Satellite Sea Surface Temperature Observations of Ocean Processes

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Credits

- Thanks to the many friends and colleagues who have contributed slides!
  - Ian Robinson
  - David Llewellyn Jones
  - Sean Lawrence
  - David Smith
  - Chelle Gentemann
  - Ralph Rayner
  - Rosa Barcelia-Fernandez
  - Dudley Chelton
  - Adrian Hines
  - Matt Martin
  - John Stark
  - Dick Reynolds
  - Llars Anders Brevik
  - Soren Anderson
  - Ken Casey
  - Anne O’Carroll
Outline of lecture

• Why use satellites to observe ocean processes?
• What are we measuring on the mesoscale resolution?
• Why do we want to merge complementary SST data sets?
• What SST can we measure at global scales?
• What processing steps can be used on global data to reveal new features?
70% Earth’s surface covered by water

The final frontier…

“If I were to choose a single phrase to characterize the first century of modern oceanography, it would be a century of under-sampling.”

Walter Munk, Woods Hole Oceanographic Institute, 2000
Measuring the ocean SST

AMSR-E Sea Surface Temperature: 3-days ending 2004/09/28 - Global
One more word on in situ data...used to calibrate & validate satellite data

The modern drifter consists of a surface buoy and a subsurface drogue (sea anchor), attached by a long, thin tether. The drogue dominates the total area of the instrument and is centered at a depth of 15 meters beneath the sea surface.
Global and regional coverage

- **METOP**
  - AVHRR GAC (9km)

- **AMSRE**
  - (25/12km)

- **TRMM/TMI**
  - (25km)

- **N-17/18**
  - AVHRR LAC (1km)

- **MSG**
  - (5/10km)

- **AATSR**
  - (1km)
• Polar Orbiting infrared has *high accuracy & spatial resolution*
• Geostationary infrared has *high temporal resolution*
• Microwave Polar orbiting has *all-weather capability*
• In situ data provide *reality in all weather conditions*
Temporal sampling bias

- Only Microwave SST provides temporally unbiased sample as the IR data are obscured by seasonal clouds

(Figure: L. Guan)
What does High Resolution mean?
NESDIS 50km -> 9km -> 4km

Great Barrier Reef, Australia

Seen in 4km Data SST…

(K Casey, NOAA-NODC)
Different Global SST analysis products

<table>
<thead>
<tr>
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<th>Reynolds</th>
<th>RTG</th>
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What is the truth??

(Reynolds & Chelton, in press)
IR sensors: High spatial and radiometric resolution (AATSR)

Means for period Aug 02 – Aug 03:
- all: 0.05 K (σ 0.41 K)
- night: 0.07 K (σ 0.35 K)
- day: 0.03 K (σ 0.46 K)

AATSR is now considered a Reference data stream
Satellite SST maps provide insight to mesoscale variability

Mesoscale variability represents the 2-dimensional ocean turbulence
   The cause of the randomness of surface drifter tracks

- It is a source of energy for mixing in the ocean
  - Enhancing nutrient supply to the upper ocean
  - Ventilating below the thermocline
- It is a source of sampling "noise" when mapping ocean properties on the large (e.g. basin) scale
  - Creates problems for interpreting locally and sparsely sampled data
- Mesoscale variability grows out of the major ocean fronts
  - Contributes to cross-frontal transports of heat, etc.
- Ocean eddies allow strong heterogeneity to persist
  - Strong local fronts can form around the eddies
- Satellite SST observations are great for looking at mesoscale variability!
A mesoscale eddy in the South Atlantic

Apparent sea surface temperature in the South Atlantic from an infra-red sensor

Cooler            Warmer

The image size is 500 x 500 km.

The data set consists of 1/4 million precise measurements of temperature.
Gulf of Tehuantepec, Mexico

MODIS (Aqua)

15 November 2004
• Merged analysis product
• Galapagos islands
• Wind Jet
• Upwelling regions
Gulf of Lions Upwelling/deep water formation

- Cold dry Mistral wind blows over the Gulf of Lions cooling the surface
- Water becomes gravitationally unstable and sinks with convection
Thermal Front analysis (26/09 2/10 2007)

Major fronts around UK

Fronts + SST background
Fisheries Disaster associated with exceptional cold water intrusion into the Peng-Hu (Taiwan Strait). Economic fishery losses estimated at ~NT$350 million (US$11 million) in February 2008.

(Ming-An Lee, Kuo-Tien Lee, Y Chang and Kuo-Wei Lan National Taiwan Ocean University)
Gulf Stream meanders
Aqua MODIS
Mesoscale feature analysis

- SST gradients are quasi-stationary (in some places) due to topography
- Gulf stream is a classic
- Thus, even limited AVHRR data are useful in analysis systems!

Gradients in Daily OI using AMSR-E for January - March 2003

Credit: Tom Smith and Dick Reynolds, NCDC
Monthly SST composites SST

Monthly mean SST data from the NASA “Pathfinder” analysis for 1996. The spatial resolution is 9 km.
L4 Analysis issues

- Gradients propagate in other places
- In this case, limited data are not as useful
- Monthly averages wipe out gradients

Gradients in Daily OI using AMSR-E for August - October 2003

Credit: Tom Smith and Dick Reynolds, NCDC
TMI (microwave)-derived SST, (3-day maps ~ Sep)

From Caltabiano PhD thesis, 2005
Hovmöller Plots from TMI

From Caltabiano PhD thesis, SOC, 2005
Filtered (Radon transform) Hovmöller Plots from TMI

Tropical Instability Waves (TIW)

From Caltabiano PhD thesis, 2005
SST to observe Mesoscale processes

- **Mesoscale eddies**
  - Location and movement, evolution and decay time
  - Fine scale structures and evidence of mixing processes

- **Location of ocean fronts**
  - Only the surface outcrop is detected
  - A time sequence shows frontal meanders & cross-frontal intrusions

- **Upwelling**
  - Coastal upwelling under suitable wind conditions
  - Related to nutrients, productivity and fisheries
  - Evidence of filamentary structures, mixing and transport processes

- **Note! some mesoscale features may be hidden**
  - Patterns in the surface mixed layer may not be coupled to mesoscale thermocline structures
  - Diurnal thermocline and skin effect may hide the mixed layer
Definitions of SST

- Depth:
  - 10 μm
  - 1 mm
  - 1 m
  - 10 m

- SSTskin – SST10m (K):
  - ΔTskin
    - ~0 - 0.5K

- SSTskin
- SSTsubskin
- SSTdepth
- SSTint
- SSTfnd

(a) Night time situation, light wind

ΔTdiurnal
- ~0 – 4.0K
Measurements of SST: Diurnal thermocline

Day time time situation, strong solar radiation and light winds

Can’t measure ($\delta T < 1\text{s}$)

Infrared sensors ($\delta T \sim 10\text{s}$)

Microwave Sensors ($\delta T \sim 10^+ \text{s}$)

Contact thermometers
Ships/Buoys ($\delta T \sim \text{minutes}$)

Contact thermometers
Ships/Buoys ($\delta T \sim \text{hours}$)

SSTint
SSTskin
 SSTsubskin
SSTdepth
SSTfnd
Arabian Sea WHOI Mooring Data - Spring 1995

(1mm data estimated using Fairall et al. (1996))

Temperatures at all depths collapse to the same value before local sunrise

SSTfnd (Foundation Temperature)
Importance of the diurnal thermocline

- Develops during the day
  - Surface temperature 0.5 to 1 K warmer in the early afternoon than the previous or subsequent night. Max amplitude >5 K
- Varies with meteorological conditions
  - Strongest in summer (longer and more direct solar heating).
  - Strongest in calm conditions.
- Spatially variable within large areas
  - Patchiness on daytime images - the so-called ‘afternoon effect’...
  - Masks underlying meso-scale mixed-layer temperature patterns.
- Introduces a warm bias to SST records
  - Eliminate by using only night-time images,
  - Or ignore daytime images under particular conditions,
  - Or predict and correct for the effect (difficult to do confidently).
- You MUST consider diurnal variability when using satellite SST data!
SST features in shelf seas (North Sea)

A and B are examples of diurnal warming
Atlantic Basin scale variability
Figure 17. Cloudiness over (top) warm-core and (bottom) cold-core rings during the QuikSCAT period.

Figure 7. Component of scatterometer winds along the mean wind direction, in ring-centric coordinates rotated such that mean wind is upward in the figure. Data are binned by mean wind speed, data set, and type of ring, and averaged across all rings.

(D. Chelton and Park et al, 2006)
SST at larger scales

• Applications to large scale oceanography exploit the unique benefits of satellite data
  - Global coverage with good spatial detail
  - Repeated coverage over many years
  - A consistent view from the same sensor
  - Opportunity to combine data from different sensor types

• Special data analysis methods for time series of large scale images
  - Creating climatologies
  - Producing anomalies
  - Hovmöller plots

• A new look at large scale ocean phenomena
Monthly mean Satellite SST: 1997

Monthly mean SST data from the NASA “Pathfinder” analysis for 1997. The spatial resolution is 9 km.
Using GMPE: Arctic Sea Ice retreat and Ensemble Median SST anomaly
May - Nov 2007

Ensemble Median SST for 20070501
Median SST anomaly for 20070501

SST (C)
Sea Ice Conc. (%)

Anomaly (K) referenced to Reynolds OIv2.0 from EUMETSAT OSI-SAF SST 1985-2000
Significant differences existed between ensemble members SST errors led to increased errors in NWP and ocean forecasts

OSTIA minus ensemble

RTG minus ensemble

Resulted in operational implementation a new SST analysis at the Met Office called OSTIA
• Old NWP SST didn’t capture the warming.

OSTIA – climatology

OSTIA – NWP SST

NWP Bias 925hPa, 48hr forecasts
Ocean processes from Space

• Climatology of the oceans
  - Observe the whole world ocean at once
  - Isolate the seasonal cycle
  - Identify long term fluctuations or trends
  - Look for characteristic patterns of ocean behaviour

• Large scale propagating features
  - El Niño/La Niña
  - Tropical instability waves
Making Seasonal climatologies from an image time series

Instead of using monthly averages, we can use any interval, e.g. 3 days, 8 days, as long as the same calendar interval is used from each year.

(Note: Ideally the climatology should also map the standard deviation)

(I Robinson)
Generating Anomaly Datasets for SST or other variables

Composite SST map for a specific period e.g. days 172-176 in 2005

Select the data for days 172-176 from the N-year climatology
(Note that the period must match the way the climatology is constructed.)

Subtract relevant climatology from SST map.

Anomaly for days 172-176 in 2005

(I Robinson)
Example OSTIA SST and Anomaly (1985-2001)

• Satellite instruments provide the best spatial and temporal coverage of SST capturing beautiful mesoscale structures
• Satellite SST measurements are complex at and you need to consider the vertical structure of the surface layer
• The diurnal variability of SST is a significant challenge to the interpretation and application of SST observations
• Use Surface wind information with satellite SST measurement data sets!!
• Regional high resolution maps of SST are available from a number of different satellite instruments and contain information in their own right
• Combined analysis products must account for diurnal variability and bias corrections
• Always remember these are not pictures but measurements - millions of them!!!
• We can look at details this afternoon.
Thank you
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Any questions?