STATEMENT OF WORK "A" FOR IMPLEMENTING ARRANGEMENT #9 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

1. Task #1 – Support for the WRFDA Component of the CWB Operational System and Improvement of the Performance of WRFDA

During the year 2011, TECRO's designated representative, the Central Weather Bureau (CWB), implemented OP23, which included WRFDA V3.2.1/WRF V3.1.1, and WPS V3.2.1, in the CWB operational environment. In 2012, the staff of AIT's designated representative, the University Corporation for Atmospheric Research (UCAR), will work closely with CWB staff to upgrade the CWB operational system to OP24, which will include WRFDA V3.3.1/WRF V3.3.1 and WPS V3.3.1, and will continue to provide technical support to CWB on the WRFDA component of the CWB operational system.

1.1 Support for the WRFVar component of CWB operational system (UCAR: 0.20 FTE)

TECRO's designated representative, CWB, will inform AIT's designated representative, UCAR, in a timely fashion (via e-mail or teleconferences) of any WRFDA problems encountered during operation. UCAR will troubleshoot WRFDA-related problems in modules OBS_FGGE_PROC, 3DVAR_OBSPROC, WRFDA and update_bc. UCAR will provide technical consultation, and work with CWB to keep all of the codes synchronized between UCAR and CWB. UCAR will continue to provide training to CWB with regard to basic theory in variational data assimilation and the code structure of WRFDA.

1.2 Upgrade FSO utility in WRFDA and staff training for CWB (UCAR: 0.10 FTE)

In 2011, AIT's designated representative, UCAR, finished development of the utility of Forecast error Sensitivity to Observations (FSO) and coupled the FSO with the CWB OP23 system. In 2012, UCAR will continue to upgrade the FSO capability and provide training to TECRO's designated representative, CWB.

1.2.1 Upgrade of FSO utility in WRFDA

In the CWB operation system, the new analysis produced by WRFDA will be used to update lateral boundary conditions (LBCs) (by da_update_bc) before making the forecast. In WRF FSO applications, the adjoint model takes the forecast error gradient as input at the verification time, integrates backward in time to the analysis time, and produces the forecast error gradient with respect to the initial condition (IC) and the forecast error gradient with respect to LBC. The adjoint of update_bc is needed to combine the two forecast error gradients together to form the input gradient to the adjoint of analysis. In the current WRFDA FSO applications, the adjoint of update_bc is missing and the gradient information due to the update_bc is ignored. In 2012, AIT's designated representative, UCAR, will develop the adjoint of da_update_bc to improve the accuracy of FSO utility in WRFDA employed by TECRO's designated representative, CWB.

For limited–area forecast models the forecast errors not only come from the IC, but also come from the lateral boundary condition (LBC). So, for limited-area model FSO applications, the derived forecast error gradient with respect to LBC gives us the opportunity to improve the LBC forecast strategy. TECRO's designated representative, CWB, in collaboration with, AIT's designated representative, UCAR, will investigate the optimized LBC strategy for the CWB OP24 system, such as the update_bc strategy and LBC frequency.

1.2.2 Training of CWB Staff

AIT's designated representative, UCAR, will provide training and technical consultation to TECRO's designated representative, CWB, on FSO applications as needed.

1.3 Development and testing of hybrid variational/ensemble data assimilation (UCAR: 0.50 FTE)

TECRO's designated representative, CWB, is currently running the WRFDA-3DVAR operationally and has also implemented the WRF/DART system in research mode. In the WRFDA system, there is another option named "hybrid", which runs a 3DVAR minimization but with the additional input of ensemble perturbations to take into account flow-dependent background error covariance, i.e., "the error of day". In 2012, AIT's designated representative, UCAR, will:

1.3.1 Couple the DART ensembles to the WRFDA-hybrid

In principal, WRFDA-hybrid can make use of ensemble information from any source. Because TECRO's designated representative, CWB, has implemented the WRF/DART ensemble data assimilation system, it is natural to adopt the DART ensembles as the input of WRFDA-hybrid for the first implementation of the hybrid data assimilation system. Two schemes for coupling will be considered: one-way coupling of DART to WRFDA and two-way coupling between DART and WRFDA. In the one-way coupling scheme, ensemble perturbations from the DART analyses will provide input to the WRFDA-hybrid but receive no feedback from the WRFDA analysis to the DART. In the two-way coupling scheme, WRFDA-hybrid analysis will provide feedback to the DART analysis, i.e., the mean fields of the DART ensemble analyses will be replaced by the WRFDA-hybrid analysis while keeping the DART ensemble perturbations unchanged.

1.3.2 Provide training on the WRFDA-hybrid for the CWB visitor

TECRO's designated representative, CWB, will send a visitor to AIT's designated representative, UCAR, to learn and test the WRFDA-hybrid data assimilation technique. UCAR will deliver the corresponding software and provide necessary training to the CWB visitor. UCAR will work with CWB to set up the hybrid test case on the CWB machine. If needed, UCAR staff will visit CWB and present a tutorial lecture.

1.3.3 Conduct hybrid data assimilation (DA) experiments and evaluate impact by comparing to 3DVAR and DART

AIT's designated representative, UCAR, will run several experiments over the CWB 45km domain. Hybrid experiments will be developed based upon current CWB TWRF/3DVAR operational configuration, including Typhoon relocation and bogus data assimilation in a 12-hour partial cycling framework. The benchmark DART experiment will be performed in close collaboration with the DART team. Hybrid experiments will include both one-way and two-way schemes. The sensitivity to ensemble

size in the hybrid may be also evaluated. The performance on typhoon track and intensity will be assessed based on results from these hybrid data assimilation experiments.

1.4 Improve the WRFDA Background Error Covariance Matrix (UCAR: 0.25 FTE)

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

In 2011, AIT's designated representative, UCAR, reviewed the Japanese Geographical Survey Institute (GSI) and WRFDA CV3 implementation, and developed the flowchart for both of the related parts of the codes. In the setup stage, the detailed differences of balance regression coefficients between GSI and CV3 have been understood. In 2012, UCAR will:

- Further investigate the implementation of horizontal and vertical recursive filter and normalized standard deviation in setup stage; 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.

UCAR will provide a complete report on this work to TECRO's designated representative, CWB.

Finally, UCAR will develop an additional BE option in WRFDA to mimic the GSI BE implementation.

1.4.2 Help WRFDA CV6 BE tuning for TWRF

There are two major considerations in WRFDA CV6 BE: latitude-dependent statistics and more multivariate correlations. To understand the impact of these two parts on the analysis and to improve the typhoon forecasts with TWRF, AIT's designated representative, UCAR, will:

- Carefully review the CV6 gen_be code, and generate a sample CV6 BE file for typhoon Morakot (2009080312Z to 2009080712Z). The code and file will be provided to TECRO's designated representative, CWB, for the correctness crosscheck of the code and scripts;
- Conduct the single ob tests with CV6 BE; and
- Use the current TWRF CV5 BE single ob tests as the benchmark to tune the standard deviation and horizontal length-scales for CV6 BE.

From this work, UCAR will provide the suggested tuning factors to TECRO's designated representative, CWB, for TWRF forecast. CWB will conduct experiments for more typhoon cases and provide UCAR with feedback.

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

Performance Period:

a.	Provide support for WRFDA	01/01/12 – 11/30/12
b.	Upgrade FSO and CWB staff training	01/01/12 – 11/30/12
c.	Development and testing of hybrid variational/ensemble data assimilation	01/01/12 – 11/30/12
d.	Improve WRFDA background error covariance matrix	01/01/12 – 11/30/12

Resources Required: 1.05 FTE UCAR staff

Deliverables:

1.	A report summarizing all of the supporting activities in 2012	11/30/12
2.	The upgraded scripts and adjoint code of da_update_bc	11/30/12
3.	A report summarizing the results of from the upgraded FSO system	11/30/12
4.	WRFDA-hybrid software, including scripts to couple the DART and WRFDA	11/30/12
5.	A report summarizing the hybrid results and recommendations for future improvements	11/30/12
6.	WRFDA BE code to mimic the GSI BE implementation	11/30/12
7.	A report about the GSI BE and WRFDA CV3 BE implementation	11/30/12
8.	Suggested tuning factors for WRFDA CV6 BE	11/30/12

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

In 2011, AIT's designated representative, UCAR, found that the WRF/DART system provides better ensemble forecasts of Typhoon Morakot (2009) as compared to the full and partial cycling 3DVAR system. The DART system also shows positive impact from assimilation of RO data in reducing the forecast track errors of Typhoon Morakot. In addition, the performance of the WRF/DART system is comparable to the 3DVAR system over the Western Pacific Ocean when verified against marine surface pressure and satellite thickness observations.

In 2012, the goal of the proposed DART tasks is to further improve the performance of the WRF/DART system, particularly over the radiosonde dense continental areas, and to make the performance of the DART system comparable or competitive with the 3DVAR system in terms of two-week and domain-averaged statistics. These improvements on WRF/DART are necessary before it can be considered for operational application at TECRO's designated representative, CWB. In fact, the advantages of the WRF/DART ensemble system, particularly running in a partial cycling mode, are in the analysis and prediction of extreme high impact weather events, whereas 3DVAR systems may or may not work well because the background error covariance is not flow dependent.

2.1 Improving WRF/DART (UCAR: 0.3 FTE)

2.1.1 Use of stochastic kinetic energy backscatter scheme in WRF/DART

AIT's designated representative, UCAR, will apply the newly developed stochastic kinetic energy backscatter (BS) scheme in WRF/DART data assimilation. UCAR will test and tune the scheme and the related DART parameters for optimal performance. The DART analyses and 6-hour forecasts with and without the use of the BS scheme will be verified against observations for two two-week periods, one in summer and the other in winter. The tuned parameters of the scheme and DART will be delivered to TECRO's designated representative, CWB. CWB will evaluate the benefits of using the scheme for typhoon forecasts.

2.1.2 Tuning of localization parameters over radiosonde dense area

AIT's designated representative, UCAR, will fine-tune the DART localization parameters over the radiosonde-dense continental area. The analyses and 6-hour forecasts will be examined against observations for a two-week summer period. A new set of DART parameters will be delivered to TECRO's designated representative, CWB.

2.1.3 Technical support for the assimilation of EC bogus data

TECRO's designated representative, CWB, will test the assimilation of EC bogus data with WRF/DART and evaluate the benefits of assimilation of these data for a two-week period against real observations and EC analyses. AIT's designated representative, UCAR, will assist CWB to implement the new observation types into DART and to learn the details about observation processing procedures. CWB will examine the impact of various observation types.

When there is time and resources available, CWB may evaluate the performance of WRF/DART running in a "partial cycling" mode. In such mode, the NCEP GFS analyses will be used to replace the WRF/DART ensemble mean analyses periodically (e.g., every 12 hours). This new procedure should suppress the growth of the WRF model forecast biases and maintain the validity of the flow-dependent ensemble forecast error covariance, and improve the performance of the WRF/DART system. UCAR will collaborate with CWB on this effort and provide technical support as needed. CWB will evaluate the impact of the partial cycling for a two-week period. It is understood that this task is optional and will be carried out only when time and resources are available.

2.2 Support for developing a hybrid DART/3DVAR system (UCAR: 0.05 FTE)

In support of the development of a 3D-Var ensemble hybrid data assimilation system, AIT's designated representative, UCAR, will provide technical consultation to the NCAR WRFVAR team. UCAR will also make parallel data assimilation experiments for comparison with the hybrid system.

2.3 Evaluation of the stochastic kinetic energy backscatter (BS) scheme on ensemble prediction system (UCAR: 0.35 FTE)

The current CWB ensemble prediction system (EPS) consists of 20 members, with a mixture of perturbed initial condition and physics options. In 2012, TECRO's designated representative, CWB, and AIT's designated representative, UCAR, will collaborate to assess and improve the performance of the CWB EPS system. CWB and UCAR will work together to compare the performance of the EPS system with mixed physics options versus the BS scheme. CWB and UCAR will test and tune the BS scheme for its application in CWB EPS.

2.3.1 Performance inter-comparison between the operational CWB EPS and BS scheme (UCAR: 0.05 FTE)

For this task, TECRO's designated representative, CWB, will conduct two-week to month-long forecast experiments during the Meiyu season with the current mixed physics options, the BS scheme itself, and the combined mixed physics option with BS scheme (total of three sets of experiments). CWB will compare the performance of these three experiments in terms of mean errors and ensemble spread. AIT's designated representative, UCAR, will provide technical consultation on the use of stochastic BS scheme, and assist in the evaluation and interpretation of the results.

2.3.2 Evaluation of the BS scheme on typhoon track forecast (UCAR: 0.3 FTE)

For this task, AIT's designated representative, UCAR, will perform ensemble forecast experiments for a typhoon case jointly selected by TECRO's designated representative, CWB, and UCAR using configuration similar to that of the CWB EPS. Three sets of experiments will be performed. The first will use mixed physics options, the second will use the BS scheme by itself, and the third will use the combined mixed physics options and BS scheme. UCAR will test and tune the BS scheme for its application for typhoon prediction, and evaluate the performance of these three experiments in terms of

ensemble mean errors and ensemble spread. It is anticipated that these experiments will be performed using the 45-km grid of the CWB operational configuration.

2.4 Support of WRF/DART test at CWB (UCAR: 0.15 FTE)

AIT's designated representative, UCAR, (specifically staff member Dr. Hui Liu) will provide prompt technical consultation and support to TECRO's designated representative, CWB, on the use of WRF/DART system at CWB. Dr. Liu will visit and conduct WRF/DART training at CWB.

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

Performance Period:	
a. Examine the benefits of the new stochastic kinetic energy BS scheme with DART and fine-tune WRF/DART localization parameters	01/1/12 – 11/30/12
b. Test the benefits of adding EC bogus data; evaluate impact of various observation types	01/1/12 – 11/30/12
c. Support of the development of the hybrid system	01/1/12 – 11/30/12
d. Evaluation of the BS scheme on ensemble prediction of typhoon forecast	01/1/12 – 11/30/12
e. Provide support and training for WRF/DART at CWB	01/1/12– 11/30/12
Resources Required:	0.85 FTE UCAR staff

Deliverables:	
1. An improved version of WRF/DART code and namelists	11/30/12
2. Report on the results of WRF/DART improvements from use of the BS scheme and the EC bogus data	11/30/12
3. Report on the results of the BS scheme on ensemble prediction of a typhoon case	11/30/12
4. Training materials for WRF/DART	11/30/12

3. 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 approximately 70 GPS stations in Taiwan. The system includes jobs that analyze data in hourly, two-hourly, and daily batches. In addition, data from surface meteorology stations in Taiwan are used to compute surface pressure and temperature values at 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). Significant accomplishments from 2011 related to this task include an adjustment in reference station data in response to the Great Tohoku earthquake in Japan, the transition to the IGS08 reference frame, and the completion of a scientific manuscript summarizing a diurnal variability in PW observed with cGPS stations around Taiwan. For 2012, UCAR proposes continued analysis of CWB cGPS data, a study to evaluate the timing and correlation of the diurnal variability in PW and rainfall, and a trip to Taiwan and CWB to investigate the use of slantwise delay observations for high-resolution nowcasting and forecasting applications. 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 applications. 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;
- UCAR will implement a new method to compute zenith delay and PW uncertainty measurements in the hourly and two-hour processing systems based upon a sliding window method that combines delay and PW estimates from multiple sub-daily runs; and
- UCAR will resubmit the annual request to the Japanese Geographical Survey Institute (GSI) to continue using the cGPS stations within 500km of Taiwan for meteorological applications.

3.2 Evaluating the timing and correlation of diurnal PW variability and rainfall

In 2011, AIT's designated representative, UCAR, and TECRO's designated representative, CWB, collaboratively wrote a manuscript on the large diurnal variability in PW around Taiwan during the Meiyu, summer, and autumn rainfall seasons. UCAR will continue this investigation by evaluating the correlation and timing of this diurnal PW signal with non-synoptically forced rainfall around the island. This work will focus on the potential use in monitoring the strength of diurnal PW variability with subsequent rain events. This work will be summarized in a manuscript for publication.

3.3 Travel to Taiwan to investigate the potential application of slantwise delay observations

Slantwise delay observations and slant water vapor observations provide enhanced monitoring of small-scale moisture variability when compared with zenith delay and PW estimates. The increased spatial and temporal resolution that slant estimates provide are important for both nowcasting applications as well as high resolution data assimilation for short term forecasting applications. A staff member of AIT's designated representative, UCAR, will travel to Taiwan in the first half of 2012 and give a presentation to CWB scientists and forecasters on the potential use and application of slant measurement for operational applications.

Table 1: Proposed Task List for 2012

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 • Implement all software updates as needed • Create new method to describe uncertainty in PW and zenith delay estimates • Resubmit request to Japanese GSI to include their cGPS stations in routine CWB analysis

Diurnal PW variability and rainfall study	• Provide rainfall data for Taiwan for 2010-2011	• Evaluate timing and correlation of diurnal PW variability and rainfall. • Manuscript describing results of investigation.
Slant delay investigation	• Arrange the visit of UCAR staff to CWB	• Trip to Taiwan to investigate and discuss potential of slant delay observations for nowcasting/forecasting applications
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 01/01/12 – 12/31/12
b. Investigation of diurnal PW variability and rainfall 01/01/12 – 12/31/12
c. Investigation of possible applications of slant delay data for CWB nowcasting/forecasting 01/01/12 – 06/30/12
d. Technical support of GPS analysis 01/01/12 – 12/31/12

Resources Required: .15 FTE UCAR staff

Deliverables:

1. New PW and delay uncertainty estimates for hourly and two hourly analysis systems 03/30/12
2. Manuscript summarizing correlation of diurnal PW variability and rainfall in Taiwan 11/30/12
3. UCAR trip to Taiwan to explore the potential benefit of slant delay observations for CWB nowcasting and forecasting applications 06/30/12

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

In 2011, substantial biases in soil temperature and moisture were discovered after the CWB HRLDAS implementation even though comparisons with local Taiwan soil observations looked positive. These biases resulted in WRF/HRLDAS simulations that were significantly warmer and drier than simulations using GFS initial conditions. The precipitation forcing used by HRLDAS (CMORPH satellite) was found to be too low, especially in winter. WRF solar radiation used in HRLDAS was found to be high relative to ERA-Interim. Toward the end of 2011, analysis was done 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 2012, the primary focus of this task is to fix these substantial biases in soil temperature and moisture through improved forcing fields, parameter tuning and improved surface coupling.

During 2012, UCAR scientists will also provide assistance and technical consultation to CWB for the further development, operational implementation, and related testing of HRLDAS.

4.1 Improve the temperature and moisture bias in HRLDAS

AIT's designated representative, UCAR, will assist in the continuing evaluation conducted by TECRO's designated representative, CWB, to compare HRLDAS output for several test cases with GFS initial conditions and Taiwan local observations. Based on the results, UCAR will provide suggestions to improve the near-surface forecast by:

Adjusting the precipitation and solar radiation forcing data (e.g., by monthly bias correction) to minimize forcing biases that directly affect soil initial conditions produced by HRLDAS;

Incorporating new forcing datasets, e.g. GLDAS radiation and precipitation, NCEP gridded gauge precipitation analysis;

Developing a systematic method of improving HRLDAS/Noah parameters (such as vegetation and soil properties);

Updating the soil texture datasets over Mainland China; and

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

4.2 Improve the temperature and moisture bias in WRF

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 several 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.

4.3 Technical support on HRLDAS

A staff member of TECRO's designated representative, CWB, will visit AIT's designated representative, UCAR, for three months beginning in April 2012. Yu-Chun Hung will be hosted by UCAR staff, Michael Barlage. CWB staff will work with UCAR staff on fixing the HRLDAS warm/dry biases, WRF biases, and continue to learn and improve the CWB HRLDAS operational implementation. UCAR staff will provide technical support as needed.

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

Performance Period:	
a. Improvement of HRLDAS soil moisture and temperature biases	01/01/12 – 11/30/12
b. Improvement of WRF surface temperature and moisture biases	01/01/12 – 11/30/12
c. Visit of Yu-Chun Hung	04/01/12 – 06/30/12
Resources Required:	0.20 FTE UCAR staff
Deliverables:	
1. Report on HRLDAS performance improvement	06/30/12
2. Final report documenting the results of HRLDAS task	11/30/12

5. Task #5 – Improvement of WRF Model Operational Performance

During 2011, 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. Improvements were made to surface wind forecasts and a better understanding of the performance of the Kain-Fritsch parameterization was obtained. The forecast behavior of convection over both the land and ocean in the high- and low-resolution domains was also investigated. During 2012, UCAR and CWB will collaborate to further improve the WRF forecasts, by investigating known biases attributable to the WRF model physics parameterizations. 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 (0.50 FTE)

AIT's designated representative, UCAR, will collaborate with TECRO's designated representative, CWB, on investigation and improvement of the forecasts of 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 typhoon precipitation forecasts on the 5-km grid

WRF forecasts on the 5-km grid have shown a tendency for excessive typhoon rainfall over the Taiwan mountains. AIT's designated representative, UCAR, will conduct a series of experiments on such a typhoon case (e.g. Morakot 2009) to determine the factors that cause this over-prediction.

These experiments will include changing the microphysics, changing the convective parameterization on the 15-km grid, and testing different PBL schemes. Additional diagnostic fields will be added to the model and new plotting and diagnostic programs will be developed as necessary. UCAR will perform a similar study on another typhoon case to be selected by TECRO's designated representative, CWB.

UCAR will also examine a wintertime case (to be chosen by CWB) as some of these operational forecasts have shown a high bias in precipitation as well. Since the dynamics of winter precipitation over Taiwan are much different than those associated with a typhoon, these cases are also of interest.

UCAR will deliver a final report about the precipitation forecasts over 5-km domain.

5.1.2 Investigate the dry bias for afternoon thunderstorms over Taiwan

Both TECRO's designated representative, CWB, and climate modelers have noted a distinct dry bias in afternoon thunderstorms over Taiwan. This dry bias does not seem to be related to initial conditions since accurate initial moisture fields provided by GPSPW measurements are quickly forgotten by the model. AIT's designated representative, UCAR, will conduct experiments of a typical case (as suggested by CWB). These experiments will include modifying the radiation physics, examining the impact of land surface properties on the convection, and studying the evolution of the modeled PBL.

UCAR will deliver a final report about the WRF forecasts of afternoon thunderstorms.

5.1.3 Improve convective forecasts over the ocean

The WRF model has shown a moist bias over tropical and sub-tropical oceans near the PBL top. This problem is more pronounced when the new trigger function for the Kain-Fritsch scheme is used. Preliminary tests in 2011 by AIT's designated representative, UCAR, have shown that the use of a more active shallow convection scheme may help to remove the build-up of the shallow cloud. UCAR will continue these tests in 2012. The test period of June 2008 will be used for this task.

In addition, UCAR will test a new ocean boundary condition to examine if it may help to alleviate the over-prediction of moisture in the oceanic boundary layer.

UCAR will deliver a shallow convection scheme that will show improvement for the over-prediction of cloud near the PBL top. UCAR will also make a recommendation on the ocean boundary condition to TECRO's designated representative, CWB.

5.2 Consult and advise CWB on the operational WRF model (0.1 FTE)

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 providing consultation to CWB about aspects of running the model. Staff from UCAR will assist visitors from CWB in their WRF investigations.

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	01/01/12 – 11/30/12
b. Consult and advise CWB on the operational WRF	01/01/12 – 11/30/12
Resources Required:	0.60 FTE UCAR staff
Deliverables:	
1. Final report on WRF prediction of topographic rainfall	11/30/12
2. Final report on WRF prediction of afternoon thunderstorms	11/30/12
3. A shallow convective scheme compatible with the Kain-Fritsch parameterization	11/30/12

6. Task #6 – Project Management and Coordination

Because the tasks proposed for 2012 require close collaboration between 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, and the data transfer "ftp" command must be established and updated on a timely and regular basis. The exchange visits between CWB and UCAR staffs are also necessary. Also, to keep CWB informed on the progress of the project, monthly reports need to be prepared and delivered. 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:

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

With the CWB and UCAR web pages, the updated version of the 3D-Var system, WRF/DART system, experimental results, and progress reports, etc. are easily exchanged between the two groups. In 2012,

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.

6.2 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 Drs. Hui Liu, John Braun, Wei Wang, Hans Huang, Zhiquan Liu, Xin Zhang and Yong-Run Guo will 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.

6.3 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.

6.4 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 on both the WRF model and the WRF-VAR data assimilation system.

6.5 Project administrative support (.12 FTE)

The UCAR COSMIC Program Office will provide administrative support for this project. This includes: (i) monitoring of the project budget, staff time-charges, and other spending; (ii) arranging travel for staff of AIT's designated representative, UCAR, and TECRO's designated representative, CWB, and filing all the related paper work; (iii) support for monthly meetings; (iv) support for the preparation of project reports and deliverables; and (v) administrative support for CWB visitors (e.g., health insurance, visa paper work).

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

Performance Period:	
a. Update and maintain both CWB and UCAR CWB project web pages	01/01/12 – 11/30/12
b. Site visit to CWB	01/01/12 – 11/30/12
c. Telephone conferences via Skype	01/01/12 – 11/30/12
Resources Required:	0.1 FTE UCAR scientific staff and 0.12 FTE UCAR administrative staff
Deliverables:	
1. Updated web page for project	11/30/12

2.	Site visits	11/30/12
3.	Brief monthly reports to CWB management	02/01/12 - 10/01/12
4.	Summary report of WRF User's Workshop on WRF model and WRF-VAR data assimilation system	09/30/12

II. Budget

The following are the estimated costs for Implementing Arrangement #9A:

Tasks	FTE	Personnel Cost	Travel/Training	Total
Task #1	1.05 FTE	$205,000	$6,000	$ 211,000
Task #2	0.85 FTE	$145,000	$6,000	$ 151,000
Task #3	0.15 FTE	$36,000	$3,000	$ 39,000
Task #4	0.20 FTE	$54,000	$3,000	$ 57,000
Task #5	0.60 FTE	$140,000	$6,000	$ 146,000
Task #6	0.22 FTE	$42,000	$6,000	$ 48,000
Total	**3.07 FTE**	**$622,000**	**$30,000**	**$ 652,000**

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 #9A, 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 $652,000 USD. The detailed financial arrangements are described in the Implementing Arrangement #9, 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. Assignments for the CWB staff members will be as follows:

Testing of the CWB operational WRFVar/WRF system for a longer period of time;

Providing the necessary datasets to UCAR;

Participating in WRFVar and WRF/DART data assimilation experiments and results analysis; and

Performing WRF physics tests.