SOLVE-II Flight Report: Friday, 01/24/2003

Paul A. Newman

Flight Type: SAGE-III occultation & vortex survey flight

Flight Objectives:

1. SAGE III occultation: 70.51˚N, 9.05˚E at 10:58:33 UT
   - 3 sun runs: 1st at 35 kft, 2nd at 31 kft, 3rd at 35 kft
2. Profile by flying northward across the vortex edge which is tilting northward with altitude
3. Overflight of Ny Ålesund
4. Profile remnant of eastern lobe of vortex
5. Near pass of Thule
6. Profile remnant of western lobe of vortex

Flight Plan (UT):

08:53 Takeoff
10:30 Sun run #1
10:59 SAGE III occultation
11:10 Sun run #2
11:40 Schoeberl lands in Kiruna
11:50 Sun run #3
13:13 Ny Alesund Overpass
15:34 Western point near Thule
18:50 Landing

Forecast Meteorology:

In contrast to the situation on the previous flight of January 21, when the stratospheric vortex was split into eastern and western hemispheric lobes, the vortex is a single, albeit elongated elliptical circulation system at both 700K and 480K. The bulk of the vortex is in the western hemisphere, centered about 15˚ north of Hudson's Bay, with a long arm extending across the pole into Russia. The ellipse rotates clockwise with altitude slightly, which means that at our longitudes the edge of the vortex slopes poleward with latitude. At 480K, the edge of the vortex should be near 72˚N at the longitude of Kiruna. Not much change is expected in the next few days, with rapidly moving waves along the edge causing fluctuations in the position of the vortex edge.

In the lower troposphere a strong southwesterly flow at 700 hPa from about (30˚W, 50˚N) to the northwest Russian Arctic is carrying successive waves toward central Scandinavia. For January around takeoff we do not expect any precipitation, though there may be some significant winds (10-15 knots) from the southwest in advance of the next approaching system. That same system should produce high clouds in the Kiruna region. Depending on timing, it may have begun to snow by landing time.

At flight levels the upper tropospheric low pressure system that dominated the circulation in the north central Atlantic from 55˚ to 80˚N on January 21 has retreated somewhat and moved slightly eastward, from west of Spitsbergen to just east. The tropospheric storm pushing into Norway has created a more nearly zonal flow from Iceland to northern Scandinavia, instead of the southwesterly flow on January 21. The approaching system has extended the main region of high tropopauses (which are south of the jet core over southern Norway) into a sliver extending southeast-northwest into the SAGE occultation area at (10˚E, 69˚N). Nevertheless, the tropopause should still be no higher than 31Kft at the SAGE occultation. This region is downstream of a cold pool in the upper troposphere over Greenland, though trajectory analyses do not suggest unusually low values of water vapor or tropospheric dehydration. Over Spitsbergen, the tropopause should be quite low, reaching a minimum altitude of about 5-6 km. Another high tropopause region is over the northwestern corner of the flight track near Thule, where it might reach 30000 feet. However, only over the SAGE occultation point will the high tropopause (which will be moist and cloudy) pose a potential problem for the lidar instruments

Wind at cruise altitude should not exceed 50 knots. However, on climb out (and return) over Kiruna, 70 knot winds may be encountered as the aircraft passes through the northern reaches of the jet (whose maximum winds are well over 100 knots into south central Scandinavia).

Some gravity wave induced turbulence is expected during the flight, particularly near Thule. Significant stratospheric gravity wave activity is expected over the eastern Greenland coast and over Scandinavia as a whole.

Flight Meteorology:

Flight Report:

We were delayed on the roll-out while we waited for the Falcon and Geophysica to be pulled out of the hangar. This delayed our take-off to 09:05, putting us approximately 12 minutes behind schedule. This compromised our first way-point, resulting in some real-time flight planning near the northern Norwegian coast. We real-time executed a 7-minute sun run as we were delayed to our first sun run between 09:49Z and 09:56 just to the SE of our planned sun runs.

On climb out, we passed through a jet of about 50 kts from the SW. Passed out of cirrus clouds at about 29 kft and through the tropopause at about 31 kft. We arrived at 35 kft prior to this "preliminary" sun run and saw H_2O of 5 ppmv, CO of 35 ppbv, ozone of 291 ppbv, and a theta value of 322K - clearly lowest most stratospheric air. Winds were 60 kts out of the west. This was higher than expected by the forecast. DIAPER reported a plume "hit" at 10:11Z.

Started our "first" sun run at 10:33 UT. GAMS/LAABS and DIAS reported sun tracking near the start of the sun run. H_2O was slightly higher than earlier at 5.2 ppmv, while CO was 34.5, ozone=299, T=-56.6, theta = 326.4, V=54 @ 255˚. Cirrus below us was at about 27.5 kft. During the run, DIAL reported an aerosol layer between 14-15 km. AROTAL-Langley reported multiple layers: the same layer that DIAL saw at 14-15, a second layer at 18, and an optically thin layer between 20 and 25 km, and perhaps a small layer between 26-27 km. AROTAL-LaRC reported that this layer had an optical depth of 10^{-5}/km. We ended the run at 10:52 with a solar zenith of 89.8˚. All 3 solar instruments reported good data.

After completing the 1st sun run, we descended to 31 kft for our second run. The wind was almost parallel to our track, so it was unlikely that we would cross our plume on the track, and DIAPER reported that was the case. After we had completed the descent, H_2O had increased to 9.6 ppmv, CO=79.5 ppbv, ozone=143 ppbv, theta=307.4 K, T=-57.9˚C, V=41kts @ 245˚. This put us just marginally into the stratosphere.

We started our 2nd run at 11:13Z. All 3 solar instruments began to track the sun shortly after we started. Again, AROTAL-LaRC saw the same set of layers on this sun run. We ended this 31 kft sun run at 11:32 with a zenith angle of 89.6˚. All 3 solar instruments tracked the sun and collected data.

At 11:42Z, we were cleared back to 35 kft. On this back leg, AATS-14 had a problem, and they had to re-start the instrument. At 11:47 they began to track the sun again. At 11:48 we were back at 35 kft, and we began our turn to start the 3rd sun run. During the turn, H_2O was 5 ppmv, CO was 35 ppbv, ozone=305 ppbv, T=-56.2˚C, theta = 326.5, v=61 at 268˚.

Started our 3rd and final sun run at 11:54Z. DIAS and AATS-14 acquired the sun in the turn, and GAMS/LAABS acquired the sun after we leveled off. The SZA was 90.1˚ at the start of the run. We ended the run at 12:11Z with a zenith angle off 90˚. All 3 solar instruments reported good data acquired during the run.

We turned northward towards Spitzbergen at 12:11, and ascended to 37 kft. After we leveled off at a latitude of 71˚15'N, H_2O=3.7 ppmv, CO=29.5, ozone=412, T=-56.3, theta=335.9, and V=47 @ 266˚. As we flew northward along this track (~72˚45'N) AROTAL-LaRC reported that the aerosol layer at 29 km had moved upward to 31 km. The cirrus layer below us also disappeared near 72˚N. Below us was marine stratus with tops at about 2 km.

Moving northward towards Ny Alesund, we passed from the vortex edge into the core of the vortex at altitudes near 20 km. DIAL showed a near continuous layer of ozone that we less than 2 ppmv at altitude near 19 km. AROTAL-GSFC also showed this low layer. As the forecast showed, winds at our flight level of 37 kft fell off as we moved towards Ny Alesund: at 77˚45'N, the wind was 21 kts @ 296˚.

Overflew Ny Alesund at 13:21 UT, approximately 8 minutes beyond our ETA. Once again, the town was clear as we overflew. During the overpass, DIAL and AROTAL were seeing a fairly deep layer with mixing ratios of ozone less than 2 ppmv at 19 km.

We turned westward shortly after passing Ny Alesund and ascended to 38 kft. Most of the tracers didn't change much, since we were moving into colder air, and the potential temperature surfaces were lifting. That is, although we were moving northward at fixed altitude, the air we were sampling was from a lower, less of a pure stratospheric altitude. H_2O=3.6, CO=31.2, ozone=421, T==60.5, theta=333.7, V= 10 kts @ 261˚.

The horizon to our south was really vivid, with beautiful layers of cirrus.

SP2 reported that they were measuring large numbers of incandescent particles at 37 kft that were probably black carbon.

Ozone in the 15-25 km layer was showing consistent values of less than 2 ppmv. The aerosol layer at 31 km disappeared, and the layer at 16 km had strengthened. This layer was clearly evident as we transited from Ny Alesund to Thule. Over Northern Greenland the layer was at an altitude of 17.5 km, while near the date line, the layer was at about 16.25 km. This suggests that the

Ozone mixing ratios were seen to be less than 2 ppmv almost everywhere in the vortex. The layer that was less than 2 ppmv extended from 16 to 22 km. Below 16 km, the values uniformly dropped to about 0.1 ppmv near the tropopause. Over Northern Greenland, the tropopause was at an altitude of about 8 km.

Began our climb to 40 kft at 15:07 UT. Near the western end of our track at 40 kft: H_2O=3.7 ppmv, CO=29.3 ppbv, ozone=413 ppbv, T=-64.9˚C, theta=335.7 K, v=23 kts @ 230˚. Thick cirrus stratus clouds were below us with tops at about 33.5 kft. The prominent aerosol layer we'd been tracking since Ny Alesund was now at about 19.5 km, but was starting to disappear.

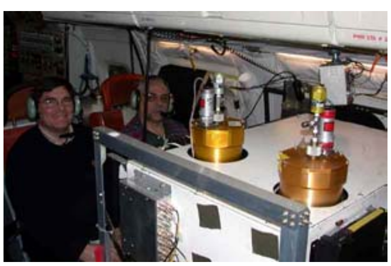

Figure 1. Jim Podolske of NASA/Ames and Tom Slate of NASA/Langley sit in front of the DAACOM/DLH instrument. This instrument makes extremely precise measurements of H_2O, CH_4, CO, and N_2O.

We turned to back towards the east at 15:40 UT, and we started to climb to 41 kft. Just prior to ascent at 40 kft, H_2O=3.6, CO=28.7, ozone=422, theta=337.8, T=–64.1, and V=13 @ 231. After ascent to 41 kft, H_2O=3.4 ppmv, CO=26.9 ppbv, ozone=455 ppbv, T=-65˚C, theta=340.4 K, v=17 kts @ 211˚. This area was roughly the center of the vortex for the 460 K isentropic surface. Ozone mixing ratios at 20 km were somewhat higher than 2 ppmv in this region, suggesting weaker ozone loss.

Some good views of the ice sheets spreading out from Northern Greenland. Ice bound islands with enormous glaciers. Rocks, ice, & snow. It makes Kiruna look like the tropics. It sure is nice to be flying in an airplane with 4 engines.

Figure 2. Broken Ice sheet on the NW side of Greenland near 75˚N.

The layer that we'd been seeing at 19 km near the vortex core moved downward in altitude as we flew eastward. Near 33˚W it had descended to about 14 km. It appeared that a low ozone feature was associated with this aerosol layer.

We also continued to observe low ozone values of less than 2 ppmv in the 16-22 km layer as we continued eastward. These low values generally mirrored the values that we'd seen on the westward track from Ny Alesund.

Crossed the Greenland coastline at about 17:04 UT. H_2O=3.5 ppmv, CO=27.4 ppbv, ozone=489 ppbv, T=-63˚C, theta=343.7 K, v=16 kts @ 291˚. In this region, ozone values of less than 2.0 ppmv at 19-22 km were becoming a bit sporadic. At altitudes above the aircraft, temperatures were becoming steadily warmer as we flew westward and ozone mixing ratios were becoming steadily higher. The aerosol layer that we'd seen on the way to Spitzbergen near 29-30 km reappeared. This layer of aerosol appears to be a sheet of air containing high aerosol concentrations that is just outside the polar vortex at altitudes near 30 km.

Near the prime meridian, or our eastward track, ozone increased to over 600 ppbv. At 73˚34'N, 2˚16'E, H_2O=3.1 ppmv, CO=23.4 ppbv, ozone=617 ppbv, T=-58.9˚C, theta=350.8 K, v=33 kts @ 286˚, MTP tropopause at 31 kft, DIAL "chemical" tropopause was at 7 km or about 26 kft.

A great aurora at about 17:57 UT, 4˚45'E to the right of the plane as we headed eastward. Some red color to it, and a distinct cyclonic spiraling.

Ozone continued to increase as we moved eastward, temperatures also increased. The aerosol layer AROTAL/Langley was watching had descended to 26 km, and a second layer had appeared at about 31 km. AROTAL/GSFC observed a thermal inversion that was between 37 and 50 km with a lapse rate of about –4K/km. Temperatures decreased moving eastward on a constant altitude at these levels.

Began our descent into Kiruna at 18:40UT, near the Norwegian coastline. Landed in Kiruna at 19:06 UT.

Pilots: Ed Lewis, Bill Brockett
Navigator: Kevin Hall
Mission managers: Chris Miller & Bob Curry
Mission scientist on board: Paul A. Newman.

Status Report: Instrument – PI

DIAPER (in situ aerosols) – Anderson
A good flight. Collected lots of aerosol data, with 1 plume intercept.

SP2
SP2 worked today. Got data over 95% of the flight, 3-4,000 particles.

FastOz – Avery
Worked well. One computer reboot.

DACOM/DLH (in situ trace gases and open path water vapor) – Diskin
Worked well. Problem with methane channel.

PANTHER (in situ PAN and other trace gases) – Elkins
A very good flight. Had to reboot 3 times, a loss of only 15 minutes of data.

MTP (microwave temperature profiler) – Mahoney
Had a great flight. A fairly isothermal profile above the tropopause. A warm stratosphere.

AATS-14 (sun photometer) – Russell
Had a good flight. Tracked well, good data.

GAMS/LAABS (solar occultation ozone, aerosols and oxygen A band) – Pitts
Instruments worked well.

DIAL (Lidar ozone and aerosol above and below the AC) – Browell
Worked well. Got a lot of interesting data.

AROTAL (Lidar ozone, aerosols and temperature above the AC) - McGee/Hostetler

GSFC – Had a real good flight. Saw the predicted behavior. Interesting inversion at 45 km in temperature data.
LaRC – Got some good data. Interesting aerosol data.

DIAS (Direct beam solar irradiance) – Shetter
Dandy flight. Got data all through the sun runs. Not much in the UV.

FCAS/NMASS (in situ aerosols) – Reeves
Automated.

Differential GPS – Muellerschoen
Worked well when it was going. Rubber band fix worked.

ICATS
Had a really good flight.

Figure 3. ICATS operators Mark Corlew and Joe Arnold. ICATS provides various basic parameters for all of the investigators. These parameters include aircraft performance, winds, temperatures, and position information.

Plots (flight plan, solar zenith angles, Rel. humidity):

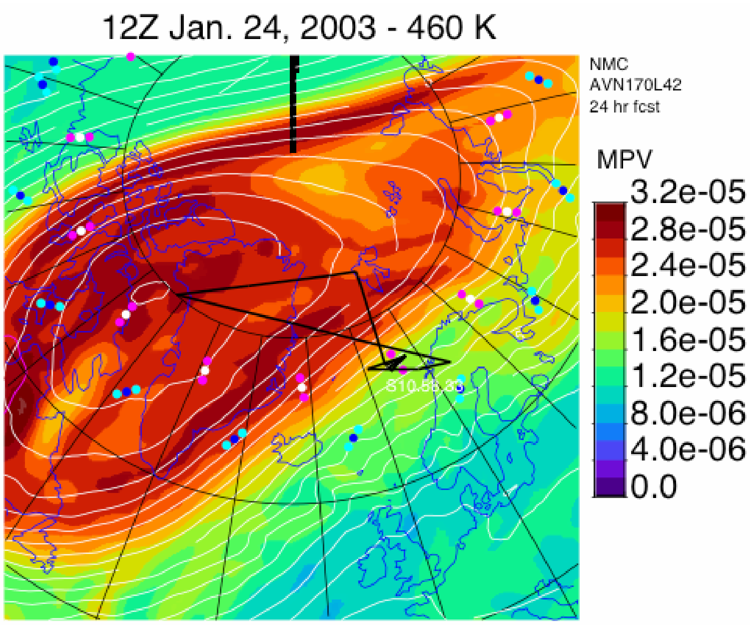

Figure 4. January 24, 2003 DC-8 flight plan (black) superimposed on a 12Z map of modified potential vorticity (color image) for the 460K isentropic surface. The thick magenta line on the left shows the 195 K temperature contour. The white point indicates the SAGE III occultation point and the dark blue points are POAM occultation points. The white lines are Montgomery stream function lines (winds blow parallel of these line).

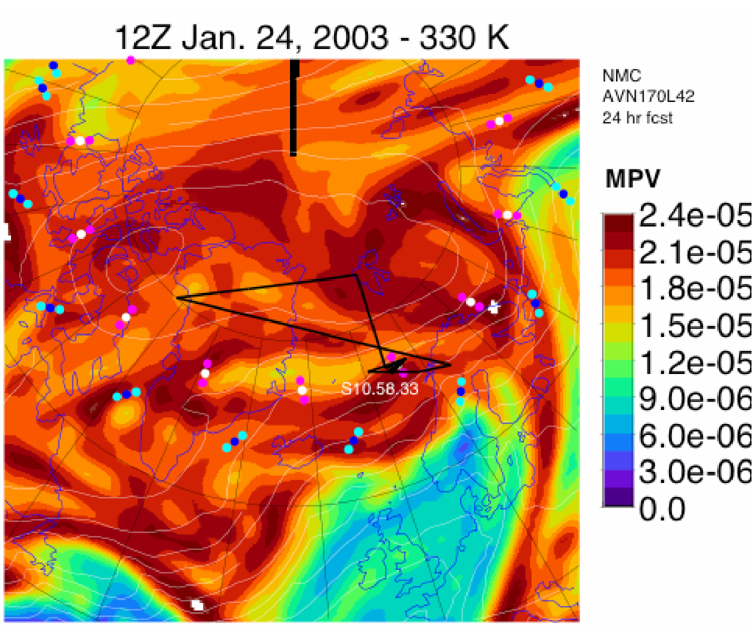

Figure 5. As in the previous figure, but for the 330K isentropic surface (approximately the DC-8 flight altitude)

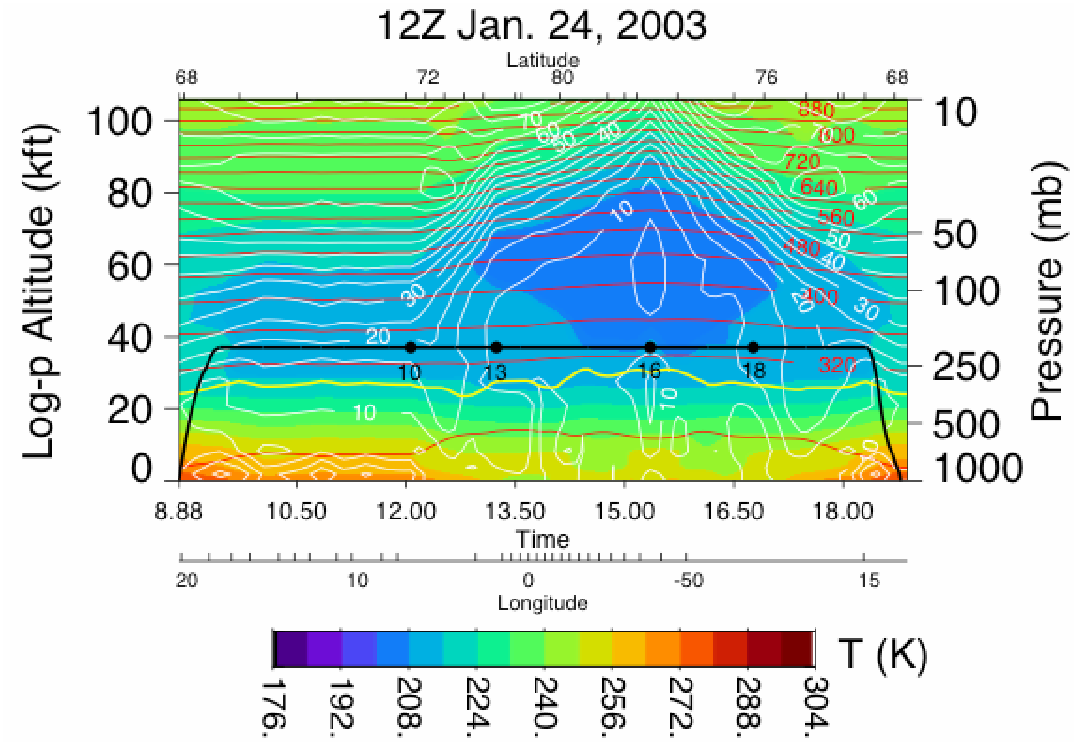

Figure 6. Curtain plot following the flight of January 24, 2003. The colors indicate temperature values (see scale at bottom of the figure). Red contours are potential temperature (K), white contours are wind speeds (m/s), and the yellow contour shows the tropopause.

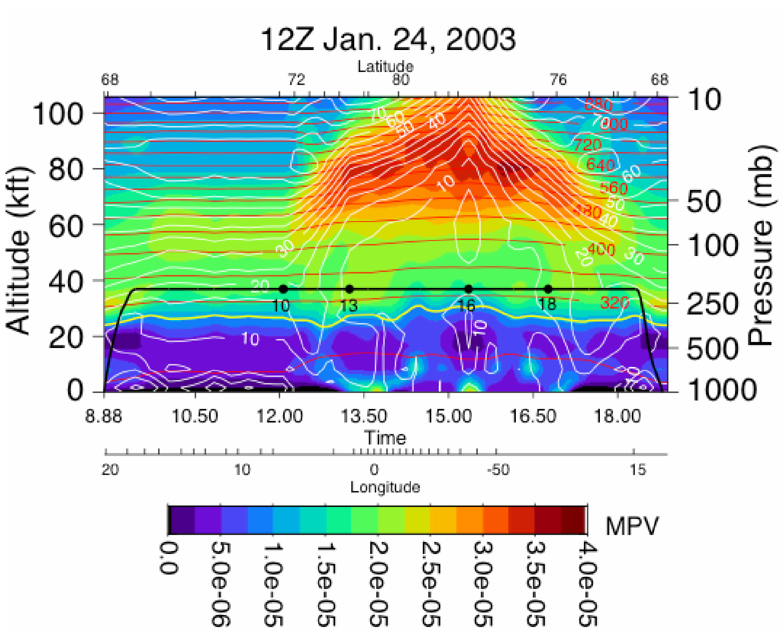

Figure 7. Curtain plot following the flight of January 24, 2003. The colors indicate potential vorticity values, where red-orange shows vortex material, and blues-green shows mid-latitude material. Red contours are potential temperature (K), white contours

are wind speeds (m/s), and the yellow contour shows the tropopause. Ignore PV values below the tropopause.

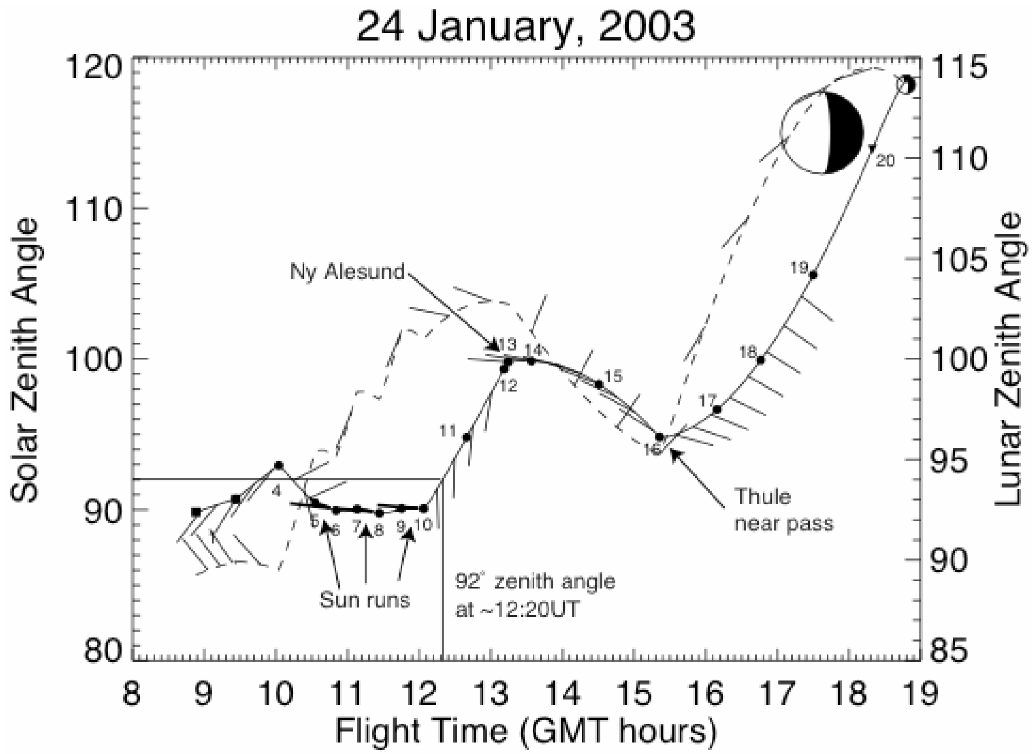

Figure 8. Solar and lunar zenith angles for the flight path shown in the previous figures.