Optical Path Transmittance: OPTRAN. Forward and Adjoint Modeling

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Traditional Fast Transmittance Model

- Interpolate T(P), q(P) to fixed pressure levels
- Predictors T, q
- Include zenith angle as a predictor
- Predictand is transmittance departure or optical depth, multiple linear regression

Optical Path Transmittance (OPTRAN) approach

- Regression on levels of absorber amount
- Predictors are a function of T, P, q
- Zenith angle implicit in absorber amount
- Arbitrary pressure profile permitted
- Predictand is absorption coefficient for H_2O, O_3, mixed gases
- Permits changes to ‘mixed gas’ amounts as well

Heritage

- McMillin, Fleming and Hill (AO,1979)
- McMillin, Crone, Goldberg, Kleespies (AO,1995)
- McMillin, Crone, Kleespies (AO,1995)
- Three papers in the works

OPTRAN performance

- Water vapor channel much better than RTTOV
- Temperature channels generally not quite as good as RTTOV (before McMillin improvements)

What's this adjoint stuff it all about?

1DVAR / maximum probability solution is that which minimizes a 'cost' or 'penalty function:

$$\mathbf{J}(\mathbf{x}) = (\mathbf{x}-\mathbf{x}^{b})^{T}\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}^{b}) + (\mathbf{y}^{o}-\mathbf{y}(\mathbf{x}))^{T}\mathbf{O}^{-1}(\mathbf{y}^{o}-\mathbf{y}(\mathbf{x}))$$

where $\mathbf{x}^{b}$ is an initial estimate given by the model state vector, $\mathbf{x}$ is the model state for which the solution is desired, $\mathbf{y}^{o}$ is the vector of observations, $\mathbf{y}(\mathbf{x})$ is an operator which transforms the model state vector into the same parameters as the observations, and **B** and **O** are the background and observational error covariance matrices respectively. For our purposes, $\mathbf{y}(\mathbf{x})$ is the radiative transfer operator. Note that **O** is a combination of observational errors and radiative transfer errors. (This is just a least squares problem)

What's it all about: part deux

How do we find the minimum? From first quarter Calculus: Take the first derivative and set it equal to zero.

$$\nabla \mathbf{J}(\mathbf{x}) = \mathbf{B}^{-1}\left(\mathbf{x} - \mathbf{x}^{\mathrm{b}}\right) - \mathbf{K}(\mathbf{x})^{\mathrm{T}}\ \mathbf{O}^{-1}\left(\mathbf{y}^{\mathrm{o}} - \mathbf{y}(\mathbf{x})\right) = 0$$

where **K(x)** is the matrix of partial derivatives of **y(x)** with respect to the elements of **x**. (factor of 2 divides out)

What's it all about: part trois

It is evident that the solution requires both the forward radiative transfer operator **y(x)**, and the transpose of its derivative, $\mathbf{K(x)^T}$. $\mathbf{K(x)^T}$ is called the adjoint, or Jacobian.

$$\mathbf{x = \{ T_1, T_2, T_3, \ldots, T_n, q_1, q_2, q_3, \ldots, q_n, \ldots\}}$$

$$\mathbf{y(x) = \{R_1, R_2, R_3, \ldots, R_m\}^T}$$

What's it all about, part quatre

$$K(x)^T = \begin{bmatrix} \frac{\partial R_1}{\partial T_1} & \frac{\partial R_2}{\partial T_1} & \frac{\partial R_3}{\partial T_1} & \cdots & \frac{\partial R_m}{\partial T_1} \\ \frac{\partial R_1}{\partial T_2} & \frac{\partial R_2}{\partial T_2} & \frac{\partial R_3}{\partial T_2} & \cdots & \frac{\partial R_m}{\partial T_2} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \frac{\partial R_1}{\partial T_n} & \frac{\partial R_2}{\partial T_n} & \frac{\partial R_3}{\partial T_n} & \cdots & \frac{\partial R_m}{\partial T_n} \\ \frac{\partial R_1}{\partial q_1} & \frac{\partial R_2}{\partial q_1} & \frac{\partial R_3}{\partial q_1} & \cdots & \frac{\partial R_m}{\partial q_1} \\ \frac{\partial R_1}{\partial q_2} & \frac{\partial R_2}{\partial q_2} & \frac{\partial R_3}{\partial q_2} & \cdots & \frac{\partial R_m}{\partial q_2} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \frac{\partial R_1}{\partial q_n} & \frac{\partial R_2}{\partial q_n} & \frac{\partial R_3}{\partial q_n} & \cdots & \frac{\partial R_m}{\partial q_n} \end{bmatrix}$$

What's it all about, part cinq

In olden days (say 1990), computation of $\mathbf{K(x)}^T$ required N+1 forward model calculations using forward (or backward) finite differencing (centered required 2N+1). Thus these techniques were only used in limited studies

In these modern times, using adjoint coding techniques $\mathbf{K(x)}^T$ can be computed with the effort of about 3 forward model calculations.

What are these all the models?

- The tangent linear model is derived from the forward model

  - gives the derivative of the radiance with respect to the state vector (vector output, m channels)

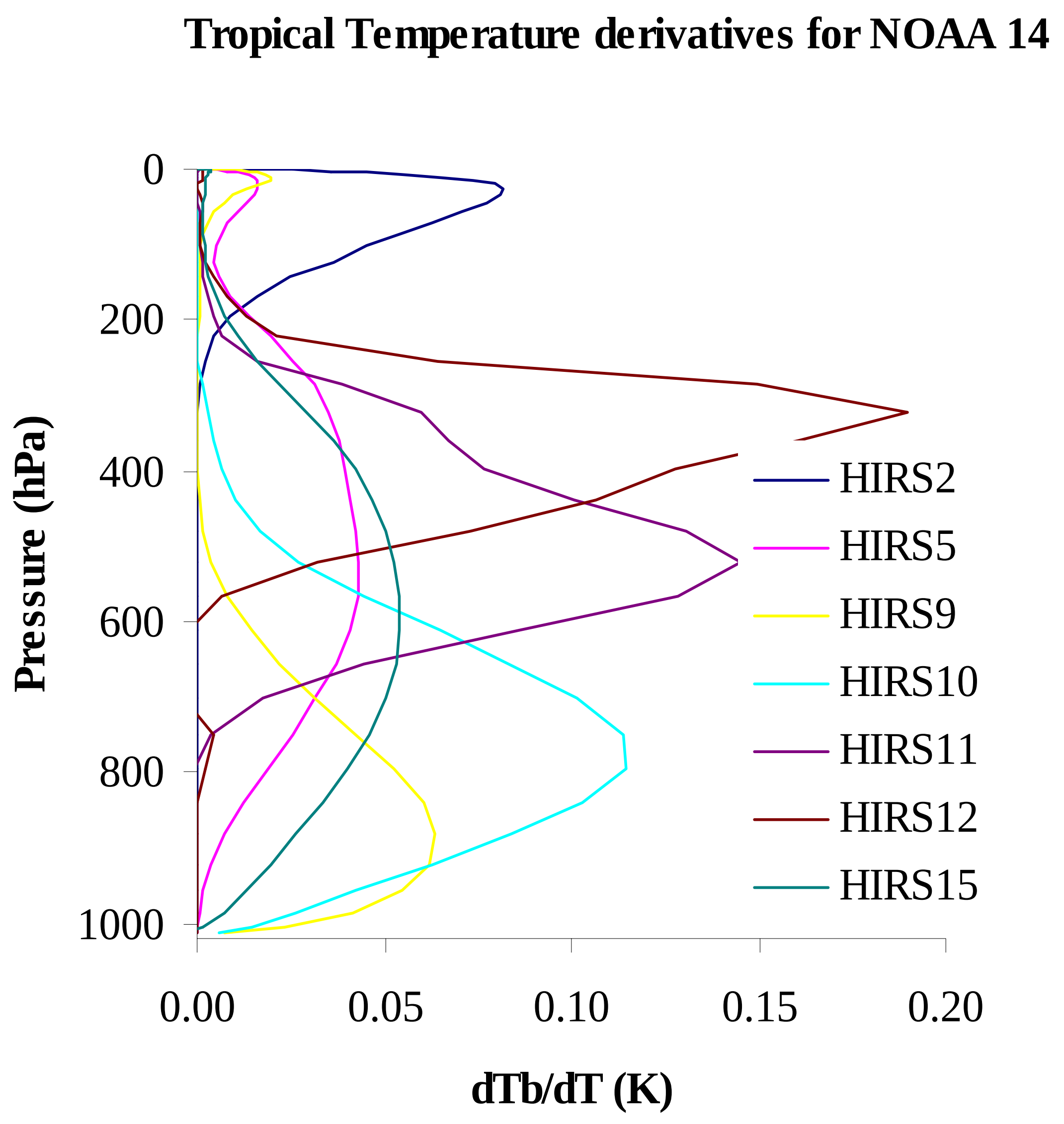
- The adjoint is derived from the tangent linear model

  - gives the transpose of the derivative of the radiance with respect to the state vector (vector output, N variables)

- The Jacobian is derived from the adjoint model

  - gives the transpose of the derivative of the radiance with respect to the state vector by channel (matrix output, Nxm)

- At NCEP, only the forward and the Jacobian models are actually used, but all models must be developed and maintained in order to assure a testing path, and to make sure the performance is correct.



Tropical Temperature derivatives for NOAA 14
Pressure (hPa)
0
200
400
600
800
1000
0.00
0.05
0.10
0.15
0.20
dTb/dT (K)
HIRS2
HIRS5
HIRS9
HIRS10
HIRS11
HIRS12
HIRS15

Why can't we just use the Tangent Linear Model?

- You can.
- However, it still takes N TL calculations.
- You avoid the finite differencing because the TL is the analytic derivative, but you just get a vector of radiances for each call. You still have to call it for each element of the input vector.

Testing

- Testing the code is rigorous and analytic
- Each code is tested for consistency with the model from which it was developed
- Code is tested bottom up, lowest level first.
- Full TL model is tested before moving to adjoint
- Full Adjoint is tested before moving to Jacobian

Adjoint Compiler

- Giering and others have written compilers that generate TL and adjoint code
- Some people at NCAR swear by them
- Others swear at them (just kidding)
- We feel that better optimization can be achieved by hand coding.

Summary

- Quick overview of OPTRAN
- Description of Adjoint and associated models
- Keep these brave souls who will take the coding class in your thoughts.

Class Participants Please Remain for a Few Minutes