Towards Assimilation of cloud and precipitation data at the Met Office

Sue Ballard 3rd May 2005

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Content

- Strategy for Var
  - Current
  - Development
- Convective scale - MOPS
- Observations available
- AMSU
- SSMI and SSMI/S
- Geostationary Imagery data
- Summary

Strategy

Limit control variables:

moisture, cloud, temperature, vertical velocity are not independent

don't have good statistics for individual cloud water variables

Limit physics in linear model to essentials:

cost

linear model is generating flow dependent background errors not detailed forecast

Therefore:

Have total water increments as interface and control variable

Control variable – scaled (eg by saturation humidity) – currently RHtotal'

balanced components removed – not yet

need to cope with stratospheric moisture as well as tropospheric

cloud and non-gaussian errors – Holm Transform

Interface to observation operators and PF model qt' and theta'

not conservative set but more independent than qt' and thetal'

Based on Smith 1990 statistical cloud scheme – smoothed and approximated:

liquid only or cloud water only – need to develop treatment of ice

Current – global 4DVAR, UK/Europe 12km 3DVAR 4km spin-up

Limit control variables: increments
stream function, velocity potential, unbalanced pressure, relative humidity

Limit physics in linear model (PF=Perturbation Forecast) to essentials:
original: surface friction
recent: removal of supersaturation, production and advection of cloud water,
removal of cloud water by precipitation with timescale

Interface: PF to Obs: Specific humidity/relative humidity, theta,u,v,p, density
Control variable to PF: as PF to Obs plus cloud water from previous step

Control variable – scaled (eg by saturation humidity) – currently RH'

Observations – humidity only , no cloud or precipitation , cloud free radiances in Var

Mesoscale – relative humidity nudging from cloud cover analysis (surface and GEOIR)
(MOPS data) latent heat nudging from surface precipitation rates (radar)
Testing – cloud in Var – cloud cover to rh – obs of no cloud impt
Development – precip in var – moisture flux convergence

Development– global 4DVAR, Europe 12km 4DVAR 4km UK 3DVAR plus MOPS

Limit control variables: increments
stream function, velocity potential, unbalanced pressure, total relative humidity

Limit physics in linear model (PF=Perturbation Forecast) to essentials:
add convection, surface exchanges, boundary layer mixing, update microphysics

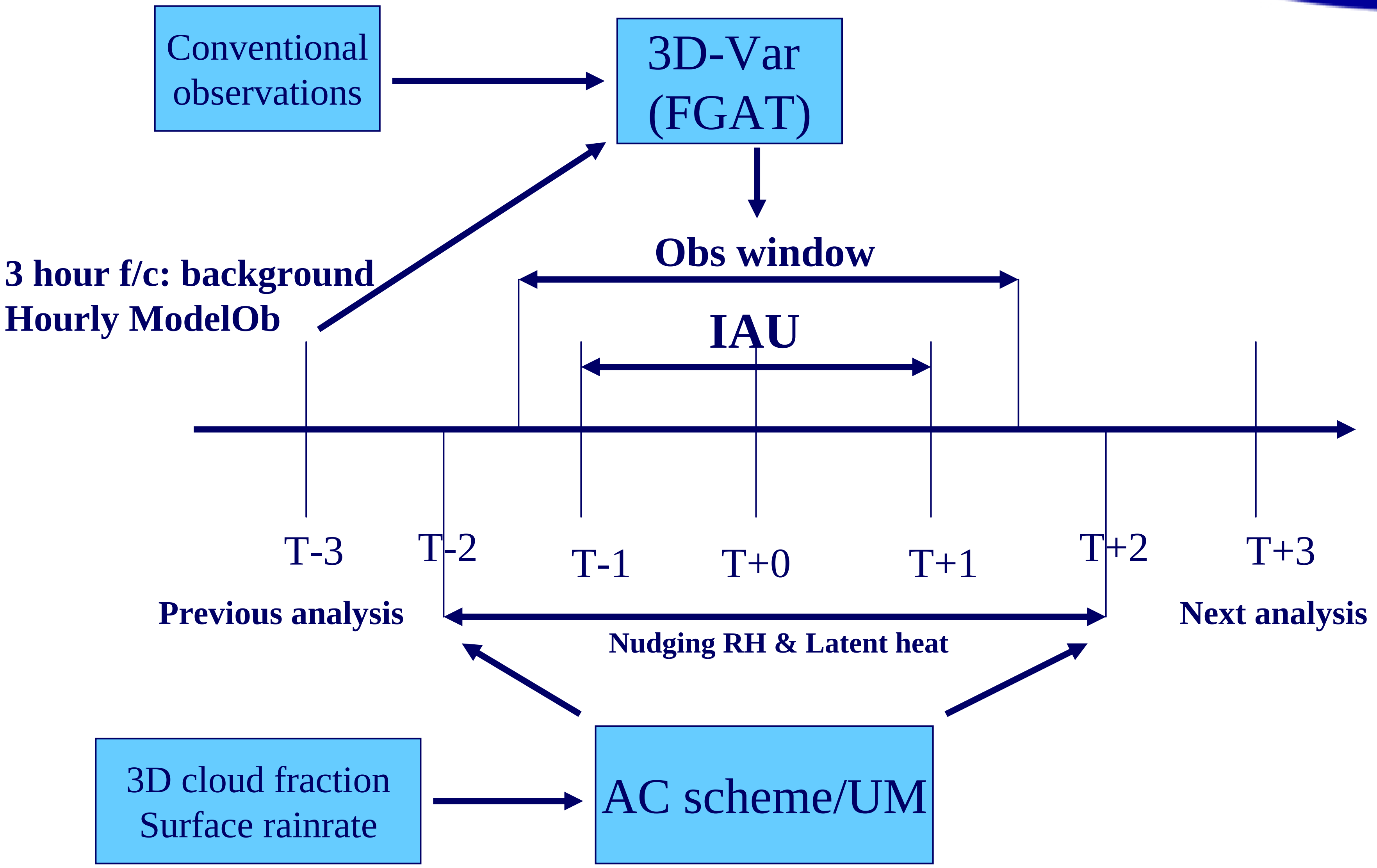
Interface:
PF to Obs: total water/RHtot, theta,u,v,p, density,
precipitation (3D, surface, accumulation/rate), diagnose cloud liquid water increments
– nonlinear every 10 iterations of minimization

Control variable to PF: linear
as PF to Obs apart from ppn – diagnose cloud water increments

Observations – humidity only , no cloud or precipitation , cloud free radiances in Var
development – cloudy ice free AMSU, cloud free SSMI/S, cloudy SSMI/S,
European – 4DVAR of surface precipitation rates/accumulation, cloudy GEOIR

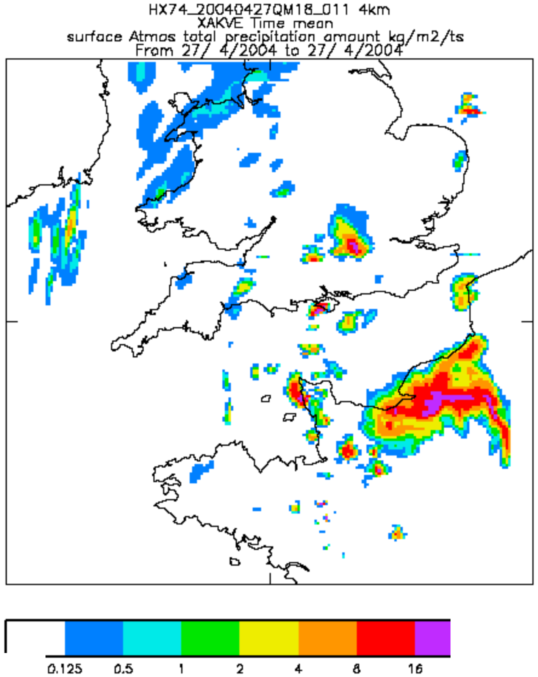
4km – relative humidity nudging from cloud cover analysis (surface and GEOIR)
latent heat nudging from surface precipitation rates (radar)

3D-Var system including MOPS RH and LH nudging via AC scheme



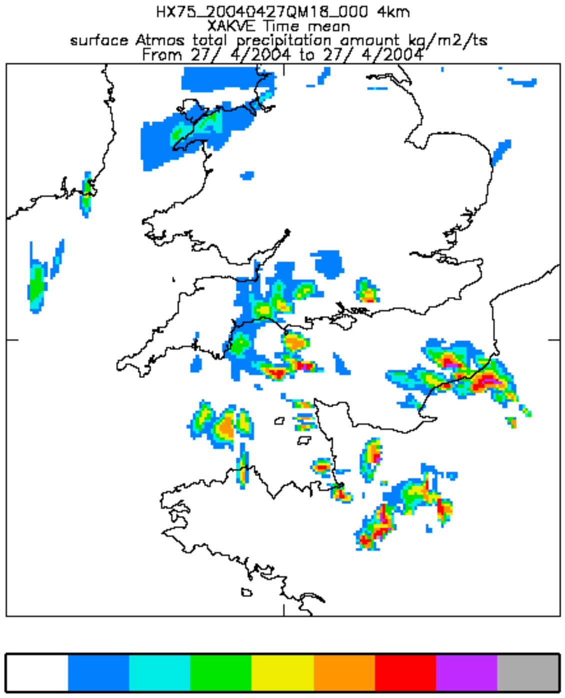
Impact of MOPS data

Accumulated precipitation
19-20UTC 27th April 2004
From 18UTC analysis

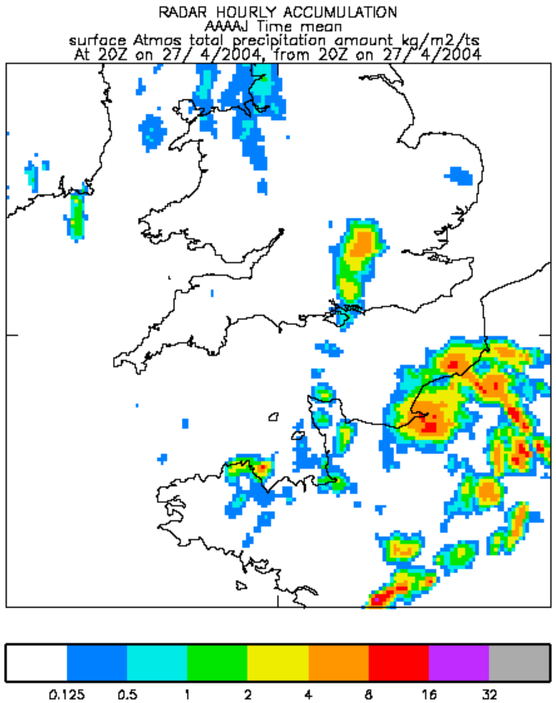


With MOPS

No MOPS



radar



Observation Types

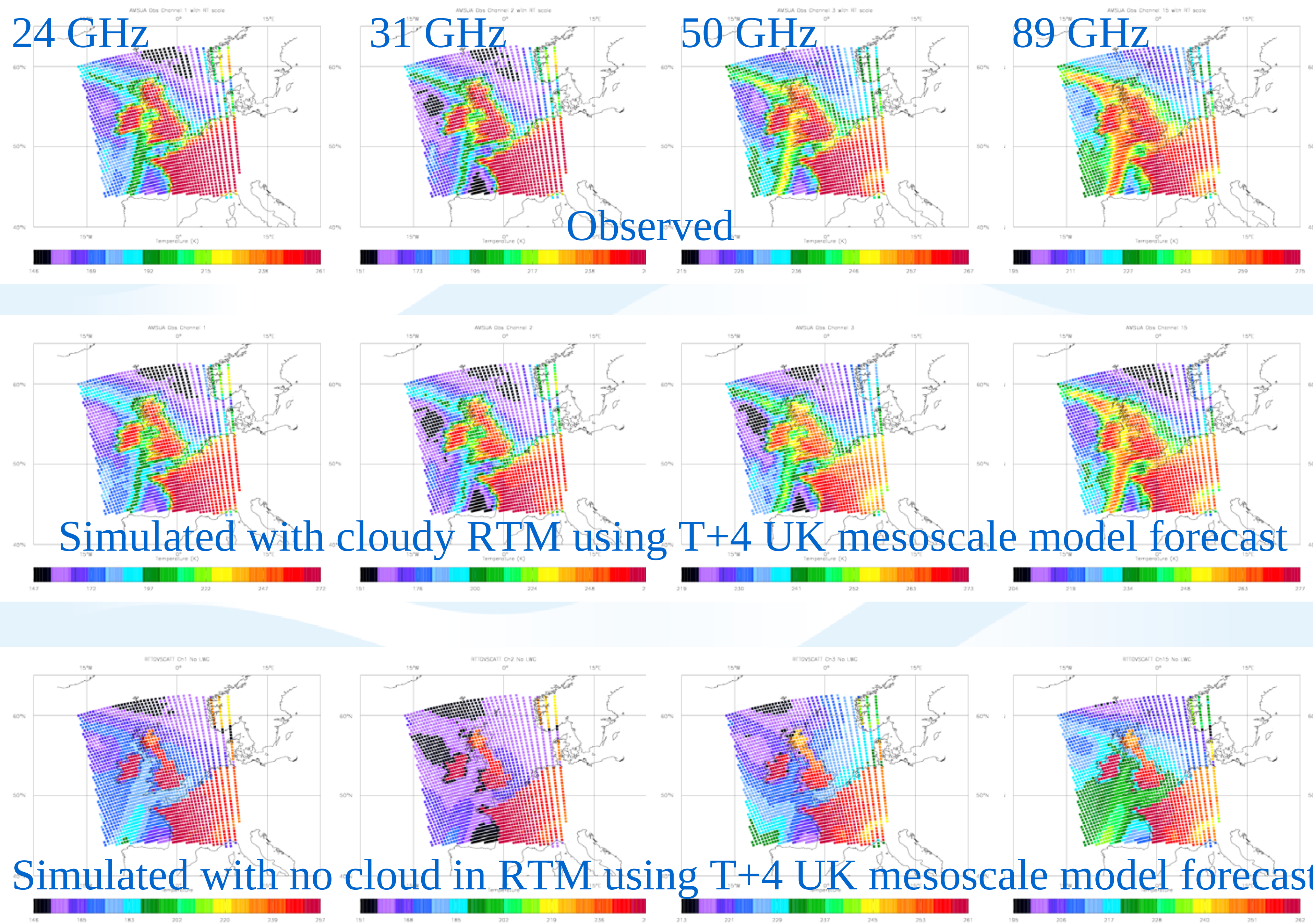
Data Source	Observation	Input to H
MOPS	Cloud cover –> RH or qt/qs	Cconv,C_l q,T,p or qt,T,p
MOPS	ppn rate	Moisture flux convergence or ppn
SSM/I And SSMI/S	TCWV, TCL radiance	q,T,p,qcl
AMSU-A 23&31GHz	radiance	q,T,p,qcl, ppn,qice, C
GPS imagery	Cloud top pressure	C, cconv,qcl,qice convqc
radar	reflectivity	qcl,qice,ppn

Scattering RT validation

- Case study validation of scattering RT output vs satellite observations indicate that we are ready to move towards use of AMSU-A window channels for cloud liquid water assimilation

- Testing on incremental cloud liquid water operator underway (for AMSU-A 23GHz + 31GHz initially)

- There remain many scientific issues with higher frequency channels that are sensitive to scattering from ice particles

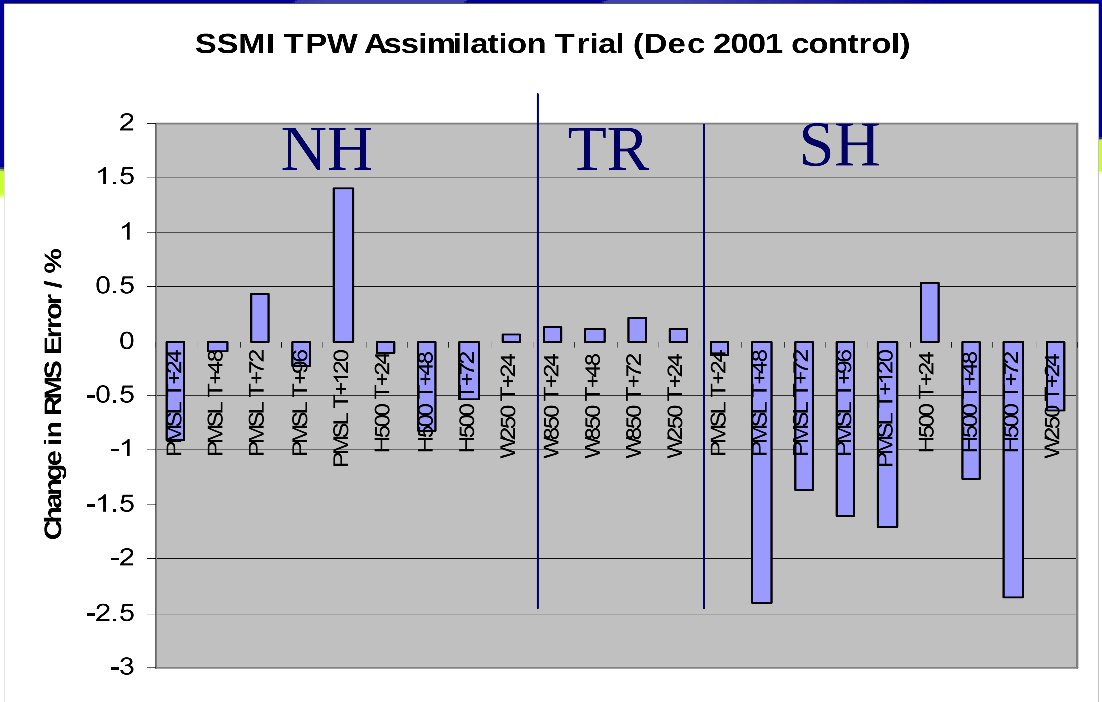

24 GHz
31 GHz
50 GHz
89 GHz
Observed
Simulated with cloudy RTM using T+4 UK mesoscale model forecast
Simulated with no cloud in RTM using T+4 UK mesoscale model forecast

SSMI

- Operational processing uses ocean surface WS from 1D Var pre-processing step, TCWV not assimilated.
- Latest 3DVar experiments assimilating TCWV gave mixed results – some improvements in tropics, degradation to SH PMSL and geo-potential heights in storm tracks (* see plots) – near neutral overall
- Reasons for this are: QC (almost all cloudy data used), treatment of bias and lack of profile information (esp. in unstable areas)
- Plan to test & implement radiance assimilation late 2005, cloud free radiance, early experiments look promising (reduced spin down) (* see plots).
- Bias correction will use T_2 and TCWV as predictors – although new spectroscopy at 22 GHz and T dependent ε errors explain most of the biases.

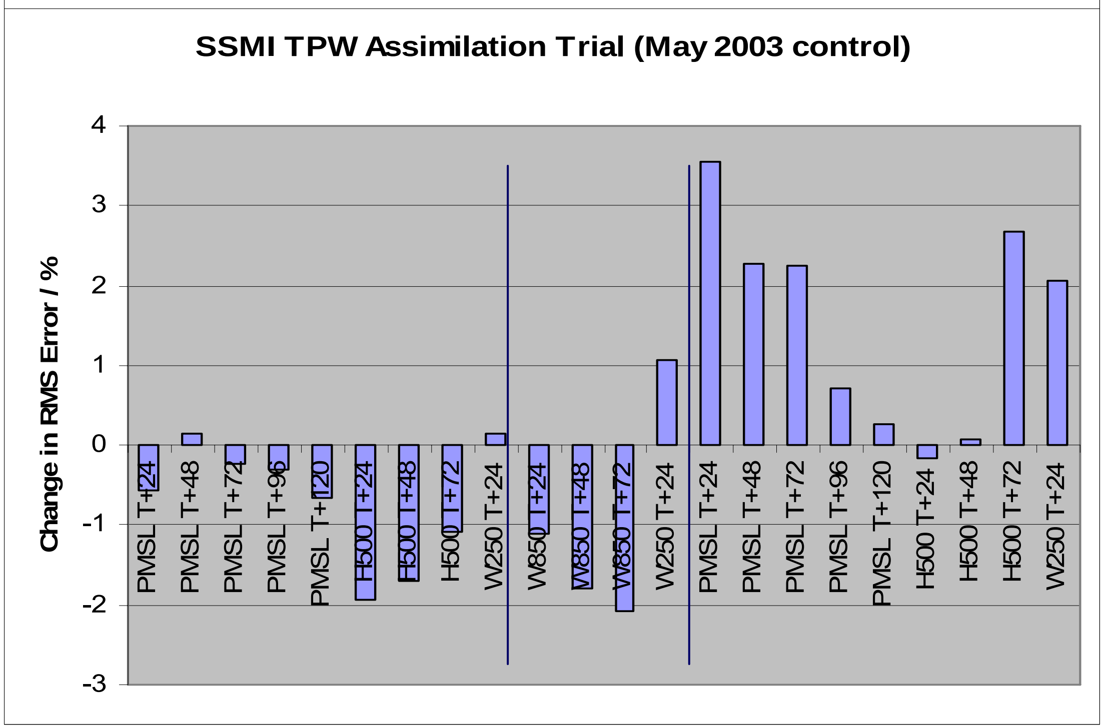
SSMIS

- Data stream set up April 2005 – plan to assimilate radiances late 2005
- Day 1 aim is redundancy for NOAA 15 AMSU-A
- Day 2 aim is optimal exploitation of radiances in cloudy areas
- To meet T sounding requirements Day 1 system will involve 2 stage pre-processing : (averaging + QC) + 1D Var
- 1D Var gives:
  - T above model top
  - clw profiles
  - QC (LWP, convergence)
  - channel selection
- Clear AND cloudy radiances passed to 4D Var, with 1D Var clw profiles, to LWP_{MAX}.
- Preliminary analyses of sample data indicate in terms of noise the instrument is within pre-launch specifications.



15 Day Trial

TPW + bias retuning verification vs observations -0.10 %



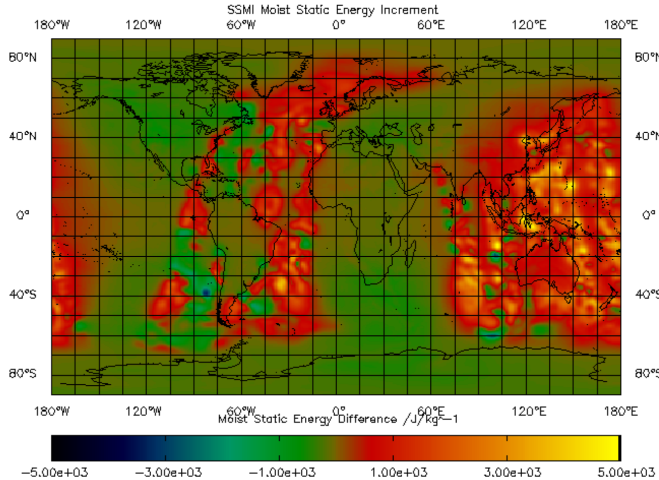
38 Day trial

TPW assimilation only verification vs observations +0.44%

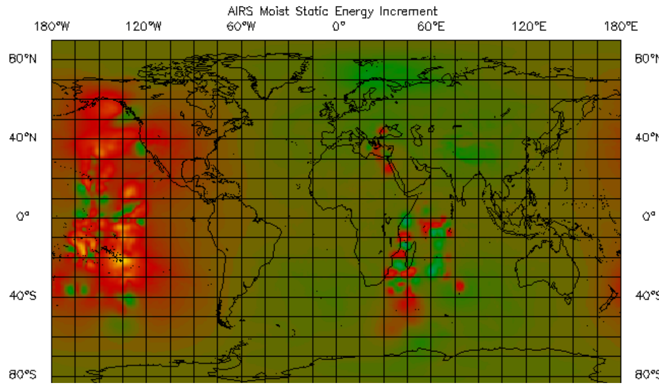
Moist Static Energy

$$S_e = c_p T + L_v q + gz$$

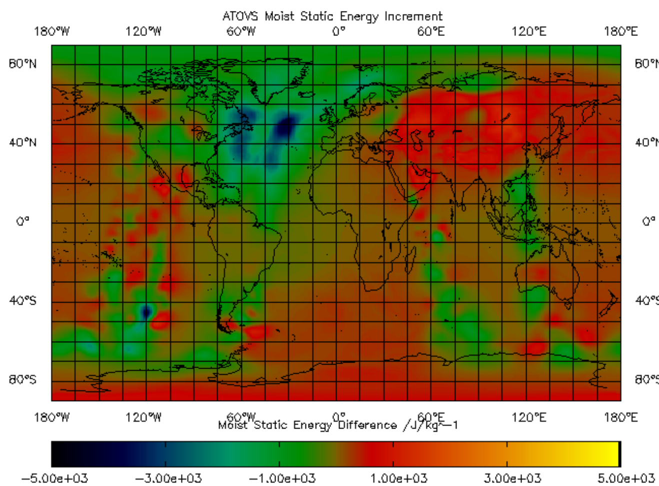
SSMI

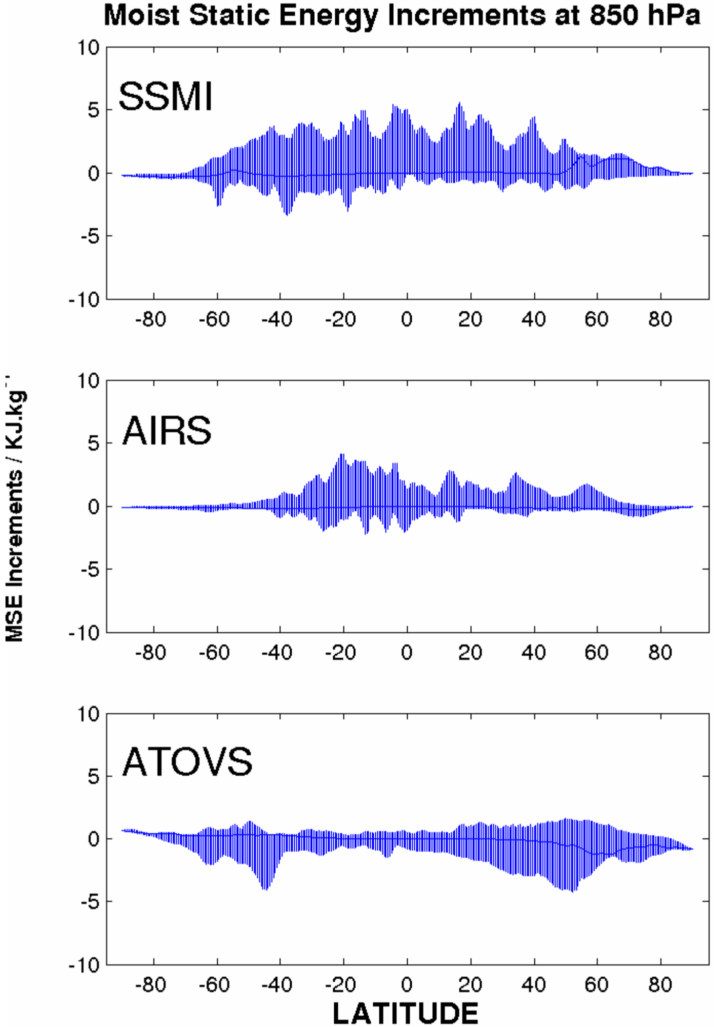


AIRS



ATOVS

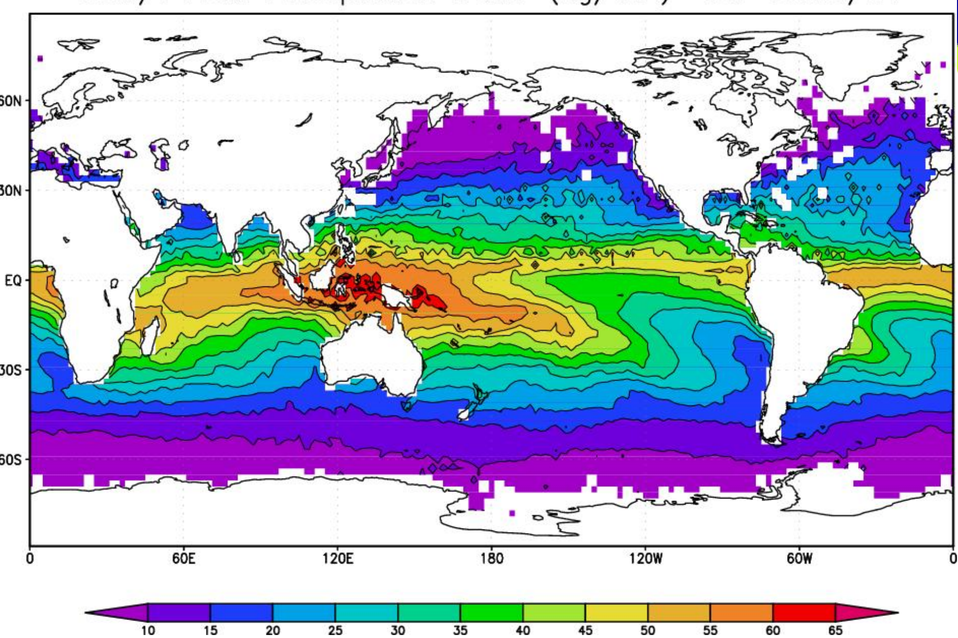




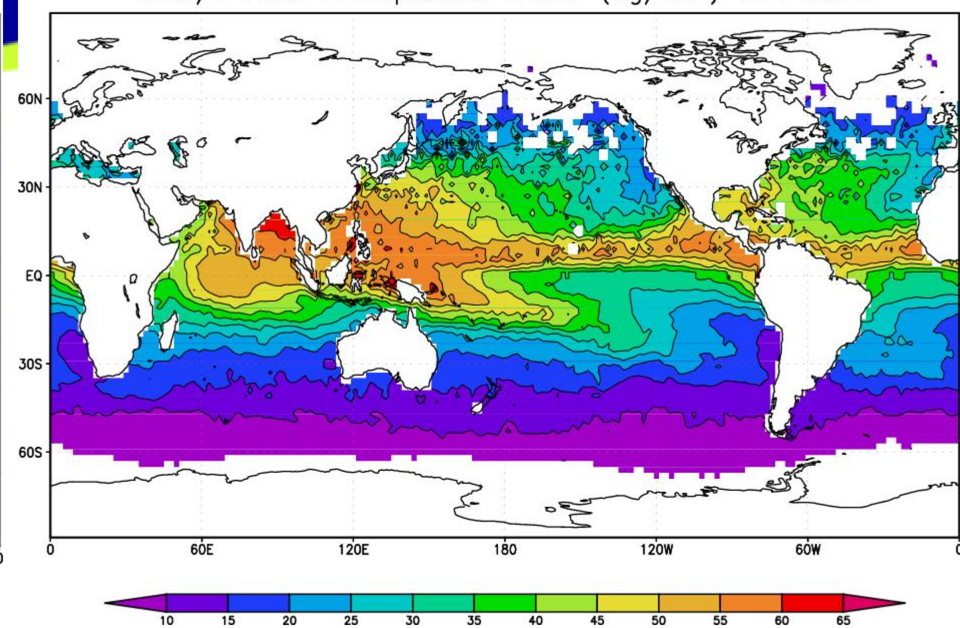
SSMI adds large ‘energy’ increments ….everywhere

TCWV Climatology & Model Biases

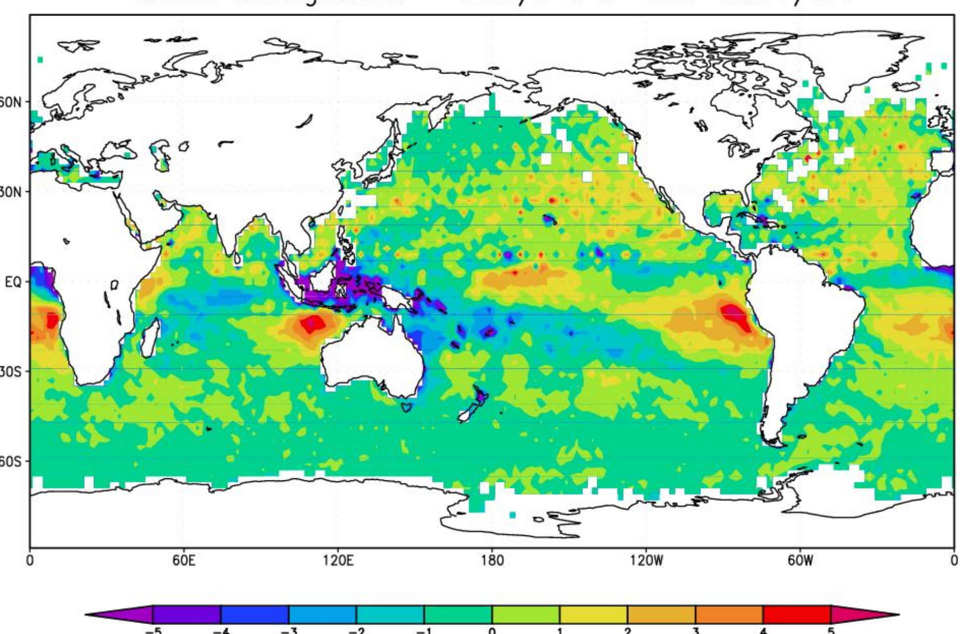
SSM/I Total Precipitable Water (kg/m2) DJF 2003/04



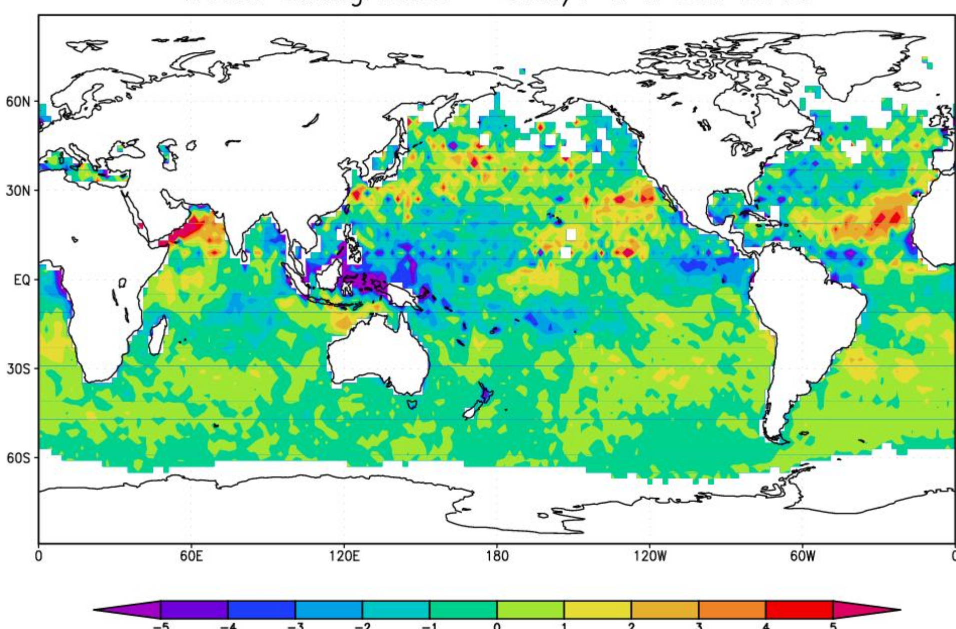
SSM/I Total Precipitable Water (kg/m2) JJA 2003



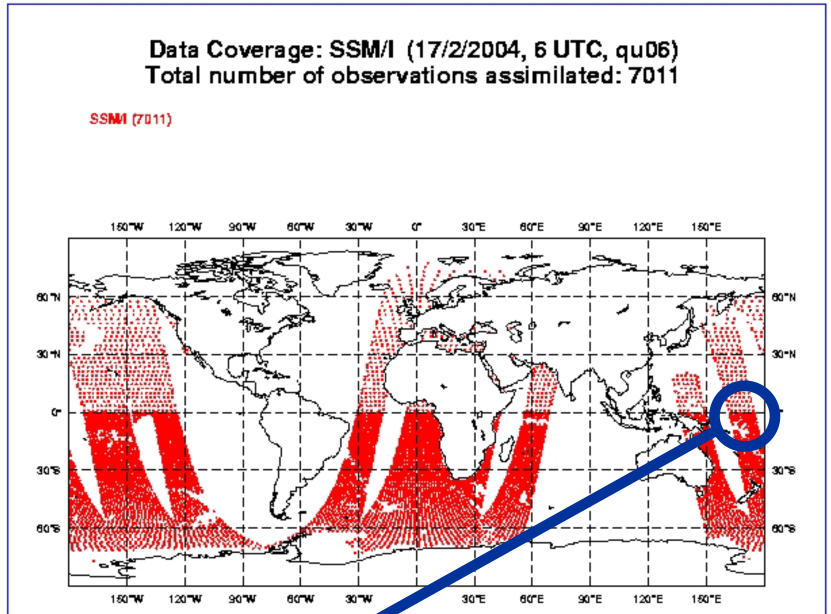
Model Background – SSM/I TPW DJF 2003/04



Model Background – SSM/I TPW JJA 2003



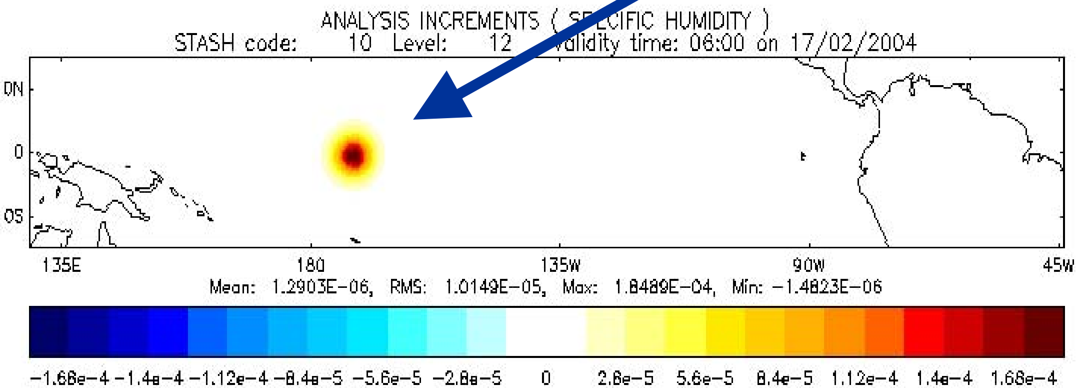
Single Ob Experiment



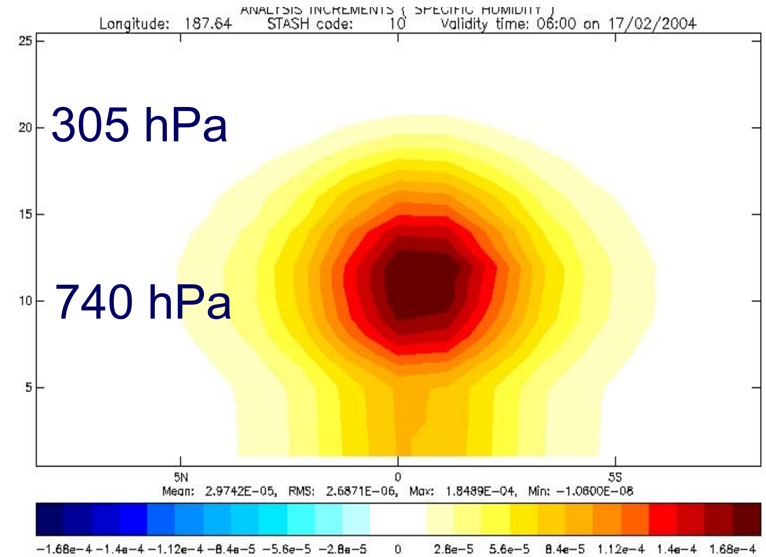
TCWV:

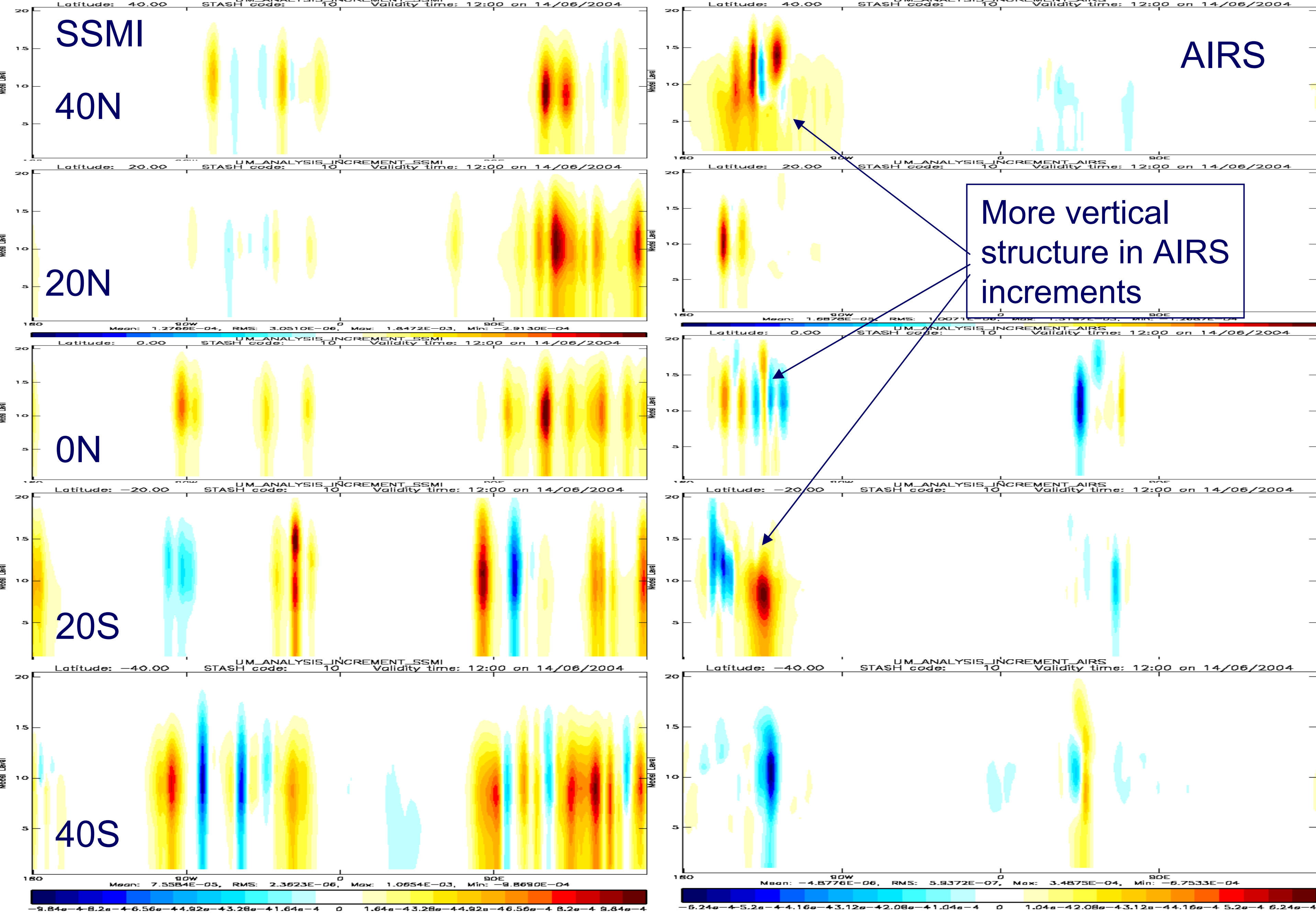
OBS = 56.6 $kg.m^{-2}$

MOD = 53.8 $kg.m^{-2}$

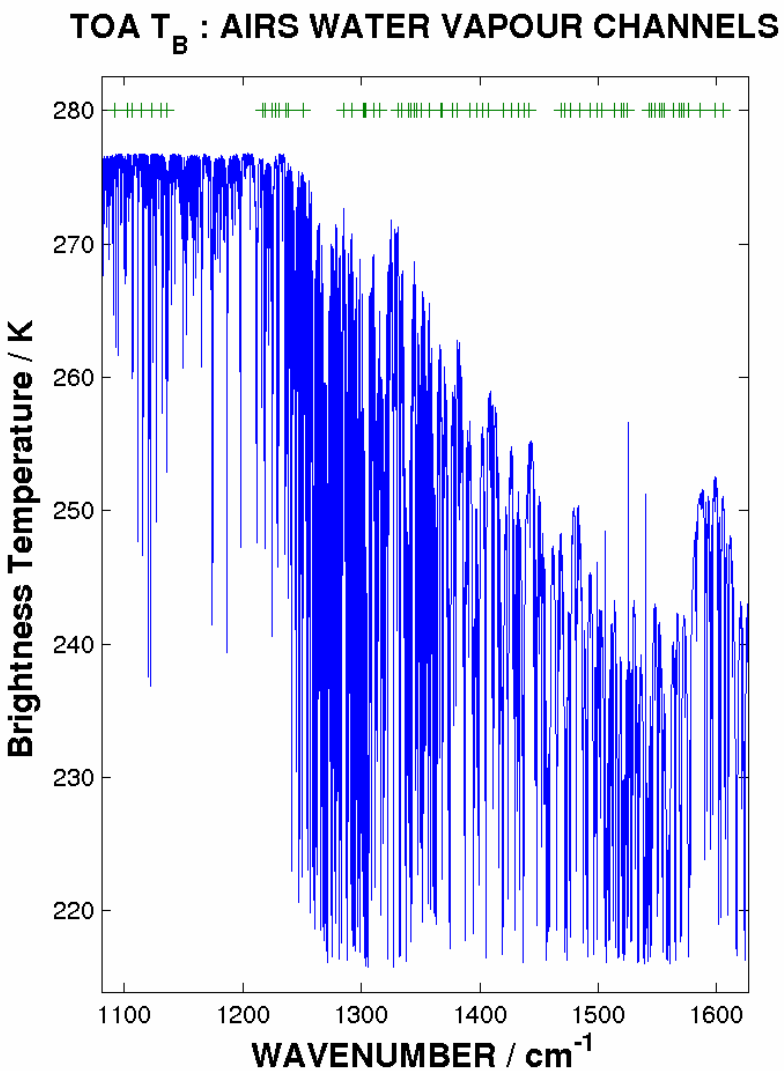


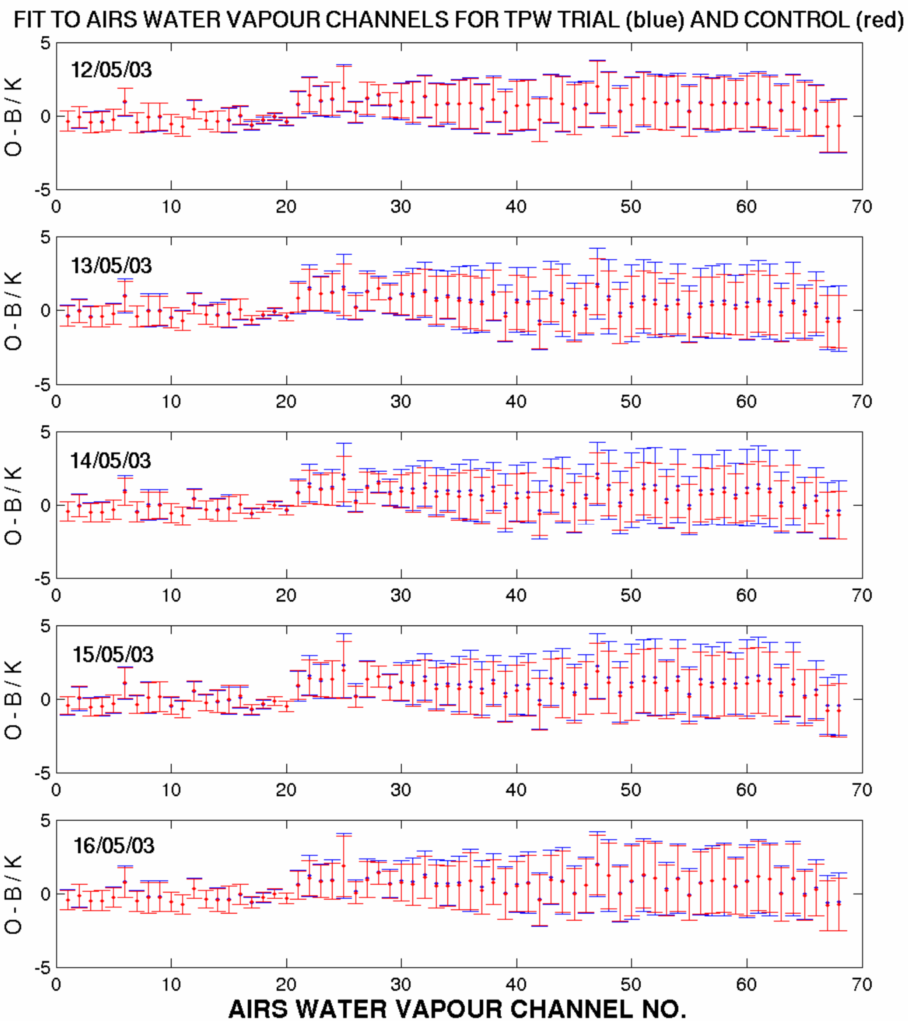
Meridional cross section




SSMI
40N
20N
0N
20S
40S
AIRS
More vertical structure in AIRS increments

VERIFICATION OF HUMIDITY FIELDS AT T+6 USING AIRS RADIANCES





- > Humidity fields degraded by SSMI (at T+6)!

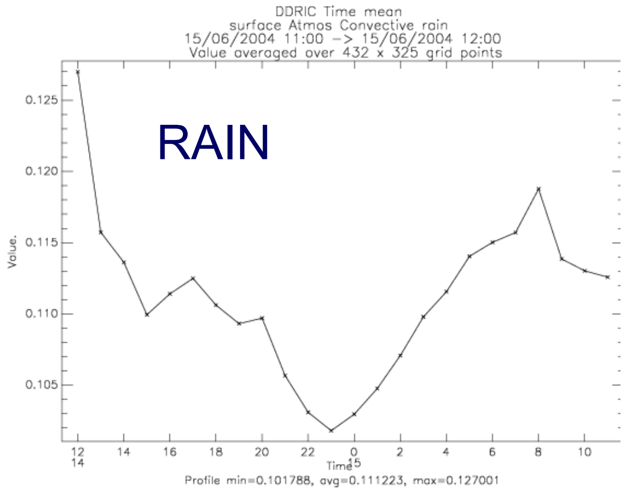
Spin Down of Convective Precipitation over 24 hours

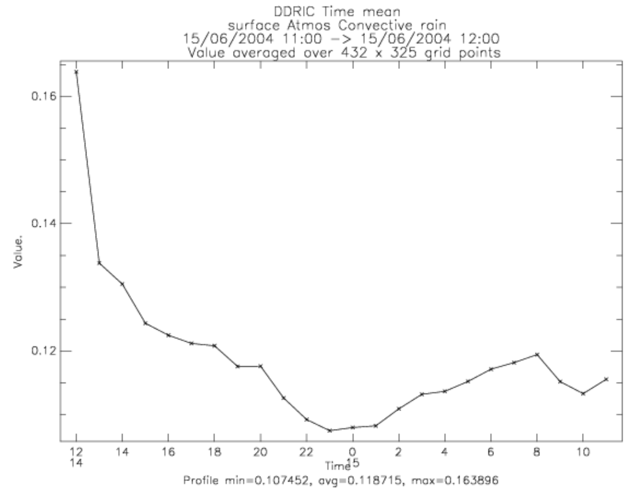
Radiance Assimilation

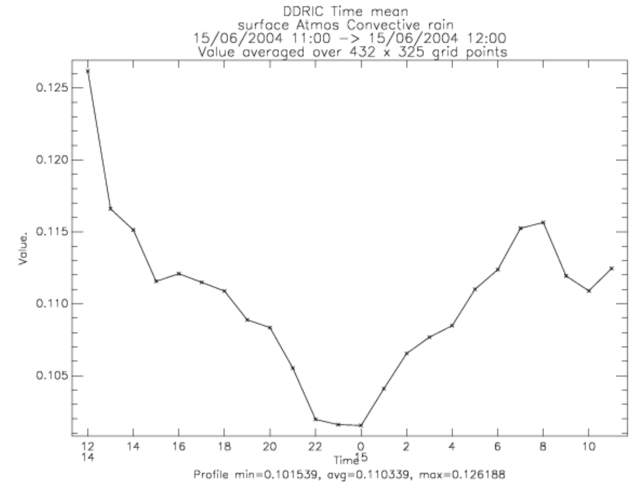
Product (TCWV& WS) Assimilation

No Assimilation

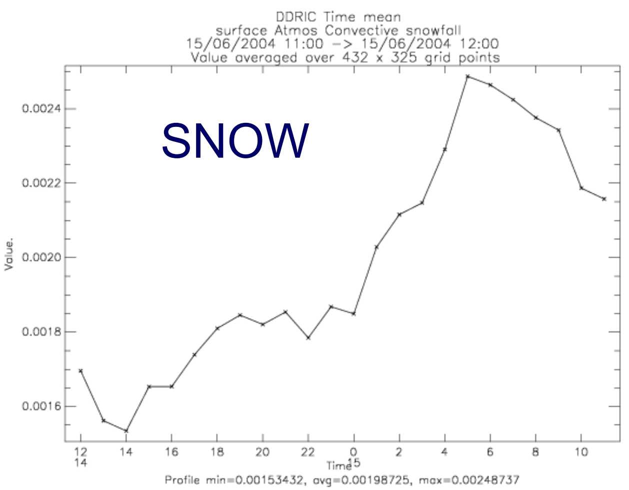
RAIN

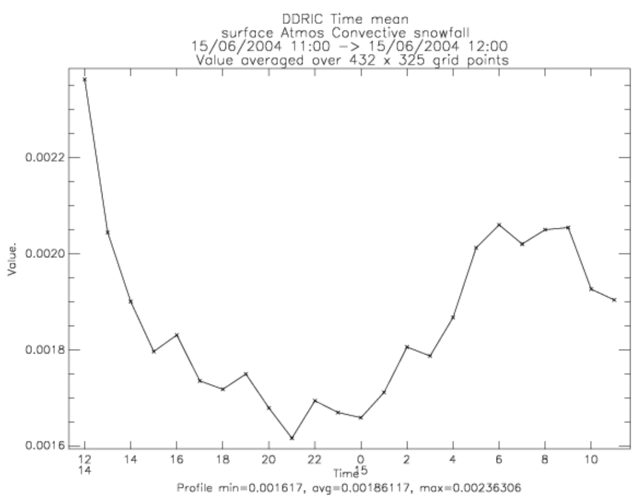


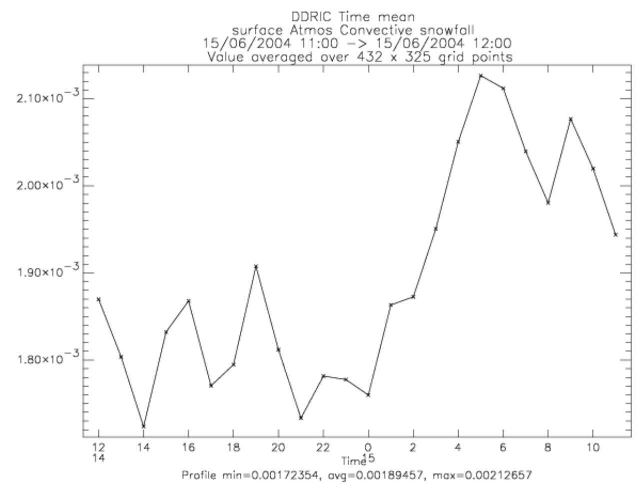




SNOW







Assimilation of imagery sequences

- Aim to improve forecasts of mid-latitude cyclones – rapid development means rapid growth of forecast errors from small initial condition error

- Sequences of geostationary satellite imagery depict development of major cloud systems - evolving cloud signals contain dynamical information which hope to extract through 4D-VAR assimilation of sequences of observed IR brightness temperatures

- Changing cloud top height or shape in image sequence should enable a model response that extends to low-level fields through dynamical links to produce sequence of model states which better fit observed imagery

- Observations are TOA brightness temperatures from IR window channel of geostationary satellites

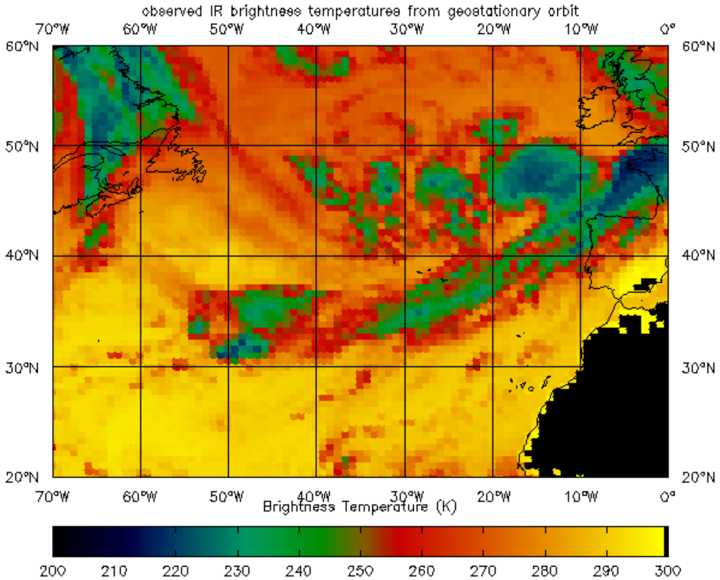
- Model variables radiatively active at this frequency: temperature, humidity, cloud amounts and water contents (liq and ice)

- Use radiative transfer model (RTTOVCLD) to compute model equivalents of observed T_B's from model fields

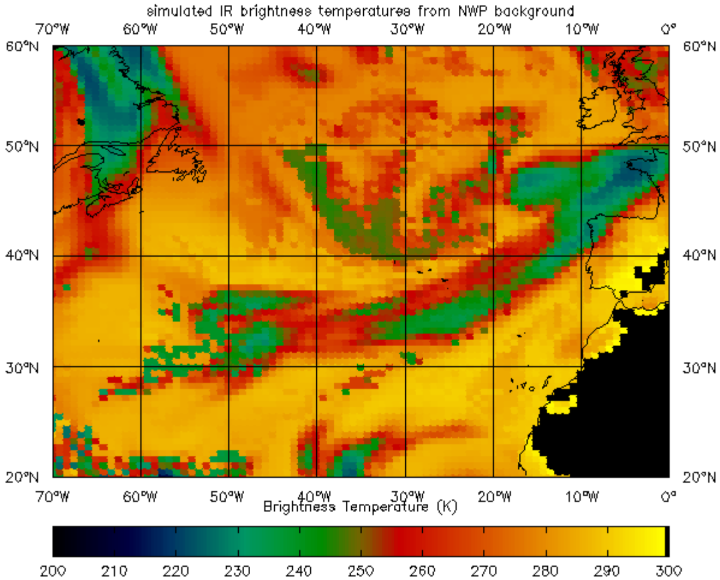
- Compare obs and “modelobs” – difference contributes to penalty in variational assimilation equation, which seek to reduce through assimilation

Simulation of a stage from explosive cyclogenesis 14-10-2002 12Z

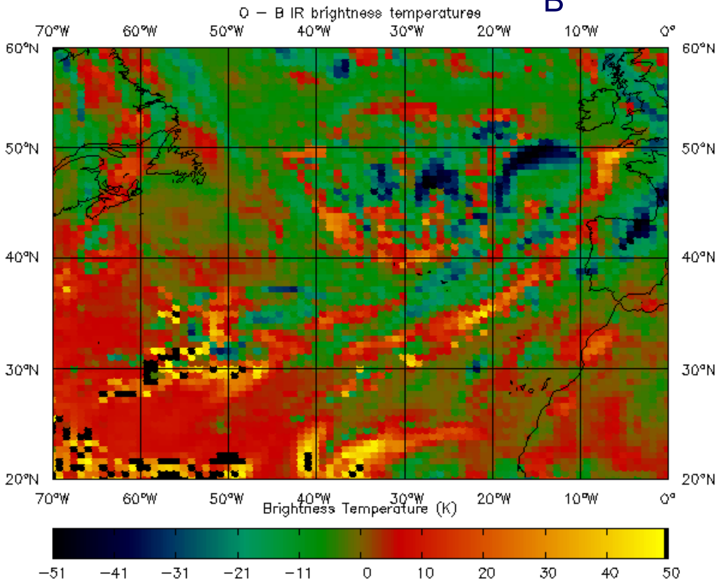
Observed T_Bs



Simulated T_Bs



Observed – Simulated T_Bs



- Mean difference 0.03 K
- Max difference 78.5 K (model cloud in tropical cloud-free region)
- Min difference -63.6 K (model under-represents intense development)

Summary

- Testing cloud incrementing operator diagnosing cloud water from total water
- Aiming for:
  - 4D-Var of cloud and precipitation in NAE (North Atlantic and European Model) 12km 2006
    - Need to replace MOPS LHN and humidity nudging
  - AMSU-A cloudy radiances
  - SSMI/S cloudy radiances
  - 3D-cloud cover analyses in Var

Questions & Answers

Key to following slides

- Trial results for 2 trials. Mixed. Degradation to SH in 2nd trial
- Moist Static energy SSMI vs AIRS vs ATOVS : SSMI makes a big and widespread impact on analysis
- Biases – complex. Model, seasonally and RTM dependent
- Single Ob experiment
- Analysis increments – SSMI has no profile information cf AIRS
- Using AIRS to validate SSMI short term moisture forecasts
- Early tests of Radiance Assimilation for SSMI – reduces spin down (more QC applied) cf products