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

Richard W. Reynolds

Huai-Min Zhang

Thomas M. Smith

National Climatic Data Center

NESDIS, NOAA, Asheville, NC, USA

Chelle L. Gentemann

Frank Wentz

Remote Sensing Systems

Santa Rosa, CA, USA

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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^{o} 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

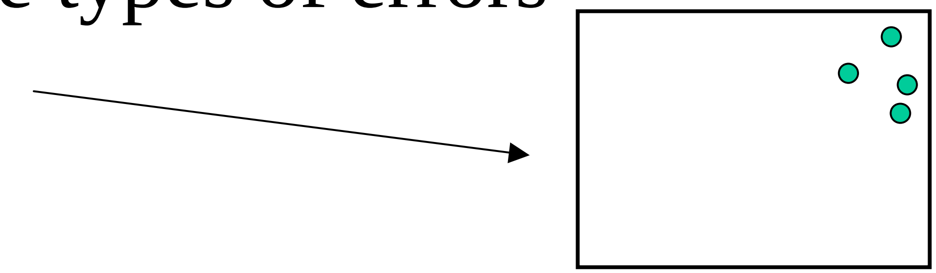
Outline

- 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

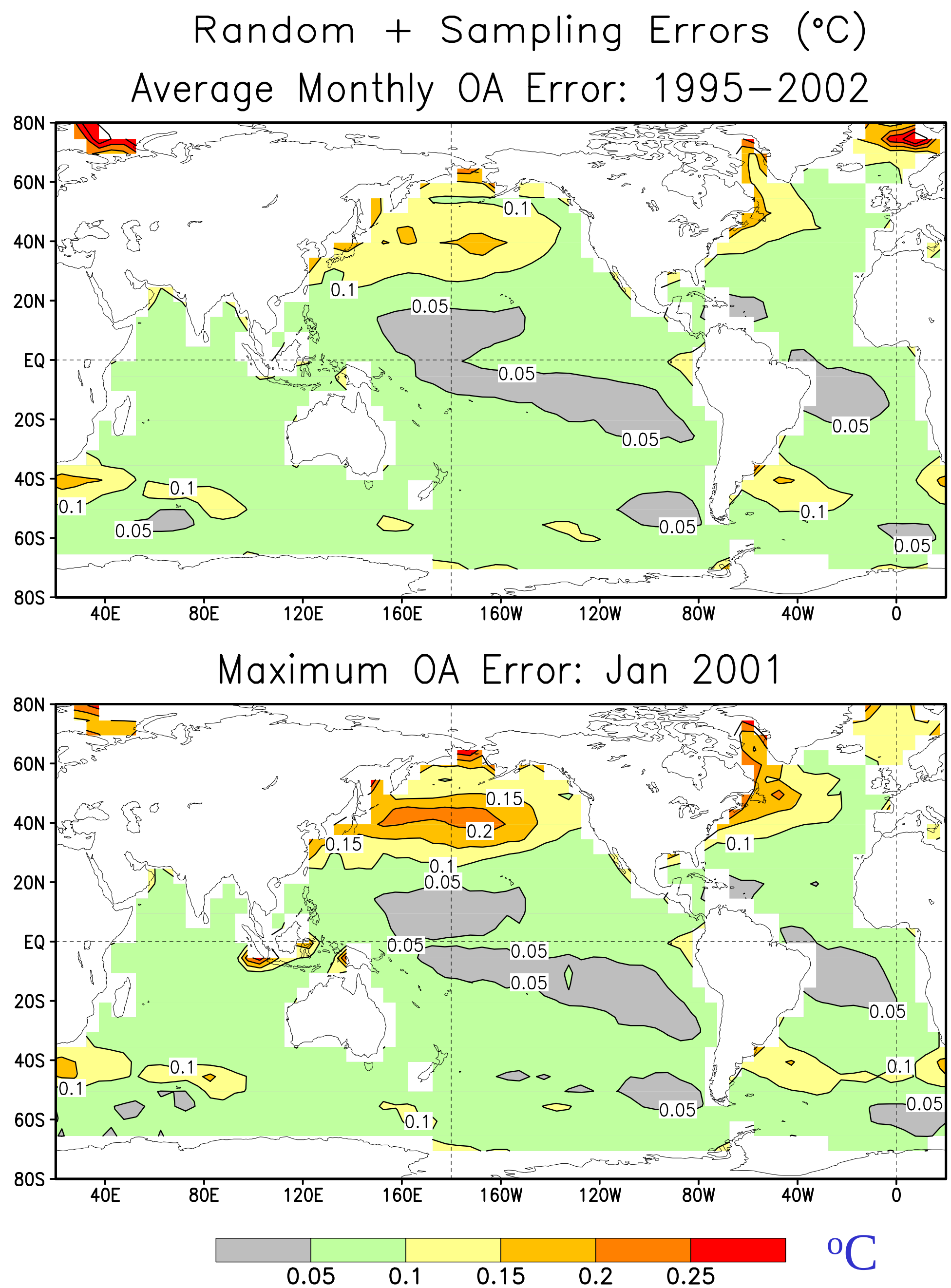
    - Ship ~ 1.3°C
    - Buoy ~ 0.5°C
    - Day Satellite ~ 0.5°C
    - Night Satellite ~ 0.3°C
  - Bias: average difference between observation & truth

Buoy Network

- GOAL: Assume required SST accuracy is 0.5^{o}C monthly on 5^{o} 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^o spatial grid
- Upper panel: Average OA error
- Lower panel: Largest monthly OA error
- Maximum error < 0.3^{o}C



Random and Sampling Errors - Summary

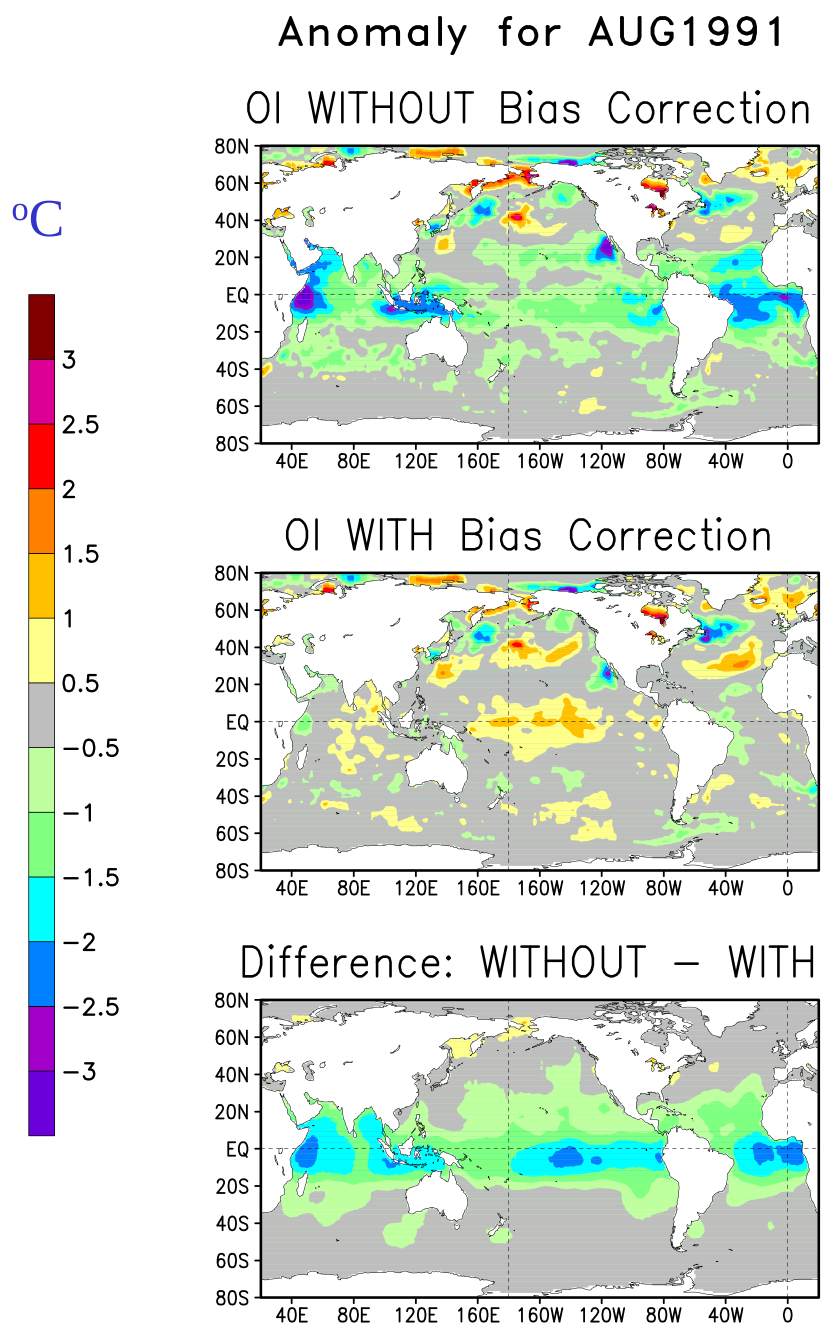
- OA results show that random plus sampling errors are small $< 0.3^{o}C$
  - This is due to the high density of satellite observations
  - The addition of microwave satellite observations would further reduce these errors in regions with persistent cloud cover

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

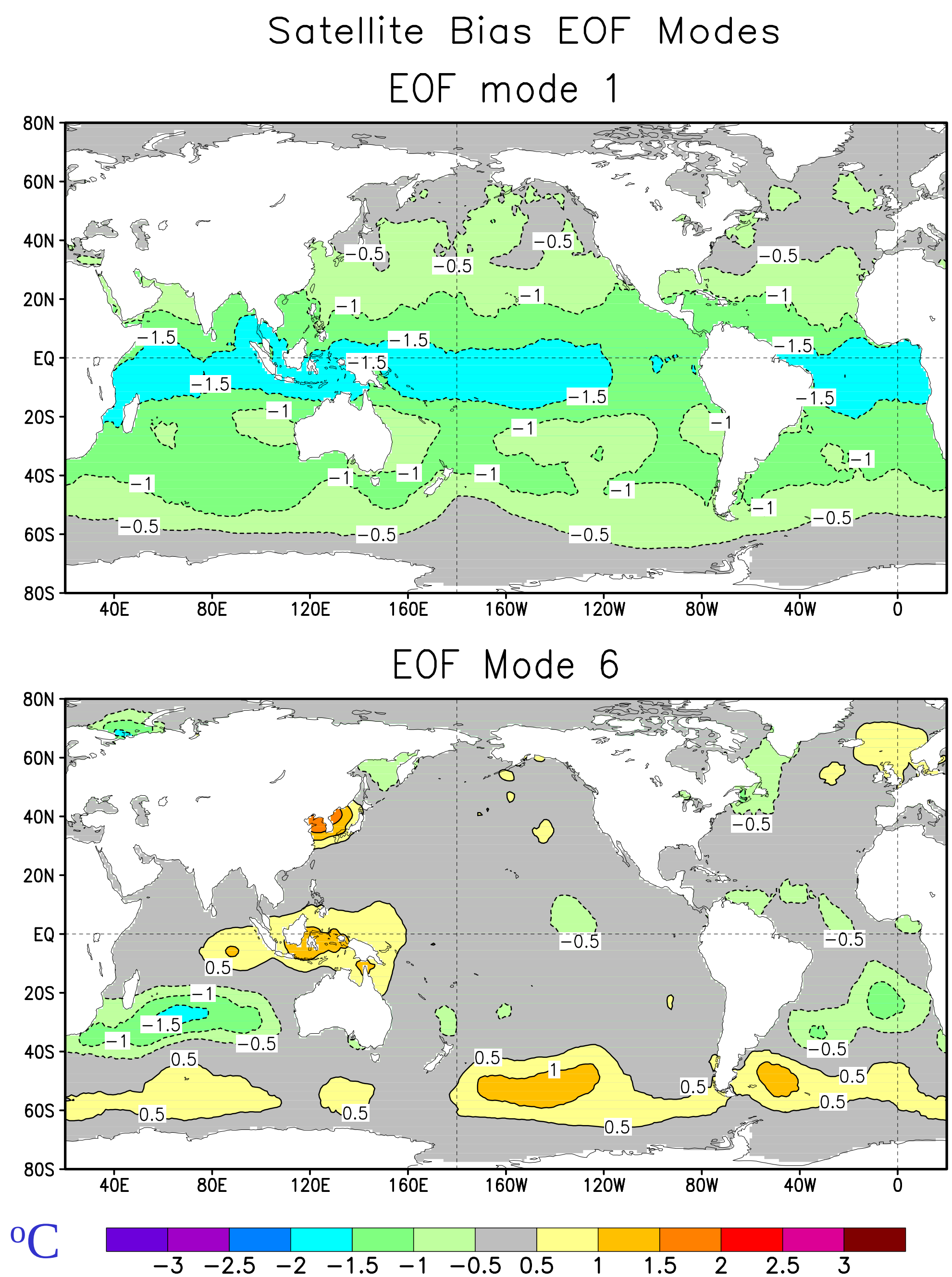
OI Analyses following the Mt. Pinatubo Eruptions

- 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°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^{o}S
  - The signal south of 30^{o}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)

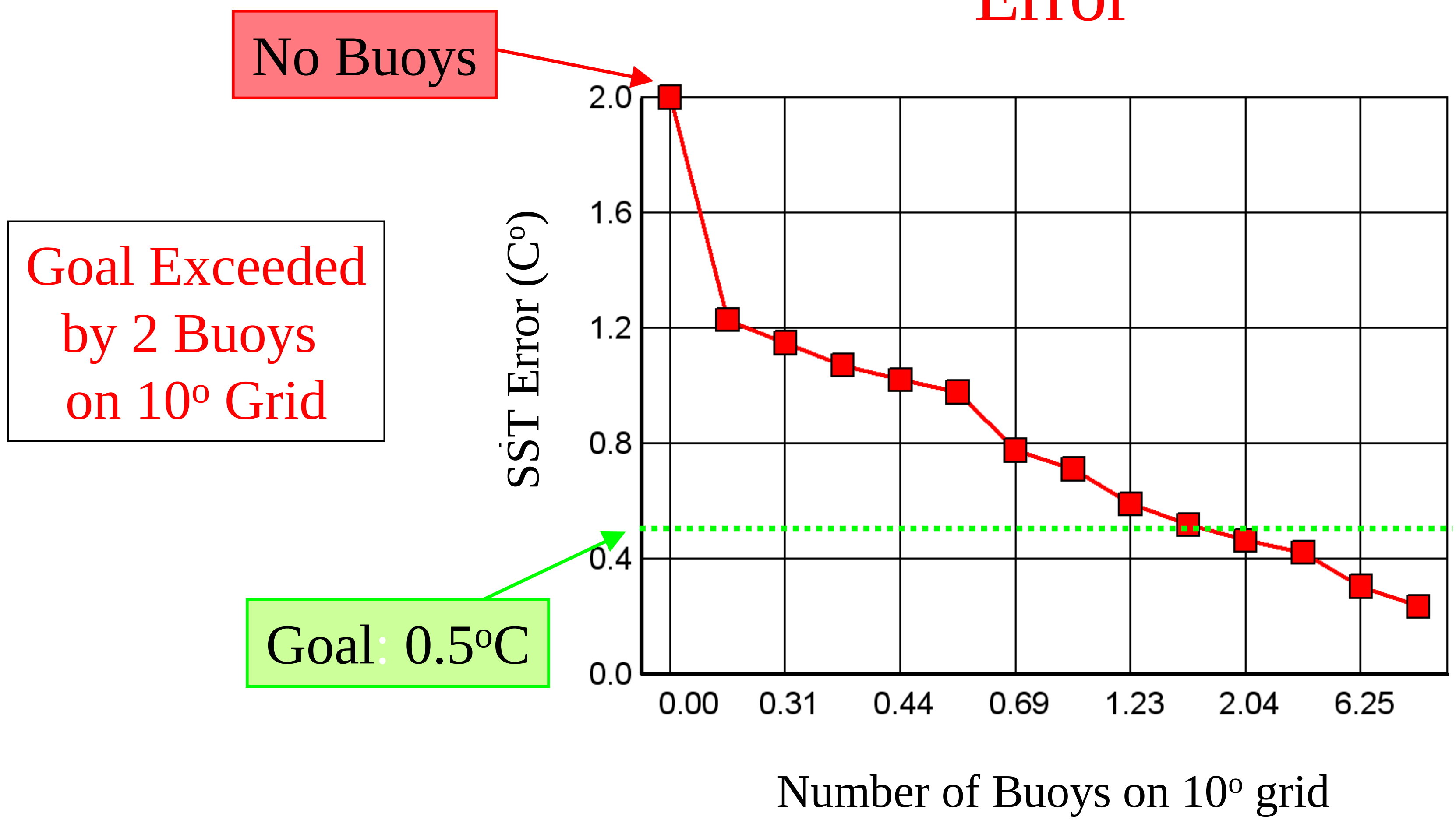
Simulation of Bias Errors-2

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

Potential SST Satellite Bias Error

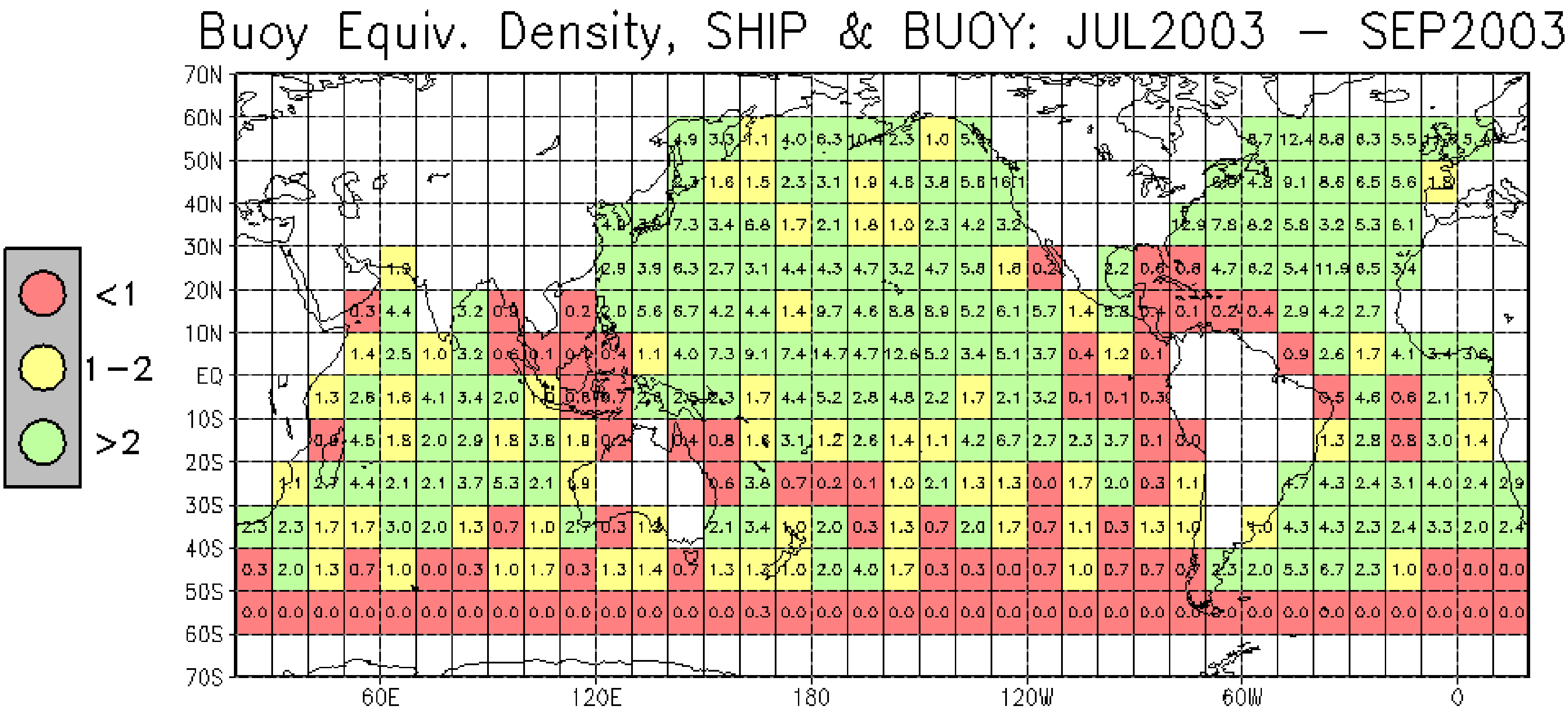


Horizontal Axis converted to buoy density on a 10° grid

Buoy Equivalent Density

"Buoy Equivalent" defined by: Number of Ships/6 + Number of Buoys

Because ships are nosier than buoys, 6 ships equals 1 buoy

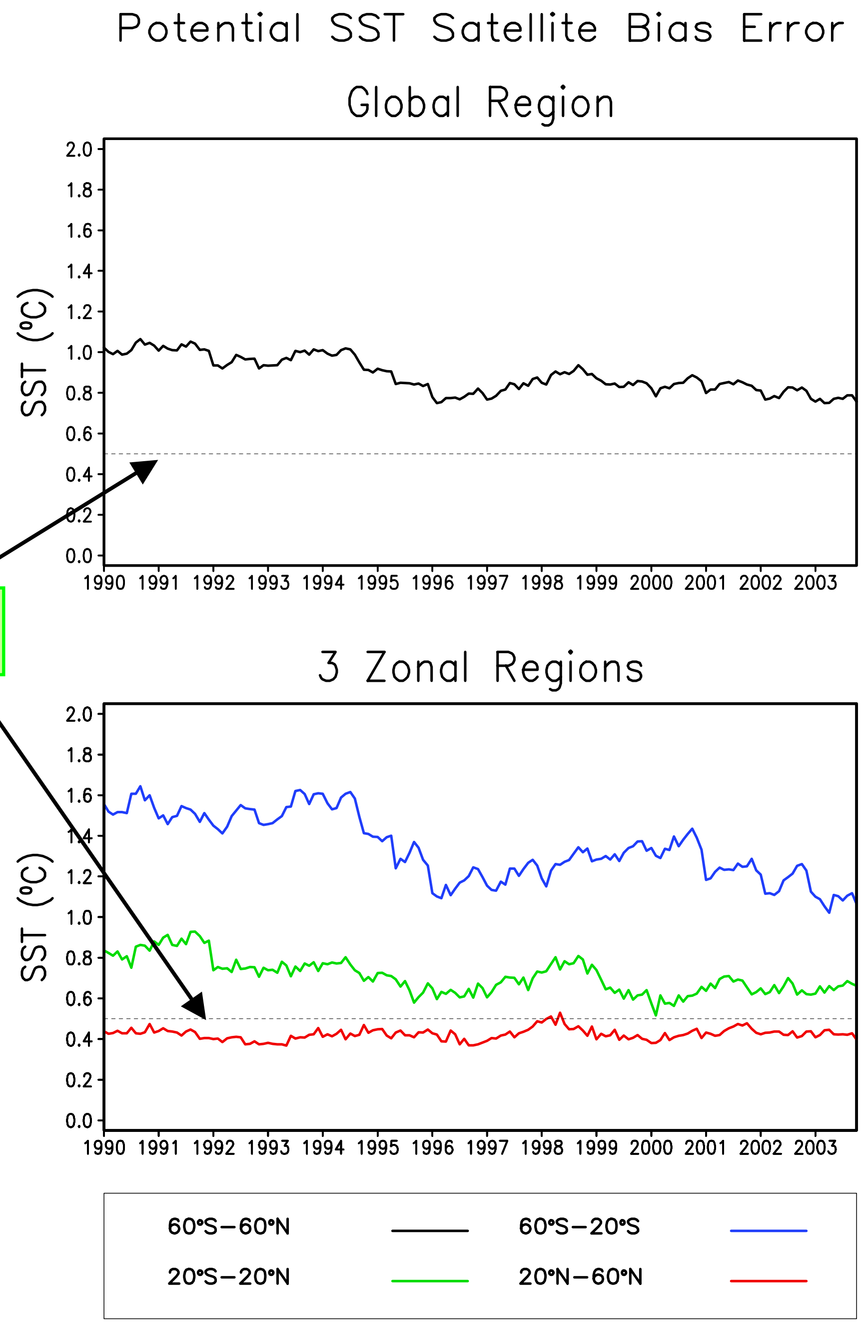


Potential SST Satellite Bias Error

- Upper panel: Global Error
  - 60°S - 60°N
- Lower Panel: Zonal Errors
  - 60°S - 20°S
  - 20°S - 20°N
  - 20°N - 60°N

Goal: 0.5°C

- 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



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^{o}C on a monthly 5^{o} spatial grid
- Ship and buoy data are needed to reduce any potential satellite bias errors below 0.5^{o}C
  - Present ship and buoy data distribution is not adequate south of 30^{o}N especially between 60^{o}S and 30^{o}S
  - To reduce satellite bias error, 2 buoys are needed on a 10^{o} grid; This requires **250** additional buoys between 60^{o}S-60^{o}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^{o}S to 38^{o}N
  - From December 1997 to present

Use Microwave SSTs in NOAA Optimum Interpolation (OI)

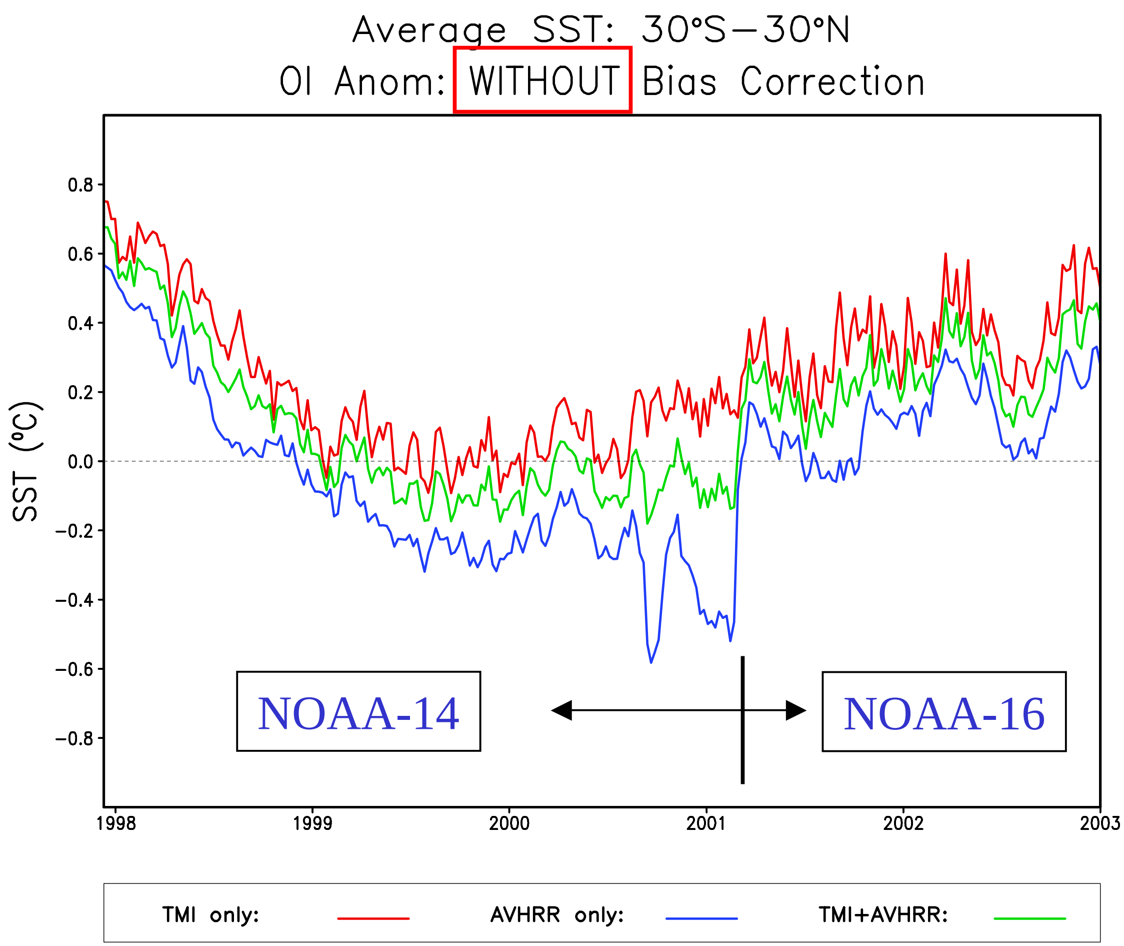
- Compute OI analysis with in situ & satellite data
  - Withhold 20% of buoys to use as independent data
  - Compute weekly OI from 10 December 1997 to 3 January 2003
- Six OI analyses computed
  - 2 groups
    - **with** satellite bias correction
    - **without** satellite bias correction
  - 3 analyses 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

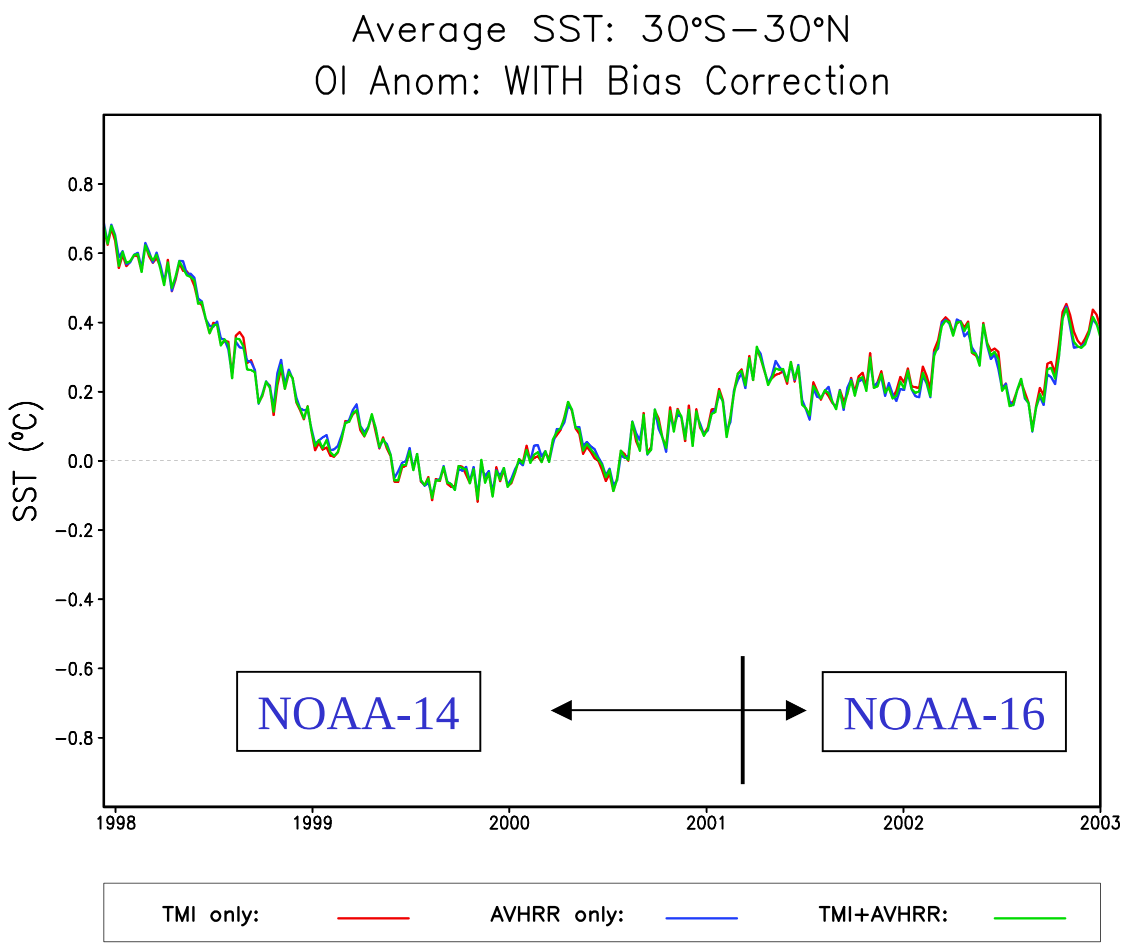


Weekly OI Anomaly

Average: 30ºS-30ºN

OI analyses **with** bias correction

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

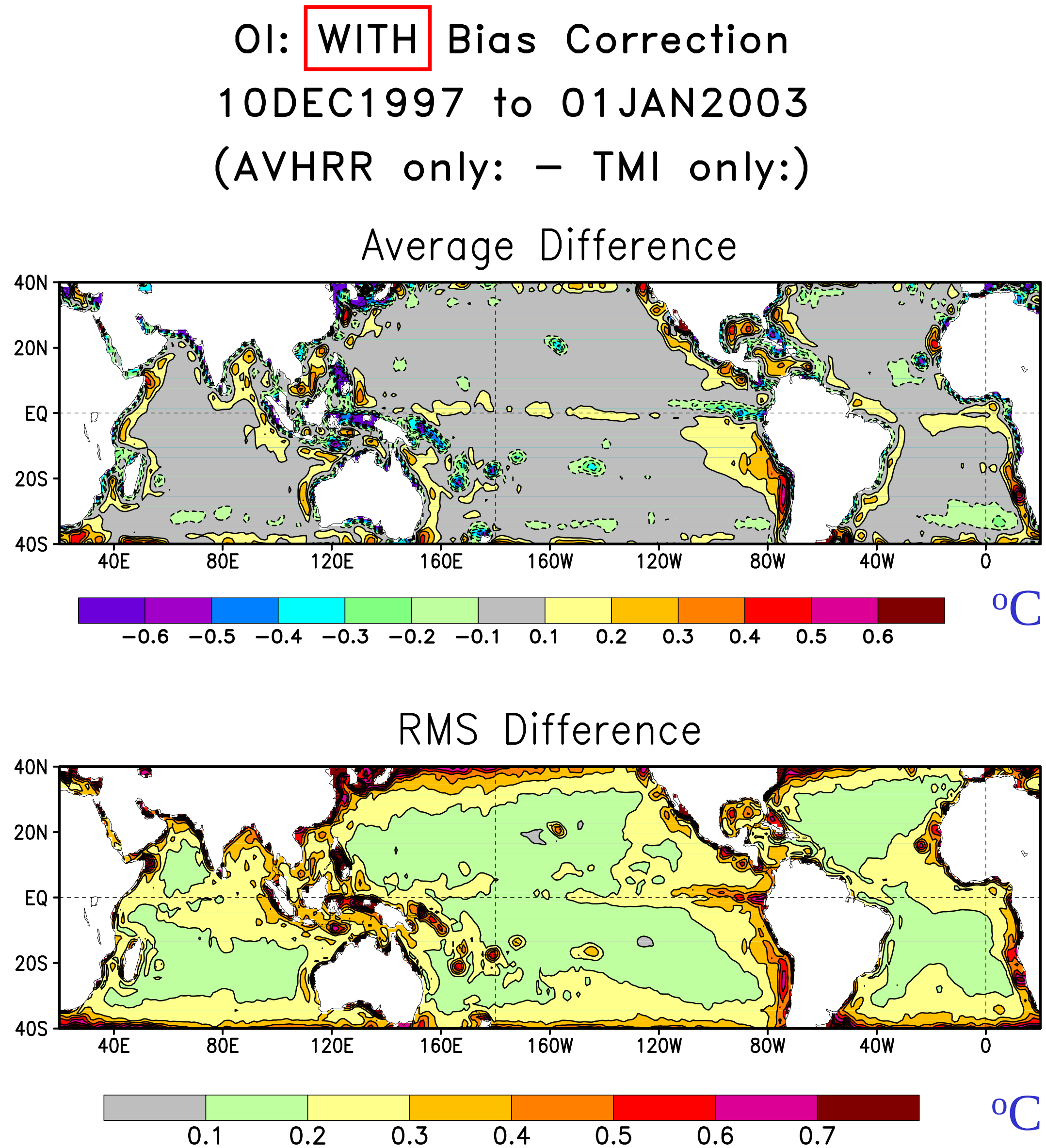


Mean and RMS difference

AVHRR only - TMI only

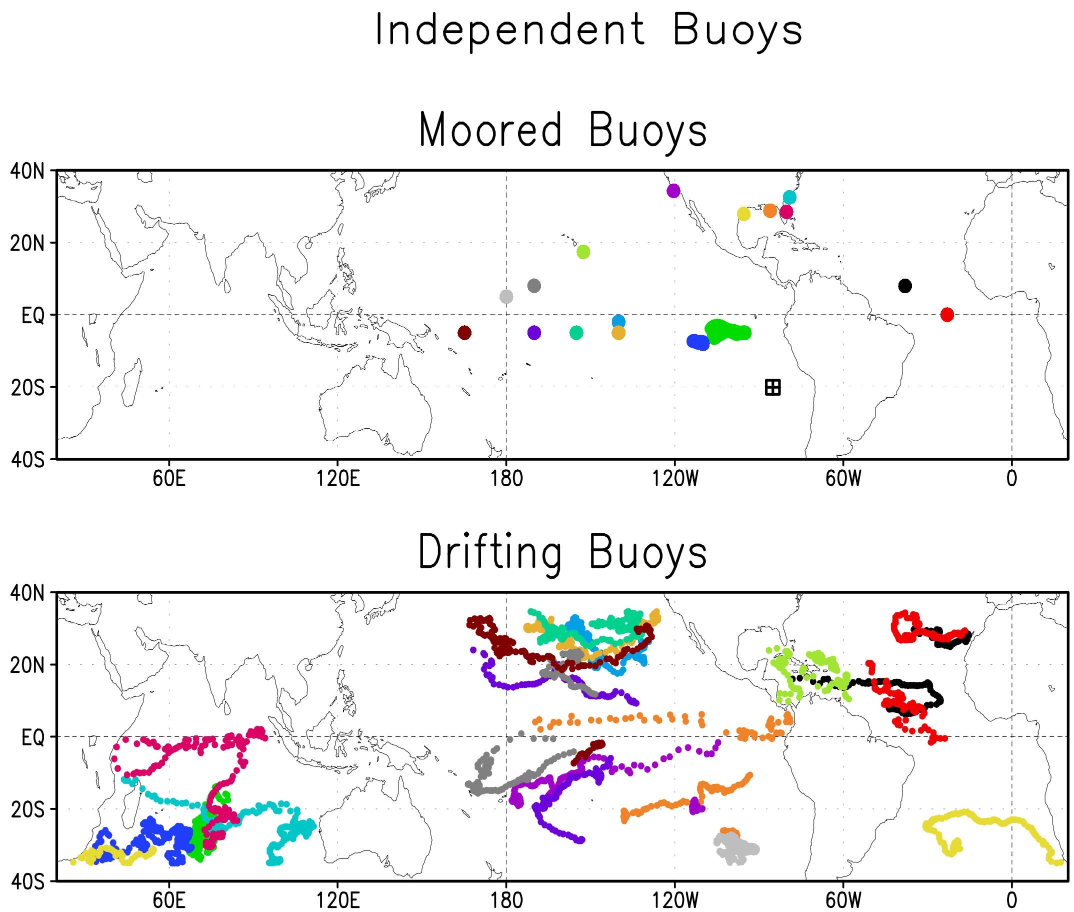
OI **with** bias correction

- 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



Distribution of Withheld Buoys

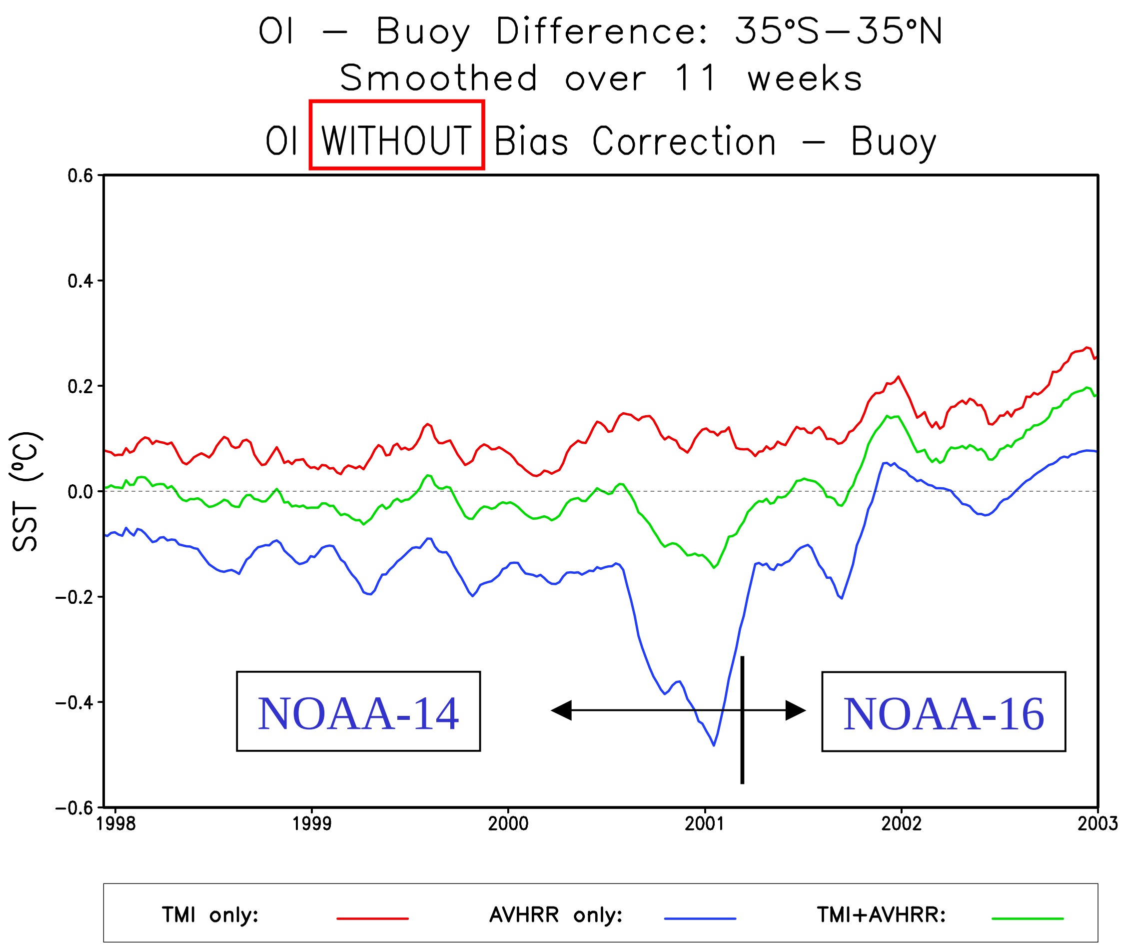
- Moored buoys provide better data
- Drifting buoys provide better coverage
- ID's are reused
- Some regions have little data



Smoothed Average Weekly Difference

OI – All Withheld Buoys

- 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



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^{o} 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