

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 TAIPEI ECONOMIC AND CULTURAL REPRESENTATIVE OFFICE IN THE UNITED STATES AND THE AMERICAN INSTITUTE IN TAIWAN 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 Taipei Economic and Cultural Representative Office in the United States (TECRO) and the American Institute in Taiwan (AIT) for Technical Cooperation associated with the Establishment of Advanced Data Assimilation and Modeling Systems, which provides for technical cooperation between TECRO's designated representative, the Taiwan Central Weather Bureau (CWB) and AIT's designated representative, the U.S. University Corporation for Atmospheric Research (UCAR), this Statement of Work addresses tasks that will be undertaken by the joint team of personnel of TECRO's designated representative, CWB, and AIT's designated representative, UCAR. 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 TECRO's designated representative, CWB, and AIT's designated representative, UCAR), the accomplishments are 1) the WRFV ar 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 on 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 synoptic 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 synoptic data, has been tested for Typhoon Haitang. 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, TECRO's designated representative, CWB, and AIT's designated representative, UCAR, 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	04/01/07-

short period of time	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
<u>Resources Required:</u>	35% UCAR
<u>Deliverables:</u>	
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 TECRO's designated representative, CWB, will collaborate with staff of AIT's designated representative, UCAR, 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:

<u>Performance Period:</u>	
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

<u>Resources Required:</u>	45% UCAR
<u>Deliverables:</u>	
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.

<u>Performance Period:</u>	
a) Training of GPS PW retrieval (not to exceed one week)	1/1/07-12/31/07
<u>Resources Required:</u>	10% UCAR
<u>Deliverables:</u>	
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 TECRO's designated representative, CWB, and AIT's designated representative, UCAR, 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.

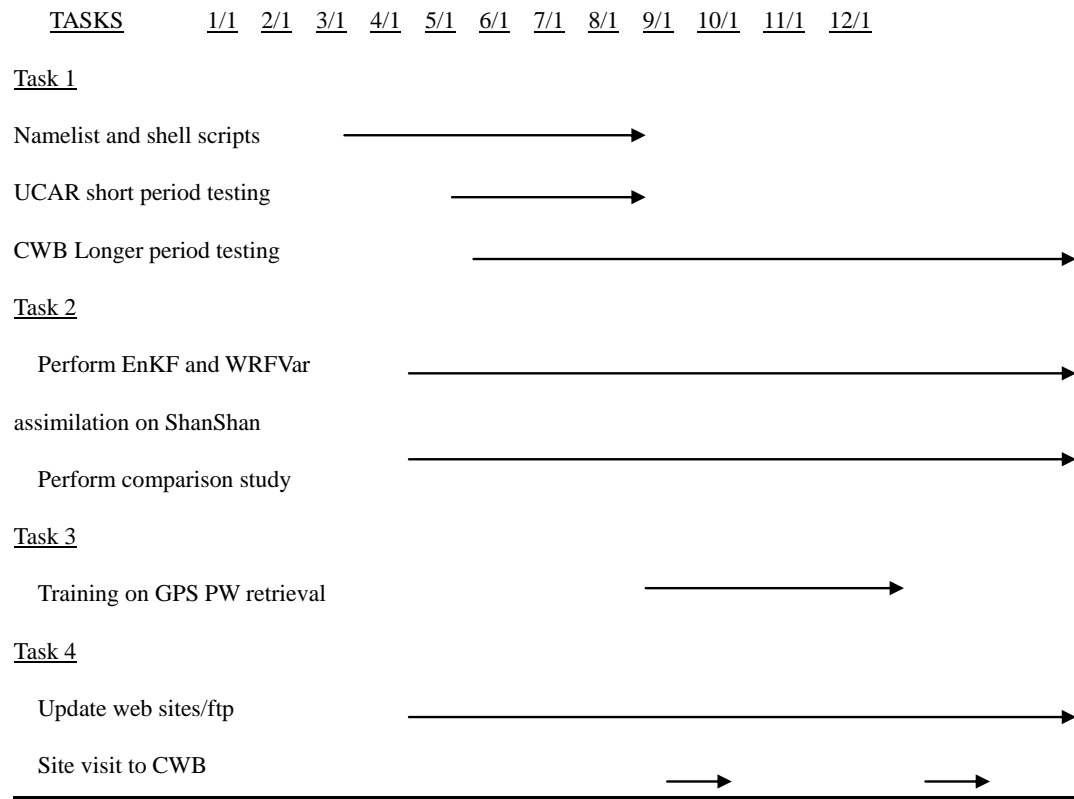
The following summarizes the schedule and resources required for Task #4:

Performance Period:	
1. Updated CWB project web pages on both CWB and UCAR sides	1/07-12/31/07
2. Site visit to CWB	4/1/07-12/31/07
<u>Resources Required:</u>	10% UCAR
<u>Deliverables:</u>	
1. Updated web page for project	12/31/07
2. Site visits	12/31/07

3.0-Schedule

<u>Functions</u>	<u>Milestones</u>
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 甘梯圖



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