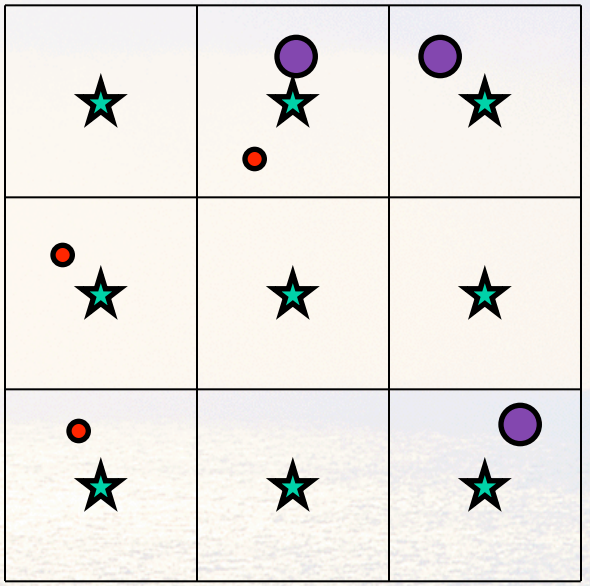
Objective Determination of Feature Resolution in an SST Analysis

Richard W. Reynolds (NOAA, CICS)

Dudley B. Chelton (Oregon State University)

What is an Analysis?

- An analysis is a field produced on a regular grid (★) usually using irregularly spaced data
- The data (•,●) are weighted by distance to the analysis point and by a noise-to-signal ratio



Input SST Data

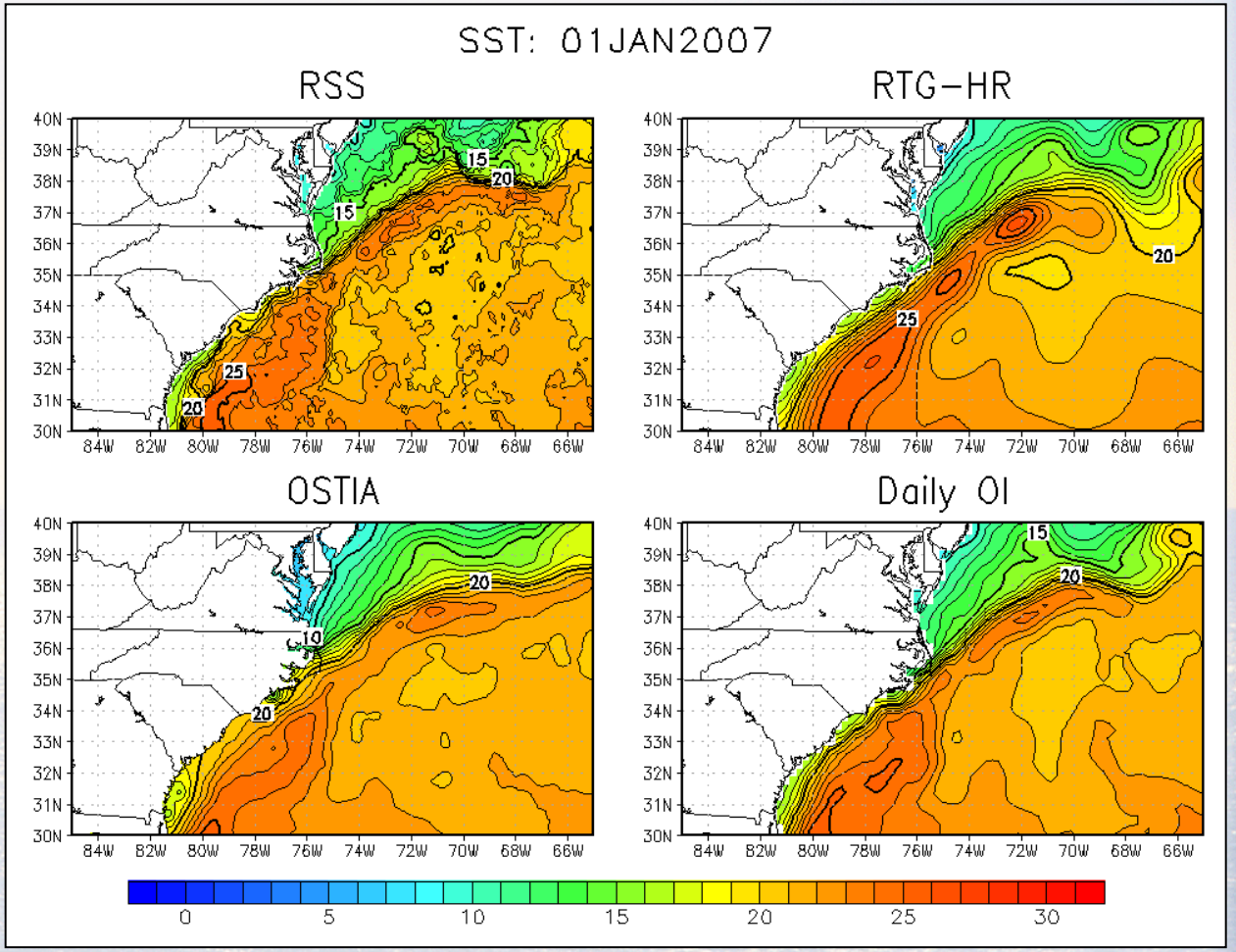
- In situ data: directly measured SST observations from ships and buoys
- Remotely sensed satellite Infrared SSTs
  - 1-9 km resolution
  - Observations must be cloud free
  - E.g., AVHRR (1981-present)
- Remotely sensed satellite Microwave SSTs
  - 50 km resolution
  - Observations can be made through clouds but must be precipitation free
  - E.g., AMSR (2002-present)

Background

- GHRSST (The Group for High Resolution SST) includes many high resolution SST analyses
  - There are differences in input data, grid resolution, analysis procedures
  - There are important differences in analyzed SSTs and analysis resolution
- Reynolds and Chelton compared 6 SST analyses for 2006-08 to try to identify analysis problems and determine whether any of the analyses are superior

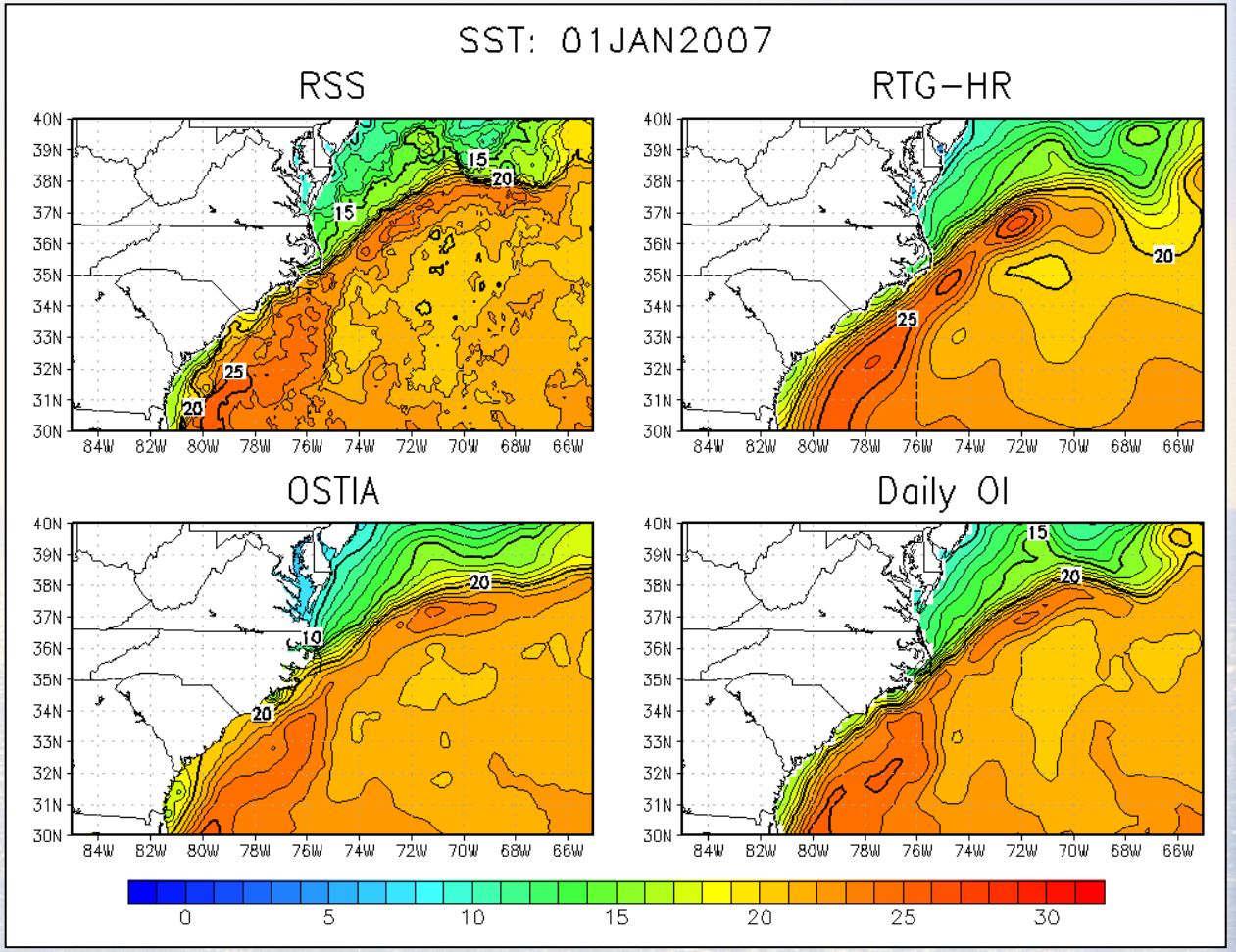
SST Analyses, 1 January 2007

- **RSS OI**
  - **(~1/11)° grid**
- **NCEP RTG-HR**
  - **(1/12)° grid**
- **UK OSTIA**
  - **(1/20)° grid**
- **NCDC Daily OI: (AMSR + AVHRR)**
  - **(1/4)° grid**
- **Spatial scales differ**
- **Differences can exceed 5°C off coast**



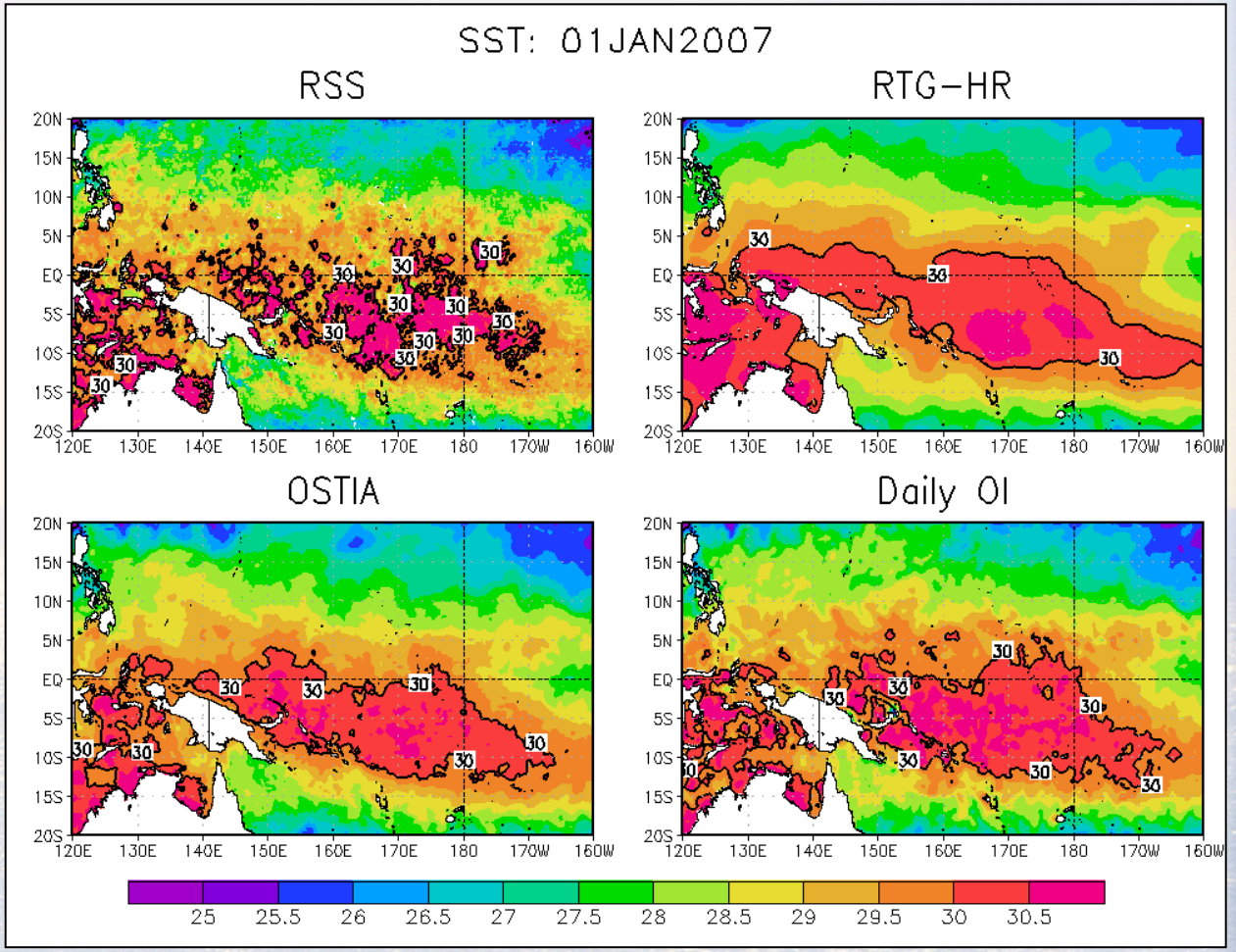
SST Analyses, 1 January 2007

- **RSS OI**
  - **(~1/11)° grid**
- **NCEP RTG-HR**
  - **(1/12)° grid**
- **UK OSTIA**
  - **(1/20)° grid**
- **NCDC Daily OI: (AMSR + AVHRR)**
  - **(1/4)° grid**
- **Spatial scales differ**
- **Differences can exceed 5°C off coast**



SST Analyses, 1 January 2007

- **RSS OI**
  - **(~1/11)° grid**
- **NCEP RTG-HR**
  - **(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?**



Results

- There is no clear correlation between resolution and spatial grid size
  - GHRSST and other analysis producers emphasize grid resolution over actual analysis resolution
  - Users are confused about the difference
- If the analysis resolution is pushed beyond the spatial and temporal resolution of the data: the apparent SST signal is simply just noise
- How can we objectively define the analysis resolution?

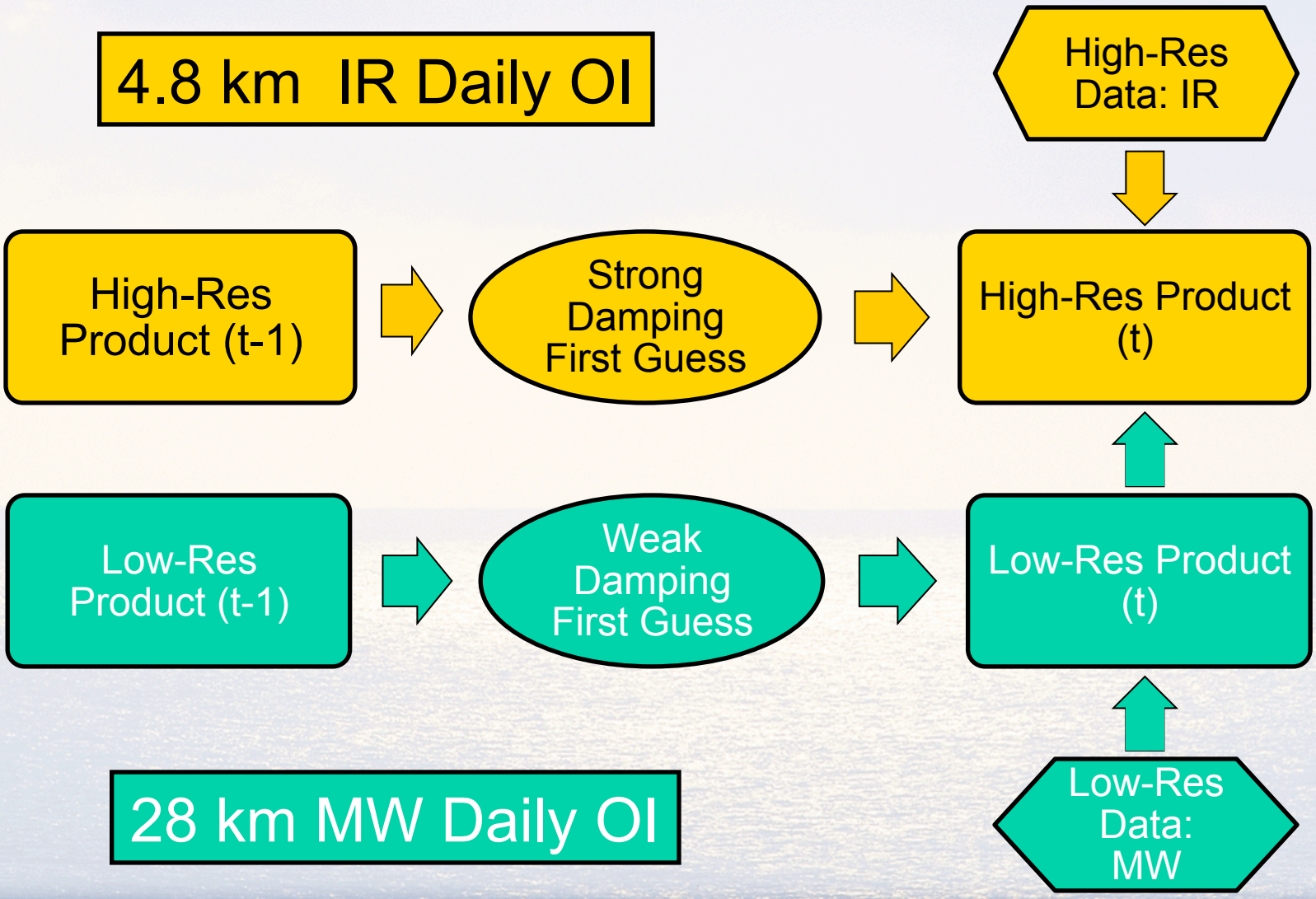
Experiments with Synthetic Data

- Analyze the complete SST fields produced by an ocean general circulation model (OGCM) on a high-resolution grid over a given time period
  - Assume these fields are "truth"
  - Sub-sample the full SST field using actual satellite observation times and locations
- Use the full and sub-sampled (reduced) SST fields as "Data"
- Produce SST analyses of the full and reduced SST data sets
  - Compare the results

SST from ECCO2 is "Truth"

- 1/16° OGCM (courtesy Dimitris Menemenlis)
  - Estimating the Circulation and Climate of the Ocean, Phase II (ECCO2) ocean model
  - Horizontal model grid : 6.9 km at equator; 4.9 km at 45° lat
- Use model SST data for 2 daily periods
  - January 1993; July 1993
- Use AMSR and Pathfinder AVHRR data coverage (day plus night) for 2 daily periods
  - January 2004; July 2004
  - Note: Actual AMSR and AVHRR SSTs are NOT used
  - Linearly interpolate model SSTs to pathfinder v5 grid (4.8 km at equator) for simulated high-res AVHRR data
  - Smooth model SSTs to 50 km and average on 1/4° grid (27.8 km at equator) for simulated low-res AMSR data

Two Stages

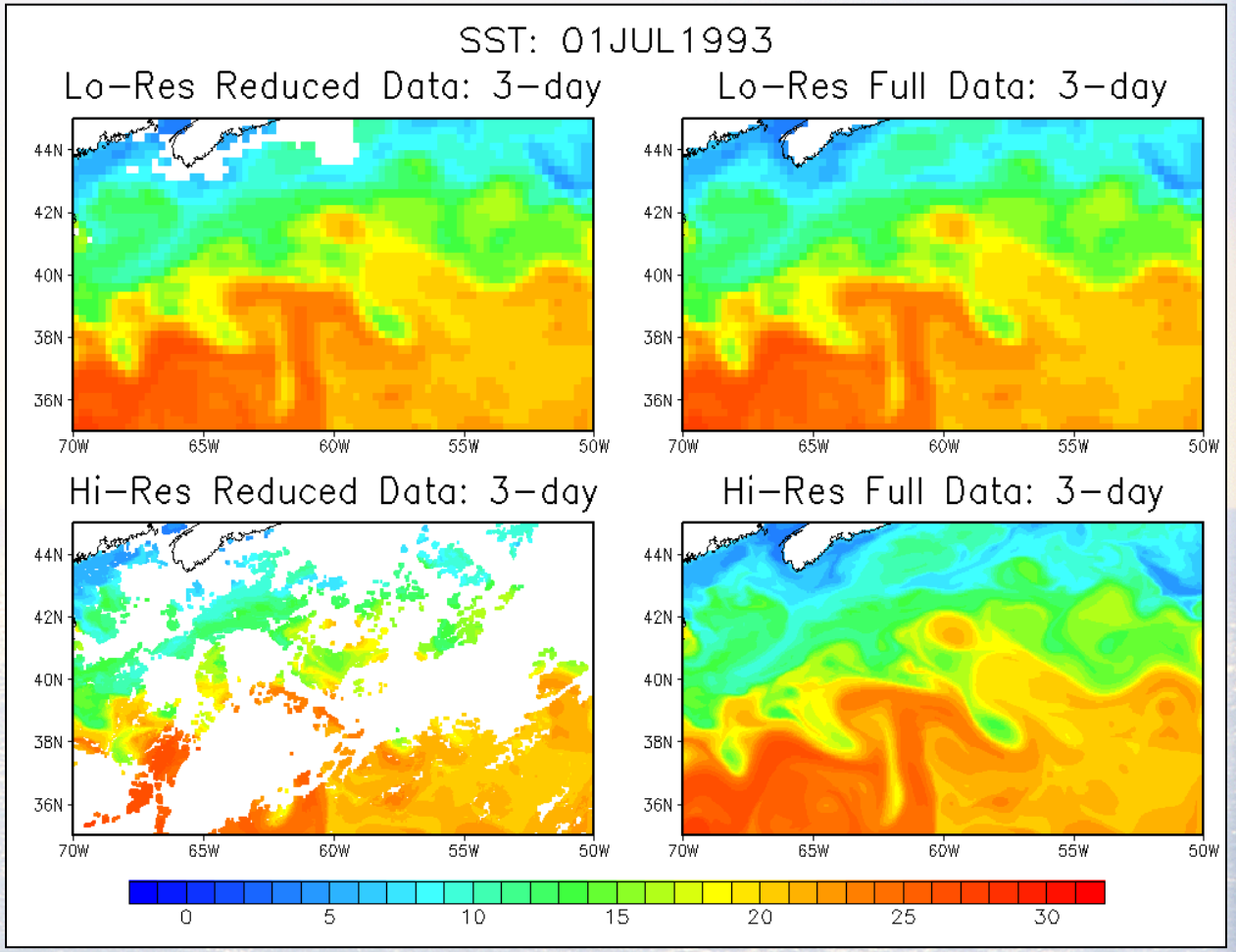

4.8 km IR Daily OI
High-Res Data: IR
High-Res Product (t-1)
Strong Damping First Guess
High-Res Product (t)
Low-Res Product (t-1)
Weak Damping First Guess
Low-Res Product (t)
28 km MW Daily OI
Low-Res Data: MW

Results

- Daily low- and high-resolution OI run for two one-month periods using complete "data" coverage (full) and data subsampled to simulate actual satellite data coverage (reduced)
  - Because of limited high resolution coverage due to clouds: 3 days of low- and high-resolution data were used
  - Two periods; January & July 1993 using January & July 2004 data coverage
- Products to be examined
  - Low-resolution data (3-day): Full & Reduced
  - Low-resolution OI analysis: Full & Reduced
  - High-resolution data (3-day): Full & Reduced
  - High-resolution OI analysis: Full & Reduced

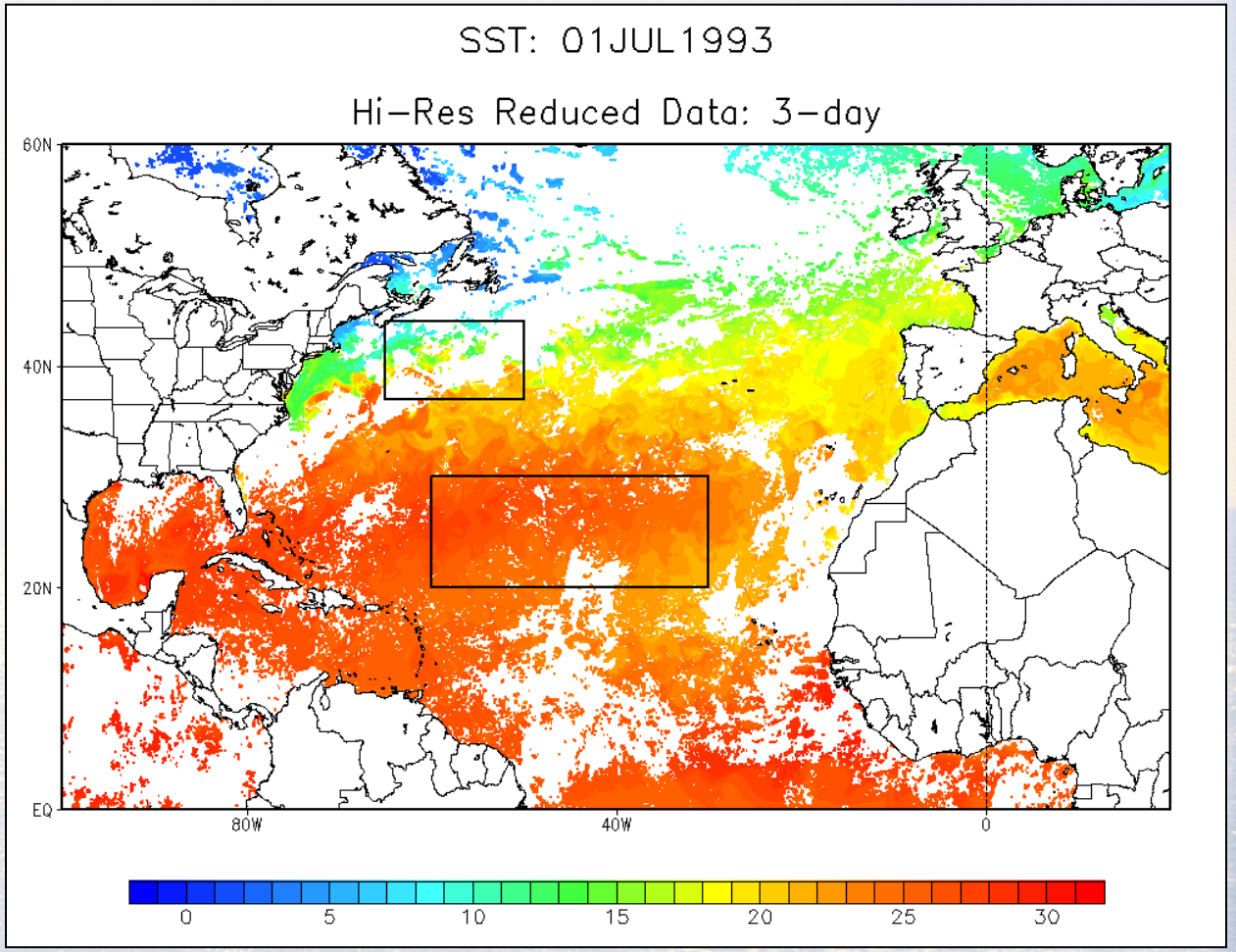
SST Data, 1 July 1993

- **Simulated Low-Resolution Data: top 2 panels**
  - **Small differences between Reduced (left) and Full sampling (right)**
- **Simulated High-Resolution Data: bottom 2 panels**
  - **Large differences between Reduced (left) and Full sampling (right)**
- **High and Low resolution feature differences are apparent**



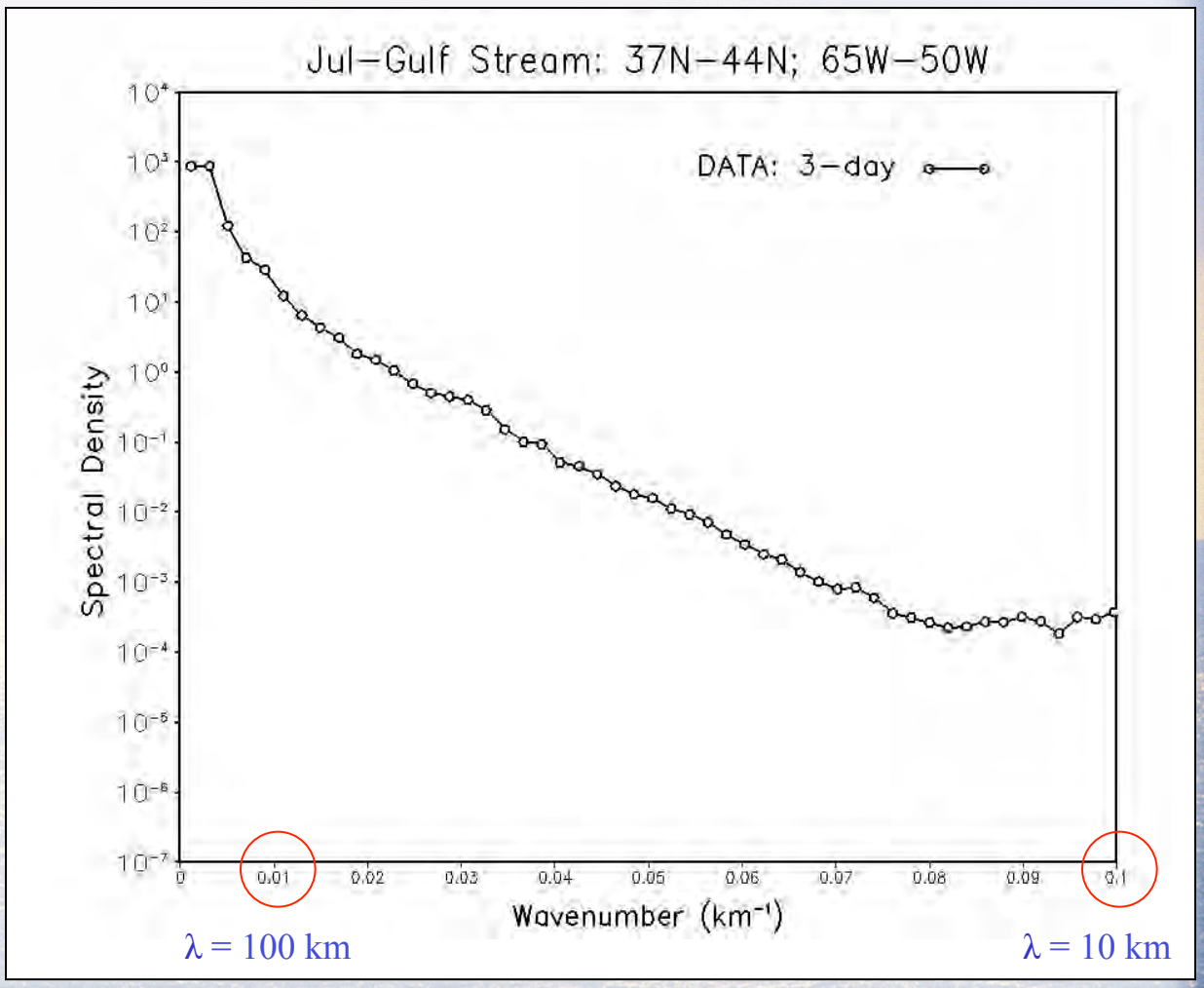
SST Hi-Res Reduced Data, 1 July 1993

- **Focus is on the zonal wavenumber (λ^{-1}) of spatial variance for 2 regions:**
  - **Gulf Stream**
  - **Sargasso Sea**
- **Wavenumber spectra computed:**
  - **Monthly average for 31 days along zonal line at center of the box**
  - **Daily average along 31 zonal lines closest to zonal line at the box center**



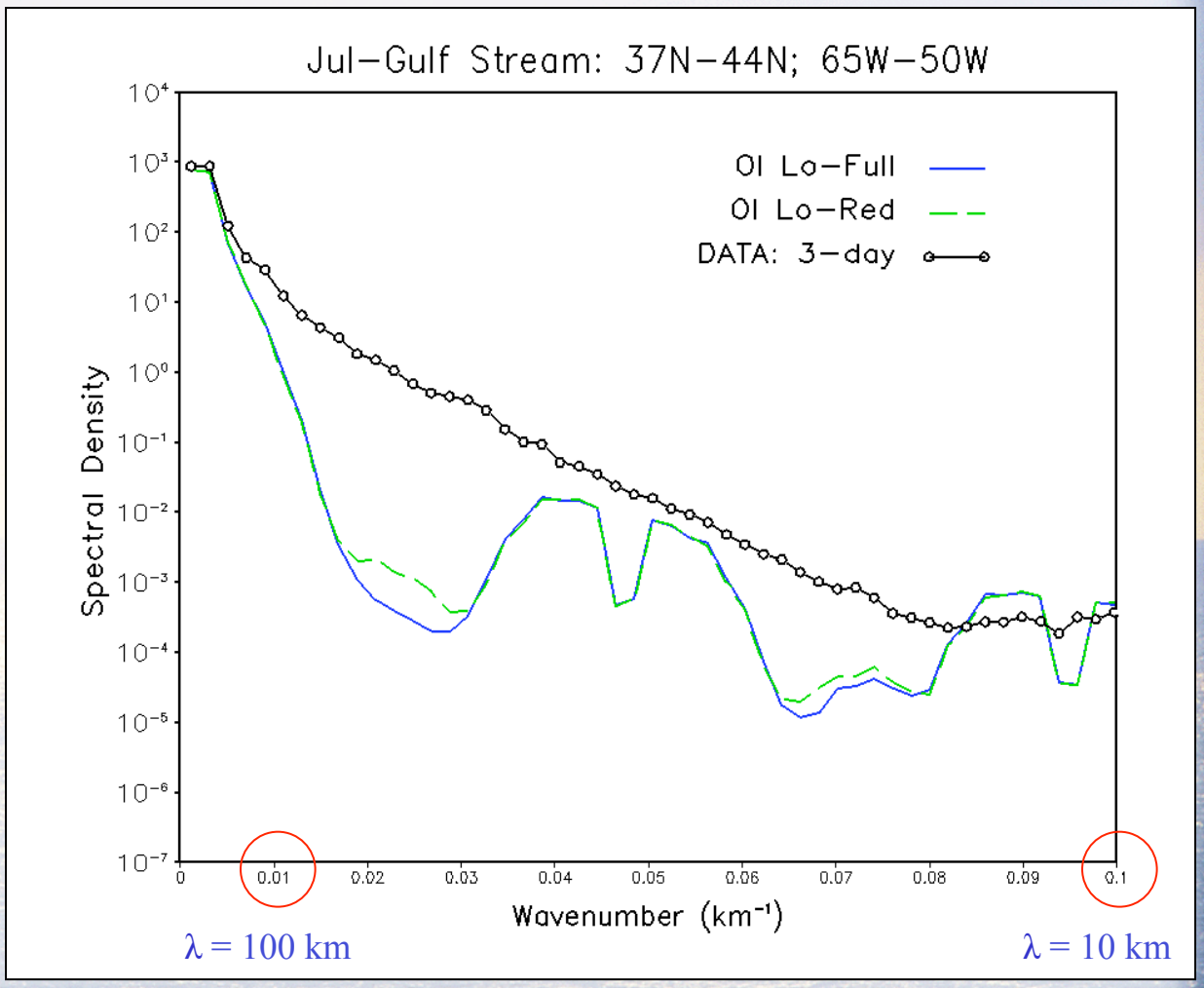
Gulf Stream Auto-Spectra, July 1993

- **Horizontal Axis**
  - Wavenumber (λ^{-1})
  - Range: 0-0.1 km^{-1}
- **Vertical axis**
  - Spectral density
  - Powers of 10
- **3-days of hi-res data**
  - Data Range: 10^{3} - 10^{-3}
  - Roughly flat: 0.08 - 0.10 km^{-1}
- **Min resolution ~ 12 km**
  - **Model grid = 5.2 km at 40.5° lat**
  - Smallest Nyguist λ = 10.4 km



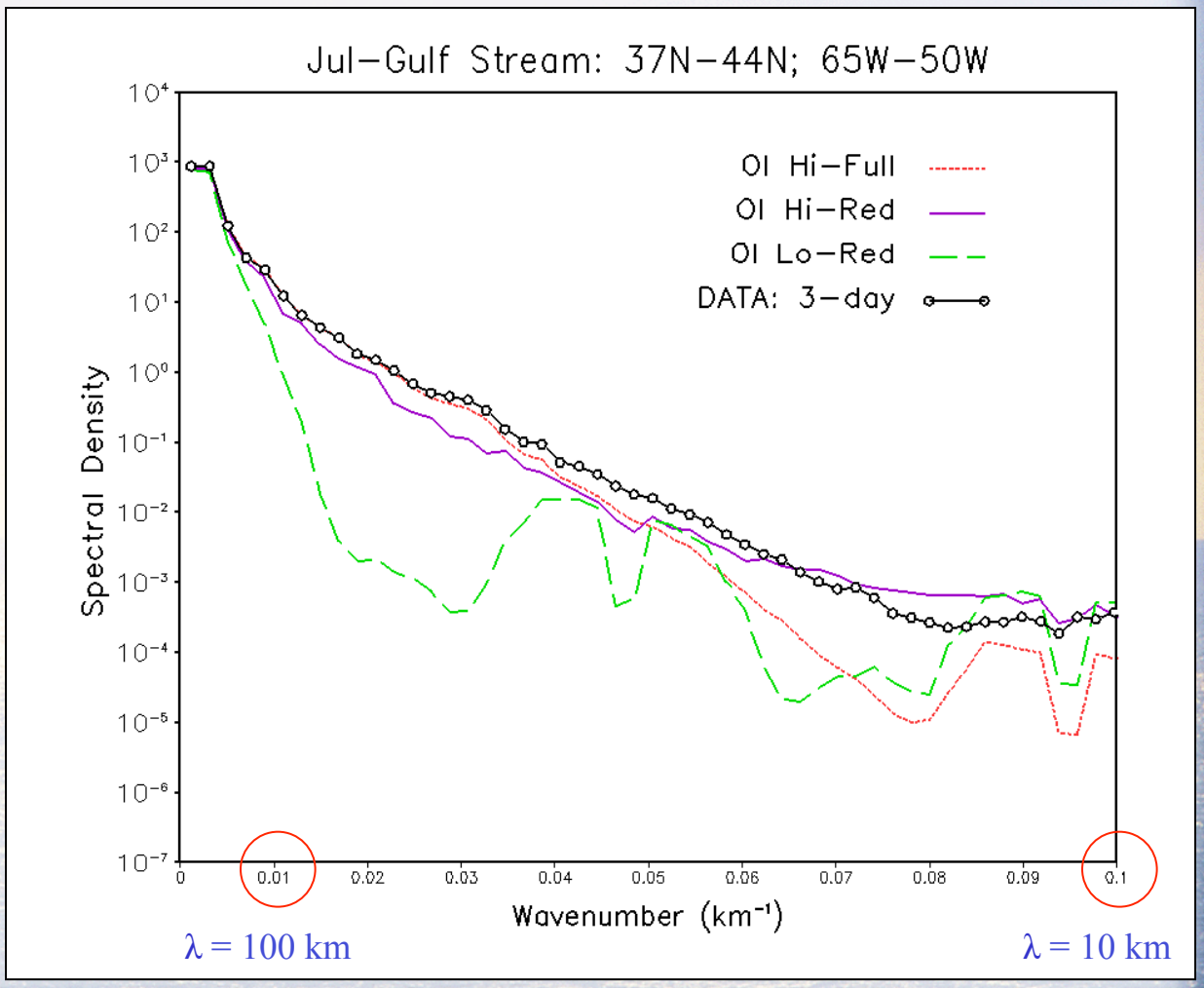
Gulf Stream Auto-Spectra, July 1993

- **Showing**
  - **Data Hi-Res Full**
  - **OI Low-Res Full & OI Low-Res Red**
- **Both OI Low-Res versions very similar & lower than data**
  - **10^1 ~ 0.01 km^{-1}**
  - **10^4 ~0.02-0.03**
- **OI Low-Res has ringing at high λ^{-1}**
  - **Due to bilinear interpolation from low to high resolution**



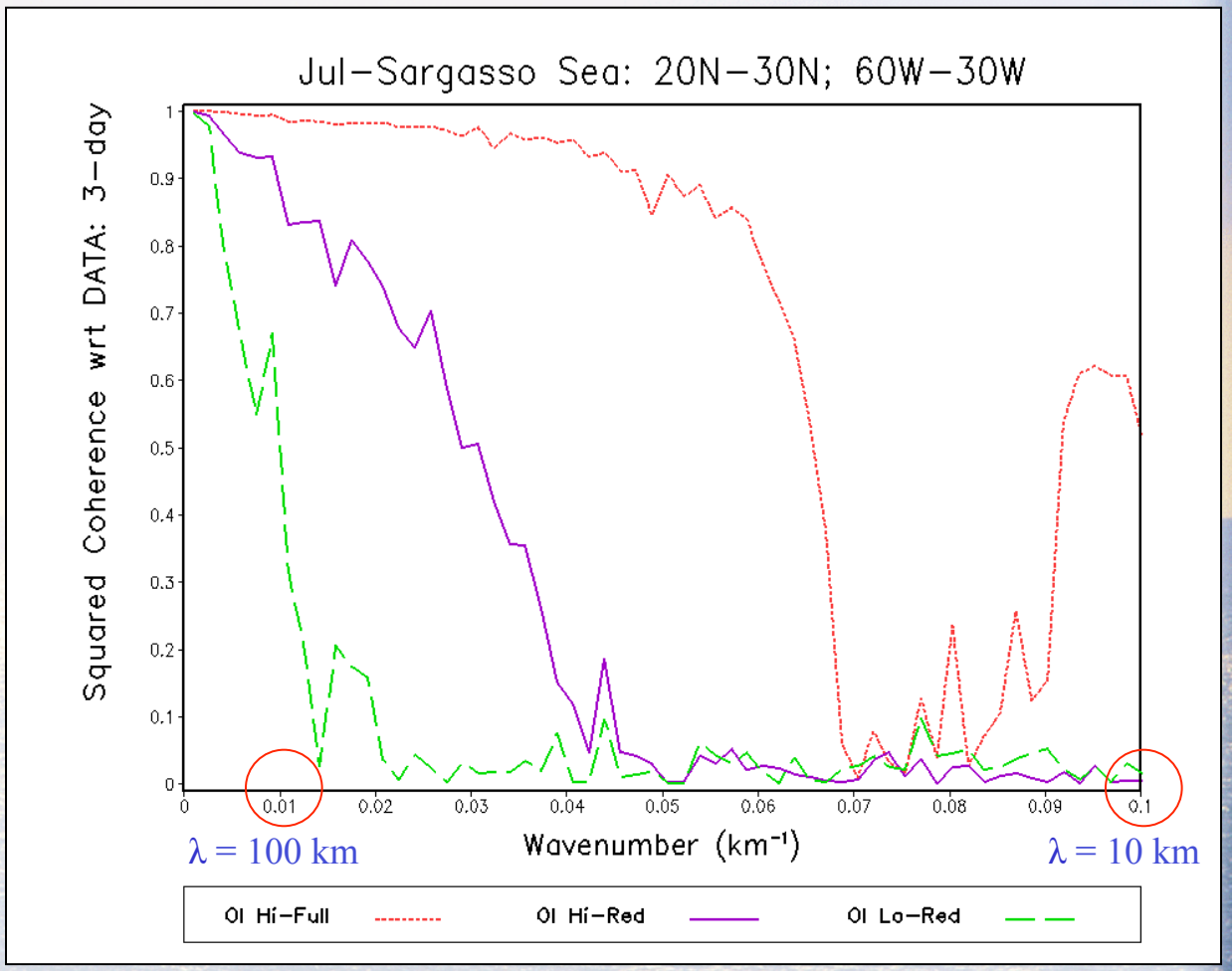
Gulf Stream Auto-Spectra, July 1993

- **Add OI Hi-Res**
  - **Both OI Hi-Res Full & OI Hi-Res Red very similar to DATA at wavenumbers (λ^{-1}) smaller than 0.06 km^{-1}**
  - **OI Hi-Res Full smaller than both Data & OI Hi-Res Red above 0.06 km^{-1}**
  - **OI Hi-Res Full has ringing at λ^{-1} above 0.08 km^{-1}**
- **What is signal?**
- **What is noise?**



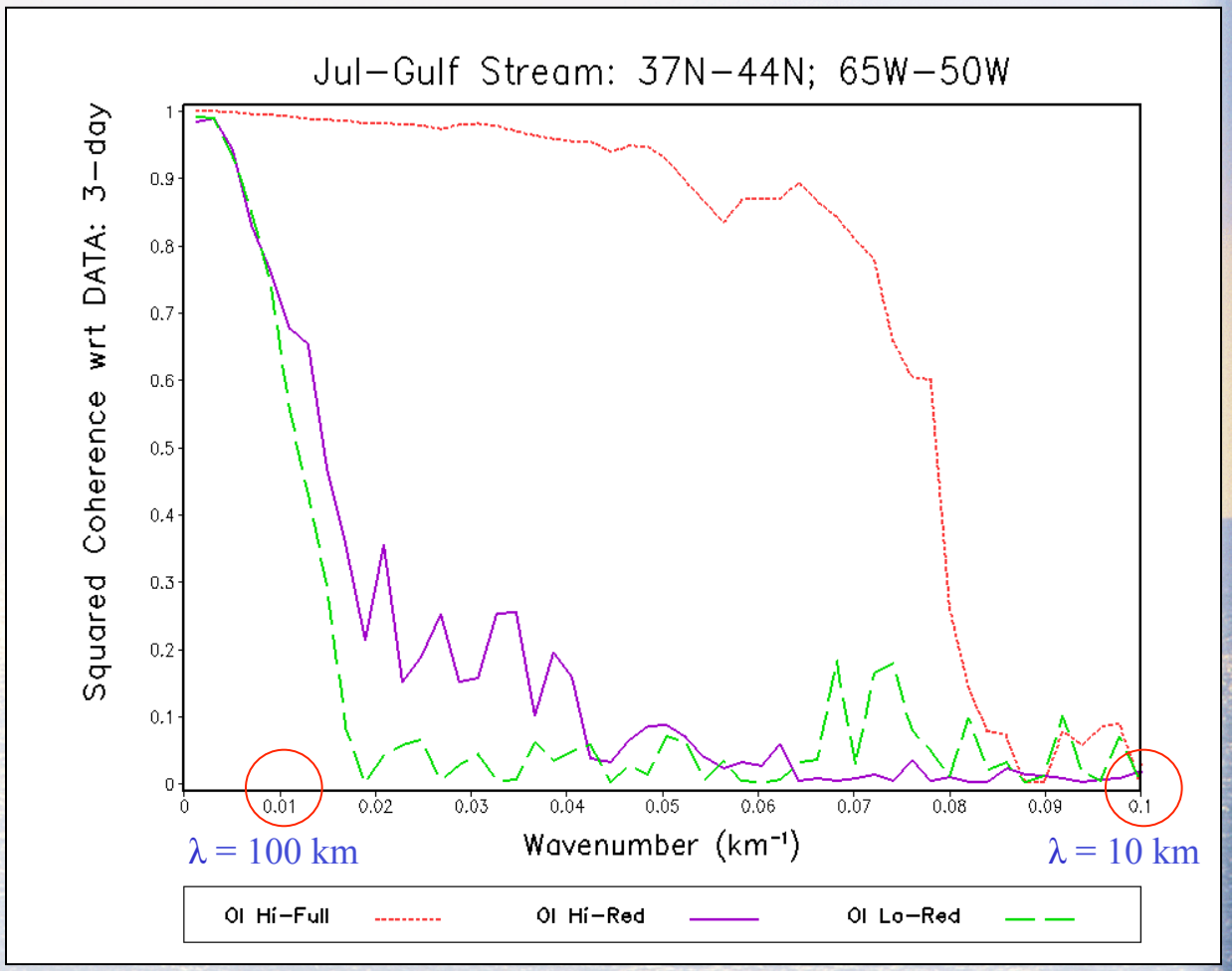
Sargasso Squared Coherence (γ^2), July 1993

- **Coherence: correlation as a function of wavenumber (λ^{-1})**
- **Coherence computed with respect to 3-days of data**
- **OI Low-Res Red**
  - **OI Low-Res γ^2 only 0.5 at 0.01 km^{-1} and then drops quickly**
- **OI Hi-Res Full**
  - **OI γ^2 above 0.9 until 0.07 km^{-1} and then drops quickly**
- **OI Hi-Res Red**
  - **γ^2 above 0.7 until 0.03 km^{-1} and then drops**



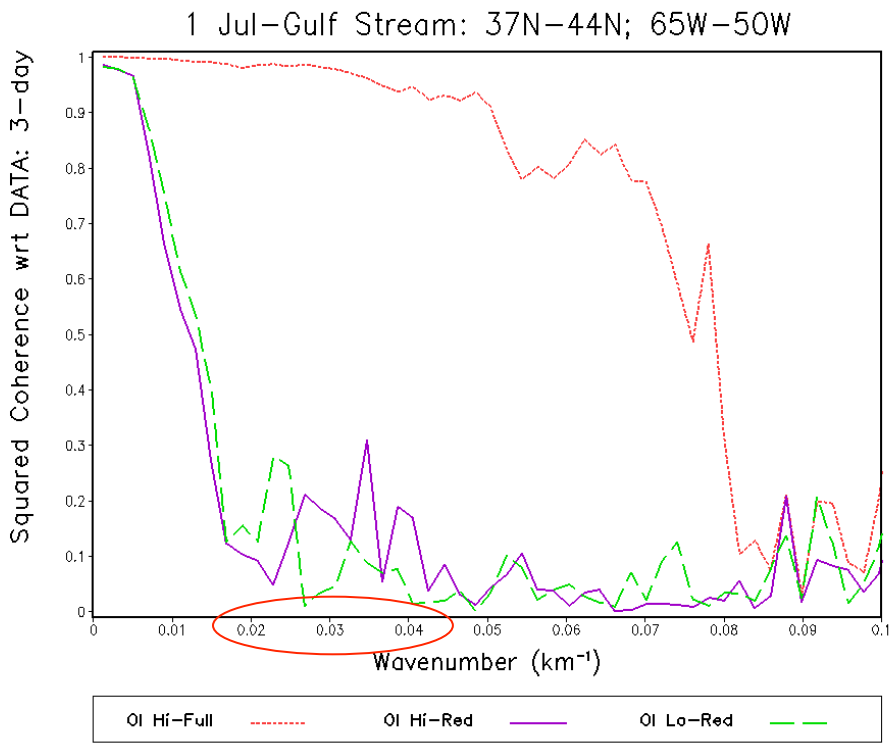
Gulf Stream Squared Coherence (γ^2), July 1993

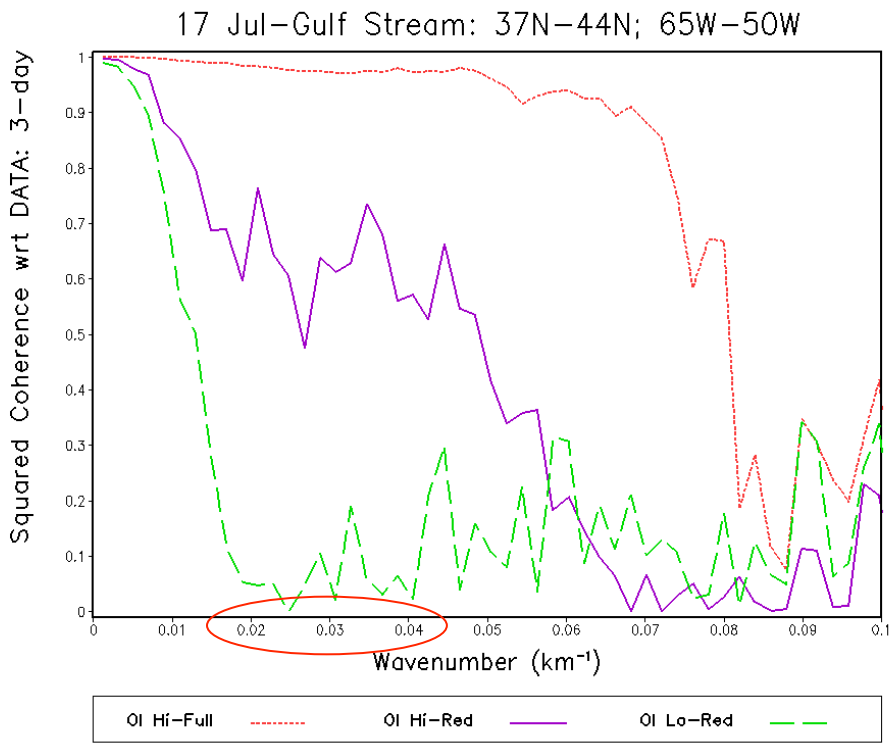
- **OI Low-Res Red**
  - **OI Low-Res γ^2 only 0.6 at 0.01 km^{-1} and then drops quickly**
- **OI Hi-Res Full**
  - **OI γ^2 above 0.9 until 0.06 km^{-1} and then drops quickly**
- **OI Hi-Res Red**
  - **γ^2 above 0.7 until 0.6 at 0.01 km^{-1} and then drops**
  - **Little monthly high resolution!**
  - **January even worse**



Gulf Stream Squared Coherence (γ^2)
1 & 17July 1993

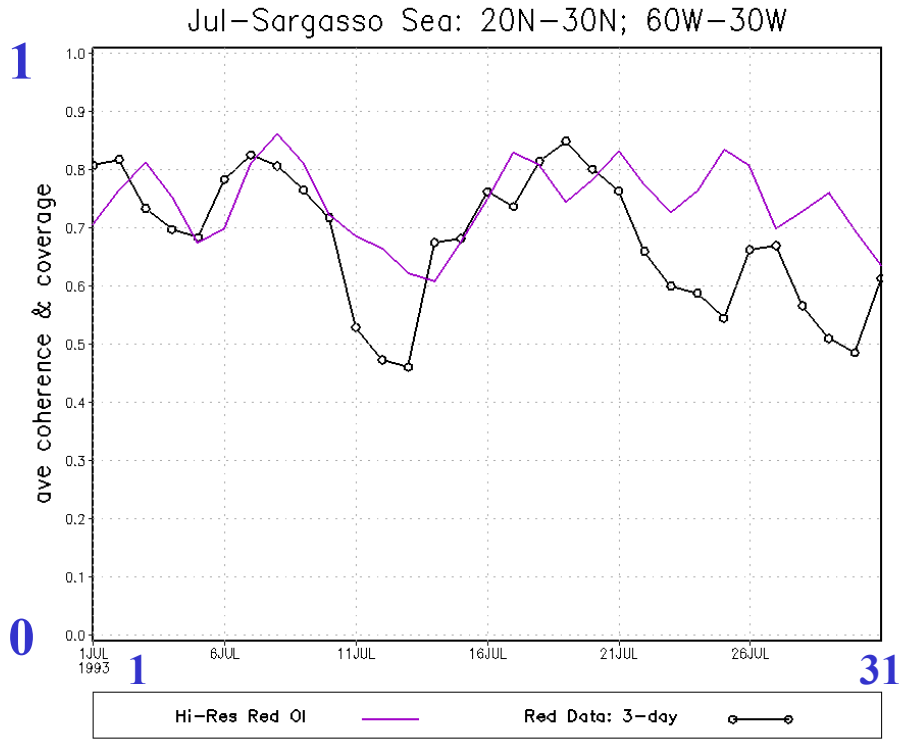
- **Left panel: 1 July: Right panel: 17 July**
- **OI Low-Res Red & OI Hi-Res Full**
  - **Both days show results very similar to monthly results**
- **OI Hi-Res Red**
  - **Much larger γ^2 values below 0.06 km^{-1} on 17 July 19993 compared to 1 July 1993**

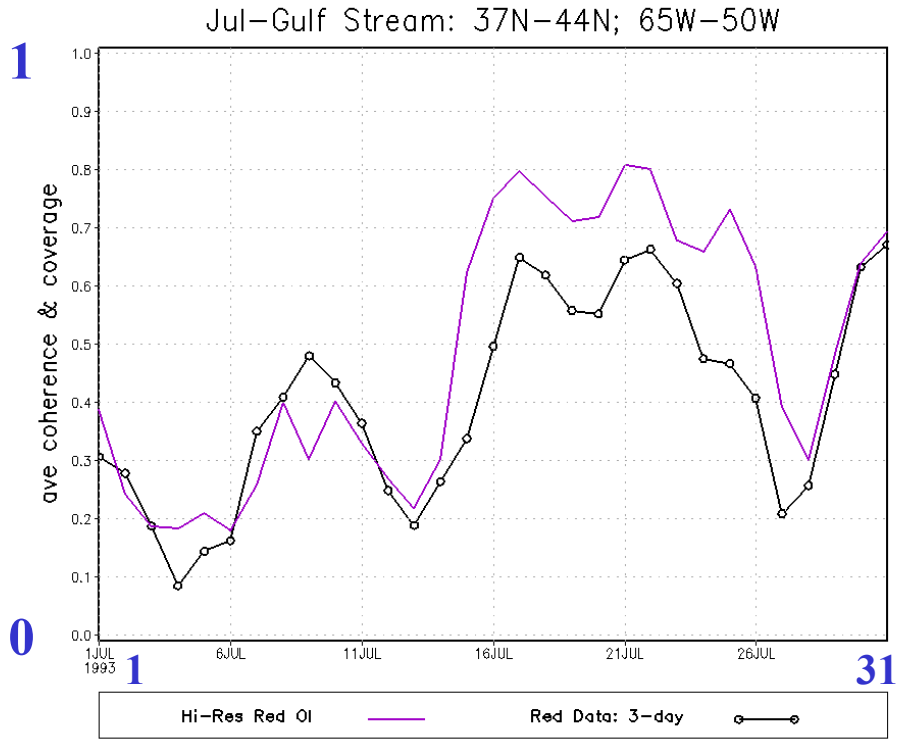




Sargasso & Gulf Stream Regions
Daily Coverage & Coherence for July 1993

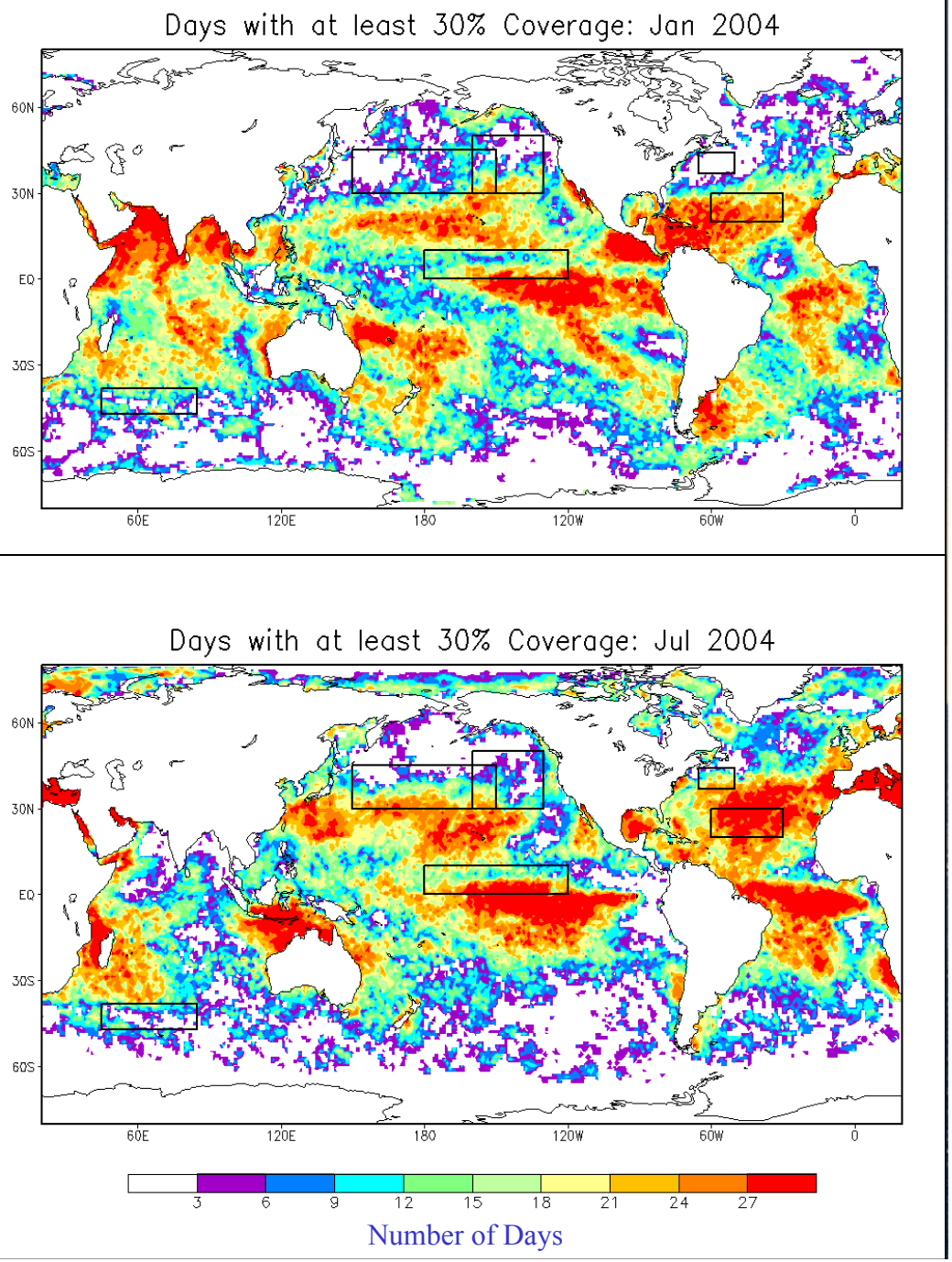
- X-axis: July Days, 1-31
- Y-axis: Daily Fraction of Coverage for Reduced Data, 0-1
- Y-axis: Average OI Hi-Res Coherence (γ) with Reduced Data
  - Average computed between 0.2 and 0.4 km^{-1}
- Note rough correlation between the 2 curves
  - Coverage can be used as proxy for Coherence



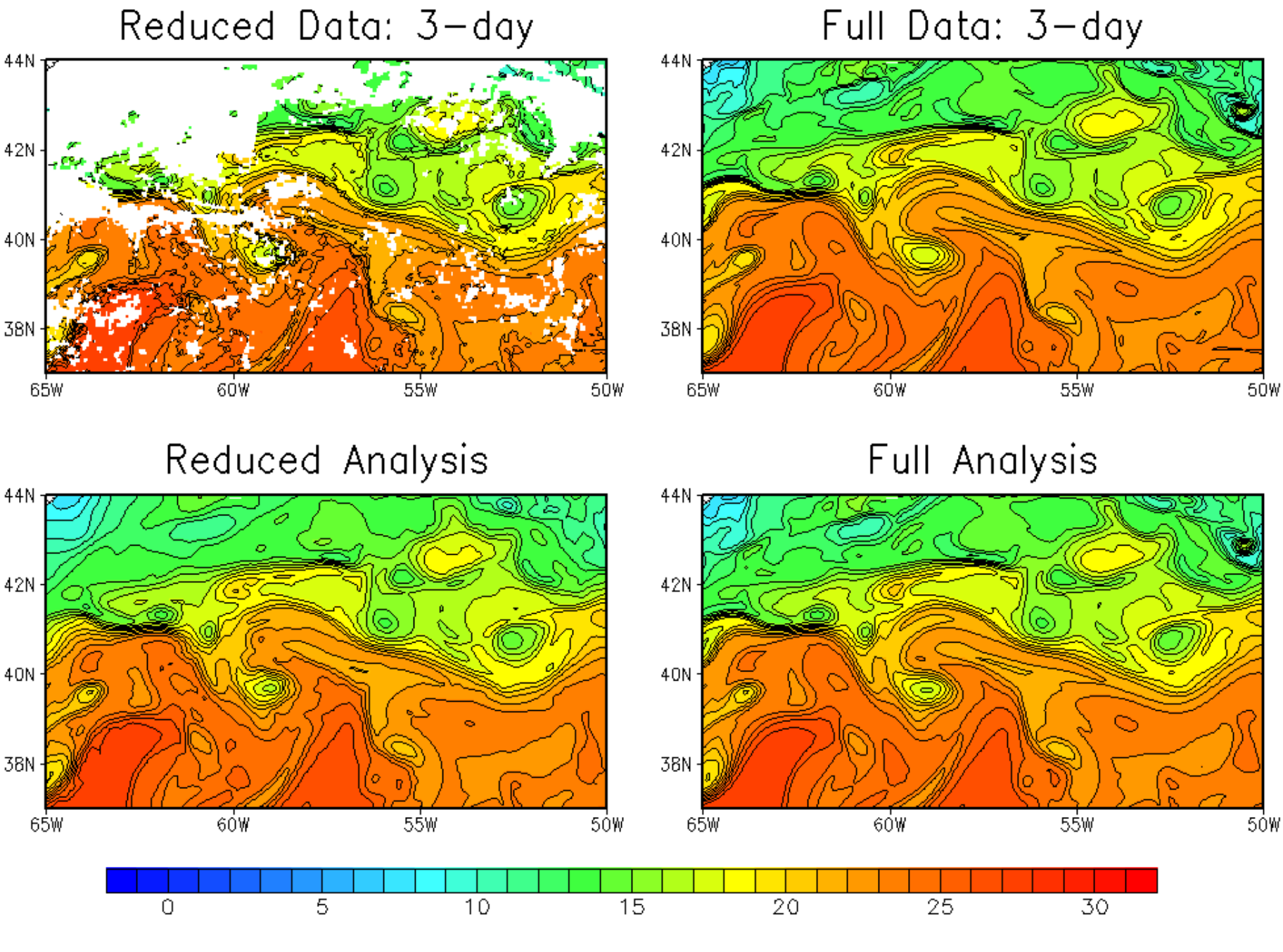


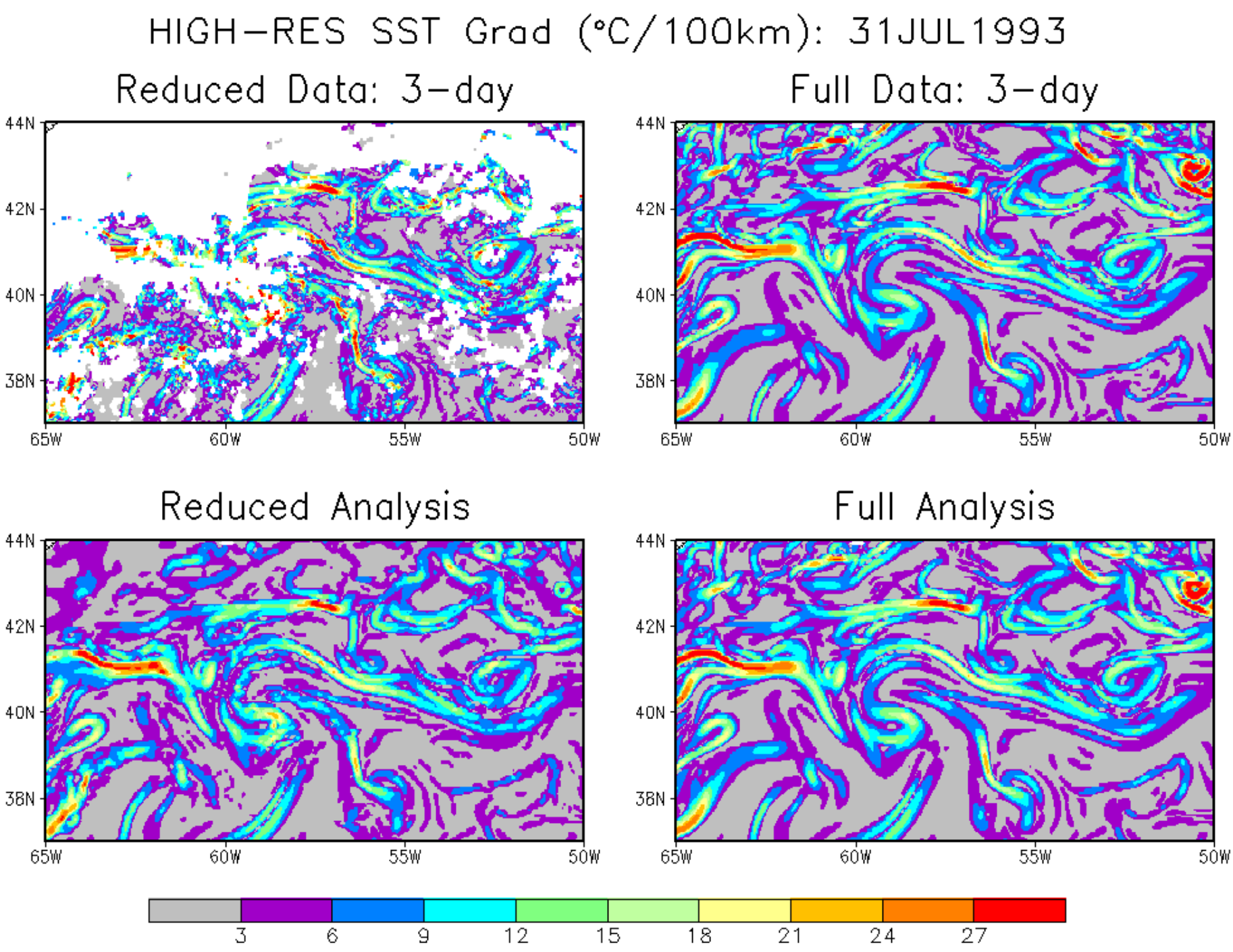
30% Coverage Days: January & July 2004

- Number of days with at least 30% ocean grid points with data
  - Computed on 1° spatial grid
  - January - top
  - July - bottom
- Note strong seasonal differences, for example
  - Gulf Stream
  - N. Hem Indian Ocean
  - Mediterranean
- Users now have a simple way to understand
  - Where high resolution analysis is possible
  - How often it is possible

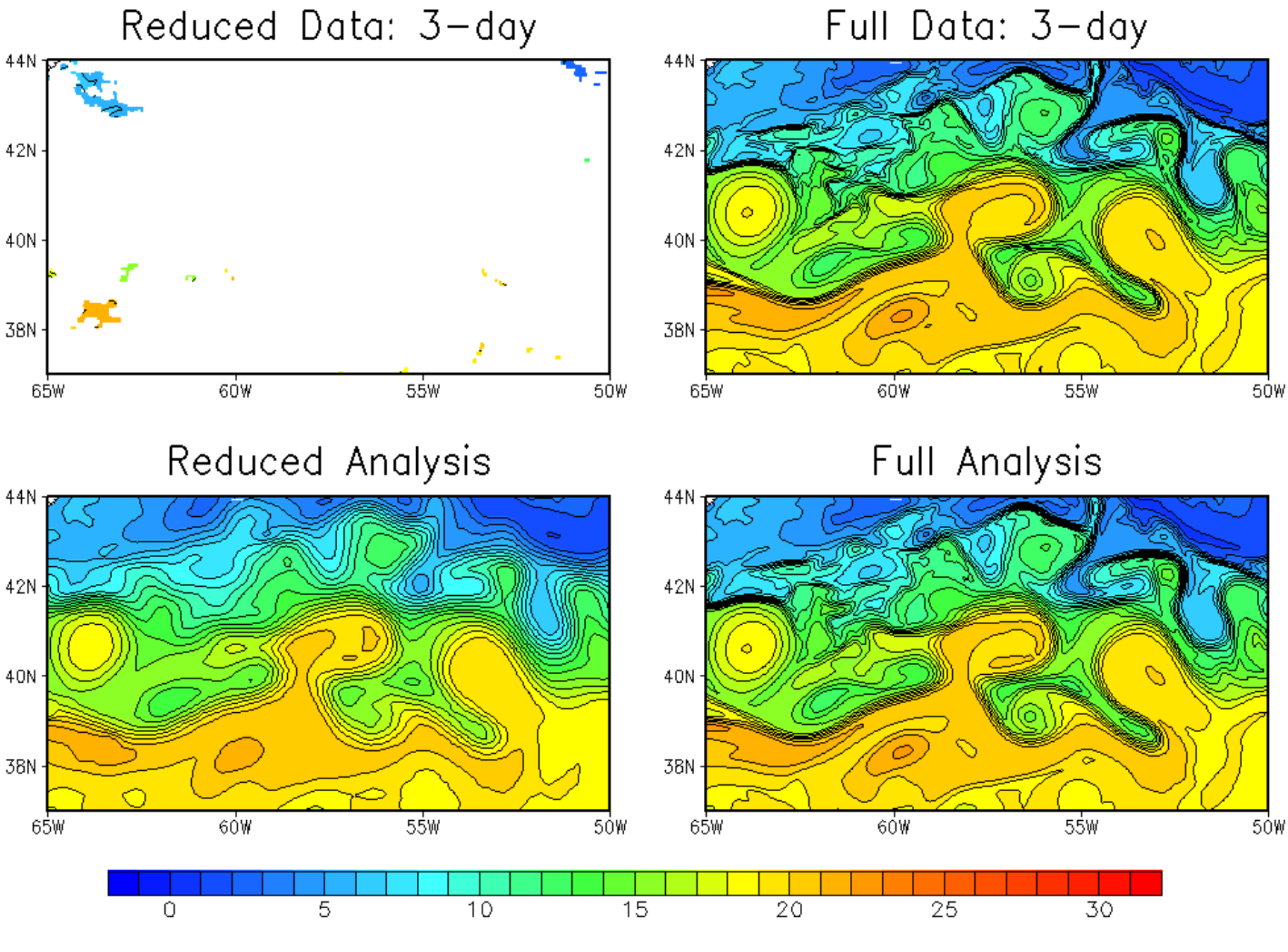


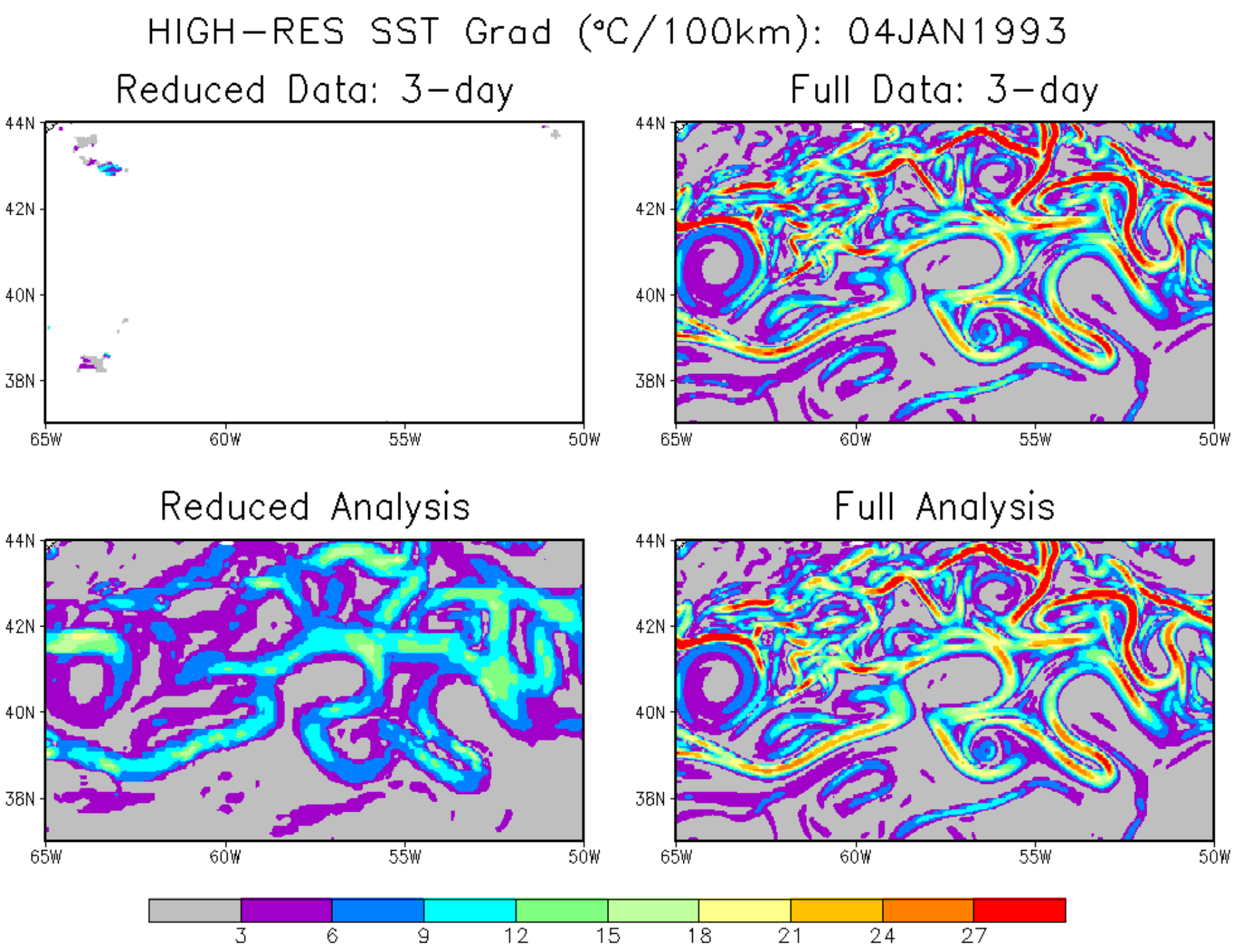
HIGH-RES SST: 31JUL1993




HIGH–RES SST Grad (°C/100km): 31JUL1993
Reduced Data: 3–day
Full Data: 3–day
Reduced Analysis
Full Analysis
44N
42N
40N
38N
65W
60W
55W
50W
3
6
9
12
15
18
21
24
27

HIGH-RES SST: 04JAN1993




HIGH-RES SST Grad (°C/100km): 04JAN1993
Reduced Data: 3-day
Full Data: 3-day
Reduced Analysis
Full Analysis
44N
42N
40N
38N
65W
60W
55W
50W
3
6
9
12
15
18
21
24
27

Summary

- Using "Synthetic SST Data" as "Truth" is a useful procedure for studying the effects of sampling errors on SST analyses
  - Noise has not be added to the model SST
  - Thus, high resolution simulations are optimistic
- Monthly maps of data coverage can provide a useful way for users to understand where and how often high-resolution analyses actually have high-resolution signals