Annual WWW Technical Progress Report on the GDPS 2001

Country: Germany

Centre: NMC Offenbach

1. Summary of highlights

The modelling suite at DWD consists of the global icosahedral-hexagonal gridpoint model GME (average mesh size ~ 60 km, i.e. 163842 gridpoints/layer, 31 layers) and the nonhydrostatic limited-area "Lokal-Modell" LM (mesh size ~ 7 km, 325 x 325 gridpoints/layer, 35 layers). LM is used operationally at the national meteorological services of Greece, Poland and Switzerland and at the regional meteorological service in Bologna (Italy), too.

The hydrostatic high-resolution regional model HRM of the DWD is being used as operational model at nine national/regional meteorological services, namely Brazil-INMET, Brazil-Navy, China, Israel, Italy, Oman, Romania, Spain and Vietnam. For lateral boundary conditions, GME data are sent via the Internet to the HRM and LM users.

During the year 2001 the main improvements of the NWP suite included:

- *20/03/01: Production of the GME run up to 174h based on a data cut-off of 2h 14min instead of 3h 40min. The previous "early run" of GME up to 78h with a data cut-off of 2h 14min has been stopped.*
- *05/04/01: A prognostic turbulent kinetic energy (TKE) equation and an improved derivation of near surface variables have been introduced in LM.*
- *18/06/01: Aircraft data (AMDAR) are being used in the nudging data assimilation scheme of LM.*
- *29/08/01: A sea state model for the Mediterranean Sea (MSM) with a mesh size of 0.25° x 0.25° driven by 10m winds of GME has been added to the operational suite. MSM provides sea state forecasts up to 174h based on 00 and 12 UTC analyses.*

A new high performance computer at DWD has been installed in the autumn of 2001. The IBM RS/6000 SP consists of 80 nodes with 16 processors each. The processors are equipped with a 375 MHz CPU (Power 3-II). Most of the nodes possess 8 GByte of shared memory, some possess 16 Gbyte. The peak performance of the total 80 node system (1280 processors) is around 2 Teraflop/s. The operational NWP suite will be fully ported to this new computer platform until the first quarter of 2002.

2. Equipment in use

2.1 Main computers

2.1.1 CRAY J932 (Operating system UNICOS)

32 CPUs with 8 GBytes memory, cycle speed 10 ns
Peak performance in one CPU 200 Mflops
4 seperate IO-Clusters
160 GBytes of diskspace
Access to STK ACS

Used for research

2.1.2 CRAY T3E (Operating system UNICOS/mk)

Processor cycle speed is 1.667 ns
776 Processors with 128 Mbytes memory
8 Processors with 1024 Mbytes memory
32 Processors with 512 MBytes memory
1024 GBytes of diskspace

Used for research and for operational forecasts

2.1.3 ORIGIN 2000 (Operating System IRIX)

System of four ORIGIN 2000 servers
70 Processors, cycle speed 4 ns
62 GBytes memory
8627 GBytes of diskspace
Access to STK ACS (3490E, SD3-Drives, 9840-Drives)

The system consists of servers for development, pre- and postprocessing, file distribution, Hierarchical Storage Management and the Oracle Database Implementation at DWD.

2.2 Networks

2.2.1 Ethernet

Connects Workstations, X-Terminals and PC's via router to the CRAYs and the ORIGIN 2000 servers

2.2.2 FDDI

Connects the Telecommunication System and the CRAYs.

2.2.3 HIPPI

The CRAYs and the ORIGIN 2000 servers are connected by HIPPI via a HIPPI-switch.

2.2.4 ATM

Access from the LAN to the ORIGIN 2000 systems is done via routers to the ATM-connected computers.

2.3 Special systems

2.3.1 Satellite data system

Microvax 4000-300 (Operating system VMS)
Used for preparation of satellite pictures (from METEOSAT and NOAA), vertical profiles of temperature and humidity (from NOAA).

2.3.2 Interactive graphical system

A number of SGI work stations and colour plotters are used for presentation of satellite- and radar data as well as model output, surface forecast charts significant weather charts, and other interactive graphics,
The MAP (Meteorological Application and Presentation System) Workstation is used to display and animate all available meteorological data sources.

2.3.3 Telecommunication system

Stratus continuum and X.25-switches
Used for connections to GTS, ECMWF, EUMETSAT, national PTT network.

3. Data and products from GTS in use

At present nearly all observational data from the GTS are used. GRIB data from the France and GRIB data from the UK, the US and the ECMWF are used. In addition most of the MOTNE data are used as well. In addition most of the OPMET data are used.

Typical figures for 24 hours are:

SYNOP, SHIP	53.000 reports,
TEMP, part A	1.100 reports,
METAR	32.000 reports,
PILOT, part A	600 reports,
AIREP, AMDAR	28.000 reports,
SATEM, part A	11.000 reports,
SATOB, section 2	240.000 reports,
SATOB, section 3	6.000 reports,
SATOB, section 4	4.300 reports,
SATOB, section 5	68.000 reports,
SATOB, section 7	20.000 reports,
GRIB	7.500 bulletins,
BUFR	700 bulletins

4. Data input system

Fully automated system. Incoming reports in character orientied code forms are converted into BUFR before storing them into a data base.

5. Quality control system

There is no quality control system in use regarding outgoing data to the GTS except for formal structure.

5.1 Quality control of incoming data

The formats of all coded reports are checked and if necessary and possible corrected. Surface and upper air reports are checked for internal consistency before storing them into a data base.

6. Monitoring of the observing system

Surface observations and upper air observations are monitored quantitatively only on the national level. DWD acts as a lead centre for monitoring the surface observations in Region VI. At present, only the surface pressure observational data are checked.

7. Forecasting systems

7.1 System run schedule and forecast ranges

Preprocessing of GTS-data runs on a quasi-real-time basis about every 6 minutes on the ORIGIN 2000.

Independent 4-dim. data assimilation suites are performed for both models, GME and LM. For the GME, analyses are derived for the analysis times 00, 06, 12 and 18 UTC based on an intermittent optimum interpolation scheme. For the LM, a continuous data assimilation system based on the nudging approach provides analyses at hourly intervals.

The early forecast runs of GME and LM with a data cut-off of 2h 14 min after the main synoptic hours 00, 12 and 18 UTC consist of 48-h forecasts for LM and 78-h forecasts of the GME. They provide early numerical guidance to the Central Forecasting Office. In parallel to the early runs, a local sea state model (LSM, 3rd generation WAM) provides forecasts for North, Baltic and Adriatic Sea areas.

The main forecast runs have a data cut-off of 3 h 30 min after the main synoptic hours 00 and 12 UTC and consist of 174-h forecasts of the GME and a global sea state model (GSM, 3rd generation WAM).

7.2 Medium range forecasting system (4-10 days)

7.2.1 Data assimilation, objective analysis and initialization

As far as GME is in use for medium range forecasting, the same procedures are applied as for short range forecasting described in item 7.3.1.

7.2.2 Model

Medium range forecasts at the DWD are mainly based on the ECMWF system (deterministic model and EPS). Additionally, GME (see 7.3) forecasts up to 7 days augment the model guidance available.

7.2.3 Numerical weather prediction products

ECMWF and GME global forecasts are available up to day 7. The ECOMET catalogue of the DWD global model products is given in annex 1.

7.2.4 Operational techniques for application of NWP products

A statistical interpretation scheme is applied to ECMWF and GME forecasts to provide medium-range forecasts for some German areas up to day 7. The scheme is based on the PPM philosophy. The interpretation results based on ECMWF and GME forecasts are averaged because verification results show that this average scores significantly better than each single model interpretation. Such a simple averaging proves to be a cost effective approach to reduce both the error and the error variance in medium-range forecasts (simplest ensemble prediction). The forecast parameter derived are:

Daily maximum and minimum temperatures, relative sunshine duration, daily precipitation amount and probability, wind speed and direction, probability of thunderstorm, probability of fog.

A new method to produce medium range forecasts in plain language for the public which had been introduced in 1999 was further developed and adapted to user requirements in the years 2000 and 2001. It allows for a centralized medium-range forecast activity. For this purpose a particular software was developed by DWD, which produces texts automatically from a data base. The data base is derived from the scheme described above. Every day in the beginning of the forecast business the meteorologist examines and – where necessary – postprocesses the data base and only then the text gen-

erator will be started. The automatically produced texts contain all significant weather parameters like cloud cover, precipitation, wind and extreme temperatures. In addition to this the automatic text production is in use for worldwide forecasts, which are available by dialling a premium rate number on a fax machine, on a telephone answering device or on mobile telephones using short message system (SMS). The latter ones are produced however without forecasters' intervention.
First steps were made in medium range forecasting concerning a risk assessment of extreme weather for the forecast interval 120 hours down to 24 hours by a very simple and subjective interpretation of EPS results.
Agrometeorological forecasts cover a wide span of applications aiming at a reduction of the use of insecticides and fungicides or at an optimization of the water supply to plants. NWP results are combined with additional models which calculate the drying of leaves or the temperature and water balance in the ground.

7.3 Short-range forecasting system (0-72 hrs)

Operational short-range forecasting is based on the products available from GME and LM, where LM covers the time period up to 48 h only.
The short-range forecasts for Central Europe up to 48 hours are derived from the limited-area "Lokal-Modell" LM. Fig. 1 shows the model domain of LM and Fig. 2 the model levels. The LM is designed as a flexible tool for forecasts on the meso-ß and on the meso-γ scale as well as for various scientific applications down to grid spacings of about 100 m. For operational numerical weather prediction, LM is nested in the GME.

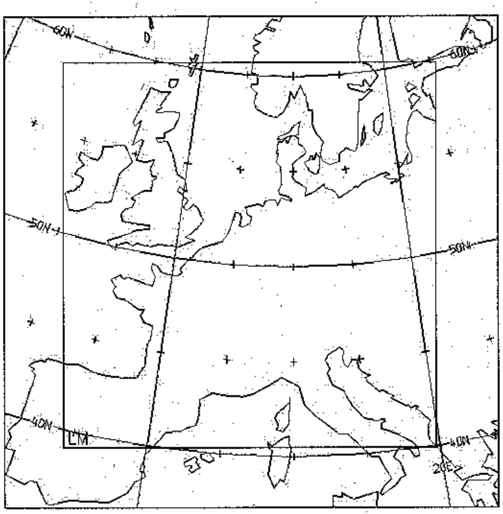

Figure 1 Model domain of the "Lokal-Modell" LM mesh size ~ 7 km, 325 x 325 gridpoints.

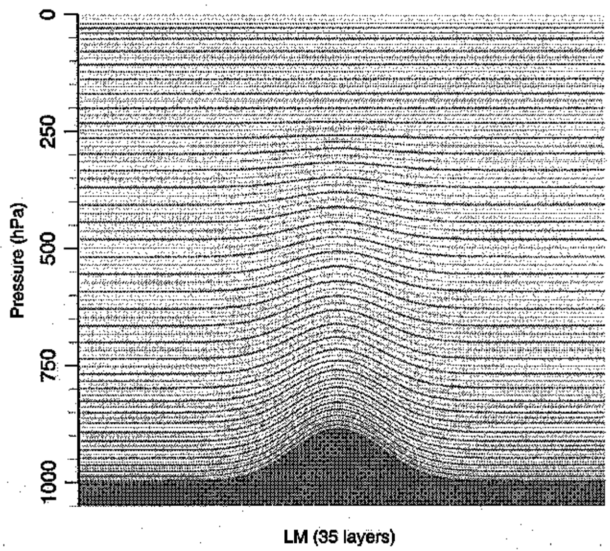

Figure 2 Model layers of LM.

7.3.1 Data assimilation, objective analysis and initialization

Global Model (GME)

a) Global analysis of mass, wind field and humidity

The program for the global analysis of mass and wind field, formerly developed by ECMWF, was ported to MPP systems by DWD with the support of the PALLAS software house.

Analysis method	3-dimensional multivariate optimal interpolation (humidity 2-dimensional). Direct use of thickness data. Box method.
Analysed variables	Φ, u, v, Rel. Hum.
Horizontal anal. grid	icosahedral grid of the GME (average mesh size of 60 km)
Vertical resolution	31 hybrid layers (see GME)
Products	a) On icosahedral-hexagonal grid of the GME (163842 gridpoints/layer, 31 layers) Variables: p_s, T, u, v, q_v, q_c b) On a regular geographical grid, 480 x 361 points (0.75° x 0.5°) 12 pressure levels 1000, 950, 850, 700, 500, ..., 50 hPa Variables: p_{msl}, T, Φ, u, v, Rel. Hum.
Assimilation scheme	Intermittent data assimilation. Insertion of data every 6 hours. 6-h forecast used as first guess. All observations within a ± 1.5-h window used as synoptic. Cut-off time 2 h 14 min.
Initialization	Incremental digital filtering initialization (*Lynch, 1997*) consisting of a 3-h adiabatic backward run and a 3-h diabatic forward run centered at the initial time. The filtering is performed in vertical mode space; only the external mode plus the first nine internal ones are filtered.

b) Global analysis of surface parameters

Analysis method	Correction method
Analysed variables	Sea surface temperature (SST) and snow cover
Horizontal anal. grid	On icosahedral-hexagonal grid of the GME (average mesh size of 60 km)
Data used	SST: Synop-Ship, US-SST analysis as background, US-data of ice border. Snow cover: Snow depth, present and past weather, precipitation amount, temperature analysis. History taken into account. US-data of ice border.

Local Model (LM)

a) Limited-area analysis of atmospheric fields

The data assimilation system for the LM is based on the observation nudging technique (*Schraff, 1997*). The variables nudged are the horizontal wind, temperature, and humidity at all model layers, and pressure at the lowest model level. The lateral spreading of the observational information is horizontal, or optionally along model layers or isentropic surfaces. At present, the scheme uses only conventional data of type TEMP, PILOT, SYNOP, BUOY, AIRCRAFT and AMDAR.

Analysis method	Observation nudging technique
Analysed variables	p, T, u, v, Rel. Hum.
Horizontal anal. grid	325 x 325 points (0.0625° x 0.0625°) on a rotated latitude/longitude grid
Vertical resolution	35 hybrid layers (see LM)
Products	All analysis products are given on the 325 x 325 grid and available at hourly intervals. a) On the 35 LM layers Variables: p, T, u, v, w, q_v, q_c b) On 10 pressure levels (1000, 950, 850, 700, 500, ..., 200 hPa) Variables: p_{msl}, Φ, T, u, v, ω, Rel. Hum. c) On 4 constant height levels (1000, 2000, 3000, 5000 m) Variables: p, T, u, v, w, Rel. Hum.
Assimilation scheme	Continuous data assimilation. Insertion of data in 3-h cycles. Cut-off time 2 h 14 min for LM runs.
Initialization	None

b) Limited-area analysis of soil moisture

Analysis method	2-dimensional (vertical and temporal) variational technique
Analysed variables	soil moisture of 2 soil layers at 00 UTC
Horizontal anal. grid	325 x 325 points (0.0625° x 0.0625°) on a rotated latitude/longitude grid
Data used	2-m temperature analyses at 12 and 15 UTC

c) Limited-area analysis of other surface parameters

Analysis method	Correction methods
Analysed variables	Sea surface temperature (SST) and sea ice cover, snow cover
Horizontal anal. grid	325 x 325 points (0.0625° x 0.0625°) on a rotated latitude/longitude grid
Data used	SST: Synop-Ship, US-data of ice border, sea ice cover analysis from BSH (German Institute for shipping and hydrology) for the Baltic Sea and indirectly satellite data (via NCEP-SST and GME_SST analyses). Snow cover: Snow depth, present and past weather, precipitation amount, 2-m temperature analysis (plus model prediction).

Additionally, the plant cover is derived on a weekly basis by evaluation of satellite data (NDVI index).

7.3.2 Model

7.3.2.1 Schematic summary of the global model GME

Domain	Global
Initial data time	00, 12, 18 UTC
Forecast range	174 h (from 00 and 12 UTC), 48 h (from 18 UTC)
Prognostic variables	p_s, T, u, v, q_v, q_c
Vertical coordinate	hybrid sigma/pressure (*Simmons and Burridge, 1981*), 31 layers
Vertical discretization	Finite-difference, energy and angular-momentum conserving
Horizontal grid	Icosahedral-hexagonal (*Sadourny et al., 1968*), mesh size between 55 and 65 km, average mesh size 60 km; Arakawa-A grid
Horiz. discretization	Finite-difference, second order
Time integration	3-time-level, leapfrog, split semi-implicit scheme, $\Delta t = 4$ min, time filter. For moisture variables (water vapour, cloud water): Positive-definite, shape-preserving horizontal advection (SL-scheme).
Horizontal diffusion	Linear, fourth order
Orography	Grid-scale average based on a 1-km data set
Parameterizations	Surface fluxes based on local roughness length and stability (*Louis, 1979*) Free-atmosphere turbulent fluxes based on a level-two scheme (*Mellor and Yamada, 1974*) Sub-grid scale orographic effects (blocking and gravity wave drag) based

on *Lott and Miller, 1997*

Radiation scheme (two-stream with two solar and five longwave intervals) after *Ritter and Geleyn (1992)*, full cloud-radiation feedback based on predicted clouds

Mass flux convection scheme after *Tiedtke (1989)*

Kessler-type grid-scale precipitation scheme with parameterized cloud microphysics

Two-layer soil model *(Jacobsen and Heise, 1982)* including simple vegetation and snow cover; prescribed climatological values at about 40 cm depth for temperature and at 100 cm depth for soil moisture.

Over water: Fixed SST from SST analysis; roughness length according to Charnock's formula

Analyses and forecasts (up to 78 h) data of GME are sent twice daily (for 00 and 12 UTC) via the Internet to several other national weather services (e. g. Brazil, , China, Greece, Israel, Italy, Oman, Poland, Romania, Spain, Switzerland, Vietnam). These data serve as initial and lateral boundary data for regional modelling. For a detailed description of GME, see *Majewski, 1998* and *Majewski et al., 2002.*

7.2.3.2 Schematic summary of the "Lokal-Modell" LM

Domain	Central Europe
Initial data time	00, 12, 18 UTC
Forecast range	48 h
Prognostic variables	p, T, u, v, w, q_v, q_c, TKE
Vertical coordinate	Generalized terrain-following, 35 layers (see Fig. 2)
Vertical discretization	Finite-difference, second order
Horizontal grid	325 x 325 points (0.0625° x 0.0625°) on a rotated latitude/longitude grid, mesh size 7 km; Arakawa-C grid, see Fig. 1.
Horiz. discretization	Finite-difference, second order
Time integration	Three-time-level, leapfrog, split explicit scheme (*Klemp and Wilhelmson, 1978*) with the extensions proposed by *Skamarock and Klemp* (*1992*), $\Delta t = 40$ s, time filter. Optionally, a two-time-level split-explicit scheme (*Wicker and Skamarock, 1998*) and a 3-d semi-implicit scheme (*Skamarock et al., 1997*) are available.
Horizontal diffusion	Linear, fourth order

Orography	Grid-scale average based on a 1-km data set. Topography has been filtered to remove grid-scale structures
Parameterizations	Surface fluxes based on local roughness length and stability (*Louis, 1979*)
	Free-atmosphere turbulent fluxes based on a level-2.5 scheme with prognostic TKE (*Mellor and Yamada, 1974*)
	Radiation scheme (two-stream with two solar and five longwave intervals) after *Ritter and Geleyn (1992)*, full cloud-radiation feedback based on predicted clouds
	Mass flux convection scheme after *Tiedtke (1989)*
	Kessler-type grid-scale precipitation scheme with parameterized cloud microphysics
	Two-layer soil model *(Jacobsen and Heise, 1982)* including simple vegetation and snow cover; prescribed climatological values at about 40 cm depth for temperature and at 100 cm depth for soil moisture.
	Over water: Fixed SST from SST analysis; roughness length according to Charnock´s formula

7.3.3 Numerical weather prediction products

Short-range forecasts are based on direct model output (DMO) of the LM and on statistically corrected values (simple Kalman filtering). MOS guidance based on GME data is provided, too.
The ECOMET catalogue of the LM is given in annex 2.

7.3.4 Operational techniques for application of NWP products

NWP results are used for a variety of further applications. Some of these applications are briefly described below.
Short range forecasts of weather and temperature in pictorial form are automatically produced for online presentation on the Internet using Kalman filtered forecasts of both GME (worldwide) and LM (national).
The state of road surfaces is predicted by a road weather forecast system (SWIS – Strassenzustand- und Wetter-Informations-System) using Kalman filtered forecasts of the "Lokal-Modell" LM and an energy balance model of the road surface.
The influence of weather on human health is forecasted using a bio-synoptical weather classification scheme and the predicted vorticity, temperature and humidity. The thermal stress on a prototype human being is calculated with an energy balance model which additionally employs forecasted wind and cloudiness.
Agrometeorological forecasts cover a wide span of applications aiming at a reduction of the use of insecticides and fungicides or at an optimization of the water supply to plants. NWP results are combined with additional models which calculate the drying of leaves or the temperature and water balance in the ground.
Significant weather charts which are in use as general guidance for the aeronautical consulting business in the regional forecasting offices and which are issued as products for general aviation cover the middle european area in a layer from surface up to 24 500 ft. As additional information jet-axes and

cat areas are included if within the layer. Icing conditions and turbulence areas are described. The charts are produced interactively on work stations using LM results in combination with conventional synoptic methods.

During the season an advice for gliding pilots is prepared which may be received via facsimile. It presents charts of the lowest cloud base or the height of thermal activity, precipitation, wind direction and wind speed for several times during the day. It is based on LM data.

During the summer months an UV-B index is evaluated using predicted stratospheric temperatures, TOVS data, and a high resolution radiation model.

7.4 Specialized forecasts

7.4.2 Models

7.4.2.1 Trajectory Models

Trajectory model:

Forecast variables	r (λ, φ, p or z, t)
Data supply	u, v, w, p_s from NWP forecasts (or analyses)
Numerical scheme	1st order Euler-Cauchy with iteration (2nd order accuracy)
Interpolation	1st order in time, 2nd (GME) or 3rd (LM) order in space

a) Daily routine (ca. 1500 trajectories)

Trajectories based on LM forecasts:

Domain	Domain of LM (see Fig. 1)
Resolution	0.0625° (as LM)
Initial data time	00, 12 UTC
Trajectory type	Forward trajectories for 36 German, Czech, Swiss, and French nuclear and chemical installations, backward trajectories for scientific investigations
Forecast range	48-h trajectories, optional start/arrival levels

Trajectories based on GME forecasts:

Domain	Global
Resolution	~ 60 km (as GME)
Initial data time	00, 12 UTC
Trajectory type	72-h forward trajectories for ca. 60 European nuclear sites and 8 German regional forecast centers, backward trajectories for 37 German radioactivity measuring sites and 8 forecast centers using consecutive +6h to +18h forecast segments.

	96-h backward trajectories for the GAW mountain stations Zugspitze, Jungfraujoch, Sonnblick and Hohenpeißenberg, and to the German meteorological observatories.
	72-h backward trajectories for 5 African cities in the framework of the METEOSAT-MDD program, disseminated daily via satellite from Bracknell.
	120-h backward trajectories for the German polar stations Neumayer (Spitzbergen) and Koldewey (Antarctica) and the research ships Polarstern and Meteor, disseminated daily.
	168-h forward trajectories for 14 Eastern European nuclear power plants.
	Mainly backward trajectories for various scientific investigations.
Forecast range	168h forward and backward trajectories, optional start/arrival levels

b) Operational emergency trajectory system, trajectory system for scientific investigations:

Models	LM or GME trajectory models
Domain	LM or global
Data supply	u, v, w, p_s from LM or GME forecasts or analyses, from current data base or archives
Trajectory type	Forward and backward trajectories for a choice of offered or freely eligible stations at optional heights and times in the current period of 7 to 14 days.
Forecast range	48-h (LM) or 168-h (GME)
Mode	Interactive menu to be executed by forecasters

7.4.2.2 Sea wave models

Domain	Global	North, Baltic and Adriatic Sea Areas
Numerical scheme	Deep water, 3rd generation WAM	Deep water, 3rd generation WAM
Wind data supply	GME: u, v at 10 m	LM and GME: u, v at 10 m
Grid	geographical (regular lat/lon)	geographical (regular lat/lon)
Resolution	0.75° x 0.75°	0.167° x 0.10°
Initial data time	00 and 12 UTC	00 and 12 UTC
Forecast range	174 h	48 h
Model output	significant wave height, frequency, direction	
Initial state	sea state adapted to analysed wind field over last 12 h	
Verification	Available on request	

7.4.3. Numerical Weather Prediction Products

The forward and backward trajectories are an important tool for emergency response activities. In addition to these forecasts for concentration and deposition of radionuclides are produced using a Lagrangian Particle Dispersion Model.
Based on the Sea wave models charts are produced for swell and significant wave height, frequency and direction .

7.4.4 Operational techniques for applications of NWP results

Forecasts of the optimal (shortest and/or safest) route of ships are evaluated using the results of the global sea wave model and of NWP in the ship routing modelling system of the DWD. The system calculates isochrones taking into account the impact of wave and wind on different types of ships.

A very special application of the NWP result is a hydrological one. A model-system called SNOW-D allows for estimating and forecasting snow-cover development and areal melt water release. The model enables a daily calculation and forecast of grid-point values of the water equivalent of the snow cover and meltingwater release. The snow cover development is computed with the help of physically-based model components which describe accumulation (build-up, increase), metamorphosis (conversion, change) and ablation (decrease, melting).
The model input data are

- 6-hour interval averages of air temperature and vapour pressure
- global radiation/duration of sunshine and precipitation totals of the last 24 h
- three times a week additional data from a part-time network (depth of snow cover, water equivalent of snow cover)
- output data of the „Lokal-Modell"

The model output contains

- current values of the snow cover (reference point 06.00 UTC)
    - snow depth (in cm)
    - water equivalent (in mm)
- specific water equivalent (in mm/cm)

- forecast values of snow cover development (forecast interval maximum 48 hours, forecasting for 6-h-intervals)
    - water equivalent (in mm)
    - precipitation supply, defined as the sum of meltwater release and rain (in mm)

The results are provided grid-oriented and with a blanket coverage for Germany. A summary of the grid values can be made for any area required.

In addition to SNOW-D, a new model-system called SNOW-BW was developed for Baden-Württemberg and will be extended to Rhineland-Palatinate in 2002. This model is similar to SNOW-D but it runs every 6 hours and has a higher temporal resolution (1 hour). Not only DWD measurements but also data from regional networks (UMEG) are integrated in the data sampling procedure. Universal Kriging is used for regionalization of measured values to the computational grid.

The strongly improved physics uses wind speed (which is neglected in SNOW-D) for computation of turbulent transfer of heat and moisture taking into account the atmospheric static stability.
The model output contains the quantities of SNOW-D but in addition forecast values of snow depth, snow temperature, ice content and so on can be derived.

8. Verifications

Tables 1 up to 6 show verification results of GME for the european region (36° - 72° N, 12°W – 42 °E), tables 7 up to 12 for the extratropical northern hemisphere and tables 13 up to 18 for the extratropical southern hemisphere. In all tables forecast times vary from 12 h up to 156 h in intervals of 24 hours. P156.h stands for the RSME-values of persistence and climate for the rsme-values of climate.

8.1 European Region

Table 1 GEOPOTENTIAL 500 hPa RMSE

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
12.h	9	10	9	8	8	7	8	7	8	8	10	10	8.5
36.h	19	21	19	19	17	15	16	14	17	19	23	20	18.1
60.h	30	35	29	31	26	25	26	22	29	30	41	34	29.9
84.h	45	50	43	47	39	36	35	33	41	42	57	52	43.4
108.h	65	71	56	64	56	50	44	45	52	61	76	71	59.3
132.h	86	89	70	81	73	62	54	55	72	81	100	93	76.4
156.h	106	105	81	100	86	72	61	62	90	90	119	109	90.2
p156.h	172	219	125	141	135	102	102	97	120	137	160	203	142.7
climate	137	161	90	108	121	86	84	74	112	117	136	184	117.5

Table 2 GEOPOTENTIAL 500 hPa ANOMALY CORRELATION

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
12.h	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.997
36.h	0.99	0.99	0.98	0.98	0.99	0.98	0.98	0.98	0.98	0.98	0.98	0.99	0.983
60.h	0.97	0.96	0.94	0.95	0.97	0.94	0.94	0.94	0.96	0.95	0.95	0.97	0.954
84.h	0.94	0.92	0.88	0.88	0.94	0.88	0.89	0.86	0.92	0.90	0.90	0.93	0.902
108.h	0.85	0.85	0.80	0.79	0.88	0.76	0.80	0.74	0.86	0.79	0.82	0.87	0.818
132.h	0.75	0.76	0.70	0.68	0.80	0.63	0.70	0.62	0.74	0.62	0.69	0.79	0.707
156.h	0.66	0.65	0.60	0.53	0.72	0.50	0.66	0.55	0.59	0.55	0.60	0.73	0.611

Table 3 PRESSURE MSL RMSE

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
12.h	1.1	1.2	1.0	0.9	0.9	0.8	0.8	0.9	0.9	1.0	1.2	1.1	0.98
36.h	2.2	2.3	2.1	2.0	1.7	1.5	1.7	1.5	1.5	1.9	2.4	2.1	1.91
60.h	3.2	3.6	3.1	3.1	2.5	2.4	2.6	2.4	2.6	2.8	4.1	3.4	2.29
84.h	4.6	4.9	4.6	4.2	3.4	3.2	3.4	3.4	3.6	4.1	5.7	5.2	4.18
108.h	6.3	6.7	5.9	5.4	4.7	4.2	4.0	4.2	4.6	5.8	7.4	6.9	5.52
132.h	8.4	8.5	6.9	6.5	6.1	5.1	4.7	4.9	6.1	7.4	9.3	8.8	6.89
156.h	10.0	9.7	7.7	7.9	7.2	5.6	5.3	5.4	7.4	8.4	10.5	9.9	7.91
p156.h	17.6	16.5	11.0	11.2	9.8	7.0	7.9	6.9	9.9	11.5	13.9	16.1	11.61
climate	12.9	12.4	8.6	7.2	7.3	5.1	5.6	5.3	8.8	8.6	11.9	14.8	9.03

Table 4 PRESSURE MSL ANOMALY CORRELATION

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
12.h	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1.00	0.992
36.h	0.98	0.98	0.97	0.96	0.97	0.96	0.95	0.95	0.98	0.97	0.97	0.98	0.968
60.h	0.96	0.94	0.92	0.90	0.93	0.90	0.89	0.88	0.95	0.93	0.92	0.95	0.922
84.h	0.92	0.88	0.83	0.79	0.88	0.80	0.83	0.77	0.89	0.85	0.85	0.87	0.848
108.h	0.84	0.78	0.73	0.68	0.78	0.66	0.75	0.64	0.82	0.72	0.77	0.77	0.745
132.h	0.72	0.67	0.65	0.53	0.64	0.48	0.63	0.56	0.71	0.55	0.65	0.65	0.621
156.h	0.61	0.57	0.56	0.33	0.49	0.40	0.56	0.53	0.59	0.42	0.57	0.59	0.518

Table 5 TEMPERATURE 850 hPa RMSE

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
12.h	0.9	0.9	0.8	0.8	0.8	0.8	0.9	0.8	0.8	0.9	0.9	0.9	0.86
36.h	1.4	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.3	1.5	1.5	1.5	1.37
60.h	1.8	2.0	1.9	1.8	1.7	1.6	1.7	1.6	1.7	1.9	2.2	2.0	1.84
84.h	2.3	2.5	2.6	2.3	2.2	2.0	2.2	1.9	2.1	2.4	2.9	2.6	2.35
108.h	2.9	3.2	3.2	3.0	2.8	2.5	2.6	2.3	2.5	3.0	3.5	3.3	2.89
132.h	3.5	3.8	3.7	3.6	3.4	3.0	3.0	2.7	2.8	3.6	4.1	4.1	3.46
156.h	4.1	4.4	4.1	4.2	4.0	3.5	3.4	3.1	3.3	4.0	4.5	4.8	3.95
p156.h	6.3	7.1	6.4	5.6	5.8	5.0	4.7	4.7	4.6	5.2	5.7	6.6	5.64
climate	4.4	5.1	4.8	4.7	4.8	4.0	3.8	3.4	3.9	4.6	4.7	6.2	4.53

Table 6 TEMPERATURE 850 hPa ANOMALY CORRELATION

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
12.h	0.97	0.98	0.98	0.98	0.98	0.97	0.97	0.96	0.97	0.97	0.97	0.97	0.973
36.h	0.92	0.94	0.94	0.94	0.96	0.93	0.93	0.91	0.93	0.93	0.93	0.93	0.932
60.h	0.87	0.87	0.90	0.88	0.93	0.89	0.89	0.86	0.88	0.87	0.86	0.89	0.883
84.h	0.81	0.81	0.82	0.81	0.89	0.81	0.82	0.79	0.82	0.80	0.77	0.83	0.815
108.h	0.72	0.71	0.72	0.71	0.81	0.72	0.74	0.70	0.75	0.69	0.67	0.75	0.725
132.h	0.59	0.59	0.63	0.60	0.71	0.60	0.65	0.59	0.68	0.54	0.52	0.63	0.610
156.h	0.47	0.50	0.57	0.49	0.63	0.48	0.56	0.49	0.55	0.45	0.43	0.51	0.511

8.2 Extratropical northern hemisphere

Table 7 GEOPOTENTIAL 500 hPa RMSE

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
12.h	11	11	10	10	9	8	8	8	9	9	10	11	9.5
36.h	22	22	20	20	18	17	16	17	17	19	21	22	19.3
60.h	34	35	32	31	28	27	25	27	27	31	33	34	30.3
84.h	47	49	45	44	39	37	35	37	39	43	46	49	42.5
108.h	61	65	58	58	51	49	44	47	52	56	60	63	55.3
132.h	74	79	71	72	62	60	52	56	66	69	74	77	67.8
156.h	86	91	84	85	74	70	59	64	77	80	88	89	78.9
p156.h	129	146	137	125	106	99	85	91	105	116	127	146	117.7
climate	101	118	102	94	89	78	68	70	88	94	108	130	95.0

Table 8 GEOPOTENTIAL 500 hPa ANOMALY CORRELATION

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
12.h	0.99	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99	1.00	1.00	0.994
36.h	0.97	0.98	0.98	0.98	0.98	0.97	0.97	0.97	0.98	0.97	0.98	0.98	0.976
60.h	0.94	0.95	0.95	0.94	0.94	0.93	0.93	0.92	0.94	0.94	0.95	0.96	0.941
84.h	0.88	0.91	0.90	0.88	0.89	0.87	0.86	0.84	0.89	0.87	0.90	0.92	0.884
108.h	0.80	0.84	0.83	0.80	0.81	0.77	0.78	0.74	0.80	0.79	0.83	0.87	0.804
132.h	0.71	0.76	0.73	0.68	0.72	0.65	0.69	0.62	0.69	0.68	0.75	0.80	0.707
156.h	0.62	0.67	0.63	0.56	0.61	0.53	0.59	0.51	0.58	0.59	0.64	0.74	0.606

Table 9 PRESSURE MSL RMSE

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
12.h	1.5	1.4	1.2	1.2	1.2	1.1	1.1	1.2	1.2	1.2	1.3	1.4	1.25
36.h	2.6	2.6	2.2	2.2	2.0	1.9	1.9	2.0	2.0	2.3	2.4	2.7	2.23
60.h	3.8	3.7	3.3	3.2	2.8	2.7	2.7	2.7	3.0	3.3	3.6	3.8	3.21
84.h	5.0	4.9	4.5	4.3	3.6	3.4	3.4	3.6	3.9	4.4	4.8	5.2	4.26
108.h	6.4	6.4	5.7	5.5	4.6	4.3	4.1	4.4	5.0	5.6	6.1	6.5	5.38
132.h	7.6	7.7	6.8	6.7	5.6	5.2	4.8	5.0	6.0	6.8	7.5	7.7	6.45
156.h	8.6	8.8	7.8	7.6	6.4	5.9	5.4	5.5	7.0	7.6	8.8	8.7	7.35
p156.h	12.8	13.2	13.0	10.2	8.9	7.9	7.0	7.2	9.2	10.6	11.6	12.4	10.34
climate	9.4	10.3	9.6	7.3	6.6	5.7	5.2	5.6	7.1	7.9	9.4	11.1	7.93

Table 10 PRESSURE MSL ANOMALY CORRELATION

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
12.h	0.99	0.99	0.99	0.99	0.98	0.98	0.97	0.98	0.98	0.99	0.99	0.99	0.986
36.h	0.96	0.97	0.97	0.96	0.96	0.94	0.93	0.93	0.95	0.95	0.96	0.97	0.954
60.h	0.91	0.93	0.94	0.91	0.91	0.88	0.86	0.87	0.90	0.90	0.92	0.93	0.905
84.h	0.84	0.87	0.88	0.83	0.84	0.81	0.78	0.77	0.83	0.83	0.86	0.87	0.836
108.h	0.75	0.79	0.81	0.71	0.75	0.69	0.69	0.66	0.74	0.73	0.77	0.80	0.741
132.h	0.64	0.70	0.72	0.57	0.63	0.57	0.58	0.56	0.63	0.61	0.64	0.72	0.631
156.h	0.55	0.61	0.62	0.44	0.51	0.45	0.47	0.47	0.50	0.50	0.51	0.65	0.523

Table 11 TEMPERATURE 850 hPa RMSE

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
12.h	1.0	1.0	0.9	1.0	1.0	1.0	1.0	1.0	0.9	1.0	1.0	1.1	0.98
36.h	1.8	1.7	1.6	1.7	1.6	1.6	1.5	1.6	1.5	1.6	1.7	1.8	1.63
60.h	2.3	2.3	2.2	2.2	2.1	2.1	1.9	2.0	1.9	2.1	2.2	2.3	2.13
84.h	2.8	2.8	2.8	2.8	2.5	2.5	2.3	2.4	2.4	2.6	2.7	2.9	2.63
108.h	3.4	3.5	3.4	3.3	3.0	2.9	2.7	2.7	2.8	3.0	3.2	3.4	3.12
132.h	3.9	4.1	3.9	3.9	3.4	3.3	3.0	3.1	3.2	3.5	3.7	4.0	3.59
156.h	4.4	4.6	4.5	4.3	3.8	3.6	3.3	3.4	3.6	3.9	4.2	4.4	4.01
p156.h	6.0	6.3	6.3	6.2	5.5	4.9	4.4	4.6	5.0	5.4	6.0	6.0	5.55
climate	4.7	5.0	4.8	4.8	4.5	3.7	3.3	3.4	4.0	4.4	4.8	5.2	4.39

Table 12 TEMPERATURE 850 hPa ANOMALY CORRELATION

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
12.h	0.98	0.98	0.98	0.98	0.97	0.96	0.96	0.96	0.97	0.97	0.98	0.98	0.971
36.h	0.93	0.94	0.94	0.93	0.92	0.90	0.89	0.88	0.91	0.92	0.93	0.94	0.920
60.h	0.87	0.89	0.89	0.88	0.87	0.83	0.83	0.81	0.86	0.85	0.89	0.89	0.865
84.h	0.80	0.83	0.82	0.81	0.81	0.76	0.76	0.73	0.79	0.78	0.82	0.84	0.798
108.h	0.73	0.74	0.74	0.73	0.74	0.68	0.69	0.64	0.71	0.71	0.75	0.77	0.719
132.h	0.64	0.65	0.65	0.64	0.67	0.59	0.61	0.56	0.62	0.61	0.67	0.69	0.632
156.h	0.54	0.55	0.55	0.55	0.58	0.50	0.54	0.47	0.54	0.52	0.57	0.61	0.545

8.3 Extratropical southern hemisphere

Table 13 GEOPOTENTIAL 500 hPa RMSE

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
12.h	12	11	13	14	14	15	16	16	15	14	13	13	13.8
36.h	26	25	28	31	32	34	33	34	32	30	29	29	30.2
60.h	40	38	43	46	49	53	49	53	49	45	44	44	46.0
84.h	54	50	58	63	67	71	65	70	64	59	58	56	61.2
108.h	66	64	74	79	83	89	81	85	78	73	71	67	75.7
132.h	78	76	88	92	96	102	96	98	90	82	83	77	88.3
156.h	90	85	100	104	107	116	108	111	102	90	94	86	99.4
p156.h	99	116	131	130	138	143	146	133	131	134	116	118	127.8
climate	77	84	94	97	111	105	119	108	105	100	89	98	98.7

Table 14 GEOPOTENTIAL 500 hPa ANOMALY CORRELATION

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
12.h	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.990
36.h	0.93	0.96	0.95	0.95	0.96	0.95	0.96	0.95	0.95	0.96	0.95	0.95	0.951
60.h	0.85	0.90	0.89	0.87	0.90	0.87	0.91	0.88	0.88	0.90	0.87	0.89	0.884
84.h	0.73	0.82	0.79	0.77	0.81	0.76	0.84	0.78	0.79	0.82	0.78	0.81	0.793
108.h	0.60	0.71	0.66	0.65	0.71	0.64	0.76	0.68	0.69	0.73	0.67	0.72	0.685
132.h	0.45	0.59	0.53	0.53	0.61	0.53	0.66	0.57	0.59	0.65	0.55	0.64	0.575
156.h	0.31	0.49	0.40	0.42	0.52	0.41	0.57	0.47	0.49	0.58	0.43	0.56	0.471

Table 15 PRESSURE MSL RMSE

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
12.h	1.5	1.4	1.6	1.8	1.8	1.9	1.8	2.0	1.8	1.8	1.7	1.7	1.74
36.h	3.0	2.7	3.2	3.6	3.7	3.8	3.6	4.0	3.6	3.3	3.2	3.2	3.41
60.h	4.3	4.0	4.6	5.1	5.3	5.6	5.3	5.6	5.2	4.7	4.4	4.4	4.86
84.h	5.5	5.0	5.8	6.4	6.9	7.3	6.8	7.1	6.6	5.9	5.5	5.4	6.19
108.h	6.5	6.2	7.1	7.7	8.2	8.8	8.4	8.7	7.8	7.1	6.6	6.3	7.45
132.h	7.5	7.3	8.3	8.7	9.4	10.0	9.8	10.1	9.0	7.8	7.6	7.0	8.54
156.h	8.4	8.1	9.3	9.6	10.5	11.3	10.8	11.0	10.1	8.5	8.5	7.7	9.49
p156.h	9.0	9.5	11.6	11.5	13.0	13.2	13.9	12.4	12.1	11.6	10.1	10.2	11.51
climate	6.9	7.2	8.6	8.7	10.7	10.2	11.2	10.2	9.7	8.9	8.1	8.4	9.05

Table 16 PRESSURE MSL ANOMALY CORRELATION

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
12.h	0.97	0.98	0.98	0.98	0.98	0.98	0.99	0.98	0.98	0.98	0.98	0.98	0.980
36.h	0.89	0.93	0.93	0.91	0.93	0.92	0.94	0.92	0.92	0.93	0.91	0.92	0.922
60.h	0.79	0.84	0.84	0.81	0.86	0.84	0.88	0.84	0.84	0.86	0.83	0.86	0.841
84.h	0.67	0.75	0.74	0.69	0.77	0.73	0.80	0.74	0.75	0.77	0.74	0.77	0.744
108.h	0.54	0.63	0.61	0.58	0.67	0.61	0.69	0.62	0.65	0.67	0.63	0.69	0.634
132.h	0.40	0.51	0.50	0.47	0.58	0.50	0.59	0.50	0.55	0.59	0.52	0.61	0.526
156.h	0.26	0.41	0.38	0.38	0.48	0.38	0.50	0.42	0.44	0.52	0.41	0.53	0.426

Table 17 TEMPERATURE 850 hPa RMSE

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
12.h	1.1	1.0	1.1	1.2	1.2	1.2	1.2	1.3	1.2	1.2	1.2	1.1	1.18
36.h	1.9	1.8	1.9	2.1	2.1	2.2	2.2	2.5	2.2	2.2	2.0	2.0	2.10
60.h	2.4	2.3	2.5	2.7	2.7	2.8	2.9	3.2	3.0	2.8	2.6	2.6	2.71
84.h	2.8	2.7	3.0	3.2	3.3	3.4	3.3	3.8	3.5	3.3	3.1	3.0	3.19
108.h	3.2	3.1	3.4	3.5	3.7	3.8	3.7	4.1	3.9	3.6	3.4	3.4	3.57
132.h	3.5	3.4	3.7	3.9	4.0	4.1	4.1	4.5	4.2	3.9	3.7	3.6	3.90
156.h	3.8	3.7	4.0	4.1	4.2	4.4	4.4	4.8	4.5	4.2	3.9	3.9	4.16
p156.h	4.2	4.6	4.8	4.8	4.9	5.0	5.2	5.4	5.2	5.0	4.8	4.5	4.87
climate	3.4	3.8	4.4	4.7	4.7	4.4	4.6	5.1	4.5	4.2	3.8	3.8	4.30

Table 18 TEMPERATURE 850 hPa ANOMALY CORRELATION

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
12.h	0.95	0.96	0.96	0.96	0.97	0.96	0.96	0.96	0.96	0.96	0.95	0.95	0.959
36.h	0.84	0.87	0.88	0.88	0.89	0.87	0.88	0.87	0.88	0.87	0.86	0.86	0.871
60.h	0.73	0.79	0.80	0.81	0.82	0.79	0.80	0.78	0.78	0.79	0.77	0.77	0.786
84.h	0.63	0.71	0.72	0.73	0.74	0.70	0.73	0.70	0.70	0.71	0.68	0.69	0.703
108.h	0.54	0.62	0.64	0.66	0.66	0.62	0.66	0.64	0.63	0.63	0.58	0.61	0.626
132.h	0.45	0.55	0.57	0.59	0.61	0.55	0.59	0.57	0.57	0.56	0.51	0.54	0.555
156.h	0.35	0.48	0.50	0.55	0.56	0.50	0.53	0.51	0.50	0.51	0.44	0.48	0.495

9. Plans for the future

The next major upgrade of the GME system is planned for the first quarter of the year 2003. The mesh size will be reduced from 60 to 30 km, and the number of layers increased from 31 to 35. For LM, the next major upgrade will be introduced in 2004 with a reduction of mesh size from 7 down to 2.8 km, and an increase of the number of layers from 35 to 45. This high a resolution aims mainly at the explicit prediction of deep convection which is a major forecasting problem in Germany during the warm season. The further development of LM is co-ordinated in the Consortium for Small-Scale Modelling (COSMO). Current members of COSMO are the weather services of Germany, Greece, Italy, Poland and Switzerland

Concerning applications of NWP results it is planned to make a more systematic approach to severe weather forecasting by making use of objective methods based on the EPS provided by the ECMWF. For any kind of postprocessed specialized forecasts of the parameters temperature, wind and significant weather MOS will be used instead of Kalman Filtering.

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