Validation de la dynamique de différentes (ré-)analyses dans la haute troposphère et la basse stratosphère à l'aide d'observations ballon longue durée

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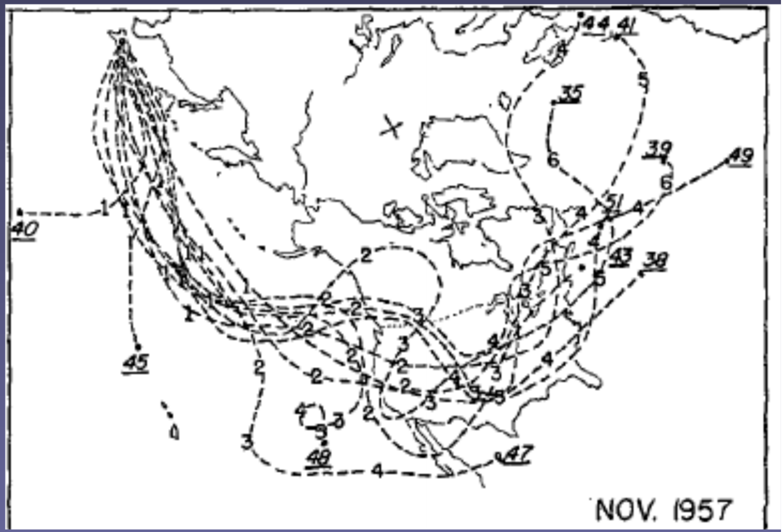
Outline

- Historical introduction
- Pre-satellite era: Eole experiment (1971-72)
- Modern satellite era
  - Polar balloon flights: Vorcore (2005)
  - Equatorial balloon flights: Pre-Concordiasi (2010)
- Conclusions and future flights

Introduction

- Long duration balloons
  - Closed, non-expansible (plastic), superpressure balloons able to perform “horizontal soundings” in the atmosphere
    - Advected by the winds on constant-density surface
    - Balloon lifetime limited by leak of the lifting gas, energy, political/safety considerations
  - Used since the end of World War II: US navy operational “Transosonde” program to collect meteorological data at 300 hPa upwind of the US over the Pacific Ocean
    - Few-day flights
    - Balloons located through radio triangulation



Angell, 1960

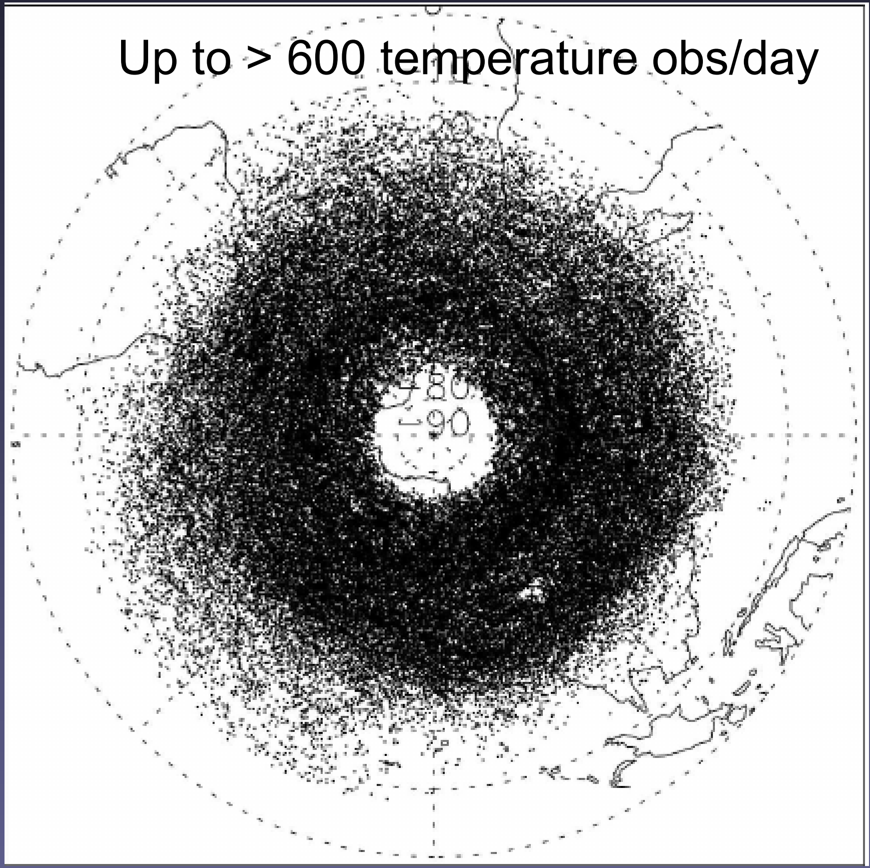
Introduction

- Long duration balloons
  - NCAR “GHOST” program 1967-71 (V. Lally), about 60 flights
    - Larger balloons => 200 and 100 hPa
    - Emphasis toward the Southern Hemisphere
    - Daily (noon) positions with a “sunseeker”
    - Global circulation of the SH UT (Solot and Angell, 1972)

A superpressure balloon in the 1960s

Introduction

- Long duration balloons
  - French-US “Eole Program” Aug. 1971- Dec. 72
  - 480 balloons launched, 80,000 observations
  - Mean flight duration: ~ 100 days
  - Flight level: ~ 200 hPa
  - Balloon located through a devoted satellite mission (!)
    - Several positions/day/balloon
  - Atmospheric temperature and pressure sensors

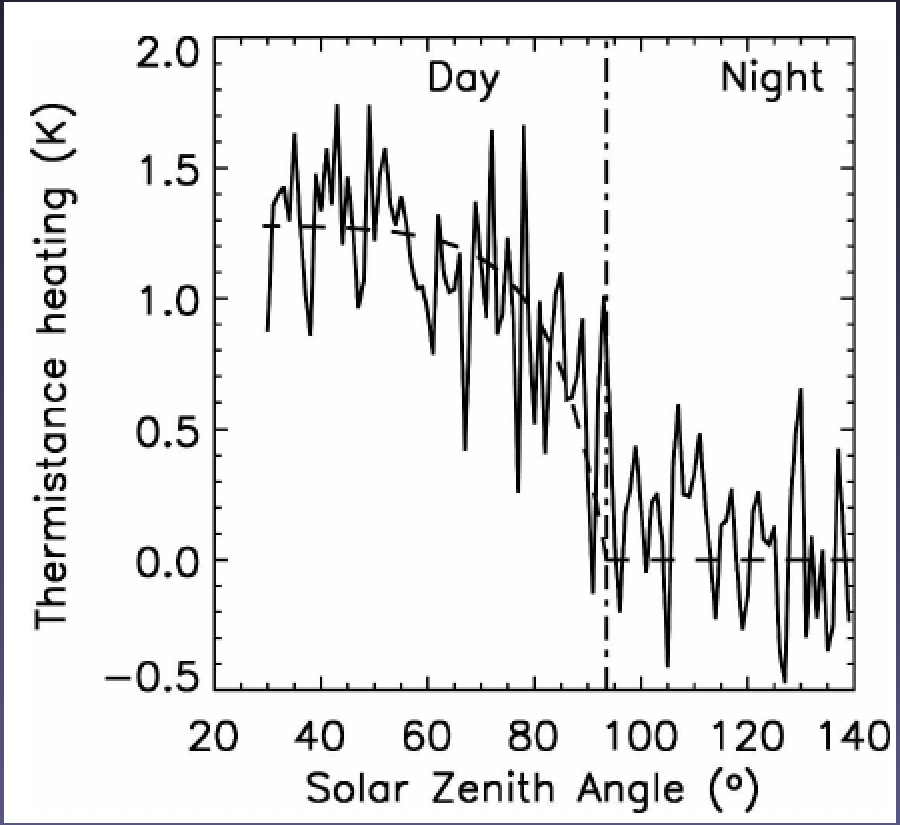


Up to > 600 temperature obs/day

Eole observation locations (Hertzog et al., 2006)

Comparison of Eole Observations with NCEP/NCAR and ECMWF ERA-40

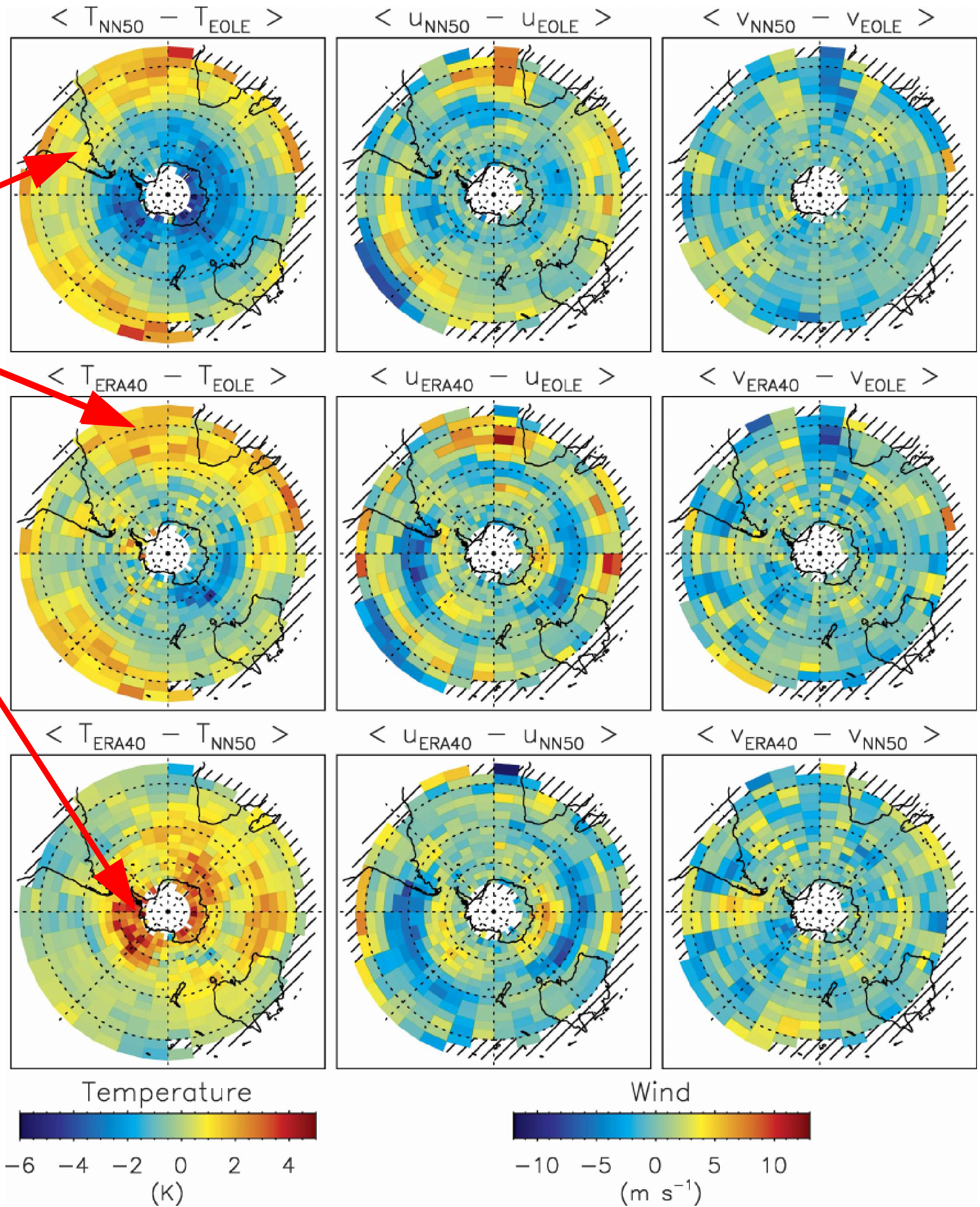
- Quality check on the observations
  - Detection of outliers in pressure measurements (which is used to locate the balloon in the vertical)
  - Winds
    - computed from balloon positions less than 5 hr apart
    - σ ~ 1.1 m/s, arising from horizontal and vertical position uncertainties
  - Temperature
    - Empirical adjustment for daytime radiation effect
    - σ ~ 0.8 K
- Reanalyses fields interpolated on the balloon observations
    - Cubic spline in time/space
    - Vert. coordinate: Log(pressure)
- Observations not assimilated in any reanalysis



Biases

Reanalyses warmer than balloon observations in the subtropics, but colder at higher latitudes. Stronger biases in NN50.

Significant differences (> 3 K) at polar latitudes between both reanalyses



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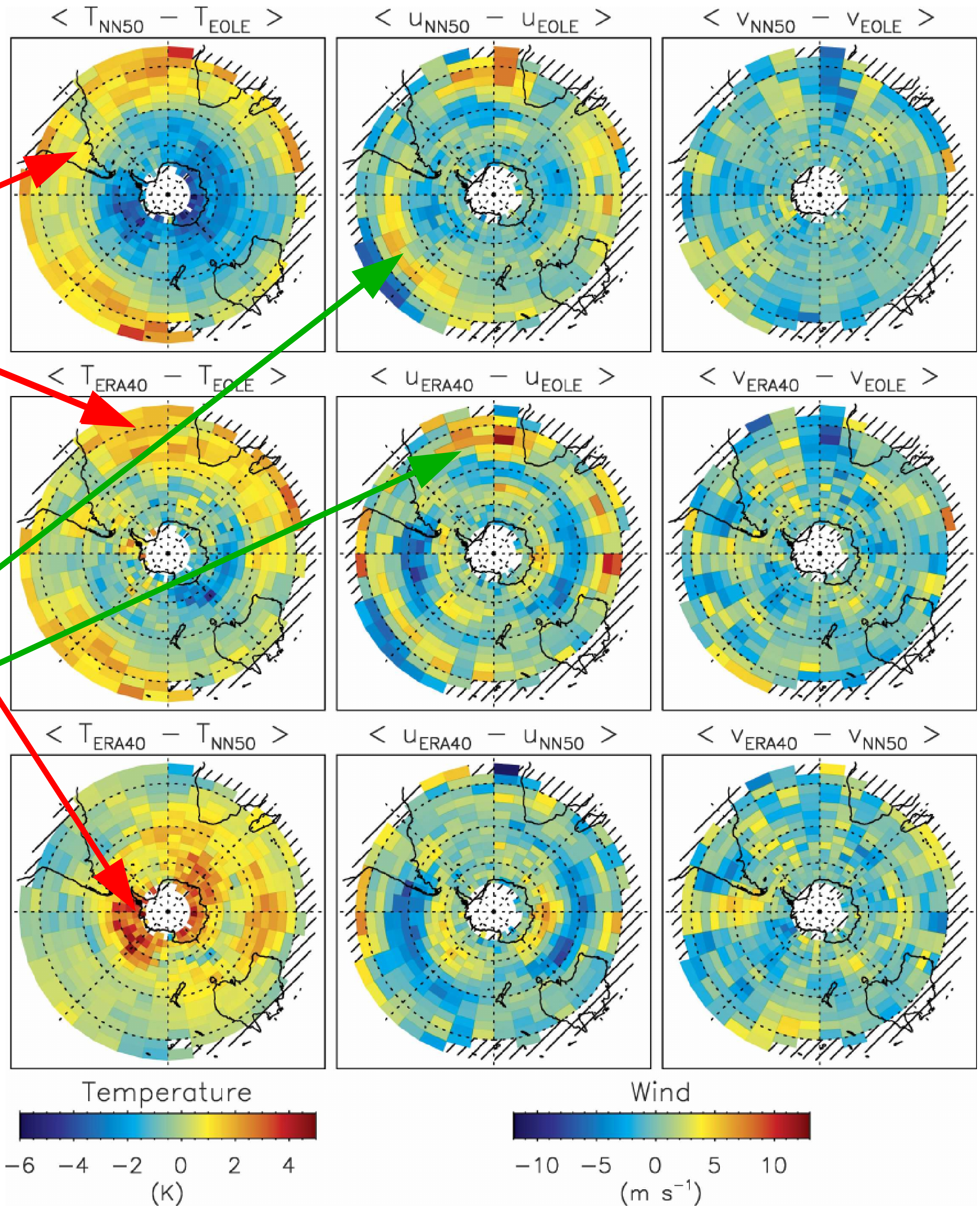

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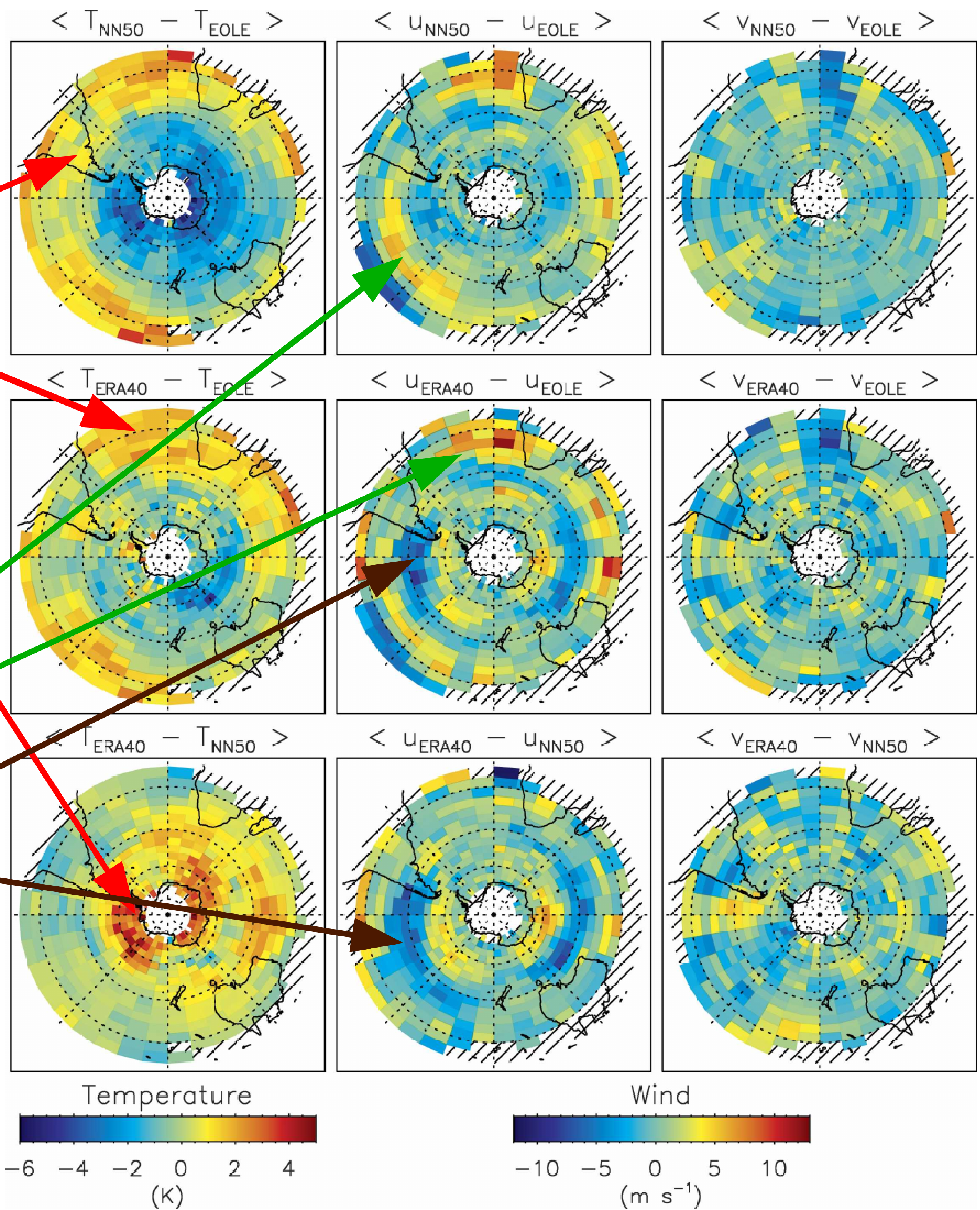

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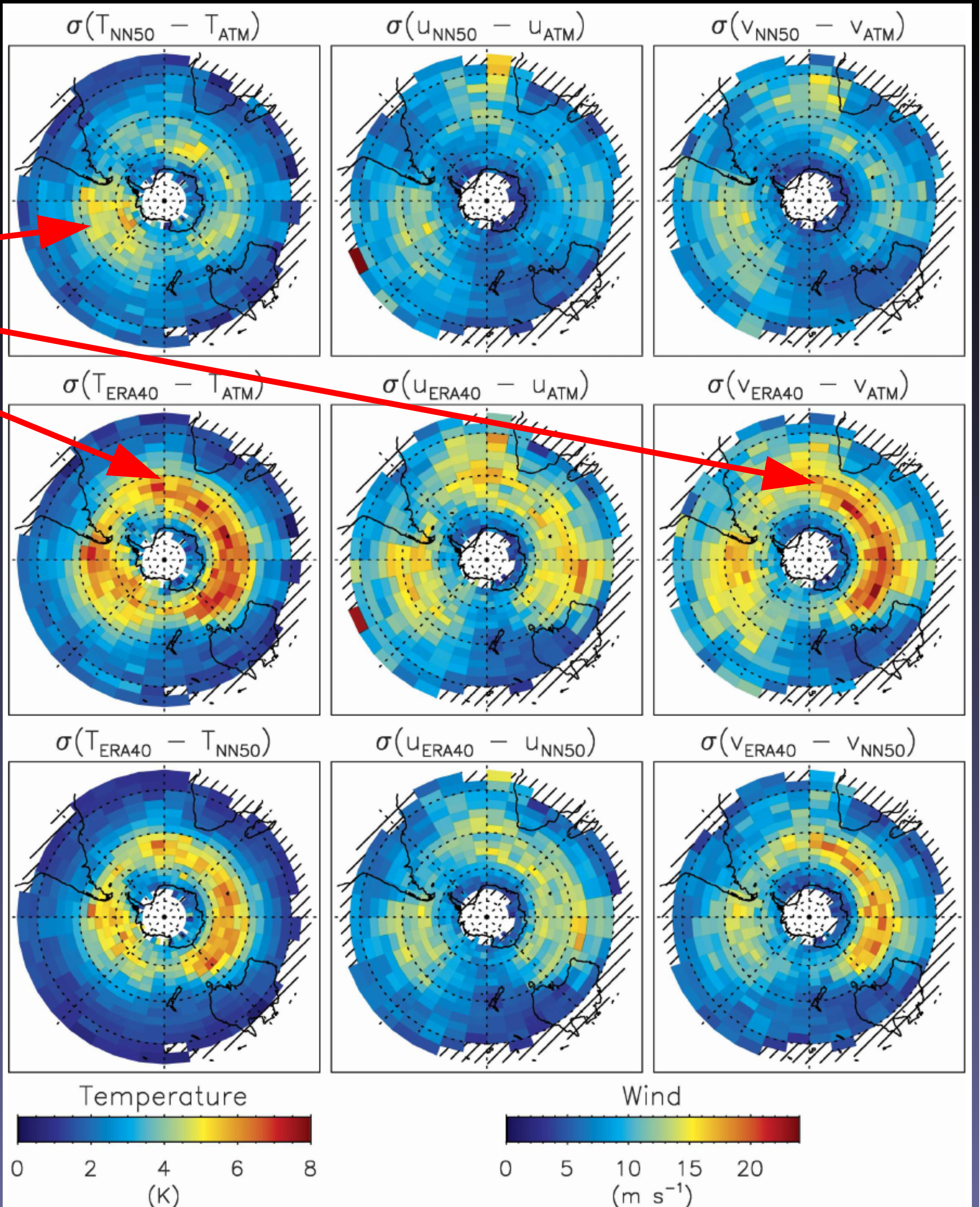
Subtropical jet displaced northward (over the oceans) in reanalyses

Hints of a double jet structure in ERA 40

No significant bias in the meridional wind

Standard deviations



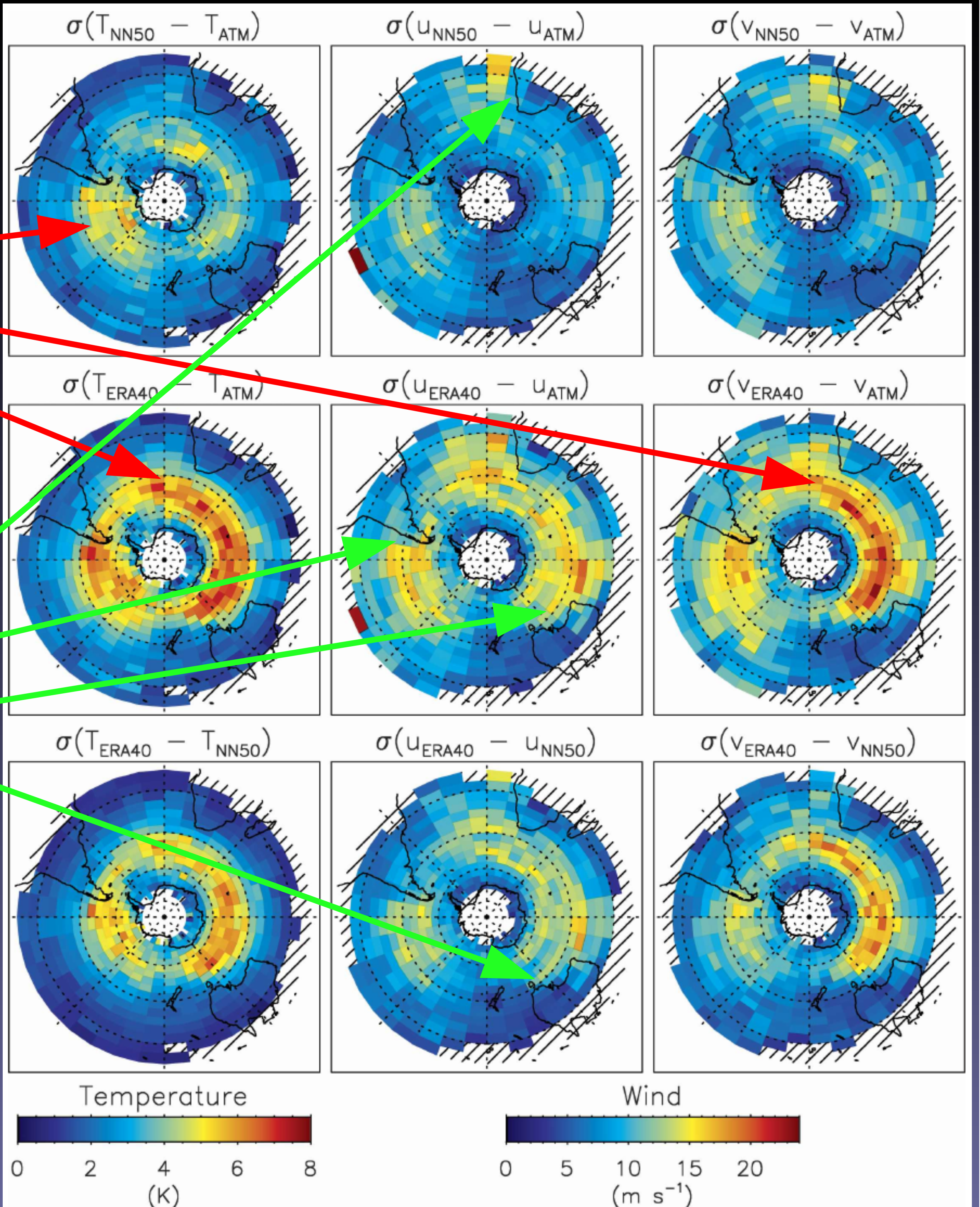
Largest differences in the SH storm tracks, where both reanalyses underestimate the observed synoptic variability. ERA 40 performs significantly worse than NN50.

Standard deviations

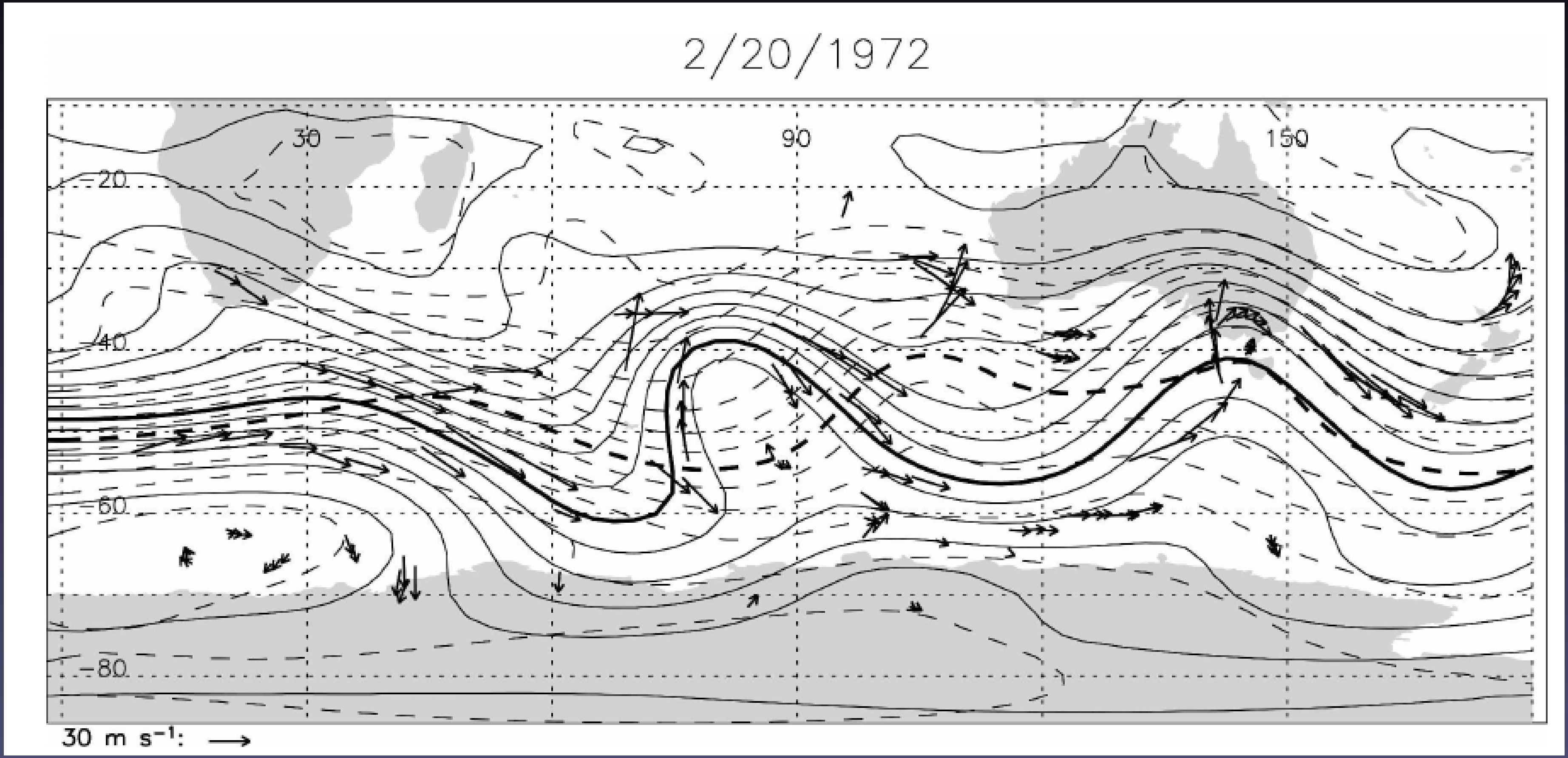
Largest differences in the SH storm tracks, where both reanalyses underestimate the observed synoptic variability. ERA 40 performs significantly worse than NN50.

Impact of continental upper-air observations is evident over South America, South Africa, Australia and downstream.

Over the oceans, local standard deviations of differences can be up to 5 K, and 15 m/s!

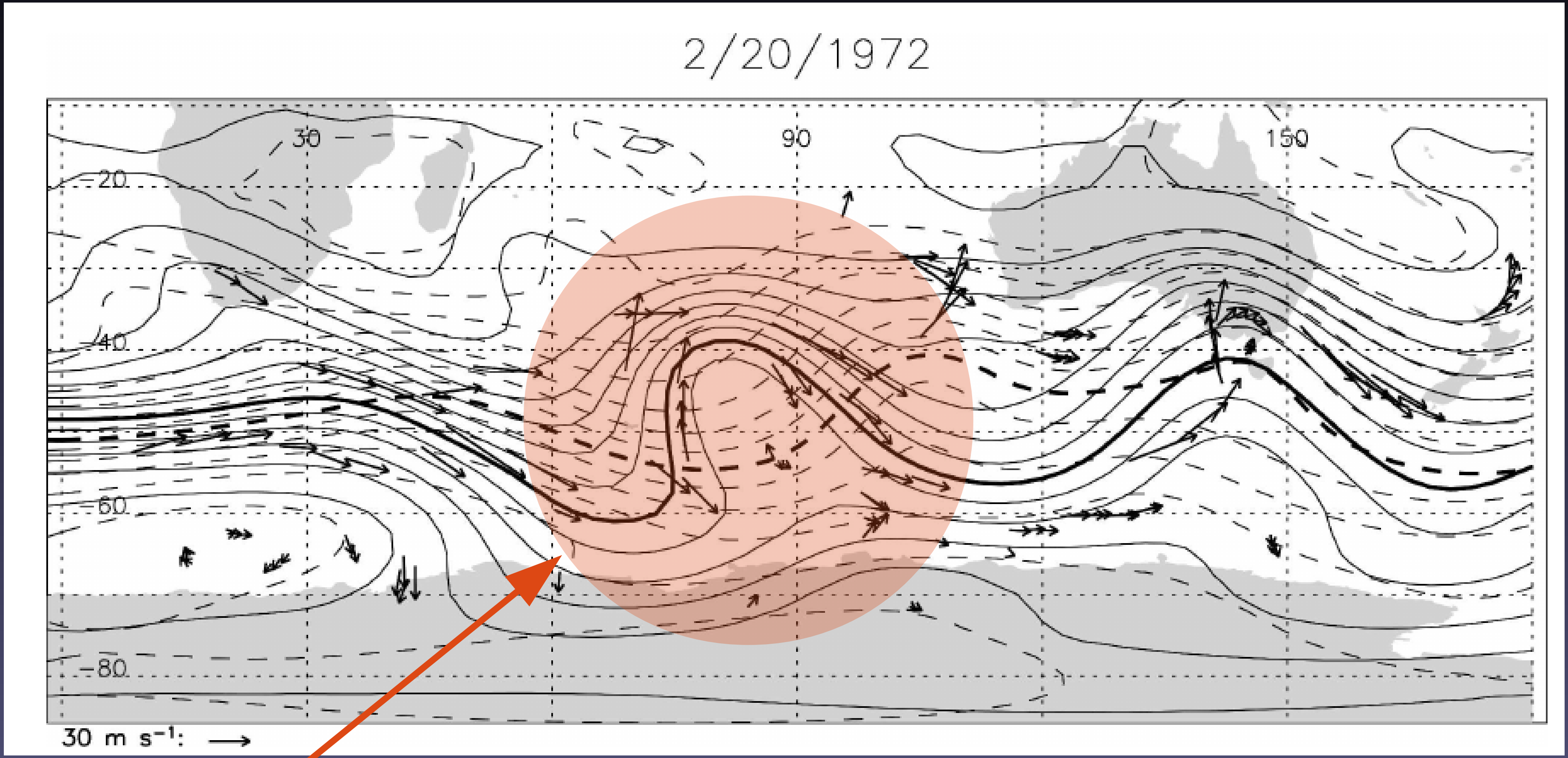


An example



NN50 (solid) and ERA40 (dashed) geopotential heights
Arrows: Balloon observations

An example



NN50 (solid) and ERA40 (dashed) geopotential heights
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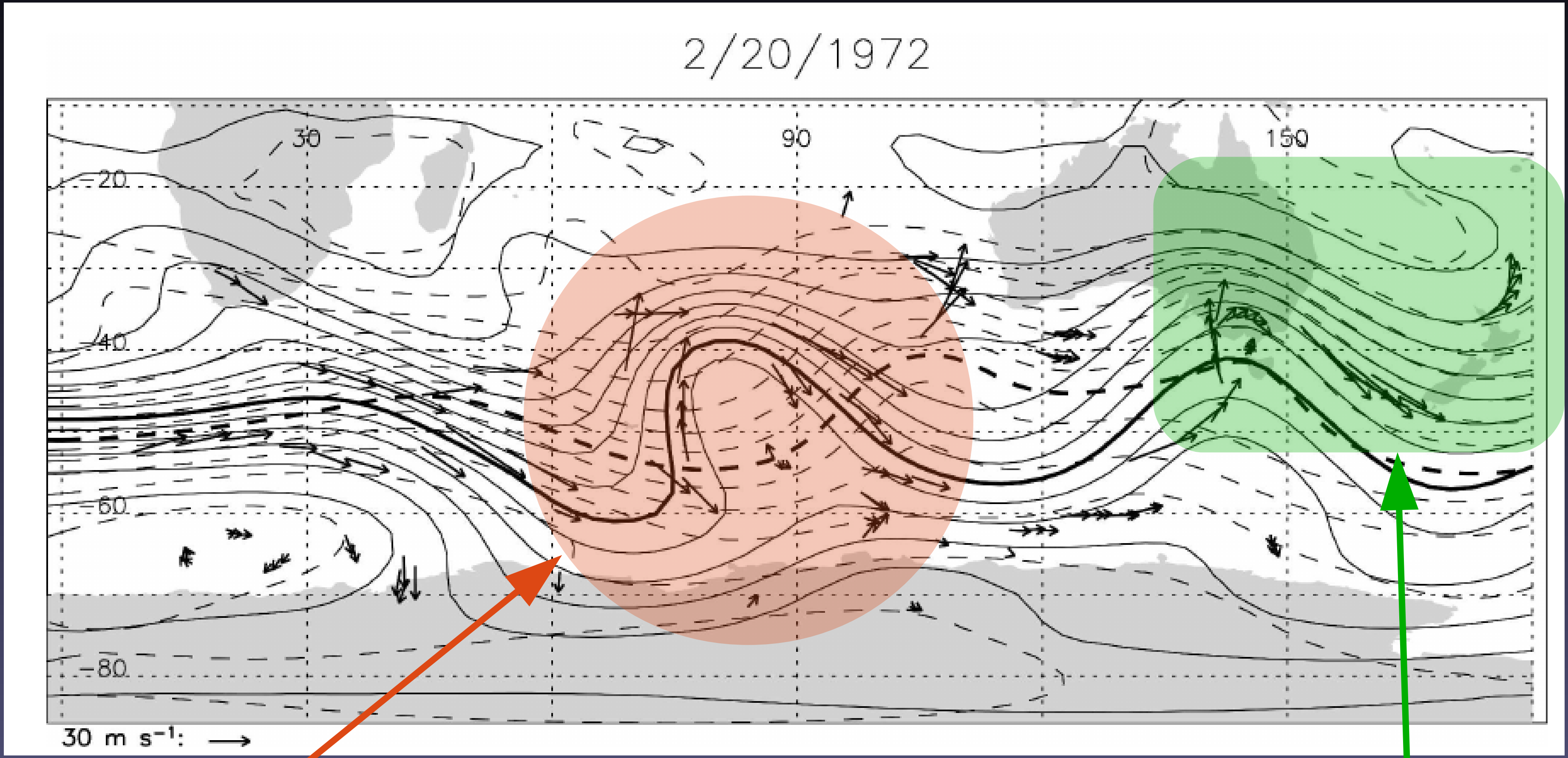
Synoptic-scale disturbance over the Indian ocean consistent in both NN50 GPH and balloon winds, but missed by ERA-40

An example



NN50 (solid) and ERA40 (dashed) geopotential heights
Arrows: Balloon observations

Synoptic-scale disturbance over the Indian ocean consistent in both NN50 GPH and balloon winds, but missed by ERA-40

Better agreement between observations and both reanalyses over Australia and downstream

More recent comparisons: Vorcore 2005

Vorcore campaign

Sep. 2005 – Feb. 2006, Antarctica

27 balloons (12-m diameter), 60 and 80 hPa (lower stratosphere)

Modern satellite systems for positioning (GPS) and communication with the ground

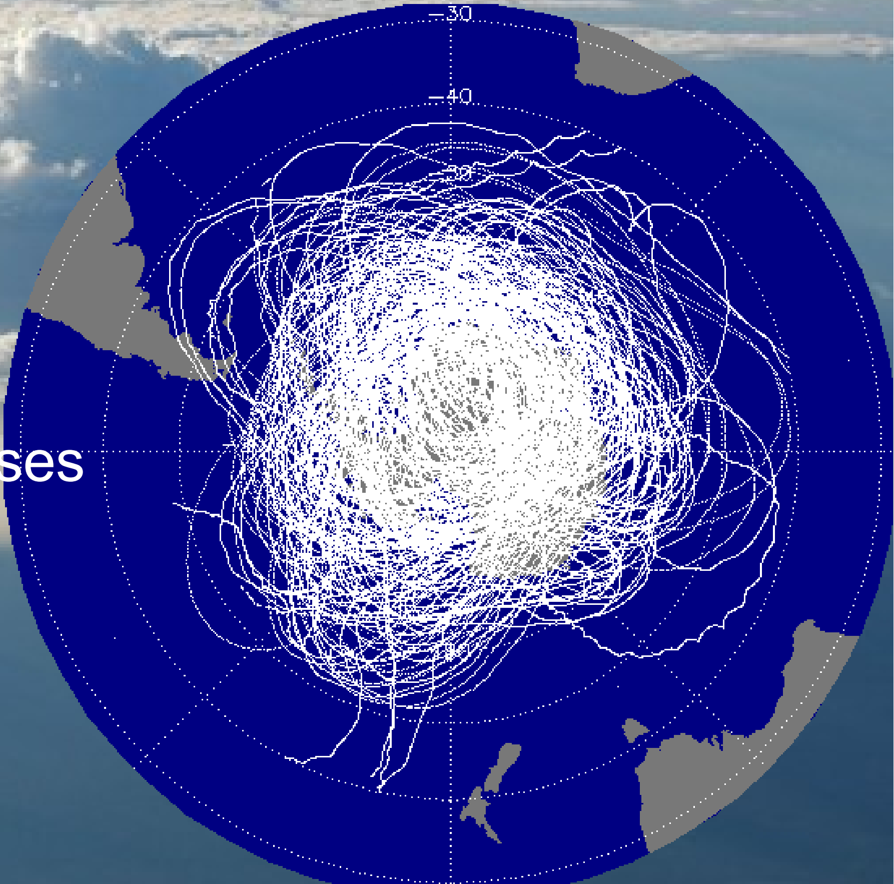
u, v (GPS), P, T every 15 minutes

Accuracies: 0.1 m/s, 10 Pa, 0.25 K

Observations were not assimilated by NWPs

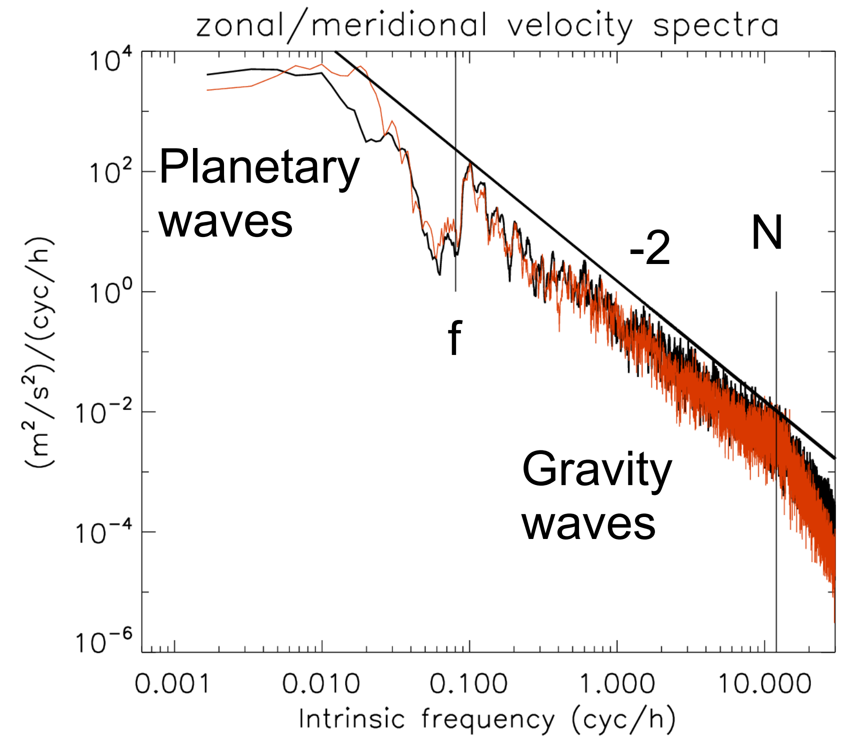
Comparisons with ECMWF operational analyses and NCEP/NCAR reanalyses (Boccara et al., 2008)

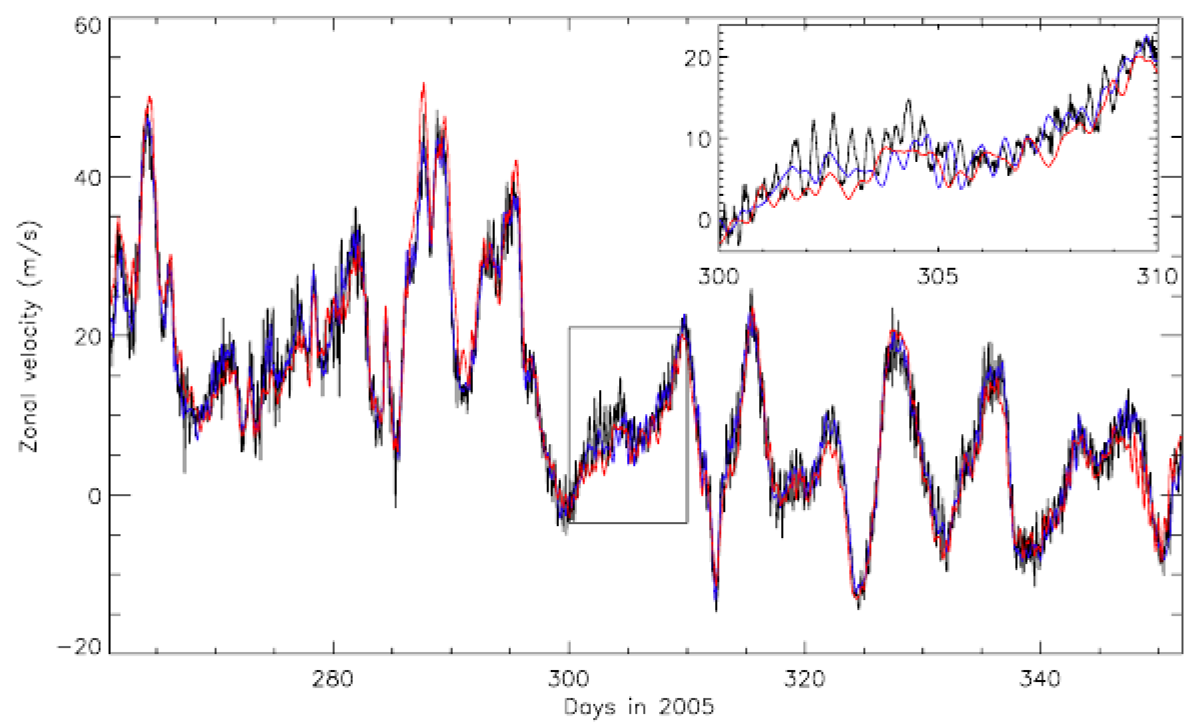
150,000 obs



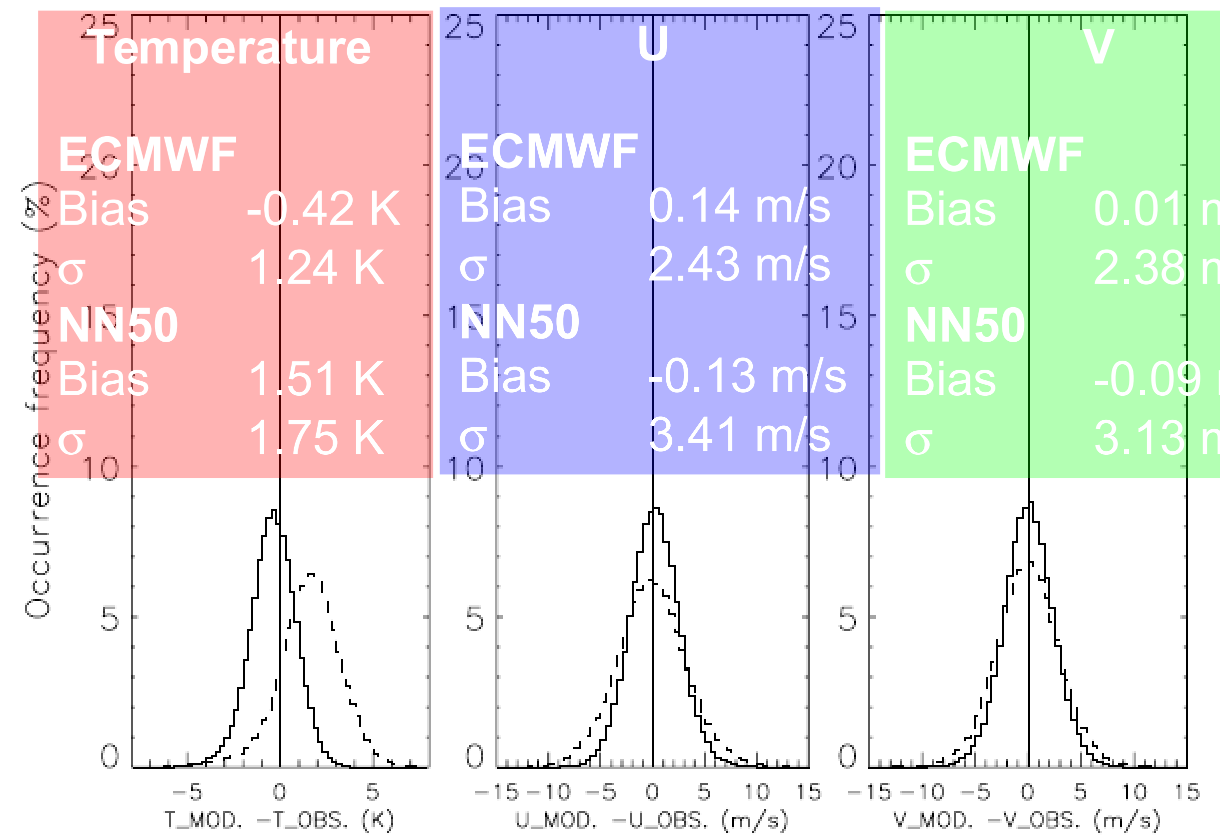
Comparisons with ECMWF oper analyses and NCAR/NCEP

- Balloon observations resolve gravity waves, which are hardly present in the analyses
- Excellent agreement with(re)-analyses





Pdf of differences



Temperature

ECMWF	
Bias	-0.42 K
σ	1.24 K
NN50	
Bias	1.51 K
σ	1.75 K

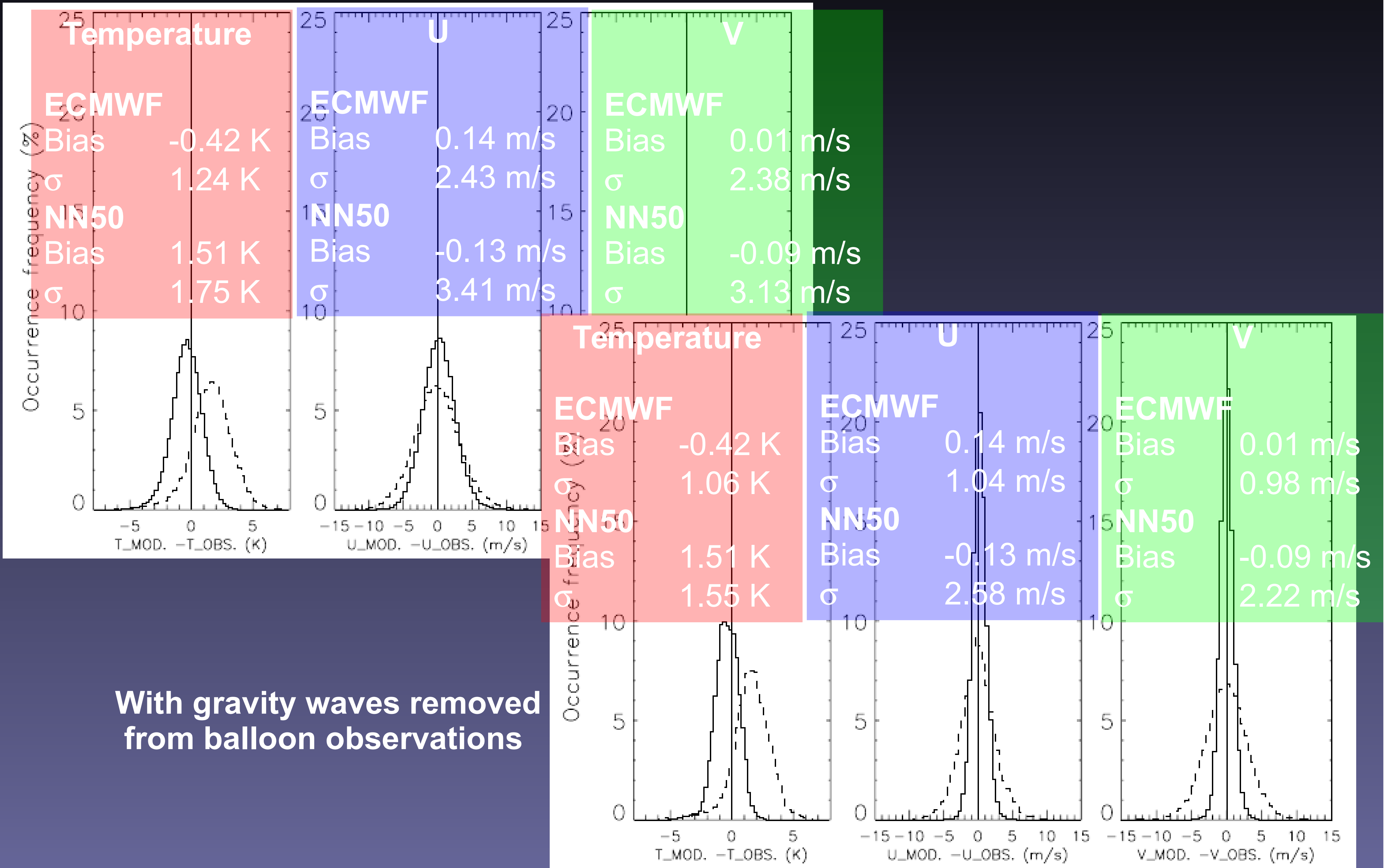
U

ECMWF	
Bias	0.14 m/s
σ	2.43 m/s
NN50	
Bias	-0.13 m/s
σ	3.41 m/s

V

ECMWF	
Bias	0.01 m/s
σ	2.38 m/s
NN50	
Bias	-0.09 m/s
σ	3.13 m/s

Pdf of differences



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Temperature

ECMWF

Bias	-0.42 K
σ	1.06 K

NN50

Bias	1.51 K
σ	1.55 K

U

ECMWF

Bias	0.14 m/s
σ	1.04 m/s

NN50

Bias	-0.13 m/s
σ	2.58 m/s

V

ECMWF

Bias	0.01 m/s
σ	0.98 m/s

NN50

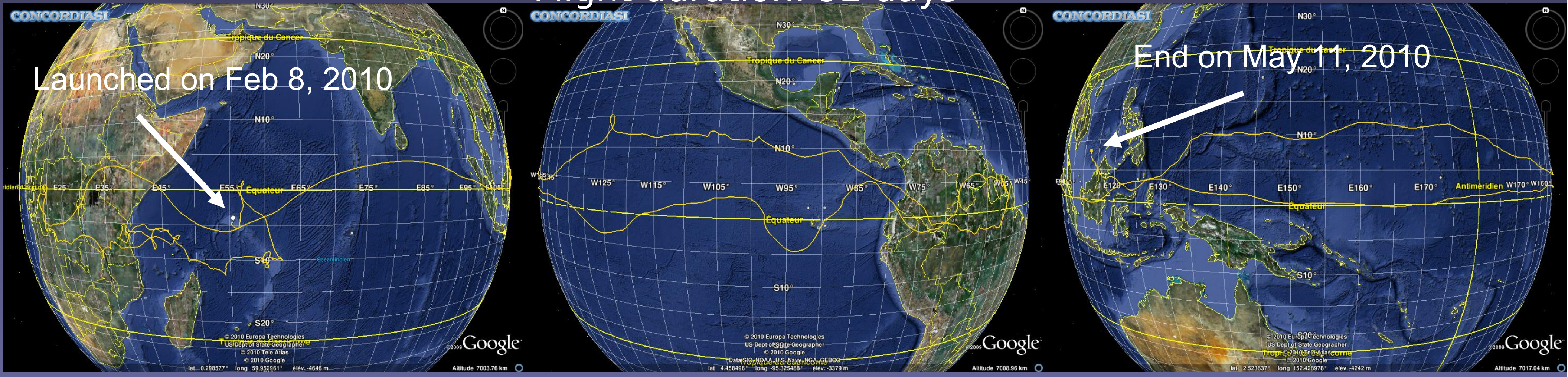
Bias	-0.09 m/s
σ	2.22 m/s

With gravity waves removed from balloon observations

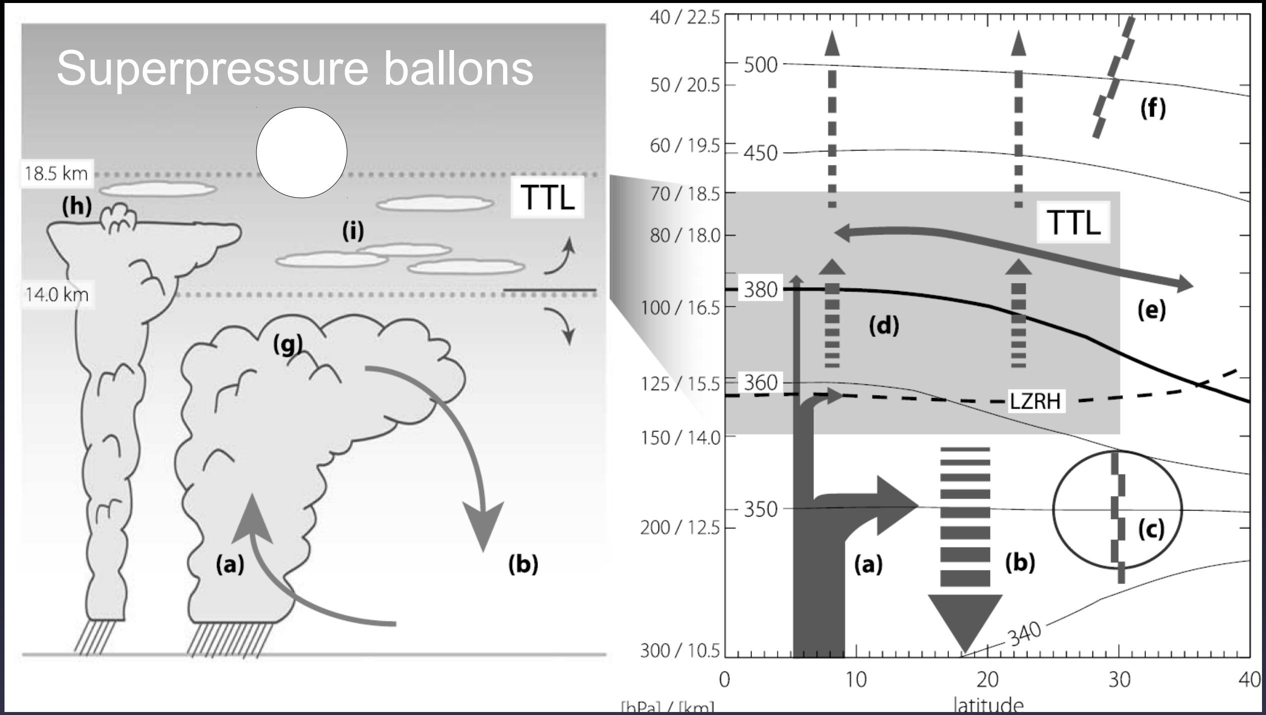
Pre-Concordiasi (2010)

- Long-duration balloons
  - 3 flights, 3-month long
  - GPS, P, T, hor. wind velocities (balloon displ.)
    - Accuracy: 1.5 m, 10 Pa, 0.2 K, 0.1 m/s
    - **Measurements every 30 s**
- Observations were not assimilated by NWPs
- Comparisons w/ ECMWF operational analyses (and ERA-i) and MERRA reanalyses (Podglajen et al., 2014)

Flight duration: 92 days

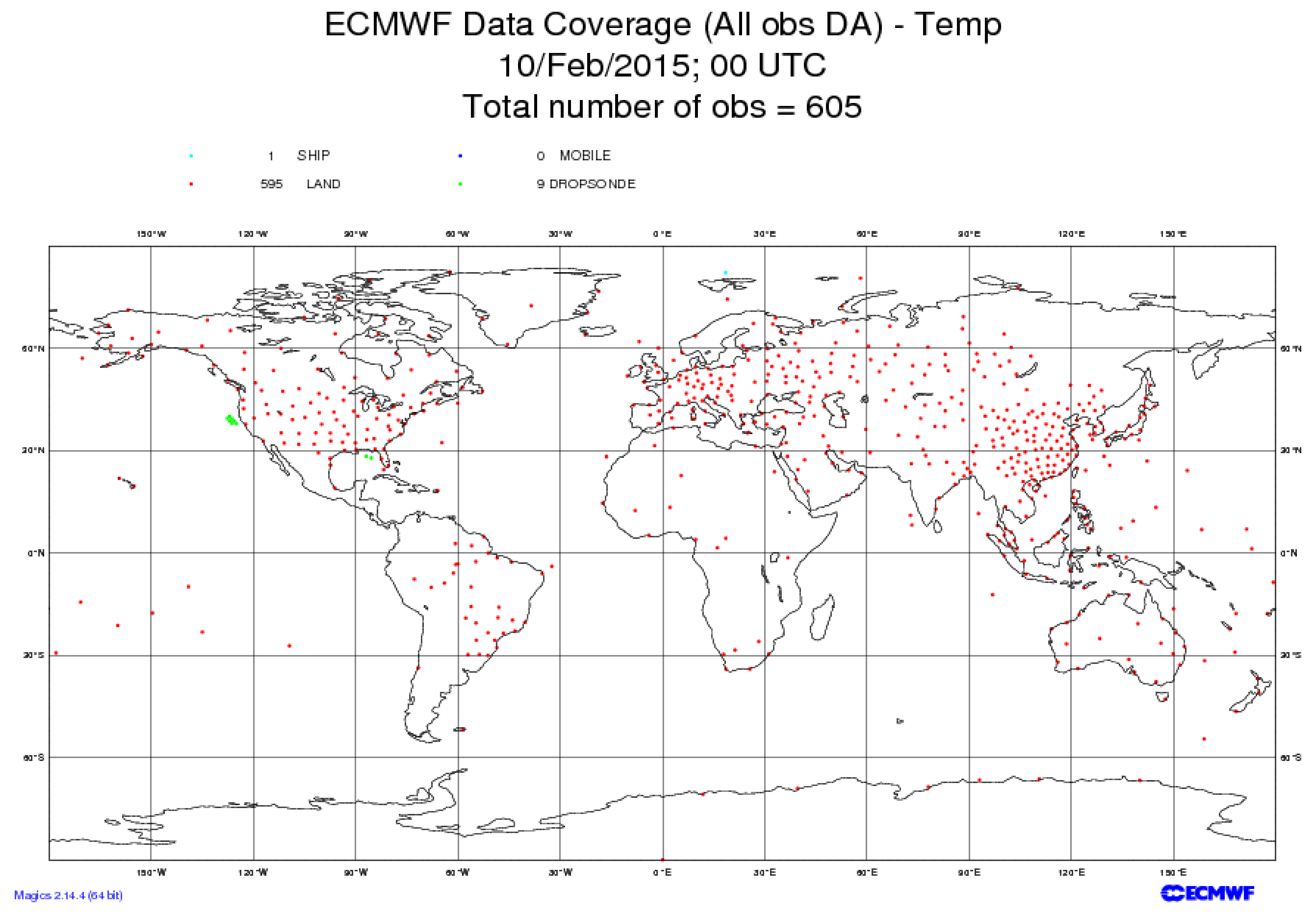


Motivations



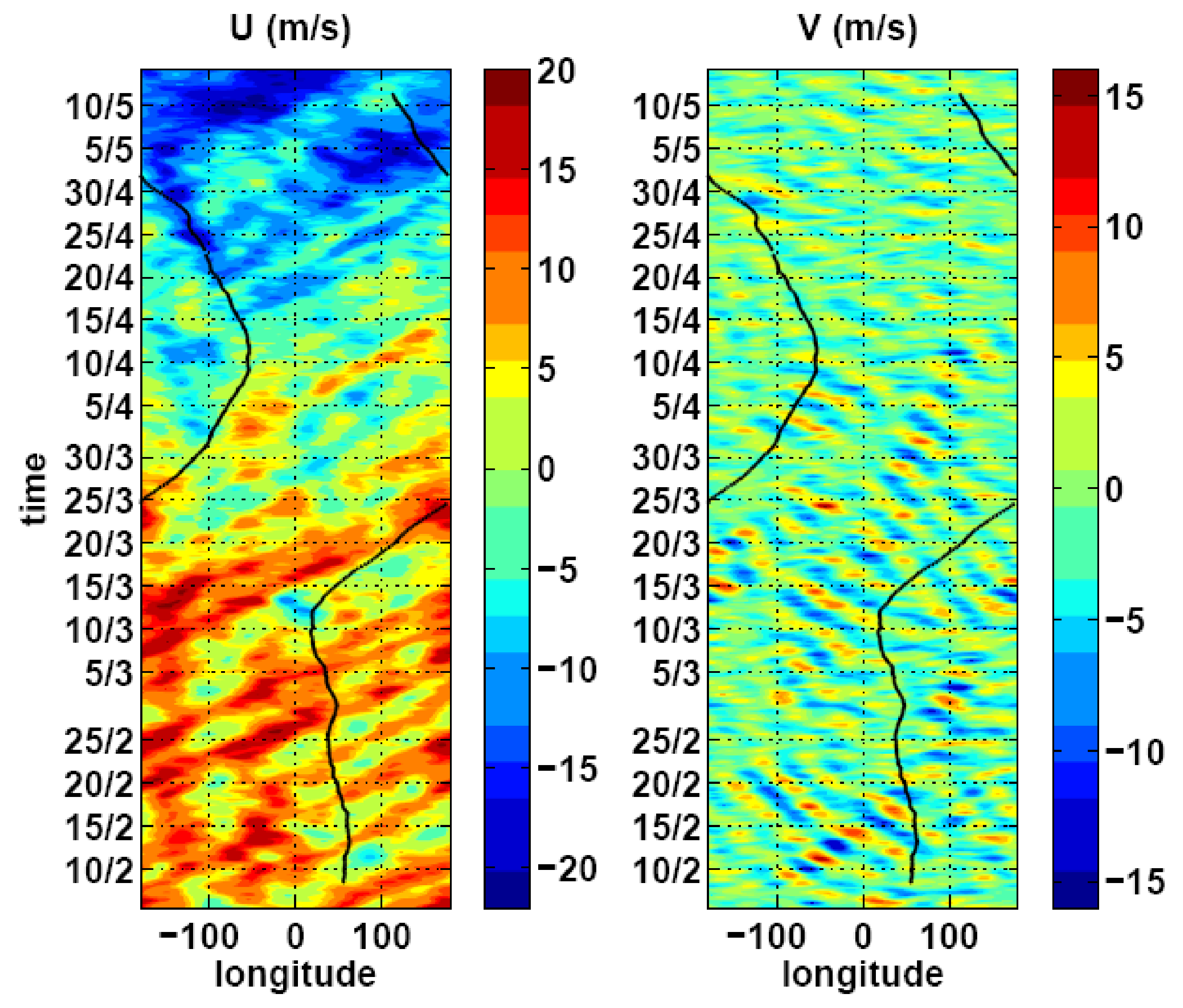
(Fueglistaler et al., 2009)

- Study of the equatorial UTLS or Tropical Tropopause Layer (TTL)
  - Mesoscale processes: convection, waves, cirrus and dehydration
- Analyses are widely used to study transport in the TTL...
  - … but (upper-air) wind observations are actually very scarce in the tropics (at least above the mean convective level of detrainment)



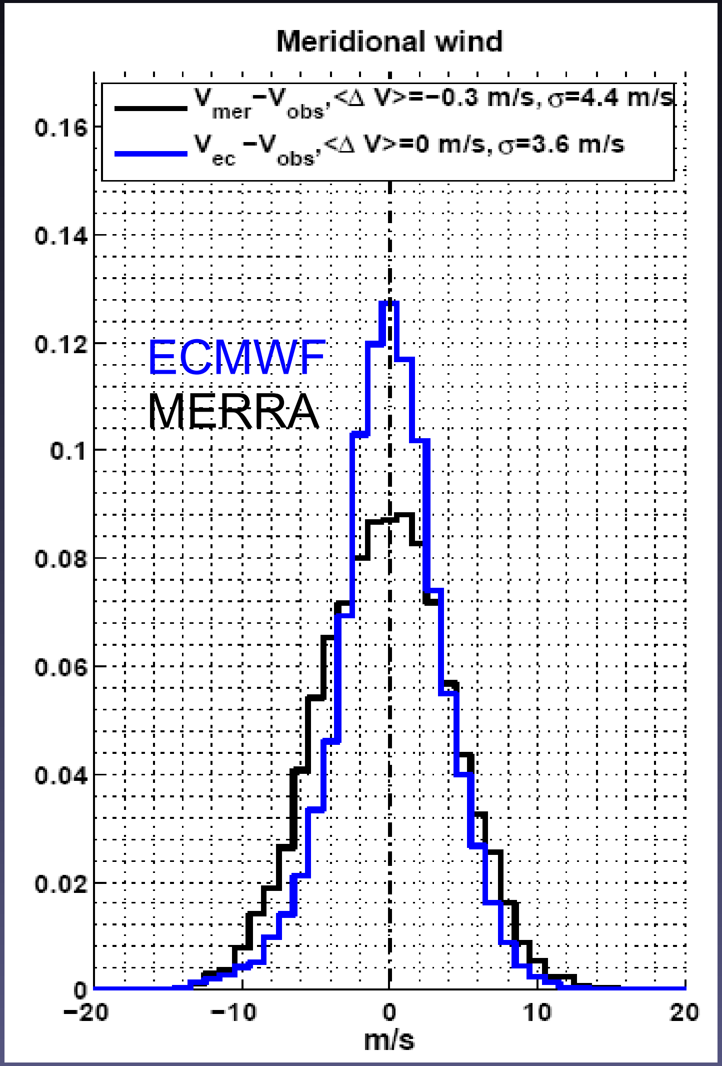
Void areas over the Oceans and Africa =>
NWP winds poorly constrained by the current observation system in the tropics

Dynamical context



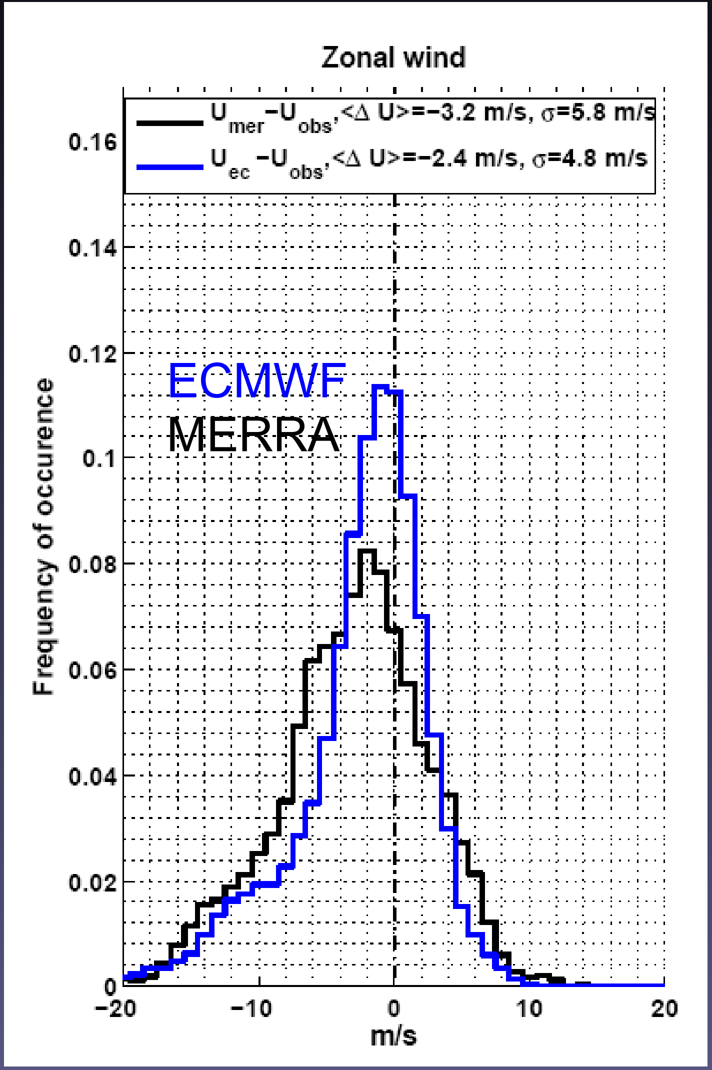
Hovmöller diagram of ECMWF winds @ 57 hPa during the campaign:
QBO shift, Kelvin and Rossby-gravity (Yanai) waves

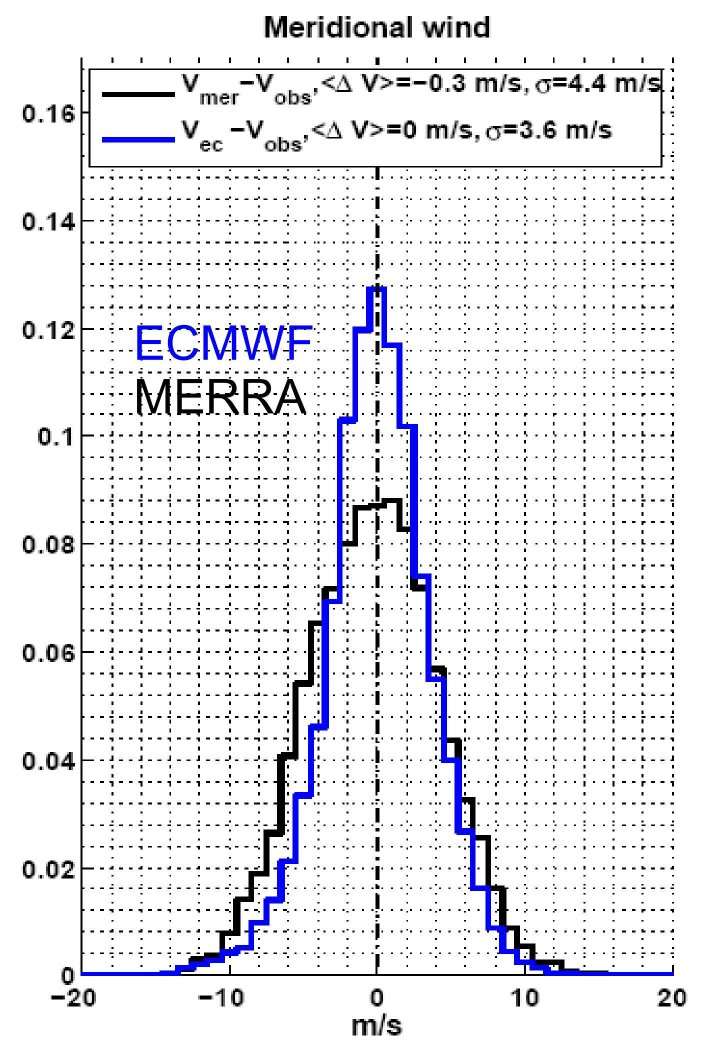
Difference statistics



Part of this difference is associated with unresolved small-/meso-scale motions...
Yet the standard deviation numbers are larger than above Antarctica.

Difference statistics





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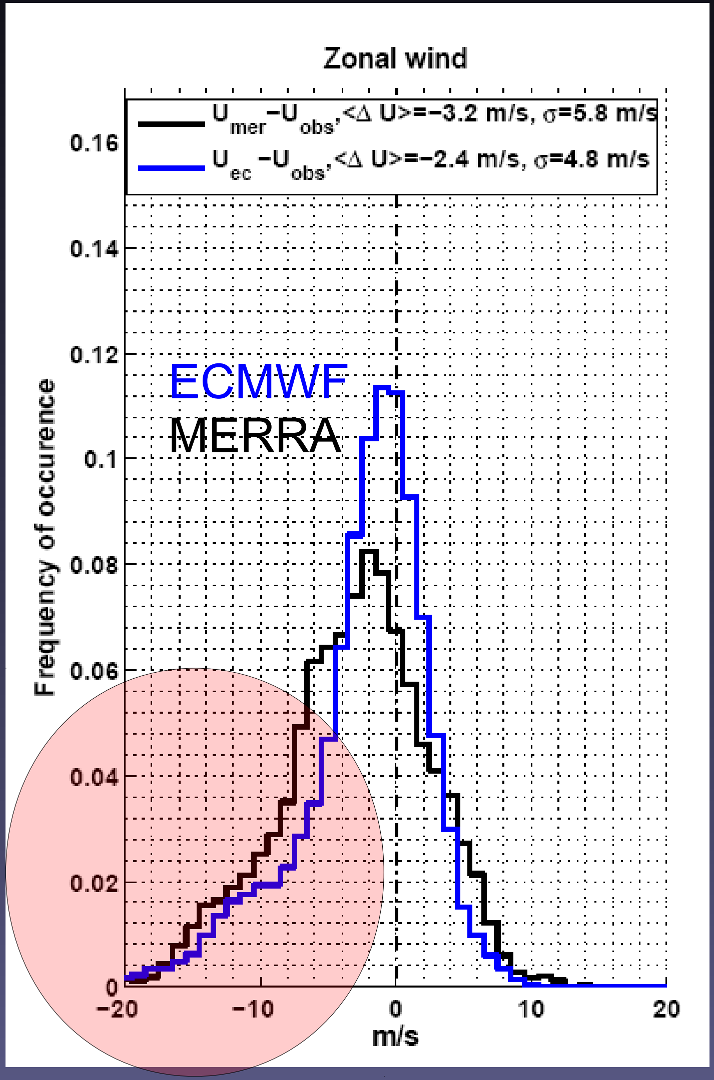
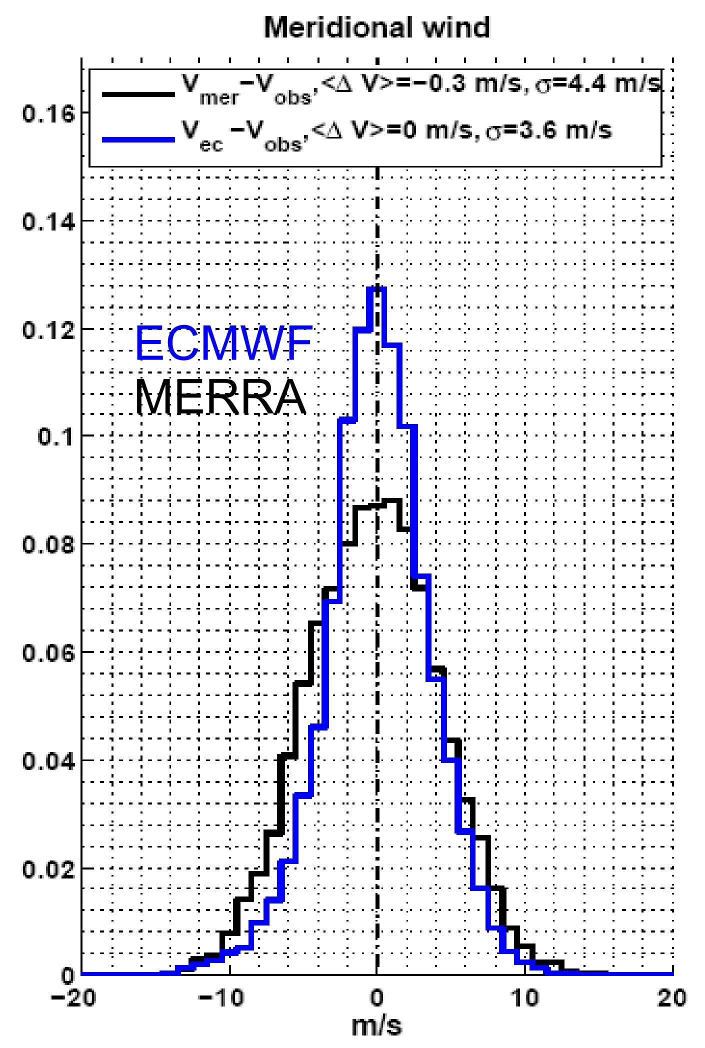
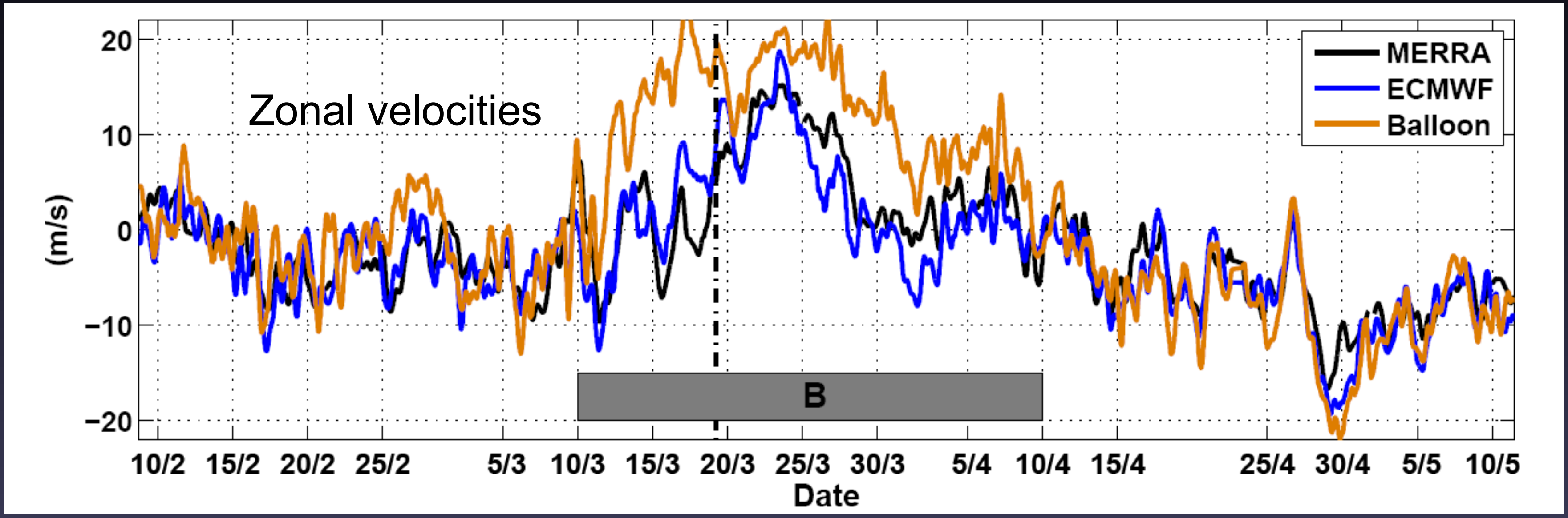




Wind timeseries



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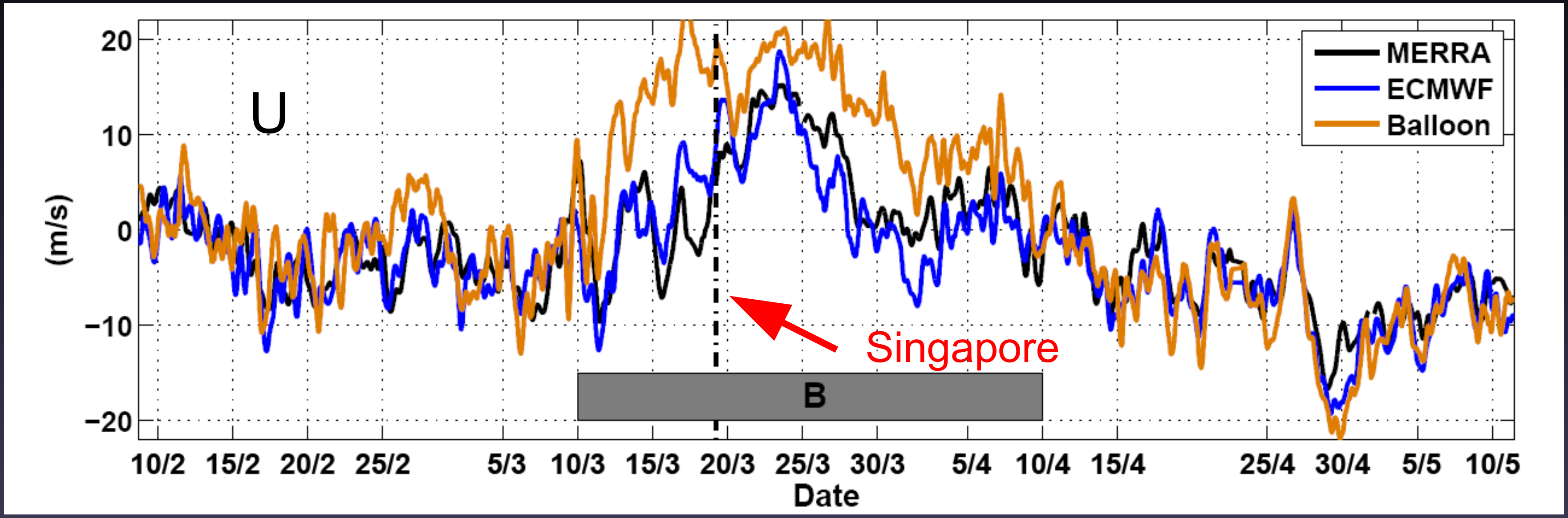
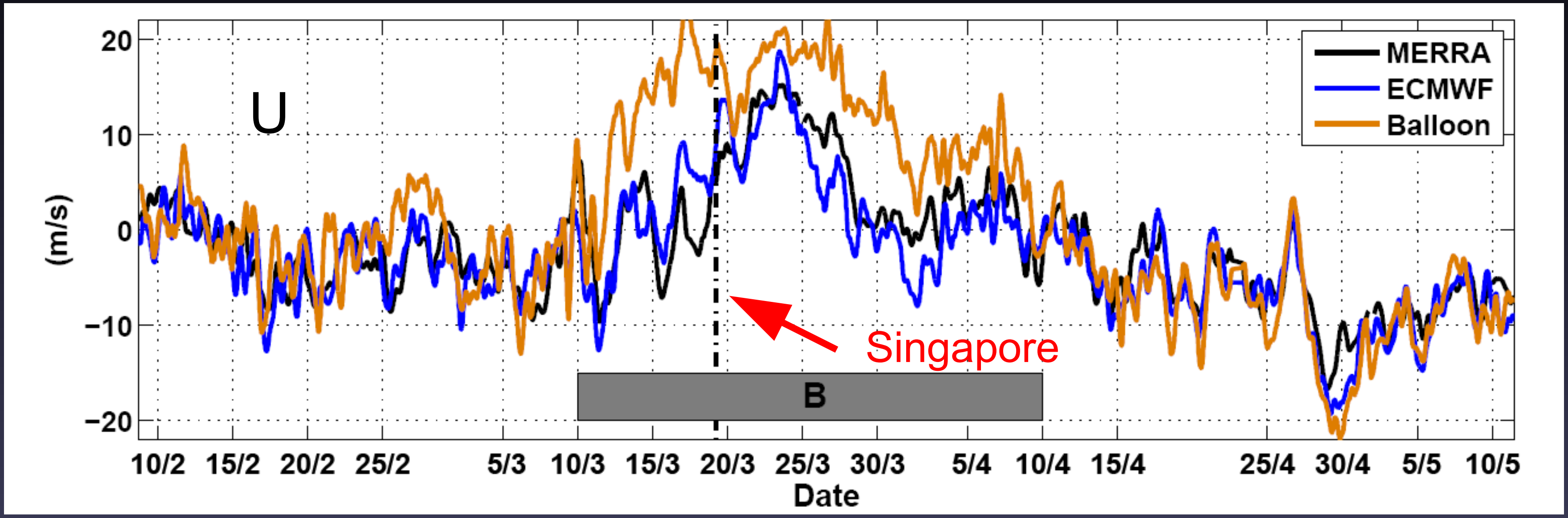


Month-long period with differences up to 15 m/s in both NWP products

Wind timeseries



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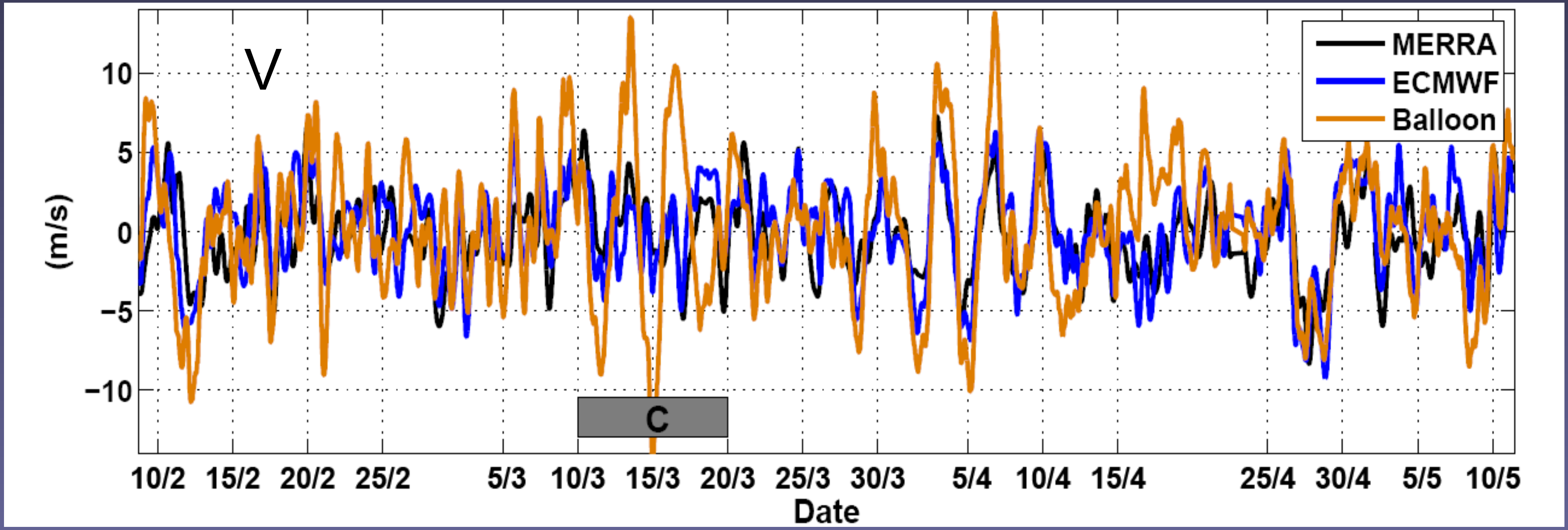
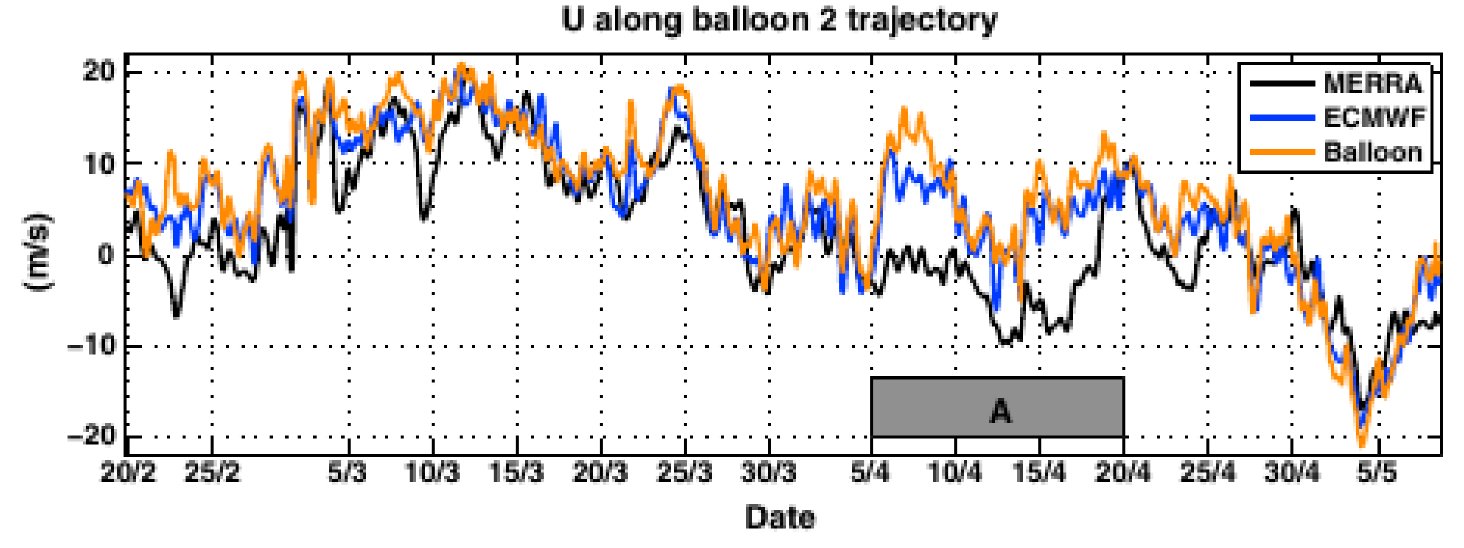
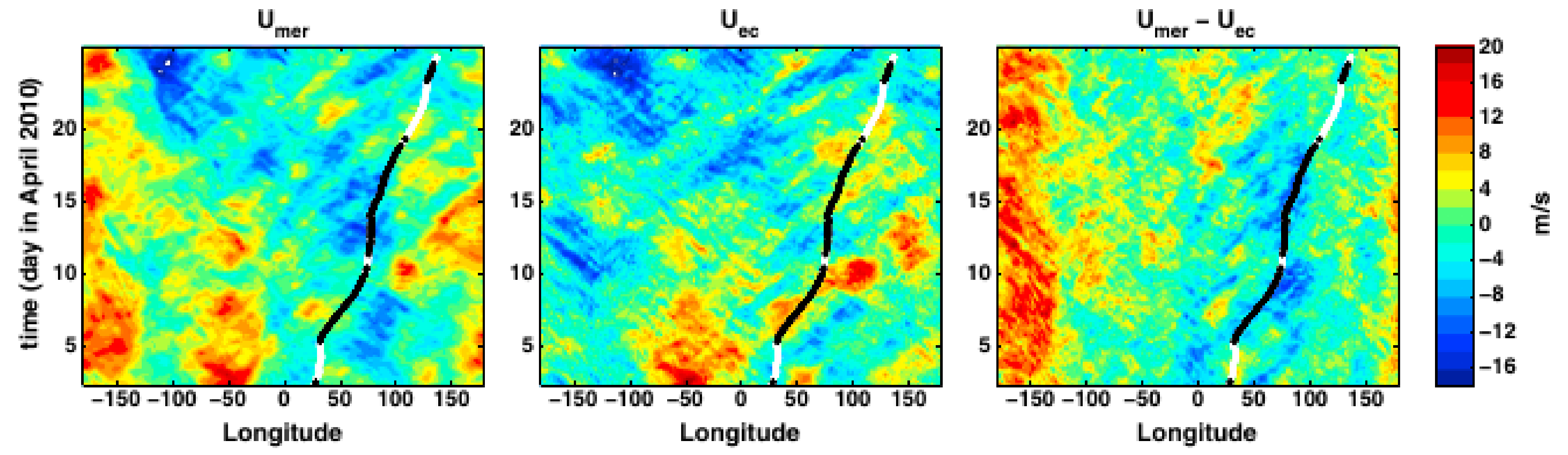


Cause of discrepancies: equatorial waves



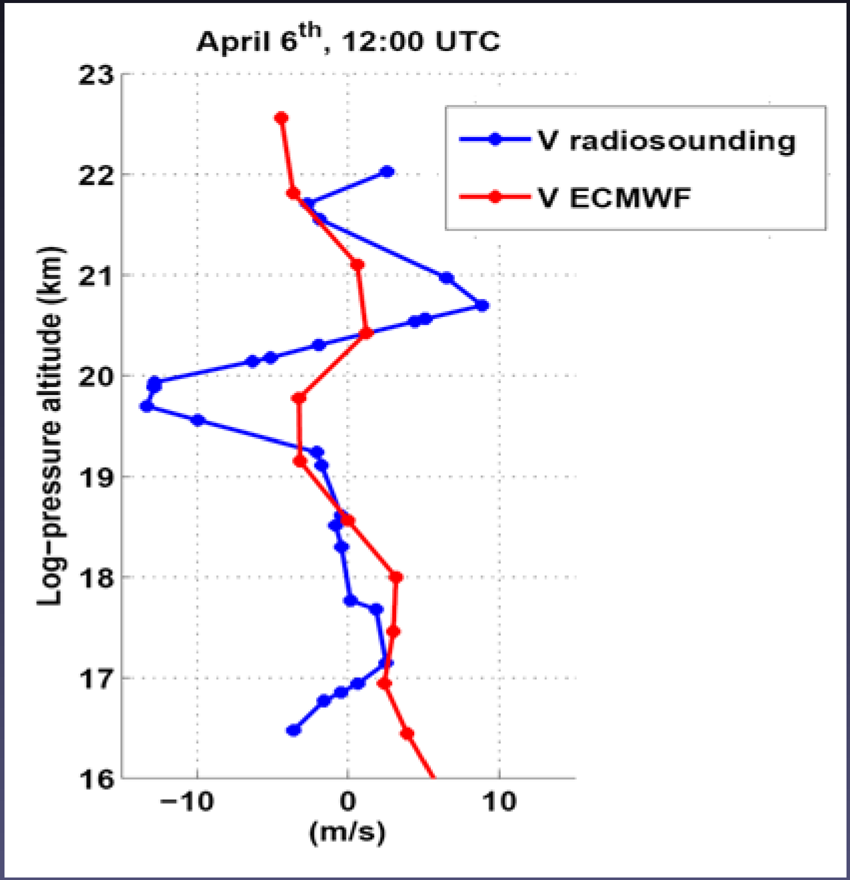


Kelvin wave packet essentially missed by MERRA reanalyses over the Indian Ocean

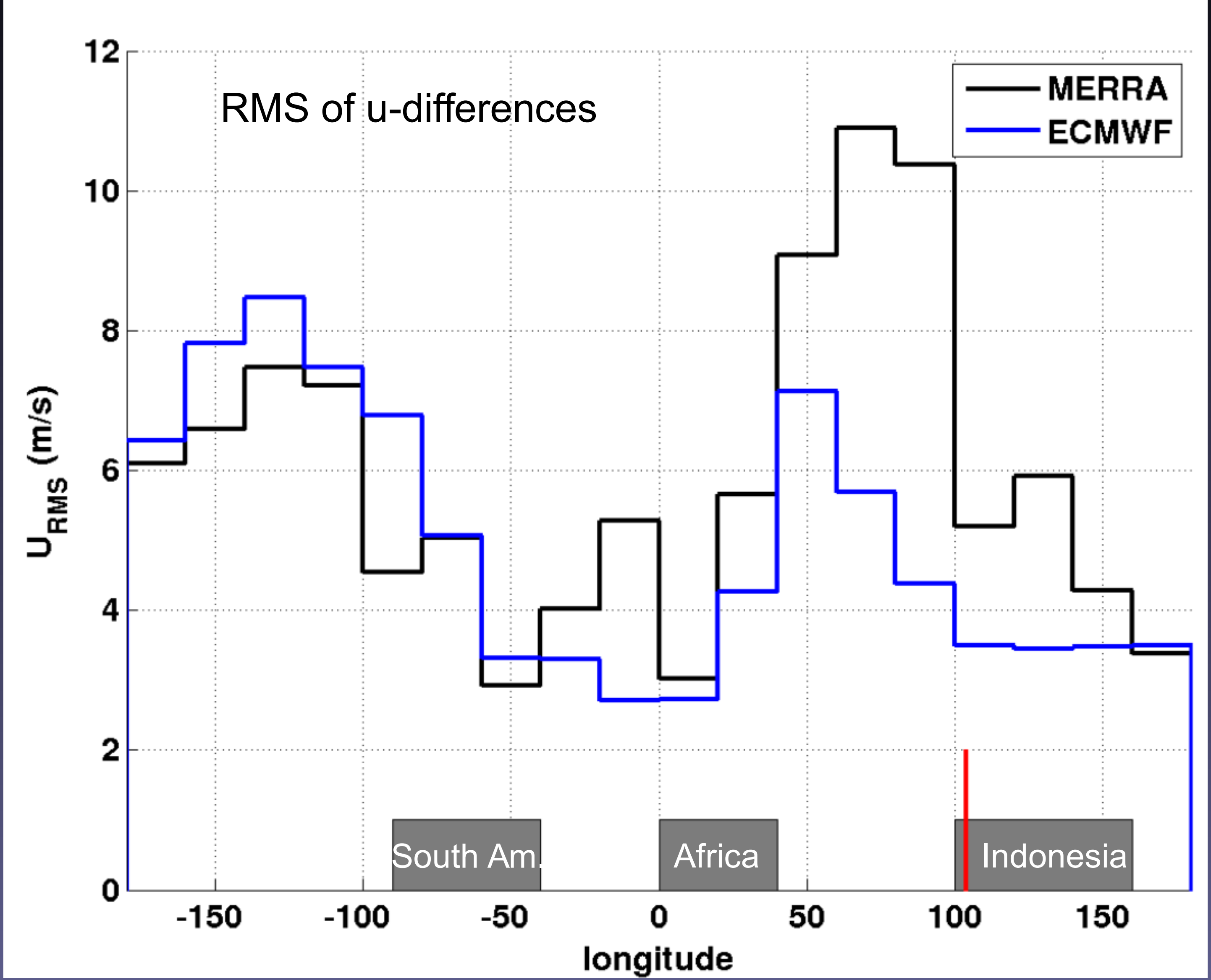
Cause of discrepancies: model vertical resolution

Meridional velocity in Singapore radiosounding
and ECMWF operational analyses
during the passage of a Yanai wave packets

Equatorial waves can have small (2-3 km) vertical wavelength, and still large amplitudes => in spite of assimilation, they may only be marginally resolved in NWPs



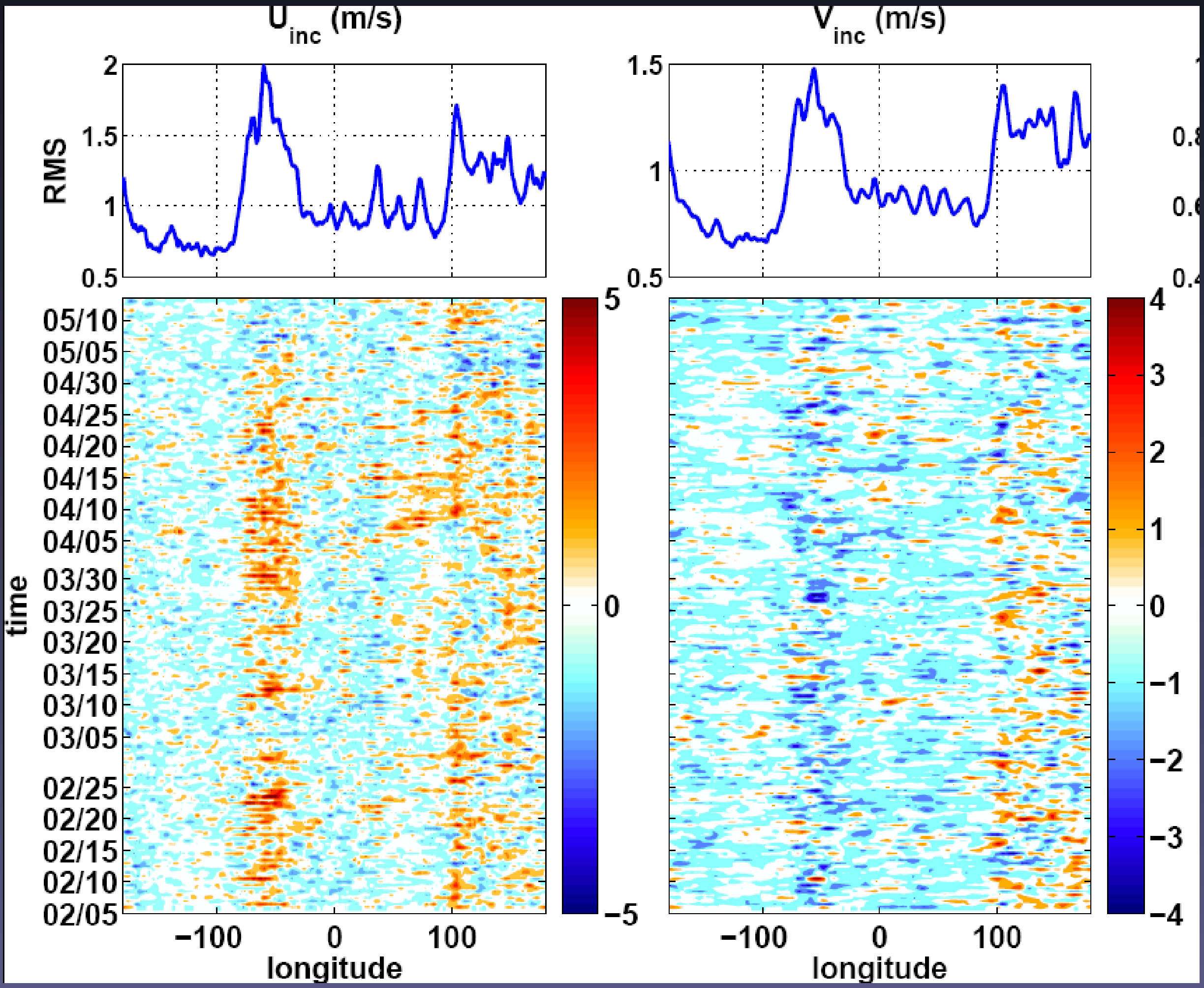
Cause of discrepancies: observation distribution



Errors twice as large over regions void of conventional observations

Constraints on ECMWF analyses

5S-5N wind increments in ECMWF operational analyses



Significant increments over South America and Indonesia...
Model dynamics is almost free-running over the rest of the equatorial belt

Conclusions

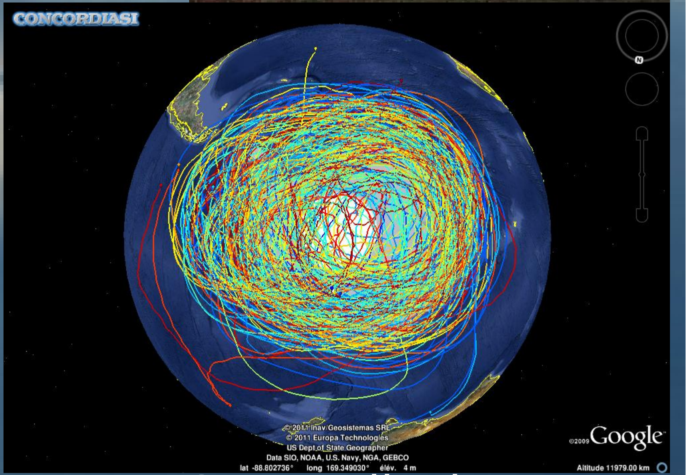
- Past reanalyses (NCAR/NCEP and mostly ERA-40) had difficulties in capturing synoptic-scale variability in the poorly observed SH storm track in the early 1970's
- Excellent agreement between (re-)analysis meteorological fields and independent observations at extra-tropical latitudes
- Large, long-lasting errors in the UTLS equatorial dynamics in current (re-)analysis products
    - Prominence of equatorial waves in the equatorial wind variability
    - Sparse constraints on upper-air winds (above convection)

Strateole 2: A long-duration balloon campaign
at the Equator (2018-2021)

http://tinyurl.com/strateole

- 3 campaigns from late 2018 to late 2021
  - Up to 22-24 flights per campaign
  - Flights in the upper TTL (around 18 km) and in the lower stratosphere (around 20 km)
  - Launch from an equatorial site
    => balloons will stay in the ‘tropical pipe’ and provide observations representative of the whole equatorial belt

- Observations available in near-real time
  - Flight level meteorology (P, T, winds)
  - Backscatter lidar on some flights
  - In-situ water vapor, ozone, aerosol
  - Profiling capabilities down to ~ 4 km below the balloons



Concordiasi
19 flights, Sept-Jan 2010