Discrete Backus-Gilbert Method for Reducing RFI Effects

A. S. Jones and P. J. Stephens

Colorado State University/CIRA, Fort Collins CO

jones@cira.colostate.edu

INTRODUCTION

A more computationally efficient Backus–Gilbert (BG) algorithm has been developed in which the integrations are discretized and the properties of this discretization are exploited. Inclusion of an error minimization condition in this Discrete Backus–Gilbert (DBG) method (Stephens and Jones, 2002) as well as general properties of error minimization in all BG methods has also been studied thoroughly (Stephens and Jones, 2005a). This method will be used to improve sensor spatial resolution by dynamically trading sensor noise for spatial noise in radio frequency interference (RFI) contaminated environments where recalculation of the BG coefficients are necessary.

A 2D generalized version of the DBG method that can be easily adapted to any sensor is developed in detail (Stephens and Jones, 2005c). In particular, issues regarding the definition of the input space (swath) versus the output space (geo-location) are considered. Also, the impact of geometric variations on the footprint pattern representation errors is considered (Stephens and Jones, 2005b). All of this analysis has been used to implement the DBG algorithm for the WindSat sensor and results of the method are presented in the following figures.

GOALS

The research goals of this work are:

1) Develop a method that can exchange noise and spatial resolution of satellite data sets while considering impacts of dynamic RFI conditions that expected in a battlefield environment (Stephens and Jones, 2005a).
2) Determine error sensitivities of the antenna pattern functions to satellite orbital geometries (Stephens and Jones, 2005b).
3) Generalize the approach so that it can be implemented efficiently for several sensors and unique cross-sensor combinations (Stephens and Jones, 2005c). This should result in considerable future cost-savings to programs such as the National Polar Orbiting Environmental Satellite System (NPOESS) Data Exploitation (NDE) that will require substantial cross-sensor and advanced data merger capabilities.

RESULTS

One of the key controls in the BG method is the θ parameter which determines the location of the solution within the noise/resolution tradeoff curve (see Fig 1 above). Traditionally BG solutions have used a fixed θ minimization approach. This creates physical interpretation problems in regards to the final solution given dynamic noise sources such as RFI. A horizontal cross-section of RFI behaviors is shown in Fig. 2 and 3. The new approach localizes the effect of the RFI impacts (Stephens and Jones, 2005a).

RESULTS

Fig. 1

Backus-Gilbert Method Theory

From Stephens and Jones (2005a)

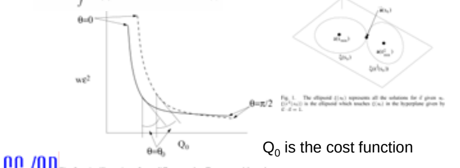
$$S_{ij}(r_0) = \frac{1}{\eta}\int (r-r_0)^2 G_i(r) G_j(r) dr, \quad (5)$$

$$u_i = \int G_i(r) dr. \quad (9)$$

$$(\cos\theta \boldsymbol{S} + w \sin\theta \boldsymbol{E}) \cdot \vec{a} = \boldsymbol{W}(\theta) \cdot \vec{a} = \lambda(\theta)\vec{u}. \quad (24)$$

With the constraint given by eqn. (8), we find

$$\vec{a}(\theta) = \frac{\boldsymbol{W}(\theta)^{-1} \cdot \vec{u}}{\vec{u} \cdot \boldsymbol{W}(\theta)^{-1} \cdot \vec{u}}. \quad (25)$$



Q_0 is the cost function

Fig. 2. An illustration of two different trade-off curves and how the same value of θ = θ0 can lead to different values of Q0.

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Fig. 2

RFI Impacts using the Traditional Minimization Method

- **Q_0 effects are localized with the addition of RFI, This means that the spatial filter is accommodating the RFI by adjusting the spatial "resolution" fit**
- **Error effects of RFI are spread throughout the integration domain**

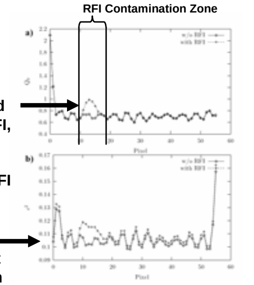

Fig. 8. Comparison with and without RFI. a) is the value of Q_0 and b) is the value of the error squared.

From Stephens and Jones (2005a)

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Fig. 3

RFI Impacts using the Fixed Q_0 Minimization Method

- **θ effects are localized with the addition of RFI, This means that the spatial filter is accommodating the RFI by adjusting the noise**
- **Error effects of RFI are now localized**
- **Results in a more realistic error behaviors**

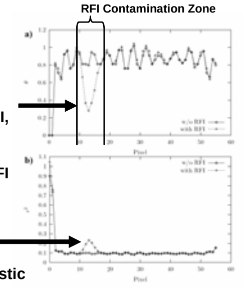

Fig. 7. Comparison of a) the value of θ required to fix Q_0 with and without the RFI. (b) shows the RFI has a localized impact on the error squared.

From Stephens and Jones (2005a)

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2D RFI IMPACTS

Fig. 4

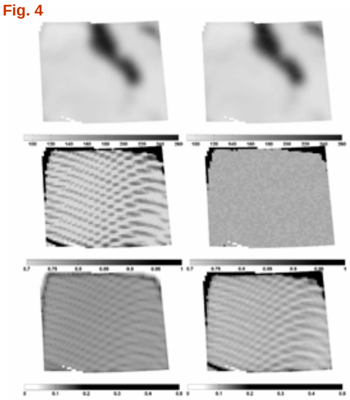

Fig. 4. Series of figures comparing the method of fixing θ (left) to fixing Q_0 (right); (top) estimated temperatures (middle) value of Q_0 for each point and (bottom) value of ϵ^2 for each point.

Table 1

variable	Swath Space	Earth Space
x_i	•	
x_0		•
x	•	•
$G(x_i, x)$	•	
$F(x_0, x)$		•
$J(x_0, x)$		•

Table 1: The space in which the variables are defined in general. The integration variable x can be in either space, but must be transformed into Earth space during some computations.

Fig. 5

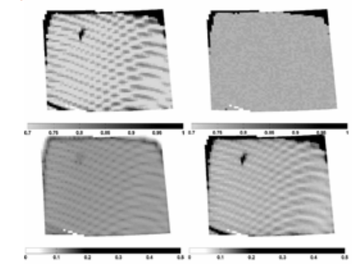

Fig. 5. Same as figure 4 except without the temperature estimates and using a modified error covariance matrix representing RFI contamination (see text).

Optimal variable spaces for an efficient 2D DBG implementation are shown in Table 1. A detailed discussion of the rationale is available in Stephens and Jones (2005c). The approach allows a 2D DBG toolkit to be created that is suitable for a wide range of BG applications.

For example, 2D results from a traditional BG method (fixed θ) are shown on the left side of Fig. 4, with results from fixing the cost function, Q_0, during the minimization is shown on the right of Fig. 4. While the estimated temperatures are similar (Fig. 4 – top), the values of Q_0 are substantially different (Fig. 4 – middle), which impacts the resultant error fields, ϵ^2 (Fig. 4 – bottom).

When a area of simulated RFI is added in the upper left of the 2D image (See Fig. 5) we can see that the cost function field is heavily impacted in the traditional approach which spreads or smears the RFI across the entire BG integration domain. By holding the cost function approximately constant we ensure that the RFI remains localized (contrast images at the bottom of Fig. 5). Retaining a localized effect of RFI is much more realistic, and desirable from a data assimilation perspective since the assimilation approaches can easily tolerate dynamic noise within their mathematical formulizations. This is preferable to the traditional method which instead allows the localized "resolution" of the data to be adjusted instead of the local noise.

ADAPTABILITY

Fig. 6a Bilinear

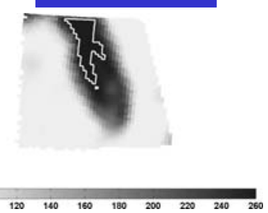

Fig. 6b 5%

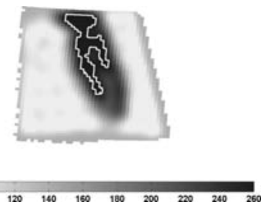

Fig. 6c 25%

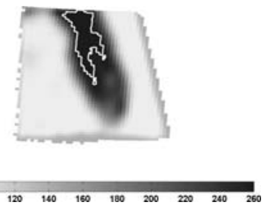

Fig. 6d 50%

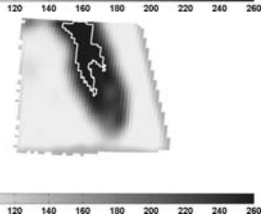

Fig. 6e 100%

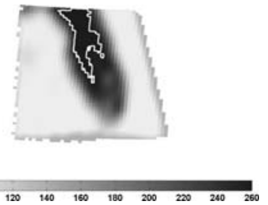

Figure 6. The sequence of estimates as the number of singular values is increased: a) bilinear interpolation, b) 5% of the singular values, c) 25 %, d) 50%, and e) 100%.

Conclusions

This work shows that a common BG toolkit can be developed using generalized components that is suitable for all microwave satellite radiometers. This allows for more sharing between applications, plus encourages the use of tested and standardized components to improve the accessibility and use of the BG method. It is desirable to have a common tool that can colocate data to a particular application grid. Multiple grids would be more easily setup using the DBG toolkit. Future work will focus on deployment of these technologies with the parallel Data Processing and Error Analysis System (DPEAS) software framework (Jones and Vonder Haar, 2002).

References

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