Direct assimilation of cloud affected infrared radiance observations in the ECMWF 4D-VAR

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ECMWF
Why do we need to use cloud affected IR data ...?

• Just using clear-sky observations is a major under-use of very high cost instruments such as AIRS and IASI

• Use of only clear-sky data could bias the assimilation system to have the characteristics of dry regions

• We believe that cloudy areas are meteorologically sensitive and constraining analysis errors in these regions (i.e. with observations) is important.
Sensitive areas and cloud cover

Location of sensitive regions
Summer-2001 (no clouds)

sensitivity surviving high cloud cover

monthly mean high cloud cover

sensitivity surviving low cloud cover

monthly mean low cloud cover

From McNally (2002) QJRMS 128
Fundamental issues

• The cloud uncertainty in radiance terms may be an order of magnitude larger than the T and Q signal (i.e. 10s of kelvin compared to 0.1s of kelvin)

• The radiance response to cloud changes is highly non-linear (i.e. $H(x) = H_x(x)$)

• Errors in background cloud parameters provided by the NWP system may be too large to provide an accurate linearization point and difficult to characterize

• Trade off between having enough cloud variables for an accurate RT calculation while limiting the number of cloud variables to those that can be uniquely estimated in the analysis from the observations
Two approaches to assimilate cloud affected infrared radiances

Simplified system:
• very simple cloud representation
• currently limited to overcast scenes
• no information on clouds taken from model
• no back interaction with model via physics

Advanced system:
• very complex cloud representation
• all cloud conditions treated
• information on clouds taken from model
• back interaction with model via physics

\[ X = (T, Q, V, c_p, c_f) \]

\[ X = (T, Q, V, c_{iw}, c_{lw}, c_c) \]
Experience with simplified Cloudy IR Radiance Assimilation

(only overcast conditions used)

See McNally (2009) QJRMS 135, 1214-1229 for more details…
Why overcast scenes...?
Why use cloudy radiances only in overcast conditions?

- Overcast clouds are least ambiguous in the radiance data.
- Cloud control vector collapses to a single number (cp).
- Problems with cloud overlap assumptions vanish.
- No cross-talk between cloud and surface variables.
- Termination of jacobians at cloud top provides new high vertical resolution information on temperature.
Impact of overcast data on the ECMWF analysis…
Clear and Cloudy Jacobians (impact at the cloud top)

\[ \frac{dR}{dT^{500}} = 0 \quad \text{and} \quad \frac{dR}{dT^*} = 1 \]

full cloud at 500hPa
Temperature increments above low clouds

Overcast data coverage from HIRS, AIRS and IASI and the estimated cloud top pressure
Temperature increments above low clouds

Overcast data coverage from HIRS, AIRS and IASI and the estimated cloud top pressure

Analysis temperature increments at 700hPa
Temperature increments above high clouds

Overcast data coverage from HIRS, AIRS and IASI and the estimated cloud top pressure
Temperature increments above high clouds

Overcast data coverage from HIRS, AIRS and IASI and the estimated cloud top pressure

Analysis temperature increments at 250hPa
...do these extra increments at the cloud top do any good..?
Improved analysis fit to isolated radiosonde observations

Monthly averaged RMS temperature increment difference (CLOUDY minus CTRL). Shaded areas indicate a reduction in increments in excess of 0.1K when the cloud radiances are assimilated.
...forecast impact ...?
Cloud obscured singular vector?

In this case the use of overcast observations resulted in analysis differences in an area suggested to be sensitive by the singular vector locations.

Extra overcast data used compared to CTRL.

500hPa temperature analysis difference (K)

Location of leading 500hPa singular vectors

SH 500hPa Z

CNTRL CLOUDY
Towards an Advanced Cloudy IR Radiance Assimilation
Towards an **Advanced** Cloudy IR Radiance Assimilation

Cloudy radiances $R_{\text{cal}}$ are simulated via a chain of forward operators $(M,RT)$. The fit of the analysis to the observations is computed $(Jo)$

$Jo = (R_{obs} - R_{\text{cal}})$

Jo is minimized by perturbing the analysis variables according to gradients from a chain of adjoint operators $(RT^*,M^*)$
Adjusting analysis variables to fit the cloudy radiance observations
Summary and Plans

• The simplified assimilation of overcast HIRS, AIRS and IASI works very well and became operational at ECMWF in 2009.

• We are in the process of developing the advanced cloudy assimilation system (drawing on experience from a similar scheme for rain affected microwave radiances)

• Initially, cloud parameters (clw,ciw,cc) will be diagnostic and driven by the model physics via adjustments in the analysis control vector variables (T,Q and V).

• Later the cloud parameters will be tested as full variables in the analysis control vector (but this will require accurate background error observations.
End

(...almost...)
Assimilation of ozone sensitive IASI radiances in the ECMWF 4D-VAR

Wei Han and Tony McNally
IASI Ozone Experiments

**Baseline System:**
T511 (40Km) full operational data (no O3 observations)

**UV System:**
As baseline plus UV data from SBUV and OMI

**IASI System:**
As baseline plus 16 IASI ozone channels
*(LW cloud detection and channel 1585 anchored to zero bias correction, other channels VarBC)*
Impact of IASI Ozone Channels

Zonal mean cross section of full ozone field (shaded) and mean analysis difference with and without IASI ozone channels (units are mass mixing ratio)
Verify against MLS (20090615-20090630)

- BASELINE
  - No O3 OBS

- BASELINE
  - +SBUV+OMI

- BASELINE
  - +IASI 16 O3 Channels
Verify against MLS  (20090615-20090630)

BASELINE
No O3 OBS

BASELINE
+SBUV+OMI

BASELINE
+IASI 16  O3 Channels
Summary and Plans

• The assimilation of **16 IASI ozone channels** produces an analysis in **good agreement with MLS data**. This agreement is better than a baseline system (with no ozone observations), but also better than a system using SBUV and OMI data.

• The use of **cross-band cloud detection** using IASI LW channels is crucial to identify clouds in the presence of ozone errors.

• The **anchoring of the assimilation** to one uncorrected IASI ozone channel is also important, the system cannot be bias corrected against the NWP model.

• Exploring the potential for **4DVAR stratospheric wind tracing** is a priority.
End
Background 2D cloud parameters (comparison with AVHRR)

AVHRR cluster analysis based on imager pixels within the IASI field of view – one week of data 2008-08-07 to 2008-08-14