SST Temperature Algorithms

By

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Outline

• Radiative transfer for Thermal Infrared (TIR) satellites
• Linear Algorithms
• Types of Coefficients
• Skin measurements vs. bulk measurements
• Non-linear algorithms
• Cloud and aerosols
Radiation at the Sensor

\[ L_w(\lambda) = \varepsilon B(T_s, \lambda) \approx .10 \text{mm} \]
Radiation at the Sensor

\[ L_w(\lambda) = \varepsilon B(T_s, \lambda) \]

\( T_s, \varepsilon \)

\( L_w (\lambda) \) is the radiance at the sensor, \( T_s \) is the temperature at the sensor, \( \varepsilon \) is the emissivity, and \( B(T_s, \lambda) \) is the blackbody radiation at wavelength \( \lambda \).
Radiation at the Sensor

\[ L_{\text{sat}}(\lambda) = L_w(\lambda) \tau(\lambda) + L_{\text{atm}}(\lambda) \]

\[ T_s, \varepsilon \quad L_w(\lambda) = \varepsilon B(T_s, \lambda) \sim 0.10mm \]
Single Channel SST

\[ L_{sat}(\lambda) = L_w(\lambda)\tau(\lambda) + L_{atm}(\lambda) \]

**How it Works**

Computes \( L_{atm} \) and \( \tau(\lambda) \) from Radiative Transfer model (e.g. MODTRAN) fed with atmospheric profiles (T,q)*

*Requires Satellite or radiosonde profiles

**Uncertainties**

- Uncertainties from satellite fed profiles
- Modeling water vapor absorption is has limitations which can affect the single channel estimation of SST
Multiple Channel Sea Surface Temperature (MCSST)

Two Unknowns: Sea Surface Temperature (SST), water vapor absorption

\[
SST = T_i + \gamma(T_i - T_j) \quad \gamma \rightarrow \text{water vapor absorption}
\]

Types of MCSST’s

<table>
<thead>
<tr>
<th>Algorithm Name</th>
<th>Thermal Bands</th>
<th>Day/Night usage</th>
</tr>
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<tbody>
<tr>
<td>Dual Window</td>
<td>3.7 and 11 µm</td>
<td>Night</td>
</tr>
<tr>
<td>Split Window</td>
<td>11 and 12 µm</td>
<td>Day and Night</td>
</tr>
<tr>
<td>Triple Window</td>
<td>3.7, 11, and 12 µm</td>
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- 3.7 < 11 < 12 in terms of water vapor absorption
- 3.7 is affected by sunlight and generally not used in daytime measurements
Split Window Example

- Both blue and red curves are Top of Atmosphere Radiance computed with same parameters except the Blue (high humidity) is perturbed by 3x’s

<table>
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<tr>
<th></th>
<th>11 μm (K)</th>
<th>12μm (K)</th>
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<tr>
<td>MODIS humid</td>
<td>287.74</td>
<td>286.44</td>
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<tr>
<td>MODIS dry</td>
<td>290.43</td>
<td>289.89</td>
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Surface Temp=292.8
## Coefficient Development

\[ Ts = a + bT_i + c(T_i - T_j) + d(T_i - T_j)(1 - \sec \theta) \]

Reduces errors due to large view angles which arise because of the radiative transfer equation’s inherent non-linearity.

## Types of Regression Coefficients

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Coefficient Development

Lake to lake variation of surface temperature, elevation and water vapor necessitate custom lake coefficients

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Skin Temperature vs. Bulk Temperature

- Satellite senses radiation from the skin (~10μm)
- Sensible and latent heat fluxes cool the skin in relation to the bulk
- Stratification of thermal profile occurs during daytime
- Strong winds act to mix the daytime profile and then resembles the nighttime (dashed)

* From Donlon et. al. 2002
Typical Skin Bulk Differences

- Low wind speeds correspond to larger variance in skin effect
- Positive skin effect shows some correlation to higher air temperatures
- Variance of the Skin effect for Tahoe is larger than typical values found in oceans
- Daytime skin effect has largest variance and many positive values
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Take home message
Nighttime bulk measurements have less variance than daytime
Non-linearity Issues

• MCSST assumes that water vapor absorption is constant
• Water vapor absorption is a non-linear function w.r.t temperature
• Leads to problems in dry polar regions and hot regions
• Radiative transfer equation is non linear with respect to high amounts of water vapor e.g. $\exp(-kx) \neq (1 - kx)$
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### NLSST Equations

$$ T_s = aT_{11} + bT_{\text{guess}} (T_{3.7} - T_{12}) + c(1 - \sec \theta) + d \rightarrow \text{NLSST(triple)} $$

$$ T_s = a + bT_i + c(T_i - T_j)T_{\text{guess}} + d(T_i - T_j)(1 - \sec \theta) \rightarrow \text{NLSST(split)} $$
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- \( T_{\text{guess}} \) can be climatological, modeled, or from the MCSST equation
- Operational MODIS and NOAA AVHRR products both use NLSST equations
- MODIS creates separate coefficient sets for low and high water amounts, and different viewing geometries
- Hulley et. al. 2011 demonstrated that the non-linear equations do not improve SST measurements over Tahoe and Salton Sea
# Bayesian Retrieval of SST

## What is it?
- Performs a simultaneous retrieval of skin temperature and total water content
- Uses Bayesian (Rodgers) statistical methods and a radiative transfer calculation for each SST measurement

## Inputs
- First guess SST ($T_a$)
- expected variance of the state variables (SST and TPW)
- error variance of each channel
- Measurements and Radiative Transfer
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### Further Examination
- Each coefficient represents a weighted derivative
- Weights are determined by the a priori and error variances

### Reformatted Equation

\[ T_s = T_a + a_i [T_i - F_i(T_a)] + a_j [T_j - F_j(T_a)] \]

**Coefficient**

\[ a_i \rightarrow \left( w_{SST} \frac{\partial T_i}{\partial SST} \right)^{-1} - \left( w_{TPW} \frac{\partial T_i}{\partial TPW} \right)^{-1} \]
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Take Home Message
• Creates a custom coefficient set for each satellite scene that accounts for influence of water vapor, $a priori$ statistics of SST, and error statistics of satellite measurements
• Highly sensitive to tuning parameters (error variances, state variances) and first guess SST
Clouds and Aerosols

• Clouds absorb outgoing radiation and re-emit it back to the ground
• Each satellite channel is affected differently by the structure and location of clouds
• Clouds can affect adjacent clear sky measurements

Cloud Summary

\[ T_s > T_{\text{satellite}} \]

\[ T_s \]
Clouds and Aerosols

Aerosol Summary
- Radiation in Thermal bands (11 and 12 μm) have little sensitivity to aerosols distribution
- 3.7 μm has small sensitivity to aerosols
- Volcanic eruptions will thermal and shortwave bands

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\[ T_s \]
Summary

• Single channel works best when you have good atmospheric profile information
• Split Window is most widely used because of its ease of use and robustness
• Custom coefficients for each individual lake increases accuracy of SST measurements from satellite
• Skin effect adds uncertainty in reconciling bulk and skin measurements
• Schemes exist for AVHRR, MODIS, and ATSR which address non-linearity issues in the split window and triple window
References


