# Package: gmwmx2 (via r-universe)

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**Title** Estimate Functional and Stochastic Parameters of Linear Models with Correlated Residuals and Missing Data

**Version** 0.0.6

**Description** Implements the Wavelet Moment Regression (WAMORE) inference framework presented in Voirol, L., Xu, H., Zhang, Y., Insolia, L., Molinari, R. and Guerrier, S. (2026) <doi:10.48550/arXiv.2607.16264>. Provides computationally efficient estimation of functional and stochastic parameters of linear models with correlated residuals, including settings with missing data. Includes functions to download and plot Global Navigation Satellite System (GNSS) position time series from the Nevada Geodetic Laboratory and estimate tectonic velocities and crustal uplift using composite stochastic models.

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## +.sum_model *Add to a* sum_model *object*

### Description

Add to a sum_model object

### Usage

```
## S3 method for class 'sum_model'
e1 + e2
```

### Arguments

| | |
|---|---|
| e1 | Left operand. |
| e2 | Right operand. |

### Value

A sum_model.

### Examples

```
m1 <- wn(sigma2 = 1)
m2 <- ar1(phi = 0.8, sigma2 = 0.5)
m3 <- pl(kappa = 0.3, sigma2 = 2)
model <- (m1 + m2) + m3
```

## +.time_series_model *Add to a* time_series_model *object*

### Description

Combines time_series_model and/or sum_model into a sum_model.

### Usage

```
## S3 method for class 'time_series_model'
e1 + e2
```

### Arguments

| | |
|---|---|
| e1 | Left operand. |
| e2 | Right operand. |

## Value

A sum_model.

## Examples

```
m1 <- wn(sigma2 = 1)
m2 <- ar1(phi = 0.8, sigma2 = 0.5)
model <- m1 + m2
model
```

---

ar1 *AR(1) process (*time_series_model*)*

---

## Description

Constructs a time_series_model for a stationary AR(1) process with parameter phi and innovation variance sigma2. The model is $X_t = \phi X_{t-1} + \varepsilon_t,\ \varepsilon_t \overset{\text{i.i.d.}}{\sim} N(0, \sigma^2)$. The autocovariance is $\gamma(h) = \mathrm{cov}(X_t, X_{t+h}) = \frac{\sigma^2}{1-\phi^2}\,\phi^{|h|}$.

## Usage

```
ar1(phi = NULL, sigma2 = NULL)
```

## Arguments

| | |
|---|---|
| phi | AR(1) coefficient in (-1, 1). |
| sigma2 | Innovation variance (> 0). |

## Value

A time_series_model object.

## Examples

```
mod <- ar1(phi = 0.8, sigma2 = 1)
mod
```

`df_estimated_velocities_gmwmx` *Estimated northward and eastward velocity and their standard deviation using the GMWMX estimator*

## Description

Estimated northward and eastward velocity and standard deviation for a subset of 1202 GNSS station with more than 10 years of daily data.

## Usage

```
df_estimated_velocities_gmwmx
```

## Format

A data frame with 1202 rows and 12 variables:

**station_name** Name of the GNSS station.

**estimated_trend_N** Estimated northward velocity trend (in meters per day).

**std_estimated_trend_N** Standard deviation of the estimated northward velocity trend.

**estimated_trend_E** Estimated eastward velocity trend (in meters per day).

**std_estimated_trend_E** Standard deviation of the estimated eastward velocity trend.

**length_signal** Length of the signal (in days).

**estimated_trend_N_scaled** Scaled estimated northward velocity trend (multiplying by 365.25 for yearly values).

**std_estimated_trend_N_scaled** Scaled standard deviation of the estimated northward velocity trend.

**estimated_trend_E_scaled** Scaled estimated eastward velocity trend (multiplying by 365.25 for yearly values).

**std_estimated_trend_E_scaled** Scaled standard deviation of the estimated eastward velocity trend.

**latitude** Latitude of the GNSS station.

**longitude** Longitude of the GNSS station.

---

`download_all_stations_ngl`

*Download all stations name and location from the Nevada Geodetic Laboratory*

---

## Description

Download all stations name and location from the Nevada Geodetic Laboratory

## Usage

```
download_all_stations_ngl(verbose = FALSE)
```

## Arguments

| | |
|---|---|
| `verbose` | A `boolean` that controls the level of detail in the output of the `wget` command used to load data. Default is `FALSE`. |

## Value

Return a `data.frame` with all stations name, latitude, longitude and heights.

## Examples

```
df_all_stations <- download_all_stations_ngl()
head(df_all_stations)
```

---

`download_estimated_velocities_ngl`

*Download estimated velocities using the MIDAS estimator provided by the Nevada Geodetic Laboratory for all stations.*

---

## Description

Download estimated velocities using the MIDAS estimator provided by the Nevada Geodetic Laboratory for all stations.

## Usage

```
download_estimated_velocities_ngl(verbose = FALSE)
```

## Arguments

| | |
|---|---|
| `verbose` | A `boolean` that controls the level of detail in the output of the `wget` command used to load data. Default is `FALSE`. |

## Value

Return a data.frame with all stations name, information about the time series for each station, estimated velocities and estimated standard deviation of the estimated velocities.

## Examples

```
df_estimated_velocities <- download_estimated_velocities_ngl()
head(df_estimated_velocities)
```

---

# download_station_ngl *Download GNSS position time series and steps reference from the Nevada Geodetic Laboratory with IGS14 or IGS20 reference frame.*

---

## Description

Download GNSS position time series and steps reference from the Nevada Geodetic Laboratory with IGS14 or IGS20 reference frame.

## Usage

```
download_station_ngl(station_name, verbose = FALSE, reference_frame = "IGS20")
```

## Arguments

| | |
|---|---|
| station_name | A string specifying the station name. |
| verbose | A boolean that controls the level of detail in the output of the wget command used to load data. Default is FALSE. |
| reference_frame | A string with value either "IGS14" or "IGS20" that specify which reference frame to use. Default is "IGS20". |

## Value

A list of class gnss_ts_ngl that contains three data.frame: The data.frame df_position which contains the position time series extracted from the .tenv3 file available from the Nevada Geodetic Laboratory, the data.frame df_equipment_software_changes which specify the equipment or software changes for that stations and the data.frame df_earthquakes that specify the earthquakes associated with that station.

## Examples

```
station_1LSU <- download_station_ngl("1LSU")
attributes(station_1LSU)
```

`flicker` *Flicker noise process (*`time_series_model`*)*

## Description

Constructs a `time_series_model` for flicker noise with variance `sigma2`. The process has spectral density $S(f) \propto \frac{1}{|f|}$. Hence, $\kappa = -1$ (Bos et al., 2008). The process is non-stationary and its covariance matrix is assumed to be given by

$$\mathbf{C} = \sigma^2 \mathbf{U}^\top \mathbf{U},$$

where $\mathbf{U} \in \mathbb{R}^{N \times N}$ is an upper-triangular Toeplitz matrix with entries

$$U_{i,j} = \begin{cases} h_{j-i}, & j \geq i, \\ 0, & j < i, \end{cases} \qquad i, j = 1, \ldots, N.$$

The coefficients $\{h_i\}_{i \geq 0}$ define a causal linear filter and are given recursively by

$$h_0 = 1, \qquad h_i = \left(i - \frac{\kappa}{2} - 1\right) \frac{h_{i-1}}{i}, \quad i > 0.$$

## Usage

```
flicker(sigma2 = NULL)
```

## Arguments

| | |
|---|---|
| `sigma2` | Innovation variance (> 0). |

## Value

A `time_series_model` object.

## References

Bos MS, Fernandes RMS, Williams SDP, Bastos L (2008). "Fast error analysis of continuous GPS observations." *Journal of Geodesy*, 82, 157-166.

## Examples

```
mod <- flicker(sigma2 = 1)
mod
```

## generate — *Generate a time series from a* time_series_model *or* sum_model *object*

### Description

Generate a time series from a time_series_model or sum_model object

### Usage

```
generate(object, n, seed = NULL, ...)
```

### Arguments

| | |
|---|---|
| object | A time_series_model or sum_model. |
| n | Length of series to generate. |
| seed | Optional integer seed for reproducibility. |
| ... | Passed to method. |

### Value

A generated_time_series (single model) or generated_composite_model_time_series (sum model).

### Examples

```
# Single model
m1 <- ar1(phi = 0.8, sigma2 = 1)
y1 <- generate(m1, n = 200, seed = 123)
plot(y1)

# Composite model
m2 <- wn(sigma2 = 1) + pl(kappa = 0.3, sigma2 = 2)
y2 <- generate(m2, n = 200, seed = 123)
plot(y2)
```

## gmwm2 — *GMWM estimator*

### Description

Implements the Generalized Method of Wavelet Moments (GMWM) estimator to fit a time_series_model, a sum_model or a numeric vector.

## Usage

```
gmwm2(x, model, omega = NULL, method = "L-BFGS-B", control = list(), ...)
```

## Arguments

| | |
|---|---|
| x | Numeric vector, or a generated_time_series / generated_composite_model_time_series object (its series is used). |
| model | A time_series_model or sum_model. |
| omega | Optional weighting matrix. If NULL, a default based on the empirical WV confidence intervals is used. |
| method | Optimization method passed to stats::optim. |
| control | Optional list of control parameters for stats::optim. |
| ... | Additional arguments passed to stats::optim. |

## Details

The GMWM estimator solves a weighted least-squares criterion of the form

$$\{\hat{\boldsymbol{\nu}} - \boldsymbol{\nu}(\boldsymbol{\theta})\}^{\top} \boldsymbol{\Omega} \{\hat{\boldsymbol{\nu}} - \boldsymbol{\nu}(\boldsymbol{\theta})\}$$

where $\hat{\boldsymbol{\nu}}$ denotes the empirical wavelet variance and $\boldsymbol{\nu}(\boldsymbol{\theta})$ the corresponding theoretical wavelet variance implied by the model parameters $\boldsymbol{\theta}$. The weighting matrix $\boldsymbol{\Omega}$ defaults to a diagonal matrix with entries proportional to the inverse squared width of the empirical WV asymptotic confidence intervals. Provide omega to use a custom weighting (e.g., from a theoretical covariance).

## Value

An object of class gmwm2_fit with elements: theta_hat (real space), theta_domain (constrained space), model, empirical_wvar, theoretical_wvar, optim, and n.

## References

Guerrier, S., Skaloud, J., Stebler, Y., and Victoria-Feser, M.-P. (2013). Wavelet-variance-based estimation for composite stochastic processes. *Journal of the American Statistical Association*, 108(503), 1021-1030. doi:10.1080/01621459.2013.799920.

## Examples

```
n = 10000
mod = wn(20) + ar1(phi = .995, sigma2 = .2)
y = generate(mod, n = n, seed = 123)
plot(y)
fit = gmwm2(y, model = wn() + ar1())
fit
plot(fit)
```

gmwmx2 *GMWMX estimator*

## Description

Dispatches either to the generic regression interface (design matrix + response) or to a gnss_ts_ngl workflow.

Convenience wrapper that selects the missing or non-missing implementation based on the presence of NA values in y.

## Usage

```
gmwmx2(X, ...)

## Default S3 method:
gmwmx2(X, y, model, omega = NULL, method = "L-BFGS-B", control = list(), ...)

## S3 method for class 'gnss_ts_ngl'
gmwmx2(
  X,
  n_seasonal = 2,
  vec_earthquakes_relaxation_time = NULL,
  component = NULL,
  model = NULL,
  omega = NULL,
  method = "L-BFGS-B",
  control = list(),
  ...
)
```

## Arguments

| | |
|---|---|
| X | A gnss_ts_ngl object (GNSS time-series interface). |
| ... | Reserved for future extensions. |
| y | Response vector for a generic regression interface. |
| model | Stochastic model specification. |
| omega | Optional weighting matrix. If NULL, uses inverse CI width. |
| method | Optimization method passed to stats::optim. |
| control | Control list passed to stats::optim. |
| n_seasonal | Number of seasonal signals. |
| vec_earthquakes_relaxation_time | Relaxation time for each earthquake. |
| component | Component to estimate ("N", "E", or "V"). |

### Value

A fitted model object.

A fitted model object.

A fitted model object.

---

## markov_two_states *Markov two-state missingness model (*missingness_model*)*

---

### Description

Constructs a missingness_model representing a two-state Markov process for missing/observed indicators. The process takes values in $\{0, 1\}$, where 1 indicates observed and 0 indicates missing.

### Usage

```
markov_two_states(p1 = NULL, p2 = NULL)
```

### Arguments

| | |
|---|---|
| p1 | Transition probability from observed (1) to missing (0). |
| p2 | Transition probability from missing (0) to observed (1). |

### Value

A missingness_model object.

### Examples

```
mod <- markov_two_states(p1 = 0.05, p2 = 0.95)
mod
z <- generate(mod, n = 200, seed = 123)
plot(z)
```

---

## matern *Matern process (*time_series_model*)*

---

### Description

Constructs a time_series_model for a Matern covariance process with variance sigma2, range lambda, and smoothness alpha. The autocovariance is $\gamma(h) = \mathrm{cov}(X_t, X_{t+h}) = \frac{2\sigma^2}{\Gamma(\alpha-1/2)2^{\alpha-1/2}}|\lambda h|^{\alpha-1/2}\mathcal{K}_{|\alpha-1/2|}(|\lambda h|)$ where $\mathcal{K}_\omega(x)$ is the modified Bessel function of the second kind of order $\omega$.

### Usage

```
matern(sigma2 = NULL, lambda = NULL, alpha = NULL)
```

### Arguments

| | |
|---|---|
| sigma2 | Marginal variance (> 0). |
| lambda | Range/scale parameter (> 0). |
| alpha | Smoothness parameter in (1/2, 10). |

### Value

A time_series_model object.

### References

Lilly JM, Sykulski AM, Early JJ, Olhede SC (2017). "Fractional Brownian motion, the Matérn process, and stochastic modeling of turbulent dispersion." *Nonlinear Processes in Geophysics*, 24(3), 481-514.

### Examples

```
mod <- matern(sigma2 = 1, lambda = 0.2, alpha = 1.0)
mod
```

---

## pl *Stationary Power-Law process (*time_series_model*)*

---

### Description

Constructs a time_series_model representing a stationary power-law process with parameters kappa and sigma2. In the frequency domain, a power-law process is often described by a spectrum $P(f) = P_0 f^{\kappa}$ (Bos et al., 2008), where $f$ is the frequency, $P_0$ is a constant and $\kappa$ is the spectral index. Note that we use the convention that the power spectral density satisfies $P(f) \propto |f|^{\kappa}$, where $\kappa > -1$ ensures second-order stationarity. This corresponds to the alternative notation $P(f) \propto |f|^{-\alpha}$ with $\alpha = -\kappa$. The autocovariance $\gamma(h) = \mathrm{cov}(X_t, X_{t+h})$ used here (Hosking, 1981) is $\gamma(0) = \sigma^2 \frac{\Gamma(1+\kappa)}{\Gamma(1+\kappa/2)^2}$, and for $h > 0$ $\gamma(h) = \frac{-\kappa/2+h-1}{\kappa/2+h}\,\gamma(h-1)$.

### Usage

```
pl(kappa = NULL, sigma2 = NULL)
```

### Arguments

| | |
|---|---|
| kappa | Power-law parameter in (-1, 1). |
| sigma2 | Process variance (> 0). |

### Value

A time_series_model object.

## References

Bos MS, Fernandes RMS, Williams SDP, Bastos L (2008). "Fast error analysis of continuous GPS observations." *Journal of Geodesy*, 82, 157-166.

Hosking JRM (1981). "Fractional differencing." *Biometrika*, 68(1), 165-176.

## Examples

```
mod <- pl(kappa = -0.5, sigma2 = 2)
mod
```

---

# plot.generated_composite_model_time_series

*Plot a* `generated_composite_model_time_series` *object*

---

## Description

Produces stacked line plots for each component and the sum for a `generated_composite_model_time_series` object.

## Usage

```
## S3 method for class 'generated_composite_model_time_series'
plot(x, ...)
```

## Arguments

| | |
|---|---|
| `x` | A `generated_composite_model_time_series`. |
| `...` | Additional arguments passed to `plot()`. |

## Value

Invisibly returns `x`.

## Examples

```
m2 <- wn(sigma2 = 1) + ar1(phi = 0.8, sigma2 = 0.5)
y2 <- generate(m2, n = 200, seed = 123)
plot(y2)
```

## plot.generated_missingness *Plot a* generated_missingness *object*

### Description

Produces a step plot for a generated_missingness object.

### Usage

```
## S3 method for class 'generated_missingness'
plot(x, ...)
```

### Arguments

| | |
|---|---|
| x | A generated_missingness. |
| ... | Additional arguments passed to plot(). |

### Value

Invisibly returns x.

### Examples

```
m0 <- markov_two_states(p1 = 0.05, p2 = 0.9)
z0 <- generate(m0, n = 200, seed = 123)
plot(z0)
```

## plot.generated_time_series *Plot a* generated_time_series *object*

### Description

Produces a single line plot for a generated_time_series object.

### Usage

```
## S3 method for class 'generated_time_series'
plot(x, ...)
```

### Arguments

| | |
|---|---|
| x | A generated_time_series. |
| ... | Additional arguments passed to plot(). |

### Value

Invisibly returns `x`.

### Examples

```
m1 <- wn(sigma2 = 1)
y1 <- generate(m1, n = 200, seed = 123)
plot(y1)
```

---

## plot.gmwm2_fit *Plot method for a* gmwm2_fit *object*

---

### Description

Plots empirical wavelet variance with the fitted theoretical curve and, for sum models, component-implied theoretical curves.

### Usage

```
## S3 method for class 'gmwm2_fit'
plot(
  x,
  show_ci = TRUE,
  col_emp = "black",
  col_theo = "darkorange",
  col_ci = "#e6f7fb",
  lwd = 2,
  pch_emp = 16,
  pch_theo = 21,
  cex_theo = 1.4,
  legend_pos = "auto",
  ...
)
```

### Arguments

| | |
|---|---|
| `x` | A `gmwm2_fit` object. |
| `show_ci` | Logical; if TRUE and available, show empirical CI bars. |
| `col_emp` | Color for empirical WV points/line. |
| `col_theo` | Color for theoretical WV line. |
| `col_ci` | Color for empirical WV CI band. |
| `lwd` | Line width for theoretical curve. |
| `pch_emp` | Plotting character for empirical points. |
| `pch_theo` | Plotting character for theoretical points. |
| `cex_theo` | Size for theoretical points. |
| `legend_pos` | Legend position (e.g., "topleft") or "auto". |
| `...` | Additional arguments passed to `plot()`. |

## Value

The input object, invisibly.

## Examples

```
n = 10000
mod = wn(20) + ar1(phi = .995, sigma2 = .2)
y = generate(mod, n = n, seed = 123)
plot(y)
fit = gmwm2(y, model = wn() + ar1() )
fit
plot(fit)
```

---

# plot.gmwmx2_fit_gnss_ts_ngl *Plot a* gmwmx2_fit_gnss_ts_ngl *object*

---

## Description

Plot a gmwmx2_fit_gnss_ts_ngl object

## Usage

```
## S3 method for class 'gmwmx2_fit_gnss_ts_ngl'
plot(x, ...)
```

## Arguments

| | |
|---|---|
| x | A gmwmx2_fit_gnss_ts_ngl object. |
| ... | Additional graphical parameters. |

## Value

No return value. Plot a gmwmx2_fit_gnss_ts_ngl object.

## Examples

```
# station_data = gmwmx2::download_station_ngl("1LSU")
# fit station with WN and PL
# fit1 <- gmwmx2(
#   station_data,
#   n_seasonal = 2,
#   model = wn() + pl(), component = "N"
# )
# fit1
# plot(fit1)
```

## plot.gnss_ts_ngl *Plot a* gnss_ts_ngl *object*

### Description

Plot a gnss_ts_ngl object

### Usage

```
## S3 method for class 'gnss_ts_ngl'
plot(x, component = NULL, ...)
```

### Arguments

| | |
|---|---|
| x | A gnss_ts_ngl object. |
| component | A string with value either "N", "E" or "V" that specify which component to plot (Northing, Easting or Vertical). |
| ... | Additional graphical parameters. |

### Details

Calendar years are shown above each time-series panel, with spacing chosen automatically from the time span (approximately six labels). Modified Julian Dates are retained below.

### Value

No return value. Plot a gnss_ts_ngl object.

### Examples

```
station_1LSU <- download_station_ngl("1LSU")
plot(station_1LSU)
plot(station_1LSU, component = "N")
plot(station_1LSU, component = "E")
plot(station_1LSU, component = "V")
```

## print.gmwm2_fit *Print method for a* gmwm2_fit *object*

### Description

Print method for a gmwm2_fit object

### Usage

```
## S3 method for class 'gmwm2_fit'
print(x, digits = 4, show_initial_parameters = FALSE, ...)
```

### Arguments

| | |
|---|---|
| x | A gmwm2_fit object. |
| digits | Significant digits for printing. |
| show_initial_parameters | Logical; if TRUE, also show the initial parameters used for optimization. |
| ... | Unused. |

### Value

The input object, invisibly.

### Examples

```
n = 10000
mod = wn(20) + ar1(phi = .995, sigma2 = .2)
y = generate(mod, n = n, seed = 123)
plot(y)
fit = gmwm2(y, model = wn() + ar1() )
fit
```

---

## print.gmwmx2_fit *Print method for a* gmwmx2_fit *object*

---

### Description

Displays a table of regression coefficients with standard errors and summarizes the fitted stochastic model with estimated parameters.

### Usage

```
## S3 method for class 'gmwmx2_fit'
print(x, digits = 4, ...)
```

### Arguments

| | |
|---|---|
| x | A gmwmx2_fit object. |
| digits | Significant digits to display. |
| ... | Passed to print methods. |

### Value

The input object, invisibly.

## print.gmwmx2_fit_gnss_ts_ngl *Print method for a* gmwmx2_fit_gnss_ts_ngl *object*

### Description

Displays regression coefficients with standard errors and confidence intervals, along with the fitted stochastic and missingness models.

### Usage

```
## S3 method for class 'gmwmx2_fit_gnss_ts_ngl'
print(x, digits = 4, ...)
```

### Arguments

| | |
|---|---|
| x | A gmwmx2_fit_gnss_ts_ngl object. |
| digits | Significant digits to display. |
| ... | Passed to print methods. |

### Value

The input object, invisibly.

## rw *Random walk process (*time_series_model*)*

### Description

Constructs a time_series_model for a random walk with innovation variance sigma2. The auto-covariance returned is the mean of the diagonal and super-diagonals of the covariance matrix. The model is $X_t = X_{t-1} + \varepsilon_t,\ \varepsilon_t \overset{\text{i.i.d.}}{\sim} N(0, \sigma^2)$.

### Usage

```
rw(sigma2 = NULL)
```

### Arguments

| | |
|---|---|
| sigma2 | Innovation variance (> 0). |

### Value

A time_series_model object.

## Examples

```
mod <- rw(sigma2 = 1)
mod
```

---

wn *White noise process (*time_series_model*)*

---

## Description

Constructs a time_series_model for white noise with variance sigma2. The process is defined as $X_t \overset{\text{i.i.d.}}{\sim} N(0, \sigma^2)$ with autocovariance $\gamma(h) = \text{cov}(X_t, X_{t+h}) = \sigma^2 \mathbf{1}\{h = 0\}$

## Usage

```
wn(sigma2 = NULL)
```

## Arguments

| | |
|---|---|
| sigma2 | Innovation variance (> 0). |

## Value

A time_series_model object.

## Examples

```
mod <- wn(sigma2 = 1)
mod
```

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