THE UNIVERSITY of ADELAIDE

Assoc. Prof. Mark Thyer

High quality daily subseasonal streamflow forecasts? Ask MuTHRE!

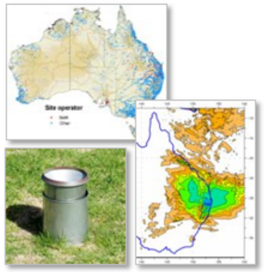
Aim: *Produce daily subseasonal (0-30 day) streamflow forecasts with high quality performance for a range of lead times and aggregation scales (daily to monthly)*

Australian Government
Bureau of Meteorology

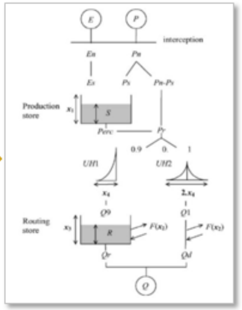
Key Innovation

MuTHRE: Multi-temporal hydrological residual error model addresses a range of hydrological errors:

- ***Seasonality:*** Errors vary systematically by month
- ***Dynamic Biases:*** Errors vary by year, due to hydrological non-stationarity
- **Extreme errors:** Occasional very large errors, poorly represented by common Gaussian distribution



Daily Rainfall Forecasts (ACCESS-S + Rainfall Post-Processing)



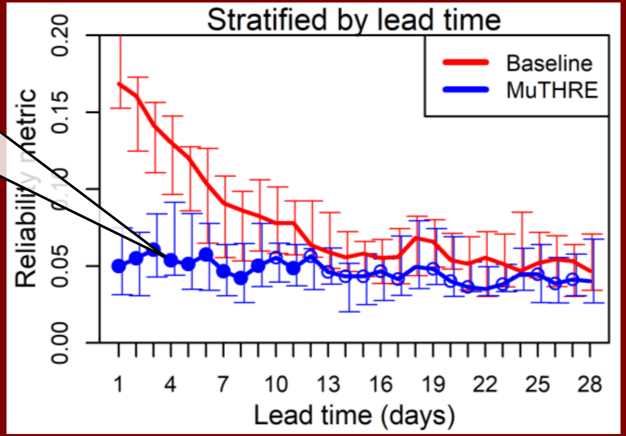
Daily Rainfall=>Streamflow using rainfall-runoff modelling

Post-processing of daily streamflow forecasts using probabilistic residual error models

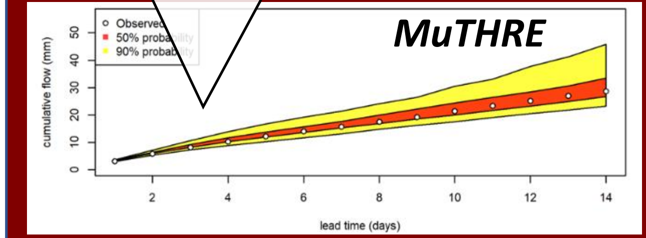
Key Outcomes

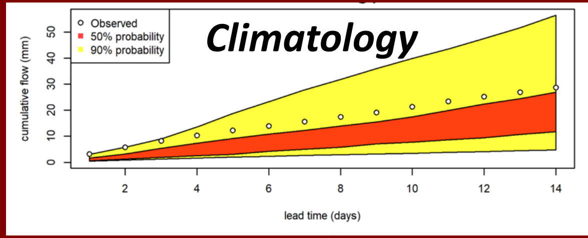
- Consistent high forecast quality for range of time scales (daily-monthly), lead times, months & years

Significantly improved reliability for short lead times (see right), dry months and drought years



Far sharper than climatology (~30% of climatology for 1-3 days lead time)





See paper for more details

McInerney et al, 2020, WRR: Multi-temporal Hydrological Residual Error Modeling for Seamless Subseasonal Streamflow Forecasting

https://doi.org/f8k5

School of Civil, Environmental and Mining Engineering

THE UNIVERSITY of ADELAIDE

Do you want high quality subseasonal daily streamflow forecasts? Ask MuTHRE!

Assoc. Prof. Mark Thyer
Dr David McInerney
Prof Dmitri Kavetski

Prof. George Kuczera

Science and Innovation/Research

GOULBURN-MURRAY WATER

THE UNIVERSITY of ADELAIDE

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

Australian Government
Bureau of Meteorology

MURRAY–DARLING BASIN AUTHORITY

Outline

- Motivation and Aims
- Overview and Key Innovations of Subseasonal Streamflow Forecasting System using MuTHRE
- Forecast Evaluation Approach
- Key Outcomes
- Summary: Features and Benefits

Australian Bureau of Meteorology: Water Information Products

Australian Government
Bureau of Meteorology

Perspective | **Situational awareness** | **Foresight**

PAST | **PRESENT** | **FUTURE**

DECADES | YEARS | MONTHS | WEEKS | DAYS | DAYS | WEEKS | MONTHS | YEARS | DECADES

National water account

Water balance reporting

Water market website

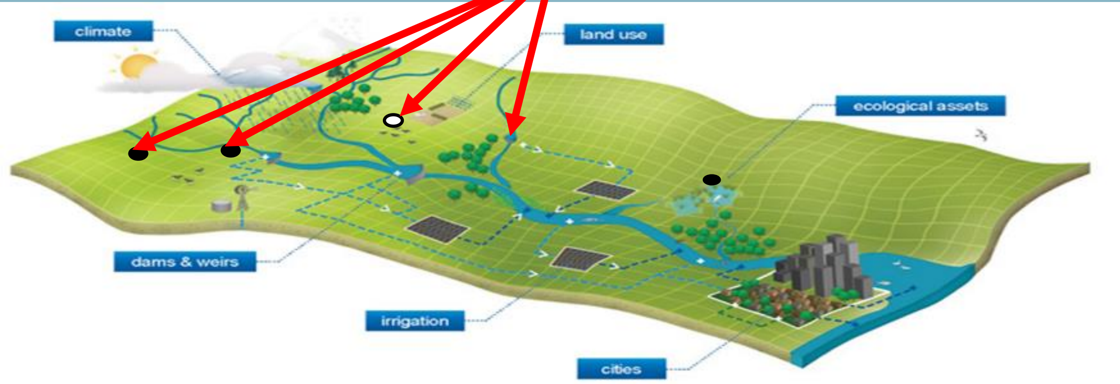
Flood and short-range forecasts

Sub-seasonal forecasts

Seasonal forecasts

Long-term trends

Daily streamflow forecasts



Key Gaps in Current Capability: Seamless Subseasonal Daily Streamflow Forecasts

- Daily forecasts for 0-30 day lead time
- Seamless forecasts with consistent quality at range of time scales (daily/weekly/monthly)

Subseasonal Streamflow Forecasting: Motivation

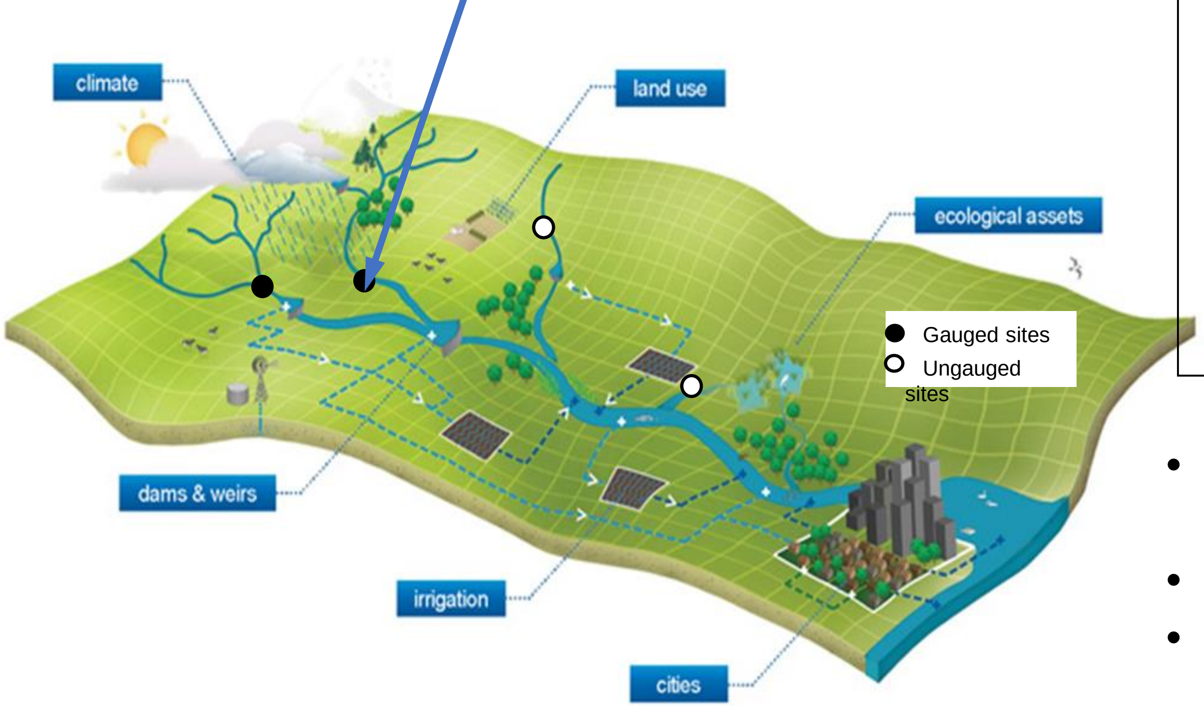
Feature and Benefits	Seven Day Streamflow Forecasts	Seasonal Streamflow Forecasts	Subseasonal Streamflow Forecasts
Monthly forecasts for 1-3 months lead time	✘	✓	✘
Subdaily forecasts for up to 7 days for flood purposes	✓	✘	✘
High quality forecasts at multiple sites Australia wide	✓	✓	?
Seamless daily forecasts for 0-30 day lead time	✘	✘	✓
Potential integration into real-time river-system decision making tools (e.g. eWater Source)	✓	✘	✓
Enable basin managers to quantify forecast risks of high/low flow daily events	✓	✘	✓

Subseasonal forecasts will lead to 'step change' in the adoption of forecasts by key water agencies

Slide 5

Seamless Site Forecasts: Aims and Outcomes

Aim: Seamless daily forecasts at gauged sites for 0-30 day lead time



Dynamic Streamflow Forecasting System

Rainfall forecasts (daily)

↓

Rainfall → Runoff Model

↓

Streamflow post-processing

Key Outcomes:

1. Developed NEW Multiple-Temporal Hydrological Residual Error Model (MuTHRE)

2. Reliable across a range of
- lead times (0-30 days)
- time scales (daily/weekly/monthly)
- stratified performance (months/ years)

3. Sharper than climatology

- Technology is independent of hydro. model – potentially useful for other hydro. models
- Published in journal, Water Resources Research,
- Reviewer comments: “*Presents a novel approach to post-process probabilistic forecasts and enhance temporal consistency in skill across horizons*”

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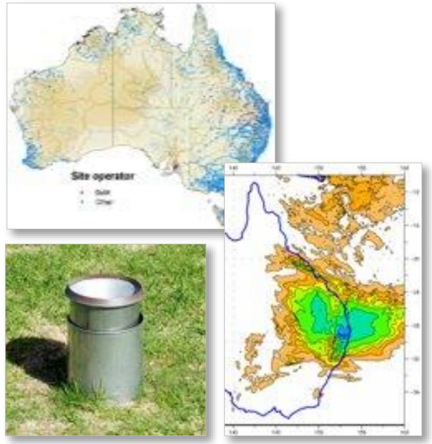
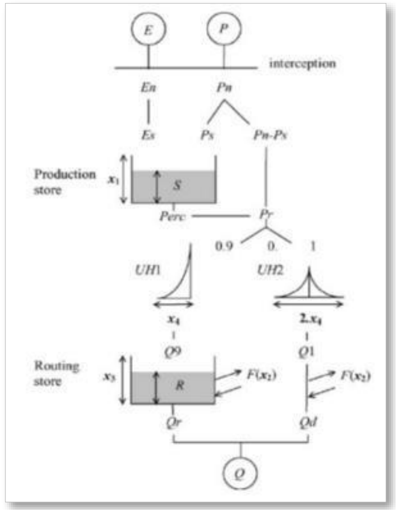
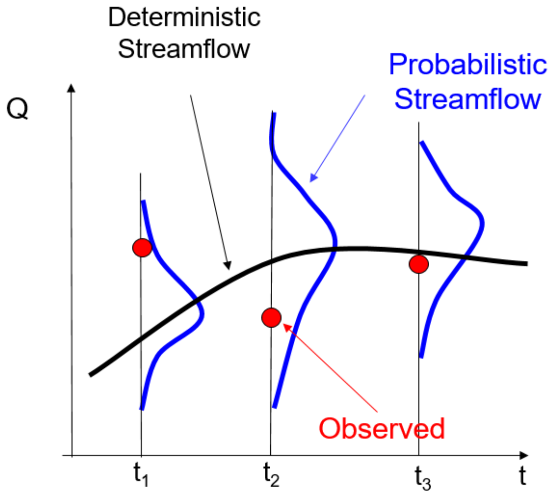
Subseasonal Streamflow Forecasting System



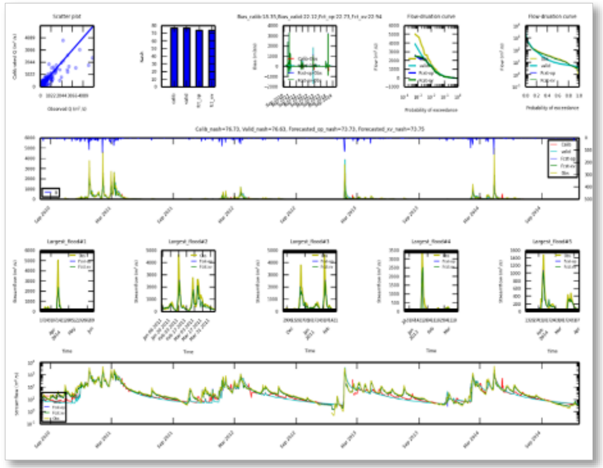
Daily Rainfall Forecasts (ACCESS-S + Rainfall Post-Processing)



Daily Rainfall=>Streamflow using rainfall-runoff modelling



Post-processing of daily streamflow forecasts using probabilistic residual error models



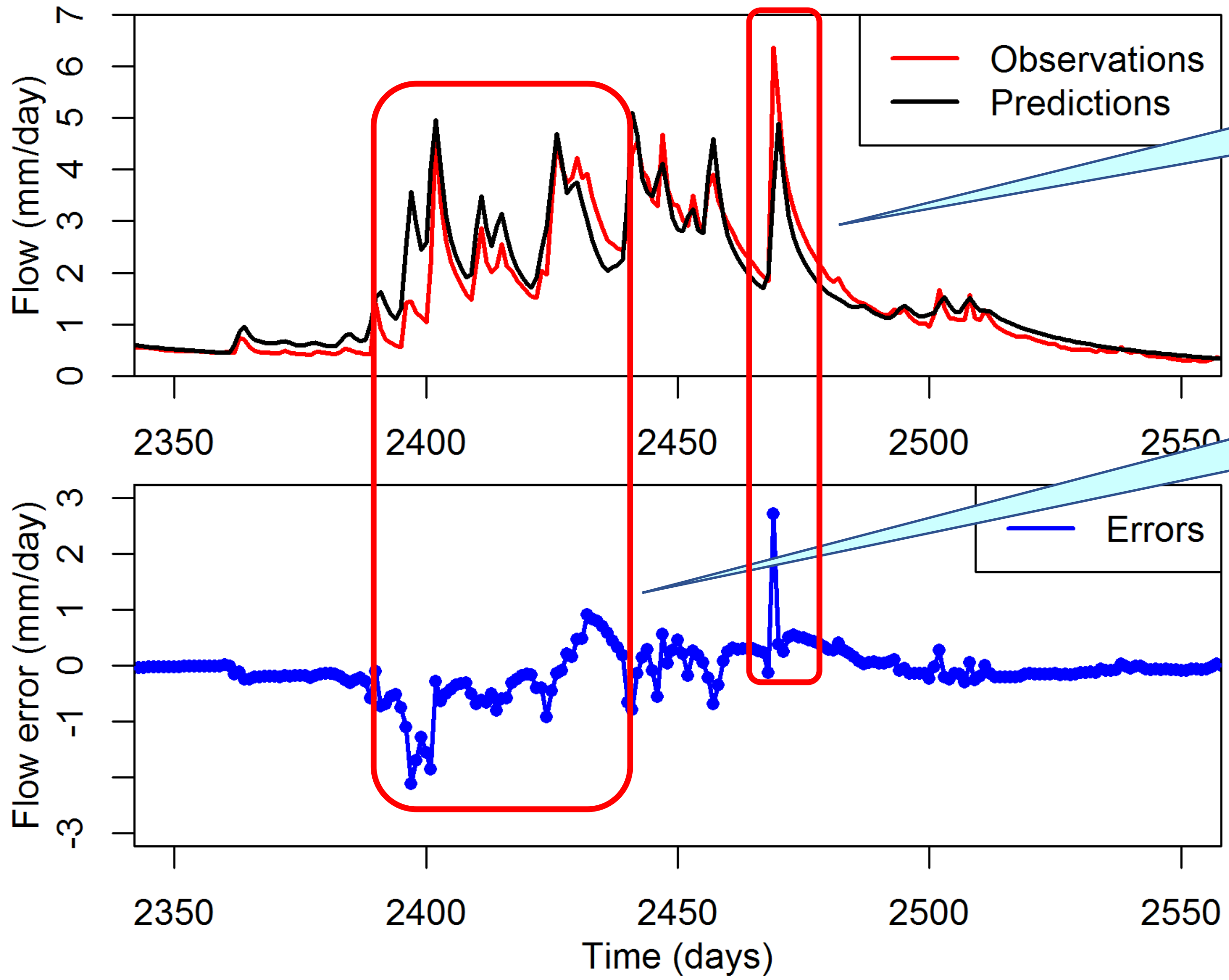
Forecast daily streamflow

Rainfall forecasts are reliable due advances in ACCESS-S and rainfall post-processing

Q: Is it important to account for hydrological residual errors for reliable streamflow forecasting?
A: Yes, very!! (key point of presentation)

Key features of Residual Errors in Hydrological Modelling

Residual errors are predictive errors from hydrological model, Residual Error = Qobs - Qhydro



Heteroscedastic Errors:
larger errors in larger flows

[McInerney et al, 2017]

Persistence in Errors: same sign over multiple time steps (not independent)

[Evin et al, 2013]

Other features known but not commonly represented in residual error models:

- **Seasonality:** Errors vary systematically by month
- **Dynamic Biases:** Errors vary systematically by year, performance different in wet and dry years due to hydrological non-stationarity
- **Extreme errors:** Occasional very large errors, poorly represented by common Gaussian distribution

McInerney, D., M. Thyer, D. Kavetski, J. Lerat, and G. Kuczera (2017), Improving probabilistic prediction of daily streamflow by identifying Pareto optimal approaches for modeling heteroscedastic residual errors, *Water Resour Res*, *53*(3), 2199-2239,

Evin, G., M. Thyer, D. Kavetski, D. McInerney, and G. Kuczera (2014), Comparison of joint versus postprocessor approaches for hydrological uncertainty estimation accounting for error autocorrelation and heteroscedasticity, *Water Resour Res*, *50*(3), 2350-2375, doi:

Key Innovations: MUTHRE Model

Deterministic streamflow from rainfall-runoff model

Baseline Residual Error Model

- Heteroscedasticity
- Persistence
- Gaussian Errors

Probabilistic Streamflow

- Commonly represented in most residual error models

Deterministic Streamflow from rainfall-runoff model

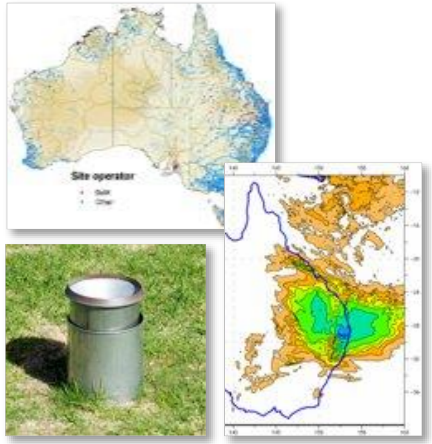
- **Mu**lti-**T**emporal **H**ydrological **R**esidual **E**rror (MUTHRE) Model
- Incorporates wide range of common residual errors in Hydrological Models

- Heteroscedasticity
- Dynamic biases
- Seasonality
- Persistence
- Mixed Gaussian for extreme errors

Probabilistic Streamflow

- Previous studies showed importance of individual components
- MUTHRE first time all components combined and used for subseasonal streamflow forecasting

Subseasonal Streamflow Forecasts => using MUTHRE Model



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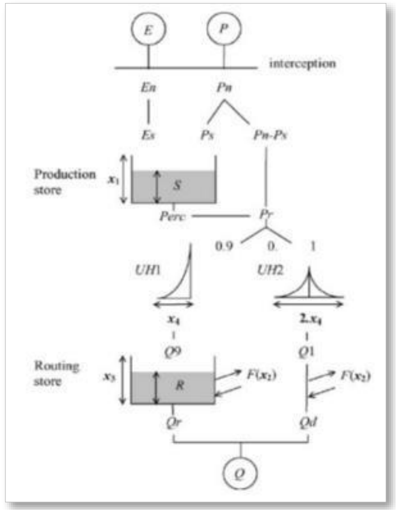


Daily Rainfall=>Streamflow using rainfall-runoff modelling

MUTHRE Model

Heteroscedasticity

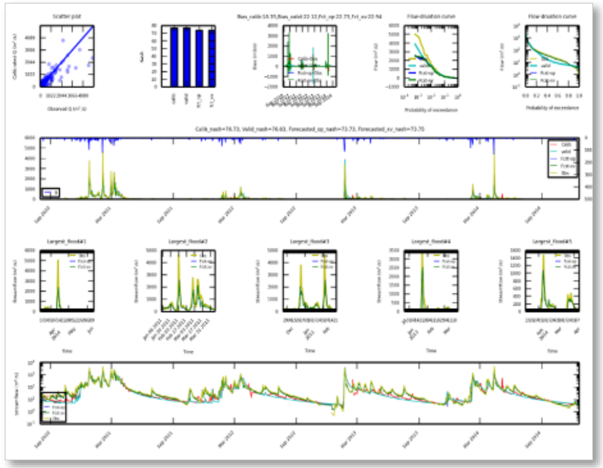
Dynamic Biases

Seasonality

Persistence

Mixed Gaussian for extreme errors

Post-processing of daily streamflow forecasts using probabilistic residual error model



Forecast daily streamflow

- First time all components used for subseasonal streamflow forecasting
- Compared with forecasts using Baseline model instead of MUTHRE

Will the MUTHRE be able to achieve seamless forecasts?

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Forecast Evaluation: What makes a good probabilistic forecast?

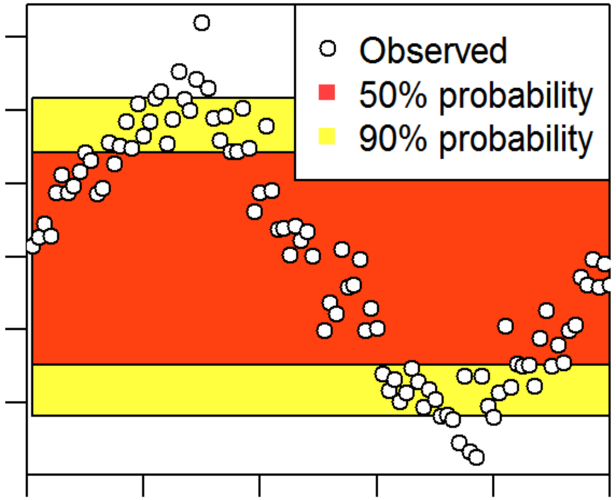
Water management is about "balancing risks" of high/low flow events (floods/droughts)

"High quality" probabilistic forecasts are:

Reliable: Forecast probabilities are reliable (i.e. 90% limits are "truly" 90% cf with observations)

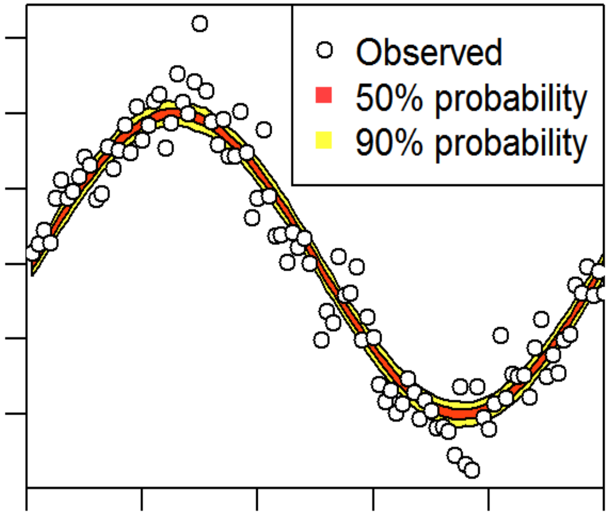
Sharpness: Width of uncertainty in forecast (aka forecast is "precise")

Reliable, but not sharp



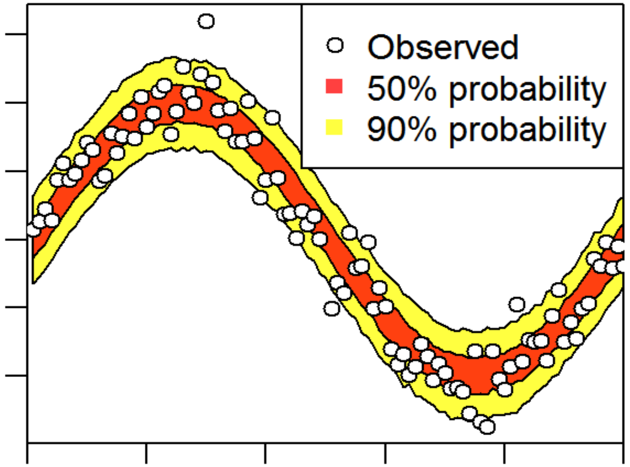
"Climatology": over-estimates risks
=> missed opportunities
to take advantage of events

Sharp, but not reliable



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

Reliable, sharp, unbiased



Reliable and sharp forecasts:

=> Accurate risks of high/low flow events

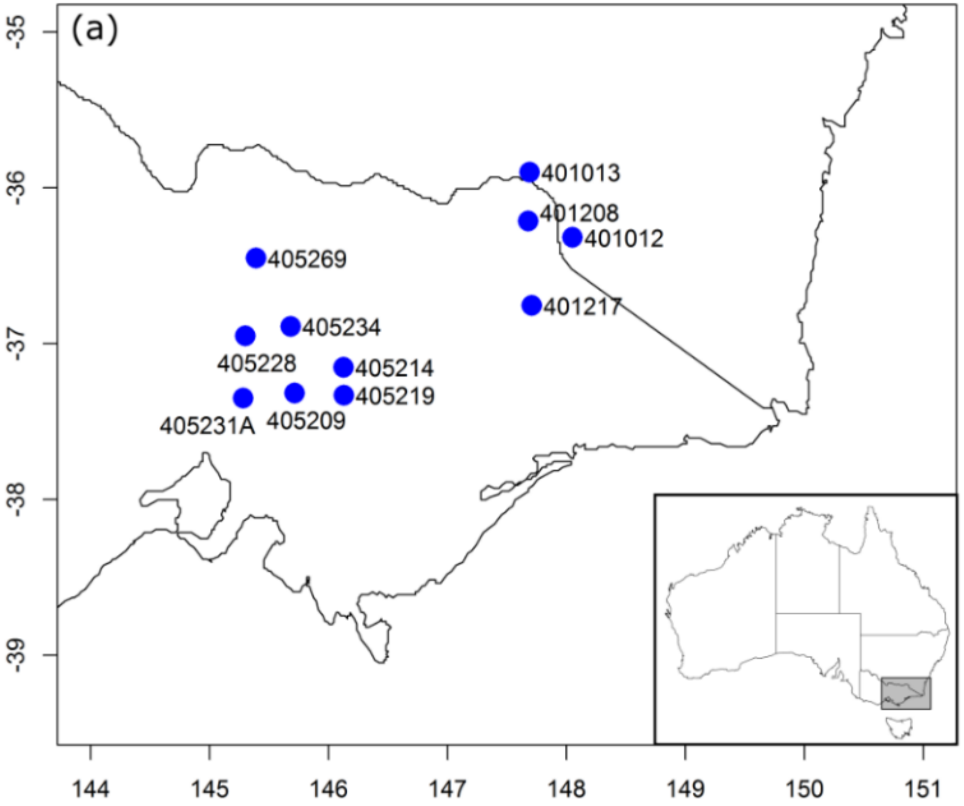
=> Better management decisions

=> Greater industry uptake

Forecast Evaluation Approach: Comprehensive and Systematic

- Range of commonly used metrics to capture key aspects of forecast performance
  - Reliability, Sharpness, Volumetric Bias, CRPS
- Focus on reliability as forecast probabilities are important for risk-based decisions
- NEW: Range of time scales/stratified evaluations to assess performance consistency
  - Daily and Monthly Time Scales
  - Stratified by Lead Time/Months/Years
- Focus on performance consistency important for seamless forecasting
  - Industry: Enables a single forecasting product to be used for multiple decisions
  - Bureau: Simpler to maintain a single forecasting product with multiple uses

Seamless Site Forecasts: Evaluated on High Impact Test Catchments



Name	Area (km²)
Murray River at Biggara	1257
Jingellic Creek at Jingellic	390
Cudgewa Creek at Berringama	351
Gibbo River at Gibbo Park	390
Delatite River at TongaBridge	368
King Parrot Creek at Flowerdale	181
Seven Creeks river at Kialla West	1513
Seven at D/S Polly McQuinns Weir	148
Hughes Creek at Tarcombe Rd	474
Acheron River at Taggerty	630
Goulburn River at Dohertys	700

Key Unregulated catchments in Upper Murray (4) and Golburn Rivers (7)

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Key Outcomes

1. Compare subseasonal streamflow forecasts MUTHRE vs BASELINE
2. Stratified by lead time/months/years
3. Present selected key results, for further details see journal paper

Water Resources Research

Research Article

Multi-temporal hydrological residual error modelling for seamless sub-seasonal streamflow forecasting

David McInerney, Mark Thyer, Dmitri Kavetski, Richard Laugesen, Narendra Tuteja, George Kuczera

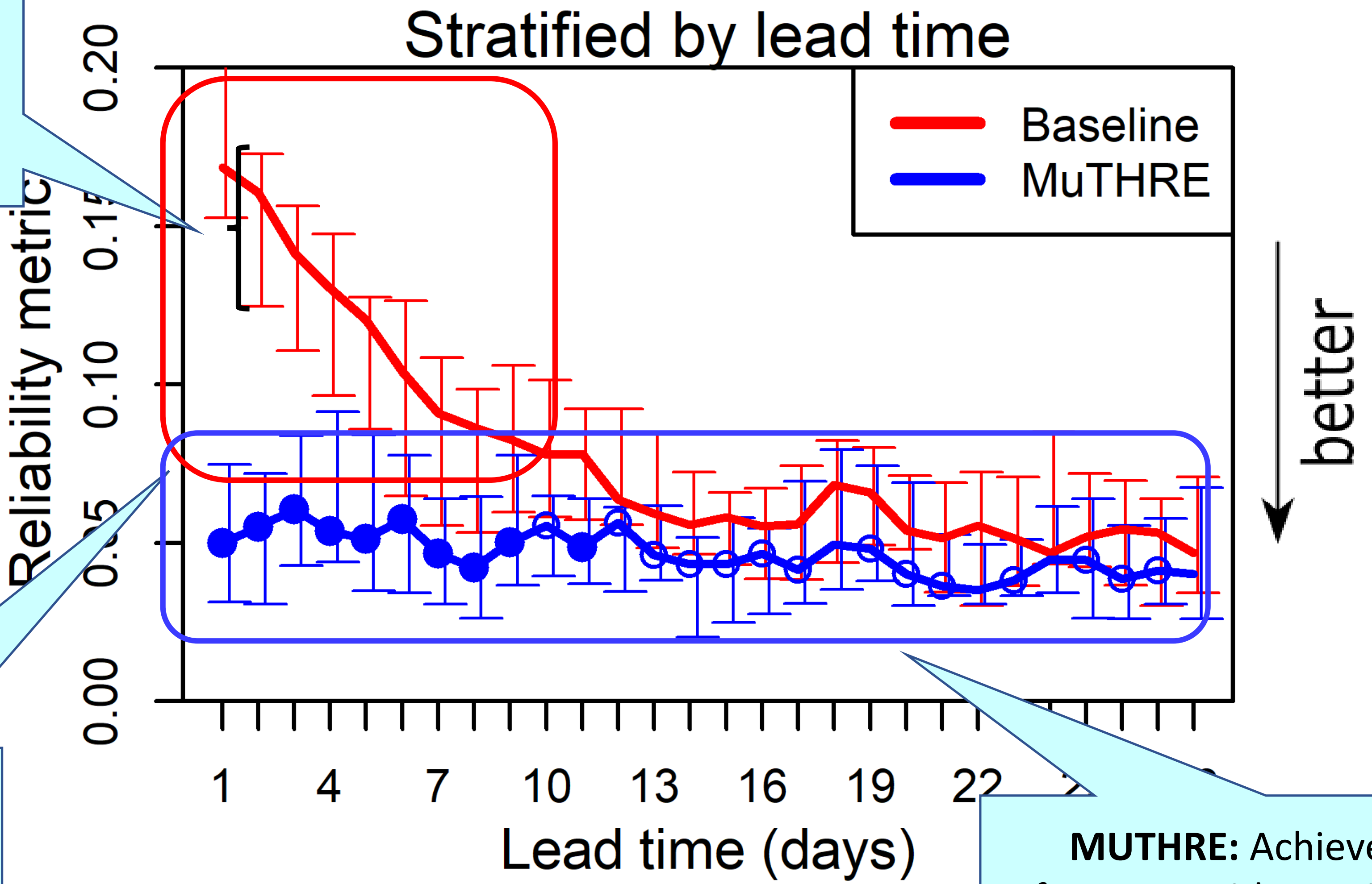
First published: 01 September 2020 | https://doi.org/10.1029/2019WR026979

https://doi.org/f8k5

MUTHRE shows Large improvements in reliability for short lead times

Bars provide range of metric for different catchments
Solid line is median

Reliability Metric : Represents "error" in forecast probabilities => lower is better



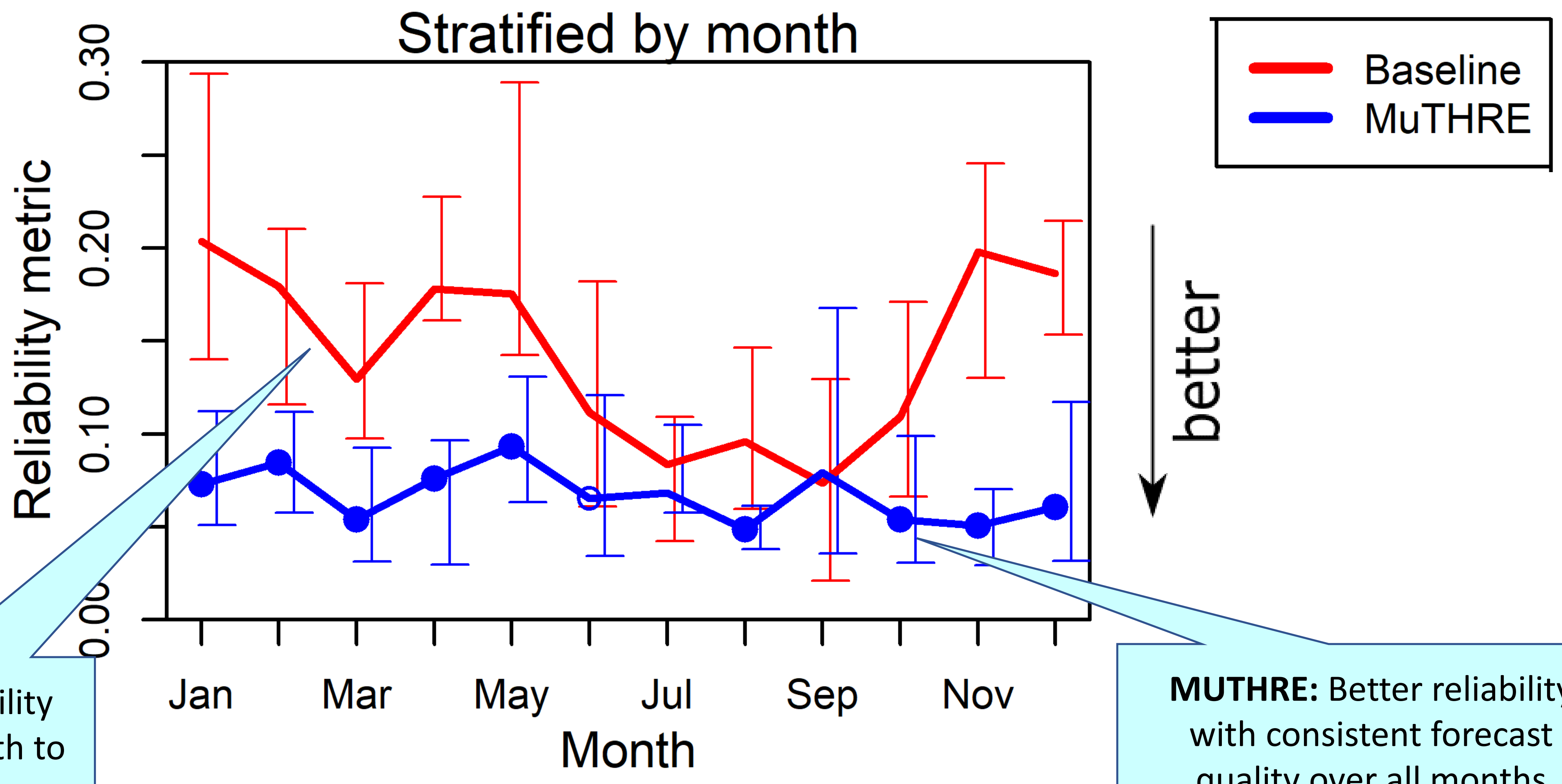
Baseline: Similar to current dynamical streamflow forecasting system

MuTHRE: NEW Multiple-Temporal Hydrological Residual Error Model

Baseline: Poor reliability for shorter lead times <10 days

MUTHRE: Achieved seamless forecasts with consistent forecast quality for all lead times

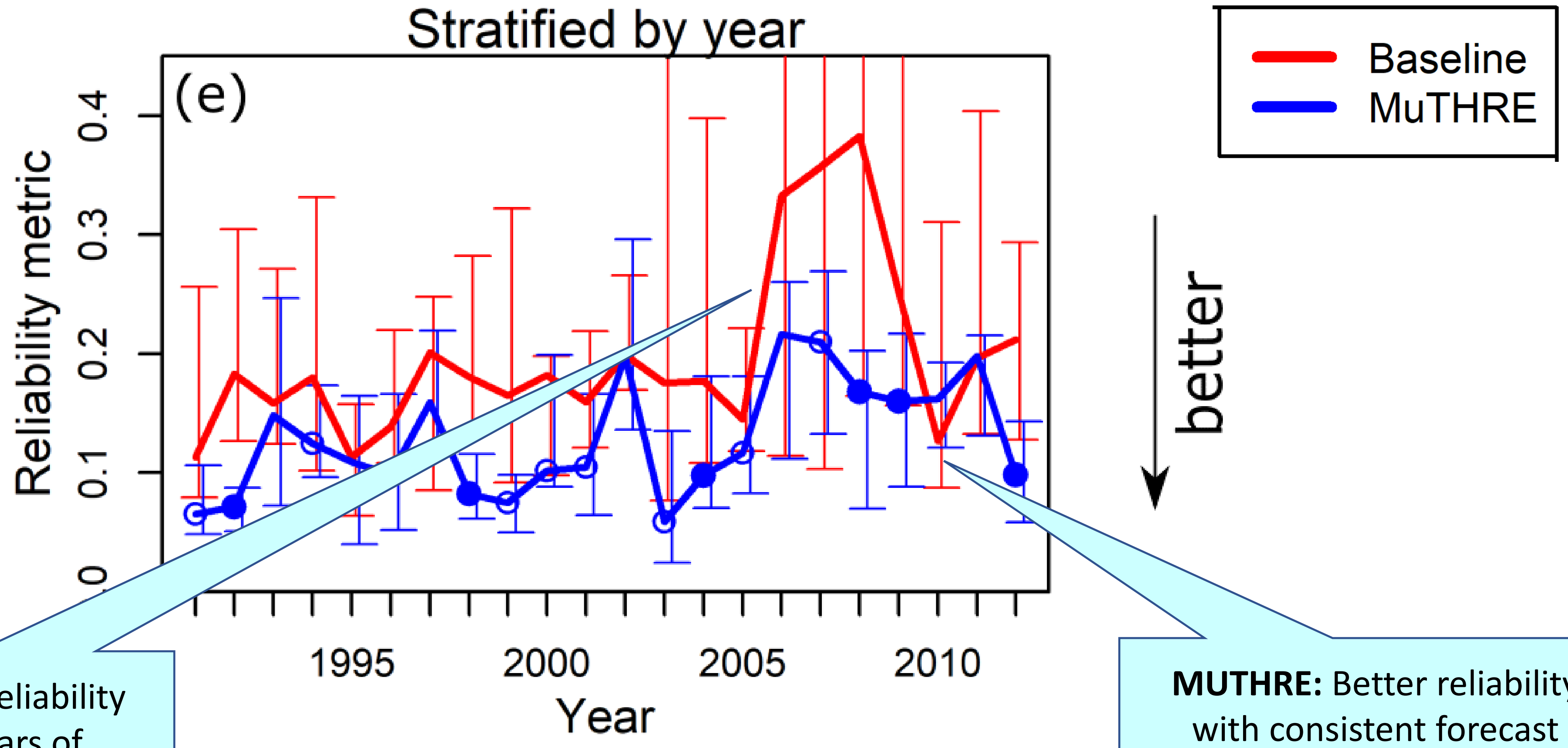
MUTHRE shows large improvements in reliability for dry months



Baseline: Reliability varies from month to month

MUTHRE: Better reliability with consistent forecast quality over all months

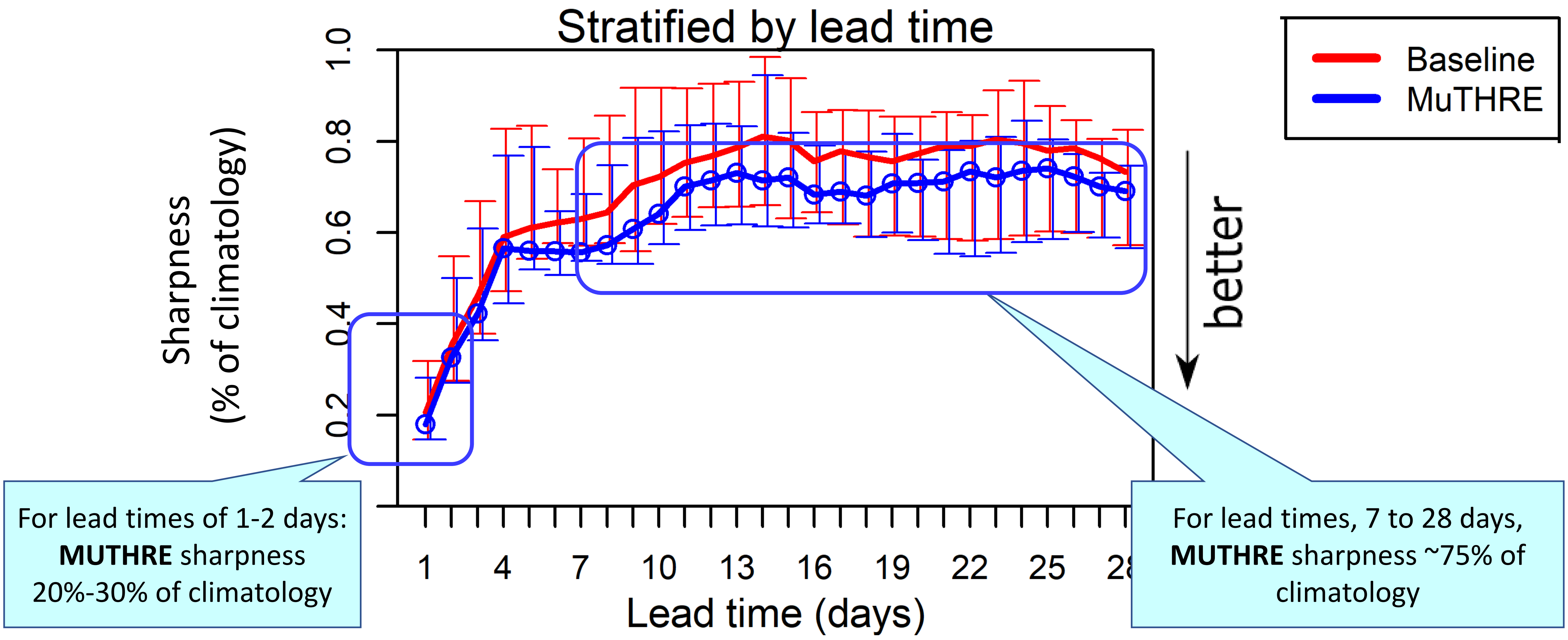
MUTHRE shows large improvements in reliability for drought years



Baseline: Poor reliability during dry years of Millennium drought

MUTHRE: Better reliability with consistent forecast quality over all years

MUTHRE shows improvements in sharpness



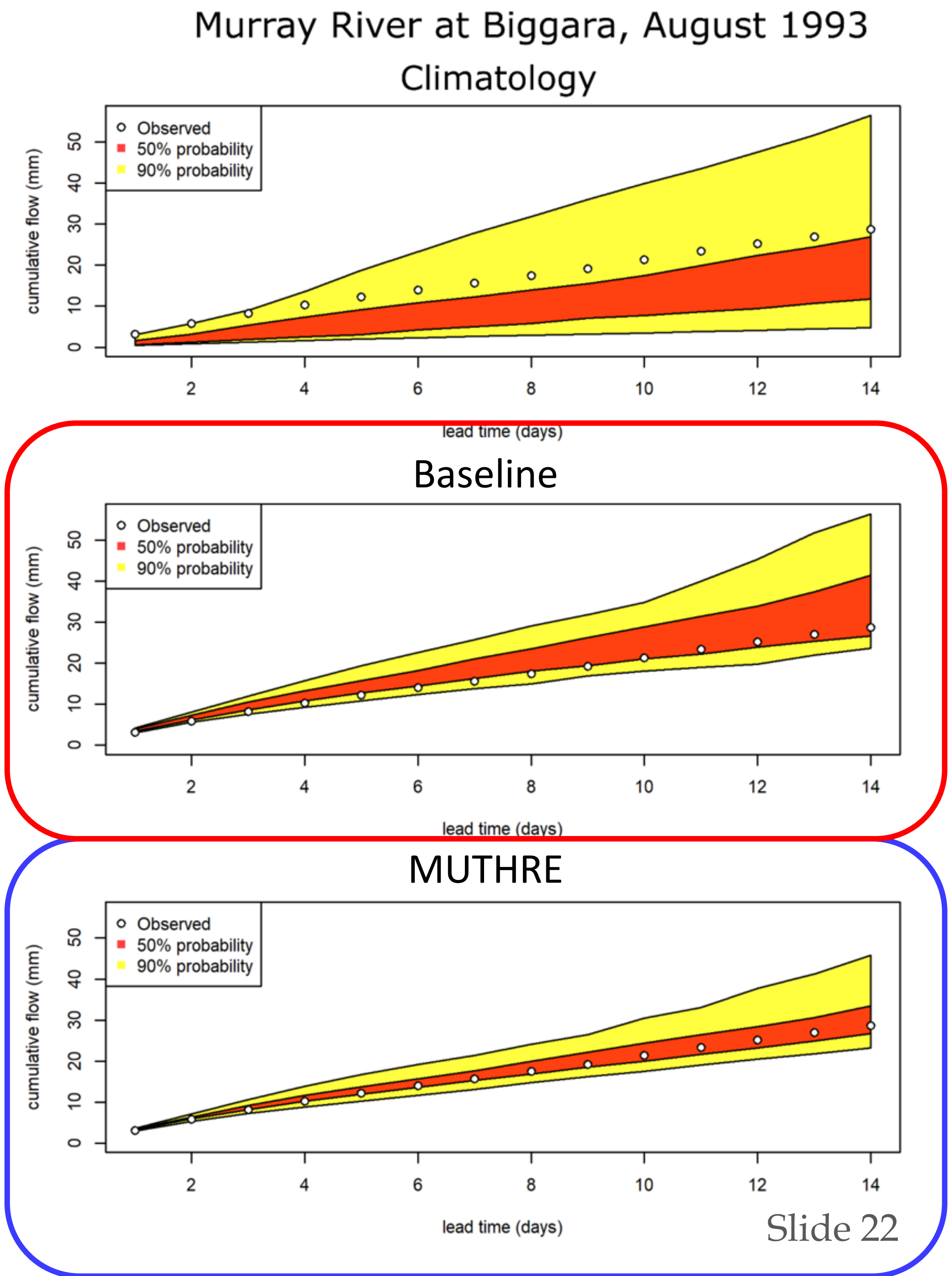
- MUTHRE forecasts are consistently sharper than baseline for all lead times

MuTHRE provides seamless forecasting capabilities

- Forecast of cumulative streamflow over two week period for typical catchment
  - Based on daily time series of forecasts

Baseline forecasts are sharper than climatology

MUTHRE forecasts are sharper than baseline and much sharper than climatology



MUTHRE: Which components contributes to the performance improvements?

Deterministic streamflow from rainfall-runoff model

- **Mu**lti-**T**emporal **H**ydrological **R**esidual **E**rror (MUTHRE) Model
- Incorporates range of common residual errors in Hydrological Models

Heteroscedasticity

Dynamic Biases

Seasonality

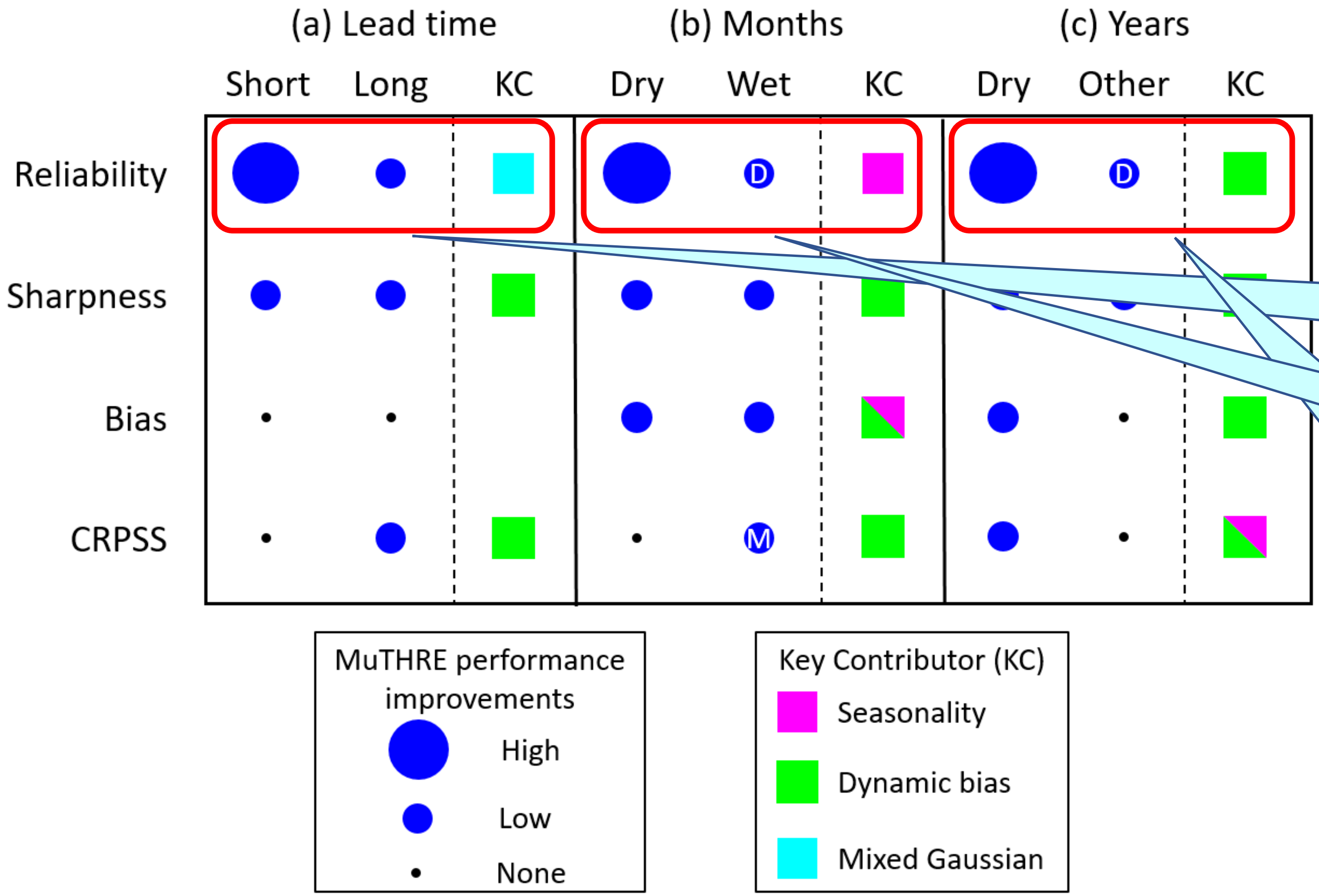
Persistence

Mixed Gaussian for extreme errors

Probabilistic Streamflow

- Seasonality ?
- Dynamic Biases (due to hydrological non-stationarity) ?
- Extreme errors poorly represented by Gaussian Distribution ?

Key Contributors to Performance Improvements



Reliability

- High performance improvements in stratified reliability

For short lead-times (<10 days) improvement due to the mixed-Gaussian component

For dry months (Nov to May) due to seasonality component

For dry years (2006-2009) due to the dynamic bias component

High = *Practically* significant improvement (>20% difference) achieved in *majority* of lead times/months/years
Low = *Statistically* significant improvements (<20% difference) achieved in *majority* of lead times/months/years
None = No practical or statistically significant improvement

Summary

Features

- MuTHRE model delivers consistently high forecast quality for range of time scales/lead times/months/years
- Achieves seamless subseasonal streamflow forecasts for 0 to 30 day lead time
- Significantly improved reliability for short lead times, dry months and drought years
- Much sharper than climatology
- Demonstrated results on high-impact catchments in Upper Murray/Goulburn Rivers

Water Resources Research

Research Article

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Benefits

- Enables integration of daily forecasts into river system models
- Potential for step-change increase in use of forecasts by water industry
- Highlights importance of hydrological modelling and comprehensive treatment of uncertainty for reliable streamflow forecasts.
- Innovations are independent of hydrologic model/rainfall forecasts
- Can be applied to other hydrological/land surface models.
- Easily take advantage of future improvements in rainfall forecasts
- Questions? Email: mark.thyer@adelaide.edu.au