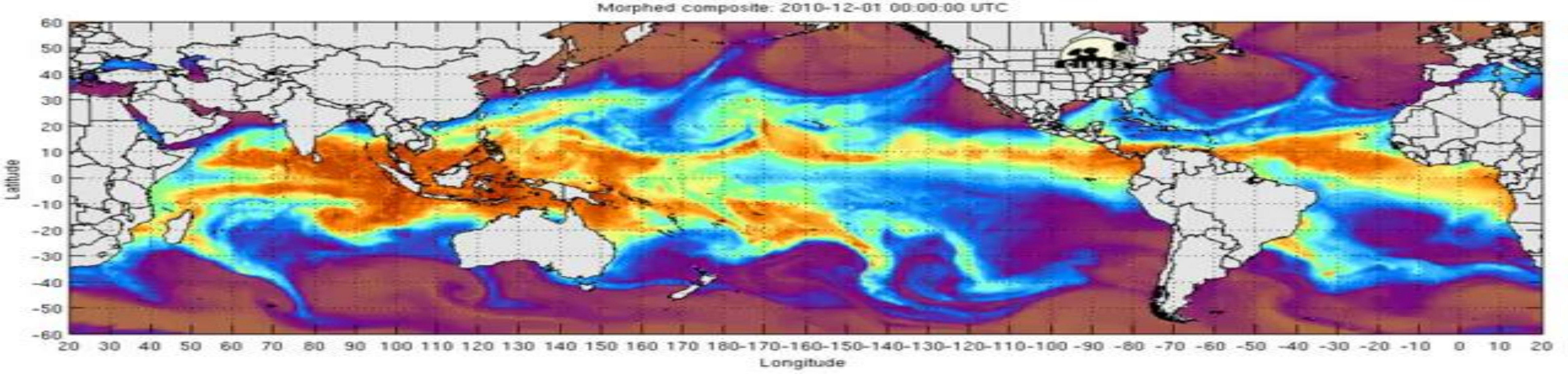
THE DYNAMICS OF ATMOSPHERIC RIVERS



Helen Dacre[1], Oscar Martinez-Alvarado[2], Kevin Hodges[1,2], Cheikh Mbengue[3]

1. University of Reading, 2. National Centre Atmospheric Science, 3. University of Oxford

PRESENTATION OUTLINE

AIM: To describe the dynamics of atmospheric rivers

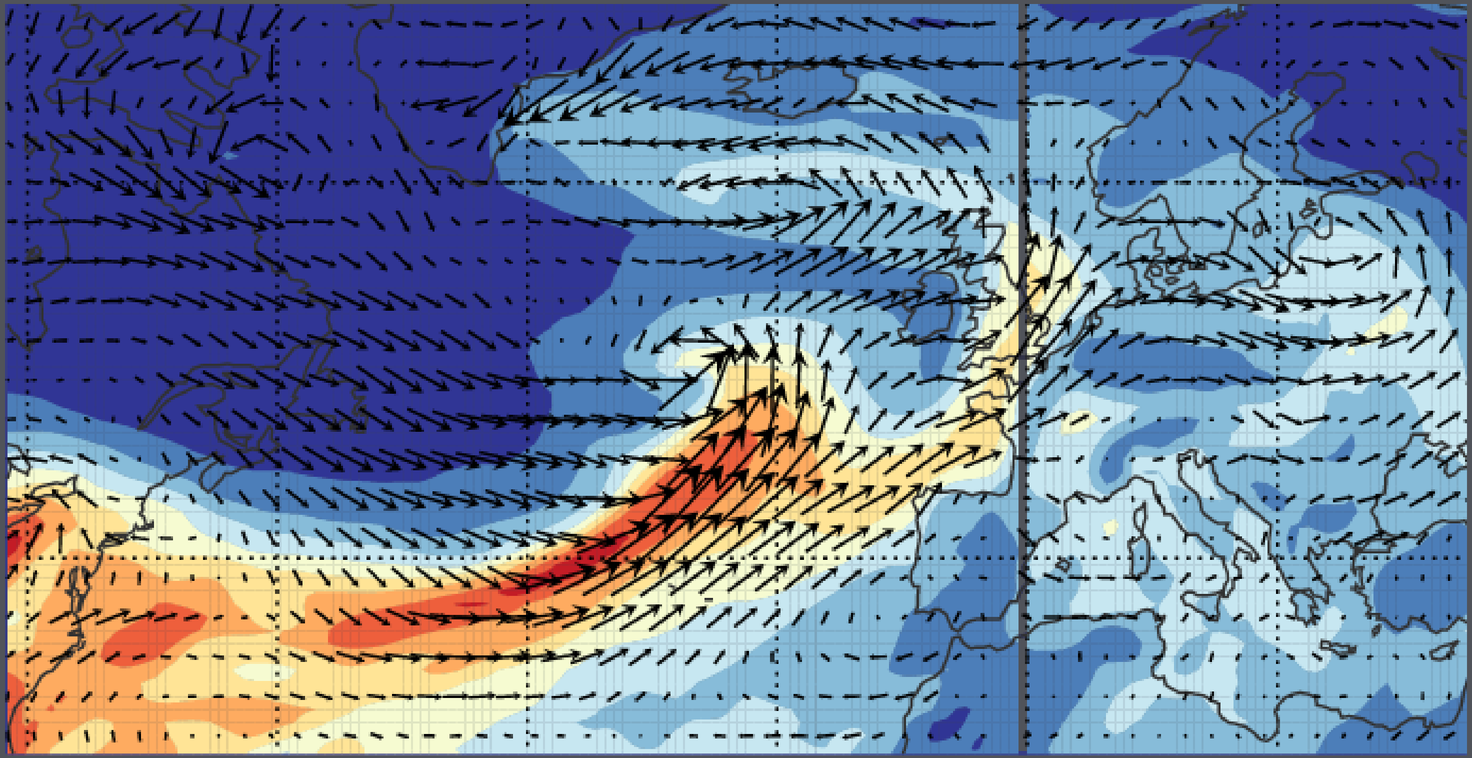
- Intro to atmospheric airflows – case study
- Calculating moisture budgets – case study
- Composite airflows and moisture budgets
- Sensitivity of precipitation and IVT to atmospheric moisture
- Estimating precipitation efficiencies

CASE STUDY: 31 JAN 2002

Track of storm and position relative to maximum intensity

Dacre et al. (2015), BAMS

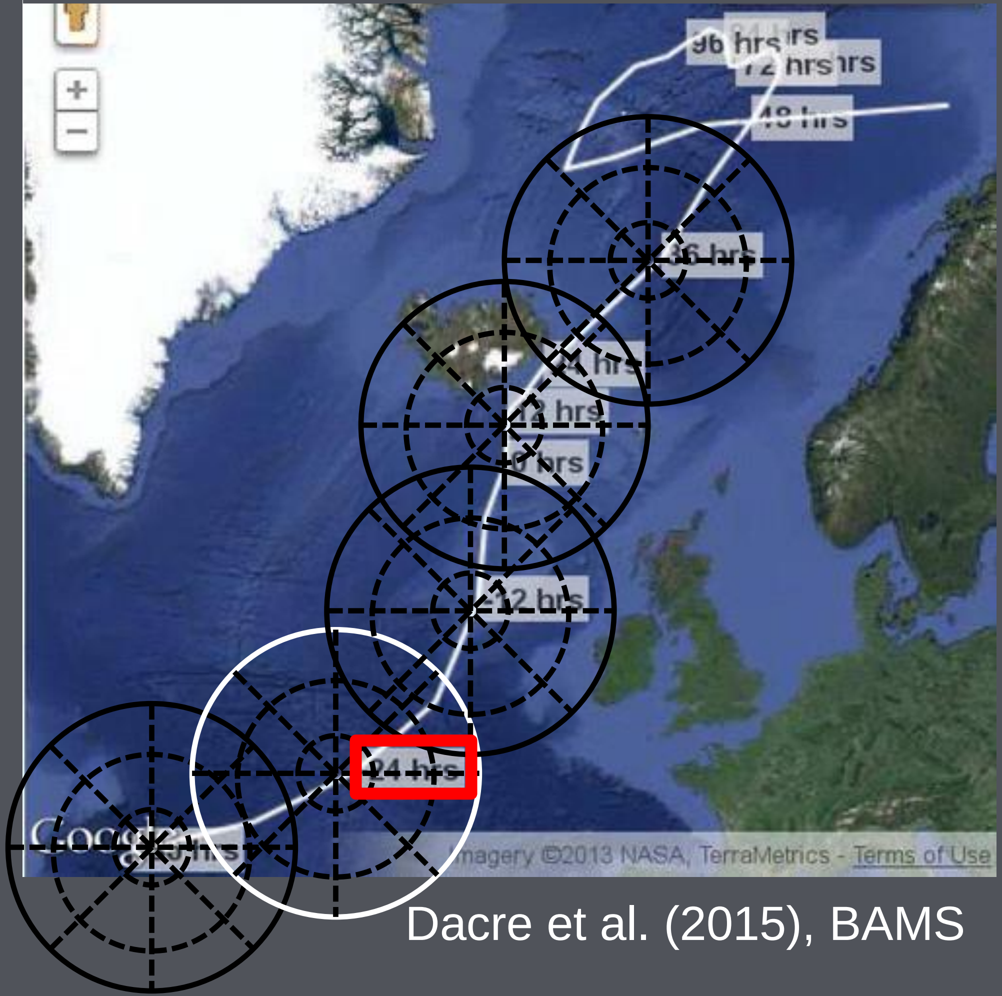
ERA-Interim TCWV
925 hPa Earth-relative winds (vectors)
18 UTC 31 Jan 2002



FOCUS ON ATMOSPHERIC RIVER

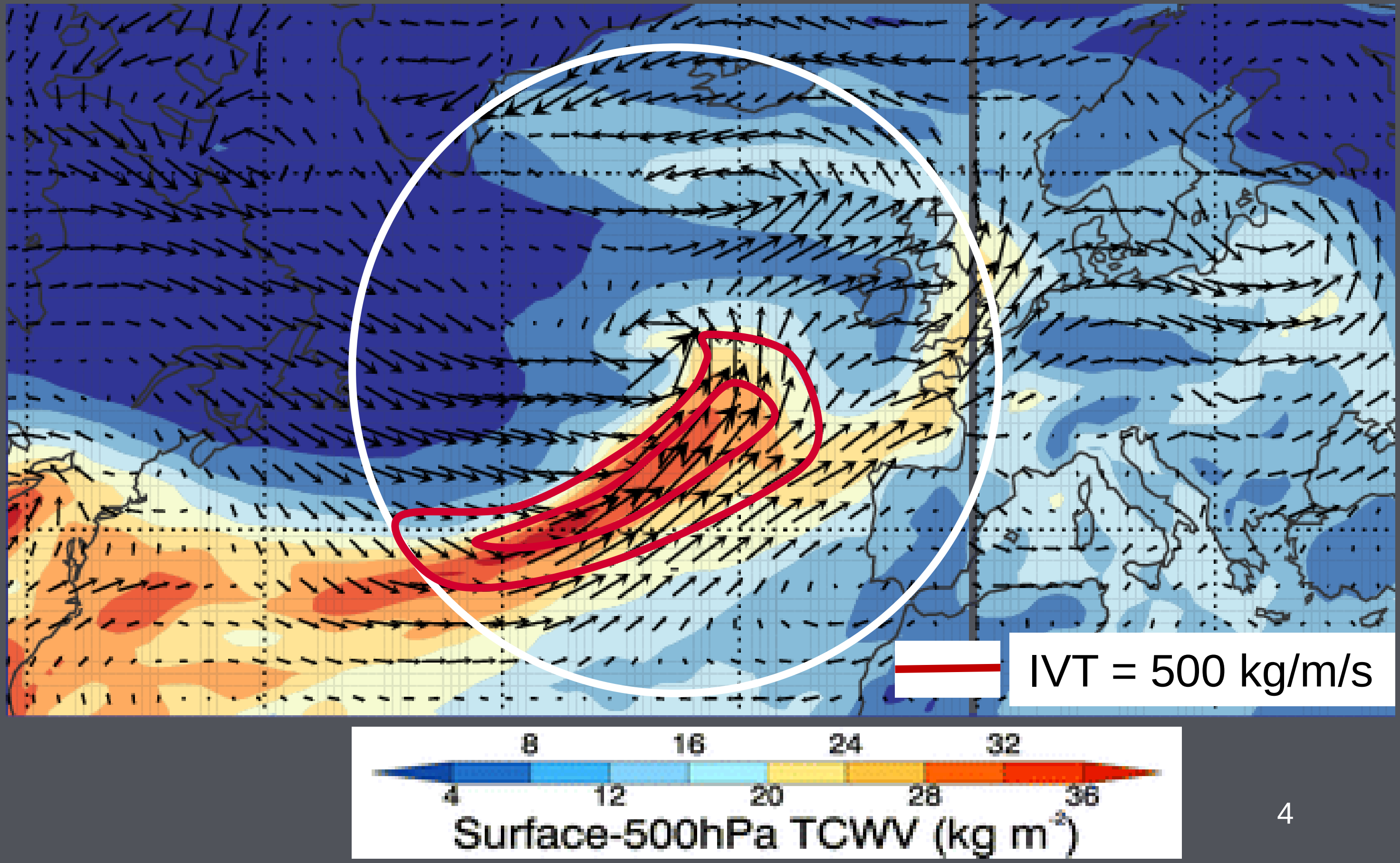
University of Reading

Track of storm and position relative to maximum intensity



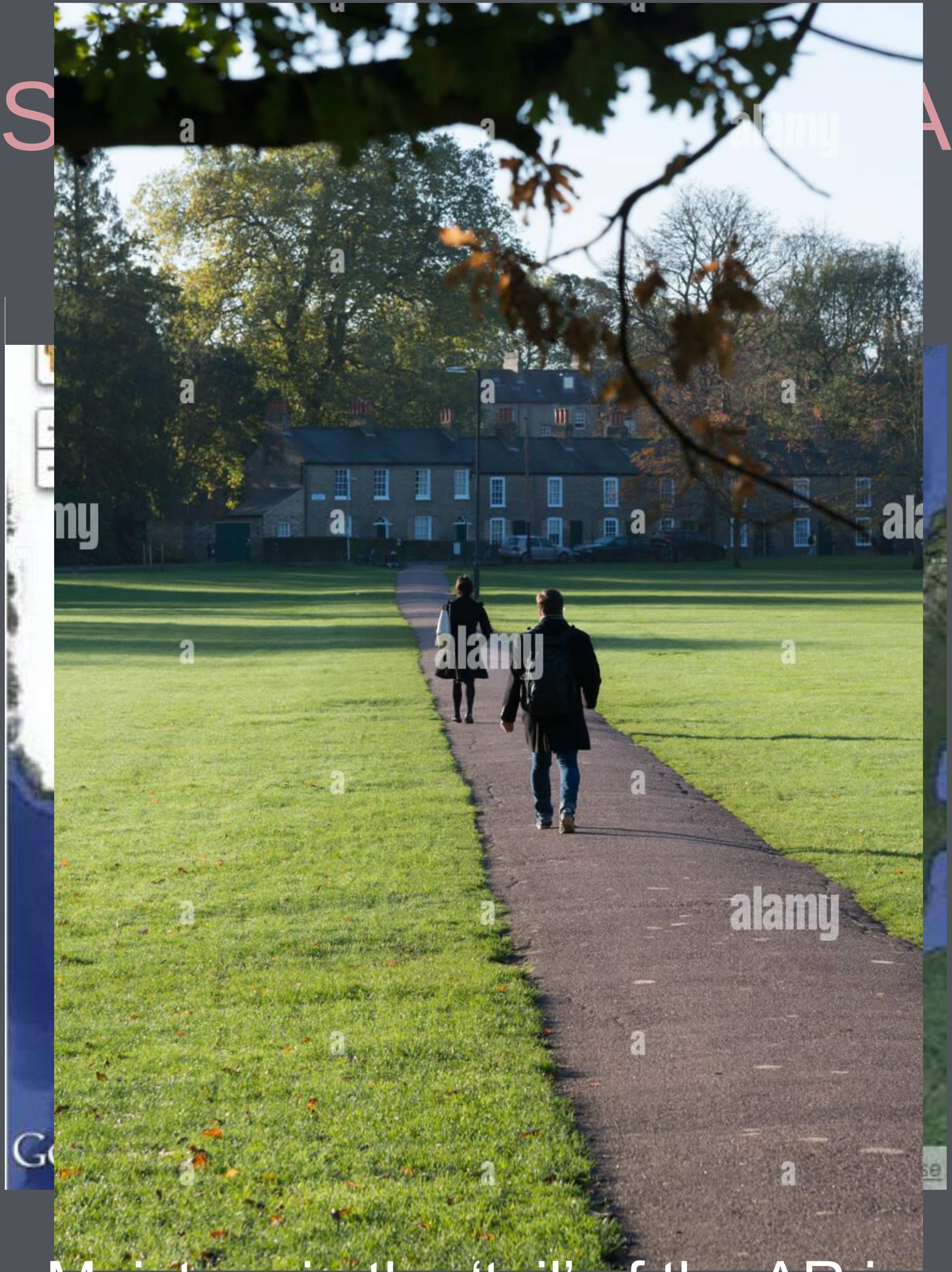
Dacre et al. (2015), BAMS

ERA-Interim TCWV
925 hPa Earth-relative winds (vectors)
18 UTC 31 Jan 2002

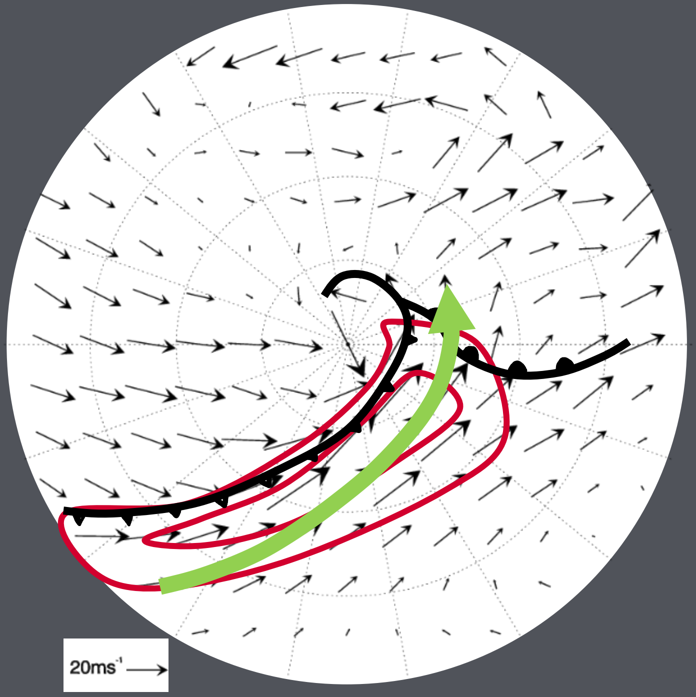


S AIRFLOWS

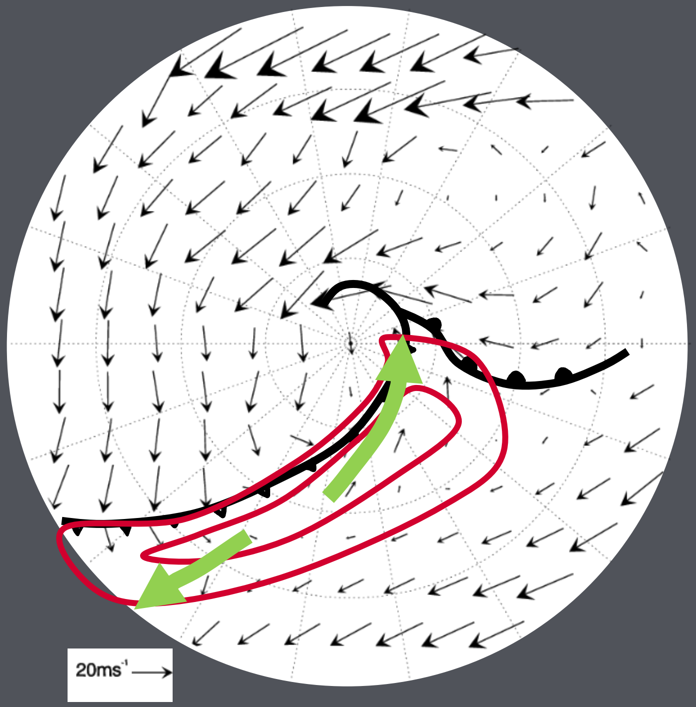
University of Reading



ERA-Interim IVT
925hPa Earth-relative winds
18 UTC 31 Jan 2002



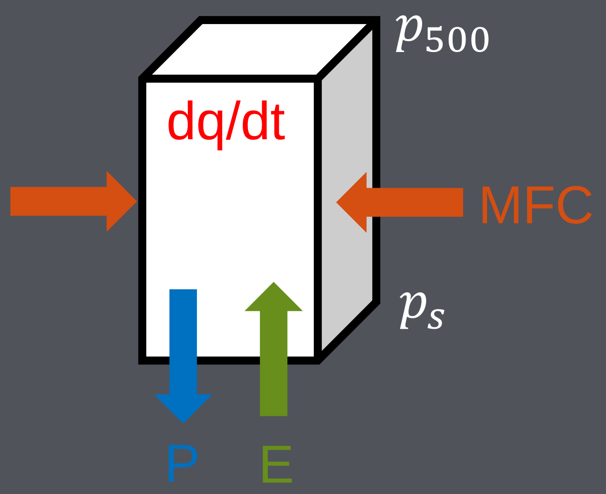
ERA-Interim IVT
925hPa Storm-relative winds
18 UTC 31 Jan 2002



IVT = 500 kg/m/s

- Moisture in the 'tail' of the AR is moving too slowly to catch up with the storm centre

WHAT CAUSES FILAMENTS OF TCWV?



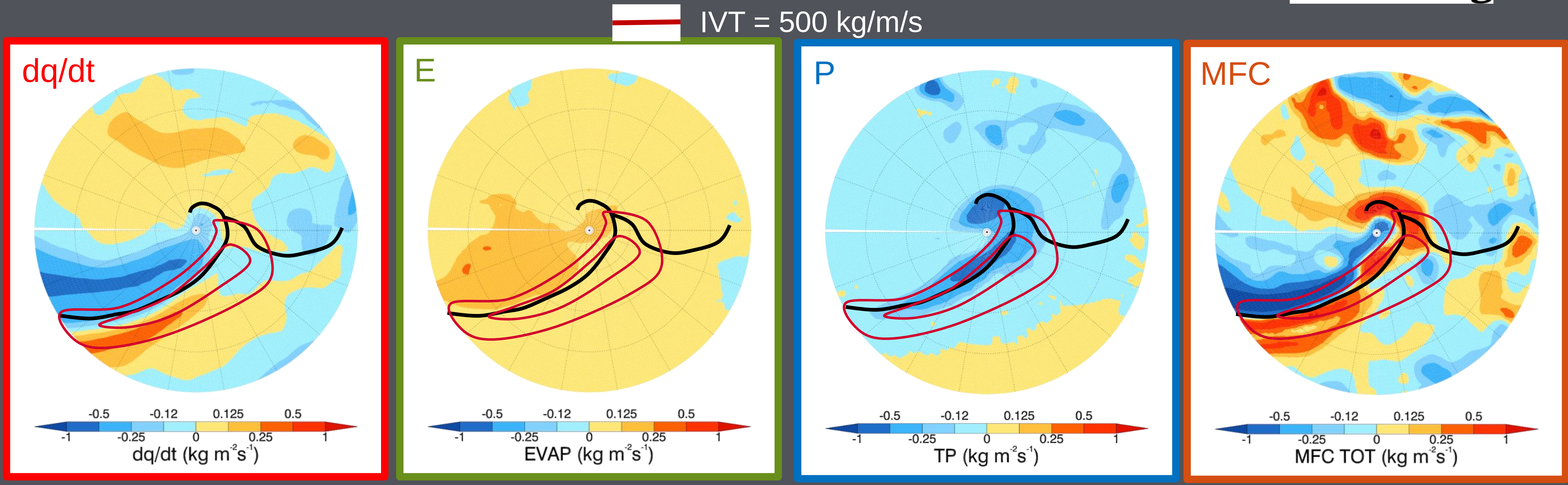
$$\frac{1}{g}\int_{p_{500}}^{p_s}\frac{\partial q}{\partial t}dp = E - P + \frac{1}{g}\int_{p_{500}}^{p_s}\nabla\cdot(q\mathbf{u})dp$$

Vertically integrated rate of change of water vapour	Surface evaporation flux	Surface precipitation flux	Vertically integrated moisture flux convergence

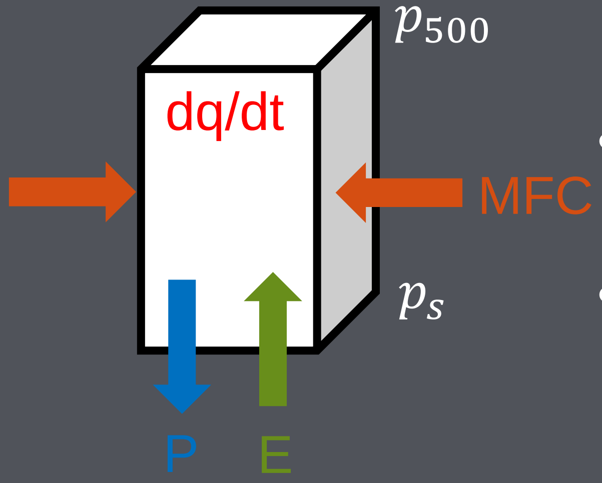
- Calculate each term in the **water vapour budget equation** for each gridbox column within the storm

University of Reading

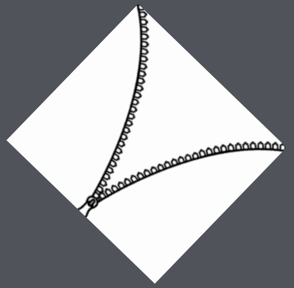
STORM MOISTURE BUDGET TERMS



Dacre at al. 2015

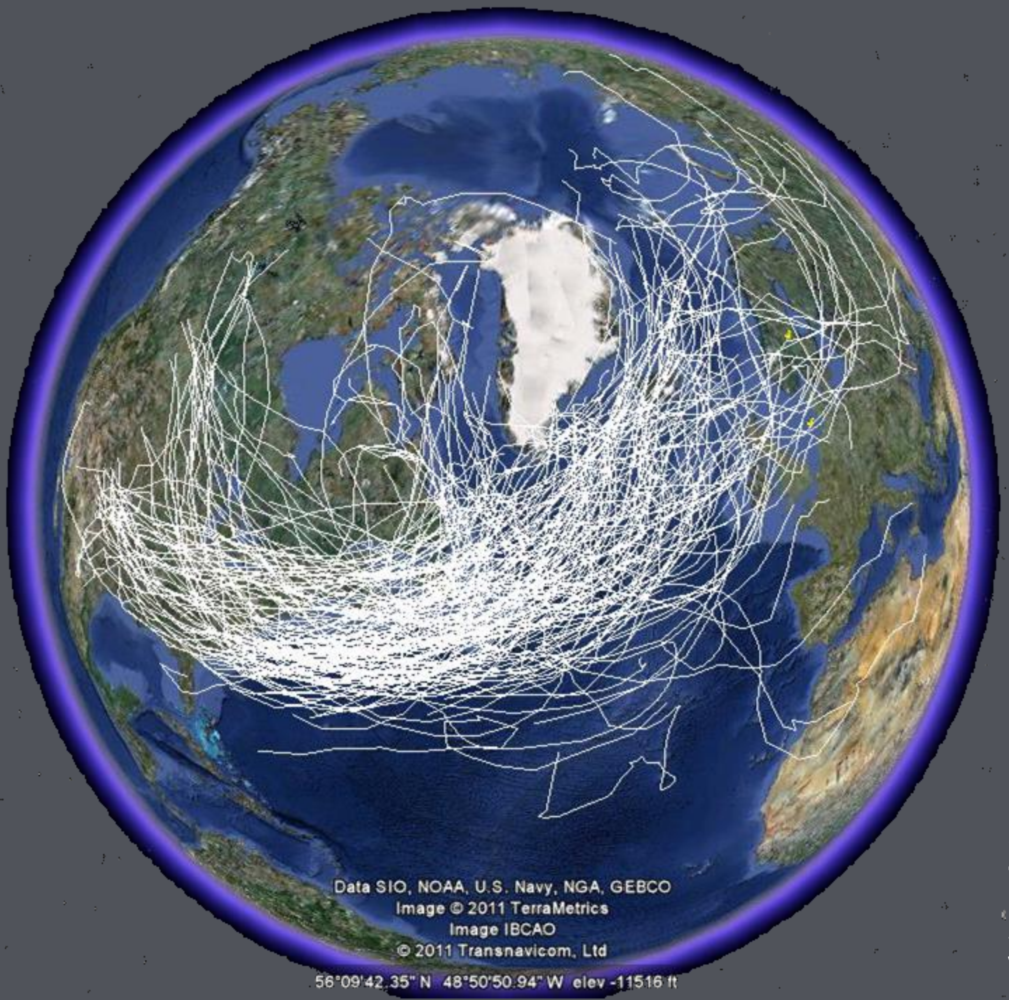


- The extension of the AR from the subtropics is due to MFC ahead of the storm cold front
- The storm sweeps up moisture in the environment as it moves

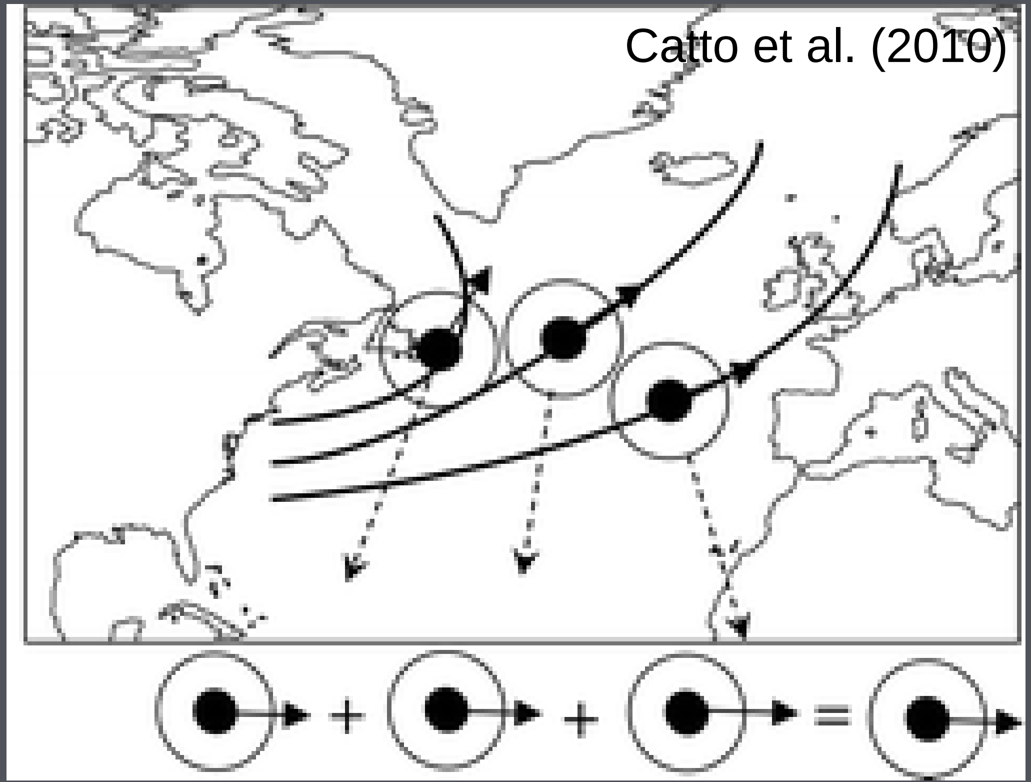


STORM TRACKS VARY IN DIRECTION

Tracks of 200 intense storms in 1990-2008 DJF



Dacre et al. (2012), BAMS

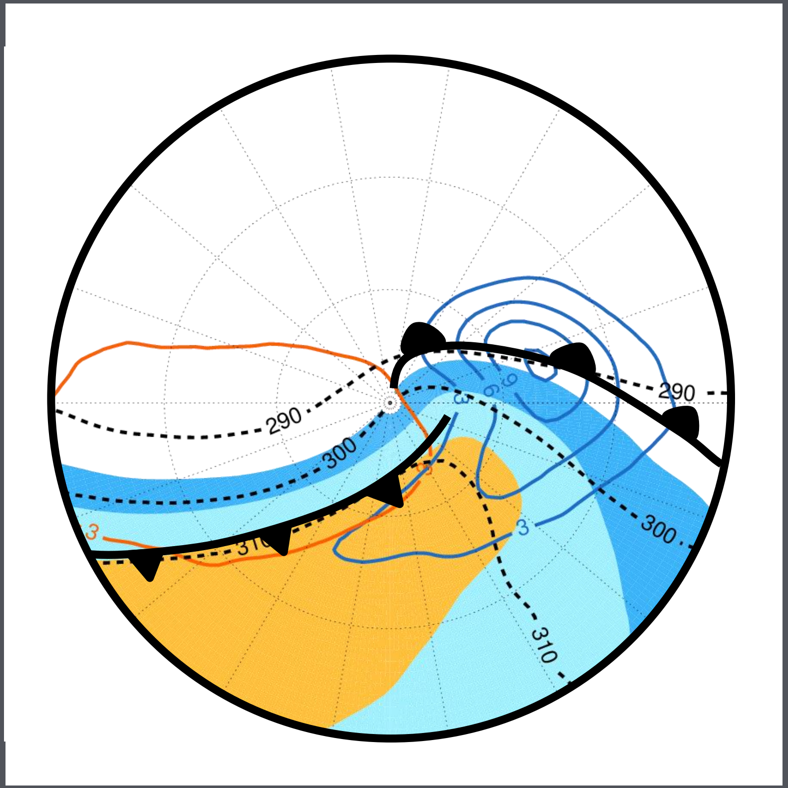


1. Extract fields from ERA-I along storm tracks within 1500 km radius surrounding the cyclone position
2. Rotate storm centred fields so travel is left to right
3. Composite 200 intense storms at times relative to max intensity

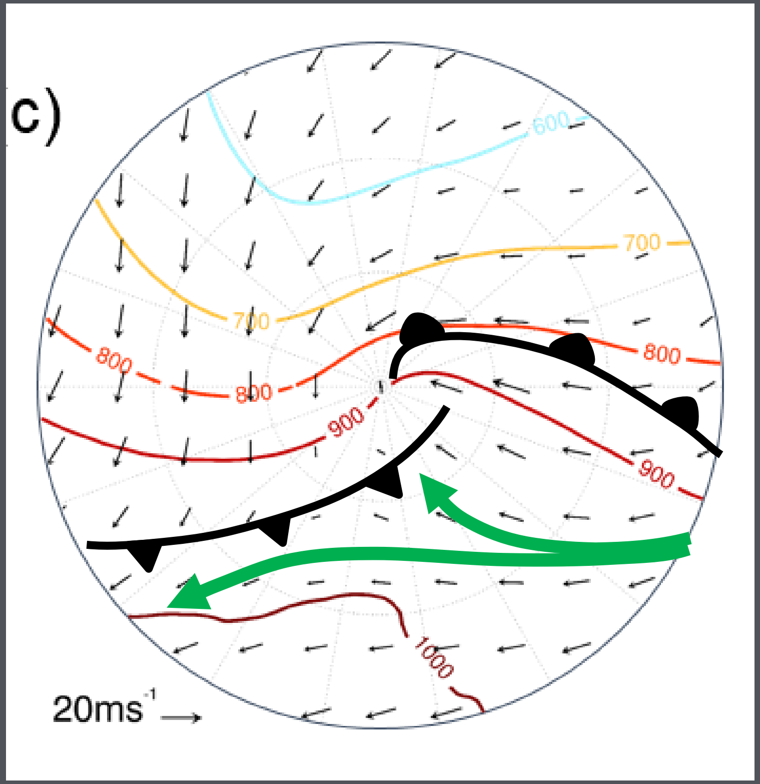
COMPOSITE AIRFLOWS

Composite storm-centred fields 24 hours prior to time of maximum intensity

Storm motion →



TCWV (filled contours), Precipitation (blue), Evaporation (orange), 925 hPa θ_e (black dashed)



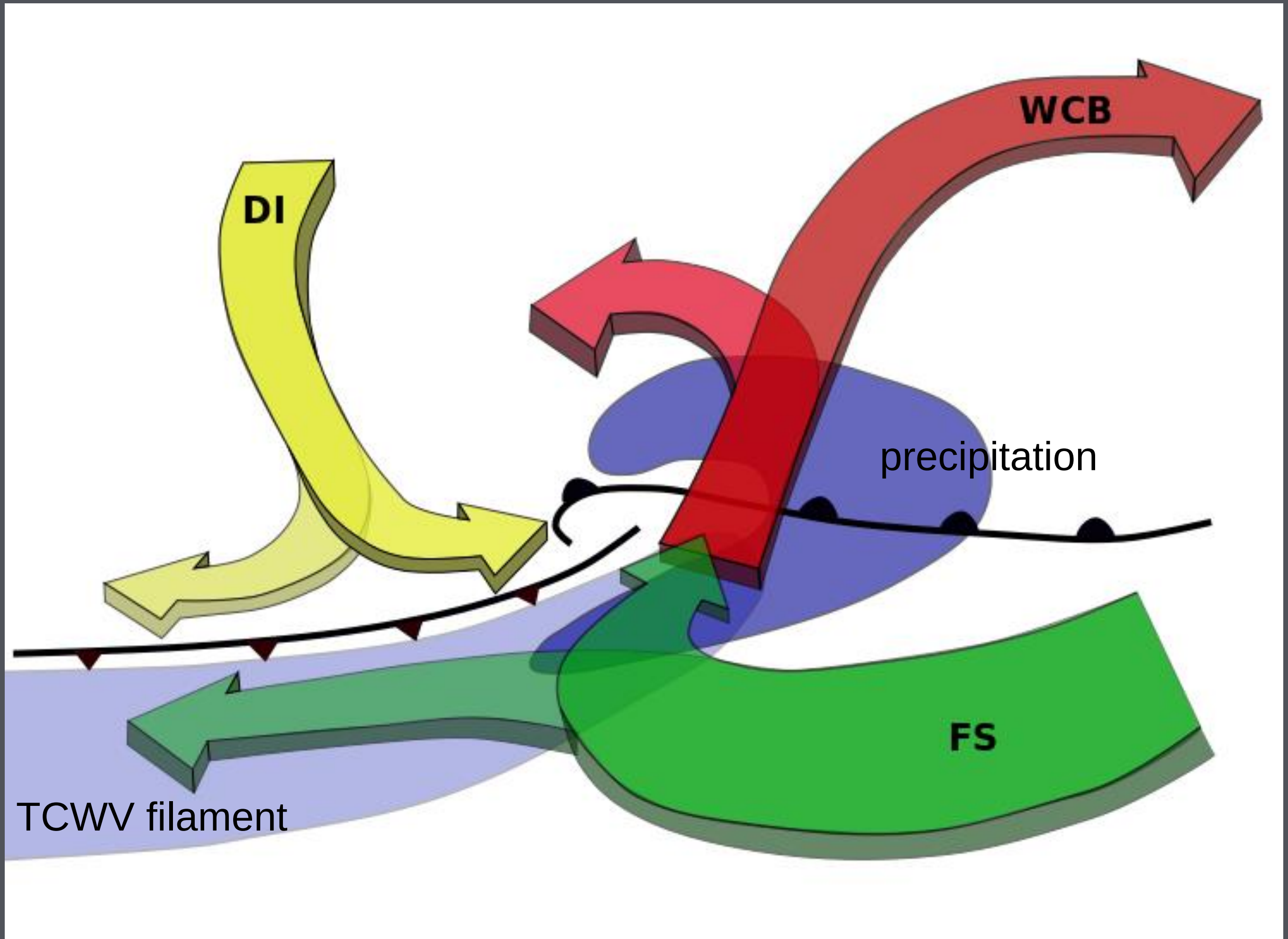
Pressure in hPa (contours) and storm-relative winds on 285 K θ surface

- Low-level feeder-airstream can be identified in the storm composites

FEEDER-AIRSTREAM

University of Reading

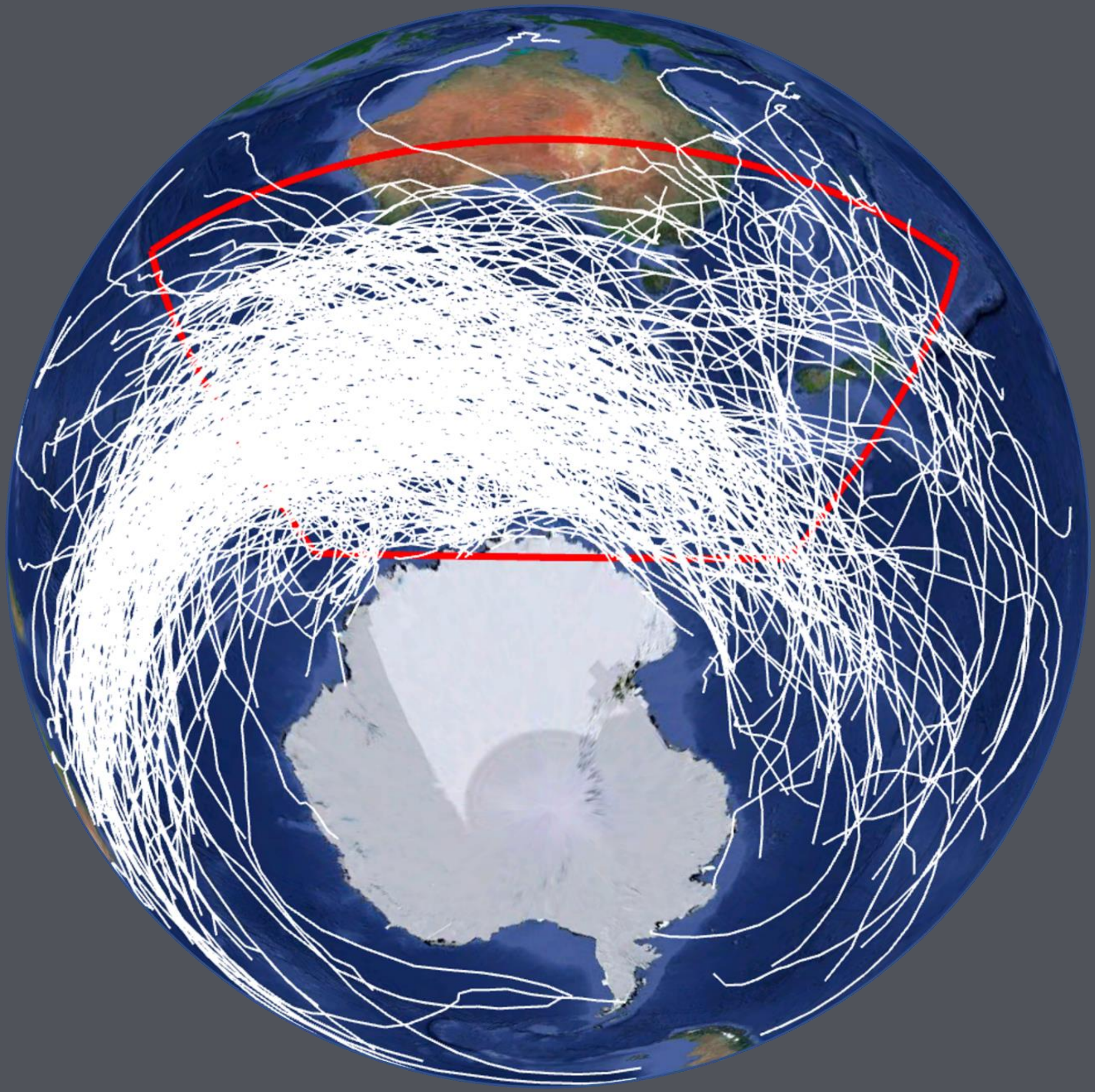
Schematic of storm-relative airflows overlaid on surface features



Precipitation (dark blue), high TCWV (light blue), Warm conveyor belt (red), Dry intrusion (yellow), Feeder airstream (green)

Dacre at al. 2019

SOUTHERN OCEAN STORM TRACKS

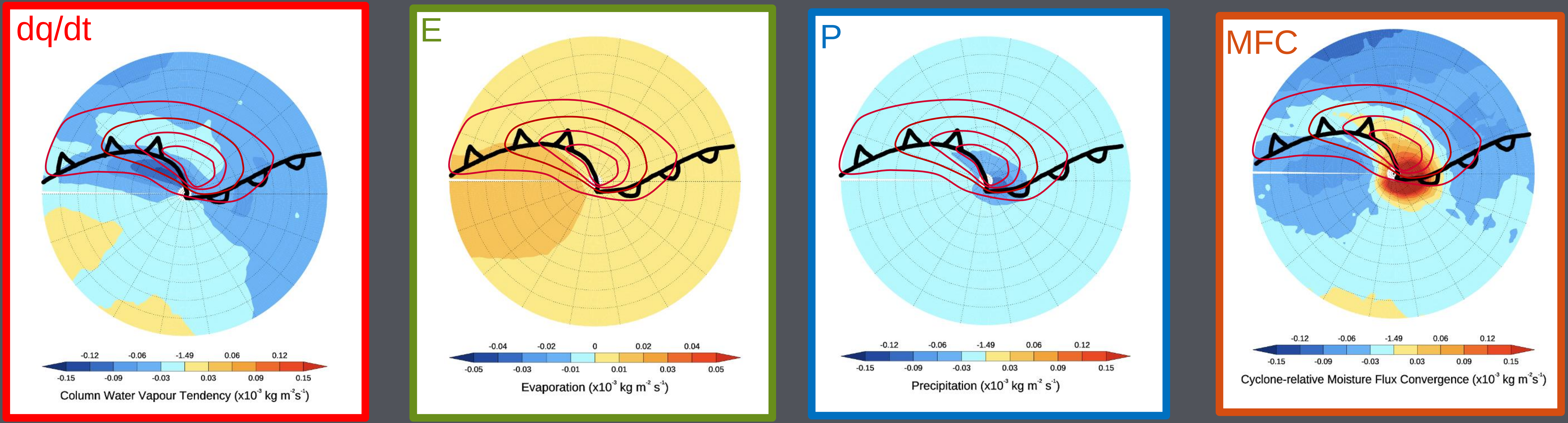


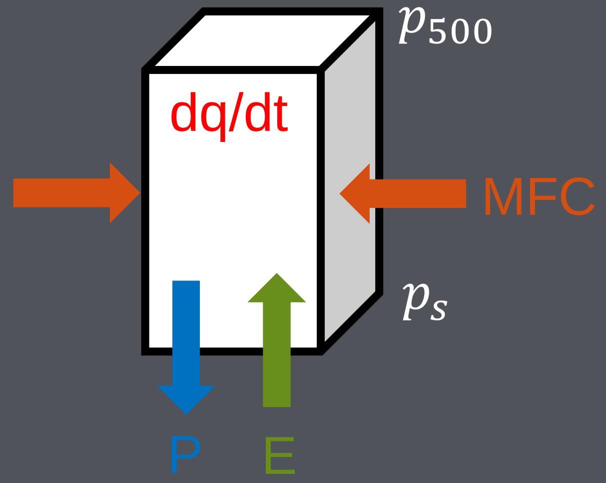
Tracks of 400 intense extratropical storms in ERA5 between March-September 1979-2021

COMPOSITE MOISTURE BUDGET TERMS

University of Reading

Cyclone motion → IVT = 250 kg/m/s





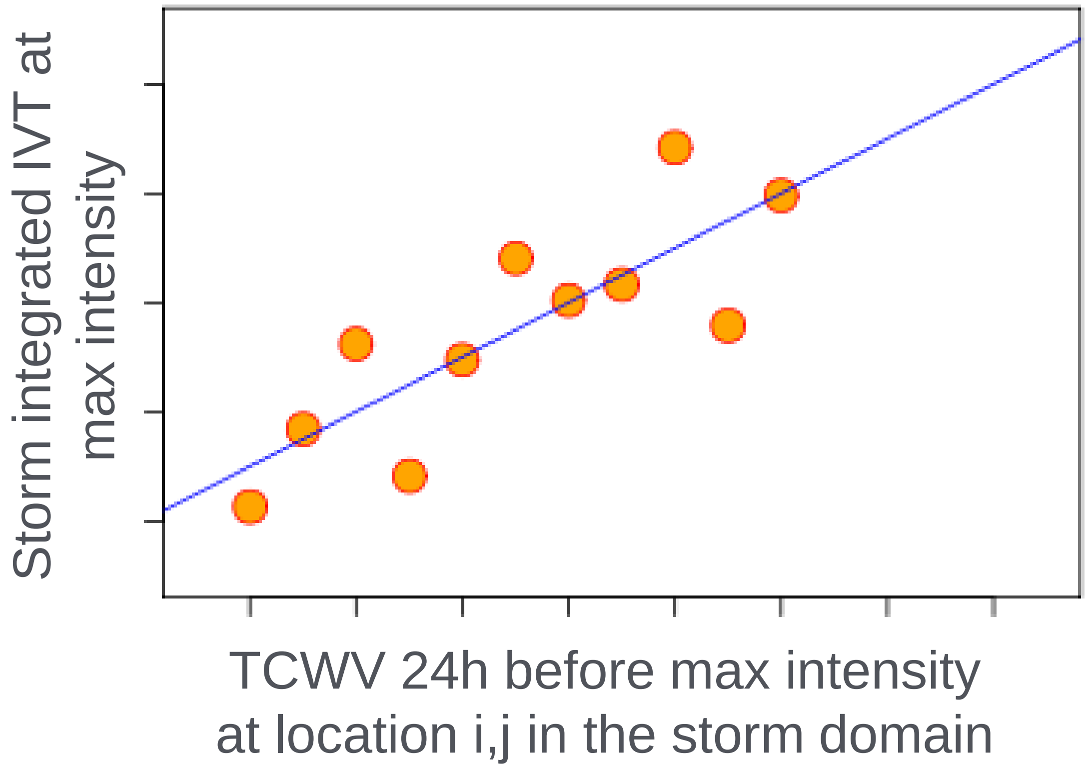
Southern Ocean storm composites

- Composite moisture terms very similar to case study
- Moisture accumulation at leading edge of AR caused by storm sweeping up moisture in environment

QUANTIFYING RELATIONSHIP BETWEEN PRECIP AND TCWV 24HRS EARLIER

University of Reading

$$\frac{\partial (IVT)_{T+0}}{\partial (TCWV_{i,j})_{T-24}} \times \sigma_{TCWV_{i,j}} = S_{i,j}$$



Dacre and Gray (2013), GRL

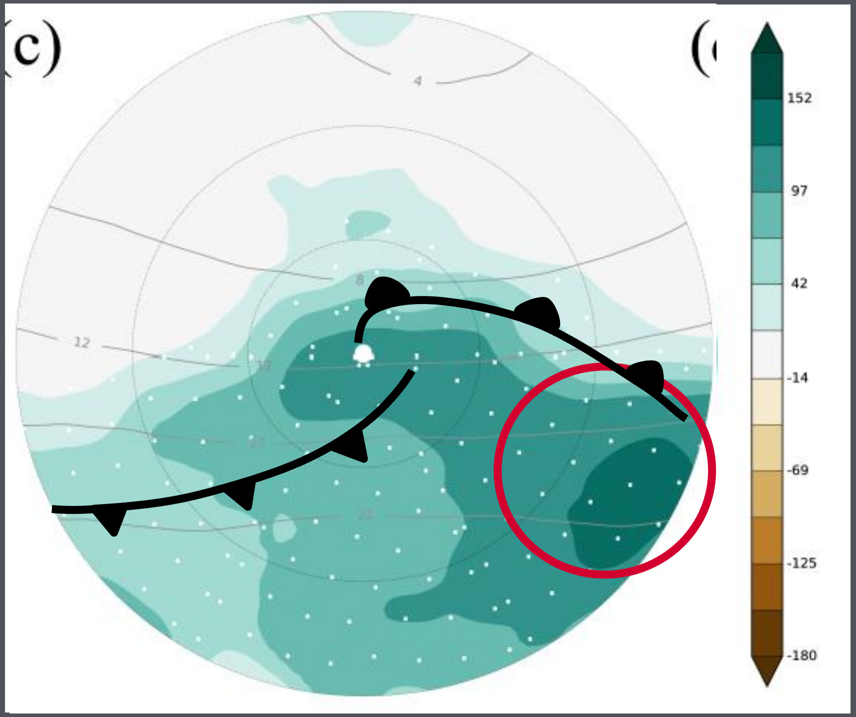
Ensemble sensitivity at each point in the domain, $S_{i,j}$, is calculated using lagged linear regression

AR IVT IS RELATED TO DOWNSTREAM TCWV 24HRS EARLIER

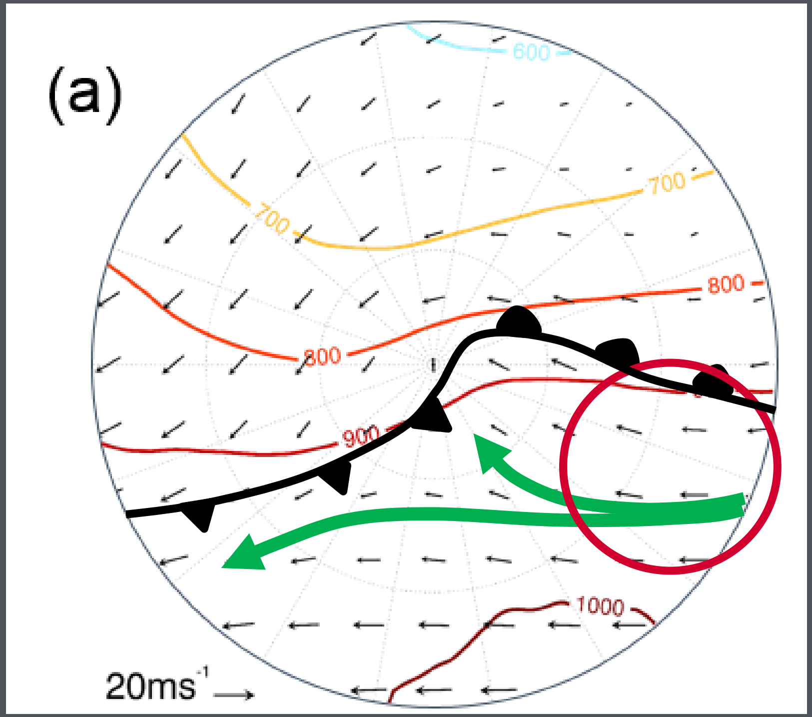
University of Reading

storm motion →

Composite TCWV at T-48 (contours) and sensitivity of IVT (kg m^{-1} s^{-1}) at T-24 to TCWV at T-48



Pressure in hPa (contours) and storm-relative winds (vectors) on 285 K θ surface at T-48

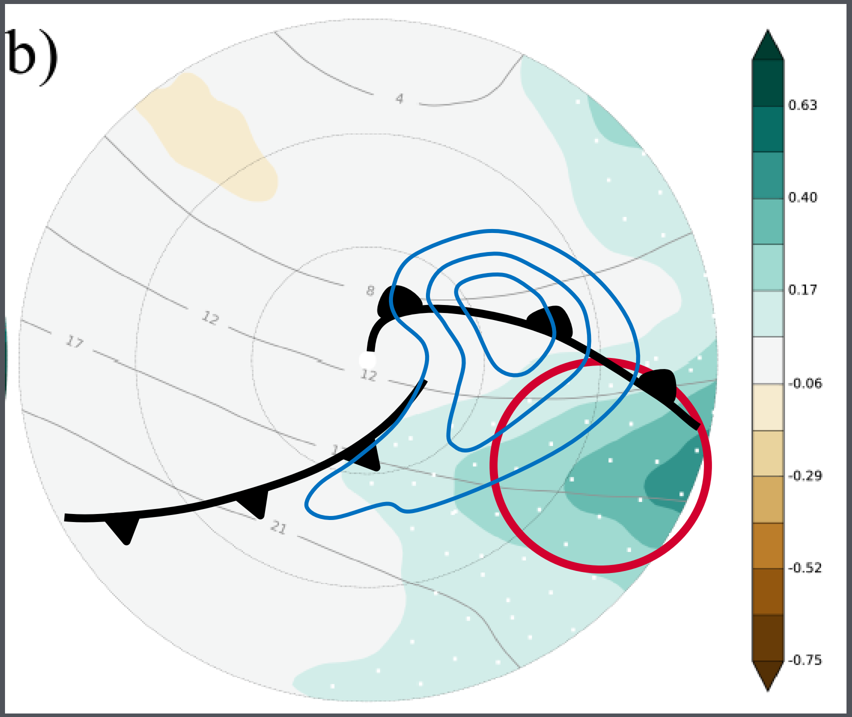


- A sensitivity value of 100 kg m^{-1} s^{-1} = 1 std dev increase in background TCWV there is a corresponding increase in total IVT of 100 kg m^{-1} s^{-1}

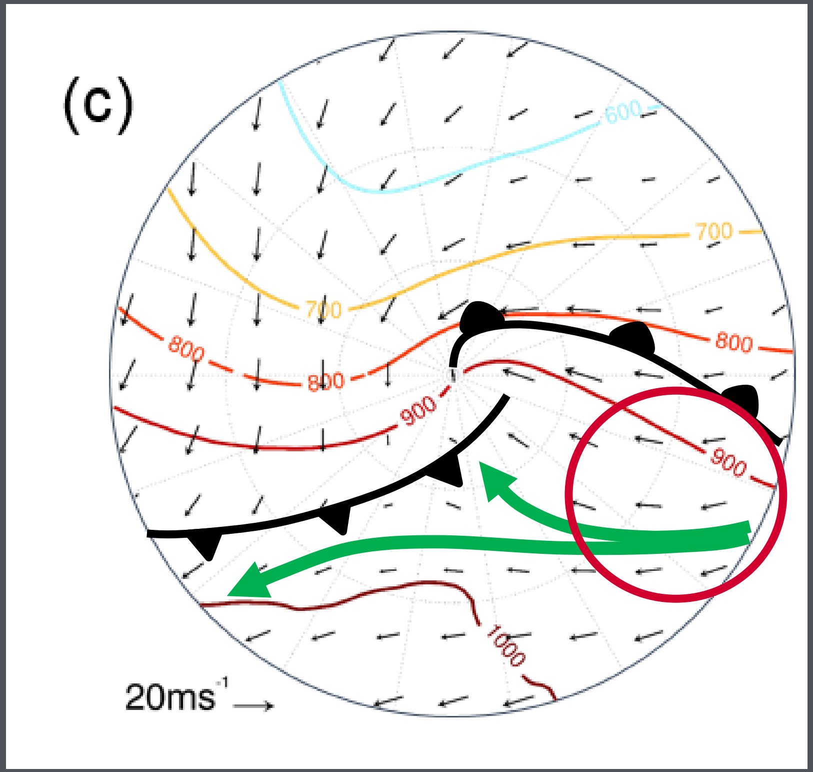
CYCLONE PRECIPITATION IS RELATED TO DOWNSTREAM TCWV 24HRS EARLIER

storm motion →

Composite sensitivity of precipitation (kg m^{-2}) at max intensity to TCWV 24 hrs earlier



Pressure in hPa (contours) and cyclone-relative winds (vectors) on 285 K θ surface at T-24

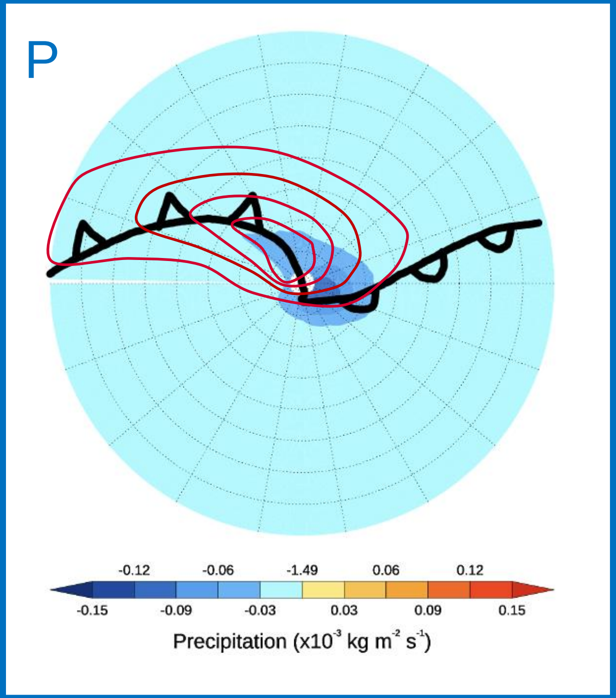


- Storm precipitation is sensitive to TCWV in the environment ahead of the storm 24 hours earlier

PRECIPITATION EFFICIENCY

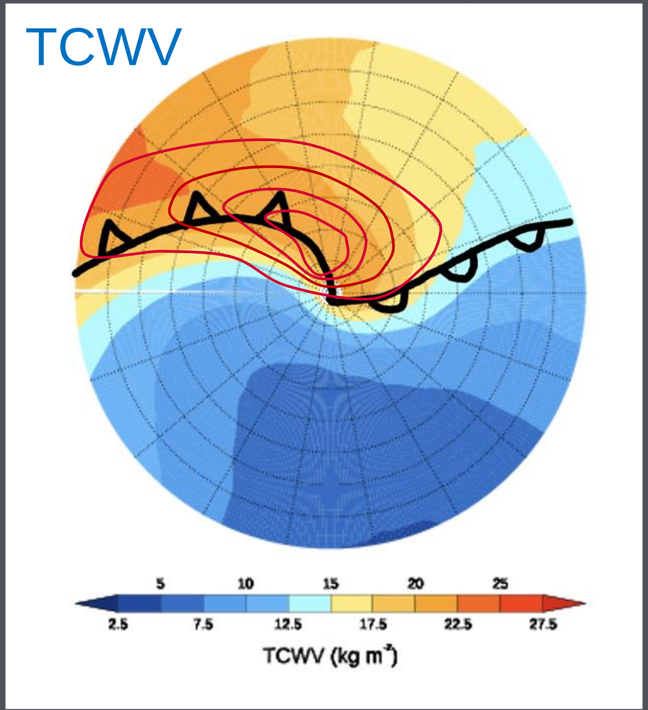
storm motion

IVT = 250 kg/m/s



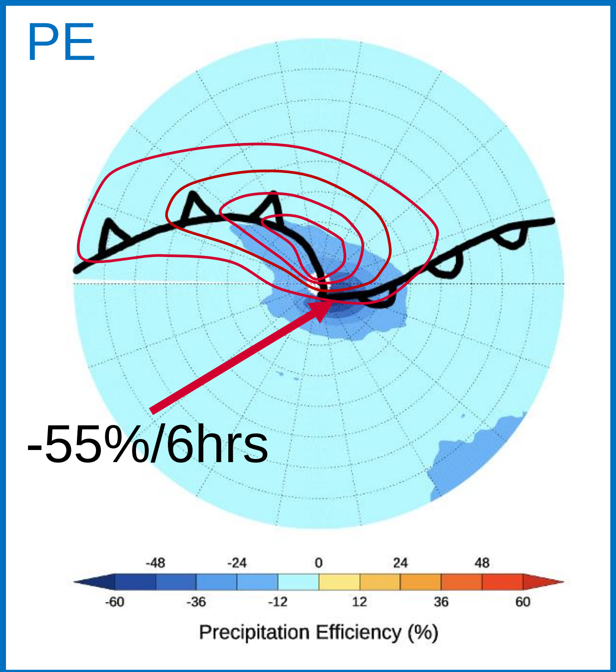
Southern Ocean storm composite precipitation (kg m^{-1} s^{-1}) at T-24

÷



Southern Ocean storm composite TCWV (kg m^{-1}) at T-30

=



Southern Ocean storm composite Precipitation efficiency %/6hrs at T-24

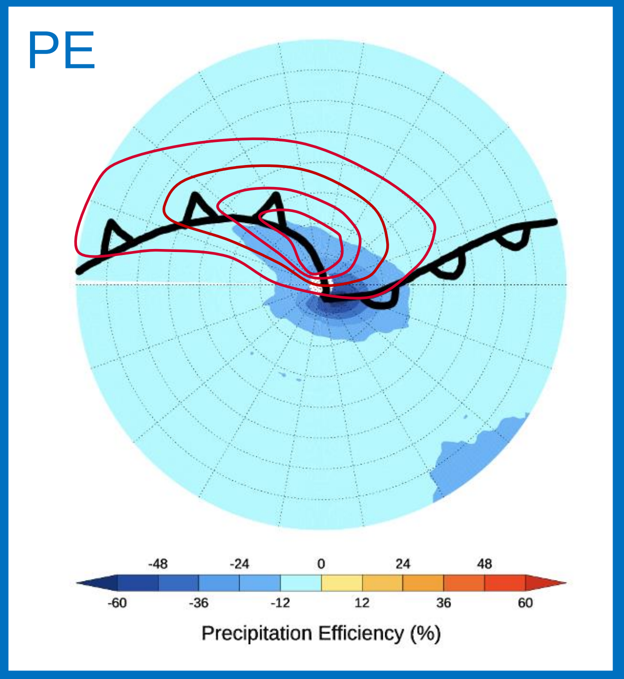
$$PE = \frac{P_t}{TCWV_{t-6}}$$

- Precipitation efficiency is the amount of water that is lost from the atmosphere through precipitation compared to the available water vapour in the atmosphere
- Precipitation efficiency highest -55%/6hrs close to the storm centre

SOUTHERN OCEAN COMPOSITE MOISTURE EFFICIENCIES

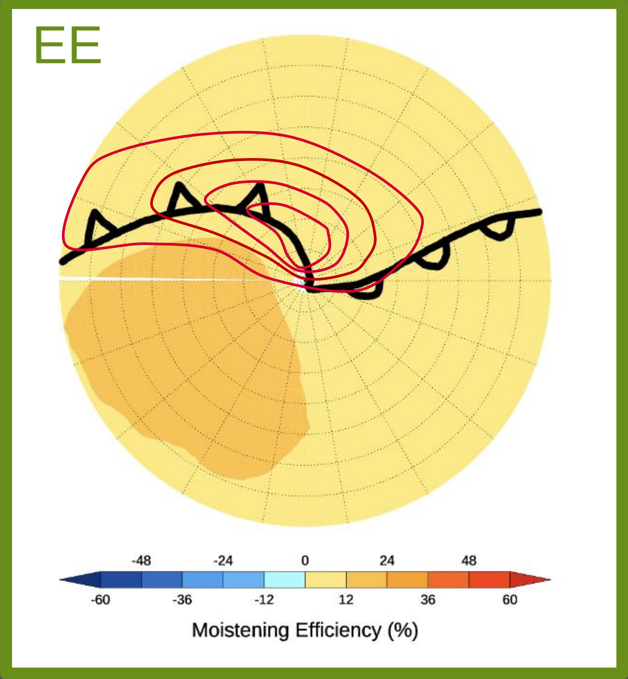
storm motion →

IVT = 250 kg/m/s



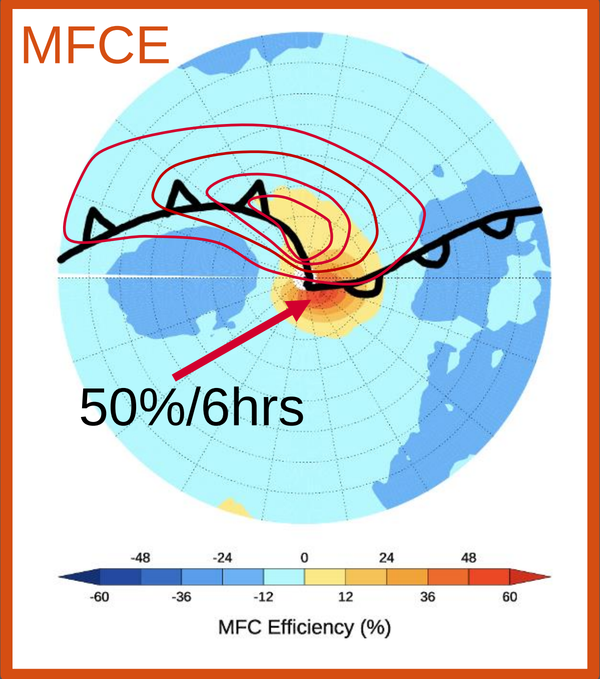
Precipitation Efficiency (%/6hrs) at T-24

$$PE = \frac{P_t}{TCWV_{t-6}}$$



Evaporation Efficiency (%/6hrs) at T-24

$$EE = \frac{E_t}{TCWV_{t-6}}$$



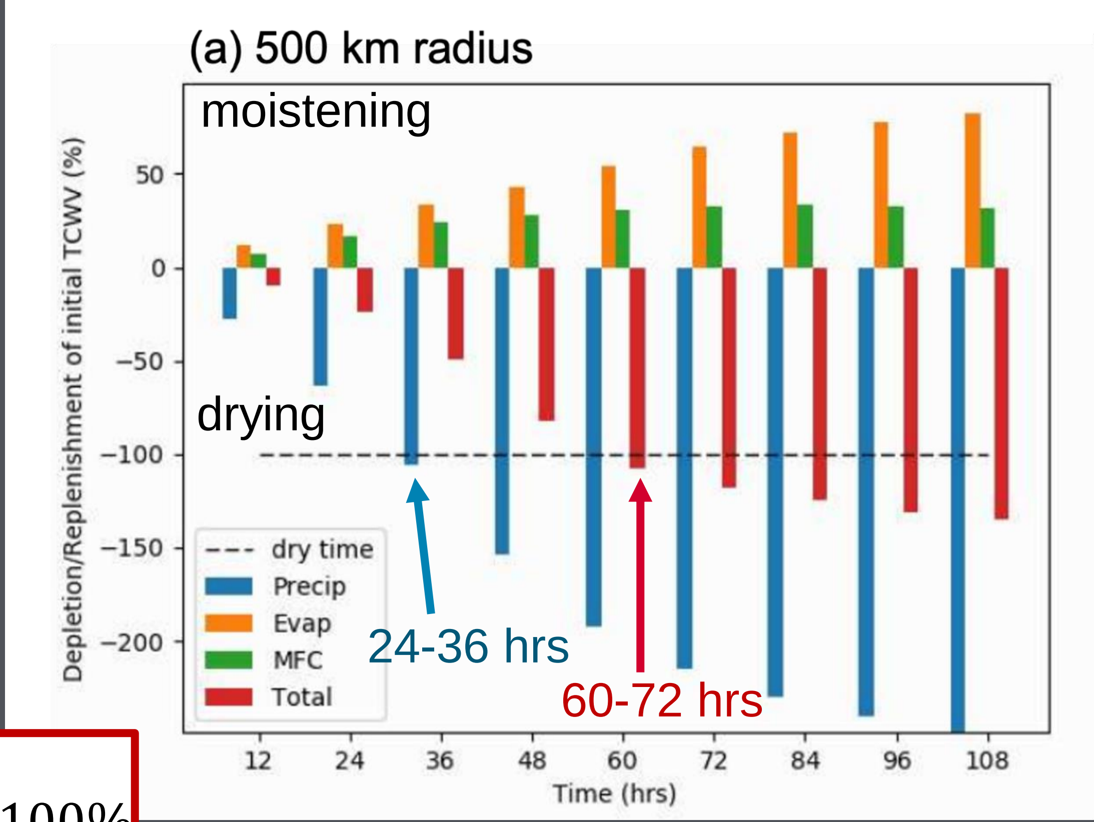
Moisture Flux Convergence Efficiency (%/6hrs) at T-24

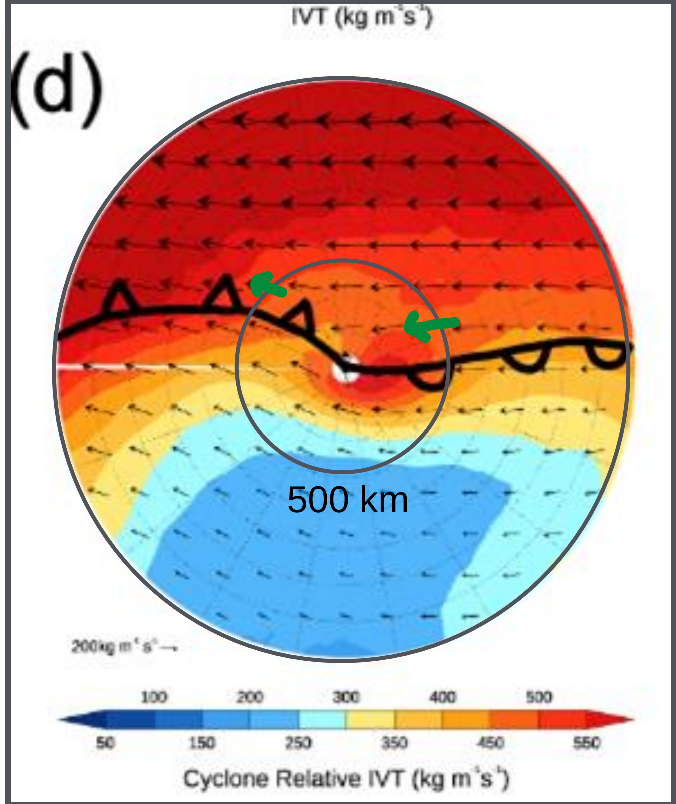
$$MFCE = \frac{MFC_t}{TCWV_{t-6}}$$

- Moisture flux convergence efficiency 50%/6hrs replenishes moisture lost via precip

HOW QUICKLY DO STORMS DRY OUT?

Accumulated storm moisture



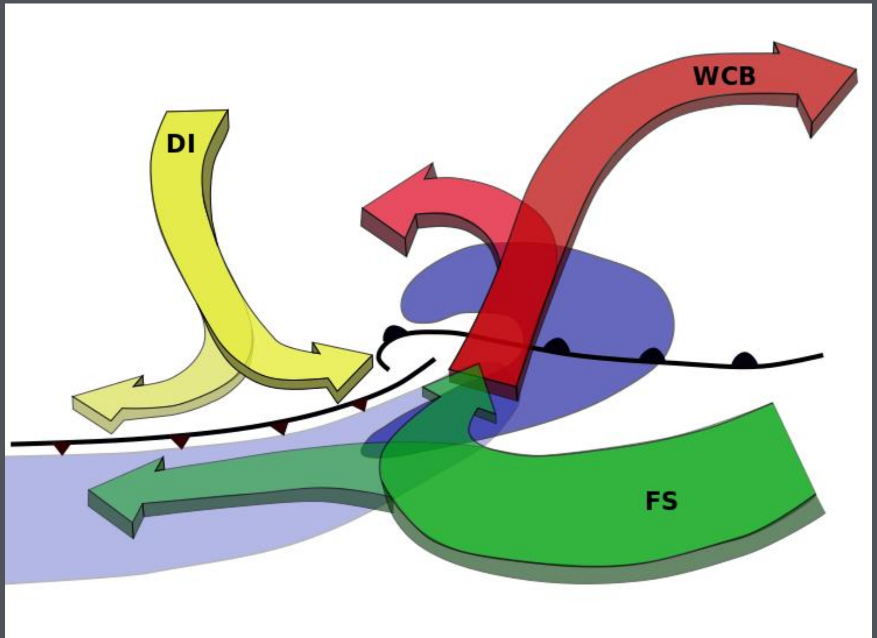


$$\frac{\sum_{t=t_0}^{PDT}\int_0^r P_t dr}{\int_0^r TCWV_{t_0} dr} = -100\%$$

$$\frac{\sum_{t=t_0}^{TDT}\int_0^r (P_t + E_t + MFC_t) dr}{\int_0^r TCWV_{t_0} dr} = -100\%$$

- The initial moisture content of storms is lost 24-36 hours after cyclogenesis
- Local evaporation and moisture flux convergence doubles the precipitating phase of storms

CONCLUSIONS



Q. Where does the moisture replenishing the storm come from?

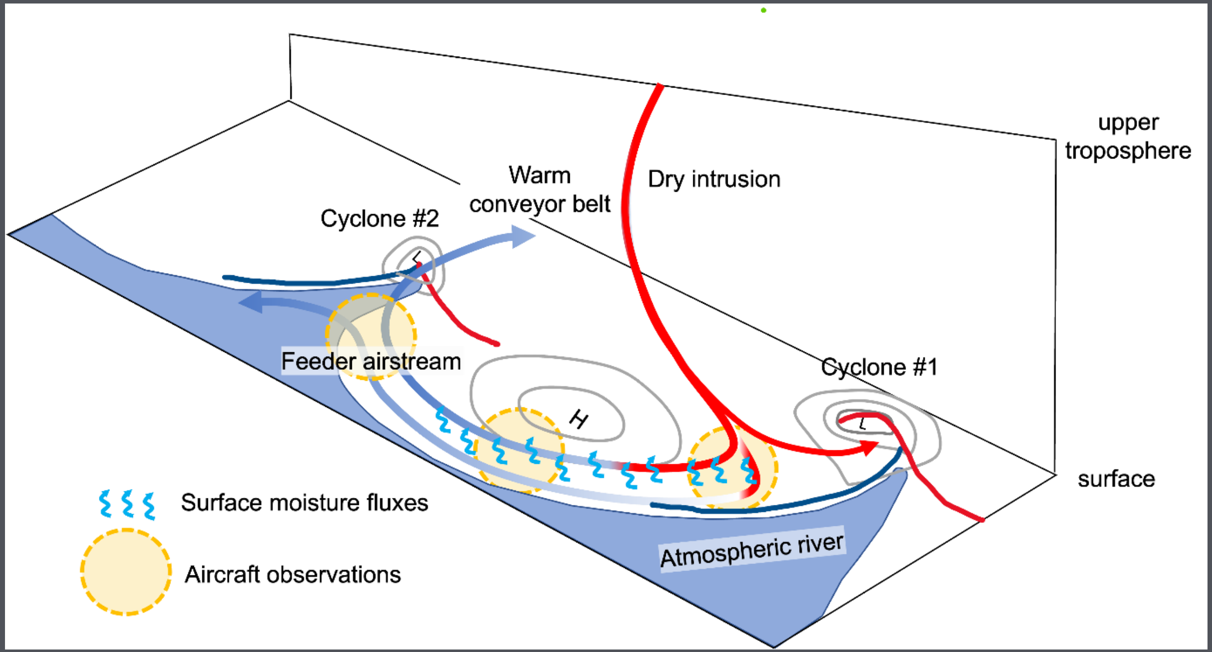
- *The feeder airstream provides a continuous supply of moisture to storms in their developing stage*
- *Moisture ahead of the storm converges along the cold front as it is swept up by the moving storm forming a filament of high TCWV*

Q. How long would it take to deplete all a storm's initial moisture via precipitation?

- *The initial moisture content is removed via precipitation within 30 hours*
- *Local evaporation and moisture flux convergence doubles the precipitating phase of storms*

DISCUSSION

- Does IVT skill peak after 72 hours because evaporation beneath the DI of previous cyclone preconditions the atmosphere for subsequent cyclone?
- Is the increase in skill for successive IOPs because the initial condition of the environment for subsequent cyclones develop is improving?
- Could impact of buoys and dropsondes on the forecast be performed relative to the AR feature to reduce the random errors and systematic geographical errors?

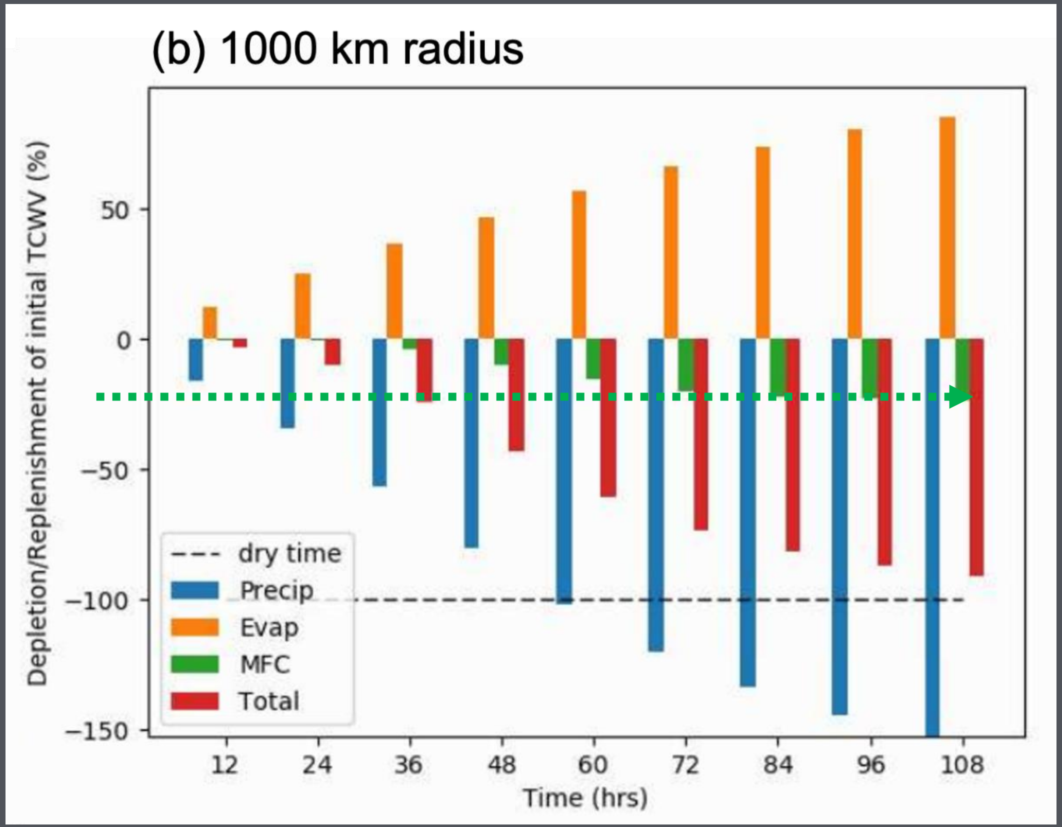


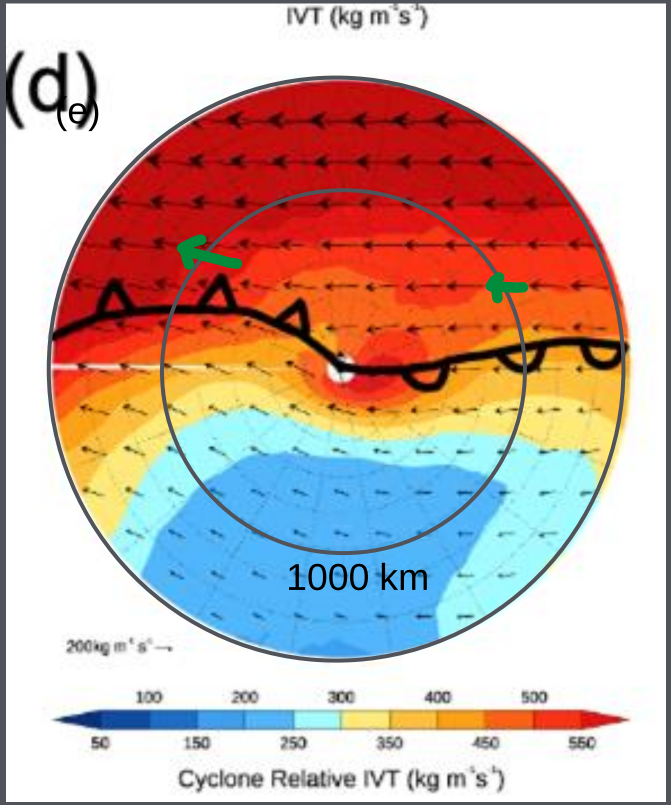
EXTRA SLIDES

University of Reading

HOW QUICKLY DO CYCLONES DRY OUT?

University of Reading





- Moisture is exported out of the cyclone as it travels
- This moisture forms the filament that is left behind by the poleward travelling cyclone indicating it's path