MIKE Zero & MIKE URBAN

Climate Change

Scientific Documentation

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1 Introduction

MIKE software makes it possible to generate climate change scenarios for a large number of the models available within the MIKE Zero and the MIKE URBAN suite. The functionality is based on the work reported by the Intergovernmental Panel for Climate Change (IPCC) in the Fourth Assessment Report (AR4) and more recent research results on global sea level rise. The climate change projections are taken directly from the IPCC work and other references, and thus the MIKE software does not include any climate models.

The following sections are not meant to report on the climate change projections but are merely meant to explain how the projections have been adapted to the MIKE Powered by DHI software suite. For an insight in the climate change modelling carried out for the IPCC AR4, please visit the site http://www.ipcc.ch/ for more information. Results from other sources used by the MIKE software are referred to in the following.

2 Projections of Climate Variables

Projections of climate variables are constructed based on the so-called delta change factor method. The delta change factors indicate how much a certain variable (e.g. precipitation) will change over time compared to a baseline (reference) period. The MIKE climate change scenario tool modifies time series of precipitation, temperature and potential evapotranspiration according to the geographic location and the projection year. The change factors are derived from the climate model projections for various emission scenarios.

2.1 Global Circulation Model Projections

The work reported in the IPCC AR4 report includes results of a number of so-called Global Circulation Models (GCM). Some of the outcomes of the GCMs are predicted future changes for air temperature and precipitation based on a number of emission scenarios.

GCM results reported by IPCC are air temperature and precipitation as well as air temperature and precipitation anomalies that are defined as deviations from the reference values taken as the average over the period 1961-1990. The anomaly predictions are in the form of absolute changes. The data are spatially and temporally varied. The former is covered through the use of gridded values whereas the latter is represented by an average value per month.

Further, the data are a function of the projection year. The data are given as average values for a number of 20-year time spans. The time spans are

- 2011-2030
- 2046-2065
- 2080-2099
- 2180-2199

Note that not all the GCMs provide data for all of the above periods.

Thus, a data set (precipitation, air temperature and anomalies) consists of up to 4 sets (different projection years) of 12 monthly values per grid point per emission scenario.

Emission scenarios

The IPCC has defined a number of emission scenarios that have been used as input to the GCMs. Results of the three most common scenarios have been included in the MIKE software. The three scenarios are listed below with a short description as defined by the IPCC:

- **SRA1B**: A future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies, with the development balanced across energy sources.

- **SRA2**: A very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines.

- **SRB1**: A convergent world with the same global population as in the SRA1B storyline but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies.

Available GCMs and emission scenarios

It is not the goal here to advise on which GCMs or emission scenarios should be used for evaluating the climate change. For this, the user is referred to the IPCC guidance documents or other sources. The MIKE software can work with any subset of GCMs and emission scenario possible. If more than one GCM is used, the delta change factors will be taken as the average over the GCMs chosen.

Below follows an overview of the data available for the individual GCMs. The table sums up the data available for the various combinations of GCM and emission scenario.

Model (GCM)	Acronym	Emission scenario		
		SRA1B	SRA2	SRB1
BCCR:BCM2	BCM2	✓	✓	✓
CCCMA:CGCM3_1-T47	CGMR	✓		
CCCMA:CGCM3_1-T63	CGHR	✓		✓
CNRM:CM3	CNCM3	✓	✓	✓
CONS:ECHO-G	ECHOG	✓	✓	
CSIRO:MK3	CSMK3	✓	✓	✓
GFDL:CM2	GFCM20	✓	✓	✓
GFDL:CM2_1	GFCM21	✓	✓	✓
INM:CM3	INCM3	✓	✓	✓
IPSL:CM4	IPCM4	✓	✓	✓
LASG:FGOALS-G1_0	FGOALS	✓		✓
MPIM:ECHAM5	MPEH5	✓	✓	✓
MRI:CGCM2_3_2	MRCGCM	✓	✓	✓
NASA:GISS-AOM	GIAOM	✓		✓
NASA:GISS-EH	GIEH	✓		
NASA:GISS-ER	GIER	✓	✓	✓
NCAR:PCM	NCPCM	✓	✓	
NIES:MIROC3_2-HI	MIHR	✓		✓
NIES:MIROC3_2-MED	MIMR	✓	✓	✓
UKMO:HADCM3	HADCM3	✓	✓	✓
UKMO:HADGEM1	HADGEM	✓	✓	
NCAR:CCSM3	NCCCSM	✓	✓	✓

Please refer to the IPCC sources (given as hyperlinks in the model column of the above table) for more information on the particulars of the various GCMs and the emission scenarios.

As mentioned previously, the climate variables that are taken from the GCM projections are air temperature and precipitation. This is augmented by potential evapotranspiration in the MIKE software. The following sections will give details on how projected changes of the three climate variables are integrated within the MIKE software. Please note that not all combinations above provide precipitation.

2.2 Air Temperature

The air temperature anomalies are given as gridded delta change values, i.e. the values represent the absolute deviations from the reference values. In the MIKE software the temperature delta change values are taken at any geo-referenced position represented by a latitude and longitude coordinate set. To achieve this bilinear interpolation is carried out from the gridded values to the specific location. Further, to predict values for any future year (also for years not covered by the 20-year time spans) the data is interpolated linearly between the years.

2.3 Precipitation

Precipitation amounts may vary drastically within a modelling area. This variation is on a sub-scale that is not reflected in the coarse grid used by the GCMs. To compensate for the sub-scale variation, the delta change values for precipitation have been converted to relative changes within each of the grid cells. This is done using the absolute change $\Delta precipitation$ and the absolute precipitation for the future scenario $precipitation_{scenario}$, i.e.

$$\Delta precipitation_{\,relative} = \frac{precipitation_{scenario}}{precipitation_{scenario} - \Delta precipitation} \qquad (2.1)$$

If the reference precipitation ($precipitation_{scenario} - \Delta precipitation$) is equal to zero, a relative change is not sensible and then $\Delta precipitation_{relative}$ is set equal to 1. Further, if the reference precipitation is very small, the relative change may become very (unrealistically) large and hence an upper limit on the relative change of 5 is introduced.

As for the change factors of air temperature, bilinear interpolation is used in space and linear interpolation is used in time to determine the relative changes for any location and any year.

2.4 Potential Evapotranspiration

A simple temperature-based method is used to estimate changes in potential evapotranspiration. Potential evapotranspiration [m/s] is calculated as (Kay and Davies, 2008)

$$PE_T = \begin{cases} \dfrac{R_e(T+5)}{\lambda \rho_w 100} & if\ (T+5) > 0 \\ 0 & otherwise \end{cases} \qquad (2.2)$$

Where

λ	is the latent heat flux (2.45 10^6 J/kg)
ρ_w	is the density of water (1000 kg/m^3)
R_e	is the extraterrestrial radiation (J/m^2/s)
T	is the mean daily air temperature (°C)

The reference potential evapotranspiration is calculated using the reference temperature. The change in potential evapotranspiration is calculated from the change in temperature using

$$\Delta PE_T = \frac{R_e}{\lambda \rho_w 100} \Delta T \qquad (2.3)$$

The relative change is then found as

$$PE_{T\,relative} = \begin{cases} \dfrac{PE_{Tscenario}}{PE_{Tscenario} - \Delta PE_T} & if\ (T_{scenario} - \Delta T + 5) > 0 \\ 1 & otherwise \end{cases} \quad (2.4)$$

Which is equivalent to

$$PE_{Trelative} = \begin{cases} \dfrac{\max(T_{scenario} + 5{,}0)}{(T_{scenario} - \Delta T + 5)} & if\ (T_{scenario} - \Delta T + 5) > 0 \\ 1 & otherwise \end{cases} \quad (2.5)$$

Note that the relative potential evapotranspiration through this formula is not allowed to become negative. Further, as for relative precipitation changes, an upper limit on the relative change of 5 is introduced.

2.5 Modifying Times Series of Climate Variables

The MIKE climate change tool will make a copy of an existing setup and modify the time series of climate data according to a given future year, selected GCMs and emission scenario. These time series are then used instead of the original climate time series in the climate change scenario model setup to assess the possible impact of climate change.

The time series modification works as follows:

A set of 12 (one for each month) change factors are determined based on

- Latitude and longitude
- Selected GCMs
- Projection year
- Emission scenario

If the time series is air temperature, the change factors will be added to the individual values within the time series, i.e. the January change factor (in ^{o}C) will be added to all values in the time series occurring in January etc.

If the time series is precipitation or potential evapotranspiration, the change factors will be multiplied with the individual values within the time series, i.e. the January change factor (dimensionless) will be multiplied with all values in the time series occurring in January etc.

3 Projections of Sea Level Rise

Sea level rise can be divided into 4 contributions

$$SLR = \Delta SL_G + \Delta SL_{RM} + \Delta SL_{RG} + \Delta SL_{VLM} \quad (3.1)$$

Where

SLR	is the sea level rise
ΔSL_G	is the change in the global mean sea level
ΔSL_{RM}	is the regional variation in sea level from the global mean due to meteo-oceanographic factors
ΔSL_{RG}	is the regional variation in sea level due to changes in the earth's gravitational field
ΔSL_{VLM}	is the change in sea level due to vertical land movement

The MIKE climate change tool only considers the global sea level change. The other three terms must be estimated and supplied by the user and subsequently added to the global sea level change.

Projections of global sea level rise are available for the same three emission scenarios as used for the climate data. Projections published in IPCC AR4 (Meehl et al, 2007) as well as projections from three more recent publications (Horton et al, 2008; Grinsted et al., 2009; Vermeer and Rahmstorf, 2009) are available. Since publication of the IPCC AR4 report, sea level projections have been widely debated. Observations of accelerations of the ice sheet discharges in Greenland and Antarctica could not be explained by state-of-the-art ice sheet models, suggesting that the IPCC AR4 projections underestimated the sea level rise. A number of studies have been conducted following IPCC AR4 using different semi-empirical methods that relate changes in global sea level with changes in temperature or other climate variables. Results from three of these studies have been included in the MIKE software.

The published results are reported as ranges of projections of sea level rise and have been included in the MIKE software as a lower, a mean, and an upper level. The ranges of projections by 2100 are shown in the table below.

Acronym	**Range of projected sea level rise [m] by 2100 relative to the period 1980-1999**			**Reference**
	SRA1B	SRA2	SRB1	
IPCC AR4	0.20-0.51	0.22-0.55	0.19-0.40	Meehl et al. (2007)
Horton2008	0.62-0.88	0.68-0.89	0.54-0.75	Horton et al. (2008)
Grinsted2009	0.99-1.44	1.01-1.48	0.77-1.16	Grinsted et al. (2009)
Vermeer2009	0.97-1.56	0.98-1.55	0.81-1.31	Vermeer and Rahmstorf (2009)

For describing the temporal evolution of sea level rise a quadratic function has been fitted to the data as suggested by Nicholls et al. (2011). For each of the three scenarios the predicted temporal evolution of global sea level rise is illustrated in the figures below for the four different sea level rise models, represented by the lower, mean and upper level.

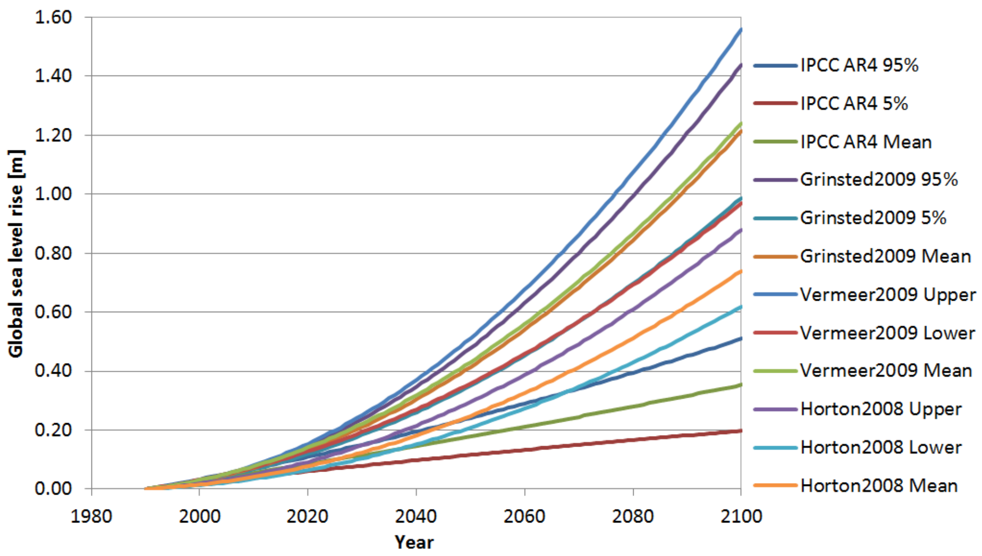

Figure 3.1 Global sea level rise for the various models for the emission scenario A1B

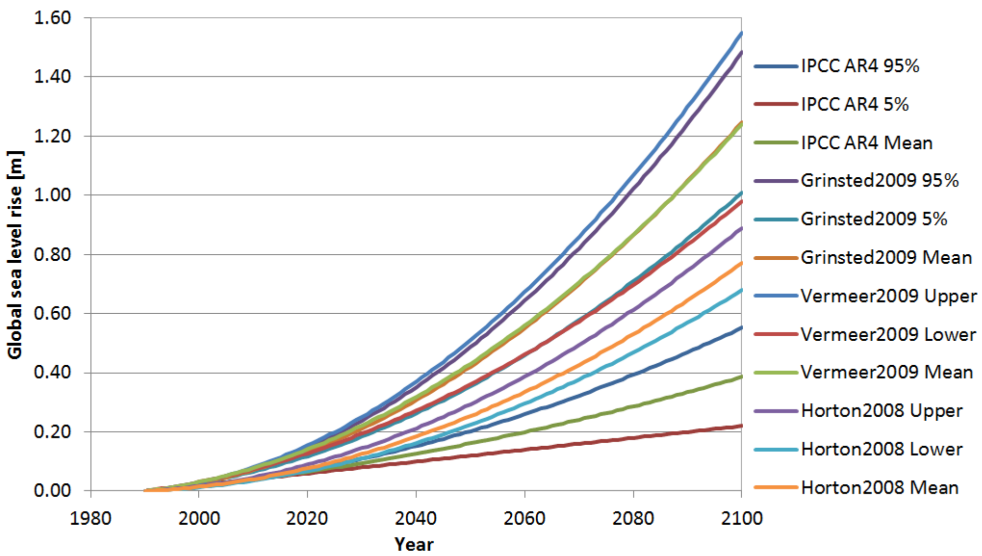

Figure 3.2 Global sea level rise for the various models for the emission scenario A2

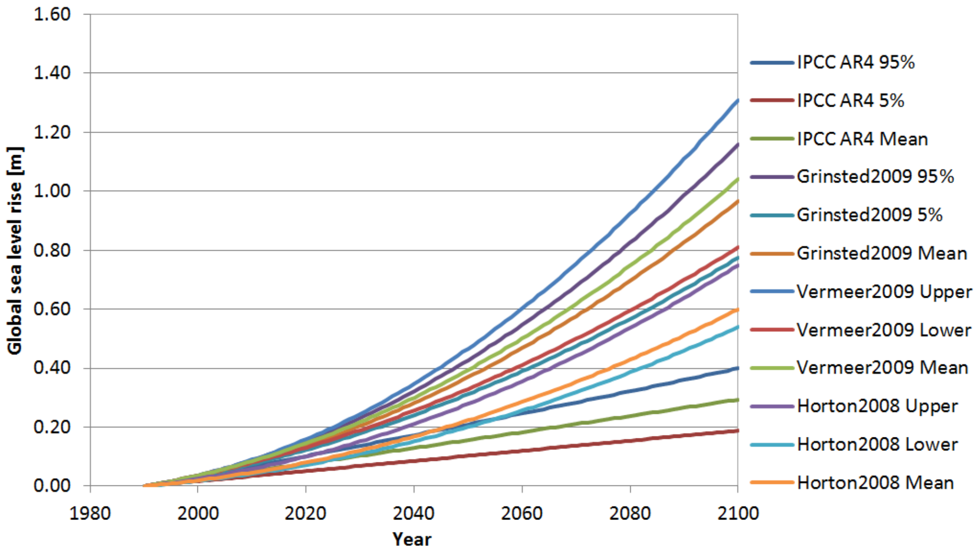

Figure 3.3 Global sea level rise for the various models for the emission scenario B1

3.1 Modifying Times Series of Sea Level

For sea level projections only global values are available, and thus the geographical location is not used when modifying water levels. Furthermore, the sea level rise does not have a variation over the year, i.e. there is only one value which is applied to the whole simulation period.

The sea level time series modification works as follows:

One delta change value is determined based on

- Selected sea level rise model (including choice of lower, mean or upper level)
- Projection year
- Emission scenario

Note that the water level changes should only be applied at sea level boundaries, and thus the user must identify the water level boundary conditions which represent a sea level. The delta change value for the sea level rise is an absolute value that is added to the identified sea level boundary values.

4 References

/1/ Grinsted, A., Moore, J. C., Jevrejeva, S., 2009, Reconstructing sea level from paleo and projected temperatures 200 to 2100 AD, Clim. Dyn. 34, 461–472. (doi:10.1007/s00382-008-0507-2).

/2/ Horton, R., Herweijer, C., Rosenzweig, C., Liu, J., Gornitz, V., Ruane, A.C., 2008, Sea level rise projections for current generation CGCMs based on the semi-empirical method, Geophys. Res. Lett., 35, doi:10.1029/2007GL032486

/3/ Kay, A. L., Davies, H.N., 2008, Calculating potential evaporation from climate model data: A source of uncertainty for hydrological climate change impacts, Journal of Hydrology, 358, 221– 239.

/4/ Meehl, G.A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S.C.B. Raper, I.G. Watterson, A.J. Weaver and Z.-C. Zhao, 2007: Global Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

/5/ Nicholls, R.J., Hanson, S.E., Lowe, J.A., Warrick, R.A., Lu, X., Long, A.J. and Carter, T.R., 2011, Constructing Sea-Level Scenarios for Impact and Adaptation Assessment of Coastal Area: A Guidance Document. Supporting Material, Intergovernmental Panel on Climate Change Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA), 47 pp.

/6/ Vermeer, M., Rahmstorf, S., 2009, Global sea level linked to global temperature. Proc. Natl. Acad. Sci. USA 106, 21 527–21 532. (doi:10.1073/pnas.0907765106).