# The assimilation of stratospheric satellite data at ECMWF

- The satellite observing system
- The assimilation approach
- Key strengths of the observing system
- Key limitations of the observing system
- Challenges …

# Satellite observing system currently assimilated at ECMWF

NOAA polar orbiting spacecraft (NOAA-15,16,17)
- AMSUA / HIRS / AMSUB ( and SBUV…next)

NOAA / EUMETSAT / JMA GEO spacecraft
- MVIRI / SEVIRI

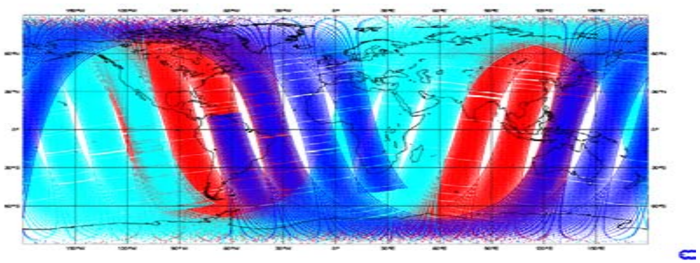
NASA polar orbiting AQUA / TERRA satellite
- AIRS / AMSUA / MODIS

DMSP polar orbiting spacecraft (F13 / F14 / F15)
- SSM/I (SSM/IS soon …)

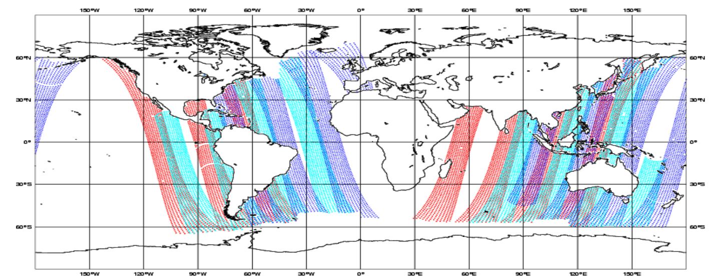
NASA polar orbiting QuickScat

# Geographical coverage of satellite observing system

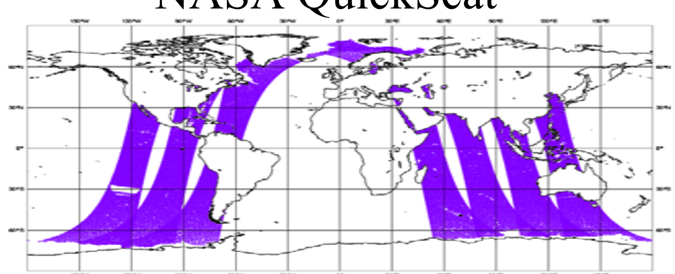
NOAA AMSUA/B HIRS



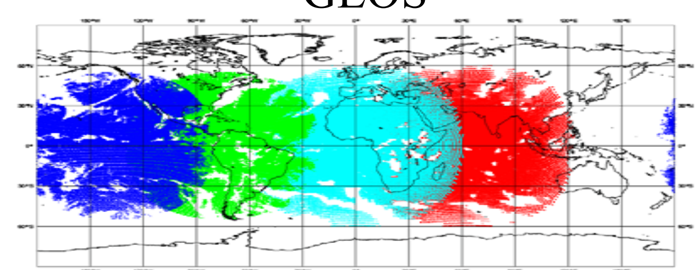
DMSP SSM/I



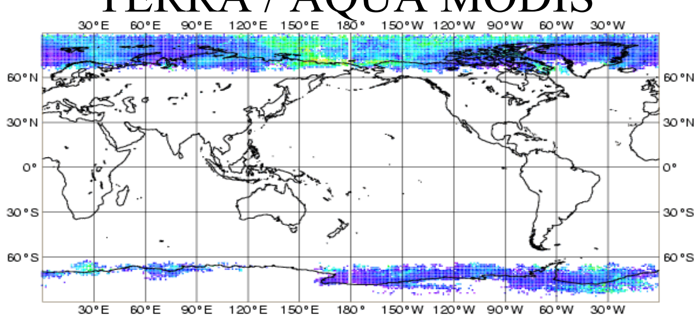
NASA QuickScat



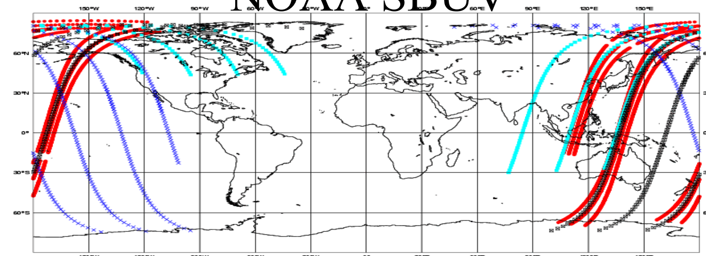
GEOS



TERRA / AQUA MODIS




NOAA SBUV



# Satellite data sensitive to the stratosphere

These are all passive temperature sounding channels measured by near-nadir scanning instruments (microwave and infrared)

Radiative transfer (RT) equation

$$L(\nu) \approx \int_0^\infty B(\nu, T(z)) \left[ \frac{d\tau(\nu)}{dz} \right] dz$$

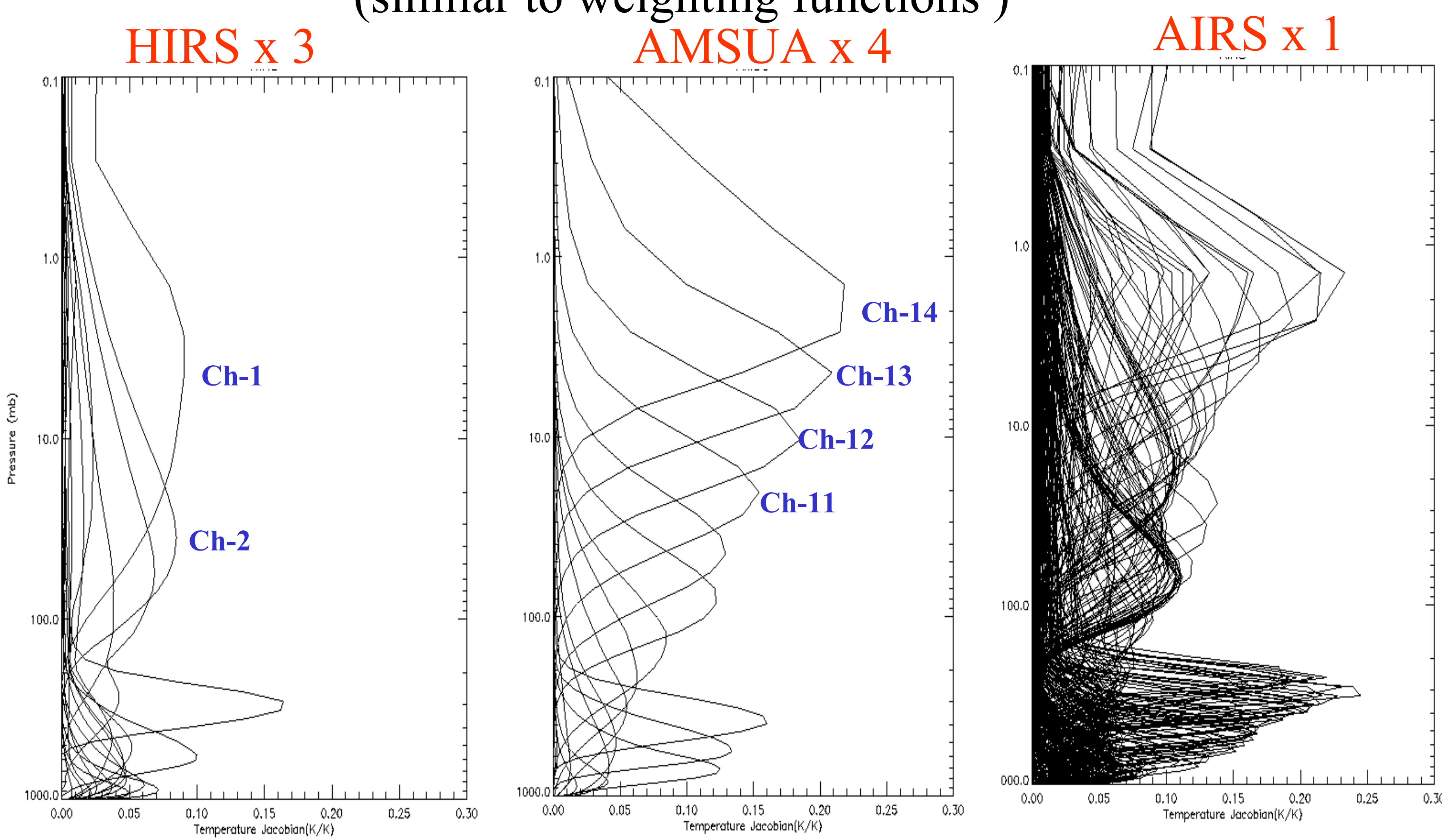
*Where B=Planck function*
*J = transmittance*
*T(z) is the temperature*
*z is a height coordinate*

Assuming the primary absorber is a well mixed gas (e.g. oxygen or CO2) the measured radiance is essentially a vertically weighted average of the atmospheric temperature profile.

The vertical averaging is described by the weighting function or jacobians of the radiative transfer equation

# Jacobians for satellite data sensitive to the stratosphere

(similar to weighting functions )



# The data assimilation system

Raw (i.e. unprocessed) **radiances** are assimilated **directly** in to the 4DVAR analysis system, which finds the trajectory of atmospheric states that best minimizes a cost or penalty function

$$J(x) = (x - x_b)^T \mathbf{B}^{-1} (x - x_b)$$

Fit to the background

$$+ \sum_i (y_i - \mathrm{H}[x_i])^T \mathbf{R}^{-1} (y_i - \mathrm{H}[x_i])$$

Fit to the observations

$$+ Jc$$

Other constraints

Subject to the additional implicit hard constraint that the atmospheric states follow the model equations

$$\forall i, x_i = \mathbf{M}_{0 \rightarrow i}(x)$$

# Assimilation of satellite retrievals versus radiances in operational NWP

Whatever approach is adopted to convert radiance measurements to temperature, humidity etc…The use of satellite retrievals is less attractive for a number of reasons:

1) They **retain characteristics of the a priori information** used in the inversion that are very difficult to remove.

3) The inversion process takes place in the absence of valuable **constraining information from other observations**

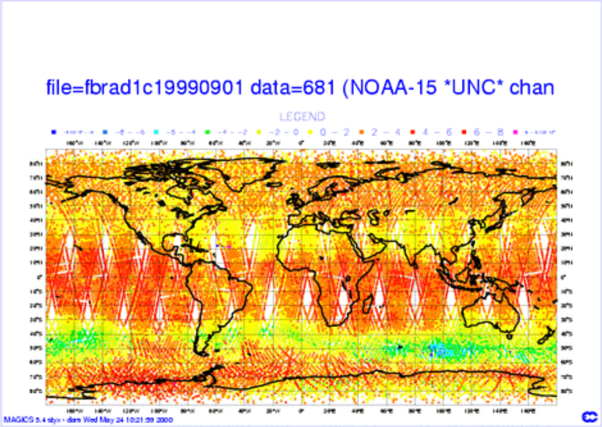
2) They generally have **complicated error structures** that are difficult to model in the subsequent assimilation.

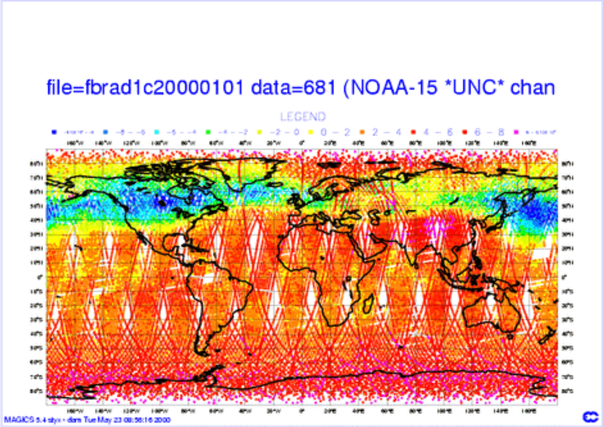
3) The distribution of retrievals may often be significantly **delayed** (during the commissioning phase) whereas raw radiances can be **available almost immediately after launch** (e.g. NOAA-16 AMSUA into OPS in 6 weeks).

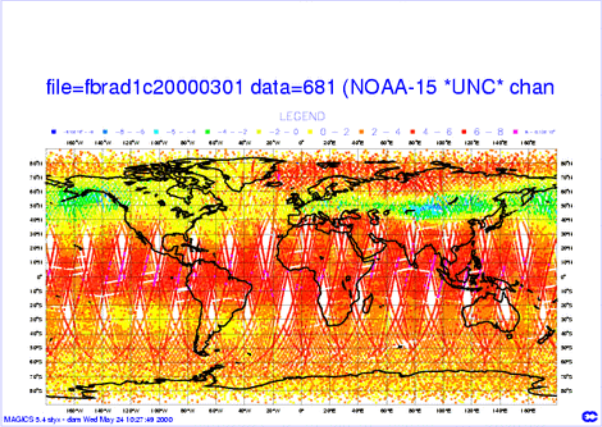
# Key strengths of the current observing system

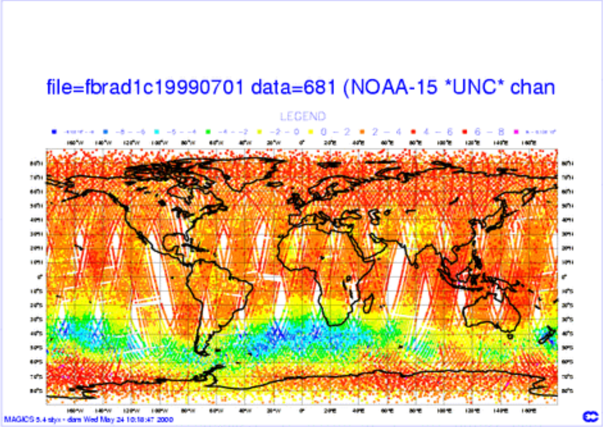
- Generally well calibrated instruments with known heritage
- High horizontal resolution
- Frequent time sampling (with same sensors on multiple spacecraft)
- Long time series of similar data (operational missions continuity)

# NWP model errors observed by AMSU-A channel 14

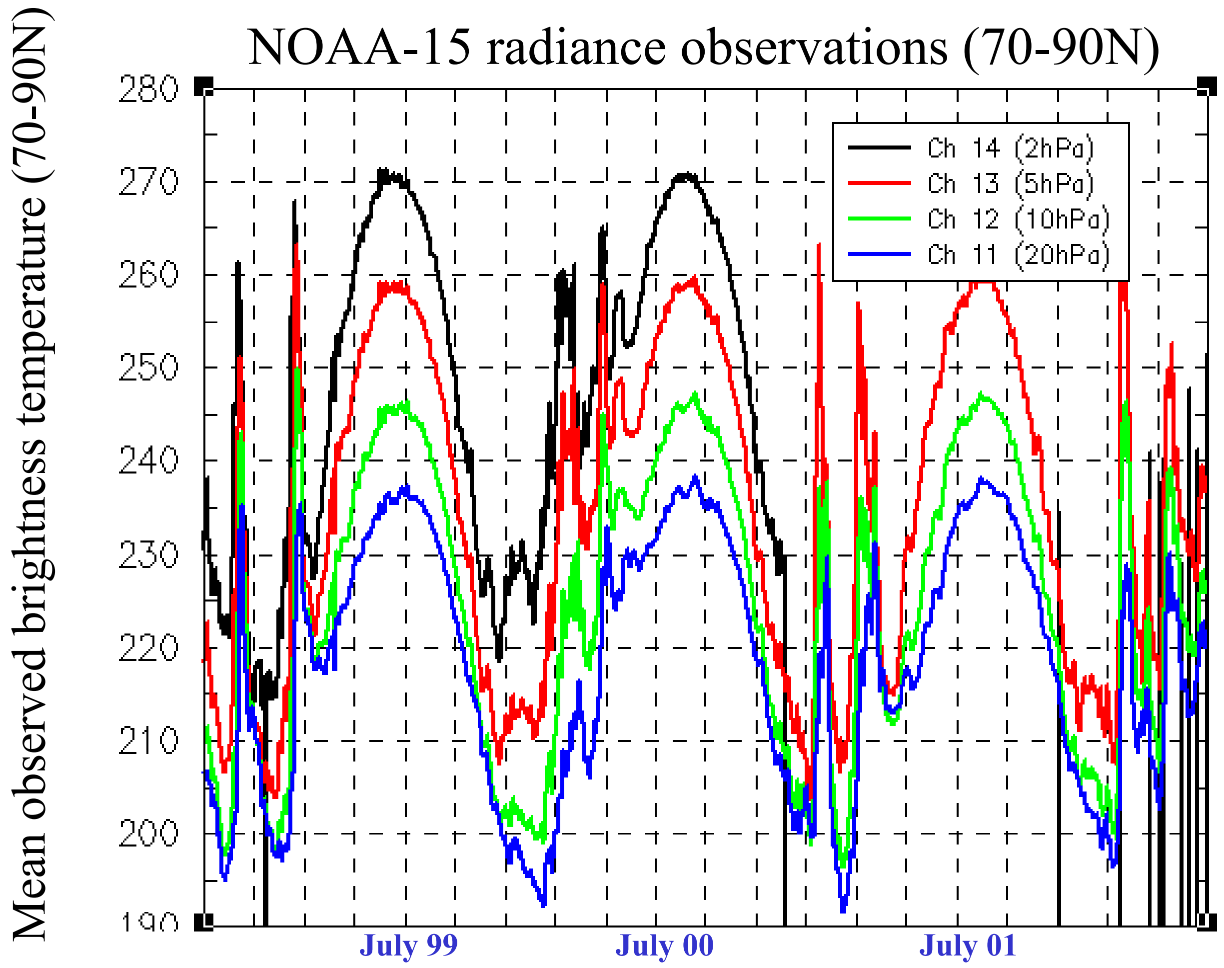


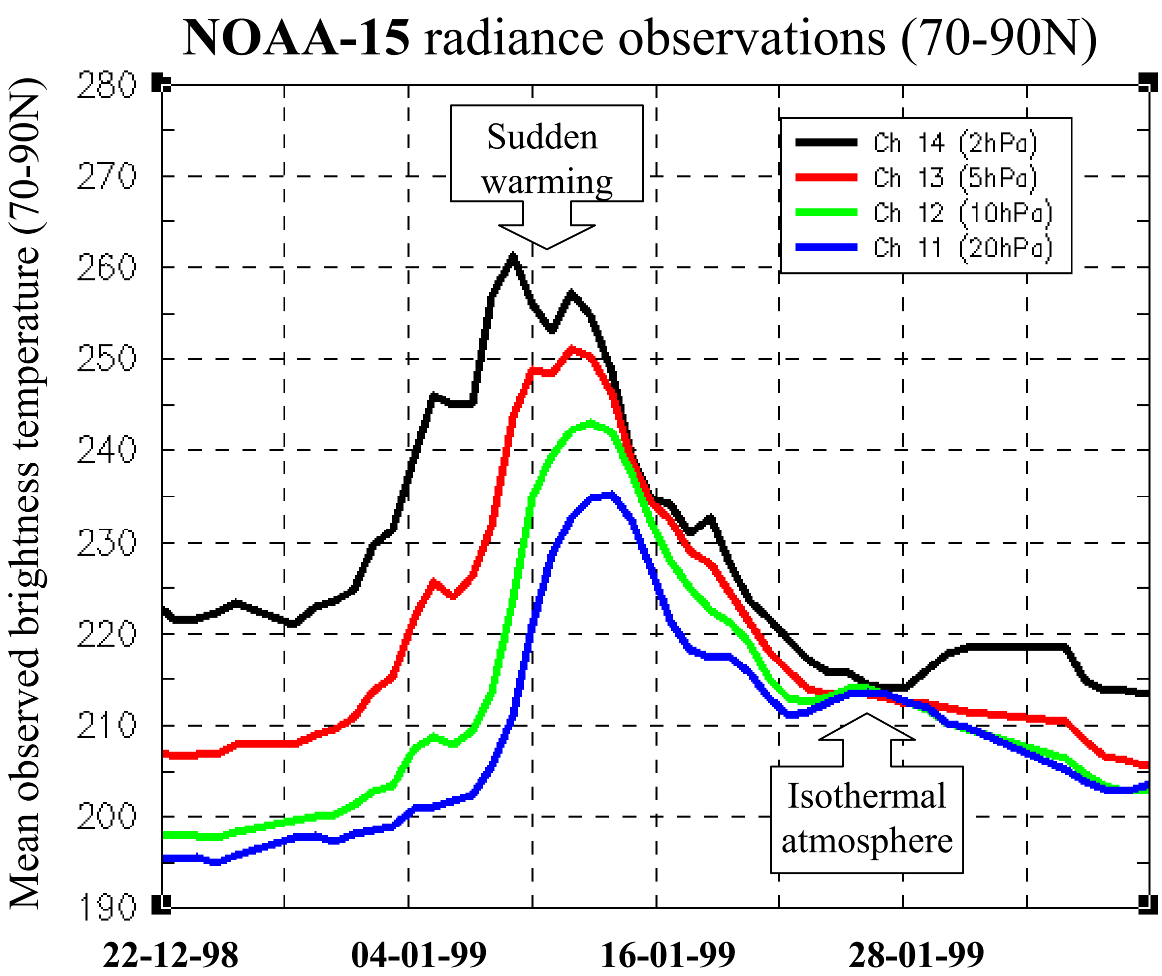



# Occurrence of sudden warmings with AMSU-A (Autumn 98 – Spring 2002)



# Vertical structure of sudden warmings (from AMSUA)




Winter 1998 / 1999

# Key limitations of the current observing system

1. Systematic errors (biases)
2. Vertical resolution

# Systematic errors

The observations have systematic errors:

- Poor instrument calibration
- Poor spectral characterization
- Environmental influences on instrument (icing)

The radiative transfer models have systematic errors:

- Poor spectroscopy
- Poor approximations to physics (e.g. layering)
- Non-modelled phenomena (e.g. non-LTE / Zeeman splitting)

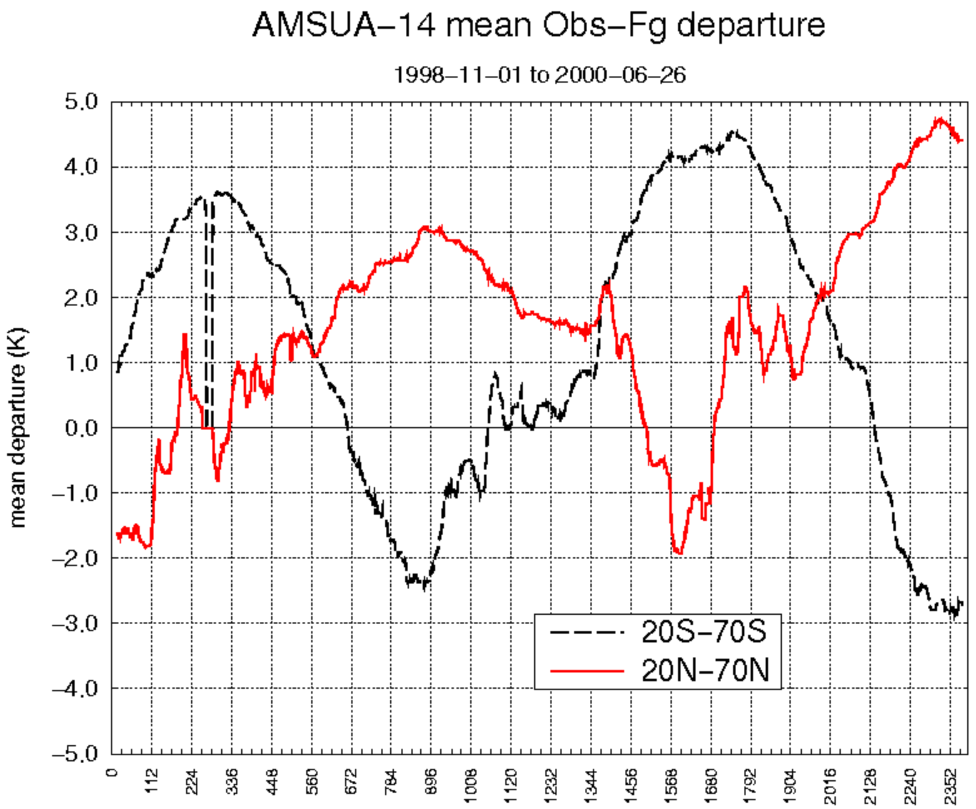
Traditionally (in NWP) biases in the data / RT model are diagnosed and corrected using the analysis (or 6hr FC) in the vicinity of high quality radiosonde data …**but this is not an option in the stratosphere**

# Diagnosing systematic errors…

… What if the NWP analysis/FC is wrong ?

This time series shows an apparent systematic error in AMSU channel 14 (peaking ~ 1hPa).

By checking against other research data (HALOE and LIDAR data) the bias was confirmed as a NWP model temperature bias and the channel is now assimilated with no bias correction

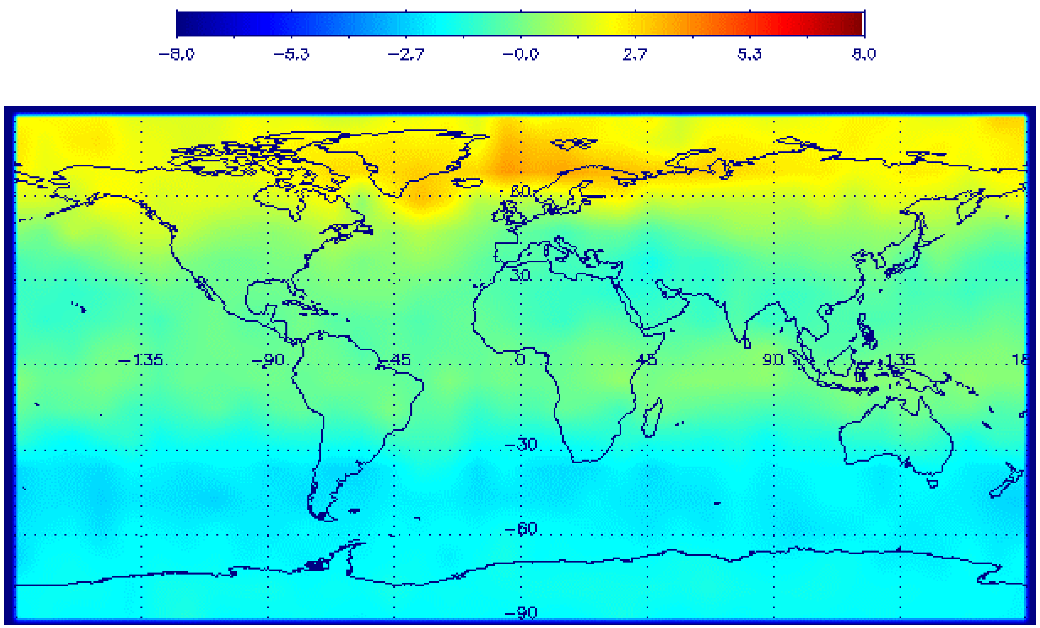


# Diagnosing systematic errors…

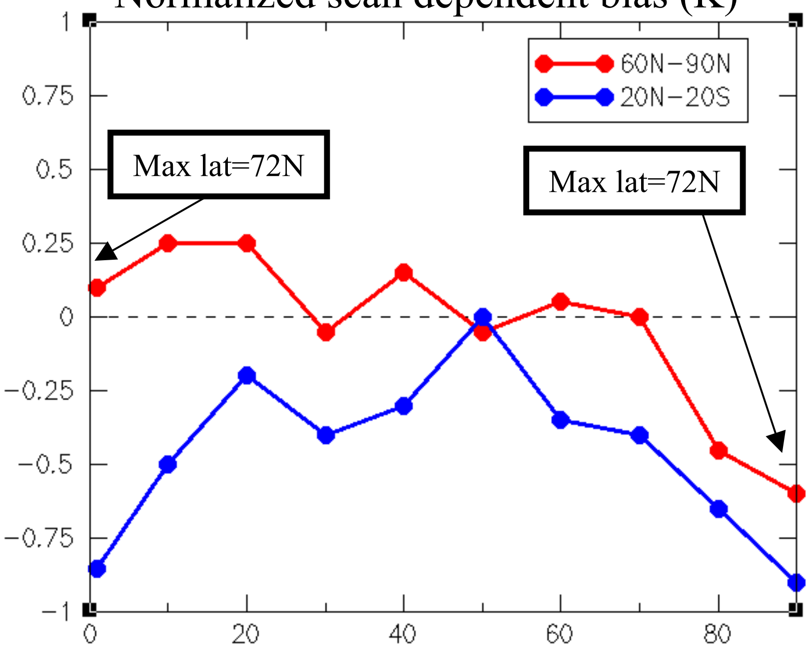
## What if the NWP analysis/FC is wrong … scan dependent biases ?

Systematic errors in the analysis/FC **lapse rate** can give **apparent scan dependent biases** (symmetric and asymmetric) , which can be (wrongly) attributed to the instrument / RT model. Larger systematic lapse-rate errors are more common in the stratosphere.

Mean Obs-fg Tb for AIRS ch-75 (15.0microns)



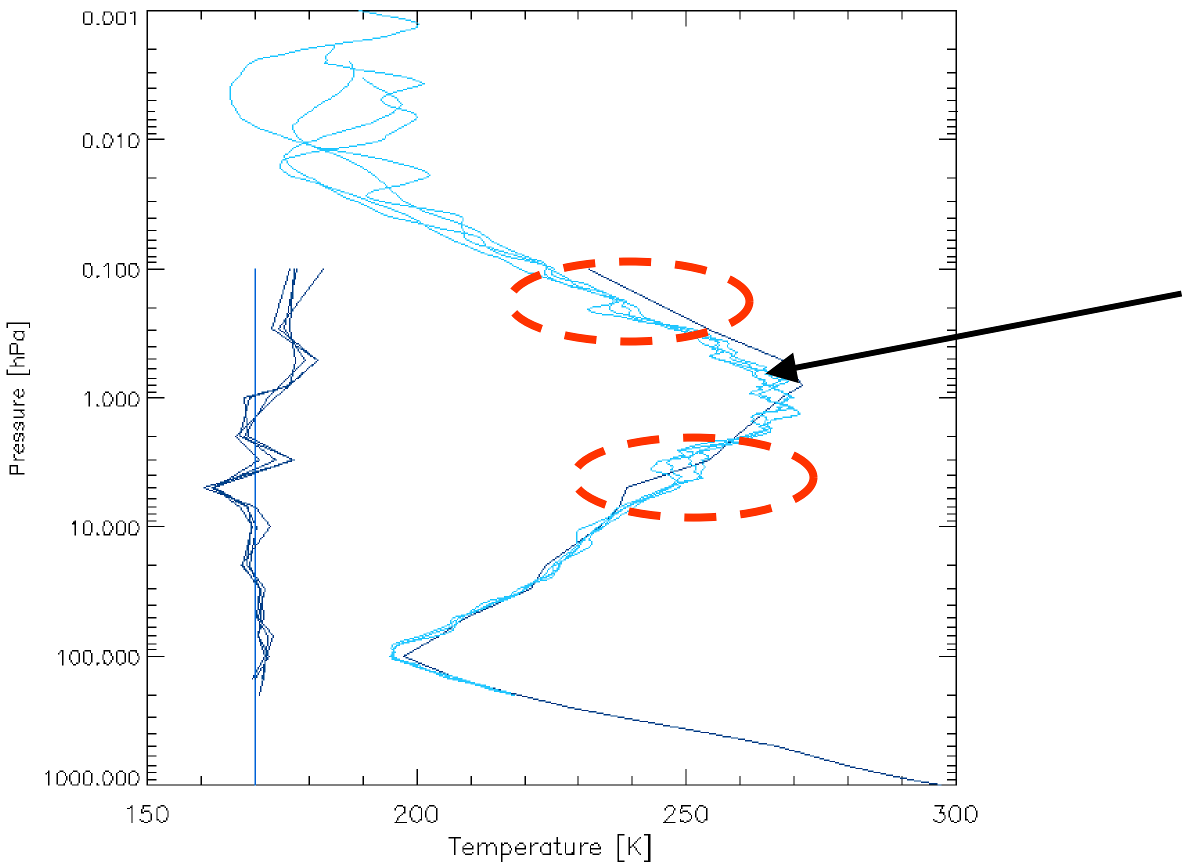

Normalized scan dependent bias (K)



# Vertical resolution

The physics of passive nadir sounding results in the channel jacobians / weighting functions being **broad vertical averages** of temperature. This severely **limits the vertical resolution** of the information provided

Lidar data (blue) ECMWF (black)

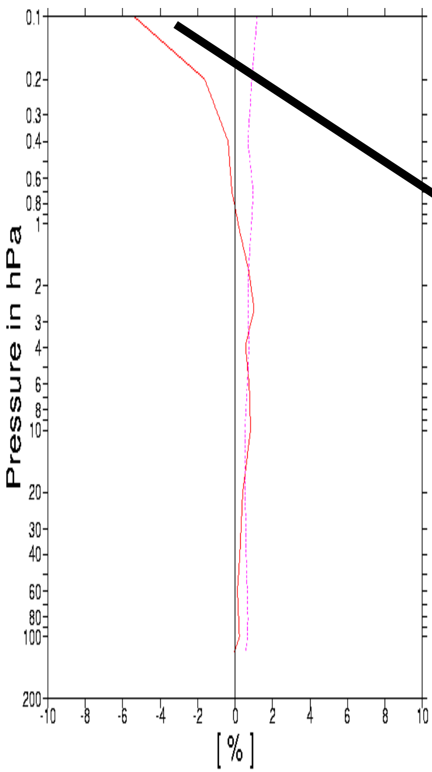


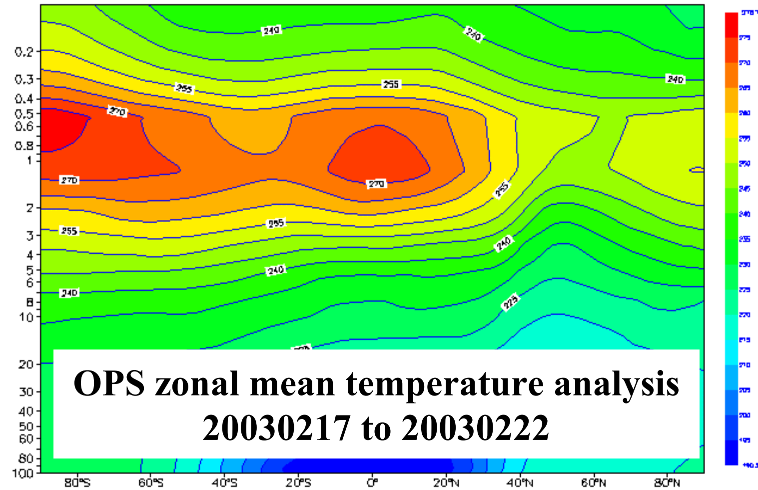

While the assimilation of radiance data from the AMSUA gave good improvements to the analyzed temperatures around the stratopause, there was some evidence of a lack of vertical skill.

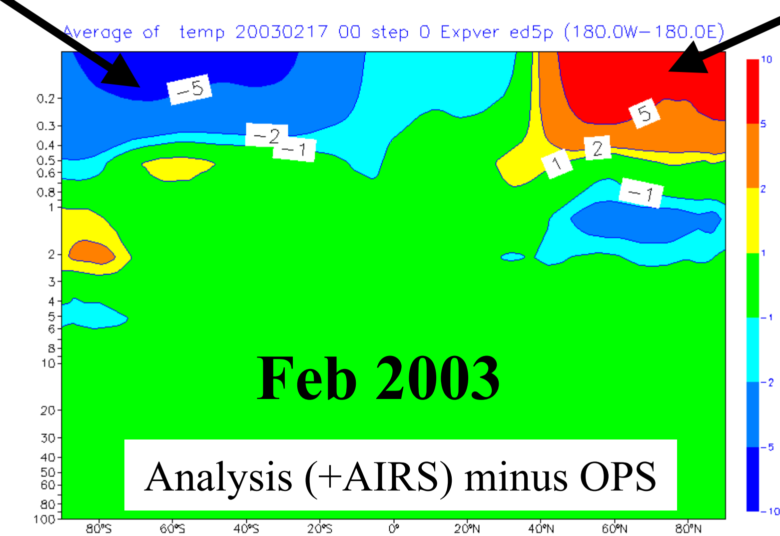
# Improvements with AIRS radiances

(good agreement with MIPAS temperature retrievals)

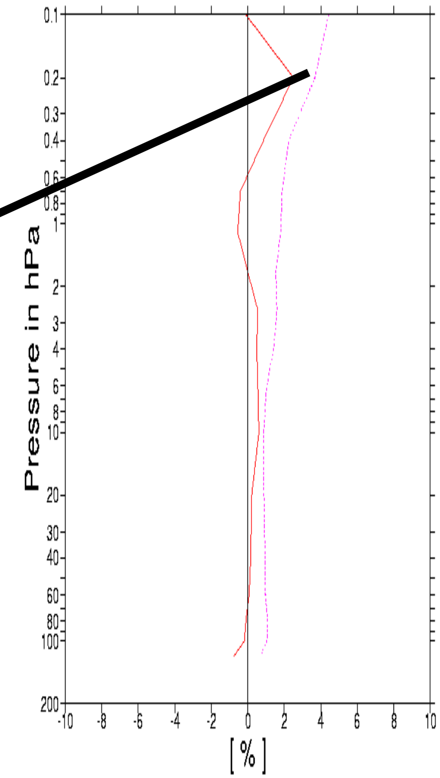
MIPAS retrievals (65-90S)
(20030217-20030222)
minus OPS analysis



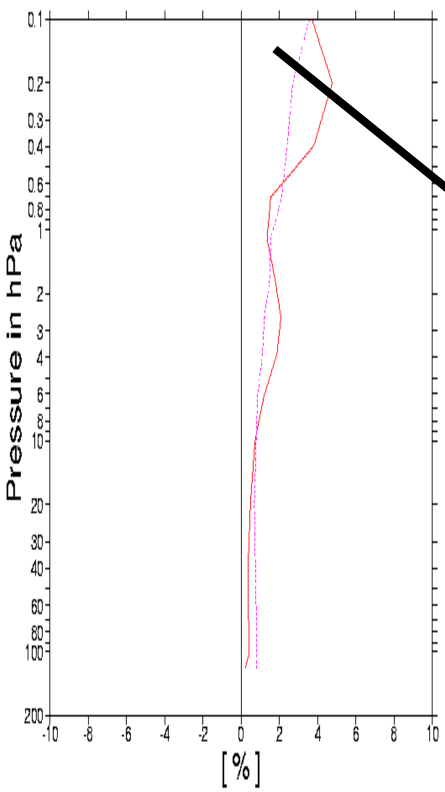



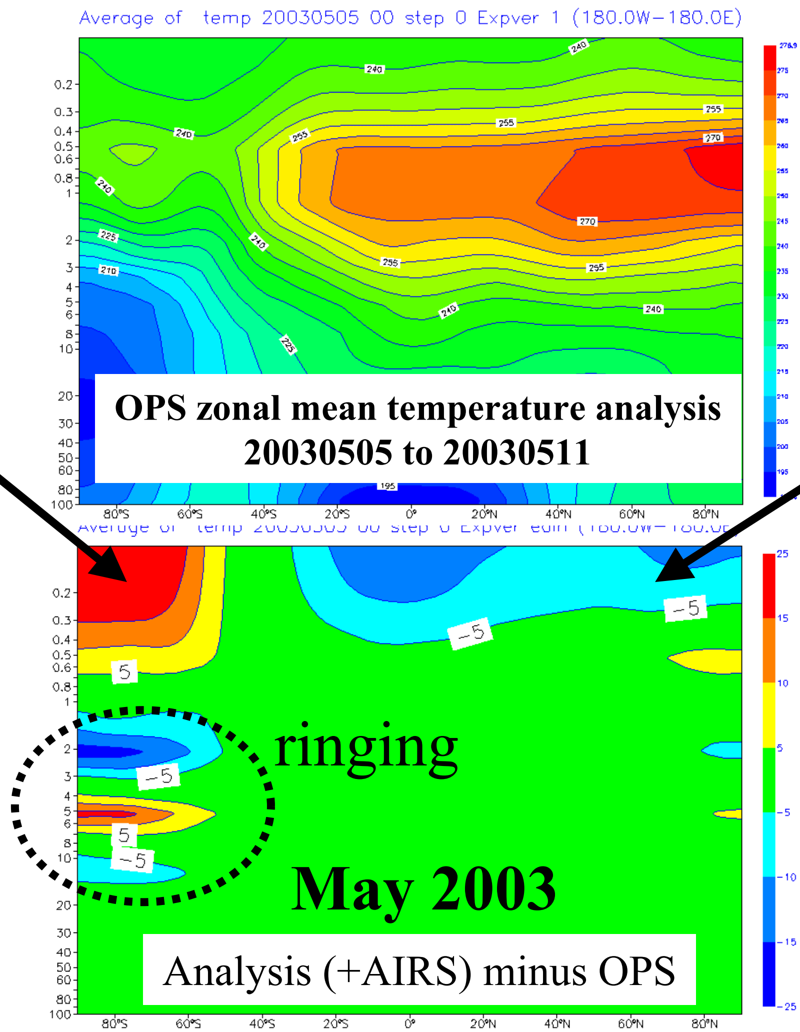

MIPAS retrievals (65-90N)
(20030217-20030222)
minus OPS analysis



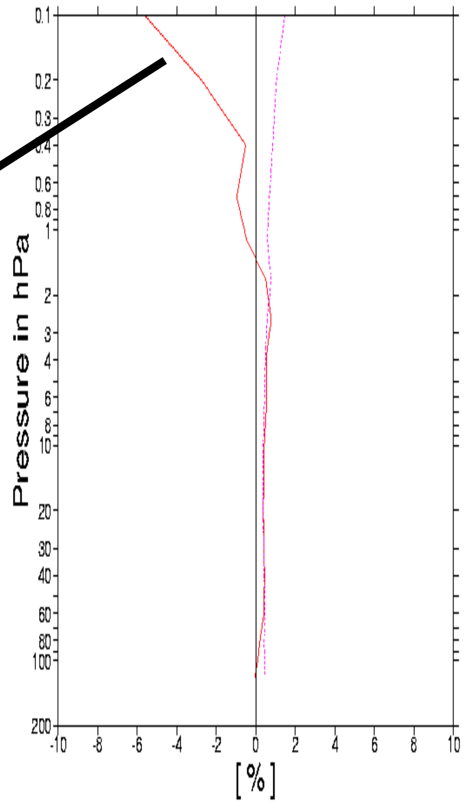
# Vertically oscillating increments

MIPAS retrievals (65-90S)
(20030217-20030222)
minus OPS analysis



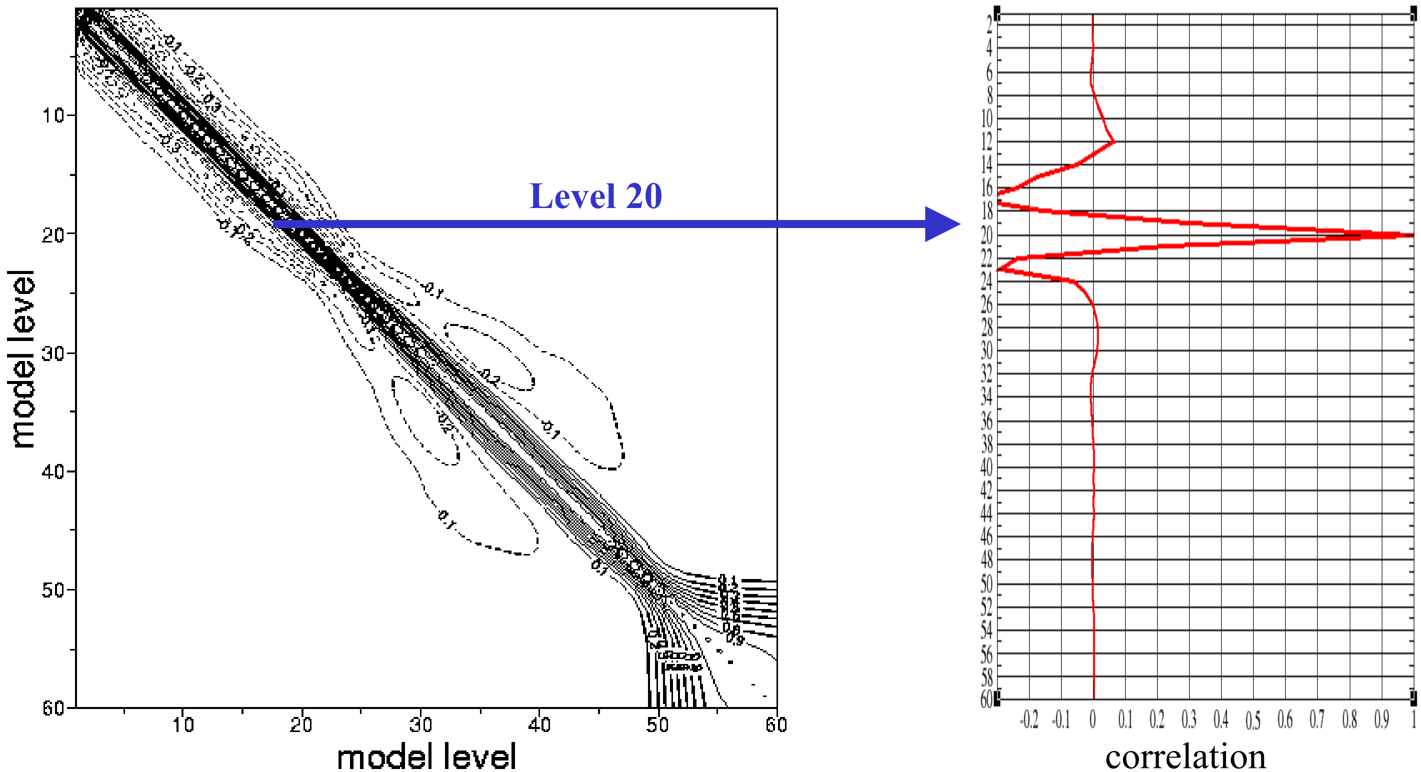

MIPAS retrievals (65-90N)
(20030217-20030222)
minus OPS analysis



# Vertical correlation of background temperature errors

These are generally very sharp (describing random background errors) and as such do not prevent oscillating increments in between broad overlapping channels

Globally averaged correlation of temperature errors in 4DVAR



# Challenges …

- Improve our understanding of systematic errors (i.e observations / RT / NWP model) … lack of high quality data to estimate them ?

- Tune analysis structure functions (error covariances) specifically for the types of error we have in the stratosphere (i.e. systematic and random) …lack of high quality/resolution data to estimate them ?

- Make effective use of new operational instruments with improved vertical resolution / coverage (AIRS, SSM/IS, IASI, CrIS)

- Make synergistic use of very high vertical resolution (i.e. limb sounding) satellite data in the assimilation (currently only used for diagnosis)