Seasonal Streamflow Forecasting for Water Management: Advances and Opportunities

Mark Thyer, David McInerney, Dmitri Kavetski

Intelligent Water Decisions Research Group, University of Adelaide

Fitsum Woldemeskel, Julien Lerat, Daehyok Shin, Narendra Tuteja,

Water Forecasting Services, Bureau of Meteorology

George Kuczera

School of Engineering, University of Newcastle

Key Messages

Hydrology Matters:

Advances in hydrological science improve the quality of seasonal streamflow forecasts

Humans Matter:

Translation of research into national-scale impact relies on commitment from a team of passionate humans

Key Messages

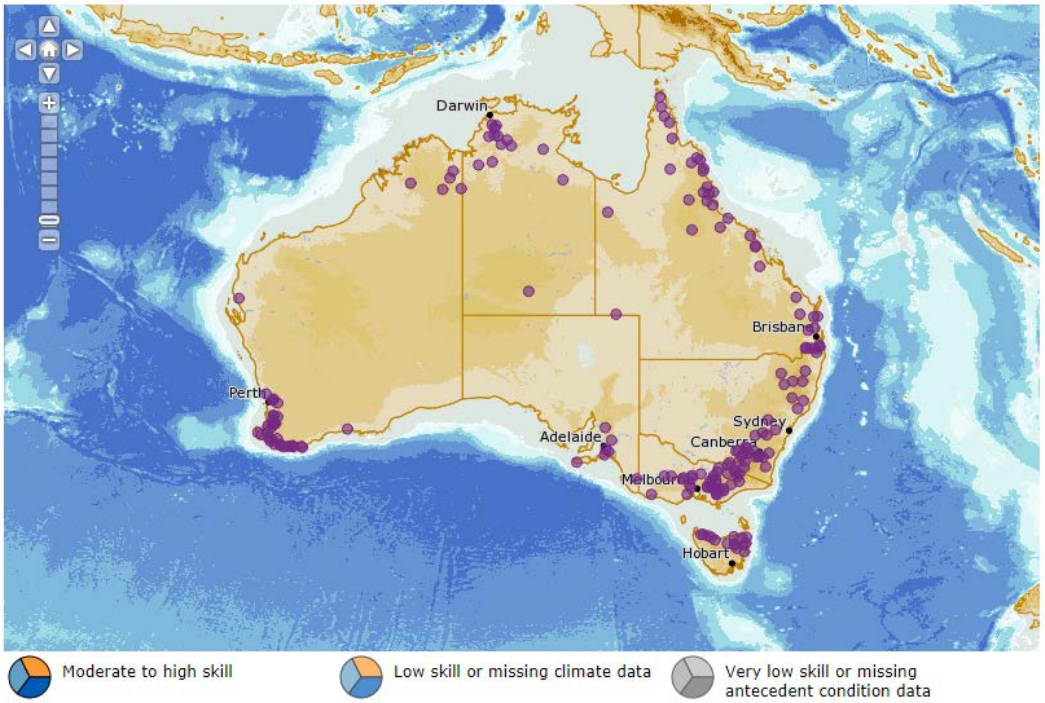
Hydrology Matters:

Advances in hydrological science improve the quality of seasonal streamflow forecasts

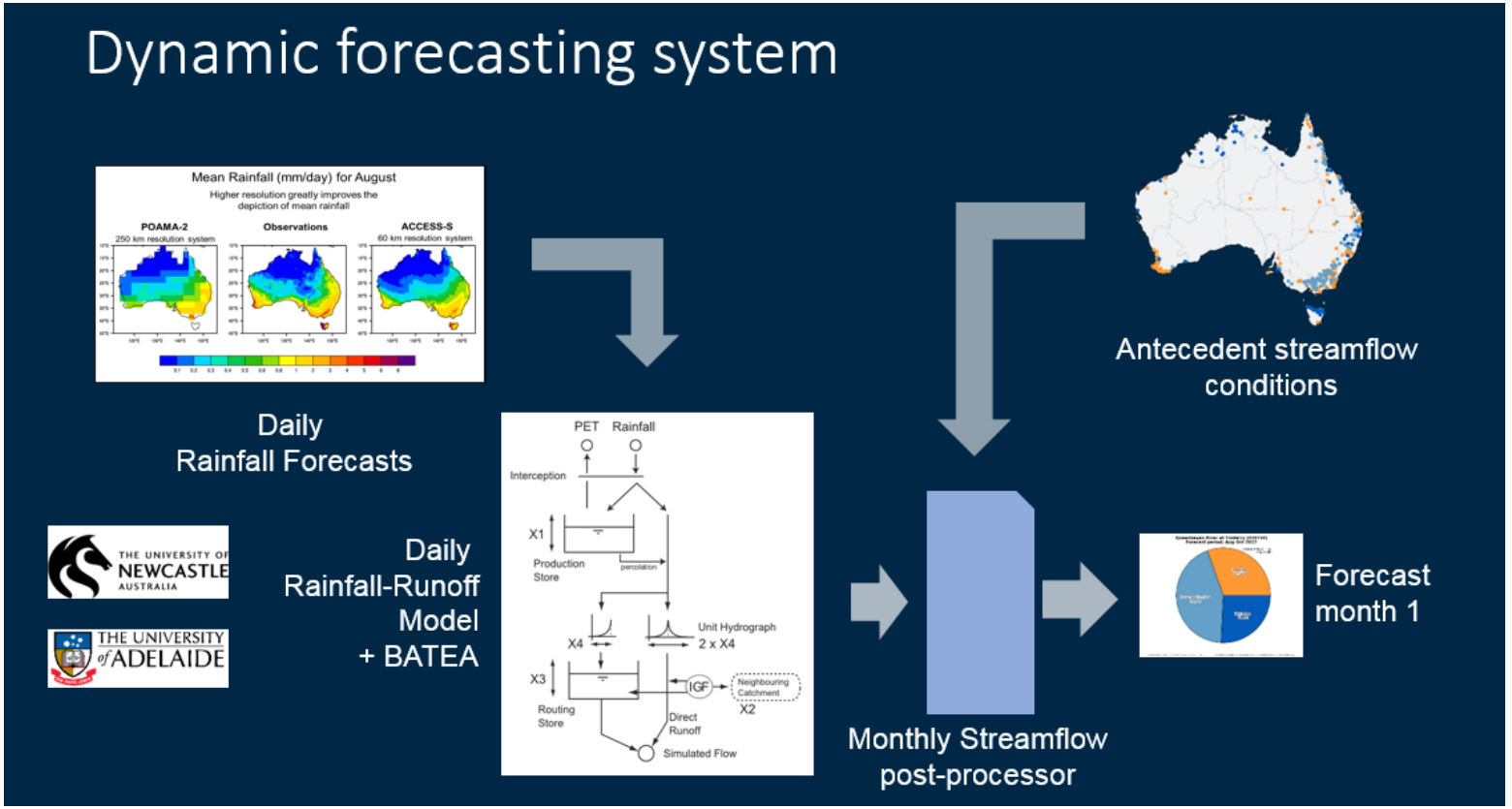
Humans Matter:

Translation of research into national-scale impact relies on commitment from a team of passionate humans

BOM seasonal streamflow forecasting service



- Provides 1-3 month ahead streamflow forecasts at sites around Australia
- Used each month by water managers around Australia to inform decisions
- Operational since about approx. 2010: Statistical Forecasting System (CSIRO)
- Long-term partnership between UoA and BOM to develop **dynamical streamflow forecasting** system
- Bureau's Strategic Objective (defined by users) : Provide high quality monthly streamflow forecasts Australia-wide



- Numerous sources of uncertainty in forecasting “chain”
  - Rainfall forecast errors (downscaling, missing processes etc.)
  - Rainfall-runoff model errors (data errors, structural errors etc.)
- Probabilistic forecasts aim to capture forecast uncertainty
- Key input to risk-based decision making for users

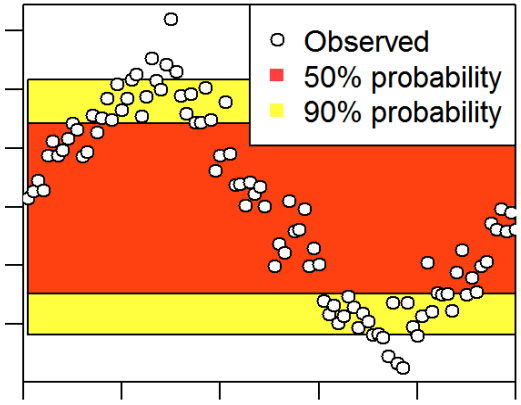
What makes a good probabilistic forecast?

- Water management is about "balancing risks" of high/low flow events (floods/droughts)
- "Good" probabilistic forecasts are:

  Reliable: Forecast probabilities are reliable (i.e. consistent with observed data)

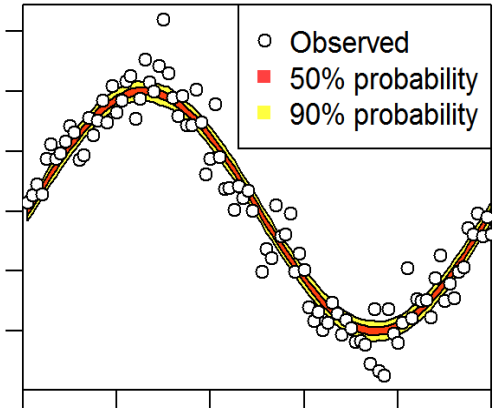
  Sharp: Small uncertainty in forecast (aka forecast is "precise")

Reliable, but not sharp



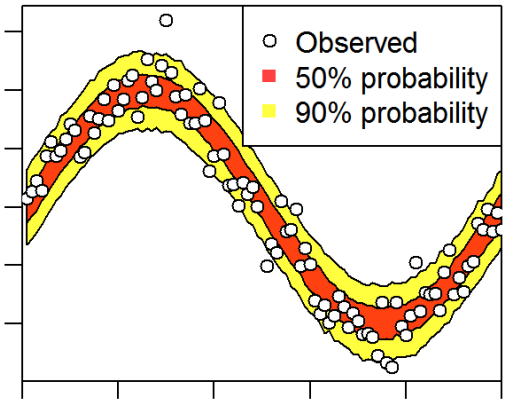
"Conservative": over-estimates risks => missed opportunities
Aka "Climatology"

Sharp, but not reliable



"Over-confident": under-estimate risks, can't manage high/low flows

Reliable, sharp, unbiased

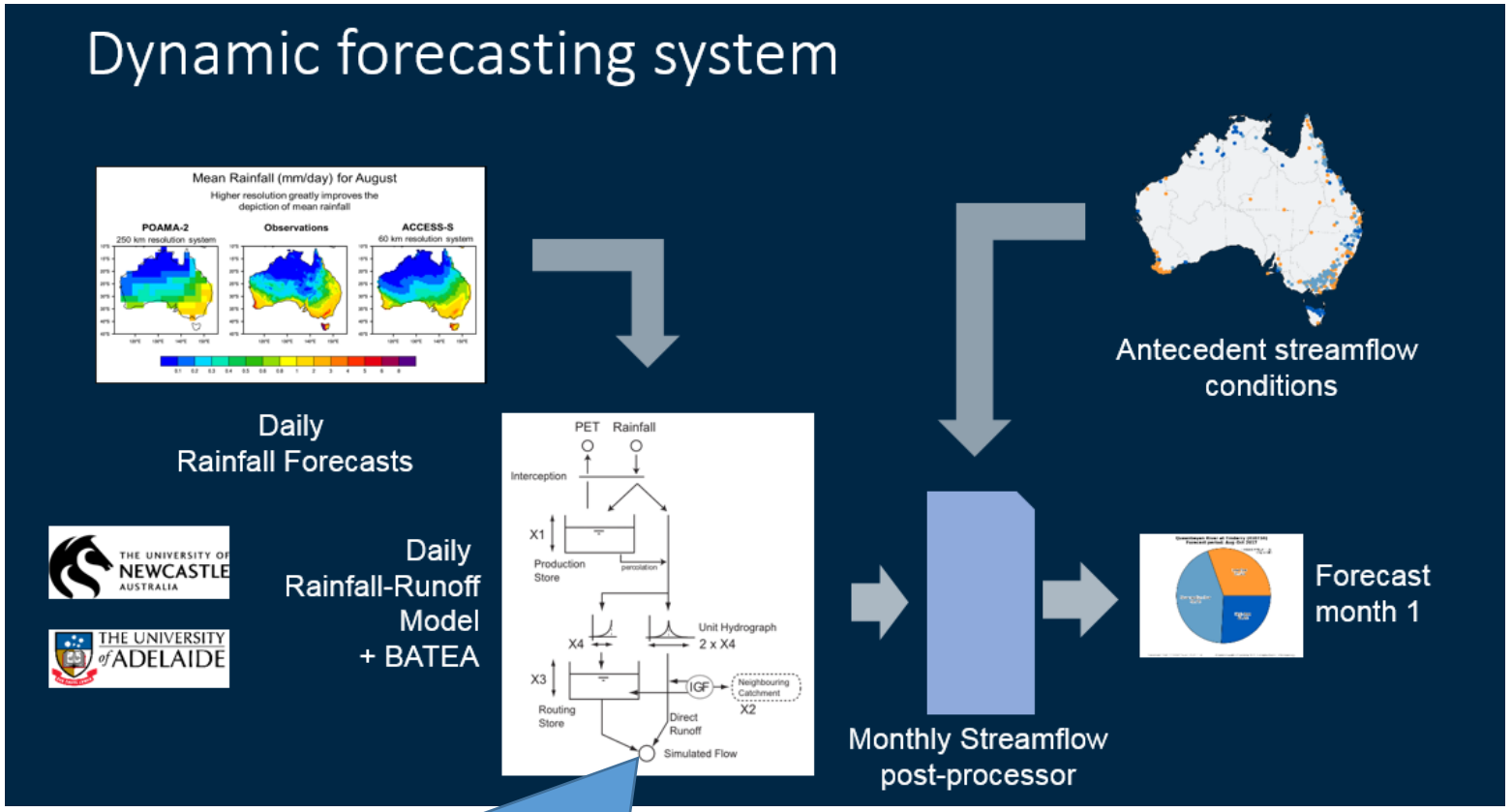


- Reliable and sharp forecasts of high/low flow events

  => Better management decisions

  => Greater industry uptake and impact of streamflow forecasting products

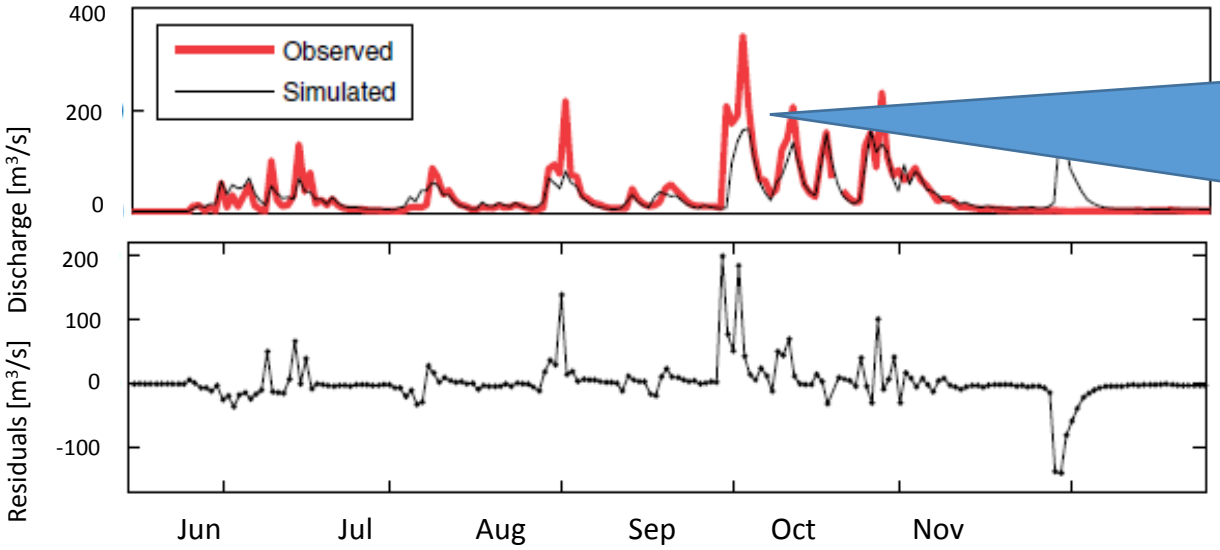
- **Bureau's Strategic Objective**: Provide high quality monthly streamflow forecasts Australia-wide



Improving probabilistic predictions of daily streamflow

Improving probabilistic predications of daily streamflow: Motivation

- Predictions from hydrological models used to inform management decisions
- Hydrological model predictions are often highly uncertain



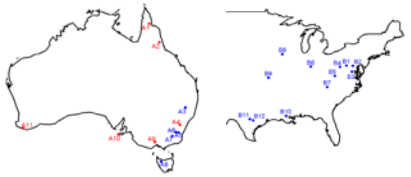
Source of Uncertainty:

- Rain gauge missed rainfall?
- Model missing a process?
- Streamflow gauge problem

- Uncertainty analysis critical for reliable risk assessment

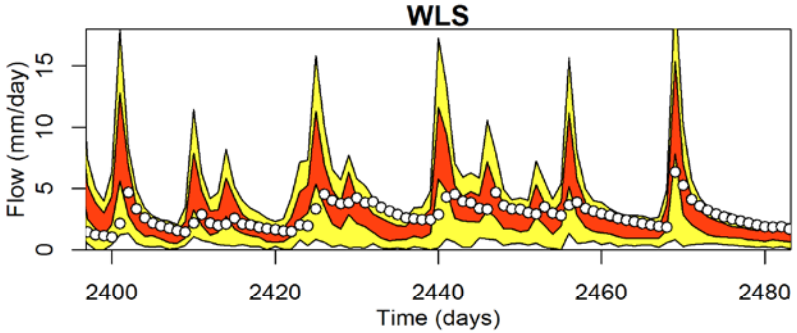
  => Risk = Probability x Consequence

Improving probabilistic predications of daily streamflow: Outcomes

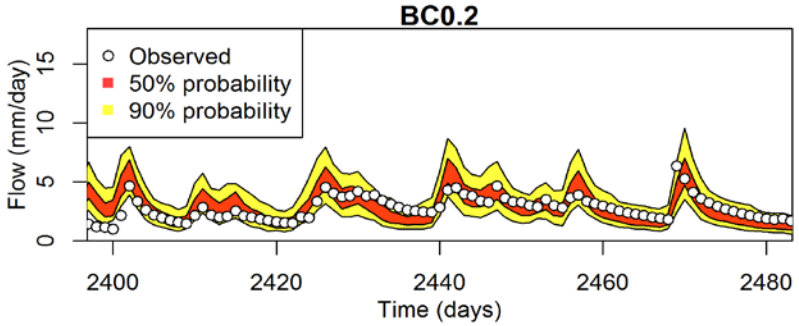


- Wide range of "residual error models" to quantify predictive uncertainty
- Comprehensive comparison with multiple catchments (Aus/USA) metrics, hydrological models
- **Provided recommendations on simplified practical approaches to quantify predictive uncertainty**
- We bust the myth that uncertainty quantification is too hard!

Before: Poor reliability and Sharpness



After: Improved Reliability and Sharpness



Reduced predictive uncertainty by 50%!

[McInerney et al., 2017]

Water Resources Research

RESEARCH ARTICLE

10.1002/2016WR019168

Key Points:
- Choice of heteroscedastic error modeling approach significantly impacts on predictive reliability, precision, and bias, over 46 case studies
- Pareto optimal performance (out of eight residual error schemes) provided by Box-Cox transform with power parameter λ fixed between 0 and 0.5
- Empirically identified limitations of individual residual error schemes are

Improving probabilistic prediction of daily streamflow by identifying Pareto optimal approaches for modeling heteroscedastic residual errors

David McInerney[1], Mark Thyer[1], Dmitri Kavetski[1,2], Julien Lerat[3], and George Kuczera[2]

[1]School of Civil, Environmental and Mining Engineering, University of Adelaide, Adelaide, SA 5005, Australia, [2]School of Engineering, University of Newcastle, Callaghan, NSW 2308, Australia, [3]Bureau of Meteorology, Canberra, ACT 2600, Australia

Abstract Reliable and precise probabilistic prediction of daily catchment-scale streamflow requires statistical characterization of residual errors of hydrological models. This study focuses on approaches for rep-

[McInerney et al., 2018]

ELSEVIER

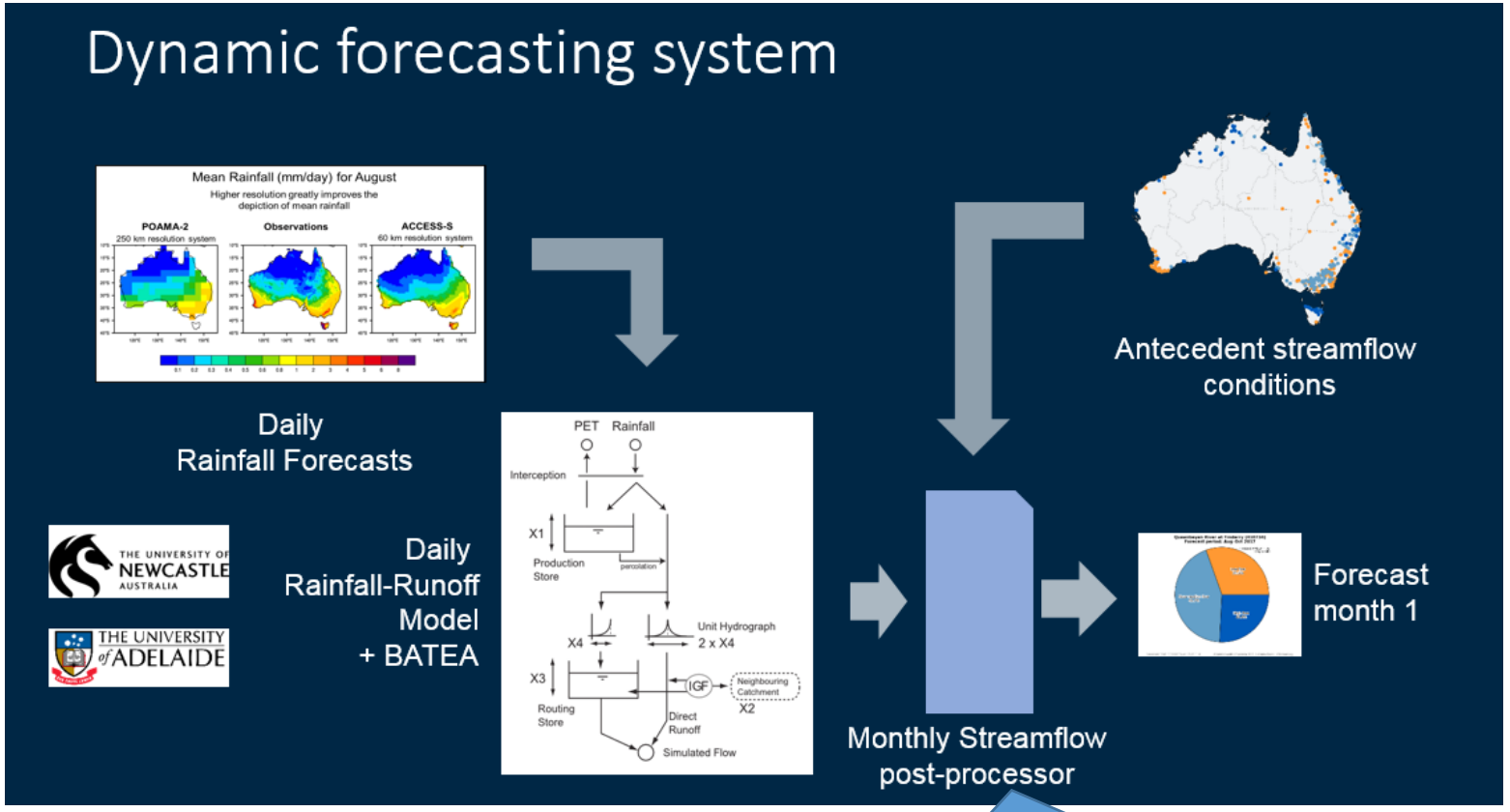
Environmental Modelling & Software

Volume 109, November 2018, Pages 306-314

A simplified approach to produce probabilistic hydrological model predictions

David McInerney [a], Mark Thyer [a], Dmitri Kavetski [a], Bree Bennett [a], Julien Lerat [b], Matthew Gibbs [c], George Kuczera [d]

- **Bureau's Strategic Objective:** Provide high quality monthly streamflow forecasts Australia-wide

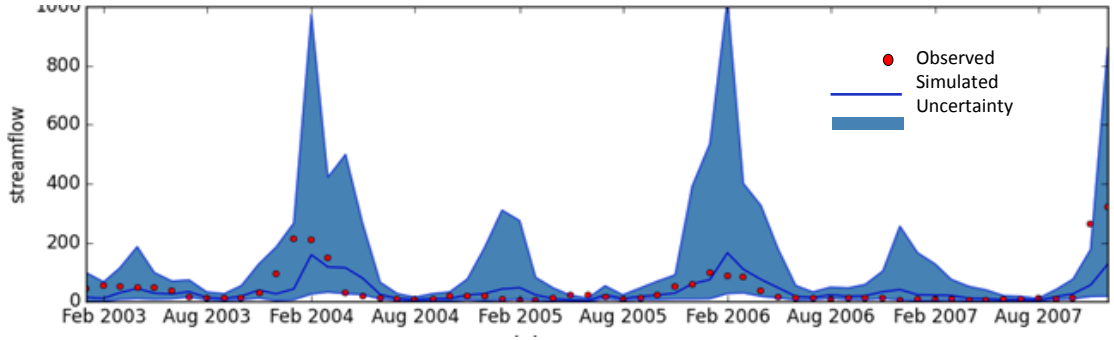


Improving post-processing of monthly streamflow forecasts

Improved monthly streamflow forecasts

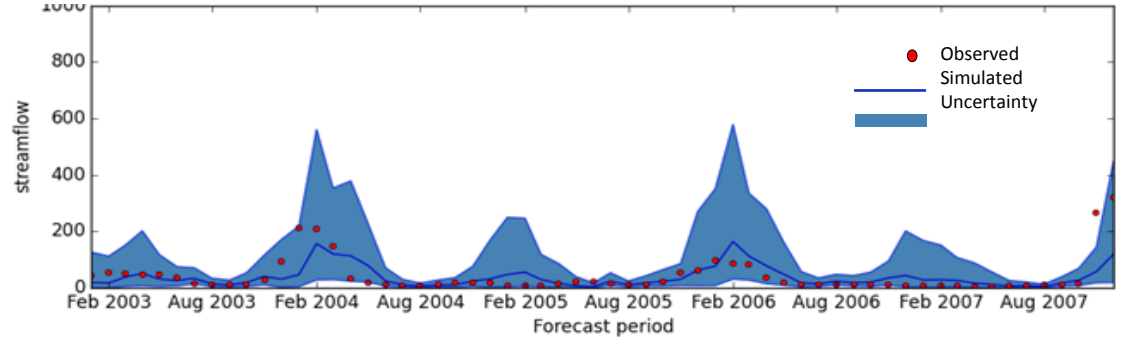
- Implemented recommendations of McInerney et al (2017) developed at daily scale to monthly forecast post-processing

Before



- Reasonable reliability
- Poor sharpness: 150% of climatology (historical record)

After



- Similar reliability
- Better sharpness: 75% of climatology
- Forecasts more valuable for users

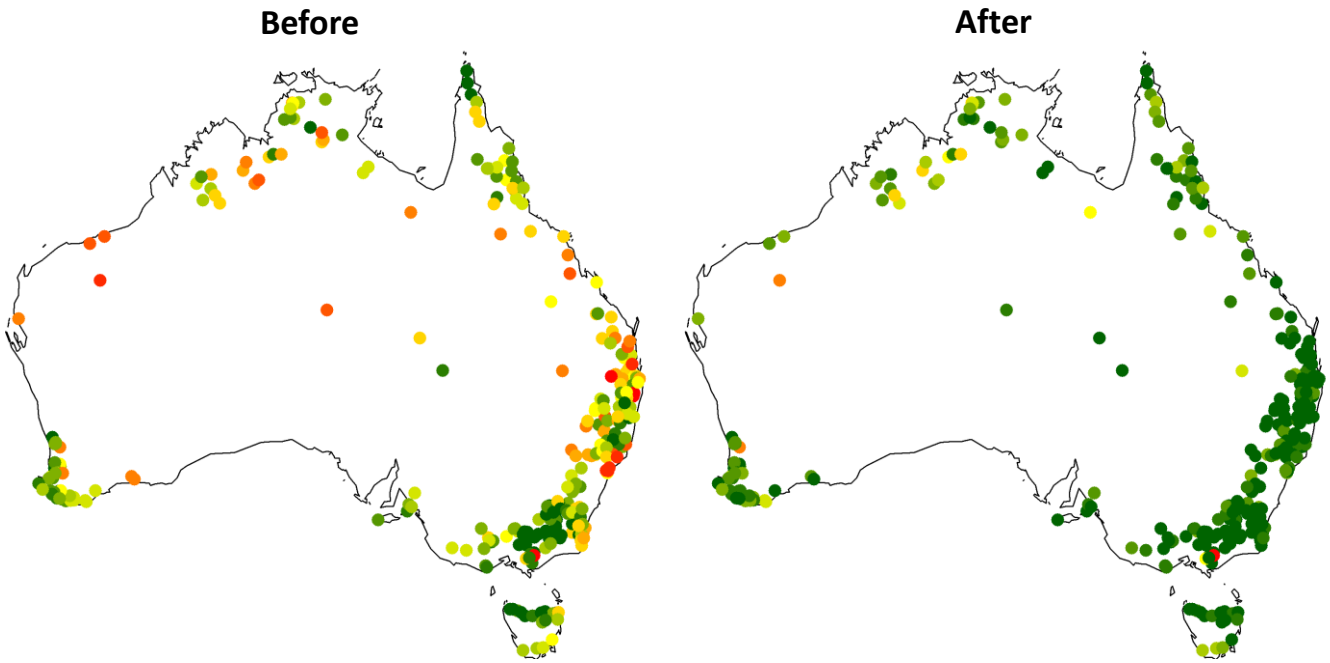
[*Woldemeskel et al.*, 2018]

Evaluating post-processing approaches for monthly and seasonal streamflow forecasts

Fitsum Woldemeskel[1], David McInerney[2], Julien Lerat[3], Mark Thyer[2], Dmitri Kavetski[2,4], Daehyok Shin[1], Narendra Tuteja[3], and George Kuczera[4]

[1]Bureau of Meteorology, VIC, Melbourne, Australia
[2]School of Civil, Environmental and Mining Engineering, University of Adelaide, SA, Australia
[3]Bureau of Meteorology, ACT, Canberra, Australia
[4]School of Engineering, University of Newcastle, Callaghan, NSW, Australia

Monthly forecasts Australia-wide: Improved reliability and sharpness



High Forecast Skill (Green): Higher reliability and sharpness

Low Forecast Skill (Red): Lower reliability and sharpness

Increased sites with high forecast skill from ~30% to >80%

[*Woldemeskel et al.*, 2018]

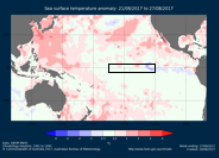
Evaluating post-processing approaches for monthly and seasonal streamflow forecasts

Fitsum Woldemeskel[1], David McInerney[2], Julien Lerat[3], Mark Thyer[2], Dmitri Kavetski[2,4], Daehyok Shin[1], Narendra Tuteja[3], and George Kuczera[4]

[1]Bureau of Meteorology, VIC, Melbourne, Australia
[2]School of Civil, Environmental and Mining Engineering, University of Adelaide, SA, Australia
[3]Bureau of Meteorology, ACT, Canberra, Australia

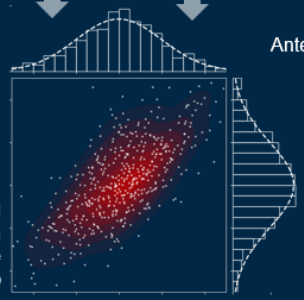
Seasonal Streamflow Forecasts:
Merging Statistical and Dynamical Forecasts: Best of Both Worlds

Statistical forecasting model



Climate indices

Antecedent streamflow conditions



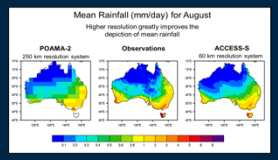
Multivariate normal distribution in transformed space (BJP)

Forecast month 1

Forecast month 2

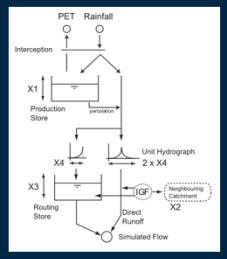
Forecast month 3

Dynamic forecasting model



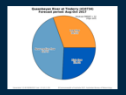
ACCESS-S Rainfall Forecasts

Antecedent streamflow conditions



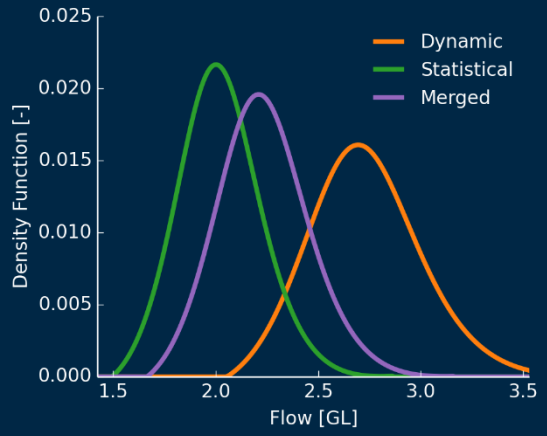
GR4J + BATEA

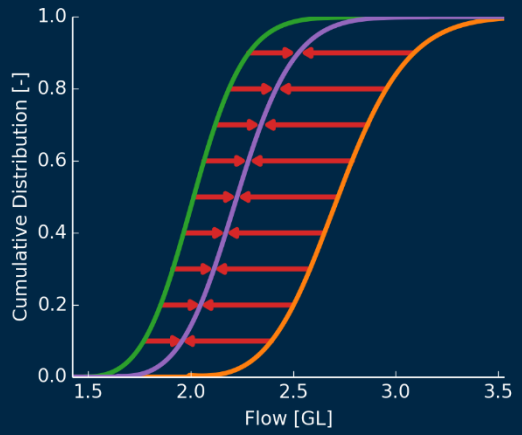
Streamflow post-processor



Forecast month 1

Merged Forecasts



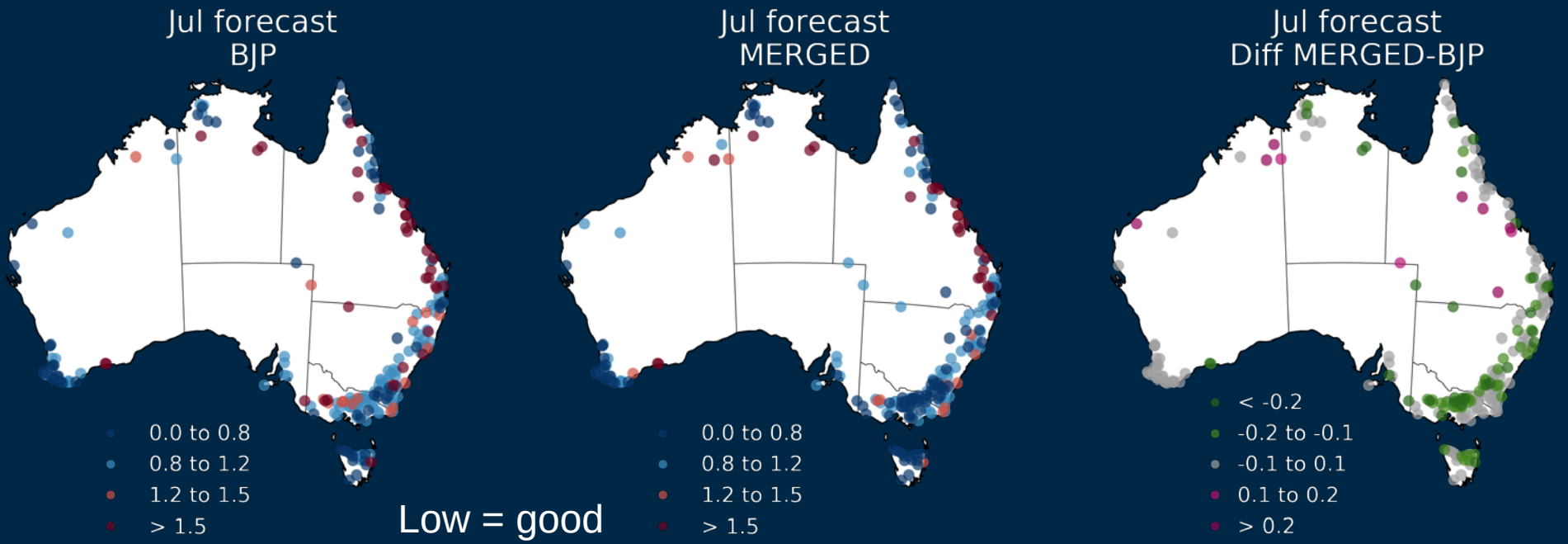


Schepen and Q. J. Wang. Model averaging methods to merge operational statistical and dynamic seasonal streamflow forecasts in Australia. Water Resources Research, 51(3):1797–1812, 2015

Evaluation of Merged Forecasts: Australia-wide

Reliability: Statistical and merged forecasts are similar

Sharpness: Merged forecasts improve sharpness by ~ 20%



Incorporating hydrological knowledge and advances from dynamical forecasts leads to reliable and sharper probabilistic monthly forecasts

Achieves Bureau's strategic objective of operational high-quality streamflow forecasts Australia-wide

Future Research: Subseasonal Streamflow Forecasting

Current capabilities: Seasonal Forecasts

- Seasonal streamflow forecasts at **single site** at **monthly time step** for multiple locations in Australia

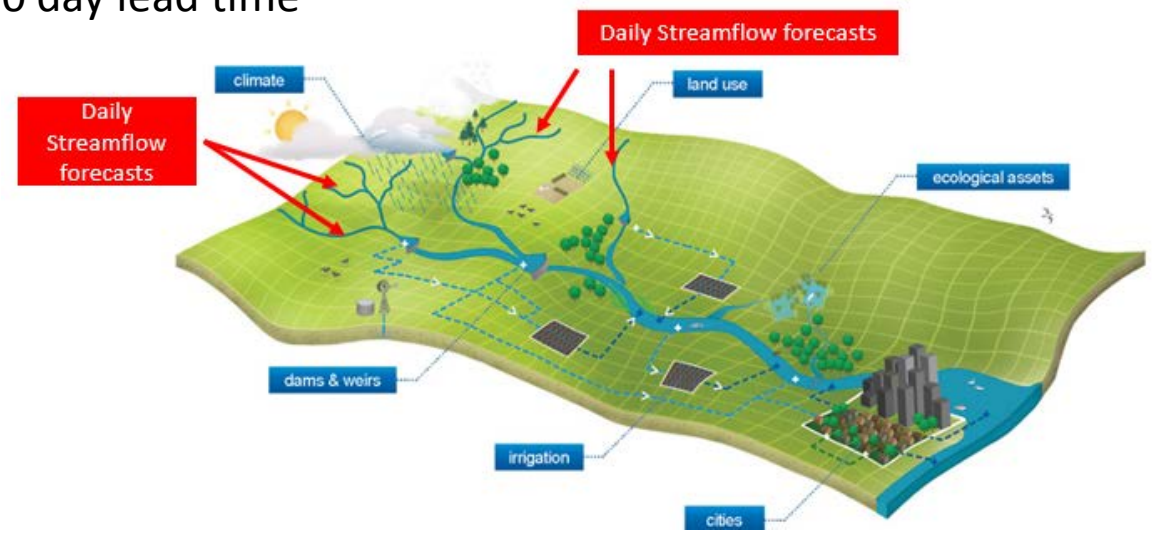
Required new capabilities (defined by industry/users needs) : Subseasonal Forecasts

- Sub-seasonal streamflow forecasts to provide **river basin scale forecasts** at multiple sites at **daily time step** for 0-30 day lead time
- Ideally suited for dynamical forecasting system

Australian Government
Bureau of Meteorology

MURRAY–DARLING BASIN AUTHORITY

GOULBURN-MURRAY WATER



Key Benefits

- Enable integration of forecasts into real-time decision-making tools (e.g. Source)
- Enable basin managers to better forecast risks of extreme events (high/low flow periods)
- Improve the management of water allocations to enhance economic growth opportunities for irrigated agriculture and reduce environmental risks.

Key Challenges

- Developing high quality daily probabilistic forecasts in **both** time and space

Key Messages

Hydrology Matters:

Advances in hydrological science impact on quality of seasonal streamflow forecasts

Humans Matter:

Translation of research into national-scale impact relies on commitment from a team of passionate humans

Team of Passionate Humans

National Agency's (BoM)

Meaningful societal impact of research occurs when all are working together

Key Components of Passionate Team

- Strong Leadership
- Commitment and Persistence
- Shared Vision – Co-created
- Flexibity to Adapt to changes in Strategic Priorities
- Regular and Open Engagement
- Mutual Respect and Trust

Summary

- Advances in Dynamical Streamflow Forecasting System have lead to reliable and sharper seasonal streamflow forecasts
  - Achieve Bureau's strategic objective of high-quality seasonal streamflow forecasts Australia-wide
- Future Research Focus: Sub-seasonal streamflow forecasts at 0-30 day lead time at river basin scale.
  - Addressing a key user need for river basin management
- Achieving societal impact from research advances relies on a committed team of passionate people:
  - Researchers, govt agencies, water industry and users working together

Connect with Mark Thyer:

THE UNIVERSITY of ADELAIDE