Implementing Arrangement Number 3

Consultancy Services

for the

Enhancement of the CWB Data Assimilation System

to the

AGREEMENT

between the

AMERICAN INSTITUTE IN TAIWAN

and the

TAIPEI ECONOMIC AND CULTURAL REPRESENTATIVE OFFICE IN THE
UNITED STATES

for

TECHNICAL COOPERATION

associated with

ESTABLISHMENT OF ADVANCED DATA ASSIMILATION

AND MODELING SYSTEMS

ARTICLE I – SCOPE

This Implementing Arrangement describes the cooperative scientific, technical, engineering and administrative activities to be undertaken by the American Institute in Taiwan (AIT) and its designated representative, the University Corporation for Atmospheric Research (UCAR), to provide consultancy services for the Enhancement of the CWB Data Assimilation System. This is a cooperative effort between AIT, through its designated representative, UCAR, and the Taipei Economic and Cultural Representative Office in the United States (TECRO), through its designated representative, the Central Weather Bureau (CWB), of the Ministry of Transportation and Communications (MOTC). This Implementing Arrangement pertains to the Agreement (dated January 12, 2005, hereinafter referred to as the Agreement) between AIT and TECRO for Technical Cooperation associated with the Establishment of Advanced Data Assimilation and Modeling Systems and is a part of the Agreement.

ARTICLE II – AUTHORIZATION

The activities described in this Implementing Arrangement will be carried out under the general terms and conditions established by the Agreement. The Agreement was entered into by the parties pursuant to the Taiwan Relations Act of April 10, 1979, Public Law 96-8 (22 USC 3301 et seq.).

ARTICLE III – SERVICES

Taiwan is extremely vulnerable to the passage of tropical cyclones (TCs). In a typical year, three to four typhoons have an impact on the island, with one or two making landfall. However, a typhoon does not need to make direct landfall for Taiwan to experience damaging winds and heavy rains. The forecasting of typhoons around Taiwan is a very challenging task, because Taiwan is surrounded by ocean, where there are few traditional meteorological observations. AIT's designated representative, UCAR, will provide software and consulting services for the implementation of an advanced data assimilation system (e.g., WRFVar) into CWB's operational environment. AIT's designated representative, UCAR, will perform WRF-based EnKF data assimilation and assess its impact on typhoon prediction, in close collaboration with TECRO's designated representative, CWB. AIT's designated representative, UCAR, will also provide training on ground-based GPS water vapor retrieval to TECRO's designated representative, CWB. The technical cooperation between the designated representatives of AIT and TECRO will be performed in accordance with the terms and conditions of the Agreement and this Implementing Arrangement No. 3.

This Implementing Arrangement is specifically focused on: a) providing technical consultation and software for the operational implementation of the WRFVar data assimilation system, b) performing WRF-based EnKF data assimilation experiments and

assessing its impact on typhoon prediction, and c) training of ground-based GPS water vapor retrieval software, and d) continued interaction on WRFVar data assimilation systems.

The technical cooperation to be undertaken under the auspices of this Implementing Arrangement is defined by the following tasks. Task details, including specific work to be performed, performance period, and estimated cost for each task are contained in the attached Statement of Work.

A summary description of the tasks to be performed during this period is provided below.

Task #1 – Support and enhancement of the WRFVar system for CWB operation

The WRFVar data assimilation system, developed by AIT's designated representative, UCAR, will be implemented on CWB's newly procured IBM computer by TECRO's designated representative, CWB. AIT's designated representative, UCAR, will provide support as necessary to TECRO's designated representative, CWB, to ensure successful operation of WRFvar at CWB. UCAR will provide technical assistance on the following sub-tasks: (a) design the WRFVar operational configuration, (b) perform short duration WRFVar/WRF testing, and (c) support CWB's effort on pre-operational tests for a longer period of time.

Task #2 – Exploration of the WRF-based Ensemble Kalman Filter (EnKF) data assimilation

In 2007, staff of AIT's designated representative, UCAR, will collaborate with staff of TECRO's designated representative, CWB, on the testing of WRF-based ensemble Kalman filter (EnKF) data assimilation system for a typhoon case in the vicinity of Taiwan. In particular, AIT's designated representative, UCAR, will assess the impact of COSMIC GPS radio occultation (GPSRO) soundings on the prediction of a typhoon case, and compare the performance between WRF-based EnKF system and WRFVar. AIT's designated representative, UCAR, will conduct the following three sub-tasks: a) WRF-based EnKF assimilation of COSMIC GPSRO data on a typhoon case, b) comparison between WRFVar and EnKF, and c) training of WRF-based EnKF data assimilation system.

Task #3 – Training on Ground-based GPS PW data processing

CWB, TECRO's designated representative, currently operates a network of approximately 80 ground-based GPS receivers. These receivers can potentially provide real-time precipitable water (PW) monitoring, which is important for short-range weather prediction. CWB is interested in establishing capability to process data from the CWB ground-based GPS network for PW retrieval. Dr. John Braun, staff of AIT's designated representative, UCAR, will travel to Taiwan for the period of one week, and provide

training on GPS PW retrieval. CWB is responsible for (i) obtaining the necessary third party software (e.g., Bernese 5.0), (ii) necessary computing facility, (iii) ground-based GPS data from the CWB network. UCAR staff will provide necessary software developed by UCAR and the training on GPS PW retrieval.

Task #4 – Continued Interaction on WRF-Var System

Because the tasks proposed for 2007 require close collaboration between the staffs of AIT's designated representative, UCAR, and TECRO's designated representative, CWB, the exchange of information and progresses between CWB and UCAR in a timely manner is crucial. Effective and efficient communication methods, such as the web pages for the project, the data transfer "ftp" command etc. must be established and updated timely and regularly. The exchange of visit between CWB and NCAR/UCAR staff are also necessary to ensure the smooth execution of this collaboration. AIT's designated representative, UCAR, will conduct the following two sub-tasks: a) Updated and improve the CWB project web pages at NCAR, and b) site visit to CWB.

ARTICLE IV – FINANCIAL PROVISIONS

TECRO is required to reimburse AIT for all costs incurred by AIT's designated representative, UCAR, in association with the project covered by this Implementing Arrangement. AIT will transfer to UCAR all payments made by TECRO to AIT for costs incurred by UCAR in association with this Implementing Arrangement.

The total cost for activities described in this Implementing Arrangement is mutually agreed to be U.S. $120,000. TECRO agrees to transfer fifty percent of the funds to AIT within one month after the signing of this agreement, with the remaining fifty percent to be transferred upon completion of the tasks set forth in this Implementing Arrangement No. 3. It is agreed and understood that the payment will be provided in U.S. dollars.

ARTICLE V – INTELLECTUAL PROPERTY CONSIDERATIONS

Intellectual Property - The parties agree that no Intellectual Property or other Proprietary Information will be provided under this Implementing Arrangement. Intellectual Property and Proprietary Information are defined as software, designs, processes, drawings, data, and modeling systems which includes, but is not limited to, all versions, derivative works, updates, improvements, modifications, enhancements and releases thereof, patents, patent applications, continuations-in-part, inventor rights in the United States and any foreign countries and applications therefore. In the event that any activities under this Implementing Arrangement require the use of the other party's Intellectual Property or Proprietary Information, the parties shall in good faith enter into negotiations to reduce to a mutually agreeable writing the obligations and terms associated with such understandings.

Public Domain Technology - The Weather Research and Forecasting (WRF) model, as well as its associated data assimilation systems (e.g., WRFVar, WRF-based EnKF), were developed by the National Center for Atmospheric Research (NCAR) with significant participation of the broad scientific community. The WRF model, WRF-Var and WRF-based EnKF systems are in the public domain. Both parties agree that the WRF model, WRFVar and WRF-based EnKF systems and any modifications, revisions, enhancements, updates, or improvements shall remain in the public domain and are not considered Proprietary Information.

ARTICLE VI – EFFECTIVE DATE, AMENDMENT, AND TERMINATION

This Implementing Arrangement takes effect 1 January 2007 and the completion date of tasks described in this Implementing Arrangement is 31 December 2007. This Implementing Arrangement may be amended and/or terminated in accordance with the terms and conditions of the Agreement.

FOR THE AMERICAN INSTITUTE
IN TAIWAN

FOR THE TAIPEI ECONOMIC AND
CULTURAL REPRESENTATIVE
OFFICE IN THE UNITED STATES

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Name of person signing

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Name of person signing

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Position

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Position

6/13/07
....
Date

7/11/07
....
Date

Statement of Work
For Implementing Arrangement Number 3
Consultancy Service
For the
Enhancement of the CWB data assimilation system

Subject to the AGREEMENT
between the
American Institute in Taiwan
and the
Taipei Economic and Cultural Representative Office in the United States
for
Technical Cooperation
associated with
Establishment of Advanced Data Assimilation and Modeling Systems

1.0 - Background and Objectives

In accordance with the terms of Implementing Arrangement No. 3 (IA#3) of the Agreement between the American Institute in Taiwan (AIT) and the Taipei Economic and Cultural Representative Office in the United States (TECRO) for Technical Cooperation associated with the Establishment of Advanced Data Assimilation and Modeling Systems, which provides for technical cooperation between AIT's designated representative. the U.S. University Corporation for Atmospheric Research (UCAR) and TECRO's designated representative, the Taiwan Central Weather Bureau (CWB), this Statement of Work addresses tasks that will be undertaken by the joint team of personnel of AIT's designated representative, UCAR, and TECRO's designated representative, CWB. The two designated representatives cooperate on the development of data assimilation systems.

With the CWB-UCAR 2006 collaborative project (through joint efforts between the staffs of AIT's designated representative. UCAR, and TECRO's designated representative, CWB), the accomplishments are 1) the WRFVar 2.1 system has been delivered to CWB from UCAR, and the semi-operational testing with the WRFVar/NFS system has been running successfully on CWB's new IBM p5-575 Cluster 1600; 2) the background error statistics (BES) estimates (cv_options=5) for summer and winter months are derived based on the CWB NFS model forecasts, and the BES interpolation capability has been developed. 3) a WRFVar-based observation verification package was developed; 4) more types of observations, QuickSCAT, AWS, Dropsonde, GPSRO bufr data, and CWB GPSPW data, can now be ingested into the WRFVar assimilation system; 5) the WRFVar FGAT technique has been tested; 6) one-month of CWB GPS PW measurements were processed, and their impact on the forecasting of Typhoon Haitang assessed. For further enhancement of the data assimilation system in CWB, including performing CWB WRFVar pre-operational tests, technical support or WRFVar

operation, training on ground-based GPS PW processing software, and exploration of ensemble Kalman filter (EnKF) data assimilation on a selected case, the following tasks will be completed by the CWB and UCAR joint efforts in the year of 2007.

2.0 - Task Descriptions

In terms of the overall program schedule, the following four tasks have been identified as being critical during the January 1 to December 31, 2007, time period. These are listed below, along with the estimated proportion of resources that is to be allocated to each task.

- Task #1 – Support and enhancement of the WRFVar system for TECRO's designated representative, CWB, operation (35%)
- Task #2 – Exploration of the WRF-based Ensemble Kalman Filter (EnKF) data assimilation (45%)
- Task #3 – Training on Ground-based GPS PW data processing (10%)
- Task #4 – Continued interaction on WRF data assimilation systems (10%)

These four tasks are described in more detail below.

Task #1 – Support and enhancement of the WRFVar system for CWB operation

During the year 2006, some of the new techniques on WRFVar background error statistics (BES) estimates, and new observation pre-processors for asynoptic data, such as QuikSCAT, AWS, BUFR format COSMIC GPS radio occultation data (GPSRO), were developed. An innovative technique, FGAT (first guess at appropriate time) in WRFVar, to account for these asynoptic data, has been tested for Typhoon Hailang. Although all of these new developments have been delivered to CWB, they have not been fully implemented in the CWB operational WRFVar system. In 2007, UCAR staff will work with CWB staff to implement these new developments in the WRFVar system for operational use.

a) Design the WRFVar operational configuration

   The CWB's operational NWP system will be migrated to WRF and WRFVar starting in July 2007. This will be based on Version 2.1 of WRF and WRFVar. In order to ensure smooth transition from the current modeling system to the WRF-based system, extensive testing is needed during pre-operational testing. Technical support and consultation is also needed once the WRF-based system becomes operational. As a first step, AIT's designated representative, UCAR, and TECRO's designated representative, CWB, will need to finalize the system configuration for the WRF-based NWP system. CWB will provide the domain settings and UCAR will develop the namelist files and related shell scripts.

b) WRFVar/WRF testing at UCAR

To ensure the robustness of the WRF/WRFVar system for TECRO's designated representative, CWB's operation, staff of AIT's designated representative, UCAR, will perform testing for a short period of time (on the order of two weeks). CWB will provide the necessary FGGE observation data for the selected period. CWB staff will make decision with regards to the types of observations to be used in the CWB WRF operational system. To facilitate the testing at UCAR, CWB will provide the data, as required, for the first guess fields and lateral boundary in WRF netCDF format (maybe interpolated from CWB global forecast). UCAR staff will conduct the end-to-end WRFVar/WRF run with NCEP GFS data or from the data CWB provided in UCAR IBM (bluevista or blueice) for the selected time period.

c) TECRO's designated representative, CWB, will conduct the pre-operational tests at CWB for a longer period of time

CWB should download the namelist files, shell scripts, and all the WRFVar system codes from the UCAR-CWB web page, and then conduct the pre-operational tests for a longer period of time, such as one or two months. CWB staff should assess the test's results with WRFVar-based verification package (from the 2006 CWB project) or CWB's own verification package. CWB staff will inform UCAR staff on any troubles encountered during the pre-operational tests in a timely fashion. UCAR staff will trouble shoot WRFVar related problems in modules, OBS_FGGE_PROC, 3DVAR_OBSPROC, WRFVar and update_bc. If necessary, UCAR staff will travel to Taipei to work with CWB staff to resolve problems.

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

Performance Period:

a. develop the namelist files and shell scripts for pre-operational configuration	1/1/07 – 06/30/07
b. end-to-end tests on UCAR IBM for short period of time	04/01/07 - 06/30/07
c. post results of WRFVar/WRF tests for short period of time on web page	04/01/07 - 06/30/07
d. timely responses to solve WRFVar related problems	04/01/07 – 12/31/07

Resources Required: 35% UCAR

Deliverables:

1. namelist files and shell scripts for pre-operational configuration	06/30/07
2. Brief report on experiment results for short period of time in UCAR	12/31/07

Task #2 – Exploration of the WRF-based Ensemble Kalman Filter (EnKF) data

assimilation

In addition to the 3DVar approach of the data assimilation, CWB is interested in experimenting with other state-of-the-art techniques for data assimilation. In 2007, staff of AIT's designated representative, UCAR, will collaborate with staff of TECRO's designated representative, CWB, on the testing of a WRF-based ensemble Kalman filter (EnKF) data assimilation system for a typhoon case in the vicinity of Taiwan. In particular, we will assess the impact of COSMIC GPSRO soundings on the prediction of a typhoon case, and will compare the performance between WRF-based EnKF system and WRFVar. This work will be primarily carried out at UCAR by UCAR staff, with the active participation of the CWB staff visiting UCAR in Boulder.

a) Conduct WRF-based EnKF assimilation of COSMIC GPSRO data on a typhoon case

UCAR staff will set up the WRF-based EnKF system, and perform COSMIC GPS RO data assimilation on Typhoon ShanShan, which occurred in September 2006. UCAR will also assess the impact of COSMIC GPSRO on the prediction of this typhoon. CWB staff will provide all available data used operationally for this case. CWB staff will participate in numerical experimentation and analysis of the results.

b) Comparison between WRFVar and WRF-based EnKF

In order to have an assessment on the advantages and disadvantages of the EnKF system, it would be desirable to perform WRFVar assimilation of the same case, using the same observational data. UCAR and CWB staff will collaborate on the assimilation of COSMIC GPSRO data using the WRFVar system, and compare its performance with the WRF-based EnKF system. We will examine the performance in terms of track error, intensity errors, and the impact of COSMIC GPSRO data.

c) Training on WRF-based EnKF data assimilation system

UCAR staff will provide basic training on the WRF-based EnKF system to CWB staff visiting UCAR. UCAR staff will provide the EnKF code and running shell scripts to CWB staff. UCAR staff will provide assistance and technical consultation needed to ensure CWB staff can run the WRF-based EnKF system on the UCAR computing facility. UCAR staff will transfer all the necessary codes and running shells to CWB and help CWB staff establish the ability to run the WRF-based EnKF at the CWB computing facility. The EnKF system will be provided as it is run on the UCAR computing facility. CWB staff will be responsible for necessary software modifications and required computing libraries for the EnKF system in order to run on the CWB computing facility.

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

Performance Period:

a) perform WRF-based EnKF assimilation of COSMIC GPSRO data on Typhoon ShanShan	1/1/07 – 12/31/07
b) perform WRFVar assimilation of COSMIC GPSRO data on Typhoon ShanShan	1/1/07 – 12/31/07
c) conduct comparison of WRFVar and EnKF data assimilation	1/1/07 – 12/31/07
d) training of CWB staff on WRF-based EnKF system	1/1/07 – 12/31/07

Resources Required: 45% UCAR

Deliverables:

1. EnKF code and run shell scripts	12/31/07
2. Report of the comparison study between WRFVar and EnKF	12/31/07

Task #3 – Training on Ground-based GPS PW data processing (10%)

TECRO's designated representative, CWB, currently operates a network of around 80 ground-based GPS receivers. These receivers can potentially provide real-time precipitable water (PW) monitoring, which is important for short-range weather prediction. CWB is interested in establishing the capability to process data from the CWB ground-based GPS network for PW retrieval. Staff of AIT's designated representative, UCAR, Dr. John Braun, will travel to Taiwan for the period of one week, and provide training on GPS PW retrieval. CWB is responsible for (i) obtaining the necessary third party software (e.g., Bernese 5.0), (ii) providing the necessary computing facility, (iii) providing the ground-based GPS data from the CWB network. UCAR staff will provide necessary software developed by UCAR and the training on GPS PW retrieval.

Performance Period:

a) Training of GPS PW retrieval (not to exceed one week)	1/1/07 – 12/31/07

Resources Required: 10% UCAR

Deliverables:

1. UCAR software on GPS PW retrieval	12/31/07

Task #4 – Continued interaction on WRF data assimilation systems

Because the tasks proposed for 2007 require close collaboration between the staffs of AIT's designated representative, UCAR, and TECRO's designated representative, CWB, the exchange of information and progress between CWB and UCAR in a timely manner is crucial. Effective and efficient communication methods, such as the web pages for the project, the data transfer "ftp" command etc. must be established and updated on a timely and regular basis. The exchange visits between CWB and UCAR staff are also necessary to ensure the smooth execution of this collaboration. The following work should be included:

a) Update and improve the CWB project web pages on both the CWB and the UCAR sides

The CWB project web page was setup at both UCAR and CWB in 2005. With these web pages, the updated version of the 3D-Var system, experimental results, and progress reports, etc. are easily exchanged between the two groups. In 2007, we will continue to maintain, improve, and conduct timely updates of the web pages to keep CWB staff informed on current developments.

b) Site visit to CWB

To ensure smooth execution of the project, it is desirable for UCAR staff to visit CWB. Such visits would be highly valuable to solve technical problems, and report on the progress of the project.

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

Performance Period:
1. Updated CWB project web pages on both CWB and UCAR sides   1/1/07 – 12/31/07
2. Site visit to CWB   4/1/07 - 12/31/07
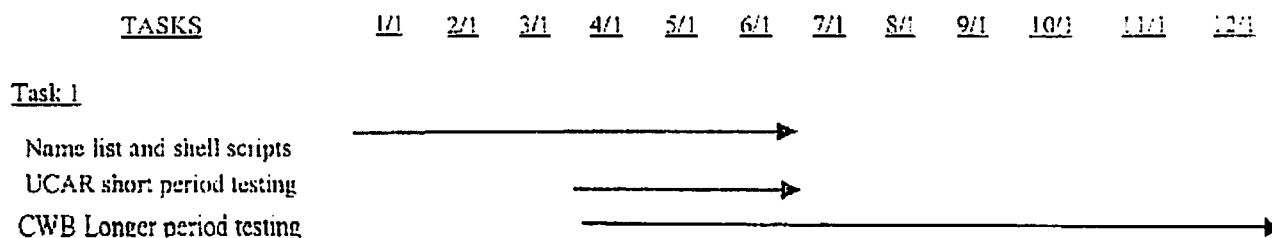
Resources Required: 10% UCAR

Deliverables:
1. Updated web page for project   12/31/07
2. Site visits   12/31/07
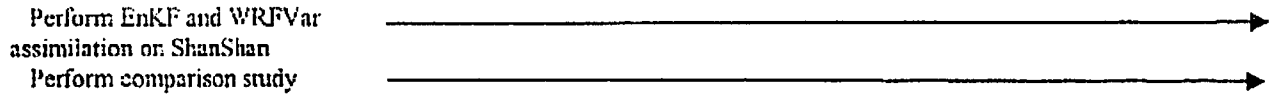
3.0 - Schedule

Functions	Milestones
1. Support and enhancement of the WRFVar system for CWB operation	12/07
2. Exploration of the WRF-based Ensemble Kalman Filter (EnKF) data assimilation	12/07
3. Training on Ground-based GPS PW data processing	12/07
4. Continued interaction on WRF data assimilation system	12/07

Schedule by Month

TASKS	1/1	2/1	3/1	4/1	5/1	6/1	7/1	8/1	9/1	10/1	11/1	12/1

Task 1

Name list and shell scripts

UCAR short period testing

CWB Longer period testing

Task 2

Perform EnKF and WRFVar
assimilation on ShanShan
   Perform comparison study

Task 3

   Training on GPS PW retrieval

Task 4

  Update web sites/ftp
  Site visit to CWB

4.0 Budget

The following are the estimated costs for Implementing Arrangement Number 3.

Tasks	Personnel	Travel/Training	Total
Task #1	$ 40,000	$ 3,000	$ 43,000
Task #2	$ 48,000	$ 3,000	$ 51,000
Task #3	$ 13,000		$ 13,000
Task #4	$ 13,000		$ 13,000
Total	$ 114,000	$ 6,000	$ 120,000

As stated in the Implementing Arrangement Number 3, the funds available from
TECRO's designated representative, CWB, to support the tasks, traveling and meeting
expenses described in this Statement of Work, will be a total of US $120,000. All budget
figures are estimates. Actual amounts will be accrued for purposes of fulfilling the
financial arrangements described in the Implementing Arrangement, in accordance with
the terms of the Agreement.

5.0 CWB Joint Team Assignments at UCAR

Several tasks require staff of TECRO's designated representative, CWB, in residence at
AIT's designated representative, UCAR. The primary efforts of CWB and UCAR staff
during the Implementing Arrangement Number 3 period will be directed toward
developing the WRFVar/WRF v2.1 operational system in the CWB environment,
performing WRF-based EnKF and WRFVar data assimilations on Typhoon ShanShan,
and performing comparisons between the two systems. The efforts of the CWB and the
UCAR staff will be directed toward the training on ground-based GPS PW retrieval
software. Specific assignments will be made to most efficiently use the available
personnel resources. Assignments for the CWB staff members would be as follows:

- Testing of the CWB operational WRFVar/WRF v2.1 system for a longer period of time
- Providing the necessary datasets to UCAR
- Participating in WRFVar and WRF-based EnKF data assimilation experiments and results analysis
- Accepting training on GPS PW retrieval