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

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

\[ T_s, \varepsilon \]

Atmosphere

Water surface

\sim 0.10 \text{mm}
Radiation at the Sensor

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

Where:
- \( L_w(\lambda) \) is the radiance at the sensor
- \( \varepsilon \) is the emissivity
- \( B(T_s, \lambda) \) is the blackbody radiation at temperature \( T_s \)

Approximately 10 mm
\[ L_{\text{sat}}(\lambda) = L_w(\lambda) \tau(\lambda) + L_{\text{atm}}(\lambda) \]

Atmosphere

Water surface

\[ T_s, \varepsilon \]

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

\[ \sim .10 \text{mm} \]
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>
</thead>
<tbody>
<tr>
<td>Dual Window</td>
<td>3.7 and 11 μm</td>
<td>Daytime</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 can act to mix the daytime profile to resemble 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 from a satellite are more accurate than daytime bulk measurements
Non-linearity Issues

- MCSST assumes that water vapor absorption is a constant
- Water vapor absorption is non-linear function of temperature
- Leads to problems in dry polar regions and hot regions
- Radiative transfer equation is non-linear with 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 both use NLSST equations
- MODIS creates separate coefficients for low and high water amounts, and different viewing geometries
- Hulley et. al. 2011 demonstrated that the non-linear equations do not yield much different results from linear equations 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 radiative transfer models 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 Coefficients represents a weighted derivative
- Weights are determined by the variances

## Reformatted Equation

$$SST = T_a + a_i [T_i - F_i(T_a)] + a_j [T_j - F_j(T_a)]$$

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 coefficients for each satellite scene that accounts for water vapor influence, a priori statistics of SST, and error statistics of satellite
- Highly sensitive to tuning parameters (error variances, state variances) and first guess SST
Clouds and Aerosols

Cloud Summary

- 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

\[ T_s > T_{satellite} \]
Clouds and Aerosols

Aerosol Summary

- Radiation in Thermal bands (11 and 12 μm) have little sensitivity to aerosols distribution
- 3.7 μm is slightly affected
- Volcanic eruptions will affect the retrievals

Cloud Summary

- 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
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 space
- Skin effect causes greater uncertainty for bulk measured temperatures
- Schemes are developed for AVHRR, MODIS, and ATSR which address non-linearity issues in the split window and triple window
References


