The Exploitation of Satellite Data at the U.K. Met Office

Roger Saunders

with the help of Steve English, Bill Bell, Mary Forsythe, Brett Candy, James Cameron and many others
Talk topics

- The Met Office satellite group and NWP SAF
- Current status of models and observation use
- Recent upgrades to use of satellite data
- Satellite data impacts
- Research into use of new data types
- Meteosat Second Generation
- METOP
SA Funding 2006/07  31 Staff in total

- Core Govt
- EUMETSAT
- Defence
- Aviation
-ESA
-Climate
The Met Office leads the NWP SAF
In final year of initial operational phase
Preparing proposal for follow-on operational phase (5 years) to start in March 2007.
Major deliverables are:
- AAPP (ATOVS/AVHRR direct readout software)
- RTTOV (Fast radiative transfer model)
- 1DVAR (Met Office and ECMWF versions)
- Satellite data monitoring (Radiance, AMVs, O₃)
- Scatterometer processor
- Reports on many aspects of satellite data
Also involved in GRAS (GPS RO) SAF
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- Global ~40km ~50Level
- North Atlantic/Europe 12km ~30level
- UK 4km ~30Level
- Re-locatable Defence and Civilian
- Trial Ensemble (global & regional) at half horizontal resolution

- Data assimilation 4DVar 6 hour window for global and regional models
## Operational data usage (Apr 2006)

<table>
<thead>
<tr>
<th>Observation group</th>
<th>Observation Sub-group</th>
<th>Items used</th>
<th>Daily extracted</th>
<th>% used in assimilation</th>
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<tbody>
<tr>
<td>Ground-based vertical profiles</td>
<td>TEMP</td>
<td>T, V, RH processed to model layer average</td>
<td>1250</td>
<td>87,92,50</td>
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<td></td>
<td>PILOT</td>
<td>As TEMP, but V only</td>
<td>850</td>
<td>92</td>
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<td>PROFILER</td>
<td>As TEMP, but V only</td>
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<td>Satellite-based vertical profiles</td>
<td>AMSU-A/B</td>
<td>Radiances directly assimilated with channel selection dependent on surface instrument and cloudiness</td>
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<td>NOAA-15/16/18</td>
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<td>Aqua AIRS</td>
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<td>Aircraft</td>
<td>Manual</td>
<td>T, V as reported with duplicate checking and blacklist</td>
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<td>14</td>
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<td>AIREPS</td>
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<td>185000</td>
<td>28</td>
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<td>Automated AMDARS</td>
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<td>Satellite atmospheric motion vectors</td>
<td>GOES 10,12 BUFR</td>
<td>High resolution IR winds IR, VIS and WV winds IR and WV</td>
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<td>Meteosat 5, 8 BUFR</td>
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<td>190000</td>
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<td></td>
<td>MTSAT SATOB</td>
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<td>4000</td>
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<td>Aqua/Terra MODIS</td>
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<td>Satellite-based surface winds</td>
<td>SSMI-13,15</td>
<td>In-house 1DVAR wind-speed retrieval</td>
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<td>Seawinds, ERS-2</td>
<td>NESDIS retrieval of ambiguous winds. Ambiguity removal in 4DVAR.</td>
<td>1800000</td>
<td>1.5</td>
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<tr>
<td>Ground-based surface</td>
<td>Land SYNOP</td>
<td>Pressure only (processed to model surface)</td>
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<td>75</td>
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<td>SHIP, Fixed Buoy Drifting BUOY</td>
<td>Pressure and wind pressure</td>
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<td>94, 92</td>
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Recent changes to use of satellite data

- Aqua AMSU-A replaced by NOAA-18 AMSU
  - Better coverage with NOAA-18
  - Issue of Aqua AMSU-A antenna correction
- AIRS central fov replaced by AIRS warmest fov
- Reintroduction of ERS-2 scatterometer winds
- Meteosat-7 AMVs replaced by Meteosat-8 AMVs
Satellite data delays

Main run data cutoff

- SSMI F15
- SSMI F14
- SSMI F13
- MODIS Terra
- MODIS Aqua
- SSMIS
- QuikScat
- AIRS
- ATOVS N18
- ATOVS N16
- ATOVS N15
- ATOVS Aqua

Delay (minutes)
Average AMSU Data Assimilated for a Main forecast Run

Control

Experiment

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EARS-Mitigating Data Delay

EARS System Overview
EARS (2)

EARS timeliness

Global Data Dump
Global
3-6 hours

EUMETSAT ATOVS Retransmission Service
Regional
30 minutes

HRPT Reception
Local
Immediate
There are plans to:

- extend coverage of EARS to the whole extra-tropical NH
- develop other regional systems (e.g. S. America, Australia / NZ)
• North Atlantic Region
• six-hour window

09/09/2003 09:00-15:00

Arrival Times of Data

- Main Run
  - NESDIS 25%
  - EARS 75%

- Update Run
  - both 100%

Graph showing percentage of observations over time for global and EARS data, with a focus on the six-hour window from 09:00 to 15:00.
Moved to use AIRS warmest FOV

This results in an increased coverage of AIRS clear sky radiances
Removed Double Peaked AIRS Channels

Channel 2107 at 2386 cm\(^{-1}\) (4.19 microns), FWHM 1.880 cm\(^{-1}\)

The sharp, strong absorption CO\(_2\) lines cause a double peak in the Jacobian.
AIRS q increments

VAR (initialised) increment into UM

No AIRS
AIRSWF
Impact on AMSU-B Channels

183 ± 7 GHz

First Iteration
No AIRS
AIRSWF

Final Iteration
No AIRS
AIRSWF
Assimilating AIRS leads to significant humidity changes.

All AIRS trials show improved fits to SSMI TCWV (not assimilated) and all AMSU-B channels.

An improvement to RH is not confirmed by sondes, where no particular effect is apparent.

We have not seen a big improvement in forecasts going from AIRS to AIRSWF.
What is the NWP SAF AMV monitoring?

NWP SAF – Numerical Weather Prediction Satellite Application Facility

A EUMETSAT-funded initiative, led by the Met Office, with partners ECMWF, KNMI and Météo-France

Aim to improve the benefits derived by European National Met. Services from NWP by developing techniques for more effective use of satellite data and to prepare for effective exploitation of new data/products.

AMV Monitoring

Displays comparable AMV monitoring output from different NWP centres in order to help identify and partition error contributions from AMVs and NWP models.

Analysis reports produced periodically (planned every 2 years to coincide with winds workshops).

Intended to stimulate discussion and to lead to improvements in AMV derivation and AMV use in NWP.

http://www.metoffice.gov.uk/research/interproj/nwpsaf/satwind_report
Data used - Mar 2006

1. 8th Feb 05 - Introduce NESDIS MODIS polar winds
2. 14th Jun 05 – GOES SATOB IR -> GOES BUFR IR and cloudy WV
3. 1st Sep 05 – start using MTSAT-1R SATOB
4. 14th Mar 06 – Meteosat-7 -> Meteosat-8
Replace Meteosat-7 IR, WV and VIS with Meteosat-8 IR10.8, WV7.3, HRVIS and VIS0.8 using same QC as applied to Meteosat-7

Impact neutral in Jul-Aug and moderately positive in Dec-Jan.

Main benefit from tropical wind fields (W250 and W850) and southern hemisphere PMSL (against both observations and analyses).

Few forecast parameters improved or degraded by more than 2%.
Forecast error evolution Aug 14th, 2004
500 hPa geopotential height

CONTROL

MODIS
Why do we struggle to see impact from AMVs?
Is it poor height assignment of some winds?
We are starting to investigate this
Discussed at IWW in Beijing
Comparison to model best-fit pressure

Vector Difference\(_i\) = \(\sqrt{((\text{ObU} - \text{BgU})^2 + (\text{ObV} - \text{BgV})^2)}\)

Model best-fit at minimum in vector difference profile.

AMV pressure and model best-fit pressure agree well in this case.
Case studies – Sahara 8th Dec

From 7th December 21:00 UTC to 8th December 2005 3:00UTC (night time)

Can also compare to other cloud top pressure products
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Comparison of impact of observing sounding data

Analysis

- No Satellite
- Losing all microwave sounders
- Losing all infrared sounder
- Losing all radiosonde T, q and u
- Losing all radiosonde T and q

Ten years ago? TOVS NESDIS retrievals, AMV, more but lower quality radiosondes
Forecast skill vs time

More forecast busts without satellite data
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Use of SSMIS
GPS radio occultation
GPS total column water vapour
Meteosat precipitation

Longer term….
NPP
AMSR-E precip
WINDSAT
Scatterometer soil moisture
ADM
SSMIS: Instrument and scan geometry

Special Sensor Microwave Imager/Sounder (SSMIS)
Orbit coverage of operationally assimilated sounders / imagers

- ATOVS (T & q)
- AIRS (T & q)
- SSMI (WS)
- SSMIS (T, q, WS)

F13, F15, F16

F17 – F20 planned for 2006 – 2011
Background: Accuracy Requirements and Initial Performance

Require $U(T_B) \sim 0.2K$

Initial evaluation indicated $U(T_B) \sim 0.5 K$
Time series of averaged innovations continue to be a useful tool for the study of SSMIS calibration issues.
Flagging solar intrusions

Yellow: rejected
Black: OK
(30 - 40% data flagged)

Improved corrections under test
At NRL/ NESDIS – will allow recovery of this data
Problems in ascending node not evident in descending node

Reflector emission

SSMIS CHP O-B

O - B / K

1K

REFLECTOR ARM TEMPERATURE / K

TIME RELATIVE TO 18Z 06/06/05 / mins

80K
Consistent with solution of heat transfer equation, assuming conductive cooling

\[ T_{\text{ant}}(t) = T_{\text{arm}}(t) + c_1 \int_0^T e^{-\tau/\sigma} \frac{dT_{\text{arm}}}{dt}(t-\tau) \, d\tau \]
Characterising $T_{\text{ANT}}$ & $\varepsilon$: Chs 2 – 7

Temp sounding channels
trop – lower strat
(AMSUA like)

Ch 1 - 5 : $\varepsilon = 0.01$
6,7 : $\varepsilon = 0.02$

$T$ corr = 30 – 40 K

(effectively calibrating reflector emissivity
using NWP T fields!?)
Conservative use of SSMIS gives significant improvement in SH forecasts of PMSL for forecast days 1 - 4 on top of 2 and 3 satellite systems.
Summary

• NWP DA systems require high quality radiances ($U(T_B) \sim 0.2K$) in temperature sounding channels to deliver improvements to forecast accuracy.

• Post launch Cal/Val program has identified two sources of significant bias associated with solar intrusions into cal warm load and thermal emission from the main reflector.

• Correction strategies have been developed to deal with both effects and the resulting radiances are of comparable quality to those from AMSU-A for the tropospheric T sounding channels.

• Assimilation experiments at the Met Office show significant benefit from assimilating T sounding channels for SSMIS in SH verified against baseline configurations with 2 and 3 AMSU’s.

• Assimilation experiments at ECMWF show SSMIS delivers > 50% the benefit of N15 AMSU against NOSAT controls.

• Further improvements are expected as correction algorithms are refined.
GPS Radio Occultation

RO Missions:
- Ørsted: 1998 –
- SunSat: 1999 –
- SAC-C: 1999 –
- CHAMP: 2000 –
- GRACE-A/B: 2002 –
- COSMIC: ? Apr 2006
- GRAS: 17 Jul 2006
CHAMP Coverage

Plot of all occultation positions with lowest altitude of data in profile indicated.
Data from 22/2/2006 to 7/3/2006.

Colours indicate lowest altitude supplied from occultation profile in km.

Plotted at 11:51 8-Mar-2006
Ground-based GPS

- Uses standard GPS navigation signals and standard geodetic-quality receivers
- Atmospheric zenith total delay (ZTD) included in position solution
- Information on ‘dry’ (ZHD) and ‘wet’ (ZWD) components
- IWV = (ZTD-ZHD)/k = ZWD/k (k ~6.5)
- European collaboration via EUMETNET E-GVAP (& previously EU COST-715 & TOUGH)
- Semi-operational hourly data downloads from 500+ stations over Europe
- Processed to Total Zenith Delay in <2 hours
Ground-based GPS over Europe

NRT stations processed by all (571 sites)
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Meteosat vs MSG: Differences

Meteosat 7
- 30 Minutes
- 3 Channels
- 2500 x 2500 pixels
- 5 km at SSP (2.5km)

Meteosat 8
- 15 Minutes
- 12 Channels
- 3712 x 3712 pixels
- 3 km at SSP (1km)
MSG channels

New MSG channels

IR window ~ 10.8μm

WV absorption ~6.7μm

VIS ~0.6μm

INFRARED

Methylene (CH₄)

Nitrous oxide (N₂O)

Oxygen (O₂) and Ozone (O₃)

Carbon dioxide (CO₂)

Water vapor (H₂O)

Atmosphere

Wavelength (m)

Percent of incoming radiation absorbed
Day-time correlations – 1200Z, 1st December 2005

2-d day
(0.8 μm, 10.8 μm)
c.c. = 0.61

3-d day
(0.8 μm, 3.9 μm, 10.8 μm)
c.c. = 0.68

4-d day
(0.8 μm, 1.6 μm, 3.9 μm, 10.8 μm)
c.c. = 0.78

2-d night
(10.8 μm, 12.0 μm)
c.c. = 0.46

3-d day
(0.8 μm, 3.9 μm, 10.8 μm)
c.c. = 0.75

2-d day
(0.8 μm, 10.8 μm)
c.c. = 0.61

1-d
(10.8 μm)
c.c. = 0.45
Simulated imagery at Met Office

- Use regional NWP analysed fields of T(p), RH(p), Ts as input to fast RT model (RTTOV-7)
- Estimate cloud at each level from RH (if RH > 80% then cloud fraction assigned 0-1)
- Compute cloud overlap (maximal or random)
- Run RTTOV with cloud layers seen by satellite
- All IR channels simulated for each model grid box (clear+cloudy)
- Display alongside measured SEVIRI imagery
- Only 6.2um used at present by forecasters
Simulated MSG imagery from NWP
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METOP preparations

- Launch on 17 July from Baikonur
- Testing systems using NCEP simulated METOP datasets
- Data reception tests using EUMETCAST
- Use ATOVS within a few months of launch
- Use ASCAT, GRAS and IASI within 18 months of launch
IASI Implementation

- IASI poses huge challenges because of the volume of data
  - 8461 channels, 120 observations per scan
- We will reduce this data volume by using only 300 channels and one in four observations
  - Channels selected on the basis of information content
  - Reduces data volume of one IASI to about the level of three ATOVS
- Initially, we will use the data in a very similar way to AIRS
  - Sea only
  - Clear only (via 1D-Var cloud detection)
Satellite data increases

Number of satellite sensors for NWP

- COSMIC
- TERRA
- GMS/MTSAT
- GOES
- METEOSAT
- CORIOLIS
- ADM
- ADEOS
- AQUA
- QSCAT
- NPP
- METOP
- ENVISAT
- ERS
- DMSP
- NOAA

Year

No. of instruments
0 10 20 30 40 50 60

+ FY-3?
Any questions?