Sea Surface Temperature (SST) Analyses for Climate and Their Errors

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Purpose

- Improve the accuracy of the NOAA blended optimum interpolation (OI) SST analysis for climate by using new data

- OI analysis:
  - Computed weekly and monthly on 1° spatial grid for November 1981 to present
  - Uses AVHRR infrared (IR) satellite and in situ (ship and buoy) data
  - Preliminary step corrects any large scale satellite biases with respect to the in situ data
Outline

• PART 1: Determine where new buoys are needed to improve SST accuracy

• PART 2: Determine impact of microwave satellite data on the OI
Errors Discussed

• There are three types of errors
  – Sampling:
  – Random:
    in OI random observation error is
    • Ship \(~1.3^\circ\text{C}\)
    • Buoy \(~0.5^\circ\text{C}\)
    • Day Satellite \(~0.5^\circ\text{C}\)
    • Night Satellite \(~0.3^\circ\text{C}\)
  – Bias: average difference between observation & truth
Buoy Network

• GOAL: Assume required SST accuracy is 0.5°C monthly on 5° spatial grid, everywhere (Needler, et al. 1999, OceanObs’99)

• If random observational error is known, analysis sampling and random errors can easily be computed
  – From OI, Optimum Average (OA), etc.
OA Random & Sampling Error

- OA error uses
  - AVHRR satellite, ship, buoy & sea ice SST data
  - Computed monthly on a 5° spatial grid

- Upper panel: Average OA error
- Lower panel: Largest monthly OA error
- Maximum error < 0.3°C
Random and Sampling Errors - Summary

- OA results show that random plus sampling errors are small $< 0.3^\circ$C
  - This is due to the high density of satellite observations
  - The addition of microwave satellite observations would further reduce these errors in regions with persistent cloud cover
Bias Errors

- **Biases occur with all satellite data** due to instrument and algorithm problems
  - Typical bias: 0.2 to 0.5°C
  - Worst case bias: 2 to 3°C
- There is no convenient algorithm to compute bias
- **We don't know when biases will occur**
- **Biases were computed by simulations** using the monthly NOAA blended OI analysis
  - Spatial empirical orthogonal functions (EOFs) of biases were computed from the differences of the OI with and without the satellite bias correction
OI Analyses following the Mt. Pinatubo Eruptions

- Data used: AVHRR satellite, ship, buoy & sea ice SST data
- Upper panel: OI analyses without satellite bias correction
- Middle panel: analysis with satellite bias correction
- Bottom panel: difference
  - $2^\circ$C is typical maximum magnitude
Bias EOF Modes 1 and 6

- Upper Panel: Mode 1
  - Selected because it is the largest mode, primarily due to Mt. Pinatubo
- Lower panel: Mode 6
  - Selected as the mode with the largest signal near 50°S
  - The signal south of 30°S will usually be underestimated because of limited ship and buoy data there
Simulation of Bias Errors-1

- Determine optimal buoy distribution needed to reduce simulated satellite biases
- OI analysis used with bias correction
  - For Jan 1990 to Dec 2002 with climatology as first guess (FG)
- Define Gaussian Noise Functions, \( a(t) \) & \( b(t) \), with mean of 0 and variance of 1
- Satellite SSTs are simulated at actual data locations
  - Satellite SSTs = FG(t) + Bias(t)
  - where Bias(t) = EOF(i) * a(t), i is the EOF (1-6)
Simulation of Bias Errors-2

- Buoy data are simulated on a regular grid
  - Buoy Grid: 1 buoy per 20°, 18°, 16°, 15°, 14° 12° 10°, 9°, 8°, 7°, 6°, 4° & 2°
  - Buoy SSTs = FG(t) + 0.5°C * b(t), where the buoy random error is 0.5°C

- Compute RMS Differences between the simulated OI and First Guess over time
  - If there were no buoy data, the RMS residual would be equal to the absolute value of the EOF
  - If there were complete buoy and/or ship sampling, the RMS would be 0
Potential Satellite SST Bias Error

- Average of 6 EOF simulations gives a **Potential Satellite SST Bias Error** as a function of buoy density
  - **Potential** is used because if satellite data have no biases, no buoy data are needed
  - By definition the EOFs are scaled so that the potential bias error without buoys is 2°C, a worst case bias error
Number of Buoys on 10° Grid

SST Error (°C)

Potential SST Satellite Bias Error

No Buoys

Goal Exceeded by 2 Buoys on 10° Grid

Goal: 0.5°C

Horizontal Axis converted to buoy density on a 10° grid
"Buoy Equivalent" defined by: Number of Ships/6 + Number of Buoys

Because ships are nosier than buoys, 6 ships equals 1 buoy
Potential SST Satellite Bias Error

- **Upper panel: Global Error**
  - 60°S - 60°N

- **Lower Panel: Zonal Errors**
  - 60°S - 20°S
  - 20°S - 20°N
  - 20°N - 60°N

- Number of buoys needed to reach density of 2 per 10° grid
  - 60°S - 60°N ~ 250 Buoys
  - Buoys needed by zonal band
    - 60°S - 20°S ~ 150 buoys
    - 20°S - 20°N ~ 100 Buoys
    - 20°N - 60°N ~ 0 Buoys

**Goal: 0.5°C**
Part 1: Summary

- Satellite data greatly reduces SST sampling and random errors over ship and buoy data data alone
  - This error is presently below 0.3°C on a monthly 5° spatial grid
- Ship and buoy data are needed to reduce any potential satellite bias errors below 0.5°C
  - Present ship and buoy data distribution is not adequate south of 30°N especially between 60°S and 30°S
  - To reduce satellite bias error, 2 buoys are needed on a 10° grid; This requires 250 additional buoys between 60°S-60°N
Part 2: Microwave and IR SSTs

- **Microwave vs. infrared (IR) satellite data**
  - Microwave can see through clouds while IR cannot
  - Microwave has lower spatial resolution than IR
  - Microwave cannot retrieve data near land

- **Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) produces SSTs**
  - From 38°S to 38°N
  - From December 1997 to present
Use Microwave SSTs in NOAA Optimum Interpolation (OI)

- Compute OI analysis with in situ & satellite data
  - Withhold 20% of buoys to use as independent data
  - Compute weekly OI from 10 December 1997 to 3 January 2003

- Six OI analyses computed
  - 2 groups
    - with satellite bias correction
    - without satellite bias correction
  - 3 analyses within each group
    - TMI only
    - AVHRR only
    - TMI + AVHRR
Weekly OI Anomaly

Average: 30°S-30°N

OI analyses **without** bias correction

- AVHRR only OI has negative bias relative to TMI only OI
  - Roughly -0.2°C
  - Roughly -0.5°C from Oct 2000 - Feb 2001; End of NOAA-14
  - OI weights night AVHRR stronger than day AVHRR

- Combined TMI + AVHRR OI roughly the average of other OI analyses
Weekly OI Anomaly
Average: 30°S-30°N

OI analyses with bias correction

- OI analyses are almost the same
- Large scales biases have been corrected
- Everything is perfect or is it?
Mean and RMS difference

**AVHRR only - TMI only**

**OI with bias correction**

- RMS difference includes both bias and variability but mean gives sign
- Large RMS differences near islands, north of 30°N and south of 30°S, along the coastlines and the equator
- Biases have already been corrected on large spatial scales but residuals remain especially in regions without in situ data

**OI: WITH Bias Correction**

10DEC1997 to 01JAN2003

(AVHRR only: - TMI only:)

**Average Difference**

**RMS Difference**
Distribution of Withheld Buoys

- Moored buoys provide better data
- Drifting buoys provide better coverage
- ID's are reused
- Some regions have little data
AVHRR has negative bias especially during October 2000 - February 2001 – End of NOAA-14 lifetime

TMI has overall positive bias

Combined TMI + AVHRR product has lowest bias

Smoothed Average Weekly Difference

OI – All Withheld Buoys

OI – Buoy Difference: 35°S–35°N
Smoothed over 11 weeks

Oi WITHOUT Bias Correction – Buoy

NOAA-14

NOAA-16

1998 1999 2000 2001 2002 2003

SST (°C)

TMI only: AVHRR only: TMI+AVHRR:
Part 2: Summary

- Satellite data should be bias corrected for use in climate SST analyses such as the OI.
- For the OI with bias correction there is no quantitative advantage or disadvantage of adding TMI to the OI analysis with AVHRR data.
- For the OI without bias correction TMI + AVHRR was better than TMI only or AVHRR only.
  - Bias errors in the two products are independent and often tend to cancel.
- Because there are regions without in situ data and restricted AVHRR coverage due to cloud cover, both TMI and AVHRR should be used in the OI.
Conclusions

- **Potential Satellite SST Bias Errors can be reduced**, especially in the middle latitude Southern Hemisphere, if the buoy density is maintained at 2 buoys per 10° grid
  - 250 buoys are needed

- **Microwave satellite data can improve the SST accuracy** of the OI using only in situ and IR satellite data
  - Because microwave errors and IR errors are independent
  - Because in situ data coverage is not optimal