SST Temperature Algorithms

By

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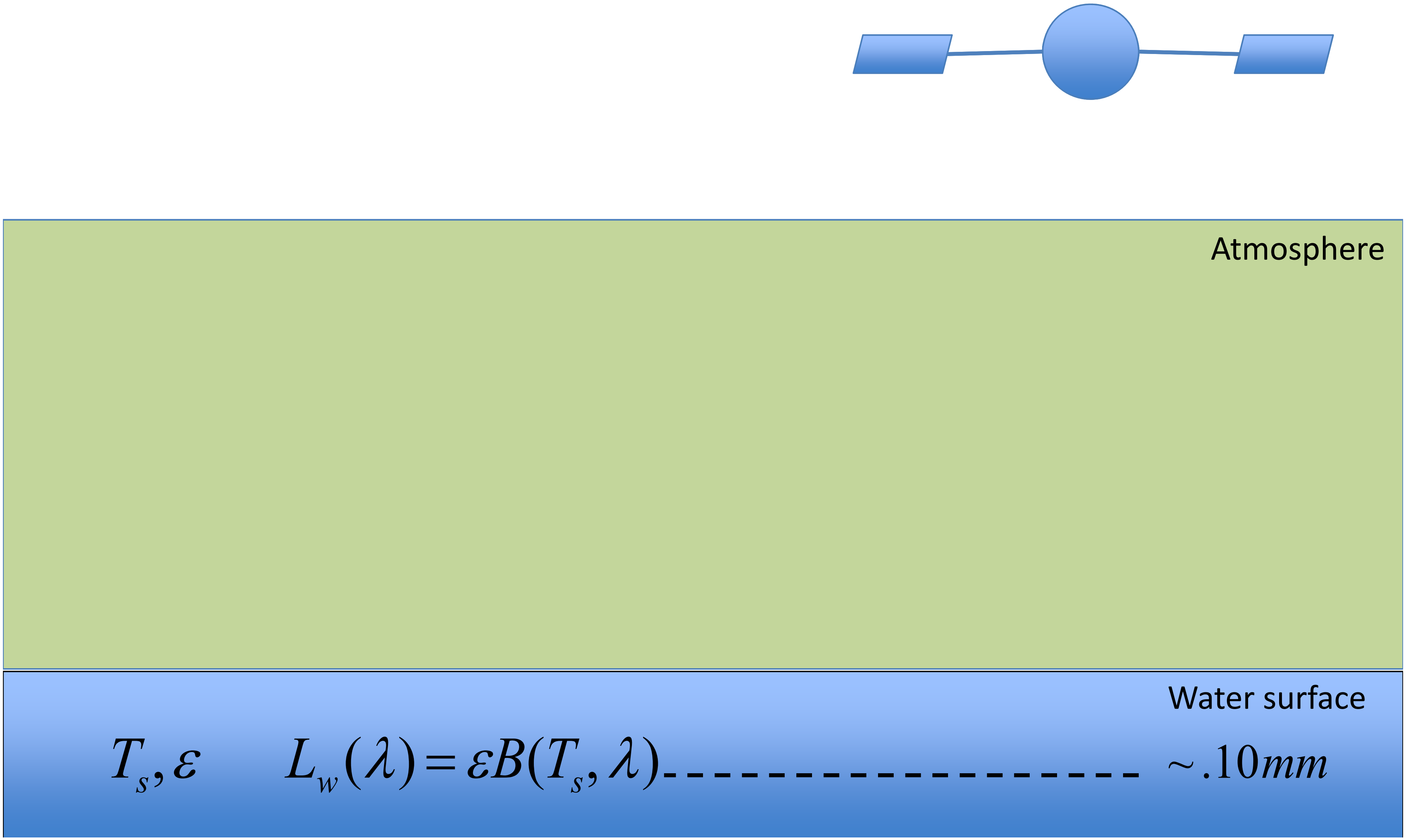
Outline

- 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



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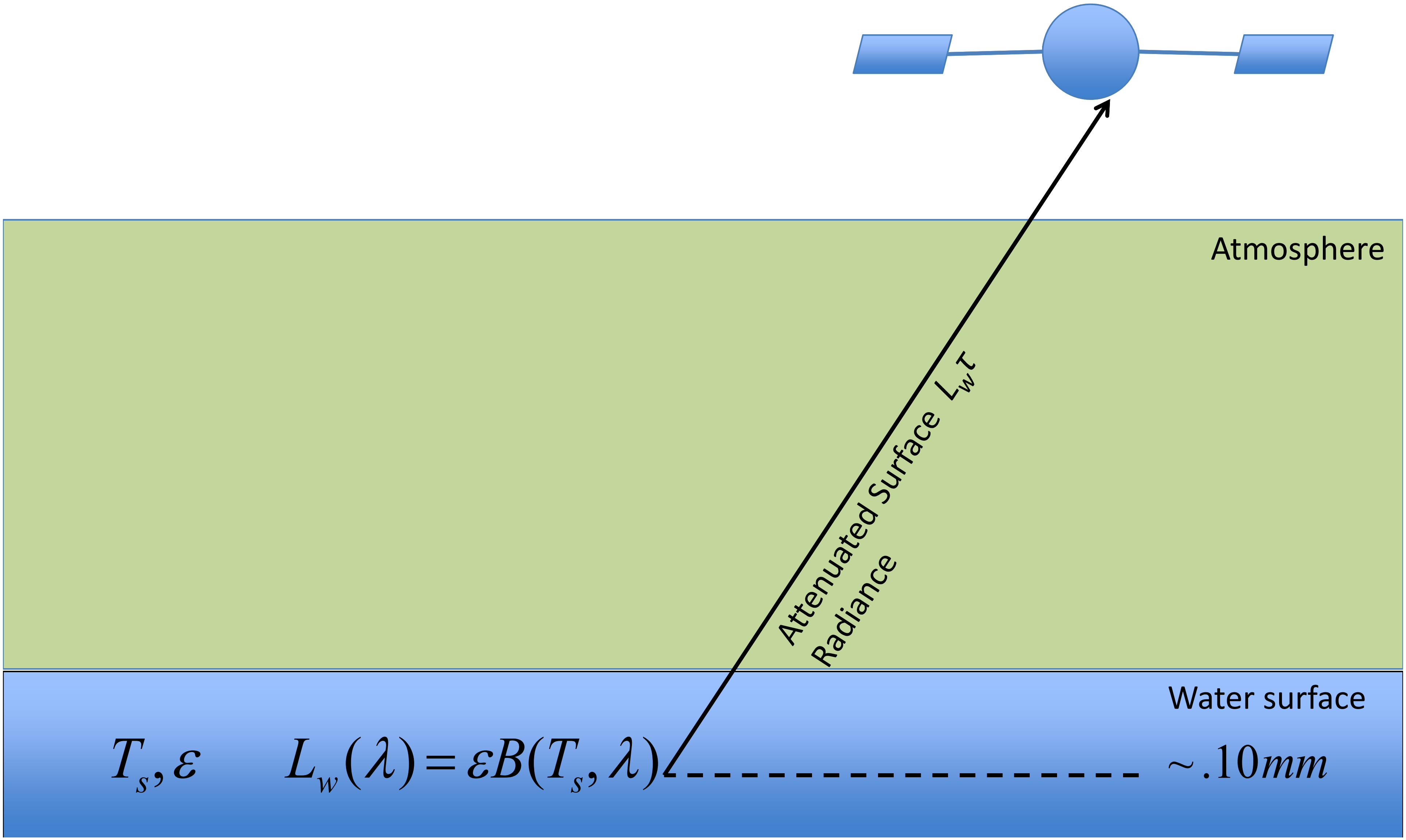
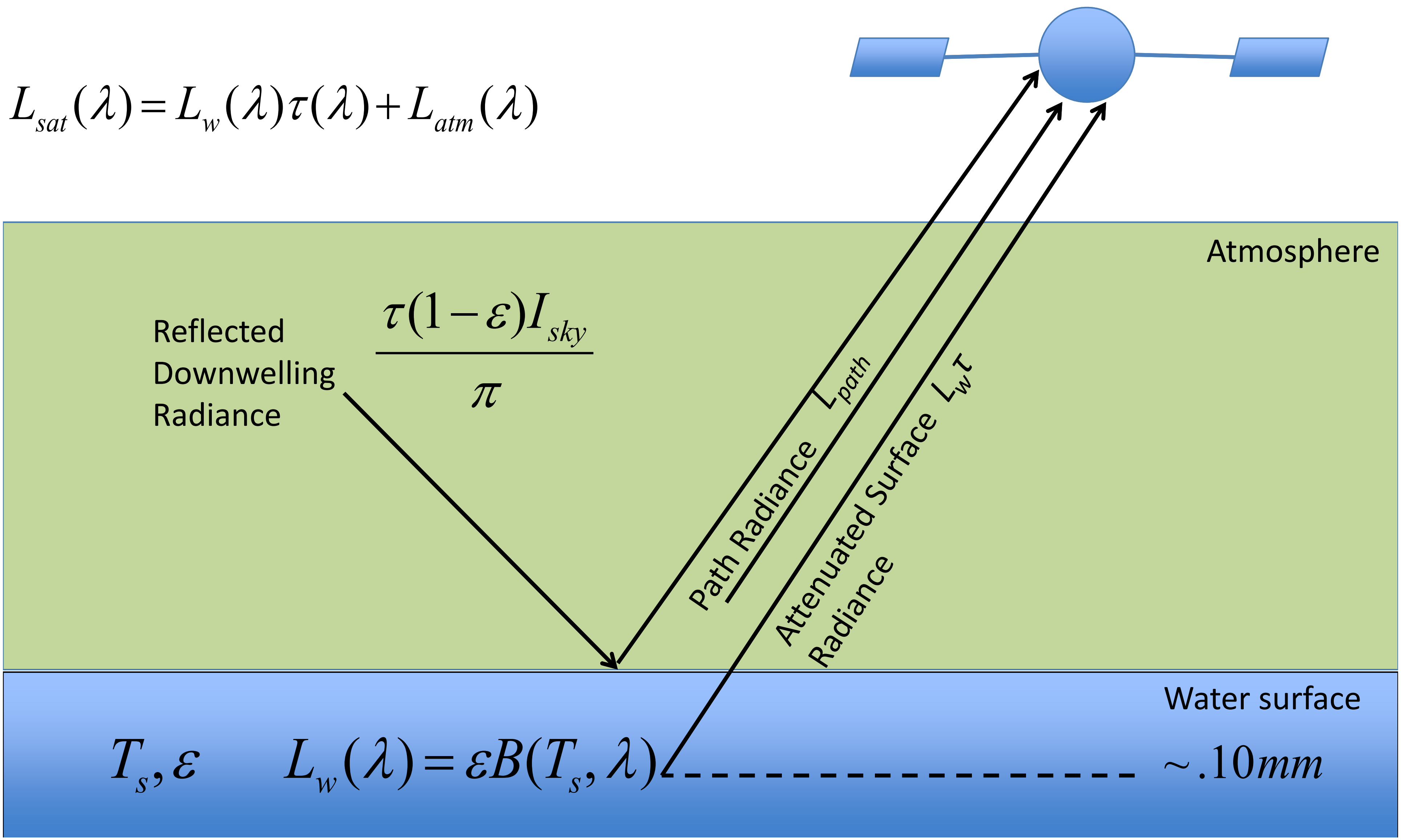


Radiation at the Sensor

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



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

$$SST = T_i + \gamma(T_i - T_j) \qquad \gamma \rightarrow \text{water vapor absorption}$$

Types of MCSST's

Algorithm Name	Thermal Bands	Day/Night usage
Dual Window	3.7 and 11 µm	Night
Split Window	11 and 12 µm	Day and Night
Triple Window	3.7, 11, and 12 µm	Night

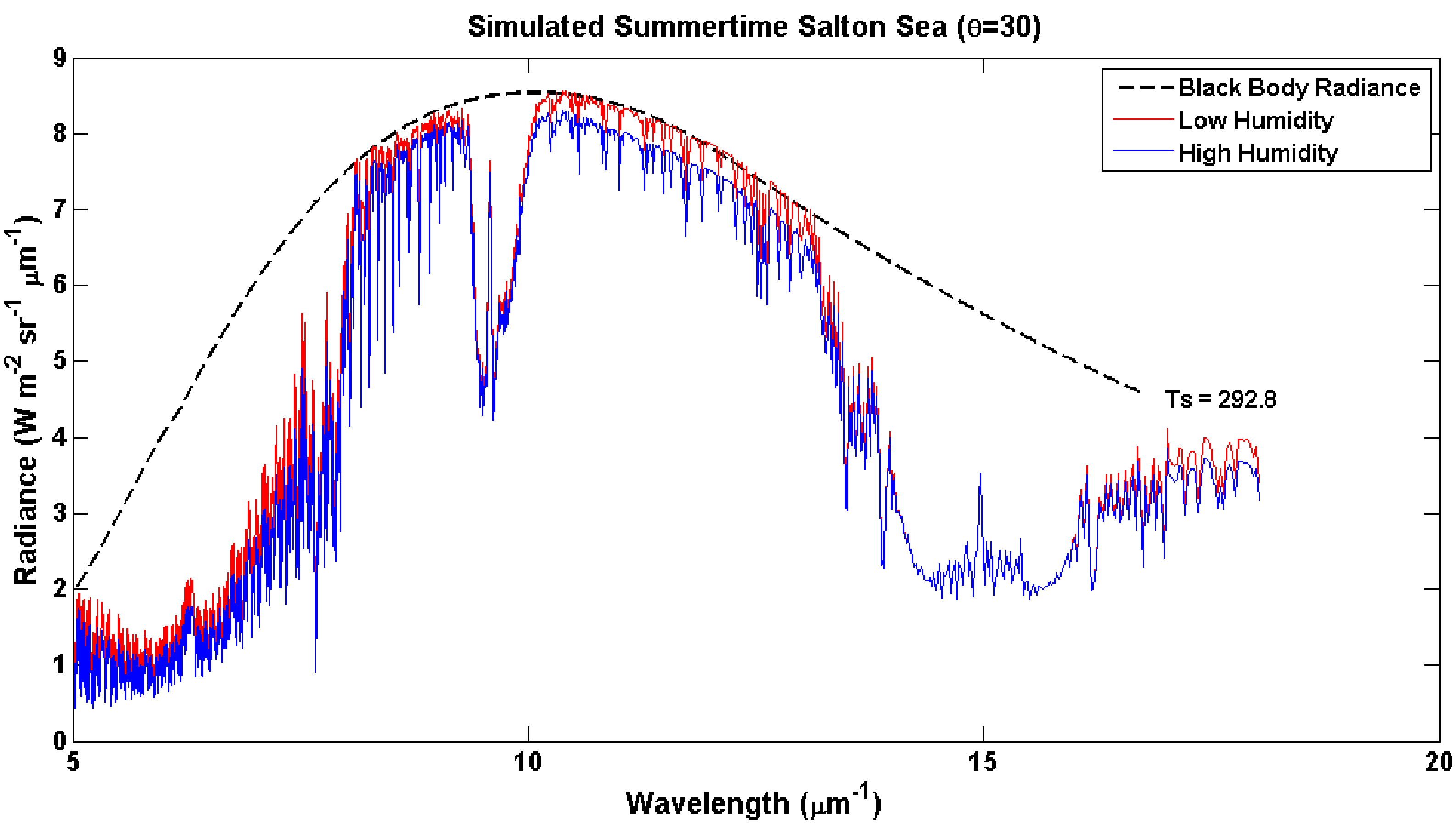
- 3.7 < 11 < 12 in terms of water vapor absorption
- 3.7 is affected by sunlight and generally not used in daytime measurements

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

Surface Temp=292.8

	11 µm (K)	12µm (K)
MODIS humid	287.74	286.44
MODIS dry	290.43	289.89



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

Method	Skin/Bulk	Instruments	Issues	Studies
Regression to radiometers	Skin	ATSR2, AATSR, MODIS	Lack of Lakes with radiometer measurements	Hook et. al. 2003
Regression to Buoys	Bulk	Pathfinder (AVHRR)	Uncertainty in skin effect	Kilpatrick et. al. 2001
Physical Simulations	Skin	ATSRx, MODIS	Ensuring physical simulations capture natural variability	Hulley et. al 2011, Wan and Dozier 1997

Coefficient Development

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

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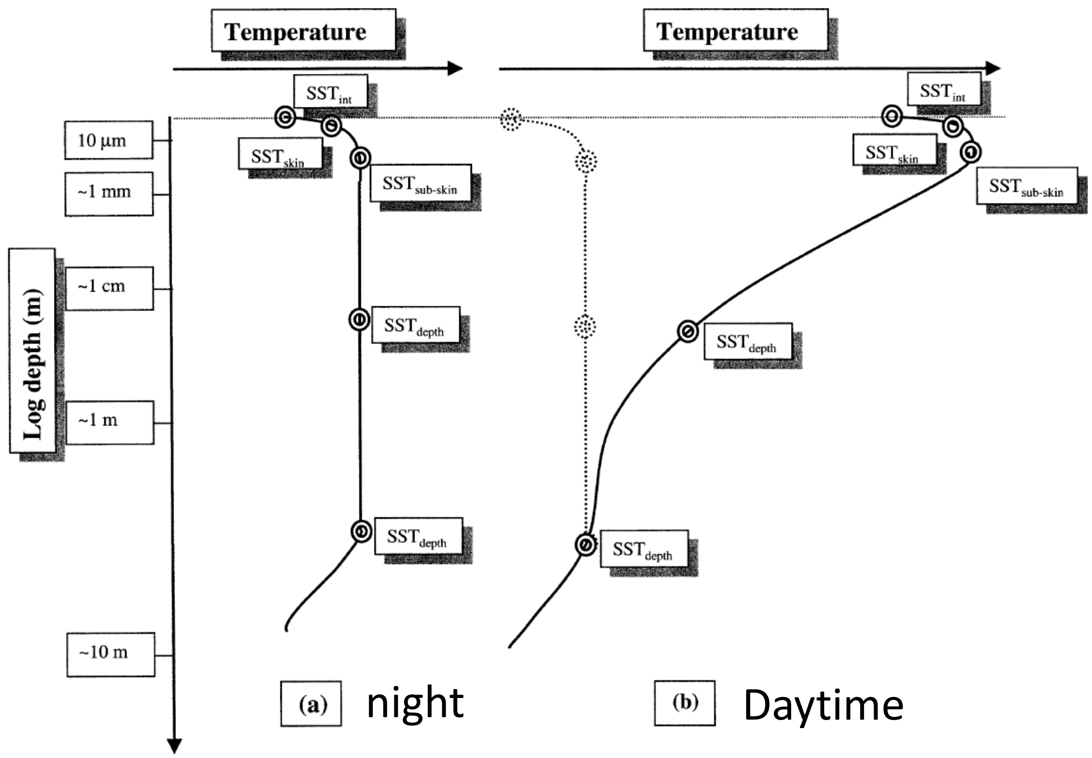
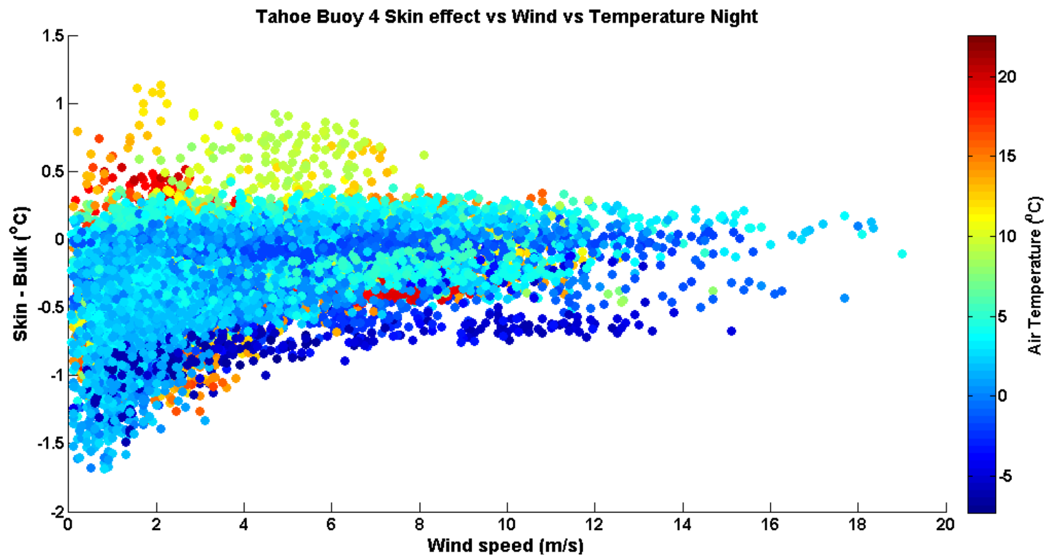
Skin Temperature vs. Bulk Temperature

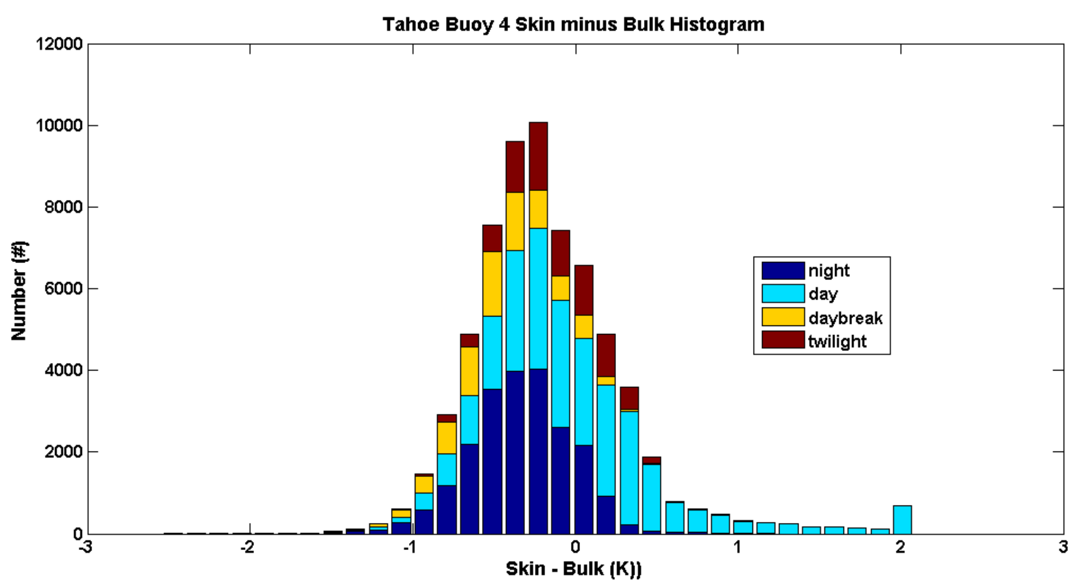
- Satellite senses radiation from the skin (~10µm)
- Sensible and latent heat fluxes cool the skin in relation to the bulk
- Stratification of thermal profile occurs during daytime
- Strong winds act to mix the daytime profile and then resembles the nighttime (dashed)



* From *Donlon et. al. 2002*

Typical Skin Bulk Differences





- Low wind speeds corresponds 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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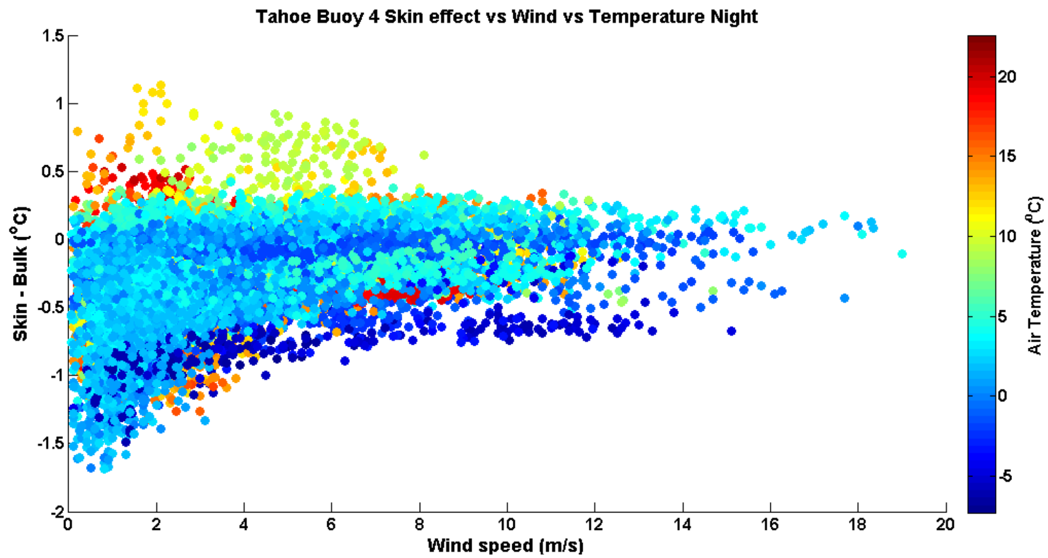

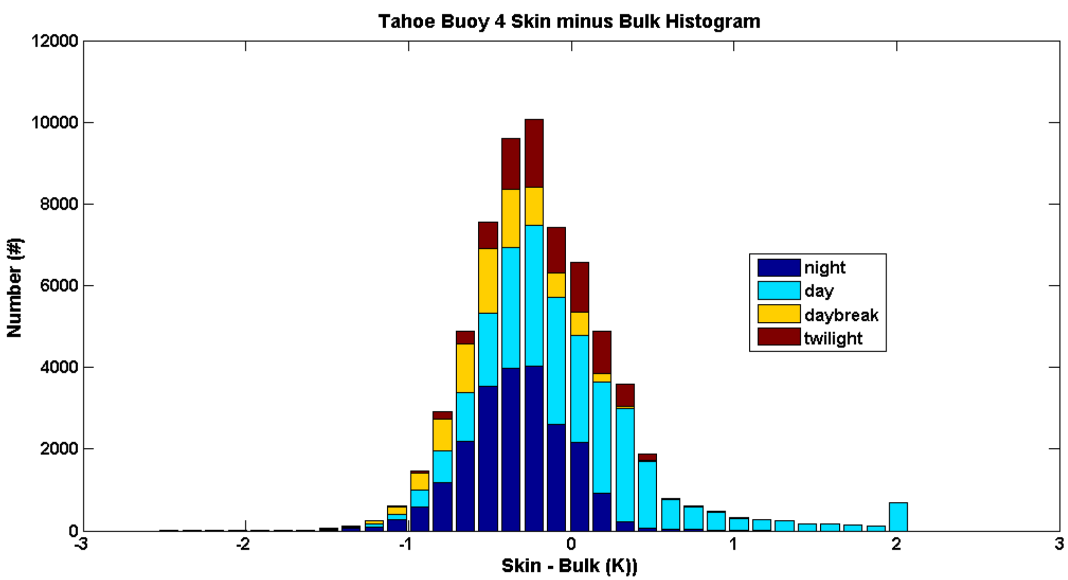

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Take home message

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

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

$$T_s = a + bT_i + c(T_i - T_j)T_{guess} + d(T_i - T_j)(1-\sec\theta) \rightarrow \text{NLSST(split)}$$

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- T_{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

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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
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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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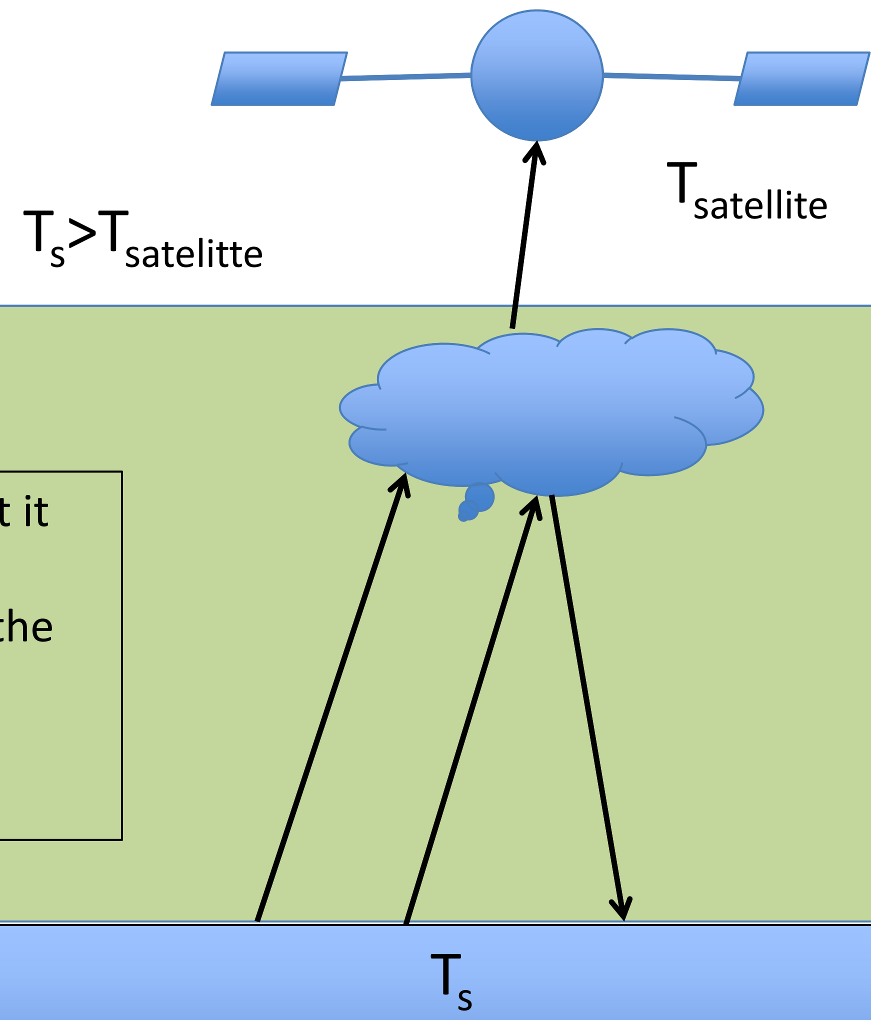
Take Home Message

- 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



Cloud Summary

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

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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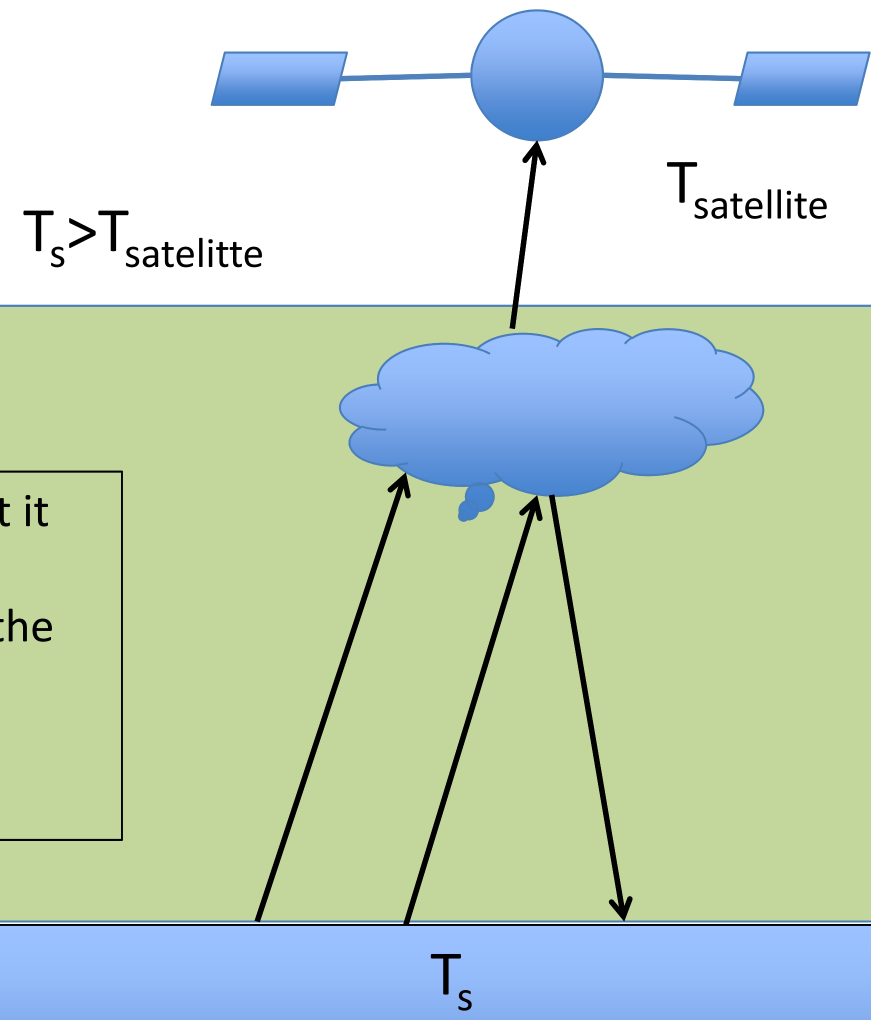

Summary

- 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

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