

The THORPEX Legacy: Achievements and lessons for the future from 10 years of THORPEX observational campaigns

David Richardson

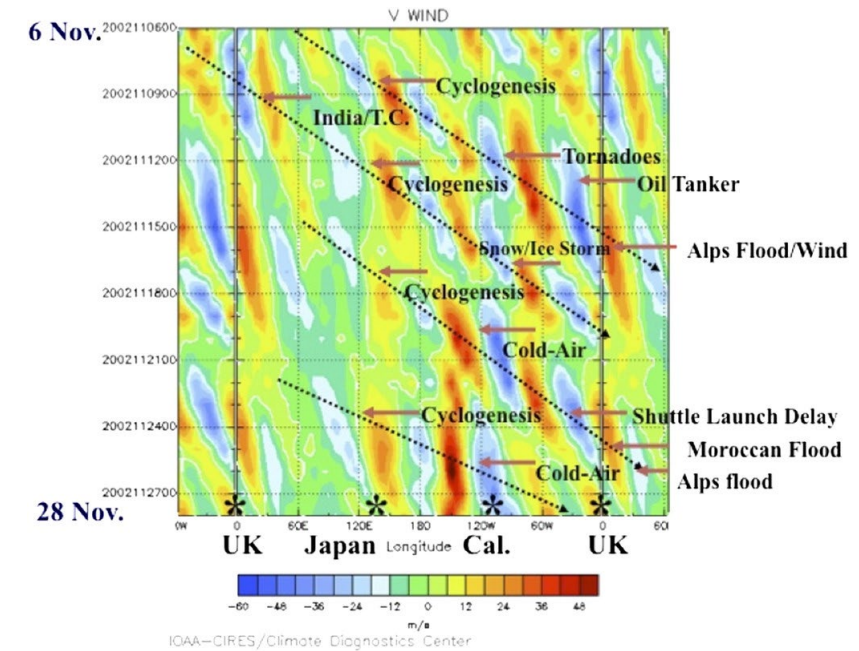
ECMWF

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Introduction to THORPEX

- The Observing System Research and Predictability Experiment (THORPEX)
- THORPEX – a World Weather Research Programme
- Accelerating improvements in the accuracy of one-day to two-week high-impact weather forecasts for the benefit of society, the economy and the environment
- Ten-year programme established in 2003 by WMO Congress
 - Predictability and dynamical processes
 - Global observing system design
 - Data assimilation and observing strategies
 - Societal and economic applications
- Series of coordinated observational campaigns to improve understanding of atmospheric predictability and to test innovative real-time observing strategies
- Adaptive, flow-dependent observation data targeting



THORPEX field campaigns

- With observation targeting
 - A-TReC (2003)
 - AMMA-THORPEX (2006)
 - Greenland Flow Distortion Experiment (GFDex) (2007)
 - COPS/E-TReC (2007)
 - PREVIEW (2008)
 - Norway IPY-THORPEX (March 2008)
 - T-PARC (2008)
 - Winter TPARC (2008-9)
 - MEDEX (autumn 2008, 2009)
 - Concordiasi (2010)
 - HyMEX (2012)
- Other THORPEX field campaigns
 - T-NAWDEX-FALCON (2012)
 - Storm Studies in the Arctic (STAR)
 - THORPEX Arctic Weather Prediction Initiative (TAWPEPI)
 - DIAbatic influences on Mesoscale structures in ExTropical storms (DIAMET)

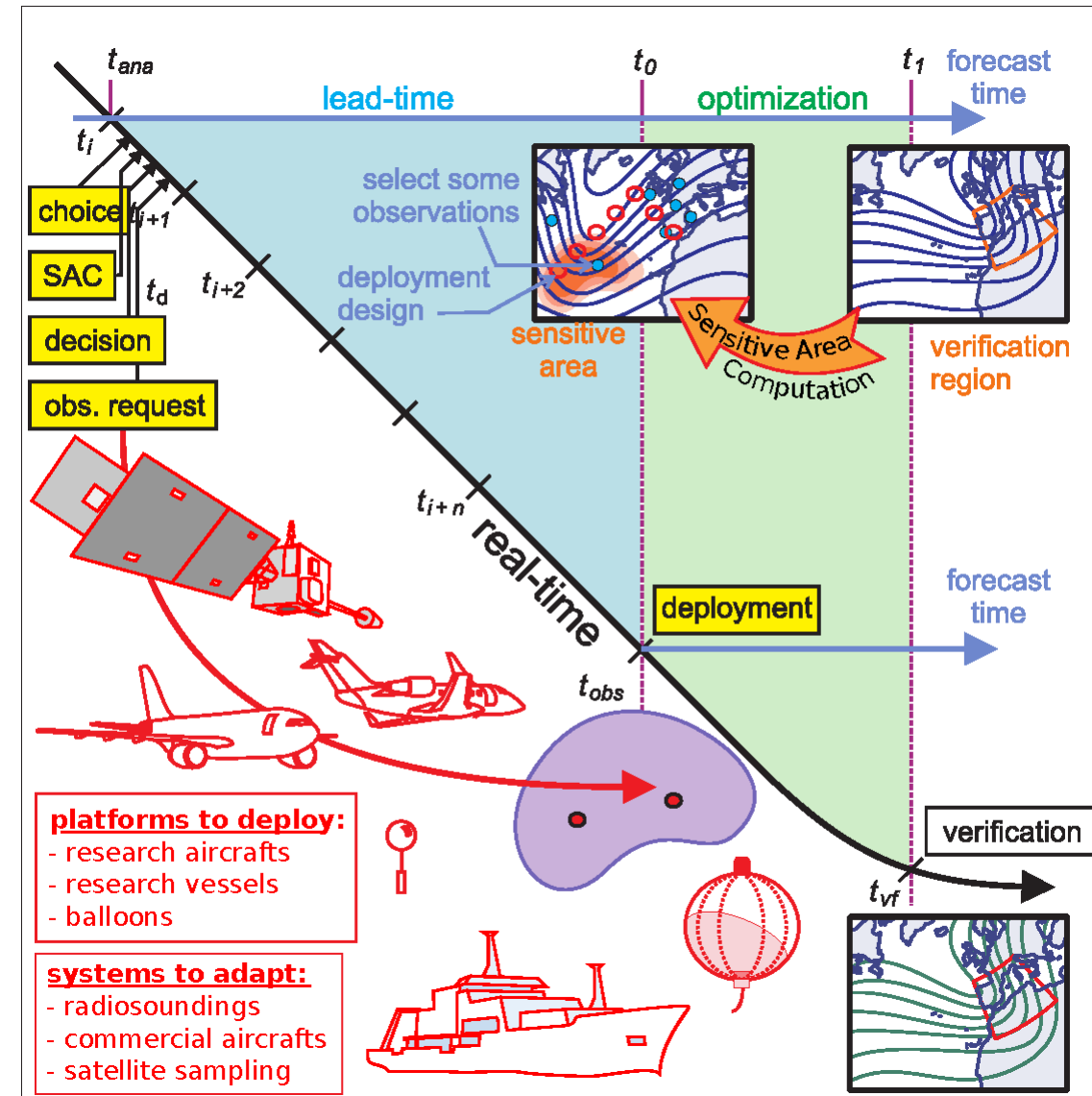


Data targeting, adaptive observations

“Is targeting a viable future component of the GOS, and if so, what weather events, regimes and forecast lead times should be targeted and what are the optimal targeting strategies?” (THORPEX International Research Implementation Plan)

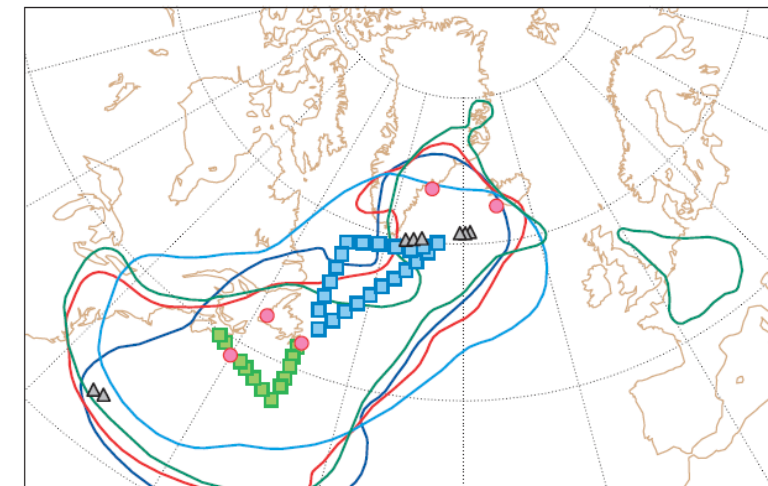
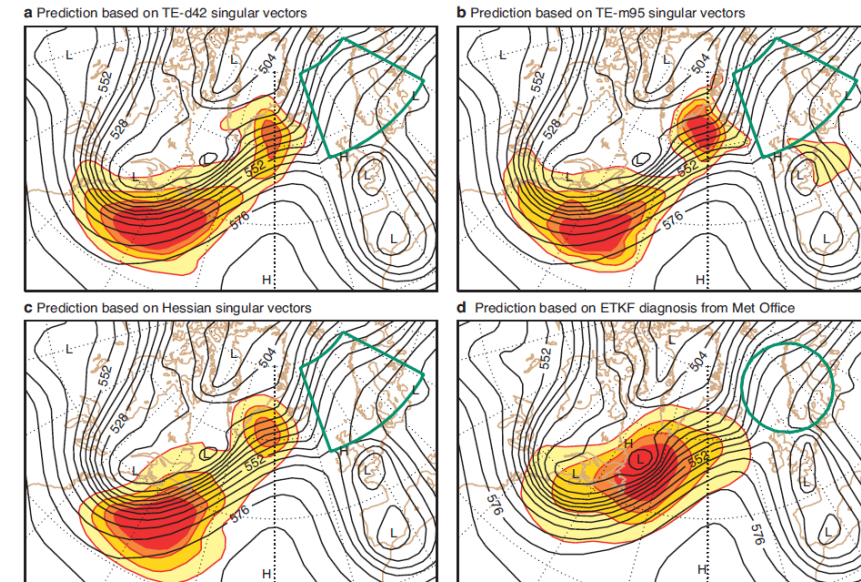
Observation targeting process:

1. Case identification: which forecast/region has potential high impact or large uncertainty associated?
2. Sensitive area prediction: where might a more accurate definition of the initial state of the atmosphere benefit the quality of the forecast over the region in question?
3. Observation selection: which additional observations should be deployed?
4. Observation deployment: make the required observations and distribute in real time via GTS



Atlantic THORPEX Regional Campaign (A-TReC)

- First THORPEX field campaign (Oct-Dec 2003)
- Aim: to test feasibility of quasi-operational targeting of observations using a variety of platforms
 - 66 operational radiosonde stations in Europe and Canada (06/18)
 - European ASAP fleet (13 ships)
 - European AMDAR fleet (550 aircraft)
 - Rapid scan winds from GOES, METEOSAT
 - Dropsondes from research aircraft (NOAA G-IV, UND Citation, DLR Falcon)
- Virtual operations centre at Met Office, Exeter
 - Twice daily teleconferences
 - Sensitive Area Predictions (SAPs) on ECMWF web site from ECMWF, Met Office
 - Additional forecast charts, SAPs (NCEP, NRL) and discussion via ftp server



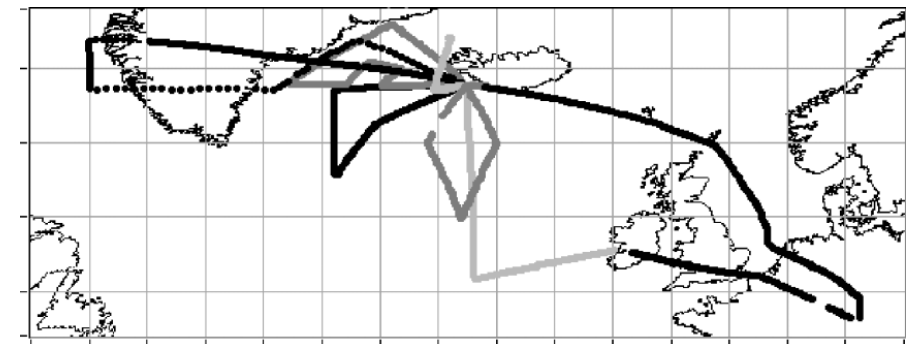
Leutbecher et al., 2005. ECMWF Newsletter 102

Atlantic THORPEX Regional Campaign (A-TReC)

- 21 cases with extra obs (23,000 AMDAR, 65 ASAP, 214 radiosondes, 277 dropsondes) real-time on GTS
- Impact on forecasts: overall small but positive benefit
 - Twice as many cases improved as deteriorated
 - Large verification area for more significant impact
 - impact of targeted observations varied significantly with the numerical model system
- Limitations:
 - Differences between SAP methods
 - Often no targetable obs in target area
 - Often uncertainty much reduced between case selection and observation deployment (2-3 days later)
 - Very time consuming - significant automation needed to make real-time adaptive control feasible

Test of airborne Doppler lidar (DLR Falcon)

- Lidar wind profiles and collocated dropsondes
- Demonstrated quality of lidar wind profiles
- Potential benefit of improved wind observations over Atlantic



DLR Falcon flight tracks during A-TReC, Weissmann & Cardinali, 2007

ECMWF Data Targeting System (DTS)

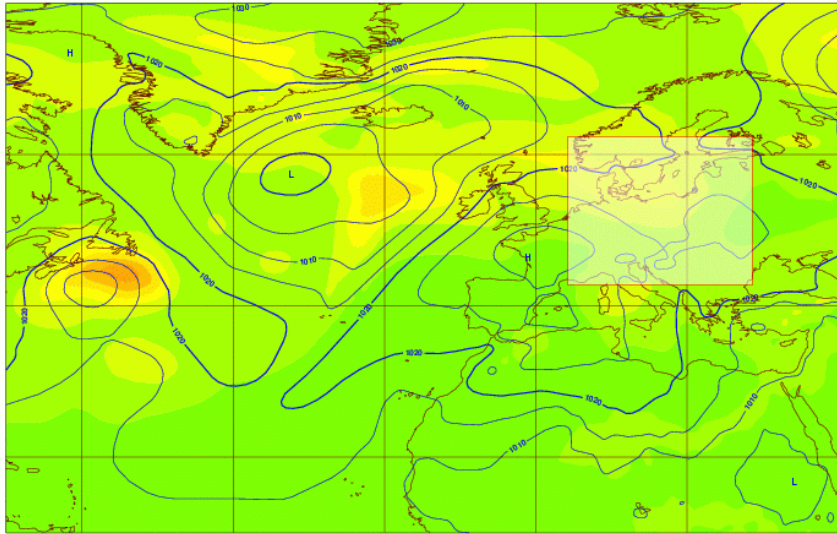
- Interactive web-based system to provide data targeting information and request additional observations to improve short-range (1-3 days) forecasts of potentially high-impact or high uncertainty weather events in Europe
- DTS developed by ECMWF in partnership with Met Office and EUCOS
- Funded by EU project EURORISK-PREVIEW and EUCOS
- Long-term trial to test operational feasibility

Case Proposal

Case Proposal Deadline: 23/04/2008 at 10:30 UTC

Forecast Charts (EPS Mean/Spread):
[2008042512](#) [2008042600](#) [2008042612](#) [2008042700](#) [2008042712](#) [2008042800](#)

Wednesday 23 April 2008 00UTC ©ECMWF Ensemble Forecast t+060 VT: Friday 25 April 2008 12UTC
 Surface: Mean sea level pressure: Ensemble mean (contours, hPa) / Ensemble spread (shaded, hPa)



Proposed by: dts_dwd2a (23/04/2008 at 09:44 UTC)

Lat1: 62.3	Lon1: 4.3	Verification Time:	2008042512
Lat2: 42.9	Lon2: 28.5	Target Time:	2008042418

Case Description:

Increased spread of mslp over NE Germany and W Poland related to a surface trough. Some models (NOGAPS, GME) predicting an increased surface trough or a surface low triggering deep convection by convergence near surface. Potential for severe weather probably might be low.

Status: Accepted
 Justification By Lead User:
 Not much suggestion of heavy rain from ensembles or deterministic runs though GFS shows moderate CAPE and potential for heavy showers/TS.

ECMWF Data Targeting System (DTS)

- Requests to compute sensitive areas are automatically submitted for all accepted cases (lead-user responsibility).
 - Total Energy Singular Vectors (ECMWF)
 - Ensemble Transform Kalman Filter (Met Office, MeteoFrance)
- Available targetable platforms are indicated
- Observation requests can be initiated

< APR 2008 >

S	M	T	W	T	F	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30			

Accepted Cases

A.551.2008042612
A.552.2008042600

Proposed Extra Observations

Links

- [Show Cases](#)
- [Monitoring](#)
- [News \(0\)](#)

Administration

- [Observation](#)
- [Evaluation](#)

Extra Observation Proposal Deadline: 22/04/2008 at 13:30 UTC

SAC Results

ukmo	msl	z500	t850
meteo-france	msl	z500	t850
ecmwf	msl	z500	t850

ECMWF-SAP based on TE-SVs (molst TL95) and MSL

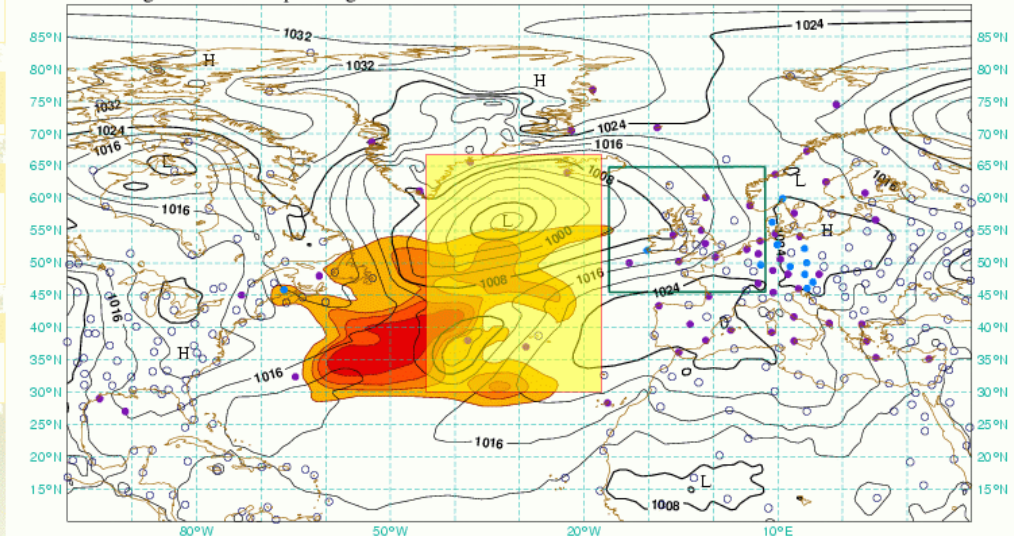
Valid time: 20080424, 06 UT (Targeting Time)

Shading: areas of 8, 4, 2, 1 x10⁴ km²

trajectory initialized from fc 20080422, 00 UT +54 h

Targ. time: 20080424, 06 UT / Verif. time: 20080426, 12 UT (opt: 54h)

• targetable • operating ○ not available



Proposal Form

Lat1: 66.8 Lon1: -44.4 Verification Time: 2008042612
 Lat2: 30.3 Lon2: -17.5 Target Time: 2008042406

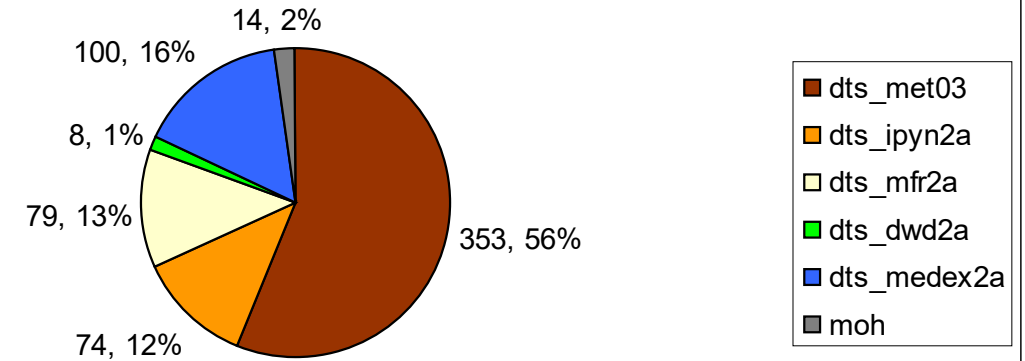
Observation List:

```
AHDAR
04018 63.97 -22.6
04360 65.6 -37.63
ASEU04 37 -29
ASEU05 38 -38
!----
```

ECMWF Data Targeting System (DTS)

- 11-month trial (4 February - 19 December 2008)
- 184 sets of observation requests
 - 1402 radiosonde requests, 87% deployed
 - 226 E-ASAP (ship sondes), 54% deployed
 - 224 E-AMDAR (aircraft)
- Successful demonstration of real-time adaptive control of operation observing systems
- Efficient - feasible for operational use (case selection, control of SAP computations, observation requests)
- Remote operation, multi-partner requests
- Monitoring of deployments (auditing, QC)
- DTS database of cases for future study
- SAP grib files archived in MARS
- Prediction of ship position would be helpful

Cases Proposed by DTS Users
(4 Feb - 19 Dec 2008)



Extra Observation Monitoring

< APR 2008 >						
S	M	T	W	T	F	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30			

Extra Observations
Requested
Targeted

Links
Show Cases
Observations
News (1)

Station List Targeted on 20080423

Station	Case(s)	Latitude	Longitude	Target Time	Obs status	Description
71600	552	43.93	-60.02	2008042318	Deployed	-
71801	552	47.62	-52.75	2008042318	Deployed	-
71815	552	48.57	-58.57	2008042318	Deployed	-
78016	552	32.37	-64.68	2008042318	Deployed	-
AMDAR	552			2008042318	Requested	-
ASEU04	552	37	-29	2008042318	Deployed	-

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T-PARC

- Sensitive areas from up to 6 different centres displayed in common format
- Icons toggle between calculations from different centres and overlays

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Publications Newsletters Manuals Library
News&Events Calendar Employment Open Tenders

T-PARC DTS Home > Show Extra Observation Proposals

Extra Observation Proposal (T-PARC)

Only Lead user can propose extra observations!

			SAC Results								
JMA	msl	z500	vo850	NRL	msl	z500	vo850	NTU	msl	z500	vo850
UWash	msl	z500	vo850	NOAA HRD	msl	z500	vo850	ECMWF	msl	z500	vo850
UMiami/NCEP	msl	z500	vo850	UKMO	msl	z500	vo850	UYonsei	msl	z500	vo850

ECMWF-SAP based on TE-SVs (moist TL95) and MSL
 Valid time: 20080928, 00 UT (Targeting Time)
 Shading: areas of 8, 4, 2, 1 x 10⁴ km²
 trajectory initialized from fc 20080926, 00 UT +48 h
 Targ. time: 20080928, 00 UT / Verif. time: 20080930, 00 UT (opt: 48h)

Accepted Cases

- A.649.2008093000
- A.650.2008093000
- A.651.2008093000
- A.652.2008093000
- A.654.2008093000
- A.655.2008100100
- A.656.2008093000
- A.657.2008092900
- A.658.2008100100
- A.659.2008100100

Proposed Extra Observations

Links

- Show Cases
- News (0)

ECMWF SVs

JMA SVs

NRL SVs

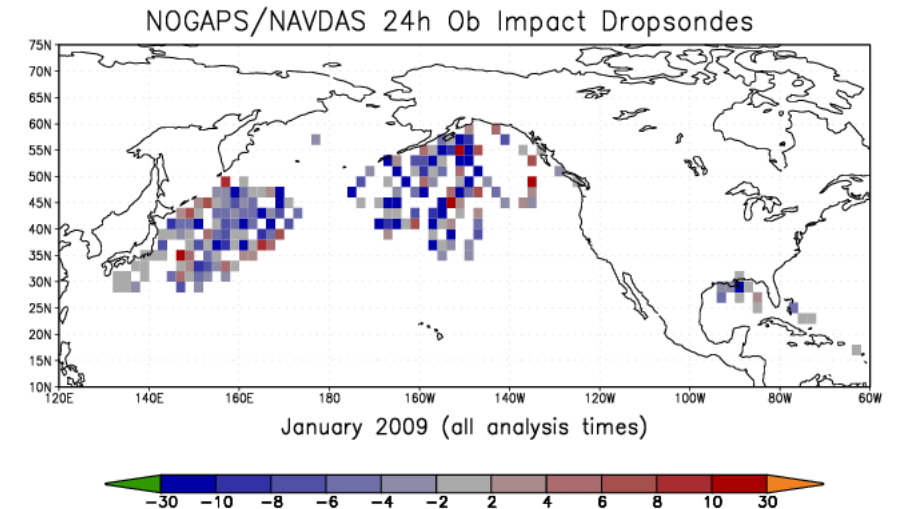
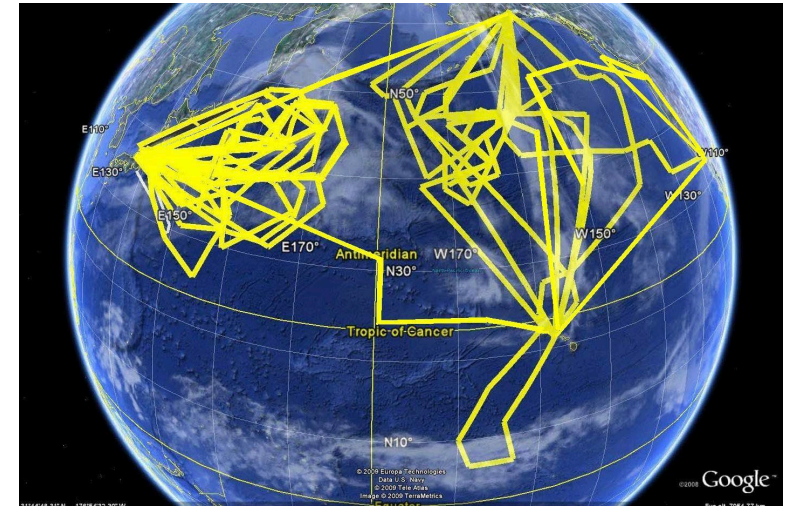
U. Yonsei SVs

NCEP/U. Miami ETKF

UKMO ETKF

Winter T-PARC

- Downstream forecast sensitivity to observations across the North Pacific and in the environment of the strong winter jet stream and midlatitude cyclones.
- NOAA G-IV (Japan), USAF WC-130 (WSR)
- Tropical convection > extratropical storms in western N Pacific > impact over N America
- Role of Rossby-wave propagation in the development of weather events over N America and the Arctic over 3-6 days
- Impacts on forecast accuracy of improved observations of the vertical structure of developing cyclones over the North Pacific
- Impacts on forecast accuracy of improved observations of diabatic processes in winter cyclones over the North Pacific



Harr & Wu, 2015

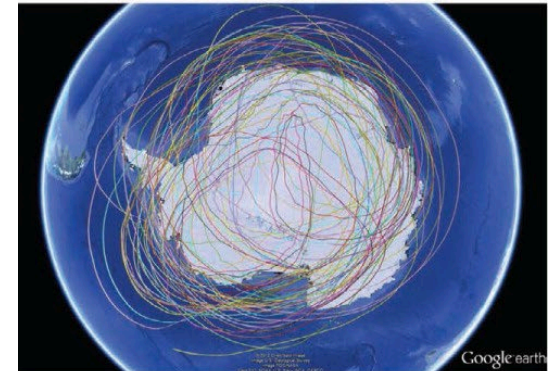
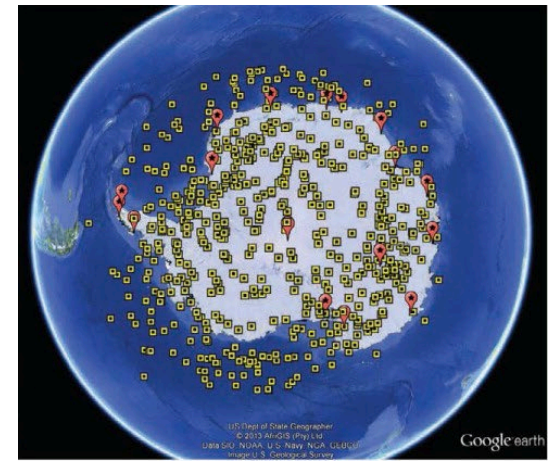
Concordiasi

Stratospheric balloons

- Temperature, ozone, and particle size along near-Lagrangian paths
- 13 driftsonde gondolas produced 644 high-quality soundings
 - Calibration of IASI
 - Validation against radiosondes
 - targeted in regions of gravity wave activity and in areas that exhibit sensitivity of numerical weather prediction to initial conditions.

Driftsondes developed, tested and evolved through several THORPEX campaigns

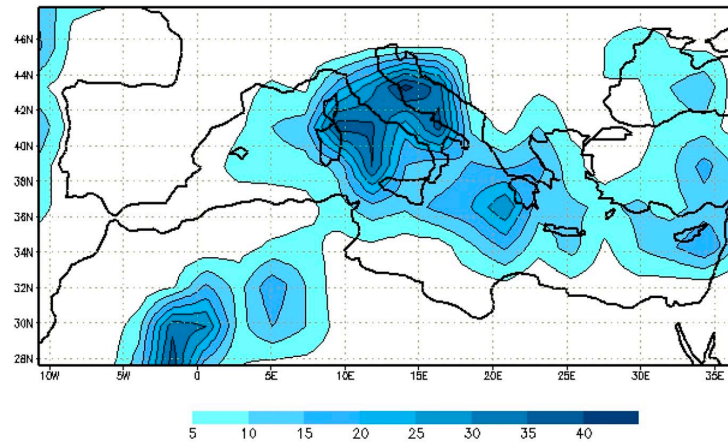
- AMMA-THORPEX (2006)
- T-PARC (2008)
- Concordiasi (2010)



Cohn et al, 2013

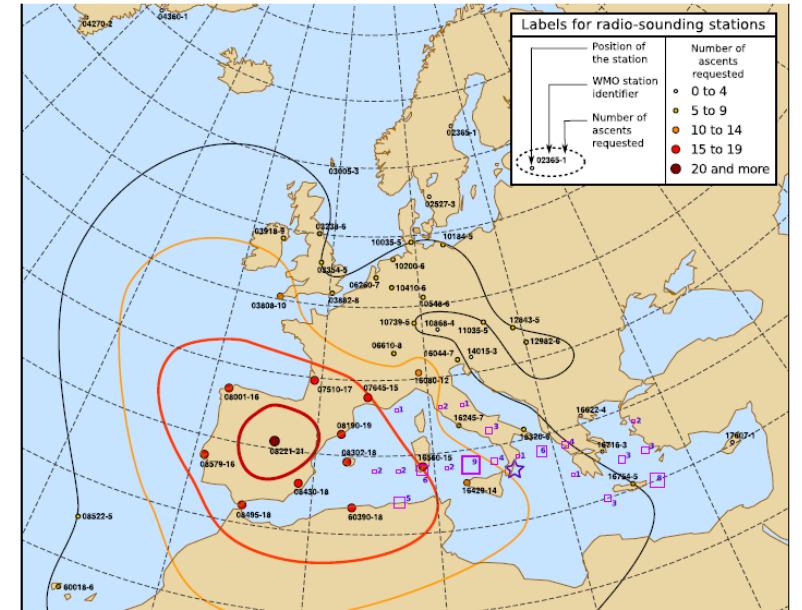
High-impact weather in the Mediterranean

- MedEx (2008, 2009)
 - improving understanding and forecasting of cyclones that produce high impact weather in the Mediterranean

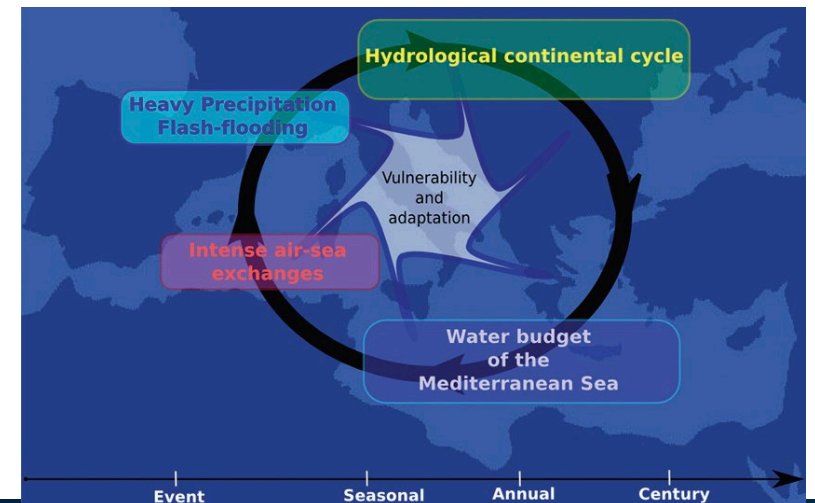


Climatology of intense cyclones (Jansa et al, 2014)

- HyMeX (2010-2020)
 - Mediterranean water cycle, high-impact weather events and societal impacts



Forecast sensitive areas (Jansa et al, 2011)



THORPEX - observation targeting

- Data Targeting System: efficient real-time adaptive control and monitoring of observation deployments
 - Radiosondes, ships, commercial aircraft, satellite, driftsondes, research aircraft
 - Logistical challenges
 - Limited targetable/adaptive observing platforms in sensitive areas
- Identification of dynamically sensitive regions: tropical cyclones, mid-latitude waveguides, polar disturbances, and tropical–extratropical interactions
 - Dependence on sensitive area computation methodology
- Forecast benefits?
 - in some cases; limitations due to sampling constraints
 - data assimilation methodology
 - model error
 - evaluation methodology (OSE, FSOI)
 - focus on deterministic forecast error (cf reduction in ensemble uncertainty)
- Societal impacts and cost-effectiveness?

Field campaigns and studies related to THORPEX						
Name	Periods and cases	Forecasts	Techniques	Targeted observations	Main results of evaluations	Key references
A-TReC	Oct–Dec 2003; 32 events	1–3-day high-impact weather events, mostly over Europe; a few storms affecting eastern North America	SV; ETKF; adjoint (dry and moist); observation sensitivity	Dropwindsondes from four aircraft; special rawinsondes; drifting buoys; AMDAR; airborne Doppler Wind Lidar (DWL); rapid-scan Atmospheric Motion Vectors (AMVs)	Small positive impact over large domains; overall improvement in 32% of 38 forecasts using the Met Office (UKMO) system; for ECMWF, forecasts of mean sea level pressure were improved (by at least 10%) in 24% of all cases; NOGAPS FSO showed the highest impact per observation by targeted dropwindsondes	Langland (2005); Rabier et al. (2008)
ECMWF studies (no field component)	Winter 2003–04 (92 cases); summer 2004 (91 cases); Jul–Sep 2008; Dec 2008–Feb 2009	2 days over North America and Europe, 3–4 days in the Southern Hemisphere	SV	Operationally assimilated observations removed from target or random areas; Density of radiance data increased in target areas	Removing targeted observations over Pacific (Atlantic) reduced 2-day forecast errors of 500-hPa Z by 4.0% (2.0%); greater reduction than removing observations in random locations; increasing the radiance data density in SV target areas improved forecasts at all levels up to 3 days in the Southern Hemisphere	Buizza et al. (2007); Cardinali et al. (2007); Bauer et al. (2011)
AMMA (THORPEX component)	Aug 2006	1–3-day African weather events, including easterly waves	Adjoint; ETKF	Rawinsondes over Africa; dropwindsondes launched from driftsonde gondolas	Large impact on analysis fields over Africa and improvement of 1-day precipitation over the central Sahel; positive downstream impact over Europe in the 2–3-day range	Faccani et al. (2009); Agustí-Panareda et al. (2010)
Greenland Flow Distortion Experiment (GFDEX)	Feb–Mar 2007; four cases	1–2-day forecasts across northwest Europe	SV; ETKF	Supplemental rawinsondes; dropwindsondes from aircraft around southern Greenland and Iceland	Neutral to small forecast improvements, max 5%	Renfrew et al. (2008); Irvine et al. (2009)
Convective and Orographically Induced Precipitation Study (COPS)/European THORPEX Regional Campaign (E-TReC)	Jun–Aug 2007; during COPS, 25 flights for water vapor lidar; during E-TReC, simultaneous aircraft missions upstream	24–36-h precipitation over France and Germany	Adjoint; SV; ETKF for E-TReC	DWL, airborne water vapor lidar (COPS), dropwindsondes from aircraft (E-TReC); EUCOS rawinsondes and enhanced AMDAR over central and southern Europe	COPS airborne water vapor lidar produced a positive impact on forecasts of 6-hourly precipitation out to 24 h; precipitation sum forecasts over the entire period improved by 10%	Wulfmeyer et al. (2008); Bielli et al. (2012)
International Polar Year/THORPEX	Mar 2008; three flights	1–2-day polar lows	SV; ETKF	Dropwindsondes released from DLR aircraft	Variable improvements depending on forecast time and verification metric	Irvine et al. (2011)
T-PARC Summer Phase/Tropical Cyclone Structure 2008 (TCS-08)	Aug–Sep 2008	1–4-day TCs and extratropical transition in the western North Pacific; a few non-TC cases	SV; ETKF; adjoint; ADSSV; ensemble variance	>1500 dropwindsondes from four aircraft; DWL and water vapor lidar; rawinsondes and observations on research vessels, driftsondes, rapid-scan geostationary AMVs	20%–40% improvement to NCEP GFS and KMA WRF track forecasts; modest improvements to forecasts up to 3 days in ECMWF and JMA	Weissmann et al. (2011)
T-PARC Winter Phase	Jan–Mar 2009	1–5-day winter storms over North America	ETKF	Dropwindsondes from NOAA and USAF aircraft; rawinsondes over Russia	75% of the 52 forecast cases of 1–5 days were improved; magnitude of improvement not published	Y. Song (2011, personal communication)
EURORISK PREVIEW/MEDEX	For PREVIEW, Feb–Dec 2008; 54 events; for MEDEX, Oct–Dec 2009; 132 cases	1–2-day high-impact weather events over Europe and especially the Mediterranean	SV; ETKF; Kalman filter sensitivity	For PREVIEW, 1402 land stations; 226 European Meteorological Network (EUMETNET) EU-Automated Shipboard Aerological Programme (E-ASAP) ship-based measurements. For MEDEX, 484 additional rawinsondes in Europe and Algeria	Modest average improvements (2%) with supplemental rawinsondes; more substantial improvements with additional targeted satellite data (9%) during MEDEX; impacts were more modest during PREVIEW (for a subset of autumn cases)	Jansa et al. (2014); Campins et al. (2013)
Concordiasi	Sep–Nov 2010	1–4-day events in Antarctica	SV	25% of 644 dropwindsondes launched from 13 driftsondes were targeted	Improvement of short-range forecasts in Naval Research Laboratory (NRL), NASA, ECMWF, and Météo-France, using FSO; dropwindsonde impact was small compared with satellite data, though large impacts were seen in upper-tropospheric winds and lower-tropospheric temperatures; qualitative impact on forecast fields in ECMWF and Météo-France systems using OSEs	Rabier et al. (2013); Boullot et al. (2016)
HyMeX	2012–present	Droughts and heat waves; mesoscale heavy precipitation	SV	American and European research aircrafts, rawinsondes, AMDAR, and drifting boundary layer (BL) balloons	Evaluations to be completed	

Majumdar, 2016, BAMS

THORPEX legacy

- Continuing framework for cooperation and collaboration
- Follow-on projects HIWeather, Subseasonal to seasonal (S2S), Polar Prediction Project (PPP)
- Earth-system approach
- TIGGE – THORPEX Interactive Grand Global Ensemble
 - Archive of real-time operational ensemble forecasts from global centres
- THORPEX vision – a Global Interactive Forecasting System (GIFS)?
 - Adaptive control of observing system
 - Interactive control of ensemble forecast generation

GIFS today?

- Autonomous observing systems
- Data driven ensembles – fast forecast production
- Direct Observation Prediction – rapid initialization
- ML/AI for sensitive areas?

Thank you!

