Efforts on variational cloud-clearing with CrIS data at NCEP

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Introduction

The variational assimilation of satellite radiance observations has contributed the forecast skill increase of the Global Forecast System (GFS) at NCEP. However, satellite observations at most of meteorologically important areas have not been used in the presence of cloud. For infrared (IR) channels, only clear-sky data has been assimilated in the Grid-point Statistical Interpolation system (GSI), the NCEP operational data assimilation system. This limits the ability to continue improving the model initial condition through assimilating radiance data over partly cloudy and cloudy regions. NCEP has begun to develop a new algorithm to use the data in partly cloudy areas by removing cloud radiative effects. In this algorithm, cloud-clearing parameters will be estimated simultaneously together with other meteorological variables within the variational framework. The preliminary results of this study using the CrIS data is reported at the conference.

Cloud-clearing methodology

Following Chahine (1977) and Joiner and Rokke (2000), the observed radiance at channel i from field of view (FOV) j can be written as

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

$\boldsymbol{\alpha}_{j,k}$ is the cloud type k fraction in FOV j, R_{clr}^i is the clear-sky radiance at channel i and $R_{cld}^{i,k}$ is the radiance at channel i from the cloud type k with fraction $\boldsymbol{\alpha}_{j,k}$.

The cloud-cleared radiance can be derived if assuming R_{clr}^i and $R_{cld}^{i,k}$ are the same in the 3x3 FOVs in a single CrIS field of regard (FOR) and eliminating $R_{cld}^{i,k}$,

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

$\boldsymbol{\eta}_k$ are the cloud-clearing parameters. They depend on the cloud fraction $\boldsymbol{\alpha}_{j,k}$ only, so they are channel-independent. These parameters can be solved by using model guess simulated clear-sky radiances and observed radiances in adjacent pixels at cloud sounding channels in a least-square sense.

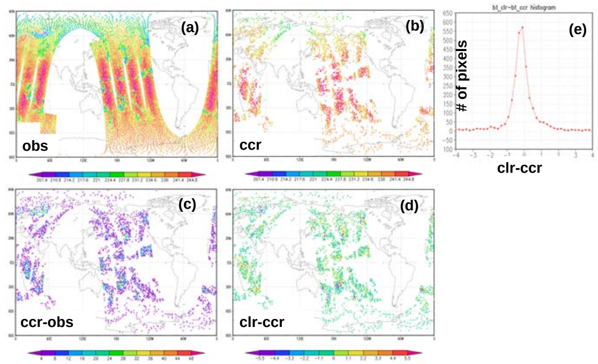


Fig. 1 (a) the CrIS brightness temperature (BT) observations (obs) at Dec. 12, 2013, 00Z cycle for the channel with wave number=741.3cm^-1; (b) reconstructed clear-column BT (ccr) over cloudy areas; (c) the BT difference between ccr and obs; (d) the difference between CRTM simulated clear-sky (clr) BT and ccr; (e) histogram of clr-ccr.

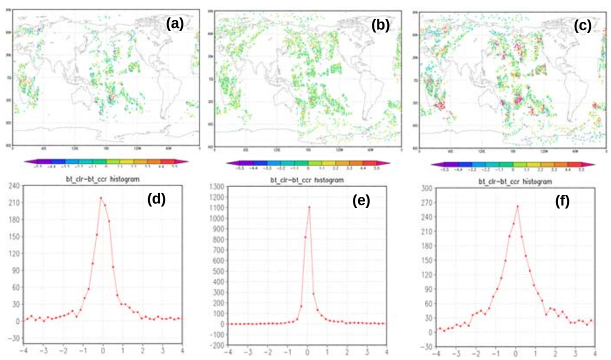


Fig. 2 Same as Fig. 1 (d) and (e) but for channels with wave number=702.74cm^-1, 749.63cm^-1 and 843.88cm^-1.

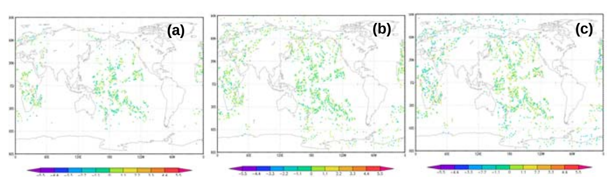


Fig. 4 Same as Fig. 2 (a)-(c) but for pixels with amplification factor A<=5 only.

Noise amplification factor

The reconstructed clear-column radiances will be treated as other IR clear-sky radiances when being assimilated except for amplifying the observation error by a factor of $A = \sqrt{\left(1 + \sum_{k=1}^{K} \boldsymbol{\eta}_k\right)^2 + \sum_{k=1}^{K} \boldsymbol{\eta}_k^2}$.

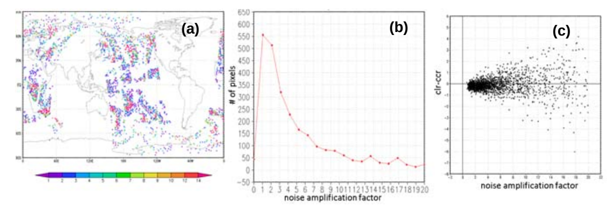
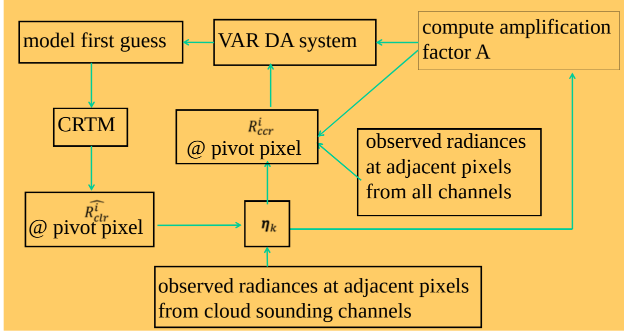


Fig. 3 (a) the noise amplification factor horizontal map, (b) its histogram and (c) the scatter plot of clr-ccr VS noise amplification factor for the same channel as in Fig. 1.

Flow chart of variational cloud-clearing



Summary and future work

Our variational cloud-clearing algorithm is being developed and still in early stage. Initial results demonstrate the algorithm works as expected. Data assimilation experiment will be done to evaluate the impact of using additional cloud-clearing radiances on global forecast scores and analyses.