Retrospective Analysis of Regional Climate

Phase I: German Reanalysis Project

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Kick-Off Meeting: Hans Ertel Centre for Weather Research (HErZ)
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Outline

I. Introduction
   1. Atmospheric reanalyses
   2. Requirements
   3. Project objectives
   4. Project structure
   5. Outlook

II. Work packages
1. Atmospheric reanalyses

➔ What is a reanalysis?

- Assimilation of past observations into a physical model
- From heterogeneous monitoring networks
- With a fixed data assimilation system and model

➔ Why reanalyses?

- Four-dimensional fields
- Physically consistent in space and time
- Physically consistent between parameters
1. Atmospheric reanalyses

<table>
<thead>
<tr>
<th>Current reanalyses</th>
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</thead>
<tbody>
<tr>
<td>ERA-Interim</td>
<td>ECMWF</td>
<td>T255 L60</td>
<td>1989-present</td>
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<tr>
<td>ERA-40</td>
<td>ECMWF</td>
<td>T159 L60</td>
<td>1958-2001</td>
</tr>
<tr>
<td>Japanese Reanalysis (JRA-25)</td>
<td>JMA</td>
<td>T106 L40</td>
<td>1979-2004</td>
</tr>
<tr>
<td>NCEP Reanalysis AMIP-II (R2)</td>
<td>NCEP</td>
<td>T62 L28</td>
<td>1979-present</td>
</tr>
<tr>
<td>NCEP Reanalysis I (R1)</td>
<td>NCEP</td>
<td>T62 L28</td>
<td>1948-present</td>
</tr>
<tr>
<td>MERRA</td>
<td>NASA</td>
<td>0.5° x 0.5°</td>
<td>1979-2010</td>
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<tr>
<td>Climate Forecast System Reanalysis (CFSR)</td>
<td>NCEP</td>
<td>T382 L64</td>
<td>1979-????</td>
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<tr>
<td>20th Century Reanalysis (20CR)</td>
<td>NOAA</td>
<td>T62 L28</td>
<td>1871-2008</td>
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<tr>
<td>North American Regional Reanalysis (NARR)</td>
<td>NCEP</td>
<td>32 km</td>
<td>1979-present</td>
</tr>
<tr>
<td>Arctic System Reanalysis (ASR)</td>
<td>PMG</td>
<td>10-20 km</td>
<td>2000-2010</td>
</tr>
</tbody>
</table>

www.reanalysis.org
2. Requirements

→ High-resolution regional reanalysis
  - Europe
  - Germany

→ Learnt from global reanalyses
  - End-to-end programme
  - Sustained and with long-term perspective
  - Adequate evaluation of products
  - Dissemination beyond the research domain
3. Objectives

- Provide a **quality controlled** retrospective analysis of regional climate and its **uncertainty** in an area covering **at least Germany**

- Provide **detailed diagnostics** of the energy, water, and momentum cycles of the reanalysed atmospheric climate state

- Optimise climate monitoring by **synergetic use** of different monitoring networks

- Incorporate **satellite data** for validation and their subsequent use in assimilation
4. Project structure

- **ERA-interim**
- **COSMO-EU**
- **COSMO-DE (ST/FULL)**
- **Satellite Forward Operators**
- **Reforecasts**
- **Disaggregation & Transfer Functions**
- **COSMO-DE (LT/HOM)**
- **Quality Control & Data Publication**
5. Outlook

- **Global Reanalyses or ICON (?)**
- **COSMO-DE with EnKF, LETKF (?)**
- **Assimilation of Satellite Data**
- **20CR Ensembles**
- **COSMO-DE Ensemble**

**WP1**
- ERA-interim
- COSMO-EU
- ERA-40 or 20CR

**WP2**
- Disaggregation & Transfer Functions

**WP3**
- Quality Control & Data Publication

**WP4**
- Satellite Forward Operators

**WP5**
- Reforecast
Outline

I. Introduction

II. Work packages

WP1: COSMO-DE reanalysis (C.O.)
WP5: Quality control and data publication (C.O.)
WP3: Verification by satellite forward operators (S.C.)
WP2: Disaggregation and transfer functions (P.F.)
WP4: Reforecasts (P.F.)
WP1: COSMO-DE reanalysis

- ERA-interim
- COSMO-EU
- COSMO-DE (ST/FULL)

WP2: Disaggregation & Transfer Functions

WP3: Satellite Forward Operators

WP4: Reforecasting

WP5: Quality Control & Data Publication
WP1: COSMO-DE reanalysis

- **COSMO-DE** (2.8 km)
  - **Fixed** version of the **operational** analysis system
  - Continuous data assimilation (**nudging scheme**)
  - Latent heat nudging (**LHN**)
  - 1-hourly boundary data from COSMO-EU

- **COSMO-EU** (7 km)
  - **Fixed** version of the **operational** analysis system
  - Soil moisture analysis (**SMA**)
  - 3/6-hourly boundary data from global reanalyses
WP1: COSMO-DE reanalysis

⇒ Short-term experiment (ST/FULL): 2007-2011
  ▪ Most comprehensive set of observation data incl. RADAR
  ▪ Boundary data: ERA-interim

⇒ Long-term experiment (LT/HOM): ...
  ▪ LHN via disaggregation of precipitation data
  ▪ Statistical transfer functions $T_{2m} \rightarrow T_{925hPa} / T_{850hPa}$
  ▪ Boundary data: ERA-40 or 20CR

⇒ Current experiments
  ▪ Test run (1 month) in NUMEX on SX8 (Klimarechner)
WP5: Quality control and data publication

- WP1: ERA-interim → COSMO-EU → COSMO-DE (ST/FULL)
- WP2: ERA-40 or 20CR → Disaggregation & Transfer Functions
- WP3: Satellite Forward Operators
- WP4: Reforecasts
- WP5: Quality Control & Data Publication
WP5: Quality control and data publication

➔ Assess the uncertainty in reanalysis data
  - Verification based on observations retained from assimilation (e.g. COPS/GOP)
  - Reanalyses require a probabilistic point of view
  - Methods like e.g. Bayes factors (A. Röpnack)

➔ Dissemination
  - Citable data publication
  - Proper communication of uncertainties
WP3: Verification by satellite forward operators
WP3 Verification by satellite and GOP data

- Evaluate the short term reanalysis for 2007/08 data using the General Observation Period (GOP) data set from the priority program SPP1167 “Quantitative precipitation forecasts”

- Develop a fast microwave radiative transfer model as AMSU (Advanced Microwave Sounding Unit) forward operator

- Apply microwave forward operators to subsets of the reanalysis data

Potential of GOP data

Bias in Integrated Water Vapor (IWV) as a function of model start time in UTC

Assimilation of radiosonde data with dry Bias
Potential of GOP data

COSMO-EU drier than COSMO-DE models much too dry in Sep 2008

Cloud base height too high in summer and too low in winter

precipitation is over-estimated in winter

Potential of GOP data


Identification of compensating Bias contributions
Importance of boundary conditions
Multi-variate evaluation
Why microwave satellite observations?

- since 1978 microwave observations are available from a series of polar orbiting satellites (TIROS, NOAA 6-7, SSM/I, Metop..)
- microwave radiances provide temperature and humidity information in clear & cloudy situations and are routinely assimilated in several NWP models
- over land rough estimates of precipitation are derived using the scattering signal

Well suited for reanalysis due to long coverage and integrative assessment of temperature, humidity, and hydrometeors
Microwave satellite observations for precipitation

Development of fast forward operator

- Ill-determined precipitation retrieval makes model-to-observation approach necessary
- RTTOV developed within NWPSAF is a very fast radiative transfer model for infrared and microwave satellite sensors to foster data assimilation
  - V9 includes crude approach of scattering
- Existing detailed radiative transfer model (active and passive) at IGMK (Mech) adapted to COSMO-DE

New flexible operator suitable for long-term model evaluation

What caused COSMO TB underestimation?

- high amount of graupel and liquid water in upper troposphere
- amount reduced during model spin-up but still evident in forecasts
- in stratiform situation situations snow is produced via latent heat nudging
WP3: Workplan

🚀 Microwave forward tool

- build-up of modular microwave radiative transfer module
- investigation of cloud parametrization assumptions & speed-up, comparison with RTTOVS
- adaptation to reanalysis

🎯 Evaluation of Reanalysis

- implementation of diagnostic output into reanalysis to match observation characteristics
- case studies to optimize multi-variate evaluation (ceilometer, GPS, MSG, AMSU, Cloudsat)
- long-term evaluation
WP2: Disaggregation and transfer functions
WP2: Disaggregation of Precipitation

**Assimilation of Precipitation**
- LHN every time step
- Rain radar composite
  - Available since 2007

**Disaggregation of Precipitation**
- Based on gauge observations
- Further information from satellite data,...

Provide area-wide precipitation at high spatial and temporal resolution
WP2: Disaggregation of Precipitation

- **Multiplicative Cascade Models**
  - **Scaling** (simple) of moments on different spatial or temporal scale
  - **Good**
    - Conserves precipitation amount
    - No negative precipitation
    - Information can be assimilated
  - **Problems**
    - Handle no-rain regions
WP2: Disaggregation of Precipitation

⇒ Gaussian Markov random fields (GMRF)
  ▪ Scale independent formulation of continuous process
  ▪ GMRF – solutions of SPDE
  ▪ Latent Gaussian process with covariates
  ▪ Geostatistical concepts - Kriging
  ▪ GMRF
    ▪ Fast even for large data set
    ▪ Bayesian formulation provides information about uncertainty

From Lindgren, Rue, Lindström (2011)
WP2: Transfer Functions

- Assimilation of 2m temperature
  - Soil Moisture Analysis

- Transfer functions for lower tropospheric temperature
  - Provide vertical temperature profiles based on 2m temperature
    \[ T_{2m} \rightarrow T_{925hPa} / T_{850hPa} \]
  - Vertical transfer functions using multivariate regression techniques
  - Derived from radiosonde profiles, aircraft reports …

Disaggregation and transfer functions allow for conditional simulation – generate ensemble of realizations
WP4: Reforecasts

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WP4: Reforecasts

➔ Perform reforecasts for selected periods
  - Investigate balance equations for conserved quantities
    - Energy and water balance
    - Ertel’s PV
  - Tendencies within first few minutes
  - Long-term tendencies

Detect systematic inconsistencies due to data assimilation, indicate instabilities, and define model deficiencies and calibration requirements
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