SCIAMACHY	Operation Change Request	OCR No: 036 Issue: A

Title: SCIAMACHY limb measurements in the mesosphere and lower thermosphere

Description of Request:

A number of trace gas emissions can be identified in the upper mesosphere in the SCIAMACHY limb measurements, including NO from the γ-bands, OH at ~ 308 nm, O_2, Mg, Mg^+, atomic oxygen, O^+, Fe, Fe^+, and Na. A tomographic retrieval algorithm using all daytime limb and nadir measurements of one orbit for mesospheric emission species has been developed at the Institute of Environmental Physics, University of Bremen, and has so far been applied successfully to the metallic species Mg and Mg^+. This retrieval code enables us to retrieve altitude profiles of mesospheric and thermospheric emitters up to around 400 km of altitude, but with a very limited vertical resolution above the altitude of the highest limb-scan at around 93 km.

A number of the species mentioned above have significant contributions in the lower thermosphere, between 90 – 150 km, above the highest SCIAMACHY limb altitude. This is especially true for O, NO and the metals and metal ions. A new state was therefore defined in OCR 030 with limb-scans shifted to the lower ionosphere, scanning the altitude range of 60 - 150 km instead of from the surface up to ~ 93 km as in the normal SCIAMACHY limb mode. Measurements in this new state were carried out during 20 orbits on August 8 and 9, 2007 (orbits 28433 - 28452). These measurements show very clear emission features between 95 - 150 km altitude especially from Mg^+, Mg, O and NO. Examples of line emissivities of several trace gases as well as number densities of Mg/Mg^+ derived from these orbits are shown and discussed in Annex 1. These data show that measurements in the new SCIAMACHY mesosphere/thermosphere state work very well, and have the potential to greatly increase our knowledge of a fairly unknown atmospheric region, the upper mesosphere/lower thermosphere region. Continuous measurements with this state will especially improve our knowledge of atmospheric metals and metal ions, which have been measured for the first time on a global scale by SCIAMACHY (see Scharringhausen et al, 2007; 2008), but which have a large contribution from the lower ionosphere, a region at the moment not covered by SCIAMACHY (see also letters of recommendation from Prof. John Plane, University of Leeds, UK, and Dr. A. Aikin, The Catholic University of America, Washington, DC). Also, regular measurements covering the lower ionosphere will improve SCIAMACHY measurements of NO and ozone from the O_2 bands as they make it possible to control how well the 2D retrieval covers the ionospheric impact. This is especially important as SCIAMACHY to our knowledge is the only instrument that has the capacity to measure NO in the upper mesosphere, a region where NO is supposed to be highly variable due to transport from the lower thermosphere as well as due to the impact of energetic particle precipitation events. SCIAMACHY measurements of NO in the mesosphere / lower thermosphere region have the potential to investigate the impact of both processes and their role for the stratospheric NOy budget for a long time-period and on a global scale; these data will provide important input in research related to solar-climate interactions as, e.g., the international research program CAWSES (Climate and weather of the sun-earth system) propagated by SCOSTEP (www.scostep.ucar.edu).

Therefore, we request the following change:

- To change the setting of the limb sequence to the 'mesosphere-thermosphere' state defined in OCR_030 for a number of 30 orbits per month on a regular basis from spring 2008 on until the end of the SCIAMACHY operation period. The 30 orbits can be spaced either directly after each other or into two bins of 15 orbits each.

This will provide a reasonable global distribution for every measurement period of the new state, even if the coverage is not very good. The amount of data collected from spring 2008 to the end of the SCIAMACHY measurement period in 2012 or even 2013 will provide a unique database of species in the lower ionosphere; especially for the metals and metal ions, no other instrument provides comparable measurements in this altitude region and on a global scale.

Originator: M. Sinnhuber, IFE	Date of Issue: 2008-02-26	Signature: MS 2008-02-26

Assessment of SSAG (necessary for requests by scientists):
As recommended by John Plane and Arthur C. Aiken in their support letters, the regular (monthly) execution of UMLT measurements will allow to make unique contributions to our understanding of MULT processes. The analysis of the OCR is therefore strongly recommended. A final decision on implementation has to take into account the impact on the nominal limb measurements.

SSAG: H. Bovensmann, IFE	Date: 28.2.2008	Signature: via e-mail 28.2.2008

Classification of OCR: C

OCR Analysis (incl. Implementation Option):

The identical 'test' in OCR_030 was implemented via a temporary modification of certain state parameters. This would also be an option here but since OCR_036 requires to execute on a routine basis about 30 orbits per month it is strongly recommended to implement OCR_036 via permanent modifications. These impact

- Mission scenarios: Introduce regular mesosphere/thermosphere measurements thus reducing the number of regular limb measurements
- States: For a permanent implementation a dedicated mesosphere_thermosphere state has to become part of the set of 70 on-board states
- Timelines: Regular execution of the mesosphere_thermosphere state requires the definition of new permanent timelines.

Mission scenarios:

The 30 orbits with the mesosphere_thermosphere measurements shall be executed as one block per month in the time period when no subsolar measurements are planned. This reduces the need for defining a large number of new timelines.

States:

One of the currently unused states has to be overwritten permanently thus defining a new state Limb_Mesosphere_Thermosphere (lmt01). Prime candidate is state ID 55 (Moon_Pointing_Troposphere, mop03) since in the past it was shown that the moon_troposphere state cannot be executed due to the low altitude of the moon which confuses the Sun Follower. An alternative would be one of the nadir small swath width (e.g. nad09) or limb small swath width states. No orbital phase dependency exists for the new state mesosphere_thermosphere state, i.e. one single state is sufficient to cover the complete illuminated part of the orbit.

Parameter settings of the mesosphere_thermosphere state include

- Basic profile: Currently no spare basic profile exists. Two options are proposed
    - Use profile from limb_mesosphere state: The scan would start in the thermosphere at 150 km and step downwards to the requested minimum altitude at 60 km. It has to be decided whether this approach is suitable for data analysis. A dark current measurement at an altitude of 250 km is inserted at the end of the state.
    - Modify elevation basic profile 3 to provide a height level of 60km above horizon: This profile is presently used in 7 Sun and moon observation states. All 7 states are executed using the target data provided with the START TIMELINE MCMD. Thus in all these states the position defined by the basic profile is overwritten by information produced by the PMC in those scan phases, when the SF-system is controlling the mirror position. This is the case for all 7 states using elevation basic profile 3. Using basic profile 3 may require a thorough test phase to ensure that none of the Sun and moon measurements is indeed affected.
- PET values: These will be set to channel 1 = 1.5 sec, channel 2 = 1.5 sec, channels 3-6 = 0.375 sec, channels 7 & 8 = 1.5 sec (according to e-mail dated March 27th).
- Co-adding table: All co-adding factors are set to 1 sec (according to e-mail dated March 27th).
- State index table: Depending on which state will be modified the corresponding index for the co-adding table used will be updated, if needed.

Timelines:

Two new timelines are required permanently on-board for measurements after the SO&C window. They are the equivalents to t/l 47 and 50 and include the new mesosphere_thermosphere state which replaces all other limb states. One of the t/l IDs is 14 (the unused moon_troposphere t/l), the other will be t/l 15. In addition, the 4 limb states usually executed before sunrise shall also scan the mesosphere and thermosphere. Therefore two more timelines are required. These are t/l 1 and 2 with subset 02 which are exchanged whenever limb_mesosphere_thermosphere measurements are planned. A new timeline set 35 will be generated and uploaded whit the permanent implementation of OCR_036.

Note: It is planned to synchronize SCIAMACHY's mesosphere_thermosphere measurements with MIPAS' upper atmosphere observations. This requires an informal mission planning interface between SOST and RGT/ESRIN.

It is proposed to implement the modified state as a test state first and execute it in a test timeline (t/l set 9) for about 14 orbits. Timeframe of test timeline scheduling depends on OCR acceptance. Once data analysis has confirmed correct functioning of the state configuration, the complete new timeline set 35 shall be generated and uploaded for routine operations.

SOST: M.Gottwald, E.Krieg, DLR-IMF (ESA, Industry if necessary)	Date: 31/03/08	Signature: via e-mail 31/03/08
Approval of Proposed Implementation:		
Originator Approval: M. Sinnhuber, IFE	Date:05/06/08	Signature: via e-mail 05/06/08
SSAG Approval: H. Bovensmann	Date:04/06/08	Signature: via e-mail 04/06/08
Decision / Approval: 1. The modifies state shall be tested as proposed by SOST. 1a. The modified state test shall be extended until end October 2008 2. Decision for the final implementation will be given after SPEC approval		
DLR Approval for the test: Ch. Chlebek	Date: 06/06/08:	Signature: via e-mail 06/06/08
DLR Approval for the extended test phase: A. Friker	Date: 16/06/08:	Signature: via e-mail 16/06/08
SPEC approval for the final implementation Prof. Dr. J. Burrows Dr. I. Aben H. Förster Ch. Chlebek	 Date: 03/09/08 Date: 23/09/08 Date: 25/09/08 Date: 03/09/08	 Signature: via e-mail 03/09/08 Signature: via e-mail 23/09/08 Signature: via e-mail 25/09/08 Signature: via e-mail 03/09/08
Implementation by SOST: Permanent implementation of OCR_036 occurs on November 3rd in orbit 34922. Then new final flight configurations for states (FFS_081103) and timelines (FFT_081103) become applicable. The parameter settings are identical to those from the tests and are given in the annex. With the new final flight configurations limb_mesosphere_thermosphere measurements are executed for 2 days per month. One day is correlated with MIPAS operating in Upper Atmosphere mode. The other is separated by about 15 days (depends on lunar visibility since limb_mesosphere_thermosphere observations can only be planned without moon measurements).		
SOST: M. Gottwald, E. Krieg, DLR-IMF	Date: 01/10/08	Signature: via e-mail 01/10/08

Annex 1: Preliminary analysis of SCIAMACHY thermospheric observations during orbits 28433 – 28452 (OCR 30)

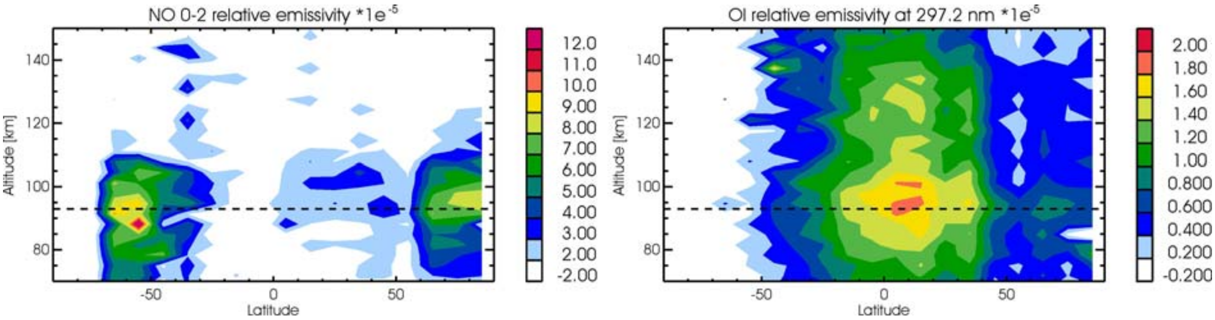

Figure 1: Relative emissivities of the NO 2-0 γ band at 245 nm (left) and the OI relative emission at 297.2 nm (right), obtained from 20 orbits of the new SCIAMACHY mesosphere-thermosphere mode. The dashed line shows the highest tangent altitude of the 'normal' SCIAMACHY limb mode.

A number of trace gas emissions can be identified in the upper mesosphere in the SCIAMACHY limb measurements, including NO from the γ-bands, OH at ~ 308 nm, O_2, Mg, Mg^+, atomic oxygen, O^+, Fe, Fe^+, and Na. A tomographic retrieval algorithm using all daytime limb and nadir measurements of one orbit for mesospheric emission species has been developed at the Institute of Environmental Physics, University of Bremen, and has so far been applied successfully to the metallic species Mg and Mg^+. This retrieval code enables us to retrieve altitude profiles of mesospheric and thermospheric emitters up to around 400 km of altitude, but with a very limited vertical resolution above the altitude of the highest limb-scan at around 93 km.

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In Figure 1, latitudinal averages over all 20 orbits of relative emissivities are shown for two emission lines observed in SCIAMACHY channel 1: the NO 2-0 γ band transition around 245 nm, and the OI transition at 297.2 nm. Relative emissions were obtained in the following way: first, spectra were divided by the solar spectrum of the same day. Then the spectral background resulting from Rayleigh scattering of solar radiation was fitted and subtracted, and finally, the average value of the three central channels of the resulting emission signal was obtained as the relative emissivity along the line-of-sight. The highest tangent altitude of the normal SCIAMACHY limb measurement mode is given as a dashed line around 93 km in both figures. As can be seen, both emission signals have significant contributions from altitudes above this line. NO has the strongest signals in polar latitudes around 90-105 km in the northern hemisphere, around 75 - 110 km in the southern hemisphere, where downwelling of NO into the polar winter mesosphere occurs. A secondary week peak of NO can be observed at 105 km altitude reaching from northern subtropics to middle latitudes. The atomic oxygen OI line shows the strongest signal in tropical and subtropical latitudes, where O is produced from O_2 photolysis. Maximal values occur around 95 km, but significant values reach up to around 140 km in the tropics.

In Figure 2, latitudinal averages of number densities of Mg and Mg^+ are shown retrieved from the emission lines around 280 nm respectively 285 nm, derived from the 20 orbits of the new mesosphere / thermosphere state. For comparison, latitudinal averages of the month July derived from SCIAMACHY measurements of the years 2002 - 2006 with the same retrieval routine but from the normal SCIAMACHY limb sequence which reaches up to only 93 km, are shown in Figure 3. Both retrievals reach up to around 400 km, the altitude information above the highest tangent altitude deriving from the tomographic type retrieval using overlapping limb and nadir measurements.

A number of features show up in both measurements, namely a layer of enhanced Mg^+ around 100 km altitude, and two upward reaching branches of enhanced Mg^+ values, one in northern polar regions, and one in northern subtropics. Though the process of upwelling of Mg^+ in polar regions is probably uplift in the Earth magnetic field, accompanying values of enhanced neutral Mg are observed in the same altitude range, probably produced by recombination reactions of Mg^+ with electrons.

These features are more clearly observed in the new state, and the altitude of the Mg^+ and Mg layer can be determined more precisely than for the normal state, as the altitude resolution of the new state is much better above 93 km. Equally, peak values of the 100 km layer are much larger, because the vertical smoothing is so much better. Measurements of the new state show that the upwelling branch of polar Mg appears mainly at altitudes above 200 km, while upwelling of Mg^+ reaches over a much larger altitude range, from the layer at 100 km upwards. A new feature not observed in the normal state is the enhanced layer of Mg^+ between 150 and 200 km which also is accompanied by a similar layer of enhanced values of neutral Mg. As they occur mainly above the highest altitude of even the new mesosphere / thermosphere state, the information for this layer must come mainly from different total column contents of the limb- and nadir measurements. Though high values of Mg^+ have been observed by in-situ measurements in the mid-thermosphere before, these results are rather unexpected, and should be investigated in more detail.
These first results of SCIAMACHY measurements in the lower thermosphere already show that SCIAMACHY mesosphere-thermosphere measurements have a large potential of yielding new and unexpected insights into an atmospheric region that is still widely unkown. This is not only true for the metallic species Mg, Mg^+, Fe, Fe^+ and Na, but also for NO, O and O_3, which also are observed within the SCIAMACHY range.

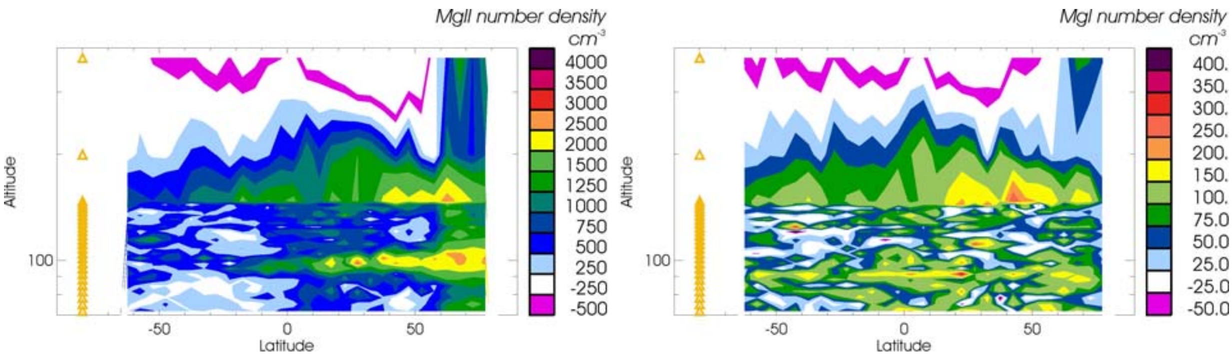

Figure 2: Left: latitudinal mean of Mg^+ number densities (cm^{-3}) obtained during orbits 28433-28452, the first 20 orbits of the SCIAMACHY mesosphere-thermosphere mode, carried out on August 8 and 9, 2007, averaged over 5° of latitude. Right: latitudinal mean of neutral Mg number densities obtained during the same orbits for the same latitudinal spacing. Yellow crosses show the centre of the retrieval altitude grid. Below 150 km, the vertical spacing of the retrieval grid reflects the spacing of limb tangent altitudes; above 150 km, the spacing reflects the altitude resolution of the tomographic retrieval.

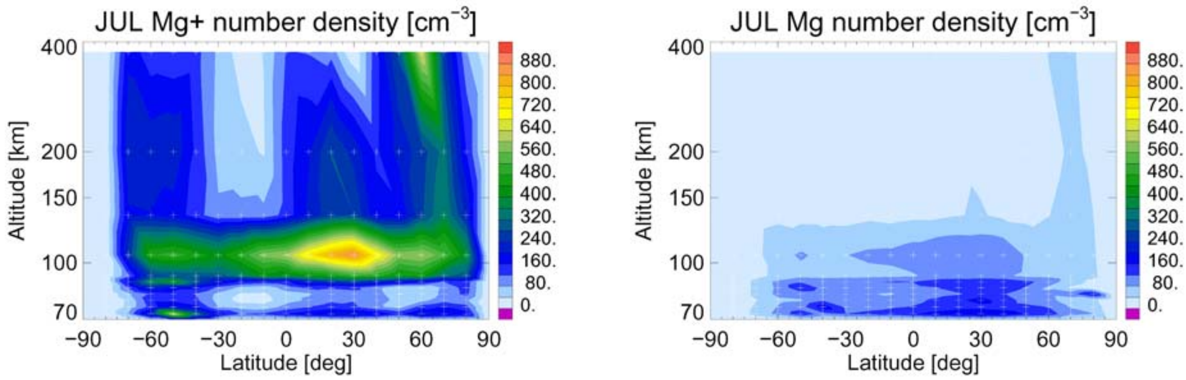

Figure 3: Latitudinal means of Mg^+ (left) and neutral Mg (right) for July for the years 2002-2006, obtained with the same retrieval as the measurements in Figure 1, but measured with the normal troposphere-stratosphere limb mode. White crosses denote the centres of the retrieval grid boxes. Adapted from [M. Scharringhausen, PhD thesis, University of Bremen, 2007].

Annex: Detailed State Design

This modified limb state shall be executed in the nominal limb observation direction. As starting height for the ESM is defined by basic profile 5, i.e. 150km, ASM position will be flight direction. The ASM scan motion will be as in a nominal limb state. The ESM steps will be executed in inverse direction compared to a nominal limb state to cover the specified height range. At the end of the 30 horizontal scans a step upwards of the ESM to a position at 350km above the horizon still within the TCFoV takes place by using the modified ESM basic profile 3. This position will be maintained for a duration of 1.6875 sec to produce dark signals in pointing mode (no horizontal scans). PET and Co-adding factors are defined according to an e-mail dated March 27th

State events:

Time		Event	IFOV	
			altitude (km)	elevation (deg)
T0	0 sec	Start of measurement	150	24.47
T1	T0 + 50.625 sec	End 30 downward limb scans	60	26.24
T2	T0 + 50.875 sec	Start measurement in TcFoV (limb pointing at constant elevation) Dark Reference	350	20.00
T3	T0 + 52.313 sec	End measurement in TcFoV (limb pointing at constant elevation)	350	20.00

Table 1: Illustration of IFoV, LoS altitude and elevation for the different phases of the Limb Mesosphere_Thermosphere states. Due to the seasonal variations all figures are accurate to within several seconds only.

Details of the parameter settings follow below.

The following parameter tables are updated for state **ID55 Limb Mesosphere_Thermosphere**:

State duration table:

	State ID	Restart Time	(SDPU) Mode	SDPU Duration (Number of BCPS)	Wait Measurement Execution	State Duration	Scanner Reset Wait	
Limb_Mesosphere_Thermosphere	55	27	LIMB	837	13369	14303	172	changed duration (new state design) due to OCR_036

All times are set according to a nominal limb_state.

State Index:

	State ID	Cluster Definition Index	Coadding Index High Data Rate	Coadding Index Low Data Rate	Measurement Category ID
Limb_Mesosphere_Thermosphere	55	1	10	10	27

Note:
A special measurement category is introduced to distinguish this state from a nominal limb-state.

PET Table:

	State ID	Data Rate	Channel 1a	Channel 1b	Channel 2b	Channel 2a	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8	State ID	Data Rate	Channel 1a	Channel 1b	Channel 2b	Channel 2a	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8	
Limb_Mesosphere_Thermosphere	55	Low	1,5	1,5	1,5	1,5	,375	,375	,375	,375	1,5	1,5	55	High	1,5	1,5	1,5	1,5	,375	,375	,375	,375	1,5	1,5	**changed due to OCR_36**

<u>Note:</u>
Low rate only is applicable. Co-adding factors in all clusters is set to 1.

Scanner state parameter table:

Scanner State Parameter #55	55	Limb_Mesosphere_Thermosphere							
	Common	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	Phase 7	Phase 8
STATE ID	55								
spare									
Relative Scan Profile 1 Factor	-006								
Relative Scan Profile 2 Factor	000								
Relative Scan Profile 3 Factor	004								
Relative Scan Profile 4 Factor	000								
Relative Scan Profile 5 Factor	000								
Relative Scan Profile 6 Factor	000								
Number of Scan Phases	5								
Duration of Phase [msec]		1300,0	50625,0	250,0	1438,0	840,0	0,0	0,0	0,0
Phase Type		0	1	0	1	0	0	0	0
Azimuth Centering of Relative Scan Profile		1	1	0	0	0	0	0	0
Azimuth Filtering		0	0	0	0	0	0	0	0
Az. Inverse Rel. Scan Profile for Even Scan		1	1	0	0	0	0	0	0
Azimuth Correction of nominal Scan Profile		2	2	0	0	0	0	0	0
Azimuth Relative Scan Profile Identifier		3	3	0	0	0	0	0	0
H/W constellation		3	3	3	3	3	0	0	0
Azimuth Basic Scan Profile Identifier		2	2	9	9	0	0	0	0
Azimuth Number of Repetition of Rel. Scan		0	29	0	0	0	0	0	0
spare									
Elevation Centering of Relative Scan Profile		1	1	0	0	0	0	0	0
Elevation Filtering		0	0	0	0	0	0	0	0
El. Inverse Rel. Scan Profile for Even Scan		0	0	0	0	0	0	0	0
Elevation Correction of nominal Scan Profile		2	2	0	0	0	0	0	0
Elevation Relative Scan Profile Identifier		1	1	0	0	0	0	0	0
spare									
Elevation Basic Scan Profile Identifier		5	5	3	3	0	0	0	0
Elevation Number of Repetition of Rel. Scan		0	29	0	0	0	0	0	0

The timing is exactly as for standard limb-states but the elevation steps are executed towards horizon.

Scanner basic profile table:

Since the standard basic ESM profile 3 is defined in all SFS-states (47, 49, 50, 51, 54, 56, 57) but overwritten by the values of the *START_TL* MCMD, basic profile 3 is used to produce the required fixed height of 350km:

Scanner Basic Profile EU								
Basic Scan Profile ID	Basic Scan Rate		Basic Scan Position					
	Azimuth [10-6 rad/sec]	Elevation [10-6 rad/sec]	Azimuth [10-6 rad]	Elevation [10-6 rad]				
3	000131	000000	-0000471239	-174533		OCR_36	ESM-position 350km	

LMT (ID 55) timing inputs for timeline generation:

RTCS	STT_01
RTCS set-up	636 cts
RTCS cleanup	275 (762-636-23+172)
total RTCS-duration	762 cts
WME	13369 cts (31*27*16 +1 - 24)
WSR	172 cts
state duration	14303 cts (762+13369+172)

set-up	636 cts
cleanup	275 cts
measurement	13392 cts (31*27*16)
total duration	14303 cts
SDPU duration	837 bcps

phase 1	1300 msec
phase 2	50625 msec
phase 3	250 msec
phase 4	1438 msec
phase 5	840 msec