Variational Cloud-Clearing with CrIS Partially Cloudy Data at NCEP

Haixia Liu[1,2]
Andrew Collard[1,2]
John Derber[2]

[1]I. M. Systems Group, Rockville, Maryland
[2]NCEP/EMC, College Park, Maryland

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Outline

- Why cloud-clearing?
- Cloud-clearing methodology
- Impact of the Cloud-Cleared Radiance (CCR) on temperature analysis
- Evaluate CCR impact in the operational configuration
- Summary

Motivations

- Most of the global domain is affected by clouds
  - IR is used in current NCEP operation only over clear-sky regions or from the channels that peak well above cloud tops.
- Efforts on using IR cloudy radiances
  - Explicitly describe clouds
    - Simplified clouds with the assumption of single-layer clouds
    - Sophisticated cloud profiles are estimated.
  - Cloud-clearing: is a method to remove the cloud radiative effect by comparing adjacent pixels within one field of regard (FOR). It aims at using partially cloudy data.
    - Looking for accurately retrieved clear-column radiances (CCR) with error usually less than 0.5K. Consider online retrieval method which can provide product consistent with other data.
    - CrIS is chosen because it has many T/cloud sounding channels with small noise, arrayed as 3x3 array of 14km diameter spots (nadir spatial resolution). Bias is small too.

Cloud-Clearing Methodology

$FOV1: R_1 = (1 - \alpha 1) \times R_{clr} + \alpha 1 \times R_{cld}$ (1)

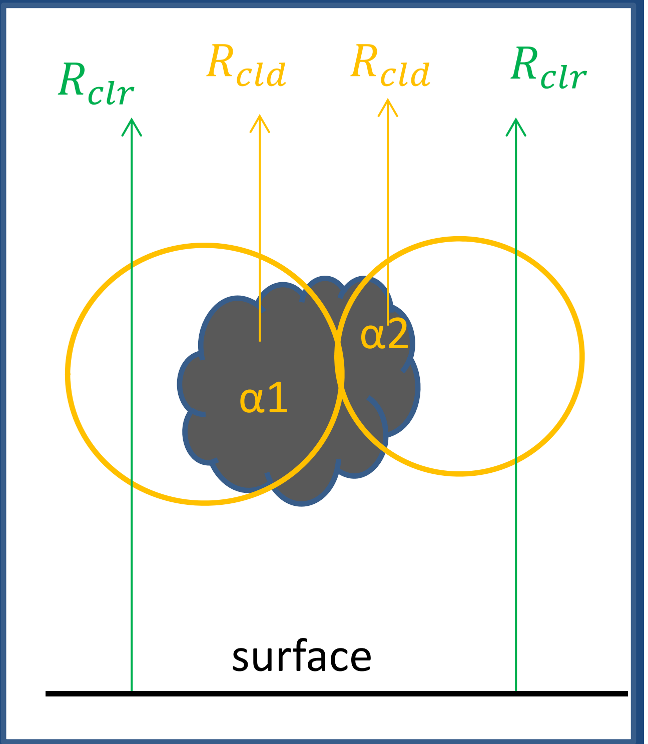
$FOV2: R_2 = (1 - \alpha 2) \times R_{clr} + \alpha 2 \times R_{cld}$ (2)

Assume: R_{clr} and R_{cld} in the 2 adjacent FOVs are same

After eliminating the R_{cld} from above 2 equations, we can get:

$R_{clr} = R_1 + \boldsymbol{\eta} \times (R_1 - R_2)$, (3)

where $\boldsymbol{\eta} = \alpha 1 / (\alpha 2 - \alpha 1)$ and $\alpha 1 \neq \alpha 2$

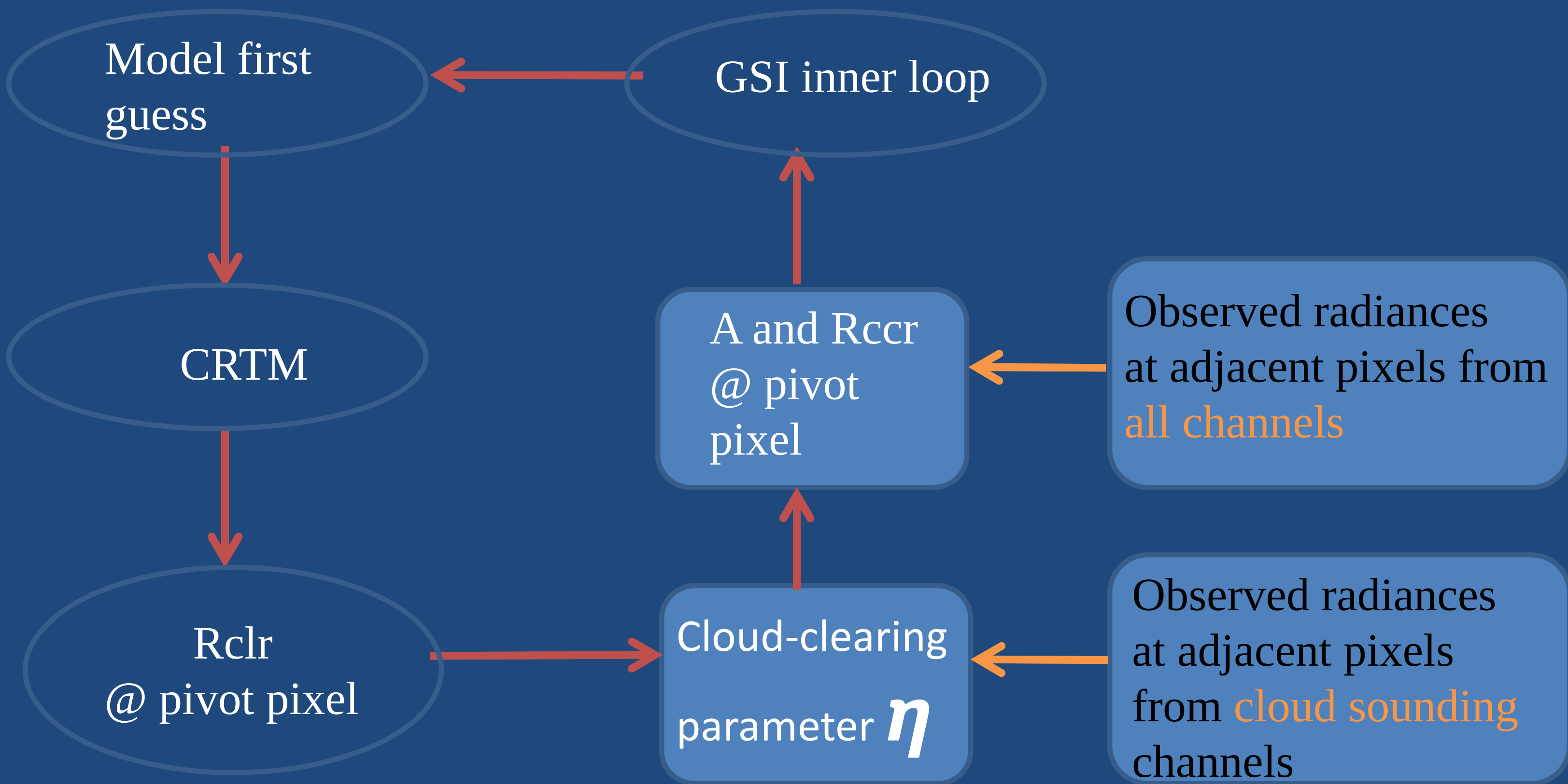


Extend to multiple cloud layers and more adjacent pixels:

$R_{ccr} = R_1 + \boldsymbol{\eta}_1 \times (R_1 - R_2) + \boldsymbol{\eta}_2 \times (R_1 - R_3) + \ldots\ldots + \boldsymbol{\eta}_k (R_1 - R_{k+1})$, (4)

$\boldsymbol{\eta}_1, \boldsymbol{\eta}_2$ … are cloud-clearing parameters which depend on α only. They can be estimated using a set of cloud sounding channels to solve an over-estimated problem in a least-square sense.

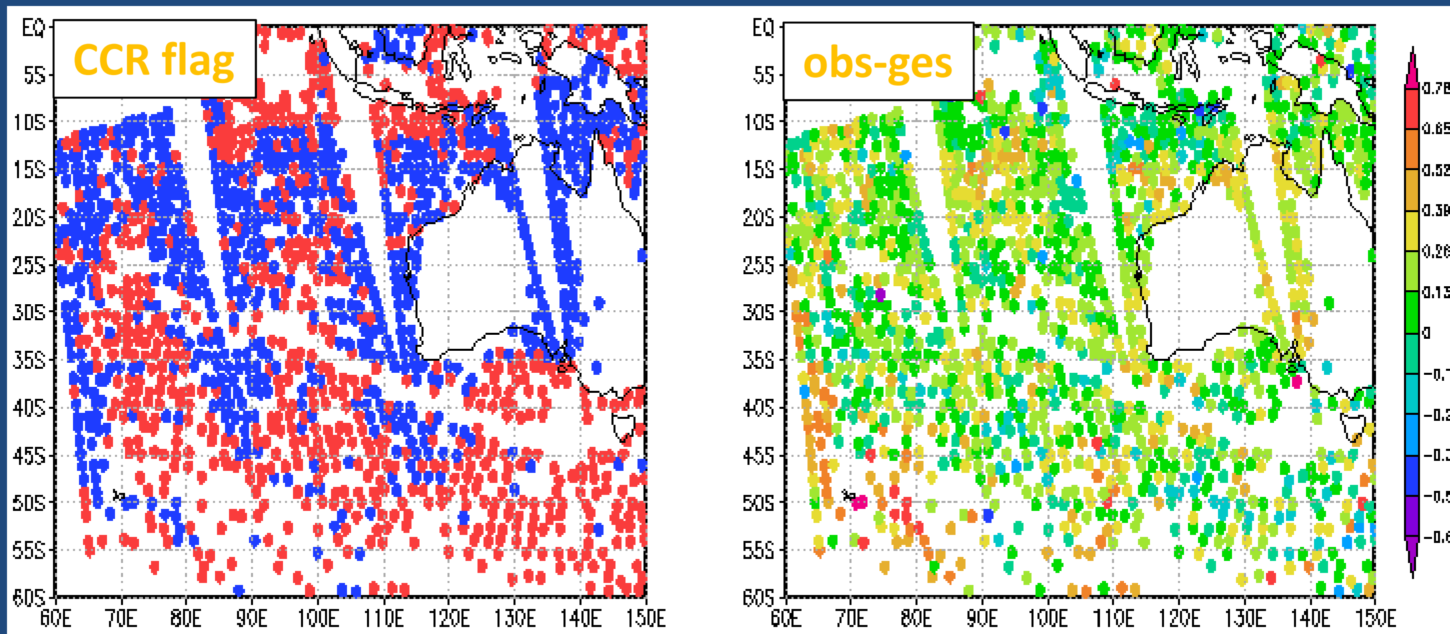
Flow Chart of Variational Cloud-Clearing



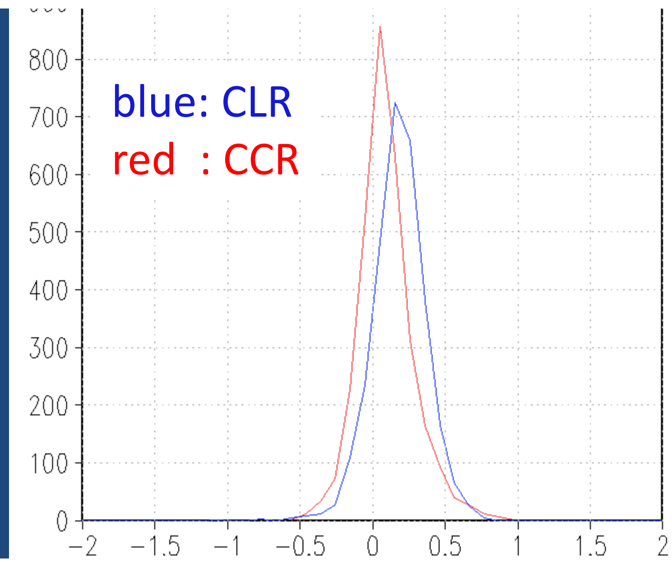
The cloud-clearing parameters are estimated and updated inline together with other meteorological variables within the variational framework and reconstructed Rccr is assimilated with all other available observations.

OBS-GES of R_ccr VS R_clr

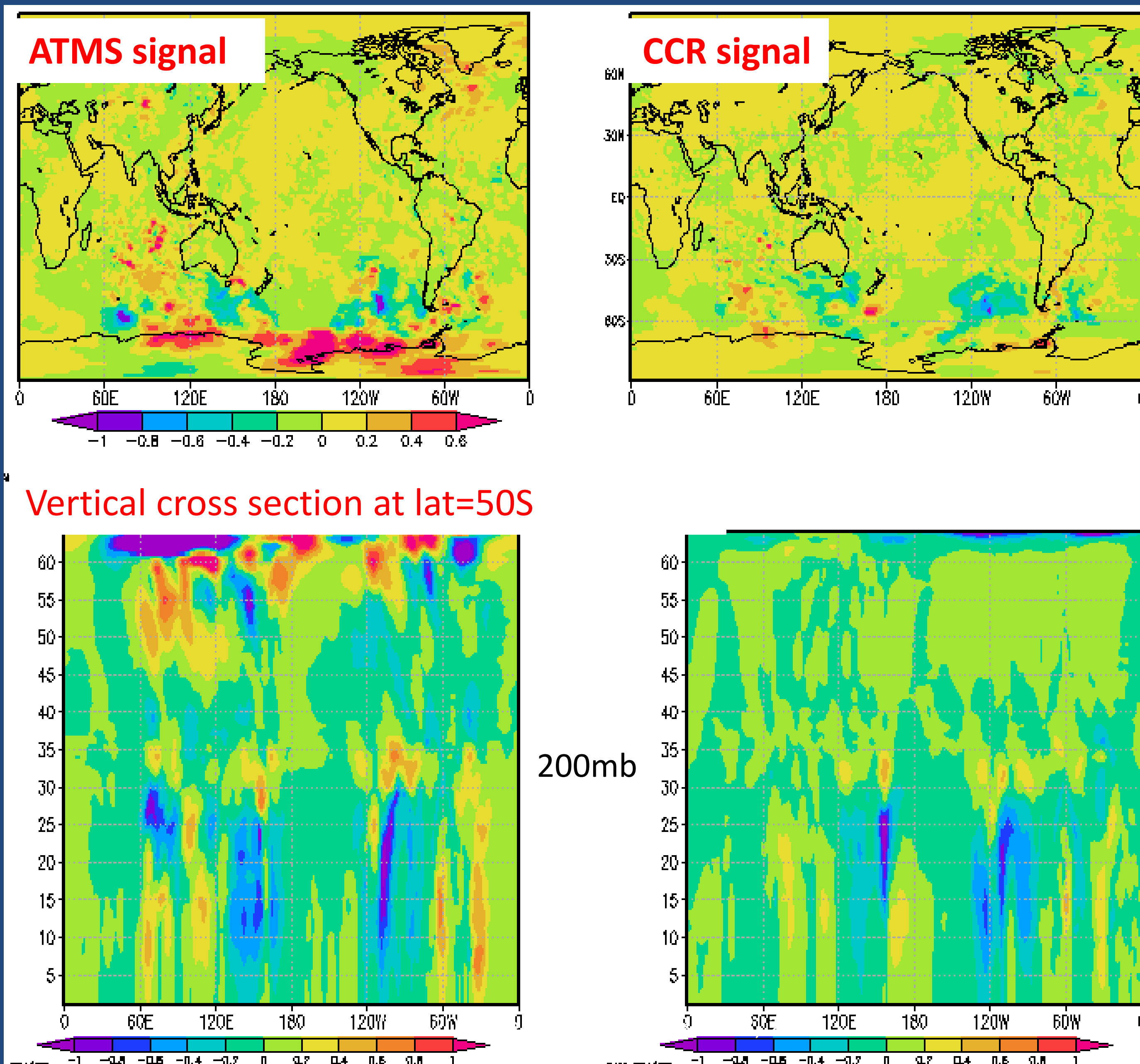
blue: CLR
red : CCR



- ❖ R_CCR QC:
  over sea only; inhomogeneous FOR
  Cloudy FOR; A < threshold
- ❖ R_CCR compensates clear-sky data void regions, especially for low peaking channels.
- ❖ R_CCR has similar obs-ges characteristics as the R_CLR does.

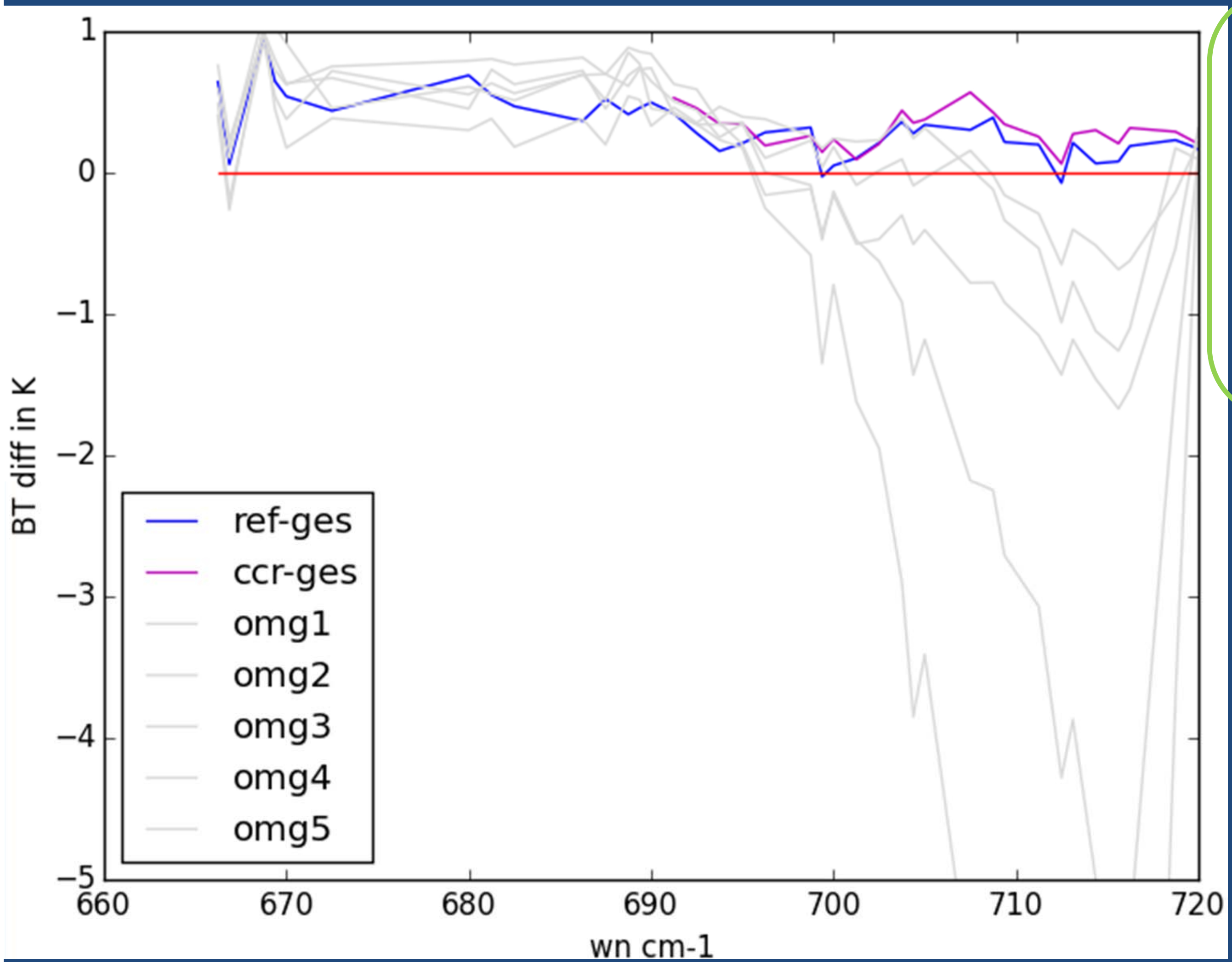


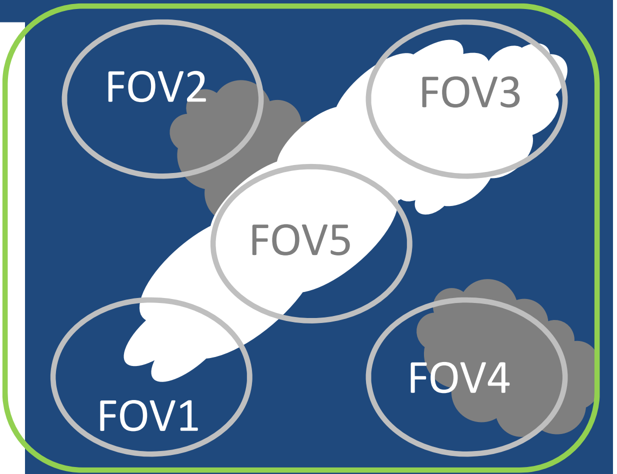
Impact on the T anal & Comparison with ATMS



- ❖ CCR provide a T signal generally consistent with the ATMS does.
- ❖ No CCR over land
- ❖ CCR affects the T field over troposphere only.

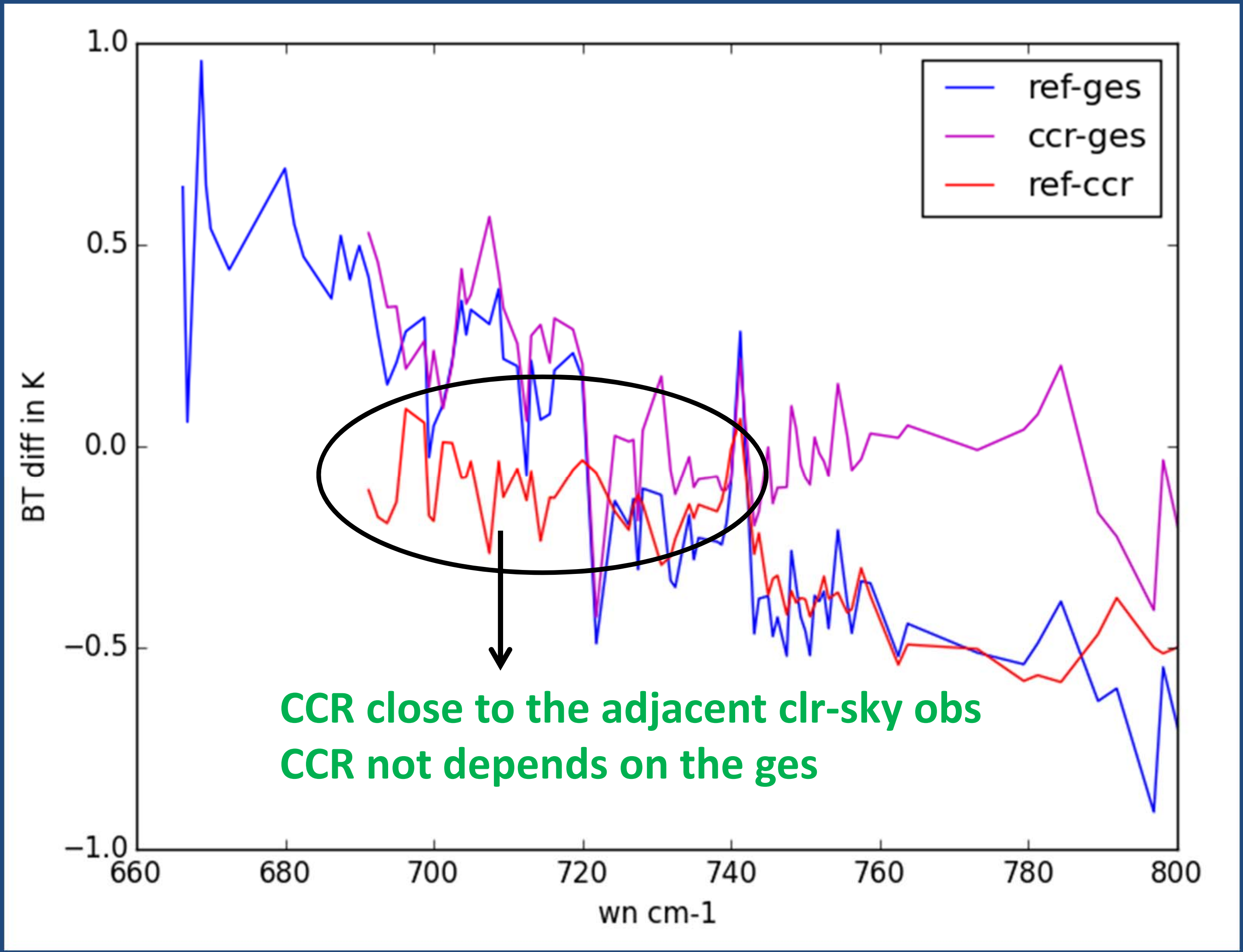
Validate CCR with adjacent clear-sky obs





The adjacent clear-sky obs was used as a reference to the 'truth' to validate the CCR.

Validate CCR with adjacent clear-sky obs



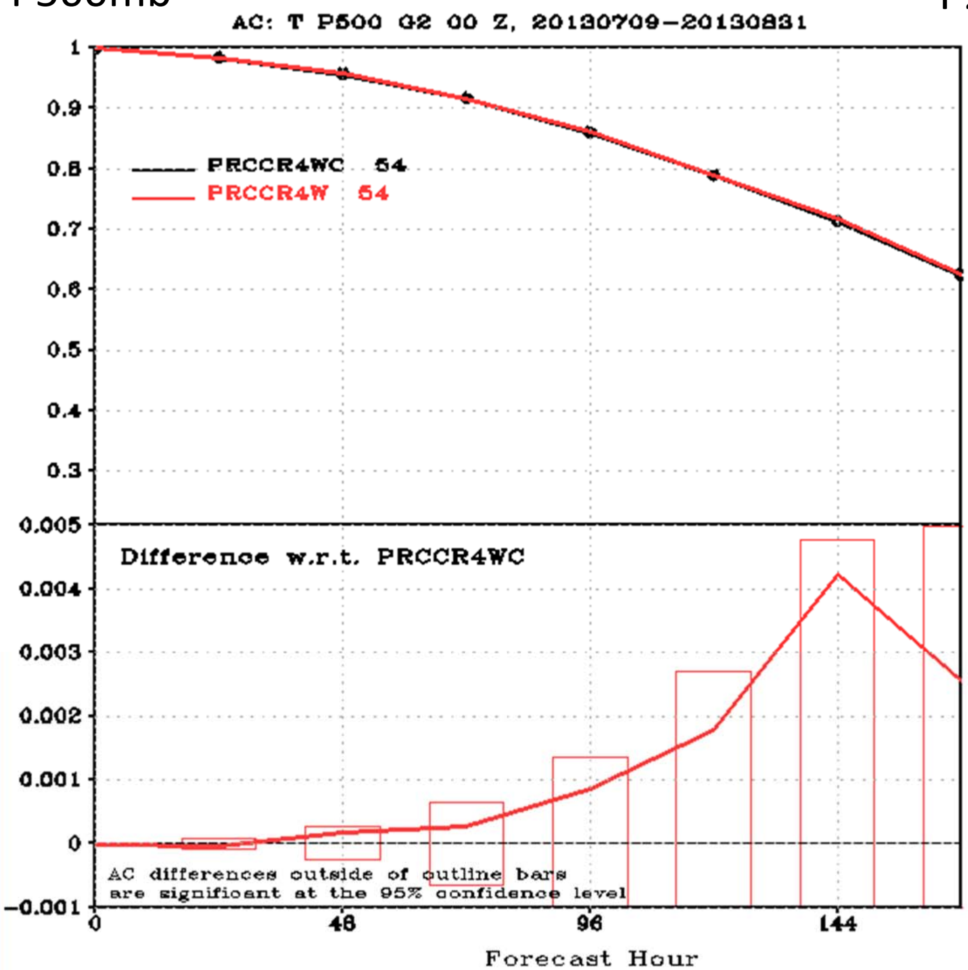
CCR close to the adjacent clr-sky obs
CCR not depends on the ges

Experiment Configuration

- CNTL :
  - Period: 2013070100-2013083118. The first week results will be discarded as a spin up period.
  - 3D-hybrid GSI
  - Resolution T670-T254, L64
  - All data used in operation
- CCR :
  - CrIS cloud-cleared radiance (CCR) data turned on. 1st trial to perform inline cloud-clearing with CrIS and then variationally assimilate the CCRs data. The impact of CCRs on global analysis and forecast scores will be evaluated.

Anomaly Correlation: T

P500mb



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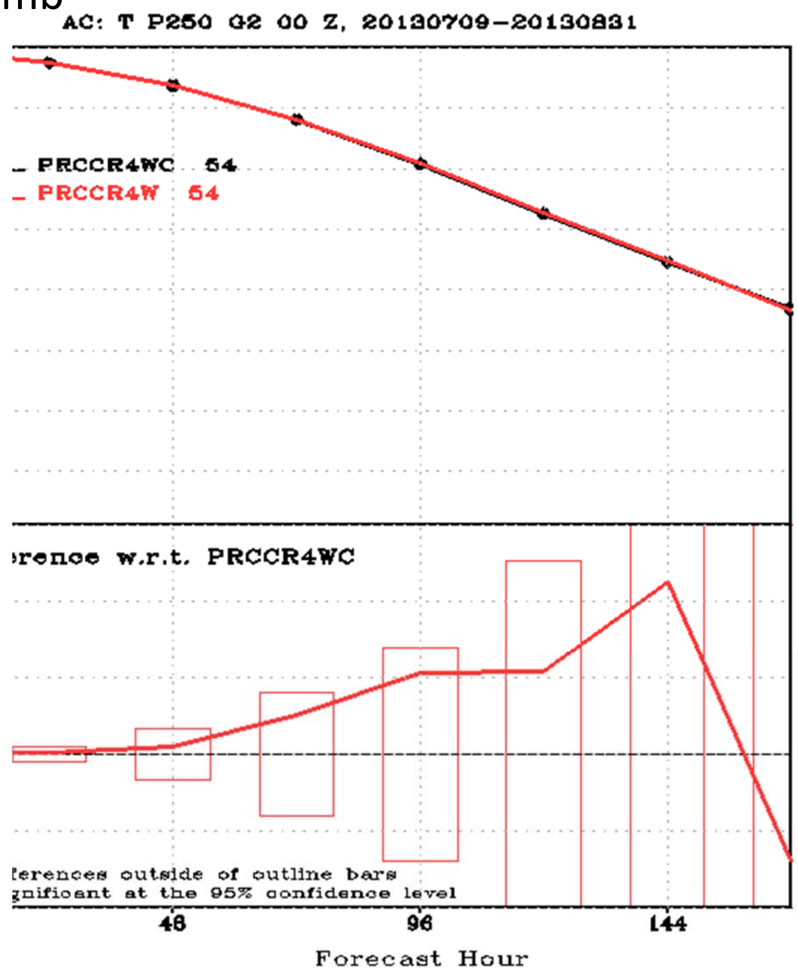

Summary

- The cloud-clearing method has been implemented into the NCEP data assimilation system.
- The obs – ges characteristics for CrIS R_ccr were studied.
- The CrIS R_ccr impact on the T analysis is consistent with that from the ATMS.
- R_ccr is validated using adjacent clear-sky data and it was found that a priori affects the cloud-clearing for low-peaking channels.
- The parallel experiment results show neutral impact.
- R_ccr obs errors are conservative and need to be tuned in future experiments.

Backup slides

Cloud Clearing Methodology

$$R_j^i = \left(1 - \sum_{k=1}^{K} \alpha_{j,k}\right) \times R_{clr}^i + \sum_{k=1}^{K} \alpha_{j,k} \times R_{cld}^{i,k}$$

(Joiner and Rokke, 2000)

$$R_{ccr}^i = R_1^i + \boldsymbol{\eta}_1 \times (R_1^i - R_2^i) + \boldsymbol{\eta}_2 \times (R_1^i - \times R_3^i) + \ldots\ldots + \boldsymbol{\eta}_k (R_1^i - R_{k+1}^i),$$

$$\begin{pmatrix} \widehat{R_{clr}^1} - R_1^1 \\ \widehat{R_{clr}^2} - R_1^2 \\ \ldots\ldots \\ \widehat{R_{clr}^{ich}} - R_1^{ich} \\ \ldots\ldots \\ \widehat{R_{clr}^n} - R_1^n \end{pmatrix} = \begin{pmatrix} R_1^1\text{-}R_2^1 & R_1^1\text{-}R_3^1 & \ldots\ldots & R_1^1\text{-}R_{k+1}^1 \\ R_1^2\text{-}R_2^2 & R_1^2\text{-}R_3^2 & \ldots\ldots & R_1^2\text{-}R_{k+1}^2 \\ & \ldots\ldots\ldots\ldots & & \\ R_1^i\text{-}R_2^i & R_1^i\text{-}R_3^i & \ldots\ldots & R_1^i\text{-}R_{k+1}^i \\ & \ldots\ldots\ldots\ldots & & \\ R_1^n\text{-}R_2^n & R_1^n\text{-}R_3^n & \ldots\ldots & R_1^n\text{-}R_{k+1}^n \end{pmatrix} \begin{pmatrix} \boldsymbol{\eta}_1 \\ \boldsymbol{\eta}_2 \\ \ldots\ldots \\ \boldsymbol{\eta}_k \end{pmatrix}$$

Implemented the cloud-clearing method into the GSI outer loop. The cloud detection inside of the GSI (minimum residual method Eyre and Menzel 1989) is used to detect cloudy pixels and only inhomogeneous FORs are chosen for cloud-clearing. Focus on CrIS only.

Obs Errors for R_ccr

The R_ccr is a retrieved product and its error will be amplified with a factor A (Chris Barnet).

$$A = \sqrt{(1+\sum_{k=1}^{K}\boldsymbol{\eta}_k)^2 + \sum_{k=1}^{K}\boldsymbol{\eta}_k^2}$$