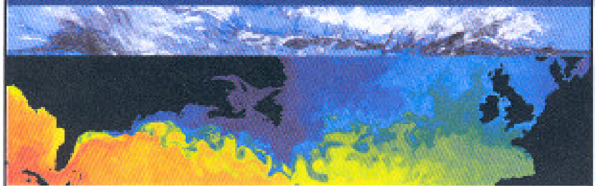
附錄1 英國氣象局4份簡報資料

NCOF

The National Centre for Ocean Forecasting

Operational Wave Modelling

Dr Gary Fullerton, May 2006



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Contents

NCOF

- Met Office Wave Model
  - Ocean Wave Model Introduction
  - Operational Configurations
  - Wave Model Formulation
  - Wave Current Interaction
  - Verification

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The Ocean Wave Forecast Model

NCOF

Applications:

- Ship routing
  - avoid high waves
- Nearshore waves
  - Coastal Engineering/Flooding
- Swell prediction: Offshore supply and construction
  - Heavy-lift barges
  - Cable laying
- Hindcast analysis
  - Revisit specific events

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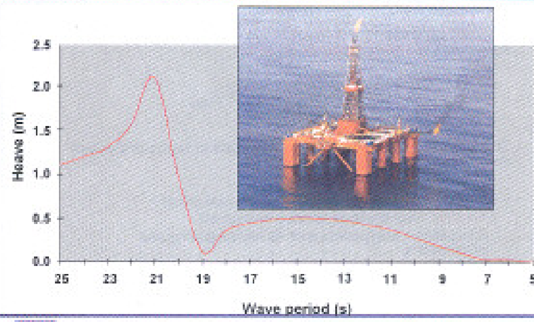
Sedco Explorer: Vessel Heave Response

NCOF



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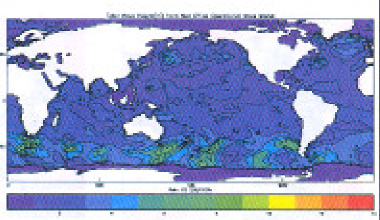
Global Model

NCOF

- 60km grid
- 5 day forecast (updated twice daily)
- Forcing from hourly 10m Global NWP winds
- Daily ice edge from satellite data
- Depth dependent group velocity
- Refraction
- Bottom friction
- Great circle turning



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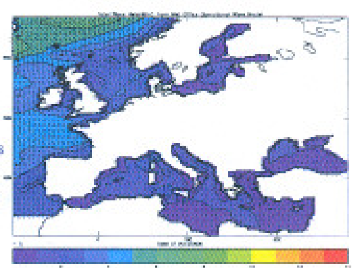
European Model

NCOF

- 35km grid
- 2 day forecast (updated twice daily)
- Forcing from hourly 10m Global NWP winds
- Open boundaries from global wave model
- Soon to be replaced with 12km NAE



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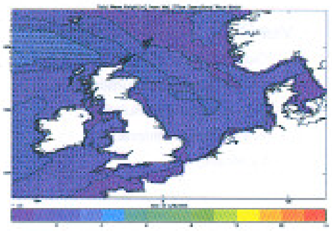
UK Waters Model

NCOF

- 12km grid
- 2 day forecast (updated four times daily)
- 5 day forecast without currents (updated twice daily)
- Forcing from hourly UK NWP winds and time-varying currents
- Global model produces boundary conditions



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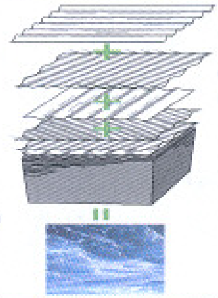
Wave Model Formulation

NCOF

- The wave energy spectrum
  - Linear superposition of surface gravity waves for a range of frequency and direction
  - Phase-averaged – no information on individual crests and troughs



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Wave Model Formulation

NCOF

- Operational wave model predicts the offshore wave energy spectrum via energy balance equation

$$\frac{\partial E}{\partial t} + c_g \nabla E = S_{nl} + S_{in} + S_{diss}$$

- The wave model represents the sea state in terms of the two-dimensional energy spectrum E (f, θ)
  - Input – Wind forcing, linear and exponential growth
  - Transfer – Nonlinear wave-wave interactions
  - Dissipation – phenomena such as wave breaking and whitecapping
- 2nd Generation wave model – parameterise the non-linear effects

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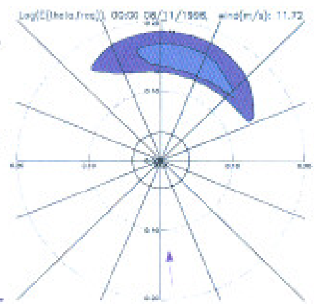
The Ocean Wave Forecast Model

NCOF

- Wave energy is specified for 13 logarithmically spaced frequencies and 16 directions at each gridpoint
- Wave periods in the range 3 seconds to 25 seconds are represented



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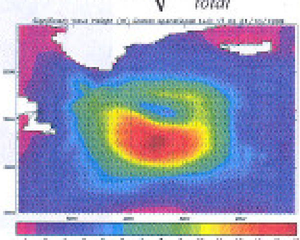
Ocean Wave Forecast Model Output

NCOF

- Outputs
  - Significant wave height
  - Wave period (peak and up crossing)
  - Wave direction (mean)
  - Swell / windsea separation
  - 2d spectra E(f, θ) output at designated points
  - 1d spectra E(f) output at every gridpoint

$$SWH = 4\sqrt{E_{total}}$$



Irene 21/10/1999

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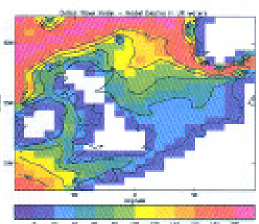
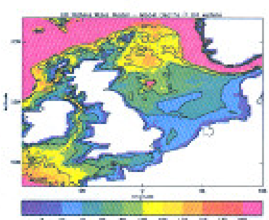
Offshore wave model limitations: bathymetry

NCOF

- Bathymetry plays an important role in the evolution of ocean waves
- Good representation of bathymetry is essential for realistic predictions



Global Wave model bathymetry



UK Waters Wave model bathymetry

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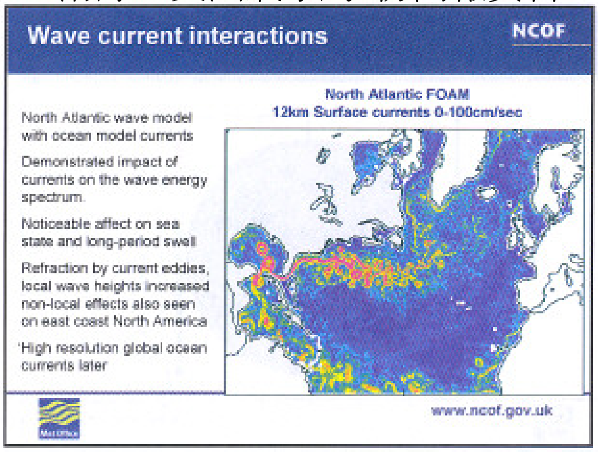

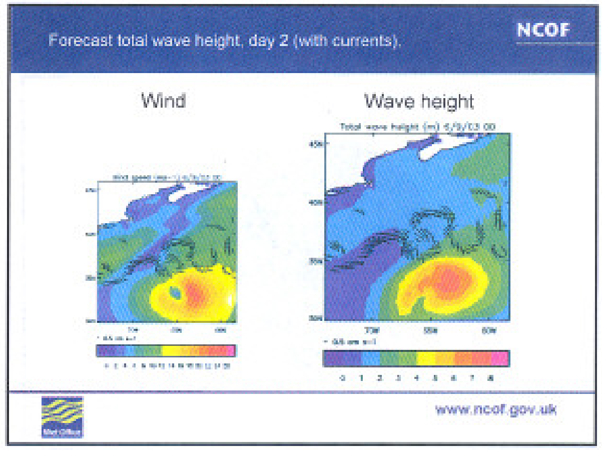

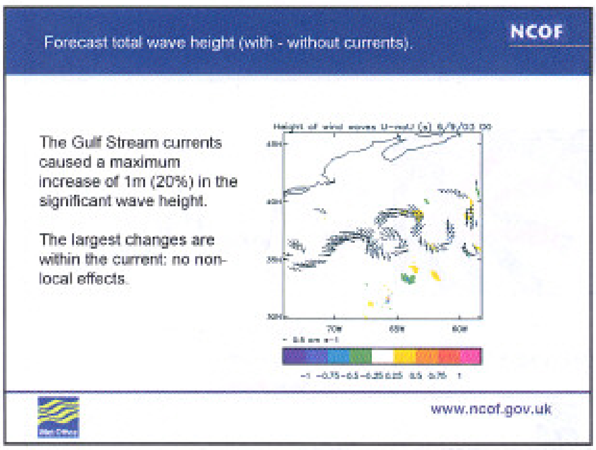

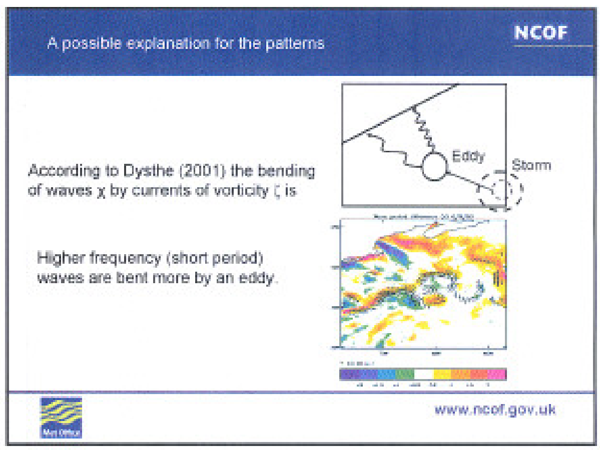

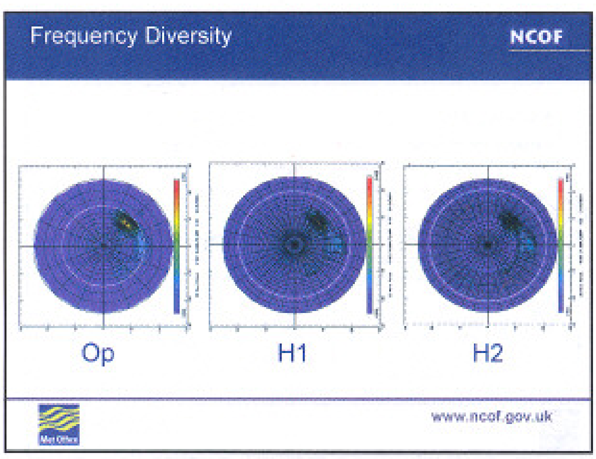

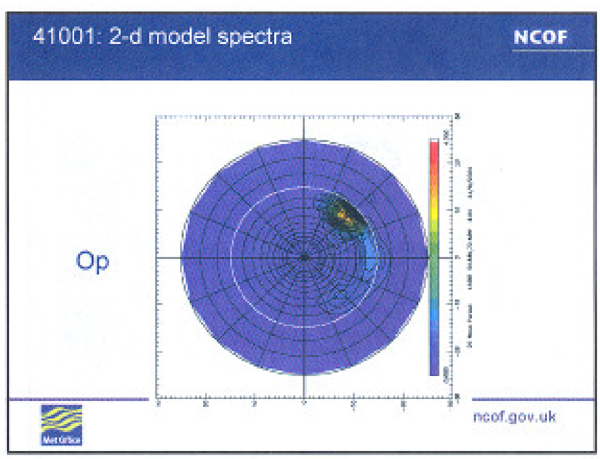

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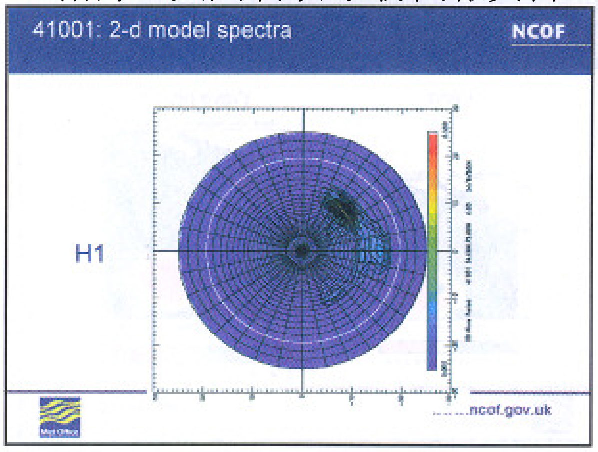

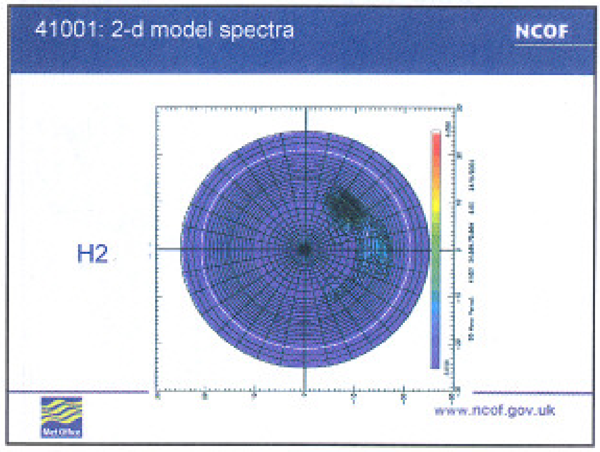

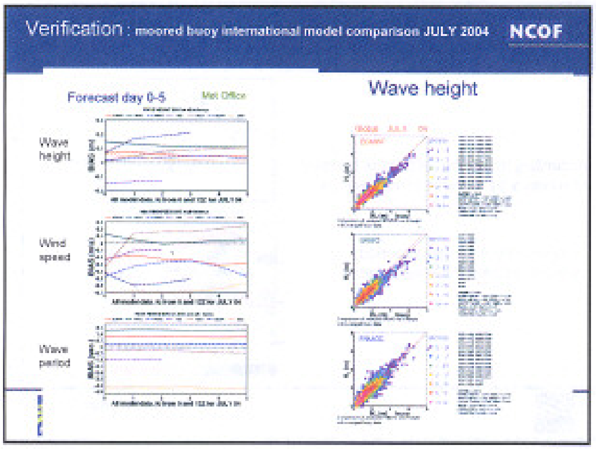

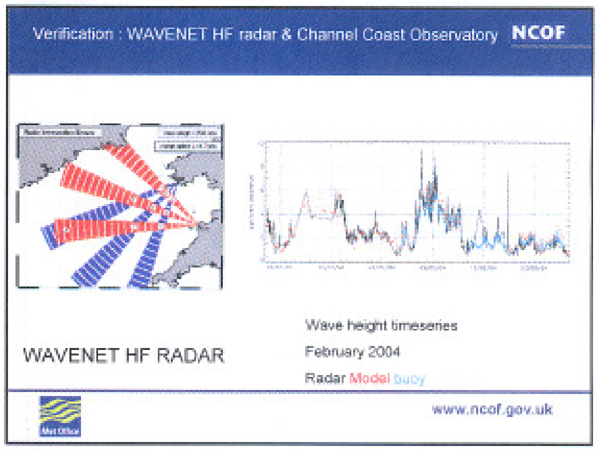

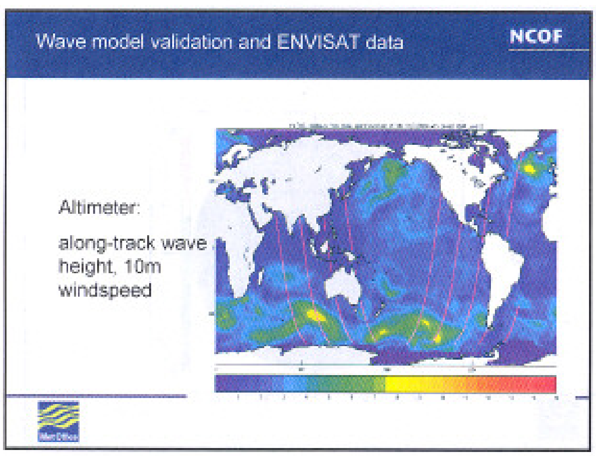

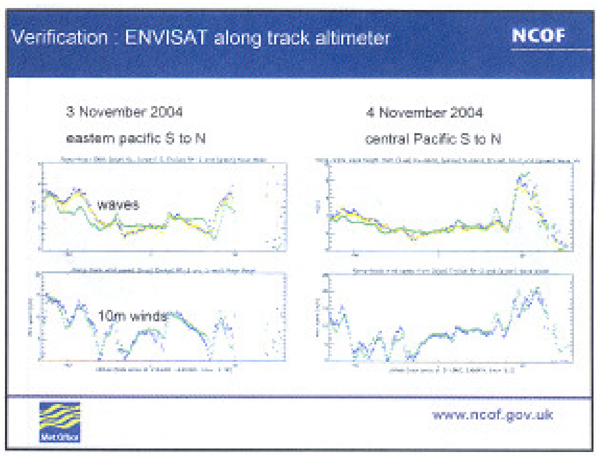

附錄1 英國氣象局4份簡報資料

Summary

NCOF

- The Met Office runs three operational ocean models
  - Global, European, UK Waters
  - Output Wave Height, Period and Direction.
- 2nd Generation Spectral model
  - Performs well, cost-effective, flexible
  - Off-shore waves
- Verification an important part of the process
  - Monitoring satellite and buoy data

Met Office

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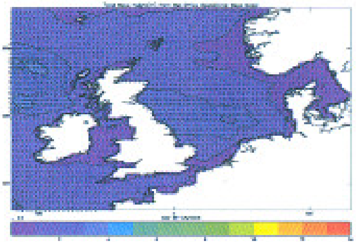
Thank you

gary.fullerton@metoffice.gov.uk



附錄1 英國氣象局4份簡報資料

NCOF

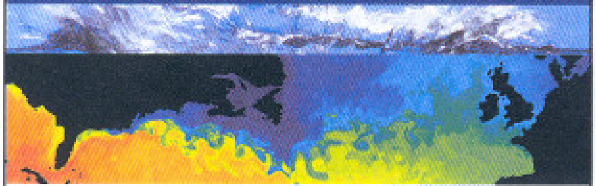
The National Centre for Ocean Forecasting

NCOF Deep ocean modelling activities

Adrian Hines, Craig Donlon

Visit of Dr Glory Shu and Dr Jason Yu

9th May 2006



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Contents

NCOF

- NCOF ocean modelling activities
  - Open ocean: FOAM
  - Sea surface temperature: OSTIA
  - Shelf seas modelling
  - Wave and surf-zone modelling

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NCOF Ocean Modelling Activities

NCOF

Open ocean forecasting:
FOAM

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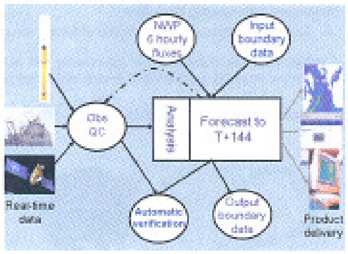
Forecasting the open ocean: the FOAM system

NCOF

FOAM = Forecasting Ocean Assimilation Model

- Operational real-time deep-ocean forecasting system
- Daily analyses and forecasts out to 6 days
- Low resolution global to high resolution nested configurations
- Relocatable system deployable in a few weeks
- Hindcast capability (back to 1997)



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FOAM system

NCOF

- Ocean model
  - Z-level, primitive equation model
  - Same code as used in Hadley Centre climate models
  - Rigid lid
  - Kraus-Turner + K-profile vertical mixing
  - Simple advective sea-ice model
  - Flow Relaxation Scheme at open boundaries for nested models
- Operational system
  - Run daily on 7 NEC SX6 processors
  - Responsibility of operational teams; 7-day operator support
  - Boundary data provided to operational Shelf Seas model
  - Automated verification system running at T+7 days

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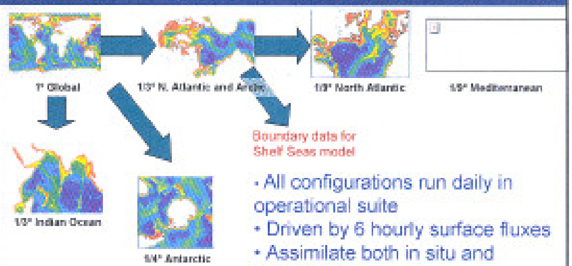
FOAM configurations run in operational suite

NCOF



- All configurations run daily in operational suite
- Driven by 6 hourly surface fluxes
- Assimilate both in situ and satellite data
- Data delivered to Navy each day

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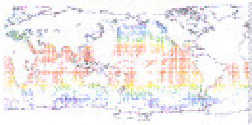
Data assimilation

NCOF

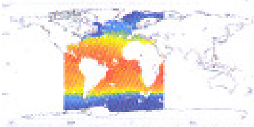
- All FOAM configurations assimilate a range of data:
  - Temperature and salinity profiles including Argo floats
  - Satellite altimeter Sea Surface Height
  - In situ and satellite Sea Surface Temperature
    - New generation of satellite SST products being tested
  - Sea-ice concentration
- OI type scheme based on Analysis Correction scheme of Lorenc et al. (1991).
  - One analysis performed at midnight each day using observations from the previous day.
  - Analysis increments are nudged into the model during the following 24 hours.

Improved satellite SST data

Current SatSST data: c. 3000 obs daily



New data: Atlantic > 2.5 million obs daily



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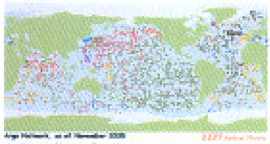
Data assimilation – impact of Argo

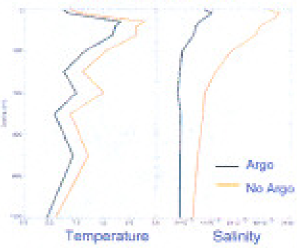
NCOF

- Impact assessed in 4 ½ year hindcast runs
  - 1° Global, 1/3° N. Atlantic & Arctic, 1/9° N. Atlantic configurations
  - Assimilating T, S profiles and SST
  - Runs repeated with Argo data withheld
- Clear demonstration of impact of Argo



Argo float distribution November 2005

Global model RMS errors



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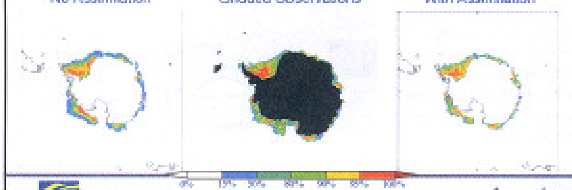
Sea-ice data assimilation

NCOF

- A system for assimilating sea-ice concentration data into FOAM has been developed with funding from ESA
  - Assimilation improves representation of the ice, especially the ice edge
- A scheme for the assimilation of ice velocity has also been developed which adapts the stresses on the ice to match observations



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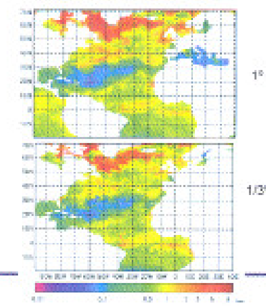
Ecosystem modelling

NCOF

- Development of open ocean water clarity capability
  - Hadley Centre Ocean Carbon Cycle model (HadOCC) has been coupled with the FOAM system
  - FOAM-HadOCC running at 1°, 1/3° and 1/9° resolution
  - Assessment of initial year-long integrations underway
  - Ocean colour data assimilation scheme (developed by NOCS) implemented and testing commenced

FOAM-HadOCC Surface Chlorophyll (mg m⁻³) for 6th June 2003



New ocean model: transition to NEMO

NCOF

NEMO is the Nucleus for European Modelling of the Ocean

- It is an ocean modelling framework that includes an ocean model, sea-ice model, and various peripheral software

NEMO will deliver a unified shelf seas / deep ocean model system

- Increased efficiency through effort focused on a single system
- A state of the art, well structured code that is easy to maintain
- Easier collaboration
  - Collaborative approach will provide more rapid development
  - Shorter lead times for pull through of developments to operations

Overall transition to NEMO expected to complete by 2008

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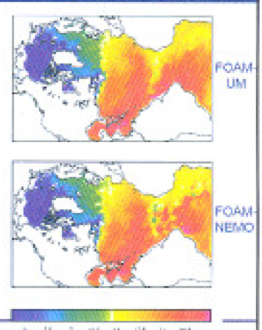
Progress with NEMO

NCOF

- Hindcast system set up
  - 1/3° North Atlantic and Arctic configuration
  - Interfaces to NWP surface fluxes, data assimilation scheme, open boundary data
- Assessment of hindcast results underway
  - After 6 months integration fields are similar at large scale to equivalent UM run
  - Significant differences at smaller scales
- Initial tests of NEMO for shelf seas
  - Initial test configuration covering UK shelf
  - Developments delivered by European partners within Mersea Integrated Project
    - S-coordinate code tested
    - Explicit free surface code tested
  - Next step is a basic tidal simulation



Temperature at 100m depth

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NCOF Ocean Modelling Activities

NCOF

Sea surface temperature: OSTIA

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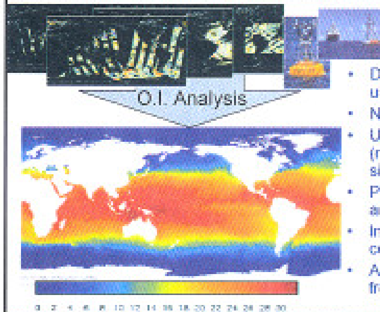
OSTIA Operational Sea surface Temperature and sea Ice Analysis

NCOF



- Daily 1/20° global analysis using optimal interpolation.
- Near real time.
- Using GHRSST-PP satellite (microwave & IR) and in situ data.
- Persistence based analysis.
- Includes satellite bias correction.
- Analysis results available from www.ghrsst-pp.org

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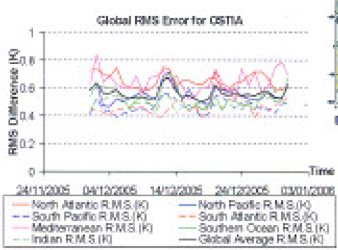
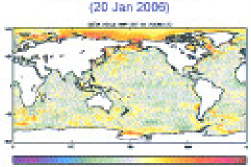
Validation : Regular Inter-comparison & validation

NCOF

- Comparison with other analyses.



OSTIA – NWP SST
(20 Jan 2006)



- RMS error less than 0.8K in all areas in Dec 05.

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Met Office Shelf Seas Ecosytem Modelling

John Siddorn

Met Office, Exeter,
9th May 2006

Contents

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1. POLCOMS-ERSEM
A Coupled hydrodynamic-ecosystem model

POLCOMS
Proudman Oceanographic Laboratory Coastal-Ocean Modelling System

3D baroclinic model
- Arakawa B grid, hybrid S-coordinates in vertical
- Piecewise Parabolic Method advection
- Horizontal pressure gradients, improving performance over steep topography

ERSEM
European Regional Seas Ecosystem Model

Bulk Biomass Functional Group Model (FGM)
- Divides the ecosystem into aggregated groups representing basic functional roles (production, consumption and decomposition).
- Subdivided into size classes to create a foodweb.
- Physiological processes and population dynamics are described by fluxes of carbon or nutrients between functional groups.

Plymouth Marine Laboratory   Proudman Oceanographic Laboratory

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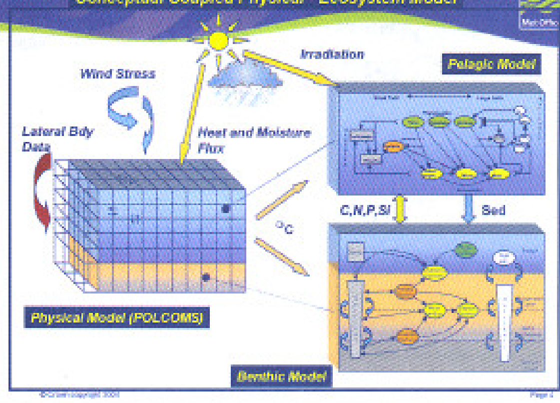
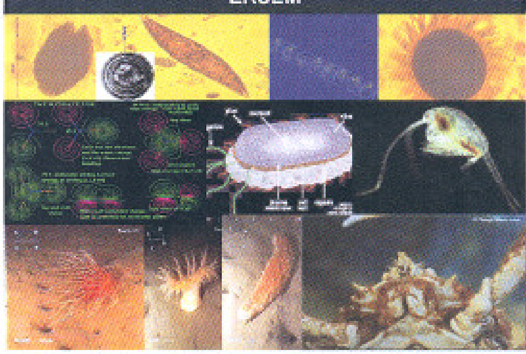
Conceptual Coupled Physical - Ecosystem Model



European Regional Seas Ecosystem Model
ERSEM



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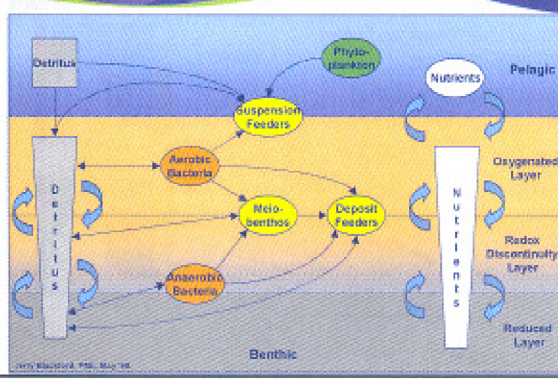
1. POLCOMS-ERSEM
Benthic chemistry and food web



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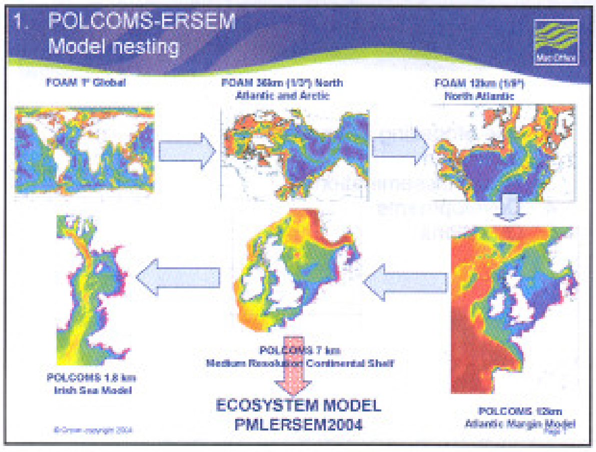
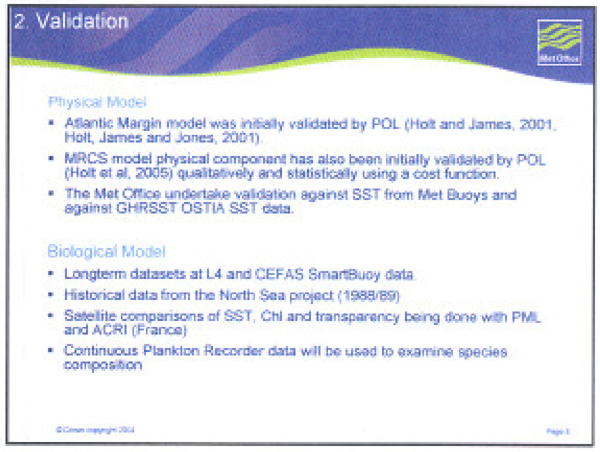
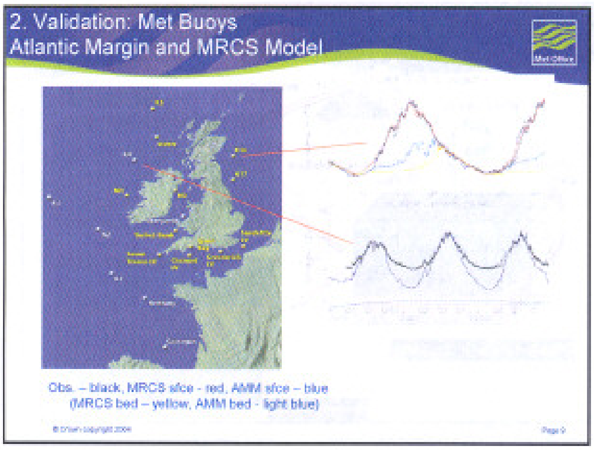
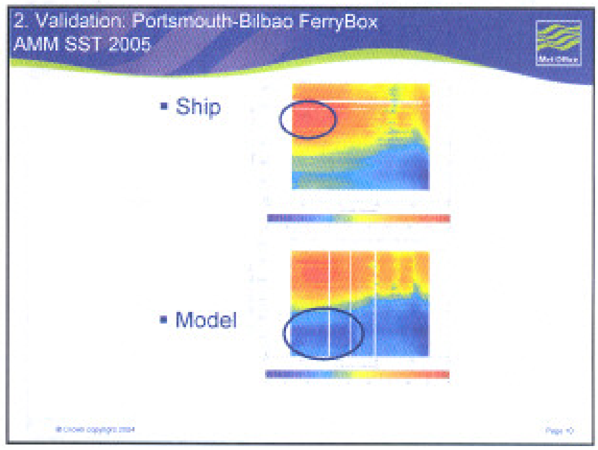
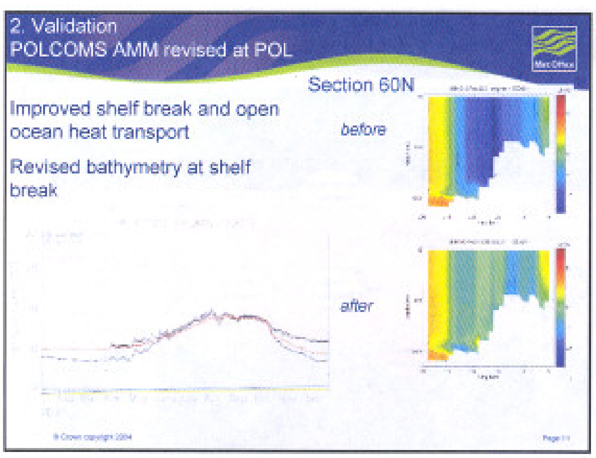
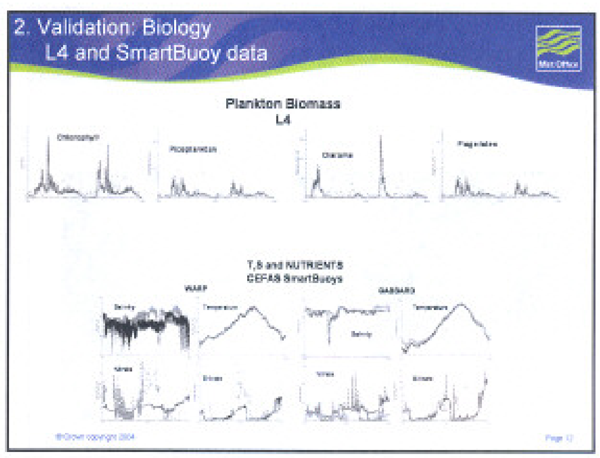


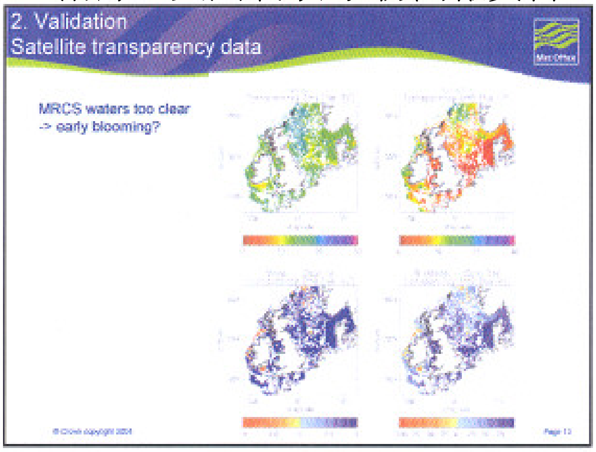


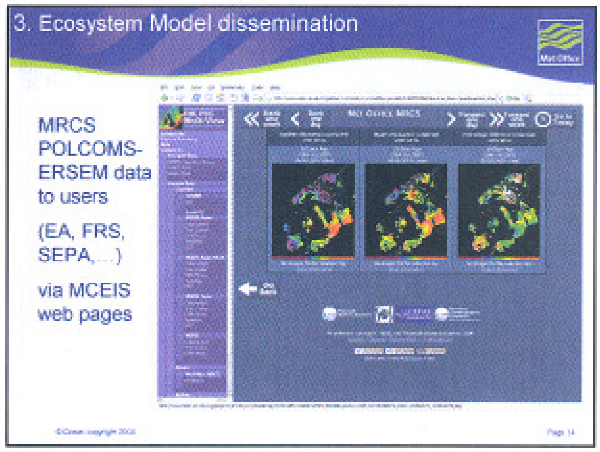


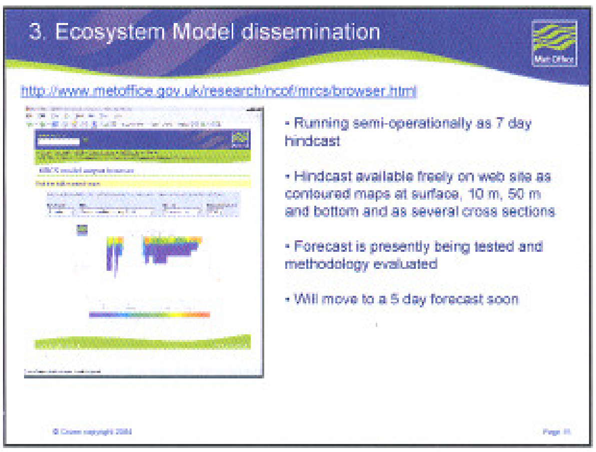


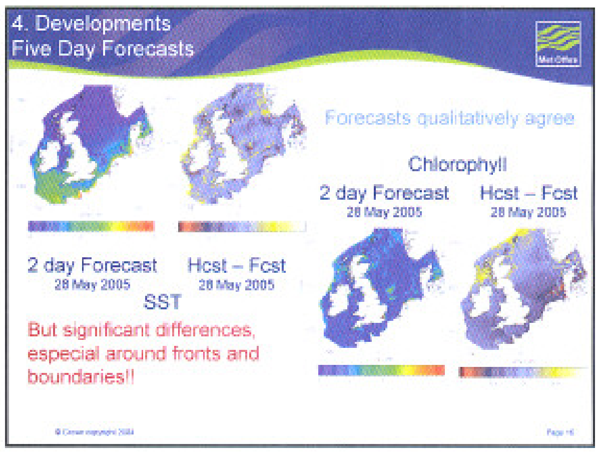


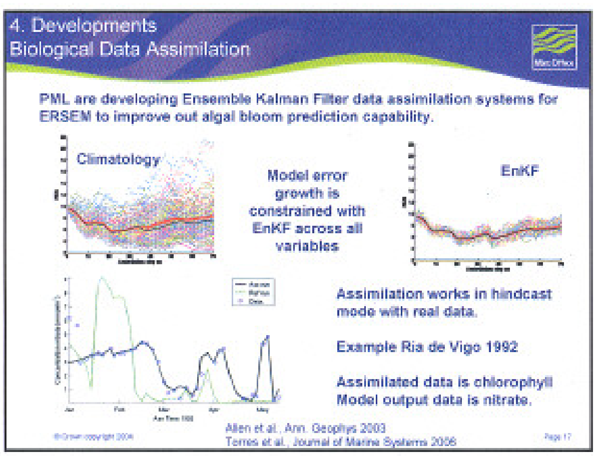


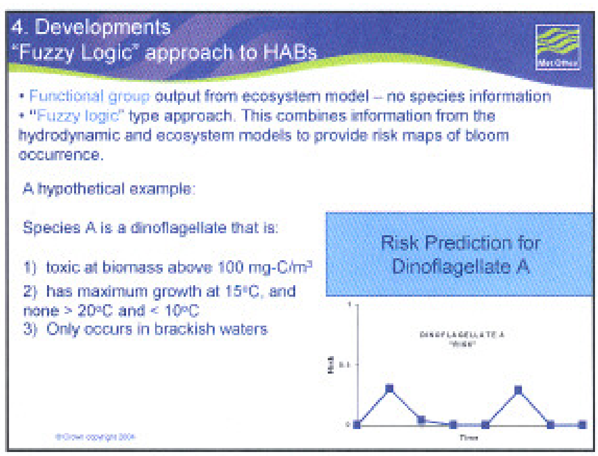

2. Validation
Satellite transparency data
MRCS waters too clear
-> early blooming?


3. Ecosystem Model dissemination
MRCS
POLCOMS-
ERSEM data
to users
(EA, FRS,
SEPA,...)
via MCEIS
web pages

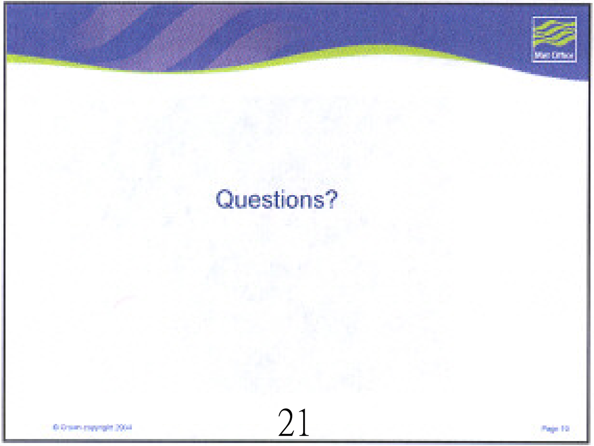

3. Ecosystem Model dissemination
http://www.metoffice.gov.uk/research/ncof/mrcs/browser.html
• Running semi-operationally as 7 day hindcast
• Hindcast available freely on web site as contoured maps at surface, 10 m, 50 m and bottom and as several cross sections
• Forecast is presently being tested and methodology evaluated
• Will move to a 5 day forecast soon


4. Developments
Five Day Forecasts
Forecasts qualitatively agree
Chlorophyll
2 day Forecast
28 May 2005
Hcst – Fcst
28 May 2005
2 day Forecast
28 May 2005
Hcst – Fcst
28 May 2005
SST
But significant differences, especial around fronts and boundaries!!

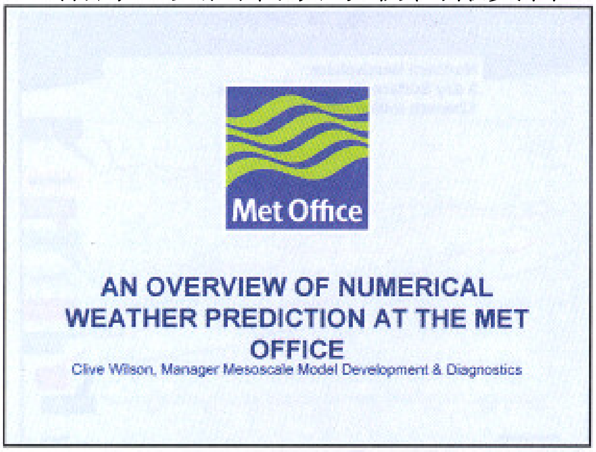

4. Developments
Biological Data Assimilation
PML are developing Ensemble Kalman Filter data assimilation systems for ERSEM to improve out algal bloom prediction capability.
Climatology
Model error growth is constrained with EnKF across all variables
EnKF
Assimilation works in hindcast mode with real data.
Example Ria de Vigo 1992
Assimilated data is chlorophyll
Model output data is nitrate.
Allen et al., Ann. Geophys 2003
Torres et al., Journal of Marine Systems 2006

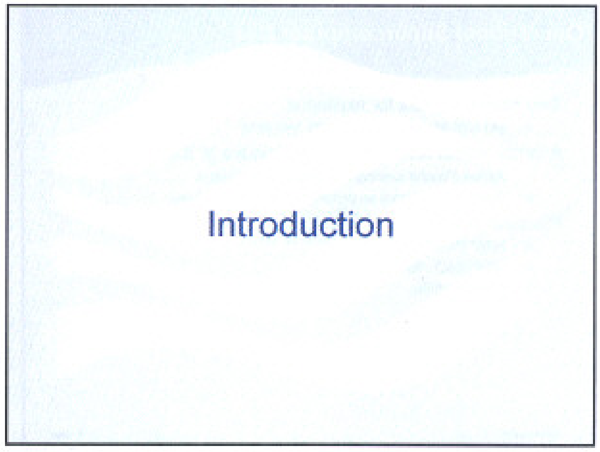

4. Developments
"Fuzzy Logic" approach to HABs
• Functional group output from ecosystem model – no species information
• "Fuzzy logic" type approach. This combines information from the hydrodynamic and ecosystem models to provide risk maps of bloom occurrence.
A hypothetical example:
Species A is a dinoflagellate that is:
1) toxic at biomass above 100 mg-C/m³
2) has maximum growth at 15°C, and none > 20°C and < 10°C
3) Only occurs in brackish waters
Risk Prediction for Dinoflagellate A
Time

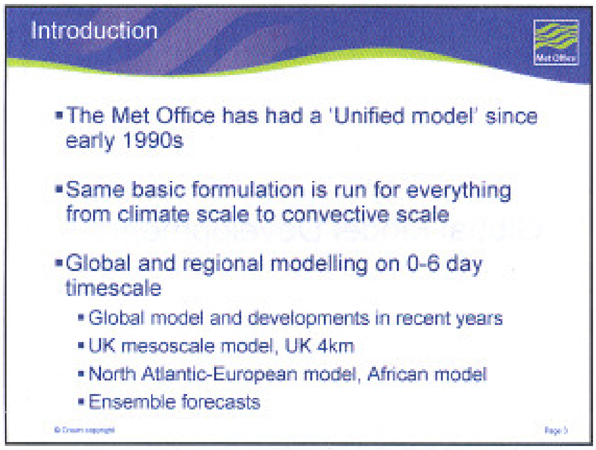
附錄1 英國氣象局4份簡報資料

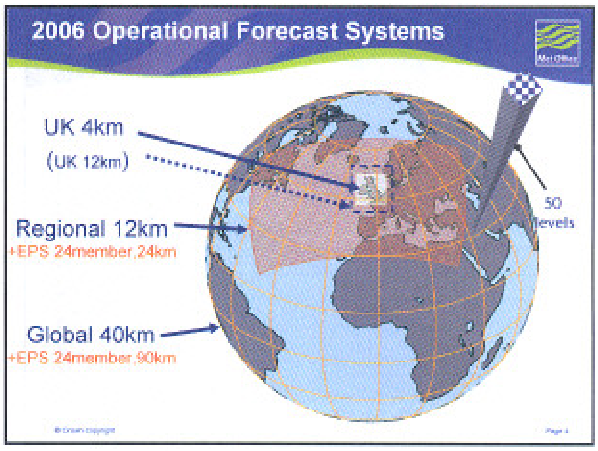


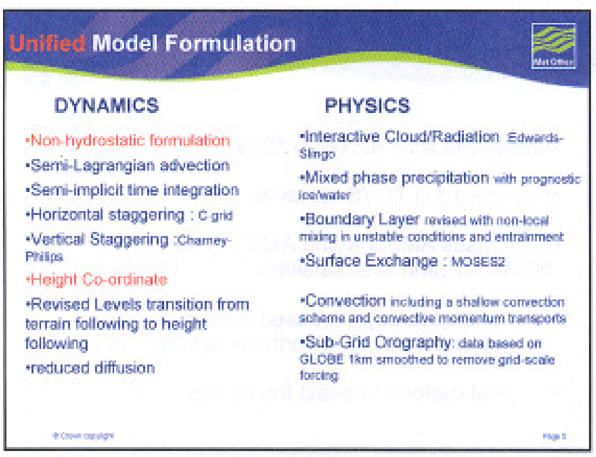
附錄1 英國氣象局4份簡報資料

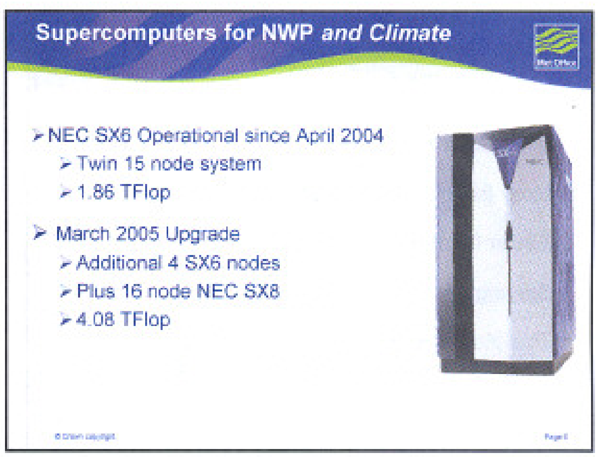












附錄1 英國氣象局4份簡報資料

Operational Supercomputer Use

Two computer halls for resilience
- (A) SX8-M16 + SX6-M15 ; (B) SX6-M19

A single model restricted to 4 SX8 nodes (6 SX6 nodes)
- Allows Parallel running of Global and UK suites
- Reduced efficiency as processor numbers increase

Planned User Allocations
- NWP Production ~15%
- NWP R&D ~30%
- Climate ~55%,

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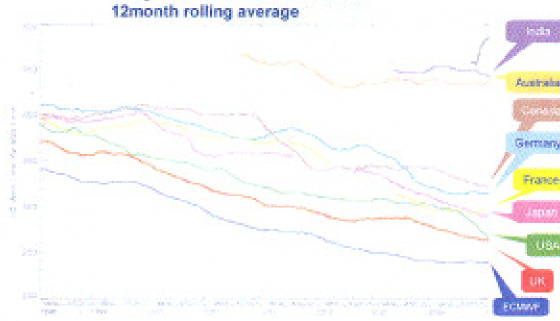
Verification: Comparisons of Weather Services

Northern Hemisphere:
3 day Surface Pressure Forecasts
12month rolling average



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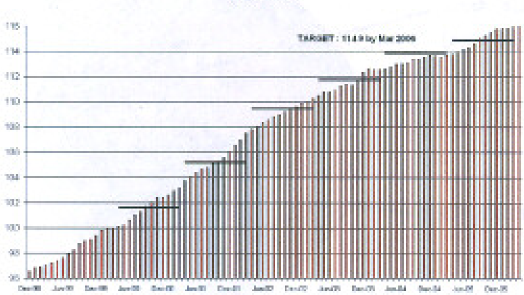
Improving NWP Performance: NWP Index

36month rolling average for a basket of verification measures



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Global Model Developments

Global Model Developments – 3D-Var

- Introduced in 1999
- More flexible, portable and maintainable code
- Easier to introduce new observation types
- Staging post for moving to 4D-Var
- Trial indicated forecast improvement, particularly in tropics and southern hemisphere

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Global Model Developments - ATOVS

- Introduced with 3D-Var in 1999
- Replaced 1-d TOVS retrievals
- Comprises AMSU-A and AMSU-B data on NOAA-15 (and later satellites)
- Forecast accuracy increased 20% in southern hemisphere and 5% in northern hemisphere
- Tropical cyclone forecast tracks improved

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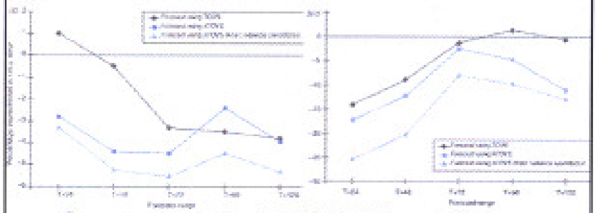
附錄1 英國氣象局4份簡報資料

Global Model Developments - ATOVS



- Percentage reduction in RMS MSLP forecast errors
- Left: Northern hemisphere
- Right: Southern hemisphere
- Direct radiance assimilation implemented a few months later

Global Model Developments – New Dynamics

- Dynamics changes
  - Non-hydrostatic model with height as the vertical co-ordinate
  - Charney-Philips grid staggering in the vertical (potential temperature is on the same levels as the vertical velocity)
  - C grid staggering in the horizontal (u-component is east-west staggered from temperatures and v-component north-south staggered)
  - Semi-Lagrangian advection scheme
  - Semi-implicit time scheme

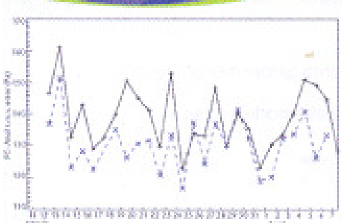
Global Model Developments – New Dynamics

- Physics changes
  - Edwards-Slingo radiation scheme with non-spherical ice spectral files
  - Large scale precipitation with prognostic ice microphysics
  - Vertical gradient area large-scale cloud scheme.
  - Convection with CAPE closure, momentum transports and convective anvils

Global Model Developments – New Dynamics

- Physics changes - continued
  - Boundary-layer scheme which is non-local in unstable regimes
  - Gravity-wave drag scheme which includes flow blocking
  - GLOBE orography dataset
  - MOSES (Met Office Surface Exchange Scheme) surface hydrology and soil model scheme
  - Non-sequential physics coupling

Global Model Developments – New Dynamics



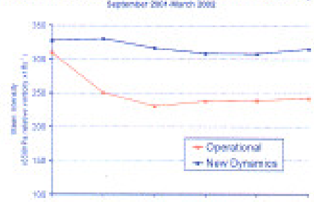
Northern hemisphere 24-hour RMS MSLP forecast errors.

New Dynamics is dashed line

- Northern hemisphere improved more than southern hemisphere
- Reduced wind biases
- Better handling of storms
- Mid-tropospheric warm bias worse
- Introduced Summer 2002

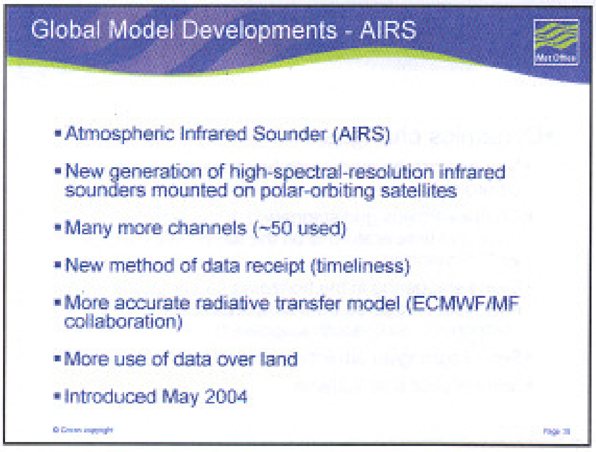
Global Model Developments – New Dynamics

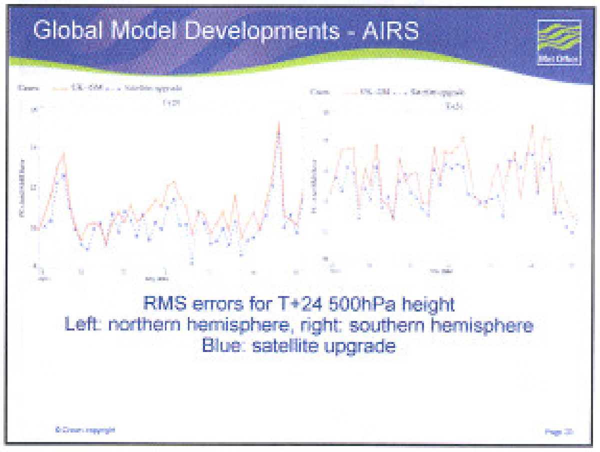
Mean Forecast Tropical Cyclone Intensity

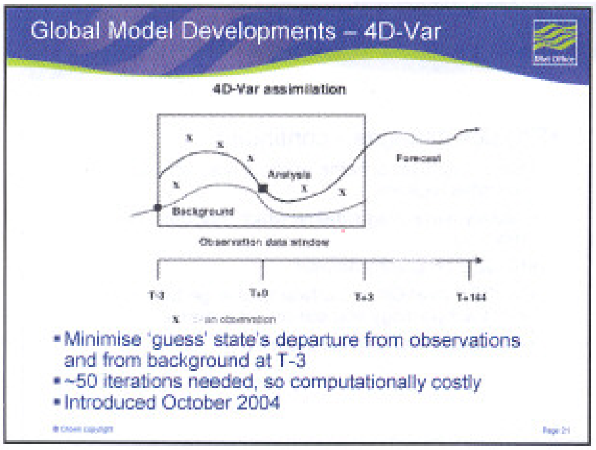


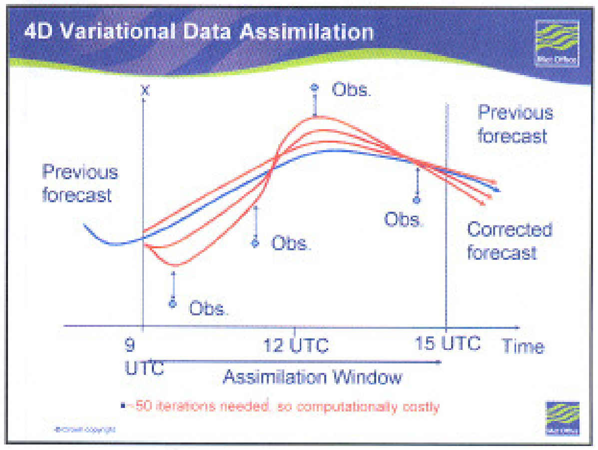
- 'Spin down' of tropical cyclones eliminated
- Track forecasts improved by ~8%

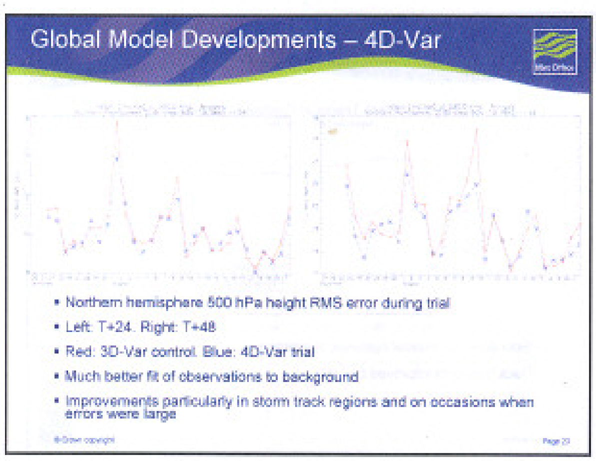
附錄1 英國氣象局4份簡報資料

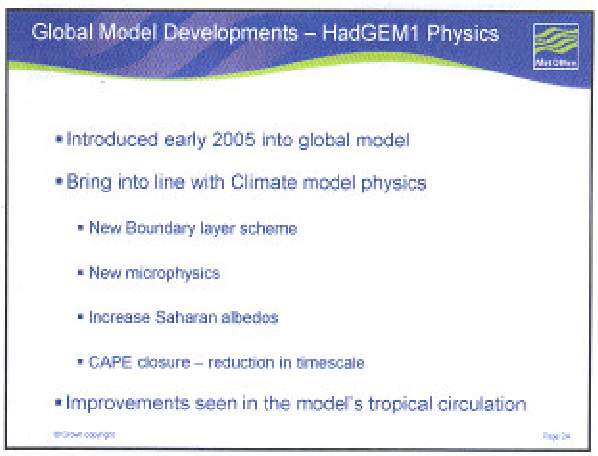












Global Model Developments – MODIS winds

- Atmospheric motion vectors / cloud track winds used for many years
- Geostationary satellites cannot see high latitudes
- AMV production now possible from MODIS instruments on Terra and Aqua satellites
- Introduced in early 2005

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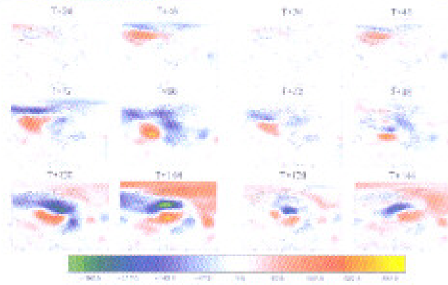
Global Model Developments – MODIS winds



- Forecast error growth for a trial case – 500 hPa winds
- Left: control. Right: trial with MODIS data

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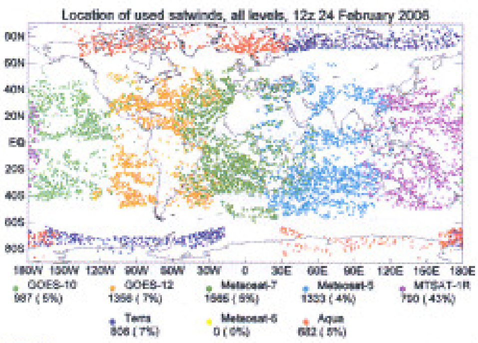
Global Model Developments – MODIS winds



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Global Model Developments – Resolution increase

- Implemented December 2005
- Horizontal
  - 0.5625 ° x 0.375° (~40km over UK)
  - 48% increase in horizontal
- Vertical
  - 38 to 50 levels
  - Most extra levels in stratosphere
  - 'Lid' raised from 39km to 63km

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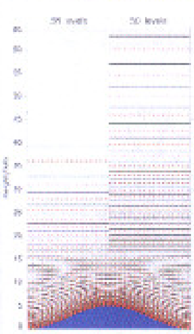
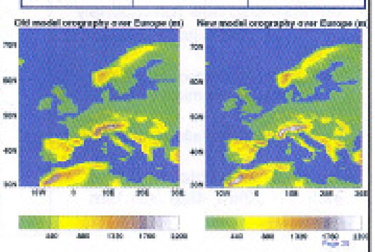
Enhanced Resolution Global Model



	N216 38L	N320 50L
Grid points	432 (EW) x 325 (NS)	640 (EW) x 481 (NS)
Resolution: Mid-lat Equator	~60 km 93 km	~ 40 km 63 km
Time-step	20 min	15 min



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Global Model Developments – Resolution increase

- Improved fit to observations in 4D-Var (particularly stratospheric ATOVS)
- Improved short-range forecasts
- Reduced wind biases in extra-tropics
- Improved stratosphere
- Increased levels of eddy kinetic energy
- Deeper tropical cyclones
- Improved tropics – MSLP, 850 winds, precipitation
- More rapid error growth
- Mixed signal for tropical winds
- Southern hemisphere performance v. observations poorer in one trial

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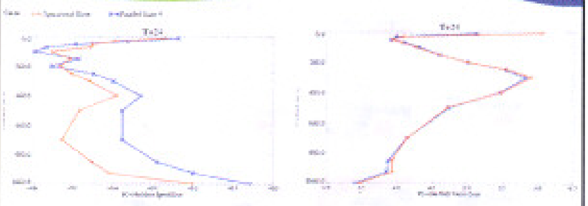
附錄1 英國氣象局4份簡報資料

Global Model Developments – Resolution increase

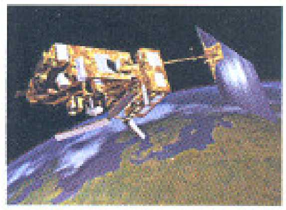


Northern Hemisphere T+24 wind speed bias (left) and RMS error (right)

Red: Old resolution. Blue: New resolution

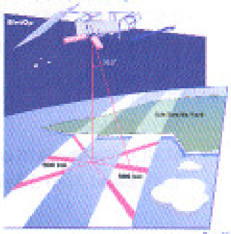
Global Model Developments – The Future

- March 2006
  - Convection and boundary layer scheme changes
  - Optimisation of use of AIRS data (which had to be temporarily removed in December 2005)
- 70 levels in 2007
- MetOp satellite
- Launch July 2006



Global Model Developments – The Future

- MetOp
  - Additional ATOVS
  - Infrared Atmospheric Sounding Interferometer (IASI)
    - ~300 channels will be used c.f. ~50 for AIRS
  - Radio Occultation
    - Refraction of radio signals between MetOp and GPS satellites – pressure, temperature
  - ASCAT
    - Twin swathe scatterometer



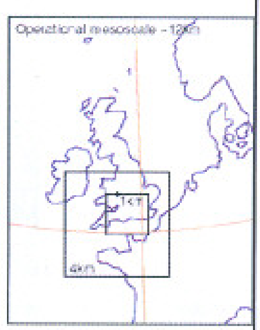
Data Assimilation Developments

- Global 4DVAR operational: October 2004
- Regional 4DVAR operational: March 2006
  - Next steps:
    - More use of satellite data
    - Better incremental physics
    - Assimilation of Cloud and Precipitation observations
- Surface Analyses
  - Global 1.5m temperature and humidity analysis => updating of soil moisture estimates: Introduced September 2005
  - IGBP vegetation data used in all configurations
  - Next steps
    - Improved representations of time-varying surface fields, such as snow cover

Limited area & Fine scale Model Configurations

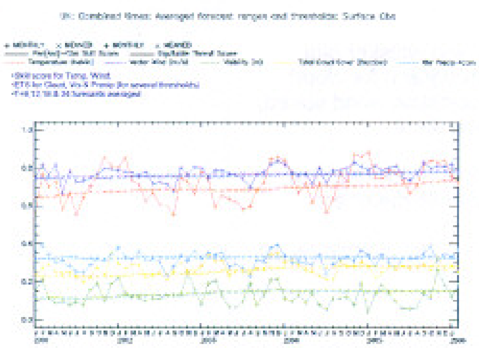
UK Mesoscale Model

- Current operational mesoscale 12km 38 levels
- 4km version of model (whole UK domain) also now run routinely
  - 3D-Var, 38 level (to be increased to 75)
  - Mass flux restricted convection scheme (allows much explicit convection)
  - Prognostic rain (allows advection)
- High resolution trial model includes 12km, 4km and 1km nested



附錄1 英國氣象局4份簡報資料

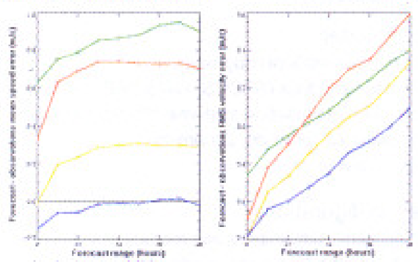
UK Verification Scores



North Atlantic-European Model

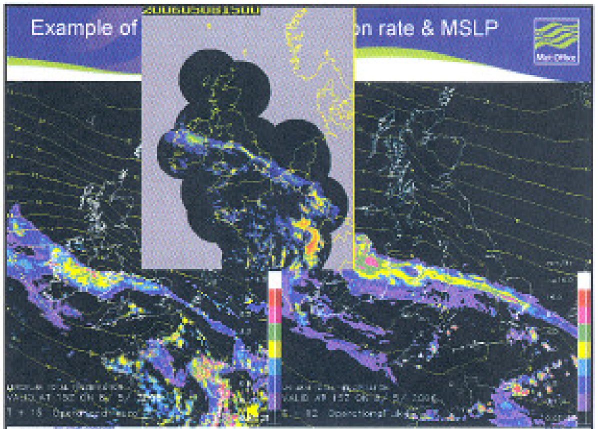
- 12km resolution (0.11° x 0.11°)
- 36-hour forecast
- Aim to produce better forecasts for NW Europe
- Will replace 12km UK mesoscale model when performance matched
- Change to 4D-Var in March 2006 has provided major improvement

North Atlantic-European Model

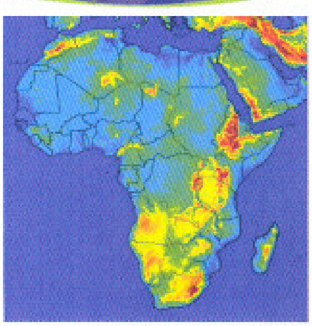


- 10m wind errors, UK area.
- Left: mean speed. Right: RMS vector wind
- Green: global. Blue: UK mesoscale.
- Red: 20km NAE. Yellow: 12km NAE

Example of ... n rate & MSLP



Other Regional Models – Africa (20km)



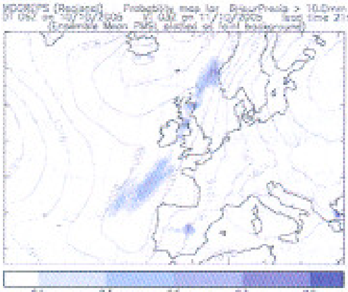
- Support through Voluntary Cooperation Programme WMO
- Web products available (password)
- Aim to give African NMSs access to state-of the-art NWP

Ensemble Forecasting

- New venture for the Met Office
- Complement ECMWF 3-10 day ensembles
- Emphasis on short range (0-3 days), high resolution regional capability
- Global ensemble run to provide LBCs
- Global
  - 90km, 24 members, 72 hours, 4D-Var
- Regional
  - 24km, 24 members, 36 hours, start from 6 hour global forecast

附錄1 英國氣象局4份簡報資料

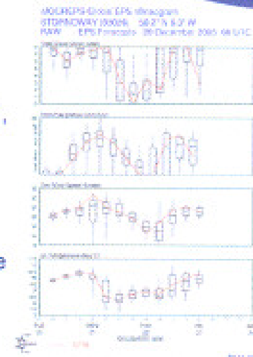
Ensemble Forecasting



- 12-hour forecast probability of 6-hour precipitation total exceeding 10mm

Ensemble Forecasting

- Box and whisker plot (meteogram) for cloud, precipitation, wind speed, temperature
- Whisker – full range of ensemble members
- Box – inter-quartile range



Summary

Summary

- Global model
  - Continuous work on upgrades
  - New satellite data (ATOVS, AIRS, IASI, AMVs)
  - New data assimilation systems (3D-Var, 4D-Var)
  - New science (physics, dynamics)
  - Higher resolution
- Other configurations
  - 12km, 4km, 1km mesoscale models
  - North Atlantic-European mode
  - Relocatable regional models
  - Ensembles

The End