A Proposal for the NOAA/OAR Funding Opportunity of FY 13 Joint Hurricane Testbed

Doppler Radar Data Assimilation and the Hurricane Intensity Forecasts in HWRF

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Abstract

Doppler radar observations from coastal and airborne Doppler radars are important data source for hurricane vortex. During this project, we will implement a Doppler radar data assimilation capability in the advanced data assimilation system, Gridpoint Statistical Interpolation (GSI), for the Hurricane Weather Research and Forecasting (HWRF) model. Some of the algorithms that are in the WRF 3-dimensional variational (WRF 3D-Var) data assimilation and have been proved successful in research will be ported, improved and tested with GSI. The work will be based on the current Doppler radar data assimilation effort at NCEP/EMC as an enhancement instead of replacement. In order to verify the enhanced Doppler radar data assimilation capability, we will conduct experiments with historical hurricane cases and assess the impact of Doppler radar data assimilation with GSI on hurricane intensity forecasts in the HWRF. We will also perform real-time verifications in the hurricane season of 2014 with the available data from airborne and coastal Doppler radars using GSI and HWRF as well.

Hurricane intensity and intensity change are highly related to vortex structures. In order to have an improved intensity forecast, the vortex initialization should be improved in the first place using observations in the vortex's inner region. In WRF 3D-Var, there are two algorithms in Doppler radar data assimilation that could benefit the GSI system. One is the scheme for vertical velocity increments and another is the microphysics to produce cloud water and rainwater increments in the analysis. Doppler radial velocity contains the vertical velocity information, and reflectivity contains cloud and rainwater information. Assimilation of such information is important in defining the detailed structures of vortex. Porting of the related components from WRF 3D-Var into GSI will enable the system directly assimilating radial velocity and reflectivity data, which is the first priority of this project. The case studies and real-time evaluation of the enhanced system in the hurricane season of 2014 will also reveal how the analytical vortex structures from Doppler radar data assimilation impact hurricane intensity and intensity change. This will compose a major scientific objective of this project.

The project is proposed for two years. The PI (Qingnong Xiao) and a post-doctorial research scientist will be mainly responsible for the execution of this project. Close collaborations among the PI, the postdoc, and staff from NCAR/DTC, NCEP/EMC and NOAA/NHC will be established during the project. We will conduct runs in real time for the 2014 hurricane season (June – October 2014) to assimilate data from coastal and airborne Doppler radars, compare the results with other operational forecasts, and refine the developed system for consideration of possible operational application. The technical algorithms, system settings and interesting results will be summarized to documentations and disseminated to the hurricane forecasting community. We anticipate that an advanced Doppler radar data assimilation scheme in GSI will be further enhanced and implemented for its vortex initialization in order to improve hurricane intensity forecast. A young postdoc scientist will be trained in Doppler radar data assimilation using GSI and hurricane forecast using HWRF. This project will also foster the transition of Doppler radar data assimilation from research to operational applications.

Statement of Work

During the past two decades, forecast of hurricane track has been steadily improved. However, intensity forecast remains unsatisfactory. Studies have shown that the vortex structures can significantly affect hurricane intensity behavior (Xiao et al. 2000; 2009a). Hurricane initialization using an advanced data assimilation technique is a key procedure to extend lead-time for hurricane intensity forecasts with increased certainty (Davis et al. 2008). Assimilation of the observed information in the vortex region should be implemented in the hurricane initialization procedure for an improve hurricane intensity forecast.

Doppler radar observations from coastal and aircraft Doppler radars are important data source for hurricane vortex. Assimilation of Doppler radar data in hurricane initialization is of significant interest to the hurricane forecasting communities but with a lot of challenges (Marks et al. 1998; Xiao et al. 2007; 2009b). The complexity comes from how we should establish the data assimilation system for hurricanes that are usually in the low latitude, compounded by a lack of data over the ocean and inadequate computer resources to resolve the inner core. With recent catastrophic events for the U.S. like Katrina (2005) and Sandy (2012) and rapid intensifiers just prior to landfall like Charlie (2004) and Humberto (2007), research on the hurricane intensity issue becomes an emergent topic in hurricane community in order to improve one to five day forecasts with a focus on rapid intensity change. From the several-year practice of real-time hurricane forecasts using the advanced-research Hurricane WRF (AHW) model (Davis et al. 2008; Xiao et al. 2009a; b), one conclusion is that an advanced analysis scheme needs to be implemented for improved vortex initialization.

Atmospheric data assimilation is a process that incorporates observational data into numerical models with consideration of both observation and model background information. Currently, there are several data assimilation techniques that can be used for hurricane initialization. The four-dimensional variational (4D-Var) data assimilation (Courtier et al. 1994) and Ensemble Kalman filter (EnKF, Evensen 1994) are two of the most advanced schemes in algorithm formulation and technique design. As we all know in the data assimilation community, however, the development of adjoint model in 4D-Var is tedious, labor-intensive, and often subject to errors (Xiao et al. 2008a). EnKF data assimilation is still a research topic, subject to sampling errors and immature for widely accepted operational applications. At NCEP, the operational data assimilation (including that for hurricane prediction model HWRF) is Gridpoint Statistical Interpolation (GSI, Wu et al. 2002), a 3-dimensional variational (3D-Var) data assimilation system. Computationally, 3D-Var is much faster than 4D-Var or EnKF. It can be easily implemented with various observations and applied in operational applications. The GSI data assimilation is still considered as an advanced data assimilation system, which is currently used for the NOAA/NCEP's operational Global Forecast System (GFS) and North American Mesoscale Model (NAM). It is also the data assimilation system for the Hurricane Weather Research and Forecasting (HWRF) model for hurricane initializations combined with the relocation technique (Liu et al. 2006). GSI has provided HWRF with state-of-the-art, efficient data assimilation capabilities.

In order to improve the hurricane intensity forecast, Doppler radar data assimilation using GSI is proposed in this project for hurricane vortex initialization with the target to improve the hurricane intensity prediction using HWRF model. According to the Announcement of FY 13 Joint Hurricane Testbed, there are six issues required to be addressed in the Statement of the Work as follows:

- *Proposed duration of the project:*

This project will be executed for two years, starting from 1 August 2013 to 31 July 2015.

- *Technical approaches and prior research results*:

GSI is a 3-dimensional variational data assimilation system, which is currently used for the HWRF model. It produces analysis through the iterative minimization of a prescribed cost (or penalty) function, so as to optimally synthesize observations in a model-consistent framework. Mathematically, the functional to be minimized is

$$J(\mathbf{x}') = \frac{1}{2}[(\mathbf{x}')^T \mathbf{B}^{-1}(\mathbf{x}') + (\mathbf{H}\mathbf{x}' - \mathbf{d})^T \mathbf{R}^{-1}(\mathbf{H}\mathbf{x}' - \mathbf{d})] \tag{1}$$

where $\mathbf{x}' = \mathbf{x} - \mathbf{x}_b$ is the vector of analysis increment and $\mathbf{x}_b$ is the background state (first-guess) vector. $\mathbf{H}$ is the linearized observation operator. $\mathbf{d}$ is the innovation vector calculated by

$$\mathbf{d} = \mathbf{y}_{obs} - H(\mathbf{x}_b)\,, \tag{2}$$

where H is observation operator and $\mathbf{y}_{\text{obs}}$ is observation vector. $\mathbf{B}$ is the background error covariance matrix and $\mathbf{R}$ is the observation error covariance matrix.

The control variables are defined on the model grid. According to Wu et al. (2002), the control variables in GSI are streanfunction (ψ), unbalanced part of velocity potential (χ), the unblanced part of temperature, unbalanced part of surface pressure and pseudo-relative humidity which is defined as the water vapor mixing ratio divided by the saturated value from the background field. The cost function minimization is performed in terms of analysis increments. Recursive filters are applied in all three directions (x, y, and z directions). The preconditioned conjugate-gradient algorithm (Gill et al. 1981) was chosen because the multiple filters in the horizontal direction are easier to implement in the solution algorithm. The amplitudes and scales of the background error are defined as functions of latitude and height. More details of the GSI 3D-Var data assimilation system can be referred in Wu et al. (2002).

The capability of assimilating Doppler radial velocity in GSI is developed at NCEP but without vertical velocity increments (personnel communication). We will port the algorithm of vertical velocity increments in WRF 3D-Var (Barker et al. 2004; Skamarock et al. 2008) to GSI. Based on Richardson's (1922) derivation, a balance equation that combines the continuity equation, adiabatic thermodynamic equation, and hydrostatic relation is derived and expressed as:

$$\gamma p \frac{\partial w}{\partial z} = -\gamma p \nabla \cdot \boldsymbol{V_h} - \boldsymbol{V_h} \cdot \nabla p + g\int_z^{\infty} \nabla \cdot (\rho \boldsymbol{V_h}) dz \tag{3}$$

where w is vertical velocity, $\boldsymbol{V_h}$ is the vector of horizontal velocity (components u and v), γ the ratio of specific heat capacities of air at constant pressure/volume, p pressure, ρ density, T

temperature, c_p specific heat capacity of air at constant pressure, z height, and g the acceleration due to gravity. For simplicity, hereafter Eq. (3) will be referred to as Richardson's equation. Linearizing Eq. (3) by writing each variable in terms of a basic state (overbar) plus a small increment (prime) gives

$$\begin{aligned} \gamma \bar{p} \frac{\partial w'}{\partial z} &= -\gamma p' \frac{\partial \bar{w}}{\partial z} - \gamma \bar{p} \nabla \cdot \boldsymbol{V}_{\boldsymbol{h}}' - \gamma p' \ \nabla \cdot \overline{\boldsymbol{V}_{\boldsymbol{h}}} - \overline{\boldsymbol{V}_{\boldsymbol{h}}} \cdot \nabla p' \\ &- \boldsymbol{V}_{\boldsymbol{h}}' \cdot \nabla \bar{p} + g \int_z^\infty \nabla \cdot (\bar{p} \boldsymbol{V}_{\boldsymbol{h}}') dz + g \int_z^\infty \nabla \cdot (\rho' \overline{\boldsymbol{V}_{\boldsymbol{h}}}) dz \end{aligned} \quad . \tag{4}$$

The basic state (overbar) variables satisfy Eq. (3). They also satisfy the continuity equation, thermodynamic equation and hydrostatic equation. The linear equation (4) is discretized, and its adjoint code is developed according to the code of the linearized equation (Xiao et al., 2005).

The linearized Richardson's equation (4) builds a relation of vertical velocity increment and the increments of other variables. It is a higher-order approximation of the continuity equation than the incompressible continuity equation or anelastic continuity equation, and the computation is affordable. More importantly, it constitutes an efficient linkage between dynamic and thermodynamic fields because the thermodynamic equation is directly involved in the derivation of Richardson's equation (refer the derivation in Xiao et al. 2005). The analysis fields should be more balanced than using a simple incompressible continuity equation or anelastic continuity equation. Because the vertical velocity increments can be produced with the linear and adjoint of the Richardson's equation incorporated in the minimization procedure, the observation operator for Doppler radial velocity include vertical velocity component. For radar scans at nonzero elevation angles, the fall speed of precipitation particles (terminal velocity) has to be taken into account. The observation operator for the Doppler velocity will be enhanced during this project, which will includes the contributions from vertical velocity and terminal velocity.

Radar reflectivity measures the radar's signal reflected by precipitation hydrometeors. To assimilate radar reflectivity directly, data assimilation system should be able to produce the increments of the hydrometeors (at least, the rainwater mixing ratio). In the work of Xiao et al. (2007), a microphysics process is introduced in WRF 3D-Var. The microphysics scheme is a column model and integration of the column model for a half hour can usually achieve the steady state of the moisture and hydrometeors. A warm rain microphysical process and its adjoint are used in WRF 3D-Var, which includes condensation of water vapor into cloud (P_{CON}), accretion of cloud by rain (P_{RA}), automatic conversion of cloud to rain (P_{RC}), and evaporation of rain to water vapor (P_{RE}). These are the major processes of hydrometeor cycle in the summer season.

The autoconversion term, P_{RC}, is represented by

$$P_{RC} = \begin{cases} k_1 (q_c - q_{crit}), & q_c \geq q_{crit} \\ 0, & q_c < q_{crit} \end{cases} \quad , \tag{5}$$

where q_c is the cloud water mixing ratio, $k_1 = 10^{-3} s^{-1}$, $q_{crit} = 0.5 g \cdot kg^{-1}$. The accretion of cloud water by rain is parameterized by

$$P_{RA} = \frac{1}{4}\pi\rho a q_c E N_0 \left(\frac{p_0}{p}\right)^{0.4} \frac{\Gamma(3+b)}{\lambda^{3+b}}, \tag{6}$$

where Γ is the gamma-function; E is the collection efficiency; p is pressure; p_0=1000 hPa, N_0=8X10^6 m^{-4}, a=841.99667 and b=0.8. The evaporation of rain can be determined from the equation:

$$P_{RE} = \frac{2\pi N_0(S-1)}{A+B}\left[\frac{f_1}{\lambda^2} + f_2\left(\frac{a\rho}{\mu}\right)^{1/2} S_c^{\ 1/3}\left(\frac{p_0}{p}\right)^{0.2}\frac{\Gamma(\frac{5+b}{2})}{\lambda^{\frac{5+b}{2}}}\right], \tag{7}$$

where f_1=0.78, f_2=0.32. The condensation P_{CON} is determined according to Asai (1965) by

$$P_{CON} = \frac{q_v - q_{vs}}{1 + \dfrac{L_v^{\,2} q_{vs}}{R_v C_{pm} T^2}}, \tag{8}$$

where q_{vs} is saturated water vapor mixing ratio, L_v, R_v, and C_{pm} are latent heat of condensation, gas constant for water vapor, and specific heat at constant pressure for moist air, respectively.

The tangent linear and its adjoint of the scheme were developed in WRF 3D-Var. During the 3D-Var minimization, the tangent linear and adjoint of the microphysics column model are integrated for a half hour to produce q_c and q_r increments. The warm rain scheme builds a constraint: the relation among rainwater, cloud water, moisture and temperature. When rainwater information (from reflectivity) enters the minimization procedure, the forward microphysical process and its backward adjoint distribute this information to the increments of other variables (under the constraint of the warm rain scheme).

We should point out that the warm rain process largely represents the microphysics in hurricanes in the lower levels (below freezing line). Extension of the scheme to simple ice (Dudhia 1989) should be straight away, that the cloud water becomes cloud ice and rainwater becomes snow when the background temperature below the threshold of freezing. We can test the strategy in the project. Once the 3D-Var system can produce q_c and q_r increments, the setup of the observation operator for assimilation of reflectivity is straightforward. If the attenuation is taken care of during preprocessing, we can adopt the observation operator from Sun & Crook (1997),

$$Z = 43.1 + 17.5\log(\rho q_r), \tag{9}$$

where Z is reflectivity in the unit of dBZ and q_r is the rainwater mixing ratio. The relation (9) is derived analytically by assuming the Marshal-Palmer distribution of raindrop size.

Usually, radar reflectivity data go through attenuation correction procedure during data preprocessing (Snyder et al. 2010). Recently, Xue et al. (2009) implemented another approach that includes attenuation in the observation operator and assimilate the attenuated radar data.

Such a procedure does not require prior assumption about the types of hydrometeor species along the radar beams, and allows us to take advantage of knowledge about the hydrometeors obtained through data assimilation and state estimation. According to Xue et al. (2009), the attenuated radar reflectivity is

$$Z'(r) = 10\log_{10}[Z_e(r)A(r)] \ , \tag{10}$$

where $Z_e(r)$ is the equivalent reflectivity factor before attenuation, and $A(r)$ is the two-way path-integrated attenuation (PIA) factor. In Eq. (10),

$$A(r) = \exp(-0.46\int_0^r k(s)ds), \tag{11}$$

where k is the attenuation coefficient ($dB \cdot km^{-1}$).

There are three novel achievements in the Doppler radar data assimilation within WRF 3D-Var. First, the vertical velocity increments were included via a new balance equation, Richardson's equation, in the physical transform routine of WRF 3D-Var. With this development, the three-dimensional components of radial velocity can be assimilated into the analysis (Xiao et al. 2005). Second, we introduced hydrometeor increments via a microphysics scheme (a column model) in the 3D-Var system. Assimilation of reflectivity data can generate water hydrometeor analyses, which are balanced with other variables via microphysical process (Xiao et al 2007). Third, the Level II Doppler radar data (radial velocity and reflectivity) are directly assimilated into WRF 3D-Var analyses by minimizing the misfit between the observations and their model counterparts. No retrievals are needed. Sugimuto et al. (2009) evaluated the capability using the Observation System Simulation Experiment (OSSE). In the real case study for a squall-line case observed during the IHOP_2002 campaign, we applied the WRF 3D-Var system to 4-km resolution for multiple Doppler radar data assimilation, and produced substantial improvement on QPF with a marginal increase of the computation cost with respect to the non-radar or single-radar data assimilation experiment (Xiao and Sun 2007). The system was applied in operational application in the Korea Meteorological Administration and showed its benefits to the Korea weather prediction (Xiao et al. 2008b). In our recent study of the hurricane initialization using airborne Doppler radar data (Xiao et al. 2009b), the Doppler radar data assimilation algorithms also showed its potential in hurricane intensity prediction.

During the past years, we have conducted numerous experiments using WRF 3D-Var Doppler radar data assimilation. The developed programs and subroutines are mature and portable. In addition, we have obtained a great deal of experiences in Doppler radar data assimilation. These experiences will benefit the proposed project significantly. In this project, we will first evaluate the Doppler radar data assimilation capability in GSI, and compare its differences with WRF 3D-Var. Some techniques that have been proved successful in WRF 3D-Var will be ported to GSI and tested in our experiments and real-time applications.

- *The project work plan*

The project is proposed for two years. Close collaborations among the PI, a postdoc and staff from NCAR/DTC, NCEP/EMC and NOAA/NHC will be established during the project. The tasks and schedule are as follows:

1. GSI and HWRF preparation

In order to execute the project, the PI will visit NCAR/DTC or NCEP/EMC to prepare GSI and HWRF for this project. The PI has contacted Dr. Ming Hu at NCAR/DTC and Drs. Qingfu Liu and Mingjing Tong at NCEP/EMC, and they are willing to help for an initial setup of the GSI and HWRF systems for the project.

2. Comparing the differences of Doppler radar data assimilation in GSI and WRF 3D-Var

As we know, Doppler radar data assimilation has been developed in both GSI and WRF 3D-Var. The algorithms for radial velocity are similar, but the approaches for reflectivity assimilation are different. During this project, we will evaluate the advantage and weakness of each system in dealing with Doppler radar data assimilation, and find out which subroutines or functions can be adapted from WRF 3D-Var to GSI. We will conduct this task at the Center for Severe Weather Research (CSWR) from August to September 2013.

3. Porting the necessary codes from WRF 3D-Var to GSI

Since 2002, the PI and his colleagues at NCAR have developed the Doppler radar data assimilation capability in WRF 3D-Var. Both radial velocity and reflectivity can be directly assimilated using WRF 3D-Var (Xiao et al. 2005; 2007). Although in GSI there are many similar algorithms for Doppler radar data assimilation, some differences in algorithm design and technical approach exist. During this project, we will port the algorithms that have been proved successful in WRF 3D-Var to GSI. The major tasks for the porting would be how the vertical velocity increments and microphysics in WRF 3D-Var can be ported to GSI. We will have a careful examination of the GSI code structures and implement the algorithm in GSI. We will conduct this task at CSWR from October to December 2013.

4. Numerical experiments with historical hurricane cases

We will select several representative cases to conduct hurricane initialization experiments using Doppler radar data assimilation. From our experiences, it would be helpful to include some NHC estimated vortex parameters (e.g. CSLP and maximum wind) in assimilation. The historical cases such as Hurricanes Katrina (2005), Ike (2008) and Sandy (2012) would be good because the data are ready. New cases in the 2013 hurricanes season will be considered too. At least three sets of experiments will be carried out: 1) control without radar data assimilation, 2) experiment with the existing radar data assimilation in GSI, and 3) experiment with the enhanced radar data assimilation after we port some codes from WRF 3D-Var. Note all other observations used in GSI will be retained in our experiments. Additional experiments to test the sensitivity of the developed radar data assimilation algorithms may also be necessary. The work will be done at CSWR from January to May 2014.

5. Real-time verifications

The real-time run will be set up for the 2014 hurricane season (June – October 2014). We will conduct runs in real time to assimilate data from coastal and airborne Doppler radars, compare the results with other operational forecasts. The work will be conducted using the new NCAR high performance computing (HPC) system (Yellowstone). Since NCAR/DTC is pursuing similar tasks for GSI and HWRF, computation resources from NCAR will be applied. The real-time run will be conducted from June to October 2014.

6. Analyzing the results and reruns

We will analyze the numerical results from the real-time forecast using HWRF with Doppler radar data assimilation with GSI. Some reruns and fine-tuning should be necessary for the full operational application. Sensitivity experiments will be carried out to test the parameters and settings of the GSI radar data assimilation scheme. The settings and interesting results will be summarized to technical documentations, and disseminated to the hurricane forecasting community. The work schedule for this task is from November 2014 to July 2015.

The PI has NCAR super computer access and most computation work will be done using NCAR HPC. However, many evaluations and verifications of the results will be conducted using our local computers at CSWR. For hurricane forecast, the verification approach will be statistics of errors in track, central sea-level pressure (CSLP) and maximum surface (10-m) wind (MSW). Particularly we will conduct a more detailed analysis of the intensity errors and intensity bias, and compare the results with the HWRF official baseline runs. All the experiments and verification will be carried out for 5 days. Reductions of the average errors and bias in track and intensity compose the metrics for success of this endeavor. To execute the project, we will need the Doppler radar data from the coastal and airborne Doppler radars as our specific input data. In addition, the official data stream for HWRF initialization using GSI is also required.

During the project, we will periodically deliver our developed system and testing results to DTC, EMC and NHC. Specifically, we will deliver the GSI data assimilation system with the enhanced Doppler radar data assimilation, and testing results with the selected cases before the real-time runs. In 2014 hurricane season, the developed system will be implemented for real-time verification. The implemented system and testing results will be delivered at the end of 2014. The final version of the system after refinement and sensitivity study will be delivered at the end of this project in July 2015. We anticipate a success that the errors and biases of the hurricane intensity are reduced, and the enhanced system in Doppler radar data assimilation will be implemented in operational application in the future.

- *Scientific and technical documentation*

The following is our tentative timeline for deliverables of the scientific and technical documentations. We will coordinate with the JHT director for deliverables during the project.

Item	Delivered by
Documentation of Doppler radar data assimilation algorithms	May 31, 2014
User's guide for the Doppler radar data assimilation procedure, interface, and framework	December 31, 2014
Final version of the user's guide, code descriptions for the enhanced GSI Doppler radar data assimilation	July 31, 2015

- *Expected travel*

Although the PI and a postdoc are mainly responsible for execution of the project, it is actually a collaboration effort among the PI, the postdoc, staff from NCAR/DTC, NCEP/EMC and NOAA/NHC. Since CSWR and NCAR/DTC are within walking distance, the collaboration with DTC staff should be very convenient. Travels of the PI and the postdoc to EMC and NHC are planned. First of all, we will travel to EMC for 1-2 weeks for GSI and HWRF setup and initial consultation once the project is funded. We will travel to NHC and EMC during the real-time verification in 2014 hurricane season to discuss the results with the NHC and EMC staff and consult possible modifications of the system. In addition, we plan to attend the annual Interdepartmental Hurricane Conference (IHC) in 2014 and 2015 to report our technical developments and testing results.

- *JHT staff requirements*

We expect JHT staff to help for necessary Doppler radar data acquisition, and other problems that we may encounter. Because it involves four parties (CSWR, DTC, EMC and NHC), JHT as a moderator in setting up the collaborative environment will be very helpful for the success of the project.

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Budget and justification

Item		Year 1	Year 2	Total
Salary	PI (Xiao, 2 months)	$18,333	$18,700	$37,033
	Postdoc (6 months)	$25,000	$25,500	$50,500
Fringe	PI (Xiao, 2months)	$5,133	$5,236	$10,369
	Postdoc (6 months)	$7,000	$7,140	$14,140
Travel		$2,500	$2,500	$5,000
Office supplies		$500	$500	$1,000
Total direct cost		$58,466	$59,576	$118,042
F&A (68% MDTC)		$39,757	$40,512	$80,269
Total		**$98,223**	**$100,088**	**$198,311**

Personnel

Dr. Xiao (PI) will work in this project for two months/year, with the salary of $9,167/month in the first year. A postdoctoral scientist will work half time on this project, with an annual salary of $50,000 for the first year. The fringe cost at CSWR is based on 28% of salary. The salary and fringe for the second year are calculated with the 2.0% inflation.

Travel

We will collaborate with EMC and NHC staff during this project. Face-to-face communications and discussions are required. Therefore, we budget two trips (one trip for Dr. Xiao and one trip for the postdoc) to NCEP/EMC (in Washington D. C.), which cost around $1000 for each travel. One trip to NHC (in Miami) is also planned with $1200 budget. In addition, we will attend IHC conferences in 2014 and 2015 to disseminate our developments and results, and about $1400 dollars/year are budgeted for the purpose.

Office supplies

We budget $500/year for office supplies, such as print papers, tones and other small miscellaneous cost.

Indirect cost

The CSWR F&A rate is 68%.

Biographical Sketch

Qingnong Xiao
Center for Severe Weather Research
3394 Airport Road, Boulder, CO 80301
Tel: (720) 335-7647, Fax: (720) 304-0900 Email: hsiao@cswr.org

Professional preparation:

1996-1997: Post-doc., NCAR, MMM Division, Boulder, Colorado
1990-1994: Ph. D. in Meteorology, Nanjing University, China
1985-1988: M. Sc in Meteorology, Nanjing Institute of Meteorology, China

Professional experiences:

04/2012 - ; Scientist, Center for Severe Weather Research.
08/2009 - 07/2011; Associate Professor, University of South Florida, College of Marine Science. a) Teaching course "Data Assimilation for Oceanic and Atmospheric Applications"; b) Research on data assimilation using WRF-Var and En3/4D-Var; c) Coupled modeling of WRF and HYCOM
09/2004 - 08/2009: Project Scientist II, NCAR MMM Division. a) Development of WRF tangent linear and adjoint models; b) Research on the data assimilation algorithms within WRF-Var; c) Evaluations of the impact in assimilating various observational data (including satellite data and radar data) on the predictions of WRF model
09/2001- 09/2004: Project Scientist I, NCAR MMM Division. a) Development of 3DVAR system for MM5 and WRF; b) Research on 4DVAR assimilation of radar data and satellite data using MM5 4DVAR system; c) Development of a capability of radar data assimilation using MM5/WRF 3DVAR system
10/1997 - 09/2001: Assistant Scientist in Research, Department of Meteorology, Florida State University. a) Development of the adjoint of a radiative transfer model; b) 4DVAR assimilation of satellite data and other unconventional data using MM5 4DVAR system; c) Adjoint sensitivity analysis and hurricane initialization studies
04/1994-07/1996: Lecturer, and Associate Professor, Nanjing Institute of Meteorology, China

Selected Relevant Publications:

Xiao, Q., X. Zhang, C. Davis, J. Tuttle, G. Holland, P. J. Fitzpatrick, 2009: Experiments of hurricane initialization with airborne Doppler radar data for the Advanced-research Hurricane WRF (AHW) model. *Mon. Wea. Rev*., **137**, 2758–2777.

Qiu, X., **Q. Xiao,** Z.-M. Tan, and John Michalakes, 2011: Intensity forecast experiment of hurricane *Rita* (2005) with a cloud-resolving, coupled hurricane–ocean modeling system. *Quart. J. Roy. Meteor, Soc.,* **137,** 2149–2156, DOI: 10.1002/qj.899.

Huang, X.-Y., **Q. Xiao**, D. M. Barker, Xin Zhang, J. Michalakes, W. Huang, T. Hendersen, J. Bray, Y.-S. Chen, Z. Ma, J. Dudhia, Y.-R. Guo, Xiaoyan Zhang, D.-J. Won, H.-C. Lin, and Y.-H. Kuo, 2009: Four-dimensional variational data assimilation for WRF: Formulation and preliminary results. *Mon. Wea. Rev.*, **137**, 299-314.

Liu, Chengsi, **Q. Xiao**, and Bin Wang, 2009: An Ensemble-based four-dimensional variational data assimilation scheme: Part II: Observing system simulation experiments with the Advanced Research WRF (ARW). *Mon. Wea. Rev*., **137**, 1687-1704.

Xiao, Q., and J. Sun, 2007: Multiple radar data assimilation and short-range quantitative precipitation forecasting of a squall line observed during IHOP_2002. *Mon. Wea. Rev.* **135***,* 3381-3404.

Other Significant Publications:

Xiao, Q., L. Chen and X. Zhang, 2009: Evaluations of BDA scheme using the Advanced Research WRF (ARW) model. *J. Appl. Meteor., Climat*., **48**, 680-689.

Xiao, Q., Y.-H. Kuo, Z. Ma, W. Huang, X.-Y. Huang, Xiaoyan Zhang, D. Barker, J. Michalakes, and J. Dudhia, 2008: Application of an Adiabatic WRF adjoint to the investigation of the May 2004 McMurdo Antarctica severe wind event. *Mon. Wea. Rev*., **136**, 3696-3713.

Xiao, Q., Eunha Lim, D.-J. Won, J. Sun, W.-C. Lee, M.-S. Lee, W.-J. Lee, J. Cho, Y.-H. Kuo, D. Barker, D.-K. Lee, and H.-S. Lee, 2008: Doppler radar data assimilation in KMA's operational forecasting. *Bull. Amer. Meteor. Soc*., **89**, 39-43.

Davis, C. A., W. Wang, S. Chen, Y. Chen, K. Corbosiero, M. DeMaria, J. Dudhia, G. Holland, J. Klemp, J. Michalakes, R. Rotunno, and **Q. Xiao**, 2008: Prediction of landfalling hurricanes with the advanced hurricane WRF model. *Mon. Wea. Rev*., **136**, 1990-2005.

Zhang, X.-Y., **Q. Xiao**, and Patrick F. Fitzpatrick, 2007: The impact of multi-satellite data on the initialization and simulation of Hurricane Lili's (2002) rapid weakening phase. *Mon. Wea. Rev*., **135**, 526-548.

Synergistic Activities:

• Policy/Fellowship committee, Graduate Council, University of South Florida, 2010 – 2011
• Southeastern University Research Association (SURA) Standing Committee: Coastal & Environmental Research, 2010 – 2011
• Associate editor, Advance in Atmospheric Sciences, 2009 –
• Program Committee, Conference on Assimilation of Remote Sensing and In-situ Data in Modern Numerical Weather and Environmental Prediction Models, SPIE, 26-30 August 2007, San Diego, CA
• Numerical Weather Prediction Committee, China Meteorological Society (1995-1999)
• Member of WRF data assimilation team, responsible for Doppler radar data assimilation, hurricane initialization, WRF tangent linear and adjoint models, and ensemble-based WRF En4D-Var system (2001-2009)
• Ph. D. advisees and co-advisees: Jianfeng Gu (Ph.D. awarded in June 2006), Chengsi Liu (Ph.D. Awarded in October 2008), Yingli Zhu (2010 – 2011), Sha Feng (2010 – 2011), Esa-Matti Tastula (2011)

Collaborators:

Jeff Anderson (NCAR/IMAGe), Dale Barker (NCAR/MMM and UK MetOffice); David H. Bromwich (Ohio State University/Byrd Polar Research Center), Chris Davis (NCAR/MMM), Jimy Dudhia (NCAR/MMM), Patrick Fitzpatrick (MSU), Greg Holland (NCAR/MMM), Hans Huang (NCAR/MMM), Bill Kuo (MMM Division, NCAR); Jin-Luen Lee (NOAA/ESRL), Wen-Chau Lee (NCAR/EOL), Alan Lipton (AER); Chengsi Liu (USF/CMS), Hui Liu (NCAR/IMAGe), George Modica (AER); Thomas Nehrkorn (AER), Manuel Pondeca (EMC, NOAA/NCEP); Jordan Powers (NCAR/MMM), Melvyn A Shapiro (NOAA/ETL); Chris Snyder (NCAR/MMM), Jenny Sun (NCAR/MMM and RAL), Christopher S. Velden (CIMSS, University of Wisconsin); Robert Weisberg (USF/CMS), Jianjun Xu (NESDIS/STAR), Xiaolei Zou (FSU/Department of Meteorology)

Graduate and Postdoctoral Advisors:

Ph. D. advisor: Prof. Rongsheng Wu, School of Atmospheric Sciences, Nanjing University, China.
Postdoctoral advisors: Drs. Xiaolei Zou and Bill Kuo, NCAR MMM Division.

OMB Number: 4040-0004
Expiration Date: 03/31/2012

Application for Federal Assistance SF-424

* 1. Type of Submission:	* 2. Type of Application:	* If Revision, select appropriate letter(s):
☐ Preapplication	☒ New	
☒ Application	☐ Continuation	* Other (Specify):
☐ Changed/Corrected Application	☐ Revision	

* 3. Date Received: 12/06/2012	4. Applicant Identifier:
5a. Federal Entity Identifier:	5b. Federal Award Identifier:

State Use Only:

6. Date Received by State:	7. State Application Identifier:

8. APPLICANT INFORMATION:

* a. Legal Name: The Center for Severe Weather Research

* b. Employer/Taxpayer Identification Number (EIN/TIN): 73-1538354	* c. Organizational DUNS: 1309901580000

d. Address:

* Street1:	1945 Vassar Circle
Street2:	
* City:	Boulder
County/Parish:	Boulder
* State:	CO: Colorado
Province:	
* Country:	USA: UNITED STATES
* Zip / Postal Code:	80305-5603

e. Organizational Unit:

Department Name: The Center for Severe Weather	Division Name: Radar Data Assimilation

f. Name and contact information of person to be contacted on matters involving this application:

Prefix:		* First Name:	Ling
Middle Name:			
* Last Name:	Chan		
Suffix:			

Title: Administrator

Organizational Affiliation:
The Center for Severe Weather Research

* Telephone Number: 720-304-9100	Fax Number: 720-304-0900

* Email: ling@cswr.org

Application for Federal Assistance SF-424

*** 9. Type of Applicant 1: Select Applicant Type:**

M: Nonprofit with 501C3 IRS Status (Other than Institution of Higher Education)

Type of Applicant 2: Select Applicant Type:

Type of Applicant 3: Select Applicant Type:

* Other (specify):

*** 10. Name of Federal Agency:**

Department of Commerce

11. Catalog of Federal Domestic Assistance Number:

11.459

CFDA Title:

Weather and Air Quality Research

*** 12. Funding Opportunity Number:**

NOAA-OAR-OWAQ-2013-2003469

* Title:

FY 2013 Joint Hurricane Testbed

13. Competition Identification Number:

2297052

Title:

14. Areas Affected by Project (Cities, Counties, States, etc.):

Add Attachment | Delete Attachment | View Attachment

*** 15. Descriptive Title of Applicant's Project:**

Doppler Radar Data Assimilation and the Hurricane Intensity Forecasts in HWRF

Attach supporting documents as specified in agency instructions.

Add Attachments | Delete Attachments | View Attachments

Application for Federal Assistance SF-424

16. Congressional Districts Of:

* a. Applicant: 02

b. Program/Project: CO

Attach an additional list of Program/Project Congressional Districts if needed.

Add Attachment | Delete Attachment | View Attachment

17. Proposed Project:

* a. Start Date: 08/01/2013

* b. End Date: 07/31/2015

18. Estimated Funding ($):

* a. Federal	198,311.00
* b. Applicant	0.00
* c. State	0.00
* d. Local	0.00
* e. Other	0.00
* f. Program Income	0.00
* g. TOTAL	198,311.00

*** 19. Is Application Subject to Review By State Under Executive Order 12372 Process?**

☐ a. This application was made available to the State under the Executive Order 12372 Process for review on .

☐ b. Program is subject to E.O. 12372 but has not been selected by the State for review.

☒ c. Program is not covered by E.O. 12372.

*** 20. Is the Applicant Delinquent On Any Federal Debt? (If "Yes," provide explanation in attachment.)**

☐ Yes ☒ No

If "Yes", provide explanation and attach

Add Attachment | Delete Attachment | View Attachment

21. *By signing this application, I certify (1) to the statements contained in the list of certifications and (2) that the statements herein are true, complete and accurate to the best of my knowledge. I also provide the required assurances** and agree to comply with any resulting terms if I accept an award. I am aware that any false, fictitious, or fraudulent statements or claims may subject me to criminal, civil, or administrative penalties. (U.S. Code, Title 218, Section 1001)**

☒ ** I AGREE

** The list of certifications and assurances, or an internet site where you may obtain this list, is contained in the announcement or agency specific instructions.

Authorized Representative:

Prefix:

* First Name: Ling

Middle Name:

* Last Name: Chan

Suffix:

* Title: Administrator

* Telephone Number: 720-304-9100

Fax Number: 720-306-0900

* Email: ling@cswr.org

* Signature of Authorized Representative: Ling Chan

* Date Signed: 12/06/2012

BUDGET INFORMATION - Non-Construction Programs

OMB Number: 4040-0006
Expiration Date: 06/30/2014

SECTION A - BUDGET SUMMARY

Grant Program Function or Activity (a)	Catalog of Federal Domestic Assistance Number (b)	Estimated Unobligated Funds		New or Revised Budget		
		Federal (c)	Non-Federal (d)	Federal (e)	Non-Federal (f)	Total (g)
1. Weather and Air Quality Research	11.459	$	$	$ 198,311.00	$	$ 198,311.00
2. Year 2						
3.						
4.						
5. Totals		$	$	$ 198,311.00	$	$ 198,311.00

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Prescribed by OMB (Circular A -102) Page 1

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY				Total
	(1) Weather and Air Quality Research	(2) Year 2	(3)	(4)	(5)
a. Personnel	$ 43,333.00	$ 44,200.00	$	$	$ 87,533.00
b. Fringe Benefits	12,133.00	12,376.00			24,509.00
c. Travel	2,500.00	2,500.00			5,000.00
d. Equipment	0.00	0.00			
e. Supplies	500.00	500.00			1,000.00
f. Contractual	0.00	0.00			
g. Construction	0.00	0.00			
h. Other	0.00	0.00			
i. Total Direct Charges (sum of 6a-6h)	58,466.00	59,576.00			$ 118,042.00
j. Indirect Charges	39,757.00	40,512.00			$ 80,269.00
k. TOTALS (sum of 6i and 6j)	$ 98,223.00	$ 100,088.00	$	$	$ 198,311.00
7. Program Income	$ 0.00	$ 0.00	$	$	$

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SECTION C - NON-FEDERAL RESOURCES				
(a) Grant Program	(b) Applicant	(c) State	(d) Other Sources	(e)TOTALS
8. Year 2	$	$	$	$
9.				
10.				
11.				
12. TOTAL (sum of lines 8-11)	$	$	$	$

SECTION D - FORECASTED CASH NEEDS					
	Total for 1st Year	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
13. Federal	$ 98,223.00	$ 24,555.75	$ 24,555.75	$ 24,555.75	$ 24,555.75
14. Non-Federal	$				
15. TOTAL (sum of lines 13 and 14)	$ 98,223.00	$ 24,555.75	$ 24,555.75	$ 24,555.75	$ 24,555.75

SECTION E - BUDGET ESTIMATES OF FEDERAL FUNDS NEEDED FOR BALANCE OF THE PROJECT				
(a) Grant Program	FUTURE FUNDING PERIODS (YEARS)			
	(b)First	(c) Second	(d) Third	(e) Fourth
16. Weather and Air Quality Research	$ 98,223.00	$	$	$
17. Year 2				
18.				
19.				
20. TOTAL (sum of lines 16 - 19)	$ 98,223.00	$	$	$

SECTION F - OTHER BUDGET INFORMATION	
21. Direct Charges: Personnel+Fringe+Travel+Supplies	22. Indirect Charges: CSWR:68% of direct charges for 2013-2015
23. Remarks:	

ASSURANCES - NON-CONSTRUCTION PROGRAMS

Public reporting burden for this collection of information is estimated to average 15 minutes per response, including time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding the burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to the Office of Management and Budget, Paperwork Reduction Project (0348-0040), Washington, DC 20503.

PLEASE DO NOT RETURN YOUR COMPLETED FORM TO THE OFFICE OF MANAGEMENT AND BUDGET. SEND IT TO THE ADDRESS PROVIDED BY THE SPONSORING AGENCY.

NOTE: Certain of these assurances may not be applicable to your project or program. If you have questions, please contact the awarding agency. Further, certain Federal awarding agencies may require applicants to certify to additional assurances. If such is the case, you will be notified.

As the duly authorized representative of the applicant, I certify that the applicant:

1. Has the legal authority to apply for Federal assistance and the institutional, managerial and financial capability (including funds sufficient to pay the non-Federal share of project cost) to ensure proper planning, management and completion of the project described in this application.

2. Will give the awarding agency, the Comptroller General of the United States and, if appropriate, the State, through any authorized representative, access to and the right to examine all records, books, papers, or documents related to the award; and will establish a proper accounting system in accordance with generally accepted accounting standards or agency directives.

3. Will establish safeguards to prohibit employees from using their positions for a purpose that constitutes or presents the appearance of personal or organizational conflict of interest, or personal gain.

4. Will initiate and complete the work within the applicable time frame after receipt of approval of the awarding agency.

5. Will comply with the Intergovernmental Personnel Act of 1970 (42 U.S.C. §§4728-4763) relating to prescribed standards for merit systems for programs funded under one of the 19 statutes or regulations specified in Appendix A of OPM's Standards for a Merit System of Personnel Administration (5 C.F.R. 900, Subpart F).

6. Will comply with all Federal statutes relating to nondiscrimination. These include but are not limited to: (a) Title VI of the Civil Rights Act of 1964 (P.L. 88-352) which prohibits discrimination on the basis of race, color or national origin; (b) Title IX of the Education Amendments of 1972, as amended (20 U.S.C.§§1681-1683, and 1685-1686), which prohibits discrimination on the basis of sex; (c) Section 504 of the Rehabilitation Act of 1973, as amended (29 U.S.C. §794), which prohibits discrimination on the basis of handicaps; (d) the Age Discrimination Act of 1975, as amended (42 U. S.C. §§6101-6107), which prohibits discrimination on the basis of age; (e) the Drug Abuse Office and Treatment Act of 1972 (P.L. 92-255), as amended, relating to nondiscrimination on the basis of drug abuse; (f) the Comprehensive Alcohol Abuse and Alcoholism Prevention, Treatment and Rehabilitation Act of 1970 (P.L. 91-616), as amended, relating to nondiscrimination on the basis of alcohol abuse or alcoholism; (g) §§523 and 527 of the Public Health Service Act of 1912 (42 U.S.C. §§290 dd-3 and 290 ee- 3), as amended, relating to confidentiality of alcohol and drug abuse patient records; (h) Title VIII of the Civil Rights Act of 1968 (42 U.S.C. §§3601 et seq.), as amended, relating to nondiscrimination in the sale, rental or financing of housing; (i) any other nondiscrimination provisions in the specific statute(s) under which application for Federal assistance is being made; and, (j) the requirements of any other nondiscrimination statute(s) which may apply to the application.

7. Will comply, or has already complied, with the requirements of Titles II and III of the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970 (P.L. 91-646) which provide for fair and equitable treatment of persons displaced or whose property is acquired as a result of Federal or federally-assisted programs. These requirements apply to all interests in real property acquired for project purposes regardless of Federal participation in purchases.

8. Will comply, as applicable, with provisions of the Hatch Act (5 U.S.C. §§1501-1508 and 7324-7328) which limit the political activities of employees whose principal employment activities are funded in whole or in part with Federal funds.

9. Will comply, as applicable, with the provisions of the Davis-Bacon Act (40 U.S.C. §§276a to 276a-7), the Copeland Act (40 U.S.C. §276c and 18 U.S.C. §874), and the Contract Work Hours and Safety Standards Act (40 U.S.C. §§327-333), regarding labor standards for federally-assisted construction subagreements.

10. Will comply, if applicable, with flood insurance purchase requirements of Section 102(a) of the Flood Disaster Protection Act of 1973 (P.L. 93-234) which requires recipients in a special flood hazard area to participate in the program and to purchase flood insurance if the total cost of insurable construction and acquisition is $10,000 or more.

11. Will comply with environmental standards which may be prescribed pursuant to the following: (a) institution of environmental quality control measures under the National Environmental Policy Act of 1969 (P.L. 91-190) and Executive Order (EO) 11514; (b) notification of violating facilities pursuant to EO 11738; (c) protection of wetlands pursuant to EO 11990; (d) evaluation of flood hazards in floodplains in accordance with EO 11988; (e) assurance of project consistency with the approved State management program developed under the Coastal Zone Management Act of 1972 (16 U.S.C. §§1451 et seq.); (f) conformity of Federal actions to State (Clean Air) Implementation Plans under Section 176(c) of the Clean Air Act of 1955, as amended (42 U.S.C. §§7401 et seq.); (g) protection of underground sources of drinking water under the Safe Drinking Water Act of 1974, as amended (P.L. 93-523); and, (h) protection of endangered species under the Endangered Species Act of 1973, as amended (P.L. 93-205).

12. Will comply with the Wild and Scenic Rivers Act of 1968 (16 U.S.C. §§1271 et seq.) related to protecting components or potential components of the national wild and scenic rivers system.

13. Will assist the awarding agency in assuring compliance with Section 106 of the National Historic Preservation Act of 1966, as amended (16 U.S.C. §470), EO 11593 (identification and protection of historic properties), and the Archaeological and Historic Preservation Act of 1974 (16 U.S.C. §§469a-1 et seq.).

14. Will comply with P.L. 93-348 regarding the protection of human subjects involved in research, development, and related activities supported by this award of assistance.

15. Will comply with the Laboratory Animal Welfare Act of 1966 (P.L. 89-544, as amended, 7 U.S.C. §§2131 et seq.) pertaining to the care, handling, and treatment of warm blooded animals held for research, teaching, or other activities supported by this award of assistance.

16. Will comply with the Lead-Based Paint Poisoning Prevention Act (42 U.S.C. §§4801 et seq.) which prohibits the use of lead-based paint in construction or rehabilitation of residence structures.

17. Will cause to be performed the required financial and compliance audits in accordance with the Single Audit Act Amendments of 1996 and OMB Circular No. A-133, "Audits of States, Local Governments, and Non-Profit Organizations."

18. Will comply with all applicable requirements of all other Federal laws, executive orders, regulations, and policies governing this program.

19. Will comply with the requirements of Section 106(g) of the Trafficking Victims Protection Act (TVPA) of 2000, as amended (22 U.S.C. 7104) which prohibits grant award recipients or a sub-recipient from (1) Engaging in severe forms of trafficking in persons during the period of time that the award is in effect (2) Procuring a commercial sex act during the period of time that the award is in effect or (3) Using forced labor in the performance of the award or subawards under the award.

* SIGNATURE OF AUTHORIZED CERTIFYING OFFICIAL	* TITLE
Ling Chan	Administrator
* APPLICANT ORGANIZATION	* DATE SUBMITTED
The Center for Severe Weather Research	12/06/2012

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FORM **CD-511**
(REV 1-05)

U.S. DEPARTMENT OF COMMERCE

CERTIFICATION REGARDING LOBBYING

Applicants should also review the instructions for certification included in the regulations before completing this form. Signature on this form provides for compliance with certification requirements under 15 CFR Part 28, 'New Restrictions on Lobbying.' The certifications shall be treated as a material representation of fact upon which reliance will be placed when the Department of Commerce determines to award the covered transaction, grant, or cooperative agreement.

LOBBYING

As required by Section 1352, Title 31 of the U.S. Code, and implemented at 15 CFR Part 28, for persons entering into a grant, cooperative agreement or contract over $100,000 or a loan or loan guarantee over $150,000 as defined at 15 CFR Part 28, Sections 28.105 and 28.110, the applicant certifies that to the best of his or her knowledge and belief, that:

(1) No Federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress in connection with the awarding of any Federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, 'Disclosure Form to Report Lobbying.' in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers (including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements) and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure occurring on or before October 23, 1996, and of not less than $11,000 and not more than $110,000 for each such failure occurring after October 23, 1996.

Statement for Loan Guarantees and Loan Insurance

The undersigned states, to the best of his or her knowledge and belief, that:

In any funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this commitment providing for the United States to insure or guarantee a loan, the undersigned shall complete and submit Standard Form-LLL, 'Disclosure Form to Report Lobbying,' in accordance with its instructions.

Submission of this statement is a prerequisite for making or entering into this transaction imposed by section 1352, title 31, U.S. Code. Any person who fails to file the required statement shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure occurring on or before October 23, 1996, and of not less than $11,000 and not more than $110,000 for each such failure occurring after October 23, 1996.

As the duly authorized representative of the applicant, I hereby certify that the applicant will comply with the above applicable certification.

* NAME OF APPLICANT: The Center for Severe Weather Research

* AWARD NUMBER: NOAA-OAR-OWAQ-2013-200346

* PROJECT NAME: Doppler Radar Data Assimilation

Prefix:

* First Name: Ling

Middle Name:

* Last Name: Chan

Suffix:

* Title: Administrator

* SIGNATURE: Ling Chan

* DATE: 12/06/2012