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Understanding Water Quality Measurements

Collaboration work with Seqwater

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Abstract

The Queensland Bulk Water Supply Authority (trading as Seqwater) provides and monitors water for the South-East Queensland, Australia region. To help understand the factors that affect the measurement of water quality within the reservoirs, data was collected for several sites within a reservoir. This dataset focuses on 7 water quality variables taken at a variety of depths. Issues which arise include the multivariate nature of the problem, non-linear trends in both depth and time, correlations in both depth and time, interactions between these variables, instrument error and heterogeneous variances. Of particular interest to the environmentalists is the diurnal variability.

Acknowledgements

seqwater
WATER FOR LIFE

- Collaborator

Australian Government

豪日交流基金
Australia-Japan FOUNDATION

- Sponsor

CSIRO

Queensland Bulk Water Supply Authority

- Trading as Seqwater
- Began operating on 1 July 2008 as a new service provider
- Provides water for South-East Queensland
- 3 major reservoirs around Brisbane
  - Wivenhoe – 1,165,240 ML @ full capacity
  - Somerset – 379,850 ML @ full capacity
  - North Pine – 214,960 ML @ full capacity
- Water is used for:
  - Recreation
  - Irrigation
  - Industry
  - Drinking Water

Collaboration between CMIS and Seqwater

- Analysis of existing datasets
- Gain greater understanding of the variability within and between reservoirs
  - Development of a Report Card for the reservoirs
  - Spatial and Temporal Analyses
    - Daily variability
- Investigating monitoring design network
  - System design
  - Space and time representativeness
  - Spatial optimisation
  - Gaps

Lake Wivenhoe

Photograph: Andrew Watkinson (Seqwater)

Aim of current work

- Quantify impact of taking samples at different times throughout the day
  - Long-term trend
  - Seasonal trend
  - Daily trend
  - Daily trend differences between seasons (ie. Interactions)
- When do maximum/minimum levels occur throughout the day?
- Does the daily trends and maximum/minimums change throughout the year?
- What are the impacts on the current monitoring design?
- How can future sampling designs take account of the daily variability?

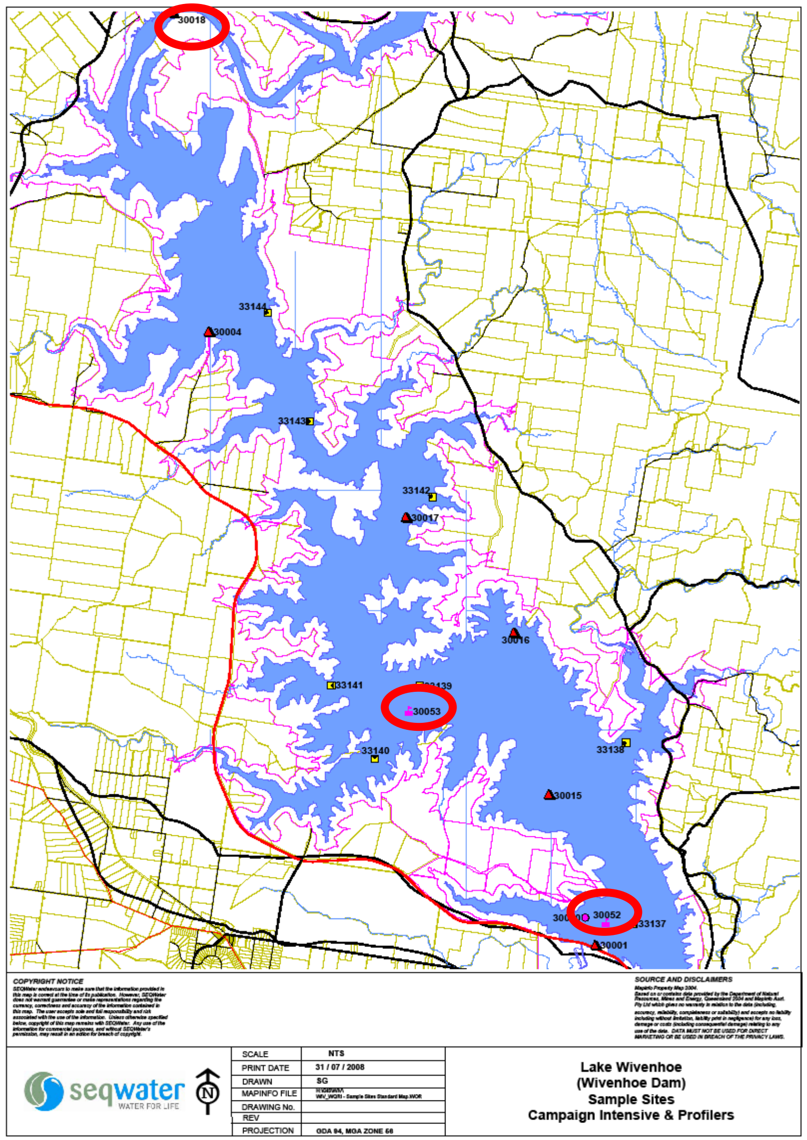
Monitoring Program data

- 6 historical sites
- 8 more recent drought sites
- Surface and bottom measurements
- Samples taken from 1 to 4+ times per month
- Some event monitoring
- Numerous water quality variables measured
- Sampling occurs at different times of the day between sites and within each site

Profiler Data

- 3 main sites
  - Dam wall (28m @ deepest)
  - Upstream site (shallow)
  - Site -mid-way upstream (deep)
- Record from surface to bottom ~1m
- Each depth is recorded every 2 hours
- Dam wall site starts recording in August 2007 (554 days)
  - The other two sites start recording sometime later
- Dam Wall site: 137, 500 observation
- Multiple variables:
  - Water Temperature, pH, Specific Conductivity, Turbidity, Chlorophyll a, Blue Green Algae, Dissolved Oxygen

Location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seqwater
WATER FOR LIFE
N
SCALE NTS
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DRAWN SG
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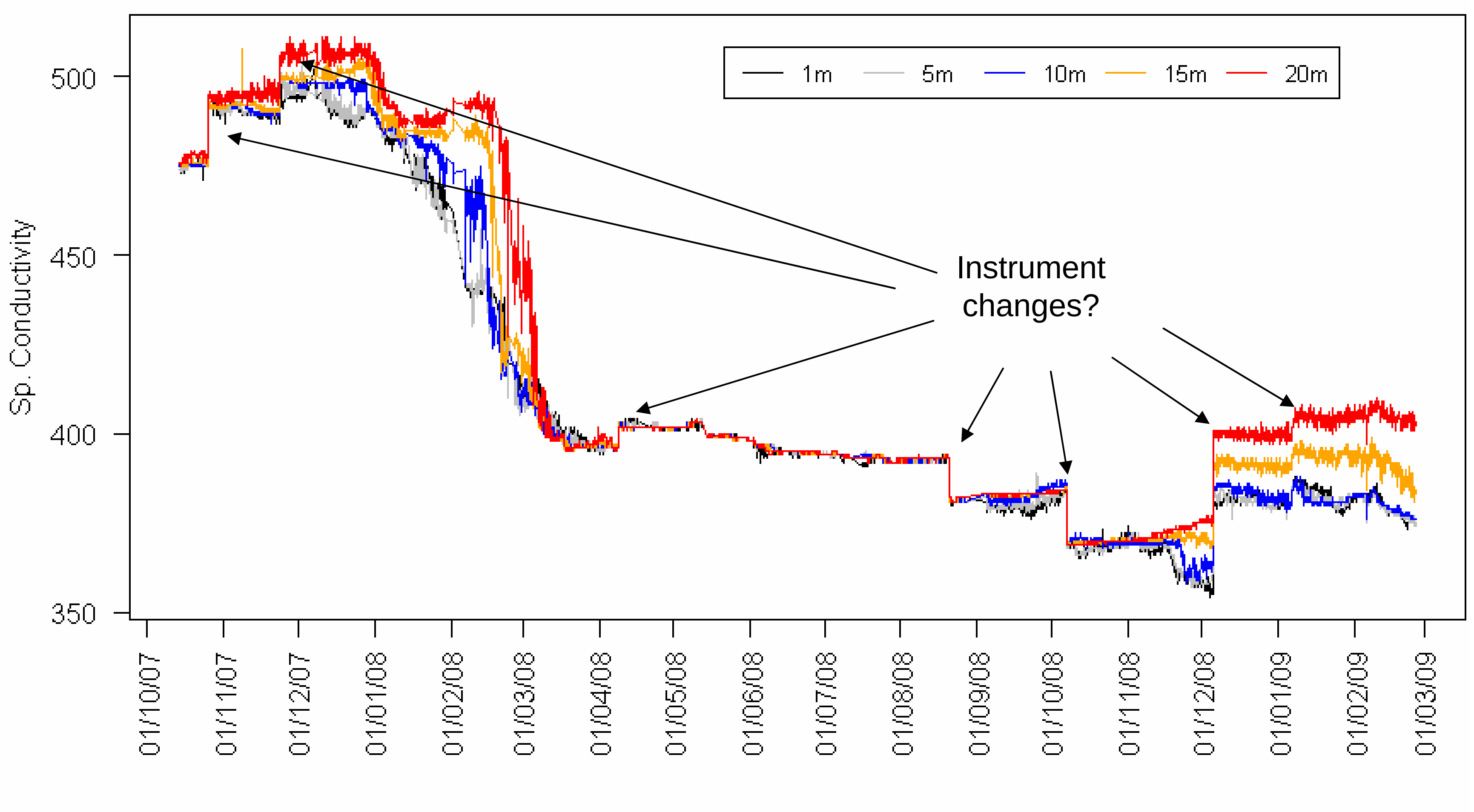
REV
PROJECTION GDA 94, MGA ZONE 56
Lake Wivenhoe
(Wivenhoe Dam)
Sample Sites
Campaign Intensive & Profilers

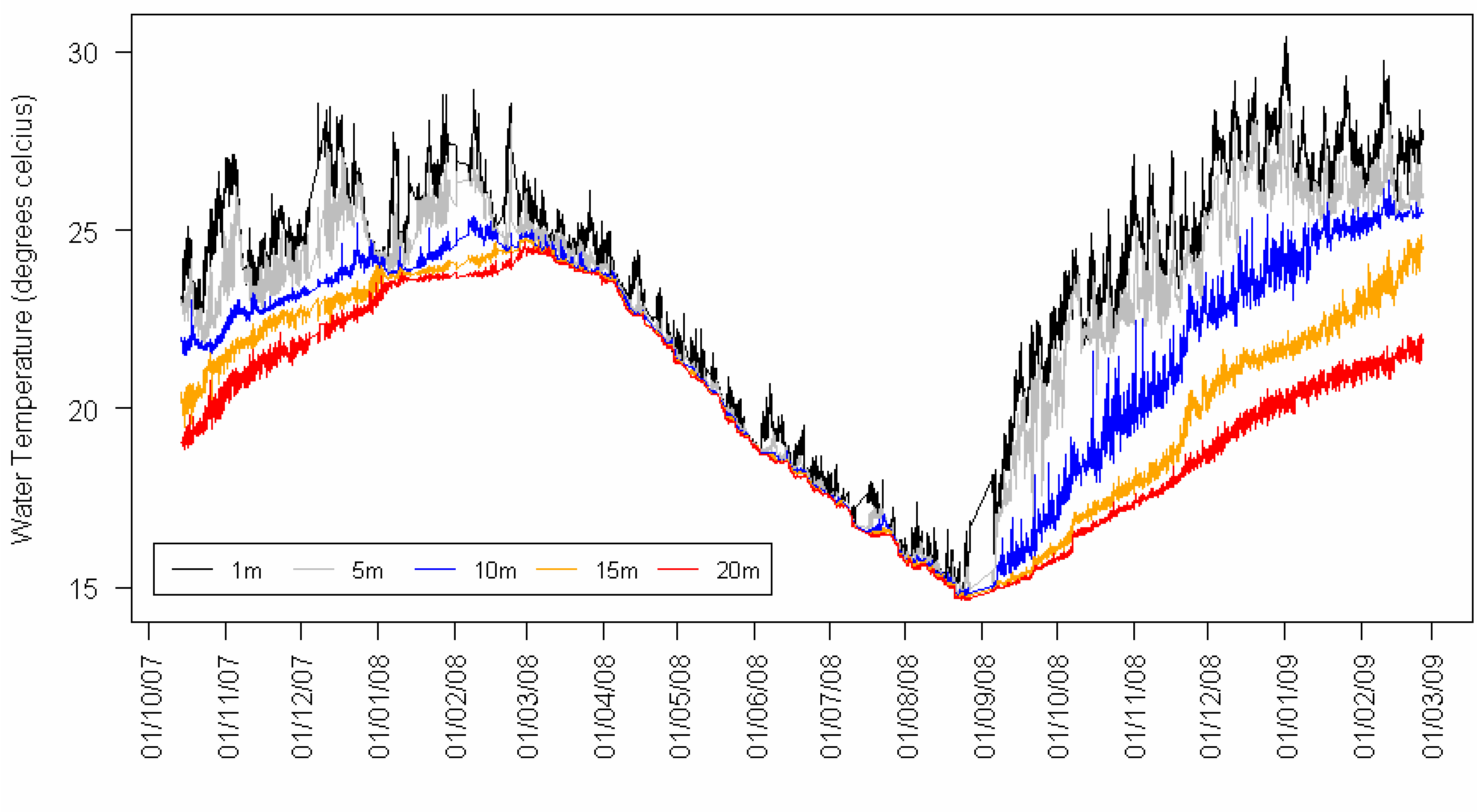
Challenges

- Too much rather than too little data (100, 000+ observations at a single site for each variable)
- Abrupt changes due to instrument calibration or replacement
- Correlation in time
- Correlation in depth
- Non-homogeneous variance
- Non-linear trends across depth and time.
  - Seasonality
  - Stratification (separation of surface and bottom layers)
- Interactions between depth and time of day
- Interactions between month & time of day
- Multivariate nature of variables

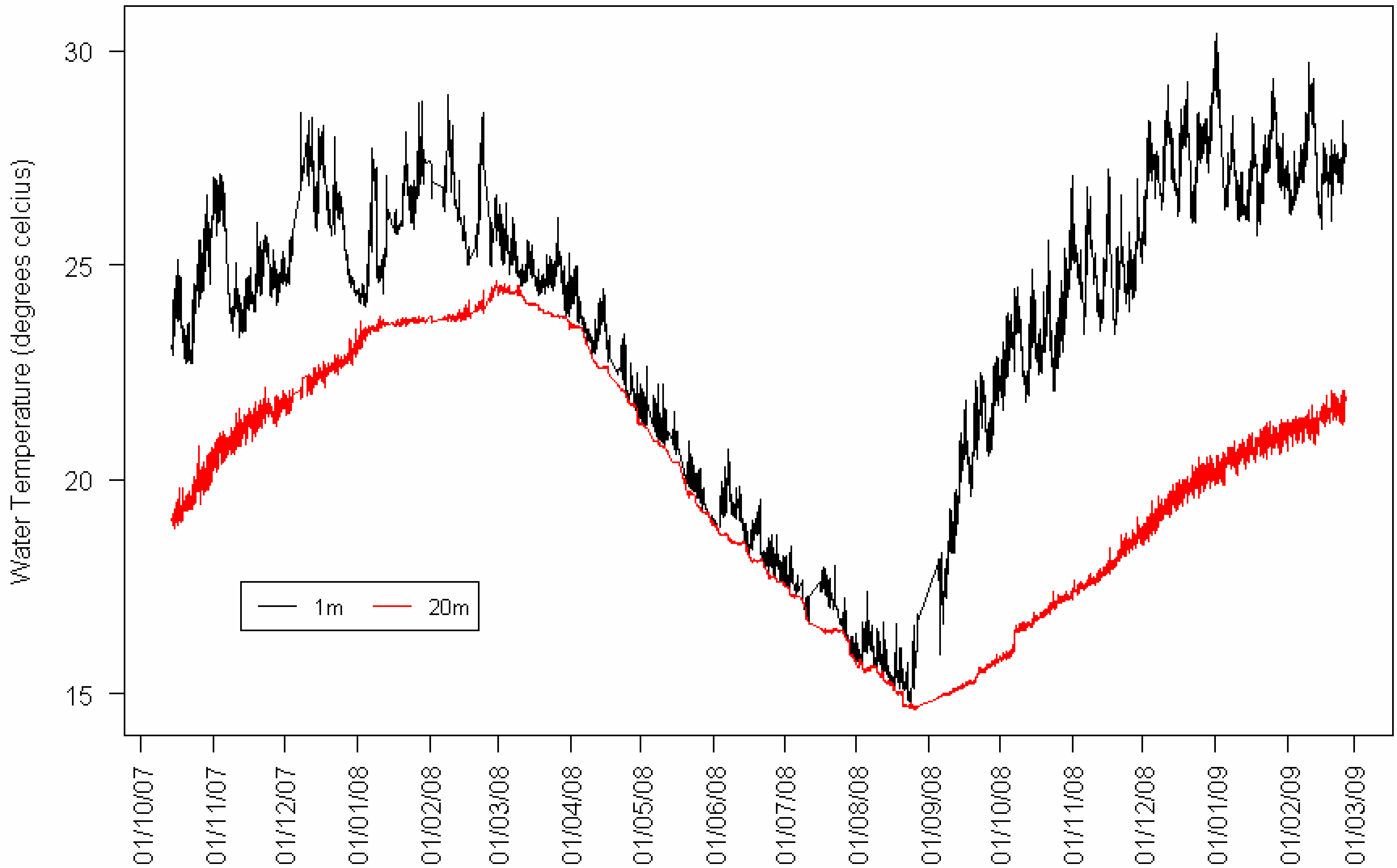
Instrument changes



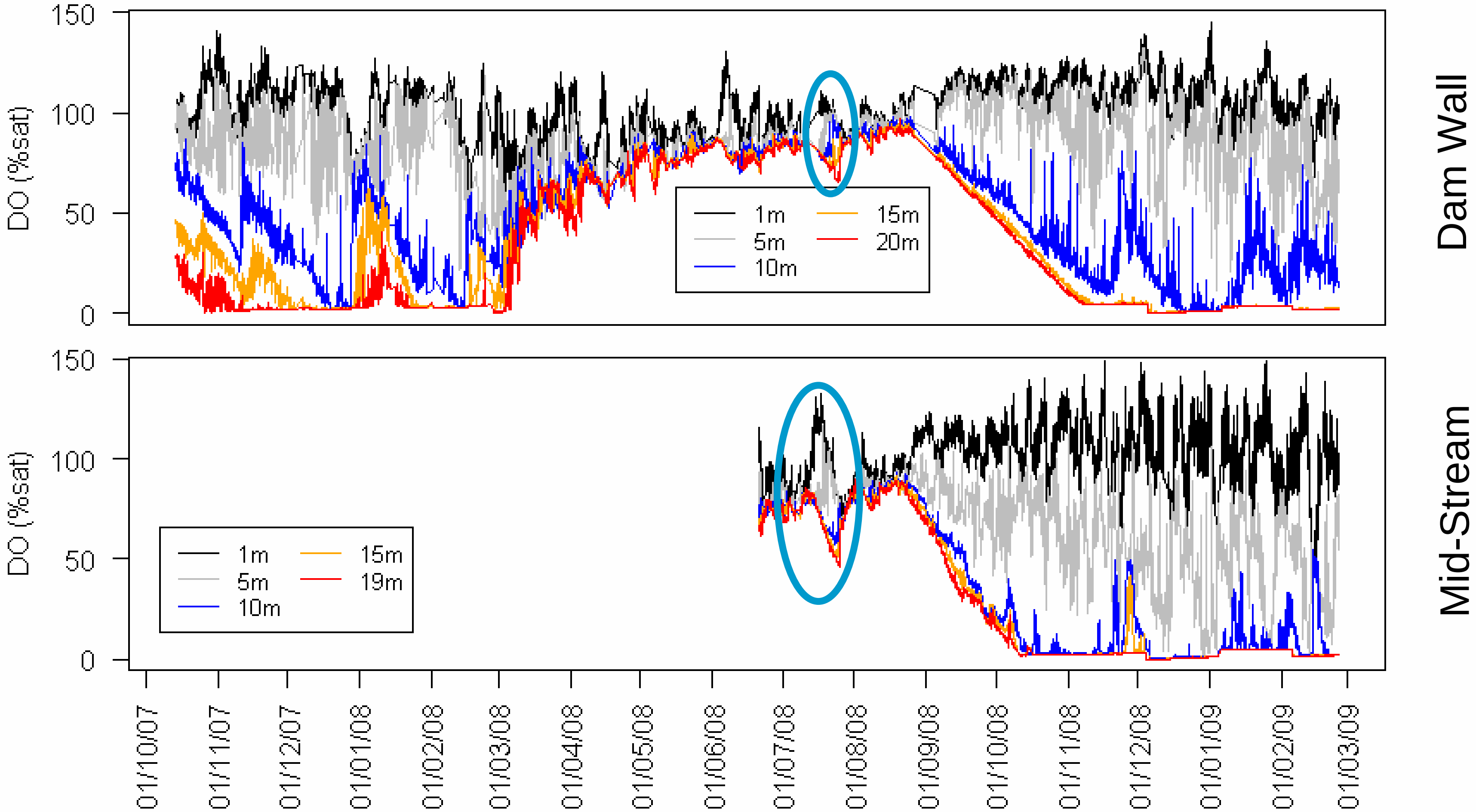
Changing variability across depths



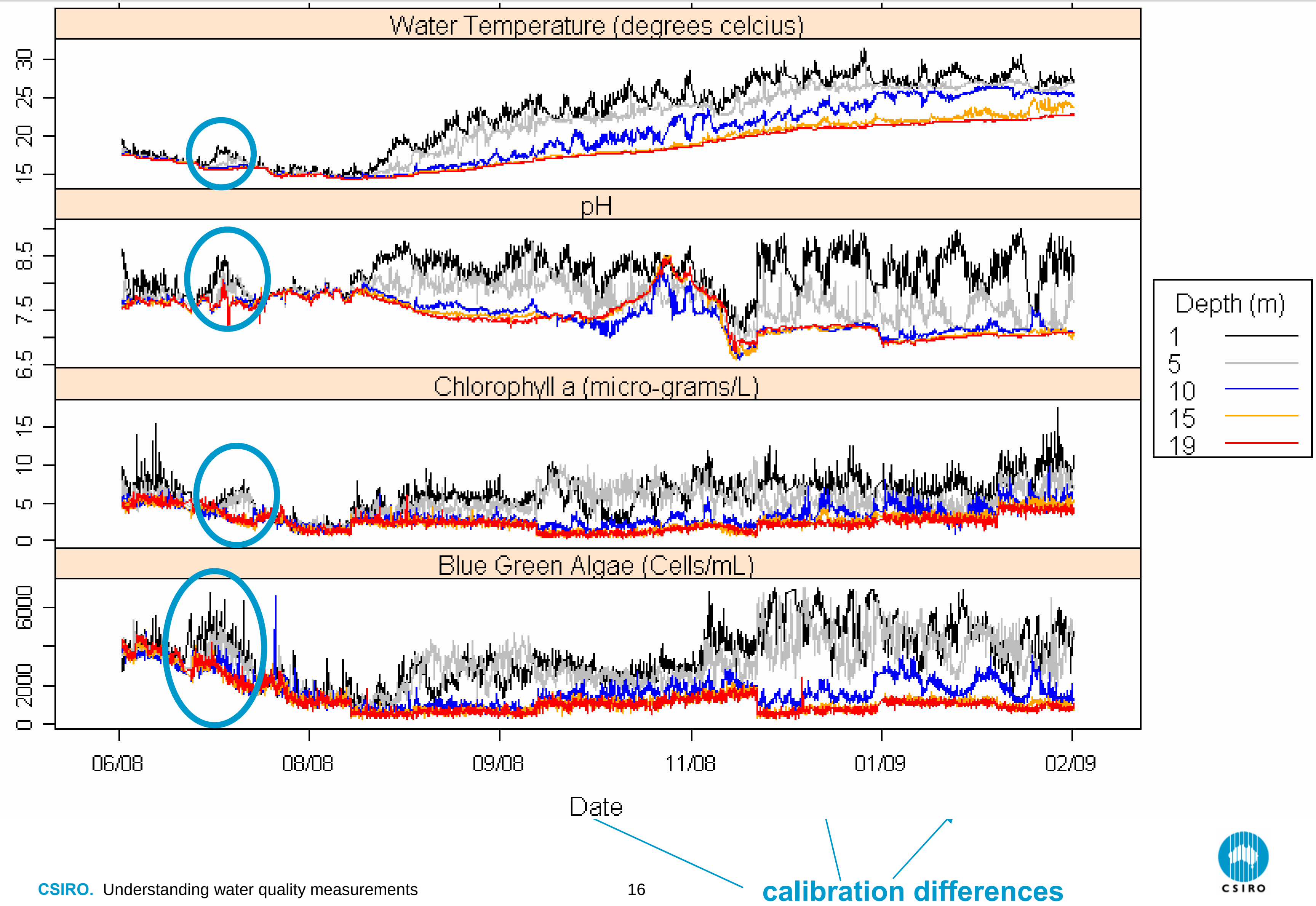
Changing variability within depth



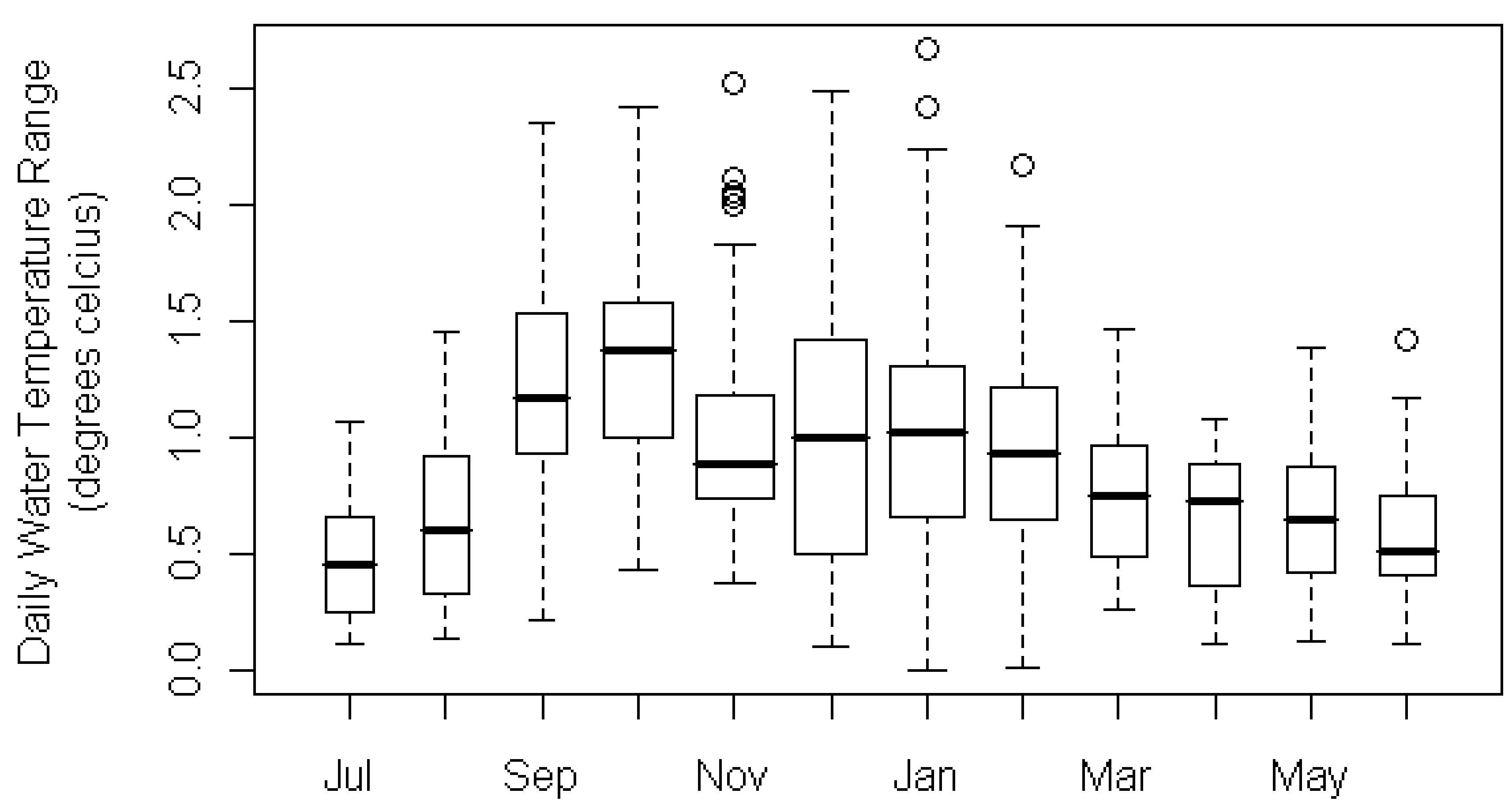
Example: stratification during low variability



Mid-stream site



Interactions between time of day and month



Assumptions for Simplified Model to extract daily trend

- Correlations in time
  - Lagged residual terms
- Each depth is independent
- Each variable is modelled independently by a univariate design
- Non-linear trends in time
  - Smooth terms.

Model process (adapted from Rigby & Stasinopoulos, 1996)

- Assume $y_i \sim N(\mu_i, \sigma_i^2)$
- Mean is modelled by: $g_1(\mu) = \sum s_j(x_j)$
- Variance is modelled by: $g_2(\sigma^2) = \sum t_k(m_k)$

where

s_j and t_k are linear or smooth terms

x_j and m_k are explanatory variables for mean and variance

g() is the link function

Iterative process

1. Assume prior weights $\omega_1 = 1$
2. Fit GAM model for mean $g_1(\mu) = \sum s_j(x_j);\ \omega_1 = 1$
3. Calculate residuals $\varepsilon_t = y_t - \hat{\mu}_t;\ \eta = \varepsilon_t / \sigma_t$
4. Calculate lagged residuals $\eta_{t-1} = \dfrac{\varepsilon_{t-1}\sigma_t}{\sigma_{t-1}}$
5. Fit GAM model to **ε²** $g_2(\varepsilon_t^2) = \sum t_k(m_k) = g(\sigma_t^2)$
6. Calculate new prior weights $\omega_1 = 1/\hat{\varepsilon}^2$
7. Refit GAM model with weights and lagged residuals covariate $g_1(\mu_{full}) = \sum s_j(x_j) + \rho\eta_{t-1};\ \omega_1 = 1/\hat{\varepsilon}^2$
8. Calculate $\hat{\mu}_t = \hat{\mu}_{full} - \rho\eta_{t-1}$
9. Repeat steps 3 to 8 until convergence

Final Model – Dam wall site (surface)

- Mean is modelled (using Simon Wood's mgcv package for R) by:

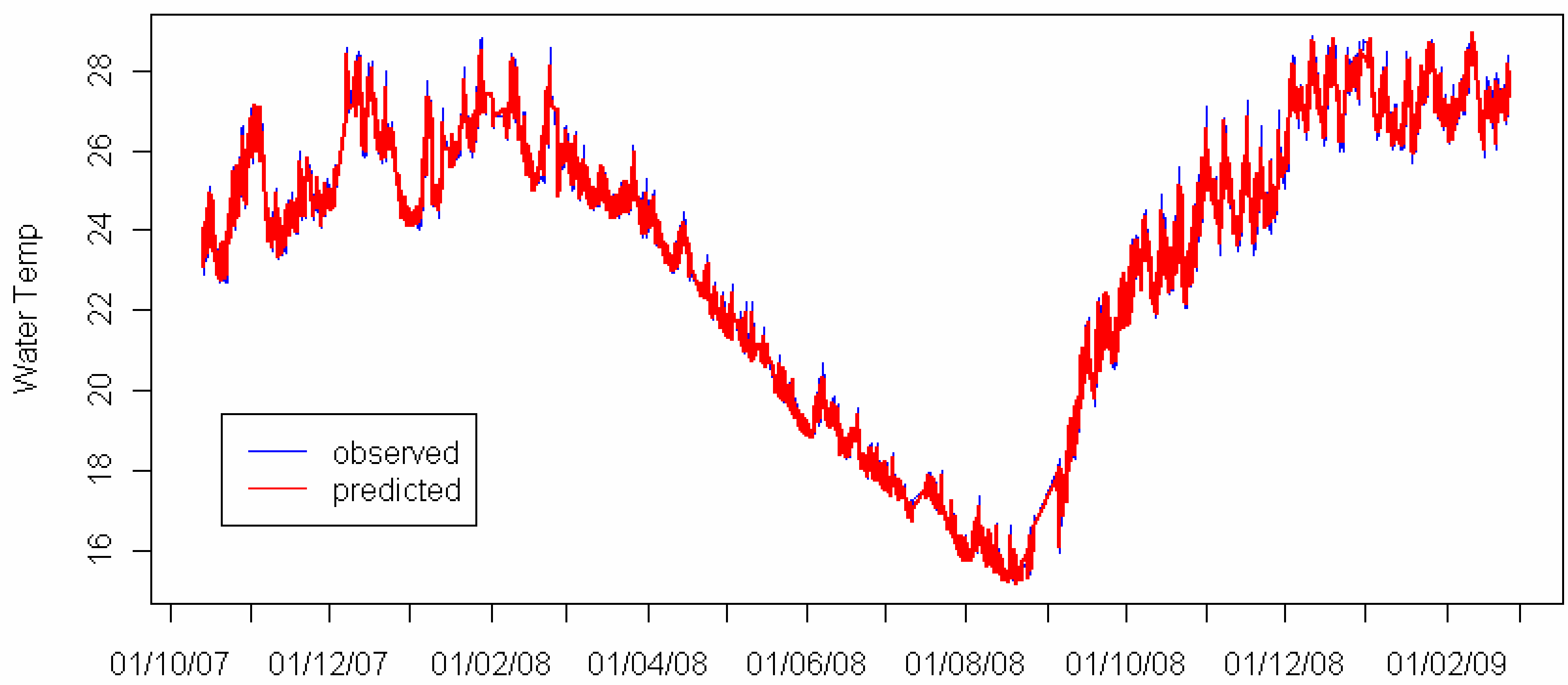
$$g_1(\mu) = a + change + s(Date, k = 100)$$
$$+ s(time, by = month, k = 7, bs = "cc") + \rho\eta_{t-1}$$

change is a categorical variable defining periods of instrument changes, η_{t-1} is a lagged residual term.

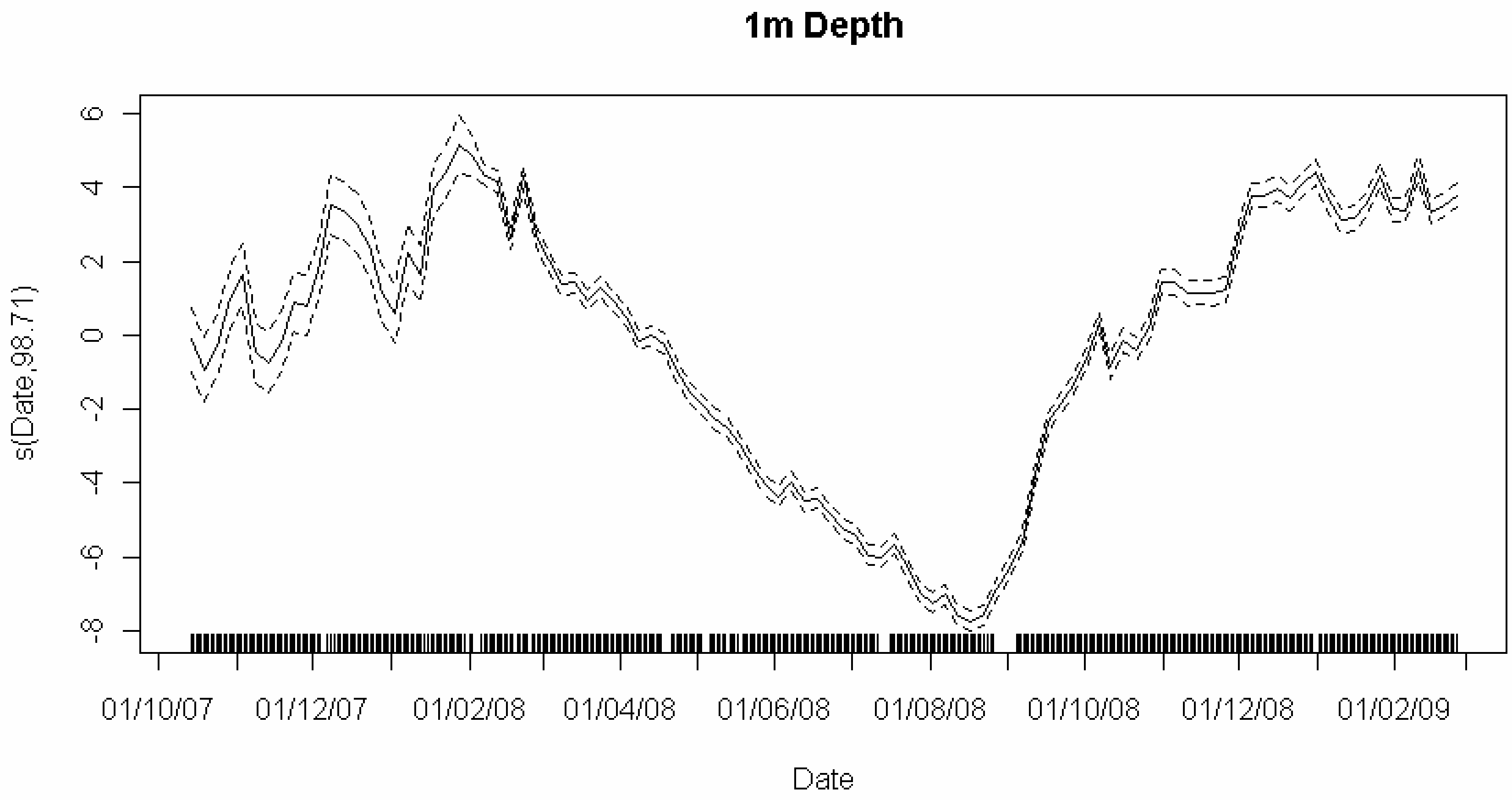
- Variance is modelled by:

$$g_2(\sigma^2) = b + s(Date) + s(time)$$

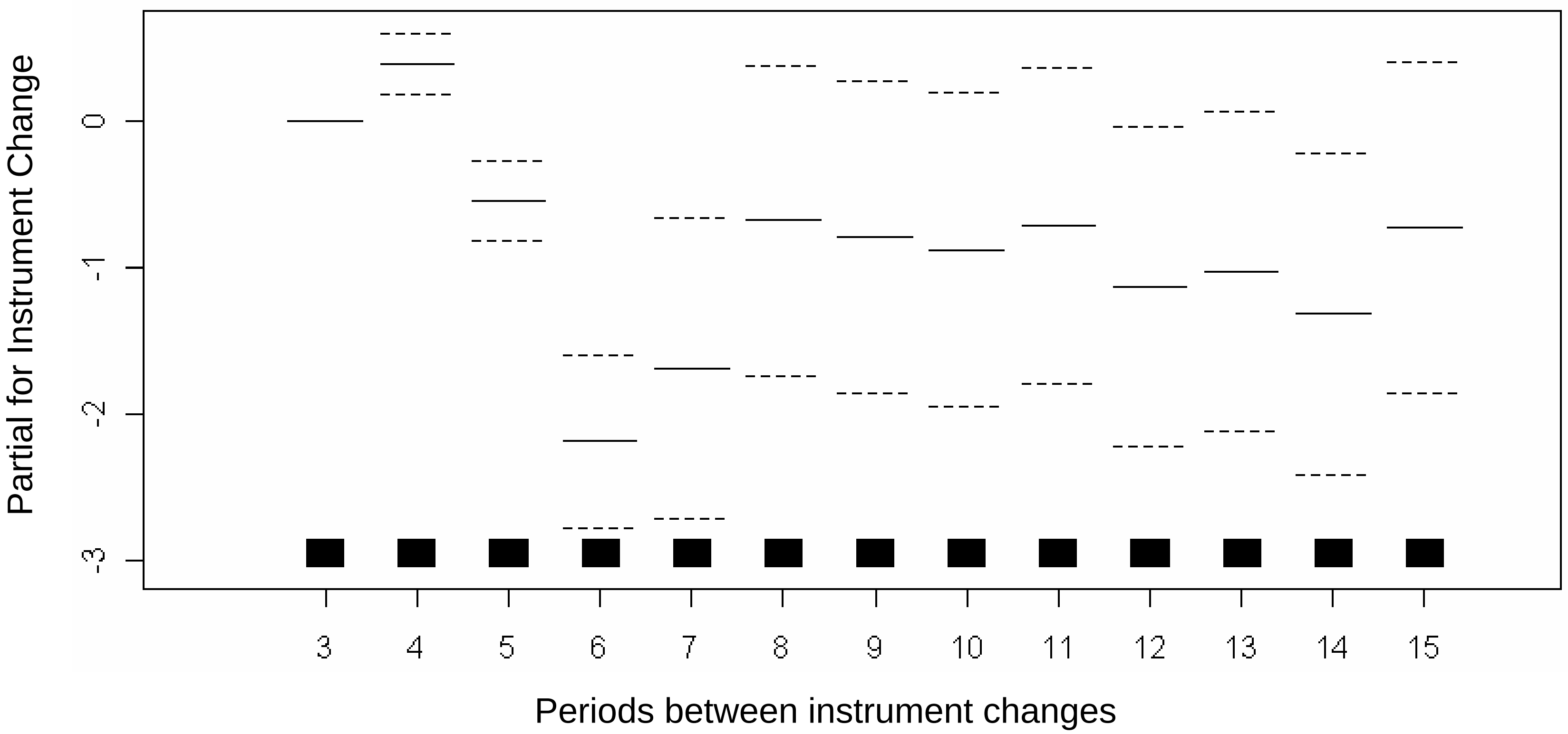
Observed and fitted values for Dam wall site 1m Depth



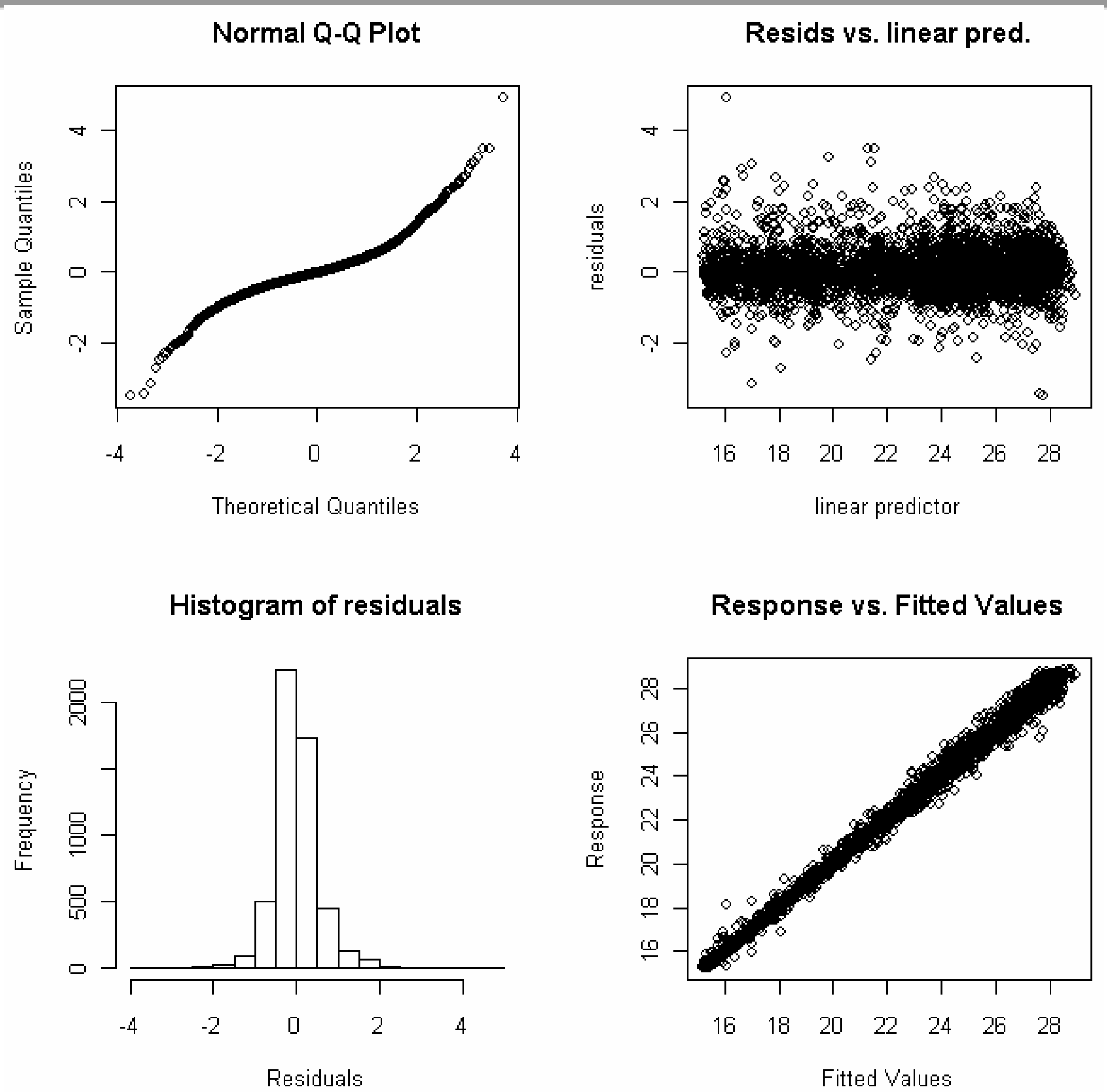
Seasonal / Longer trend covariate



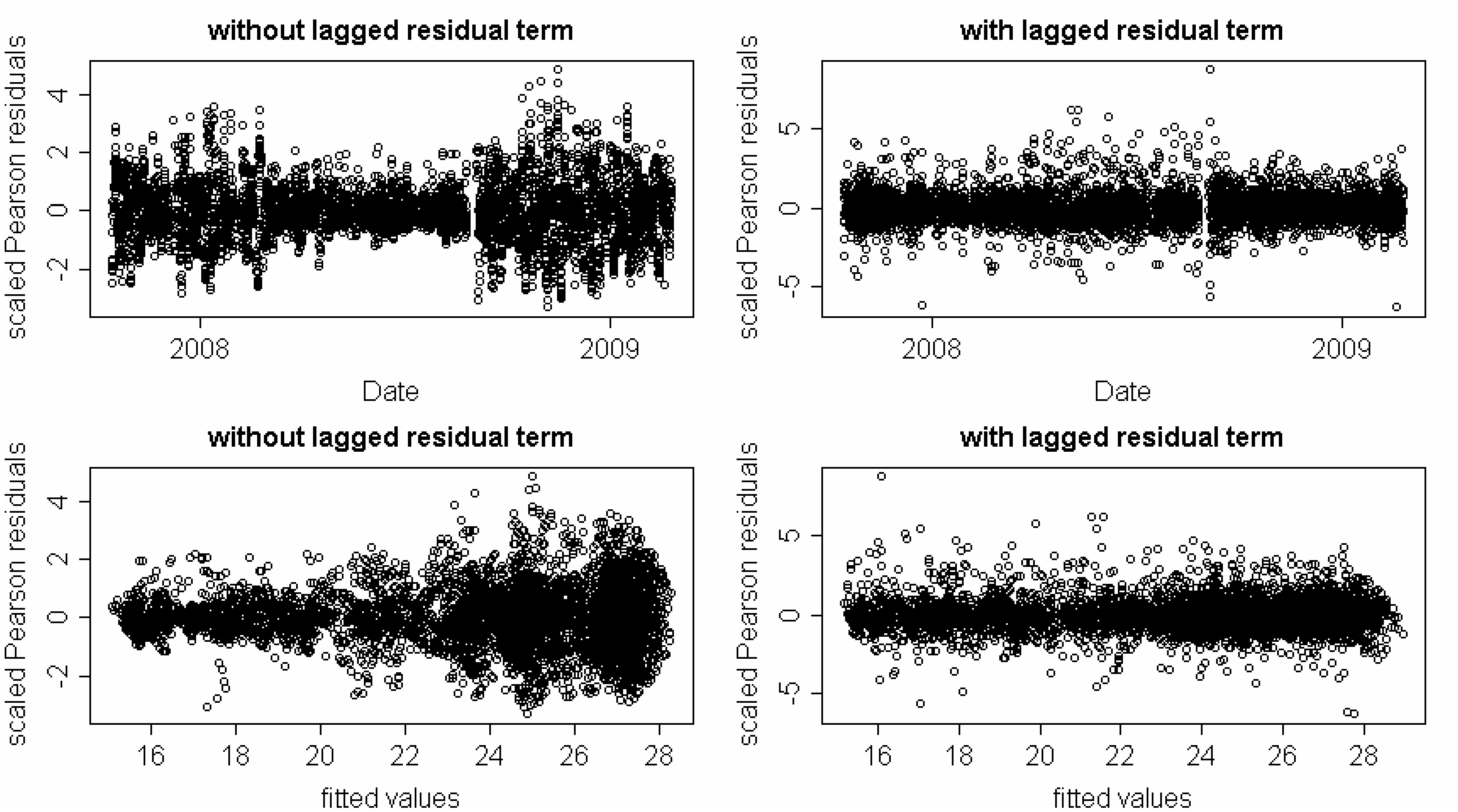
Instrument Change covariate



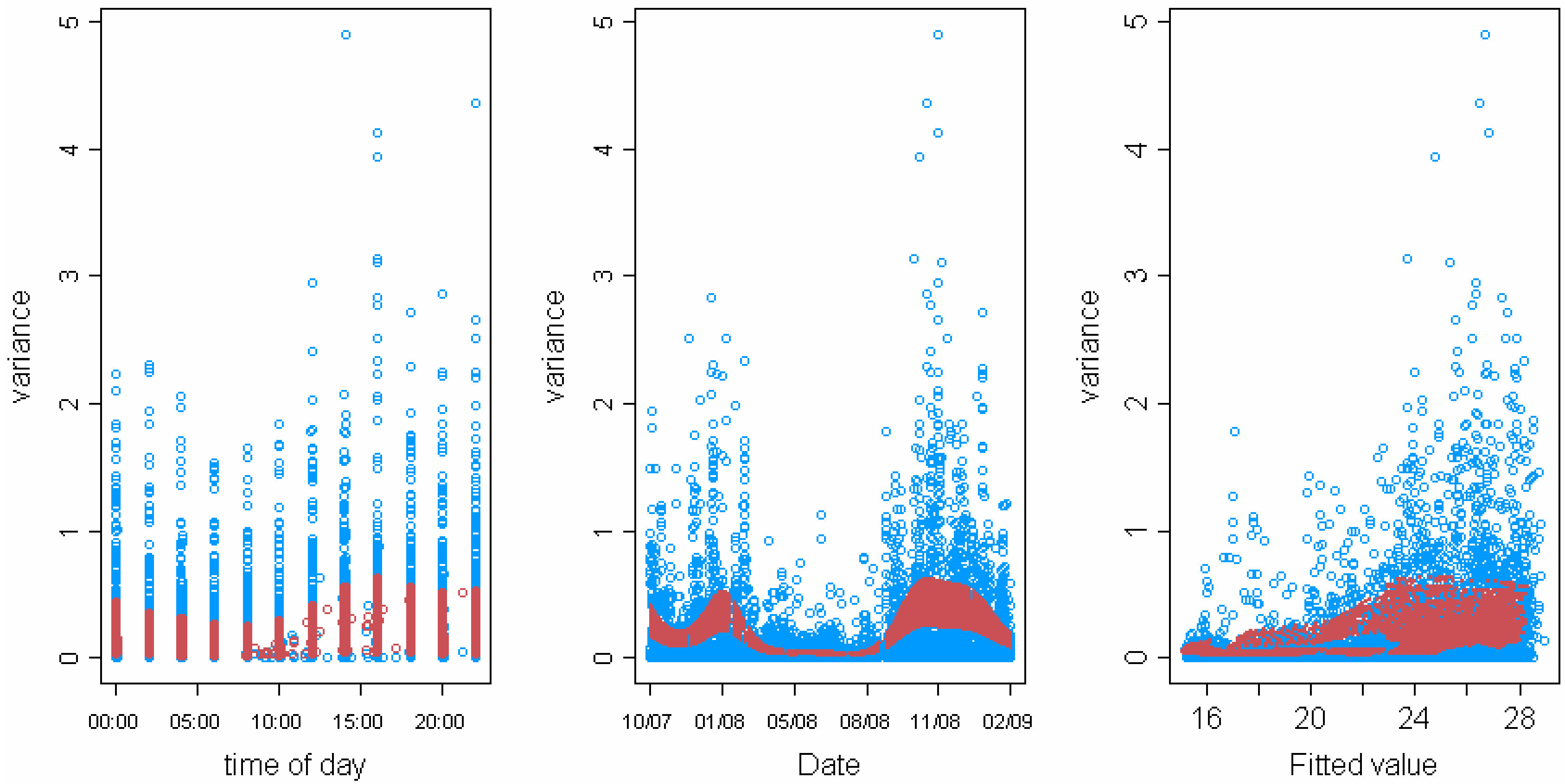
Model diagnostics



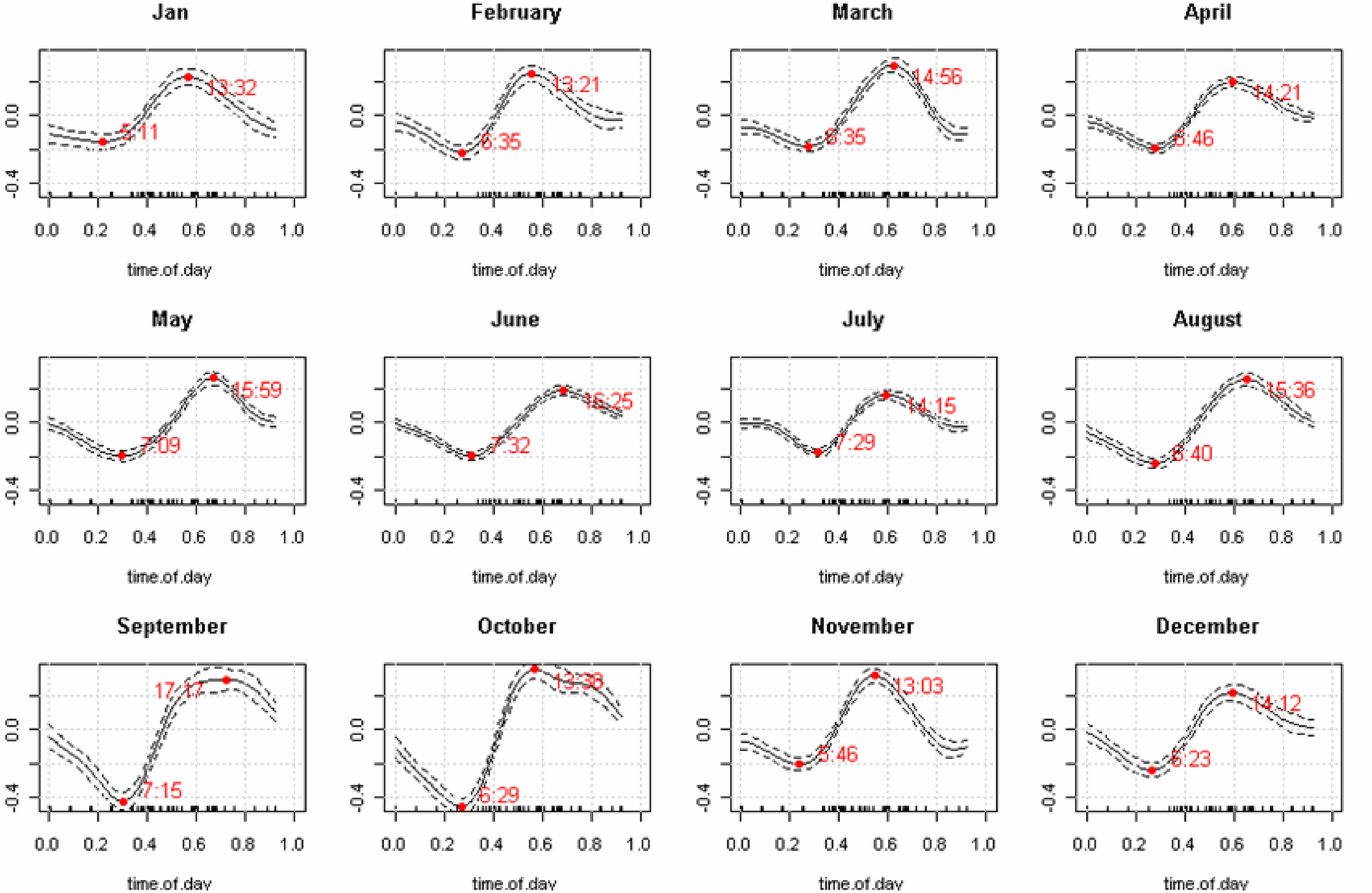
Model diagnostics cont.



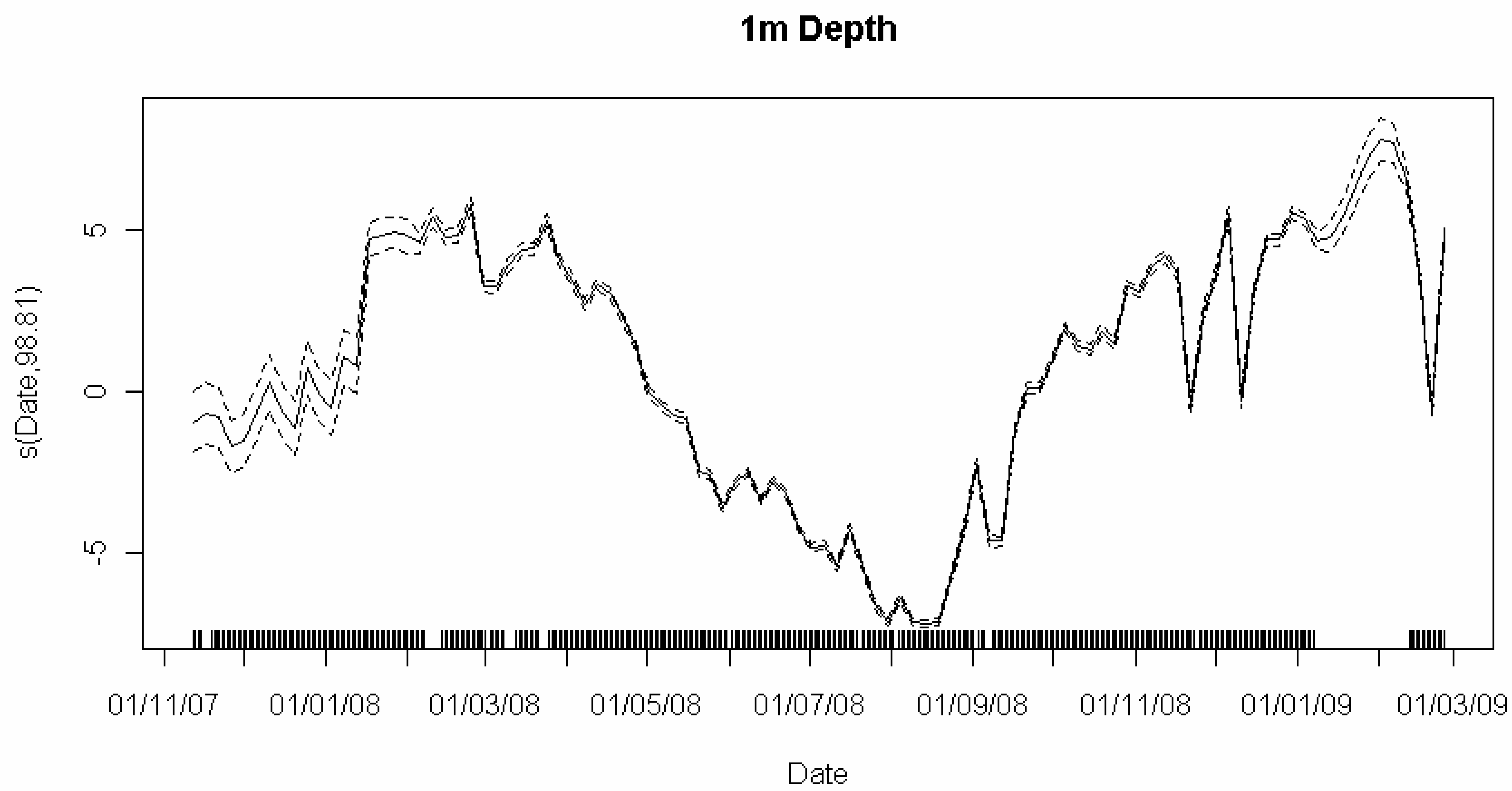
Variance function



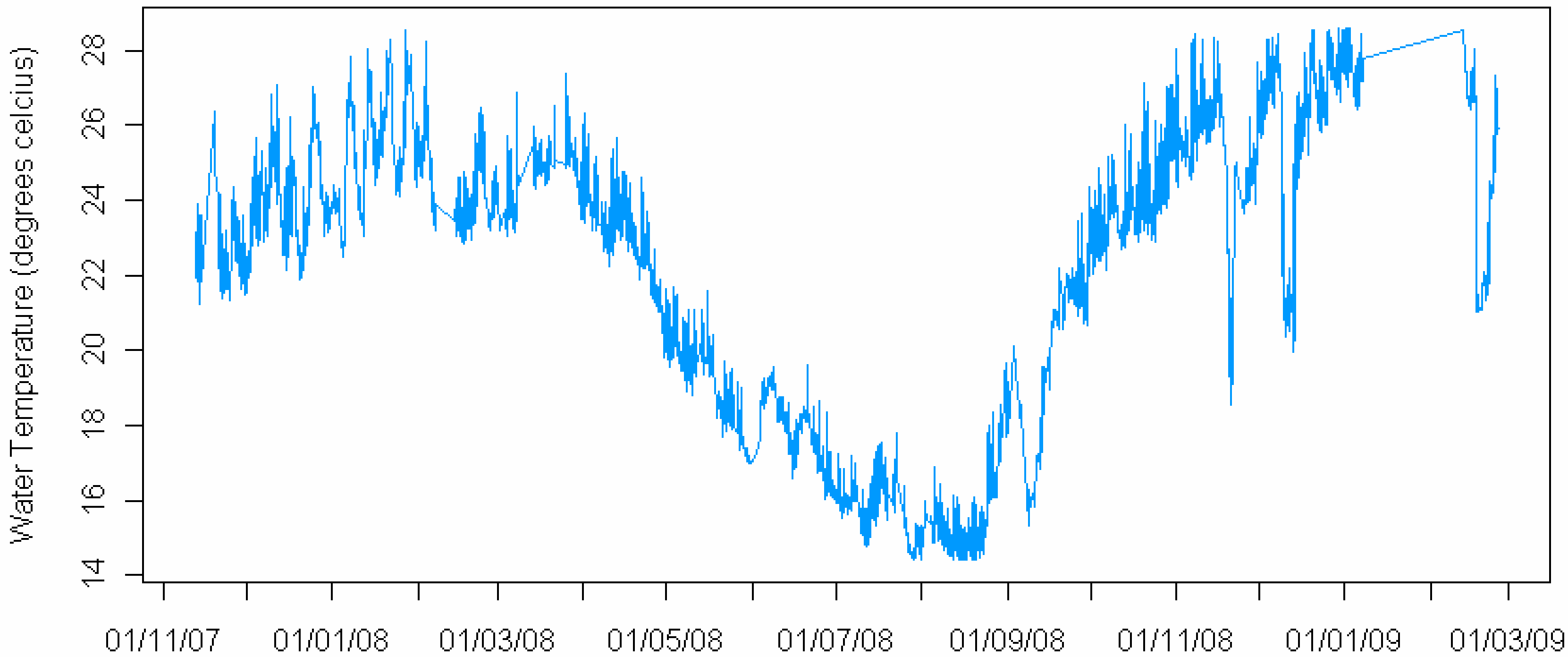
Diurnal variability (nicchu-no)



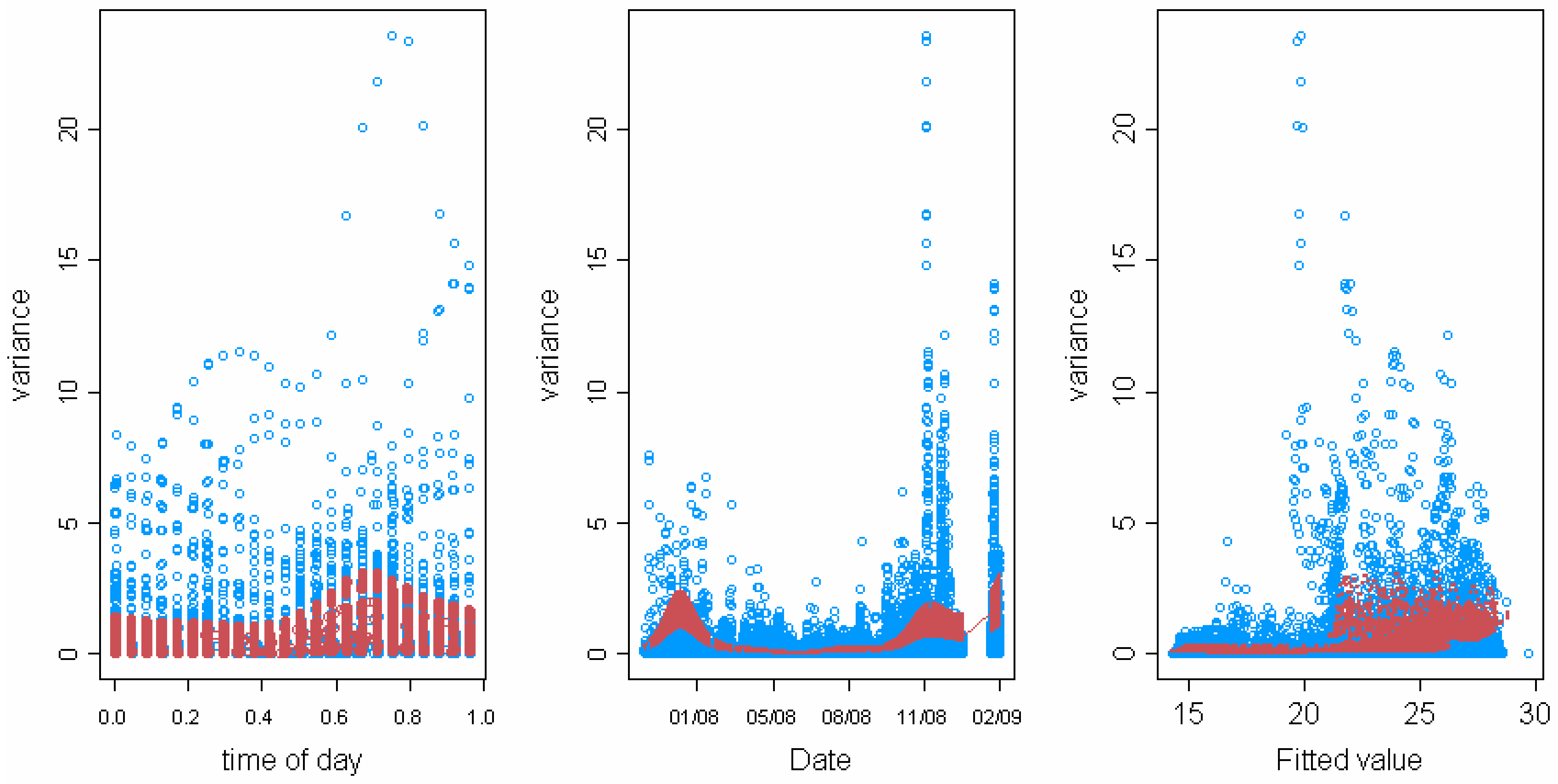
Seasonal / Longer term trend for Up Stream site 1m Depth



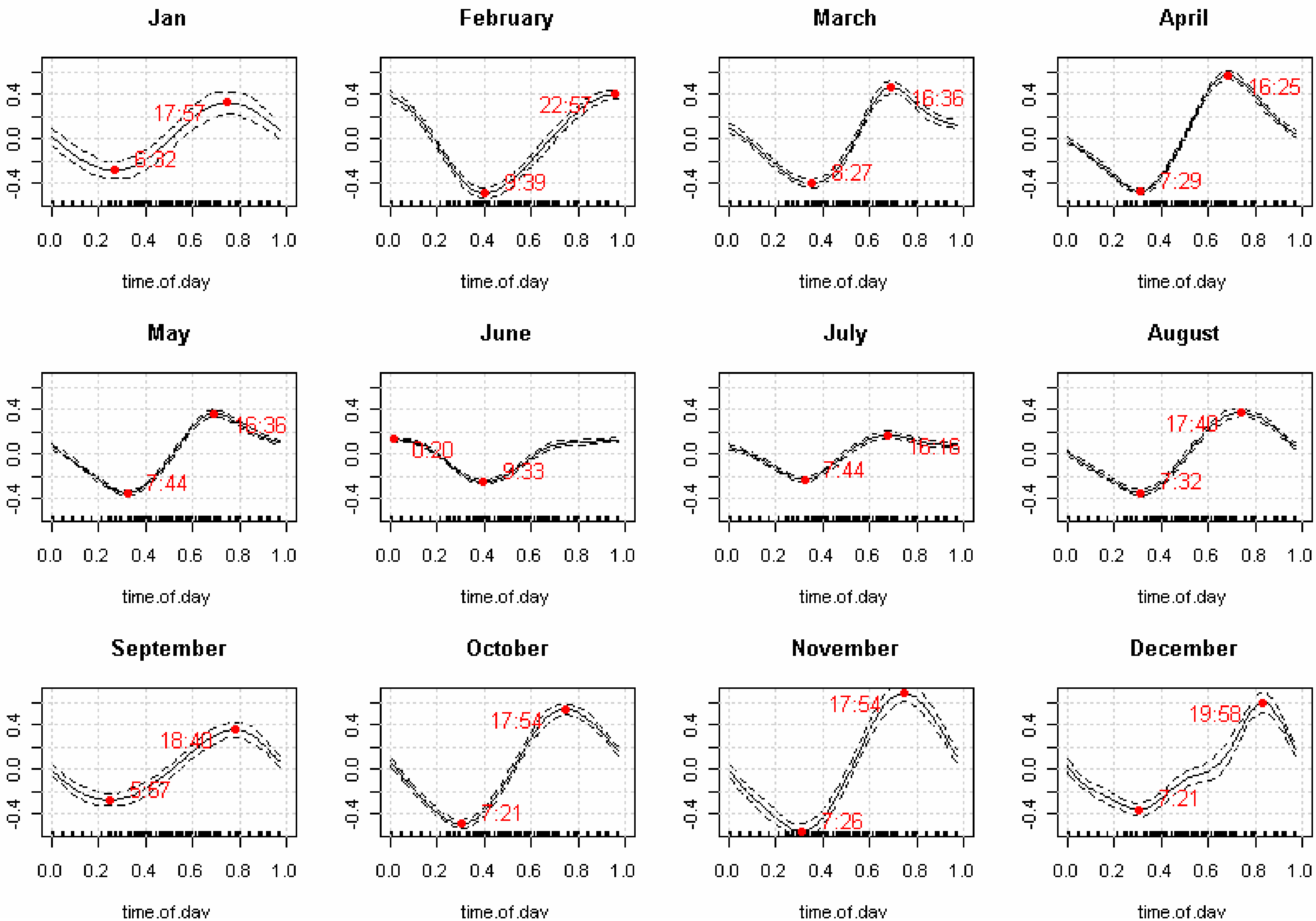
Water Temperature for Upstream Site



Variance Function



Diurnal variability at 1m depth for Upstream site



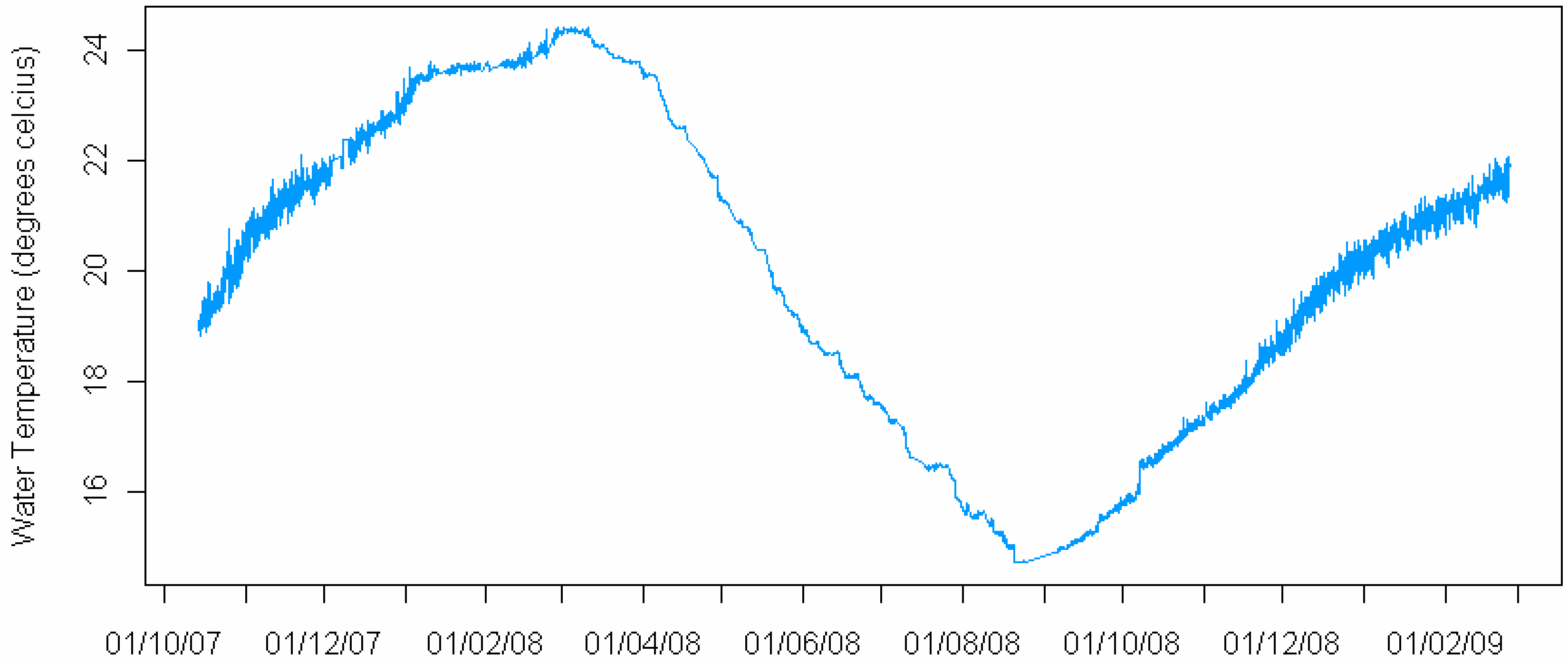
Site comparison

	Dam wall site		Up-Stream site	
Time of day	**Min**	**Max**	**Min**	**Max**
January	5:11am	1:32pm	6:32am	5:57pm
February	6:35am	1:21pm	9:39am	10:57pm
March	6:35am	2:56pm	8:27am	4:36pm
April	6:46am	2:21pm	7:29am	4:25pm
May	7:09am	3:59pm	7:44am	4:36pm
June	7:32am	4:25pm	9:33am	12:20am
July	7:29am	2:15pm	7:44am	4:16pm
August	6:40am	3:36pm	7:32am	5:40pm
September	**7:15am**	**5:17pm**	5:57am	6:40pm
October	**6:29am**	**1:38pm**	7:21am	5:54pm
November	5:46am	1:03pm	**7:26am**	**5:54pm**
December	6:23am	2:12pm	7:21am	7:58pm

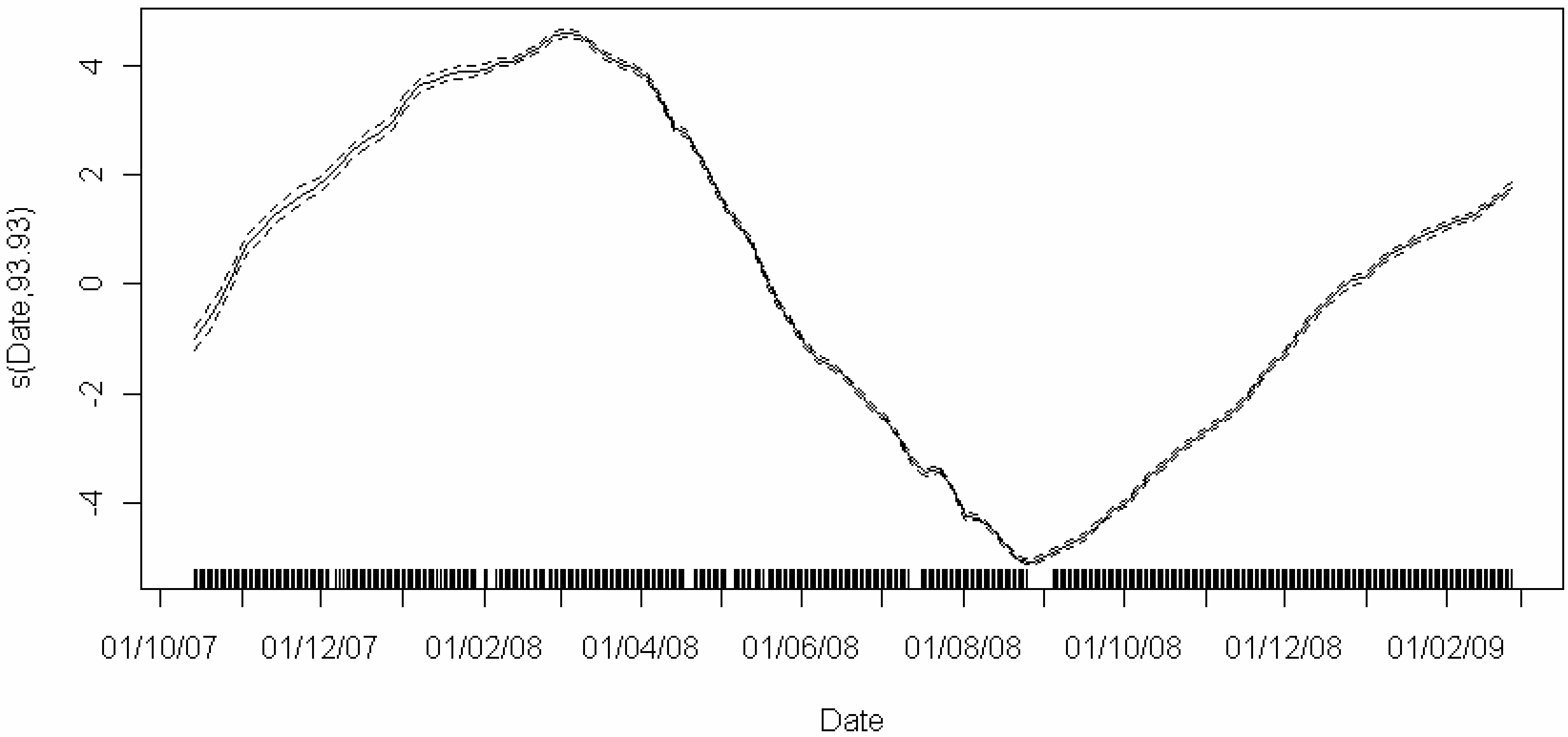
Example 2 – Bottom of Dam Wall site

- Covariates for mean:
  - Factor for periods of change due to instrument changes
  - Date
  - Time of day curve for each month
- Covariates for variance
  - Date
  - Time of day

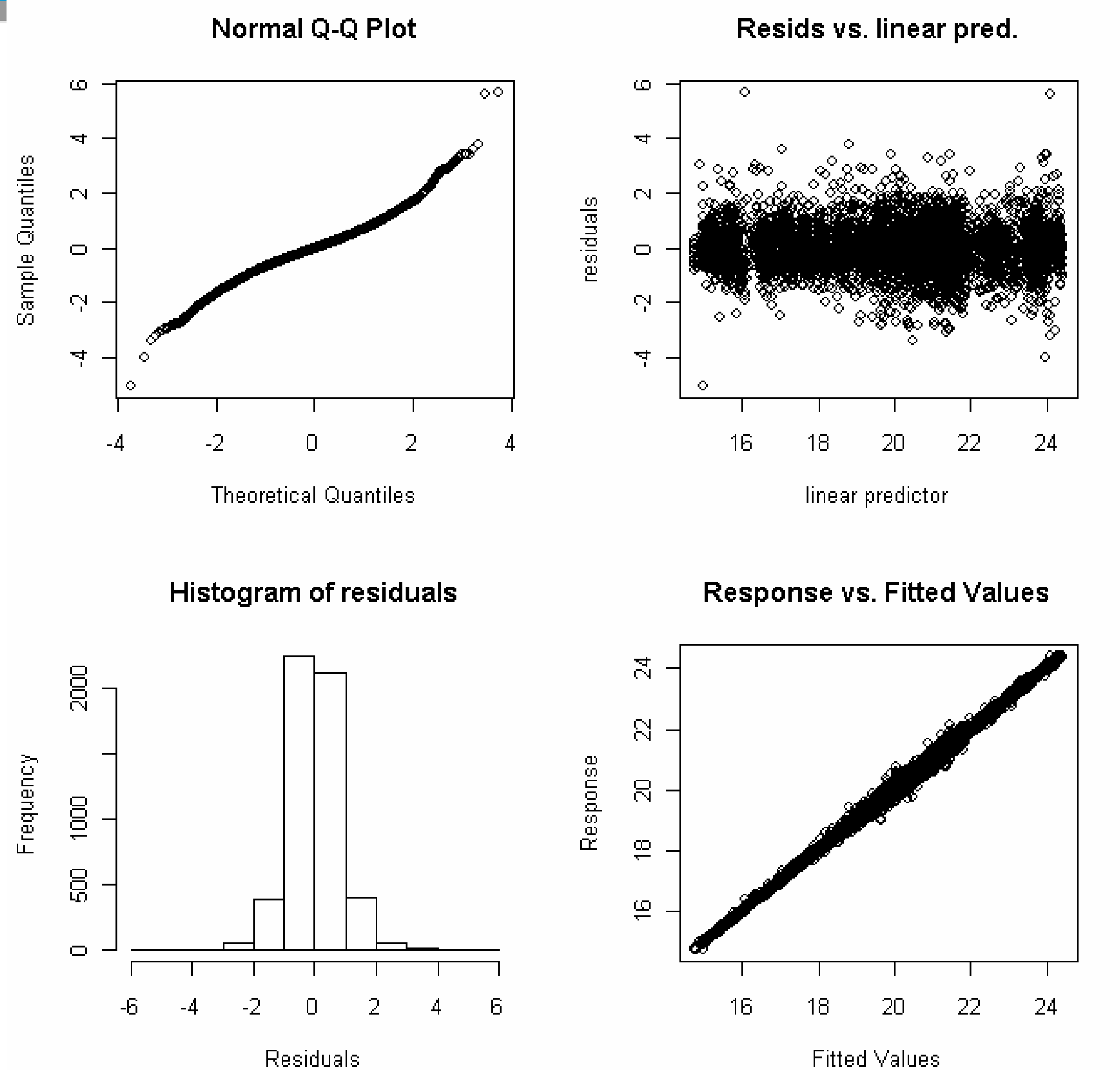
Water Temperature (bottom)

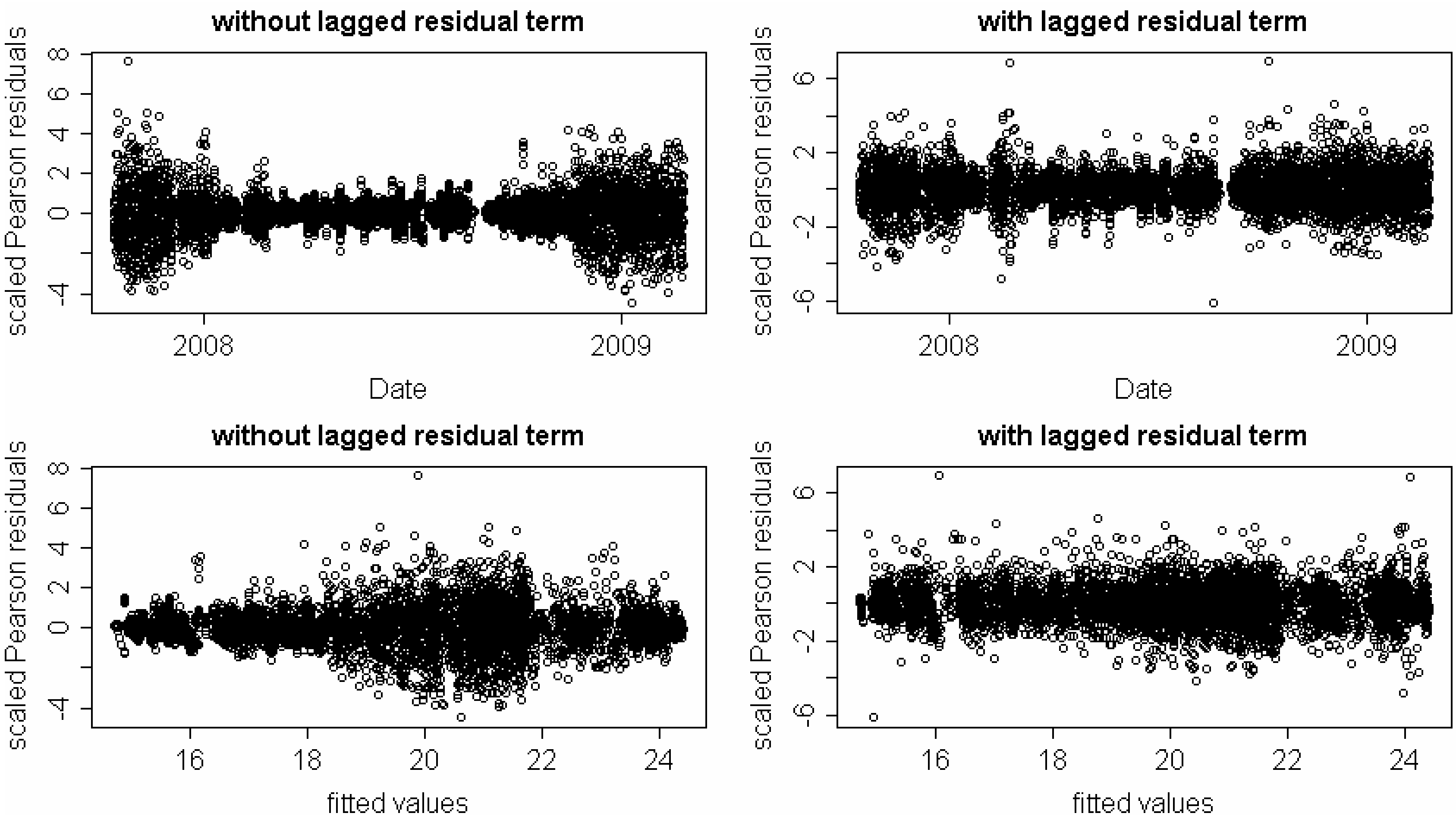


Seasonal/Longer term trend

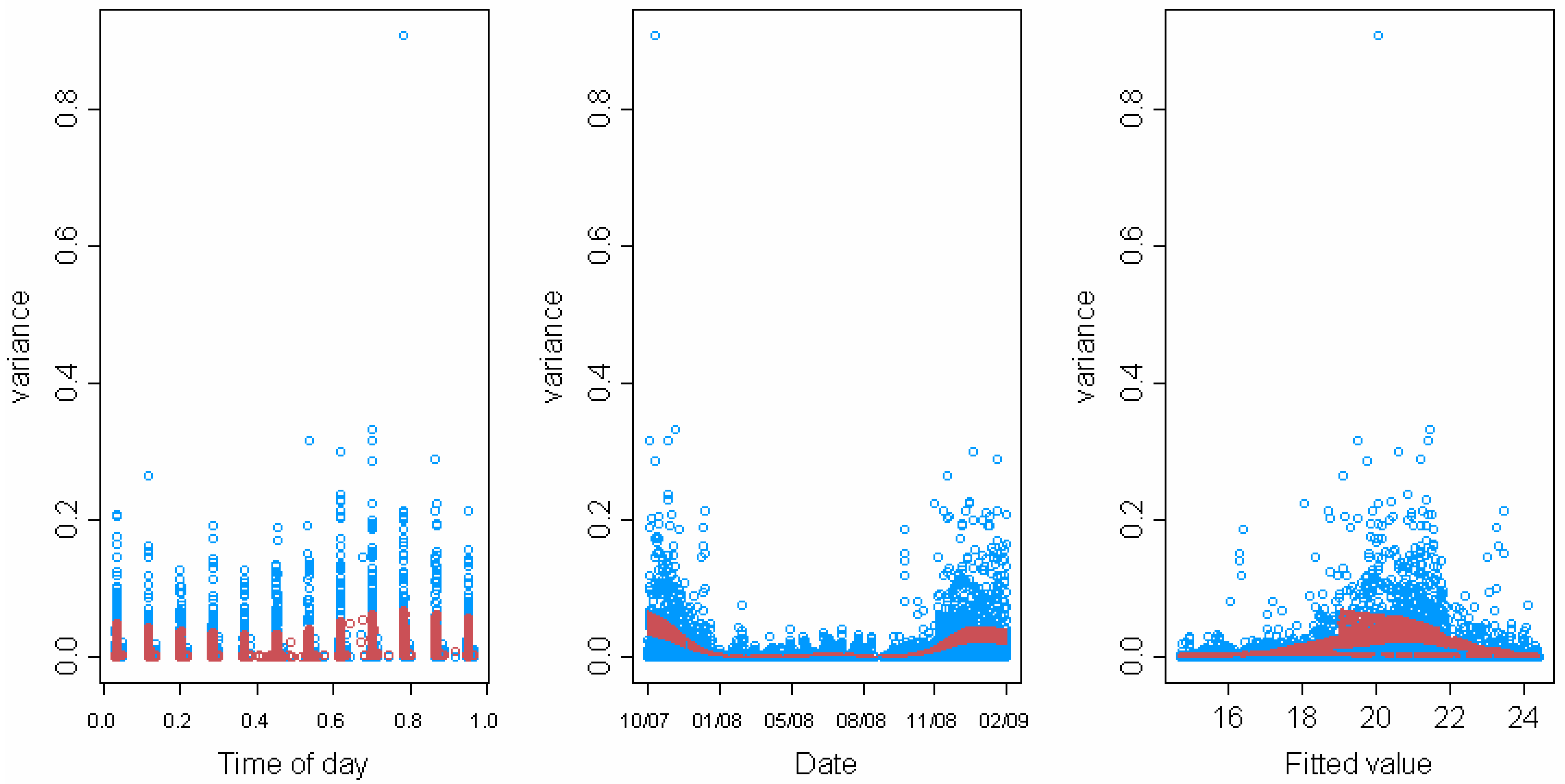


Model diagnostics

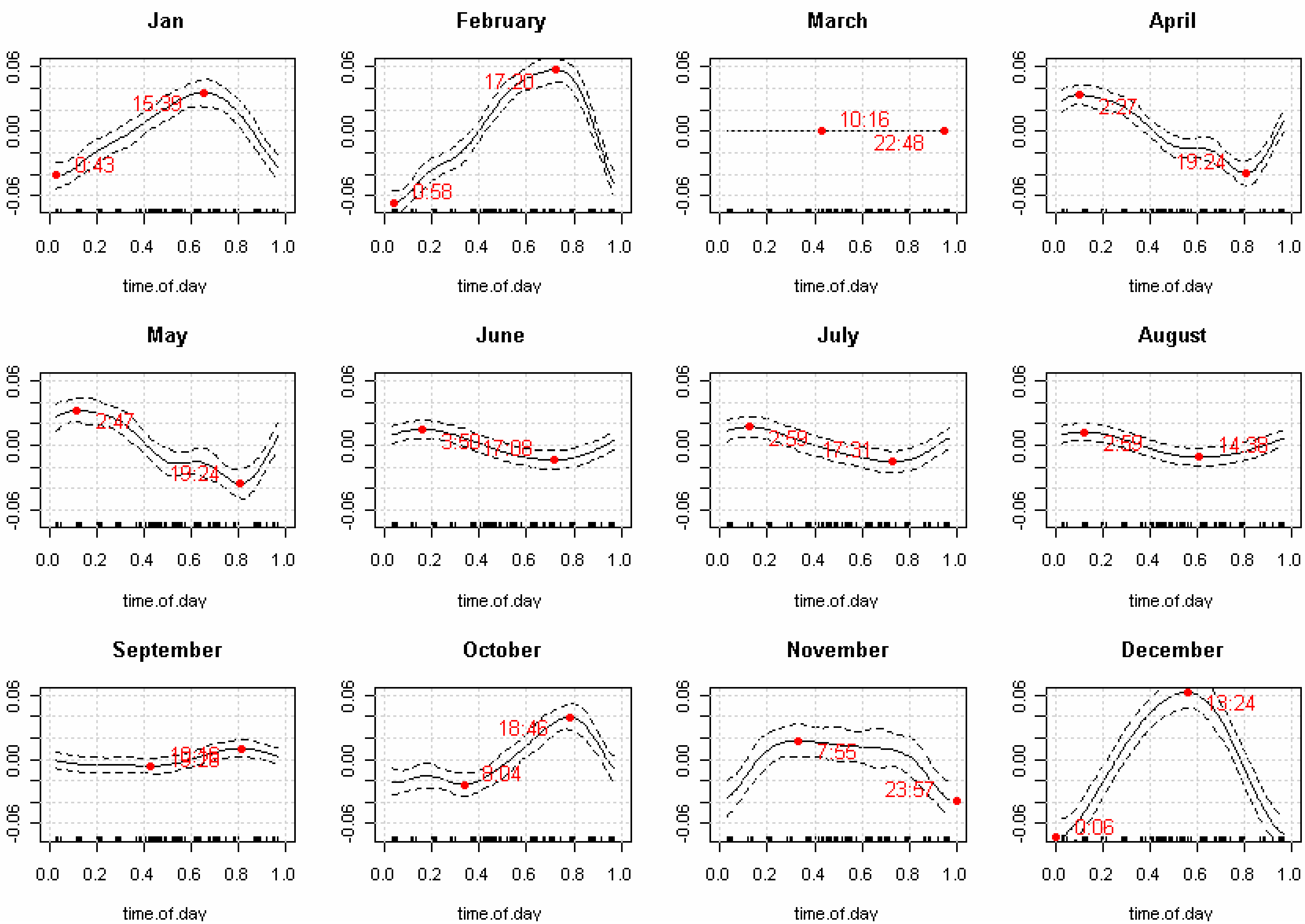



without lagged residual term
with lagged residual term
scaled Pearson residuals
-4
0
2
4
6
8
-6
-2
2
6
2008
2009
Date
16
18
20
22
24
fitted values

Variability modelled



Results - bottom



Conclusions

- Daily water temperature variability changes throughout the year.
- Daily water temperature trends at the surface differ between sites
- Models developed for water quality parameters need to account for autocorrelation and non-constant variance
- Water Temperature variability at the Dam Wall site
  - Is greatest at the surface during September and October
  - Is greatest at the bottom during December
  - Is lowest at the surface during July
  - Is lowest at the bottom during March (no significant trend)

Future Work

- Models for depth covariate
  - Possible interactions between depth and time, depth and date
  - Correlations between depths
  - Stratification – separation between surface and bottom layers
- Alternative methods for modelling autocorrelation and non-constant variance
- Investigate Time Series alternatives
  - Generalized Autoregressive Conditional Heteroscedastic process

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Thank you

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