

# **STATEMENT OF WORK**

## **FOR IMPLEMENTING ARRANGEMENT NO. 2 CONSULTANCY SERVICES FOR THE OPERATIONAL IMPLEMENTATION OF THE WRF-VAR SYSTEM AND TYPHOON DATA ASSIMILATION SUBJECT TO THE AGREEMENT BETWEEN THE AMERICAN INSTITUTE IN TAIWAN AND THE TAIPEI ECONOMIC AND CULTURAL REPRESENTATIVE OFFICE IN THE UNITED STATES**

### **1.0 - Background and Objectives**

This Statement of Work addresses tasks that will be undertaken by the joint team of UCAR and CWB personnel in accordance with the terms of Implementing Arrangement No. 2 (IA#2) 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 University Corporation for Atmospheric Research (UCAR), and TECRO's designated representative, the Taiwan Central Weather Bureau (CWB). The technical work at UCAR will be performed by the UCAR COSMIC Project Office and the Mesoscale and Microscale Meteorology Division of the National Center for Atmospheric Research (NCAR/MMM). The two designated representatives have cooperated on the development of data assimilation systems.

With the accomplishments of the CWB-UCAR 2005 collaborative project (through joint efforts between NCAR/MMM and CWB staff), the WRF-Var system has been delivered to CWB from NCAR/MMM, and is running successfully in the CWB environment. The retrospective runs over a 45-km resolution CWB domain have been completed by CWB for two periods (winter month: January 2005, and summer months: August to September 2005) with the WRF-Var and the CWB NFS (Non-hydrostatic Forecast System) model, using CWB observations on CWB PC Linux cluster (WRF-Var) and VPP5000 (NFS model). Three days, 6-hourly cycling data assimilation experiments on the Typhoon Dujuan case over a 45-km resolution CWB domain have been completed by NCAR/MMM. The GPS radio occultation (RO) data from the CHAMP mission are also included in these 3D-Var assimilation experiments. For the purposes of the operational implementation of the WRF-Var system on CWB's new IBM computer system and further enhancement of the WRF-Var system, especially for typhoon forecast, the following three tasks will be completed by the CWB and NCAR/MMM joint efforts in the year of 2006.

### **2.0 - Task Descriptions**

In terms of the overall program schedule, the following three tasks have been identified as being critical during the January 1 to December 31, 2006, time period. These are listed below, along with the estimated proportion of resources that are to be allocated to each task.

- Task #1 – Establishing a WRF-Var/NFS operational system on CWB's newly procured computer (50%)
- Task #2 – Enhancement of the WRF-Var system (40%)
- Task #3 – Continued interaction on the WRF-Var system (10%)

These three tasks are described in more detail below.

#### **Task #1 – Establishing a WRF-Var/NFS Operational System on CWB's Newly Procured Computer**

During the year of 2005, CWB completed the retrospective runs for two periods (winter month: January 2005, and summer months: August to September 2005) with the WRF-Var and the CWB NFS (Non-hydrostatic Forecast System) model, using CWB observations on CWB PC Linux cluster (WRF-Var) and VPP5000 (NFS model). NCAR/MMM has completed three days, 6-hourly cycling data assimilation experiments on the Typhoon Dujuan case with WRF-Var and WRF model on PC Linux and NCAR's IBM machine. In general, the use of the WRF-Var system has resulted in a positive impact on the forecasts. CWB has recently purchased a new IBM computer. By July 2006, all of the current operational NWP systems should be migrated to the IBM. To achieve this goal, several improvements need to be made on the WRF-Var/NFS semi-operational system on CWB's newly procured computer. They are described below:

- a) Successfully compile all of the system codes, and improve the efficiency to meet the operational requirement.

The WRF-Var/NFS data assimilation and modeling system include many components. All of the codes including the decoder programs, OBS preprocessor, WRF-Var, and NFS model, should be ported to the CWB's new IBM computer system. First, CWB staff (with the assistance of IBM staff) should ensure all the codes can be compiled successfully, and NCAR/MMM will provide advice during this process. Second, CWB staff should ensure the WRF-Var/NFS system on the new computer produces the same results as that from the old computer system; and, NCAR/MMM will help to debug the problems, if any. Third, CWB software engineers will improve the computing efficiency to meet the operational requirements; and, NCAR/MMM will provide technical consultation, as needed.

- b) Increase of the WRF-Var/NFS model resolution to 15-km for improving the skill of typhoon forecasts.

In 2005, we used the WRF-Var system at 45-km resolution for typhoon data assimilation experiments. This is not optimal for typhoon forecasts. It is desirable to establish a WRF-Var/NFS model system at 15-km resolution. Several sub-tasks need to be performed. First, the 45-km/15-km WRF-Var/NFS model cycling runs should be setup based on the CWB domain settings. Second, both 45-km and 15-km 3D-Var analyses should be performed using the same background error statistics (BES) as before (NCEP global BES, cv\_options=3). A comparison should be made between 15-km results with those from the 45-km model. Third, both 45-km and 15-km 3D-Var analyses should be performed using the newly derived 45-km and 15-km BES (cv\_options=5). Experiments should be performed to assess the impact of analysis resolution (45 km vs. 15 km) on both the intensity and track forecasts for a typhoon. This work will be done jointly by CWB and NCAR/MMM staff.

- c) Derivation of the new background error statistics (cv\_options=5) based on the CWB NFS forecast data.
  - i) A complete set of new background error statistics including winter and summer months, and at both 45-km and 15-km resolution, will be derived based on the CWB NFS forecast

datasets. This work will be done jointly by NCAR/MMM and CWB staff. They will perform cross-check for their results, and CWB staff will be trained at NCAR/MMM for the use of the wrfvar/gen\_be code.

- ii) Improve the WRF-Var code to the (cv\_options=5) BES for a different domain (the domain setting is different from the domain over which the BES was derived). NCAR/MMM staff will have the responsibility for the development of this code, and provide a testing report.
  - iii) Conduct the subjective tuning of the BES, based on the single observation tests. A selected period of analysis/forecast experiments will be conducted to examine the tuning effects. CWB staff will work together with NCAR/MMM staff on this task.
  - iv) Develop the objective BES and observation error statistics (OES) tuning technique. NCAR/MMM staff will develop the code for certain objective tuning techniques, such as variational tuning, and provide the code to CWB for further testing.
- d) Develop the WRF-Var-based observation verification package.

To evaluate the performance of the WRF-Var/NFS model, an appropriate verification package should be developed, in addition to verification against analysis. We propose to develop a WRF-Var-based observation verification package. This will include the following tasks: i) to generate the quality controlled observation datasets (QCed OBS); ii) to split the WRF forecast files to be single time forecast files; iii) to run wrfvar code to get the (O-B) files; and iv) to calculate and plot the bias and RMS errors. This work will be mainly performed by NCAR/MMM staff.

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

Performance Period:

|   |                   |
|---|-------------------|
| a) Compile all the system codes and improve efficiency        | 1/1/06 – 7/31/06  |
| b) Increase of the WRF-Var/NFS model resolution to 15-km      | 1/1/06 – 06/30/06 |
| c) Derivation of the new background error statistics          | 1/1/06 – 12/31/06 |
| d) Develop the WRF-Var-based observation verification package | 1/1/06 – 12/31/06 |

Resources Required:

50%

Deliverables:

|  |          |
|--|----------|
| 1. Shell scripts and 15-km experiment results                          | 06/30/06 |
| 2. Newly derived BES files for 45-km/15-km resolution                  | 07/31/06 |
| 3. Updated wrfvar code for cv_options=5 BES                            | 12/31/06 |
| 4. Report of the tuning BES experiments                                | 12/31/06 |
| 5. Objective BES and OES tuning code                                   | 12/31/06 |
| 6. The code and shell script for wrfvar-based obs verification package | 06/30/06 |

## Task #2 – Enhancement of the WRF-Var System

Even though the WRF-Var system can be operated in the CWB operational environment, the system needs to be enhanced to improve its performance. The following three sub-tasks will be performed:

a) assimilation of more types of observations; b) test the WRF-Var FGAT technique with asynoptic observations; and c) assimilation of ground-based GPS PW data. They are described as the following:

- a) Assimilation of more observations, such as QuikSCAT, AWS, and GPS RO data in BUFR format.
  - i) CWB has already received the QuikSCAT (NASA Quik Scatterometer) sea surface wind in its operational database, and the WRF-Var system has the capability of assimilating the QuikSCAT Level 2B data. NCAR/MMM staff will conduct the test run with the CWB QuikSCAT data, and provide a report of the preliminary results.
  - ii) CWB will collect the AWS (Automatic Weather Station) data over the Taiwan area. CWB and NCAR/MMM staff will work together to assimilate these high temporary resolution data in the 6-h cycling WRF-Var/WRF model runs, and give a report of the experiment results.
  - iii) Although the WRF-Var system can assimilate the GPS RO data (wetPrf) downloaded from COSMIC/CDAAC, it is in the netCDF format, not a standard WMO observation format --- BUFR. As an operational system, we must make the WRF-Var system ingest the GPS RO BUFR-format data. NCAR/MMM will develop the decoder program for GPS RO BUFR data for use with the WRF-Var system.
- b) Test the WRF-Var FGAT technique with asynoptic observations.

Several types of observations are of high temporary resolution, and are available outside the synoptic observation time of 0000 or 1200 UTC. For these observations, the FGAT technique can partly account for the difference between the analysis time and observation time. NCAR/MMM staff will test the FGAT technique with CWB data and give a report of the preliminary results.

- c) Assimilation of ground-based GPS PW data.

Currently, CWB operates 16 ground-based GPS stations where surface meteorological observations are available. It is desirable to perform assimilation of ground-based GPS precipitable water (PW) from these 16 GPS stations and assess its potential value in local weather analysis and prediction as a demonstration project. There are three sub-tasks needed for this task:

- i) Selection of case.

We intend to select a typhoon case that took place in 2005. Most likely, the Hai-Tung Typhoon case will be chosen. The decision will be made jointly between CWB and NCAR/MMM.

- ii) Collection and processing of ground-based GPS data.

CWB will provide the ground-based GPS data, along with the surface meteorological

observations, for the selected case to NCAR/MMM. The UCAR COSMIC Project Office will process these data for GPS PW retrieval, using the existing UCAR retrieval software.

iii) Assimilation of ground-based GPS PW data.

Data assimilation experiments will be performed with and without the ground-based GPS PW data at both 45-km and 15-km. The impact of GPS PW data on local weather analysis and prediction will be assessed.

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

Performance Period:

- |  |                   |
|--|-------------------|
| a) Assimilation of more observations                           | 1/1/06 – 07/31/06 |
| b) Test the WRF-Var FGAT technique with asynoptic observations | 1/1/06 – 12/31/06 |
| c) Assimilation of ground-based GPS PW data                    | 1/1/06 – 12/31/06 |

Resources Required:

40% NCAR/MMM

Deliverables:

- |  |          |
|--|----------|
| 1. Obs preprocessor for QuikSCAT, AWS, and GPS RO BUFR data                | 6/30/06  |
| 2. New decoder program for GPS RO BUFR data                                | 6/30/06  |
| 3. A report of assimilation of more observations                           | 7/31/06  |
| 4. A report of test the WRF-Var FGAT technique with asynoptic observations | 12/31/06 |
| 5. Processed ground-based GPS PW data                                      | 12/31/06 |
| 6. Report on the impact of ground-based GPS PW data                        | 12/31/06 |

**Task #3 – Continued interaction on WRF-Var**

Because the tasks proposed for 2006 require close collaboration between the CWB and NCAR/MMM staff, the exchange of information and processes between CWB and NCAR/MMM 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. Of course, the site visits to CWB by NCAR/MMM staff are also necessary. All these are to guarantee CWB having the updated WRF-Var system, testing results, and reports from NCAR/MMM. The following work should be included:

- a) Update and improve the CWB project web pages on both CWB and NCAR/MMM sides.

The CWB project web page was setup at both NCAR/MMM and CWB in 2005. With these web pages, the updated version of the WRF-Var system, experimental results, and progress reports, etc. are easily exchanged between the two groups. In 2006 we’ll continue to maintain, improve, and timely update the web pages to keep CWB staff up-to-date on current developments.

- b) Site visit to CWB.

To ensure smooth execution of the project, it is desirable for NCAR/MMM 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 #3:

**Performance Period:**

- a) Updated CWB project web pages in both CWB and NCAR/MMM sides 1/1/06 – 12/31/06
- b) Site visit to CWB 4/1/06 - 12/31/06

**Resources Required:**

10% NCAR/MMM

**Deliverables:**

- 1. Updated web page for project 06/30/06
- 2. Site visits 12/31/06

### 3.0 Schedule

| Functions   | Milestone |
|---|-----------|
| 45/15-km WRF-Var/NFS semi-operational system on CWB's newly procured computer | 7/31/06   |
| Derivation of the new background error statistics                             | 12/31/06  |
| Develop the WRF-Var-based observation verification package                    | 12/31/06  |
| Assimilation of QuikScat, AWS, and BUFR GPS RO                                | 7/31/06   |
| WRF-Var FGAT Test   | 12/31/06  |
| Assimilation of ground-based GPS PW   | 10/31/06  |

#### Schedule by Month

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

Successfully compile all the system code. →

→

#### 45/15-km WRF-Var/NFS Exps

Derivation of new BES →

WRF-Var-based verification →

#### Task 2

Assimilation QuikScat,  
AWS, and BUFR GPS  
RO



Test WRF-Var FGAT test



Assimilation of  
ground-based GPS PW



### **Task 3**

Update NCAR/CWB Web  
pages



Site visit to CWB



## **4.0 Budget**

The following are the estimated costs for Implementing Arrangement No. 2:

| Tasks   | Personnel  | Travel/Training | Total      |
|---------|------------|-----------------|------------|
| Task #1 | \$ 75,000  |                 | \$ 75,000  |
| Task #2 | \$ 60,000  |                 | \$ 60,000  |
| Task #3 | \$ 9,000   | \$ 6,000        | \$ 15,000  |
| Total   | \$ 144,000 | \$ 6,000        | \$ 150,000 |

## **5.0 CWB Joint Team Assignments at NCAR/MMM**

Several tasks require CWB staff to be in residence at NCAR/MMM. The primary effort of CWB staff at NCAR/MMM during the Implementing Arrangement No. 2 period, will be directed toward developing the semi-operational system with WRF-Var in the CWB environment. It is important that one CWB staff member be available to work at NCAR/MMM facilities during this period. Specific assignments will be made to most efficiently use the available personnel resources. Assignments for the CWB staff member(s) will be as follows:

- Implement the WRF-Var/NFS system in CWB computer environment;
- Conduct the related experiments at CWB; and
- Provide the necessary dataset to NCAR/MMM.