4th VALUE Training School
Validation of Regional Climate Change Projections

Brief history and overview of downscaling

Douglas Maraun

Wegener Center for Climate and Global Change

Outline

History of Downscaling

Overview of downscaling approaches

History of Downscaling

Overview of downscaling approaches

History of Downscaling · Origins in weather forecasting

First AGCM Simulation, 1956

QUARTERLY JOURNAL
OF THE
ROYAL METEOROLOGICAL SOCIETY

Vol. 82   APRIL 1956   No. 352

551.513.1 : 551.509.33 : 681.14

The general circulation of the atmosphere : a numerical experiment

By NORMAN A. PHILLIPS
The Institute for Advanced Study, Princeton, U.S.A.

(Manuscript received 17 October 1955)

First statistical downscaling, 1959

GEOMAR

672 JOURNAL OF METEOROLOGY VOLUME 16

OBJECTIVE PREDICTION OF FIVE-DAY MEAN TEMPERATURES DURING WINTER [1]

By William H. Klein, Billy M. Lewis, and Isadore Enger

United States Weather Bureau, Washington, D. C.

(Manuscript received 4 March 1959)

ABSTRACT

A statistical screening procedure is used to derive linear multiple-regression equations which express 5-day mean surface temperature as a function of 5-day mean 700-mb heights centered 2 days earlier. Application of these equations to heights obtained from barotropic prognoses would have produced temperature predictions of positive skill during the test winter of 1957–58.

The forecasts can be considerably improved by including as a predictor the local value of 5-day mean surface temperature for a period 4 days earlier than the forecast period. When this term was combined with the barotropically-estimated heights, objective temperature predictions comparable in accuracy to conventional forecasts were made by multiple-regression equations. Further work is in progress to obtain additional improvement by screening the entire field of surface temperature.

First statistical downscaling

Choice of predictors

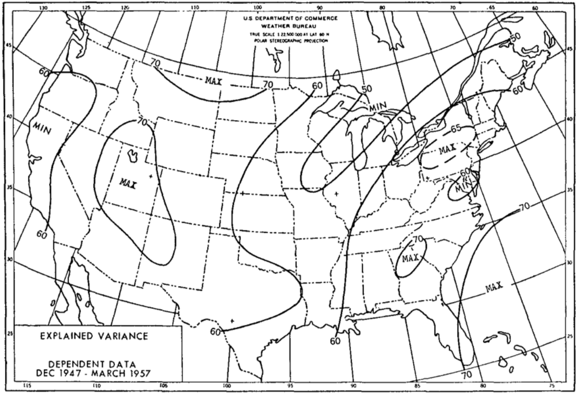


FIG. 6. Square of multiple correlation coefficient between anomalies of 5-day mean surface temperature and 700-mb height 2 days earlier. From 2 to 5 heights were selected by screening technique using the *F*-test at the 1 per cent level of significance. Analysis is based upon values at 30 cities on dependent sample of 140 winter cases from December 1947 to March 1957.

First statistical downscaling

Linear regression

$$\hat{T}\,(\text{Cleveland}) = 0.21 - 0.189\,h\,(60\text{N}, 120\text{W}) + 0.168\,h\,(40\text{N}, 90\text{W}) + 0.059\,h\,(50\text{N}, 80\text{W}) \quad (3)$$

First model output statistics, 1972

December 1972 HARRY R. GLAHN AND DALE A. LOWRY 1203

The Use of Model Output Statistics (MOS) in Objective Weather Forecasting

Harry R. Glahn and Dale A. Lowry

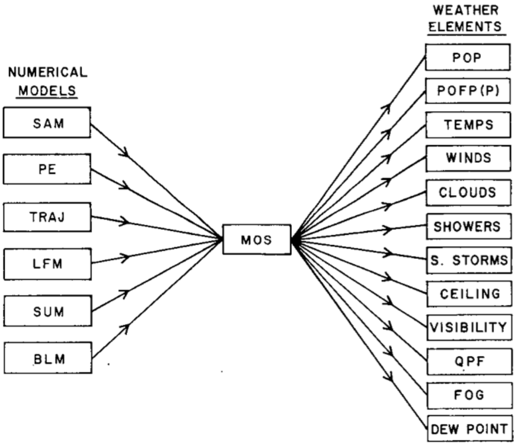
Techniques Development Laboratory, National Weather Service, NOAA, Silver Spring, Md. 20910

(Manuscript received 16 March 1972, in revised form 27 July 1972)

ABSTRACT

Model Output Statistics (MOS) is an objective weather forecasting technique which consists of determining a statistical relationship between a predictand and variables forecast by a numerical model at some projection time(s). It is, in effect, the determination of the "weather related" statistics of a numerical model. This technique, together with screening regression, has been applied to the prediction of surface wind, probability of precipitation, maximum temperature, cloud amount, and conditional probability of frozen precipitation. Predictors used include surface observations at initial time and predictions from the Subsynoptic Advection Model (SAM) and the Primitive Equation model used operationally by the National Weather Service. Verification scores have been computed, and, where possible, compared to scores for forecasts from other objective techniques and for the official forecasts. MOS forecasts of surface wind, probability of precipitation, and conditional probability of frozen precipitation are being disseminated by the National Weather Service over teletype and facsimile. It is concluded that MOS is a useful technique in objective weather forecasting.

Early MOS System



Klein & Glahn, B.A.M.S., 1974

Typical Predictors

GEOMAR

Predictor	Today max	Tonight min	Tomorrow max	Tomorrow night min
a) Trajectory Model				
Surface temperature	24, 24*	24, 24*	24, 24*	24*, 24**
Surface dew point	24*	24*	24*	24**
850-mb temperature	24, 24*	24, 24*	24, 24*	24*, 24**
700-mb temperature	24, 24*	24, 24*	24, 24*	24*, 24**
700-mb 12-hr net vert displ	24*	24*	24**	24**
700-mb 24-hr net vert displ	24*	24*	24**	24**
850-mb 12-hr net vert displ	24*	24*	24**	24**
850-mb 24-hr net vert displ	24*	24*	24**	24**
700-mb relative humidity	24*	24*	24**	24**
850-mb relative humidity	24*	24*	24**	24**
700-mb-surface mean rel hum	24*	24*	24**	24**
Surface 12-hr horiz conv	24*	24*	24**	24**
b) PE Model				
1000-mb height	24	36	48	48*
850-mb height	24	36	48	48*
500-mb height	12, 24	24, 36	36, 48	48, 48*
1000-500-mb thickness	12, 24	24, 36	36, 48	48, 48*
1000-850-mb thickness	12, 24	24	36, 48	48, 48*
1000-mb temperature	12, 24, 24*	24*, 36, 36*	36*, 48, 48*	48, 48*, 48**
850-mb temperature	12, 24, 24*	24*, 36, 36*	36*, 48, 48*	48, 48*, 48**
700-mb temperature	24	24	24*	24*
Boundary layer potential temp	12, 24, 24*	24*, 36, 36*	36*, 48, 48*	48, 48*, 48**
Boundary layer *U* wind	12, 24*	24*, 36*	36*, 48*	48*, 48**
Boundary layer *V* wind	12, 24*	24*, 36*	36*, 48*	48*, 48**
850-mb *U* wind	24*	24*	24**	24**
850-mb *V* wind	24*	24*	24**	24**
700-mb *U* wind	24	24	24*	24*
700-mb *V* wind	24	24	24*	24*
400–1000-mb mean rel hum	12*, 24*	24*, 36*	36**, 48**	48*, 48**
Precipitable water	18*	30*	42**	42**
Precipitation amount	24	36*	48*	48**
850-mb vertical velocity	24*	24*	24**	24**
650-mb vertical velocity	24*	24*	24**	24**
c) Other Variables				
Sine day of year	00	00	00	00
Cosine day of year	00	00	00	00
Latest surface temperature	06	—	—	—
[illegible]	06	—	—	—

Klein & Glahn, B.A.M.S., 1974

Perfect Prognosis vs. MOS

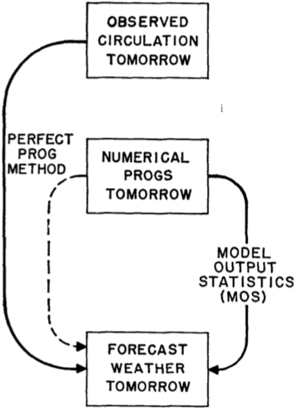


FIG. 1. Two methods of combining numerical and statistical weather forecasting in schematic form.

- PP was born out of necessity
- When long enough model simulations available, MOS was developed.

Glahn & Lowry, J. Appl. Met., 1972; Klein & Glahn, B.A.M.S., 1974

First limited area models, 1966

Howcroft, J.G. 1966. Fine-Mesh Limited-Area Forecasting Model. Tech. rept. U.S. Air Weather Service, Scott Air Force Base.

September 1969 665

UDC 551.509.313

DEVELOPMENT OF A LIMITED AREA FINE-MESH PREDICTION MODEL

JOSEPH P. GERRITY, JR., and RONALD D. McPHERSON

National Meteorological Center, Weather Bureau, ESSA, Suitland, Md.

ABSTRACT

A limited area, fine-mesh, primitive equation barotropic model has been integrated using data observed at 500 mb. The lateral boundary conditions used in the model required that no change occur on the boundary during the 24-hr forecast. The predictions compare favorably with those obtained with the barotropic and baroclinic models in operational use at the National Meteorological Center.

First limited area models

barotropic, approx. 190km resolution, constant lateral boundary conditions, 24h simulation

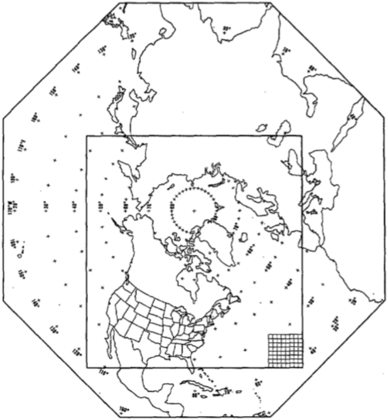


FIGURE 1.—Polar stereographic map of the Northern Hemisphere showing the octagon within which data were available. Also shown is the rectangular boundary of the limited-area fine mesh within which the model equations were solved. In the lower right-hand part of the rectangle a portion of the fine-mesh grid is illustrated.

History of Downscaling · Downscaling in climate research

First climate model, 1967

VOL. 24, NO. 3 JOURNAL OF THE ATMOSPHERIC SCIENCES MAY 1967

Thermal Equilibrium of the Atmosphere with a Given Distribution of Relative Humidity

Syukuro Manabe and Richard T. Wetherald

Geophysical Fluid Dynamics Laboratory, ESSA, Washington, D. C.

(Manuscript received 2 November 1966)

ABSTRACT

Radiative convective equilibrium of the atmosphere with a given distribution of relative humidity is computed as the asymptotic state of an initial value problem.

The results show that it takes almost twice as long to reach the state of radiative convective equilibrinm for the atmosphere with a given distribution of relative humidity than for the atmosphere with a given distribution of absolute humidity.

Also, the surface equilibrium temperature of the former is almost twice as sensitive to change of various factors such as solar constant, CO_2 content, O_3 content, and cloudiness, than that of the latter, due to the adjustment of water vapor content to the temperature variation of the atmosphere.

According to our estimate, a doubling of the CO_2 content in the atmosphere has the effect of raising the temperature of the atmosphere (whose relative humidity is fixed) by about 2C. Our model does not have the extreme sensitivity of atmospheric temperature to changes of CO_2 content which was adduced by Möller.

First climate projection, 1975

VOL. 32, NO. 1 JOURNAL OF THE ATMOSPHERIC SCIENCES JANUARY 1975

The Effects of Doubling the CO_2 Concentration on the Climate of a General Circulation Model[1]

SYUKURO MANABE AND RICHARD T. WETHERALD

Geophysical Fluid Dynamics Laboratory/NOAA, Princeton University, Princeton, N.J. 08540

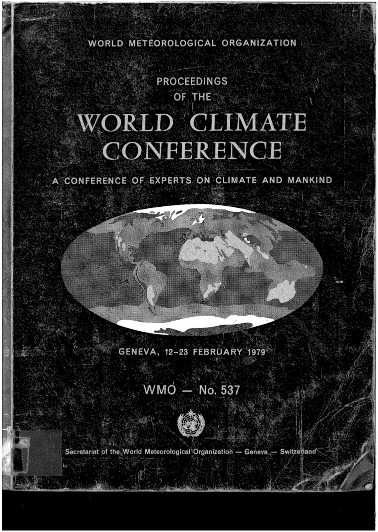
(Manuscript received 6 June 1974, in revised form 8 August 1974)

ABSTRACT

An attempt is made to estimate the temperature changes resulting from doubling the present CO_2 concentration by the use of a simplified three-dimensional general circulation model. This model contains the following simplifications: a limited computational domain, an idealized topography, no heat transport by ocean currents, and fixed cloudiness. Despite these limitations, the results from this computation yield some indication of how the increase of CO_2 concentration may affect the distribution of temperature in the atmosphere. It is shown that the CO_2 increase raises the temperature of the model troposphere, whereas it lowers that of the model stratosphere. The tropospheric warming is somewhat larger than that expected from a radiative-convective equilibrium model. In particular, the increase of surface temperature in higher latitudes is magnified due to the recession of the snow boundary and the thermal stability of the lower troposphere which limits convective heating to the lowest layer. It is also shown that the doubling of carbon dioxide significantly increases the intensity of the hydrologic cycle of the model.

First world climate conference, 1979

led to the establishment of the WCRP and later the IPCC



First IPCC meeting, 1988

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WORLD CLIMATE PROGRAMME PUBLICATIONS SERIES

WMO/UNEP INTERGOVERNMENTAL PANEL
ON CLIMATE CHANGE

REPORT OF THE FIRST SESSION

OF THE

WMO/UNEP INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC)

Geneva, 9 - 11 November 1988

IPCC - 1

TD - No. 267

World Meteorological
Organization

United Nations Environment
Programme

Establishment of Working Group 1-3

3.2 The Panel agreed that its work included three main tasks :

(i) Assessment of available scientific information on climate change;

(ii) Assessment of environmental and socio-economic impacts of climate change;

(iii) Formulation of response strategies.

3.3 The Panel decided to establish three Working Groups to accomplish these tasks in the most efficient and expeditious manner. Each Working Group should deal with its assigned task while close co-ordination of their activities should be ensured. It was specifically pointed out that the activity of the Working Group on response strategies would heavily depend on the results obtained by the other Working Groups. Nevertheless, the three Working Groups should start their work immediately. All three Working Groups should take into consideration, in their work, available assessment results obtained by relevant international and national bodies and programmes, including the World Climate Programme.

First regional climate change & impact studies

- Use past climates as analogues for warmer future climate (e.g., Wigley et al., 1986)
  Critique: forcing of past climates different from future climate ⇒ also response patterns different.

- Impact model sensitivity studies (e.g., Schwarz, 1966)
- Change factor approach (e.g., Mearns et al., 1984)
- Interpolation of GCM surface variables (e.g., Cohen and Allsopp, 1988; Wigley et al., 1990)
  Critique: GCMs do not simulate realistic fields beyond a minimum skillful scale (Grotch and MacCracken, 1991); climate change at regional scale might differ from climate change at large scale (Giorgi et al., 1991).

First ESD in climate research, 1984

OCTOBER 1984 KIM, CHANG, BAKER, WILKS AND GATES 2069

The Statistical Problem of Climate Inversion: Determination of the Relationship between Local and Large-Scale Climate

J.-W. KIM,[1] J.-T. CHANG,[2] N. L. BAKER,[3] D. S. WILKS AND W. L. GATES

Department of Atmospheric Sciences and Climatic Research Institute, Oregon State University, Corvallis, OR 97331

(Manuscript received 12 August 1981, in final form 9 July 1984)

ABSTRACT

The estimation of the most probable local or mesoscale distribution of a climatic variable when only the large-scale value is given may be viewed as a sort of climate inversion problem. As an initial statistical study of this question, the monthly-averaged surface temperature and monthly total precipitation for stations in Oregon are analyzed for the purpose of relating their most probable mesoscale distributions to the large-scale monthly anomalies.

The first empirical orthogonal mode of the covariance matrix of mesoscale transient departures explains 78.2 and 80.8% of the total variance of temperature and precipitation, respectively. The time structure of the first mode is predominantly seasonal and is in phase with the large-scale anomalies, and the correlation coefficient between this oscillation and the large-scale anomaly is 0.96 for temperature and 0.95 for precipitation. The most probable mesoscale distribution as specified by only the first empirical orthogonal function is predictable with relative error of less than 37.9% for temperature and 37.1% for precipitation if the corresponding large-scale anomaly is known with an error of less than 10%. These results may be useful in the study of local climatic impacts with large-scale climate models.

First conceptual discussion, 1985

Introduction of the term “downscale”

THE USE OF GENERAL CIRCULATION MODELS IN THE ANALYSIS OF THE ECOSYSTEM IMPACTS OF CLIMATIC CHANGE

W. LAWRENCE GATES

Climatic Research Institute

and

Department of Atmospheric Sciences, Oregon State University, Corvallis, OR 97331, U.S.A.

Abstract. The use of general circulation models in the estimation of the impact of climatic change on the global ecosystem is seen to depend primarily on their ability to reliably depict the seasonal and geographical distribution of the changes in surface climate variables. While present GCMs generally simulate the observed distribution of surface air temperature reasonably well, they show significantly different changes in the equilibrium temperature as a result of doubled CO_2, for example. These disagreements are attributed to differences in the model's resolution and parameterization of subgrid-scale processes. Such model-dependent errors notwithstanding, much more information of possible use in impact analysis can be extracted from general circulation model simulations than has generally been done so far. The completeness, consistency and experimental possibilities offered by simulated data sets permit the systematic extraction of a wide variety of statistics important to the surface ecosystem, such as the length of the growing season, the duration of rainless periods, and the surface moisture stress.

Assuming further model improvements, the elements of a model-assisted methodology for climate impact analysis are seen to be: (1) the determination of the seasonal and geographical distribution of that portion of simulated climatic changes which are both statistically and physically significant; (2) the transformation of the (significant) large-scale climatic changes onto the local scale of impact (the climate 'inversion' problem); and (3) the design of specific statistical parameters or functions relevant to local ecosystem impacts.

The Karl et al. paper, 1990

VOLUME 3 JOURNAL OF CLIMATE OCTOBER 1990

A Method of Relating General Circulation Model Simulated Climate to the Observed Local Climate. Part I: Seasonal Statistics

THOMAS R. KARL*

*NOAA/NESDIS/NCDC, Asheville, North Carolina

WEI-CHYUNG WANG**

**Atmospheric and Environmental Research, Inc., Cambridge, Massachusetts

MICHAEL E. SCHLESINGER@

@University of Illinois, Department of Atmospheric Science, Urbana, Illinois

RICHARD W. KNIGHT*

*NOAA/NESDIS/NCDC, Asheville, North Carolina

DAVID PORTMAN**

**Atmospheric and Environmental Research, Inc., Cambridge, Massachusetts

(Manuscript received 5 May 1989, in final form 16 April 1990)

The Karl et al. paper, 1990

Insights and Ideas

The good

- Downscaling in climate science is similar to PP and MOS in NWP;
- Only free atmospheric variables as predictors;
- Problem of extrapolation.

The bad

- Variance inflation (actually, after Klein et al., 1959);
- Muddled understanding of PP and MOS.

The von Storch et al. paper, 1993

GEOMAR

JUNE 1993 VON STORCH ET AL. 1161

Downscaling of Global Climate Change Estimates to Regional Scales: An Application to Iberian Rainfall in Wintertime

HANS VON STORCH, EDUARDO ZORITA, AND ULRICH CUBASCH

Max-Planck-Institut für Meteorologie, Hamburg, Germany

(Manuscript received 17 June 1991, in final form 29 May 1992)

ABSTRACT

A statistical strategy to deduct regional-scale features from climate general circulation model (GCM) simulations has been designed and tested. The main idea is to interrelate the characteristic patterns of observed simultaneous variations of *regional* climate parameters and of *large-scale* atmospheric flow using the canonical correlation technique.

The large-scale North Atlantic sea level pressure (SLP) is related to the regional, variable, winter (DJF) mean Iberian Peninsula rainfall. The skill of the resulting statistical model is shown by reproducing, to a good approximation, the winter mean Iberian rainfall from 1900 to present from the observed North Atlantic mean SLP distributions. It is shown that this observed relationship between these two variables is not well reproduced in the output of a general circulation model (GCM).

The implications for Iberian rainfall changes as the response to increasing atmospheric greenhouse-gas concentrations simulated by two GCM experiments are examined with the proposed statistical model. In an instantaneous "2 CO_2" doubling experiment, using the simulated change of the mean North Atlantic SLP field to predict Iberian rainfall yields, there is an insignificant increase of area-averaged rainfall of 1 mm/month, with maximum values of 4 mm/month in the northwest of the peninsula. In contrast, for the four GCM grid points representing the Iberian Peninsula, the change is −10 mm/month, with a minimum of −19 mm/month in the southwest. In the second experiment, with the IPCC scenario A ("business as usual") increase of CO_2, the statistical-model results partially differ from the directly simulated rainfall changes: in the experimental range of 100 years, the area-averaged rainfall decreases by 7 mm/month (statistical model), and by 9 mm/month (GCM); at the same time the amplitude of the interdecadal variability is quite different.

The von Storch et al. paper, 1993

Insights and Ideas

- Predictor scale should be larger than minimum skillful scale (Perfect prognosis);
- Predictors should be informative, i.e., explain large fraction of local weather.

Delta change; change factor weather generators

Delta change

- Add/multiply simulated long-term change to present observational series (e.g., Rosenzweig, 1985; Santer, 1985).

Weather generators

- Wet day generator: Gabriel and Neumann, 1962;
- Precipitation generators: Katz, 1977; Buishand, 1977;
- Weather generator: Richardson, 1981.

Change factor weather generators

- Change factor weather generator: Wilks, 1988.

Perfect Prognosis weather generators

- WG conditioned on observed day-to-day weather types: Hay et al., 1991; Bardossy and Plate, 1991; Bardossy and Plate, 1992;
- WG conditioned on GCM simulated weather types: Matyasovszky et al., 1993;

The first regional climate model, 1989

GEOMAR

A REGIONAL CLIMATE MODEL FOR THE WESTERN UNITED STATES

ROBERT E. DICKINSON, RONALD M. ERRICO, FILIPPO GIORGI, and GARY T. BATES
National Center for Atmospheric Research, Boulder, CO 80307-3000, U.S.A.*

Abstract. A numerical approach to modeling climate on a regional scale is developed whereby large-scale weather systems are simulated with a global climate model (GCM) and the GCM output is used to provide the boundary conditions needed for high-resolution mesoscale model simulations over the region of interest. In our example, we use the National Center for Atmospheric Research (NCAR) community climate model (CCM1) and the Pennsylvania State University (PSU)/NCAR Mesoscale Model version 4 (MM4) to apply this approach over the western United States (U.S.). The topography, as resolved by the 500-km mesh of the CCM1, is necessarily highly distorted, but with the 60-km mesh of the MM4 the major mountain ranges are distinguished. To obtain adequate and consistent representations of surface climate, we use the same radiation and land surface treatments in both models, the latter being the recently developed Biosphere-Atmosphere Transfer Scheme (BATS). Our analysis emphasizes the simulation at four CCM1 points surrounding Yucca Mountain, NV, because of the need to determine its climatology prior to certification as a high-level nuclear waste repository.

The first RCM projection, 1991

First climate bias correction, 2002

October 2002   HAY ET AL.   571

Use of Regional Climate Model Output for Hydrologic Simulations

L. E. Hay,* M. P. Clark,+ R. L. Wilby,# W. J. Gutowski, Jr.@ G. H. Leavesley,* Z. Pan,@
R. W. Arritt,@ and E. S. Takle@

*Water Resources Division, U.S. Geological Survey, Denver, Colorado
+Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, Colorado
#Department of Geography, King's College London, Strand, London, United Kingdom
@Department of Agronomy, Geological and Atmospheric Sciences, Iowa State University, Ames, Iowa

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 107, NO. D20, 4429, doi:10.1029/2001JD000659, 2002

Long-range experimental hydrologic forecasting for the eastern United States

Andrew W. Wood and Edwin P. Maurer
Department of Civil and Environmental Engineering, University of Washington, Seattle, Washington, USA

Arun Kumar
Climate Prediction Center, NOAA National Center for Environmental Prediction, Camp Springs, Maryland, USA

Dennis P. Lettenmaier
Department of Civil and Environmental Engineering, University of Washington, Seattle, Washington, USA

MOS and bias correction, 2003

1 March 2003 WIDMANN ET AL. 799

Statistical Precipitation Downscaling over the Northwestern United States Using Numerically Simulated Precipitation as a Predictor*

Martin Widmann and Christopher S. Bretherton

Department of Atmospheric Sciences, University of Washington, Seattle, Washington

Eric P. Salathé Jr.

Climate Impacts Group, Joint Institute for the Study of the Atmosphere and Ocean/School of Marine Affairs, University of Washington, Seattle, Washington

(Manuscript received 8 October 2001, in final form 13 May 2002)

Stochastic bias correction, 2014

6940 JOURNAL OF CLIMATE VOLUME 27

Stochastic Model Output Statistics for Bias Correcting and Downscaling Precipitation Including Extremes

GERALDINE WONG AND DOUGLAS MARAUN

GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany

MATHIEU VRAC

Laboratoire des Sciences du Climat et de l'Environnement, CEA Saclay, Gif-sur-Yvette, France

MARTIN WIDMANN AND JONATHAN M. EDEN

School of Geography, Earth and Environmental Sciences, University of Birmingham, Birmingham, United Kingdom

THOMAS KENT

School of Mathematics, University of Leeds, Leeds, United Kingdom

(Manuscript received 4 October 2013, in final form 14 April 2014)

History of Downscaling · Coordination

Model intercomparison and validation

- Project to Intercompare Regional Climate Simulations (PIRCS, Takle et al., 1999)
- PRUDENCE (Christensen and Christensen, 2007)
- STARDEX (Haylock et al., 2006; Goodess et al., 2010)
- ENSEMBLES (Hewitt, 2005; van der Linden and MItchell, 2009)
- NARCCAP (Mearns et al., 2009)
- CORDEX (Giorgi)
- VALUE (Maraun et al., 2015)
- CORDEX-ESD

Climate information distillation and ethical aspects

- How to construct regional climate information from multiple, apparently contradictive, sources (observed trends, expert knowledge, GCMs, RCMs, PP, bias correction)?
  WCRP expert workshop on climate information distillation, Santander, Oct. 2014;
  IPCC workshop on regional climate projections, Sep. 2015;
  WCRP frontier projects.

- Providing plausible, defensible and actionable information is an inherently ethical problem (Hewitson et al., 2014; Maraun et al., 2015).

History of Downscaling

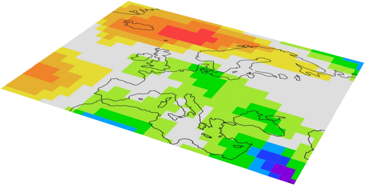
Overview of downscaling approaches

Overview of downscaling approaches · Dynamical Downscaling

Dynamical Downscaling

Nest a limited area RCM into a global GCM

Large Scales



GCM

Regional Scales

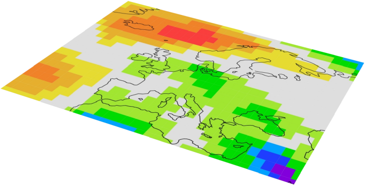
Local Scales

Maraun et al., Rev. Geophys., 2010

Dynamical Downscaling

Nest a limited area RCM into a global GCM

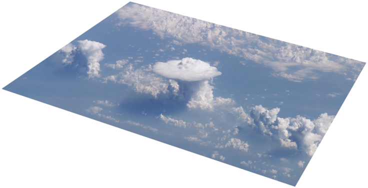
Large Scales



GCM

Regional Scales

Local Scales



Observations

Maraun et al., Rev. Geophys., 2010

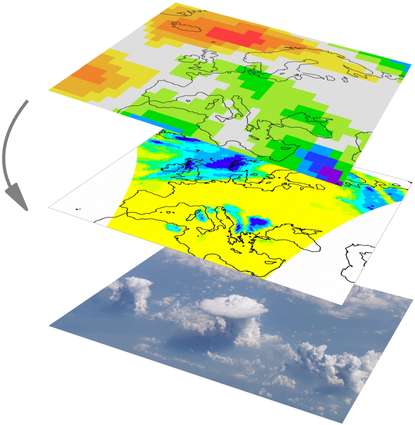
Dynamical Downscaling

Nest a limited area RCM into a global GCM

Large Scales

Regional Scales

Local Scales



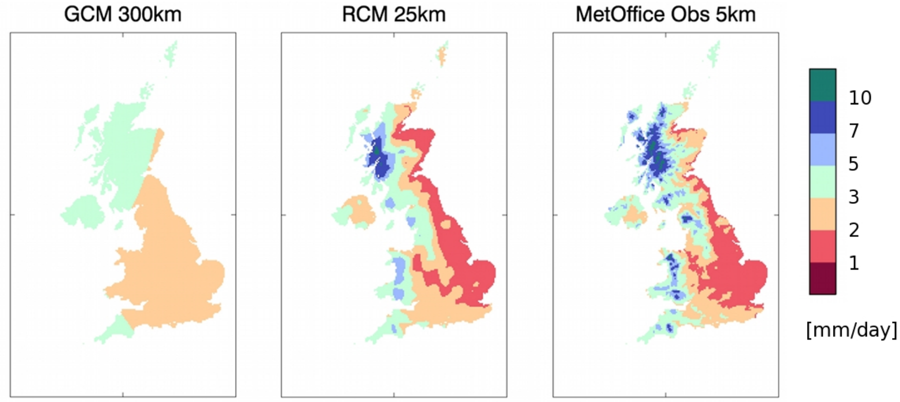
GCM

RCM

Observations

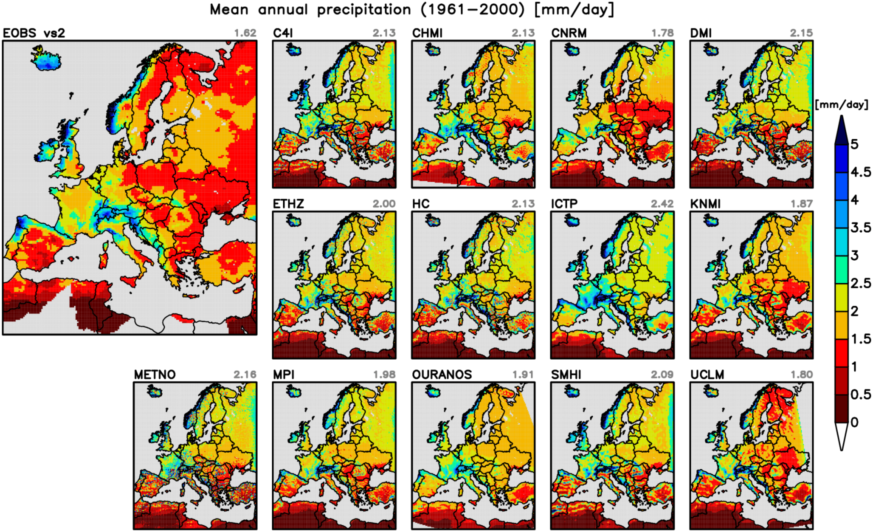
Maraun et al., Rev. Geophys., 2010

RCMs add value



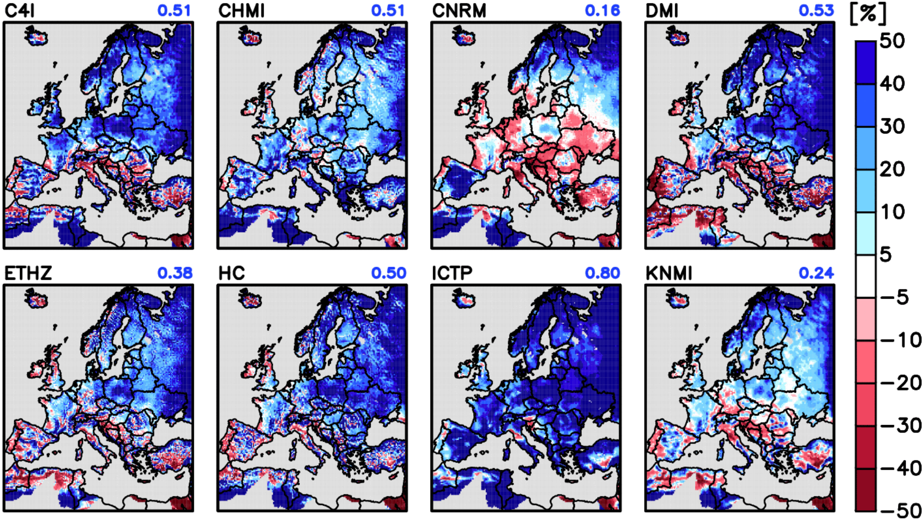
Maraun et al., Rev. Geophys., 2010

RCMs are biased



Kotlarski, unpublished

RCMs are biased

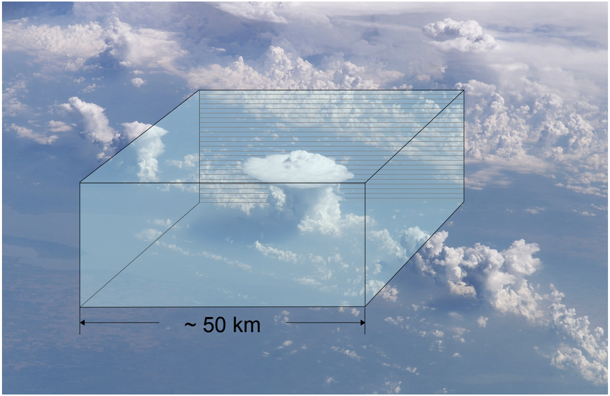


Kotlarski, unpublished

Sub-grid parameterisations

NASA

Sub-grid parameterisations



Small scale processes are included by empirically derived relationships

NASA

Overview of downscaling approaches · Statistical Downscaling

The basic idea

Mapping between a large (or larger) scale predictor X and the expected value of a local-scale predictand Y:

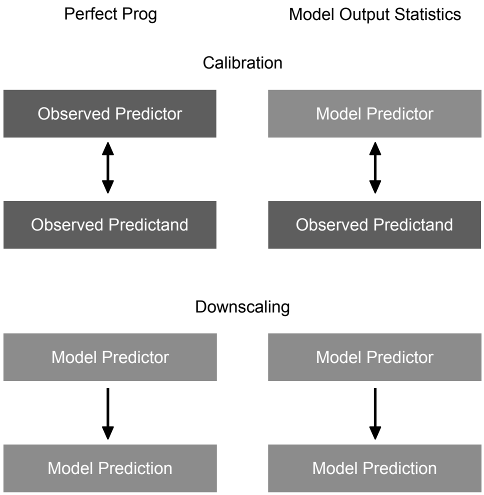
$$E(Y|X) = f(X, \beta)$$

β: vector of unknown parameters

Variability not explained by X can be modelled as noise η.

Observed X for calibration $\Rightarrow$ Perfect Prog (PP);
Modelled X for calibration $\Rightarrow$ Model Output Statistics (MOS).

PP vs. MOS

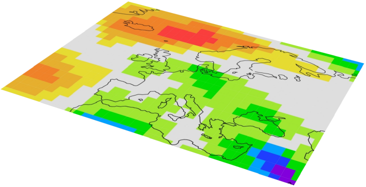


Maraun et al., Rev. Geophys., 2010

The concept

Perfect Prog(nosis, PP) establishes a statistical link between observed large and local scales

Large Scales



GCM

Regional Scales

Local Scales

Maraun et al., Rev. Geophys., 2010

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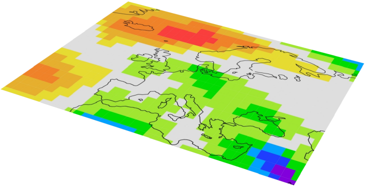

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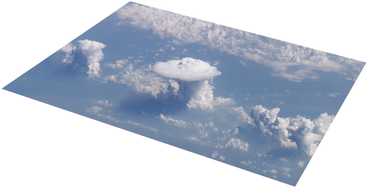

Observations

Maraun et al., Rev. Geophys., 2010

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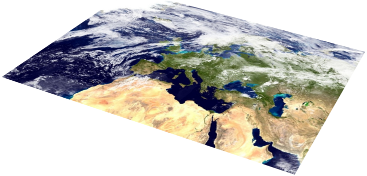
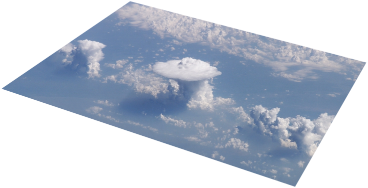


Observations

Regional Scales

Local Scales



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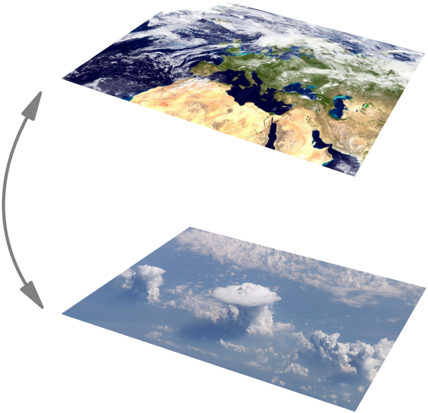

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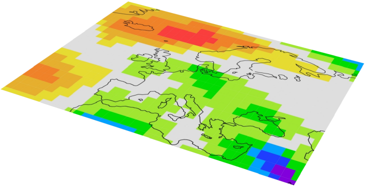

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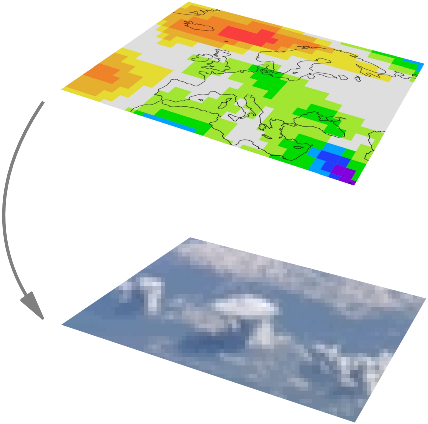


GCM

Downscaling

Maraun et al., Rev. Geophys., 2010

Predictor Choice

Predictors are required to be

- informative
- stationary relationship with predictand
- capturing long term variability
- well represented by GCMs (PP condition)

Predictors need to capture

- atmospheric circulation (pressure fields, airflow indices, weather types)
- temperature
- moisture

Predictors are often transformed, e.g., by PCA, “physical” transformations or cluster analysis.

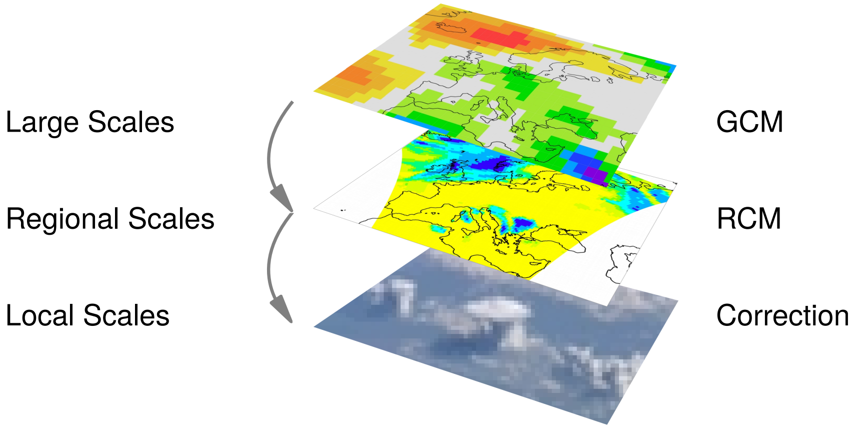
Charles et al., Clim. Res., 1999; Wilby et al., J. Hydrol., 1998; Wilby & Wigley, Int. J. Climatol., 2000;
Maraun et al., Rev. Geophys., 2010

Limitations of PP

- Stationarity assumption often questionable;
  (depends heavily on the predictor choice)
- Often only single site models;
- In general no full spatial fields;
- Mesoscale physics not considered.

Model output statistics (MOS)

also called bias correction, corrects specific model output



Glahn & Lowry, 1972; Maraun et al., Rev. Geophys., 2010

Limitations of MOS I

- Delta method does not account for dynamical changes;
- Most current approaches correct only long term distributions;
- Stationarity assumption questionable;
- When calibrated against gridded data, limited resolution;
- When calibrated against station data, no full fields; variability underestimated by most approaches;
- Most approaches do not correct location bias;
- Almost no methods for extremes.

Overview of downscaling approaches · Weather generators

Simple unconditional weather generator (WG)

1. Markov chain to model wet- and dry-day sequence:

$$p_{ij}(t) = P(X_t = j | X_{t-1} = i), \quad i, j \in (0, 1)$$

2. Gamma distribution to model rain amount on a wet day:

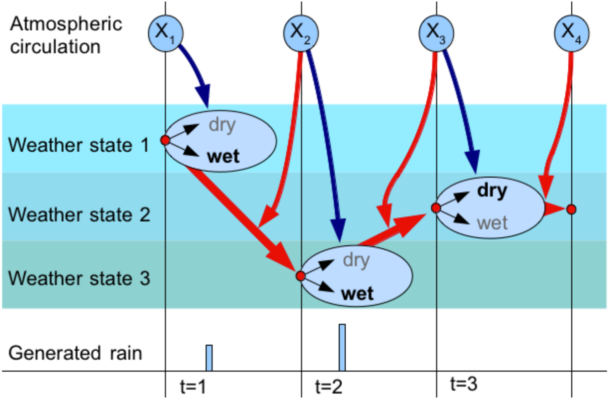
$$P(y_i > y_0 | i = 1) \sim \Gamma(k, \theta)$$

k: shape
θ: scale

(some WGs model individual storm cells)

Schematic of a weather generator

Hidden Markov model for transitions and logistic regression for wet and dry days



Maraun et al., Rev. Geophys., 2010, after Vrac & Naveau, Wat. Resour. Res., 2007

PP and MOS WGs

PP WGs

The parameters of the WG are conditioned on large scale weather.

MOS WGs

The parameters of the WG are conditioned on the RCM grid box values.

Change Factors

Condition parameters of unconditional weather generators on RCM grid box climate.