

**Statement of Work
for Implementing Arrangement #11
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 2013, TECRO's designated representative, the Central Weather Bureau (CWB), implemented OP25, which included Weather Research and Forecasting (WRF) model data assimilation (WRFDA) V3.4.1/WRF V3.3.1, and WPS V3.3.1, in the CWB operation. In 2014, AIT's designated representative, the University Corporation for Atmospheric Research (UCAR), will work closely with CWB to upgrade the CWB operational system to OP26, which will include WRFDA V3.5.1 and some enhancement for the WRF model based on Version 3.3.1. UCAR will also continue to provide technical support to CWB on the WRFDA component of the CWB operational system.

1.1 General Support for the CWB OP26 System

In 2014, AIT's designated representative, UCAR, will provide general technical support to the hybrid-DA system during the transition from the OP25 to the OP26 at TECRO's designated representative, CWB. UCAR will provide solutions and necessary training related to the hybrid-DA system in support of the OP26 operations to CWB.

1.2 Support the Implementation of the Dual Resolution Hybrid-DA in OP26 System

AIT's designated representative, UCAR, will first revisit the dual resolution hybrid-DA in the new nested 15/3-km domain that is provided by TECRO's designated representative, CWB. UCAR will examine the performance, validity and robustness of the dual resolution hybrid-DA algorithm over Taiwan's complex terrain. Second, UCAR will assist CWB in the implementation of the dual resolution hybrid-DA in the OP26 operational system.

1.3 Support the Upgrade of the EAKF System

AIT's designated representative, UCAR, will provide support and consultation for the upgrade of the EAKF system to TECRO's designated representative, CWB.

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

Performance Period:

Provide support for OP26

01/01/14 – 11/30/14

Resources Required:

0.15 FTE

UCAR staff

Deliverables:

- | | |
|--|----------|
| 1. A report on the activities for operational support. | 11/30/14 |
| 2. A report on the dual resolution hybrid-DA test over the 15/3-km domain. | 11/30/14 |

Task 2: Development of a convective scale DA system for CWB

In 2013, AIT's designated representative, UCAR, conducted a case study of Typhoon Fanapi using an upgraded version of WRF 3DVar and 4DVar with the radar data assimilation capability. This upgraded version includes a new method for the assimilation of reflectivity, a new momentum control variable option CV7, and the adjoint of the Kessler scheme. The code with a namelist that was used over the CWB 5km domain was delivered to TECRO's designated representative, CWB, at the end of 2013. In 2014, UCAR will train and provide technical consultation to CWB personnel to further improve the system. UCAR will also continue to develop the 4DVar system for radar and precipitation data assimilation. The upgraded system will be tested using a Meiyu front case. These tasks are described as the following:

2.1 Improve 3DVar System for Convective-scale Assimilation and Forecast

The current WRFDA 3DVAR system can be used for convective scale data assimilation with radar assimilation capabilities, but further tuning and development are needed. AIT's designated representative, UCAR, will host a visitor from TECRO's designated representative, CWB, and train the visitor on the system and assist the visitor in making some improvements. This is mainly a CWB task; UCAR's role is consulting and supervision of the visitor. The items under consideration are:

- Radar data quality control for a Meiyu test case;
- Development of CV7 (UV control variable) background error covariance for CWB;
- Conduct single observation tests with CV7;
- Assessment of the performance of the 3DVar with CV7 for 3h, 1h, and 30-min update cycles; and
- Improve the performance of the rapid update 3DVar with multiple outer loop cycles.

2.2 Unify the 4DVar Development Branches with the WRFDA Trunk

AIT's designated representative, UCAR, will merge the convective scale development branch with the WRFDA trunk to deliver a unified WRFDA system for both synoptic scale and convective scale applications to TECRO's designated representative, CWB. The new features of the unified system include CV7 UV control variables; reflectivity data assimilation with humidity pseudo observations; Kessler warm rain microphysics; and the continuity constraint. The current continuity constraint can only work in serial mode and will be parallelized.

2.3 Testing and further Development of the Precipitation 4DVar Capability

AIT's designated representative, UCAR, will test the precipitation assimilation with the unified 4DVar code using the stage IV data over the Continental US. In the meantime, with help from TECRO's designated representative, CWB, UCAR will develop the 4DVar capability to assimilate the CWB precipitation data. UCAR will report the testing result and deliver the developed code to CWB.

2.4 Testing and further Development of the Unified WRFDA 4DVar at 3-km Mesh

AIT's designated representative, UCAR, will test and improve the performance of the unified 4DVar system using CWB's 3km grid mesh. The test will be done first without and then with radar data. The following subtasks will be performed without radar data:

- Examine the performance of the unified 4DVar with UV control viable without radar DA using a Meiyu case;
- Improve the performance with multi-incremental scheme; and
- Examine the impacts of assimilation window and DFI for the CWB 3-km domain.

2.5 Evaluating Radar DA Performance using the Unified WRFDA 4DVar

AIT's designated representative, UCAR, will test the radar data assimilation capability using the unified WRFDA 4DVar and improve its performance. A Meiyu case will be used for the test and sensitivity study. UCAR will perform the following subtasks:

- Repeat the tasks in 2.4 but with radar data assimilation;
- Conduct sensitivity experiments by tuning several assimilation parameters; and
- Evaluate the performance and sensitivity using the Meiyu case.

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

Performance Period:

a. Provide support for OP26 system	01/01/14 – 11/30/14
b. Development of the convective scale DA system	01/01/14 – 11/30/14

Resources Required:

1.00 FTE
UCAR staff

Deliverables:

1. A report on convective 3DVar tests (with CWB visitors)	11/30/14
2. The updated (unified) WRFDA code	11/30/14
3. A report on 4DVar of precipitation data	11/30/14
4. A report on 4DVar of radar data	11/30/14

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 in 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 in Taiwan. The system includes jobs that analyze data in daily and sub-daily (hourly and two-hour) batches in both a standard double difference and precise point-positioning (PPP) mode. In addition, data from surface meteorology stations in 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, as well as the computation of station coordinates and PW estimates in a post-processed (daily) solution. For 2014, UCAR will work closely with CWB to continue the analysis of CWB cGPS data, modify the processing structure to include data from up to 120 stations based upon an expansion of the CWB cGPS network, upgrade the GPS analysis software to Bernese Version 5.2, and conduct an evaluation of PW data products produced by the PPP strategy. 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 current processing elements 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. The 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 New CWB Stations into Routine Processing

The CWB cGPS network was recently upgraded in instrumentation and expanded to 120 stations. AIT's designated representative, UCAR, will incorporate data from the new stations into the daily and sub-daily processing systems. The new and upgraded stations use a modern Global Navigation Satellite System (GNSS) receiver that may be able to track both GPS and GLONASS signals (dependent on the firmware options purchased for the instrument). This task will only include the use of GPS data. 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 Implementing Arrangement.

3.3 Update Processing System to Bernese Software Version 5.2

The primary data analysis software utilized for this task is the Bernese GNSS Analysis Software. Currently, the CWB processing system uses version 5.0 of the software for its analysis. The most current version of the software is now version 5.2. CWB will be responsible for purchasing this version of the software from the Astronomical Institute at the University of Berne. AIT's designated representative, UCAR, will be migrating the processing system to this new version.

3.4 Evaluate Performance of Precise Point Positioning (PPP) Analysis

AIT's designated representative, UCAR, will evaluate the performance of the PPP processing system for atmospheric applications. This will include a report that compares the PPP results to both near real time and post-processed (daily) products.

Table 3.1: Proposed Task List for 2014

Description	CWB tasks	UCAR tasks
Analysis of CWB Network	<ul style="list-style-type: none"> • Continue collection of GPS data • Continue providing surface meteorology observations for use in GPS analysis 	<ul style="list-style-type: none"> • Monitoring and analysis of GPS data • Resubmit request to Japanese GSI to include their cGPS stations in routine CWB analysis.
Incorporate new CWB stations into Routine Processing	<ul style="list-style-type: none"> • Provide hourly data files to the CWB ground based processing computer (gdgps) 	<ul style="list-style-type: none"> • Compute a-priori coordinates for new stations, ocean loading parameters, and incorporate data into all processing jobs.
Update processing system to Bernese Software Version 5.2	<ul style="list-style-type: none"> • Acquire official software update (version 5.2) from the University of Bern 	<ul style="list-style-type: none"> • Modify existing processing system to work within this updated version of the analysis software.
Design and install PPP analysis system	<ul style="list-style-type: none"> • None 	<ul style="list-style-type: none"> • Build and install hourly and daily PPP processing system. Data products will not be generated in real-time.
Technical support	<ul style="list-style-type: none"> • None 	<ul style="list-style-type: none"> • Archive and monitor all GPS related processing. • Assist CWB staff with technical support on as needed basis.

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

Performance Period:

a. Analysis and monitoring of CWB GPS network	01/01/14 – 11/30/14
b. Incorporate new CWB stations into routine analysis	01/01/14 – 06/30/14
c. Migrate CWB processing system to Bernese V5.2 software	01/01/14 – 09/30/14
d. Evaluate Performance of PPP Analysis Strategy	01/01/14 – 09/30/14
e. Technical support of GPS analysis	01/01/14 – 11/30/14

Resources Required:

0.25 FTE UCAR staff

Deliverables:

1. Incorporate new CWB cGPS stations into analysis system	06/30/14
2. Upgrade CWB analysis system to Bernese Version 5.2.	09/30/14
3. Provide report on PPP analysis strategy	09/30/14

Task 4: Improvement of WRF Model Operational Performance

During 2013, 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. Over-prediction of precipitation in the high-resolution grid over Taiwan was found to be sensitive to the WRF model's diffusion which is carried out on the model's terrain-following surfaces. An improved shallow convection scheme from WRF Version 3.5.1 was tested and implemented in the

CWB OP25 code to address the issue of oceanic convection. In 2014, UCAR and CWB will collaborate to further improve the WRF precipitation forecasts in the Taiwan region by testing a new and improved diffusion scheme. UCAR will further examine WRF model's radiation performance and its impact on model biases. UCAR and CWB will also collaborate on testing the new operational configuration of the model. Additionally, UCAR will provide consultation and assistance to CWB on the operational WRF system.

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

4.1.1 Investigate and Improve Precipitation Forecasts on the 5-km Grid over Taiwan

During 2013, AIT's designated representative, UCAR, found that WRF forecasts of precipitation on the 5-km grid were sometimes sensitive to the parameterization of horizontal diffusion. UCAR will test modifications of the diffusion scheme and examine the impact on 5-km precipitation forecasts.

4.1.2 Examine and Evaluate WRF's Radiation Prediction

During 2013, AIT's designated representative, UCAR, and TECRO's designated representative, CWB, found that switching to RRTMG radiation in the WRF model significantly reduced model radiation and temperature biases. Even though the surface radiation fluxes have been improved, biases still exist when compared with output from ECMWF Interim analysis. In 2014, UCAR will investigate this bias further. Once the bias is identified, UCAR will research and propose remedies to improve this aspect of the model.

4.1.3 Evaluate Model Configuration for 15/3 km

As TECRO's designated representative, CWB, begins to configure and evaluate the new operational grid for its future NWP system, AIT's designated representative, UCAR, will work closely with CWB on this task. UCAR will provide support and consultation on domain design, choice of physics, and will participate in examination and discussion of test results.

4.2. 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. In 2014, UCAR will perform the following tasks:

4.2.1 General Support for CWB OP25 and OP26 Systems

This task will include the investigation of WRF problems identified by CWB and consultation to CWB about aspects of running the model.

4.2.2 Update WRF Code for Processing Lateral Boundary Conditions

In order to shorten the data waiting-time to start the operational forecast at CWB, WRF model code will be updated to provide the capability to process and utilize individual lateral boundary condition times separately. This will allow the WRF model to start its integration as soon as two times of GFS data become available.

4.2.3 Investigate the Possibility of Using GFS Tropopause Fields in IC/BC

To represent atmospheric conditions accurately in the model's initial and lateral boundary files, generally, more information is better. This task will investigate the possibility of using the GFS-predicted atmospheric conditions at the tropopause and maximum wind levels to supplement the data at constant pressure levels.

4.2.4 Consult CWB on Using Alternative SST Data from NCEP

In 2013, UCAR demonstrated that using the SST field contained in the standard GFS dataset may present problems along coastlines of Taiwan due to its low resolution, and in some instances, it had an adverse effect on the precipitation forecast over Taiwan. Using alternative higher-resolution SST data can alleviate the problem. In 2014, UCAR will consult with CWB on evaluating any potential impact of this alternative SST source in the operational system.

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

Performance Period:

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|---|---------------------|
| a. Investigate the behavior of WRF model diffusion on the prediction of precipitation over Taiwan | 01/01/14 – 11/30/14 |
| b. Investigate the performance of radiation in WRF | 01/01/14 – 11/30/14 |
| c. Consult and advise CWB on the operational WRF | 01/01/14 – 11/30/14 |

Resources Required:

0.45 FTE UCAR staff

Deliverables:

- | | |
|---|----------|
| 1. A report on WRF prediction of topographic rainfall | 11/30/14 |
| 2. A report on the behavior of WRF radiation | 11/30/14 |
| 3. A report on support of CWB operational system | 11/30/14 |

Task 5: Project Management and Coordination

The tasks proposed for 2014 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 continued 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.

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

With the use of CWB and UCAR web pages, reports, presentations, and software are easily exchanged between the two groups. In 2014, AIT's designated representative, UCAR, will continue to maintain, improve, and provide timely updates of the web pages to keep TECRO's designated representative, CWB, informed on current developments.

5.2 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 Jenny Sun, Hans Huang, and Wei Wang may visit CWB for a one or two-week period. Reports from each of the visits will be produced and posted on the UCAR web page. Other UCAR staff, including Dr. Bill Kuo, will visit CWB as needed. It is also expected that senior CWB staff Dr. Jing-Shan Hong will visit UCAR in June for the mid-term review, and 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.

5.3 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. After each teleconference, a report will be produced and posted on the project web page.

5.4 Monthly 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.

5.5 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 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 5:

Performance Period:

a. Update and maintain both CWB and UCAR CWB project web pages	01/01/14 – 11/30/14
b. Site visits to CWB	01/01/14 – 11/30/14
c. Telephone conferences via Skype	01/01/14 – 11/30/14

Resources Required:

0.1 FTE UCAR
scientific staff and
0.05 FTE UCAR
administrative staff

Deliverables:

- | | |
|--|--------------------|
| 1. Updated web page for project | 11/30/14 |
| 2. Site visits | 11/30/14 |
| 3. Brief monthly reports to CWB management | 03/01/14- 10/01/14 |

II. Budget

The following are the estimated costs for Implementing Arrangement #11:

Tasks	FTE	Personnel Cost	Travel/Training	Total
Task #1	0.15	30,000		30,000
Task #2	1.00	250,000	20,000	270,000
Task #3	0.25	50,000		50,000
Task #4	0.45	90,000	10,000	100,000
Task #5	0.15	30,000	40,000	70,000
Total	2.0	450,000	70,000	520,000

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 #11, 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 \$520,000 USD. The detailed financial arrangements are described in the Implementing Arrangement #11, 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.