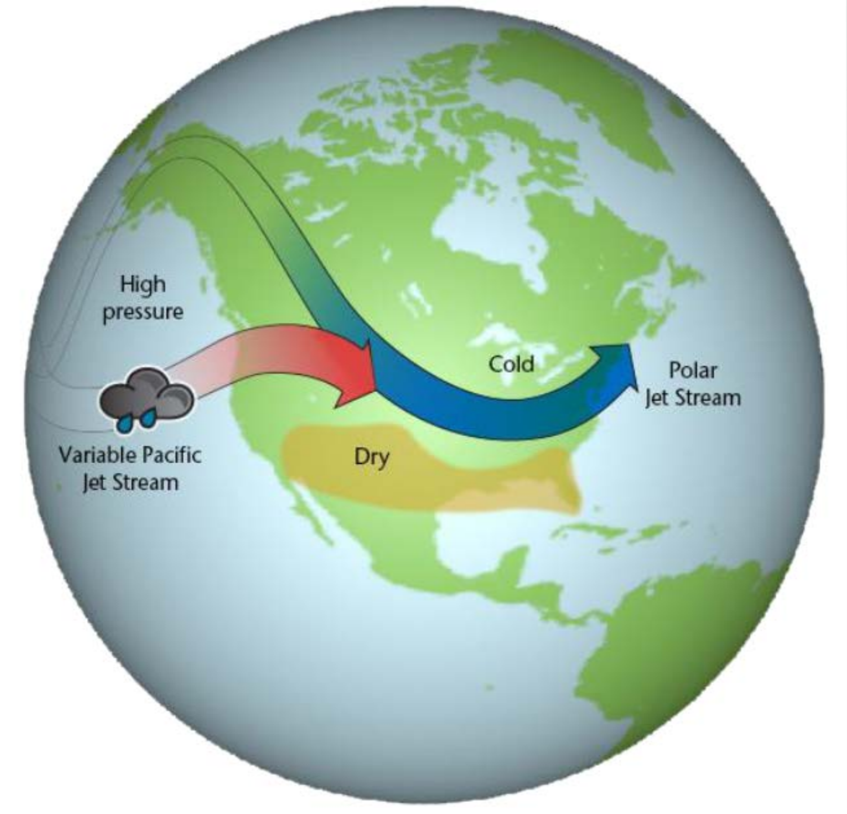
Introduction

- Why do we care about the tropical warm pool?
- How do you like your winter so far?
  - Especially central and eastern US
- Signature of La Nina influence on US winter weather



La Nina occurring?

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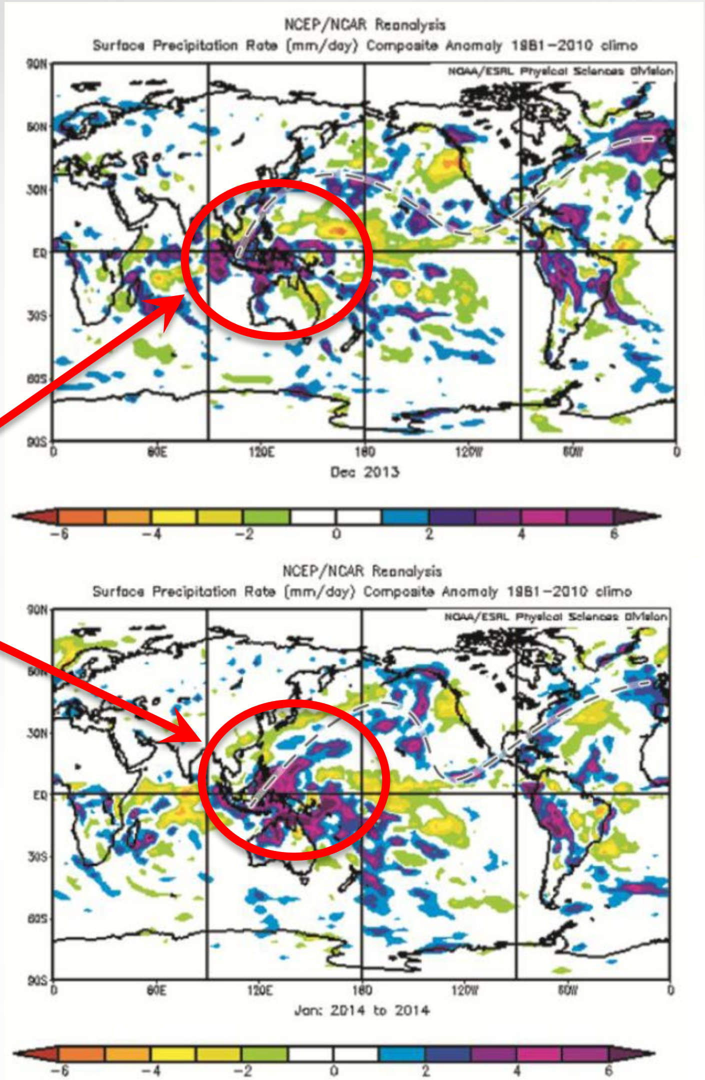
- Typically defined by SST anomalies
  - Southern Oscillation Index (SOI, Aus BoM) and Oceanic Nino Index (ONI, National Climatic Data Center) are neutral
- But NCEP Reanalysis shows La Nina-like precipitation anomalies
- So while our SST-based definition of “La Nina” hasn’t been met, the associated convective and precipitation signature has occurred, which is what drives the circulation

Dec 2013

Jan 2014



Why should we care to understand the tropical warm pool regime?

- Unlike Vegas, what happens in the warm pool doesn’t stay in the warm pool!
- The warm pool area drives teleconnections all over the globe, including here in the USA.
- ARM and ASR objectives of improving global models cannot be effectively achieved without furthering our understanding of tropical warm pool processes, variability, and teleconnections.

Review of Tropical Western Pacific (TWP) Research Highlights

CHUCK LONG (and many, many contributors!)

Pacific Northwest National Laboratory

Richland, WA

March 12, 2014

Early ARM TWP Scientific Concerns

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- From the beginning ARM recognized the importance of the TWP and Arctic regimes as the climatological antipodes of the Earth system.
  - A significant lack of scientifically usable data for cloud and radiation research
- Original ARM Science Plan (1996) identified some very basic TWP scientific issues and led to the initial TWP science goals:
  - Determining the magnitude of the surface radiation budget terms and their spatial and temporal variability.
  - Identifying bulk and optical properties of clouds in the TWP and how these properties affect the radiation budget.
  - Understanding the linkages among sea surface temperature, ocean–atmosphere coupling, surface radiation budget, and tropical convection.
  - Determining vertical transports of water vapor, energy, and momentum in convective cloud systems.

TWP Sites

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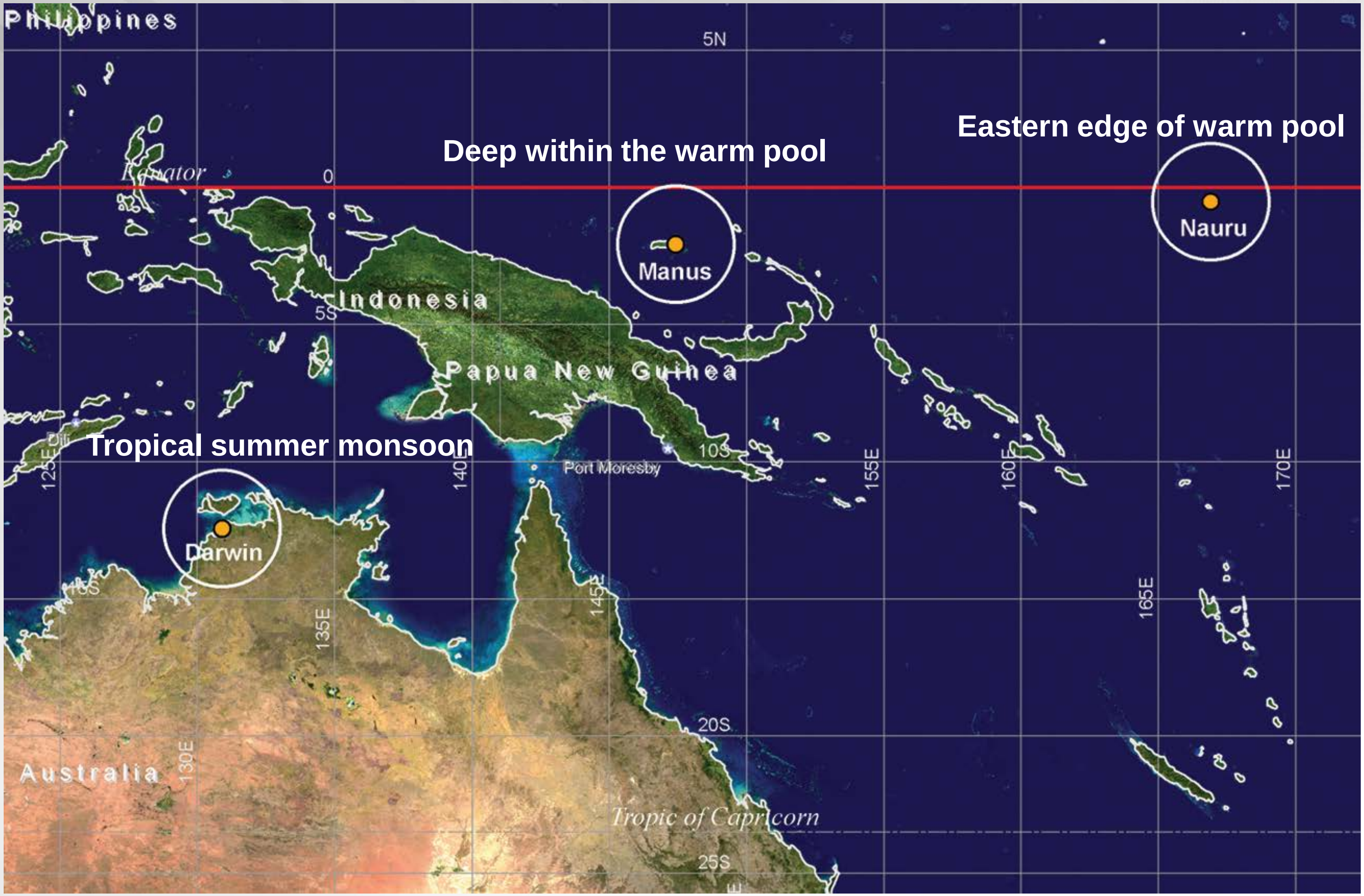

Surface Radiation Budget and Variability

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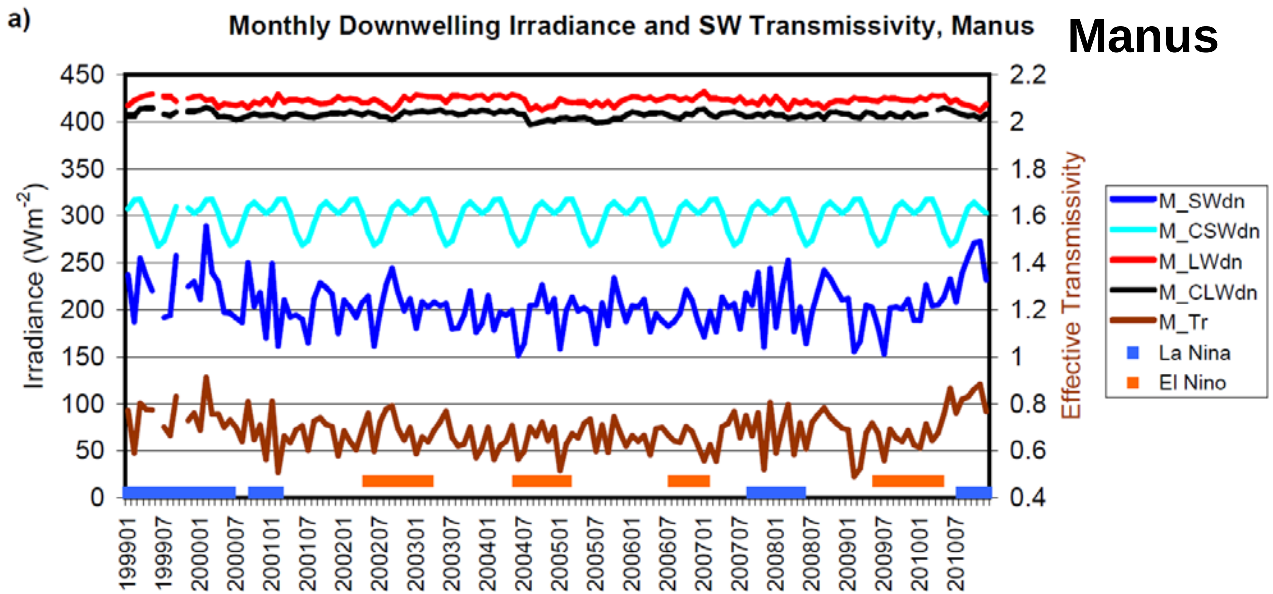
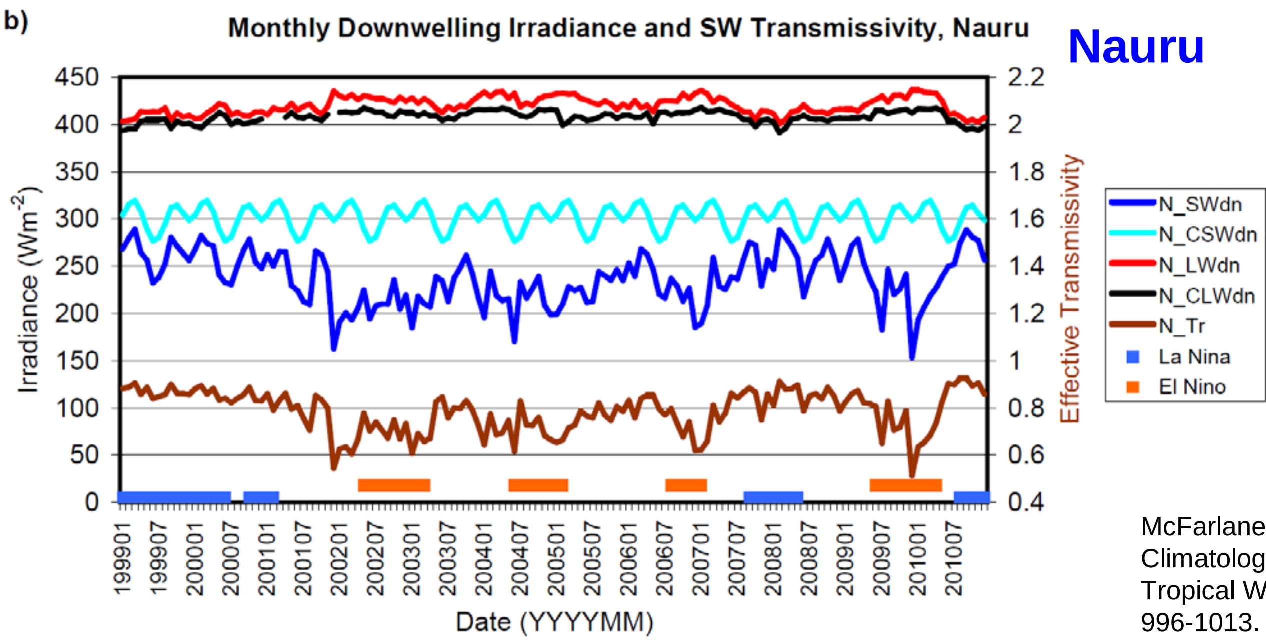




- (Manus/Nauru)
- Clr SWdn about same: (300/302)
- SWdn (205/237)
- SW CRE (-95/-65)
- Clr LWdn about same (407/408)
- LWdn also about same (423/421)
- LW CRE small (15/12)
- Manus Tr 0.6-0.8
- Nauru >0.8 half the time, often associated with La Nina periods

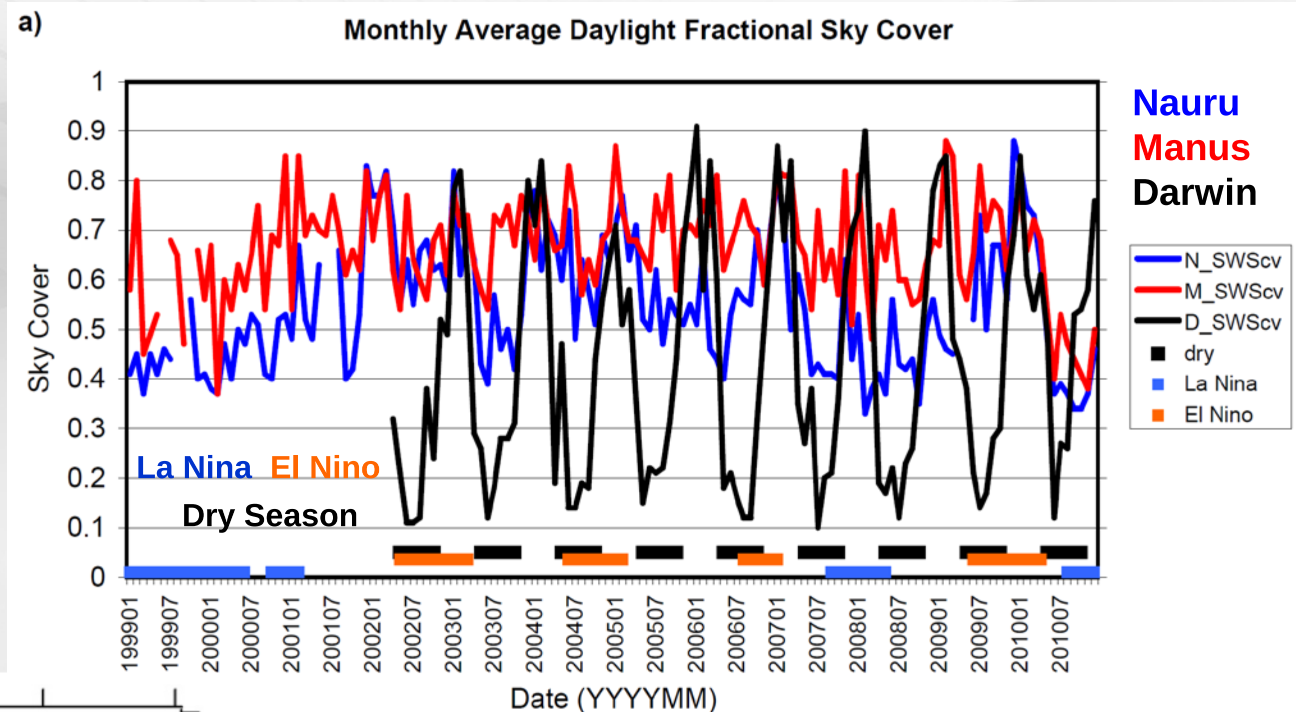
McFarlane, S. A., C. N. Long, J. Flaherty, 2013: A Climatology of Surface Cloud Radiative Effects at the ARM Tropical Western Pacific Sites. J. Appl. Meteor. Climatol., 52, 996-1013. doi: http://dx.doi.org/10.1175/JAMC-D-12-0189.1

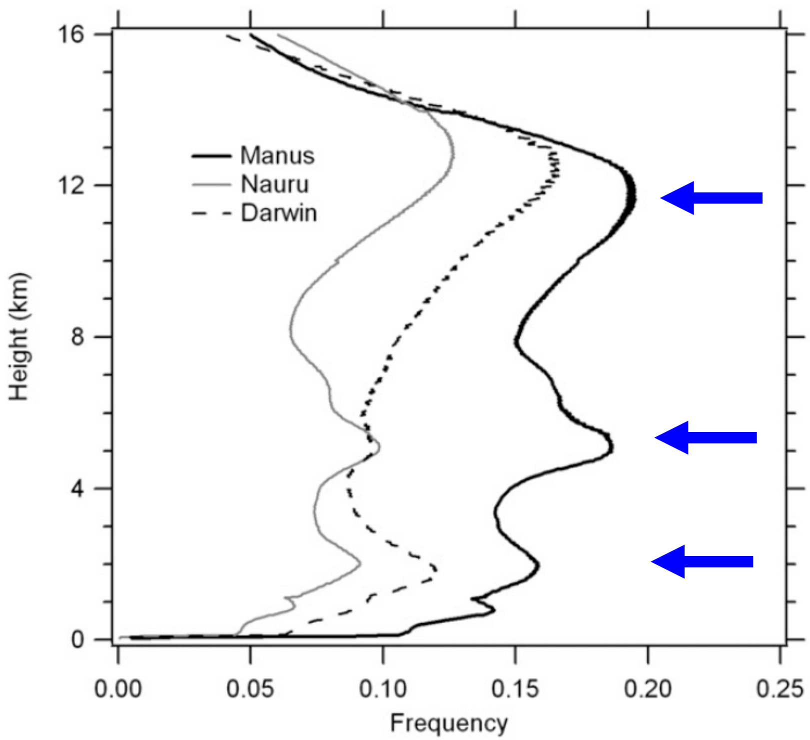
Bulk Cloud Properties

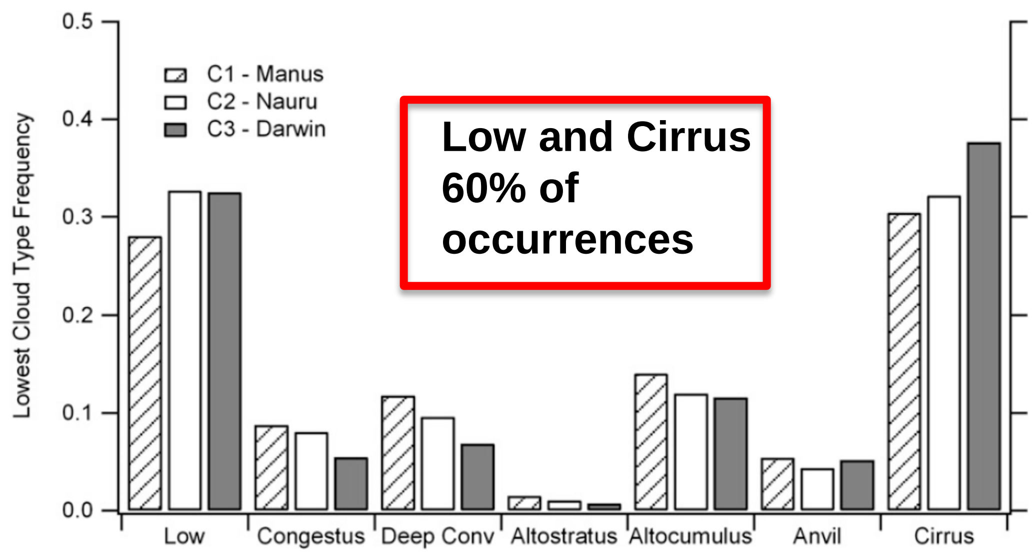
Nauru influenced by ENSO, Manus not

Darwin distinct differences for wet/dry seasons

Trimodal distribution (shallow, midlevel, and high clouds)







Low and Cirrus 60% of occurrences

Lowest Cloud Occurrence

Bulk Optical Properties and Radiative Effects

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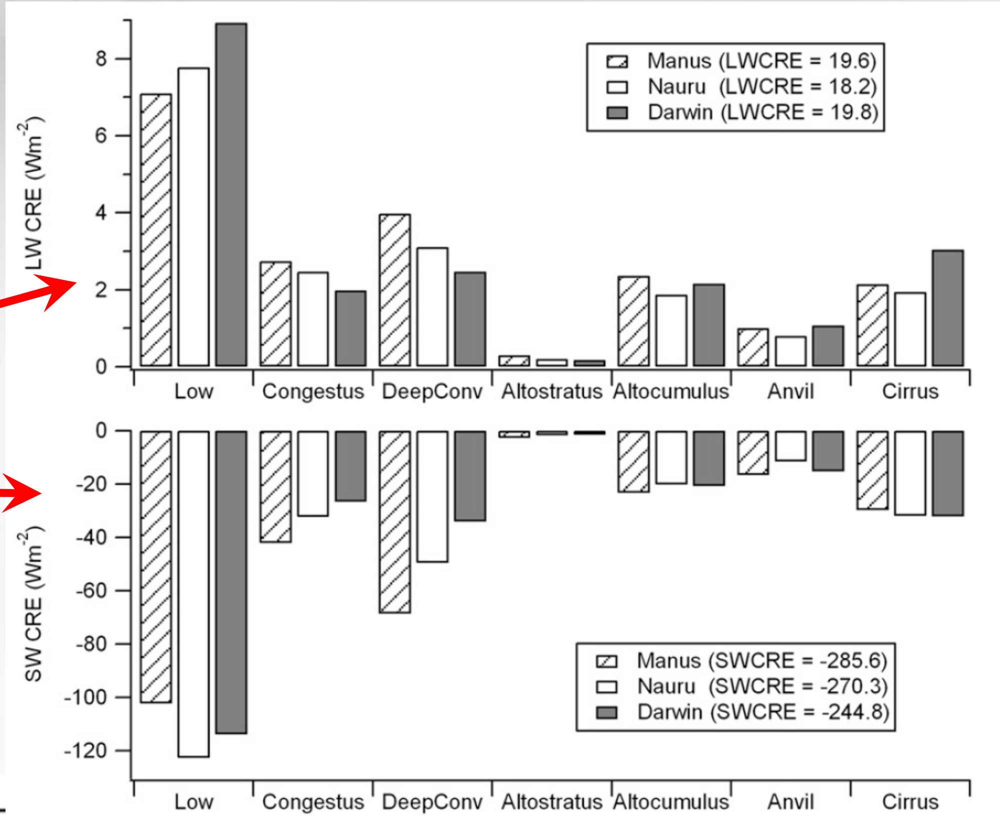
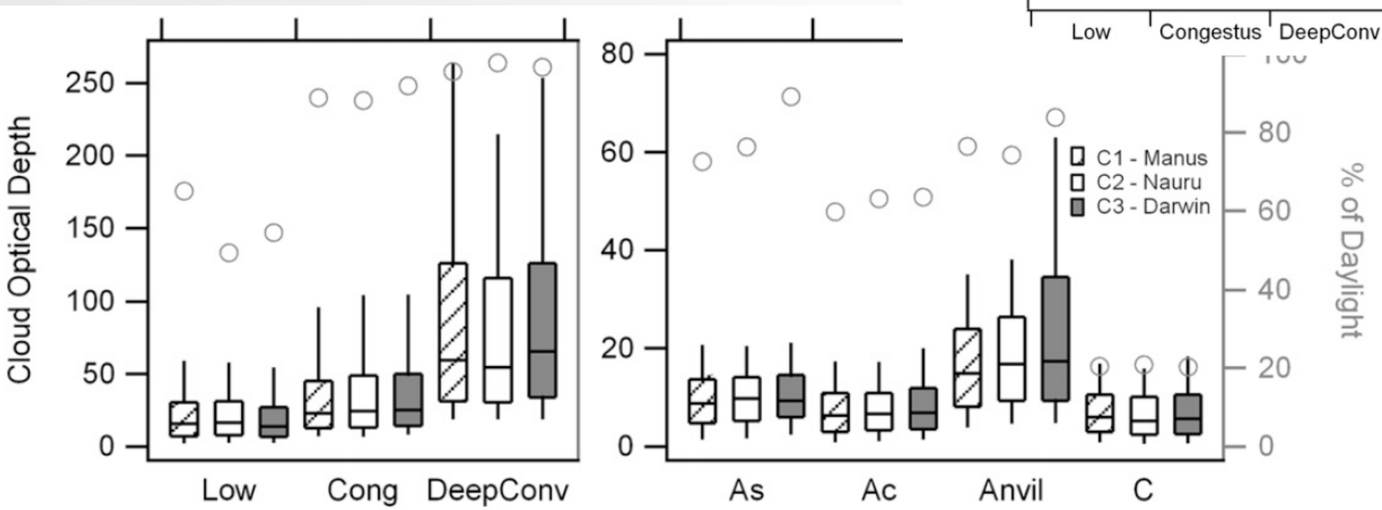
Mean Cloud Radiative Effect (CRE) by cloud type for each site

LW CRE dependent on cloud base height (temperature)

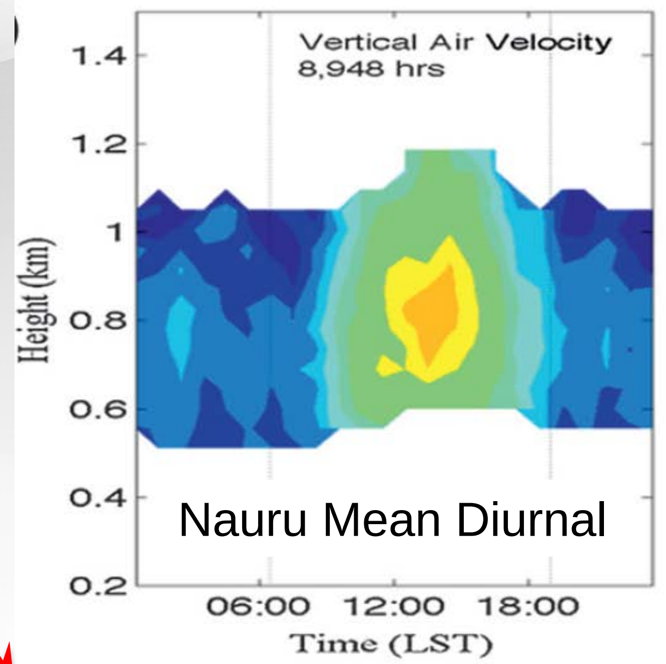
SW CRE dependent on cloud optical depth

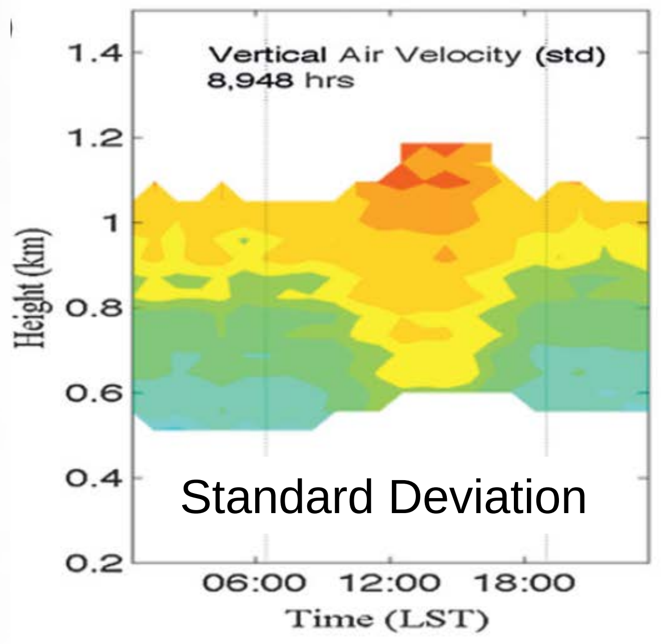




Cloud Properties and the Environment

- Statistical distributions of in-cloud vertical velocity (Kollias and Albrecht 2010)
- Environmental characteristics and shallow to deep convective transitions (Jensen and Del Genio 2006)
- Cirrus microphysics relationship to convection (Mace et al. 2006; Comstock et al. 2002)





Kollias, P., and B. A. Albrecht, 2010: Vertical velocity statistics in fair-weather cumuli at the ARM TWP Nauru climate research facility. J. Climate, 23, 6590–6604.

Radiative Heating Rate Profiles

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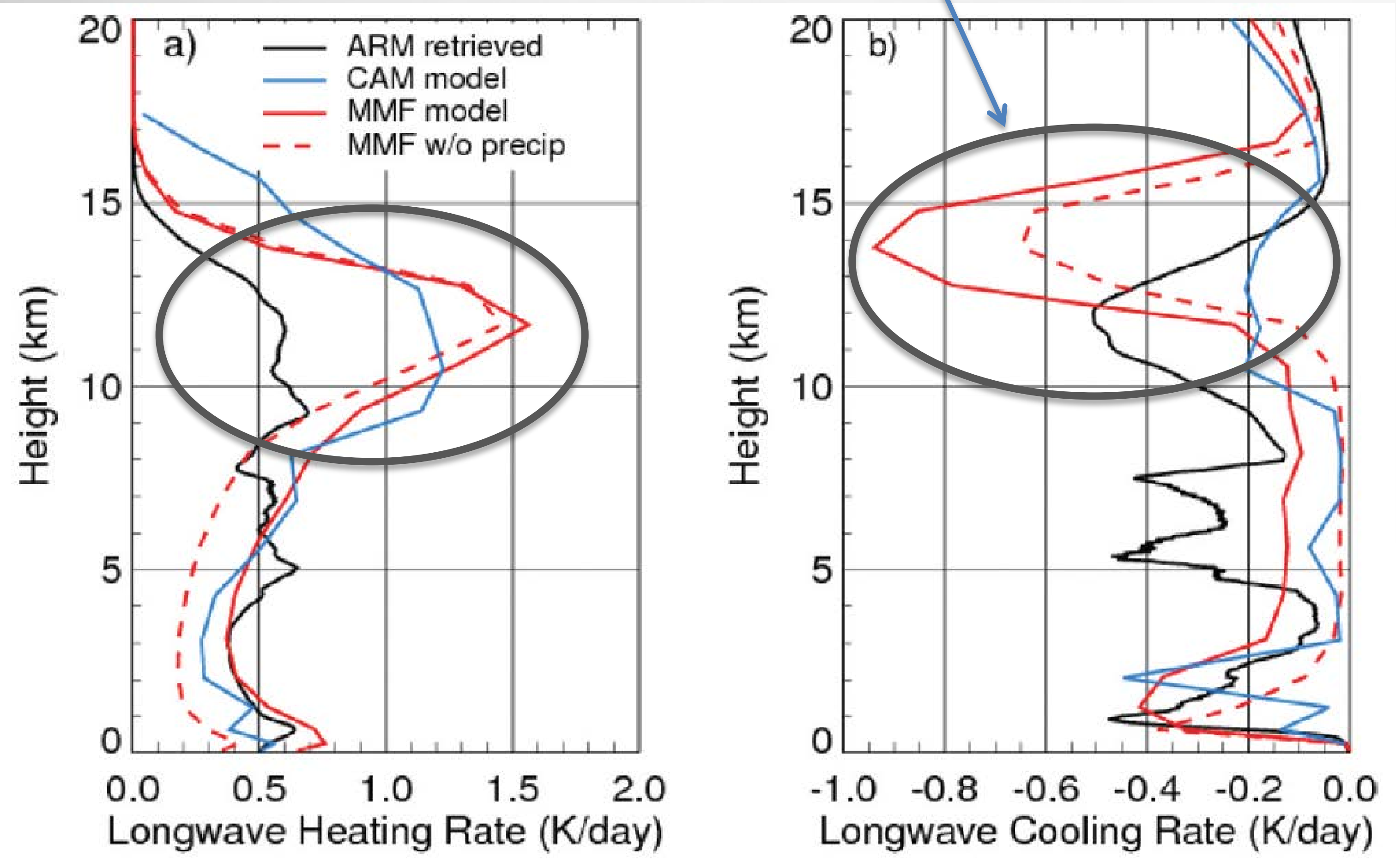
- Vertical profile of radiative heating due to tropical clouds (Mather et al. 2007; McFarlane et al. 2007; Fueglistaler and Fu 2006)
- McFarlane et al. (2007) show MMF and conventional CAM3 has more high clouds, and produces a peak LW heating & cooling about 2 km higher than the ARM retrieved profiles, with CAM having significantly less LW cooling.



Model Evaluation and Development

- Overarching goal of ARM/ASR is to improve models
- TWP long-term data on cloud and environmental vertical structure have been invaluable for testing cloud parameterizations and physical process deficiencies
  - Ovtchinnikov et al. (2006) show MMF performs better than CAM for Nauru, but not for SGP
  - Boyle et al. (2005) show CAM underpredicts low and mid clouds, but overpredicts high cloud amounts relative to ARSCL at Manus & Nauru
  - Comstock and Jakob (2004) compare ARSCL to ECMWF, show half the Nauru cirrus not associated with convective events
  - Romps and Kuang (2011) show most Nauru convective parcels originate in lowest 100m of atmosphere, implications for GCM CAPE estimates and entrainment parameterizations

TWP-ICE (Tropical Warm Pool – International Cloud Experiment)

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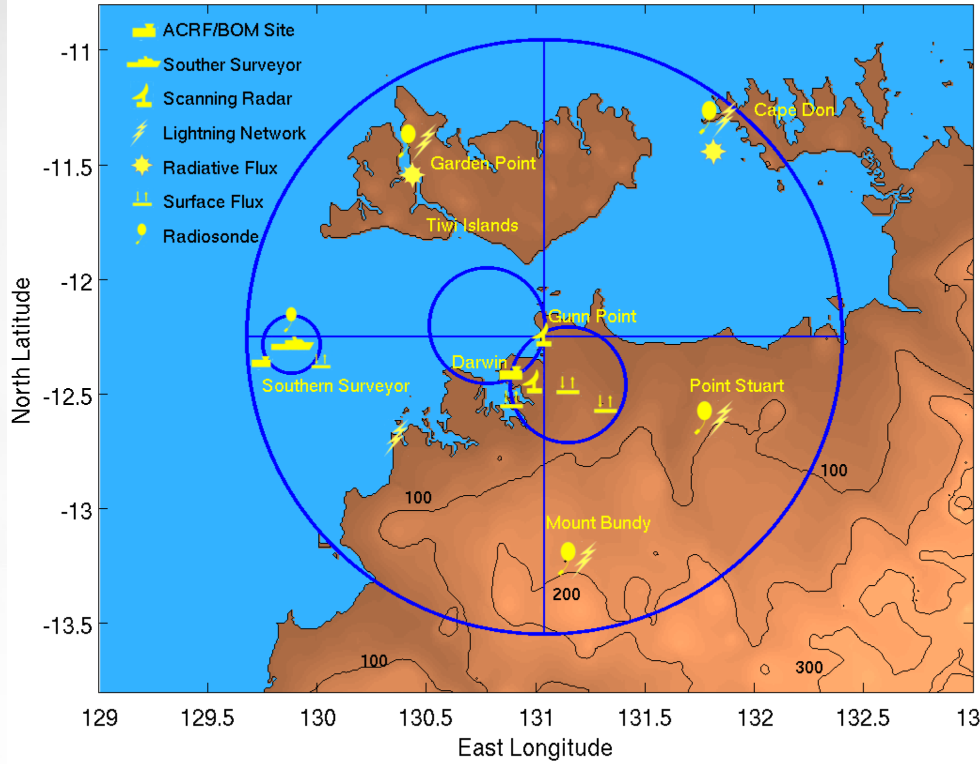
- Jan-Feb 2006 around Darwin
- Including 5 aircraft
- And 5 surrounding sonde sites
- Aimed at study of tropical convection and cirrus, including microphysics
- The only <u>model forcing data set</u> ARM TWP has produced
- Has spawned a wealth of papers and studies

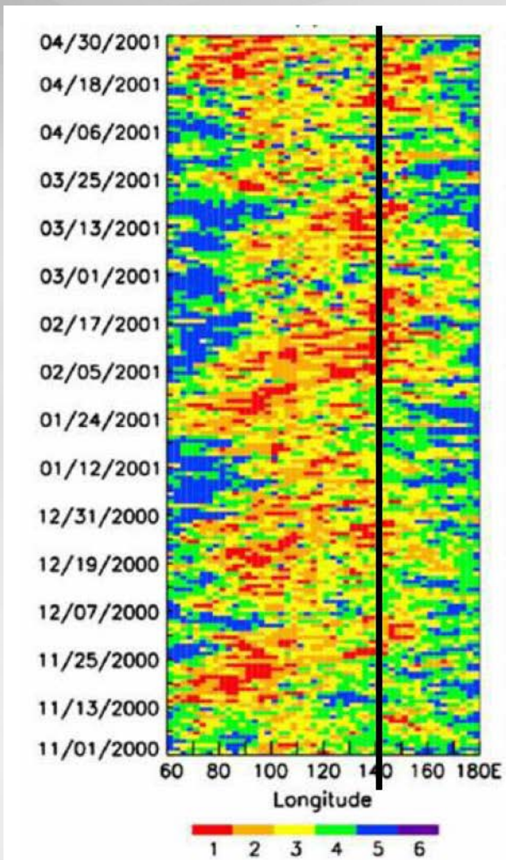


May PT, JH Mather, G Vaughan, KN Bower, C Jakob, GM McFarquhar, and GG Mace. 2008. "The tropical warm pool international cloud experiment." Bulletin of the American Meteorological Society, 89(5), doi:10.1175/BAMS-89-5-629.

Intraseasonal Variability: MJO

Manus clouds and radiation influenced by MJO, Nauru not

(Nauru influenced by ENSO, Manus not)



Cluster analysis of ISCCP cloud regimes (red = deep convective, orange = anvil, yellow = congestus, green = thin cirrus, blue = trade Cu, violet = marine Sc)

Left: TWP Hovmöller diagram of regime occurrence
Below: Composite regime occurrence vs. MJO phase (peak = 0)

(Chen and Del Genio, 2009, Clim. Dyn.)

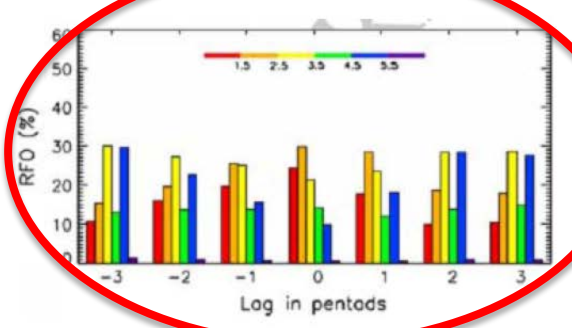
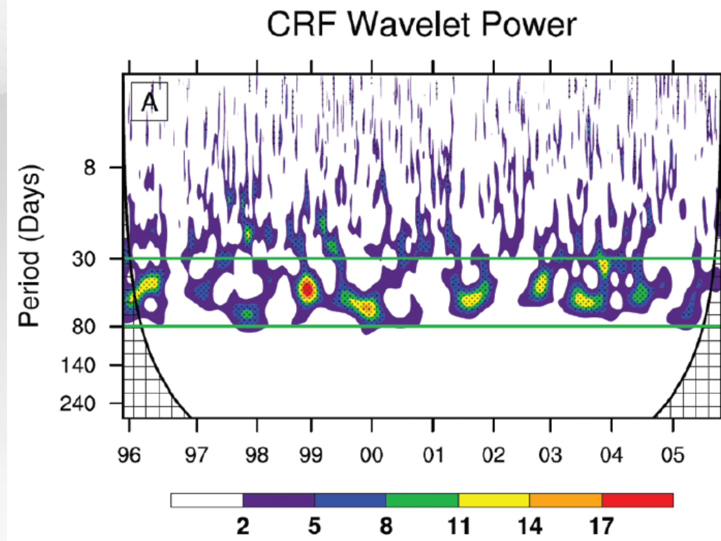
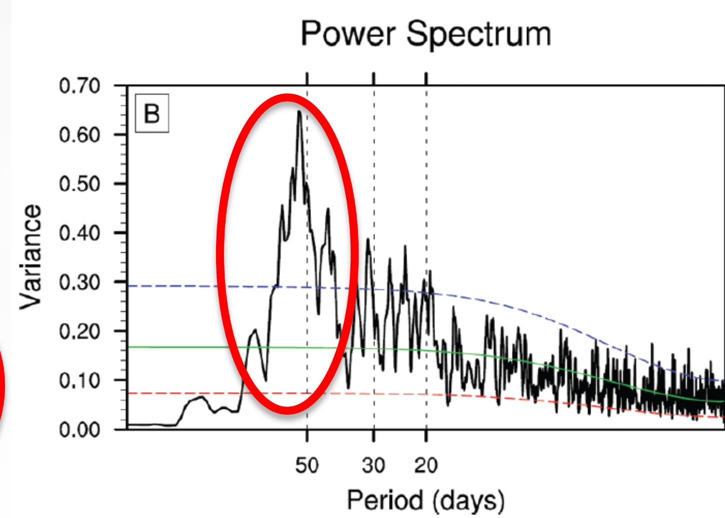


Fig. 10 Relative frequency of occurrence (*RFO*) of each cloud regime at seven lag periods in pentads of eight MJO events in 4 November–April periods from 1999 to 2003. The color scheme for the cloud regimes is the same as in Fig. 9

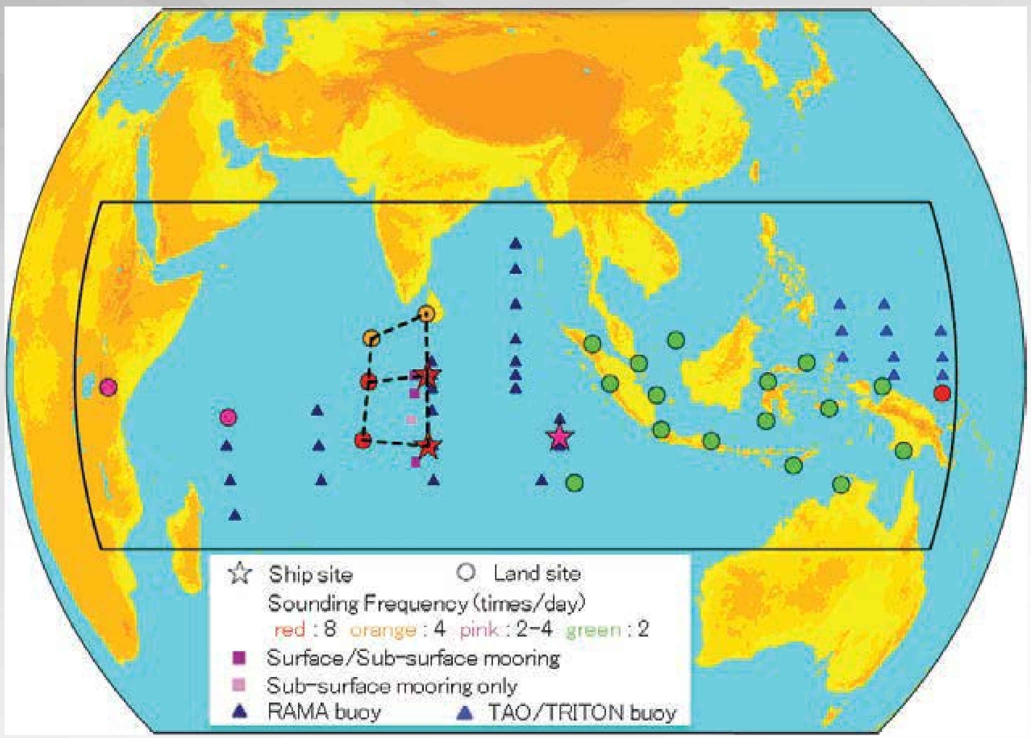
Chen, Y., and A.D. Del Genio, 2009: Evaluation of tropical cloud regimes in observations and a general circulation model. Climate Dynam., 32, 355-369.





Wang, Y., C. N. Long, J. H. Mather, and X. D. Liu, 2010: Convective signals from surface measurements at ARM Tropical Western Pacific site: Manus. Climate Dynamics, Volume 36, Numbers 3-4, 431-449, DOI: 10.1007/s00382-009-0736-z.

AMIE/DYNAMO/CINDY



Yoneyama, K., C. Zhang, and C. N. Long, 2013: Tracking Pulses of the Madden–Julian Oscillation. Bull. Amer. Meteor. Soc., 94, 1871–1891. doi: 10.1175/BAMS-D-12-00157.1

- Campaign to gather observations to test hypotheses related to MJO initiation and propagation
- Oct 2011 – March 2012
- More than 60 institutions from over 16 countries
- Model forcing data set for the Indian Ocean site
- Already several papers published, anticipated many studies over the next decade or more.

Year of Maritime Continent (YMC)
Aug 2017 – July 2018

- ARM has provided over a decade of observations in the TWP
- AMIE/DYNAMO/CINDY has provided an intensive data set primarily for the Indian Ocean area
- The intervening Maritime Continent (MC) area still represents challenges to models
  - Host one of the major equatorial convection centers
  - MC modeling issues:
    - persistent systematic errors in the observed diurnal cycle of precipitation (Neale and Slingo 2003),
    - dry biases over ocean and wet biases over land
    - MJO signals (if they have them) have difficulty propagating through the MC
- A "**Year of the Maritime Continent**" is being organized to provide a framework for the international community to collaborate in the study of the MC role in the weather-climate continuum.

Conclusions

- ARM/ASR goal of improving global models requires sufficient understanding of processes, variability, and influence of the warm pool regime
- Significant progress has been made toward the original TWP science goals using the long-term observations and campaign data
  - But still work to be done
- We have better understanding, which has led to identifying more enlightened physical (MJO) and model (precip biases) issues
- Our challenge is to define and target focused efforts toward resolving the identified (and yet to be identified) modeling issues important to ARM and ASR science objectives
- With the current plans for closing of the TWP fixed sites, future campaigns such as YMC will be critical for gathering observations, particularly model forcing data sets, needed to address identified research efforts

Information Sources

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Thank You!

- TWP research:
  - Long, C. N., S. A. McFarlane, A. DelGenio, P. Minnis, J. Mather, J. Comstock, J. Mace, M. Jensen, C. Jakob, and T. P. Ackerman (2013): ARM Research in the Equatorial Western Pacific - A Decade and Counting, BAMS, 94(5), 695-708. doi: 10.1175/BAMS-D-11-00137
- TWP history and perspective:
  - Long, C.N., J. H. Mather, and T. P. Ackerman (2014): ARM Monograph Section 2, #7: TWP Sites, Submitted to Dave Turner and Co Oct, 2013.
- Major recent campaigns:
  - May PT, JH Mather, G Vaughan, KN Bower, C Jakob, GM McFarquhar, and GG Mace. 2008. "The tropical warm pool international cloud experiment." Bulletin of the American Meteorological Society, 89(5), doi:10.1175/BAMS-89-5-629.
  - Yoneyama, K., C. Zhang, and C. N. Long, 2013: Tracking Pulses of the Madden–Julian Oscillation. Bull. Amer. Meteor. Soc., 94, 1871–1891. doi: 10.1175/BAMS-D-12-00157.1

Extra

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Satellite Comparison and Validation

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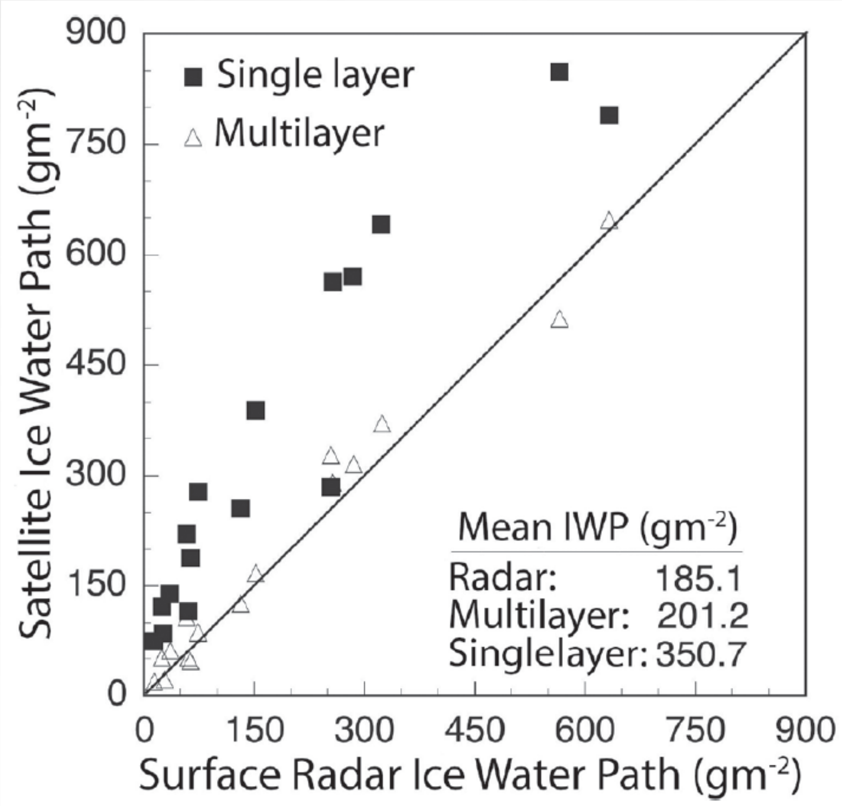
- Not an original goal of ARM
- Have been invaluable for validating and improving wide range of satellite instruments and retrievals
  - **Cirrus detection** from MODIS (Roskovensky and Liou 2003), AIRS (Kahn et al. 2005), and CALIPSO lidar (Thorsen et al. 2011)
  - **Defining cloud structure** from MISR (Kassianov et al. 2003) and geostationary satellite (Hollars et al. 2004)
  - **Ice and liquid water path retrievals** form various instruments

Comparison of VISST single layer and multilayered cloud retrieval system to Manus observations



Huang, J., P. Minnis, B. Lin, Y. Yi, T.-F. Fan, S. Sun-Mack, and J. K. Ayers, 2006: Determination of ice water path in ice-over-water cloud systems using combined MODIS and AMSR-E measurements. Geophys. Res. Lett., 33, L21801, doi:10.1029/2006GL027038.