SOLVE-II Flight Report: Friday, 01/31/2003

Mark R. Schoeberl

Flight Type: SAGE-III occultation & North Pole flight

Flight Objectives:

1. SAGE Occultation
2. Vortex sample in cold air pool
3. (Russian airspace)
4. Vertical profile over Ny A.
5. In situ and laser intercomparison
6. Vortex Edge crossing
7. Takeoff 8:22 GMT
8. Flight Length ~9:30

Flight Plan (UT):

08:22 Takeoff
09:33 Sun run #1 – Waypoint 5
9:53 SAGE III occultation – Waypoint 6 (72˚ 16 N, 30˚)
10:45 Sun run #2 – Waypoint 7
11:04 Easternmost Waypoint 10 (68˚E 78˚ 15N)
13:09 Spiral descent/Ascent – Waypoints 11-12
16:27 Outside the vortex westernmost Waypoint 14
17:59 Landing

Forecast Meteorology:

The vortex has formed into a triangular shape with the long point extending southward to the west of the Scandinavian Peninsula almost into Germany. Take off will be inside the vortex. We will then proceed to the coldest region of the vortex in Russian airspace. We then will turn west and do a descent/ascent maneuver near Spitzbergen. We will then exit the vortex between Spitsbergen and Iceland, with a waypoint east of Iceland. The vortex edge is defined by a strong frontal system that stretches from eastern Canada to England. We expect some turbulence along this front at aircraft altitude. The vortex is shedding material at a rapid rate.

Flight Meteorology:

Relative humidity forecasts were again right on target. Clouds formed below the aircraft just about exactly where predicted.

Flight Report:

Took off at 8:19 UT. Kiruna clear. As we flew to waypoint 4 over the Atlantic, we moved through some cirrus that decreased as we ascended. MTP reported the tropopause at 10 km (32 kft). Ozone increased very rapidly as we crossed the tropopause from 70 ppbv to 240ppbv. CO went from 90 to 44 ppbv. The forecast tropopause was 270 hPa but we observed it a little higher – 275. By the time we had leveled off at 35 kft, ozone was up to 285 ppbv, H_2O was down to 5.5 ppmv, CO had decreased to 34 ppbv, at a theta value of about 320 K. H_2O rose to 9 ppm at flight level. As we proceed along ozone slowly decreased to 180 ppbv. PANTHER is dead; pump may have a burned-out FET.

Winds were somewhat different direction at altitude than predicted so we were slightly late in arriving at the sun run Waypoint 6, so we turned a little early from WP5 to make up time. Sun run #1 began 9:38 12 – hit occultation point at 9:43:30. Ozone fields very uniform up to the occultation point with 2.2 to 2.4 ppmv at 18 km. This air did not have vortex air characteristics – as we had sampled the previous flights, yet it was clearly predicted to be inside the vortex (see discussion at the end of this report). All solar instruments reported successful acquisition of the data. In situ ozone 161 ppbv, CO 83 ppbv, H_2O 7.3 ppmv. No aerosols above the aircraft, broken clouds below the aircraft at 1-2 km tops from the surface (GPS). DC-8 contrails were observed at altitude. Winds are from 360˚@20 kts.

In situ ozone rose to 190 ppbv as we turned back at the end of the sun run. The tropopause was at 9.5 km. There appears to a structure in ozone and CO aligned with the wind field about 20 ppbv in amplitude ozone at flight altitude (32 kft) – we crossed this structure repeatedly as we did the sun runs. This feature was about 1/4 to 1/3 the width of the sun run track and had an amplitude of 150 ppb in ozone. The second sun run began at 10:20 – about 3 minutes late. This feature was not well correlated with H_2O (8 ppmv). The feature is about 60 km wide. SP2 reported some particles – possibly from our own exhaust. We did not do a descent to look for exhaust because AATS need to take data at the same altitude.

All sun-run instruments worked well. As we proceeded northward of 72˚N ozone in the 17-20 km region began to drop rapidly below 2 ppmv according to both AROTAL and DIAL. The drop corresponded to higher zenith angles.

Lowest values ozone values were ~1.4 –1.6 ppmv at 20 km according to AROTAL near 76˚N. Temperatures declined inside the cold pool to 197K at 20 km. These are consistent with the slope of the MTP temperatures. No evidence of PSC layers in the center of the cold pool. In situ ozone slowly rose to 203 ppbv with CO at 60 ppbv and H_2O at 8.8 ppmv. DIAL noted a polluted region below the aircraft – probably Arctic haze. It was clear below the aircraft and we could see DIAL's nadir laser beam reflected on the icy surface. The potential temperature was 312K at WP 10.

We climbed to flight level 380 just beyond Waypoint 10. Ozone at 18 km began to slowly increase according to AROTAL, and we flew toward Spitsbergen. Temperatures

at 18 km approached 195K – but no evidence of PSCs. In situ ozone rose to 400 ppbv, with CO at 28 ppbv and H20 at 3.7ppmv – this is really lower stratospheric air.

The Project Scientist and the Navigator worked out a change in the planned descent routine. We will descend to 10 kft before waypoint 12, and then head south along the wind vector for 10 minutes then ascend. The 10-minute leg is to use the lidars over the region we descended through. Thus we will effectively calibrate the lidars with the in situ ozone. We will then head west and intercept the flight track south of WP12. The sonde will be passing in front of us as we head west. South of Franz Josef land we picked up a very mild chop- winds were from the north, and the chop probably was lee waves propagating to our altitude from the islands. There was a lot of variability in ozone during this short period (2 minutes) with anti-correlation between ozone and CO. Ozone began to decrease as we approached the descent point – 375 ppbv, CO 30 ppbv, H_2O 4 ppmv, potential temperature 312.

We began the downward spiral at 13:20, sky was clear to the surface. Ozone began to decrease and CO increase – ozone fell to below 200 ppb at ~33,500kft, there was a layer of almost 120 ppb ozone at 32 Kft then went up then down again. This was near the tropopause (30 kft). Ozone showed a lot of structure and then decreased more rapidly as we entered the tropopause. Ozone flattened out at 50 ppbv with CO at 134.8. Particle instruments reported we might be seeing our own exhaust. CO increased slowly to 143, H_2O 92 at 20 kft.

DIAPER reported an aerosol layer at 23 KF – Dial detected the layers at 7.5, 6.3 km and a layer below at 3.6. Winds dropped to 11kts at 13 kft; potential temperature of 277. H_2O rose to 230 ppm CO and ozone remained steady. In situ instruments report another aerosol layer near 10.5kft. At 13:49 we leveled off at 10 Kft. H_2O 461 ppmv, ozone and CO steady. We began the southeast track along the wind vector. 50% of the particles appear to contain black carbon at this altitude. The in situ aerosol instruments reported four aerosol layers down to 10 kft (~3 km) that could be seen by AROTAL and DIAL looking back upward. Wind speed 13 kts, potential temperature 228K, MTP estimates the surface temperature to be 260K, the IR surface temperature agrees with this value.

We began the ascent at 14:07UT. We began to see the aerosol layers observed on the way down and seen by the lidars on the level flight. Ozone and CO held steady with water vapor slowly dropping. We hit the tropopause at 280 hPa, about 9.5 km. Ozone jumped to 120 ppmv and began to rise rapidly. There was structure in ozone and CO at the tropopause. We ascended to 39 Kft after the circle ascent at 14:36UT.

AROTAL showed ozone increasing in the 15-20 km region as we approached the vortex edge. At 73 N we are approaching the vortex edge predicted to be just beyond WP 13. Dial indicated clouds below the aircraft. We will be crossing a frontal boundary at WP13. The aircraft is ascended to 41 Kft. at 15:32UT. In situ ozone shows considerable wave like structure anti-correlated with CO. AROTAL and DIAL show ozone increasing below 20 km. Potential temperature 341 K, wind 40 kts and beginning to veer to the west (head wind) consistent with model predictions. The plane turned east at Waypoint 13

instead of 14 – mission managers quickly caught the error and got us back on course. Very light turbulence as we crossed the jet to the east of Iceland. In situ ozone was a 334 ppbv, CO at 36, H_2O at 4.3 an 70N, 2 W, 16:07 UT. We began to exit the vortex at this point according to AROTAL who reported increasing ozone and aerosol layers below 20 km. These layers were actually visible out the window.

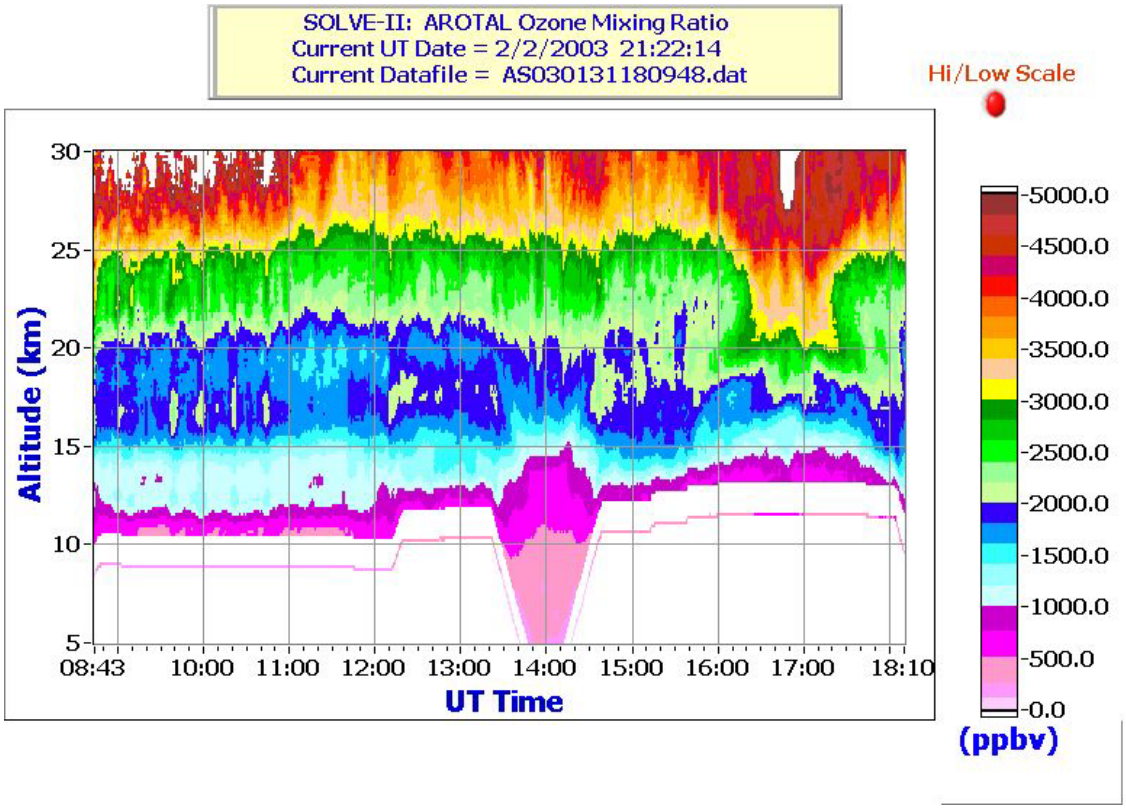
Figure 1. Faint aerosols observed as we exited the vortex near Iceland. Yes, I know they are hard to see, but we all saw them.

As we flew east from WP 13, we encountered regular oscillations that were visible in the in situ ozone and CO measurements. This appears to be a combination of light gravity waves and feedback in the flight computer that causes the altitude to oscillate with about 100 ft amplitudes. West of Norway we began to enter the vortex again (6˚ W, 68˚N).

The vortex ozone characteristics recorded by AROTAL were very different from those recorded on the outbound leg at 20 km despite the fact that the PV plots suggested that they should be the same. There may be a problem with they're lower zenith angle measurements – we decided to run to Kiruna at altitude and then descend in a spiral so we could check out this possible problem. Ozone 490 ppmv at 42 kft, and CO 24, H_2O 3.3 ppmv, PT 342K over Kiruna. As we descended, we went through some cirrus ozone was 90 ppbv at 20 kft.

Post-analysis comment. The spiral descent and ascent was a big winner for everyone. The particle guys got good material and the in situ measurements along with the lidar measurements will be invaluable for comparison and calibration.

AROTAL found some problems early in the flight with the data taken at lower zenith angles. They have corrected their data for this problem in post-processing. The correct plot appears below.



The lower solar zenith angle data can be seen as the noisy region at 30 km up to about 10:30. Below that altitude the data looks pretty seamless, indicating a good correction. The dip maneuver at about 13:30 can be seen as well as the transit out of the vortex at 16:00 to 17:00.

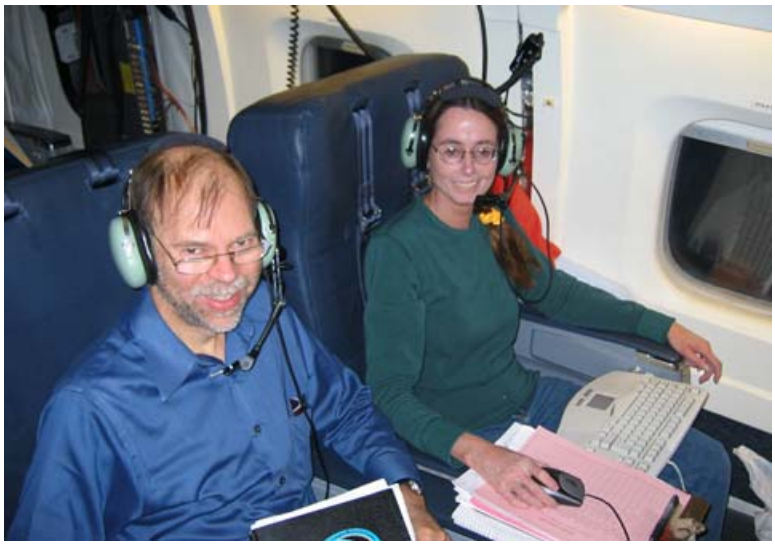


Figure 2. Bill Grant and Susan Kooi of the NASA Langley DIAL lidar team.

Pilots: Ed Lewis, Dick Ewers
Navigator: Kevin Hall
Mission Managers: Chris Miller & Tom Mace
Mission Scientist onboard: Mark R. Schoeberl

Status Report: Instrument – PI

DIAPER (in situ aerosols) – Anderson
Optical probes worked – Nephalometer, CN, and PSAP failed to get data due to a disk failure.

SP2- Had a good flight. Worked well

FastOz – Avery
Instrument had a good flight. Loved the descent.

DACOM/DLH (in situ trace gases and open path water vapor) – Diskin
One of best flights – some computer hiccups – lost a little data.

PANTHER (in situ PAN and other trace gases) – Elkins
Pump broke – no data.

MTP (microwave temperature profiler) – Mahoney
Had a good flight. Tropopause heights were lower over Nova Zemlya than predicted

AATS-14 (sun photometer) – Russell
Excellent flight.

GAMS/LAABS (solar occultation ozone, aerosols and oxygen A band) – Pitts
Worked fine.

DIAL (Lidar ozone and aerosol above and below the aircraft) – Browell
Worked well.

AROTAL (Lidar ozone, aerosols and temperature above the aircraft) - McGee/Hostetler
GSFC – Good flight.
LaRC – Good flight.

DIAS (Direct beam solar irradiance) – Shetter
Worked fine through the sun runs.

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

Differential GPS – Muellerschoen
Worked well. Some drop outs in transmission to AROTAL

ICATS
Had a good flight.

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

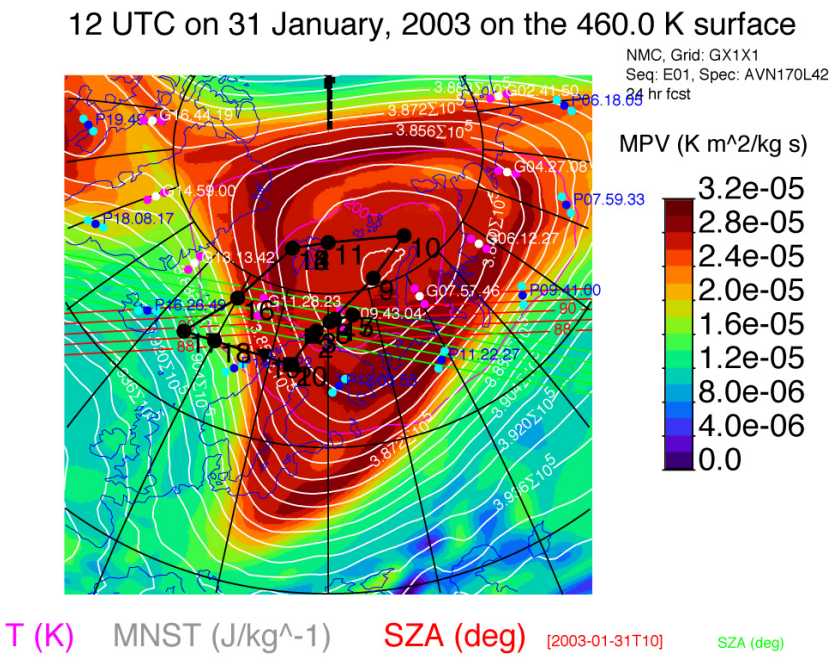


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Figure 1. January 31, 2003 DC-8 flight plan (black) superimposed on a 12Z map of modified potential vorticity (color image) for the 460K isentropic surface. The thick magenta line on the left shows the 200- and 205-K temperature contours. The white 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). The dashed green line extending between Spitzbergen and Northern Greenland indicates the axis of a PV low. A maximum of ozone was observed on both the northbound leg and southbound legs of this flight at approximately the position of this dashed green line.

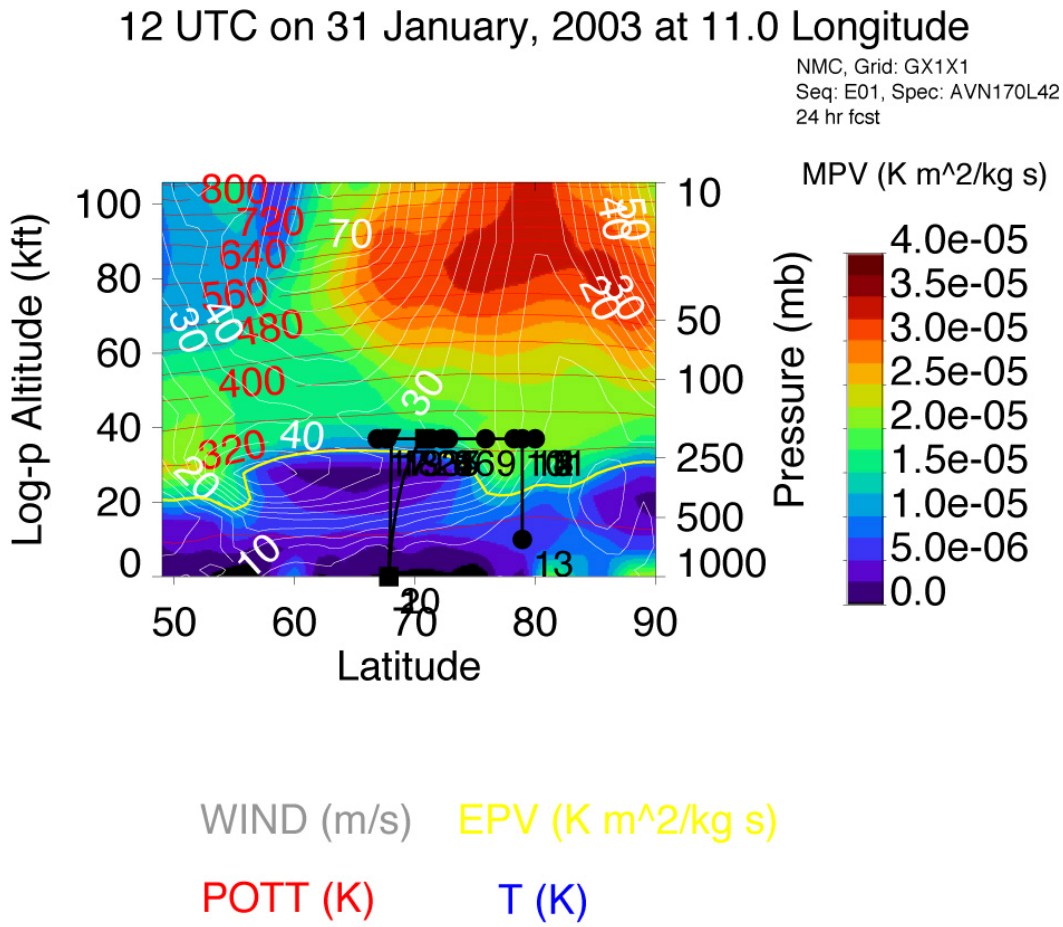

Figure 2. Transect plot from 50˚N to 90˚N at a longitude of 11˚E. The colors indicate potential vorticity values, where red-orange shows vortex material, and blues-green shows mid-latitude material. Red contours are potential temperature (K), white contours are wind speeds (m/s), and the yellow contour shows the tropopause. Ignore PV values below the tropopause.

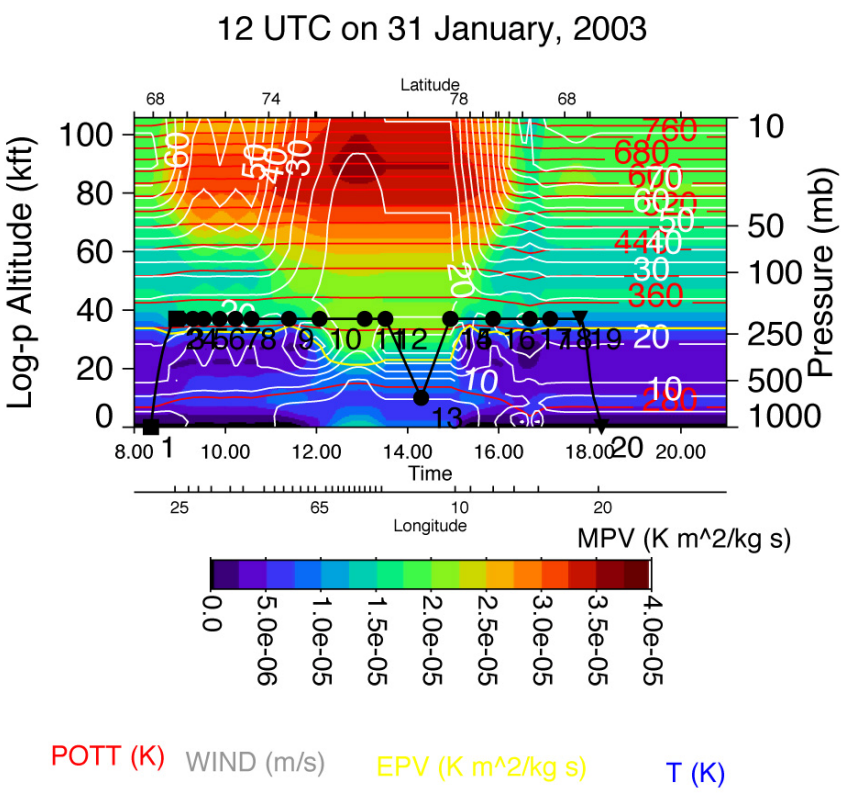

Figure 3. Curtain plot following the flight of January 31, 2003. The colors indicate temperature values (see scale at bottom of the figure). Red contours are potential temperature (K), white contours are wind speeds (m/s), and the yellow contour shows the tropopause.

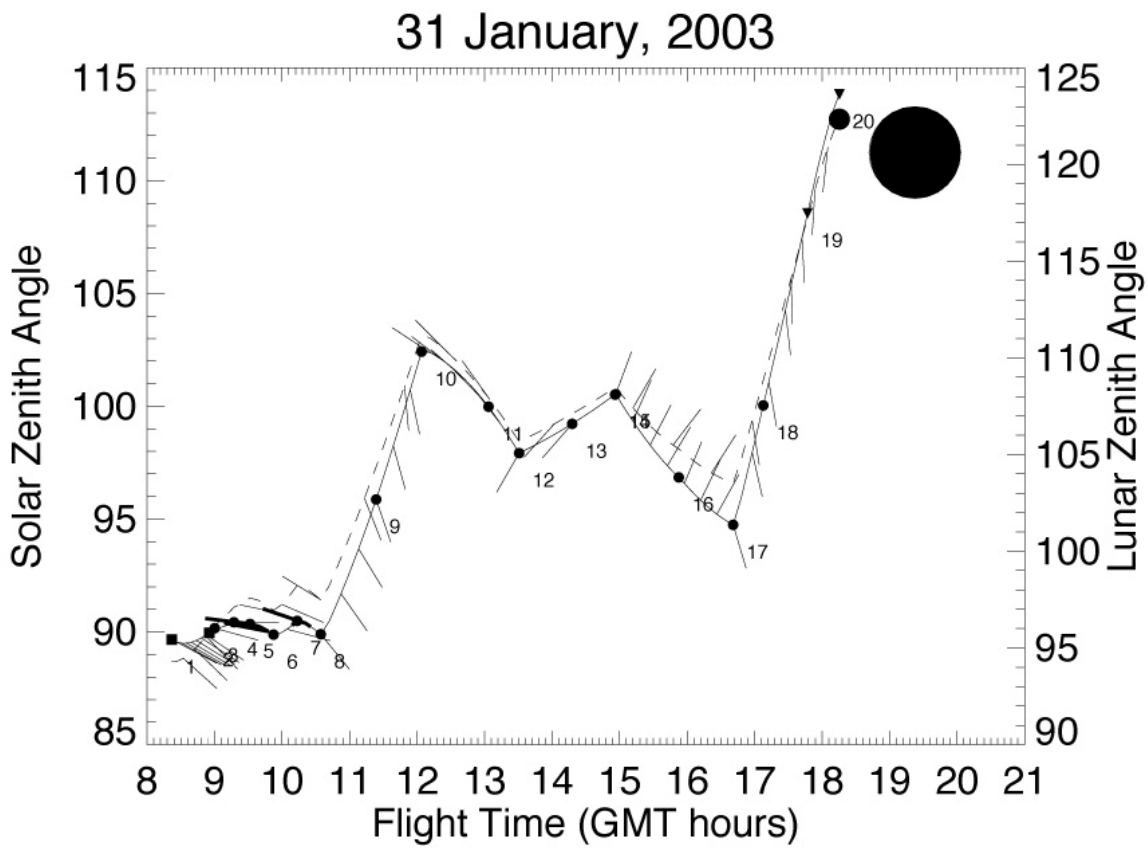

Figure 4. Solar and lunar zenith angles for the flight path shown in the previous figures.

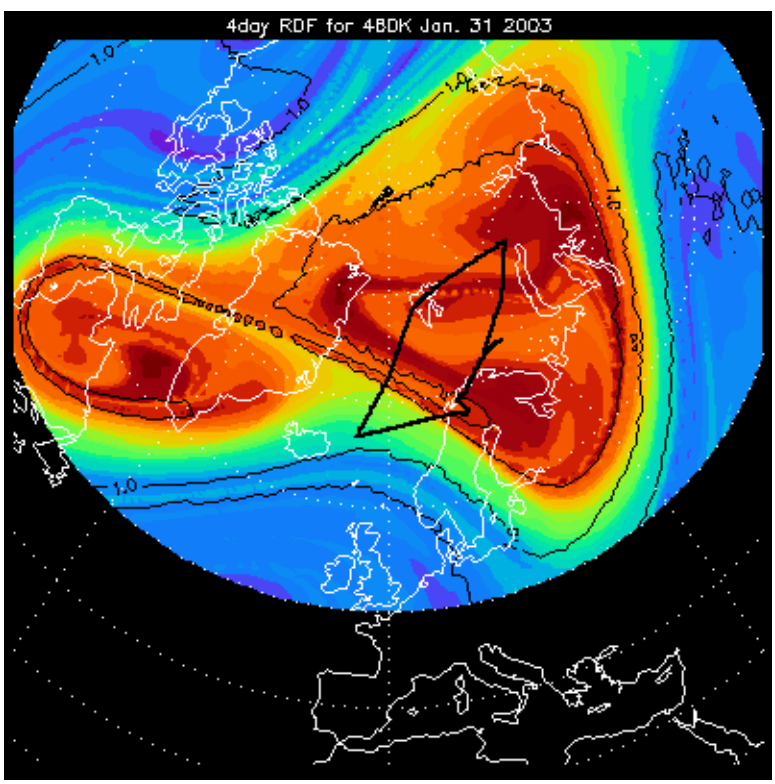

Figure 5. Seven-day RDF of the vortex using Data Assimilation Office data