 100.0 | 0.76 | 0.095 | 0.16 | 0.32 | 0.135 | 0.03 |
| 146.8 | 0.93 | 0.10 | 0.16 | 0.45 | 0.17 | 0.03 |
| 215.4 | 1.25 | 0.10 | 0.16 | 0.45 | 0.49 | 0.03 |
| 316.2 | 2.75 | 0.10 | 0.16 | 0.45 | 0.49 | 0.03 |

Table 2—Relaxation times (days) versus zonal wavenumber

| Wave-number | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| Time | 3.5 | 2.5 | 2.5 | 2.5 | 1.5 | 1.5 | 1.5 |