Hydrologic Verification

NWM-Related Activities

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Hydrologic Evaluation

- Hydrologic modeling needs to be underpinned by solid evaluation
- Several verification activities are ongoing at OWP, NCAR and OAR which support NWM research and operations
- Potential exists for collaboration between these applications and MET package, and more broadly with verification across the hydrologic landscape (EMC, NASA, USGS efforts, NGGPS, UFS). But currently unclear what links are.
- As models extend into new application spaces and higher resolutions, the importance--and degree of difficulty--of verification increases
  - NWM CONUS-wide high-resolution hydrologic modeling
  - Flood inundation mapping
  - Coastal coupling
  - Hyper-resolution modeling
  - Groundwater modeling

Verification Issues Associated with Multiple Sources of Flooding at Coast

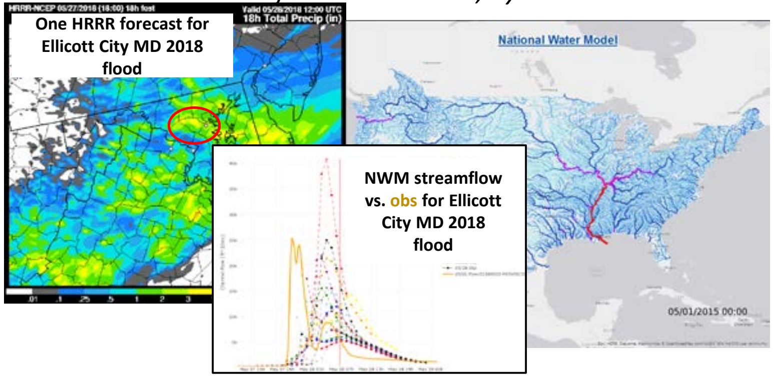
- Multiple sources of flooding exist at the coast
    - Wind and tide (storm surge, waves and high tide)
    - Rainfall-driven (river and flash floods)
    - Environmental (sea level rise and subsidence)
- This complicates verification of Integrated Water Prediction models
- Verification issues
    - Availability of data
        - Spatial extent of flooding (especially at high resolution) difficult to obtain/determine
        - Comprehensive suite of data rarely available
            - Difficult to determine relative contribution of flood processes
            - Difficult to verify process representation within model and relative error contribution
        - Storm emergency conditions (and/or darkness) can prevent data acquisition
    - Difficult to reconcile sources of observations (i.e., high water marks with timing indicators)
    - Multiple quantities to verify (both model outputs and forcing inputs) in linked fashion
    - Multiple observation formats and sources complicate use and interpretation
    - Crowd-sourced data promising but often suffers from lack of detail and quality control

Sources of Error: Model Forcing Versus Hydrologic Modeling

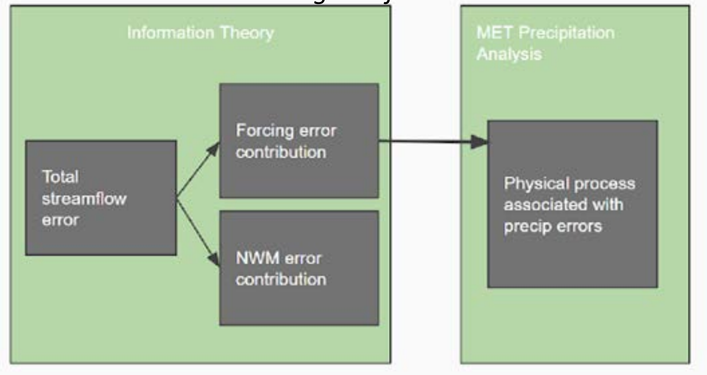
➢ *Charge: OWP Evaluate Forcings Project: Begin exploring how to disentangle NWM error from forcing errors (FY18)*

- Explore methods that are ideally:
  - Flexible; work across regions, time scales
  - Understandable by researchers, forecasters, model developers
- Initial approaches:
  - Statistical error separation methods ("Information Theory")
  - Traditional meteorological verification methods correlated with traditional hydrologic verification methods

NWM errors stem from both atmos, hydro model sources



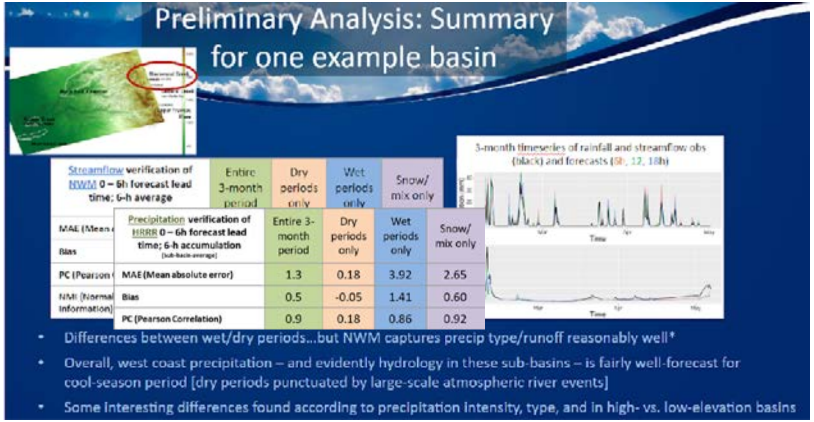
Evaluate Forecast Forcings Project initial method sketch



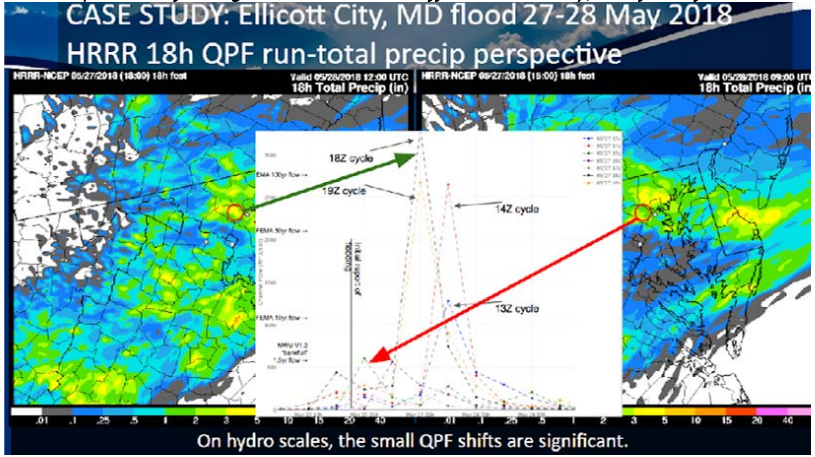
Sources of Error: OWP Evaluate Forecast Forcing Project

- Work to date:
  - Regional, single-season prototype combining verification of precip (forcing skill, uncertainty) and streamflow forecast (uncertainty)
  - Ellicott City, MD 2018 flood case study
- *Preliminary* results:
  - California cold season prototype: short-term forcing quite skillful; suggests *for this particular region and this particular evaluation period* forecast error more from NWM itself. NWM error from rain-snow/melt processes relatively small.
  - Ellicott City: Basin-to-basin and cycle-to-cycle variability in QPF and NWM errors (hydro-significant QPF errors; streamflow timing errors even with good forcing forecasts *for this particular event*)
  - "Traditional" met verification (using MET software) critical to physical process, error understanding
  - Information theory: potentially promising but steep learning curve; requires longer data records, meteorological context
  - Region-specific, weather-specific hydro verification while complex, is likely to be of greatest benefit to NWM error understanding

Summary of California 3-month prototype assessment



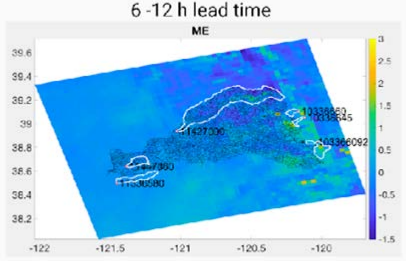
Example: Both forcing and NWM errors affect Ellicott City, MD flood forecasts



Using MET to Link Errors in Model Output to Forecast Forcings

Examples of MET software used to understand forecast forcing errors (e.g., gridstat, series_analysis, MODE…)

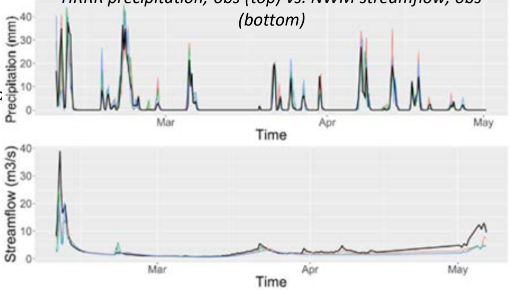
Feb – Apr 2017 HRRR vs. StageIV precipitation bias over American River (CA) watershed



MET-calculated skill scores binned by weather phenomena

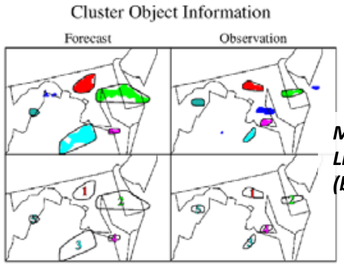
Precipitation verification of HRRR 0 – 6h forecast lead time; 6-h accumulation (Sub-basin-average)	Entire 3-month period	Dry periods only	Wet periods only	Snow/ mix only
MAE (Mean absolute error)	1.3	0.18	3.92	2.65
Bias	0.5	-0.05	1.41	0.60
PC (Pearson Correlation)	0.9	0.18	0.86	0.92

HRRR precipitation, obs (top) vs. NWM streamflow, obs (bottom)



Feb – Apr 2017 HRRR vs. StageIV precipitation (top), NWM streamflow (bottom) over American River (CA) watershed

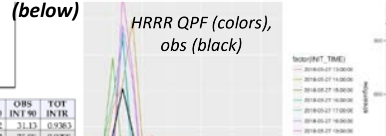
To connect forcing variables with streamflow, had to create own/use other software



CLUS PAIR	CEN DIST	ANG DIFF	FCST AREA	OBS AREA	INTER AREA	UNION AREA	SYMM DIFF	FCST INT 50	OBS INT 50	FCST INT 90	OBS INT 90	TOT INTR
1	3.09	48.45	250	131	103	278	175	18.88	17.38	32.42	31.13	0.9383
2	5.49	14.39	470	99	80	489	409	17.88	14.25	42.42	25.08	0.9098
3	6.93	19.34	467	66	66	467	401	17.52	14.44	37.52	22.63	0.8970
4	16.27	13.16	41	54	0	95	95	14.26	13.50	21.19	19.00	0.7511
5	9.89	1.77	50	73	0	123	123	14.80	16.25	32.03	20.50	0.7478

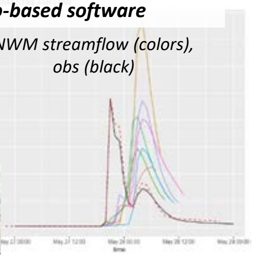
MODE analysis for case study of Ellicott City, MD 2018 flood (left)
Link to hydro using independent/rwrfhydro-based software (below)

HRRR QPF (colors), obs (black)



Watersheds near Ellicott City, MD

NWM streamflow (colors), obs (black)



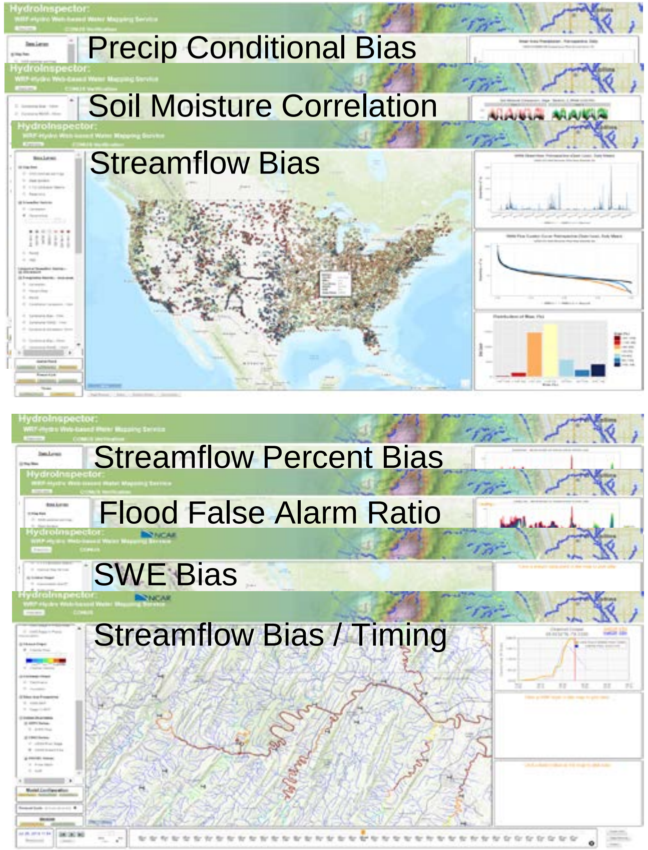
- For precipitation & other forcings verification, MET already contains most critical tools and capabilities. Possible improvements for hydro might include:
  - Quick/easy regional analysis tools for hydrologic units/hydro-relevant regions (e.g: RFC regions, HUC regions)
  - Easier basin masking/defining, ability to analyze atmospheric variables (e.g., precip) upstream of "closing" stream point
  - Easier aggregation over more hydro-relevant time scales, hourly to daily statistics
  - Software to connect, correlate gridded fields with point measurements in way that accounts for hydro processes (e.g., consider watershed concentration time)
  - Hydro-targeted applications for NWM 1-km output gridded fields (from terrain/land surface model variables to channels)
  - Hydro-specific scores such as Nash Sutcliffe Efficiency index, Kling-Gupta efficiency,…
  - Make output more GIS-compliant, facilitate watershed vis.

Ongoing Evaluation: NWM R2O Evaluation Activities at NCAR

HydroInspector Website (online GUI)

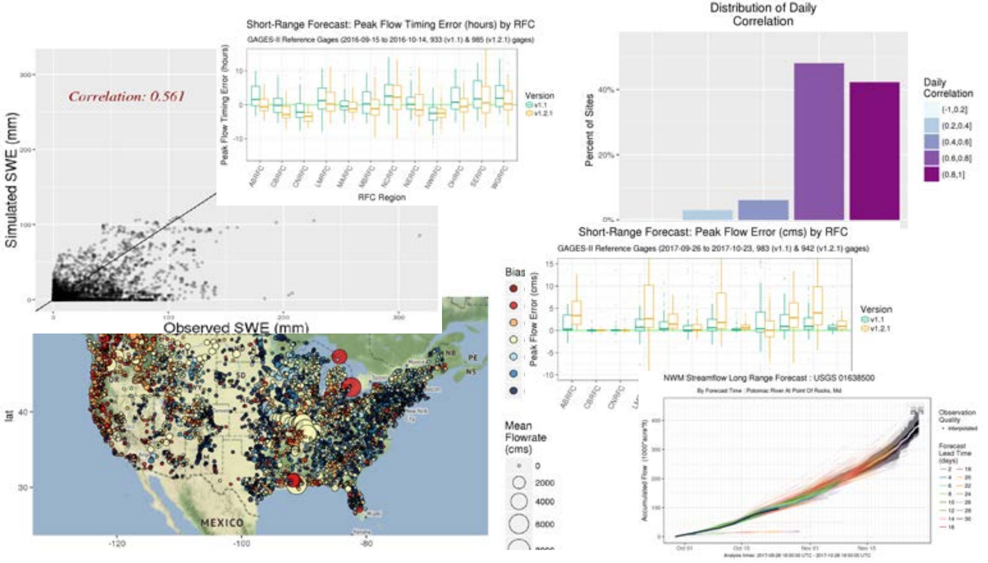
25-Year NWM Retrospective

Real-time NWM



Support for NWM Operational Upgrades

- Provides evidence basis for upgrades
- Multivariate (streamflow, snow, precip, soil moisture, energy flux) and multi-metric (bias, corr, timing, etc)
- Various displays (histograms, areal maps, scatter plots, box plots)



Ongoing Evaluation: OWP Water Resource Evaluation Service

- OWP tasked to provide a comprehensive service for evaluating the quality of existing and emerging OWP and RFC models and forecast systems
- WRES System developed in a series of phases
  - Phase 1 (deployed June 22, 2018)
    - <u>Target Users:</u> OWP personnel for internal evaluation
    - Core functionality (data ingest, conditioning, pairing, metrics, basic products)
  - Phase 2 (scheduled for deployment in Aug, 2019)
    - <u>Target Users:</u> RFC forecasters
    - Implements gridded evaluation, GUI, web-services for RFCs
  - Phase 3 (scheduled for deployment in Nov, 2020)
    - <u>Target Users:</u> External users
    - Provide web services to external users (details tbd)
- WRES will investigate the use of MET for two purposes:
  - Comparison and benchmarking, both performance and accuracy
  - Potential to leverage spatial verification methods within MET (e.g, MODE)

Summary

- Unique verification challenges exist with respect to hydrologic applications, particularly when considering fine resolutions, coastal processes and complex interactions between forcing and model output
- Several verification activities and capabilities are currently under development as part of number of hydrologic initiatives across several agencies
- While each of these is driven by specific end-user needs, there exists the possibility for crossover work