MeteoSolutions

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Short-term Prediction of Wind and Temperature Profiles based on Profiler RADAR data for the use by a Wake Vortex Warning System at Frankfurt Airport

WakeNet3-Europe Workshop on Short-Term Weather Forecasting for Probabilistic Wake-Vortex Prediction
DLR Oberpfaffenhofen, Germany, 10th May 2010

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Company Profile

Your partner for software development and research in meteorology.

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Software systems

Conception and development of software systems for

☞ **processing (operational, round the clock)**

☞ **visualization (GUI, Web)**

of meteorological data

☞	**Platforms:**	**MS-WINDOWS®, UNIX (Linux, AIX, IRIX)**
☞	**Programming languages:**	**JAVA, J2EE, XML, C/C++, IDL, FORTRAN, Open GL, Perl, PHP, HTML**
☞	**Databases:**	**ORACLE, MySQL**

Requirements: high data availability demands

high system stability, resilience, robustness

Research projects

- Scientific processing and analysis of meteorological data
- Statistical evaluation
- Development of meteorological methods
- Visualization of meteorological data

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Company Profile

DWD

Since 2002 MeteoSolutions GmbH is one of three main IT partners to develop meteorological software systems for the German National Weather Service

bfg

Bundesanstalt für Gewässerkunde

DFS Deutsche Flugsicherung

EUMETSAT

Landesbetrieb Straßen, Brücken und Gewässer der Stadt Hamburg

Wake Vortex Warning System at Frankfurt Airport

Background / Starting point:

- narrow distance of the glideslopes of parallel runways 07L, 07R
- wake vortices are hazardous for following aircraft
- minimum distance of 1500m for two landing aircraft for safety reasons causes capacity limits of EDDF
- existing WVWS is only valid within the first 80m above ground

Aim:

- Glideslope extension of the Wake Vortex Warning System to a minimum height of 1500m above ground.
- Short Term Prediction of wind and temperature profiles up to 20min ahead with an update cycle of 2min and temporal resolution of 2min

Glideslope Extension

Facilities:

- Chain of sonic anemometers in cross runway direction
- Wind Temperature Profiler RADAR (WTR)

Basic requirements / conditions:
- fixed schedule
- fixed budget
- straightforward implementation
- resource-saving algorithm

=> Prediction using statistical methods of time series analysis.

Project Tasks:

- Data analysis to find the characteristics of WTR data
- Development of a short term prediction algorithm for wind and temperature profiles
- Development of criteria for critical weather situations
- Software Prototyping

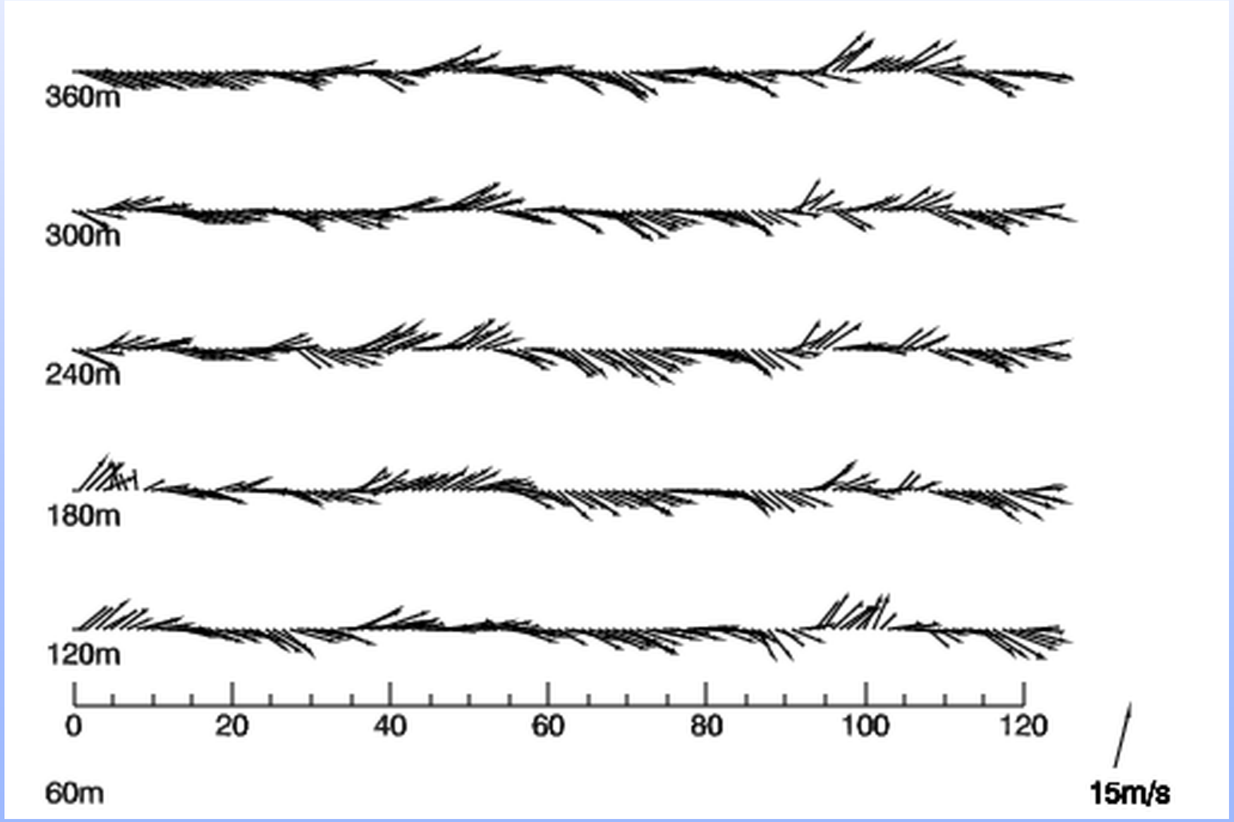
Data Analysis

WTR data base:

- Data from comparable WTR of Forschungszentrum Karlsruhe
- Data from various weather situations in Mai and June 2000
- Transformation of windspeed and direction in downwind (u) and crosswind (v) component referring to runways 07R and 07L

Data Analysis

Example of horizontal windvectors measured by WTR over a timerange of 120min in 5 heightlevels



Data Analysis

Basic assumptions of WTR-data characteristics / Working hypothesis:

- Time series data consists of deterministic trend and stochastic residual
- Atmospheric parameters behave periodically on all scales

Time series analysis methods:

- Split data up into trend and residual
- Analysis of the periodic behavior of the trend
- Autocorrelation functions of residual
  - -> order of AR-process
  - -> stationarity

Results:

- Nonlinear trendmodel is represented by a cosinoidal process function with 5 elements.
- the stochastic residual is represented by an univariat autoregressive process, AR(3)-process (Box and Jenkins)
- stochastic part of the signal is used to determine 95% confidence interval

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Prediction Algorithm, in detail

1. Least squares fitting of the cosinoidal trendmodel to the latest 32 measured values of the timeseries
2. Prediction of the trend by extrapolating the trendmodel into the future (20min ahead)
3. Calculation of the residual of the latest 32 measured values.
4. Iterative Determination of the AR(3)-model and application to the 20min prediction timerange.
5. Combination of the predicted trend and residual
6. Calculation of the 95% confidence interval

cosinoidal process

$$x_n = \sum_{k=0}^{4} a_k X_k(n), \qquad n = 1, \ldots, N$$

$$X_0(n) = a_0$$

$$X_1(n) = a_1 \cos\left(\pi \frac{n}{N}\right)$$

$$X_2(n) = a_2 \cos\left(2\pi \frac{n}{N}\right)$$

$$X_3(n) = a_3 \sin\left(\pi \frac{n}{N}\right)$$

$$X_4(n) = a_4 \sin\left(2\pi \frac{n}{N}\right)$$

$$N = 32$$

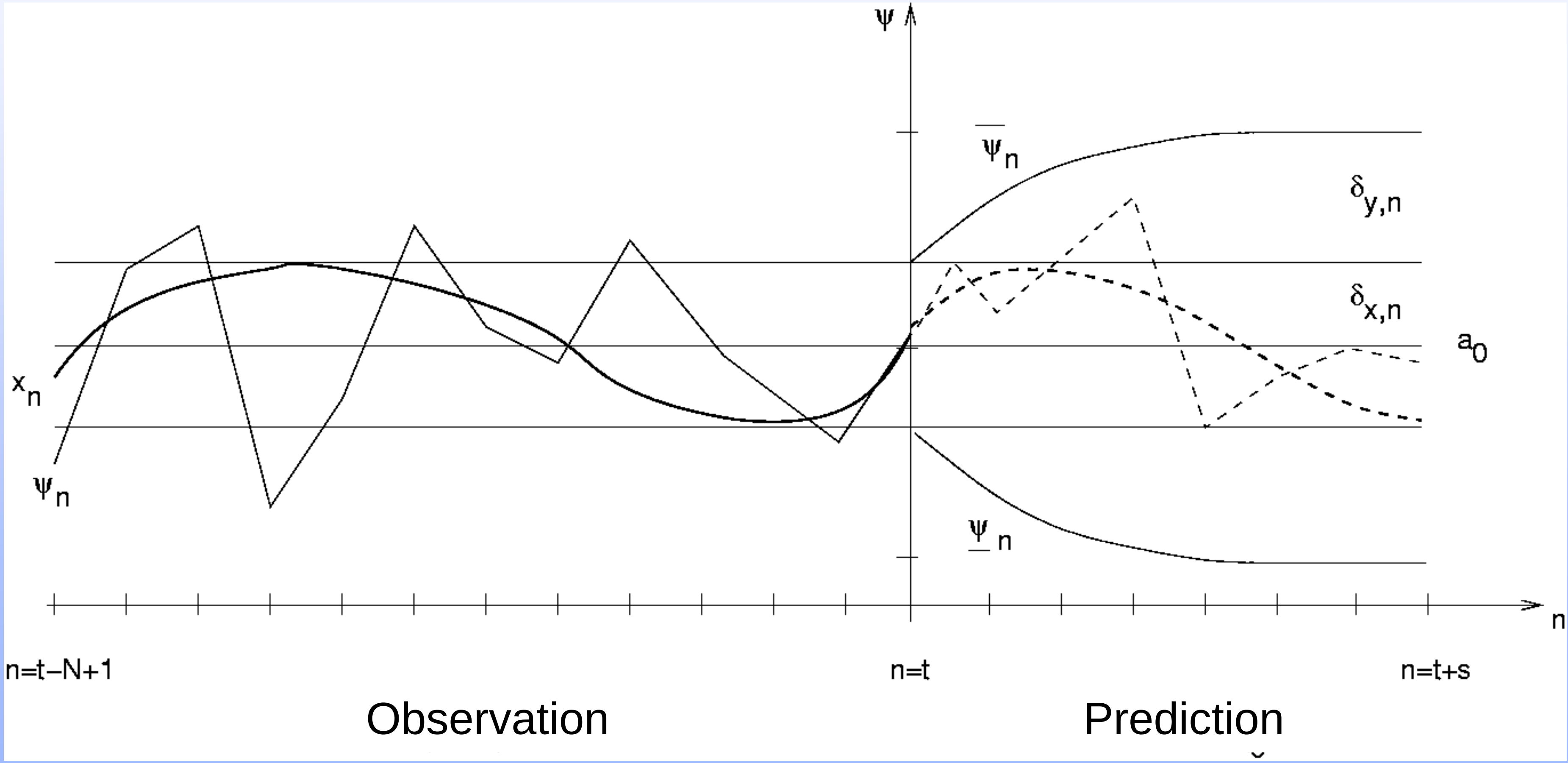
Use least squares fit to estimate a_k

univariate autoregressive process

$$y_n = \sum_{k=1}^{3} \phi_k y_{n-k}$$

Use Yule-Walker equations to estimate ϕ_k

Prediction Algorithm, in detail



confidence interval

$$[\overline{\psi}_{t+s}(s), \underline{\psi}_{t+s}(s)] = \psi_{t+s} \pm \delta_{WTR,t+s}(s)$$

$$\delta_{WTR,t+s}(s) = \delta_{x,t} + \delta_{y,t+s}(s)$$

$\delta_{x,t}$ from the Amplitudes of the harmonic trendmodel

$\delta_{y,t+s}(s)$ from the parameters of the stochastic AR-model

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Algorithm, overwiew

Step 1: Check for missing data,
Plausibility check of the input data

Step 2: Apply prediction algorithm to the windcomponents u,v,w and temperature T at all heightlevels 60 m, 120 m, 180 m, ... , 1500 m

Step 3: Detection of critical weather situations across the actual measurements and the predicted wind and temperature profiles.

Software Implementation

Requirements:
- high data availability
- high system stability, resilience, robustness
- one-to-one implementation of the concept

Methods to meet high quality standards of DFS:
- Component based and object-oriented design
- „programming by contract“
- Unit-tests
- Code-reviews
- C++ - programming-guidelines by DFS

Future Work / Outlook

Adaption of the forecast models to the real time data form the windprofiler at Frankfurt Airport.

Improvement of the fitting method of the harmonic trendmodel to the windprofiler data (Konopka, DFS, 2003)

Long-term validation of the algorithm results (Konopka, DFS, 2004)

The presented work was developed by MeteoSolutions GmbH on behalf of DFS Deutsche Flugsicherung GmbH (DFS) in 2003.

Scientific consultancy by Prof. T. Hauf

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