# Satellite-based Model Parameterization of Diabatic Heating

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Future meteorological satellites are expected to provide much needed fine-scale information that can improve the accuracy of weather and climate models. As one application of this improved capability, we introduce the concept of a generalized parameterization framework using satellite datasets that will increase the accuracy and the computational efficiency of weather and climate modeling. In an atmospheric model, several different parameterizations usually are used to reproduce the various physical processes. However, it is generally unrealistic to separate the processes in this artificial way since the observations and physics make no such artificial separation. Thus, we propose a new unified parameterization framework to remove the unrealistic separation between parameterizations.

The traditional procedure to parameterizing physics in weather and climate models at spatial scales that are too small to be explicitly resolved in the models is to separately represent turbulence fluxes, shortwave radiative fluxes, longwave radiative fluxes, and convective and stratiform cloud-precipitation processes. These traditional parameterizations are typically one-dimensional (1-D) column models that interact with the dynamical core of a given atmospheric model. The parameterizations are then used to diagnose the effect of these physical processes within the model. However, such a separation is not realistic as the parameterized processes are, in fact, 3-D and may interact with each other.

With respect to convective cloud parameterizations, a cumulus parameterization workshop [*Tao et al.,* 2003] concluded that there are three major approaches to cumulus parameterization: traditional, statistical, and super parameterization (or multiscale modeling framework (MMF)). Most traditional column-based convective parameterization schemes presently use a mass flux [e.g., *Grell,* 1993; *Kain,* 2004] or quasi-equilibrium approach [*Arakawa and Schubert,* 1974]. The statistical approach is a statistical parameterization based on the analysis of cloud resolving model output [*Tao et al.,* 2003].

The super-parameterization approach uses data from many cloud resolving model (CRM) simulations to diagnose the cloud system response to large-scale parameters. In MMF a full 2-D CRM is embedded within each grid cell of a large-scale model [*Randall et al.,* 2003]. However, the MMF is presently very computationally expensive and is, as yet, impractical for operational weather forecasting, ensemble simulations, or climate simulations.

There was also a consensus from a cumulus parameterization workshop [*Tao et al.,* 2003] that a consistent, comprehensive cloud database (associated with clouds and cloud systems that developed in different geographic locations) should be generated from the ensemble of CRMs for use in the development and improvement of cumulus parameterization schemes. These cloud data are to be generated in close collaboration with parameterization developers. However, new and innovative ideas for the optimal way to use the CRM data sets are needed.

We propose a different approach in which satellite and other available observations are used to construct unified parameterizations, which include the combined effect of each of the atmospheric physics processes. Since the observations are sampling reality, this assures that 3-D interactions are implicitly included.

## *Methodology*

To illustrate the methodology, we focus first on subgrid-scale diabatic effects. As given by *Pielke* [2002], the conservation equation for potential temperature can be written as

$$\partial\theta/\partial t = -u\partial\theta/\partial x - v\partial\theta/\partial y - w\partial\theta/\partial z + S_\theta \qquad (1)$$

The source/sink term $S_\theta$ includes all of the diabatic physics, which, in a model, is decomposed into separate parameterizations and a resolvable term for phase changes of water.

Our methodology is that instead of using separate physics to compute the terms that comprise $S_\theta$, observed data are used to construct this term in the format of a transfer function (e.g., a look-up table), as proposed by *Matsui et al.* [2004] and *Pielke et al.* [2006] for the individual parameterizations that comprise $S_\theta$.

The remote sensing community uses such an approach routinely in its algorithms, for example, to convert satellite radiances into variables [e.g., *Kidder and Vonder Haar,* 1995]. There is also a direct analogy to the approach several investigators have made in land surface modeling. Like the convective parameterization problem, the land surface parameterizations are fraught with highly complex interactions between vegetation, soil, and moisture. Given this complexity, some modelers have resorted to simpler models constrained by satellite observations to recover fluxes as a residual. In particular, *McNider et al.* [1994], *Jones et al.* [1998], *Alapaty et al.* [2001], and others have proposed and used morning satellite surface tendencies to infer the moisture availability and evening tendencies to infer heat capacity [*McNider et al.,* 2005]. The triangle method of *Gillies et al.* [1997] is another example where a look-up table approach is used to derive surface energy fluxes from satellite observed values of vegetation fraction and surface radiant temperature.

We propose a similar methodology for parameterizations in atmospheric models. In the following, the method is illustrated for the physics of diabatic heating, but it can be applied to any quantities that are parameterized within weather and climate models.

The procedure is as follows:

1. Satellite and other complementary observations are used to obtain potential temperature, the horizontal winds, water vapor, liquid water, and ice for each of the footprints that are viewed by the satellite over a period of time. These data need to be transferred to a grid point format.

2. The individual terms in equation (1) are directly computed for the sampling time period of the observations: (a) $\partial\theta/\partial t$ and (b) $u\partial\theta/\partial x$ and $v\partial\theta/\partial y$, while $w\partial\theta/\partial z$ is diagnosed using the spatial gradient of the horizontal wind field ($w$ is diagnosed from the conservation of mass and/or using quasi-geostrophic theory when applicable). The value of $S_\theta$ is then computed as a residual: $S_\theta = u\partial\theta/\partial x + v\partial\theta/\partial y + w\partial\theta/\partial z + \partial\theta/\partial t$.

3. The model resolved portion of $S_\theta$ can be subtracted out also, $<S_\theta> = S_\theta - Lw\partial q_s/\partial z$, where $L\partial q_s/\partial z$ is the latent heat of model-resolved phase change when $q$ is equal to $q_s$ and $w > 0$ ($q_s$ is the saturation specific humidity). This calculation can be generalized to include phase changes of liquid and ice also, and $w$ is the grid volume averaged vertical velocity. The quantity $<S_\theta>$ is then the subgrid-scale diabatic contribution.

The unified parameterization is the transfer function **T**,

$$\mathbf{T} = [f(\text{observation input of } u\partial\theta/\partial x + v\partial\theta/\partial y, \partial\theta/\partial t, u\partial q/\partial x + v\partial q/\partial y, \partial q/\partial t, \text{time of year, latitude})] \rightarrow \mathbf{<S_\theta>},$$

which can be expressed as a look-up table.

Two necessary conditions for this approach to provide an accurate unified parameterization are (1) that the satellite observations, complemented with other observations, are sufficiently accurate with the needed spatial and temporal resolution and (2) that the satellite observations encompass a broad and global range of meteorological conditions. The latter condition is satisfied given the global observing systems. The validity of the first condition must be investigated specifically for the available observations, including the cloud library from multiscale modeling framework (W. K. Tao et al., Multi-scale modeling system: Development, applications, and critical issues, submitted to *Monthly Weather Review,* 2007), as well as for promising new satellite instrumentation (Geosynchronous

Imaging Fourier Transform Spectrometer: GIFTS; see Figure 2 at http://ams.confex.com/ams/pdfpapers/70174.pdf [*Li et al.*, 2004], and platforms, e.g., Geostationary Operational Environmental Satellite-R; GOES-R). Those massive data sets can be efficiently hardwired through the unified LUT or neural network approach as proposed by *Matsui et al.* [2004] and *Pielke et al.* [2006].

### Proof of Concept

The proof of concept of the new methodology is to use regional model simulations, to construct **T** since each of the input values can be obtained from the model fields and the value of $<S_\theta>$ can be computed by summing each of the diabatic terms that are calculated in the model using the traditional 1-D, separate parameterizations.

The goal is to recreate $<S_\theta>$ from the sum of the turbulent flux divergence, the shortwave radiative flux divergence, the longwave radiative flux divergence, the phase changes of water on the subgrid scale, and cumulus cloud flux divergence of θ. If we refer to this value of $<S_\theta>$ as $<<S_\theta>>$, and the transfer function calculated version as $<S_\theta>$, then the methodology is successful if the diabatic heating calculated by the traditional way using separate parameterizations, $<<S_\theta>>$, produces essentially the same result as using the transfer function approach, $<S_\theta>$; i.e., $<<S_\theta>> \approx <S_\theta>$, and the calculation of $<S_\theta>$ is computationally much more rapid. After we prove the concept, $<S_\theta>$ can then replace the separate, more computationally expensive individual calculations of the subgrid diabatic terms. The transfer function **T** can replace the traditional approach of parameterization.

To demonstrate skill of the method when remotely sensed data are used to construct **T**, the proof of concept experiments will also include computation of the source/sink term from simulated satellite data, denoted by $\langle S_\theta^* \rangle$. The simulated satellite data are computed from the model fields so as to have spatial and temporal resolution and error characteristics of the actual satellite data, including future sensors. Coarser spatial and temporal resolution of the simulated data relative to the model produces representativeness errors in $\langle S_\theta^* \rangle$ Amplitude errors assigned to the individual fields (i.e., temperature, humidity, wind) would reflect the data accuracy resulting from the measurement and retrieval errors. The quantity $\langle S_\theta^* \rangle$ is by definition stochastic because it contains information about the errors in the data. This property implies that an ensemble average of model simulations using $\langle S_\theta^* \rangle$ from a range within the error margins should be compared with the control model simulation. A small difference between the two model results would imply high skill of the method. This difference represents a global measure of the impact of the data errors. In the proof of concept experiments, the simulated data errors could be varied to determine desired resolution and accuracy in the data to result in a satisfactory estimate of $<S_\theta>$. The results of this analysis will assist satellite developers in decisions with respect to the needed accuracy of future instrumentation and will assist the modeling community in developing improved assimilation and computationally efficient simulation models.

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