Multi-Sensor Satellite Retrievals of Sea Surface Temperature

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With contributions from many…

Outline

- Motivation/Background
- Input Products
- Issues in Merging SST Products
- Existing Multi-Sensor SST Products
- Summary

Motivation

- Increasing demands on SST resolution and accuracy
- Passive microwave data is highly complementary to traditional infrared sources
  - Infrared provides high resolution and high accuracy but is obscured by clouds
  - Microwave provides coverage through non-precipitating clouds but has coarser resolution and generally poorer accuracy
  - Both sensors subject to different error sources

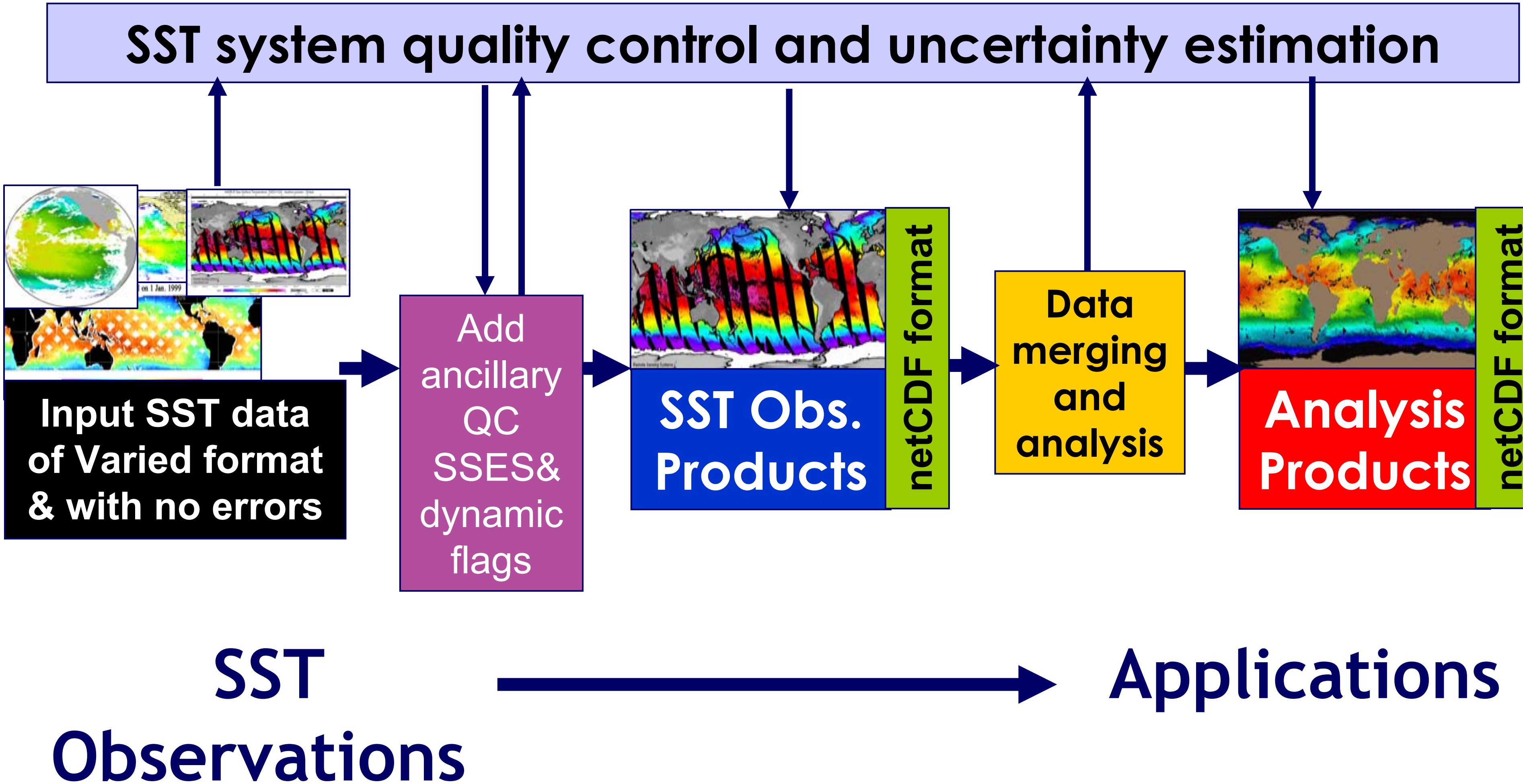
GODAE High-Resolution SST Pilot Project

- Provide rapidly and regularly distributed, global, multi-sensor, high-quality SST products at a fine spatial and temporal resolution
  - Most promising solution to combine complementary infrared and passive microwave satellite measurements with quality controlled in situ observations from ships and buoys
- www.ghrsst-pp.org

GHRSST-PP

GODAE High Resolution Sea Surface Temperature Pilot Project

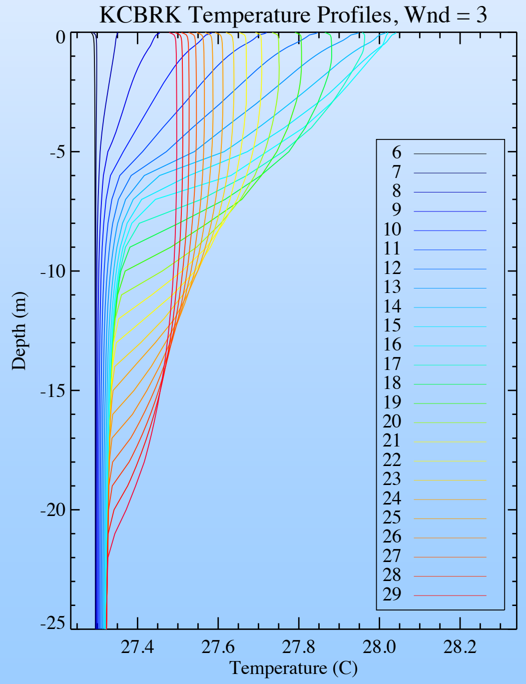
The GHRSST-PP Strategy

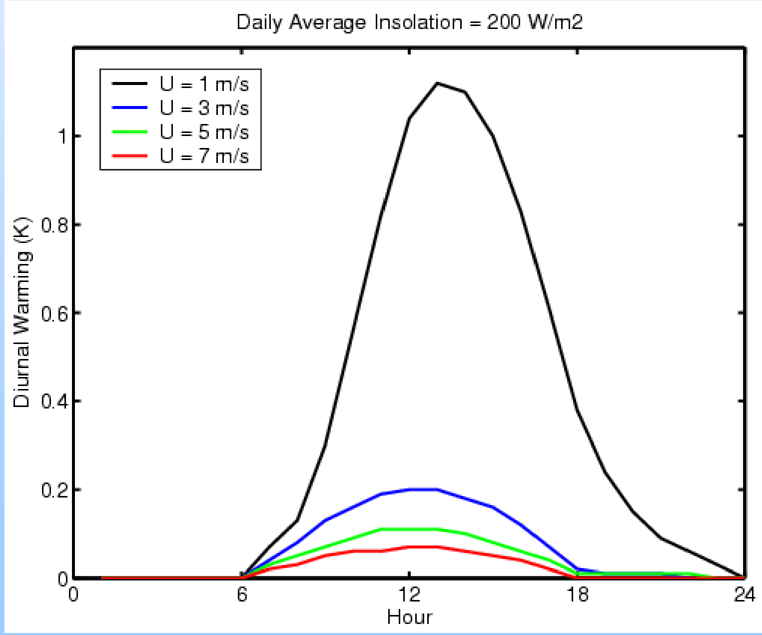


Slide courtesy Craig Donlon, Met Office

The Problem

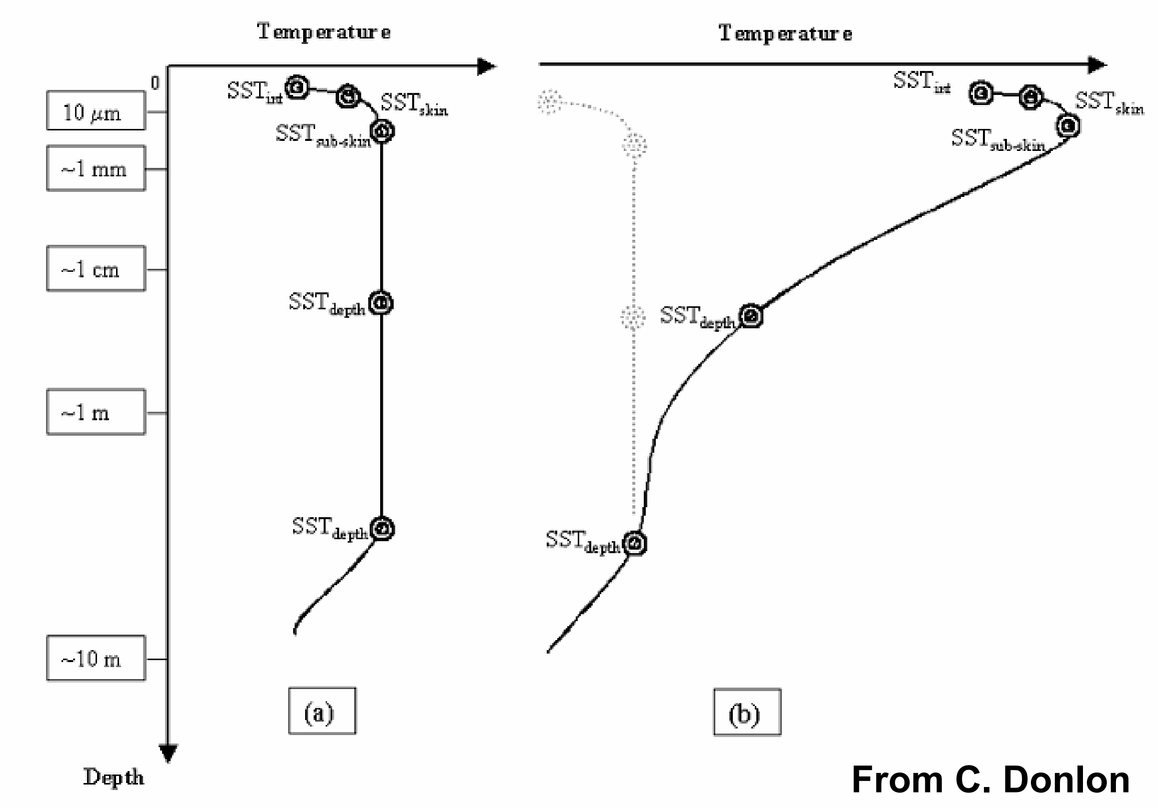
- Observations from multiple satellites and sensors with different measurement times, different effective measurement depths, and different error sources
- These must be combined into a single consistent product with known accuracy characteristics





Definition of SST

- Interface SST
- Skin SST
- Sub-skin SST
- SST_{Depth}
- Foundation SST



Input SST Products

- **Infrared**
  - AVHRR
  - AATSR
  - MODIS
  - GOES Imager
  - SEVIRI
  - MTSAT-1R
- **Microwave**
  - TMI
  - AMSR-E
  - WindSat

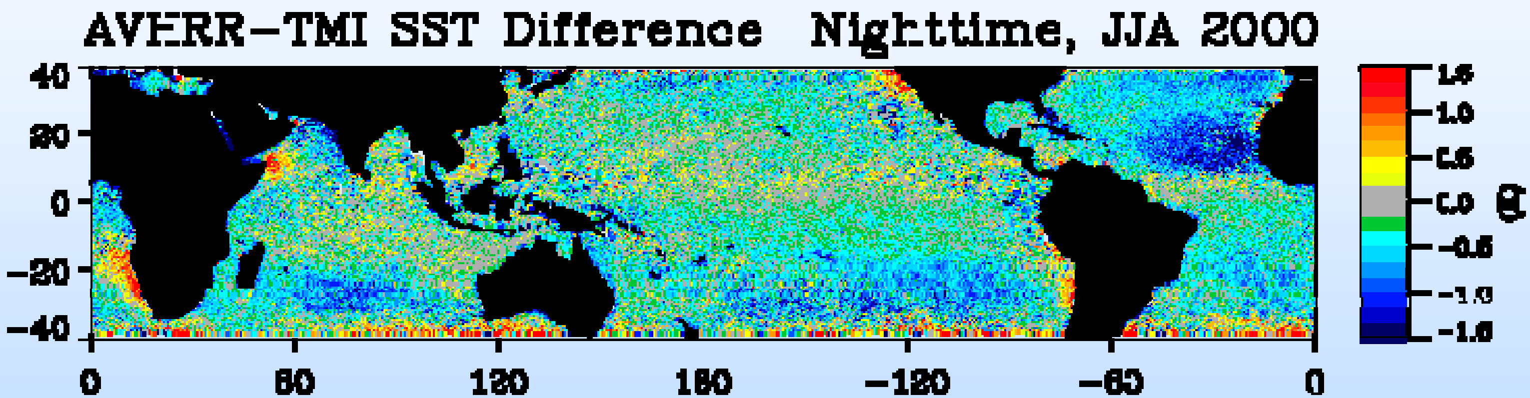
Key Blending Issues

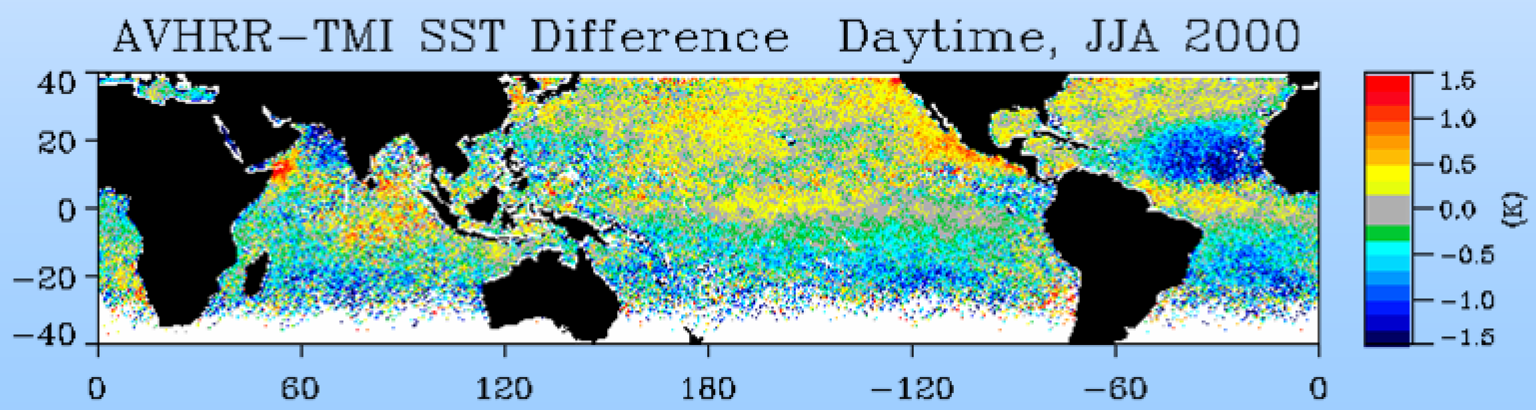
- Correction for sensor-dependent retrieval errors and bias
  - Effects of wind speed, water vapor, aerosols, atmospheric stability, etc.
  - Buoys used as accuracy reference
- Reference retrievals to common time and effective measurement depth
  - Diurnal warming and skin layer effects
  - Daily reference taken as foundation temperature
- Merging technique
  - Treatment of different resolution
  - Separate provision of diurnal variations

Reconciling Sensor Errors

Observed Differences Between Infrared and Microwave Products

Detailed comparisons between infrared and microwave SST products show complex spatial and temporal differences.

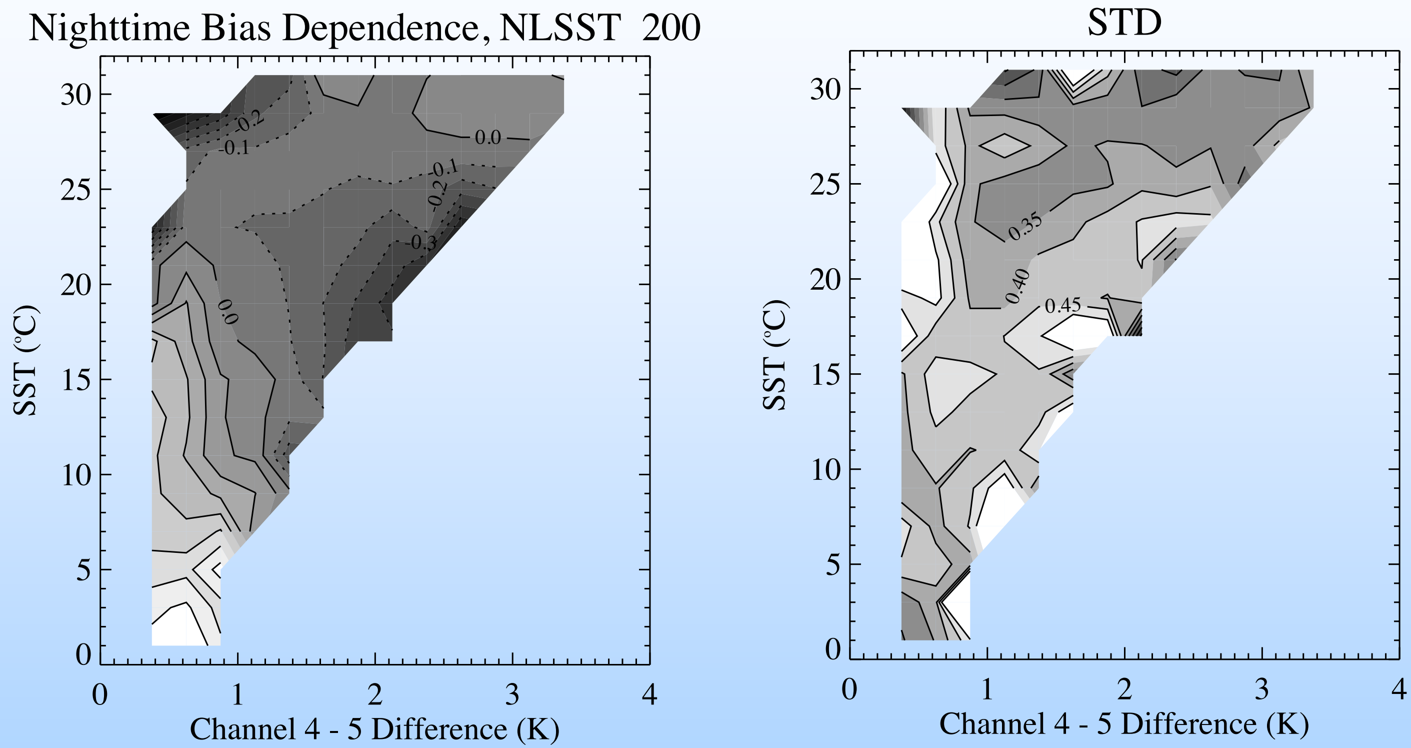




Error Characterization Approach

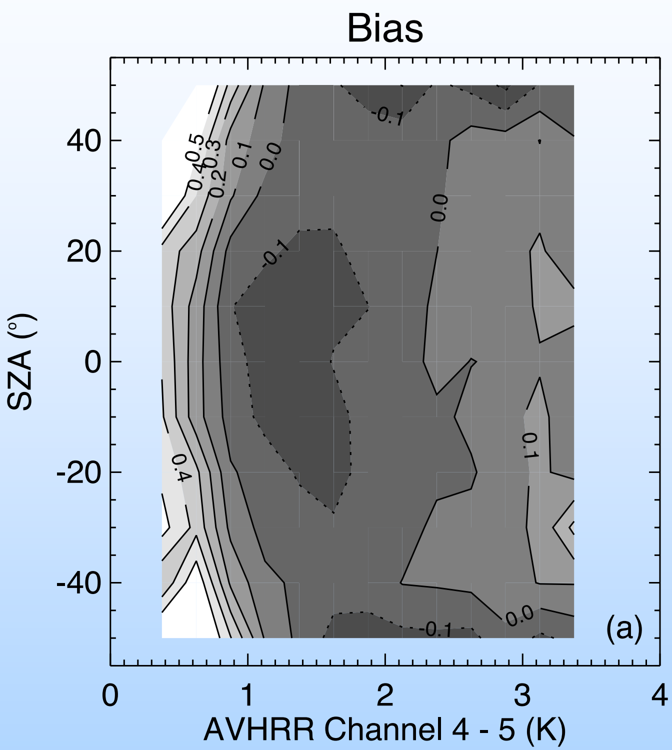
- Bias and rms error estimates derived from collocations with buoy data
- Determined dependence of uncertainties on sensor and environmental parameters
- Uncertainty estimates expressed through multi-dimensional look-up table
- Parameter combinations evaluated through reduction in sensor-buoy and sensor-sensor differences

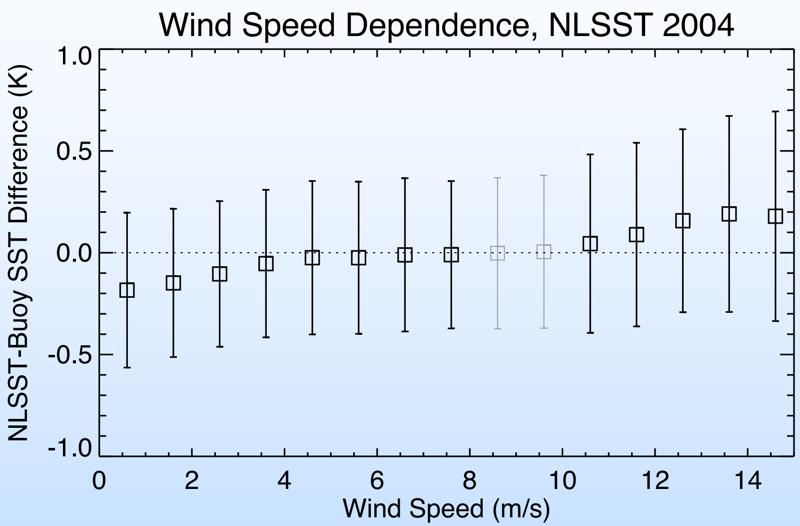
AVHRR Uncertainty Sources

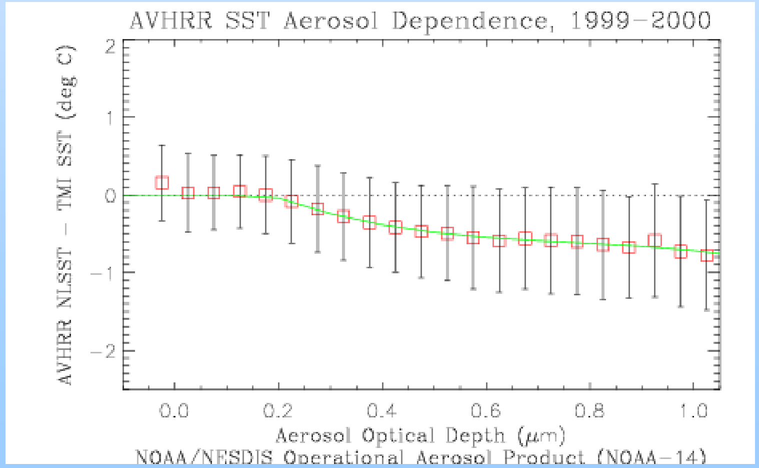


From Castro et al., 2008

AVHRR Uncertainty Sources (2)

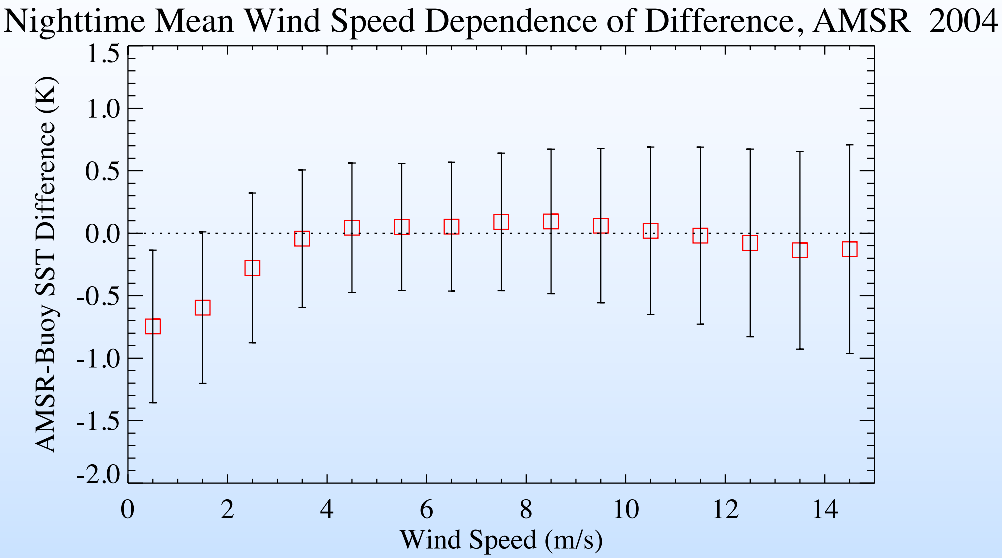


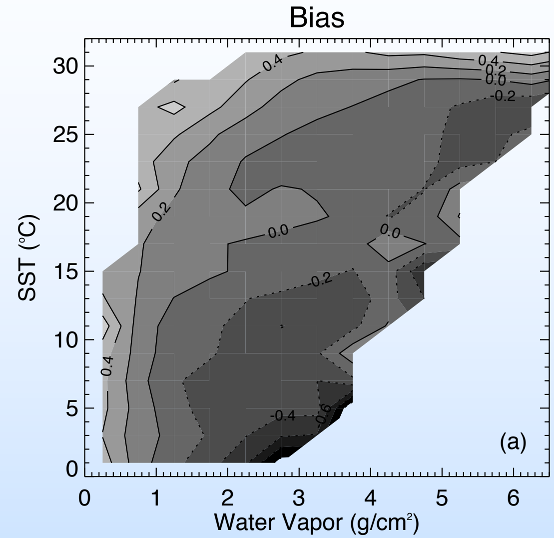


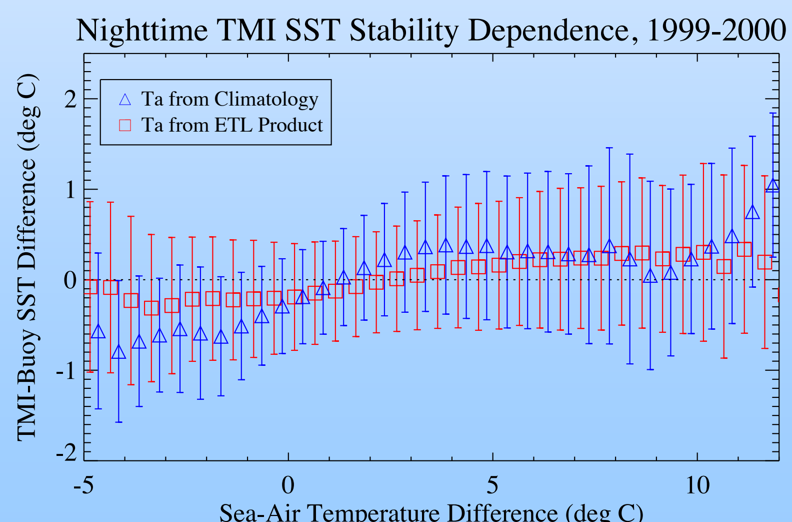


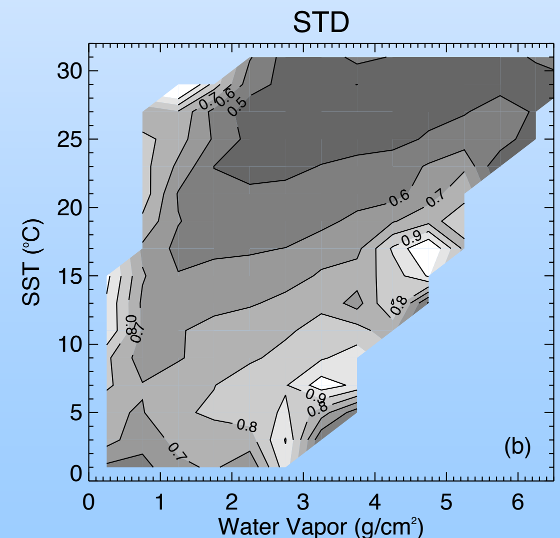
From Castro et al., 2008

Microwave Uncertainty Sources



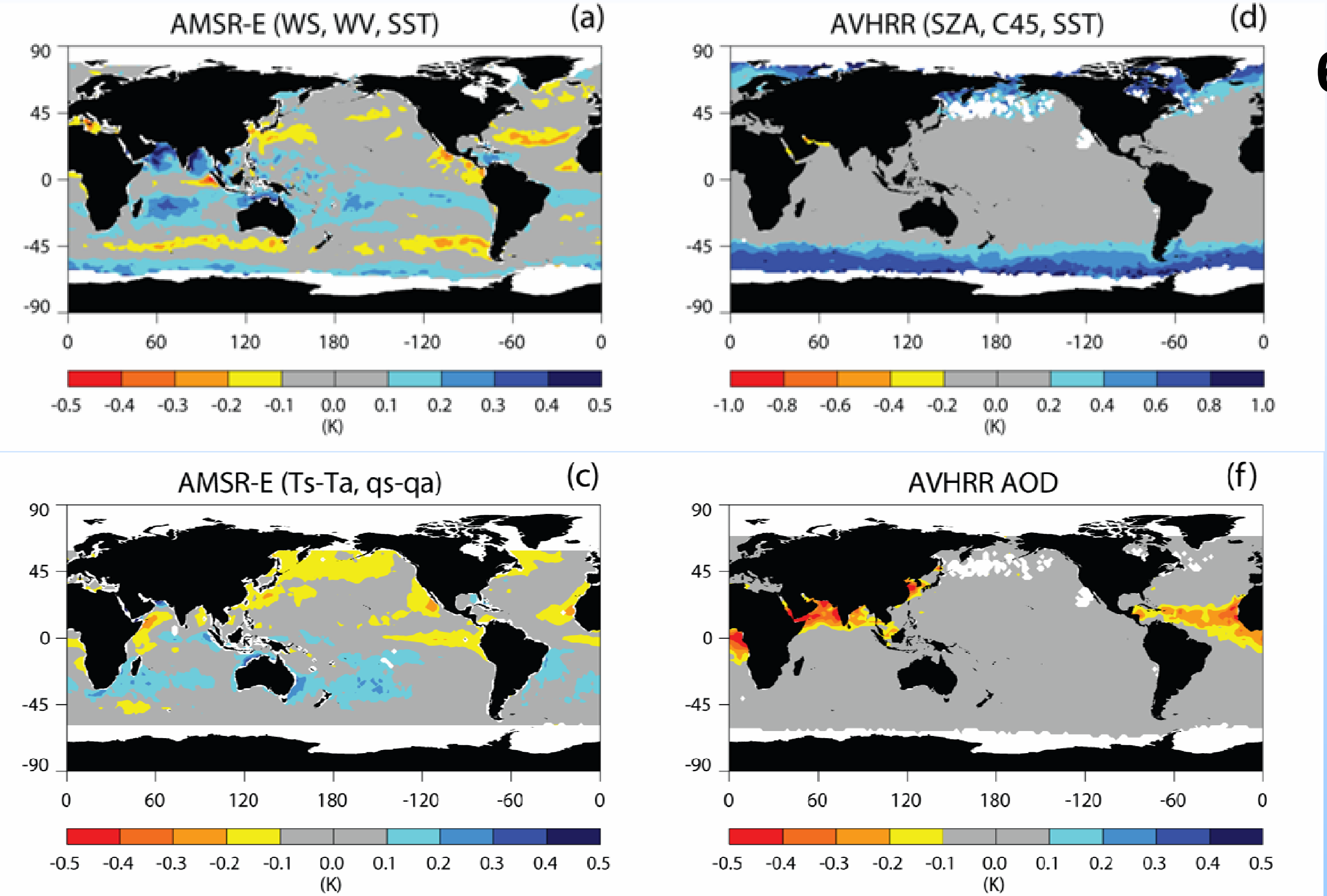






Resulting Bias Corrections

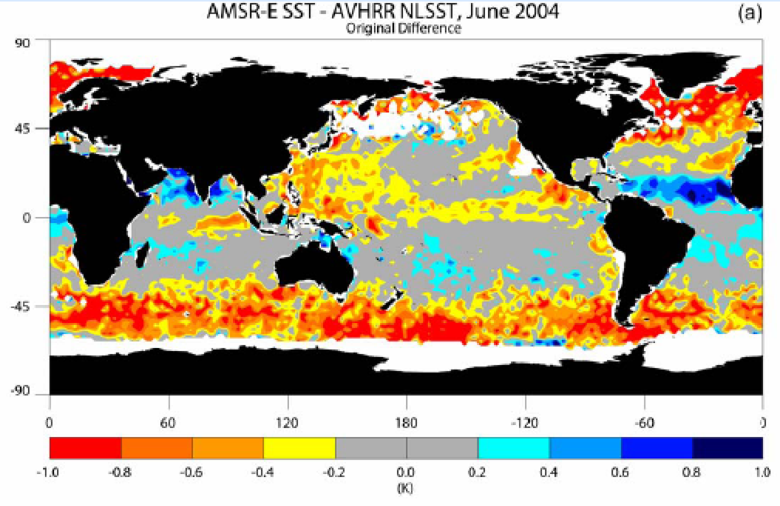
6/04

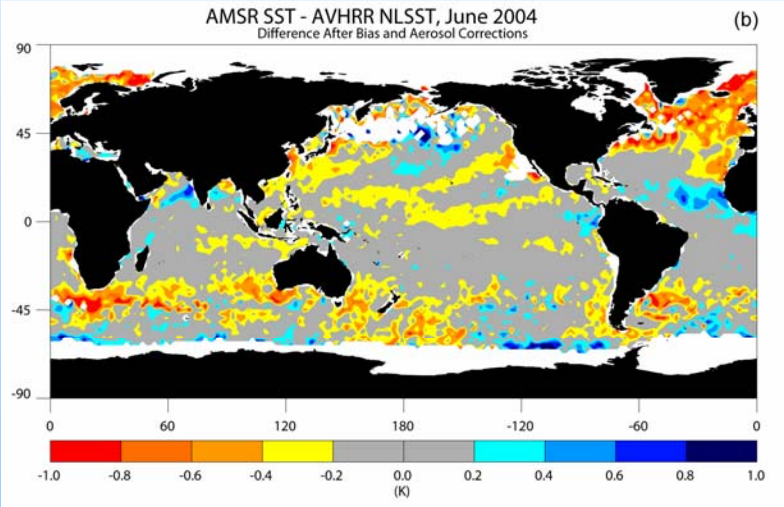


From Castro et al., 2008

Impact of Bias Corrections

- AVHRR adjustments applied based on brightness temperature difference, SST, SZA, and aerosol optical depth
- AMSR-E adjustments based on wind speed, water vapor, SST and atmospheric stability
- Application of bias adjustments reduced differences between satellite products





Before Adjustment — **Bias: -0.09 K**, **RMS: 0.58 K**

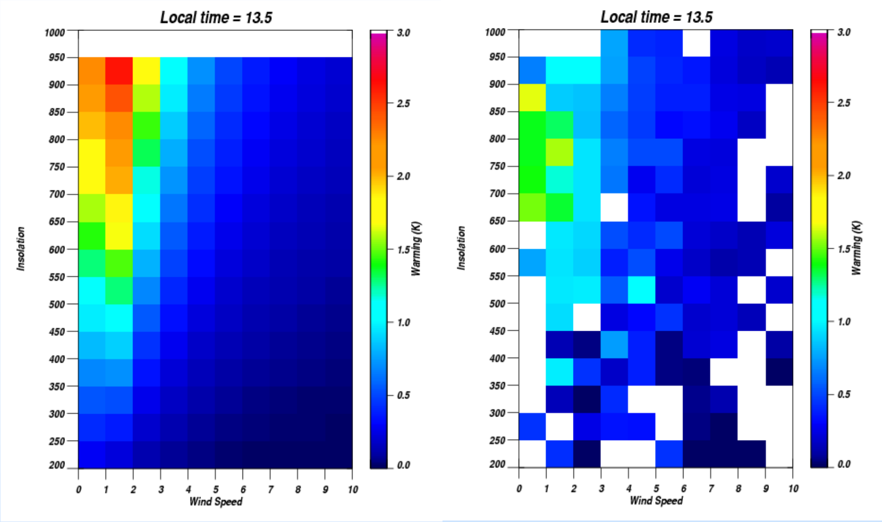
After Adjustment — **Bias: -0.08 K**, **RMS: 0.45 K**

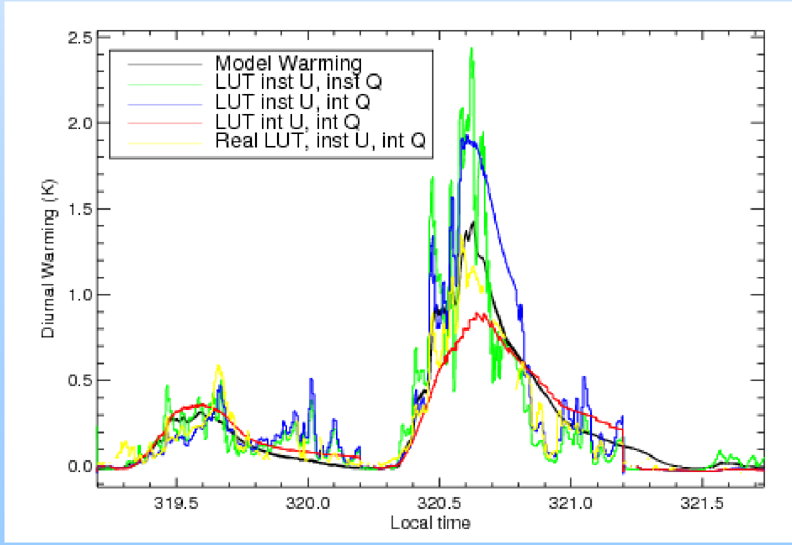
Treatment of Diurnal Warming

- Each retrieval adjusted to “foundation” to remove any component of diurnal warming
- Multiple approaches:
  - Exclusion of observations at low wind speeds where warming expected
  - Look-up tables as functions of wind speed and insolation
  - Simplified parameterizations
  - More detailed mixed layer models
- Challenge: Must form estimates based solely on observations available from satellites

Application of Look-Up Tables

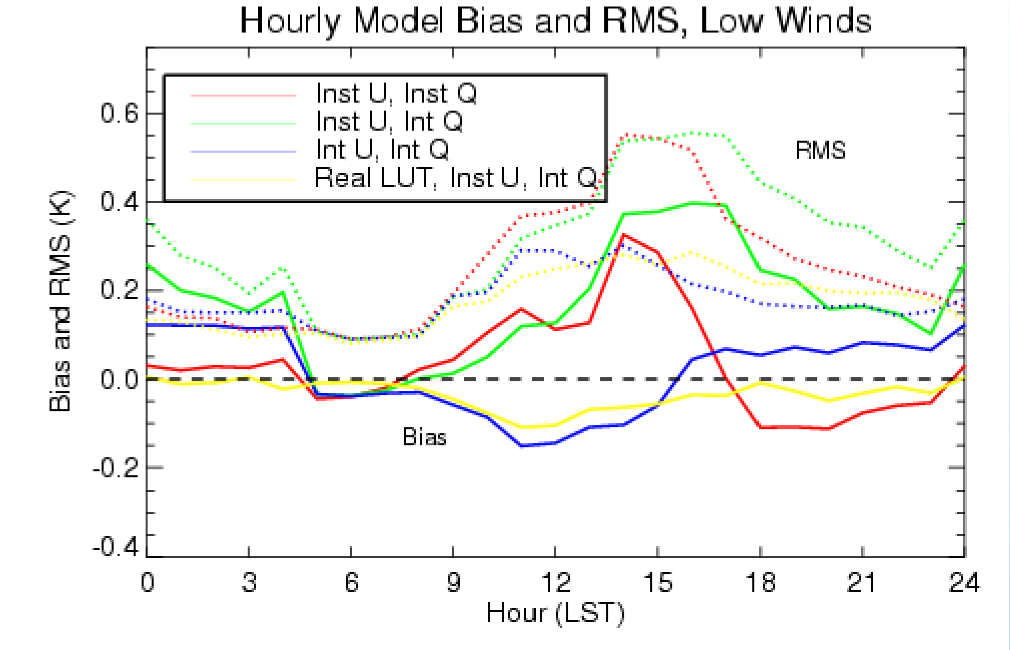
- Developed LUT from idealized and real forcing
- Applied different formulations to replicate full model results
- From idealized forcing, tables using instantaneous wind speed overestimate warming
- Use of integrated wind speed and integrated insolation better replicate model physics
- Best results obtained with LUT derived from cruise forcing and expressed in terms of instantaneous wind speed and integrated insolation





Overall LUT Representation Accuracy

- **Best overall results again obtained from LUT for instantaneous wind speed and integrated insolation when derived from cruise forcings**
- **Errors resulting solely from LUT representation reach approximately 0.1 K in bias and 0.3 K in RMS**



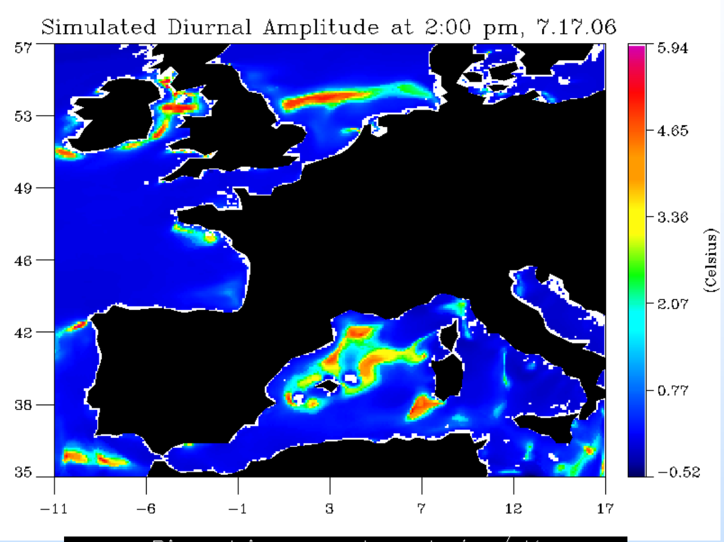
Results compiled from diverse set of cruise observations and LUT errors in replicating full model determined as a function of local hour

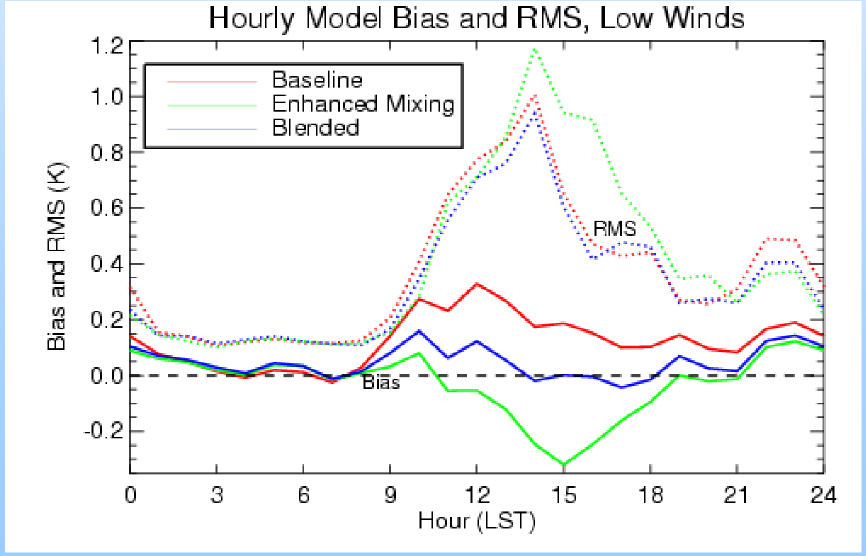
Detailed Models for Diurnal Warming

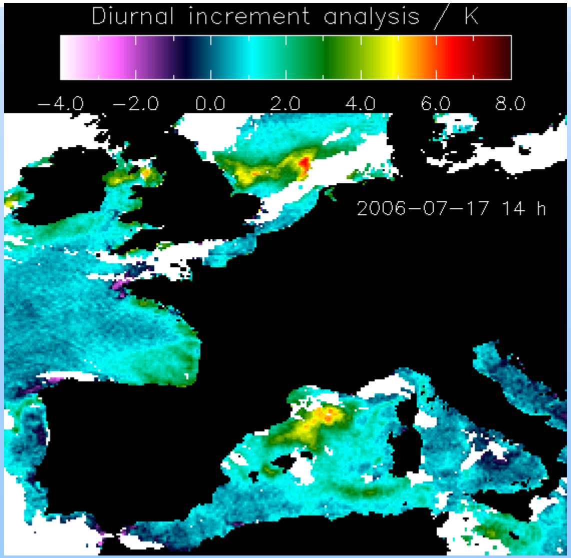
- Performance of multiple detailed diurnal warming models being evaluated in GHRSST Diurnal Variability Working Group
  - Kantha and Clayson (1995) second moment turbulence closure
  - Fairall et al. (1996) simplified bulk warm layer model
  - Global Ocean Turbulence Model (GOTM)
  - Profiles in Ocean Surface Heating (POSH) (Gentemann, 2007)

Application of New Blended Model

- Full Kantha-Clayson warming model modified to blend two turbulence schemes
- Results show improved ability to simulate both cruise and satellite observations of diurnal warming
- Underlying model accuracy of < 0.1 K bias and ~1 K rms

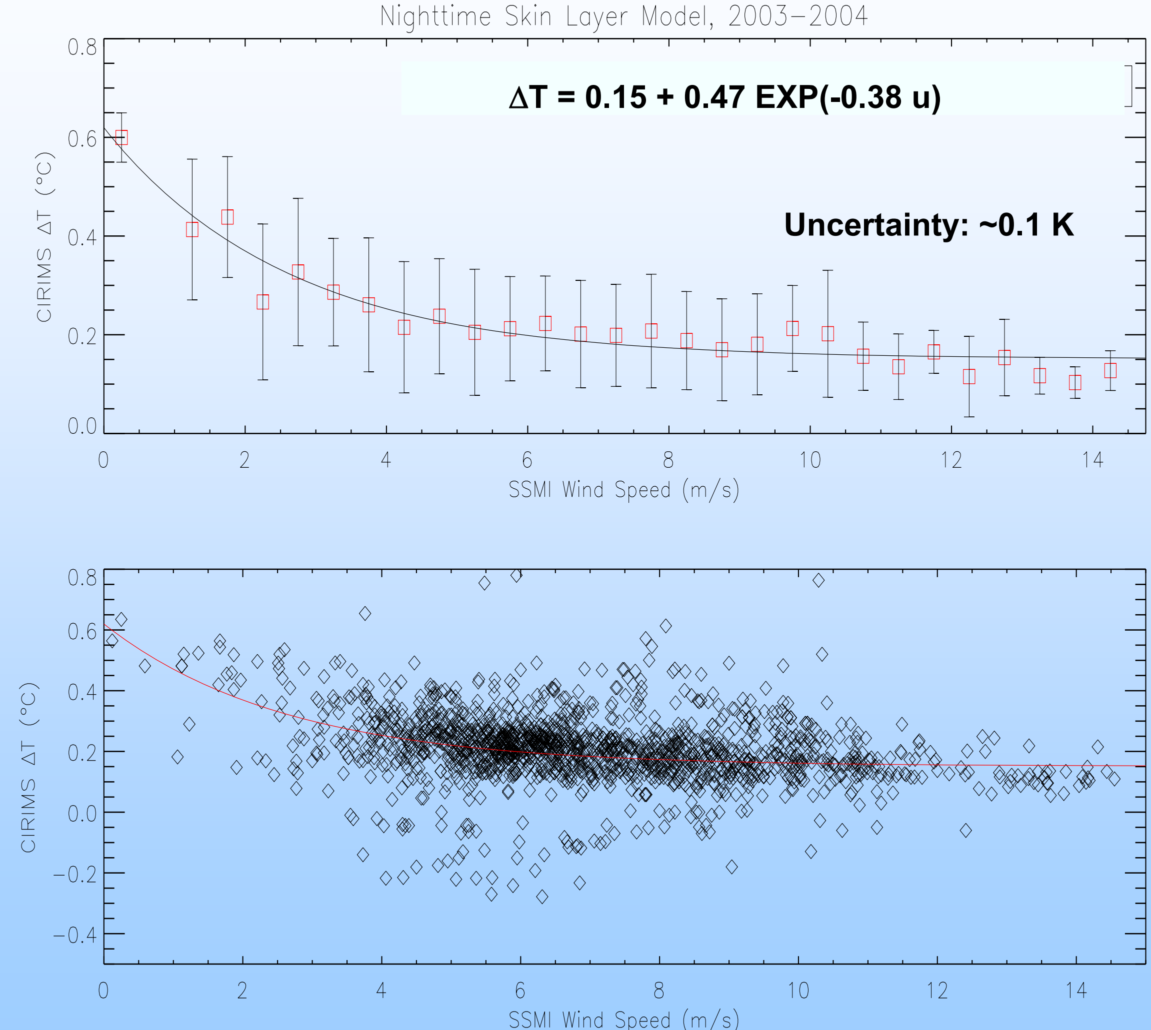






Skin Layer Effects

- Assessed application of skin layer model with satellite data
- Developed revised fit with added cruise observations
- Skin layer estimates incorporated in MW L2P data

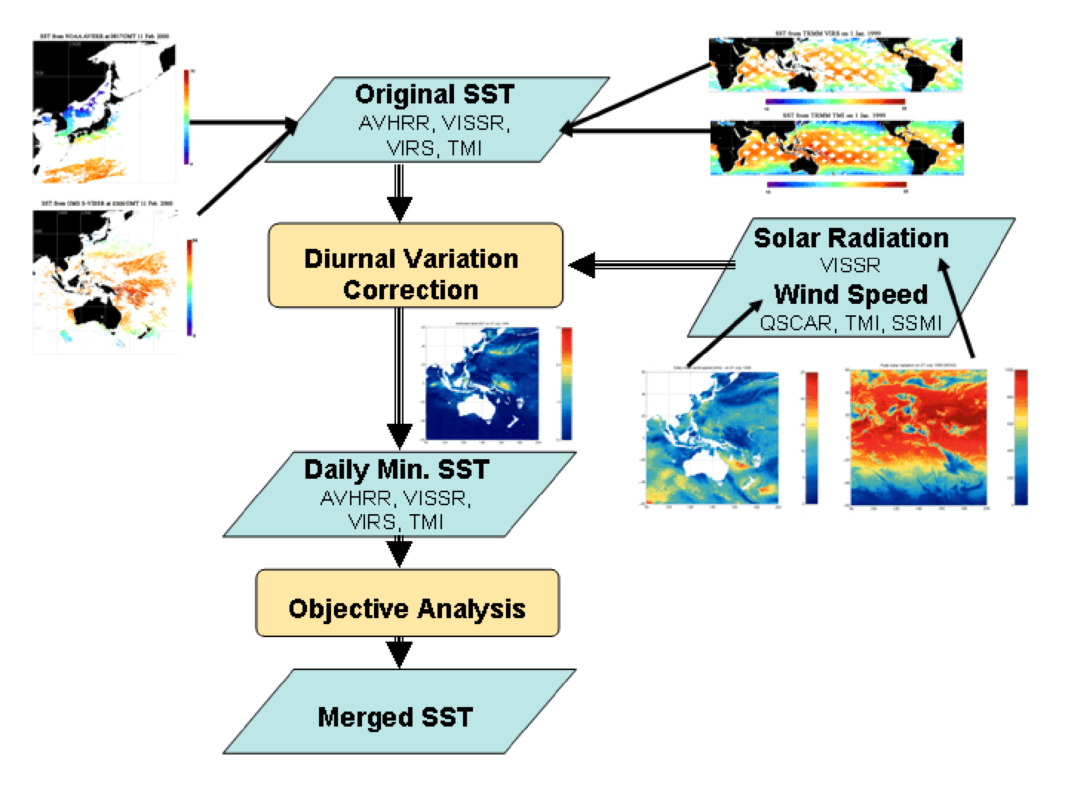


From S. Castro

Multi-Sensor Analyzed SST Products

- Many new products now available
- Most based on optimal interpolation
- Wide differences in products combined, resolution, and regions

Next Generation SST



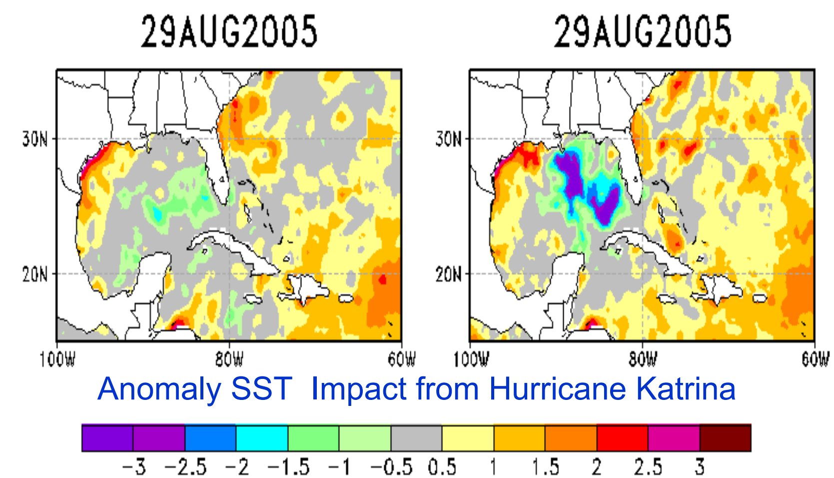
- Created by Hiroshi Kawamura, Tohoku University, Japan
- http://www.ocean.caos.tohoku.ac.jp/~adeos/sst/

Daily OI Version 2

Project Goals

1. **Produce Daily OI on 1/4° spatial grid**
   - Include satellite bias correction with respect to in situ data
2. **Compute analysis for entire period with satellite data**
3. **Make product useful for climate**

AVHRR-only AMSR+AVHRR



Anomaly SST Impact from Hurricane Katrina

Current Status

1. **Uses AVHRR + In Situ Data**
   - January 1985 - present
2. **Uses AMSR + AVHRR + In Situ Data**
   - June 2002 - present
3. **Interim (1 day of data) and final (3 days of data) versions**
4. **Ship SSTs corrected using buoy SSTs**

Looking Forward

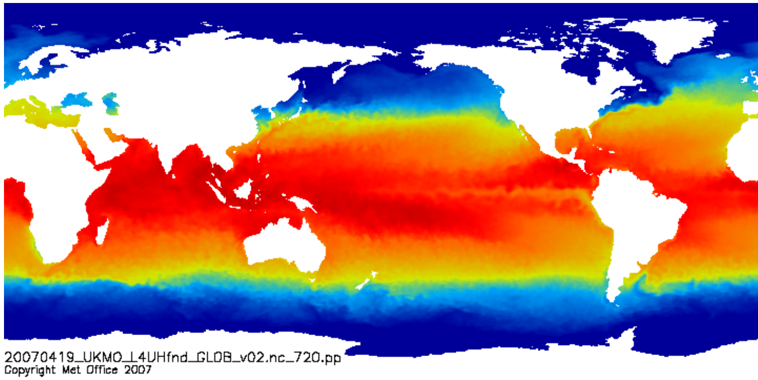
1. **Version2 becomes operational**
2. **Add ATSR and TMI**
3. **Use Pathfinder NOAA-7 data when available**

http://www.ncdc.noaa.gov/oa/climate/research/sst/oi-daily.php

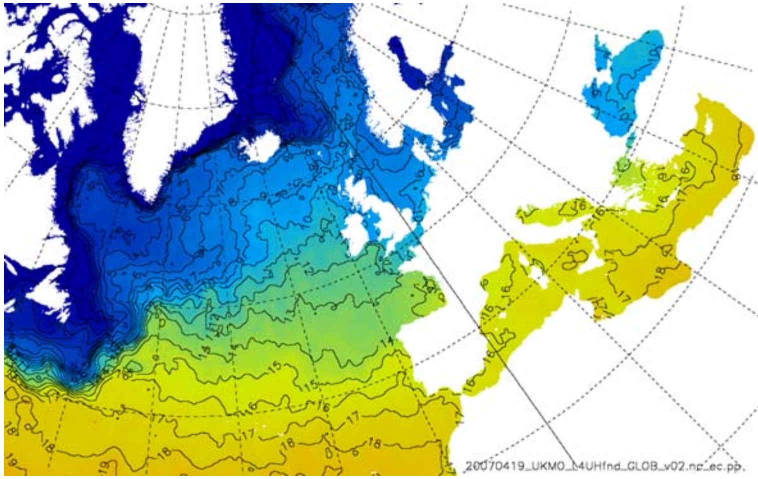
Dick Reynolds, NCDC

Operational SST & Sea Ice Analysis

- Daily 1/20° (~5.6km) global SST analysis.
    - Analysis of the 'foundation' SST [pre-dawn or below the diurnal warm layer].
- Blend of data sources, using satellite (microwave & IR) and in situ data.
    - Using many GHRSST data products.
    - Almost all Medspiration products.
- Now running daily, operationally.
- Using a variational scheme, with persistence based background.
- Uses sea ice analysis performed by EUMETSAT OSI-SAF (met.no / DMI).



Sample analysis for 19 Apr 2007



Slide courtesy John Stark, Met Office

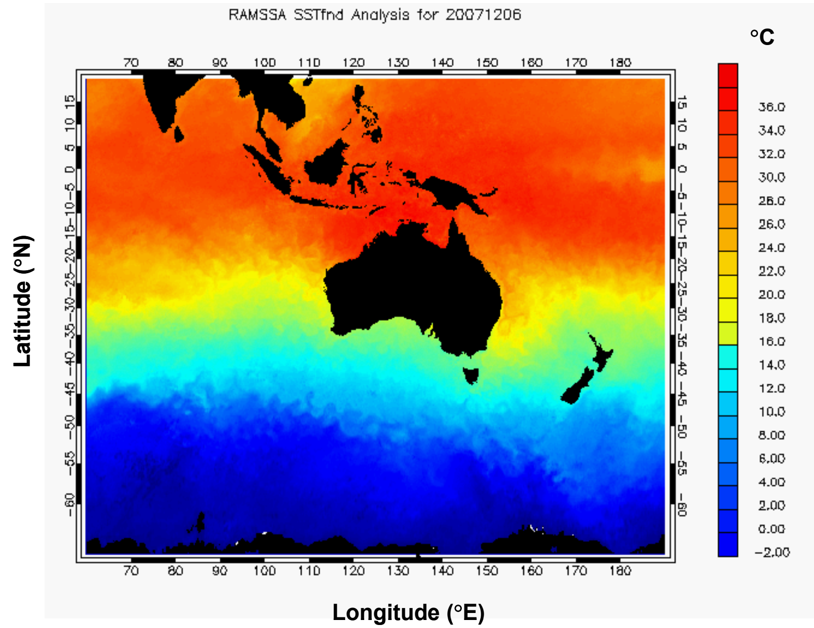
BoM Regional Australian Multi-Sensor SST Analysis System

V1.0: Operational 13 Jun 2007
-> RT input to BoM NWP models
V1.1: Operational 26 Oct 2007
Depth: Foundation
Resolution: Daily, 1/12°
Domain: 60°E - 170°W , 20°N - 70°S
Observation correlation length scale: 12 km
Background correlation length scale: 20 km
BGF: Combination of previous day's RAMSSA and previous BoM weekly global SSTblend analysis

Based on legacy BoM optimal interpolation regional SST analysis system (Smith et al., 1999)

Data Inputs:

- 1 km HRPT AVHRR (NOAA-17, -18)
- 9 km NESDIS GAC AVHRR (NOAA-17, -18, METOP-A)
- 25 km AMSR-E (Aqua) **L2P**
- 1/6° AATSR (EnviSat)
- Buoy and ship obs (GTS)
- 1/12° NCEP ice edge analyses



Daily foundation SST analyses available by ~0330 UT as netCDF L4 files from http://godae.bom.gov.au and http://ghrsst-pp.jpl.nasa.gov

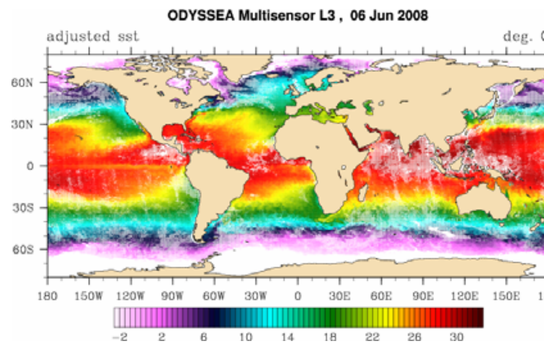
Slide courtesy Helen Beggs, BoM

MERSEA Products

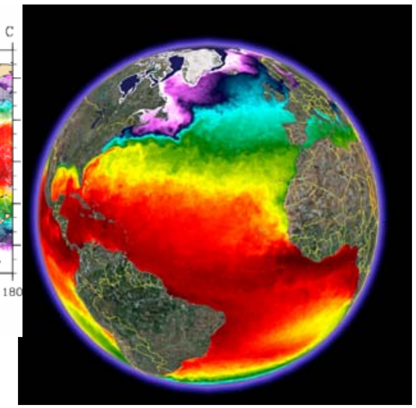
Multisensor L3/L4 products

- Global ODYSSEA analysis, daily, 0.1° (AATSR, NOAA LAC/GAC 17/18, SEVIRI, AMSRE, TMI, *METOP, GOES 11/12*), near-real time
- Atlantic analysis, daily, 0.05°, (AATSR, NOAA LAC/GAC 17/18, SEVIRI, AMSRE, TMI, METOP), near-real time
- Mediterranean analysis, daily, 1/16° (IR multi-sensor), near real-time and delayed mode

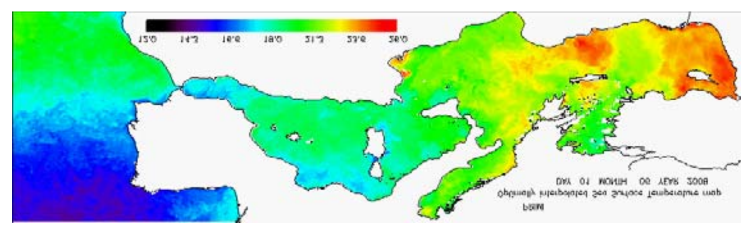
Ifremer/ODYSSEA



global multisensor L3



global analysis L4



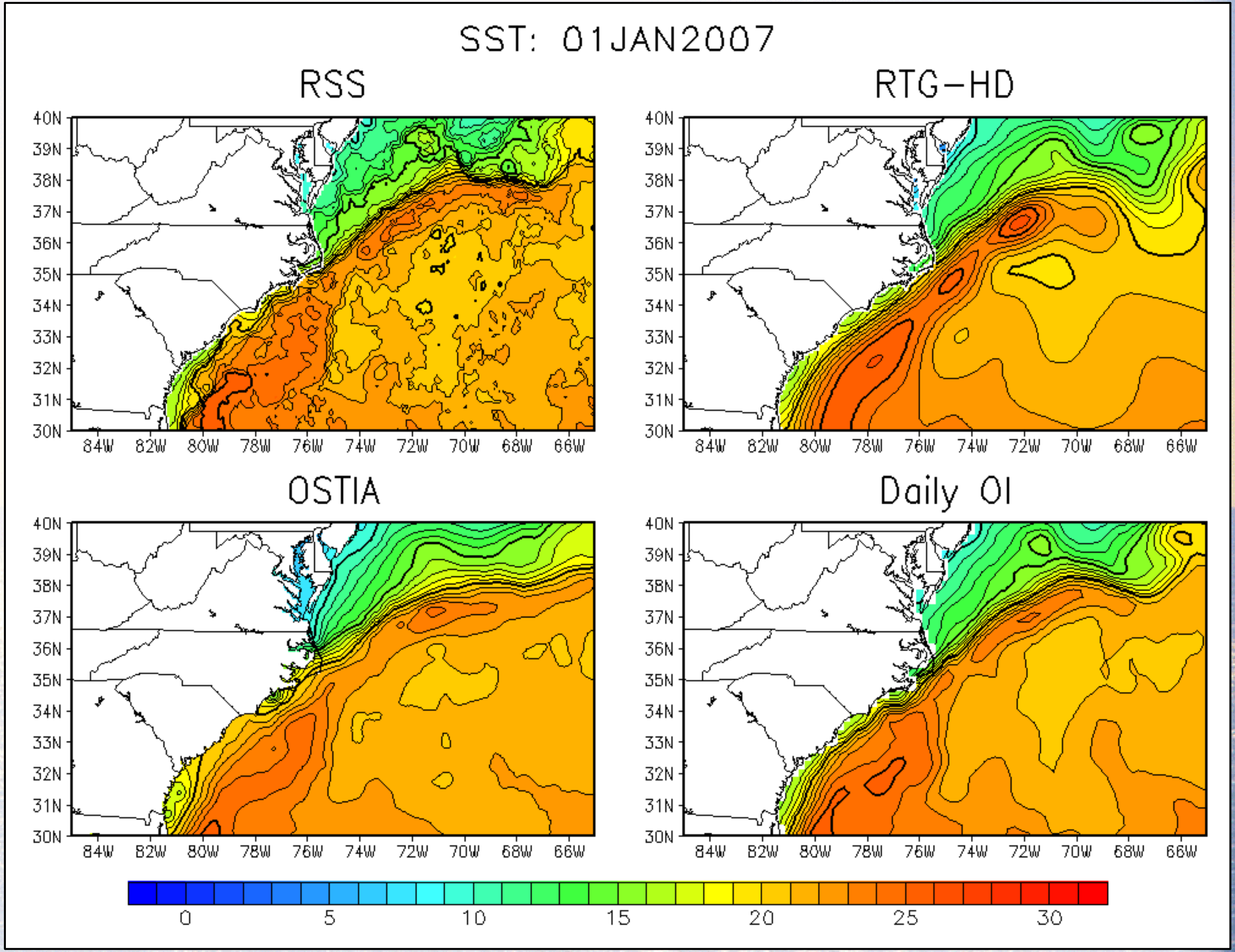
Mediterranean analysis L4

Slide courtesy Jean-Francois Piolle, Ifremer

SST Analyses,1 January 2007

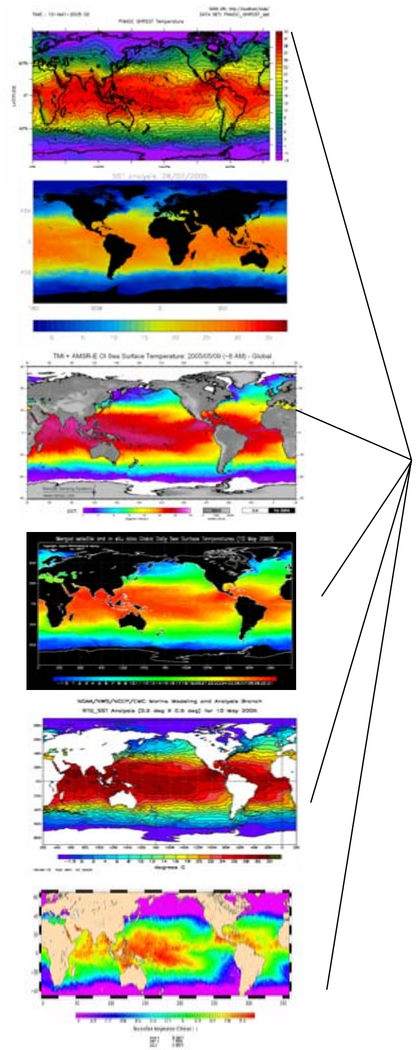
- **RSS OI**
  - (~1/11)° grid
- **NCEP RTG-HD**
  - (1/12)° grid
- **UK OSTIA**
  - (1/20)° grid
- **NCDC Daily OI:** (AMSR + AVHRR)
  - (1/4)° grid

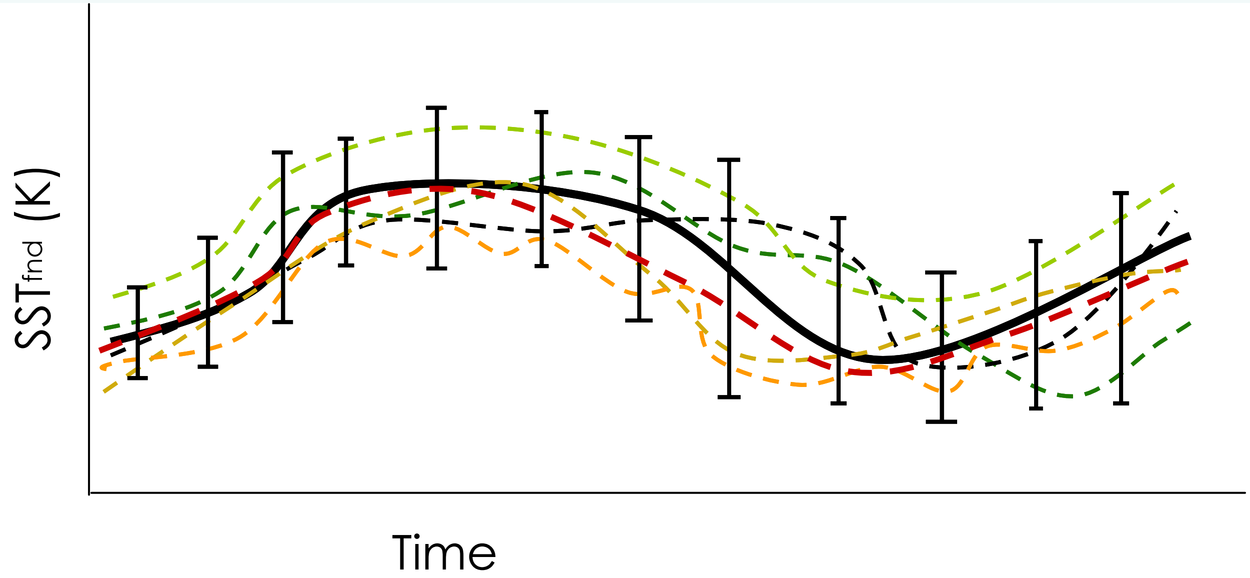
- **This is a daily average**
  - What spatial scales are justified?



Slide courtesy Dick Reynolds, NCDC

Global Multi-Product (L4) Ensemble

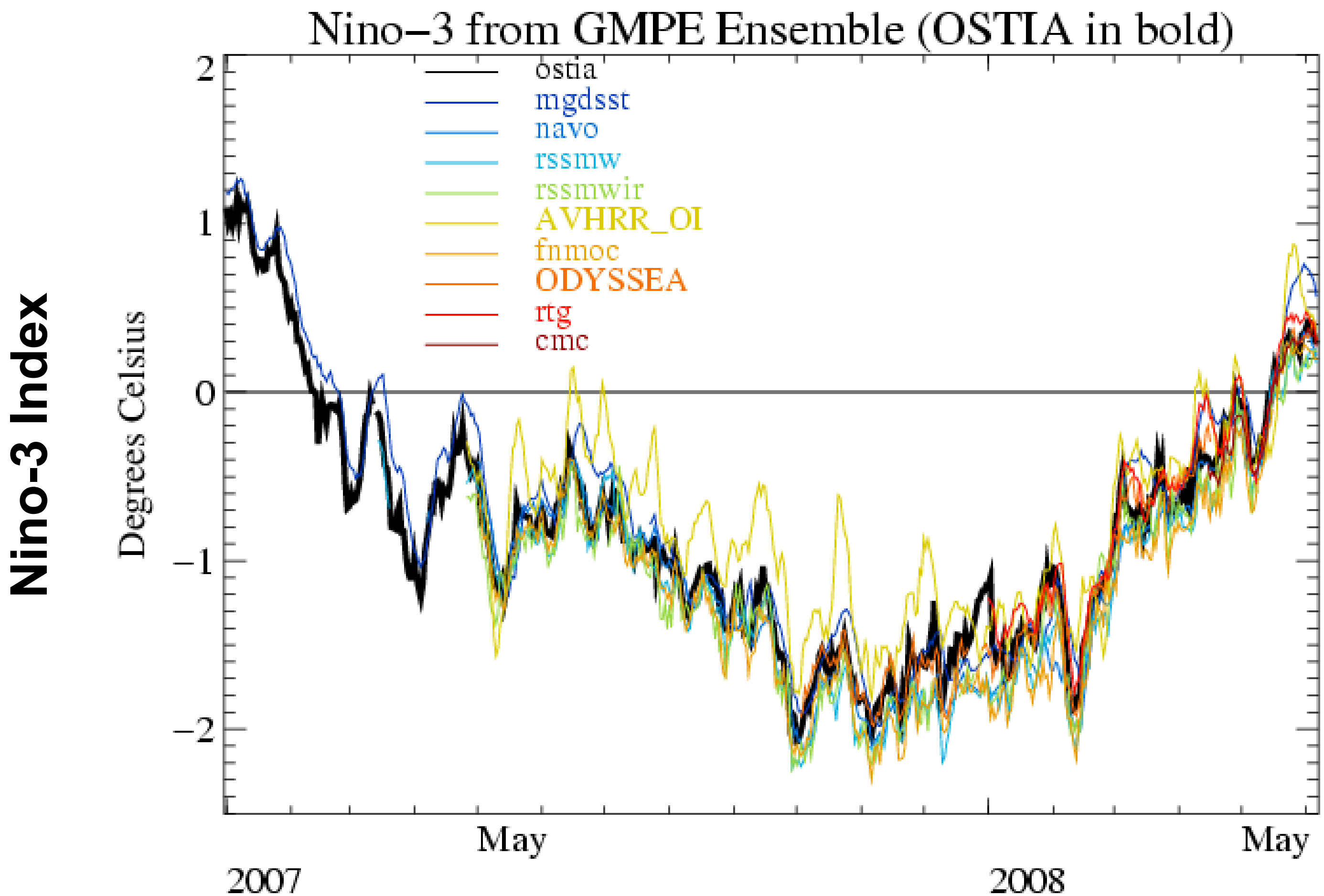




- Optimal way forward - preserves regional autonomy maximises benefits to user community
- Requires a framework to deliver the ensemble product – L4 format descriptor
- Stimulates better products and scientific/production interactions
- GMPE: Verification, Inter-comparisons, Uncertainty estimation and confidence building, NRT climate monitoring

Users :

- Seasonal forecasting:



Slide courtesy John Stark, Met Office

GHRSST-PP
GODAE High Resolution Sea Surface Temperature Pilot Project

Met Office

http://www.ghrsst-pp.org

Summary

- The complementary nature of infrared and microwave data enable exciting new SST products
- Significant issues include compensating for different error characteristics, different measurement times, and different effective measurement depths
- Many new multi-sensor analyzed SST products are now available
- Full intercomparison and accuracy evaluation of these products is now required

AVHRR Uncertainty Sources (3)