Assimilation of satellite data at ECMWF: Highlights

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18 March 2003

Outline

- Importance of current satellite observations in the ECMWF NWP system
- Recent enhancements of the satellite data usage at ECMWF
- Preparation for new satellite missions
  - ENVISAT
  - Advanced Sounders (AIRS-AQUA, *IASI-METOP, NPOESS*)
  - ADM
- Further challenges
  - Assimilation of clouds and precipitations
  - Assimilation of GPS radio-occultation measurements

Importance of current satellite observations in the ECMWF system

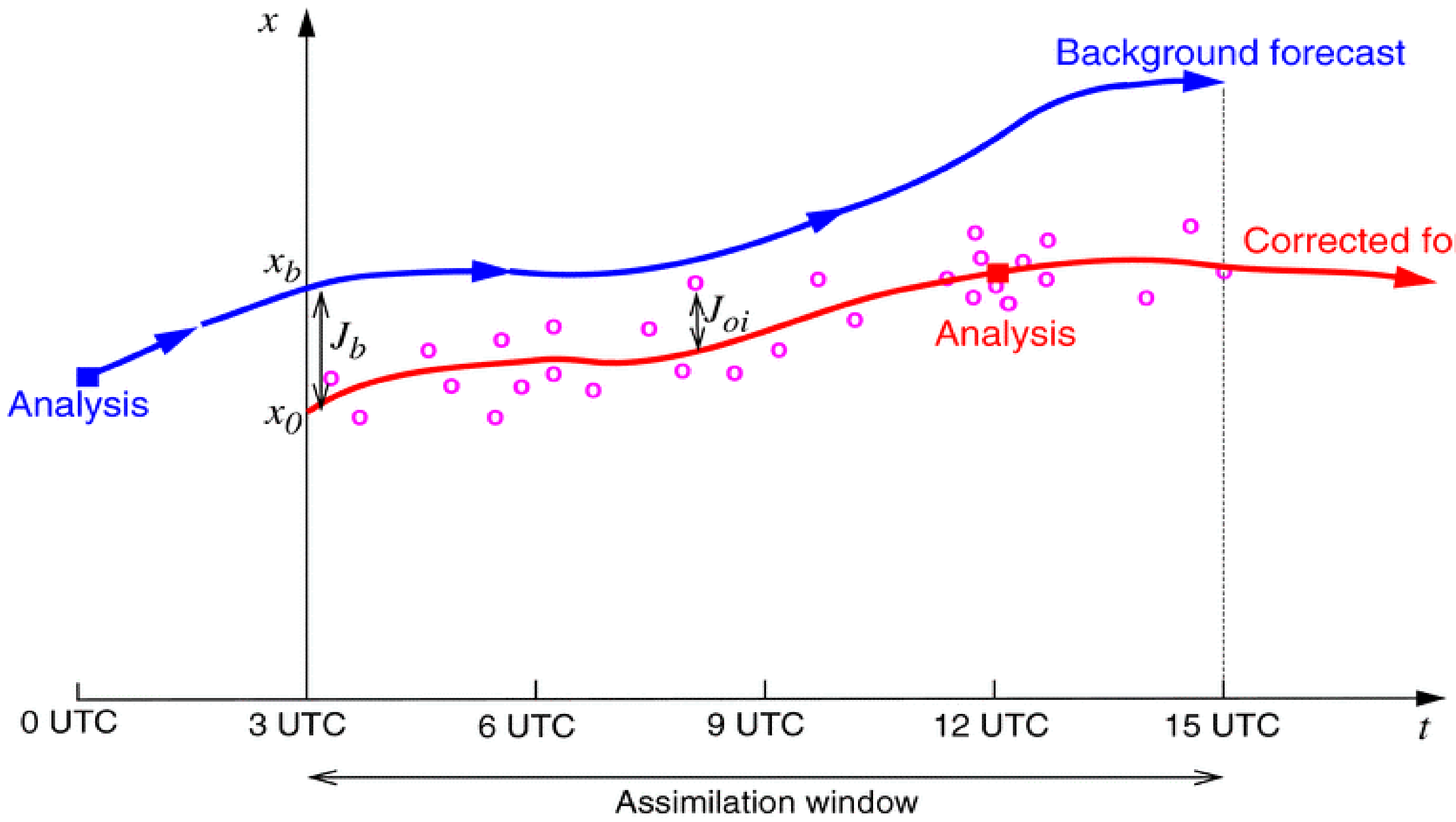
- **Satellite data have progressively become an essential part of the observing system used at ECMWF**

- **Satellite data represent by far the largest volume of data (and associated computing cost) used in the ECMWF data assimilation system**

- **Satellite data have recently caught up radiosondes in terms of forecast skill impact over NH**

- **4D-Var is particularly appropriate to assimilate high time frequency data**

4D-Variational Analysis of Observations (4D-Var)



Current data count (31/01/2003 00Z)

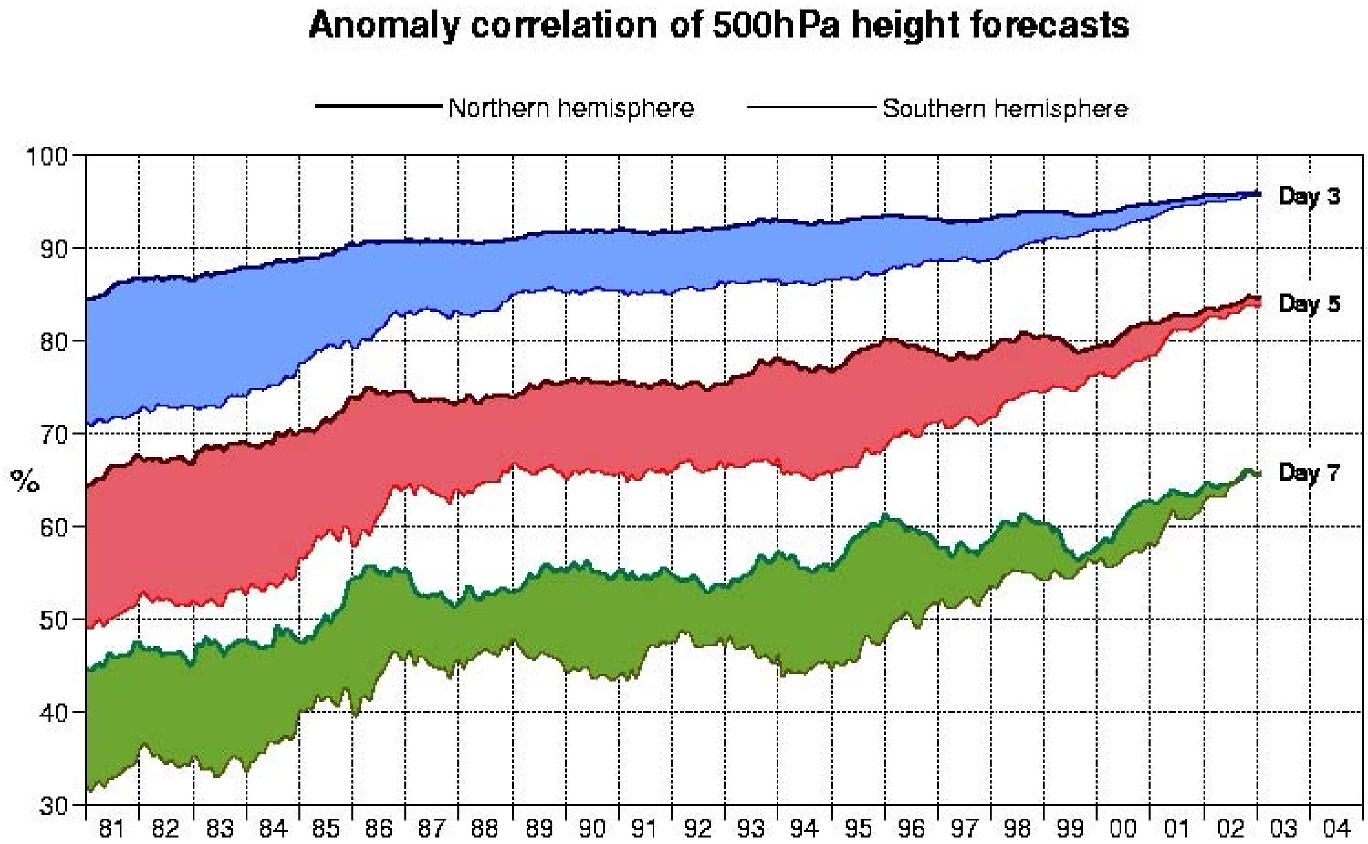
Data entering the screening

Synop:	166207	(1.1%)
Aircraft:	251024	(1.7%)
Satob/modis:	618434	(4.2%)
Dribu:	7480	(0.005%)
Temp:	108520	(0.7%)
Pilot:	78006	(0.5%)
Upper Sat :	13151980	(90%)
PAOB:	538	(0.00%)
Scat:	225330	(1.6%)
TOTAL:	14607519	(95.8%)

Data assimilated

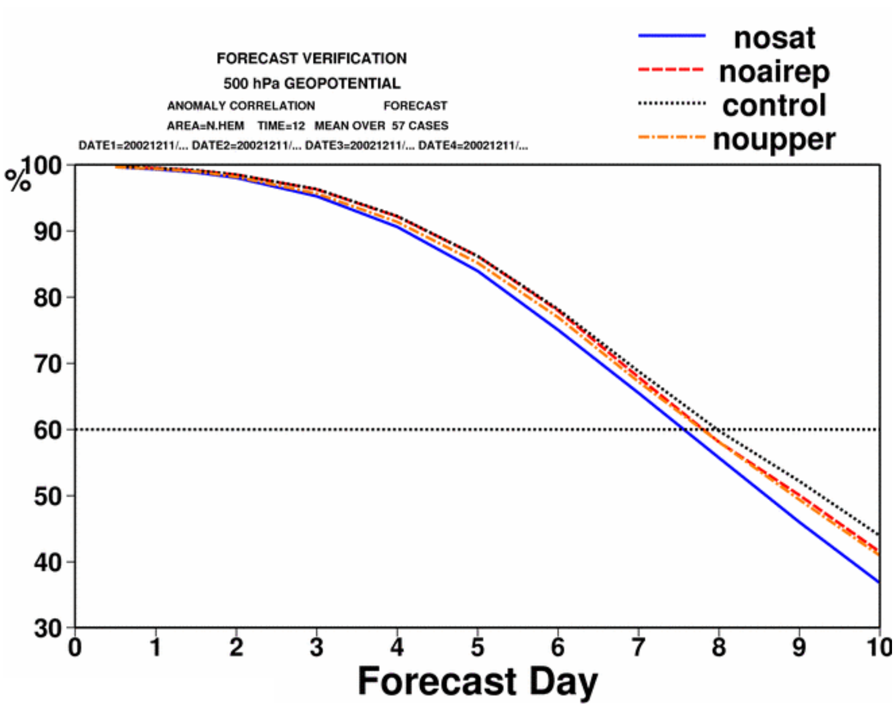
Synop:	37065	(2.5%)
Aircraft:	157817	(10.8%)
Satob:	83532	(5.7%)
Dribu:	3669	(0.25%)
Temp:	60887	(4.2%)
Pilot:	44498	(3.0%)
Upper Sat :	960561	(65.6%)
PAOB:	182	(0.01%)
Scat:	115692	(7.9%)
TOTAL:	1463903	(79.2%)

Evolution of forecast skill for northern and southern hemispheres

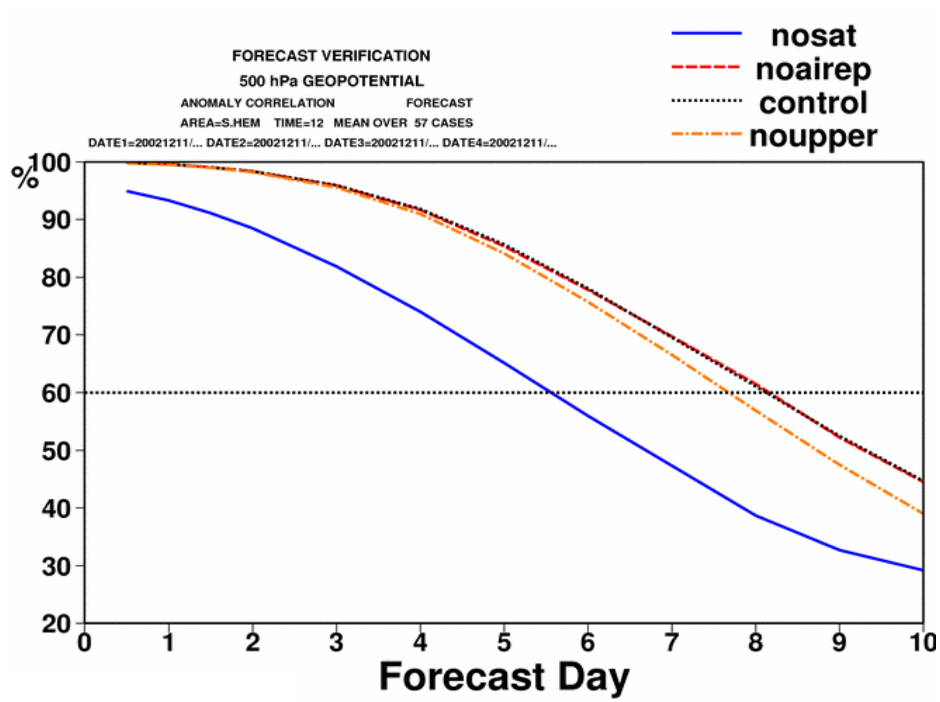


Latest Observing-System Experiments

Northern hemisphere



Southern hemisphere

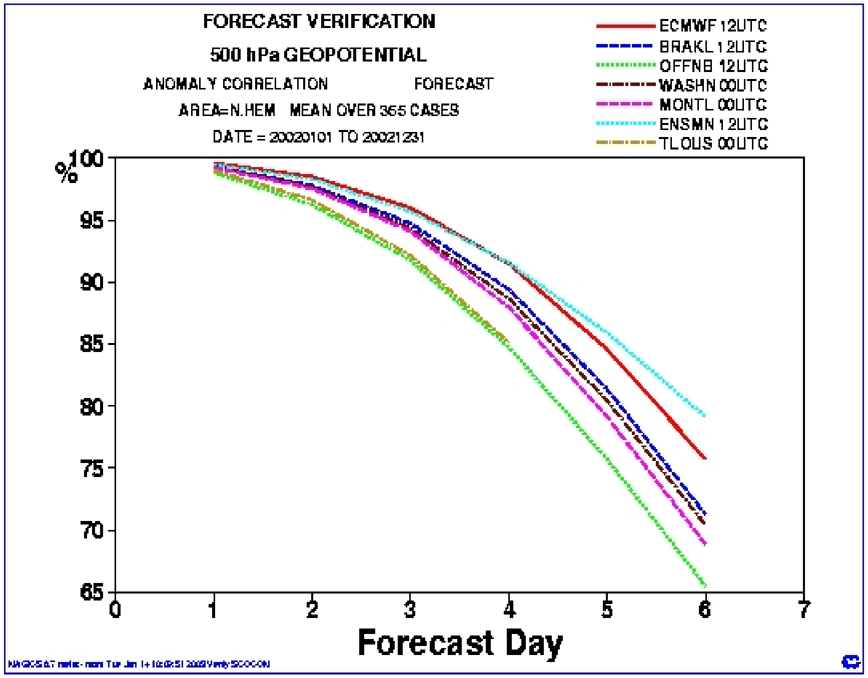


Verification against control analysis

Comparison with other NWP centres (year 2002)

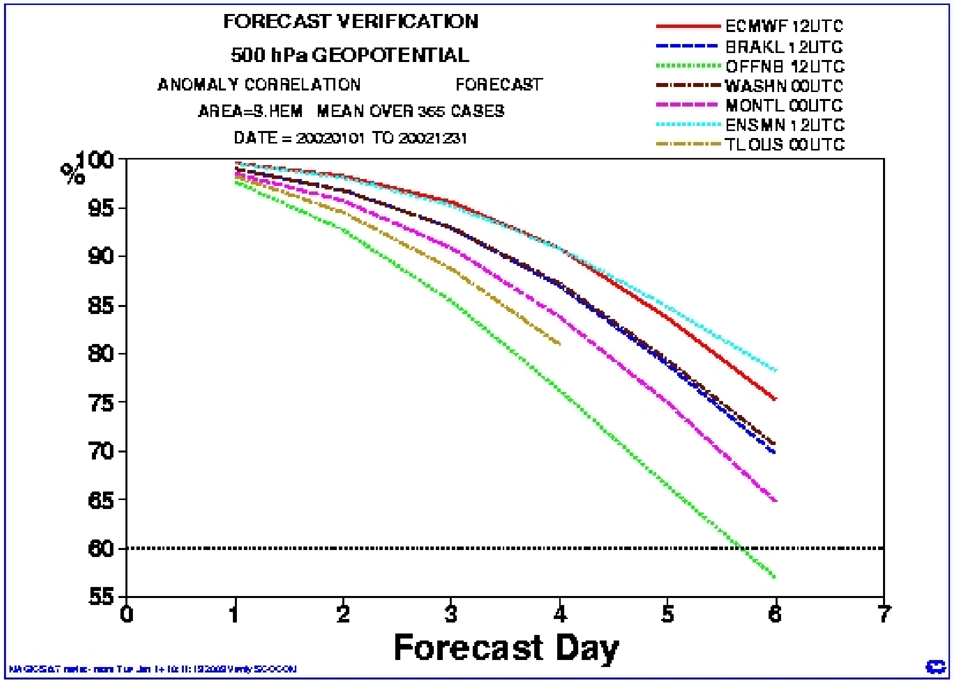
Northern hemisphere

(500 hPa)

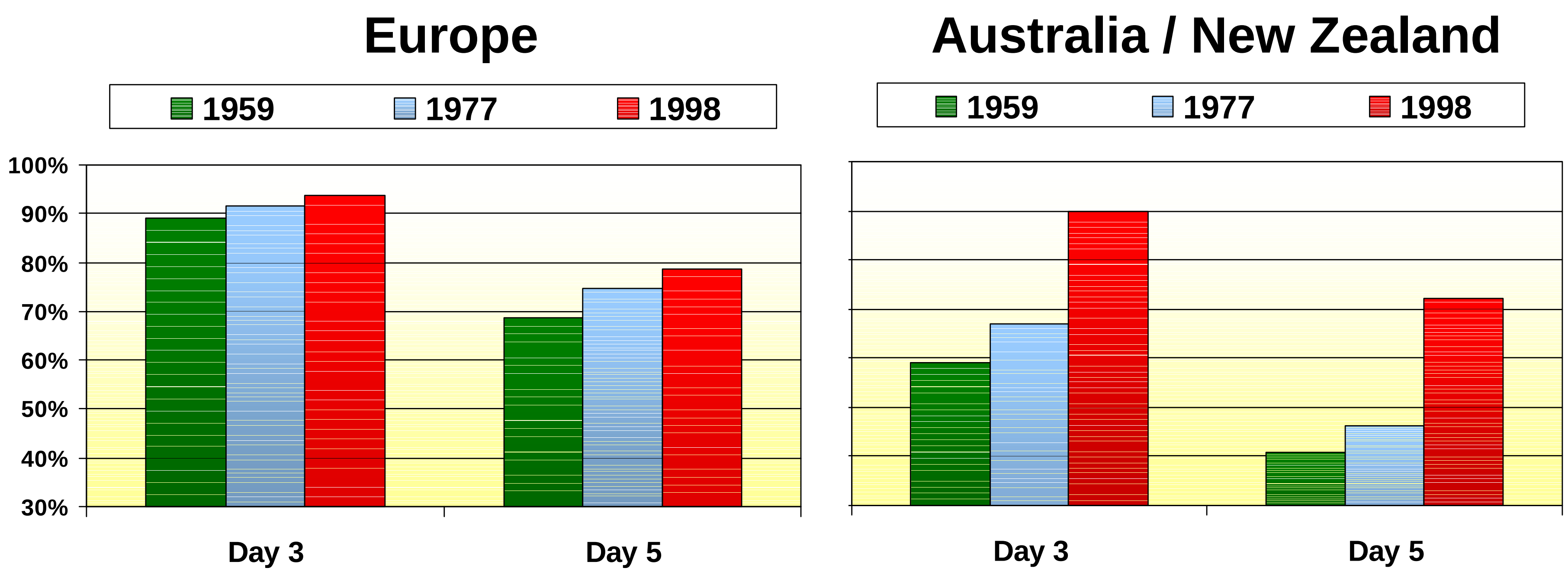


Southern hemisphere

(500 hPa)



Applying today's processing to past observations: accuracy of forecasts from the ERA-40 re-analyses



Recent enhancements of the satellite data usage in the ECMWF system

- Assimilation of water vapour radiances from geostationary satellites
- Assimilation of QuikScat surface winds
- Assimilation of ozone data (TOMS, GOME, SBUV)
- Direct assimilation of SSM/I radiances
- Assimilation of MODIS atmospheric motion winds
- Assimilation of 3 sounding missions (NOAA-15/16/17)
- Reintroduction of more infrared channels in the assimilation system

Recent enhancements of the satellite data usage at ECMWF

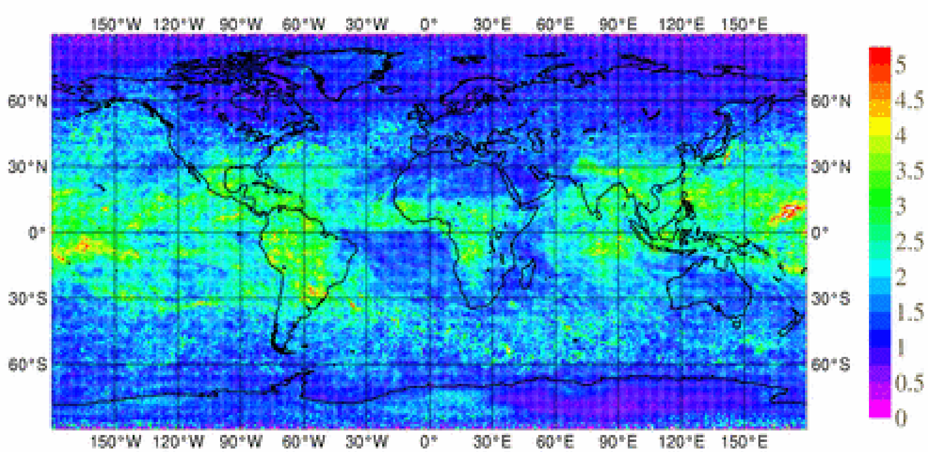
- Assimilation of water vapour radiances from METEOSAT
  - Outcome:
    - Adjustment in areas of known model deficiencies
    - Improved fit to HIRS-12 and AMSU-B data
    - Positive to neutral forecast impact
    - Noticeable impact of upper level winds/geopotential
    - Good grounds for MSG CAL/VAL and assimilation
- Extension to GOES satellites (CIMSS/NESDIS)
    - Similar impact

Assimilation of Meteosat-7

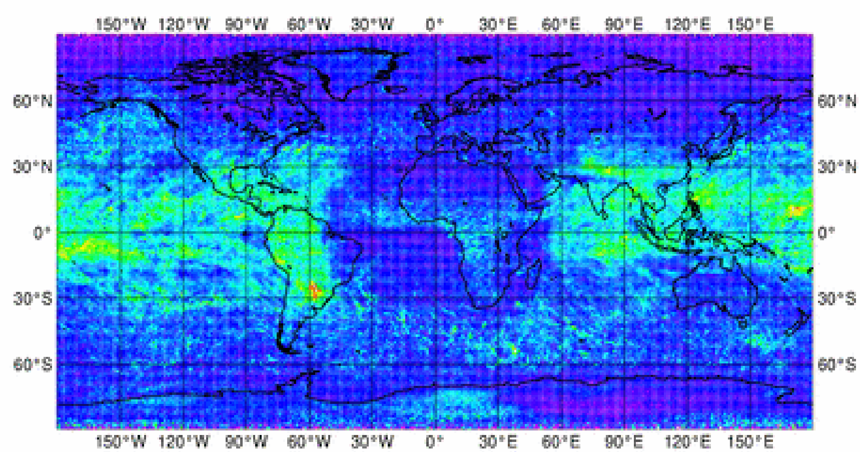
Technical aspects:

- Implementation described last year
- Data quality: - Solar stray light affected images excluded
  - Use of %clear information in CSR
  - $\rightarrow$ Improved quality indicators, e.g. based on results of cloud detection scheme (thresholds) may be useful

Impact of the data: Visible with passive HIRS-12 radiances (NOAA-15)

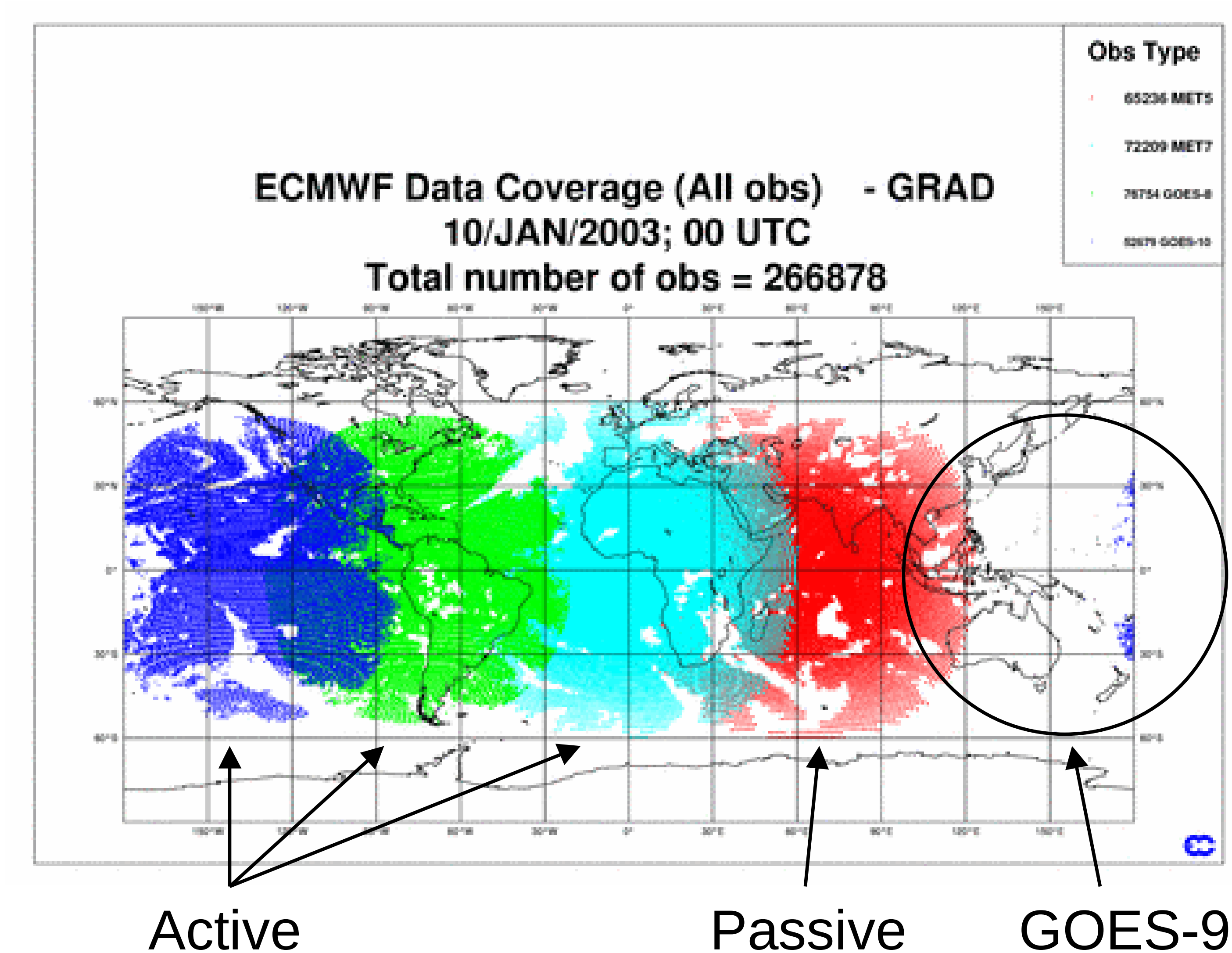


STDV (HIRS-12 – model first guess)



STDV (HIRS-12 – model analysis)

Current coverage with geostationary radiances

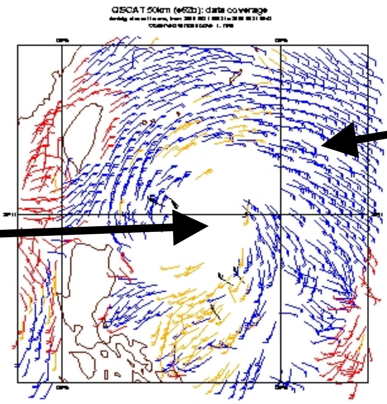


Recent enhancements of the satellite data usage at ECMWF

- QuikScat data have been assimilated operationally since January 2002:
    - Importance of monitoring and quality control
    - Careful handling of rain contamination problem (that does not exist with ERS-2 scatterometer)
    - Further refinements of the rain QC needed
    - Evidences of better tracking of tropical cyclones
    - Positive scores in the SH (neutral in NH)
    - Experience capitalised (together with ERS-2) towards ASCAT
- Note: ERS-2 platform still used for the RA and SAR (possibly soon scatterometer)

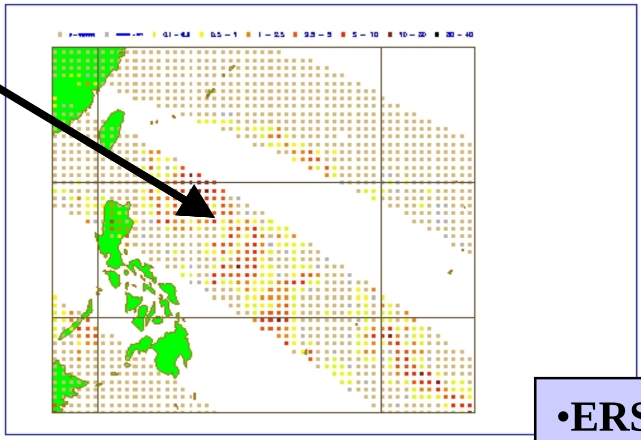
Quikscat assimilated operationally since January 2002 (SCAT work supported by ESA)

Super Typhoon Bilis



Big gaps in data coverage due to rain contamination

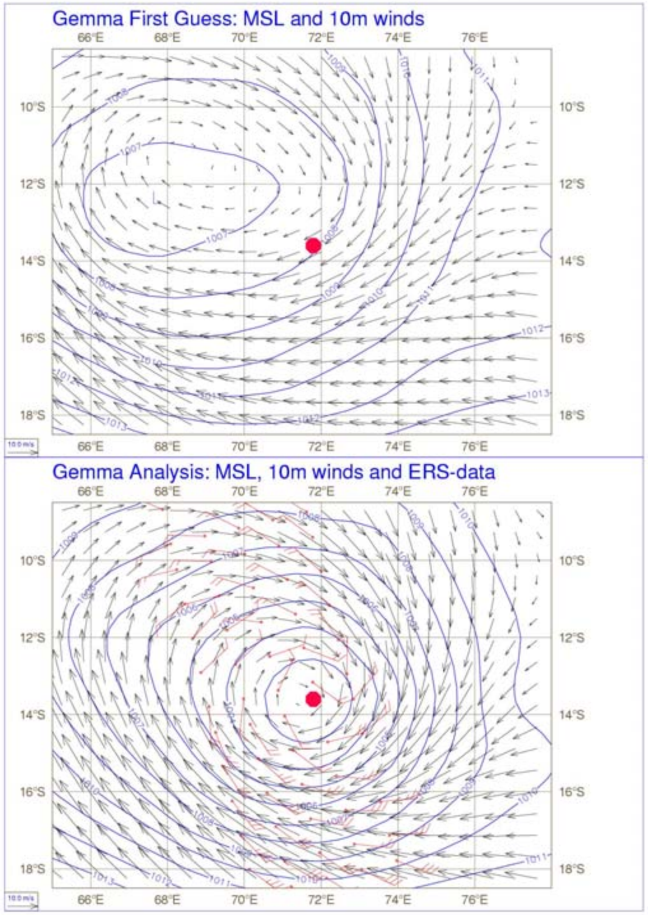
But large scale environment is well observed and dynamically constrained by 4D-Var



TRMM data: precipitation (mm/hour)

- ERS-2 Scat did not have this problem
- ASCAT will not have this problem
- Note: ERS-2 SAR and RA are assimilated operationally and ERS-2 SCAT may come back shortly

Example of the analysis correction by the assimilation of ERS-2 in the ECMWF 4D-VAR system



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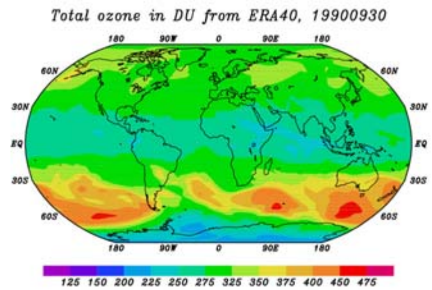
Recent enhancements of the satellite data usage at ECMWF

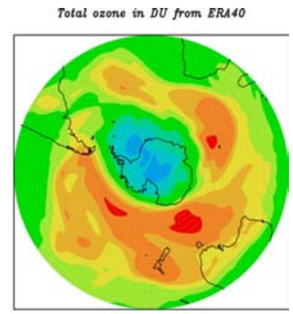
- **Ozone data are assimilated operationally since 9 April 2002:**
  - **GOME (Global Ozone Monitoring Experiment)**
    - **ERS-2**
    - **Total column ozone**
    - **NRT retrievals from KNMI**
    - **Approx. 20000 observations daily (14000 used)**
  - **SBUV/2**
    - **NOAA-16 (NOAA-14)**
    - **NESDIS retrievals**
    - **6 ozone layers:**
      - .1-1 hPa, 1-2 hPa, 2-4 hPa, 4-8 hPa, 8-16 hPa, 16hPa-surface
      - Approx 1400 observations daily (1200 used)

Total column ozone – Ozone hole

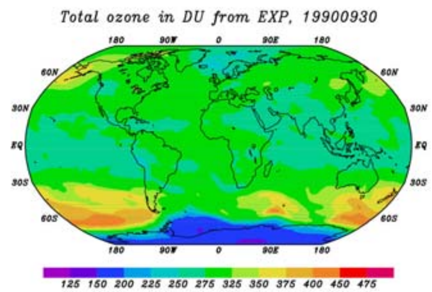
30 Sept. 1990

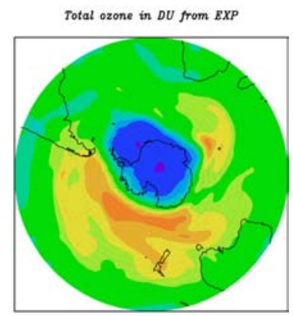
No O3 assim.



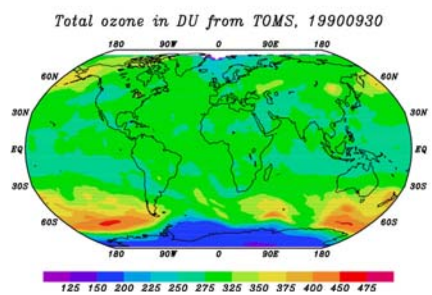


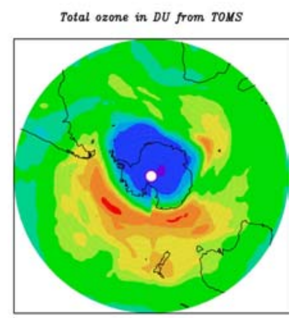
With O3 assim





TOMS



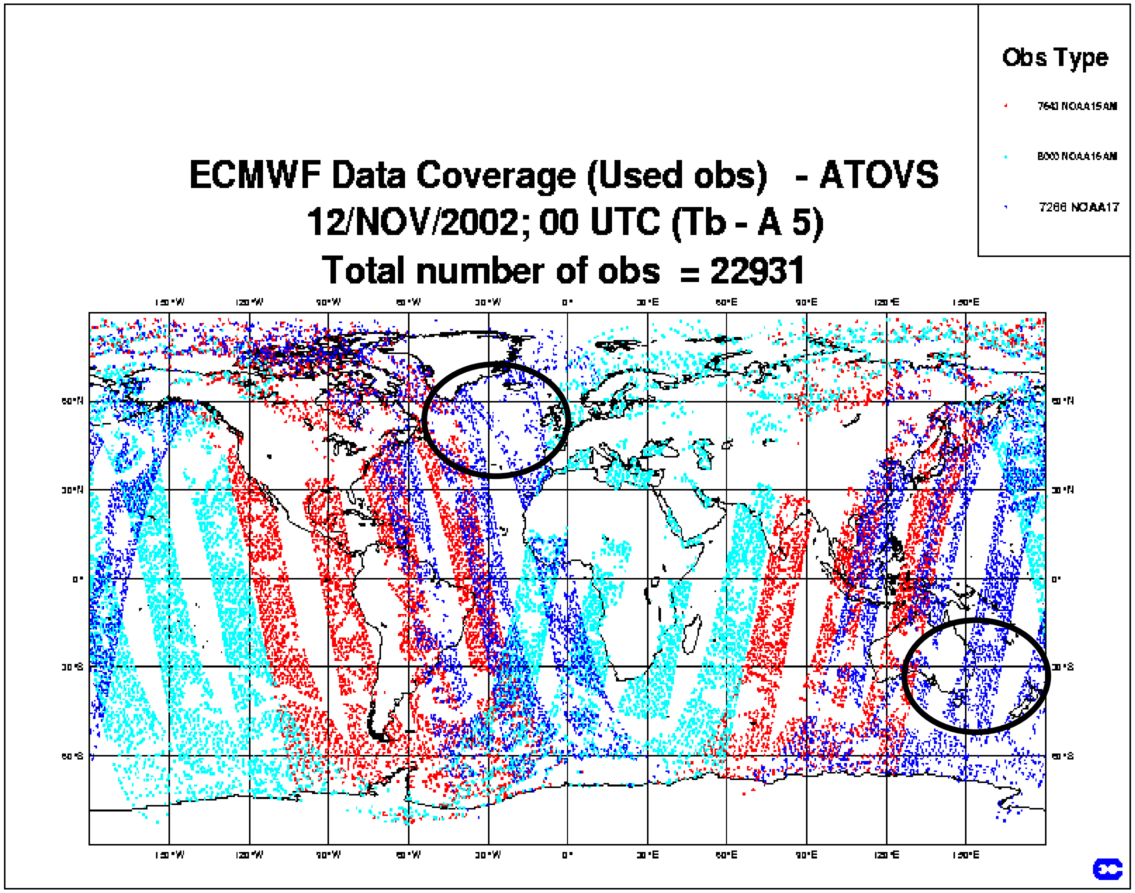


Used AMSU-A channel 5 provided by 3 satellites
(-3h / +3h centred around 00 UTC)

NOAA-15 (07:30 am) | NOAA-16 (13:30 pm) | NOAA-17 (10:00 am)

- NOAA-17 nicely fills the 00 UTC gap in SW Pacific and NE Atlantic Oceans

- Note the shift between NOAA-15 and NOAA-17
  - The quadrature is not optimal with NOAA-16
  - Potential risks of redundancy and more important gaps when NOAA-15 ceases



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Preparation for current and future missions

- **ENVISAT**
- **AIRS**
- **ADM**

ENVISAT data monitored

NRT level-2 'Meteo' products:

- **MIPAS (MIP_NLE_2P): O_3, H_2O, T, P profiles**
- **GOMOS (GOM_RR_2P): O_3, H_2O, T profiles**
- **SCIAMACHY (SCI_RV_2P): column O_3 (nadir)**
- **RA-2: wave height, surface wind**
- **ASAR: wave spectra**

Monitoring

- **Passive assimilation:** **Data are not assimilated actively, but go through the assimilation system and statistics (e.g. first-guess departures) are calculated**

- **Use assimilation system to evaluate data quality, biases, instrument and algorithm stability (can also show model problems)**

- **Output statistics:**
- **- Number of data**
- **- Mean**
- **- Stdev of**

} **Observations**

Departures (first-guess, analysis)

Monitoring of SCIAMACHY Meteo data (SCI_RV__2P): Ozone

- Meteo products from ftp-ops.pdk.envisat.esa.int, converted into BUFR format at ECMWF (use of ESA BUFR data should hopefully start this week)

- SCIAMACHY ozone data about 25 DU lower than KNMI GOME data over much of tropics and mid-latitudes

- Unrealistically large values at high latitudes

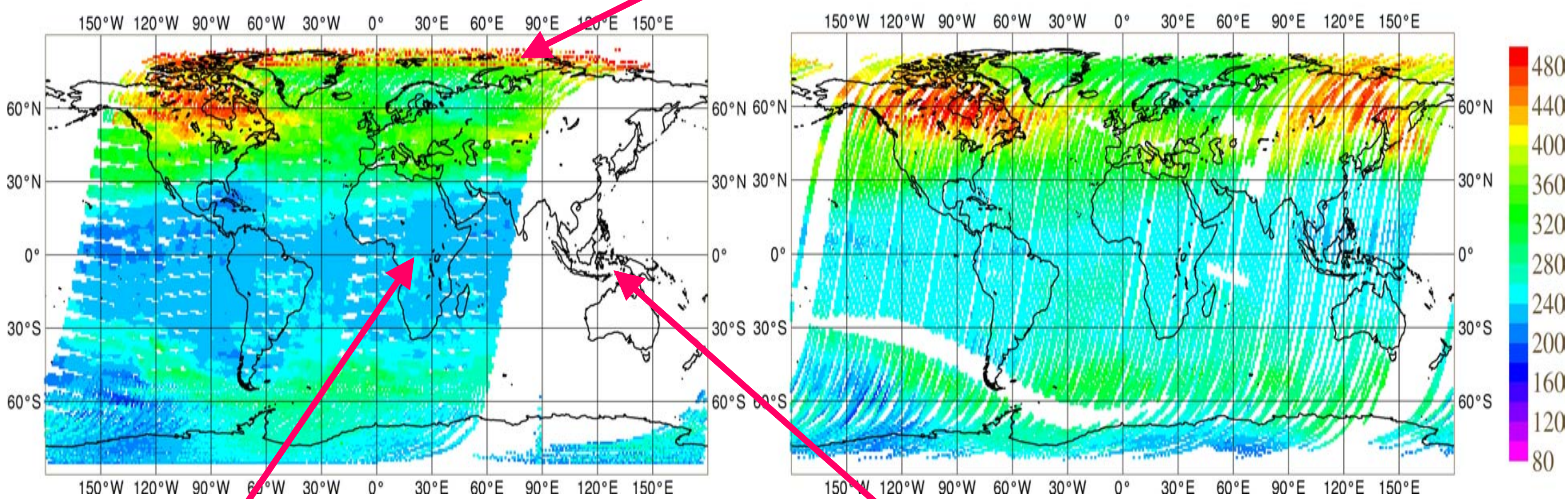
- No geolocation information (e.g. sza, fov) in Meteo data

SCIAMACHY total column ozone: 3.-8.3.2003

SCIAMACHY

GOME (KNMI)

Large SCIAMACHY values at high lat



SCIAMACHY about 25 DU too low

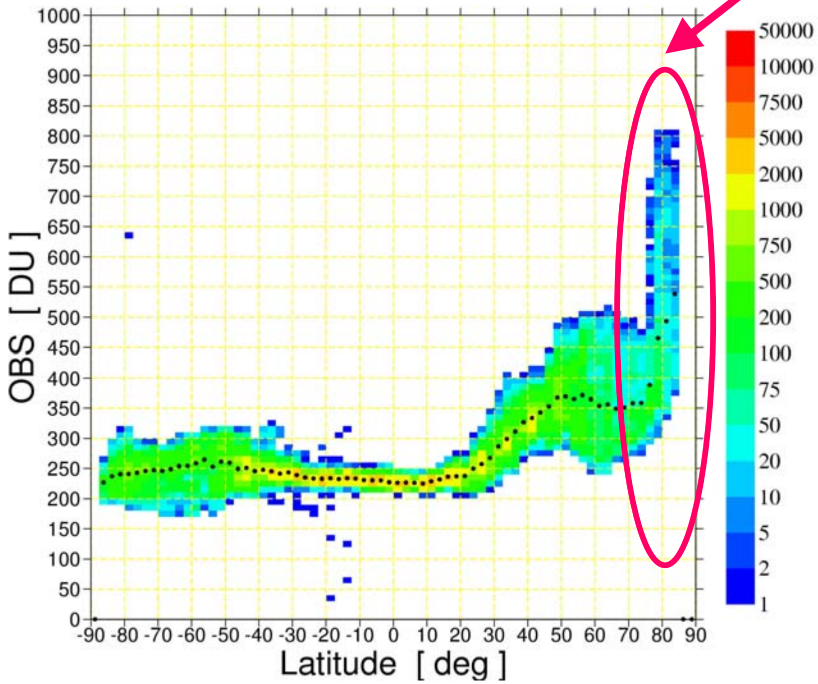
Data gap; data not received in NRT

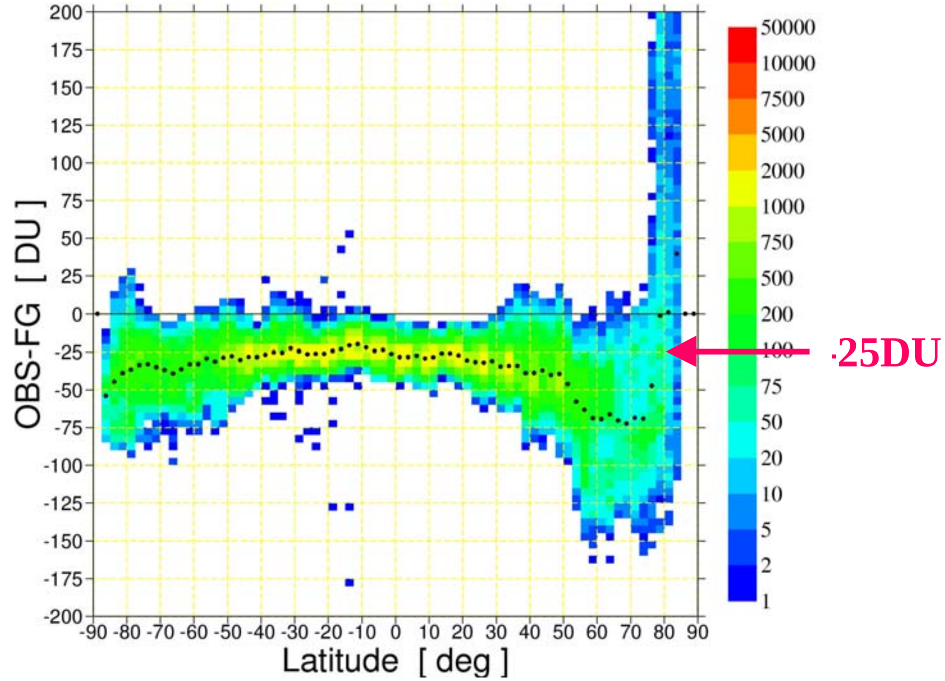
SCIAMACHY total column ozone: 3.-8.3.2003

Observation values

Fg departures

Large SCIAMACHY values at high lat

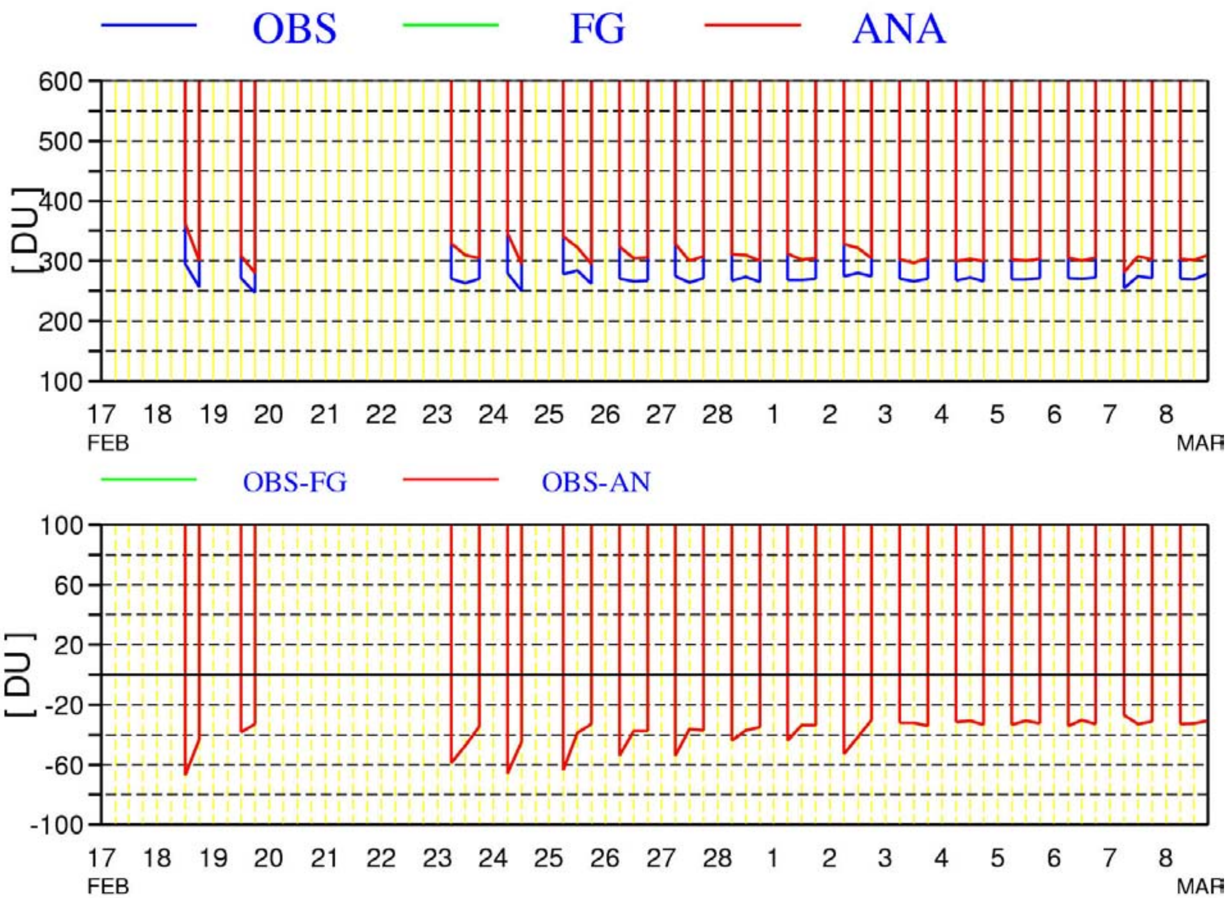




SCIAMACHY total column ozone (global mean): 17.2.-8.3.2003

Obs. and analysis

Departures

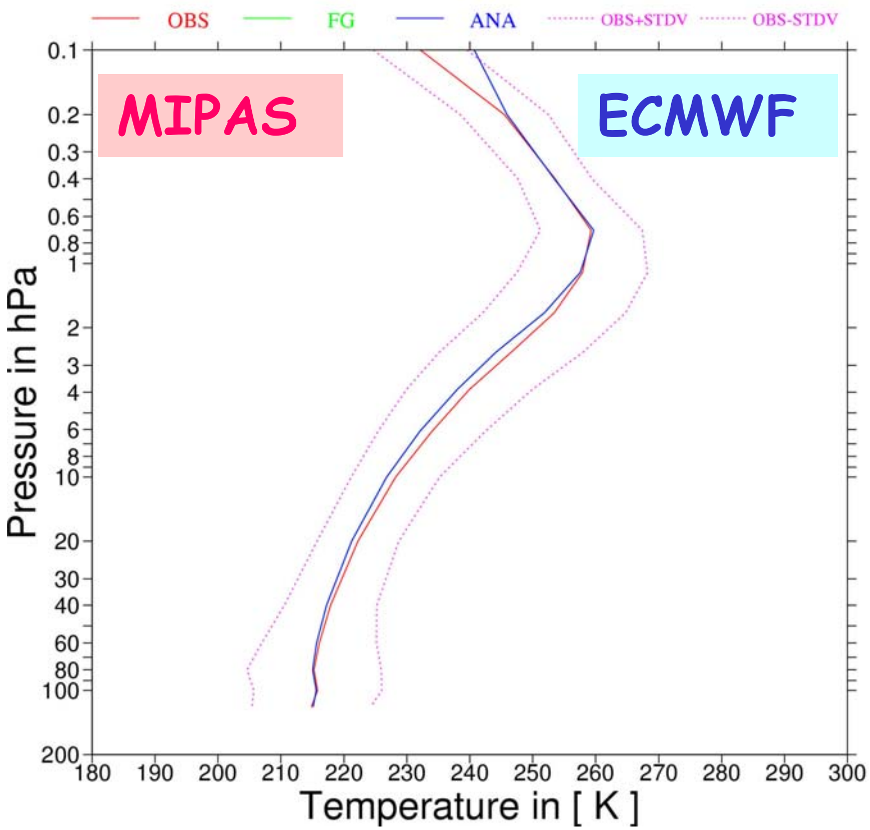


Monitoring of MIPAS Meteo data (MIP_NLE_2P) Temperature

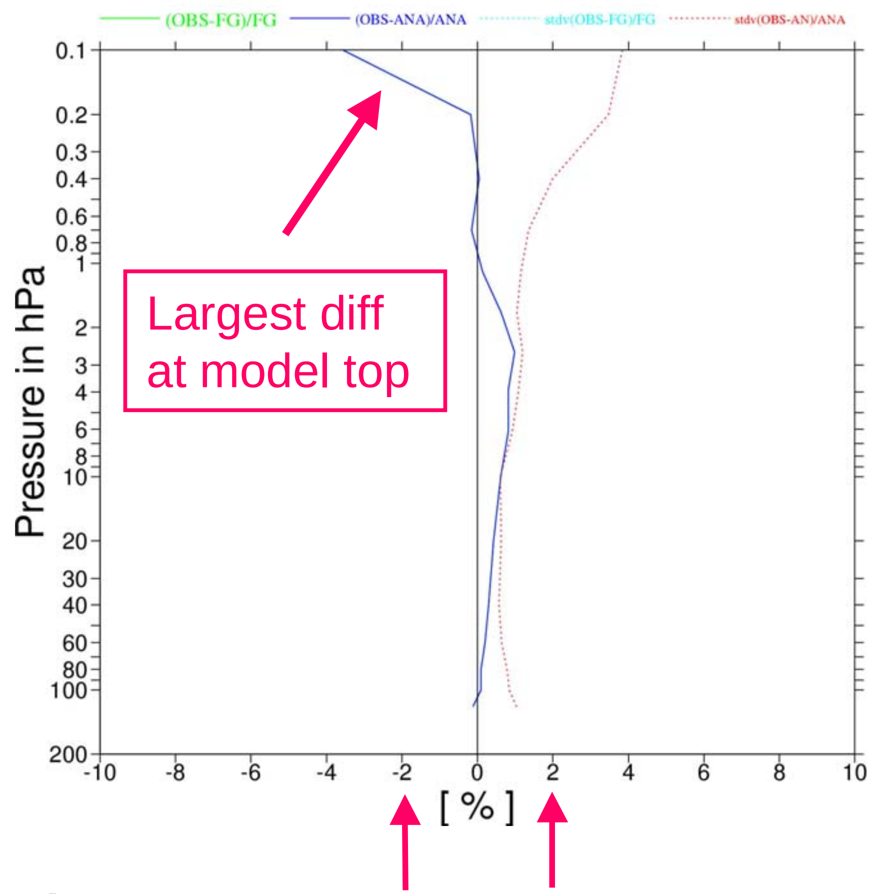
- Good agreement of MIPAS temperatures with ECMWF analyzed temperatures over large part of stratosphere (diff < 2%)
- Largest differences at 0.1 hPa (ECMWF model top)
- Some signs of cloud contamination

MIPAS Temp. profiles (global averages): 3.-8.3.2002

Obs. and analysis



Departures



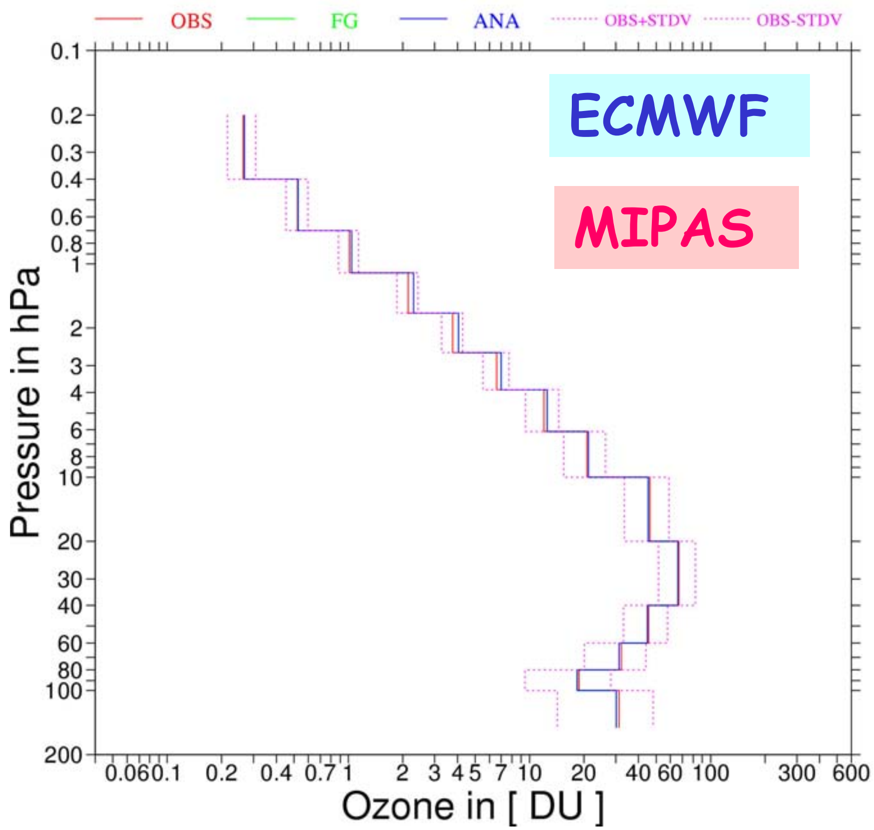
-2 2%

MIPAS Ozone

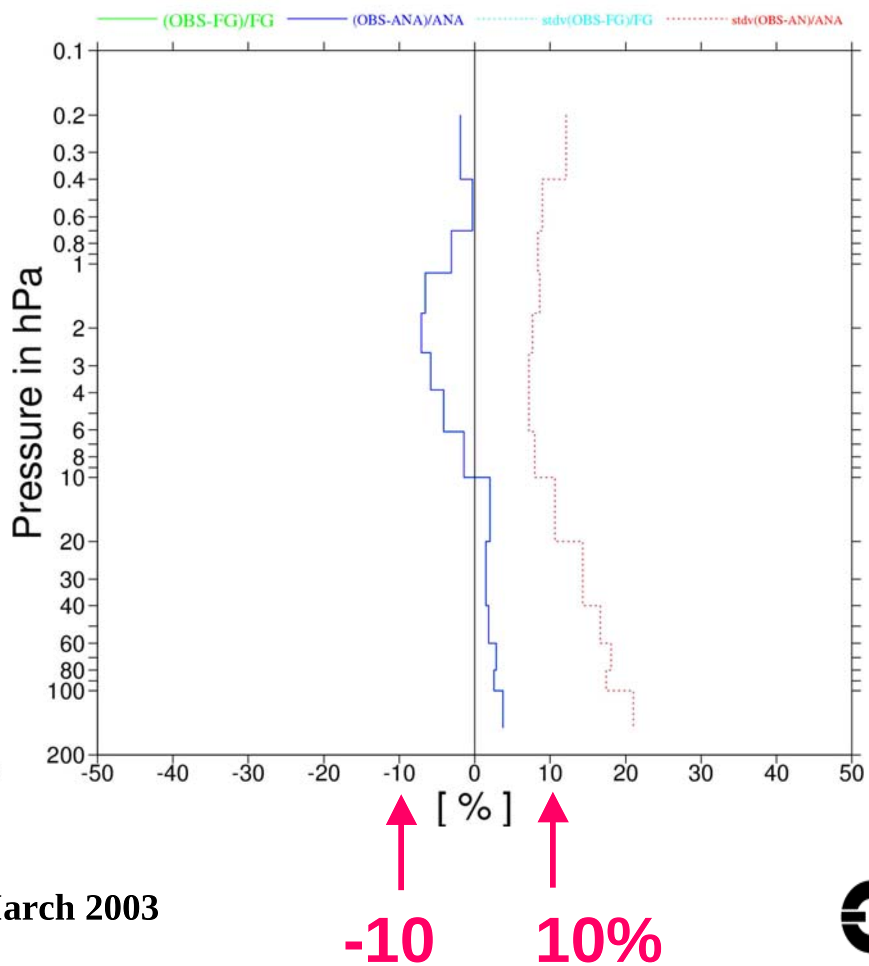
- Reasonable agreement with ECMWF ozone over large part of stratosphere (within +/- 10%)
- Some differences might be explained by known ECMWF model bias: e.g.
  - tropical O3 max. lower in ECMWF than MIPAS
  - 90-65°N: ECMWF > MIPAS over large part of stratosphere

MIPAS ozone profiles (global averages): 3.-8.3.2002

Obs. and analysis



Departures



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MIPAS - Water Vapour

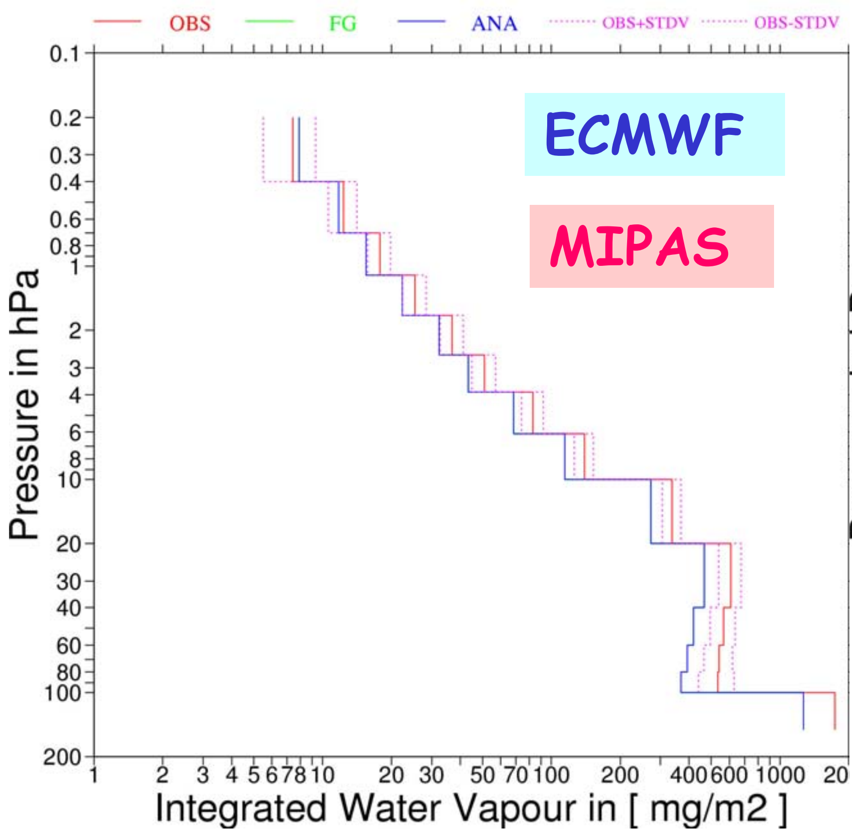
- MIPAS water vapour values generally larger than ECMWF values (diff > 20 % over much of the globe)
- Diff. too large to be completely explained by dry bias of ECMWF model

- Unrealistically large MIPAS water vapour values at lower end of profiles (cloud contamination ?)

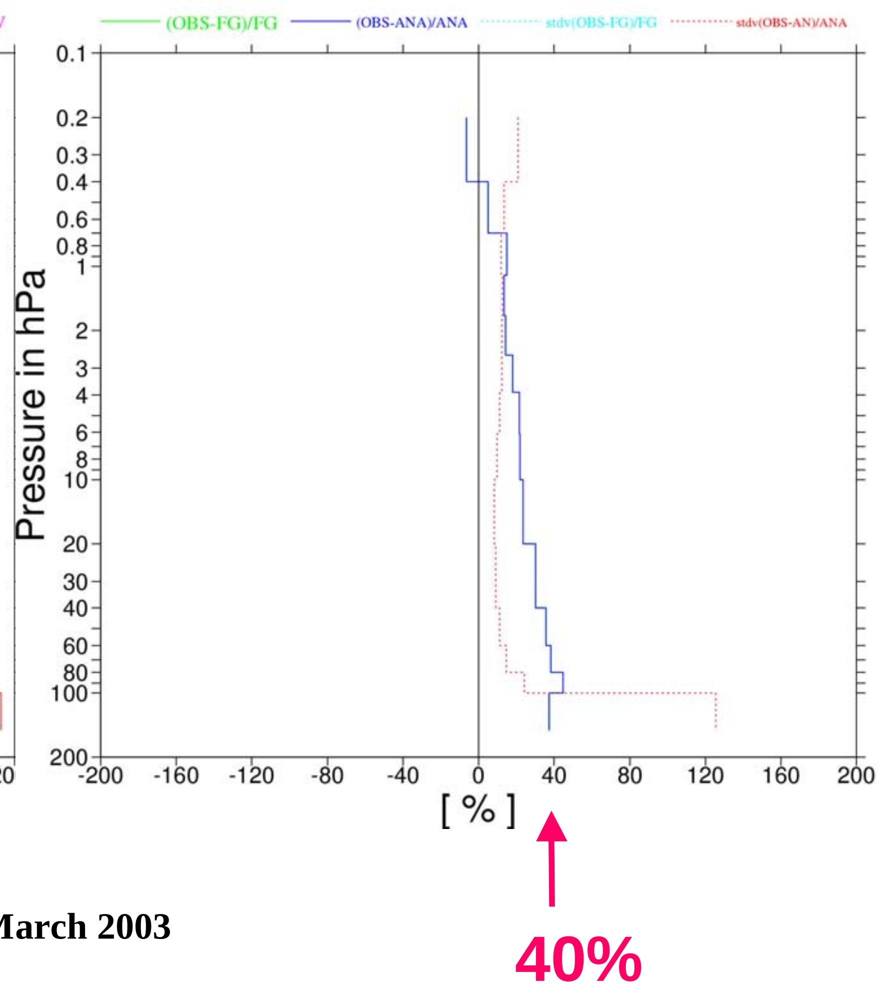
(Reduced number of unrealistically large MIPAS water vapour values, but some remain after upgrade on 13.11.2002)

MIPAS water vapour profiles (global averages): 3.-8.3.2002

Obs. and analysis

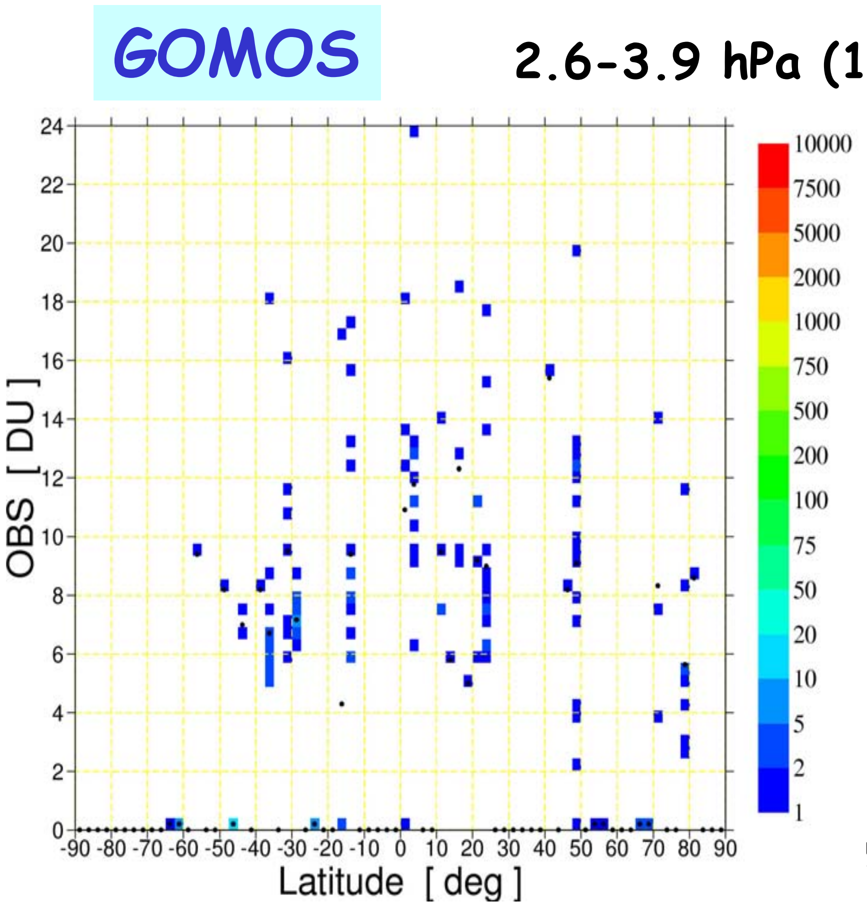


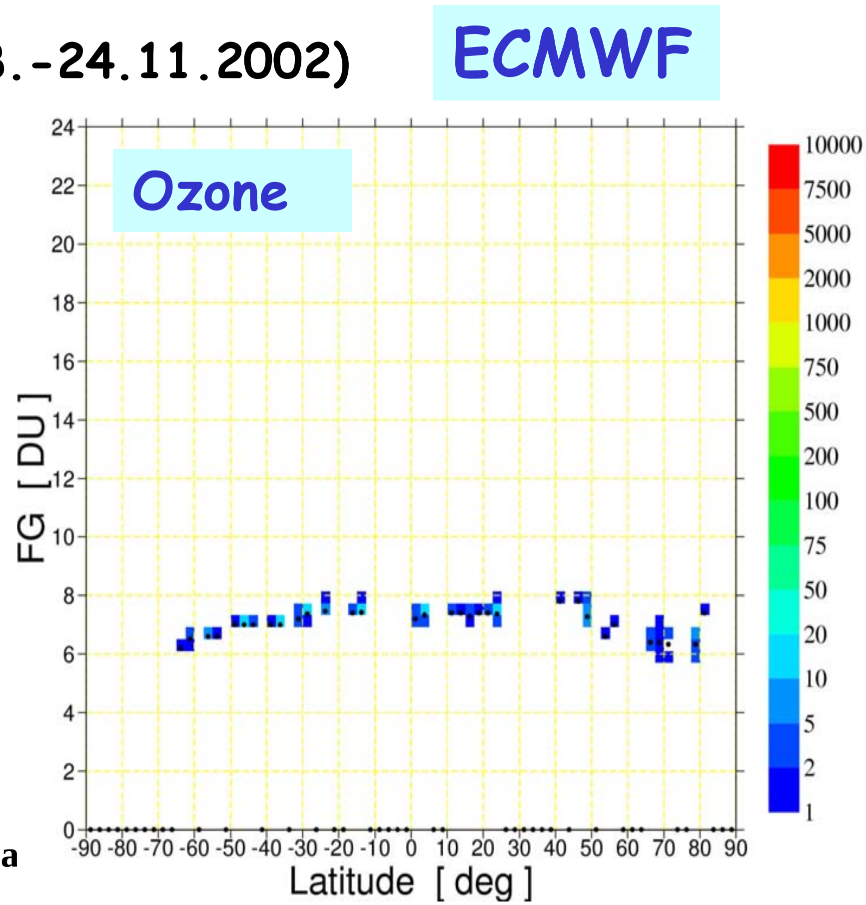
Departures



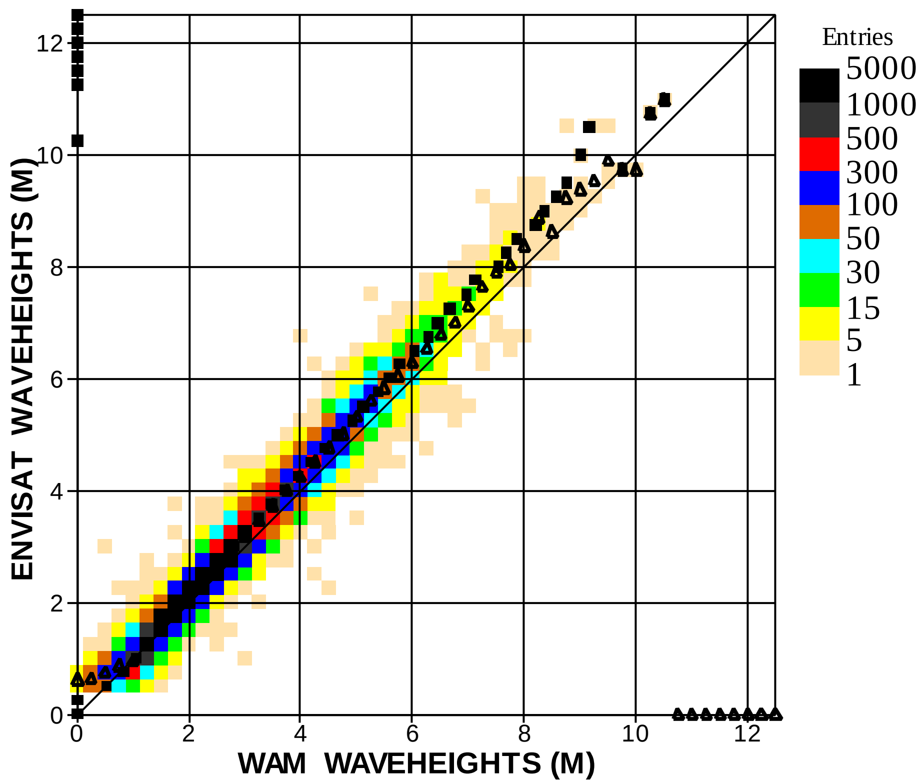
Monitoring of GOMOS Meteo data (GOM_RR__2P)

- PDS GOMOS data quality worse than MIPAS data quality
- Currently, PDS data not worth analysing (need access to ACRI data)





ENVISAT RA-2 Ku-Band
Significant Wave Height



STATISTICS

ENTRIES	46004
MEAN WAM	2.5214
MEAN ENVISAT	2.6816
BIAS (ENVISAT - WAM)	0.1603
STANDARD DEVIATION	0.2092
SCATTER INDEX	0.0830
CORRELATION	0.9871
SYMMETRIC SLOPE	1.0661(0.0008)
REGR. COEFFICIENT	1.0645(0.0008)
REGR. CONSTANT	-0.0023(0.0022)

Comparison between ENVISAT Altimeter Ku-Band and WAM (analysis) significant wave heights for February 2003 (Global)

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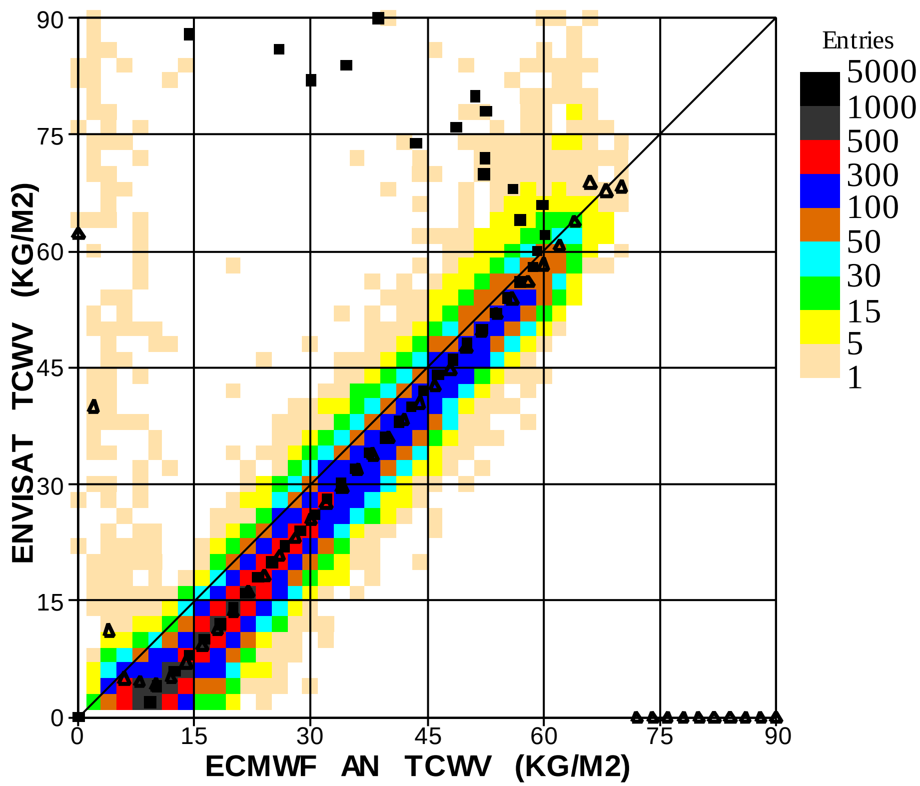
ENVISAT MWR
Total Column Water Vapour



STATISTICS

ENTRIES	33669
MEAN ECMWF	27.4621
MEAN ENVISAT	22.9434
BIAS (ENVISAT - ECMWF)	-4.5187
STANDARD DEVIATION	5.8461
SCATTER INDEX	0.2129
CORRELATION	0.9390
SYMMETRIC SLOPE	0.9093(0.0024)
REGR. COEFFICIENT	1.0531(0.0021)
REGR. CONSTANT	-5.9764(0.0658)

Comparison between ENVISAT MWR and ECMWF (analysis) Total Column Water Vapour for February 2003 (Global)

(Note: Most of the outliers are either near ice edges (North & South Poles) or very close to land.)

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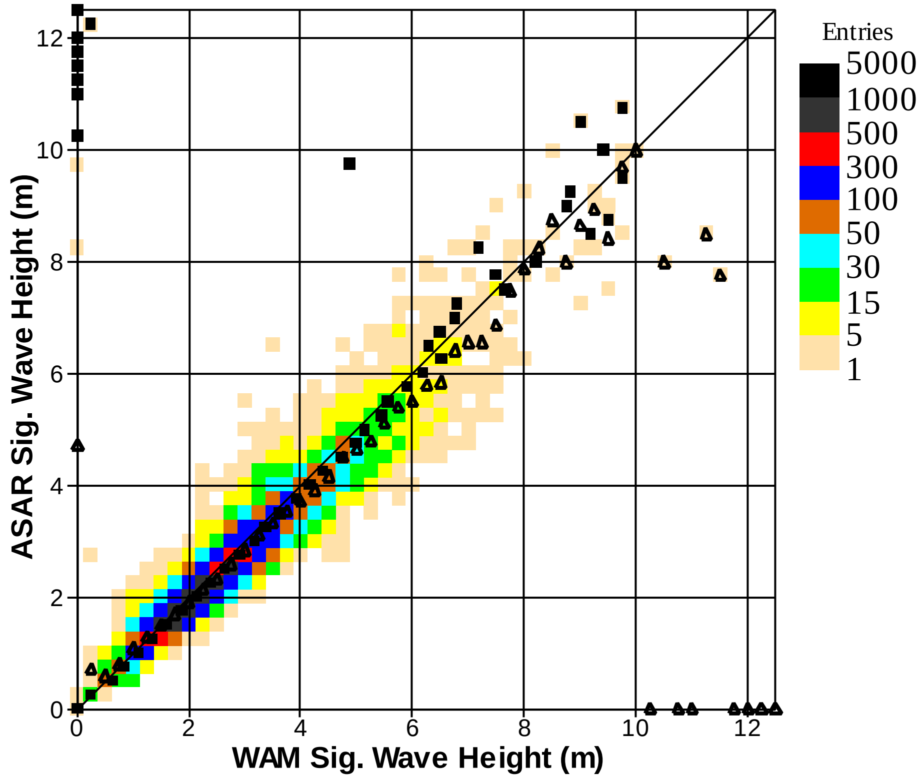
ENVISAT ASAR
Significant Wave Height



STATISTICS

ENTRIES	15363
MEAN WAM	2.6085
MEAN ASAR	2.4872
BIAS (ENVISAT - WAM)	-0.1212
STANDARD DEVIATION	0.3881
SCATTER INDEX	0.1488
CORRELATION	0.9455
SYMMETRIC SLOPE	0.9542(0.0025)
REGR. COEFFICIENT	0.9051(0.0025)
REGR. CONSTANT	0.1262(0.0072)

Comparison of WAM Significant Wave Height with That of ENVISAT ASAR for February 2003 (Global)

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Summary and Outlook

• Monitoring of Meteo products at ECMWF

• SCIAMACHY: Values ca. 10% lower than ECMWF or GOME (KNMI) over large parts of globe

• MIPAS: Profile values seem reasonable, possible cloud contamination at bottom of profiles

• GOMOS: Worse data quality than MIPAS. Large scatter. Water vapour values unrealistically large.PDS data currently not worth analysing

•Wave instruments: good quality (apart from identified outliers for the MWR)

- Continuation of monitoring

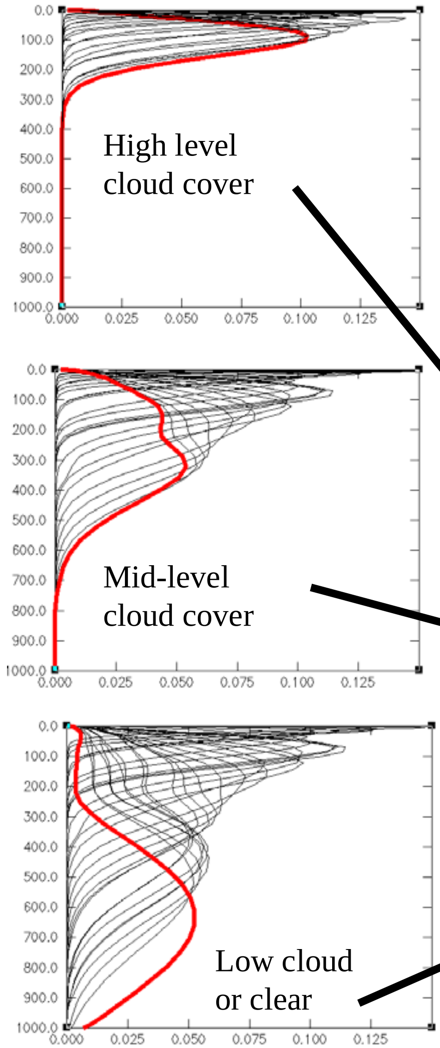
- Experimental assimilation of ENVISAT data

AIRS (NASA): Progress towards an assimilation strategy at ECMWF

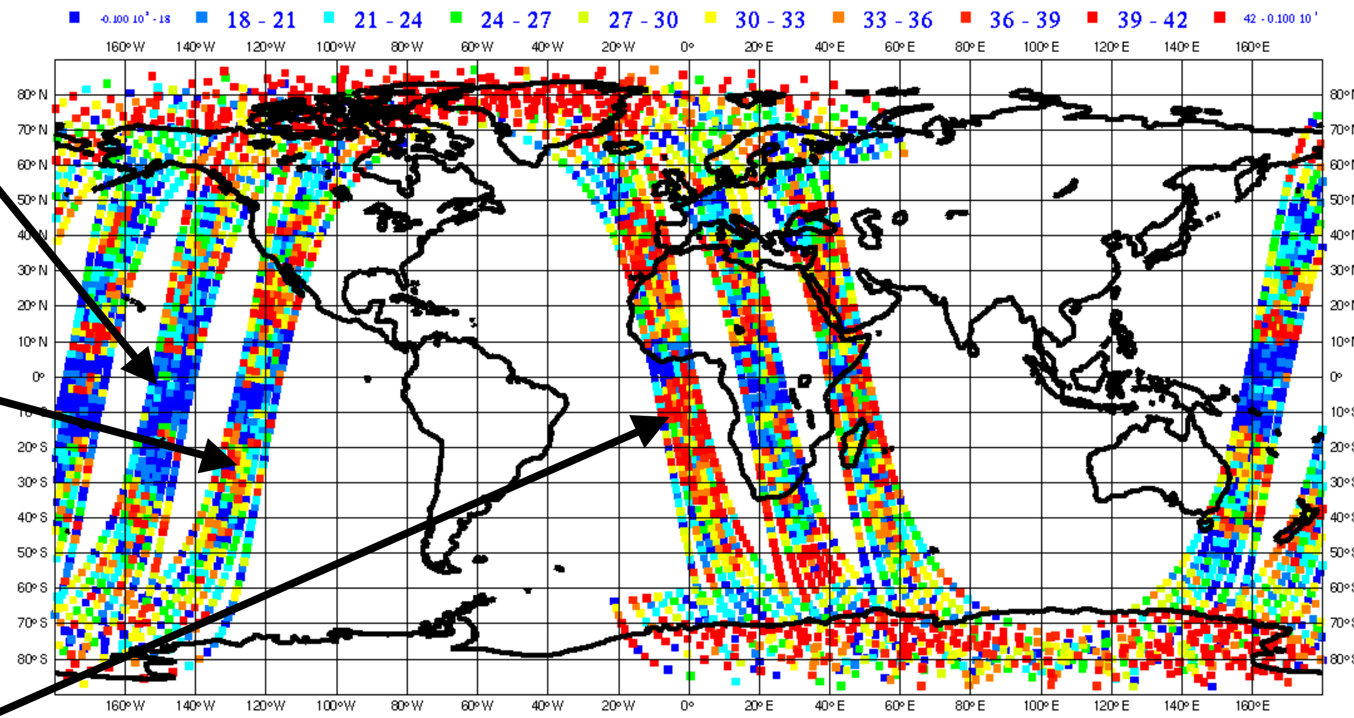
- To fully exploit the potential of AIRS, several issues have to be tackled
  - Handle the data volume from advanced sounders efficiently
    - Technically absorb a substantial increase of data count in the system
    - Scientifically extract the maximum information content from the full spectrum
  - Design an efficient cloud detection scheme
    - clouds can severely limit the information from advanced infrared sounders (probably in the most crucial areas)
  - Design an effective monitoring system able to cope with multichannel information
- Airs provides a CO2 column estimation capability

Cloud detection and channel use above clouds

Temperature
weighting functions



Index of lowest AIRS long-wave channel determined cloud-free
(clouds and AIRS radiances simulated from ECMWF model)



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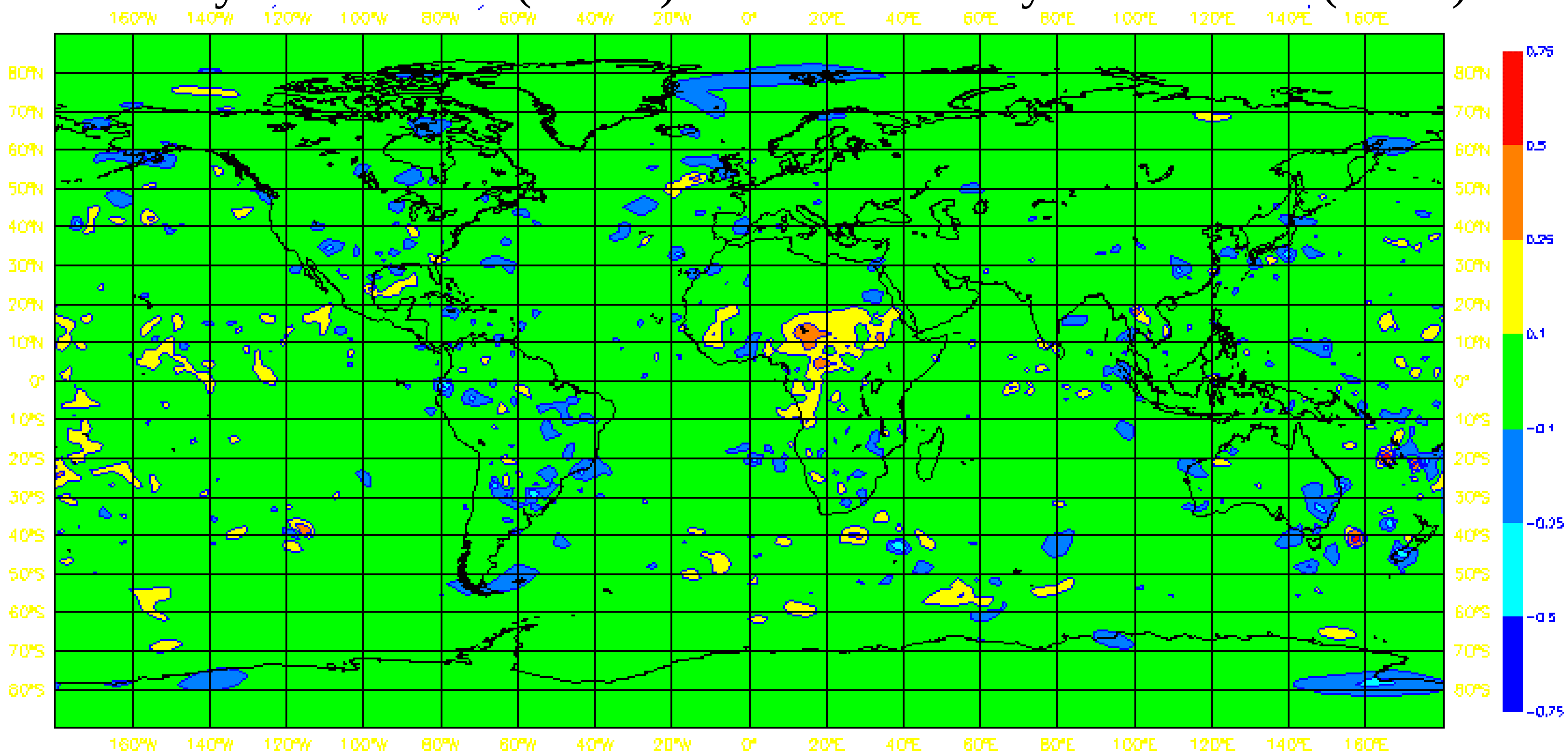
Impact of AIRS on ECMWF assimilation system

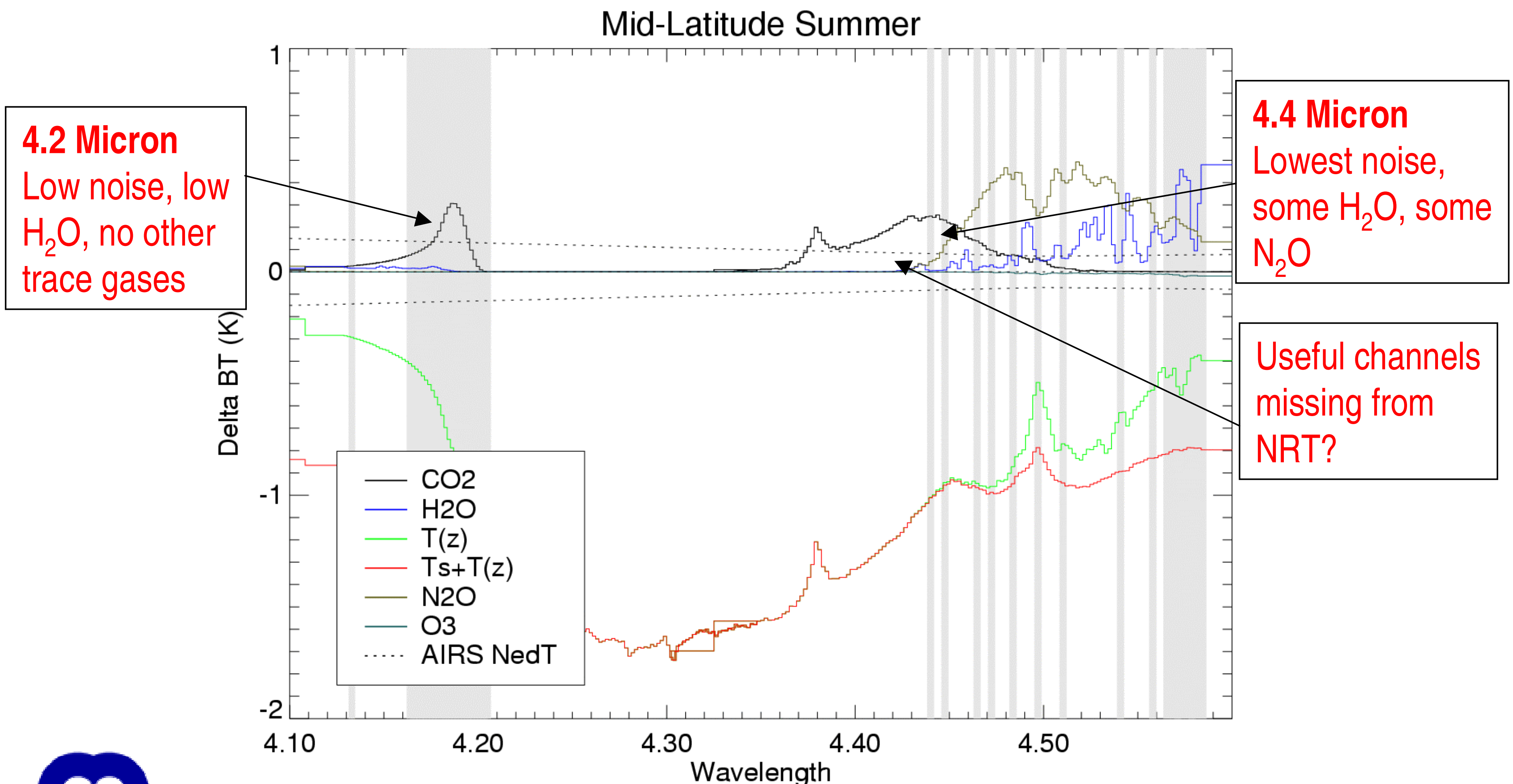
The assimilation of AIRS causes a reduction in the analysis increments at radiosonde locations

RMS analysis increment (CTRL) *minus* RMS analysis increment (AIRS)



Channel selection for CO2 estimation from AIRS (and IASI)

- **4.2 - 4.4 micron range appears promising**



COCO (EU project)

Radiance data from the Atmospheric Infrared Sounder (AIRS) on board Aqua are assimilated in the ECMWF integrated forecast model (IFS) to improve the temperature and water vapour analysis.

The radiances also contain information about other trace gases in the atmosphere, such as CO_2, O_3, CH_4.

A EU funded project (COCO) was started to estimate CO_2 mixing ratios from these AIRS observations using the 4D-Var environment of the ECMWF forecast system.

Aim is to produce reliable tropospheric CO_2 fields that can be used to improve the current CO_2 flask inversions that estimate CO_2 surface fluxes.

http://www.bgc-jena.mpg.de/projects/Coco/index_coco.html

4D-Var data assimilation

Minimize the following cost function:

$$J(\delta\mathbf{x}) = J_b + J_o$$

$$= \delta\mathbf{x}^{\mathrm{T}}\mathbf{B}^{-1}\delta\mathbf{x} + \sum_{i=0}^{n}\left(\mathbf{H}_i\delta\mathbf{x}(t_i) - \mathbf{d}_i\right)^{\mathrm{T}}\mathbf{R}_i^{-1}\left(\mathbf{H}_i\delta\mathbf{x}(t_i) - \mathbf{d}_i\right)$$

where $\delta\mathbf{x} = \mathbf{x} - \mathbf{x}_{\mathrm{b}}$: state vector increments

$\mathbf{H} = \partial H / \partial\mathbf{x}$: observation operator

$\mathbf{d}_i = \mathbf{y}_i - H_i[\mathbf{x}_b(t_i)]$: observation departures

Depending on the specification of their respective error covariance matrices B and R, the background term J_b and the observation term J_o will determine the new trajectory of the model.

CO_2 in the 4D-Var system

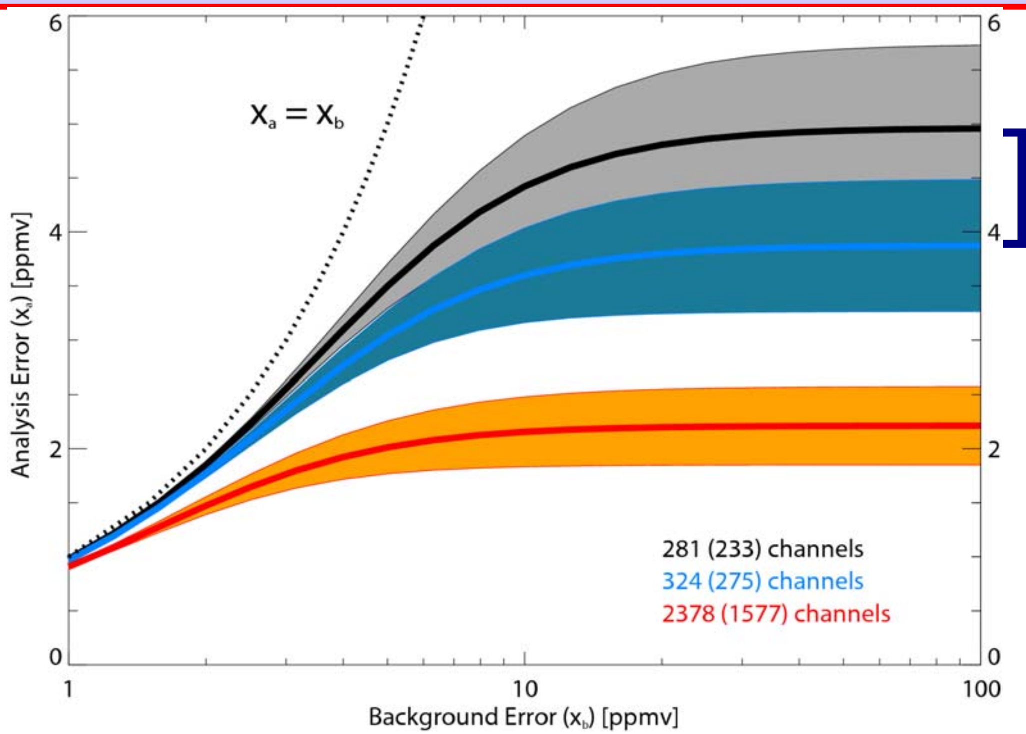
CO_2 is currently treated as an independent one-dimensional analysis variable within the 4D-Var data assimilation system.

This means that CO_2 is not a model variable and is therefore not moved around by the model transport.

It is retrieved at the observation location using the 4D-Var fields of temperature, specific humidity and ozone.

The CO_2 variable itself is limited to a column-averaged mixing ratio with a fixed profile shape.

CO_2 Error limits



Notice the large improvement by the extra CO_2 channels compared to the original 281 channels.

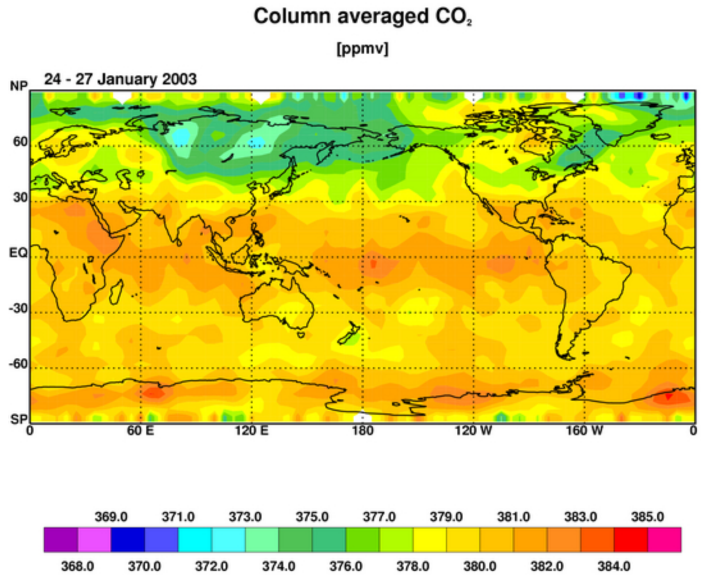
When CO_2 is retrieved as a column-averaged mixing ratio, the analysis error reaches a limit that depends on the number of spectral channels and on the specified observational error.

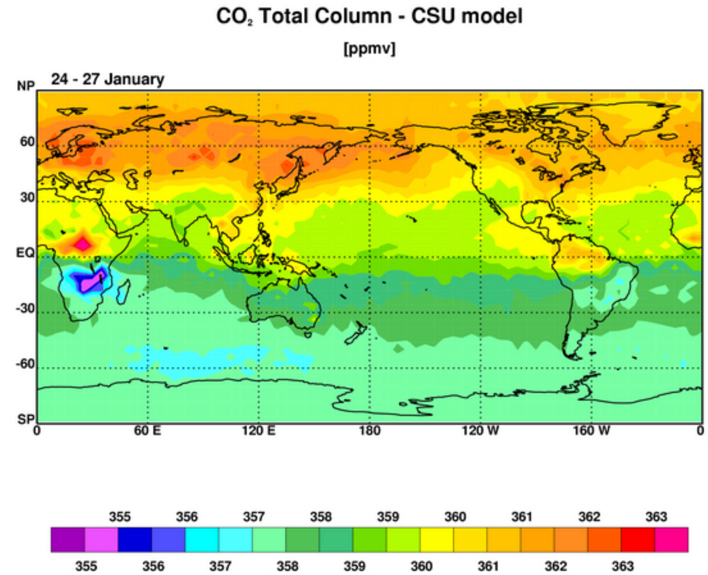
The same result can also be obtained by retrieving a CO_2 profile with background correlations set to 0.999 (setting these to 1 makes the inversion unstable).

Global assimilation with real AIRS data

- Assimilation experiments were done for the period 24 – 27 January 2003.
- 324 channels were available before the blacklisting process.
- Cloud detection algorithm is used to screen for cloud-free channels.
- Different CO_2 assimilation set-ups:
    - Single column value with the same mixing ratio in the troposphere and the stratosphere using all available channels
    - Single column value with the same mixing ratio in the troposphere and the stratosphere using 10 stratospheric channels
    - Single column value with the same mixing ratio in the troposphere and the stratosphere using 10 tropospheric channels
    - Double column (troposphere and stratosphere) experiment with all available channels

Assimilation using all channels

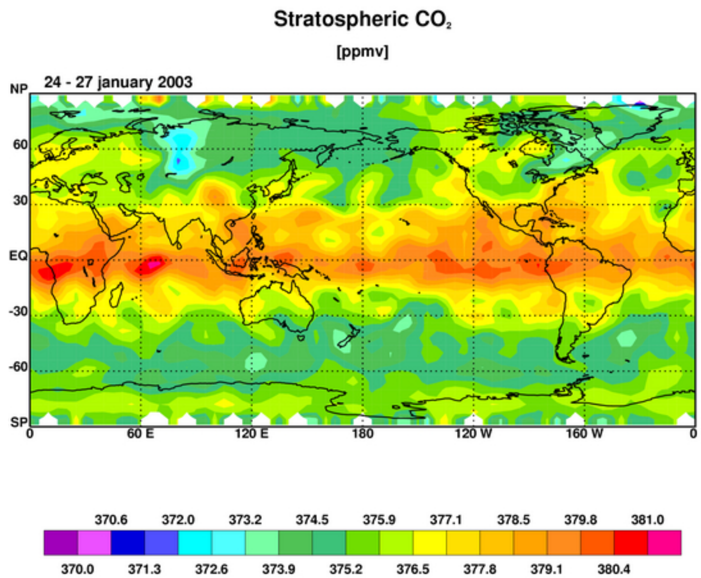


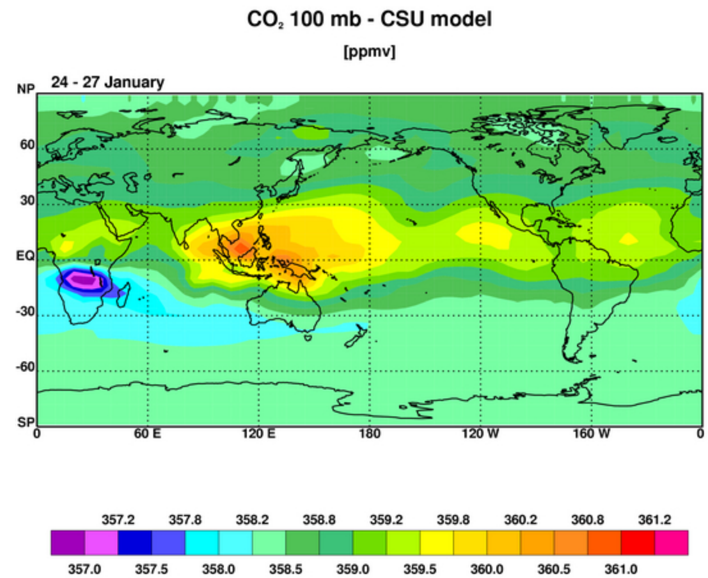


First results with the sink variable analysis using all available channels show an unexpected spatial distribution. Siberia in wintertime should have increased CO_2 levels in the troposphere, not decreased.

Note that the model results (CSU climate model) are climatological results with absolute values differing from present-day values. Results are presented here for spatial distribution only!

Assimilation using 10 stratospheric channels

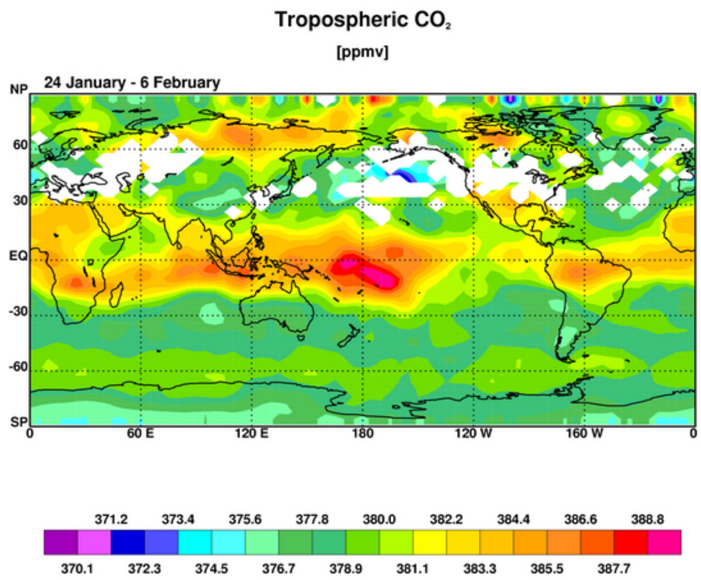


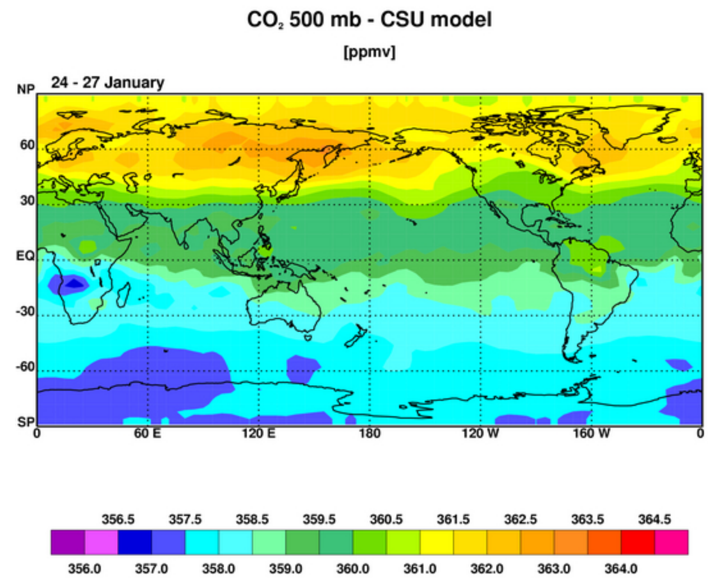


When only 10 stratospheric channels are used, the spatial distribution looks more like what we would expect. Highest concentrations in the tropics with decreasing values to higher latitudes.

Note that the model results (CSU climate model) are climatological results with absolute values differing from present-day values. Results are presented here for spatial distribution only!

Assimilation using 10 tropospheric channels

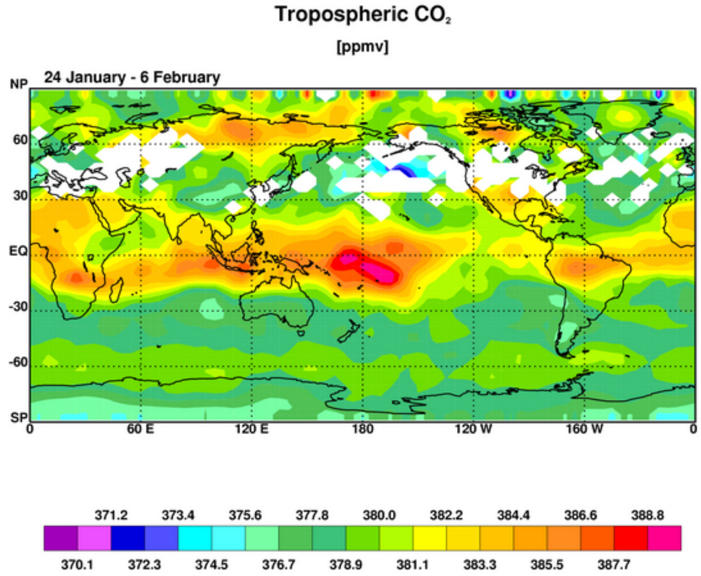


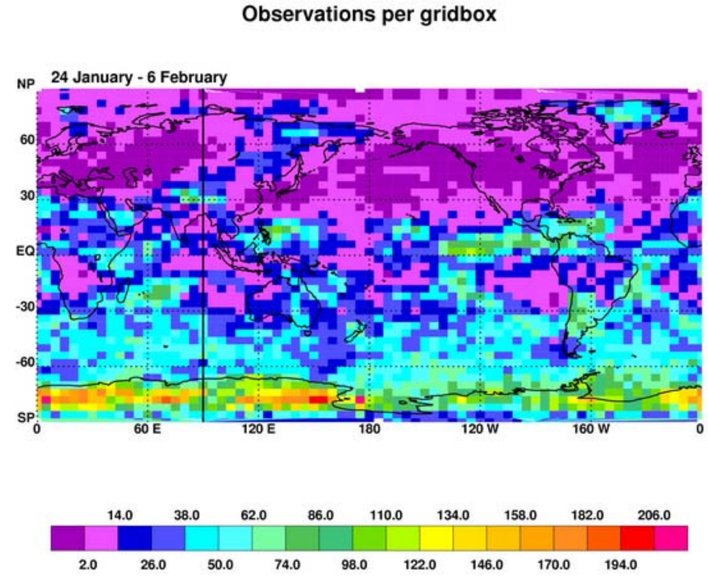


When only 10 tropospheric channels are used, we lose quite a bit of our coverage due to clouds. However, Siberia now indeed shows increased CO_2 levels in the troposphere, not decreased.

Note that the model results (CSU climate model) are climatological results with absolute values differing from present-day values. Results are presented here for spatial distribution only!

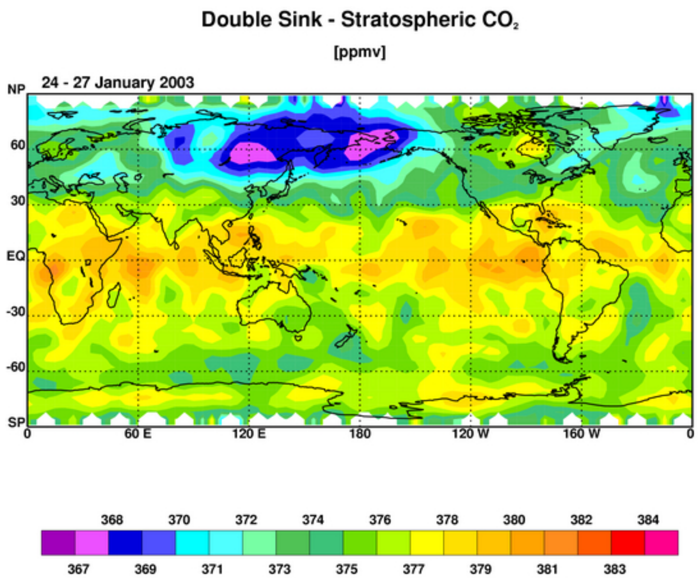
Assimilation using 10 tropospheric channels

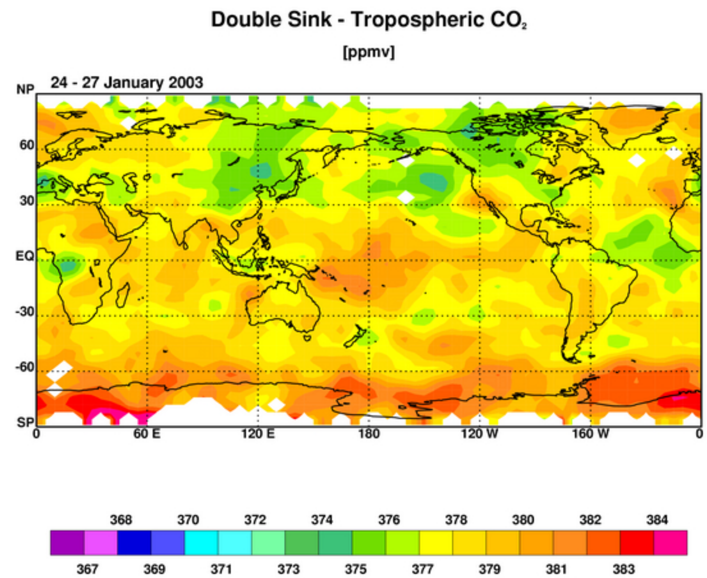




Tropospheric CO_2 (left) and number of observations per grid box as used in the average (right). Northern hemisphere in winter has a lot of cloud cover in the lower and middle troposphere. Therefore, to get a decent time average, we need a relative long time series of data.

Double column analysis





The introduction of a double column provides a bit more flexibility in the estimation of CO_2. The tropopause is estimated from the background temperature profile and independent values for stratospheric and tropospheric CO_2 are then estimated.

Problem at the moment is how to average CO_2 values that contain good information and CO_2 values that return the background value, especially in the troposphere.

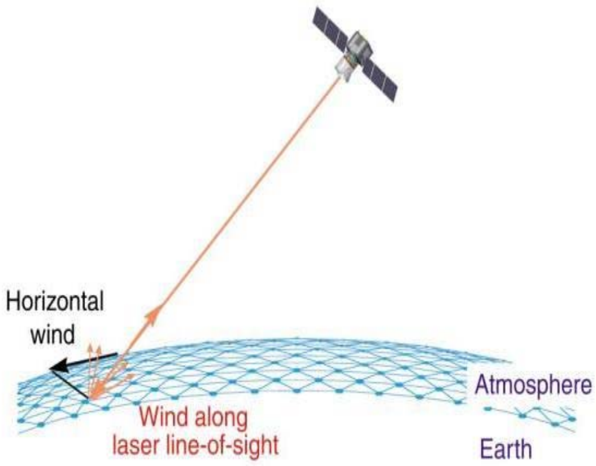
CO2: Near-future plans

- Testing of double column analysis
- Implementation of an analysis error estimate for CO_2, hopefully by making use of existing analysis error estimation that is based on the eigenvectors of the Hessian of the cost function
- Find ways to minimise the effect of the bias correction on the CO_2 analysis product
- Process more data

Preparing for ADM-Aeolus

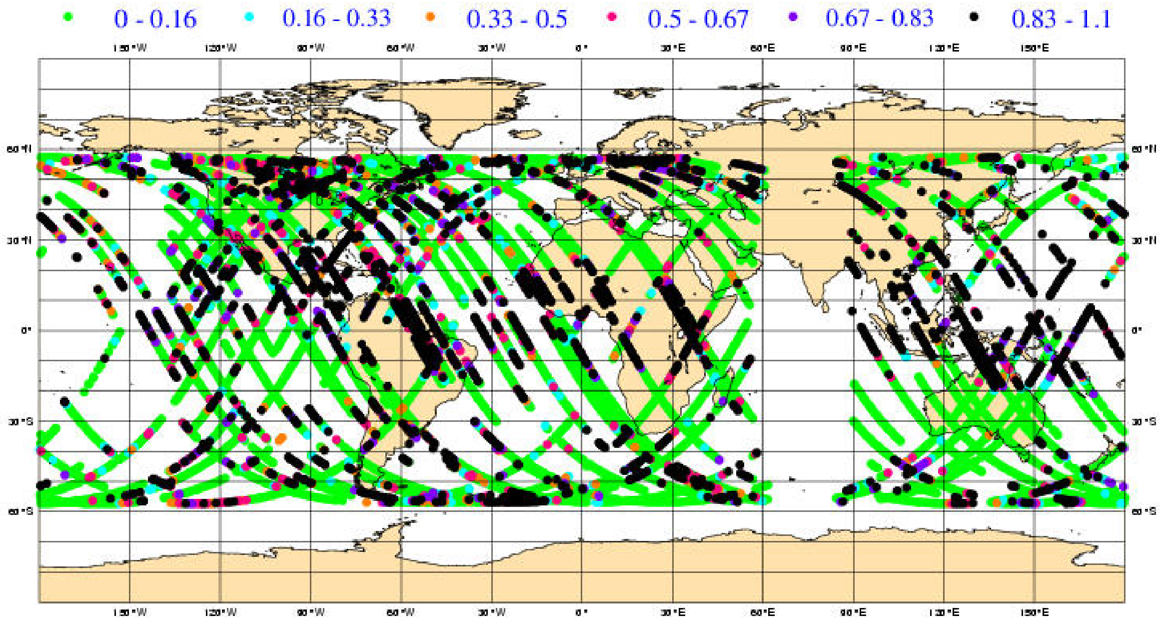
•**ADM-AEOLUS (ESA) embarking a Doppler Wind Lidar will provide a global coverage of Line of Sight wind profiles (currently forgotten by the present missions)**

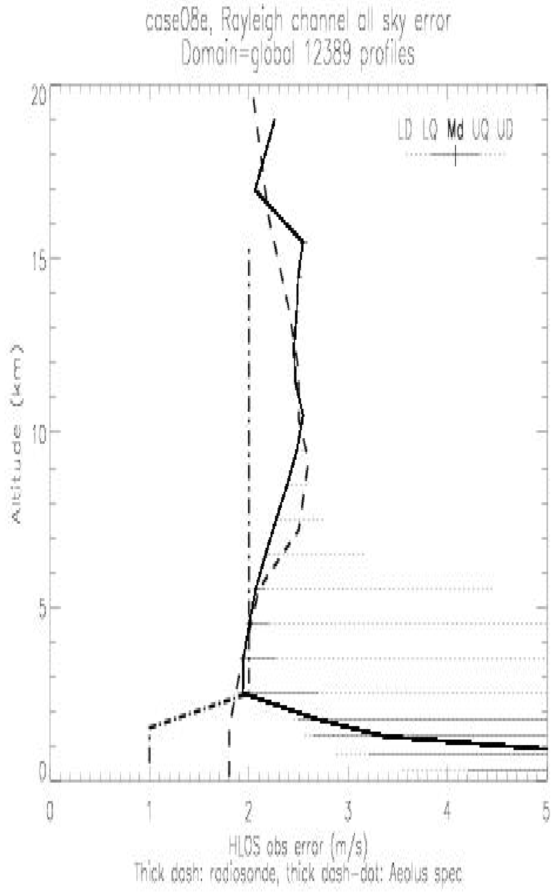
- **Accurate wind profiles are an NWP priority**
- **Erik Andersson on MAG**
- **Supporting study (EA and David Tan)**
  - **Phase A study by Lars Isaksen and Carla Cardinali**
- **Study objectives**
  - **Prepare ECMWF DA system for Aeolus data**
  - **Assess expected impact using simulated data**
  - **Feedback to mission requirements**



Aeolus Yield - Results from TN1

- Aeolus compares favourably with radiosondes
- Expect benefits in Tropics, storm tracks, jet streams
- Clouds reduce yield by 20% (50% in PBL)





Aeolus – future work

- TN2 Quality Control
- TN3 Assimilation Impact
- Outstanding issues
  - Mie channel bias (unresolved aerosol/cloud layers)
  - Optimal strategies for Level 1b processing

Further challenge: assimilation of clouds and precipitation

- **Why do global NWP systems not (or little) assimilate cloud and rain observations?**
  - **Clouds and precipitation processes are characterised by a wide range of scales:**
    - **Observing cloud/rain 4D variability is challenging**
    - **Parameterizing cloud processes in global NWP models is difficult**

However,

- **Cloud/rain info contains an important large-scale information through the dynamics**
- **Global NWP models describe cloud and precipitation with a reasonable degree of realism**
- **Increasing availability of new satellite products on clouds and precipitation**

Current and future satellite missions

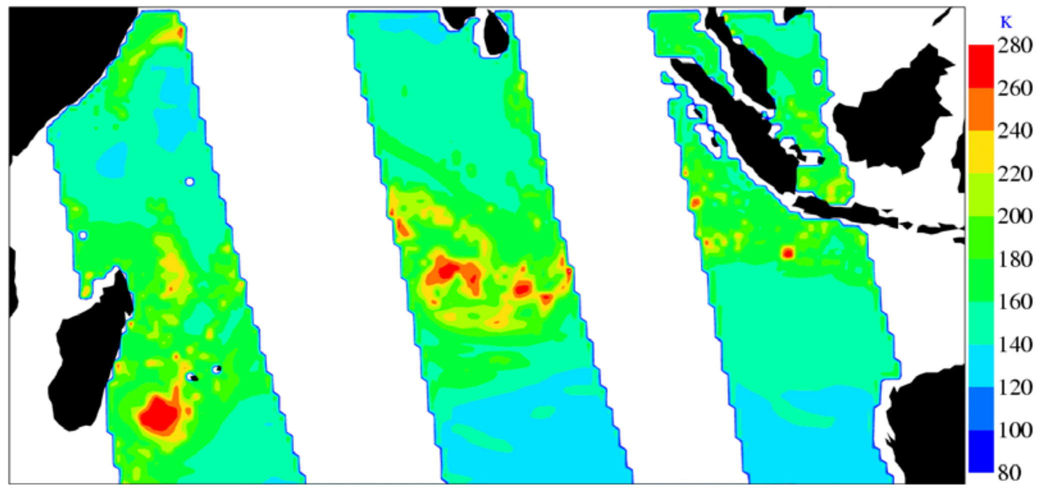
- **Cloud and rain information is already available from space:**
  - **SSM/I, TRMM, AMSR-AQUA,…**
  - **AIRS, AVHRR, MODIS, METEOSAT, GOES,…**
- **Increased availability of cloud/rain information in the near future:**
  - **For model validation and improvement:**
    - **CLOUDSAT-CALIPSO (NASA), EARTHCARE (ESA),…**
  - **For assimilation:**
    - **SSM/IS, (E)GPM, AMSR-ADEOS-2,…**

Issues

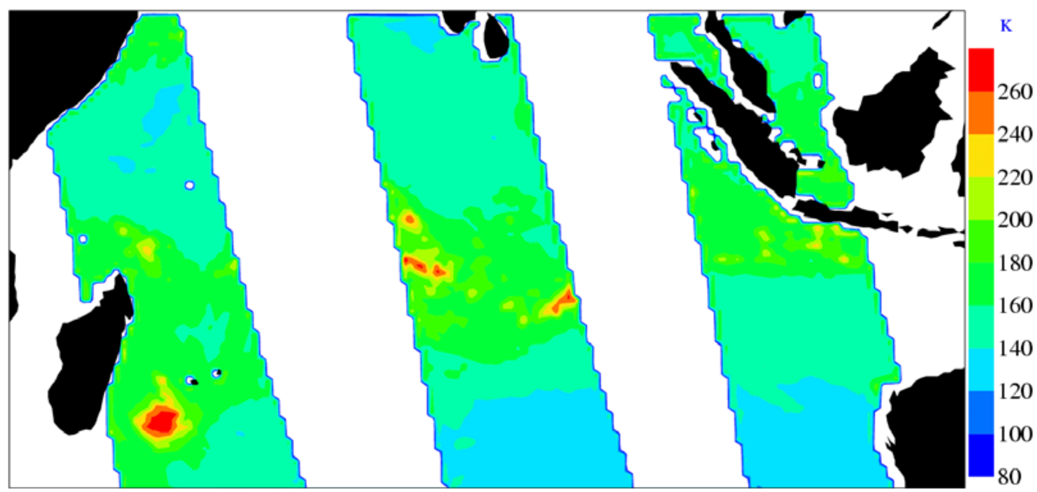
- **Model errors are assumed to be small in 4D-Var (less valid with physical processes ?)**
- **4D-Var expects smooth processes (problem of linearised physics)**
- **Rainy/cloudy systems to be analysed are assumed to be predictable (maybe true only for large scales ?)**
- **General problem of resolution/parametrisation**
- **A prerequisite to contemplate assimilation: the model has to look like the observations!**
  - **Problem of representativeness error**

Comparison of the ECMWF model with SSM/I 19.35 GHz Tb, H pol. (7 January 2001 15 UTC – Cyclone Ando)

Model



Observations



New cloud scheme for assimilation (1)
Tompkins and Janisková

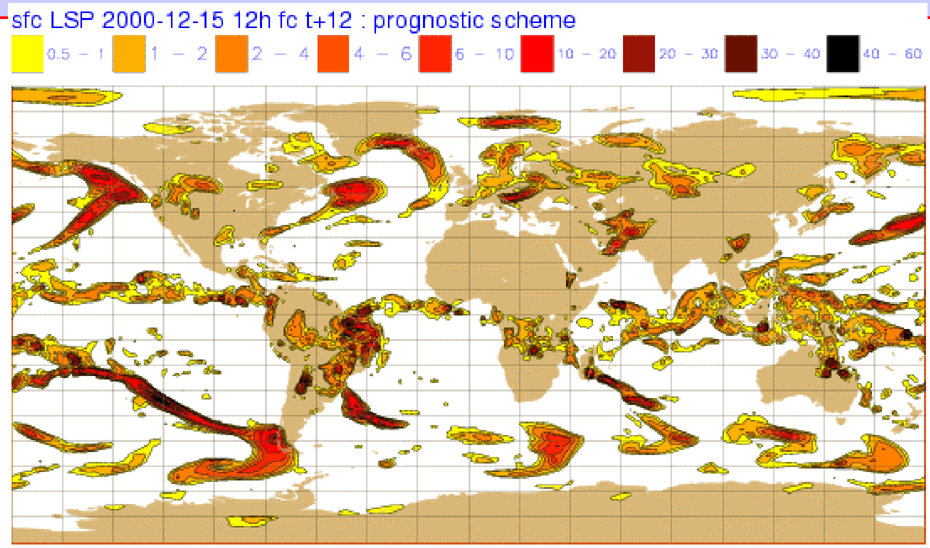
• **Problems with current diagnostic scheme:**

- **Rain is super-saturation adjustment only (no direct relation to cloud properties)**
- **Independence of cloud cover, cloud mass and rainfall renders difficult realistic assimilation of rainfall and cloud data**
- **…**

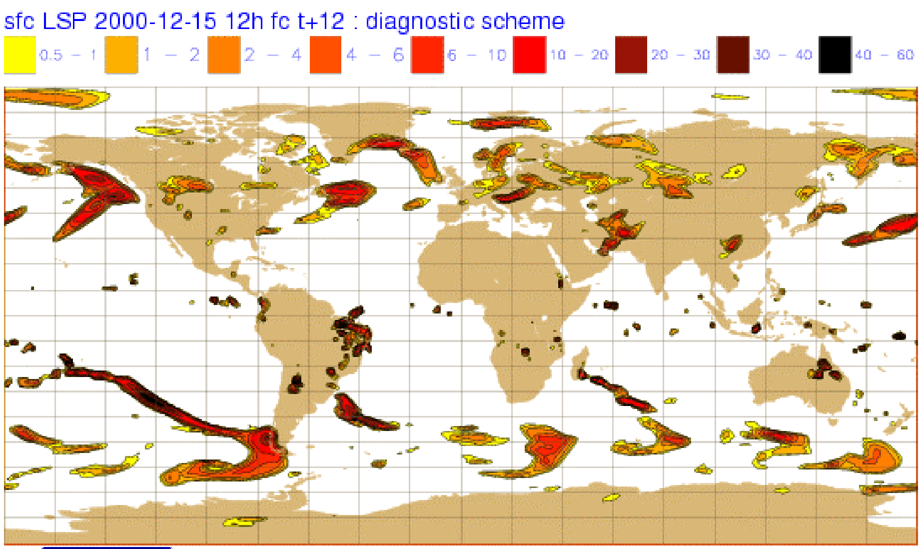
New cloud scheme for assimilation (2)
Tompkins and Janisková

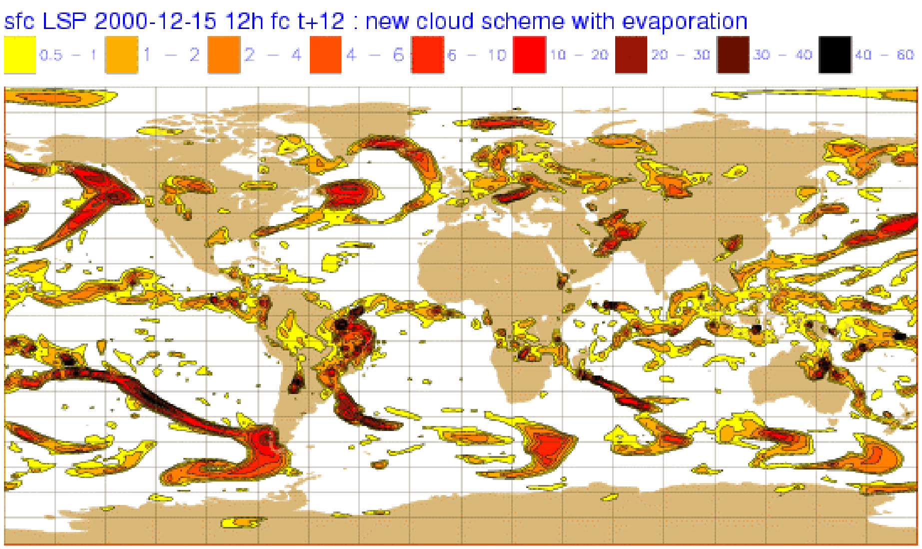
- **New simple Scheme:** Based on statistical ideas
  - Vapour, cloud mass, cloud fraction and rain are now consistent
- **More Similaritites with Prognostic Scheme:**
  - PDF for some Tiedtke (1993) processes is similar
  - Rainfall formulation is similar for warm processes
  - Convection treatment similar
- **Tests are encouraging**
  - 1 timestep "First Guess" for ARM sites
  - T159 12 hour forecasts substituting simple scheme
  - Further work with 1DVAR by Moreau and Lopez

Large scale precipitation
15 December 2000 12h fc t+12 (T159L60)



prognostic scheme

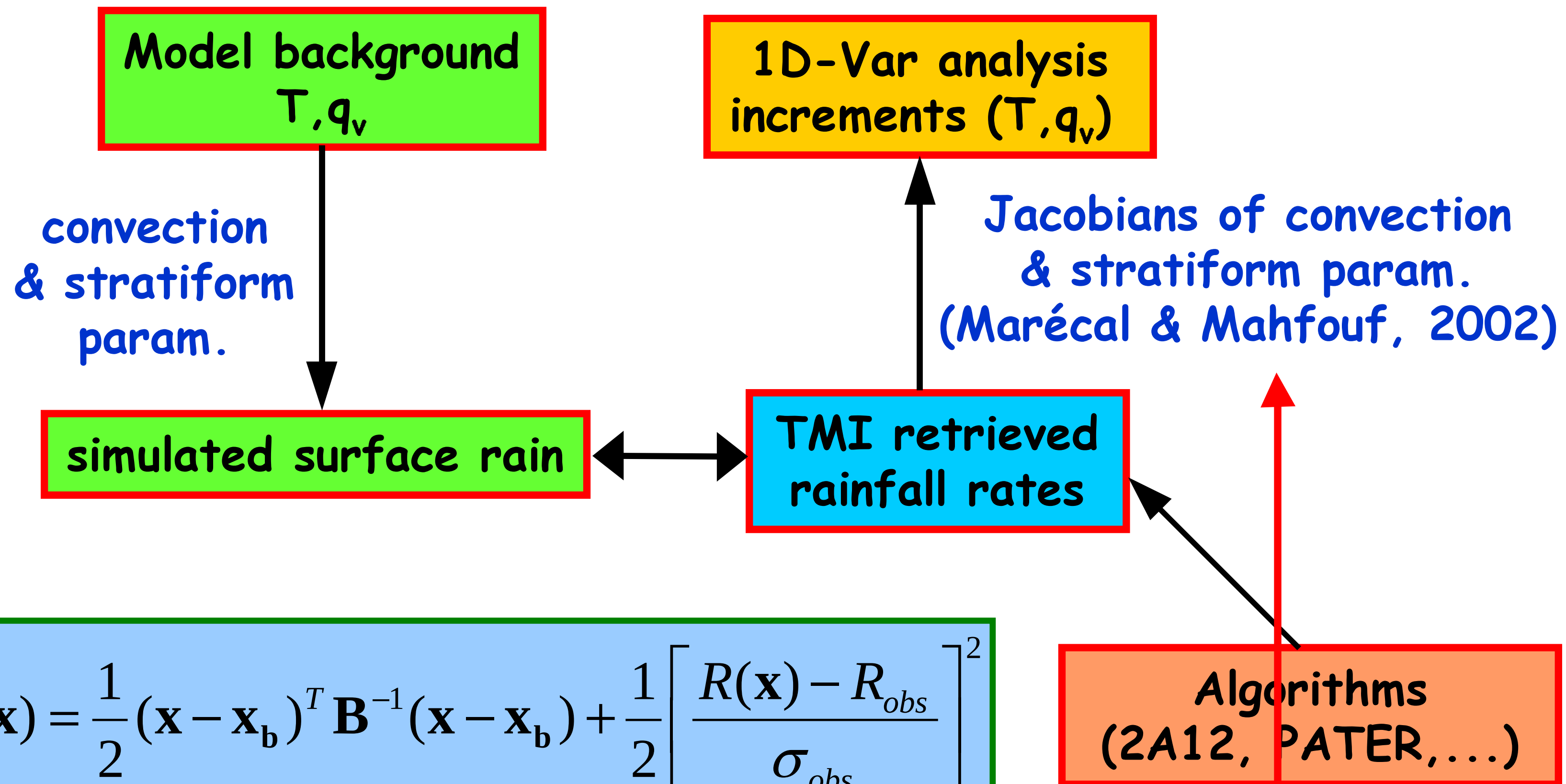




diagnostic scheme

new scheme

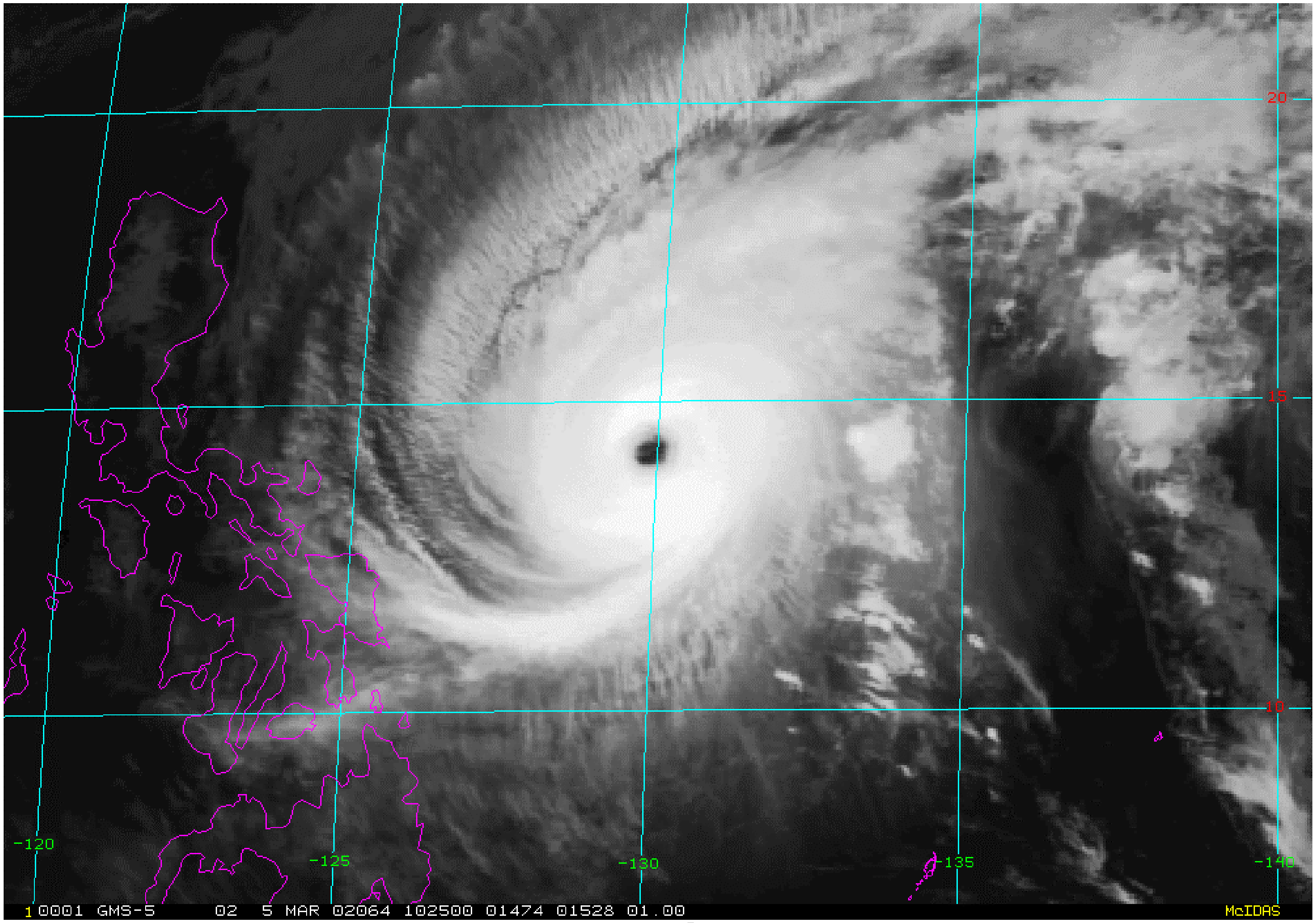
1D-Var assimilation of TMI rainfall rates



$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x}-\mathbf{x}_b)^T \mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_b) + \frac{1}{2}\left[\frac{R(\mathbf{x}) - R_{obs}}{\sigma_{obs}}\right]^2$$

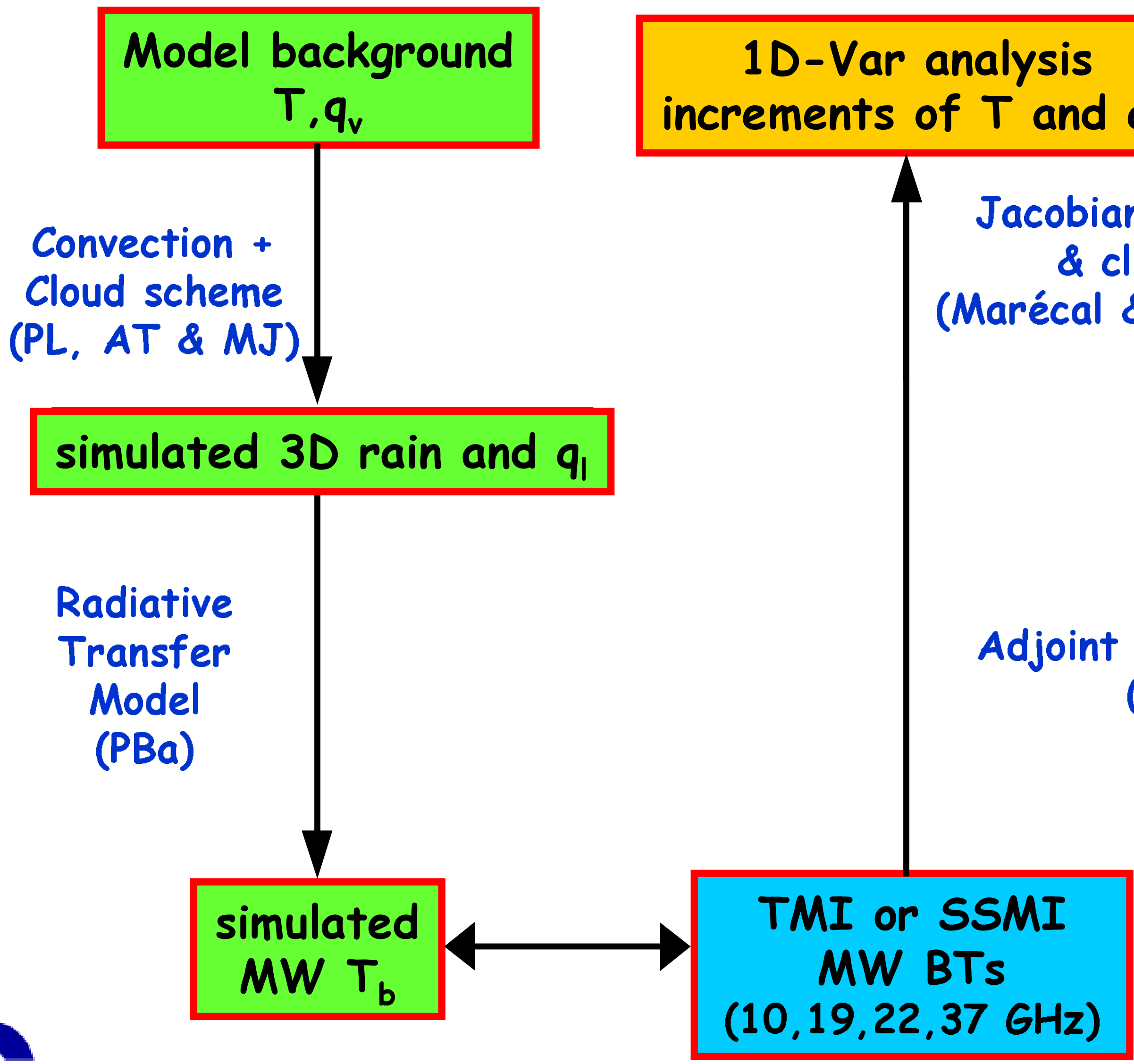
$$\nabla J(\mathbf{x}) = \mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_b) + \mathbf{R}^T\left[\frac{R(\mathbf{x}) - R_{obs}}{\sigma_{obs}}\right]$$

GMS IR image of super-typhoon MITAG: 5 March 2002 1030 UTC

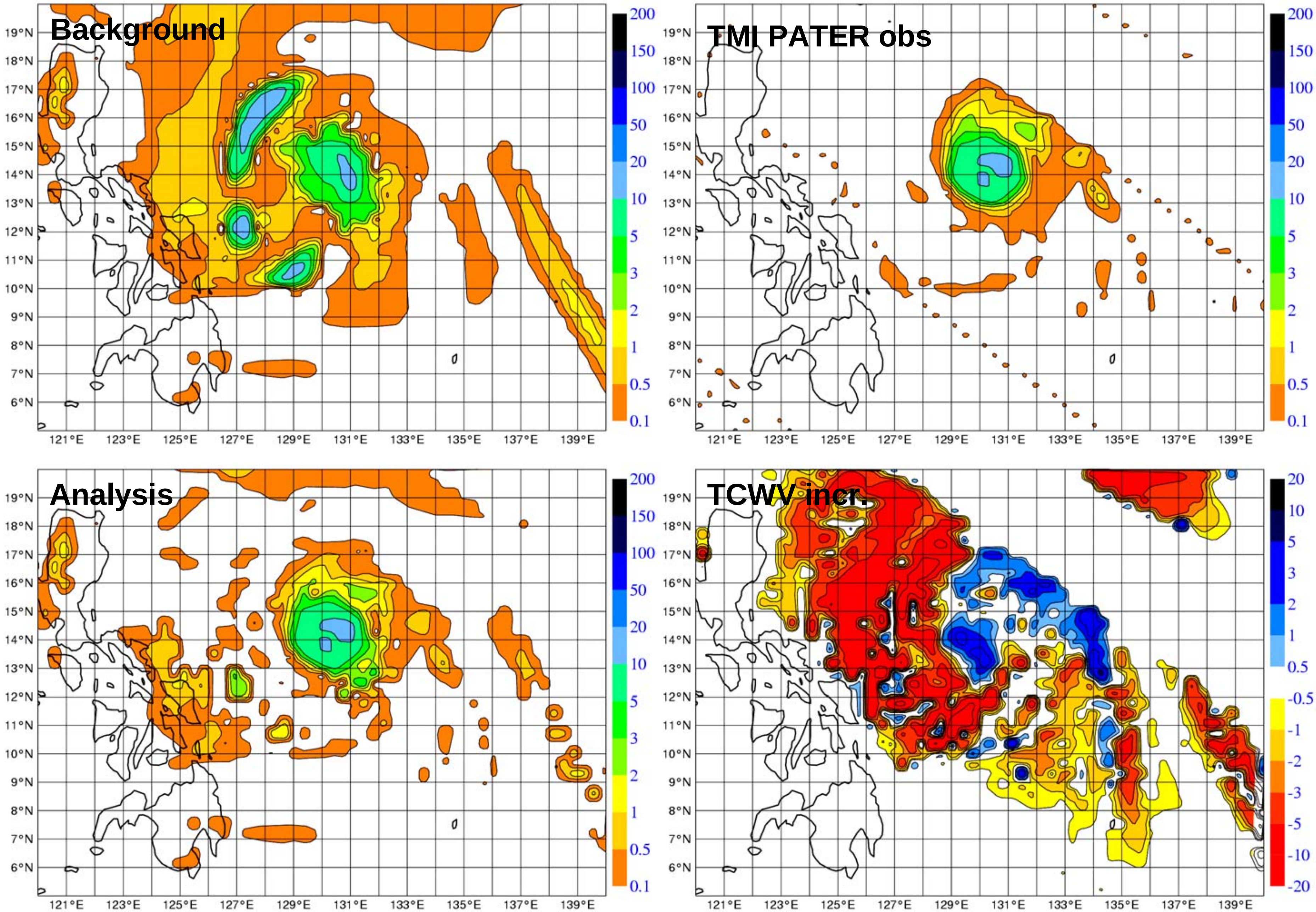


18 March 2003

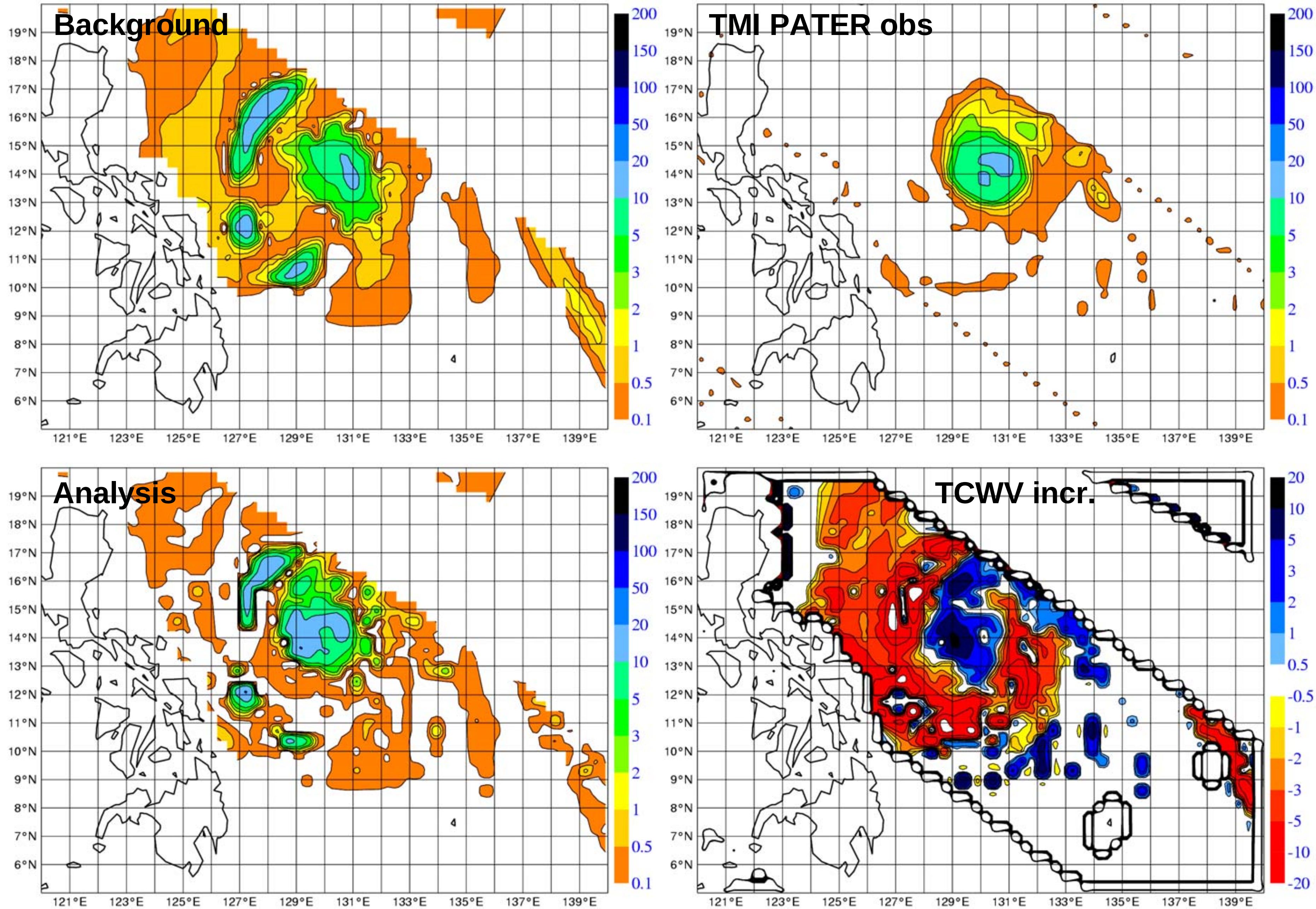
1D-Var assimilation of TMI/SSMI brightness temperatures



$$\sigma_{obs} = 3\,\mathrm{K}\,(\mathrm{V}) / 6\,\mathrm{K}\,(\mathrm{H})$$

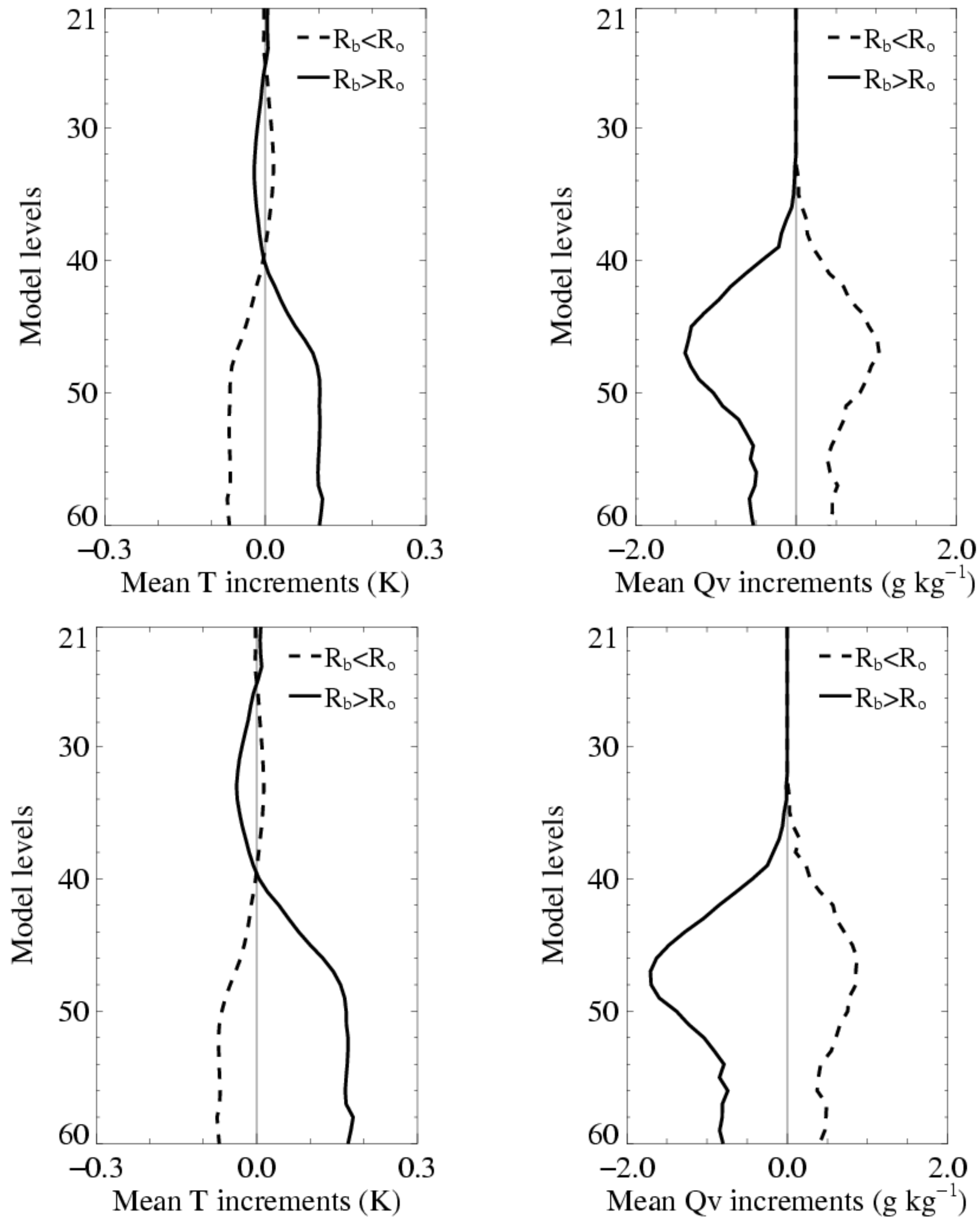


1D-Var on TMI rainfall retrievals – super-typhoon MITAG



1D-Var on TMI Brightness temp. (10V,10H,19V,19H,22V,37V,37H channels)

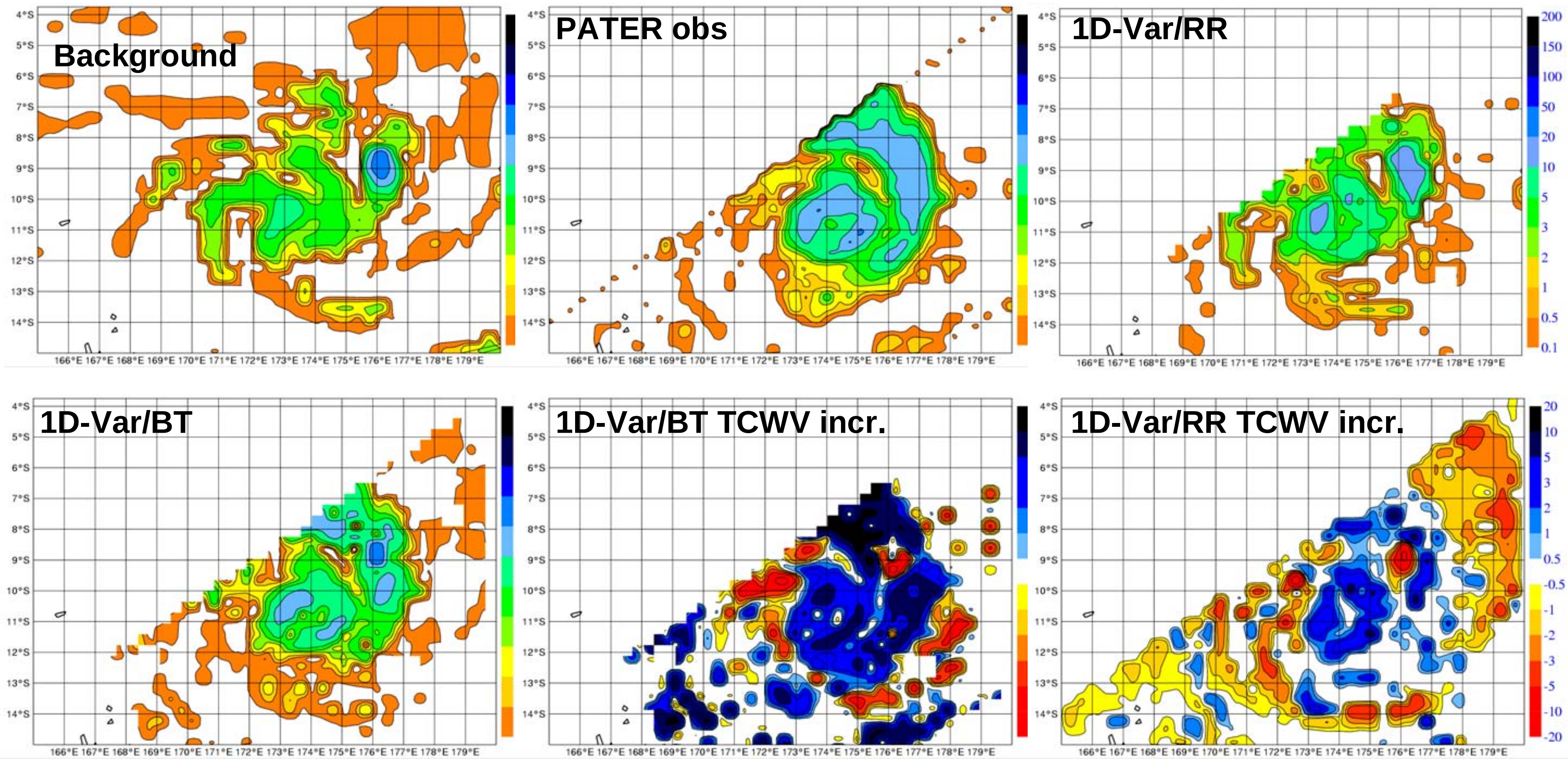
1D-Var / BTs analysis increments



3 channels

7 channels

1D-Var results



Case of tropical cyclone ZOE (26 December 2002 @1200 UTC)

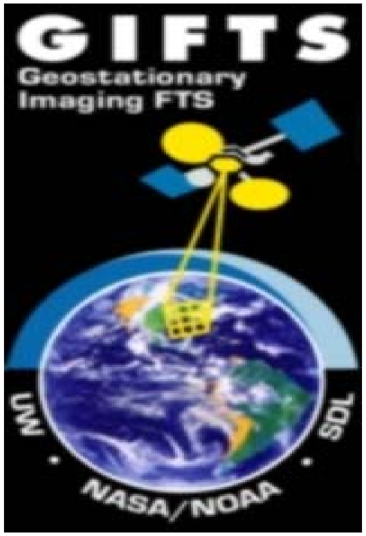
Surface rainfall rates (mm hr^{-1}) and TCWV increments (kg m^{-2})

And more…
Assimilation of GPS radio-occultation measurements

- New field in data assimilation at ECMWF
- "all weather", "high vertical resolution" and "self calibration" capabilities are attractive features for global NWP
- GPS+GALILEO will increase the number of occultations
- Research and Operational missions are up or underway:
  - CHAMP (Germany, NASA,…)
  - COSMIC (NASA,NOAA,UCAR,NSF,JPL,Taiwan,…)
  - ACE+ (ESA): GPS/GALILEO-LEO + LEO-LEO
  - GRAS (EUMETSAT)
- A stepwise approach is possible
  - Assimilation of temperature/humidity profiles
  - Assimilation of refractivity profiles
  - Assimilation of bending angles
- Collaboration with EUMETSAT to develop an assimilation strategy for radio-occultation measurements

And more…

- **GIFTS (NASA) – Geostationary Imaging Fourier Transform Spectrometer will provide high horizontal vertical and temporal resolution temperature, humidity and (indirectly) wind profiles**



And more…

Several missions will enable an improvement of the ECMWF soil moisture