WWW Technical Progress Report on the Global Data Processing System 2005

European Centre for Medium-Range Weather Forecasts

1. SUMMARY OF HIGHLIGHTS

- **16 March 2005:** Tropical Cyclone tracks from the deterministic and EPS forecasts are disseminated on the GTS in BUFR format.
- **5 April 2005:** Implementation of Cycle 29r1. This version included a new moist boundary layer scheme (more stratocumulus clouds in subtropical highs and better handling of anticyclonic low level clouds), a wavelet formulation for background error statistics (J_b), a revised use of surface pressure observations (including the use of METAR reports and an adaptative bias correction scheme) and the use of MODIS winds from AQUA (in addition to TERRA).
- **28 June 2005:** Implementation of Cycle 29r2. This included the use of new data (i.e. rain-affected SSM/I radiances, Meteosat-8 (MSG) AMVs and the Baltic sea-ice analysis from SMHI) and also some refinements in the use of existing data. J_b statistics from the new ensemble data assimilation were introduced, as well as convection changes affecting mainly low level winds.
- **Spring 2005**: EPSgrams for WMO users made available for capital cities of WMO members at:

  http://www.ecmwf.int/products/forecasts/d/charts/medium/epsgramswmo/.

Note: All model changes since 1985 are updated and made available from the ECMWF web site at:

http://www.ecmwf.int/products/data/operational_system/evolution/index.html.

In addition, there has been continuous progress towards operational dissemination of the monthly forecasts and of the multi-model seasonal forecasts. Work is also continuing towards the final validation and implementation of the Variable Resolution EPS (VAREPS) and System 3 for seasonal forecasting.

ECMWF has expanded its participation in THORPEX by taking a leading role in the development of the TIGGE archive. Several observation system experiments (OSEs) have been concluded and others have been initiated. The effort towards assessing the value of targeted observations has increased.

The EU funded project GEMS started on 1 March 2005. Thanks to previous work on the assimilation of ozone and CO_2, ECMWF should be able to progress quickly towards the first deliverables of this important project. The implementation of prognostic aerosols in the Integrated Forecasting System (IFS) is also progressing fast. Other new EU-projects include ENSEMBLES, MERSEA, PREVIEW and AMMA.

2. EQUIPMENT IN USE

The computer equipment in use at the end of 2005 is summarised in Table 1.

Table 1: Computer equipment in use for operational activities (end of 2005)

Machine	Processors	Memory (GB)	Storage (TB)	Tape Drives
2 IBM P690+ Clusters	2x2240 (1.9GHz Power4+)	2x2912	2x25	
4 HPrx4640	4x4	4x8	3	
11 IBM p-series	52	100	100	100

3. DATA AND PRODUCTS FROM GTS AND OTHER SOURCES

A summary of data received through the GTS and other sources and processed at ECMWF is given in Table 2. Data coverage maps for most of these data are available from:

http://www.ecmwf.int/products/forecasts/d/charts/monitoring//

.

4. DATA INPUT SYSTEM

Fully automated.

5. QUALITY CONTROL SYSTEM

The observational data used in the operational analysis undergo a quality control in near real-time, after having been decoded. Each observation is subject to a number of tests:

- The parameter values are compared with gross limits for the parameter. Limits depend on latitude and, for surface parameters, on the season of the year.
- Redundancy of information between the parameter values allows some internal consistency checks to be performed.
- Temporal consistency checks on observations from the same source are done for the position of moving platforms.

Table 2: Number of GTS products processed (January 2005, mean daily counts)

Datatype	Mean		Datatype	Mean		Datatype	Mean
SYNOP	62029		AMV-GOES10	210805		HIRS-NOAA17	548570
SHIP	6553		AMV-GOES12	209111		AMSUA-NOAA15	322190
METAR	44055		AMV-MET5	165956		AMSUA-NOAA16	294979
DRIBU	30562		AMV-MET7	163319		AMSUA-NOAA18	264458
MOORED	846		AMV-MET8	715452		AMSUA-AQUA	253231
AIREP	22974		AMV-TERRA	20281		SSMI-F13	24149
AMDAR	80057		AMV-AQUA	18821		SSMI-F14	22607
ACARS	94246		GRAD-MET5	284029		SSMI-F15	24413

Datatype	Mean		Datatype	Mean		Datatype	Mean
TEMP-LAND	1223		GRAD-MET7	304181		SCAT	195035
TEMP-ASAP	18		GRAD-MET8	573435		SCAT-ERS	113843
PILOT	807		GRAD-GOES9	0		OZONE-ERS	5264
DROPSONDE	2		GRAD-GOES10	295000		OZONE-NOAA14	409
PROFILER-USA	765		GRAD-GOES12	327449		OZONE-NOAA16	1299
PROFILER-EU	912		HIRS-NOAA14	190307		OZONE-NOAA17	1155
PROFILER-JAP	741		HIRS-NOAA15	23954		OZONE-MIPAS	0
AMV-GOES9	74747		HIRS-NOAA16	611558		AIRS	242755

The tests have, in general, been extracted from WMO (1982). Further tests are made during the data assimilation itself by comparison with the most recent model forecast (first guess).

6. MONITORING OF THE OBSERVING SYSTEM

The operational monitoring of all data types continues to provide the basis for decisions on the operational use of the data. The quality of observations is monitored in non real-time, based on statistics of the departures between the data and the operational 3–15 hour forecasts and analyses. All data types used in the data assimilation system are monitored in that way.

Results are published in a monthly Global Data Monitoring Report. This is available from the ECMWF web site together with other data monitoring informations by going to:

http://www.ecmwf.int/products/forecasts/monitoring/mmr/

Paper copies can be provided on request. Feedback is also provided directly to data producers.

ECMWF has continued to fulfil its rôle as lead centre for radiosonde and pilot data monitoring as requested by WMO. This includes co-ordination and liaison with other lead centres, and setting up the list of reference stations used for the exchange of verification scores for NWP products.

7. FORECASTING SYSTEM – DECEMBER 2005

7.1 System run schedule

The ECMWF Early Delivery Forecasting System comprises two 6-hour 4D-Var analyses, centred at 00 and 12 UTC, from which the main deterministic and EPS forecast are initialised. In addition there is a continuous 12-hour 4D-Var analysis (DCDA) cycle (observations from 09–21 UTC and 21–09 UTC) that runs with a delayed cut-off time to alow the maximum possible number of observations to be used. Short forecasts from the DCDA analyses are used as the background fields for the operational 00 and 12 UTC 6-hour assimilation. A schematic of the schedule for the 00 UTC operational forecasts is shown in Figure 1.

7.2 Medium range forecast system

Both the Data Assimilation, the Forecast, the Ensemble Prediction System and the Monthly Forecast System use the Integrated Forecast System (IFS) Cycle 29r2 (since 28 June 2005).

7.2.1 Data assimilation, objective analysis and initialisation

(a) Analysis

- ***Mass, humidity and wind***: Four-dimensional variational multi-variate analysis on 60 model levels; increment minimisation run at resolution T_L159L60.
- ***Surface parameters***: Sea surface temperature from NCEP Washington analysis, sea ice from SSM/I satellite data, soil water content, snow depth, and screen level temperature and humidity.

(b) Data used

- ***Global satellite data***: SATOB/AMV, (A)TOVS, AIRS, Quikscat, SSM/I, SBUV, GOME, Meteosat and GOES WV radiances and wind products and MODIS wind products.
- ***Global free-atmosphere data***: AIREP, AMDAR, TEMP, PILOT, TEMP/DROP, and Profilers from networks in the USA, Europe and Japan.
- ***Oceanic data***: SYNOP/SHIP, PILOT/SHIP, TEMP/SHIP and DRIBU.
- ***Land data*****:** SYNOP and METAR.

Data checking and validation is applied to each parameter used. Thinning procedures are applied when observations are redundant at the model scale.

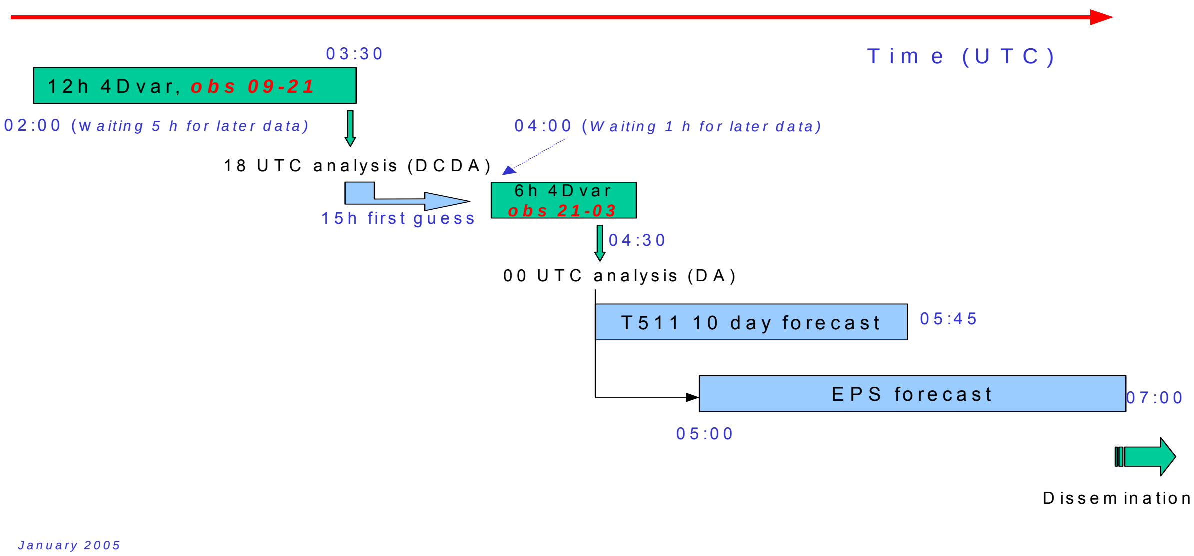


Figure 1: Schematic of ECMWF schedule for the 00 UTC analysis and forecast (an equivalent schedule is run for 12 UTC). Times in blue indicate the start and finish times of the different components.

(c) 4D-Var

Performance of higher-resolution 4D-Var. The performance of the higher-resolution 4D-Var with analysis increments at T255 (i.e. T255 inner-loops) has been assessed. It has been found that T255 analysis resolution has a beneficial impact on forecast skill (compared to the T159 resolution currently in operations), and that more information (measured in terms of degrees of freedom of the signal) is extracted from the assimilated observations.

Convergence properties of the inner/outer iterative solution algorithm. The convergence properties of the inner/outer iterative solution algorithm have been studied because higher-resolution analysis and increased non-linearity could make additional outer iterations a priority in the coming years. Reasons for current outer-loop divergence have been identified and resolved. Some benefit has been found from introducing a third outer-loop iteration with a reduced number of inner iterations in the first and second minimisations.

Wavelet J_b. A wavelet-based formulation of the background-error co-variances (Fisher, 2004) was implemented operationally in Cycle 29r1. The wavelet approach provides a better description of the regional variation of errors and their structures, making the assimilation scheme more locally adaptable. Statistics of background error calculated from ensembles of analyses exhibit clear differences in boundary-layer structure and tropopause height as represented in the vertical correlation matrices.

Analysis ensembles. New ensembles of analyses have been run to generate wavelet J_b statistics of background error for the new 91-level and the operational 60-level configurations of the IFS. The latter were incorporated into the operational analysis system in Cycle 29r2. Analysis ensembles require random perturbations to be added to every observation. The perturbations are required to have the statistical characteristics of observation error. Whereas previous ensembles applied spatially uncorrelated perturbations to all observations types, the most recent ensembles applied spatially correlated perturbations to AMV (feature tracking) wind observations – a data type for which good estimates of the spatial correlation of observation error are available.

Model error. A weak-constraint formulation of 4D-Var has been developed for the IFS (Trémolet, 2003). It cannot be implemented without simplifications in the representation of model error and its covariance statistics Q. The approach taken is to consider model error to be constant within time intervals. The two extreme cases are: (a) having only one interval, keeping model error constant for the whole assimilation window, and (b) having an interval as short as a model time-step. The latter is in principle the fully weak-constraint 4D-Var.

Model error covariance specification. The model error covariance matrix Q has to be estimated. The background error covariance matrix B is estimated from an ensemble of 4D-Var assimilations. Considering the ensemble of forecasts run from the analyses produced by the 4D-Var ensemble, at a given step, the model state of each member should represent the probability distribution for one true atmospheric state. In the same view, the model tendencies derived from each of these state should represent a distribution of possible evolutions of the atmosphere from that same state. The differences between these tendencies can be interpreted as possible uncertainties in the model, or realisations of model error. It has been assumed that Q can be estimated using the same statistical model used for B, but calibrated by data from an ensemble of model tendencies instead of short-range forecasts. This is the first attempt at modelling the model error covariance (distinct from B).

(d) Humidity, ozone, aerosols and soil moisture

Spin-down in tropical precipitation. The humidity analysis operational since October 2003 has been improved by implementing an analysis adjustment of humidity that reduces the short-term spin-down of tropical precipitation. The adjustment prevents the further increase in relative humidity when the analyzed CAPE and the background relative humidity reach predefined thresholds. As well as reducing precipitation spin-down, this change leads to improved upper tropospheric humidity and winds in the tropics.

Ozone assimilation. New GOME ozone profile retrievals provided by RAL have been assimilated in tests with the ERA system. These data appear to be of very good quality and will be used for the interim reanalysis and GEMS assimilations. Both GOME and MLS add accurate vertical information on ozone in the UT/LS region.

Aerosol assimilation. Aerosol assimilation is developed as part of the GEMS project. A pathway for the aerosol observations through the assimilation scheme and associated diagnostic software has been created using the Observational Data Base. A study of short-range forecast error has begun with a view to building a first statistical model of background error suitable for use in the J_b-term of 4D-Var.

Soil moisture analysis. The current soil moisture analysis is an Optimal Interpolation (OI) method based on the modelled first guess and analysis increments of screen-level parameters. The operational OI system successfully prevents drifts in soil moisture and improves the accuracy of modelled two-metre temperature and relative humidity. However, applications like flood forecasting, crop-growth modelling or environmental monitoring require a more accurate soil moisture analysis. To make use of future satellite data that are directly related to surface soil moisture a new surface analysis approach based on the extended Kalman filter has been developed within the ELDAS project (Seuffert et al., 2004). Experiments have revealed differences in the dynamical range and a strong negative bias in the satellite product as judged against independent model and observational data. Cumulative distribution functions have been used to reduce systematic differences in the two data sets (Drusch et al., 2005). It was found that the corrected satellite data set is in good agreement with the observations. The new method is expected to be implemented into operations in 2007.

(e) Observation usage and sensitivity

Surface pressure bias correction. A large number of METAR, land and sea SYNOP stations and DRIBU buoys are biased, by several hPa in many cases. The biases are mostly related to incorrect assumptions about the station altitude, and remain fairly constant in time. A bias correction method has been developed based on two assumptions: the observational surface pressure bias is local for a given station (no spatial correlation) and there is no, or small, model bias. This method was implemented within the operational data assimilation system with the introduction of Cycle 29r1. The scheme successfully identifies biased stations, estimates the magnitude of the bias and applies the estimated bias as a correction to the observation. Globally, about 600–800 stations are identified as sufficiently biased to require correction. Most of these stations have been on the ECMWF blacklist. Since the operational implementation about 100–150 stations have been taken off the blacklist and are now being assimilated. A significant number of the biased stations that previously were repeatedly rejected by the analysis quality control are now successfully being used by the analysis.

Impact of data on the operational system. The impact of data on the operational system is evaluated through Observing System Experiments. Recent studies include:

- General studies about the impact of the main components of the Global Observing System on the ECMWF forecast skill (Kelly et al., 2004).
- Impact of high-frequency AMDAR (aircraft data) data collection for EUCOS (the European Composite Observing System), a programme under EUMETNET (Andersson et al., 2005).
- Evaluation of an analysis of the THORPEX ATrEC campaign using targeted observations in the North Atlantic, autumn 2003 (Cardinali and Buizza, 2005).

Contribution of various terrestrial observing systems. ECMWF is participating in a EUCOS study of Observing System Experiments (OSEs) to investigate the relative contributions made by various terrestrial observing systems in global and regional NWP. ECMWF's OSEs will document the global aspects and will also provide lateral boundary conditions for the NWP centres studying regional aspects. The counterpart of this study, assessing the relative contribution of the various space observing systems, will be performed in collaboration with EUMETSAT.

Impact of observations over the Pacific and Atlantic. A series of Observing System Experiments has been performed to assess the impact of observations over the Pacific and Atlantic on forecast performance. In addition, the value of singular vectors for dynamically depicting critical observational areas is also being documented within these studies. Early results suggest that the value of observations located in areas identified by singular vectors is higher than that of observations chosen randomly, but that for the current Global Observing System, the impact of localised observations is quite small. These results need, however, to be consolidated. A potential outcome of this study could be the design of a dynamical thinning of satellite data based on selected sensitive meteorological areas.

Quality control. Tests have been performed with a reformulation of variational quality control, based on the so-called Huber norm, with emphasis on the Atlantic hurricanes in August 2004. The aim has been to retain more of the valuable observations in such extreme weather events. In one case, some improvement in hurricane position and intensity were observed when Huber-norm VarQC was applied to targeted dropsonde data. Extension of this approach to all observation types will be examined.

(f) Satellite data

Assimilation of cloud and rain-affected satellite observations. Following extensive development and experimentation over the last five years, an operational version of the 1D+4D-Var assimilation of rain-affected passive microwave radiometer observations was implemented operationally in Cycle 29r2. In contrast to all other observations, the observation operator is evaluated at the nearest model grid-point immediately after the activation of the model physics for each model time step. These developments also pave the way for a potential direct 4D-Var assimilation of radiances in cloudy and precipitating areas.

Advanced sounders. Intermittent testing of the impact of AIRS continues to confirm that the radiances have a positive impact upon forecast quality (McNally et al., 2005). A new package of changes (i.e. better data selection, emissivity model, retuned observation errors and biases, and additional information from visible image data for diagnostic use) has been implemented in Cycle 29r2. This represents another incremental step towards a more solid scientific use of the currently assimilated radiances.

Meteosat Second Generation - Radiances. Operational assimilation of Meteosat-8 SEVIRI channels WV6.2 and WV7.3 began in September 2004. This followed assimilation trials showing statistically significant impact in the northern hemisphere as well as improved fits to AMSU-B and HIRS water vapour sensitive radiance data in the Meteosat-8 observed area (Szyndel at al., 2005). Following successful assimilation of a wider range of SEVIRI channels at Météo-France into a regional model, research is in progress into the impact of assimilating the IR8.7, IR10.8, IR12.0 and IR13.4 channels over the sea.

Meteosat Second Generation - Atmospheric Motion Vectors (AMVs). Since the beginning of the operational monitoring of AMVs from Meteosat-8, several changes to the products have taken place at EUMETSAT and good stability of the wind quality has been observed since January 2005. The assimilation of Meteosat-8 AMVs (as a replacement of Meteosat-7 AMVs) became operational in June 2005. The outcome of the assimilation trials resulted in a large increase in the number of observations assimilated despite a tighter quality control applied to the winds. Forecast scores exhibited an overall neutral impact of Meteosat-8 AMVs as compared to Meteosat-7 AMVs.

Assimilation of MODIS polar winds. The external processing of MODIS polar AMVs has been noticeably improved (in particular in terms of ancillary data used for the height assignment) and transferred to NESDIS for operational production. Monitoring of the new products has clearly shown a better agreement with the model and the weight given to these observations has been modified accordingly. The assimilation of MODIS winds has been extended to include data from the AQUA as well as the TERRA satellite, as each of them provides data of similar quality.

Assimilation of ozone. Unfortunately, there have been problems with the MIPAS and GOMOS instruments, and only SCIAMACHY currently provides ozone retrievals. The quality of SCIAMACHY total column ozone retrieved by ESA has improved during the last year. After a period with large positive bias relative to ECMWF analyses (around 20 DU in the global mean between mid-October and mid-December 2004), the bias has been reduced to values around -10 DU since early January 2005. Active assimilation of total column ozone retrievals from SCIAMACHY produced by KNMI was introduced in September 2004 (Cycle 28r3). Currently, SCIAMACHY ozone columns and ozone layers from SBUV/2 on NOAA-16 are actively assimilated in the operational suite.

Bias correction. An effort to harmonise the way bias correction was applied to AIRS and AMSU-A (the two main satellite instruments driving the analysis) led to the implementation of the so-called "γ/δ"-method (Watts and McNally, 2004); the same was done for the AMSU-A instrument. This new approach reduced (at least partially) spurious vertical temperature oscillations in the stratosphere over winter poles. As for the estimation of the bias coefficients themselves, an adaptive variational bias correction method has been introduced in research mode.

(g) Scientific developments for the assimilation of data

Estimation of CO_2 from advanced sounders. One year of CO_2 estimation from AIRS has been completed as part of the EU COCO project, which has come to a successful conclusion (Engelen et al., 2004, Engelen and McNally, 2005). These estimates are being used extensively by the CO_2 modelling/inversion community to better understand surface fluxes of CO_2. Considerable confidence in the AIRS column estimates is obtained from the good agreement with in situ observations provided by JAL flight data. CO_2 is currently being incorporated as a full variable in the IFS as part of the GEMS project.

Spectral compression of data from advanced IR sounders. Investigation of techniques for spectral compression of data from advanced IR sounders continues. Initial experiments assimilating radiances reconstructed from truncated principal components showed little impact (other than the expected de-noising of the observation minus background departures). However, recent simulations have demonstrated the importance of correctly specifying the inter-channel correlation of errors in the reconstructed data. Based on this the possibility of specifying a full (or at least block-diagonal) covariance for radiance error within 4D-Var is being investigated. Efforts to estimate the values of correlations are under way. Initial experiments with a rather crude description of the full matrix already appear promising.

Radiative transfer developments. The more advanced aspects of the RTIASI radiative transfer model are being incorporated in the operationally used RTTOV model. This will allow convergence to a single fast RT model in advance of the METOP launch. The improved features (i.e. better layer integration and regression model, more vertical levels and a treatment of solar radiation, clouds and aerosols) provide a better reproduction of the underlying line-by-line calculations and will be validated against real AIRS radiance data in the near future.

Direct assimilation of MIPAS limb radiances. As part of the EU-funded project ASSET, infrared limb radiances from MIPAS can now be assimilated directly in the ECMWF analysis system in a research mode. For this, the RTMIPAS fast radiative transfer model (Bormann et al., 2005) has been implemented in the IFS, together with the tangent linear and adjoint of the model. The first implementation uses a one-dimensional observation operator that assumes local horizontal homogeneity for the radiative transfer calculations. Work has started on extending this to a two-dimensional operator that takes into account the horizontal structure of the limb-viewing plane.

Direct assimilation of GPS radio occultation bending angles. The first set of research experiments assimilating GPS radio occultation (RO) observations from the CHAMP satellite, with a one-dimensional bending angle operator, has been completed. The results demonstrated that assimilating the RO reduced the “stratospheric-ringing” over Antarctica and reduced the model temperature bias at 100 hPa in the tropics. The RO measurements improved the forecast fit to lower stratospheric radiosonde temperatures in the southern hemisphere and tropics, over the day-1 to day-5 forecast range (see Healy and Thépaut, 2005).

7.2.2 Model

(a) Specification

- ***Smallest half-wavelength resolved***: 40 km (triangular spectral truncation 511).
- ***Vertical grid***: 60 hybrid levels (top pressure: 10 Pa).
- ***Time-step***: 15 minutes.
- ***Numerical scheme***: Semi-Lagrangian, semi- implicit time-stepping formulation.
- ***Number of grid points in model***: 20,911,680 upper-air, 1,394,112 in land surface and sub-surface layers. The grid for computation of physical processes is a reduced, linear Gaussian grid, on which single- level parameters are available. The grid spacing is close to 40 km.
- ***Variables at each grid point (recalculated at each time-step)***: Wind, temperature, humidity, cloud fraction and water/ ice content, ozone content (also pressure at surface grid-points).
- ***Physics***: Orography (terrain height and sub-grid-scale), drainage, precipitation, temperature, ground humidity, snow-fall, snow-cover and snow melt, radiation (incoming short-wave and out-going long-wave), friction (at surface and in free atmosphere), sub-grid-scale orographic drag – gravity waves and blocking; ozone simplified chemistry effects, evaporation, sensible and latent heat flux, oceanic waves.

(b) Radiation and aerosols

Ice optical properties. Various parametrizations have been tested in isolation or with other modifications to the cloud scheme formulation to try to alleviate the cold temperature bias around the tropical tropopause. The main result is that a revised formulation of the ice particle size as a function of both local ice water content and temperature and the introduction of more recent ice cloud optical properties decrease this bias and give an overall better response of the IFS model at T_L95 and T_L159. However, this improvement does not translate into better objective scores of geopotential and temperature at the operational resolution, as the level of activity in the model is slightly increased relative to the L91 standard configuration. This means that the overall impact of these revised optical properties is at best neutral, if not slightly negative.

Ozone. A full interaction between prognostic ozone and radiation results in an increased cold bias above the tropical tropopause. Experimentation has been carried out to test the impact on the model results of various radiative configurations (related to cloud optical properties, shortwave radiation schemes) and different sets of coefficients for the prognostic ozone model. No definitive solution has been found yet for the increased cold temperature bias. However, this study has led to the development of a linear radiation model allowing an accurate representation of the ozone-radiation interactions to be obtained very cheaply for diagnostic purposes.

Prognostic aerosols. For the GEMS project new routines have been developed for the representation of aerosol processes. Routines for simplified sources, sedimentation, and dry and wet deposition for a three-bin representation for both sea salt and desert dust have been implemented. Work has started on developing the tangent-linear and adjoint versions of these routines. Preliminary testing with the IFS including these prognostic aerosols is ongoing.

(c) Boundary layer

Operational implementation of moist boundary layer scheme. The combined moist mass-flux/K-diffusion PBL parametrization aimed at improving boundary layer cloudiness was implemented in the operational IFS in April 2005. The new scheme, which paves the way for a unification of the PBL and shallow convection schemes, has the following ingredients: (i) moist conserved variables, (ii) a combined mass-flux/K-diffusion solver, (iii) treatment of cloud variability and (iv) a regime switch to control the transition between stratocumulus and shallow convection with typically large and small cloud cover respectively.

Stable boundary layer. There is overwhelming evidence exists that the stable boundary layers in the IFS (and many other operational models) are too diffusive, too thick, have too little wind turning and have low-level jets that are too weak. However, recent experimentation has shown again that introduction of a less diffusive stable boundary layer can lead to a deterioration of the large-scale scores. This negative impact is related to an increase of model activity and is believed to be associated with a reduction in surface drag. Further diagnostic work is underway to clarify the role of surface drag through Ekman damping.

(d) Clouds and convection

Representation of cloud microphysics. The operational cloud scheme currently employs a single prognostic cloud water variable, which is diagnostically separated into ice or liquid according to temperature. Work is being undertaken to implement a flexible framework for representing cloud microphysics, with a flexible number of bulk prognostic categories such as rain, snow, small and large ice particles, and liquid water.

Snow autoconversion. Since the sedimentation process no longer acts as proxy for the creation of snow, a separate representation of this process was implemented, based on Lin et al. (1983). The original Kessler pseudo-linear form was replaced by a Sundqvist exponential form to retain consistency with the warm phase autoconversion process. This is a subtle but important issue, since the smoothness of the physics should be as similar as possible to the simplified physics used in the data simulation system (Tompkins and Janisková, 2004).

Convection. Preparations have been made for the implementation of a 91-level version of the convection parametrization. These include a fully implicit solver for convective momentum and passive tracers, code optimisations and the introduction of many bug fixes. These modifications have been gradually introduced in model Cycles 28r4, 29r2 and 29r3. The implicit formulation for momentum is presently not yet activated as it slightly degrades the forecast scores and needs further diagnosis.

(e) Orography

Sub-grid orography scheme. An evaluation of the performance of the operational Lott and Miller sub-grid orography scheme by Brown (2004) showed that during winter, parametrized orographic torques were somewhat excessive between 20°N and 50°N. This was particularly apparent at lower resolutions. However, it also produced a significant velocity deficit downstream of the Himalayas in T511 deterministic forecasts. This deficit was also apparent by direct comparison against radio-sondes; this showed that after day-one the mean slowing in T511 zonal wind speed downstream of the Himalayas was as large as 5 ms^{-1} and occurred predominately at upper levels. This suggested that the gravity wave parametrization was too active. To alleviate this problem, tests were conducted using an effective or cut-off mountain height (rather than the full height of the sub-grid scale orography) to calculate the parametrized gravity waves. This resulted in T511 gravity wave stress over orography being reduced by around a third.

(f) Land surface processes

ELDAS. A comparison has been made between 15-month integrations over 36 European points, with and without data assimilation, with forcing by the ELDAS analysis of precipitation based on rain gauges. Results were compared with the behaviour of the same points in ERA40; soil moisture analysis increments in the ELDAS system were smaller than those of ERA40. Nevertheless, despite running with observed-based precipitation forcing, the ELDAS increments are still non-zero, suggesting systematic model deficiencies. The model is unable to sustain evaporation in late spring and summer, leading to positive soil increments. While the causes for the model underestimation of evaporation are unclear, the systematic positive water increments dampen the seasonal cycle of soil moisture.

GEOLAND. The EU-funded GEOLAND project started at ECMWF in June 2004 (and will finish in December 2006). The overall goals at ECMWF are:

- To incorporate and test in TESSEL the ISBA-Ags carbon-based description of transpiration (which will be called C-TESSEL), coupling the carbon and water cycle at the surface.
- To couple the scheme with an evolution equation for above-ground biomass, with parametrized gain and loss terms.
- To prepare a data assimilation of remote-sensing estimates of Leaf Area Index, in order to constrain the model biomass.

In order to guarantee a smooth transition to C-TESSEL, it was decided to adopt a new land cover description, ECOCLIMAP, developed by Météo-France. The revised land cover corrects the current model's overestimation of forest cover in Europe and leads to a geographically narrower distribution of the boreal forests, especially in Siberia. In addition, there is an overall reduction of minimum canopy resistance values. The impact is to produce larger evaporation in spring and summer and this leads to a marked increase of cloud cover over land. It is worth noting that despite increased late spring/early summer evaporation, there is no evidence of late summer drying in the revised simulation. There are additional impacts in spring, confined to the boreal forests areas, because the change from high to low vegetation in some areas impacts the albedo in snowy conditions. Given these rather large impacts, off-line testing of this upgraded model has started.

(g) Linear and adjoint physics

Evaluation of the new simplified moist physics in 4D-Var. 4D-Var experiments have been performed using the new simplified cloud and convection schemes. In order to avoid spurious noise in 4D-Var integrations with the fast-evolving moist processes, these parametrizations can only be used if the trajectory is stored at each time step instead of every second time step as currently in operations. Assimilation experiments run for summer and winter periods show a rather systematic decrease in the total cost function of up to 5 %. The observation and the background terms of the cost function have both been reduced indicating that the trajectory gets closer to both the observations and the model. The fit of analyses to the observations is also improved and generally more observations are used. However, the impact in terms of objective scores is only marginally positive for the summer case and neutral for the winter case. The tropical cyclone tracking for the summer case indicates that when using the new parametrizations of moist processes in 4D-Var, tropical cyclones become deeper (i.e. closer to the observations), although their trajectories are not significantly modified.

(h) Horizontal discretisation

Developments in the semi-Lagrangian scheme. In order to investigate the influence of more accurate interpolations in the semi-Lagrangian procedure, a quintic (instead of cubic) interpolation in the horizontal has been coded. Preliminary results show a slight improvement in the shape of the KE spectrum tail but slightly worse scores than the control. This research into the influence of higher order interpolations will continue. Also a scheme which does not require interpolations in the vertical is being coded. In a non-interpolating semi-Lagrangian scheme the advection is split in two parts: the advection by a velocity which would carry the air parcel from the grid point closest to the departure point of the trajectory to the arrival point, and a “residual advection” by a velocity which would carry the air parcel from the departure point to its nearest grid-point. The semi-Lagrangian procedure is applied only between the arrival points of the trajectories and the grid-point closest to the departure point of the real trajectories while the residual advection is treated in the Eulerian way as part of the right-hand-side of the equation.

Double Fourier series representation. Some preliminary tests have been made with the double Fourier series representation using the basis functions proposed by Cheong (2000). The number of points per latitude row used in the reduced Gaussian grid has been found unsuitable for the fitting of an analytical function using a double Fourier series. The fitting produces an alteration in the field with a regular pattern and large amplitude. For a reduced grid in which the number of points varies with the cosine of the latitude, this fitting error is much reduced.

(i) Other numerical aspects

A non-hydrostatic version of the IFS. A working version of the non-hydrostatic global model has been included very recently by Météo-France in Cycle 30 of the IFS/ARPEGE. Testing this (finite-difference) version at ECMWF is being planned. Exchanges of information with Météo-France are ongoing concerning the feasibility of incorporating the vertical finite-element scheme into the non-hydrostatic version of the model.

7.2.3 Numerical weather prediction products

Dissemination to Member States and Co-operating States. ECMWF forecast products are disseminated to Member States and Co-operating States using a scheduled dissemination system. A flexible interface provides appointed contacts in Member States with a wide range of numerical products to be disseminated in GRIB or BUFR. The total amount of data disseminated through the RMDCN (wide area network) at the end of 2005 was about 20 Gbytes per day.

Dissemination via other means. Numerical products are disseminated via the Global Telecommunications System (50 to 64,000 bits per second) operated under WMO/WWW. The horizontal resolution is 2.5x2.5 degrees (dissemination in code GRIB). These products are also made available to WMO NMHSs in graphical format via the ECMWF web site. Additionally, dissemination through EUMETSAT MDD is arranged via METEOSAT towards Africa. Special dissemination agreements have also been agreed with NCEP, JRC, EUMETSAT and ESA.

Archiving. All numerical products generated by the operational and research suites are archived in the Meteorological Archive and Retrieval System (MARS). At the end of 2005, the total amount of data archived into MARS exceeded 2100 Tbytes. Around 1200 Gbytes are retrieved daily by MARS users.

7.2.4 Operational techniques for application of NWP products

No activity in this area.

7.2.5 Ensemble Prediction System

Operational system. An Ensemble Prediction System is run twice per day (00 and 12UTC). 50 members (+ one control forecast) are run for 10 days at resolution T_L255L40 with a 45 minutes time step. Initial perturbations are generated by multi-dimensional Gaussian sampling from 50 singular vectors (SV) selected at T42 resolution in the extratropics, plus up to 30 SV (5 per Tropical Cyclone) selected in the vicinity of Tropical Cyclones that have been reported on the GTS. Random perturbations of the physical tendencies (stochastic physics) are applied to the perturbed forecasts. Products are disseminated using the same dissemination as for the deterministic model. A selection is available to WMO NMHSs in graphical format via the ECMWF website at:

http://www.ecmwf.int/products/forecasts/d/charts

Note that a login password has to be requested from cdk@ecmwf.int.

Variable resolution EPS. The Variable Resolution EPS (VAREPS) has been tested using a resolution of T_L399L40 in the first leg of the forecast and a reduced horizontal resolution of T_L255L40 in the second leg. It is planned to implement VAREPS in 2006 with reduced resolution starting at day 10.

Varying the number of extra-tropical singular vectors. The impact on the EPS of varying the number of extra-tropical singular vectors (SVs) used to construct the initial perturbations has been examined. Five ensemble configurations using 8, 16, 25, 50 and 100 extra-tropical SVs were considered (T_L255L40 resolution, Cycle 28r3; scaling of initial perturbation amplitude with RNORM=1.6). The spread is quite similar in all five configurations because the width of the sampled Gaussian distribution decreases with increasing number of SVs (for constant RNORM). Results based on 27 cases suggest that ensemble scores saturate around 50 extra-tropical SVs.

Revised configuration of the Gaussian sampling. A revised configuration of the Gaussian sampling was developed, which differs from the Gaussian sampling operational since September 2004 in four aspects: (i) 50 instead of 25 extra-tropical SVs, (ii) normalised evolved SVs, (iii) a new algorithm to scale the initial perturbation amplitude and (iv) plus-minus symmetric initial perturbations of pairs of members. Testing has confirmed the moderate but consistently positive impact on the EPS of the revised Gaussian sampling which had been implemented in Cycle 29r2 (April 2005).

Model tendency perturbations. The impact of adding a new scheme to perturb model tendencies based on a Cellular Automaton Stochastic Backscattering Scheme (CASBS) has been tested at various resolutions (T_L159–T_L799) and for a range of parameters controlling the spatial and temporal scales as well as the amplitude of the backscatter forcing. The scheme introduces more variability at the near-gridscale, which seems to have a positive impact on the kinetic energy spectrum. CASBS can increase ensemble spread in the late medium-range more than operational stochastic physics. Further tests to determine the optimal ratio of initial to tendency perturbation amplitudes are required. Another scheme to perturb tendencies based on Cellular Automata is under development. It attempts a better representation of the Madden-Julian oscillation by adding a non-local stochastic forcing in the tropics associated with subgrid-scale fluctuations of convective processes that are not represented by current convective schemes.

Impact of a simple bias-correction scheme on the quality of the EPS. In order to assess the potential benefits of a simple bias-correction scheme on the quality of the EPS, a limited set of re-forecasts for the period 1980–2001 has been produced. Not unexpectedly, the potential to reduce the bias varies with lead-time, variable, and season considered. For example, it seems that shorter lead times and 2m temperature benefit more from bias correction schemes than longer lead times and mean sea level pressure forecasts.

7.3 Short Range Forecasting System

No such system is run at ECMWF.

7.4 Specialized forecasts (on sea waves, sea ice, Tropical cyclones, pollution transport and dispersion, solar ultraviolet (UV) radiation)

Operational system. No specialized forecast system is run at ECMWF – but a sea wave model is integrated (two-ways coupling) within the IFS. A new version of the wave model featuring a revised parametrization of wave dissipation was implemented operationally with Cycle 29r1. It resulted in a marked improvement in wave parameters that are sensitive to the detailed description of the high frequency part of the wave spectrum.

Verification of analysis and forecast. The wave model performance during 2004–2005 has been monitored extensively. Forecast validation against buoy data and against the verifying analyses show that the quality of the wave forecast continues to be very high. The comparison of performance with other operational centres continues and shows a clear lead of the ECMWF wave model.

Assessment of modelled wind speed and wave height variability. Comparison of modelled wind speed and wave height variability with observed measures of variability from the altimeter wind and wave products and QuikScat wind products suggests that for scales smaller than 500 km the model values are underestimates. This explains a systematic underestimation in modelled wind speed of about 25 cm/s, a bias which is consistent with comparisons with buoy winds.

Collocation study using winds from QuikScat winds, buoys and the ECMWF model. A triple collocation study using QuikScat winds, buoy data and ECMWF model winds shows that, on average, QuikScat winds are unbiased with respect to buoy winds for the year 2004. However, strong QuikScat winds are higher than their buoy counterparts. In the extra-tropics ECMWF first-guess and analyzed winds are 25 cm/s weaker than buoy winds, but are more in line for strong winds. Comparison with TAO array buoy winds in the tropics suggests that the analyzed wind is too low by at least 50 cm/s.

Wind inversion algorithm for scatterometry. Work on an improved wind inversion algorithm for scatterometry was finished. Since there are physical arguments for the radar backscatter being dependent on surface stress and the sea state, a next step for improvement is to develop an inversion algorithm along these lines. First experiments using the assimilation of neutral winds have been performed.

Altimeter wind retrieval algorithm. Work was carried out to improve the altimeter wind retrieval algorithm in order to obtain smoother wind speed distributions and to get better agreement with buoy measurements, in particular for low wind speed. The enhanced algorithm was applied to ENVISAT observed radar backscatter and the resulting winds are in closer agreement with buoy and model winds, with the standard deviation of error reduced by 5–10%. Surprisingly, this result also holds for Jason altimeter winds. In this case, a rather sophisticated retrieval algorithm was developed which follows from a neural network approach and includes certain aspects of the sea state impact.

Extreme events. Three years ago, a theory for the prediction of extreme events, such as freak waves, was developed at ECMWF. These extreme events result in large deviations of the normal probability distribution of surface elevation as expressed by the kurtosis. According to theory the kurtosis depends on the cube of the wave spectrum, and it is therefore straightforward to make probabilistic statements on the occurrence of freak waves in the open ocean. The probability theory for nonlinear waves has been extended to include effects of skewness and kurtosis. For narrow-band waves a surprisingly simple result for the probability distribution function of significant wave height and maximum significant wave height was obtained. This approach validates well against laboratory observations and observations at sea.

Realistic estimates of energy and momentum fluxes. Work is in progress to provide the ocean circulation model with more realistic estimates of energy and momentum fluxes using the dissipation source function of the ocean wave model, and to include the Stokes drift in the Coriolis force exerted on the ocean. Experiments have been carried out using the seasonal forecast coupled model, and also using the POM model as implemented by the Norwegian Meteorological Office for the local region of the North Sea and Norwegian Sea. First results look promising but further experimentation is required.

Specialised products. The following specialized products are available.

- Sea wave products include spectra, significant height and periods. A “Benjamin-Feir Index” (BFI) is also derived (freak waves) – see Janssen, 2003.
- Tropical cyclone products are derived from the deterministic and EPS forecast by tracking tropical cyclones reported on the GTS forward in time using wind, pressure, vorticity and temperature forecasts (van der Grijn et al., 2005). These products are available in graphical format to WMO NMHSs via the ECMWF website at http://www.ecmwf.int/products/forecasts/d/tccurrent (login password to be requested from cdk@ecmwf.int) and via the GTS (in BUFR).
- UVB radiation and ozone content are model products archived in MARS.

7.4.1 Data assimilation, objective analysis and initialization (where applicable)

Tropical Cyclone observations reported on the GTS using BUFR or CREX format are used as seeds for the tracking and generation of Tropical Cyclone forecast products.

7.5 Extended range forecasts (10 days to 30 days) (Models, Methodology and Products)

Operational system. ECMWF has run a monthly forecast system in operational mode since October 2004. The model used is a T_L159L40 version of the IFS coupled to a 29 level ocean model similar to the one used for seasonal forecasts. The model is run once a week (Thursday) for 30 days in ensemble mode (51 members using perturbations computed using the same method as for the EPS). Hindcasts are updated each week for the same week over the last 12 years (5 members only) for calibration purposes. More details on the monthly forecast system can be found in Vitart (2004).

Skill in predicting the Madden-Julian-Oscillation. In order to assess the skill of the monthly forecasting system to predict the evolution of the Madden-Julian-Oscillation (MJO), a five-member ensemble monthly forecast has been performed every day from 15 December 1992 to 31 January 1993. An analysis of the results based on combined EOFs of velocity potential at 200 hPa, OLR and zonal wind at 850 hPa suggest that the model has some skill in predicting the evolution of the MJO up to 3 weeks in advance, but the intensity of the MJO drops by about 40% after only a few days of integration.

Impact of ocean-atmosphere interactions on the prediction of the MJO. In order to evaluate the impact of ocean-atmosphere interactions on the prediction of the MJO, an experiment has been carried out using different model configurations.

- Atmospheric model forced by persisted SSTs (like in the EPS).
- Atmospheric model forced by observed SSTs.
- Atmospheric model coupled to an ocean mixed-layer model.

Results suggest that the coupled model performs better than the atmospheric model forced by persisted SSTs, but the skill is not as good as when the atmospheric model is forced by observed SSTs. The atmospheric model coupled with an ocean mixed-layer model performs significantly better than when coupled to the ocean GCM, particularly over the Indian Ocean and the western Pacific. However, this is no longer the case when the mixed-layer model has a coarser vertical resolution, comparable to the ocean GCM vertical resolution (10-metre vertical resolution instead of 1-metre in the top layers). All those experiments display the same weakening of the MJO intensity after just a few days of integrations. This lack of variance seems to be more sensitive to the atmospheric parametrization than to the ocean-atmosphere interaction.

7.6 Long-range forecasts (30 days up to two years) (Models, Methodology and Products)

Seasonal forecasts are produced monthly ECMWF using a TL95L40 version of the IFS (Cycle 23r4) and a 29 level version of the Hamburg Ocean Primitive Equation (HOPE) model developed at the Max Planck Institute. The coupling between the two component is operated by the OASIS (Ocean, Atmosphere, Sea-Ice, Soil) interface from the Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique (CERFACS). The forecasts are run monthly for the next 6 months in ensemble mode (40 members). More details can be found at http://www.ecmwf.int/products/forecasts/seasonal/documentation/.

Since December 2004, Sea Surface Temperature (SST) forecasts from this system have been made available on the GTS using the Grib2 format.

8. VERIFICATION OF PROGNOSTIC PRODUCTS

WMO/CBS standard scores. Average of the monthly WMO/CBS standard scores for 2005 are summarised in Table 3 and Table 4; the evolution of scores over the last 8 years is also shown in graphical format in
Figure 2.

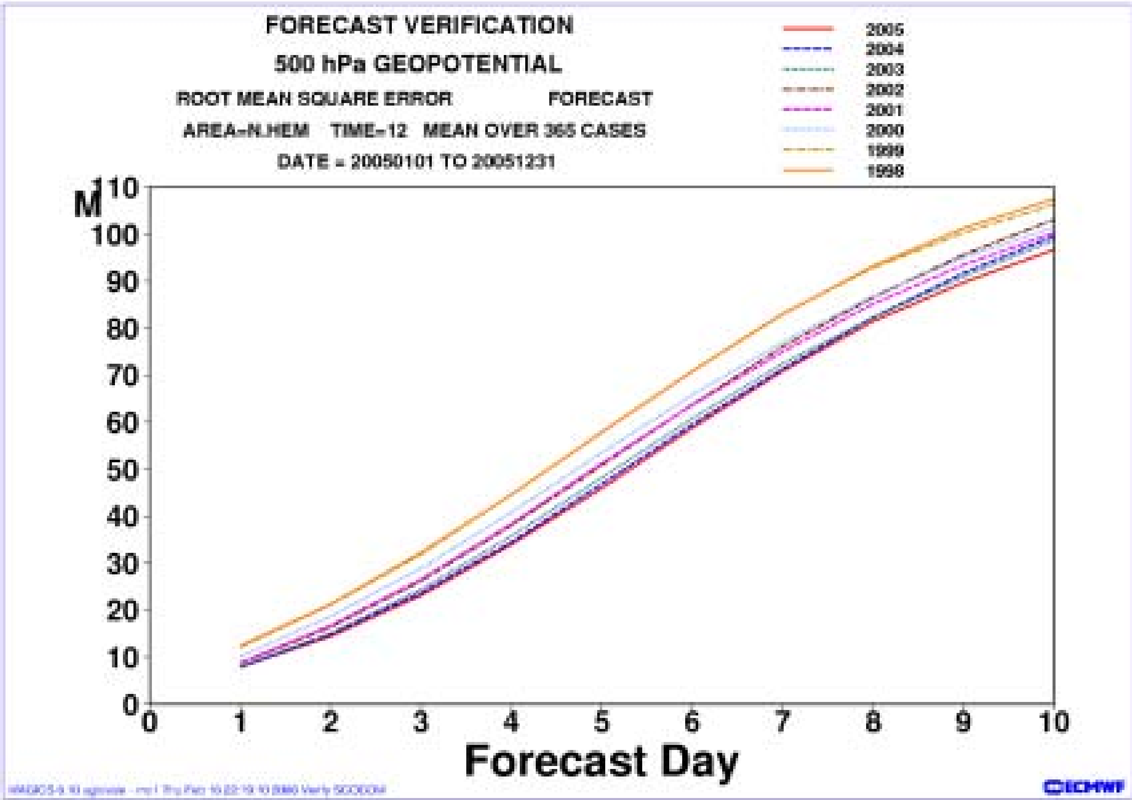
Other verifications. Following recent recommendations from CBS, a preliminary set of annual verifications statistics for the Ensemble Prediction System is given in Table 5. More data (reliability tables for 850 temperature anomalies 4 or 8 degrees above/below normal) are sent monthly to the Japanese Meteorological Agency (JMA) acting as the Lead Centre for verification of EPS forecasts. Three-monthly statistics are published on ECMWF's web site at http://www.ecmwf.int/products/forecasts/d/charts (login password to be requested from cdk@ecmwf.int. Verification statistics for the seasonal forecasts are produced routinely and displayed on ECMWF web site following standards agreed by WMO/CBS (go to the same address as given above).

Table 3: Annual scores against analyses

		24 hr		72hr		120hr	
North. Hemisphere	500-hPa height RMS (m)	**7.8**	*7.9*	**23.1**	*23.7*	**46.0**	*46.8*
	Wind RMSVE 250 hPa (ms^{-1})	**4.0**	*4.0*	**8.6**	*8.6*	**13.7**	*13.7*
South. Hemisphere	500-hPa height RMS (m)	**9.3**	*8.9*	**28.8**	*28.0*	**55.9**	*55.0*
	Wind RMSVE 250 hPa (ms-1)	**3.9**	*3.8*	**9.1**	*8.8*	**14.8**	*14.4*
Tropics	Wind RMSVE 850 hPa (ms^{-1})	**1.9**	*1.9*	**2.9**	*2.9*	**3.5**	*3.6*
	Wind RMSVE 250 hPa (ms^{-1})	**3.7**	*3.6*	**6.3**	*6.3*	**8.0**	*7.9*

Table 4: Annual scores against radiosondes measurements

VERIFICATION AGAINST RADIOSONDES in **2005** *(2004)*							
		24 hr		72hr		120hr	
		2005	2004	2005	2004	2005	2004
Asia	500-hPa height RMS (m)	**13.1**	*13.2*	**23.0**	*23.3*	**39.1**	*39.6*
	Wind 850 hPa (ms^{-1})	**3.9**	*4.0*	**5.2**	*5.3*	**6.7**	*6.9*
	Wind 250 hPa (ms^{-1})	**5.7**	*5.7*	**9.1**	*8.9*	**15.6**	*12.8*
Australia/NZ	500-hPa height RMS (m)	**10.6**	*9.9*	**20.4**	*17.6*	**38.7**	*33.5*
	Wind 850 hPa (ms^{-1})	**3.9**	*3.9*	**5.0**	*4.8*	**6.5**	*6.4*
	Wind 250 hPa (ms^{-1})	**6.0**	*5.6*	**8.7**	*8*	**12.9**	*11.7*
Europe	500-hPa height RMS (m)	**10.3**	*11.0*	**24.0**	*24.8*	**51.3**	*51.1*
	Wind 850 hPa (ms^{-1})	**3.8**	*3.8*	**4.9**	*5.1*	**6.9**	*7.2*
	Wind 250 hPa (ms^{-1})	**5.2**	*5.2*	**9.1**	*9.4*	**15.6**	*15.5*
North America	500-hPa height RMS (m)	**10.7**	*10.5*	**24.5**	*24.7*	**46.9**	*46.1*
	Wind 850 hPa (ms^{-1})	**4.0**	*4.0*	**5.5**	*5.5*	**7.6**	*7.5*
	Wind 250 hPa (ms^{-1})	**5.9**	*5.9*	**10.0**	*9.9*	**15.2**	*15.0*
North Hemisphere	500-hPa height RMS (m)	**12.0**	*12.1*	**25.8**	*26.3*	**50.5**	*50.5*
	Wind 850 hPa (ms^{-1})	**4.0**	*4.0*	**5.3**	*5.4*	**7.3**	*7.5*
	Wind 250 hPa (ms^{-1})	**5.5**	*5.5*	**9.4**	*9.4*	**14.8**	*14.6*
South Hemisphere	500-hPa height RMS (m)	**12.6**	*11.7*	**24.7**	*23*	**47.2**	*43.1*
	Wind 850 hPa (ms-1)	**4.2**	*4.2*	**5.4**	*5.3*	**7.3**	*7.1*
	Wind 250 hPa (ms^{-1})	**0.6**	*5.8*	**9.3**	*8.8*	**14.3**	*13.3*
Tropics	Wind 850 hPa (ms^{-1})	**3.8**	*3.8*	**4.3**	*4.3*	**4.7**	*4.8*
	Wind 250 hPa (ms^{-1})	**5.2**	*5.3*	**7.0**	*7.1*	**8.5**	*8.4*



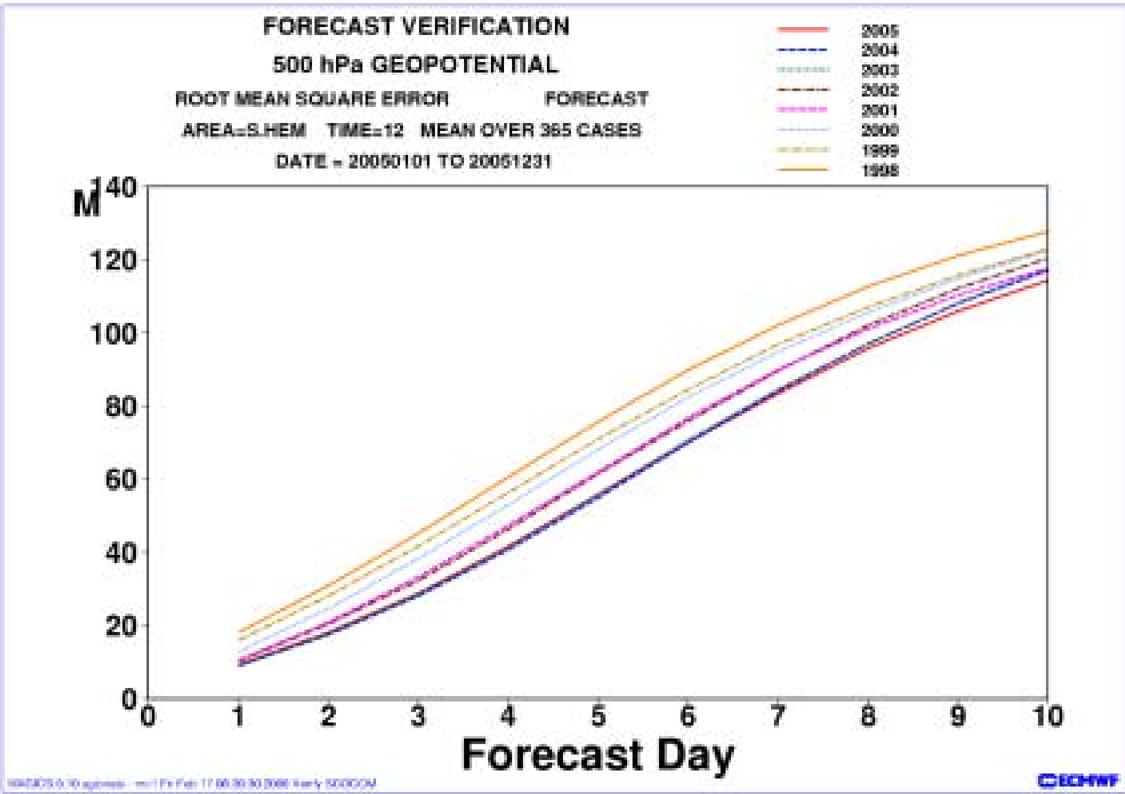


Figure 2: RMSE of 500 hPa geopotential over the nothern hemisphere (upper) and southern hemisphere (lower) extratropics over the last eight years.

Table 5: Annual scores against analyses (Ensemble Prediction System)

EPS VERIFICATION AGAINST ANALYSES in **2005** (*2004*)			72h		120hr		192hr	
			2005	2004	2005	2004	2005	2004
North Hemisphere	500-hPa height	Ensemble Mean RMSE (m)	**24.5**	*25.4*	**44.6**	*45.6*	**68.6**	*69.8*
		Ratio Spread vs EM RMSE (%)	**90.9**	*97.1*	**80.1**	*85.8*	**77.4**	*81.1*
	850-hPa Temperature	Ensemble Mean RMSE (K)	**1.63**	*1.63*	**2.35**	*2.36*	**3.23**	*3.25*
		Ratio Spread vs EM RMSE (%)	**77.3**	*84.0*	**78.7**	*84.7*	**80.8**	*84.6*
South Hemisphere	500-hPa height	Ensemble Mean RMSE (m)	**30.2**	*30.1*	**53.0**	*52.9*	**79.5**	*79.9*
		Ratio Spread vs EM RMSE (%)	**90.2**	*101.4*	**81.9**	*90.8*	**80.8**	*86.3*
	850-hPa Temperature	Ensemble Mean RMSE (K)	**1.63**	*1.60*	**2.31**	*2.30*	**3.06**	*3.06*
		Ratio Spread vs EM RMSE (%)	**82.8**	*93.1*	**84.0**	*92.2*	**86.3**	*91.8*

9. PLANS FOR THE FUTURE

9.1 Development of the GDPFS

Operational targets: 1. Cycle 30r1 (1 February 2006)

- Implement a new, high-resolution forecast system (deterministic forecast: 25 km; EPS: 50 km; data assimilation: 80 km)

Operational targets: 2. Cycle 30r2 and VAREPS (spring 2006)

- Revise the cloud scheme (ice sedimentation)
- Introduce an implicit treatment of convective momentum transport
- Introduce a variational satellite bias correction
- Thin AMDAR data in low levels
- Implement VAREPS (forecasts extended from D10 to D15 at lower resolution)
- Monitor AMSR-E, TMI, FY-2C
- Start of L91 Interim Reanalysis
- Start production of Seasonal Forecast System 3 (including real-time ocean data assimilation)

9.2 Research activities in NWP

Data assimilation

- Develop the Ensemble Data Assimilation
- Investigate weak-constraint, long-window 4D-var
- Introduce the total water control variable
- Establish observation error correlations
- Prepare observation sensitivity diagnostics
- Continue to rationalize IFS for sustained usage
- Use 3rd inner loop and revised trajectory interpolation and data usage in 4D-Var
- Use Huber norm for variational QC

Satellite data

- Improve the use of AMSU-A over land
- Assimilate FY-2C and COSMIC data
- Direct 4D-Var for assimilation of rain-affected radiances

- Improve characterization of observation error correlations for real and reconstructed AIRS radiances
- Introduce vertical interpolation between IFS and RTTOV
- Carry out Observing System Experiments
- Monitor/assimilate CHAMP, MET-9, MTSAT, SSMIS
- Introduce RTTOV-9 (includes RTIASI developments)
- Assimilate MET-9, AMSR-E, TMI
- Monitor METOP ATOVS
- Monitor/assimilate IASI and other METOP instruments
- Introduce MODIS albedo fields

Numerical aspects

- Develop a fully non-interpolating semi-Lagrangian advection
- Compare fast Legendre transform and double Fourier series options
- Develop physics on different grid to that for dynamics
- Evaluate a non-hydrostatic version of the IFS
- Provide support for sustained PRISM, GEMS-GRG and PrepIFS

Physical aspects

- Extend new PBL scheme to include shallow convection
- Introduce new soil hydrology and runoff, and use of ECOCLIMAP and C-TESSEL
- Improve entrainment parametrization for convection
- Develop CRM model suite with IFS boundary conditions for diagnostic purposes
- Investigate interaction of orography and convection
- Use AMMA observations (western Africa) for diagnostics
- Introduce turbulent orographic drag scheme and adjustments to subgrid scale orographic drag
- Implement new short-wave radiation code (RRTM-SW)
- Assimilate variational soil moisture
- Use high-resolution SST fields from NCEP

EPS and Diagnostics

- Develop methodology to generate the EPS initial perturbations from ensemble data assimilation
- Re-evaluate the use of moist and Hessian singular vectors
- Develop the new stochastic physics
- Develop methodology for calibration of EPS forecasts and combined use of EPS and deterministic forecasts
- Develop applications of EPS in hydrology and health sectors (external contracts)
- Support TIGGE and start using TIGGE data for research
- Develop an interactive diagnostics suite
- Develop a capability for relaxation experiments

Monthly and seasonal forecasts

- Document system 3

- Develop system 4 (OPA and OPA-VAR)
- Further develop the multi-model seasonal forecasting system
- Collaborate on mixed-layer modelling and MJO skill
- Enter production phase for ENSEMBLE and MERSEA projects
- Provide better products from multi-model seasonal forecasting system (EUROSIP)

Reanalysis

- Monitor the production of the interim reanalysis

Ocean waves

- Change ocean wave model and assimilation (i.e. introduce new advection scheme and assimilate scatterometer winds as neutral winds)
- Introduce interaction between ocean currents and waves
- Validate freak wave products
- Improve coastal zone (higher-resolution, effect of bottom-induced wave breaking and new representation of non-linear transfer)

GEMS

- Build initial GRG/GHG/Aerosol assimilation system
- Refine representation of aerosols in the IFS
- Refine representation of GHG in the IFS and add more trace gases
- Maintain a GEMS-compatible prepIFS version
- Start of GEMS reanalyses (2003/4) for GHG and aerosols

10. References

Andersson, E., C. Cardinali, B. Truscott and T. Hovberg, 2005: High-frequency AMDAR data – a European aircraft data collection trial and impact assessment. *ECMWF Tech. Memo. No 45*7.

Bormann, N., M. Matricardi and S.B. Healy, 2005: A fast radiative transfer model for the assimilation of infrared limb radiances from MIPAS. *Q.J.R. Meteorol. Soc*., **131**, 1631–1653.

Brown, A.R., 2004: Resolution dependence of orographic torques. *Q.J.R. Meteorol. Soc.*, **130**, 3029–3046.

Cardinali C. and R. Buizza: 2005: Observation sensitivity to the analysis and the forecast: a case study during ATReC targeting campaign. In *THORPEX Symposium Proceeding, WMO TD1237*, Commission for Atmospheric Science, World Meteorological Organization.

Cheong, H.-B., 2000: Application of double Fourier series to shallow water equations on a sphere. *J. Comput. Phys*., **165**, 261–287.

Drusch, M., E.F. Wood and H. Gao, 2005: Observation operators for the direct assimilation of TRMM microwave imager retrieved soil moisture. *Geophys. Res. Let.*, **32**, L15403, doi:10.1029/2005GL023623.

Engelen, R. J. E., E. Andersson, F. Chevallier, A. Hollingsworth, M. Matricardi, A. P. McNally, J.-N. Thépaut and P. D. Watts, 2004: Estimating atmospheric CO_2 from advanced infrared satellite radiances with an operational 4D-Var data assimilation system: Methodology and first results. *J. Geophys. Res*., **109**, D19309, doi:10.1029/2004JD004777.

Engelen, R.J. and A.P. McNally, 2005: Estimating atmospheric CO_2 from advanced infrared satellite radiances within an operational four-dimensional (4D-Var) data assimilation system: Results and validation. *J. Geophys*. Res., **110**, D18305, doi:10.1029/2005JD005982.

Fisher, M., 2004: Generalized frames on the sphere, with application to the background error covariance modeling. In *Proc. of ECMWF Seminar on Recent Developments in Data Assimilation for Atmosphere and Ocean*, ECMWF, September 2003, 87–102 (available from ECMWF library).

Healy, S.B. and J.-N. Thépaut, 2006: Assimilation experiments with CHAMP GPS radio occultation measurements. *Q.J.R. Meteorol. Soc*., In Press.

Janssen, P.A.E.M., 2003: Nonlinear four wave interactions and freak waves *J. Phys. Oceanogr*., **33**, 863–884.

Kelly, G., A. McNally, J.-N. Thépaut and M. Szyndel, 2004: Observing System Experiments of all main data types in the ECMWF operational system. In *Proc. of Third WMO Workshop on the Impact of Various Observing Systems on Numerical Weather Prediction*, Alpbach, Austria, March 2004, 63–94.

Lin, Y.L., R.D. Farley and H.D. Orville, 1983: Bulk parameterization of the snow field in a climate model. *J. Climate Appl. Meteorol*., **22**, 1065–1092.

McNally A.P., P.D.Watts, J.A. Smith, R. Engelen, G.A. Kelly, JN. Thepaut and M. Matricardi, 2006: The assimilation of AIRS radiance data at ECMWF. Accepted for publication in *Q.J.R. Meteorol. Soc*.

Trémolet, Y., 2003: Model error in variational data assimilation. In *Proc. of ECMWF Seminar on Recent Developments in Data Assimilation for Atmosphere and Ocean*, ECMWF, September 2003, 361–367 (available from ECMWF library).

Seuffert, G., H. Wilker, P. Viterbo, J.-F. Mahfouf, 2004: The usage of screen-level parameters and microwave brightness temperature for soil moisture analysis. *J. Hydromet.*, **5**, 516–531.

Szyndel, M., G. Kelly and J.-N. Thépaut, 2005: Evaluation of potential benefit of assimilation of SEVIRI radiance data from Meteosat-8 into global numerical weather prediction analyses. *Atmos. Sci. Letters*, **6**, 105–111.

Tompkins, A.M. and M. Janisková, 2004: A cloud scheme for data assimilation: Description and initial tests. *Q.J.R. Meteorol. Soc*., **130**, 2495–2518.

van der Grijn, G., J.-E. Paulsen, F. Lalaurette and M. Leutbecher, 2005: Early medium range forecasts of tropical cyclones. *ECMWF Newletter No. 102*, 7–14.

Vitart, F., 2004: Monthly forecasting. *ECMWF Newletter No. 100*, 3–13.

Watts, P.D. and A.P. McNally, 2004: The identification and correction of radiative transfer modelling errors for atmospheric sounders. In *Proc. of ECMWF Workshop on the Assimilation of High Spectral Resolution Sounders in NWP*, Reading, July 2004, pages 23-38 (available from ECMWF library).

WMO, 1982: Quality control procedures. In *Guide on the Global Data Processing System*, *WMO-N305*, World Meteorological Organization.