Contribution of HyspIRI measurements to improving the quality of satellite-derived Climate Data Records

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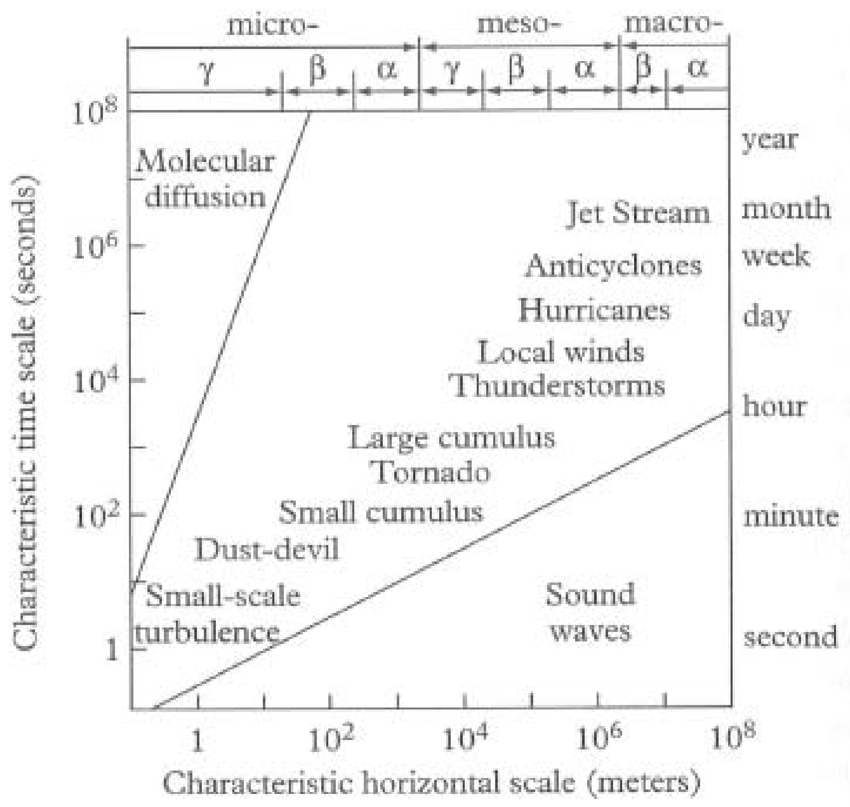
Outline

- Scales of variability in the ocean and atmosphere
- Potential of higher spatial resolution measurements
- Current limitations on CDRs imposed by medium resolution data
- Overcoming the combined geophysical and instrumental effects in CDRs

Turbulent Energy Cascade

- Energy is input to the climate system on large spatial scales and "cascades" through a sequence of turbulent processes to microscales.
- Satellite remote sensing offers a unique perspective of these processes: prime example is mesoscale oceanic variability.
- "Big whorls have little whorls that feed on their velocity, and little whorls have smaller whorls and so on to viscosity." - L.F. Richardson.

Scales of atmospheric variability



SCALES. Figure 1. *Scale definitions and different processes with characteristic time and horizontal scales.* (Adapted from Orlanski, 1975, and Oke, 1987.)

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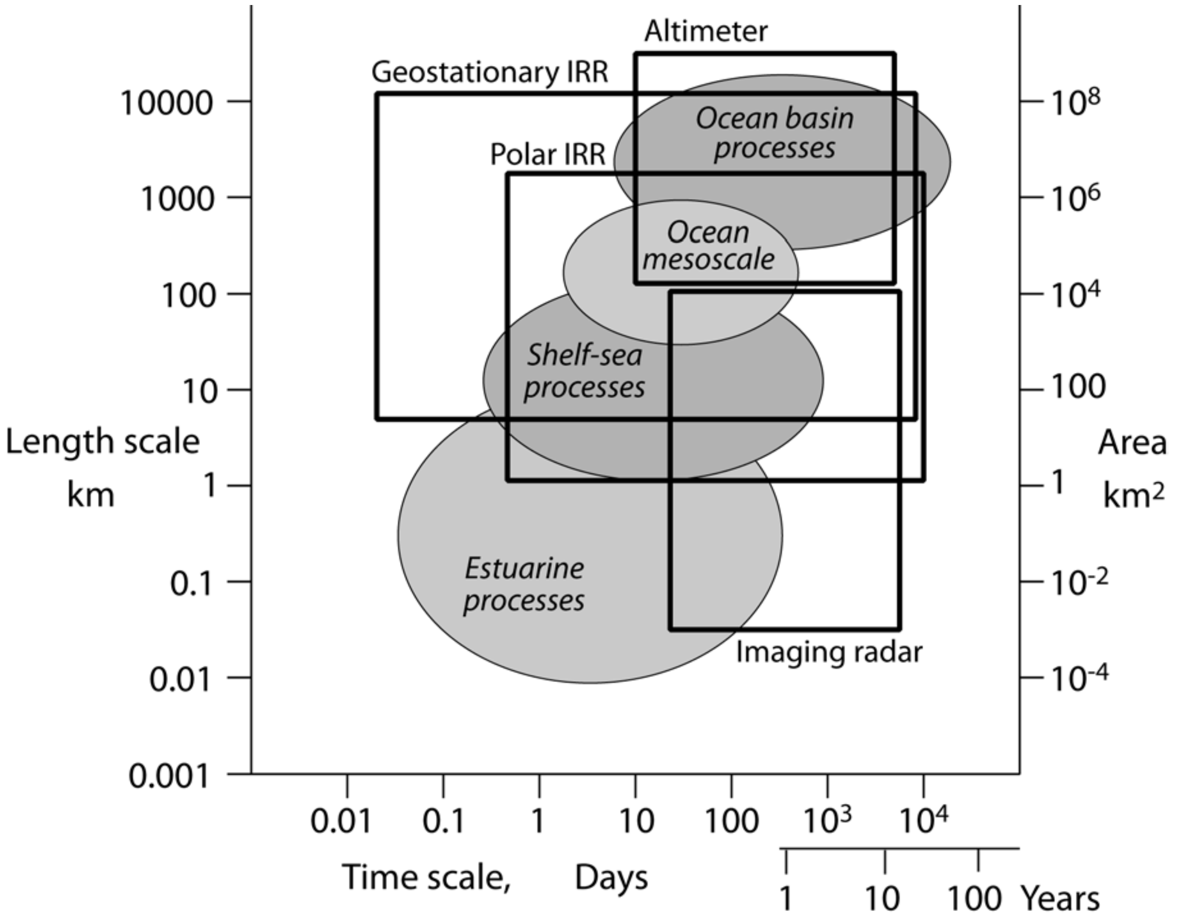
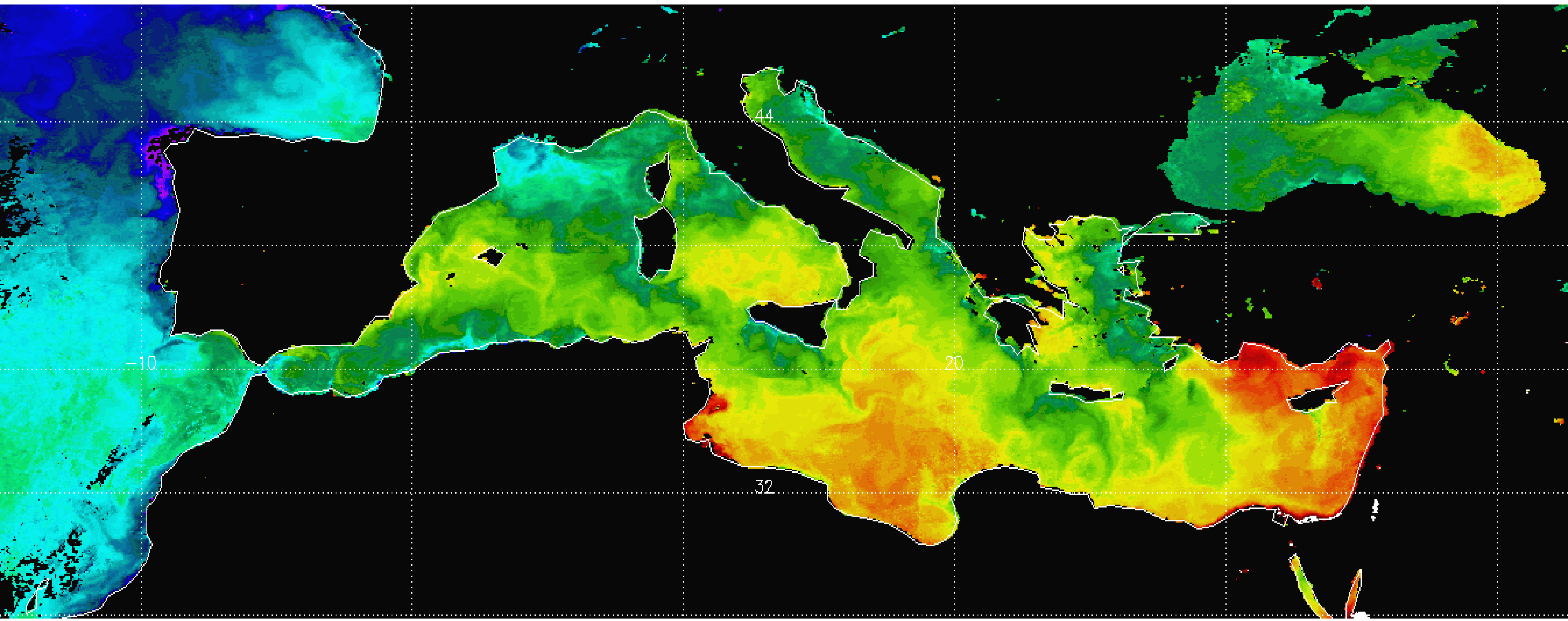
Scales of ocean variability

Sub-mesoscale variability is not limited to shelf and estuarine processes.

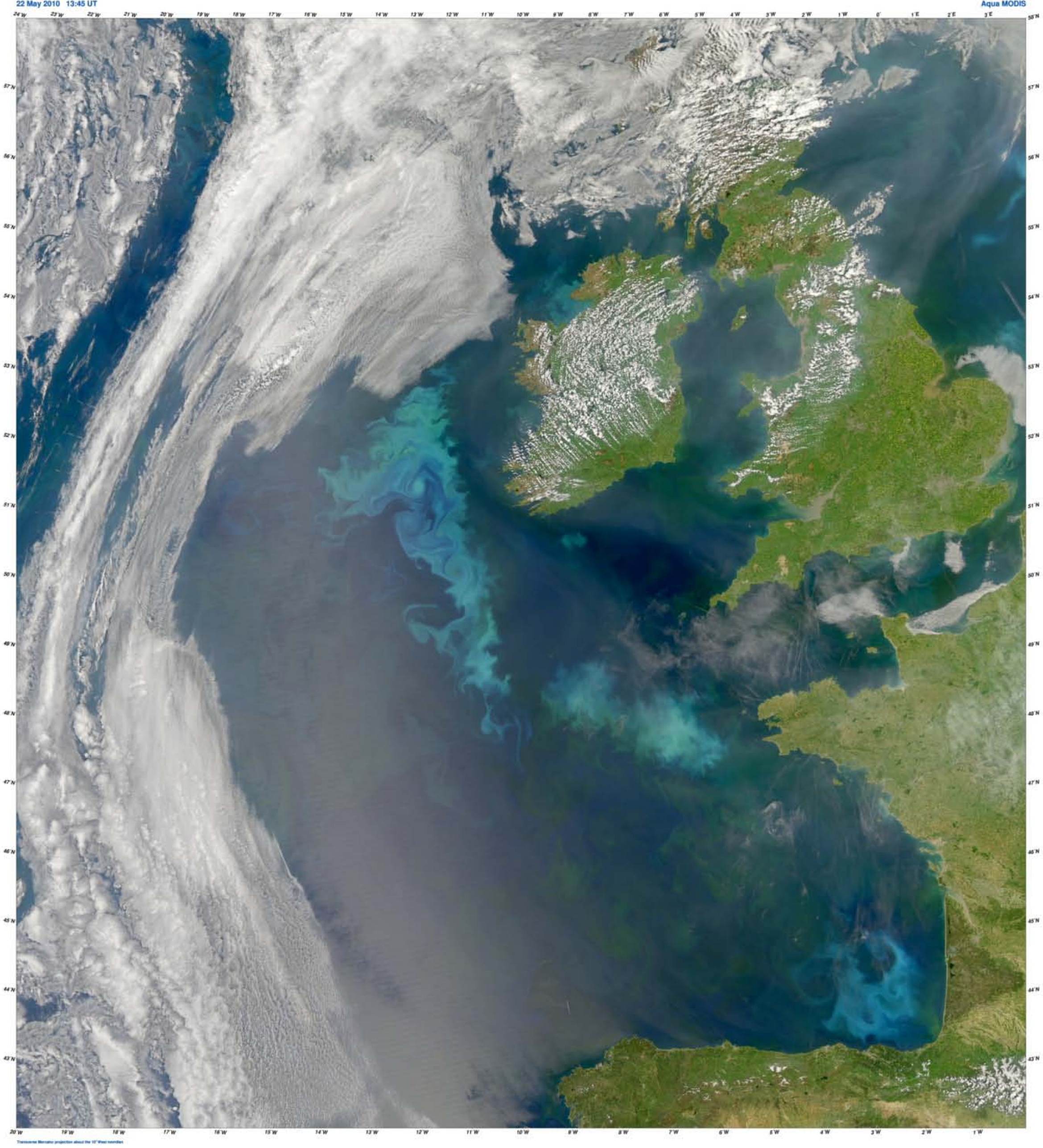


From Robinson, I. S. (2004), *Measuring the Oceans from Space. The principles and methods of satellite oceanography*, 515 pp., Springer Verlag - Praxis Publishing, Chichester, UK.

SST images reveal mesoscale variability.



Ocean Color



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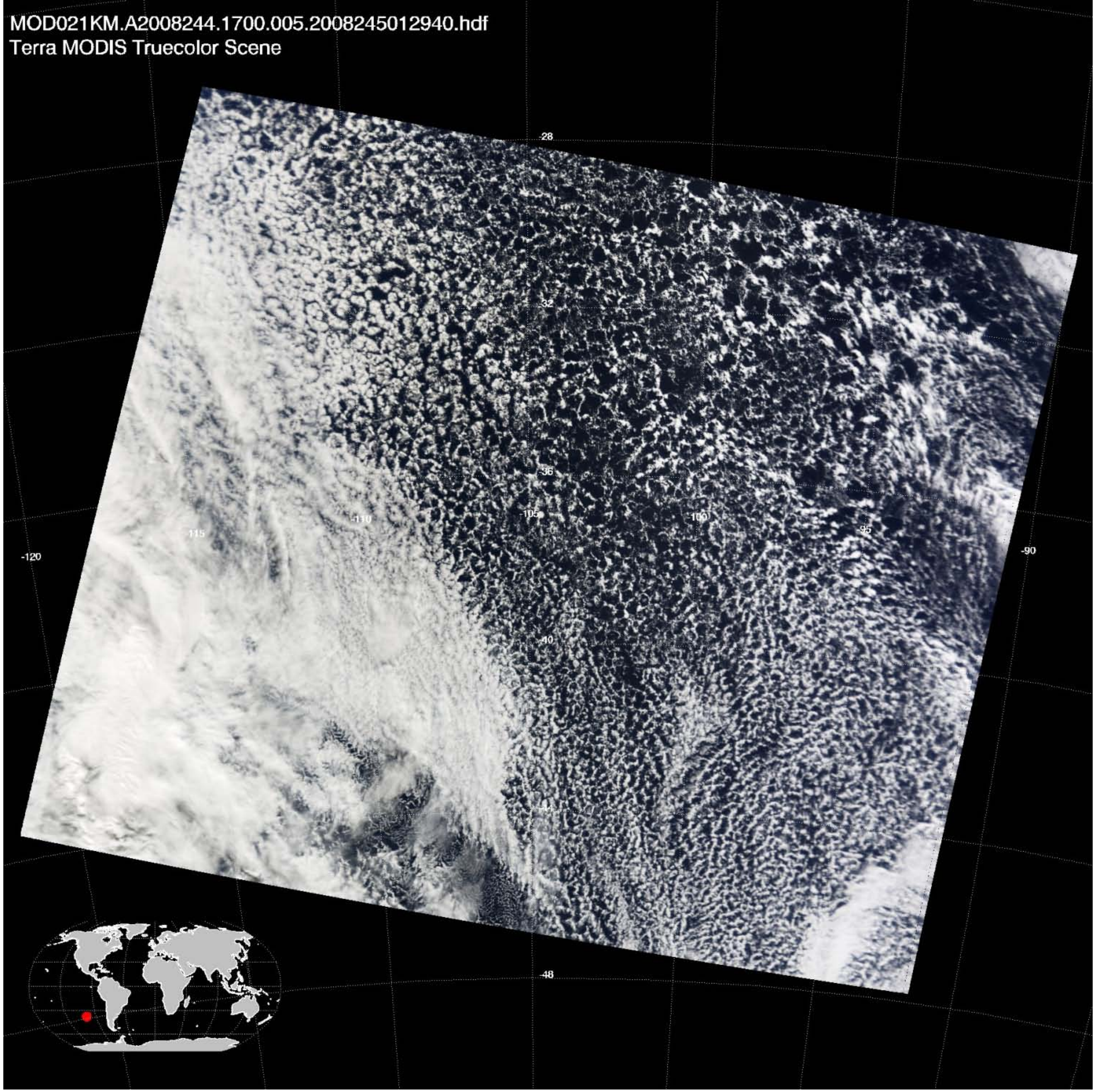
Clouds



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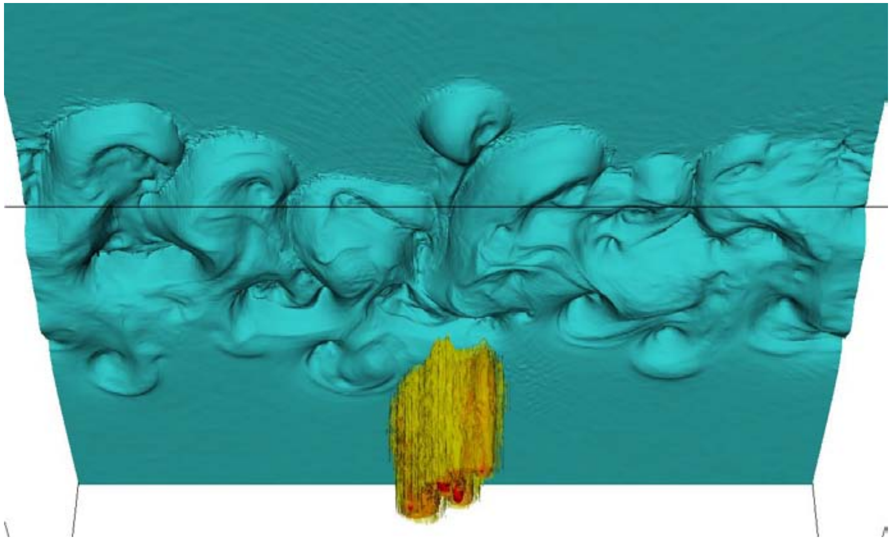
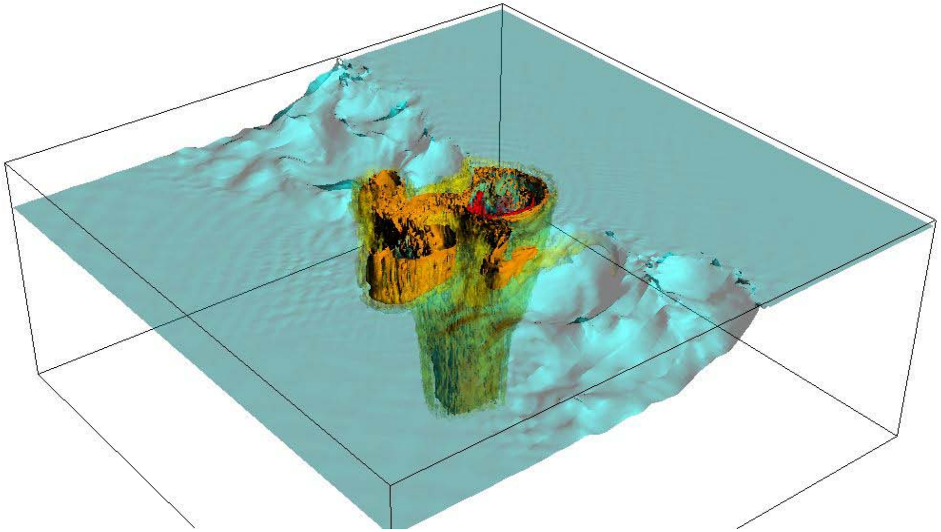
How is progress made?

- In recent decades, progress in oceanic and atmospheric science has often followed the measurements of improved instrumentation:
  - Swallow floats & satellite images of oceanic mesoscale features.
  - Radars, aircraft and satellite measurements of cloud processes.
- But now, modeling has moved beyond measurement capabilities.

High resolution simulations



From below



From above

Domain dimensions: 25x25 km
Blue: a density interface surface near the ocean surface
Orange: buoyant plume

Courtesy: Tamay Özgökmen, RSMAS - MPO

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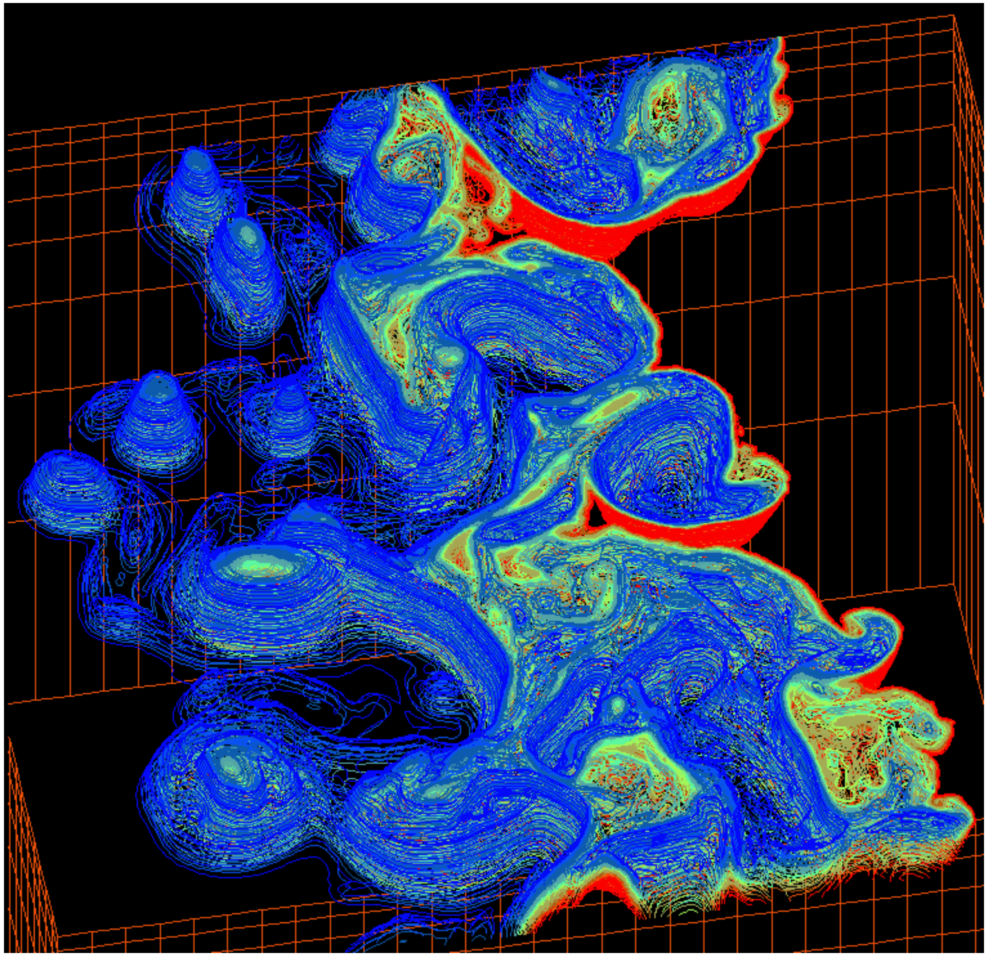
Simulations of ocean mixing

Domain dimensions: 10x10 km
A density interface surface intersecting the ocean surface.

Courtesy: Tamay Özgökmen, RSMAS - MPO



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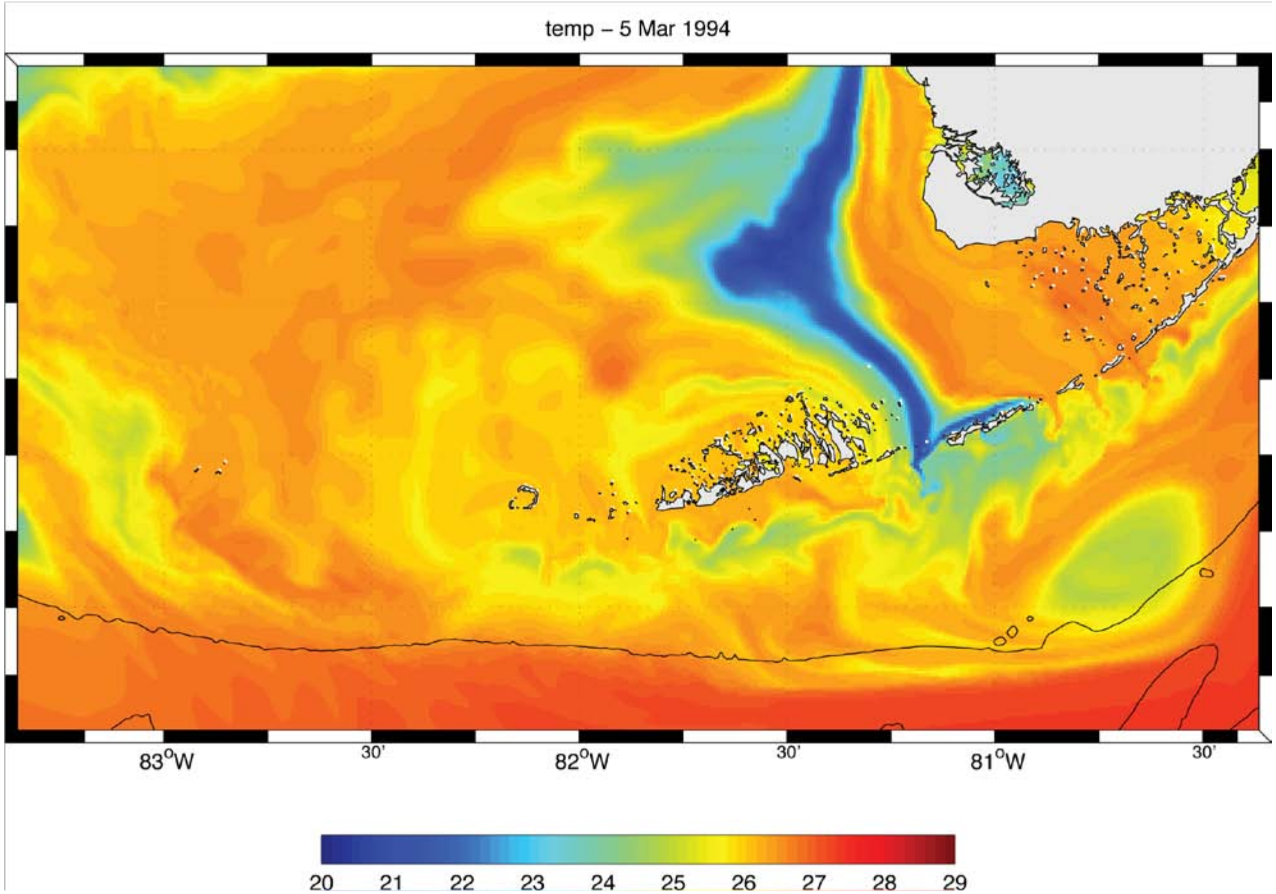
Modeled SST – Florida Keys

Grid size: 700m

Courtesy:
Dr Laurent Cherubin,
RSMAS-MPO



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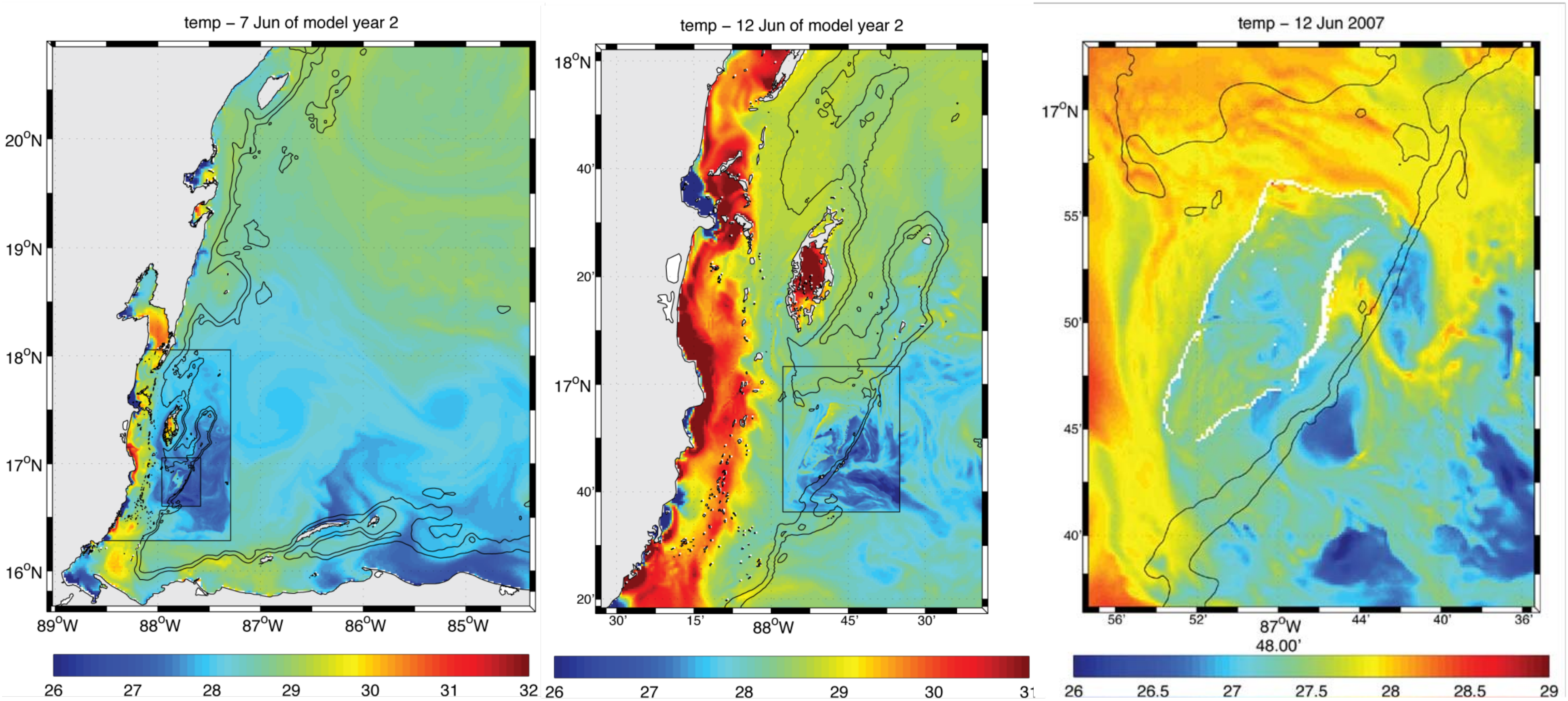
Nested Modeled SST - Belize



Nested grid resolutions: 2km → 690m → 230m

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Courtesy:
Dr Laurent Cherubin,
RSMAS-MPO

How to measure sub-mesoscale variability?

- Ship-based: cannot provide synoptic sampling, even using multiple ships; traditional instruments are good for vertical sections, but not for horizontal.
- Tracers: difficult to capture by ship tracking; airborne laser tracking is promising and under development. Overall, total tracer amount is too small and too short-lived to provide insight.
- Gliders: these are in vogue, but expensive (so not too many), and have major post-processing challenges due to aliasing by time along the path.
- Drifters: feasible, but need O(100) in a concentrated deployment, which is large enough to create environmental concerns.
- VHF radar: good, but limited to coastal zones.
- High resolution satellite imagers (SARs, VIS, IR) – a very feasible option.

Essential Climate Variables

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GCOS Essential Climate Variables

The Essential Climate Variables (ECVs;) are required to support the work of the UNFCCC and the IPCC. All ECVs are technically and economically feasible for systematic observation. It is these variables for which international exchange is required for both current and historical observations. Additional variables required for research purposes are not included in this table. It is emphasized that the ordering within the table is simply for convenience and is not an indicator of relative priority. Currently, there are 44 ECVs plus soil moisture recognized as an emerging ECV.

Domain	Essential Climate Variables
Atmospheric (over land, sea and ice)	**Surface:** Air temperature, Precipitation, Air pressure, Surface radiation budget, Wind speed and direction, Water vapour. **Upper-air:** Earth radiation budget (including solar irradiance), Upper-air temperature (including MSU radiances), Wind speed and direction, Water vapour, Cloud properties. **Composition:** Carbon dioxide, Methane, Ozone, Other long-lived greenhouse gases[1], Aerosol properties.
Oceanic	**Surface:** Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Current, Ocean colour (for biological activity), Carbon dioxide partial pressure. **Sub-surface:** Temperature, Salinity, Current, Nutrients, Carbon, Ocean tracers, Phytoplankton.
Terrestrial[2]	River discharge, Water use, Ground water, Lake levels, Snow cover, Glaciers and ice caps, Permafrost and seasonally-frozen ground, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (fAPAR), Leaf area index (LAI), Biomass, Fire disturbance, Soil moisture[3].

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Cloud properties.

Sea-surface temperature.

Sea ice.

River discharge.

Ocean colour (for biological activity).

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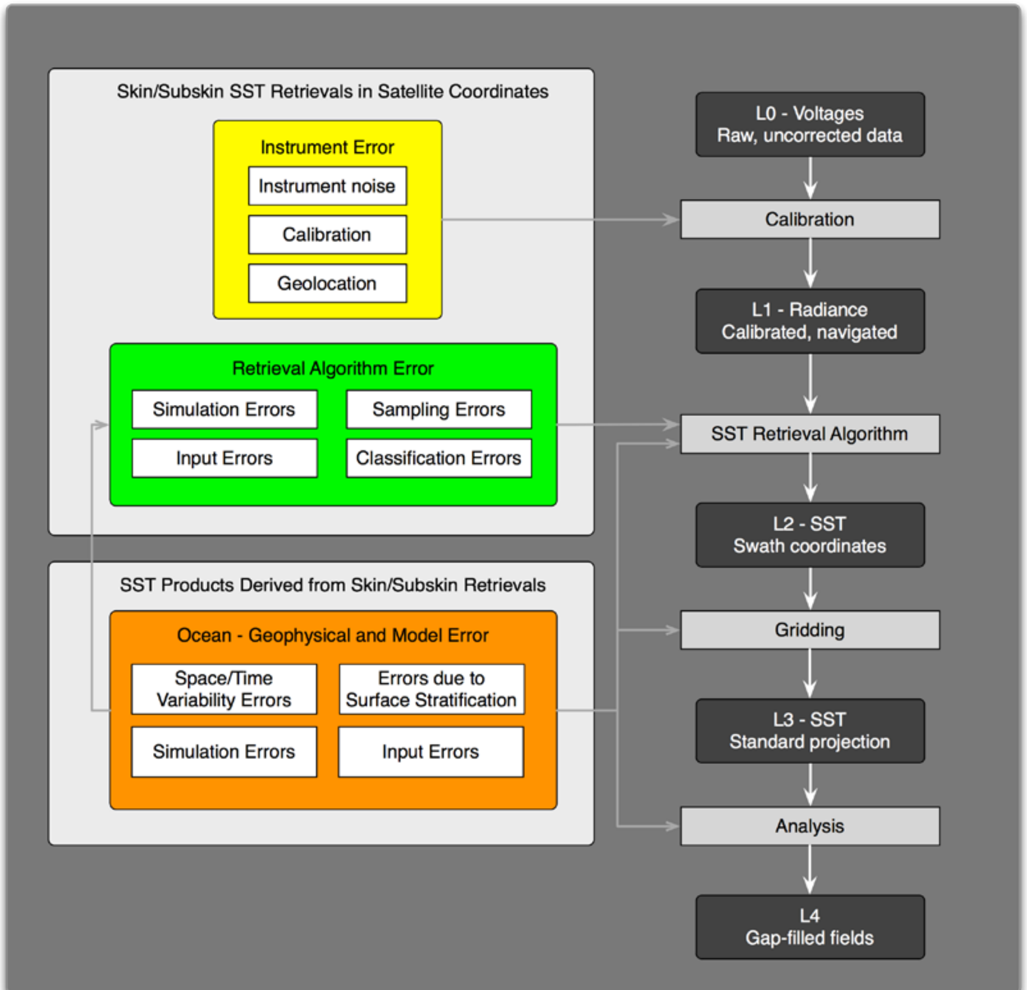
Satellite-derived CDRs

- National Academy of Sciences Report (*NRC, 2000)*: "*a data set designed to enable study and assessment of long-term climate change, with 'long-term' meaning year-to-year and decade-to-decade change. Climate research often involves the detection of small changes against a background of intense, short-term variations.*"
- *"Calibration and validation should be considered as a process that encompasses the entire system, from the sensor performance to the derivation of the data products. The process can be considered to consist of five steps:*
  - *instrument characterization,*
  - *sensor calibration,*
  - *calibration verification,*
  - *data quality assessment, and*
  - *data product validation."*

Desired SST CDR uncertainties

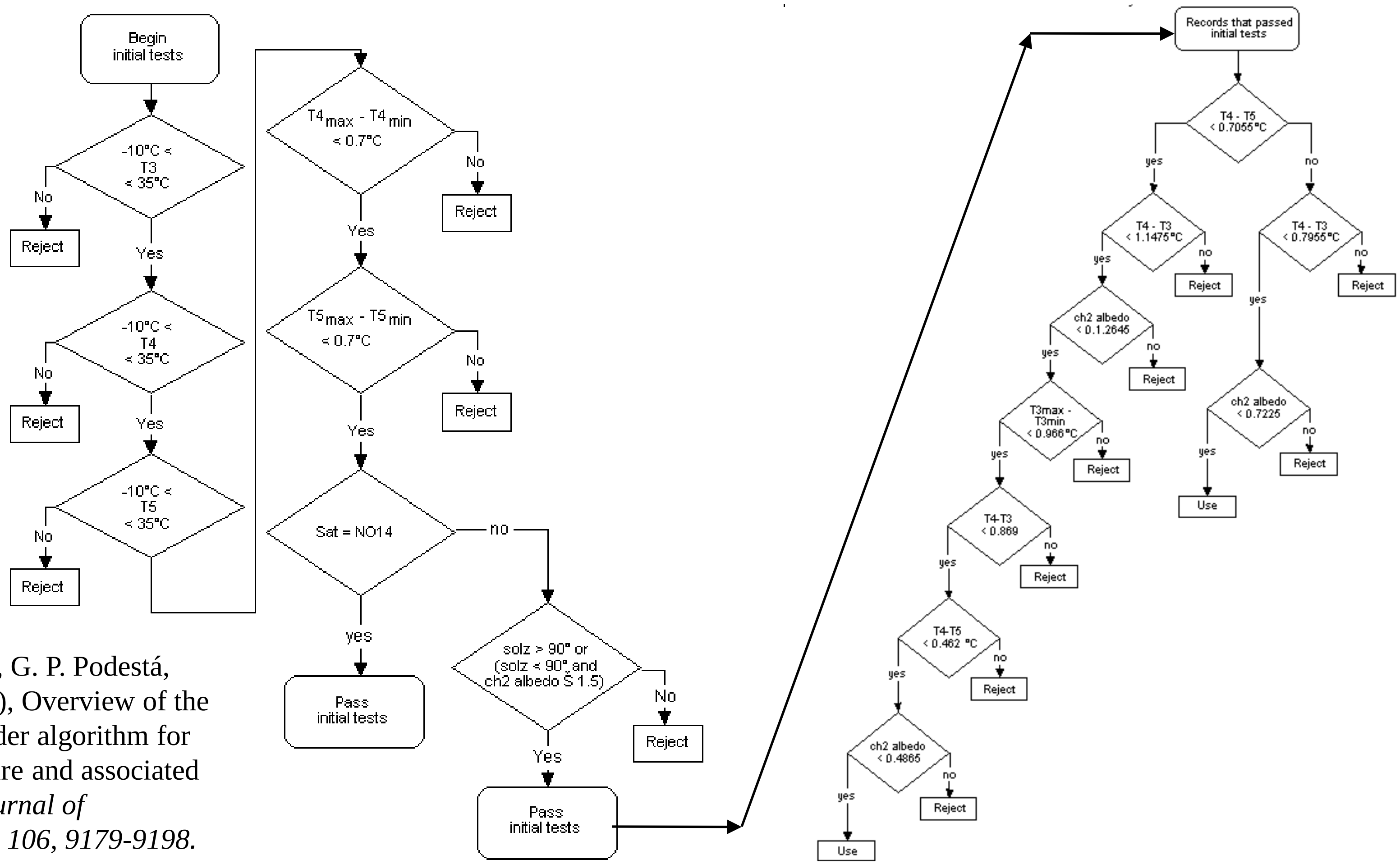
- The useful application of all satellite-derived variables depends on a confident determination of uncertainties.
- CDRs of SSTs require most stringent knowledge of the uncertainties:
  - Target accuracies: 0.1K over large areas, stability 0.04K/decade - Ohring et al. (2005) Satellite Instrument Calibration for Measuring Global Climate Change: Report of a Workshop. Bulletin of the American Meteorological Society 86:1303-1313

Sources of uncertainty in satellite-derived SSTs



Many sources of retrieval algorithm errors (green box) and geophysical and model errors (orange box) are dependent on the spatial resolution of the satellite data.

SST retrievals: identifying clouds



After Kilpatrick, K. A., G. P. Podestá, and R. H. Evans (2001), Overview of the NOAA/NASA Pathfinder algorithm for Sea Surface Temperature and associated Matchup Database, *Journal of Geophysical Research, 106, 9179-9198.*

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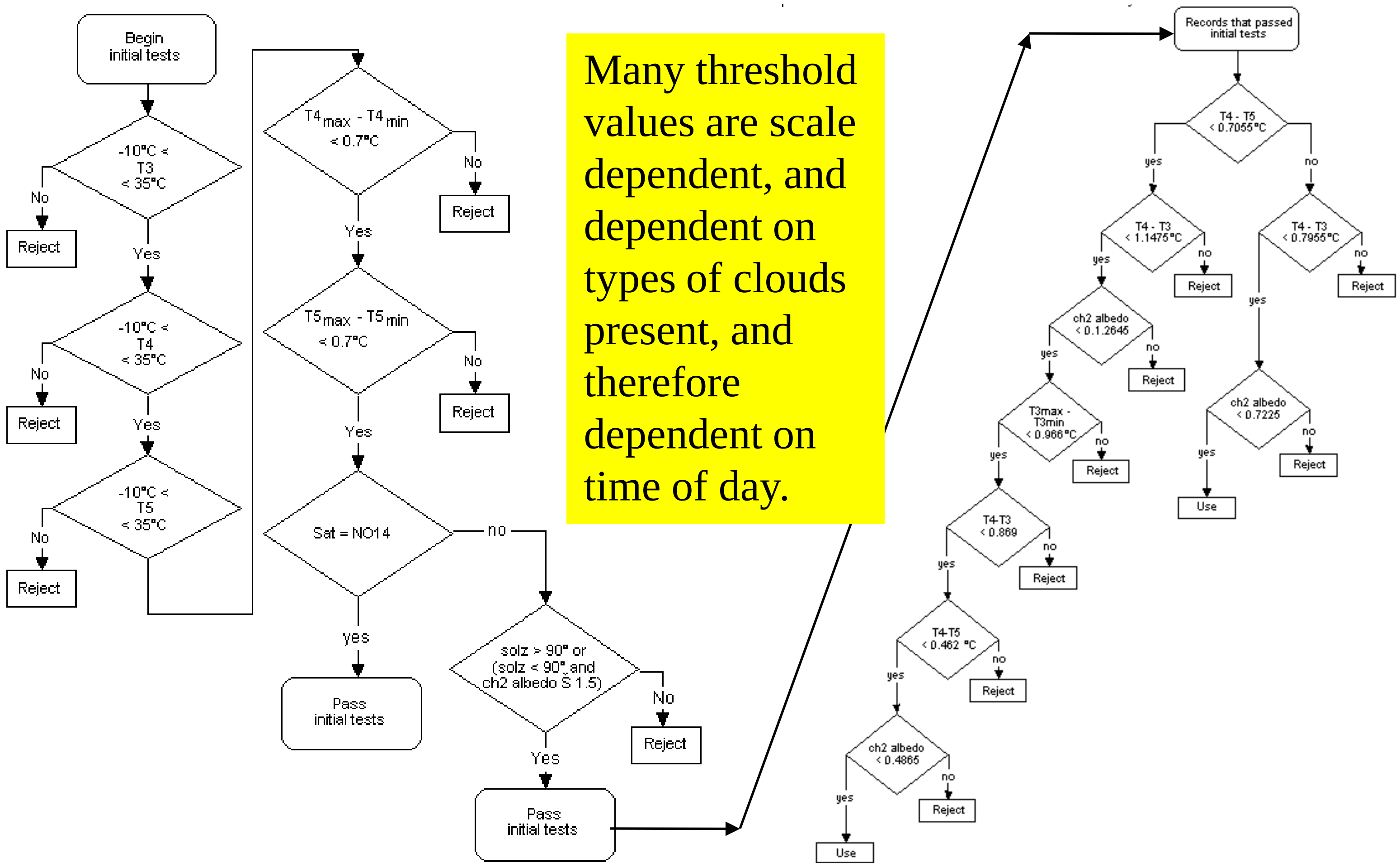
SST retrievals: identifying clouds



Many threshold values are scale dependent, and dependent on types of clouds present, and therefore dependent on time of day.

Why worry about sub-pixel variability?

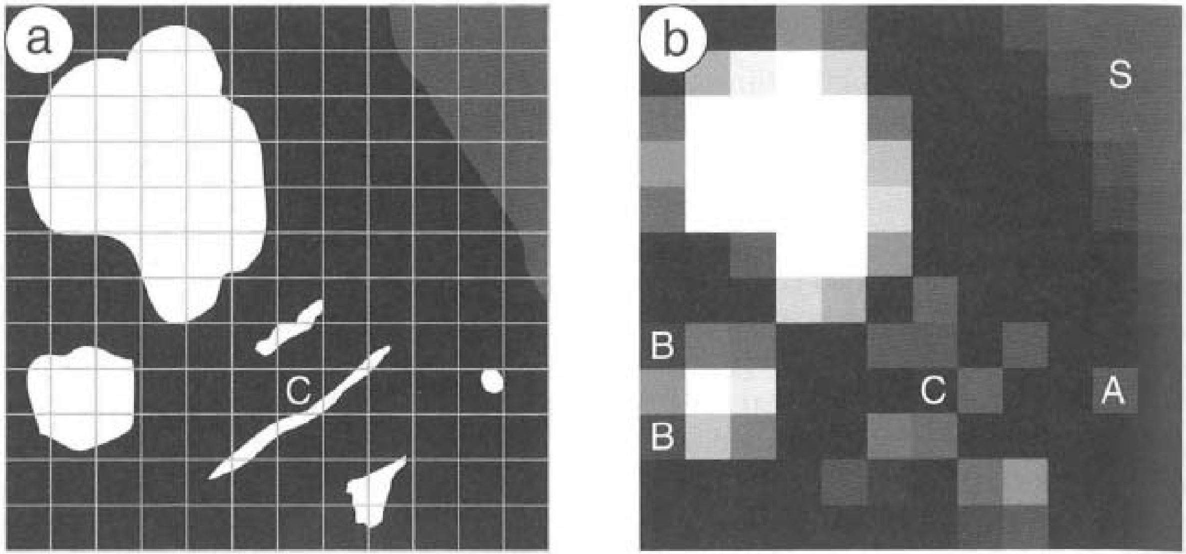


Figure 7.10. Schematic of the visible waveband view reflected from a region of partially cloudy sea. (a) As seen by a very fine resolution detector, with a coarse grid of 12 × 12 cells superimposed. (b) As it appears in the coarse pixels image.

Mixture modeling of radiances should give sub-pixel information:

$$R = \sum_{i=1}^{c} r_i a_i + e$$

From Robinson, I. S. (2004), *Measuring the Oceans from Space. The principles and methods of satellite oceanography,* 515 pp., Springer Verlag - Praxis Publishing, Chichester, UK.

Beware……

INT. J. REMOTE SENSING, 2000, VOL. 21, NO. 4, 839–843

Beware of per-pixel characterization of land cover

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R. S. DEFRIES, S. LIANG

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and K. YANG

Science Systems and Applications, Inc., Code 922, NASA-GSFC, Greenbelt MD 20771, USA

Failure to account for the MTF (Modulation Transfer Function) can lead to >10% errors in classifications

MTF of MODIS

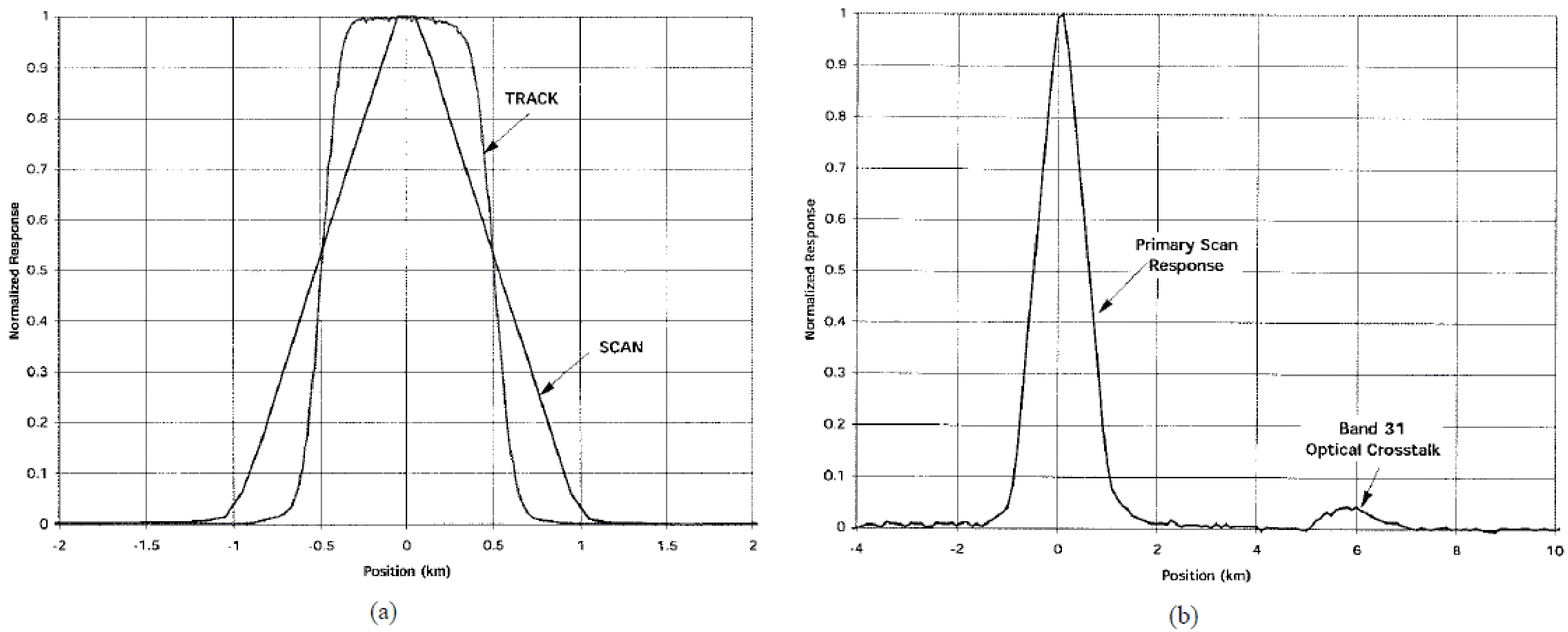


Fig. 3. Typical LSF's for MODIS. (a) Band 10, channel 6. Scan-direction LSF's are triangular due to the integration blur of the pixels in the scanning direction. Track-direction LSF's are more rectangular. (b) Band 35 has a ≈5% leak in the region of band 31 in the scan direction.

From Barnes, W. L., T. S. Pagano, and V. V. Salomonson (1998), Prelaunch characteristics of the moderate resolution imaging spectroradiometer (MODIS) on EOS-AM1, *IEEE Transactions on Geoscience and Remote Sensing, 36, 1088-1110.*

Pixel spatial response function

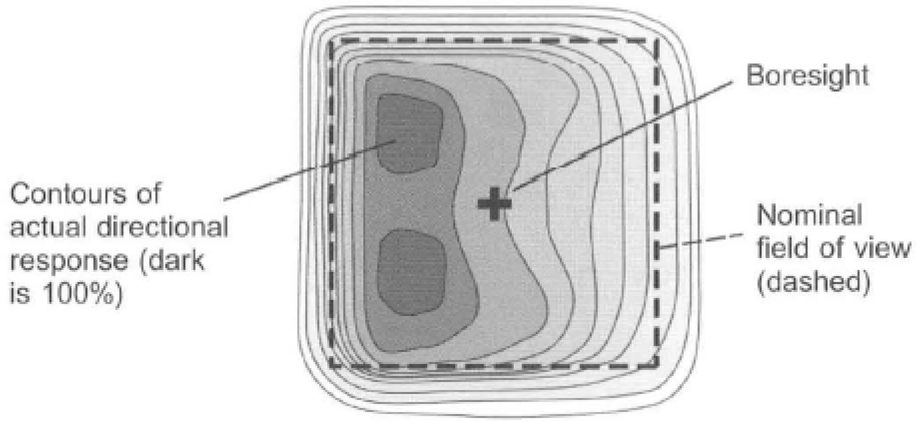
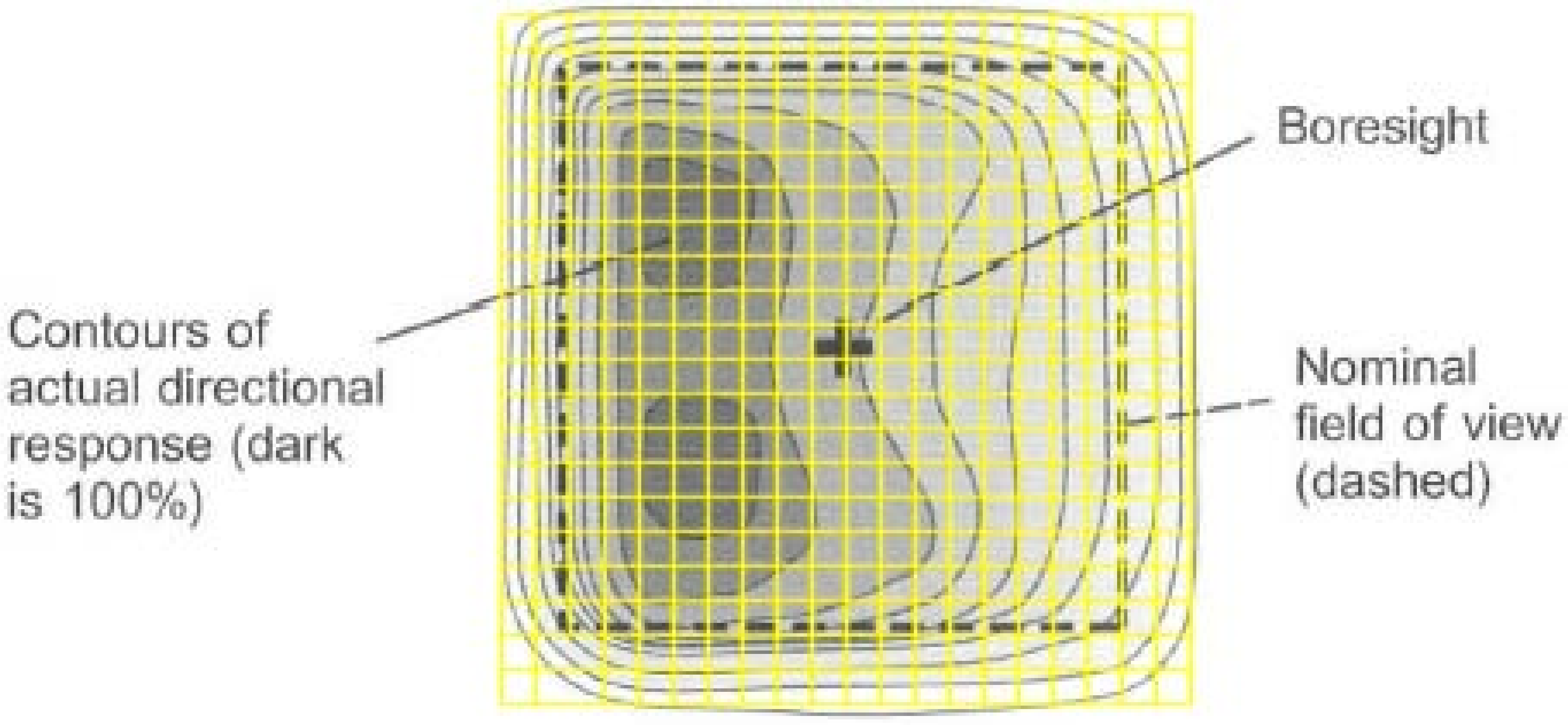


Figure 4.2. Example of a typical actual sensor 2-D response function for a sensor having a nominally square.

- Instantaneous spatial responses of detectors are not uniform.
- This compounds the MTF effect and increases errors in retrievals at the pixel scale.

From Robinson, I. S. (2004), *Measuring the Oceans from Space. The principles and methods of satellite oceanography*, 515 pp., Springer Verlag - Praxis Publishing, Chichester, UK.

HyspIRI spatial resolution



Summary

- Natural variability covers a very wide range of scales, and is not truncated at the ~1km resolution of conventional oceanic and atmospheric imagers.
- High-resolution HyspIRI data over the oceans will provide new insight into oceanic and atmospheric processes relevant to climate studies.
- Many CDRs are derived from moderate-resolution data; high-resolution HyspIRI data can provide unique data with which to test, improve, and establish the limitations on accuracies imposed by sub-pixel variability. This would guide reprocessing algorithms to improve the accuracy of CDRs.
- Improved CDRs provide a better basis for decision-makers to make hard choices… and to justify them.

One-liner….

Global HyspIRI mission **can** make a unique contribution to the climate monitoring and climate research communities.

Acknowledgements

- Colleagues at RSMAS and elsewhere
- Support from NASA PO program, Dr Eric Lindstrom

One-liner….

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