Fast radiative transfer models for assimilation of radiance observation:issues for the next generation of advanced sounders

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The assimilation of near real-time radiance observations require fast and accurate radiative transfer (RT) models.

Fast models in use at NWP centres use rapid transmittance algorithms based on accurate transmittances obtained by line-by-line computations.

Fast models errors do not generally add significantly to errors introduced by line-by-line computations so that ***the accuracy of line-by-line computations are of paramount importance for the assimilation of satellite radiance.***

High resolution infrared sounders require state-of-the-art knowledge of the atmospheric spectroscopy used in the line-by-line models.

Spectroscopic errors in line-by-line computations are introduced by spectroscopic parameters such as

→ ***line width***
→ ***line strength***
→ ***temperature dependence of the line width***

Line widths and strengths are typically known within a 10% accuracy.

The temperature dependence of the line widths is known within a 20% accuracy but is a less important source of error than line widths and strengths.

→ ***Line-by-line forward models should be updated on a regular basis with the latest line parameters obtained from databases like HITRAN and GEISA.***

→ ***Emphasis should be put on laboratory efforts to improve the knowledge of spectroscopic line parameters.***

To address these issues, a dedicated database (GEISA/IASI) is maintained within the framework of the IASI Science Sounding Working Group (ISSWG).

The GEISA/IASI database is a continuously updated version of the GEISA database and is dedicated to a limited number of molecular species relevant for the radiative transfer in the infrared.

→ ***The scope of GEISA/IASI is to provide RT developers with an agile tool that provides the latest available spectroscopic line parameters on a timely basis.***

The most important source of error in the line-by-line computations is the spectral line shape.

This is especially true for molecular species that are characterized by large optical depths, such as H_2O and CO_2.

→ ***For the remote sensing/assimilation of satellite radiances, the knowledge of the spectral line wings for these two molecules is of particular importance.***

Efforts have been made to improve the quality of the line shape available for CO_2. These include:

- → ***line mixing for CO2 Q-branches***
- → ***a far wing model for CO2 in the 15µm band that includes P- and R- branch line mixing***
- → ***a line shape for the 4.3 µm band***

For the H_2O line shape, there is still a number of outstanding issues.

Although great improvements have been made in the knowledge of the H2O line shape in the strong 6.7µm water vapour band, more work is still needed above all in the spectral region (1250 to 1400 cm^{-1}) influenced by lower tropospheric H_2O.

→ ***In fact, given the long path lengths involved, laboratory measurements are very difficult and because of the opacity of the atmosphere in this spectral region, often is too much difficult to obtain good ground based measurements.***

For water vapour, no theoretical breakthrough has yet been made to explain the nature of the continuum type absorption and line-by-line models still rely on semi-empirical formulations of the water continuum.

→ ***For H_2O we need to improve our knowledge of the continuum in the 10 µm window region and above all in the spectral region influenced by lower tropospheric H_2O (see previous slide).***

To this end, field measurements are of particular importance and laboratory measurements in the 1250 to 1400 cm^{-1} region (if long enough cells are available) would be beneficial.

It should be emphasized that results of line-by-line calculations also depend on:

→ ***treatment of molecular absorption due to heavy molecules (e.g. CFCs)***

→ ***implementation of schemes for the treatment of the continuum like absorption of CO_2, N_2 and O_2 for which recent developments have been made (N_2 and O_2).***

Having discussed the potential areas of improvement related to the line-by-line transmittances on which fast RT models are based, we can concentrate on the possible categories of improvements for fast RT models.

→ ***Some of this issues have already been addressed in RTIASI, the ECMWF fast radiative transfer model for IASI.***

Number of discrete atmospheric layers used in RT computations

The atmospheric pressure layering grid used in RT computations for satellite sounding should in principle be determined by the vertical resolution of the instrument.

→ ***RTIASI uses a vertical pressure grid of 90 levels that is adequate to keep RT errors well below the instrument noise. This is to be compared with the ~50 levels that are deemed to be necessary for low-resolution sounders.***

Source function for atmospheric emission

Fast RT models usually assume a constant value of the Planck function (i.e. equal weight is given to the radiance emitted from all regions within the layer)

In presence of an optically thick layer (e.g. clouds), this would result in too weight put on the radiance emitted in the lower parts of the layer.

→ ***To address this issue, an alternative approach has been followed in RTIASI where the parameterization of the Planck function is based on the linear in τ assumption that the source function throughout the layer is linear with the optical depth of the layer.***

Variable trace gases

The inclusion of minor gases in the state vector can be fully exploited by the current and next generation of high-resolution infrared sounders.

→ ***In RTIASI the basic elements of the state vector have been supplemented by the profiles of CO, N_2O, CH_4 and CO_2***

This requires the availability of an adequate set of training profiles that represent the profile behaviour in the whole atmosphere.

The inclusion of minor gases in a regression based fast model can become cumbersome if the number of gases is large.

Solar radiance

To enable the assimilation of high-resolution radiances in the short wave region of the infrared spectrum, a solar term has to be introduced in the RT computations.

→ ***A solar term has been introduced in RTIASI that covers the spectral region from 5 to 3.6 µm and solar zenith angles from 0° to 87°.***

The introduction of the solar term requires a dedicated fast transmittance model in the shortwave to be able to cope with the large zenith angles involved in the solar geometry.

Surface emissivity

The accurate simulation of radiances for the window regions and the lower sounding channels require an accurate knowledge of the surface emissivity.

Also, in presence of solar radiation the knowledge of the bidirectional reflectance is in principle needed.

→ ***In RTIASI the bidirectional reflectance for a wind roughened water surface is computed explicitly that includes shadowing effects. The wave slope parameter used in the scheme is obtained from a wave model.***

Scattering

The introduction of clouds and aerosols in the state vector requires the introduction of scattering effects in the radiative transfer.

Numerical methods (i.e. discrete ordinate, doubling adding) are too computationally expensive and in principle only lower order approximations (i.e. two-stream models) can be considered.

→ ***Trials have shown that since RTIASI (and in general all regression based fast models) radiances are computed using the polychromatic approximation, two-stream models are not amenable for incorporation into the code since this would result in too large inaccuracies.***

Scattering

→ ***We have introduced scattering in RTIASI by scaling the extinction optical depth with a factor that is function of the backscattering of upward and downward radiation. This rests on the hypothesis that the diffuse radiance field is isotropic and can be approximated by the Planck function.***

Radiance in presence of multi-layered clouds

The commonly used approach to treat multi-layered clouds with fractional cover CFR is to treat the cloud as an opaque cloud with fractional coverage equal to CFR times the emissivity of the cloud.

→ ***In RTIASI, an alternative, and in principle more accurate, approach has been followed that divides the satellite field of view into a number of columns (or streams) that contain either cloud-free or overcast layers. The total radiance is obtained by performing a weighted sum of the radiance in each column.***

Other outstanding issues

The assimilation of satellite radiances over land has a potential positive impact on the forecast skill. This would require an accurate emissivity model over land.

An improved treatment of the surface reflected down welling thermal radiation could be considered.

The feasibility of a fast radiative transfer model in the Empirical Ortogonal Function (EOF) space could be investigated.

Non LTE can have a significant impact for the very high-peaking channels in the 4.3 μm band and it might be worth considering its inclusion in the radiative transfer.

FINAL REMARK

Given the importance of RT for satellite radiance assimilation,

it is crucial adequate resources are invested for the continuous development and maintenance of line-by-line and fast radiative transfer models.