

Steps toward a future set of IERS products and a modified IERS structure

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1 Introduction

This document should be a working document that is supposed to be modified, corrected and supplemented as the common understanding grows of what the future IERS products should look like, what accuracy and latency they should have and what strategies should be used to produce them. It should help the participating groups to converge towards a common view of how the future IERS products should look like and the steps to be taken to reach the once established goals. The generation of a new set of rigorously combined IERS products also necessitates, to a certain extent, modifications in the structure of the IERS and its components. Therefore, all the members of the working group on Combination and all the Technique Services should contribute to the document and the discussions.

To achieve the highest accuracy and consistency for future IERS products, it is crucial to proceed towards a rigorous combination of all the parameters common to more than one space geodetic technique. Such a combination of techniques should eventually be performed for all the major products of the IERS, from multi-year solutions for reference frame realizations generated on, e.g., a yearly basis, to near real-time products such as EOP estimates produced on a daily basis.

At present we are still far away from a realization of a rigorously combined set of products. The main steps that were taken so far are the following:

- **IERS EOP Alignment Campaign:**
 - Inconsistencies between EOP series from different techniques and the official C04 and Bulletin A series were clearly identified, e.g., an offset of about 0.2 mas in the y-pole component.
 - It became clear that only a common adjustment of the reference frames and the EOPs can overcome such problems and inconsistencies.
- **IERS SINEX Combination Campaign:**
 - The SINEX format definition was extended for techniques other than GPS. It is now the crucial basis for all combination work.
 - First experiences were collected with handling SINEX files from different techniques and with combination strategies.
- **IERS Combination WG:**
 - This WG has been set up to coordinate the steps and activities aimed at a set of combined IERS products.
- **IERS Combination Pilot Project :**
 - By now the status has been reached that all the Technique Services are producing, on a routine basis, combined intra-technique solutions (except DORIS). Most of the work of the participating groups was focussed to reach this goal first, as a pre-requisite for going into the inter-technique combinations.
 - All solutions are delivered according to the initial schedule and about 1.5 years of solutions are available for testing the possible combination strategies for the routine generation of solutions on a weekly basis.

- Software packages were modified and developed to perform the combination of the intra-technique solutions.
- No routine inter-technique combined solutions are yet generated.
- Software packages performing a combination on the observation level are being developed (GRGS, TUM).
- **IVS CONT'02 Campaign Activities:**
 - Detailed analyses of combination strategies including UT1/LOD and nutation offsets and rates have been performed.
 - Local ties have been validated and checked based on the homogeneous CONT'02 data set.
 - Combination strategies including troposphere zenith delays (GPS, VLBI) have been found to be very useful to detect systematic biases between the techniques and to validate local ties.
- **IERS long term series for ITRF2004 and IERS CPP:**
 - Long time series of combined weekly intra-technique solutions are now available from all major techniques.
 - First computations of a new ITRF2004 have been done showing very encouraging results.
 - This long time series are an additional set of solutions for the IERS CPP to develop strategies for the routine generation of combined solutions.
 - Reprocessing strategies and procedures have been put in place for most of the techniques (including GPS).

Several IERS Workshops and IERS CPP Meetings were held during the last few years:

- IERS Workshop in Munich in November 2002
- IERS Retreat in Paris in April 2003
- IERS Workshop in Matera in October 2003 (Co-location)
- IERS Workshop in Napa Valley in December 2004
- IERS CRC Meeting in Nice 2002
- IERS CRC Meeting in Nice 2003
- IERS CPP Meeting in Nice 2004

Many sessions with the topic concerning the integration and combination of the space geodetic techniques were organized:

- AGU Spring 2002: Combination and Integration of Space Techniques
- EGS 2002: Evolving space geodesy techniques (SLR, GPS, DORIS, Altimetry, VLBI): Combination of techniques
- COSPAR PSD1/B2.1 Integrated Space Geodetic Systems and Satellite Dynamics
- EGS 2003: Interactions and Combination of Space Geodesy Techniques
- EGS 2004: Combination of Space Geodetic Techniques
- COSPAR 2004: GGOS Sessions
- AGU Fall 2004: Combination/Integration

The combination of the space geodetic techniques is a very active research field at present, a fact that is reflected by the number of sessions and workshops that were organized in the last few years.

2 Four Different Types of IERS Products

The IERS should strive to produce at least the following **four principle types of products** (besides such products as the IERS Conventions etc.) that have different characteristics concerning latency, generation cycle, accuracy and, possibly, computation strategy (see Table 1):

- 1) Multi-year solutions for consistent ITRF, EOPs and ICRF
- 2) Weekly final solutions to generate combined EOPs series on a routine basis
- 3) Daily rapid combined solutions for EOPs
- 4) Extrapolated EOP solutions for real-time users based on combination products

In the following each of the four different solution types will shortly be described including the input solutions, the possible strategies and the characteristics of the solutions (like, e.g., latency, accuracy, availability, ...). The present status, the short-term and the long-term development will be addressed as well as the relationship to the present IERS combination activities such as the Call for Long Time Series and the Combination Pilot Project.

Product Type	Main Parameters	Generation Cycle	Maximum Latency	Based on
Multi-Year	ITRF EOPs ICRF	Yearly	Maximum 1 year	Reprocessed high-accuracy combined long term intra-technique series
Weekly "Final"	EOPs Station Coordinates	Weekly	2 weeks	Based on the "final" routine intra-technique combined products and the multi-year solution
Daily "Rapid"	EOPs Station Coordinates Troposphere Param.	Daily	1 day	VLBI Intensives and IGS Rapid Products and ...
Daily "Predicted"	EOPs	Daily	1 day	Combined daily rapid IERS products

Table 1: Four different types of IERS products

3 Multi-Year Solutions for ITRF, EOPs, and ICRF

3.1 Present Status

At present no official multi-year IERS solution exists yet with a consistent set of site coordinates and velocities (ITRF), EOPs, and quasar coordinates (ICRF). The various parameter types are still combined individually and by different Product Centers (PCs). The new ITRF2004 solution, being generated these days, is a major, very important step towards the goal of consistent multi-year solution including ITRF, EOPS and ICRF.

3.1.1 ITRF (Station Coordinates and Velocities)

The last ITRF realization officially released is the ITRF2000 (see Altamimi et al., 2002; IERS TN 31). This solution was based on the combination of site coordinates and velocities from different techniques including full variance-covariance information. In the meantime the ITRF Combination Centers are intensively working on the ITRF2004 realization which will be based on weekly combined intra-technique solutions and will solve for the site coordinates, site velocities and EOPs (actually just the x- and y-pole coordinates at present) in a

consistent way. Through this procedure not only time series of x- and y-pole coordinates but also time series of the site coordinates will become available. These ITRF activities are based on the input material coming from the IERS Call for Long Time Series (see above).

3.1.2 EOPs

Every year the EOP PC issues a call for the submission of long, consistent time series of EOP from the technique centers or from individual analysis centers. These series are then combined using specific weights for each of the series and estimating offsets and drifts for the different series. The resulting combined EOP series are made available as the official C04 series. Deficiencies certainly are:

- The relationship of the EOP with the ITRF and the ICRF is not taken into account. It is assumed that the individual analysis centers delivering the EOP series are aligning their solutions to the ITRF2000 and the official ICRF as precisely as possible.
- The C04 series is not consistent with the ITRF2000 (e.g. a well-known offset of 0.2 mas in the y-pole coordinates).

Only a combined estimation of EOPs and ITRF (and ICRF) using the solutions of all techniques can improve the consistency.

3.1.3 ICRF (Quasar Coordinates)

The official ICRF has been computed in 1996 (see Ma et al., 1998). Since that time no new realization of the ICRF has been performed. The present ICRF is based on only one solution from one software package. In the meantime activities to compare different sets of quasar coordinates from different groups and software packages and to assess the quality of different source estimates have been performed (Feissel-Vernier, 2003, Tesmer et al., 2004). It has not yet been tested, whether a combination of different VLBI solutions will improve the radio source coordinates and whether a combination with GPS may help to stabilize the terrestrial reference frame and the EOPs and thus contribute indirectly to the quality of the ICRF.

3.2 Short-Term Goals

3.2.1 ITRF2004

The most important short-term goal is the finalization of the ITRF2004 solution based on the weekly SINEX files from the Call for Long Time Series.

Only the time series officially delivered by the Technique Services should be used for the combination. Additional solutions may be used for validation purposes (e.g. solutions based on a combination on the observation level, solutions from individual analysis centers).

The ITRF2004 solution should be based on the space geodetic data available till the end of 2004 and the official set of local ties. All ITRF CCs should use the same input series, i.e., those that are officially available at the IERS Central Bureau database (<http://iers1.bkg.bund.de/info/listFileITRF2004.php>).

Site coordinates, site velocities, site time series, EOP time series and local ties resulting from the adjustment, all consistent, should be the outcome of the ITRF2004 activities.

The ITRF PC is responsible for the generation process and the coordination between the ITRF CCs. The IERS Analysis Coordinator as well as the Technique Services should be involved in the validation of the final product.

Validation criteria for the ITRF2004/EOP2004 solution are given in the document "Validation of the ITRF2004/EOP2004 IERS Products".

AI-01: Finalization of the ITRF2004 computation and validation for the IERS DB Meeting at the AGU Fall Meeting in San Francisco **(2005-12-05)**.

3.3 Long-Term Goals

3.3.1 IERS200x

It should be the goal of the IERS to produce a new realization of the ITRS (together with EOPs and, eventually, quasar coordinates) each year. This does not necessarily mean that all the national survey institutions etc. have to adopt a new ITRF realization every year, but a new ITRF realization is very important to:

- Take into account new or more consistent models in the data analysis done by the individual techniques.
- To allow for improvements in the parameterization.
- To combine additional common parameters (e.g. troposphere zenith delays).
- To use the new data from the most recent year (to improve coordinates and velocities of more recent sites and to obtain highly consistent and accurate EOP series for the most recent year).

A future rigorously combined, consistent set of multi-year IERS products may be called **IERS200x**:

“Integrated **E**arth orientation parameters, **R**adio sources, and **S**ite coordinates **200x**”

and can be represented by the formula

$$\mathbf{IERS200x} = \mathbf{ITRF200x} + \mathbf{EOP200x} + \mathbf{ICRF200x}$$

Such a multi-year solution generated once a year should have the following characteristics:

- It should be based on the combined weekly intra-technique solutions of the different services.
- These intra-technique solutions should be based on newly reprocessed series from the individual analysis centers. This means that most of the individual analysis centers of a technique have to have the capability to reprocess (once a year) the entire time span of data available for the corresponding technique (e.g. 1993-200x for GNSS, 1984-200x for VLBI, etc.).
- The individual series should follow the latest update of the IERS Conventions concerning modelling as well as parameterization.
- As many common parameters as possible should be included in the SINEX files of the individual techniques.
- The multi-year solution should be based on the most up-to-date combination strategy.

For the next solution, i.e. IERS2005, at least the following improvements should be considered:

- Include quasar coordinates into the SINEX files.
- Extend the time span to the full history of the technique.
- Use a well-defined standard model to apply oceanic and atmospheric loading for the generation of the new solutions (atmospheric loading effects should not be averaged over 1 week, the present time resolution of the site coordinates).
- Improve common discontinuity lists and stations with non-linear behaviour.

A group consisting of the IERS Analysis Coordinator, the Analysis Coordinators of each Technique Service, and a representative of the IERS Conventions should define the standards common to all techniques to be used for the data reprocessing. The same is true

for the parameterization of common parameters. The standards relevant only to one individual technique should be defined by the Analysis Coordinators of the respective Technique Service.

- AI-02:** Form a group to define the standards concerning modelling and parameterization for the next generation of IERS200x solution with the members as proposed above **(2005-12-05)**.
- AI-03:** Ask all Technique Services to generate a list of site discontinuities and site problems (if not done already) to be merged by the IERS into one common list. A format has been proposed already **(2005-01-15)**.
- AI-04:** Encourage the IVS to deliver session-specific combined SINEX files including the quasar coordinates **(2006-06-30)**.
- AI-05:** Ask all Technique Services to generate new weekly SINEX files based on a reprocessing of the data using a well-defined set of standards **(2006-06-30)**.
- AI-06:** Ask all Technique Services to generate weekly SINEX covering the entire history of the technique **(2006-06-30)**.

Looking much farther into the future we should consider the following additional steps to be taken:

- AI-07:** Encourage the transition of IVS to sessions from 00:00 to 24:00 UT (better consistency in the parameterization for the combination of solutions) **(????-??-??)**.
- AI-08:** Encourage the Technique Services to shift to 1-day solutions, i.e., the generation of combined intra-technique solutions from day of data **(????-??-??)**.
- AI-09:** Encourage the Technique Services to include troposphere parameters into the SINEX files **(????-??-??)**.
- AI-10:** Encourage the Technique Services to include low-degree spherical harmonics coefficients of the Earth gravity field into the SINEX files to align geocenter (C10, C11, S11), the orientation of the gravity field (C21, S21, S22), and to start to consider relationships between the gravitational, geometric and dynamic (ERPs) flattening of the Earth **(????-??-??)**.
- AI-11:** Encourage the Technique Services to include Keplerian elements (or at least the three angles giving the orientation of the orbital planes) into the SINEX files **(????-??-??)**.

4 Weekly Solutions for EOPs and ITRF Monitoring

We should first point out, that there is an ambiguity in the term “weekly solutions”. The adjective “weekly” can refer to the amount of data going into a combination (i.e., one week of data) but also to the generation cycle of the solution, i.e., that a solution is produced once every week, without considering what time span of actual observation goes into a combination. When we speak of weekly solutions here, we mean solutions of this latter type, i.e., solutions that are produced once a week based on whatever information and time span seems appropriate. One of the major goals of the IERS CPP is clearly to reach a status, where combined IERS products are generated on a weekly basis with a delay of not much more than 2 weeks. This second type of IERS product is comparable to the final products of the IGS. It should be the routine high-accuracy product made available in between new realizations of the IERS200x (ITRF/EOP/ICRF) and should be consistent with the most recent ITRF/EOP/ICRF realization, providing a continuation of the EOP (and site coordinate) time series for the time interval after the last IERS200x.

4.1 Present Status

In the last year – the IERS CPP project started end of February 2004 – important progress has been achieved, although no routinely combined inter-technique solutions are yet

available. The major achievement is, that each of the technique services (except IDS, but this will change very soon, too) is now producing combined solution based on the weekly SINEX files of the individual analysis centers on a routine basis. One year ago, only the IGS was in a position to produce such combined solutions. These weekly SINEX files are the “condition sine qua non” for the inter-technique combination on a routine basis. A considerable amount of weekly solutions are now available for tests concerning the strategy to be used for the generation of routine inter-technique solutions:

- About 1.5 years of intra-technique combined SINEX files from the IERS CPP (see <http://iers1.bkg.bund.de/info/listFileCPP.php>).
- Long time series of weekly SINEX files from all techniques from the Call for submission for the ITRF2004 and the IERS CPP.

4.2 Short-Term Goals

The large amount of SINEX files available should now be used by the IERS CPP participants (that answered to call), the IERS Combination Research Centers (CRCs), and by other institutions or groups interested, to test the possible strategies for the generation of weekly combined inter-technique solutions (including or not including a longer data span of SINEX files).

Two major types of strategies can be identified:

- **Cumulative solutions**, where always the most recent week is added to a IERS200x-type solution based on the full time of weekly SINEX files and the results for the most recent week are extracted.
- **Weekly solutions** just based on one week of SINEX files but making use of the high-quality multi-year products (the most recent IERS200x with ITRF200x, ICRF200x, but also the resulting adjusted local ties) and fixing the local ties to the values resulting from the IERS200x.

These weekly solutions (of either type) are not supposed to be used for further combinations. The multi-year solutions will be generated with a new set of reprocessed solution each year for that purpose. The main purpose of the “weekly final solutions” should be the generation of consistent and accurate combined EOP estimates. In addition, the reference frame should be monitored using these solutions (thinking, e.g. of earthquakes, even silent earthquakes, site problems and anomalies, etc.). The tsunami event of December 26, 2004, has clearly shown that such a monitoring is of vital importance to keep the reference frame intact.

The weekly combined inter-technique solutions resulting from these analyses should be validated by the IERS CPP participants, the IERS CRCs or other groups.

- AI-12:** Encourage the IERS CPP participants, the IERS CRCs and other interested groups to start with the generation of the weekly routine inter-technique combination as soon as possible (????-??-??).
- AI-13:** Encourage the IERS CPP participants, the IERS CRCs and other interested groups to start with the validation of the weekly routine inter-technique combination as soon as such solutions become available (????-??-??).
- AI-14:** Encourage the Technique Services to shorten the delay between the collection of the observations and the generation of the intra-technique solutions to eventually arrive at a delay of approximately 2 weeks (????-??-??).

4.3 Long-Term Goals

The long-term goals for the generation of weekly inter-technique combinations are very similar to those envisaged for the multi-year products (see **AI-03** to **AI-11** above).

5 Daily Rapid Combined Solutions

5.1 Present Status

There are no daily products generated at the moment within the IERS. Only the IGS is generating its daily rapid satellite orbit and clock solutions and ERPs. In addition, the IGS also generates ultra-rapid products every three hours including orbit and clock predictions. The recent event of December 26, 2004, has clearly demonstrated that there is a need also for combined daily products from the IERS (better consistency and reliability than results from individual techniques). Because of disasters such as Earthquakes, volcano eruptions and tsunamis it is extremely important to monitor both, the terrestrial reference frame and the individual station coordinates (dislocations by Earthquakes) and the EOP in near real-time.

5.2 Short-Term Goal

It should be a short-term goal to study (in a non-routine mode) the quality of a combination of the VLBI Intensive measurements, which are presently performed almost every day with a session length of one hour, with the IGS rapid products. Daily rapid solutions from other techniques might be included as well. The VLBI Intensives and the IGS Rapid Products are very much complementary and might be combined with a considerable benefit: whereas the VLBI Intensives are just processed to obtain UT1-UTC estimates – pole coordinates and site coordinates have to be fixed in this process – the IGS rapid products can contribute polar motion and site coordinates (stable reference frame) but cannot accurately determine UT1-UTC.

The combination is expected to deliver better UT1-UTC determinations because of the support from GPS for the reference frame and polar motion.

Already now, some of the VLBI Intensive experiments (K5 experiments between Wettzell and Tsukuba) are transmitted to the correlator with e-Transfer, i.e. through the internet, and are available for correlation within a few hours. After a rapid processing of such VLBI Intensive sessions, the resulting SINEX output could be combined with IGS Rapid Products. For this step it would be necessary that the IGS produces daily combined SINEX files, but this should be a straight-forward process.

AI-15: Encourage the IERS CPP participants, the IERS CRCs and other interested groups to study the benefit of a combination of VLBI intensive solutions and daily solutions from the other techniques, especially GPS (????-??-??).

AI-16: Encourage the IVS to produce SINEX files including EOPs and site coordinates for the Intensive VLBI sessions (????-??-??).

AI-17: Encourage the IVS to produce such SINEX files for the Intensive VLBI sessions within one day after the observations (????-??-??).

AI-18: Encourage the IGS to produce combined intra-technique SINEX files including ERPs and site coordinates for the daily IGS Rapid Products (????-??-??).

AI-19: Encourage the ILRS and IDS to study and develop possible strategies and techniques that might result in daily rapid products similar to the IGS products for an inter-technique combination by the IERS (????-??-??).

5.3 Long-Term Goals

Long-term goals consist in the refinement of the daily solutions and their intra- and inter-technique combinations.

6 Predicted Solutions

6.1 Present Status

The predictions of the ERP time series are presently based on a confusing mixture of combined intra-technique solutions and solutions from individual analysis centers. At the moment the predictions are updated twice per week.

6.2 Short-Term Goal

The only short-term goal might be to always use the most up-to-date ERP series for the prediction algorithms: when rapid intra-technique solutions will become available, these should be used instead of series from individual analysis centers. If inter-technique combinations will eventually become available, these should be used as the basis for the ERP predictions.

In addition, the IERS Prediction Comparison Campaign (proposed by Harald Schuh) might help to identify areas of improvements in the conventional prediction schemes.

6.3 Long-Term Goals

On the long run the predictions of the EOP should be based solely on the combined rapid daily IERS inter-technique solutions and should become available on a daily basis.

7 Modified IERS Structure

In view of a future, rigorous combination scheme for station coordinates, EOPs and quasar coordinates, Product Centers dealing with the combination of just one isolated parameter type only will not make much sense anymore. Therefore, modifications to the present IERS components will certainly be necessary, at least to a certain extent. The following paragraphs describe envisaged new components and how they might be realized (including a transition phase from old to new products).

7.1 Present Structure

The present IERS structure is given in Figure 1. The components to be reconsidered in view of the establishment of a new set of rigorously combined IERS products as described above are:

- the Rapid Service and Predictions Product Center
- the Earth Rotation Product Center
- the ITRF Product Center
- the ITRF Combination Centers (ITRF CCs)

At a much later stage, also the ICRF Product Center will have to be considered (as soon as a combination of ITRF/EOP/ICRF would become more accurate than an CRF computed in the traditional way).

IERS Directing Board			
Chair: Chopo Ma			
Product Centres	Coordination and Development	Technique Services (External Services)	Unions
Earth Orientation Daniel Gambis	Analysis Coordinator Markus Rothacher	IGS Angelyn Moore Gerd Gendt	IAG Clark Wilson
Rapid Service/ Prediction William Wooden	Central Bureau IERS Data Base Bernd Richter	IVS Chopo Ma Axel Nothnagel	IAU Nicole Capitaine
International Celestial Reference System Ralf Gaume	Combination Research Centres Sheng Yuan Zhu	ILRS Peter Shelus Ron Noomen	FAGS Nicole Capitaine
International Terrestrial Reference System Zuheir Altamimi	ITRS Combination Centres (not represented in DB)	IDS Herge Fagard NN	
Global Geophysical Fluids Tonie van Dam			
Conventions Gérard Petit			

Figure 1: Present IERS Structure

As pointed out in the previous sections the new IERS ERP series will in future be based on a rigorous combination of the combined intra-technique SINEX files. It is clear that ERP predictions will still be necessary and important. Therefore, a product center routinely generating ERP predictions will still be needed. The predictions should then be based on the resulting combined inter-technique solutions, however.

The Earth Rotation Product Center, the ITRF Product Center and the ITRF CCs should, after a considerable transition phase, where both, the old and new products will be generated in parallel, be discontinued. The various combination tasks for the first three future product types should then be performed by new IERS Combination Centers (it is clear that the previous Product Center may also apply to become a new IERS CC).

7.2 Modified IERS Structure

The proposal here is, that the combination tasks to routinely generate the three new types of IERS products (i.e., the multi-year, the weekly final and the daily rapid products) should in future be performed by IERS Combination Centers (CCs). These new CCs should be selected through a Call for Participation, where institutions will be asked to apply for one or more of the combination tasks. The institutions will have to show that they have the experience and the financial background and commitment to reliably perform the routine combinations with high accuracy and consistency. There should also be a pilot phase of about half a year for each CC, where it has to demonstrate the timeliness and accuracy of its product generation. For each of the three product types more than one CC may be selected by the proposal evaluation committee, in order to increase the reliability of the resulting

products. One CC may also apply for the generation of more than one of the three products mentioned above. If more than one CC is present for one of the three products, a possible scheme would be to rotate the responsibility for the official IERS product generation among the selected CCs for this task every, e.g. 1-2 years. The CC chosen as responsible for the generation of one official product type would always have to be confirmed in their function by the IERS DB.

All the input solutions necessary to generate the multi-year and weekly final solutions are already being generated more or less routinely. Therefore, a Call for Participation for the combination of yearly multi-year solutions and routine weekly solutions could soon be prepared and issued. The daily rapid combination task cannot yet be asked for, since the corresponding input solutions from the Technique Services are not yet available.

AI-20: Prepare a Call for Participation (CfP) for those IERS CCs, that will routinely generate the yearly multi-year and the weekly final IERS products; to be decided by the IERS DB **(2005-12-05)**.

AI-21: Issue of Call for Participation (CfP) for those IERS CCs, that will routinely generate the yearly multi-year and the weekly final IERS products **(2006-01-01)**.

AI-22: Set up an evaluation committee for the proposals to be confirmed by the IERS DB **(2006-01-15)**.

AI-23: Deadline for proposal submission **(2006-04-01)**.

AI-24: Evaluation of the proposals by the evaluation committee till **(2006-05-01)**.

AI-25: Start of routine production of combined weekly final IERS products **(2006-07-01)**.

AI-26: Start generation of the IERS2005 solution **(2006-07-01)**.

AI-27: Evaluation of the pilot phase for the selected CCs **(2006-11-01)**.

AI-28: Official start of the new generation of weekly final IERS products **(2007-01-01)**.

A similar Call for Participation will be issued as soon as the generation of daily rapid products will become a reality.

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