Statement of Work "A" for Implementing Arrangement #10 Consultancy Service for the Enhancement of the CWB Regional NWP System to the AGREEMENT between the Taipei Economic and Cultural Representative Office in the United States and the American Institute in Taiwan

I. Task Descriptions

Task 1: Support for the WRFDA Component of the CWB Operational System and Improvement of the Performance of WRFDA

During the year 2012, TECRO's designated representative, the Central Weather Bureau (CWB), implemented OP24, which included Weather Research and Forecasting (WRF) model data assimilation (WRFDA) V3.3.1/WRF V3.3.1, and WPS V3.3.1, in the CWB operational environment. In 2013, AIT's designated representative, the University Corporation for Atmospheric Research (UCAR), will work closely with CWB to upgrade the CWB operational system to OP25 (Note: OP25 version is the same as OP24). UCAR and will also continue to provide technical support to CWB on the WRFDA component of the CWB operational system.

1.1 Support for the Data Assimilation Component of OP25 and the Implementation of WRF 4D-Var

1.1.1 General support for the CWB OP25 system and the FSO updates

In 2013, AIT's designated representative, UCAR, will provide general technical support to the WRFDA system during the transition from the OP24 to the OP25 at CWB. UCAR will provide solutions and necessary training related to the WRFDA system during the OP25 operations to TECRO's designated representative, CWB. UCAR will also update FSO with new features, especially a modified norm calculation weighted by mass. In addition, UCAR will investigate the possibility and validity of applying adjoint-based FSO in the hybrid WRFDA environment.

1.1.2 Support the implementation of WRF 4D-Var in OP24 or OP25

AIT's designated representative, UCAR, will first revisit the algorithm/strategy of interpolation among different resolutions used by the multiple incremental 4D-Var. Focus will be placed on the dependence, validity and robustness of the algorithm over Taiwan's complex terrain. Second, UCAR will assist TECRO's designated representative, CWB, in the implementation of the 4D-Var system in the OP24 or OP25 system. The 2008 T-PARC typhoon cases tested in the 2012 experiments will also be tested based upon the updated 4D-Var code. UCAR will compare the performance of [-3,+3] window and [0,6] window of 4D-Var and propose a 4D-Var assimilation strategy based on the experiments' results.

1.2 Development of WRFDA Background/Analysis Blending Strategies for Operational Data Assimilation and Forecasting System at CWB

AIT's designated representative, UCAR, will develop WRFDA background/analysis blending strategies for operational data assimilation and forecasting systems at CWB. UCAR will develop an off-line blending procedure to blend the Advanced Research WRF forecast (analysis) with the Global Forecast System (GFS) forecast (analysis) to form the modified background (analysis). The primary goal of such a blending is to improve the description of large-scale features in the background (analysis) state in CWB's

regional data assimilation and forecasting system. The blending will be achieved by using an incremental spatial filtering scheme.

In 2013, UCAR will:

- Develop an off-line background blending procedure using a low-pass Raymond 6th order tangent implicit filter,
- Deliver the off-line blending code to CWB, and
- Support CWB scientists with the WRFDA background/analysis blending scheme.

1.3 Development and Testing of Hybrid Variational/Ensemble Data Assimilation

In 2012, AIT's designated representative, UCAR, coupled WRFDA-hybrid to WRF/DART for a hybrid variational/ensemble data assimilation system. Comparable results between hybrid and CWB's well-tuned operational TWRF 3DVAR were obtained for three typhoon cases in September 2008. In 2013, UCAR will perform the following tasks.

1.3.1 Develop dual-resolution capability for WRFDA-hybrid data assimilation

The current WRFDA-hybrid can work only when the mean background and ensemble inputs are in the same resolution. This will limit its use for high-resolution applications. The dual-resolution hybrid will allow high-resolution mean analysis with low-resolution ensemble input. It will allow significant code development within WRFDA. In the case of two-way coupling (i.e., re-center ensemble mean by hybrid analysis), an offline program is also needed to convert high-resolution mean analysis to ensemble's resolution so that ensemble forecasts can continue for the next cycle. Newly developed code needs to be robust over the East Asia domain with complex terrain.

1.3.2 Test the dual-resolution WRFDA-hybrid and compare with previous single-resolution hybrid results

Scenarios for the experimental design can vary and need to be determined later by discussions between AIT's designated representative, UCAR and TECRO's designated representative, CWB. The primary dual-resolution setting could be at 15-km/45-km resolution. The same 2008 T-PARC cases tested will use the previous code version (i.e., OP24) for consistent comparison. A few typhoon cases in 2012, to be defined later by CWB, will be also tested based on the updated code (e.g., OP25).

1.3.3 Provide support and guidance on the utilization of the WRFDA observation operators in DART

A workable version of the WRFDA observation operators in DART has been developed through AFWA's support. AIT's designated representative, UCAR, will provide code coupling WRFDA observation operator and DART to TECRO's designated representative, CWB, and help with the installation and testing at CWB.

1.3.4 Initial implementation and testing of GSI-hybrid coupled to NOAA EnKF for WRF application at CWB

A workable version of GSI-hybrid coupled to NOAA EnKF has been developed through AFWA's support. AIT's designated representative, UCAR, will provide code to TECRO's designated representative, CWB, and help with the installation and testing at CWB.

1.4 Further develop the WRFDA Background Error Covariance Options

1.4.1 Adapt the new features from GSI background error (BE) implementation to WRFDA CV3 BE

In 2012, AIT's designated representative, UCAR, reviewed the Gridpoint Statistical Interpolation (GSI) and WRFDA CV3 implementation, and developed the flowchart of the related parts of the codes for both systems. In the setup stage, the detailed differences of balance regression coefficients and vertical length-scales between GSI and CV3 have been fully understood. The corresponding codes have already been implemented into WRFDA from GSI. In 2013, UCAR will:

- Further investigate the implementation of horizontal recursive filter and normalized standard deviation in GSI and port the corresponding codes from GSI to WRFDA; and

- Investigate the details of the BE utilization in both GSI and CV3, which includes control variable Ps and log(Ps), 3-D pressure derivation, and the recursive filter with the multiple horizontal scales, etc.

AIT's designated representative, UCAR, will develop an additional BE option in WRFDA to mimic the GSI BE implementation.

1.4.2 Help to identify the problem of insensitivity to the wind variance tuning factors in WRFDA

AIT's designated representative, UCAR, will conduct similar GSI experiments as TECRO's designated representative, CWB, completed with WRFDA in late 2012 and deliver a report to CWB.

The following summarizes the schedule and resources required for Task 1:

Performance Period:	
a. Provide support for OP25 and WRF 4D-Var implementation	01/01/13 – 11/30/13
b. Development and support of WRFDA background analysis blending strategies	01/01/13 – 11/30/13
c. Development and testing of hybrid variational/ensemble-data assimilation	01/01/13 – 11/30/13
d. Improve WRFDA CV3 using its GSI implementation as guidance	01/01/13 – 11/30/13
Resources Required:	1.1 FTE UCAR staff
Deliverables:	
1. Updated FSO system	11/30/13
2. A report describing the possibility and validation of the adjoint-based FSO in hybrid WRFDA	11/30/13
3. Code and scripts for the implementation of WRF 4D-Var in OP24 or OP25	11/30/13
4. A report summarizing the experimental results of the 4D-Var multiple incremental and time window performances	11/30/13
5. Off-line blending code	06/30/13
6. WRFDA-hybrid code with the dual-resolution capability	11/30/13
7. A report summarizing the experimental results of testing the	11/30/13

dual-resolution WRFDA hybrid	
8. The code coupling WRFDA observation operator and DART and all necessary scripts along with a test case; procedures documented in a powerpoint (ppt) file	11/30/13
9. GSI-hybrid and EnKF code and necessary scripts along with a test case	11/30/13
10. GSI-hybrid and EnKF setting parameters documented in a ppt file and reproduce UCAR's typhoon single-obs test result at CWB	11/30/13
11. Reproduce UCAR's typhoon single-obs test result at CWB (to be included in item 10)	11/30/13
12. A report about the sensitivity to wind variance tuning factors with GSI	06/30/13

Task 2
Testing and Development Support for the WRF/DART Ensemble Data Assimilation System

Current major operational ensemble systems (NCEP/GSI hybrid, Canadian global EnKF, and ECMWF) use 60-114 ensemble members in general. The 32 ensemble members used with WRF/DART testing at CWB is the minimum needed for ensemble data assimilation systems. Larger ensemble members used with WRF/DART should reduce sampling errors and lead to further improvement to the analyses and forecast of the WRF/DART system.

In 2013, AIT's designated representative, UCAR, will evaluate the benefits of using 64 ensemble members with WRF/DART for its analysis and forecast.

2.1. Evaluation of the Benefit of Using 64 Members with WRF/DART

AIT's designated representative, UCAR, will examine the benefit of using a larger ensemble size for WRF/DART analyses and forecasts, by testing the WRF/DART system with 64 members and comparing its performance with the current 32 members. The examination will focus on the analyses and forecasts of typhoons. UCAR will:

- Perform analysis experiments of the CWB TC bogus data only (using the ensemble forecasts background information from the middle times of cycling assimilations of all observation types) for both the current and larger ensemble size. UCAR will then examine the analyses of the typhoon structure to see if the analysis is improved with the larger ensemble size.
- Perform cycling assimilation experiments for a two-week period and examine the TC track and intensity forecasts with the current and larger ensemble size.
- Examine the impact on 6-hour forecasts errors verified against radiosondes.

The assimilation experiments will be performed for 4-24 September 2008 of T-PARC period, when typhoons Sinlaku and Hagupit occurred. During these experiments, the DART localization parameters and the stochastic physics forcing will be retuned to be consistent with the larger ensemble size.

2.2. Support of WRF/DART Testing at CWB

AIT's designated representative, UCAR, will provide version updates of the WRF/DART system to TECRO's designated representative, CWB, when they are available. UCAR will provide remote consultation and support to address questions and issues from CWB, including tuning of DART parameters as well as usage of the observation operators connected to 3D-Var in the hybrid system.

2.3. Support for the Application of the Stochastic Kinetic Energy Backscatter Scheme (SKEBS) in CWB's Ensemble Prediction System (EPS)

AIT's designated representative, UCAR, will provide technical assistance to TECRO's designated representative, CWB, concerning SKEBS and its application in CWB's EPS for Mei-Yu and Typhoon cases. CWB will send a staff member to visit UCAR for four months.

The following summarizes the schedule and resources required for Task 2:

Performance Period:	
a. Evaluate the benefits of using a larger ensemble size with WRF/DART and fine-tune related parameters	01/01/13 – 11/30/13
b. Support of WRF/DART testing at CWB	01/01/13 – 11/30/13
c. Support the application of SKEBS in the CWB EPS	01/01/13 – 11/30/13
Resources Required:	0.4 FTE UCAR staff
Deliverables:	
1. An updated version of WRF/DART code and namelists	11/30/13
2. Report on the results of WRF/DART improvements from use of the larger ensemble size	11/30/13

Task 3: Support and Improvement of Water Vapor Retrievals Using CWB GPS Networks

AIT's designated representative, UCAR, has previously provided support to TECRO's designated representative, CWB, in the application of data collected from continuously operating GPS (cGPS) stations on Taiwan to retrieve estimates of atmospheric water vapor. UCAR maintains and operates a data processing system at CWB to generate integrated precipitable water vapor (PW) estimates from the network of 74 GPS stations on Taiwan. The system includes jobs that analyze data in hourly, two-hourly, and daily batches. In addition, data from surface meteorology stations on Taiwan are used to compute surface pressure and temperature at the location of each of the cGPS stations. Significant products generated from these analysis jobs include the near real-time estimates of PW for monitoring and forecasting activities (hourly and two-hourly solutions), as well as the computation of station coordinates and PW estimates in a post-processed (daily) system. For 2013, UCAR proposes continued analysis of CWB cGPS data, the modification of the existing processing system to incorporate data from recently upgraded cGPS instruments, the migration of the current processing system to new computing hardware, and the development of a precise point positioning system (PPP) that may provide the potential capability to increase the total number of stations while also reducing the temporal resolution of the data products. Each of these tasks is outlined in the following sections.

3.1 Analysis of CWB GPS Network

AIT's designated representative, UCAR, will continue to monitor the analysis of the CWB cGPS network for atmospheric purposes. Specifically, UCAR will ensure that all three current processing elements (hourly, two-hourly, and daily solutions) are functioning normally and will monitor the system for data quality, data latency, and overall product quality. This task will ensure that the derived PW products are available to both researchers and forecasters who are interested in using these data. Elements of this task

include the following:

UCAR will update the Bernese Version 5.0 software package with all system updates to ensure that CWB analysis systems use the most current software package available.

The CWB analysis system incorporates data from ten additional cGPS stations operated by the Japanese Geographical Survey Institute (GSI). The access to this data is granted through a specific request to the GSI. UCAR will resubmit the annual request to the GSI to continue using the cGPS stations within 500-km of Taiwan for meteorological applications.

3.2 Incorporate Upgraded CWB Stations into Analysis System

The CWB network of cGPS stations is being upgraded to use a Trimble NetR9 instrument. This instrument is a Global Navigation Satellite System (GNSS) receiver that is capable of tracking both GPS and GLONASS signals. It also provides data in a streaming mechanism that reduces latency. The existing atmospheric processing structure at CWB will need significant restructuring to utilize data from these new instruments. AIT's designated representative, UCAR, will modify the current processing structure to use the data from these sites on an as available basis. The incorporation of data from the NetR9 instruments will only include data from GPS satellites. Significant effort is needed to ensure that GLONASS data can be used in a near real-time atmospheric analysis system and is beyond the scope of this current agreement.

3.3 Migrate CWB Processing System to New Computing Hardware

TECRO's designated representative, CWB, is currently acquiring new computing hardware to support the analysis of real-time GPS data. AIT's designated representative, UCAR, will work in collaboration with CWB to port all elements of the current processing system to this new hardware. This computing upgrade will decrease the latency of the PW retrievals, allow for more stations to be analyzed, and minimize the potential loss of processing capability due to hardware failure. All elements of the processing system will be transitioned to this new hardware. The web display of CWB results will remain on the existing web server (taccop5g).

3.4 Design and Install PPP Analysis Strategy

AIT's designated representative, UCAR, will design and test a PPP atmospheric analysis strategy. This system will diverge from the current processing systems (hourly, two- hourly, and daily) in that it will not rely on a double difference processing structure. Rather, it will incorporate precise satellite orbit and clock information provided by the International GNSS Service (IGS) or the Center for Orbit Determination in Europe (CODE). The advantage of a PPP strategy is that it is computationally more efficient, allowing more sites to be analyzed with lower latency and greater temporal fidelity. UCAR will design and install hourly and daily processing systems that are based on PPP methods. The PPP analysis (both daily and hourly) will be run with a latency of up to one day to ensure the availability of high quality orbit and clock information. Depending on the accuracy of the PPP solutions, and the future availability of real-time high quality clock and orbit products, TECRO's designated representative, CWB, may choose to adopt this analysis strategy in future agreements. UCAR will create a report summarizing the PPP data products in comparison to the current hourly and daily products.

Table 3.1: Proposed Task List for 2013

Description	**CWB tasks**	**UCAR tasks**
Analysis of CWB Network	• Continue collection of GPS data • Continue providing surface meteorology observations for use in GPS analysis	• Continued monitoring and analysis of GPS data • Incorporate all Bernese V5.0 software updates as needed • Resubmit request to Japanese GSI to include their cGPS stations in routine CWB analysis.
Incorporate Upgraded CWB Stations into Analysis	• Provide hourly data files (either rt17 or rt27 format) to the CWB analysis computers (i.e., taccop6g)	• Modify data ingest system to accommodate new file types and stations.
Migrate CWB processing system to new computing hardware	• Acquire and install new computing hardware for GPS analysis system. • Provide system administration support. This includes installation of compilers, visualization software, as well as internal and external network configuration.	• Port existing analysis system to the new computing hardware. This includes processing scripts and Bernese software.
Design and Install PPP Analysis System	• None	• Build and install hourly and daily PPP processing system. Data products will not be generated in real-time.
Technical Support	• None	• Archive and monitor all GPS related processing. • Assist CWB staff with technical support on an as needed basis.

The following summarizes the schedule and resources required for Task 3:

Performance Period:	
a. Analysis and monitoring of CWB GPS network	01/01/13 – 11/30/13
b. Incorporate upgraded CWB stations into analysis	01/01/13 – 06/30/13
c. Migrate CWB processing system to new computing hardware	01/01/13 – 06/30/13
d. Design and install PPP analysis system	01/01/13 – 09/30/13
e. Technical support of GPS analysis	01/01/13 – 11/30/13
Resources Required:	0.15 FTE UCAR staff
Deliverables:	
1. Creation and installation of new GPS data ingest software	06/30/13
2. Installation of CWB analysis system to new computing hardware	06/30/13
3. Design and install PPP analysis system	09/30/13
4. A report summarizing the PPP data products in comparison to the current hourly and daily products	09/30/13

Task 4: Support the Installation and Testing of the UCAR High-Resolution Land Data Assimilation System (HRLDAS)

In 2012, HRLDAS results showed domain-wide soil temperature and moisture that appeared to be warm and dry even though comparisons with local Taiwan soil observations showed positive results. Using these HRLDAS outputs resulted in WRF/HRLDAS simulations that were significantly warmer and drier than simulations using GFS initial conditions. The source of these biases could be due to problems in HRLDAS input fields. Analysis and sensitivity tests were performed by TECRO's designated representative, CWB, and AIT's designated representative, UCAR, to test alternate sources of HRLDAS forcing data for precipitation and surface solar radiation. In 2013, a focus of Task 4 is to implement new observational and modeling datasets to address the biases in soil temperature and moisture. Not all surface biases are due to initial conditions. This task will also focus on parameter tuning in the Noah model and improved surface coupling.

During 2013, AIT's designated representative, UCAR, will also provide assistance and technical consultation to TECRO's designated representative, CWB, for the further development, operational implementation, and related testing of the Noah land surface model in HRLDAS and WRF.

4.1 Continued Improvement of HRLDAS Initial Conditions by Improving Forcing Fields

The existing sources for HRLDAS input of solar radiation and precipitation are not optimal. This task will improve the current datasets by:

- Adjusting existing forcing data (e.g., by monthly bias correction using ERA re-analysis) to minimize forcing biases that directly affect soil initial conditions produced by HRLDAS, and

- Exploring and incorporating new forcing datasets, e.g., real-time NCEP GFS radiation forecasts (all domains) and blending NCEP global gridded gauge precipitation analysis with CMORPH (Domains 1 and 2).

4.2 Tuning of the Noah Model to Improve Performance in both HRLDAS and WRF Forecasts

Ultimately, the purpose of using HRLDAS is to improve the surface biases in the coupled WRF/HRLDAS. AIT's designated representative, UCAR, will assist in the continuing evaluation conducted by TECRO's designated representative, CWB, to compare WRF/HRLDAS output for test cases with observations using the standard CWB near-surface verification metrics, e.g., 2-meter temperature and humidity and 10-meter winds. Based on the results, UCAR will provide suggestions to improve the near-surface forecast by:

- Identifying biases for improvement,

- Comparing model surface water and energy metrics (e.g., Bowen ratio) with observations and global models,

- Improving HRLDAS/Noah parameters (including vegetation and soil properties), and

- Evaluating the model surface coupling strength and how it affects the development of surface biases.

4.3 Conversion and Testing of MODIS LAI and Albedo Product

In 2012, tests with the previously-developed MODIS FPAR product showed improvement in near-surface temperature bias through a reduction of high daytime temperature bias. During 2013, AIT's designated representative, UCAR, will:

- Convert the previously-developed MODIS climatological LAI and albedo datasets to WRF/WPS format,
- Test the MODIS climatological LAI and albedo datasets, and
- Provide to TECRO's designated representative, CWB, both the datasets and methodology to ingest datasets in the forecast model.

4.4 Exchange Visit

A staff member of TECRO's designated representative, CWB, will visit AIT's designated representative, UCAR, for one month in June. This CWB staff member will work on improving both HRLDAS and WRF biases (synchronizing Tasks 4.1 and 4.2 progress), and continue to learn HRLDAS and WRF near-surface processes.

The following summarizes the schedule and resources required for Task 4:

Performance Period:	
a. Improvement of HRLDAS forcing fields	01/01/13 – 11/30/13
b. Tuning of Noah model in HRLDAS and WRF	01/01/13 – 11/30/13
c. Conversion and testing of MODIS LAI and albedo	01/01/13 – 11/30/13
d. Exchange visit	06/01/13 – 06/30/13
Resources Required:	0.2 FTE UCAR staff
Deliverables:	
1. Updated system for HRLDAS forcing fields developed in Task 4.1	11/30/13
2. Updated HRLDAS/Noah model code and parameters developed in Task 4.2	11/30/13
3. MODIS LAI and albedo datasets with processing software developed in Task 4.3	11/30/13
4. Final report documenting the results of HRLDAS task	11/30/13

Task 5: Improvement of WRF Model Operational Performance

During 2012, AIT's designated representative, UCAR, and TECRO's designated representative, CWB, collaborated on investigating the behavior and improving the operational performance of the CWB WRF model. High-resolution precipitation forecasts over Taiwan were found to be sensitive to the WRF model's initial conditions. The issue of oceanic convection was also investigated and a new shallow convective scheme was tested. In 2013, UCAR and CWB will collaborate to further improve the WRF forecasts in the Taiwan region by testing new parameterizations and modifying existing ones. Additionally, UCAR will provide consultation and assistance to CWB on the operational WRF system, as well as advise CWB visitors to UCAR.

5.1 Investigate the Behavior of WRF Model Physics Emphasizing the Prediction of Moist Convection

AIT's designated representative, UCAR, will collaborate with TECRO's designated representative, CWB, on investigation and improvement of WRF model physics with particular emphasis on convective weather phenomena. For many reasons, the prediction of convection over and near Taiwan is a difficult problem; a fact that is borne out by occasional operational model forecast failures. CWB has noted WRF model biases in precipitation forecasts. The causes of these biases warrant further investigation. Any relevant modifications to the WRF physics code will be tested and, if demonstrated to be successful, will be provided to CWB. UCAR will also assist and mentor CWB staff members that are working on WRF model physics problems.

5.1.1 Investigate and improve precipitation forecasts on the 5-km grid over Taiwan

WRF forecasts on the 5-km grid sometimes exhibit positive precipitation biases over Taiwan and especially over the Central Mountain Range. During 2012, UCAR found that for the cases studied, the excess precipitation was caused by problems with the WRF initial conditions. However, not all precipitation biases can be explained by initial conditions. AIT's designated representative, UCAR, will conduct experiments on cases of excess precipitation for 12- to 36-hour forecasts. In such cases, the biases should not be caused by initial conditions. The cause of the biases will be identified and possible solutions will be developed.

5.1.2 Test and improve WRF shallow convection parameterization

During 2012, two shallow convection schemes (NSAS and YSU) were evaluated by AIT's designated representative, UCAR, but both had problems. The NSAS shallow scheme was not active, while the YSU scheme had a compiler-dependency issue. UCAR will continue the task in 2013 to resolve the issues, and provide testing and evaluation of the schemes to TECRO's designated representative, CWB. UCAR will also deliver the two working schemes to CWB.

AIT's designated representative, UCAR, will assist TECRO's designated representative, CWB, in implementing a different shallow convection scheme in WRF. This scheme was developed by Dr. Frank Li and is used in CWB's global model.

5.1.3 Test and improve WRF radiation parameterization

During 2012, tests revealed some significant biases in WRF's surface solar radiation. By including aerosol effects and a better representation of ozone in the radiation schemes, these biases may be reduced. The newer RRTMG radiation option (http://rtweb.aer.com/rrtm_frame.html) in the WRF model provides a framework to incorporate these atmospheric constituents. Leveraged on the development by other UCAR projects, AIT's designated representative, UCAR, has delivered a version of RRTMG with latitude and time dependent ozone, and latitude/longitude and time varying climatological aerosol to TECRO's designated representative, CWB. UCAR will continue to test and evaluate this scheme in 2013.

5.2 Consult and Advise CWB on the Operational WRF Model

AIT's designated representative, UCAR, will consult and advise TECRO's designated representative, CWB, about the operational WRF model as necessary. This task will include the investigation of WRF problems identified by CWB and consultation to CWB about aspects of running the model. UCAR staff will assist visitors from CWB in their WRF investigations. UCAR will also collaborate with CWB to

maintain and support its use of a CWB operational computer's compiler options for WRF, and provide such options to the community repository.

The following summarizes the schedule and resources required for Task 5:

Performance Period:	
a. Investigate the behavior of WRF model physics emphasizing the prediction of moist convection	01/01/13 – 11/30/13
b. Consult and advise CWB on the operational WRF	01/01/13 – 11/30/13
Resources Required:	0.4 FTE UCAR staff
Deliverables:	
1. A report on WRF prediction of topographic rainfall	11/30/13
2. WRF code for two shallow convective parameterization schemes 3. A report on the behavior of WRF shallow convection schemes	11/30/13 11/30/13
4. A report on behavior of the RRTMG scheme in WRF 5. Verify and support the CWB operational computer compiler options in the WRF model and provide such options to the WRF community	11/30/13 11/30/13

Task 6: Radar Data Assimilation using WRFVAR over Taiwan

AIT's designated representative, UCAR, will conduct a case study using Typhoon Fanapi to demonstrate the capability of WRFVAR radar data assimilation and demonstrate its ability in improving heavy rainfall prediction. Both WRF 3DVar and 4DVar radar data assimilation will be tested and compared with their respective experiments without radar data assimilation. Specific tasks in this proposed radar data assimilation study include:

6.1. Radar Data Quality Control for Typhoon Fanapi

UCAR will run VDRAS to perform the Fanapi data quality control needed for the 3D-Var and 4D-Var radar data assimilation experiments. UCAR will assist a CWB visitor in the evaluation of the CWB quality control algorithm in QPESUM and compare its performance with that of VDRAS.

6.2. Testing Radar Data Assimilation for Typhoon Fanapi with WRFVAR

UCAR will run 3D-Var radar data assimilation experiments with the newly developed reflectivity assimilation scheme using the CWB operational 5km domain at three different initial times. 0-24 hour forecasts will be conducted after each of these analyses. These data assimilation and forecast experiments will be repeated using 4D-Var with and without radar data assimilation. The forecasts will be verified against QPE data provided by CWB to demonstrate the impact of radar data assimilation using both 3D-Var and 4D-Var.

6.3. Provide Training and Consultation to CWB staff

UCAR will provide training and consultation on VDRAS radar data quality control procedure and WRF 3/4DVar radar data assimilation during the visits of CWB staff.

The following summarizes the schedule and resources required for Task 6:

Performance Period:	
a. Radar data quality control	01/01/13 – 11/30/13
b. Radar data assimilation case study of Fanapi	01/01/13 – 11/30/13
c. Training and consultation	01/01/13 – 11/30/13
Resources Required:	0.22 FTE UCAR staff
Deliverables:	
1. A report describing the results of the quality control evaluation and the data assimilation case study	11/30/13
2. 3D-Var and 4D-Var code used for the case study	06/01/13

Task 7: Project Management and Coordination

The tasks proposed for 2013 require close collaboration between TECRO's designated representative, CWB, and AIT's designated representative, UCAR. Therefore, the exchange of information and progress between CWB and UCAR in a timely manner is important. Effective and efficient communication methods, such as project web pages and ftp data transfers, will be established and updated on a timely and regular basis. Exchange visits between CWB and UCAR staff are also necessary. To keep CWB informed on the progress of the project, monthly reports will be prepared by UCAR and delivered to CWB. A monthly project meeting will be organized to ensure coordination of the various tasks and a smooth execution of the project. The following work will be included under this task.

7.1 Update and Improve both the CWB and UCAR CWB Project Web Pages

With the CWB and UCAR web pages, reports, presentations, and software are easily exchanged between the two groups. In 2013, AIT's designated representative, UCAR, will continue to maintain, improve, and conduct timely updates of the web pages to keep TECRO's designated representative, CWB, informed on current developments.

7.2 Site Visit to CWB

To ensure smooth execution of the project, it is desirable for AIT's designated representative, UCAR, to visit TECRO's designated representative, CWB. Such visits are highly valuable to resolve technical problems and report on the progress of the project. It is anticipated that Hui Liu, Jim Bresch, Wei Wang, Jenny Sun, Craig Schwartz, Hans Huang, Zhiquan Liu, Xin Zhang and/or Yong-Run Guo may visit CWB for a one or two-week period. Other UCAR staff, including Dr. Bill Kuo, will visit CWB as needed. It is also expected that senior CWB staff (Drs. Chin-Tzu Fong, Jing-Shan Hong, and Der-Song Chen) will visit UCAR in the fall to review the progress of the project and to begin preliminary planning for next year's tasks.

7.3 Teleconferences

To ensure smooth execution of the project, periodic telephone conferences will be held. These telephone conferences will focus on specific topics of interest to both parties. The telephone conferences can be initiated by either TECRO's designated representative, CWB, or AIT's designated representative, UCAR, as required by the project.

7.4 Monthly Reports and Workshop Reports

Monthly progress reports will be provided to TECRO's designated representative, CWB, to document the project's accomplishments. These reports will be brief so as not to detract from the FTE dedicated to

research. In addition, AIT's designated representative, UCAR, will provide a summary of the WRF User's Workshop to CWB.

7.5 Project Administrative Support

The UCAR COSMIC Program Office will provide administrative support for this project. This includes:

- Monitoring of the project budget, staff time-charges, and other spending;
- Arranging travel for staff of AIT's designated representative, UCAR, and TECRO's designated representative, CWB, and filing all the related paper work;
- Support for monthly meetings;
- Support for the preparation of project reports and deliverables; and
- Administrative support for CWB visitors (e.g., health insurance, visa paperwork).

The following summarizes the schedule and resources required for Task 7:

Performance Period:	
a. Update and maintain both CWB and UCAR CWB project web pages	01/01/13 – 11/30/13
b. Site visits to CWB	01/01/13 – 11/30/13
c. Telephone conferences via Skype	01/01/13 – 11/30/13
Resources Required:	0.1 FTE UCAR scientific staff and 0.12 FTE UCAR administrative staff
Deliverables:	
1. Updated web page for project	11/30/13
2. Site visits	11/30/13
3. Brief monthly reports to CWB management	03/01/13- 10/01/13
4. Summary report of WRF User's Workshop	09/30/13

II. Budget

The following are the estimated costs for Implementing Arrangement #10A:

Tasks	FTE	Personnel Cost	Travel/Training	Total
Task #1	1.10	230,000	10,000	240,000
Task #2	0.40	60,000	10,000	70,000
Task #3	0.15	28,000		28,000
Task #4	0.20	49,000	10,000	59,000
Task #5	0.40	88,000	10,000	98,000
Task #6	0.22	55,000	10,000	65,000
Task #7	0.22	45,000	35,000	80,000
Total	**2.69**	**555,000**	**85,000**	**640,000**

The budget under Personnel Cost is used to support staff of AIT's designated representative, UCAR, to perform tasks described in this Statement of Work. The figures include benefits and overhead. The Travel/Training budgets in each Task are used to support UCAR staff travel to visit TECRO's designated representative, CWB, as well as the cost associated with the training of CWB staff. The travel processed by UCAR also includes the necessary overhead. As stated in the Implementing Arrangement #10A, the total firm fixed price available from CWB to support the tasks, travel, and meeting expenses described in this Statement of Work will be a total of $640,000 USD. The detailed financial arrangements are described in the Implementing Arrangement #10, Article IV – Financial Provisions.

III. CWB Joint Team Assignments at UCAR

In order to successfully carry out this CWB-UCAR project, strong collaboration is needed between AIT's designated representative, UCAR, and TECRO's designated representative, CWB. The tasks to be performed by UCAR scientists are detailed in this Statement of Work. CWB staff will collaborate with UCAR scientists on various tasks. Some of the tasks will be performed in Taipei at the CWB. Some of the tasks will be carried out by CWB staff, while they are on assignment to work at UCAR. Specific assignments will be made to most efficiently use the available personnel resources.