An Inter-calibrated Passive Microwave Brightness Temperature Data Record and Ocean Products

Kyle Hilburn and Frank Wentz

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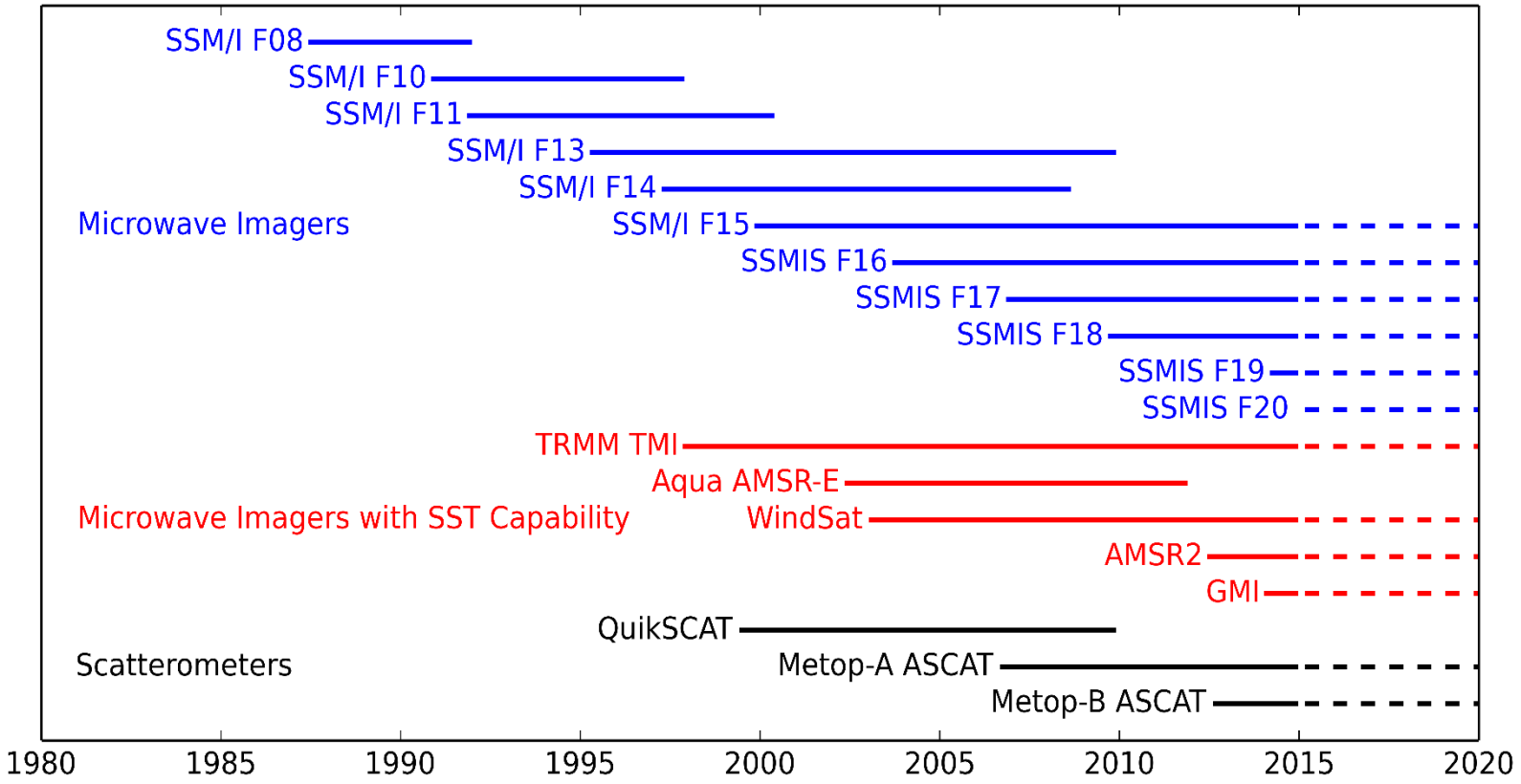
Motivation

- Irrespective of the causes of climate change, it is clear that the climate is continually changing, and that this change has an impact on world food supplies and freshwater availability.
- The increasing global population makes humans more vulnerable to the effects of climate change.
- The multi-year drought conditions in California provide a vivid example of the threats that climate change/variability can bring:
  - Freshwater availability to its 38 million residents
  - California agriculture accounts for 15% of U.S. crop receipts and produces nearly half of U.S.-grown fruits, nuts, and vegetables [*CDFA*, 2012]
- Successful adaptation to climate changes requires accurate knowledge of how the climate is changing, in particular, the spatial and temporal patterns of its variability.

Introduction

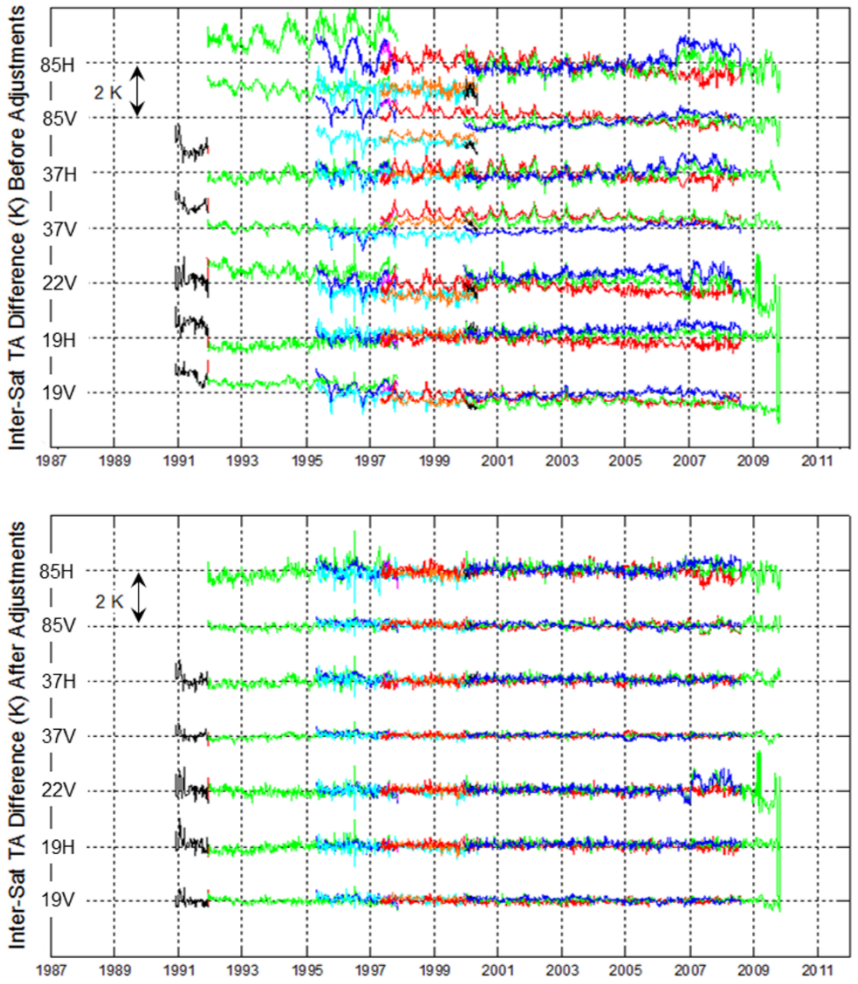
- Microwave remote sensing provides a wealth of information over the ocean
  - Ocean-atmosphere interaction is a major factor shaping the climate and its variability
  - Warm SST (>28°C) in the tropics drive deep convection in the atmosphere
  - Winds over the ocean regulate fluxes of heat, moisture, and carbon dioxide
  - Winds provide momentum to ocean currents, redistribute sea ice, and produce upwelling
  - Microwave remote sensing provides information about both SST and wind
  - Also provides information about sea ice, water vapor, clouds, and rain
- This presentation will assess the relevance and scientific impact of Remote Sensing Systems (RSS) microwave remote sensing data on our understanding of the climate
  - Scientific impact: 743 papers published over the last 14 years (2000-2013) using RSS data
  - This presentation will review the six essential climate variables provided by microwave remote sensing over the ocean
  - We will put these variables into a scientific context by highlighting recent research and discuss their relevance to the climate over land

Data



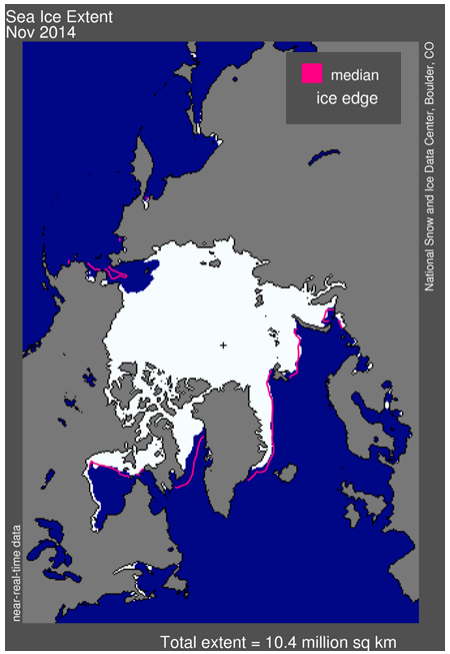
- 28 year record from 19 sensors:
  - Wind speed
  - Water vapor
  - Cloud liquid water
  - Rain rate
- 18 year record from 5 sensors:
  - Sea surface temperature
- 16 year record from 4 sensors:
  - Ocean vector wind
- Scatterometers are free of long-term drifts since winds are based on ratio of received to transmitted power
- Not shown: 36-year record of atmospheric temperature from MSU/AMSU

Methodology



- Time series of SSM/I inter-satellite TA differences
  - Before (top) and after (bottom) applying RSS inter-calibration methodology [*Wentz*, 2013]
  - Calibration to an accurate ocean radiative transfer model RTM [*Meissner and Wentz*, 2012]
  - Spillover, cross-polarization, hot-load offset, and non-linearity are adjusted to obtain the smallest inter-satellite differences
  - RTM inputs of wind, vapor, cloud from already calibrated satellites
  - RTM inputs of SST and wind direction from Reynolds and NCEP
  - Reliability of calibration at higher temperatures verified using comparisons over the Amazon
  - Separate calibration over land/ice not necessary
- Accuracy of the RTM is 0.2 K in rain-free conditions
  - Prelaunch knowledge error in spillover and hot target can be 2 K in absolute calibration
  - Thus, the ocean RTM is a better calibration reference
- Advantages of the RTM-based inter-calibration approach
  - Easily handles orbit gaps
  - Accounts for the different channel sets and viewing angles
  - Provides a precise definition of absolute calibration that can be applied to all sensors
  - Provides estimate of agreement between the RTM and measured TB

Brightness Temperature



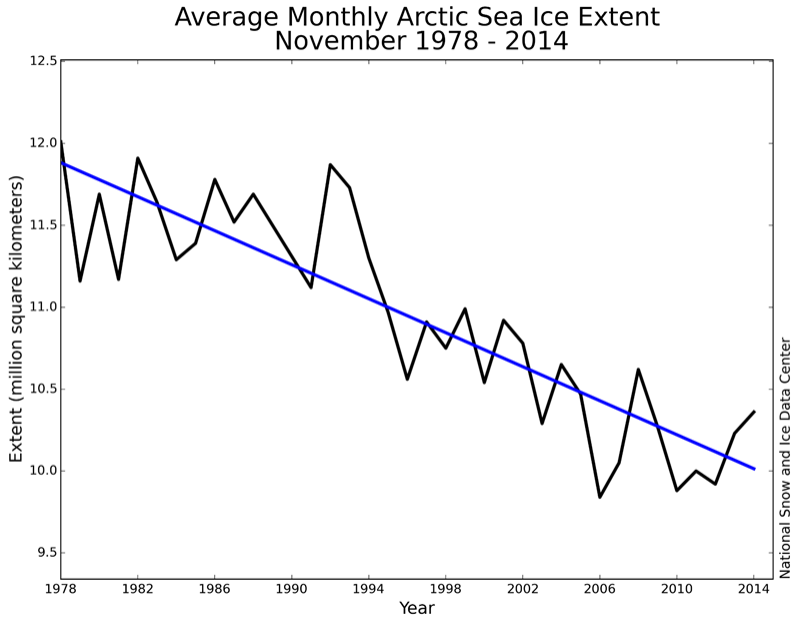
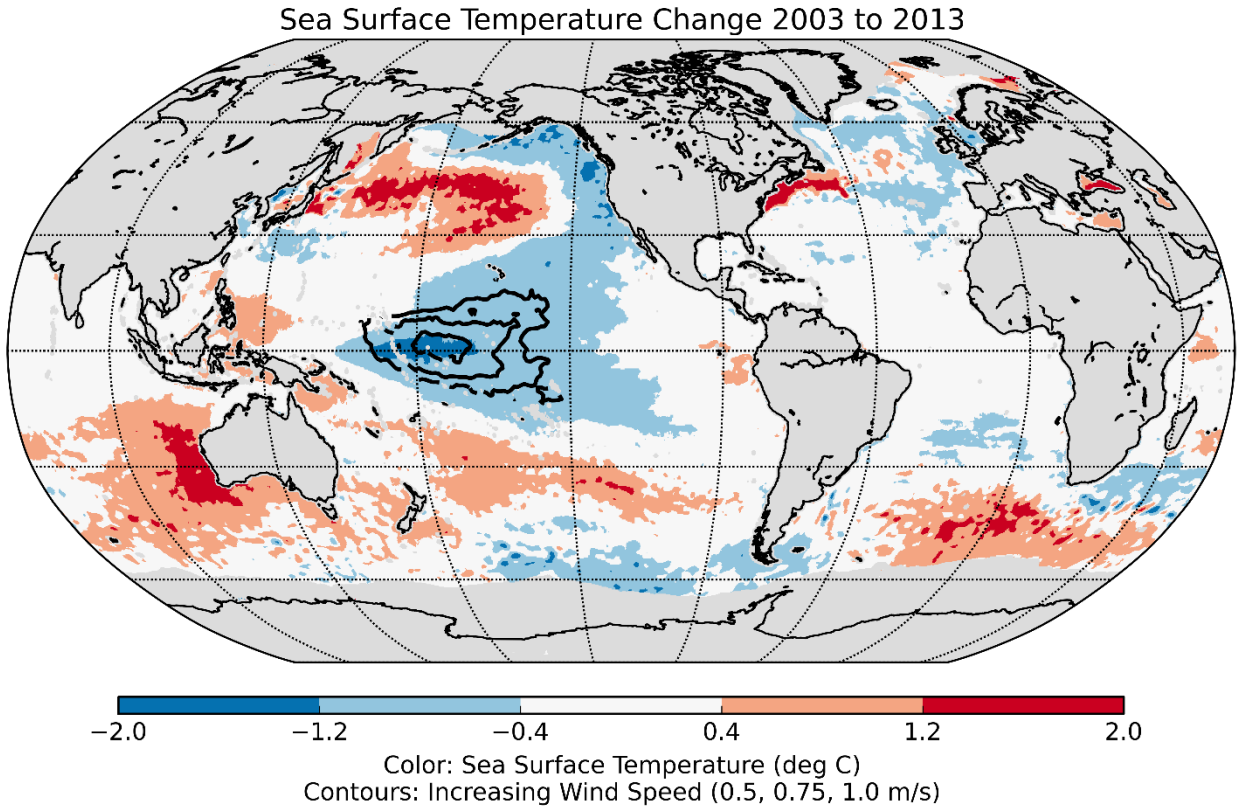


Figure [courtesy the *National Snow and Ice Data Center*] shows a map of the Nov. 2014 Arctic sea ice extent (left) and a time series (right) putting this year in context with the last 37 years

- One of the most important applications for TB is monitoring sea ice extent
- Arctic sea ice extent: 10.4M sq. km (Nov. 2014)
  - 0.5M sq. km more than the record low in 2006
  - Near-average: East Greenland, Barrents, and Kara seas
- Antarctic sea ice extent: 16.6M sq. km (Nov. 2014)
  - 0.7M sq. km above the 1981-2010 average for Nov.
  - Seasonal decline occurred at a faster-than-average pace because of persistent northerly winds reducing extent in the Bellingshausen Sea and southern Indian Ocean
- West Antarctic Ice Sheet has gone into a state of retreat due to increased basal melting caused by warm ocean water [*Joughin et al.*, 2014; *Rignot et al.*, 2014; *Schmidtko et al.*, 2014]
- Increase in warm water advection towards Antarctica believed to be caused by increase and poleward shift in ocean winds around Antarctica

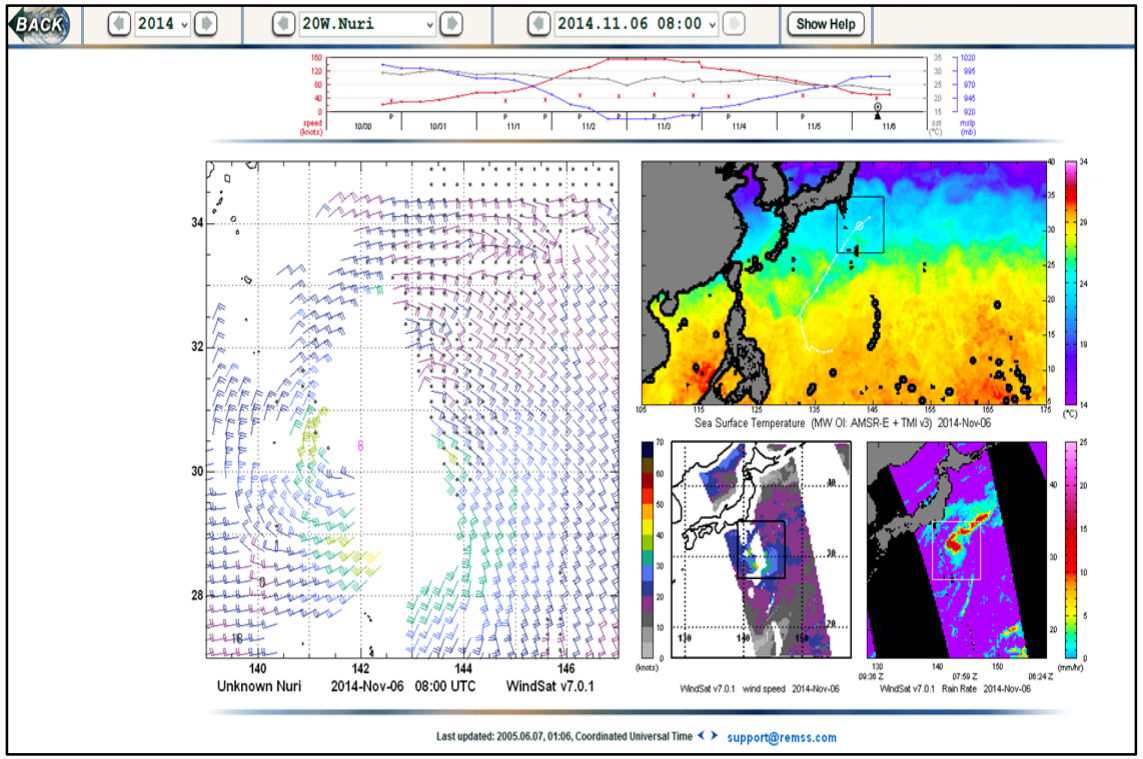
Sea Surface Temperature



RSS MW-OISST [*Gentemann et al.*, 2003, 2004]

- Classic negative phase Pacific Decadal Oscillation (PDO) pattern
  - Warm SST anomalies in the north west and north central Pacific
  - Cold SST anomalies in the north east Pacific and Gulf of Alaska
  - PDO has been in an overall negative state since 1999, but with positive PDO characteristics from 2003-2008
  - Thus, trend shows a negative PDO pattern
- In the tropics, a strong cooling signal is found along the Equator in the central Pacific
  - This corresponds to the same location where the trade winds have been increasing (black contours)
  - *England et al.* [2014] finds that the increase in the trade winds are driving Equatorial upwelling, producing colder SSTs
  - The cause of the increasing trade winds is not fully understood
  - *McGregor et al.* [2014] suggest that Atlantic warming could be a cause, but figure does not show the extensive Atlantic warming they used to force an ensemble of general circulation models
- *Benthuysen et al.* [2014] estimate two-thirds of warming off Australia due to warm water advection by Leeuwin Current, the rest due to positive air-sea heat flux into ocean

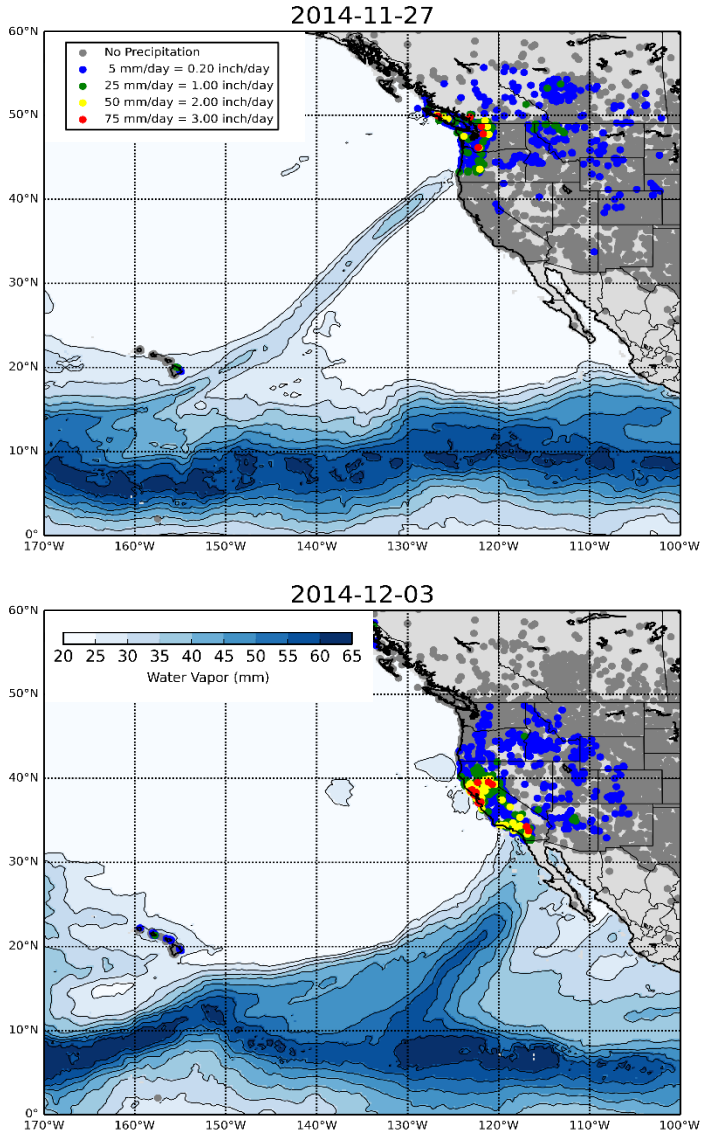
Wind Speed



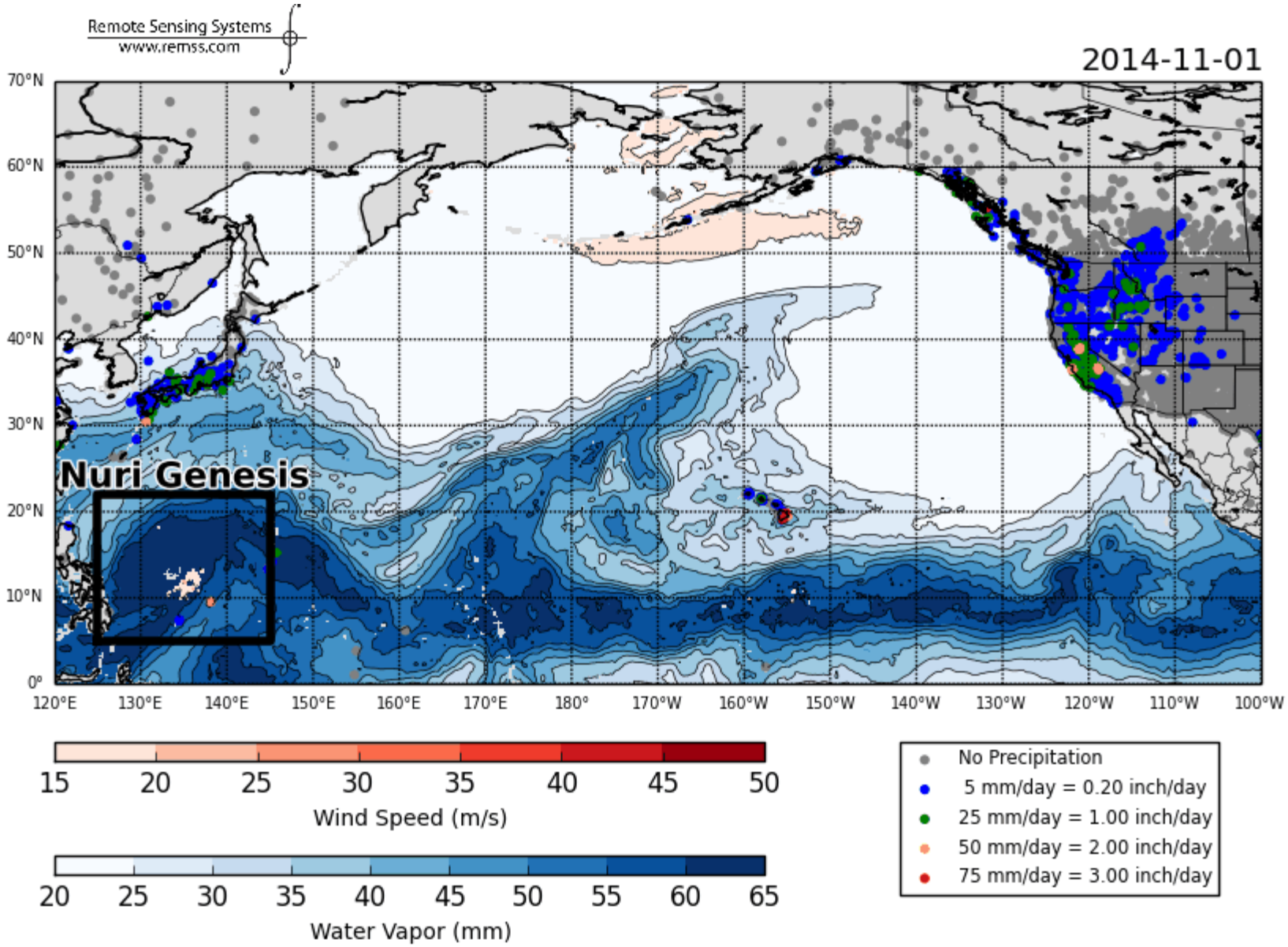
Snapshot of RSS Storm Watch page showing Super Typhoon Nuri on Nov. 6 as it was undergoing extratropical transition

- Super Typhoon Nuri
  - Formed on Oct. 30, reached peak intensity on Nov. 2.
  - Highest 10-minute sustained winds reached 57 m/s
  - Nov. 7: interacted with an unusually strong polar jet stream and became one of the most intense extratropical cyclones recorded in the North Pacific
- This interaction established an upper-level ridge over Alaska and an upper-level trough east of the Rockies
  - Nov. 11-13: 18 inches of snow for Minneapolis
  - Below-normal temperatures over eastern half of the country for most of the month; above-normal temperatures to Europe and eastern Asia
  - More information is provided by *NOAA NCDC State of the Climate Synoptic Discussion* for November 2014
- Demonstrates how one powerful storm over the Pacific can modify the hemisphere-wide circulation, with effects lasting a month after the storm
  - This is one mechanism by which the atmosphere can overcome persistent blocking high pressure
  - Relevant because of the persistent North Pacific high pressure system that has caused multi-year drought conditions for California [*Wang and Schubert*, 2014; *Swain et al.*, 2014]

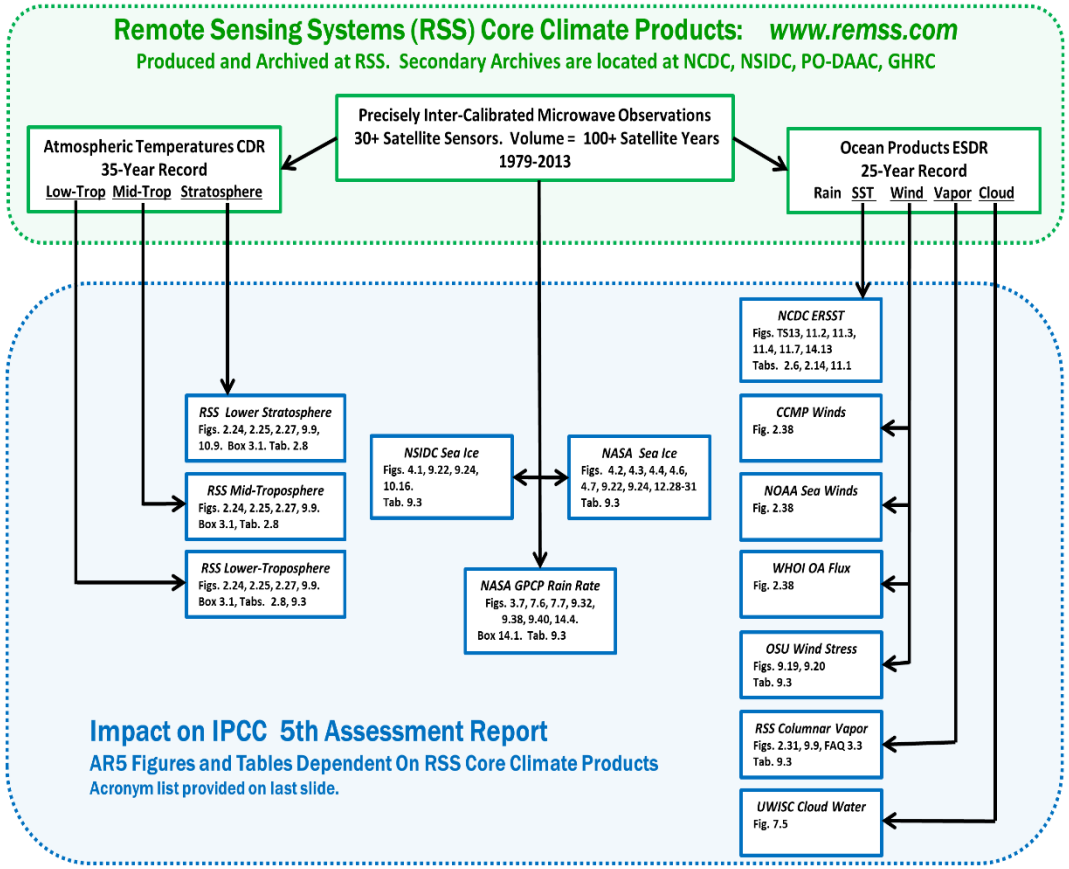
Water Vapor



- Over the past month, California's Exceptional Drought conditions benefitted from much needed precipitation
  - Brought seasonal totals to above normal for this time of year
  - Rain fell in a series of multi-day events with the first wave of light rain Nov. 20-23, a slightly stronger wave on Nov. 29 - Dec. 1, heavy precipitation Dec. 3-4, and more heavy precipitation Dec. 10-12
- Figures show RSS merged daily water vapor over the ocean and GHCN rain gauge daily totals over land
  - Nov 27 (top): The storm bringing the plume of moisture in the top panel had its origins in the western Pacific.
  - The storm appeared to interact with a pool of moisture at 150W, 13N with values of 55-60 mm on Nov. 25, but interaction was limited by the strong trade winds rapidly carrying moisture west
- California finally received heavy precipitation from Dec. 3 storm (bottom)
  - A tropical feed of moisture from the East Pacific is evident, and there was precipitation in Southern California
  - The next round of heavy precipitation did not have a tropical feed, driven instead by powerful dynamics, showing that atmospheric rivers are only part of the picture

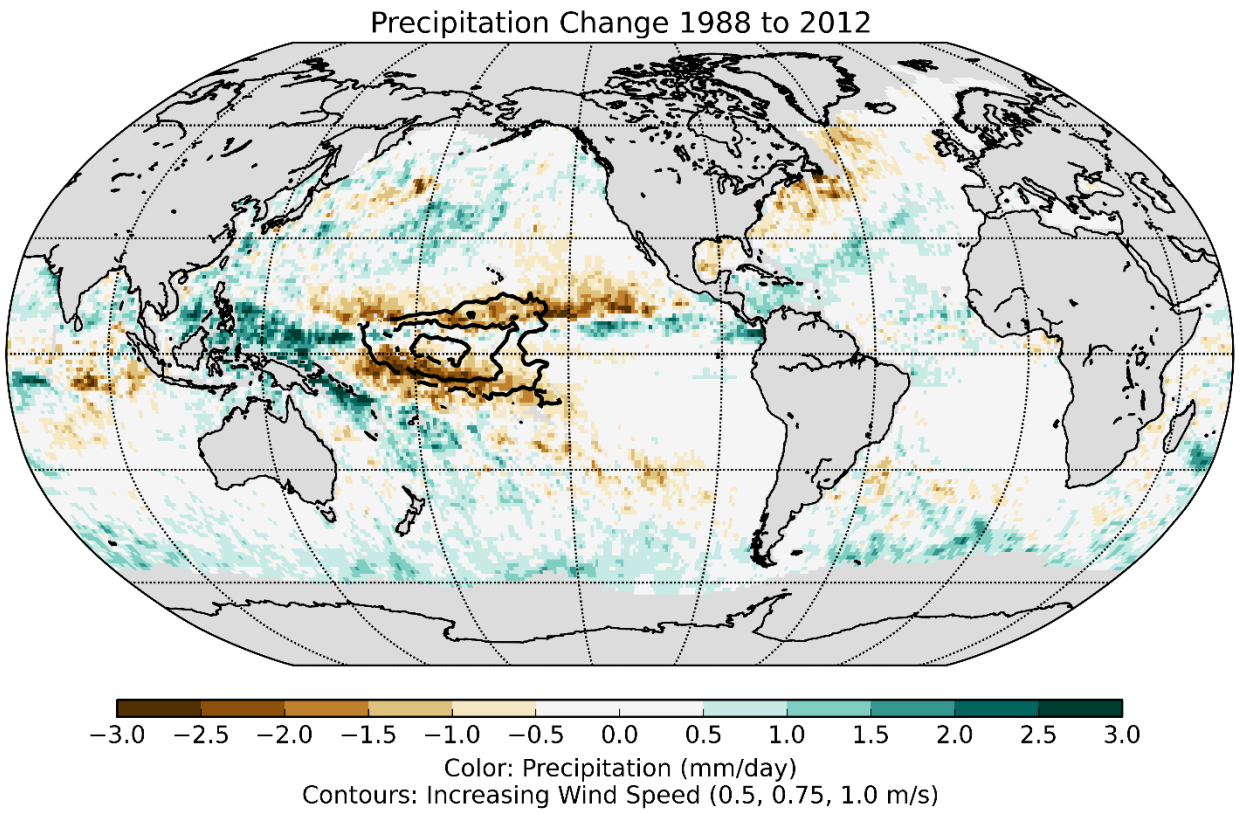

Remote Sensing Systems
www.remss.com
2014-11-01
70°N
60°N
50°N
40°N
30°N
20°N
10°N
0°
120°E
130°E
140°E
150°E
160°E
170°E
180°
170°W
160°W
150°W
140°W
130°W
120°W
110°W
100°W
Nuri Genesis
15
20
25
30
35
40
45
50
Wind Speed (m/s)
20
25
30
35
40
45
50
55
60
65
Water Vapor (mm)
No Precipitation
5 mm/day = 0.20 inch/day
25 mm/day = 1.00 inch/day
50 mm/day = 2.00 inch/day
75 mm/day = 3.00 inch/day

Cloud Water



- RSS cloud water used in IPCC 5th Assessment Report (AR5)
- Cloud water dataset constructed by *O'Dell et al.* [2008]
- In total: 13 datasets used in the AR5 report derived from RSS data
- Several datasets in AR5 make use of RSS winds, including:
  - Cross-Calibrated Multi-Platform wind product [*Atlas et al.*, 2011]
  - NOAA Sea Winds product [*Zhang et al.*, 2006]
  - WHOI OAFlux product [*Yu and Weller*, 2008]
  - OSU Wind Stress product [*Risien and Chelton*, 2006]
- RSS SSTs are used in Reynolds OISST [*Banzon and Reynolds*, 2013], which are used by NCDC ERSST
- RSS columnar water vapor dataset
- RSS atmospheric temperature from MSU/AMSU
- GPCP precipitation [*Huffman et al.*, 2009], uses RSS TB
- Cites 11 peer-reviewed papers with RSS scientists as primary authors

Rain Rate



RSS 1-deg, monthly Rain product

- Pacific Decadal Oscillation (PDO) in negative phase since 1999
- Tropics: resembles a more La Nina-like state with substantial negative precipitation anomalies in the central Pacific
- Along the Equator, the easterly trade winds in the central Pacific have been increasing (black contours)
  - Produced moisture divergence along the edges of the area, resulting in the negative precipitation anomalies
  - Produced moisture convergence in the far western Pacific, resulting in the positive anomalies
  - Trend in water vapor shows the same pattern as precipitation
- Negative anomalous latent heating associated with the observed deficit in central tropical Pacific rainfall is mainly responsible for the quasi-stationary wave patterns that increase the odds of cold winters in Europe [*Trenberth et al.*, 2014]

Summary and Conclusions

- Remote Sensing Systems produces microwave satellite data records for climate monitoring and research
  - Methodology is based on calibration to an accurate ocean radiative transfer model
  - Data have made substantial contributions to climate reports and to the body of scientific literature
  - Data quantify processes over the ocean that influence weather and climate over land
- Microwave brightness temperatures are used to monitor Arctic and Antarctic sea ice
  - The increasing winds around Antarctica are believed to be increasing the rate of Antarctic ice melt
  - This melting, which is expected to occur over the next several centuries, could raise sea level up to 16 feet
  - Adaptation, constrained by economic and human factors, will require accurate predictions of the rate of Antarctic ice melt
  - Monitoring ocean winds will likely play a role in accurate prediction of sea level rise
- Ocean winds are also important given the example of Super Typhoon Nuri
  - One powerful storm can have a hemisphere-wide impact on the atmospheric circulation; relevant to drought
  - A warmer world is likely to have more super storms like Nuri, it is important to understand the impact on climate variability
- Clear signs of PDO across northern Pacific, and tropical Pacific has tended towards a more La Nina-like state
  - Increased trade winds in the central Pacific have produced extensive cold SST anomalies
  - Increased trades produced moisture divergence and negative precipitation anomalies in central Pacific
  - Central Pacific precipitation anomalies have teleconnections with cold winters in Europe
  - Increased trades also produced moisture convergence in the far western Pacific, where precipitation has increased
  - Understanding the causes for the increased trade winds remains an area of active scientific inquiry