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5.x Post-Processing for Model Guidance and Ensembles

5.x.1 State of the Science

Statistical post-processing (StatPP) methods have been successfully applied for many decades now to weather predictions, helping to ameliorate forecast bias and to produce reliable, skillful, downscaled deterministic and probabilistic forecasts of weather events (e.g., surface temperatures and winds, sky cover, rainfall probability and amount) that are of direct importance to the user. StatPP is also used to forecast important weather elements that are not directly forecast by NWP (e.g., turbulence and tornadoes). StatPP works most smoothly when there is a relatively large sample of past forecasts that are statistically consistent in accuracy and bias with the current forecast. If such forecasts as well as high-quality analysis and/or observational data are available, then it is relatively straightforward to develop and apply statistical corrections that produce dramatically improved forecast accuracy, skill, and reliability. Examples include Model Output Statistics (MOS) and the North American Ensemble Forecast System (NAEFS) Statistical Post-process (SPP) of the NWS, and the Best Data technique used by the UK MetOffice.

Recently, the NWS embarked on a new project, known as the National Blend of Models (NBM) project, with the goal of yielding centrally produced, high-resolution, nationally consistent, statistically post-processed and blended forecast guidance for a wide range of forecast variables. Forecast inputs will initially come from a variety of global models, including the NCEP GFS and GEFS, and deterministic and ensemble predictions from the Canadian Meteorological Centre (CMC). Other future partners are possible. Blended, post-processed forecast guidance will provide a first guess for the high-resolution National Digital Forecast Database (NDFD), which is used by the NWS to make weather forecasts for across the country. The initial stages of this project were funded by the NWS' so-called "Sandy Supplemental" project. Continuing this project through to completion will require additional funds, which will hopefully continue through this NGGPS initiative. Another StatPP effort is the NAEFS SPP mentioned above. This combines GEFS, and CMC ensemble forecasts to produce a multi-model ensemble forecasts, especially for NOAA Climate Prediction Center (CPC).

The longer-term success of the National Blend is dependent on the quality of not only the underlying statistical methods, but also on the supporting databases, including reanalysis and reforecasts necessary to support the post-processing of NWS model guidance. The Sandy Supplemental did not provide any funding for the development of these data sets. Given the broad needs for reanalyses, funding from a variety of sources is needed to jumpstart the process. A team of a least half a dozen for reanalysis research, generation, and quality control is recommended, and extensive computational resources (>> 100M CPUh) are also anticipated. Additional funds would be needed to complete the reanalyses and to set up a regular production of reforecasts to continue the project for through Year 5.

What if new reanalyses are not available for initialization? In this case older reanalyses may be used, but the direct use of these may result in reforecasts with different statistical characteristics relative to the real-time forecast system, making them less useful for post-processing. A possible way to use older reanalyses and have less inconsistency may be to adjust the older reanalyses in some fashion so that the older reanalysis states are more statistically consistent with the real-time states. This approach has been explored, with some success, at Environment Canada and Meteo France, neither of which has a reanalysis. They have chosen to use ERA-Interim, with some adjustment of their near-surface and surface fields to be more consistent with the ERA-Interim states. We continue to find value in spending the time and effort to address the problem in the most scientifically defensible manner, which is to say to regularly generate reanalyses and reforecasts rather than spending resources developing technology to allow retro-fitting to older re-analyses.

Post-processing procedures require not only high-quality reforecasts but high-quality observational / analysis training data. It is anticipated that high-resolution surface reanalyses from the Real-Time Mesoscale Analysis (RTMA) will provide the high-resolution analyses for the post-processing training and validation of many fields in the National Blend. As of mid-2015, the RTMA has been improved somewhat through use of HRRR (High-resolution Rapid Refresh) forecasts as the first guess. Still, in many regions, especially in the complex terrain of the western US, there are still significant errors in RTMA analyses. Given the dependence of post-processing success on the RTMA, its improvement is an area that is considered of critical importance and deserving of NGGPS funding.

Another anticipated goal of NGGPS will be to provide useful probabilistic forecast guidance at longer leads, potentially to +30 days and beyond. There may be StatPP issues that are specific to these longer leads, where the initial-condition related signal has waned and where what marginal predictable signal there is will be linked to low-frequency modes of variability such as El Niño – Southern Oscillation (ENSO), the Madden-Julian Oscillation, Arctic Oscillation, Quasi-Biennial Oscillation, and such). It is thus an NGGPS priority to develop a better understanding of what post-processing methods work best for extended leads and then to apply them to develop new products, especially for high-impact weather (e.g., tropical cyclone frequency, drought likelihood, severe-weather potential).

One area of activity for seasonal prediction has been the development of multi-model ensemble guidance and multi-model post-processed guidance, such as through the National Multi-Model Ensemble project. Multi-model concepts are more difficult to apply at the 1-4 week leads, as there is memory of the initial condition, and ideally multiple models should be initialized with their own cycled data assimilation scheme. Accordingly, the development of multi-model products is a lower priority than the development of the supporting infrastructure (reanalyses, reforecasts) that permit one to extract maximum information from NOAA's primary chosen monthly prediction system. The consolidation of prediction efforts around one high-quality global model within NOAA was also recommended recently by the UCAR Model Advisory Committee (UMAC)

Finally, while NOAA has increased its use of post-processed guidance, we note that the post-processing activity has largely been uncoordinated. For example, probabilistic hurricane prediction and severe-storms prediction ("*Warn-on-Forecast*") might share some post-processing concepts, but the development of these technologies is happening with little coordination. Further, NOAA senior management does not have a good sense of the full portfolio of post-processing R&D, nor the relative priorities for this diverse set of activities, nor what supporting infrastructure is needed (e.g., a storage plan for reforecasts, real-time forecasts, and reanalyses). To this end, in January 2016, NGGPS supported a workshop named The Future of Statistical Post-processing in NOAA and the Weather Enterprise in College Park, Maryland. The organizers were very pleased to see substantial attendance and interest from non-NOAA (especially academic and commercial) partners. Environment and Climate Change Canada and the UK MetOffice both sent representatives. Information gathered from this workshop was briefed to NOAA managers and distilled into a document named High-Level Functional Requirements for Statistical Post-Processing in NOAA.

5.x.2 Objectives

The overall goals are to improve post-processing methods for both deterministic and ensemble models, resulting in dramatically improved model accuracy, skill, and reliability. These will be addressed by:

- Generating the supporting data sets (global reanalysis and reforecasts) necessary to support the post-processing development, including high-resolution reanalyses from a markedly improved RTMA system.
- Enhancing the (Sandy-Supplemental funded) National Blend project's post-processing for ensemble and deterministic prediction, including: (a) improving the post-processing and blending methods, allowing them to fully exploit the information in the improved ensembles, and (b) extending the post-processing and blending methods to include extra high-impact forecast variables and a wider range of forecast lead times.
- Developing post-processing techniques specific to the forecast problems of longer-lead forecasts (weeks 2-4).
- Facilitate StatPP R2O transitions within NOAA by developing a community-based software system designed to statistically post-process NWP output.

5.x.3 Milestones, Resource Requirements, and Outcomes

1. Generate a global reanalysis suitable for the initialization of NGGPS global reforecasts. Set up a durable infrastructure so that it becomes progressively easier to regenerate reanalyses every few years thereafter.
    - **Lead Organization:** EMC and ESRL/PSD
    - **Activities:**
        - Determine the configuration (period of reanalysis, resolution, ensemble size, etc.), analysis methodology, and specific observational data sets are to be used in this reanalysis.
        - Set up (and deliver) a common observation data archive that can be used for multiple current and future worldwide reanalysis efforts, perhaps in

conjunction with ECMWF and Japan Meteorological Agency (JMA) who also do reanalysis.
        - Determine the computational and storage resources needed to conduct the complete reanalysis (competing activities include reforecast generation and real-time ensemble generation). This may include scoping out cloud storage of the data.
        - Conduct tests (and leveraging tests of others) to determine how to preserve reanalysis continuity during periods when the observation data set changes, e.g., with the advent of AMSU-A radiance assimilation.
        - Determine appropriate methodologies for accounting for interactions between the land surface, ocean surface, and atmosphere, e.g., how to cycle the land state analysis in conjunction with the reanalysis.
        - Produce the reanalysis.
        - Archive the data in convenient format(s).
        - Document the reanalysis with a journal article(s).
    - **Milestones and deliverables:** By end of year 1, determine the configurations and build observation data archive structure. By end of year 2, have prepared all input observations, performed tests for reanalysis continuity, and developed methods for cycling land state. By end of year 3, deliver reanalysis, data archive, and peer-reviewed journal article.
    - **Anticipated collaborating organizations:** CPC.
    - **Priority:** Highest.
    - **Duration:** 3 years.
    - **Points of contact:** Tom Hamill (ESRL/PSD) and Michael Farrar (EMC).

2. Develop global GEFS reforecasts based on reanalyses generated above.
    - **Lead Organization:** EMC
    - **Activities:**
        - Determine the configuration (number of members, number of days between reforecasts, number of cycles per day) and what output fields are to be saved. These may include considerations of the relative benefits of using additional CPU for additional reforecasts vs. higher-resolution for the system.
        - Generate the reforecasts.
        - Archive the data in convenient format(s).
        - Document the reanalysis with a journal article(s).
    - **Milestones and deliverables:** By end of year 1, determine the reforecast configuration. Produce reforecasts starting roughly mid-way through year 2. Complete reforecasts by end of year 3, with associated journal article, and have generated the conveniently formatted archive.
    - **Anticipated collaborating organizations:** ESRL/PSD, CPC, MDL.
    - **Priority:** Highest.
    - **Duration:** 3 years.
    - **Points of contact:** Michael Farrar (EMC) and Tom Hamill (ESRL/PSD)

3. Develop improved high-resolution surface-based hourly reanalysis and real-time analysis for the US based on greatly enhanced RTMA technology.

- **Lead Organization:** EMC
- **Activities:**
  - Determine what major RTMA system improvements may be necessary to provide dramatically improved surface analyses, especially in the western US.
  - Generate the surface-based reanalyses.
  - Archive the data in convenient format(s).
  - Document the surface-based reanalyses with a journal article(s).
- **Milestones and deliverables:** By the end of year 1, evaluate several methods for improving the performance of the RTMA system; this component of the work may be suitable for collaborations with a university or NOAA lab partner. By the end of year 2, have the enhanced RTMA software developed and fully tested. By the end of year 3, have a RTMA-based reanalysis in place to support post-processing of the new reforecast data set.
- **Anticipated collaborating organizations:** Universities, ESRL divisions.
- **Priority:** Highest.
- **Duration:** 3 years.
- **Points of contact:** Manuel Pondeca (EMC) and Stan Benjamin (ESRL/GSD) .

4. Further develop and refine post-processing techniques in support of the National Blend and other high-priority NOAA projects as determined by the summit proposed above.

- **Lead Organization:** MDL
- **Activities:**
  - For National Blend / NGGPS priority (e.g., sky-cover forecasts), we expect distinct development projects. These development projects may span 2-3 years and are expected to come later in the NGGPS funding period, after reanalyses/reforecasts are available for training.
  - Possibly an NGGPS task to fund infrastructure upgrades such as the evolution of the NDFD to support probabilistic guidance or for the more extensive archival of model data in convenient formats.
- **Milestones and deliverables:** Depends on the funded activity. Generally expect that year 1 of funding will provide a new post-processing algorithm, and years 2-3 will test and operationally implement algorithm and document them in the form of a peer-reviewed article.
- **Anticipated collaborating organizations:** Universities, ESRL divisions.
- **Priority:** Moderate. Perhaps some cost-sharing from MDL.
- **Duration:** 2-3 years but starting 1-2 years hence to allow for development of reanalyses/reforecasts.
- **Points of contact:** Matthew Peroutka, MDL.

Week 2-4 product development proposed activity:

5. Develop and apply new post-processing methodologies for longer (week 2-4) forecast leads.

- **Lead Organization:** CPC
- **Activities:** Determine focus areas for development of new post-processing methodologies at the longer lead times (such as those that leverage modes of low-frequency variability (ENSO)). Additionally, deliver experimental post-processing methods for 1-2 week-range severe weather forecasts and flash drought that can be applied to weeks 3 and 4, pending their availability at a later date. Apply methodologies and verify skill. Document and report results.
- **Milestones and deliverables:** Deliver experimental post-processing methods for 1-2 week-range severe weather forecasts and flash drought that can be applied to weeks 3 and 4, pending their availability at a later date.
- **Anticipated collaborating organizations:** NCEP/EMC, to coordinate on extended-range (15-30 day) GEFS development.
- **Priority:** Medium. The challenge here is that products are needed very quickly, but reanalyses and reforecasts to +30 days lead will take some time to develop.
- **Duration:** 3 years
- **Points of contact:** Dan Collins (CPC).

6. Associated Proposal: Development of Ensemble Forecast Approaches to Downscale, Calibrate and Verify Precipitation Forecasts.

- **Lead Organization**: Dr. Dave Novak – Lead PI, NOAA/NWS Weather Prediction Center. Dr. Geoffrey DiMego – Co-PI, NOAA/NWS/EMC.
- **Activities**: Building on and leveraging the infrastructure and expertise of the Hydrometeorological Testbed (HMT) at the Weather Prediction Center (WPC) and the Mesoscale Modeling Branch of the Environmental Modeling Center (EMC), this proposal aims to enhance the skill of high-resolution quantitative precipitation forecasts (QPF) for detection of high-impact events utilizing the emerging components of the NGGPS. The work will support three key activities:
    - Downscaling deterministic and probabilistic QPF using dynamical and statistical methods.
    - Calibrating QPFs using frequency matching.
    - Assisting EMC, HMT, and WPC in evolving toward unified verification using the Development Testbed Center's (DTC) Model Evaluation Tools (MET) system.

  Since the entire NGGPS will not be fully available immediately, currently available models will be used to simulate the NGGPS for this project to proceed.
- **Milestones and deliverables**:
    - February 2015
        - Procure a workstation for the part-time contractor and initiate the project.
    - March-June 2015
        - Assess ongoing dynamically downscaled QPF products.
        - Begin development of frequency matching method to correct frequency bias of ENSQPF (WPC's in-house ensemble based QPF guidance).

- July-September 2015
  - Implement the frequency matching method for ENSQPF.
  - Refine and modify the dynamic downscaling based on verification data and availability of new models.
  - Identify any requirements for MET developers to support EMC, HMT, and WPC verification activities.
  - Prepare mid-Year project report.
- October-December 2015
  - Evaluate and refine the frequency matching method for ENSQPF.
  - Assess and refine dynamic downscaling of QPF.
- January 2016
  - Prepare the downscaling and bias-correction techniques for implementation in relevant NGGPS components.
  - Issue final project report.

- **Anticipated collaborating organizations**: Hydrometeorological Testbed at the Weather Prediction Center and the Developmental Testbed Center.
- **Priority**: High.
- **Duration**: 02/01/2015-01/31/2016.
- **Points of contact**: Dr. Dave Novak (david.novak@noaa.gov).

7. Associated Proposal: Calibration and Evaluation of GEFS Ensemble Forecasts at Weeks 2-4.

- **Lead Organization**: Ping Liu – Lead PI, State University of New York at Stony Brook.
- **Activities**: This project will decompose routinely the ensemble forecasts of GEFS at extended range into a limited number of principal components to calibrate with observations. This project will expand the existing metrics suitable for calibrating and evaluating the upgraded GEFS forecasts at weeks 2-4.
- **Milestones and deliverables**:
  - May-August 2015
    - Download reforecast data and ingest real-time ensemble forecasts of GEFS.
    - Program the PCA before calibration.
    - Calibrate the reforecasts with reconstructed signals from principal component analysis
    - Verify the calibrated signals using existing metrics of GEFS.
  - September-December 2015
    - Continue the calibration and verification on the reconstructed signals.
    - Program the calibration of blocking episodes and MJO.
    - Verify the onset of TC-genesis, blocking and MJO.
  - January-April 2016
    - Continue conventional calibration and verification on the reconstructed signals.

        - Evaluate the onset of blocking episodes and MJO.
- **Anticipated collaborating organizations**: Co-Investigators: Yuejian Zhu, NOAA/EMC and Qin Zhang, NOAA/CPC.
- **Priority**: High.
- **Duration**: 05/01/2015-04/30/2016.
- **Points of contact**: Ping Liu (ping.liu@stonybrook.edu).

8. Associated Proposal: Probabilistic Forecasts of Precipitation Type and Snowfall Amounts based on Global Ensemble Forecasts.

- **Lead Organization**: Tom Hamill – Lead PI, ESRL/PSD.
- **Activities**: Develop novel experimental post-processing methods for precipitation type and snowfall amount. For precipitation type, determine whether statistical classification methods like quadratic discriminant analysis (QDA; e.g. Hastie et al., 2001) yield sharper separations and more skillful classification of the different precipitation types than the current model output statistics (MOS) approach. For snowfall amount, extend a recent approach by Scheuerer (2014) for quantitative precipitation forecasting, such as to take the additional aspects of estimating the probability of snowfall (as opposed to liquid precipitation) and converting estimated meltwater to snowfall.
- **Milestones and deliverables**:
    - May-July 2015
        - Collate forecast and observation data at ESRL.
        - Begin a preliminary analysis of the data.
        - Test existing methods using standard metrics.
    - August-December 2015
        - Develop and study advanced post-processing methods such as QDA for precipitation type and snowfall amount.
    - January-April 2016
        - Compare strategies to deal with limited training data, with the aim of eventually calibrating forecasts at arbitrary locations.
        - Write journal article.
        - Liaise with Blender management to prepare for follow-on testing and a transition to operations.
- **Anticipated collaborating organizations**: Co-Investigators: Scott Gregory, CIRES and ESRL/GSD and Michael Scheuerer, CIRES and ESRL/PSD.
- **Priority**: High.
- **Duration**: 05/01/2015-04/30/2016.
- **Points of contact**: Tom Hamill (tom.hamill@noaa.gov).

9. Associated Proposal: An Investigation of Reforecasting Applications for Next Generation Aviation Weather Prediction: An Initial Study of Cloud and Visibility Prediction.

- **Lead Organization**: Dr. David Bright – Lead PI, NOAA/NWS/NCEP Aviation Weather Center.
- **Activities**: This exploratory project will utilize NOAA's second-generation Global Ensemble Forecast (GEFS) reforecast dataset, and be the first aviation-

based GEFS reforecast study to construct a model climatology and downscaled calibrated prediction of instrument meteorological conditions (IMC).

- **Milestones and deliverables**:
  - March 2015
    - Student hire and IT resources in place.
  - August 2015
    - Progress report to the NGGPS Program on research to date, initial findings, and any issues.
  - November 2015
    - Deliver report on the initial study on the application of reforecast data to aviation applications.
  - January 2016
    - Deliver findings at AMS Annual Meeting.
- **Anticipated collaborating organizations**: CIRA.
- **Priority**: High.
- **Duration**: 11/01/2014-01/30/2016.
- **Points of contact**: David Bright (david.bright@noaa.gov).

10. Associated Proposal: Improved Statistical Post-Processing with the Bayesian Processor of Ensemble (BPE).

- **Lead Organization**: Zoltan Toth – Lead PI, NOAA/OAR/ESRL/Global Systems Division.
- **Activities**: Bring a team of experts from NOAA operations (MDL and EMC), NOAA research (GSD), and academia together to work in a common framework. Develop scientifically based, comprehensive algorithms and software for use in unified NWS StatPP operations to address both the calibration of prognostic variables and the derivation of additional user variables. Test and demonstrate the algorithms for the calibration of prognostic variables.
- **Milestones and deliverables**:
  - Year 1
    - Milestone 1: Assemble algorithms and codes for basic end-to-end BPE system.
    - Deliverable 1: End-to-end basic BPE software tested and complete (7 months from start).
    - Milestone 2: Set up test environment for a strictly controlled comparison of BPE and EKDMOS for a selected variable at selected observation site(s) using GEFS ensemble data.
    - Deliverable 2: Testing environment prepared (10 months).
    - Milestone 3: Perform BPE - EKDOMS test.
    - Deliverable 3: Report on test results (12 months).
  - Year 2
    - Milestone 1: Expand BPE software to work on NWP grids instead of selected observation sites.
    - Deliverable 1: Gridpoint-based BPE software (6 months).

        - Milestone 2: Set up test environment for a strictly controlled comparison of BPE with NAEFS for a selected variable on a model grid using two ensembles (GEFS and CMC) and a high resolution control forecast, or another configuration consistent with NAEFS operations.
        - Deliverable 2: Testing environment prepared (9 months).
        - Milestone 3: Perform BPE – NAEFS test.
        - Deliverable 3: Report on test results (12 months).
    - **Anticipated collaborating organizations**: Co-PI's: Mark Antolik (NOAA/NWS/Meteorological Development Laboratory), Malaquias Pena (NOAA/NWS/NCEP/Environmental Modeling Center), and Roman Krzysztofowicz (University of Virginia) as Co-PI (Consultant).
    - **Priority**: High.
    - **Duration**: 03/01/2015-TBD (unfunded activities proposed through 5 years).
    - **Points of contact**: Zoltan Toth (zoltan.toth@noaa.gov).

11. Validation of Significant Weather Features and Processes in Operational Models Using a Cyclone Relative Approach

- **Lead Organization**: Dr. Brian A. Colle, Stony Brook University, SUNY, CO-I: Dr. Edmund Kar-Man Chang, Stone Brook University, SUNY
- **Activities**: This project has four main focus areas/activities:
    - Verification of extratropical cyclones, associated significant weather, and the physical processes within the Global Forecast System (GFS) model and GFS ensemble
    - Comparison of the verification results with any parallel model runs and new models to help validate and develop the next generation of models
    - Provide the cyclone relative software package to the operational centers and the broader community, so they can utilize it in their research and operational verification
    - Work with the operational centers to utilize the code in testbeds and experiments (e.g., Winter Weather Experiment at WPC).
- **Milestones and deliverables**:

    Year 1 activities
    - Dataset collection (GFS and GEFS forecasts)
    - Tracking of cyclones and matching of observation/model
    - Basic verification metrics for cyclones (intensity, speed, track) using analyses
    - Collection of other observational datasets and interpolation to grid (multi---sensor precipitation, cloud products, etc.).

- Track other important cyclone features instead of central pressure (moisture plumes, low-level jets, etc…)
- Complete cyclone relative verification for different cyclone stages (from genesis to decay) and storm intensity of the temperature, moisture, precipitation, and winds around the cyclone. Look at not only mean stats, but also various probabilistic metrics using various thresholds for these variables.
- Separate the verification results by regimes using large-scale and regional flow composites.
- Develop MET module (METViewer) to composite statistics around cyclone (plot spatially and calculate metrics), and ability to map results back to geographic grid. Potential approaches include 1) extending tropical cyclone QPF compositing capability currently under development within the DTC; 2) development of percentile thresholding capability to be able to identify key synoptic features for both categorical statistics calculations and the MODE tool; 3) extending current series analysis capability to plot time-series analysis geographically; 4) use MODE-Time Domain algorithms on cyclones to diagnose additional track attributes.

  Year 2 activities
- Apply MODE to validate important features around the cyclone (e.g. jet streaks, low-level jets, heavy precipitation, strong surface winds, etc.)
- Map the cyclone relative verification results back to the Earth---relative grid, so the results can be related to various terrain, coast and sea-surface temperature features.
- Compute cyclone relative verification for relevant physical processes: stability, surface fluxes, temperature gradients, cloud cover, and a moisture budget around the storm (flux into/out of box, surface moisture flux, and precipitation fallout).
- Provide MET software tools for various operational centers to continue the validation efforts after this project for next generation of models.
- Use software and scripts for operational ensembles and in WPC Winter Weather Experiment.
- Add several additional cases to the Mesoscale Model Evaluation Testbed (MMET) based on results of the analyses, to make them available to others in the community.

- **Anticipated collaborating organizations**: EMC, WPC, OPC, AWC, and DTC
- **Priority**: High.
- **Duration**: 05/01/2015-04/30/2015.
- **Points of contact**: Dr. Brian Colle, (brian.colle@stonybrook.edu)

12. Subseasonal Prediction over the Western US

- **Lead Organization**: Clifford F. Mass Professor, University of Washington, Co-I: Gregory J. Hakim, University of Washington.
- **Activities**: The synoptic skill of the NOAA Climate Forecasting System (CFS) will be evaluated over western North America for various projections, seasons, variables, and averaging times. Next, CFS forecasts through three months will be dynamically downscaled to mesoscale resolution (12-km grid spacing) using the WRF atmospheric model. The resulting forecasts will be post-processed to remove bias and to produce calibrated probabilistic forecasting information. The quality of the coupled system will be evaluated over a multi-year period and will hopefully lead to an improved multi-week prediction capability for the National Weather Service over the western U.S.
- **Milestones and deliverables**:

  Year 1 activities:
  - May 1- Sept. 30, 2015
    - Acquisition of archival CFS grids
    - Building WRF downscaling system
    - Beginning evaluation of synoptic skill of CFS over the western U.S.
  - October 1-April 30, 2016
    - Initiation of real-time downscaling of CFS forecasts using WRF over the western U.S.
    - Continuation of evaluation of CFS synoptic skill
    - Initiation of downscaling of CFS for archival periods.
  - May 1-Sept. 30, 2016
    - Completion of CFS synoptic evaluation
    - Continuation of real-time WRF downscaling of CFS
    - Evaluation of post-processing of CFS and WRF downscaled forecast.
  - October 1-April 2017
    - Completion of downscaling forecasts.
    - Evaluation of downscaled forecasts, including comparison to raw and post-processed CFS forecasts
    - Preparation of summary papers.
- **Anticipated collaborating organizations**: NCEP/EMC, Western Region, West Coast NWS Forecast Offices
- **Priority**: High.
- **Duration**: 05/01/2015 – 04/30/2017.
- **Points of contact**: Clifford Mass, (cmass@uw.edu).